SHiP

Philippe Mermod, on behalf of the SHiP Collaboration
LHC LLP Workshop, CERN, 29 May 2019

New physics in proton beam dump

No further LHC energy increase

→ go to **high intensities** and probe weaker couplings

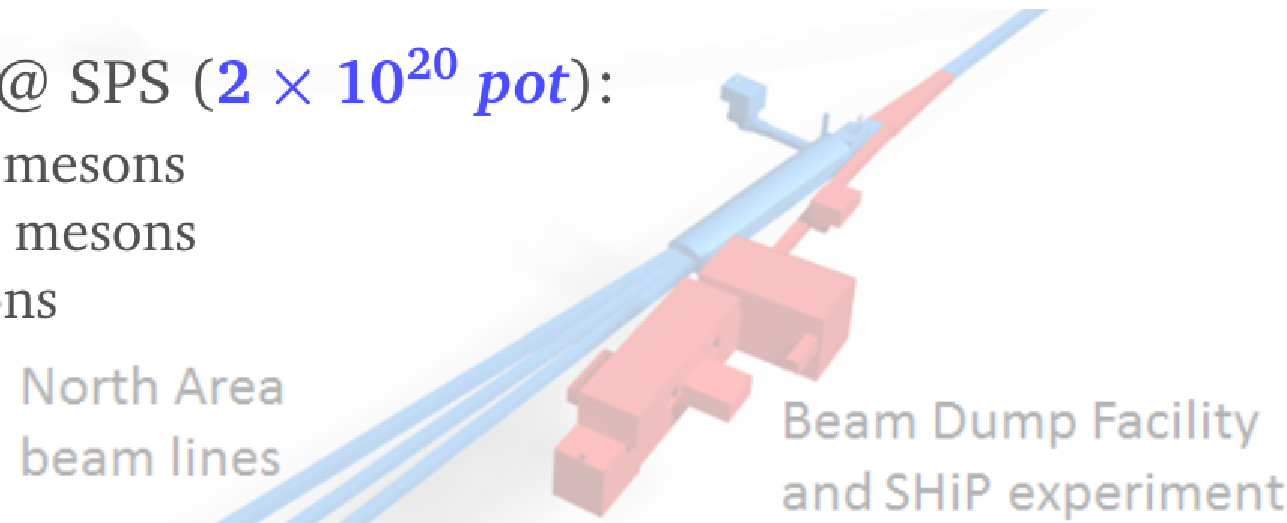
SPS provides a unique beam of high-intensity 400 GeV protons

→ Ideal setting for a CERN-based **Beam Dump Facility** (BDF)

CERN-PBC-REPORT-2018-001

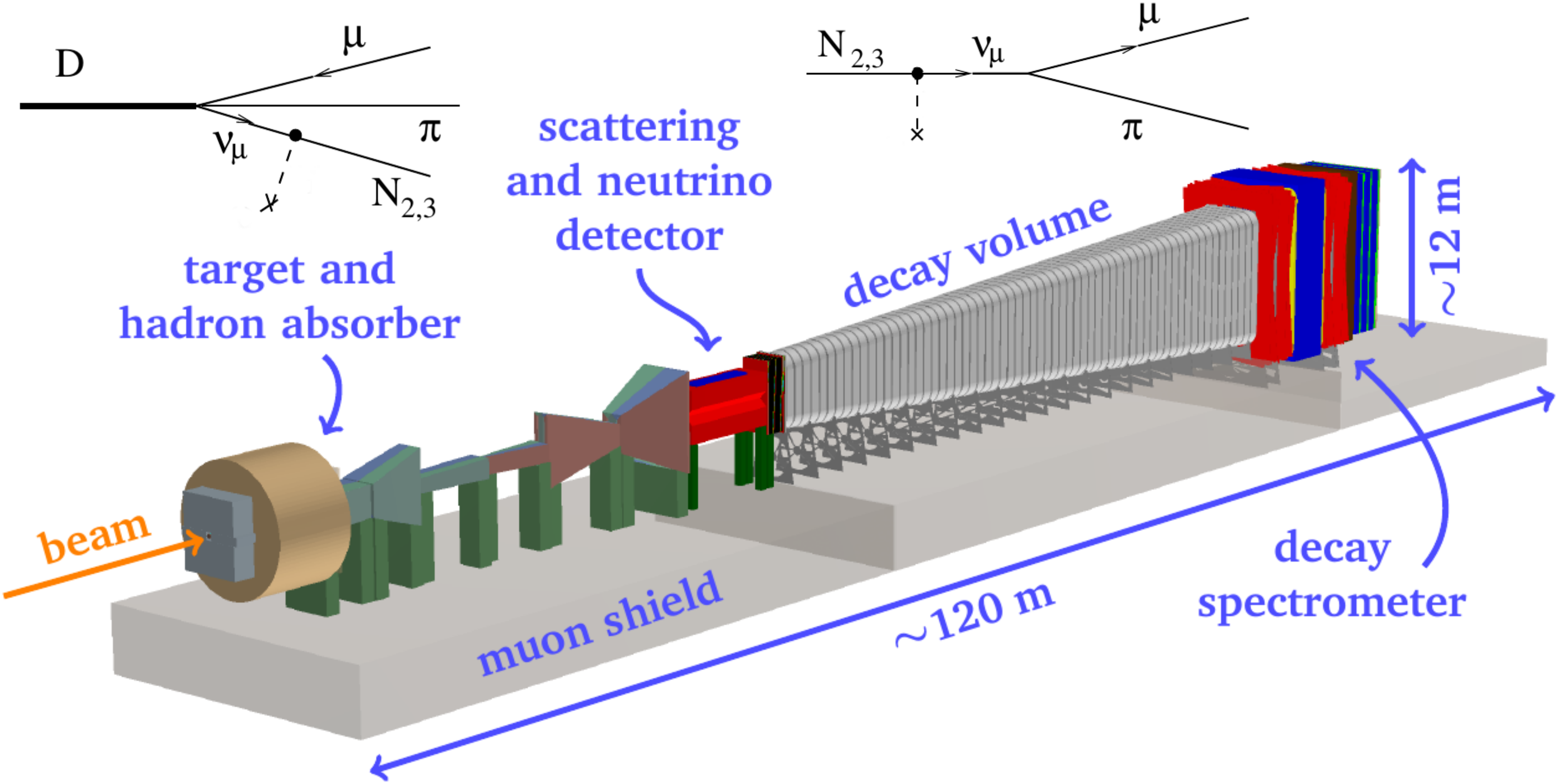
5 years of BDF @ SPS ($\mathbf{2 \times 10^{20}}$ ***pot***):

