SHADOW EoI

Search for Hidden and Dark Objects With the SPS

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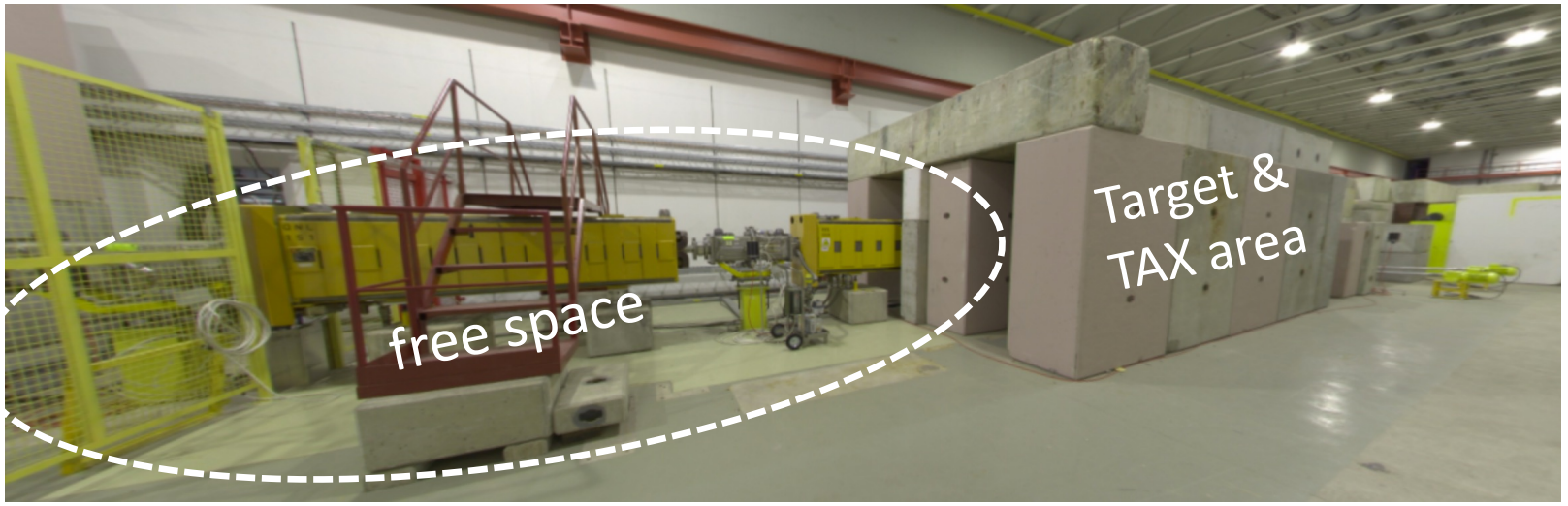
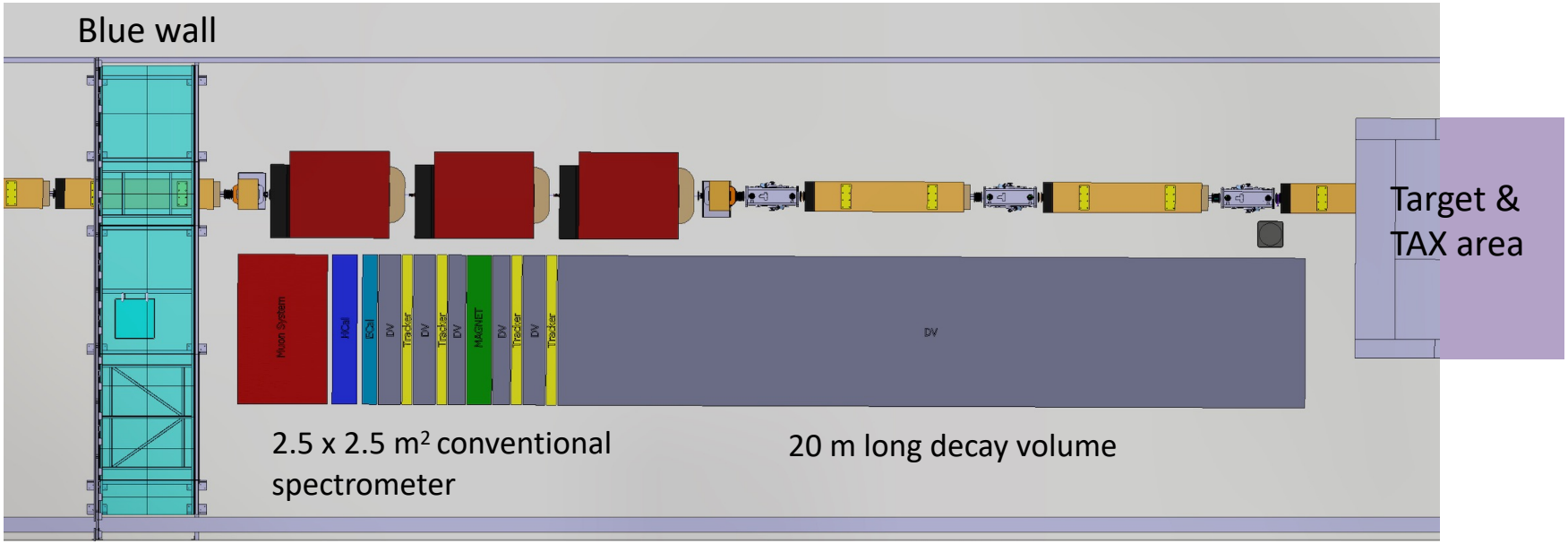
145th SPSC Meeting, CERN, 13th April 2022

Idea

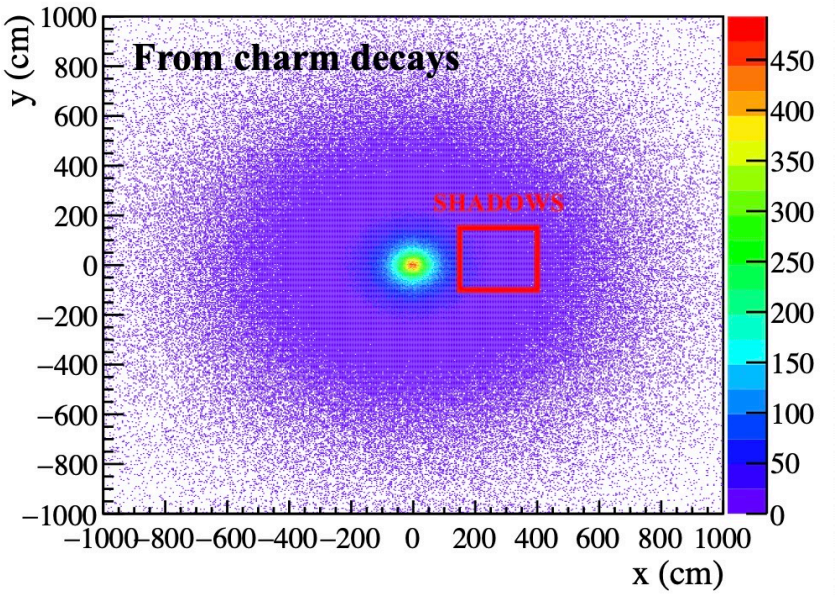
Exploit the possible 6x intensity upgrade of the 400 GeV/c proton K12 beam line in LS3

