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SHiP
Search for Hidden Particles

Search for new physics with the SHiP experiment at CERN

Ia. Bezshyiko
on behalf of the SHiP collaboration

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Outline

- ❏ What pushes us to construct any new experiments?
  What is our physics motivation.
- ❏ Why the SHiP experiment is the one who can help us to find a new physics?
- ❏ The challenges for SHiP & how we are going to handle with them.
- ❏ Background and Sensitivities studies to different physics cases.
- ❏ Where are we now?

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Physics motivation

What do we have now?

4 July 2012 → ATLAS and CMS see new particle with a mass of 125 GeV

☑ The Standard Model seems to be consistent and may work successfully up to the Planck scale!

*T. Asaka and M. Shaposhnikov *The nuMSM, dark matter and baryon asymmetry of the universe*, Phys. Lett. **B620**:17-26 (2005)

Is there something what cannot be described by it?

Experimental evidence which are not explained!

- ❑ Neutrino oscillations
- ❑ Dark matter
- ❑ Baryon asymmetry
- ❑ Flavour anomalies

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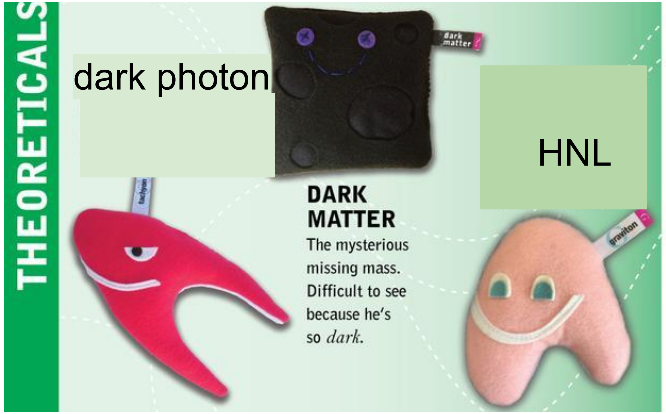
Where to look?

What can we know about these particles?

- Their decay rates must be strongly suppressed compared to Standard Model.
- New particles must be long-lived objects.
- They should interact weakly with a matter



Models	*Final states*
HNL, SUSY neutralino	$l^+\pi^-$, l^+K^-, $l^+\rho^-$ $\rho^+\rightarrow\pi^+\pi^0$
Vector, scalar, axion portals, SUSY sgoldstino	l^+l^-
HNL, SUSY neutralino, axino	$l^+l^-\nu$
Axion portal, SUSY sgoldstino	$\gamma\gamma$
SUSY sgoldstino	$\pi^0\pi^0$

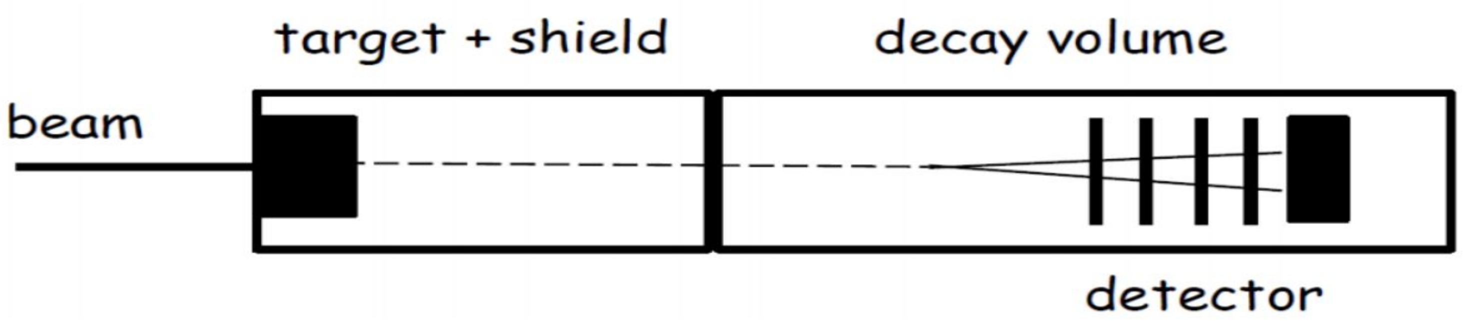
How can we find them?

Hidden Sector particles can be explored by coupling to SM particles: Vector Portal, Scalar Portal, Neutrino Portal, ALPs, etc. …

Where to look?

What requirements does it put on us experimentally?

