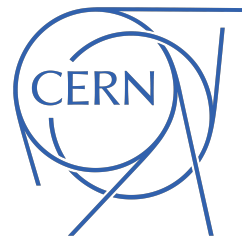




LABORATÓRIO DE INSTRUMENTAÇÃO  
E FÍSICA EXPERIMENTAL DE PARTÍCULAS

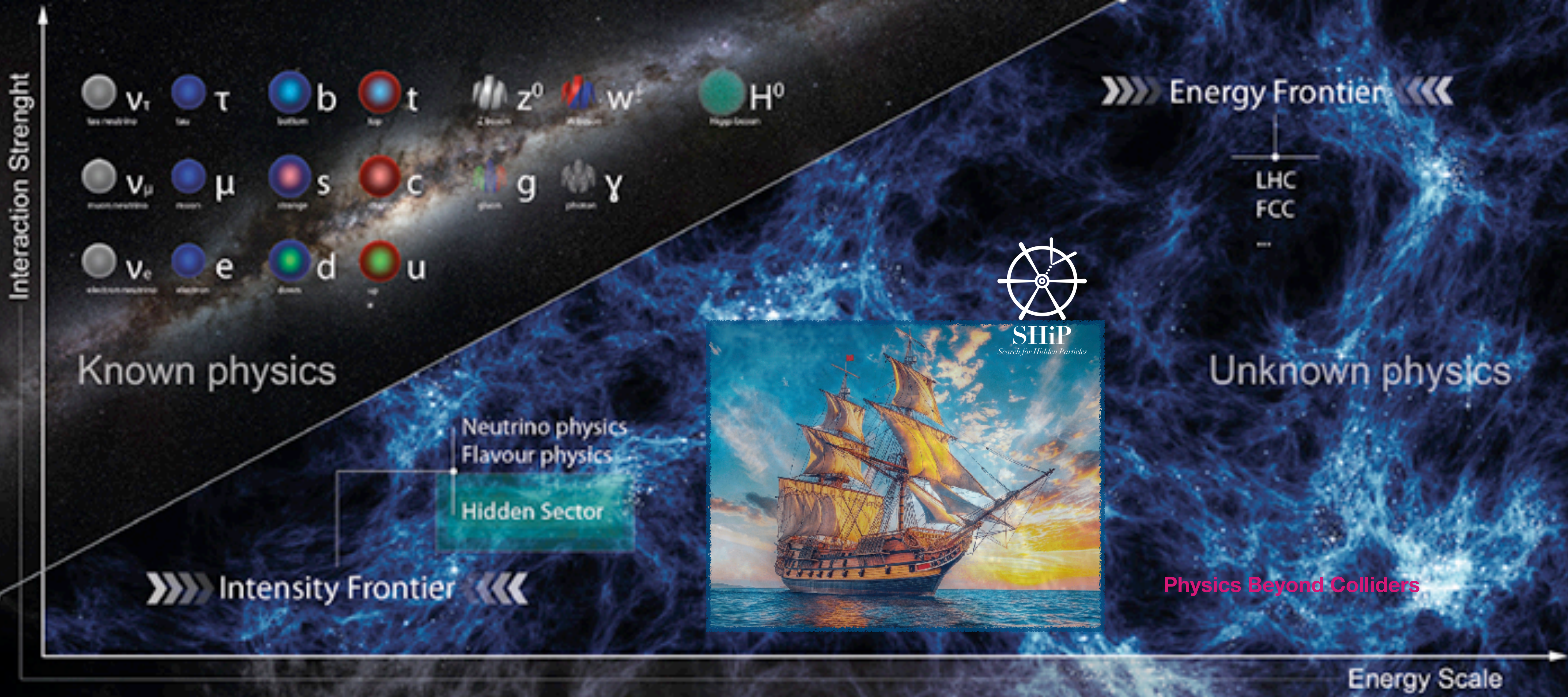


Fundação  
para a Ciência  
e a Tecnologia

# Search for Hidden Particles

N.LEONARDO, SHIP/SND@LHC LIP GROUP

Portuguese Discussion European Strategy Particle Physics, 20/1/2025



Physics Beyond Colliders

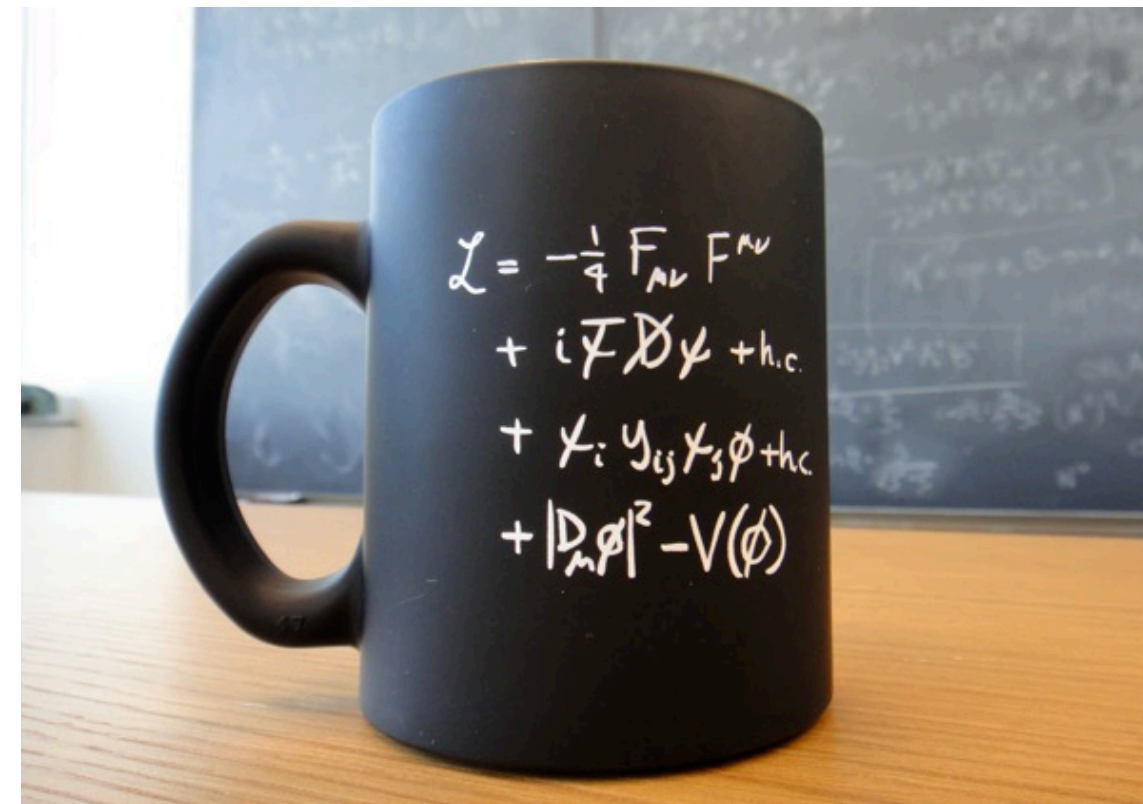
# Exploring the hidden sector of particle physics

