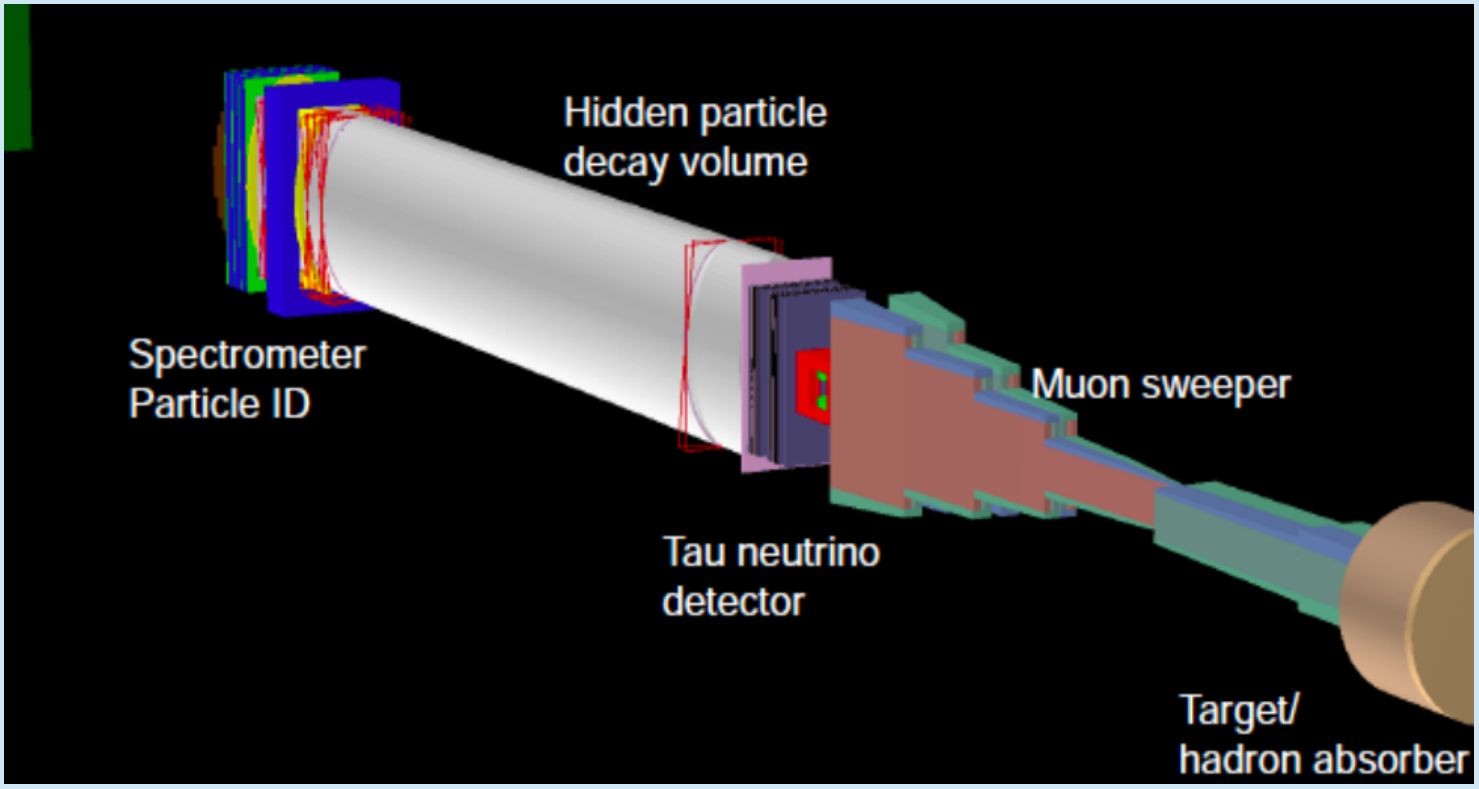
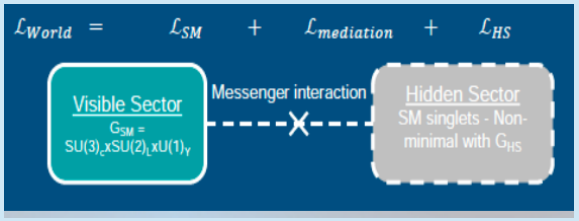
Search for Hidden Particles (SHiP): an experimental proposal at the SPS

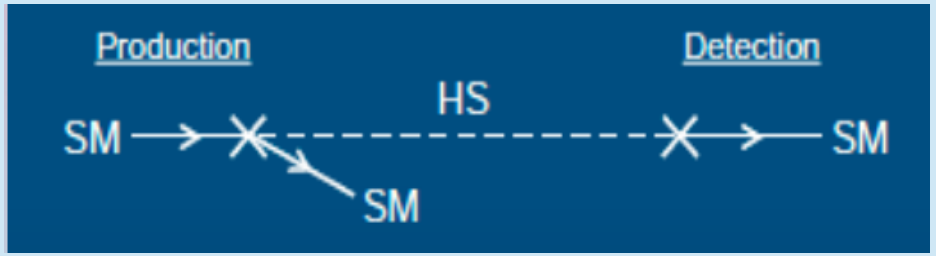
ship.web.cern.ch/ship
Mario Campanelli (UCL)
On behalf of ShiP-UK:
Bristol, ICL, RAL, UCL, Warwick



