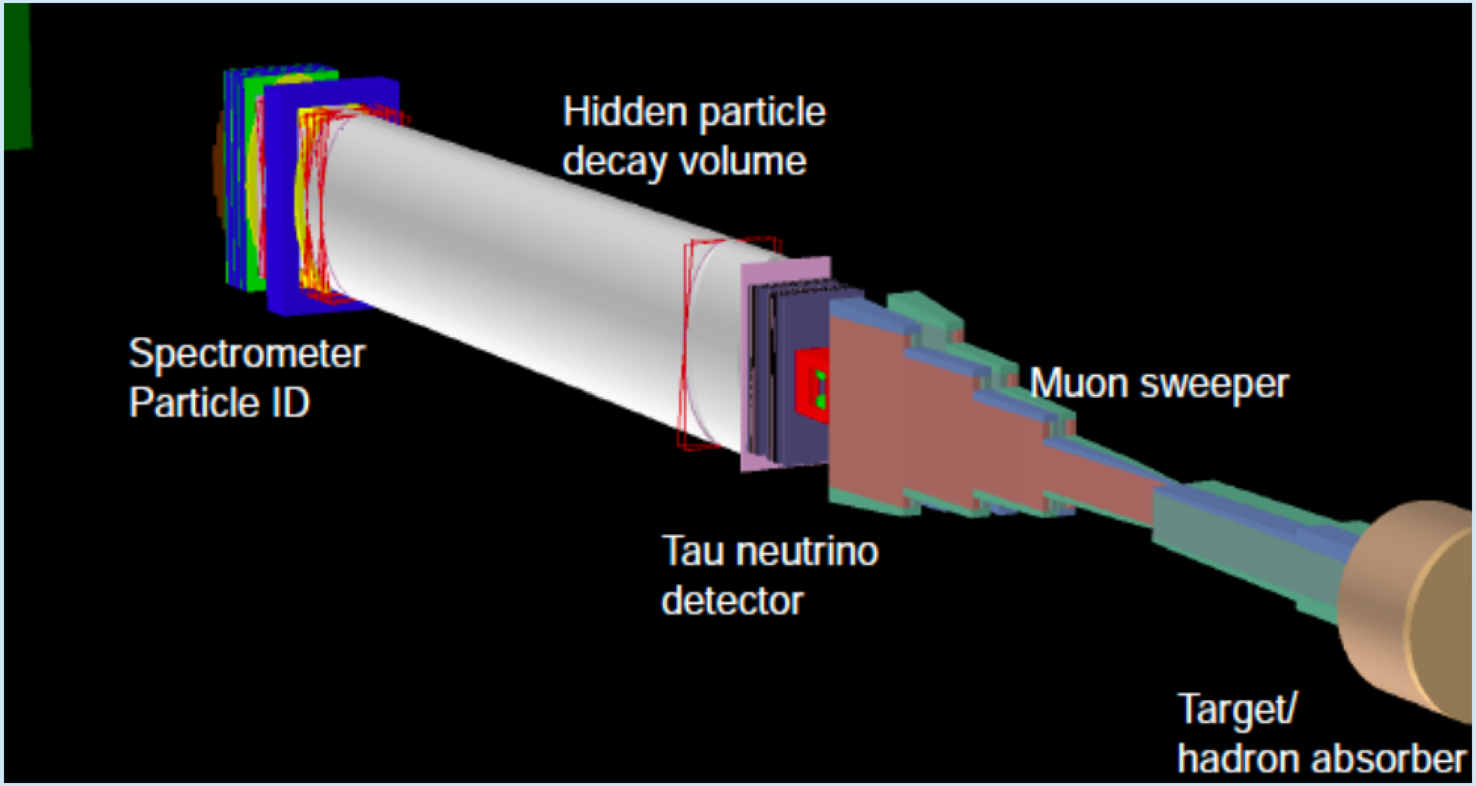
Search for Hidden Particles (SHiP): an experimental proposal at the SPS

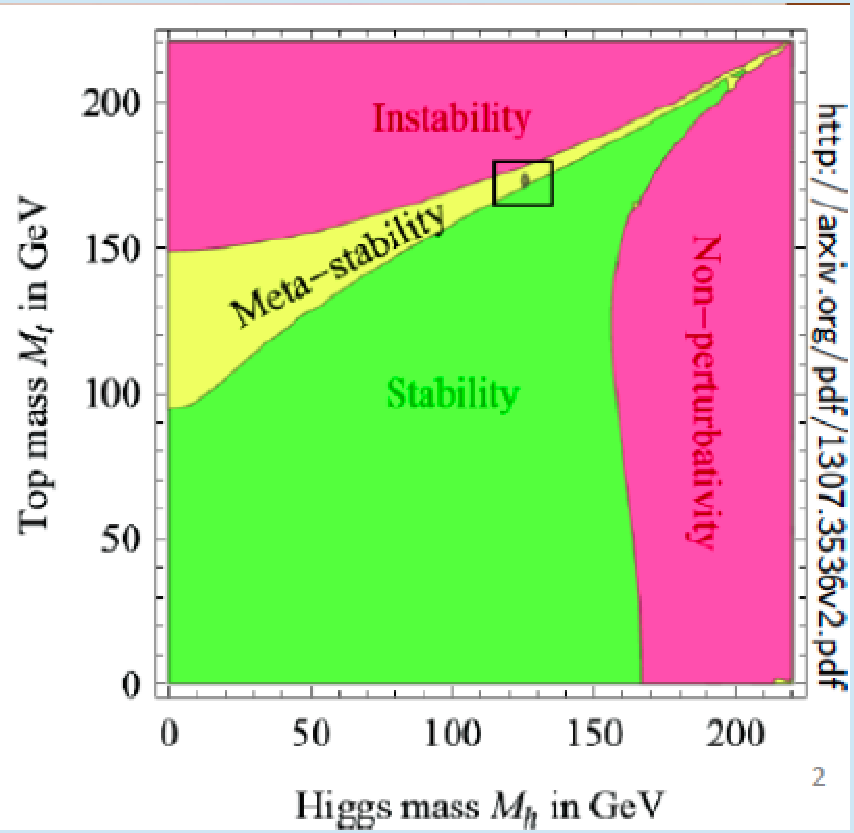
ship.web.cern.ch/ship

Mario Campanelli (UCL)
On behalf of the ShiP collaboration



The Standard Model and beyond

- All SM particles have been directly observed so far (apart from anti-ν_τ)
- Despite some anomalies, no compelling evidence of new physics found so far
- Higgs mass points to a meta-stable universe
- The SM could be valid to the Plank scale
- Naturalness only a problem if we assume new particles between EW and Plank scales



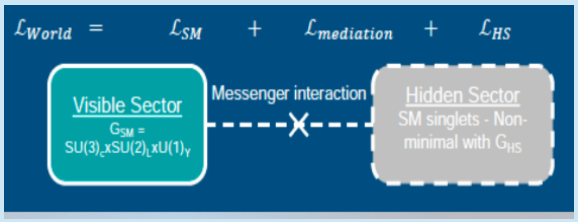
- Apart from naturalness, we do not understand:
  - Barion Asymmetry of the Universe
  - Dark Matter (indications are for cold, non-barionic)
  - The pattern of masses and mixings
  - Inflation