Physics beyond-SM needed:

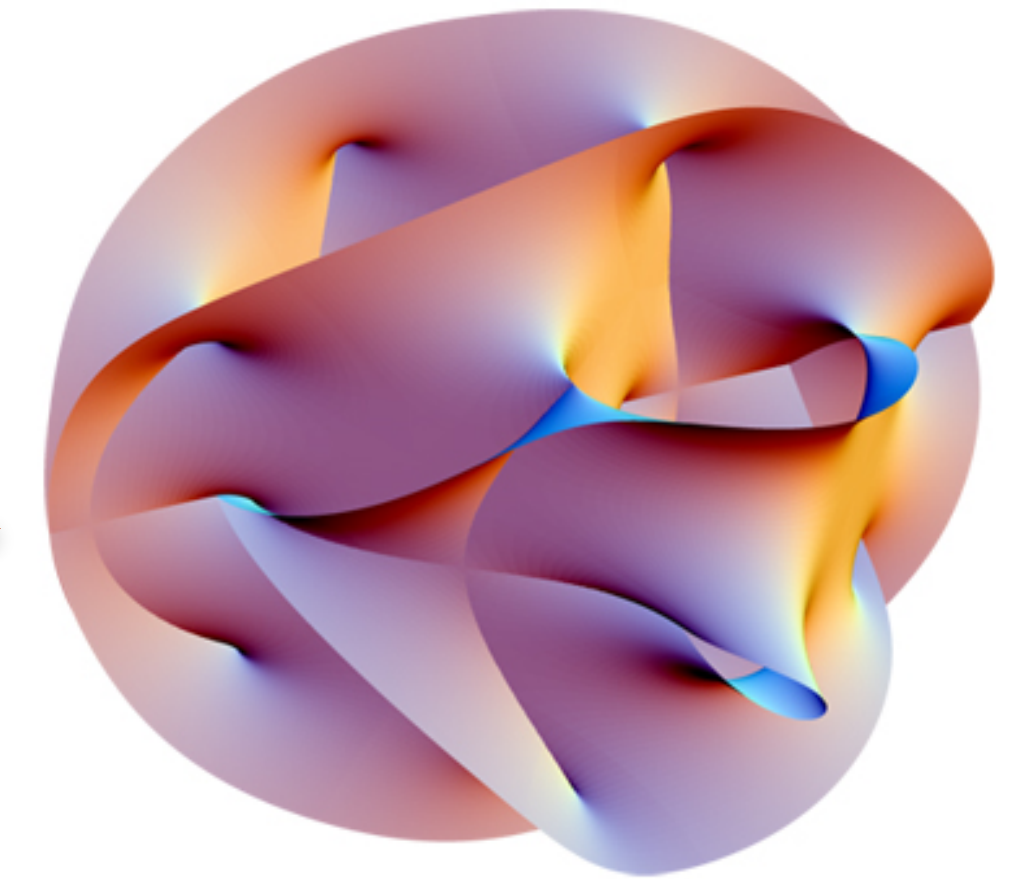
- dark matter
- neutrino masses
- baryon asymmetry

No clear guidance towards BSM:

- from theory or experiment
- no prejudice on mass, spin, coupling

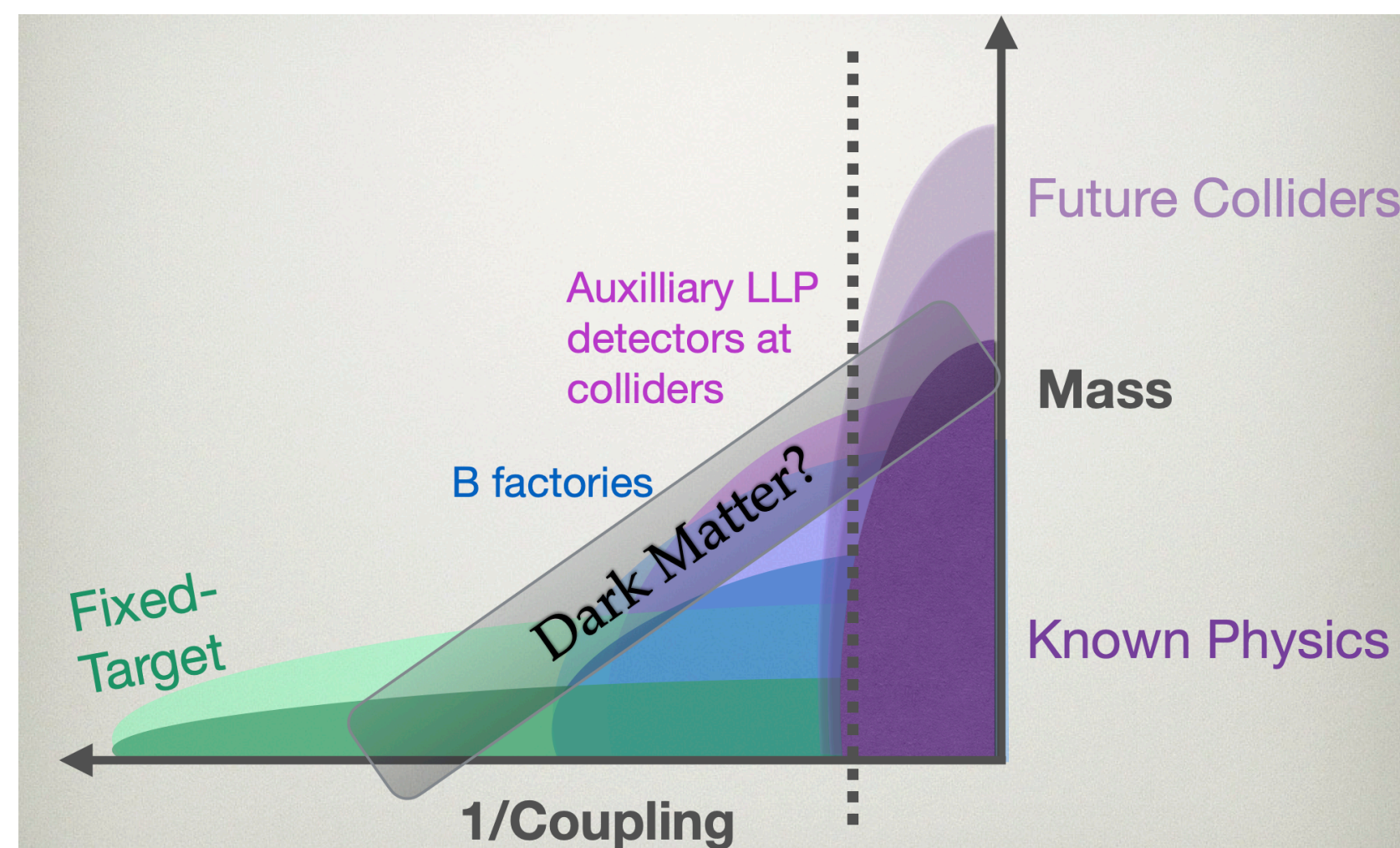
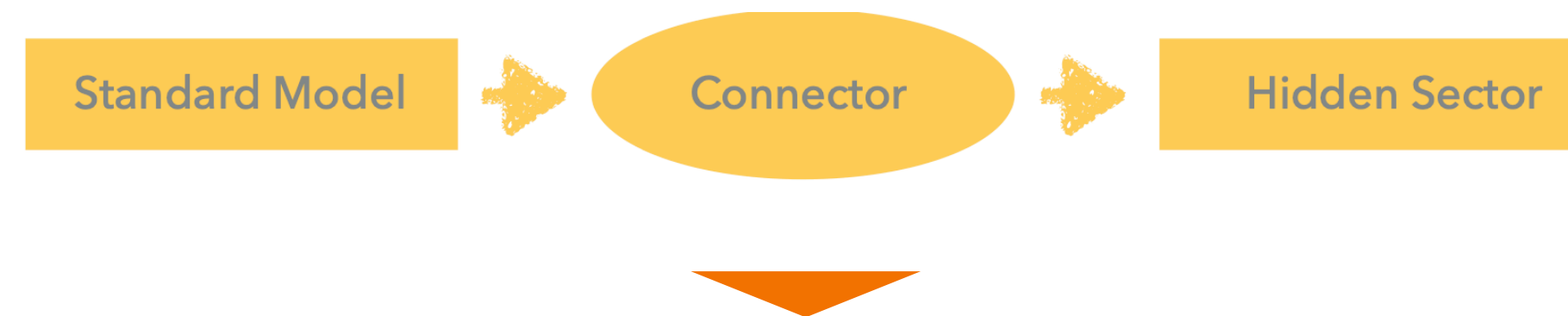