- In particular, high rates of Heavy Flavour Decays
  - High intensity beam
  - Heavy target
- Minimize the flux of SM particles in the detector
  - Hadrons
    - Heavy target
    - Iron stopper to absorb hadrons
  - Muons
    - Muon sweeper



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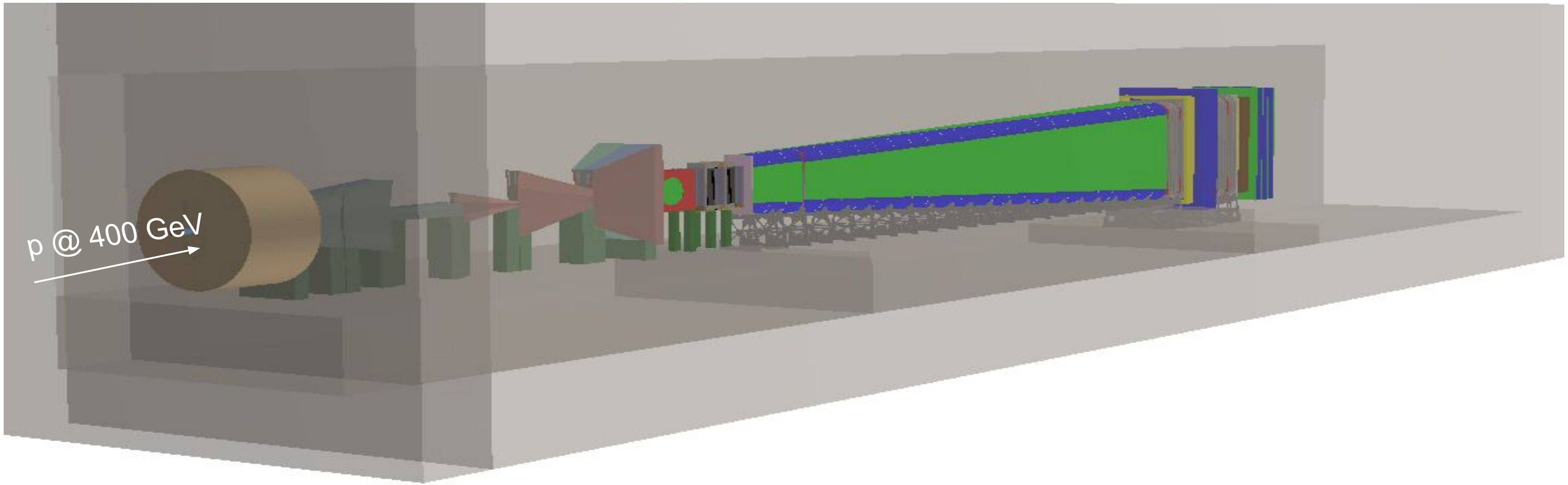
Search for Hidden Particles



SHiP is a proposed intensity-frontier experiment aiming to search for neutral hidden particles with mass up to O(10) GeV and weak couplings, down to 10^{-10} .