- 10^{18} charm mesons
- 10^{14} beauty mesons
- 10^{16} τ leptons



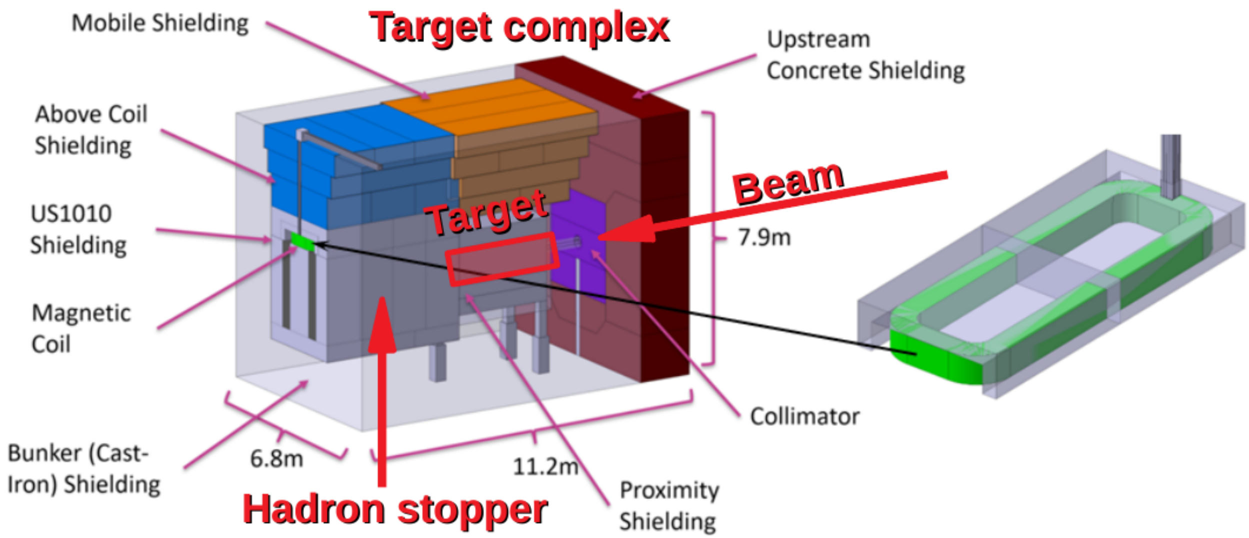
SHiP detector

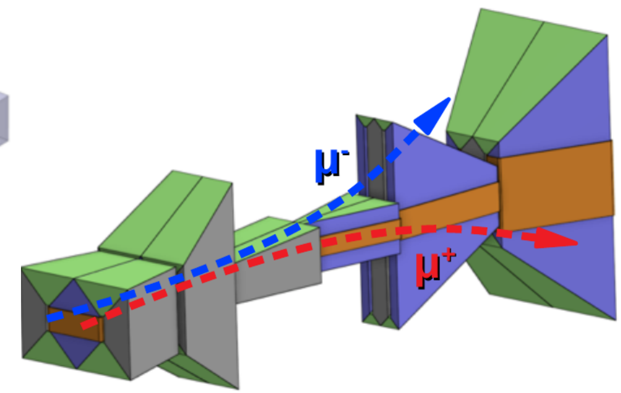
Ins-det:1504.04956
JINST 14(2019)03 P03025
CERN-SPSC-2019-010



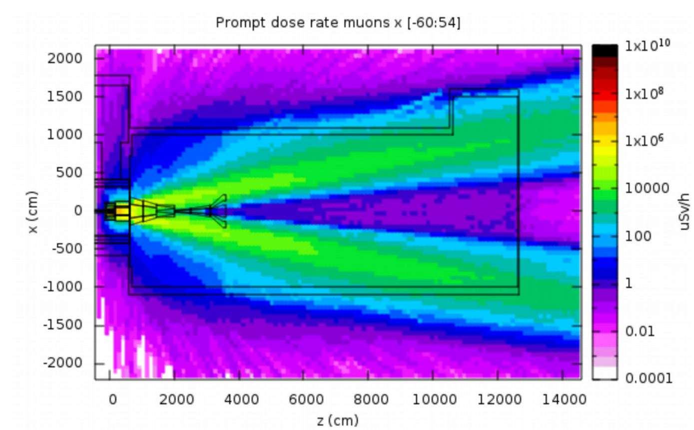
- **Discovery machine for weakly coupled LLPs**, with complementary detector for ν physics and LDM signatures
- Large acceptance – long and close to target
- Zero backgrounds using spectrometry, PID and VETO taggers

