



SHiP

Direct Search for Hidden Particles at the CERN SPS

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LPNHE IN2P3/CNRS and UPMC Paris 6

On behalf of the SHiP Collaboration

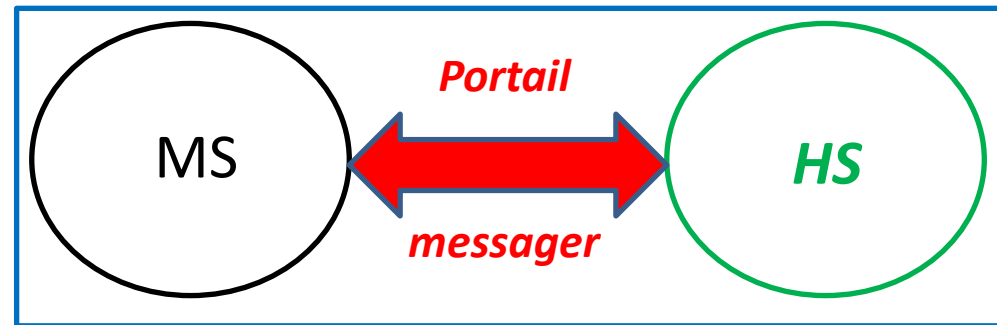
29th Rencontres de Blois May 28 – June 2, 2017

Outline

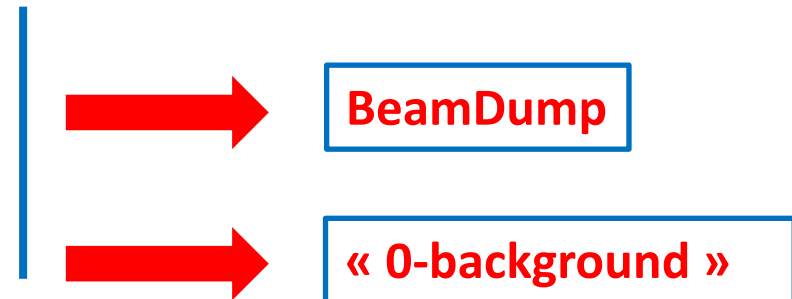
- Hidden sector portals
- SHiP: a proton beam dump experiment
- Experimental reach
- Optimization and current efforts
- SHiP in the GDR
- Outlook

Hidden Sector

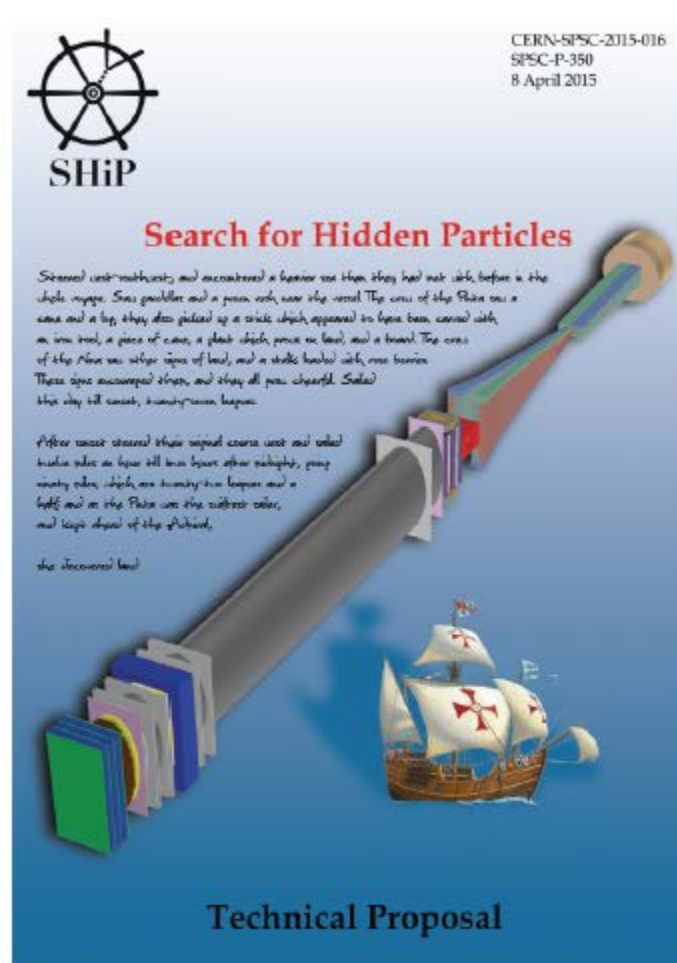
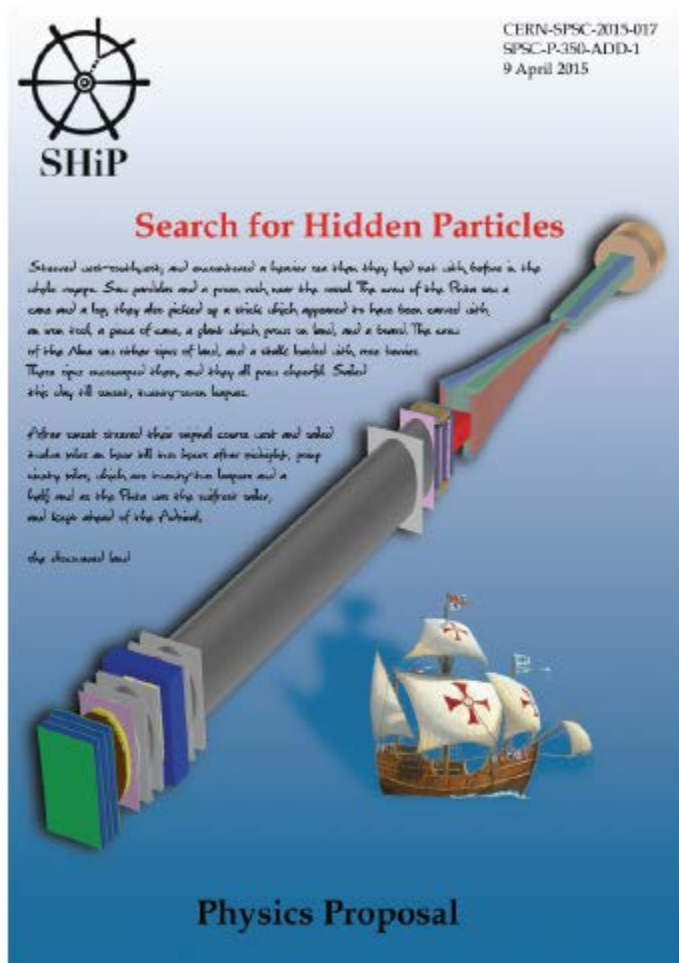
- A New Physics beyond the Standard Model must be there,
 - **At what scale ?**
- To discover it, look for the messengers (portals) of new interactions between the SM fields and the hidden fields.
- Possible portals:
 - Neutrino, Vector, Scalar, Axial.
- If the messengers are **light**, a **direct detection** is possible
 - Via **decay** or **scattering**.
- Very feeble interactions
 - A source with high intensity
 - They easily traverse matter
 - They are long-lived
 - Very rare events



SHiP Physics Paper: 1504.04855



SHiP a proton beam dump experiment

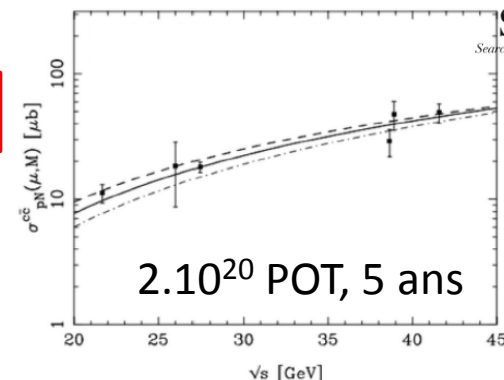


Requirements (Decay)

- Heavy flavor
- N with high P_T

$$P+A \rightarrow D \text{ or } B X, D \text{ or } B \rightarrow N l (X)$$

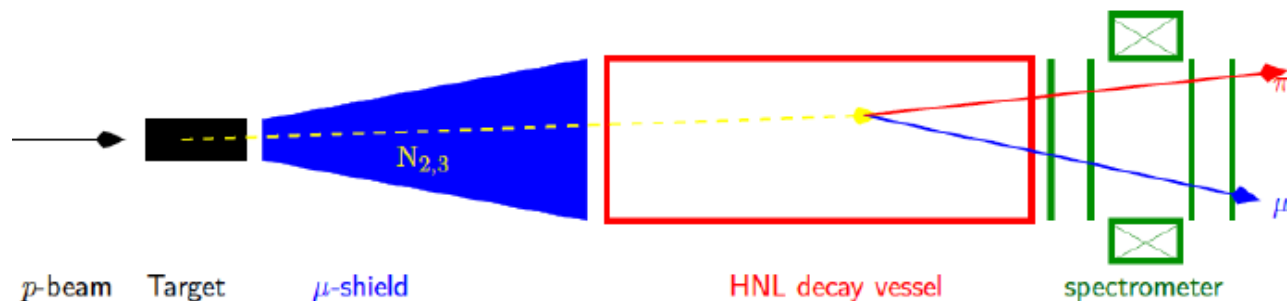
$$N \rightarrow 2/3\text{-body}$$



✓ *Decays:*

Models	Final states
Neutrino portal, SUSY neutralino	$\ell^\pm \pi^\mp, \ell^\pm K^\mp, \ell^\pm \rho^\mp, \rho^\pm \rightarrow \pi^\pm \pi^0$
Vector, scalar, axion portals, SUSY sgoldstino	$\ell^+ \ell^-$
Vector, scalar, axion portals, SUSY sgoldstino	$\pi^+ \pi^-, K^+ K^-$
Neutrino portal, SUSY neutralino, axino	$\ell^+ \ell^- \nu$
Axion portal, SUSY sgoldstino	$\gamma\gamma$
SUSY sgoldstino	$\pi^0 \pi^0$

