The Search for Hidden Particles (SHiP) experiment

Mitesh Patel (Imperial) on behalf of SHiP UK :

Bristol, Cambridge, Imperial, Liverpool, Manchester, RAL-TD, UCL

SHiP Physics Motivation & status

- Low-mass, feebly-interacting new particles can solve many problems of the SM
  - pattern of neutrino-masses and oscillation parameters; properties of dark matter, origin of cosmic inflation…
- SHiP will make the world’s leading direct searches for such particles in all the major sectors
  - probe coupling strengths ~10^4 times smaller than ever before
- SHiP will observe ~10^3 times more tau (anti-)neutrino interactions than any previous experiment
  - 1st observation of tau antineutrino, 1st measurement structure functions, tests of lepton universality in neutrino sector…
- **CERN approved the experiment in Mar 2024**
  - Only new direct-search programme at CERN in the 20+ years before a new accelerator
  - Committed 69MCHF to construction of beam-dump facility (BDF) for which SHiP is the sole user
  - Aim to take first commissioning data 2033

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A facility to Search for Hidden Particles at the CERN SPS: the SHiP physics case

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Abstract: This paper describes the physics case for a new fixed target facility at CERN SPS. The SHiP (*Search for Hidden Particles*) experiment is intended to hunt for new physics in the largely unexplored domain of very weakly interacting particles with masses below the Fermi scale, inaccessible to the LHC experiments, and to study tau neutrino physics. The same proton beam setup can be used later to look for decays of tau-leptons with lepton flavour number non-conservation, $\tau \to 3\mu$ and to search for weakly-interacting sub-GeV dark matter candidates. We discuss the evidence for physics beyond the Standard Model and describe interactions between new particles and four different *portals* — scalars, vectors, fermions or axion-like particles. We discuss motivations for different models, manifesting themselves via these interactions, and how they can be probed with the SHiP experiment and present several case studies. The prospects to search for relatively light SUSY and composite particles at SHiP are also discussed. We demonstrate that the SHiP experiment has a unique potential to discover new physics and can directly probe a number of solutions of beyond the Standard Model puzzles, such as neutrino masses, baryon asymmetry of the Universe, dark matter, and inflation.

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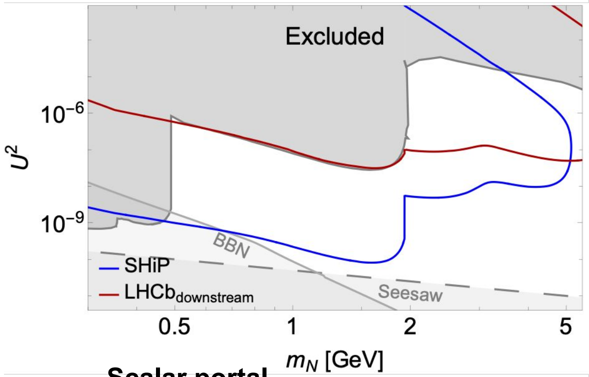
[Report by Physics Beyond Collider (PBC) study group, arXiv:1901.09966; Maryland Dark Sector Workshop 2017, arXiv:1707.04591; SLAC Dark Sector Workshop, arXiv:1608.08632…]

Hidden-sector physics performance

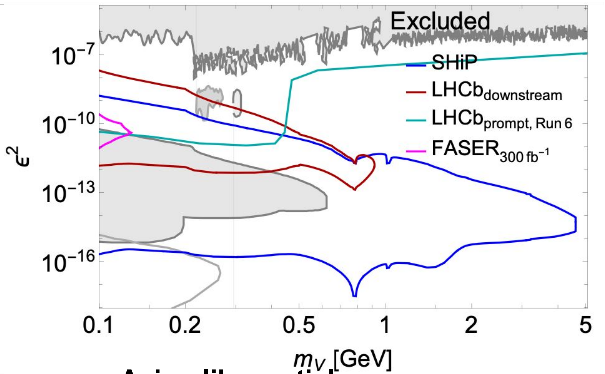
- SHiP sensitivities to new, low mass, feebly interacting particles are orders of magnitude better than competing projects
    - E.g. in the neutrino-portal, SHiP will probe 2-3 new orders of magnitude in coupling-strength squared, U^2,

- Sensitivity is not limited by backgrounds in 6 x 10^{20} PoT (15 yrs of SPS running)