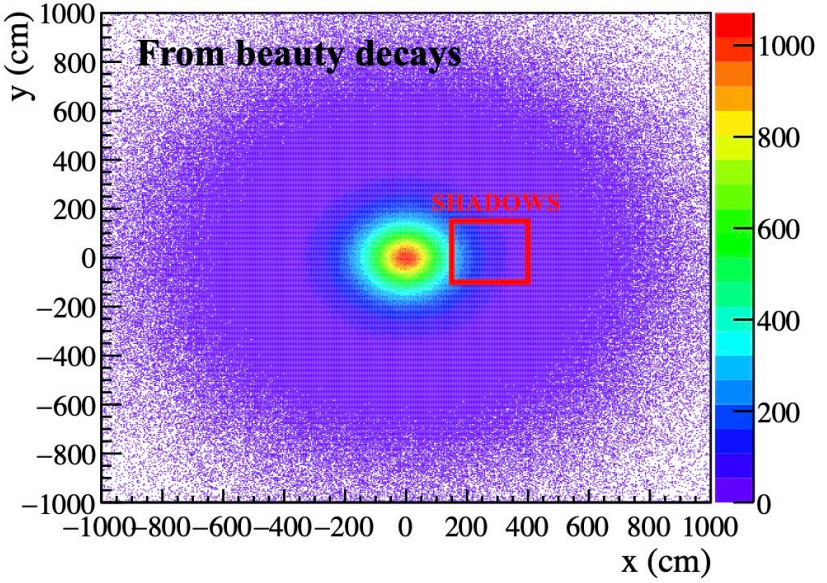




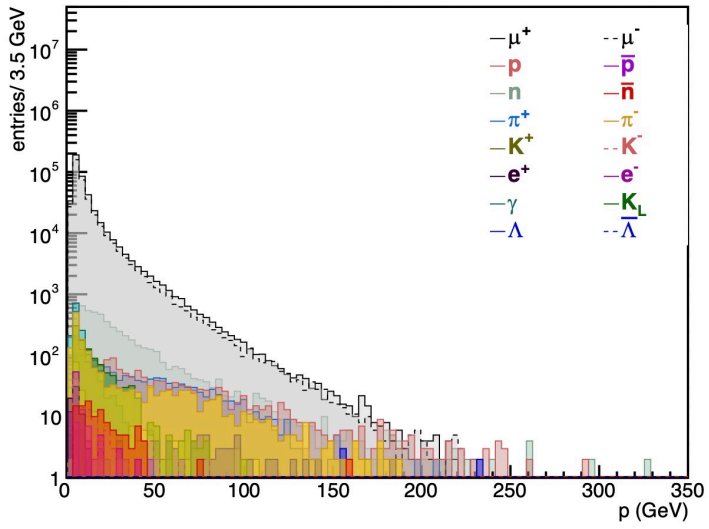
Off-Axis Concept

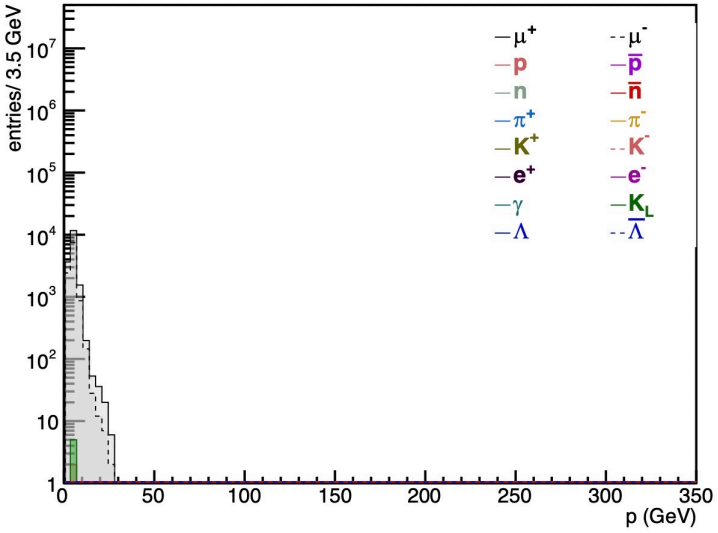
FIPs emerging at large angle from charm and beauty decays





