Prospects For The SHiP Experiment

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On behalf of SHiP Collaboration

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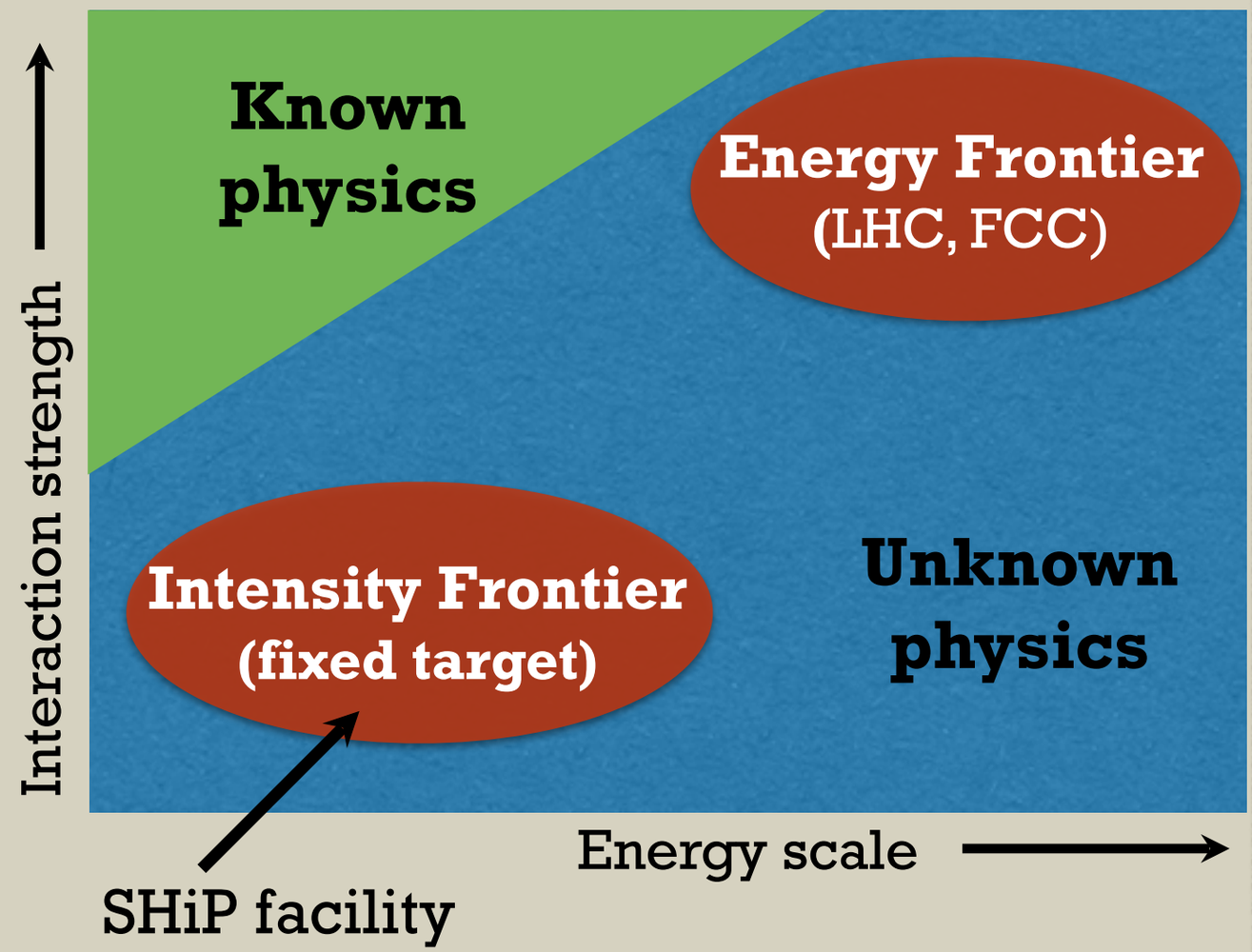
Motivation

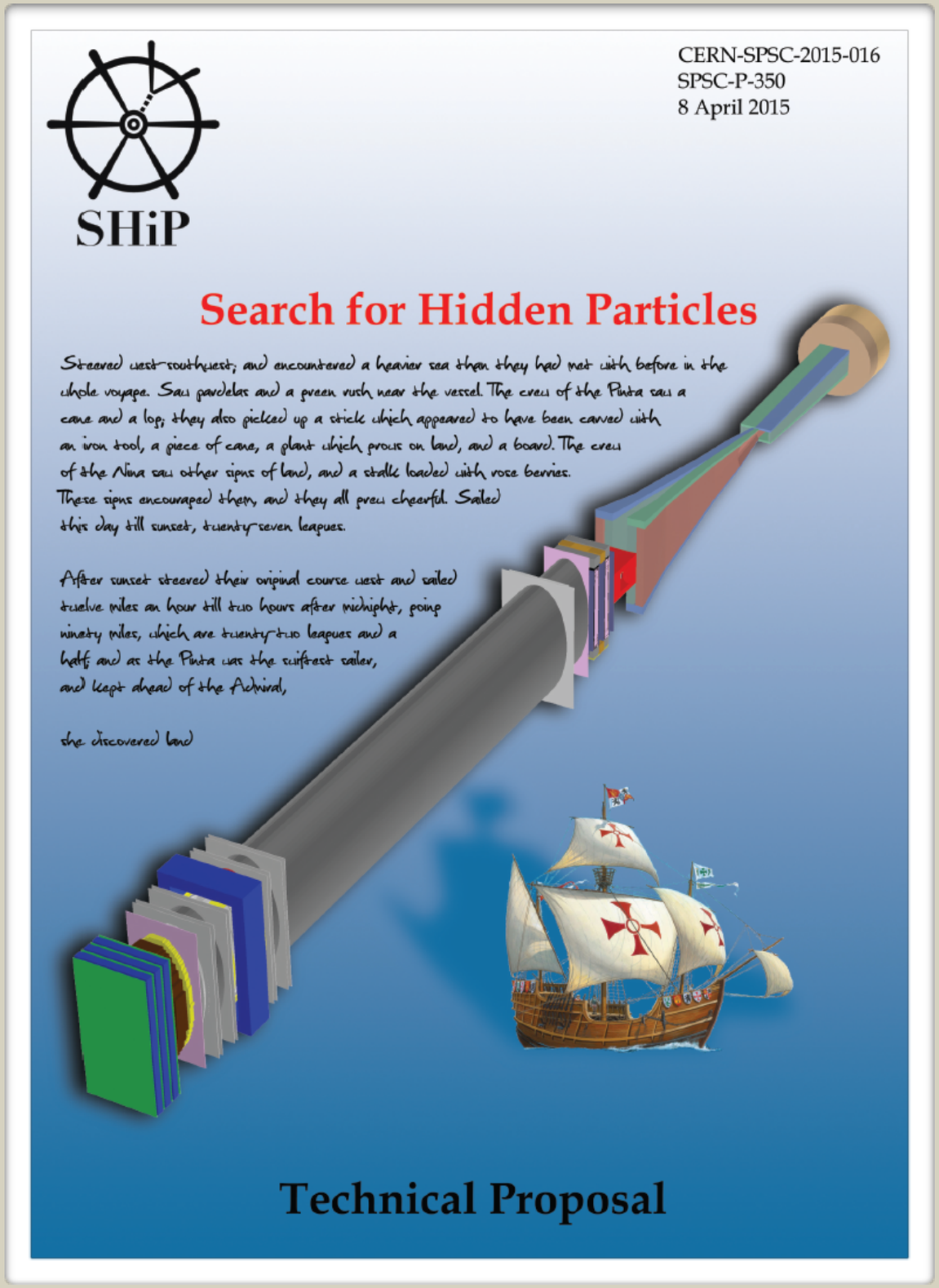
- The **Standard Model** provides an explanation for many subatomic processes
- Although very successful, it fails to explain many observed phenomena
  - **Dark Matter**
  - **Neutrino Oscillation and masses**
  - **Matter/antimatter asymmetry in the Universe**
- A **Hidden Sector (HS)** of weakly-interacting BSM particles as an explanation



Energy Frontier:
Heavy particles → high energy collisions needed

Intensity Frontier:
Very weakly interacting particles → high intensity beam needed

