Universität Zürich UZH

Physik-Institut

SHiP
Search for Hidden Particles

Future Intensity Frontier

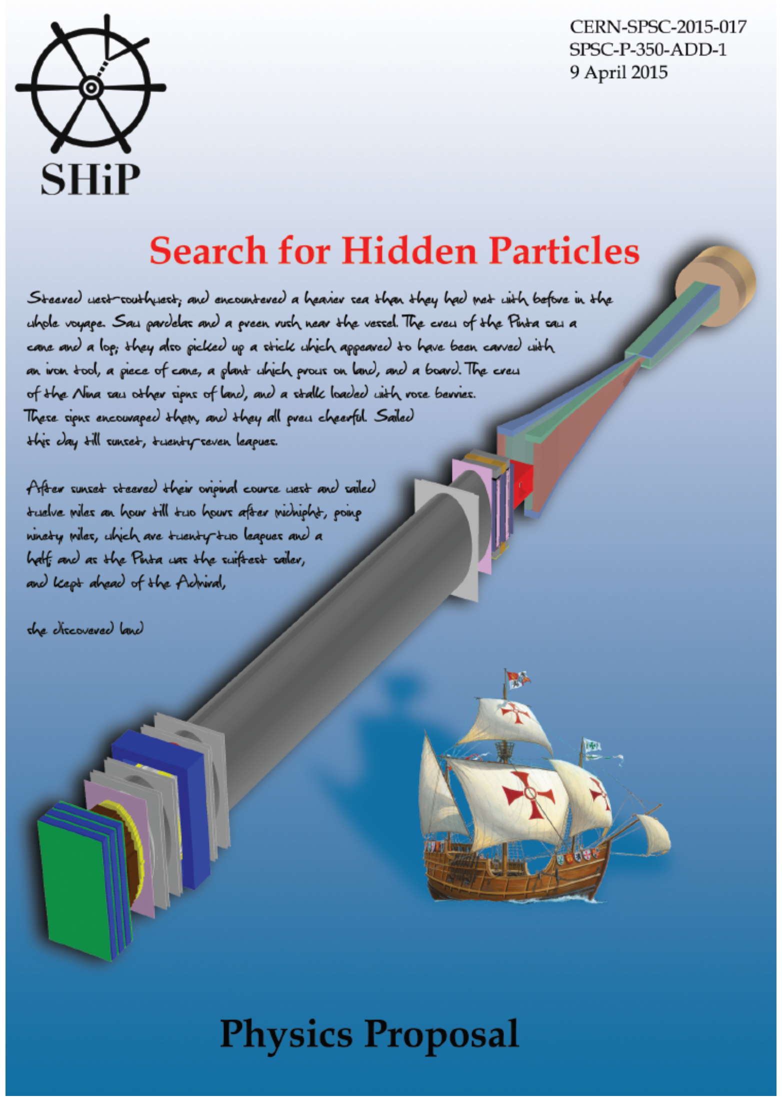
Nico Serra (Universität Zürich)
On behalf of the SHiP Collaboration

Neutrinos at High Energy Frontier
University of Massachusetts Amherst

Outline

- Introduction: why high intensity frontier?
- General concept of the experiment
- Physics case with a few examples (HNLs, Dark Photon, ALPs, Dark Scalar)
- Challenging and how to solve them:
    - High intensity and low background: Target and muon shield
    - Control the low background: Vetos and vacuum vessel
    - Many different final states: Hidden Sector Spectrometer

Introduction



CERN-SPSC-2015-017
SPSC-P-350-ADD-1
9 April 2015

SHiP

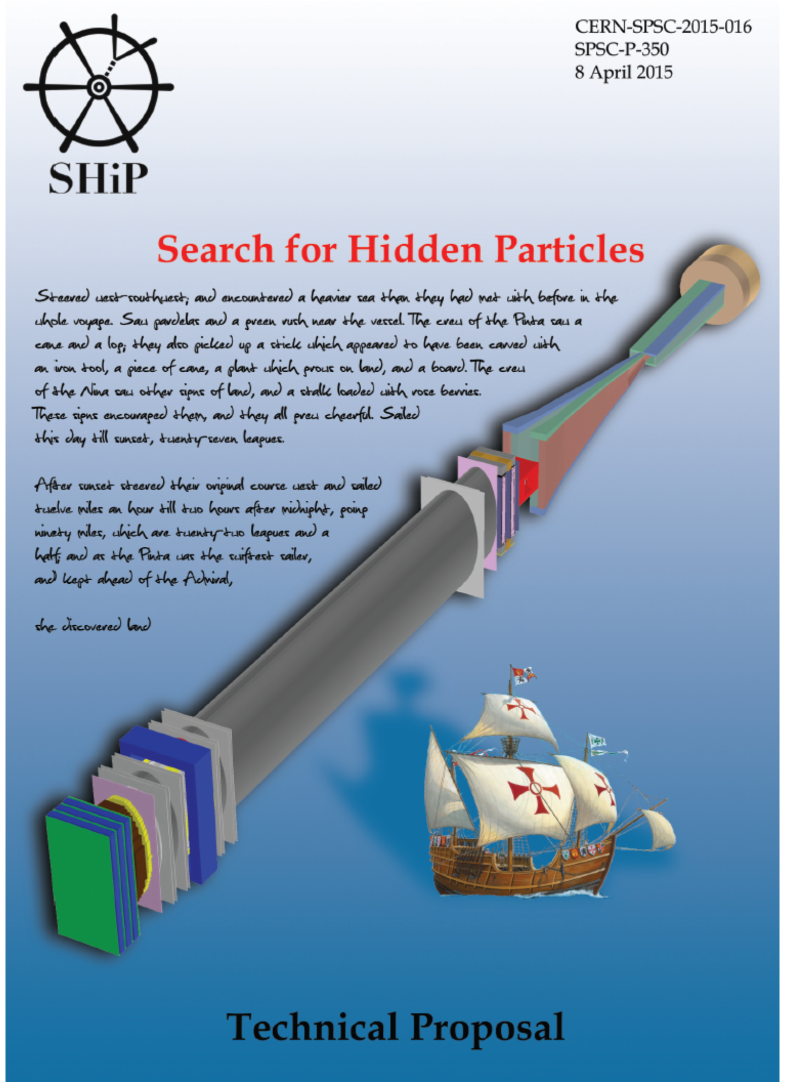
Search for Hidden Particles

Steered west-southwest; and encountered a heavier sea than they had met with before in the whole voyage. Saw pardelas and a green rush near the vessel. The crew of the Pinta saw a cane and a log; they also picked up a stick which appeared to have been carved with an iron tool, a piece of cane, a plant which grows on land, and a board. The crew of the Nina saw other signs of land, and a stalk loaded with rose berries. These signs encouraged them, and they all grew cheerful. Sailed this day till sunset, twenty-seven leagues.

After sunset steered their original course west and sailed twelve miles an hour till two hours after midnight, going ninety miles, which are twenty-two leagues and a half; and as the Pinta was the swiftest sailer, and kept ahead of the Admiral,

the discovered land

Physics Proposal



CERN-SPSC-2015-016
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Technical Proposal

- The technical proposal (250 physicists, 46 institutes, 16 countries) submitted to CERN in Apr 2015 (arXiv:1504.04956)

- Physics Paper (85 physicists, 65 institutes) accepted for publication in Review on Progress in Physics (arxiv:1504.04855)

SHiP Collaboration

~250 scientific authors

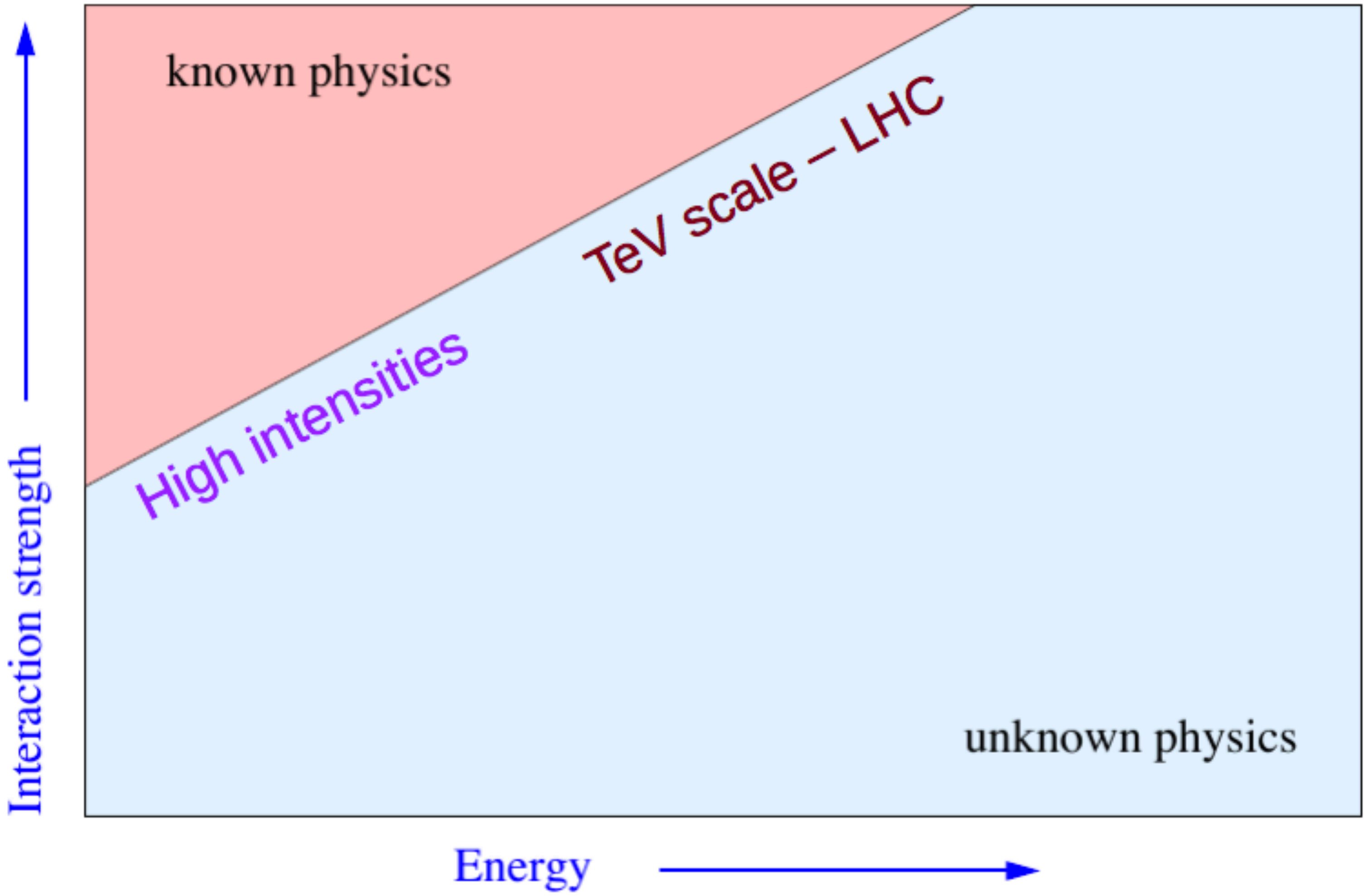
16 member countries: Bulgaria, Chile, Denmark, France, Germany, Italy, Japan, Korea, Portugal, Russia, Sweden, Switzerland, Turkey, United Kingdom, Ukraine, United States of America + CERN, DUBNA

48 member institutes: Sofia, Valparaiso, Niels Bohr Institute Copenhagen, LAL Orsay, LPNHE Paris, Berlin, Humboldt University Hamburg, Mainz, Bari, Bologna, Cagliari, Ferrara, Lab. Naz. Gran Sasso, Frascati, Naples, Rome, Aichi, Kobe, Nagoya, Nihon, Toho, Gyeongsang, LIP Coimbra, Dubna, ITEP Moscow, INR Moscow, P.N. Lebedev Physical Institute Moscow, Kurchatov Institute Moscow, IHEP Protvino, Petersburg Nuclear Physics Institute St. Petersburg, Moscow Engineering Physics Institute, Skobeltsyn Institute of Nuclear Physics Moscow, Yandex School of Data Analysis, Stockholm, Uppsala, CERN, Geneva, EPFL Lausanne, Zurich, Middle East Technical University Ankara, Ankara University, Imperial College London, University College London, Rutherford Appleton Laboratory, Bristol, Warwick, Taras Shevchenko National University Kyiv, Florida

5 associated institutes: Jeju, Gwangju, Chonnam, National University of Science and Technology "MISIS“ Moscow, St. Petersburg Polytechnic University

Physics Case

- Naturalness does not seem to be a guiding principle of Nature
- There are some anomalies in flavour physics which (if true) seem again to point out that our theory prejudice was wrong
- We should therefore not forget that we have a 2D problem (Mass VS Coupling)



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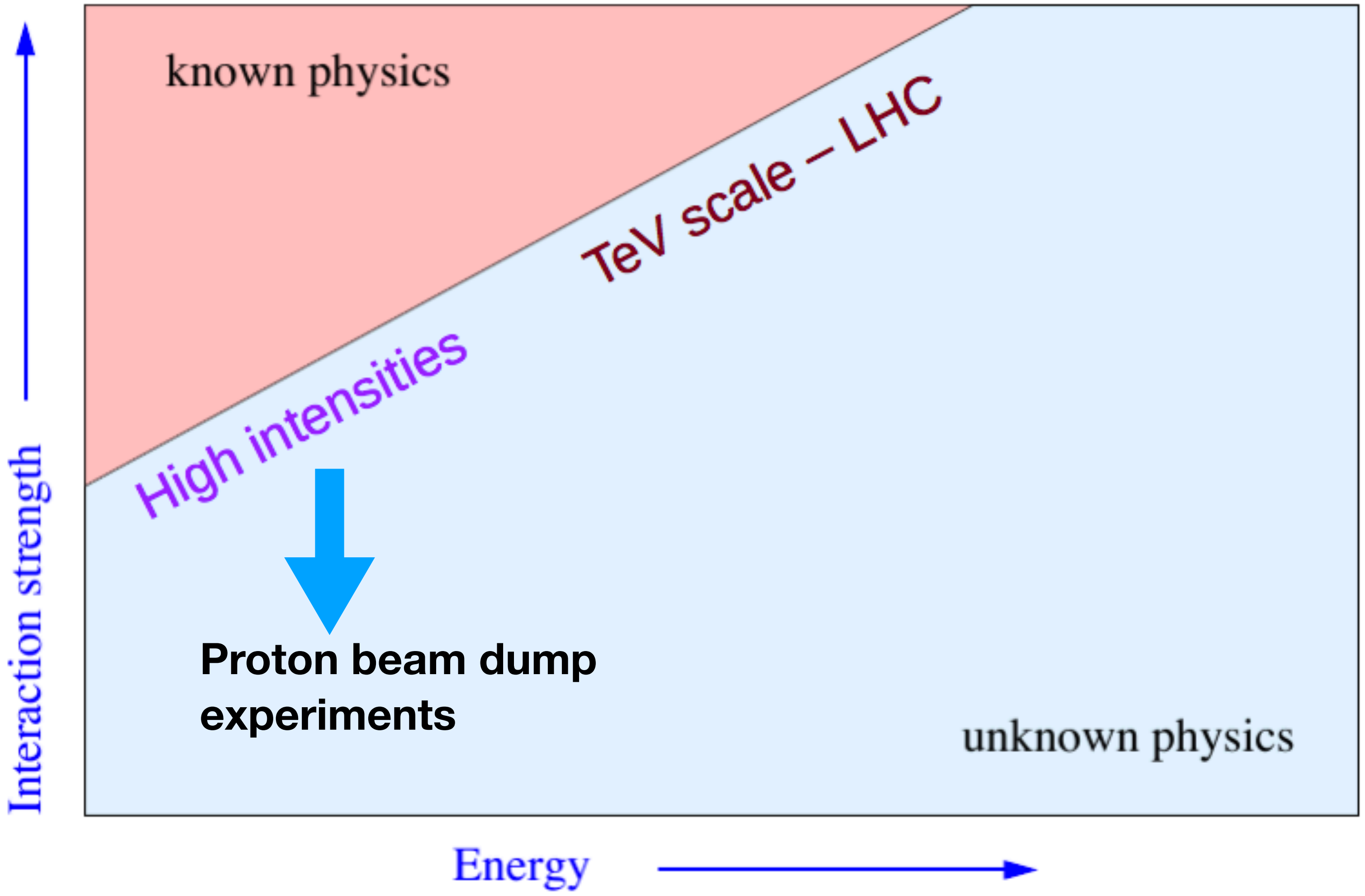
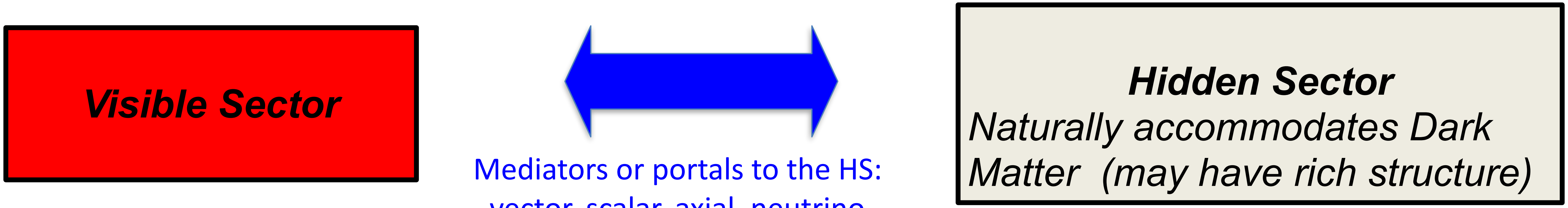


Physics Case

$L = L_{SM} + L_{mediator} + L_{HS}$



Visible Sector

Mediators or portals to the HS:
vector, scalar, axial, neutrino

Hidden Sector
Naturally accommodates Dark Matter (may have rich structure)

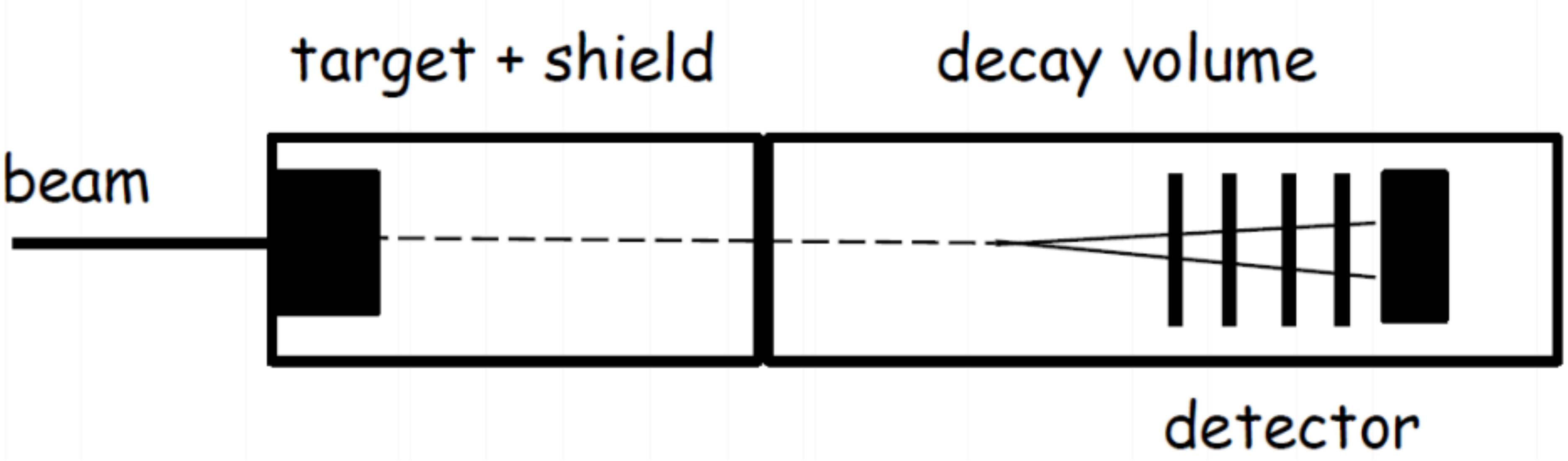
✓ HS production and decay rates are strongly suppressed relative to SM
- Production branching ratios O(10^{-10})
- Long-lived objects
- Interact very weakly with matter

Models	*Final states*
HNL, SUSY neutralino	$l^+\pi^-$, l^+K^-, $l^+\rho^-$ $\rho^+\rightarrow\pi^+\pi^0$
Vector, scalar, axion portals, SUSY sgoldstino	l^+l^-
HNL, SUSY neutralino, axino	$l^+l^-\nu$
Axion portal, SUSY sgoldstino	$\gamma\gamma$
SUSY sgoldstino	$\pi^0\pi^0$

Full reconstruction and PID are essential to minimize model dependence

Experimental challenge is background suppression

Experimental concept



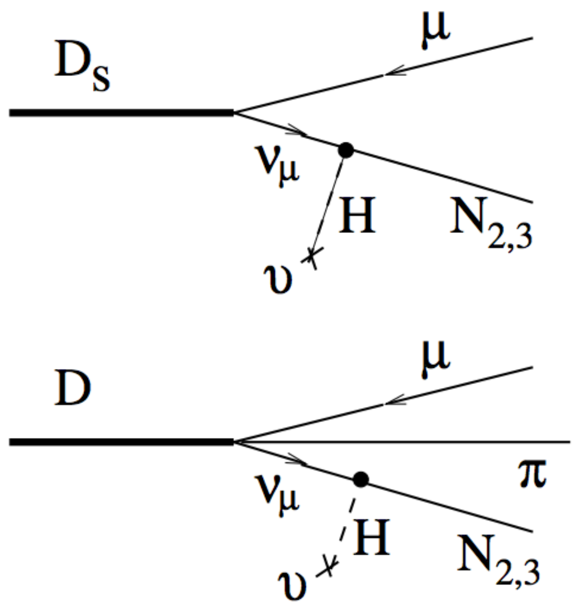
- Intensity high bin into a heavy target
  - We want particles either coming from heavy meson decays or from pN interaction
  - We want to suppress pion and kaon decays which is source of bkg

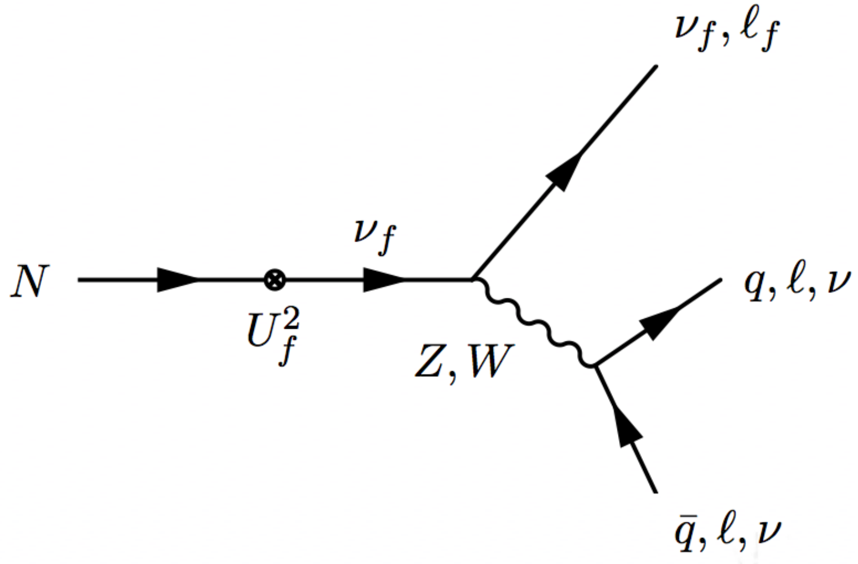
- Minimize the flux of SM particles in the detector

- Define a (large) fiducial volume where the background level is approximately zero

Sterile Neutrinos

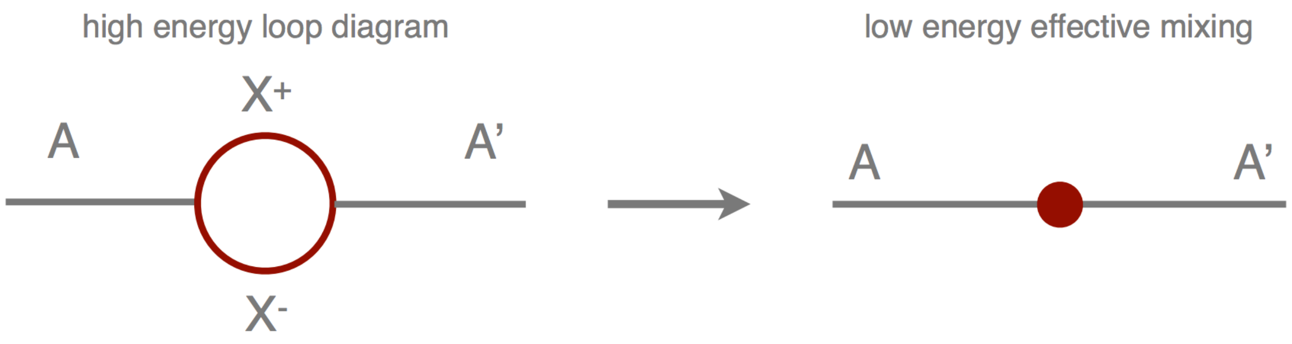
- The production of sterile neutrinos happens via mixing of sterile neutrinos with active neutrinos, i.e. it is suppressed by a factor U^2
- If the mass is small enough they can be produced in semileptonic meson decays (pions, kaons, D-mesons, B-mesons)
- The decay of sterile neutrinos also happens via mixing with active neutrinos, decay channels $N \to h\ell$, $N \to \ell\ell^{(\prime)}\nu$, $N \to h^0\nu$





Dark Photon

- Dark Matter might interact via unknown forces
- Consider an additional U(1)’ symmetry wrt which SM particles are neutral
- If we have some high mass fermions charged under U(1) and U(1)’ we have an effective coupling



$$\mathcal{L} = \overbrace{\underset{\substack{\uparrow \\ \text{QED fields}}}{\mathcal{L}_{\psi,A}} + \underset{\substack{\uparrow \\ U(1)'\text{ fields}}}{\mathcal{L}_{\chi,A'}}}^{\text{QED-like}} - \frac{\epsilon}{2} \underset{\substack{\uparrow \\ \text{field strength tensors}}}{F_{\mu\nu}F'^{\mu\nu}} + \underset{\substack{\uparrow \\ \text{mass term}}}{\tfrac{1}{2}m_{A'}^2 (A'_\mu)^2}$$

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Dark Photon

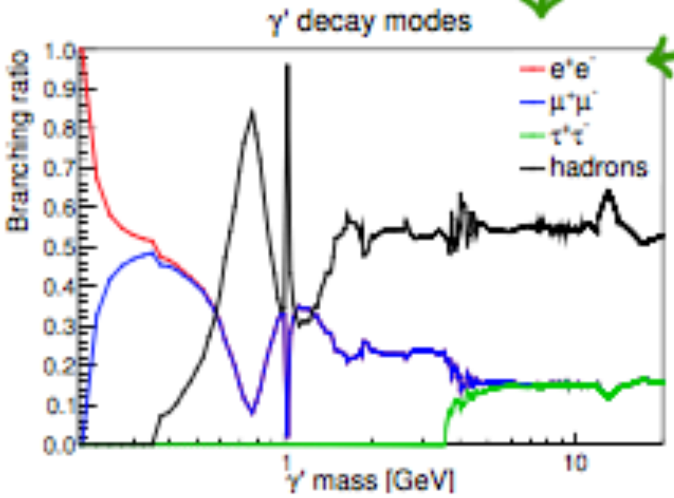
SHiP
Search for Hidden Particles

➜ Production at SHiP:

- meson decays e.g. $\pi^0 \to \gamma V$ ($\sim \epsilon^2$) *arXiv:0906.5614*
- p bremsstrahlung on target nuclei $pp \to ppV$ *arXiv:1311.3870*
- large $m_V \Rightarrow$ direct QCD production through underlying $q\bar{q} \to V$, $qg \to V$ (need some more theory work!) *arXiv:1205.3499*

➜ Decay:

$$\Gamma_{tot} = \Gamma(\ell^+\ell^-) + \Gamma(\text{hadrons}) + \Gamma(\chi\bar{\chi})$$



$$\frac{\ell\ell}{\chi\chi} \sim \frac{\alpha\epsilon^2}{\alpha_D},$$

α_D = dark fine structure constant

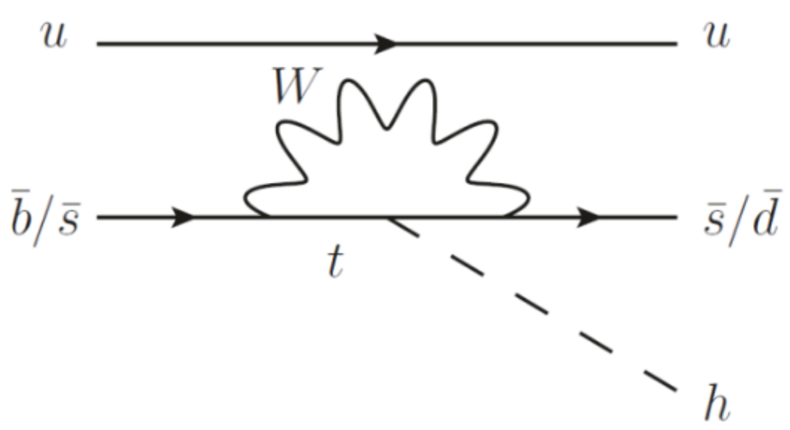
Dark Scalars

At SHiP (according with estimates) we produce around xxx B-mesons, so we can exploit the Higgs portal (search for light Dark Scalars mixing with the Higgs)

$$\mathcal{L} = \mathcal{L}_{SM} + \mathcal{L}_{HS} + (\alpha_1 S + \alpha S^2) H^\dagger H$$

$$\begin{pmatrix} H \\ h \end{pmatrix} = \begin{pmatrix} \cos\rho & -\sin\rho \\ \sin\rho & \cos\rho \end{pmatrix} \begin{pmatrix} \phi_0' \\ S' \end{pmatrix}$$

Theory references:



$$\Gamma(K \to \pi\phi) \sim (m_t^2 |V_{ts}^* V_{td}|)^2 \propto m_t^4 \lambda^5$$

$$\Gamma(D \to \pi\phi) \sim (m_b^2 |V_{cb}^* V_{ub}|)^2 \propto m_b^4 \lambda^5$$

$$\Gamma(B \to K\phi) \sim (m_t^2 |V_{ts}^* V_{tb}|)^2 \propto m_t^4 \lambda^2$$

➜ Decay: $S \to \gamma\gamma, ee, \mu\mu, \pi\pi, KK$

Axion Like Particles

strong CP problem

Dark matter

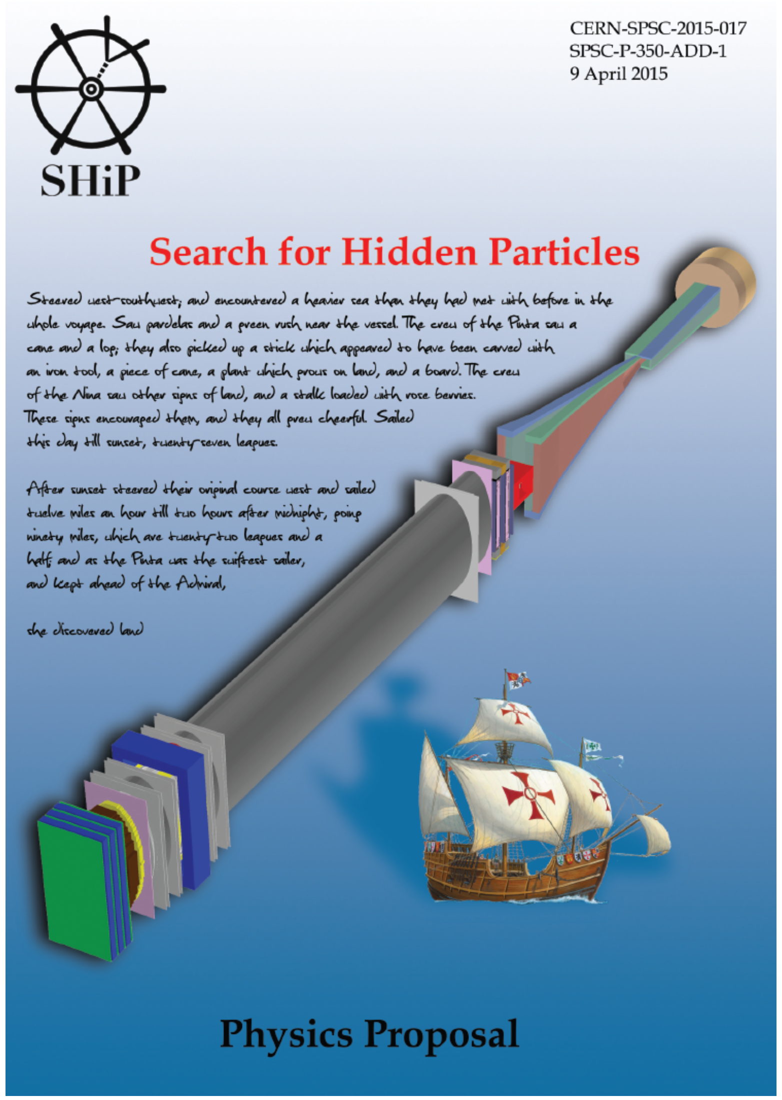
AXION

PNGBs arising from the Peccei-Quinn symmetry

- ➜ The axion mass m_A is very constrained due to the axial QCD anomaly breaking the PQ symmetry. Other ALPs are not so constrained.

- ➜ SHiP can probe ALPs coupled to gauge bosons and to SM fermions:
  - $pp \to AX,\ A \to \gamma\gamma$: all neutral, more challenging
  - $pp \to BX,\ B \to AK,\ A \to \mu^+\mu^-$

Physics Case



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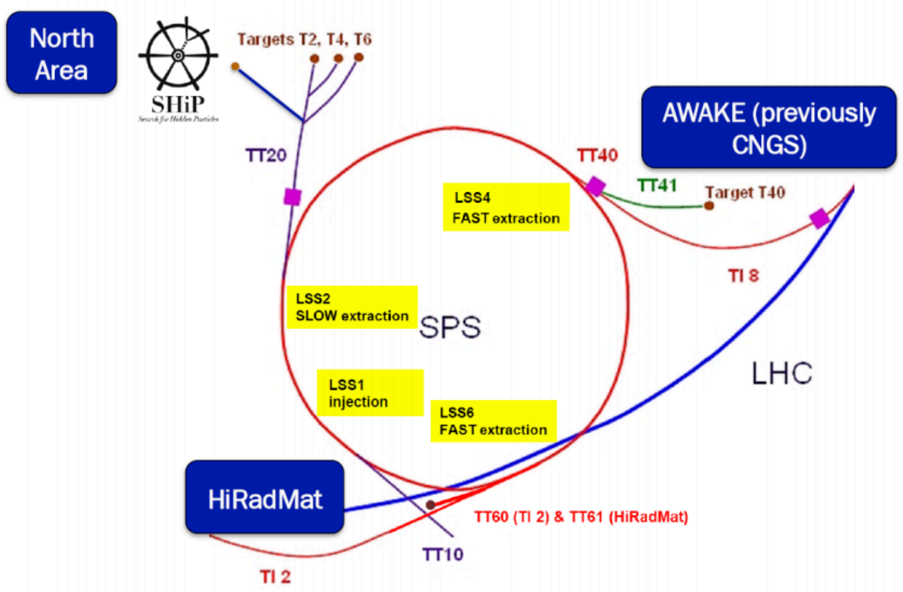
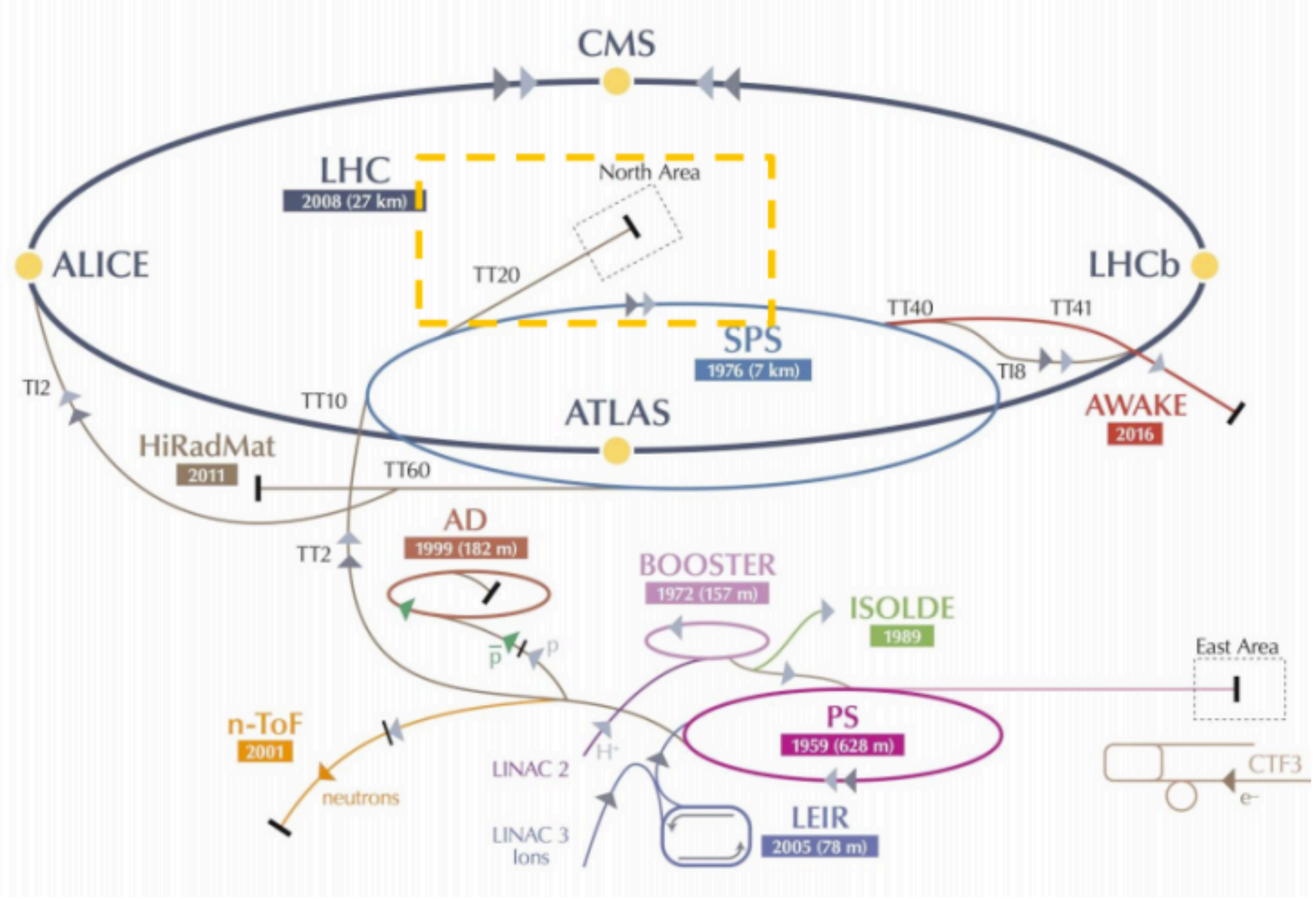
Physics Proposal

- The SHiP physics case is described in details in the Physics Proposal (Rep. Prog. Phys. 79 (2016) 124201)
- Many other models, each with large parameter space
- We want to be as inclusive as possible

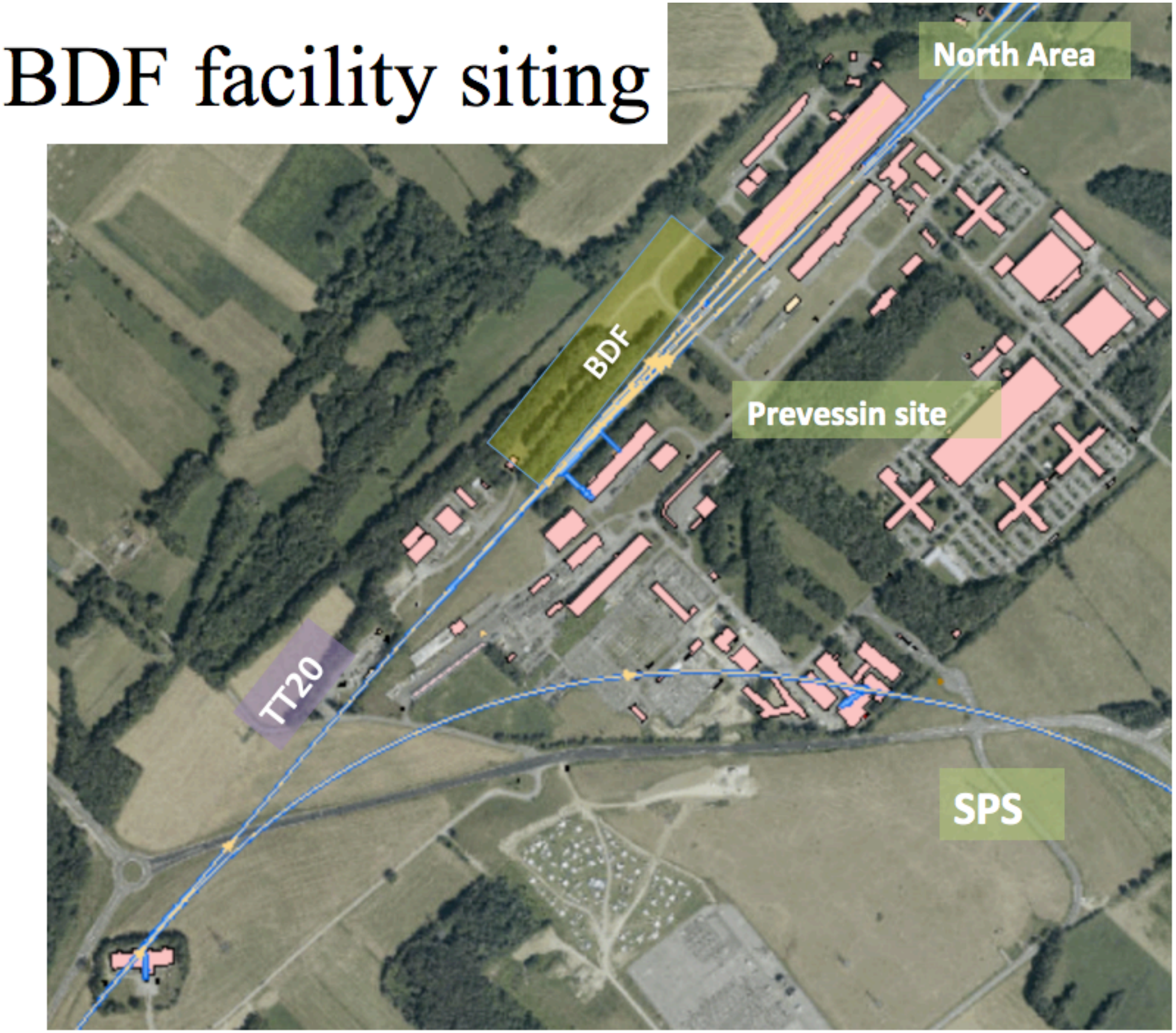
Beam Line



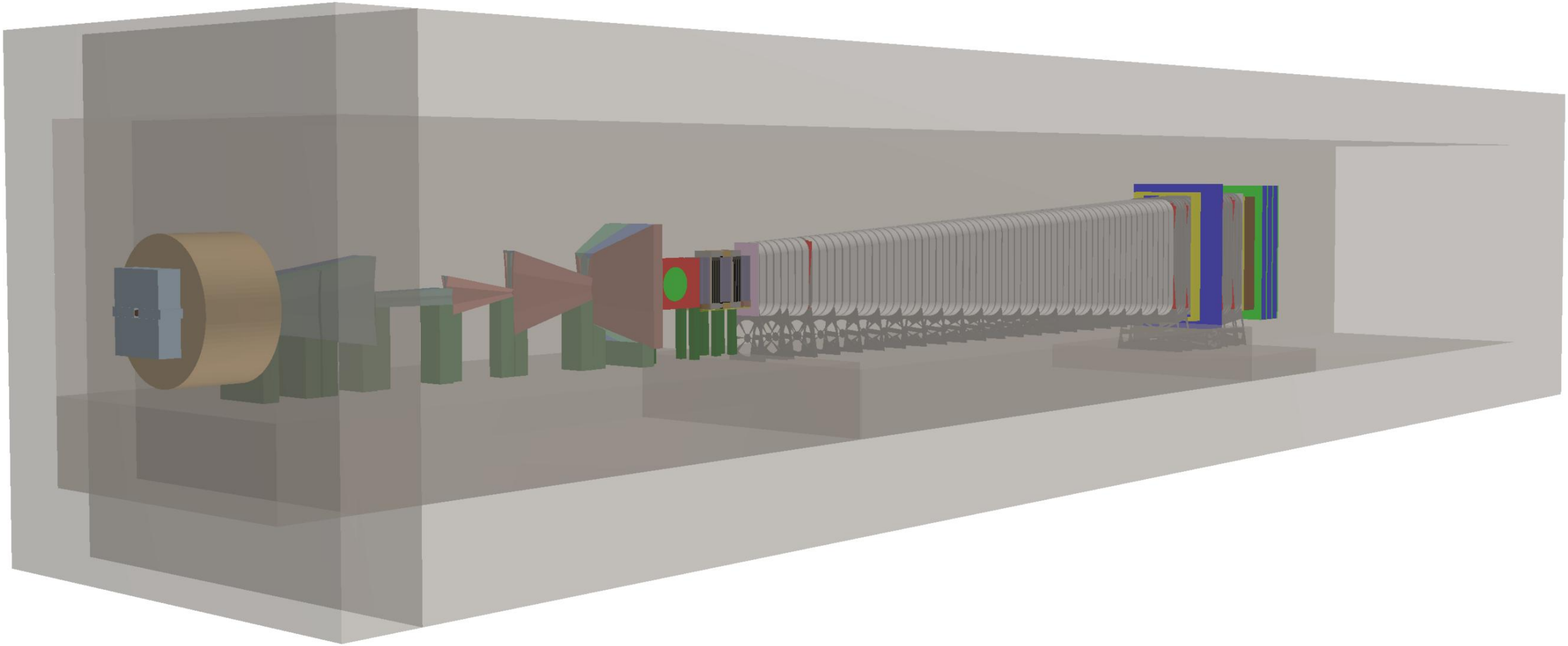


- New beam line in the north area at SPS
- Proton beam SPS@400GeV
- Possible to deliver $5\text{x}10^{20}$ PoT in ~5 years
- Operation in parallel with LHC and other beam lines at SPS

BDF Facility



Overview of SHiP



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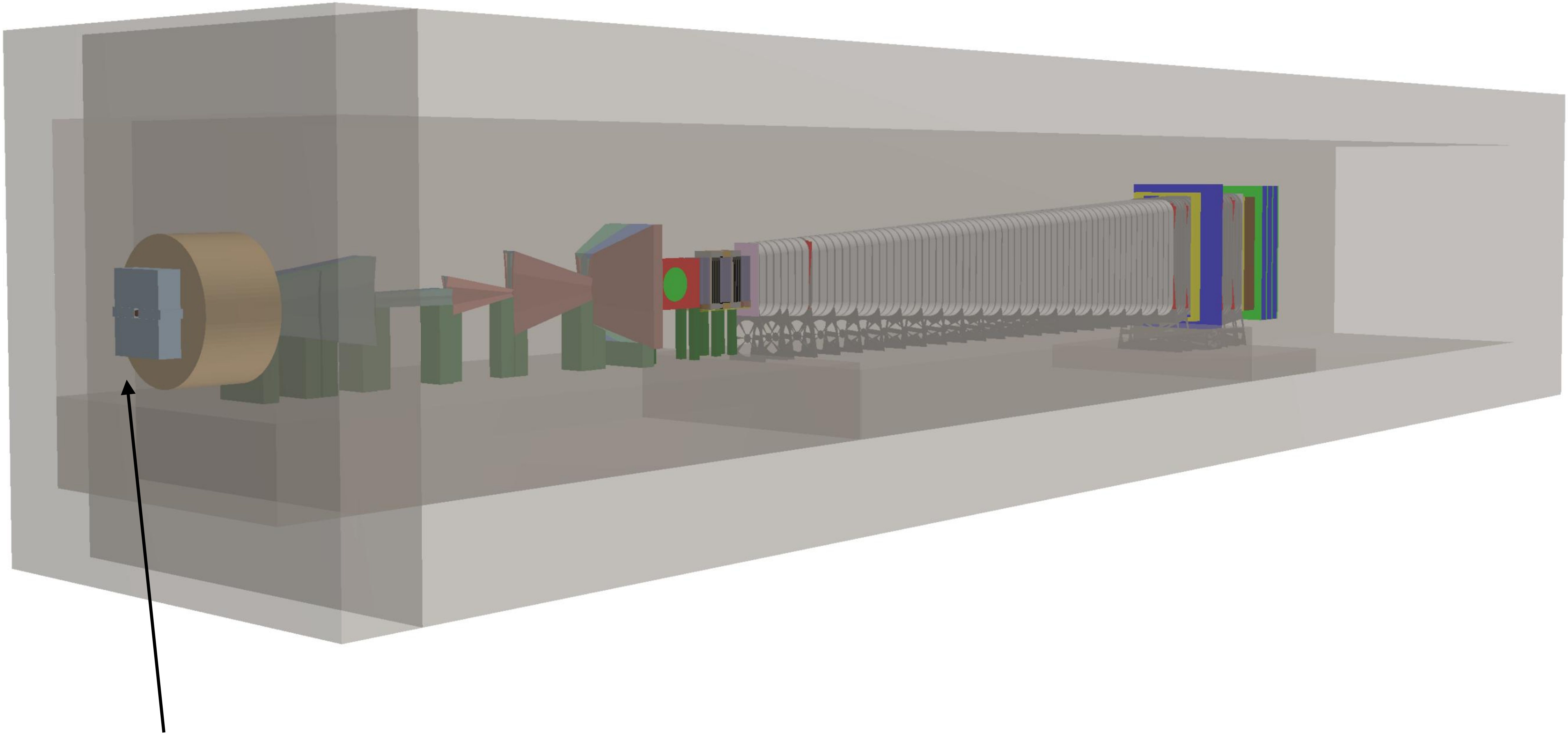
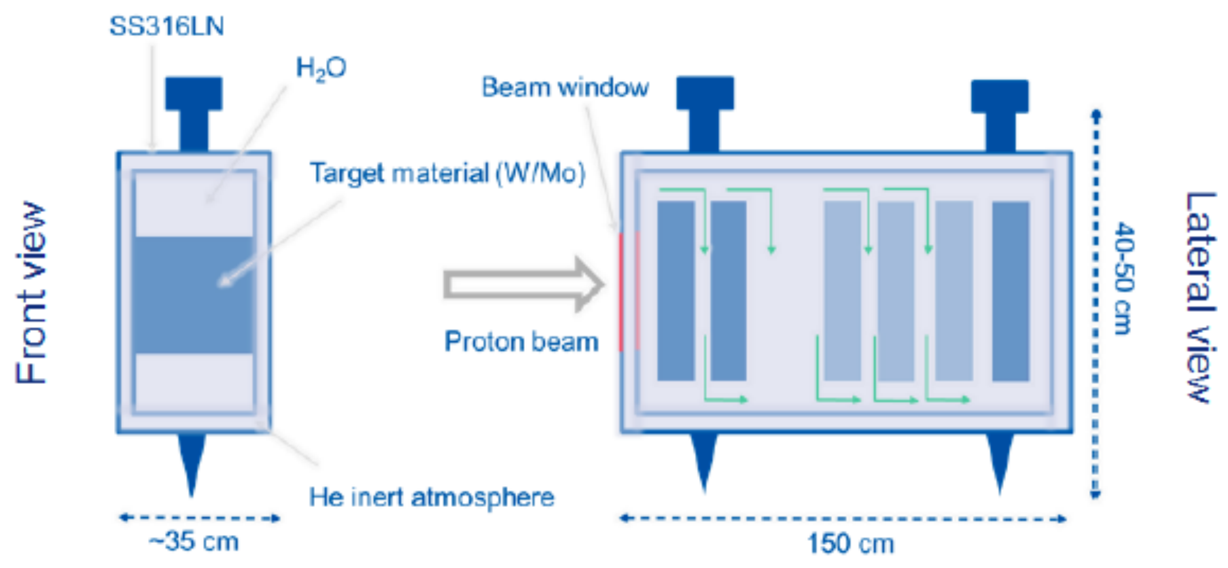