Target and muon shield



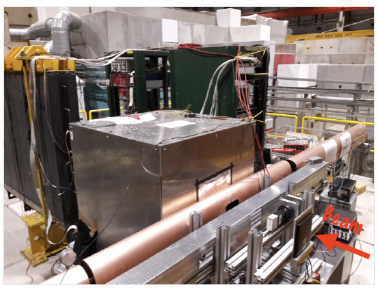


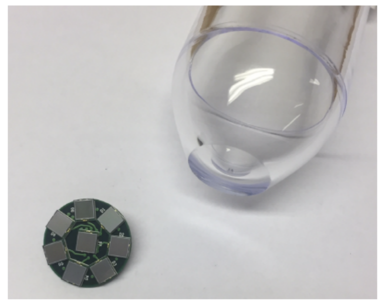
- Heavy target and hadron stopper to absorb πs before decay
- Magnet inside hadron stopper to immediately separate $\mu^{\pm}$
- Muon shield configuration optimised with machine learning
  - → μ rate reduced to ~25 kHz
- μ spectrum validated with dedicated experiment in 2018

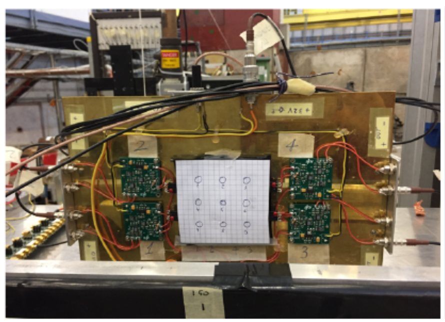


Infrastructure and detector development

- Beam line and facility being developed by CERN BDF team
- All detector subsystem have undergone
  - R&D, performance studies, optimisation
  - Phase 1 prototyping with off- and on-beam testing
- Phase 2 prototyping ongoing, beam tests in 2019-2021



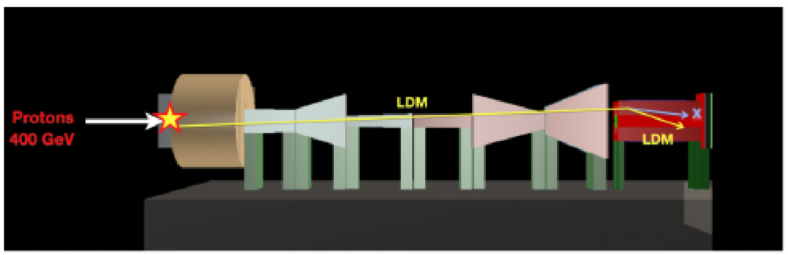


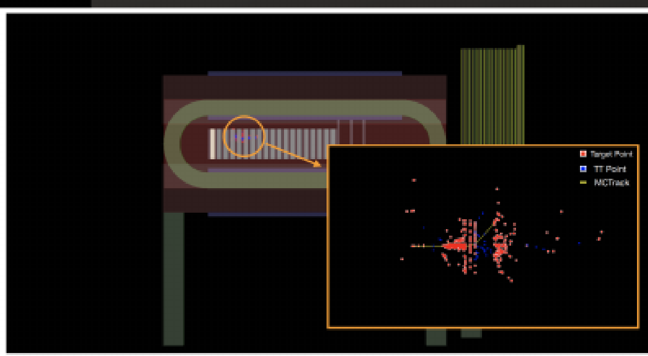


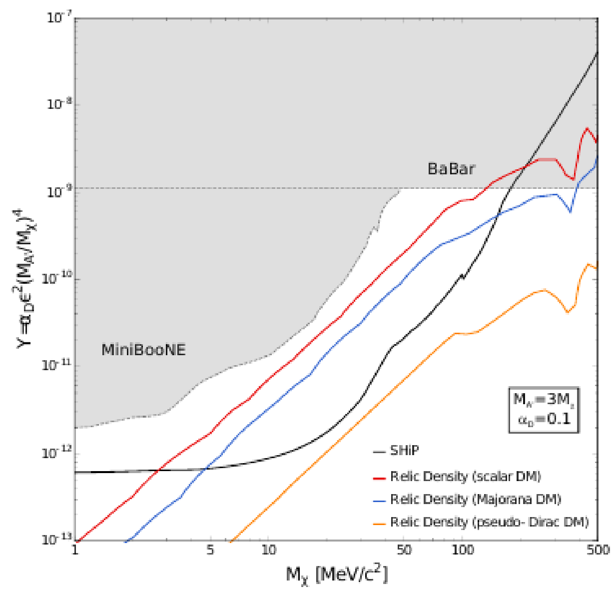

Light dark matter

benchmark: $\gamma' \rightarrow \chi\chi$, $\chi e \rightarrow \chi e$ scattering in the emulsion target
expect single EM shower w/o associated tracks

- $\bar{\nu}_e N \rightarrow eX$ background reduced by tagging extra activity at the vertex
- $\nu_e e \rightarrow \nu_e e$ slightly kinematically different
- if excess is observed $\Longrightarrow$ can switch to bunched beam and use TOF
- excess observed in real time using target tracker (R&D ongoing)