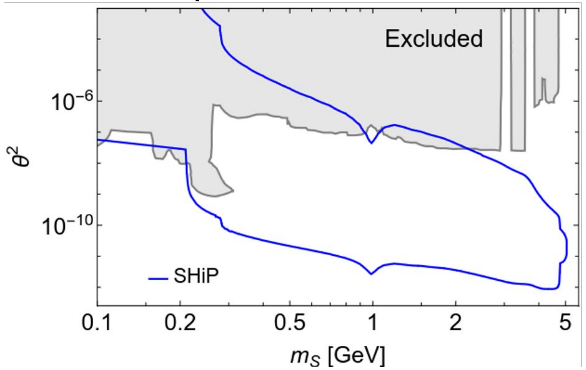
Neutrino portal



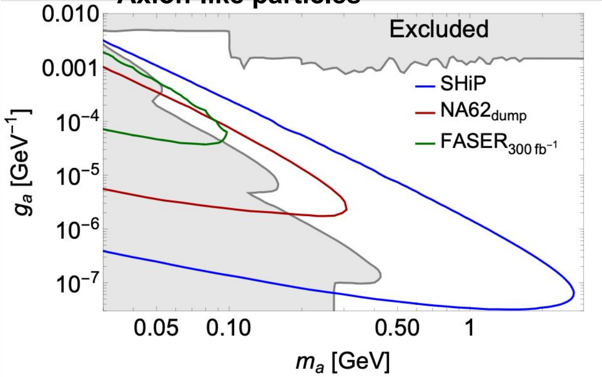
Vector portal



Scalar portal

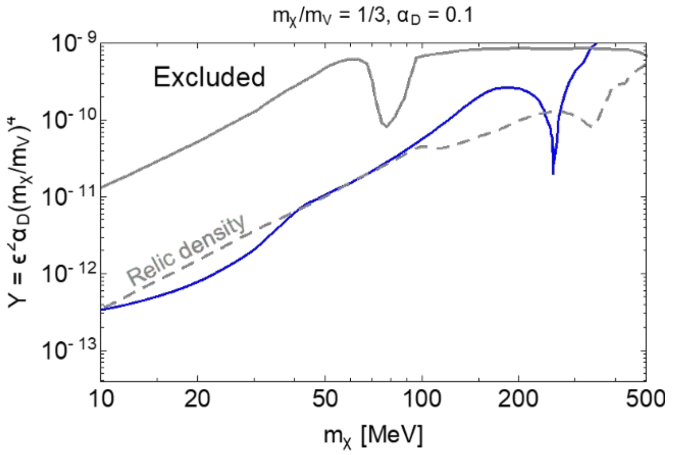


Axion-like particles



Tau neutrino physics performance

- Lepton Flavour Universality in neutrino interactions
  - $\sigma_{stat+syst}$~3% precision in ratios: v_e / v_{mu} , v_e / v_{tau} and v_{mu} / v_{tau}
- Measurement of neutrino DIS cross-sections up to 100 GeV
  - E_v < 10 GeV as input to neutrino oscillation programme (DUNE in particular)
  - V_{tau} cross-section at higher energies input to cosmic neutrino studies
  - $\sigma_{stat+syst}$<5%
- Test of F_4 and F_5 structure functions in $\sigma_{(v-CC\ DIS)}$
  - Never measured, only accessible with v_{tau}
- Can also search for light DM via shower produced from e-scatter (and nothing else)



Questions from the drafting panel

Comparison of physics goals with the current state of the art in the area. List the project's main advantages compared to competitor projects.

- See plots on previous pages - for hidden sector, factor 10^3-10^4 better in coupling-strength; for tau neutrino physics, factor 10^3 more evts
- Main advantage is the number of protons on target available at SPS, which gives yields 10*HL-LHC

~~Preferred~~ approved location for the project:

- CERN's SPS in ECN3 hall

Project timeline (if possible provide separate by the R&D, construction and exploitation periods)

- Schedule driven by SPS-schedule and need to commission experiment before 2034 long shutdown of the accelerator complex (LS4)
- Design & prototyping now-2027
- TDRs 2027 onward
- Production/construction 2027-2032
- Commissioning with first data 2033

Main risks/obstacles for realisation of physics goals (e.g. development of new technologies, construction of a new facility)

- Risk to CERN's delivery of the beam-dump facility - high-energy, intense beam over a prolonged extraction period present challenges related to both maintaining beam quality and overcoming engineering difficulties
- Risk from scale of the magnets needed for muon shield, which makes them much more difficult to implement than envisaged

Anticipated area(s) of UK involvement

- Developing large conventional magnets required for muon-shield (in UK industry) and associated background-monitoring system & readout. Shield also incorporates SHiP neutrino detector
- UK leadership: currently have Spokesperson, Chair of Collaboration board and one of two conveners of muon shield project

Total number of FTE /year required for construction/operation. What is the expected UK FTE?

- Across the collaboration construction is expected to take ~100FTE, operations is estimated to need 15-20FTE;
  the extent of UK involvement is yet to be defined

Questions from the drafting panel

Key physics deliverables (name up to 5). Be quantitative where relevant/possible

- Searches for hidden sector particles **three-four orders of magnitude better than the state-of-the-art** in all the major portals e.g. heavy neutral leptons, dark photons, hidden scalars, axion-like-particles, light sgoldstinos
- Observation of **10^3 times more tau (anti-)neutrino interactions than any previous experiment**
- 1st observation of tau antineutrino, 1st measurement structure functions, world's most precise tests of lepton universality in the neutrino sector

Please quote the datasets and running/exposure time required for the numbers above.

- 6 x 10^{20} Protons on Target (~15 years of SPS operation with current performance)

Environmental cost of construction (in units of tonnes of CO2 equivalent)

- Not known quantitatively - modifications to transfer area are trenched rather than a new tunnel; expt will make use of an existing CERN hall - hence civil engineering required is not significant

Environmental cost of operation per year (in units of tonnes of CO2 equivalent)

- Primarily energy usage of SPS which is used parasitically during HL-LHC running - hence negligible additional operational cost

Estimate of financial costs (provide separate numbers for R+D phase, construction phase and operations phase)

- R&D phase - not yet known
- Construction cost - full detector estimated to cost 55MCHF
- Operations - not yet known

Does your project plan dedicated submission(s) for the ESPPU (if so, give details).

- Expect so but not yet clear what form it will take