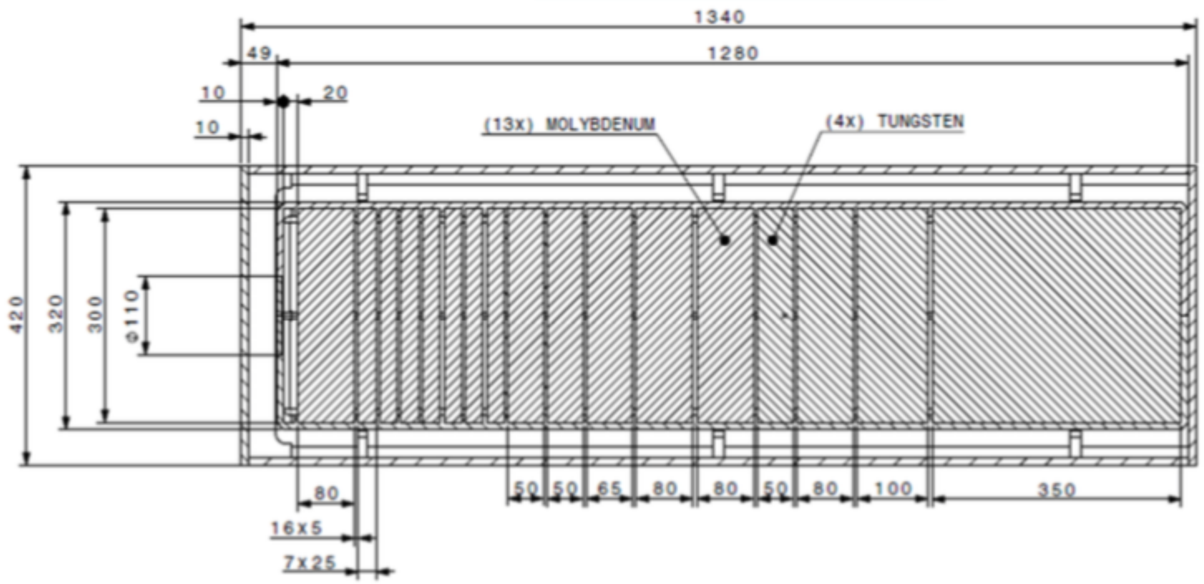
Target

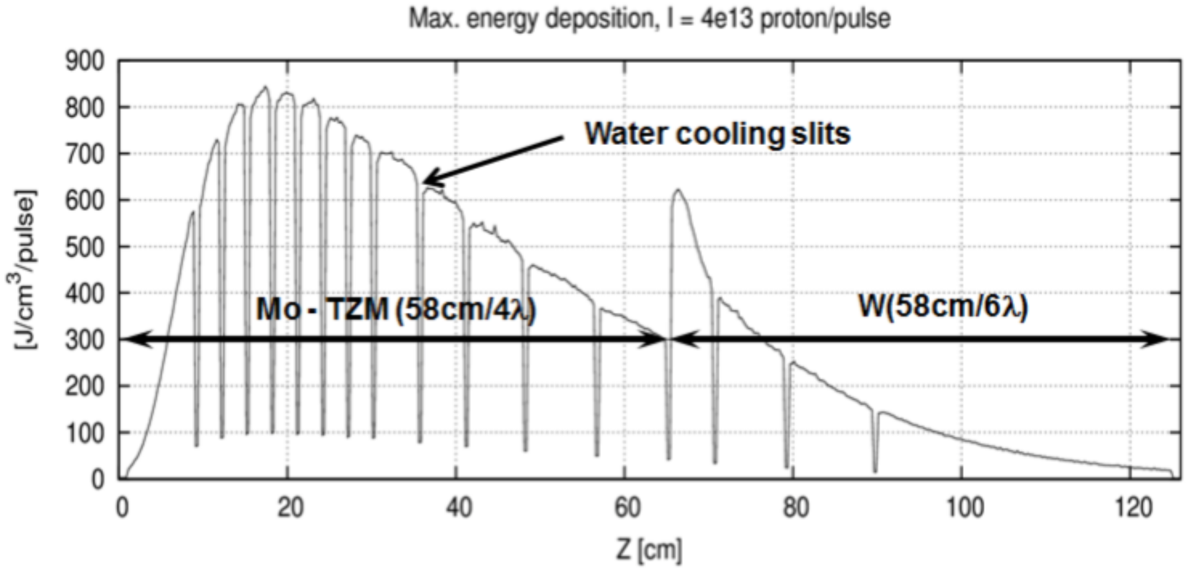
Target

- *Target dimensions*
- *Layers of Titanium/Zirconium/Molibdenum for $4\lambda_{int}$ in the core of the beam*
- *Followed by Layers of pure W*
- *Each layer is cooled by water*
- *Alternative cooling with He under study*



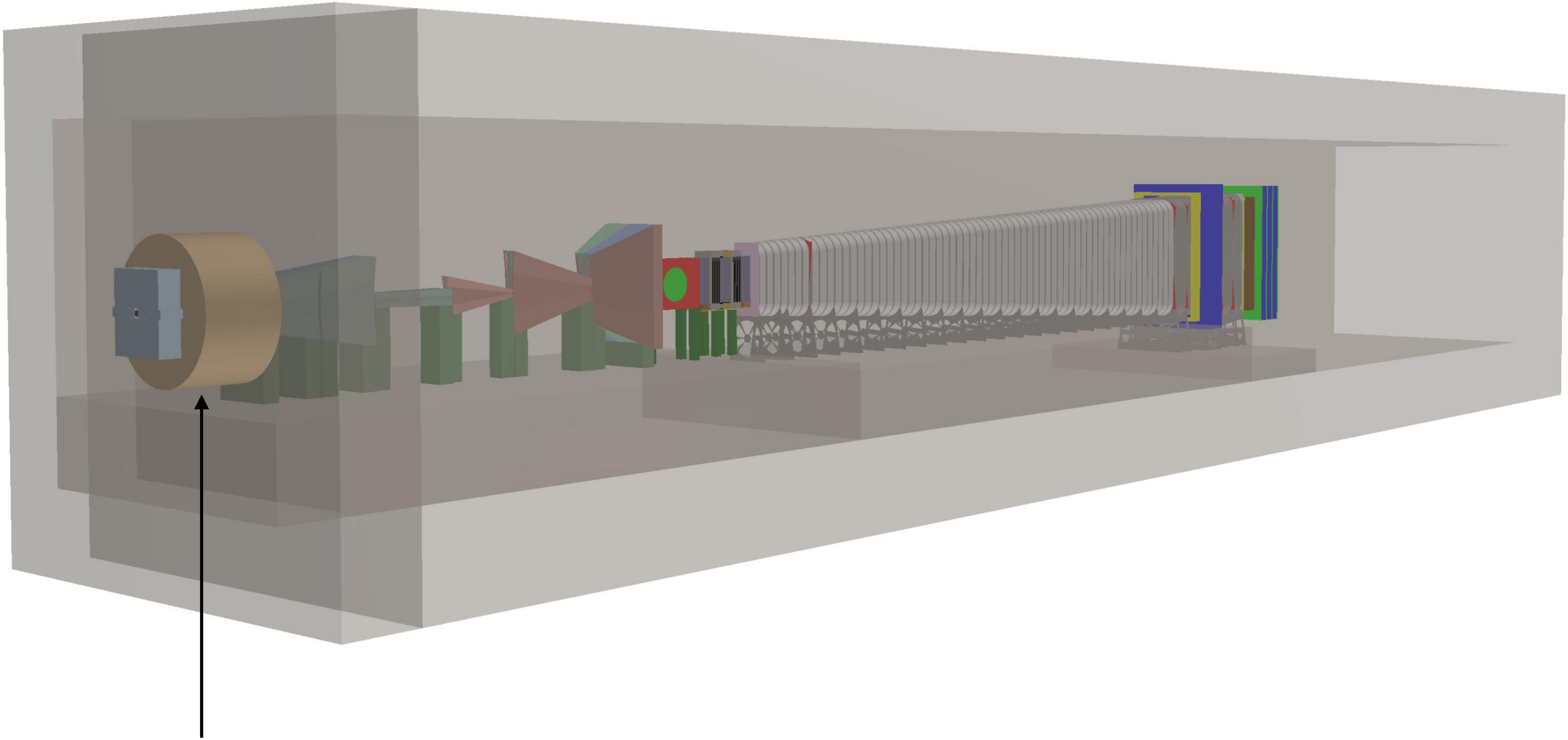
Longitudinal cross-cut





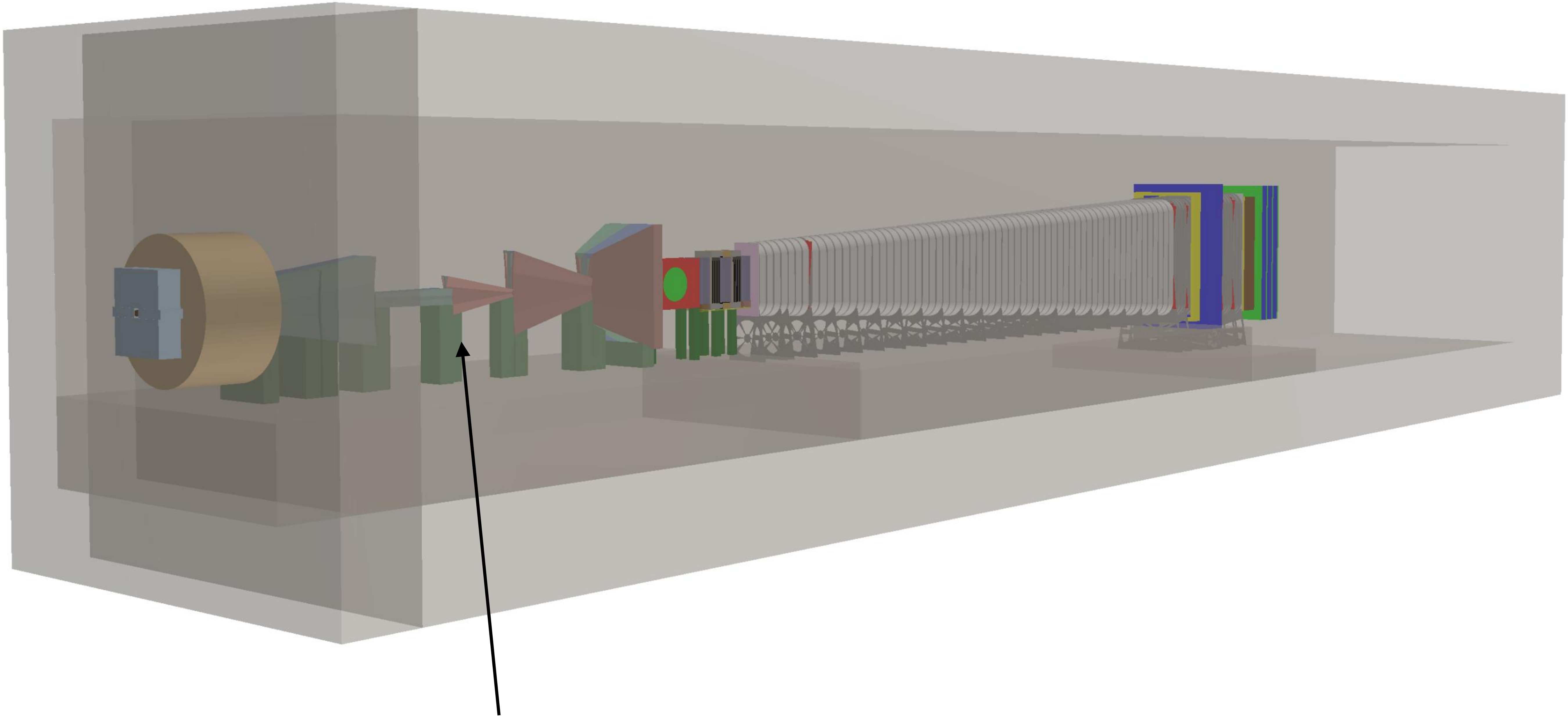
355 kW average,
2.56 MW during 1s spill

Overview of SHiP



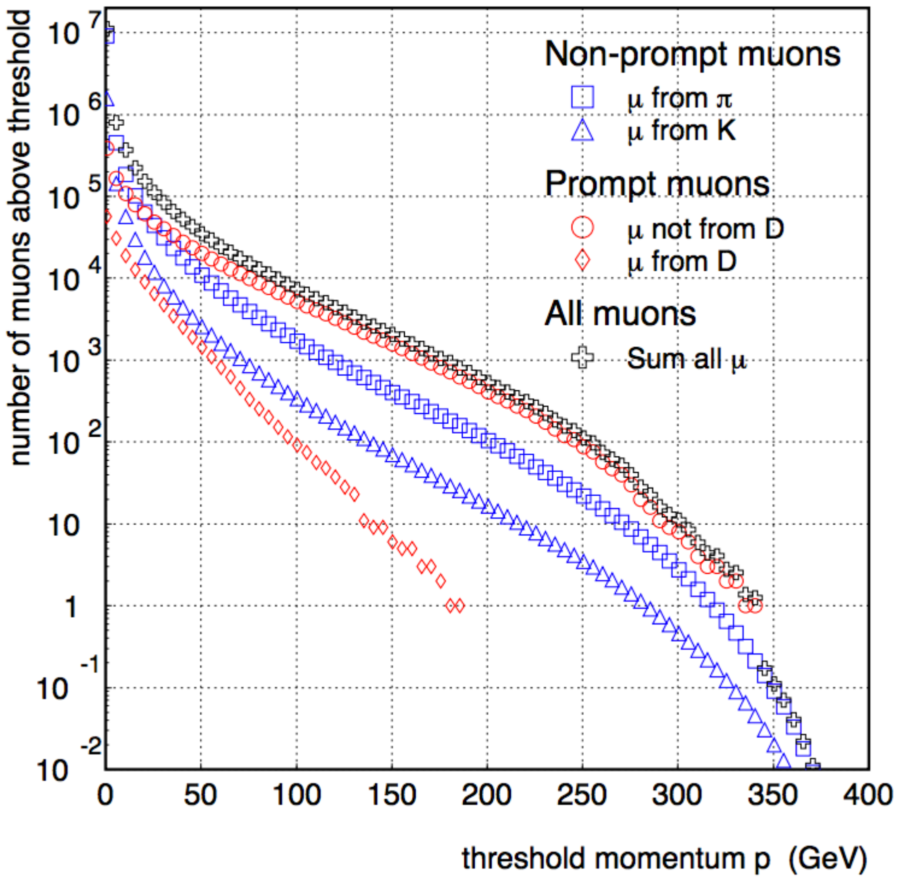
Hadron absorber

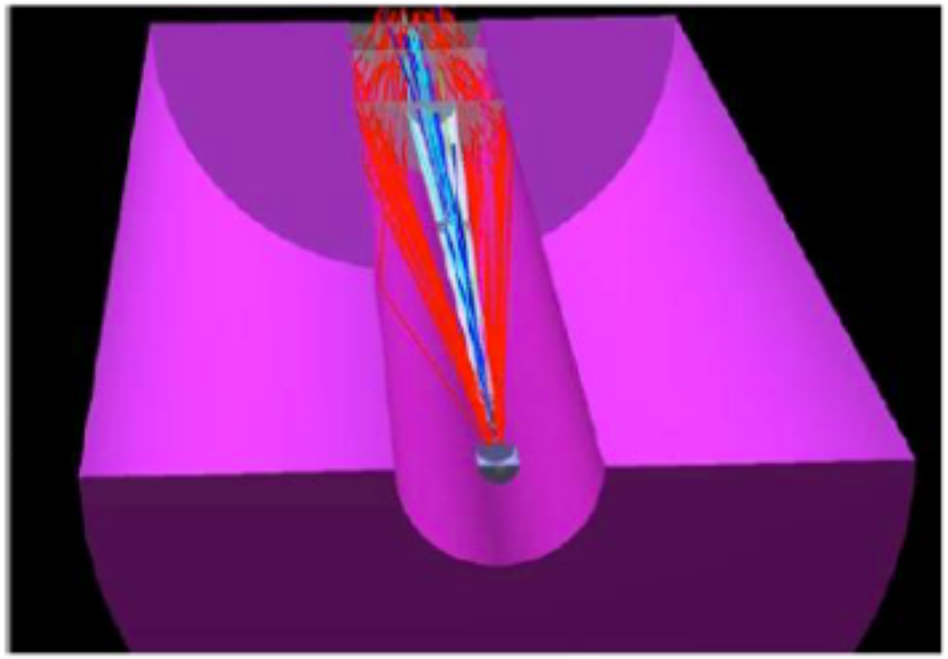
Overview of SHiP



Sweeping magnet

Muon Shield





- Distribute the bkg over a long spill: 4x10^{13} PoT/1.3 seconds
- Sweeping magnet
- Decay volume to be far away from the walls

- Heavy target stops hadrons before they decay. After the target and the hadron absorber only muons survive
- Muons come mainly from η, η' and ω

Muon Shield

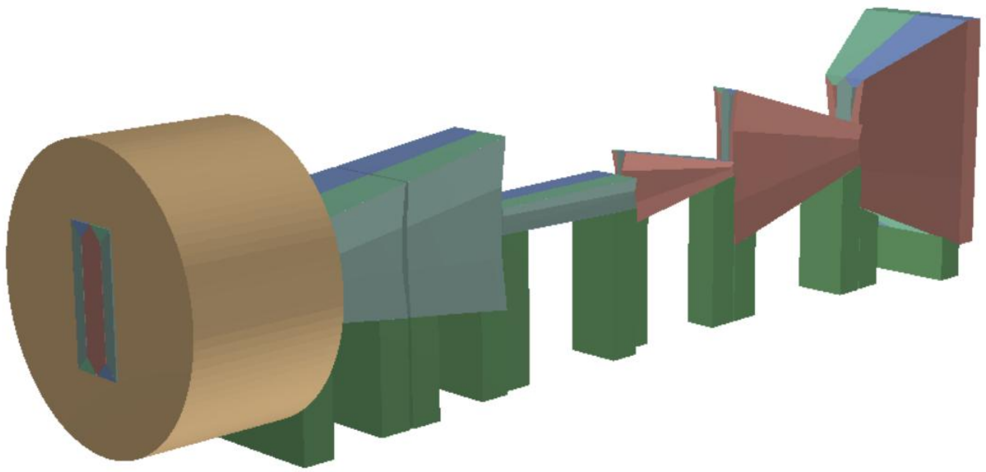
✓ *Muon flux limit driven by emulsion based neutrino detector and HS background*

✓ *Active muon shield based entirely on magnet sweeper*

with a total field integral B_y = 86.4 Tm

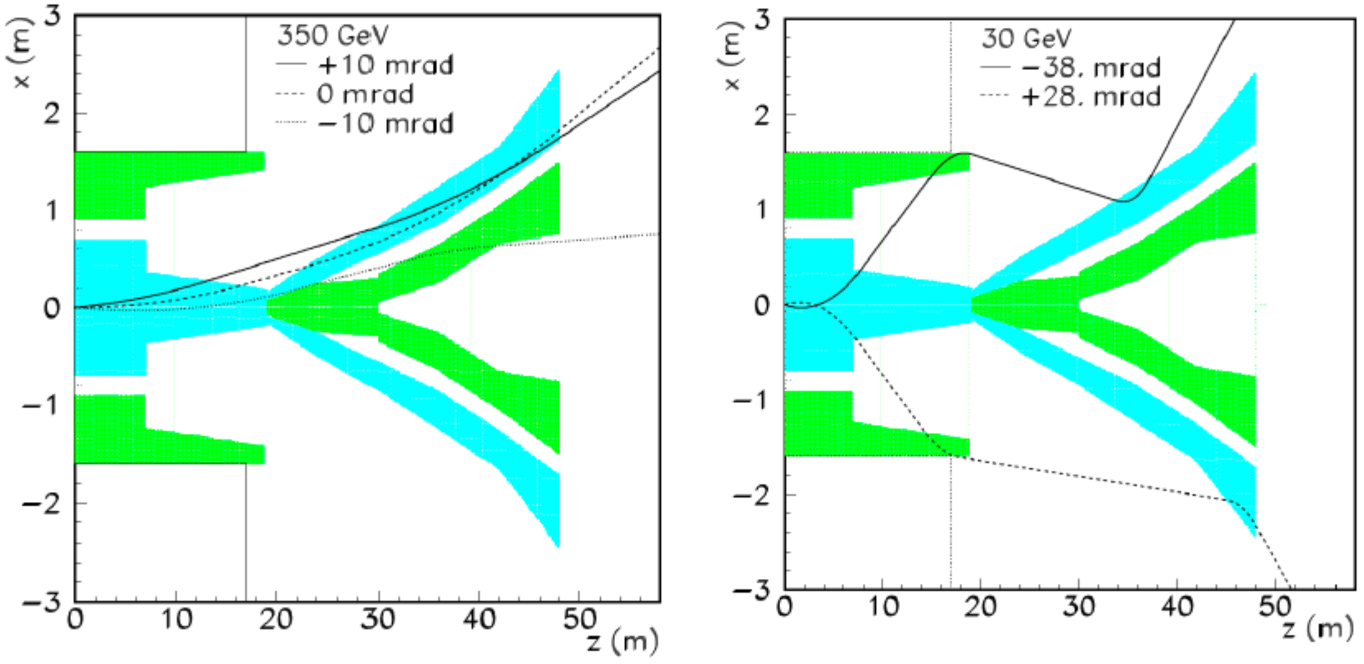
Realistic design of sweeper magnets in progress

Challenges: flux leakage, constant field profile, modeling magnet shape

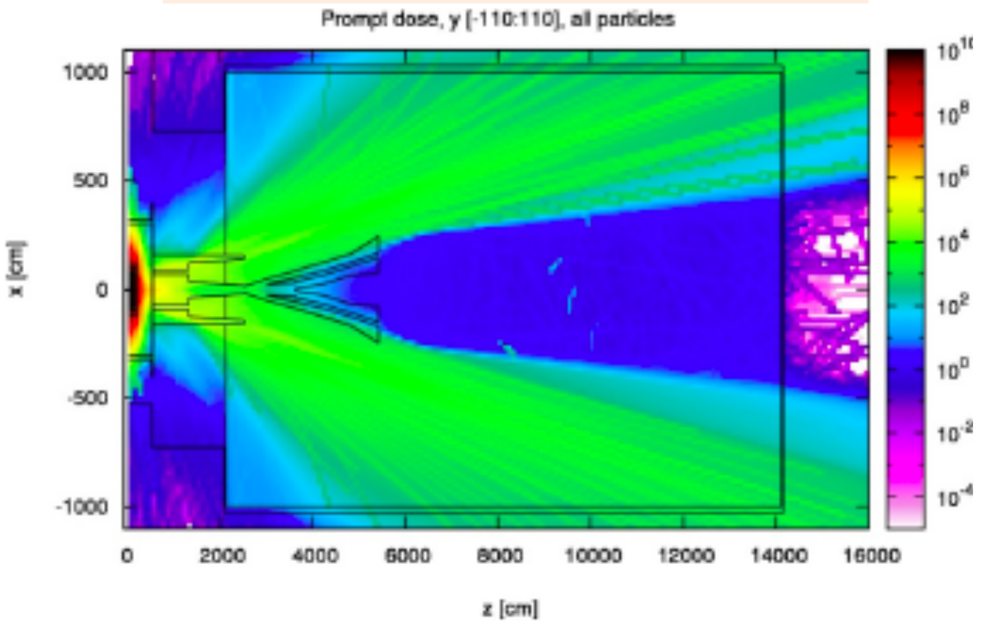


- Flux below emulsion saturation limit
- Small induced bkg in the HS spectrometer

Magnetic sweeper field



Dose rate in the SHiP hall



Muon Shield

The active muon shield in the SHiP experiment
JINST 12 P05011 2017

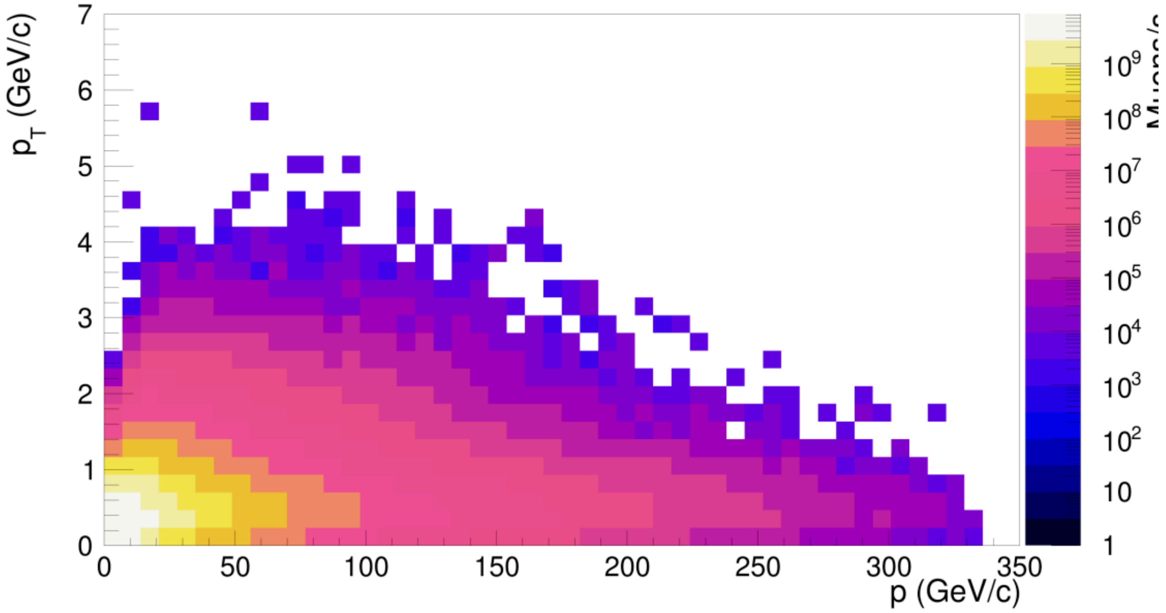


Figure 1. Transverse momentum versus momentum distribution of muons, as generated by Pythia [5, 7].