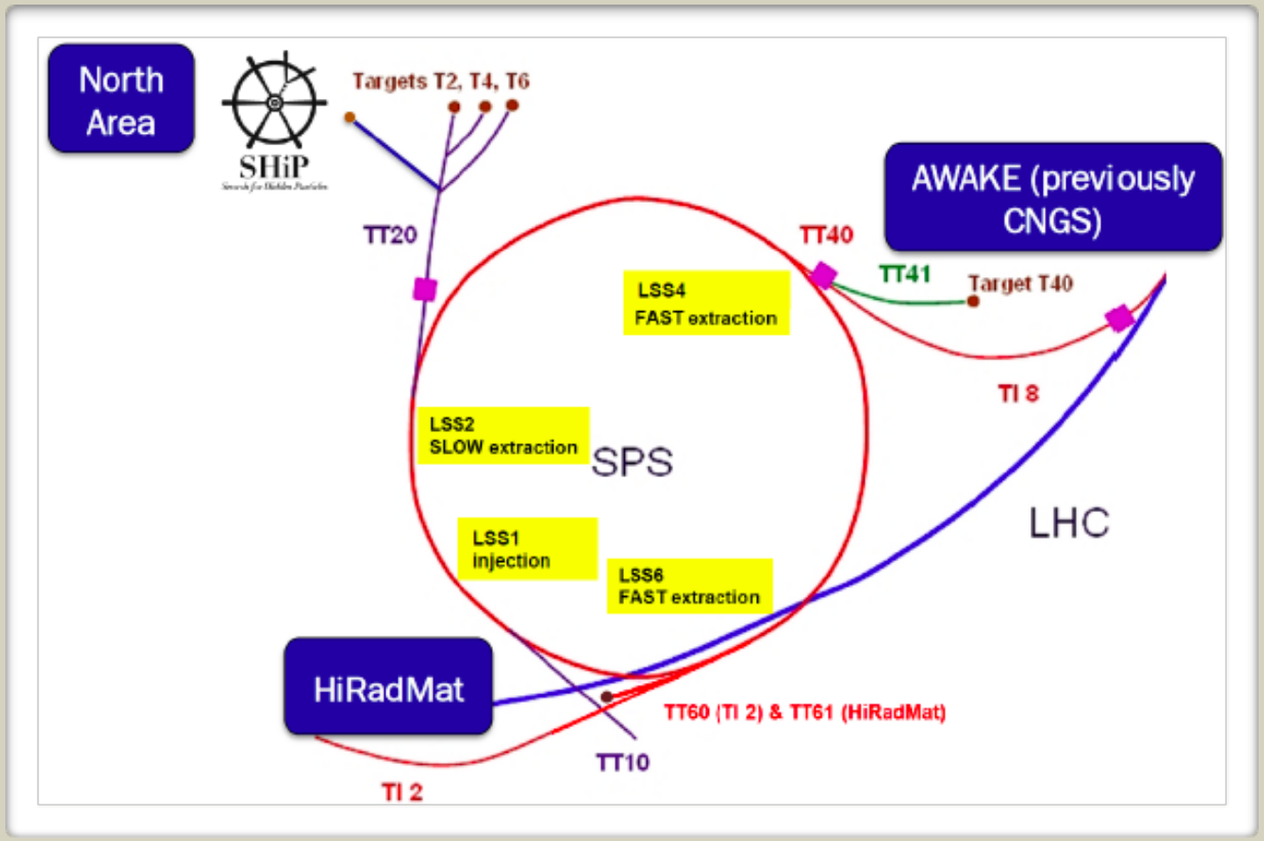
The SHiP Project

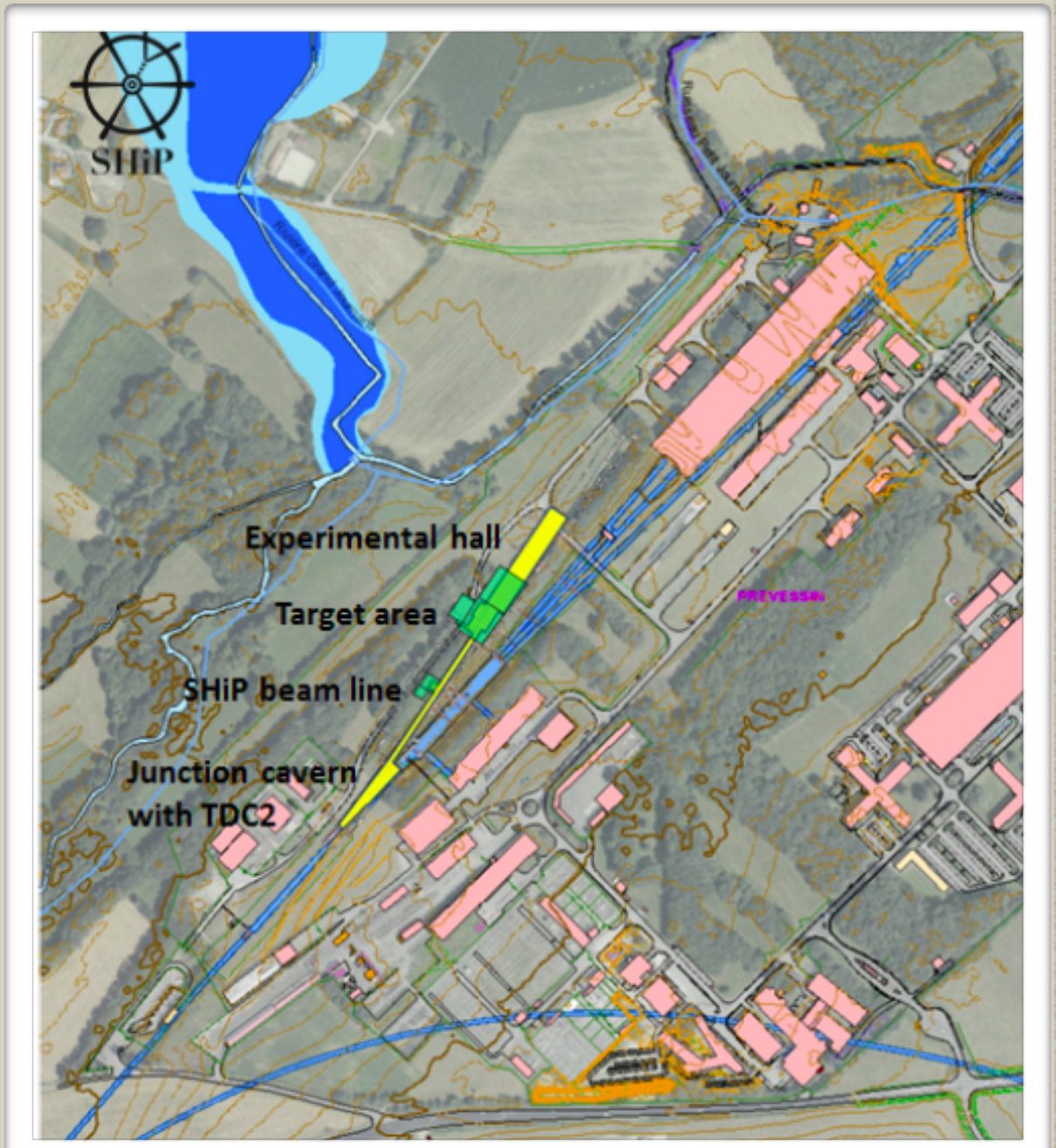


- SHiP (Search for Hidden Particles) in a proposed fixed target experiment at CERN SPS
- Collaboration of 250 members from 49 institutes, 17 countries
- Technical Proposal *arXiv:1504.04956 (2015)*
- Physics case signed by 80 theorists *Rep. Prog. Phys. 79 (2016) arXiv:1504.04855*
- Positive SPSC recommendation
- Comprehensive Design Study by 2019 → decision about approval in 2020
- Important actor in the CERN Physics Beyond Colliders study group

The SHiP Facility

- Fixed target experiment at the **CERN SPS**
- Beam: **400 GeV protons** (4×10^{13} protons per spill)
  - → 2×10^{20} pot in 5 years



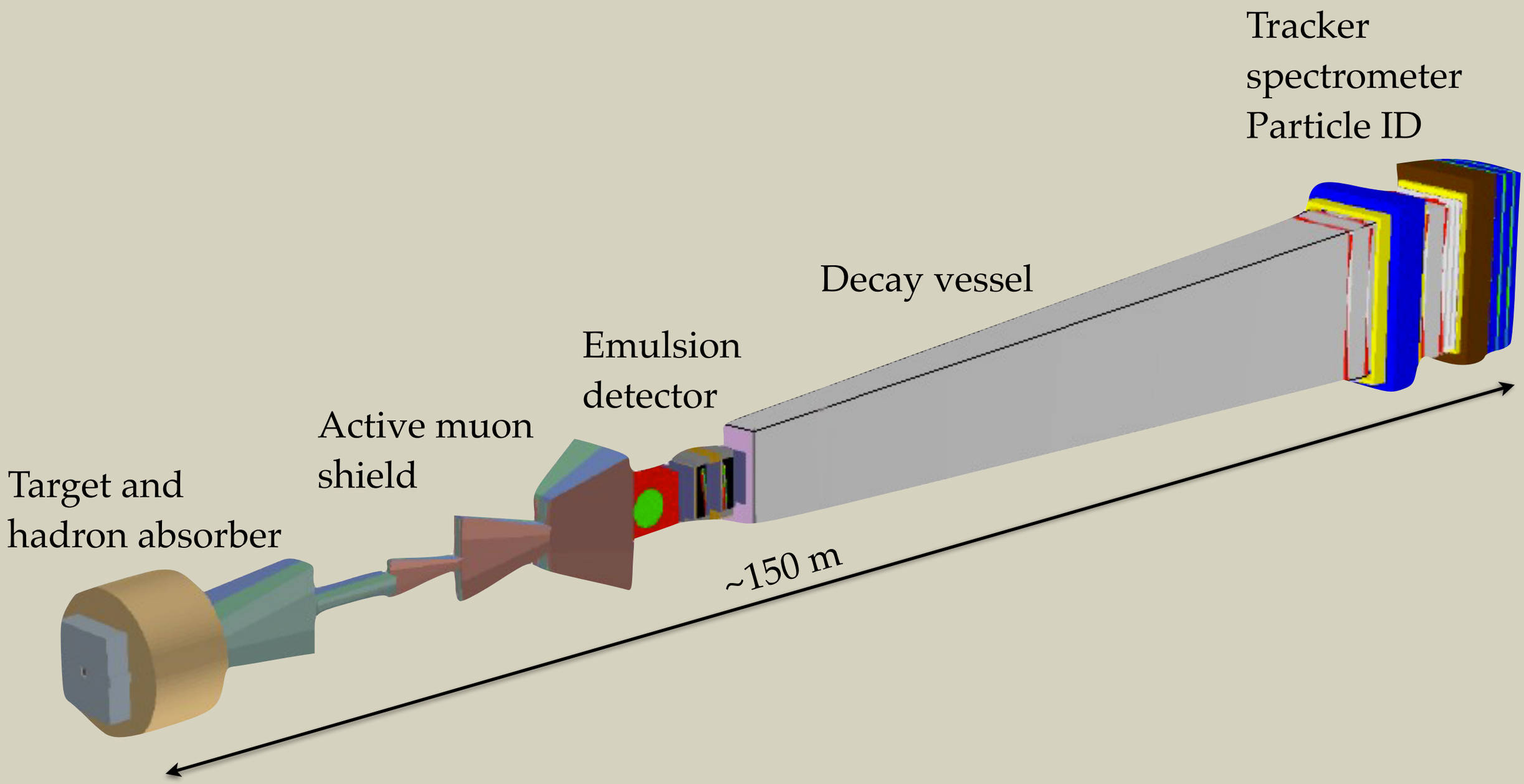


Location: Prevessin North Area site

Sharing of the TT20 transfer line and slow extraction mode with the fixed target programs

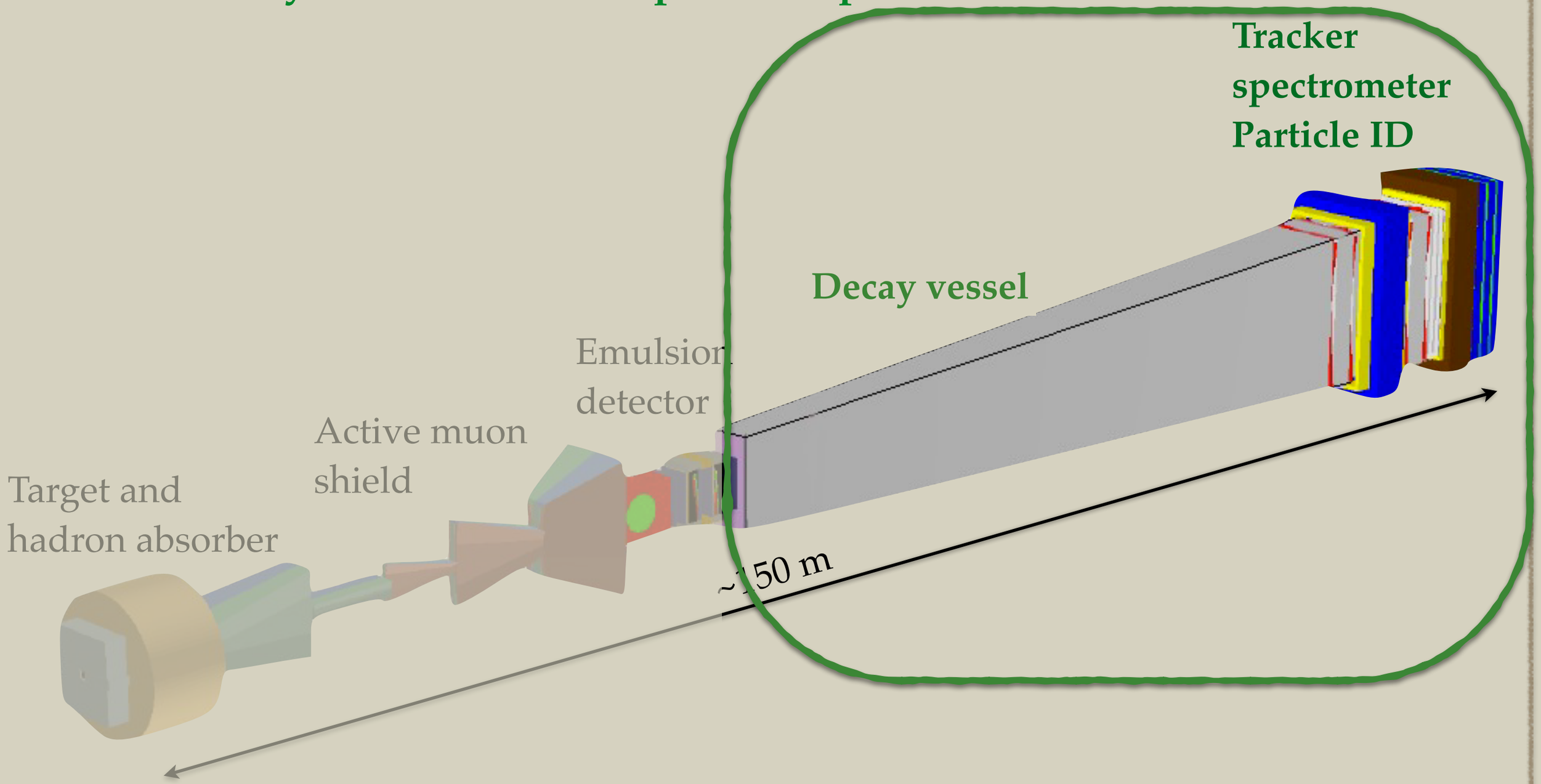
The SHiP Detector

- Designed for **large acceptance** and **zero background**
- Wide physics case



The SHiP Detector

- Designed for **large acceptance** and **zero background**
- Wide physics case
  - **Variety of Hidden Sector portals explored**



