

General Purpose Detectors

Nicholas Wardle

PPAP community meeting

16th – 17th July 2026

IMPERIAL

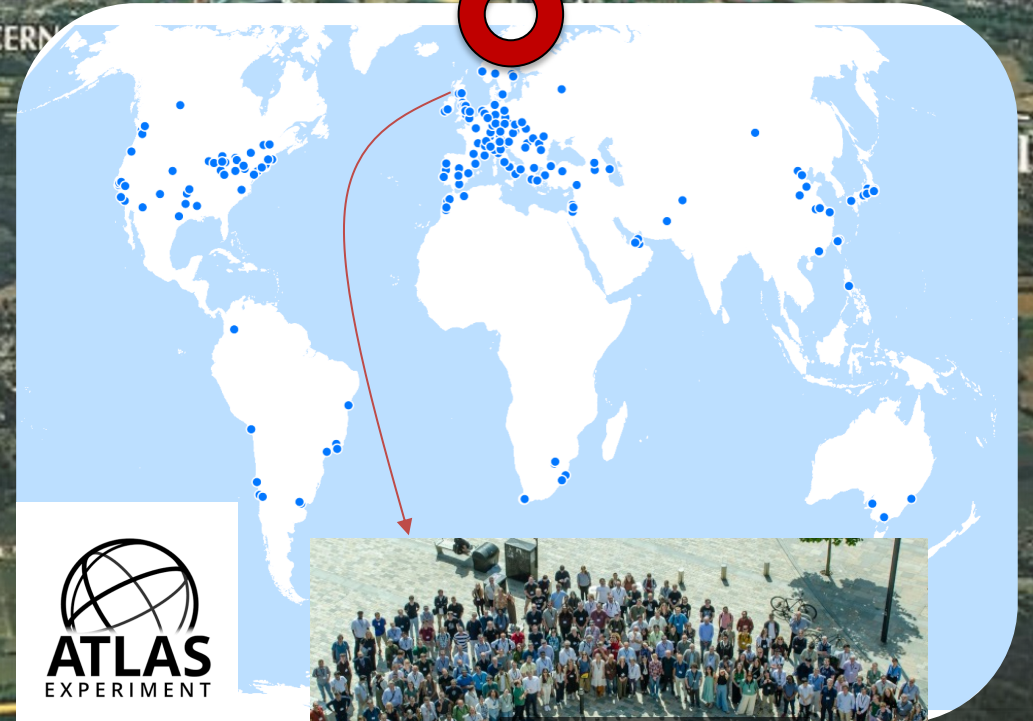


CMS

ATLAS Collaboration
246 Institutes from 40
countries
6156 active members



CMS Collaboration
286 Institutes from over 60
countries
> 6000 members



UK Institutes in ATLAS+CMS



- **15 institutions**
- 548 members → 11.7% of ATLAS Active members
- Current Collaboration Board & Publication committee chairs



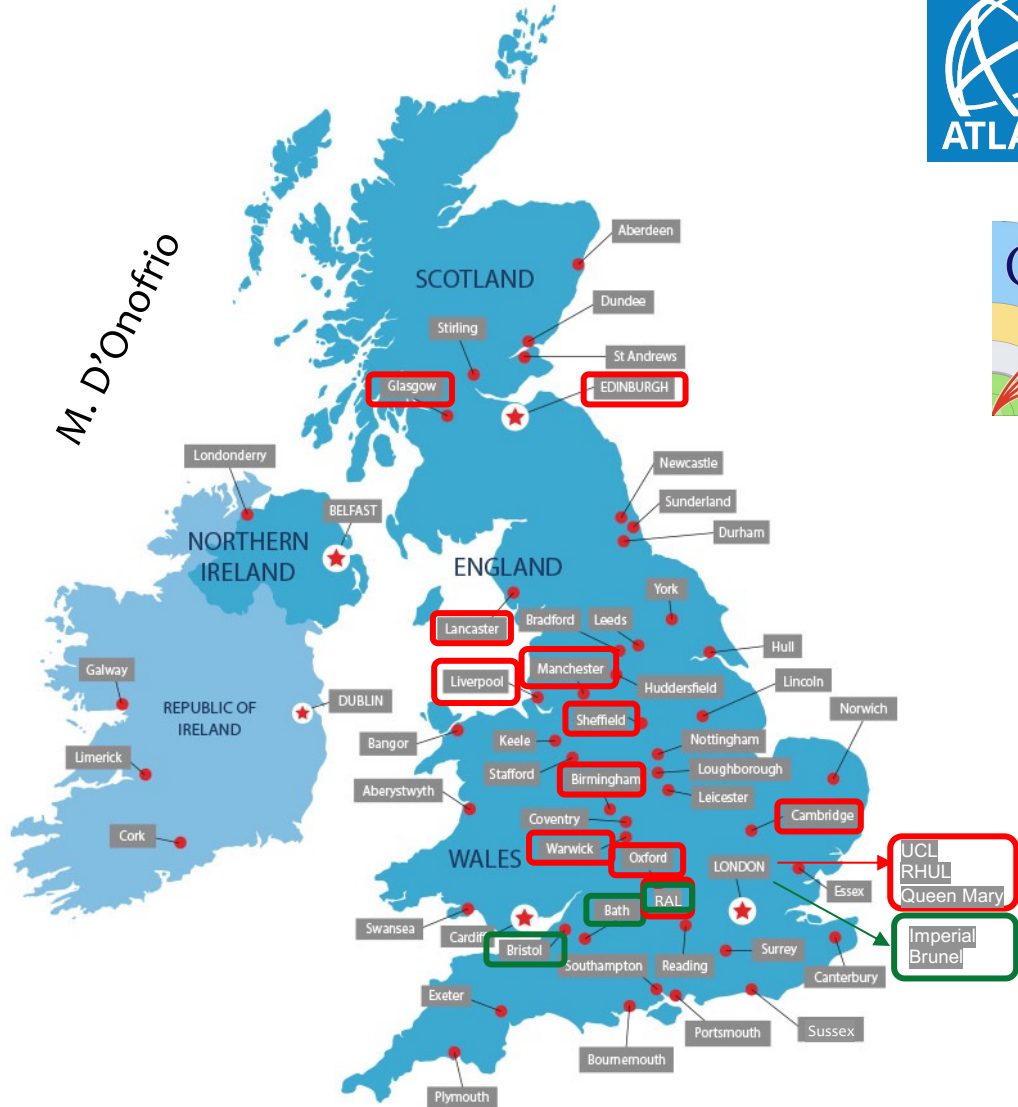
- **5 institutions** (+ several associate members)
- 168 members → 4.3% of CMS Active members
- Current L1 Trigger Coordinator & Run Coordinator

- Both UK ATLAS and CMS are founding members and have held significant number of group and sub-group convenorships & project management roles in the collaborations including spokespersons
- Significant contributions to Physics output
→ See [CMS Briefings](#) & [ATLAS UK physics results](#)

→ **UK provides significant impact in shaping GPD program at the LHC!**

Project Funding: mainly from STFC

Additional funding: EPSRC, UKRI, Royal Society, ERC, Marie Curie, Schmidt Family Foundation, Leverhulme Trust, Local (institutional) level



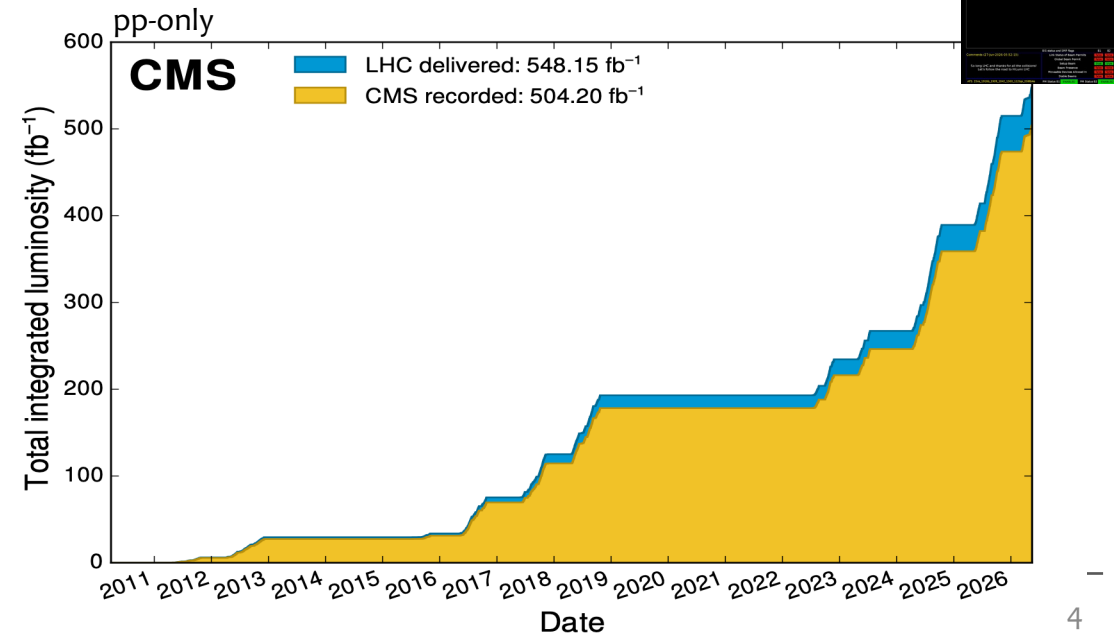
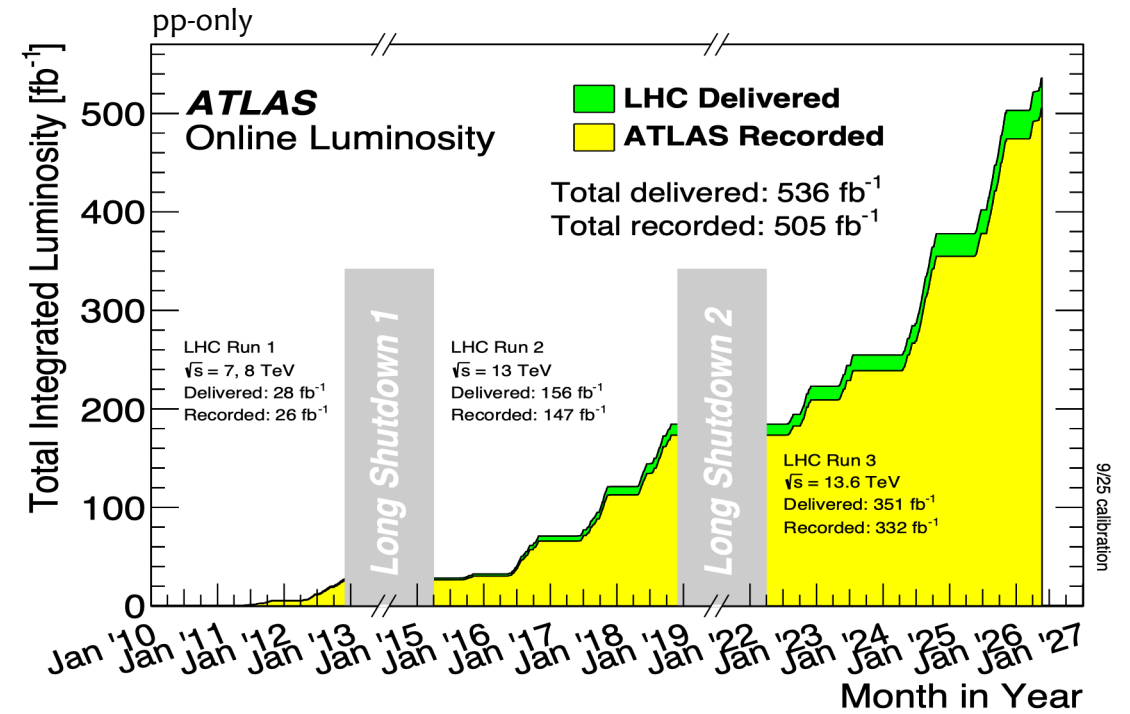
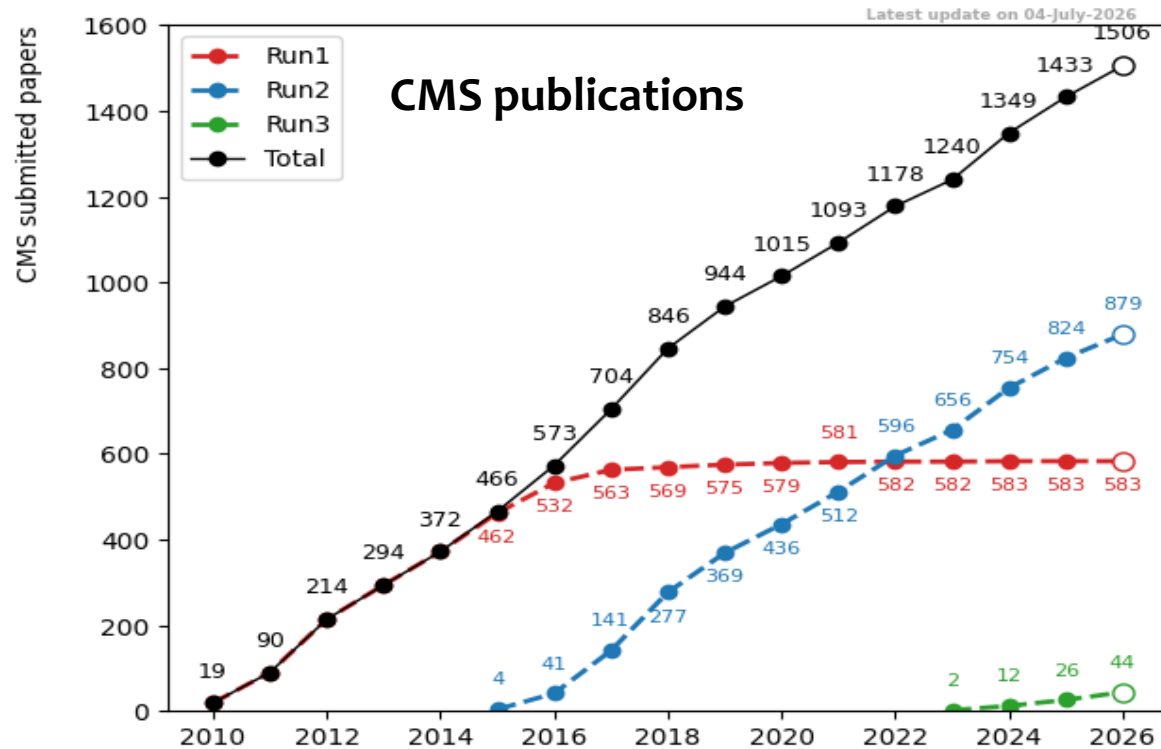
ATLAS & CMS in LHC Era

LHC performed exceptionally during Runs 1-3

- Over **500 fb⁻¹** data recorded per-experiment!

Currently **1506 (CMS)**, **1434 (ATLAS)** publications

- Vast majority of papers are from Run-1 & Run-2
- Run 3 provides $\sim 2.5\times$ **additional** data → Expect plenty **more** physics from the LHC



Upgrades during LHC

Run-3 saw upgrade of the accelerator → **increased COM energy to 13.6 TeV**

Renewed detectors and novel triggers as part of evolving upgrades towards HL-LHC

CMS GEM muon system

144 stations installed during LS2



UK contributions:



Hardware, firmware & software upgrades for L1Calo and HLT&DAQ systems

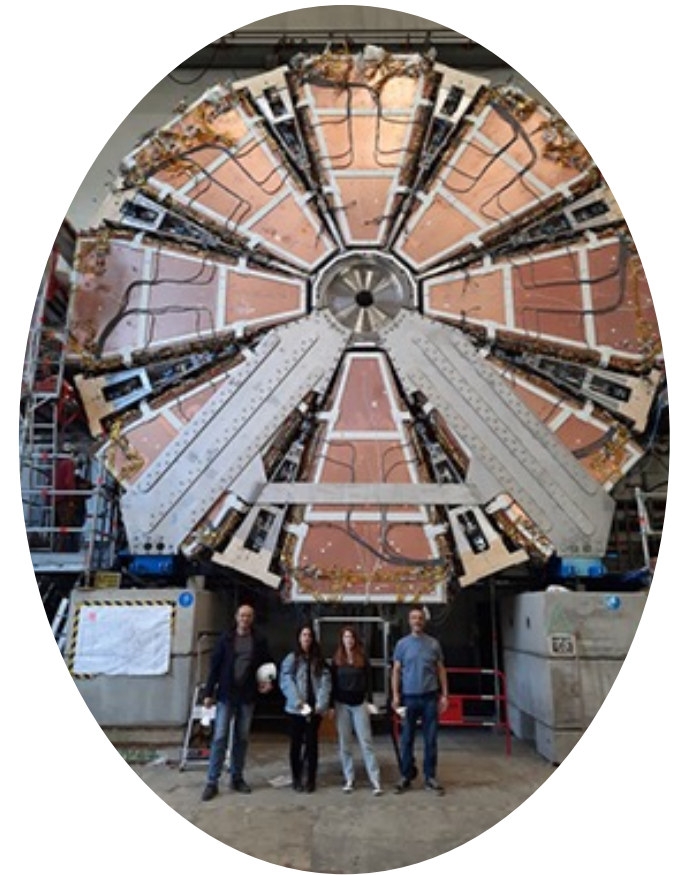


L1 trigger system (GCT) → R&D + firmware

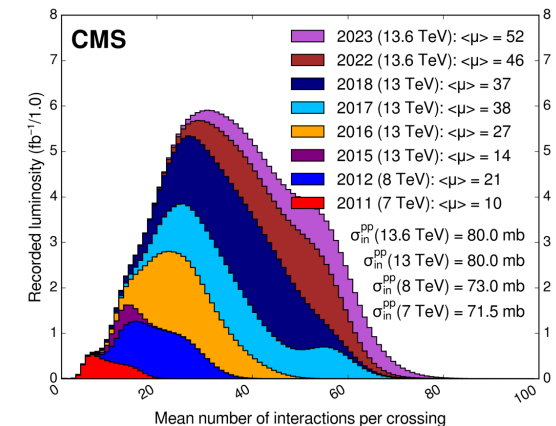
Design luminosity **exceeded already in Run 1**

→ Higher than design PU already

→ Had to get smarter, faster!

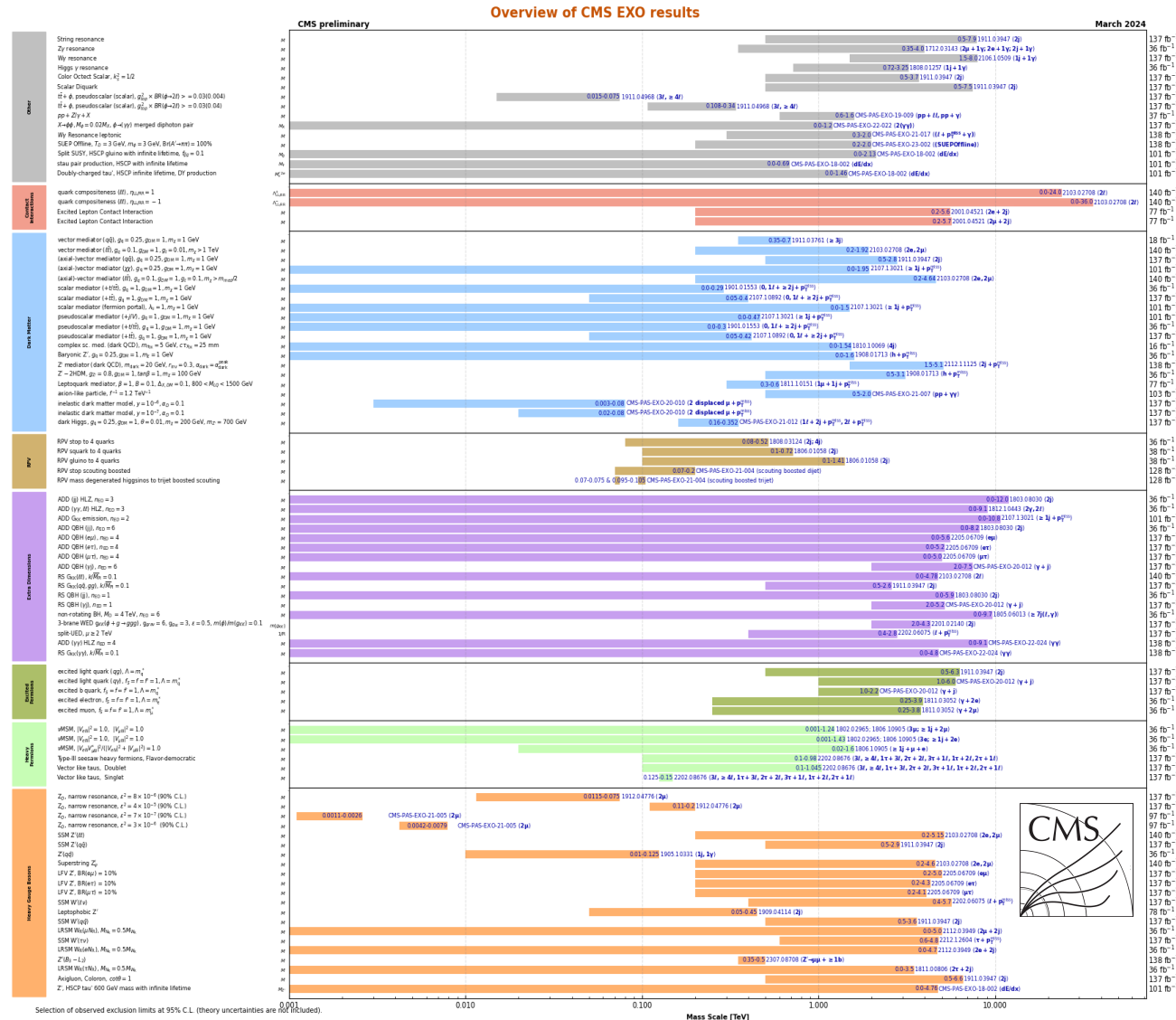


ATLAS new Small Wheel

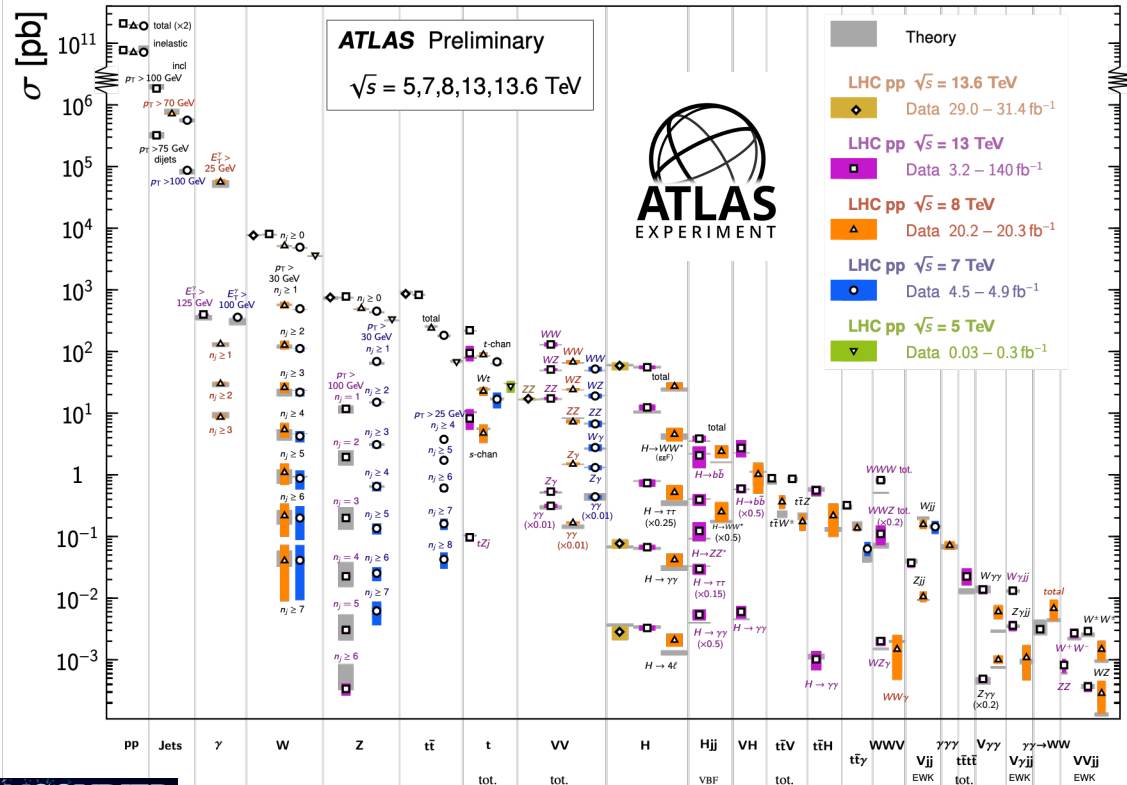


Huge range of Physics topics at the Energy Frontier!

ATLAS and CMS use the LHC as both a **discovery (search) machine** and **precision instrument**!



Status: June 2024



Cannot hope to cover everything
→ I will focus on recent highlights with **significant UK contribution**

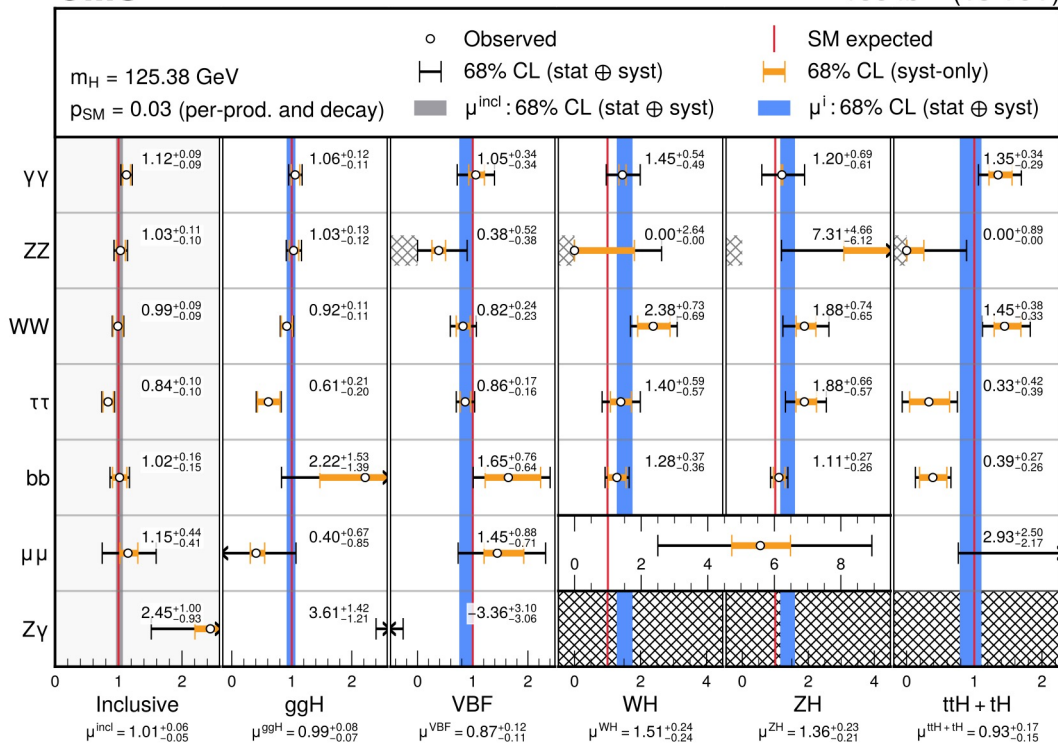
Many thanks to Monica D’Onofrio, Andy Pilkington, Sara Alderweireldt, Steve McMahon, Gavin Davies, Joel Goldstein, Sudan Paramesvaran, Alex Tapper for various inputs

Higgs boson

CMS Run-2 H-combination → explored a **wide range** of Higgs production and decay processes

CMS

138 fb⁻¹ (13 TeV)



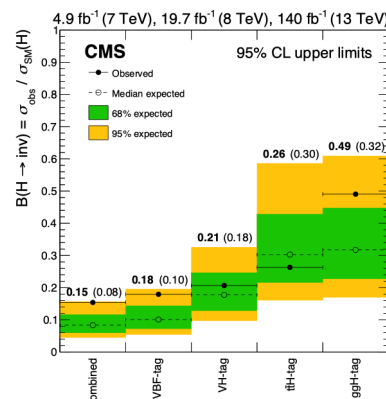
→ **Interpretation:** STXS cross-sections, (BSM) couplings, κ_λ , 2HDM, EFT

→ **UK-led:** $H \rightarrow \gamma\gamma$, $H \rightarrow \tau\tau$, $H \rightarrow \text{inv}$ & overall combination & interpretations



W/Z & 3rd Gen
couplings $\delta_k \sim 5\text{-}10\%$

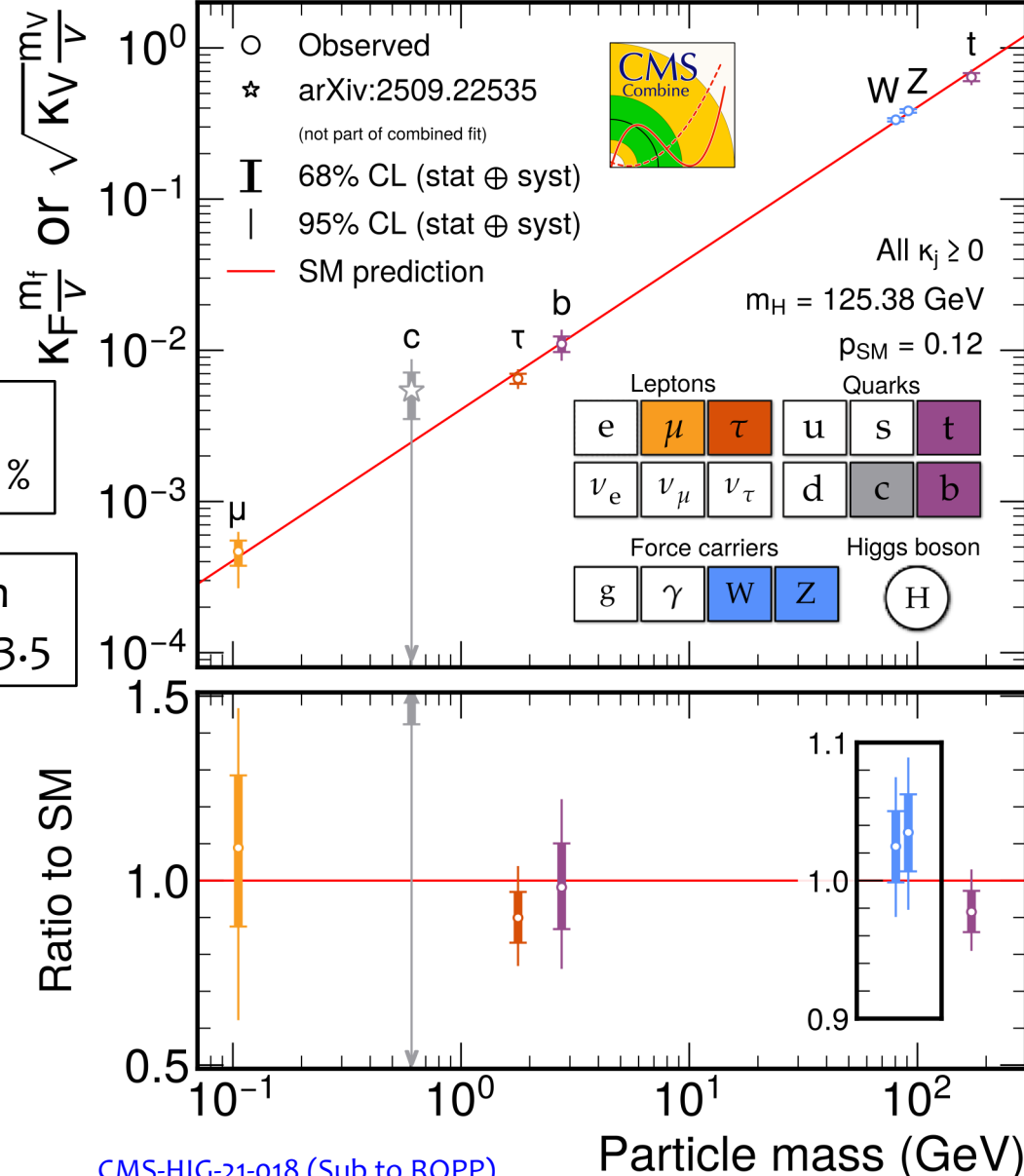
2nd Generation
 $\delta_\mu \sim 20\%$, $\kappa_c < 3.5$



+ $H \rightarrow \text{inv}$ constraints

CMS Supplementary

138 fb⁻¹ (13 TeV)



