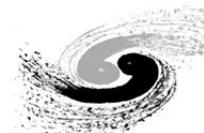


SHiP

Search for Hidden Particles



中国科学院高能物理研究所
Institute of High Energy Physics, CAS

研究生教育

Search for Hidden Particles (SHiP/NA67) experiment at the SPS Beam Dump Facility

HI ← ECN3

Note that many plots and results come from work in progress

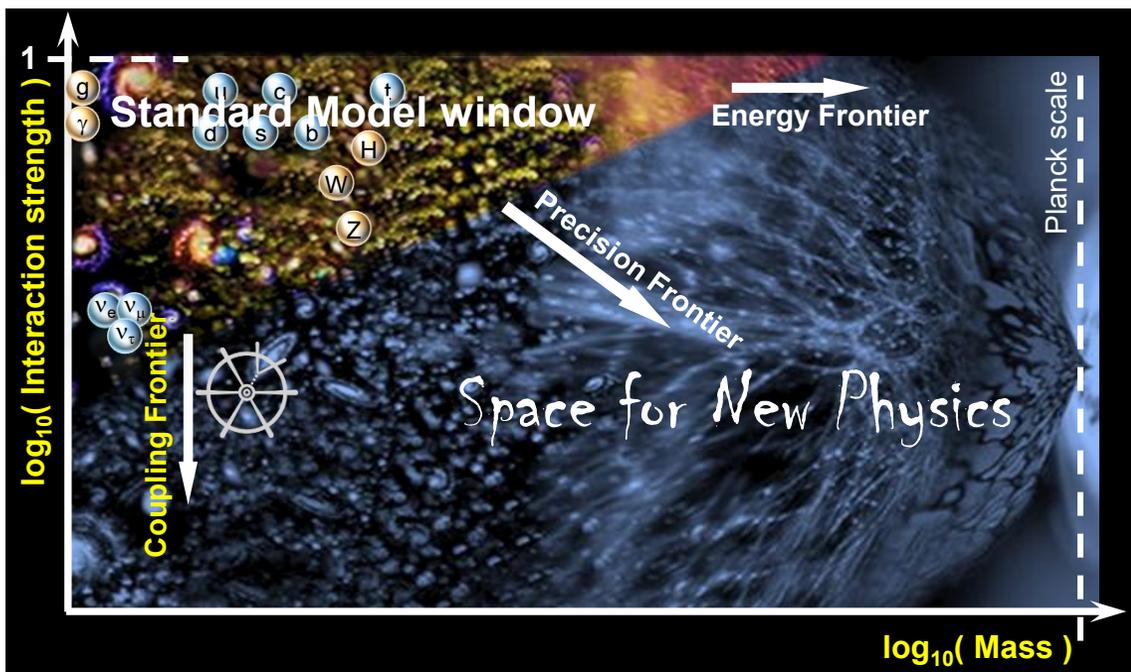
[BDF/SHiP at the ECN3 high-intensity beam facility - Technical Proposal 2023](#)

[BDF/SHiP Annual Report 2025](#)

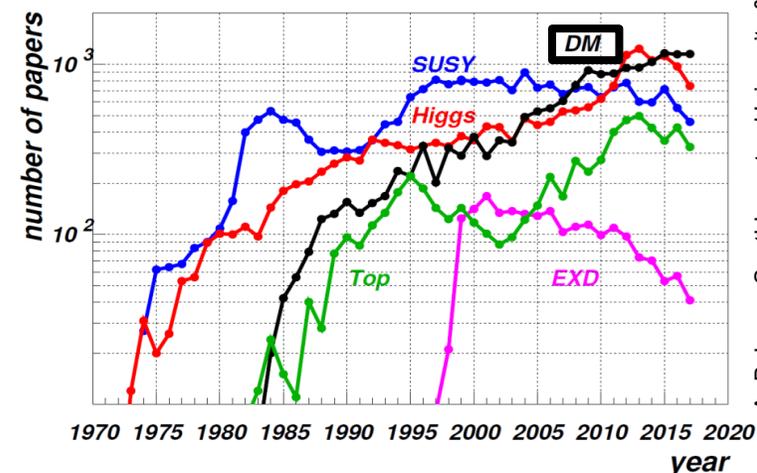
Challenge accepted



- Outstanding *observed features* that SM does not resolve, and with no experimental hints / guidance so far!
 - Precision cosmology: Evidence for dark matter is overwhelming
 - Neutrino oscillation: Mass hints to new potentially weak fields
 - Baryon flavour precision: Absence of explanation for matter-antimatter asymmetry
- New Physics** should either be very heavy *OR* interact very feebly to have escaped detection!



“Coupling Frontier” : Any Particles engaging in Feeble Interactions (FIPs) with the SM particles



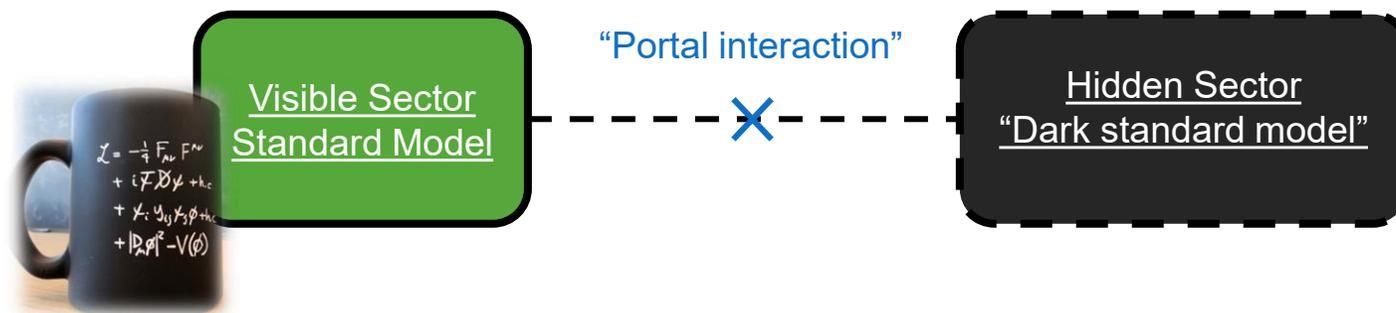
➔ Sharing the Universe already with feebly coupled, not-understood neighbours...!

Standard Model mass scale is particularly interesting to explore... – we know for sure it exists!....



- Standard Model gives us tools to implement Hidden Sector with well-defined phenomenology

$$\mathcal{L} = \mathcal{L}(\psi_{SM}, A_{SM}, H_{SM})_{dim \leq 4} + \sum_{d > 4} \frac{c_n^{(d)}}{\Lambda_{NP}^{d-4}} \mathcal{O}^{(d)} + \mathcal{L}_{portal} + \mathcal{L}(\psi_{HS}, A_{HS}, H_{HS})$$

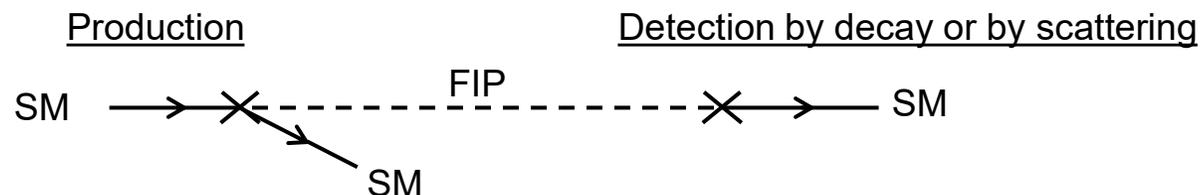


Portal interactions may “drive” dynamics observed in the Visible Sector!

- Dark Matter (trivial)
- Neutrino mass and oscillations
- Baryon asymmetry
- Hierarchy and naturalness
- Structure formation
- Inflation and Dark Energy
-

→ Plethora of alternative SM extensions!

Profiting from “portal” coupling at accelerator!





Composite operators as “portals” :

⊙ **D = 2: Vector portal**

- Kinetic mixing with massive dark/secluded/paraphoton A' : $\frac{1}{2} \varepsilon F_{\mu\nu}^{SM} F_{HS}^{\mu\nu}$
- ➔ Motivated in part by idea of “mirror world” restoring L/R symmetry, dark matter,, ...

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- ➔ Mass to Higgs boson and mass generation in dark sector, inflaton, dark phase transitions BAU, dark matter,...

⊙ **D = 5/2: Neutrino portal**

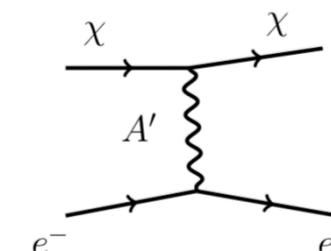
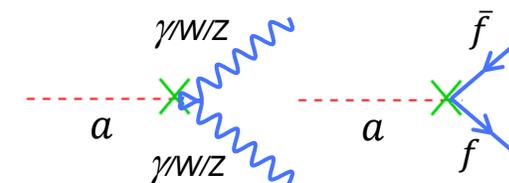
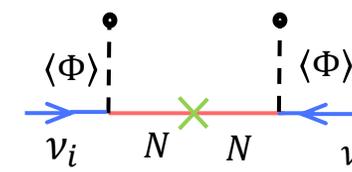
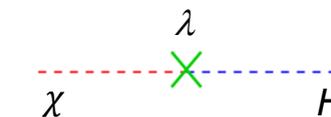
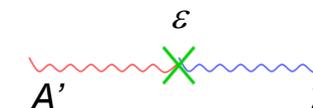
- Mixing with right-handed neutrino N (Heavy Neutral Lepton): $Y_{I\ell} H^\dagger \bar{N}_I L_\ell$
- ➔ Neutrino oscillation and mass, baryon asymmetry, dark matter

⊙ **D = 4: Axion portal**

- Mixing with Axion Like Particles, pseudo-scalars pNGB : $\frac{a}{F} G_{\mu\nu} \tilde{G}^{\mu\nu}, \frac{\partial_\mu a}{F} \bar{\psi} \gamma_\mu \gamma_5 \psi$, etc
- ➔ Generically light pseudo-scalars arise in spontaneous breaking of approximate symmetries at a high mass scale F
- ➔ Extended Higgs, SUSY breaking, dark matter, possibility of inflaton,...

⊙ **Light dark matter χ interpretation of scattering signatures**

⊙ **Also light SUSY** (Neutralino, sgoldstino, axino, saxion, hidden photinos...)



New Physics prospects in Hidden Sector



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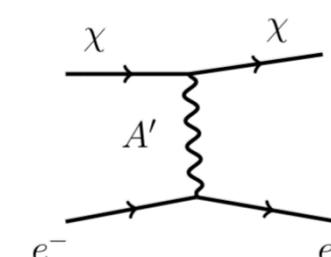
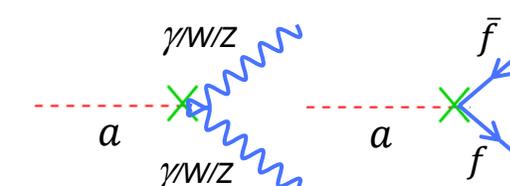
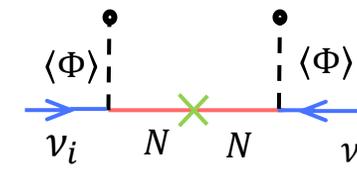
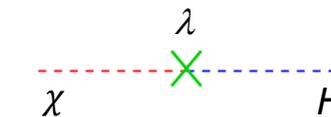
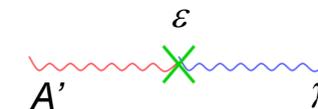
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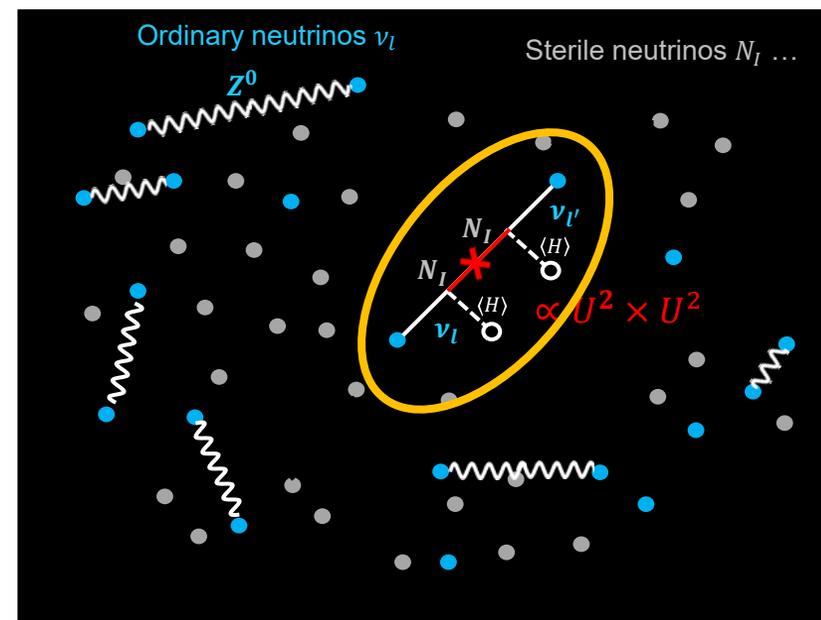
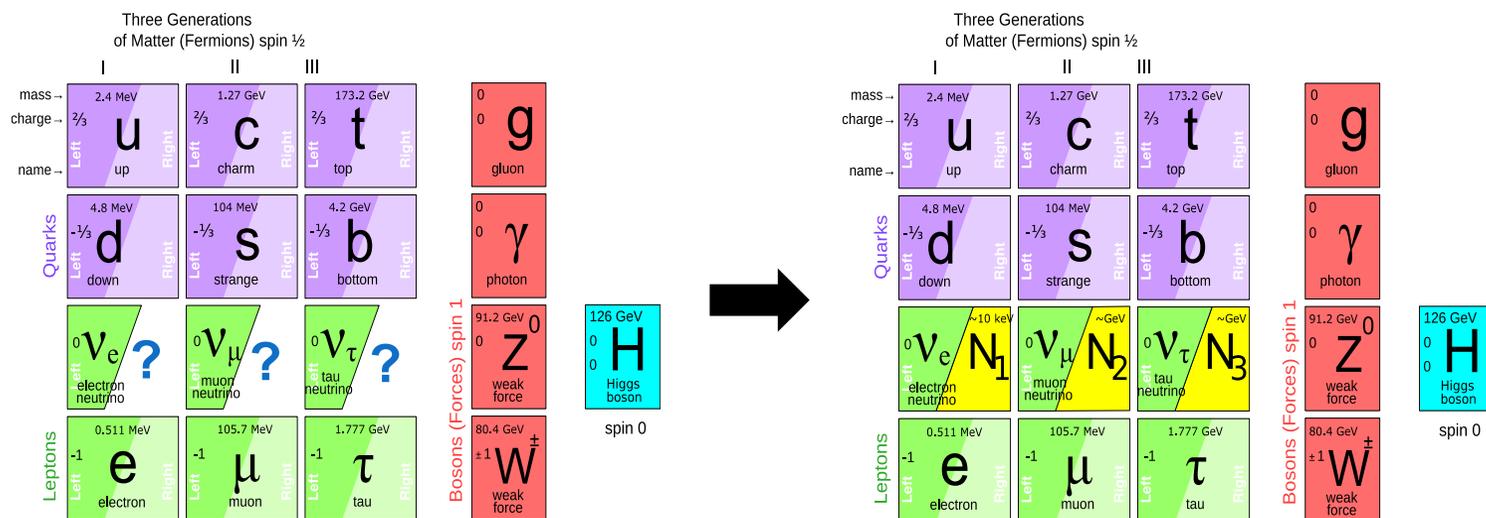
➔ As portals they are classes of generic “models”, not models by themselves!



A particular case: Making neutrinos count!



- Introduce three right-handed Majorana fermions N_I with mass $M_I^R \equiv$ "Heavy Neutral Leptons (HNL)"



- "Portal" through neutrino Yukawa coupling with right-handed neutrinos

$$\mathcal{L} = \mathcal{L}_{SM} + \sum_{\substack{I=1,2,3; \\ \ell=1,2,3(e,\mu,\tau)}} i\bar{N}_I \not{\partial} \gamma^\mu N_I - Y_{I\ell} H^\dagger \bar{N}_I L_\ell - M_I^R \bar{N}_I N_I^c + h.c$$

$\mathcal{L}_{Majorana\ mass}$
 $\mathcal{L}_{Dirac\ mass} = \frac{y_f \langle H \rangle}{\sqrt{2}} (\bar{\psi}_L \psi_R + \bar{\psi}_R \psi_L), \langle H \rangle = v \sim 174\text{ GeV}$

Minkowski 1977
 Yanagida 1979
 Gell-Mann, Ramond, Slansky 1979
 Glashow 1979

where L_ℓ are the lepton doublets, H is the Higgs doublet, and $Y_{I\ell}$ are the corresponding new Yukawa couplings

→ Lepton flavour violating term results in mixing between N_I and SM active neutrinos

NOTE: Discovery of Higgs vital for this extension!