- Decay vessel close to target
- Muon shield as short as possible





The SHiP experiment at SPS (as implemented in Geant4 for TP)

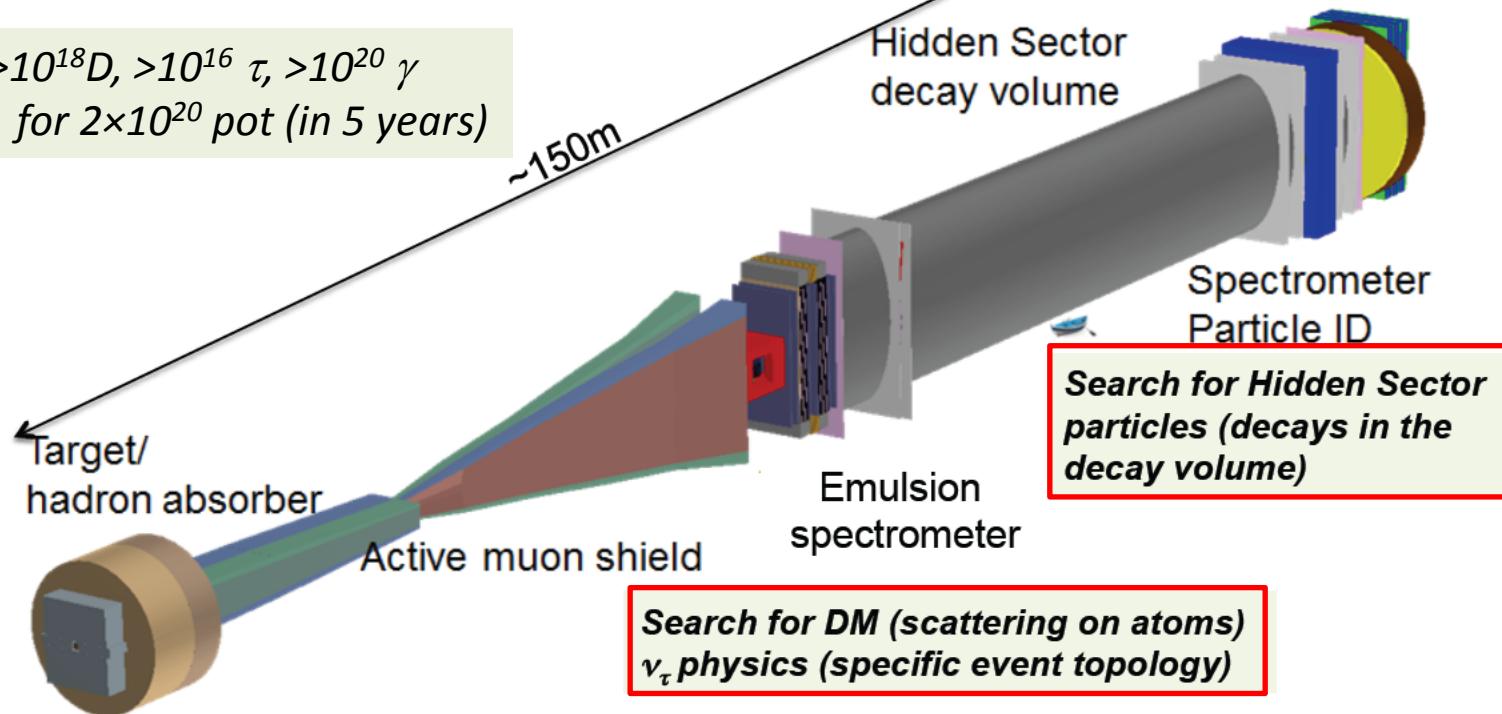
SHiP Technical Proposal:
1504.04956

“Zero background” experiment

- Muon shield
- Surrounding Veto detectors

- Dump
- Vacuum
- Timing, PID

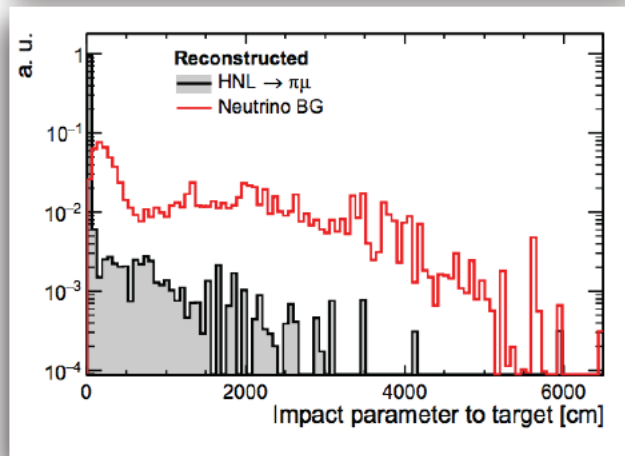
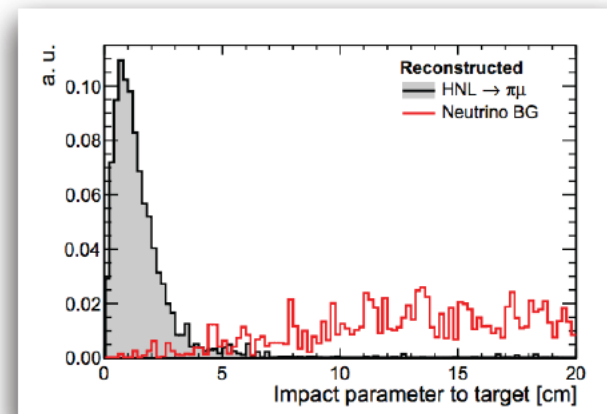
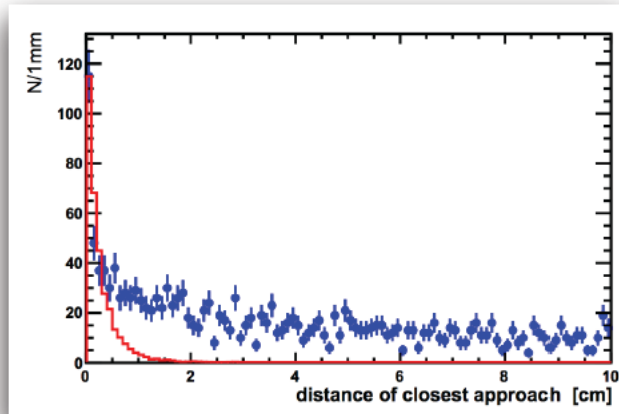
$>10^{18} D$, $>10^{16} \tau$, $>10^{20} \gamma$
for 2×10^{20} pot (in 5 years)



Beyond Collider Physics, CERN

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Kinematic Selection

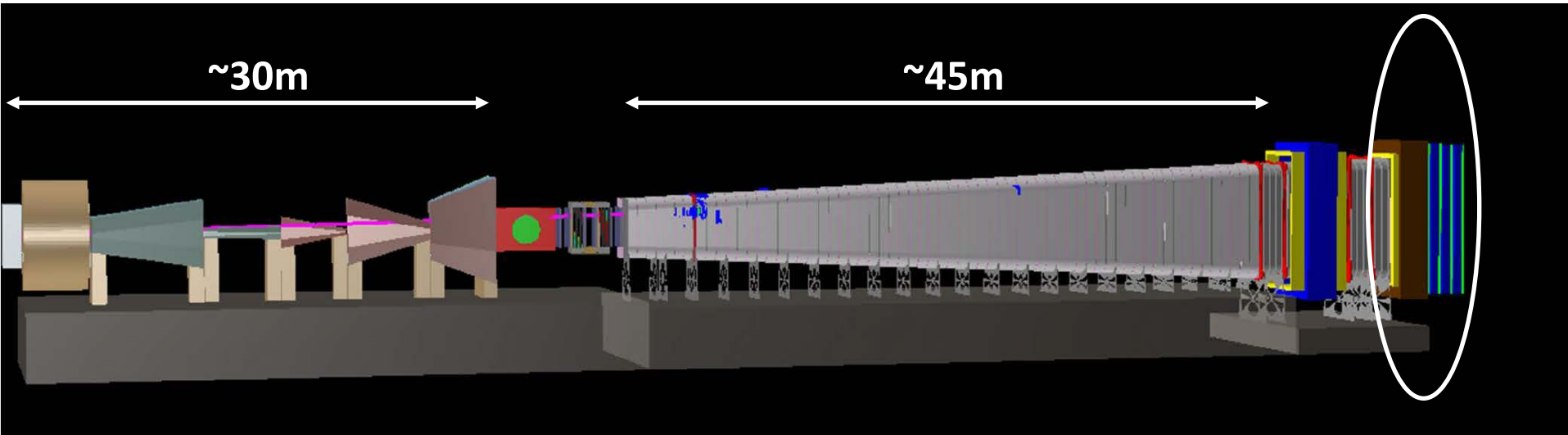


Very simple selection reduces the bkg to only a few in 5 years:

- Fiducial volume
- DOCA
- IP wrt target
- Vetos

Realistic to reach 0.1 expected bkg events for exclusive channels we have been studying so far

Detector reoptimization



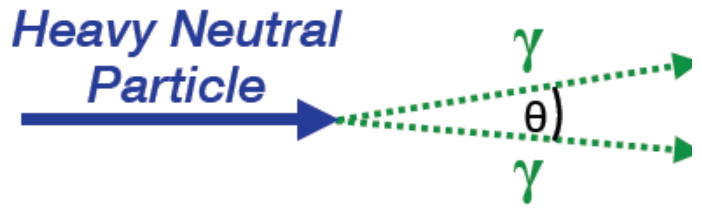
- Muon shield
 - The active muon shield in the SHiP experiment**
[arXiv:1703.03612v2](https://arxiv.org/abs/1703.03612v2) [physics.ins-det] 2017_JINST_12_P05011
- Pyramidal shape
- *PID, timing*
- Technology choices for the subdetectors

PID, timing

In the TP:

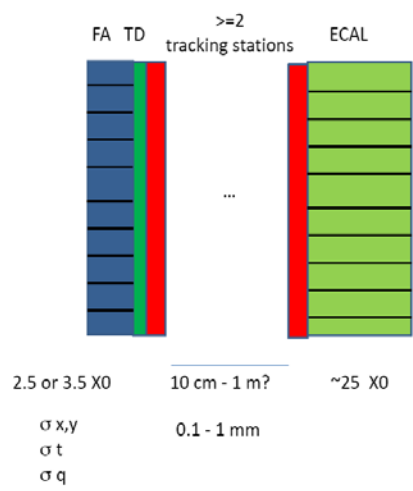
- Shashlik ECAL (+HCAL)
- Square cells (38.2 mm)².
- 22.5 X0
- $\frac{6.5\%}{\sqrt{E}} + 1\%$

But, what about:

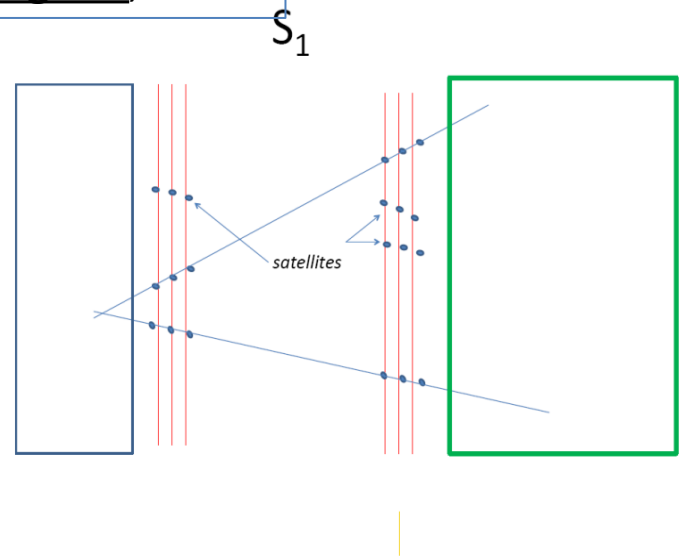


Conceptual studies in progress, like:

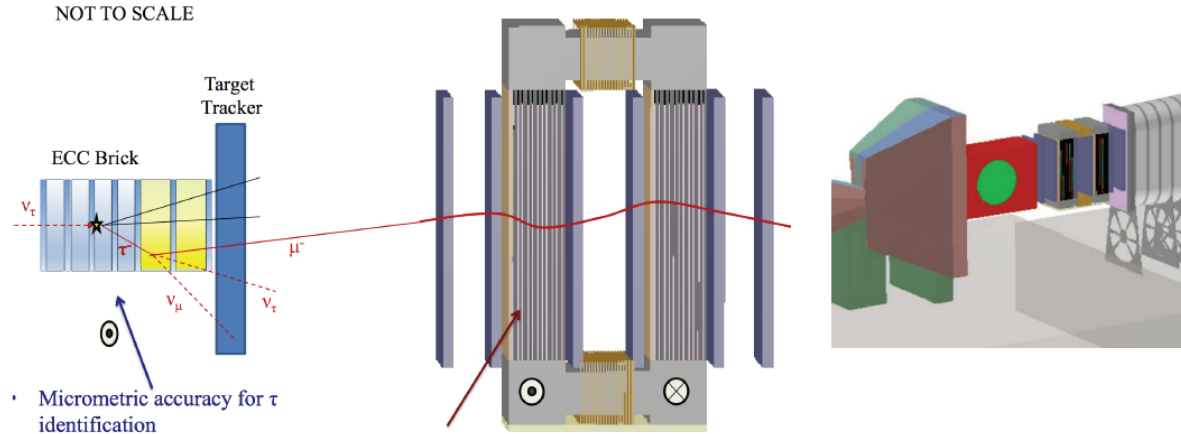
A possible setup with preshower (Feb 2017)



- Upstream point S_1 via tracking
 - Use 2 tracking stations
 - Reconstruct 3D track segments in each
 - Match them: form track candidates
 - Clean them/remove satellites using
 - energy of clusters,
 - angles
 - Vertex track candidates to determine position of the shower starting point S_1 .
- Downstream point S_2
 - Use z of the shower maximum inferred from energy
 - obtain (x,y) from the lateral shower profile
 - Which longitudinal segmentation if any?



The ν_τ Detector (Scattering)



TP

- Only 9 ν_τ events recorded to date
- $\bar{\nu}_\tau$ yet to be discovered
- $\nu_\tau / \bar{\nu}_\tau$ cross sections to be measured
- Charm physics with τ 's
- Proton structure functions
- Large ν_e flux to measure charm production

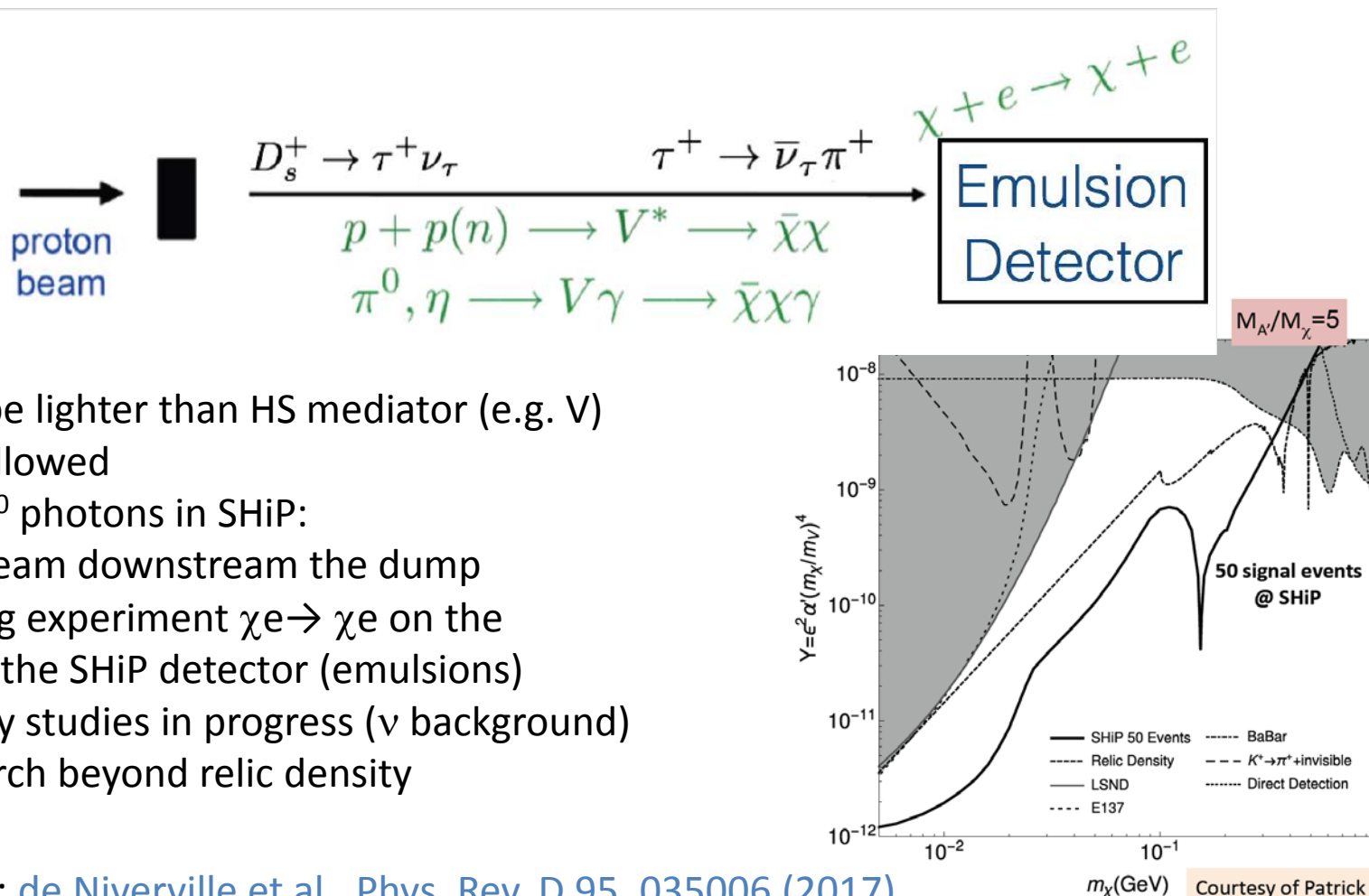
And also,

➤ Probe LFUV comparing ν_μ and ν_τ CC events ? *to be further studied.*

H. Liu, A. Rashed, A. Datta 1505.04594, Phys. Rev. D 92, 073016 (2015)

decay channel	ν_τ			$\bar{\nu}_\tau$		
	N^{exp}	N^{bg}	R	N^{exp}	N^{bg}	R
$\tau \rightarrow \mu$	570	30	19	290	140	2
$\tau \rightarrow h$	990	80	12	500	380	1.3
$\tau \rightarrow 3h$	210	30	7	110	140	0.8
total	1770	140	13	900	660	1.4

