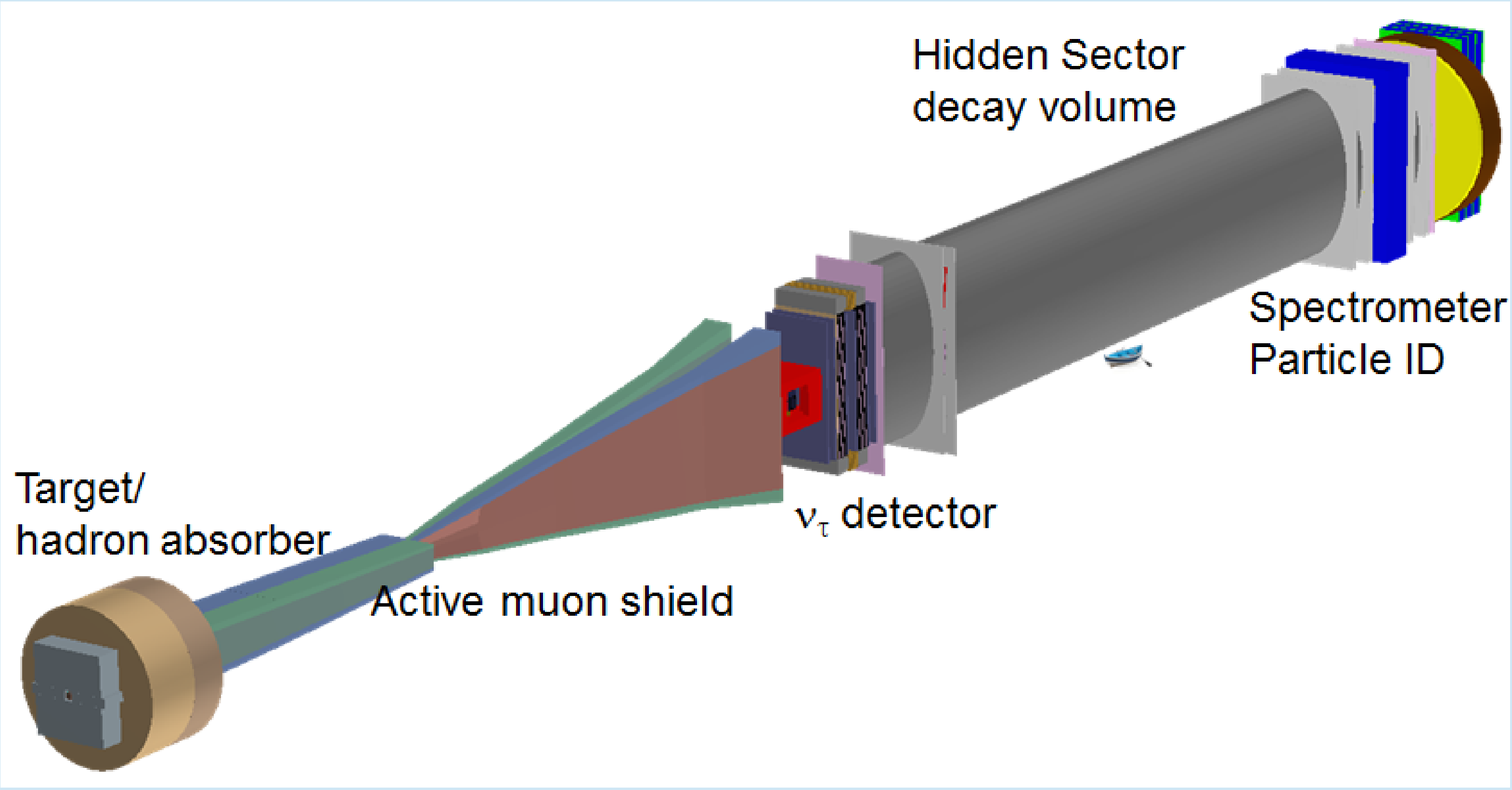
Search for Hidden Particles (SHiP): an experimental proposal at the SPS

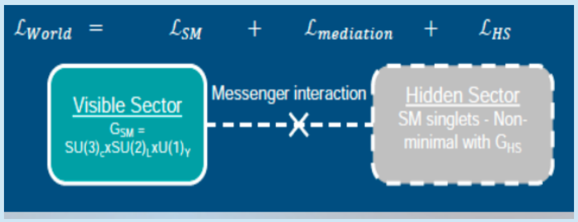
ship.web.cern.ch/ship

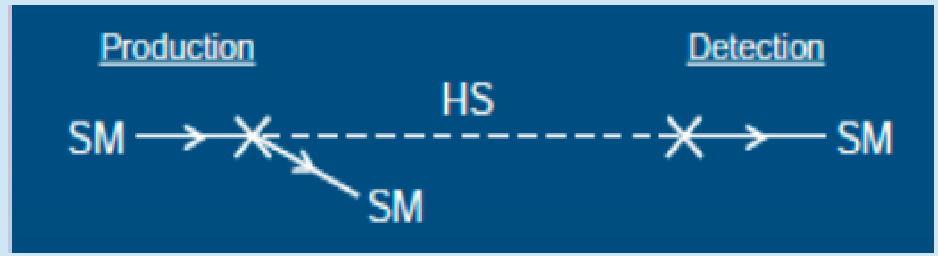
Mario Campanelli (UCL)
On behalf of ShiP-UK:
Bristol, ICL, RAL, UCL, Warwick



The “hidden sector” approach to new physics

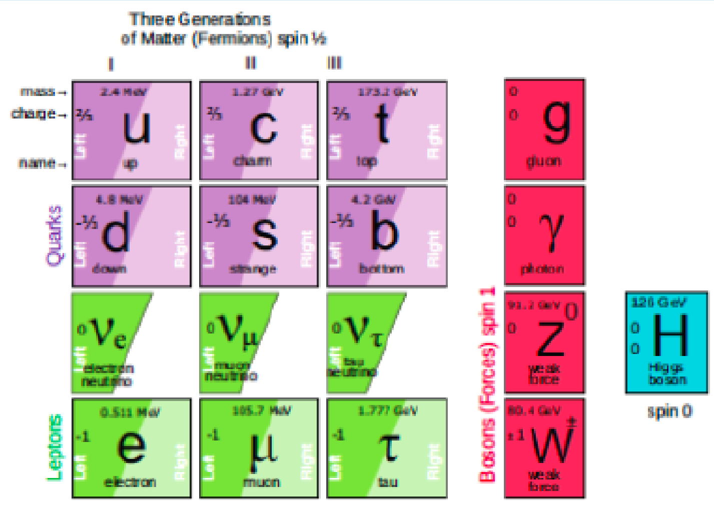
- Searches for new particles at the LHC so far unsuccessful, maybe new physics has a very small coupling?
- If an additional, weakly interacting, term to the Lagrangian could lead to particles very difficult to observe, but contributing to dark matter.