$$\mathcal{L} = \mathcal{L}_{\text{SM}} + \mathcal{L}_{\text{Mediator}} + \mathcal{L}_{\text{HS}}$$



New particles **not yet found** as:

1. too **heavy** for the available  $\sqrt{s}$   $\hookrightarrow$  energy frontier, or
2. very **feebly** interacting with SM  $\hookrightarrow$  **intensity frontier**

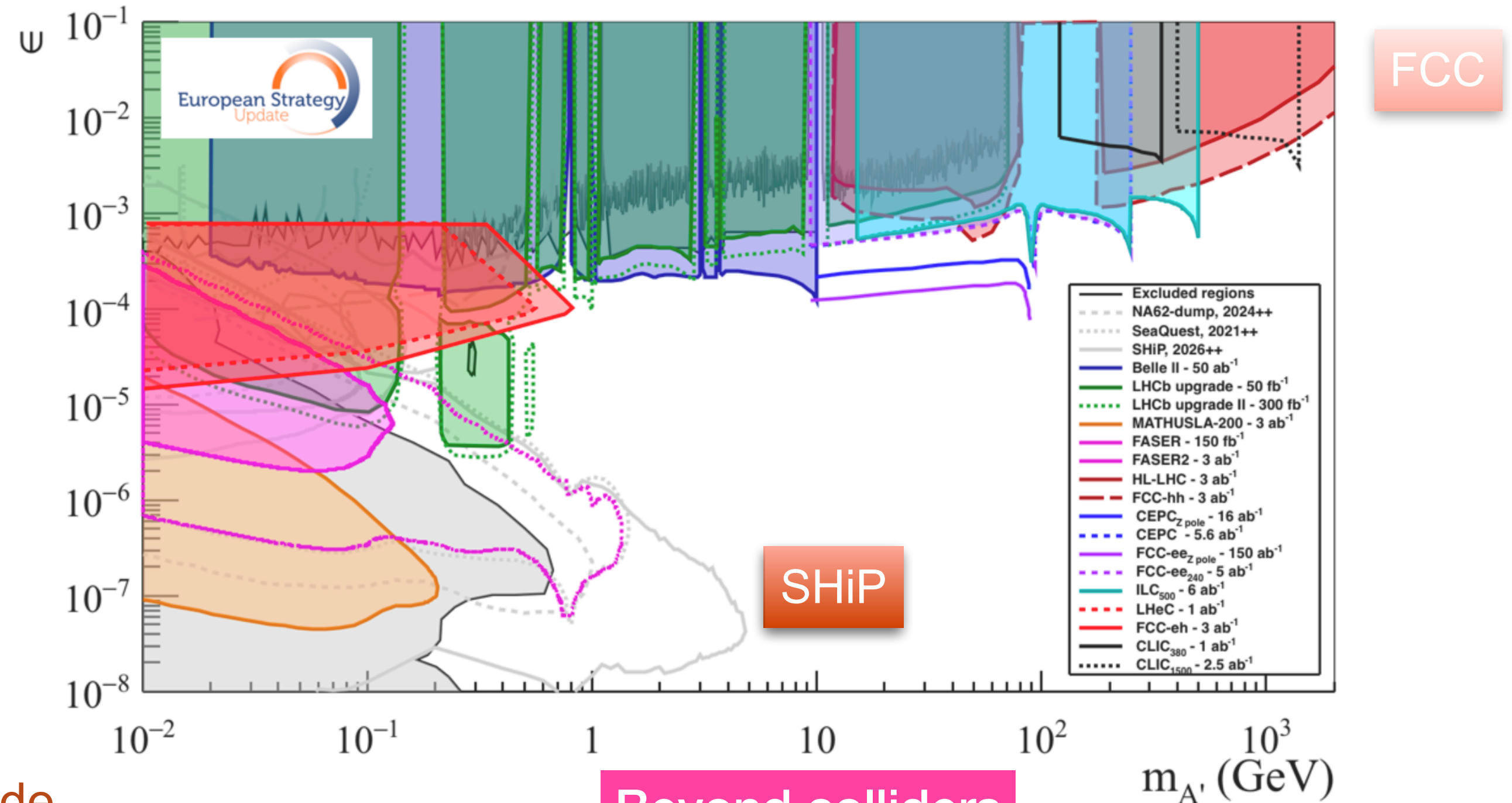
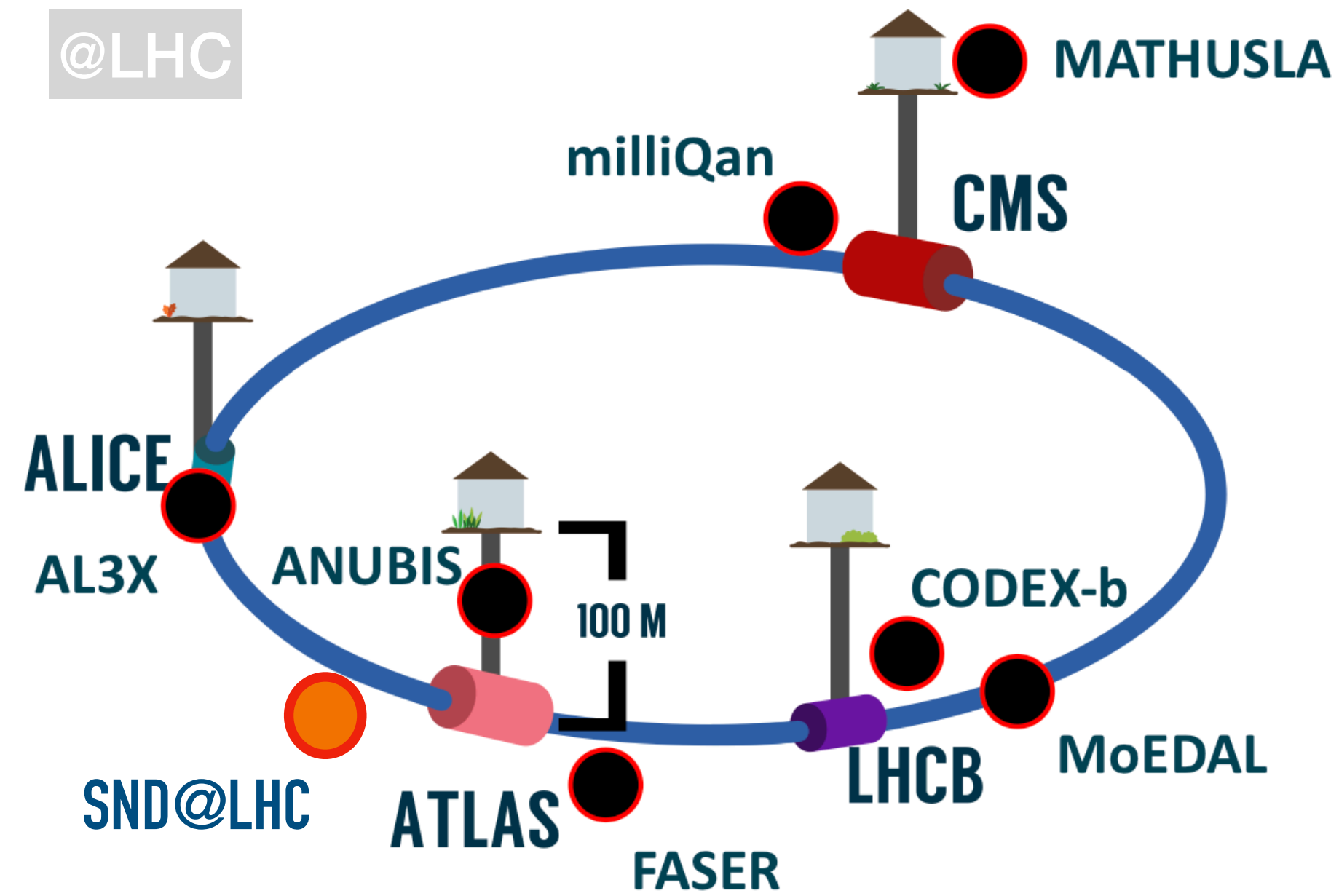


