SHiP
Search for Hidden Particles

Search for Hidden Particles at the SPS Beam Dump Facility

on behalf of the
CERN BDF Working Group and SHiP Collaboration

Previous talks on BDF/SHiP at 10th NBI 2017, M. Calviani
- **BDF/SHiP Overview**
- **BDF Design Challenges**

References in the backup slides

Motivation

Motivated by the opportunities offered by the equivalence of mass scale and coupling scale!

$$\mathcal{L}_{eff} = \mathcal{L}_{SM} + \sum_{d>4} \frac{c_n^{(d)}}{\Lambda^{d-4}} \mathcal{O}^{(d)}$$

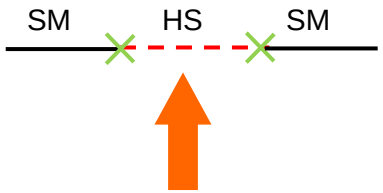
- Exploration of Feebly Interacting Particles up to now mainly as by-product of experiments built for other purposes – post-analyses, data mining, often limited to exclusion capability

- We have enough reasons to build a dedicated accelerator-based facility to explore FIPs, optimized for discovery
  - We are sharing the Universe already with feebly coupled and not-understood neighbours!
  - Attractiveness of a light feebly coupled sector in providing solutions to well established problems!
  - 7% of LHC+HL-LHC data recorded – lack of New Physics, even lack of hints to scale!
    - One of the main objectives of HL-LHC will be exploring FIPs…
  - Essential complementarity with projects in launch/commissioning on the cosmofrontier
  - Infrastructure and tools such as SPS exist and have huge potential to make exhaustive searches in the MeV – GeV range (and in the worst case bridge over to FCC…)!

Caught between a rock and a hard place

- Exhaustive search should aim at a model-independent detector setup
  - Include basic options of heavy neutral leptons, dark photons, dark scalars, ALPs, LDM, FIPs associated with high-energy scale models etc

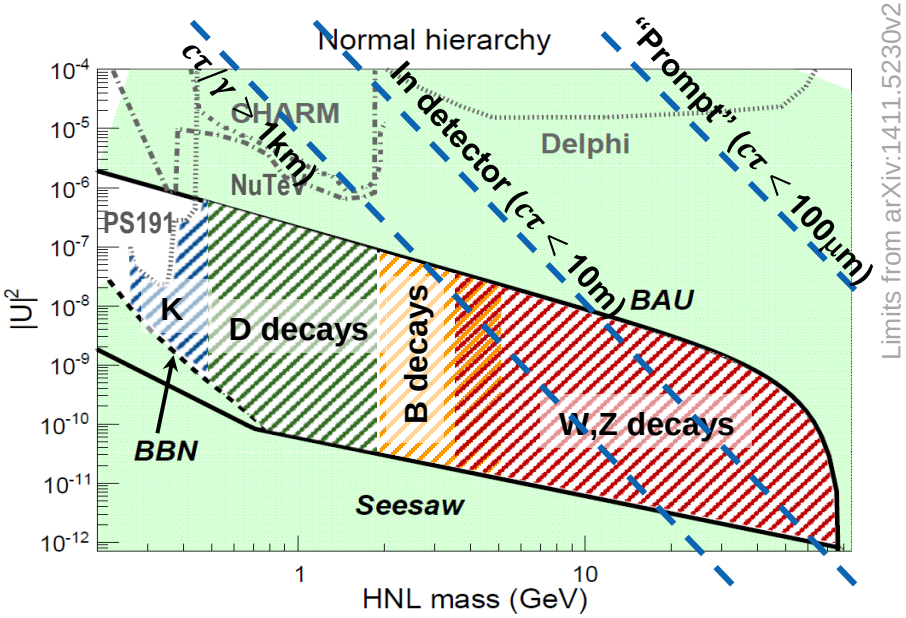
  ➔ Need massive production of $\gamma, q/g, c, b, W, Z, H$!



- Acceptance and background are the biggest challenges
  - Dilemma: background/pile-up versus absorbers/sweepers
  - New states in MeV – GeV range are typically long-lived, e.g. HNL $\tau_N \sim \frac{96\pi^2 h}{|\mathcal{U}|^2 G_F^2 M_N^5}$

  ➔$(lifetime) \otimes (\epsilon \times 4\pi)$ challenge

Similar behaviour for all types of Hidden Sector options



- Beam dump setup suitable for a large part of the interesting parameter space

  ➔ High luminosity and geometric acceptance (boost), lower particle mass, long lifetimes

Optimisation of a proton beam dump experiment

- Design for direct detection comes with no free lunches
  - Production branching ratios $\mathcal{O}(10^{-10})$ → Largest possible number of protons

    ➔ "Primary" SPS FT luminosity for a long target (e.g. 1m++ Mo, ρ_N nucleon density) with 4x10^{13} p/spill and the 4x10^{19} protons on target per year currently available in the SPS

    SPS $\mathcal{L}_{int}[year^{-1}] = 10^6 s \times \int_0^{"\infty"} \Phi_0 \times \rho_N \times e^{-l/\lambda} dl = \Phi_0 \times \rho_N \times \lambda$ = **3.6 x 10^{45} cm^{-2}** (cascade not incl.)

    ➔ **HL-LHC** $\mathcal{L}_{int}[year^{-1}] = 10^7 s \times 10^{35}$ s^{-1}cm^{-2} = **10^{42} cm^{-2}**

  - Production of charm and beauty mesons → High energy (400 GeV)
  - Production of light and heavy hadron decays, photons → Long and highest density, A and Z target

    ➔ Make all protons interact and additional production in cascade processes!

    ➔ Hadronic production cross-section $\propto A^{2/3}$

    ➔ Electromagnetic process for photons $\propto Z^2$

  - Large neutrino and muon background → Shortest λ target + minimise inlined cooling

    ➔ Force interaction of pions and kaons before decay!

Target extremely optimized for physics and experimental setup
➔ Spectrum of background depends on target optimization

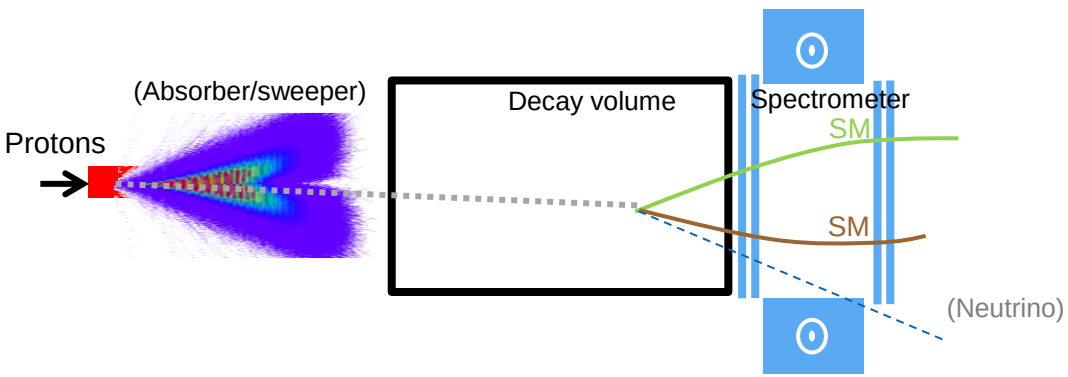
Optimisation of a proton beam dump experiment

- Large muon flux → Slow beam extraction to control bkg
- Hidden particles travel unperturbed through ordinary matter → Filtering out beam induced background
- Production angles → Decay volume as close as possible
- Long-lived objects → Long decay volume
- Residual background suppression / signal characterisation → Full reconstruction and identification of both fully and partially reconstructible modes with neutrinos

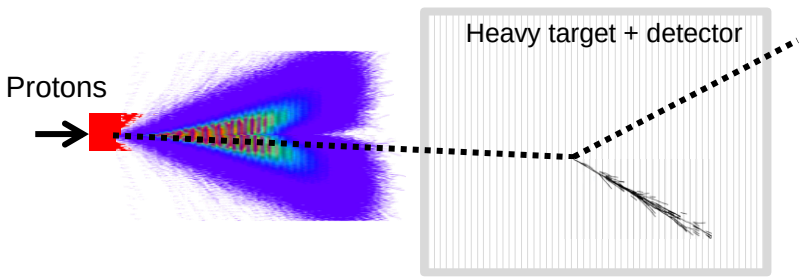
➔ Many technological synergies with other fixed target facilities at the intensity frontier

- BDF/SHiP includes combination of two direct experimental techniques

Direct search: visible decay to SM particles



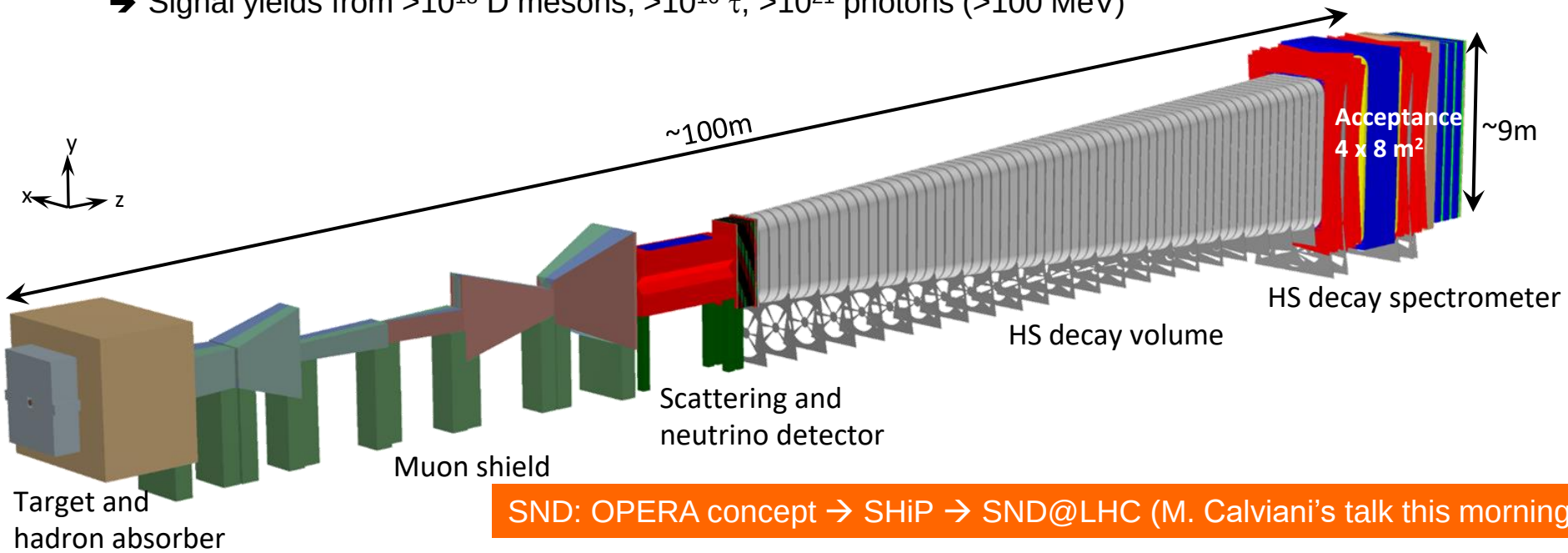
Direct search: Scattering off atomic electrons and nuclei



➔ Scattering detection system suited for studying ν interactions of all flavours, in particular ν_τ

BDF/SHiP experimental setup

- Physics cased based on 2×10^{20} protons on target (5 years of nominal operation)
  - ➔ Signal yields from $>10^{18}$ D mesons, $>10^{16}$ τ, $>10^{21}$ photons (>100 MeV)



SND: OPERA concept → SHiP → SND@LHC (M. Calviani's talk this morning)

- Designed for "zero background" in decay search
  - Muon shield for muons
  - Vacuum for neutrinos
  - Background veto taggers
  - Momentum and decay vertex information
  - Invariant mass
  - Impact parameter at target
  - Coincidence timing
  - Particle identification

	Physics model	Final state
HSDS	HNL, SUSY neutralino	$\ell^\pm\pi^\mp$, $\ell^\pm K^\mp$, $\ell^\pm\rho^\mp(\rho^\mp \to \pi^\mp\pi^0)$
	DP, DS, ALP (fermion coupling), SUSY sgoldstino	$\ell^+\ell^-$
	DP, DS, ALP (gluon coupling), SUSY sgoldstino	$\pi^+\pi^-$, K^+K^-
	HNL, SUSY neutralino, axino	$\ell^+\ell^-\nu$
	ALP (photon coupling), SUSY sgoldstino	$\gamma\gamma$
	SUSY sgoldstino	$\pi^0\pi^0$
	LDM	Electron, proton, hadronic shower
SND	ν_τ, $\overline{\nu}_\tau$ measurements	$\tau^\pm$
	Neutrino-induced charm production (ν_e, ν_μ, ν_τ)	$D_s^\pm$, $D^\pm$, D^0, $\overline{D^0}$, Λ_c^+, $\overline{\Lambda_c}^-$