- Neutrino mass matrix with both Dirac and Majorana masses

$$\mathcal{L}_{mass} = \frac{y_i \langle H \rangle}{\sqrt{2}} (\bar{\nu}_L N_R + \bar{N}_R \nu_L) + m_L^M \bar{N}_L^c N_L + m_R^M \bar{N}_R^c N_R + h.c. = [\bar{\nu}_L, \bar{N}_R^c] \begin{bmatrix} m_L^M & m_D \\ m_D & m_R^M \end{bmatrix} \begin{bmatrix} \nu_L \\ N_R^c \end{bmatrix} + h.c.$$

- With Majorana mass scale $M^R \gg m_D (= Y_{I\ell} v)$ obtain mass eigenstates

→ Active neutrino mass $\tilde{m}_1 \sim \frac{(Y_{I\ell} v)^2}{M_I^R} = \frac{m_D^2}{M^R} \sim m_\nu$

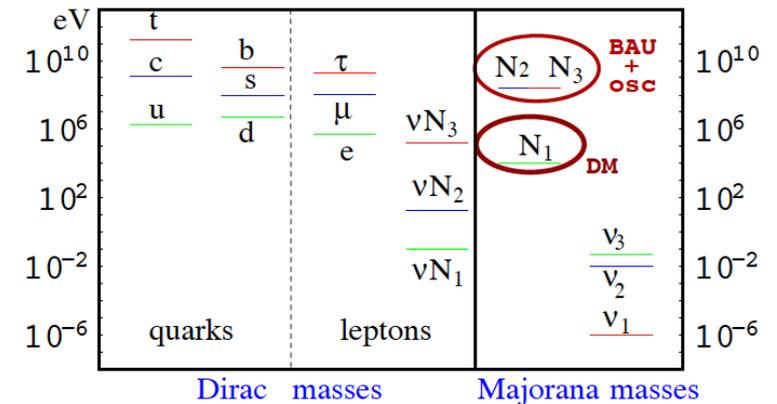
→ Heavy singlet fermion mass $\tilde{m}_2 \sim M^R \left(1 + \frac{m_D^2}{M^{R^2}}\right) \sim M^R \sim M_N$

→ See-saw mechanism (type-I)

- Effective mixing between N_I and active neutrino $\mathcal{U}_{I\ell} = \frac{Y_{I\ell} v}{M_I^R} \sim \frac{m_D}{M^R}$

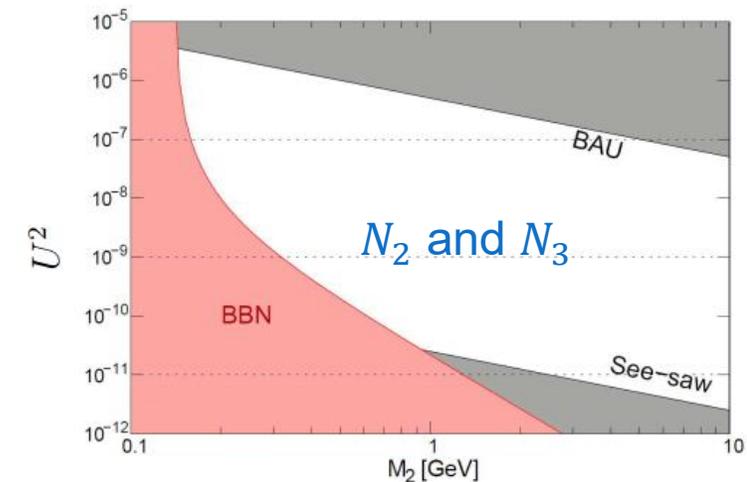
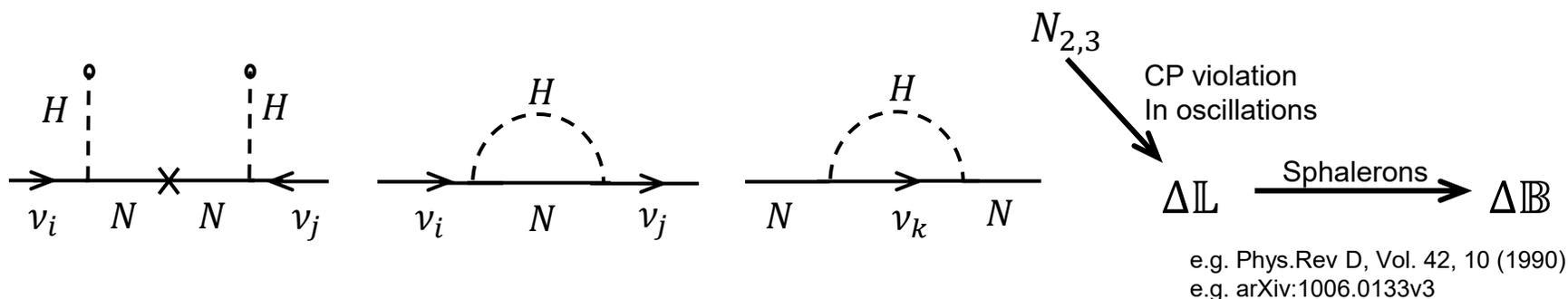
→ Total coupling $\mathcal{U}^2 = \sum_{\substack{I=1,2,3 \\ \ell=1,2,3(e,\mu,\tau)}} \frac{v^2 |Y_{\ell I}|^2}{m_I^{R^2}} \sim \mathcal{O}\left(\frac{m_\nu}{M_N}\right) > 5 \times 10^{-11} / M_N [GeV]$ (“seesaw line”)

No new energy scale!

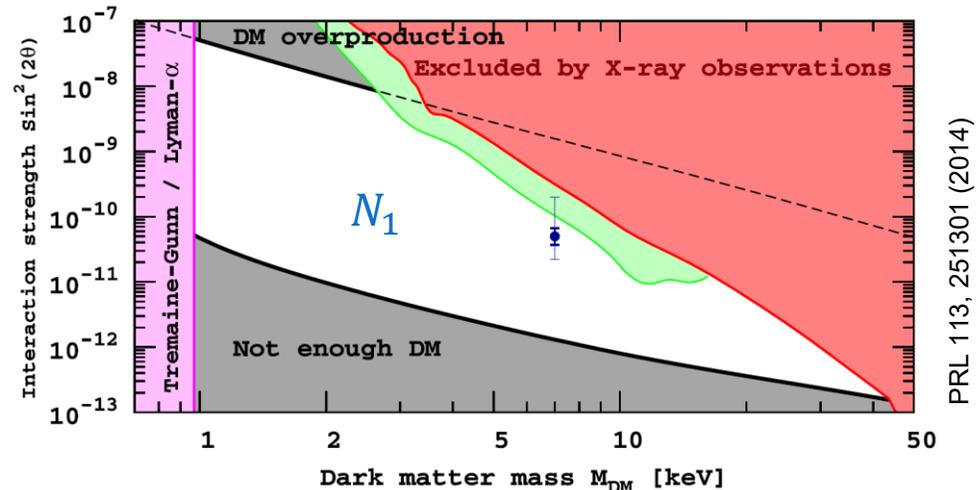
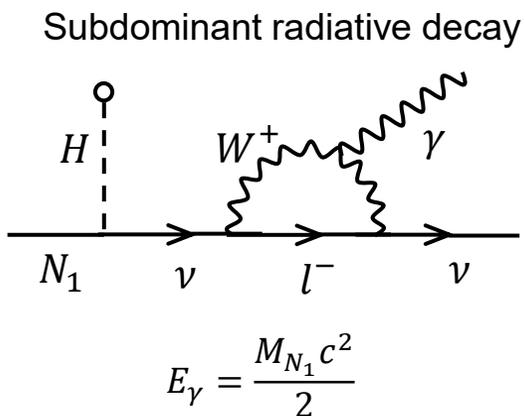




- N_2 and N_3 with degenerate mass of $\mathcal{O}(m_q/m_{l^\pm})$ (100 MeV – GeV) responsible for neutrino oscillation and tiny masses and extra CP violation through interference in oscillation leading to leptogenesis \rightarrow baryogenesis



- N_1 with very small coupling and a mass of $\mathcal{O}(\text{keV})$ as Dark Matter!

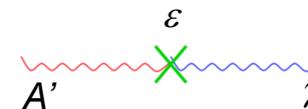




Composite operators as “portals” :

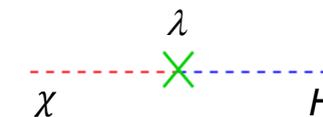
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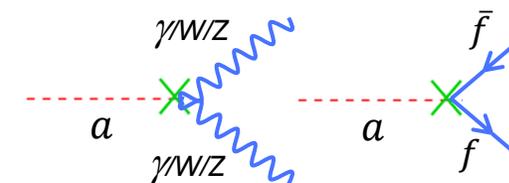


Bottom line: We need large production of $\gamma, q/g, c, b, W, Z, H$!

- Neutrino oscillation and mass, baryon asymmetry, dark matter

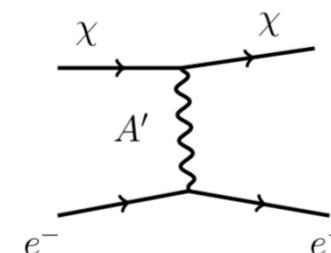
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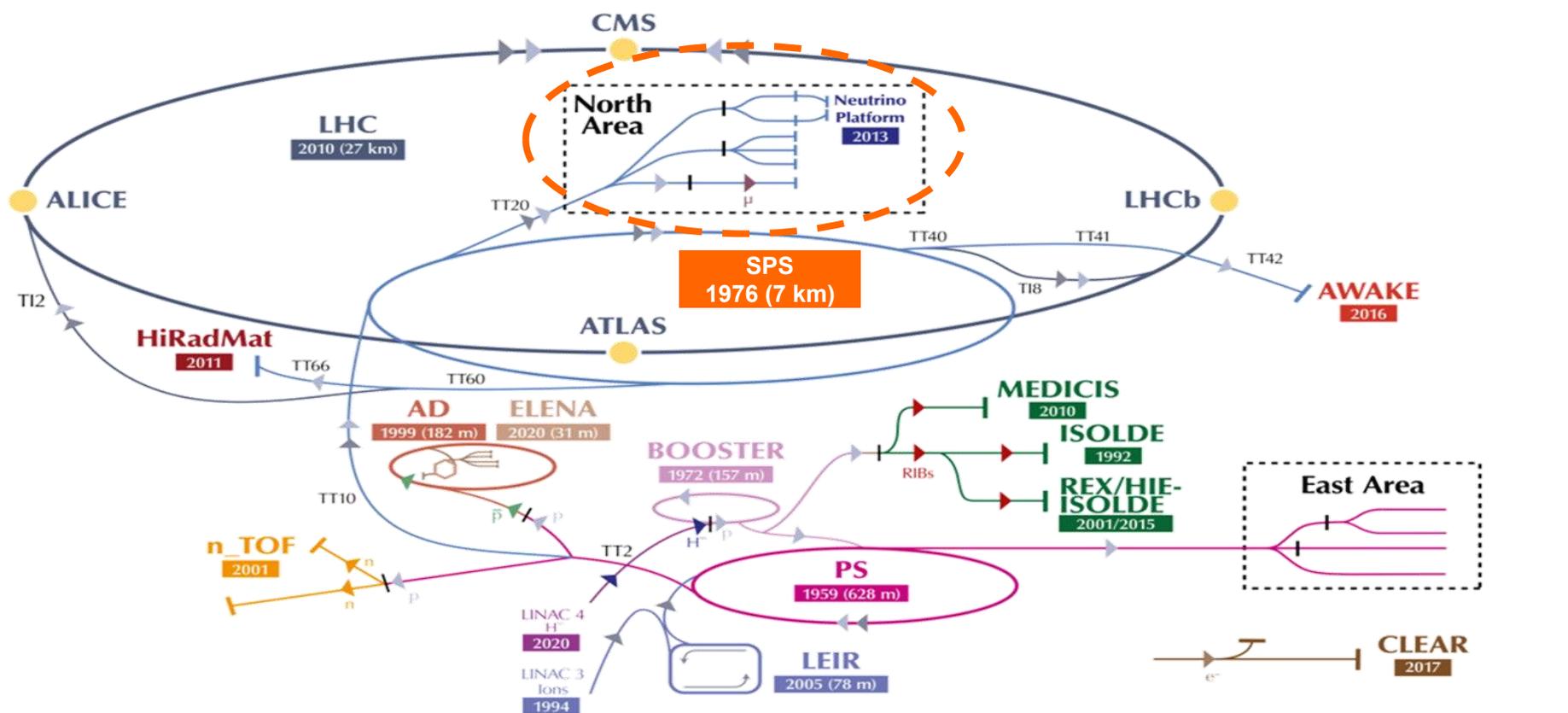


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⊙ **Light dark matter χ interpretation of scattering signatures**



CERN accelerator complex



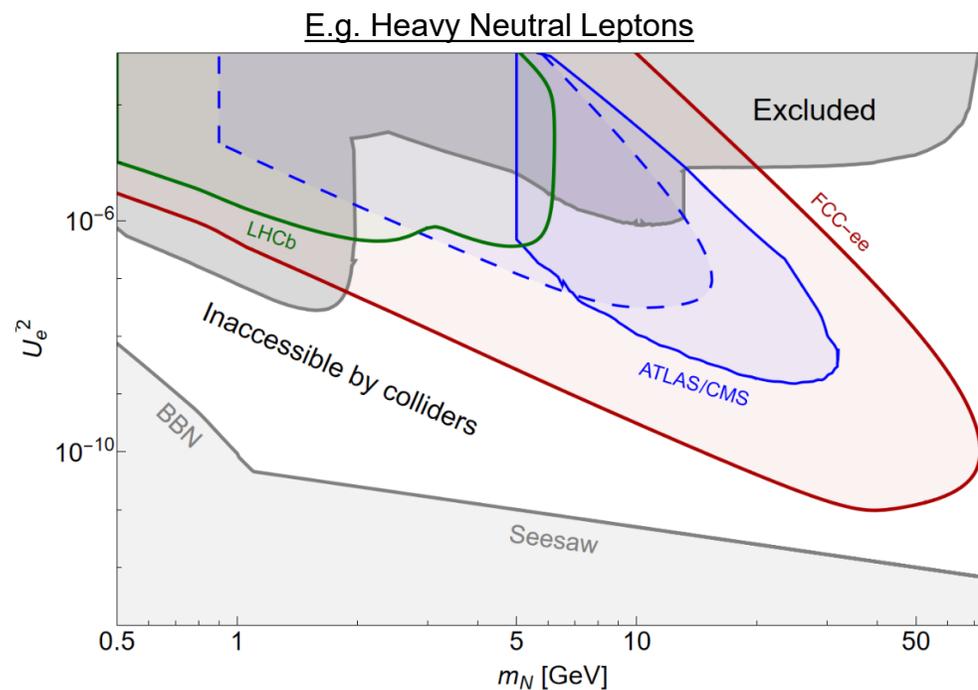
▶ H^- (hydrogen anions) ▶ p (protons) ▶ ions ▶ RIBs (Radioactive Ion Beams) ▶ n (neutrons) ▶ \bar{p} (antiprotons) ▶ e^- (electrons) ▶ μ (muons)

LHC - Large Hadron Collider // SPS - Super Proton Synchrotron // PS - Proton Synchrotron // AD - Antiproton Decelerator // CLEAR - CERN Linear Electron Accelerator for Research // AWAKE - Advanced WAKEfield Experiment // ISOLDE - Isotope Separator OnLine // REX/HIE-ISOLDE - Radioactive EXperiment/High Intensity and Energy ISOLDE // MEDICIS // LEIR - Low Energy Ion Ring // LINAC - LINear ACcelerator // n_TOF - Neutrons Time Of Flight // HiRadMat - High-Radiation to Materials // Neutrino Platform

© 2017 CERN



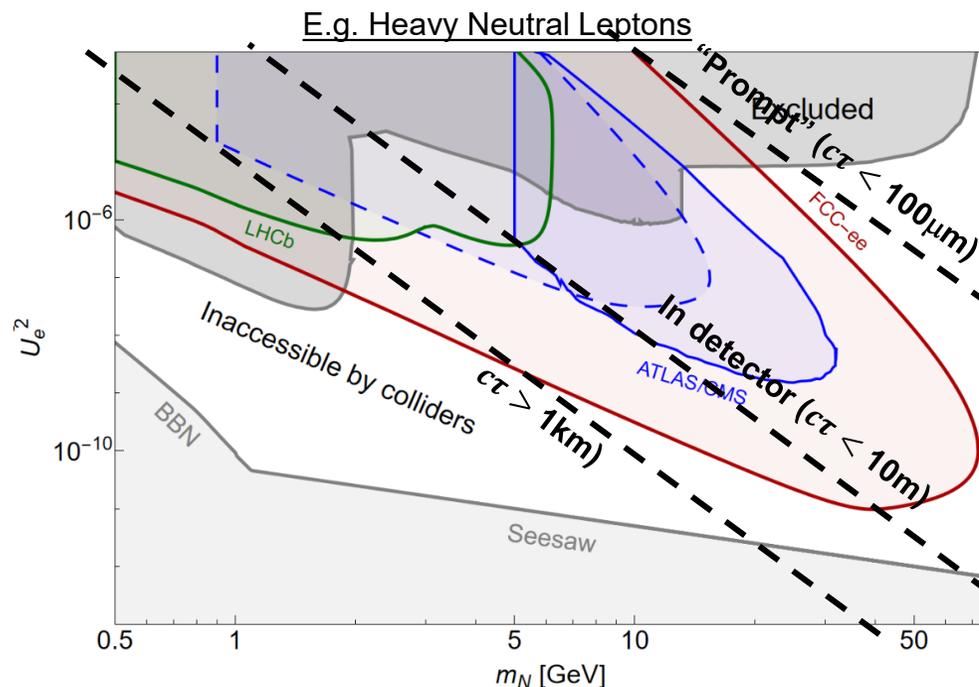
- SPS accelerator energy and intensity unique to explore FIPs
 - SPS energy and intensity provide huge production of charm, beauty and electromagnetic processes
 - Large lifetime acceptance with beam-dump setup - production modes in limited forward cone



- Return CERN SPS accelerator to full exploitation of unique physics potential
 - SHiP Physics Proposal compiled and signed by a collaboration of 80 theorists: [Rep. Prog. Phys. 79 \(2016\)124201](#)



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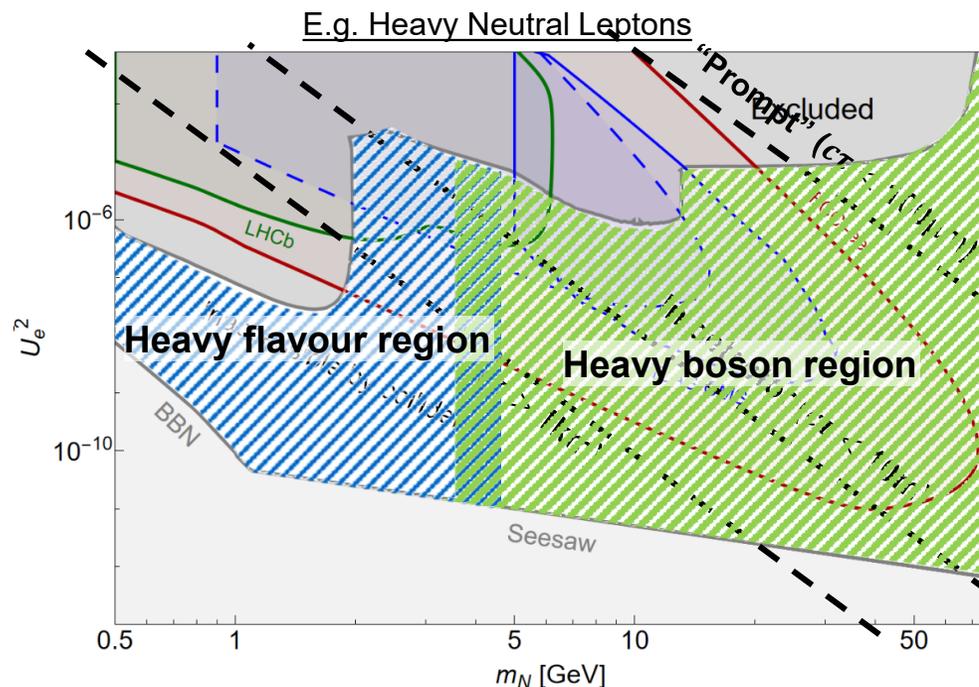
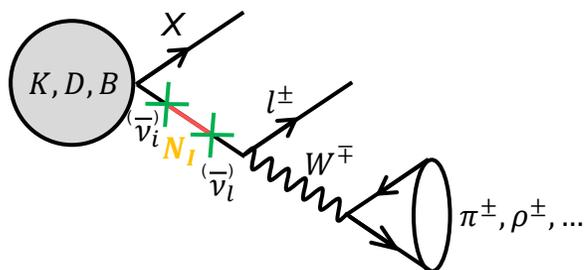