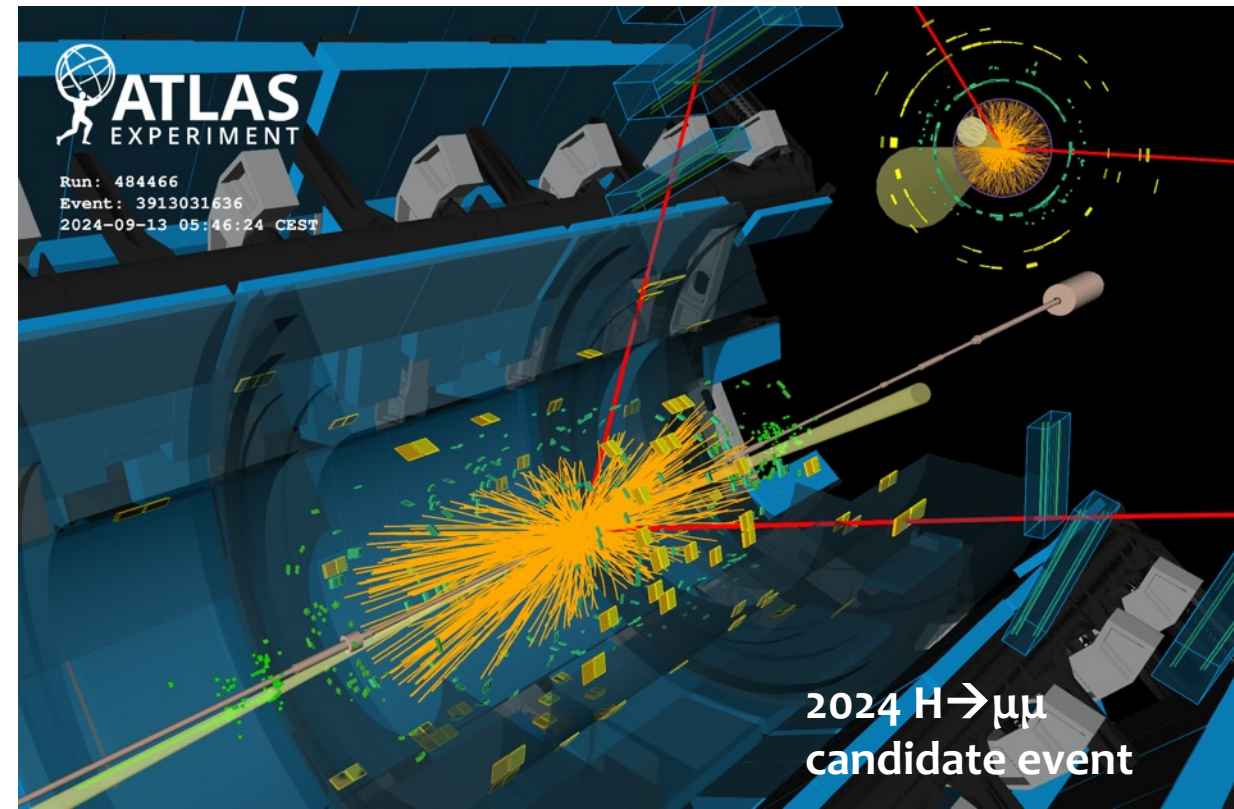
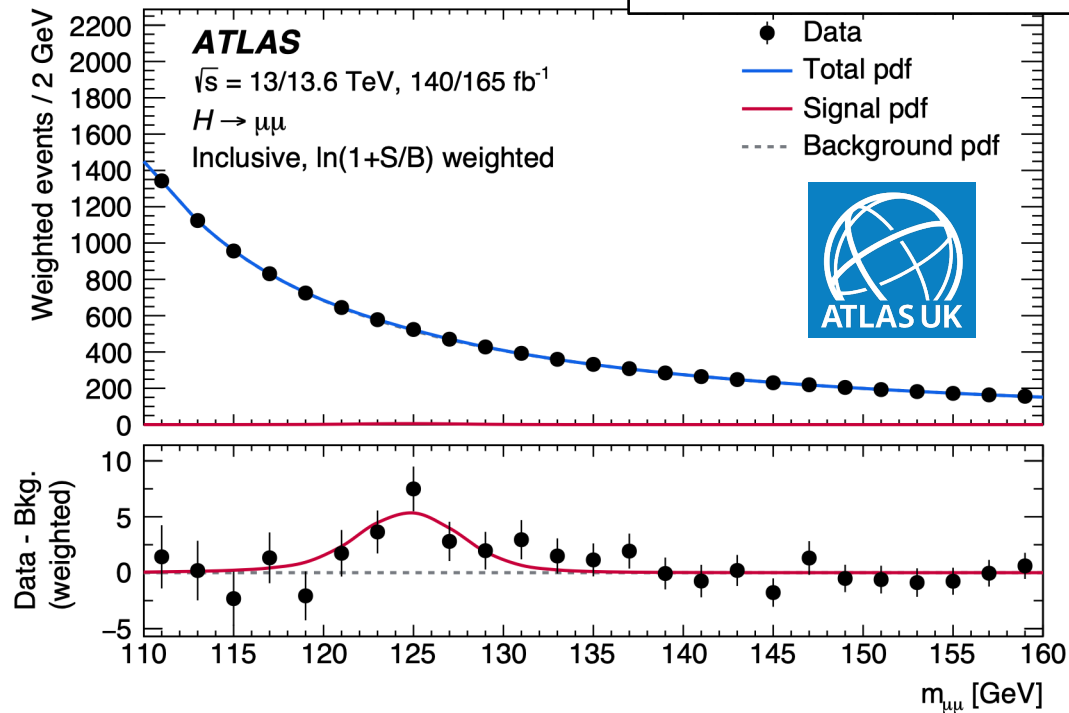
[CMS-HIG-21-018 \(Sub to ROPP\)](#)

Higgs boson

ATLAS pushes sensitivity in κ_μ with addition of **Run-3 data!**

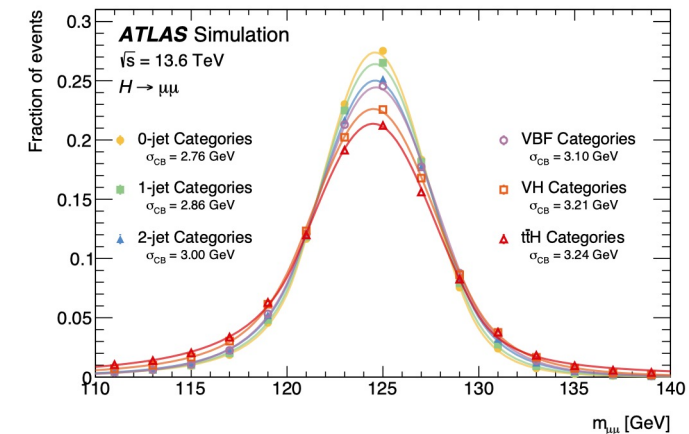
- $B(H \rightarrow \mu\mu) \sim 1/5000$
- Extremely challenging to dig out Higgs signal from Huge DY tail

First evidence of $H \rightarrow \mu\mu$
for ATLAS **3.4σ**



Improvements over Run-2 analysis:

- Huge NLO DY sample to model background pdfs
- Dedicated $\mu\mu$ vertex fit to improve mass resolution
- Additional production channels ($tt(\text{had})H, V(\text{II})H$)



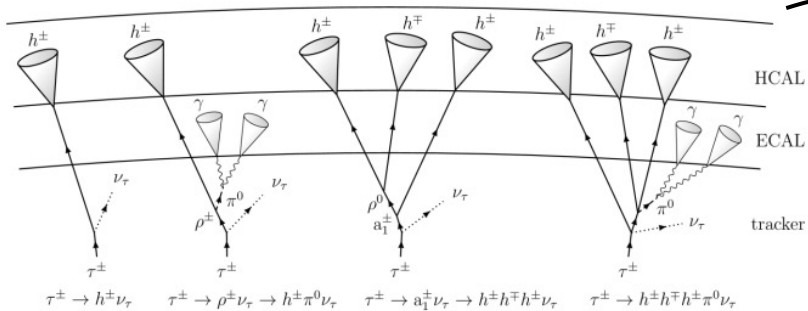
Higgs boson

CP studies of the Higgs-tau coupling in $H \rightarrow \tau\tau$ with improved sensitivity with **Run-3 data**

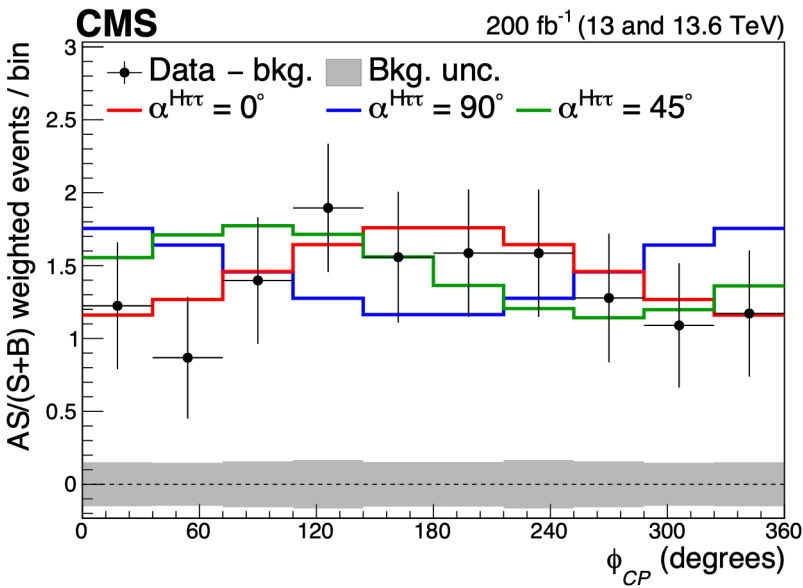


$$\mathcal{L}_\tau = -\frac{m_\tau}{v} \bar{\tau} (\kappa_\tau + i\gamma_5 \tilde{\kappa}_\tau) \tau H$$

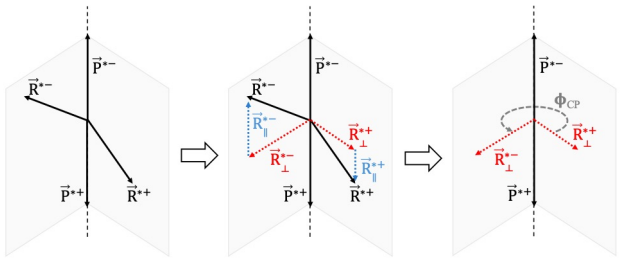
Hadronic τ decays identified using **DeepTau** algorithm



Simultaneous fit of Φ_{CP} -vs-BDT to extract Higgs signal and provide sensitivity to mixing angle $\alpha^{H\tau\tau}$

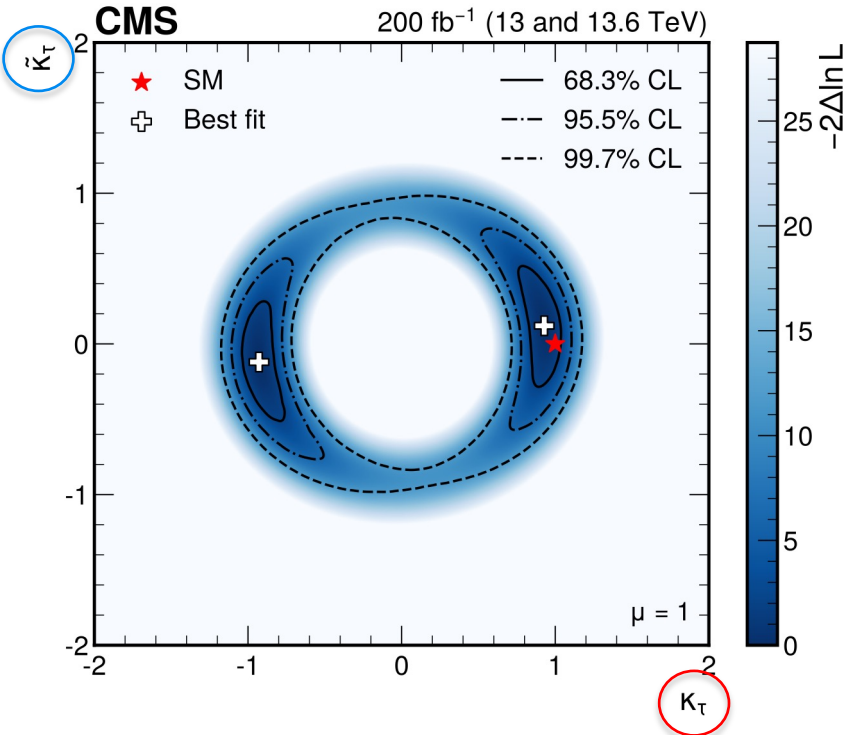


CMS-HIG-25-012 (Sub to JHEP)



Decay	π	ρ/a_1^{1pr}	a_1^{3pr}	e	μ
R	IP	π^0	PVec	IP	IP
P	$\pi^\pm$	$\pi^\pm$	$\tau^\pm$	$e^\pm$	$\mu^\pm$

$$\tan(\alpha^{H\tau\tau}) = \frac{\tilde{\kappa}_\tau}{\kappa_\tau}$$



Extract **CP-even** & **CP-odd** H- τ couplings from fit $\rightarrow$ most precise CMS measurement of CP-nature τ lepton coupling to date!

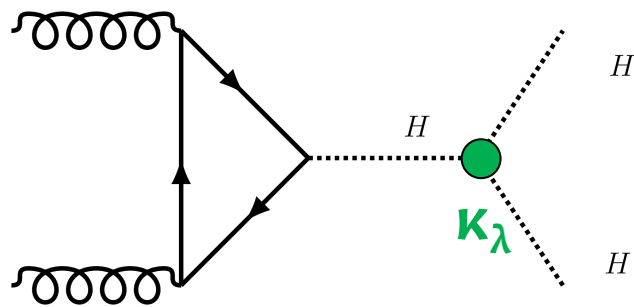
$$\alpha^{H\tau\tau} = 7 \pm 16 \text{ (stat)}_{-2}^{+3} \text{ (bbb)} \pm 2 \text{ (syst)}^\circ$$

Higgs potential

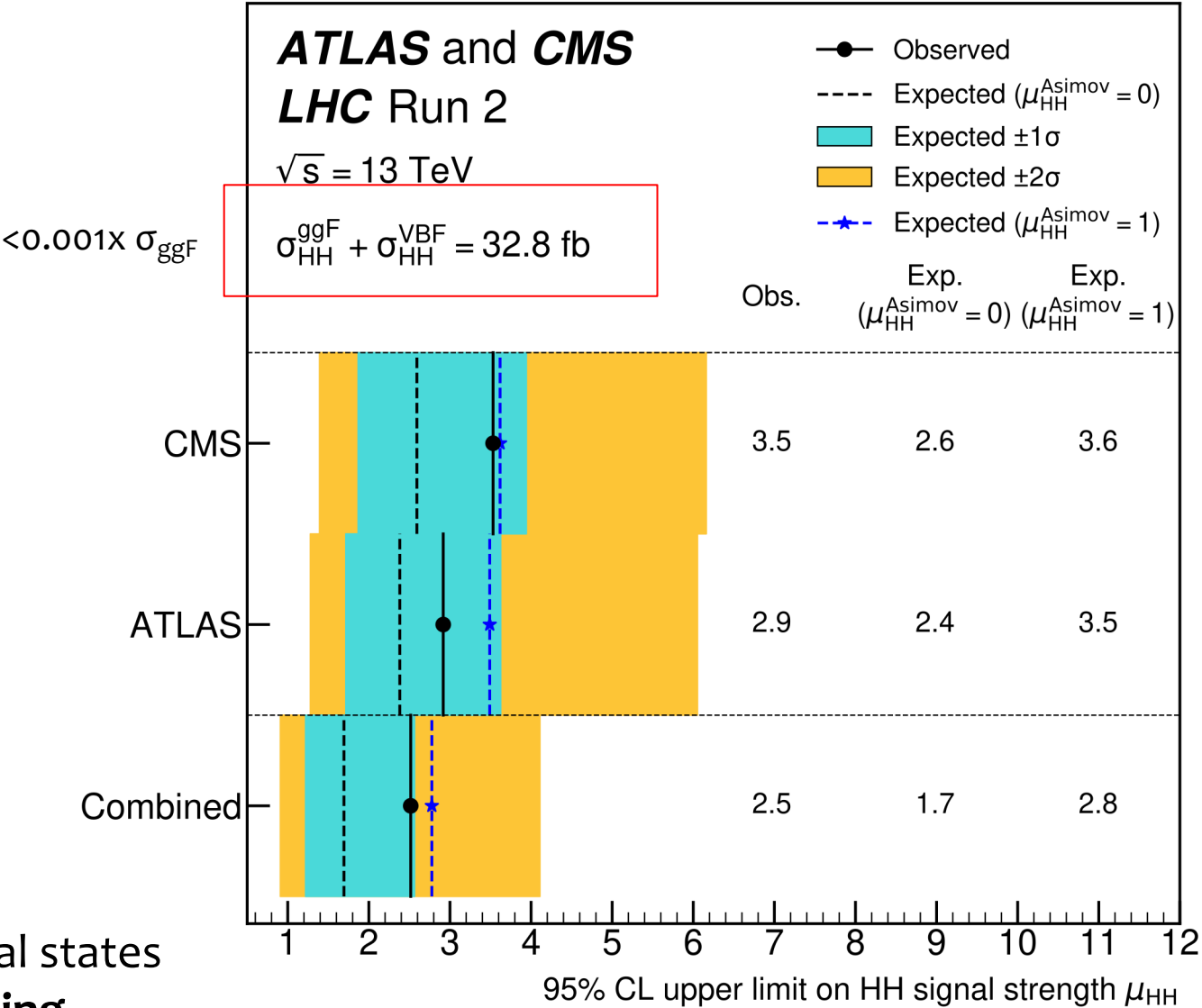
In the SM, the **Higgs potential** includes H^3 terms

$$V(H) = \frac{1}{2}m_H^2 + \boxed{\lambda v H^3} + \frac{1}{4}\lambda H^4 + \text{const}$$

“self-coupling” generates **Higgs-Higgs** interactions



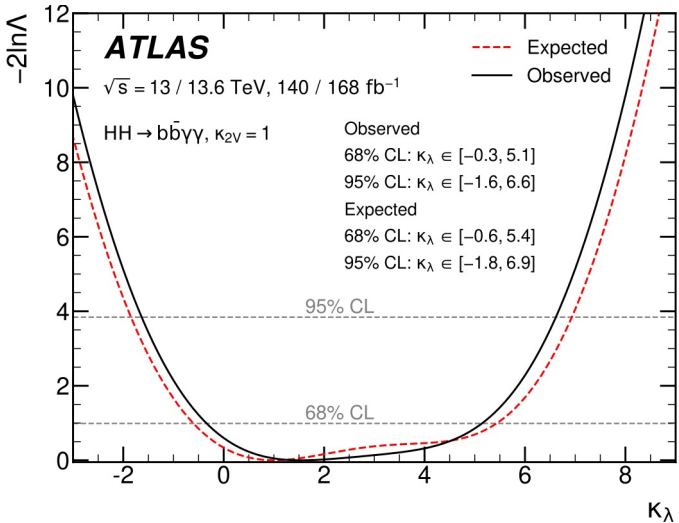
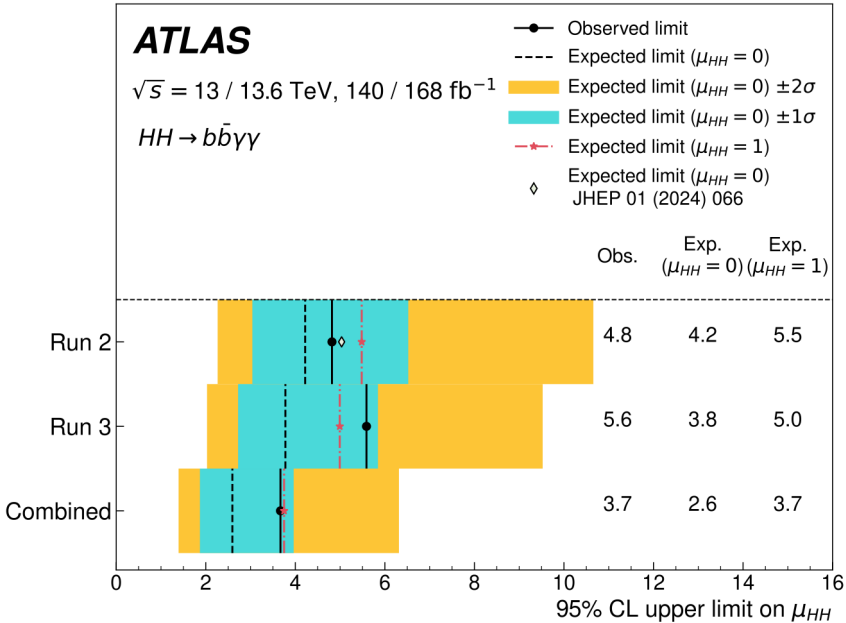
Search for di-Higgs requires Combination of final states & experiments for **best sensitivity to self-coupling**



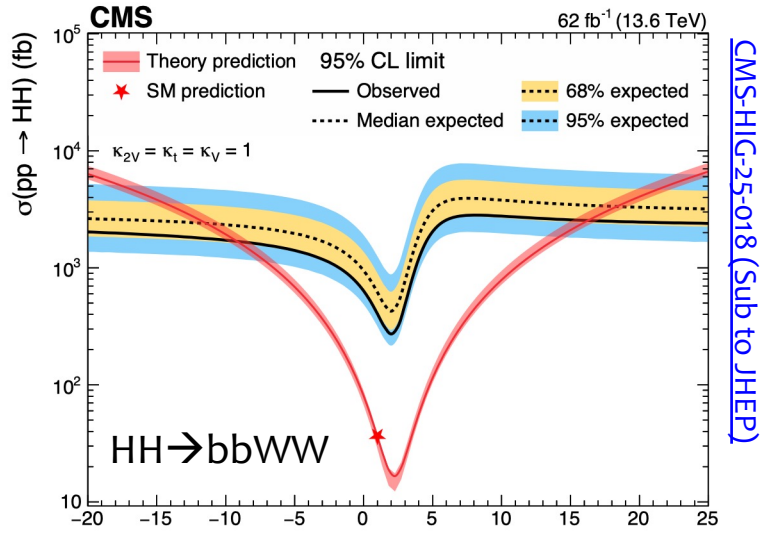
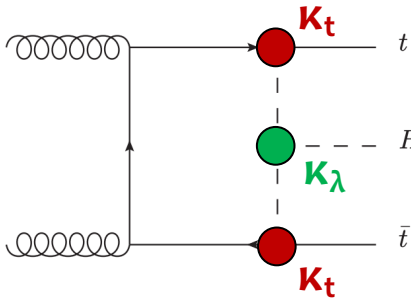
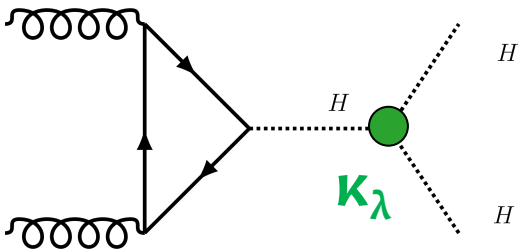
Higgs potential

UK focusing on *complimentary approaches* when contributing to this monumental task

[Phys. Lett. B 876 \(2026\) 140280](#)



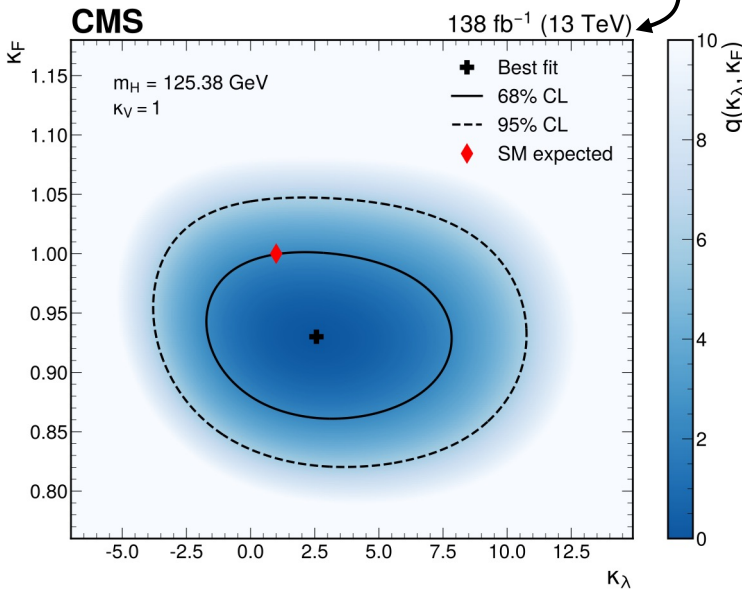
Analysis of Run-3 $HH \rightarrow 4b$ reaches sensitivity comparable with full Run-2 combination!



[CMS-HIG-25-018 \(Sub to JHEP\)](#)



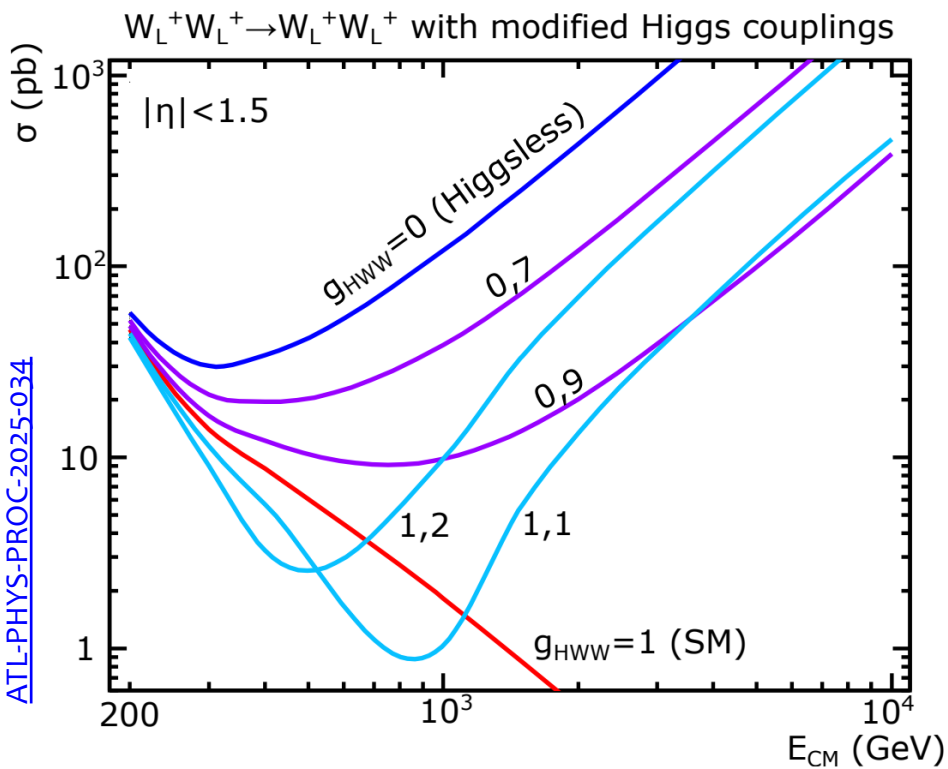
Work on additional decay channels ($\tau\tau\gamma\gamma, b\bar{b}\tau\tau, b\bar{b}WW$)
Interpretations of single Higgs cross-sections



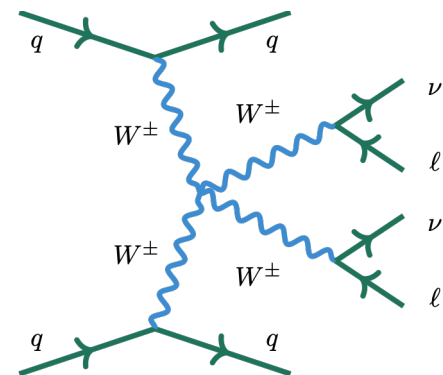
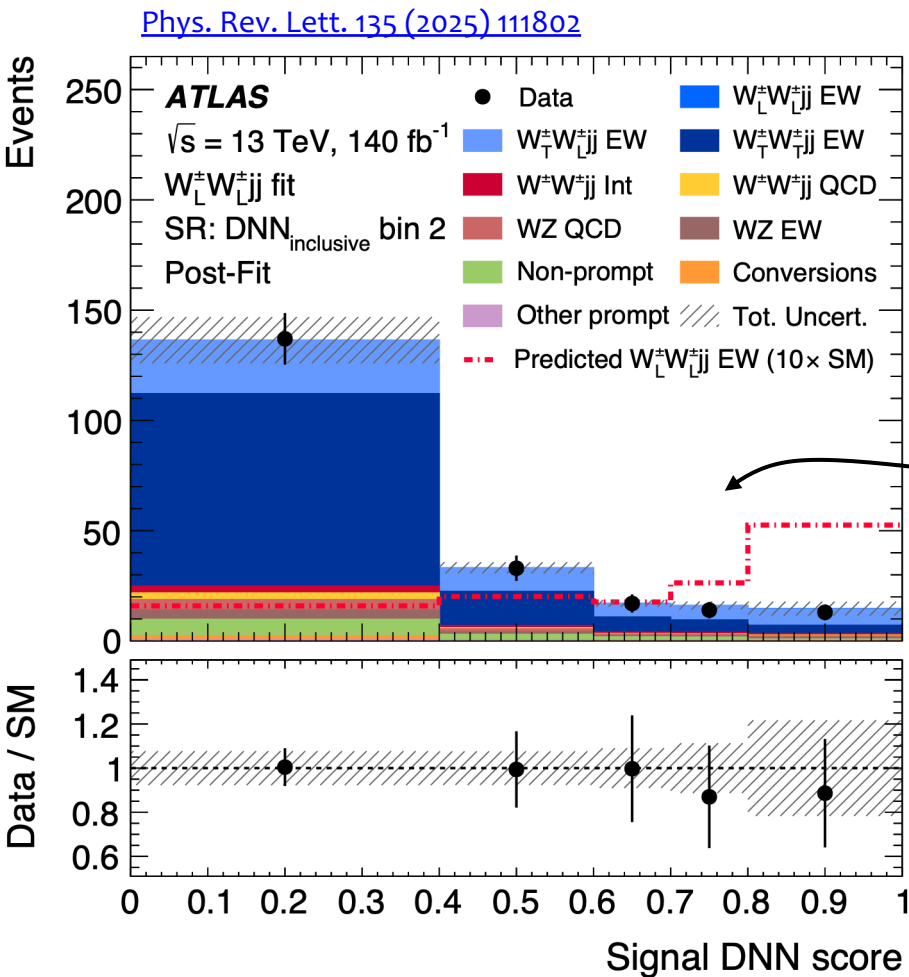
W_LW_L Scattering

Higgs boson acts to **regularise high energy behaviour** of W_LW_L scattering in Standard Model

→ Studying W_LW_L scattering provides a sensitive probe of EWSB



Evidence (**3.3σ**) of W_L in EWK production of SS W-boson pairs with ATLAS Run-2 data!