The “hidden sector” approach to new physics

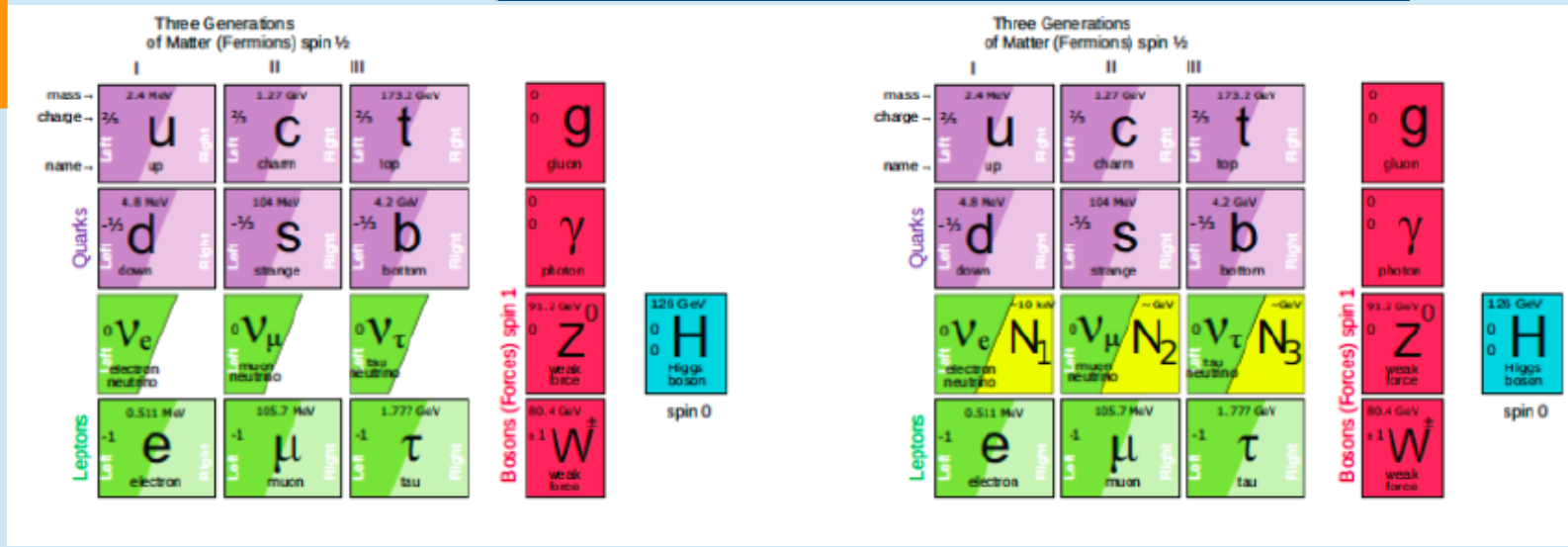
- Searches for new particles at the LHC so far unsuccessful, maybe new physics has a very small coupling?
- If an additional, weakly interacting, term to the Lagrangian could lead to particles very difficult to observe, but contributing to dark matter.





The νMSSM

T.Asaka, M.Shaposhnikov, PL B620 (2005) 17
M.Shaposhnikov Nucl. Phys. B763 (2007) 49



Particle content of SM made symmetric by adding 3 HNL: N_1, N_2, N_3

With $M(N_1)$ ~ few KeV, it is a good DM candidate (or DM can be generated outside of this model through decay of inflaton)

With $M(N_2, N_3)$ ~ GeV, could explain Barion Asymmetry of Universe (via leptogenesis), and generate neutrino masses through see-saw.

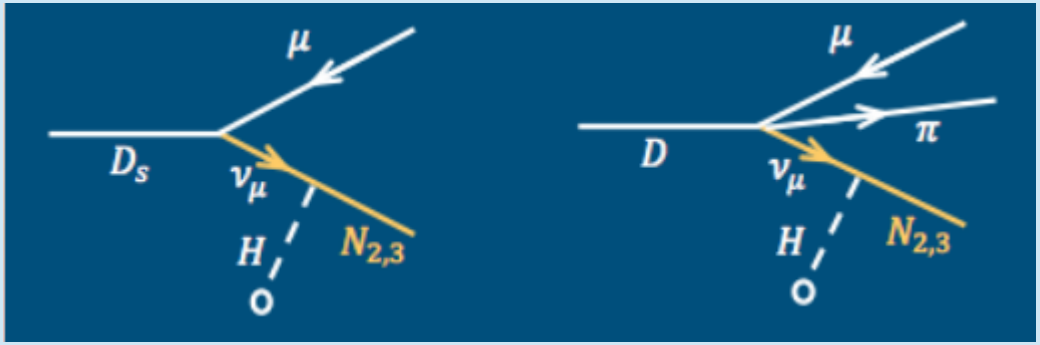
HNL production and decay modes

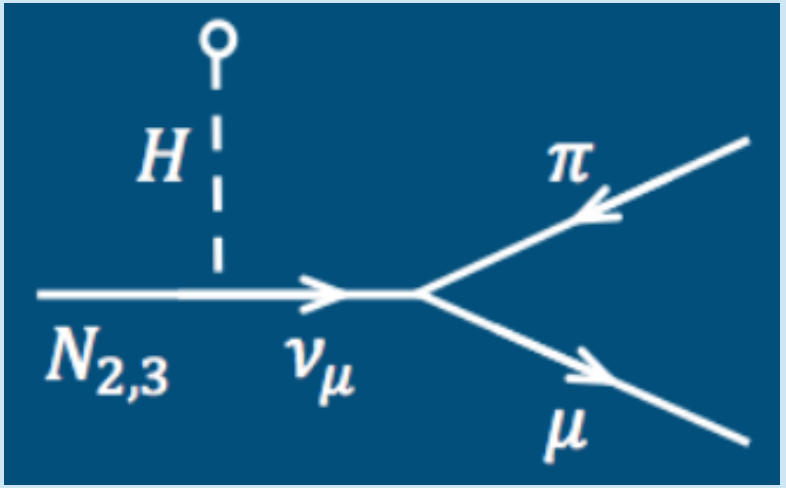
Interaction with Higgs vev leads to mixing with active neutrinos, resulting in a bahaviour similar to oscillation to the HNL and back into a virtual neutrino, that