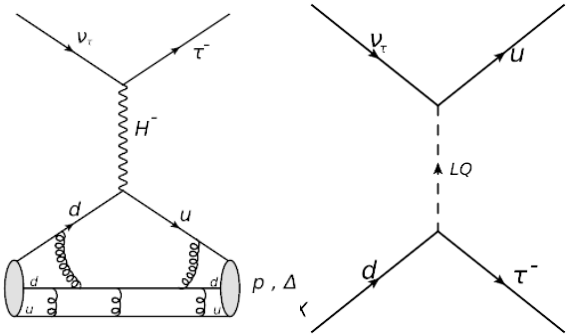
SM Physics: Prospects for ν_τ (ν_e, ν_μ)

1. First observation of $\bar{\nu}_\tau$ interaction
2. Measurement of ν_τ and $\bar{\nu}_\tau$ cross-sections

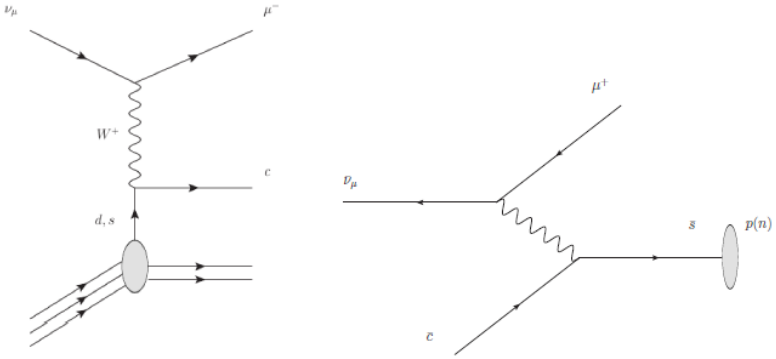
$$\frac{d^2\sigma^{\nu(\bar{\nu})}}{dxdy} = \frac{G_F^2 M E_\nu}{\pi(1+Q^2/M_W^2)^2}\Bigg((y^2x + \frac{m_\tau^2 y}{2E_\nu M})F_1 + \left[(1-\frac{m_\tau^2}{4E_\nu^2}) - (1+\frac{Mx}{2E_\nu})\right]F_2 \pm \left[xy(1-\frac{y}{2}) - \frac{m_\tau^2 y}{4E_\nu M}\right]F_3 + \frac{m_\tau^2(m_\tau^2+Q^2)}{4E_\nu^2 M^2 x}F_4 - \frac{m_\tau^2}{E_\nu M}F_5\Bigg),$$

➔ Allow extraction of F4 and F5 structure functions from charged current neutrino-nucleon DIS

➔ Beyond SM

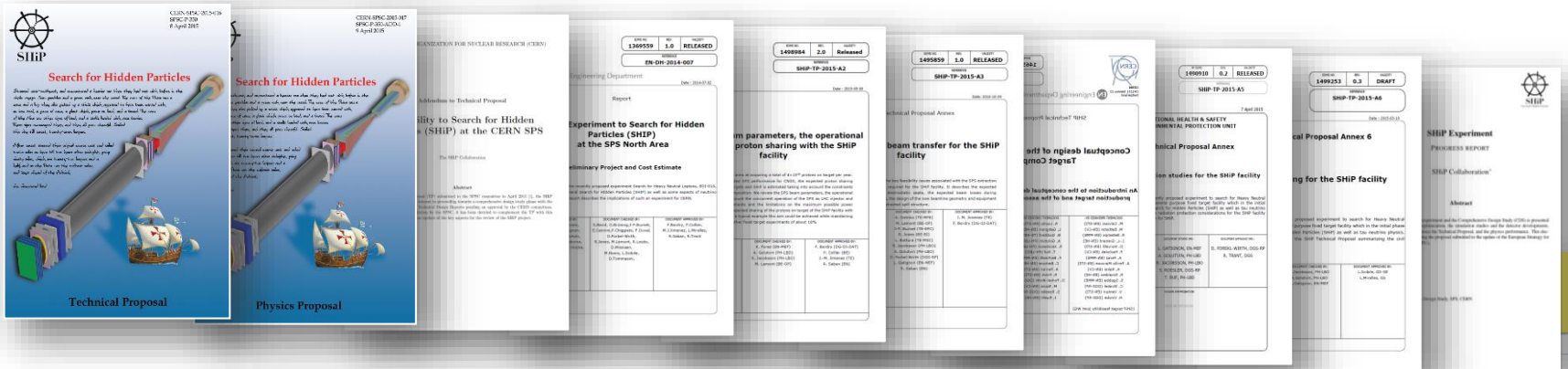


3. ν_τ magnetic moment
4. ν_e cross section at high energy
5. Testing strange quark content of nucleon through charm production
5. LFV
5. Normalization of hidden particle search

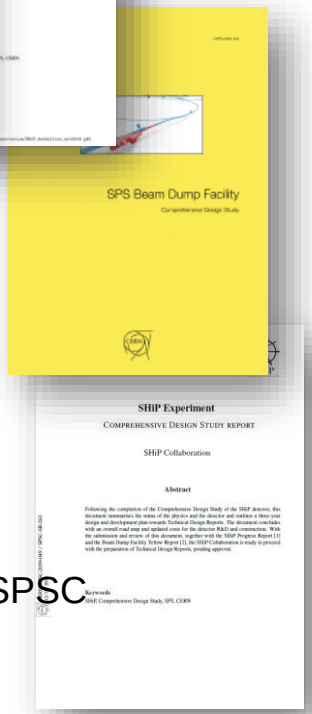


BDF/SHiP development history

- 2013 Oct: EOI with SHiP@SPS North Area as a new high intensity facility
  ...following brainstorming SHiP@IP8, SHiP@LBD, SHiP@CNGS, SHiP@WANF, SHIP@ECN3

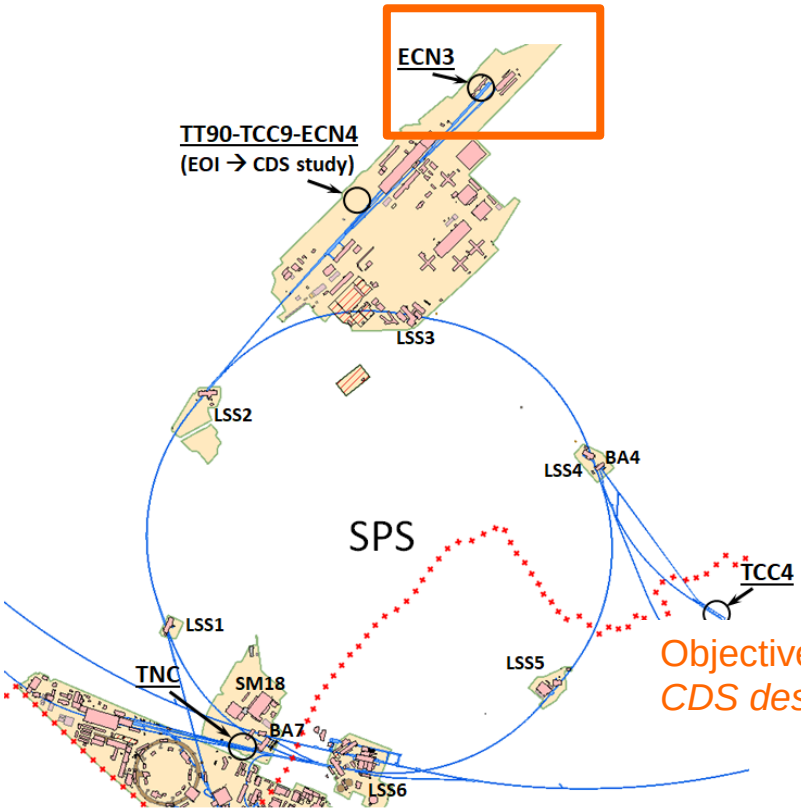


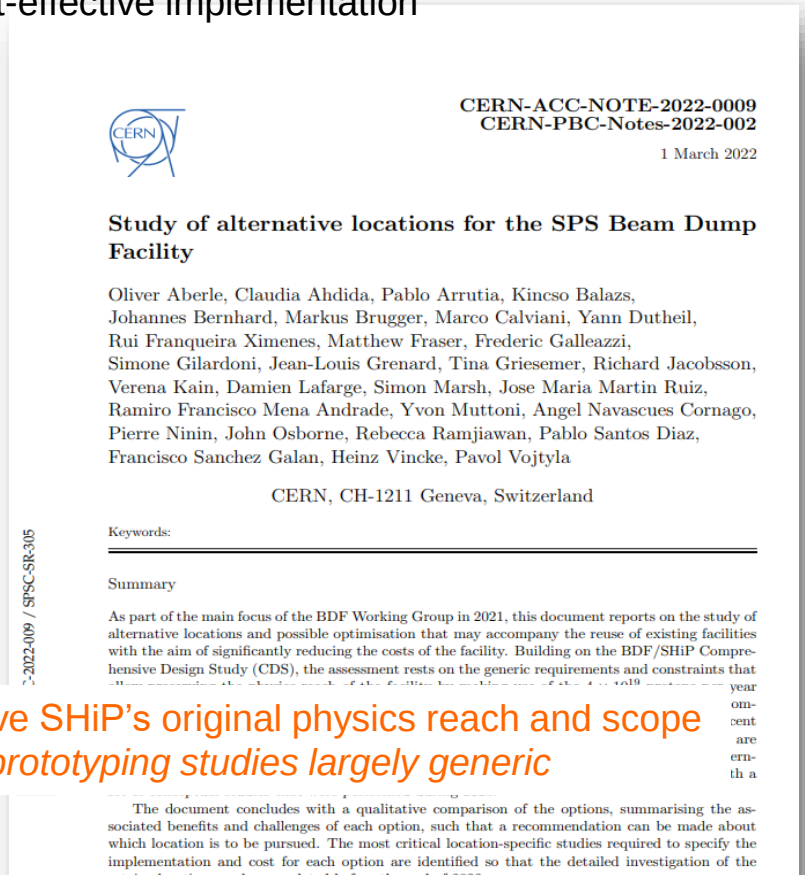
- 2014 Jan: Encouraged to form collaboration and produce TP and inter-departmental task force setup to study feasibility of facility
- 2015 Apr: TP with ~700 pages by SHiP theorists, experimentalists, and CERN accelerator, engineering, and safety departments
- 2016 Jan: Recommendation by SPSC to proceed to Comprehensive Design Study (CDS)
- 2016 Apr: CERN management launch of Beyond Collider Physics study group
  - SHiP experimental facility included under PBC as Beam Dump Facility
- 2018 Dec: EPPSU contribution submitted by SHiP and BDF, and SHiP Progress Report to SPSC
- 2019 Dec: CDS reports on BDF (Yellow Book) and SHiP submitted to SPSC
- 2020 Sep: CERN launches continued BDF R&D with SHiP MoU ontop of existing collaboration agreement
- 2022 Jul: CERN launches dedicated studies of future programme in ECN3 beam facility & decision process



Location and layout optimization study

- ESPP: strong support for physics case, suitability of CERN injector complex, and community interest in medium term/size complementary scientific programme
  - ➔ Main point: CERN budget overstrained with main ESPPU commitments
  - ➔ 2020 September: CERN launch of study for more cost-effective implementation





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CERN-PBC-Notes-2022-002

1 March 2022

Study of alternative locations for the SPS Beam Dump Facility

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Keywords:

Summary

As part of the main focus of the BDF Working Group in 2021, this document reports on the study of alternative locations and possible optimisation that may accompany the reuse of existing facilities with the aim of significantly reducing the costs of the facility. Building on the BDF/SHiP Comprehensive Design Study (CDS), the assessment rests on the generic requirements and constraints that

The document concludes with a qualitative comparison of the options, summarising the associated benefits and challenges of each option, such that a recommendation can be made about which location is to be pursued. The most critical location-specific studies required to specify the implementation and cost for each option are identified so that the detailed investigation of the

Objective: Preserve SHiP's original physics reach and scope

CDS design and prototyping studies largely generic

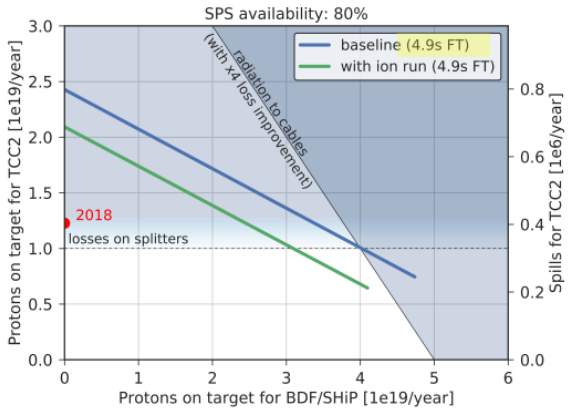
➔ CERN management/PBC encourages focus on ECN3 for BDF/SHiP

