

SHiP

Search for Hidden Particles

HI ← **ECN3**

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

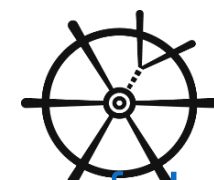
- Introduction, overview and project status -

[Note that many plots and results shown today come from work in progress](#)

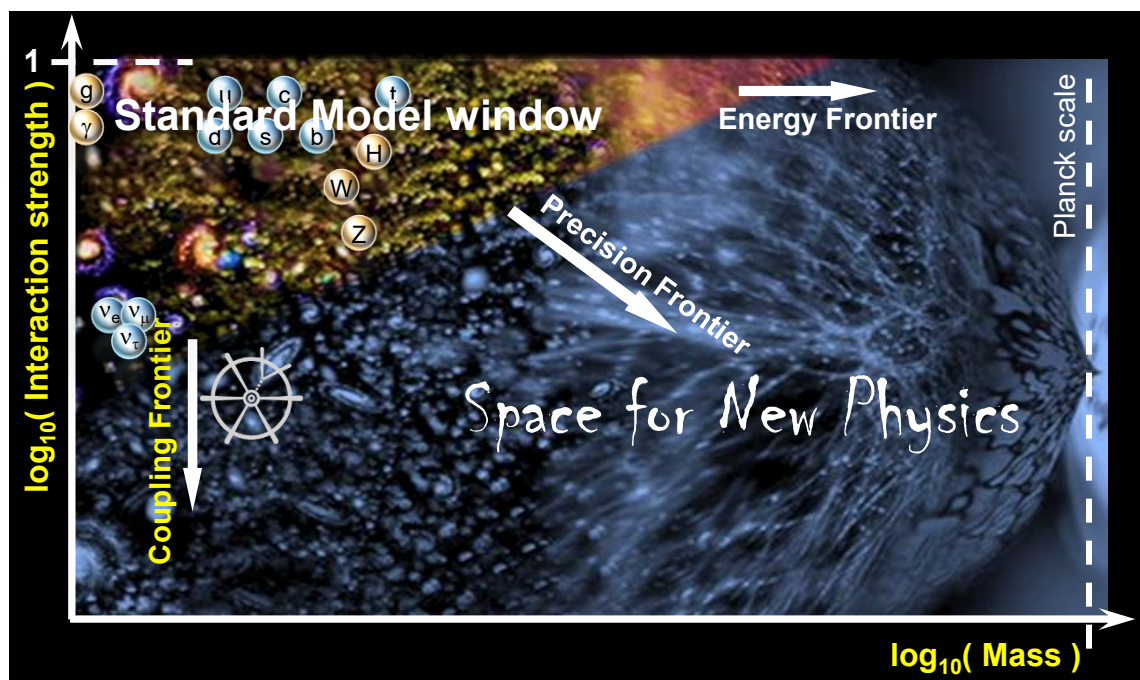
[BDF/SHiP at the ECN3 high-intensity beam facility - Technical Proposal 2023](#)

[BDF/SHiP Annual Report 2025](#)

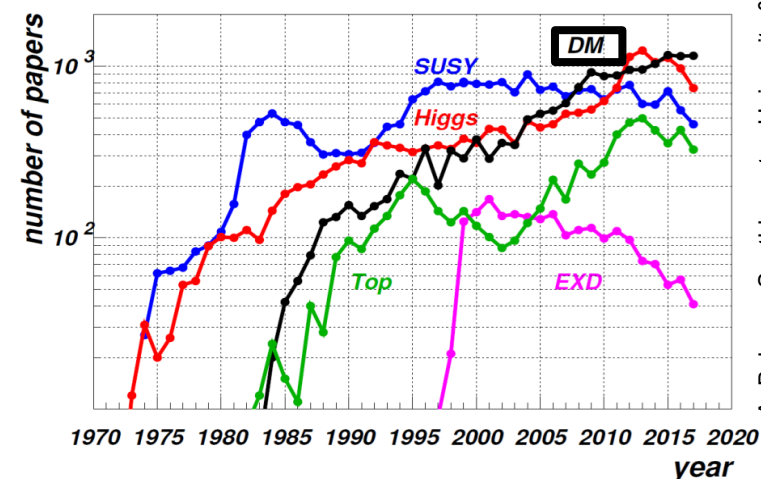
SHiP's focus – a slide for all!



- 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



A. Belyaev, Southampton University & RAL

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

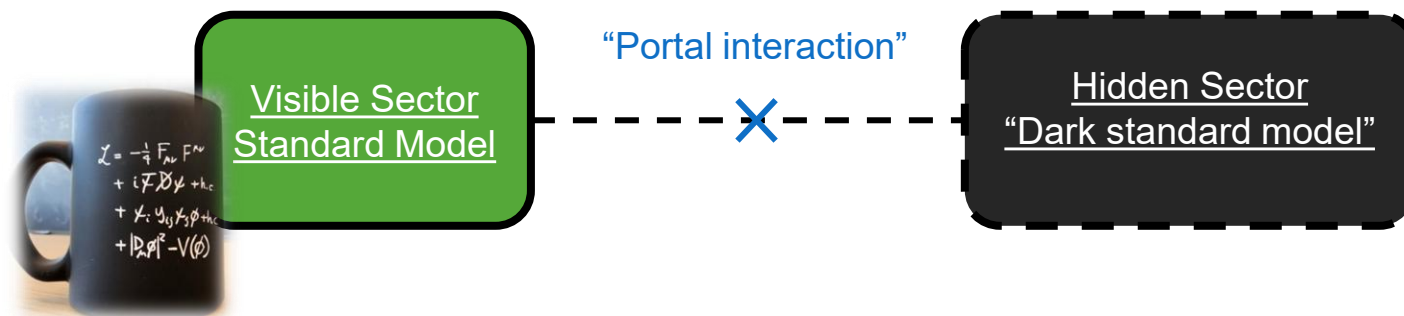
Standard Model mass scale is particularly interesting to explore... – we know for sure it exists!....

Theory of a Hidden Sector?



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

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

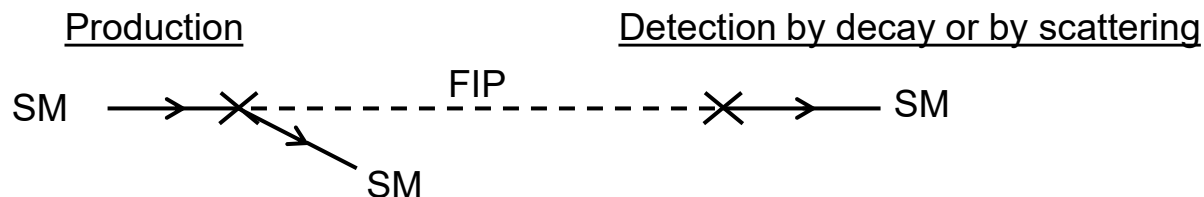


Portal interactions may “drive” dynamics observed in the Visible Sector!

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

⊙ **D = 2: Scalar portal**

- Mass mixing with dark singlet scalar χ : $(g\chi + \lambda\chi^2)H^\dagger H$
- ➔ Mass to Higgs boson and mass generation in dark sector, inflaton, dark phase transitions BAU, dark matter,...

⊙ **D = 5/2: Neutrino portal**

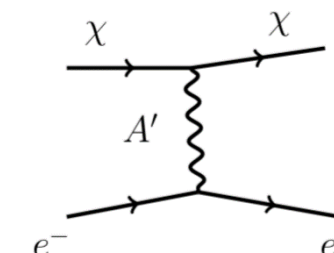
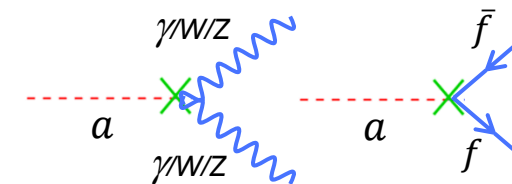
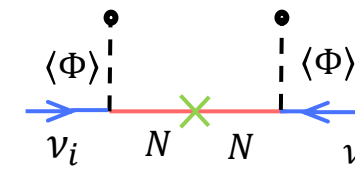
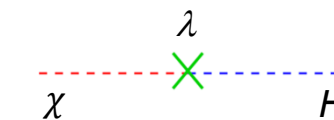
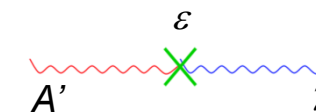
- Mixing with right-handed neutrino N (Heavy Neutral Lepton): $Y_{I\ell} H^\dagger \bar{N}_I L_\ell$
- ➔ Neutrino oscillation and mass, baryon asymmetry, dark matter

⊙ **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,....