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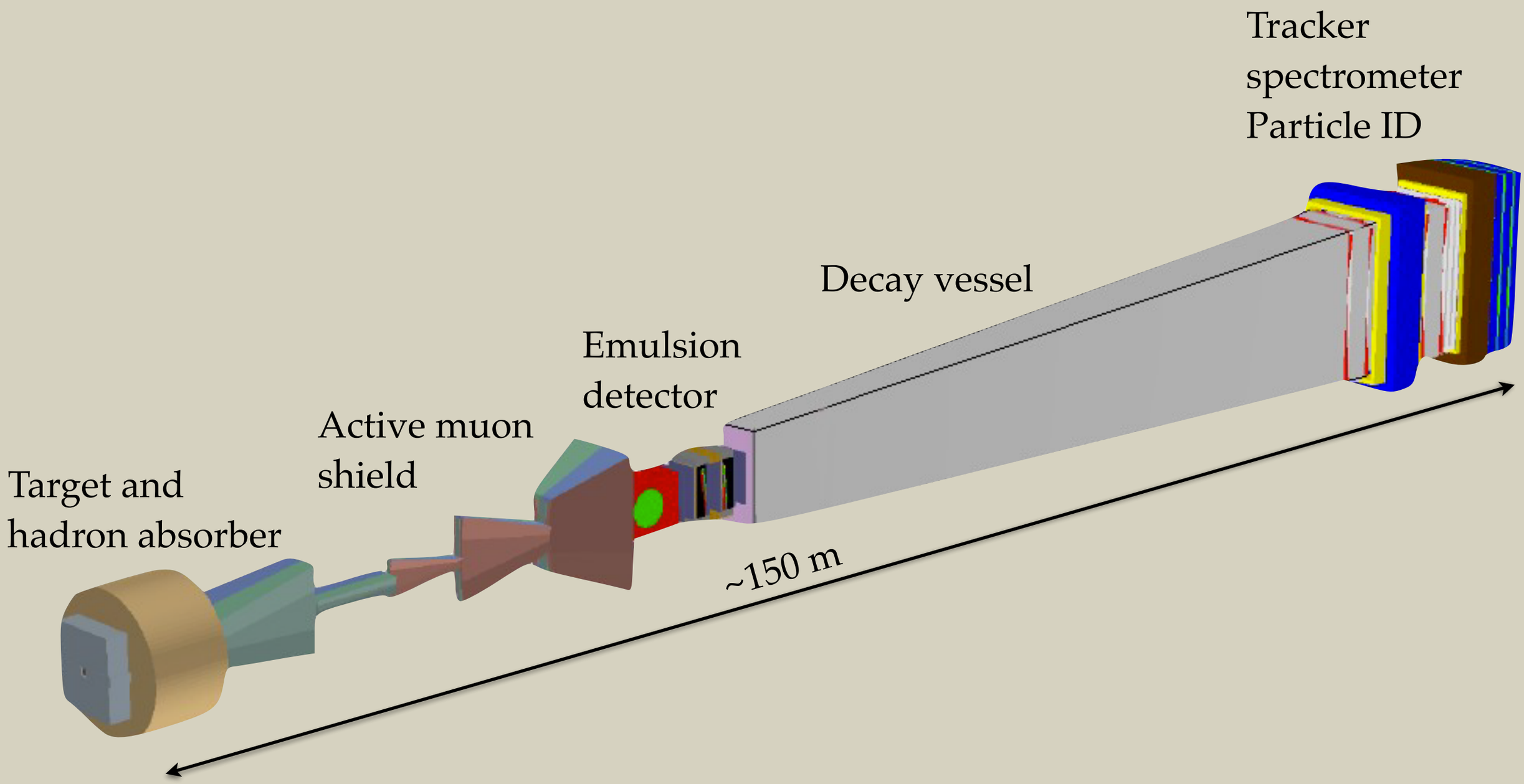
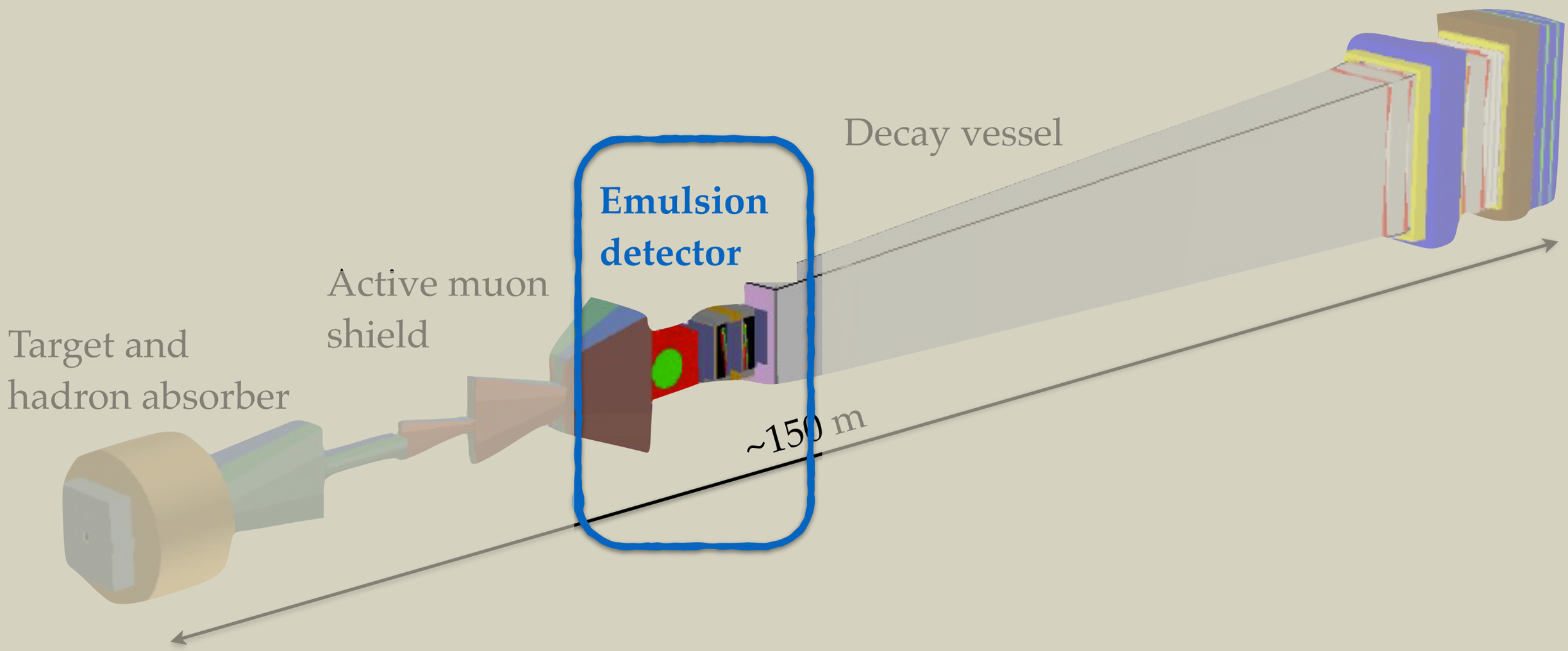


The SHiP Detector

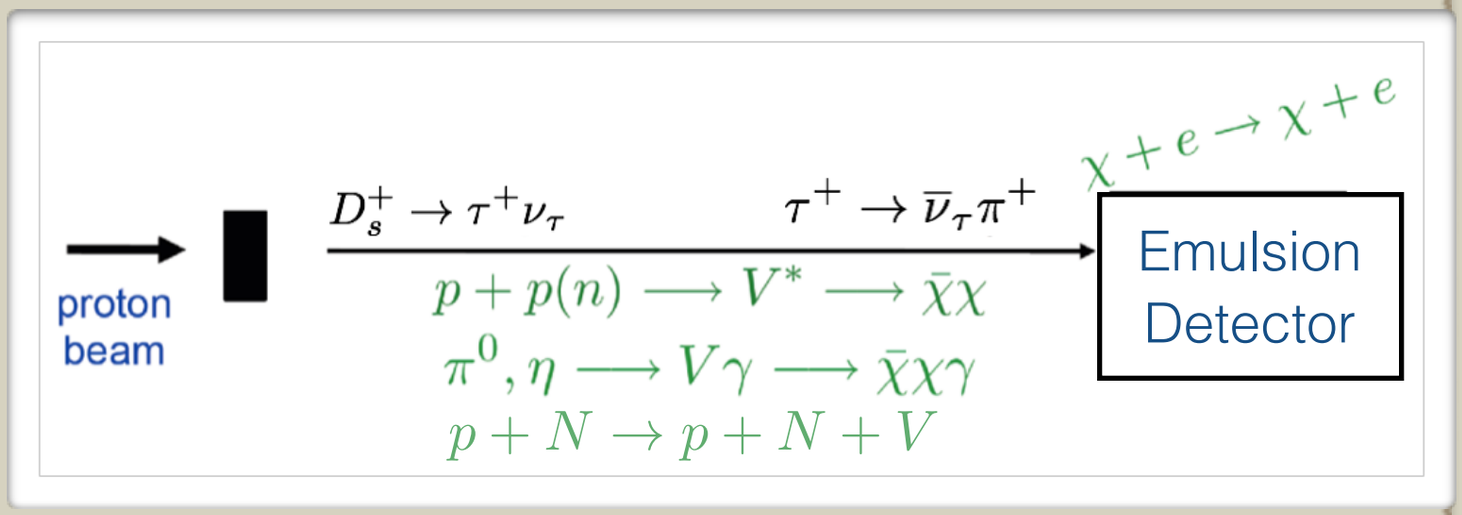
- Designed for **large acceptance** and **zero background**
- Wide physics case
  - Variety of Hidden Sector portals explored
  - **Tau neutrino physics**
  - **Light Dark Matter (LDM) Search**



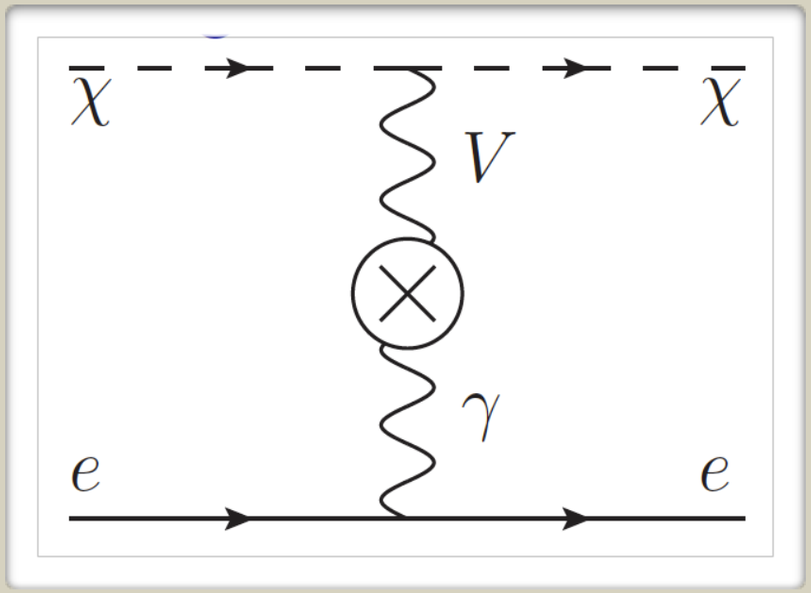
LDM Search @SHiP

LDM PRODUCTION

- Generated in the beam-dump, e.g. via light dark photon mediators (*V*)
- Main production modes
  1) direct production
  2) decay in flight
  3) resonant vector meson mixing