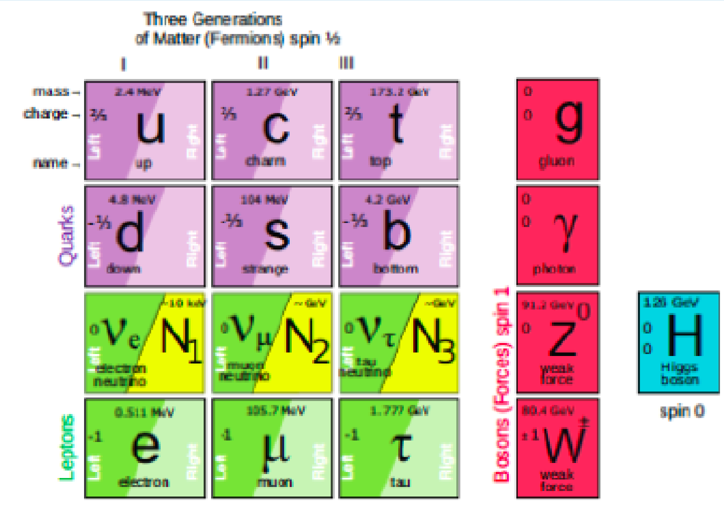




The νMSSM

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

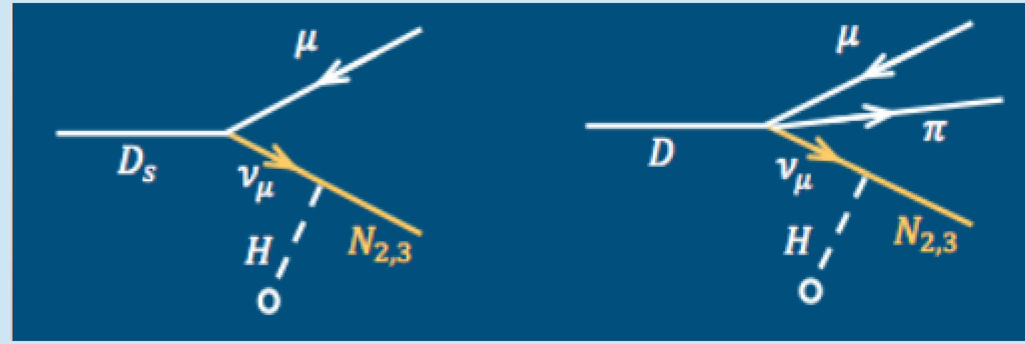
HNL production and decay modes

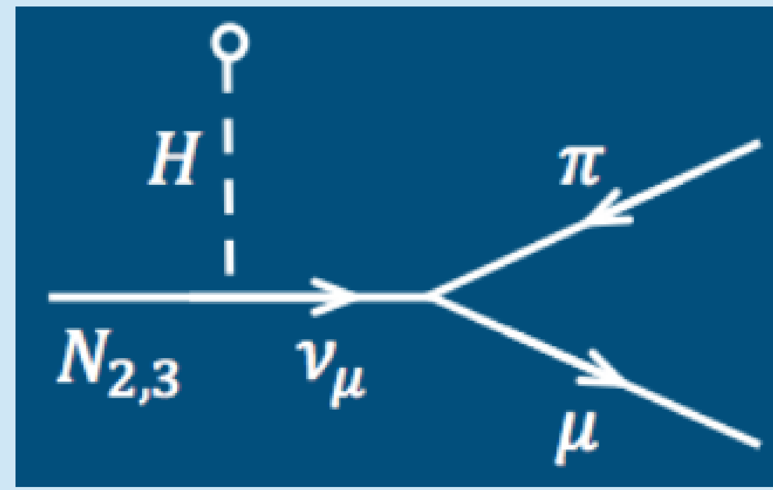
Interaction with Higgs vev leads to mixing with active neutrinos, resulting in a bahaviour similar to oscillation to the HNL and back into a virtual neutrino, that

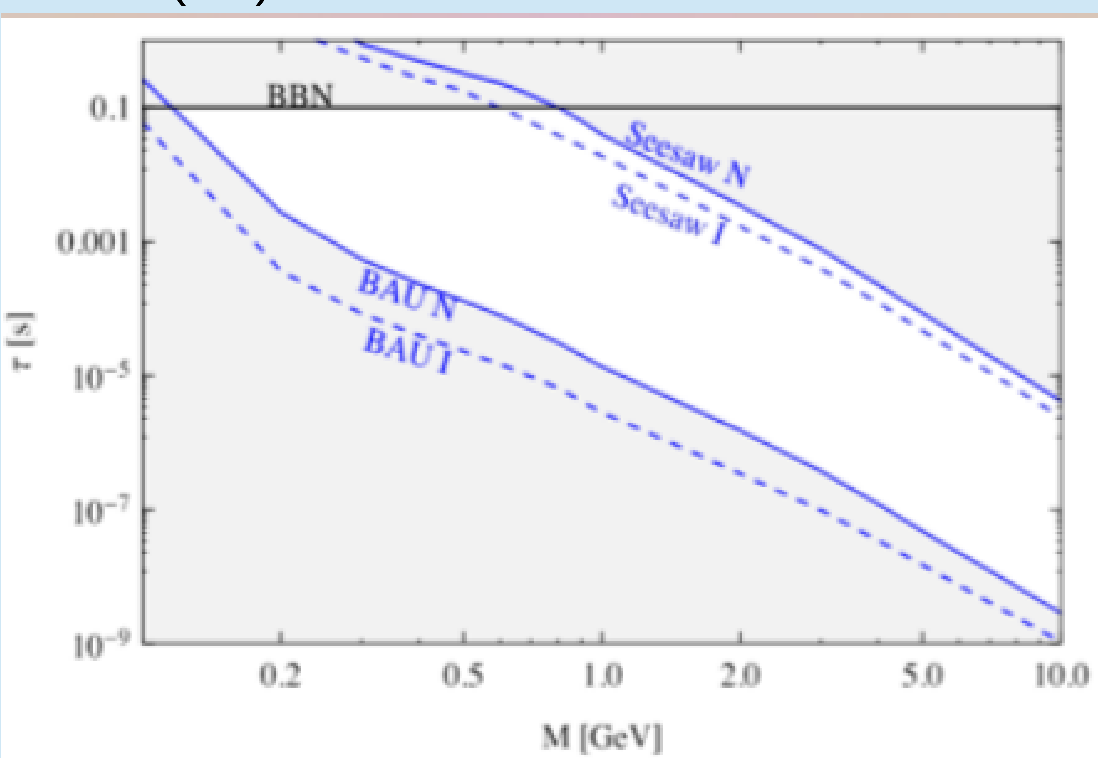
produces a muon and a W (→ hadrons, eg pions)

Exact branching fractions depend n flavor mixing

Due to small couplings, ms lifetimes, decay paths O(km)