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

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

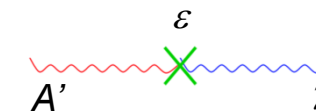




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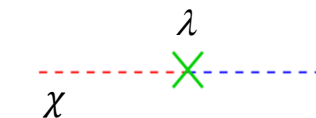
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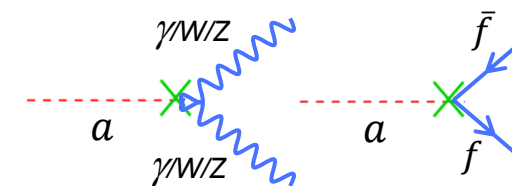


Bottom line: We need large production of $\gamma, q/g, c, b, W, Z, H$!

- ➔ Neutrino oscillation and mass, baryon asymmetry, dark matter

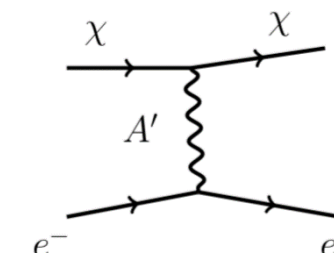
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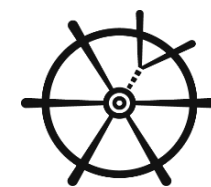
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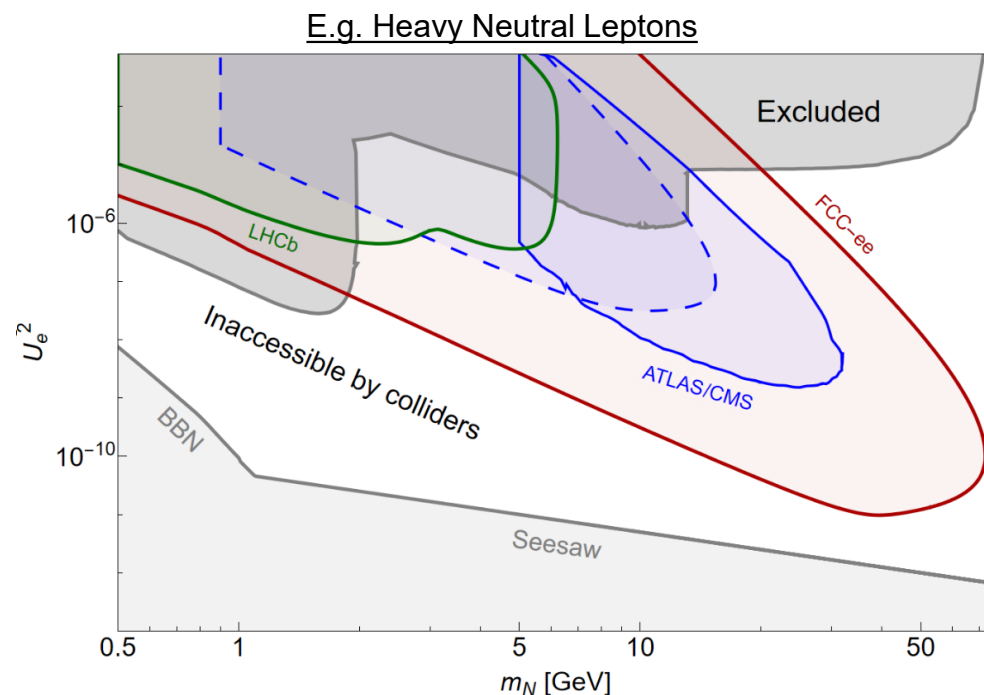
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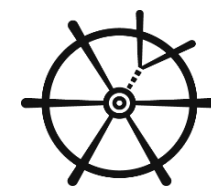


- SPS accelerator energy and intensity unique to explore FIPs
 - SPS energy and intensity provide huge production of charm, beauty and electromagnetic processes
 - Large lifetime acceptance with beam-dump setup - production modes in limited forward cone

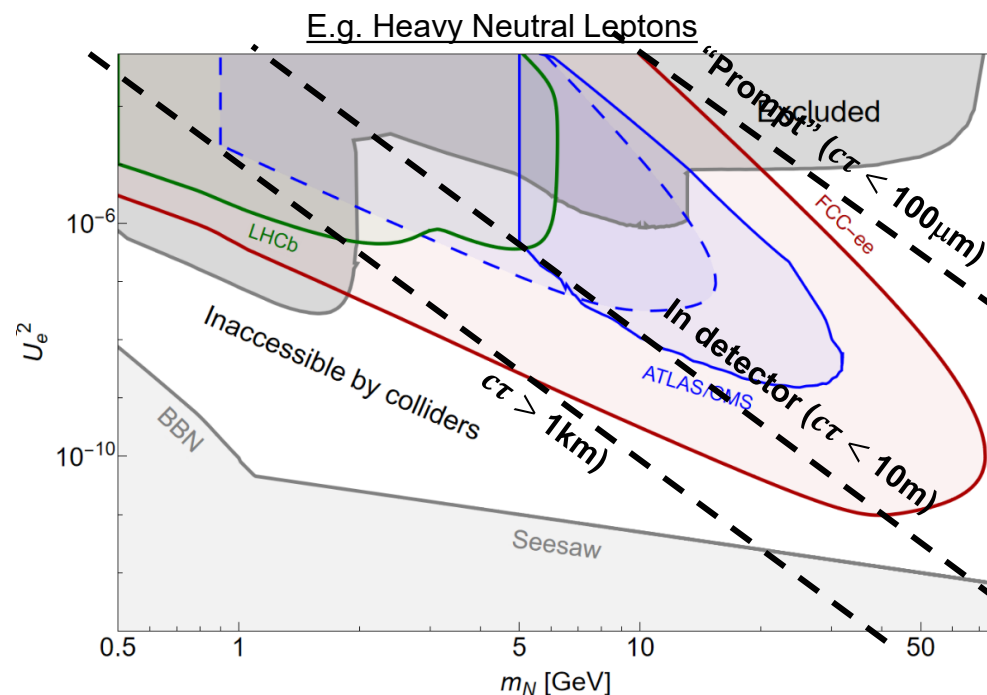


→ Return CERN SPS accelerator to full exploitation of unique physics potential

→ SHiP Physics Proposal compiled and signed by a collaboration of 80 theorists: [Rep. Prog. Phys. 79 \(2016\)124201](#)

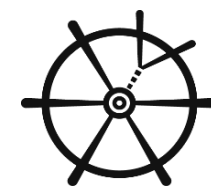


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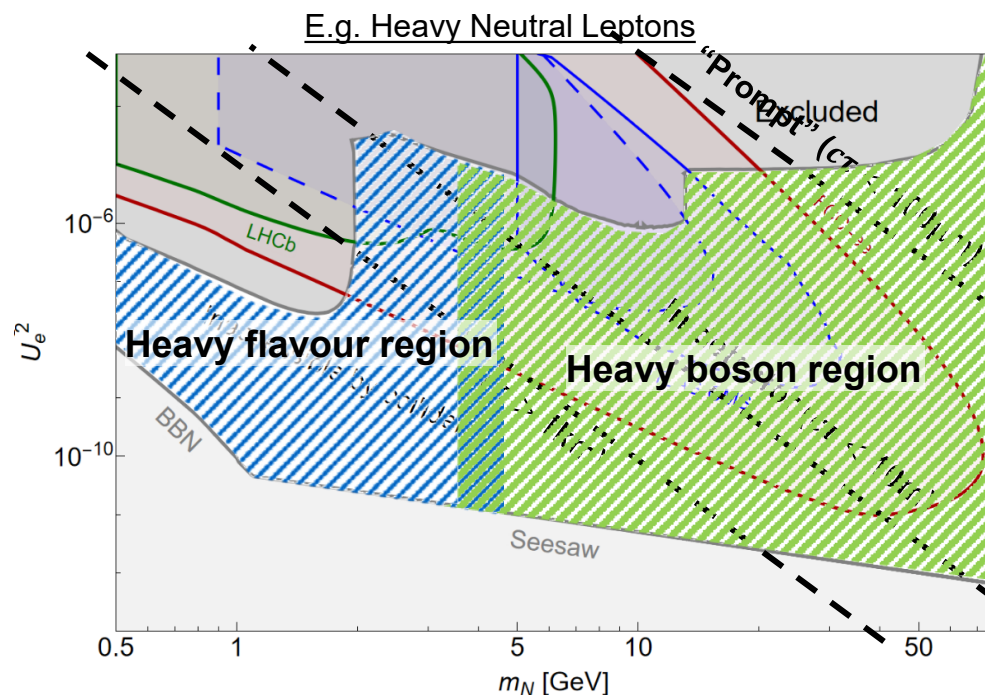
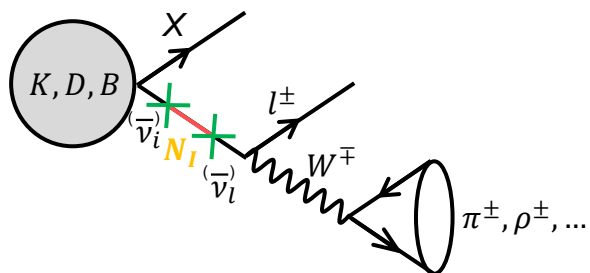