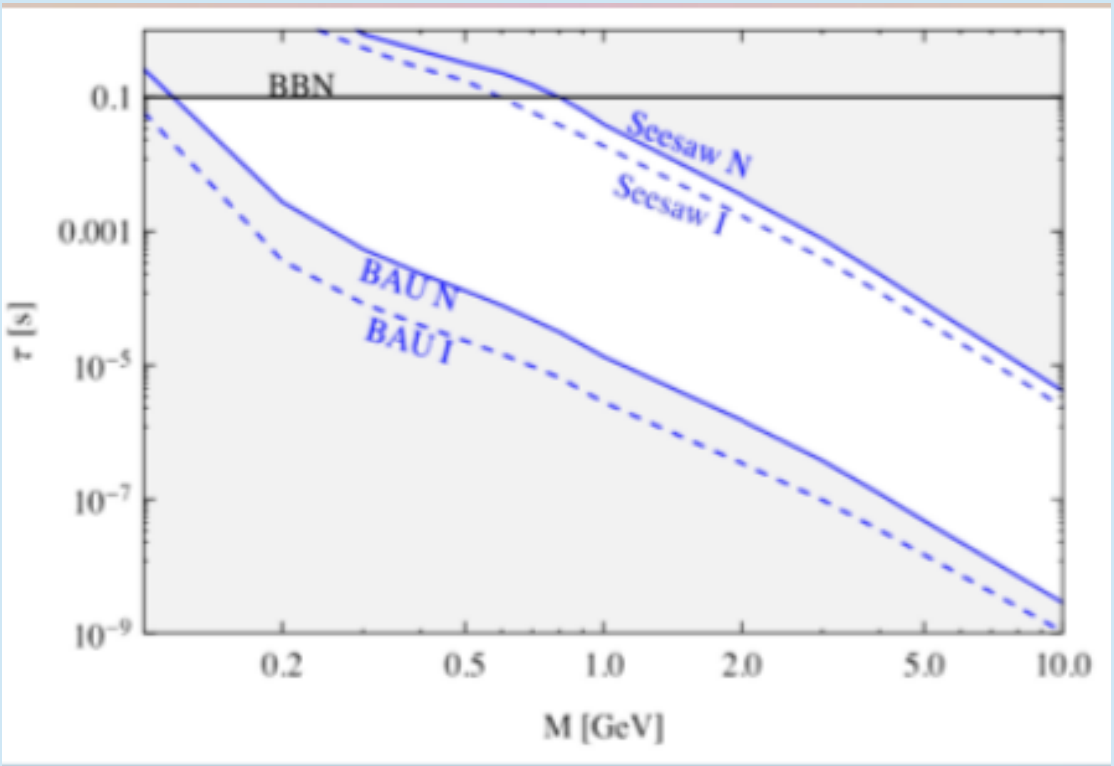
produces a muon and a W (→ hadrons, eg pions)

Exact branching fractions depend n flavor mixing

Due to small couplings, ms lifetimes, decay paths O(km)







Decay mode	Branching ratio
$N_{2,3} \rightarrow \mu,e + \pi$	0.1 – 50 %
$N_{2,3} \rightarrow \mu\text{-/e-} + \rho^+$	0.5 - 20%
$N_{2,3} \rightarrow \nu + \mu + e$	1 – 10%

An experiment in practice

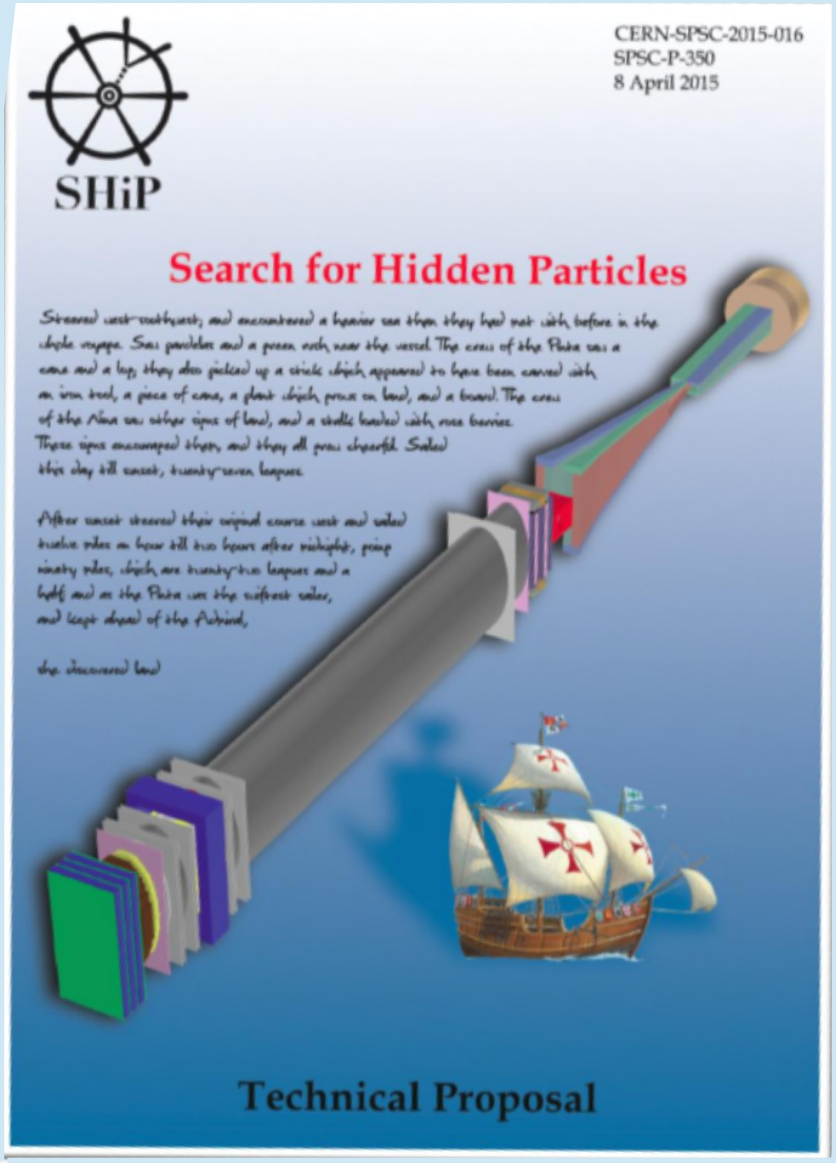
Use protons from CERN's SPS: 500 kW is 4x1E13 protons/7 s ->2E20 in 5y

Slow (ms → 1s) and uniform extraction to reduce detector occupancy and combinatorics

- HS particles produced by mesons (mainly charm) decays; need to absorb all SM decay products to minimise BG
  - → heavy material thick target, with wide beam to dilute energy deposition (different from neutrino facility)
- Muons cannot be absorbed by target
  - → active muon shield
- Long vacuum (or helium) decay tunnel away from external walls to minimise rescattering of muons and neutrons close to detector

- Far-away detector with good PID and resolutions
- An additional emulsion detector for tau neutrino studies