Similar behaviour $\tau_{FIP} \propto \frac{1}{\epsilon_{FIP}^x m_{FIP}^y}$
for all types of FIPs

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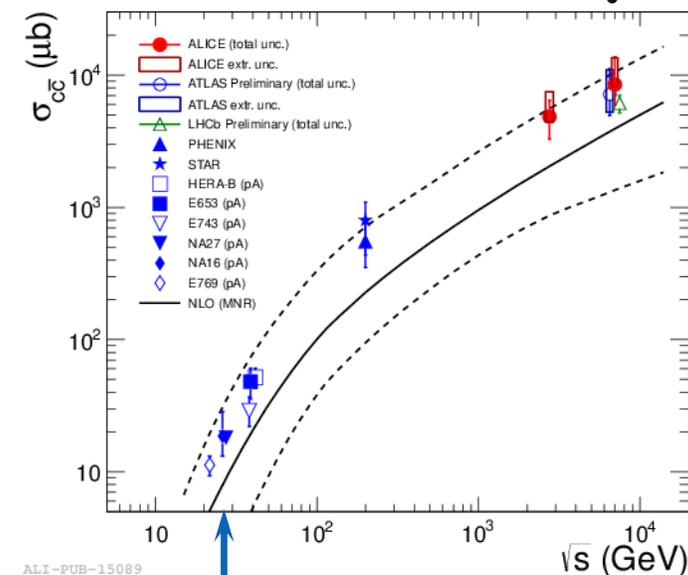
→ BDF luminosity with the **long high-A/Z target** and 4×10^{19} protons on target per year *currently available* in SPS

→ BDF@SPS $\mathcal{L}_{int} [year^{-1}] = >4 \times 10^{45} \text{ cm}^{-2}$

→ HL-LHC $\mathcal{L}_{int} [year^{-1}] = 10^{42} \text{ cm}^{-2}$

→ BDF/SHiP *annually* access to yields inside detector acceptance:

- $\sim 2 \times 10^{17}$ charmed hadrons (>10 times the yield at HL-LHC)
- $\sim 2 \times 10^{12}$ beauty hadrons
- $\sim 2 \times 10^{15}$ tau leptons
- $\mathcal{O}(10^{20})$ photons above 100 MeV
- Large number of neutrinos *detected* with 3t-W ν -target:
 $3500 \nu_\tau + \bar{\nu}_\tau$ per year, and $2 \times 10^5 \nu_e + \bar{\nu}_e / 7 \times 10^5 \nu_\mu + \bar{\nu}_\mu$ despite target design



SHiP @ $\sqrt{s} = 27 \text{ GeV}$

**Direct New Physics searches
For Hidden Sector and LDM**

**Standard Model measurements
and BSM with neutrinos**



From proposal to approval



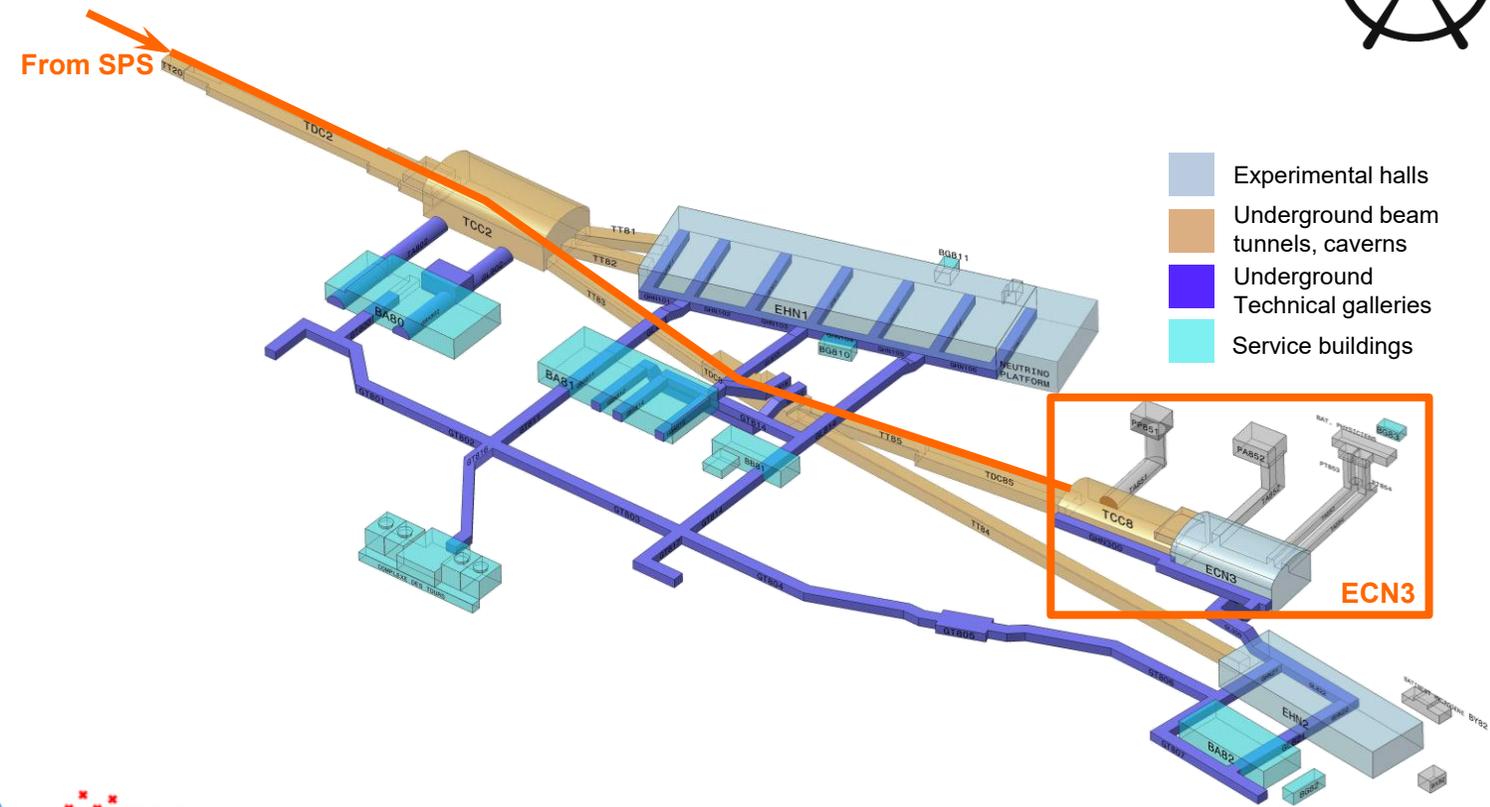
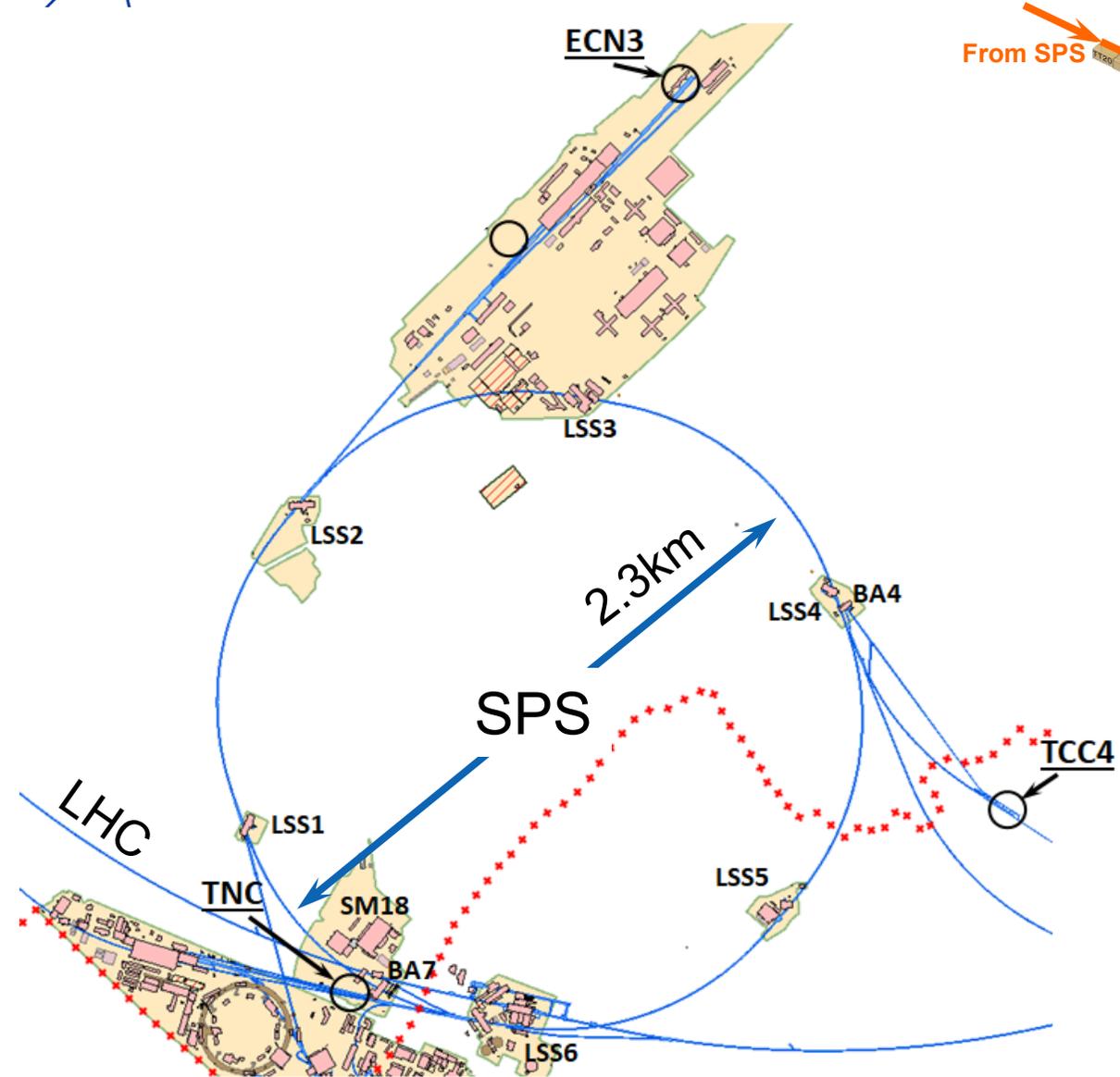
- **2013 Oct:** Seminal paper with the first proposal by a group of 16 researchers

The collage shows the following documents:

- 2013 Oct:** Technical Proposal and Physics Proposal for the SHiP experiment.
- 2014 Jan:** Engineering Department Report, Technical Proposal Annex 1, and Safety reports.
- 2015:** Technical Proposal Annex 2, 3, and 4, and various safety and health reports.
- 2016 Jan:** Comprehensive Design Study (CDS) Report for the SHiP experiment.
- 2022:** Executive Summary and SHiP Experiment Design Study Report.

- **2014 Jan:** Immediate support from CERN management to form collaboration and prepare technical proposal
- **2016 Jan:** Technical proposal accepted and recommendation to proceed to Comprehensive Design Study (CDS) of the Beam Dump Facility (BDF) for SHiP and the experiment
- **2019 Dec:** CDS reports on Beam Dump Facility and SHiP experiment submitted to CERN's committees
- **2020 Sep:** CERN launches BDF/SHiP study towards implementation in existing experimental area at CERN
- **2024 Jun:** Approval of BDF and SHiP for implementation in the SPS ECN3 area
 - HI-ECN3 project to implement BDF: 62 MCHF + consolidation of CERN's North Area in Long Shutdown 3 and 4 (170 MCHF)

SHiP @ SPS ECN3 beam facility

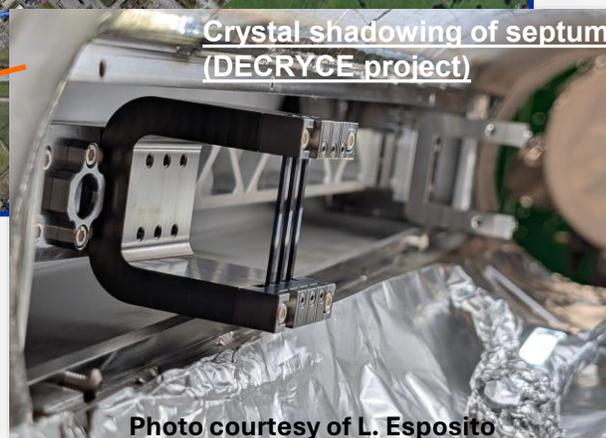
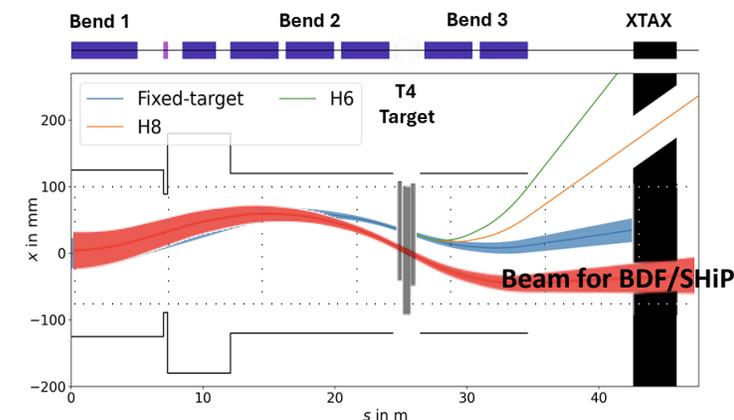
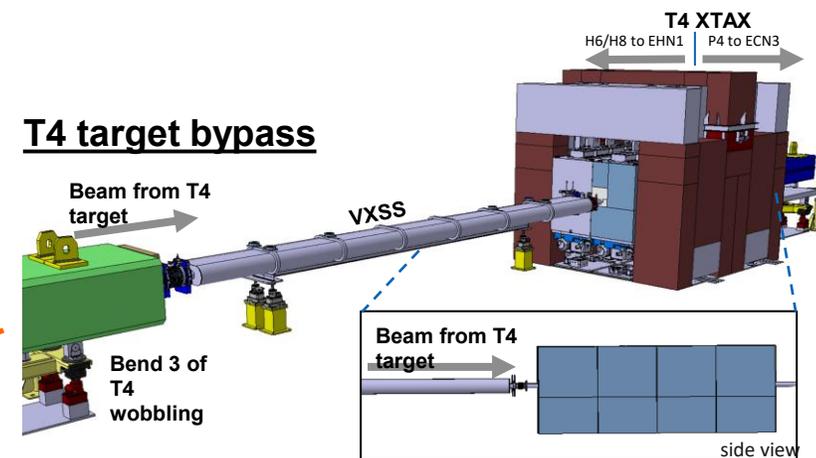
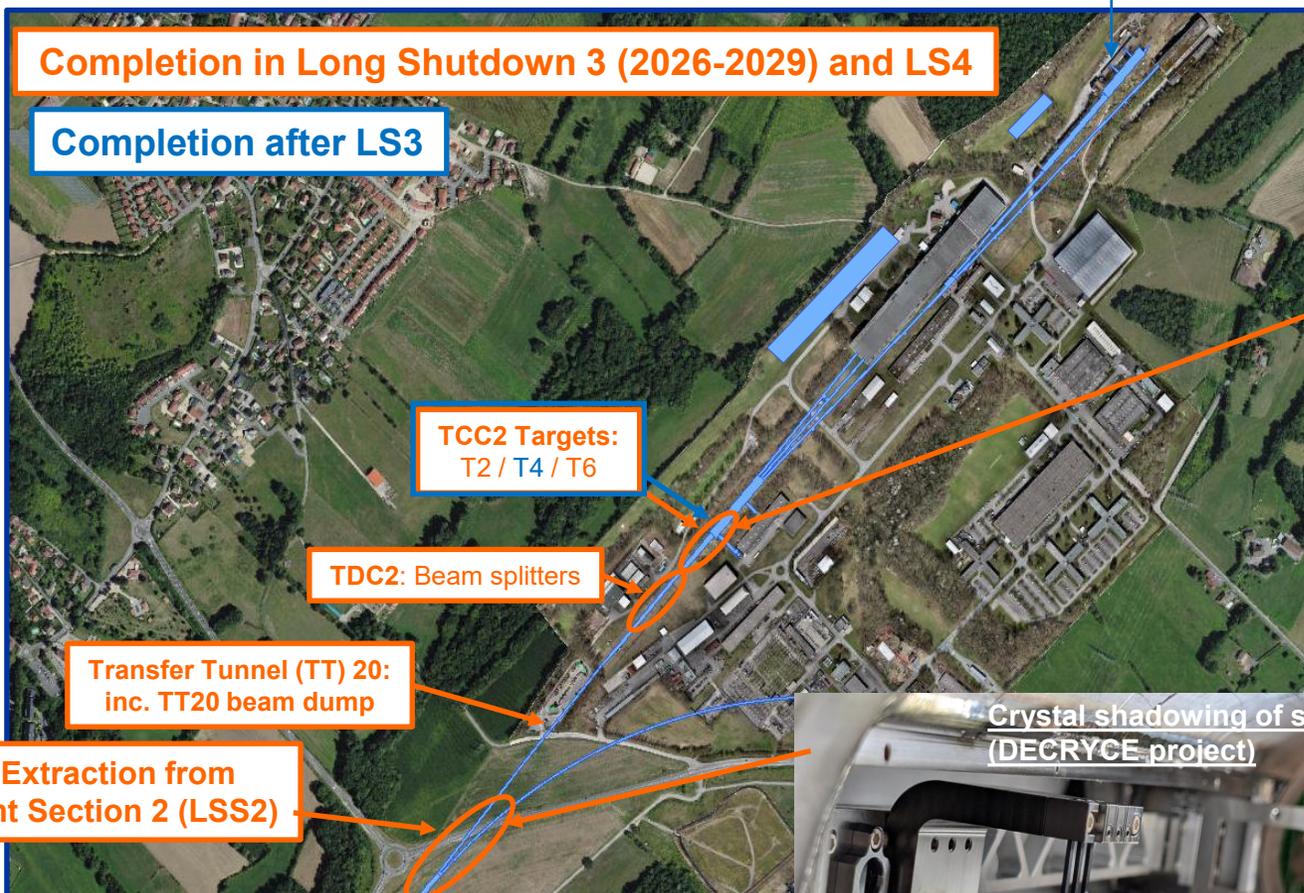