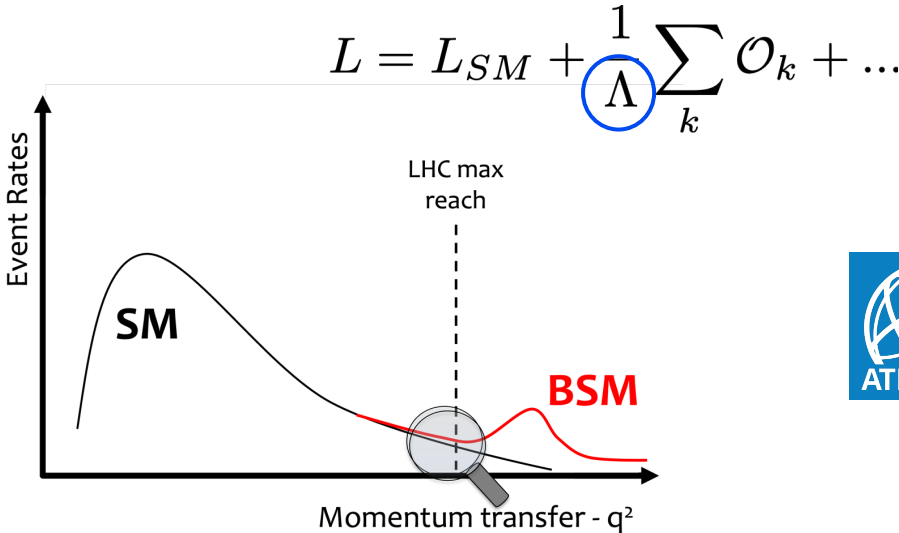


σ(W_LW_L) < 0.45 fb
@ 95% CL

SM expectation
0.19 ± 0.05 fb

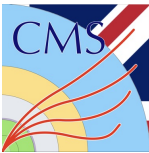
Indirect searches for new Physics

Searches for New Physics through measurements of **Standard Model processes**



Effective Field Theories (**EFT**) allow to **systematically probe** space of new physics (**NP**) models

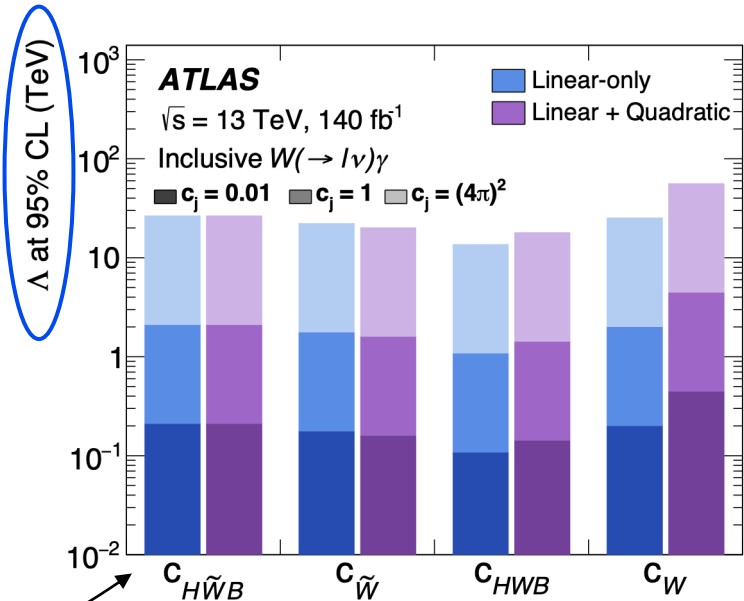
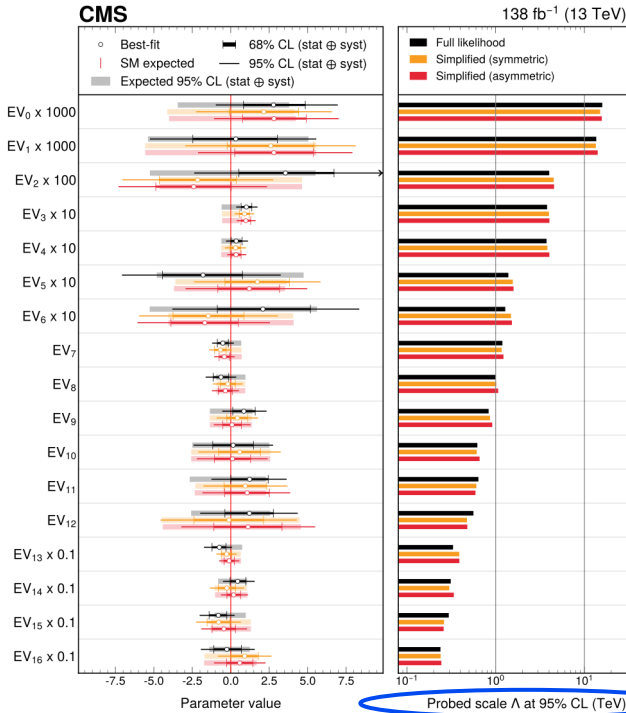
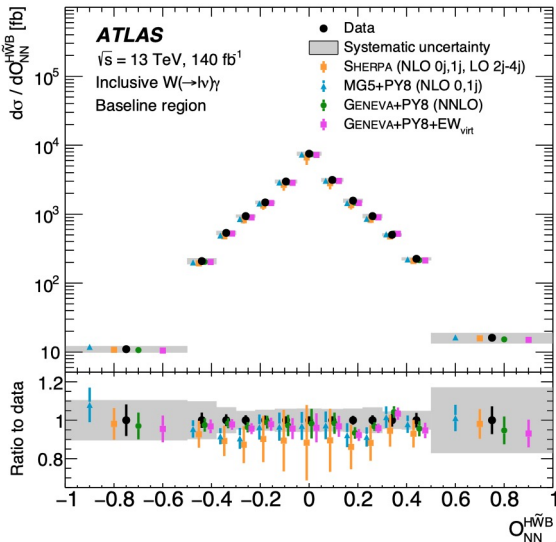
- Valid for **E** below **NP scale Λ**
- Match NP models to EFT parameters to **constrain possible BSM scenarios**



Simultaneous constraints on combinations of **CP-even Operators** from Higgs STXS measurements



Constraints on **CP-violating Operators** in $W\gamma$ cross-section measurements



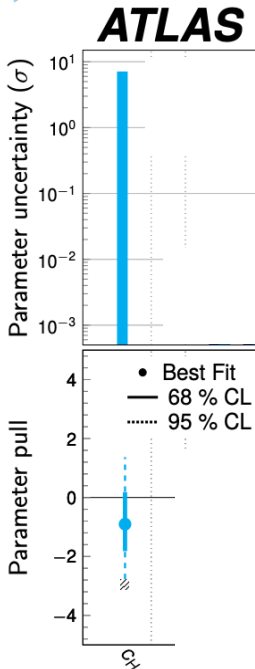
Indirect searches for new Physics

$$L = L_{SM} + \frac{1}{\Lambda} \sum_k \mathcal{O}_k + \dots$$

CERN-EP-2026-113 (Sub to JHEP)

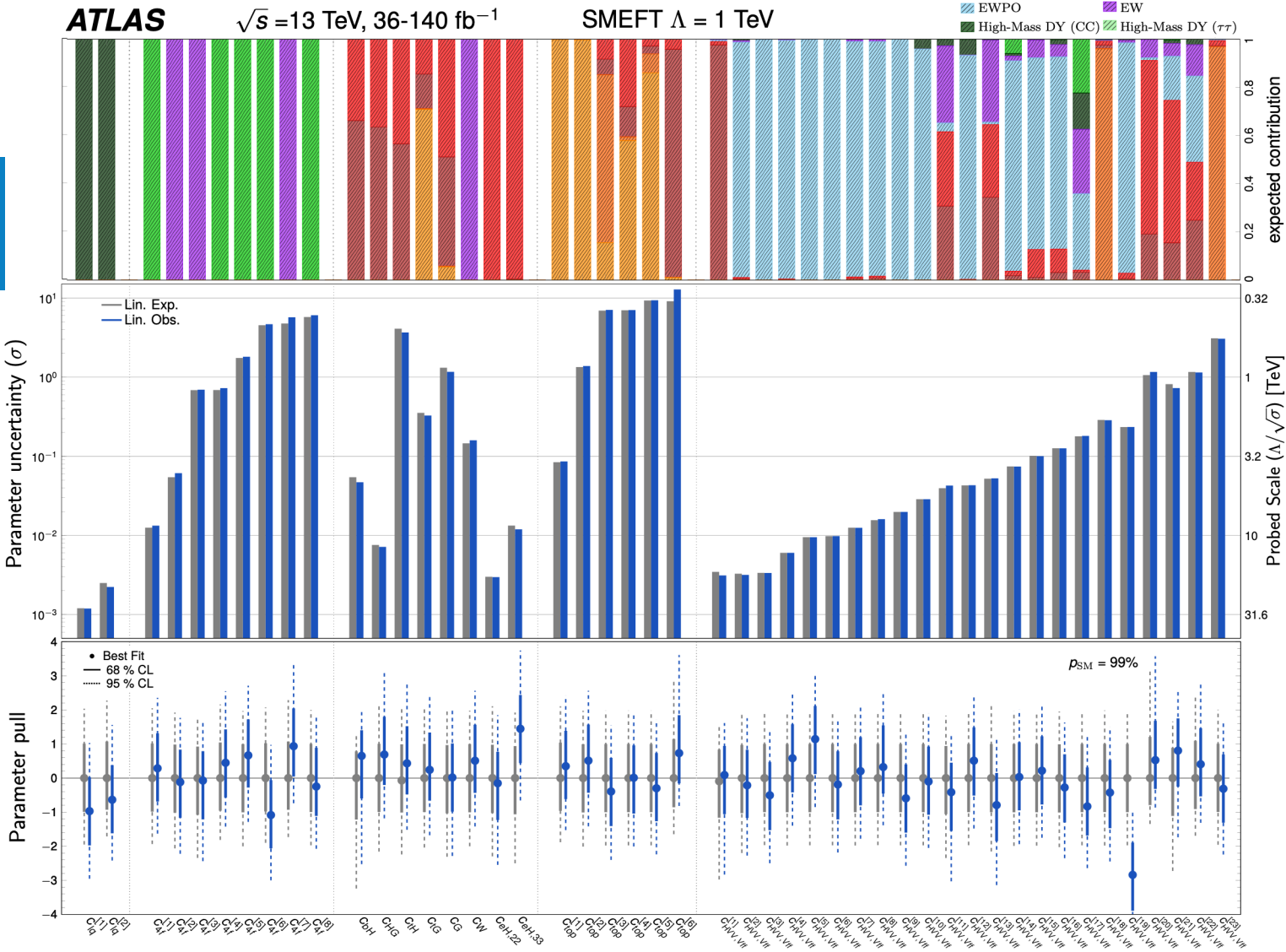
Combinations across Multiple physics processes provides **broadest possible constraints on Heavy New Physics!**

- **Higgs** ($\gamma\gamma, 4l, 2l2\nu, Z\gamma, \mu\mu, bb, \tau\tau$)
- **Diboson** ($WW, WZ, Z+jj$)
- **High mass DY** ($W, \tau\tau$)
- **Top** ($t\bar{t}$ boosted/leptonic)
- **EWPO** (LEP, SLD, ATLAS)
- **HH** ($bb\gamma\gamma, bb\tau\tau$)



Total of **48 parameters** constrained simultaneously!

Most comprehensive EFT interpretation by ATLAS to date!

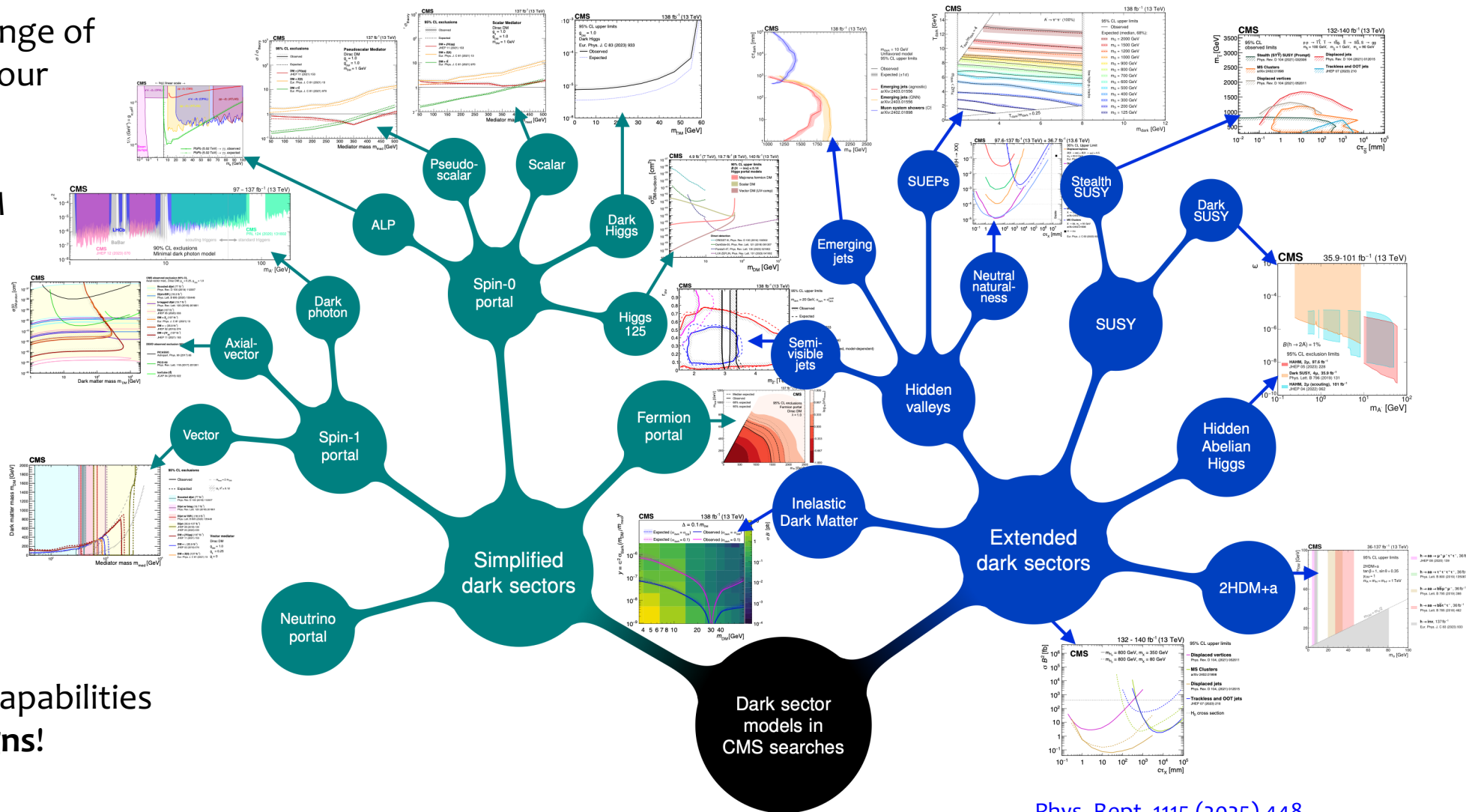


Direct searches for exotic signatures

Run-2/3 has seen a huge range of new signatures emerge in our searches

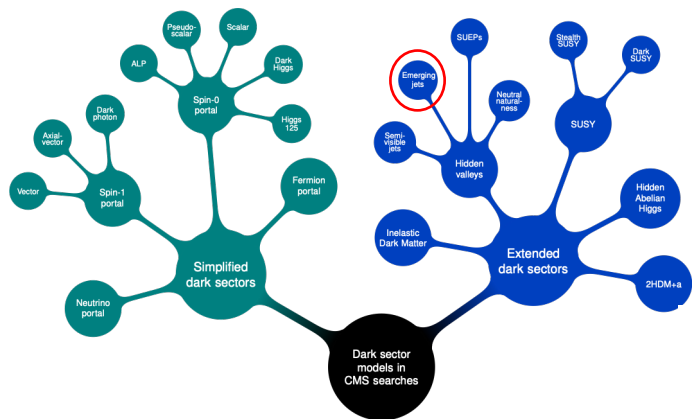
→ Sensitivity to many BSM models with challenging final states

→ ATLAS & CMS pushing capabilities well beyond original designs!

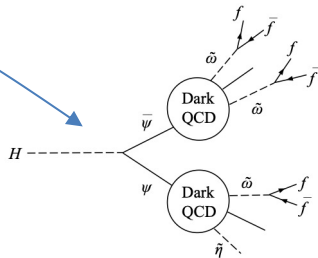
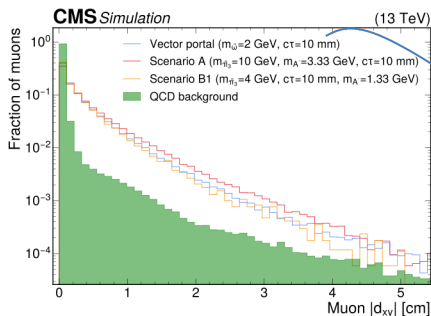


Hidden-valley models

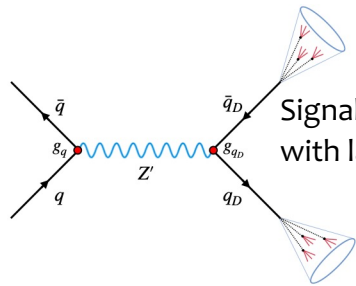
“Dark QCD” dark partons undergo showering & hadronization → long-lived dark mesons that decay to SM particles gives rise to “**emerging jet**” signatures



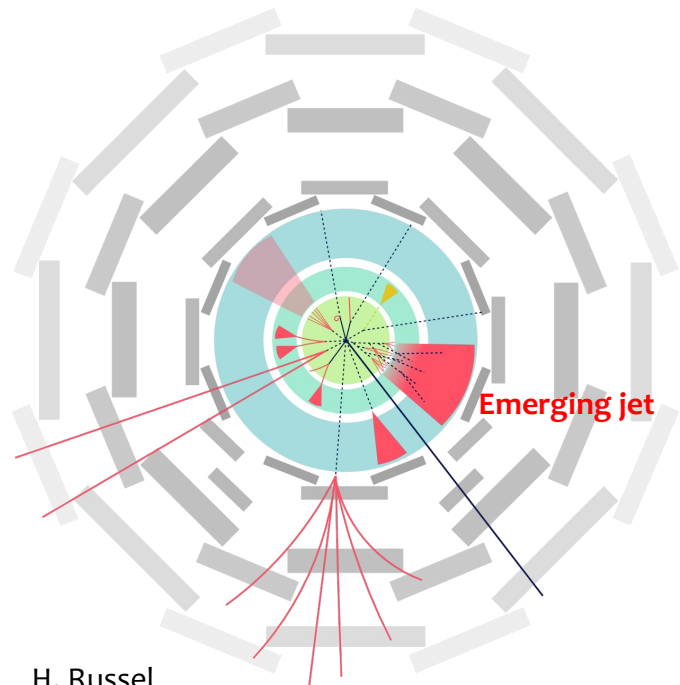
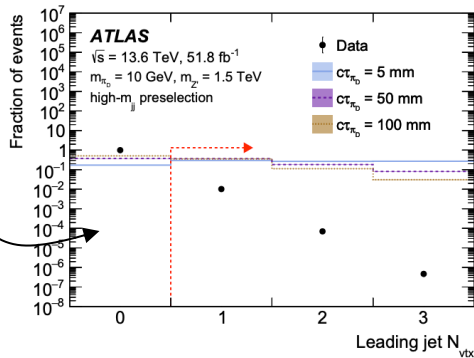
Di-muon final states search from CMS → non-prompt muon triggers in B-parking dataset



Dijet search by ATLAS → two pass tracking approach recovers high IP tracks from displaced signatures

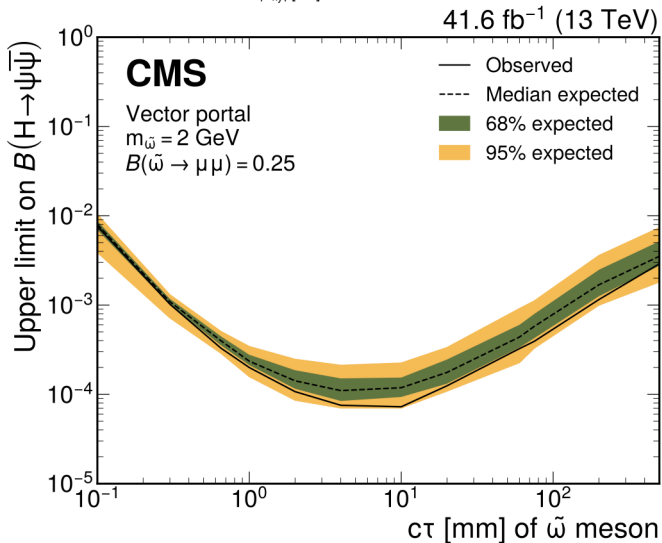


Signal exhibit jets with larger N_{vtx}

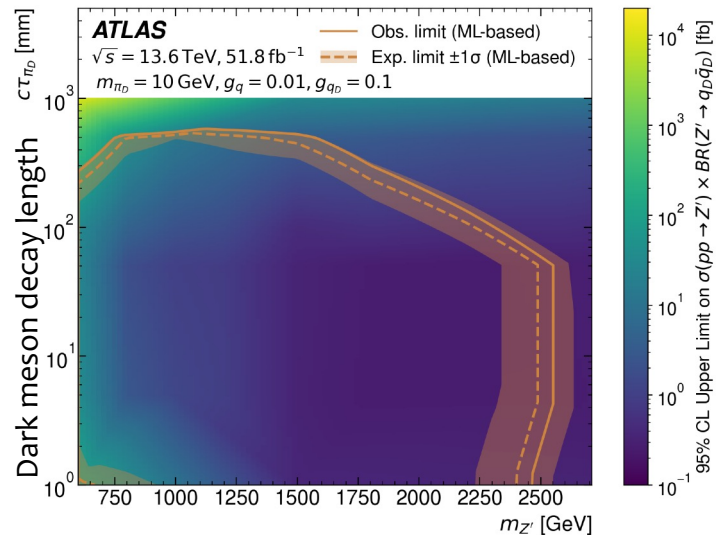


Emerging jet

H. Russel



[JHEP 03 \(2026\) 189](#)



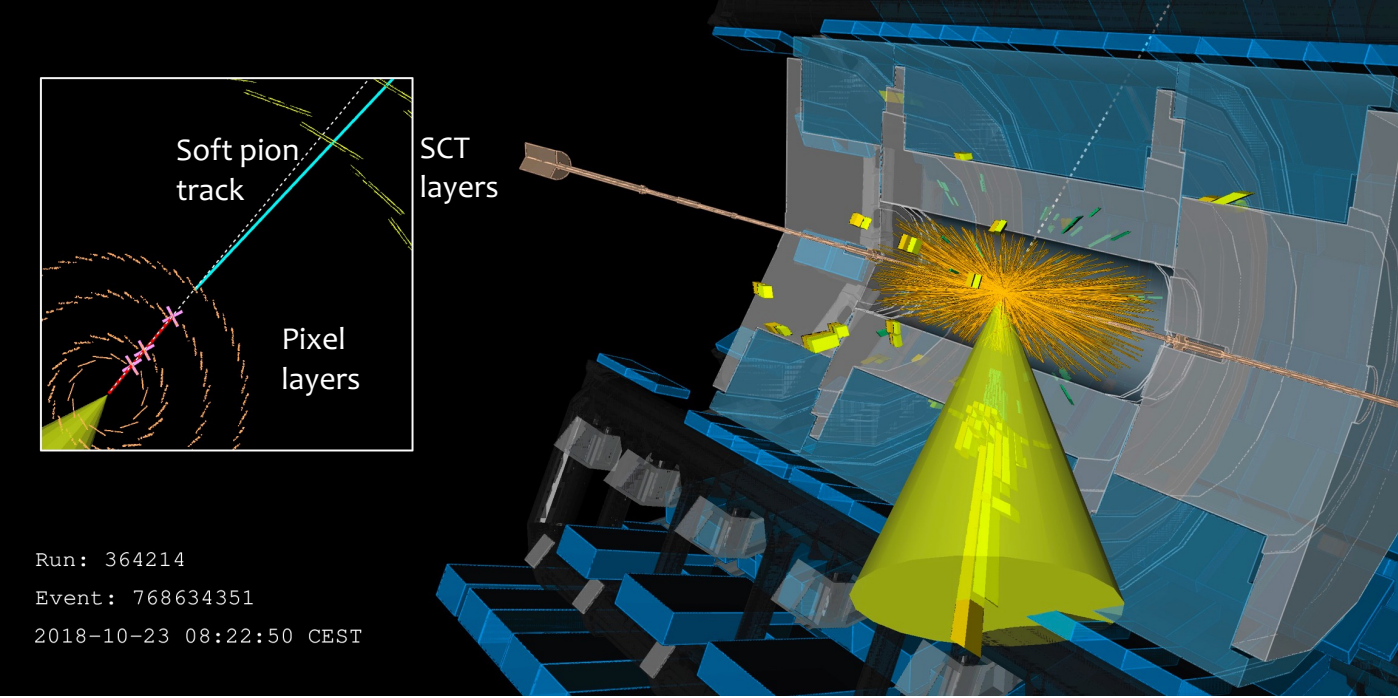
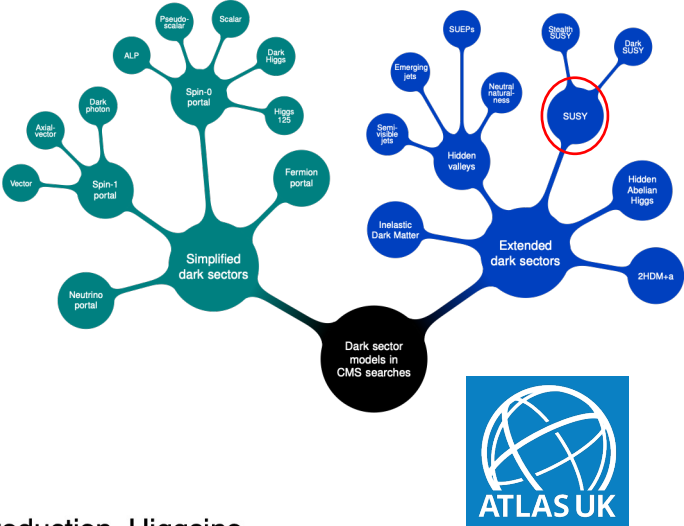
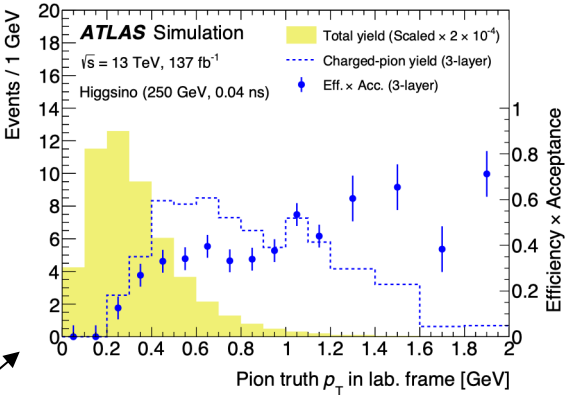
[Rep. Prog. Phys. 88 \(2025\) 097801](#)

Disappearing tracks

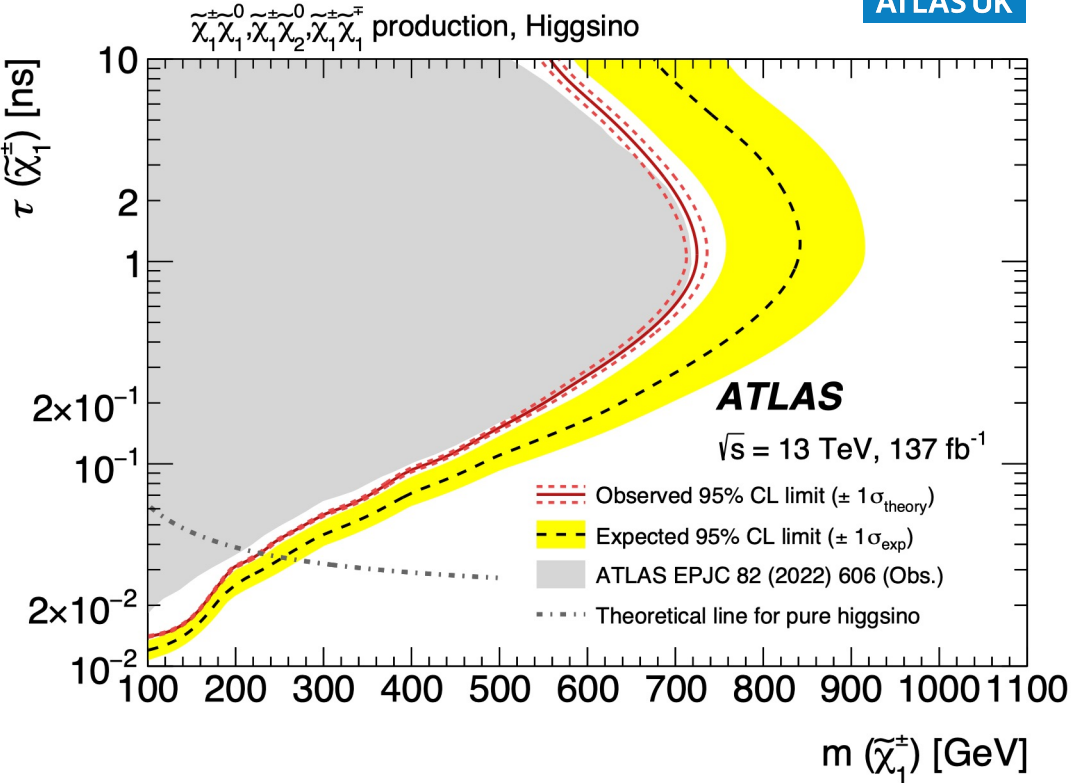
Search for heavy, long-lived charged particle that travels a **very short distance** in the innermost layers of the ATLAS experiment before decaying into undetectable particles

Several DM/SUSY models provide signatures with disappearing tracks

- Improvements in tracklet reconstruction improves efficiency when there are spurious SCT hits
- BDT used to identify presence of soft-pion expected in signal signature

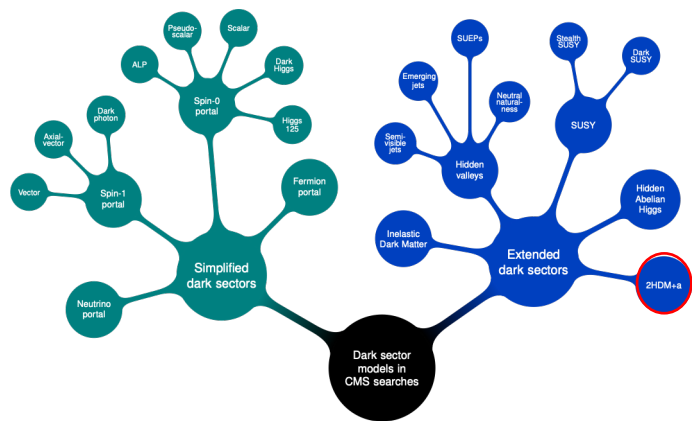


Run: 364214
Event: 768634351
2018-10-23 08:22:50 CEST

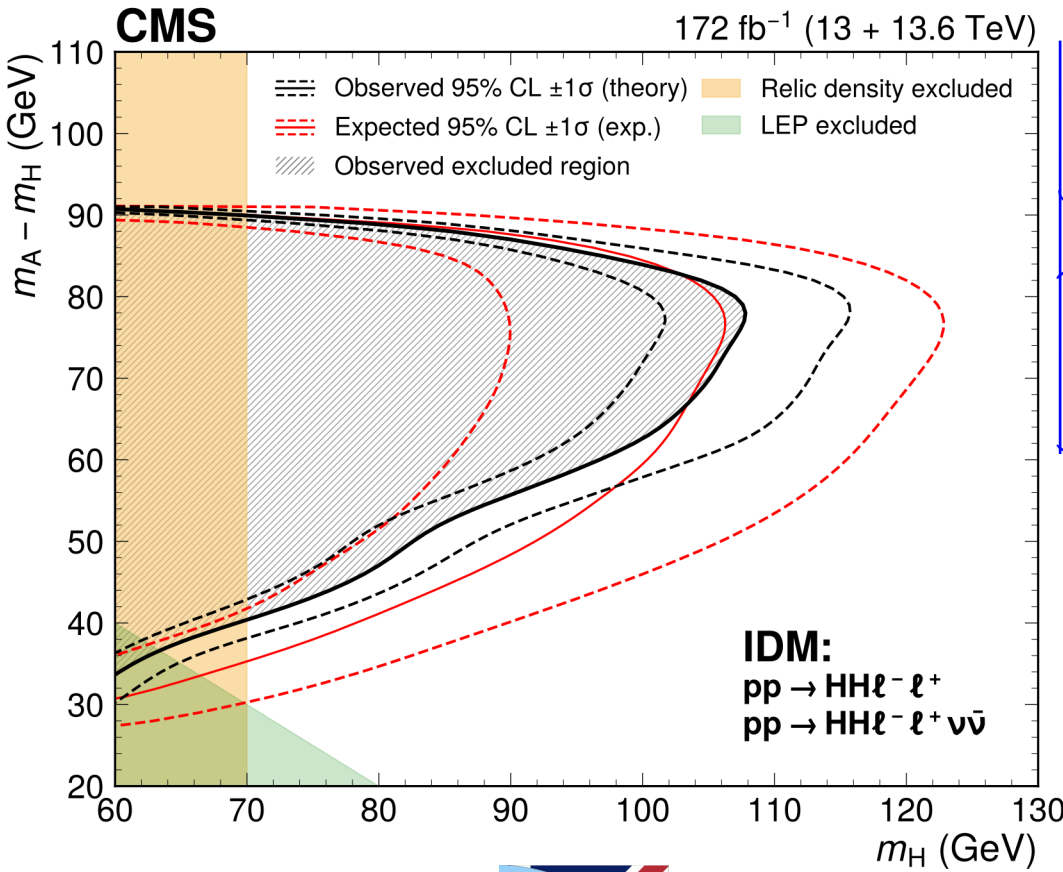
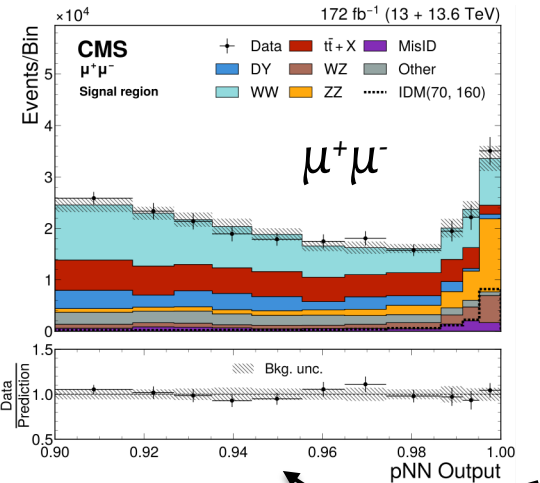
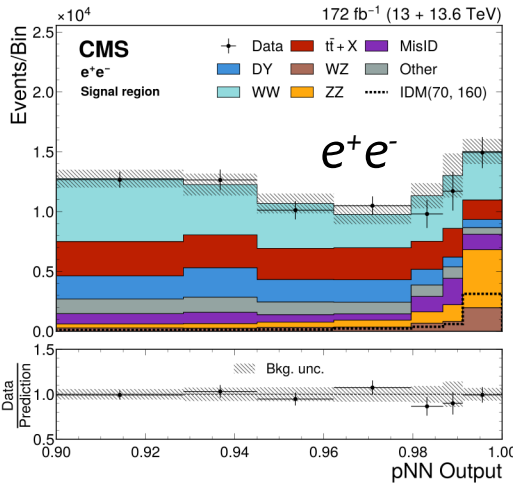
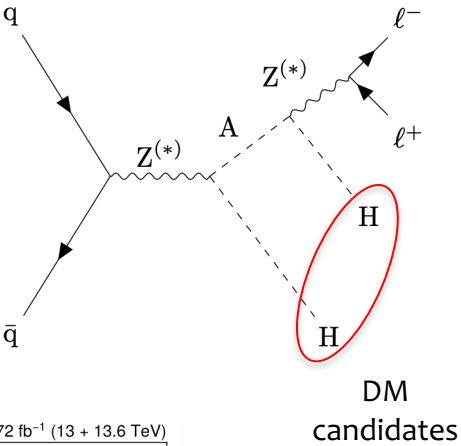


Inert Doublet Model

CMS Run-2 + Early Run-3 search for the **Inert Doublet Model**
→ First ever search @ LHC for this model!