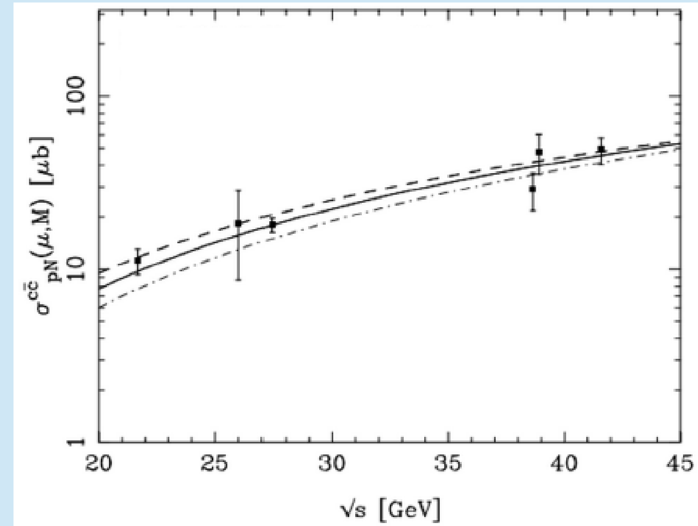




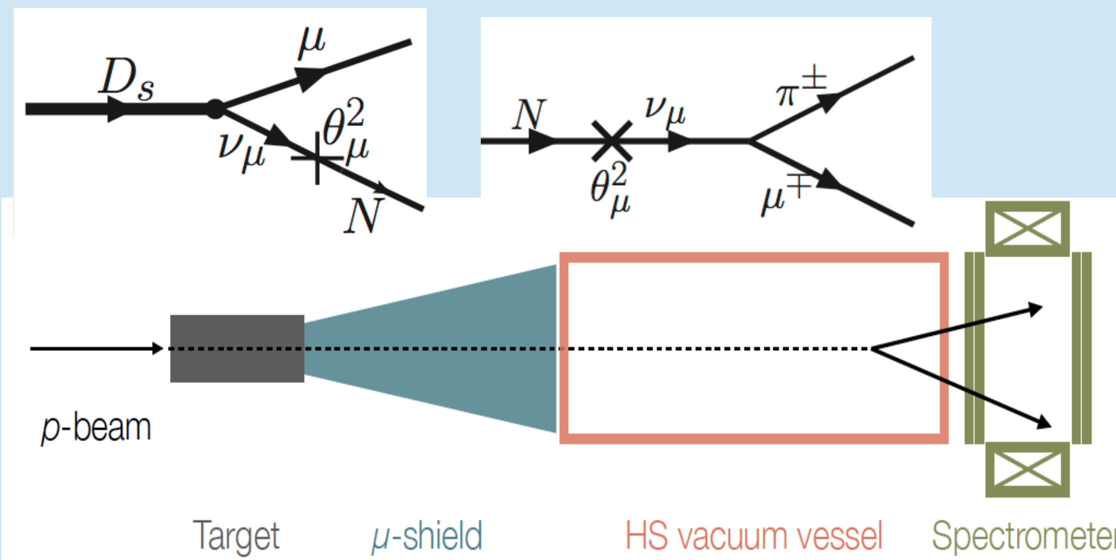
Decay mode	Branching ratio
$N_{2,3} \rightarrow \mu,e + \pi$	0.1 – 50 %
$N_{2,3} \rightarrow \mu\text{-}/e\text{-} + \rho^+$	0.5 - 20%
$N_{2,3} \rightarrow \nu + \mu + e$	1 – 10%

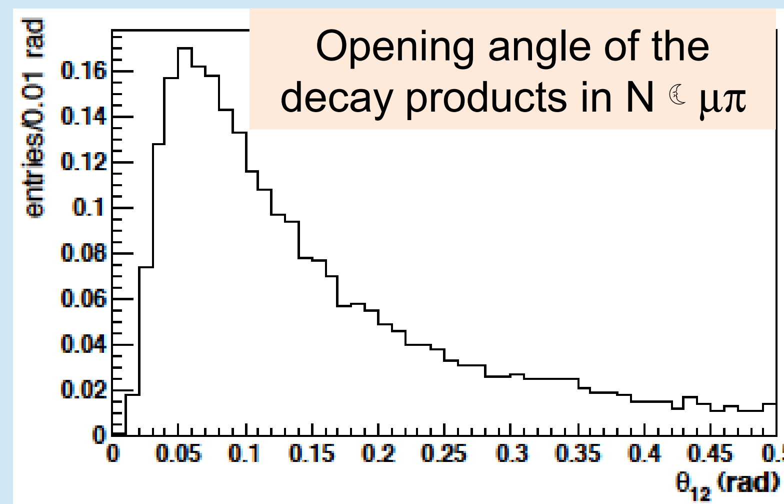
General experimental requirements
to search for HS at beam dump experiment

- ✓ *Search for HS particles in Heavy Flavour decays*
  Charm (and beauty) cross-sections strongly depend on the beam energy



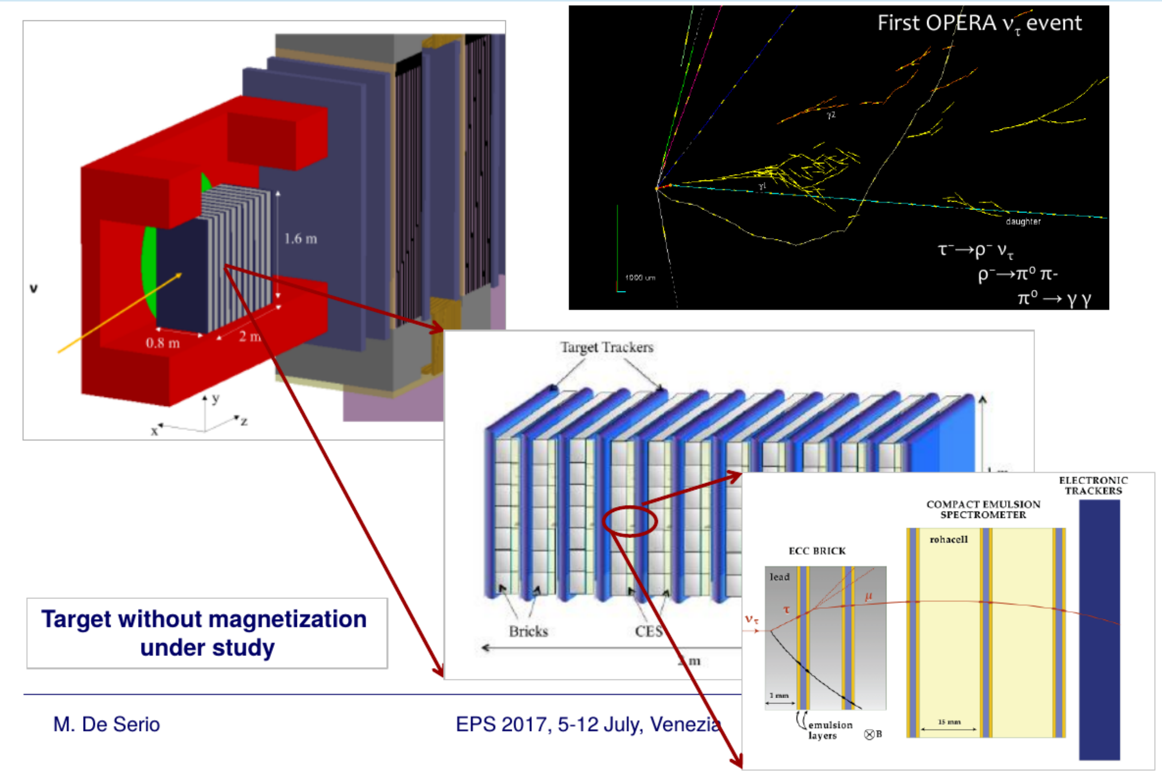
- ✓ *HS produced in charm and beauty decays have significant P_T*