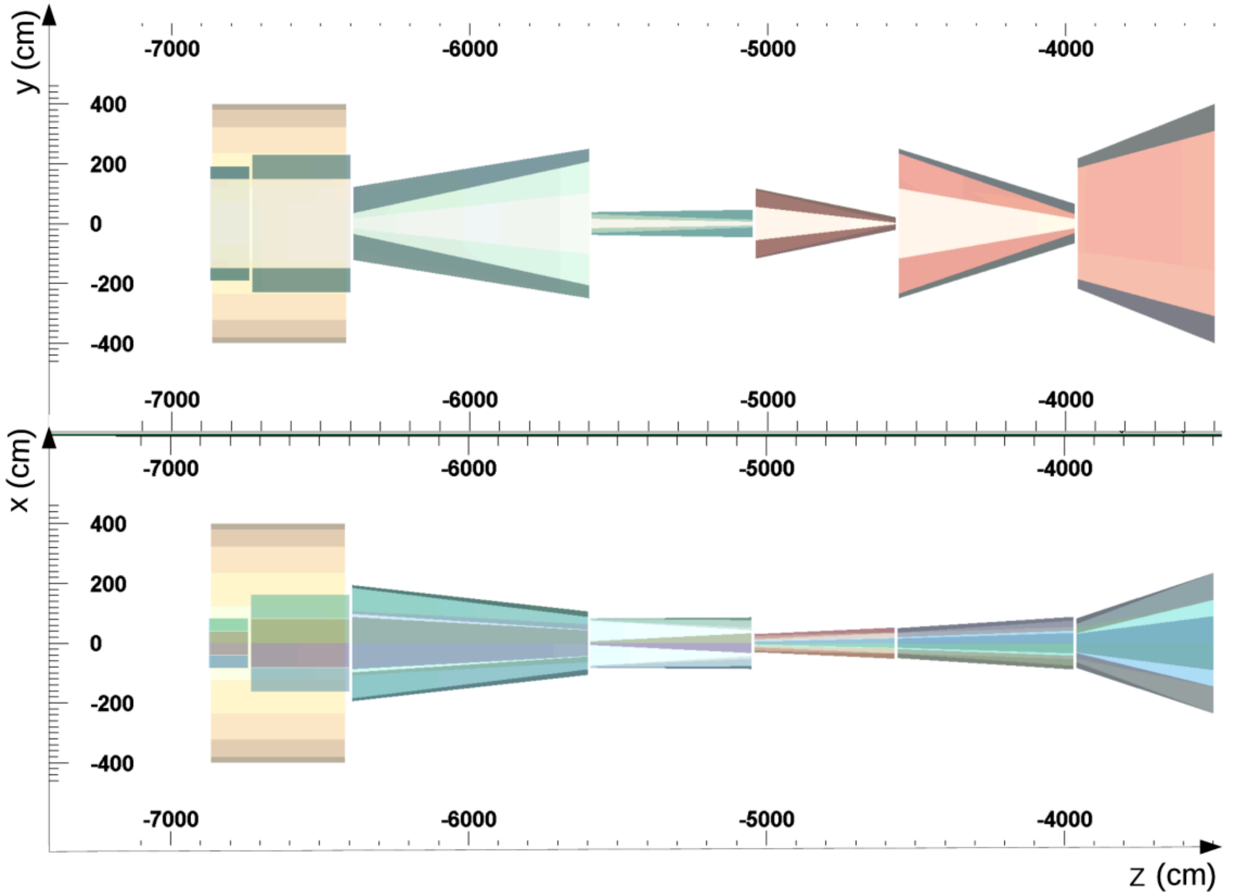


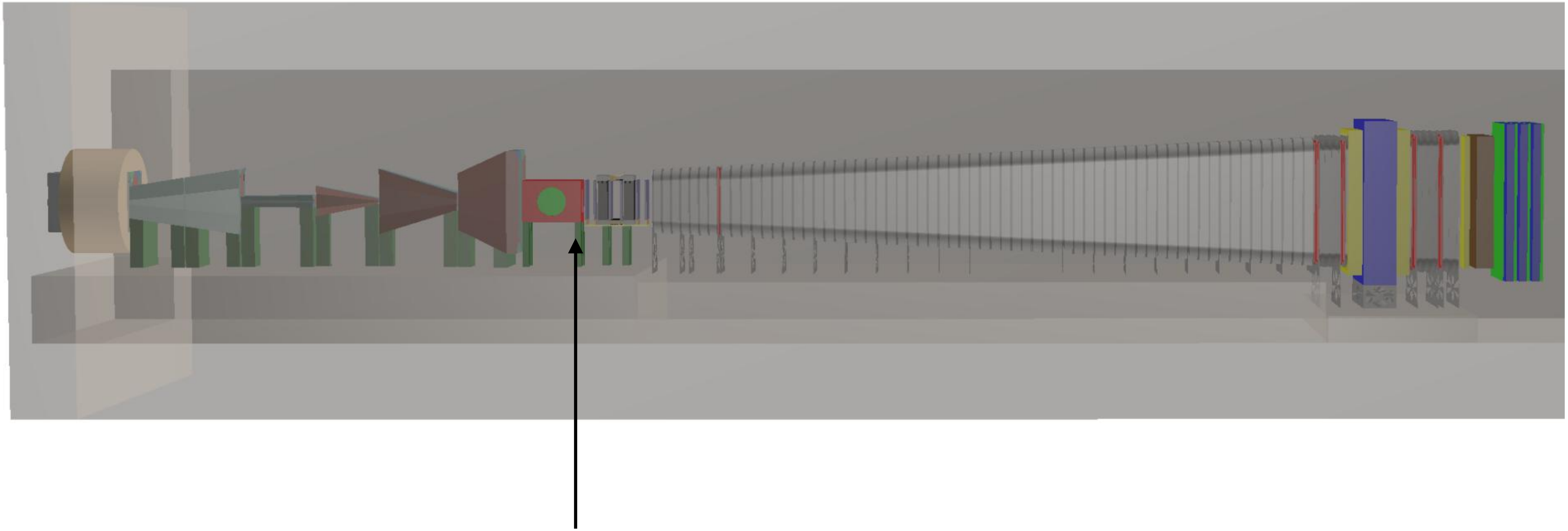
Figure 4. Geometric view of the optimized muon shield, showing at the top, the z-y plane view, and at the bottom, the z-x plane view. SHiP defines the origin of the coordinate system to be in the center of the decay vessel. Color shading is used to enhance the contrast between different magnetic field orientations.

Running the simulation with material

- ~3×10^9 muons/spill with magnets off
- With the magnet on 3×10^5 muons/spill
- ~6.5×10^4 muons/spill with p>3GeV

Opimization of the muon shield includes muon rate, weight (1.850 Tons) and length (34 meters)

Overview of SHiP

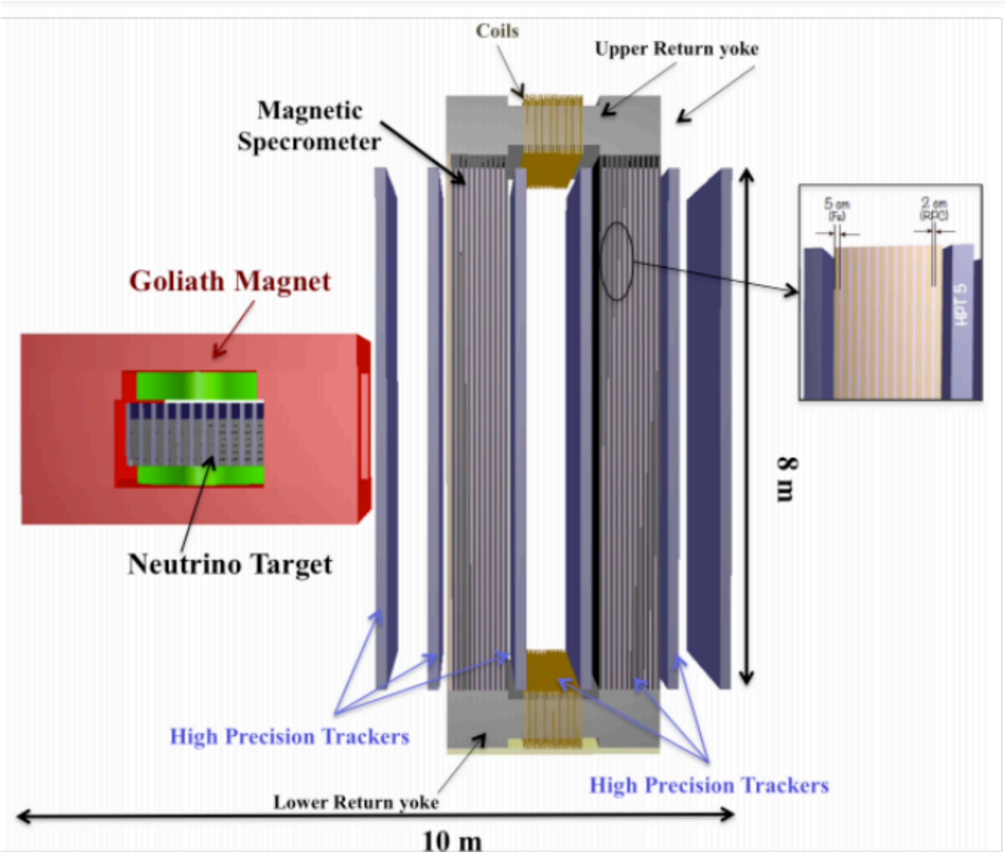


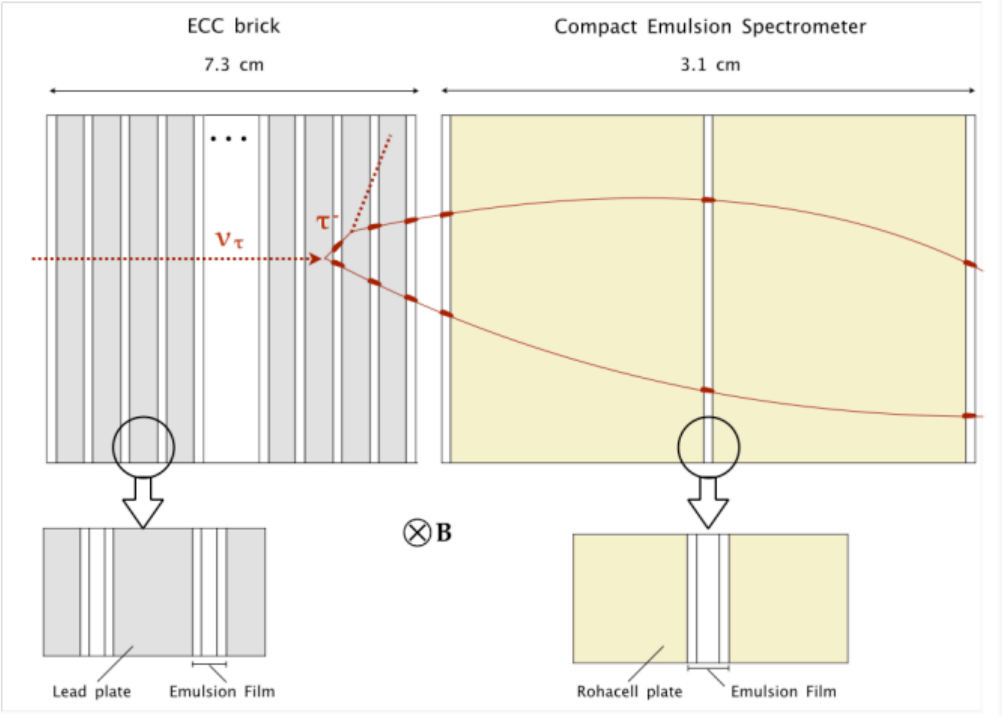
Emulsion Spectrometer Detector

- This experiment also maximises the flux of v_τ wrt to the other neutrino flavours
  - Only 9 fully reconstructed v_τ *at present*
  - *anti-v_τ never observed directly*

- If Light-DM particles (M~GeV) are produced in the target, via the decay of a hidden sector mediator, we can look for the direct interaction of the LDM particles with the ESD

Emulsion Spectrometer

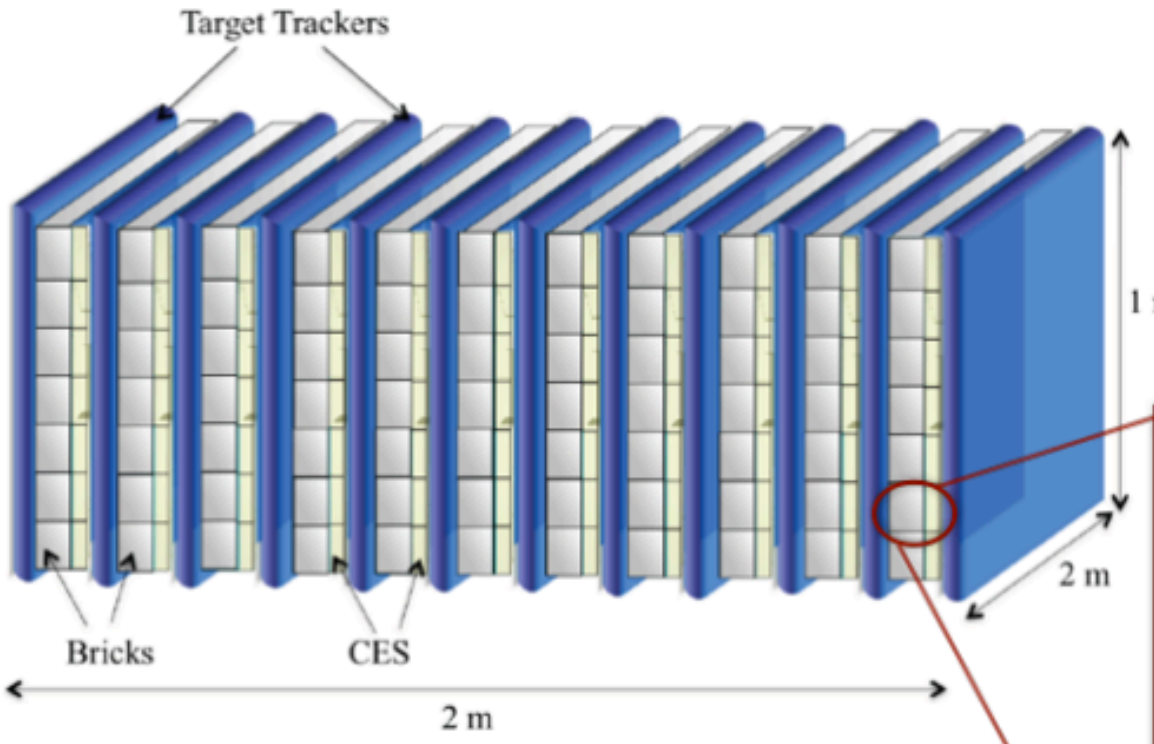




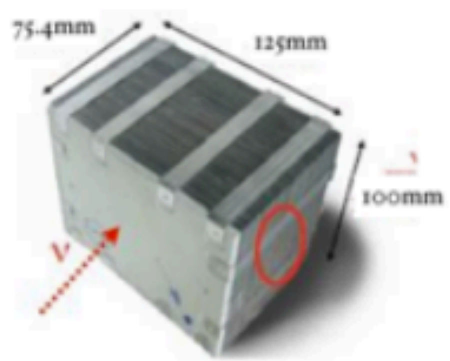
- High spacial resolution to observe the τ decay (~1mm flight length)
- Electronic detector for tracking to give the time stamp of the event
- Magnetized target to measure the τ products
- Muon magnetic spectrometer for muon identification

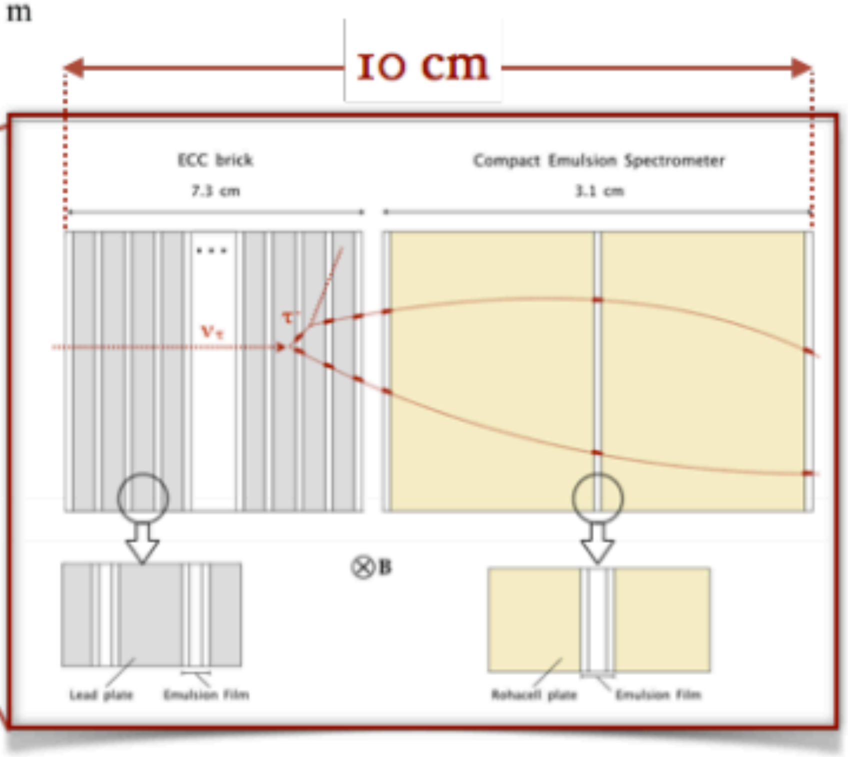
Emulsion Spectrometer

ν target + vertex detector



Fundamental unit: **Brick**



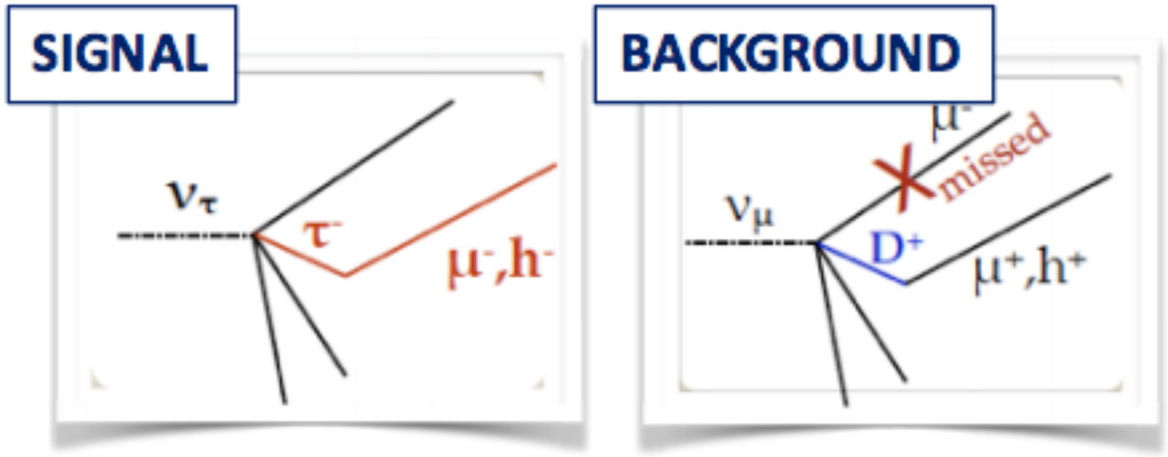


- **Emulsion Cloud Chamber technology**
- **Lead plates** (high density material for the interaction) interleaved with **emulsion films** (tracking devices with **μm resolution**)

Physics with ESD

	Φ	<E> (GeV)
ν_μ	1.7×10^6	29
ν_e	2.5×10^5	46
ν_τ	7.6×10^3	59
Anti-ν_μ	6.7×10^5	28
Anti-ν_e	9.0×10^4	46
Anti-ν_τ	3.9×10^3	58

Rates for five years of nominal operation with 2×10^{20} protons on target



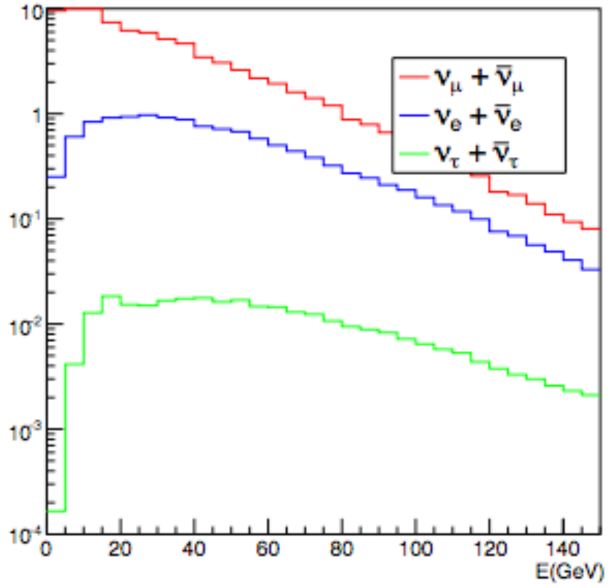
- **Structure function estimation**

$$\frac{d^2\sigma}{dx\,dy} = \frac{G_F^2 M_N E_\nu}{\pi}\left(\frac{M_W^2}{Q^2+M_W^2}\right)^2\left[\left(xy^2+\frac{m_l^2 y}{2E_\nu M_N}\right)F_1 + \left(1-y-\frac{M_N x y}{2E_\nu} - \frac{m_l^2}{4E_\nu^2}\right)F_2 \pm \left(xy\left(1-\frac{y}{2}\right)-\frac{m_l^2 y}{4E_\nu M_N}\right)F_3 + \frac{m_l^2(m_l^2+Q^2)}{4E_\nu^2 M_N^2 x}F_4 - \frac{m_l^2}{E_\nu M_N}F_5\right]$$

Estimation through ν/anti-ν data subtraction

Dependent on the lepton mass.
Relevant only for ν_τ interactions

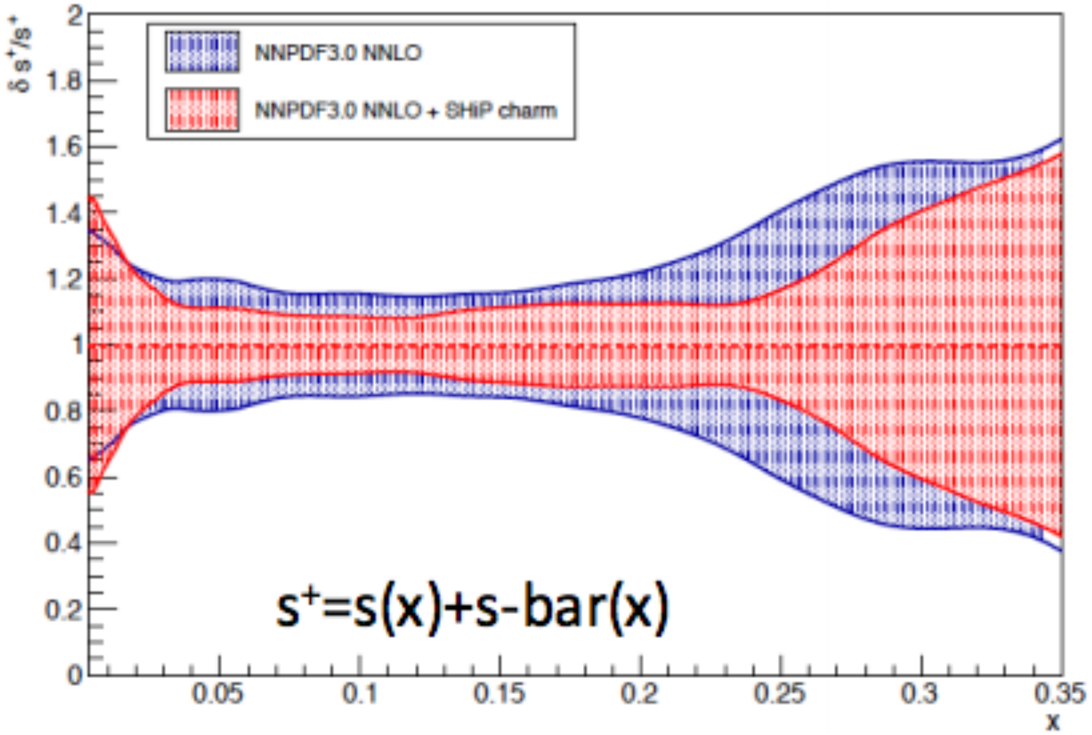
Energy spectra of DIS CC interacting ν

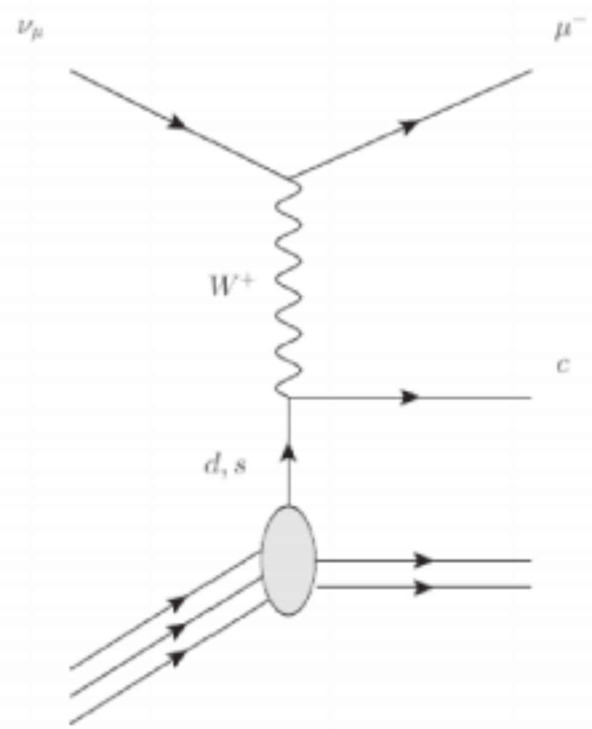


- From ν_τ and anti-ν_τ CC interactions:
  - *First evaluation of F_4 and F_5* not accessible with lighter neutrinos
- From ν_μ and anti-ν_μ CC interactions:
  - Estimation of F_3

Physics with ESD

- Charmed hadron production in antineutrino interactions selects anti-strange quark in the nucleon
  - Improvement achieved on s+/s- versus x
  - Significant gain with SHiP data obtained in the x range between 0.03 and 0.35 complementary to that of ATLAS and CMS (sensitive at lower x)





In addition

- Study of ν_e *x*-section at high energy
- Study of LFU with neutrinos

Physics with ESD

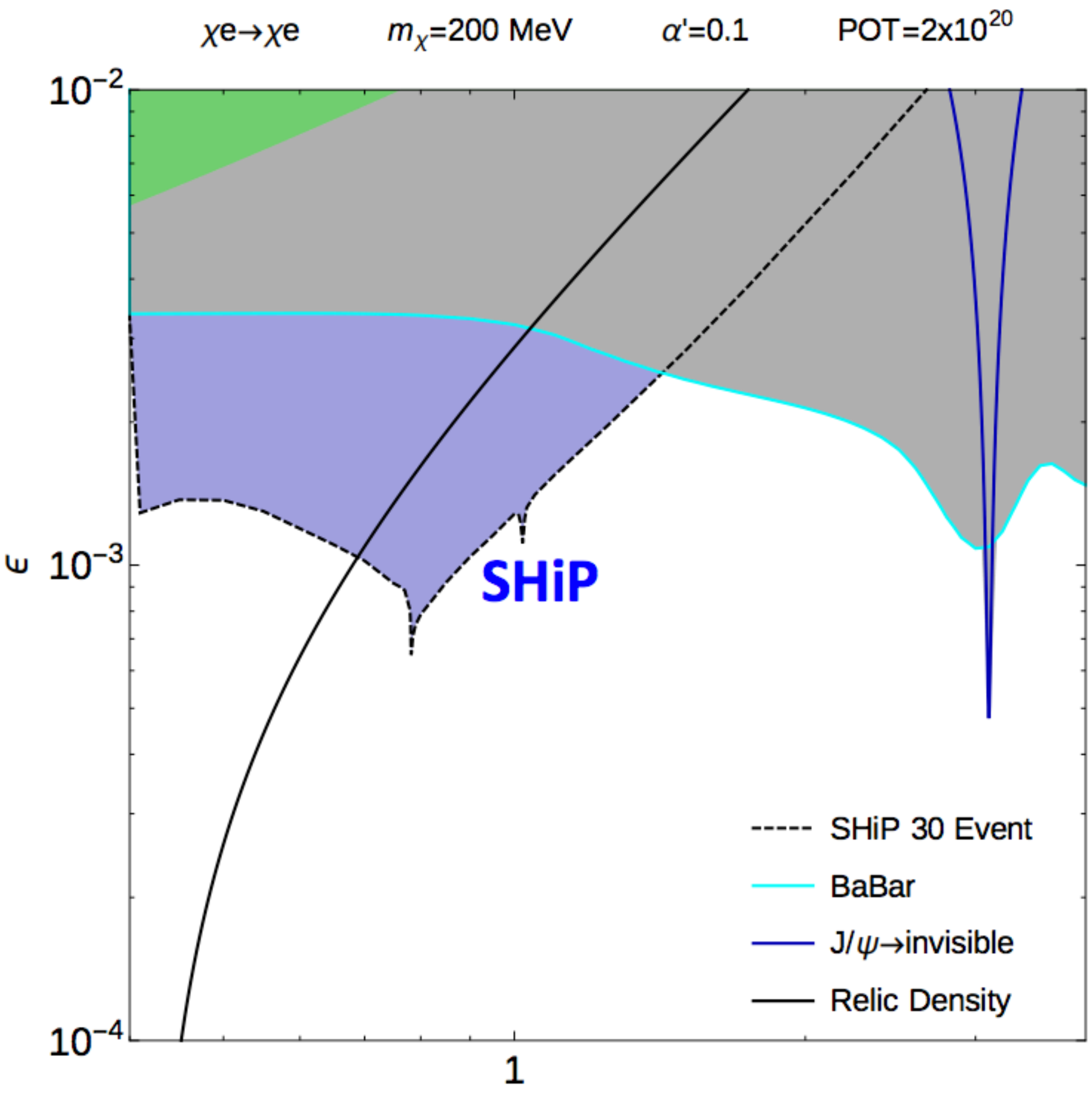
- For dark matter lighter than WIMPs “direct detection” experiments quickly lose sensitivity.