Background is dominated by forward muons and neutrinos from kaon and pion decays

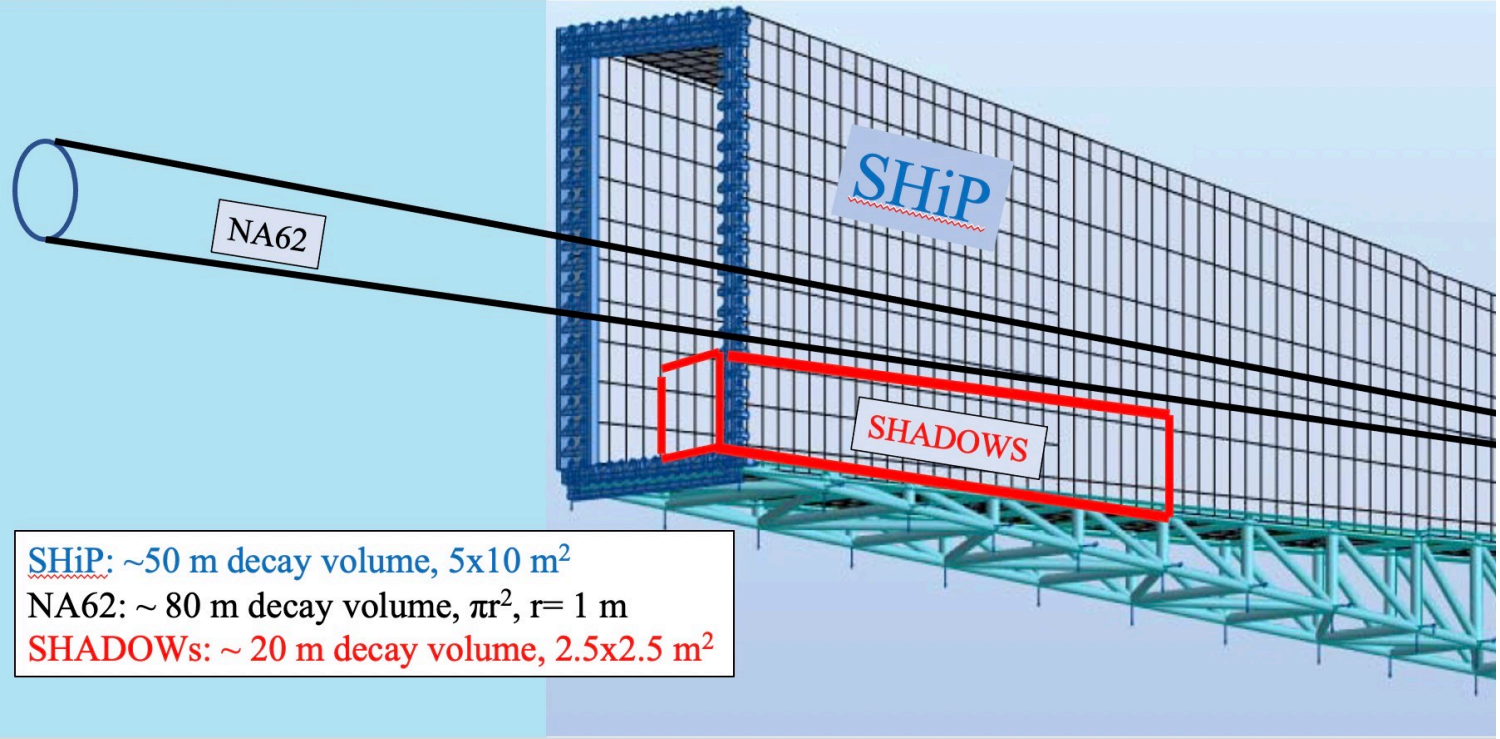




Complementarity

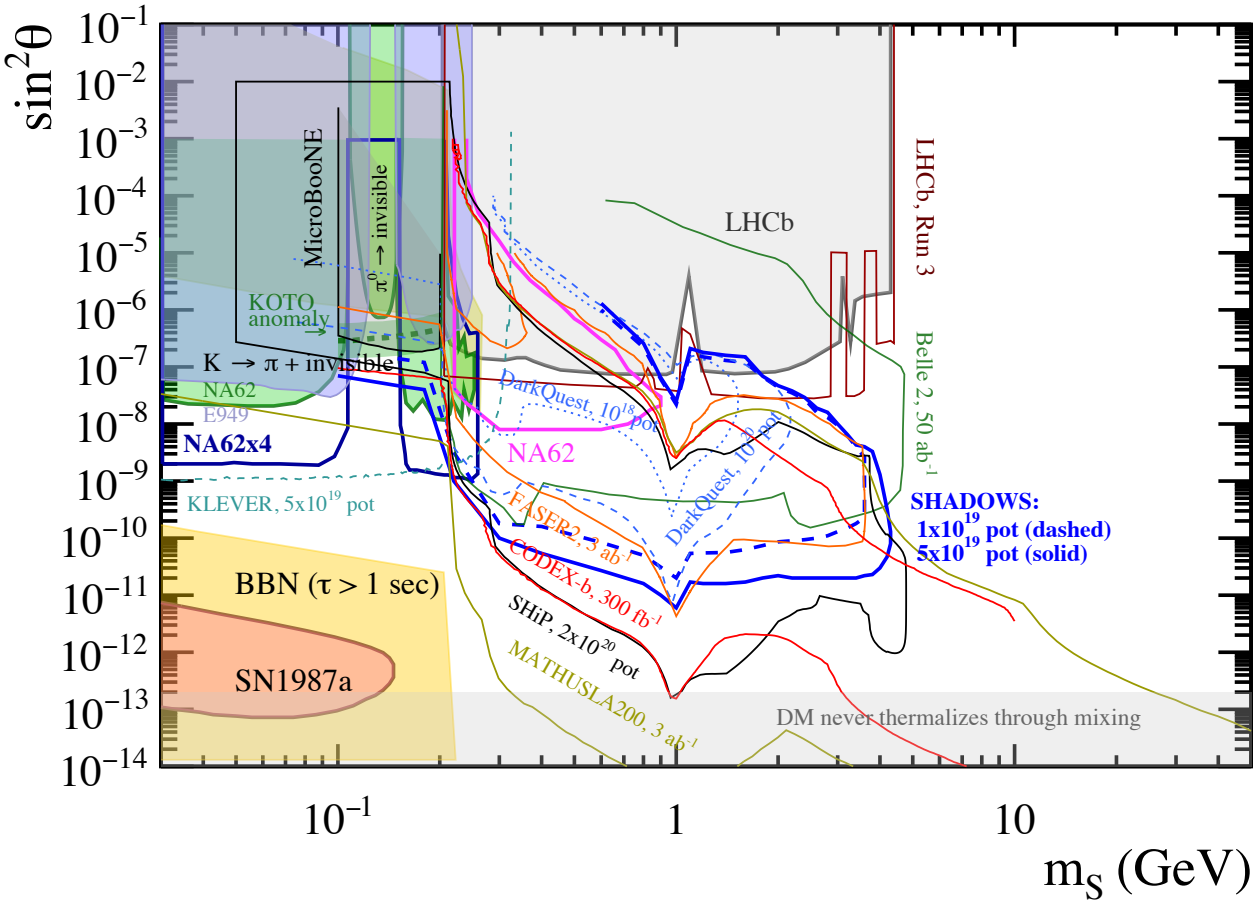
@LHC
- CODEX-b: UX85 cavern on a side of LHCb to un in parallel with LHC-HL
- FASER2: TI12 (UJ12, UJ18) enlarged cavern very forward of ATLAS
- MATHUSLA: very large area surface detector above ATLAS or LHC

@SPS
- SHiP: new major beam dump facility



Strong scientific case for searches for FIPs in general: many proposed projects in this area, and large interest driven in the community. Still some of the projects have grown to sizes where it is possible that they will never happen, and an experiment that can do most of the job on a shorter time scale is very attractive.

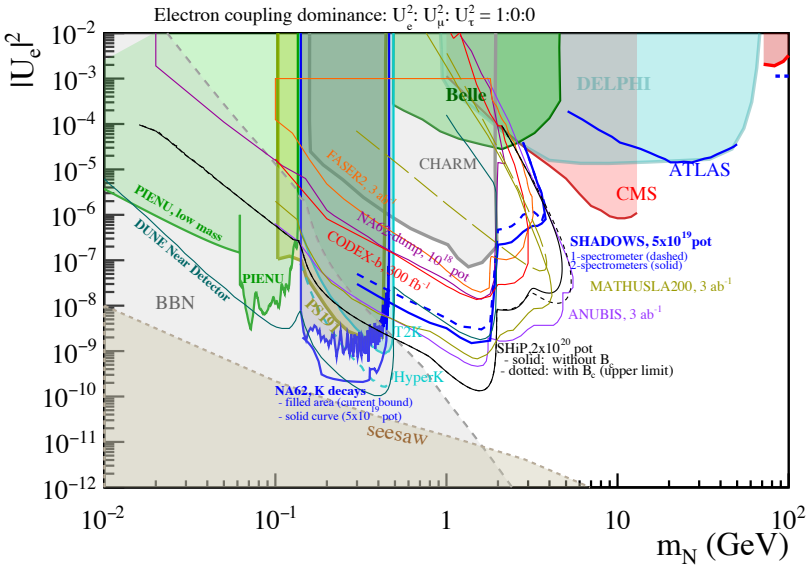
Light Dark Scalar mixing with Higgs



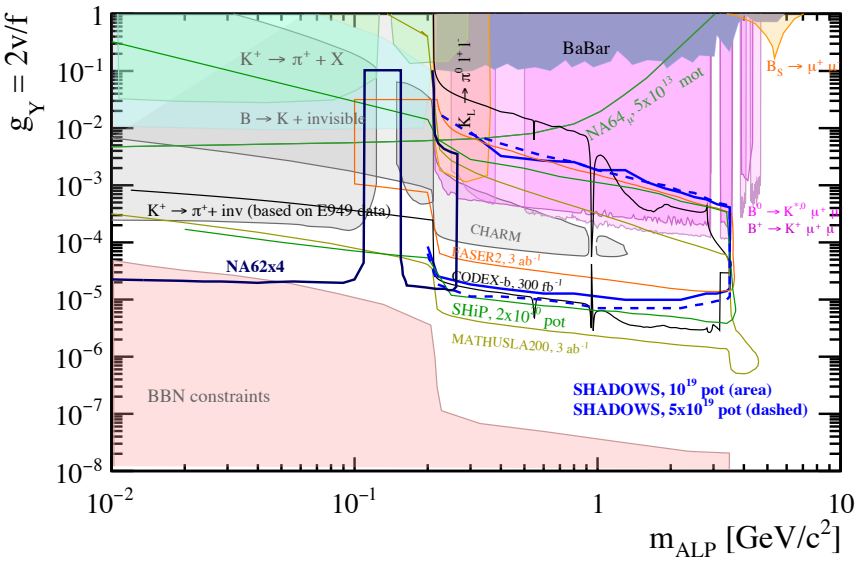
NA62++: in K-mode covers the range below K-mass, in dump-mode works on-axis. Strong complementarity with SHADOWS.

Physics Reach

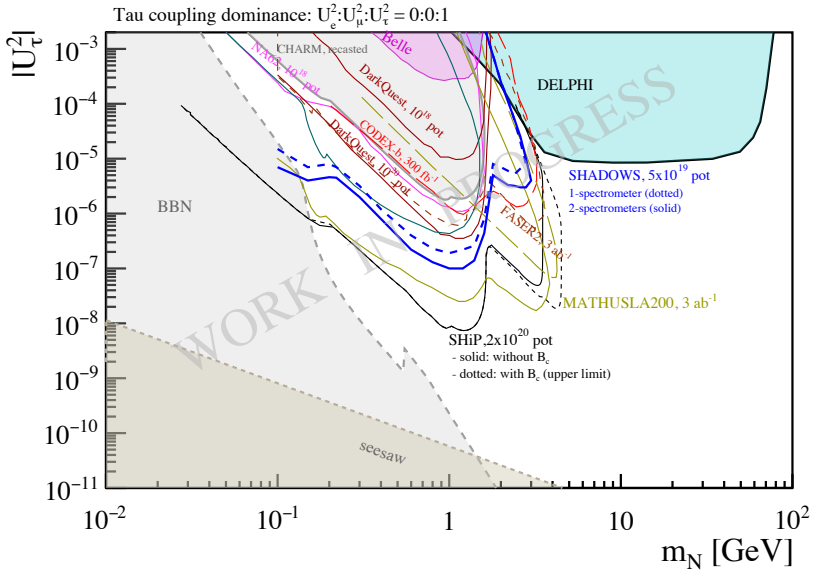
Heavy Neutral Leptons (electron coupling)