Similar behaviour $\tau_{FIP} \propto \frac{1}{\epsilon_{FIP}^x m_{FIP}^y}$
for all types of FIPs

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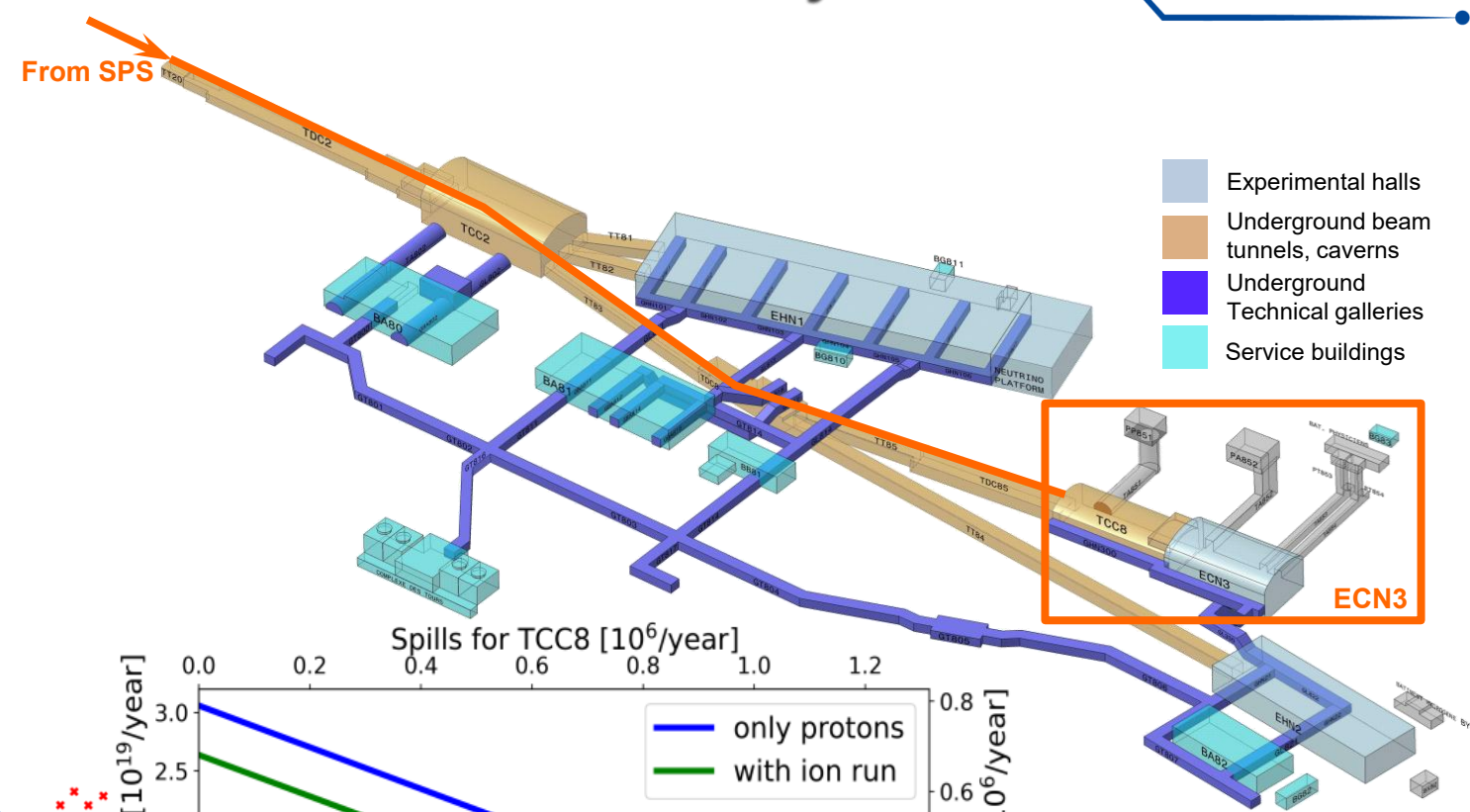
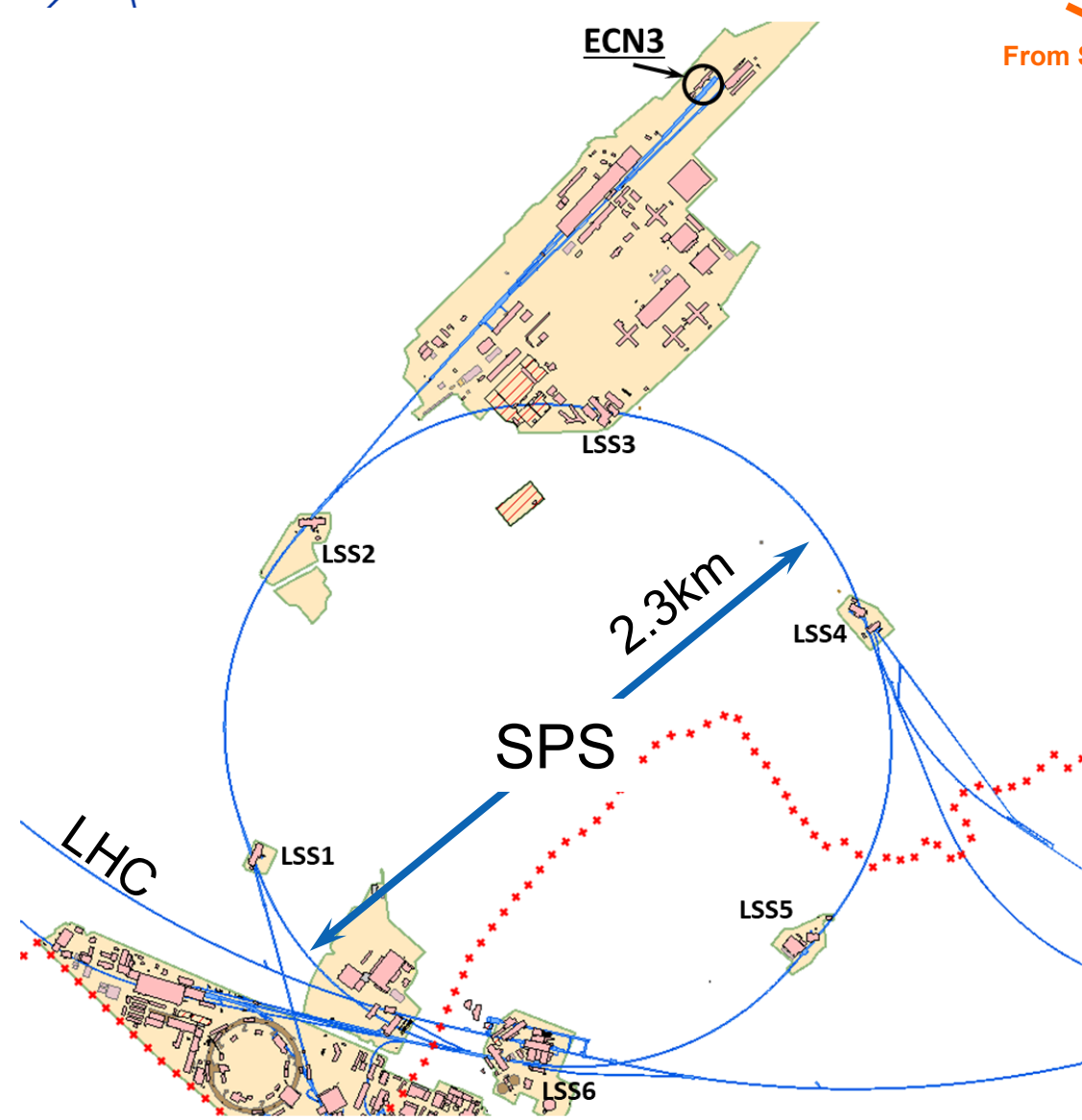
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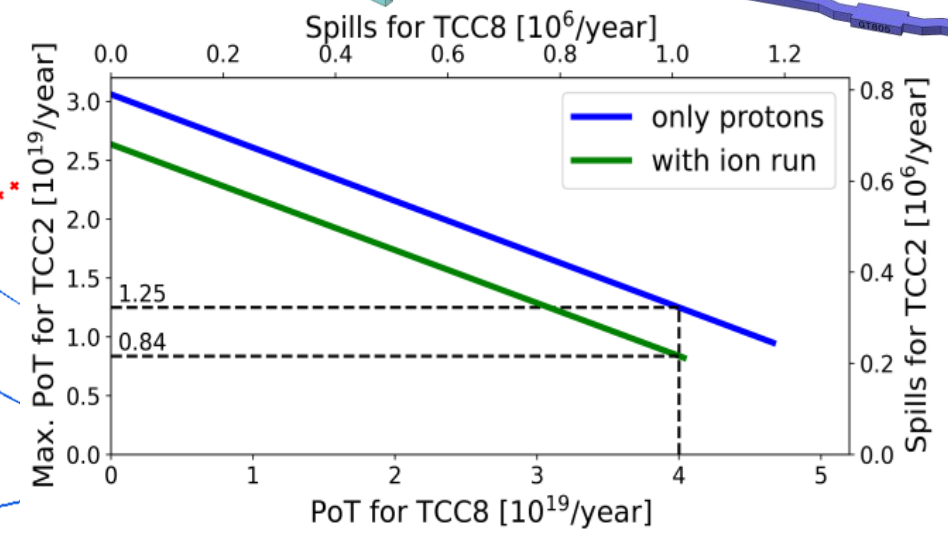
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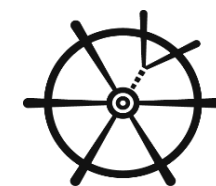
SHiP capable of addressing all classes of FIP models