Accelerator-based direct (L)DM search



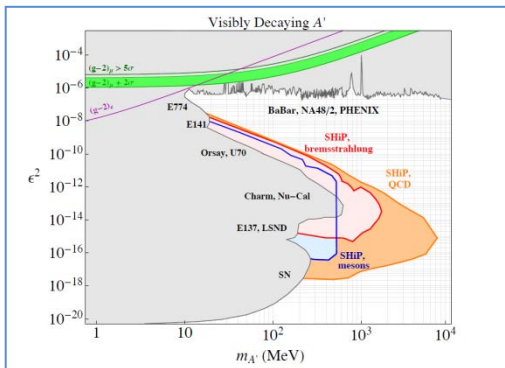
- χ could be lighter than HS mediator (e.g. V)
 - $V \rightarrow \chi\chi$ allowed
- With 10^{20} photons in SHiP:
 - A LDM beam downstream the dump
- Scattering experiment $\chi e \rightarrow \chi e$ on the atoms of the SHiP detector (emulsions)
- Feasibility studies in progress (ν background)
- LDM search beyond relic density

Pioneered in: [de Niverville et al., Phys. Rev. D 95, 035006 \(2017\)](#)

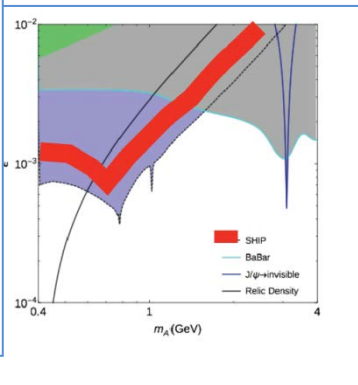
MiniBoonE: [arXiv:1702.02688v2](#) [hep-ex]

Physics proposal plots

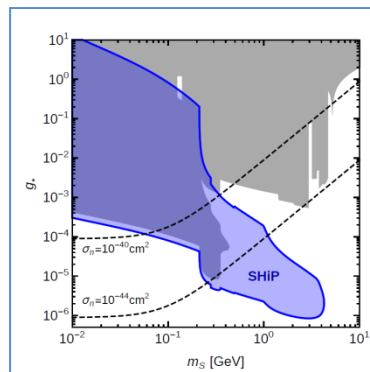
Dark photon



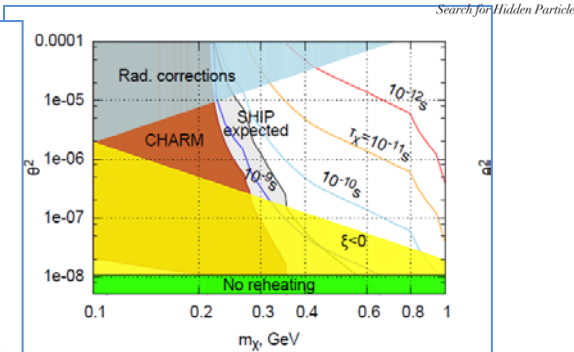
$A' \rightarrow \chi\chi$



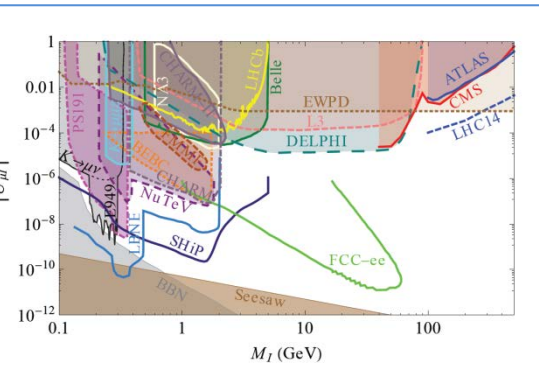
Scalar



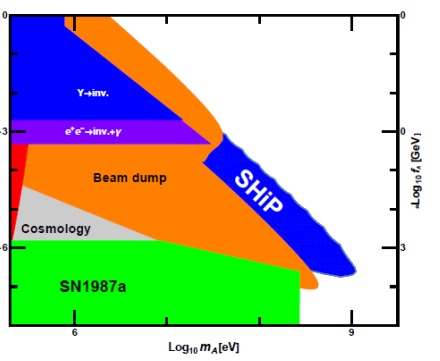
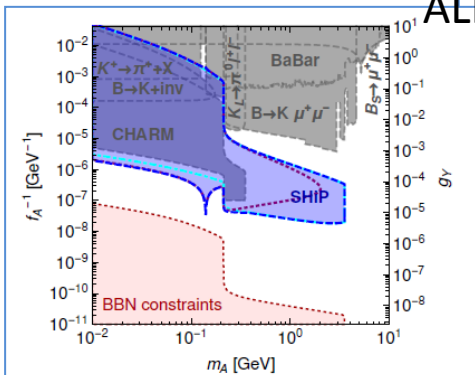
inflaton



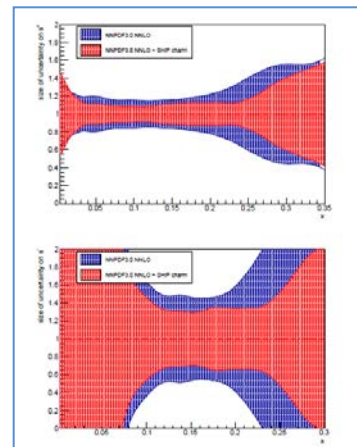
HNL



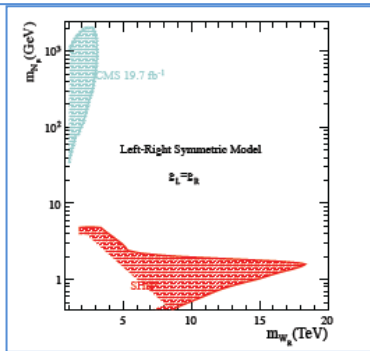
ALP



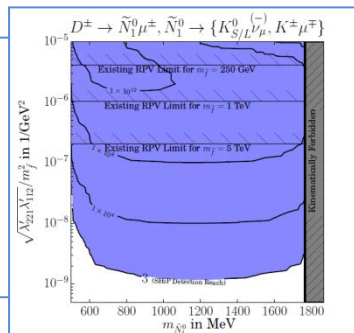
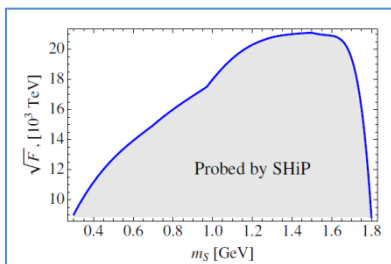
ν_τ DIS



L/R



SUSY



Physics proposal plots

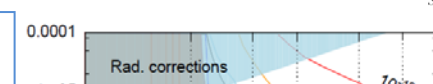
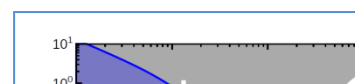
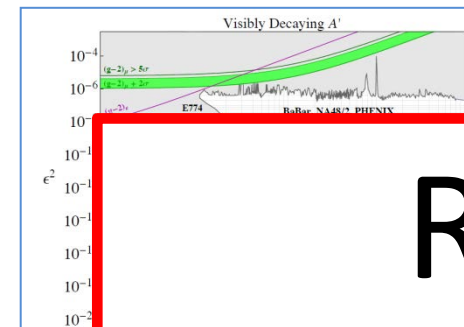
Dark photon

$A' \rightarrow \chi\chi$

Scalar

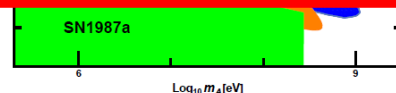
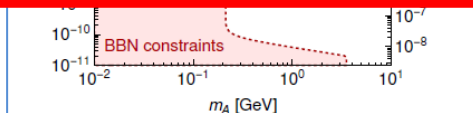
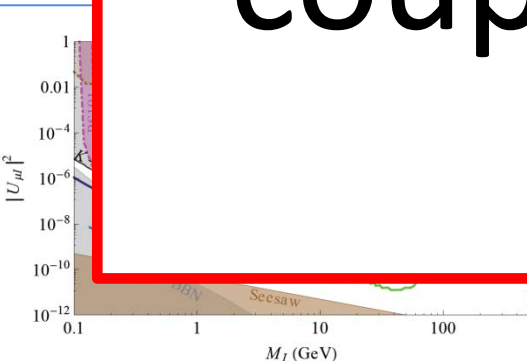
inflaton

