The SHiP experiment

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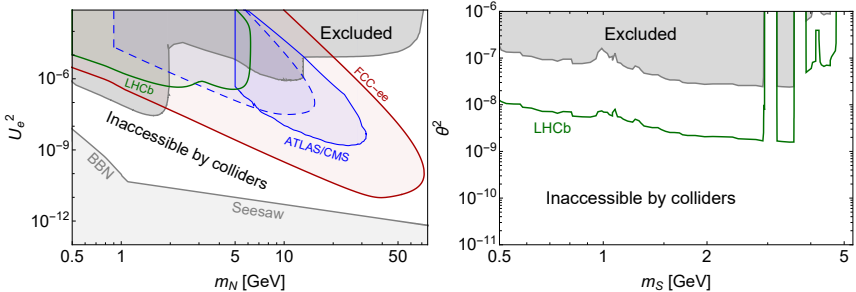
2024-06-07

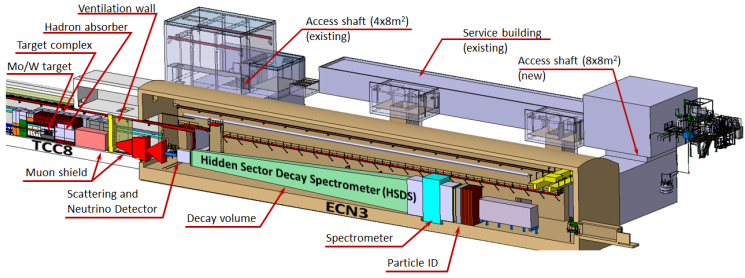
Sensitivity frontier

Many mysteries beyond the Standard Model remain, and at the GeV-scale there are plenty of areas, where New Physics could by hiding from collider experiments [see e.g. Andrea's talk for a TH overview]



SHiP is designed to explore these blank spots on the map!

[SPSC-P-369]

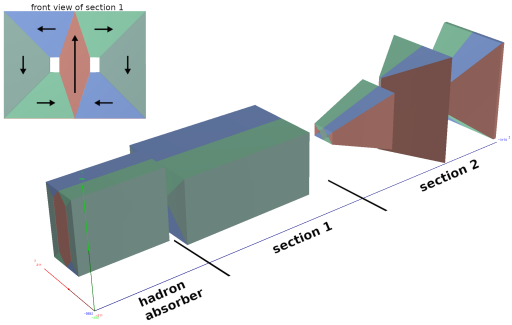


- General purpose beam dump experiment at SPS with 400 GeV and 4×10^{19} PoT per year
- Annually, 2×10^{17} charmed hadrons, 1.4×10^{13} beauty hadrons, 2×10^{15} tau leptons and $\mathcal{O}\left(10^{20}\right)$ photons above $100\ \mathrm{MeV}$, as well as unprecedented sample of ν_τ
- Plan for 15 years of running → $6 \times 10^{20}\ \mathrm{PoT}$

Muon shield

[SPSC-P-369, CERN-THESIS-2019-157, J.Phys.Conf.Ser. 934 (2017) 1, 012050, 2002.04632 10.25560/95975]

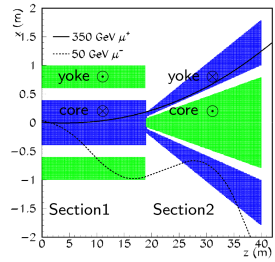
Hybrid muon shield



Hadron absorber Warm

Section 1 Superconducting

Section 2 Warm

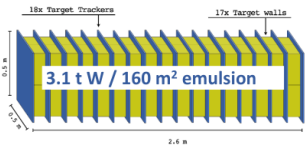


- With robust warm fallback, baseline is now a hybrid muon shield
- A new campaign of optimisation of the different options using reinforcement learning and surrogate models kicking off