The SHiP proposal

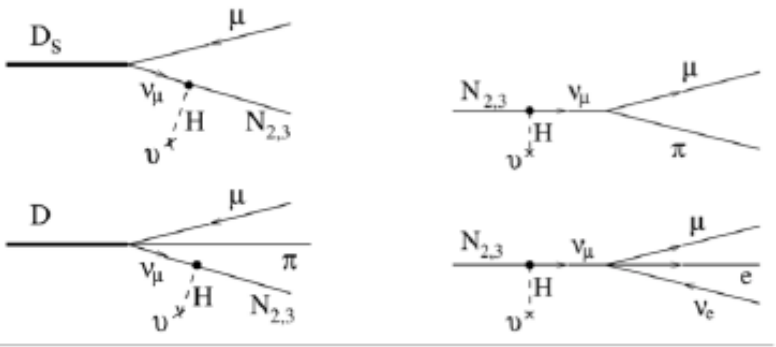


- Proposal for a new facility at the CERN SPS accelerator:
  - hidden sector detector
  - ν_τ facility

  235 experimentalists from 45 institutes and 15 countries + CERN
- Technical Proposal submitted in April last year (arXiv:1504.04956)
- Physics Proposal signed by 80 theorists (arXiv:1504.04855)
- SPSC has given the green light to the next stage, a Comprehensive Deign report, to be submitted in about 3 years
- ShiP recommended by the CERN research board

The SHiP detector

Example of creation of long-lived neutral particles ($N_{2,3}$):



Hidden Sector decay volume

Spectrometer Particle ID

Target/ hadron absorber

Active muon shield

ν_τ detector

≈12m

≈50m

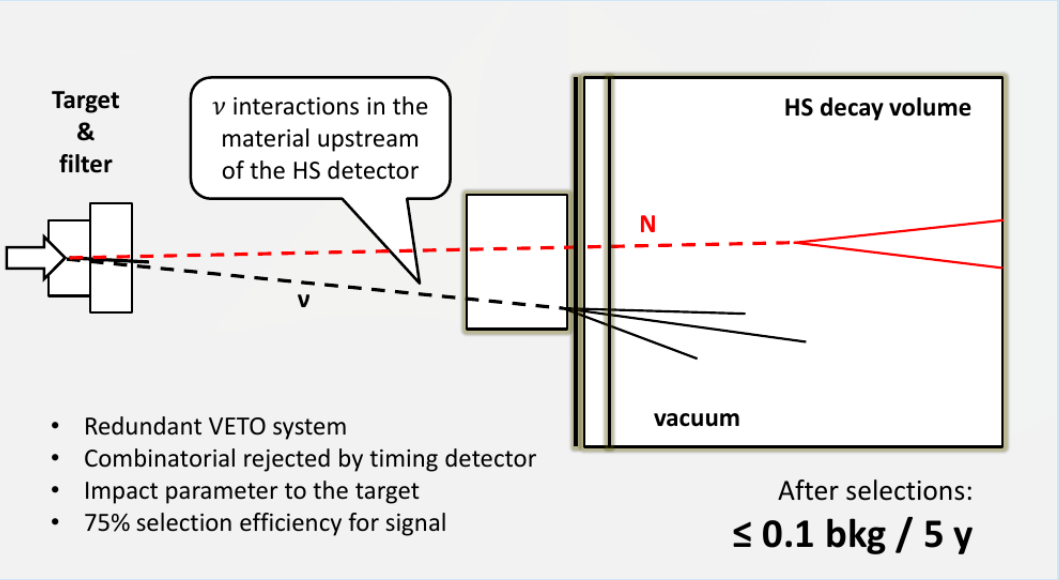
≈10m

≈50m

≈10m

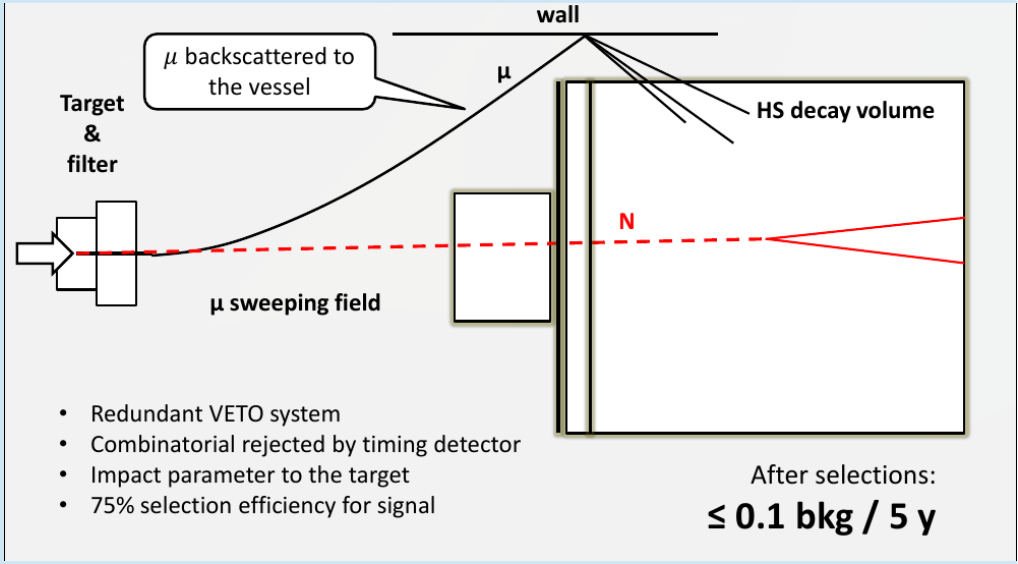
It is designed as a **background-free** experiment → need for lots of **background veto systems**

Background rejection for HNL searches



- Redundant VETO system
- Combinatorial rejected by timing detector
- Impact parameter to the target
- 75% selection efficiency for signal