Detector must be placed close to the target to maximize geometrical acceptance. Effective (and "short") muon shield is the key element to reduce muon-induced backgrounds

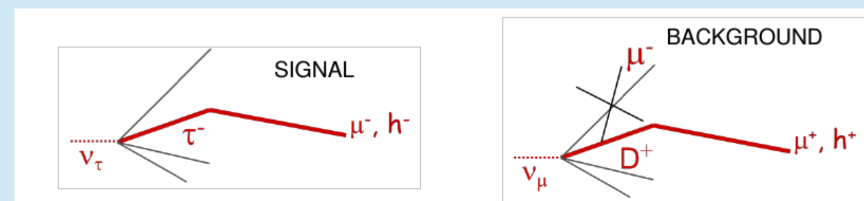
Neutrino detector and dark matter searches



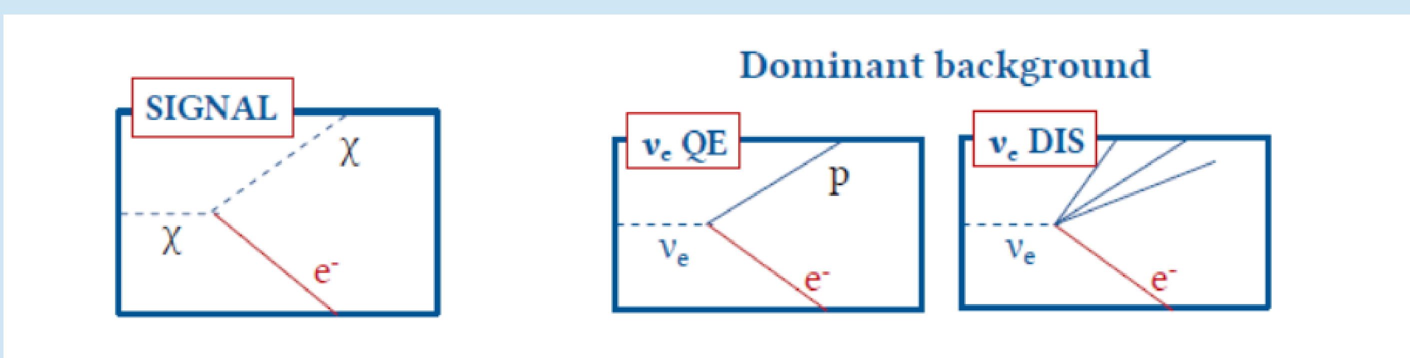
Exploit production thousands of of tau neutrinos to study its properties and structure function

Discovery of tau-antineutrino (only missing SM particle)

Muon spectrometer after target needed to suppress charm BG:



Emulsion detector will also be used to search for Dark Matter in the sub-GeV region exploiting its resolution to separate elastic scattering of DM candidates to neutrino scattering



The SHiP experiment at SPS

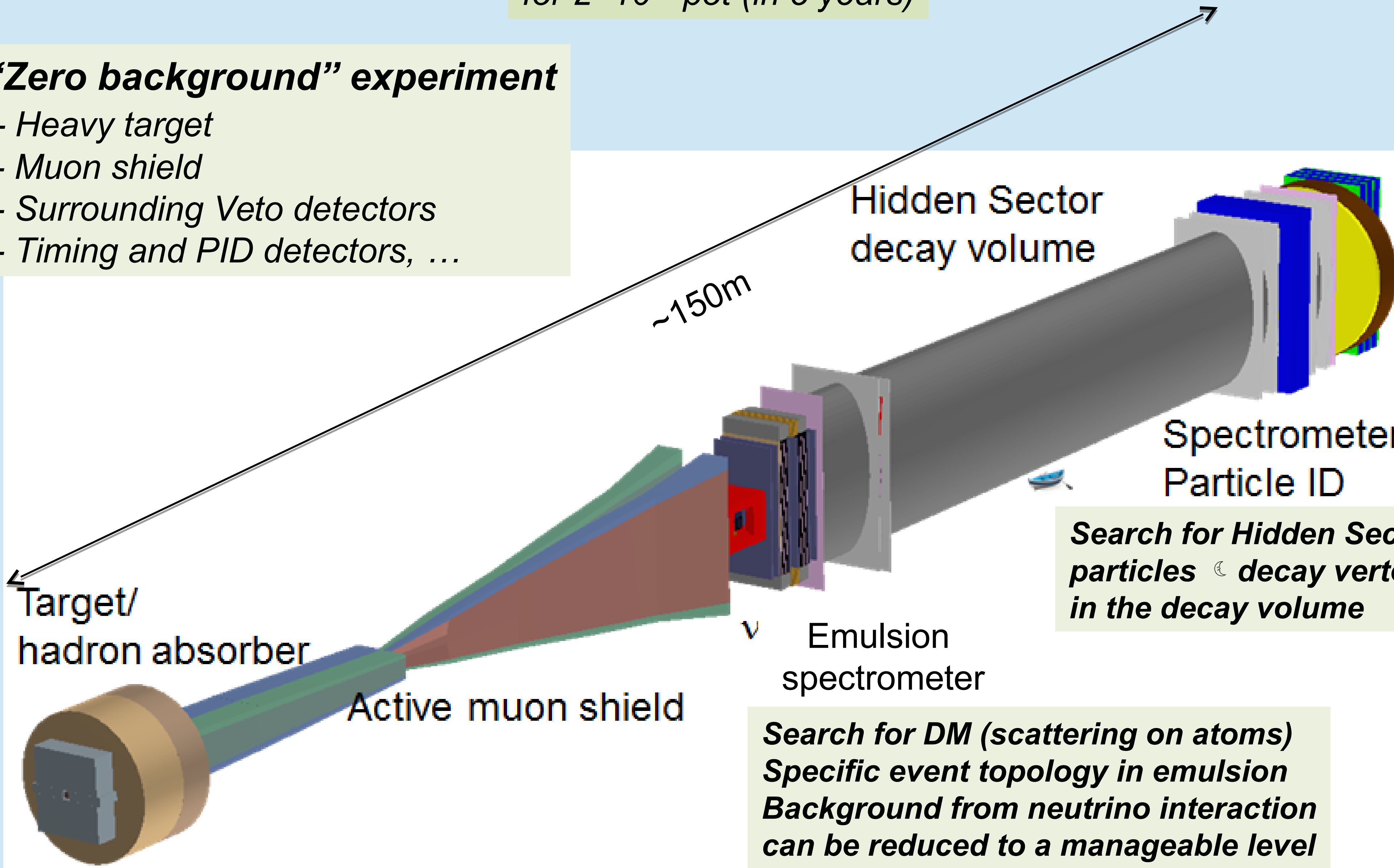
(to search for HS particles with O(10 GeV) masses)