Reach very small couplings in MeV-GeV mass range

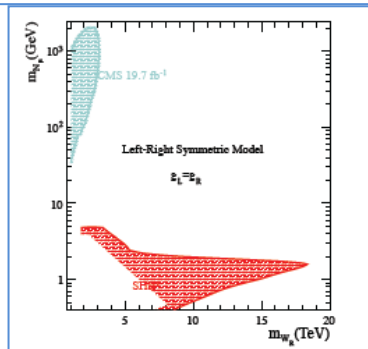


Search for Hidden Particles

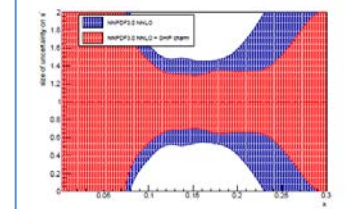
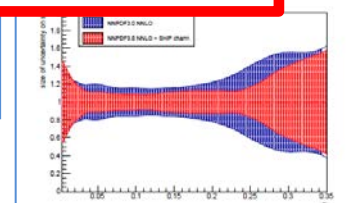
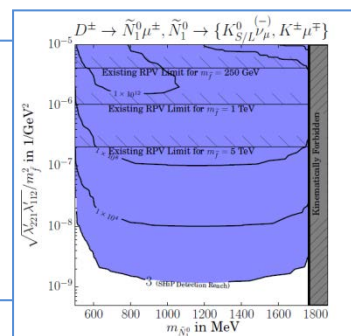
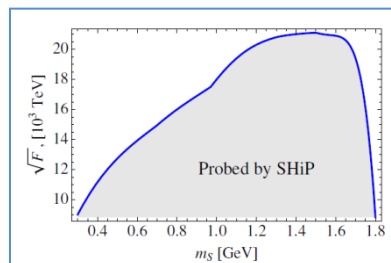
HNL



L/R



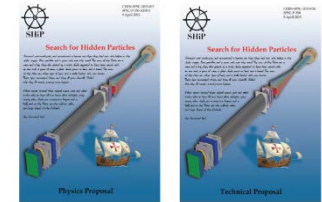
SUSY



SHiP path at CERN

Not yet approved, but a leading project for the future of CERN fixed target program

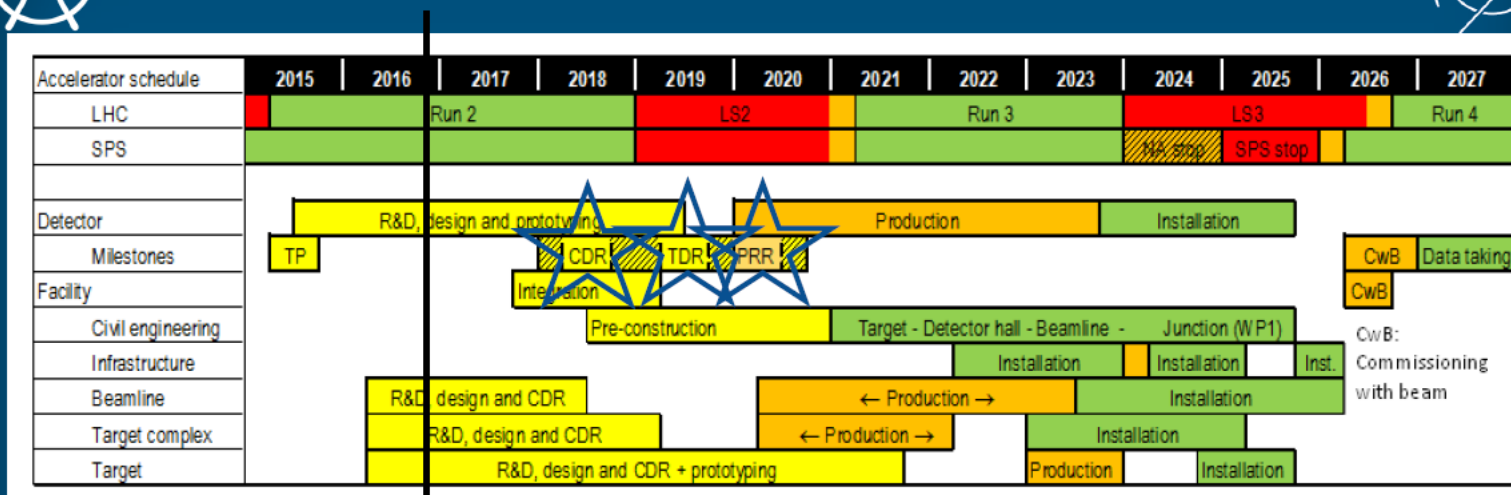
- 2013-2015
 - EOI, formation of the Collaboration, T&P proposals
- 2016 SPSC/RB/ decisions by CERN management
 - **SHiP in the 2017_2021 MTP,**
 - **PBC study group** (the 3rd of F. Gianotti's 3 pillars)
 - ~5 MCHF funding for **Beam Dump Facility feasibility study**
 - **CDS** (Comprehensive Design Study) report end 2018
 - Approval path in time with ESPP : **TDRs, Module-0's**
- ~ 5 years construction,
 - installation during LS3,
 - data while LHC Run4 (2027)



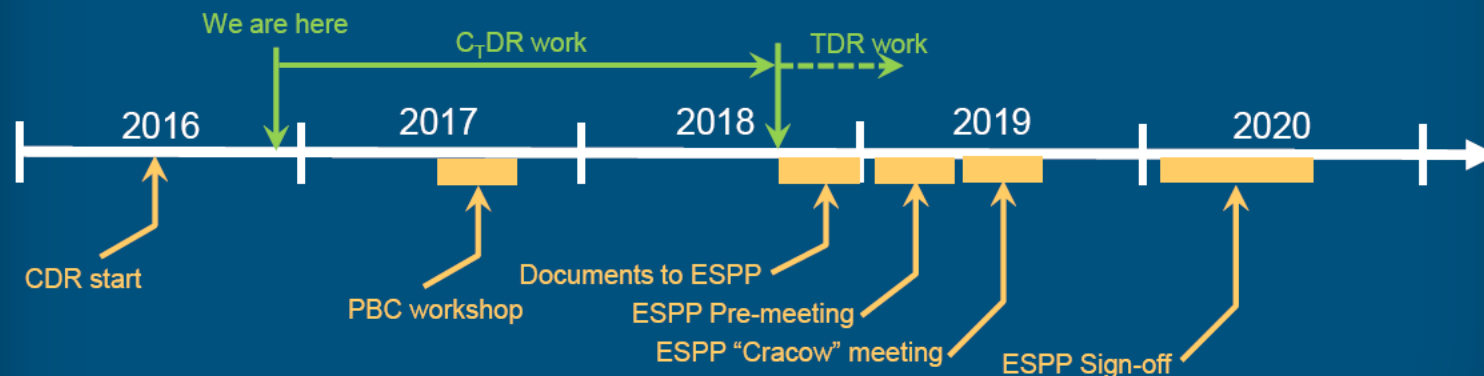
[SHiP](#) a recognized project in the greybook since 2016