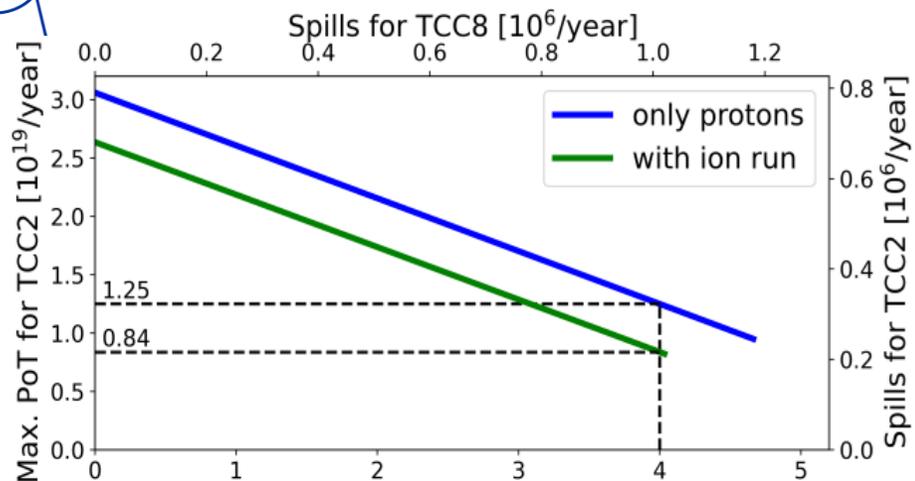
- Experimental halls
- Underground beam tunnels, caverns
- Underground Technical galleries
- Service buildings

Nominal Design Parameter	Value
Beam type	proton
Beam momentum [GeV/c]	400
Beam pulse intensity [$\times 10^{13}$ p]	4.0
Spill length [s]	1

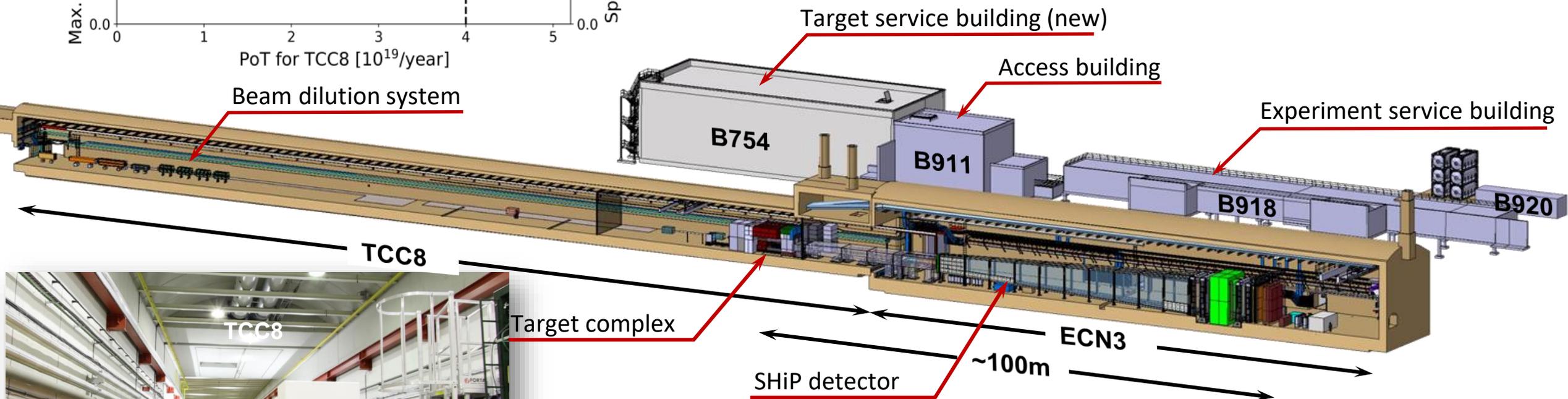
— NA-CONS consolidation project

— HI-ECN3 project





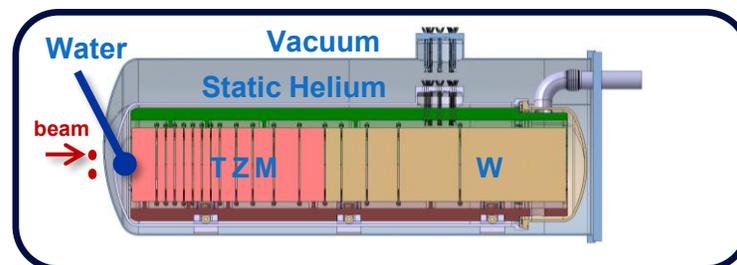
4×10^{19} protons per year at 400 GeV available



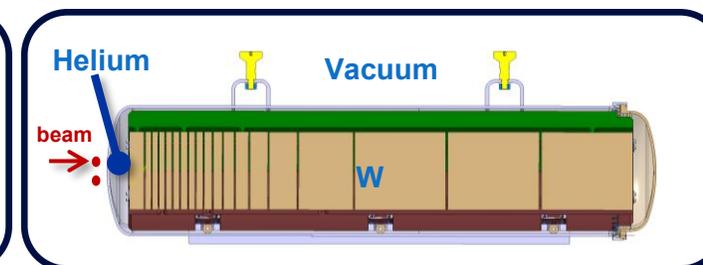
Long high-A/Z target = beam dump

Parameter	Value	Unit
Proton momentum	400	GeV/c
Nominal beam intensity	4e13	POT/spill
Total cycle length	7.2	s
Spill duration	1.0	s
Circular dilution radius	50	mm
Beam sigma (H,V) [10]	16,16	mm
Thermal power deposited in target	305	kW
Expected target lifetime	2e20	POT

Water cooled



Helium cooled



<https://doi.org/10.1103/PhysRevAccelBeams.22.113001>

Water Cooling

- Inner vessel with circulated water (~ 22 bar)
- Outer vessel with static Helium (~ 1 bar)

Dimensions and materials

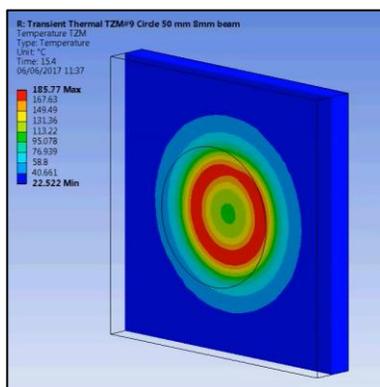
- Mass: ~2 tons (~0.9 tons of blocs)
- T ZM and W Blocks all clad in Ta2.5W
- If chosen, design would be increased in length.

Helium Cooling

- Vessel with circulated helium (~ 16 bar, 25/200 °C)

Dimensions and materials

- Total mass: ~2.3 tons (~1.3 tons of blocs)
- W blocks, maybe clad Ta or Nb or other



Sep 2025: Full tungsten target prototype

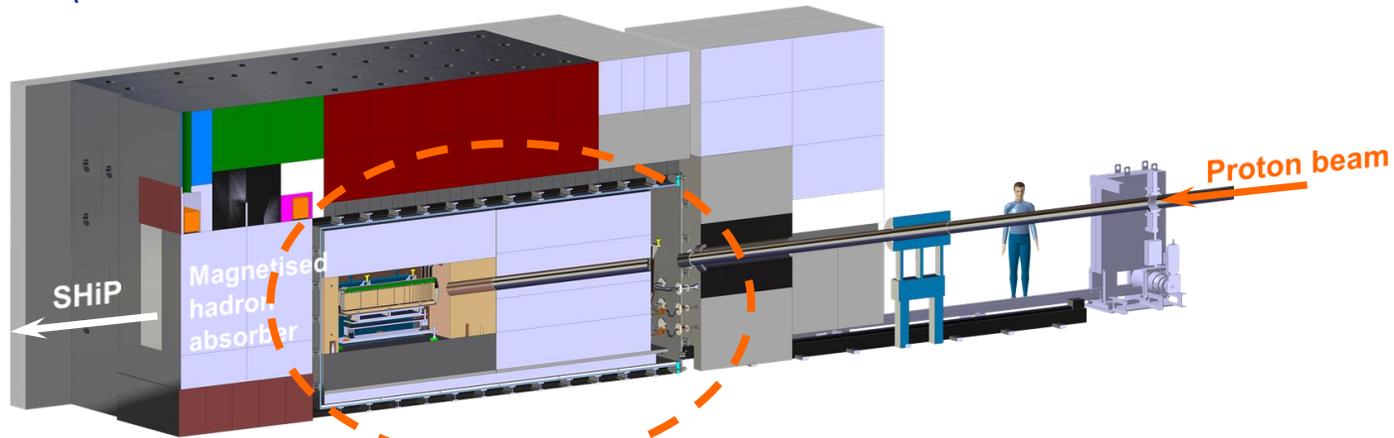
In preparation for beam tests during SPS Machine Development Sep-Nov



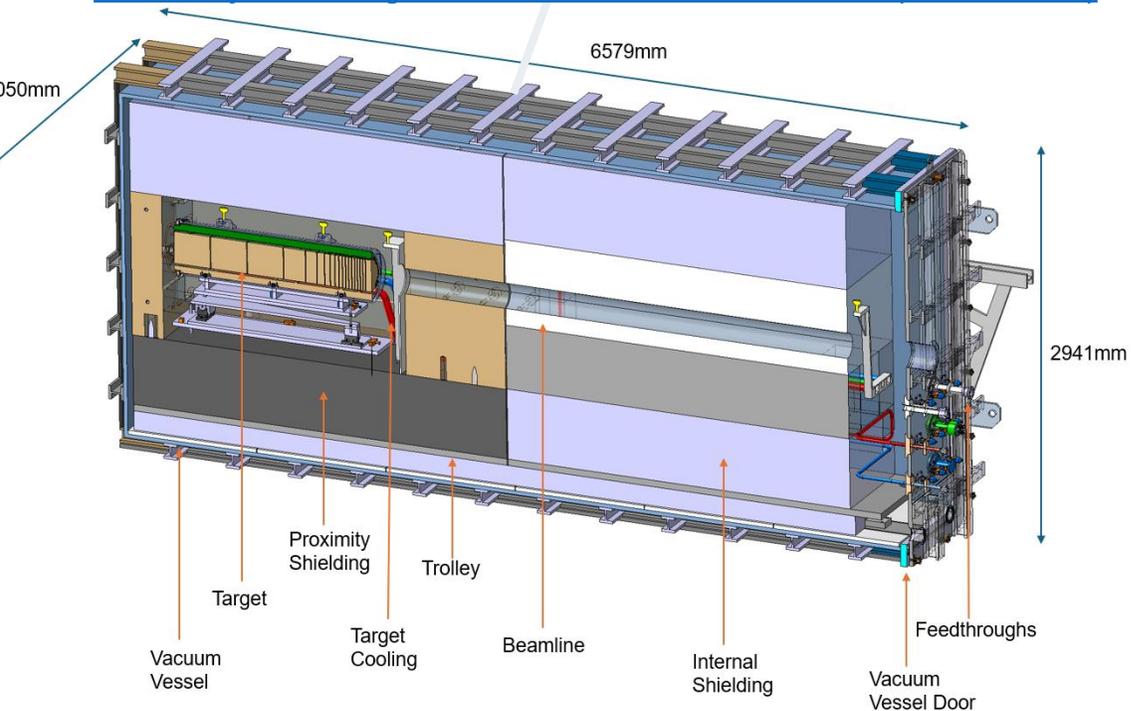
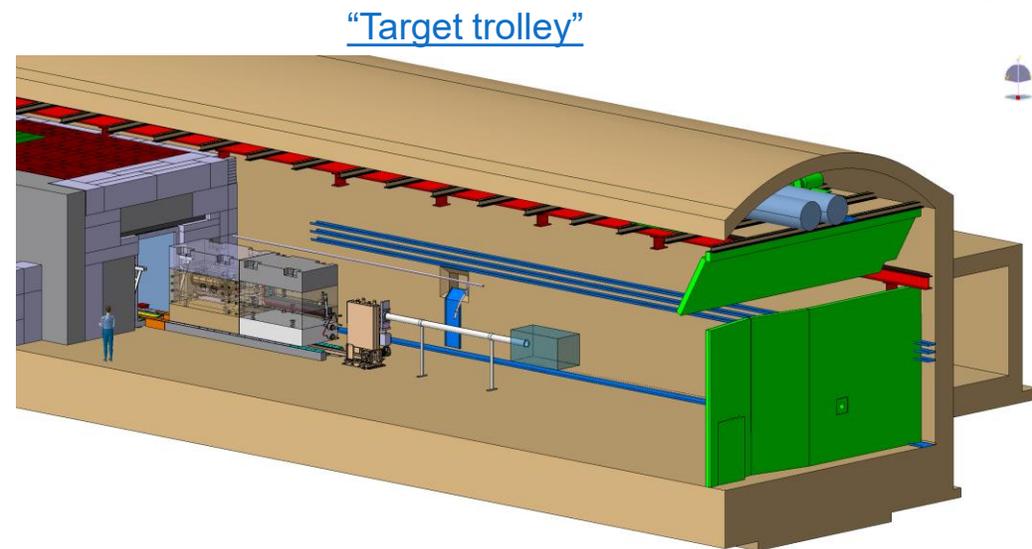
Installation of prototype target for beam tests



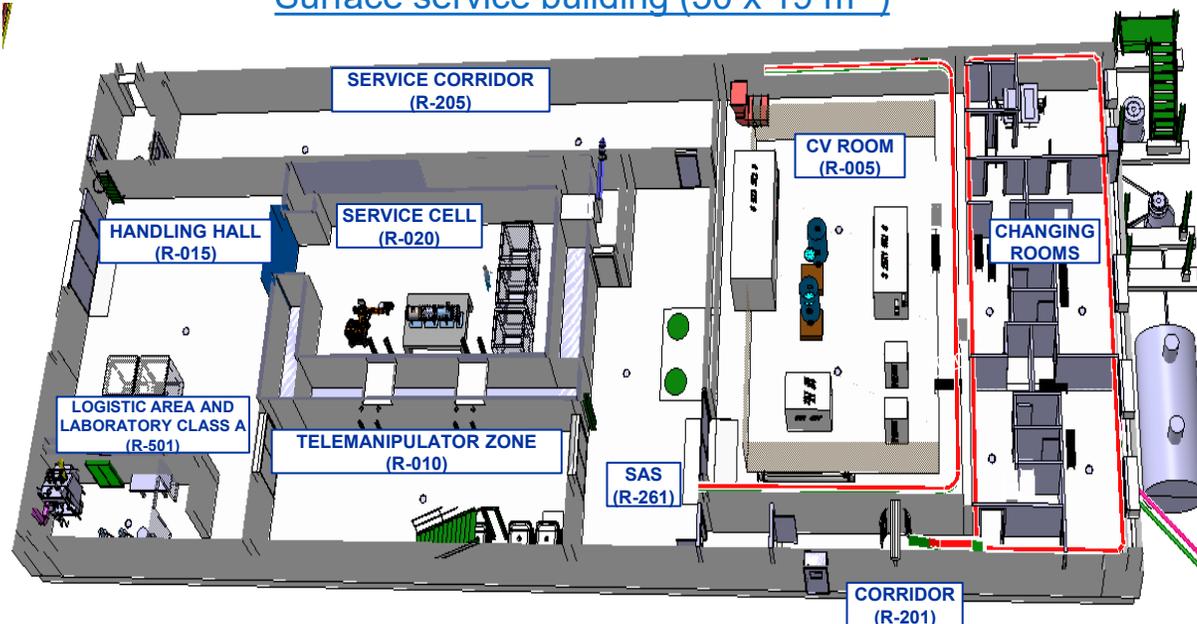
Jan 2026: Extracted W blocks for PIE



Proximity shielding embedded in vacuum vessel ($\sim 10^{-3}$ mbar)



Surface service building (50 x 19 m²)



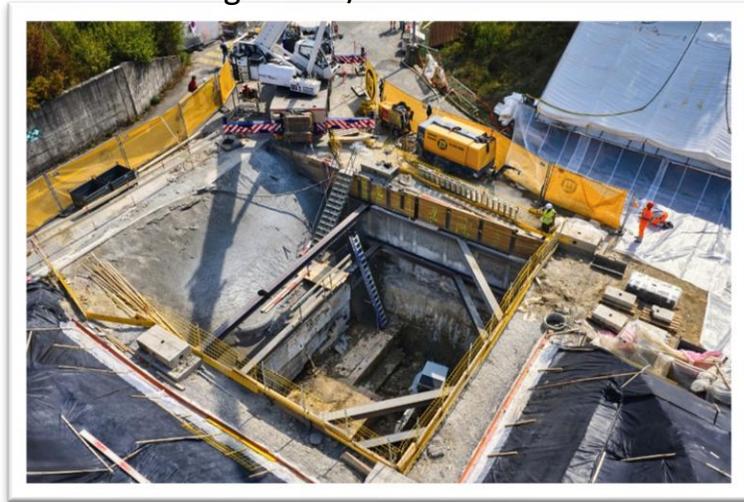
May - July 2025: Ground-breaking at ECN3 for BDF/SHiP:

Rerouting of service trench to make space for the construction of the new BDF target complex service building 754 and installation of new access door to 911



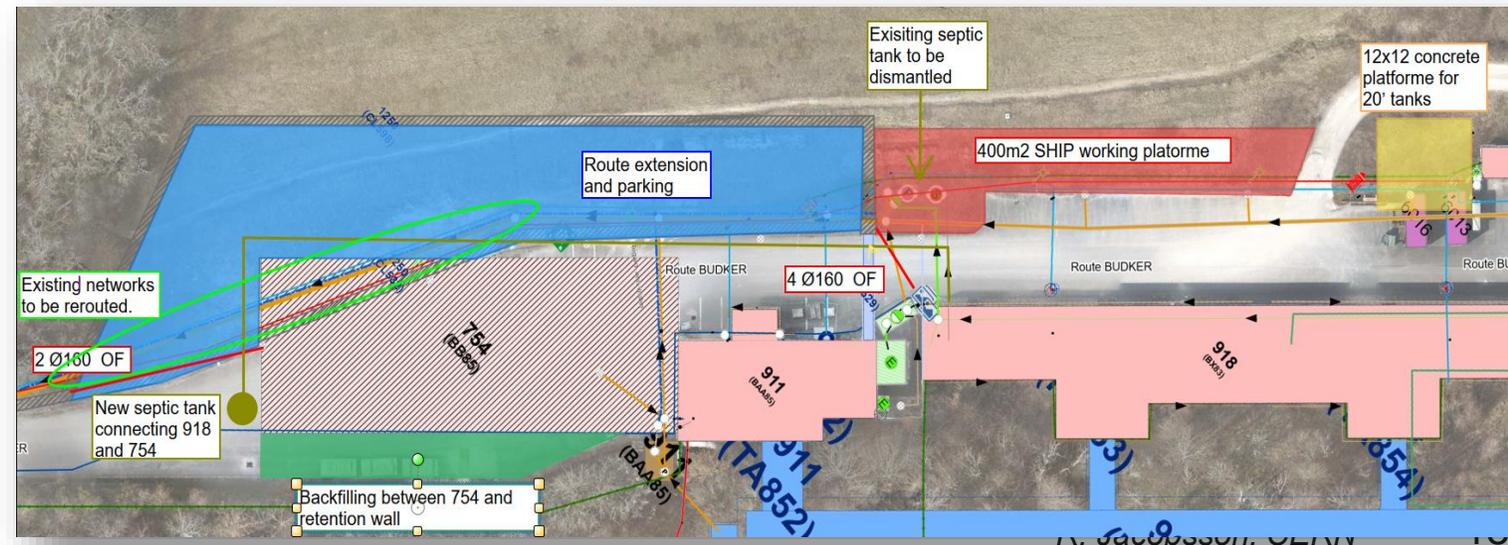
June – Sep 2025: Ground-breaking at TT7:

Recovery of 600t of iron shielding blocks from the PS neutrino facility, operated in the early 80's, to be reused for shielding at BDF/SHiP



Civil engineering procurement start Q1-2026

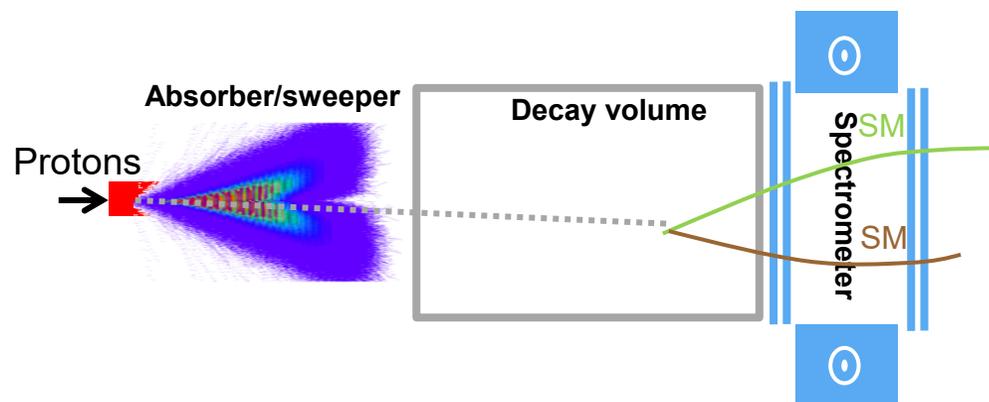
- **Oct 2025: Civil engineering project approval**
- B754 to house facility able to handle, maintain and decommission BDF target: collaboration with RWM to treat legacy CERN waste in the long-term
- Design Study of Service Cell by external contractor returned and being integrated into procurement of CE



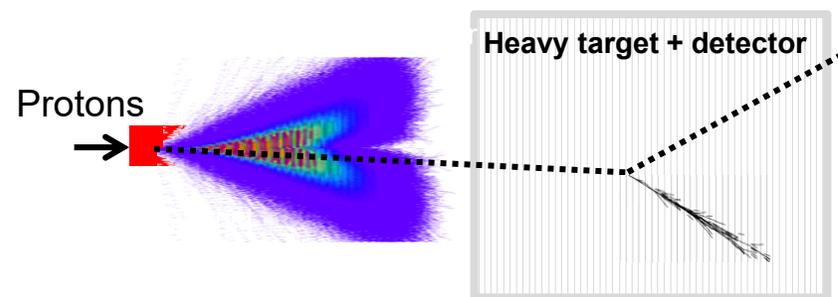


→ Explore Light Dark Matter, and associated mediators - generically domain of FIPs - and ν mass generation through :

Decay signatures



Scattering signatures

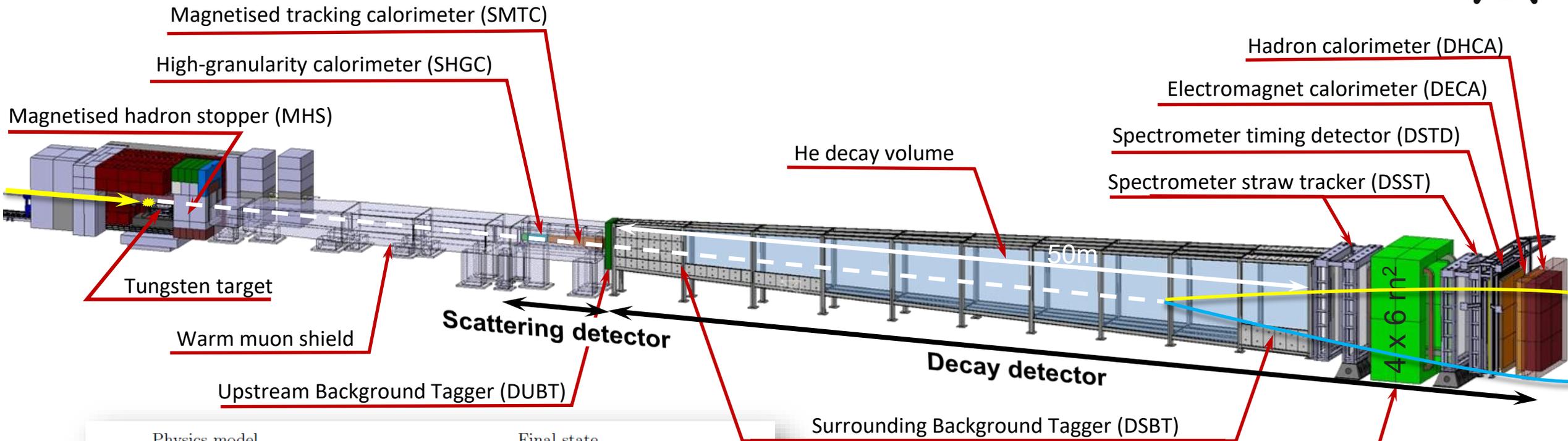
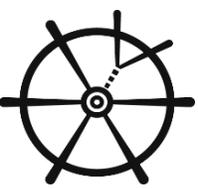


Also suitable for neutrino interaction physics with all flavours

Design for exhaustive search by aiming at model-independent detector setup

- Full reconstruction and identification of as many final states as possible of both fully and partially reconstructible modes
→ Sensitivity to partially reconstructed modes also proxy for the unknown
- **In case of discovery → precise measurements to discriminate between models / test compatibility with hypothetical signal**

Overview of SHiP experiment

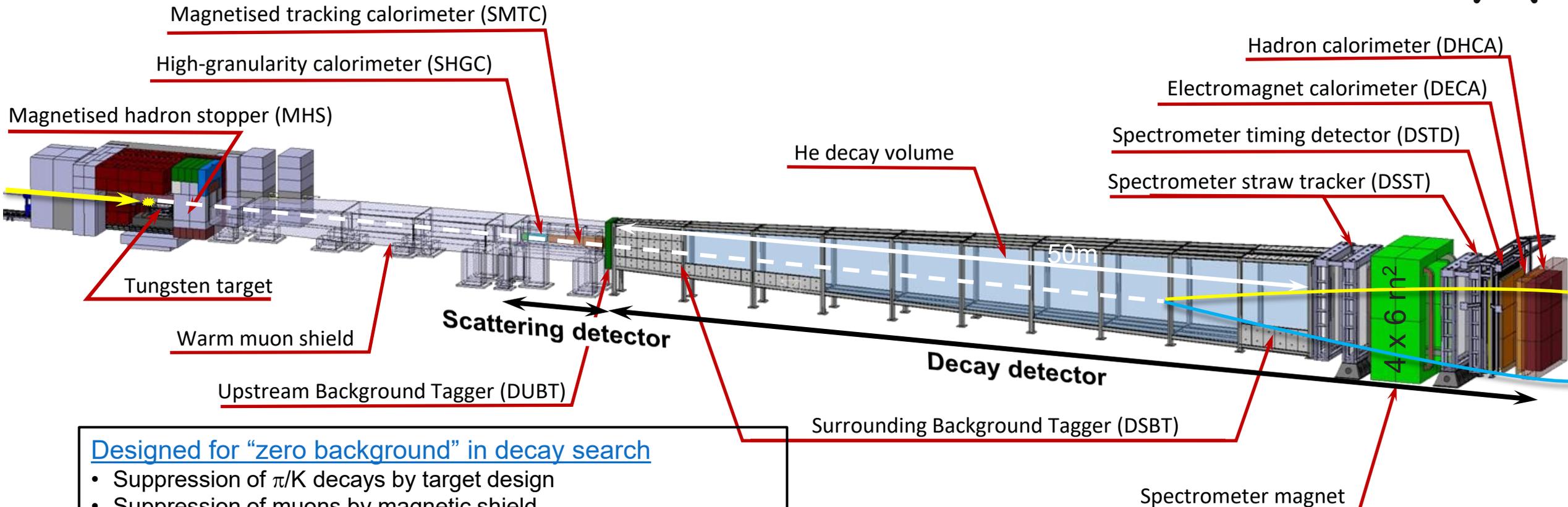


Examples of final states

	Physics model	Final state
HSDS	SUSY neutralino	$\ell^\pm \pi^\mp, \ell^\pm K^\mp, \ell^\pm \rho^\mp, \ell^+ \ell^- \nu$
	Dark photons	$\ell^+ \ell^-, 2\pi, 3\pi, 4\pi, KK, q\bar{q}, D\bar{D}$
	Dark scalars	$\ell\ell, \pi\pi, KK, q\bar{q}, D\bar{D}, GG$
	ALP (fermion coupling)	$\ell^+ \ell^-, 3\pi, \eta\pi\pi, q\bar{q}$
	ALP (gluon coupling)	$\pi\pi\gamma, 3\pi, \eta\pi\pi, \gamma\gamma$
	HNL	$\ell^+ \ell^- \nu, \pi l, \rho l, \pi^0 \nu, q\bar{q} l$
	Axino	$\ell^+ \ell^- \nu$
	ALP (photon coupling)	$\gamma\gamma$
SND	SUSY sgoldstino	$\gamma\gamma, \ell^+ \ell^-, 2\pi, 2K$
	LDM	electron, proton, hadronic shower
	$\nu_\tau, \bar{\nu}_\tau$ measurements	τ^\pm
	Neutrino-induced charm production (ν_e, ν_μ, ν_τ)	$D_s^\pm, D^\pm, D^0, \bar{D}^0, \Lambda_c^+, \bar{\Lambda}_c^-$

Challenge is background suppression

Overview of SHiP experiment



Designed for “zero background” in decay search

- Suppression of π/K decays by target design
 - Suppression of muons by magnetic shield
 - Suppression of neutrino by decay volume by evacuating air
 - Background taggers
 - Momentum and decay vertex information
 - Impact parameter at target
 - Coincidence timing
- } by main tracker
- Invariant mass
 - Particle identification
- } Not currently used in background suppression

See M. Ferro-Luzzi's talk next

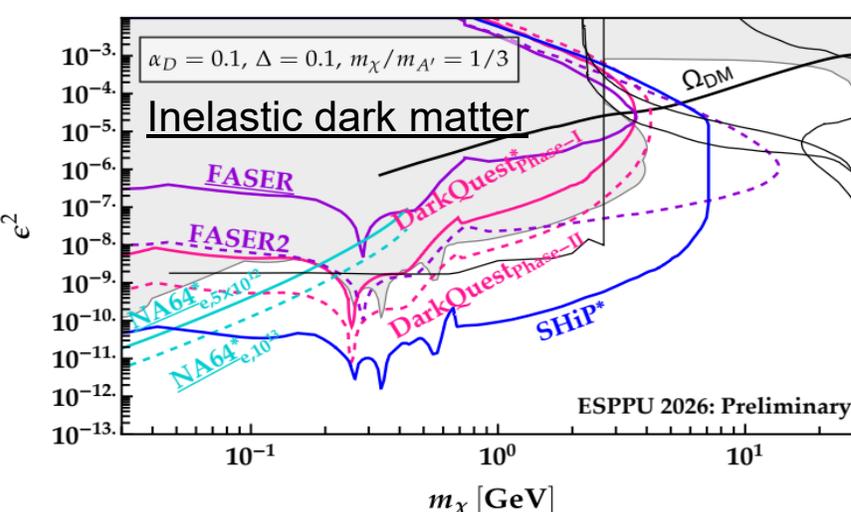
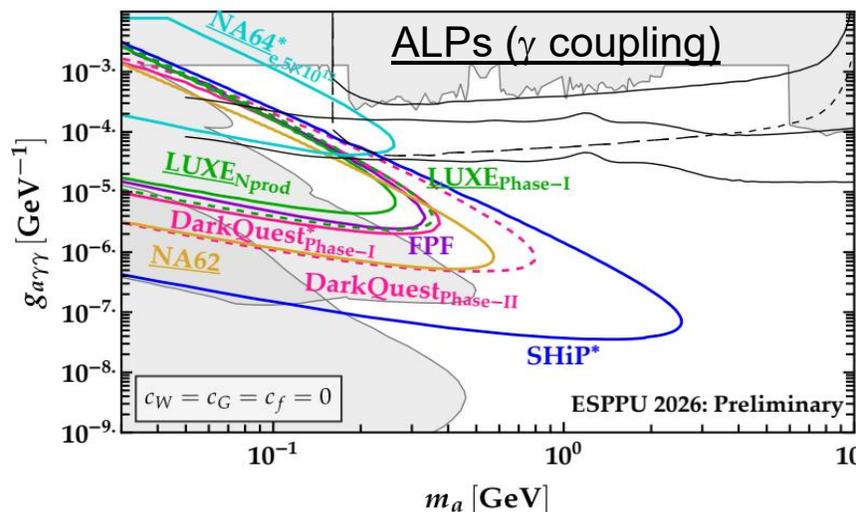
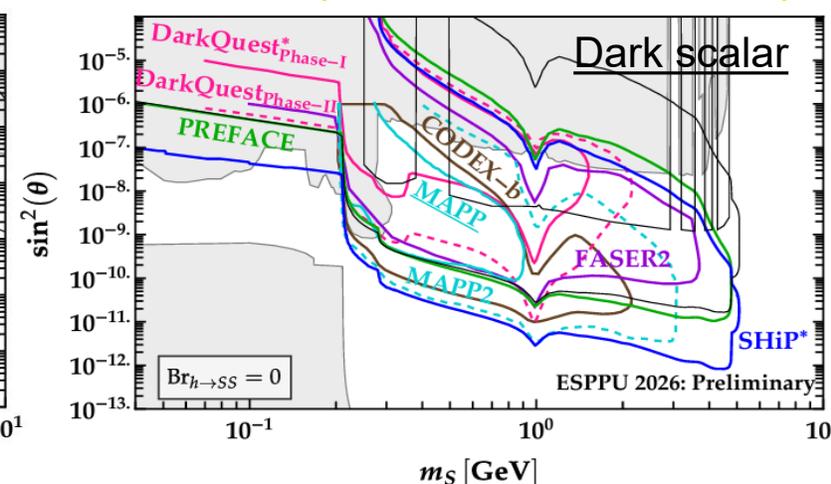
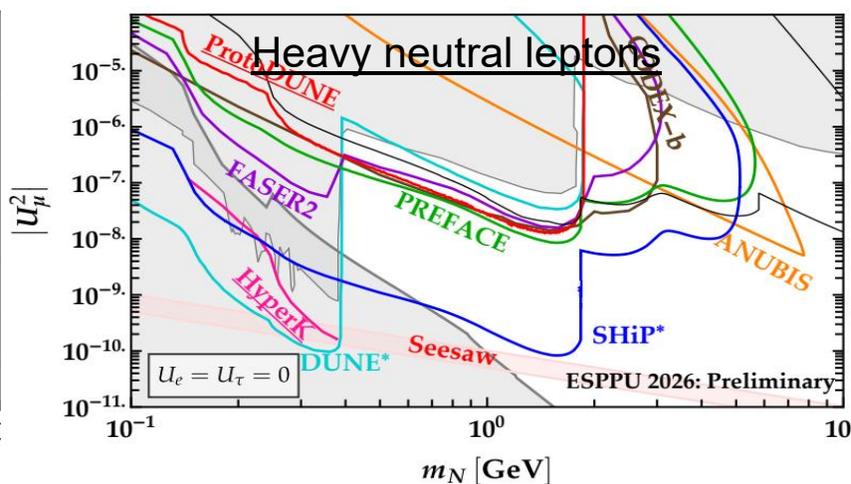
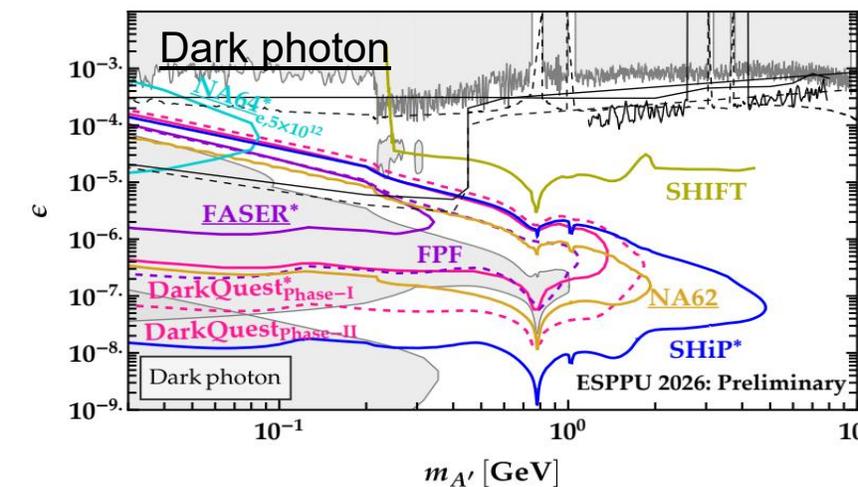
SHiP physics reach



SHiP experiment direct sensitivity to all classes of FIPs in virtually zero background environment

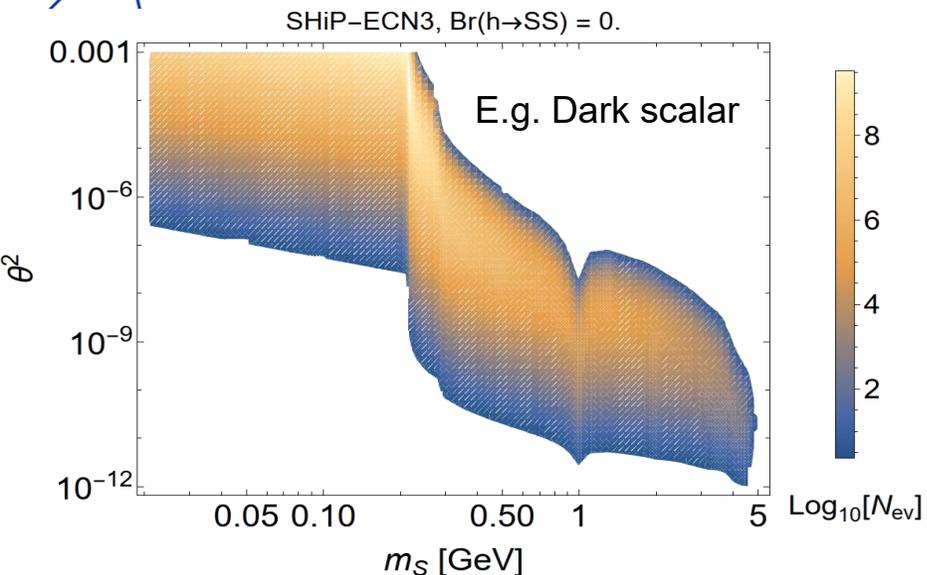
- Benchmark examples:

M. Ovchinnikov, ESPP 2026, Venice, Italy



+ also SUSY-related benchmarks

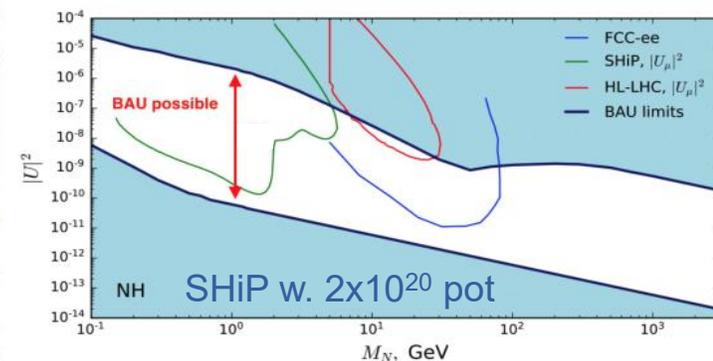
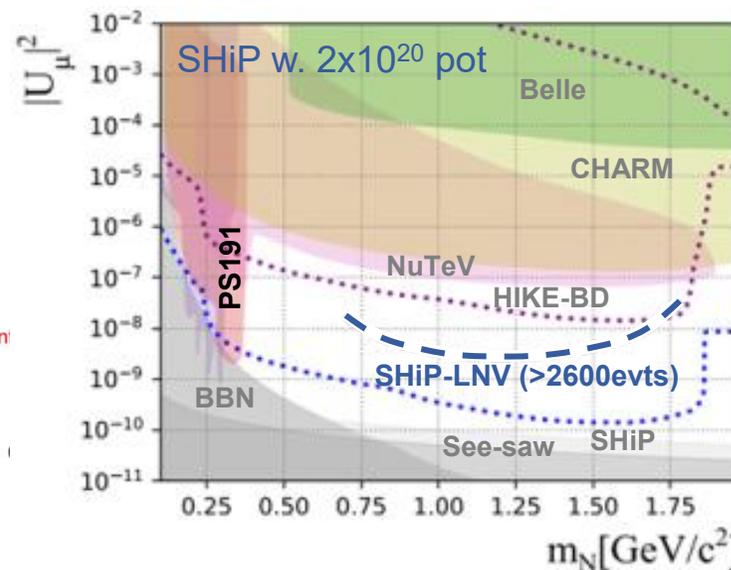
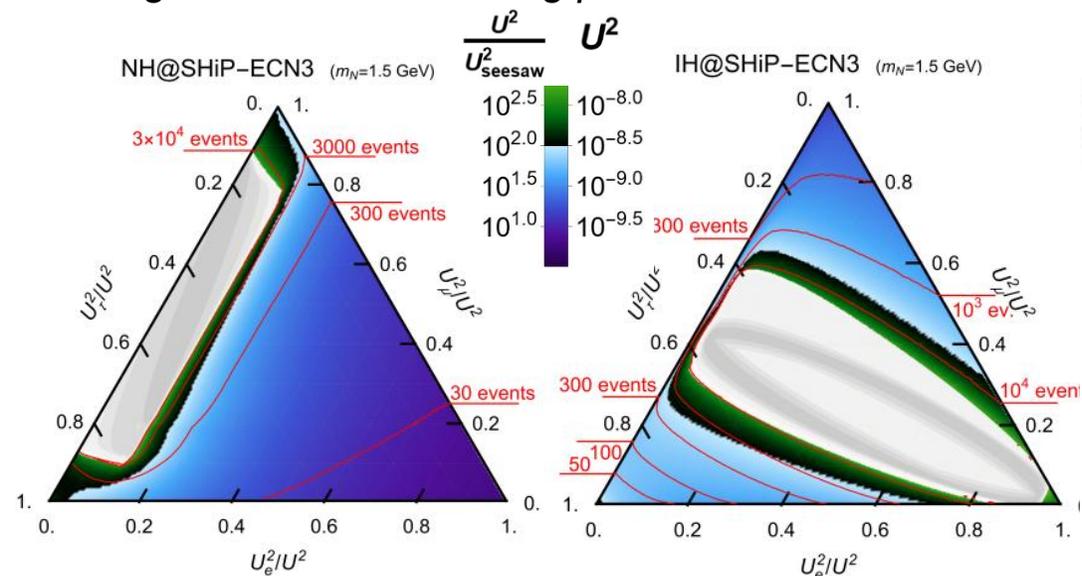
→ Exploration of (2-5 \otimes 1-2) orders of magnitude (coupling² \otimes mass) beyond current experiments



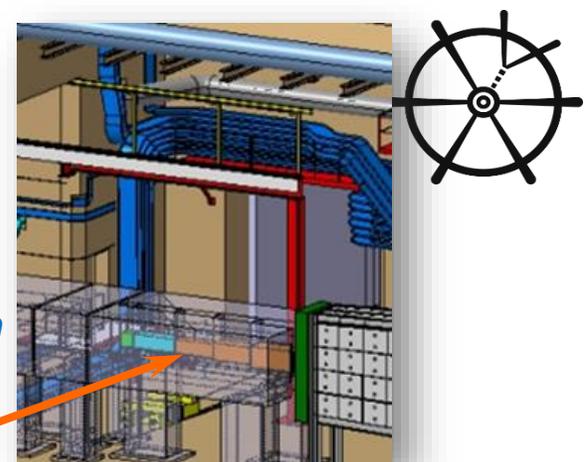
- Step 1: Characterise new object - precise mass, branching ratios, spin: $\mathcal{O}(10)$ evts
- Step 2: Test compatibility with hypothesis addressing SM issues: $\mathcal{O}(100 - 1000)$ evts

<https://arxiv.org/abs/2312.00659>
<https://arxiv.org/abs/2312.05163>

→ E.g. check if HNL mixing pattern fits neutrino flavour oscillations, and lepton number violation and BAU



LDM and neutrino scattering detector



Two complementary detector concepts

→ *Reconstruction of all ν flavours, e.m./had shower, μ momentum, charge determination*

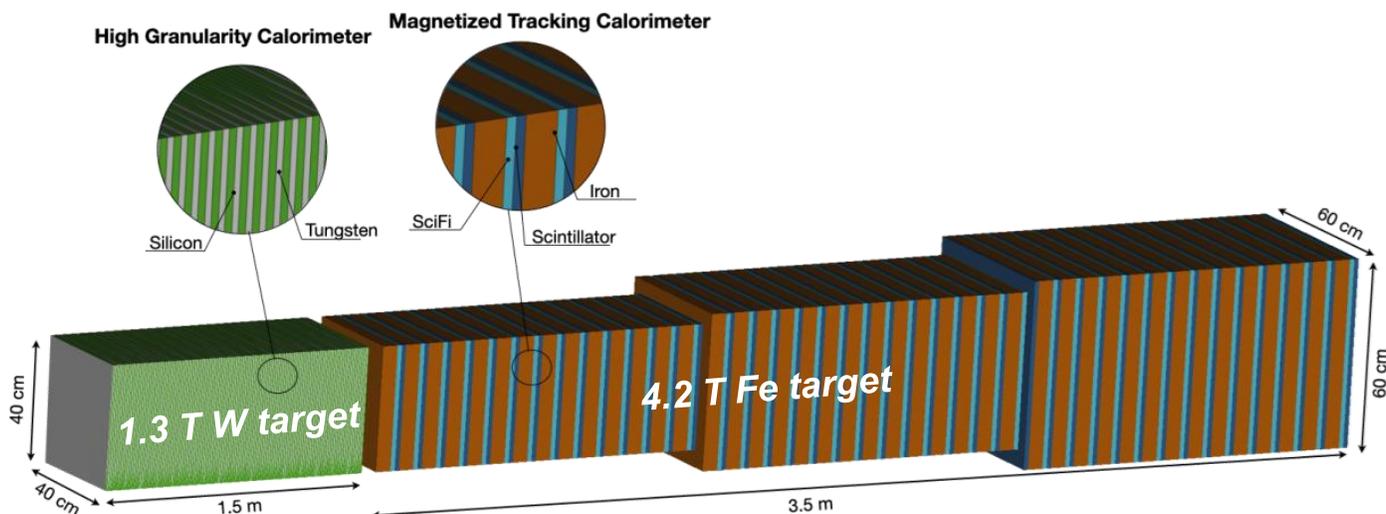
⊙ High-granularity calorimeter with silicon detector interleaved with tungsten

- ν_e, ν_τ, ν -induced charm, LDM

⊙ Magnetised tracking calorimeter with silicon, scintillating fibres & tiles interleaved with iron

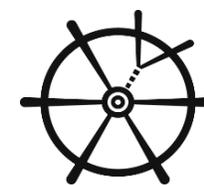
- ν_μ, ν_τ, ν -induced charm, $\nu/\bar{\nu}$ distinction

→ ν_τ identification by kinematics (high-statistics analysis) and potentially by topology (event-by-event analysis)



See M. Ferro-Luzzi's talk next

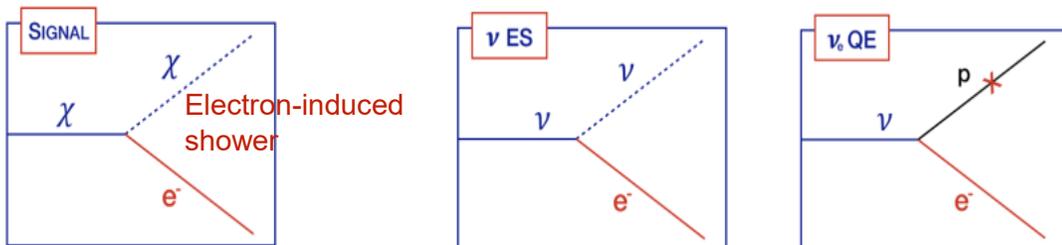
“Direct” light dark matter search



- Direct LDM search through scattering, sensitivity to ϵ^4 instead of indirect searches ϵ^2 with E_{miss} technique

→ Background is dominated by neutrino elastic and quasi-elastic scattering, for 6×10^{20} PoT

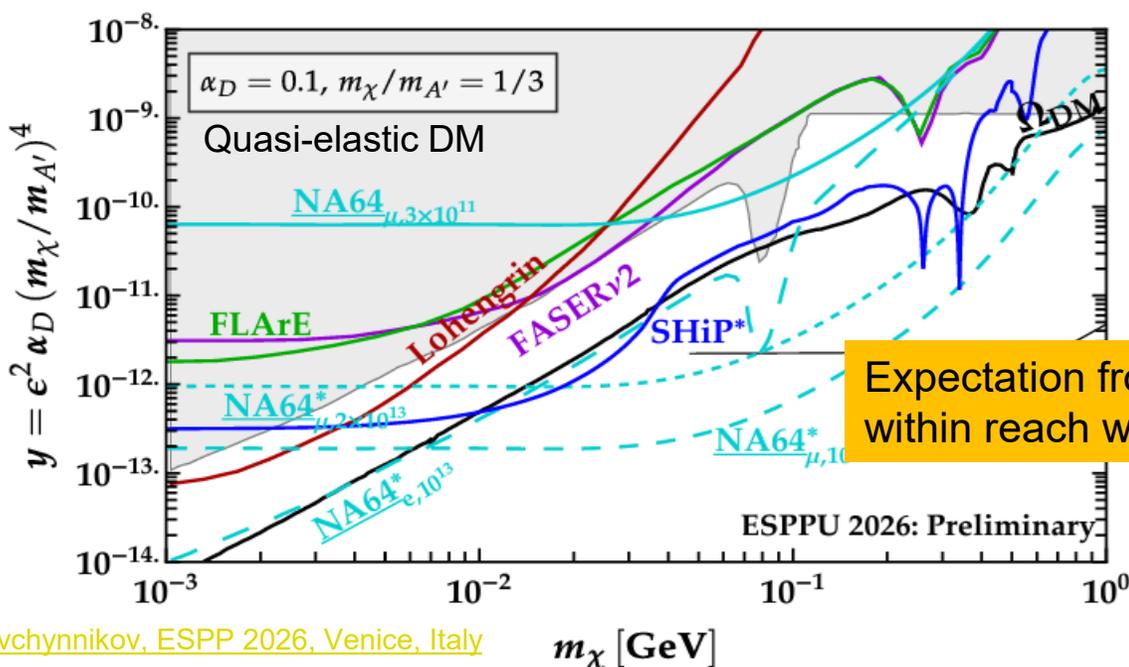
→ Clean vertex and accurate e.m. shower reconstruction



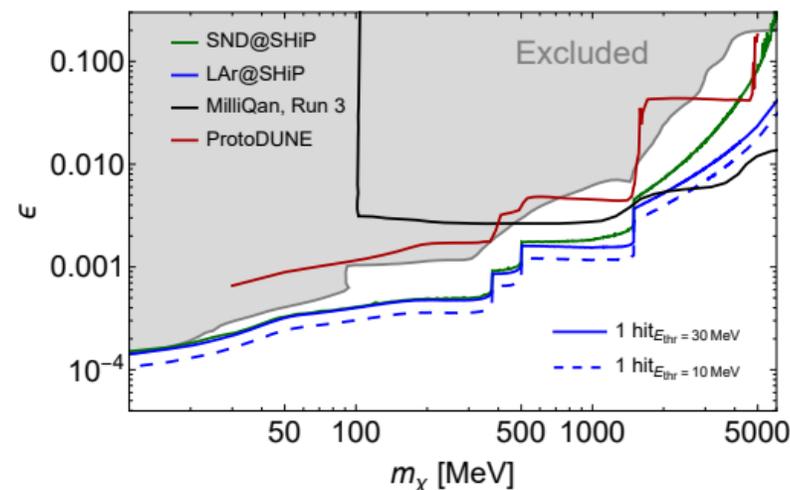
	ν_e	$\bar{\nu}_e$	ν_μ	$\bar{\nu}_\mu$	all
Elastic scattering on e^-	260	135	320	210	925
Quasi - elastic scattering	-	-	-	-	45
Resonant scattering	-	-	-	-	-
Deep inelastic scattering	-	-	-	-	-
Total	260	180	320	210	970

Need update with latest detector configuration

2312.14868v2



Milli-charged particle – electron scattering

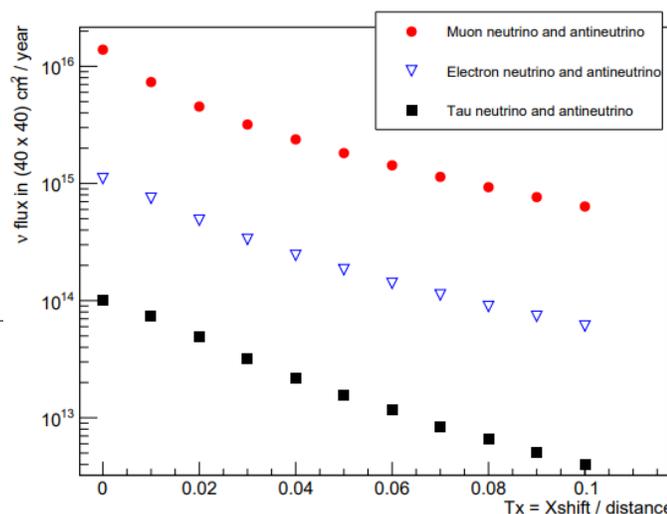


2312.14868v2

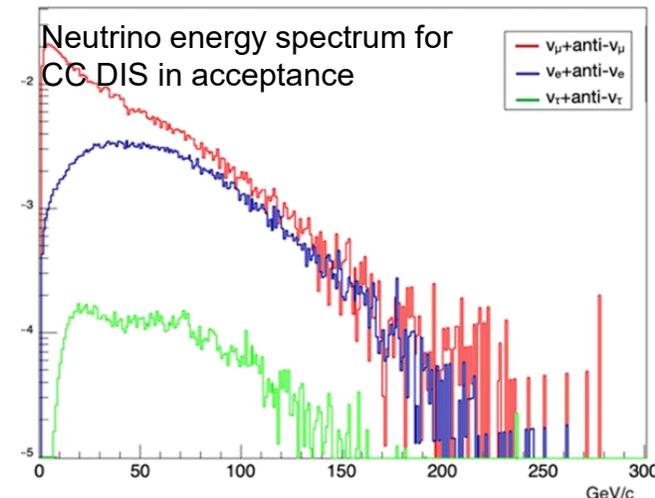


- Large sample of all neutrino flavours
 - Despite target design to suppress pion&kaon decays, $\sigma_{stat} < 1\%$ for all neutrino flavours
 - Measure kinematic variables in both CC and NC DIS

	CC DIS (W)	Charm CC DIS (W)	CC DIS (Fe)	Charm CC DIS (Fe)
N_{ν_e}	6.8×10^4	4.1×10^3	1.6×10^5	9.8×10^3
N_{ν_μ}	2.0×10^5	8.7×10^3	4.6×10^5	2.0×10^4
N_{ν_τ}	2.1×10^3	1.2×10^2	5.1×10^3	2.8×10^2
$N_{\bar{\nu}_e}$	1.4×10^4	7.4×10^2	3.7×10^4	1.9×10^3
$N_{\bar{\nu}_\mu}$	4.4×10^4	1.7×10^3	1.1×10^5	4.1×10^3
$N_{\bar{\nu}_\tau}$	1.5×10^3	8.6×10^1	3.8×10^3	2.1×10^2



annual ν fluxes at SD



- Huge sample of tau neutrinos via $D_s \rightarrow \tau \nu_\tau$

Incl. reconstruction efficiencies

Decay channel	ν_τ	$\bar{\nu}_\tau$
$\tau \rightarrow \mu$	4×10^3	3×10^3
$\tau \rightarrow h$	27×10^3	
$\tau \rightarrow 3h$	11×10^3	
$\tau \rightarrow e$	8×10^3	
Total	53×10^3	

Need update with latest detector configuration

Systematic uncertainty from knowledge of ν flux

- D_s production cross-section at SPS
 - Currently 10%, but NA65 expects to reconstruct ~ 1000 evts
 - $BR(D_s \rightarrow \tau \nu_\tau) \sim 3-4\%$
 - Cascade production of charm in thick target
 - SHiP plans dedicated experiment to measure J/ψ and charm production using muons in targets of variable depths
- Plan to reach $\sim 5\%$ uncertainty in ν_τ flux seems realistic
- $\sim 5-10\%$ uncertainty in ν_e, ν_μ flux



→ Measurement of neutrino DIS cross-sections up to 100 GeV

- $E_\nu < 10$ GeV as input to accelerator-based neutrino oscillation programme
- ν_τ cross-section input to atmospheric oscillations and cosmic neutrino studies
- $\sigma_{stat+syst} \sim 5\%$

→ LFU in neutrino interactions

- $\sigma_{stat+syst} \sim 5\%$ accuracy in ratios: ν_e/ν_μ , ν_e/ν_τ and ν_μ/ν_τ

→ Test of F_4 and F_5 ($F_4 \approx 0$, $F_5 = F_2/2x$ with $m_q \rightarrow 0$) structure functions in $\sigma_{\nu-CC DIS}$

