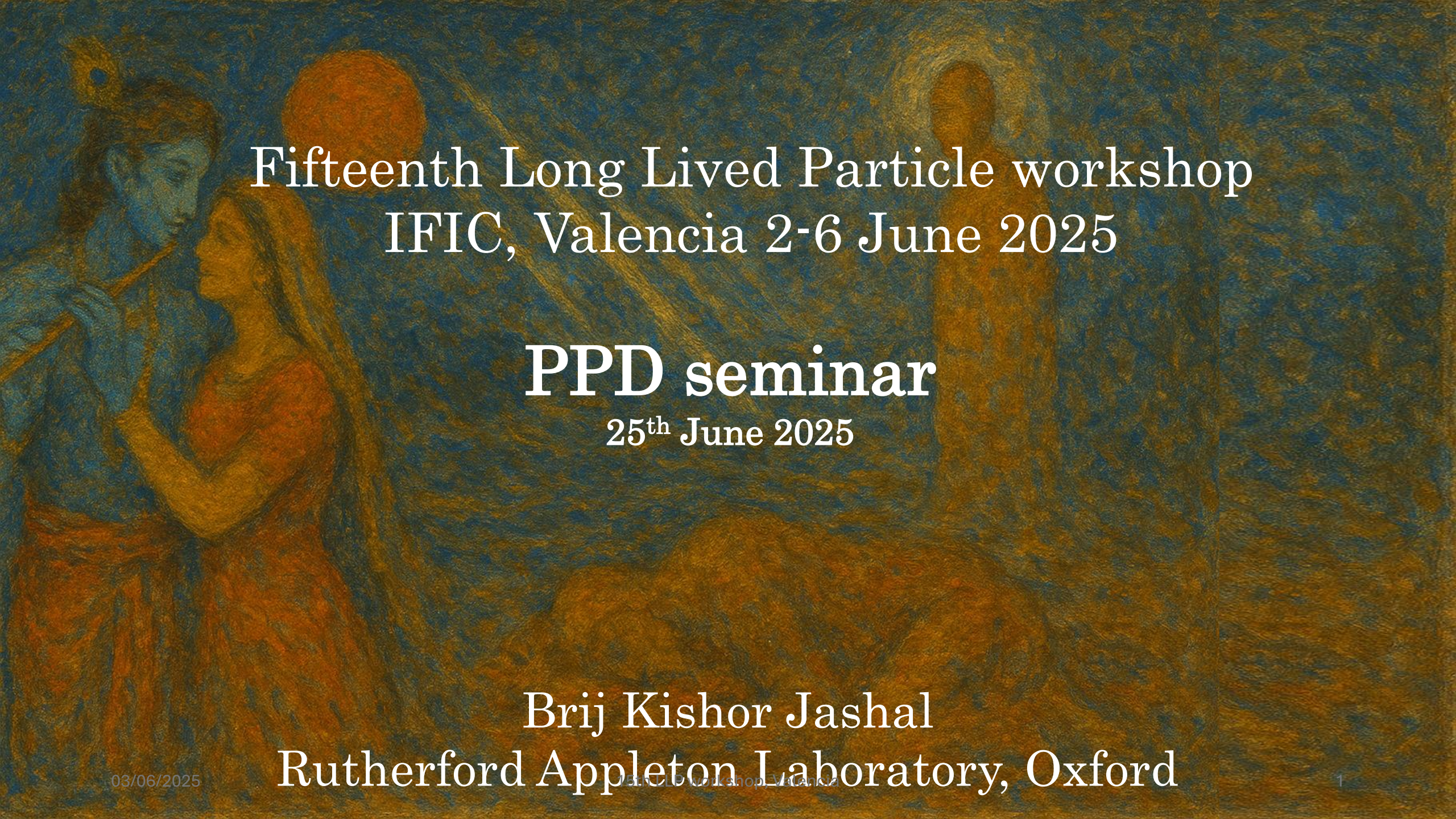


The background of the slide is a classical painting depicting Krishna and Radha. Krishna, on the left, is shown in profile, playing a flute. He has a blue complexion and is wearing a yellow dhoti. Radha, on the right, is shown in profile, looking towards Krishna. She has a fair complexion and is wearing a red sari. The background of the painting is a deep blue with a large, glowing orange sun or moon in the upper left. The overall style is reminiscent of traditional Indian art.

Fifteenth Long Lived Particle workshop
IFIC, Valencia 2-6 June 2025

PPD seminar
25th June 2025

Brij Kishor Jashal
Rutherford Appleton Laboratory, Oxford

LLP 2025

Fifteenth workshop of the
Long-Lived Particle Community

IFIC - Valencia
2 - 6 June

https://indico.cern.ch/e/LLP_June_2025

Scientific committee: Local organizing committee:

Juliette Alimena
James Beacham
Lisa Benato
Matthew Citron
Albert de Roeck
Jan Hajer
Audrey Kvam
Federico Leo Redi
Mason Proffitt
Neha Santpur
Andrii Usachov
Carlos Vázquez Sierra

Chandan Hati
Martin Hirsch
Jacobo López-Pavón
Vasiliki A. Mitsou
Laura Molina Bueno
Arantza Oyanguren
Emma Torró Pastor (chair)
Oscar Vives
Bryan Zaldivar
José Zurita (chair)



<https://indico.cern.ch/event/1441321/timetable/>

Overview talks:

- LHCb
- CMS
- ATLAS

Trigger streams

Theory and Pheno

Participant List

111 participants

Dedicated experiments

- MoEDAL-MAPP
- Beam dump experiments
- ProtoDUNE-SPS
- LUXE experiments
- MATHUSLA
- CODEX-b
- ANUBIS
- SHIFT
- SHIP
- milliQan
- Forward Physics Facility

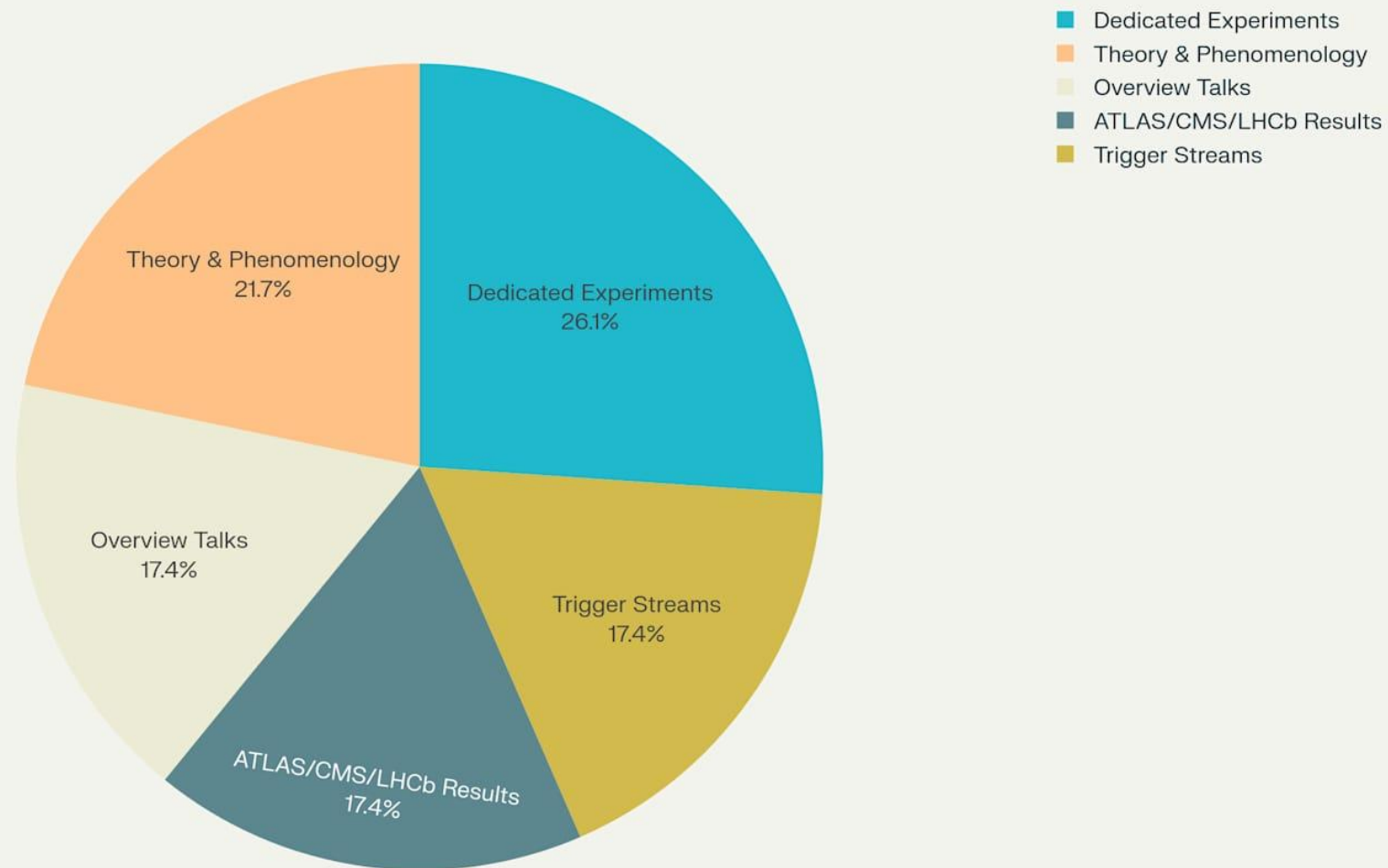
All plenary, 5 days.

Total no of talks: 65 talks

Experiments – 15+

Participants from 20+ countries

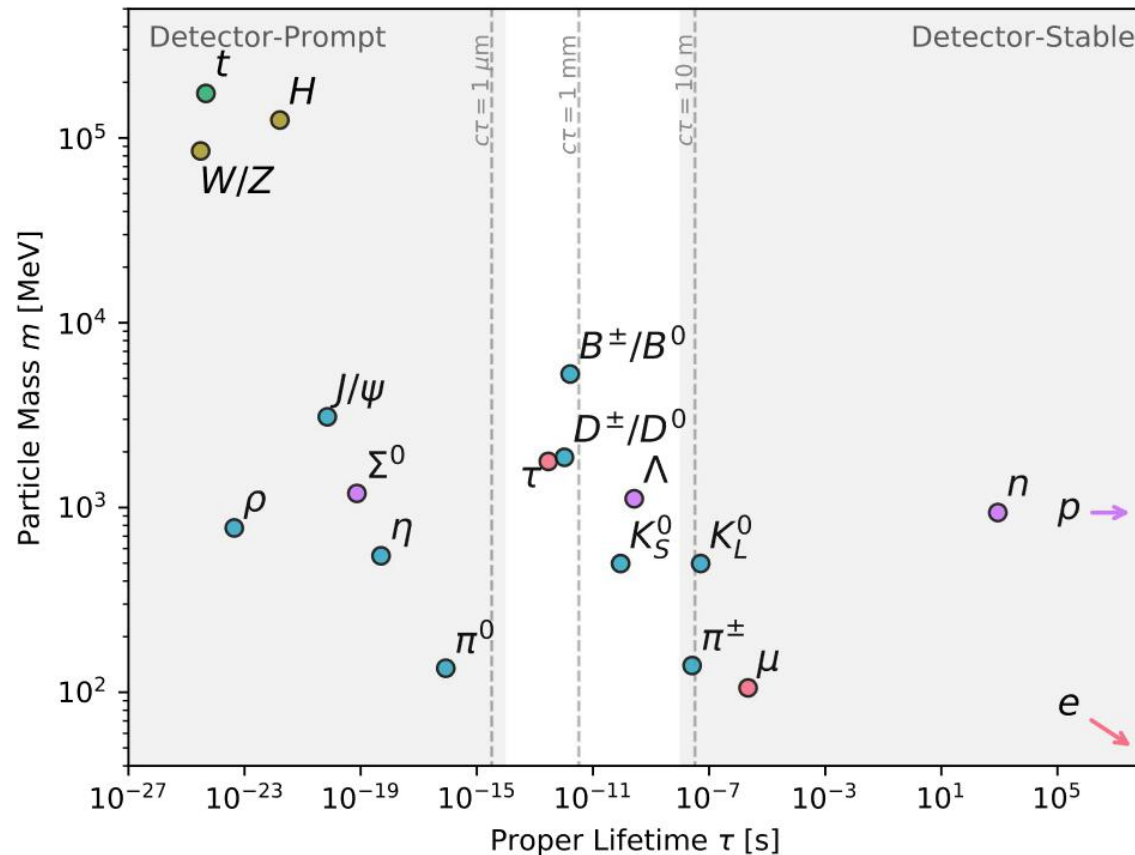
LLP2025 Session Types Distribution



Long-lived particles (LLPs):

Long living particle are a excellent probes for new physics searches in SM and beyond.

- Particle lifetimes in the SM range from $\tau \sim 2 \times 10^{-25}$ s (the Z boson) through to $\tau \sim > 10^{34}$ years (stable) (proton, electron).



$$\tau = 1/\Gamma$$

Coupling constant

LLP mass

Symmetries of the theory

Final states

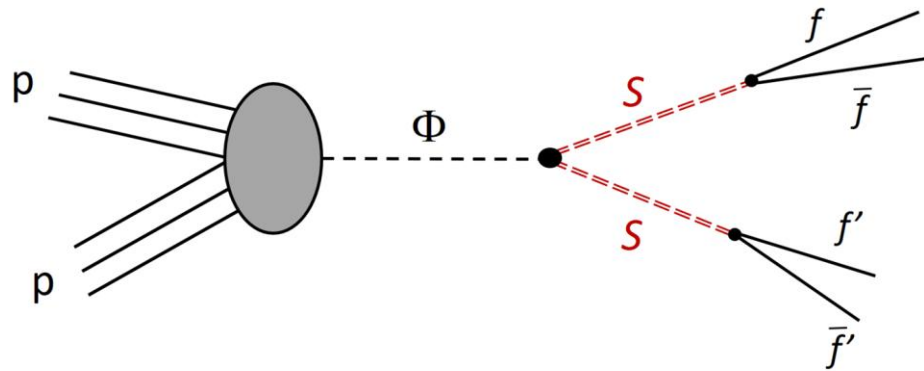
Mediator of the interaction

$$\Gamma \sim \frac{\epsilon^2}{(8\pi)^{a-1}} \frac{m^n}{M^{n-1}}$$

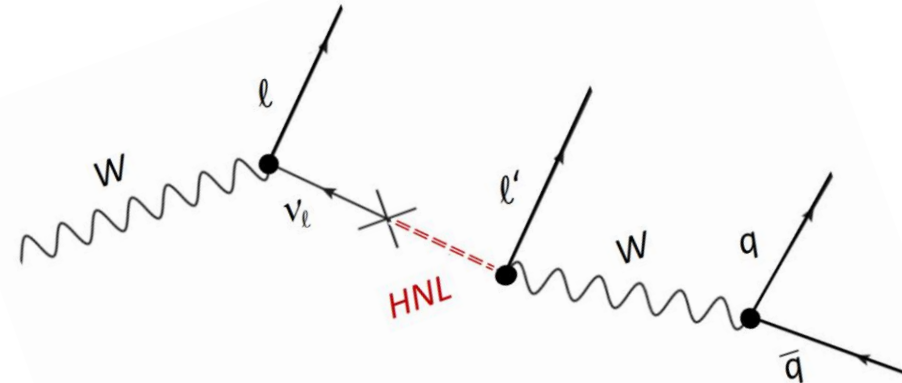
LLPs beyond the SM:

Some BSM scenarios which can include LLPs:

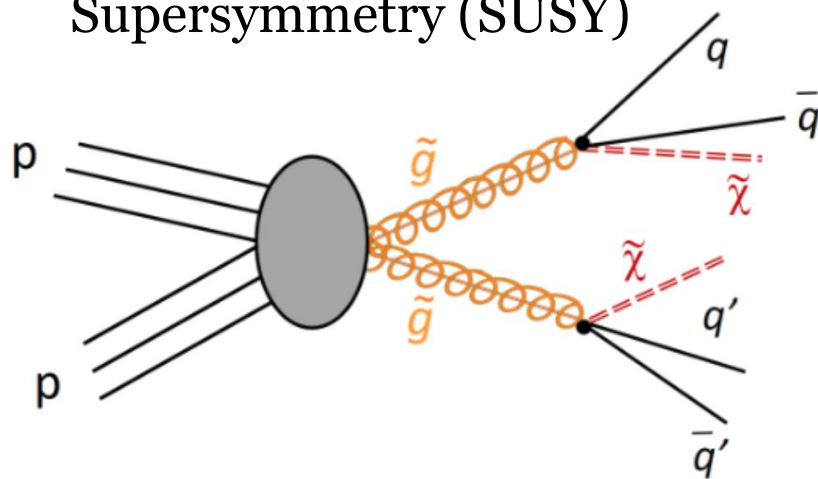
Hidden Sector particles



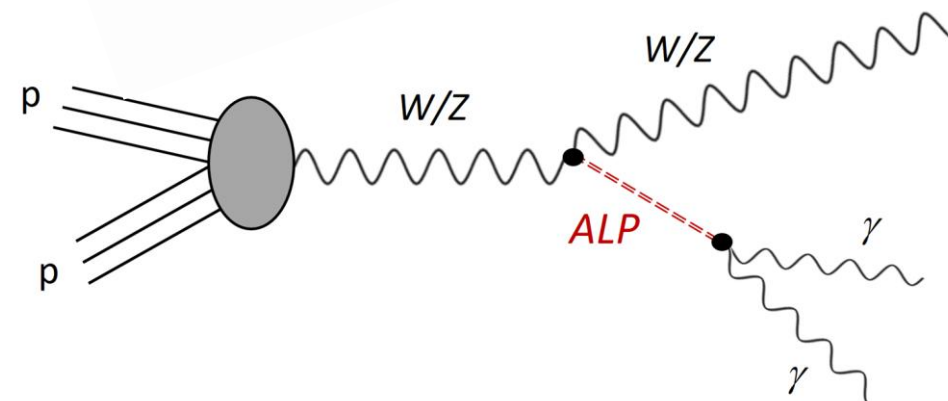
Heavy Neutral Leptons (HNLs)



Supersymmetry (SUSY)

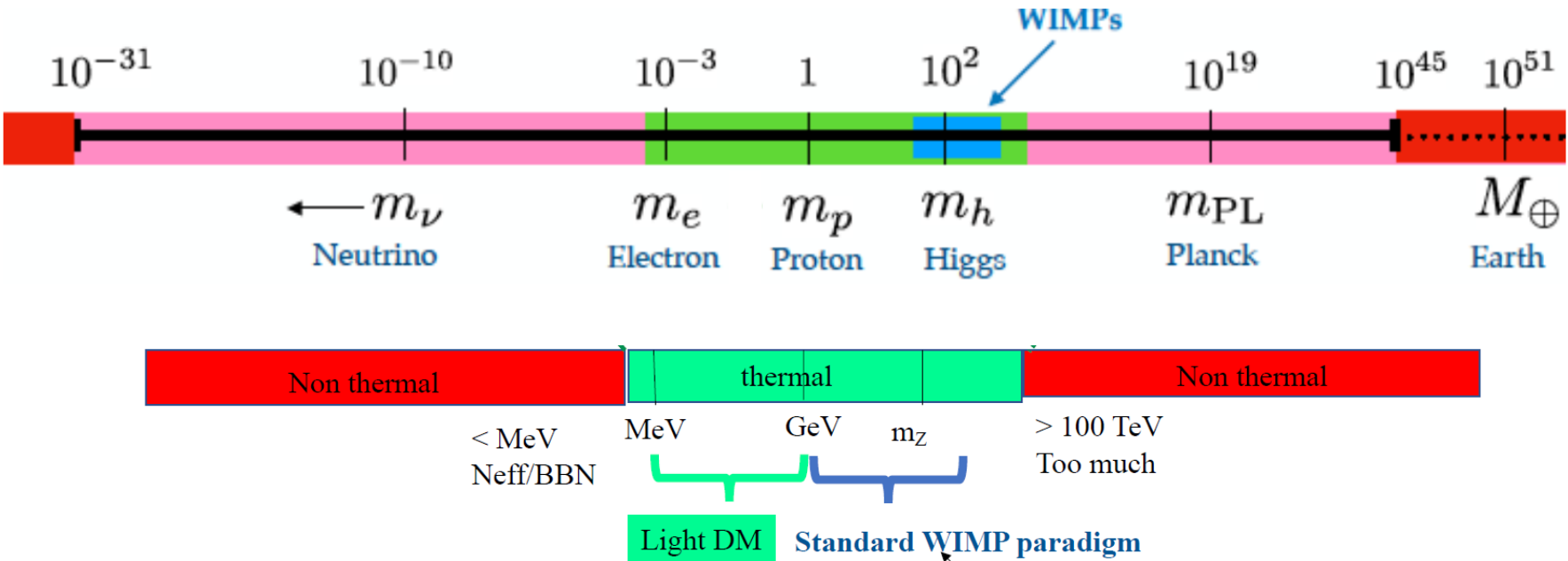


Axion-Like Particles (ALPs):



Interactions with SM particles are necessary to provide mechanisms able to
 deplete the DM abundance in the early Universe to the levels known today
 in agreement with observations in standard cosmology.
 -> DM has to interact to SM particles to deplete its initial abundance

Portal framework:
 - Expand the SM with the minimal set of operators of lowest dimension gauge-invariant and renormalizable (all but the pseudo-scalar). This guarantees that the theoretical structure of the SM is preserved and any NP is just a simple (natural?) extension of what we already know..



The best portals for Thermal light Dark Matter

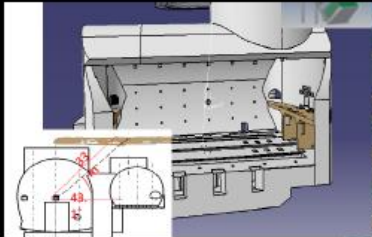
Couplings too tiny to produce thermal DM

Axion is an excellent DM Candidate but in the micro-eV range

Portal	Coupling	
Vector: Dark Photon, A'	$-\frac{\epsilon}{2 \cos \theta_W} F'_{\mu\nu} B^{\mu\nu}$	BC1, BC2, BC3
Scalar: Dark Higgs, S	$(\mu S + \lambda_{HS} S^2) H^\dagger H$	BC4, BC5
Fermion: Heavy Neutral Lepton, N	$y_N L H N$	BC6, BC7, BC8
Pseudo-scalar: Axion, a	$\frac{a}{f_a} F_{\mu\nu} \tilde{F}^{\mu\nu}, \frac{a}{f_a} G_{i,\mu\nu} \tilde{G}_i^{\mu\nu}, \frac{\partial_\mu a}{f_a} \bar{\psi} \gamma^\mu \gamma^5 \psi$	BC9, BC10, BC11

The Long-Lived Particle projects at the LHC

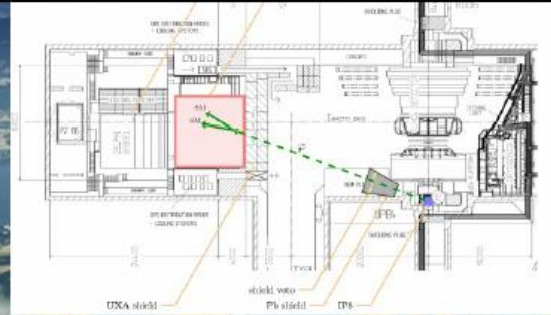
MilliQan @ CMS IP
FACET @ CMS IP



MATHUSLA @ CMS IP



CODEX-b @ LHCb IP
MOEDAL/MAPP@LHCb IP



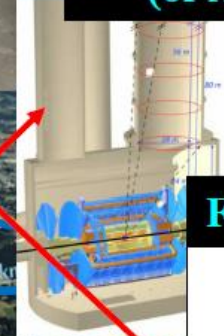
LHCb

ATLAS

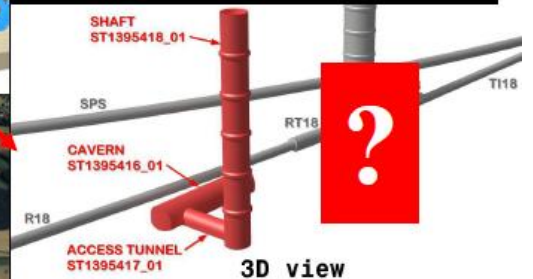
FASER @ ATLAS IP



**ANUBIS @ ATLAS shaft
(or ATLAS ceiling)**



Forward Physics Facility



CMS

SPS

LHC

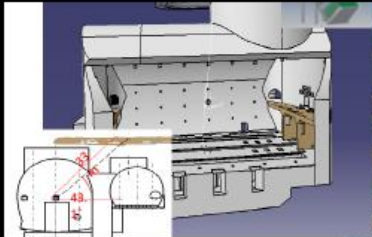
LHC 27 km

+ an active community inside ATLAS, CMS, and LHCb collaborations

The Long-Lived Particle projects at the LHC

arXiv: 2305.01715

MilliQan @ CMS IP
FACET @ CMS IP

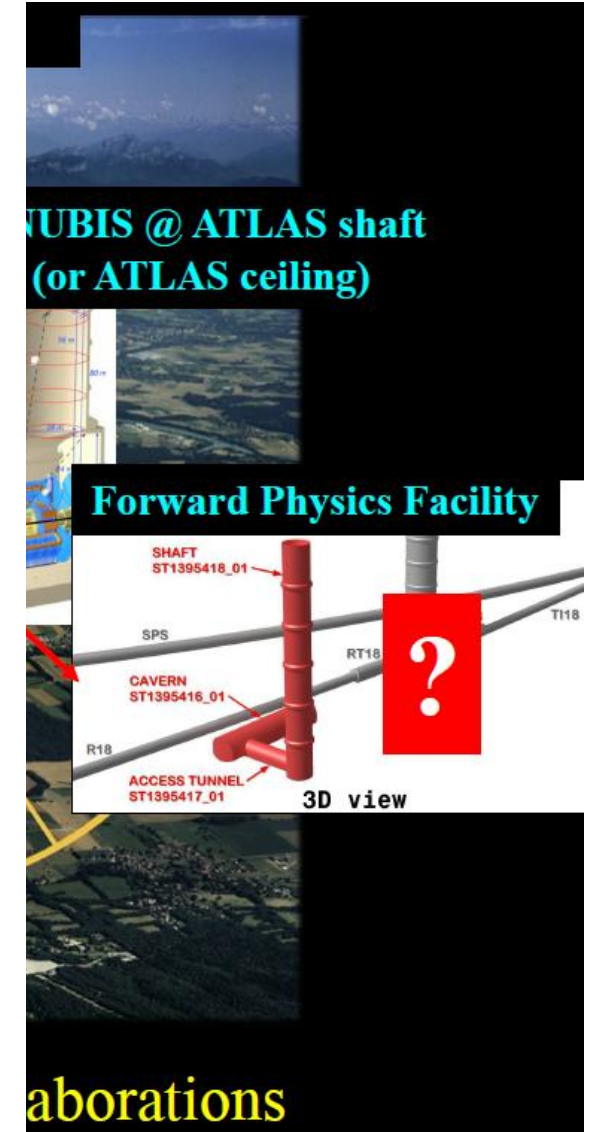


MATHUSLA @ CMS IP



+ an active c

Experiment	lab	beam	particle yield/ $\mathcal{L}$	technique	portals	timescale
current						
ATLAS [1382]	CERN	pp , 13-14 TeV	up to 3 ab^{-1}	visible, invis.	(1,2,3,4)	2042
Belle II [1219]	KEK	e^+e^- , 11 GeV	up to 50 ab^{-1}	visible, invis.	(1,2,3,4)	2035
CMS [1383]	CERN	pp , 13-14 TeV	up to 3 ab^{-1}	visible, invis.	(1,2,3,4)	2042
Dark(Spin)Quest [1256]	FNAL	p , 120 GeV	$10^{18} \rightarrow 10^{20}$	visible	(1,2,3,4)	2024
FASER [1052]	CERN	pp , 14 TeV	150 fb^{-1}	visible	(1,2,3,4)	2025
LHCb [1384]	LHC	pp , 13-14 TeV	up to 300 fb^{-1}	visible	(1,2,3,4)	2042
MicroBooNE [1385]	FNAL	p , 120 GeV (NuMi)	$\sim 7 \times 10^{20}$ pot	visible	(2,4)	2015-2021
NA62 [1174]	CERN	K^+ , 75 GeV	a few 10^{13} K decays	visible, invis.	(1,2,3,4)	2025
NA62-dump [1386]	CERN	p , 400 GeV	$\sim 10^{18}$ pot	visible	(1,2,3,4)	2025
NA64 _e [1387]	CERN	e^-/e^+ , 100 GeV	up to $1 \cdot 10^{13} e^-/e^+$	$\cancel{e}$, visible	(1,3)	< 2032
PADME [1300]	LNF	e^+ , 550 MeV	$5 \cdot 10^{12} e^+$ ot	missing mass	(1)	< 2023
T2K-ND280 [1388]	JPARC	p , 30 GeV	10^{21} pot	visible	(4)	running
proposed						
BDX [1389]	JLAB	e^- , 11 GeV	$\sim 10^{22}$ eot/year	recoil e	(1,3)	2024-2025
CODEX-b [1030]	CERN	pp , 14 TeV	300 fb^{-1}	visible	(1,2,3,4)	2042
Dark MESA [1390]	Mainz	e^- , 155 MeV	$150 \mu\text{A}$	visible	(1)	< 2030
FASER2 [1068]	CERN	pp , 14 TeV	3 ab^{-1}	visible	(1,2,3,4)	2042
FLaRE [1068]	CERN	pp , 14 TeV	3 ab^{-1}	visible, recoil	(1)	2042
FORMOSA [1068]	CERN	pp , 14 TeV	3 ab^{-1}	visible	(1)	2042
Gamma Factory [1391]	CERN	photons	up to $10^{25} \gamma/\text{year}$	visible	(1,3)	2035-2038?
HIKE-dump [1392, 1191]	CERN	p , 400 GeV	$5 \cdot 10^{19}$ pot	visible	(1,2,3,4)	<2038
HIKE- K^+ [1392, 1191]	CERN	K^+ , 75 GeV	10^{14} K decays	visible, inv.	(1,2,3,4)	<2038
HIKE- K_L [1392, 1191]	CERN	K_L , 40 GeV	10^{14} K decays	visible, inv.	(1,2,3,4)	<2042
LBND (DUNE) [1393]	FNAL	p , 120 GeV	$\sim 10^{21}$ pot	recoil e, N	(1,2,3,4)	< 2040
LDMX [1271]	SLAC	e^- , 4.8 GeV	$2 \cdot 10^{16}$ eot	$\cancel{p}$, visible	(1)	< 2030
M ³ [1394]	FNAL	μ , 15 GeV	$10^{10} (10^{13})$ mot	$\cancel{p}$	(1)	proposed
MATHUSLA [1395]	CERN	pp , 14 TeV	3 ab^{-1}	visible	(1,2,3,4)	2042
milliQan [1070]	CERN	pp , 14 TeV	$0.3\text{-}3 \text{ ab}^{-1}$	visible	(1)	< 2032
MoeDAL/MAPP [1396]	CERN	pp , 14 TeV	30 fb^{-1}	visible	(4)	< 2032
Mu3e [1397]	PSI	29 MeV	$10^8 \rightarrow 10^{10} \mu/\text{s}$	visible	(1)	< 2038?
NA64 _{μ} [1398]	CERN	μ , 160 GeV	up to 2×10^{13} mot	$\cancel{p}$	(1)	< 2032
PIONEER [1399]	PSI	55-70 MeV, π^+	$0.3 \cdot 10^6 \pi/\text{s}$	visible	(4)	phase I approved
SBND [1400]	FNAL	p , 8 GeV	$6 \cdot 10^{20}$ pot	recoil Ar	(1)	< 2030
SHADOWS [1401]	CERN	p , 400 GeV	$5 \cdot 10^{19}$ pot	visible	(2,3,4)	<2038
SHiP [1402]	CERN	p , 400 GeV	$2 \cdot 10^{20}$ pot	visible, recoil	(1,2,3,4)	<2038



10.48550/arXiv.2110.14675

Review of opportunities for new long-lived particle triggers in Run 3 of the Large Hadron Collider

Produced for the LPCC Long-Lived Particles Working Group.

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Reports on Progress in Physics

<https://doi.org/10.1088/1361-6633/ac4649>

Report on Progress

Unleashing the full power of LHCb to probe stealth new physics

M Borsato¹, X Cid Vidal^{2,*}, Y Tsai^{3,4}, C Vázquez Sierra⁵, J Zurita⁶, G Alonso-Álvarez⁷, A Boyarsky⁸, A Brea Rodríguez², D Buarque Franzosi^{9,10}, G Cacciapaglia^{11,12}, A Casais Vidal², M Du¹³, G Elor¹⁴, M Escudero¹⁵, G Ferretti⁹, T Flacke¹⁶, P Foldenauer¹⁷, J Hajer^{18,19}, L Henry^{5,6,20}, P Ilten²¹, J Kamenik^{22,23}, B Kishor Jashal⁶, S Knapen⁵, F L Redi²⁴, M Low²⁵, Z Liu^{13,26,27}, A Oyanguren Campos⁶, E Polcarpo²⁸, M Ramos^{29,30}, M Ramos Pernas³¹, E Salvioni⁵, M S Rangel²⁸, R Schäfer³², L Sestini³³, Y Soreq³⁴, V Q Tran¹³, I Timiryasov²⁴, M van Veghel³⁵, S Westhoff³², M Williams³⁶ and and J Zupan²¹

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Abstract

In this paper, we describe the potential of the LHCb experiment to detect stealth physics. This refers to dynamics beyond the standard model that would elude searches that focus on energetic objects or precision measurements of known processes. Stealth signatures include long-lived particles and light resonances that are produced very rarely or together with overwhelming backgrounds. We will discuss why LHCb is equipped to discover this kind of physics at the Large Hadron Collider and provide examples of well-motivated theoretical models that can be probed with great detail at the experiment.

Keywords: LHCb, stealth physics, BSM physics, hidden sectors, long-lived particles, dark matter

(Some figures may appear in colour only in the online journal)

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Effect of the high-level trigger for detecting long-lived particles at LHCb

Lukas Calefice^{1,2}, Arthur Hennequin³, Louis Henry⁴, Brij Jashal⁴, Diego Mendoza⁵, Arantza Oyanguren^{5*}, Izaak Sanderswood⁵, Carlos Vázquez Sierra⁴, Jiahui Zhuo⁵ and part of LHCb-RTA Collaboration

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Long-lived particles (LLPs) show up in many extensions of the Standard Model, but they are challenging to search for with current detectors, due to their very displaced vertices. This study evaluated the ability of the trigger algorithms used in the Large Hadron Collider beauty (LHCb) experiment to detect long-lived particles and attempted to adapt them to enhance the sensitivity of this experiment to undiscovered long-lived particles. A model with a Higgs portal to a dark sector is tested, and the sensitivity reach is discussed. In the LHCb tracking system, the farthest tracking station from the collision point is the scintillating fiber tracker, the SciFi detector. One of the challenges in the track reconstruction is to deal with the large amount of and combinatorics of hits in the LHCb detector. A dedicated algorithm has been developed to cope with the large data output. When fully implemented, this algorithm would greatly increase the available statistics for any long-lived particle search in the forward region and would additionally improve the sensitivity of analyses dealing with Standard Model particles of large lifetime, such as K_S^0 or Λ^0 hadrons.

Development of reconstruction strategies and algorithms at high level trigger to detect long-lived particles



LLP Community

José Zurita

2nd June 2025

- **Community** is :
 - **open**: just by being here, you are already a member!
 - **collaboration**: get in touch with your colleagues, exchange ideas, engage in discussions.
 - **curiosity**: “the only stupid question is the one you don’t ask!”
 - **creativity**: let your wildest ideas fly!
 - **respect**: no place here for harassment of any kind.

What is the LLP Community?

- Group of scientists interested exploring long-lived signatures. Operating since 2015.
- LLP also links to other experiments (e.g. DUNE, KM3NET), and to other collectives, e.g. Feebly Interactive Particles (FIPs), Long-Lived Particle Working Group.
- Organizes Community Workshops since 2017 (currently: yearly meeting)
- Milestone: LLP@LHC White Paper: [J.Phys.G 47 \(2020\) 9, 090501, 448 citations.](#)
 - Simplified models based on signatures.
 - Assessment of the coverage of current searches, making the gaps explicit.
 - Recasting of LLP studies (recommendations for presentation).
 - Explored capabilities of detector upgrades, future dedicated experiments and future
 - LLP frontier: dark showers, emerging and semi-visible jets, etc.

Long-Lived Particles

- LLPs: New Particles with macroscopic lifetimes ($\tau \sim \text{ns}$, $c\tau \sim \text{cm}$)

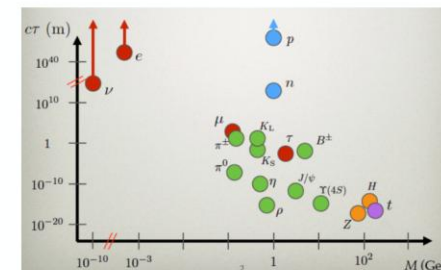
SM open issues:

EW Baryogenesis
Dark Matter
Hierarchy Problem
Neutrino Masses
Strong CP
Unification



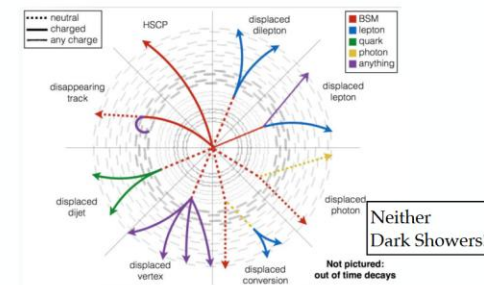
BSM Models: Supersymmetry, dark QCD, sterile neutrinos, Neutral Naturalness, Higgs Portal, Z' Portal, Hidden Valleys, ...

Exist in the SM!



large $c\tau$, small Γ :
• Compressed spectra
• Large mass hierarchies
• Small couplings

A lot of interesting signatures!



Sensitivity of “background free” studies scales with L (instead of $L^{1/2}$): room for surprises in LHC data!

IFIC

CSIC

EXCELENCIA SEVERO OCHOA

GENERALITAT VALENCIANA

VNIVERSITAT ID VALÈNCIA

ASF AE

MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES

Challenges in LLP Realm

Problem: original LHC detectors not built with LLPs as main target (except LHCb)

- a) **Triggers**: Existing menu not optimal for LLPs! LLP WG Trigger Document: [CERN-LPCC-2021-01, 2110.14675.](#)
- b) **Analysis Strategies**: Within experiments, a lot of creativity is needed!
- c) **Reinterpretation**: Use search based on model X to set constraints on model Y.
 - i) there is no standard definition of LLP objects.
 - ii) LLP backgrounds are often not possible to simulate with Monte Carlo.
- d) **New signatures: dark showers** (emerging jets, semi-visible jets, dark jets, etc.).
- e) **New Experiments**: Place external detectors to catch all LLPs produced at LHC (or other sources!).

- FASER, SND@LHC are an official LHC experiments.
- SHiP (approved March 2024).
- Other proposals updating EoL, TDRs (MATHUSLA, Codex-B, ANUBIS, ...).
- Proposal to build a Forward Physics Facility (FPF)
- [... your idea goes here!]
- [... your idea goes here:]

Reinterpretation Forum, 2003.07868
[SciPost Phys. 9 \(2020\) 2, 022](#)

“Snowmass Dark Showers”, 2203.09503
[Eur. Phys. J. C 82 \(2022\) 12, 1132](#)

Theory and Pheno

16:50 → 18:30

Theory and pheno I

Conveners: James Beacham (Max Planck Society (D3)), Dr José Francisco

Heavy Neutral Leptons in Ice, Water and Rock

Heavy neutral leptons (HNLs) are well-motivated candidates that can couple to their left-handed Standard Model transition magnetic moments. This talk discusses see as IceCube and KM3NeT can search for mass-mixed - present the first attempt at an HNL-induced double cascade searches. Second, far-forward experiments a proton-proton collisions. To this end, we introduce the Surface-based Integrated Neutrino Experiment (SI prospects for HNL searches at SINE and UNDINE usin

Speaker: Dr Nicholas Kamp (Harvard University)

LIP/VaIencia_202_...

UHE muons at KM3NeT In the context of the nc

Recently, the KM3NeT collaboration announced the d Nevertheless, the observation of this event is in 2.5-3. In fact, this is not the first anomalous measurement o events, compatible with a tau neutrino, and in strong t In this talk I will review under which conditions can BS energy neutrino telescopes at constraining models w

Speaker: Antoni Bertólez-Martínez (Departament de Física

LIP 2025 - Bertolez...

Probing long-lived HNLs via top-philic Interactio

Heavy Neutral Leptons (HNLs) provide a well-motivat and potential new physics at the TeV scale. In this talk focusing on top-philic dimension-six operators. We id top quarks and production via exotic top decays. For i as ATLAS) and far-detector experiments (including M probe new physics scales up to 12 TeV for certain op regions of HNL parameter space. These findings high the discovery potential for HNLs at the LHC.

Speaker: Rebeca Beltran (IFIC (CSIC-UV))

RbecaBeltran_LLIP_...

Probing HNL properties through their Lifetime di

Extensions of the standard model of particle physics masses as well as the baryon asymmetry of the Unive pseudo-Dirac pair, degenerate in mass with nearly ide decay law, with the only parameter that can be extract

If the seesaw scenario is extended by a third HNL, this picture, and leading to a much richer phenomenology. mass differences, even in scenarios where these are t

Speaker: Juraj Kilaric (Universiteit van Amsterdam, Nikhef)

20250601_KilaricLL... 20250601_KilaricLL...

Lepton Number Violation In Symmetry-protected Seesaw Models

Type I seesaw models, which provide an explanation for the observed small neutrino masses, additionally predict the existence of heavy neutral leptons (HNLs). In collider-observable scenarios, these HNLs must form nearly mass-degenerate pseudo-Dirac pairs, as captured by symmetry-protected seesaw models. The mass splitting within these pairs induces heavy neutrino-antineutrino oscillations, leading to observables that are sensitive to lepton number violation. We explore the potential of current and future collider experiments to quantify the amount of lepton number violation.

Speaker: Mr Bruno M. S. Oliveira (Centro de Física Teórica de Partículas (CTFP), Instituto Superior Técnico (IST), Universidade de Lisboa (UL))

Bruno M. S. Oliveira ...

09:30 → 11:00 Theory and pheno II

Conveners: Jan Hajer (CFTF, IST, Universidade de Lisboa)

09:30 Cosmology and Long-Lived Partl

In this talk, I will provide a (non-exhaustive) Matter, touching upon Heavy Neutral driven freeze-out mechanisms (from

Speaker: Jose Miguel No (IFT-UAM/CSIC)

2025_LLIP-JMNo.pdf

10:00 Exploring Long-Lived Hidden Vall

Hidden Valley (HV) scenarios featuring confinement gives rise to dark meson lifetimes where it is necessary to rein approach, we show that the existing influence on the LLP multiplicity motivates new pathways to explore f

Speaker: Joshua Lockyer

Lockyer_LLIP2025.pdf

10:20 Dark showers from sneaky dark n

I will present a minimal composite mediator. For $m_f \gtrsim 4$, the dark flavor candidates. Their relic abundance is decay. Due to their degenerate mass constraints from indirect detection at

Speaker: Adrian Carmona Bermudez

A_Carmona_LLIP25...

10:40 Probing conversion-driven freeze-out at the LHC

Conversion-driven freeze-out is an appealing mechanism to explain results from direct and indirect detection due to a very weak dark decaying into dark matter with lifetimes favorably coinciding with splitting between the long-lived particle and dark matter render We consider four different classes of searches covering the entire displaced vertices, and missing energy searches. We discuss the current constraints highlighting their complementarity. For the current analysis significantly improves its sensitivity to the scei

Speaker: Lucas Magno Dantas Ramos

talkLMOR_LLIP2025...

17:00 → 18:10 Theory and pheno III

Conveners: Jacobo Lopez Pavon (IFIC, CSIC-Universitat de Valencia (Spain)), Juliette Alimena (DESY)

17:00 Status of GeV-scale LLPs

In this talk, I explore the search for feebly interacting new physics particles (FIPs) in the GeV mass range from a theoretical perspective. I begin by emphasizing the complementarity between astrophysical and cosmological probes in exploring the FIP parameter space. I then survey the landscape of intensity frontier experiments designed to detect FIPs, addressing the principal challenge - theoretical uncertainties in FIP phenomenology, which can substantially influence experimental constraints and sensitivities. Regarding the cosmological probes, I discuss the impact of FIPs on BBN and CMB, focusing on the epoch around neutrino decoupling, a critical period at the edge of current observational capabilities. Special attention is given to recent advances in our understanding of how primordial neutrinos are affected by FIP decays into high-energy neutrinos and metastable particles, such as pions and kaons.

Speaker: Maksym Ovchymnikov (CERN)

LLIP_workshop_202_...

17:30 Leptophilic ALPs in Laboratory Experiments

In this talk I will review the collider phenomenology of leptophilic axion-like particles (ALPs), i.e. pseudoscalar particles that couple only to charged leptons. Loops of charged leptons induce effective interactions of the ALPs with photons, which depend on the momenta of the interacting particles and differ between pseudoscalar and derivative lepton couplings. I will systematically discuss the form of the interaction with photons for general external momenta and identify the regimes when it can be safely approximated by an effective coupling constant. I will use these results to derive novel constraints from LEP and calculate state-of-the-art limits from E137 and NA64 for four different scenarios, in which the ALPs couple either to a single lepton generation or universally to all, for both pseudoscalar and derivative lepton couplings. I will collect complementary bounds from astrophysics, flavour, and other laboratory experiments to chart the allowed parameter space of leptophilic ALPs in the MeV-GeV mass range.

Speaker: Marco Fedele

Fedele.pdf

17:50 Underexplored Challenges in LLP/FIP Searches at Colliders and Cosmology

Current searches for Long-Lived Particles (LLPs) and Feebly Interacting Particles (FIPs) face critical systematic limitations in collider detector geometries and cosmological analyses. At the LHC, experiments like ATLAS, CMS, and LHCb employ displaced vertex triggers that approximate detection efficiency with step functions, neglecting the probabilistic survival probability $P_{\text{surv}}(L) = e^{-L/\lambda_{\text{tot}}}$ for decays occurring at radii r . This leads to overestimated sensitivity for long-lived states ($c\tau > 10$ m), particularly at ATLAS/CMS, where edge effects near muon chambers are unaccounted for. LHCb's extended decay volume (12 m baseline) improves reach for $c\tau \sim 1$ -10 m, but momentum-dependent vertex resolution degrades for high-mass LLPs ($m \gtrsim 10$ GeV), introducing $\mathcal{O}(30\%)$ uncertainties in mass reconstruction. Furthermore, material interactions from beam-gas collisions generate $\mathcal{O}(10^4)$ fake displaced vertices per fb⁻¹ at LHCb's low- p_T thresholds ($p_T > 0.5$ GeV), necessitating non-Poissonian background treatments. Meanwhile, cosmological constraints on MeV-scale FIPs decaying during the CMB epoch ($z \sim 10^4$) assume instantaneous energy deposition, overlooking time-integrated spectral distortions $\Delta n_\gamma \propto \int T_{\text{ph}}^{-4} e^{-t/\tau} dt$, which for $c\tau \sim 10^7$ m by $\sim 50\%$. Non-thermal production mechanisms, such as $\phi \rightarrow \chi\chi$ during reheating, evade BBN bounds via $\Omega_\chi \propto T_{\text{RH}}^3/m_\chi$ dependencies, yet remain absent from joint collider-cosmology frameworks. Sub-GeV FIPs with nucleon couplings $g_{\text{N}} \sim 10^4$ further blur boundaries between collider and direct detection exclusions, leaving $\mathcal{O}(1)$ gaps in $m_{\text{N}} \sim 100$ MeV parameter spaces. To resolve these gaps, we advocate for adaptive trigger strategies combining LHCb's vertexing with ATLAS/CMS calorimeter timing ($\Delta t > 2$ ns), time-integrated cosmological likelihoods for $c\tau > 10^{10}$ m, and unified beam-gas background models across experiments. This synthesis underscores the need for detector-specific statistical frameworks and cross-disciplinary correlations to close the LLP/FIP discovery gap.