Hidden / **dark sector** accessible via portals:

- scalar portal: dark scalars, **dark Higgs**
- pseudo-scalar portal: axion-like particle, **ALPs**
- vector portal: e.g. **dark photon**, DP
- fermion portal: e.g. heavy neutral leptons, **HNLs**

Weakly-coupled new physics  $\hookrightarrow$  lead to **long-lived** signatures

# Searching for FIPs: Feebly Interacting Particles



Enormous increase in interest in FIP searches over last decade

↳ following nulls results from direct BSM searches at LHC

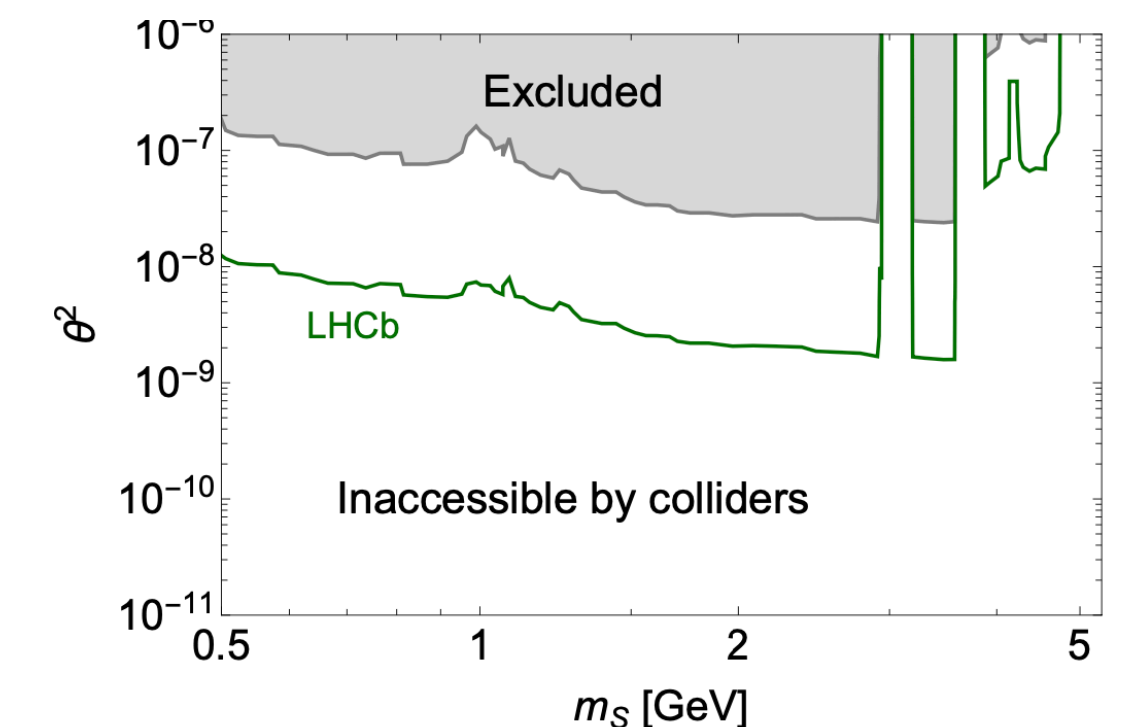
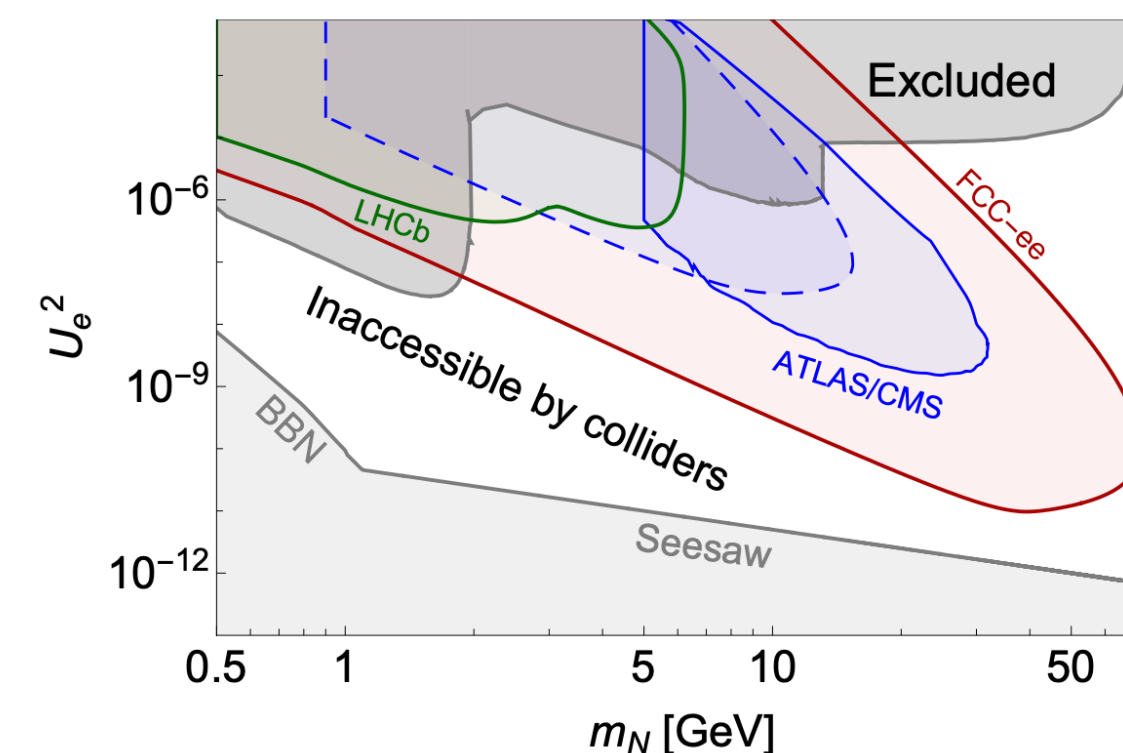
Multiple FIP-dedicated projects being prototyped, proposed