After selections:
≤ 0.1 bkg / 5 y



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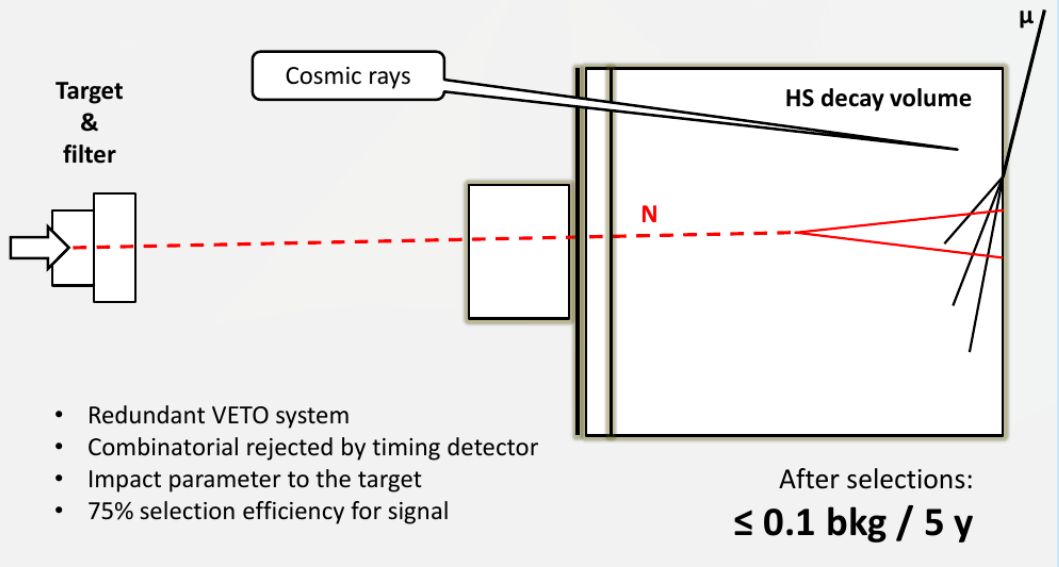

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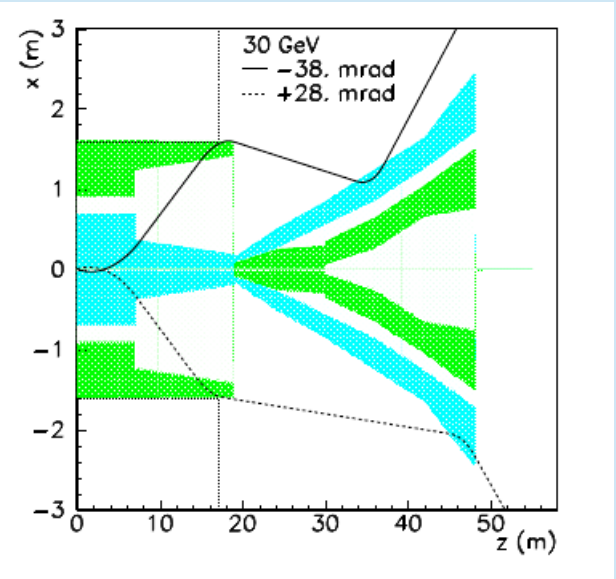
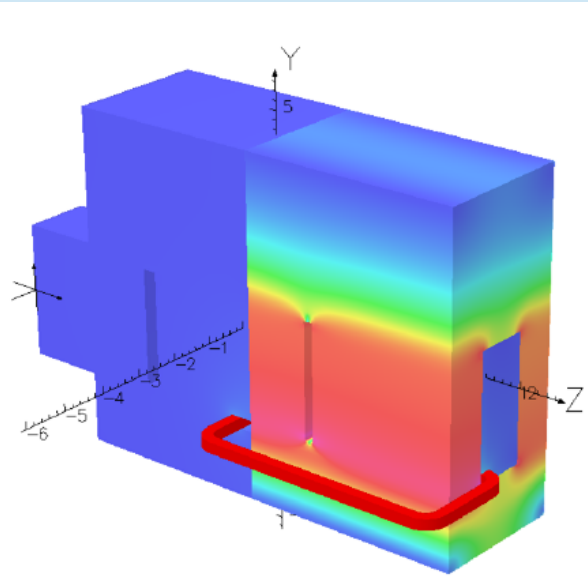
Background source	Stat. weight	Expected background (UL 90% CL)
ν-induced		
$2.0 < p < 4.0$ GeV/c	1.4	1.6
$4.0 < p < 10.0$ GeV/c	2.5	0.9
$p > 10$ GeV/c	3.0	0.8
$\bar{\nu}$-induced		
$2.0 < p < 4.0$ GeV/c	2.4	1.0
$4.0 < p < 10.0$ GeV/c	2.8	0.8
$p > 10$ GeV/c	6.8	0.3
Muon inelastic	0.5	4.6
Muon combinatorial	–	<0.1
Cosmics		
$p < 100$ GeV/c	2.0	1.2
$p > 100$ GeV/c	1600	0.002

SHiP in the UK

- UK physicists proposed the experiment and Andrei Golutvin (ICL) is the spokesperson, and muon shield group lead by UK physicists
- UK work-package: background rejection (crucial for the success of the experiment)
  - Active muon shield
  - Target design
  - DAQ and triggering



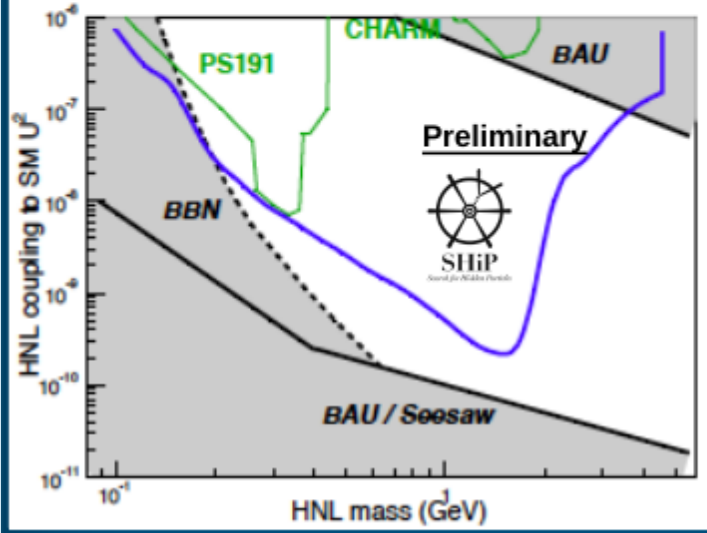


- A SoI was submitted last year, with the experiment still under SPSC review
- Since then, we had positive recommendations from the SPSC, the research board, and we are now included in the MTP. With other countries starting to get resources, we need to maintain current responsibilities
- SHiP-UK will not be able to maintain its leadership without dedicated resources to contribute to the Comprehensive Design Report.