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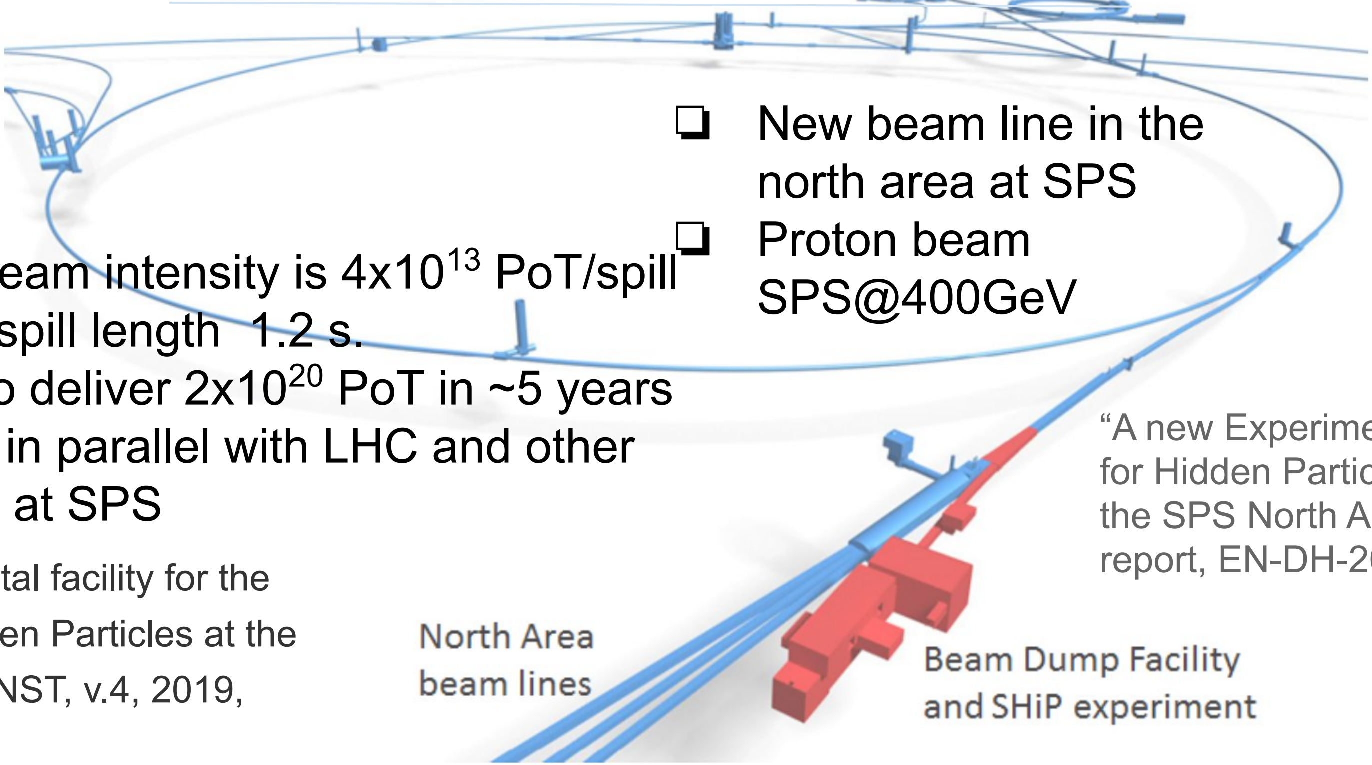
Search for Hidden Particles

- ❑ New beam line in the north area at SPS
- ❑ Proton beam SPS@400GeV

- ❑ Nominal beam intensity is $4x10^{13}$ PoT/spill
- ❑ Expected spill length 1.2 s.
- ❑ Possible to deliver $2x10^{20}$ PoT in ~5 years
- ❑ Operation in parallel with LHC and other beamlines at SPS



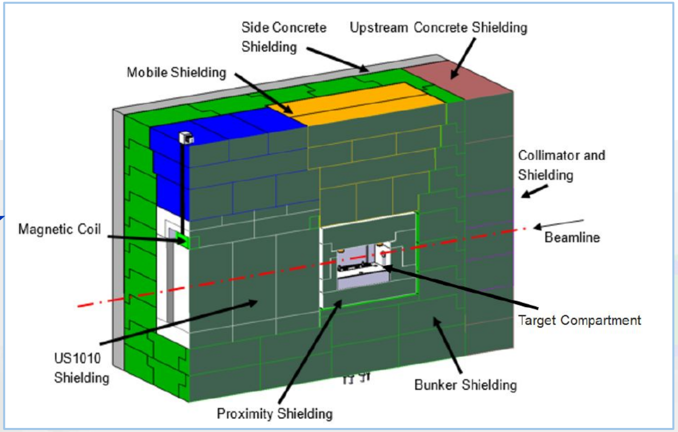
"The experimental facility for the Search for Hidden Particles at the CERN SPS", JINST, v.4, 2019, [arXiv:1504.04956]

"A new Experiment to Search for Hidden Particles (SHIP) at the SPS North Area", BDF report, EN-DH-2014-007

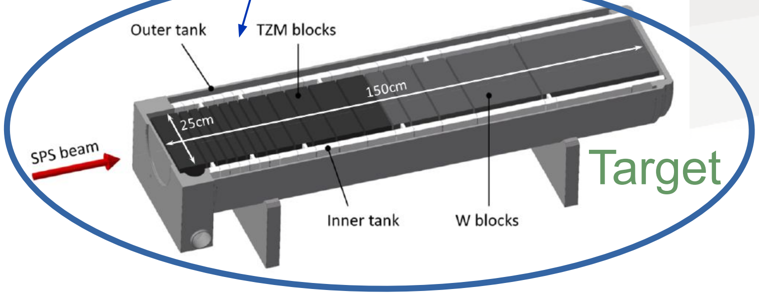
Target and absorbing systems

Hadron Absorber

p @ 400 GeV



To stop all secondary mesons which were produced in the target



Target

Maximise charm hadrons production and to absorb all SM decay products ($N_{D\ mesons/5\_years} > 10^{18}$, $N_{B\ mesons/5\_years} > 10^{14}$)

