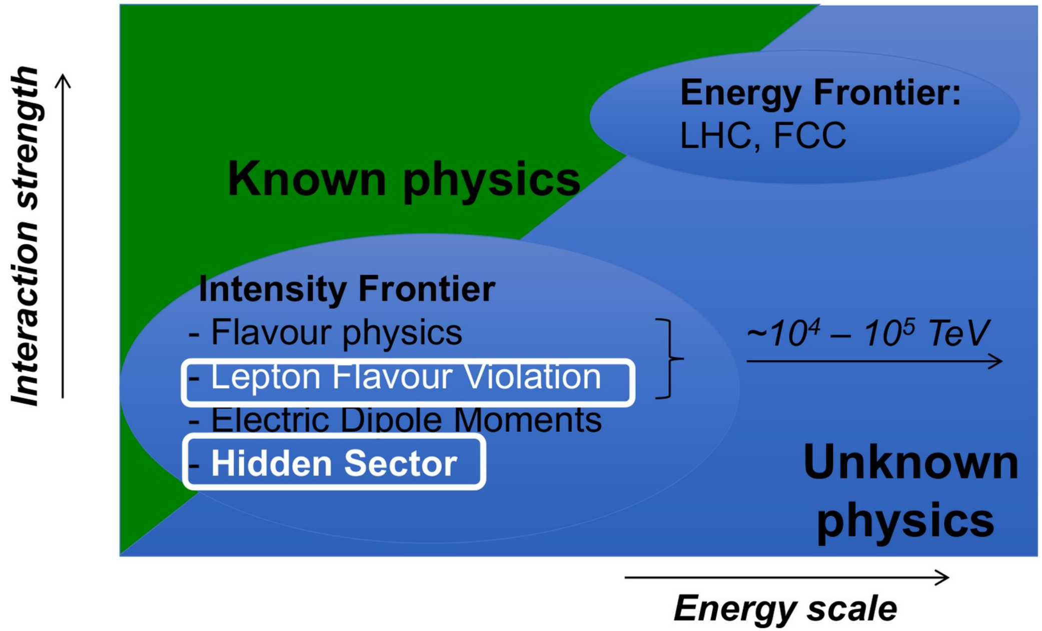
Searches for Feebly Interacting Particles at SHiP

Katerina Kuznetsova

motivation for new physics

- Matter-antimatter asymmetry
- Neutrino masses and oscillations
- Non-baryonic Dark Matter

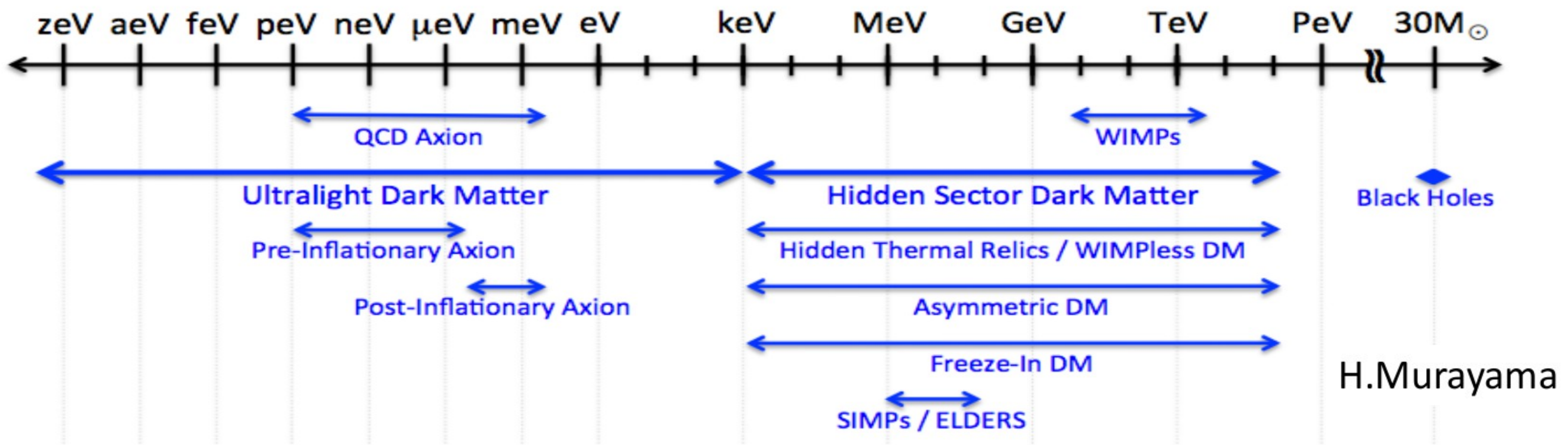
nicely introduced by Luca Stanco yesterday

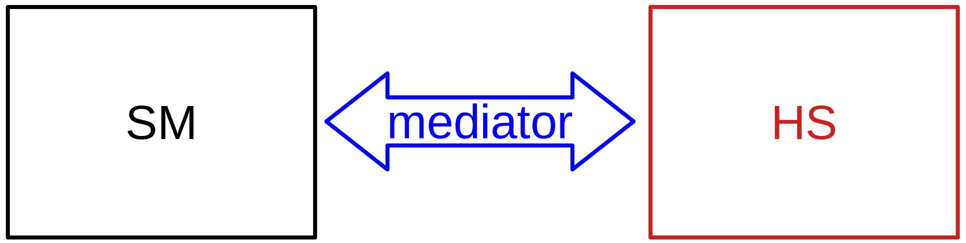


where to search for?