Two approaches:

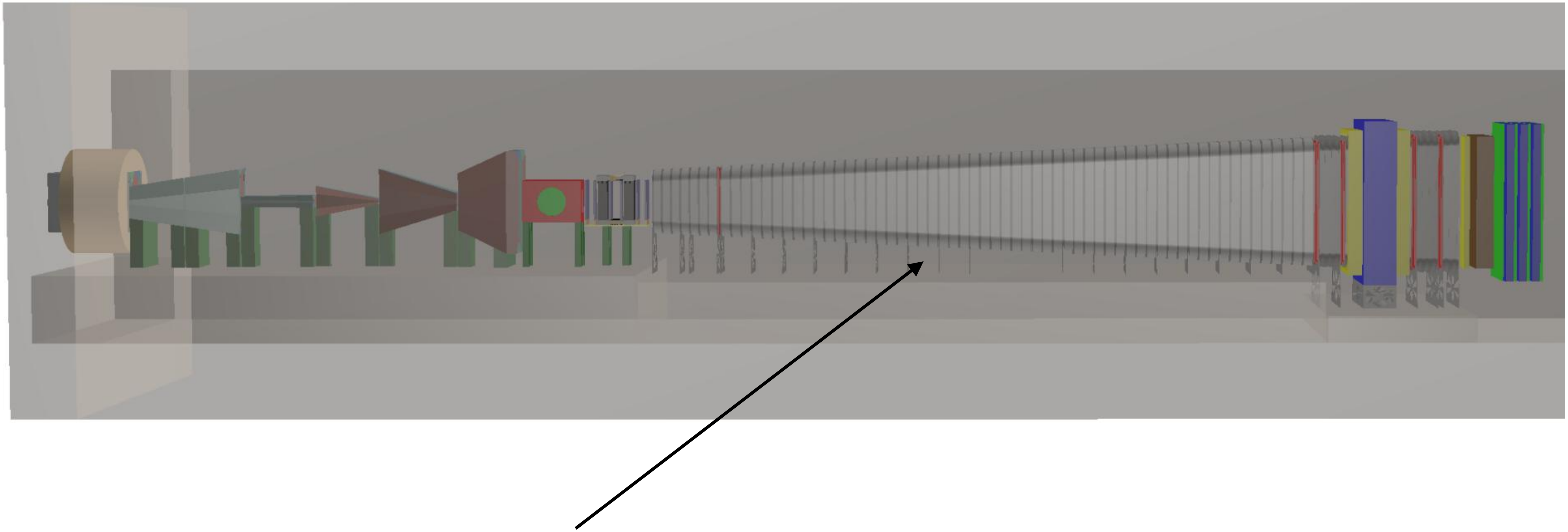
- missing mass/energy searches ($\propto U^2$)
- scattering/recoil ($\propto U^4$)

SHiP: Indirect detection via electron and nuclear recoil in nuclear emulsion:

- Main background for electron recoil from ν_e scattering, but differences in th kinematics can be exploited.

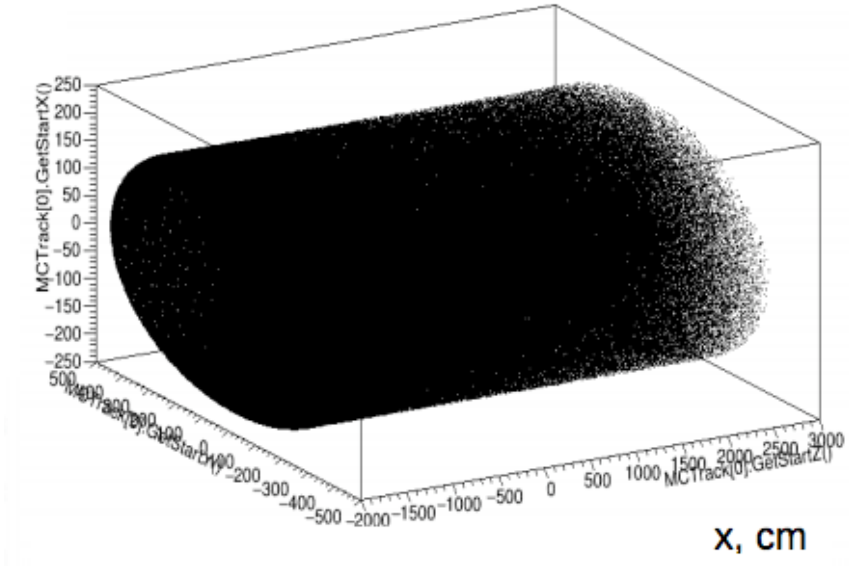


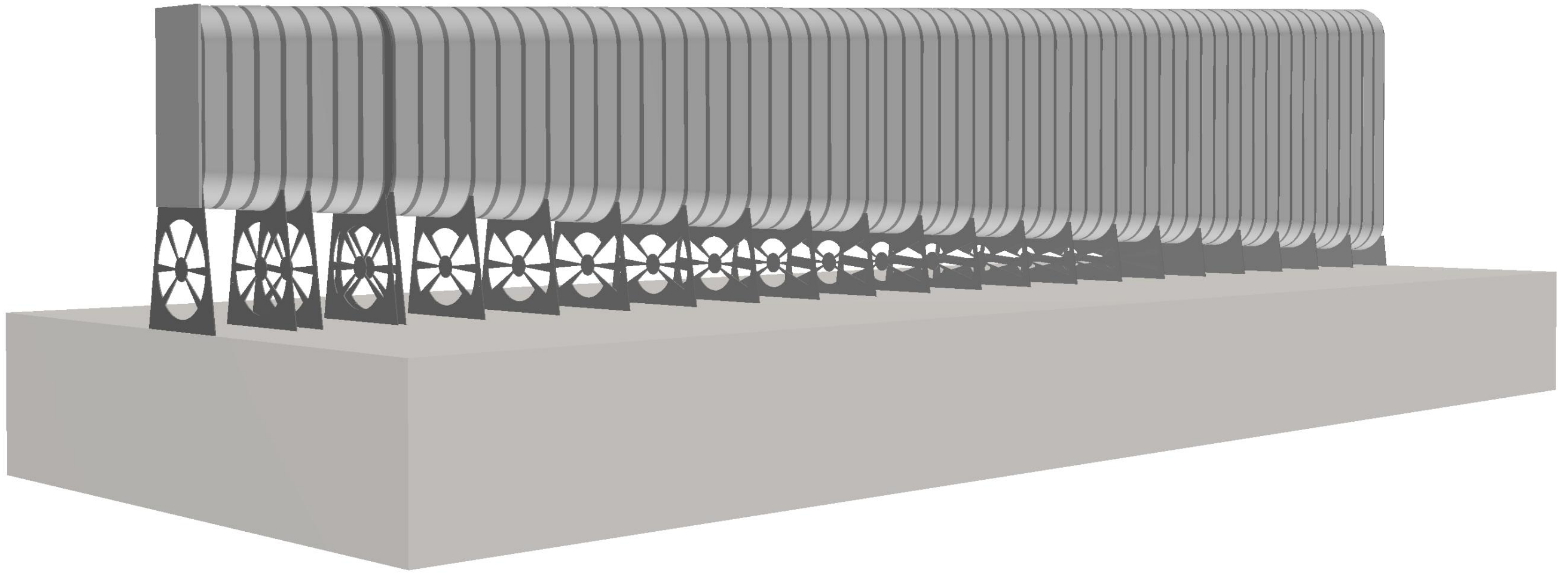
Overview of SHiP



Vacuum Vessel

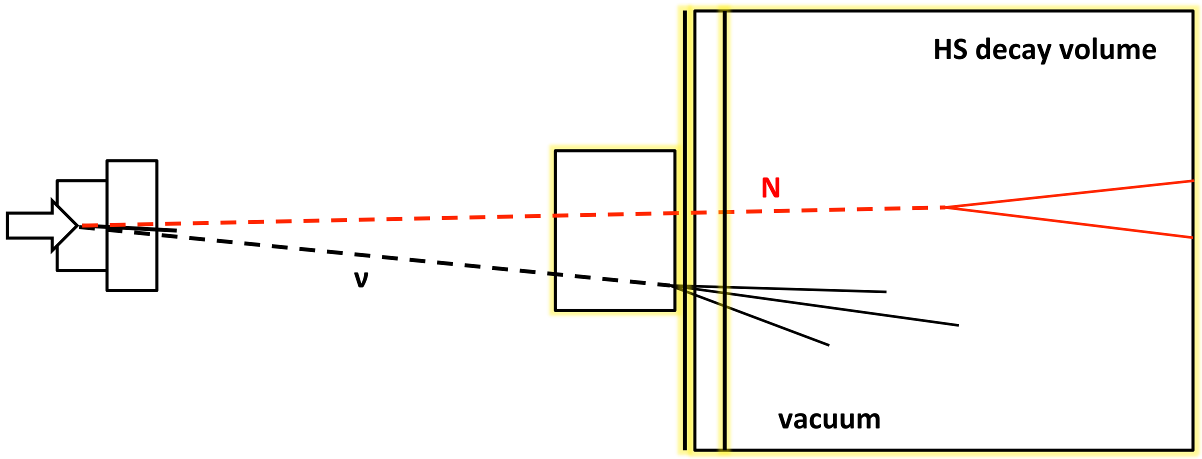
Vacuum Vessel

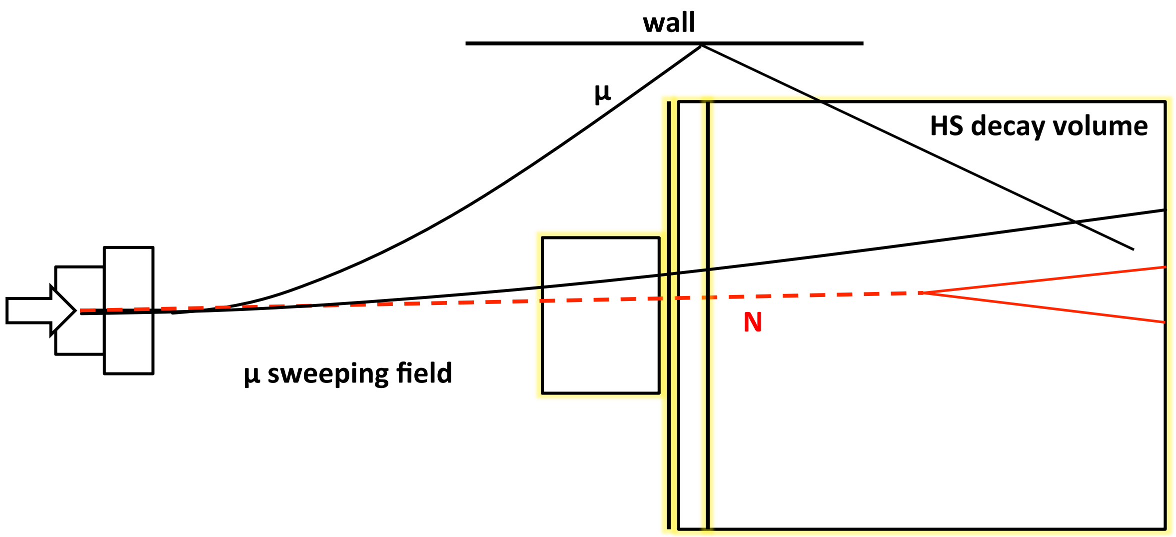


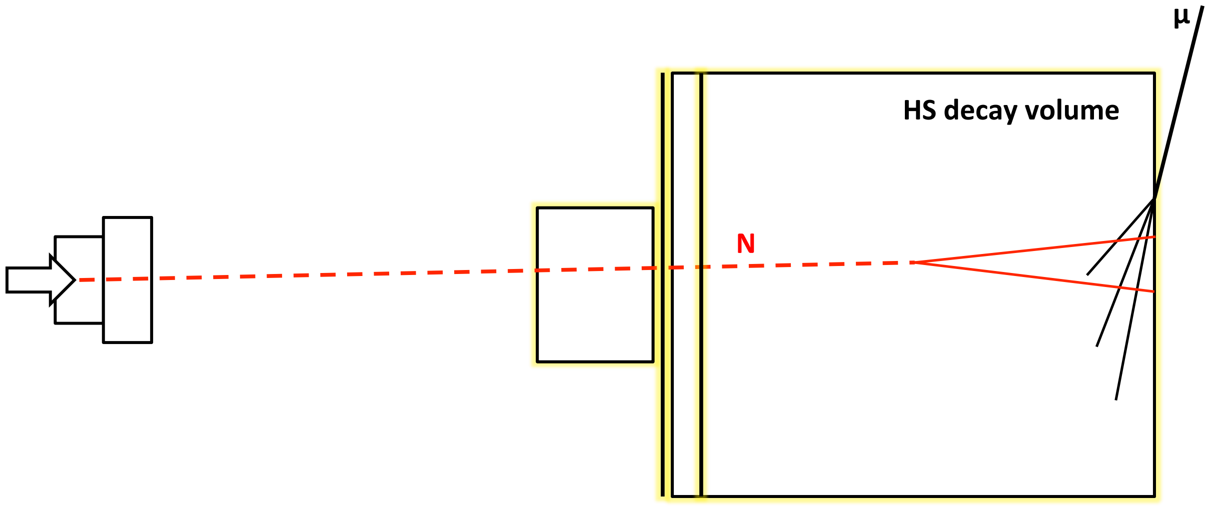


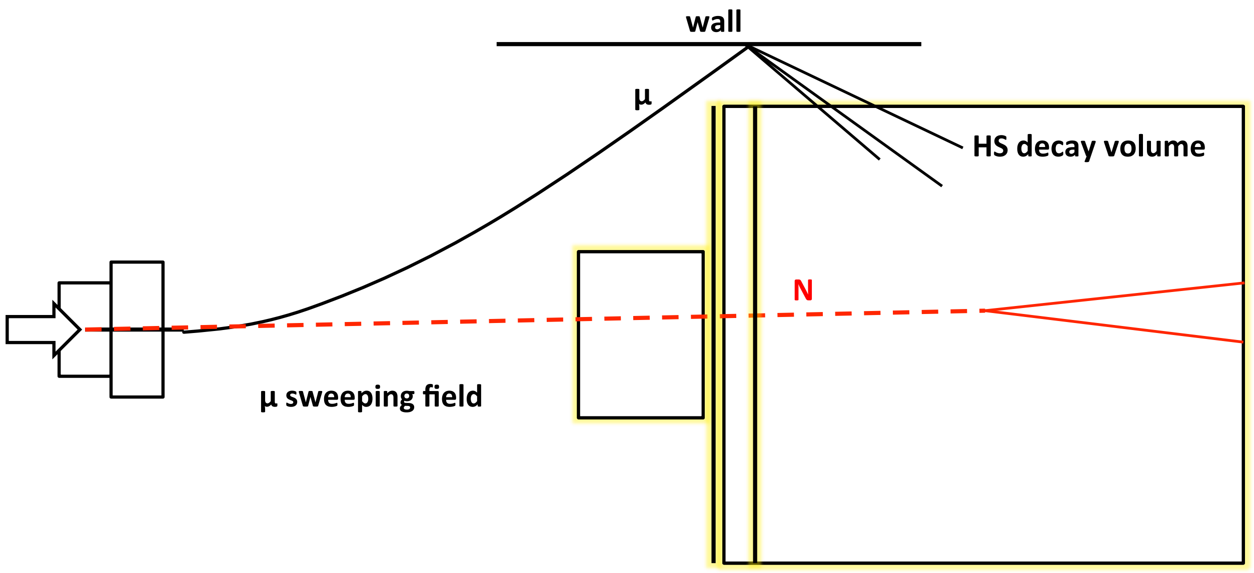
- The fiducial volume cannot be filled with air at atmospheric pressure, we would expect about 100K neutrino interaction in the experiment
- Of this about 300 would be survive a loose offline selection
- Plan to have a vacuum vessel with 10^{-3} Atm
- Piramidal frustrum shape to maximise the acceptance

Backgrounds







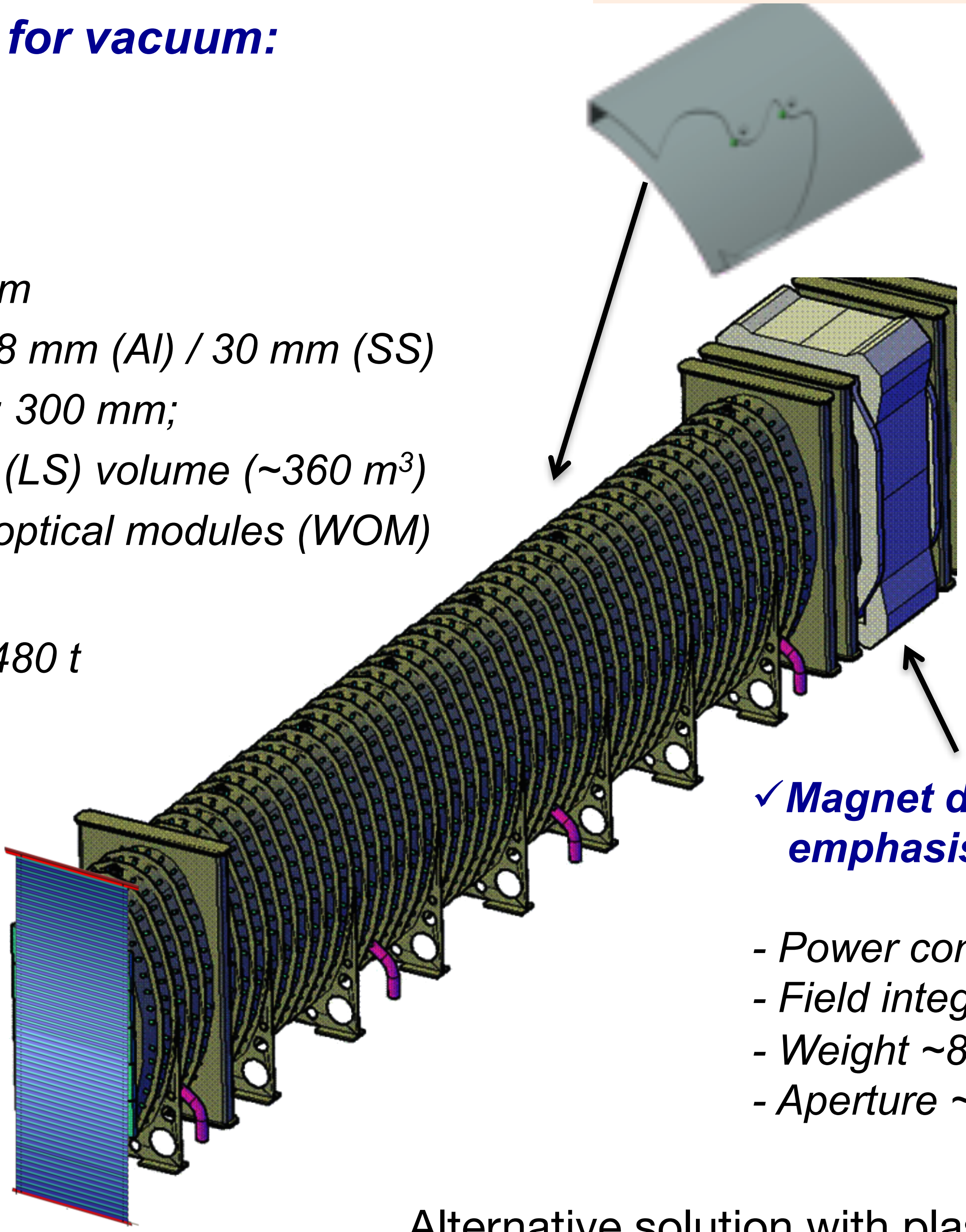


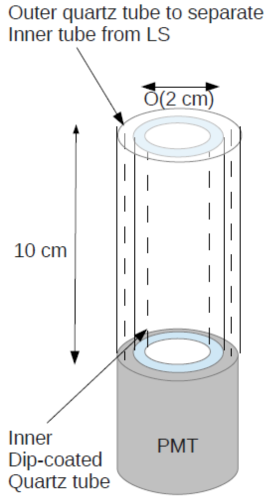
Surrounding Bkg Tagger

- ✓ ***Estimated need for vacuum:***
  ~ 10^{-3} mbar

- ✓ ***Vacuum vessel***
  - *10 m x 5 m x 60 m*
  - *Walls thickness: 8 mm (Al) / 30 mm (SS)*
  - *Walls separation: 300 mm;*
  - *Liquid scintillator (LS) volume (~360 m^3) readout by WLS optical modules (WOM) and PMTs*
  - *Vessel weight ~ 480 t*

LS cell with WOMs



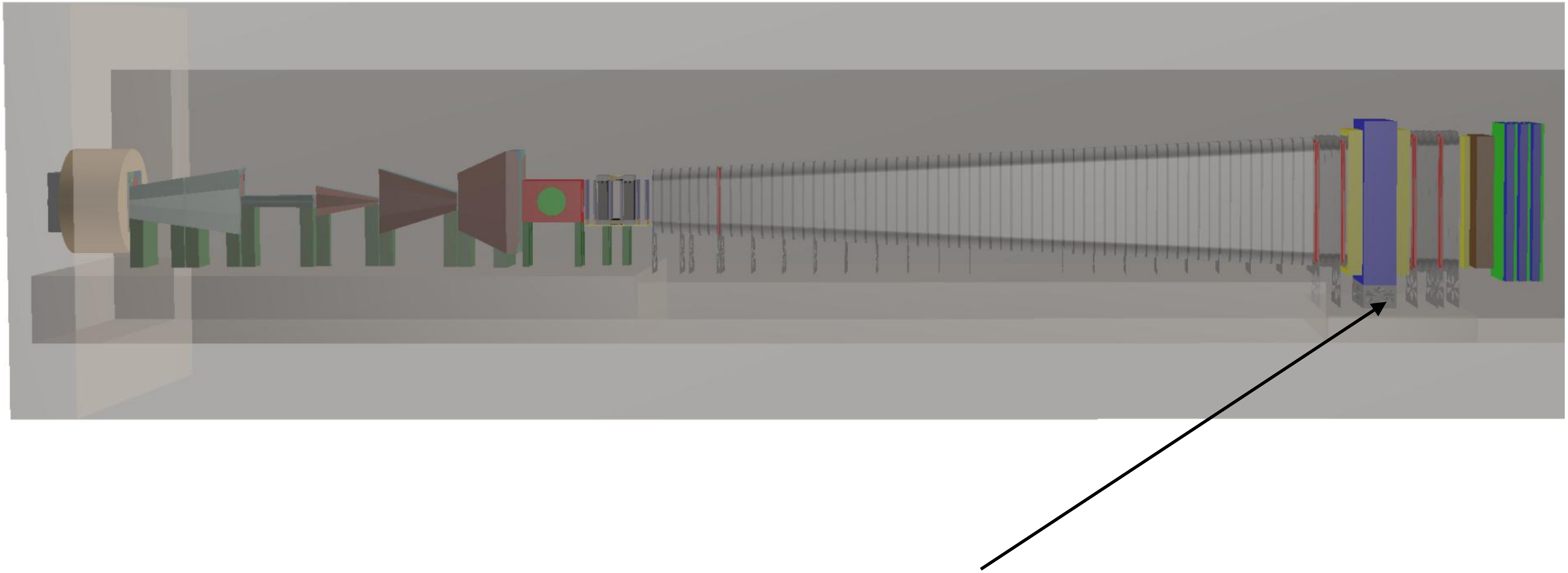


✓***Magnet designed with an emphasis on low power***

- *Power consumption < 1 MW*
- *Field integral: 0.65Tm over 5m*
- *Weight ~800 t*
- *Aperture ~50 m^2*

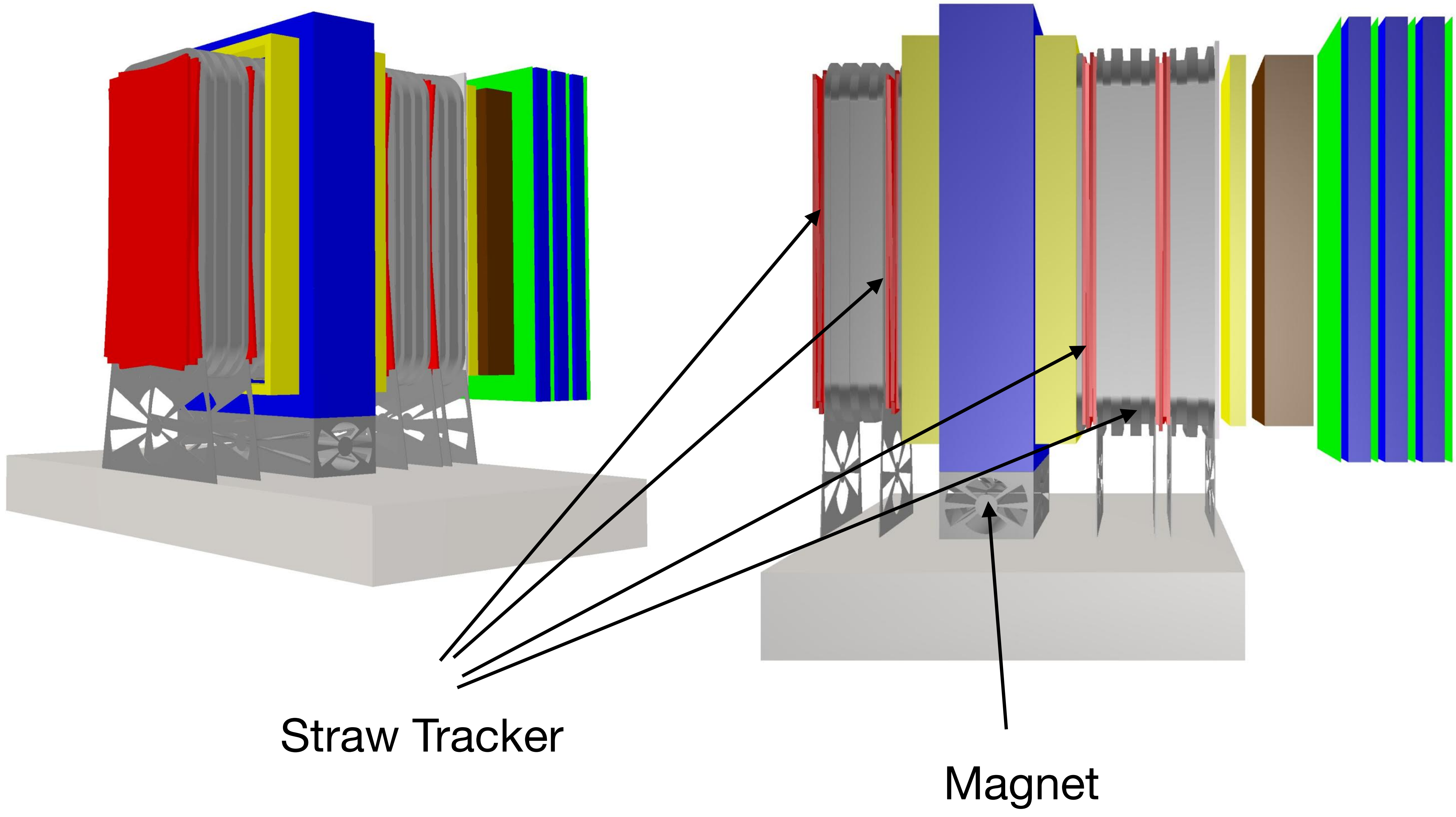
Alternative solution with plastic scintillators under study