→ heavy material thick target

→ titanium-zirconium-molybdenum (TZM) alloy followed by tungsten, and water cooled;

Muon Shielding

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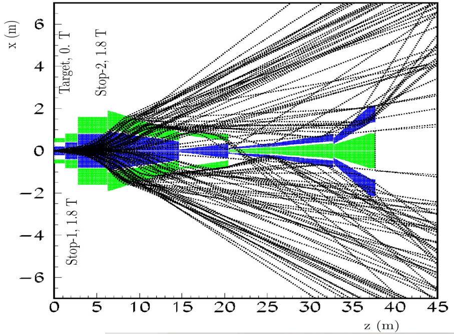
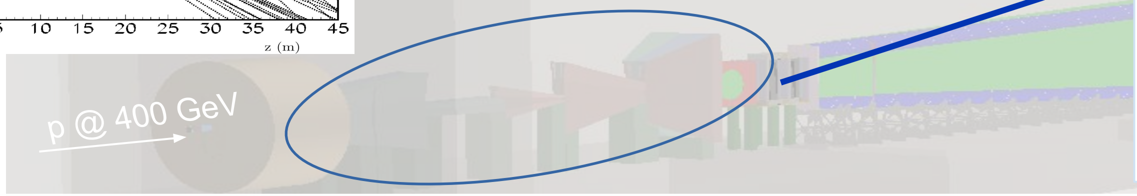
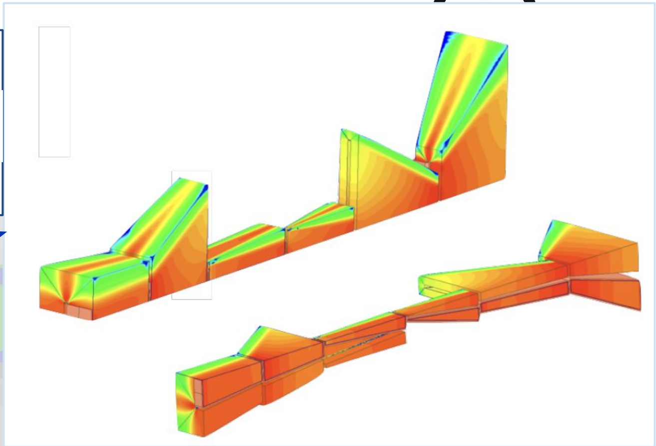
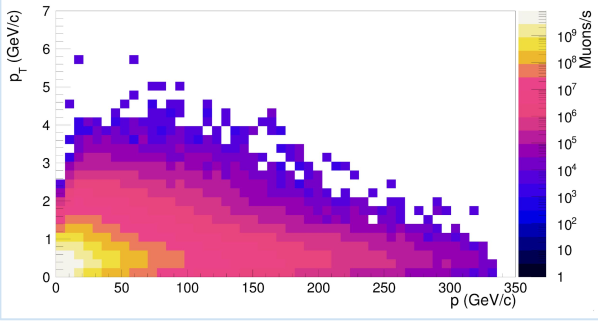


Expected number of muons:
Without shielding $\rightarrow 10^{11}$ muons/s
With shielding $\rightarrow 10^{5}$ muons/s

Muon Shield

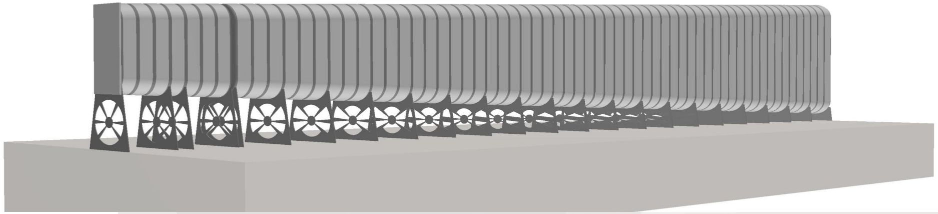




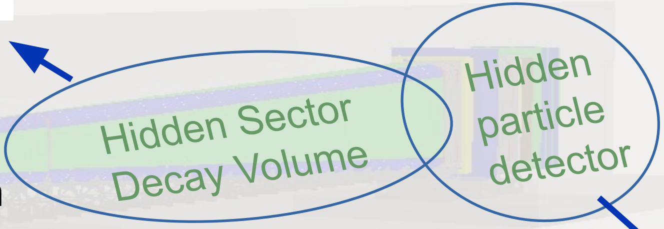


- ❑ Based on a deflection of muons away from the vicinity of the detector volume using magnetic system;
- ❑ Magnetised hadron absorber to separate muons immediately;
- ❑ Use of Grain-Oriented steel with 1.7T average field;
- ❑ Machine learning optimization for the most efficient muon shield configuration;