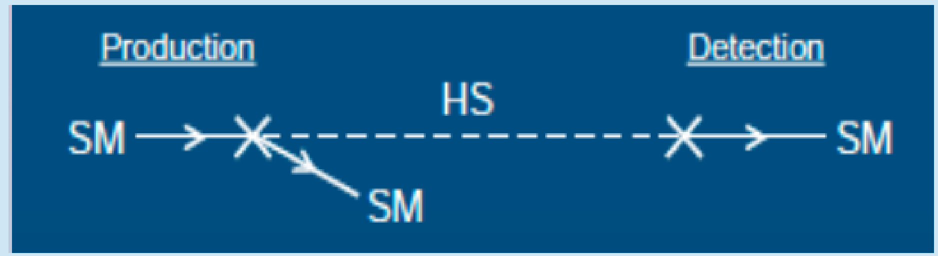
- Limits to masses of new particles being pushed in the TeV scale by the LHC.

  → “protection” against a small Higgs mass getting weaker

The "hidden sector" approach to new physics

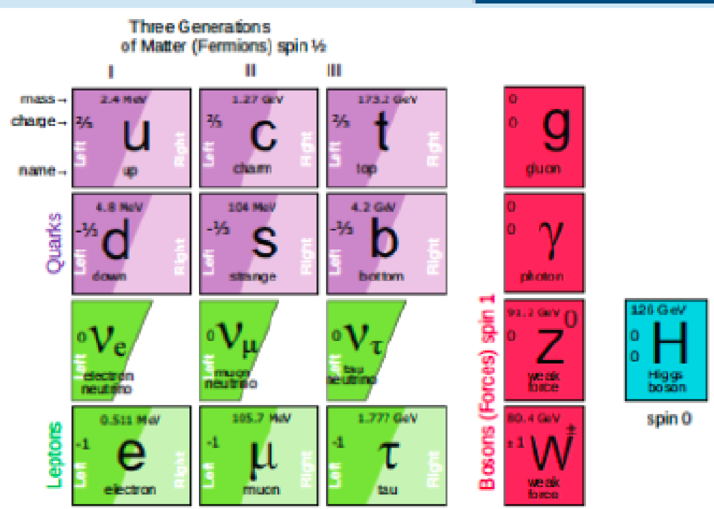
- Searches for new particles at the LHC so far unsuccessful, maybe new physics has a very small coupling?
- If an additional, weakly interacting, term to the Lagrangian could lead to particles very difficult to observe, but contributing to dark matter.

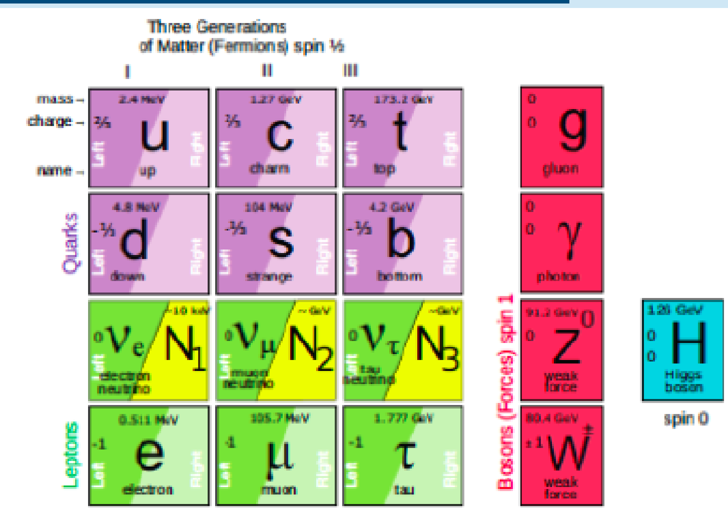




The νMSSM

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 bariogenesis), and generate neutrino masses through see-saw.

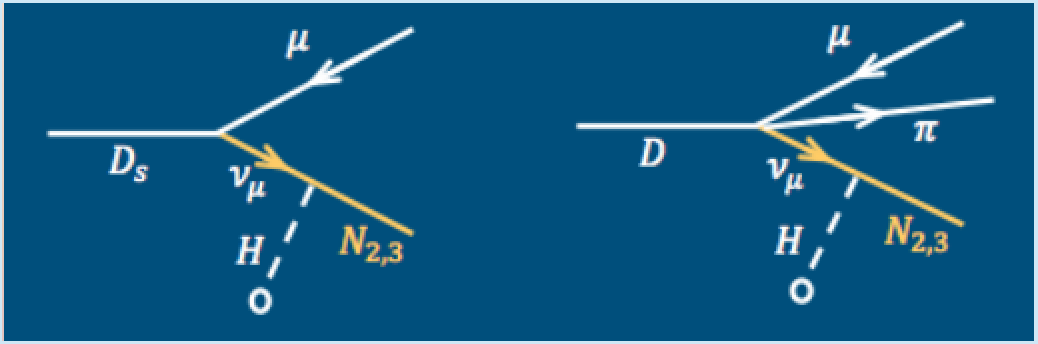
HNL production and decay modes

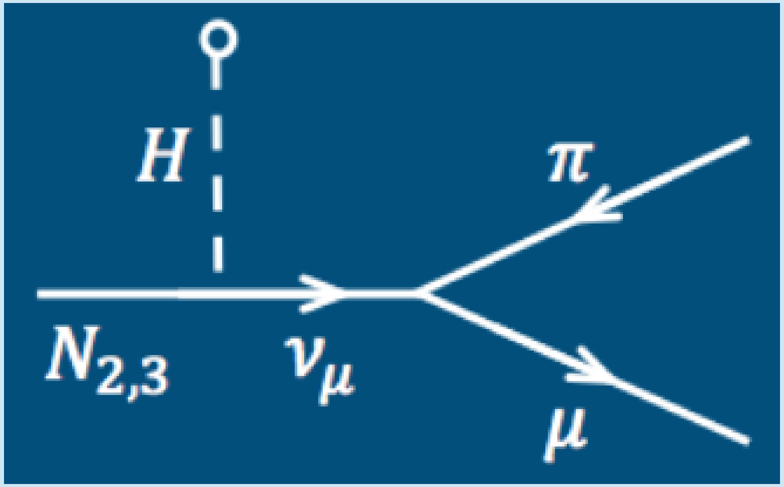
Interaction with Higgs vev leads to mixing with active neutrinos, resulting in a behaviour similar to oscillation to the HNL and back into a virtual neutrino, that