Global schedule

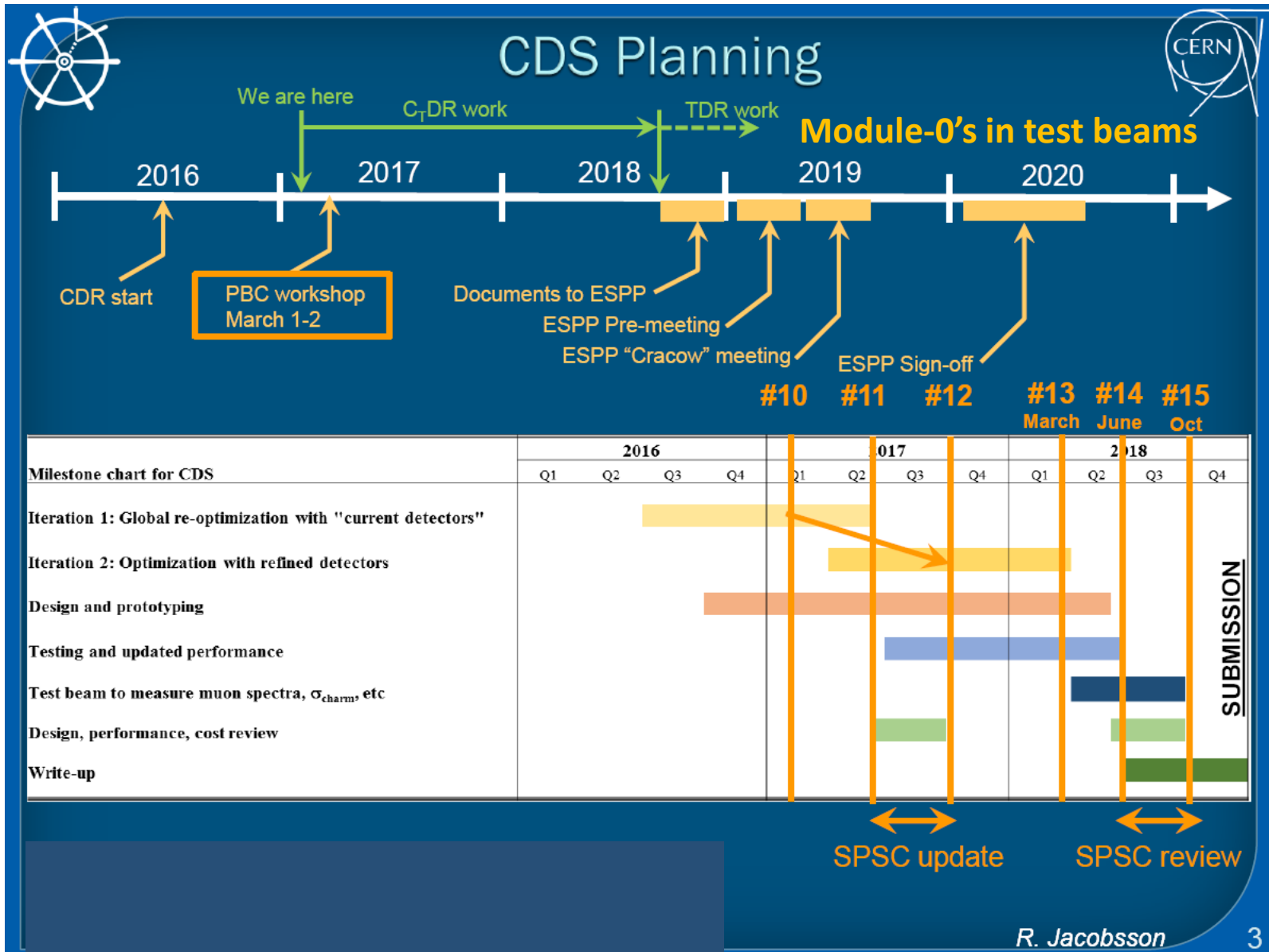


Reason for the “18-21 months to CDR”:



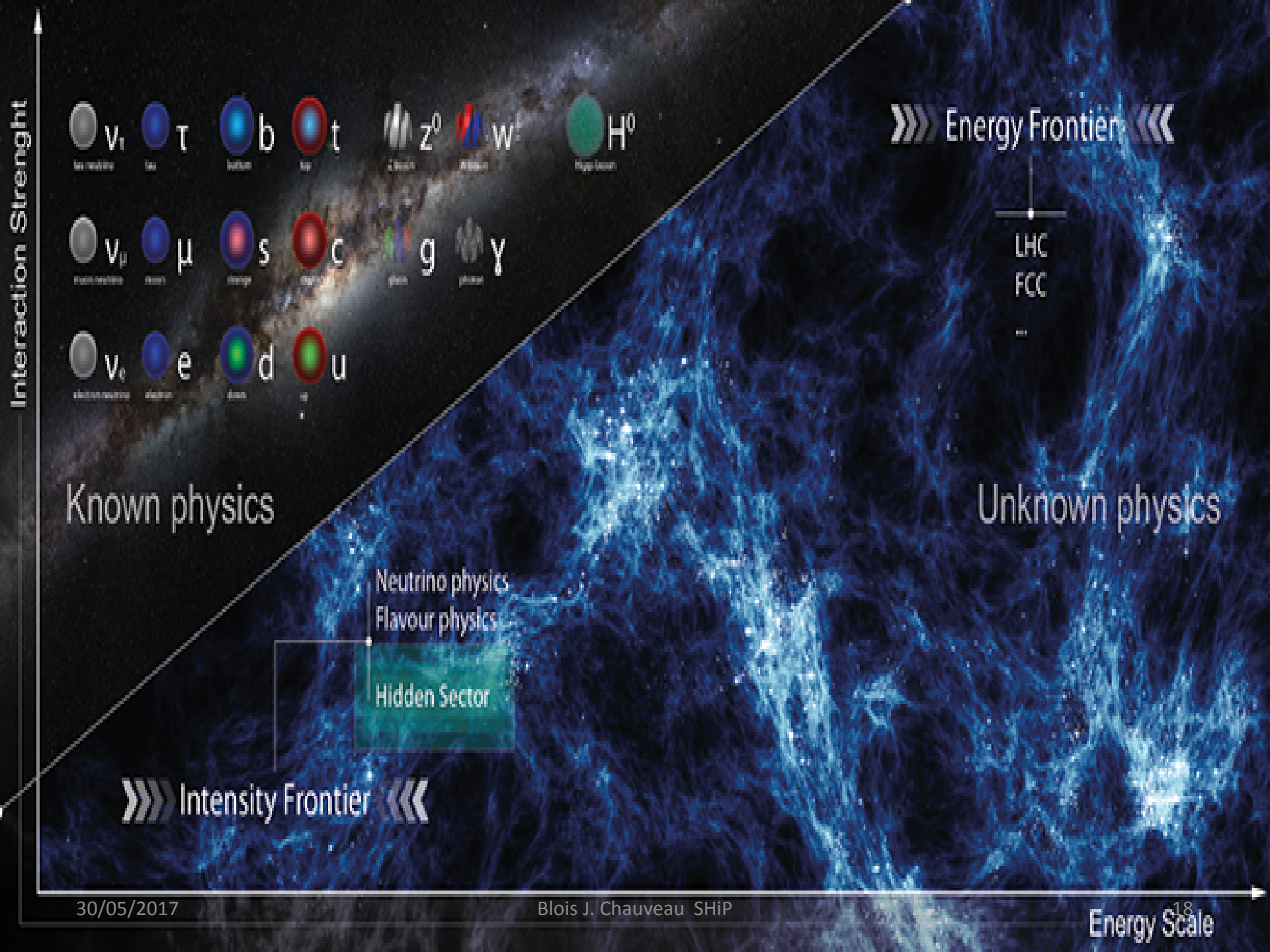
→ Be reviewed by SPSC during CDR phase in order to transition to TDR

Busy times



Perspectives

- SHiP is a proton beam dump facility
 - to take data 5 years starting in 2027, assuming approval \leq 2020
 - to reach the best sensitivity for many hidden sector particles (MeV-GeV)
 - with an apparatus currently being reoptimized to search for unknown neutral particle
 - decays, scattering,
also ν_τ physics.
 - The SHiP beamline is to be seen as a facility:
 - $\tau \rightarrow 3 \mu$?..
- Time to join (creative period).



Extra

Physics Case

- ✓ SHiP will directly search for weakly interacting New Physics. Will exceed the sensitivity of previous experiments by a few orders of magnitude