- Large (not explored) mass
  – energy frontier
- Feebly interacting particle
  - intensity frontier

mass scale of dark matter candidates

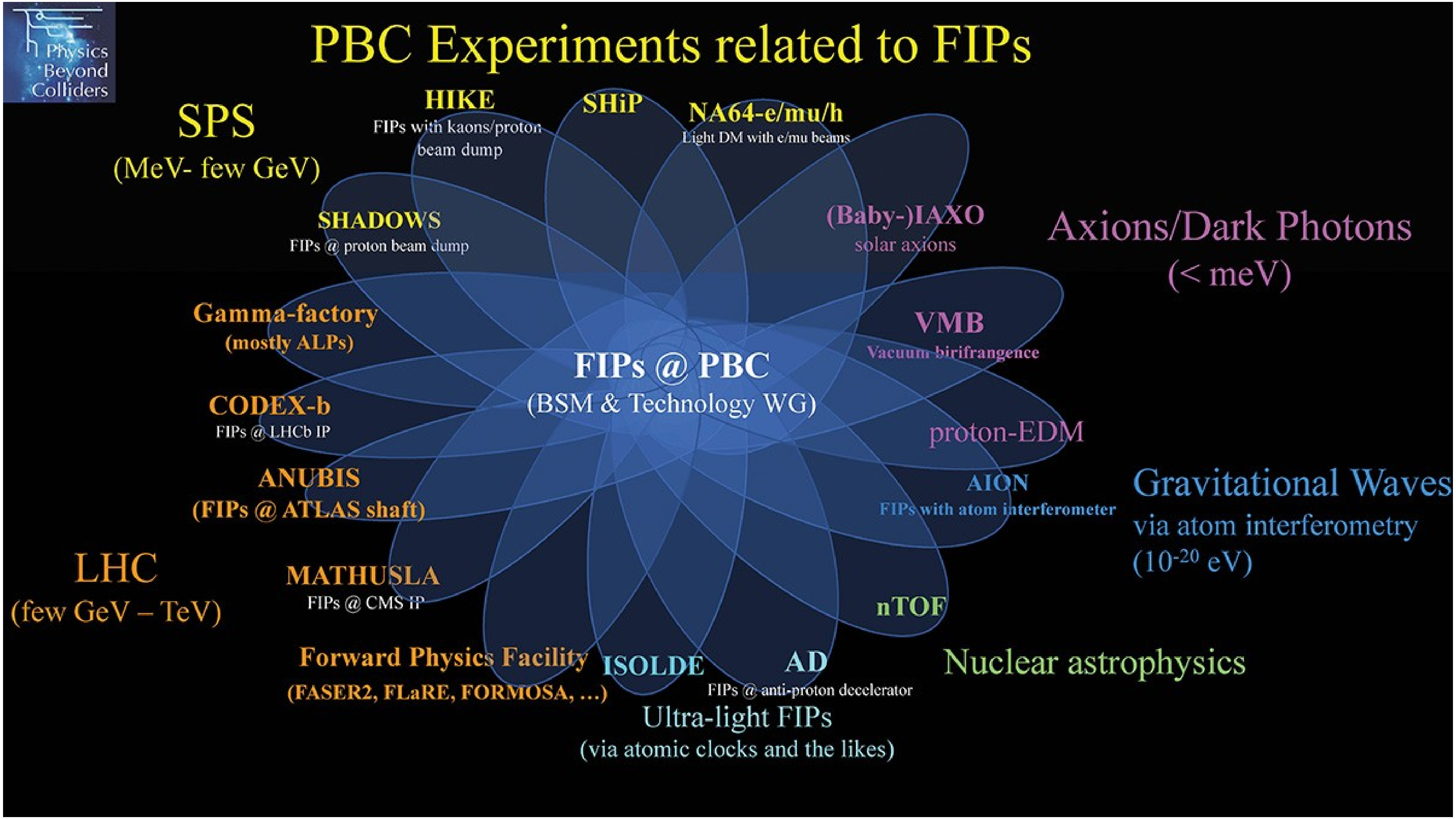




Hidden Particles:

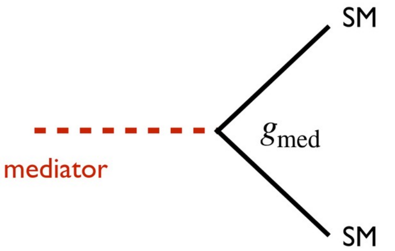
- Hidden Sector Light Dark Matter
- Mediators to Hidden Sector

***P*hysics *B*eyond *C*olliders (CERN) FIP searches**

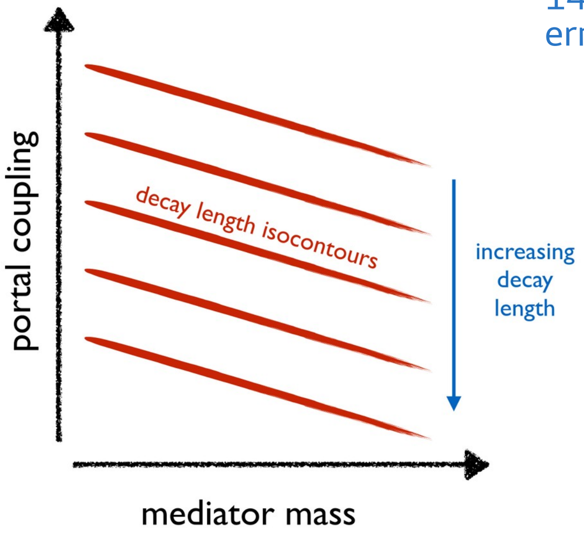


how it works?