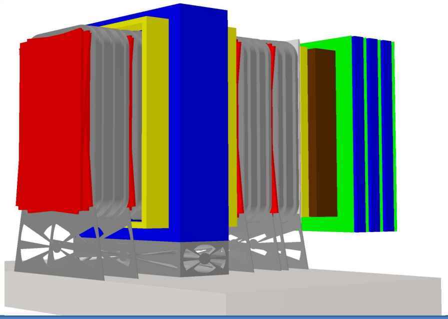
Decay spectrometer



- ❑ Vacuum decay vessel & based surrounding tagger
  → reduce the background from ν

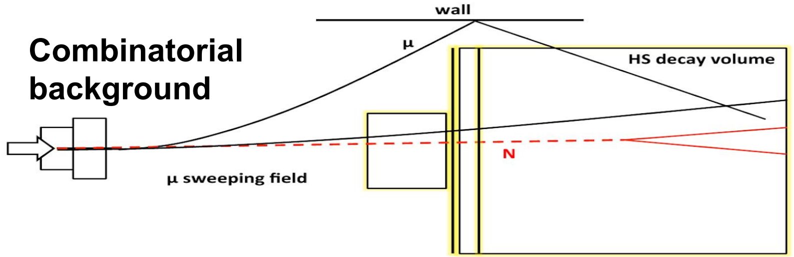


- ❑ Timing detector; <~80 ps resolution plastic scintillator bars; SiPMs/PMTs readout
  → suppress combinatorial background from muons;
- ❑ Muon detector of high efficiency
  → to separate signal muons from muon and neutrino induced background.
- ❑ Tracking stations; ultra-thin straw drift tubes oriented horizontally.
  → for vertexing and kinematics
- ❑ Longitudinally segmented ECAL
  → for particle identification and photons trajectory measurements.

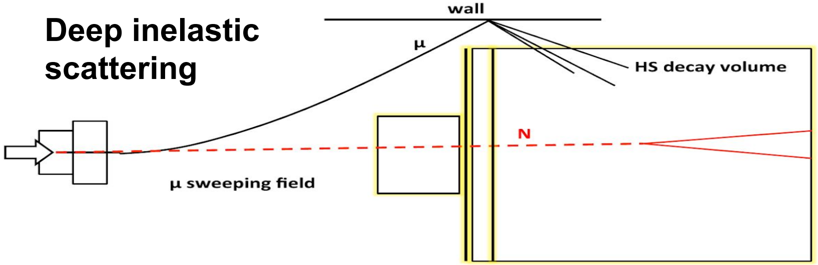


Backgrounds studies

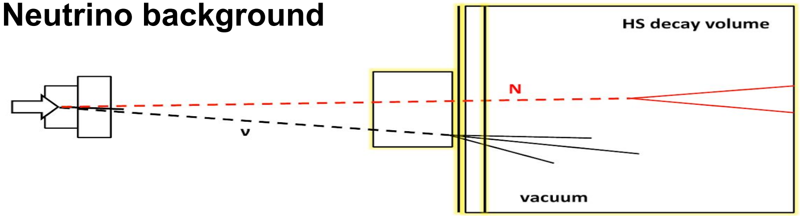
Combinatorial background



Deep inelastic scattering

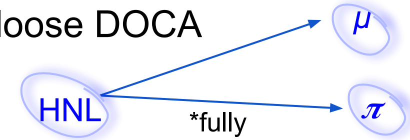


Neutrino background



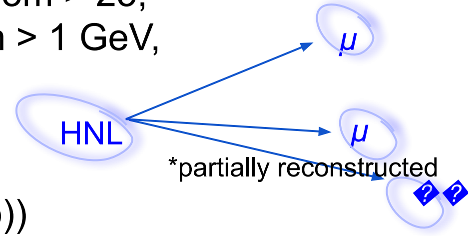
Acceptance

→ forming a vertex with a loose DOCA



Basic kinematic selection

→ Just one candidate
vertex is in the fiducial volume
tracks are reconstructed,
number of degrees of freedom > 25,
daughters track momentum > 1 GeV,
χ^2 /ndf < 5,
DOCA < 1.0 cm,
IP: < 10 cm(fully reco)
    < 250 cm (partially reco))
PID
no signal in the region of 5 cm next to a material