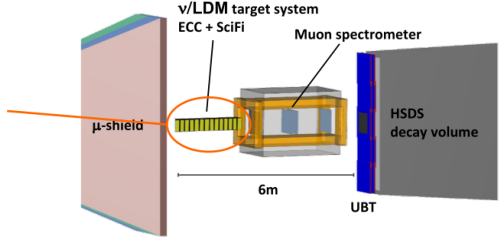
SND@SHiP: Emulsions

› SND undergoing re-optimisation for neutrino physics and light dark matter

› Original design based on OPERA and now proven at SND@LHC



(Emulsion ~4 x SND@LHC)



› SPS offers possibilities complementary to HL-LHC, lower energy and boost, space, large (anti-)neutrino yields (approx. 10^6 ν_e, 10^7 ν_μ, 10^5 ν_τ → no longer statistically limited)

[see Ettore's [I,II] and Chris's talks for more about SND@LHC and nuclear emulsions]

SND@SHiP: Silicon

[AdvSND LoI: LHCC-I-040]

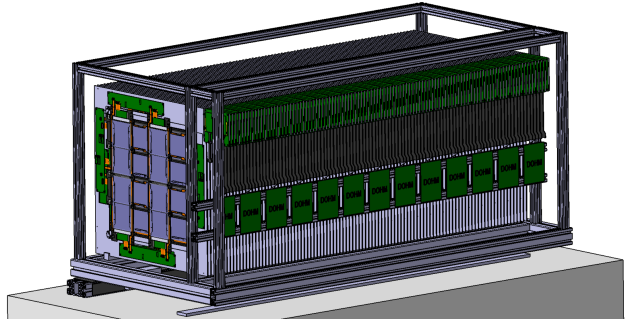
Inspired by SND@LHC upgrade for the HL-LHC

Advantages

- Realtime readout allows full integration with other detectors
- Unique signatures accessible

Challenges

- Vertex resolution of emulsions impossible to equal
- Reconstruction of “double-kink” challenging

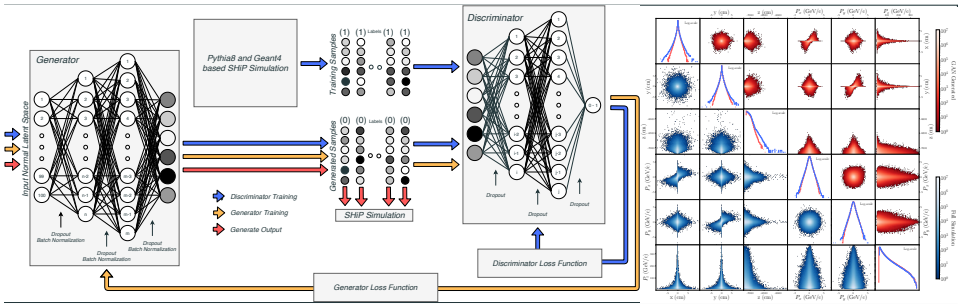


- CMS TOB modules baseline for AdvSND, sensor options for SHiP under study

Computing challenges at SHiP

SHiP faces unique challenges:

- Design intensity many orders of magnitude beyond what is possible with full simulation
  - GANs [JINST 14 (2019) P11028]
- Even rarest processes need to be understood → biasing, factorisation