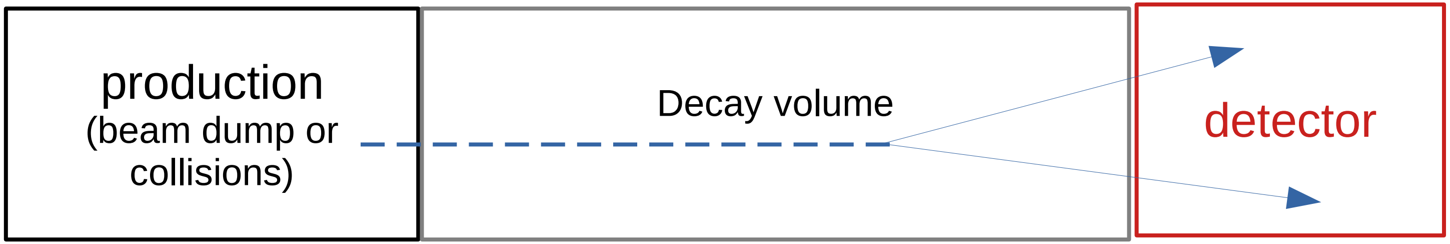
"Dark Sector Theory" lecture by Brian Batell at
14th International Neutrino Summer School 2023 at Fermilab



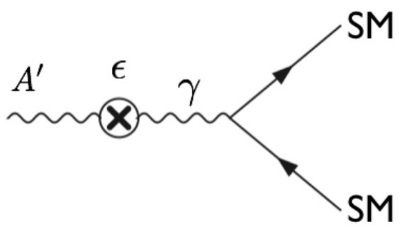
$$\Gamma_{\text{med}} = (c\tau_{\text{med}})^{-1} \sim g_{\text{med}}^2 m_{\text{med}}$$



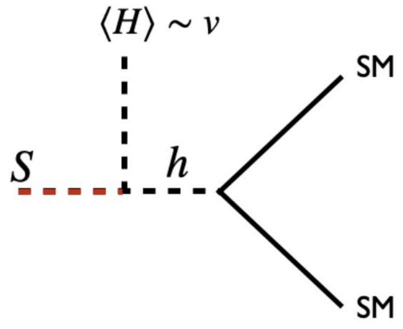
Intermediate decay length



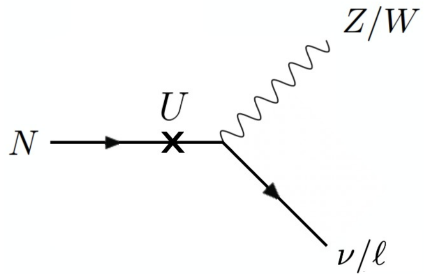
vector portal (spin 1): dark photon couples to the hypercharge field



Higgs portal (spin 0): dark scalar couples to the Higgs field



neutrino portal (spin 1/2): heavy neutral lepton (HNL) couples to one of the left-handed doublets of the SM and to the Higgs field with a Yukawa coupling



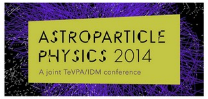
more complicated cases - for example, axion portal : axion-like-particles (ALP)

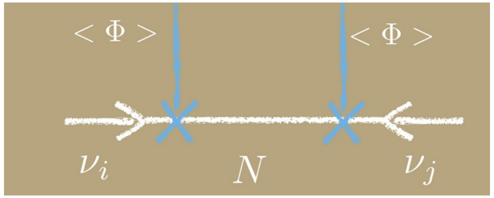
Neutrino portal: νMSM - neutrino Minimal Standard Model

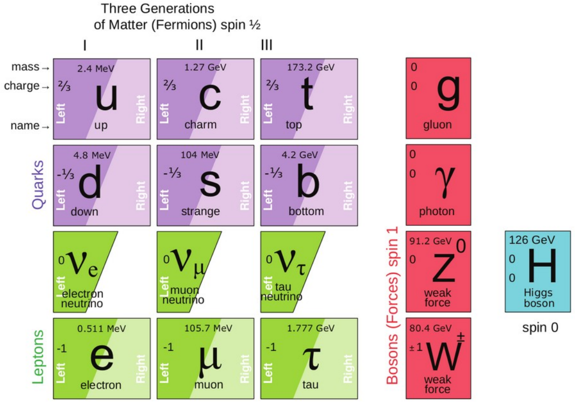
Minimal extension of the SM with three Right Handed (Majorana) Heavy Neutral Leptons : N1 , N2 , N3 .

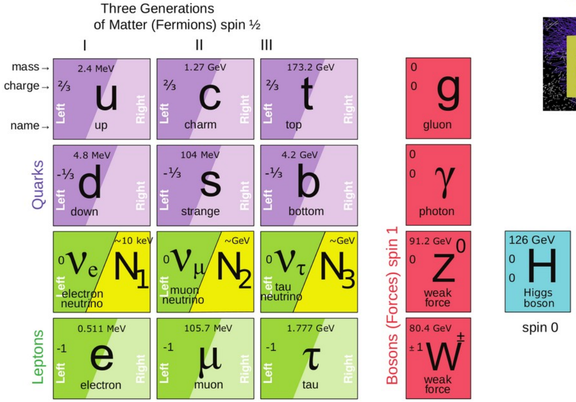
Heavy neutral leptons in cosmology

Mikhail Shaposhnikov









mixing

N1 – dark matter?

$$U_{I\ell} \sim \frac{M_D^{\ell}}{M_N^{I}} = \frac{Y_{I\ell} v}{M_N^{I}}$$

Role of N_2, N_3 with mass in 100 MeV – GeV region: “give” masses to neutrinos and produce baryon asymmetry of the Universe