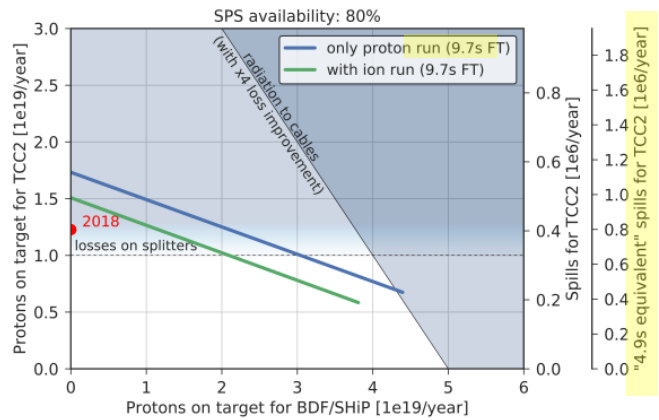
Decision process over 2022-23 for future physics programme in ECN3 defined (see slide in backup)

- Two principal "contenders": HIKE (K^+/K_L) and BDF/SHIP

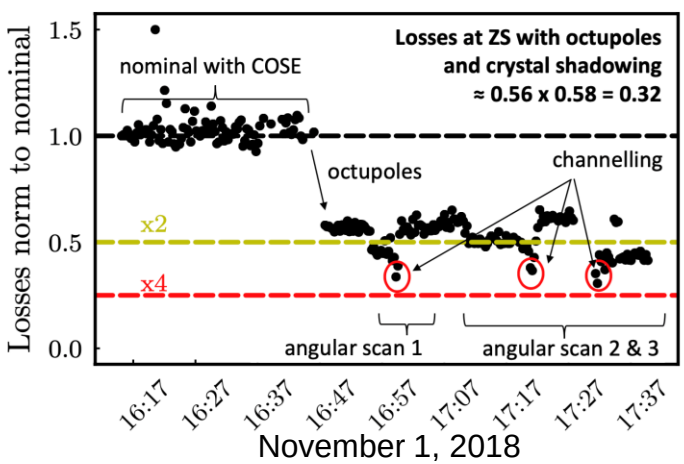
Beam delivery

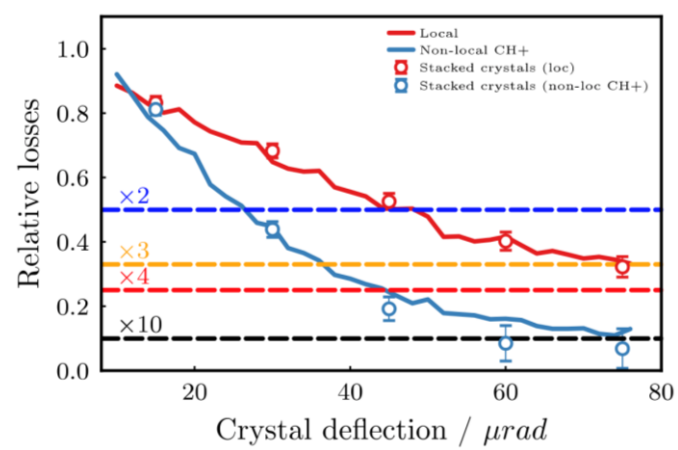
- BDF/SHiP assumes current SPS, slowly extracted 1s spills with 4×10^{13} p / 7.2s
  - Proton sharing scenarios with all current facilities around the SPS and LHC(HL-LHC):





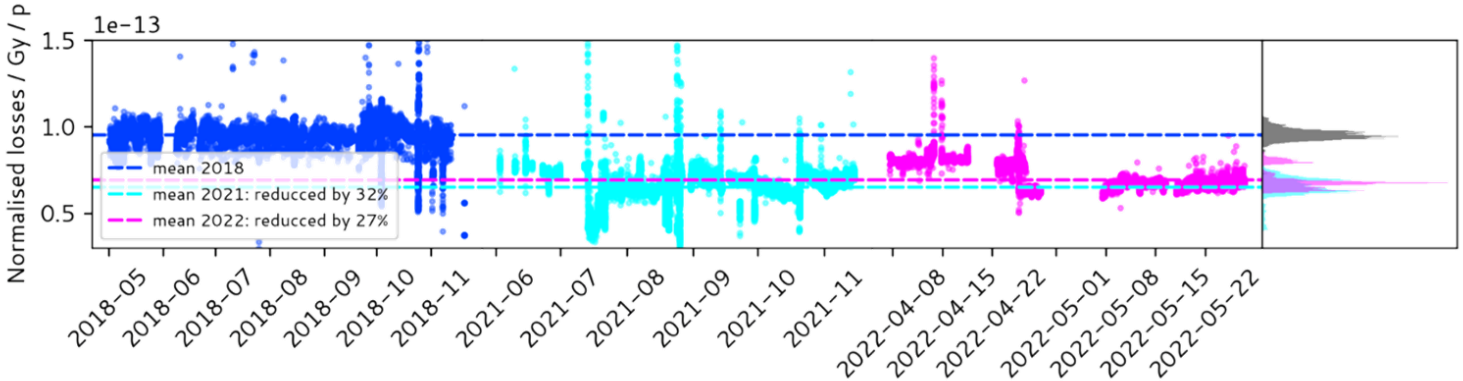
- Slow extraction of (4 + 1) x 10^{19} p/year requires reduction of losses by factor 4
  - Pioneering developments made in the field of slow extraction beam loss reduction (see references)
  - First application of thin, bent Si crystal shadowing an electrostatic septum in operation in LSS2 of SPS:



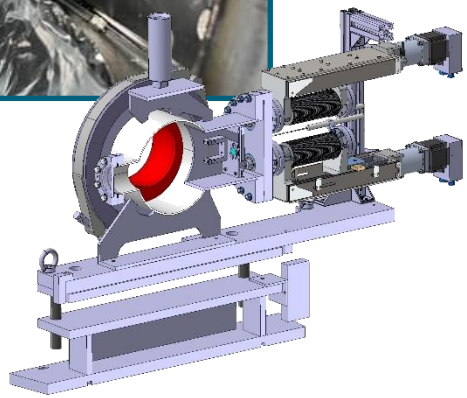


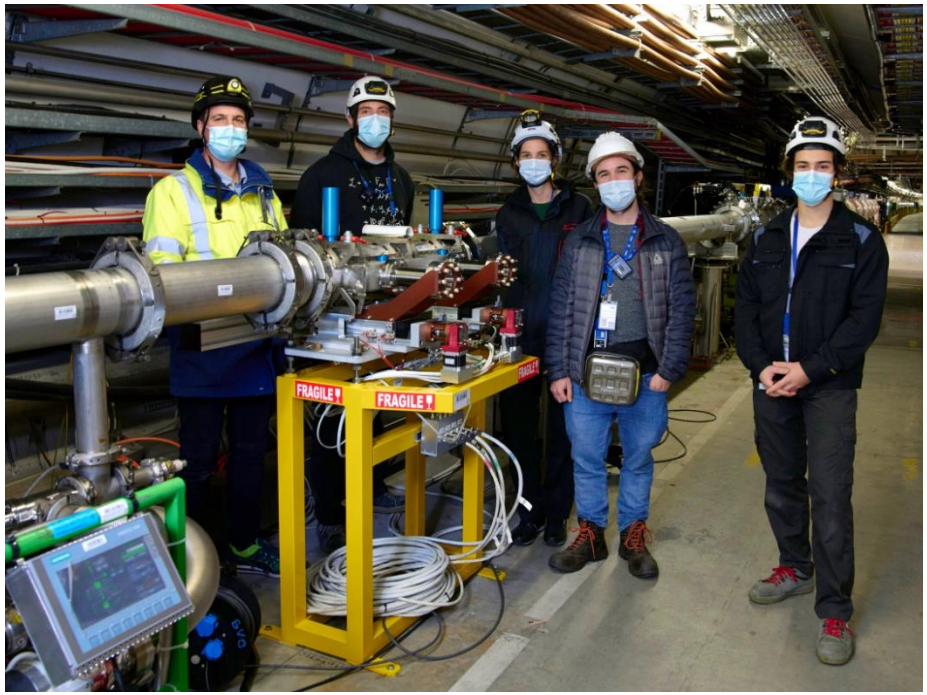
Beam delivery – slow extraction

- System in operation during 2021 and 2022



- Active R&D on-going with a new, optimized crystal shadowing system installed in SPS LSS4

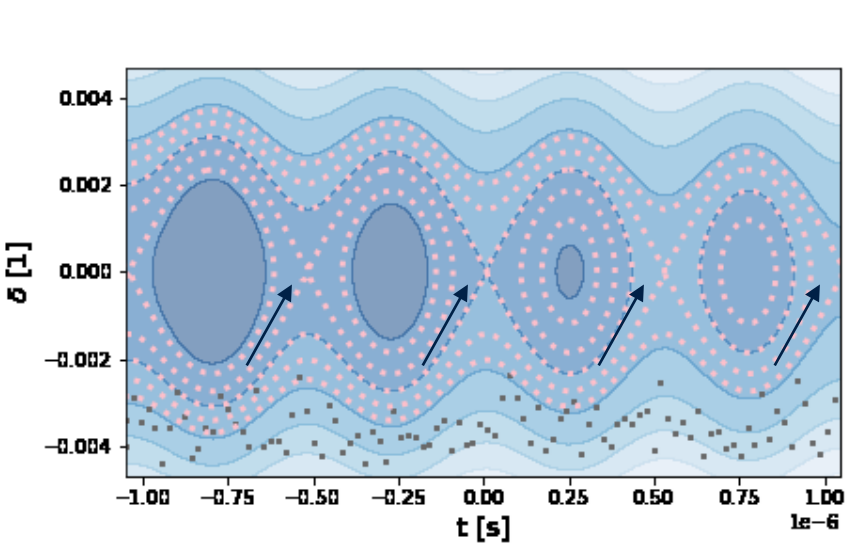


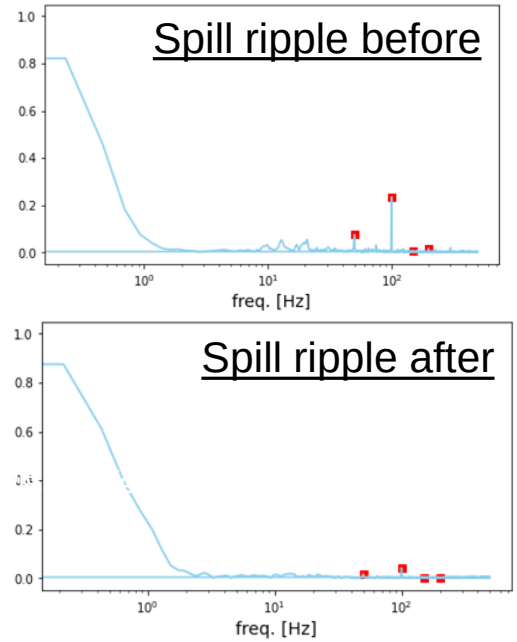


Beam delivery – spill quality

- Beam dynamics simulations of machine imperfections (power converter ripple etc.):

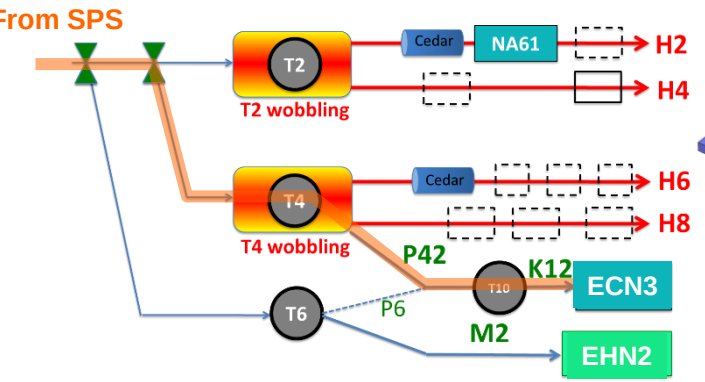
- Investigation of radiofrequency (RF) techniques to improve spill quality duty factor:
  - Empty Bucket Channeling employed with 800 MHz cavities at low voltage to suppress low frequency spill ripple carried out with NA62 collaboration:

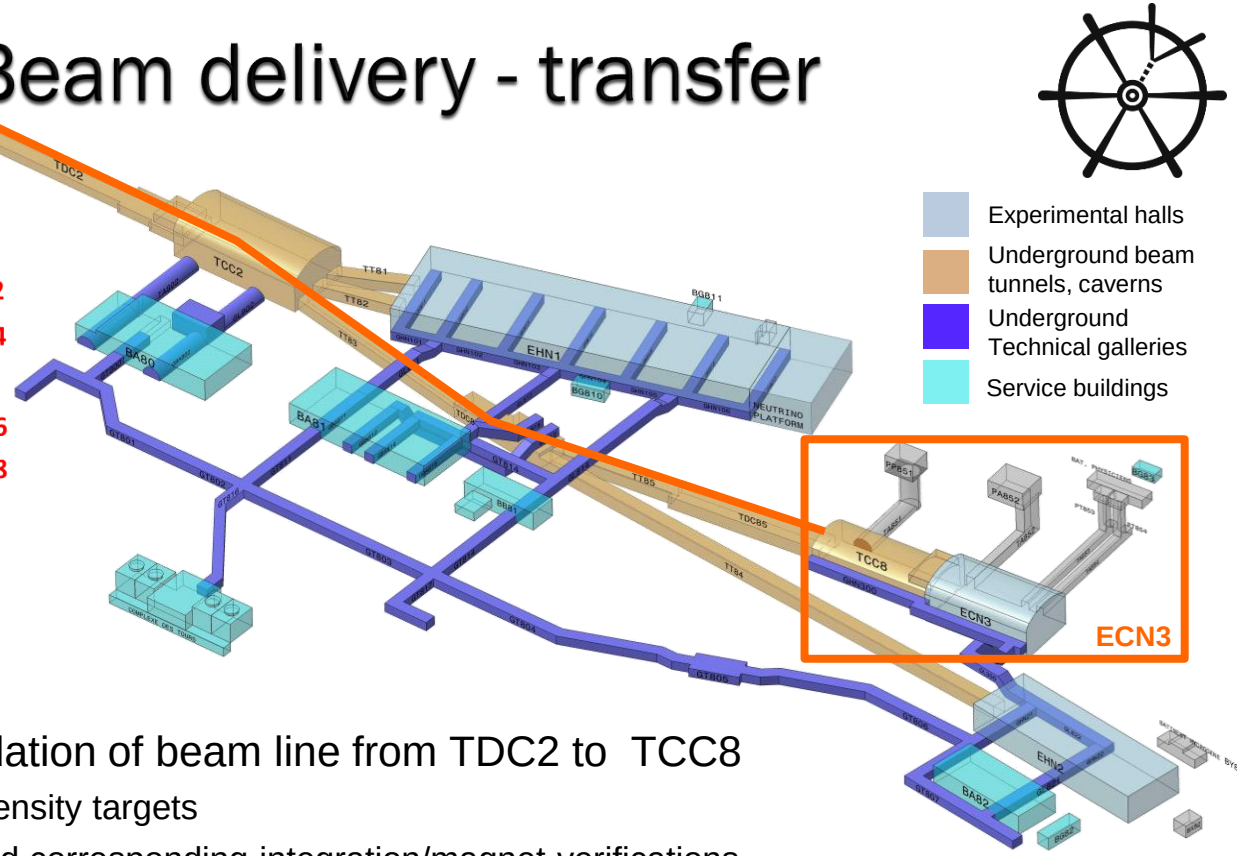




➔ Possible technique to provide slow-extracted bunched beams for time-of-flight discrimination against neutrino background in search for LDM at BDF/SHiP

Beam delivery - transfer





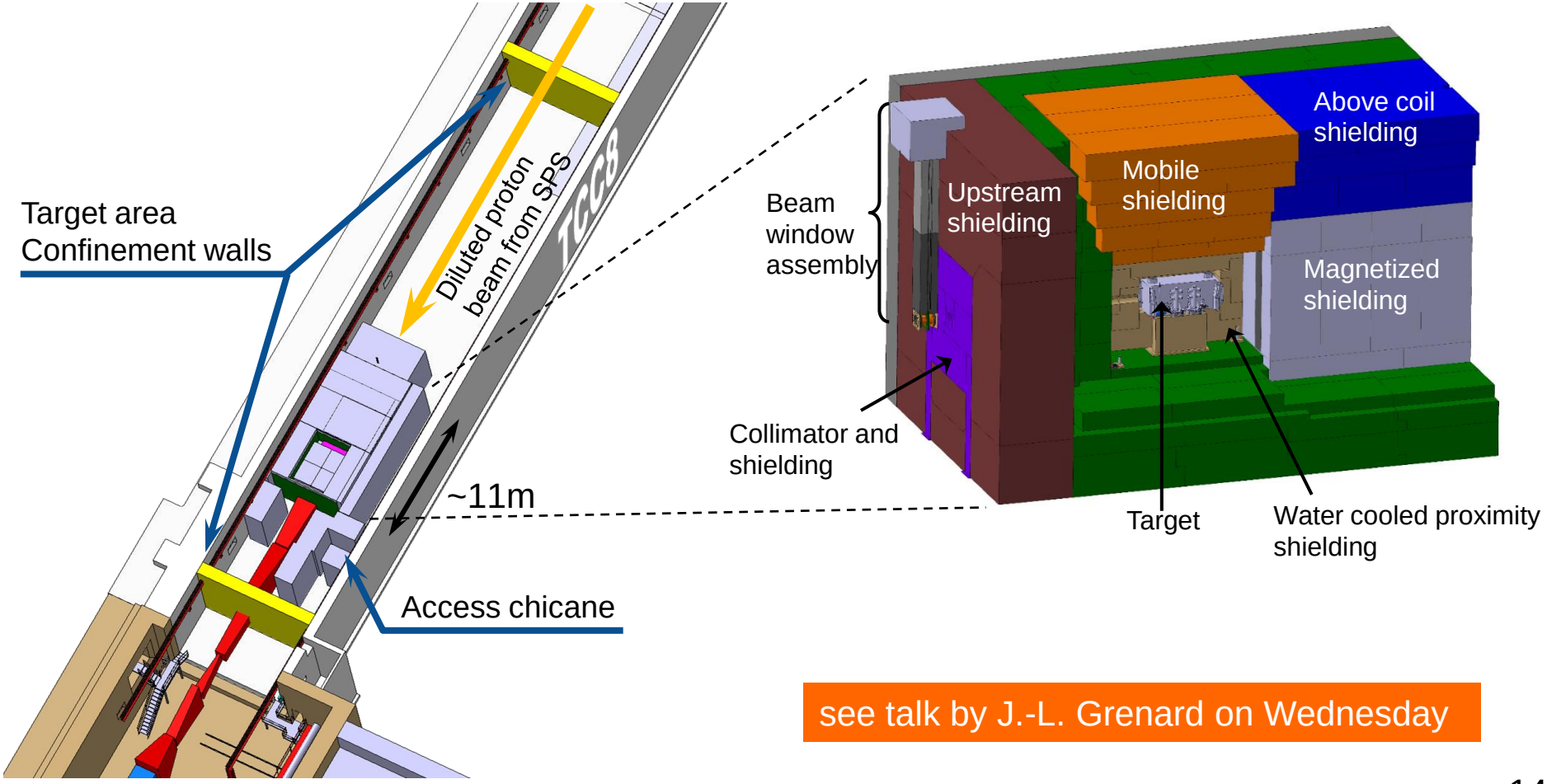
- Intensity upgrade and consolidation of beam line from TDC2 to TCC8
  - Beam delivery scenarios and intensity targets
  - Optics Studies/Updates/Tests and corresponding integration/magnet verifications
  - Improved instrumentation and respective YETS implementation (BLMs, BSGs, related beamline/vacuum)
  - Loss studies and mitigation measures
  - Target/absorber designs (TCC2 + TCC8)
  - Equipment & infrastructure needs

➔ Under study by dedicated experiment-independent "ECN3 Beam Delivery Task Force"

- Much of the consolidation/upgrade required covered by CERN's North Area Consolidation programme Phase 1 (LS3) and Phase 2 (beyond) – some re-scoping necessary

BDF/SHiP Target complex

- Optimisation for implementation in target area TCC8 of ECN3
  - Optimisation of walled confinement of complex with dedicated ventilation
  - Nitrogen as alternative to helium for inert gas embedding as for LBNF target station
  - Shielding optimization
  - Revised handling scheme with no overhead access shaft

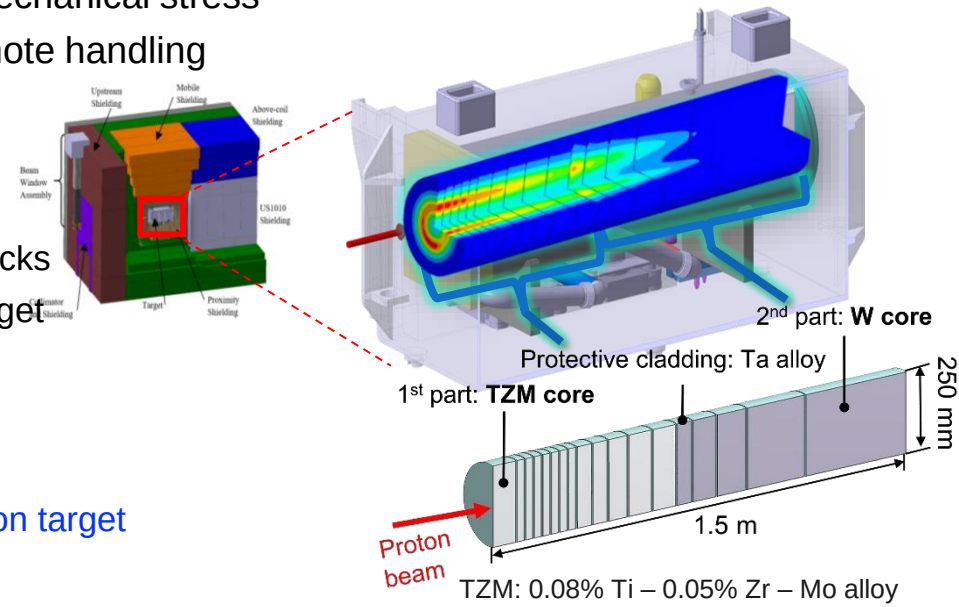


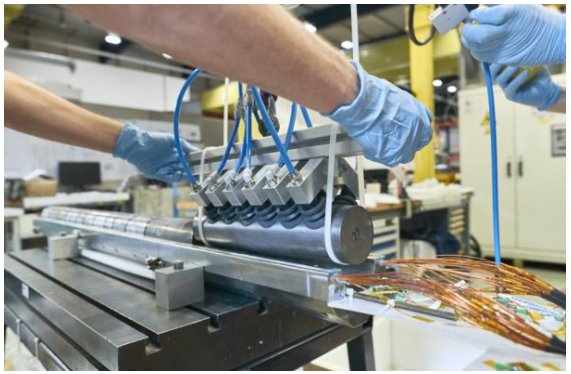
see talk by J.-L. Grenard on Wednesday

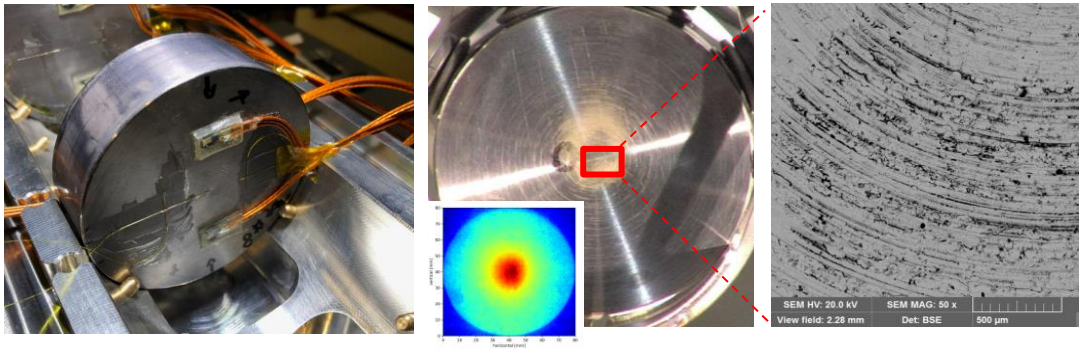
BDF/SHiP Target

- Challenges
  - High A/Z target with high beam power of up to 2.56 MW during the 1 s spill and 320 kW on average
  - ➔ High-A/Z material resilience to high flow of cooling water
  - ➔ Target block cladding behaviour under thermo-mechanical stress
  - ➔ Integrated design of target assembly for fully remote handling

- Prototyping and beam test
  - Manufacturing validation of Ta-cladded W & TZM blocks
  - Reproduce thermo-mechanical conditions of final target
  - Cross-check FEM simulations
  - Test target online instrumentation
  - Perform detailed post-irradiation examination
  - Beam tests in 2018 with a total of 2.4 x10^{16} protons on target
  - Good agreement with simulations





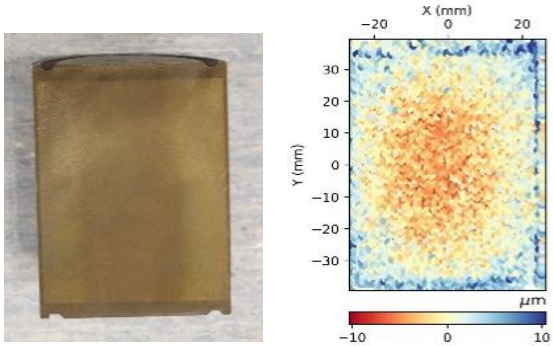


Prototype instrumentation. Visual and optical microscopy inspections during the PIE.