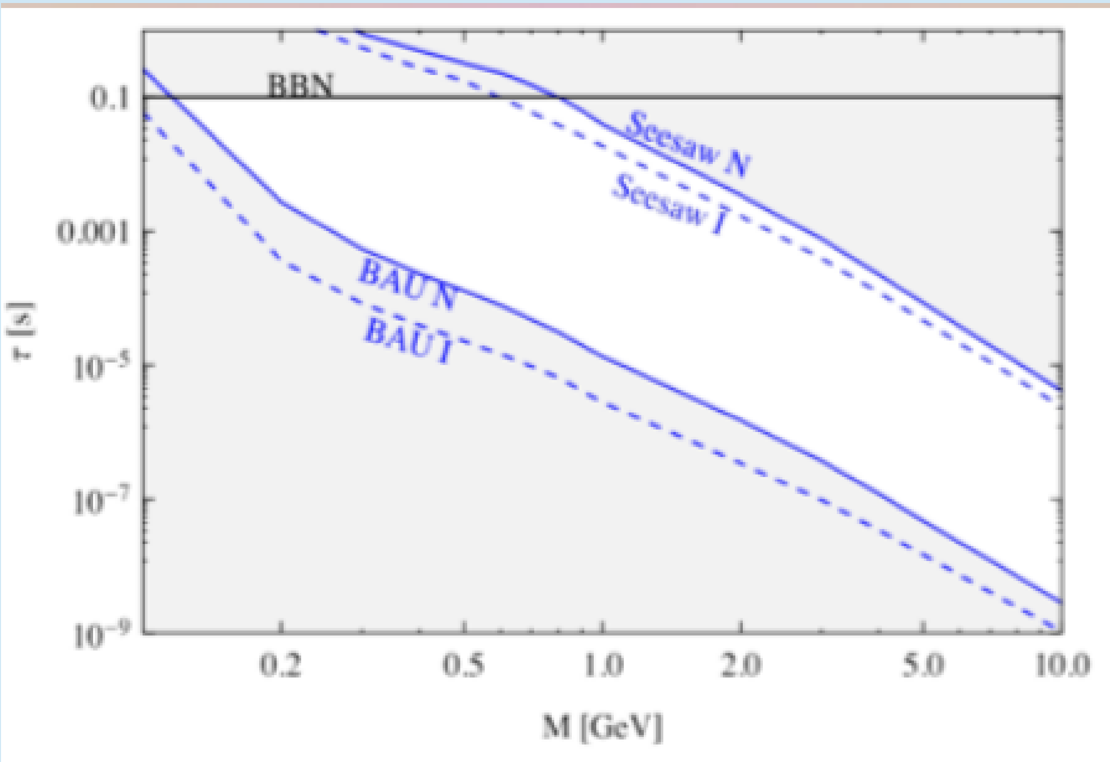
produces a muon and a W (→ hadrons, eg pions)

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 %
$N_{2,3} \rightarrow \mu^- / e^- + \rho^+$	0.5 - 20%
$N_{2,3} \rightarrow \nu + \mu + e$	1 – 10%

How to explore these phenomena? 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 neutrinos close to detector

- Hidden sector detector with good PID and resolutions
- An additional emulsion detector for tau neutrino studies

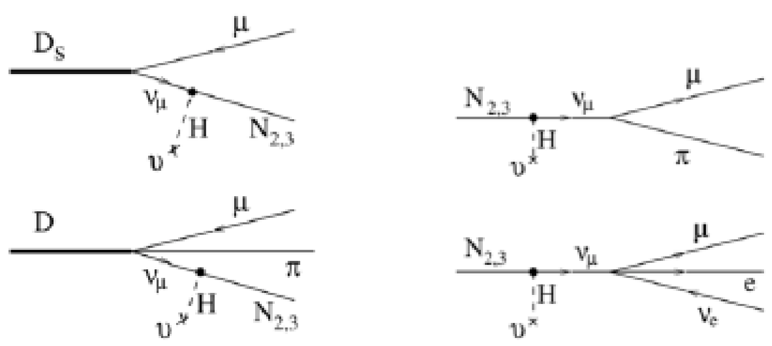
The SHiP proposal

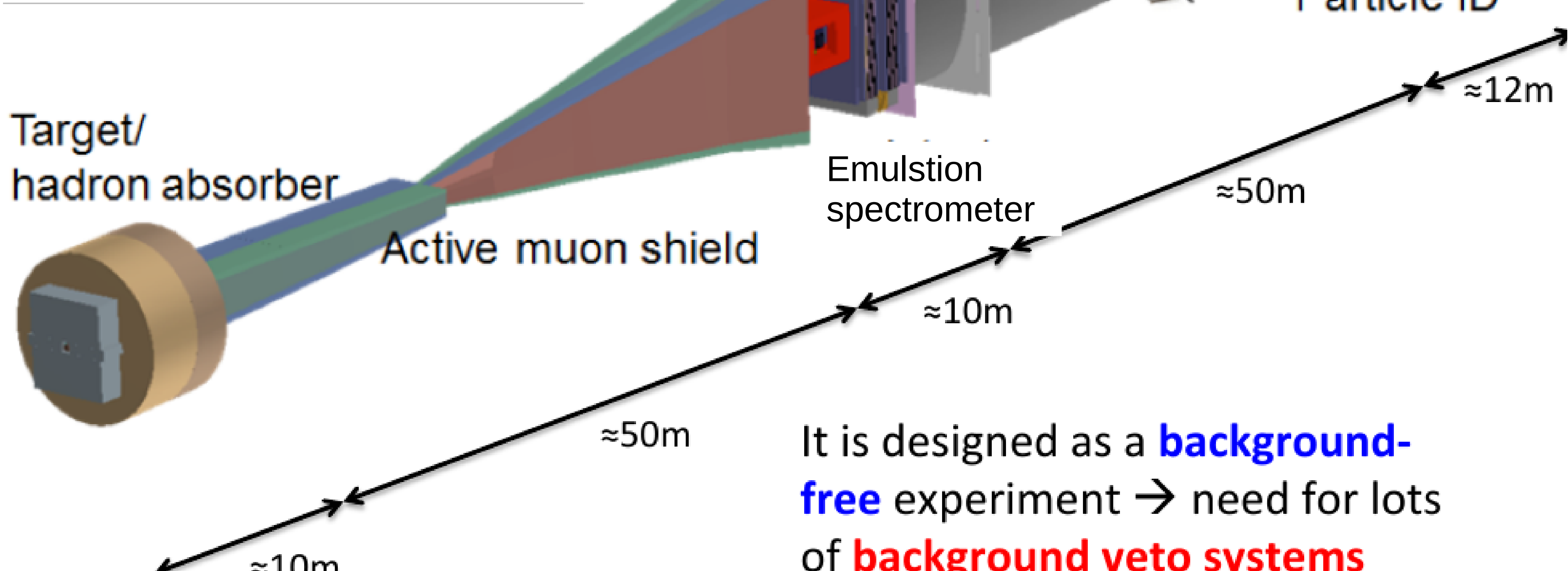
- Proposal for a new experiment at the CERN SPS accelerator:
  - hidden sector detector
  - Emulsion spectrometer for DM searches and ν_τ

  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 Design study, to be submitted in about 3 years
- ShiP recommended by the CERN research board