SHiP Technical Proposal: 1504.04956

>10^{18} D, >10^{16} τ, >10^{20} γ
for 2×10^{20} pot (in 5 years)

"Zero background" experiment

- *Heavy target*
- *Muon shield*
- *Surrounding Veto detectors*
- *Timing and PID detectors, …*



Search for Hidden Sector particles ☾ decay vertex in the decay volume

Search for DM (scattering on atoms)
Specific event topology in emulsion
Background from neutrino interaction can be reduced to a manageable level

SHiP in the CERN strategy

Preparation of CERN's future:

- ❑ vibrant accelerator R&D programme exploiting CERN's strengths and uniqueness (including superconducting high-field magnets, AWAKE, etc.)
- ❑ design studies for future accelerators: CLIC, FCC (includes HE-LHC*)
- ❑ future opportunities of diversity programme (new): "Physics Beyond Colliders" Study Group

(*) HE-LHC: FCC-hh dipole technology (~16 T) in LHC tunnel → $\sqrt{s}$ ~ 30 TeV

Important milestone: update of the European Strategy for Particle Physics (ESPP): ~ 2019-2020

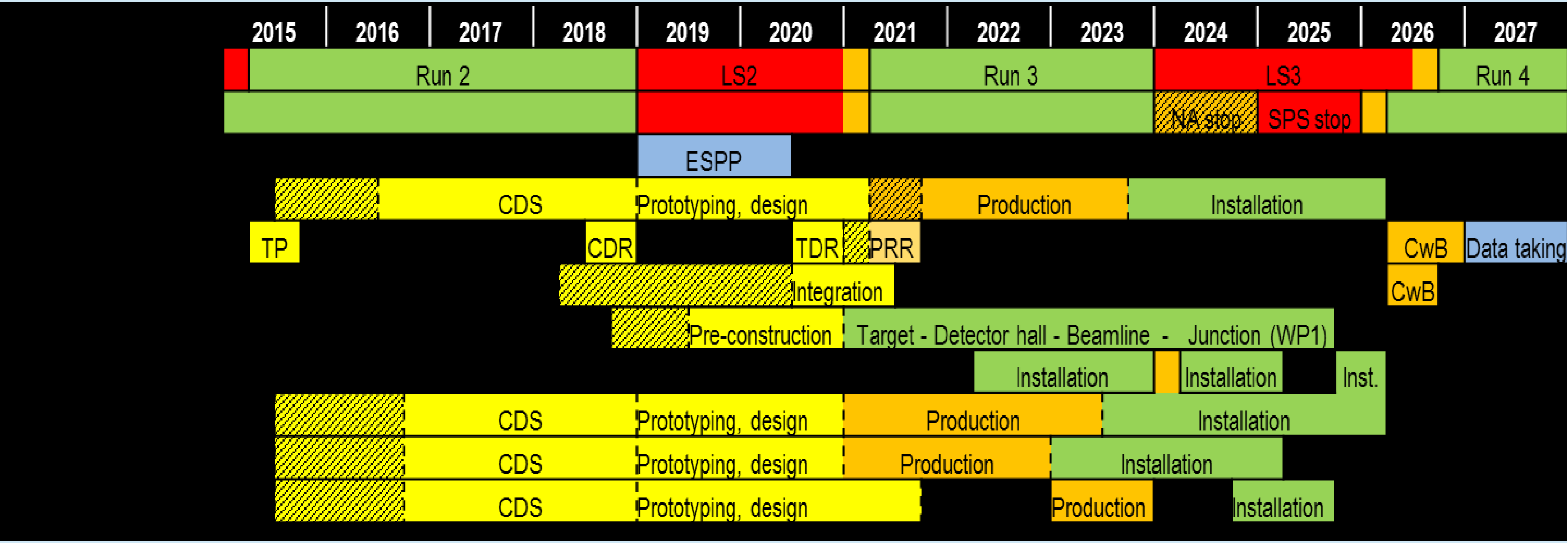
"Physics Beyond Colliders" Study Group established in March 2016

Mandate

Explore opportunities offered by the (very rich) CERN accelerator complex to address outstanding questions in particle physics through projects:

- ❑ complementary to high-energy colliders (studied at CERN: HE-LHC, CLIC, FCC)
  → we know there is new physics, we don't know where it is → we need to be as broad as possible in our exploratory approach
- ❑ exploiting the unique capabilities of CERN accelerator complex and infrastructure and complementary to other efforts in the world:
  → optimise the resources of the discipline globally

Global SHiP schedule

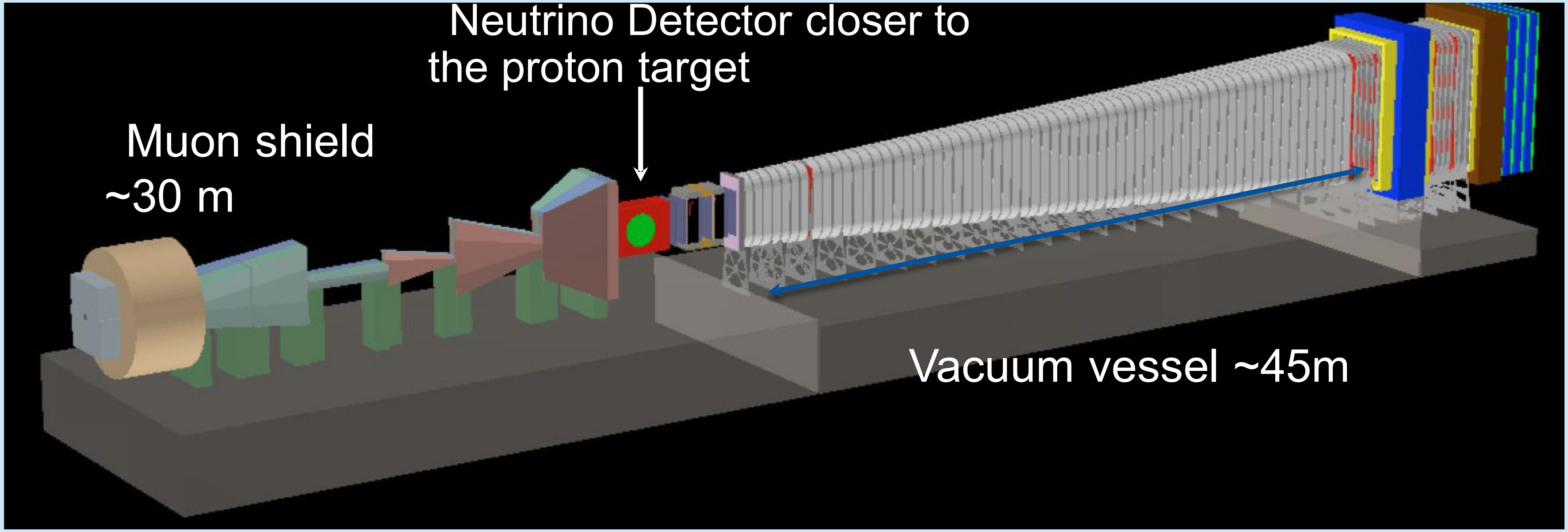


- ✓ ***Planning very well aligned with***
  - *CERN scientific strategy*
  - *Update of European strategy 2019/2020*
  - *Accelerator schedule (to be followed closely)*
  - *Production Readiness Reviews (PRR) 2020Q1*
  - *Construction / production 2020*
  - *Data taking (pilot run) 2026 (start of LHC Run 4)*