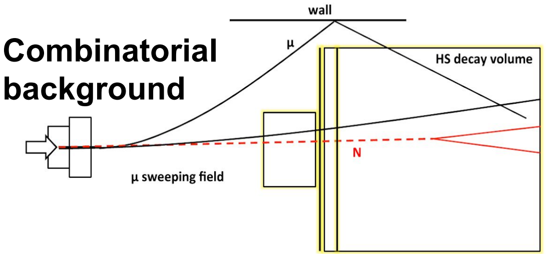


Basic selection keeps ~ 70% of signal

*at 90% CL

Backgrounds studies

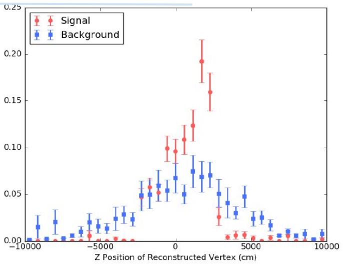
Combinatorial background

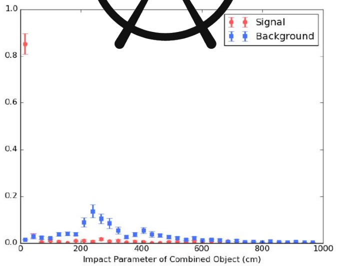


Acceptance → ~ 10^{16}

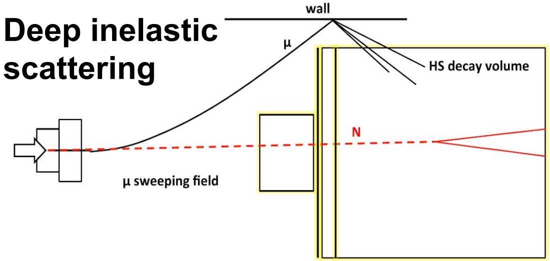
Kinematic selection → ~ 10^{9}

Timing → ~ 10^{-2}





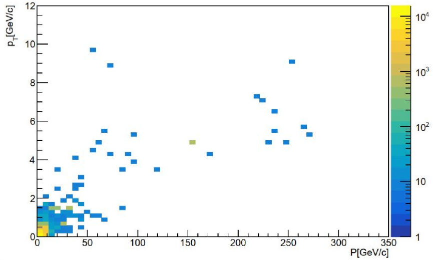
Deep inelastic scattering



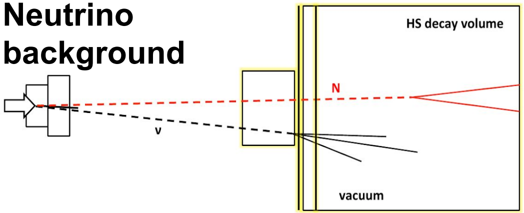
Acceptance → ~ 10^{6}

Kinematic selection → ~ 10^{2}

Assuming no correlation between VETO and selection → < $6 \cdot 10^{-4}$



Neutrino background

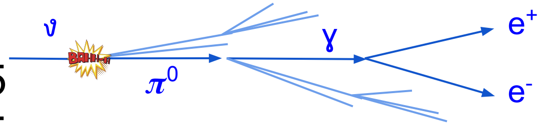


Acceptance → ~ $6 \cdot 10^{4}$

Kinematic selection → ~ 8

Decay opening angle → ~ 0.25

VETO around the vertex → ~ 0.05



*at 90% CL

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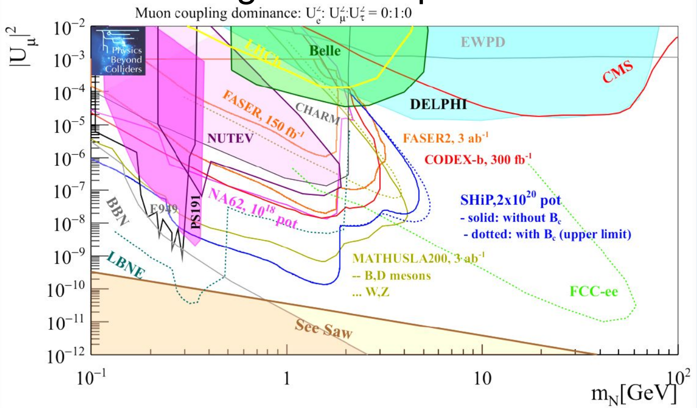
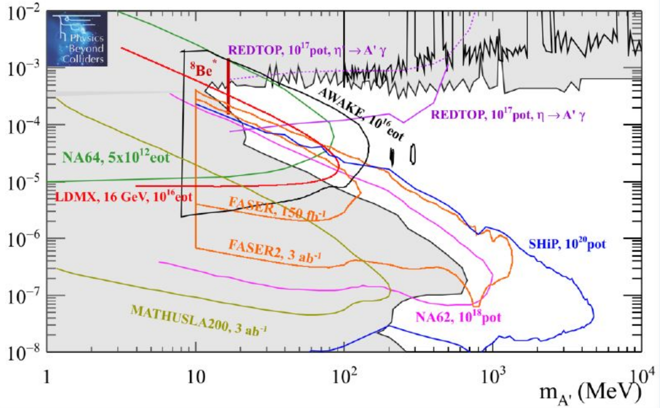
Signal sensitivities

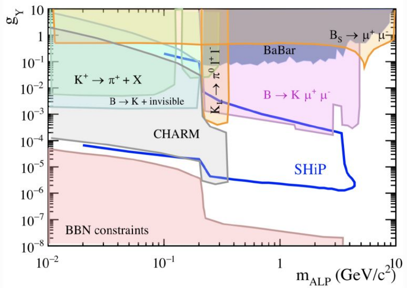
HNL, produced in heavy hadron decays, including cascade production

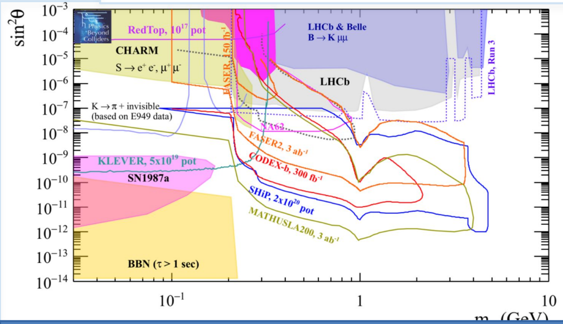


Dark Photons, produced in neutral mesons decays, proton bremsstrahlung, QCD annihilation