Speaker: Brj Kishor Jashal (Aalto Research Accelerator Laboratory)

LLP15-VLC-Brj.pdf

11:00 → 11:40 Theory and pheno VI

Conveners: Albert De Roeck (CERN), Laura Molina Bueno (Univ. of Valencia and CSIC (ES))

11:00 Dark Higgs Interpretation of H → LLP LLP searches

In this talk, I will present a reinterpretation of selected LHC searches for Higgs boson decays into long-lived particles (LLPs) in the context of a Standard Model plus scalar (SM+s) Dark Higgs model. The analysis is based on public data available in HEPData and focuses on comparing the sensitivity of different search strategies and final states. The aim is to explore how various approaches can probe different regions of the model parameter space and to examine the extent to which they provide complementary information.

Speaker: Alberto Escalante Del Valle (CIEMAT - Centro de Investigaciones Energéticas Medioambientales y Tec. (ES))

LLIP_2025_H-to_LL...

11:20 Revealing the Origin of Neutrino Masses through Displaced Shower Searches in the CMS Muon System

Remote

We study the potential to probe the origin of neutrino masses, by searching for long-lived right-handed neutrinos (RHNs) N in the $B \rightarrow L$ model and in the RHN-extended Standard Model (SM) Effective Field Theory (EFT). Despite the small active-sterile mixing $|V_{\text{N}}|^2$, RHNs are produced abundantly via SM and exotic Higgs production, as long as the Higgs mixing or EFT operator coefficient is sufficiently large. We reinterpret a search for displaced showers in the CMS muon system and we find that it is sensitive to parameter space at and below the seesaw floor, $|V_{\text{N}}|^2 \lesssim 10^{-12}$ ($\ell = e, \tau$) for $m_N \approx 40$ GeV. With existing data constraining such well-motivated scenarios of neutrino mass generation, we determine the projected sensitivity at the HL-LHC, motivating dedicated searches for long-lived RHNs with decay lengths ≈ 10 m.

Speaker: Wei Liu (Nanjing University of Science and Technology)

RECAST-LLP-RHN.pdf

09:30 → 11:10 Theory and pheno IV

Conveners: Chandra Hart, Jan Hajer (CFTF, IST, Universidade de Lisboa)

09:30 Long-lived Light Mediators in a Higgs Portal Model at the FCC-ee and FCC-hh

In the search for beyond the Standard Model (SM) physics, long-lived particles (LLPs) have emerged as potential candidates and are being explored in various ongoing experiments. Future lepton colliders, such as the FCC-ee, shall provide an excellent opportunity to probe LLPs, owing to their clean environment and improved particle identification. This study investigates the potential of the proposed Innovative Detector for an Electron-Positron Accelerator (IDEA) detector at FCC-ee in the detection of LLPs produced from B -meson and Higgs boson decays. We explore benchmark scenarios for different final states resulting from LLP decays, including a detailed analysis of the SM long-lived hadronic decays. Additionally, we propose dedicated LLP detectors with different configurations, dimensions, and locations with respect to the IDEA detector. DELIGHT II, originally proposed as a dedicated LLP detector for the FCC-hh, stands out as the detector with the maximum efficiency for detecting LLPs produced at FCC-ee. We find that cylindrical detector configurations, if feasible to construct around the IDEA detector, would also enhance sensitivity for LLPs mostly decaying outside it. We also discuss briefly the potential of FCC-hh.

Speaker: Rishita Sengupta (ICTP and Physikalisches Institut der Universität Bonn, Germany)

Rishita_S2025.pdf

09:50 Long-Lived Particle Searches at a Future Higgs Factory with the ILD experiment

Future e^+e^- colliders provide a unique opportunity for long-lived particle (LLP) searches. We present a full simulation study of LLP searches using the International Large Detector (ILD) chamber as its main tracking device. Signatures involving both very soft displaced tracks and boost Standard Model processes are considered. We pin boson decays to LLPs for a range of LLP lifetimes

Speaker: Jan Francisco Klamma (University of Wroclaw)

Klamma_S2025.pdf

10:10 Heavy Neutral Leptons without prejudice

We analyze prominent signatures in Higgs physics: Yukawa interaction with heavy neutral leptons (HNL) with active neutrinos. At the LHC, we investigate 1 bosons into SM fermions, to assess the experiment FCC-ee, we study HNL production from both Z and W . Additionally, we explore how precision Higgs mea

Speaker: Dr Kuldeep Deka (New York University Abu Dhabi)

LLIP_2025.pdf

10:30 The LOHENGRIN Experiment: Status and The

We present a proposal for a future light dark matter (LDM) experiment using the fixed-target missing momentum in The LOHENGRIN experiment uses a high-rate ring thin target to produce mainly Standard Model bre electron.

A well-motivated candidate for such a new particle a dark sector and kinetically mixes with the Higgs The LOHENGRIN experiment is estimated to react various models for dark photon masses between In the talk we will address the current status of the Monte Carlo code, LOHENGRIN+.

Speaker: Martin Schümann

The LOHENGRIN Ex...

11:40 → 13:00 Theory and pheno V

Conveners: Dr José Francisco Zurita (IFIC- Univ. of Valencia and CSIC (ES)), Lisa Benato (Austrian Academy of Sciences (AT))

11:40 Placing Bounds on New Physics with Displaced Photons

If a neutral long-lived particle decays predominantly into photons and another stable particle, its presence can be reconstructed at the LHC in the form of displaced photons. These are recognized as such in terms of their delayed arrival time t_d and a non-pointing parameter Δz_T .

In this work we present a detailed recast of a search for displaced photons in ATLAS, and show how it can be used to constrain new physics. In particular, we use the search to put bounds on the Dimension-5 Seesaw Portal (which can explain neutrino masses) and on a dark photon model coupling via a scalar portal to the Standard Model (which can explain dark matter).

Speaker: Dr Joel Jones-Perez

LLIP_JJPv1.pdf

12:00 Long-lived particles in a scotogenic-like model

Neutrino masses and dark matter (DM) might have a common origin. The scotogenic model can be considered the proto-type model realizing this idea, but many other variants exist. In this talk, I will comment on long-lived particles predicted in a scotogenic-like scenario, containing a triplet scalar. We calculate the relic density and check for constraints from direct detection experiments. The parameter space of the model, allowed by these constraints, contains typically a long-lived or quasi-stable doubly charged scalar, that can be searched for at the LHC. We reinterpret existing searches to derive limits on the masses of the scalars of the model and estimate future sensitivities in the high-luminosity phase of the LHC.

Speaker: Giovanna Cottin (Pontificia Universidad Católica de Chile (CL))

LLIP2025_GCOTTIN...

12:20 Using BDTs as Surrogate Models for BSM searches in ATLAS

In this talk, I will present a novel approach for the reinterpretation of LHC searches for long-lived particles (LLPs) using Boosted Decision Trees (BDTs). This method allows us to estimate the likelihood that events from a new physics model would have been selected in a prior analysis, based solely on truth-level information. I will discuss the development and validation of method, including its integration within the HackAnalysis framework. Furthermore, I will explore its application to an extended version of the HAHM model with asymmetric LLPs (in mass and lifetime), and highlight the promising results obtained.

Speaker: Abdelhamid Haddad (Laboratoire de Physique de Clermont-Auvergne (LPCA))

BDT as a Surrogate...

12:40 Probing exotic long-lived particles from the prompt side using the CONTUR method

A method to derive constraints on new physics models featuring exotic long-lived particles using detector-corrected measurements of prompt states is presented. The CONTUR workflow is modified to either account for the fraction of long-lived particles which decay early enough to be reconstructed as prompt, or to be sensitive to the recoil of such particles against a prompt system. This makes it possible to determine how many of signal events would be selected in the RIVET routines which encapsulate the fiducial regions of dozens of measurements of Standard Model processes by the ATLAS and CMS collaborations. New constraints are set on several popular exotic long-lived particle models in the very short-lifetime or very long-lifetime regimes, which are often poorly covered by direct searches. The probed models include feebly-interacting dark matter, hidden sector models mediated by a heavy neutral scalar, dark photon models and a model featuring photo-phobic axion-like particles.

Speaker: Bruna Pascual (Université Clermont Auvergne (FR))

20250605_LLIP2025...



Nicholas Kamp | nkamp@g.harvard.edu
 LLP 2025 | València, Spain
 2 June 2025

Where are the right-handed neutrinos?

I	II	III
2.3 MeV left u up right	1.28 GeV left c charm right	173.2 GeV left t top right
4.8 MeV left d down right	95 MeV left s strange right	4.7 GeV left b bottom right
511 keV left e electron right	105.7 MeV left μ muon right	1.777 GeV left τ tau right
< 2 eV left ν_e right	< 190 keV left ν_μ right	< 18.2 MeV left ν_τ right

No right-handed neutrinos
 in the Standard Model
 means no neutrino mass



So let's add them!
These are "heavy neutral leptons" (HNLs)

I	II	III
2.3 MeV left u up right	1.28 GeV left c charm right	173.2 GeV left t top right
4.8 MeV left d down right	95 MeV left s strange right	4.7 GeV left b bottom right
511 keV left e electron right	105.7 MeV left μ muon right	1.777 GeV left τ tau right
< 2 eV left ν_e right	< 190 keV left ν_μ right	< 18.2 MeV left ν_τ right

CERN Courier

Portals to Heavy Neutral Leptons

Mass-Mixed HNLs
 Coupling via mass mixing
 as in Seesaw Type I

Parameters

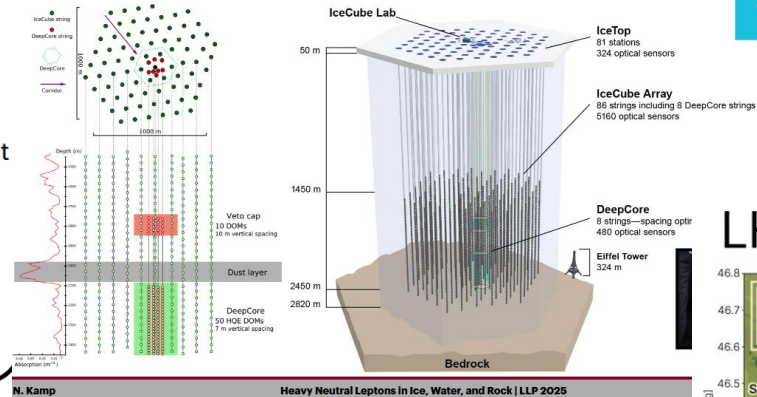
- M_N : HNL mass
- $U_{\alpha N}$: mixing matrix elements

Dipole-Portal HNLs
 Coupling via an effective
 transition magnetic moment

Parameters

- M_N : HNL mass
- $d_{\alpha N}$: effective dipole moment

The IceCube Detector

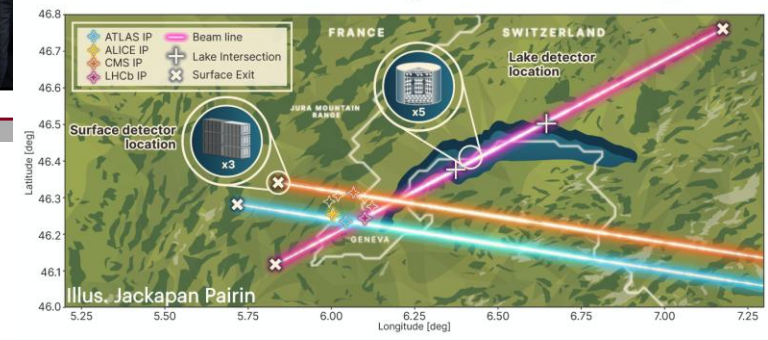


arXiv:2501.08278

Lake- and Surface-Based Detectors for Forward Neutrino Physics

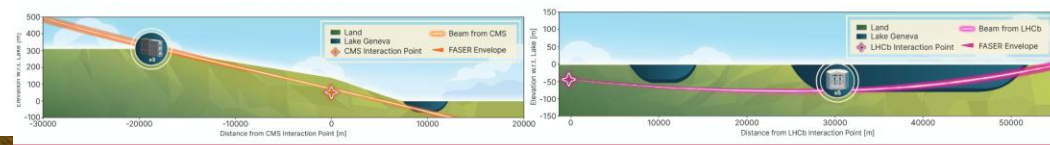
Nicholas W. Kamp,^{1,*} Carlos A. Argüelles,^{1,†} Albrecht Karle,^{2,‡} Jennifer Thomas,^{2,3,§} and Tianlu Yuan^{2,¶}
¹Department of Physics and Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge, MA 02138, US
²Department of Physics and Wisconsin IceCube Particle Astrophysics Center, University of Wisconsin–Madison, Madison, WI 53706, USA
³Department of Physics and Astronomy, University College London, London, WC1E 6BT, UK
 (Dated: January 14, 2025)

LHC Neutrinos pass through Lake Geneva

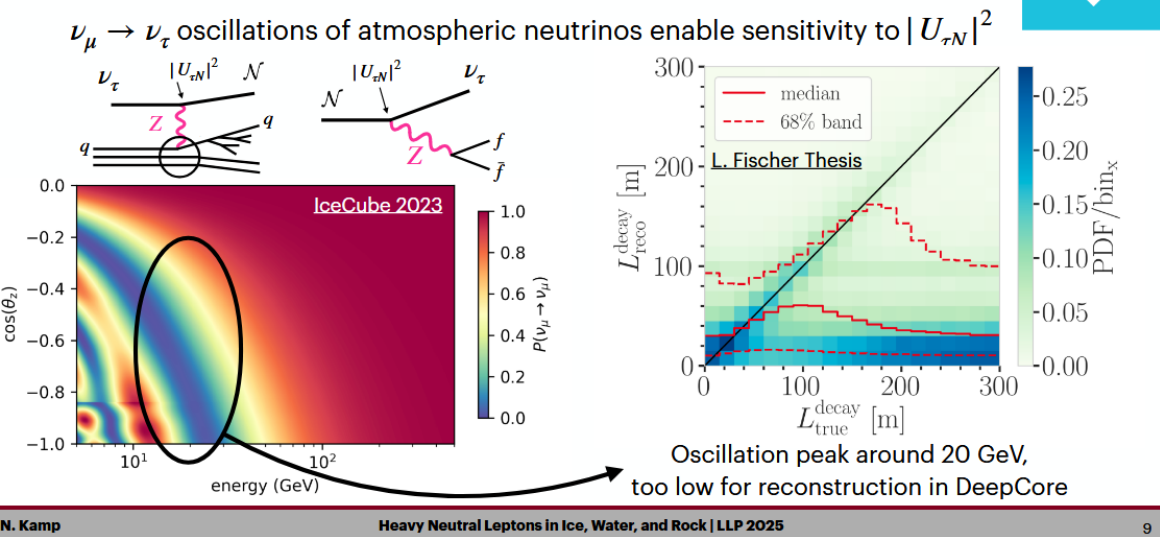


This enables the construction of large-scale lake-and-surface-based detectors that evade muon backgrounds from the p-p collision

Thanks to Benjamin Weyer and Albert De Roeck for discussions on the beam geometry



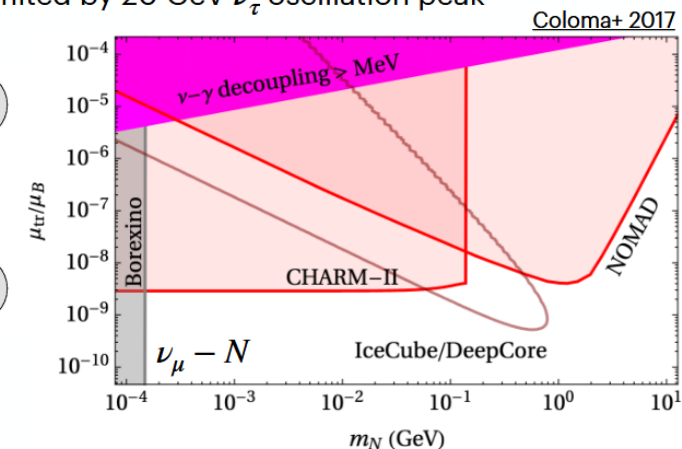
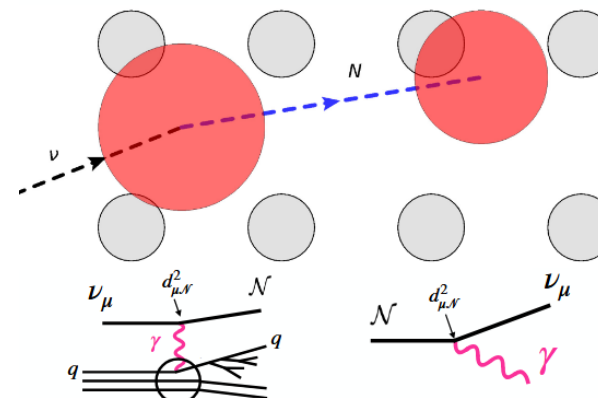
Sensitivity to Tau Mixing



Dipole-Portal HNLs @ IceCube

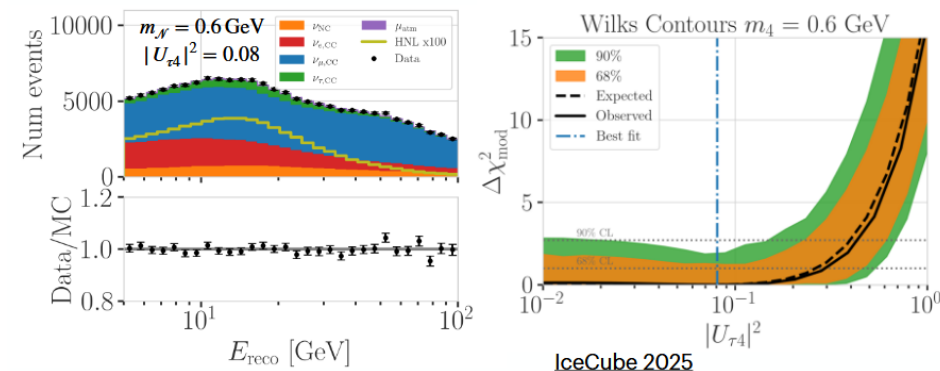
Dipole-portal HNLs also create double cascades

We consider atmospheric ν_μ : not limited by 20 GeV ν_τ oscillation peak



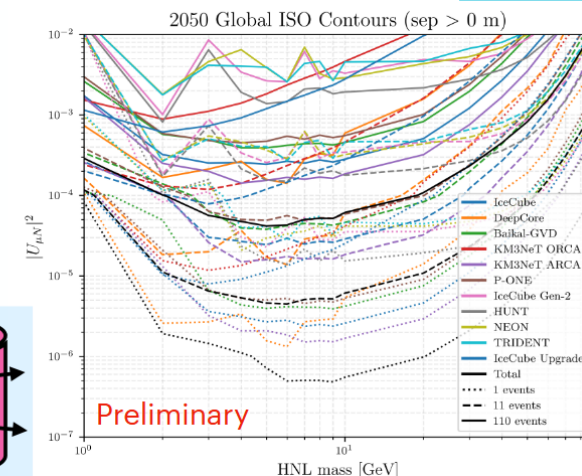
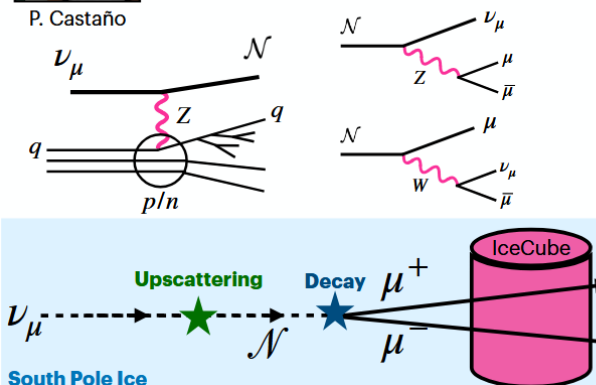
Single Cascade HNL Search

- Alternate strategy:** search for an excess of single cascades over the atmospheric neutrino background
- Severely background limited: constraints only possible at the $|U_{\tau N}|^2 \sim 0.1$ level



Muon Pairs from HNLs

Mass-mixed HNLs can also produce di-muon signatures at neutrino telescopes



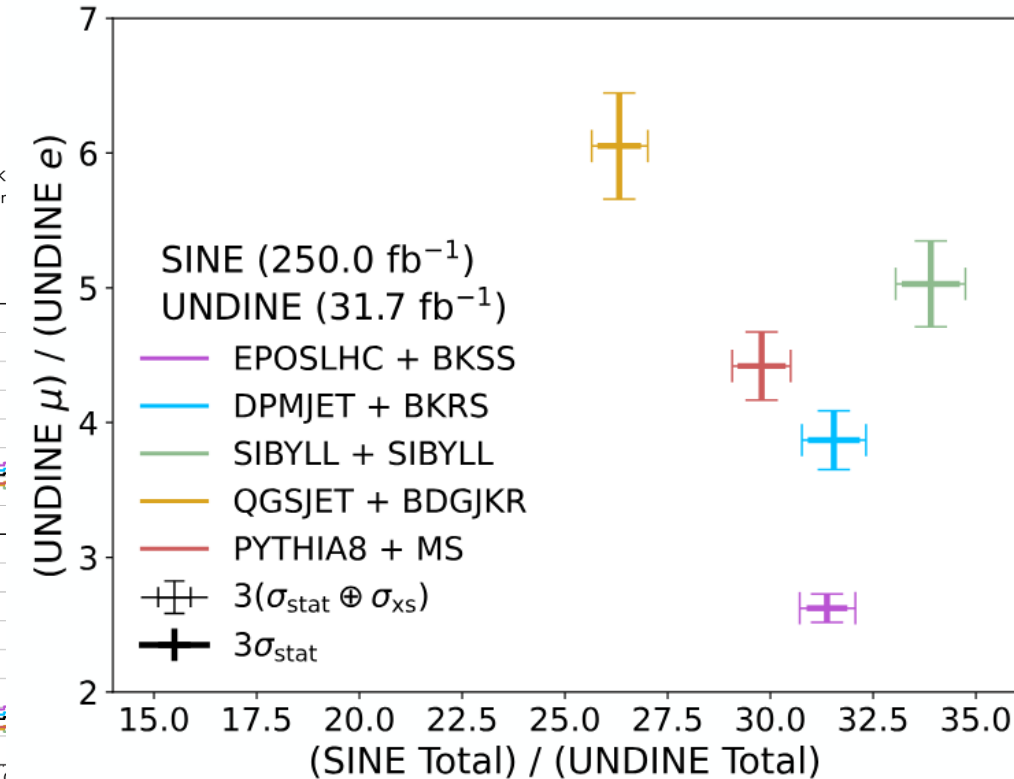
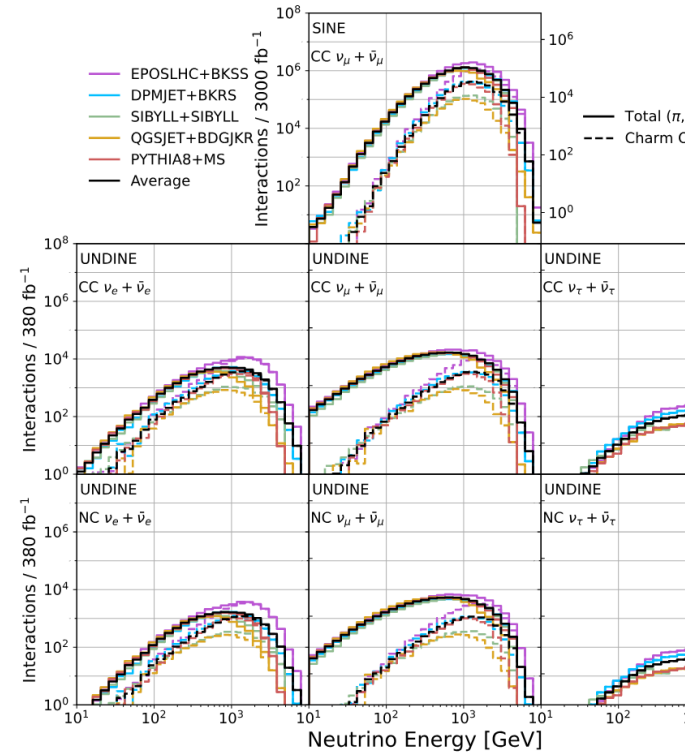
HL-LHC Event Rates

$\mathcal{O}(10\text{M})$ ν_μ interactions in SINE

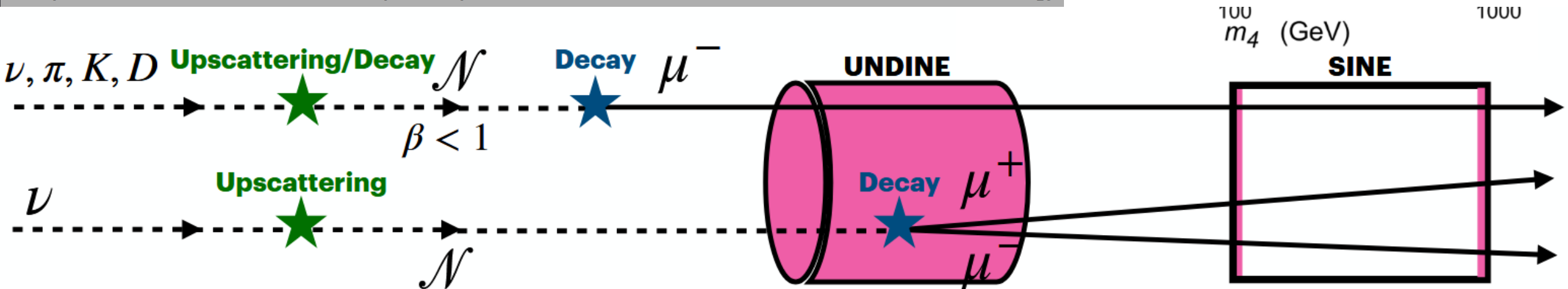
$\mathcal{O}(100\text{k})$ all-flavor neutrino interactions in UNDINE

Cost-effective opportunity to collect large collider neutrino datasets

Dataset	Total	π, K	D, Λ_c
SINE (CC $\nu_\mu + \bar{\nu}_\mu$)	$10^{6.98}$	$10^{6.84}$	$10^{6.40}$
UNDINE (CC $\nu_e + \bar{\nu}_e$)	$10^{4.68}$	$10^{4.32}$	$10^{4.42}$
UNDINE (CC $\nu_\mu + \bar{\nu}_\mu$)	$10^{5.27}$	$10^{5.20}$	$10^{4.41}$
UNDINE (CC $\nu_\tau + \bar{\nu}_\tau$)	$10^{3.07}$	0	$10^{3.07}$
UNDINE (NC $\nu_\alpha + \bar{\nu}_\alpha$)	$10^{4.87}$	$10^{4.76}$	$10^{4.24}$

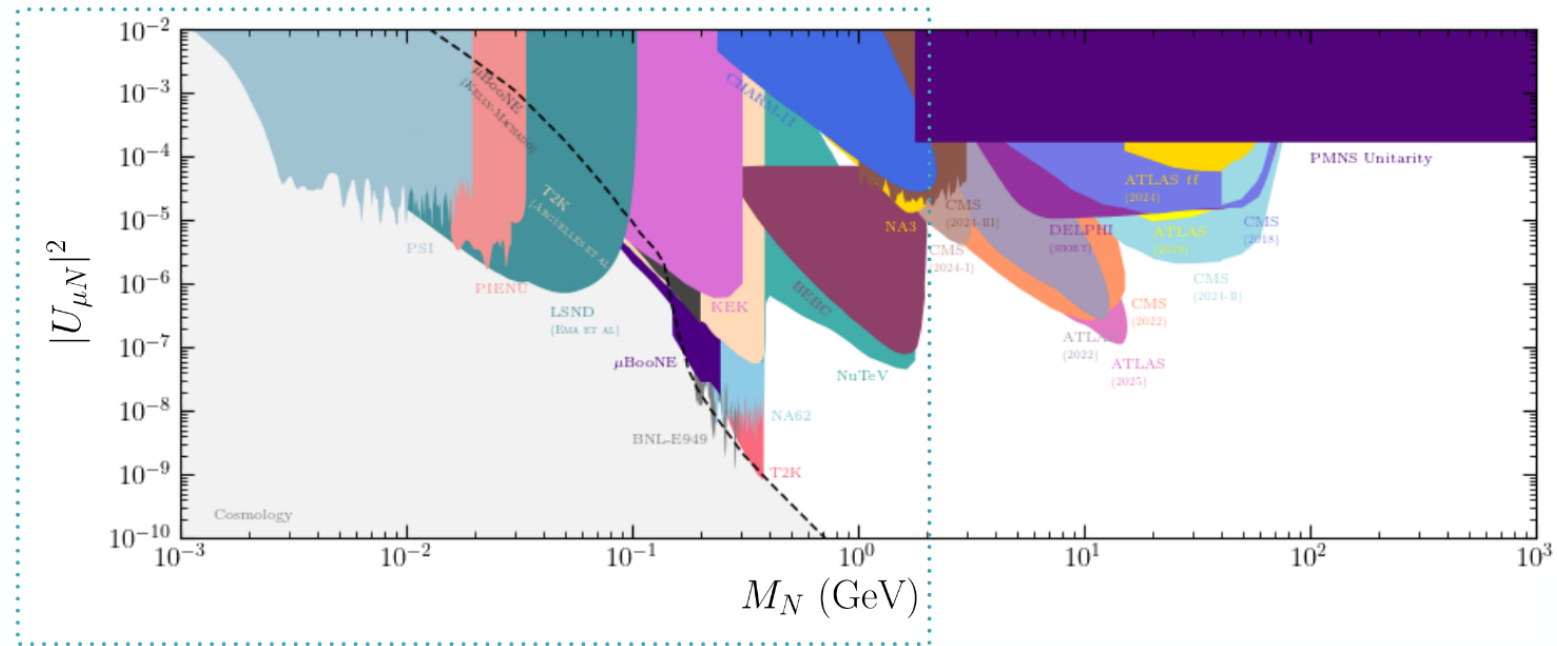


NK+ 2025



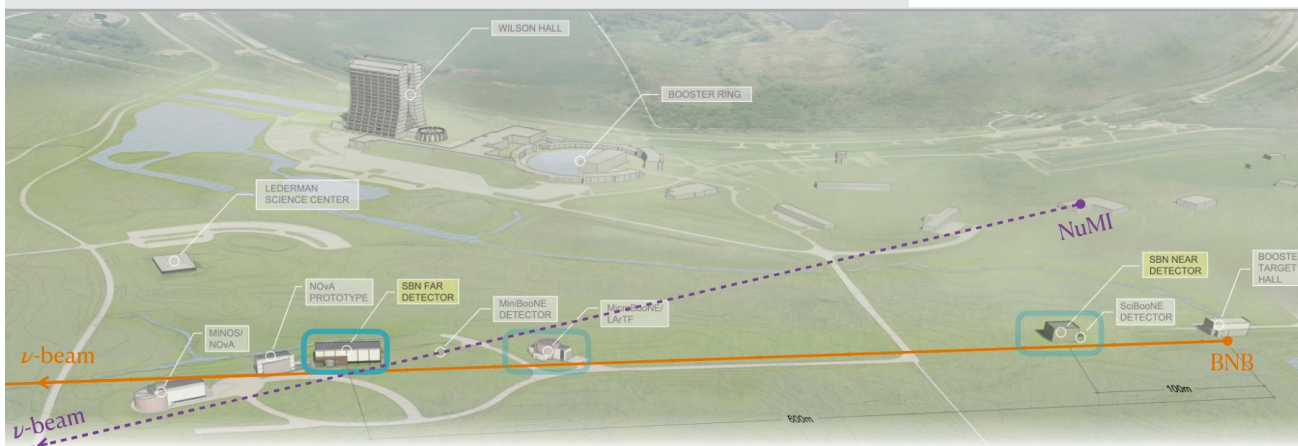
Heavy Neutral Leptons: present bounds

By J.Hernandez-Garcia



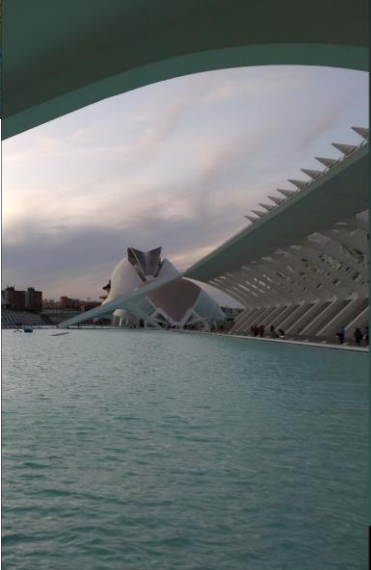
Experimental setup: BNB and NuMI

Present bounds in the HNL mass window up to ~ 2 GeV led by peak searches and beam-dump experiments



ICARUS is also exposed to the NuMI ν -beam.

NuMI: 120 GeV protons from main injector against graphite target, accumulating $6.6 \cdot 10^{20}$ PoT/year.



Probing HNL properties through their lifetime distribution

15th workshop of the Long-Lived Particle Community
LLP 2025
Valencia, June 2nd, 2025

Juraj Klarić

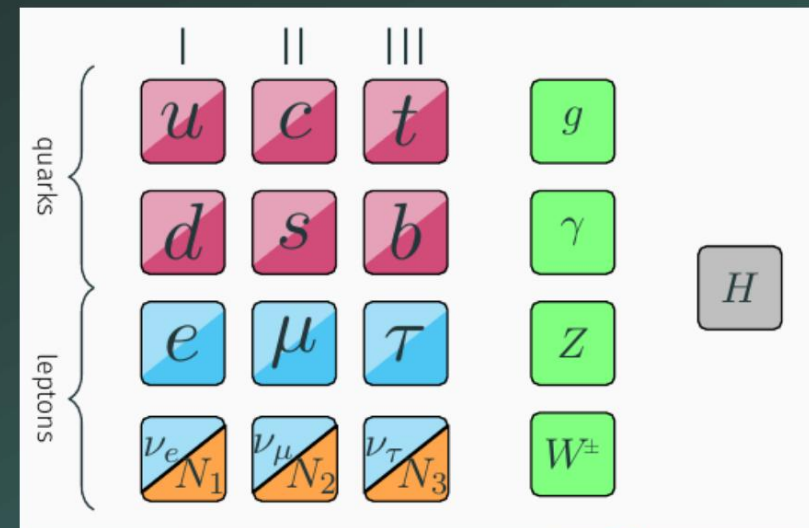
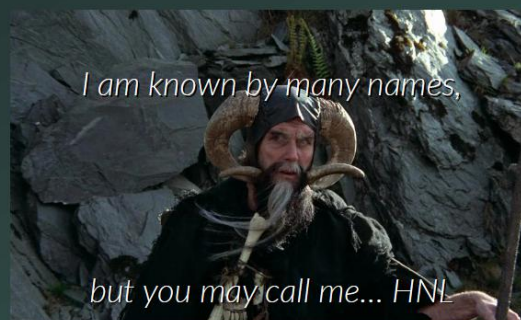


[Juraj Klarić](#)

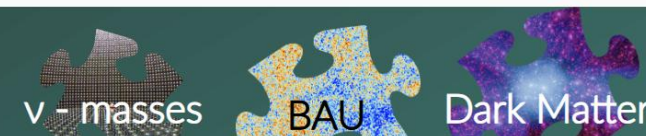
Heavy Neutral Leptons

Also known as:

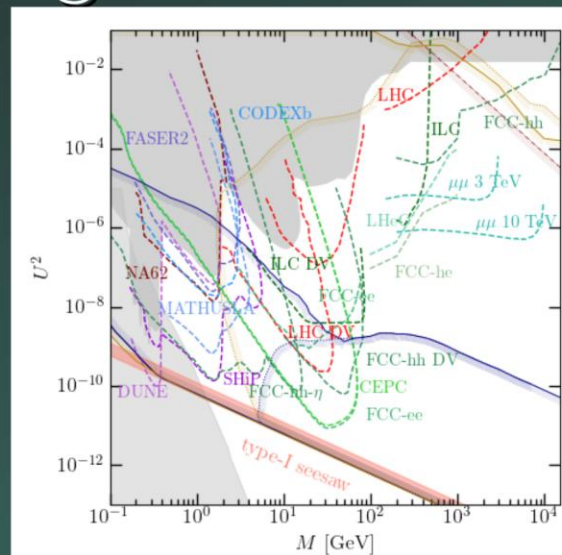
- Right-handed neutrinos
- Sterile neutrinos
- Heavy Majorana neutrinos



The parameter space seesaw & leptogenesis



- Minimal 2 HNL scenario can explain both the **neutrino masses & baryon asymmetry**
 - 3rd HNL could act as a **DM candidate**
- If $m_0 > 0$, all three HNLs need to contribute to neutrino masses
- 3rd HNL also makes much larger couplings possible
- Leptogenesis is possible in the entire exp. accessible region



How is 3>2?

$$\theta = iU_\nu \sqrt{m_\nu^{\text{diag}}} \mathcal{R} \sqrt{M_M^{-1}}$$

[Casas, Ibarra 2001]

2 HNLs

3 HNLs

- + 2 HNL masses
- + 1 complex ($\times 2$) angle
- + 2 light neutrino masses
- + 3 PMNS angles
- + 1 CP phase δ
- + 1 Majorana phase α

11 (6 free) real parameters

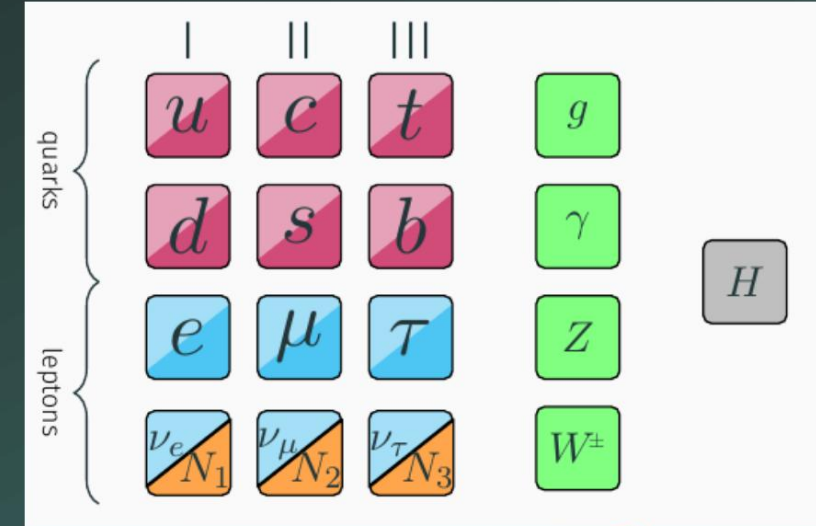
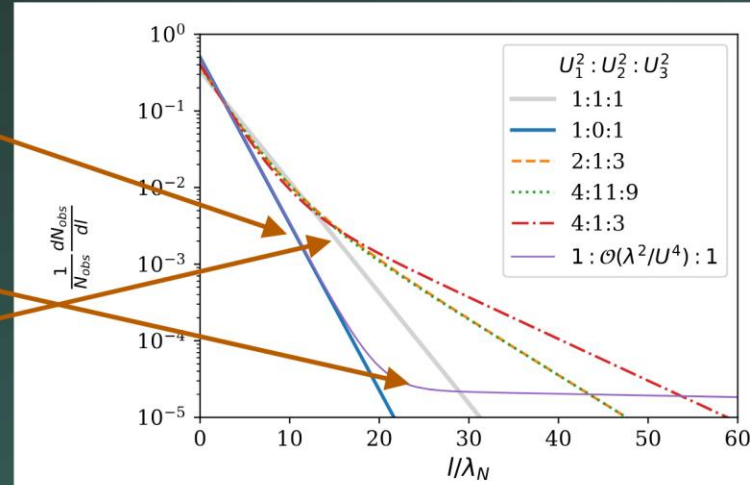
- + 3 HNL masses
- + 3 complex ($\times 2$) angles
- + 2 + 1 light neutrino masses
- + 3 PMNS angles
- + 1 CP phase δ
- + 2 Majorana phases $\alpha_{1,2}$

18 (13 free) real parameters

3HNLs: Beyond a simple decay law by Neutral Leptons

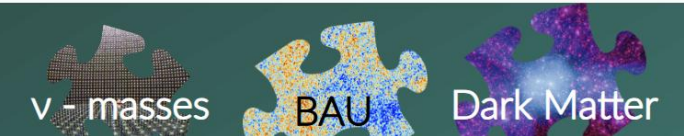
Decay distribution carries information about HNL mixing angles:

- Two of the HNLs can have equal mixings as expected in the pseudo-Dirac case
- Very long lived states** can exist
- Completely different **$O(1)$ mixing ratios** become possible



Outlook & Conclusions

- 3 HNLs, can appear quite different than **pseudo-Dirac** neutrinos even for $O(1)$ mixing angles
- This can lead to **lifetime distributions** that substantially differ from a simple **exponential decay law**
- These distributions **encode information** about the HNL mixing angles U_i^2
- The connection to the theory parameters is often not straightforward:
 - U^2 corrections can significantly alter the physical HNL states
 - Large U^2 corrections re-establish a **clear pseudo-Dirac pair**
 - The lifetime of the remaining long-lived HNL can **shed light on the mass difference parameters**



How is $3 > 2$?

$$\theta = iU_\nu \sqrt{m_\nu^{\text{diag}}} \mathcal{R} \sqrt{M_M^{-1}}$$

[Casas, Ibarra 2001]

2 HNLs

- + 2 HNL masses
- + 1 complex ($\times 2$) angle
- + 2 light neutrino masses
- + 3 PMNS angles
- + 1 CP phase δ
- + 1 Majorana phase α

11 (6 free) real parameters

3 HNLs

- + 3 HNL masses
- + 3 complex ($\times 2$) angles
- + 2 + 1 light neutrino masses
- + 3 PMNS angles
- + 1 CP phase δ
- + 2 Majorana phases $\alpha_{1,2}$

18 (13 free) real parameters

Long-Lived Particles (LLPs) could be the portal to hidden sectors addressing different Standard Model open problems

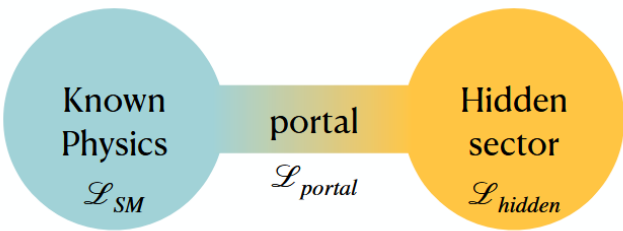
By J.Hernandez-Garcia

LLP Searches at Beam-Dump Experiments

JOSU HERNANDEZ-GARCIA

BASED ON ARXIV: 2408.03383 AND 2007.03701

ARXIV:2408.03383 and 2007.03701



BSM portal	New particle	New parameters	SM open problem
Fermion portal	HNLS – N	$M_N, U_{\alpha N}$	Neutrino masses
Axion portal	ALPs – a	m_a, f_a	Strong CP
Scalar portal	Dark scalar – S	m_S, θ	Vacuum stability
Vector portal	Dark photon – Z'	$m_{Z'}, \epsilon$	DM candidate

Phenomenology of LLP portals: HNLS

Origin of neutrino masses and mixings

HNL mixes with active neutrinos

$$\nu_\alpha = \sum_i U_{\alpha i} \nu_i + U_{\alpha N} N$$

HNL CC and NC interactions:

$$\mathcal{L}_{N,int} \supset -\frac{m_W}{v} \bar{N} U_{\alpha N}^* \gamma^\mu \ell_{L\alpha} W_\mu^+ - \frac{m_Z}{\sqrt{2}v} \bar{N} U_{\alpha N}^* \gamma^\mu \nu_{L\alpha} Z_\mu$$

Minimal model: 2 HNLS needed. Phenomenology given by 4 free parameters:

- HNL mass, M_N
- mixing with three ν_α , $U_{\alpha N}$

Heavy Neutral Leptons (HNLS)

$U_{\alpha N} \ll 1 \Rightarrow$ weaker than weak interaction

Experimental results shown single flavor dominance $\Rightarrow$ HNL coupled to one flavor at a time:

$|U_{eN}|^2 : |U_{\mu N}|^2 : |U_{\tau N}|^2 = 1 : 0 : 0$
 e dominance

$|U_{eN}|^2 : |U_{\mu N}|^2 : |U_{\tau N}|^2 = 0 : 1 : 0$
 μ dominance

$|U_{eN}|^2 : |U_{\mu N}|^2 : |U_{\tau N}|^2 = 0 : 0 : 1$
 τ dominance

The ICARUS experiment at SBN

Proposed to:

- Clarify LSND and MiniBooNE anomalies
- Explore sterile neutrino in the eV mass scale

Three liquid Ar TPCs

Taking data since 2015

μ BooNE

170 tons
Baseline: 470 m
2015 – 2021

SBND

270 tons
Baseline: 110 m
2024

ICARUS

760 tons
Baseline: 600 m
2021

Short-Baseline Neutrino (SBN)

Exposed to the Booster Neutrino Beam (BNB) produced from 8 GeV protons from the booster

Phenomenology of LLP portals: ALPs

Strong CP problem in QCD

ALP production:

- $m_a < 1 \text{ GeV}$
 $\pi^0, \eta, \eta' \cdots \times \cdots a$
- $m_a > 1 \text{ GeV}$: gluon fusion

Gluon dominance scenario

$$\delta \mathcal{L}_{a,int} = \frac{\alpha_s}{8\pi f_a} a G_{\mu\nu}^b \tilde{G}^{b\mu\nu}$$

Axion-Like Particles (ALPs)

Pheno encoded 2 free parameters:

- ALP mass m_a
- Decay constant f_a

ALP decay:

- $m_a < 3m_\pi$: $a \rightarrow \gamma\gamma$
- $m_a > 3m_\pi$: $a \rightarrow 3\pi^0, \pi^+\pi^-\pi^0$

Present bounds:

- Visible: NA62, NA48/2, BaBar, CHARM
Bounds derived in arXiv: 2201.07805 and 2201.05170
- Invisible: NA62, Belle
Bounds derived in arXiv: 2201.07805

Phenomenology of LLP portals: Dark Scalar

EW vacuum stability

Dark scalar production:

- One-loop FCNC processes
 $K^+ \rightarrow \pi^+ S$ and $K_L \rightarrow \pi^0 S$
- D decays CKM suppressed
- B decays not suppressed, but small production yield in DUNE

Scalar mixed Higgs boson

$$\mathcal{L} \supset c_2 |H|^2 S$$

Dark Scalar

Pheno encoded 2 free parameters:

- Scalar mass m_s
- Its mixing $\theta \sim c_2 v_H / m_H$

Dark scalar decay:

- $S \rightarrow e^+e^-$
- $S \rightarrow \mu^+\mu^-$
- $S \rightarrow \pi^+\pi^-$ and $S \rightarrow \pi^0\pi^0$
- $S \rightarrow K^+K^-$

Present bounds:

CHARM, KOTO, NA62, E949, SN1987A, LHCb, Belle

The DUNE experiment: the Near Detector Phase-I

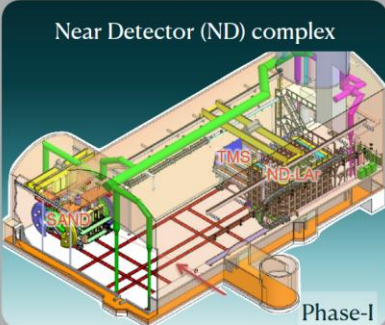
Measure initial flux composition

Systematic uncertainties on ν flux and cross section

SAND
System for On-Axis Neutrino Detection: fixed on-axis magnetized beam spectrum monitor

Exposure: $1.1 \cdot 10^{21}$ PoT/year

Near Detector (ND) complex



ND-LAr
150 ton LArTPC
Same detection technology and nuclear target of FD

TMS
The Muon Spectrometer: magnetized steel range stack serve as muon catcher for ND-LAr

PRISM: ND-LAr and TMS move up to 28.5 m off axis to facilitate measurements of different neutrino fluxes

The DUNE experiment: the Near Detector Phase-II

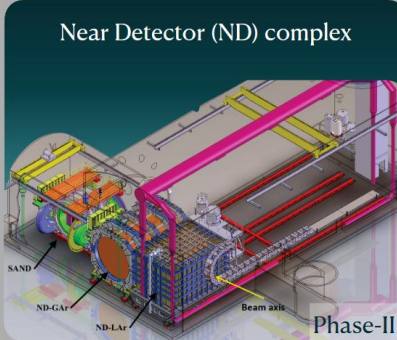
Measure initial flux composition

Systematic uncertainties on ν flux and cross section

SAND
System for On-Axis Neutrino Detection: fixed on-axis magnetized beam spectrum monitor

Exposure: $\sim 2 \cdot 10^{21}$ PoT/year

Near Detector (ND) complex



ND-LAr
150 ton LArTPC
Same detection technology and nuclear target of FD

ND-GAr
A 1 ton high-pressure gaseous Ar TPC + ECAL in a 0.5 T magnetic field

PRISM: ND-LAr and ND-GAr move up to 28.5 m off axis to facilitate measurements of different neutrino fluxes

Lepton Number Violation in Symmetry-protected Seesaw Models

Bruno M. S. Oliveira in collaboration with Stefan Antusch and Jan Hajer

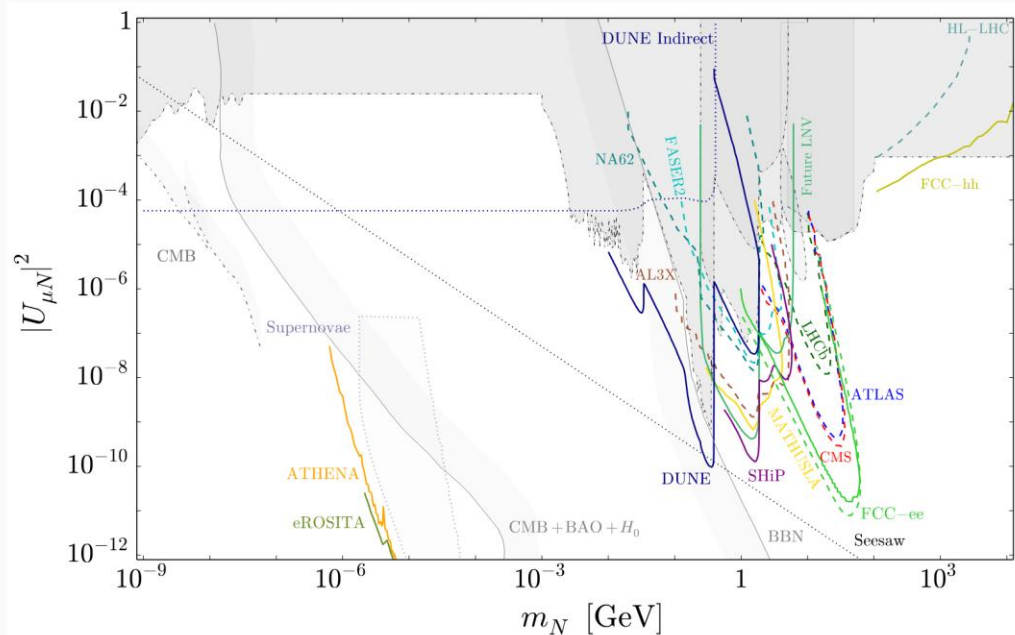
Centro de Física Teórica de Partículas (CFTP), Instituto Superior Técnico (IST), Universidade de Lisboa (UL)
CERN/FIS-PAR/0002/2021 and CERN/FIS-PAR/0019/2021

LLP2025

Fifteenth workshop of the Long-Lived Particle Community

Brun M

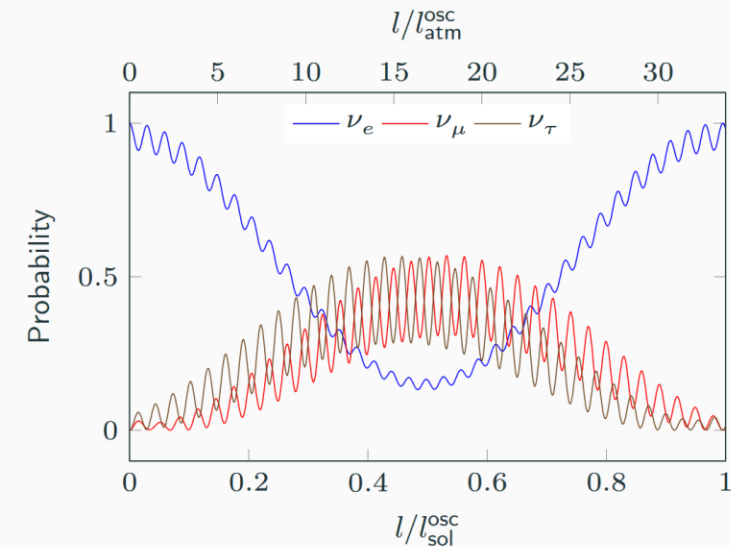
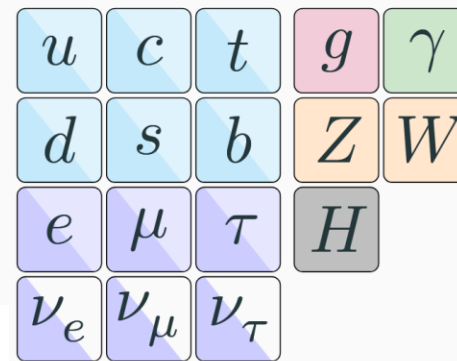
Seesaw Mechanism [1912.03058]



Small coupling: $|\theta|^2 \ll 1$
Discoverability limited by **luminosity**

High scale: $M_M \approx M_{\text{GUT}}$
Discoverability limited by **energy**

$$\text{SU}(3)_C \times \text{SU}(2)_L \times \text{U}(1)_Y$$



Colourless

Neutral

**Neutrinos are
Only left-chiral**

Massless

Unable to explain neutrino flavour oscillations

Colourless

Neutral

**Neutrinos are
Only left-chiral**

Massless

Explains neutrino flavour oscillations

UHE events at KM3NeT and ANITA

and how to leverage them for BSM (and LLPs).

working with C. A. Argüelles, A. Burgos, A. Burns, I. Esteban, J. López-Pavón, I. Martínez-Soler, J. Salvadó.