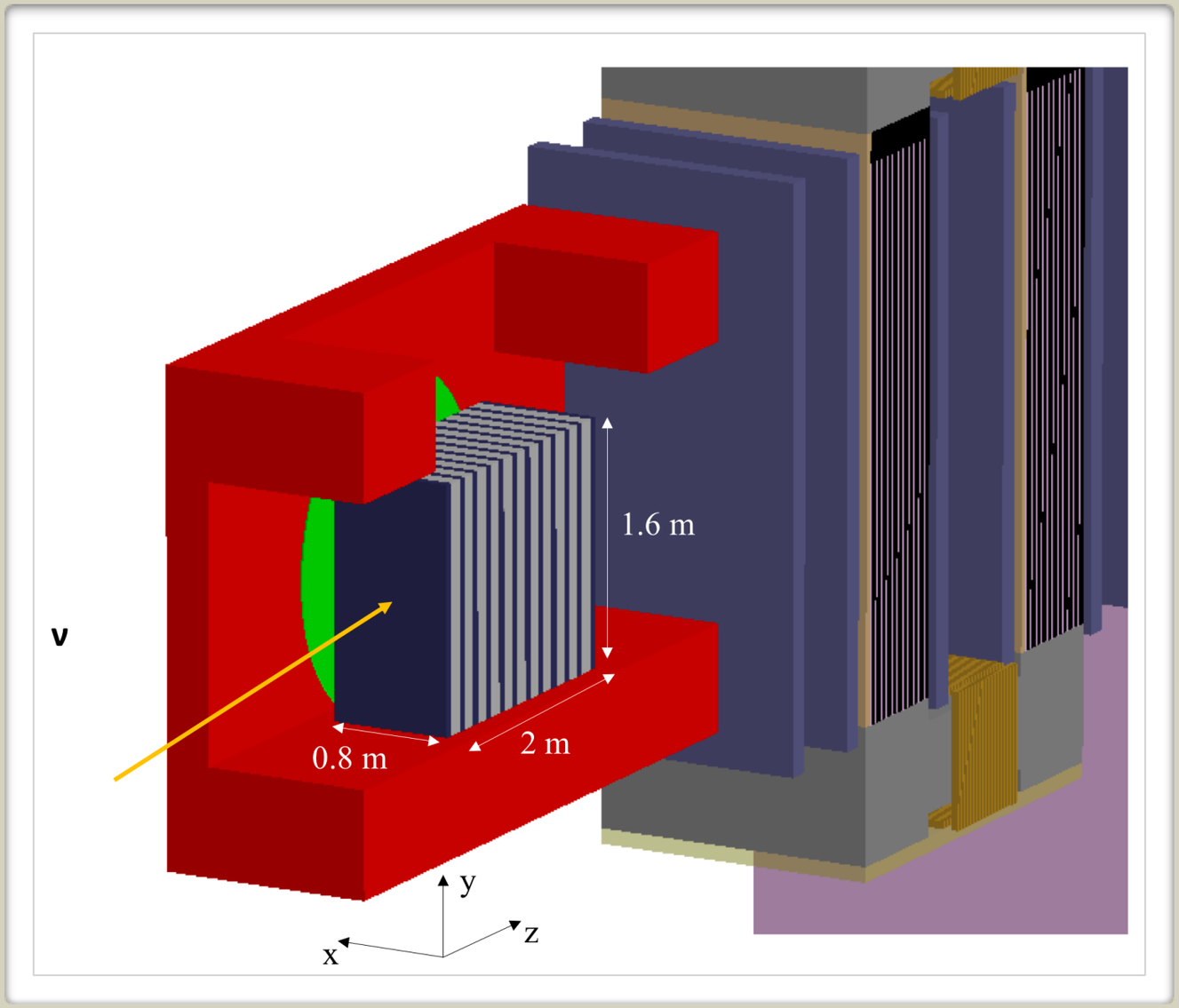


LDM DETECTION



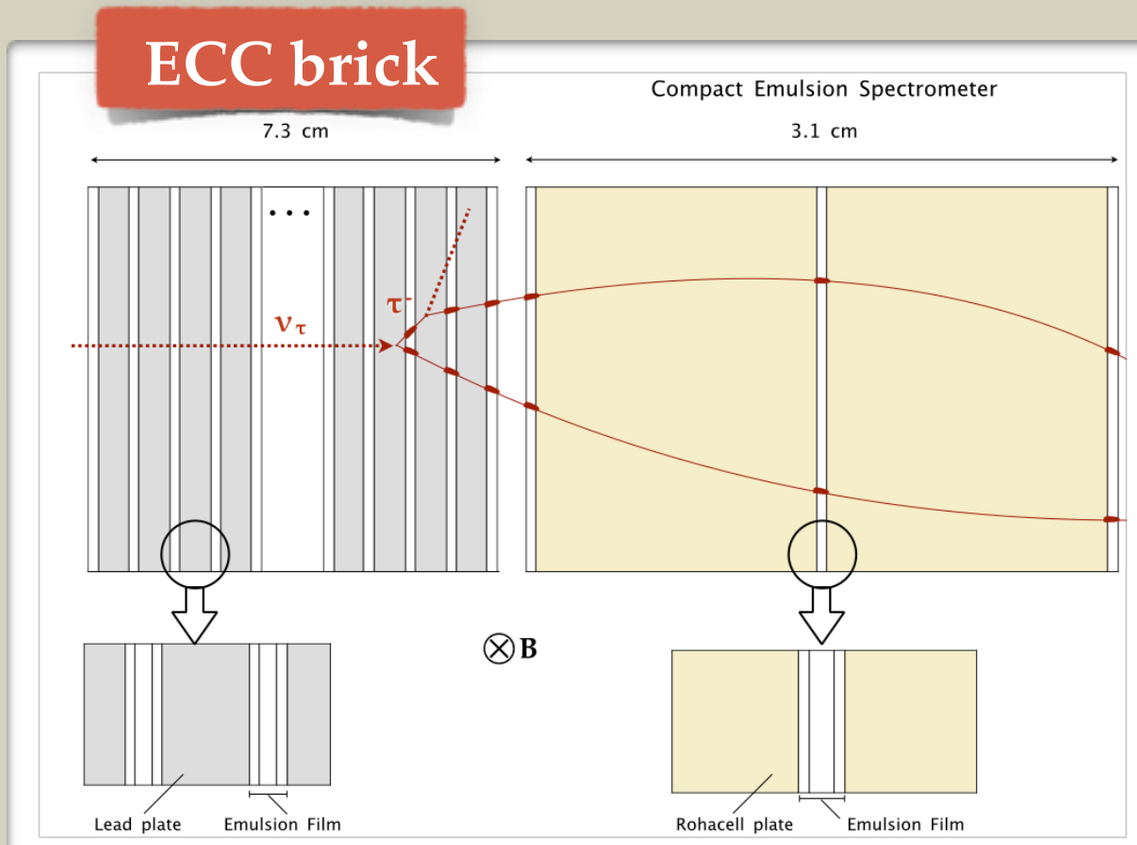
- LDM elastic scattering on atomic electrons of the target
- High energy beam dump:
  → LDM-electron scattering is highly peaked in the forward direction

The Emulsion Target



- Target made based on **E**mulsion **C**loud **C**hamber (**ECC**) technique
- ECC brick:
  - *nuclear emulsion films* → high resolution tracking detector
  - *lead plates* → passive material
- Sampling: 1 mm
- Total radiation length: 10 X_0

ECC brick

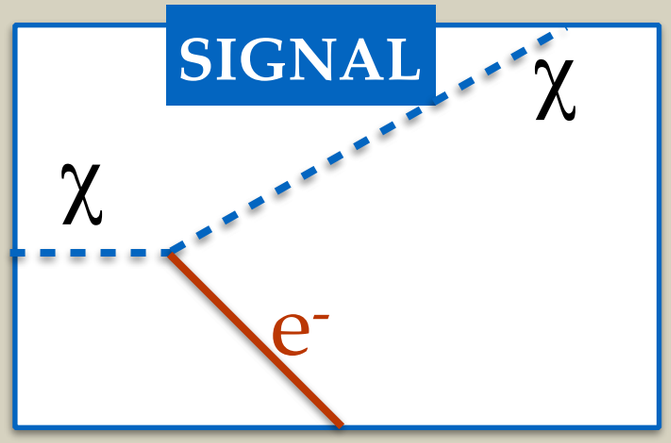


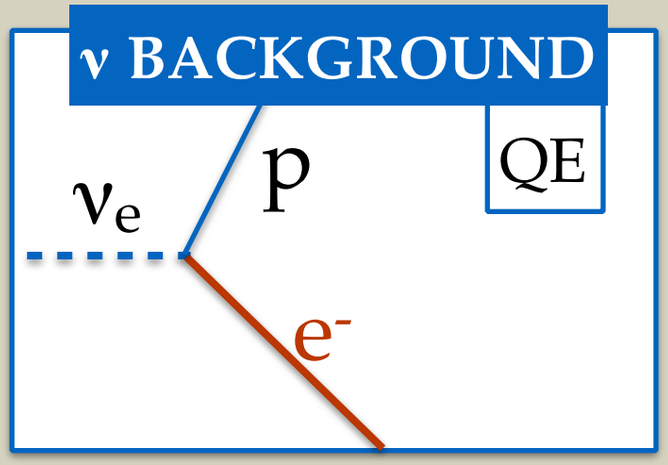
Emulsion Target

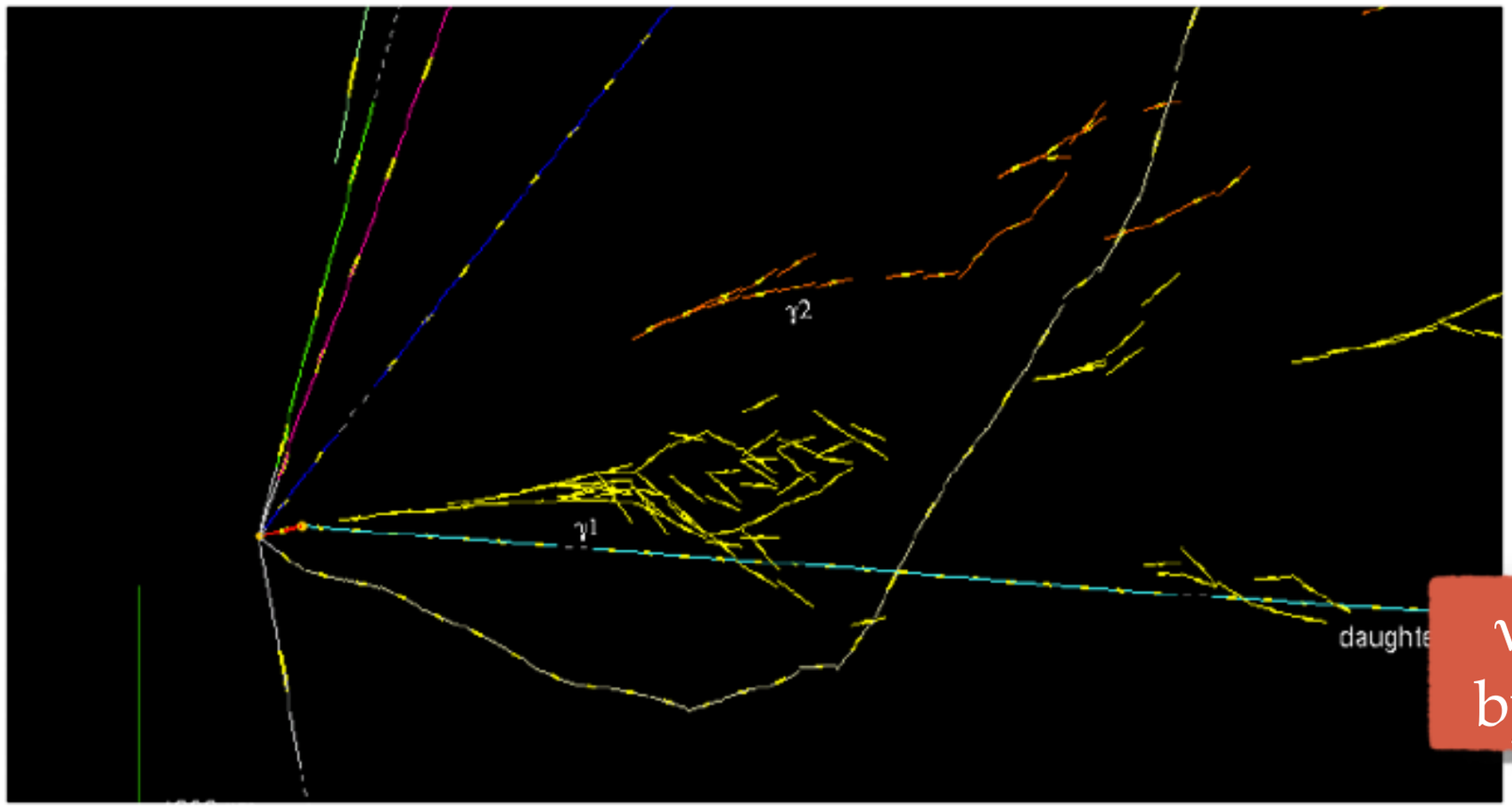
- Dimensions: 0.8 x 2 x 1.6 m^3
- Number of ECC bricks: ~900
- Total mass: ~7 tons

Electron Identification

- Emulsion detector ideally suited for Light Dark Matter search thanks to:
  - 1) micrometric position resolution
  - 2) mrad angular resolution
  - 3) high electron identification efficiency
  - 5) background reduction by observing large angle and low energy fragments produced in neutrino interactions