The SHiP detector

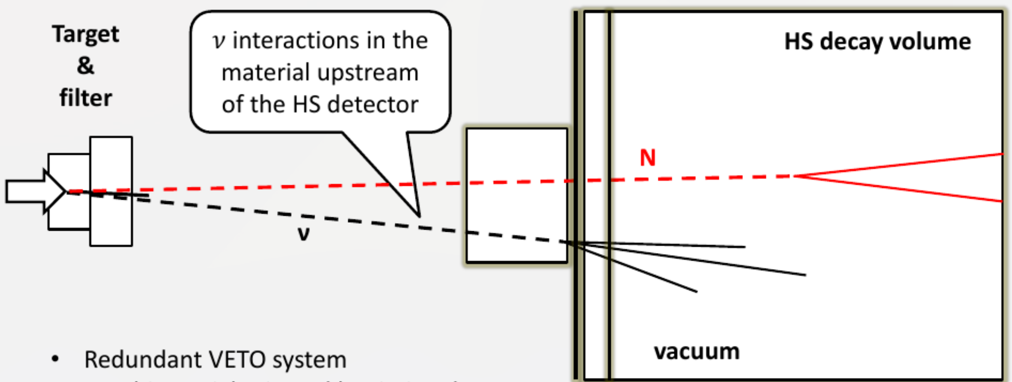
Example of creation of long-lived neutral particles ($N_{2,3}$):





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

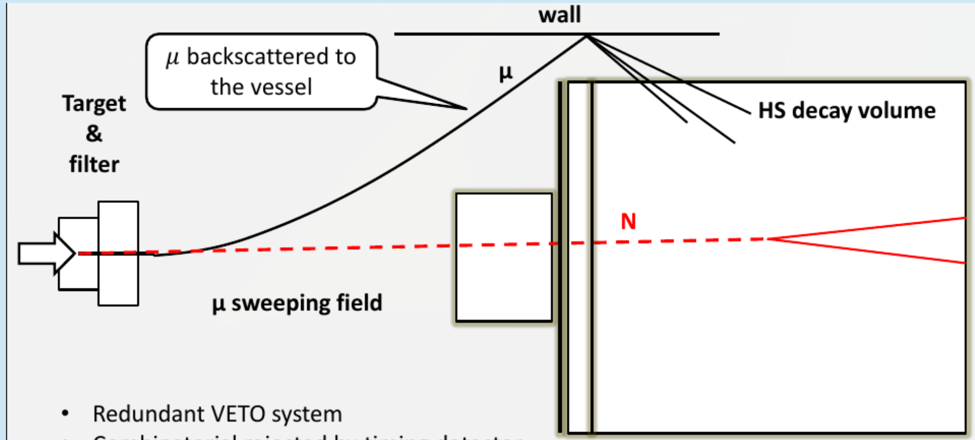
A zero-background experiment



- 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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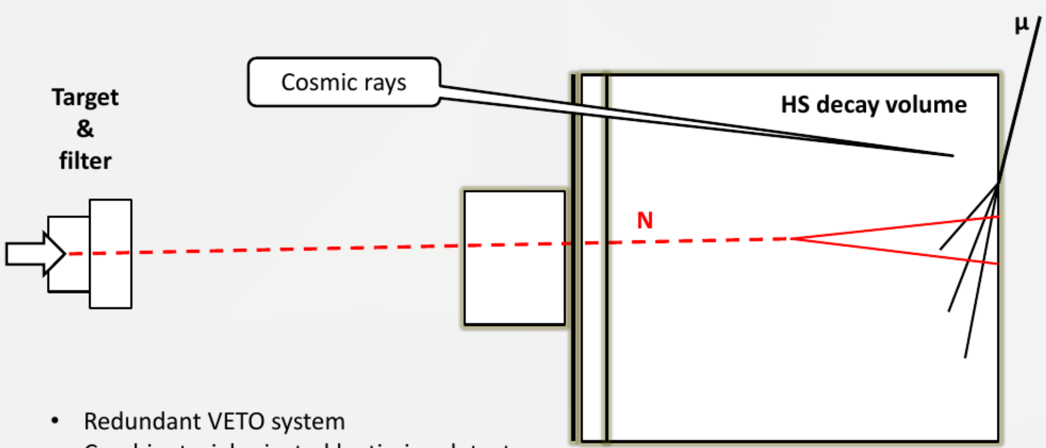

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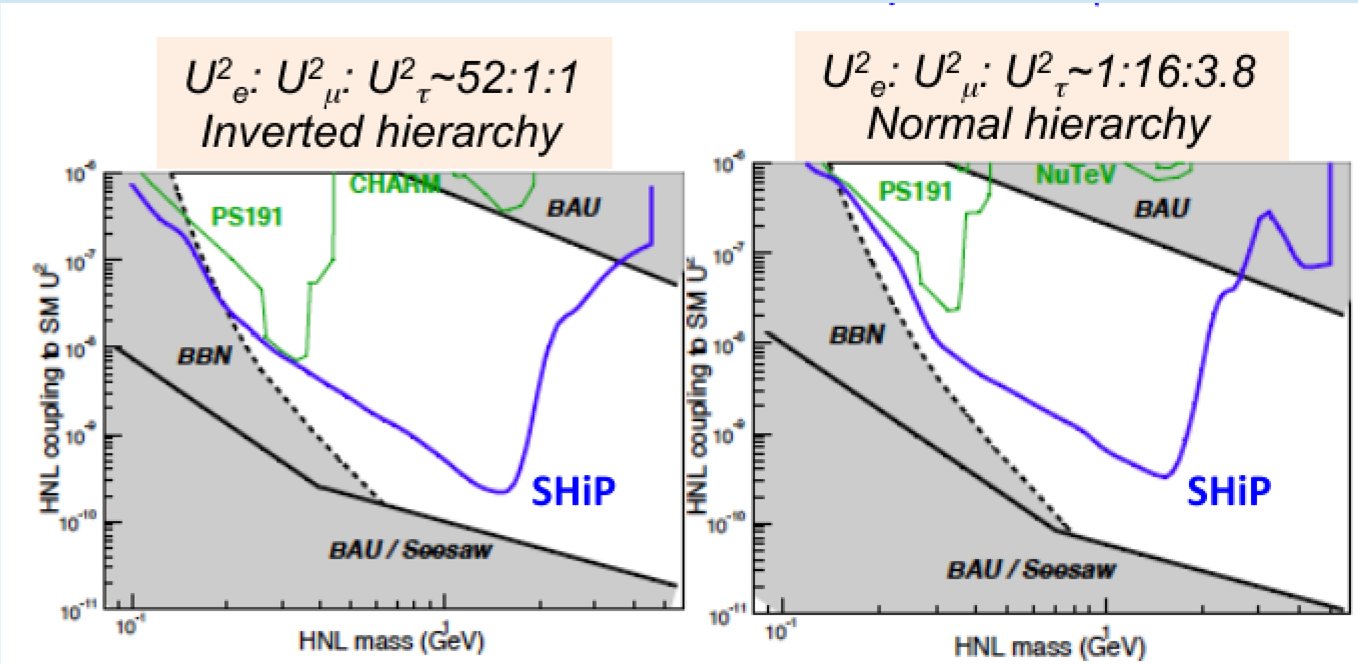
Background source	Stat. weight	Expected background (UL 90% CL)
ν-induced		
$2.0 < p < 4.0$ GeV/c	1.4	1.6
$4.0 < p < 10.0$ GeV/c	2.5	0.9
$p > 10$ GeV/c	3.0	0.8
$\overline{\nu}$-induced		
$2.0 < p < 4.0$ GeV/c	2.4	1.0
$4.0 < p < 10.0$ GeV/c	2.8	0.8
$p > 10$ GeV/c	6.8	0.3
Muon inelastic	0.5	4.6
Muon combinatorial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