Low mass splitting produces off-shell Z boson
→ no resonance peak in m_{ll}



Uses parameterized Neural Network to separate S-vs-B *optimally* across m_H - Δm plane

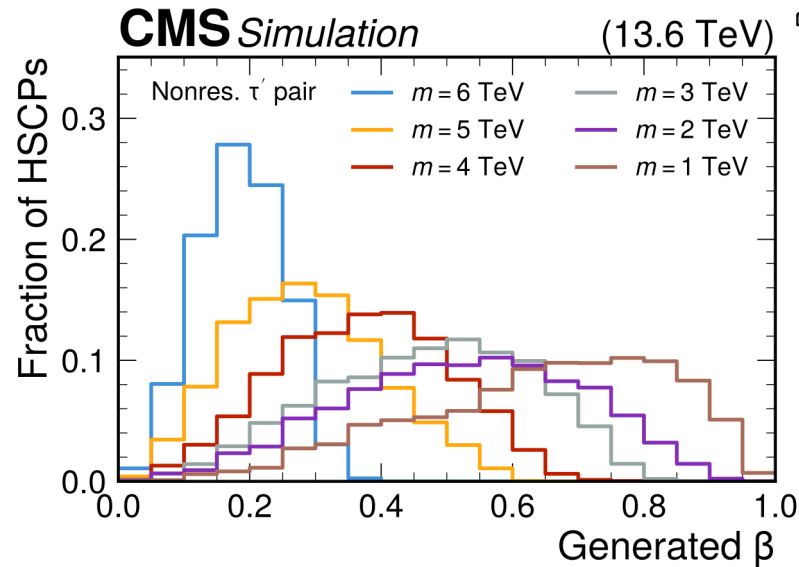


CMS-NPS-25-002 (Sub to JHEP)

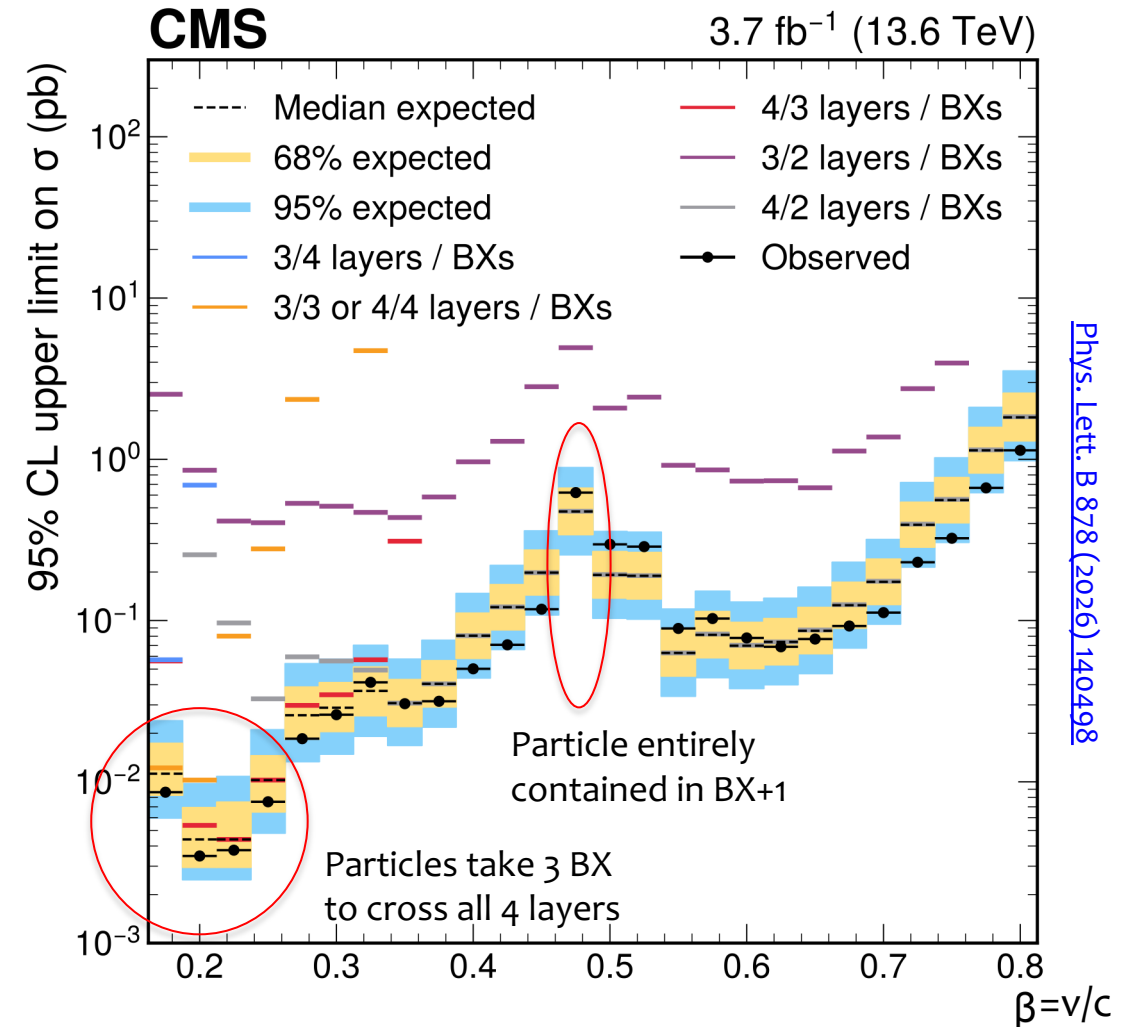
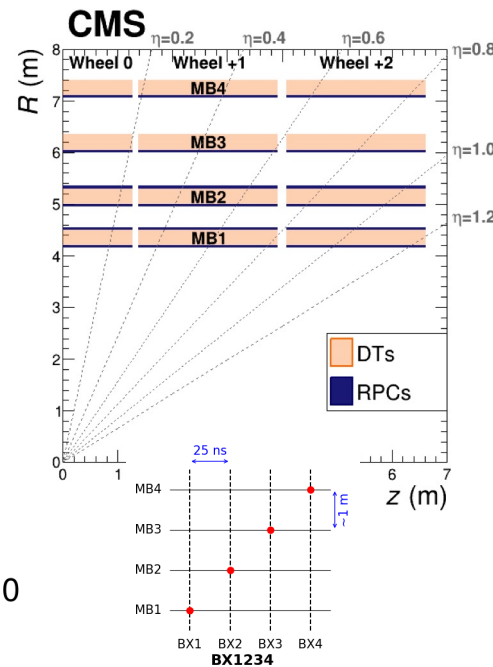
Heavy long-lived particles

Level-1 demonstrator deployed in the CMS Level-1 Trigger (L1T) during Run-3

- Allows for **triggerless** analysis → explore correlations between BXs
- First search performed using L1 muon tracks → set limits on several benchmark models for **Heavy long-lived Charged Particles**



Model-independent limits on fiducial cross-section for long-lived charged particles produced with $|\eta| < 0.83$, $p_T > 500$ GeV



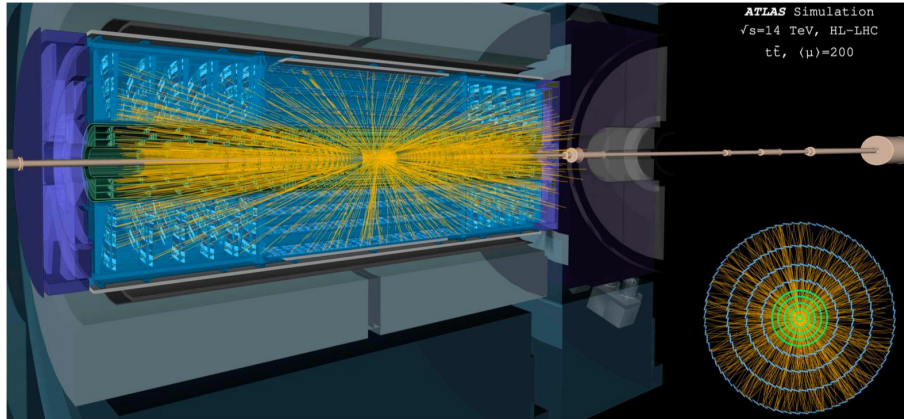
Phys. Lett. B 878 (2026) 140498

Looking to the (near) future

“The full exploitation of the physics potential of the LHC and the **HL-LHC and the completion of the high-luminosity upgrade remain the highest priorities** of European particle physics. Every effort must be made to complete the HL-LHC upgrade within the current schedule”

HL-LHC promises

- Unprecedented pile-up conditions and track density
- Challenging radiation doses
- Huge volume of data to handle

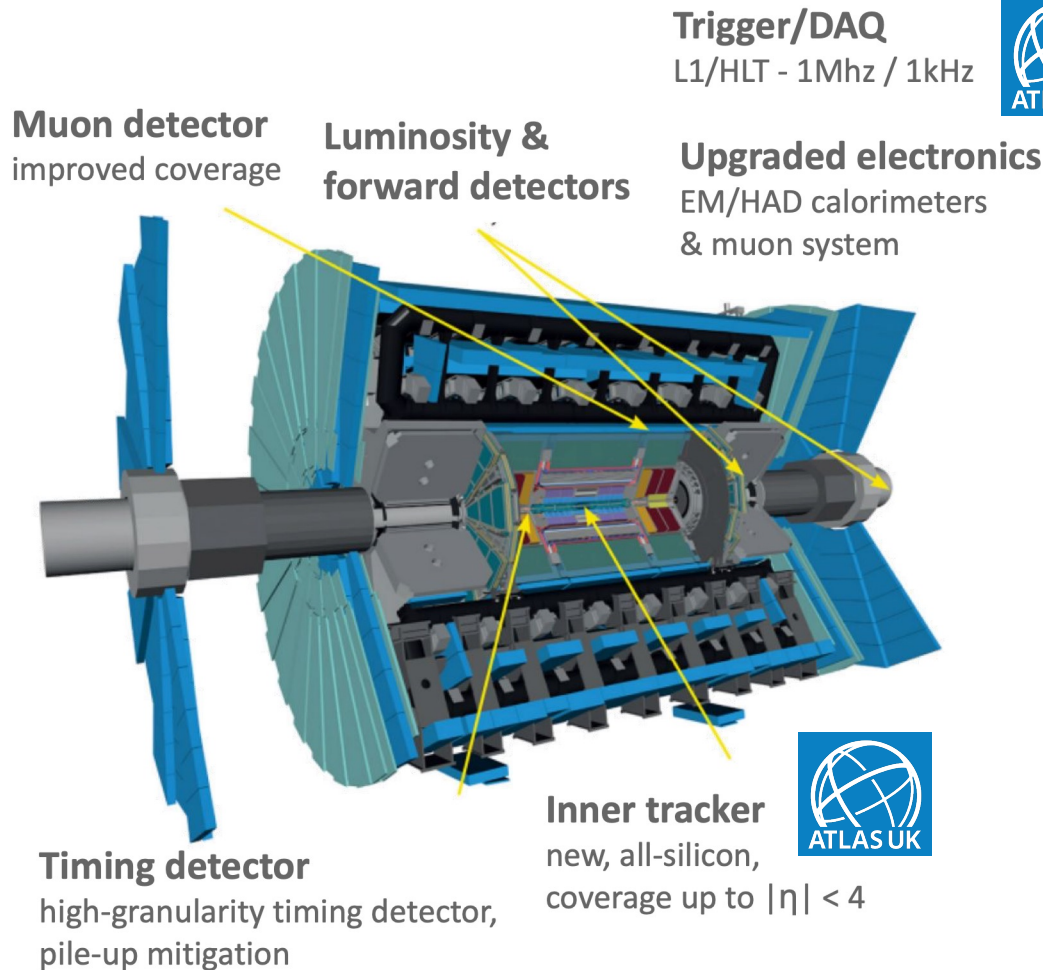


ATLAS and CMS have **ambitious upgrades well underway** to meet the challenges of the HL-LHC

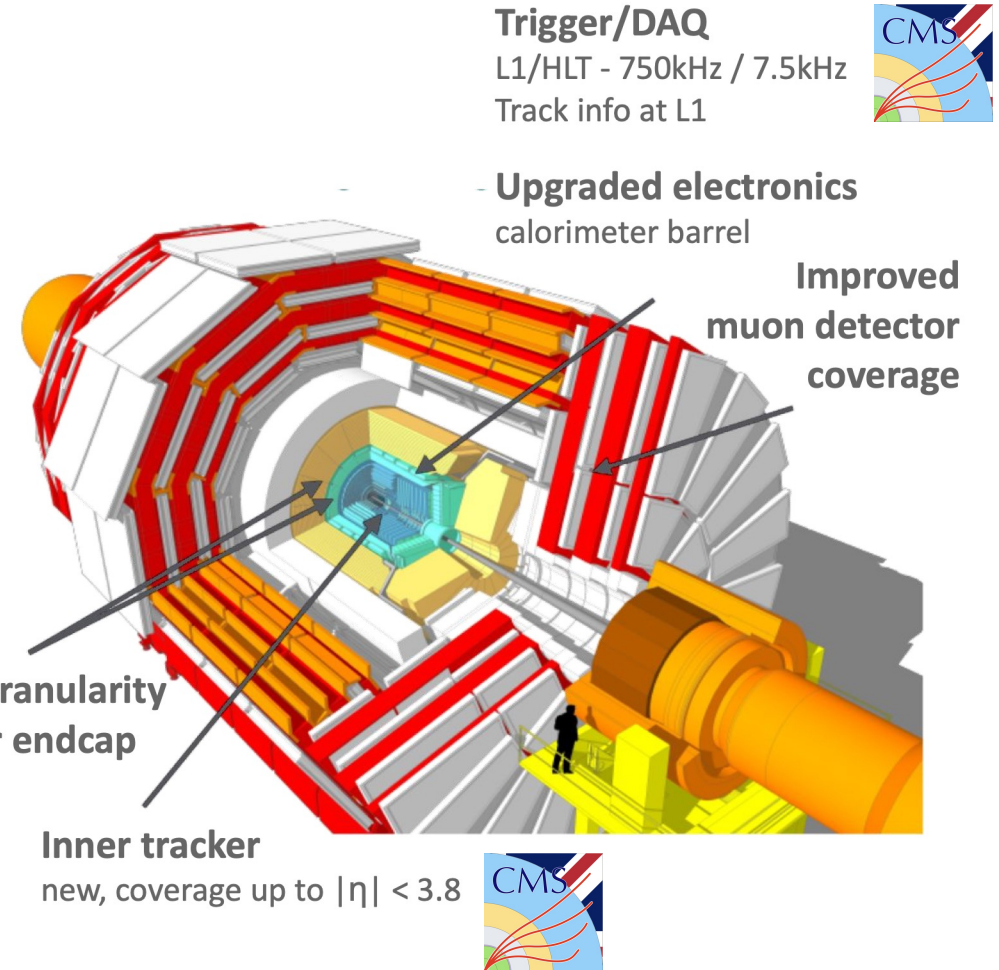
- UK leading mission critical systems
- A lot of work to do!



ATLAS and CMS upgrade overview



New high-granularity calorimeter endcap



Funding : ATLAS & CMS reduction of ~30%* - hopefully runs up until 2030

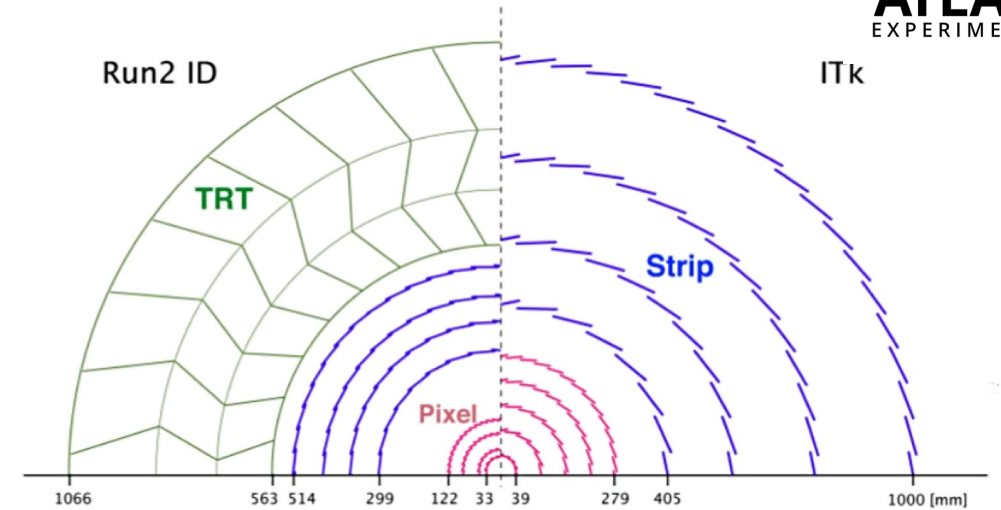
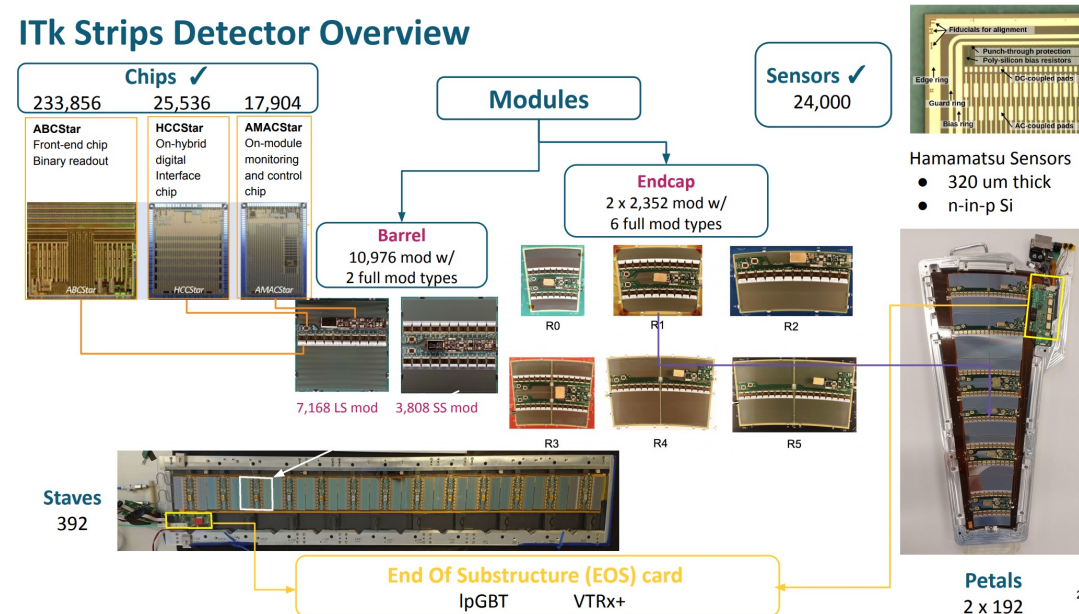
→ UK is committed to delivering key upgrades and mitigating impact on deliverables where possible but shortfall in terms of length & depth of funding **severely impacts our ability to complete MoU deliverables & potential delays to Run-4**

Highlight: Inner Tracking Detector (ITk)

One of the **main UK deliverables for ATLAS**

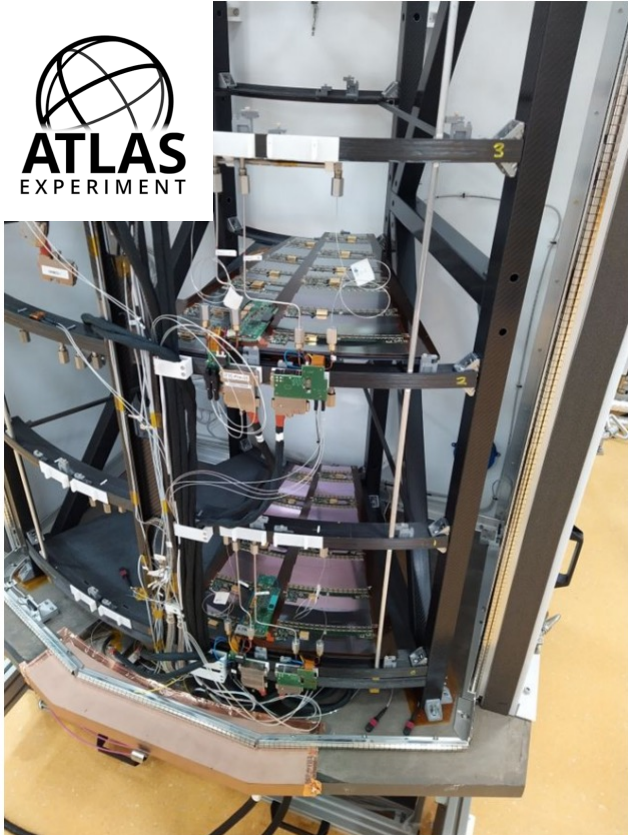
- Complete replacement of the current inner detector
 - Larger angular coverage (η : 2.5 $\rightarrow$ 4)
 - High radiation tolerance (up to 1×10^{16} neq/cm²)
 - Reduced material budget
- Very large total surface for Pixel and Strip sensors

ITk Strips Detector Overview

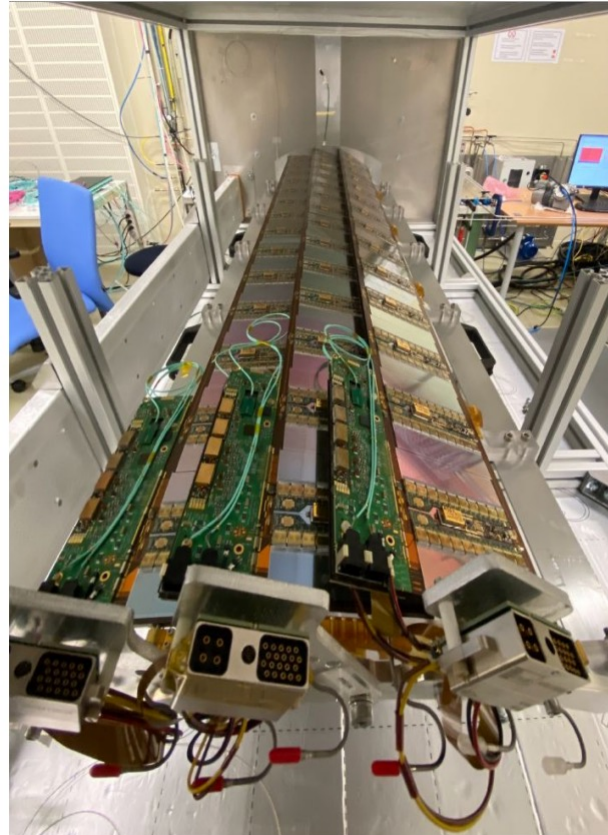


- UK is responsible to build **40% of the strip modules** and **50% of the strip local supports** (cores) + strip service modules
- UK deliverables in pixel include assemble and test **20% of ATLAS Pixel modules** and build **one endcap**
- **UK providing a lot of the leadership in the ITk**

Highlight: Inner Tracking Detector (ITk)



Endcap system tests @DESY



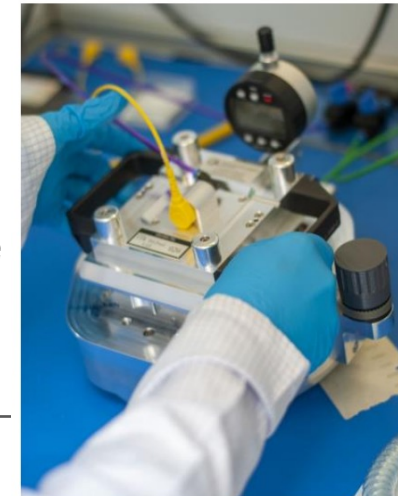
Barrel system tests @CERN (SR1)

Strips: In bulk production and going well
Integration into the outer cylinder has started at CERN

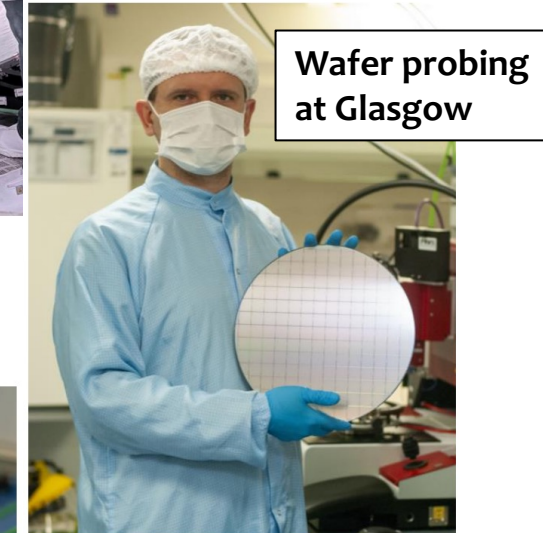


Trial Stave insertion
into the Outer
Cylinder in SR1

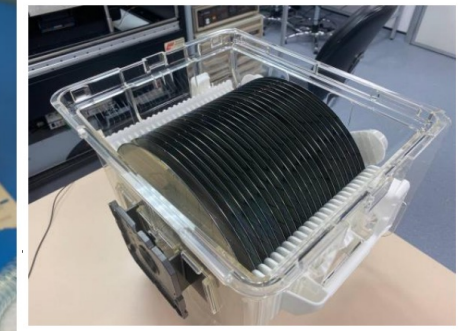
Pixels: In bulk production
and going well



Pixel module
production



Wafer probing
at Glasgow



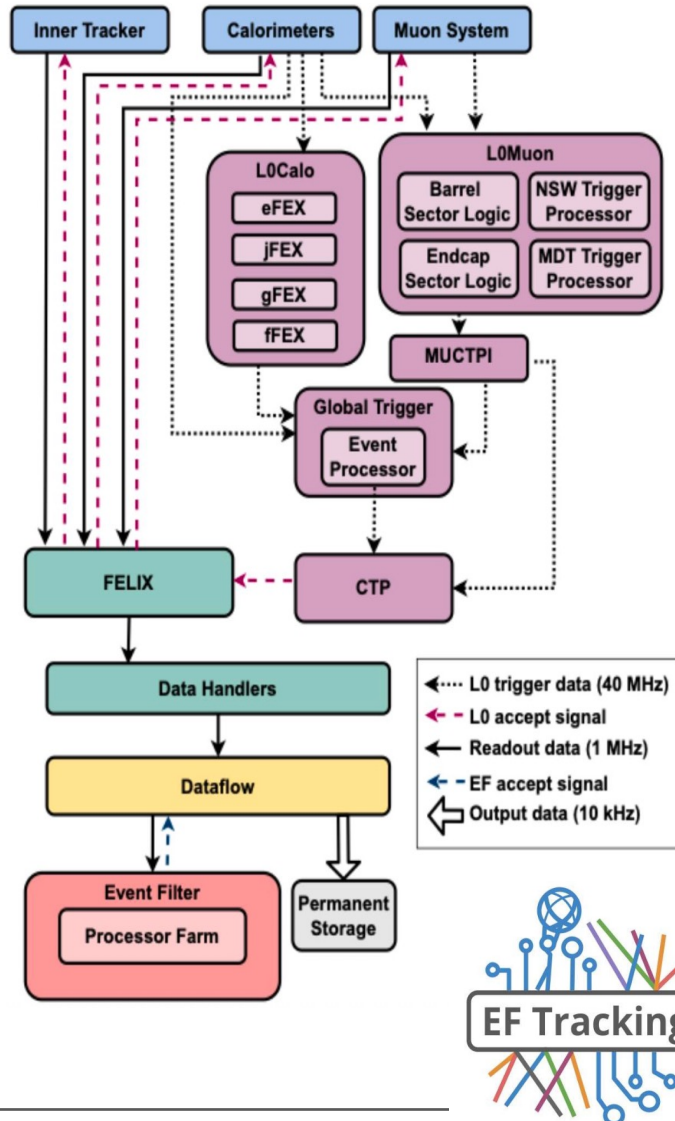
Highlight: Trigger & DAQ

Phase-II TDAQ composed of:

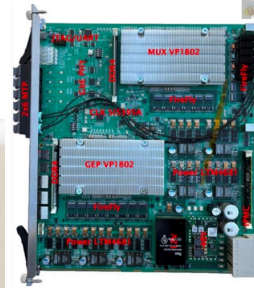
1. Lo Trigger, 2. DAQ, 3. Event Filter

UK contributions to Lo Trigger:

- **Lo Calo:**
 - **Overall** coordination
 - **eFEX** and **ROD** software and firmware
 - Update readout to 1MHz
 - Realtime path changes
- **Global Trigger:**
 - **Hardware** (Global Common Module) **design and test**
 - **Overall** coordination
 - Global Firmware **System Engineer**
 - **Software** development and management
 - **General** infrastructure
 - **Online/offline software** for LoCalo and coordination
 - **Algorithmic**
 - **Simulation**
 - gCTPi (aka **GCI**)
- **Event Filter**
 - Hardware testbeds: FPGA, GPU
 - Novel algorithms for CPU, GPU, FPGA
 - Validation, Monitoring & Coordination roles
 - Investigation of alternative technologies (e.g. Intel and AMD GPUs)



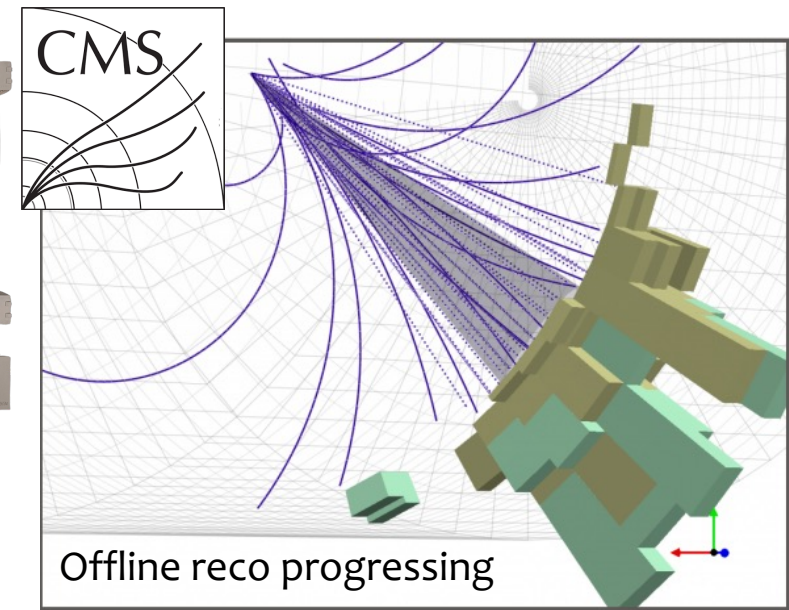
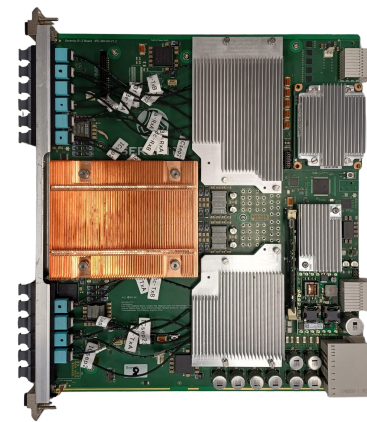
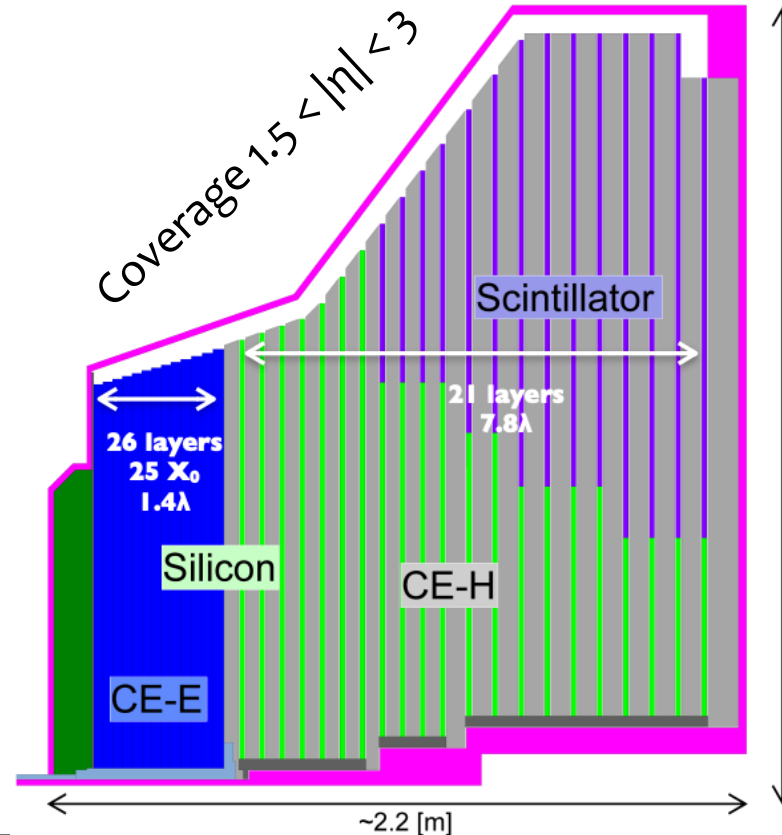
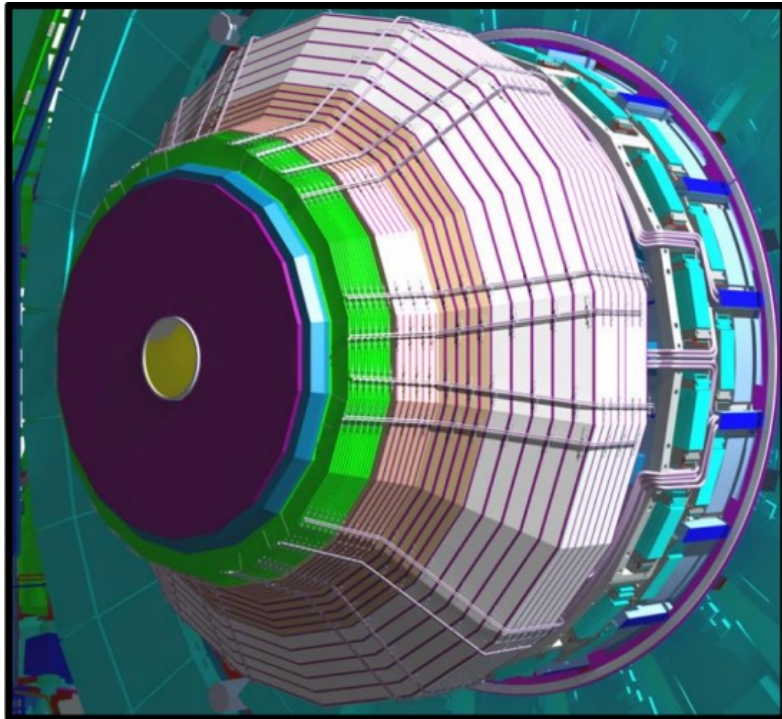
GCM integration at CERN test rig