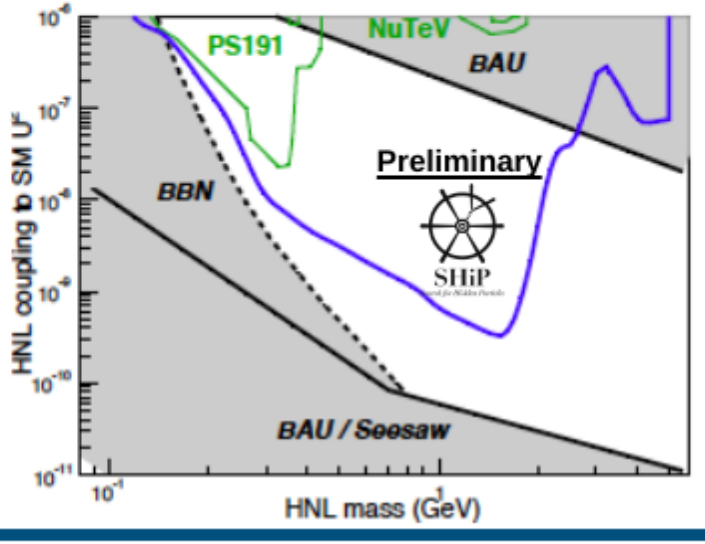
Sensitivity to HNL

- Visible decays = At least two tracks crossing the spectrometer
  - Ex. For m_N = 1 GeV with $\mathcal{U}^2$= 10^{-8} and $\mathcal{BR}(N \to \mu\pi)$ = 20%, expect ~330 signal events

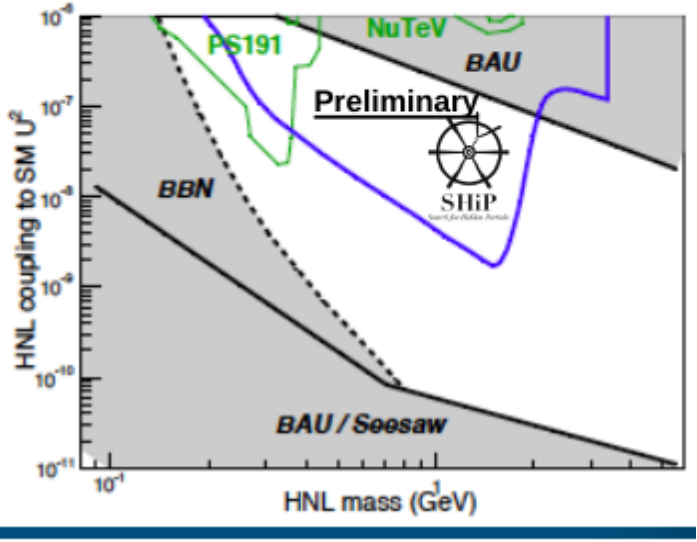
$U_e^2 : U_\mu^2 : U_\tau^2 \sim 52 : 1 : 1$, inverted hierarchy



$U_e^2 : U_\mu^2 : U_\tau^2 \sim 1 : 16 : 3.8$, normal hierarchy

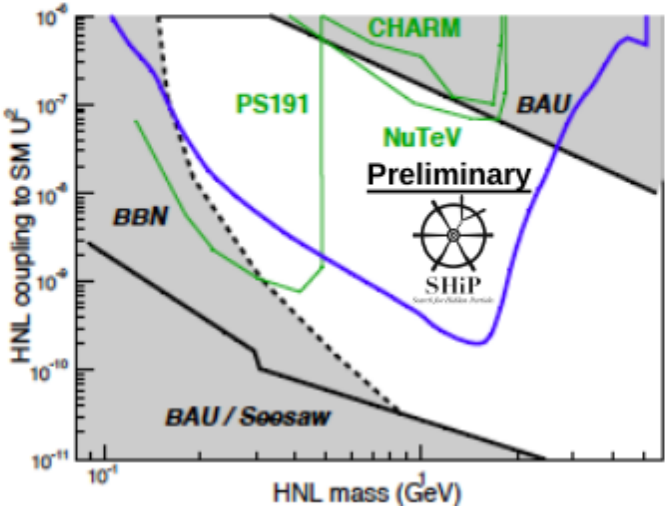


$U_e^2 : U_\mu^2 : U_\tau^2 \sim 0.061 : 1 : 4.3$, normal hierarchy

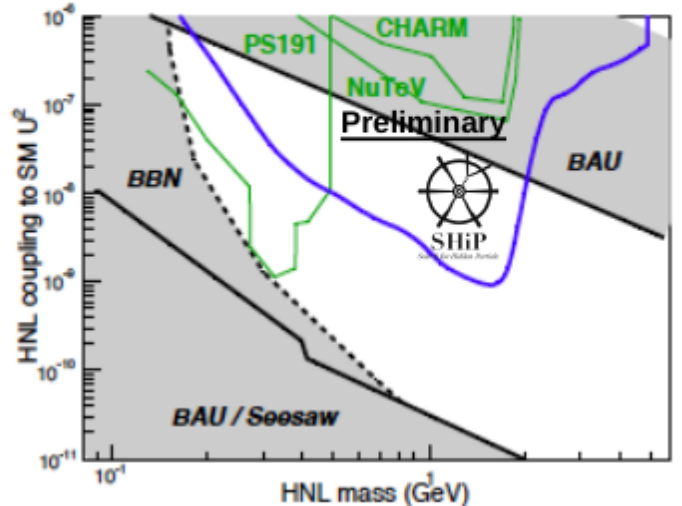


Scenarios for which baryogenesis was numerically proven

$U_e^2 : U_\mu^2 : U_\tau^2 \sim 48 : 1 : 1$, inverted hierarchy



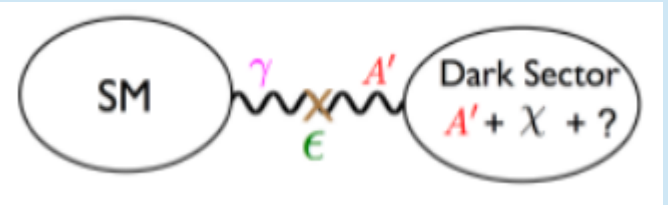
$U_e^2 : U_\mu^2 : U_\tau^2 \sim 1 : 11 : 11$, normal hierarchy