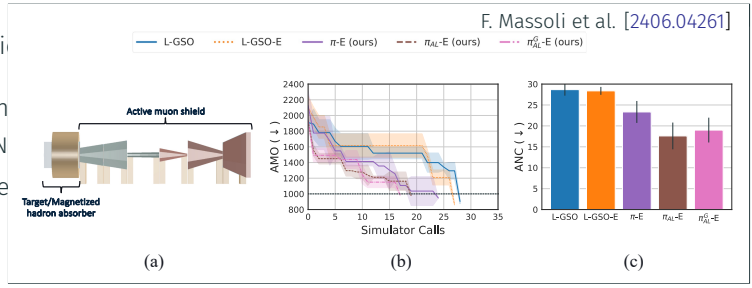


Computing challenges at SHiP

SHiP faces uni

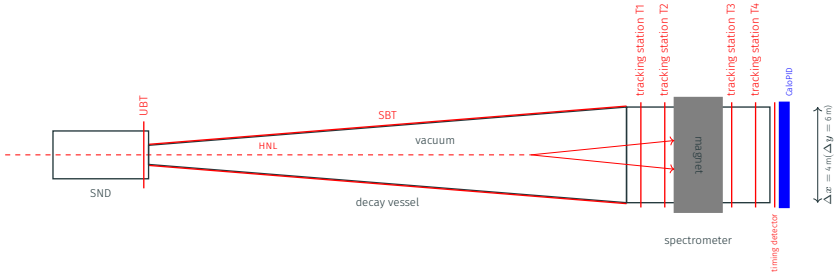
- Design in simulation
  - GAN
- Even rare

F. Massoli et al. [2406.04261]



- Well optimised muon-shield crucial to reach physics goals, many degrees of freedom
  - Bayesian optimisation [CERN-THESIS-2019-157]
  - L-GSO [2002.04632, 10.25560/95975]
  - Reinforcement learning [2406.04261]
- Reconstruction of scattering signatures in emulsions and Si non-trivial!
- How can we be sensitive to unknown unknowns? → anomaly detection using variational autoencoders [WiP]

The SHiP hidden sector detector

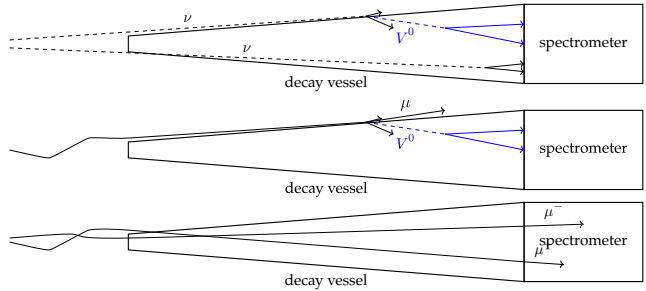


- Full spectrometer allows measurement of
  - invariant mass, impact parameter, decay vertex of signal candidate
  - distinguish between signal models using PID of decay products
- If LLPs are discovered, detector can perform precision measurements of LLPs
- Background taggers and timing detector allow powerful background rejection

Backgrounds

[See Proposal for full details]

- Very minimal selection common to all signal channels sufficient
- Background tagging under optimisation to improve signal efficiency while maintaining reliable background rejection

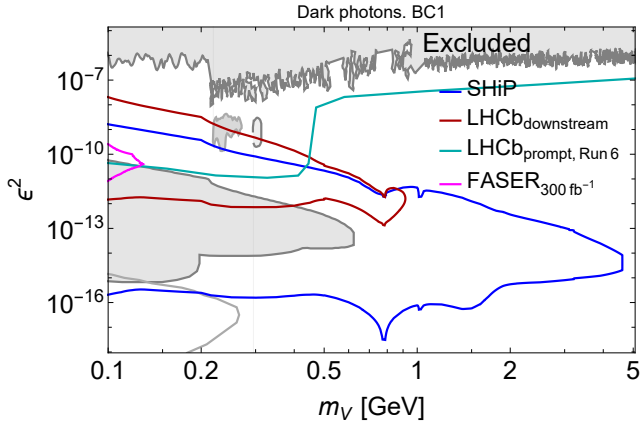


Background source	Expected events in 15 years
Neutrino DIS	< 0.1 (fully)/< 0.3 (partially)
Muon DIS (factorisation)	$< 5 \times 10^{-3}$ (fully) / < 0.2 (partially)
Muon combinatorial	$(1.3 \pm 2.1) \times 10^{-4}$