- ✓ ***Main current priority: Comprehensive Design Study by 2018***
- ✓ ***Validation of MC studies with dedicated test-beams already in 2018!***

Main goals of the SHiP optimization for the CDS

- ✓ *Further optimization of the target*
- ✓ *Configuration of the muon shield, including magnetization of the hadron stopper (**MC to be validated with data**)*
- ✓ *Shape, dimension and evacuation of the decay volume*

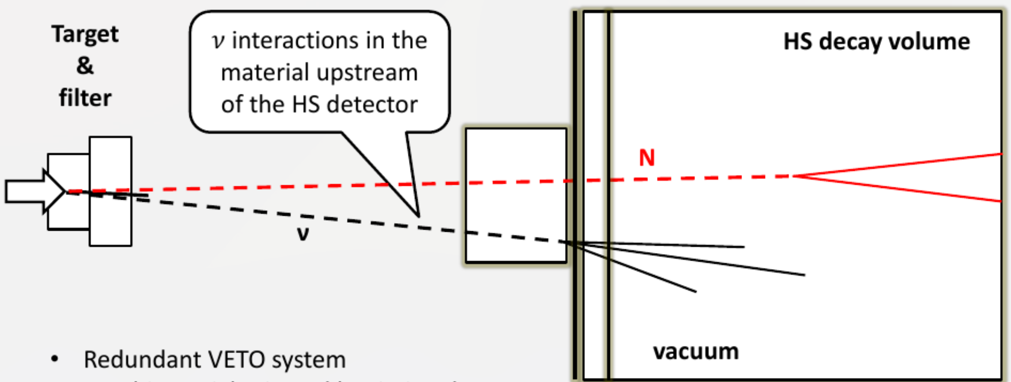


- ✓ *Optimization of the emulsion detector to search for LDM*
- ✓ *Optimization of physics performance for various sub-detectors*
- ✓ *Revisit detector technologies, including new sub-detectors, to further consolidate background rejection and extend PID*

Updated background estimates and signal sensitivities, and cost

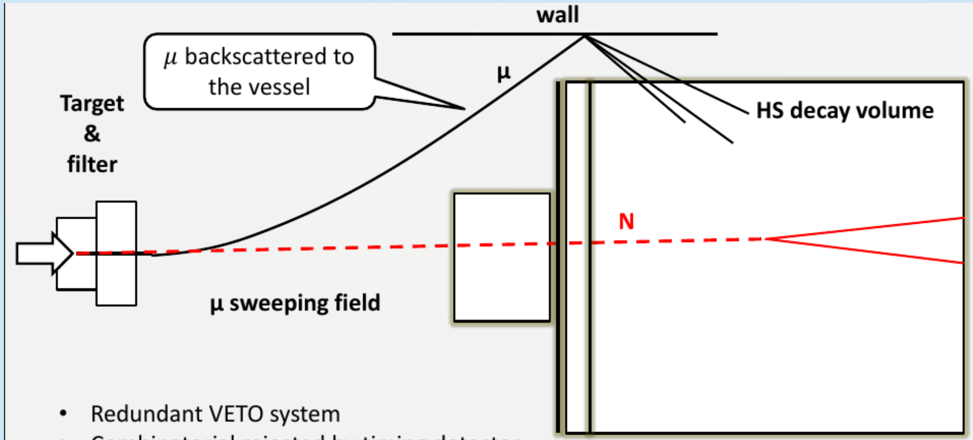
- ✓ *Contribution from the secondary interactions in the target improves signal yield by ~50% (**to be validated with data**)*

Background rejection for HNL searches



- 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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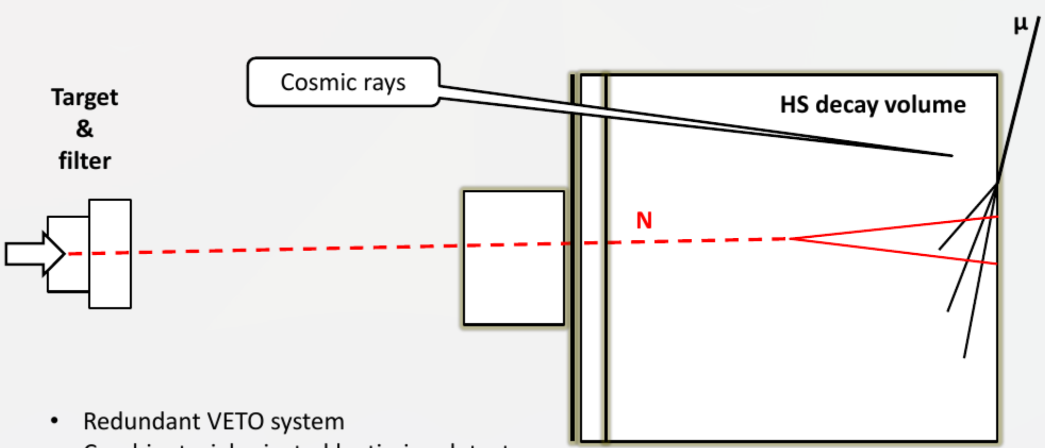