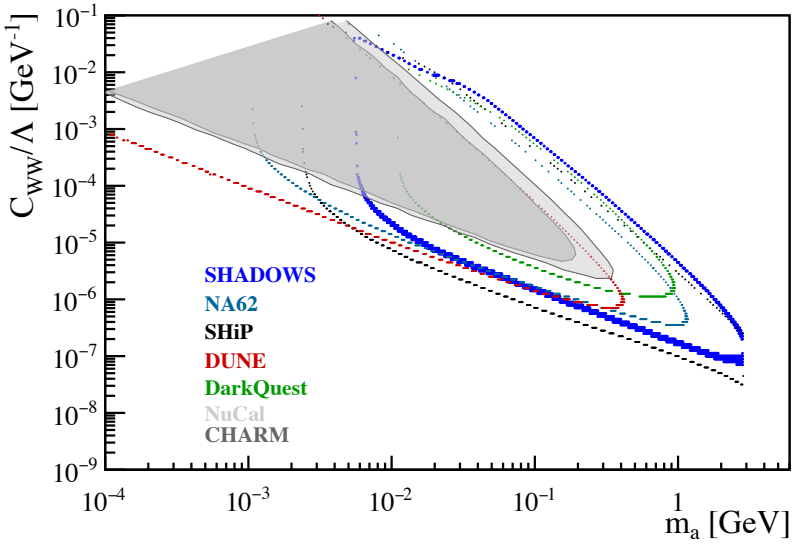
Axion-like particle at the QCD scale: fermion coupling



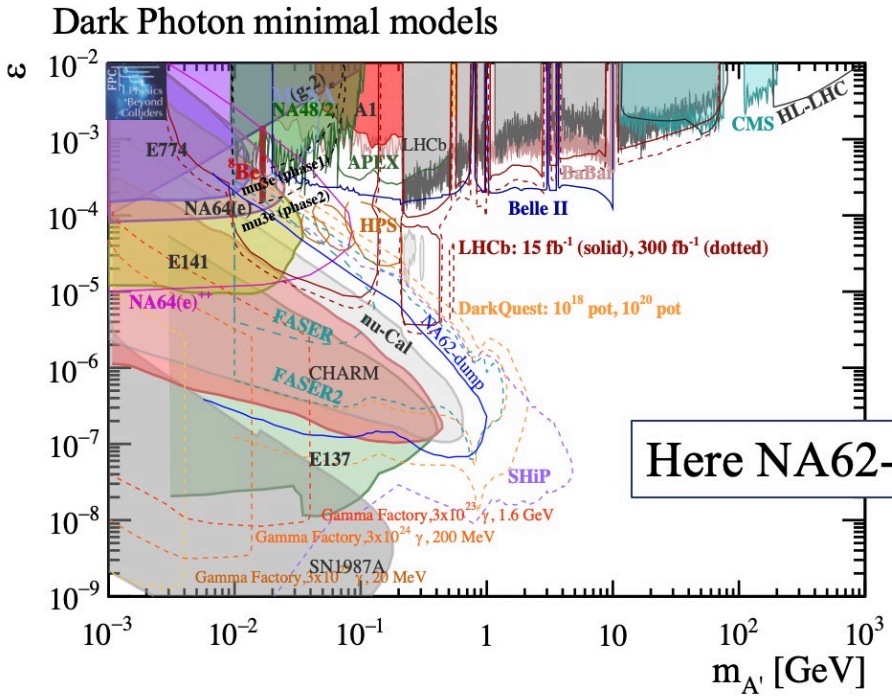
Heavy Neutral Leptons (tau coupling)

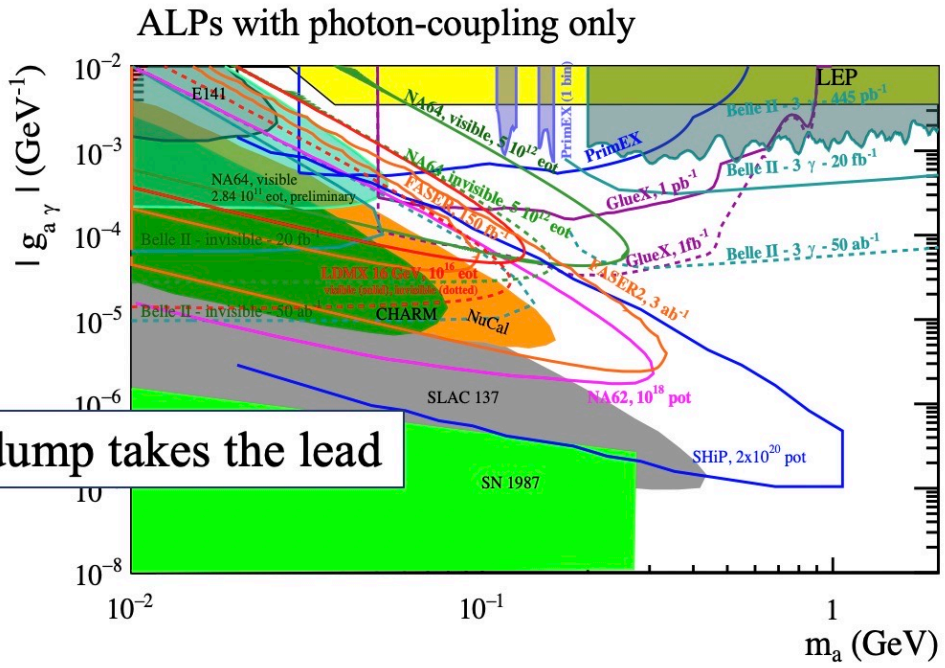


Axion-like particle at the QCD scale: W coupling



Physics Reach





Here NA62-dump takes the lead

A broad and synergistic programme for Hidden Sector
can be done in ECN3 with NA62-K, NA62-dump and SHADOWS.
Together can provide an unprecedented physics reach over international landscape

Kaon and FIP physics would add value to a future investment in the K12 beam line and running time.

Backgrounds

Preliminary considerations:

Three main backgrounds:

✓ Muon combinatorial
(based on the NA62 beam line simulation)

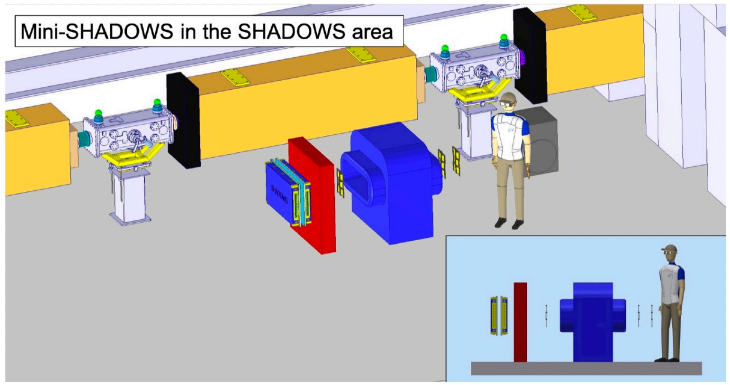
✓ Neutrinos inelastic interactions with the air in the decay volume
(not yet simulated, just analytic calculation)

✓ Muon and neutrino inelastic interactions in the material at the entrance of the vessel
(working on the NA62 beam line simulation)

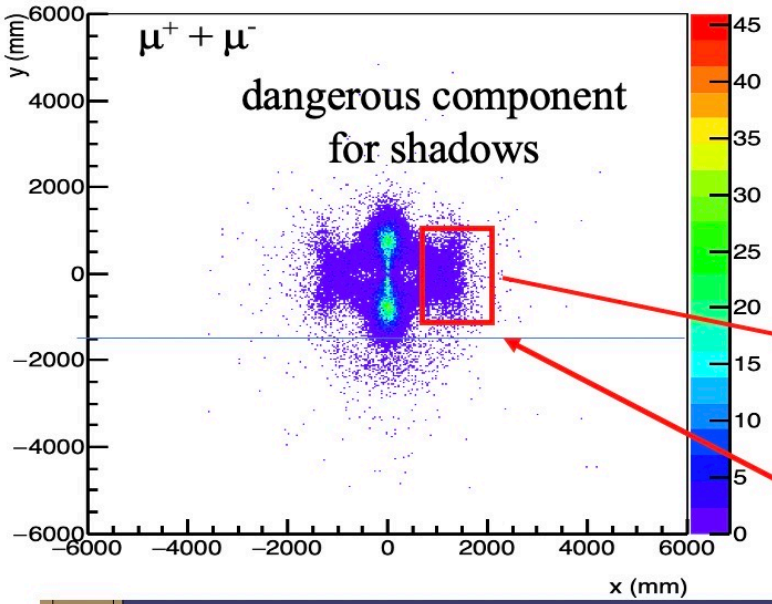
MIB still to be designed and full MC of the detector still to be implemented.
Today preliminary considerations based on the MC truth of a simulated sample of 1.3 x10^9 pot on dump.
A detailed study of the background will be done for the Proposal.