Highlight: HGCal Endcap Calorimeter

The harsh environment of HL-LHC necessitates new ideas in Calorimetry to ensure excellent Physics performance

- Improve jet energy resolution, maintain e/γ performance, cope with high-multiplicity, jet-substructure as a tool
- Need a **highly segmented sampling calorimeter** with timing information



CMS UK deliverables:

- Primarily software & firmware related to trigger path
- Clustering algorithm firmware, DAQ firmware, Timing and control integration
- **Serenity** - backend processing card for **multiple sub-detectors** (including HGCal)

Highlight: L1 Trigger



CMS UK Involved in system design, testing, algorithm development in GTT and CTL2

Involvement of UK in many of the **upstream TP subsystems** huge benefit to L1T

Important tasks for coming year:

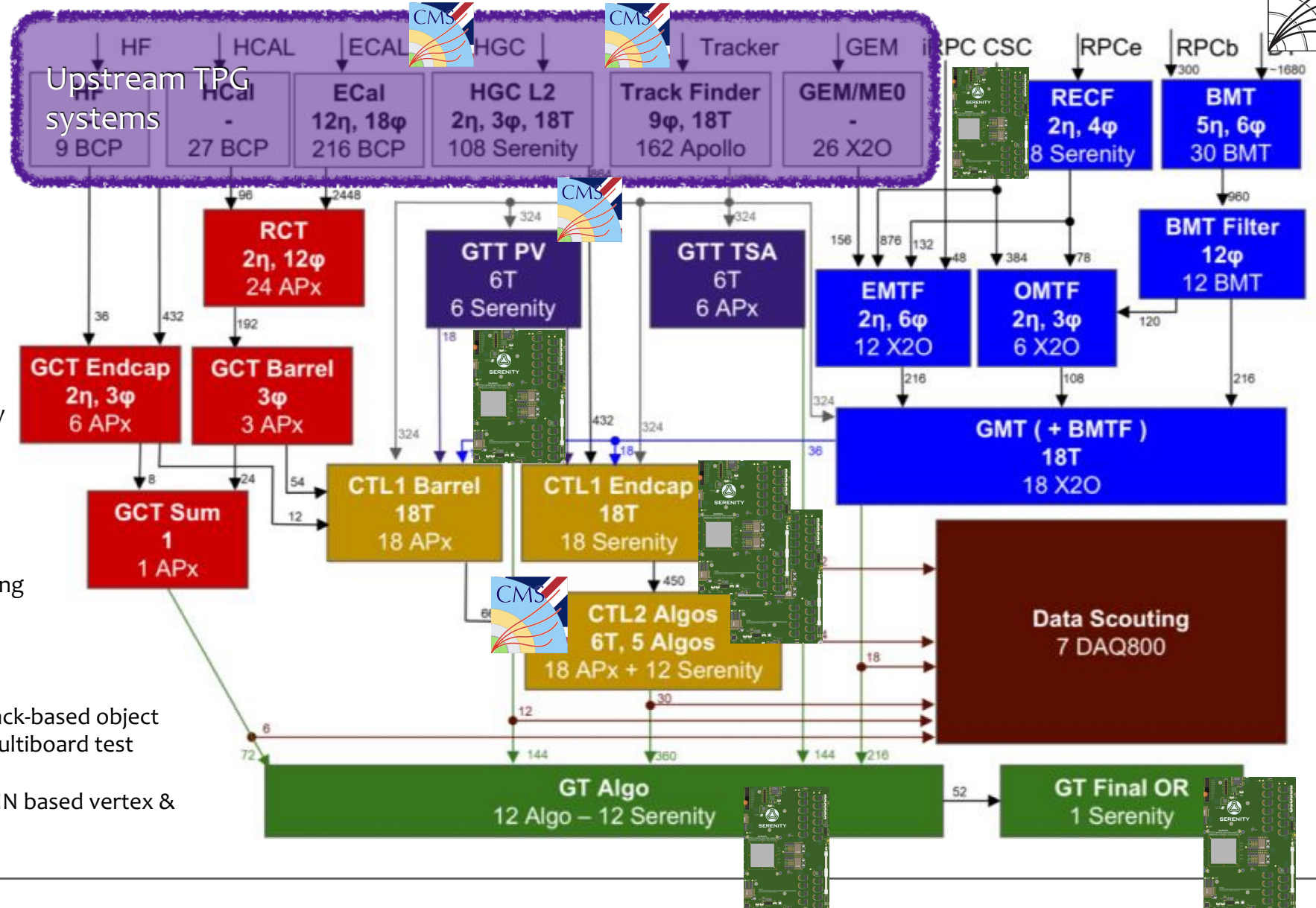
Online SW developments & more Serenity S1.Xs to facilitate complex slice tests

Correlator:

- **Jet finding** : Integrating link mapping, testing, more complex slice tests
- **ML algorithms** : Jet tagging and ensuring robustness of NN to varying detector conditions

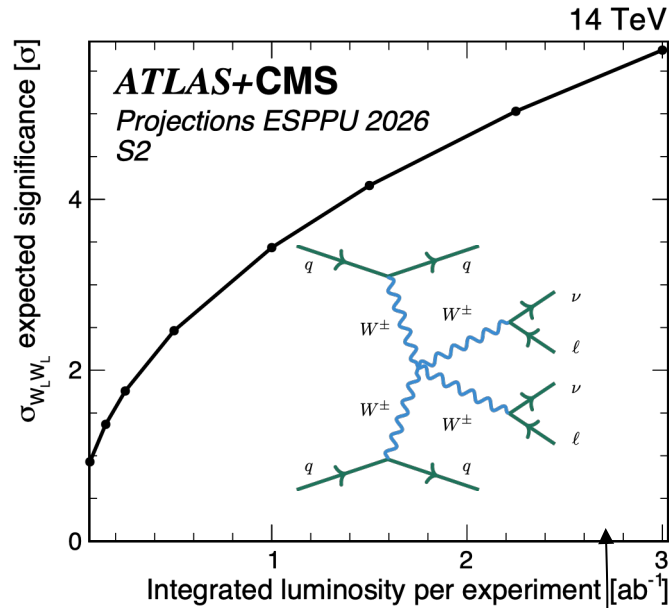
GTT:

- Full demonstration of vertexing and track-based object reconstruction on Serenity Including multiboard test with Correlator, GT, and track finder
- Development and characterisation of NN based vertex & track-to-vertex reco



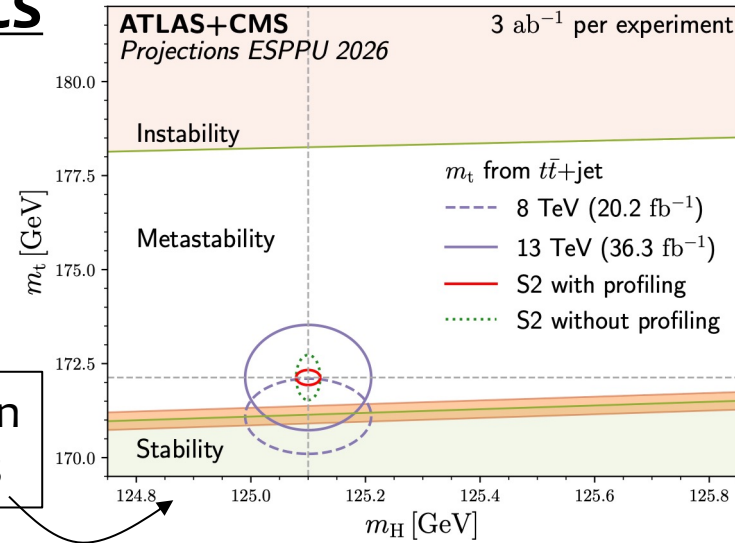
HL-LHC Potential for Physics

Recent updates in several key areas for
Physics output potential at the HL-LHC!

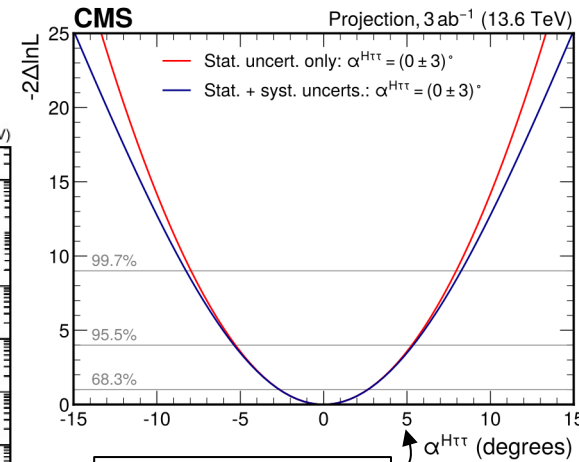
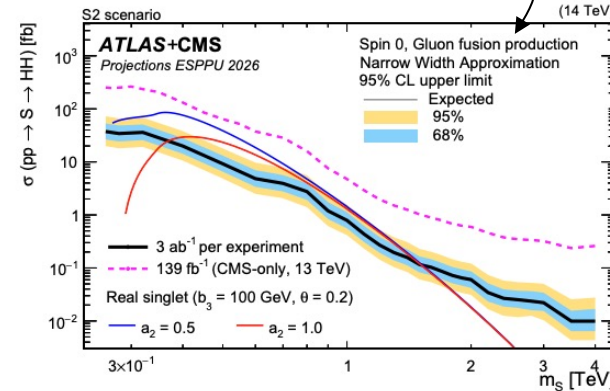


$W_L W_L$ discovery reach

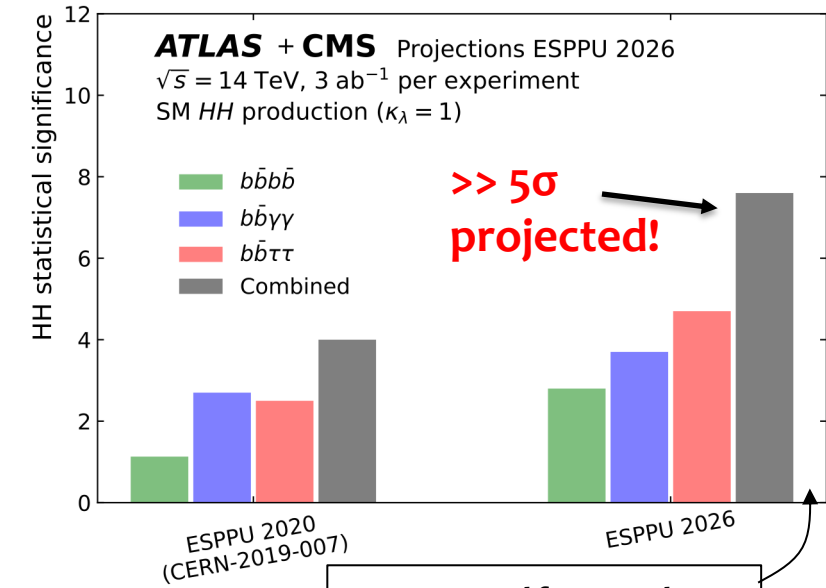
Precision masses



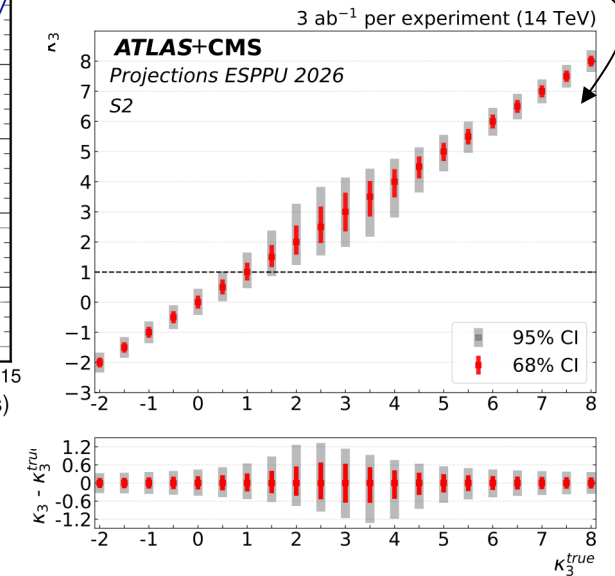
Heavy scalar searches



Higgs CP



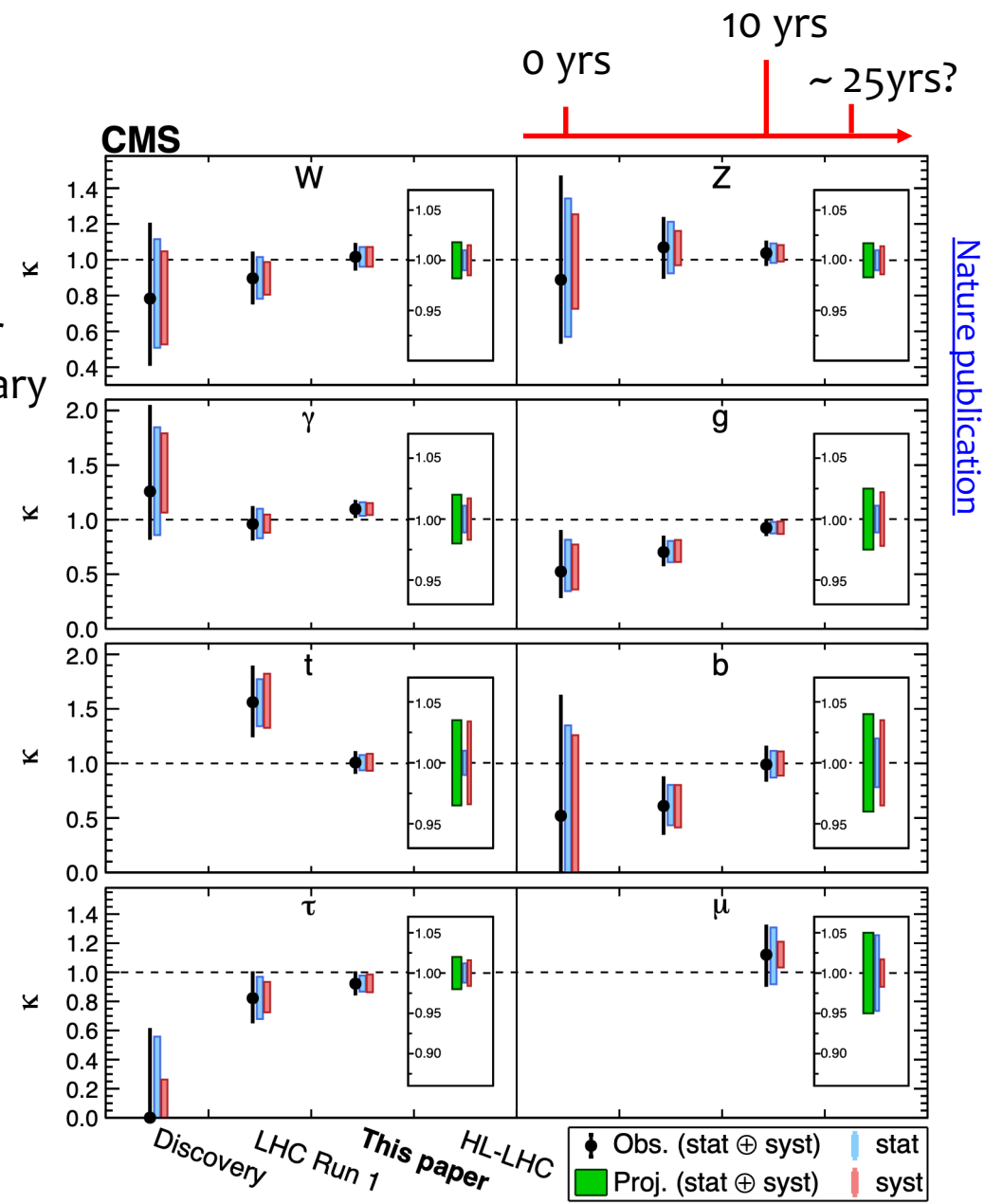
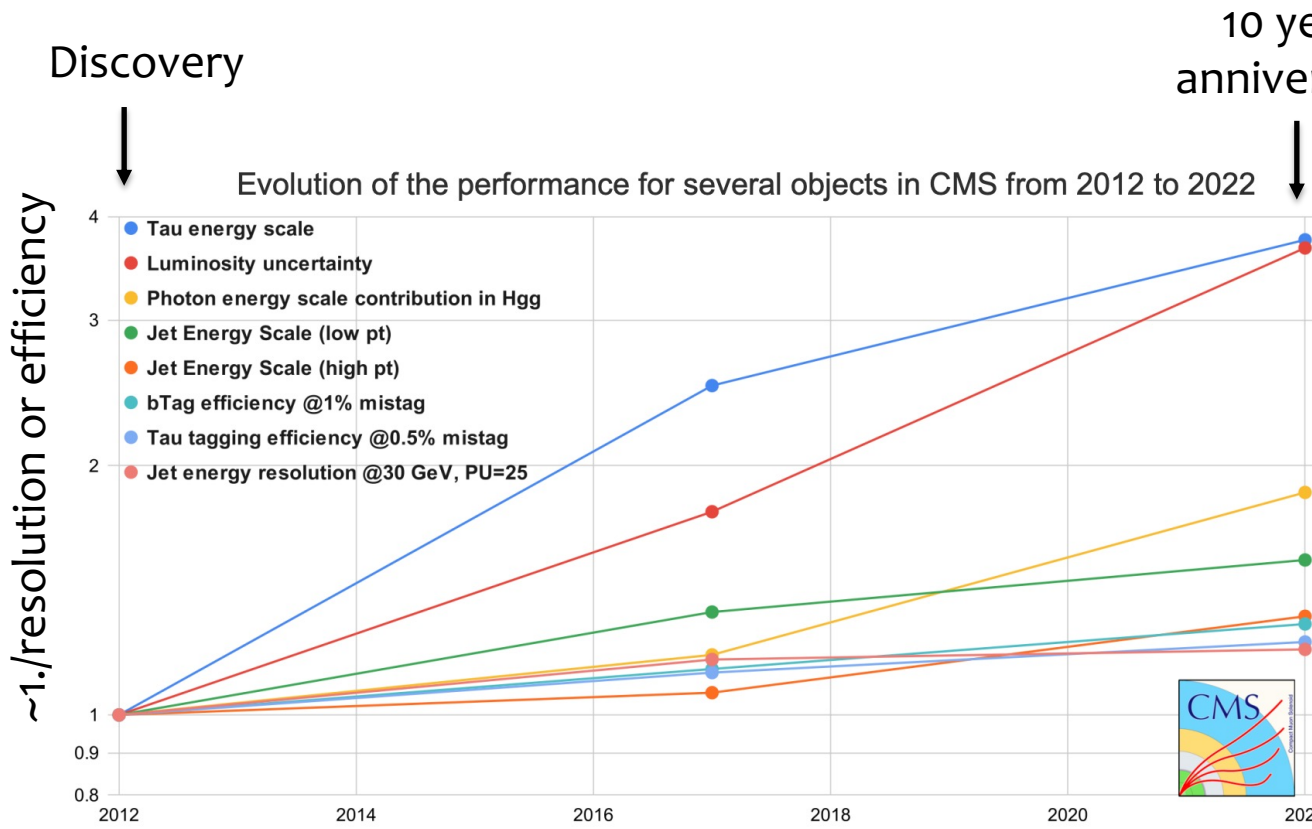
Higgs self-coupling



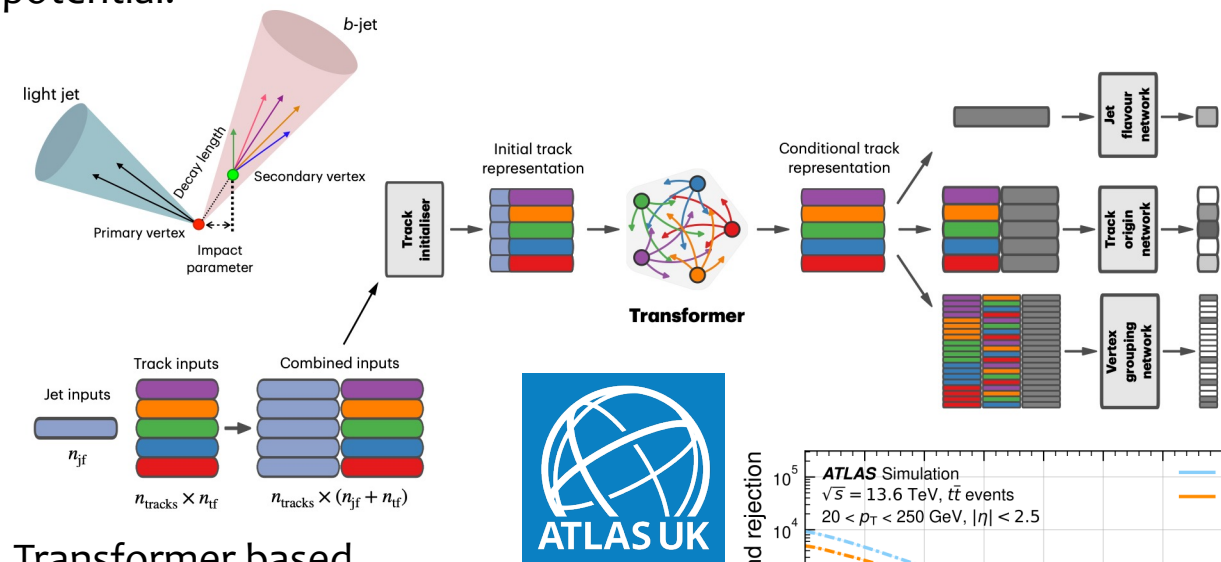
After upgrades complete, people for operations & analysis will be vital to make this happen
→ CG effort has dropped dramatically since LHC startup → will need increased CG support

No Free Lunch

Improvements in measurements & searches require more than just more data → Improvements in reconstruction techniques & calibrations will be needed for few % precision couplings @HL-LHC

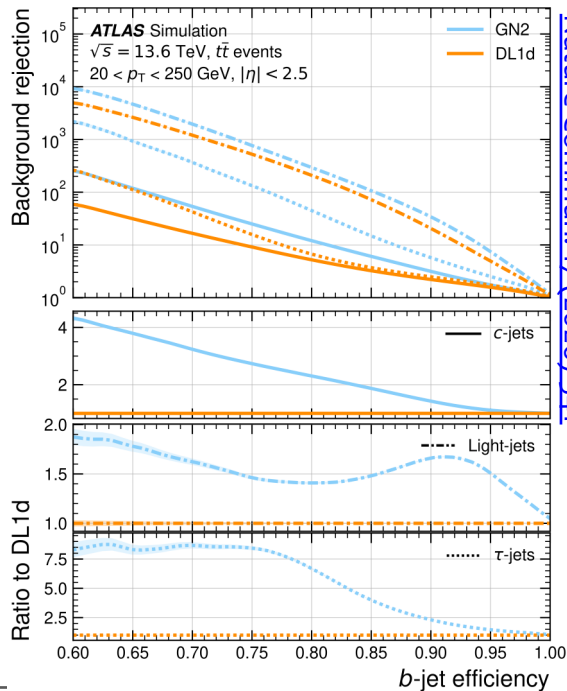
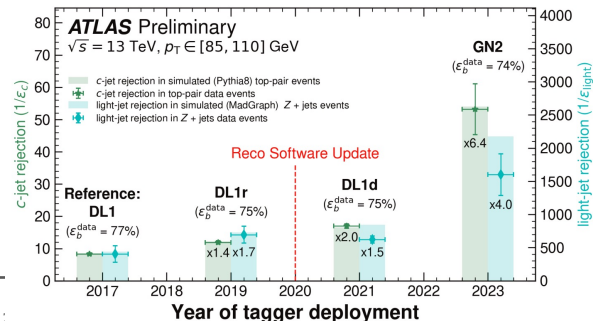


Experience from the LHC Run-3 has brought **innovative ideas** to **improve the performance** and exploit the data to its maximum potential!



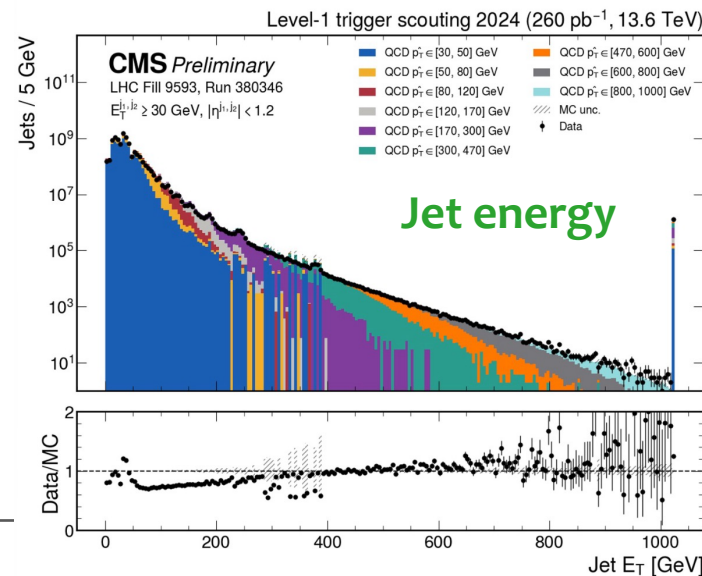
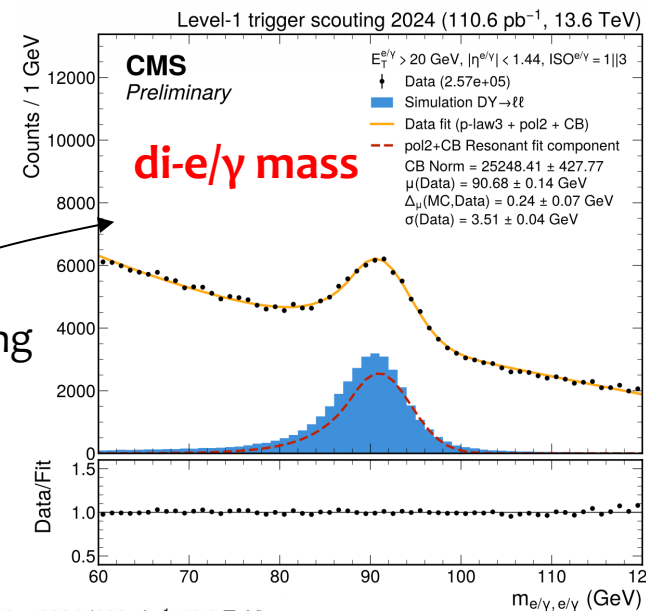
Transformer based flavour-tagging algorithm (GN2)

- Improved c-jet/light-jet rejection by 3.5/1.8 @ 70% b-tagging → vital for $HH \rightarrow 4b, bb\tau\tau$
- Improved c-tagging for H-charm



Innovative Ideas to get us there

More results expected using **e/γ** and **jets** @ Level-1



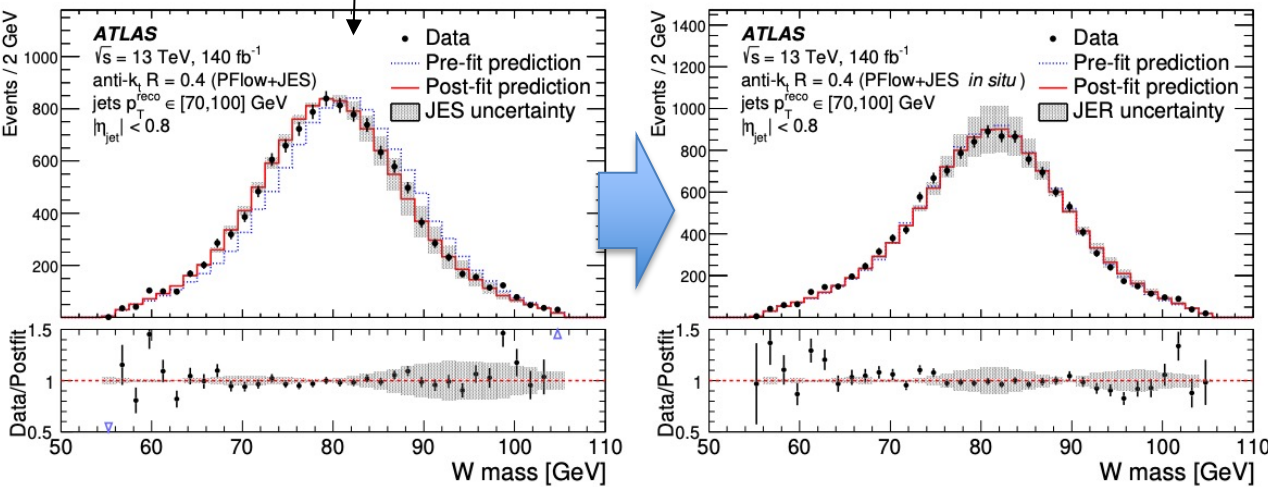
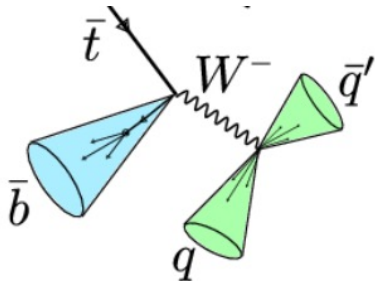
CMS-DP-2024-056

Innovative Ideas to get us there

Enhancing traditional calibration methods with novel approaches!