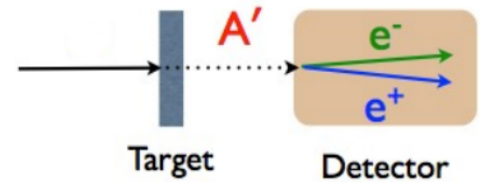


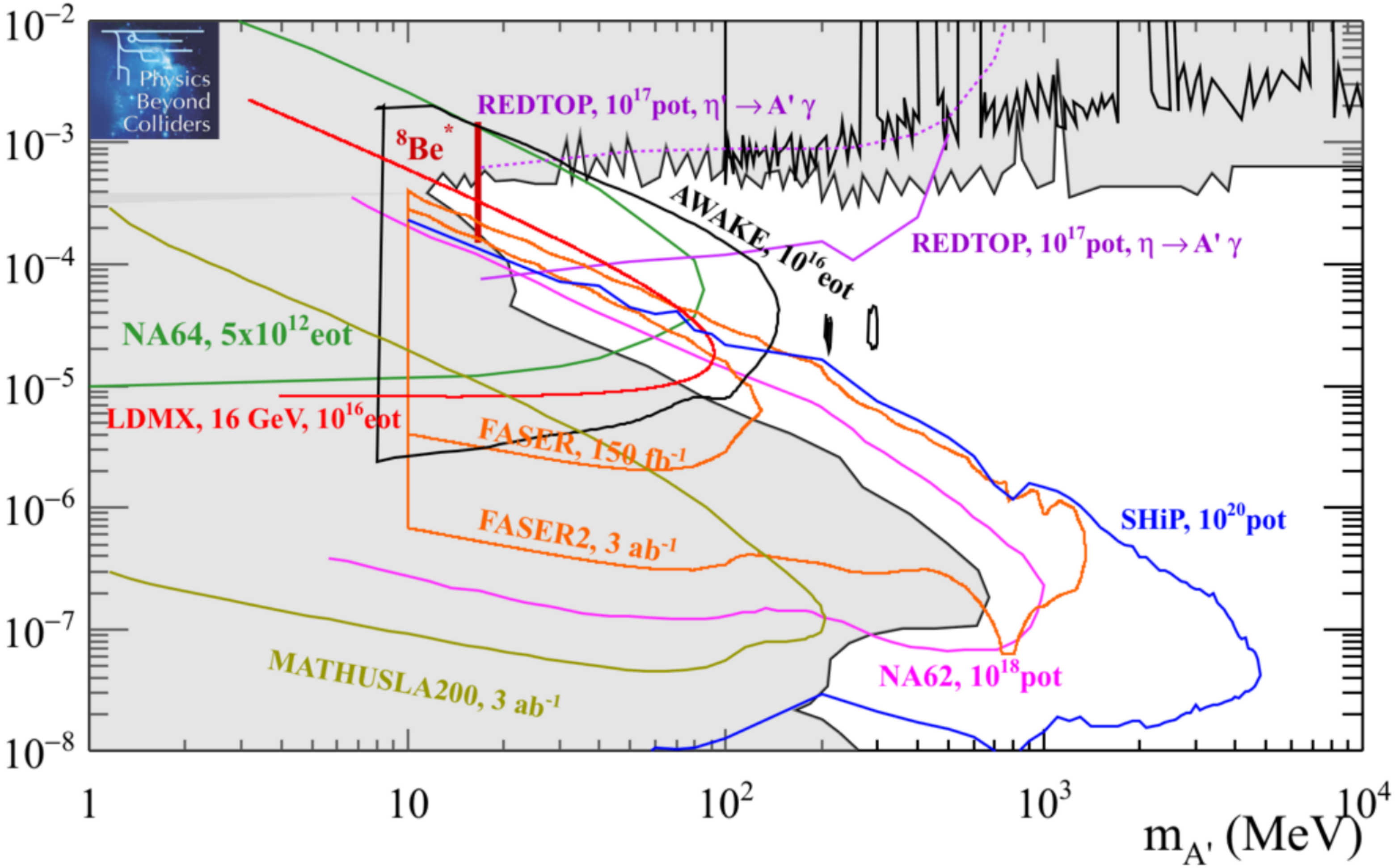




- $p \rightarrow p\gamma$
- $\pi^0 \rightarrow \gamma\gamma$
- $\eta \rightarrow \gamma\gamma$