- **Never measured, only accessible with tau neutrinos, realistically at $<10\%$**
[C.Albright and C.Jarlskog, NP B84 (1975)]

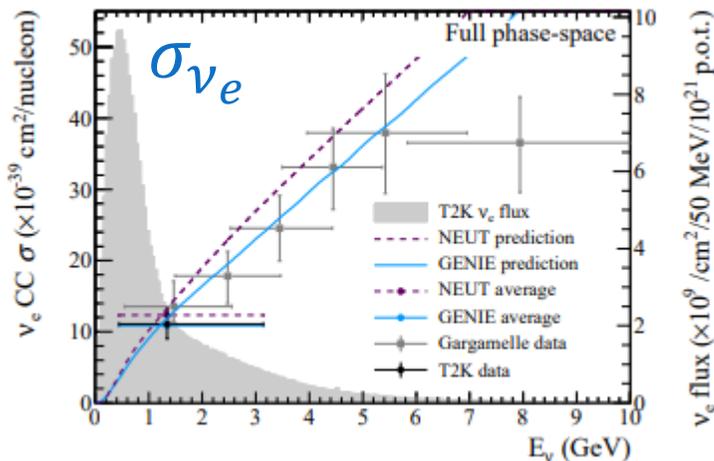
→ BSM physics with neutrino interactions

ν Lepton Flavour Violation

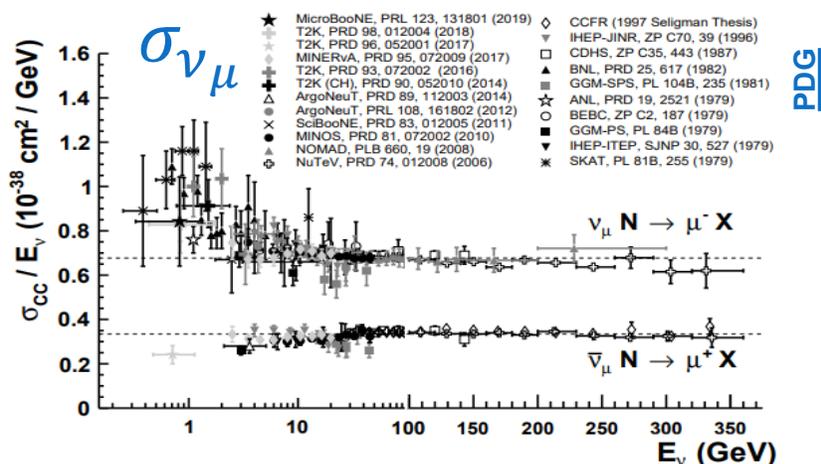
Best measurement (90's):

$$\frac{\sigma(\nu_e)}{\sigma(\nu_\mu)} = 1.09 \pm 0.17 \rightarrow \sim 15\%$$

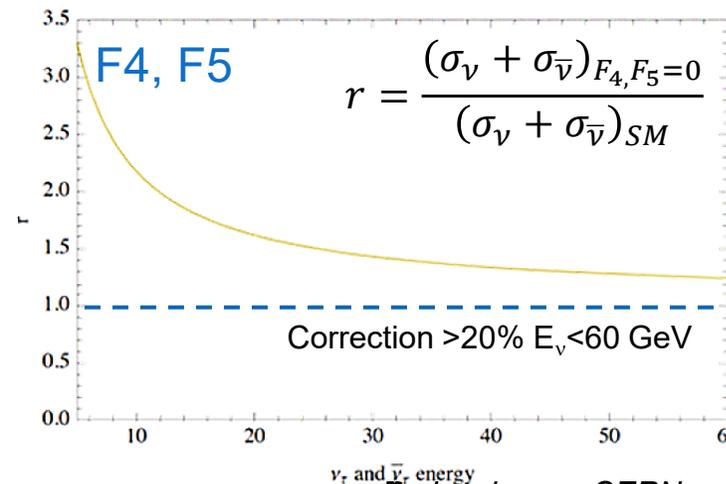
$$\frac{\sigma(\bar{\nu}_e)}{\sigma(\bar{\nu}_\mu)} = 1.46 \pm 0.34 \rightarrow \sim 23\%$$



Phys.Rev.Lett 113(24). (2014)



PDG



Rep. Prog. Phys. 79 (2016)124201

SND: Neutrino interaction physics

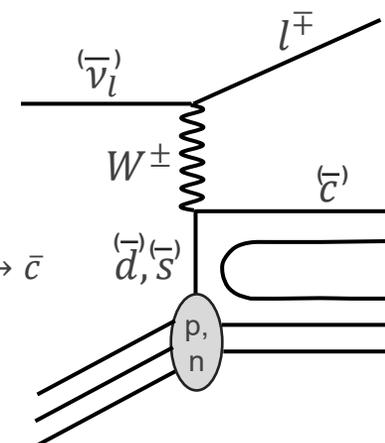


Neutrino-induced charm production

- Expect $\sim 6 \times 10^5$ neutrino induced charm hadrons for 6×10^{20} pot
 - More than an order of magnitude larger than currently available
 - Anti-charmed hadrons are predominantly produced by anti-strange content of the nucleon ($\sim 90\%$)
 - Understanding of nucleon strangeness is critical for precision tests of SM at LHC
- Improvement on $|V_{cd}|$ by directly identifying inclusive charm

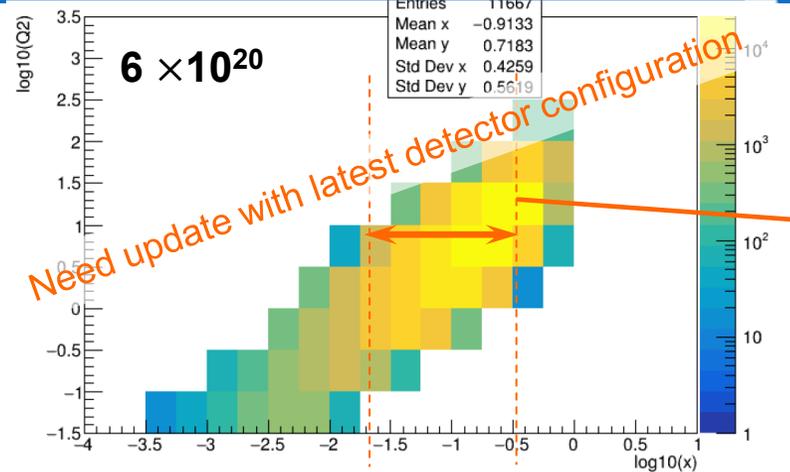
	$\langle E \rangle$ (GeV)	CC DIS with charm prod
N_{ν_μ}	57	3.5×10^5
N_{ν_e}	71	1.7×10^5
$N_{\bar{\nu}_\mu}$	50	0.7×10^5
$N_{\bar{\nu}_e}$	60	0.3×10^5
total		6.2×10^5

Need update with latest detector configuration



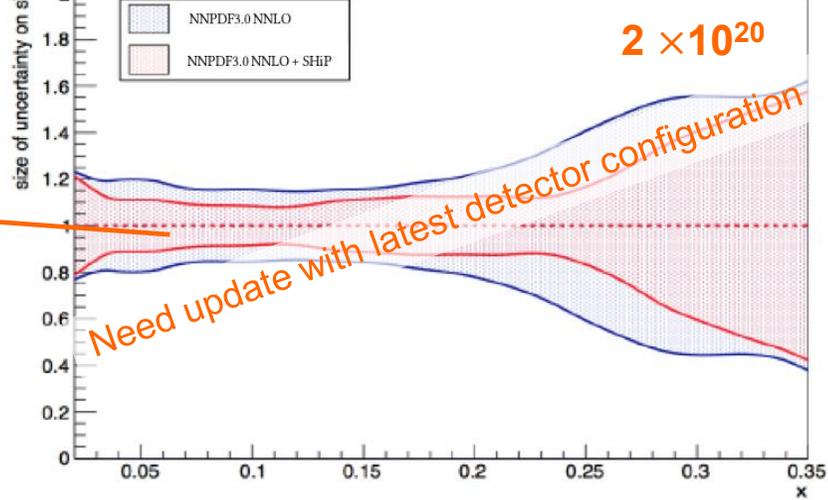
No charm candidate from ν_e and ν_τ interactions ever reported

Large data samples at SHiP will greatly improve current measurements up to high values of x



Need update with latest detector configuration

SHiP sensitivity to PDF for $x < 0.35$ (evaluated in [Prog. Phys. 79 (2016) 124201])

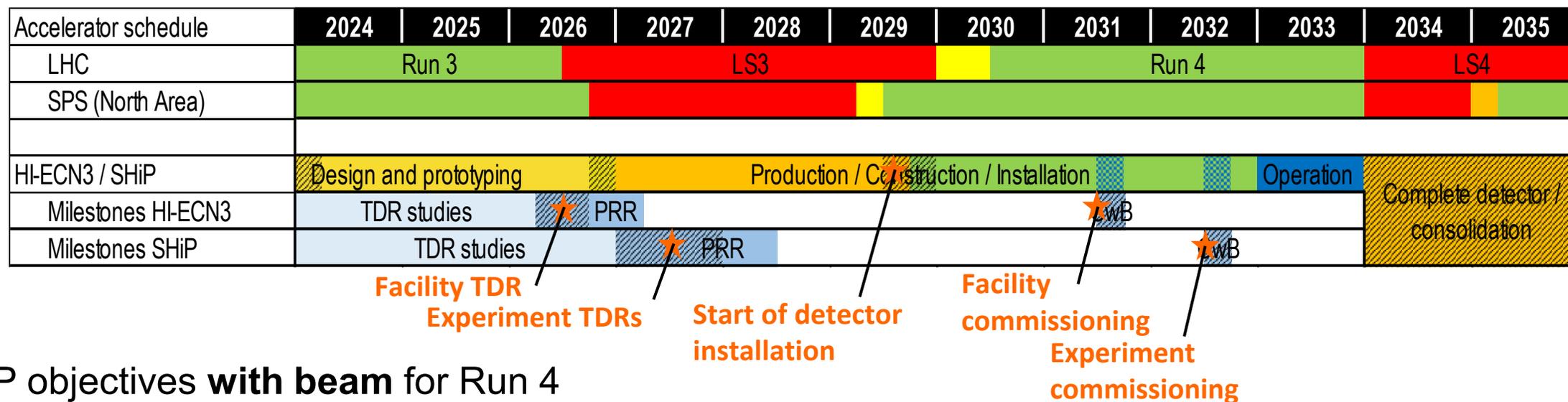


Need update with latest detector configuration

Rep. Prog. Phys. 79 (2016) 124201

2×10^{20}

SHiP schedule and Run 4 objectives



SHiP objectives with beam for Run 4

1. Facility commissioning – 2031 Q3

- SHiP central system commissioning, first measurement of backgrounds, physics performance of beam, target, muon shield and tuning of muon shield

2. Detector commissioning – 2032 Q3

- Time/space alignment and subdetector performance, measurements of backgrounds with muon shield off and air/N₂ in decay volume, reconstruction performance (efficiencies, resolutions)

3. Physics run in nominal conditions, aiming for 4×10^{19} p/target – 2033

- *Priority on detector capable of exploring FIP decays to fully reconstructible charged particle final states*

→ *Runs in 2031 - 2033 provide key input to preparation of run for full programme post-LS4 – risk mitigation*

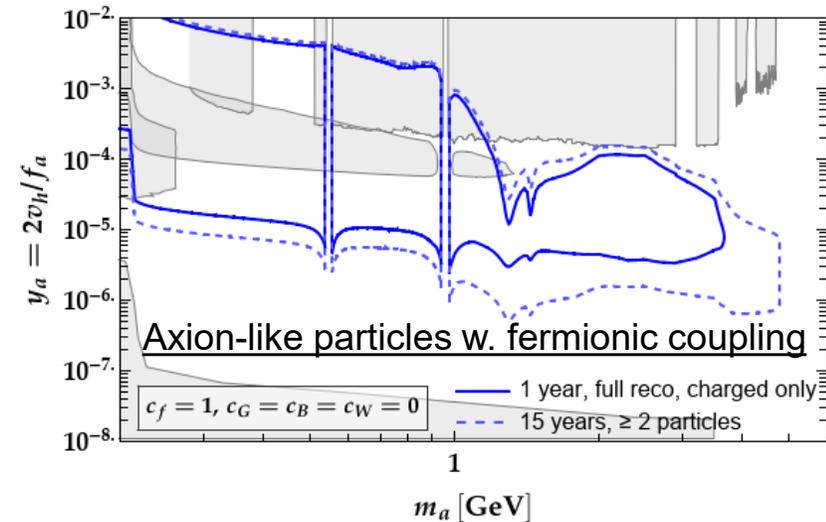
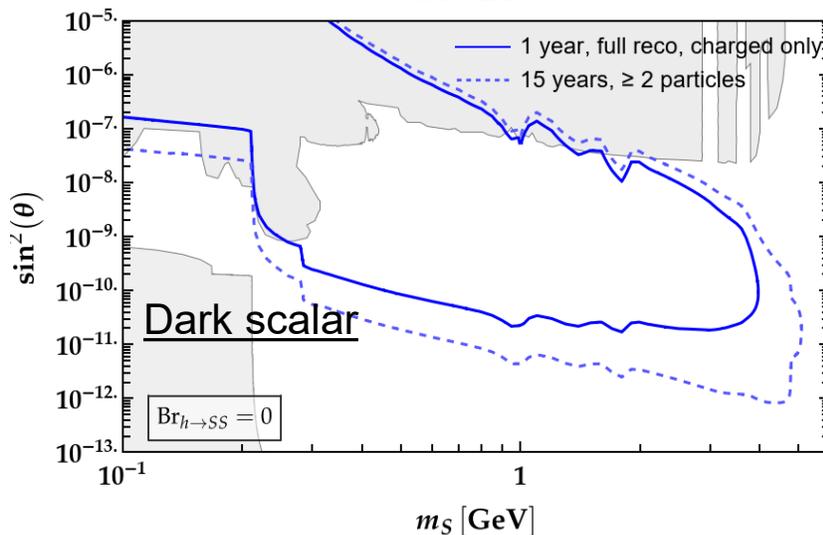
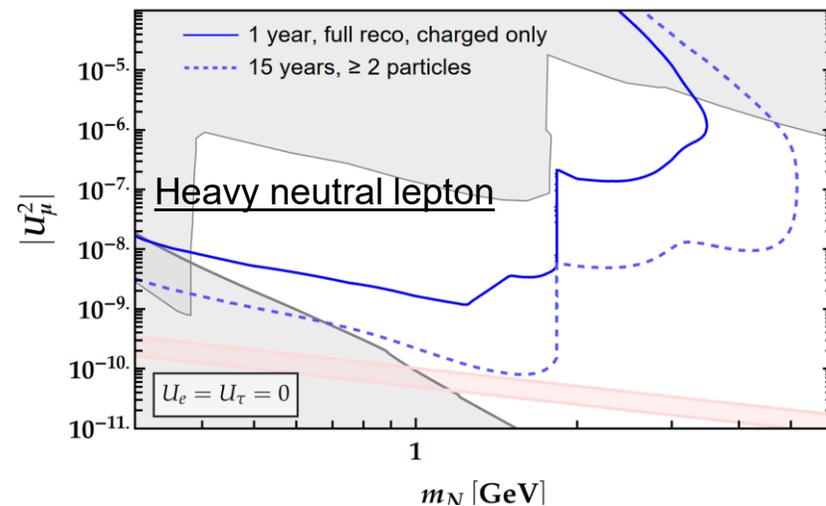
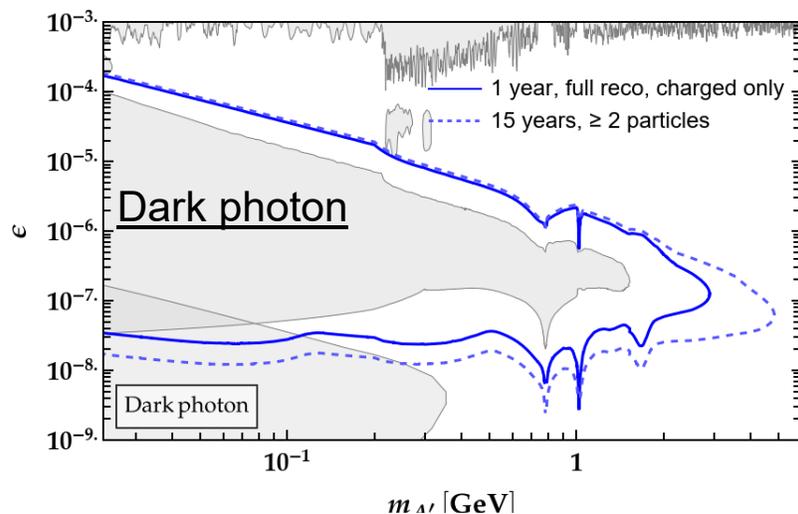
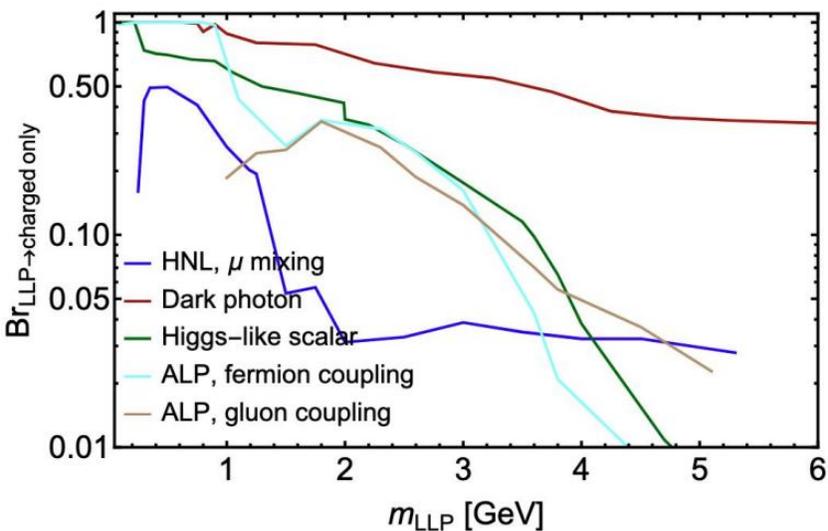
Minimal detector configuration in Run 4



Full detector aperture but focus on reconstruction of charged particles and background taggers

SHiP's sensitivity in Run 4 (4×10^{19} pot) with initial detector configuration already explores several orders of magnitude in couplings