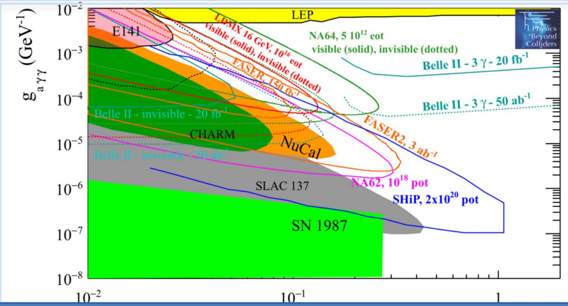


Axion-Like Particles, couples to fermions



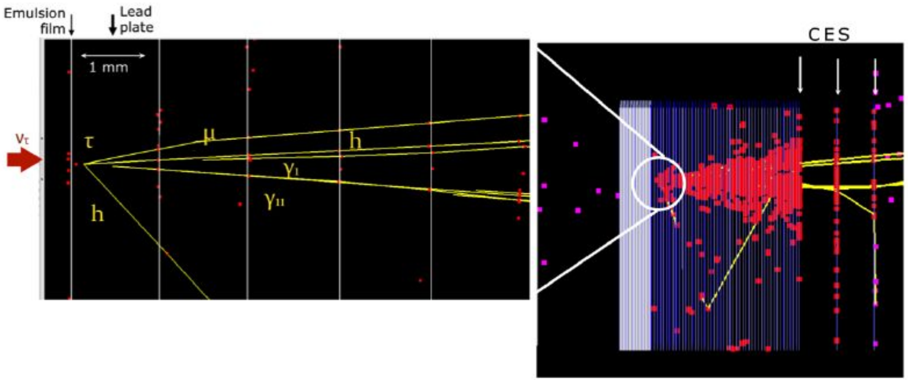


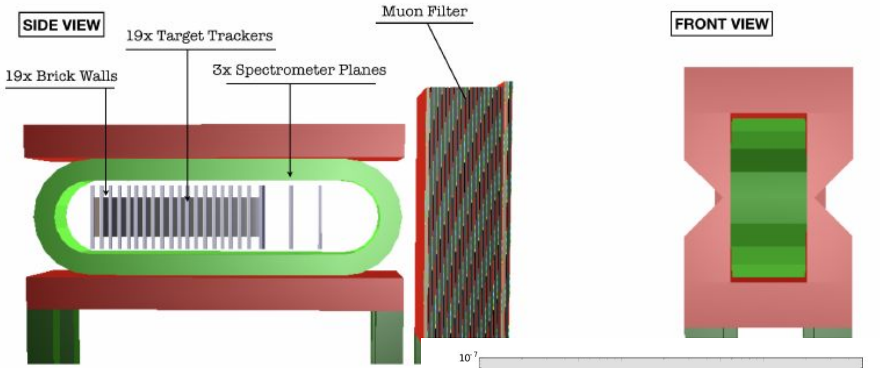
Dark Scalars, produced in B mesons decays

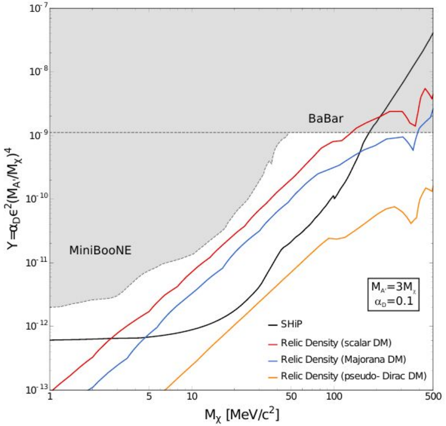


Axion-Like Particles, decaying to two gammas; dedicated ECAL

Scattering and Neutrino Detector





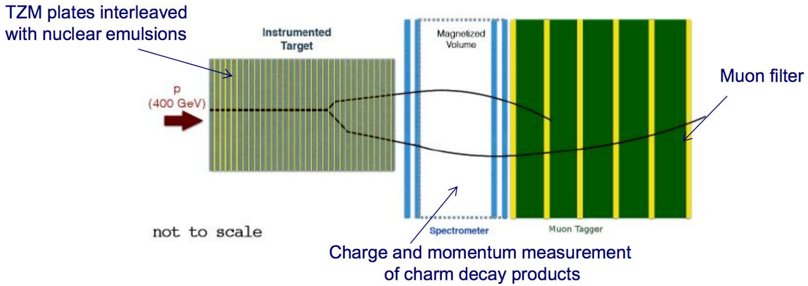


- ❑ Neutrino physics detection:
  - ❑ First observation of $\bar{\nu}_\tau$
  - ❑ Observation of $\bar{\nu}_\tau$ and ν_τ cross-sections
- ❑ Light Dark Matter detection
  - ❑ Detection of electromagnetic shower and reconstruction of origin by electronic target tracker

Simulation validation

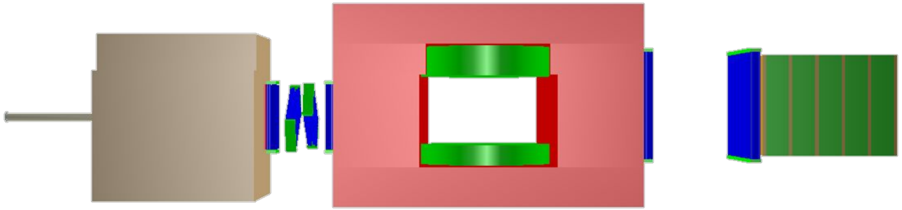
Expected number of produced hidden particles strongly depend on the charm number produced in the thick target (both, originated from the proton interaction and charm cascade).

→ Dedicated measurement with SHiP-like target at SPS July 2018: ~ 150 fully reconstructed charm -pairs



A reduction of the muon background is crucial for the experiment.
Monte Carlo spectrum must be validated with real data in the difficult phase-space corners

→ Testbeam starting in July 2018 at SPS H4 with 10^{11} POT and replica of SHiP target Mo/W



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Conclusions

- SHiP is the newly proposed experiment at SPS of CERN which will use intense beam 400GeV@SPS, heavy target, muon sweepers, Vacuum Vessel and series of vetos, Emulsion Spectrometer and HS spectrometer
- SHiP can improve present constraints for several models by orders of magnitudes, discover long living very weakly interaction non-SM particles.
- Redundant set of detectors to reduce background to zero.
- Test beams imminent to measure muon flux and charm cross-section.
- Project in is moving fast towards TDR