Sensitivities

- SHiP has full simulation for HNL with arbitrary coupling, dark photons and RPV SUSY, in excellent agreement with `SensCalc`, which is used for all other channels
- Common, minimal selecton for all channels
- Showing Physics Beyond Colliders (PBC) benchmarks here for easy of comparison: SHiP is designed to be as model-independent as possible for
  - Fully reconstructed decays to charged particles or photons
  - Partially reconstructed decays where e.g. a neutrino escapes detection
  - Diphoton vertexing possible
- All sensitivies for 15 years (6×10^{20} PoT)
- Lines from other experiments taken from the FIPs 2022 summary plots

Sensitivity: Dark photons to visible fermions (BC1)



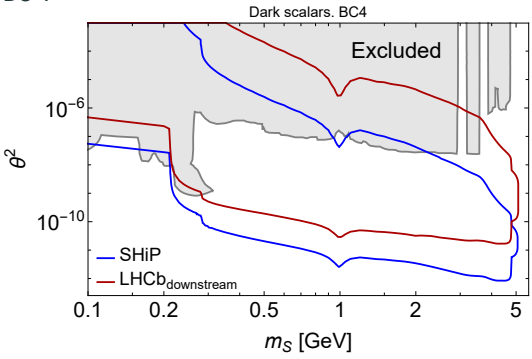
[LHCb downstream 2312.14016]

- Implemented in full simulation
- Production taken into account via:
  - Bremsstrahlung
  - Meson decay
  - QCD

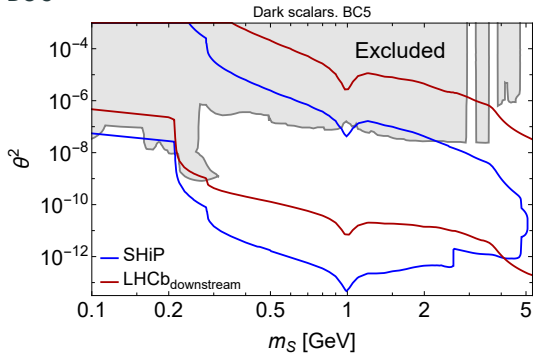
Detailed study for ECN4: Eur.Phys.J.C 81 (2021) 5, 451