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



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



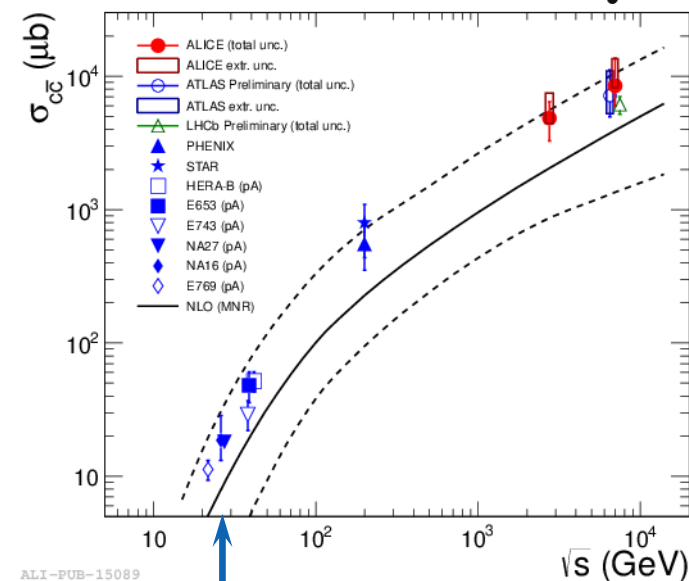
→ BDF luminosity with the **long high-A/Z target** and 4×10^{19} protons on target per year *currently available* in SPS

→ 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:

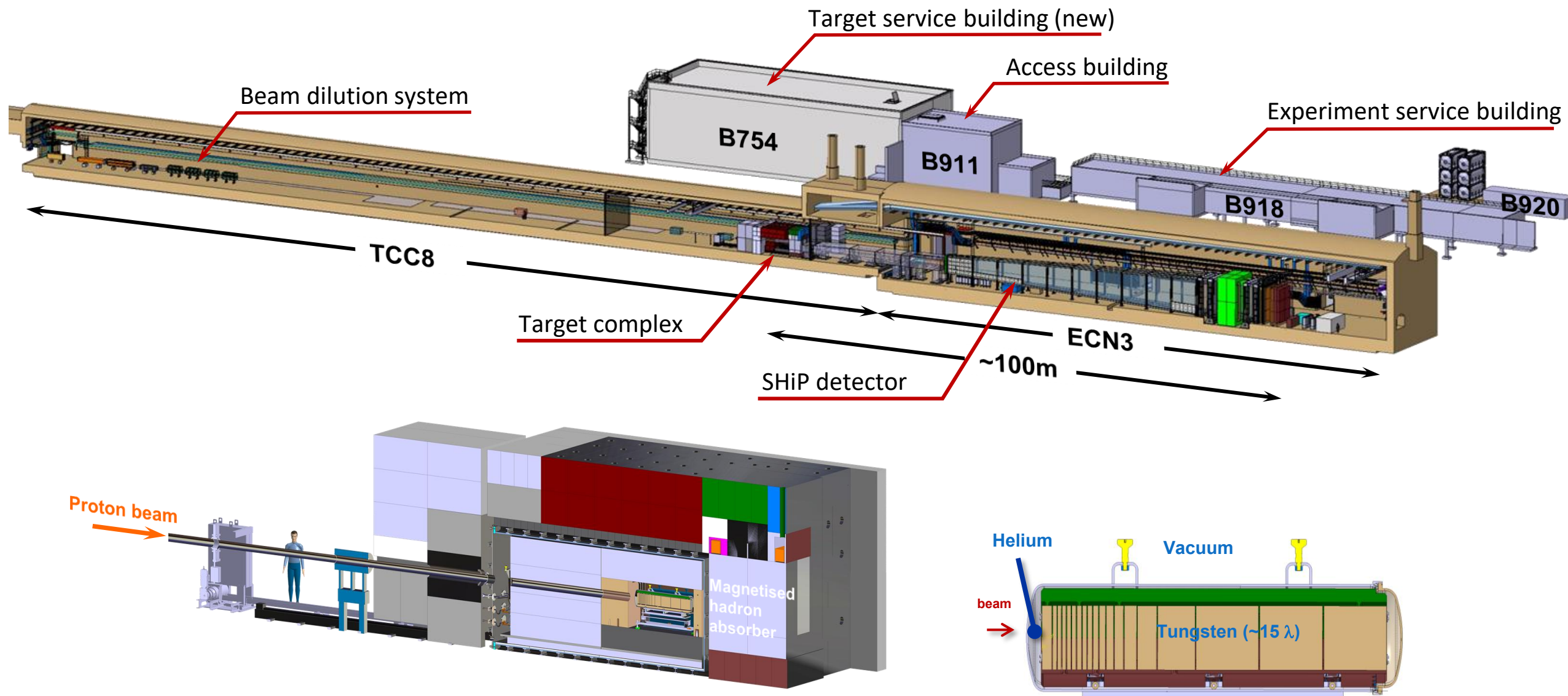
- $\sim 2 \times 10^{17}$ charmed hadrons (>10 times the yield at HL-LHC)
- $\sim 2 \times 10^{12}$ beauty hadrons
- $\sim 2 \times 10^{15}$ tau leptons
- $\mathcal{O}(10^{20})$ photons above 100 MeV
- Large number of neutrinos *detected* with 3t-W ν -target:
 $3500 \nu_\tau + \bar{\nu}_\tau$ per year,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



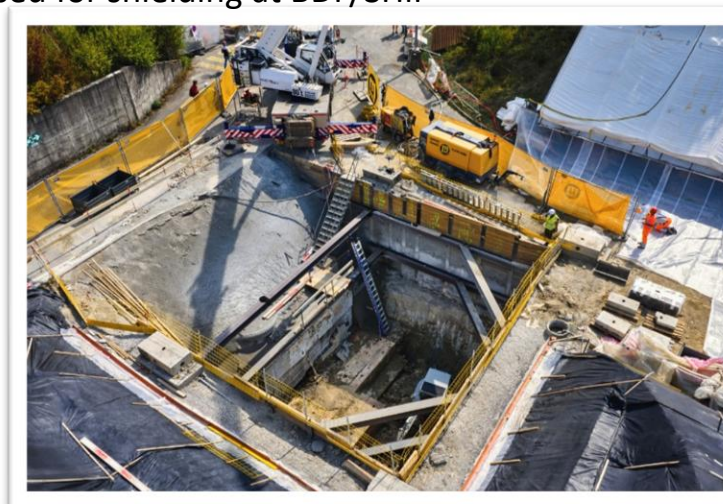
May - July 2025: Ground-breaking at ECN3 for BDF/SHiP:

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



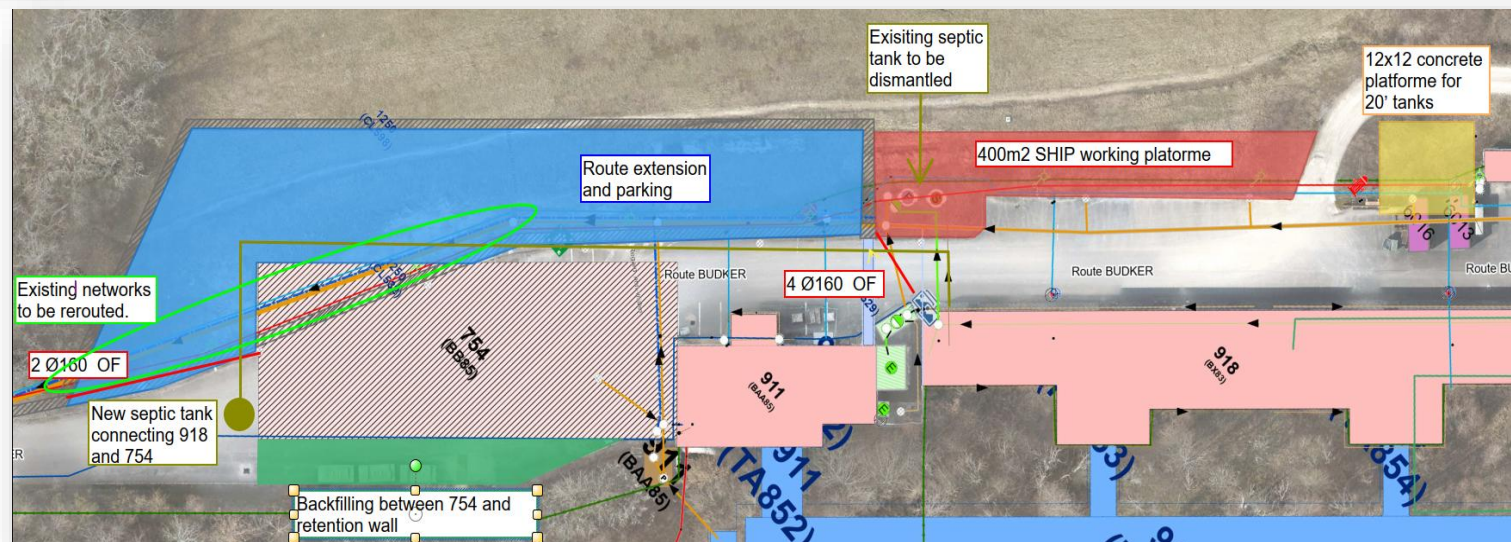
June – Sep 2025: Ground-brea.....

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 Q4-2026

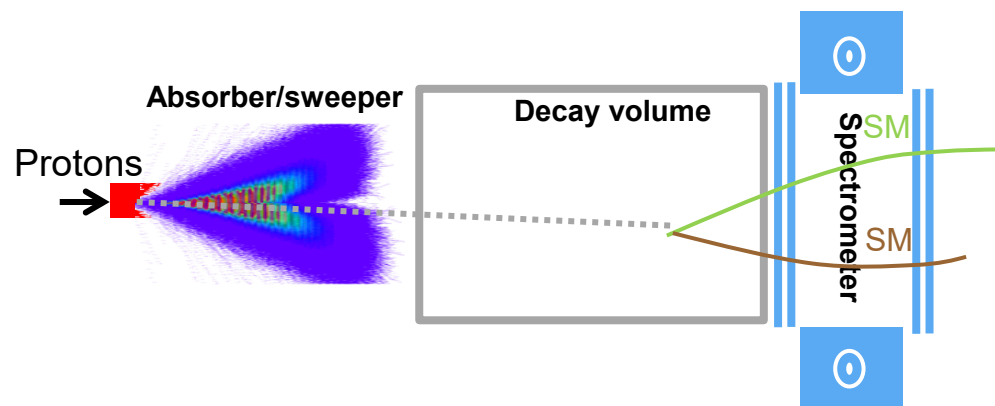
- **Oct 2025: Civil engineering project approval**
- B754 to house facility able to handle, maintain and decommission BDF target: collaboration with RWM to treat legacy CERN waste in the long-term
- Design Study of Service Cell by external contractor returned and being integrated into procurement of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



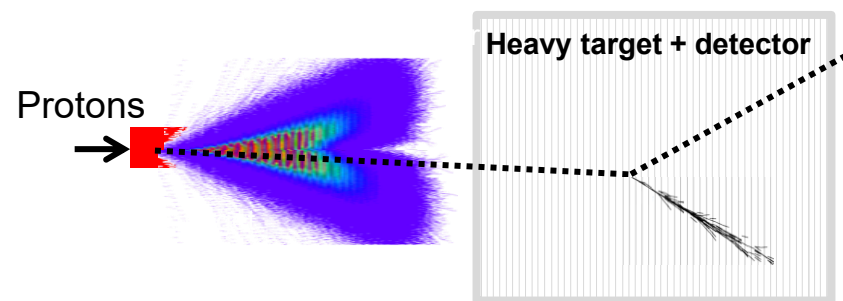


Two-in-one detector concept:

Decay signatures



Scattering signatures

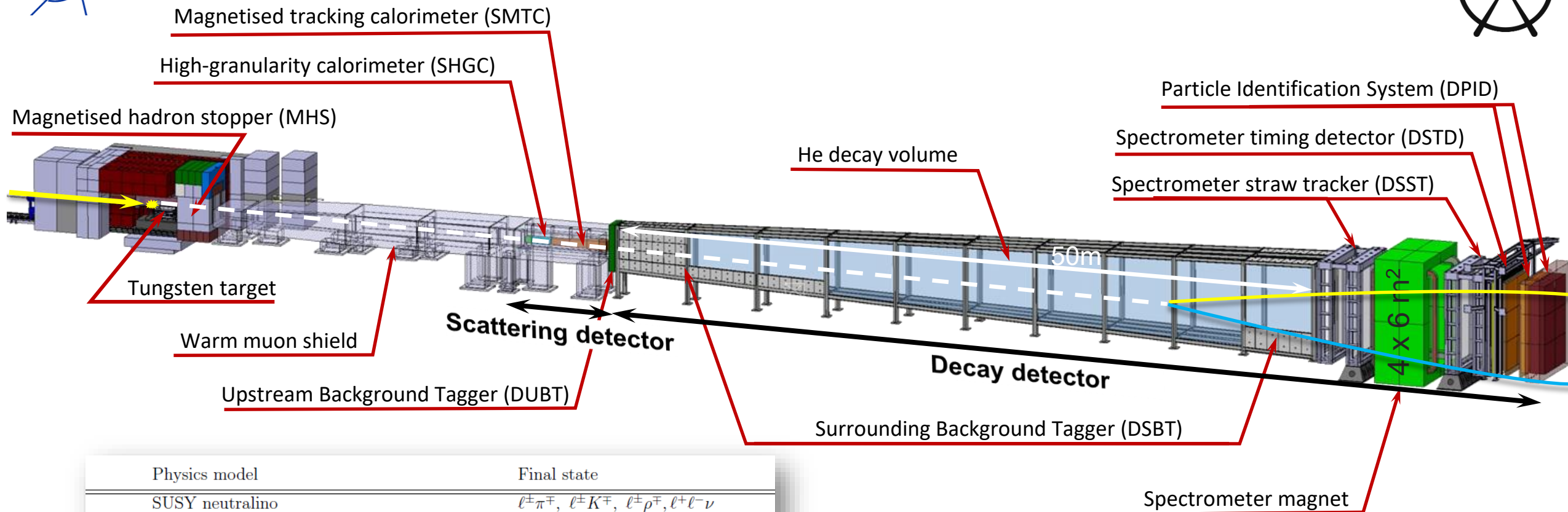
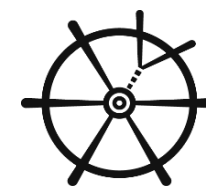


Also suitable for neutrino interaction physics with all flavours

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**

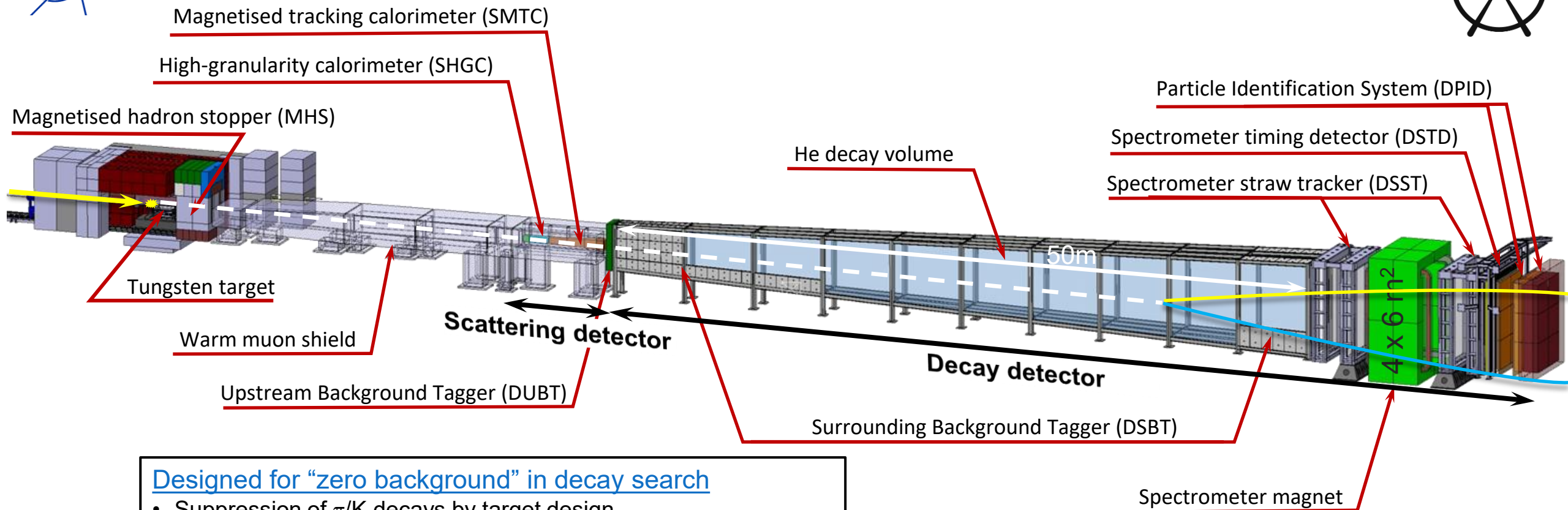
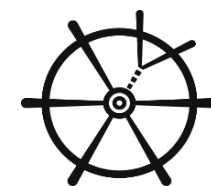
Overview of SHiP detector