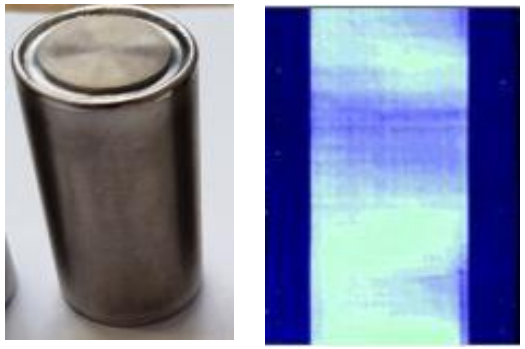
BDF/SHiP Target

Ongoing activities

- PIE of the prototype target
  - Understand survivability of target materials & cladding-core bonding
- BDF Cladding R&D with Nb-alloys
  - Assess the viability of alternative claddings
- Loss-Of-Cooling Accident studies
- Cladding residual stress measurments
- Oxidation test campaign
- Feasibility study of liquid-Pb BDF target

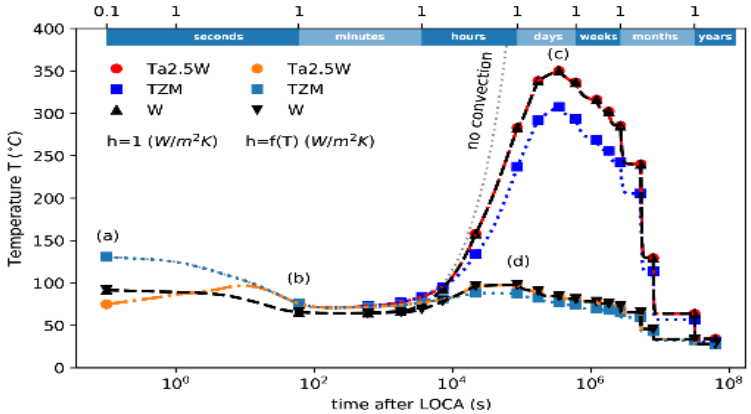


Residual stress measurements via the Counter method



Successfully bonded Nb-alloy cladded block. UT imaging

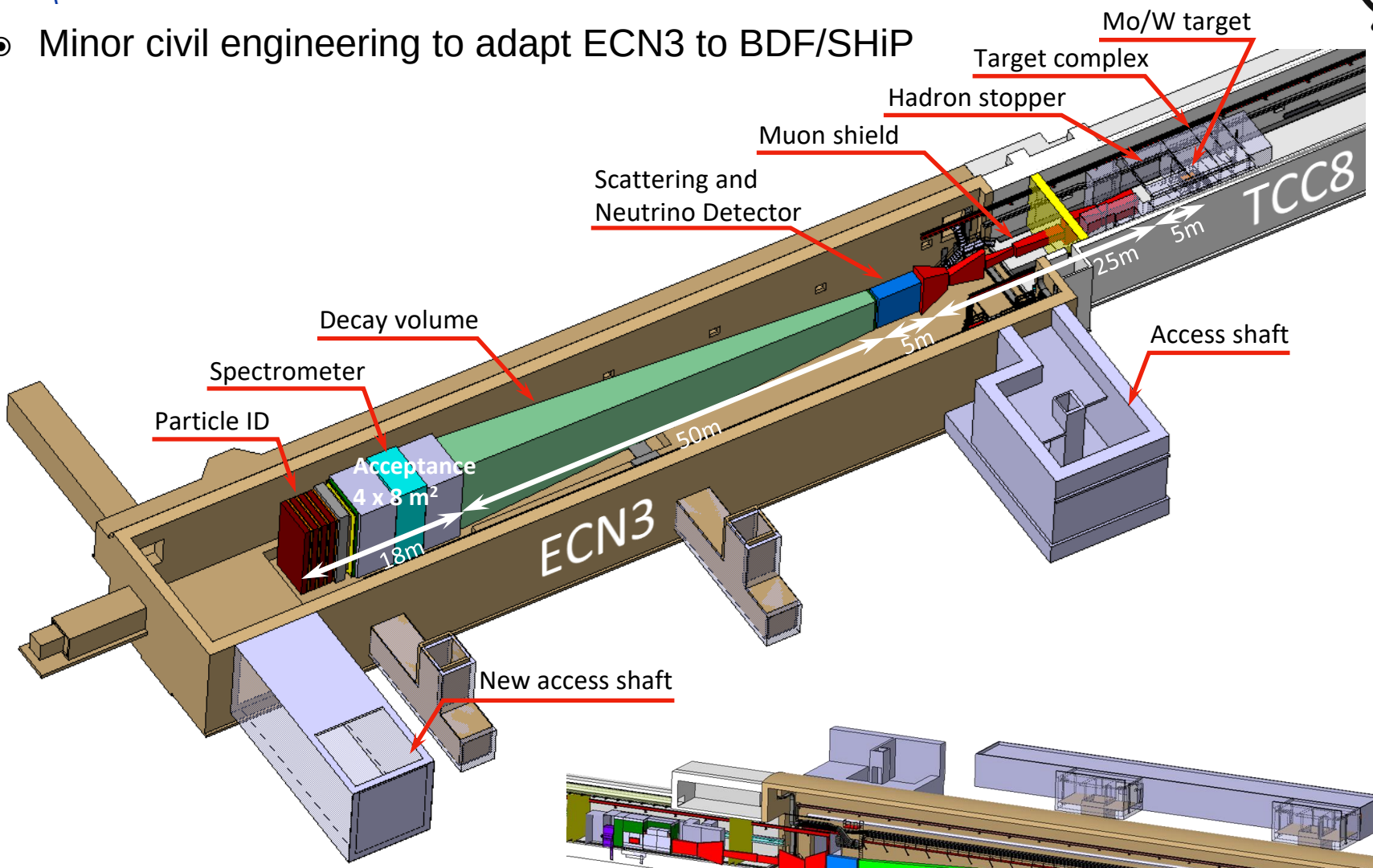
Ta2.5W degradation at different temperatures under oxidizing atmosphere

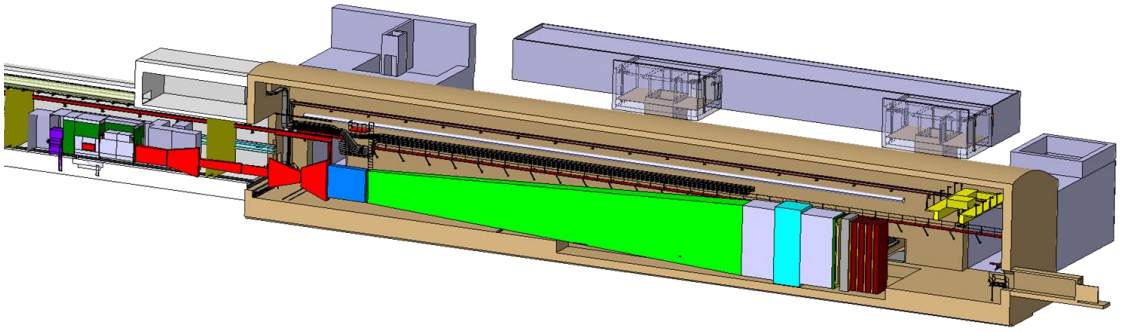


Thermal evolution during LOCA

Integration

- Minor civil engineering to adapt ECN3 to BDF/SHiP



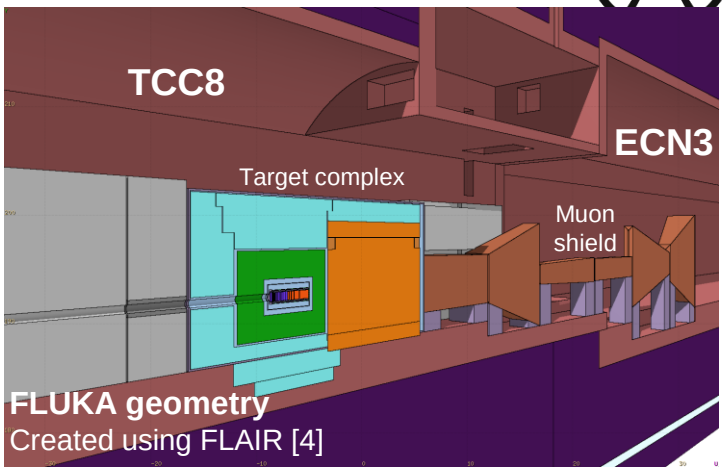


Radiation protection

PROMPT RADIATION
Goal is to reduce above-ground prompt radiation to comply with the given RP limits. Additional soil on top of TCC8/ECN3 as well as reuse of existing shielding blocks allow for a partial shielding reduction wrt. CDS design

RESIDUAL RADIATION
Shielding design also takes into account limitation of activation in the target and experimental areas

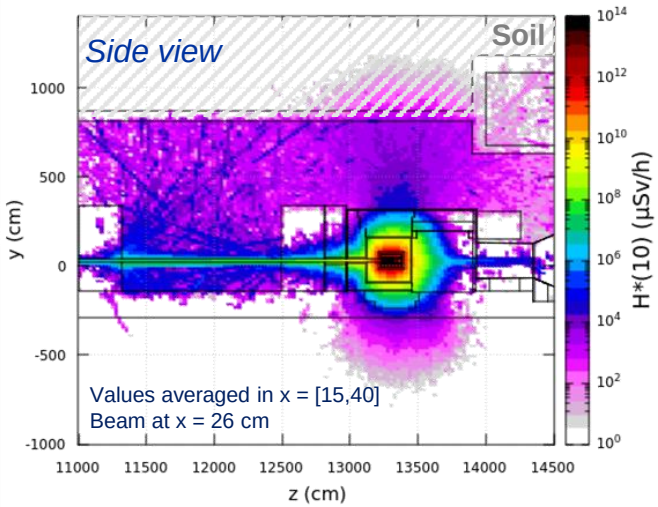
AIR AND GROUND WATER ACTIVATION
Air activation is being reduced with the help of a N_2 vessel and shielding. Activation and contamination of ground water and soil is prevented with additional shielding in the cavern floor



FLUKA hosted by CERN (FLUKA v4-2.2), [1-3]

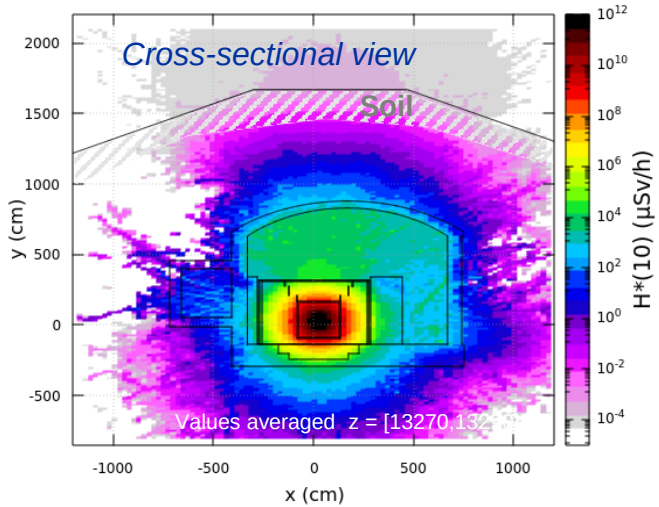
Preliminary results normalized to $4 * 10^{13}$ proton/spill with 6000 spill/day

Prompt ambient dose equivalent in TCC8



Prompt dose rates are well contained in the BDF target/dump area

Prompt ambient dose equivalent at target



Floor iron shielding reduces prompt dose rates inside the soil allowing soil activation (H-3, Na-22) to be below given design limits

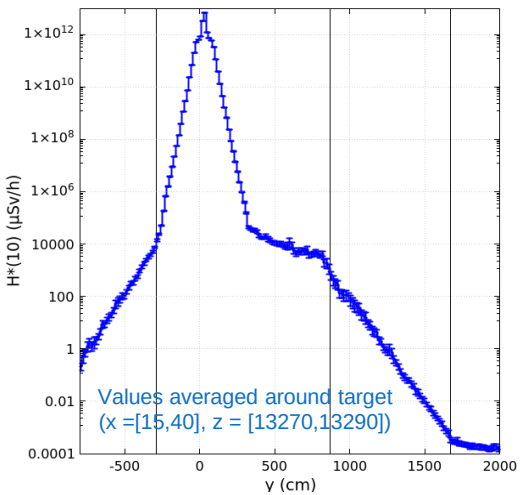
Radiation protection

ENVIRONMENTAL IMPACT

Studies for the environmental impact from prompt radiation and releases of activated air are being finalized, but first results indicate that the given design fulfills CERN's dose objective for the public of <10 uSv/year