Sensitivity: Dark Scalars

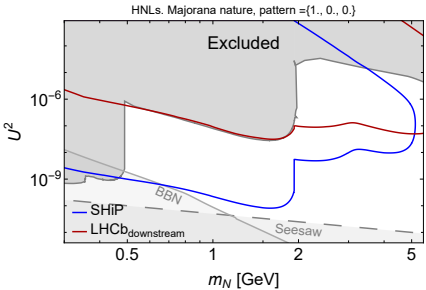
BC 4

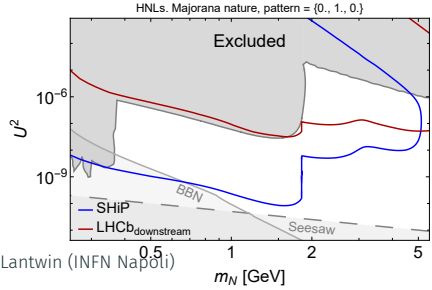


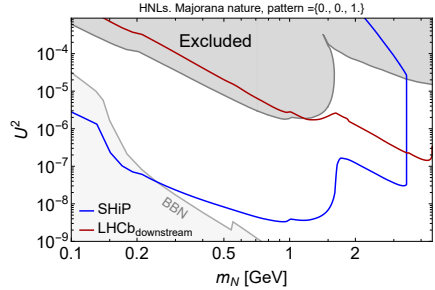
BC 5



Sensitivity: HNL



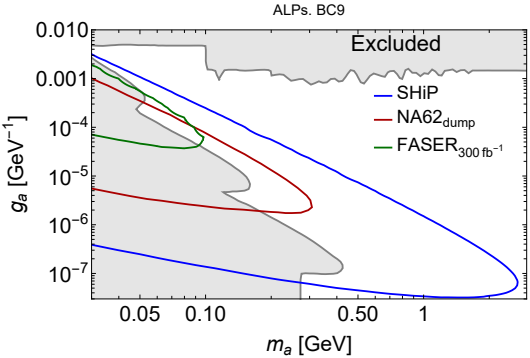


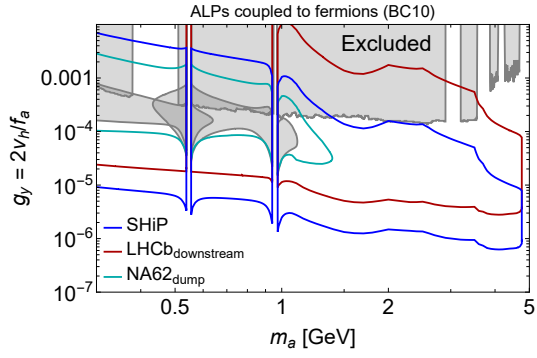


- Arbitrary coupling ratios implemented in full simulation
- Production from charm and beauty hadrons considered
- Could measure HNL oscillations in large regions of currently unexplored parameter space, see JHEP 04 (2020) 005

Detailed study for ECN4: JHEP 04 (2019) 077

Sensitivity: ALPs

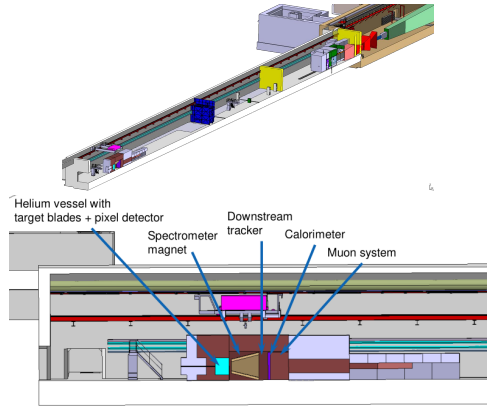




BDF beyond SHiP

Several groups outside of SHiP have started evaluation concurrent uses of the BDF facility, which provides a unique spectrum of particles at very high intensity!

› TauFV upstream of BDF



[L. Krzempek]

Plenty of space for new ideas!

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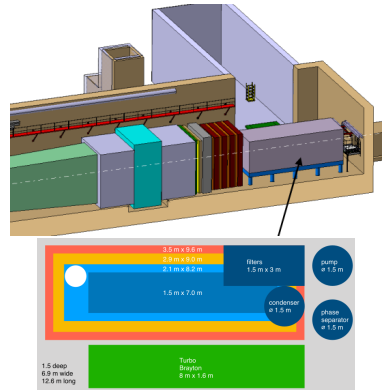
- TauFV upstream of BDF
- LAr TPC for long lived particles, light dark matter and neutrinos



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[F. Resnati, JHEP 02 (2024) 196]

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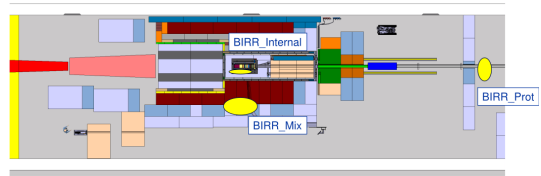
- TauFV upstream of BDF
- LAr TPC for long lived particles, light dark matter and neutrinos
- Irradiation facility for development of radiation hard electronics (e.g. for FCC), nuclear physics and astrophysics



[M. Calviani]

Plenty of space for new ideas!

Conclusion

- SHiP is a general-purpose beam dump experiment exploring the sensitivity frontier in decay and scatter, complementary to the LHC.
- In March 2024, SHiP/BDF at the ECN3 beamline of the SPS has been approved for the TDR phase
  - TDRs by 2026
  - Commissioning 2031

We're ready to set sail, now the real work starts!

Plenty of room to get involved in for new groups and individuals (physics (ex and ph), hardware, software, ML...)