↳ at LHC (incl. dedicated FPF) and beyond

SHiP's recent approval facilitates framework for collaboration

↳ allows not only to detect FIPs but measure their properties

Beyond colliders



# SHiP, approval history

- 2013: Letter of Intent, 1310.1762
- 2015: Technical + Physics proposals, 1504.04956/CERN-SPSC-2015-040
- 2019: CDS report, CERN-SPSC-2019-049
- 2021: **SND@LHC approved**, SHiP neutrino detector prototype
- 2023: BDF/SHiP at ECN3, CERN-SPSC-2023-033
- 2023: CERN approves high-intensity upgrade of ECN3
- 2024: **CERN approves SHiP** for exploring ECN3 facility
- 2026: TDR (ongoing)

**Since last ESPPU (2020), significant cost reduction achieved by adopting existing ECN3 cavern instead of building new ECN4 BDF facility**



CERN-SPSC-2015-017  
SPSC-P-350-ADD-1  
9 April 2015

## SHiP Experiment COMPREHENSIVE DESIGN STUDY REPORT

SHiP Collaboration

### Abstract

Following the completion of the Comprehensive Design Study of the SHiP detector, this document summarises the status of the physics and the detector and outlines a three-year design and development plan towards Technical Design Reports. The document concludes with an overall road map and updated costs for the detector R&D and construction. With the submission and review of this document, together with the SHiP Progress Report [1] and the Beam Dump Facility Yellow Report [2], the SHiP Collaboration is ready to proceed with the preparation of Technical Design Reports, pending approval.

**Keywords**  
SHiP, Comprehensive Design Study, SPS, CERN



CERN-SPSC-2022-032 / SPSC-I-258  
7 November 2022

## BDF/SHiP at the ECN3 high-intensity beam facility Letter of Intent

BDF Working Group, SHiP Collaboration

### Abstract

The BDF/SHiP collaboration has proposed a general-purpose intensity-frontier experimental facility operating in beam-dump mode at the CERN SPS accelerator to search for feebly interacting GeV-scale particles and to perform measurements in neutrino physics. BDF/SHiP complements the world-wide program of New Physics searches by exploring a large region of parameter space which cannot be addressed by other experiments, and which reaches several orders of magnitude below existing bounds. The SHiP detector is sensitive both to decay and scattering signatures of models with heavy neutral leptons, dark photons, dark scalars, axion-like particles, light dark matter and other feebly interacting particles. In neutrino physics, BDF/SHiP can perform unprecedented measurements with tau neutrinos and neutrino-induced charm production. Following the Technical Proposal submitted in 2015, the subsequent three-year Comprehensive Design Study (CDS), and the recent study of BDF/SHiP in existing beam facilities around the SPS, this paper restates the motivation and reports on the implementation and physics performance of BDF/SHiP in the SPS ECN3 high-intensity beam facility.

**Keywords:** Beam Dump Facility, BDF, SHiP, SPS, ECN3

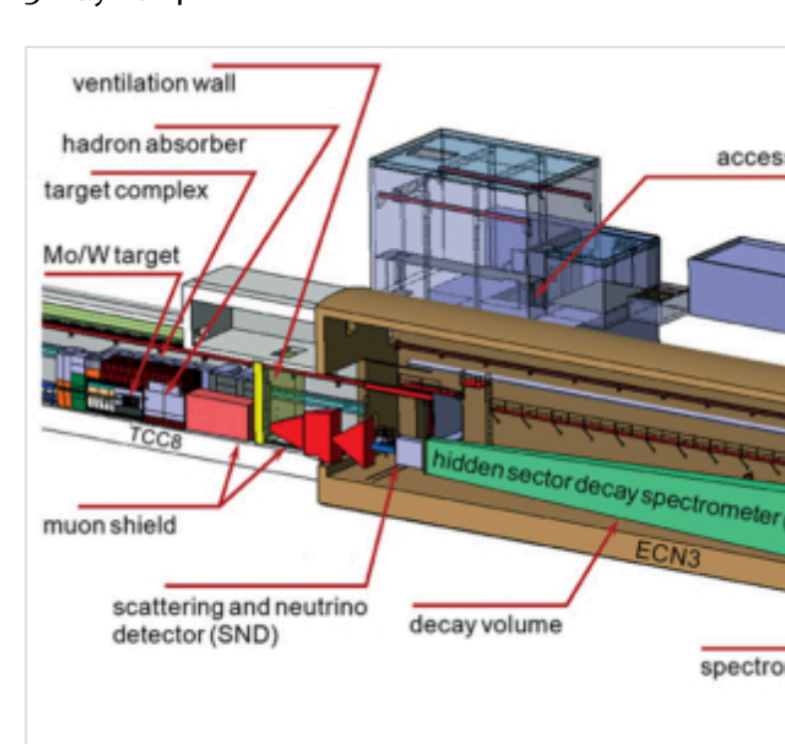
CERN-SPSC-2022-032 / SPSC-I-258  
08/11/2022