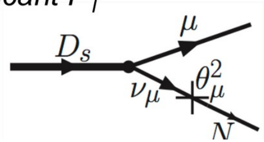
Amsterdam, June 26, 2014 – p. 9

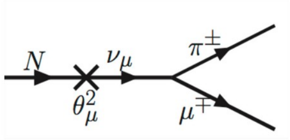
SHiP experiment

SHiP Technical Proposal - 2015

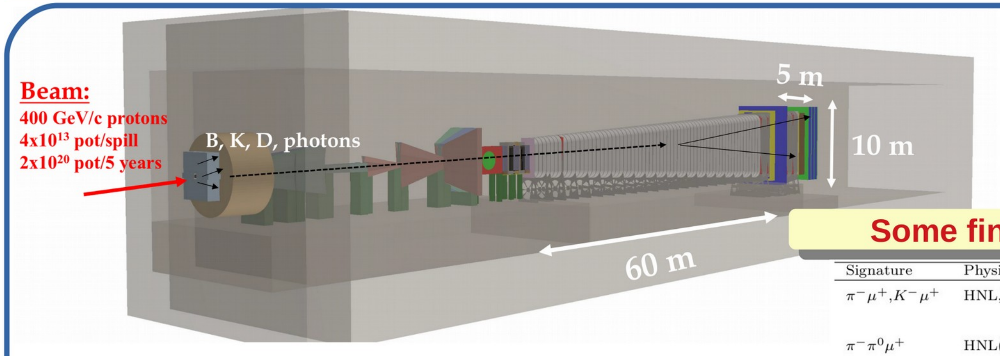
At CERN SPS: σ(pp→ssbar X)/σ(pp→ X) ~ 0.15
σ(pp→ccbar X)/σ(pp→ X) ~ $2\ 10^{-3}$
σ(pp→bbbar X)/σ(pp→ X) ~ $1.6\ 10^{-7}$

✓ *HS produced in charm and beauty decays have significant P_T*





SHiP physics – search for new particles



- Signal: hidden particles from K, **D**, B decays
  - HNL
  - Dark photon
  - Dark scalars
  - Axions and axion-like particles
  - …
- BG: aiming o(1) event for $2\text{x}10^{20}$ pot (5 years) in a selected data sample (at least the HNL case)
  "BG free experiment"

Some final states from TP

Signature	Physics	Backgrounds
$\pi^-\mu^+$,$K^-\mu^+$	HNL,NEU	RDM, $K^0_L \to \pi^-\mu^+\nu_\mu$
$\pi^-\pi^0\mu^+$	HNL($\to \rho^-\mu^+$)	$K^0_L \to \pi^-\mu^+\nu_\mu(+\pi^0)$, $K^0_L \to \pi^-\pi^+\pi^0$
π^-e^+,K^-e^+	HNL, NEU	$K^0_L \to \pi^-e^+\nu_e$
$\pi^-\pi^0e^+$	HNL($\to \rho^-e^+$)	$K^0_L \to \pi^-e^+\nu_e$, $K^0_L \to \pi^-\pi^+\pi^0$
μ^-e^++p^{miss}	HNL,HP($\to \tau\tau$)	$K^0_L \to \pi^-\mu^+\nu_\mu$, $K^0_L \to \pi^-e^+\nu_e$
$\mu^-\mu^+$+p^{miss}	HNL,HP($\to \tau\tau$)	RDM, $K^0_L \to \pi^-\mu^+\nu_\mu$
$\mu^-\mu^+$	DP,PNGB,HP	RDM, $K^0_L \to \pi^-\mu^+\nu_\mu$
$\mu^-\mu^+\gamma$	CS	$K^0_L \to \pi^-\pi^+\pi^0$, $K^0_L \to \pi^-\mu^+\nu_\mu(+\pi^0)$
e^-e^++p^{miss}	HNL,HP	$K^0_L \to \pi^-e^+\nu_e$
e^-e^+	DP,PNGB,HP	$K^0_L \to \pi^-e^+\nu_e$
$\pi^-\pi^+$	DP,PNGB,HP	$K^0_L \to \pi^-\mu^+\nu_\mu$, $K^0_L \to \pi^-e^+\nu_e$ $K^0_L \to \pi^-\pi^+\pi^0$, $K^0_L \to \pi^-\pi^+$

RDM – random dimuon, HNL – Heavy Neutral Lepton, NEU – neutrolino, HP - Higgs Portal, DP – Dark Photon...