Overview of SHiP



Hidden Sector Spectrometer

HS Spectrometer



Tracking System

Main difference with Na62:
5m length, vacuum 10^{-2}mbar,

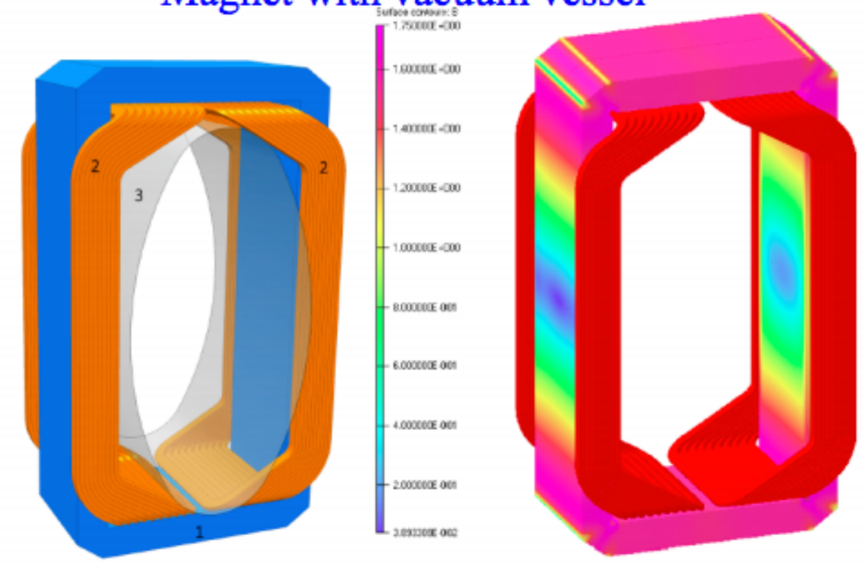
- *material budget per station 0.5% X_0*
  - *position resolution 120 μm per straw,*

8 hits per station on average

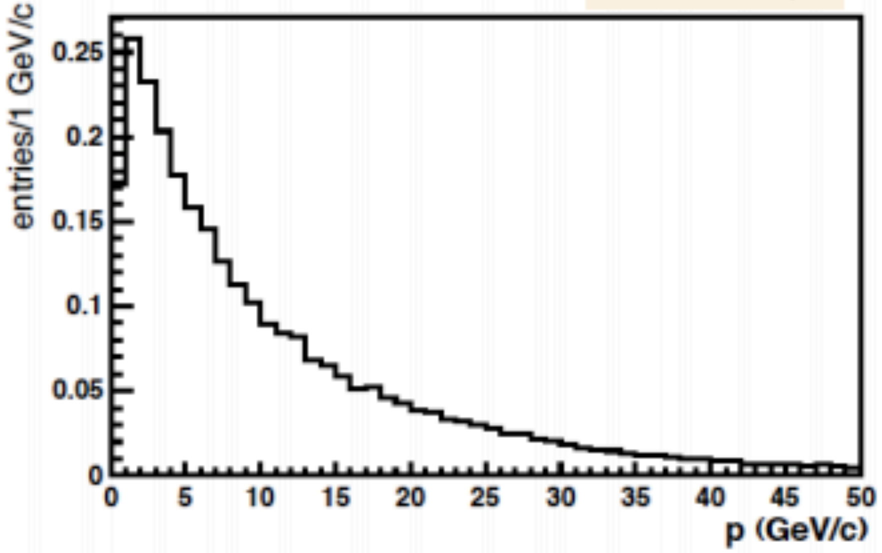
$$\left(\frac{\sigma_p}{p}\right)^2 \approx [0.49\%]^2 + [0.022\%/(\mathrm{GeV}/c)]^2 \cdot p^2$$

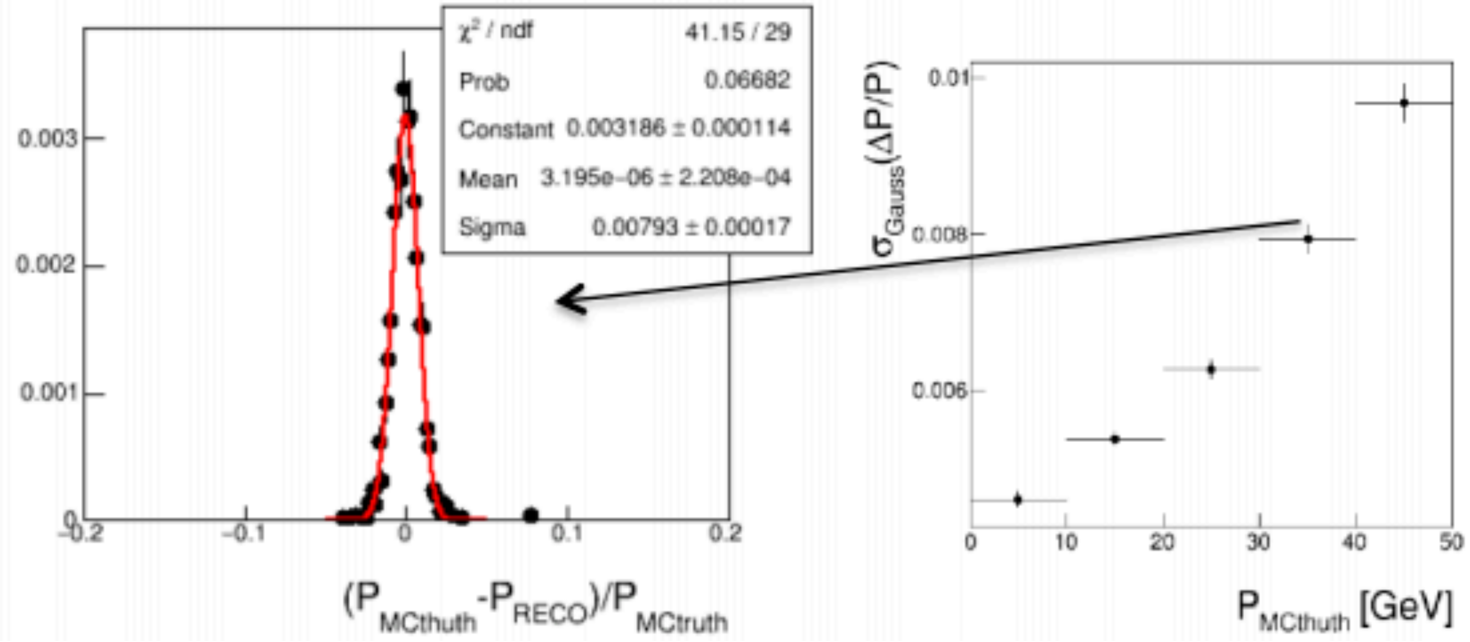
Momentum resolution is dominated by multiple scattering below 22 GeV/c
(For HNL → $\pi\mu$, 75% of both decay products have P < 20 GeV/c)

Magnet with vacuum vessel

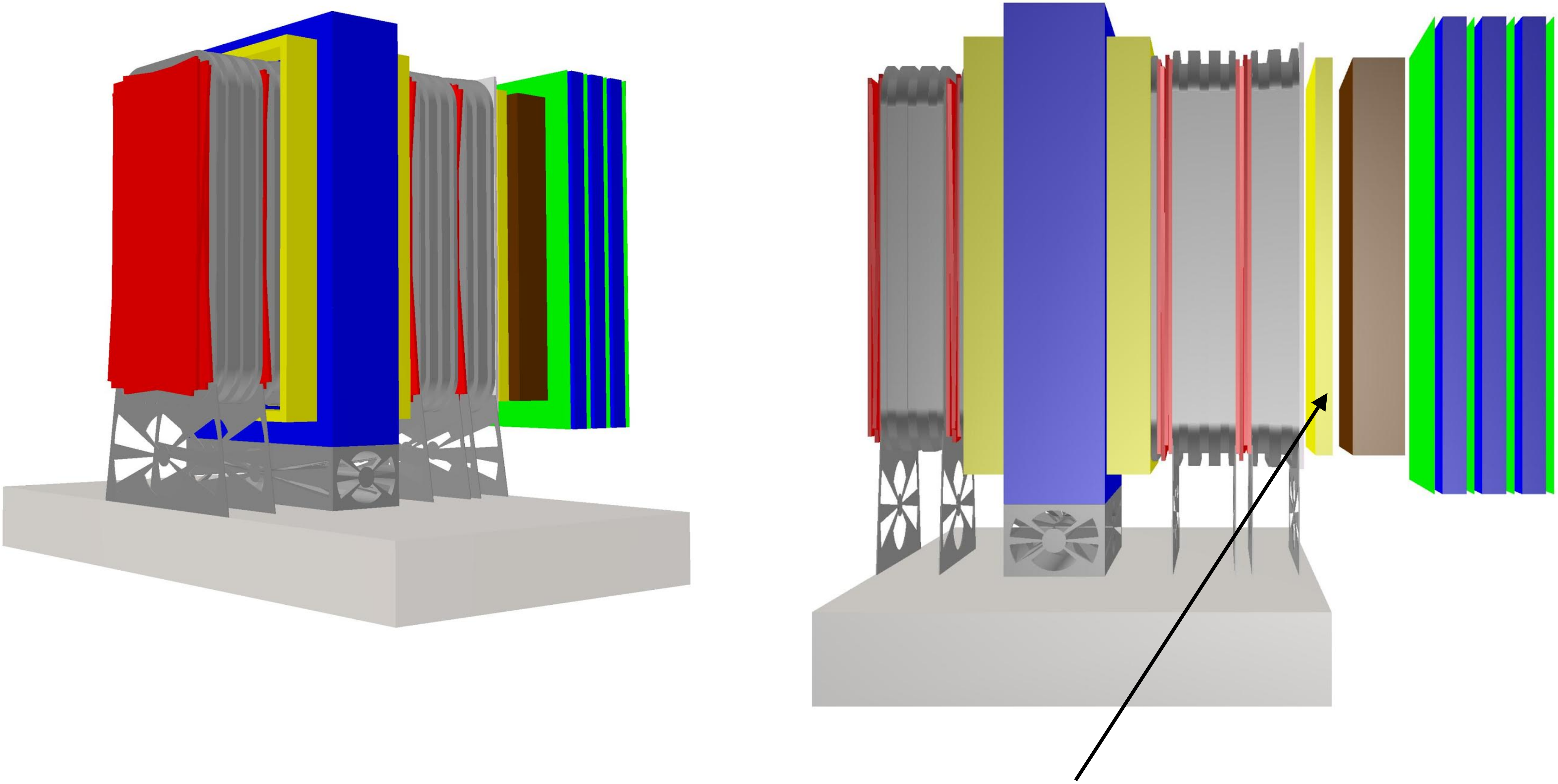


HNL→πμ



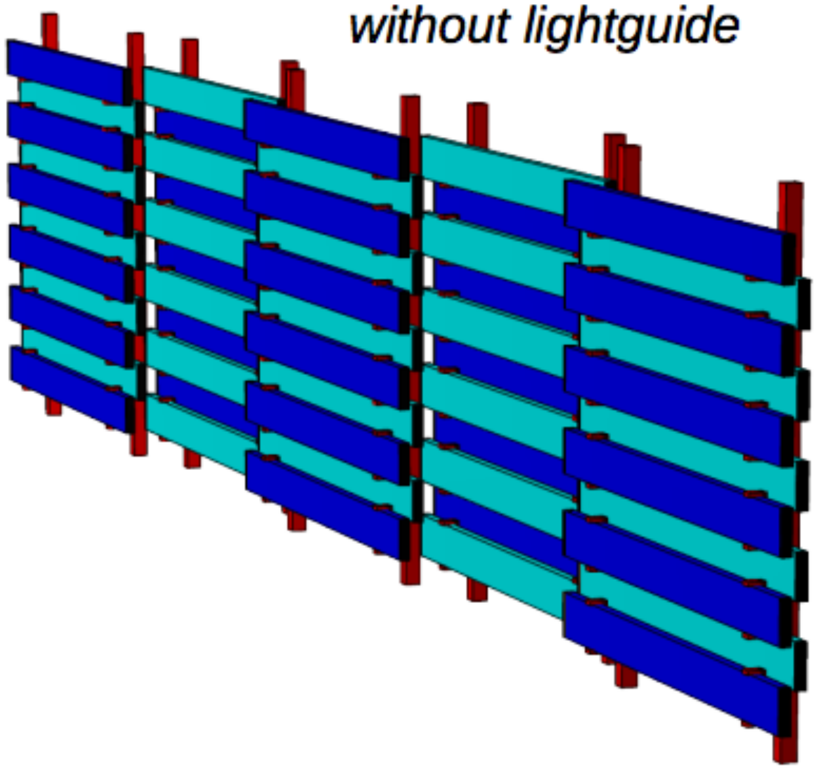


HS Spectrometer



Physics Case

Challenges:
- Large area
- Required time resolution <100ps



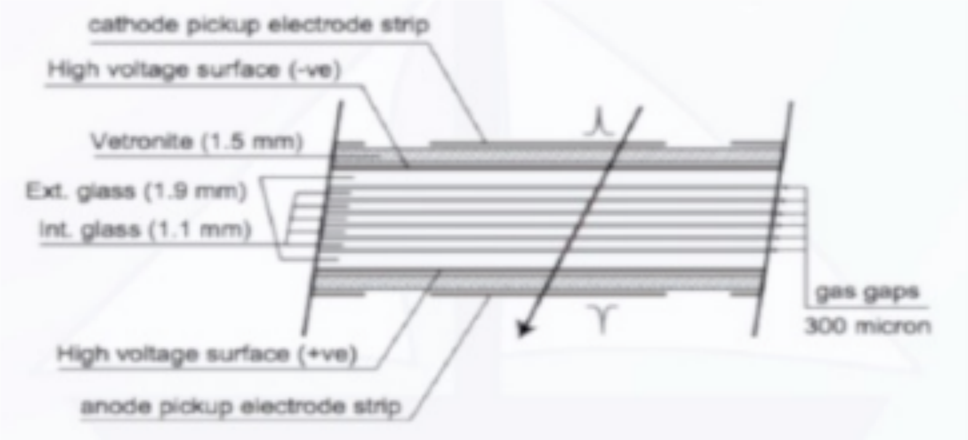
5-columns setup without lightguide

NA61/SHINE, bars with PMTs

UniGe 2006

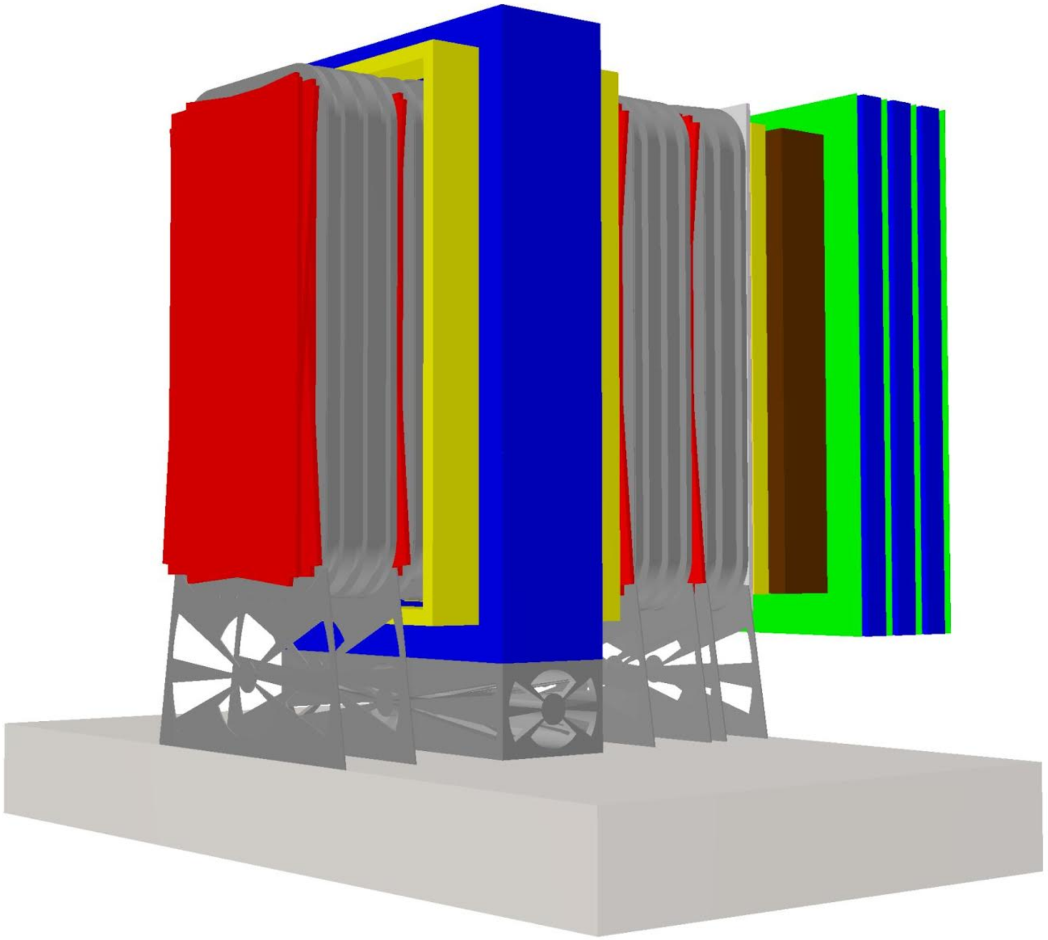
NA61/SHINE ToF
- 100ps resolution in NA61/Shine ToF
- Size of scintillator counter 120x10x2.5 cm^3
- Total active area 1.2x7.2 m^2

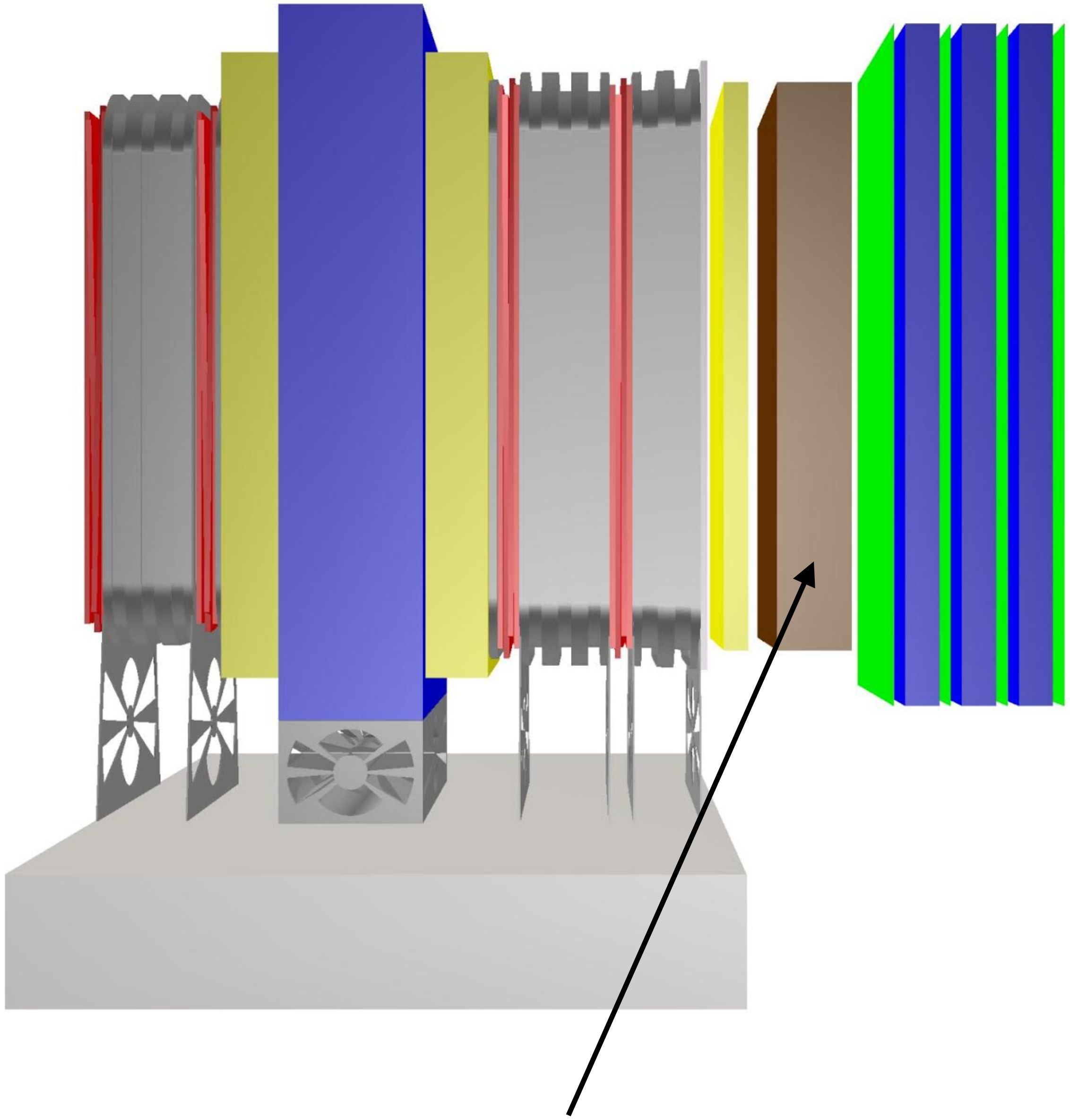
Multi-gap resistive plate chambers (MRPC)
- ALICE ToF and EEE project
- 61 chambers x 120 cm strips, 3 cm pitch
- 50 ps resolution achievable



- Plastic scintillating bars read-out by SiPM

HS Spectrometer

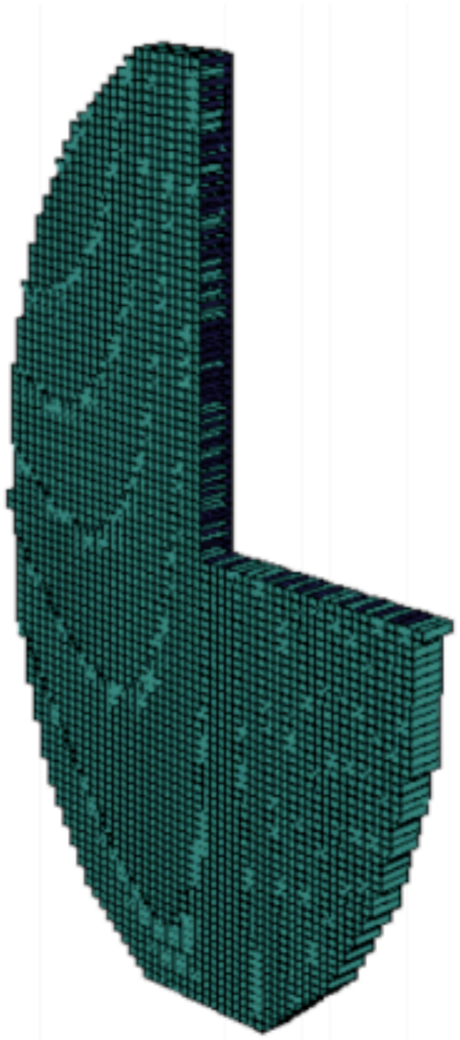


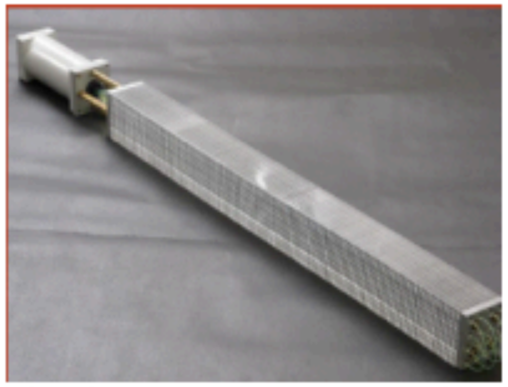


Calorimeter

ECAL

- Almost elliptical shape (5 m x 10 m)
- 2876 Shashlik modules
- 2x2 cells/modules, width=6 cm
- 11504 independent readout channels

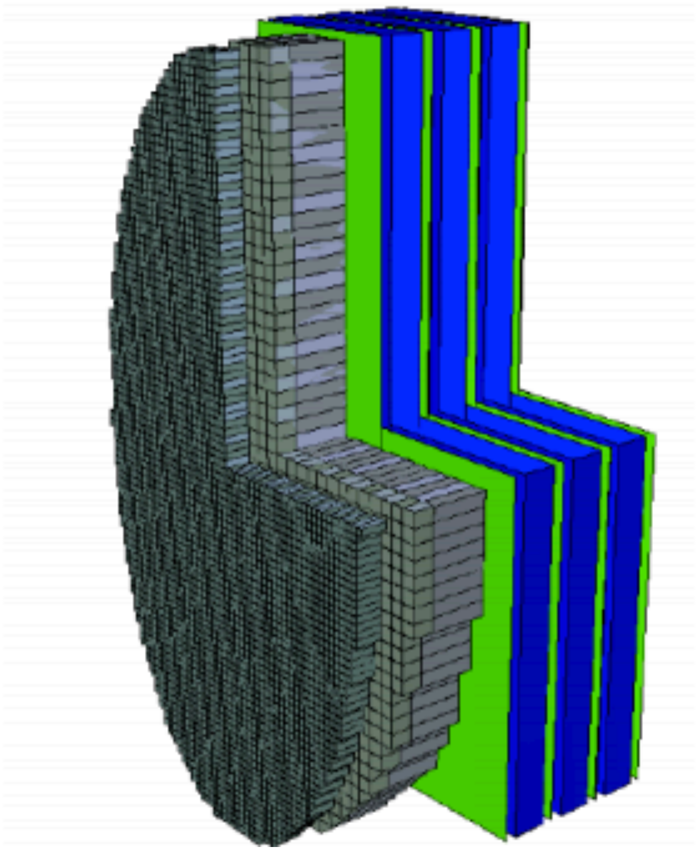




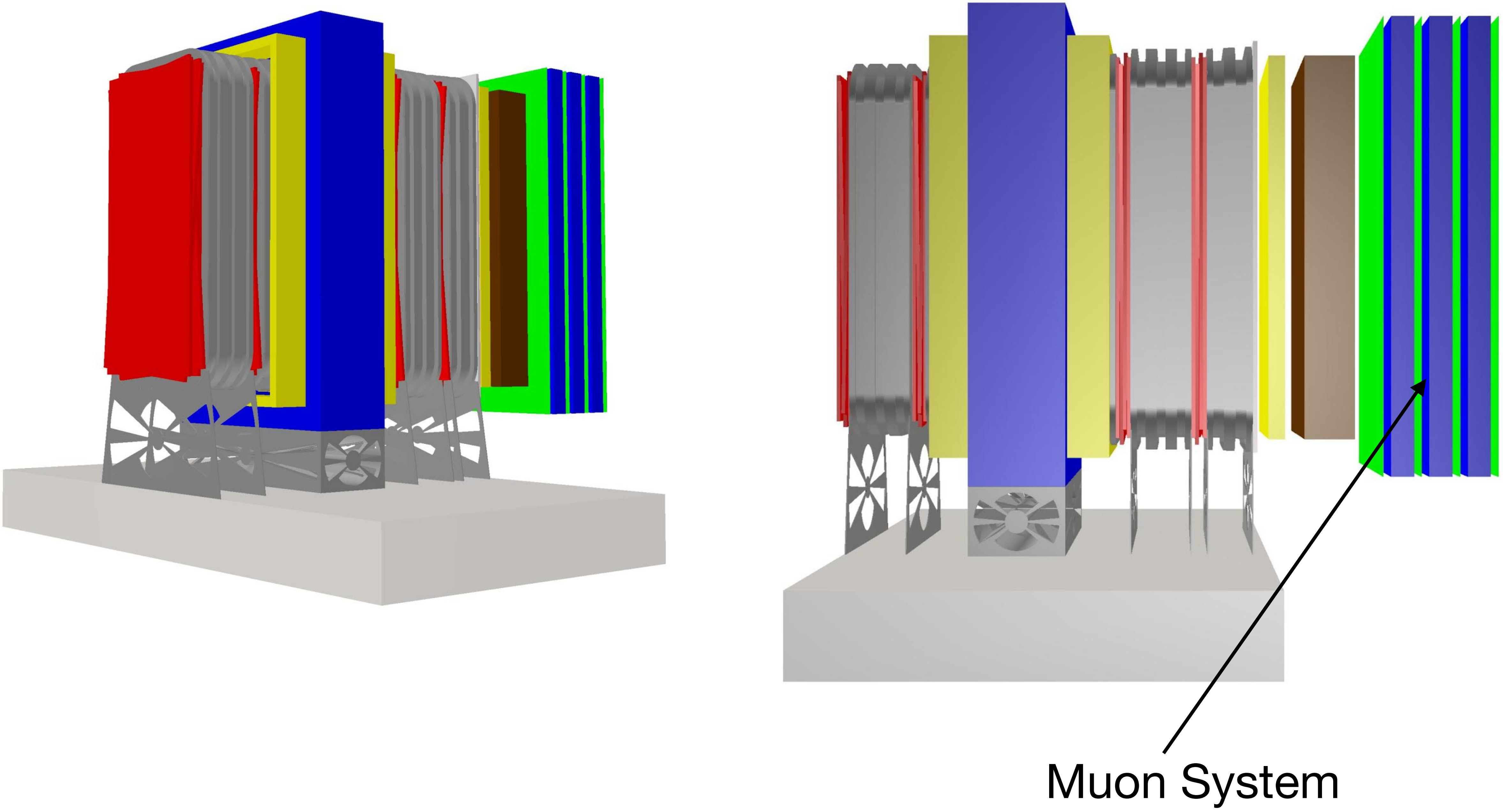
Dimensions	60x60 mm^2
Radiation length	17 mm
Moliere radius	36 mm
Radiation thickness	25 X_0
Scintillator thickness	1.5 mm
Lead thickness	0.8 mm
Energy resolution	1%