	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 detector

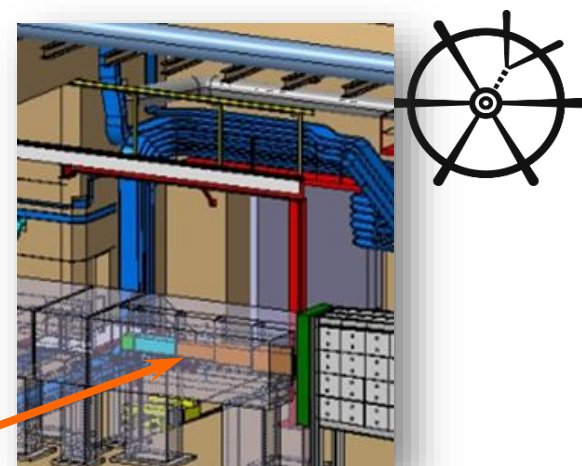


Designed for “zero background” in decay search

- 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 } by main tracker
- Impact parameter at target
- Coincidence timing
- Invariant mass } Not currently used in background suppression
- Particle identification

See Anne-Marie’s talk

Scattering Detector



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

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

- $\sigma_{stat+syst} \sim 5\%$

→ 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 $\sigma_{\nu-CC DIS}$ ($<10\%$)

→ Neutrino-induced hyperon production

→ Neutrino-induced charm production: nucleon strangeness, $|V_{cd}|$ ($<2\%$),...

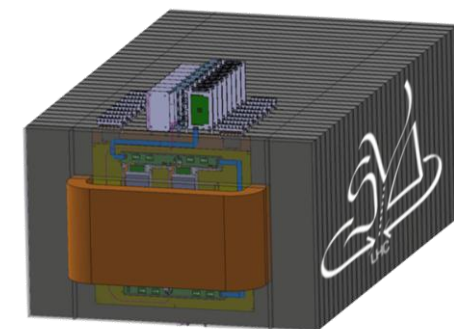
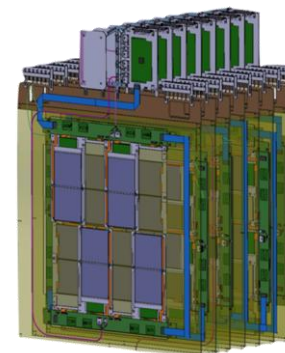
→ BSM physics with neutrinos

Clean vertex and accurate e.m. shower reconstruction

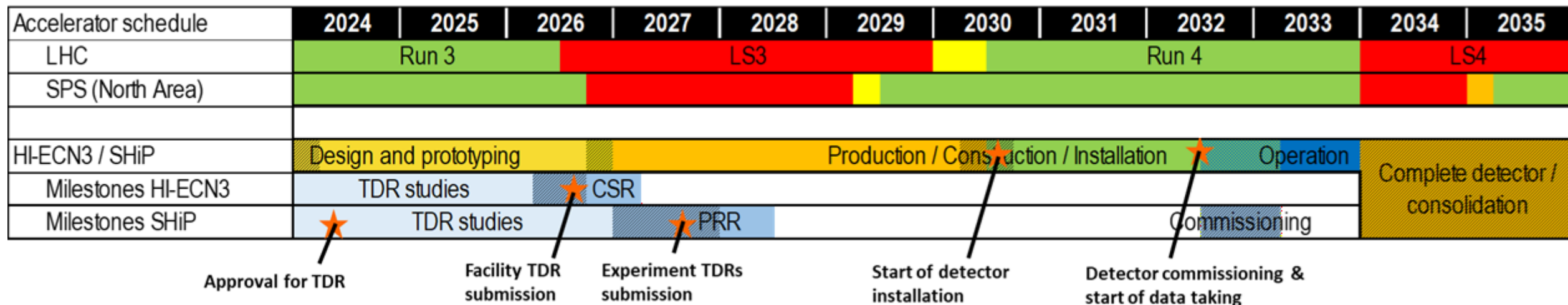
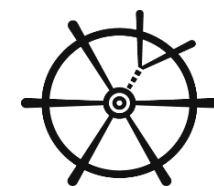
→ Direct LDM search through scattering, sensitivity to ϵ^4

	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

Detector prototyping in the context of the SND@LHC experiment upgrade



See Massi's talk



SHiP objectives for Run 4

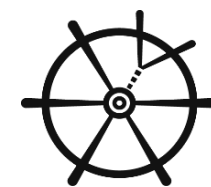
1. **Detector commissioning and facility commissioning – 2032 Q3-Q4**

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

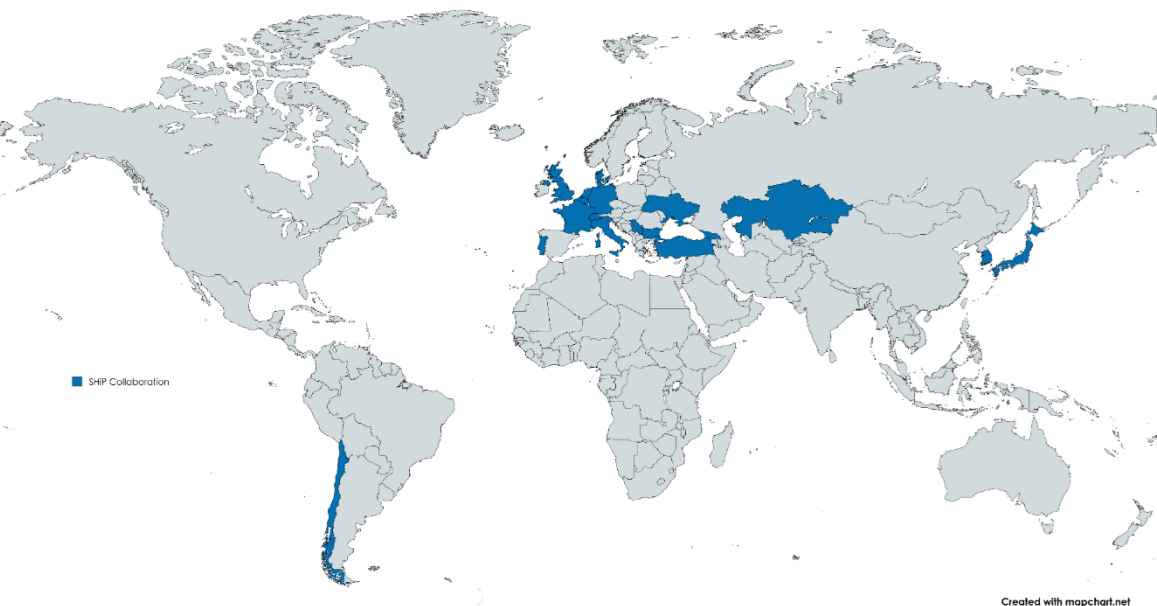
2. **Commissioning + physics run in nominal conditions, aiming for 4×10^{19} p/target – 2033**

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

→ *Run 4 provide key input to preparation of run for full programme post-LS4 – risk mitigation*