Possible benchmark:

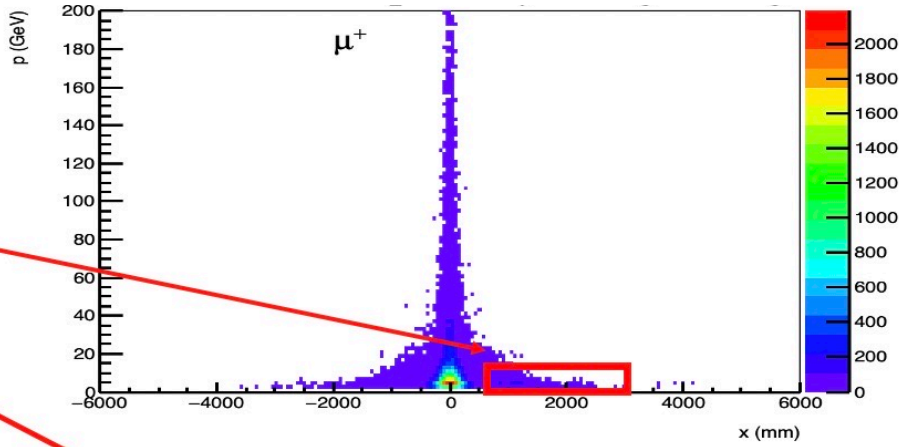
Mini-SHADOW for the measurement of the muon flux

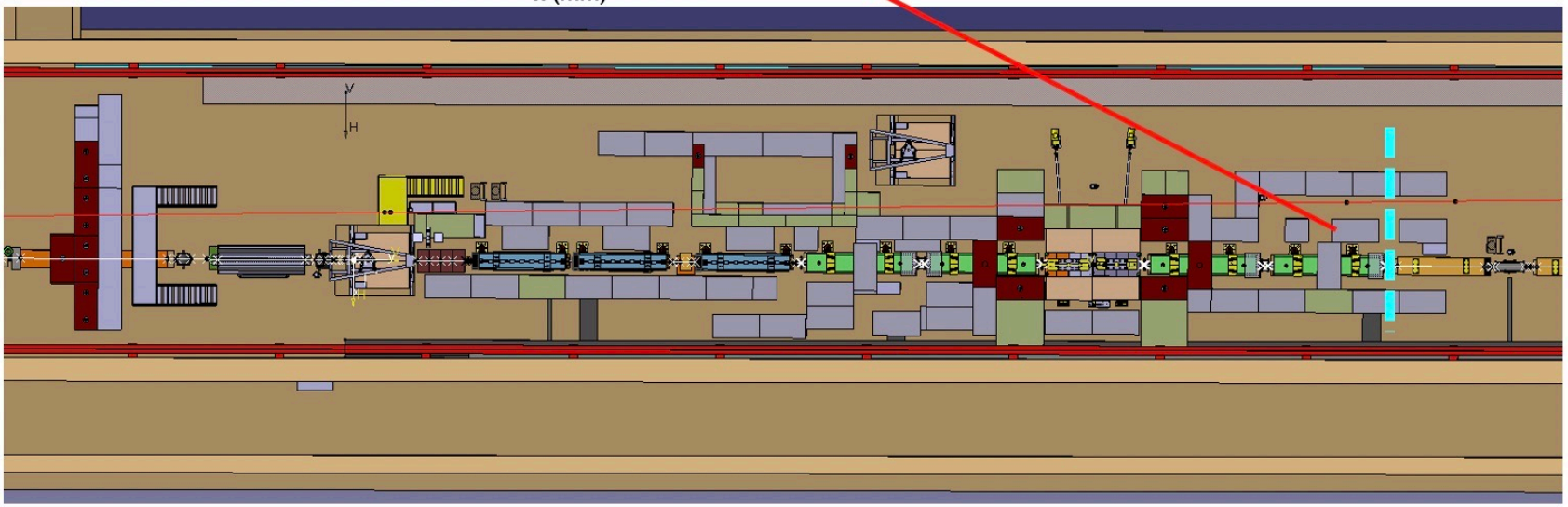


Muon Background

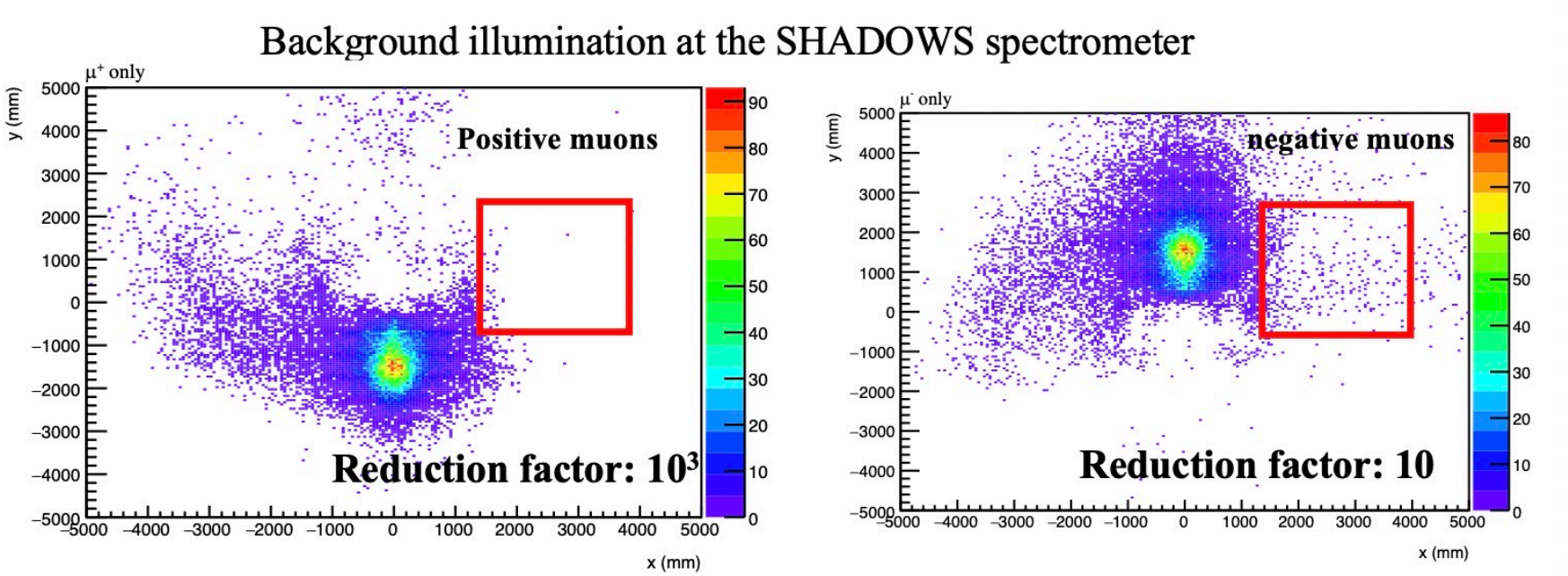


Low-p (<15 GeV) muons that can be swept away by a magnetized iron block (MIB)