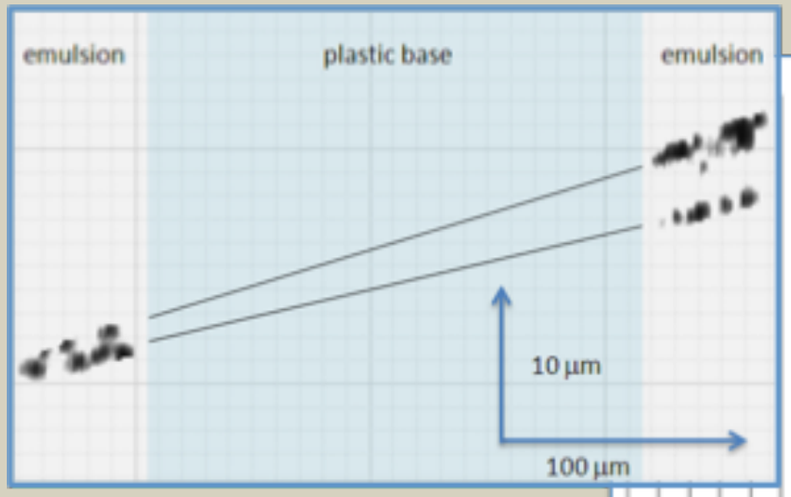


Feasibility demonstrated by the OPERA experiment

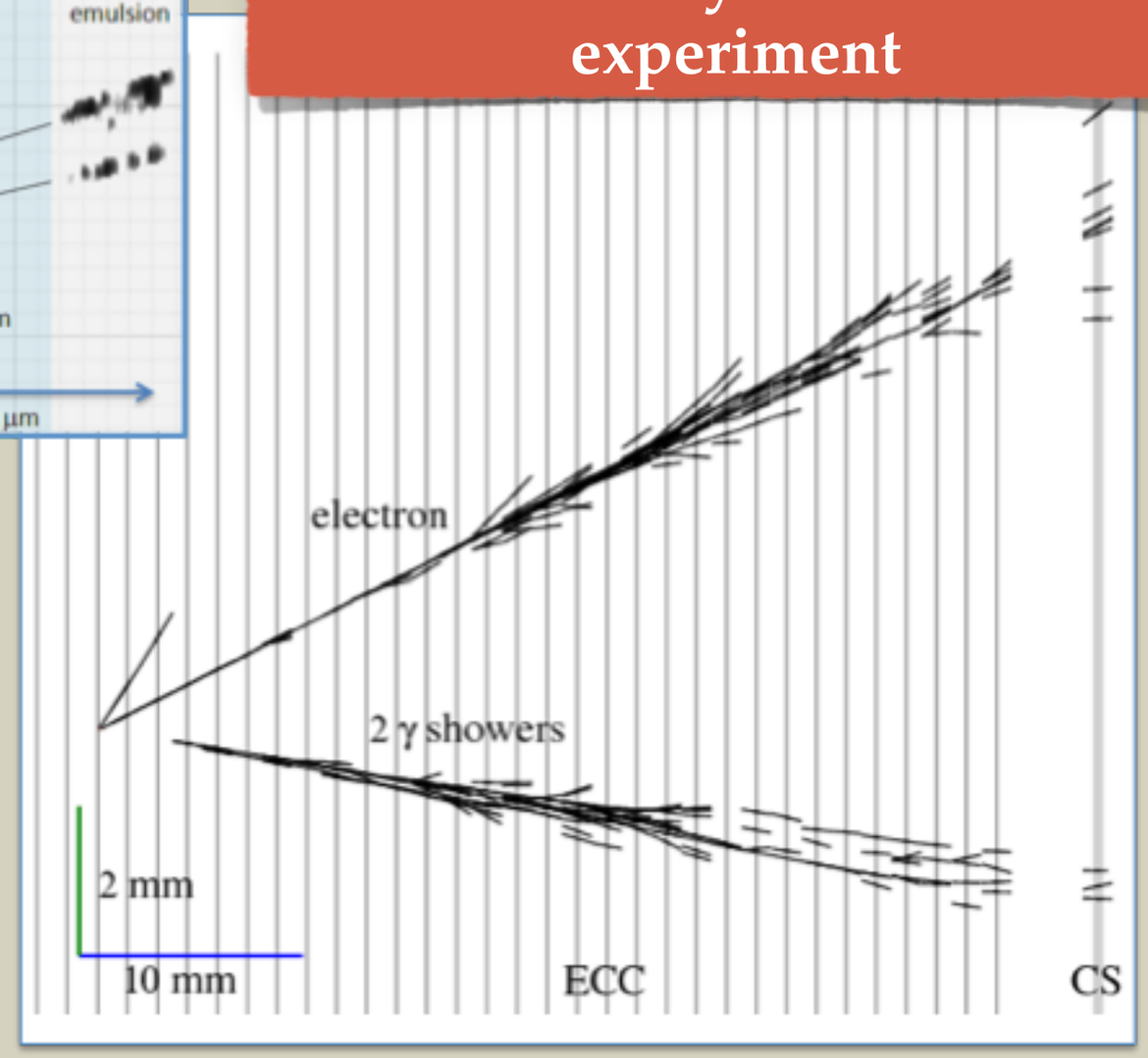
$\nu_\mu \rightarrow \nu_\tau$ candidate observed by the OPERA experiment

Electron Energy Measurement

- ECC brick is a high sampling calorimeter with micrometric accuracy (10 X_0)
  - → Number of track segments in a cone around electron proportional to electron energy



electron neutrino interaction observed by the OPERA experiment

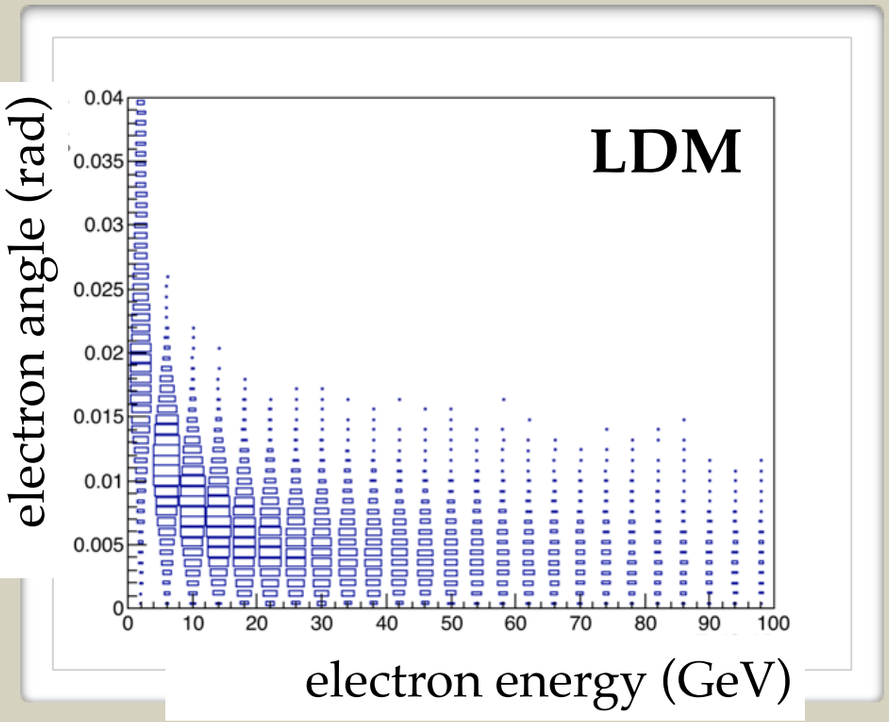


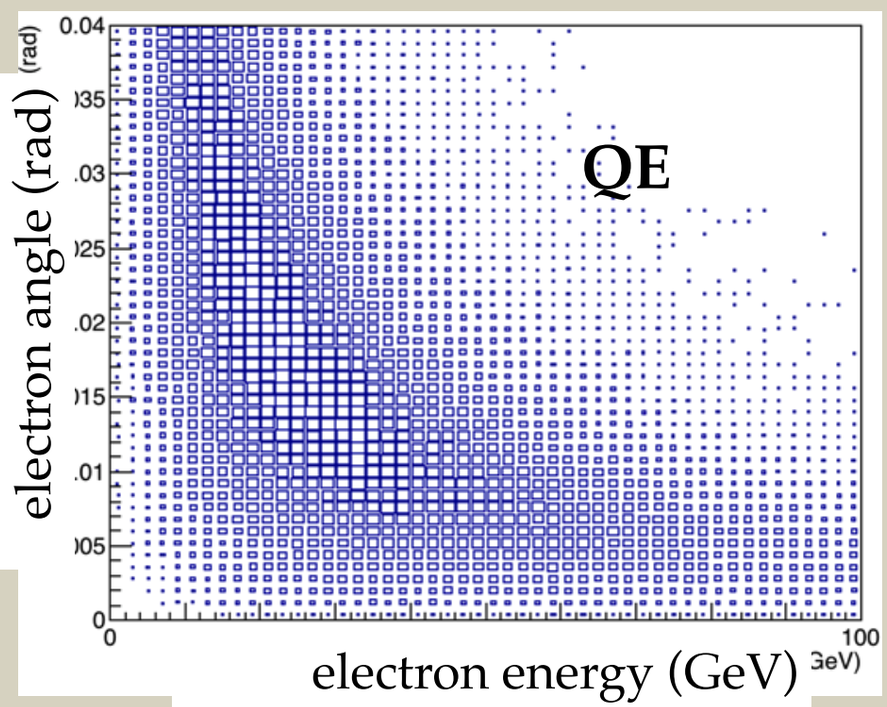
- Unique capability of distinguishing em showers induced by electron from those produced by gamma conversion
- 34 electron neutrinos identified by the OPERA experiment

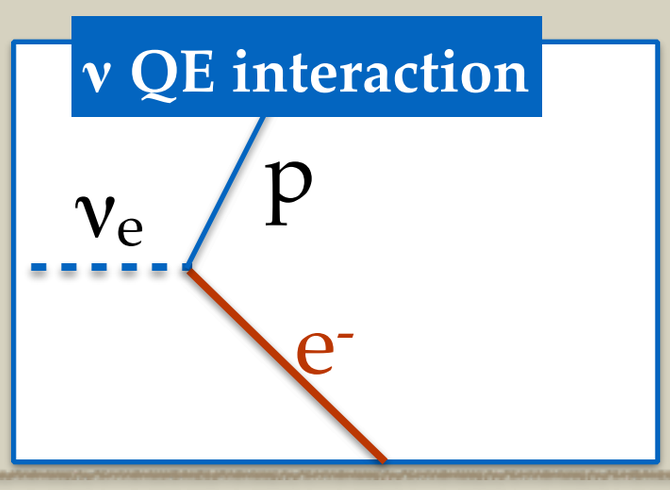
partial statistics in
JHEP 1307 (2013) 004

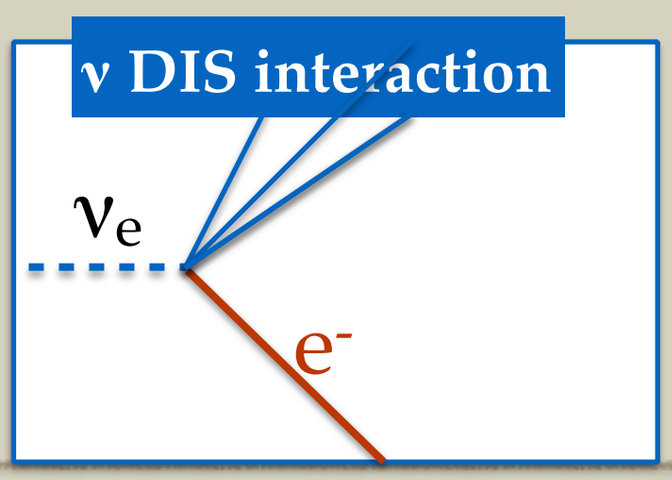
Background

- Dominant background comes from **neutrino interactions**, where only one electron is reconstructed in the final state:
  1) Quasi-elastic scattering **(QE)**
  2) Elastic scattering on electrons **(ES)**
  3) Resonant scattering **(RS)**
  4) Deep inelastic scattering **(DIS)**
- **Background rejection:**
  - observation hadronic jet in DIS and proton in QE neutrino interactions
  - Use energy-angle correlation of the detected electron to discriminate LDM scattering against neutrino interactions