33 institutes + 5 associate institutes from 18 countries, and CERN and JINR



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

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

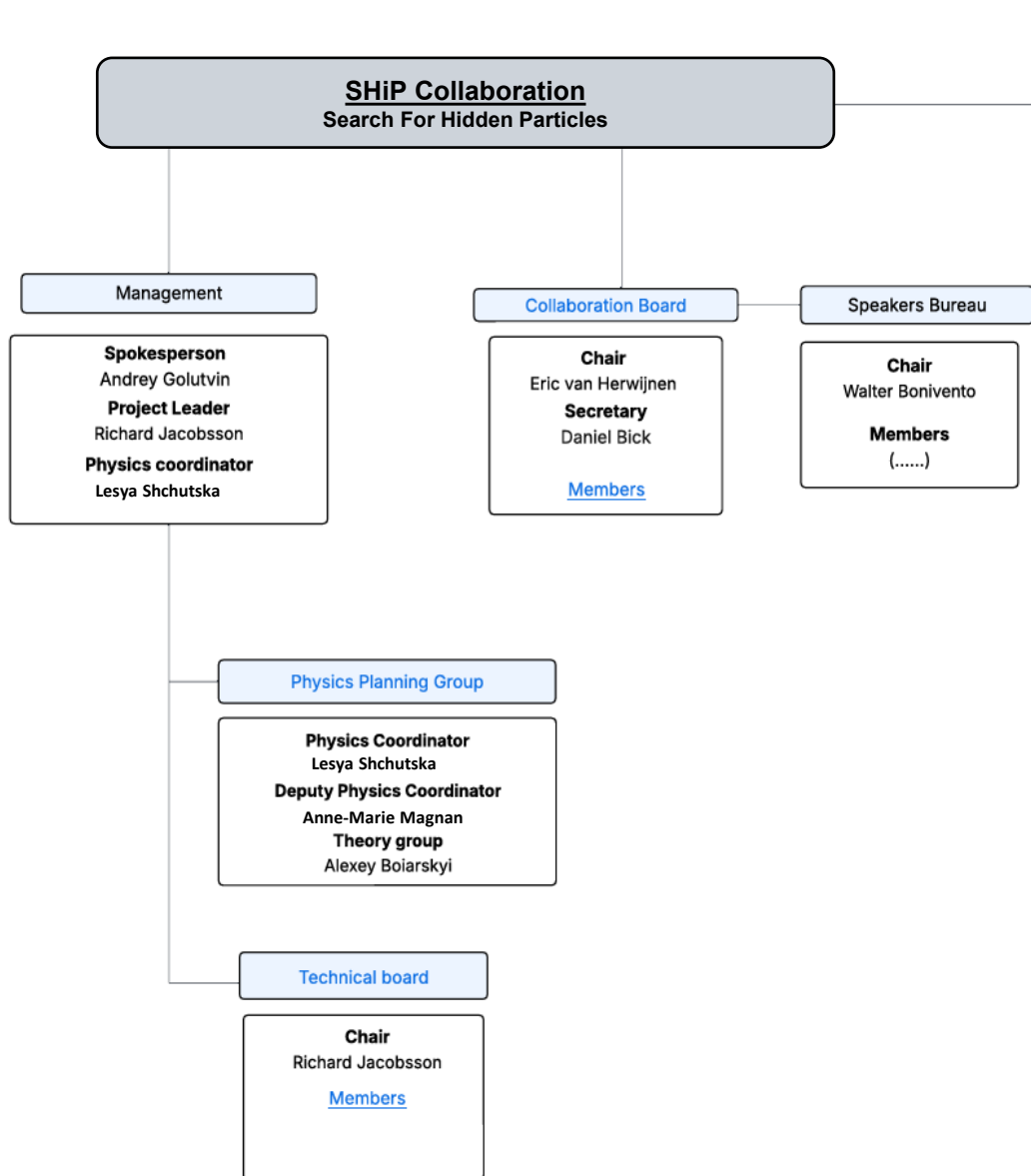
slanted: also in SND@LHC. New groups are regularly joining SND@LHC; they will eventually join SHiP (Genova, Catania, Salerno)

Recently joined in 2024-2025

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

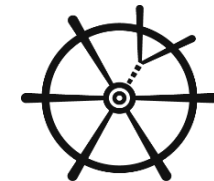
- Wuppertal joined in March 2026
- Application from Aachen (Germany) and Hefei institutes USTC and ASIPP (China) received (April 2026)

CERN Grey book Experiment's detail



Sub-projects	Abbr.	2026		2026		To be confirmed TDR submission
		Lead group	Convener 1	Convener 2		
Muon Shield						
Common Warm Muon Shield	CWMS	CERN	M. Ferro-Luzzi	M. Liebsch		2027 - Q1
Scattering Detector	SD		G. De Lellis	A. Di Crescenzo		
Sd Emulsion Target	SEMT	Nagoya	M. Komatsu			
Sd High-Granual Calorimeter	SHGC					
Sd Tracking Calorimeter Pads	STCP	Gent	K. Skovpen			
Sd Tracking Calorimeter sciFi	STCF	EPFL	L. Shchutska -->			
Decay Detector	DD					
Dd Volume Helium	DVOH	CERN	P. Santos Diaz	A. Miano		2027-Q3
Dd Background Tagger Straw	DBTS	Liverpool	T. Bowcock			2027-Q4
Dd Background Tagger Timing	DBTT	Gent/EPFL	K. Skovpen			
Dd Surround Background Tagger	DSBT	Berlin	H. Lacker	H. Fischer		2027-Q2
Dd Spectrometer Magnet	DSMG	CERN	F. Savary	L. Baudin		2027-Q4
Dd Spectrometer Straw Tracker	DSST	Hamburg	D. Bick			2027-Q4
Dd Spectrometer Timing Detector	DSTD	Zurich -->	G. Vasquez	C. Betancourt		2027-Q3?
Dd ECAI	DECA	Mainz		R. Wanke		
Dd Ecal Precision Layers	DEPA		W. Bonivento			
Dd HCAI	DHPA	Mainz		R. Wanke		
Infrastructure						
Common INFrastructure	CINF	CERN	P. Santos Diaz			TBD (2027-Q3?)
Control and data handling						
Common ELEctronics	CELE	IJClab	J. Maalmi	D. Breton		2028 - Q1
Common ONLine system	CONL	CERN	F. Alessio			
Common CoMPuting	CCMP	CERN	E. Gamberini			
Common Physics SoftWare	CPSW	Seigen	O. Lantwin			w. "physics TDR"?

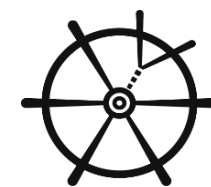
Detector cost and initial configuration



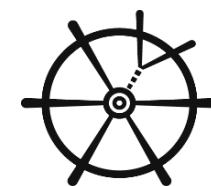
[kCHF]	Sub-projects	Cost SHiP (2025 costing)		Common Fund for	
		Construction	Run4 Initial	baseline	
Muon Shield		10,000			
	Common Warm Muon Shield	10,000	10,000	50%	5,000
Scattering Detector		10,107			
	Sd Emulsion Target (w/o emulsion)	312	?	0%	0
	Sd High-Granular Calorimeter	6,854	?	0%	0
	Sd Tracking Calorimeter sciPads	1,494	?	0%	0
	Sd Tracking Calorimeter sciFi	1,447	?	0%	0
Decay Detector		27,619			
	Dd VOLume	714	714	50%	357
	Dd Background Tagger Straw	546	546	0%	0
	Dd Background Tagger Timing	318	318	0%	0
	Dd Surround Background Tagger	3,738	?	0%	0
	Dd Spectrometer Magnet	11,000	11,000	30%	3,300
	Dd Spectrometer Straw Tracker	3,168	3,168	0%	0
	Dd Spectrometer Timing Detector	471	471	0%	0
	Dd ECAI	2,760	LHCb PS/SPD	0%	0
	Dd Ecal Precision Layers	3,953	?	0%	0
	Dd HCAI	LHCb HCAL	951	?	0
Infrastructure		1,000			
	Common INFrastructure	1,000	1,000	0%	0
Control and data handling		1,500			
	Common ELEctronics	400	300	100%	
	Common ONLine system	400	400	50%	200
	Common CoMPuting	700	500	50%	350
	Common Physics SoftWare			0%	0
Total		50,226	28,417	18%	9,207

- Also investigating recycling of some NA62 components

Draft of MoU for “Prototyping and Construction of SHiP” has been prepared for discussion