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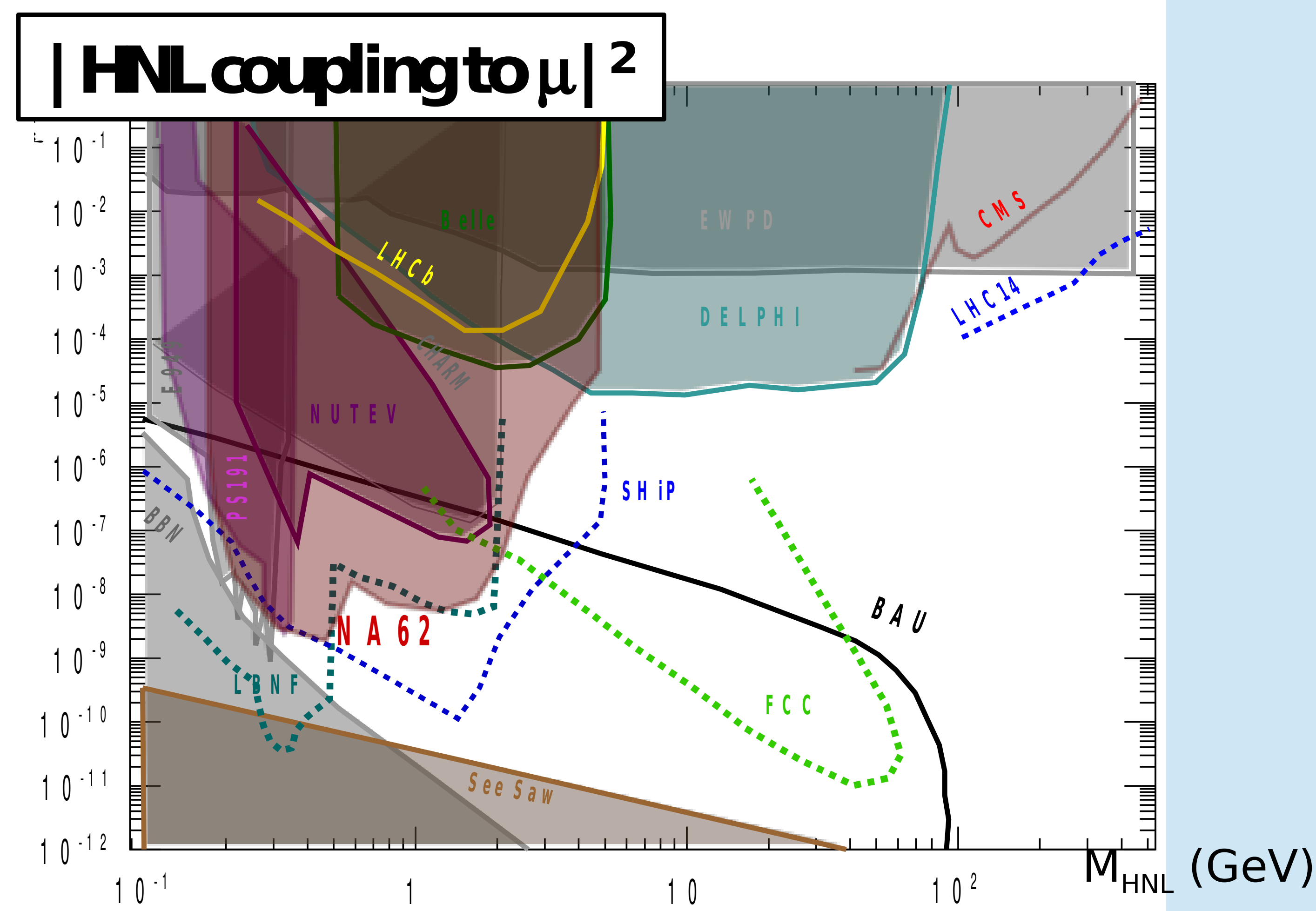
Background source	Stat. weight	Expected background (UL 90% CL)
ν-induced		
$2.0 < p < 4.0$ GeV/c	1.4	1.6
$4.0 < p < 10.0$ GeV/c	2.5	0.9
$p > 10$ GeV/c	3.0	0.8
$\overline{\nu}$-induced		
$2.0 < p < 4.0$ GeV/c	2.4	1.0
$4.0 < p < 10.0$ GeV/c	2.8	0.8
$p > 10$ GeV/c	6.8	0.3
Muon inelastic	0.5	4.6
Muon combinatorial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

Future prospects and comparison with other facilities

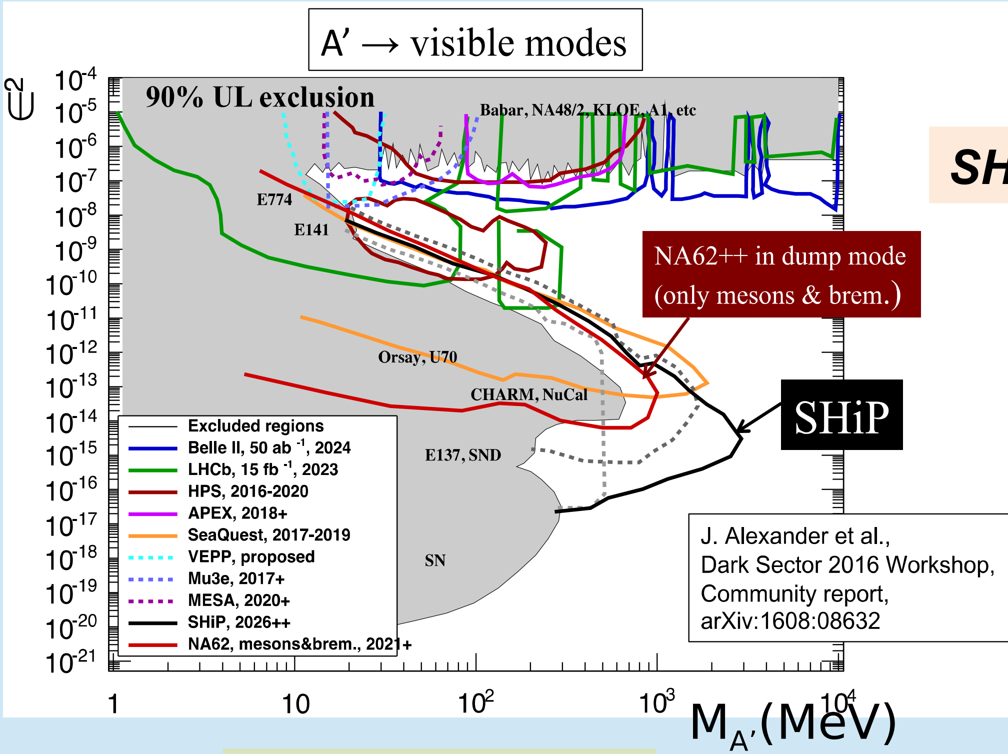
HNLs:



- ✓ $M_{HNL} < M_b$ LHCb, Belle2
  SHiP will have much better sensitivity
- ✓ $M_b < M_{HNL} < M_Z$ **FCC in e^+e^- mode** (improvements are also expected from ATLAS / CMS)
- ✓ $M_{HNL} > M_Z$ **Prerogative of ATLAS/CMS @ HL LHC**

SHiP will also have the best prospects for HS particles produced in heavy flavour decays, e.g. hidden scalars