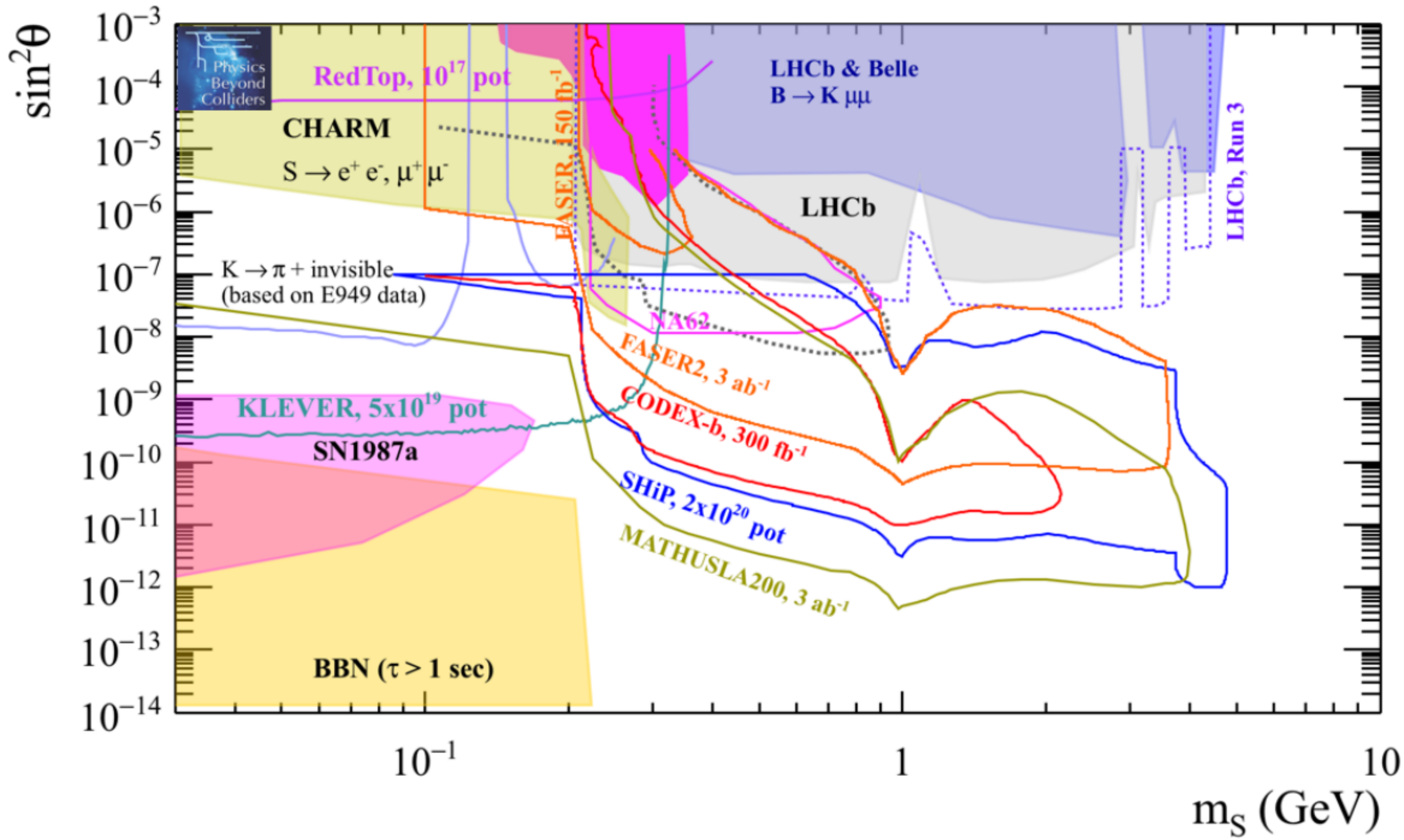
Dark photons





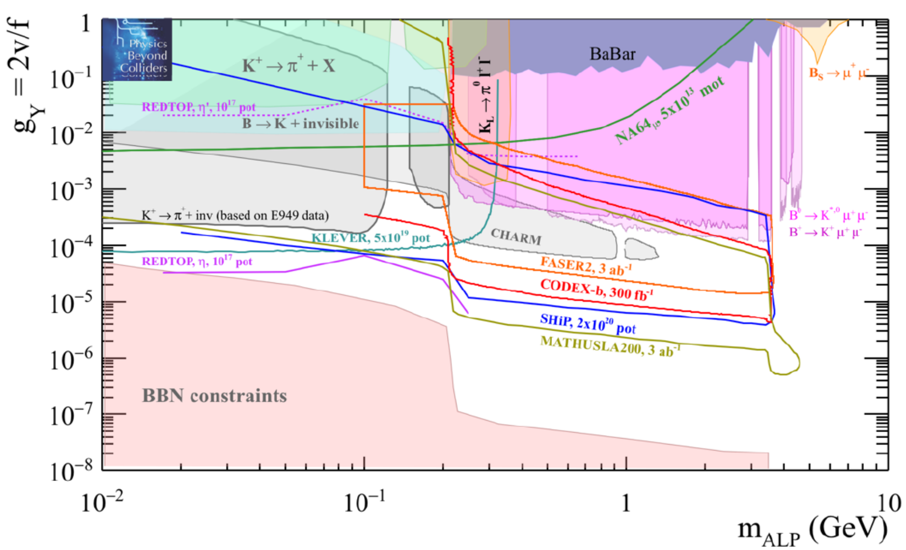
Dark scalars

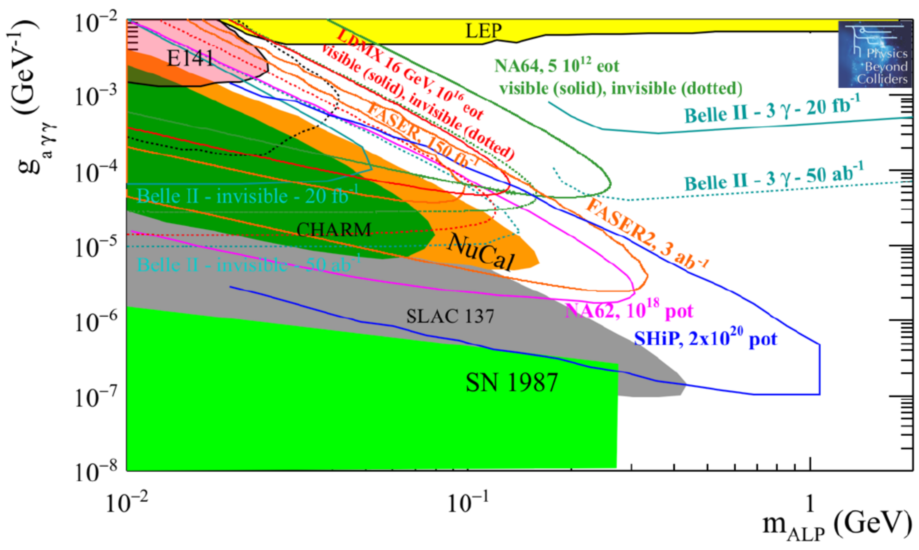