BDF/SHiP @ ECN3

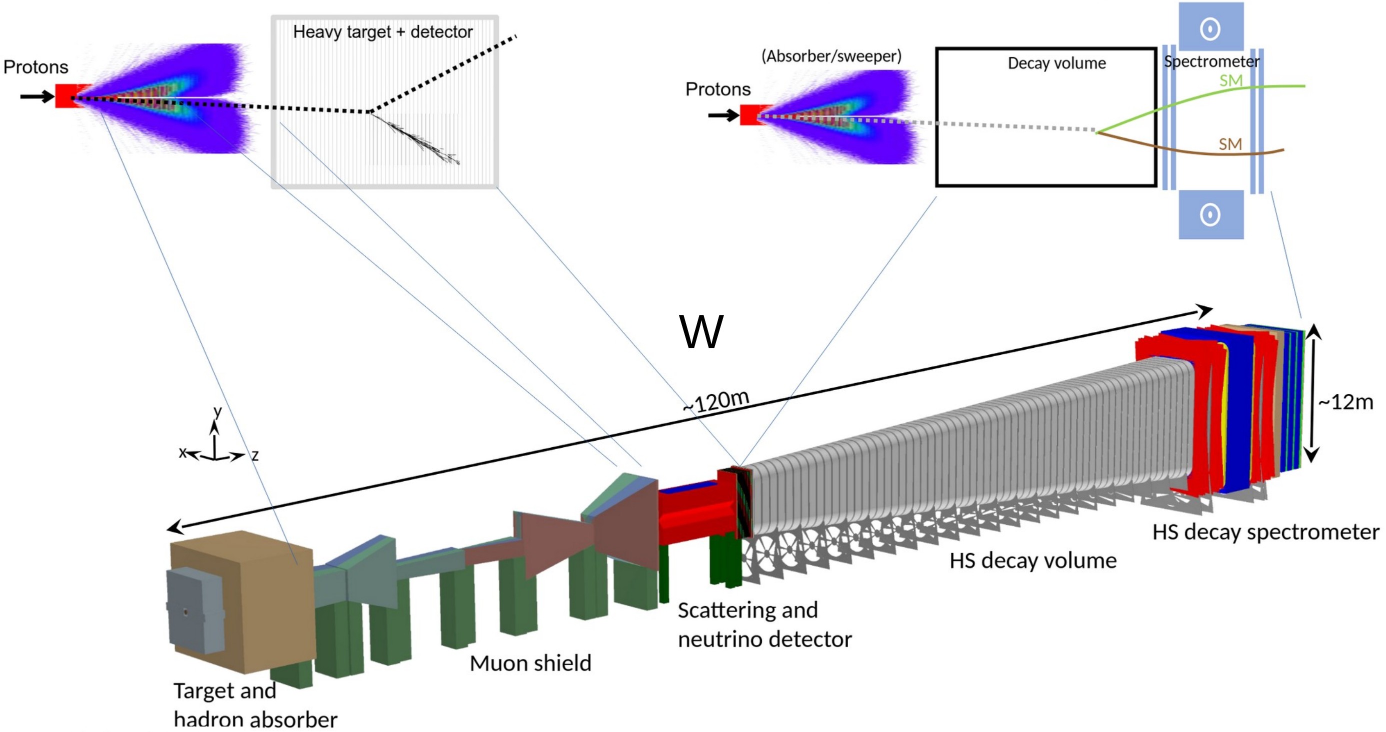
Heiko Lacker
HU Berlin

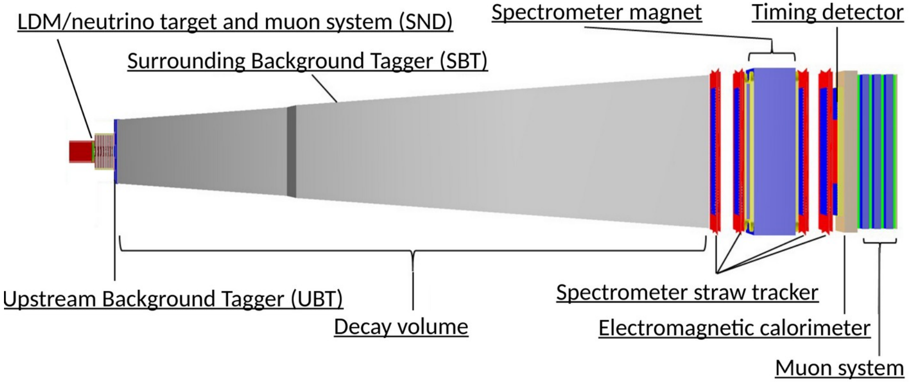
SHiP
Search for Hidden Particles

Physics Beyond Colliders workshop
Nov 07, 2022

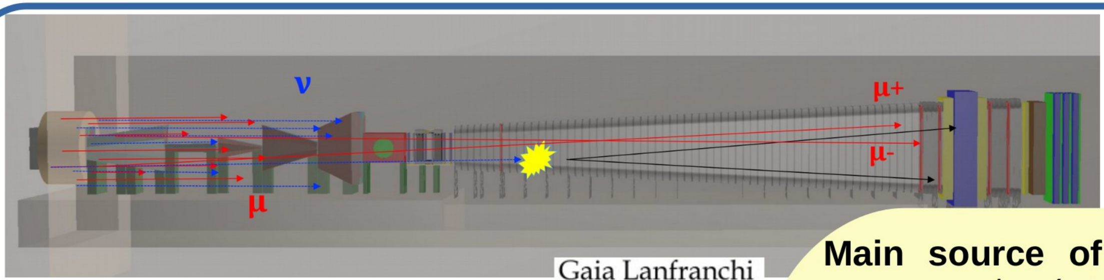
Scattering off atomic electrons (and nuclei)

Decay to SM particles





SHiP background conditions



Gaia Lanfranchi
LNF-INFN
Journèe SHiP – Physics du secteur cachè - Paris - Octobre 2017

Background reduction with

- Heavy target (11 λ) wrt 40 cm Be
- h-absorber + active muon shield
- Veto taggers
  - Liquid / plastic scintillators of the vacuum vessel walls (SBT)
  - Upstream veto before the vessel entrance (UVT)
  - Tracking veto just after the vessel entrance (SVT)
- Timing detector

Main source of SST occupancies - low energy e+/e- (~10^7/spill, under study) – veto, tracking,..

Most problematic physics background - neutrino-induced BG – from the inelastic scattering after the upstream veto: ~ 10^{11} ν/spill

Main source of such BG – vessels walls even for 10^{-3} mbar vacuum

Escaped/cosmics muons O(10^4 μ/spill) are source of

- products of inelastic scattering

- combinatorial BG

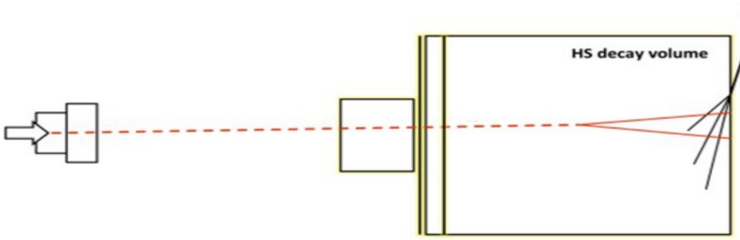
Veto (UVT, SVT, SBT) and timing detectors should significantly reduce BG; even more reduction will come from event reconstruction

Pythia/Geant simulation with complete description of detector and infrastructure

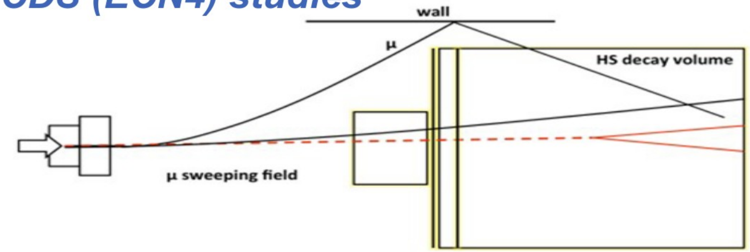
- ✓ *(10^{11}) muons (>1 GeV/c) per spill of $4x10^{13}$ protons on target (pots)*
- ✓ *4.5×10^{18} neutrinos and $3x10^{18}$ anti-neutrinos in acceptance in 2×10^{20} pots*