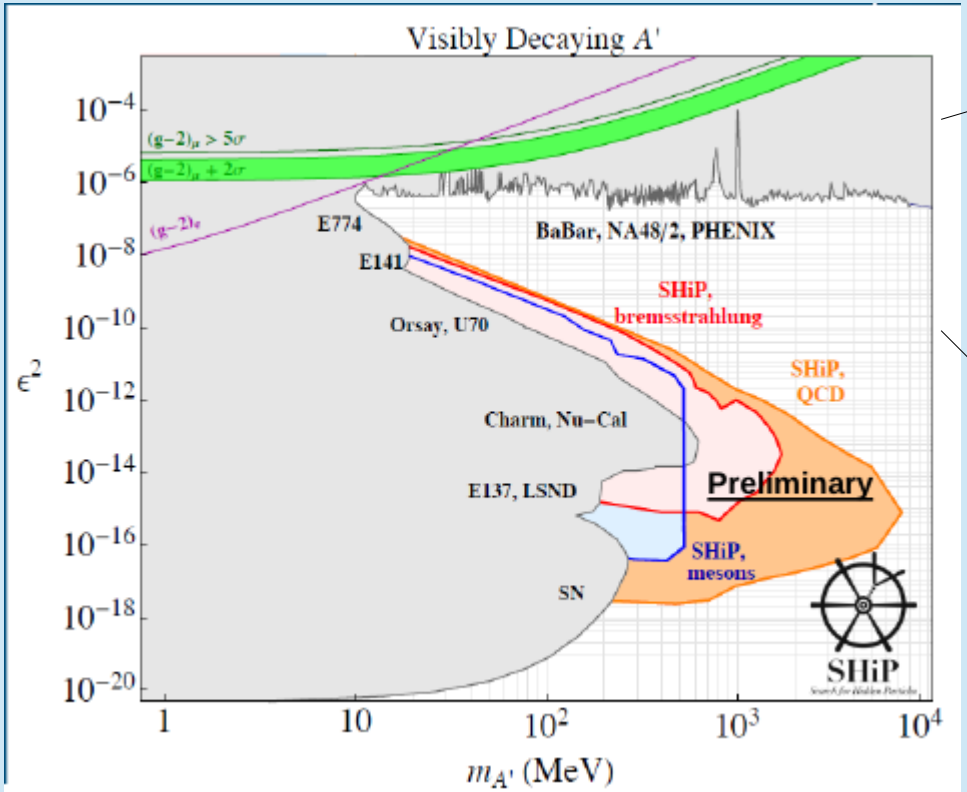


Sensitivity to dark photons

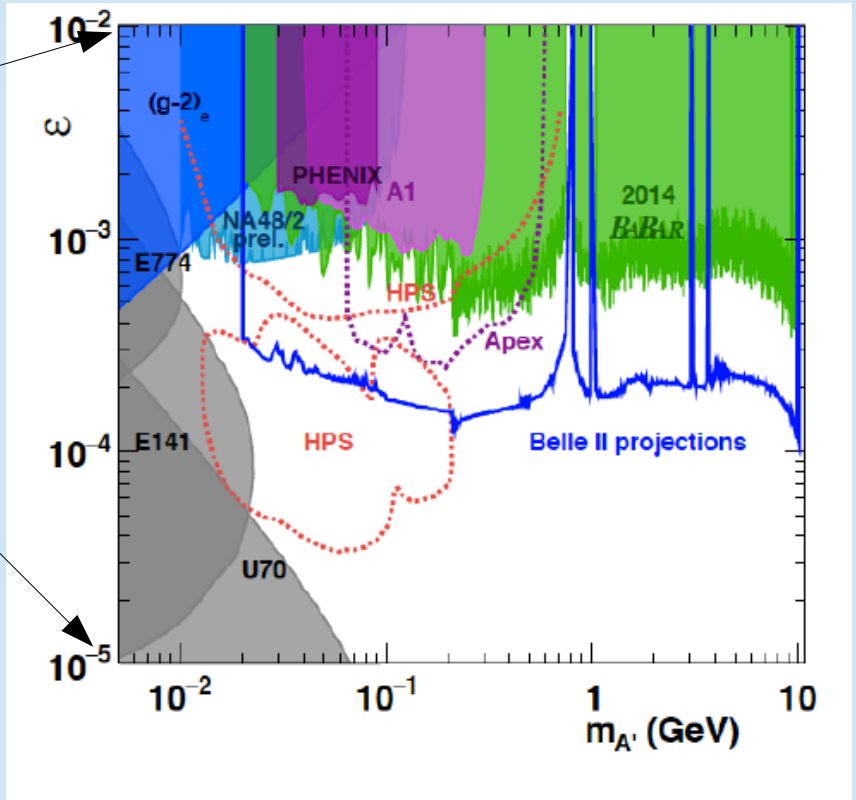
Production

- Decays of $\pi^0 \rightarrow V\gamma$, $\eta \rightarrow V\gamma$, $\omega \rightarrow V\pi^0$
- Proton bremsstrahlung and parton bremsstrahlung above Λ(QCD)
- Decay into pair of SM particles
- SHiP will have a unique sensitivity