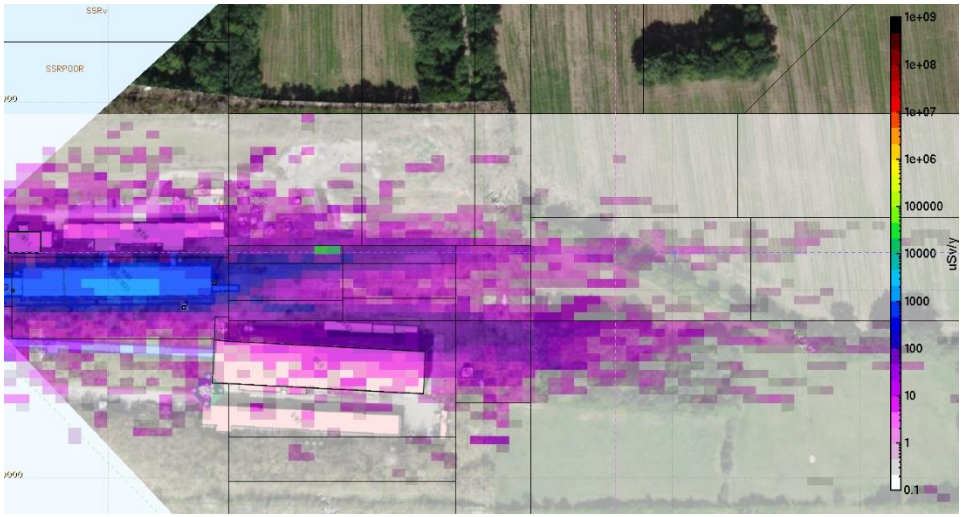
Preliminary results normalized to $4 * 10^{13}$ proton/spill with 6000 spill/day

Prompt ambient dose equivalent along y



Prompt dose rates above-ground are well below the limit of a Non-designated Area (2.5 uSv/h)

Prompt ambient dose at ground level per year

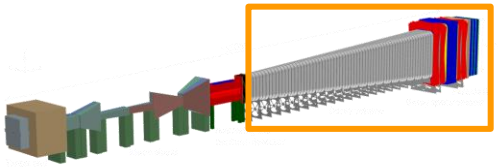


Prompt dose rates above-ground are well below the limit for public areas

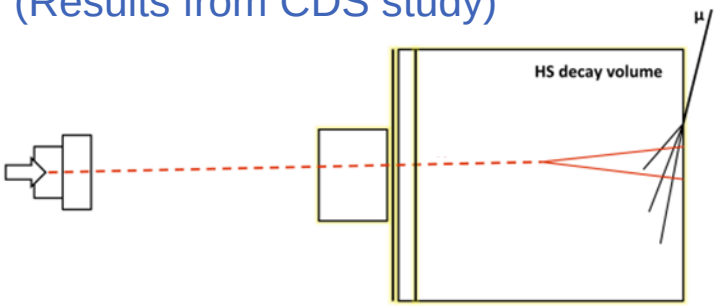
Physics performance in decay search

Pythia/Geant simulation (+GAN) with complete description of detector and infrastructure

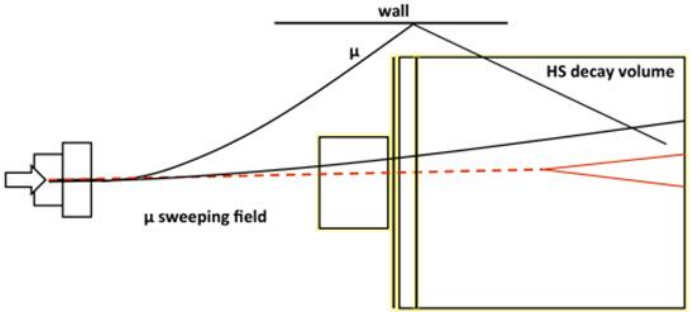
- $\mathcal{O}(10^{11})$ muons (>1 GeV/c) per spill of 4×10^{13} protons
- 4.5×10^{18} neutrinos and 3×10^{18} anti-neutrinos in acceptance in 2×10^{20} proton on target



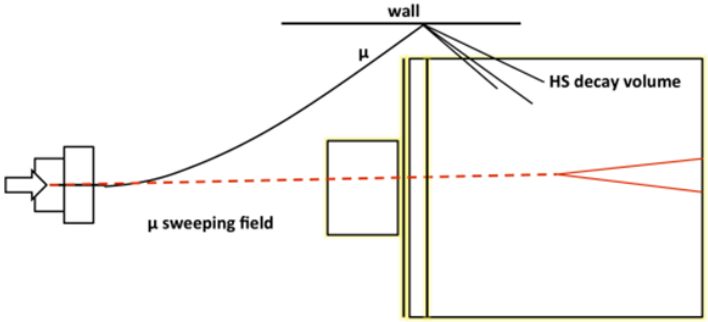
Backgrounds in decay search (fully reconstructible/partially with neutrinos) in 2×10^{20} pots/5 years (Results from CDS study)



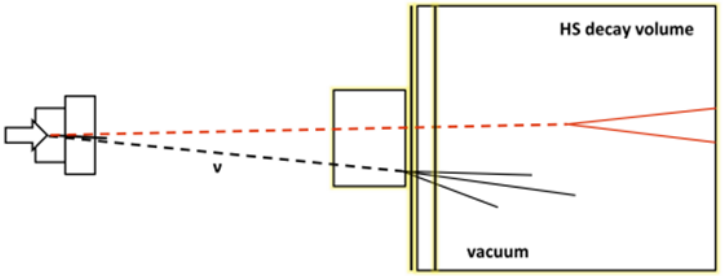
Cosmics: negligible



Muon combinatorial: $1.2\times10^{-2}\pm1.2\times10^{-2}$



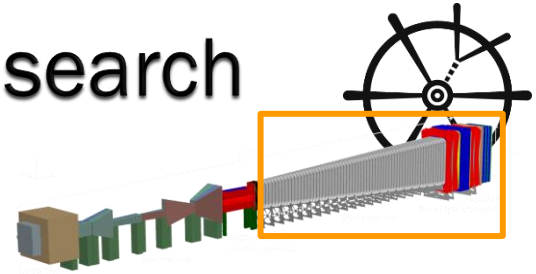
Muon DIS: 6×10^{-4}



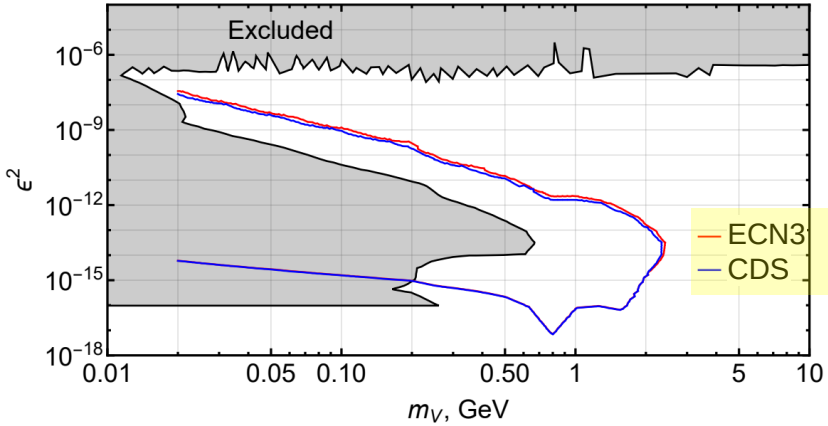
Neutrino DIS: 0.1 (fully) / 0.3 (partial)

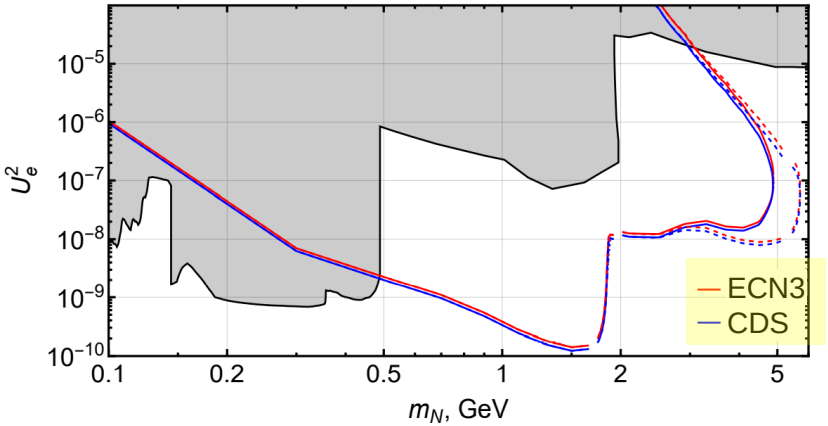
Preliminary: Ongoing studies with the reoptimisation in ECN3 confirm similar levels

Physics performance in decay search

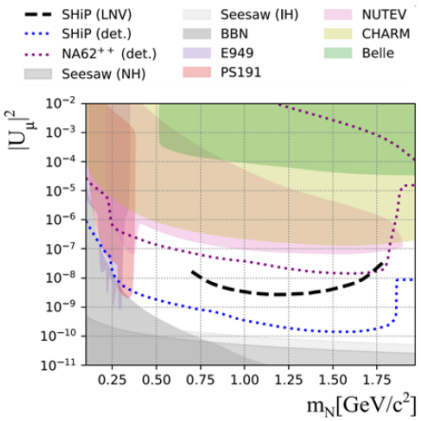


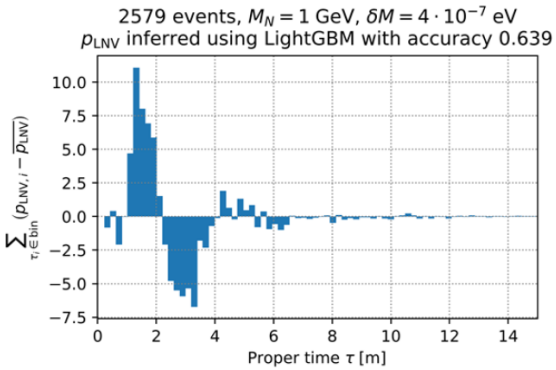
- Reoptimised experimental setup provides same signal acceptance
  - Preliminary results comparing ECN3 with original CDS design, here examples with Dark Photons and Heavy Neutral Leptons





ECN3 background estimates and signal acceptances preserves BDF/SHiP's physics perforamance

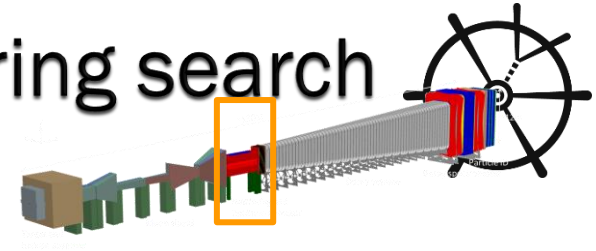




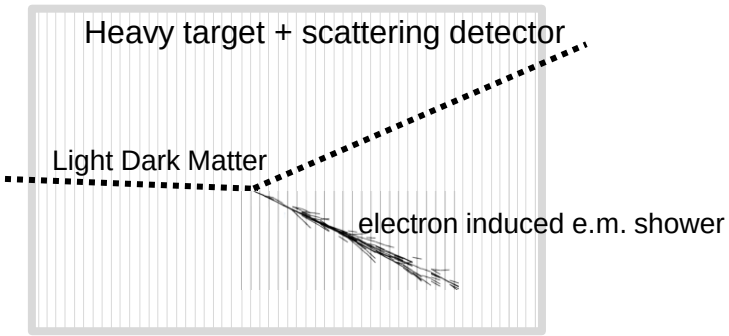
Left: lower bound on the SHiP sensitivity to HNL lepton number violation (black dashed line). Reconstructed oscillations between the lepton number conserving and violating event rates as a function of the proper time for a HNL with the parameters $M_N = 1\,\mathrm{GeV}/c^2$, $|U|_\mu^2 = 2 \times 10^{-8}$ and mass splitting of 4×10^{-7} eV.