Toni Bertólez-Martínez
2305.03746, 250X.YYYYY
LLP 2025

Instituto de Ciencias del Cosmos
UNIVERSITAT DE BARCELONA

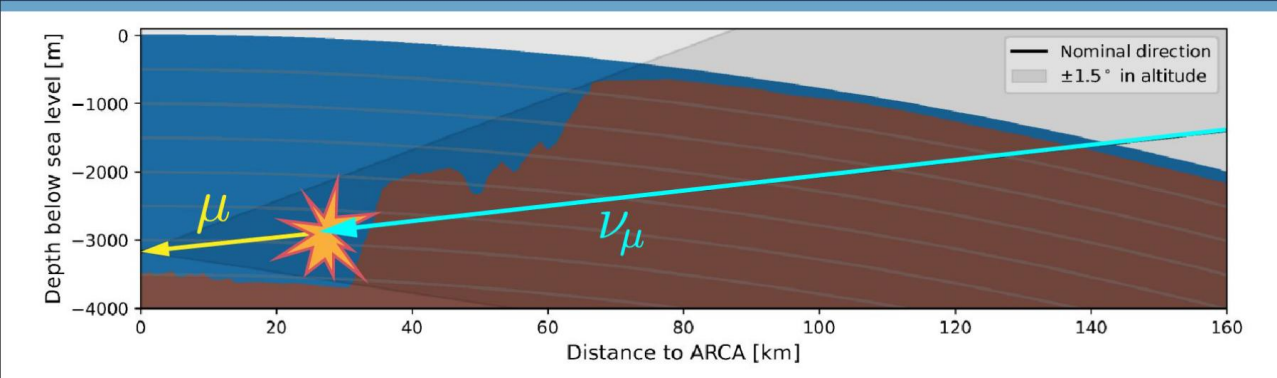
T Bertolez-Martinez

A neutrino with the highest energy ever measured

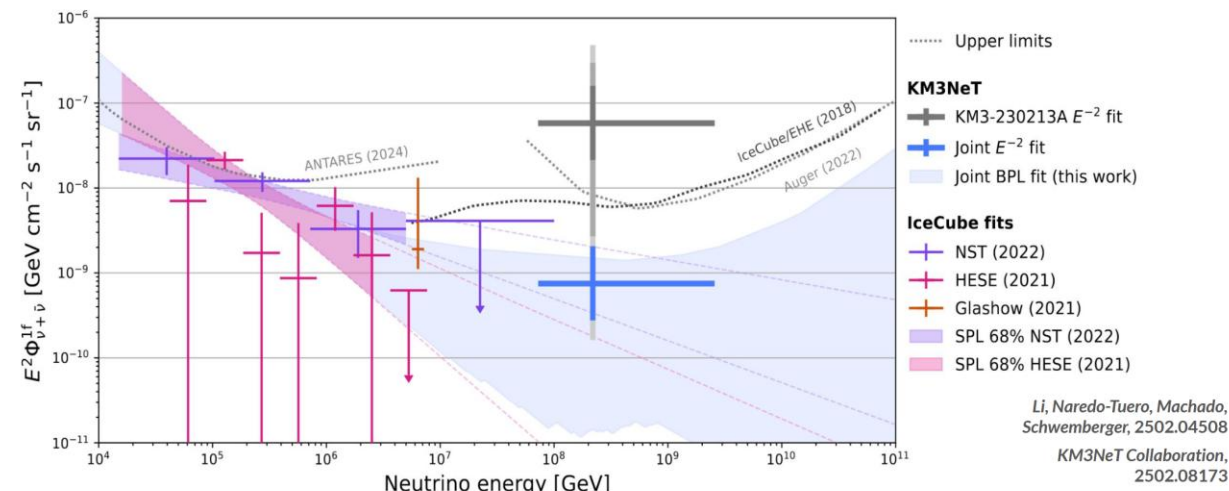
They measured a muon with energy $E_\mu = 120_{-60}^{+110}$ PeV $\xrightarrow{\text{interpretable as}}$ a muon neutrino with energy $E_\nu = 110 - 790$ PeV (68%)

KM3NeT Collaboration, Nature 638 (2025) 8050, 376-382

The Earth-skimming direction is consistent with it.



KM3NeT is in tension with IceCube



The necessary (constant and isotropic) flux to explain the KM3NeT event is in a 2.5σ to 3.8σ tension with the non-observation of IceCube.

The ANITA-IV events

These are **four** up-going electromagnetic cascades, with

ultra-high energies $E = \mathcal{O}(1)$ EeV , and **Earth-skimming** trajectories $L = \mathcal{O}(300)$ km .

The events have distinguishable zenithal angle, and **completely different azimuthal angle**.

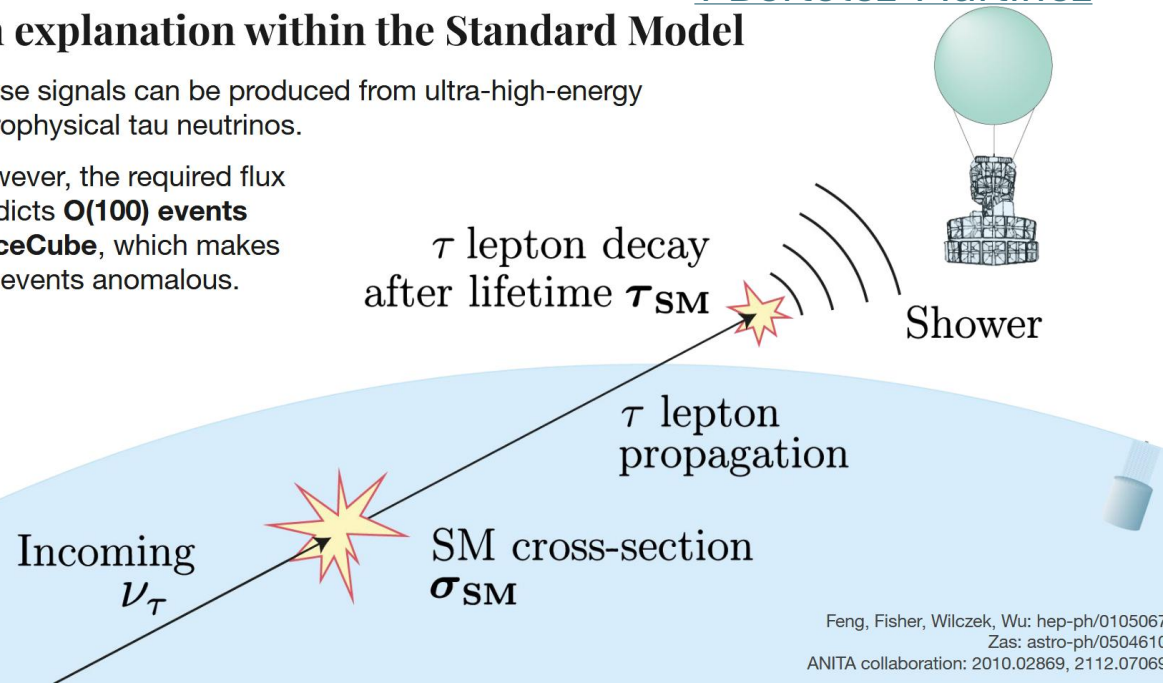
The fact that all happened in a single month suggests a diffuse flux origin.

Not to scale.

An explanation within the Standard Model

These signals can be produced from ultra-high-energy astrophysical tau neutrinos.

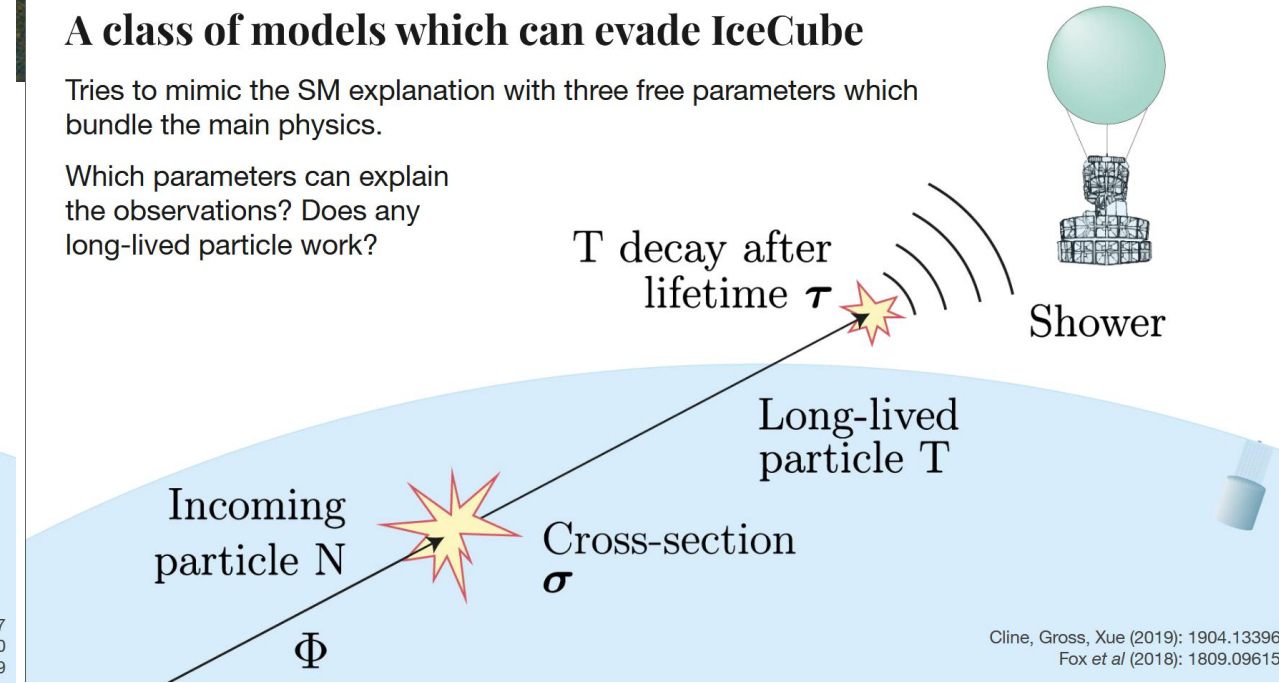
However, the required flux predicts **O(100) events in IceCube**, which makes the events anomalous.



A class of models which can evade IceCube

Tries to mimic the SM explanation with three free parameters which bundle the main physics.

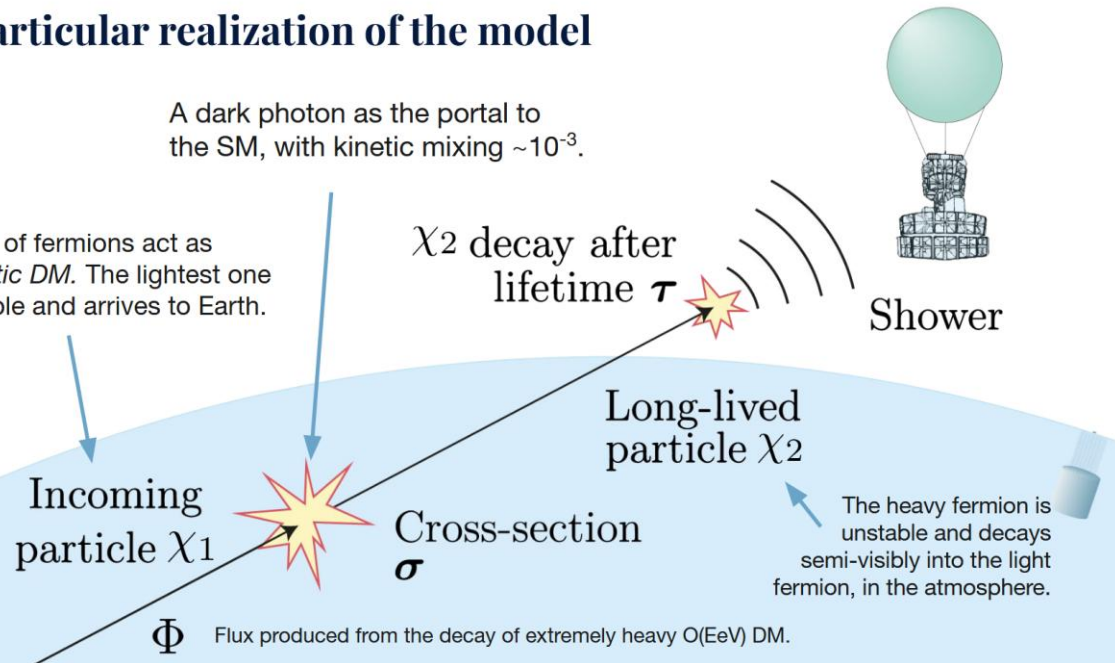
Which parameters can explain the observations? Does any long-lived particle work?



A particular realization of the model

A dark photon as the portal to the SM, with kinetic mixing $\sim 10^{-3}$.

A pair of fermions act as *inelastic DM*. The lightest one is stable and arrives to Earth.

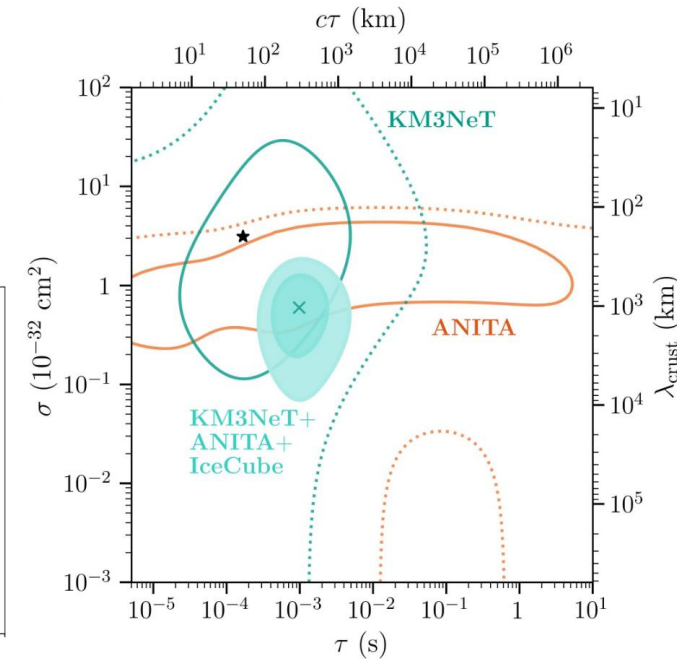
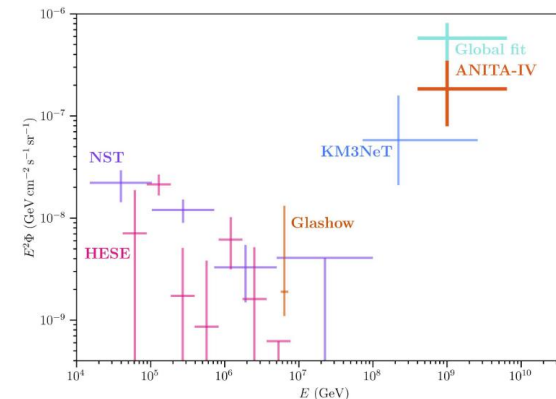


Global fit

A global explanation w/ANITA-IV becomes harder to fit, with the BF slightly below 4σ . A way out is extremely-elastic scatterings in the LLP production.

$$\sigma = 0.2\sigma_{SM} \quad \Phi = 8 \text{ km}^{-2} \text{ day}^{-1}$$

$$\tau = 5\tau_{SM} \quad \text{Br}(T \rightarrow \mu) = 0.3$$

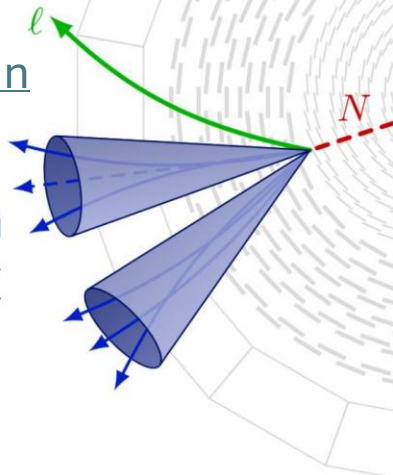




Probing long-lived HNLs with top-philic interactions @ LHC

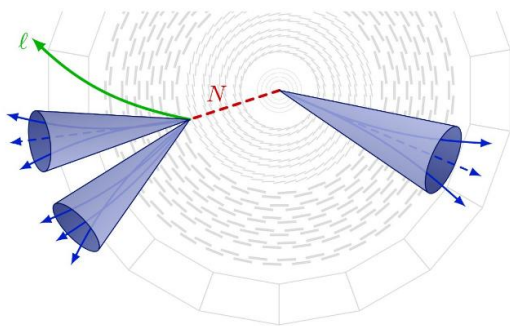
Rebeca Beltrán (IFIC Valencia)
rebeca.beltran@ific.uv.es

based on JHEP 05 (2025) 238 with G. Cottin, J. Günther, M. Hirsch, A. Titov, Z. S. Wang



ATLAS search proposal

Signal: **displaced vertex (DV)** from HNL decay accompanied by **jets**



Two-stage event selection:

Event-level	4, 5 or 6 jets with $p_T > 90, 65, 55$ GeV *Discovery prospects: identify b -jets
Vertex-level	4 mm $< R_{xy} < 300$ mm , $ z < 300$ mm 1 track with $ d_0 > 2$ mm 5 tracks with $\begin{cases} \gamma\beta_{xy}c\tau > 520 \text{ mm} \\ p_T/ q > 1 \text{ GeV} \end{cases}$ $m_{DV} > 10$ GeV

+ parameterized efficiencies at vertex-level from [2301.13866]

Inspired by :

- recast [2404.06126] for ATLAS “DV+jets” search [2301.13866]
- past 8 TeV search for DVs at ATLAS [1504.05162]

N_R SMEFT and top-philic interactions

N_R SMEFT : SMEFT + sterile N

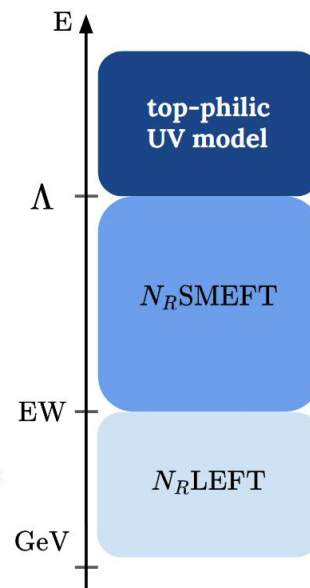
Model: electroweak HNLs + heavy particles at NP scale mediating interactions between **top quarks** and HNLs. At low energies:

$$\mathcal{L}_{N_R\text{SMEFT}} \supset \mathcal{L}_{\text{SM}+N_R}^{(4)} + \sum \frac{1}{\Lambda^2} c_{\mathcal{O}}^{ijkl} \mathcal{O}_{ijkl}^{(6)}$$

Top - HNL operators

Underexplored, but promising @ LHC due to high top production rates

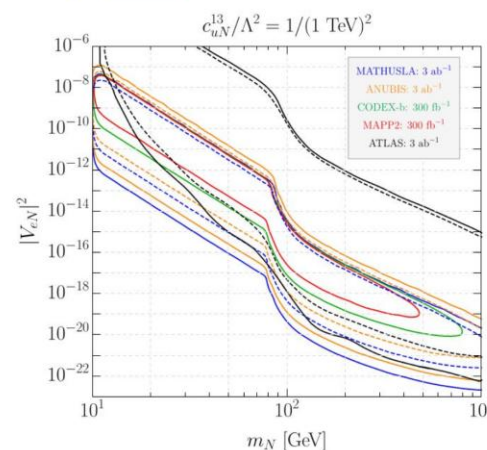
This talk: how **LLP searches** can probe **top-philic HNLs**



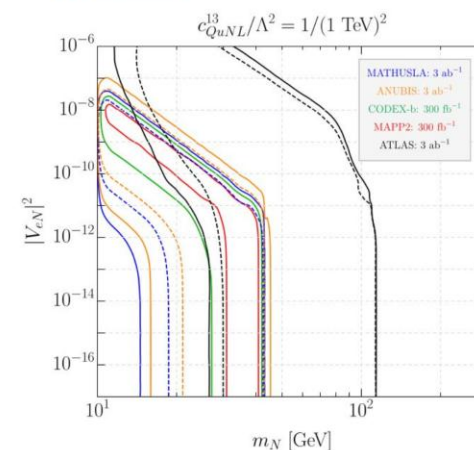
Sensitivity prospects: $(m_N, |V_{eN}|^2)$

$\sqrt{s} = 14$ TeV

1 $\mathcal{O}_{uN}^{13} (\overline{u}_R \gamma^\mu t_R) (\overline{N}_R \gamma_\mu N_R)$



2 $\mathcal{O}_{QuNL}^{13} (\overline{u}_L t_R) (\overline{N}_R \nu_L) + (\overline{d}_L t_R) (\overline{N}_R e_L)$



Solid (dashed): 3 (30) signal events

Exploring Long-Lived Hidden Valleys

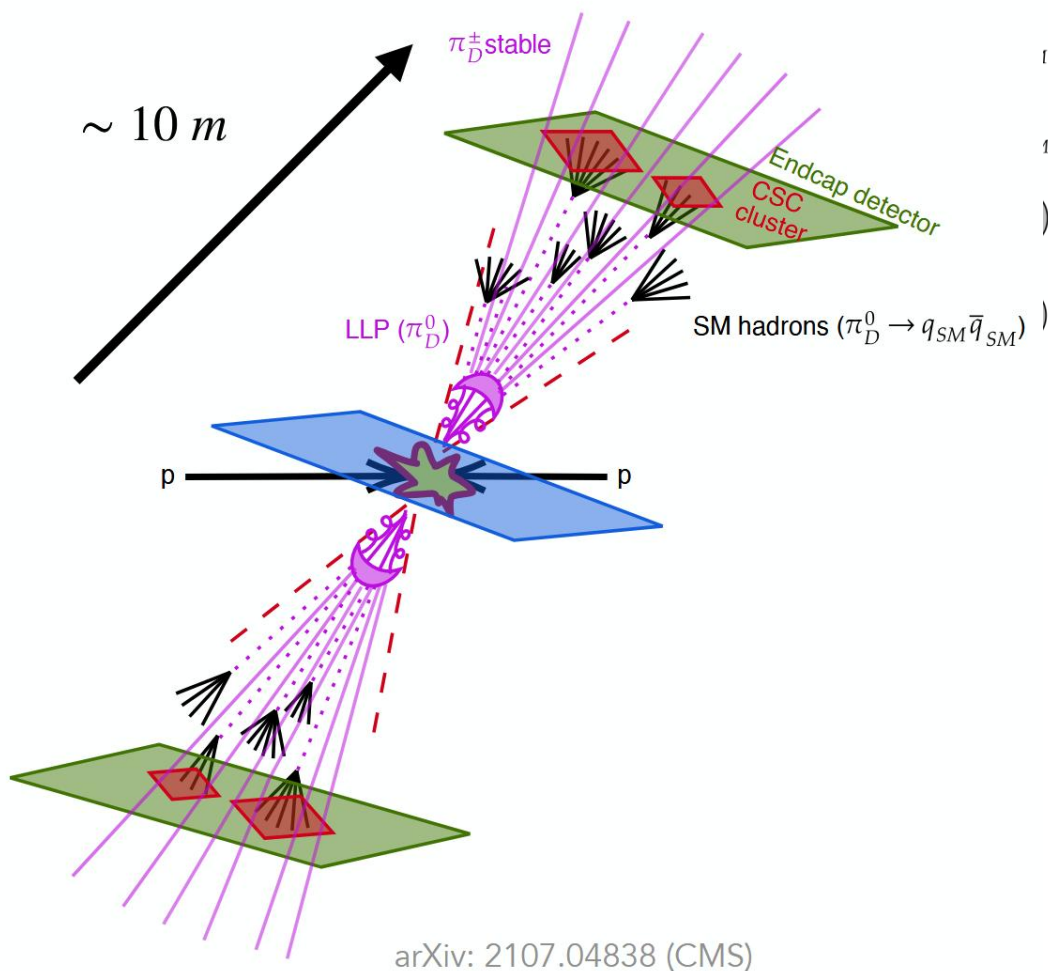
Constraining dark sectors in the muon endcap

Joshua Lockyer

joshua.lockyer@uni-graz.at

Collaboration with: Suchita Kulkarni & Wei Liu

Based on:
arXiv:2505.03058



arXiv: 2107.04838 (CMS)

Confining Hidden Valley models

- Hidden Valley (HV) models extend the SM with a new dark sector uncharged under the SM gauge group, instead connecting to the SM through a heavy mediator, here we use a $U(1) Z_D$.

Theory
arXiv:0604261, M.J. Strassler et al.
arXiv:1502.05409, P. Schwaller et al.
arXiv:1503.00009, T. Cohen et al.
arXiv:0712.2041, T. Han et al.

Standard Model:

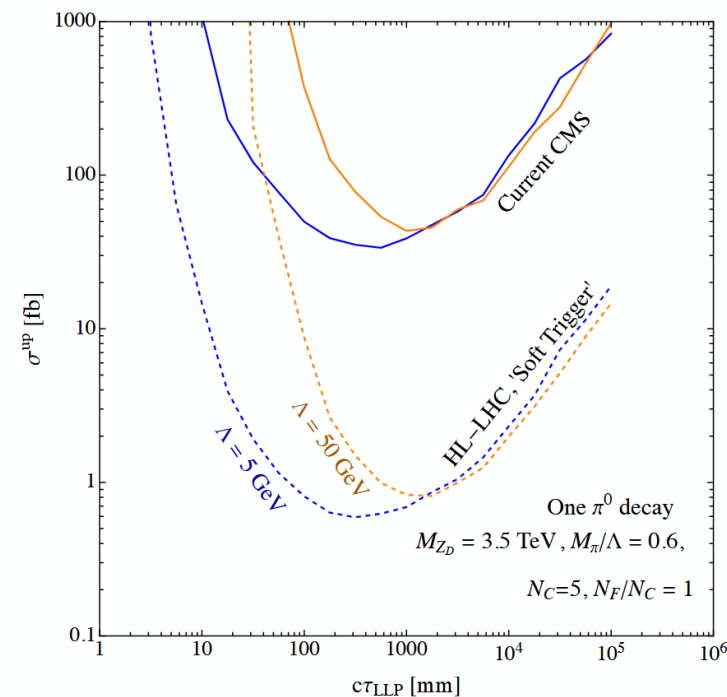
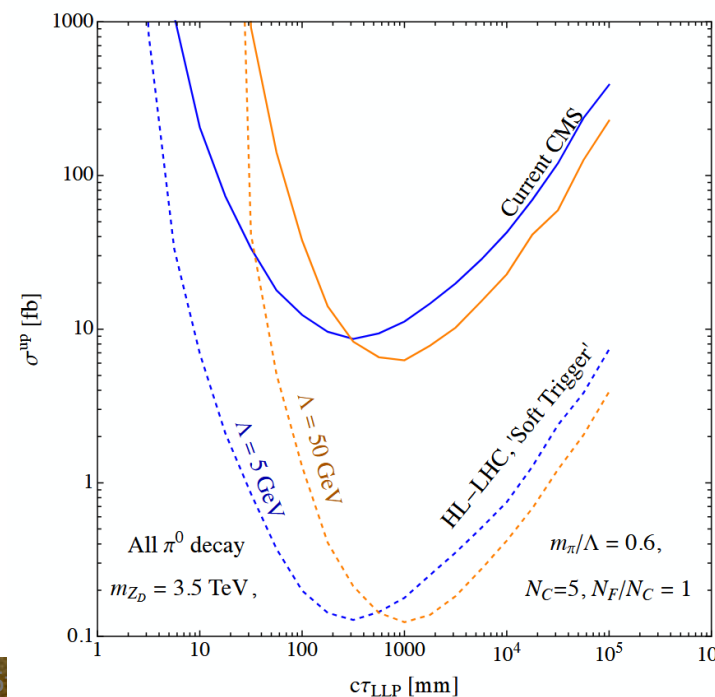
$SU(3)_C \times SU(2)_L \times U(1)_Y$

Heavy Z_D
mediator

$SU(N_C)$
dark sector
gauge group
with N_F dark
quarks.

Experimental searches:
arXiv:2112.11125 (CMS)
arXiv:2305.18037 (ATLAS)
arXiv:2505.02429 (ATLAS)
arXiv:2102.10874 (ATLAS)
arXiv:2403.01556 (CMS)

- Focus on dark sectors with a $SU(N_C)$ gauge group with N_F flavours of degenerate fundamental Dirac fermions (dark quarks). Such sectors are characterised by four parameters; N_C , N_F , Λ and m_π/Λ . Confinement ensures the formation of bound states; in our case dark mesons - typically dark pions or dark rhos.
- Certain classes of HV models resembling QCD present novel collider signatures and exciting opportunities for new physics discovery. Many searches already exist at colliders for the signatures of QCD-like dark sectors.



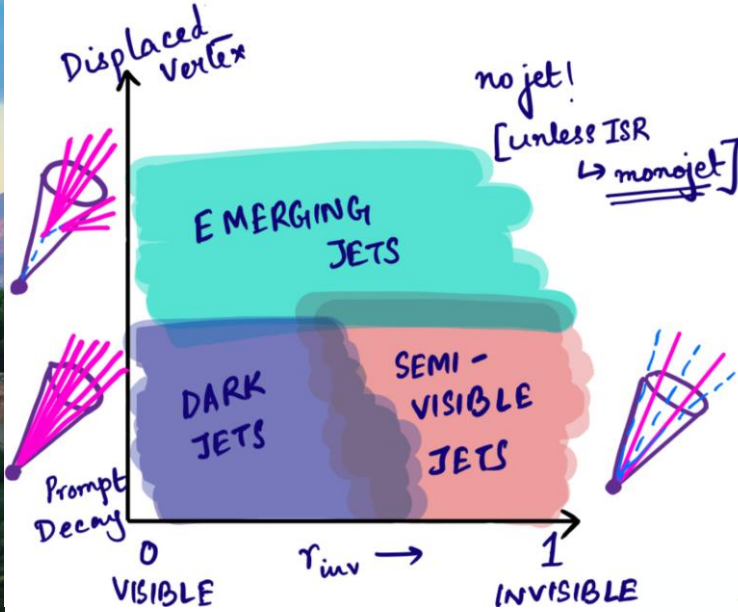
DARK SHOWERS FROM SNEAKY DM



UNIVERSIDAD DE GRANADA
FT&E
High Energy Theory

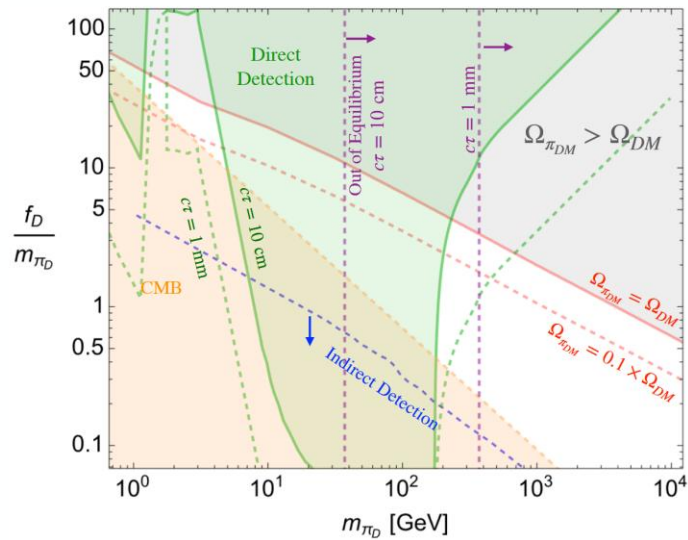
LLP2025 VALENCIA
ADRIAN CARMONA BERMUDEZ

'Dark Showers from Sneaky Dark Matter'
AC, Elahi, Scherb, Schwaller. JHEP (in press),
arXiv: 2411.15073

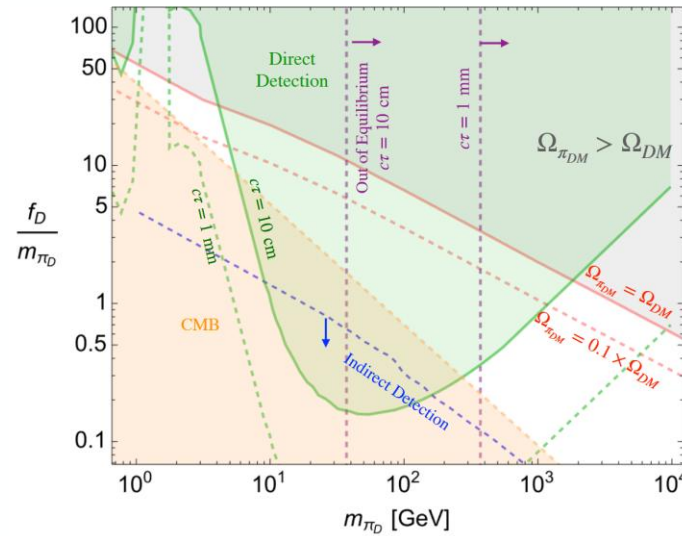


DM PHENOMENOLOGY

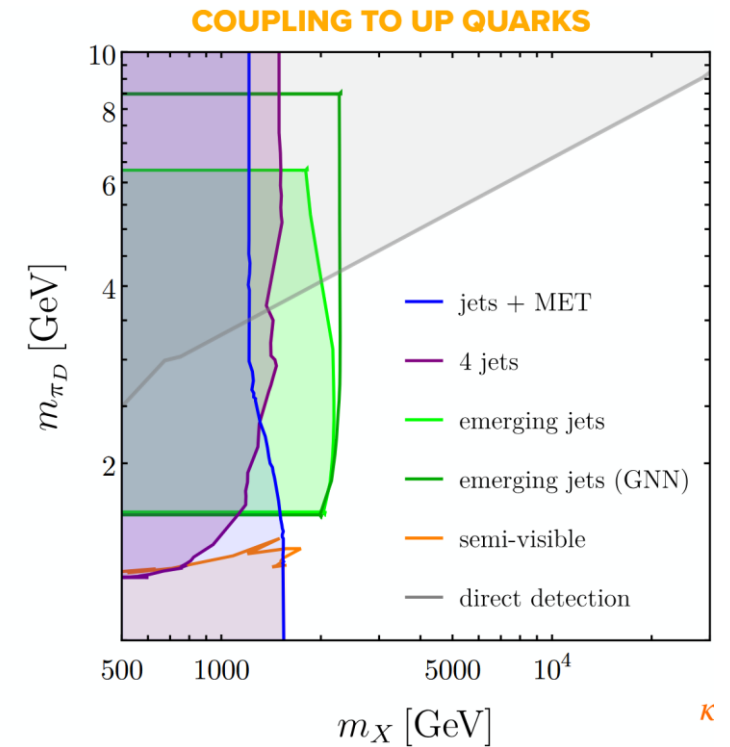
Natural motivation to look for long-lived particles!



COUPLING TO UP QUARKS



COUPLING TO DOWN QUARKS



Probing conversion-driven freeze-out at the LHC



by A. Lessa, J. Heisig, Lucas Magno D. Ramos

ArXiv: 2404.16086
Phys.Rev.D 110 (2024)

Main References

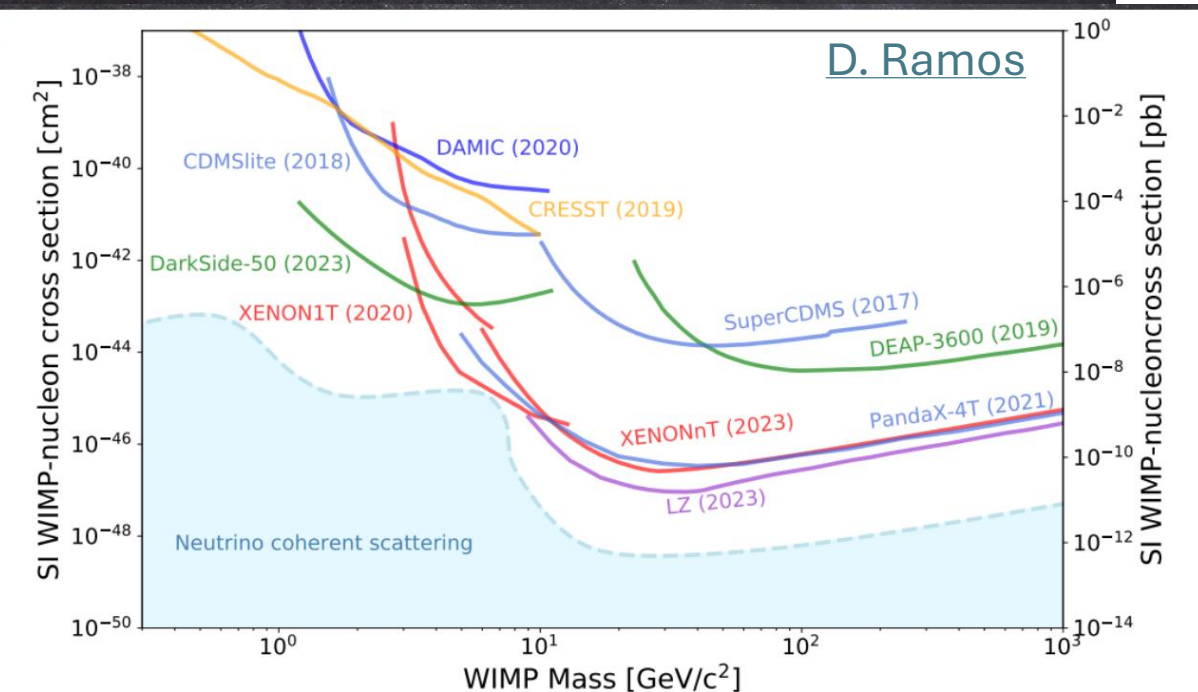
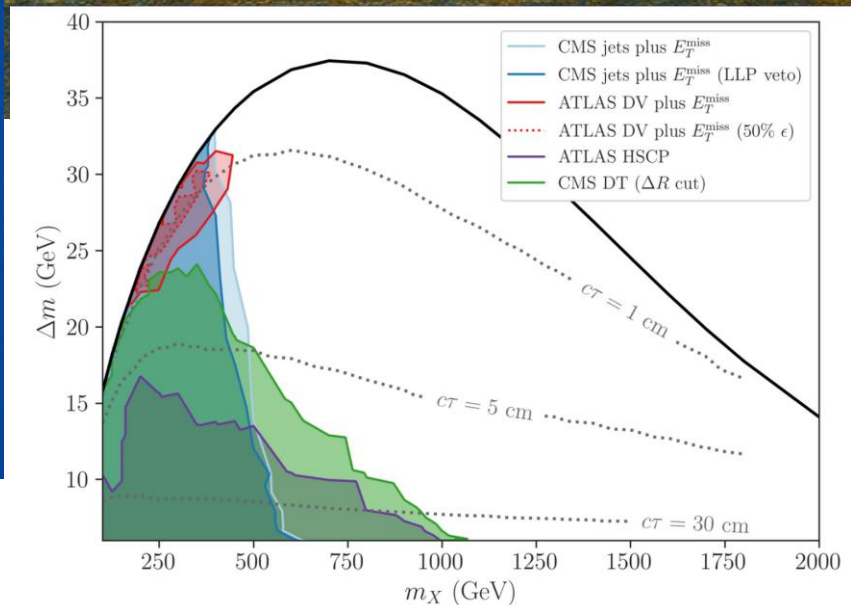
"Probing conversion-driven freeze-out at the LHC", arXiv:2404.16086

"Fourth Exception in the Calculation of Relic Abundances", arXiv: 1705.08450

"Coannihilation without chemical equilibrium", arXiv:1705.09292

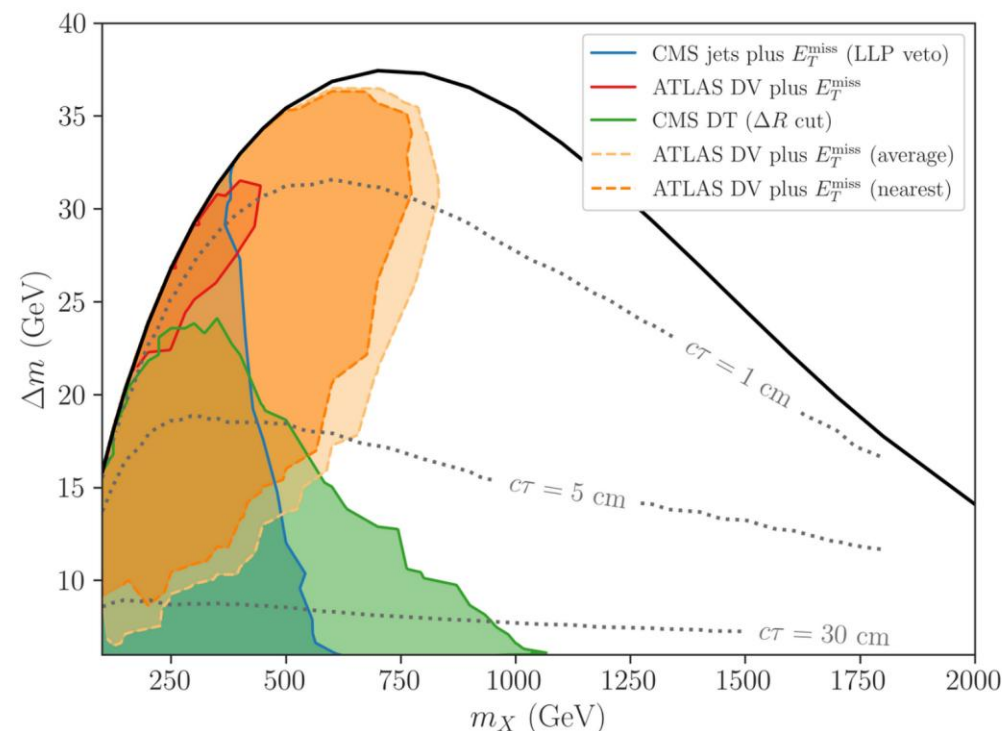
Searches:

ATLAS-SUSY-2018-42 / CMS-EXO-19-010
CMS-EXO-16-044 / ATLAS-SUSY-2016-08
ATLAS-SUSY-2018-13 / CMS-EXO-20-004



D. Ramos

PDG Review of Particle Physics, 2024; Section 27. Dark Matter



The LOHENGRIN Experiment: Status and Theory Predictions

Martin Schürmann^{a*}
for the LOHENGRIN study group:

Philip Bechtle, Christian Bespín, Dominique Breton, Carlos Orero Canet, Klaus Desch, Herbi Dreiner, Oliver Freyermuth, Rhorry Gauld, Markus Gruber, César Blanch Gutiérrez, Hazem Hajjar, Matthias Hamer, Jan-Eric Heinrichs, Adrian Irls, Jochen Kaminski, Laney Klippahhn, Hans Krüger, Michael Lupberger, Jihane Maalmi, Roman Pöschl, Dennis Proft, Leonie Richarz, Tobias Schiffer, Patrick Schwäbig, Martin Schürmann, Dirk Zerwas.