Couples to Higgs in FCNC K and B decays



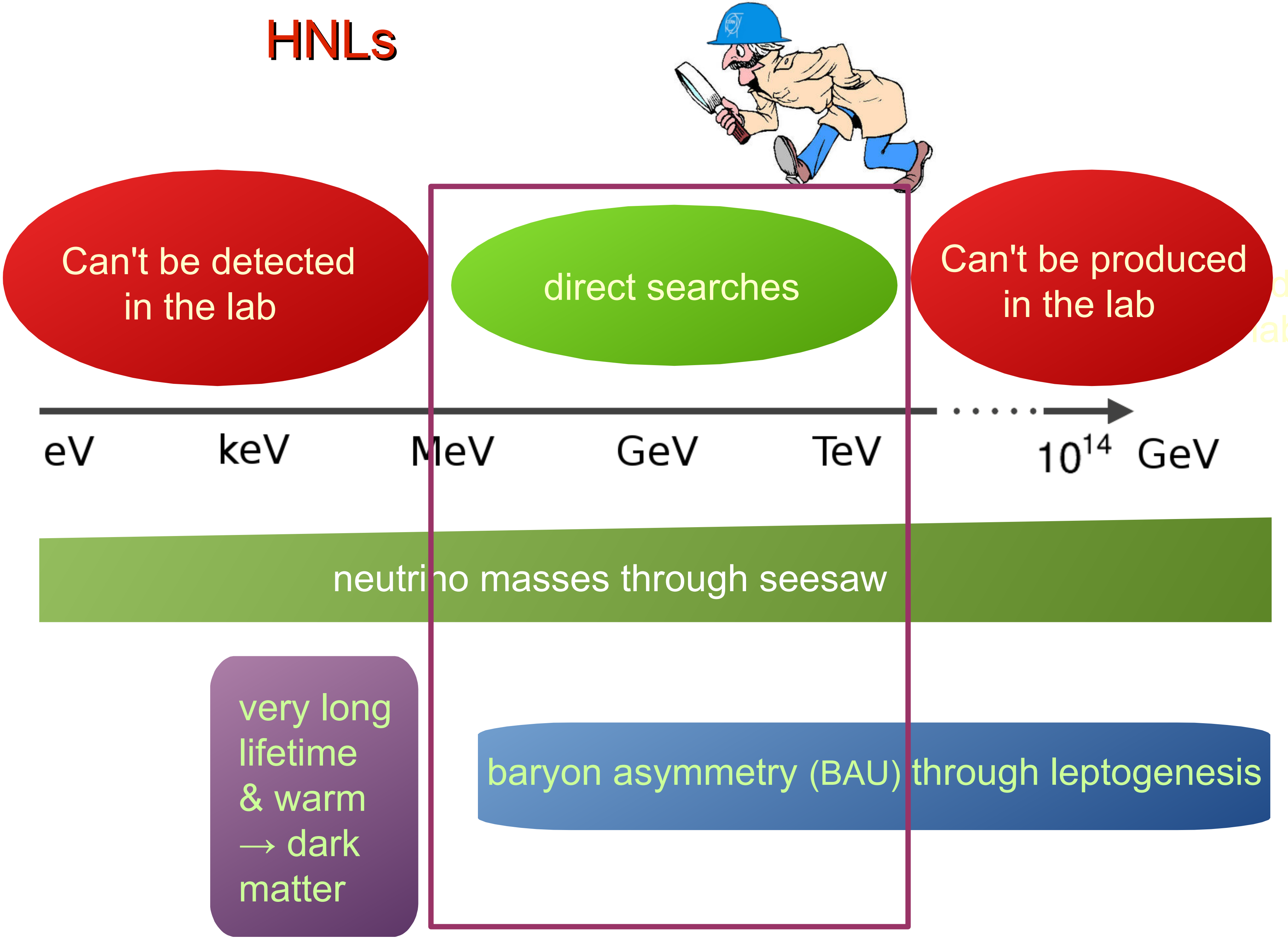
ALPs

- SplitCal developed for ALP → $\gamma\gamma$
- Can couple to fermions (left) and to photons (right)