approval 2024

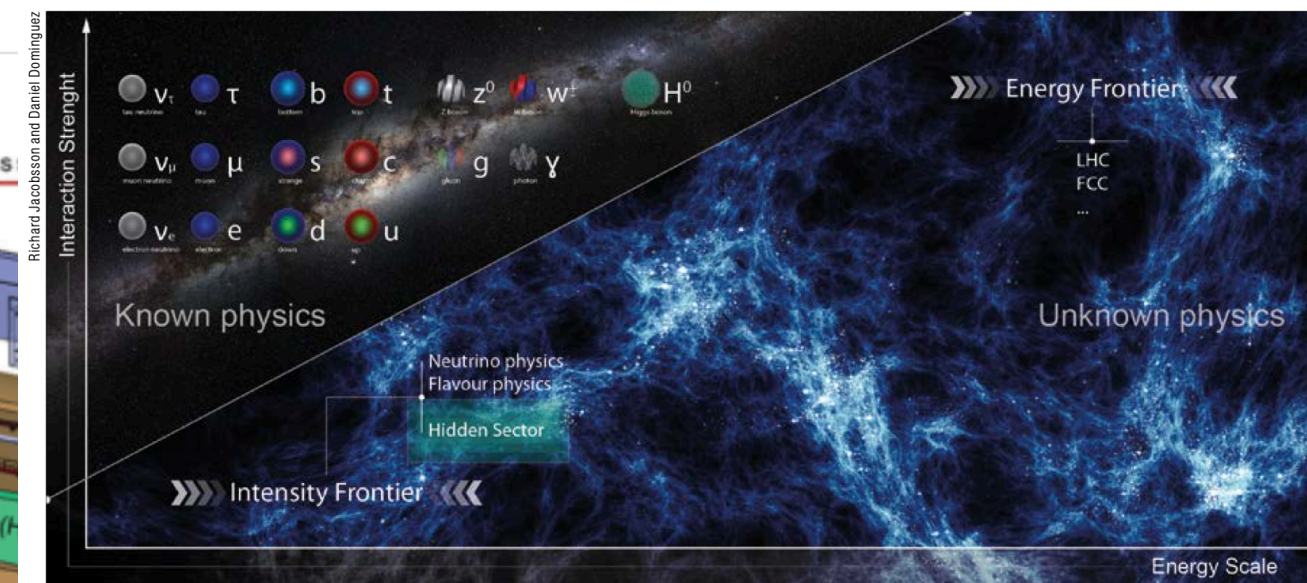
SEARCHES FOR NEW PHYSICS | NEWS

## SHiP to chart hidden sector

3 May 2024



Full speed ahead Layout of the SHiP experiment the ECN3 hall. Credit: SHiP collab.



SHiP is a new experiment at the intensity frontier aimed at exploring the hidden sector.

## SHiP sets a new course in intensity-frontier exploration

## SHiP sets sail to explore the hidden sector

The experiment is designed to detect very feebly interacting dark-matter candidate particles

19 APRIL, 2024 | By Corinne Pr...

## Green light to build revolutionary new experiment at CERN to search for unknown particles

20 April 2024

## SHiP collaboration sets course on New Physics

Panos Charitos 26th Jun 2023

SHiP (Search for Hidden Particles) is a newly proposed experiment for CERN's Super Proton Collider (SPC) to explore the challenging

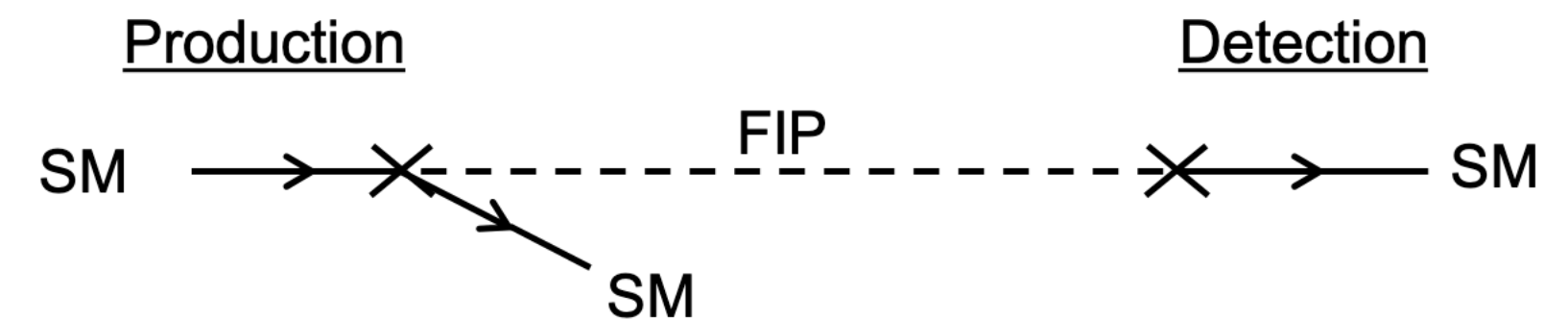
have now observed all the particles of the Standard Model, however it is clear that it is not the ultimate theory. Some yet unknown particles or interactions are required to explain a number of observed phenomena in particle physics, astrophysics and cosmology, the so-called beyond-the-Standard Model (BSM) problems, such as dark matter, neutrino masses and oscillations, baryon asymmetry, and the matter-antimatter asymmetry of the universe. These phenomena are well-established observationally, but their energy scale is unknown. The new physics. of new LHC data collected at  $\sqrt{s} = 13$  TeV will soon probe the TeV scale for new particles with couplings at the level. The experimental effort in flavour physics, and