J.-L. Tastet and I. Timiryasov, arXiv:1912.05520

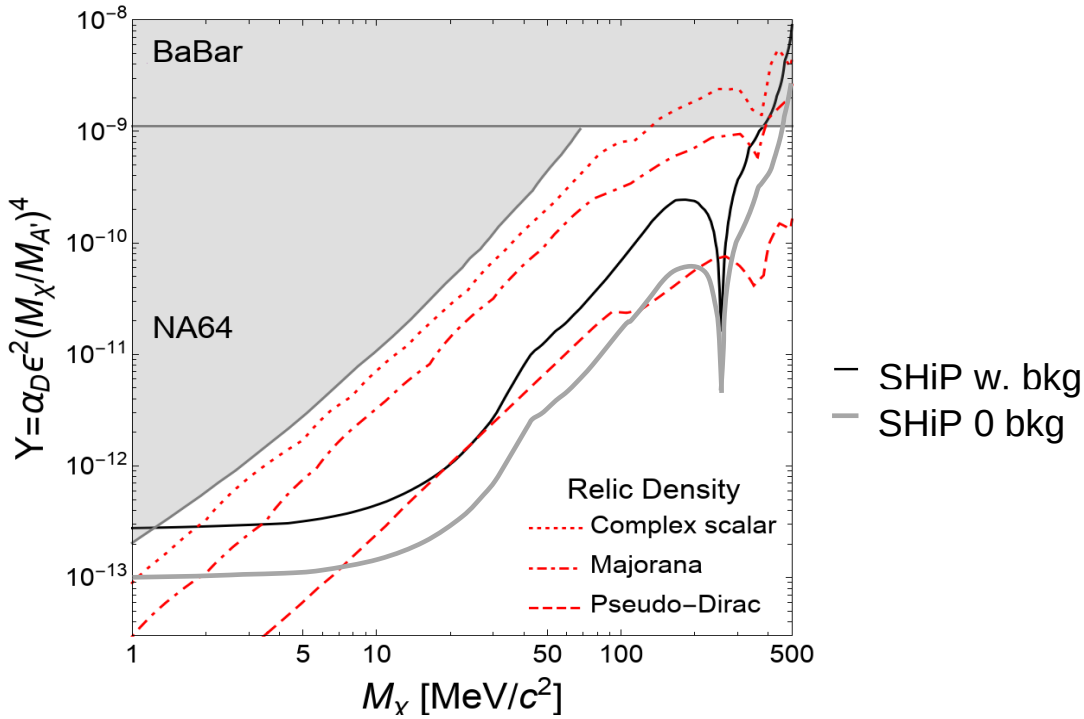
Physics performance in scattering search



- Backgrounds, e.g. $\nu_l + e^- \rightarrow \nu_l + e^-$, $\bar{\nu_e} + p \rightarrow n + e^+$, etc
- After combined geometrical, topological and kinematical selection, with one visible track at vertex being an electron: 230 expected events in 2x10^{20} protons on target in CDS study

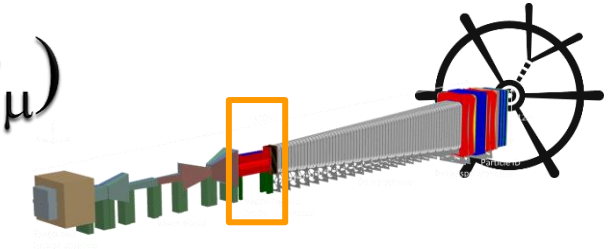


	ν_e	$\bar{\nu}_e$	ν_μ	$\bar{\nu}_\mu$	all
Elastic scattering on e^-	68	41	60	38	207
Quasi - elastic scattering	9	9			18
Resonant scattering	-	5			5
Deep inelastic scattering	-	-			-
Total	77	55	60	38	230



Under study for BDF/SHiP@ECN3, results underway

Prospects for ν_τ (ν_e, ν_μ)



- ν_τ most elusive particle in SM
  - DONUT experiment 9 events with 1.5 expected background
  - OPERA experiment 5 events from $\nu_\mu \rightarrow \nu_\tau$ oscillation
  - ➔ No distinction between ν_τ and $\bar{\nu}_\tau$
- Results from CDS study with 8-tonne scattering target & 2x10^{20} protons on target/5 years nominal operation

➔ Expected number of neutrino CC DIS

	$\langle E \rangle$ [GeV]	CC DIS interactions
N_{ν_e}	59	1.1×10^6
N_{ν_μ}	42	2.7×10^6
N_{ν_τ}	52	3.2×10^4
$N_{\bar{\nu}_e}$	46	2.6×10^5
$N_{\bar{\nu}_\mu}$	36	6.0×10^5
$N_{\bar{\nu}_\tau}$	70	2.1×10^4

➔ Expected number of observed $\nu_\tau/\bar{\nu}_\tau$ signal events

Decay channel	ν_τ	$\bar{\nu}_\tau$
$\tau \rightarrow \mu$	1200	1000
$\tau \rightarrow h$	4000	3000
$\tau \rightarrow 3h$	1000	700
Total	6200	4700

➔ Neutrino induced charm events

	<E> (GeV)	CC DIS with charm prod	Charm fractions (%)
N_{ν_μ}	55	1.3×10^5	4.7
N_{ν_e}	66	6.0×10^4	5.7
$N_{\bar{\nu}_\mu}$	49	2.5×10^4	4.2
$N_{\bar{\nu}_e}$	57	1.3×10^4	5.1
total		2.3×10^5	

Under study for BDF/SHiP@ECN3, results underway

Conclusion and outlook

- *Bright future for the Dark Sector*
  - Very much increased interest in feebly interacting particles after LHC Run 1
  - Vital complementarity to the advances and upcoming telescopes in astrophysics and cosmology

- BDF/SHiP is a mature general-purpose platform for exploration of feebly interacting particles
  - Set up for discovery through direct detection
  - Also unique opportunity for neutrino physics, in particular ν_τ

- Facility and physics case based on the current proton injector complex, SPS, and the existing ECN3 beam facility

- Detector R&D and design is at an advanced level
  - ➔ But many exciting developments still and looking forward to welcoming new groups!
  - ➔ SHiP collaboration: 55 institutes and 332 members

- Possible timeline
  - ECN3 Decision process 2022-2023
  - ~2-3 years for TDR, followed by preparation for construction, component production
  - Decommissiong/Consolidation/Modification/Installation of beamline & BDF/SHiP ~4-5 years starting from beginning LS3
  - Commissioning / operation from 2030

Backup slides

Decision process on ECN3 future programme

Decision Timeline for the Facility - SPSC

- **Produce list of candidate experiments for ECN3 (November 2022).**
  - By then **the experiments have submitted Letters of Intent.**
  - First discussion of these Letters of Intent in the November 2022 SPSC meeting.
  - Prepare first input on different experiment options to the December 2022 Research Board meeting.
- **First report by ECN3 Beam Delivery Taskforce (December 2022).**
  - To deliver document to IEFC on physics 'agnostic' feasibility for high-intensity facility in ECN3.
- **Final SPSC statement on meaningful physics justification for a high-intensity ECN3 facility (February 2023).**
  - Necessary input for next MTP, defined in March 2023 RB (including or not the high-intensity facility).
- **Research Board decision on go-ahead for launching preparatory work for high intensity beam to ECN3.**
  - Based on SPSC and IEFC inputs.
  - The accelerator sector must provide the upgrade plan for high-intensity beam delivery to ECN3.
- **Need more detailed information from the experiments (mid-late 2023).**
  - Full proposals (or at least provide sufficient details for a correct SPSC judgement).
- **Final SPSC conclusions on the experiments (November 2023).**
  - Recommendation on the future ECN3 physics program to the Research Board for final decision.

CERN management/SPSC/PBC

BDF/SHiP main documentation

References

[1] W. Bonivento, A. Boyarsky, H. Dijkstra, U. Egede, M. Ferro-Luzzi, B. Goddard, A. Golutvin, D. Gorbunov, R. Jacobsson, J. Panman, M. Patel, O. Ruchayskiy, T. Ruf, N. Serra, M. Shaposhnikov and D. Treille, *Proposal to Search for Heavy Neutral Leptons at the SPS*, Tech. Rep. CERN-SPSC-2013-024, SPSC-EOI-010, SPSC-EOI-010 [1310.1762], CERN, Geneva (Oct, 2013).

[2] G. Arduini, M. Calviani, K. Cornelis, L. Gatignon, B. Goddard, A. Golutvin, R. Jacobsson, J. Osborne, S. Roesler, T. Ruf, H. Vincke and H. Vincke, *A new Experiment to Search for Hidden Particles (SHIP) at the SPS North Area*, Tech. Rep. EDMS 1369559, EN-DH-2014-007 (July, 2014).

[3] SHiP collaboration, *A Facility to Search for Hidden Particles (SHiP) at the CERN SPS - Technical Proposal*, Tech. Rep. CERN-SPSC-2015-016, SPSC-P-350, SPSC-P-350, [1504.04956], CERN, Geneva (Apr, 2015).

[4] SHiP collaboration, *A Facility to Search for Hidden Particles (SHiP) at the CERN SPS (Addendum to Technical Proposal)*, Tech. Rep. CERN-SPSC-2015-040, SPSC-P-350-ADD-2, CERN, Geneva (Oct, 2015).

[5] G. Arduini, B. Goddard, L. Gatignon and K. Cornelis, *The SPS beam parameters, the operational cycle, and proton sharing with the SHiP facility*, Tech. Rep. CERN-SHiP-NOTE-2015-004, EDMS 1498984 (Mar, 2015).

[6] B. Goddard, M.A. Fraser, J. Borburgh, B. Balhan, G. Le Godec, M. Zerlauth, D. Tommasini, V. Kain, K. Cornelis, J. Wenninger, L. Jensen, B. Todd, J. Bauche and B. Puccio, *Extraction and beam transfer for the SHiP facility*, Tech. Rep. CERN-SHiP-NOTE-2015-005, EDMS 1495859 (Apr, 2015).

[7] M. Calviani, M. Battistin, R. Betemps, J.-L. Grenard, D. Horvath, A. Perillo Marcone, A.J. Rakai, R. Rinaldesi, S. Sgobba, C.C. Strabel, V. Venturi, H. Vincke, A.P. Perez and A. Pacholek, *Conceptual design of the SHiP Target and Target Complex*, Tech. Rep. CERN-SHiP-NOTE-2015-006, EDMS 1465053 (Apr, 2015).

[8] C.C. Strabel, H. Vincke and H. Vincke, *Radiation protection studies for the SHiP facility*, Tech. Rep. CERN-SHiP-NOTE-2015-007, EDMS 1490910 (Apr, 2015).

[9] J.A. Osborne and M. Manfredi, *Civil Engineering for the SHiP facility*, Tech. Rep. CERN-SHiP-NOTE-2015-008, EDMS1499253 (Mar, 2015).

[10] SHiP collaboration, *The experimental facility for the Search for Hidden Particles at the CERN SPS*, *Journal of Instrumentation* **14** (2019) P03025.

[11] H. Bartosik, G. Arduini, M.A. Fraser, L. Gatignon, B. Goddard, R. Jacobsson, V. Kain and E. Koukovini Platia, *SPS Operation and Future Proton Sharing scenarios for the SHiP experiment at the BDF facility*, Tech. Rep. CERN-ACC-NOTE-2018-0082, CERN-PBC-Notes-2021-008 (Dec, 2018).

[12] S. Alekhin et al., *A facility to search for hidden particles at the CERN SPS: the SHiP physics case*, *Reports on Progress in Physics* **79** (2016) 124201 [1504.04855].

[13] C. Ahdida et al., *SPS Beam Dump Facility - Comprehensive Design Study*, CERN Yellow Reports: Monographs, CERN, Geneva (Dec, 2019), 10.23731/CYRM-2020-002, [1912.06356].

[14] SHiP collaboration, *SHiP Experiment - Progress Report*, Tech. Rep. CERN-SPSC-2019-010, SPSC-SR-248, CERN, Geneva (Jan, 2019).

[15] SHiP collaboration, *SHiP Experiment - Comprehensive Design Study report*, Tech. Rep. CERN-SPSC-2019-049, SPSC-SR-263, CERN, Geneva (Dec, 2019).

[16] SHiP collaboration, *Sensitivity of the SHiP experiment to Heavy Neutral Leptons*, *JHEP* **04** (2019) 077 [1811.00930].

[17] SHiP collaboration, *Sensitivity of the SHiP experiment to dark photons decaying to a pair of charged particles*, *Eur. Phys. J. C* **81** (2021) 451 [2011.05115].

[18] SHiP collaboration, *Sensitivity of the SHiP experiment to light dark matter*, *JHEP* **04** (2021) 199 [2010.11057].

[19] T.E.S. Group, *Deliberation document on the 2020 Update of the European Strategy for Particle Physics*, Tech. Rep. CERN-ESU-014, Geneva (2020), DOI.

[20] *CERN Medium Term Plan 2021 - 2025*, Tech. Rep. CERN/SPC/1141/Rev., CERN/FC/6412/Rev., CERN/3499/Rev. (September, 2020).

[21] *BDF WG mandate*, 2021. https://pbc.web.cern.ch/bdf-mandate.

[22] *Memorandum of Understanding for the collaboration on the SPS Beam Dump Facility R&D programme*, February, 2022. https://edms.cern.ch/document/2708441.

[23] M. Ferro-Luzzi, *How the distance of the cavern walls affects the background rates*, Tech. Rep. CERN-SHiP-INT-2022-001 (Jan, 2022).

[24] *Safety code f rev. - radiation protection*, 2006. https://edms.cern.ch/document/335729.

[25] B. Balhan, P. Bestmann, D. Bjorkman, J. Borburgh, M. Butcher, M. Calviani, M. Di Castro, M. Donze, L.S. Esposito, M.A. Fraser, F. Galluccio, Y. Gavrikov, S. Gilardoni, B. Goddard, L.O. Jorat, A. Harrison, S. Hirlander, R. Jacobsson, V. Kain, I. Lamas Garcia, J. Lendaro, A. Masi, D. Mirarchi, M. Pari, J. Prieto Prieto, S. Redaelli, R. Rossi, W. Scandale, R. Seidenbinder, P. Serrano Galvez, L. Stoel, F.M. Velotti and C. Zamantzas, *Improvements to the SPS Slow Extraction for High Intensity Operation*, Tech. Rep. CERN-ACC-NOTE-2019-0010, CERN-PBC-Notes-2021-007 (Mar, 2019).