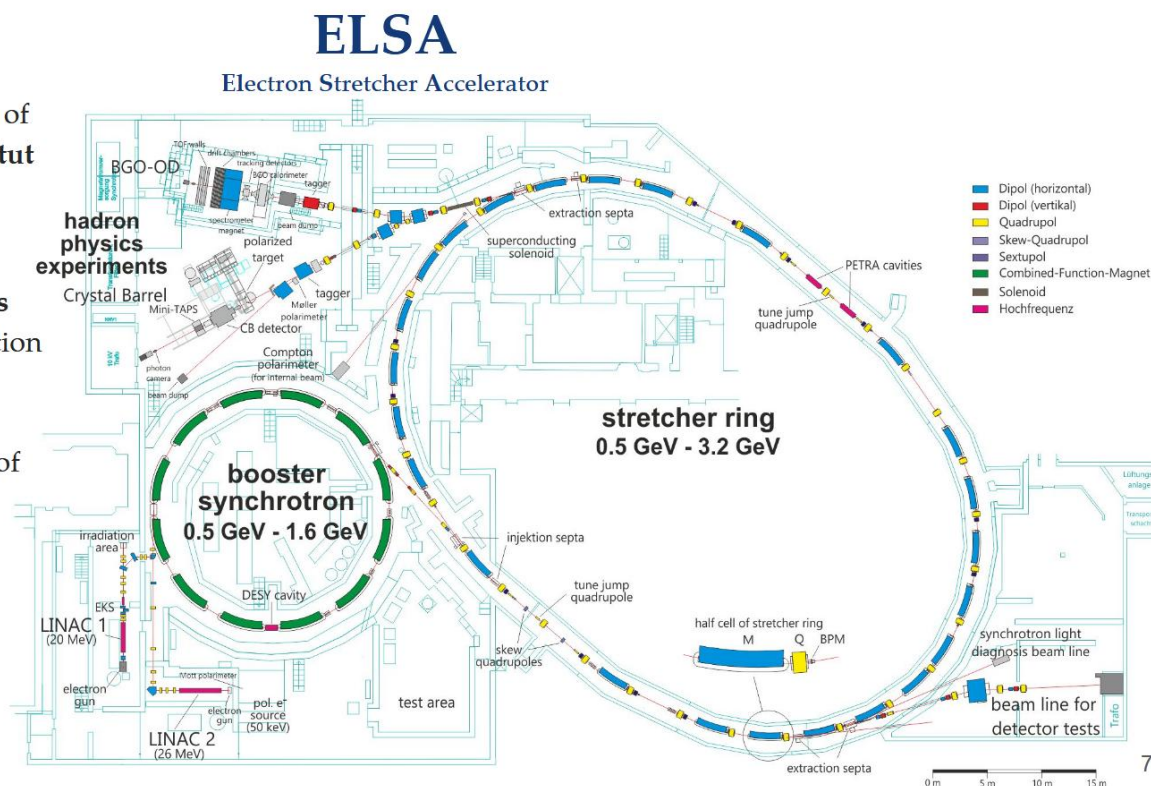
Bechtle, P., Bespín, C., Breton, D. et al.

A proposal for the Lohengrin experiment to search for dark sector particles at the ELSA Accelerator.
Eur. Phys. J. C 85, 600 (2025).

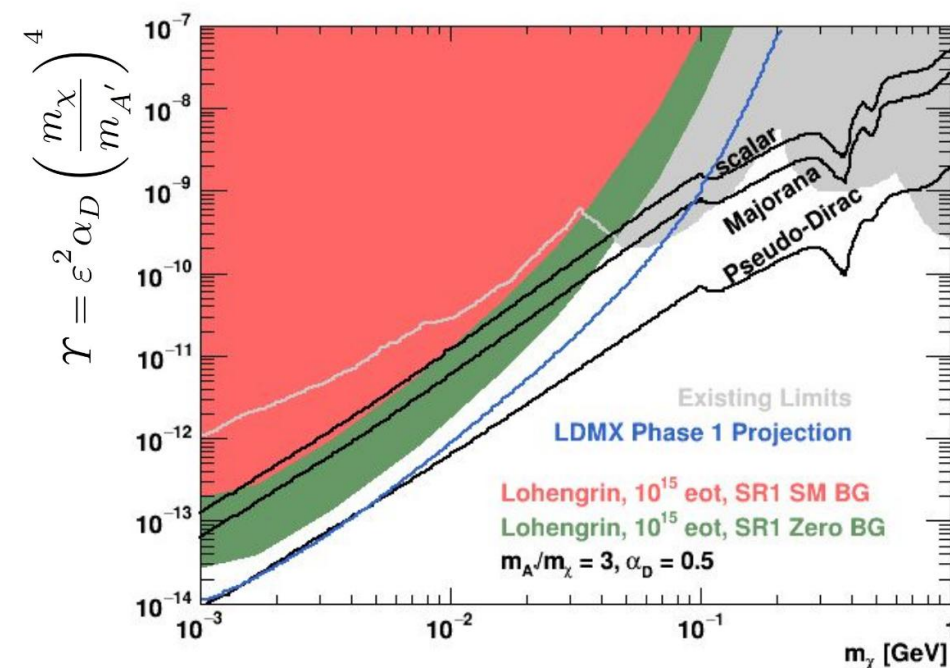
Located in the basement of
the **Physikalisches Institut
in Bonn**

- 3.2 GeV beam of (on average) **single electrons** through resonant extraction
- Small energy spread of 0.8‰
- Effective extraction rate of 100 MHz

=> $\sim 10^{15}$ EOT within a year



- Conservative estimate
- Simple cut and count analysis
- 90% CL
- With some further improvements, LOHENGRIN will probe the **scalar and Majorana thermal relic targets** in low mass region.



Placing Bounds on Dark Matter with Displaced Photons

Joel Jones-Pérez
Pontificia Universidad Católica del Perú (PUCP)

Based on the following work

F. Delgado, L. Duarte, JJP, C. Manrique-Chavil, S. Peña (2205.135)
L. Duarte, JJP, C. Manrique-Chavil (2311.179)
P. Arias, B. Díaz, L. Duarte, JJP, W. Rodriguez, D. Zegarra (25xx.xx)

arXiv > hep-ex > arXiv:2106.02048

High Energy Physics - Experiment

[Submitted on 3 Jun 2021 (v1), last revised 9 Jan 2022 (this version, v3)]

A very high energy hadron collider on the Moon

James Beacham, Frank Zimmermann

The long-term prospect of building a hadron collider around the circumference of a great proton-proton center-of-mass collision energy of 14 PeV -- a thousand times higher than project are presented, including siting, construction, availability of necessary materials of concrete feasibility of each. Machine parameters and vacuum requirements are explored organizations in establishing a permanent Moon presence, a CCM could be the (next-to-machines, such as the proposed Future Circular Collider at CERN or a Super Proton-Pro as an important stepping stone towards a Planck-scale collider sited in our Solar System.

So maybe LLPs are the new SUSY?

Let's hope not!!!

Prelude

- On Monday, James gave a speech wishing for LLP 2625 workshop.
- Which reminded me...

SUSY2215

SUSY: THE NEW HOPE

• QUANTUM MECHANICS AND QFT STILL HOLD

• THE ORBITAL COLLIDER STILL SEES NOTHING

THREE CENTURIES OF TRIUMPH FOR SUSY AND STRINGS!

The seasonal trends

Extremely-weeny constrained SUSY

NSFWMSSM

FF3C10ACBA9-MSSM

MSSM retrograde

Anthropic landscaping and trimming it down

The problem of condensed matter: They still don't get it

Strings - The Perpetual Revolution

Number of free parameters: P or NP complete?

Invited seminar

How to ensure your model remains predictability-free

Forum

Is choice moral?

"Every time you choose a path of action, a multiverse is killed"

Special topic

If the universe is not supersymmetric is it necessarily existing?

The perpetual conference

5 Jan - 5 Mar: Chamonix

15 Mar - 30 June: Hainan Island

1 July - 15 Sep: Wailea, Maui

15 Sep - 20 Nov: Jumeirah 1

21 Nov - 24 Dec: Hainan Island

Sponsored by:

The Milner-Zuckerberg Institution

15th LLP workshop, Valencia

Placing Bounds on Dark Matter with Displaced Photons

Joel Jones-Pérez

Pontificia Universidad Católica del Perú (PUCP)

Based on the following work:

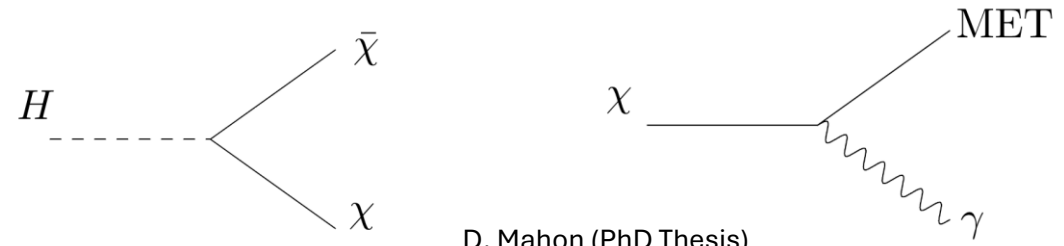
F. Delgado, L. Duarte, JJP, C. Manrique-Chavil, S. Peña (2205.13550)

L. Duarte, JJP, C. Manrique-Chavil (2311.17989)

P. Arias, B. Díaz, L. Duarte, JJP, W. Rodriguez, D. Zegarra (25xx.xxxxx)

Displaced photon search

- Trigger: isolated lepton with $p_T > 27$ GeV.



D. Mahon (PhD Thesis)
ATLAS (ATLAS-CONF-2022-017)
ATLAS (2209.01029 [hep-ex])

Issue:

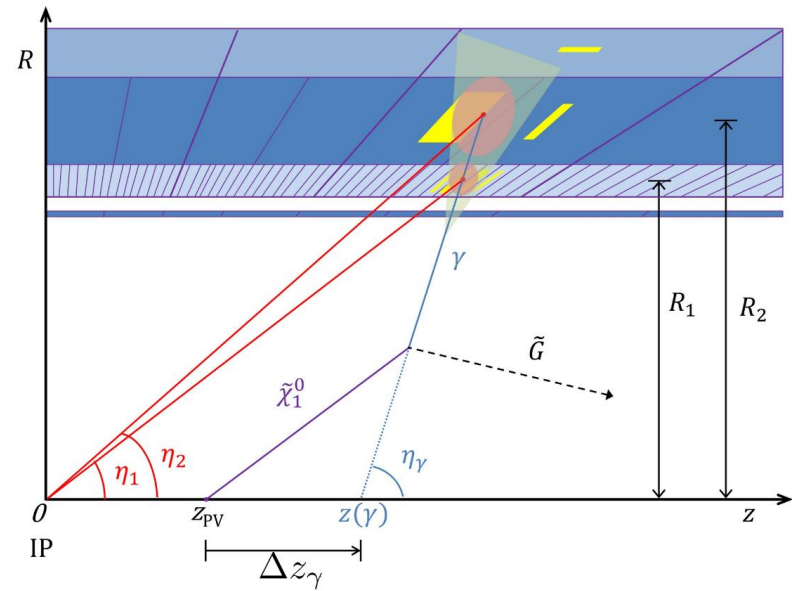
Final state photons are somewhat soft!
Probably not much MET

How do you distinguish displaced photons?

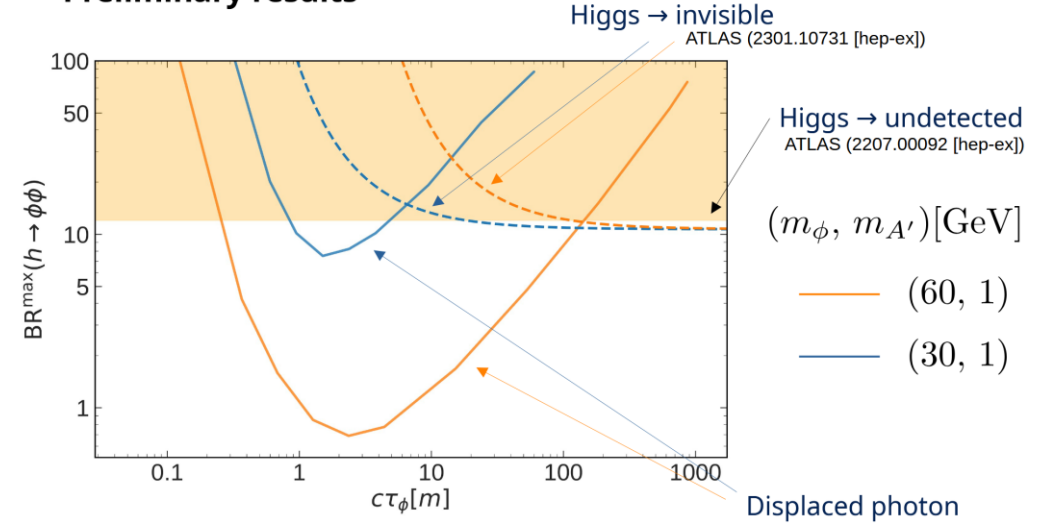
Photons coming from long-lived particles take longer to reach the ECal, and do not point towards the primary vertex.

Important variables:

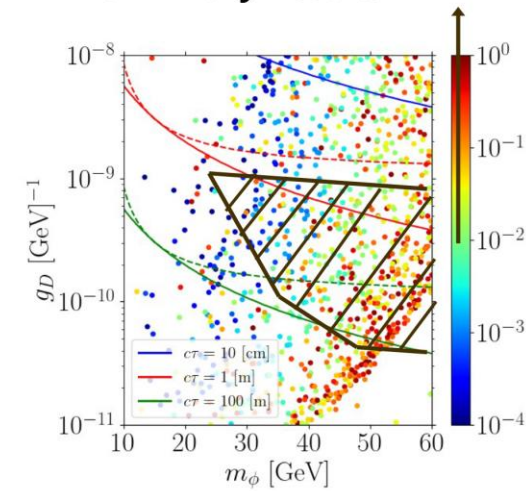
t_γ $|\Delta z_\gamma|$



Preliminary results



Preliminary Results



Improved Mass Bounds on HECOs via Dyson-Schwinger Resummation Technique

Emanuela Musumeci (IFIC, Valencia)

in collaboration with
J.Alexandre , N.E. Mavromatos, V. A. Mitsou

Based on [Phys. Rev. D 109, 036026](#)

[Phys. Rev. D 111, 076010](#)

025
EFT workshop of
the Long-Lived Particle
Community

Long-Lived Particle Searches at a Future Higgs Factory with the ILD experiment

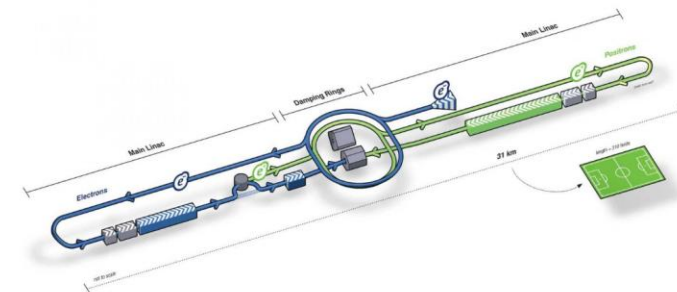
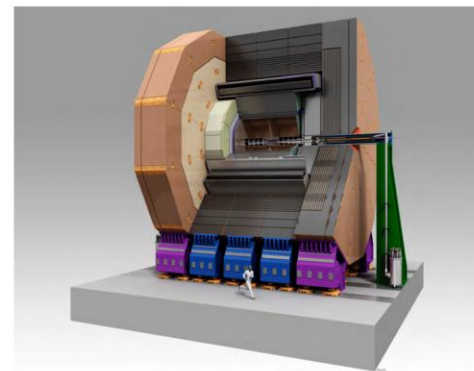


International Large Detector (ILD)



- Multi-purpose detector for an e^+e^- Higgs Factory (HF)
- Example: the International Linear Collider (ILC), with baseline c.m.s. energy 250-500 GeV
- Possible operation at other HF proposals now under study

↑
this study



4 July 2025

Jan Klamka, LLP searches with the ILD experiment

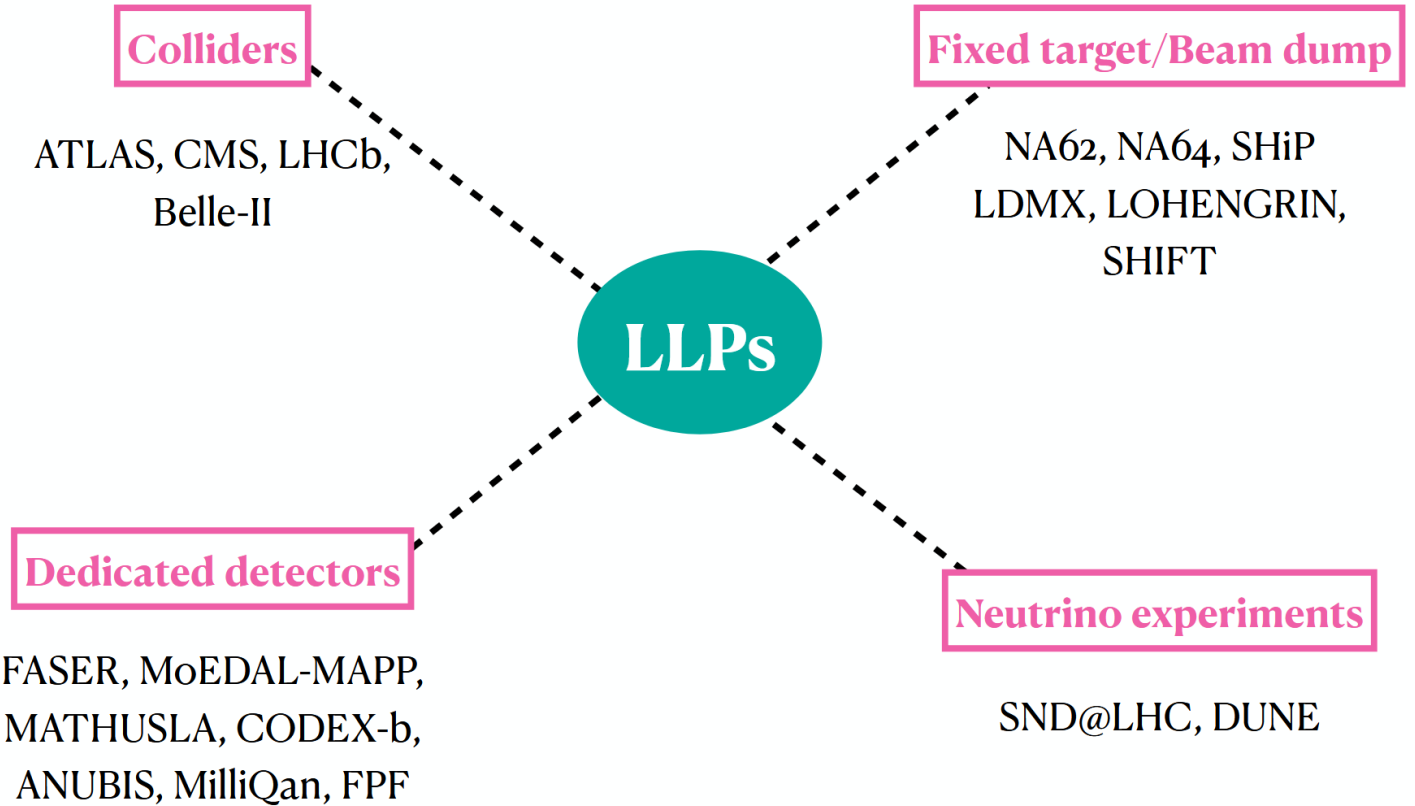
3

Overview talks:

- LHCb
- CMS
- ATLAS

Dedicated experiments

- MoEDAL-MAPP
- Beam dump experiments
- ProtoDUNE-SPS
- LUXE experiments
- MATHUSLA
- CODEX-b
- ANUBIS
- SHIFT
- SHIP
- milliQan
- Forward Physics Facility



(*) not a complete list!

LHCb overview and latest results

Andrii Usachov
VU Amsterdam and Nikhef

on behalf of the LHCb collaboration

LLP searches at LHCb

Displaced leptons

- Dark photon [PRL 120 \(2018\) 061801](#), [PRL 124 \(2020\) 041801](#)
- Low-mass dimuon resonances [JHEP 10 \(2020\) 156](#)
- (heavy) LLPs decaying to $e^\pm \mu^\pm \nu$ [EPJC 81 \(2021\) 261](#)
- Majorana neutrino [PRL 112 \(2014\) 131802](#)
- Light boson from $b \rightarrow s$ decays [PRL 115 \(2015\) 161802](#), [PRD 95 \(2017\) 071101](#)

Displaced jets

- HNL in $W^\pm \rightarrow \mu^\pm \mu^\pm jet$ [EPJC 81 \(2021\) 248](#)
- LLP $\rightarrow jet jet$ [EPJC 77 \(2017\) 812](#)
- LLP $\rightarrow \mu + jets$ [EPJC 77 \(2017\) 224](#)

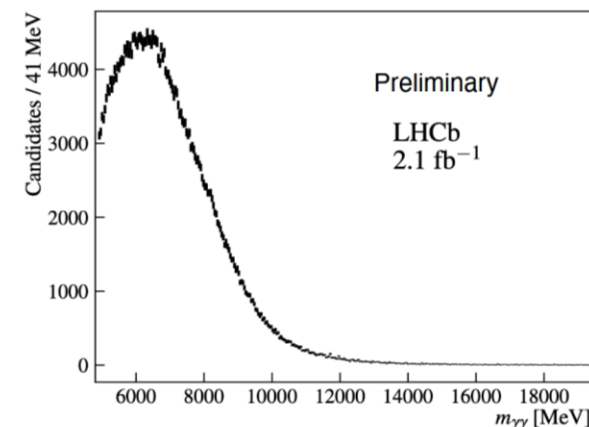
Fully neutral:

- Low mass ALPs: Search for resonances decaying to photon pairs **[New, preliminary]**

Search for resonances decaying to photon pairs

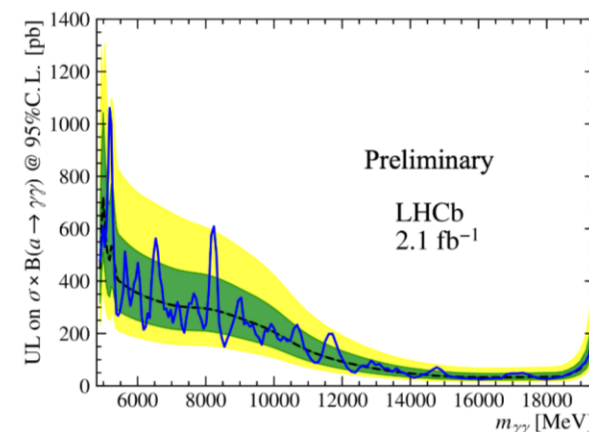
Backgrounds

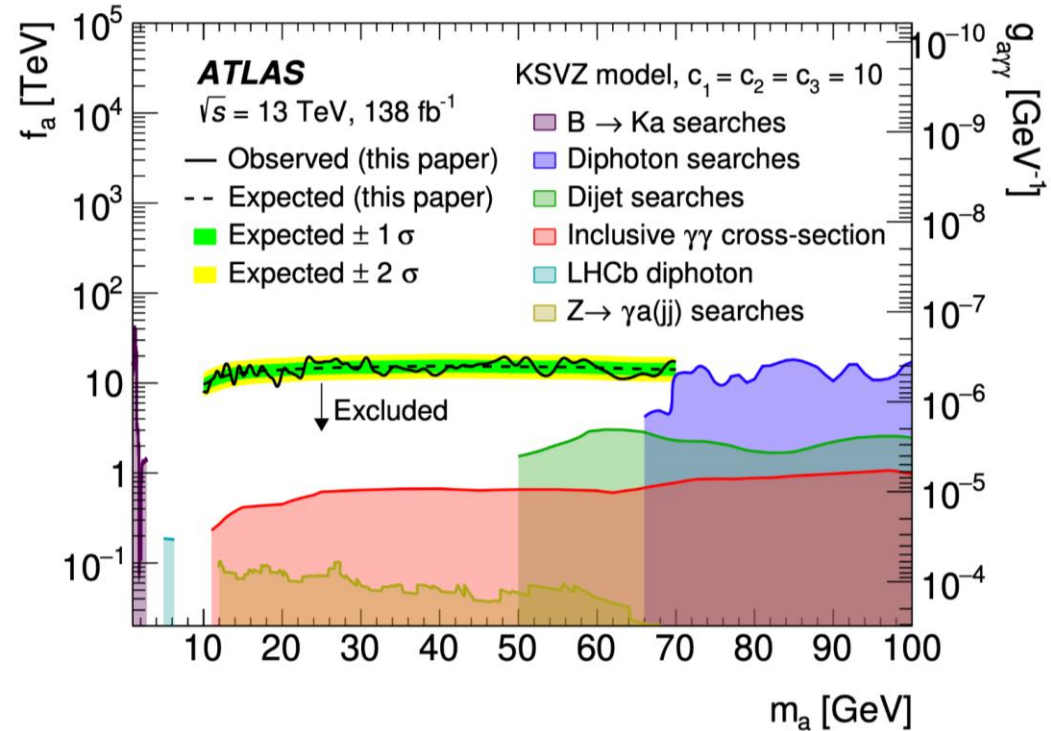
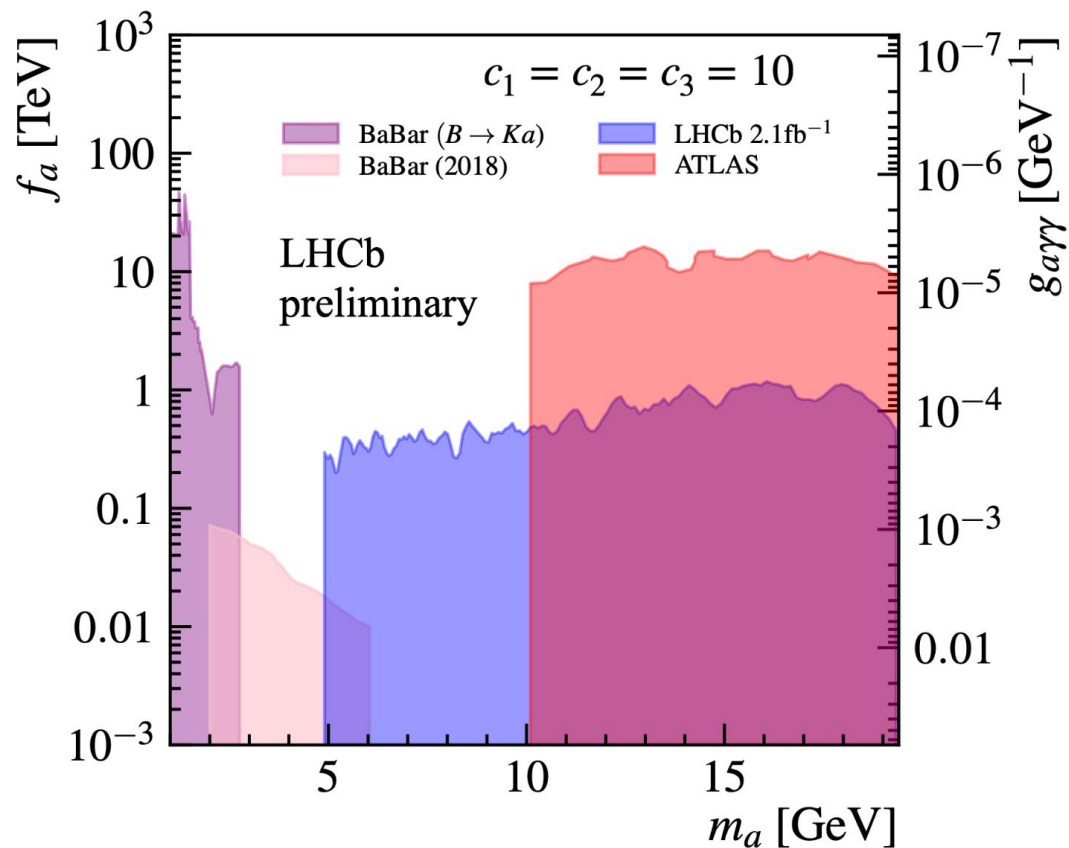
- No substantial peaking backgrounds in considered inv. mass window
- Contributions from b - and c -hadrons found to be negligible compared to the background level
- $B \rightarrow \pi^0 \pi^0$ strongly suppressed by tight PID
- Combinatorial photons mostly coming from π^0 and η decays



Bump hunt

- Scan in $[-5\sigma, 5\sigma]$ windows
- Legendre polynomials to model the background [JINST 12 P09034](#)
- Upper limits using CLs method to the [4.9 GeV, 14.9 GeV] range
- The first LHCb analysis using only neutrals in the final state





- In Run 3 LHCb is covering both di-muon and di-electron modes

- Strongest limits by LHCb for ALPs decaying to $\gamma\gamma$ between 4.9 and 10 GeV**
- Stronger limits by ATLAS above 10 GeV
- Also limits for the SM decays @ 95% CL

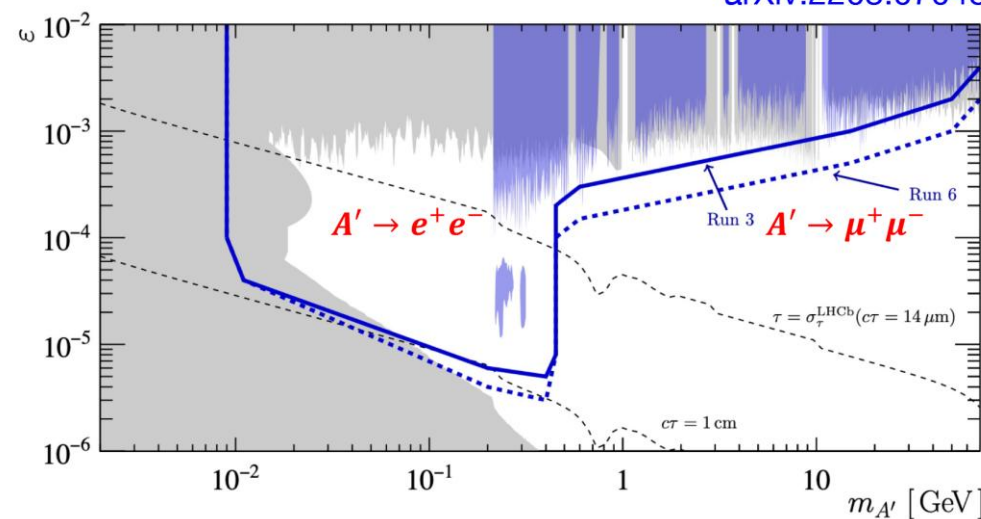
$$BR(B_s^0 \rightarrow \gamma\gamma) < 2.68 \times 10^{-5}$$

$$BR(B^0 \rightarrow \gamma\gamma) < 0.8 \times 10^{-5}$$

$$\sigma(pp \rightarrow \eta_b X) \times BR(\eta_b \rightarrow \gamma\gamma) < 765 \text{ pb} \text{ (84 pb)}_{\text{fiducial}}$$

first direct limit on ground-state bottomonium production in pp collisions

arXiv:2203.07048



LLPs at CMS

Bryan Cardwell
on behalf of the CMS Collaboration

Show off some cool ways CMS is trying to discover BSM LLPs *right now*

Highlight some cool ways CMS might discover BSM LLPs *in Run-3 data*

Mention some cool ways CMS might discover BSM LLPs *in HL-LHC data*

Stay at a high level and leave the details to the experts:

- Tuesday: [Daniel](#) and [Kai Hong](#)
- Thursday: [Sam](#), [Rob](#), [Jannicke](#), and [Daniel](#)
- Friday: [Ang](#)

Soft displaced track

[CMS-PAS-SUS-24-01](#), [Sam's talk on Thursday](#)

Backgrounds from $Z \rightarrow \nu\nu$ and $W \rightarrow \ell\nu$ with signal-like tracks

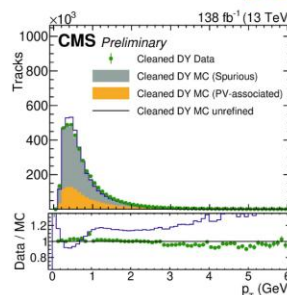
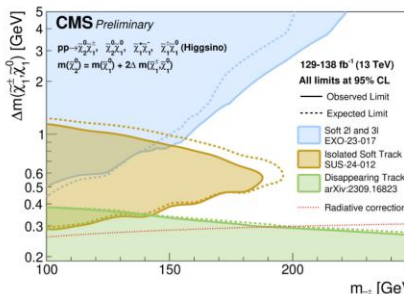
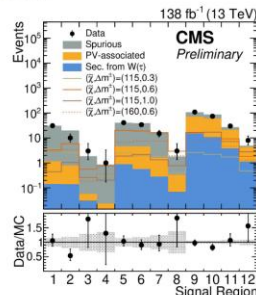
- Tracks mostly from underlying evt, PU, or misreconstruction
- Estimated from MC-based templates corresponding to each bg track category

NN-based MC corrections in cleaned-DY control region

- Remove muons from $Z \rightarrow \mu\mu$ events and add muon p_T to MET
- Study high-MET events without affecting soft tracks
- Dedicated NN corrects for mismodeling of track parameter uncertainties
- Use MC with refined track parameters as inputs to track-classifier NN

Results consistent with SM prediction

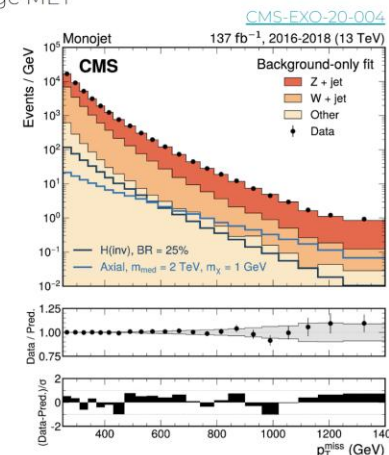
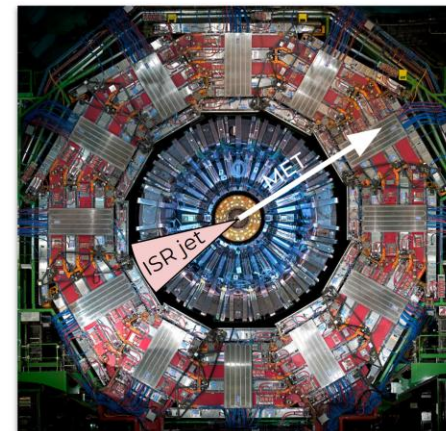
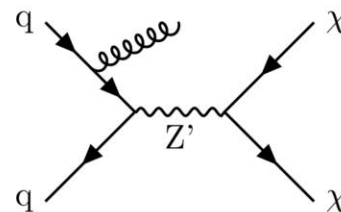
Constrain Higgsino DM with most stringent limits to date



Monojet+LLP strategy

Reminder: monojet signature

- Initial-state radiation (ISR) jet provides a kick to invisible particles
- Identify potential signal events via large momentum imbalance (MET)
- Powerful, model independent, but large $Z \rightarrow \nu\nu$ background out to large MET

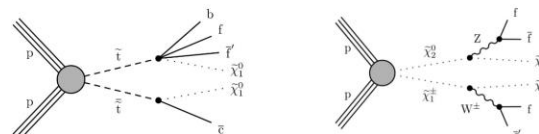


Soft displaced vertex

[Ang's talk on Friday](#)

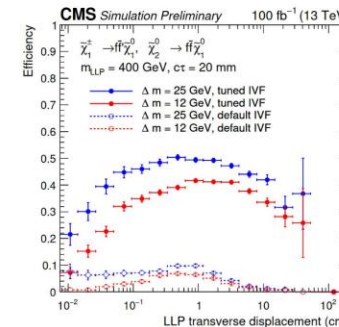
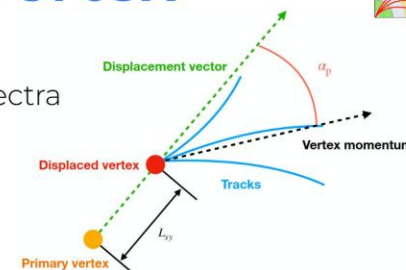
Target LLPs in BSM scenarios with compressed mass spectra

- Most LLP energy carried away by invisible particles
- Consider stop coannihilation and bino-wino coannihilation models



Soft displaced vertices

- ≥ 2 tracks with $p_T > 0.5$ GeV, sensitivity out to ~ 30 cm
- Previous CMS search required ≥ 5 tracks, $p_T > 1$ GeV, and within beampipe
- Tune vertex reco to allow sensitivity to
 - large opening angles
 - non-pointing topology



2018 B-Parking dataset

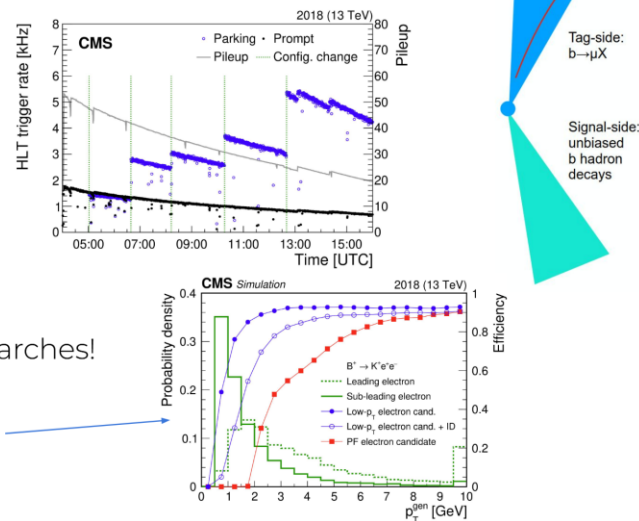
[CMS-EXO-23-007](#)

CMS recorded 10 billion events w/ unbiased b-hadron decays during 2018

- Motivated by B flavor anomalies
- Triggering on single displaced "tag" muon provides pure, unbiased b-hadron sample
- Vary muon p_T and displacement thresholds throughout LHC fill to maximize acceptance
- Park on disk and reconstruct *after* 2018 run

Also an incredible playground for LLP searches!

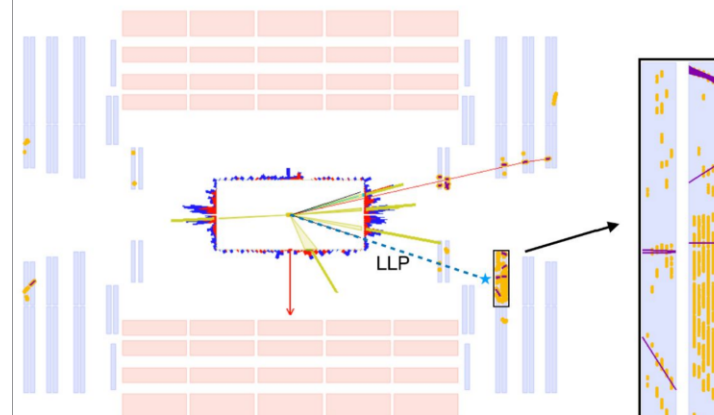
- Access to low-mass and compressed scenarios
- Bonus: low- p_T electron reconstruction algorithm



Muon Detector Shower (MDS) signature

Use CMS muon system and steel return yoke as a sampling calorimeter

- Large radius, excellent shielding, sensitive to hadronic and EM showers
- Signal sensitive to LLP energy, not mass $\rightarrow$ sensitivity to very low-mass LLPs
- Unique to CMS!



Expanding MDS search program over last few years

- MET triggers: [CMS-EXO-20-015](#)
- Lepton triggers: [CMS-EXO-22-017](#)
- B-parking: [CMS-PAS-EXO-24-004](#) (NEW!)
- With τ : [CMS-EXO-23-015](#) (NEW!)

Dark showers in B-parking

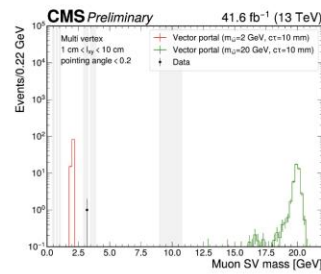
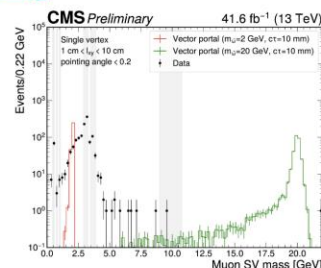
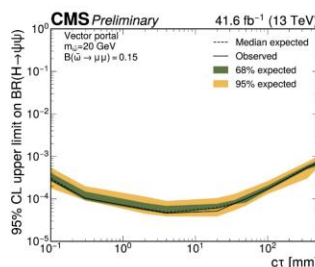
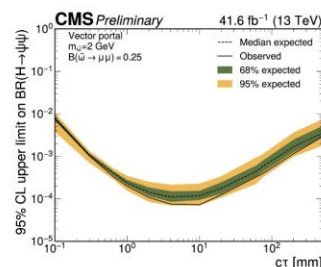
[CMS-PAS-EXO-24-008](#) Kai Hong's talk on Tuesday

Signal extraction

- Sliding window fit, interpolate background from sidebands
- Mask regions around SM resonances

No significant excess, constrain $H \rightarrow$ dark parton BR

- Most sensitive to date for shorter decay lengths and masses down to 2 GeV
- First limits for extended dark shower models with masses down to 0.33 GeV



MDS in B-parking

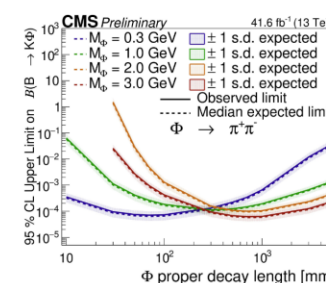
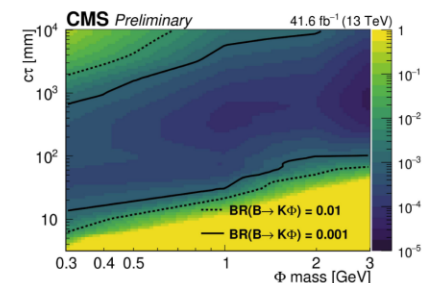
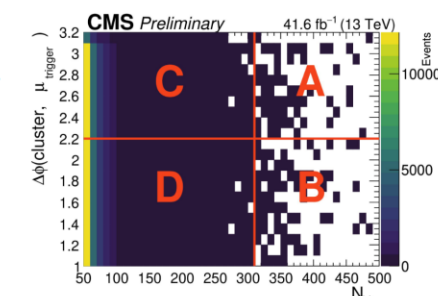
[CMS-PAS-EXO-24-004](#) Daniel's talk on Tuesday

Background estimate

- Punch-through jets
 - Measure jet $\rightarrow$ MDS fake rate in WJets-enriched data sample
- Remaining backgrounds
 - ABCD using number of MDS hits and $\Delta\phi(\text{MDS}, \mu)$

Observation consistent with SM prediction

- Set limits on $B \rightarrow K\Phi$ branching ratio
- Sensitive to BR down to $\sim 10^{-5}$, most stringent to date



Run-3 LLP triggers

[CMS-DP-2023-043](#) [Kiley's talk from LLP2024](#)

Suite of dedicated LLP triggers brought online in Run 3

- Features new paths and improvements at L1 and HLT

Improved triggers already lead to impactful early Run-3 LLP results (shown last year)

- Improved displaced di-muon ([CMS-EXO-23-014](#))
- Improved displaced jet ([CMS-EXO-23-013](#))

New triggers will enable powerful Run-3 searches (to be shown next year?)

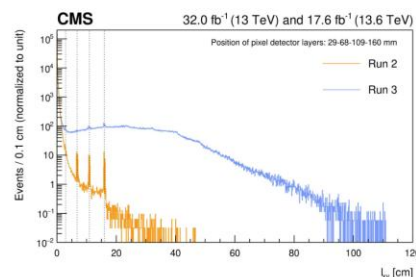
- Delayed jets w/ ECAL timing
- Delayed and displaced jets from LLP decays in HCAL
- Dedicated MDS trigger
- and more!

Run-3 scouting and parking

[CMS-EXO-23-007](#) [Rob's talk on Thursday](#)

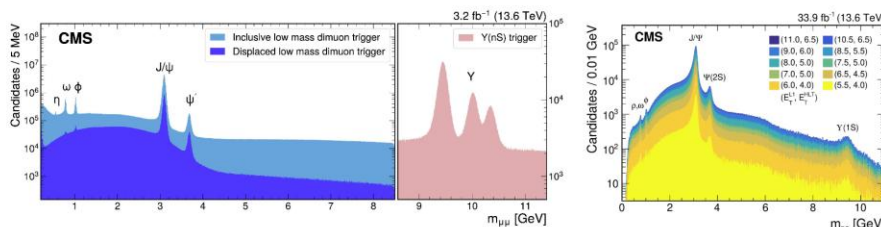
Scouting

- Increased GPU usage leads to increased performance
- Meaningfully improved displaced μ acceptance
- Low- p_T electron and photon triggers



New parking steams in Run-3 to target low-mass and low-momentum final states

- Low-mass di-muon
- Low-mass di-electron
- Vector Boson Fusion



Run-3 anomaly detection triggers

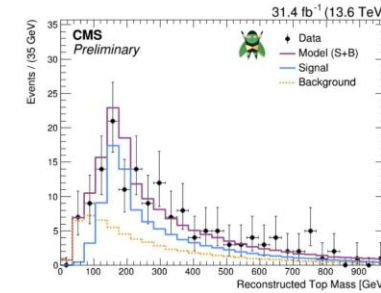
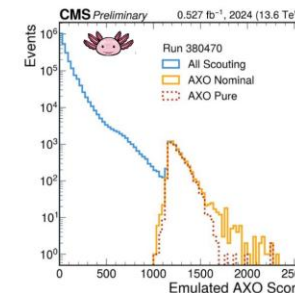
[CMS-DP-2024-059](#) [CMS-DP-2024-121](#) [Jannicke's talk on Thursday](#)

We don't know what new physics looks like

- What if we're throwing out all the interesting events before we even analyze them?
- Idea: Signal-agnostic triggers to catch "weird" events!