Sensitivity to HNL

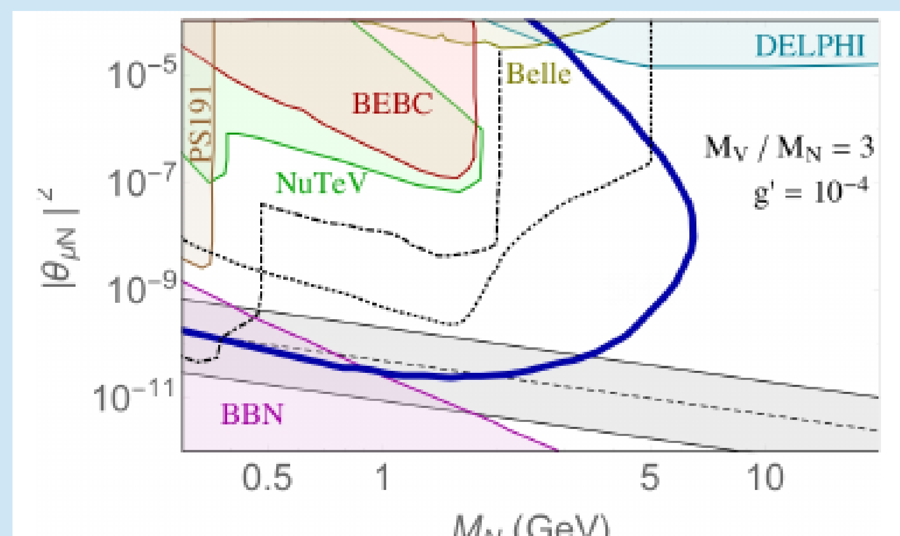


Just an example; many more recent papers and accessible regions of phase-space:

Drewes et al. (2016)
Hernandez et al. (2016)
Hernandez (2015)
Etc...

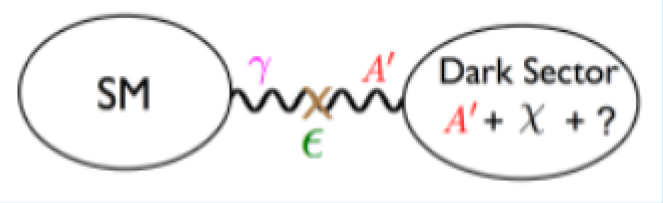
New development:
B-L gauge symmetry model
(enhanced HNL production)

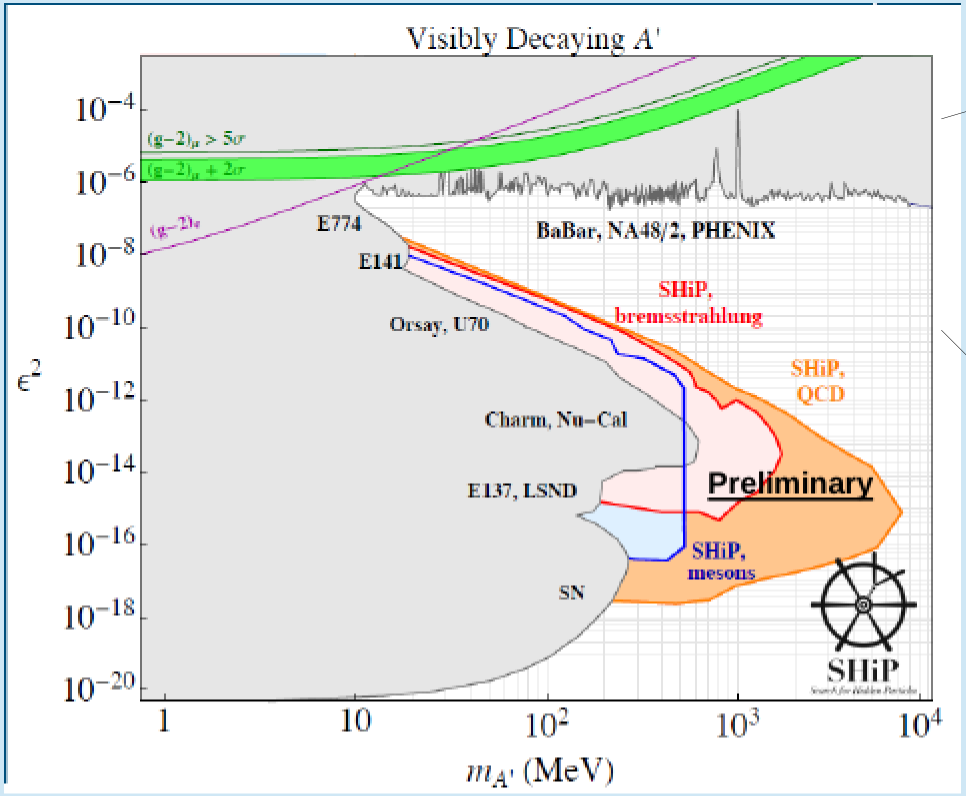
(Batell et al. 1604.06099)