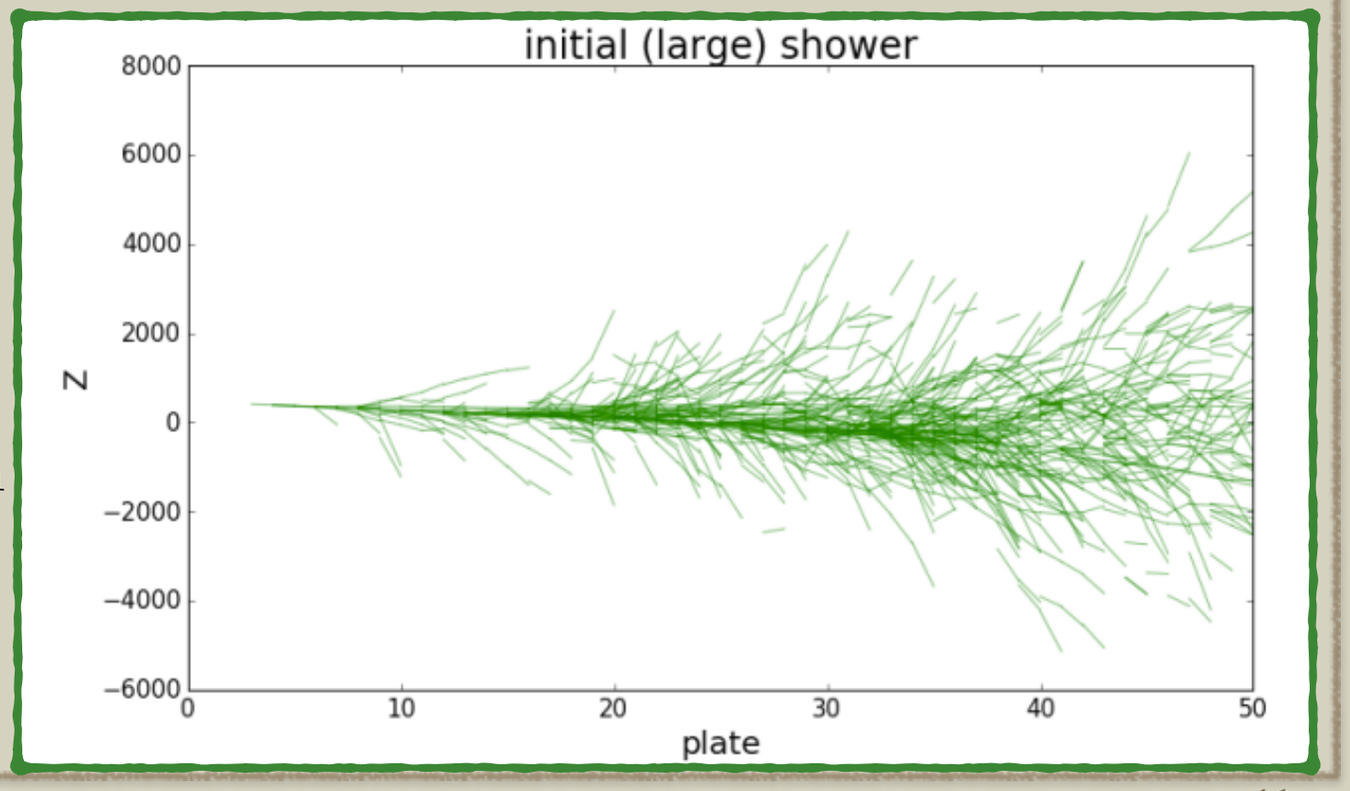
Background

- Estimation of background contamination (Technical Proposal)

	ν_e	$\bar{\nu}_e$	ν_μ	$\bar{\nu}_\mu$	all
1) Quasi-elastic scattering	105	73			178
2) Elastic scattering on e^-	16	2	20	18	56
3) Resonant scattering	13	27			40
4) Deep inelastic scattering	3	7			10
Total	137	109	20	18	284

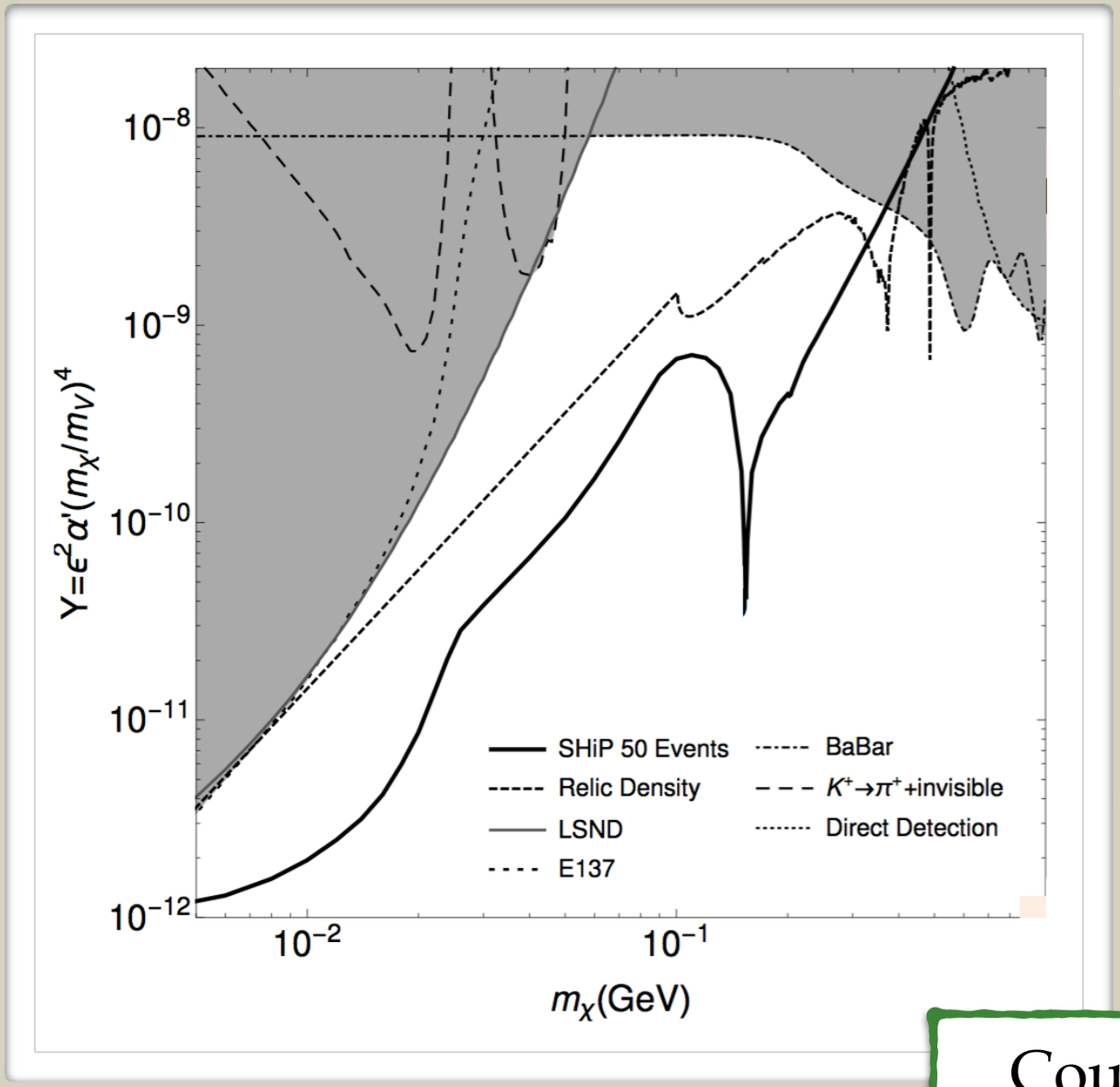
- 10 tons of lead
- 2×10^{20} p.o.t.
- Selection cuts applied:
- electron angle in [10,20] mrad
- electron energy < 20 GeV
- selection efficiency 50%

- Under study:
  - improvement in electron energy resolution with machine learning techniques
  - enhancement of background rejection power with MVA selections



LDM Prospects @SHiP

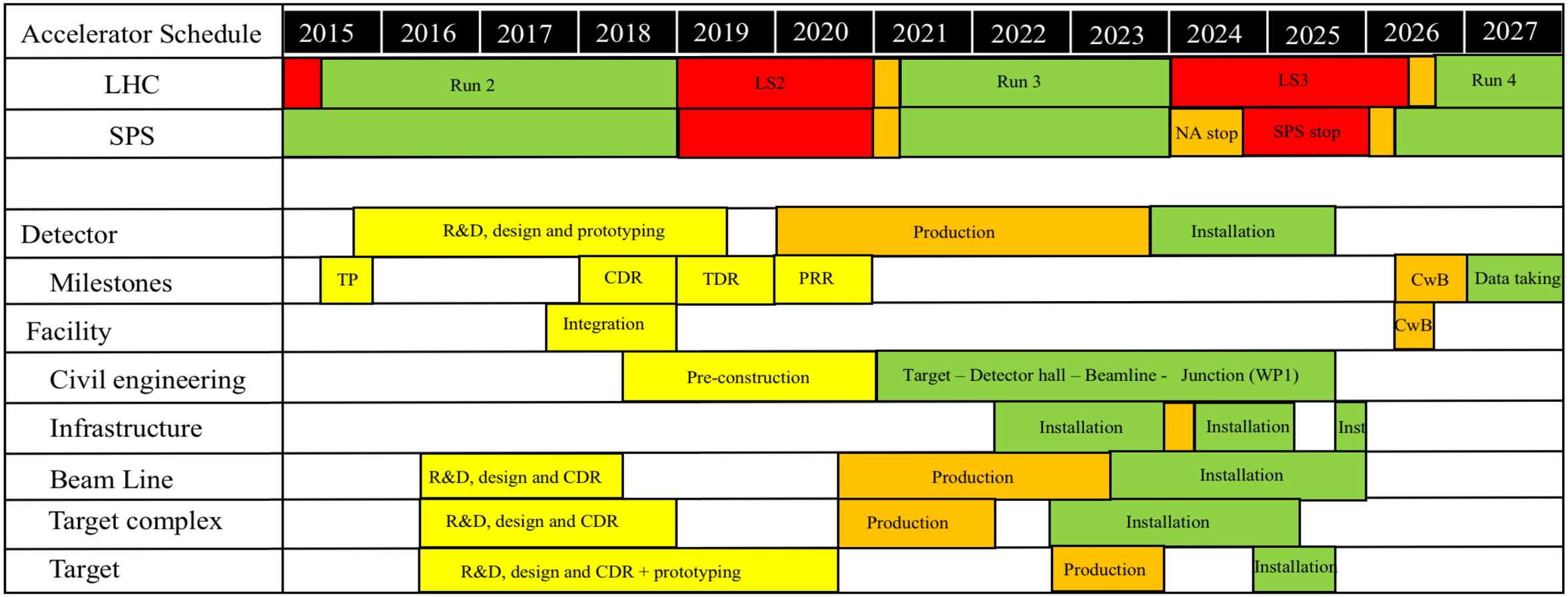
- Parameter space (Y vs m_χ) expected to generate **50 events** in SHiP



- $m_V / m_\chi = 5$
- 2.5 tons of lead
- Target geometry: cylinder with 0.52 m radius and 2.1 m length
- 2×10^{20} p.o.t.
- selection efficiency assumed to be 50%

Courtesy of P. deNiverville

Project Schedule



- **Form SHiP Collaboration** — **December 2014 ✔**
- **Technical Proposal** — **April 2015 ✔**
- **Positive SPSC recommendation for CDS** — **September 2016 ✔**
- Comprehensive Design Study — 2018
- Construction and Installation — 2021-2025
- Commissioning and data taking — 2026

Conclusions

- SHiP is a fixed target experiment proposal al CERN SPS at the intensity frontier
- High energy beam dump: large variety of Hidden Sector portals explored
- Emulsion detector ideally suited for LDM detection
- LDM search have strong potential in SHiP

Perspectives:

- Optimization of Emulsion Detector geometry to enhance SHiP sensitivity to LDM
- Full evaluation of SHiP sensitivity and background for LDM search