For example, probe HNL couplings close to the ultimate see-saw limit

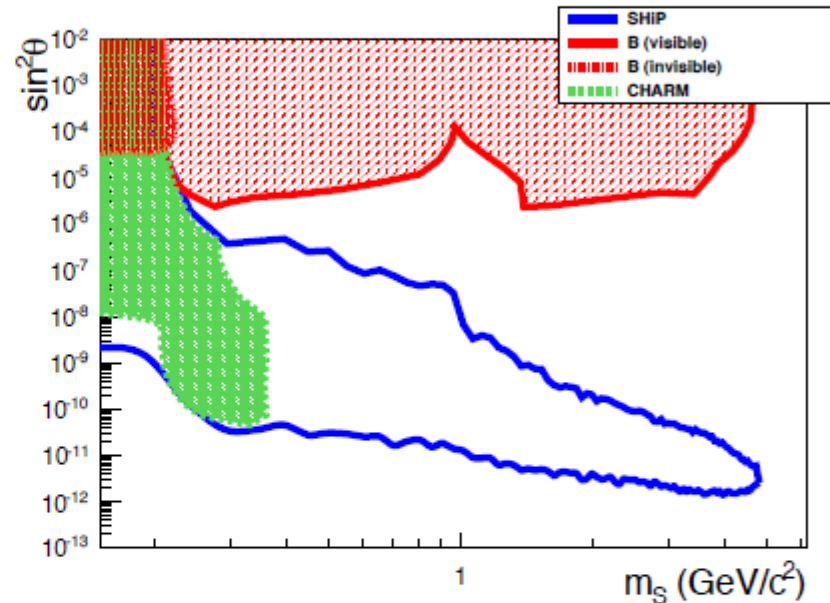
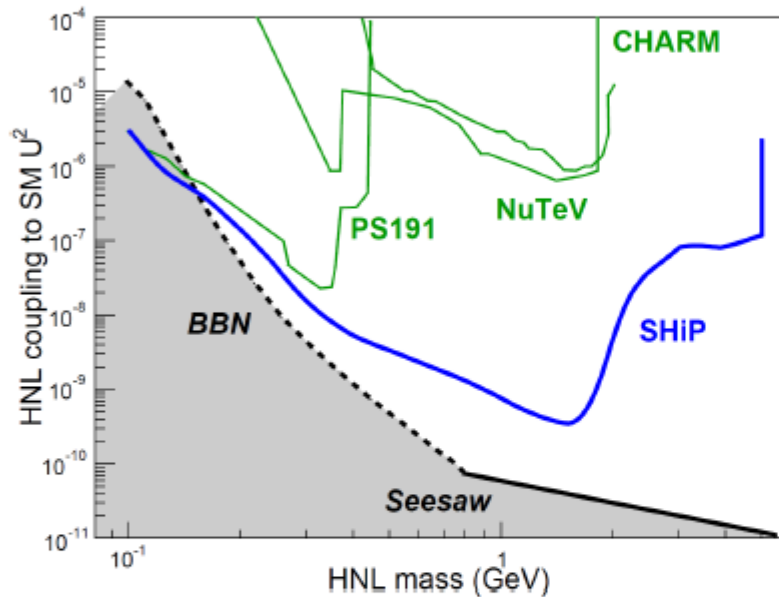
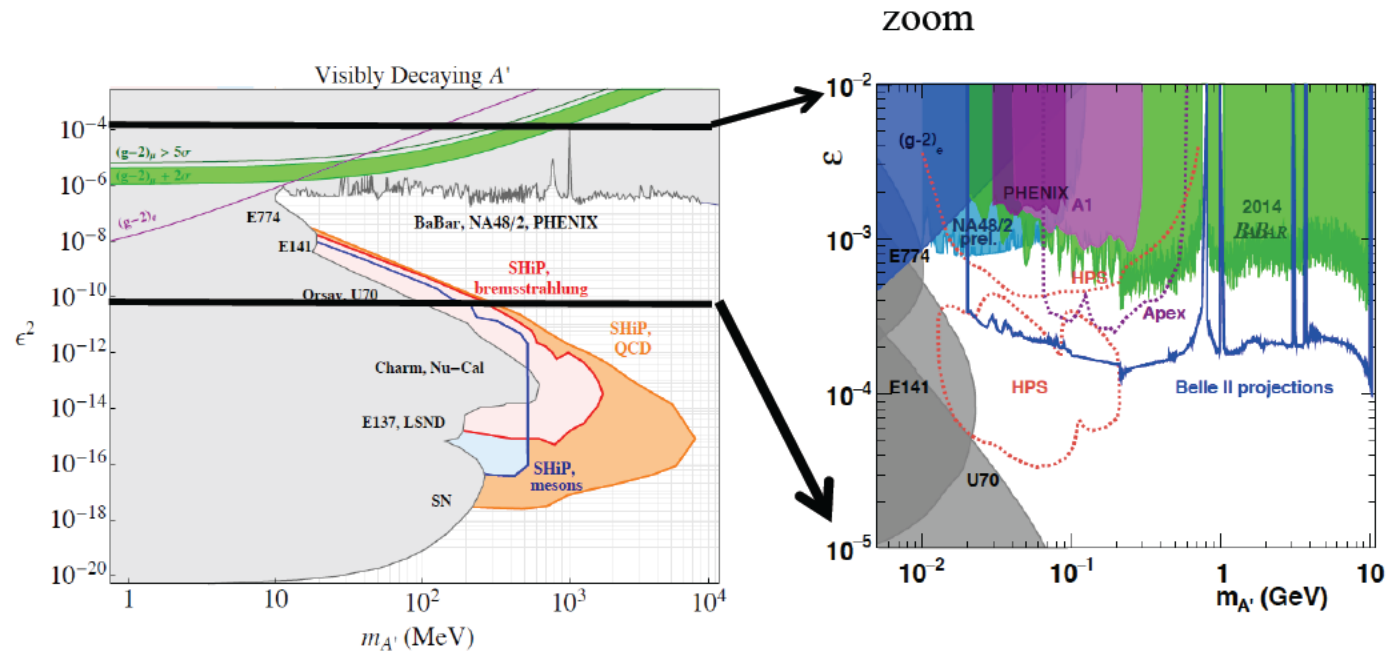


Table 2.1: Summary of the main decay modes of hidden particles in various models ($\ell = e, \mu$)

Models	Final states
Neutrino portal, SUSY neutralino	$\ell^\pm \pi^\mp, \ell^\pm K^\mp, \ell^\pm \rho^\mp, \underline{\rho^\pm \rightarrow \pi^\pm \pi^0}$
Vector, scalar, axion portals, SUSY sgoldstino	$\ell^+ \ell^-$
Vector, scalar, axion portals, SUSY sgoldstino	$\pi^+ \pi^-, K^+ K^-$
Neutrino portal, SUSY neutralino, axino	$\ell^+ \ell^- \nu$
Axion portal, SUSY sgoldstino	$\gamma\gamma$
SUSY sgoldstino	$\pi^0 \pi^0$

Under discussion: improve photon detection (with Preshower), and PID in general

Sensitivity to $A' \rightarrow \text{visible}$: SHiP vs HPS, APEX and Belle-II



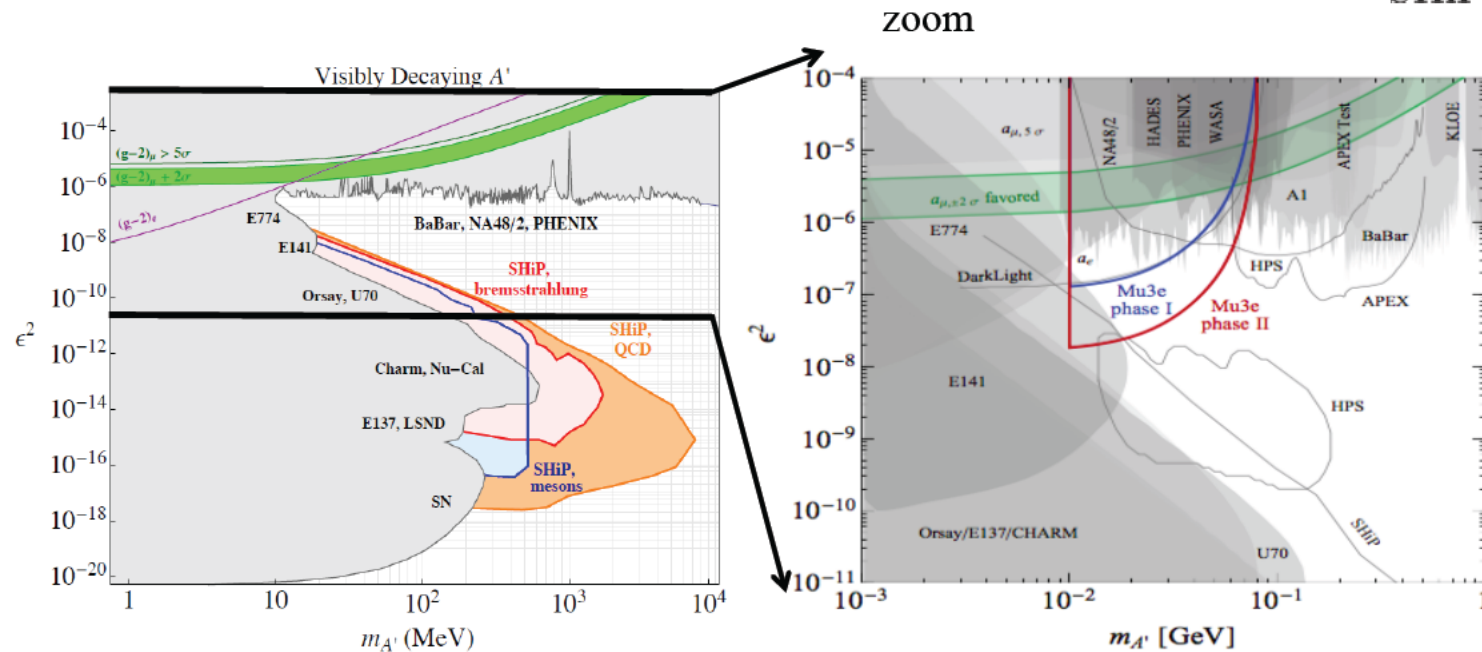
SHiP will have sensitivity in a range that cannot be covered by any current or planned experiment

Caveat: these limits are valid in the assumption that A' does not decay in dark matter

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G. Lanfranchi at SLAC April workshop

Sensitivity to $A' \rightarrow \text{visible}$: SHiP vs Mu3e phase-I and phase-II



SHiP will have sensitivity in a range that cannot be covered by any current or planned experiment

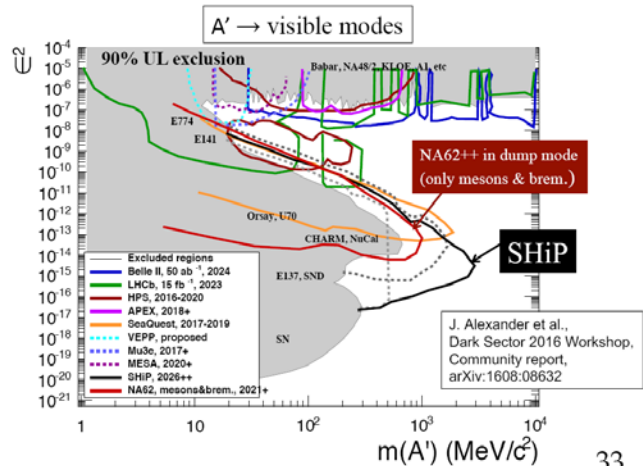
Caveat: these limits are valid in the assumption that A' does not decay in dark matter