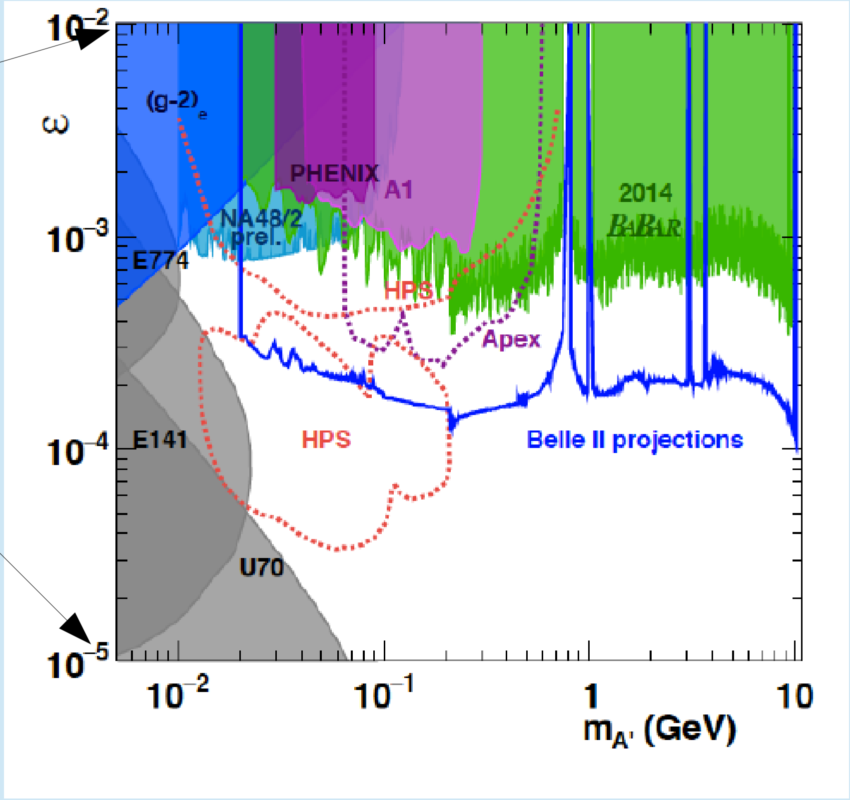
Sensitivity to dark photons

- 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 for low couplings



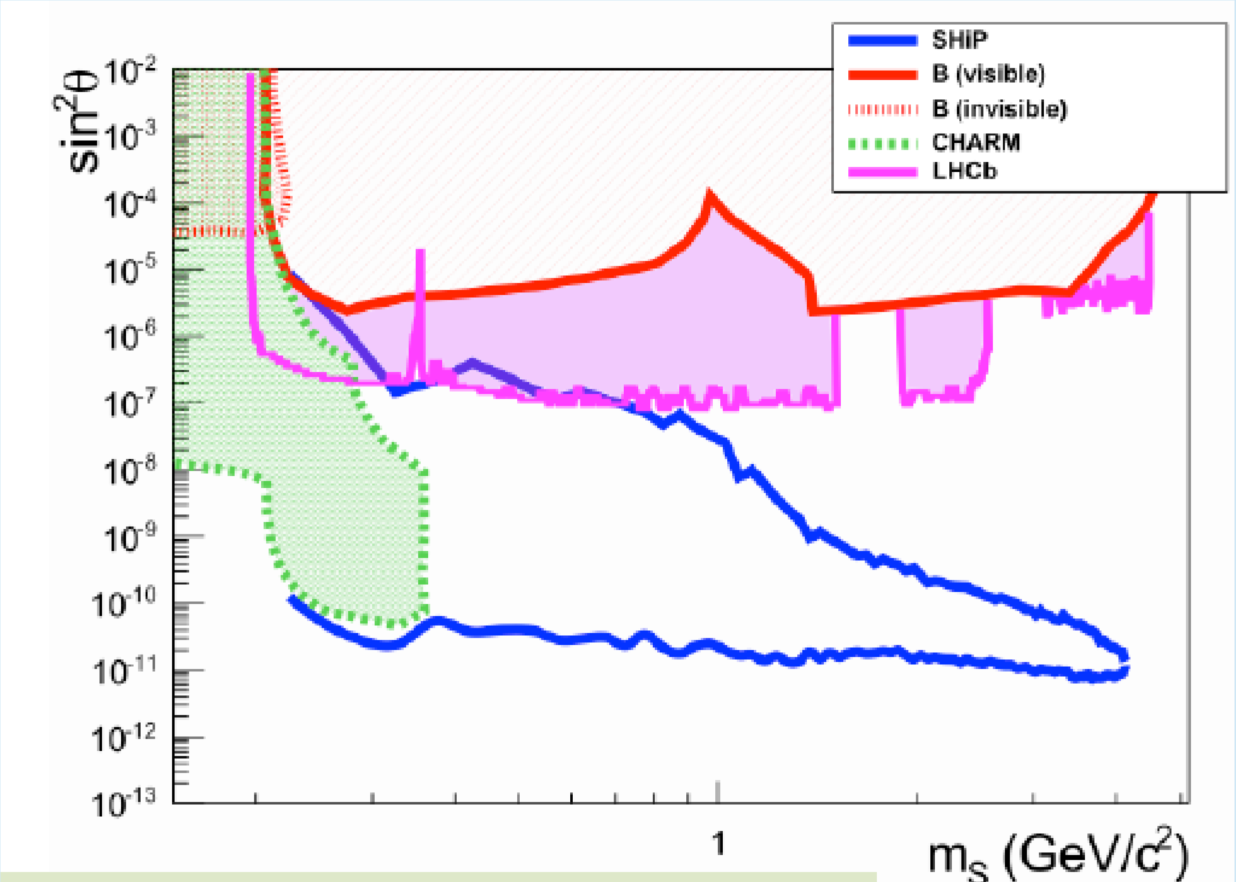


Planned and future experiments

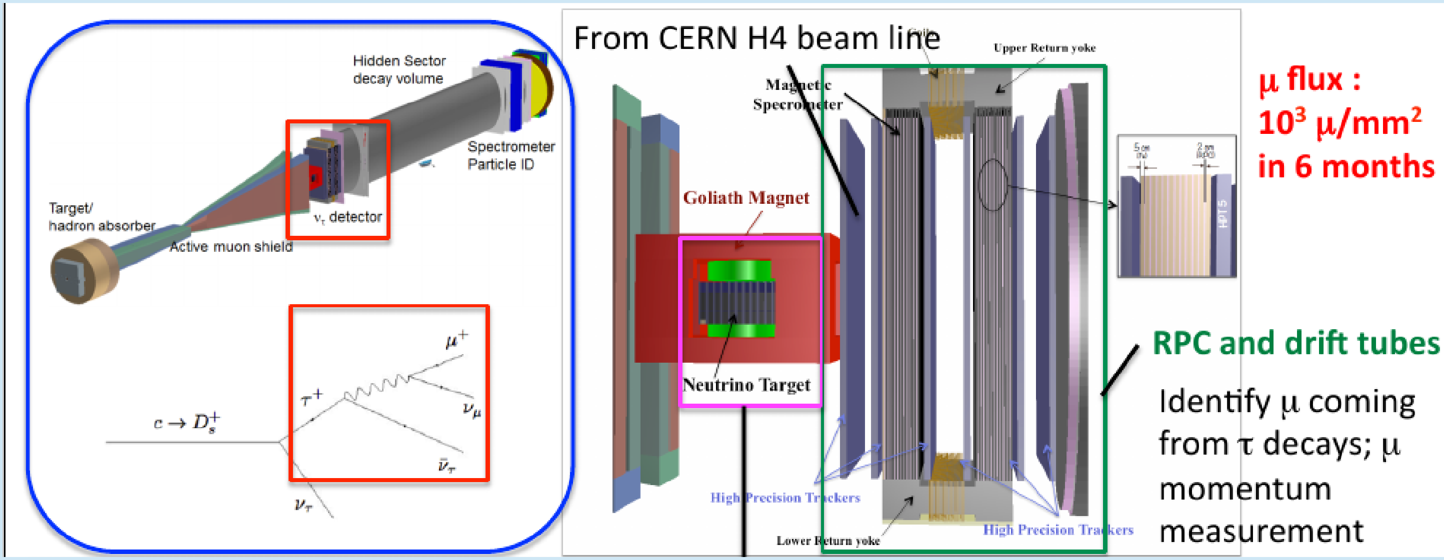


Hidden scalars

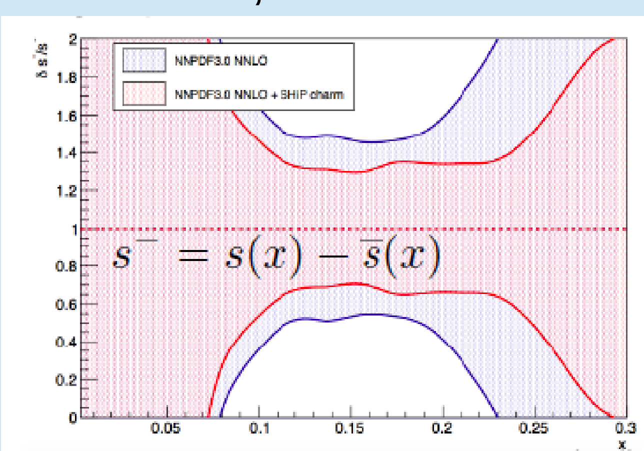
- Can mix with the SM Higgs, with angle θ
- Mainly produce in penguin B and K decays
- Displaced vertex for decays into pairs of SM particles (e^+e^-, $\mu^+\mu^-$, $\pi^+\pi^-$, K^+K^-, ...)

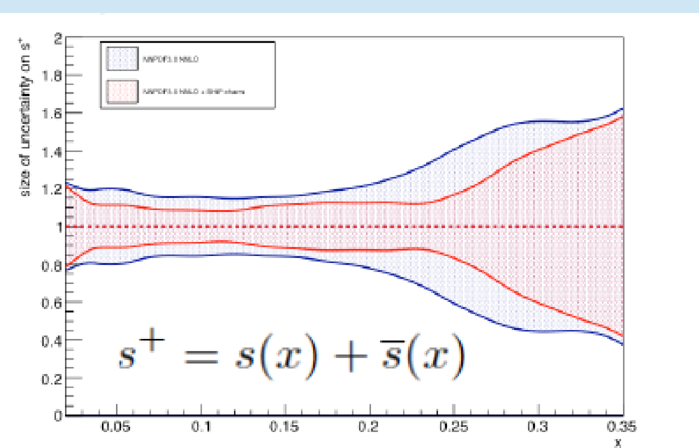


Neutrino physics