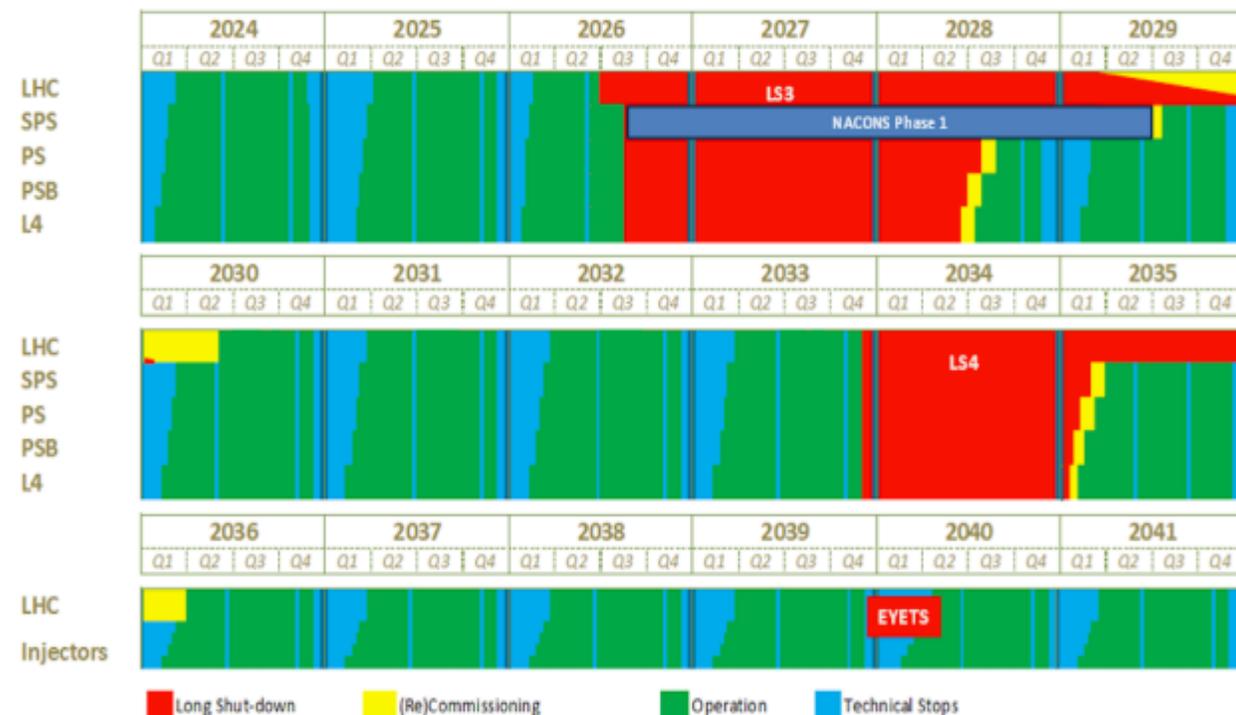
Branching fraction of fully reconstructed Charged-particle final states





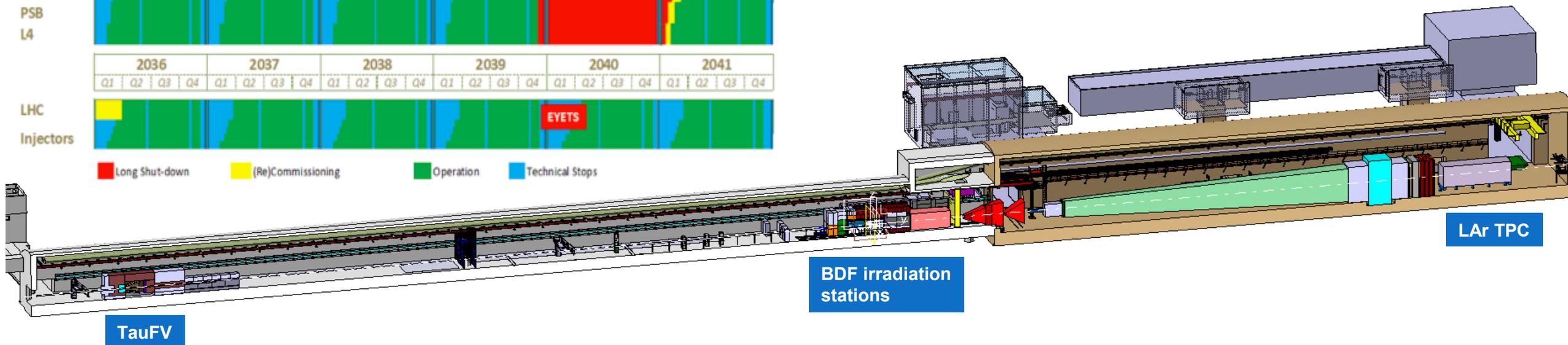
→ SHiP physics exploration stretches over 15 years

Long Term Schedule for CERN Accelerator complex



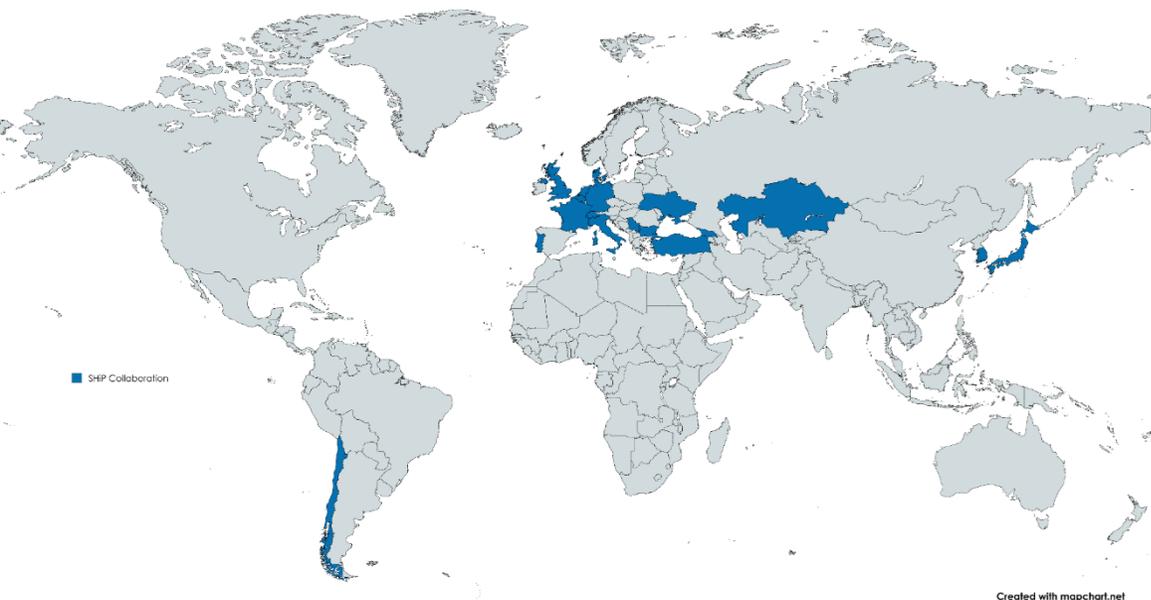
Preliminary studies of opportunities to extend physics programme *synergetically with SHiP*:

1. Irradiation stations (nuclear astrophysics and accelerator / material science applications)
[n_ACT@BDF: A Neutron Activation Station at the SPS Beam Dump Facility \(BDF\)](#)
2. LArTPC to extend search for FIPs using different technology
3. TauFV to search for lepton flavour violation and rare decays of tau leptons and D-mesons





33 institutes + 9 associate institutes from 18 countries



Country	Institute
Belgium	University of Ghent
Bulgaria	University of Sofia
Chile	Saphir/UNAB
Denmark	Niels Bohr Institute
France	IJCLab
Georgia	Georgia Technical University, Tbilisi
Germany	Humboldt University of Berlin Constructor University Bremen University of Freiburg University of Hamburg Forschungszentrum Jülich Karlsruhe Institute of Technology University of Mainz University of Siegen
Italy	University & INFN Bari University & INFN Bologna University & INFN Cagliari University Federico II & INFN Napoli
Japan	Nagoya University Associated: Aichi University of Education, Kariya Nihon University, Tokyo Kobe University

Recently joined in 2024-2025

Strengthened by addition of new group(s) in 2024-2025

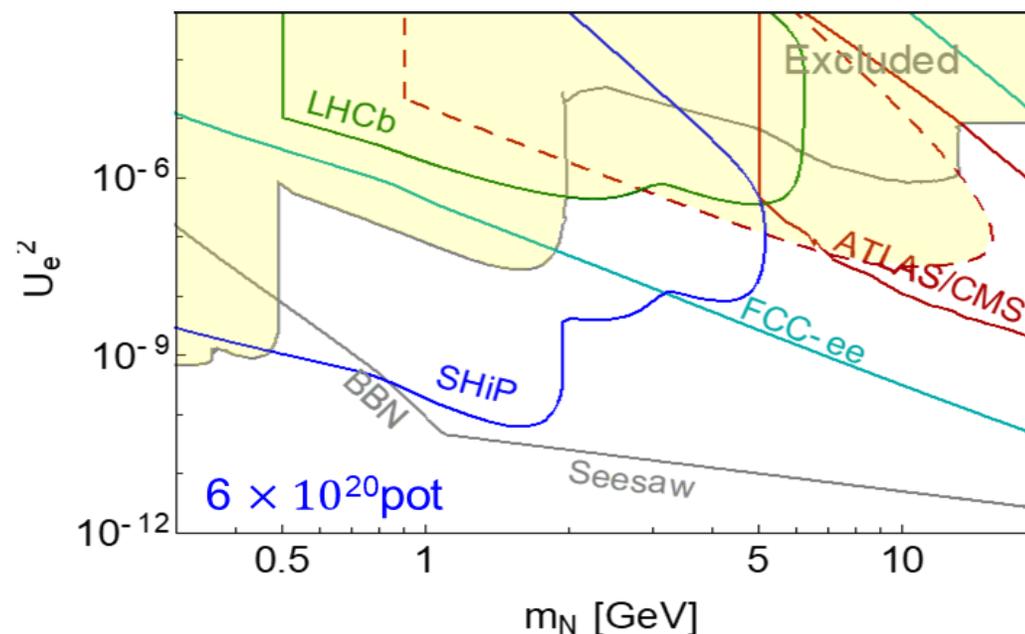
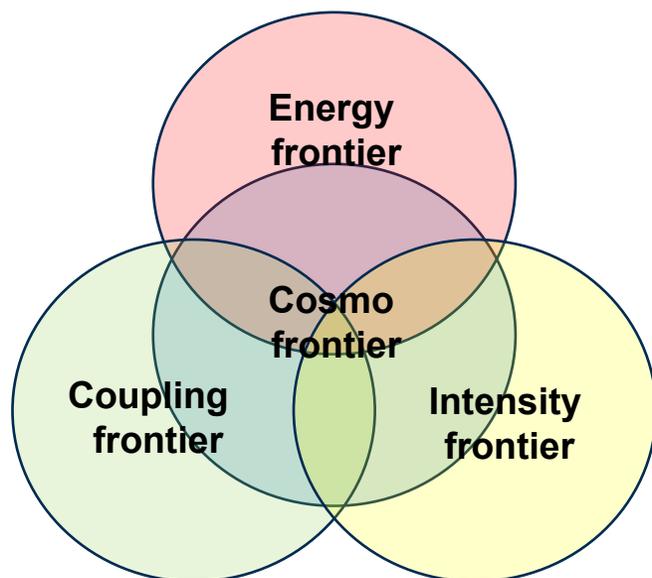
Country	Institute
Kazakhstan	Institute of Experimental Physics, Almaty
Korea	Gyeongsang National University, Jinju Associated: Gwangju National University of Education Jeju National University Physics Department, Korea University, Seoul Sungkyunkwan University, Suwon City
Netherlands	Leiden University
Portugal	LIP, Lisbon & Coimbra
Serbia	University of Belgrade
Switzerland	EPFL University of Zurich
Turkey	Middle East Technical University Department of Physics and Engineering, Ankara University
Ukraine	Taras Shevchenko National University of Kiev
United Kingdom	H.G. Wills Physics Laboratory, University of Bristol Imperial College London University of Liverpool University College London
	CERN JINR

slanted: also in SND@LHC. New groups are regularly joining SND@LHC; they will eventually join SHiP (Genova, Catania, Salerno)

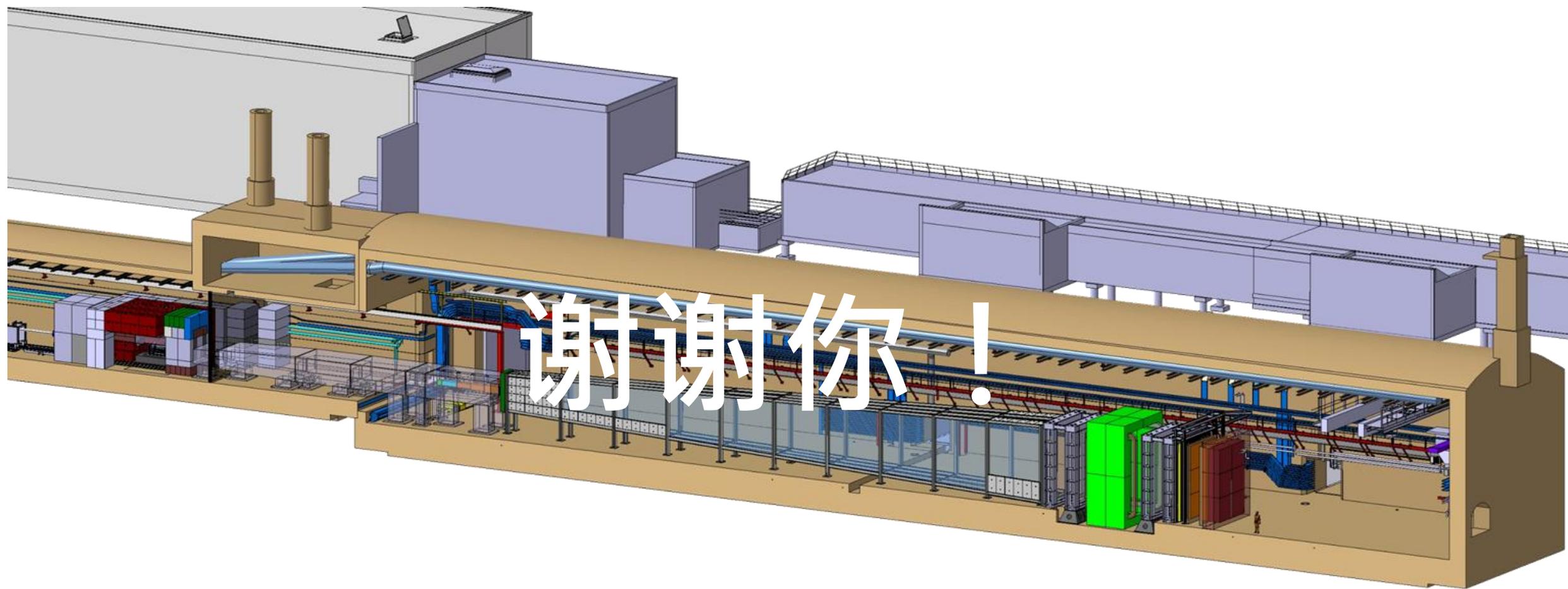
- Full baseline detector cost: ~50 MCHF
- Initial detector configuration for Run 4: ~30 – 35 MCHF



- Unique physics potential of SPS to explore “*Coupling Frontier*” with synergies with collider searches and searches in astrophysics/cosmology
 - Rich neutrino physics programme, including physics of tau neutrino interactions
- BDF/SHiP capable of covering the heavy flavour region of parameter space, out of reach at collider experiments
 - Capability not only to establish existence but to measure properties and test compatibility with solutions to SM problems
 - Unique complementarity to FIP searches at HL-LHC and future e^+e^- -collider, where FIPs can be searched in boson decays



→ Technological and operational steppingstone to FCC

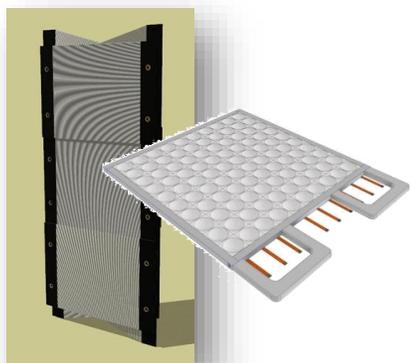
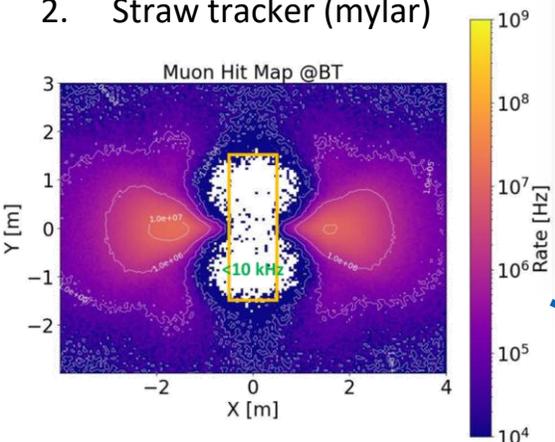


Decay detector technologies



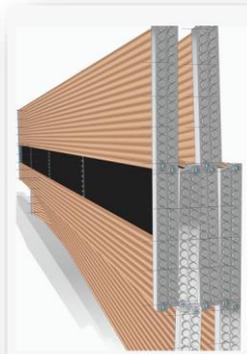
Upstream Background Tagger (eff >99%)

- $\sigma_{\text{space}} \sim 100 \mu\text{m}$, $\sigma_{\text{time}} \sim 200 \text{ ps}$
- 1. Scintillating tiles + SiPM
- 2. Straw tracker (mylar)



Spectrometer Straw Tracker

- $\sigma_{\text{space}} \sim 120 \mu\text{m}$
- Mylar straws



Spectrometer Timing Detector

- <math>< 100 \text{ ps}</math>
- Scintillating bars + SiPM



Hadron calorimeter

- PID
- Scintillating bars/tiles



Decay volume
• He balloon



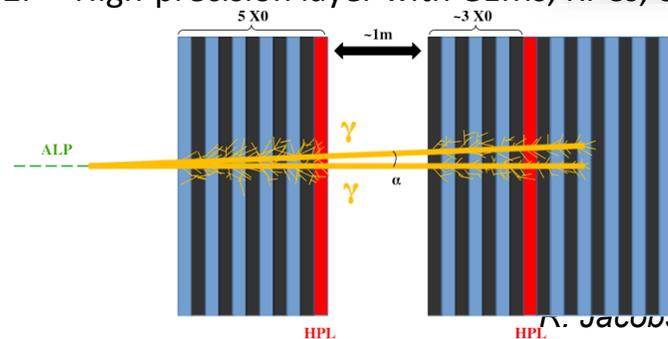
Spectrometer magnet

- 4m x 6m, 0.6 – 0.7 Tm
- HTS technology (MgB_2)



Electromagnet Calorimeter

- PID + shower axis <math>< 5 \text{ mrad}</math>
- 1. Scintillating tiles/bars
- 2. High-precision layer with GEMs, RPCs, or SciFi



Surrounding Background Tagger

- $\sigma_{\text{space}} \sim \mathcal{O}(\text{cm})$, $\sigma_{\text{time}} < \text{ns ps}$
- Liquid scintillator + WLS optical modules