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G. Lanfranchi at SLAC April workshop

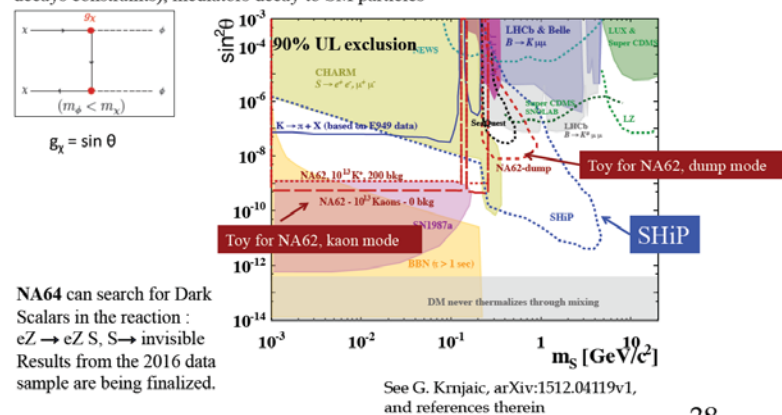
Experimental landscape

Dark Photons in visible modes: past and future sensitivities

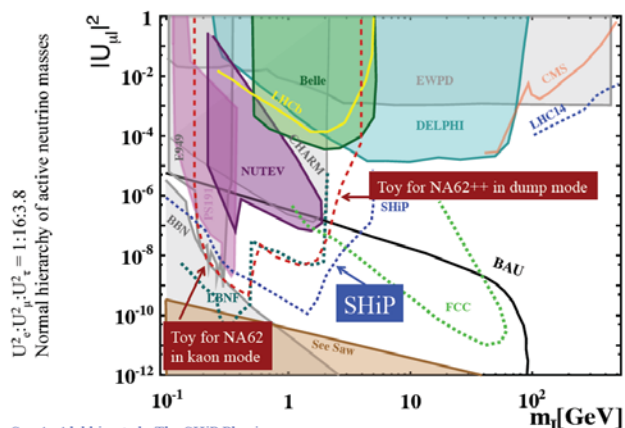


Dark Scalars in visible modes: past and future sensitivities

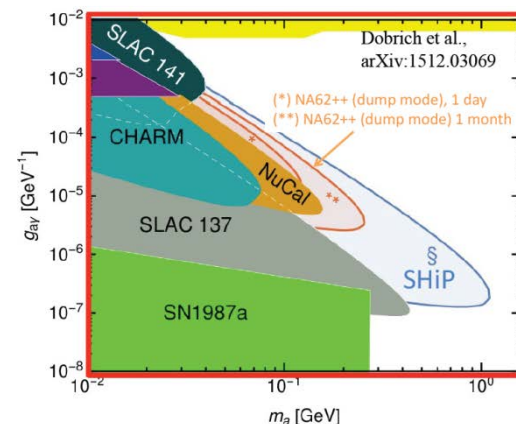
Secluded annihilation via mediators (only possibility compatible with CMB and rare mesons decays constraints), mediators decay to SM particles



Heavy Neutral Leptons: past and future sensitivities

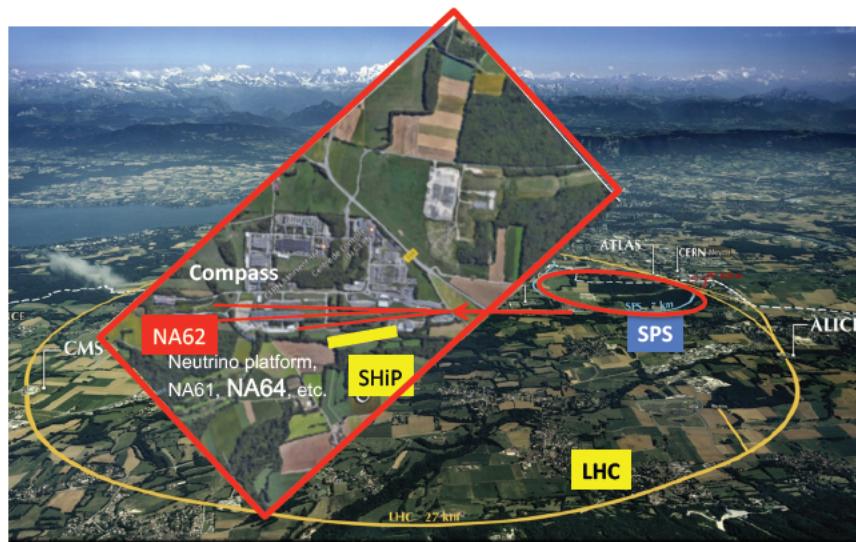


ALPS contour limit from past and future beam-dump experiments in the "high" mass region (0.1-1.0) GeV

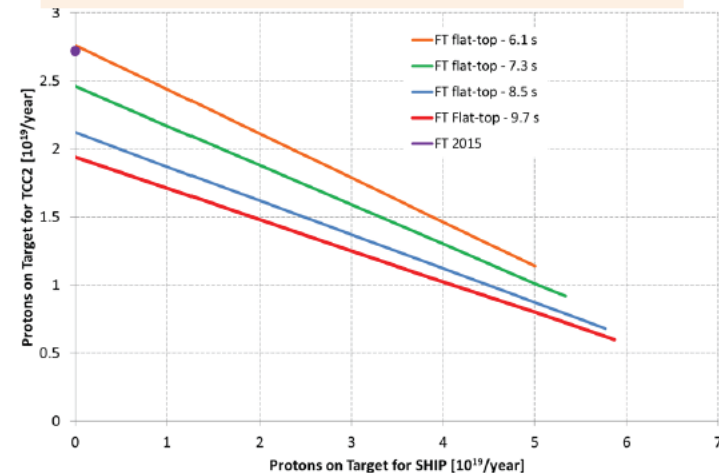


The Fixed-target facility at the SPS: Preveessin North Area site

Very intense proton beam with highest in the world energy delivered to fixed target exp. at CERN SPS. The aim is to deliver with 4×10^{13} protons / spill (at slow extraction)

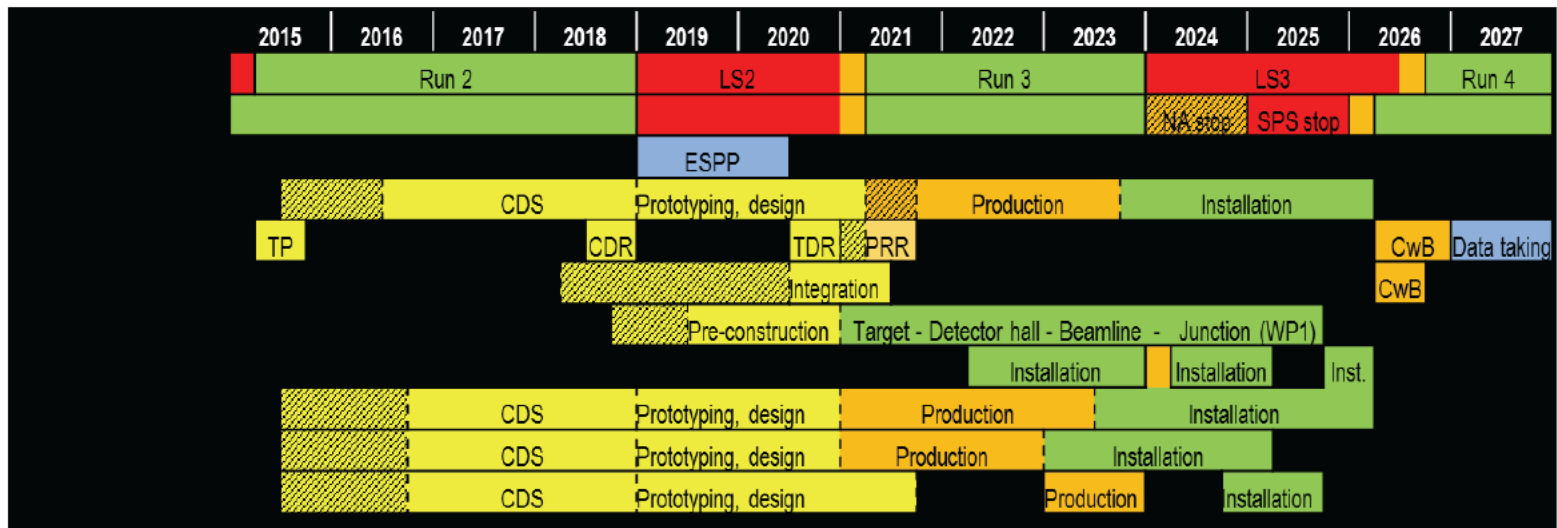


Sharing of pot between current fixed target exp. and planned Beam Dump Facility (BDF)



Proposed implementation is based on minimal modification to the current SPS complex

Global SHiP schedule



✓ **Planning very well aligned with**

- Update of European strategy 2019/2020
- Accelerator schedule (to be followed closely)
- Production Readiness Reviews (PRR) 2020Q1 →
- Construction / production 2020 →
- Data taking (pilot run) 2026 (start of LHC Run 4)

✓ **Main current priority: Comprehensive Design Study by 2018**

LDMA 2017

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