- An OPERA-like tau neutrino emulsion detector
- Current status of tau neutrino measurements:
  - DONUT observed 9 events (from charm), OPERA 5 events (from oscillations)
- Ship can increase by 200 the current tau neutrino sample, discover tau anti-neutrinos, measure structure functions and constrain strange PDFs (with ν_μ)

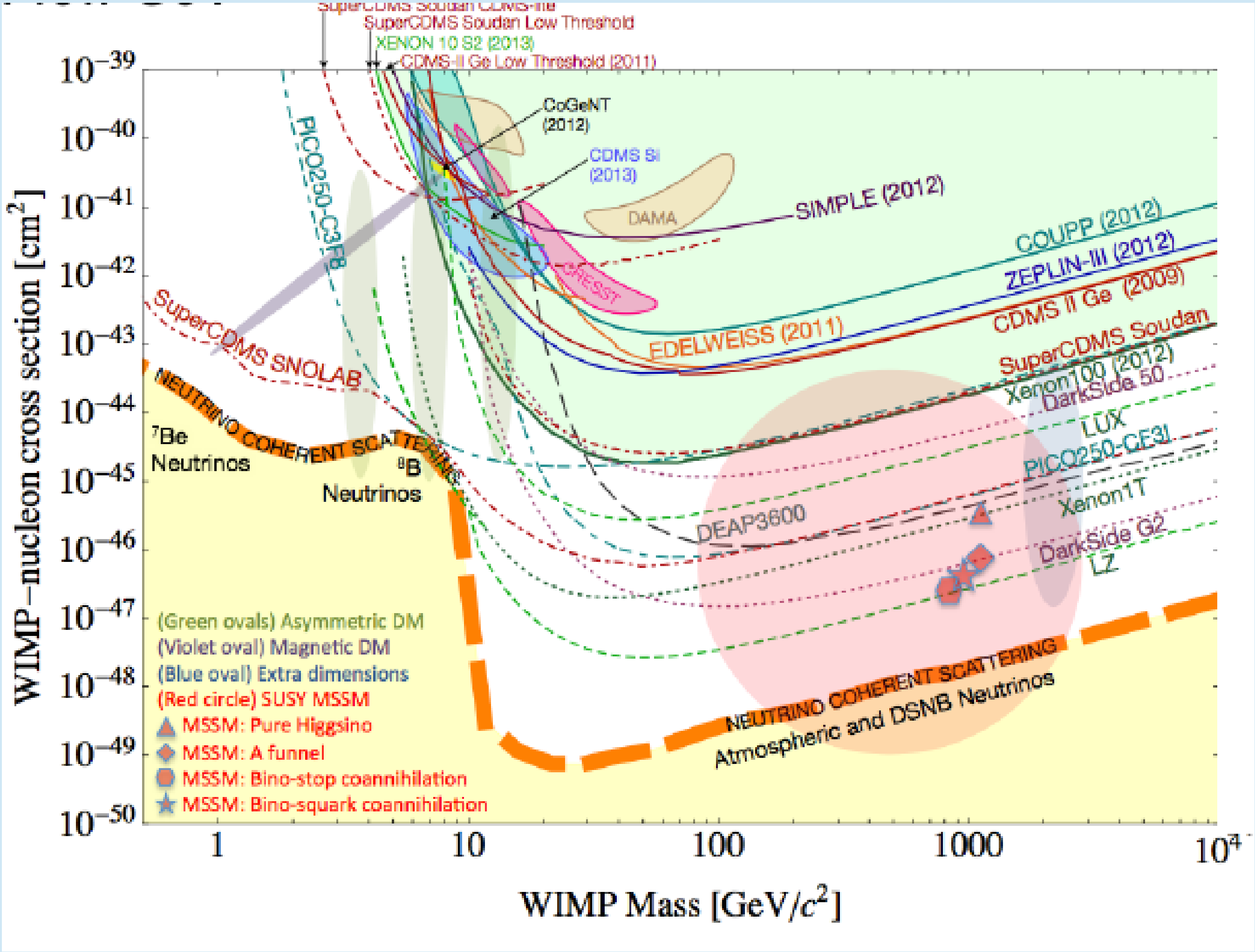




Light dark matter

Theoretically, DM could be as light as 10-22 eV, but most of the searches focus on WIMPs with masses above 10 GeV: little sensitivity below

However, sub-GeV DM predicted by SUSY, hidden sector, extra dimension models...