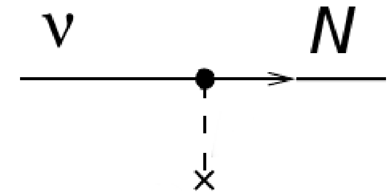




HNLs

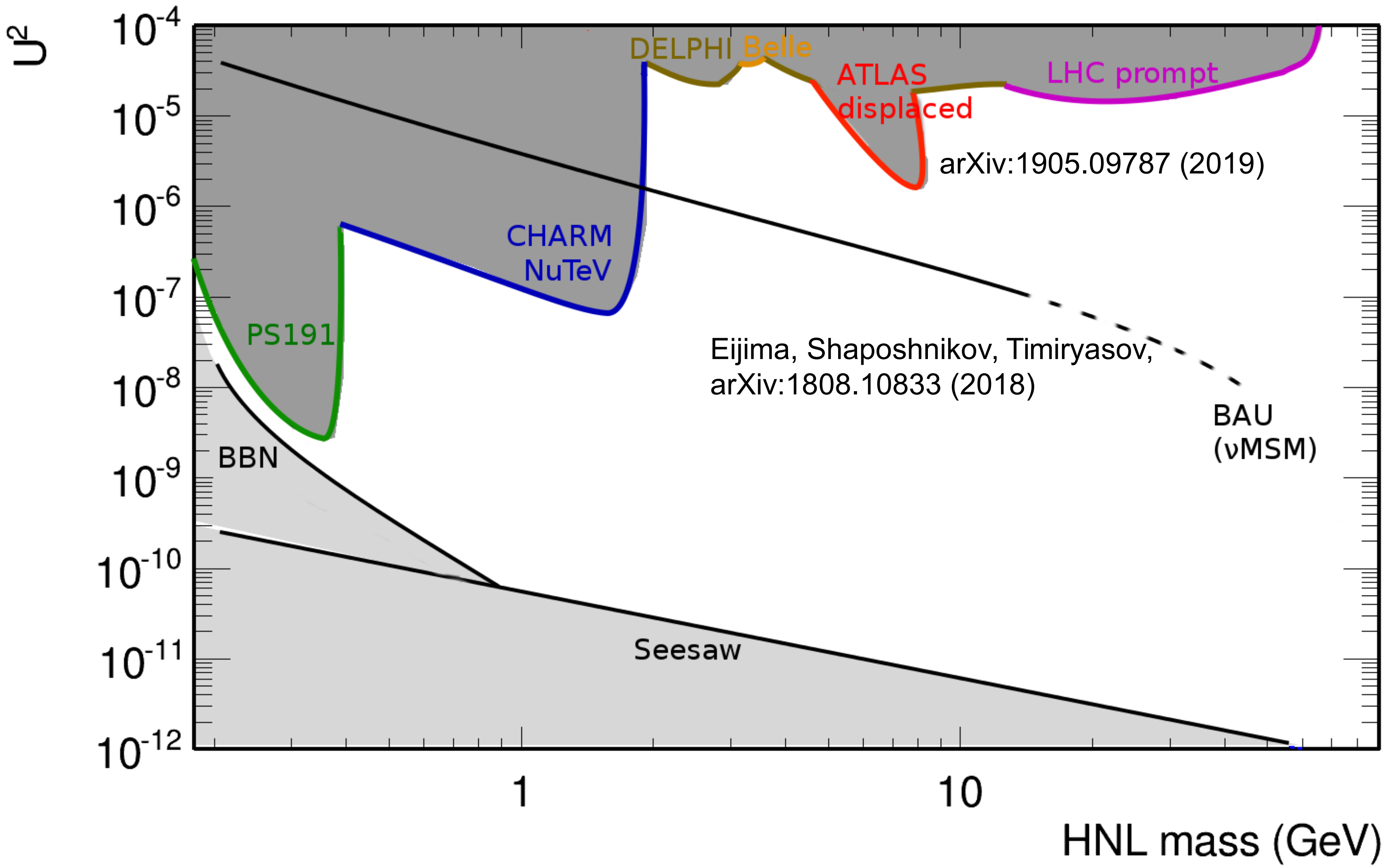

Can't be detected in the lab
direct searches
Can't be produced in the lab
eV
keV
MeV
GeV
TeV
10^{14} GeV
neutrino masses through seesaw
very long lifetime & warm → dark matter
baryon asymmetry (BAU) through leptogenesis

HNL production and detection in the lab



Very small mixing

- High-intensity beams
- Displaced decays



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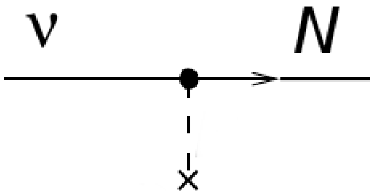