Backgrounds in decay search (fully reconstructable/partially with neutrinos) in pots/5 years

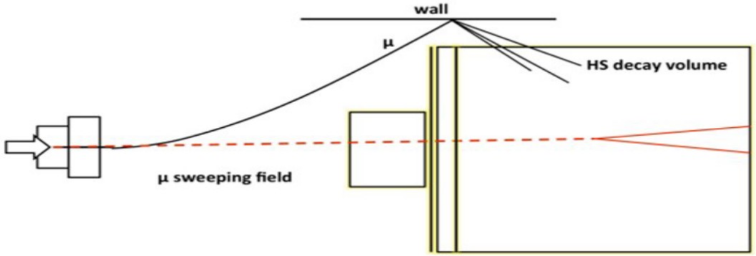
Reminder of CDS (ECN4) studies



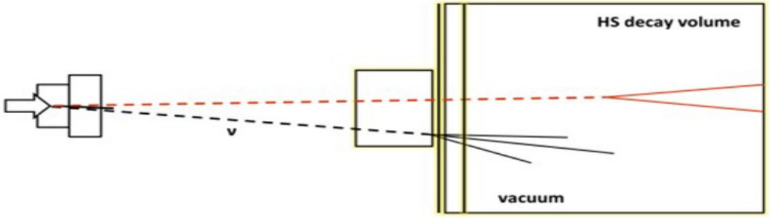
Cosmics: negligible



Muon combinatorial: (1.2 +- 1.2) x 10^{-2}



Muon DIS: 6 x 10^{-4}



Neutrino DIS: <0.1 (fully) / <0.3 (partial)

Comparable for ECN3

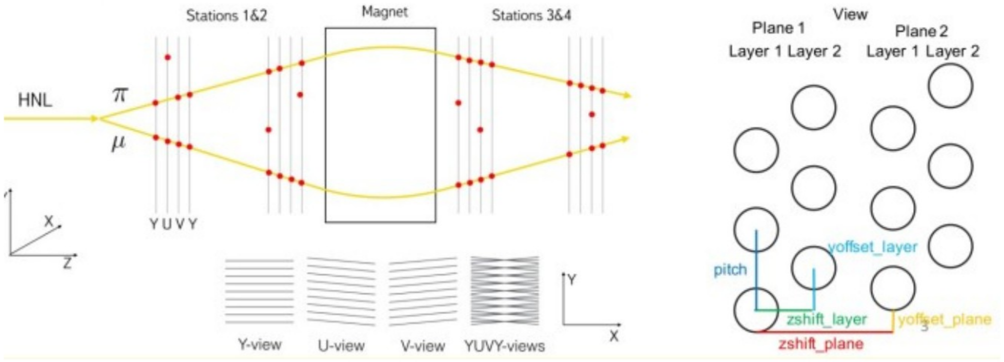
SST requirements

- HNL production and its μπ decay is a key detector optimisation process, but not the only process of interest
- We expect **few (or no)** signal events on top of a few BG events for 5 years of running => **we need 100% track detection efficiency** to reconstruct final states
- Even though veto detectors allow to reject most of the BG, the rest needs **to be identified offline using SST information**

- **Important cuts (BG rejection)**:
  - Vertex quality
  - Fiducial volume cut = f(vertex position)
  - Impact parameter on the target

    =f(track P, spacial. resolution)
- **Important quantity (signal reconstruction):**
  - Minv = f(track momentum)

SHiP Spectrometer Straw Tracker (SST)

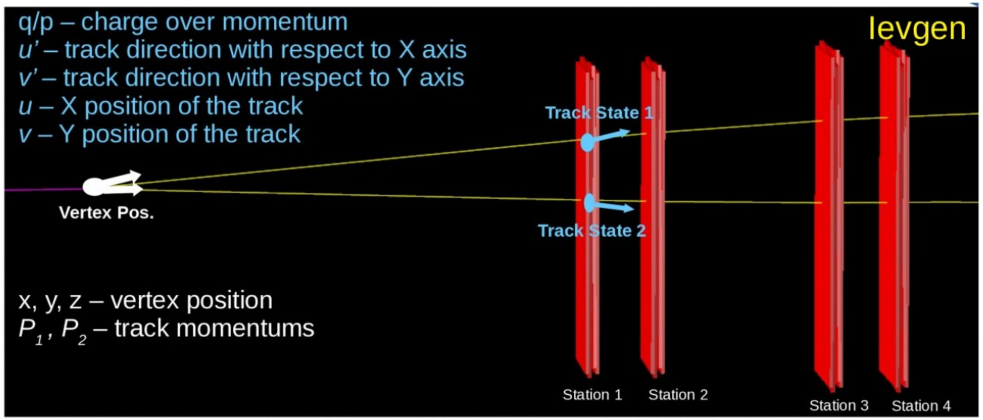


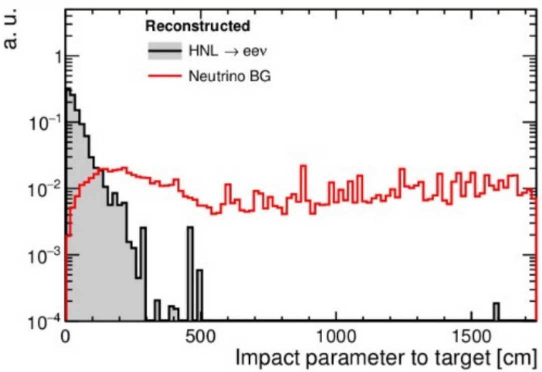
- Ultra light straw stations operating in vacuum: 4 YUVY stations = ~20k straws
- Acceptance 5x10m^2 (=>4x10m^2)
- Straws of 20mm diameter, 30um diameter gold-plated tungsten wire
- Spacial resolution better than 120 um