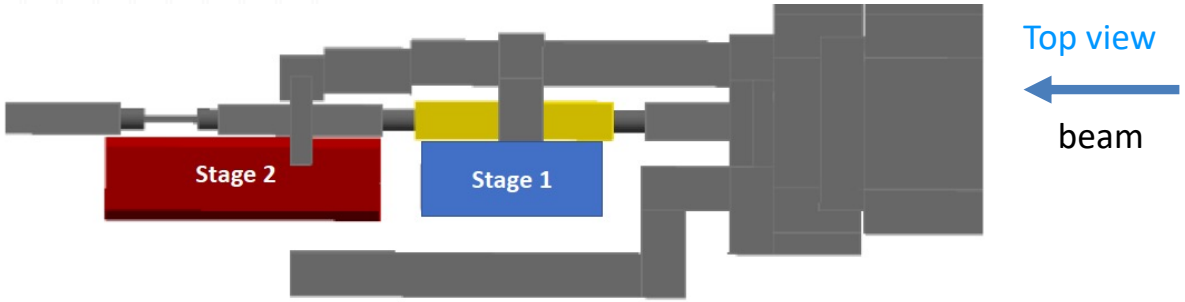


MIB Sweeping System

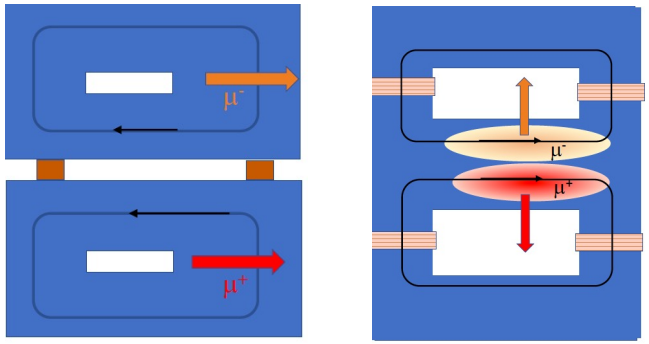


Stage 2: horizontal bending

Stage 1: vertical bending



Front view



MIB optmization is under study

Combinatorial Muons

N(μμ) initial = 4×10^6 /spill after MIB

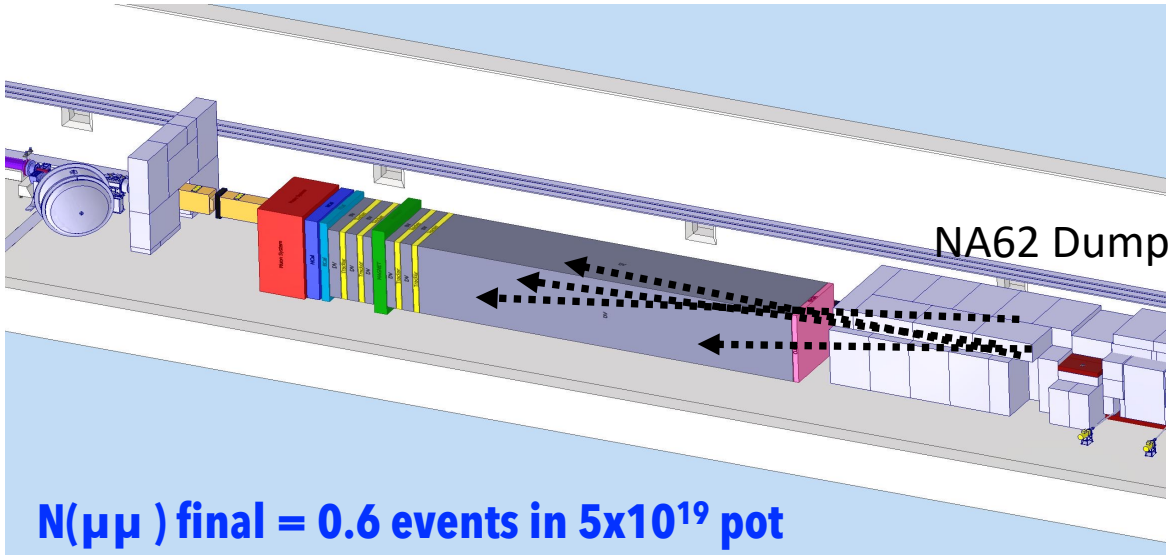
1) timing: Require 2 muons in 3 sigma window of the Timing layer N(μμ): 2400/spill

2) Upstream Veto: assume eff = 99.5%. Probability of non-vetoing two tracks: $2.5\ 10^{-5}$

3) Vertex in FV: Probability to have a vertex in FV: $3\ 10^{-3}$

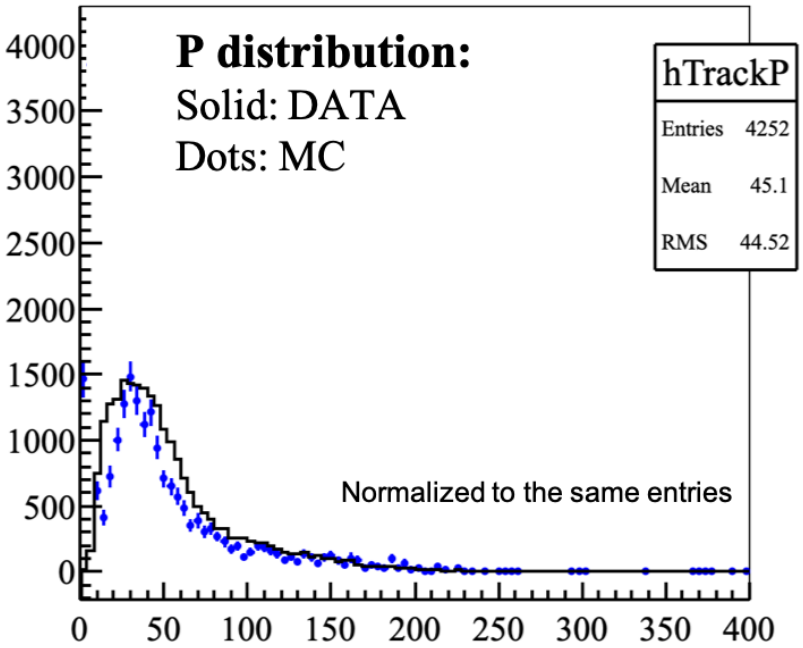
4) Pointing: Probability to point back to impinging point of protons onto the dump: 10^{-3}

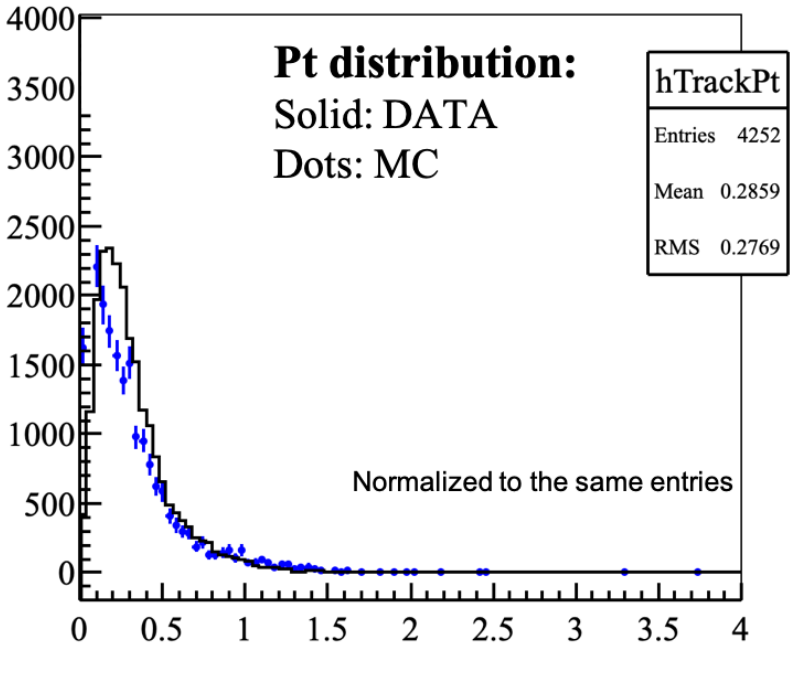
ALL IN ALL : 2×10^{-7} μμ /spill, 3×10^6 spills in 5×10^{19} pot



Backgrounds

NA62 has collected about 1.7 x10^{17} pot in dump in November 2021





This data set allows to validate the output of the MC simulation (based on BDSim package, GEANT4). Shapes of distributions are reasonably well reproduced, simulated rates are under-estimated by a factor 3 in the momentum range of interest for SHADOWS.