Future prospects and comparison with other facilities

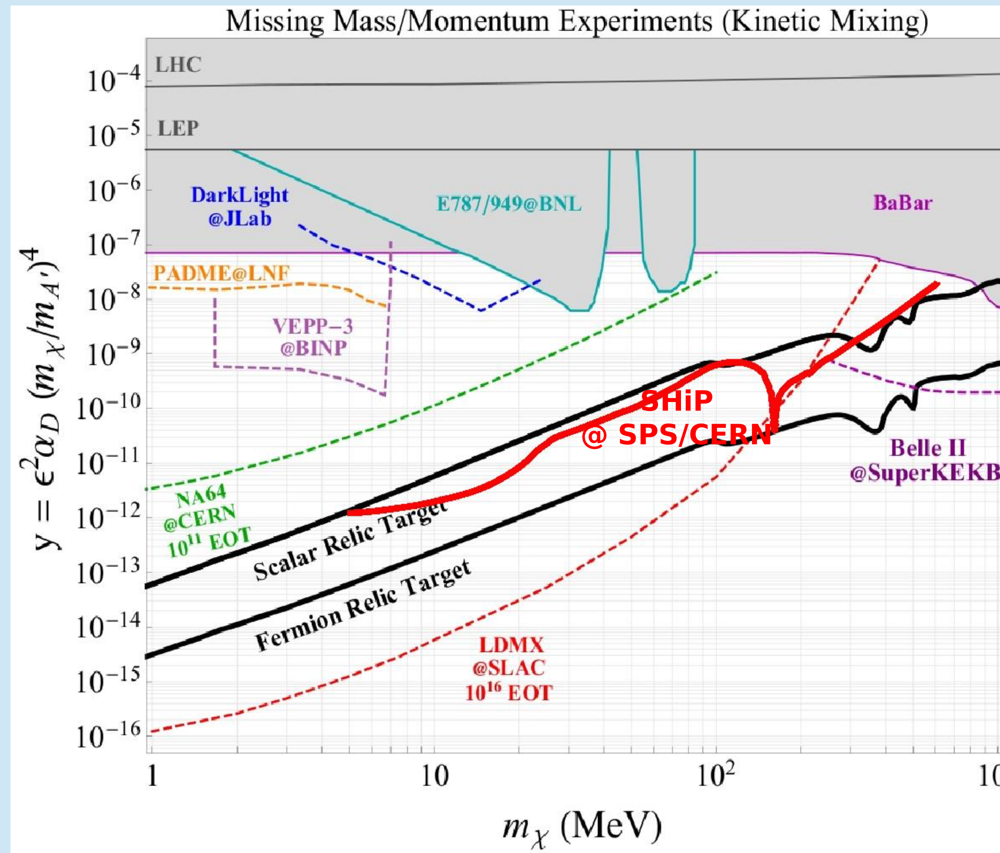


Dark photons:

SHiP is unique up to O(10GeV) and $\varepsilon^2 < 10^{-11}$

Light Dark Matter

$M_{A'}/M_{\chi}=3$



Dark sectors 2016: 1608.08632

Detection via scattering

- ***SHiP has unique potential for M_χ <1GeV***
- *BDX in JLab may have a competitive sensitivity for M_χ <10 MeV*

Missing mass / energy technique

- *Belle II – comparable to SHiP for M_χ>0.5 GeV with 50 ab^{-1} provided that low energy mono-photon is implemented*
- *LDMX (under discussion at SLAC) has the best prospects for M_χ< 100 MeV Time scale is unclear.*

SHiP in the world

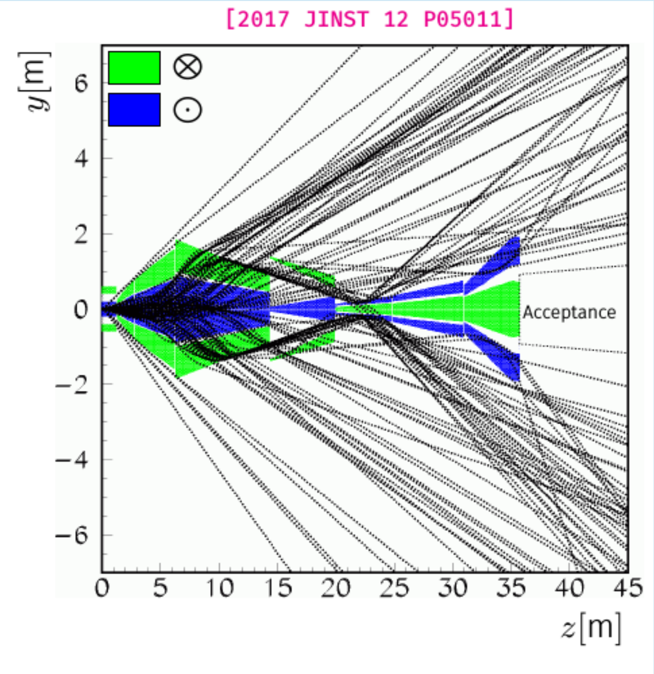
SHiP
Search for Hidden Particles

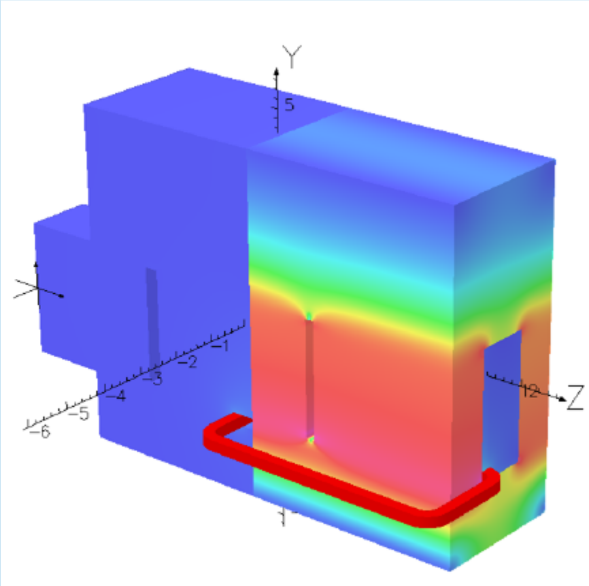
Technical Proposal: [CERN-SPSC-2015-016]
Physics Proposal: [CERN-SPSC-2015-017]

SHiP in the UK

- UK physicists proposed the experiment and Andrei Golutvin (ICL) is the spokesperson. Following groups lead by UK physicists:

  - Muon Shield design
  - Background suppression
  - Signal models





- UK work-package: BG rejection (crucial for the success of the experiment)
  - Active muon shield
  - Target design
  - DAQ and triggering
- Plan to submit an SoI soon to participate to the R&D phase and test-beams
- A.Golutvin received a prestigious grant from the Russian Federation that will help building prototypes, but some resources (travel money, engineering support) needed from STFC to contribute to the Comprehensive Design Report and maintain current leadership.
- On the long run, muon shield will be a common-fund item, STFC resource request will be limited to post-docs, students, engineering support and common funds.

Conclusions

- Light hidden-sector particles can solve many problems of the SM, SHiP is the only dedicated detector for this physics
- CERN has a very favourable view on the project, with a large physics group and engineering/beamline design support.
- The SPSC asked the experiment to produce a Comprehensive Design Report, and the Research Board has favourably recommended it
- A test-beam program has been proposed, and received positive comments from the SPSC. Already in 2018 we plan to test prototypes of the muon shield and measure charm production in neutrino target
- UK physicists proposed the experiment, we have the spokesperson and are in charge of the muon shield system as well as the main physics groups
- Our main responsibility (muon shield) will mainly be built from common funds
- We require commensurate resources to preserve the current roles and maintain the strong impact we have in the collaboration during the CDR phase and beyond