Choose jets for fitting

$$\chi^2 = \frac{(m_t^{\text{reco}} - m_t^{\text{gen}})^2}{\Sigma_t^2} + \frac{(m_W^{\text{reco}} - m_W^{\text{gen}})^2}{\Sigma_W^2}.$$



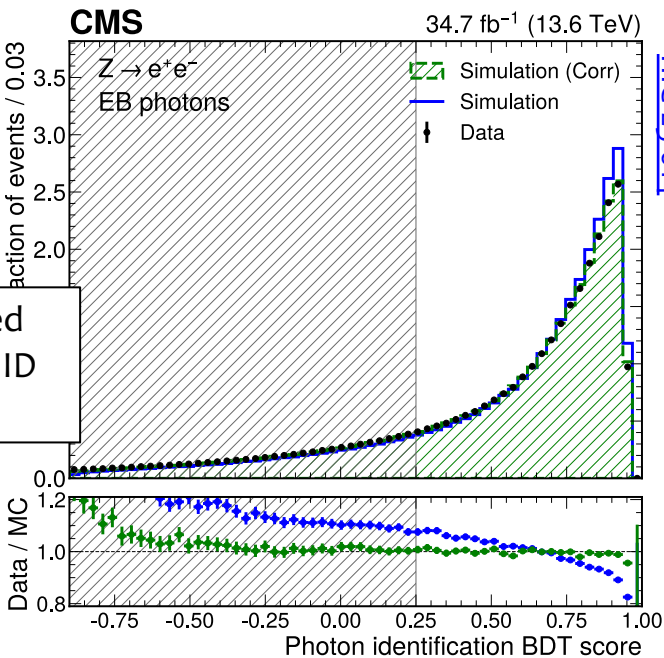
In-situ Jet-calibration using hadronic top decays



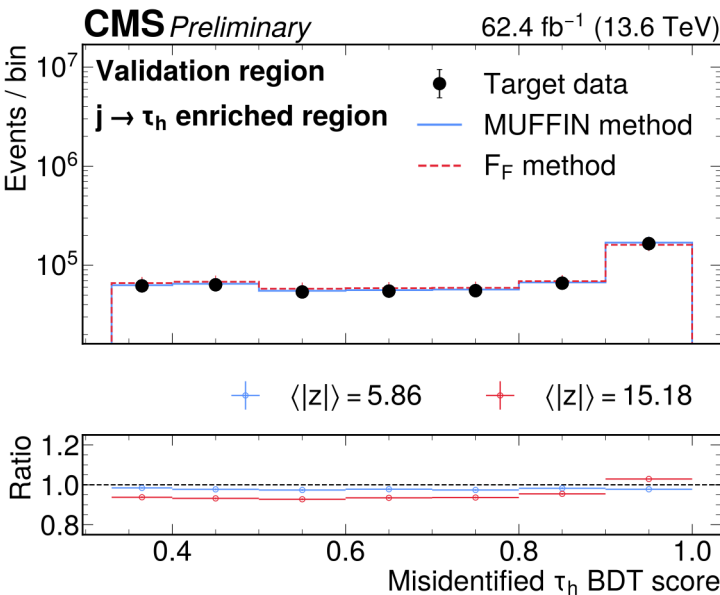
[CERN-EP-2025-262 \(Sub to EPJC\)](#)

Parametric ML-based calibration for e/γ showers and j→τ fake estimation

Observe dramatically improved data/MC agreement in photon ID after using corrected inputs



[HIG-23-014](#)



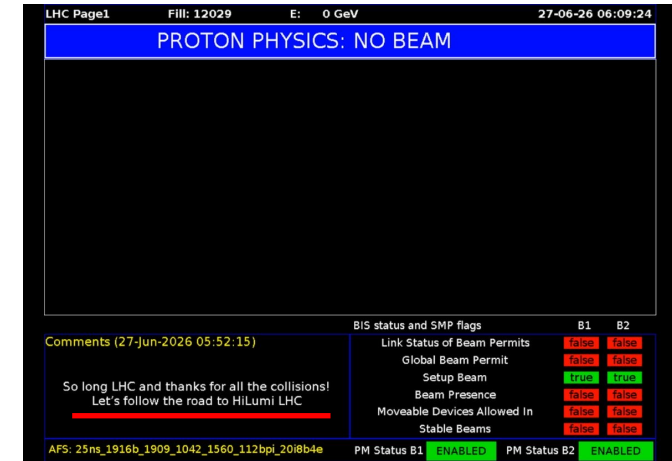
Greatly improved estimation of τ→j fakes in H→ττ analyses using multivariate distributions

[TAU-25-001](#)

Summary

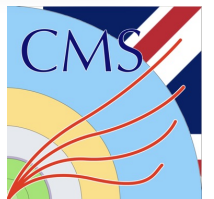
LHC run has finished with ATLAS and CMS recording over 500 fb^{-1} each!

- ATLAS and CMS are physics generating facilities → new ideas are constantly explored that are dynamic and innovative
- **Many UK-lead contributions not mentioned here:** B-physics, forward physics, Heavy-ion, entanglement (tt, Higgs)!



The HL-LHC upgrade of both experiments is well advanced but still plenty to do!

- **Challenges are also opportunities**, understanding the complexity of new detectors and technologies is key for future facilities and can become a joined effort!
- Different focus in **technologies/projects** for ATLAS & CMS is strength of UK GPD community
- Physics prospects for HL-LHC offer incredible opportunities:
 - Higgs-self couplings, New physics models, precision measurements
 - Probably conservative, given constant improvements but will need more innovation to make the most of the HL-LHC
 - ATLAS and CMS UK will contribute to overall goals in complementary ways
 - Funding is a serious issue to meet commitments and exploit physics potential
- **None of the above will happen without people to do it!**



UK collaborations remain excited for preparations for & data-taking in Run-4!

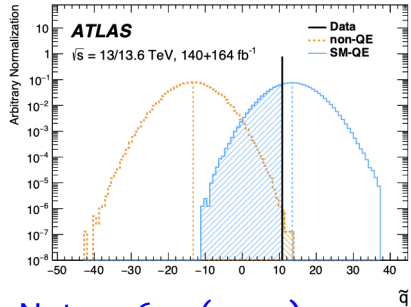


Thanks!

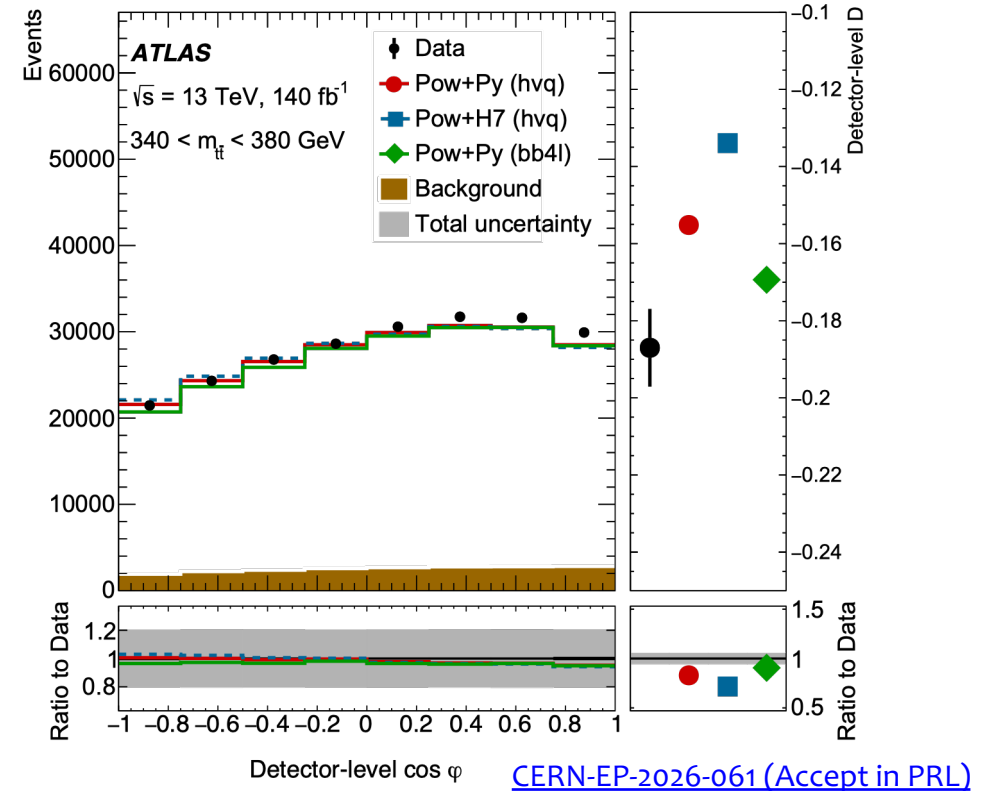
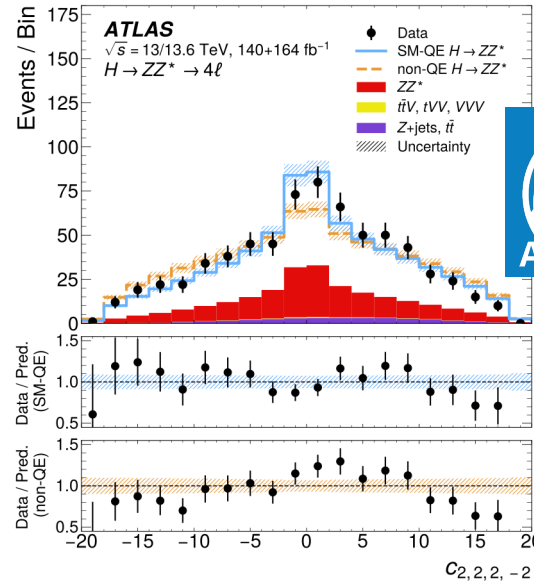
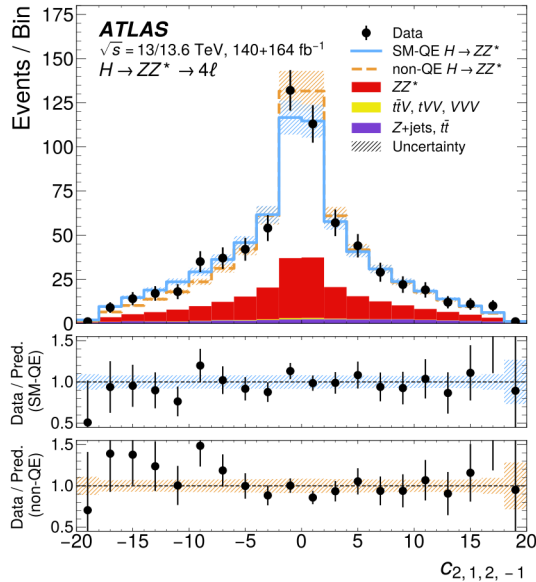
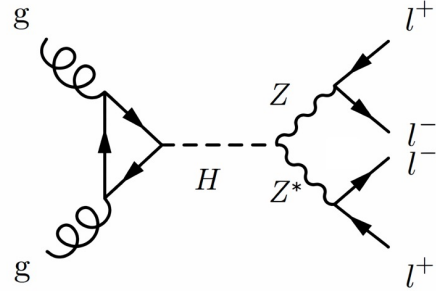
Backup Slides

Entanglement studies

Studies of fundamental Quantum Physics property (entanglement) in $H \rightarrow ZZ$ and tt final states by ATLAS



[Nature 633 \(2024\) 542](#)



$D = -0.537 \pm 0.002 \text{ (stat.)} \pm 0.019 \text{ (syst.)}$ for
 $340 < m_{t\bar{t}} < 380 \text{ GeV}$

No-entanglement excluded $> 5\sigma$

Data disfavour separate state hypothesis at a significance of 4.7σ

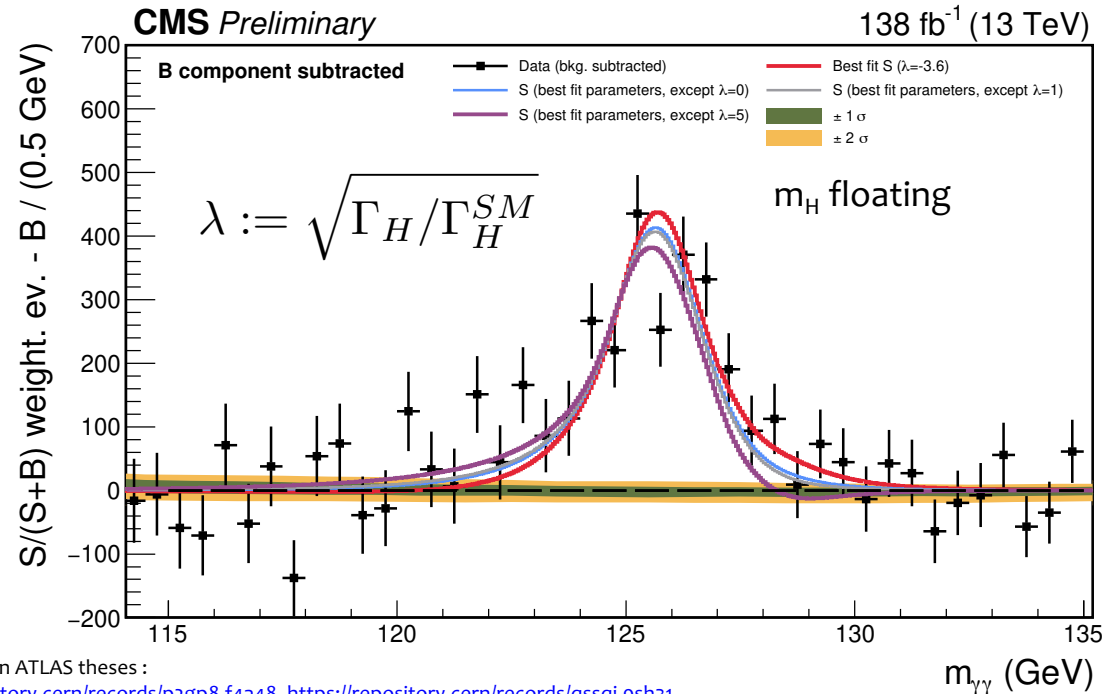
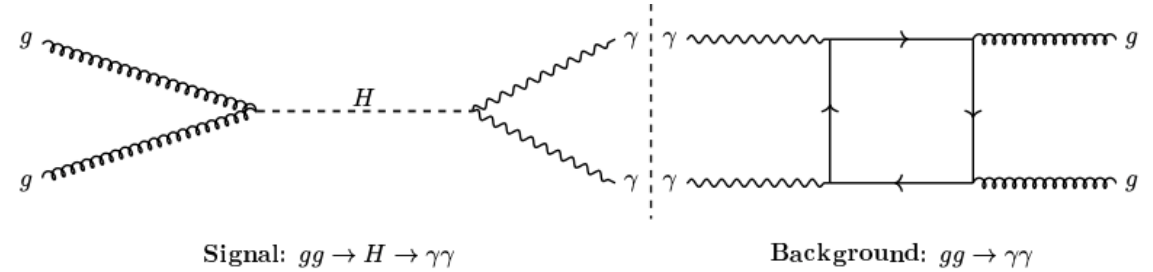
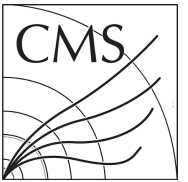
Measuring the Higgs width Γ_H

Sensitivity to Higgs boson width through interference effects in $H \rightarrow \gamma\gamma$ analysis

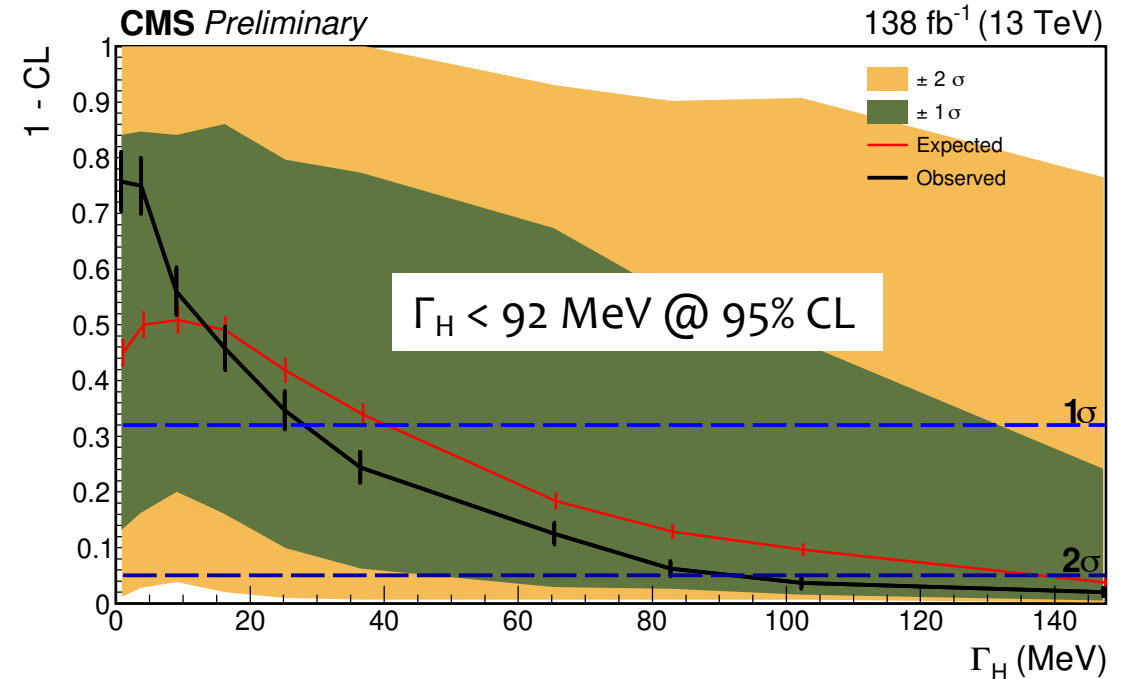
- Differential cross-section of signal (+interference)

proportional to $c_g c_\gamma = \sqrt{\mu_F \Gamma_H / \Gamma_H^{SM}}$

- Interference causes deviation in Higgs line shape that can be measured in the data!



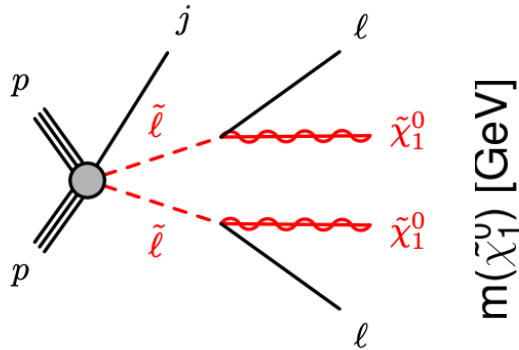
HIG-25-004



Also studied in ATLAS theses:
<https://repository.cern/records/p2gp8-f4a48>, <https://repository.cern/records/qssqj-gsh31>

Slepton production in the compressed range

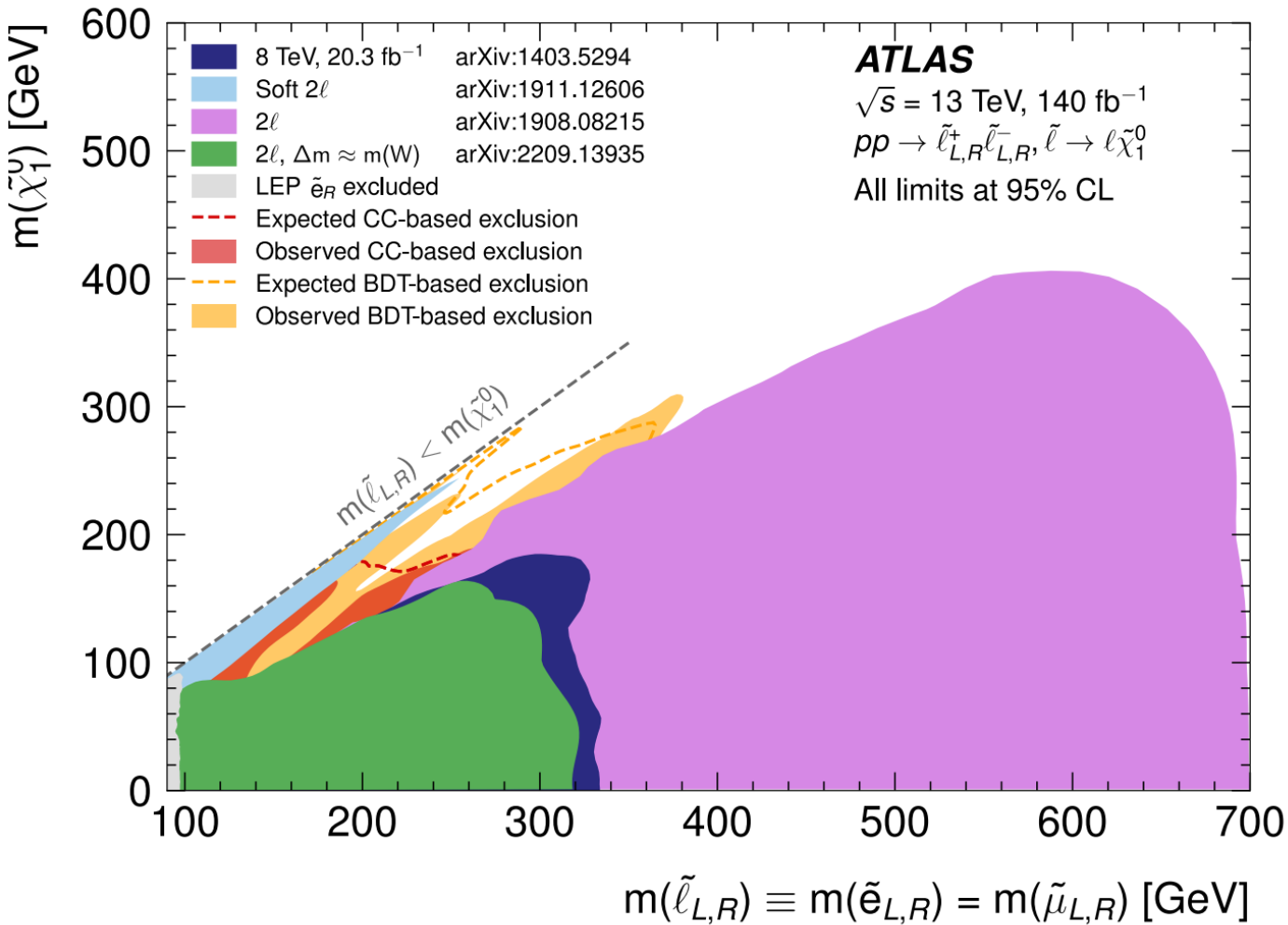
JHEP 08 (2025) 053



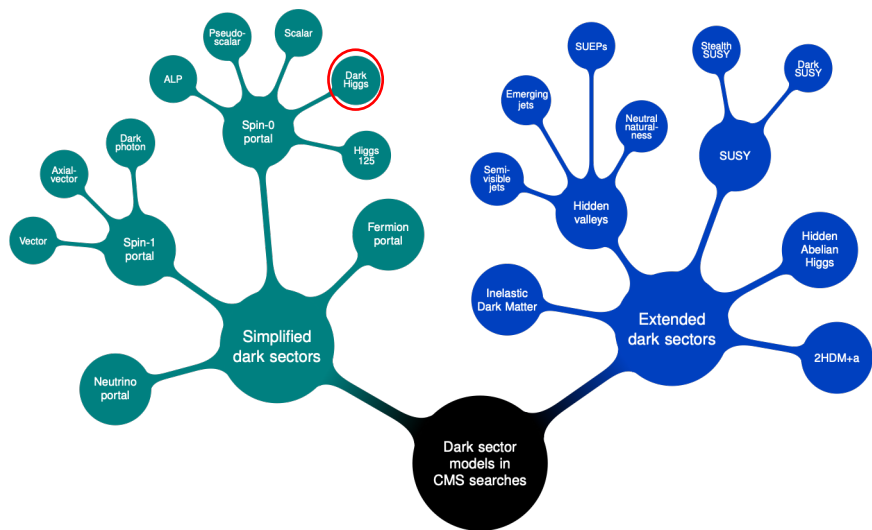
Challenging "corridor" region, where the mass difference, Δm , between the slepton ($\tilde{e}$ or $\tilde{\mu}$) and the lightest neutralino ($\tilde{\chi}_1^0$) is less or similar to the mass of the W boson

Significantly strengthens the constraints on benchmark models compared to previous searches + largely addresses a long-standing sensitivity gap in the mass plane

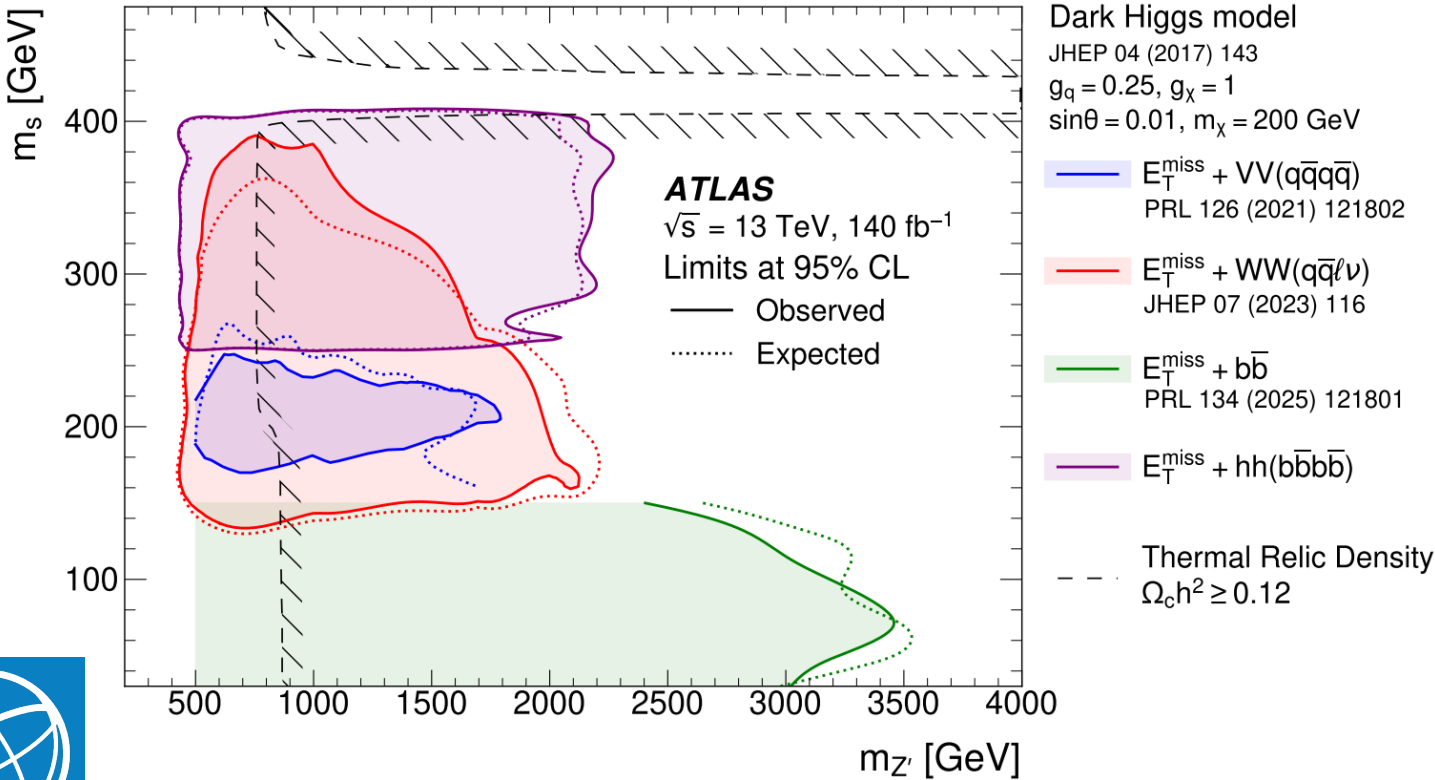
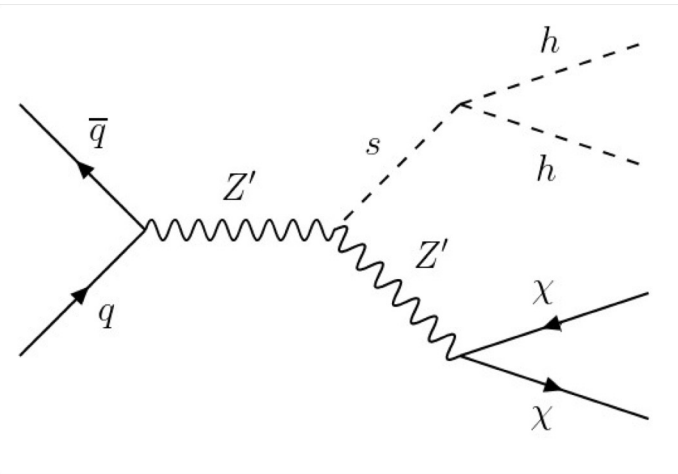
Limits also provided relaxing mass constraints among slepton flavours



Dark Higgs Searches

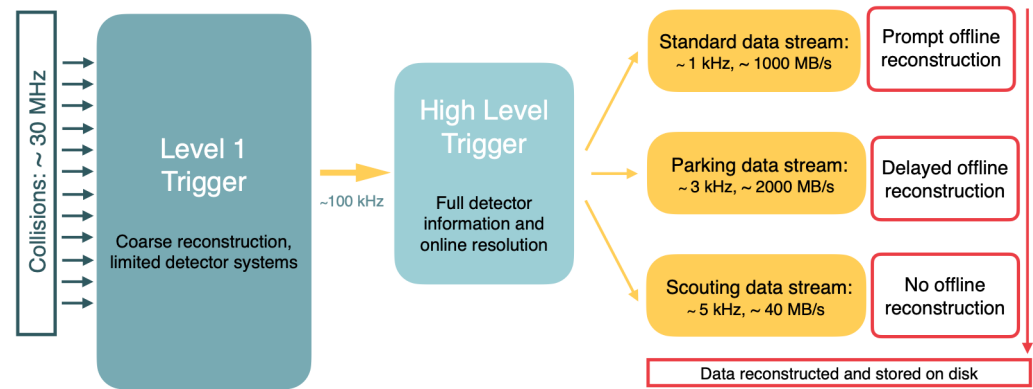


Target final states with at least three b -tagged jets, produced by the pair of Higgs boson decays, in events with significant p_T^{miss}



Scouting & data parking

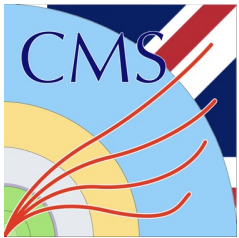
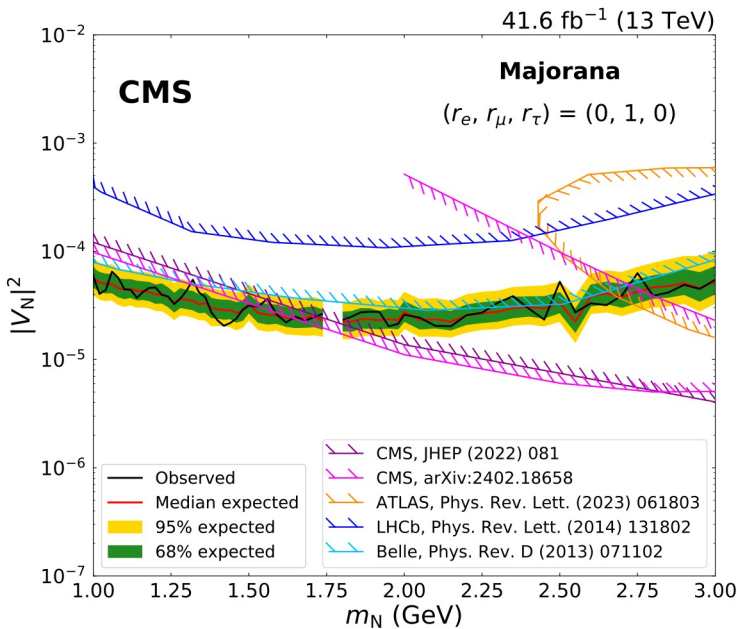
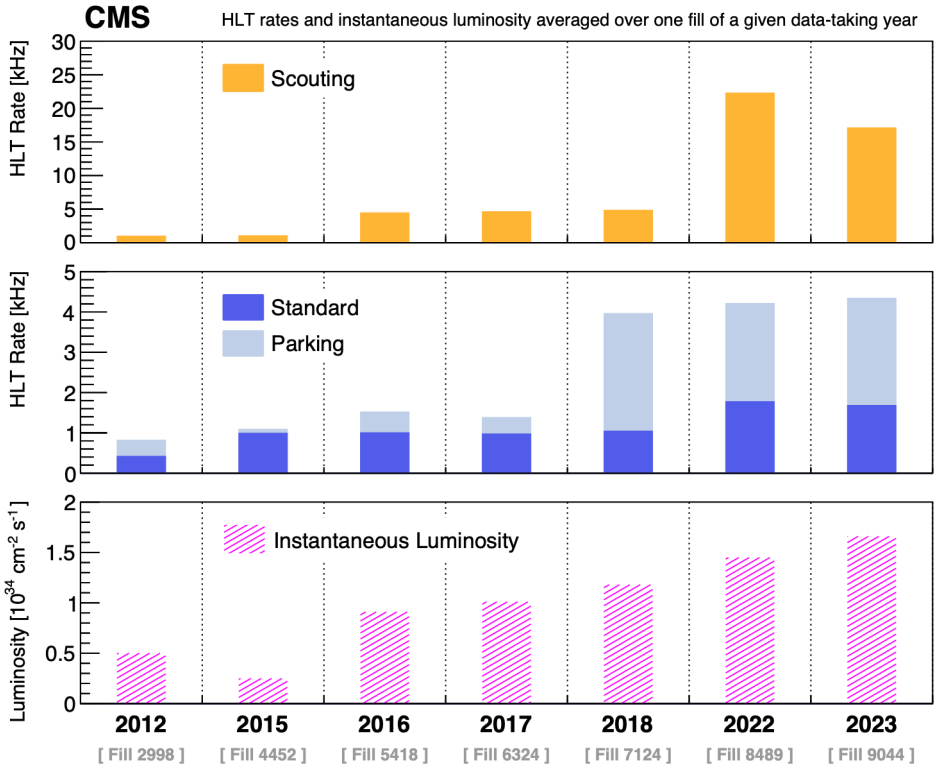
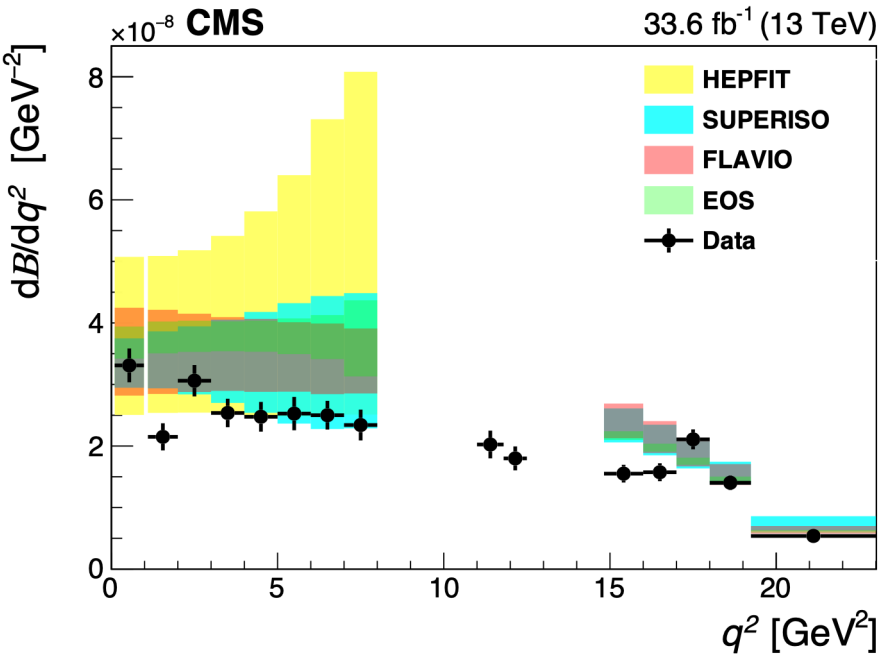
Data flow for a typical 2018 data-taking scenario