of preparations, CERN has approved a groundbreaking new experiment

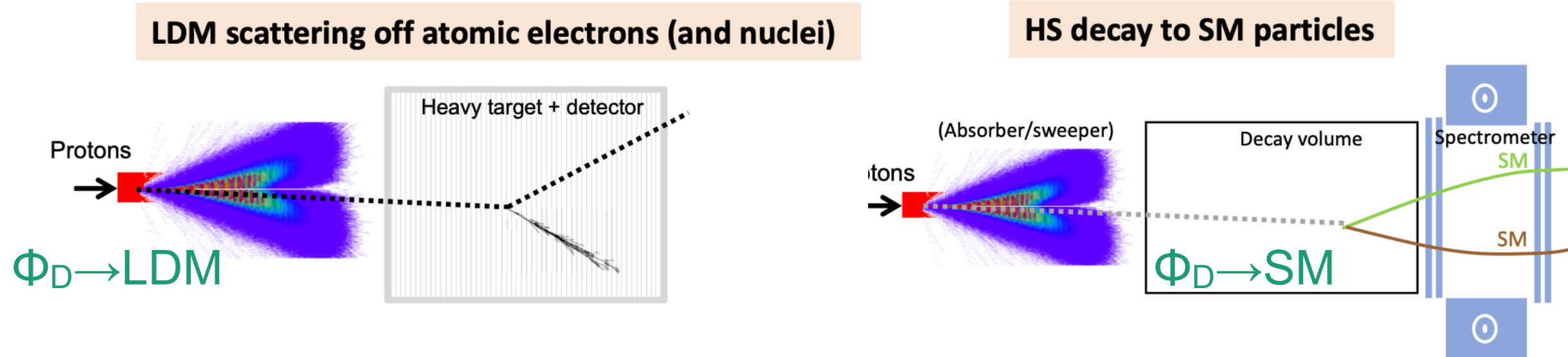
# SHiP, specs

- general-purpose **intensity-frontier** experiment facilitating comprehensive investigation of **hidden sector** of particle physics in the GeV scale, to explore the high-intensity SPS beams of 400 GeV protons in dump mode
  - $4 \times 10^{19}$  protons-on-target (PoT) per year; full physics program 15 years running will yield  $6 \times 10^{20}$  **PoT**
  - integrated **luminosity per year**: SPS  $> 4 \times 10^{45} \text{ cm}^{-2}$  vs HL-LHC  $= 10^{42} \text{ cm}^{-2}$
  - each year:  $\sim 10^{17}$  charm hadrons,  $\sim 10^{12}$  beauty hadrons,  $\sim 10^5$  tau leptons,  $\sim 10^{20}$  photons  $> 100 \text{ MeV}$ , tau neutrinos
- wide physics program: probe new **FIP** particles, small couplings, GeV scale masses, long lifetimes ( $c\tau$ : 50-100m), through decay or scattering, along with precision **neutrino** measurements

◉ FIPs produced promptly and form decay of heavy flavour  $\rightarrow$



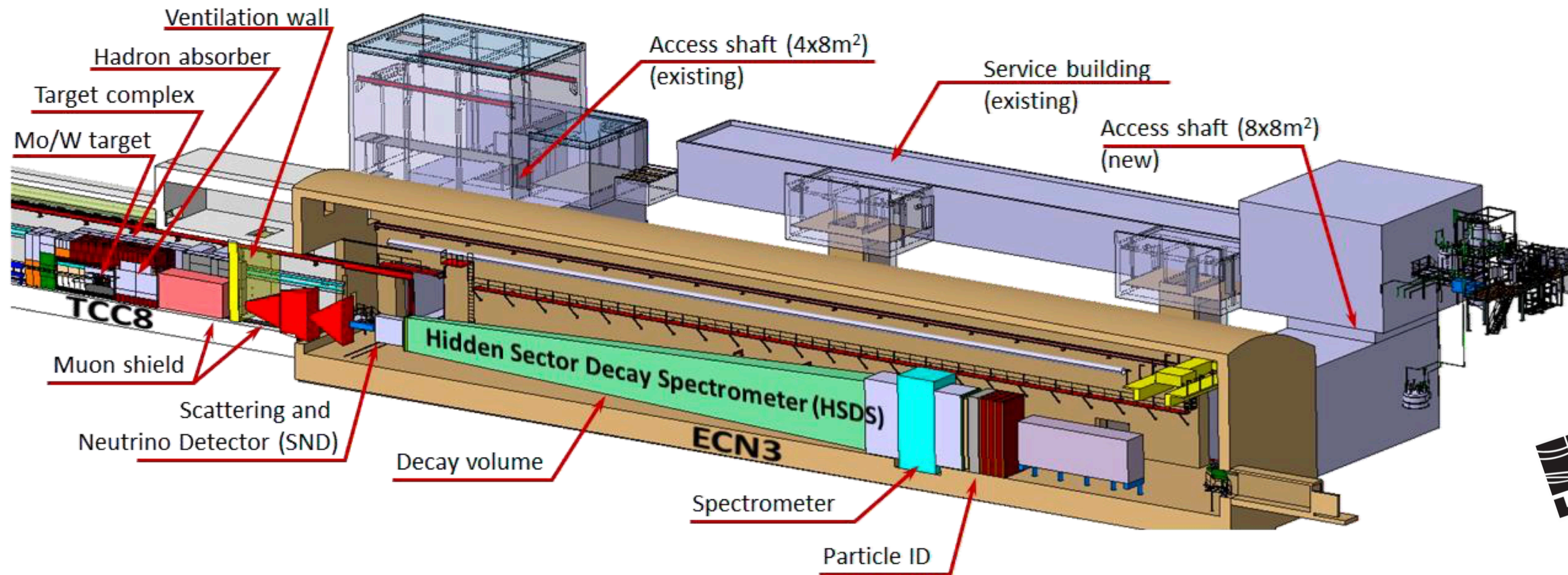
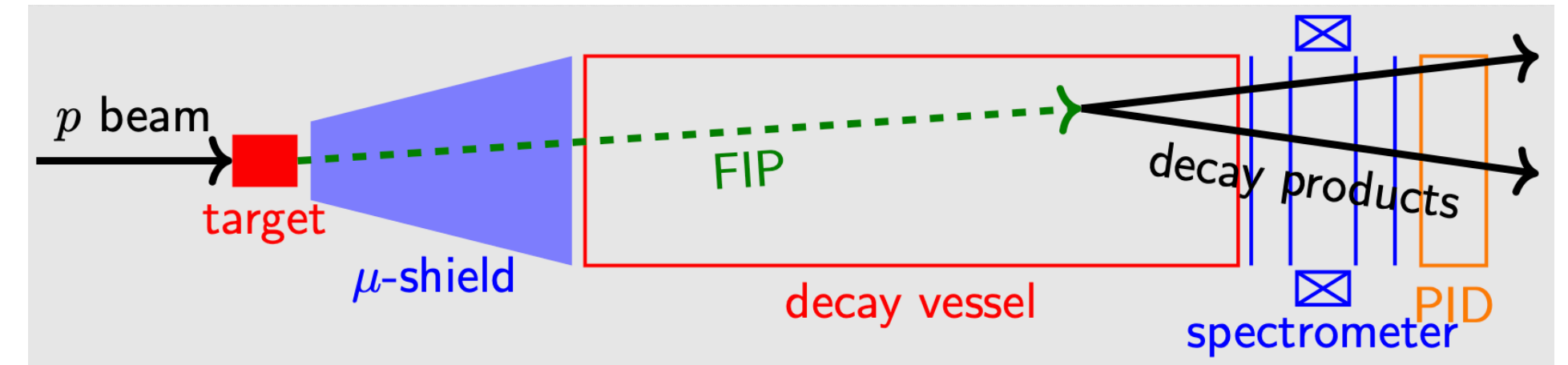
## Two FIP direct-search techniques