And most recently:

- **The SHiP experiment at the proposed CERN SPS Beam Dump Facility, EPJC 82, Article number: 486 (2022)**
- **Reconstruction of 400 GeV/c proton interactions with the SHiP-charm project, under internal review, to be submitted to EPJC**
- **BDF/SHiP Location and Layout Study, SPSC-2022-009**

Specific documentation

- Progress on slow extraction technique
  - *M.A. Fraser et al., Demonstration of slow extraction loss reduction with the application of octupoles at the CERN Super Proton Synchrotron, Phys. Rev. Accel. Beams 22, 123501 (2019)*
  - *B. Goddard et al., Reduction of 400 GeV/c slow extraction beam loss with a wire diffuser at the CERN Super Proton Synchrotron, Phys. Rev. Accel. Beams 23 (2020)*
  - *V. Kain et al., Resonant slow extraction with constant optics for improved separatrix control at the extraction septum, Phys. Rev. Accel. Beams 22, 101001 (2019)*
  - *F.M. Velotti et al., Septum shadowing by means of a bent crystal to reduce slow extraction beam loss, Phys. Rev. Accel. Beams 22, 093502 (2019)*

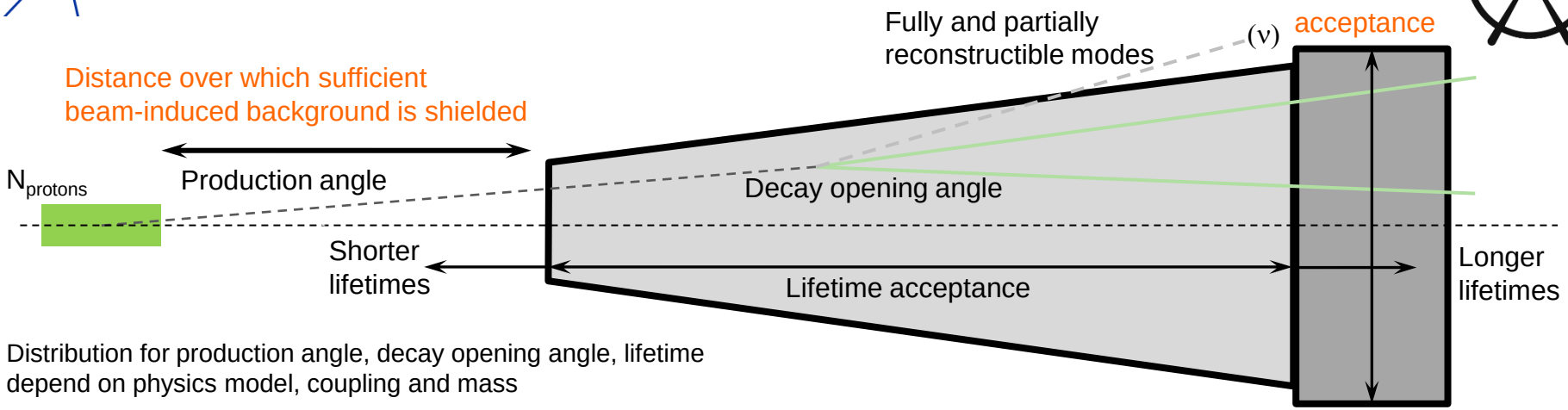
- Beam dynamics simulations of machine imperfections (power converter ripple etc.):
  - *M. Pari et al., Characterization of the slow extraction frequency response, Phys. Rev. Accel. Beams **24**, 083501 (2021)*
  - *P. A. Arrutia Sota et al., Millisecond burst extractions from synchrotrons using RF phase displacement acceleration, Nuclear Inst. and Methods in Physics Research, A 1039 (2022) 167007*

Specific documentation

- BDF/SHiP target
  - *E. Lopez Sola, M. Calviani, P. Avigni, M. Battistin, J. Busom Descarrega, J. Canhoto Espadanal, M. A. Fraser, S. Gilardoni, B. Goddard, D. Grenier, R. Jacobsson, K. Kershaw, M. Lamont, A. Perillo-Marcone, M. Pandey, B. Riffaud, S. Sgobba, V. Vlachoudis, and L. Zuccalli, Phys. Rev. Accel. Beams **22**, 113001 – Published 15 November 2019*
  - *Busom Descarrega, Josep & Calviani, Marco & Hutsch, Thomas & Sola, Edmundo & Perez Fontenla, Ana & Marcone, Antonio & Sgobba, Stefano & Weissgaerber, Thomas. (2020). Application of hot isostatic pressing (HIP) technology to diffusion bond refractory metals for proton beam targets and absorbers at CERN. Material Design & Processing Communications. 2. 10.1002/mdp2.193*
  - *E. Lopez Sola, M. Calviani, O. Aberle, C. Ahdida, P. Avigni, M. Battistin, L. Bianchi, S. Burger, J. Busom Descarrega, J. Canhoto Espadanal, E. Cano-Pleite, M. Casolino, M. A. Fraser, S. Gilardoni, S. Girod, J-L. Grenard, D. Grenier, M. Guinchard, C. Hessler, R. Jacobsson, M. Lamont, A. Ortega Rolo, M. Pandey, A. Perillo-Marcone, B. Riffaud, V. Vlachoudis, L. Zuccalli, Beam impact tests of a prototype target for the beam dump facility at CERN: Experimental setup and preliminary analysis of the online results, Physical Review Accelerators and Beams, 10.1103/PhysRevAccelBeams.22.123001, **22**, 12, (2019)*
  - *R. Franqueira Ximenes et al., "CERN BDF Prototype Target Operation, Removal and Autopsy Steps", in Proc. IPAC'21, Campinas, SP, Brazil, May 2021, pp. 3559-3562. doi:10.18429/JACoW-IPAC2021-WEPAB365*

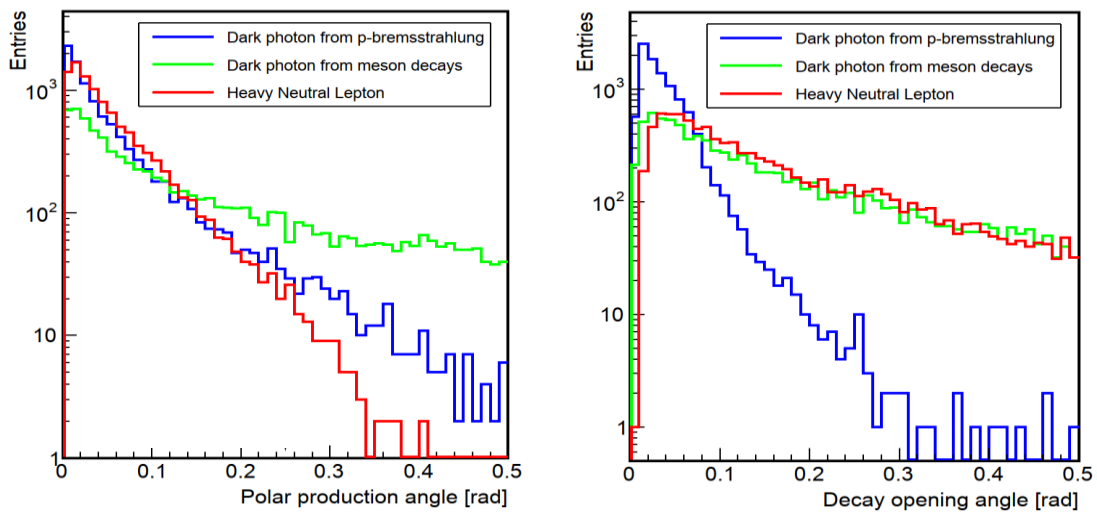
- Radioprotection
  - *[1] Website: https://fluka.cern*
  - *[2] C. Ahdida, D. Bozzato, D. Calzolari, F. Cerutti, N. Charitonidis, A. Cimmino, A. Coronetti, G. L. D'Alessandro, A. Donadon Servelle, L. S. Esposito, R. Froeschl, R. García Alía, A. Gerbershagen, S. Gilardoni, D. Horváth, G. Hugo, A. Infantino, V. Kouskoura, A. Lechner, B. Lefebvre, G. Lerner, M. Magistris, A. Manousos, G. Moryc, F. Ogallar Ruiz, F. Pozzi, D. Prelipcean, S. Roesler, R. Rossi, M. Sabaté Gilarte, F. Salvat Pujol, P. Schoofs, V. Stránský, C. Theis, A. Tsinganis, R. Versaci, V. Vlachoudis, A. Waets, M. Widorski, New Capabilities of the FLUKA Multi-Purpose Code, Frontiers in Physics 9, 788253 (2022)*
  - *[3] G. Battistoni, T. Boehlen, F. Cerutti, P.W. Chin, L.S. Esposito, A. Fassò, A. Ferrari, A. Lechner, A. Empl, A. Mairani, A. Mereghetti, P. Garcia Ortega, J. Ranft, S. Roesler, P.R. Sala, V. Vlachoudis, G. Smirnov, Overview of the FLUKA code, Annals of Nuclear Energy 82, 10-18 (2015)*
  - *[4] V. Vlachoudis, FLAIR: A Powerful But User Friendly Graphical Interface For FLUKA, in Proc. Int. Conf. on Mathematics, Computational Methods & Reactor Physics (M&C 2009), Saratoga Springs, New York (2009)*

Detector optimization for ECN3

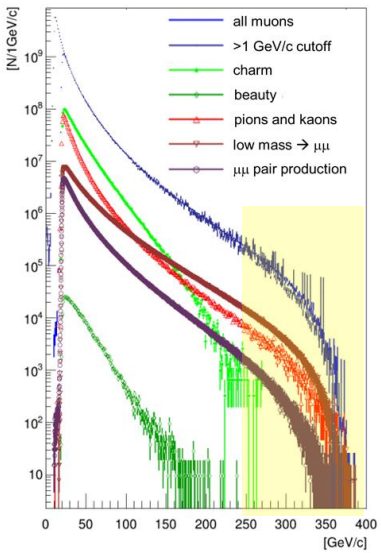


Distribution for production angle, decay opening angle, lifetime depend on physics model, coupling and mass

Production angles and decay opening angles (1 GeV/c^2 HNL and DP)



Muon spectrum for 5x10^{13} protons on target



- ➔ Reduction in transversal size compensated by shortening distance to target
  - ➔ Effectively on muon shield
  - ➔ Background suppression is combined effect of upstream shielding ⊗ detector ~ "working point"

History of the “NAHIF” and ECN3

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH

CERN/SPS/EA 77-2

CERN/SPSC/77-72
SPSC/T-18
16 August 1977

The SPS North Area High Intensity Facility

N A H I F

A Review of the Project and of Possible Beams

G. Brianti, N. Doble

5. RADIATION PROBLEMS

Assuming that the direct use of the protons in ECN 3 will be the exception rather than the rule, most of the problems of radiation dose to components and induced activity will be in TCC 8, in a well-defined region between the target(s) and the proton dump(s). The total number of protons lost there in a given period will be comparable to that for the neutrino beams, but the total running time in a calendar year may be somewhat less.

Remanent dose rates ranging from 1 to 10 rem/h are to be expected in the most exposed places, but decaying rapidly toward 100 to 10 mrem/h outside the shielded section alongside the beam.

Measures to cope with this situation are :

- A beam layout devised to localize radiation problems in areas as distant as possible from access points,
- Collimation and shielding of critical elements,
- Crane with remote handling possibilities,
- Plug-in systems (improved) for all elements in exposed areas,
- 'Automatic' vacuum connections (under study),
- Cable runs, terminal boxes, pipes and valves located in a service gallery for maximum protection against radiation damage to the cables and for easing the work of personnel,
- Recirculatory (closed loop) ventilation system,
- Local closed-loop demineralised-water circuits for cooling the most heavily irradiated elements,
- Tools for handling at distance the most critical components (under study),
- Local protections of intervention personnel to be put in place when needed (under study).

*) Corresponding to a radiation dose rate of $\sim$ 0.1 mrem/h for 10^{13} protons per pulse every 10 seconds.

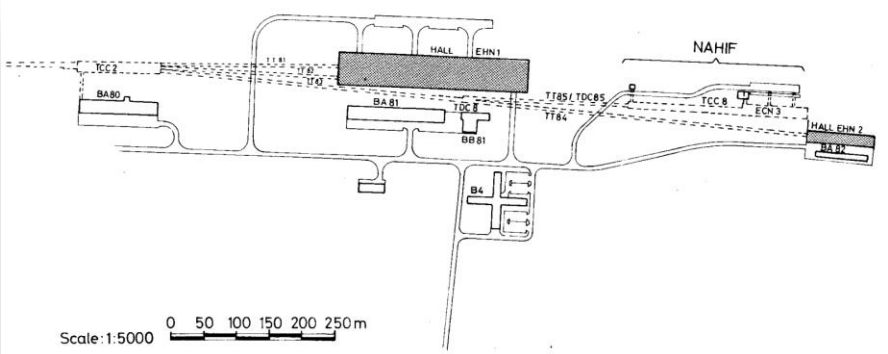


Fig:1-SPS NORTH EXPERIMENTAL AREA

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However, a word of caution is appropriate. Some of the above items have yet to be designed and, subsequently, they would have to be tested in order to prove their suitability. The experience with the neutrino tunnel suggests modesty and caution in this field. Nevertheless, one of the elements most lacking in the neutrino tunnel, namely space, is more generous in this case and should normally allow for far better solutions. Well thought-out intervention procedures should also be of great help.

ACKNOWLEDGEMENTS

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