Two L1 anomaly detection triggers active in CMS: **AXOLITL** and **CICADA**

- Similar concepts:
 - Autoencoder-based
 - Trained on Zero-Bias dataset
 - Very nice logos
- Different inputs:
 - High-level physics objects
 - Low-level calorimeter images



Both taking data since 2024!

- Exploration and analysis design underway $\rightarrow$ stay tuned!

Phase-2 upgrade

MIP Timing Detector

- ~ 30 -60 ps timing resolution in the barrel and endcap
- [Direct handle for delayed signals, mass determination of invisible particles, ...](#)
- Precision timing in the barrel will be *unique to CMS*! Critical for high-mass BSM particle searches

Track information in L1 trigger

- Trigger directly on displaced tracks or vertices
- Veto prompt tracks to trigger on emerging signatures

High-Granularity Calorimeter

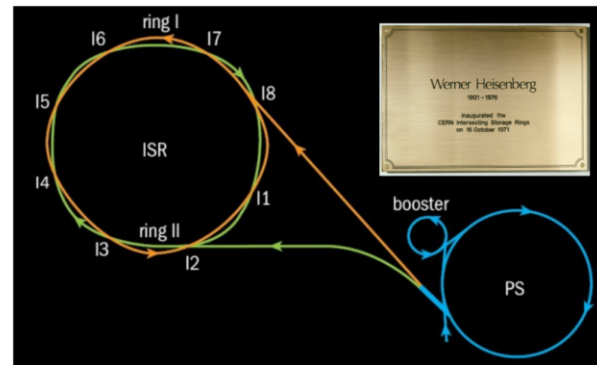
- Precise trajectory, energy, and time measurements for individual particles within a shower

ATLAS Overview

Louie Dartmoor Corpe (Clermont-Ferrand)

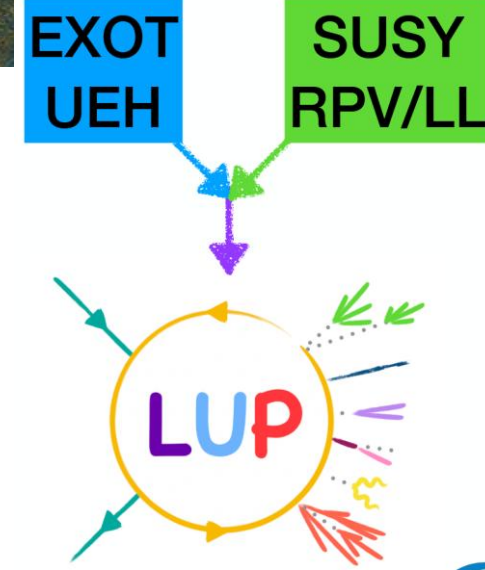
To begin... a warning from history

- 1971: **Intersecting Storage Rings (ISR)** at CERN marked **birth of hadron colliders**
- $\sqrt{s} = 30 \text{ GeV}$: enough for bound states of **c- and b-quarks** (at time undiscovered!!)
- ...but theoretical bias suggested "new physics" to manifest in forward direction
Transverse direction not instrumented !!
- **ISR could have discovered J/ψ and Y...** but **did not**: instrumentation in wrong place.
CERN left as a bystander during November revolution in US.



2025: theoretical bias for prompt new physics preventing a discovery?

This time, **no alternative collider** to save us... but **still time to adjust our strategy.**



- Two first ATLAS Run-3 Searches are LLP:

Short Title	Group	Journal Reference	Date	$\sqrt{s}$ (TeV)	L	Links
search...	search.	search...	search	13.6		search...
Search for emerging jets NEW	EXOT	Submitted to RPP	2025-05-04	13.6	51.8 fb ⁻¹	Documents 2505.02429 Inspire Briefing Internal
Displaced e/mu lepton pairs	SUSY	Accepted by PRD	2024-10-22	13, 13.6	140 fb ⁻¹ , 56.3 fb ⁻¹	Documents 2410.16835 Inspire Internal

No longer true that LLP searches are "slow" part of ATLAS search programme. Now among the fastest! Testament to excitement + dynamism of community

The ATLAS LUP programme: at LLP-XV

CMS+ATLAS
HS Summaries

Hidden Valley

Gordon's talk

CalRatio+X

MSVx

Julian's talk

ALPs

Displaced/unusual
hadronic activity

Dark
Photon

Prompt ALP re-
interpretation

Marzieh's talk

Lepton-jets

Displaced/unusual
leptonic activity

SUSY RPV

Prompt LJ

Displaced
dileptons Run2+3

Heavy
Neutral Leptons

Yvonne's talk

Displaced
HNL

Guglielmo's talk

Emerging
Jets

Emerging
Jets Run 3

Luka's talk

Weird Jets

(Semi-
visible jets)

Prompt
SVJ s-channel

SUEP

Multi-
charged
particles

Weird Ionisation

Fractionally
charged
particles

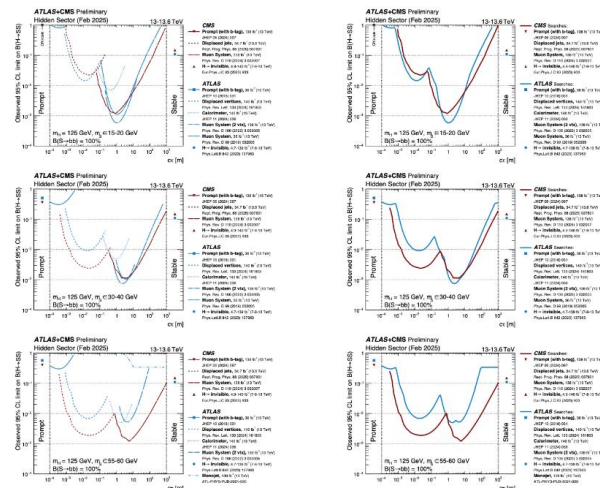
Judith's talk

dE/dX

Magnetic
monopoles

Slow-
moving/heavy
charged
particles

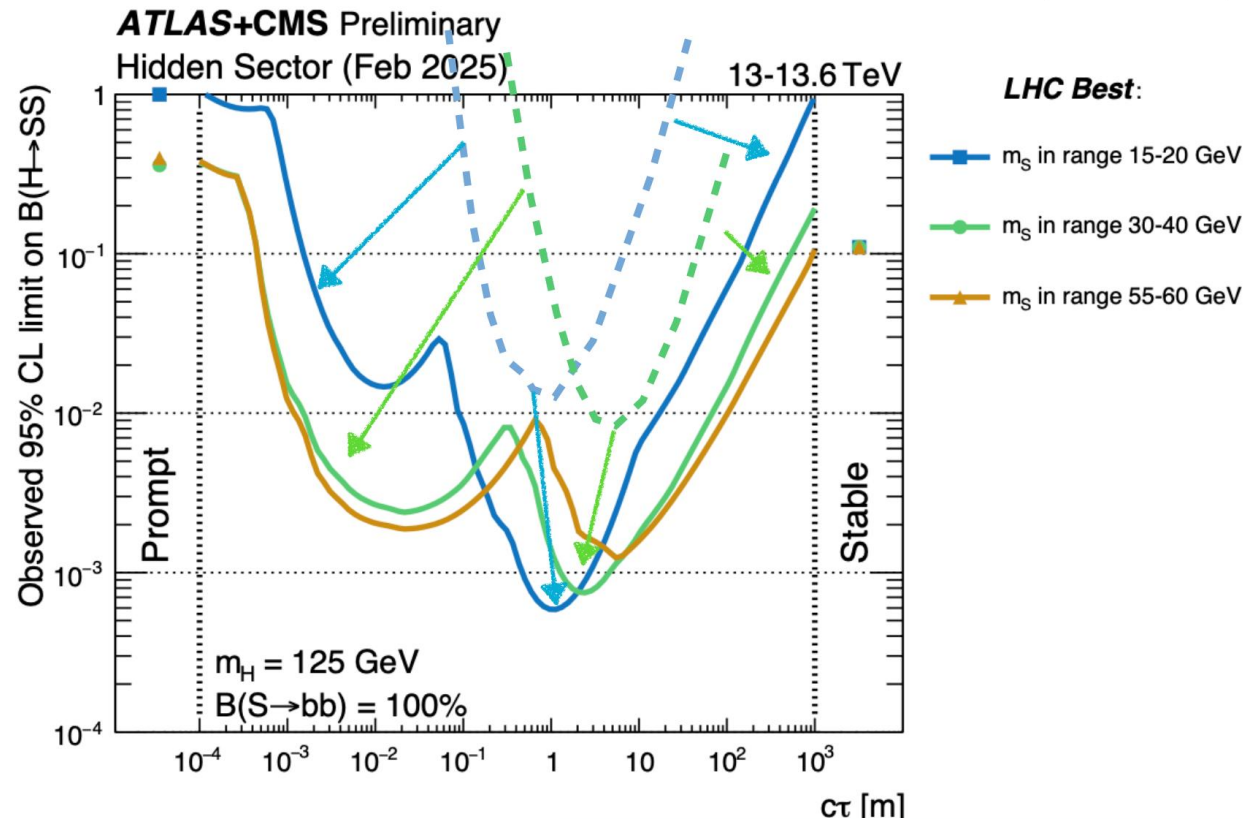




ATL-PHYS-PUB-2025-002
<https://cds.cern.ch/record/2924617>



- Extrapolation from prompt exotic Higgs searches
- Exploit the new ATLAS tracker with much better resolution in Run 4.
 - Large Radius Tracking for ITk!
- New technologies: Event Picking



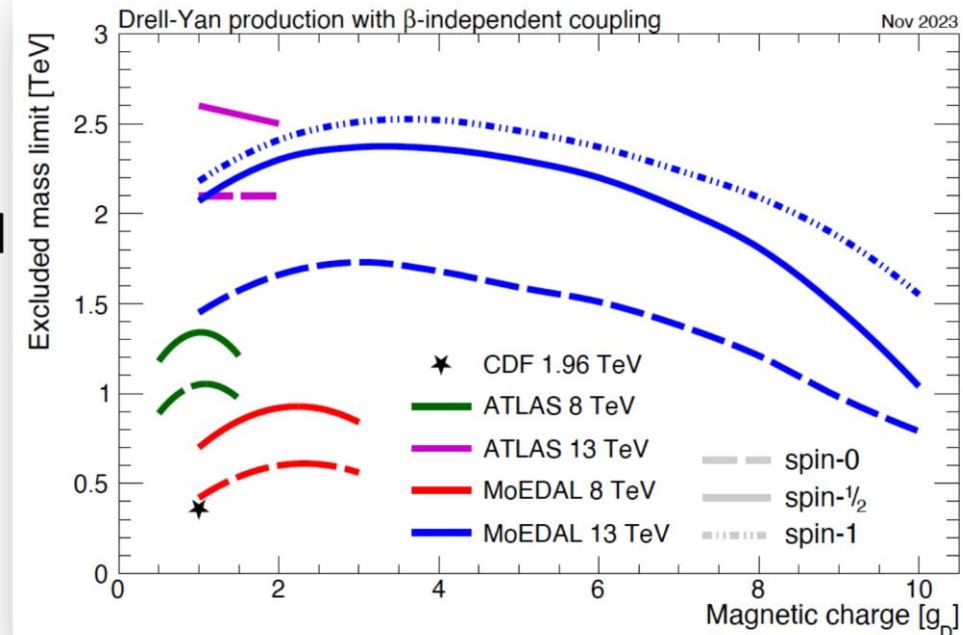
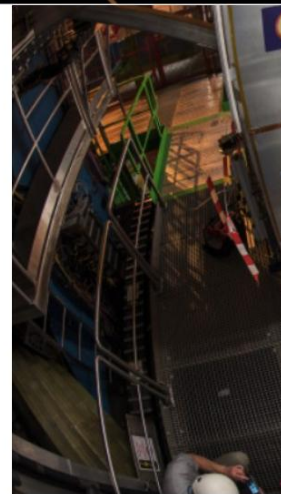
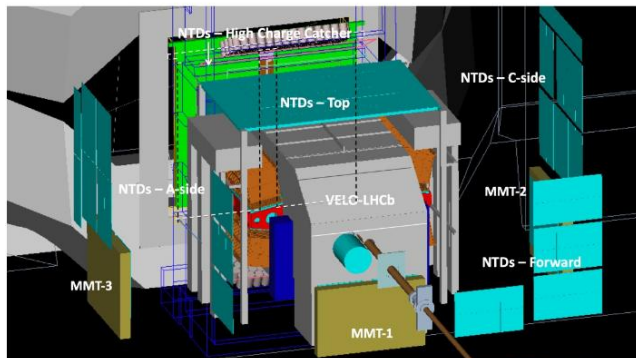
- Exploit developments in b-tagging.
- And c-tagging ??
- Lighter LLPs should be more forward:
 - Exploit new timing detector HGTD in the endcaps to reject beam-induced backgrounds
 - ITk improves tracking from $|\eta| < 2.5 \rightarrow |\eta| < 4$

The MoEDAL-MAPP experiment – Status Report

Igor Ostrovskiy (University of Alabama)
for the MoEDAL-MAPP collaboration

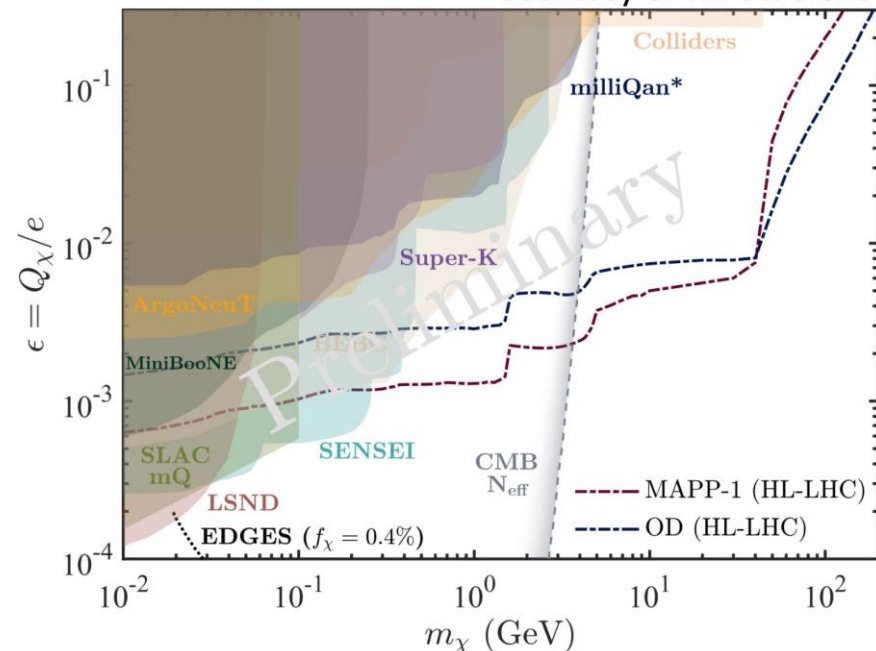
Monopole and other Exotics Detector At LHC

- MoEDAL is optimized to search for **magnetic monopoles (MMs)** and other highly ionizing particles (HIPs) with magnetic and/or electric charge (dyons, nuclearites, Q-balls,)
- Currently, 15 institutions from 9 countries. Approved by CERN 2009, started data-taking Spring 2015
- Deployed at IP8 in the LHCb's VELO cavern. Uses nuclear track detectors (NTDs), trapping volumes (MMTs) and TimePix detectors
- World-leading limits** on $g > 2g_D$ monopole production in p-p collisions, pioneered searches for production in Pb-Pb collisions via the Schwinger mechanism (**first reliable mass limits**)
- World-leading limits** on production of spin-1 highly electrically charged objects (HECOs) with $10 < q/e < 20$ and $50 < q/e < 350$ in p-p collisions



JHEP 08 (2016) 067, PRL 118 (2017) 061801, PLB 782 (2018) 510, PRL 123 (2019) 021802, EPJC 82 (2022) 694, EPJC 82 (2022) 694, PRL 126 (2021) 071801, PRL 126 (2021) 071801

Courtesy of M. Staelens

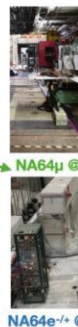
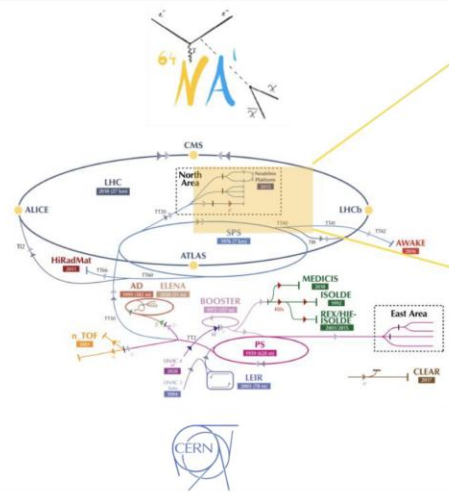


Latest results from the NA64 experiment

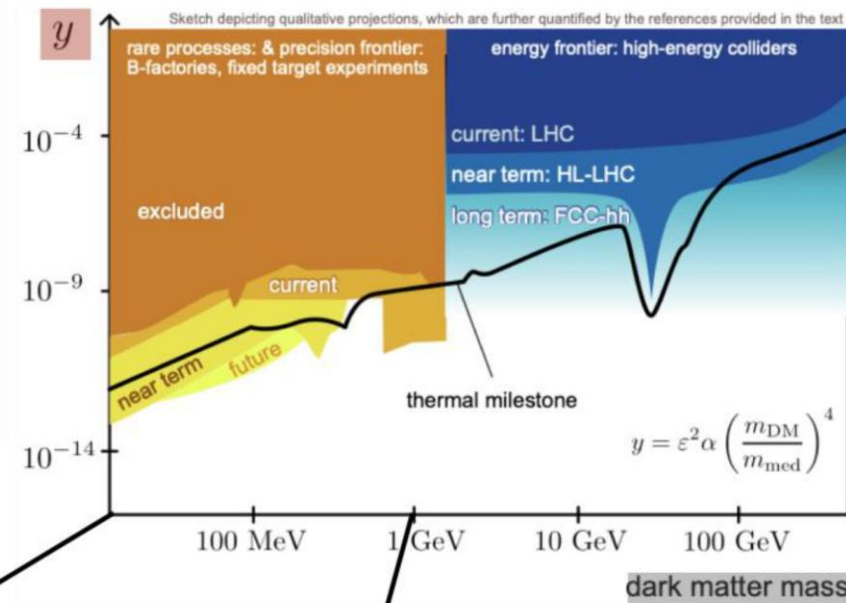
Balint Radics
on behalf of the NA64 collaboration

The NA64 experiment @ CERN SPS

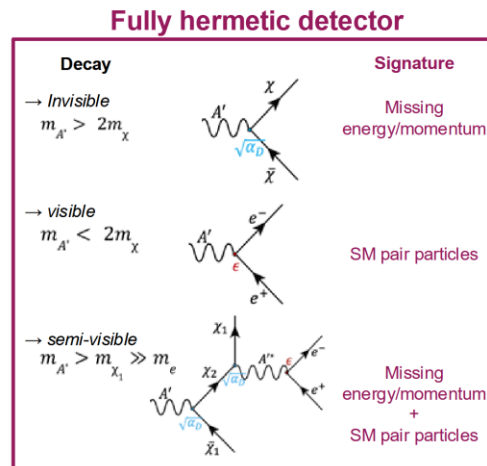
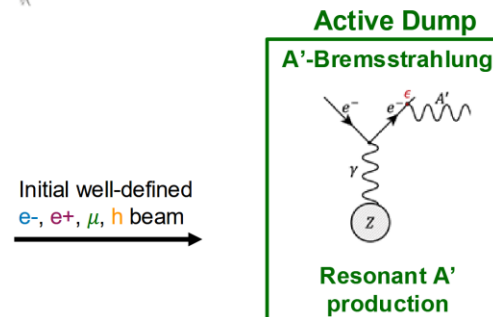
A **fixed target** experiment LDM candidates and other New Physics (NP) extensions using **electron** (e^-), **positron** (e^+), **muon** (μ) and **hadron** (h) beams.



NA64 physics target

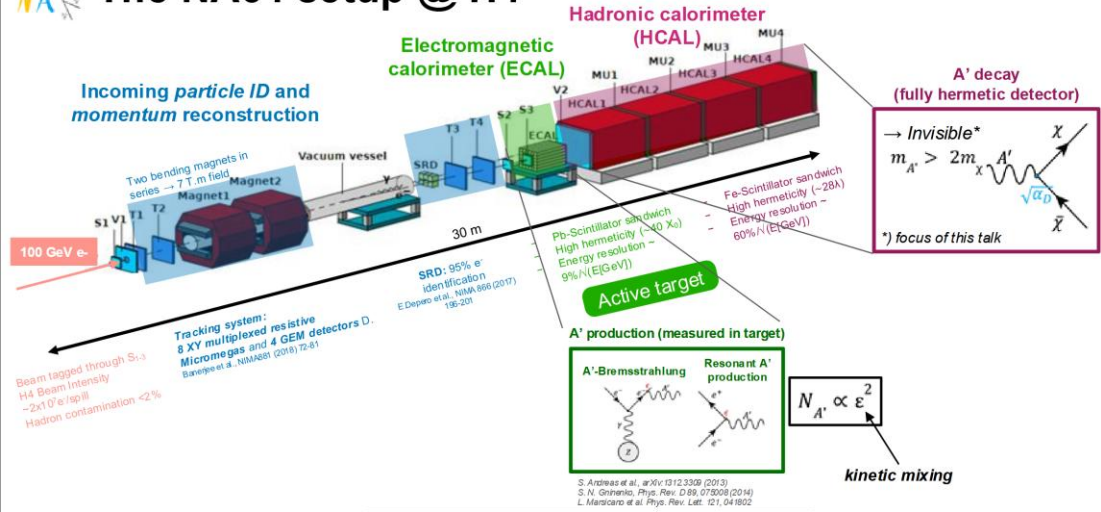


Method of search at NA64



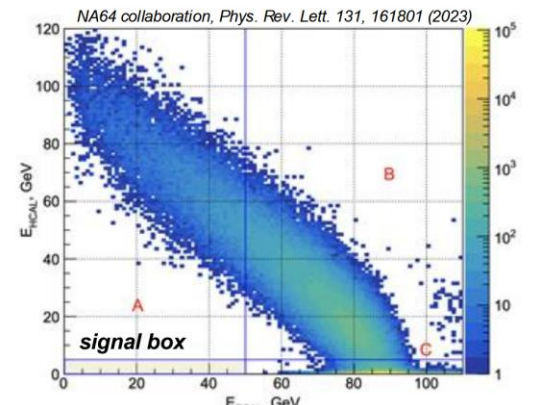


The NA64 setup @ H4



Signal: Missing energy/momentum

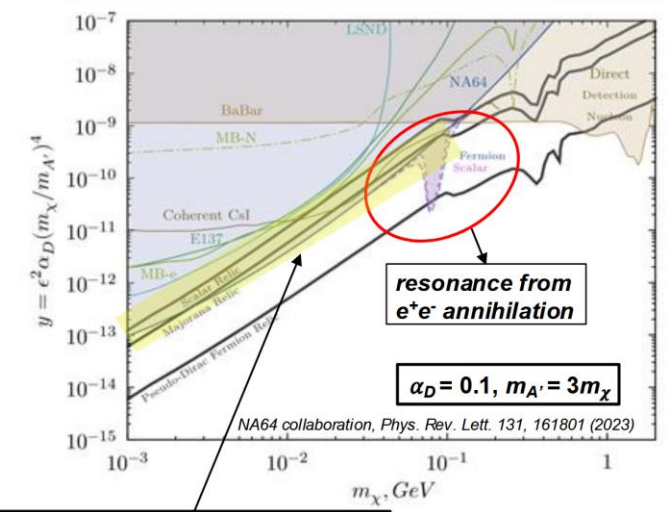
Current status: NA64e- @ 100 GeV



Background source	Background, n_b
(i) dimuon losses or decays in the target	0.04 ± 0.01
(ii) $\mu, \pi, K \rightarrow e + \dots$ decays in the beam line	0.3 ± 0.05
upstream interactions	0.16 ± 0.12
ding n, K_L^0	< 0.01
ly)	0.51 ± 0.13

from the NA64 experiment

No signal in 9.37×10^{11} EOT observed

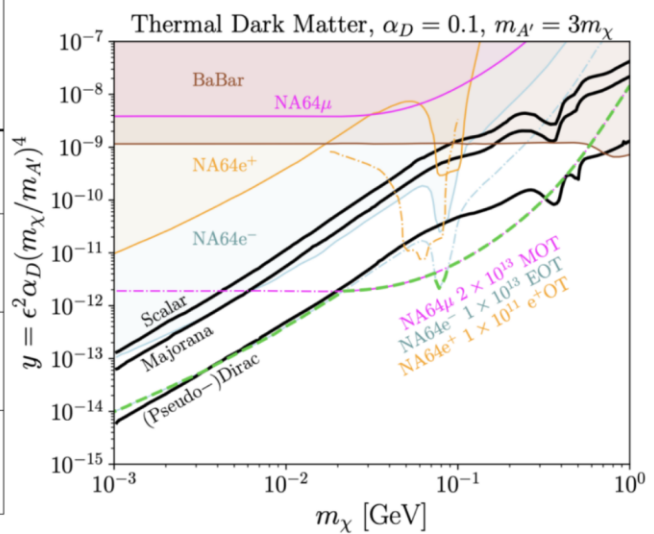


Excludes Majorana and scalar thermal targets for $m_{A'} < 0.1$ GeV
→ Goal before LS3: collect 3×10^{12} EOT to fully cover these targets

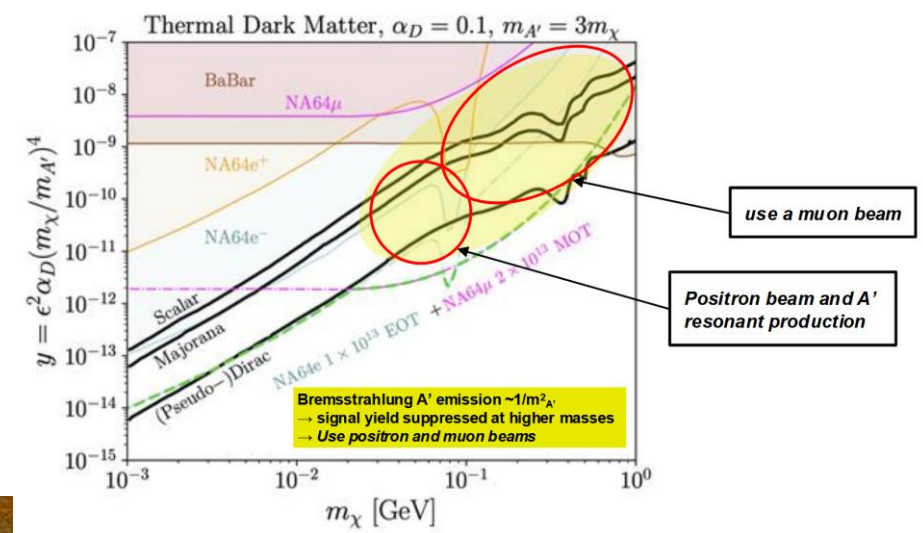
Summary and Outlook



Beam	Motivation	Pre-LS3 Statistics	Run 4 [particles on target]
NA64e-	Leptophilic DS coupled to e^- LDM, inelastic DM, ALPs, scalar, Z' , X17 ...	3×10^{12} (2×10^{12})	10^{13}
NA64e+	LDM (higher masses < 0.25 GeV, several mediators axial, vector, pseudoscalar, scalar),...	10^{11} (a 70, 60, y test a 40 GeV)	$> 10^{11}$ for different energies
NA64mu	Leptophilic DS coupled to μ LDM (higher masses > 0.1 GeV, ALPs, Z' , muon g-2, millicharge, $\mu \rightarrow \tau, \dots$)	3.5×10^{11}	2×10^{13}
NA64h	Hadrophilic DS Invisible decays of η, η', K_0	Addenda of a dedicated program under preparation	



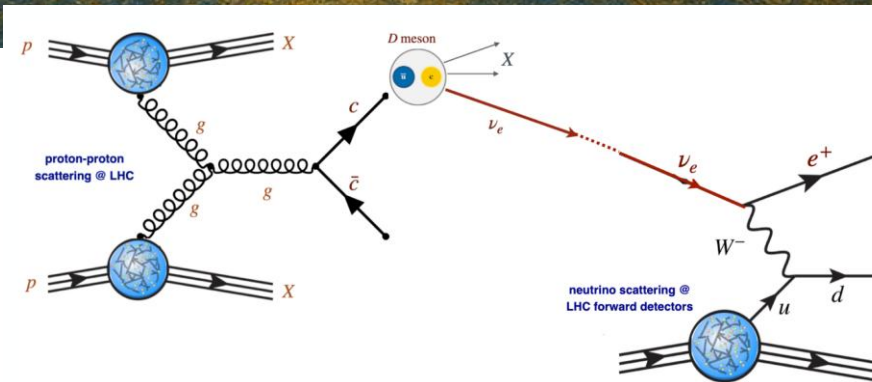
How can we enlarge the sensitivity at higher masses?



The high-sensitivity NA64 hunt for New Physics has just begun!

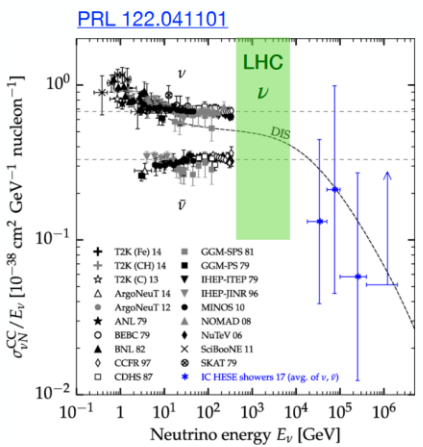
Recent Results from the SND@LHC Experiment

Zhibin Yang, on behalf of SND@LHC Collaboration

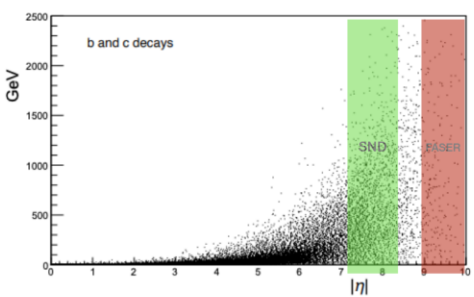
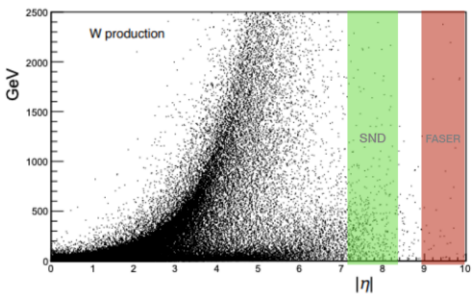


Adapted from Juan Rojo's CERN TH seminar

Neutrinos at the Large Hadron Collider

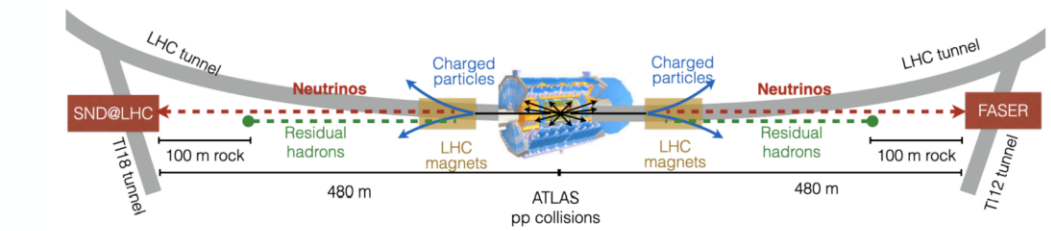
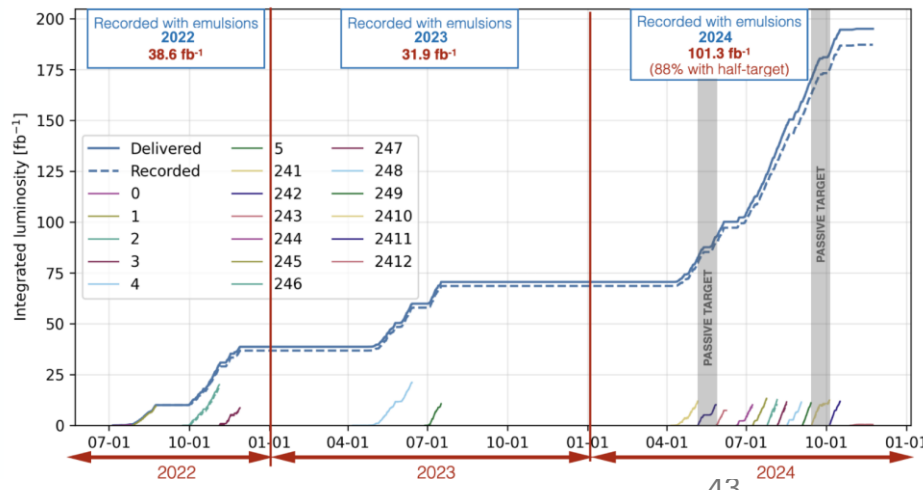


- Scattering and Neutrino Detector at the LHC
- Neutrinos from LHC
 - Large flux in the forward region
 - Unexplored energy region (300 GeV ~ a few TeV)
- SND@LHC ($7.2 < \eta < 8.4$) and FASER ν ($\eta > 9$)



Scatter plots of neutrino energy versus pseudo-rapidity (η) in pp collision events [arXiv:2004.07828]

Flavour	Neutrinos in acceptance		CC neutrino interactions		NC neutrino interactions	
	$\langle E \rangle$ [GeV]	Yield	$\langle E \rangle$ [GeV]	Yield	$\langle E \rangle$ [GeV]	Yield
ν_μ	130	3.0×10^{12}	452	910	480	270
$\bar{\nu}_\mu$	133	2.6×10^{12}	485	360	480	140
ν_e	339	3.4×10^{11}	760	250	720	80
$\bar{\nu}_e$	363	3.8×10^{11}	680	140	720	50
ν_τ	415	2.4×10^{10}	740	20	740	10
$\bar{\nu}_\tau$	380	2.7×10^{10}	740	10	740	5
TOT		4.0×10^{12}		1690		555



LONG LIVED PARTICLE SEARCHES AT



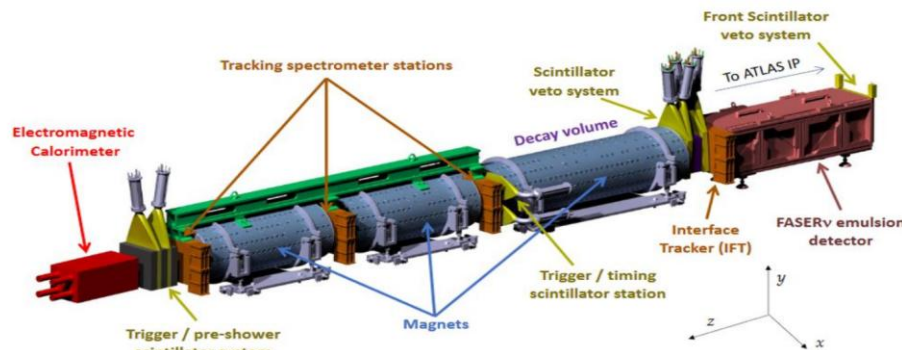
Sinead Eley*

(University of Liverpool, UK)

**on behalf of the FASER collaboration*

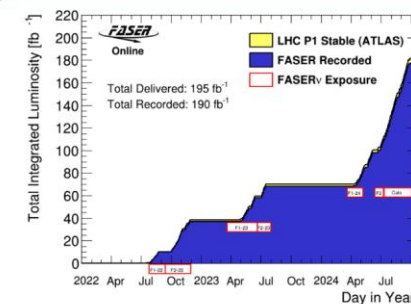
THE FASER DETECTOR

- Small inexpensive detector
 - 20cm aperture
 - ~7m in length

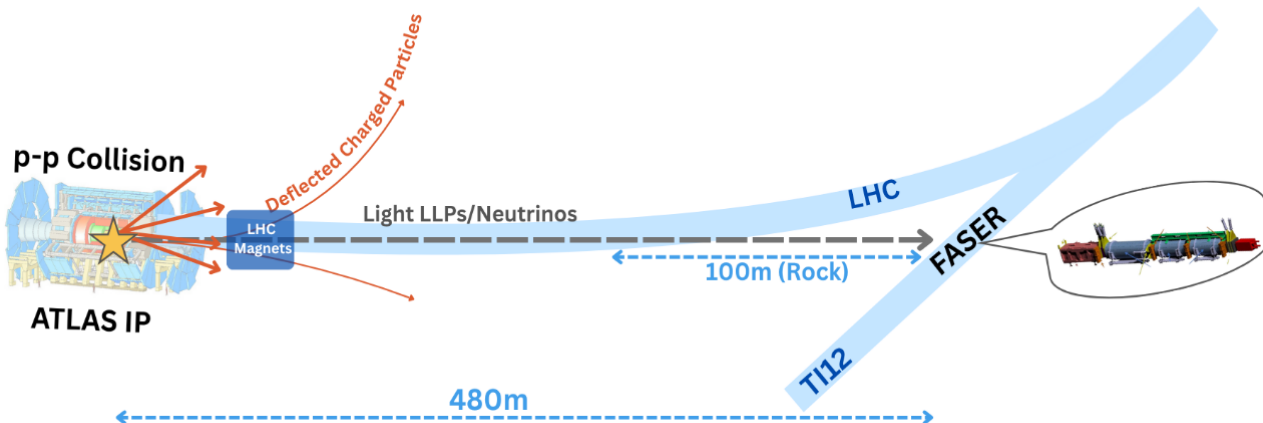


3

OPERATIONS



- Began taking data at start of LHC Run 3 (2022)
 - Successfully collected ~ 190 fb⁻¹ (>97% of delivered luminosity)
- All detector components working well
 - Successful operations during lifetime

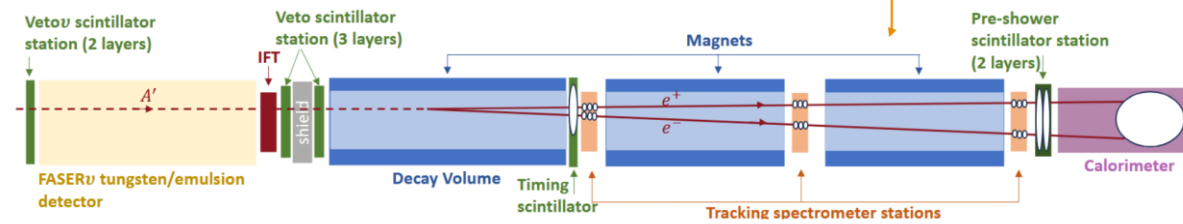


DARK PHOTON: RESULTS

FASER Dark Photon 2023 2308.05587

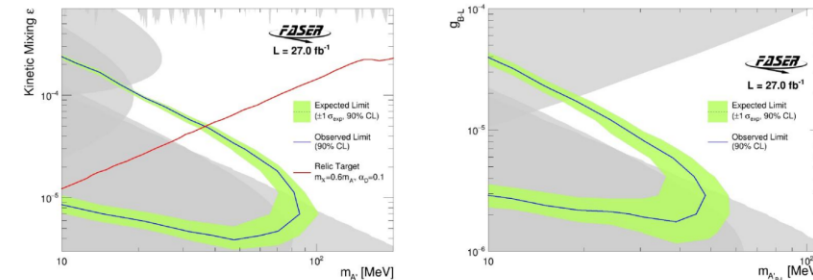
Expected signature

- No signal in veto
- Two close by tracks reconstructed within the fiducial volume
- Large energy deposit in EM calorimeter



- Zero events observed
 - Set limits on previous unconstrained parameter space
 - Region motivated by dark matter thermal relic density
 - First improvement of sensitivity in this region since 1990's!

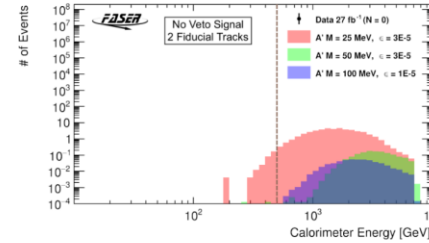
Sensitivity Reach



Dark Photon (A')

B-L Gauge Boson (A'_{B-L})

Calorimeter Energy Distribution for data (and A' MC samples)

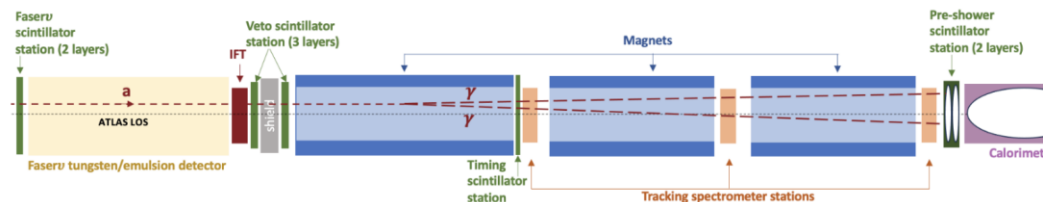


ALPS: SEARCH

- Using 2022/2023 dataset (57.7 fb^{-1})

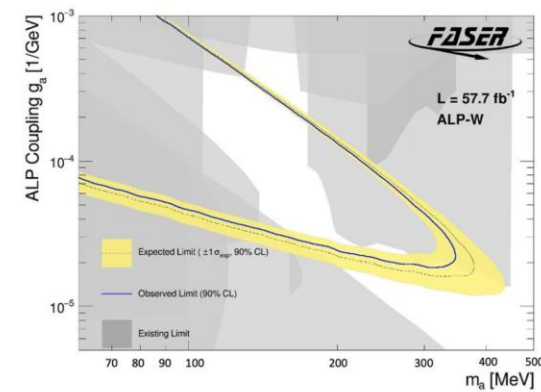
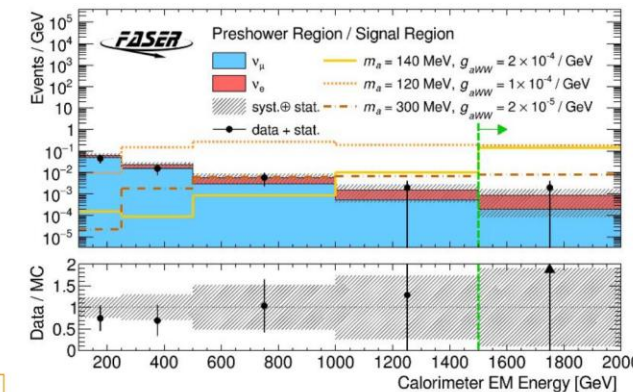
Expected signature

- No signal in either veto or timing scintillators
- EM-like signature in pre-shower
- Signal (>10 MIPs) in second preshower layer
- Large energy deposit in calorimeter ($E > 1.5 \text{ TeV}$)



ALPS: RESULTS

- Main model targeted (See backup for more model interpretations)
 - ALP-W (Coupling to W Boson)
 - 1 event observed
 - Compatible with background estimate
- Sets limits in previously unconstrained parameter space

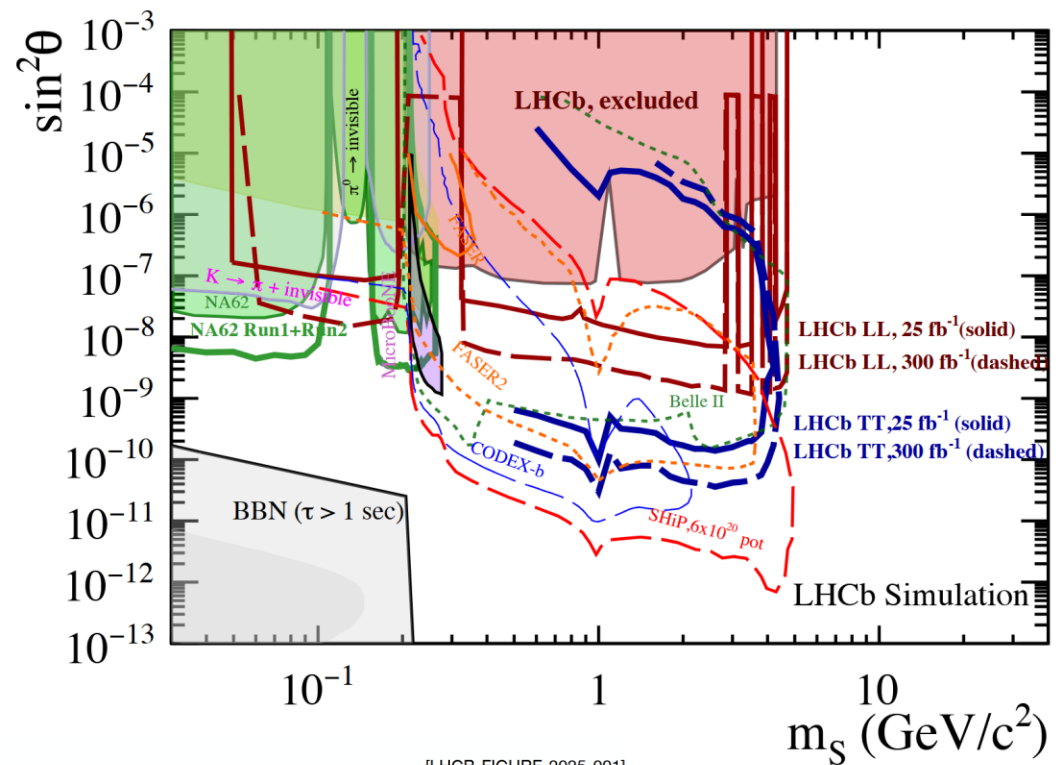
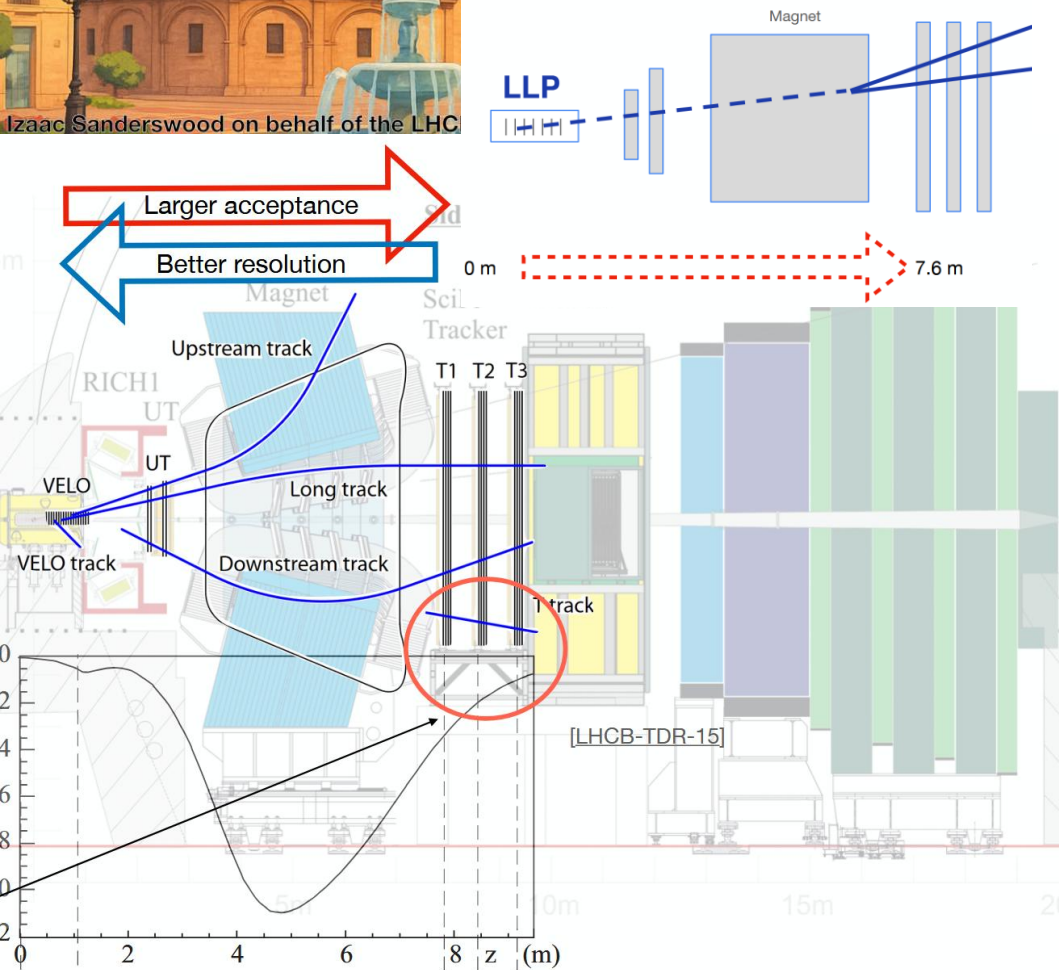


Searches for displaced Scalar decays to dimuons: LHCb's extended reach in Run 3

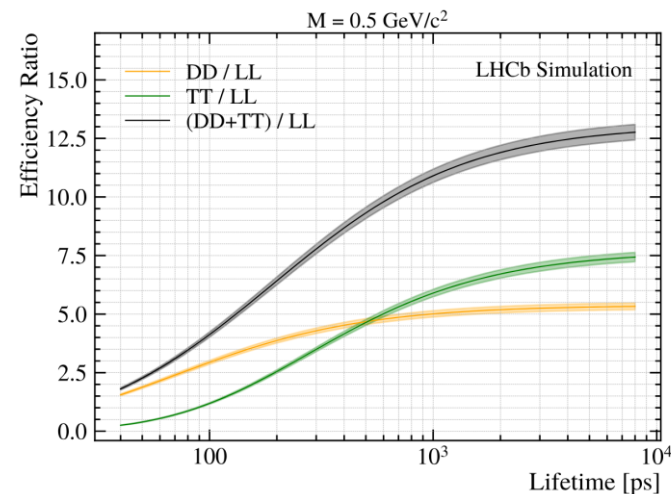
LLP2025: Fifteenth workshop of the Long-Lived Particle Community



Izaak Sanderswood on behalf of the LHC



[LHCb-FIGURE-2025-001]



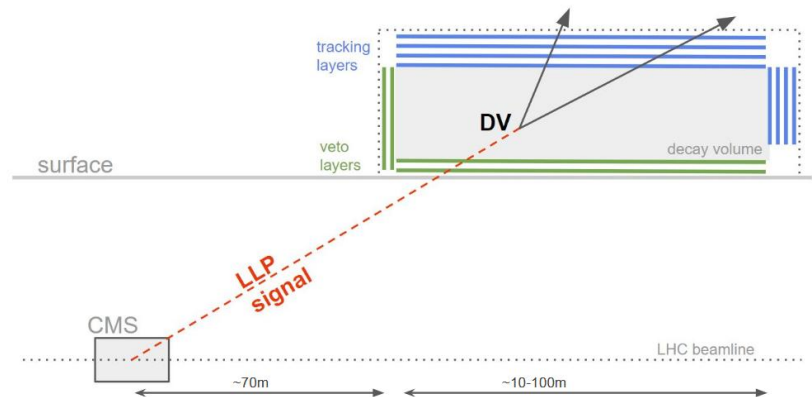
Searches for Long-Lived Particles with MATHUSLA

Runze (Tom) Ren for MATHUSLA collaboration
03/06/2025, LLP2025, València

MATHUSLA is proposed to solve the challenges of LLP detection in LHC main detectors

Background: Collider background is shielded by ~100 m of earth
→ Two to three orders more sensitive to longer lifetime

Trigger: MATHUSLA could supply an L1 trigger to CMS to ensure LLP production recorded!