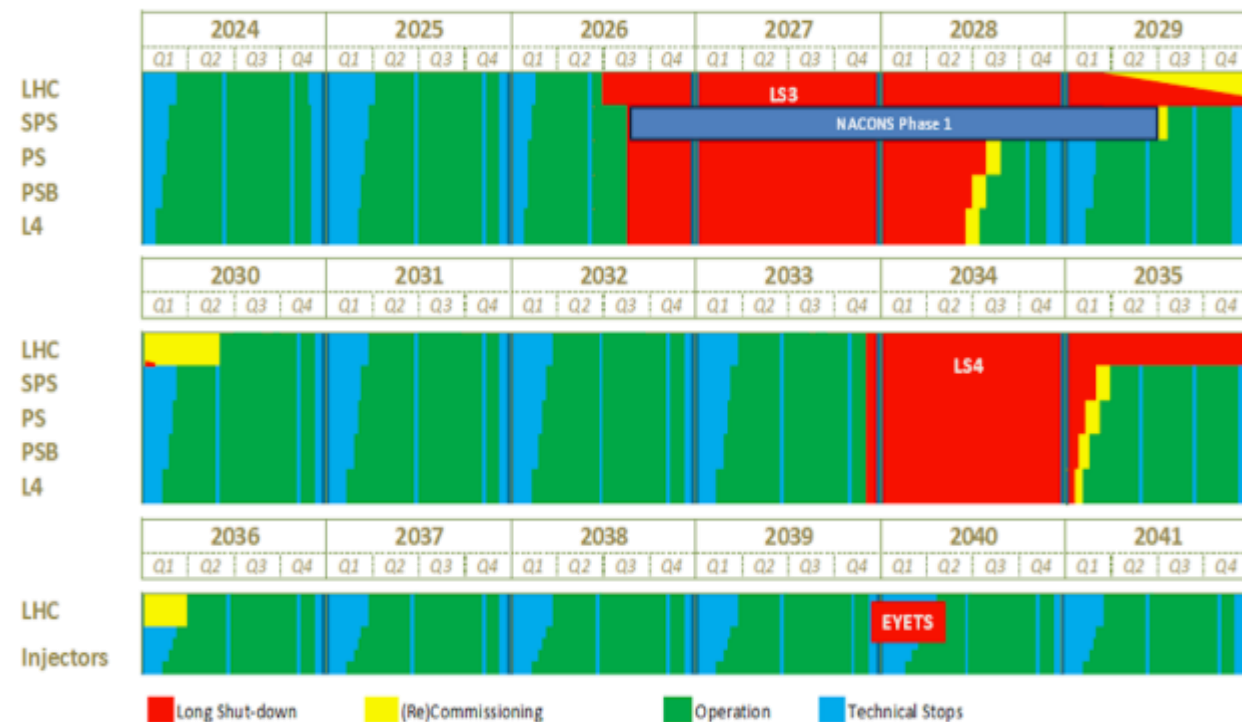


Slides for further discussion



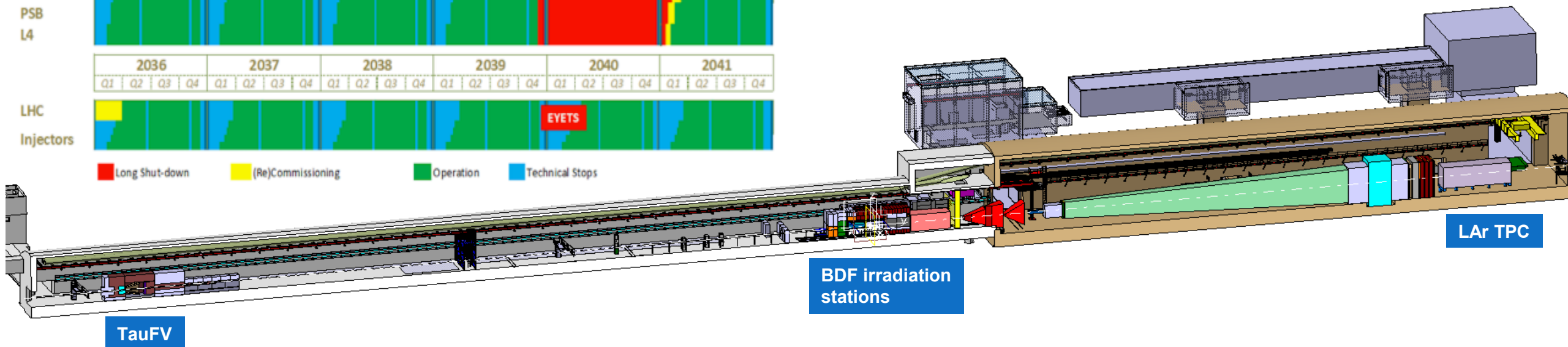
→ SHiP physics exploration stretches over 15 years

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

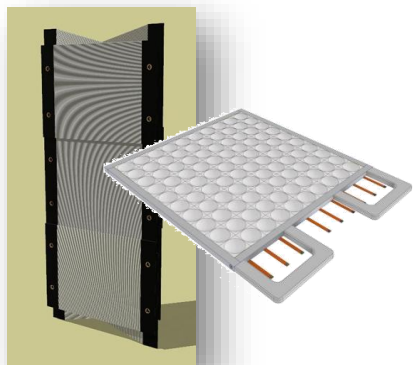
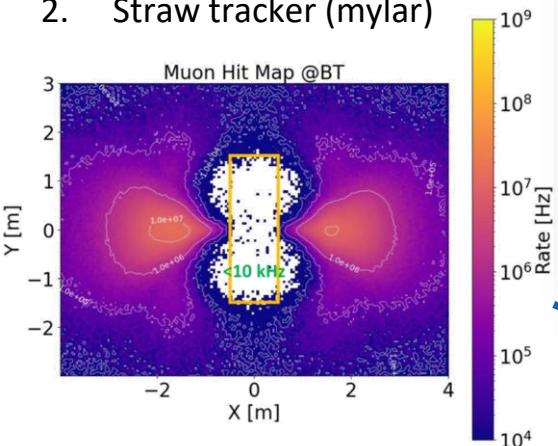


Decay detector technologies



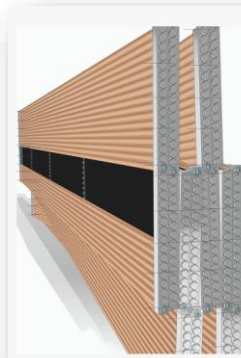
Upstream Background Tagger (eff >99%)

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



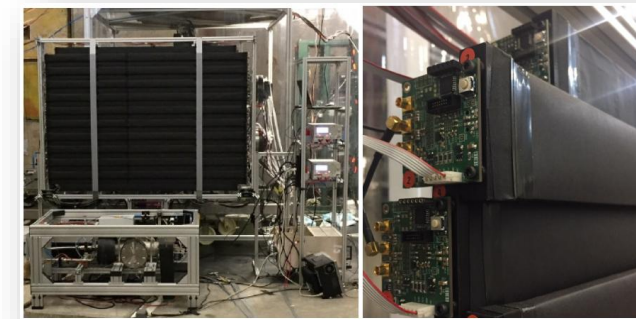
Spectrometer Straw Tracker

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



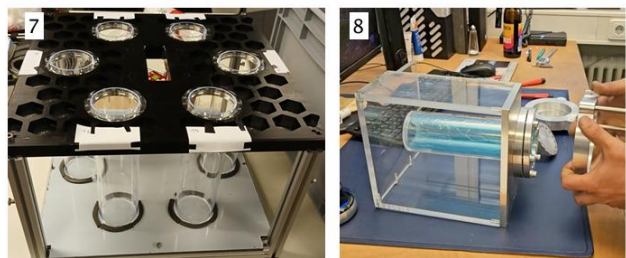
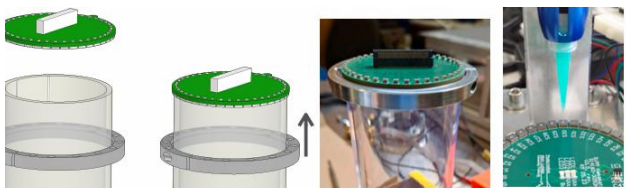
Spectrometer Timing Detector

- <100 ps
- Scintillating bars + SiPM



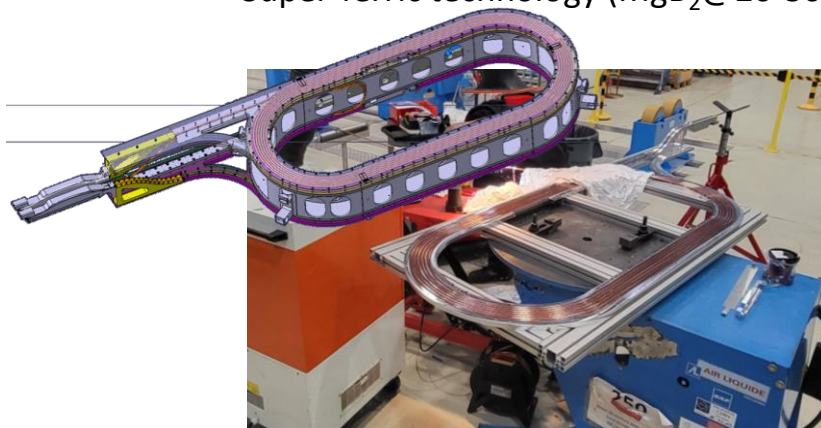
Surrounding Background Tagger

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



Spectrometer magnet

- 4m x 6m, 0.7 Tm
- Super-ferric technology (MgB_2 @ 20-30K)



PID system

- LHCb PS/SPD, HCAL
- PID + shower axis <5mrad
- High-precision layer with GEMs, RPCs, or SciFi