Very small mixing ⇨

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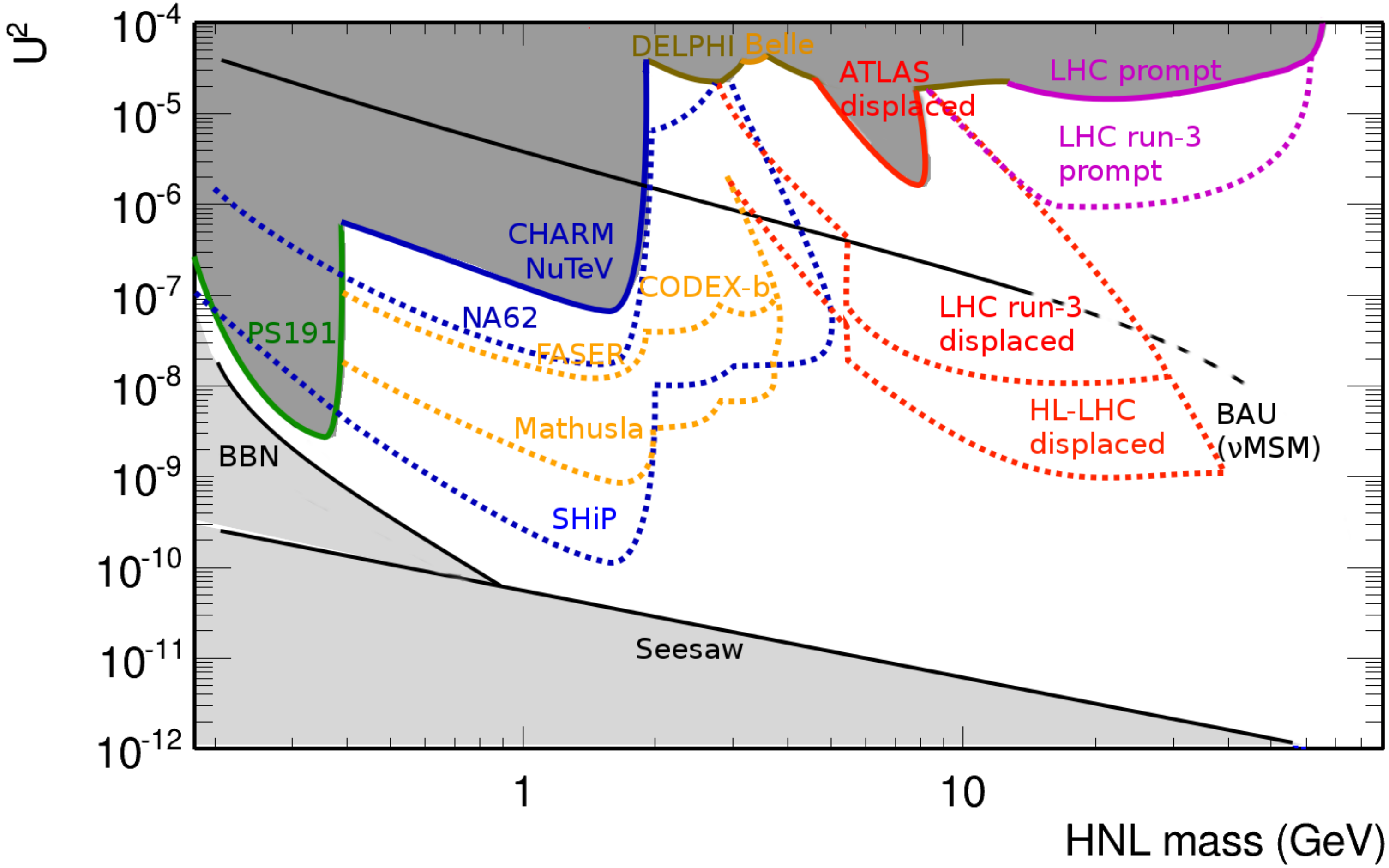


Summary and outlook

In the absence of new physics at the TeV scale, searches for **light new physics** are gathering momentum

- Possibly key to explaining dark matter, baryon asymmetry, neutrino masses...
- Probing low couplings to the SM, which means:
  - High-intensity beams
  - Long lifetimes → displaced decay signatures
- BDF at CERN SPS
  - Can host the SHiP experiment – great discovery potential, complementary to LHC and other approaches
  - Can fit other experiments after SHiP or at the same time
- Project in very good shape, moving fast towards TDR

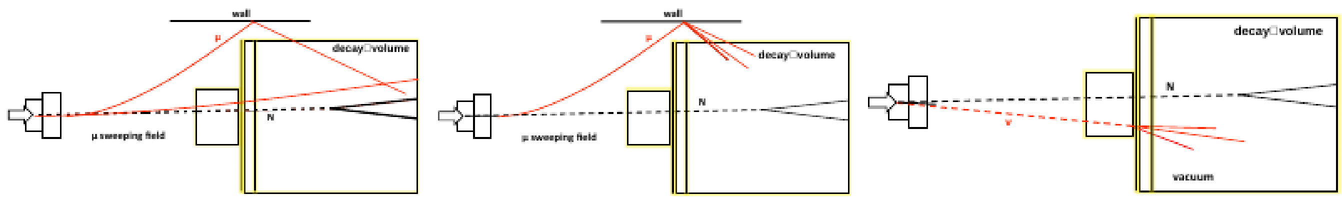
extras

Comparison with previous beam dump experiments

Experiment	PS191	NuTeV	CHARM	SHiP
Proton energy (GeV)	19.2	800	400	400
Protons on target ($\times 10^{19}$)	0.86	0.25	0.24	20
Decay volume (m^3)	360	1100	315	1780
Decay volume pressure (bar)	1 (He)	1 (He)	1 (air)	10^{-6} (air)
Distance to target (m)	128	1400	480	80-90
Off beam axis (mrad)	40	0	10	0

Table: Comparison of the experimental conditions for HNL search experiments [SHiP Tech. Prop. 1504.04956].

SHiP is a 0 background LLP experiment



- **Muon combinatorial:**
  - $10^{16} \xrightarrow{\text{selection}} 10^{9} \xrightarrow{\text{timing}} 10^{-2}$ candidates in 5 years @ $90\% CL$
  - ML used to generate large sample of dangerous μ
- **Muon inelastic:**
  - 5 years of SHiP simulated
  - ~~correlation~~ between VETO and selection: $< 6 \times 10^{-4}$ @ $90\% CL$
- **ν interactions:**
  - 10 years of SHiP simulated, increasing to 100
  - ν-air: $< 10^{-2}$ with pressure ~ 1 mbar
  - ν-material: $5 \times 10^{5} \begin{cases} \xrightarrow{\text{cuts (fully reco)}} 0 \\ \xrightarrow{\text{cuts (part. reco)}} 2 \xrightarrow{\text{opening angle}} 0 \end{cases}$ @ $90\% CL$