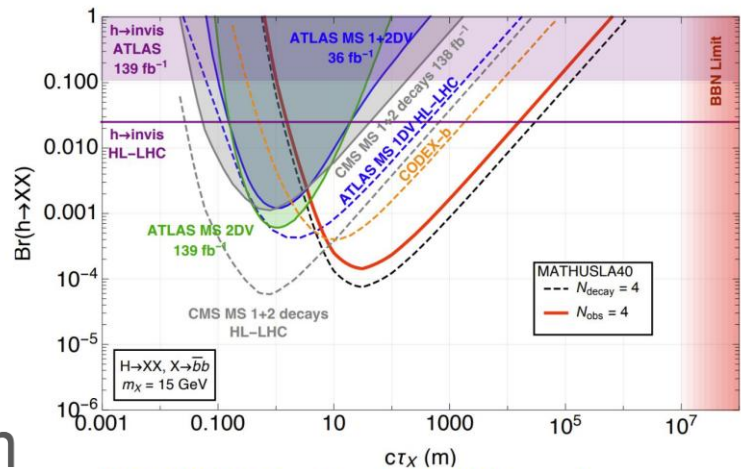
<https://arxiv.org/pdf/2503.20893>
New design after downsizing from 100x100m to 40x40m, i.e.,
MATHUSLA40



Sensitivity

Primary physics case:

hadronically decaying O(10-100 GeV) LLPs.
e.g., LLPs in exotic Higgs decays.



MATHUSLA40 extends HL-LHC reach
far beyond main detector projections.

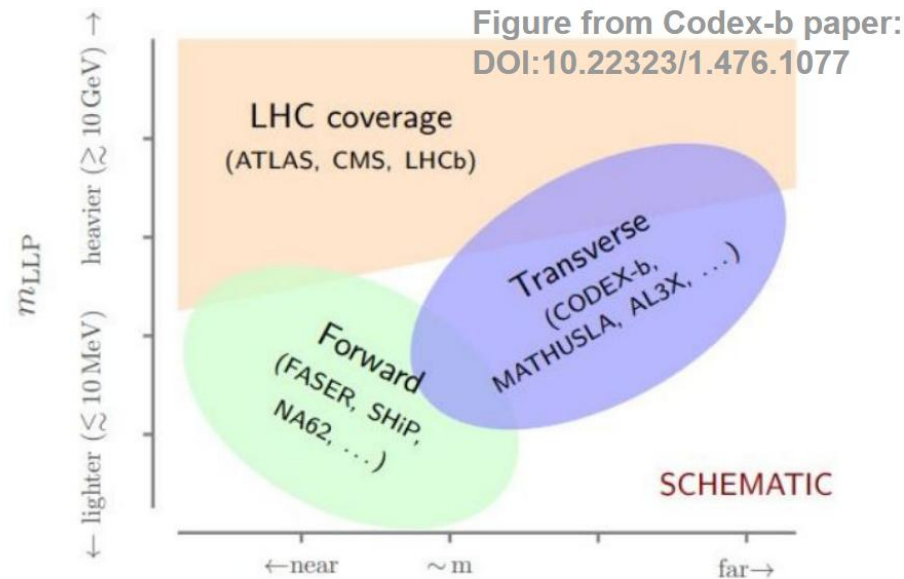
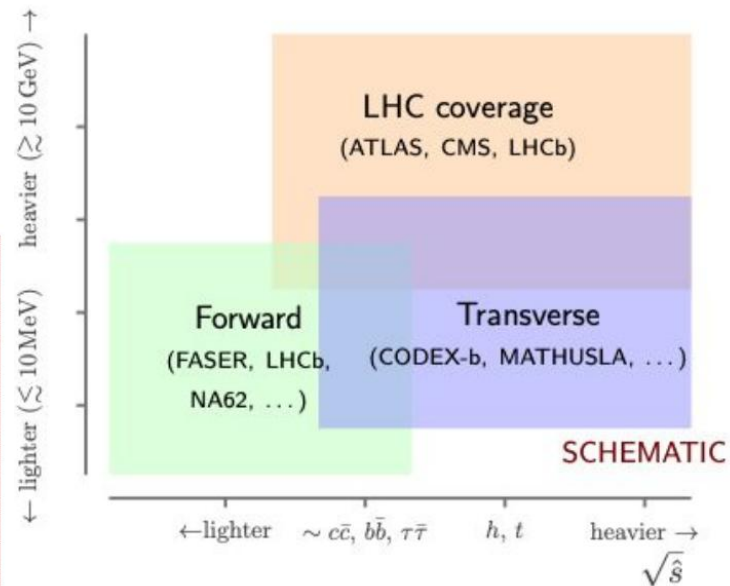


Figure from Codex-b paper:
DOI:10.22323/1.476.1077



	Exposure (x5 year)	Generator
LHC muon	1	MADGRAPH+PYTHIA
Atmospheric neutrino	2	GENIE+PYTHIA
Cosmic proton	1/32	PARMA
Cosmic neutron	1/27	CRY

Extrapolated to 5 years using ABDC

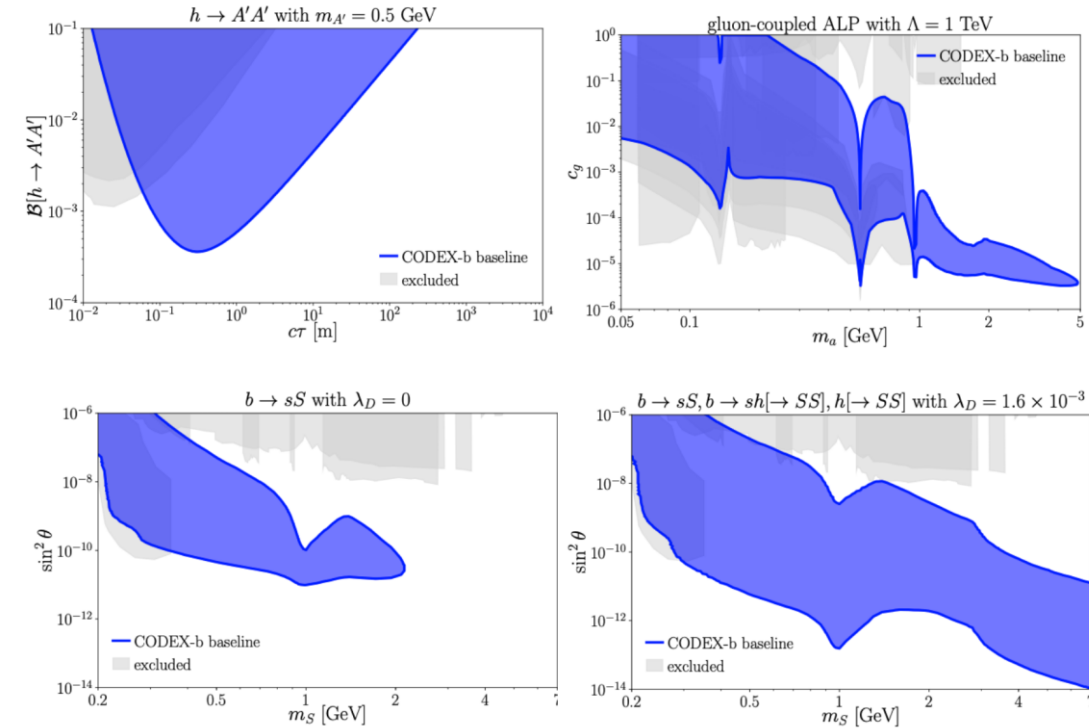
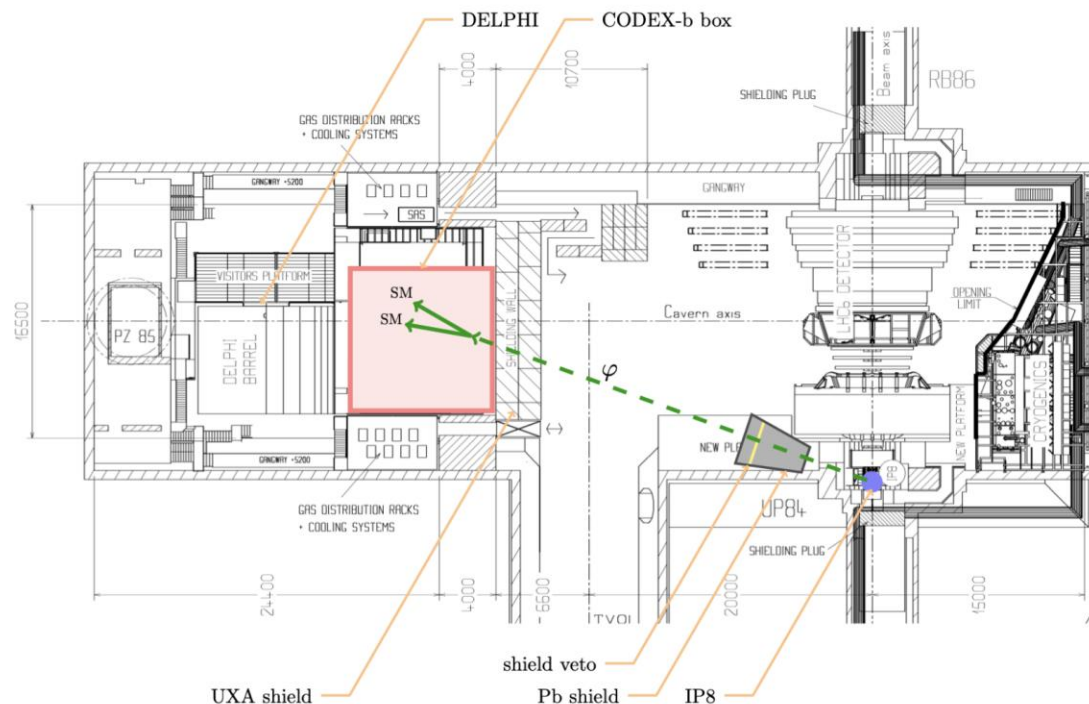
Update on the CODEX-b experiment

Emilio X. Rodríguez Fernández¹

On behalf of the CODEX-b collaboration

¹Instituto Galego de Física de Altas Enerxías (IGFAE)

- Transverse LLP detector in LHCb experimental cavern ($\sim 30m$ away from IP8).
- $10 \times 10 \times 10 m^3$ fiducial detector.
- ATLAS BIS-78 RPC tracking technology.
- Almost zero background experiment: UXA shield + active vetoes $\rightarrow \sim 32\lambda/300fb^{-1}$.



- Fully develop **Sim/Reco framework**.
- Demonstrate **integration with LHCb**.
- **Slow control framework** being developed.
- **Data Collection and Transmission (DCT)** modules will be in hand in **August**.





ANUBIS: Exploring the Projected Sensitivity to exotic LLP models and the current status of proANUBIS

LLP2025

Gaseous detector R&D, DRD1: FCC long-term goal

2033+: FCC detector construction & exploitation

2035+: Run 5 full ANUBIS+ATLAS data taking

2033+: bulk ANUBIS deployment in cavern (LS4)

2030+: Run 4 partial ANUBIS data taking

2028+: partial ANUBIS deployment in cavern (LS3)

2026+: ANUBIS detector R&D (electronics, R/O) engineering for cavern deployment

2025: proANUBIS data analysis, Letter of Intent

2024: PBC model #7 (#8, #9), proANUBIS data taking

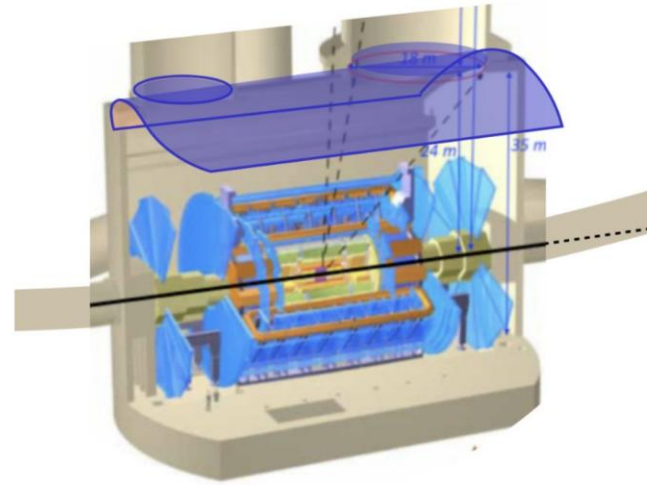
2023: finalise geometry, PBC model #6, proANUBIS

2022: seed funding for proANUBIS

2021: ANUBIS location & prototype conception

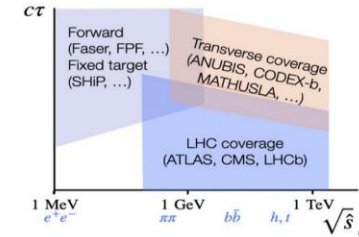
2020: proANUBIS sensitivity studies

2019: ANUBIS conception

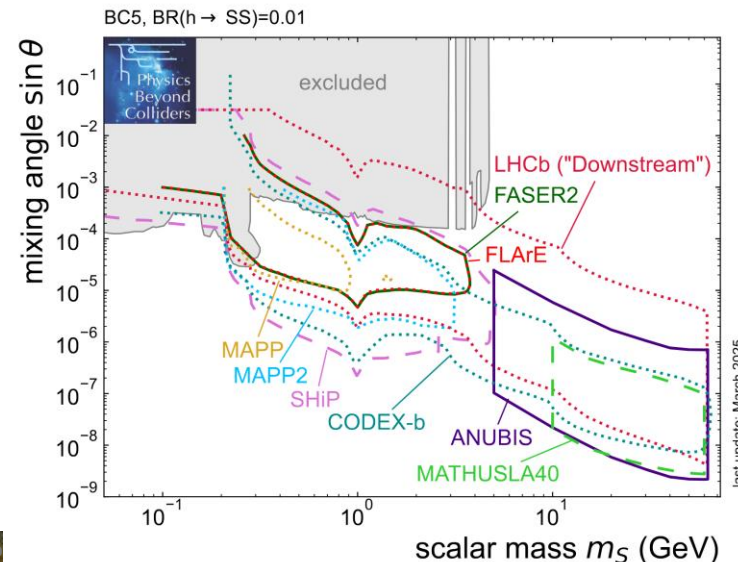


ANUBIS proposes to cover the shaded region (blue) with RPC detectors

- Large, **air-filled** ATLAS experimental cavern provides ideal decay volume.
 - Large nuclear interaction length reduces punch-through backgrounds.
 - ATLAS detector information can actively veto collision products.
- Transverse position provides sensitivity to higher-mass LLP models (>1 GeV) and electroweak-scale+ mediators.
 - Strong complementarity with forward physics facilities.



CERN-PBC-Report-2-25-003



SHIFT

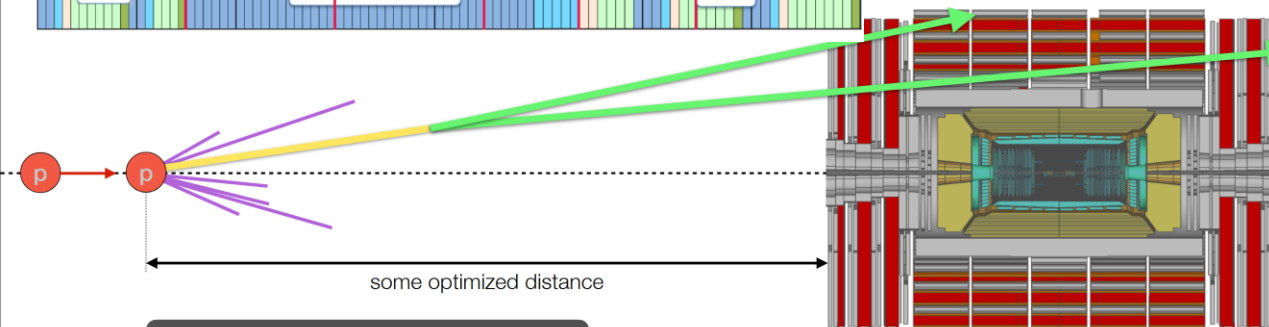
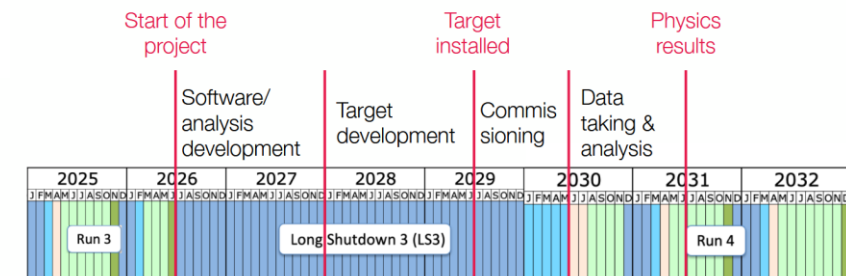
SHifted I nteraction on a F ixed T arget

LLP Workshop — 3/06/2025

JHEP 2024, 204

arxiv: 2406.08557

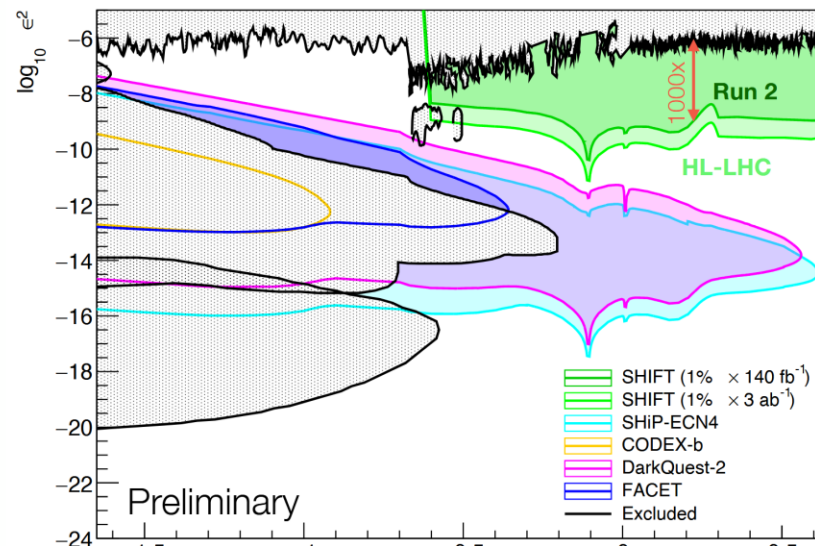
Jeremi Niedziela (DESY)



Lower $\sqrt{s} \approx 115$ GeV
Large decay volume
High acceptance
Backgrounds shielding

Just move the collision!
A's will mostly miss the detector...

Sensitivity: What do we gain?

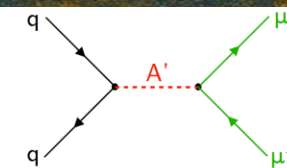


Dark Photons

- Simple dark photon scenario, following PBC recommendations.
- 1% of CMS luminosity dedicated to SHIFT.
- SHIFT covers a unique phase space.
- 2-3 orders of magnitude improvement over existing limits.

Some technical details

- Calculated with SensCalc [arxiv: 2305.13383](https://arxiv.org/abs/2305.13383)
- QCD & DY bkg. estimated with Pythia ✓
- Absorption in the material included ✓



Technical feasibility

Gaseous fixed target

- Similar to SMOG2.
- Just 1 gas type (e.g., neon).
- Dedicated insertion system.
- Cost: ≈ 300 kCHF.

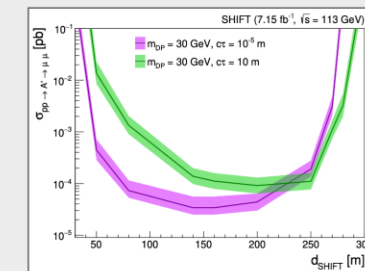
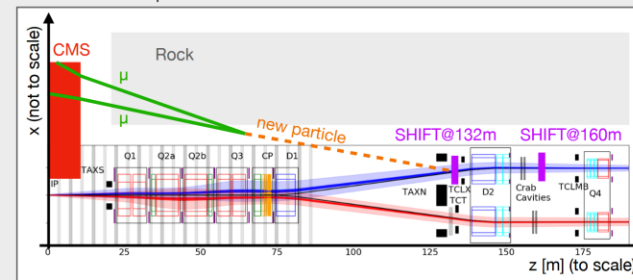


Luminosity & beam lifetime

- Aiming at 1% of the CMS rate for SHIFT.
- Requires higher pressure than in SMOG2.
→ Doable (also according to experts).
- Beam loss $< 1\%$ over a 10-hour run.

HL-LHC integration

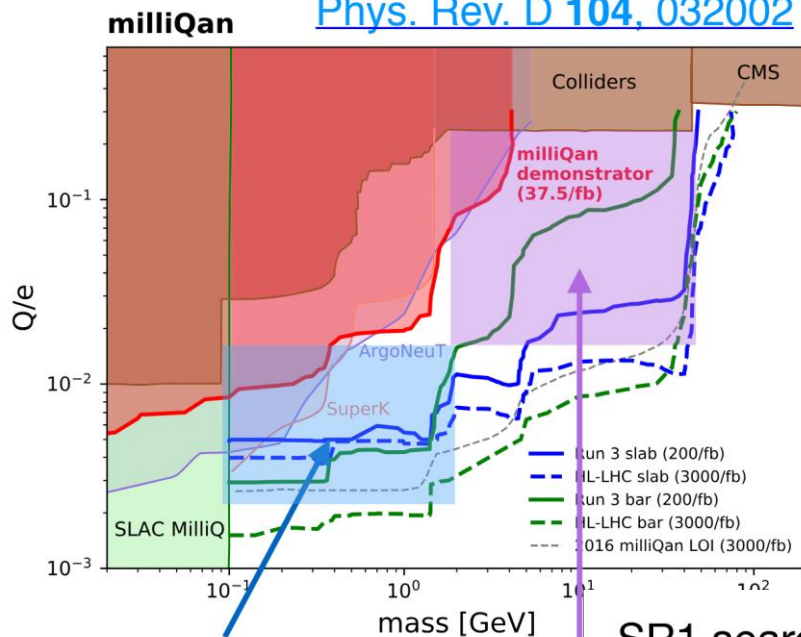
- Luckily, there are empty sections in the interesting region.
- The bulk of particles avoids interaction with instrumentation.



Distance optimization

- Interplay between acceptance, decay volume, and material survival.
- 150-250 meters is good.
- 160 meters is best for a wide range of models.

Phys. Rev. D 104, 032002



Charge limited region: very high mCP flux but low efficiency (Bars)

Acceptance limited region: efficiency but mCP flux (Slabs)

SR1 search results

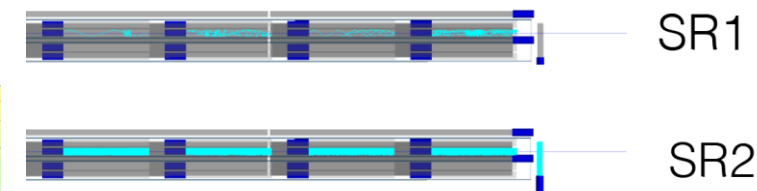
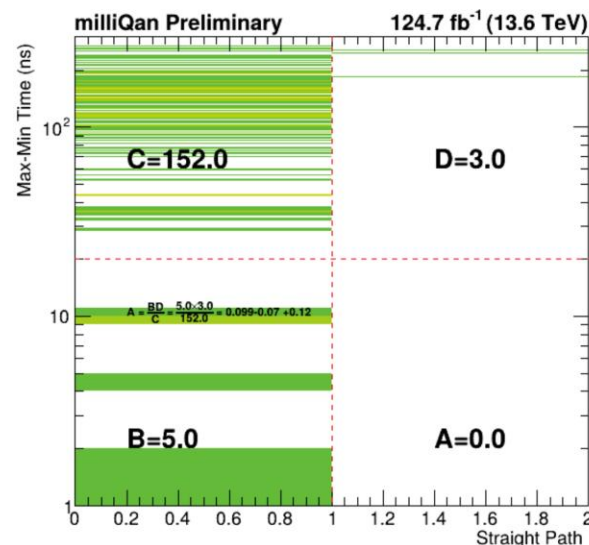
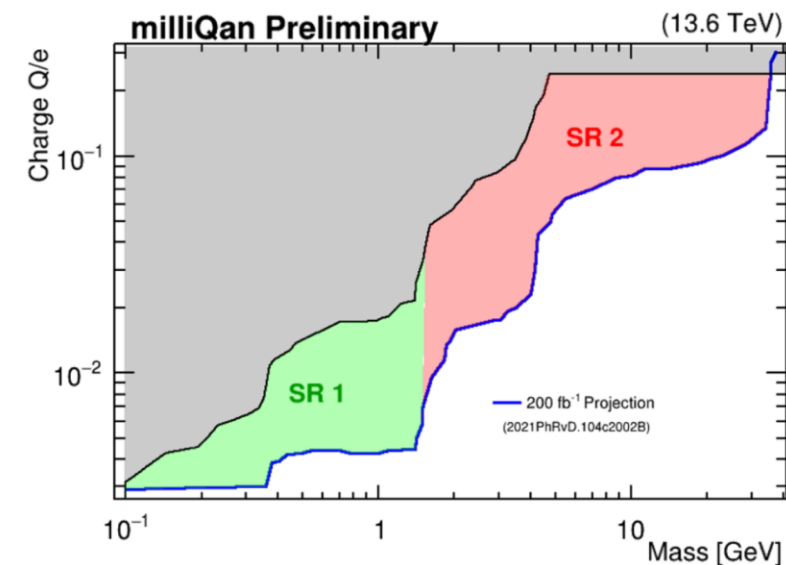
- Prediction: $0.10^{+0.12}_{-0.07}$
- Observation: 0

Result:
Observation consistent with background expectation

No mCP signal :(

Search in two orthogonal signal regions

- SR1: lower charges
 - Veto events w/ hits in **front/back panels** and **saturating pulses** deposited in any bar
- SR2: higher charges
 - Require events to have ≥ 1 hits in **front/back panel** (but with < 70 nPE)



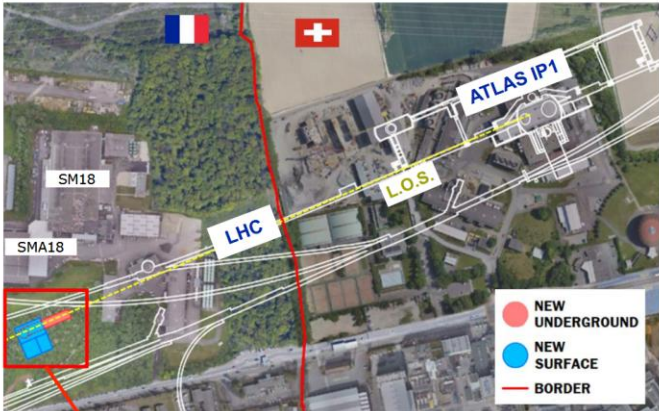
The Forward Physics Facility at the LHC



Juan Salvador Tafoya Vargas (UC Davis)
on behalf of the FPF community

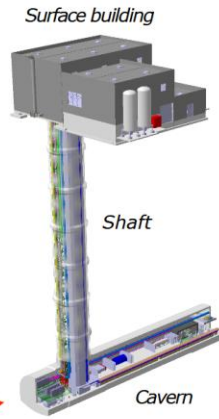
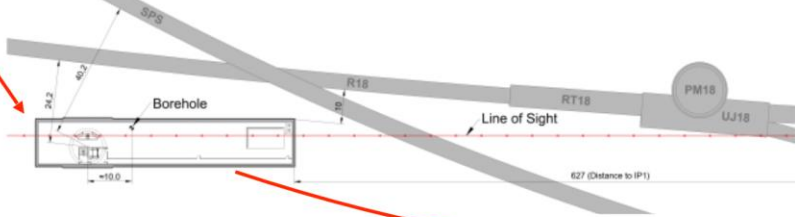
LLP2025, Valencia 2025.06.04 UCDAVIS

The facility

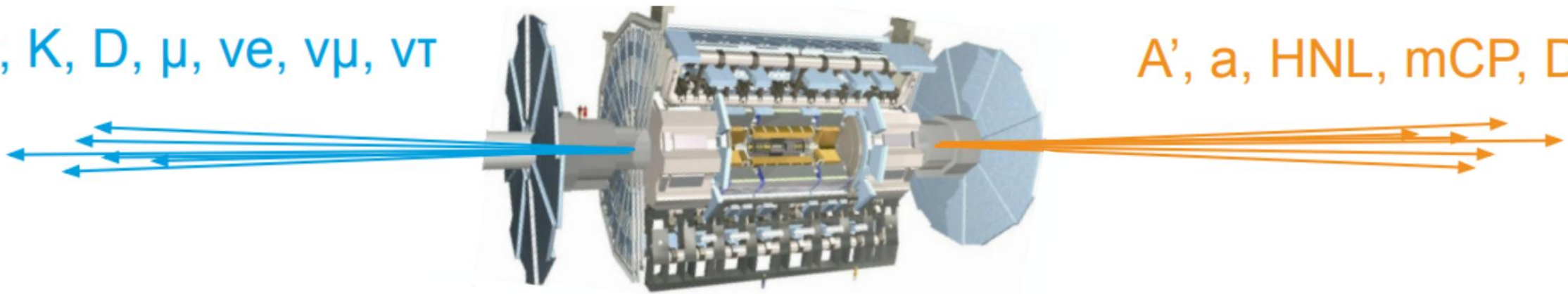


Location fixed!

- 627m away from ATLAS IP1 at 90m of depth on french soil
- 10m away from LHC tunnel → safe to access during stable beams
- Main dose given by collision muons from IP1



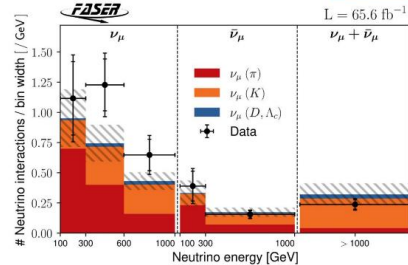
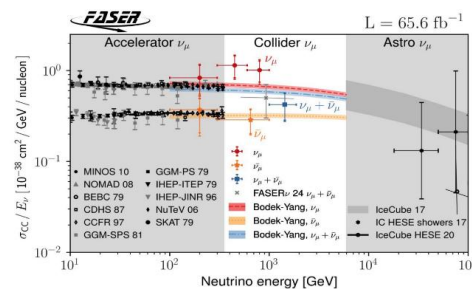
$\pi, K, D, \mu, \nu_e, \nu_\mu, \nu_\tau$



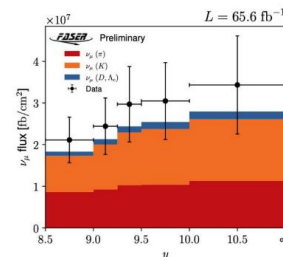
FASER

$$n_{\nu,obs} = 338.1 \pm 19.0(\text{stat.}) \pm 8.8(\text{sys.})$$

See Wissal Fil

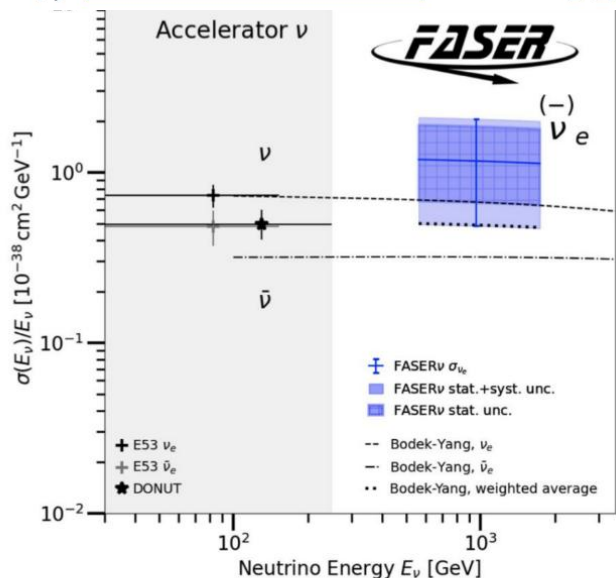


First differential neutrino interaction measurement in the TeV energy range ([Phys. Rev. Lett. 134, 211801](#))



Rapidity bin	[8.5, 9.0]	[9.0, 9.25]	[9.25, 9.5]	[9.5, 10]	[10, infinity)
Uncertainty Sources					
MC Stat. unc.	1.5	1.2	1.0	1.1	1.0
Geant4 + GENIE unc.	1.3	4.3	3.5	3.6	1.8
Neutrino Flux Modeling unc.	38.3	29.4	19.5	23.0	22.4
LOS unc.	29.9	3.5	0.2	9.0	12.7
Mass	3.3	2.3	1.6	1.9	1.5
Luminosity	6.9	4.8	3.4	4.0	3.2
Total	49.2	30.4	20.2	25.4	26.0

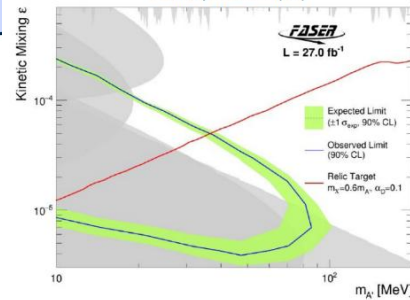
ν_μ flux as a function of the rapidity y ([CERN-FASER-CONF-2025-001](#))



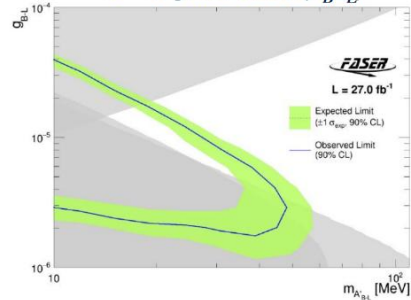
Measurement of ν_e and ν_μ cross sections in the TeV range for 130 kg target mass x 9.5 fb⁻¹ ([PhysRevLett.133.021802](#))

FASER

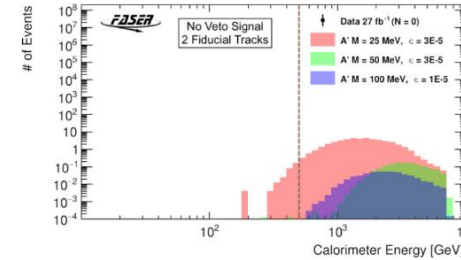
Dark photon (A')



$B - L$ gauge boson (A'_{B-L})



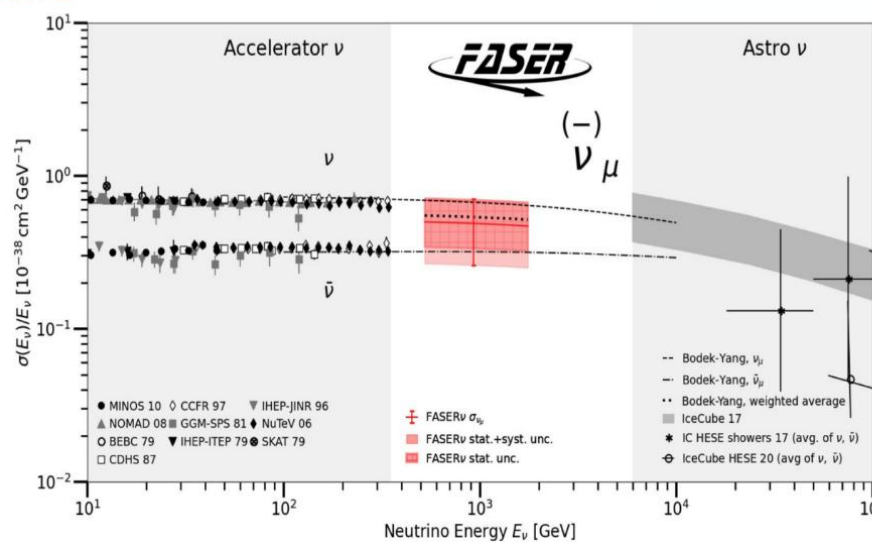
Dark photon search with 2022 data (27 fb⁻¹) ([2308.05587](#))



Axion-like particles search with 2022/2023 data (57.7 fb⁻¹) ([2410.10363](#))

UC DAVIS

UC DAVIS

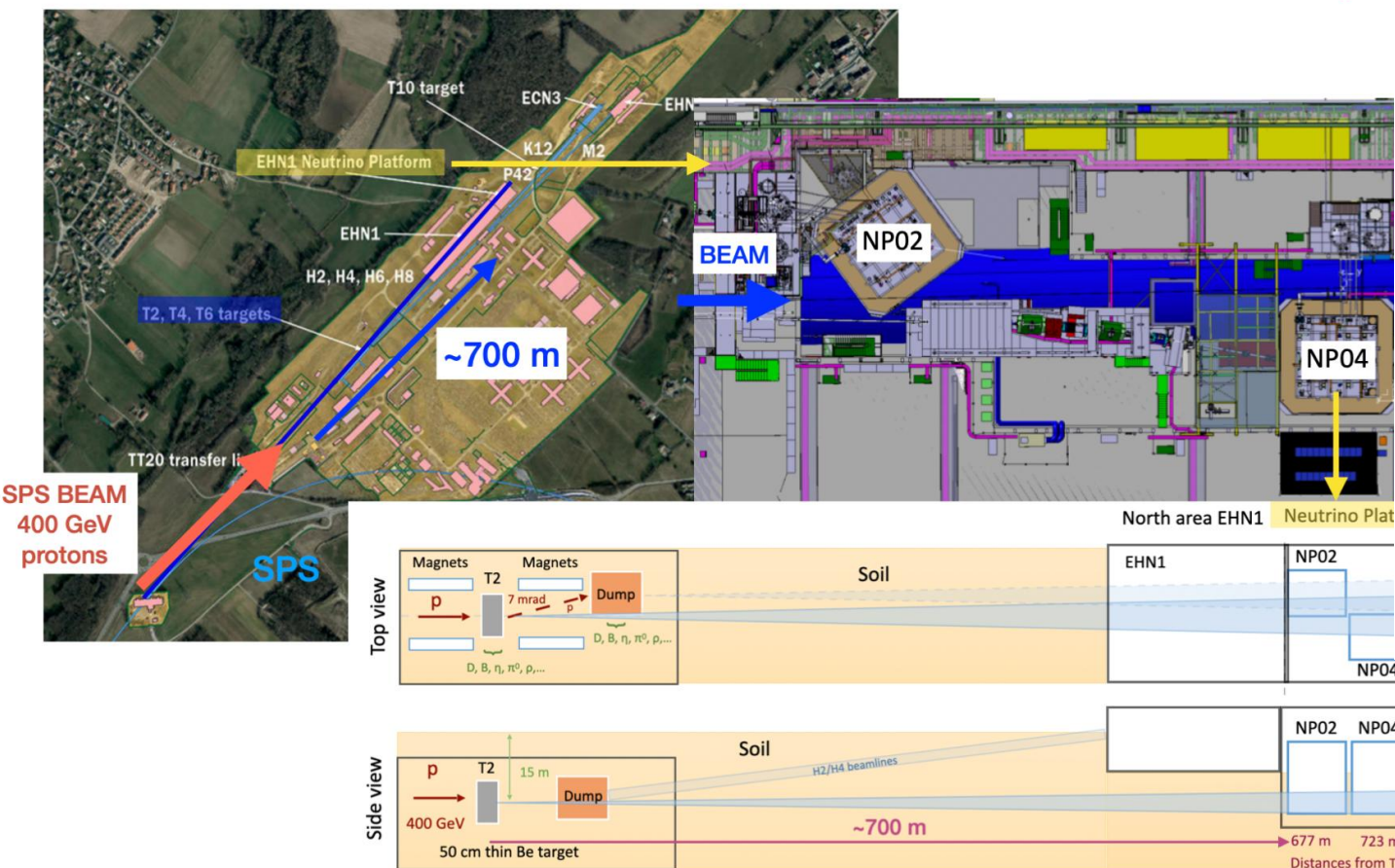


BSM searches @ProtoDUNE-SPS

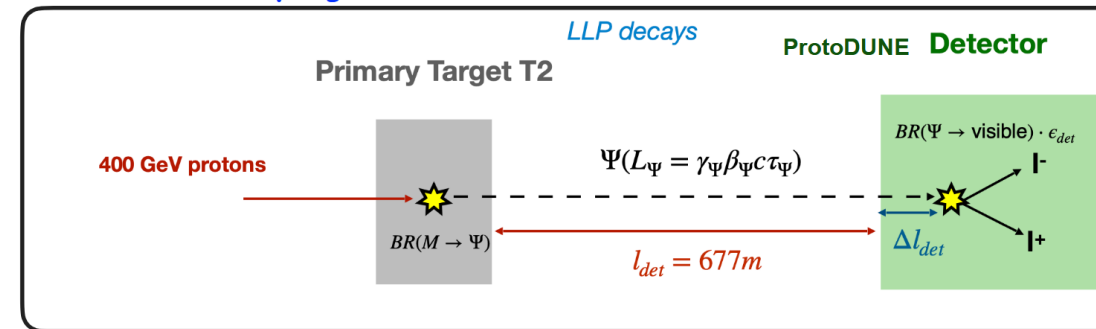
Animesh Chatterjee

On behalf of the ProtoDUNE-BSM working group

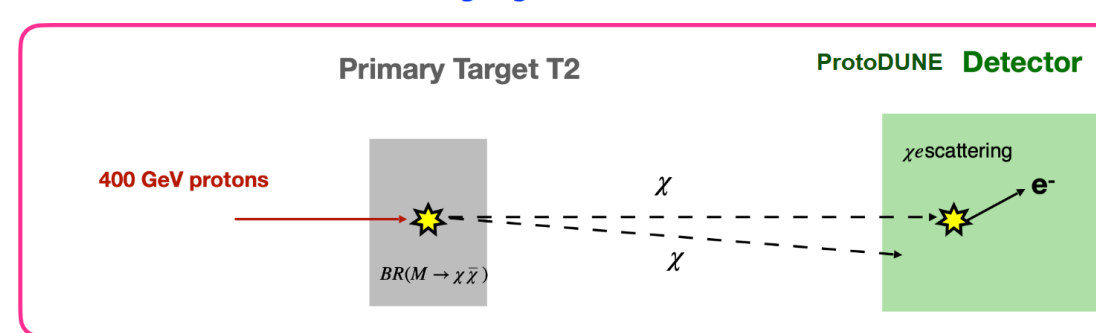
Motivation: ProtoDUNE-SPS Setup



a) LLP/BSM decay signatures



b) LLP/BSM Particles scattering signatures

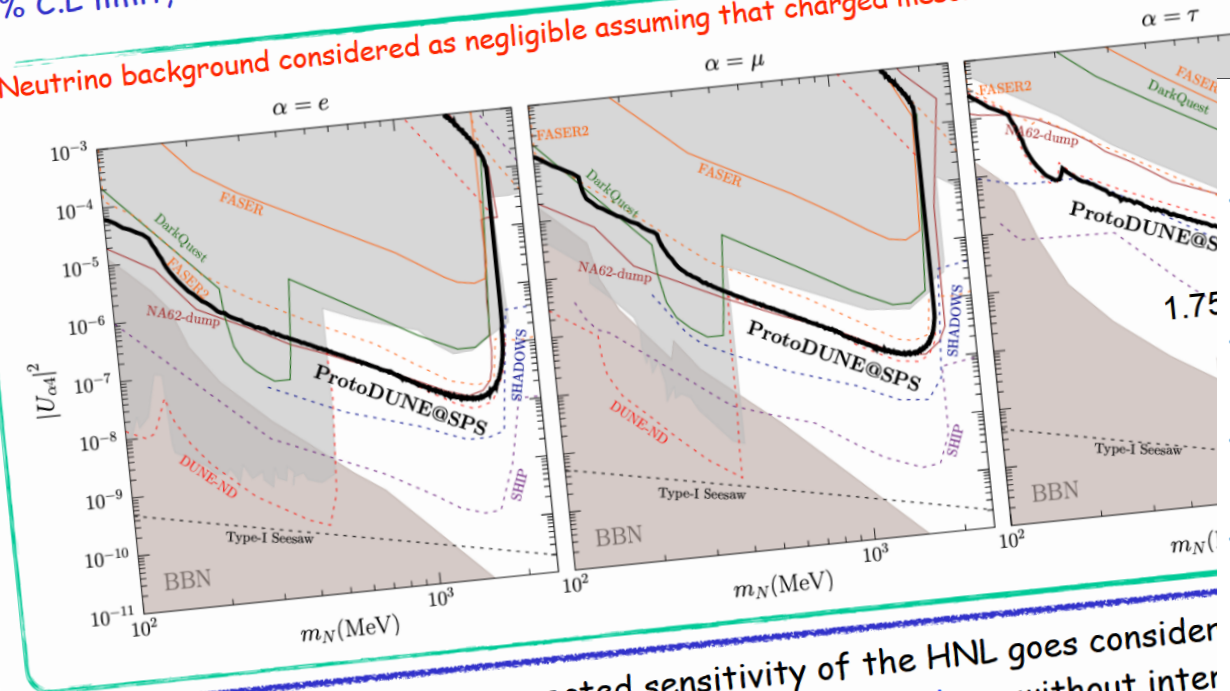


The Proposal : HNLs sensitivity@ProtoDUNE

[https://link.springer.com/article/10.1007/JHEP01\(2024\)134](https://link.springer.com/article/10.1007/JHEP01(2024)134)

90% C.L limit, 1.75×10^{19} POT (5 years), Decays considered: $N \rightarrow \nu e e, \nu \mu \mu, \nu e \mu, e \pi, \mu \pi, \nu \pi^0$

Neutrino background considered as negligible assuming that charged mesons will be deflected by the magnets



* This study shows that the expected sensitivity of the HNL goes consider current constraints using facilities that are **already in place**, without inter the experimental program in the North Area at CERN, and within a relative timescale

See more : P. Coloma, J. López-Pavón, L. Molina-Bueno and S. Urrea, JHEP 01 (2024), 134 doi:10.1007/JHEP01(2024)134
LLP25, June 2-6, 2025, A.Chatterjee

Summary and outlook

- * The excellent imaging capabilities of the ProtoDUNE detectors (LArTPC) with high energy SPS beam make them ideal setup (mini-dump) for LLP/BSM particles in Beyond Standard Model scenarios
- * Such a setup offers the possibility to search for both long lived unstable particles and stable particles
- * Currently, we are focused on carrying out the feasibility study to search for LLP decays, HNL as golden channel.
- * We have recently formed a working group to identify and work to validate the proposal:
 - We are developing a realistic simulation framework including the main beam elements and the ProtoDUNE detectors.
 - A simplified software trigger used and tested with the summer NP04 runs.
 - We are in a process to show the proof-of-principle by identifying "neutrino like" events with the data taken during the summer @NP04.
 - In process to develop analysis tools for signal (HNL) and background event selection
- * This would be the "first" setup at CERN to search for BSM signatures using LArTPC technology, useful for future proposed experiments e.g. SHiP.