Back-up Slides

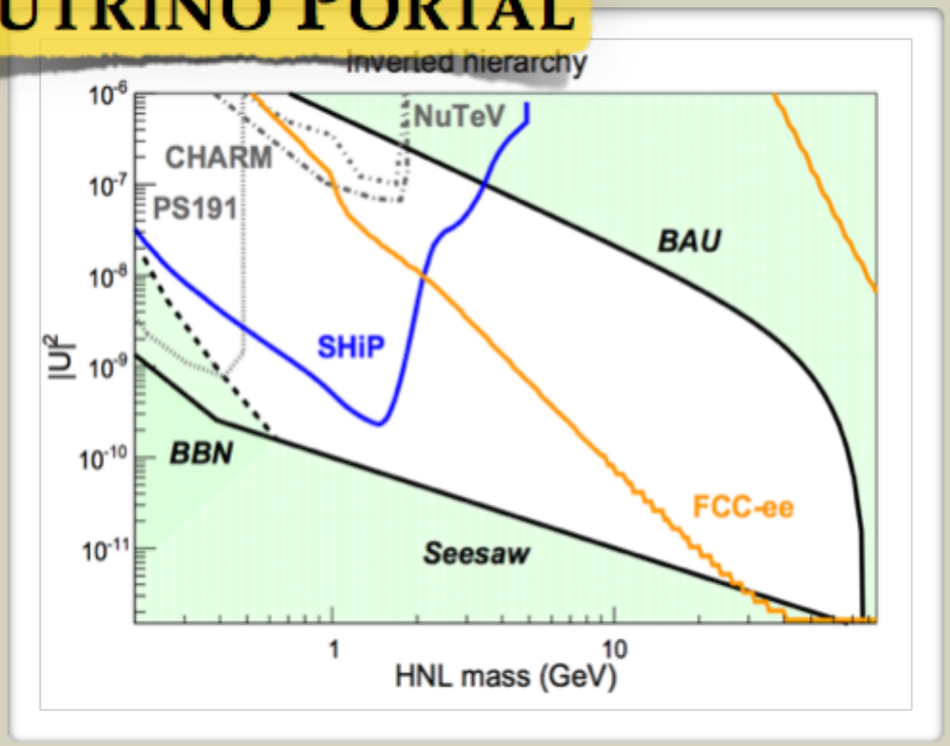
COSTS

Item	Cost (MCHF)	
Facility		**135.8**
Civil engineering	57.4	
Infrastructure and services	22.0	
Extraction and beamline	21.0	
Target and target complex	24.0	
Muon shield	11.4	
Detector		**58.7**
Tau neutrino detector	11.6	
Hidden Sector detector	46.8	
Computing and online system	0.2	
Grand total		**194.5**

Sensitivities

Based on 2×10^{20} pot @400 GeV in 5 years

Neutrino Portal



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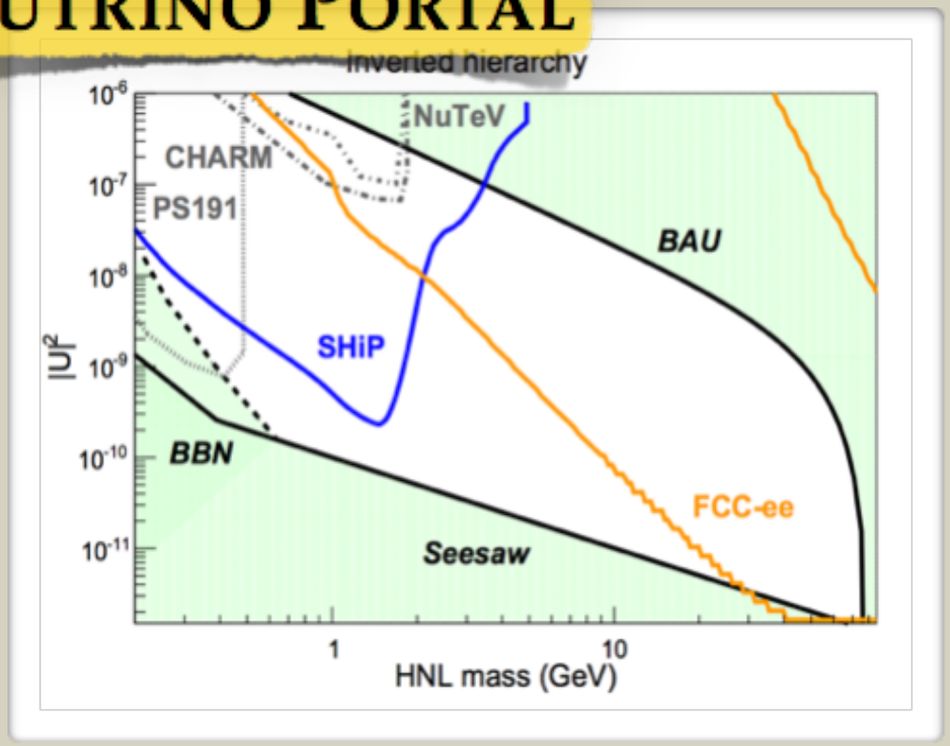
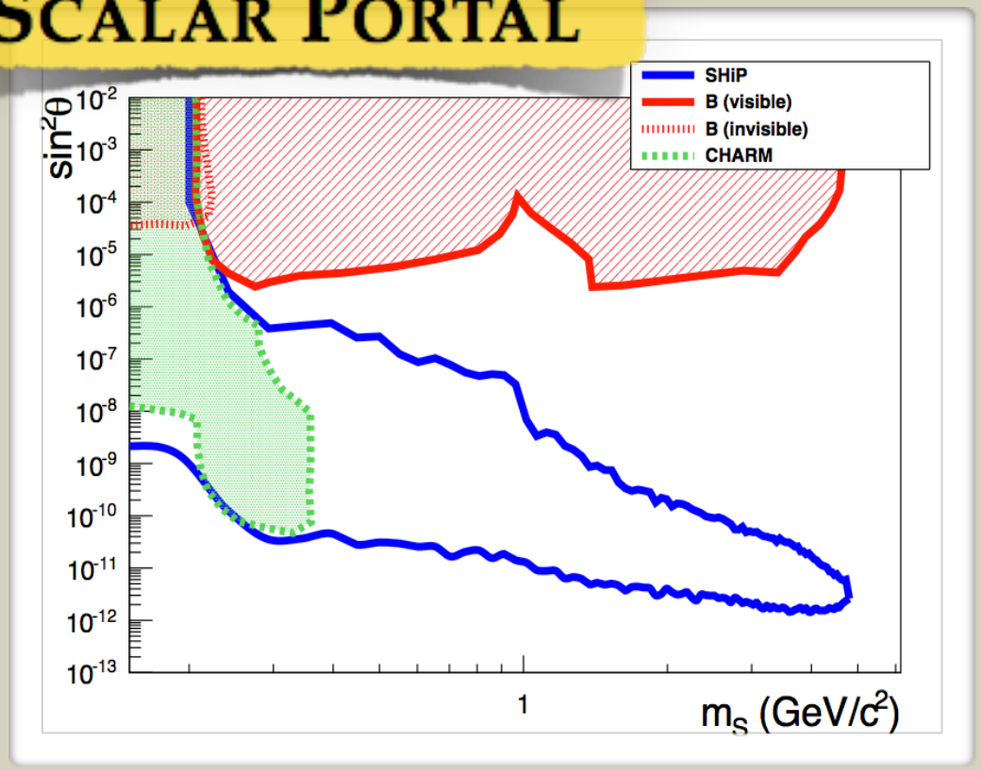


Scalar Portal



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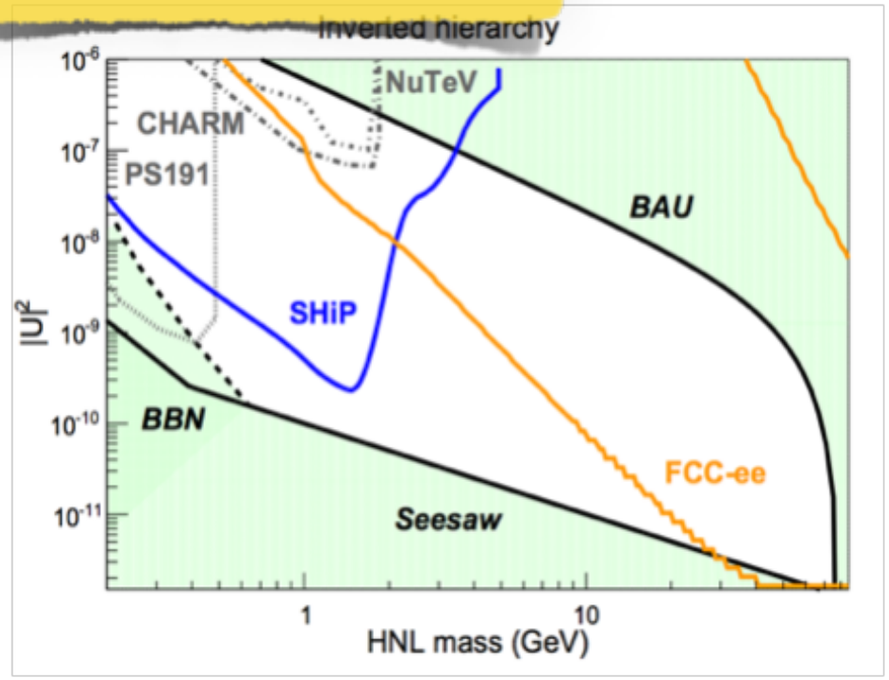

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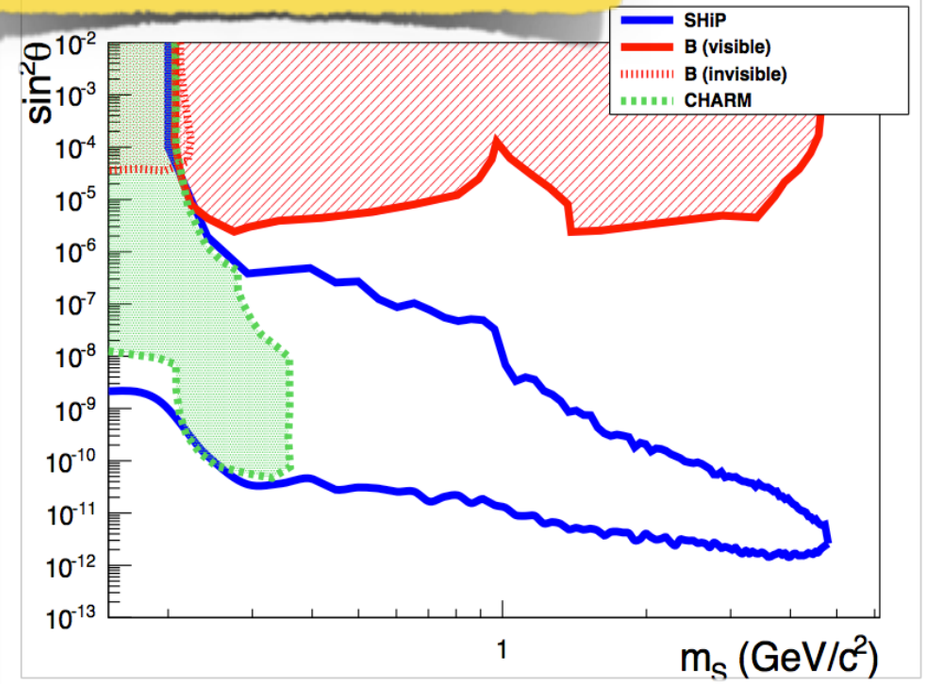
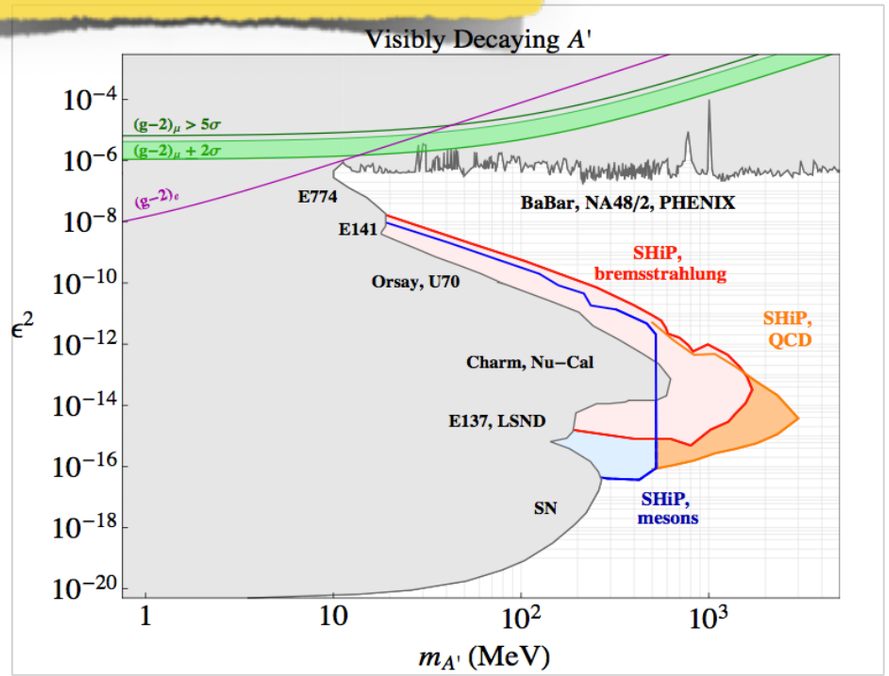