HCAL

- Matched with ECAL acceptance
- 2 stations
- 5 m x 10 m
- 1512 modules
- 24x24 cm^2 dimensions
- Stratigraphy: N x (1.5 cm steel+0.5 cm scint)
- 1512 independent readout channels

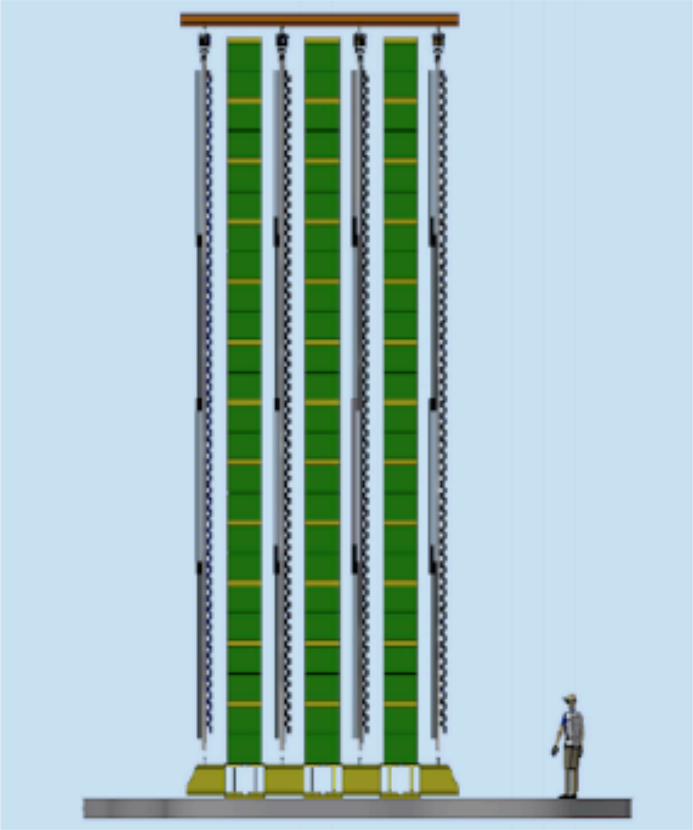


HS Spectrometer



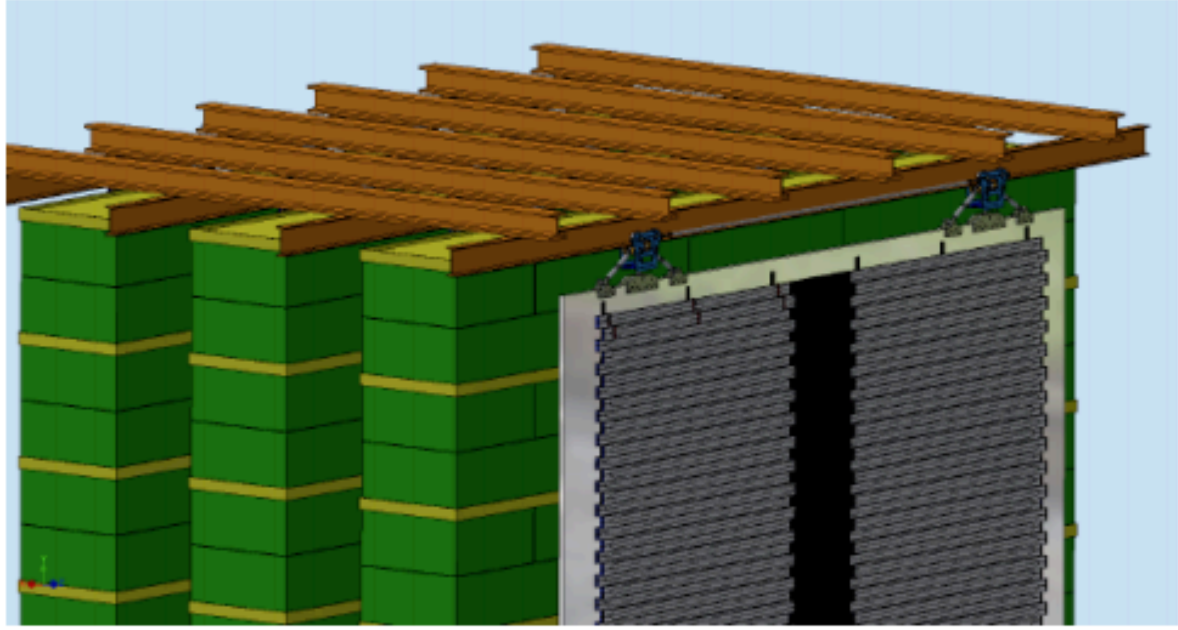
Muon System

Based on scintillating bars, with WLS fibers and SiPM readout



Technical Proposal (preliminary design)
- 4 active stations
- transverse dimensions: 1200x600 cm2
- x,y view
- 3380 bars, 5x300x2 cm3/each
- 7760 FEE channels
- 1000 tons of iron filters

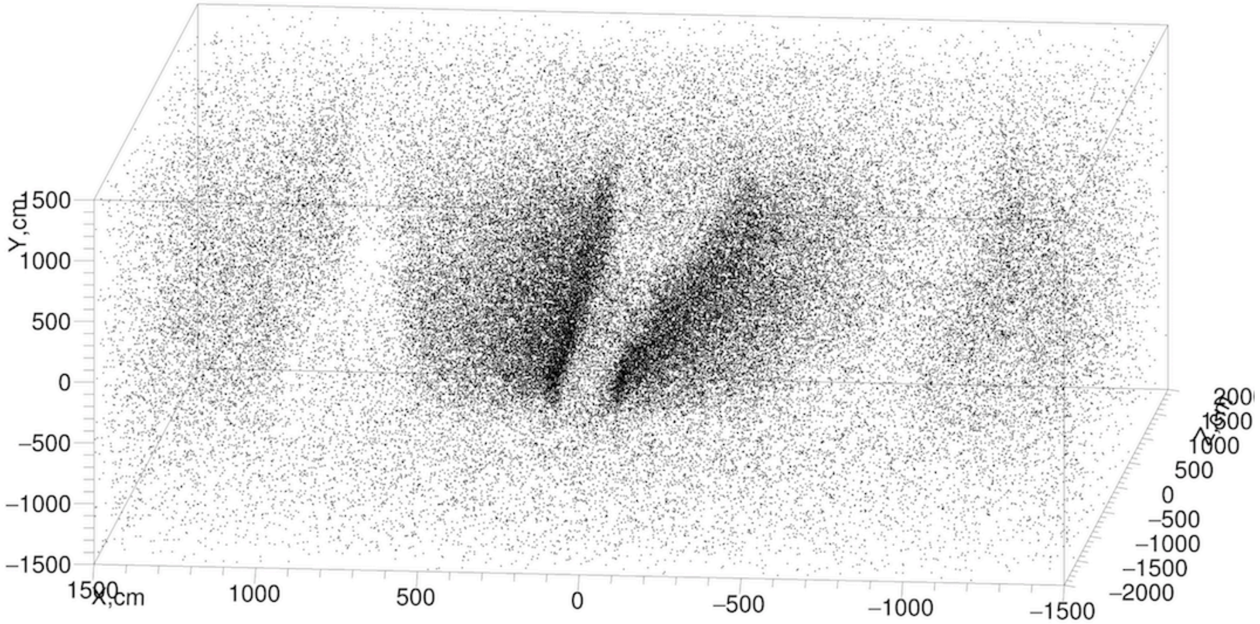
Requirements:
1) High-efficiency identification of muons in the final state
2) Separation between muons and hadrons/electrons
3) Complement timing detector to reject combinatorial muon background

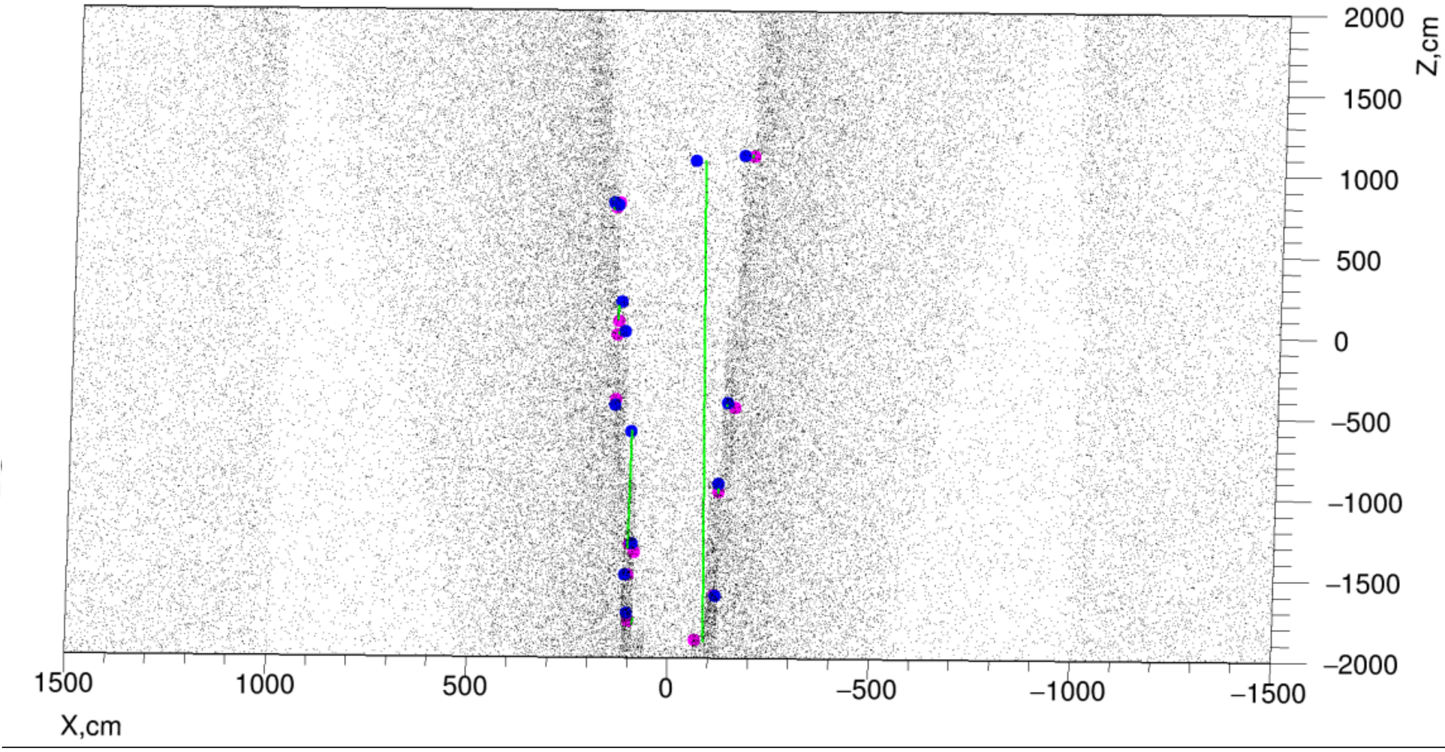


Background

Using the expected rate of muons (with sweeping magnets) the main background consists of neutrino inelastic:

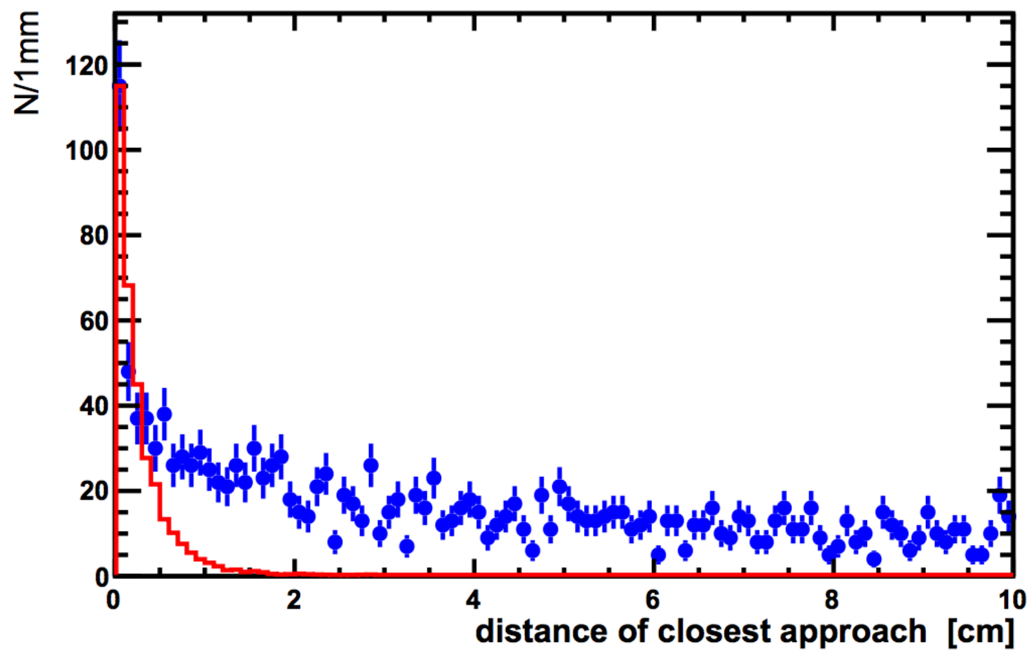
- Reduced rate of inelastic muons, efficiently killed by vets
- Cosmic muons killed by veto (+ bad pointing)
- Combinatorial muons killed by timing

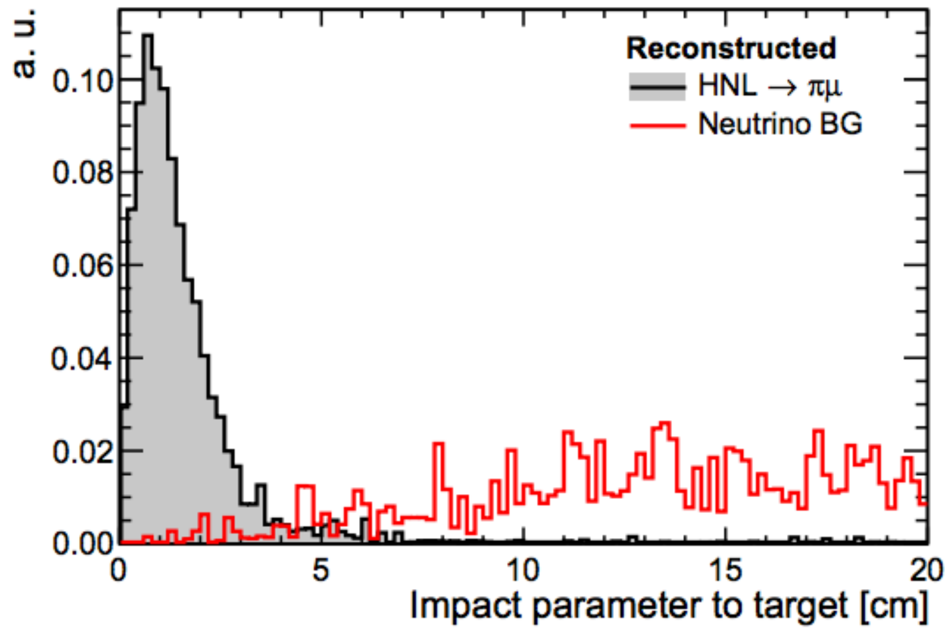


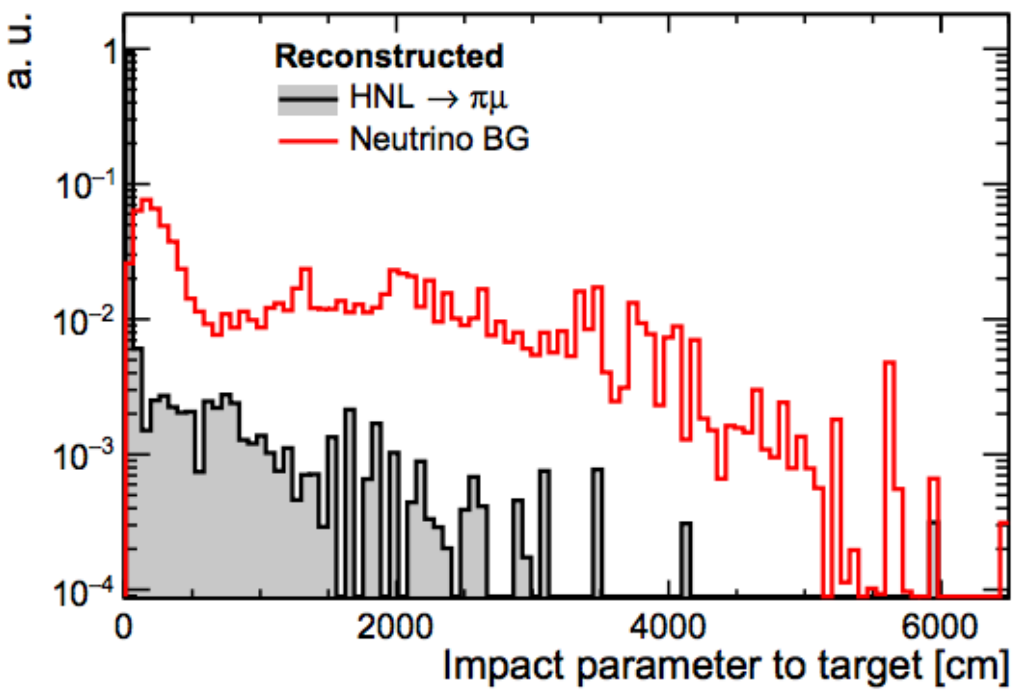


- Generating about 5 years of SHiP data taking estimate compatible with 0 bkg events
- Preparing a large simulation corresponding to 10x 5 years of SHiP

Background





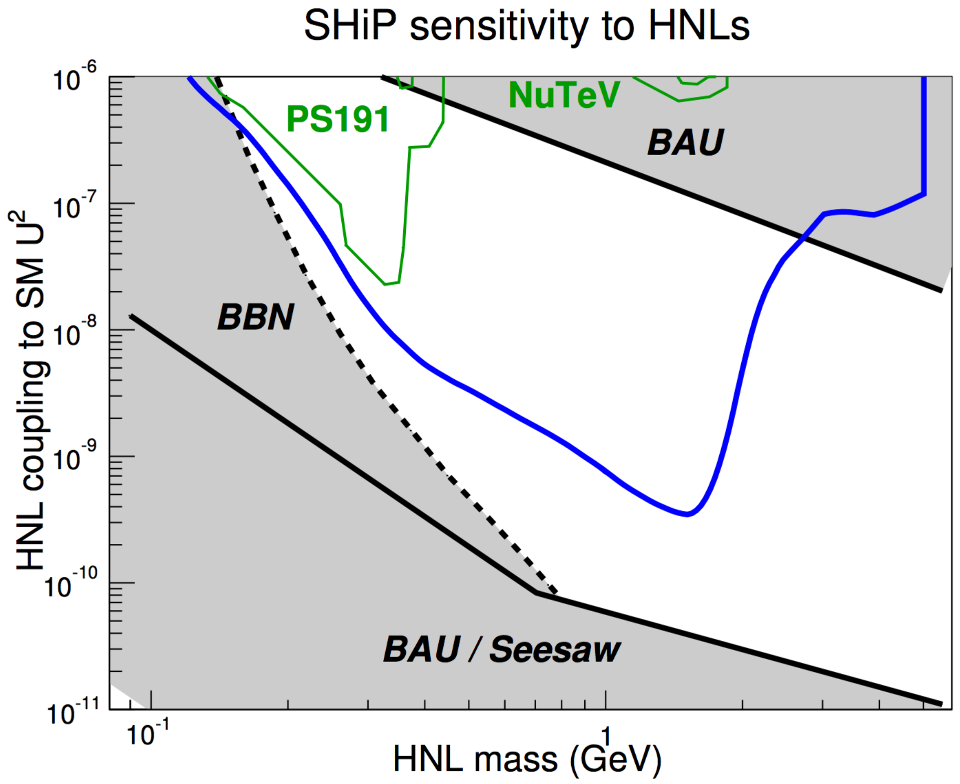


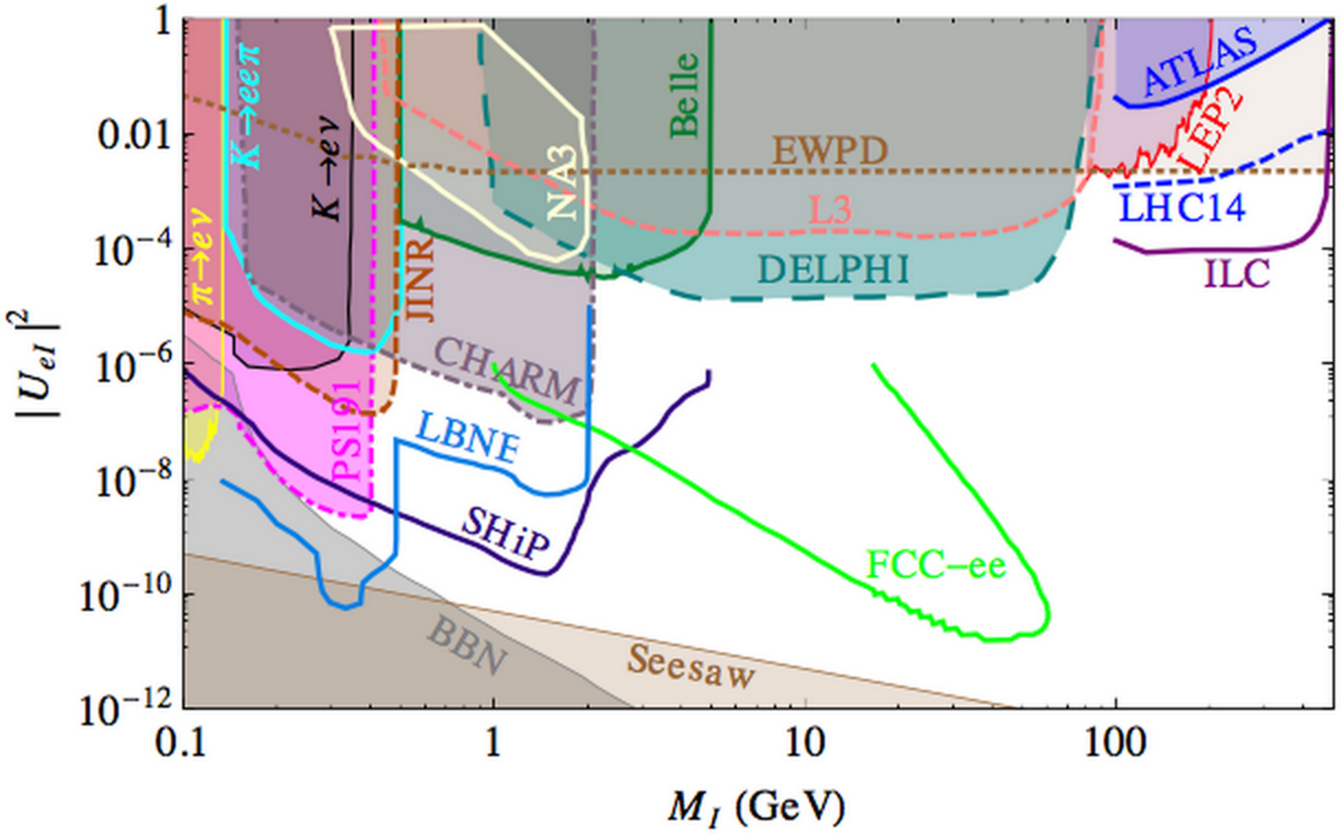
Very simple selection reduces the bkg to only a few in 5 years:

- Fiducial volume
- DOCA
- IP wrt target
- Vetos

Realistic to reach 0.1 expected bkg events for all channels we have been studying