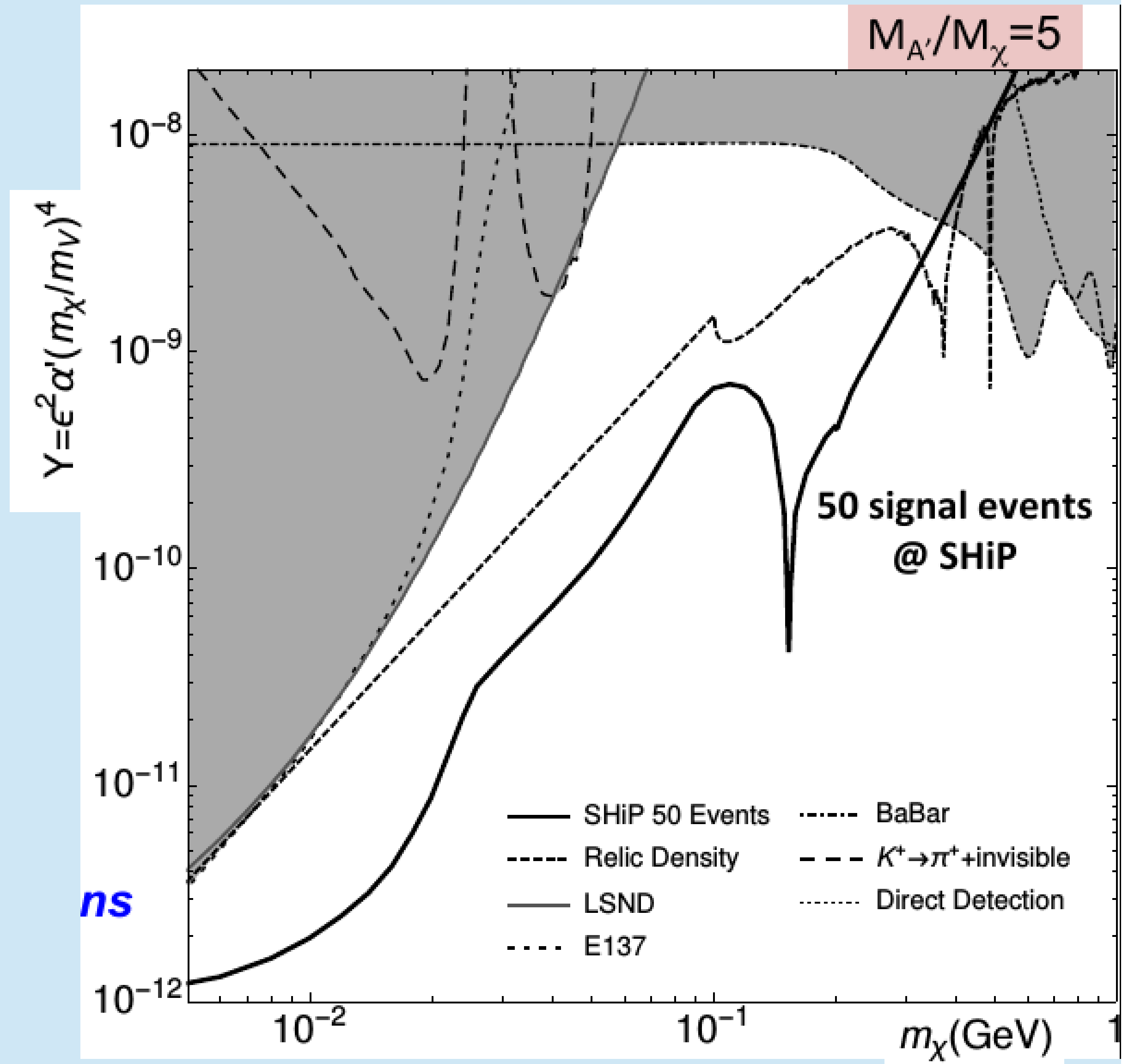


Direct detection of DM in SHiP

- Light dark matter can be produced in a beam dump, as a decay product eg. of a dark photon

LDM particles detected from their scattering on the emulsion spectrometer

- Studies still ongoing (need further reduction of neutrino BG), but sensitivity goes beyond relic density in a minimal hidden photon model



SHiP at CERN and timeline

From Fabiola's June presentation to the CERN staff:

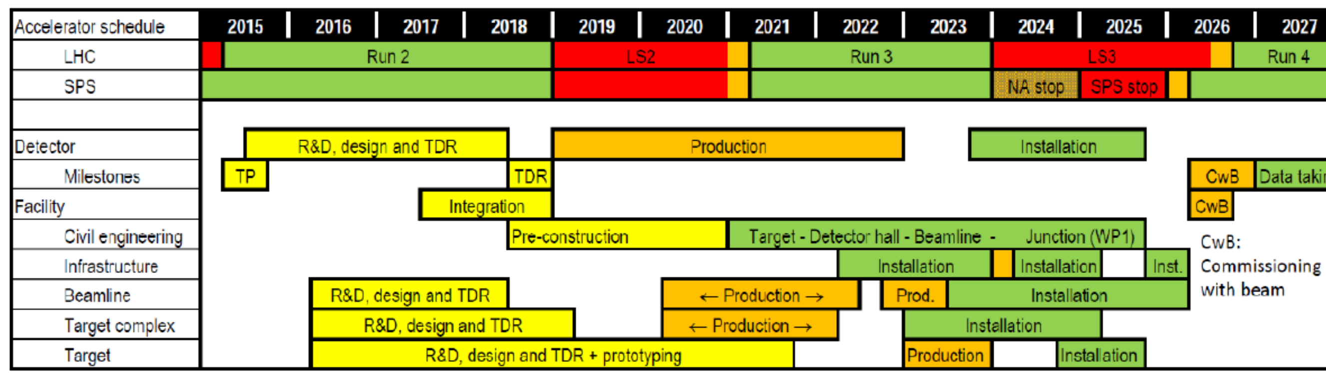
Main changes compared with last-year MTP

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

talk from A. Golutvin at the PBC kick-off meeting



Addendum to the TP: SPSC-P-250

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.

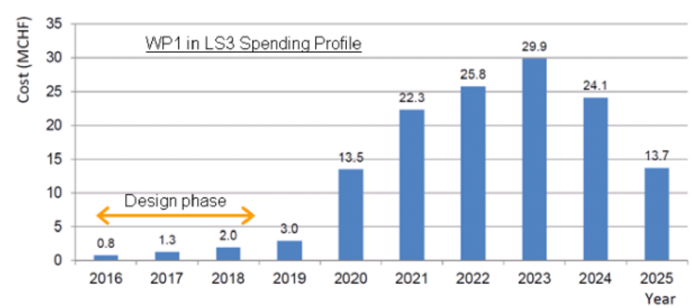


Figure 4.3: Overall cost profile for the construction of the facility in MCHF in the new baseline schedule with WP1 in LS3, as shown in Figure 4.2.

Conclusions

- Light hidden-sector particles can solve many problems of the SM, and SHiP is the only dedicated detector to discover them
- Two complementary detectors:
  - Long decay volume with spectrometer for long-lived particles
  - Emulsion spectrometer for neutrinos and direct DM
- Despite its uniqueness and innovative potential, it relies on existing technologies
- Unique discovery potential due to design and SPS characteristics; complementary to high-energy LHC searches