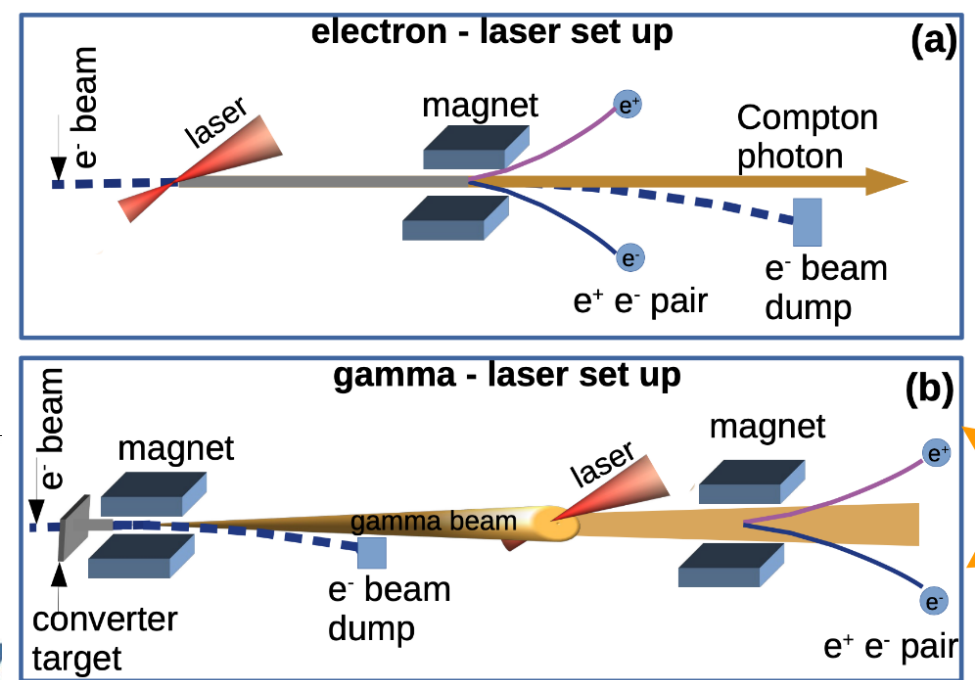
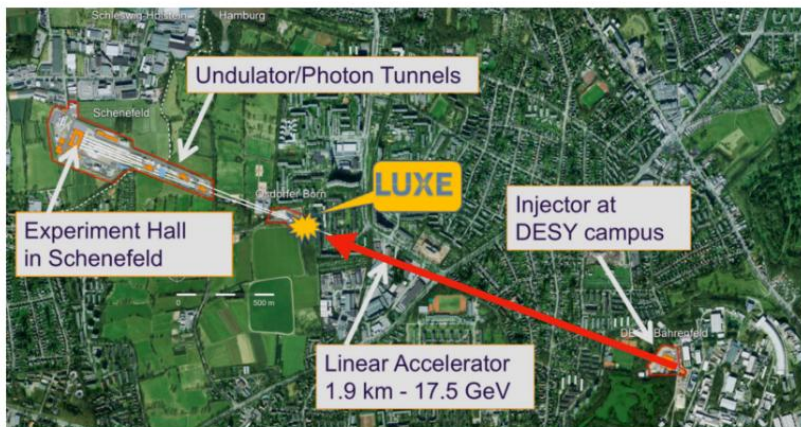
Probing for light new particles with the LUXE experiment

RAQUEL QUISHPE on behalf of the LUXE collaboration

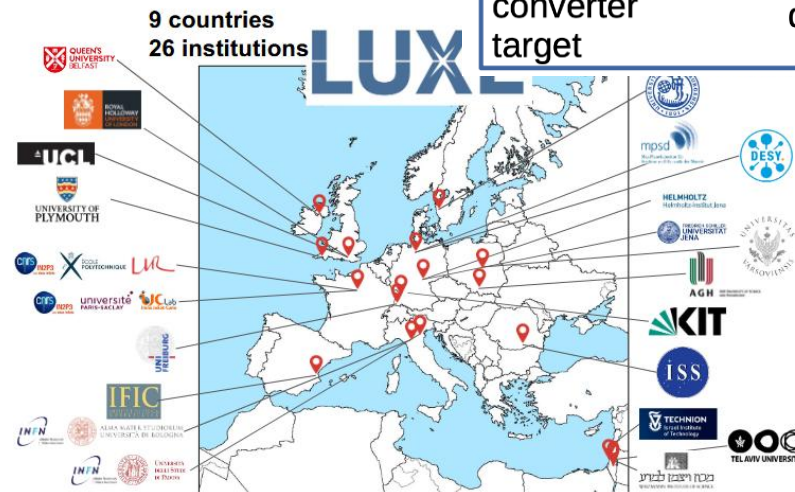
KIT – Karlsruhe Institute of Technology

Laser Und XFEL Experiment

- Based at DESY and European XFEL (Eu.XFEL) in Hamburg and Schenefeld, Germany
- LUXE will collide Eu.XFEL electrons and bremsstrahlung photons with a high-intensity laser



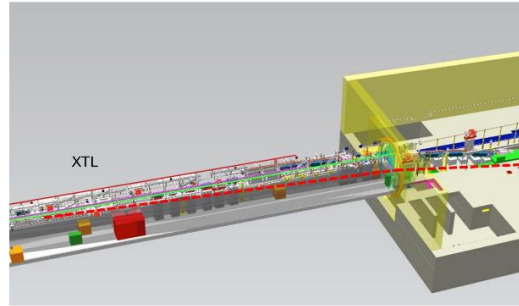
Unique
in LUXE



- CDR** done in 2021, **TDR** done in 2023, reached CD-1
- Input to ESPPU** done in 2025
- Physics goals:**
study strong-field QED and **ALPs searches**

LUXE experimental area and timeline

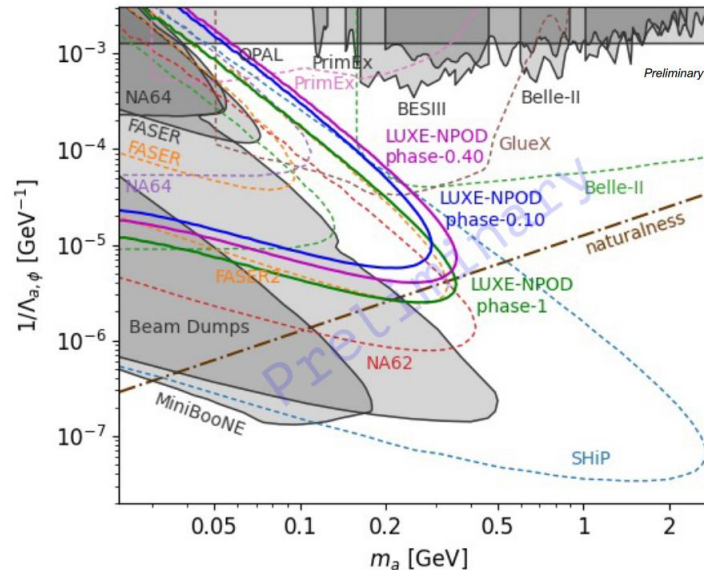
- LUXE uses high-quality 16.5 GeV EuXFEL e-beam before undulators
 - #electrons/bunch: 1.5×10^9
 - Repetition rate: 10 Hz
- Continuous data-taking with variable laser spot size (unique in LUXE)
- Funding of beamline through ELBEX



	2025	2026	2027	2028	2029	
Extraction beamline (ELBEX)	Design	Procurement	Installation*			(*)
LUXE Laser		JeTi 40 operated at DESY	Procurement + Installation			
LUXE Detectors	Design, Procurement	Construction, Testing	Installation			

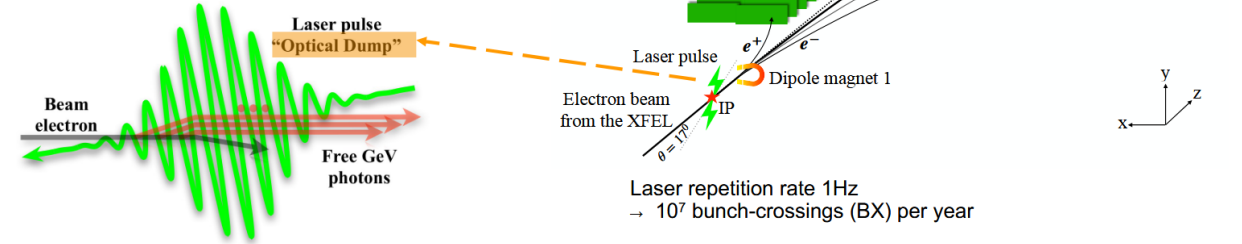
Summary

- LUXE-NPOD acts as a background-free optical dump allowing the production of light ALPs with large couplings
- LUXE-NPOD competitive with FASER2 or NA62-dump
- Exciting windows of opportunities and challenges ahead



LUXE-NPOD project

- NPOD: New Physics searches with an Optical Dump**
- Collide a beam of 16.5 GeV electrons with the laser
- The laser behaves as a thick medium, leading to the production of a large flux of hard photons O(GeV)
- Photons see the laser as a transparent medium and can reach the physical dump
- Lower background from gamma photons



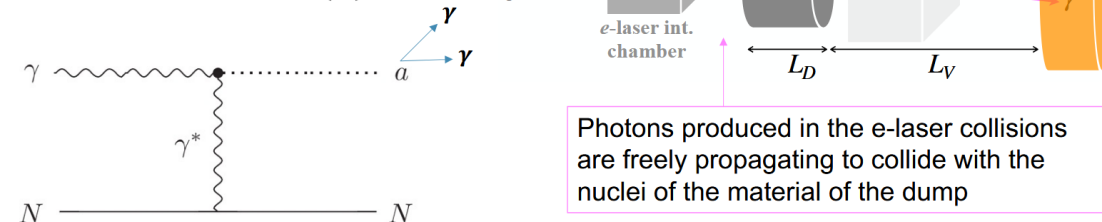
NP production mechanisms

- Secondary NP production:**

- Axion-like particles (ALPs) and scalar ($X = a, \phi$) production through Primakoff mechanism with a displaced decay to 2 hard photons

$$\mathcal{L}_{a,\phi} = \frac{a}{4\Lambda_a} F_{\mu\nu} \tilde{F}^{\mu\nu} + \frac{\phi}{4\Lambda_\phi} F_{\mu\nu} F^{\mu\nu}$$

- ALP mass up to $\mathcal{O}(1)\text{GeV}$



Trigger streams

15:00 → 16:50

Trigger streams

Conveners: Arantza Oyanguren (IFIC - Valencia), Matthew Daniel Citron (University of California Davis (US))

15:00

ATLAS: TLA/anomaly

🕒 25m

Speaker: Tatiana Ovsiannikova (University of Washington (US))

 LLP2025_slides.pdf

15:30

CMS: scouting & parking

🕒 20m

CMS continues to explore innovative data acquisition strategies, such as data scouting and data parking, to enhance sensitivity to BSM physics signatures. Data scouting targets low-mass and low-momentum regimes typical of many LLP scenarios by enabling the high-rate recording of reduced-content event information taken directly from the CMS trigger system, thereby accessing regions of phase space beyond the reach of conventional trigger strategies. Data parking, in parallel, also records events using relaxed selection thresholds but retains the full raw detector information for offline reconstruction, which can be deferred to accommodate resource constraints. These complementary approaches have proven instrumental in probing challenging signatures from both SM and BSM processes, including LLPs. In this talk, I will review recent developments in these strategies during Run 3 and discuss prospects for the future.

Speaker: Robert John Bainbridge (Imperial College (GB))

 250605_CMS_Scout...

15:55

CMS: Anomaly Detection Triggers

🕒 12m

Anomaly detection triggers offer a model-agnostic approach to capturing a wide range of beyond the Standard Model (BSM) signatures, including those from long-lived particles (LLPs). This talk presents an overview of the two machine learning-based anomaly detection triggers deployed in the CMS Level-1 trigger in 2024: AXOL1TL and CICADA. I will discuss their design, implementation, and integration into the CMS trigger. The talk will also outline future directions for enhancing sensitivity to LLPs with such triggers by incorporating Level-1 tracking and precision timing information.

Speaker: Jannicke Pearkes (University of Colorado Boulder (US))

 2025_06_05_LLP20...

16:10

BuSca: New Strategies for LLP Searches at 30 MHz at LHCb

🕒 15m

The new fully software-based trigger of the LHCb experiment operates at a 30 MHz data rate, opening a search window into previously unexplored regions of physics phase space. The BuSca (Buffer Scanner) project at LHCb acquires and analyses data in real time, extending sensitivity to new lifetimes and mass ranges thanks to the recently deployed Downstream tracking algorithm. BuSca identifies hotspots indicative of potential new particle candidates in a model-independent manner, providing strategic guidance for developing new trigger lines. To control background, regions with minimal detector material interactions are selected, and pairs of same-sign tracks are used to suppress combinatorial background. This talk presents the results from the analysis of the first data.

Speaker: Valerii Kholoimov (Instituto de Física Corpuscular (Univ. of Valencia))

 BuSca_LLP2025_Kh...

16:30

Discussion

🕒 20m

The Run3 triggers for LLP analysis

T. Ovsianikova (UWashington, US) tovsiank@uw.edu
on behalf of the ATLAS Collaboration



Isolated high pt track trigger

- Target: Heavy charged particles
- Particles leave isolated high- p_T track in the ID
- Seeded with MET L1 with additional 80 GeV Met cut to reduce the full-scan tracking

LLP signatures

New Dedicated triggers in Run3:

Meta stable particles

Isolated high pt track trigger

HIP, multi-charged:

Large dE/dx trigger

Displaced jets in the ID

Displaced jet trigger

Disappearing tracks

Disappearing track trigger

Emerging jets

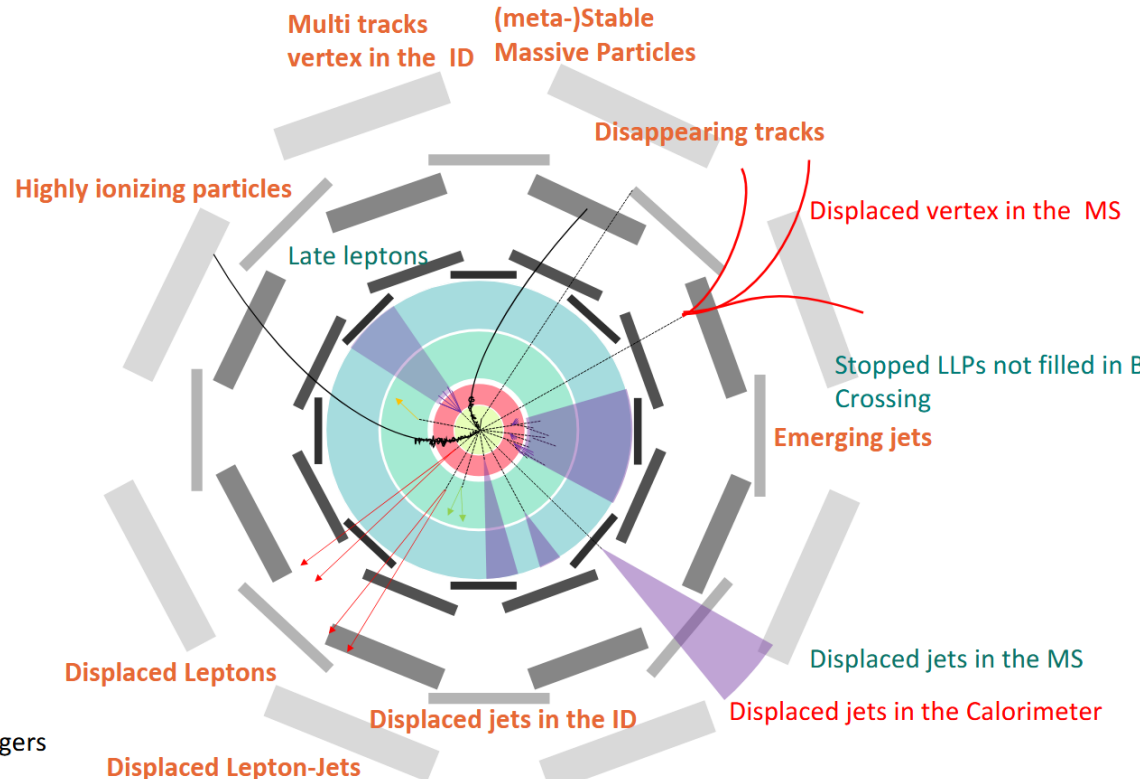
Emerging jets trigger

Displaced leptons:

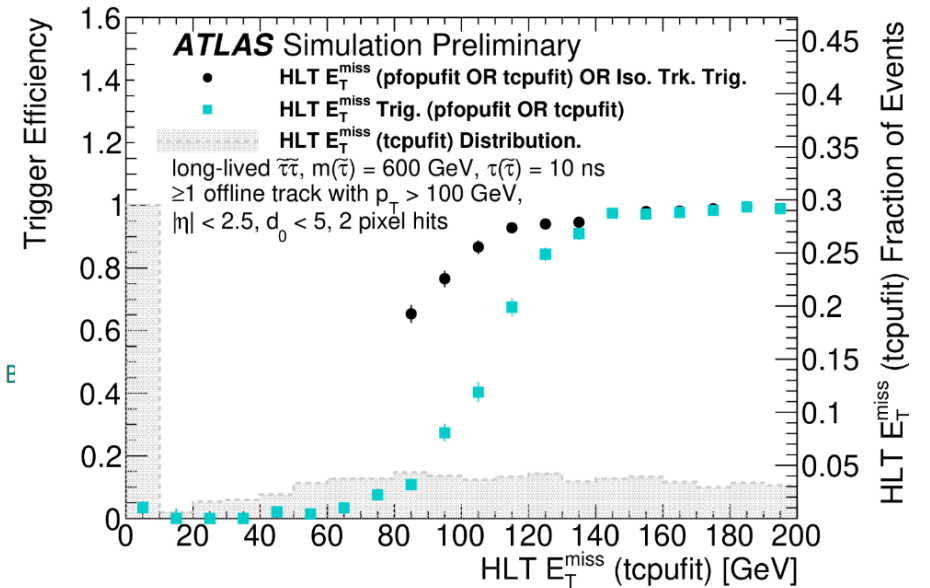
Displaced lepton trigger

Displaced vertex in ID:

Hit-based displaced vertex triggers



Run 3 triggers paper ([arXiv:2401.06630](https://arxiv.org/abs/2401.06630))



- Run 2 HLT tracking limited to maximum transverse impact parameter (d_0) of 10 mm
- Improvements to reconstruction allow Large Radius Tracking (LRT) to run in the HL
- LRT provides tracking with a maximum d_0 of 300 mm
- Runs after Standard Tracking and only considers unused

- Looks for tracks which have Pixel hits and few/no SCT hits
- Such tracks could be produced by a charged particle which decays to neutral particles between the Pixel and SCT detectors
- Four categories based on the number of Pixel and SCT hits

Displaced lepton triggers

- LLPs may also decay into SM leptons resulting in displaced electrons, muons, and taus:
- Uses all clusters in regions of interest in Roi to run LRT
- Lower threshold w.r.t Run 2
- New tau trigger in developments

Hit-based displaced vertex triggers

Target: Neutral LLPs with decay produces displaced vertex (DV) or jet

Two hit-based DV triggers:

- Use hits not associated with standard full-scan tracks
- Select jets with many hits on outer ID layers, few on inner layers
- DV jets BDT-based selection uses fraction of hits in each ID layer

Emerging jets triggers

Target: dark sector, decays into hadrons

Two topologies:

- ISR gluon with di-jets (one is Large-R)
- Di-Jets with non prompt tracks/soft tracks

TJA triggers

Designed to reduce the bandwidth by saving only reconstructed objects

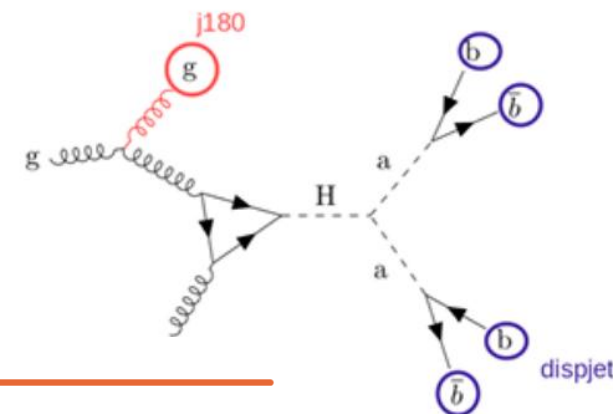
Increases low mass sensitivity

Relies on the jet's performance

Run3: HLT jets corrected with an offline jet calibration configured for Run 3 reconstruction

Displaced jets triggers

Neutral LLPs hadronic decays



Further improvements:

IIP Run 3 trigg
L1 anomaly detecti

Semi-visible jets, ALP to di-photon

- TLA+PEB(Partial Event Building)- based trigger (Low masses)

Dark photons:

- Dark photon jet trigger
- Combined VBF with MS only or calratio jets

Calratio Pileup mitigation:

- Use information about calorimeter layers + ML

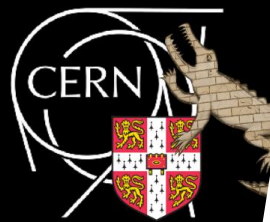
Triggers based on out-of-time energy deposits from slow-moving particles:

- Combine calorimeter timing with tracker info on various L1 seeds
- L1 trigger uses timing
- Additional streams to collect samples for out-of-time background

Anomaly detection triggers:

ML-based Anomaly Detection triggers for L1 and HLT to make model-agnostic searches for BSM

LLP2026 Workshop @ Cavendish Laboratory



SCHEDULE / DATES

- 29/06 - 03/07/2026
(Monday-Friday)



The Place of Pioneering Physics

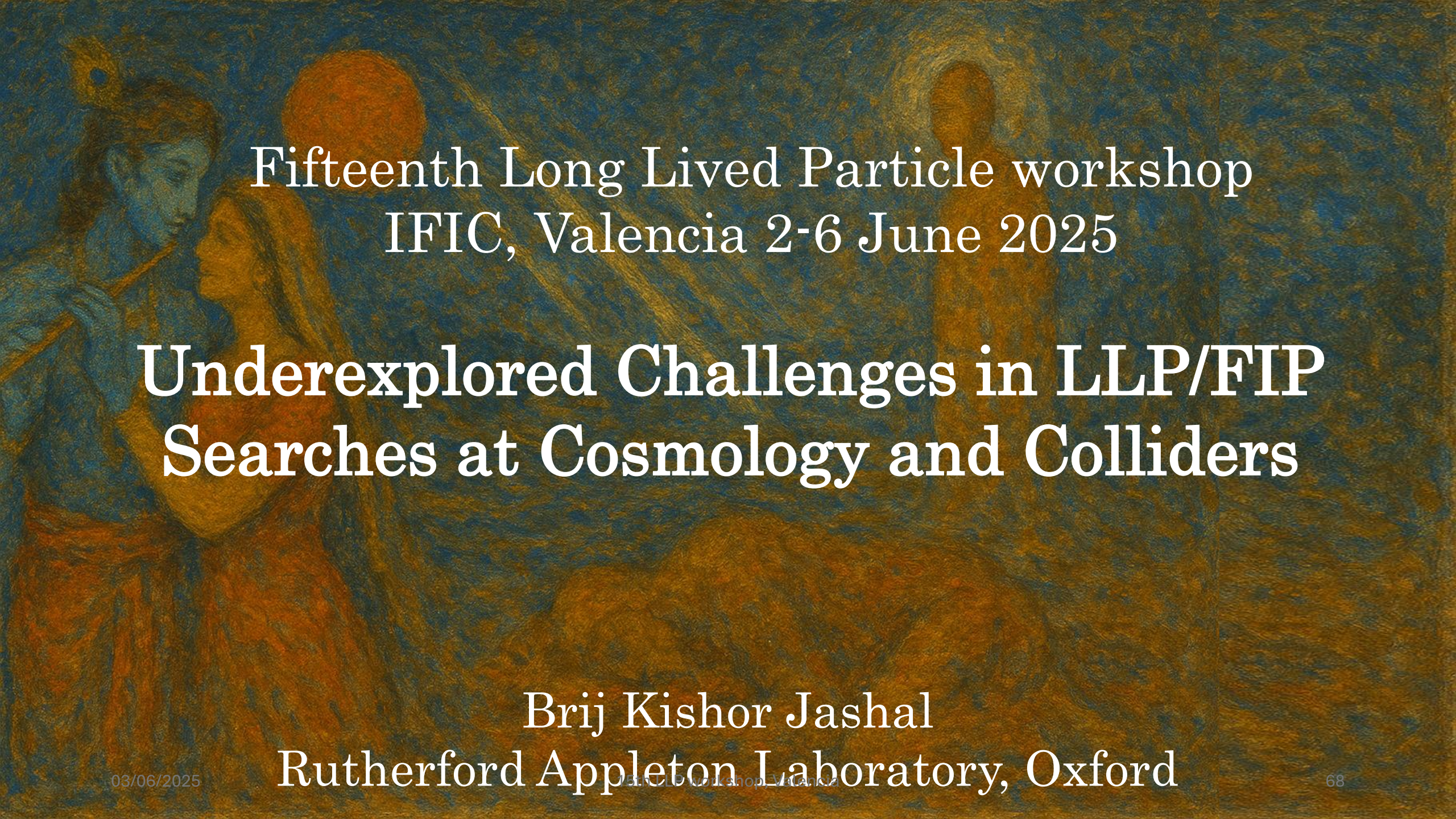
Since it was founded in 1874, the Cavendish Laboratory has been at the forefront of discovery in physics. The core Laboratory's programme has been, and continues to be, experimental physics, supported by excellence in theoretical physics.

[Explore Cavendish Laboratory →](#)

Oleg Brandt • Tina Potter • Michael Revere

Workshop Dinner



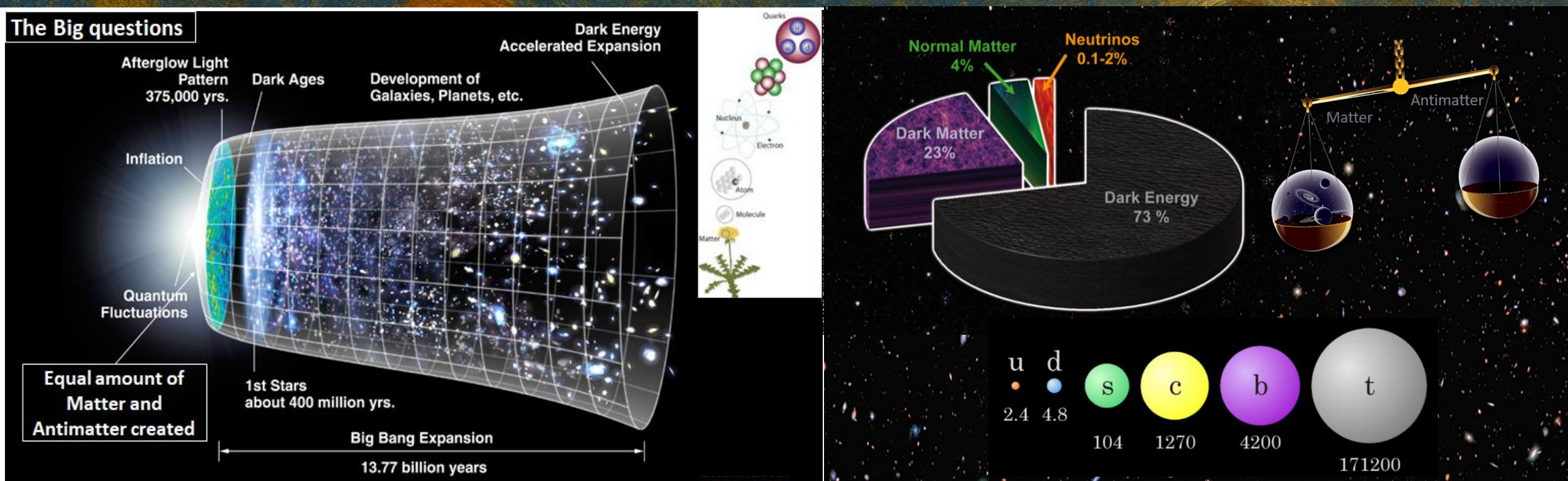


Fifteenth Long Lived Particle workshop
IFIC, Valencia 2-6 June 2025

Underexplored Challenges in LLP/FIP Searches at Cosmology and Colliders

Brij Kishor Jashal
Rutherford Appleton Laboratory, Oxford

Underexplored challenges: Cosmology



Do we really know that we don't know ~95% of the universe. ??

“Degree of skepticism must not only be pardonable but should be laudable”

Λ CDM concordance cosmology, based on Friedman equations(1922) recently going through a crises

$$G_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

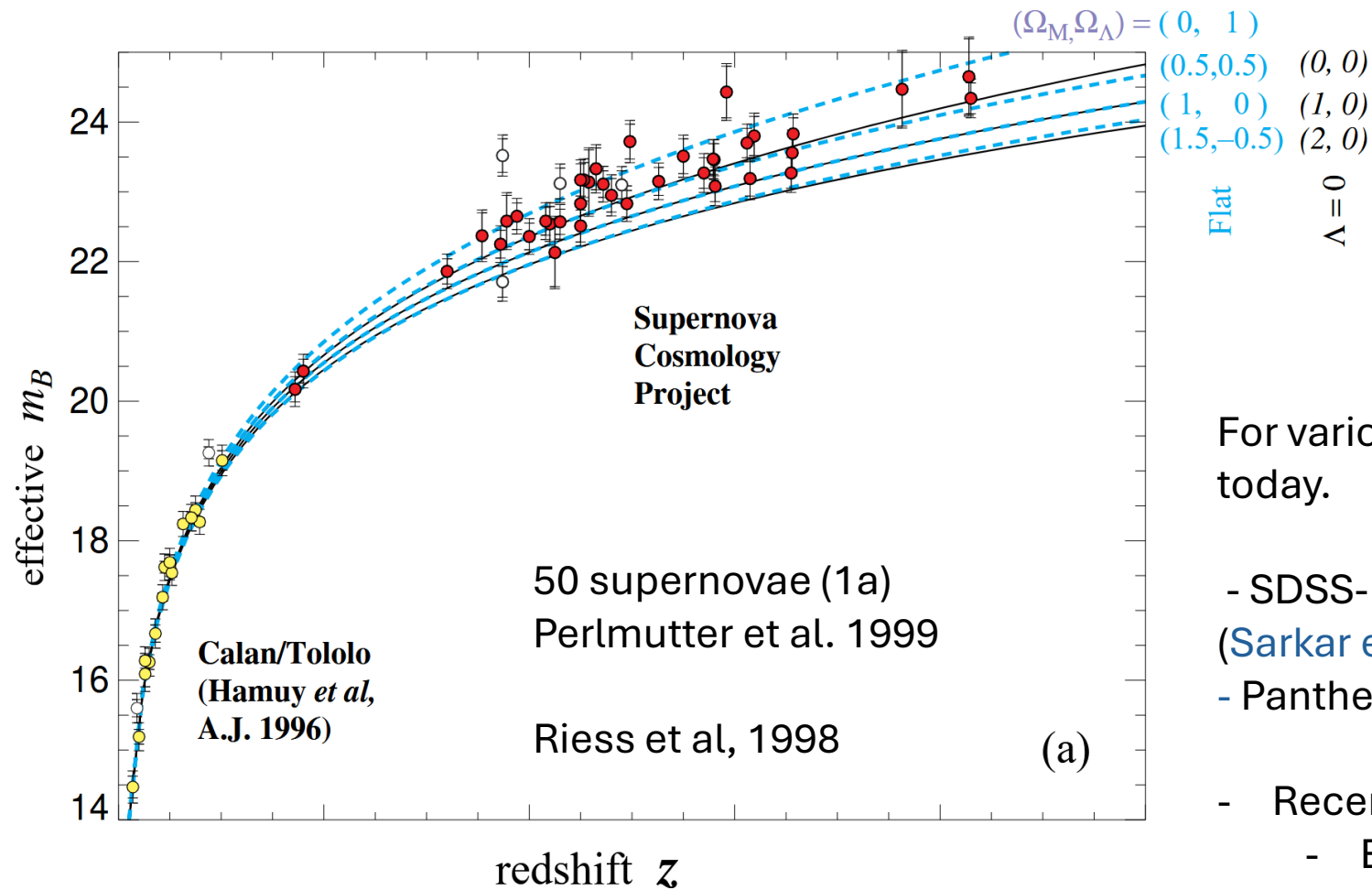
$$\left(\frac{\dot{a}(t)}{a(t)} \right)^2 = \frac{8\pi G}{3} \rho(t) - \frac{\kappa c^2}{a^2(t)} + \frac{\Lambda c^2}{3}$$

$$\frac{\ddot{a}(t)}{a(t)} = -\frac{4\pi G}{3} \left(\rho(t) + \frac{3p(t)}{c^2} \right) + \frac{\Lambda c^2}{3}$$

Underexplored challenges: Cosmology: Dark energy

Manifesto: Challenging the standard cosmological model [10.1098/rsta.2024.0036](https://arxiv.org/abs/10.1098/rsta.2024.0036)

Sarkar et al, 29 May 2025 [2505.23526](https://arxiv.org/abs/2505.23526)



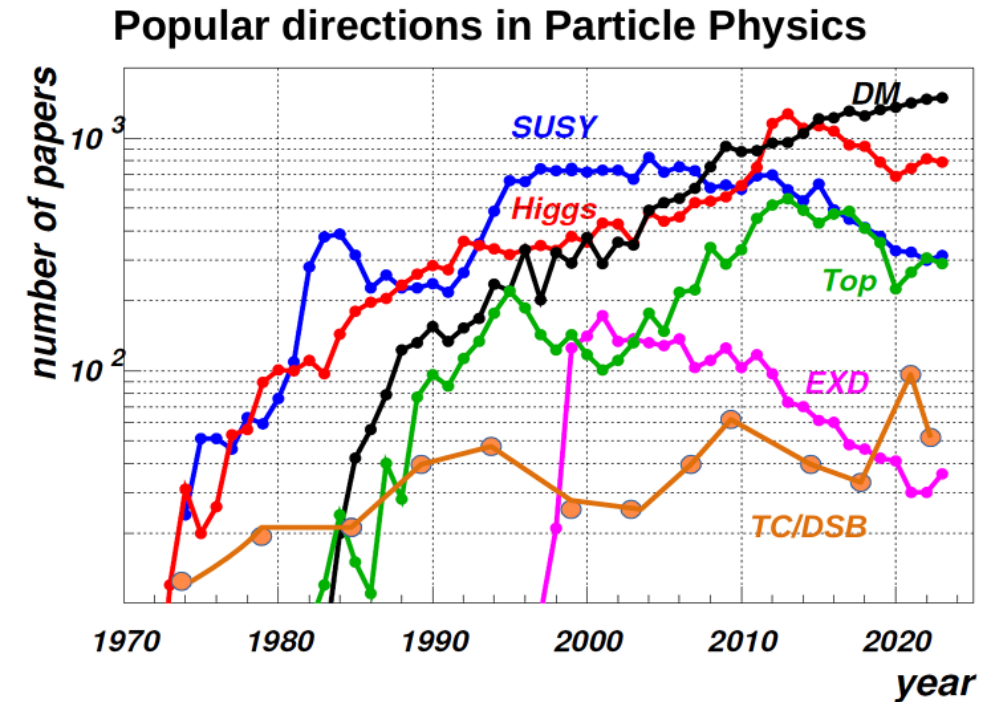
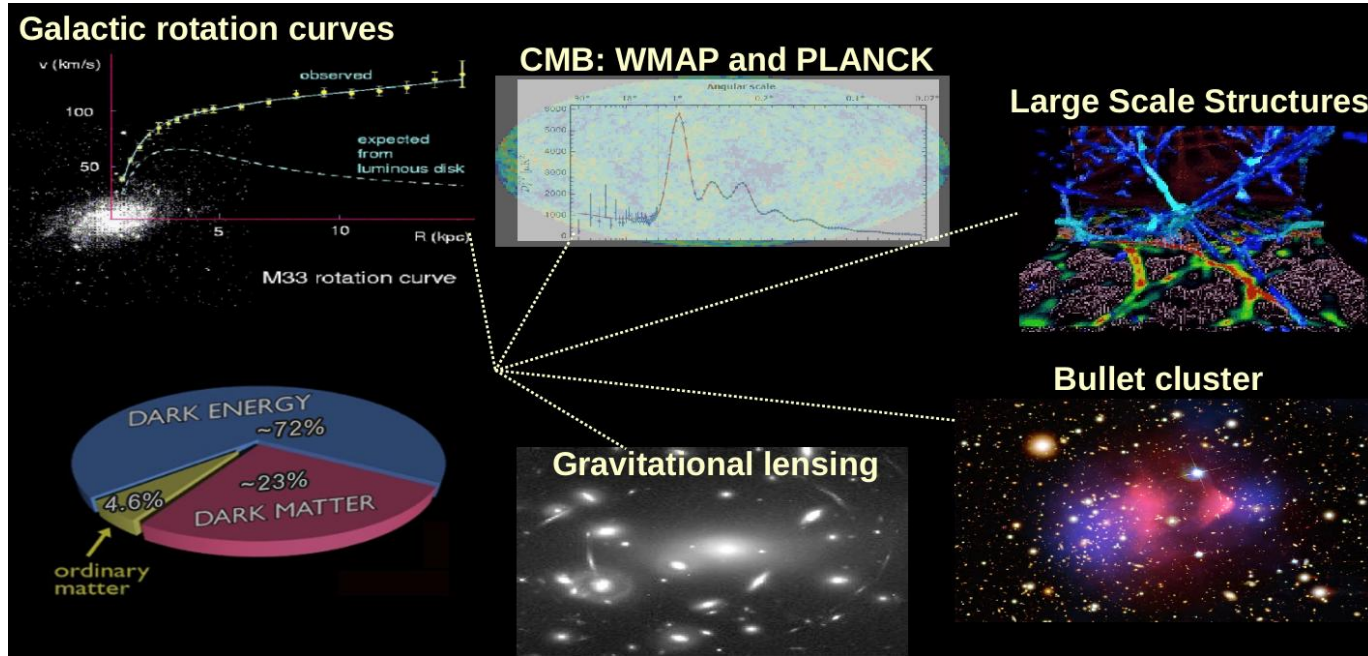
“.... High redshift supernovae appear almost 0.15 mag ($\sim 15\%$ in flux) fainter than the low redshift supernovae”
(Compared to expectations for $\Lambda = 0$ universe)

For various reasons people are revisiting this conclusion today.