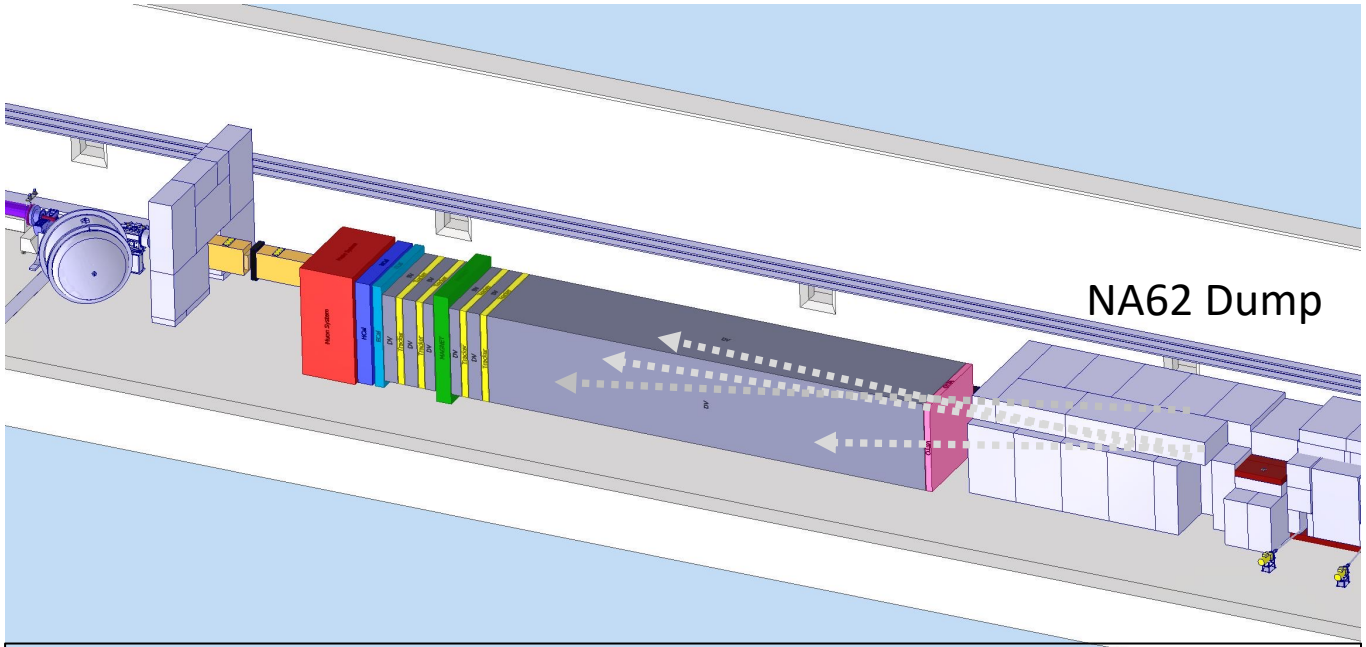
Caveat: simulation bechmarked on forward 1% of the phase space
issue in normalization, possible alternate sources when off axis.

Number of neutrinos in SHADOWS acceptance:

$$N_\nu = N \times 2 \cdot \chi_{c\bar{c}} \times 2 \cdot BR(c \to e/\mu X) \times \epsilon_{\text{acc}} \sim 6 \cdot 10^{15}$$

Number of inelastic interactions in 20 m long decay volume filled by air at atmospheric pressure, for $E\nu \sim 10$ GeV:

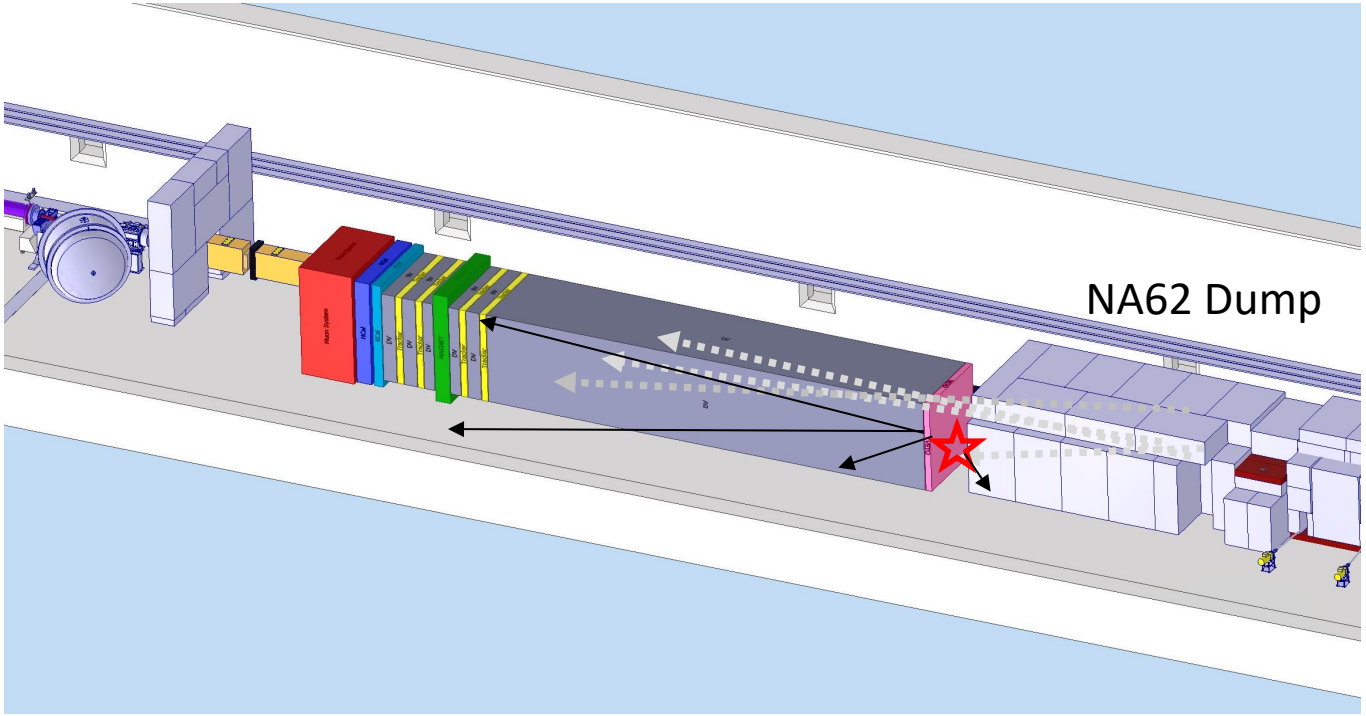
$$N_{\nu \text{ inelastic int.}} = N_\nu \times 10^{-13} = 6 \cdot 10^{15} \times 10^{-13} = 600$$



N(ν inel. interactions in DV, 1 mbar) = 0.6 events in 5x10^{19} pot

Secondary Interactions

These interactions give signal in the Upstream Veto (UV), form a vertex very close to the boundaries of Decay Volume and do not point back to the impinging point of the proton beam onto the dump. Work in Progress.

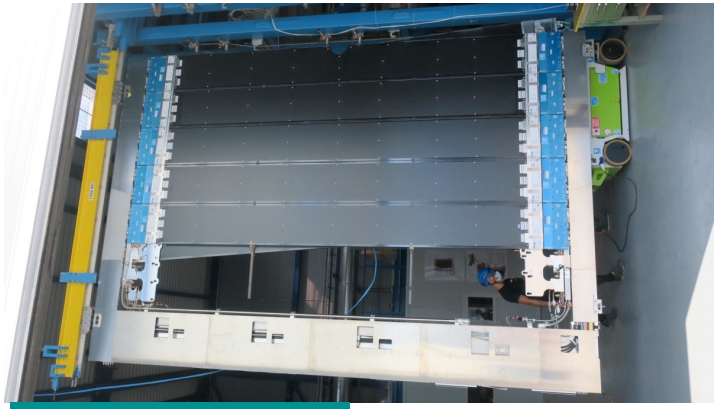


Caveat: A vacuum vessel would add a lot of un-vetoed material
Neutrino flux has not been simulated