Z – not in scale – vertex in tens meters from the SST

input

output



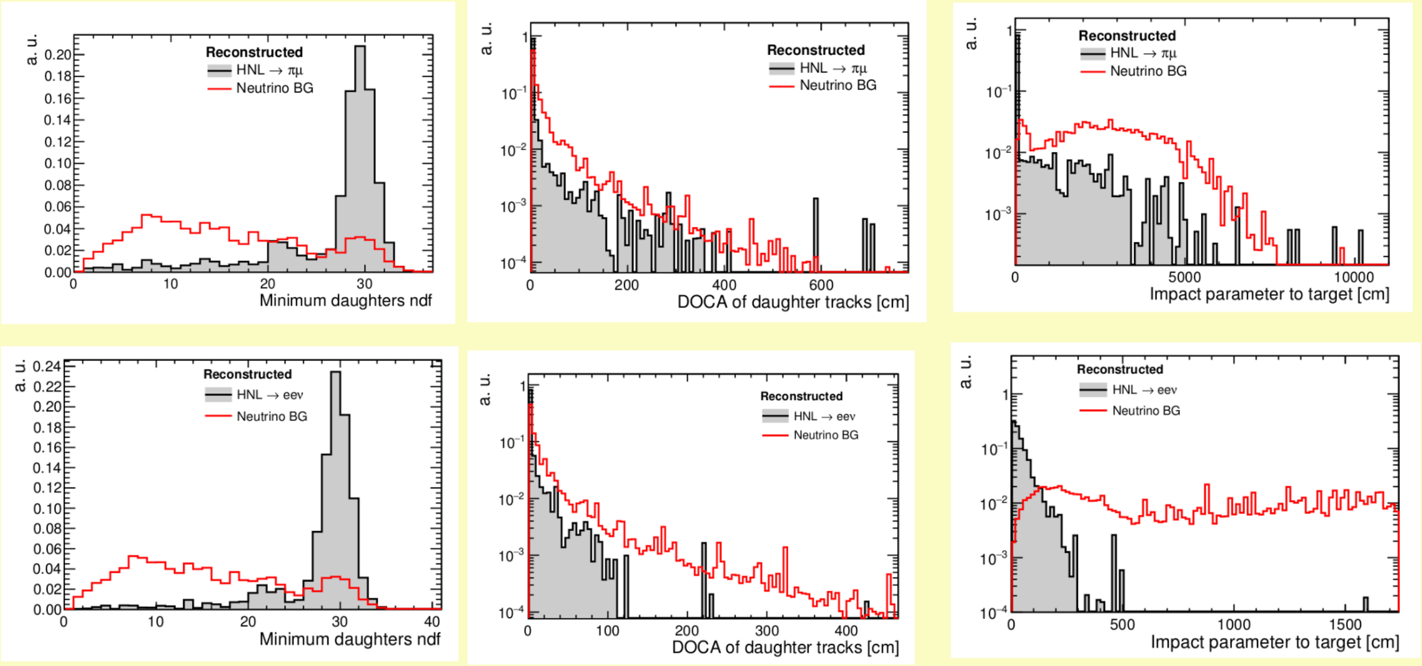


Tracking/vertexing parameters DOCA, IP, NDF and Chi2/NDF are powerful variables to distinguish BG and signal