- SDSS-II/SNLS-3 Joint Lightcurve Analysis (JLA) 740 SNe, (Sarkar et al 2019)
- Pantheon+ - 1540 Rameez et al. 2024, 2411.10838
- Recent challenges to cosmological principle
 - Ellis & Balldwin test anomaly (Secrest et al. 2021, 2022, Wagnveld et al, 2023)
 - Cosmic dipole anomaly, Sarkar et al, [2505.23526](https://arxiv.org/abs/2505.23526)
 - Bulk flows in local universe (Watkins et al. 2023)

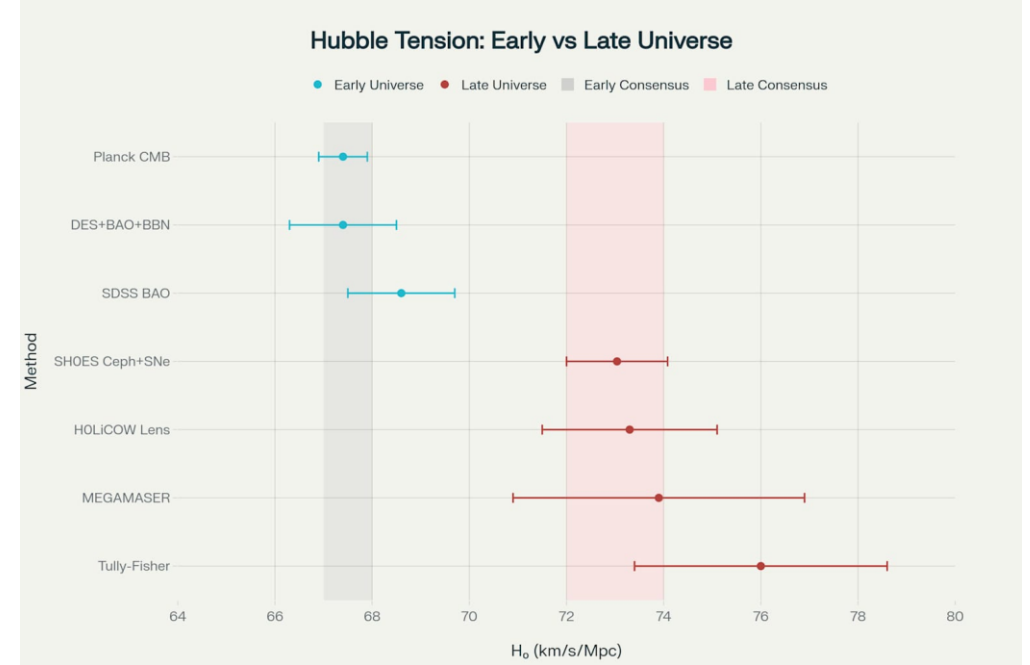
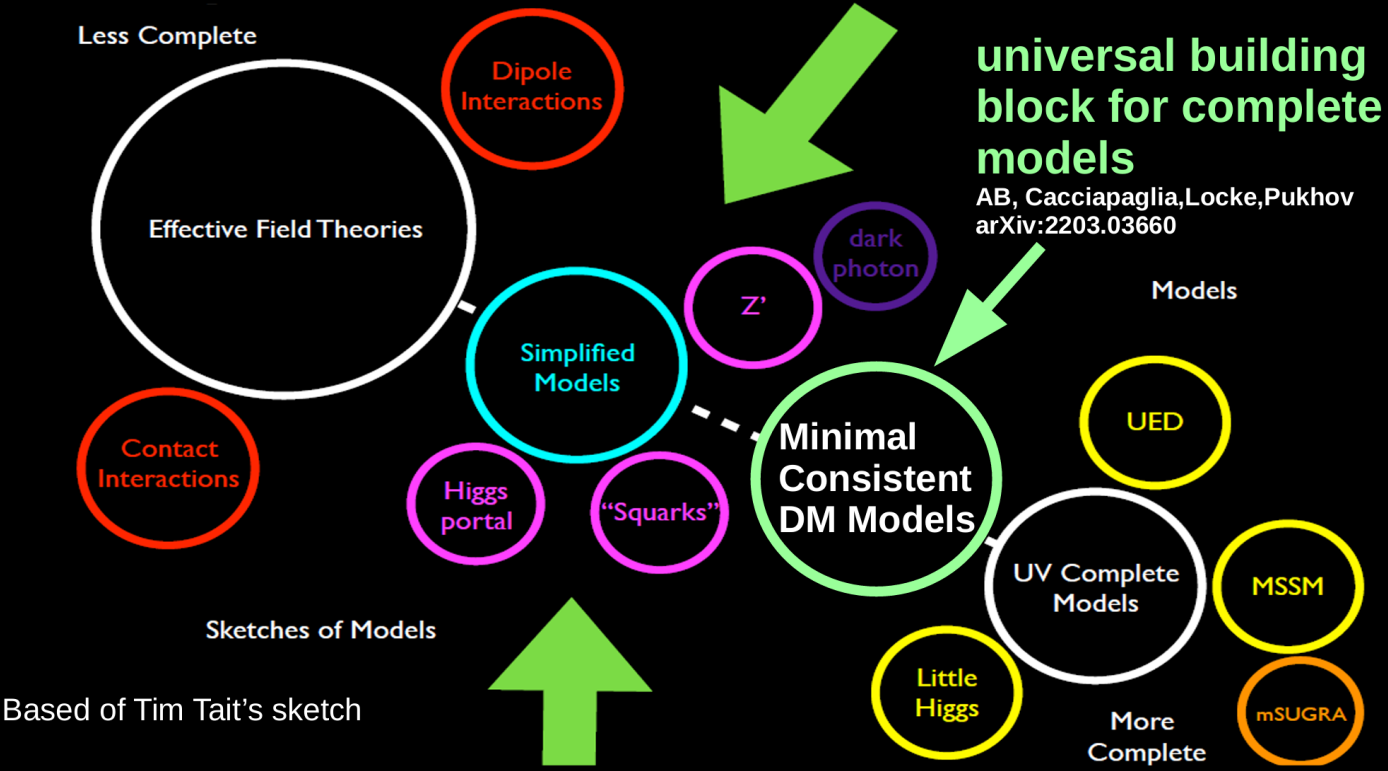
The statistical method critics: March et al.(2011), Karpenka (2014), Nielsen et al (2015), Dam et al. (2017)

Underexplored challenges: Cosmology: Dark matter



Underexplored challenges: Cosmology: Dark matter

Theory Space with Dark Matter



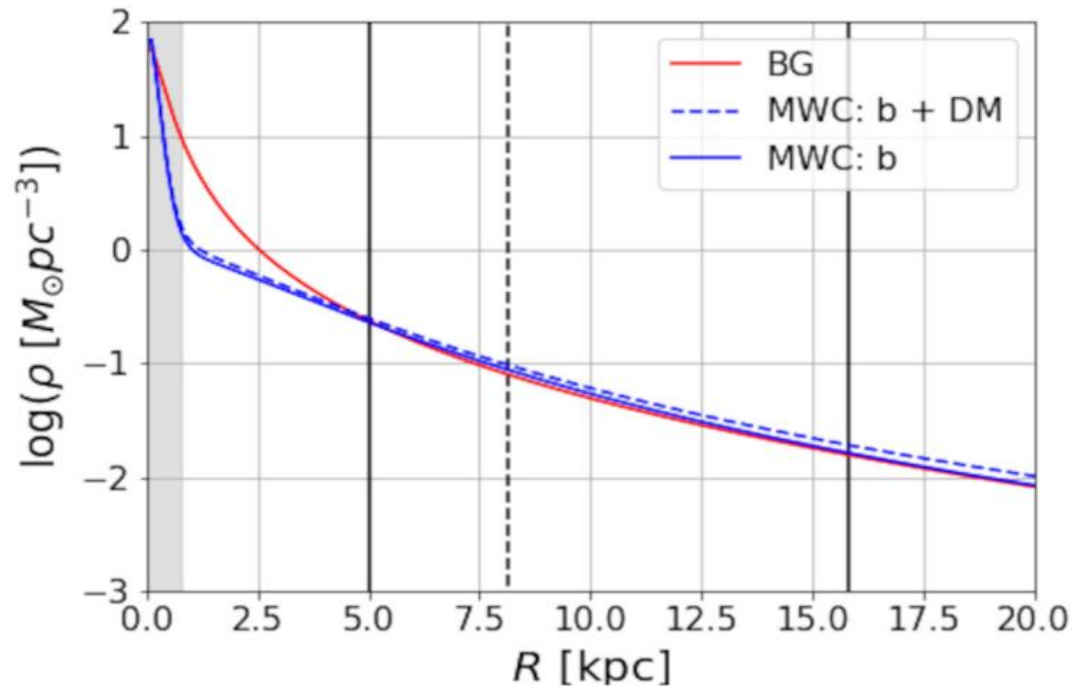
- 5σ tension between early and late universe H_0 measurements:
 - Planck CMB: $H_0 = 67.4 \pm 0.5$ km/s/Mpc
 - SH0ES Cepheids+SNe: $H_0 = 73.04 \pm 1.04$ km/s/Mpc
- Potential implications for dark sector physics

Underexplored challenges: Cosmology: Dark energy

Manifesto: Challenging the standard cosmological model [10.1098/rsta.2024.0036](https://arxiv.org/abs/10.1098/rsta.2024.0036)

On testing CDM and geometry-driven Milky Way rotation curve models with *Gaia* DR2

M. Crosta et al. [10.1093/mnras/staa1511](https://arxiv.org/abs/10.1093/mnras/staa1511)



ABSTRACT

Flat rotation curves (RCs) in disc galaxies provide the main observational support to the hypothesis of surrounding dark matter (DM). Despite of the difficulty in identifying the DM contribution to the total mass density in our Galaxy, stellar kinematics, as tracer of gravitational potential, is the most reliable observable for gauging different matter components. From the *Gaia* second data release catalogue, we extracted parallaxes, proper motions, and line-of-sight velocities of unprecedented accuracy for a carefully selected sample of disc stars. This is the angular momentum supported population of the Milky Way (MW) that better traces its observed RC. We fitted such data to both a classical, i.e. including a DM halo, velocity profile model, and a general relativistic one derived from a stationary axisymmetric galaxy-scale metric. The general relativistic MW RC results statistically indistinguishable from its state-of-the-art DM analogue. This supports the ansatz that a weak gravitational contribution due to the off-diagonal term of the metric, by explaining the observed flatness of MW's RC, could fill the gap in a baryons-only MW, thus rendering the Newtonian-origin DM a general relativity-like effect. In the context of Local Cosmology, our findings are suggestive of the Galaxy's phase space as the exterior gravitational field in equilibrium far from a Kerr-like inner source, possibly with [no need for extra matter to account for the disc kinematics](#).

Balasin & Grumiller (2008, BG)

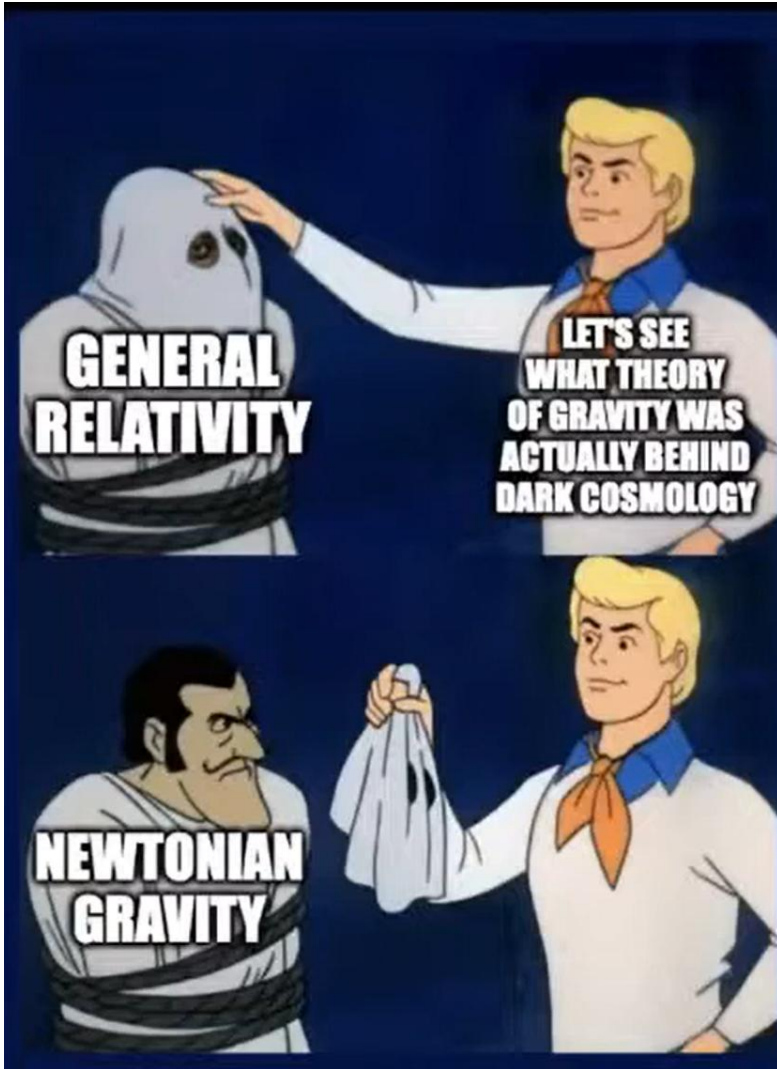
McMillan (2017), Pouliasis et al. (2017), and Eilers et al. (2019).

- **Fritz Zwicky's 1933 Paper:** *The Redshift of Extragalactic Nebulae: Coma cluster*

- **Vera Rubin & Kent Ford's 1970 paper** on rotation curves of spiral galaxies

Dark sector cosmology

Manifesto: Challenging the standard cosmological model [10.1098/rsta.2024.0036](https://doi.org/10.1098/rsta.2024.0036)



$$G_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

Ellis, “On the Raychaudhry equation

Volume 69, pages 15–22, (2007)

“Space tells matter how to move
Matter tells space how to curve”: Wheeler

However, in Λ CDM cosmology
Friedmann equation +
linear Newtonian perturbations

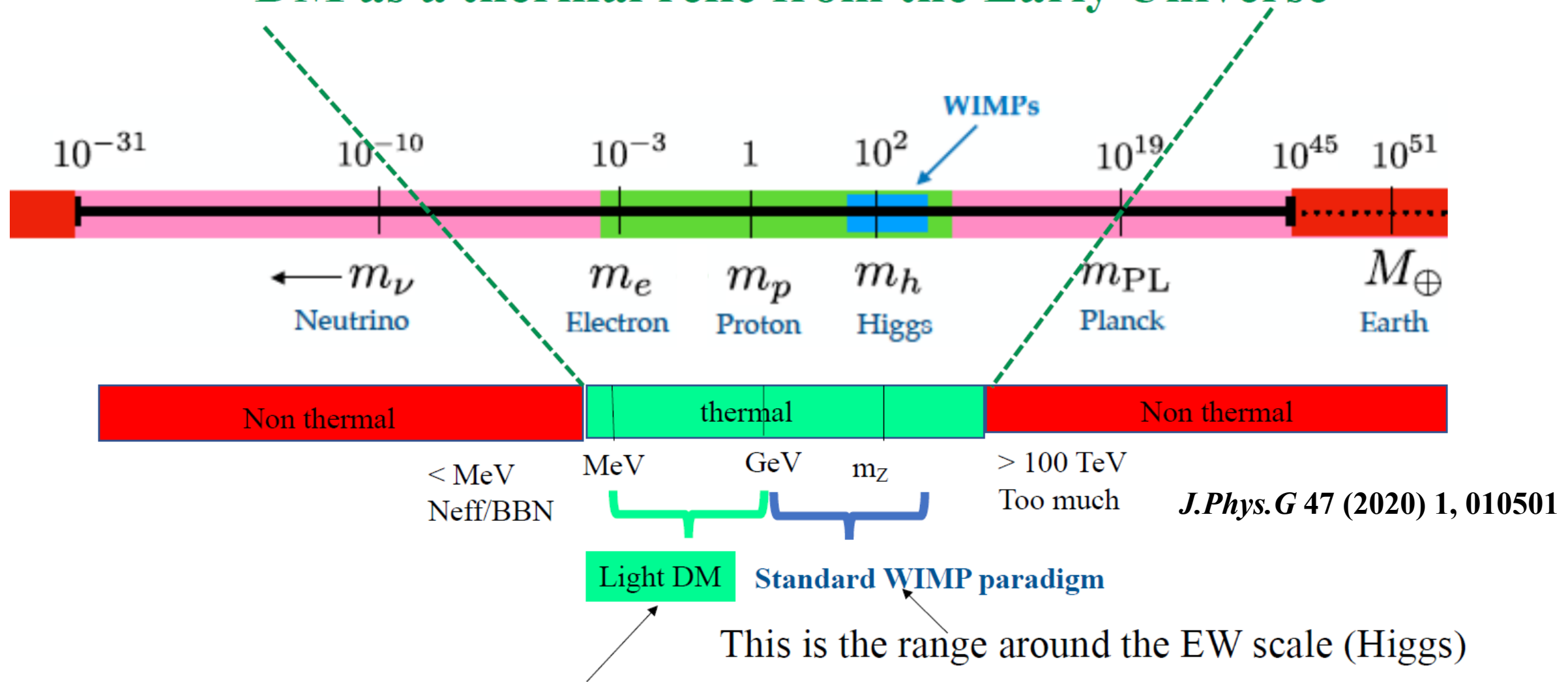
$$\left(\frac{\dot{a}(t)}{a(t)}\right)^2 = \frac{8\pi G}{3}\rho(t) - \frac{\kappa c^2}{a^2(t)} + \frac{\Lambda c^2}{3}$$

$$\frac{\ddot{a}(t)}{a(t)} = -\frac{4\pi G}{3}\left(\rho(t) + \frac{3p(t)}{c^2}\right) + \frac{\Lambda c^2}{3}$$

*“Friedman tells space how to expand without curving
newton tells matter how to move”*

Dark Matter: a huge range of possible masses

DM as a thermal relic from the Early Universe



This is the range of familiar matter (electron, proton,...)

2

Dark Matter: Constraining phase space

Vector DM with the Higgs portal

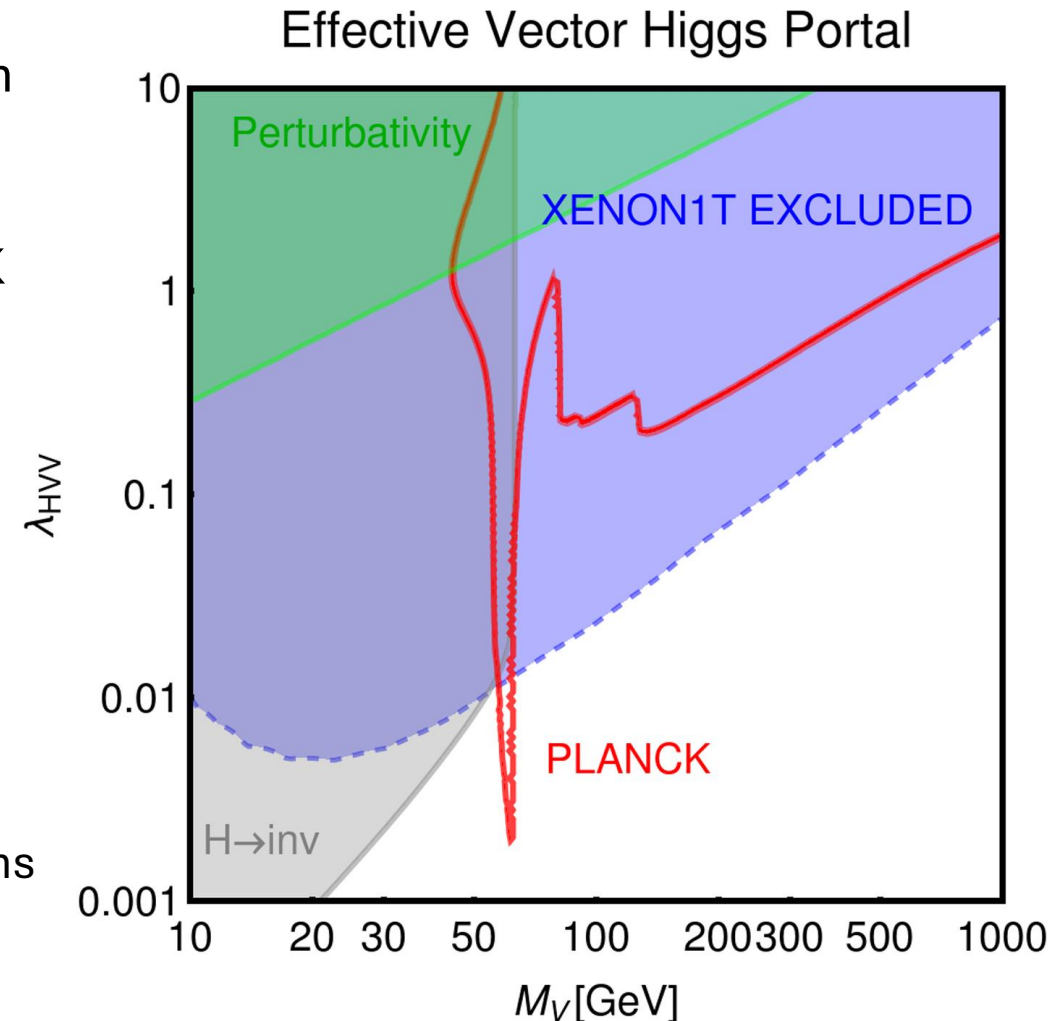
- Since VDM ‘talks’ to SM via Higgs, $V_D V_D H$ coupling is **limited from above** by DM direct detection and $H \rightarrow \text{DM DM Br}$
- Since DM Relic density should be equal or below the PLANCK relic density limit $\Omega h^2 \simeq 0.11$ $V_D V_D H$ coupling is **limited from below**
- The Higgs portal VDM parameter space is very limited by interplay of collider, DD and DM relic density

Fermionic Portal for Vector Dark Matter (FPVDM)

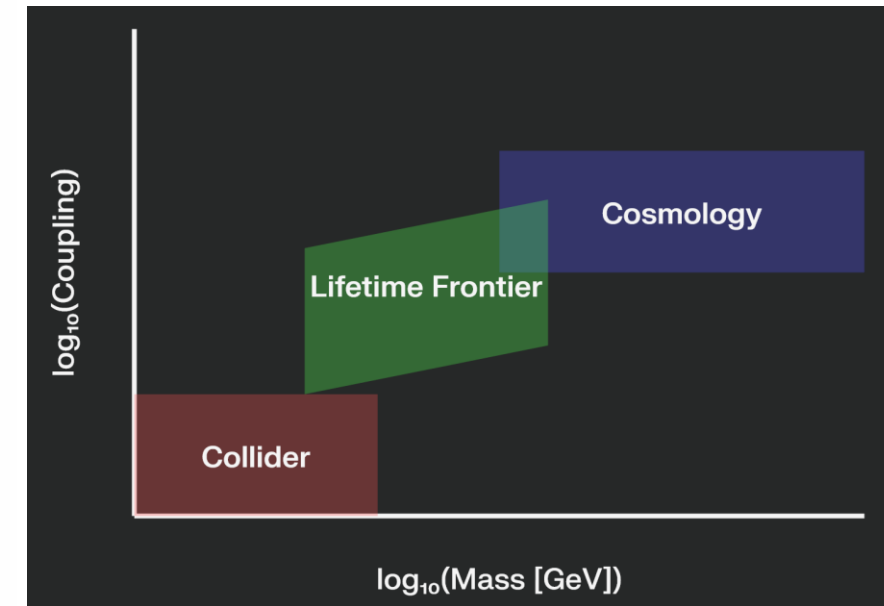
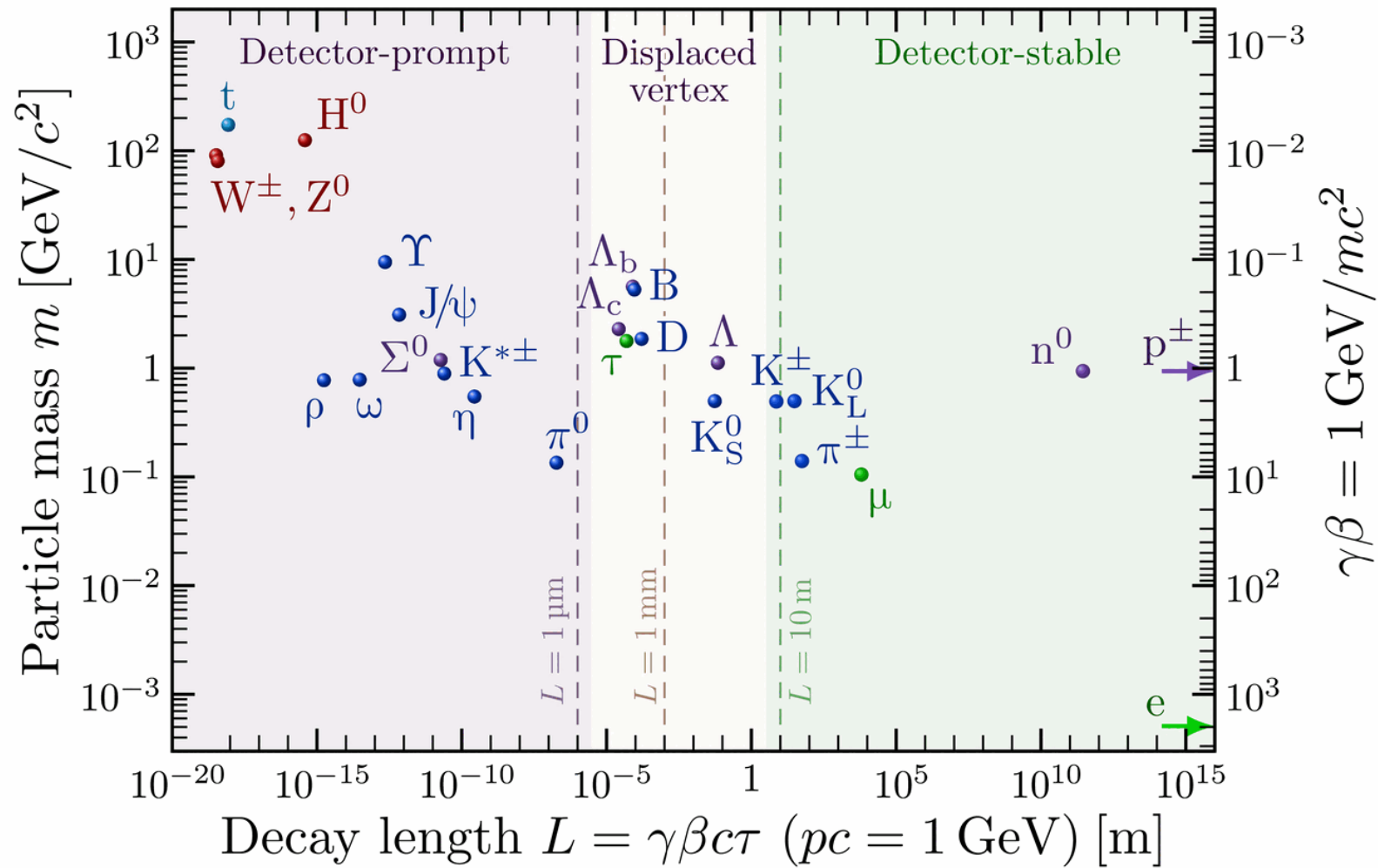
- It is the framework, representing the class of models
- Various realisations are possible, including one or several VL fermions [Deandrea, Moretti, Panizzi, Ross, Thongyoi, AB arXiv:2204.03510,2203.04681]

Baek, Ko, Park, Senaha 1212.2131
DiFranzo, Fox, Tait 1512.06853,
Farzan, Akbarieh 1207.4272

Deandrea, Moretti, Panizzi, Ross, Thongyoi, AB
arXiv:2204.03510,2203.04681
Lebedev, Lee, Mambrini 1111.4482,

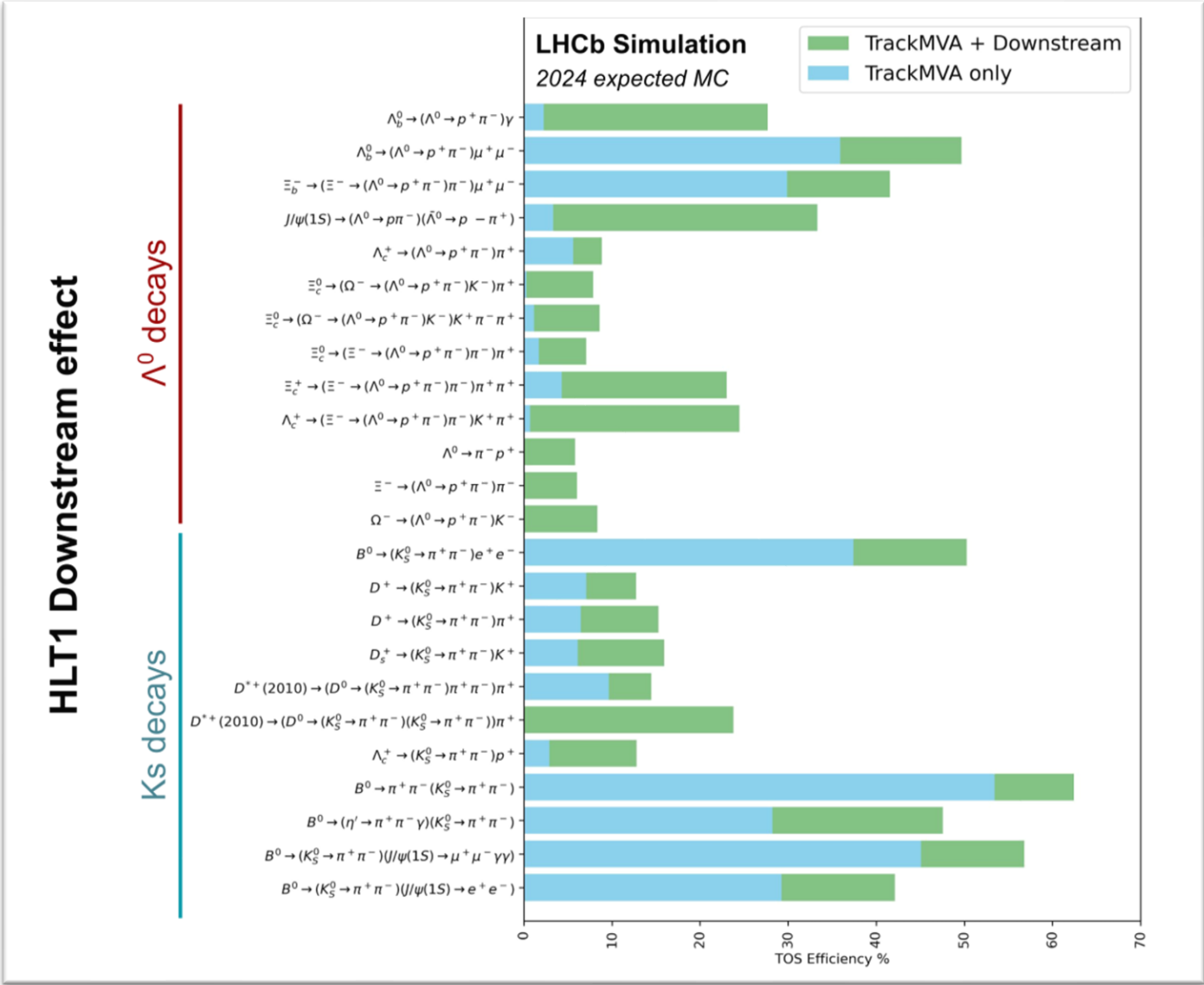


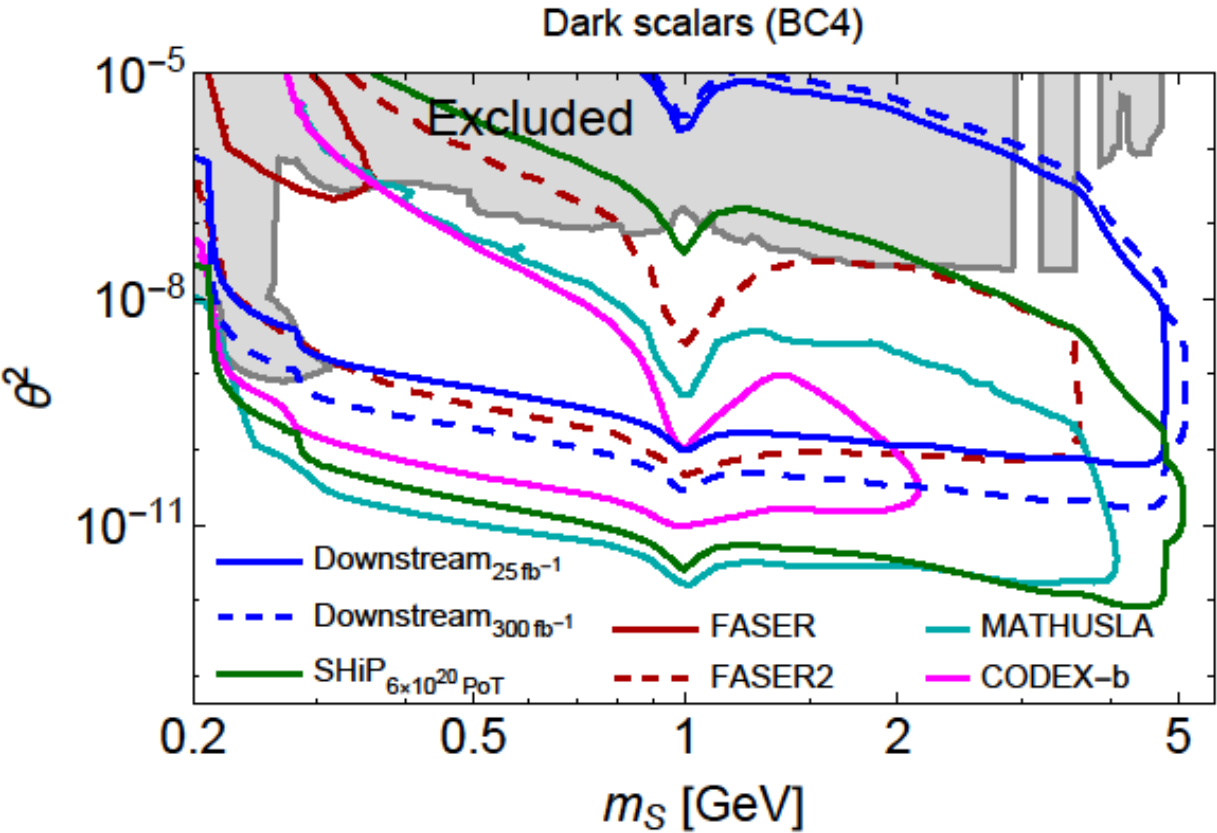
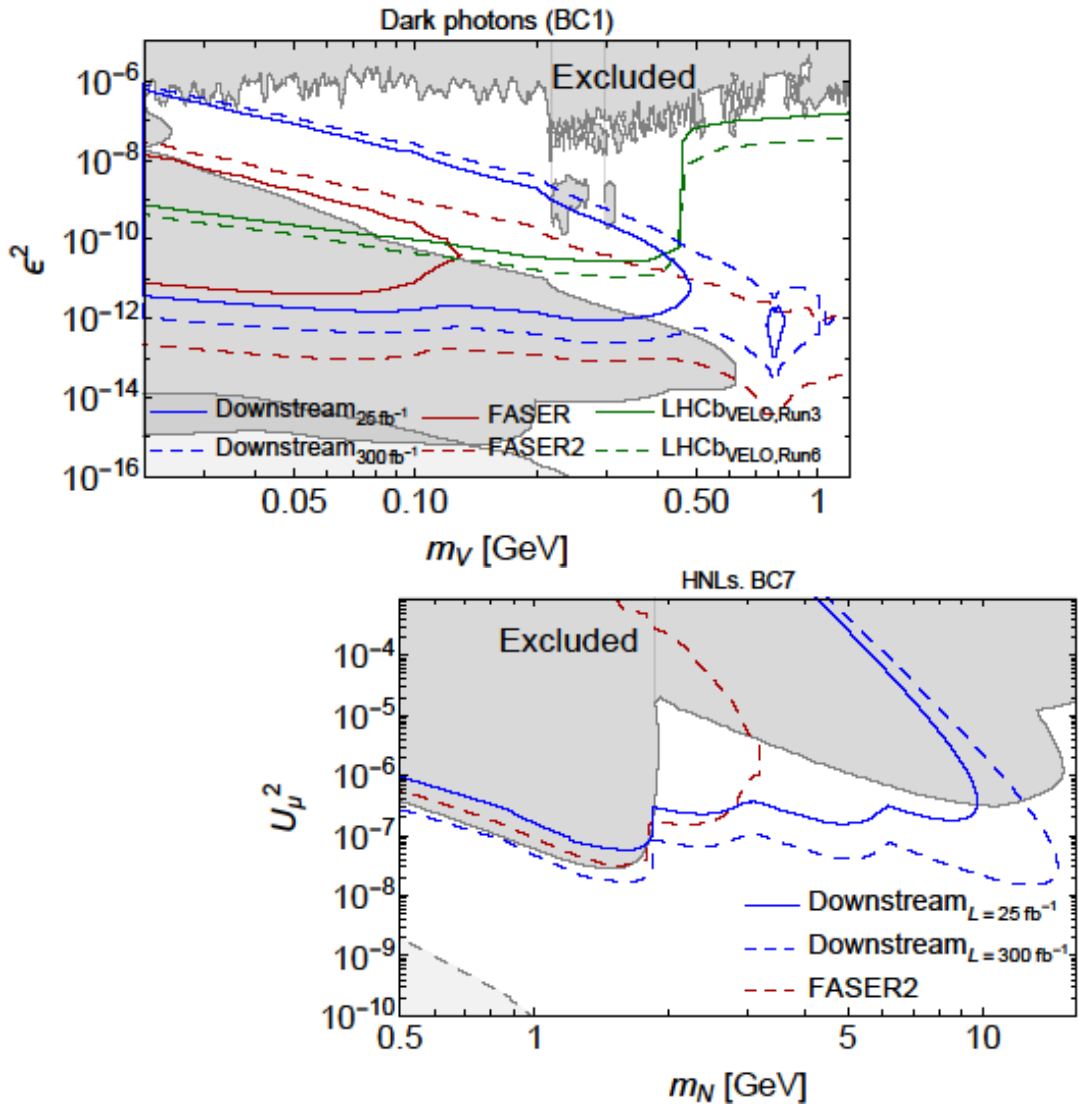
SM LLP physics crucial for precision era



$$P_{\text{surv}}(L) = e^{-L/\gamma c\tau}$$

Channel	DD/LL proportion	Interest
b-hadron decays		
$\Lambda_b^0 \rightarrow \Lambda \gamma$	3.4	γ polarization, BR
$\Xi_b^- \rightarrow \Xi^- \gamma$	25	γ polarization, BR
$\Omega_b^- \rightarrow \Omega^- \gamma$	13	γ polarisation, BR
$B^+ \rightarrow K_S^0 K_S^0 \pi^+$	2.8	CPV, BR
$B^+ \rightarrow K_S^0 K_S^0 K^+$	2.7	CPV, BR
$B_s^0 \rightarrow K_S^0 K_S^0$	3.6	CPV, BR
Charm physics		
$\Lambda_c^+ \rightarrow \Lambda K^+$	4.4	Polarization studies
$\Xi_c^- \rightarrow \Xi^- \pi^-$	8.4	Polarization studies
$D^0 \rightarrow K_S^0 K_S^0$	1.8	CPV
$J/\psi \rightarrow \Lambda \bar{\Lambda}$	4.8	Polarization studies, BR
Strange physics		
$K_S^0 \rightarrow \mu^+ \mu^-$	0.6	BR
$K_S^0 \rightarrow \mu^+ \mu^- \mu^+ \mu^-$	0.8	BR
$K_S^0 \rightarrow \gamma \mu^+ \mu^-$	0.8	BR

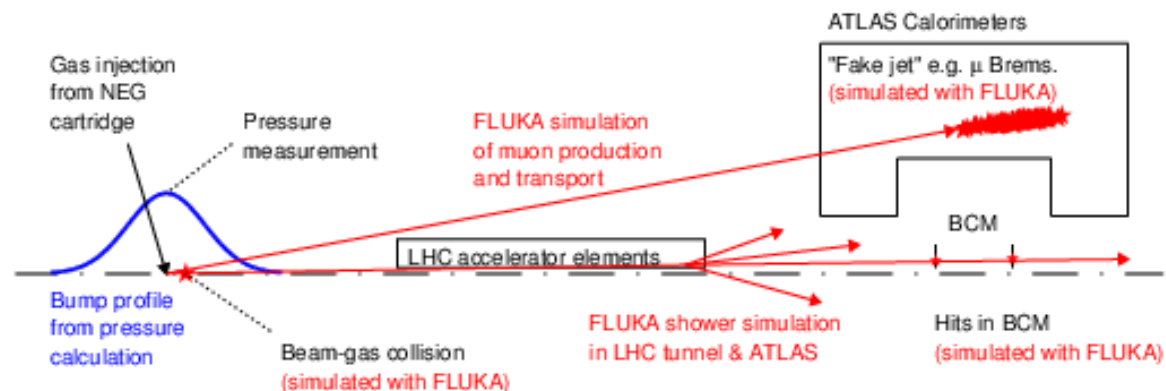




The interplay between an LLP's boost and detector capabilities manifests in several ways that can impact sensitivity if not carefully considered

Challenges: Beam gas background

- **ATLAS Search for Neutral LLPs Decaying to Displaced Jets (2024) arXiv:2407.09183**
- **Background composition:**
 - Beam-gas collisions produced fake displaced jets through:
 - Inelastic proton-gas interactions $\rightarrow$ electromagnetic showers $\rightarrow$ calorimeter energy deposits mimicking LLP decays
 - Measured fake jet rates scaled linearly with LHC beam vacuum pressure ($R \propto p$) [19/06/P06014](#)
- **Impact on LLP Sensitivity:**
 - Without mitigation, beam-gas backgrounds would dominate over signal in regions with:
 - Vertex displacements: $30 \text{ cm} < c\tau < 4.5 \text{ m}$
 - Low LLP boost ($\beta\gamma < 2$), where decay products are spatially resolvable
 - Simulated beam-gas events showed topological similarity to LLP signatures:
 - Non-prompt timing ($\Delta t \sim 1\text{--}10 \text{ ns}$ vs. collision products)
 - Multi-track vertices displaced from primary interaction point



[2024 JINST 19 P06014](#)

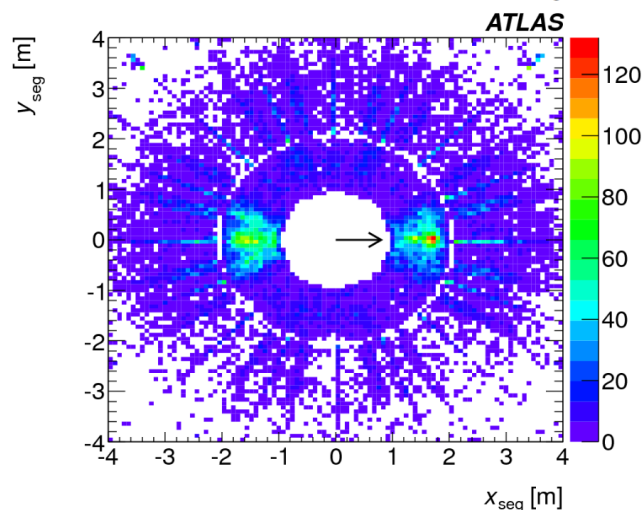
Challenges: Beam gas background

2024 JINST 19 P06014

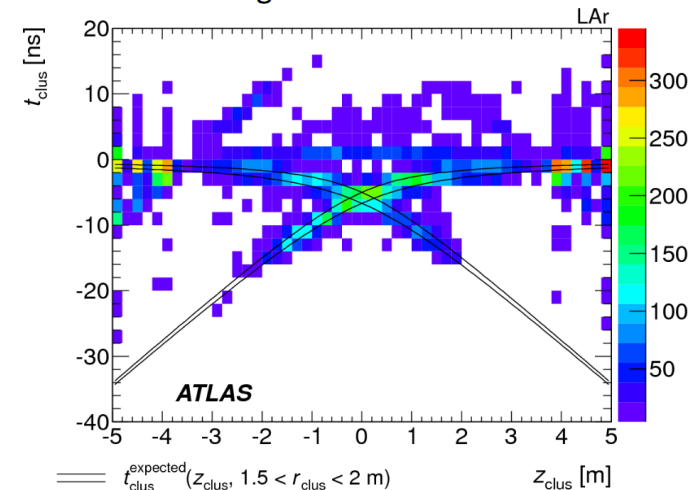
Mitigation Strategies: The analysis employed:

- **Timing Cuts:**
 - Exploited ns-level calorimeter timing to reject out-of-time beam-gas events (90% rejection efficiency)
- **Data-Driven Background Modeling:**
 - Used ABCD method in signal-free regions to residual beam-gas contributions
- **Vacuum Pressure Monitoring:**
 - Leveraged ATLAS Beam Conditions Monitor (BCM) rates to veto periods with elevated beam-gas activity

Location of muon hits from beam background



Timing / position of reconstructed jets from beam background in calorimeter



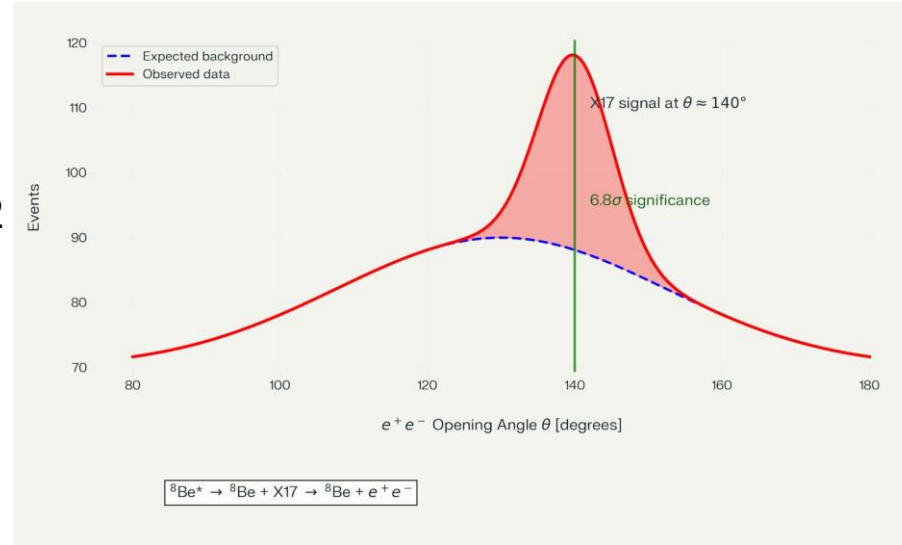
LHC Experiments and their LLP Search Focus:

Experiment/Detector	Primary LLP Signature Focus	Key Detector Region/Focus	Typical $c\tau$ Range (approx.)
ATLAS	Displaced Jets/Leptons, Charged LLPs, HNLs, Dark Photons	Inner Detector, Calorimeters, Muon Spectrometer	~ 0.1 mm to several meters
CMS	Displaced Jets (Inner Tracker), Displaced Showers (Muon Endcaps)	Inner Tracker, Endcap Muon Detectors (CSCs)	~ 0.1 mm to ~ 100 mm (Inner), $\sim$ cm to $\sim$ tens of meters (Muon)
LHCb	Very Displaced Vertices (Dimuons, Hadrons)	Forward Spectrometer (VELO, UT, SciFi)	~ 0.1 mm to ~ 1 meter
FASER	Light, Weakly-Coupled Particles (Dark Photons, ALPs, Sterile Neutrinos)	Far-Forward Region (100m from IP), Decay Volume, Spectrometer	$\sim$ tens to hundreds of meters
MATHUSLA	Neutral LLPs (Hadronic, Leptonic)	Surface Detector (40m scale), Air-filled Decay Volume	$\sim$ tens of meters to ~ 0.1 seconds

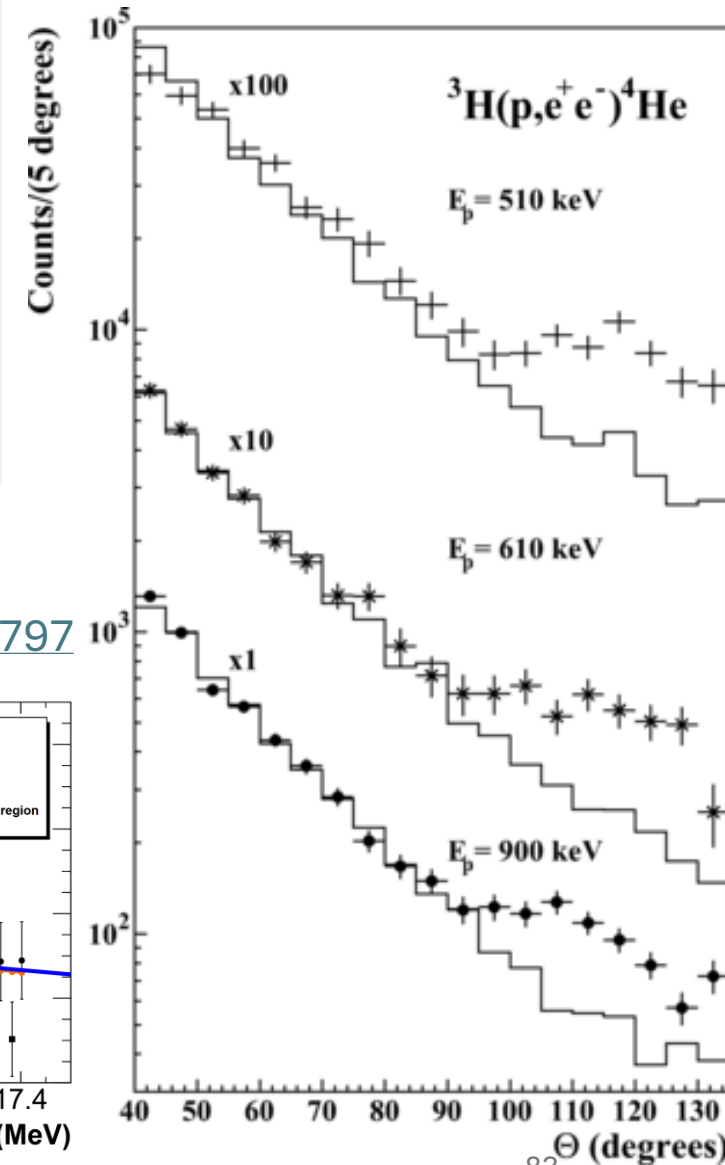
Joint analysis framework ? e.g combined analysis of $B_s^0 \rightarrow \mu^+ \mu^-$

The X17: a 17 MeV boson ?

- Atomki: Phys. Rev. C 104, 044003 (2021)
- Evidence for/against in 2024:
 - VNU 4 sigma arXiv:2401.11676v2
 - MEG-II exclude it but do have 1.5 σ excess. arXiv:2411.07994v1
- All these use $p + {}^n\text{A} \rightarrow e^+e^- + {}^{n+1}\text{A}$
 - Study angles in outgoing electron/positron

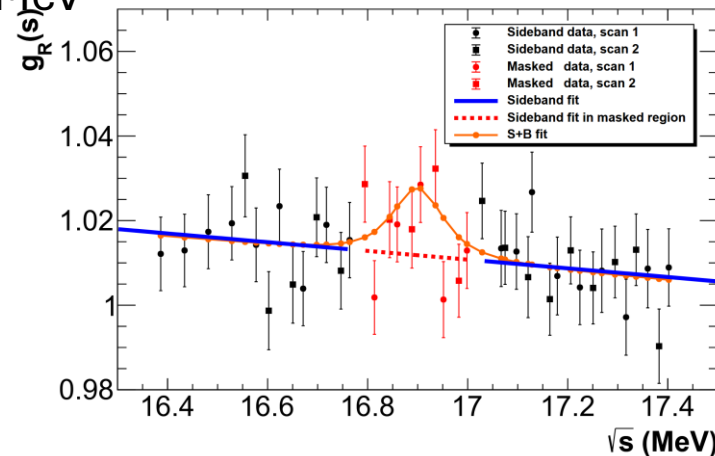


PhysRevC.104.044003



- PADME CERN seminar today at 11:00 , paper came out yesterday
- PADME uses DAΦNE positrons on diamond target
 - beam energy 265–300 MeV, $\rightarrow \sqrt{s}$ 16.4 and 17.5 MeV
- Measure the cross-section
 - Unblind $\sim 2.5 \sigma$ excess

[PADME 30 May 2025 ; 2505.24797](#)



- The X17's proposed kinetic mixing with the Standard Model photon is a common portal for dark photons, which can be long-lived if the kinetic mixing is sufficiently small



Thank you