Scouting & parking
review paper : **Phys. Rept. 1115 (2025) 678**

Physics cases include

- $B^+ \rightarrow K^+ \mu^+ \mu^-$
- Heavy Neutrino searches



More use of scouting going forward

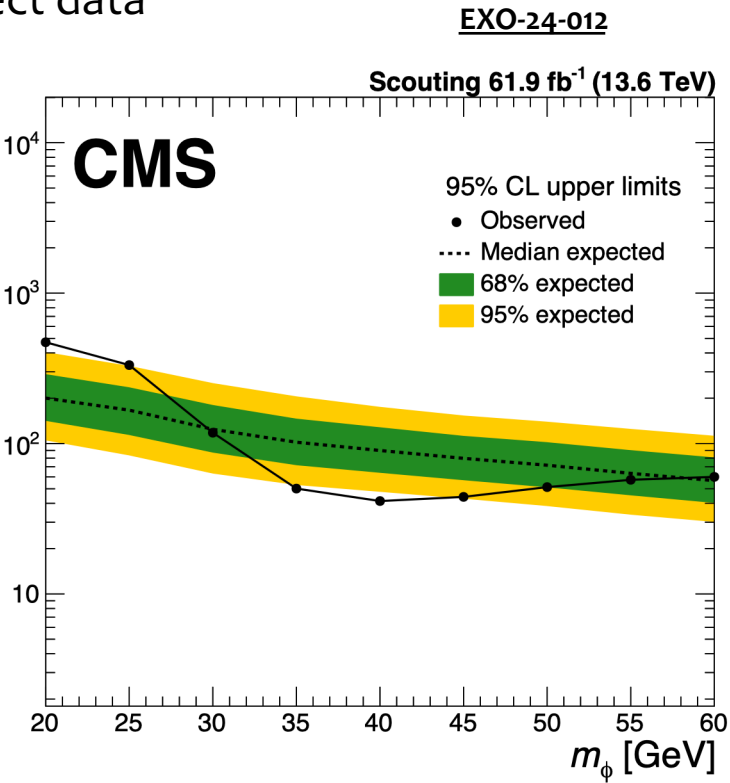
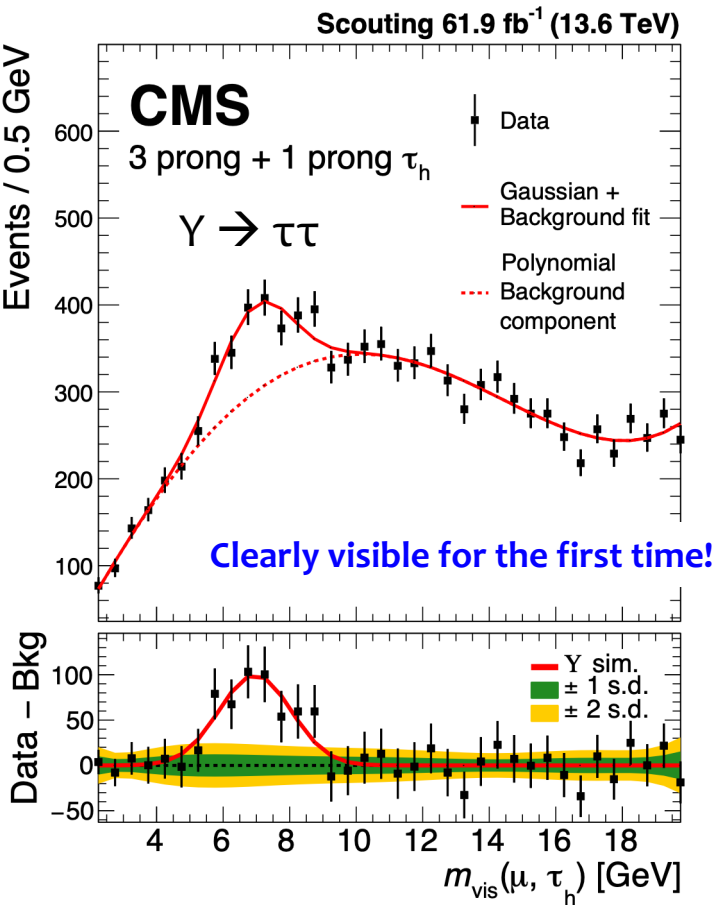
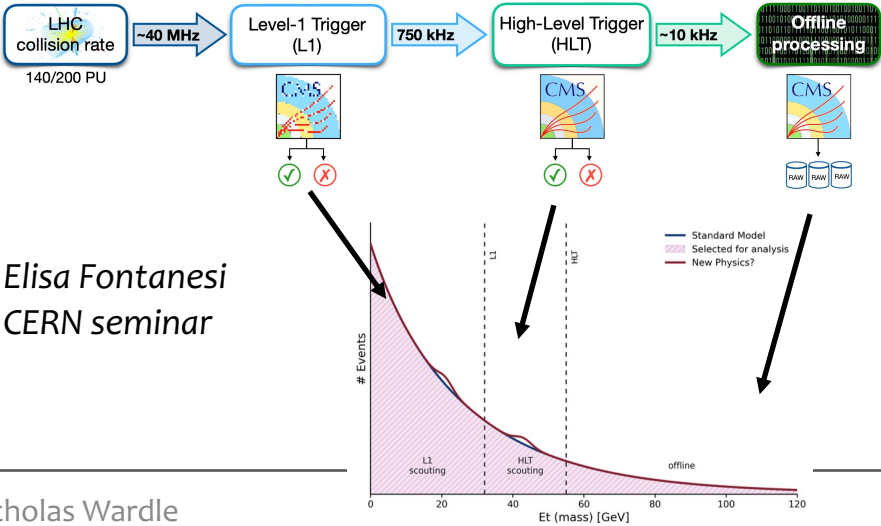
Smaller coupling and lighter mass scales → need **different trigger strategies** to collect data

Search for low mass resonances decaying to $\tau\mu\tau_h$ in scouting stream

- TauNet for low- $p_T \tau_h$
- **First ever inclusive limit in the final state below 60 GeV**

Standard Candles $Z/\gamma \rightarrow \tau\tau$ in scouting data!

Expansion of scouting @ HL-LHC a natural route for exploratory searches!



Higgs timeline

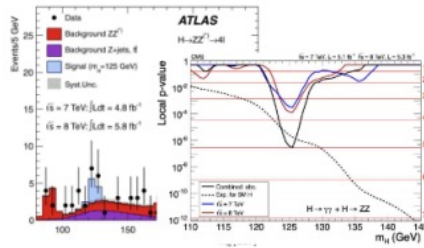
Marina Kolosova (LHCP 2026)

2010



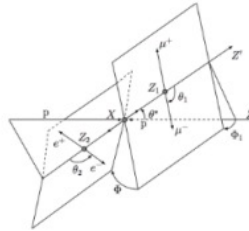
First Higgs boson searches begin

2012



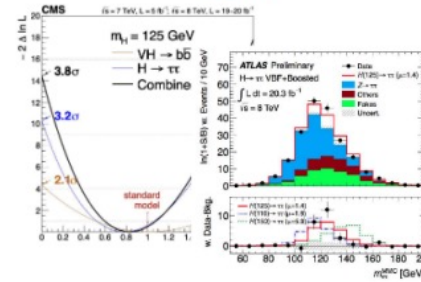
Discovery of the Higgs boson

2013



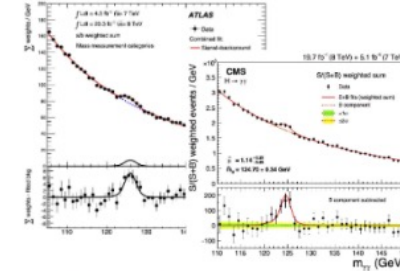
$J^P = 0^+$

2014



Evidence of Higgs boson decay to fermions

2014



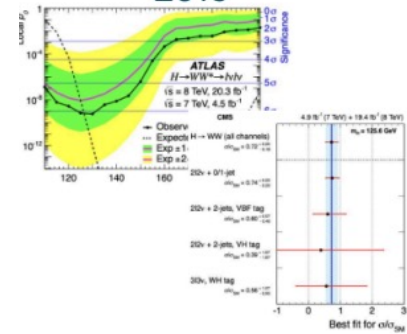
Higgs boson mass measurement

2015



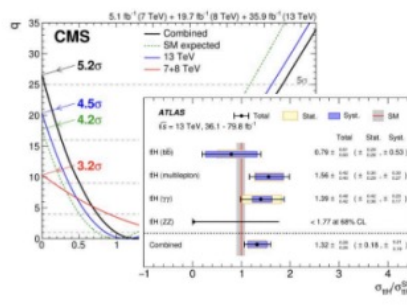
LHC @ 13 TeV, H production rates increase, start of precision measurements era

2015



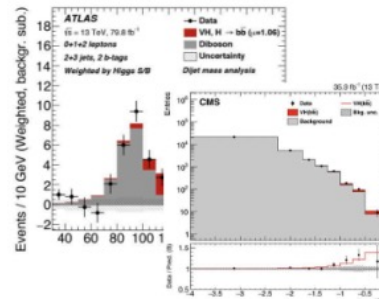
Evidence of $H \rightarrow WW^*$

2018



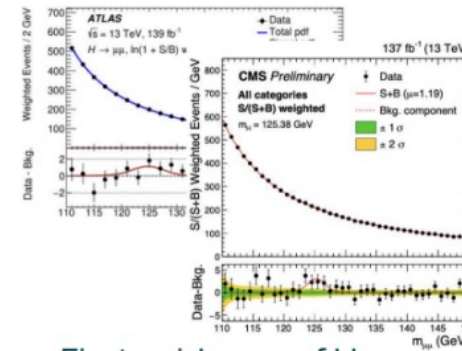
Observation of ttH

2018



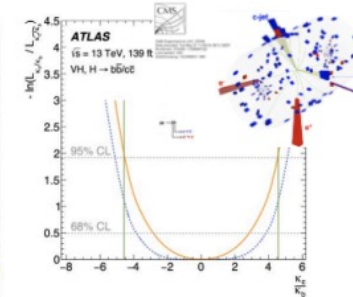
Observation of $H \rightarrow bb$

2020



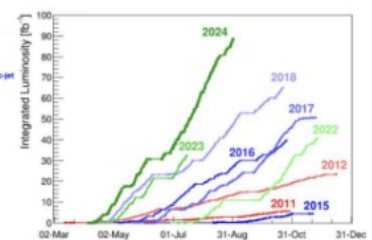
First evidence of $H \rightarrow \mu\mu$

2022



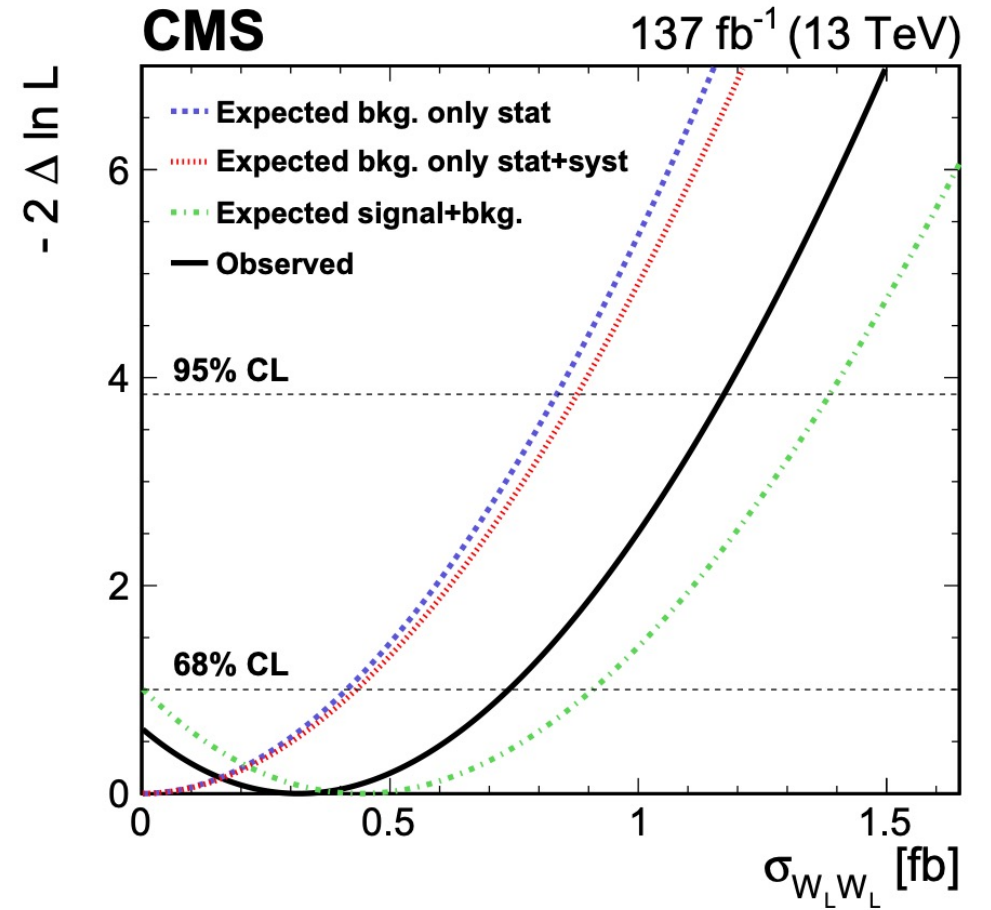
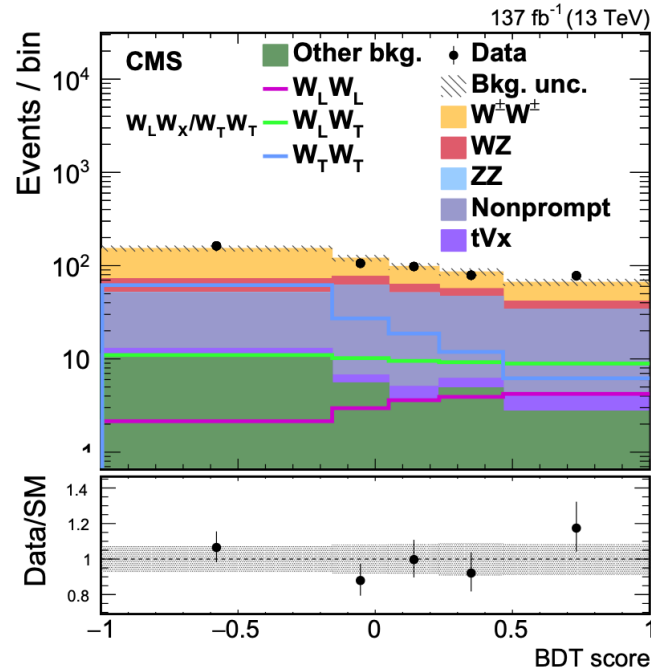
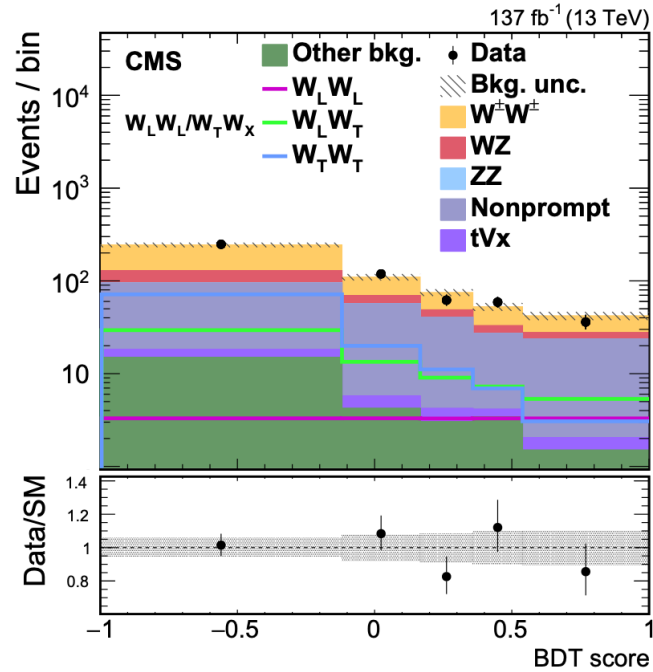
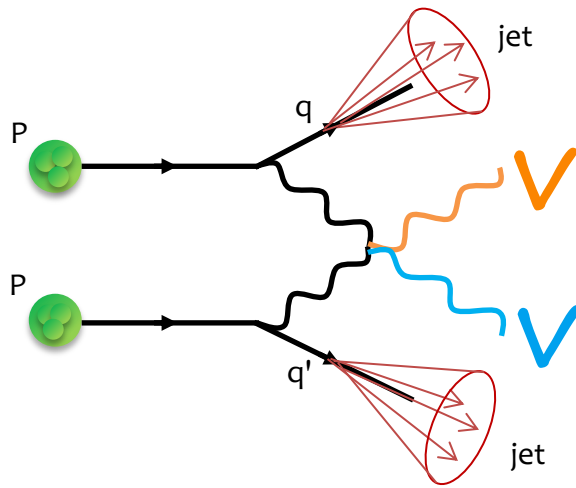
First search for $H \rightarrow cc$

2022-2026



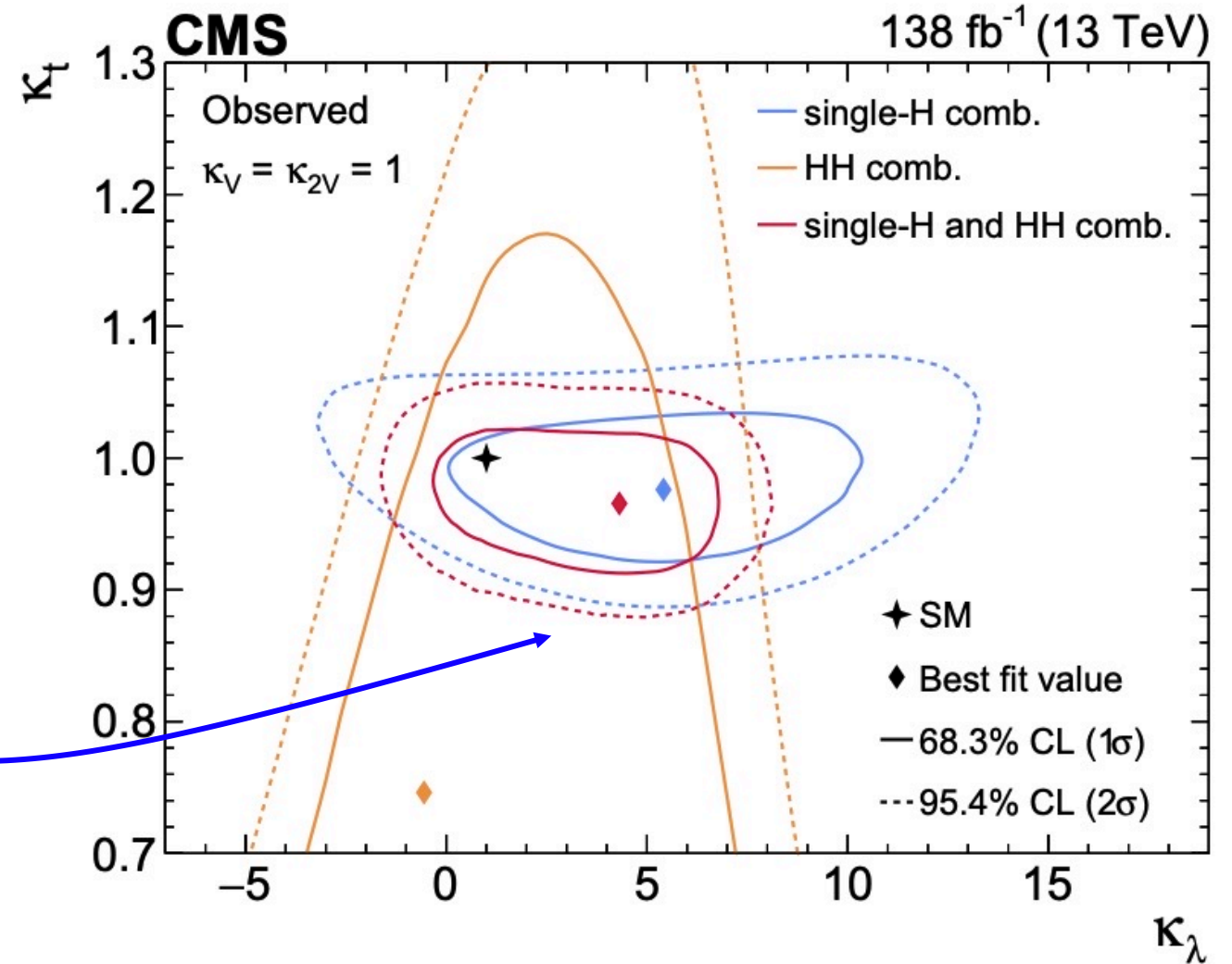
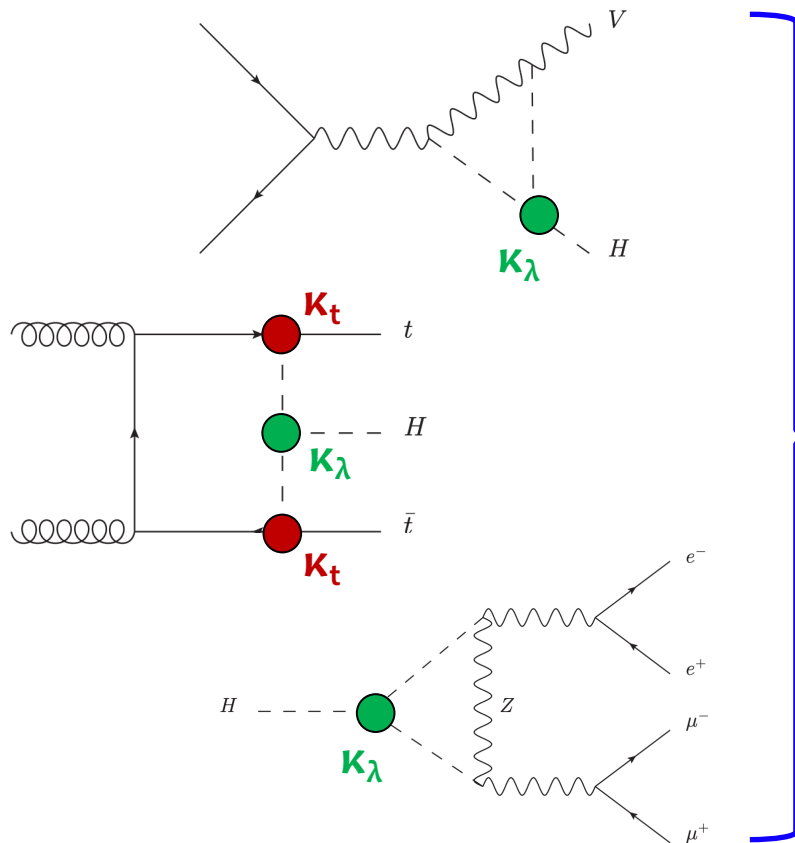
LHC @ 13.6 TeV

CMS W_L



Higgs boson self-coupling

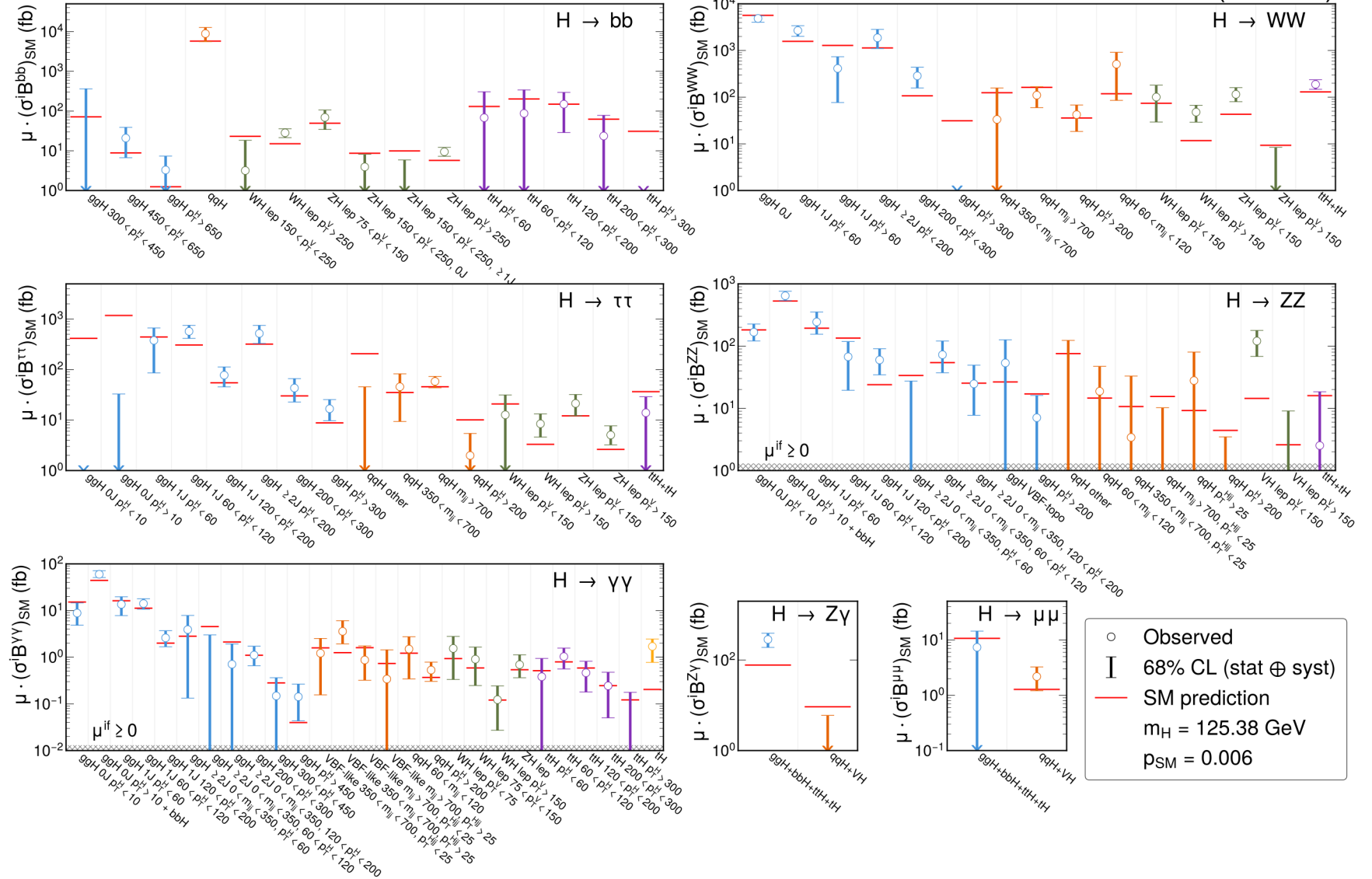
Constraining the Higgs boson self-coupling requires **more than just di-Higgs searches**



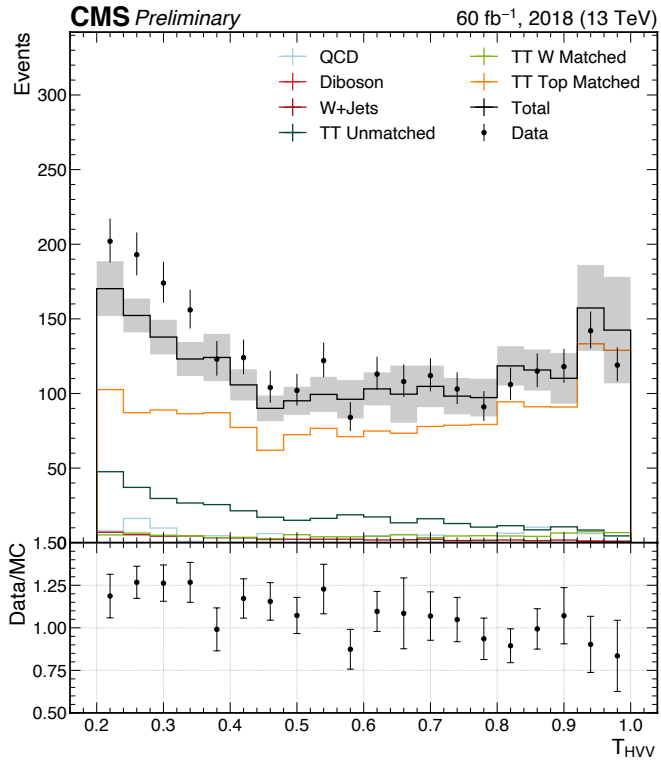
Precision (single) Higgs boson measurements also sensitive to Higgs self-coupling! Lift degeneracies with other Higgs couplings

STXS Higgs cross-sections

CMS



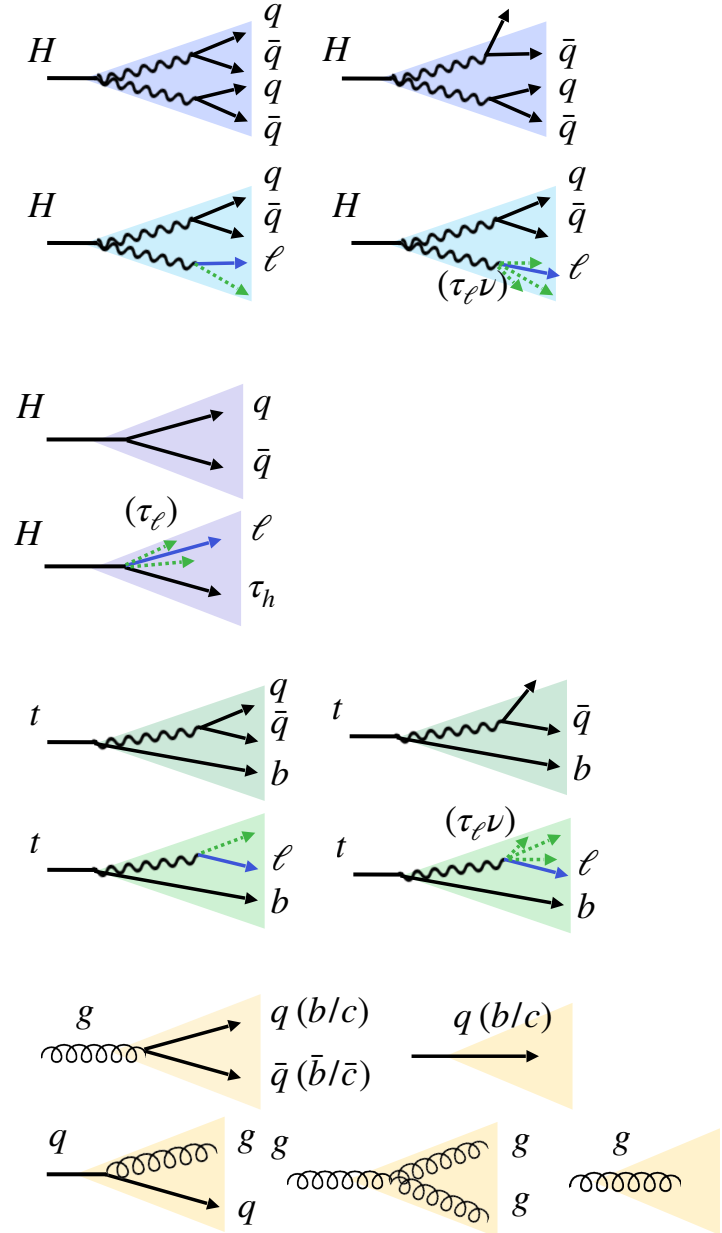
CMS Taggers (Global ParT)



$$T_{\text{HVV}} = \frac{P_{\text{HVV}4q} + P_{\text{HVV}3q}}{P_{\text{QCD}} + P_{\text{Top}} + P_{\text{HVV}4q} + P_{\text{HVV}3q}}$$

Lund-plane reweighting for T_{HVV} output to calibrate efficiencies in $\text{HH}(\text{bbVV})$