SST for BG reduction

Ref https://cds.cern.ch/record/2214085/files/ship-note-hnls.pdf

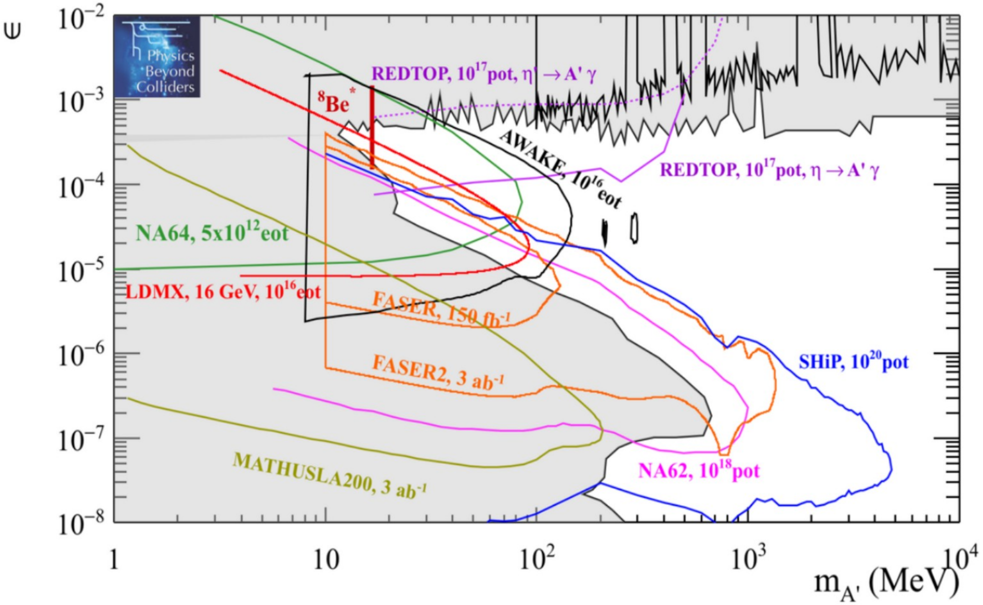
TP geometry



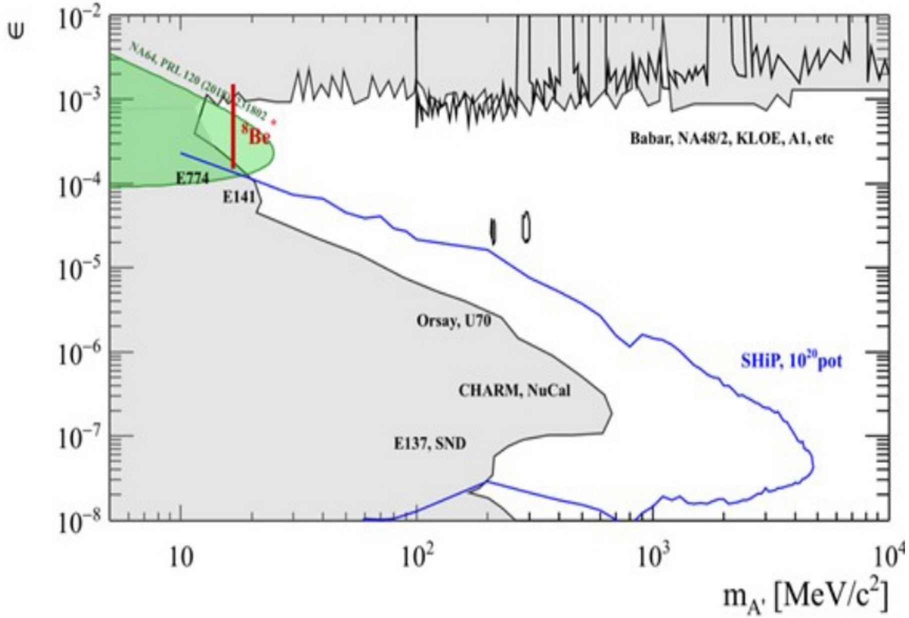
Here only some of cuts are illustrated

DOCA, IP, NDF and Chi2/NDF are powerful variables to distinguish BG and signal

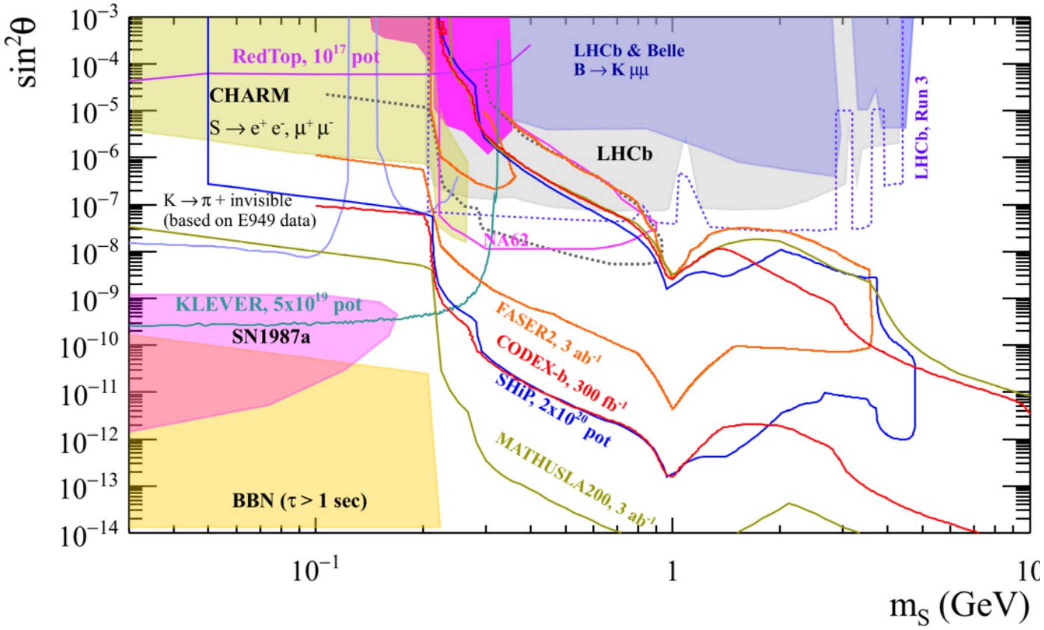
dark photon



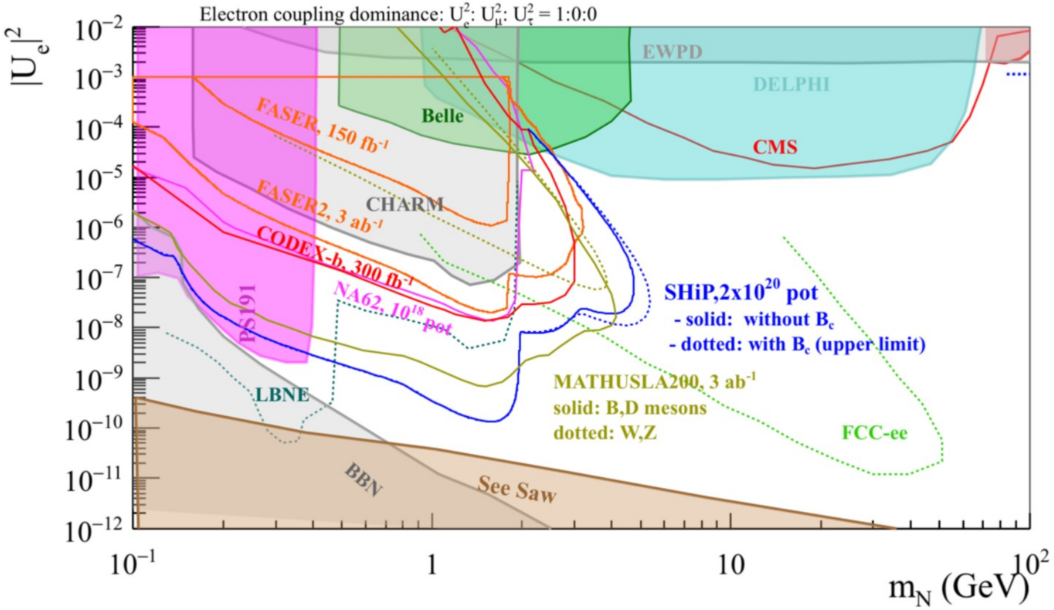
UPD: ECN3



dark scalar



HNL



UPD2022: SHiP sensitivity ECN3 are comparable

waiting for the decision...