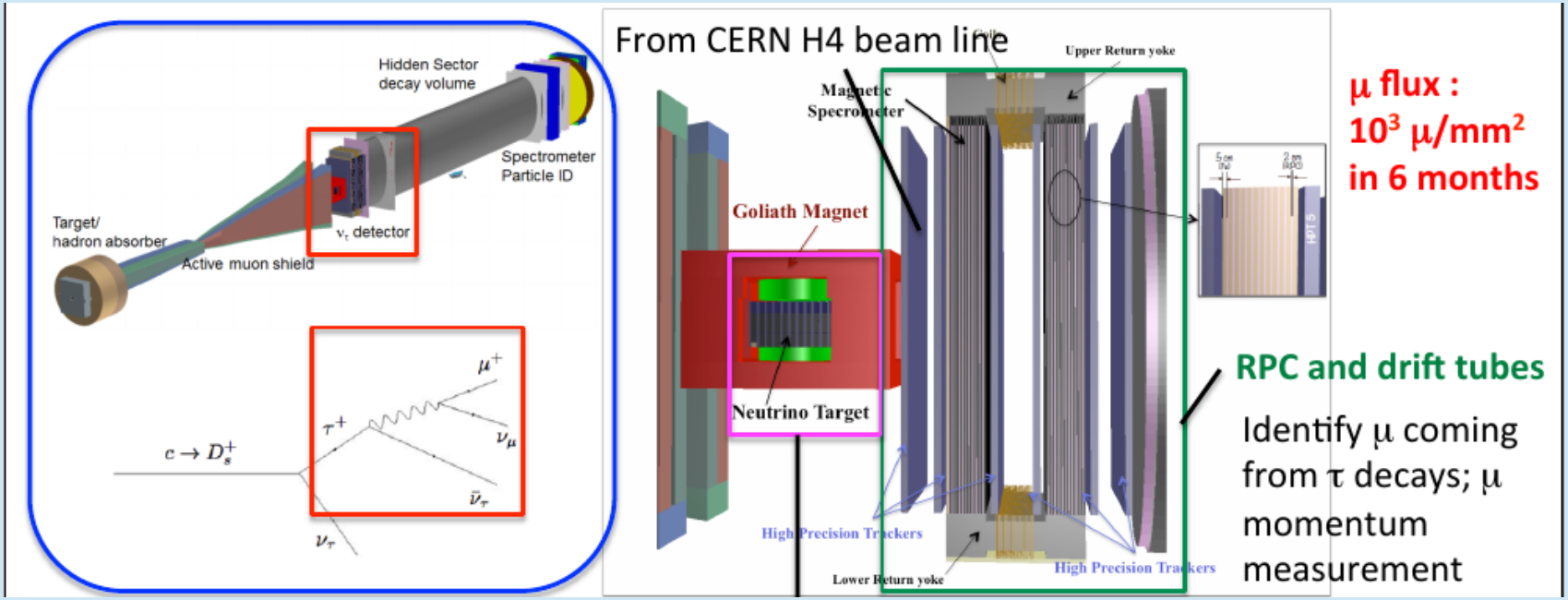




Planned and future experiments



The ν_τ detector



- An OPERA-like tau neutrino emulsion detector
- Current status of tau neutrino measurements:
  - DONUT observed 9 events (from charm), OPERA 4 events (from oscillations)
  - No tau antineutrino has been even observed
- Ship can increase by 200 the current tau neutrino sample, discover tau antineutrinos and measure structure functions

SHiP at CERN and timeline

From Fabiola's June presentation to the CERN staff:

Main changes compared with last-year MTP

Funding for neutrino activities, through CERN Neutrino Platform, now covers commitments to US LBNF project described in the previous MTP (~ 20 MCHF were missing).
No new commitments made.

Beam dump facility at the North Area: small funding included in the accelerator R&D budget to complete key technical feasibility studies in time for the ESPP.
SHiP experiment recommended by the Research Board to prepare comprehensive design study as input to the ESPP

❑ future opportunities of diversity programme (new): "Physics Beyond Colliders" Study Group

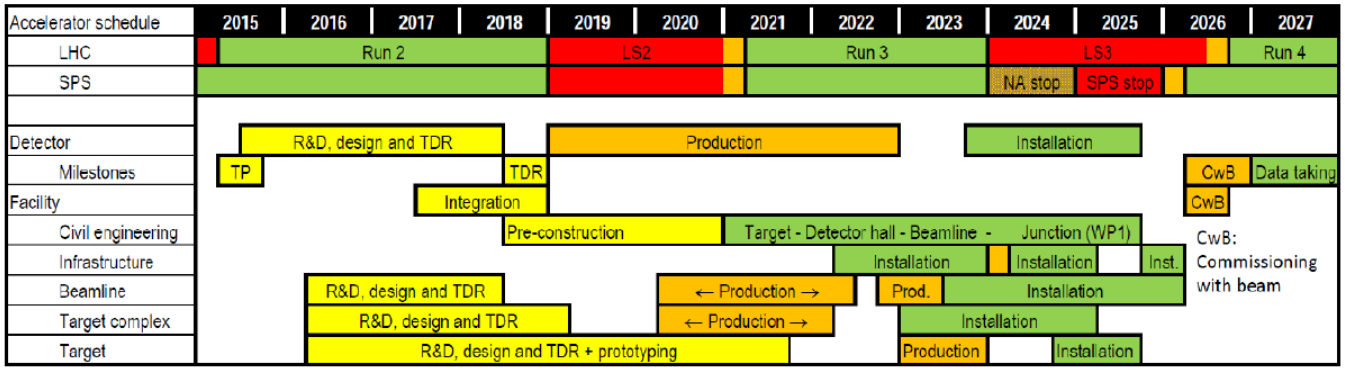


Figure 4.2: New baseline project schedule for the facility and SHiP experiment with WP1 in LS3 and adapted to latest accelerator schedule MTP 2016-2020 V1.

From CERN's medium term plan

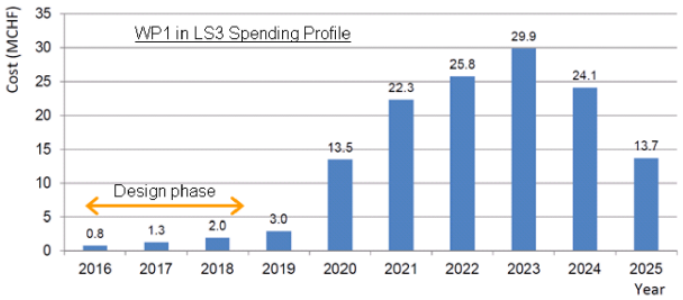


Figure 4.3: Overall cost profile for the construction of the facility in MCHF in the new baseline schedule with WP1 in LS3, as shown in Figure 4.2.

Conclusions

- Light hidden-sector particles can solve many problems of the SM, and SHiP is the only dedicated detector to discover them
- The SPSC asked the experiment to produce a Comprehensive Design Report, and the Research Board has favourably recommended it
- UK physicists proposed the experiment, we have the spokesperson and are in charge of the muon shield system
- We require commensurate resources and some recognition from the UK community to preserve the current roles and maintain the strong impact we have in the collaboration during the CDR phase and beyond