Exploring the existing solutions

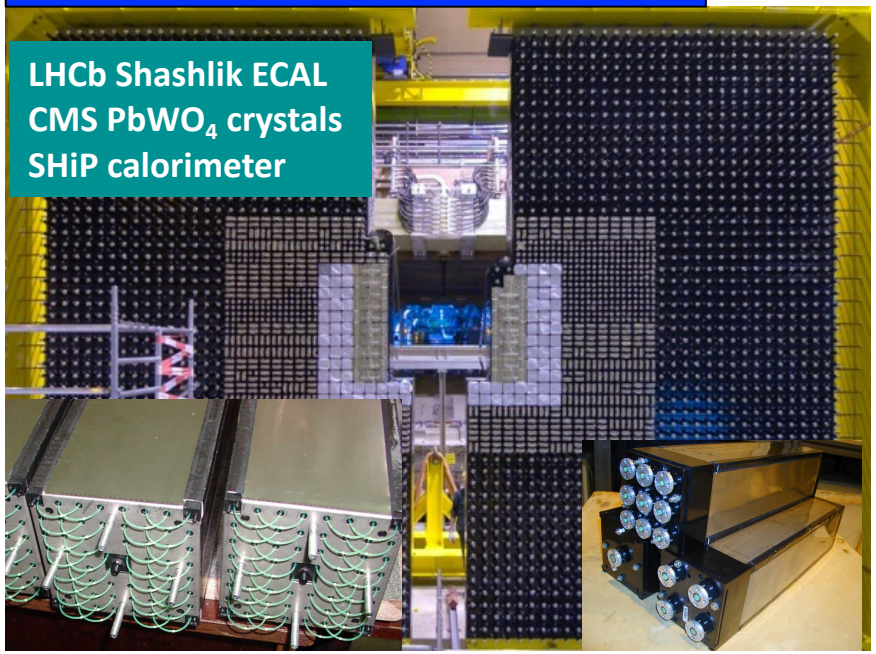
Possible interest: Heidelberg, CERN,…

NA62 STRAW chamber



LHCb SciFi modules

Possible interest: Mainz. Karlsruhe, INR,…

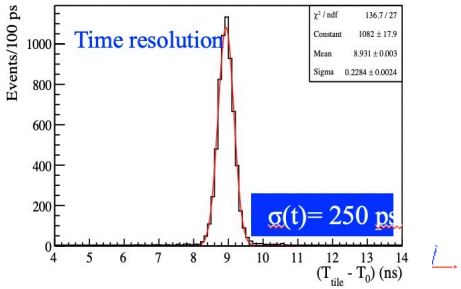


LHCb Shashlik ECAL
CMS $PbWO_4$ crystals
SHiP calorimeter

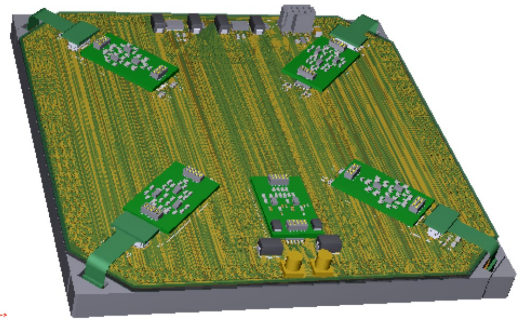
Possible interest: INFN (Frascati, Bologna, Ferrara), INR, ..

INFN / AIDA-innova

Efficiency > 99.5%



Sci tiles + SiPM



Cost

Table 2. Very preliminary cost estimate of SHADOWS sub-detectors.

Sub-detectors	Possible Technology	very preliminary) cost
Upstream Veto	Micromegas	0.2 MCHF
Decay Vessel	in vacuum	1 MCHF
Dipole Magnet	warm	4-5 MCHF
Tracker	NA62 Straws or SciFi	3 MCHF
Timing Layer	small scintillating tiles	0.1-0.2 MCHF
ECAL	Shashlik	2-3 MCHF
Muon	scintillating tiles	0.4-0.5 MCHF
TDAQ & offline		o(1-2) MCHF
Total		$\sim 11.6 - 14.9$ MCHF

The detector costs are assumed to be covered by SHADOW

The strategy of re-using detector technologies from other experiments is beneficial both for scheduling and costs. And they seem to be talking to the right groups to make that happen.

Infrastructure

Critical items in beam line/infrastructure:

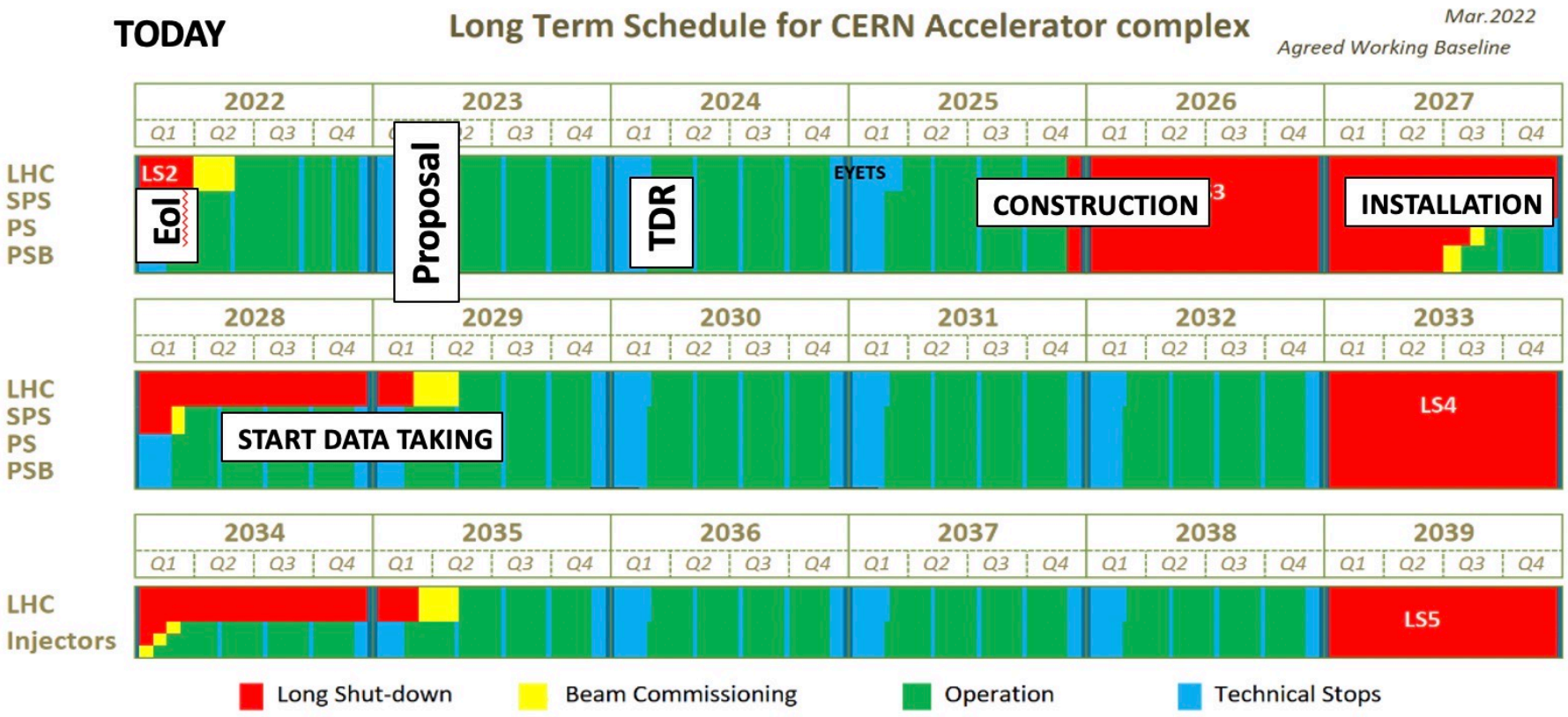
1. MIB (design and realization) as part of the K12 TAX shielding (largely in common with NA62);
2. New TAX system (both K12 and P42 TAXes) (able to stand × 6 intensity) (in common with NA62);
3. Integration studies for SHADOWS detector in ECN3/TTC8.
4. Radiation Protection studies for beam intensity ×6 (in common with NA62);
5. Refurbishment of the electrical infrastructure of the area, power converters for MIB, tracker dipole.

Critical items for SHADOWS:

1. Dipole magnet of the tracker;
2. Decay vessel.

Caveat: A not negligible investment is required for the beam line upgade
A sizeable fraction would be synergic with NA62++

Timeline



Aggressive schedule justified by the strategy to point to an experiment done for a reasonable cost at a reasonable time scale.

Minutes

The SPSC **takes note** of the expression of interest SPS-EOI-022 in searching for a large variety of feebly interacting particles in the MeV-GeV mass range, possibly produced in the interactions of an upgraded high-intensity K12 proton beam with a high-Z material dump at SPS (SHADOW).

The Committee **encourages** the proponents to supplement additional information provided in form of a proposal. The proposal should conform to the standards and benchmarks of the PBC working group, include a complete study of the possible background sources with an assessment of the relative uncertainties and mitigation measures, and a detailed evaluation of the necessary beam line modifications and required resource allocations.