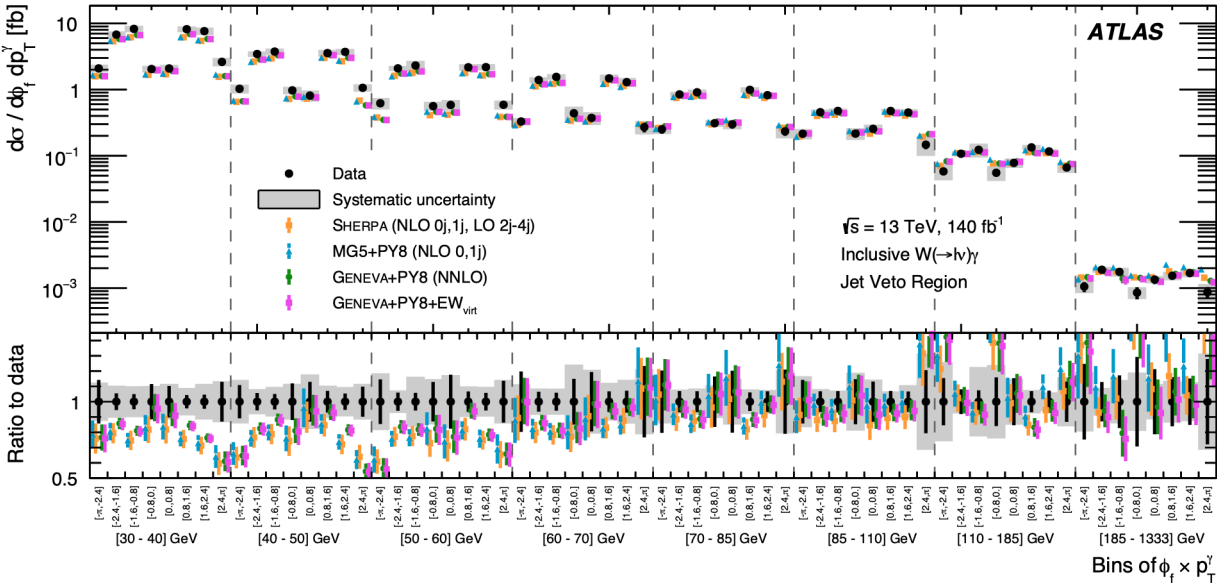
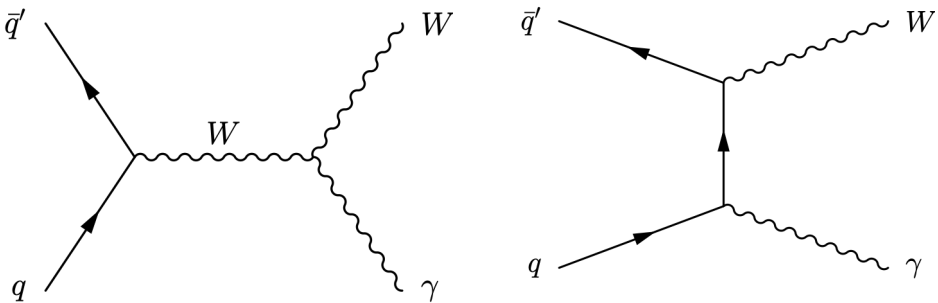
Process	Final state, prongness	heavy flavour	# of classes
$H \rightarrow VV$ (full-hadronic)	qqqq	0c/1c/2c	3
	qqq		3
$H \rightarrow WW$ (semi-leptonic)	$e\nu qq$	0c/1c	2
	$\mu\nu qq$		2
	$\tau_e\nu qq$		2
	$\tau_\mu\nu qq$		2
	$\tau_h\nu qq$		2
$H \rightarrow qq$		bb	1
		cc	1
		ss	1
		qq (q=u/d)	1
$H \rightarrow \tau\tau$	$\tau_e\tau_h$		1
	$\tau_\mu\tau_h$		1
	$\tau_h\tau_h$		1
$t \rightarrow bW$ (hadronic)	bqq	1b + 0c/1c	2
	bq		2
$t \rightarrow bW$ (leptonic)	$b e \nu$	1b	1
	$b \mu \nu$		1
	$b \tau_e \nu$		1
	$b \tau_\mu \nu$		1
	$b \tau_h \nu$		1
QCD		b	1
		bb	1
		c	1
		cc	1
		others (light)	1

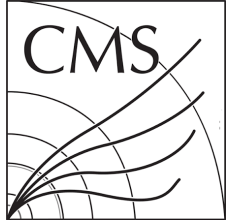


New constraints on CPV in multiboson

Differential cross-section measurements of $pp \rightarrow W\gamma$

Wilson coefficient	Observable	Includes $ M_{d6} ^2$	k -factor	95% CL [TeV^{-2}]	
				Expected	Observed
c_W/Λ^2	$\phi_f \times p_T^\gamma$	no	no	$[-0.37, 0.38]$	$[-0.42, 0.36]$
		yes	no	$[-0.12, 0.11]$	$[-0.06, 0.06]$
		no	yes	$[-0.23, 0.25]$	$[-0.28, 0.21]$
		yes	yes	$[-0.09, 0.09]$	$[-0.05, 0.05]$
$c_{\bar{W}}/\Lambda^2$	$O_{NN}^{\bar{W}}$	no	no	$[-0.53, 0.54]$	$[-0.74, 0.23]$
		yes	no	$[-0.61, 0.36]$	$[-0.67, 0.19]$
		no	yes	$[-0.32, 0.32]$	$[-0.45, 0.14]$
		yes	yes	$[-0.43, 0.25]$	$[-0.54, 0.11]$
c_{HWB}/Λ^2	$\phi_f \times p_T^\gamma$	no	no	$[-1.21, 0.90]$	$[-0.67, 1.21]$
		yes	no	$[-0.97, 0.82]$	$[-0.47, 0.67]$
		no	yes	$[-0.84, 0.62]$	$[-1.09, 0.50]$
		yes	yes	$[-0.76, 0.60]$	$[-0.58, 0.38]$
$c_{H\bar{W}B}/\Lambda^2$	$O_{NN}^{H\bar{W}B}$	no	no	$[-0.39, 0.39]$	$[-0.59, 0.13]$
		yes	no	$[-0.39, 0.39]$	$[-0.60, 0.13]$
		no	yes	$[-0.20, 0.21]$	$[-0.31, 0.07]$
		yes	yes	$[-0.20, 0.21]$	$[-0.31, 0.07]$



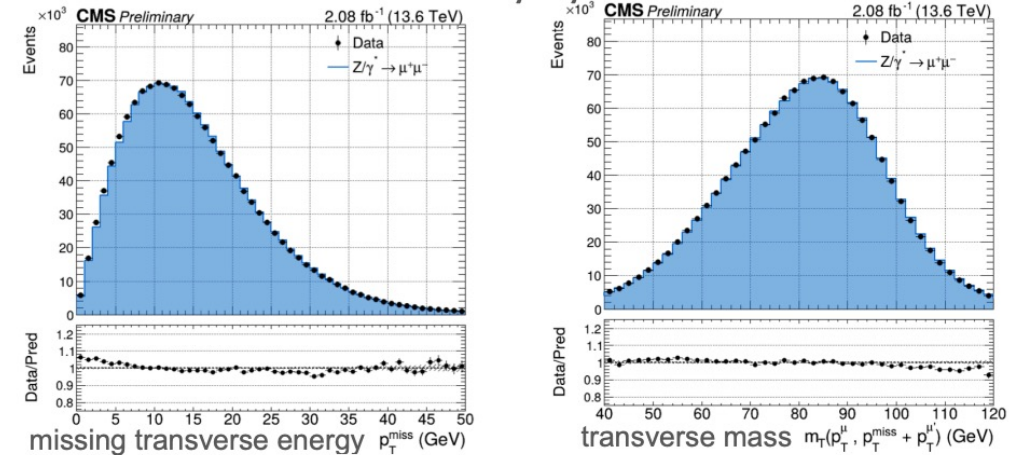


2026 low pileup pp runs

- Special run(s): low pileup 13.6 TeV, collected 2.24 fb^{-1} (95% eff.), and for 2.4 TeV collected 3.3 pb^{-1} (94% eff.)
- Physics motivation:
 - W mass using transverse mass (m_T)
 - B physics with low- p_T muon triggers, low combinatorics
 - Diffractive & small- x physics program

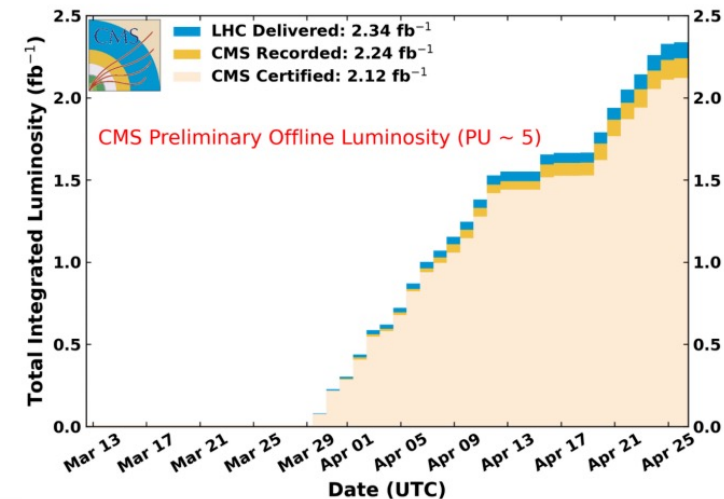
Out-of-the-box understanding in low PU mode

$$Z \rightarrow \mu^+ \mu^-$$



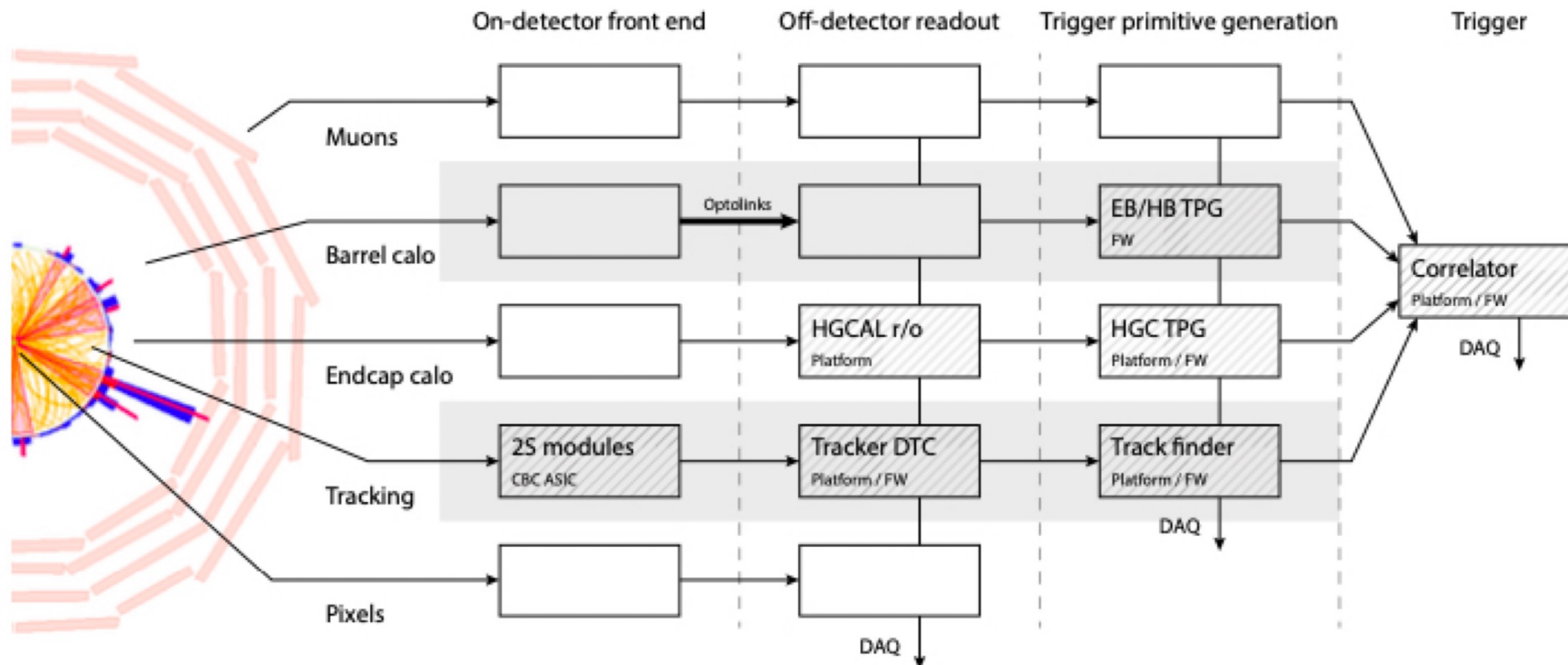
CMS Integrated Luminosity, pp, 2026, $\sqrt{s} = 13.6 \text{ TeV}$

Date included from 2026-03-13 17:08:30 to 2026-04-26 01:39:53 UTC



UK CMS upgrade contributions

Based (largely) on common electronics platform (Serenity) contribute to tracker, calorimetry and trigger



○Common platform

○Tracker

○ECAL barrel

○HGCAL

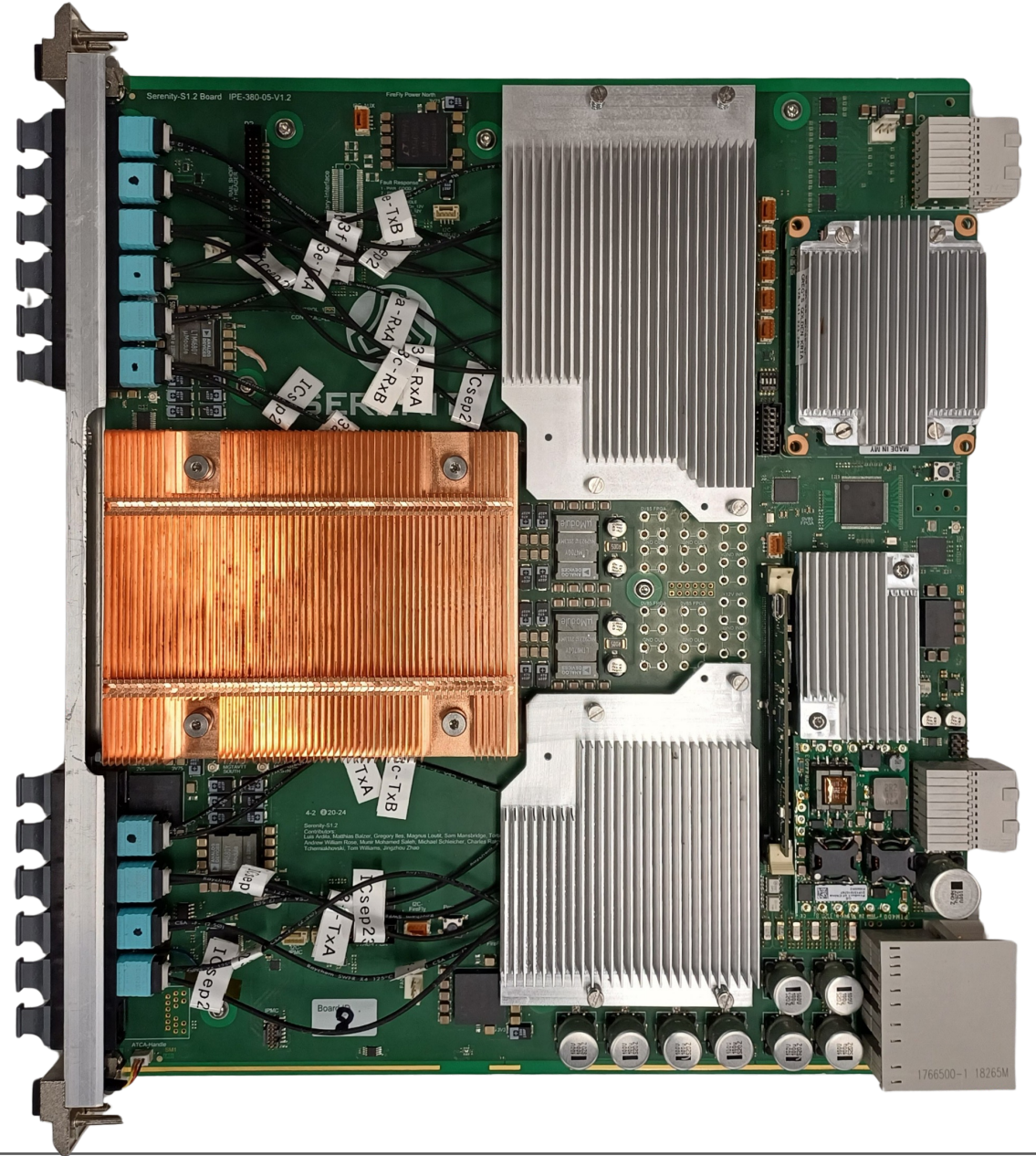
○Level-1 Trigger



Serenity



- Scope
 - Providing a back-end processing card to multiple sub-detectors
 - TK, MTD, HGC, L1T, RPC, DT & PPS
 - Almost 800 cards
 - AMD VU13P with 124 optical links at up to 25Gb/s each.
 - Much more complex than previous cards due to size, on board CPU and mechanical aspects.
 - Not just the hardware but the full firmware & software stack.
- UK involvement
 - Involved in all aspects of the card from design, firmware, software, test & procurement
 - **Single Technical dev** with input from whole of CMS UK



CMS Phase-II tracker

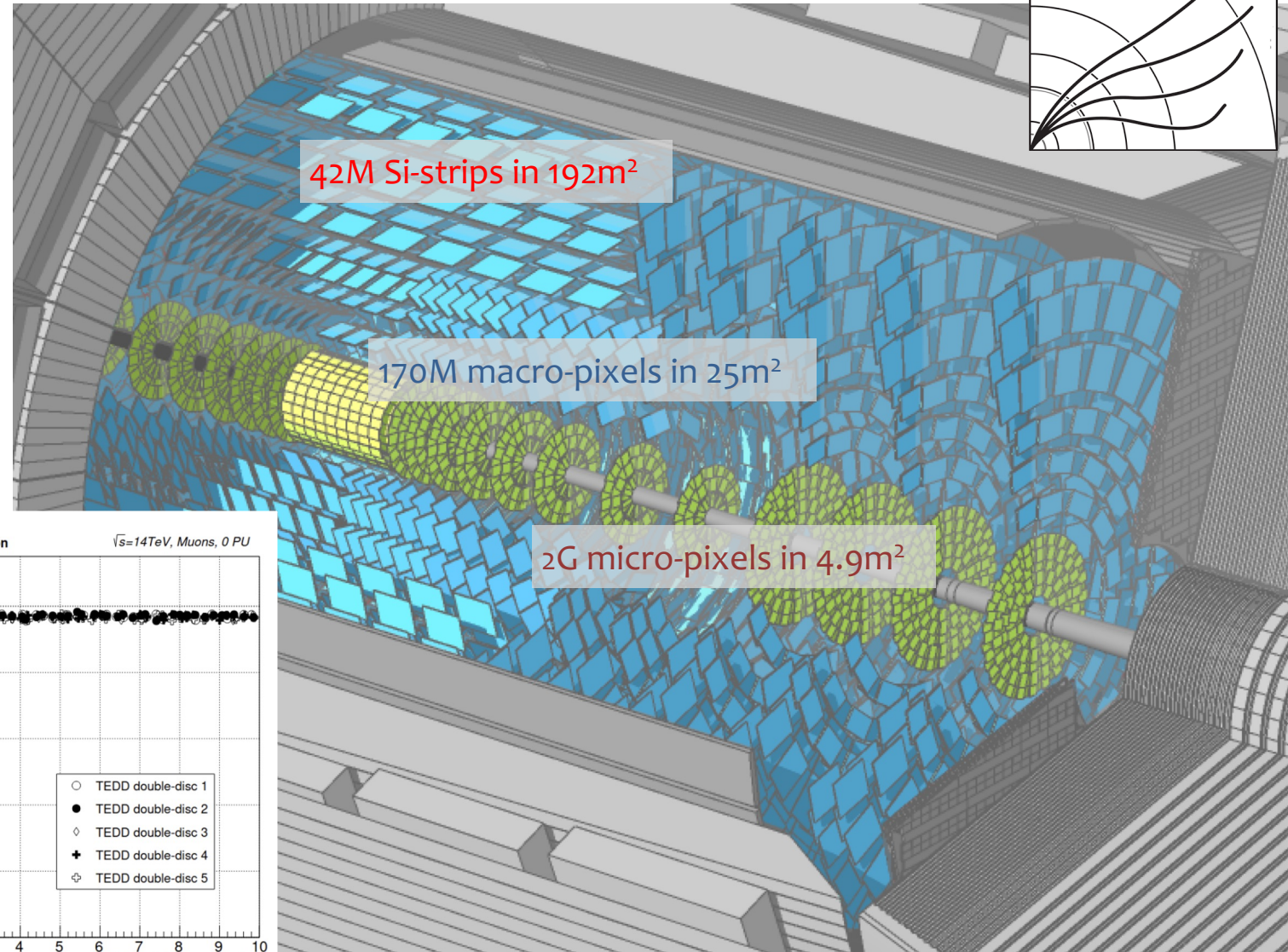
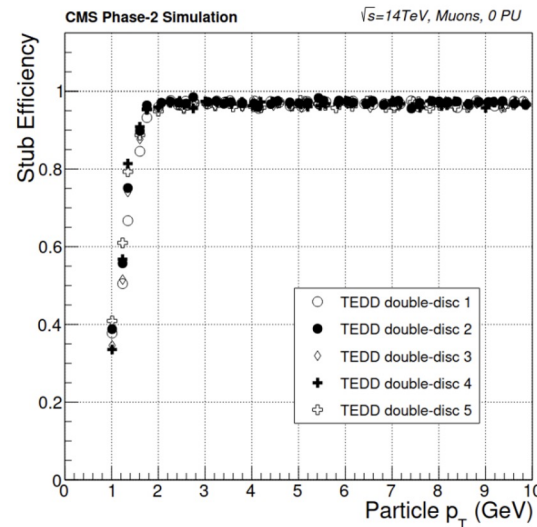
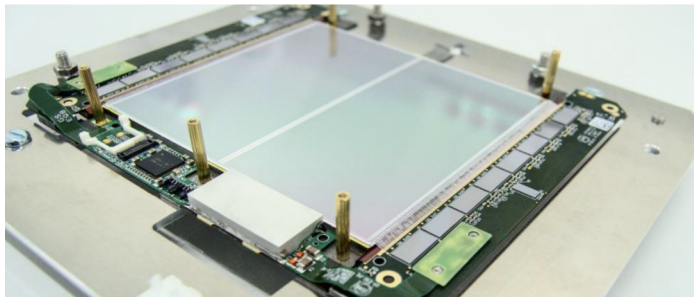
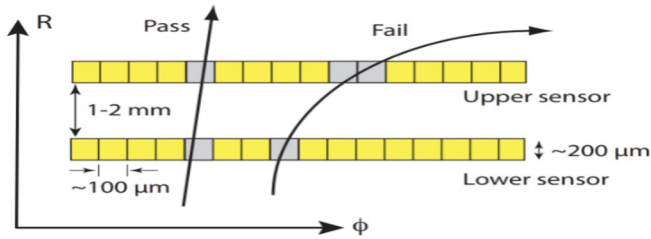


Phase-2 Tracker will have the same general envelope as the Phase 1. Divided into two regions:

- Inner Tracker ($r < 20\text{cm}$)
- Outer Tracker ($r > 20\text{cm}$) → UK focus

But some differences obvious at first glance

- High- η pixel tracking → improved forward jet reco (eg: for VBF Higgs)
- Tilted Inner Barrel → fewer modules despite high PU (lower material)
- Outer Tracker instrumented with “pT-modules” → ***new*** will provide tracking information to L1 trigger



CMS bPOL strategy (local power converter)

- The bPOL converter has issues after radiation (total ionizing dose, TID), enhanced by cold temperatures
 - There is a clear risk, some V6 will stop working along the way
 - All V6 issues have been fixed in FX1, but there is a clear risk, FX1, a new ASIC, may not work
- CMS is following an adaptable hybrid strategy, **respecting schedule**
 - using v6/FX at all low/high TID volumes (as in the table)
- **We are adapting all systems to minimize the risk of using V6, in case FX1 fails**

Cristian Baldenegro



System	Quantity	Radiation [MRad]	Step in production	Accessible after installation	USE	Schedule Mitigation
Tracker PS	5600	12 to 80	1st - module	NO	FX1	Assemble bare modules add bPOL later
Tracker 2S	7600	2 to 12	1st - module	NO	FX1	Assemble modules replace bPOL later
HGCAL Si	54000	1 to 25	2nd - cassette	NO	V6 & FX1	Small boards, TID boundary set to respect schedule
Endcap Timing	15000	3 to 100	2nd - dee	Difficult (LS4)	FX1	Needs bPOL only in 2027
IT (Pixels)	1400	68 to 135	2nd - structure	Difficult (EYETS)	FX1	Needs bPOL only in 2027
Barrel Timing	3000	3.2	2nd - Tray	NO	V6	Assembling with v6
ME0	2200	0.5	1st - module	NO	V6	Assembling with v6
Barrel Calorimeter	10000	0.8	1st - electronics	NO	V6	Assembling with v6
HGCAL Tile	8500	0.25	1st - tileboard	NO	V6	Assembling with v6

bPOL: V6 current ASIC, FX1 next chip coming back mid June TID: Total Ionizing Dose



Status of bPOL Problems

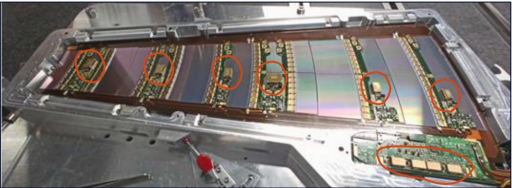


- bPOL DC-DC voltage regulators used in ITk (pixel and strips), HGTD, LAr calorimeter
 - Total ~70,000 bPOLs needed (majority in ITk strips and LAr)
- **Problem:** combination of radiation and operation in cold temperature led to failures after increased amount of stress time
- **Strategy:**
 - ITk strips and LAr: use current bPOLs but with redesigned module wire-bonding (strips) or redesigned front board PCB (LAr) to reduce stress load
 - ITk pixel and HGTD: move to new redesigned bPOLs if schedule allows

Elisabeth Schopf

Elisabeth Schopf

Red circles = bPOLs
(ITk strips endcap petal)



Level-1 trigger and High-level trigger

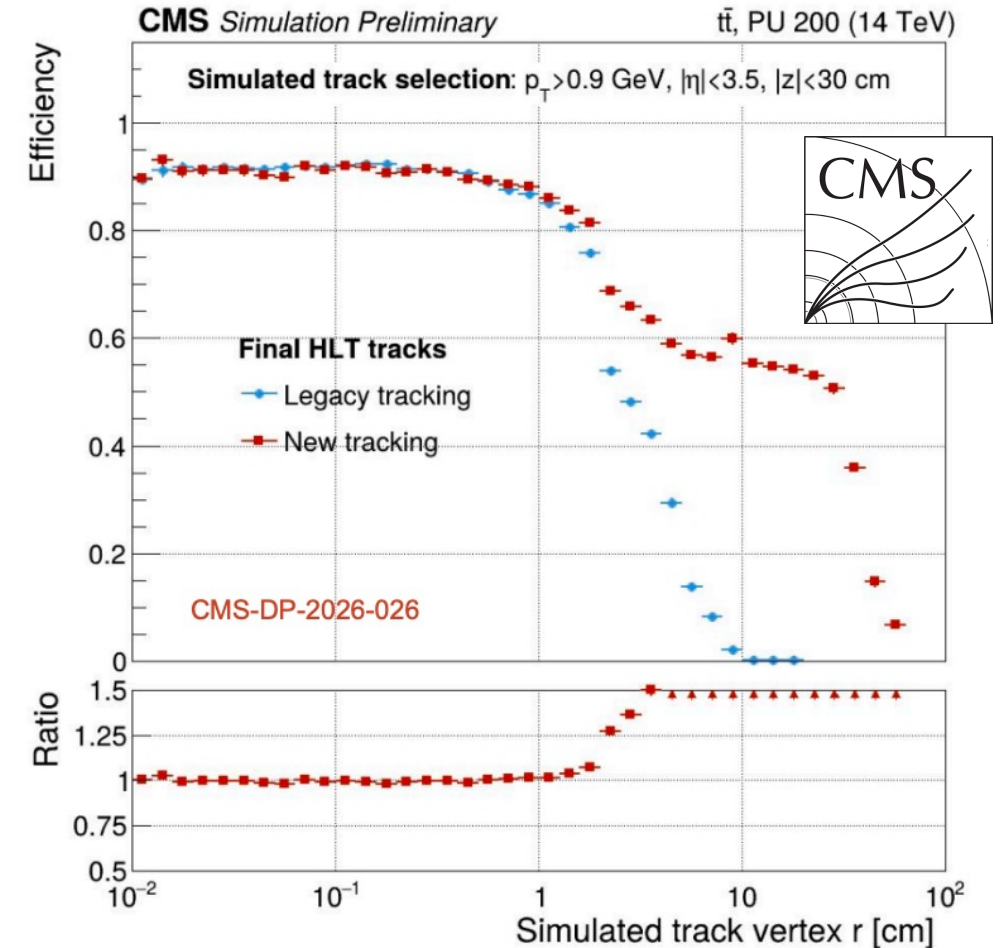
New Phase-2 tracking at HLT

Phase-2 L1T/HLT preparations continue:

- New AI-based jet p_T calibration, improved low- p_T tau reconstruction for scouting, and studies of CPU/GPU acceleration for real-time event processing
- L1T hardware entering production phase; the new Versal FPGA for Global Muon Trigger has been ordered

New Phase-2 HLT tracking:

- Combines modern tracking algorithms to maintain good performance at HL-LHC conditions while significantly reducing computing time and increasing processing throughput



Cristian Baldenegro

- Strong progress across all systems → timeline remains tight but robust plans put into place to accelerate production

Elisabeth Schopf

- Some highlights:

- **ITk**: module production ramping up in all sites with optimised distribution system for parts
- **HGTD**: readout ASICs fully delivered, LGADs production at advanced stage, achieved ~50ps resolution
- **Calo**: electronics production progressing, performance of multiple front-end boards in a single crate tested
- **Muons**: new SMDT chambers fully delivered, RPC resolved technical issues with performance instabilities



Setup for cosmics with new muon chambers



ITk strips stave



HGTD demonstrator



ATLAS Event Filter Technology Choice

- [Technology Choice](#): study leading to decision on processors for Run-4 Event Filter:

- CPUs, GPUs, FPGAs
- ~500ms latency available to reject events
- Dominated by ITk tracking

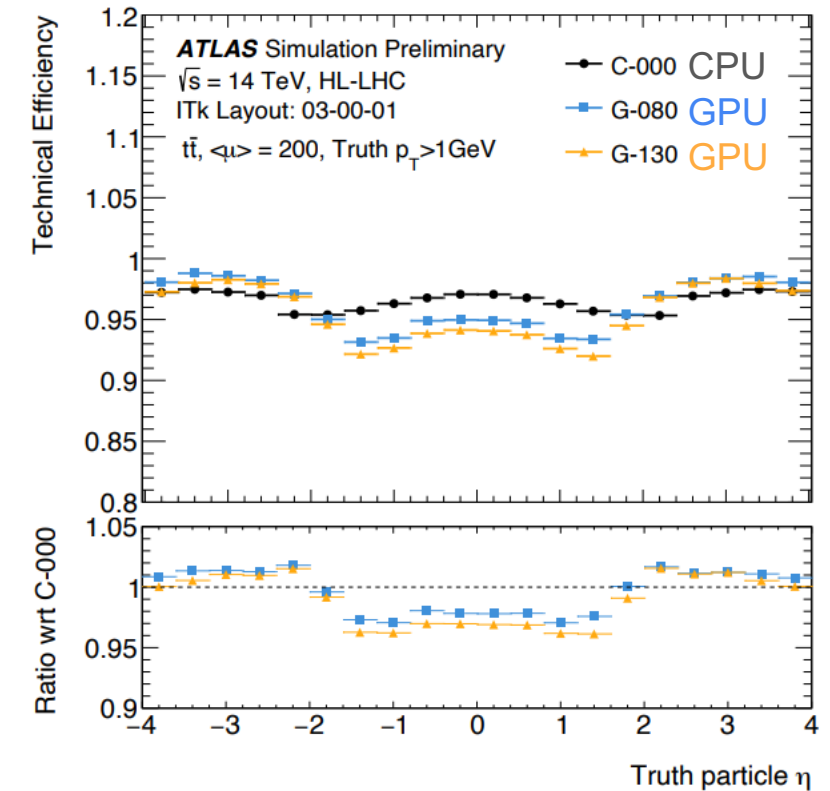
- Significant UK effort (20+ staff and students) across all three technologies

- Hardware testbeds: FPGA, GPU
- [Novel algorithms](#) for CPU, GPU, FPGA
- Validation and monitoring
- Coordination roles
- Investigation of alternative technologies (e.g. Intel and AMD GPUs)



- **Final decision: CPU + GPU** with CPU-only backup

- Big effort to get everything ready for Run-4



Will Panduro & Steve McMahon