	Physics model	Final state
HSDS	HNL, SUSY neutralino	$l^\pm \pi^\mp, l^\pm K^\mp, l^\pm \rho^\mp (\rho^\mp \rightarrow \pi^\mp \pi^0)$
	DP, DS, ALP (fermion coupling), SUSY sgoldstino	$l^+ l^-$
	DP, DS, ALP (gluon coupling), SUSY sgoldstino	$\pi^+ \pi^-, K^+ K^-$
	HNL, SUSY neutralino, axino	$l^+ l^- \nu$
	ALP (photon coupling), SUSY sgoldstino	$\gamma\gamma$
	SUSY sgoldstino	$\pi^0 \pi^0$
SND	LDM	Electron, proton, hadronic shower
	$\nu_\tau, \bar{\nu}_\tau$ measurements	$\tau^\pm$
	Neutrino-induced charm production ( $\nu_e, \nu_\mu, \nu_\tau$ )	$D_s^\pm, D^\pm, D^0, \bar{D}^0, \Lambda_c^+, \bar{\Lambda}_c^-$

SHiP: dual-platform experiment that combines both

# SHiP Detector @ECN3



timing RPC technology for SHiP  
first prototype tested at CERN

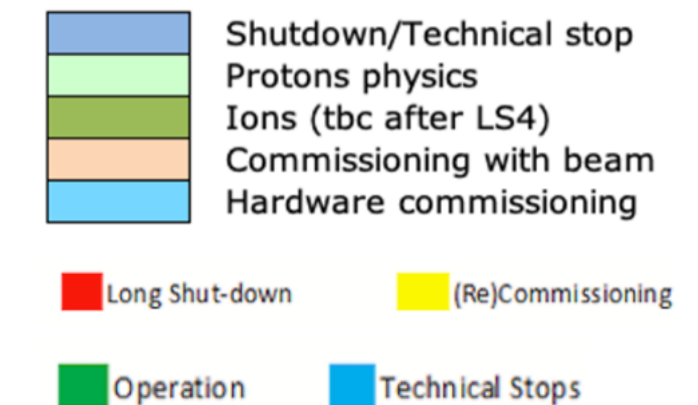
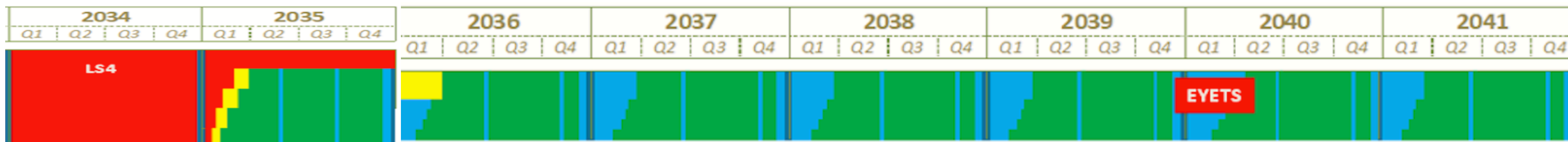
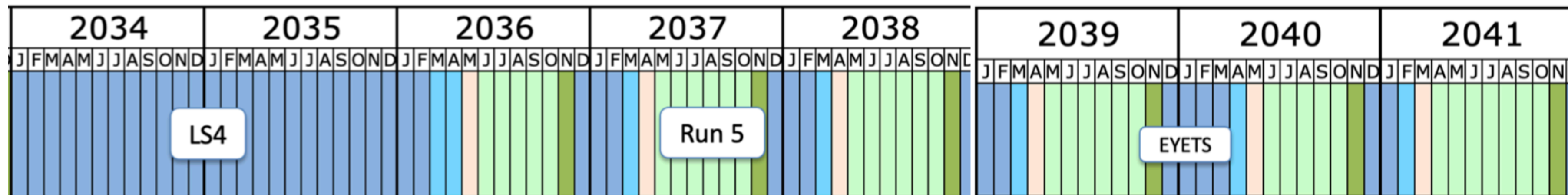
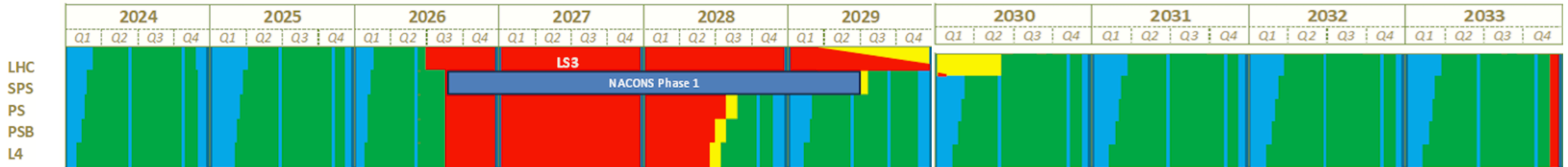
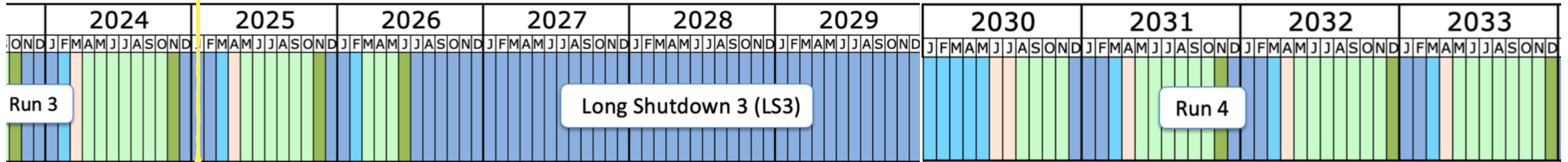
## Portuguese group responsibilities & involvement:

- veto detector (UBT; group responsibility in the SHiP proposal)
  - timing detector option with RPC technology
  - neutrino detector (SND) option with Silicon technology
- ➔ R&D in full synergy with SND@LHC upgrade for HL-LHC



# CERN: long-term schedule

2022-2026 LHC RUN3 ATLAS/CMS PHASE1, SND  
 2030-2041 HL-LHC ATLAS/CMS PHASE2, ADVSND  
 2032-2045 SHIP  
 2045-2060 (?) FCCEE  
 2070-2095 (?) FCCHH



<http://lhc-commissioning.web.cern.ch/schedule/LHC-long-term.htm>

<https://home.cern/news/opinion/accelerators/updated-schedule-cerns-accelerators>