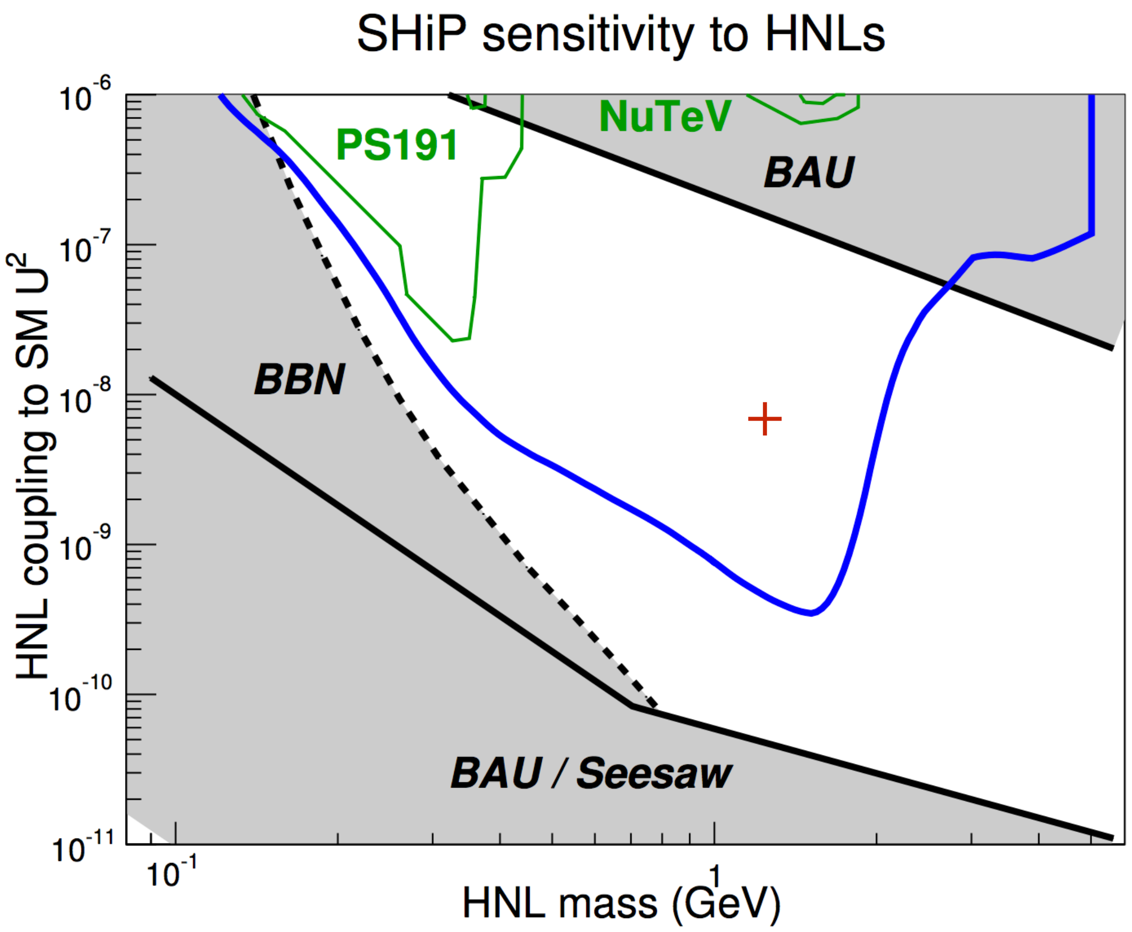
Sensitivities

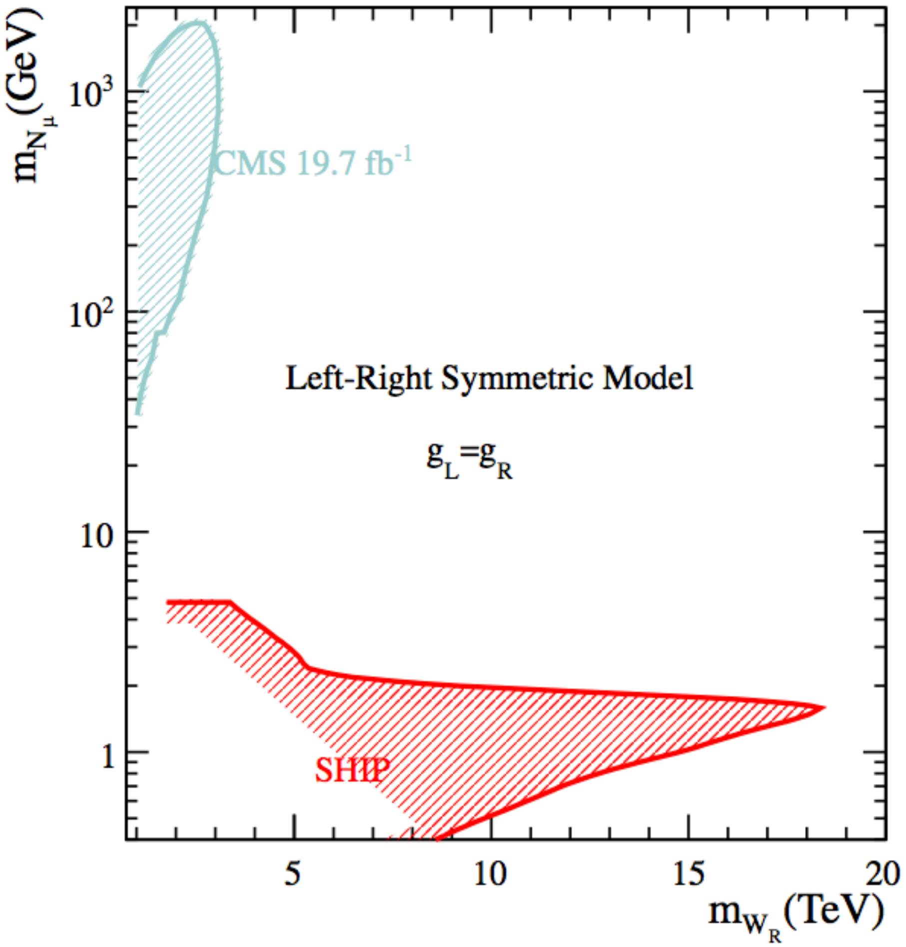




- SHiP can improve by up to 4 orders of magnitudes limits on sterile neutrinos below the B-meson mass

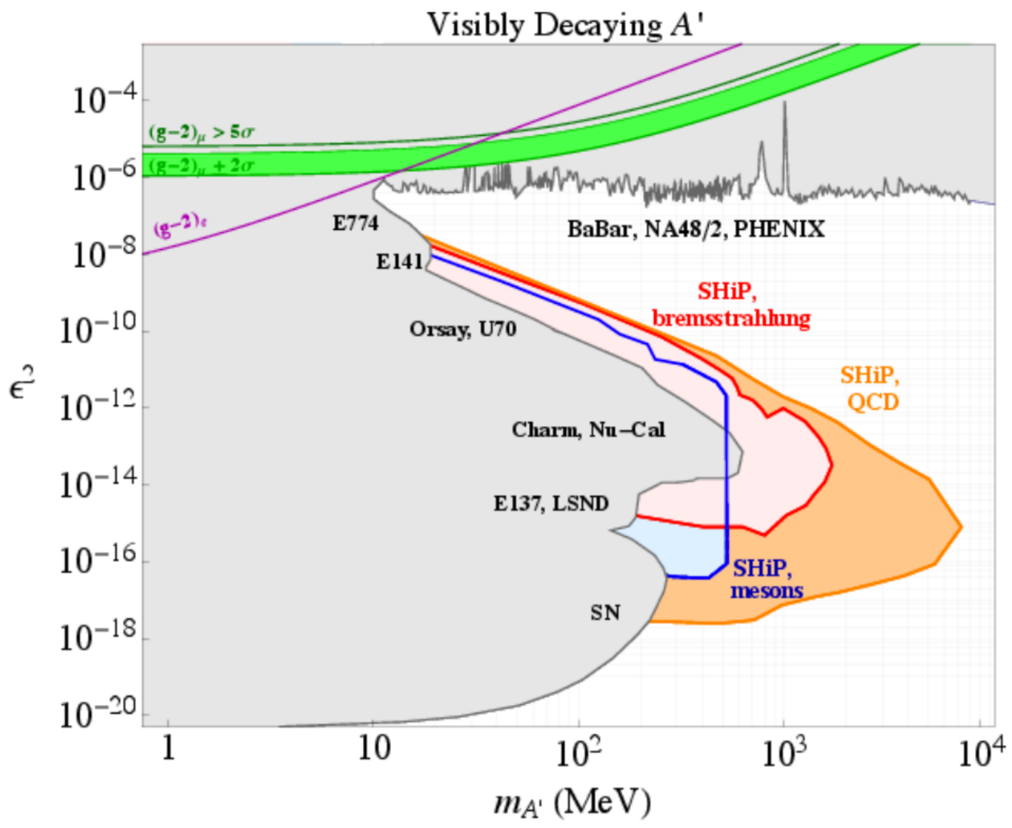
Sensitivities

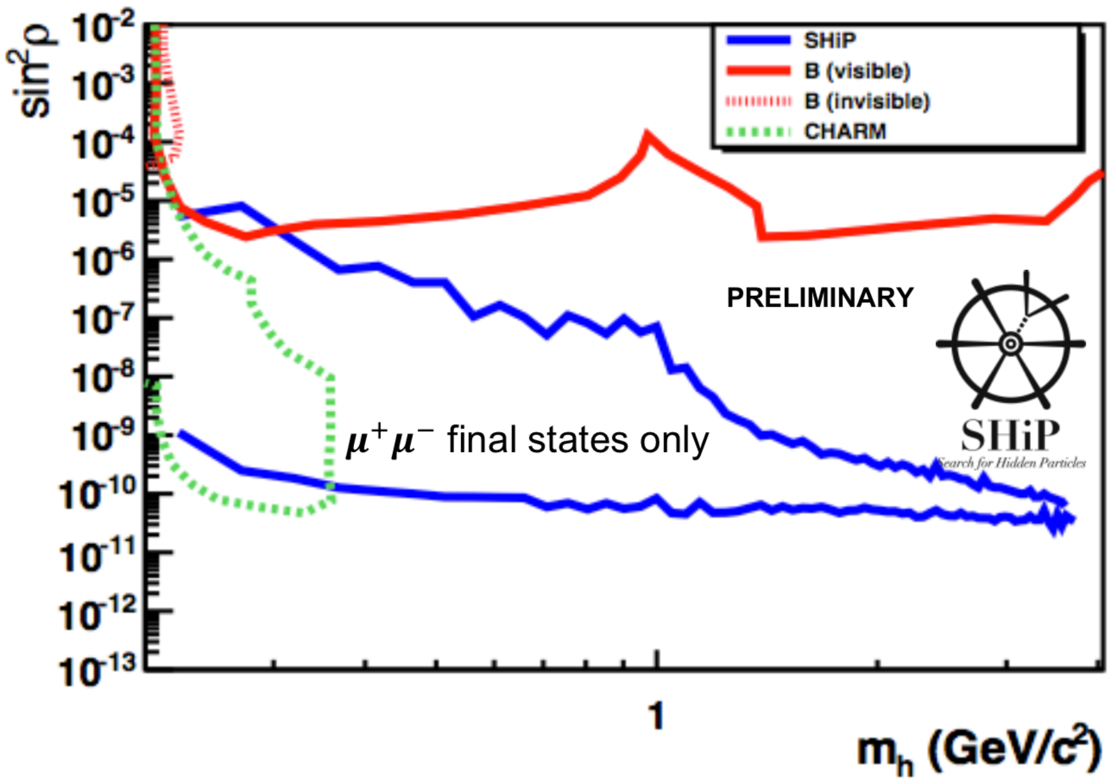




- SHiP can improve by up to 4 orders of magnitudes limits on sterile neutrinos below the B-meson mass
- E.g. $U^2=10^{-8}$ and M=1GeV (~50 times lower than the present limit) SHiP will see more than 1000 fully reconstructed events, i.e. SHiP would discover sterile neutrinos in less than a week of running!
- The result can be reinterpreted for instance in the context of the Left-right symmetric model

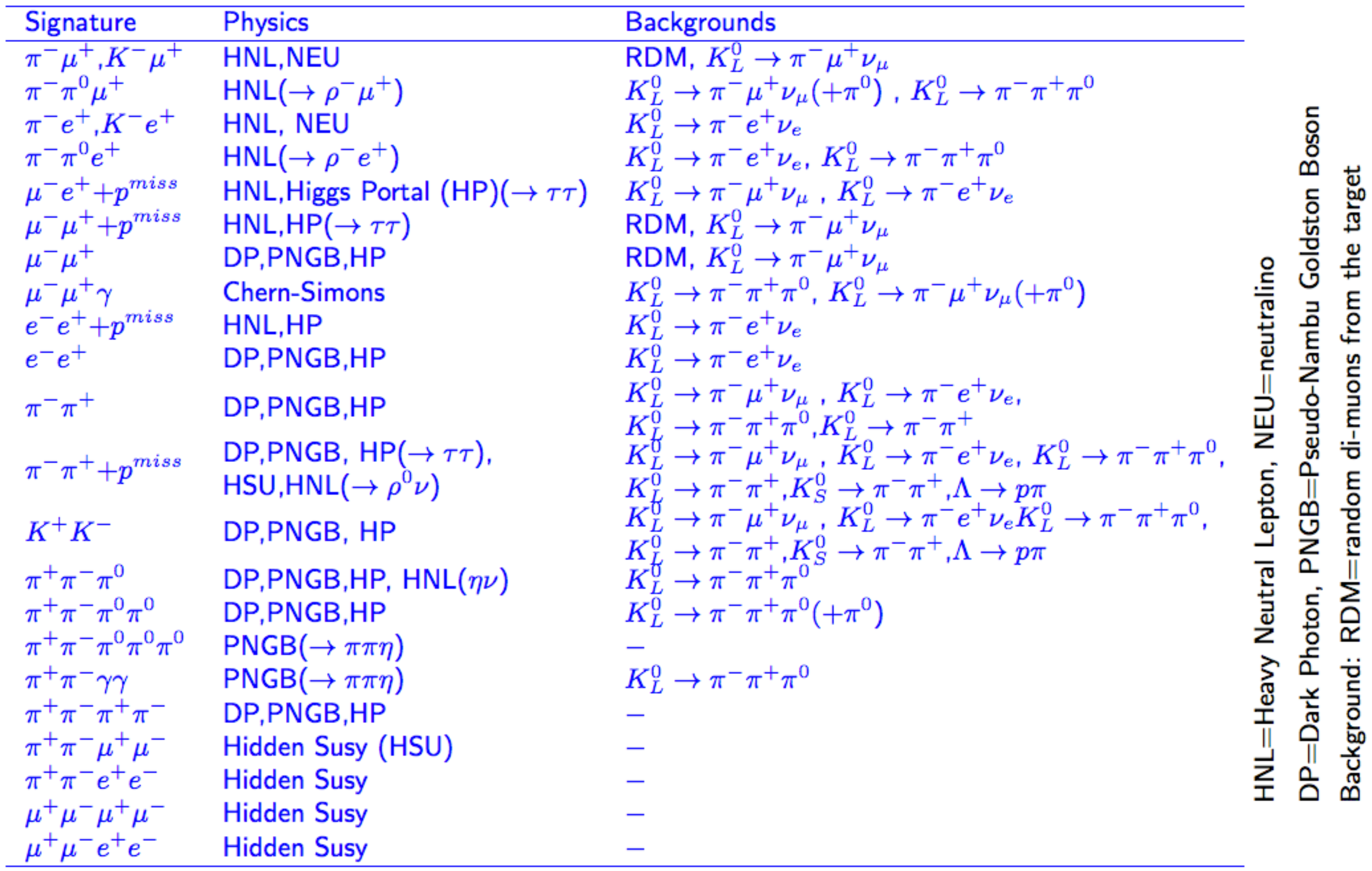
Sensitivities





- Large improvement in sensitivity for Dark Photon and Dark Scalar
- Cascade production of DP (and LDM) not taken into account at the moment
- Many other model under study

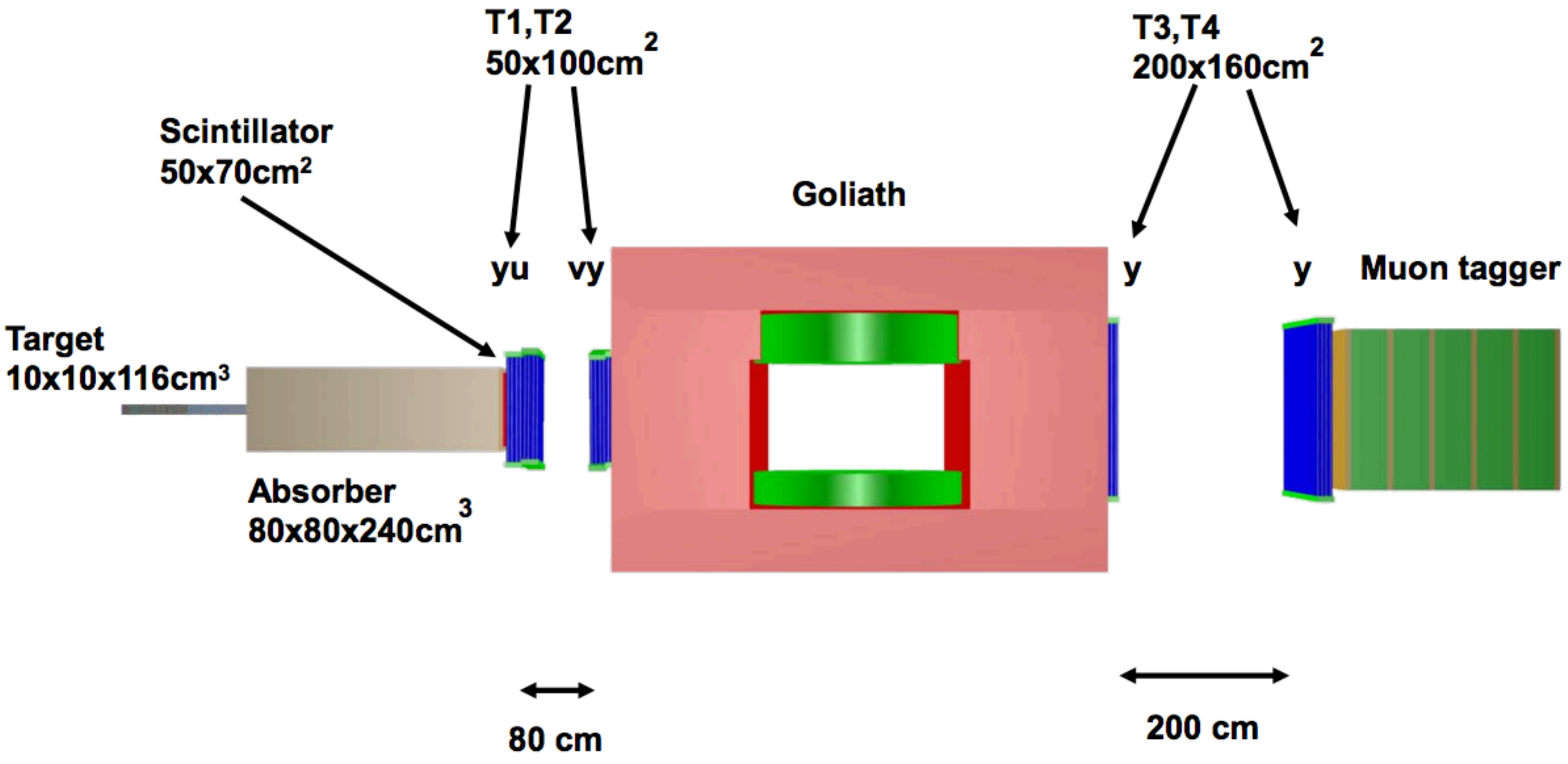
Physics signals



Signature	Physics	Backgrounds
$\pi^-\mu^+$,$K^-\mu^+$	HNL,NEU	RDM, $K^0_L \to \pi^-\mu^+\nu_\mu$
$\pi^-\pi^0\mu^+$	HNL($\to \rho^-\mu^+$)	$K^0_L \to \pi^-\mu^+\nu_\mu(+\pi^0)$, $K^0_L \to \pi^-\pi^+\pi^0$
π^-e^+,K^-e^+	HNL, NEU	$K^0_L \to \pi^-e^+\nu_e$
$\pi^-\pi^0e^+$	HNL($\to \rho^-e^+$)	$K^0_L \to \pi^-e^+\nu_e$, $K^0_L \to \pi^-\pi^+\pi^0$
μ^-e^++p^{miss}	HNL,Higgs Portal (HP)($\to \tau\tau$)	$K^0_L \to \pi^-\mu^+\nu_\mu$, $K^0_L \to \pi^-e^+\nu_e$
$\mu^-\mu^+$+p^{miss}	HNL,HP($\to \tau\tau$)	RDM, $K^0_L \to \pi^-\mu^+\nu_\mu$
$\mu^-\mu^+$	DP,PNGB,HP	RDM, $K^0_L \to \pi^-\mu^+\nu_\mu$
$\mu^-\mu^+\gamma$	Chern-Simons	$K^0_L \to \pi^-\pi^+\pi^0$, $K^0_L \to \pi^-\mu^+\nu_\mu(+\pi^0)$
e^-e^++p^{miss}	HNL,HP	$K^0_L \to \pi^-e^+\nu_e$
e^-e^+	DP,PNGB,HP	$K^0_L \to \pi^-e^+\nu_e$
$\pi^-\pi^+$	DP,PNGB,HP	$K^0_L \to \pi^-\mu^+\nu_\mu$, $K^0_L \to \pi^-e^+\nu_e$, $K^0_L \to \pi^-\pi^+\pi^0$,$K^0_L \to \pi^-\pi^+$
$\pi^-\pi^+$+p^{miss}	DP,PNGB, HP($\to \tau\tau$), HSU,HNL($\to \rho^0\nu$)	$K^0_L \to \pi^-\mu^+\nu_\mu$, $K^0_L \to \pi^-e^+\nu_e$, $K^0_L \to \pi^-\pi^+\pi^0$, $K^0_L \to \pi^-\pi^+$,$K^0_S \to \pi^-\pi^+$,$\Lambda \to p\pi$
K^+K^-	DP,PNGB, HP	$K^0_L \to \pi^-\mu^+\nu_\mu$, $K^0_L \to \pi^-e^+\nu_e K^0_L \to \pi^-\pi^+\pi^0$, $K^0_L \to \pi^-\pi^+$,$K^0_S \to \pi^-\pi^+$,$\Lambda \to p\pi$
$\pi^+\pi^-\pi^0$	DP,PNGB,HP, HNL($\eta\nu$)	$K^0_L \to \pi^-\pi^+\pi^0$
$\pi^+\pi^-\pi^0\pi^0$	DP,PNGB,HP	$K^0_L \to \pi^-\pi^+\pi^0(+\pi^0)$
$\pi^+\pi^-\pi^0\pi^0\pi^0$	PNGB($\to \pi\pi\eta$)	–
$\pi^+\pi^-\gamma\gamma$	PNGB($\to \pi\pi\eta$)	$K^0_L \to \pi^-\pi^+\pi^0$
$\pi^+\pi^-\pi^+\pi^-$	DP,PNGB,HP	–
$\pi^+\pi^-\mu^+\mu^-$	Hidden Susy (HSU)	–
$\pi^+\pi^-e^+e^-$	Hidden Susy	–
$\mu^+\mu^-\mu^+\mu^-$	Hidden Susy	–
$\mu^+\mu^-e^+e^-$	Hidden Susy	–

HNL=Heavy Neutral Lepton, NEU=neutralino
DP=Dark Photon, PNGB=Pseudo-Nambu Goldston Boson
Background: RDM=random di-muons from the target

Measuring muon flux



- SHiP uses sweeping magnets to reduce the muon flux
- It is important to know the muon spectrum

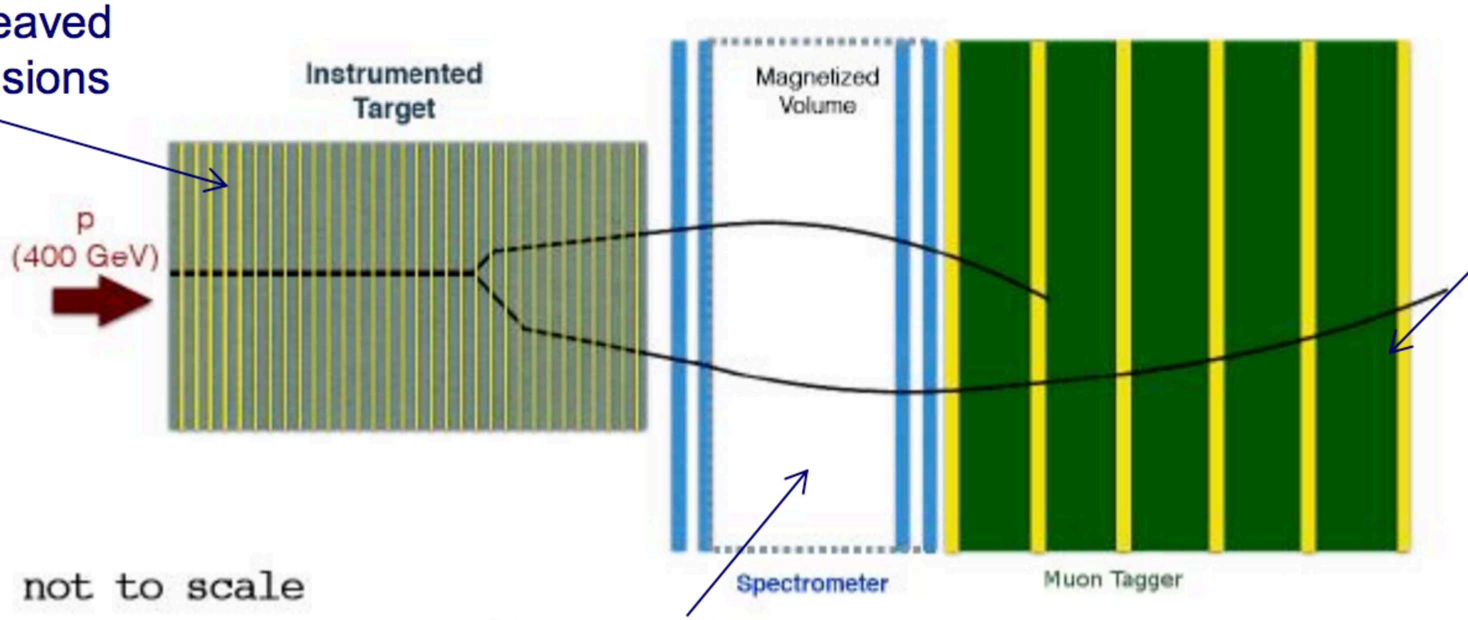
Measurement of the expected muon flux using 400 GeV protons on a replica of the SHiP target at H4

Charm xsection

Both the expected flux of hidden particles and the expected number of ν_τ interactions strongly depend on the number of charmed hadrons produced in the SHiP p target.

Due to the thickness of the SHiP p target (12 λ_{int}),the contribution of charm cascade production is expected to increase the charm rate by a factor of 2.

→ Dedicated measurement of $d^2\sigma/ (dE\ d\Omega)$ using 400 GeV protons on a SHiP-like target at H4



TZM plates interleaved with nuclear emulsions

Muon filter

Charge and momentum measurement of charm decay products

Conclusions

- Given Naturalness is challenged by LHC searches, we should remember that the search for physics beyond the SM is 2D (energy, coupling)

- There are several models that predicts new particles at the GeV scale, coupling weakly with SM, e.g. sterile neutrinos at the GeV scale is a viable option

- The newly proposed SHiP experiment at SPS of CERN consists of:
  - Intense beam 400GeV@SPS with $2x10^{20}$ PoT in 5 years
  - Heavy target to maximise the signal (from direct production and heavy mesons) and minimise the bkg (muon and neutrino iduced)
  - Muon sweepers, Vacuum Vessel and series of vetos
  - Emulsion Spectrometer and HS spectrometer

- Realistic to reduce the bkg to a negligible level (<<1) in 5 years within the fiducial volume —> Improve present constrains for several models by orders of magnitudes (or hopefully discover long living very weakly interaction non-SM particles)

Thanks for the attention