Vector Portal



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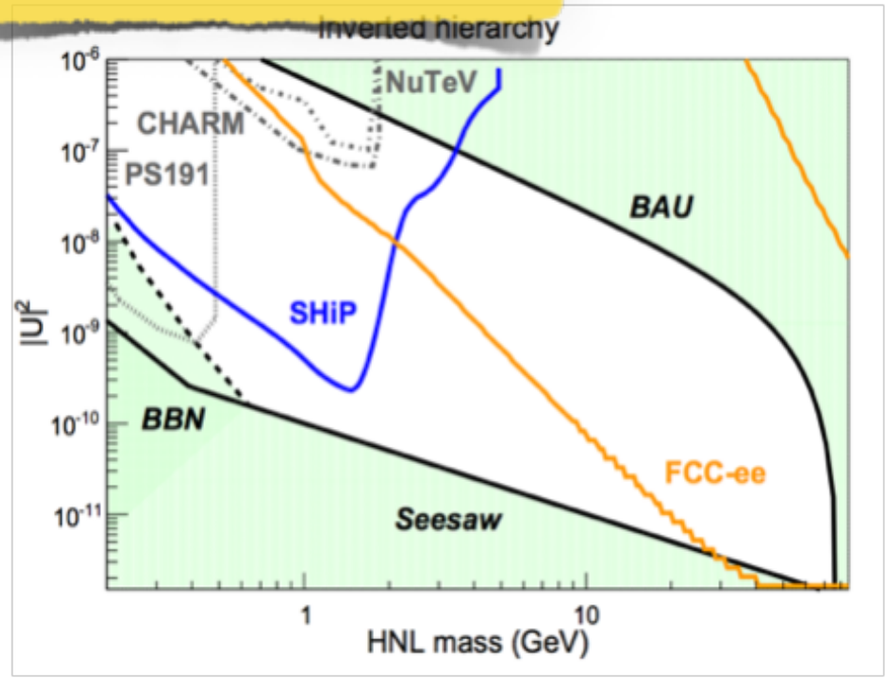

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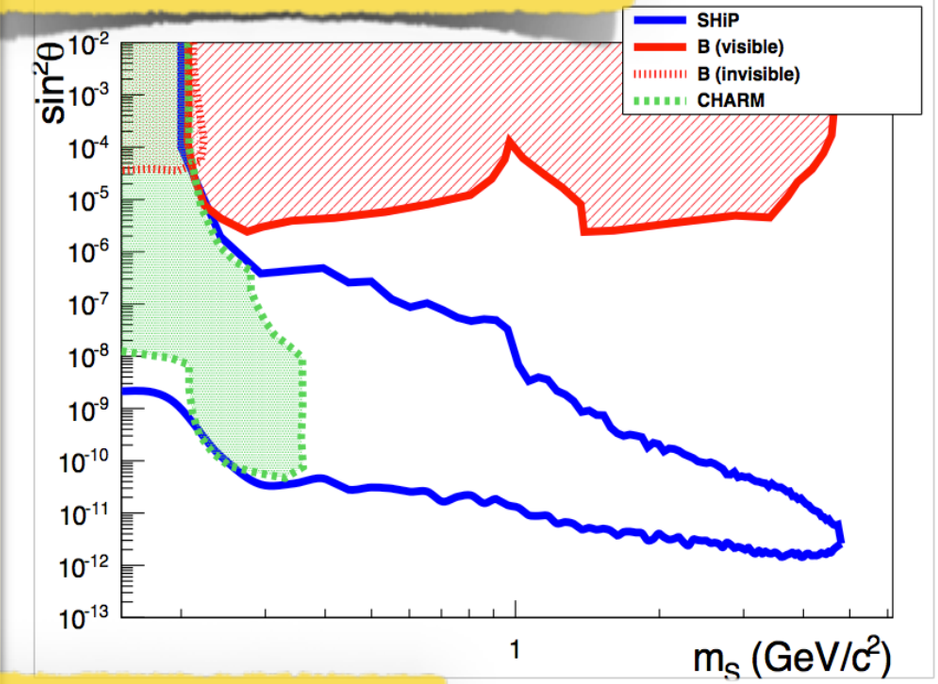
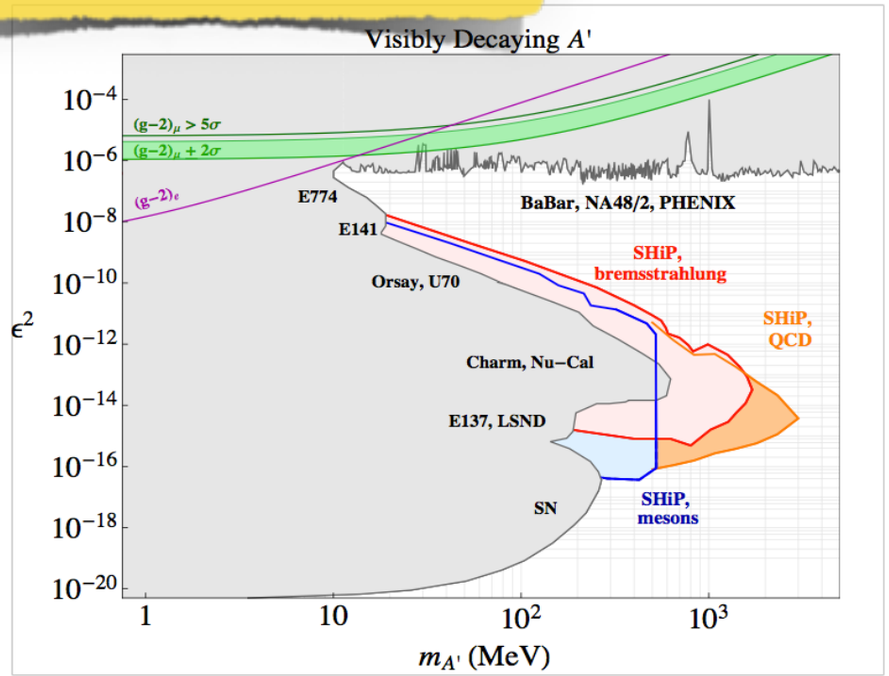
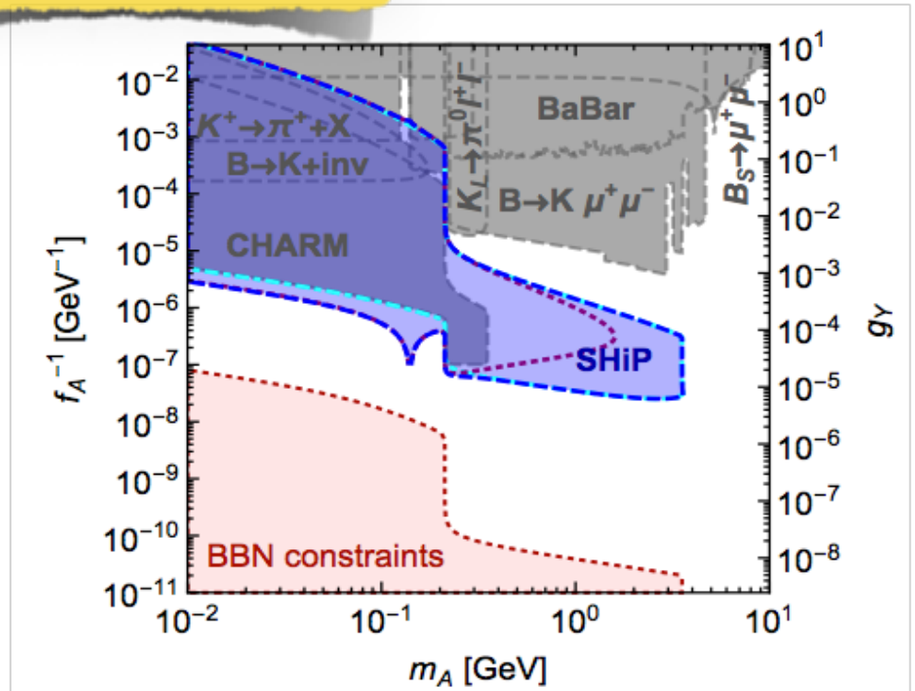


Vector Portal

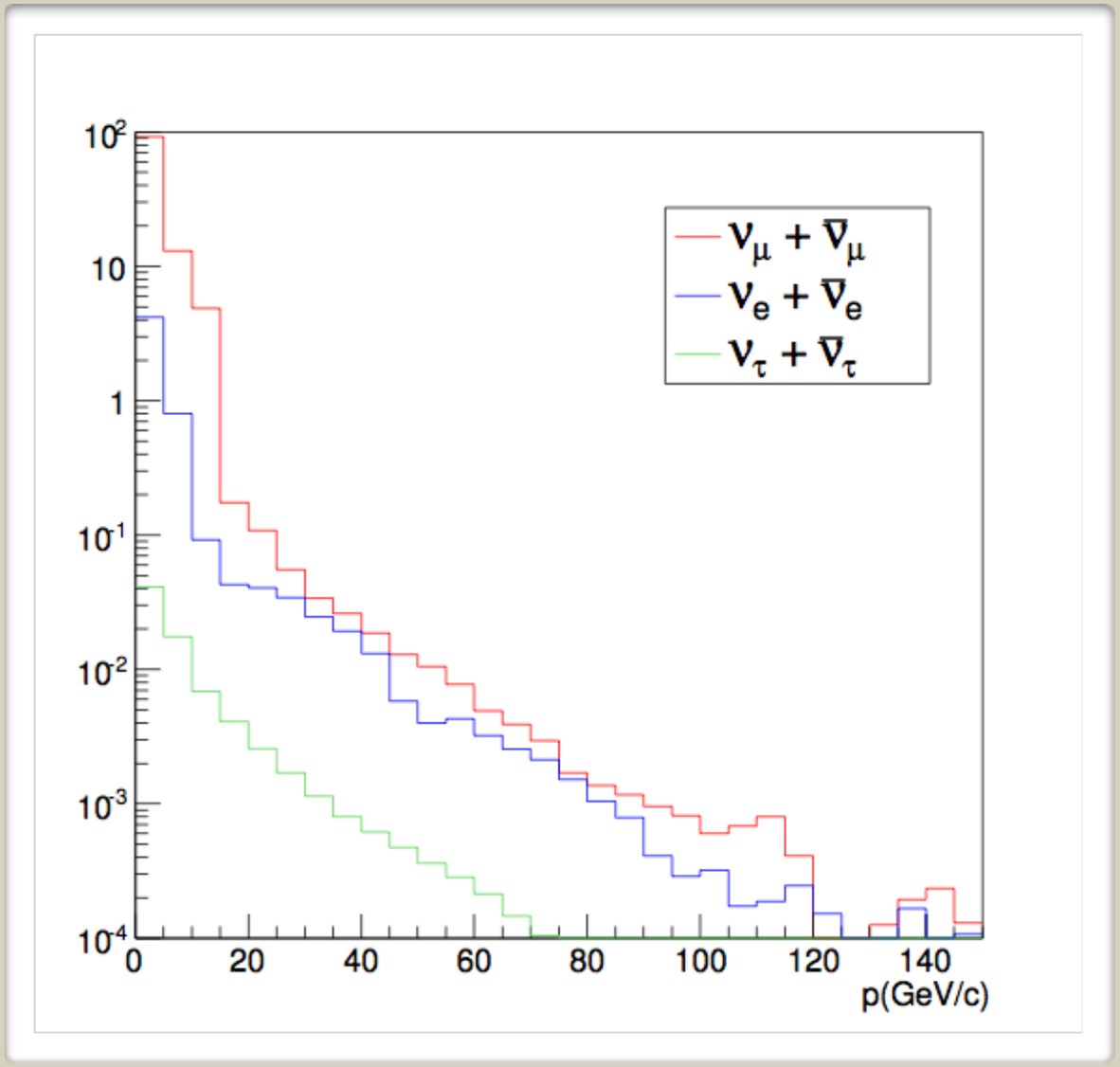


Axion Portal



Neutrino Physics @SHiP

- High neutrino flux expected
- Unique possibility of performing studies of ν_μ, ν_e, ν_τ



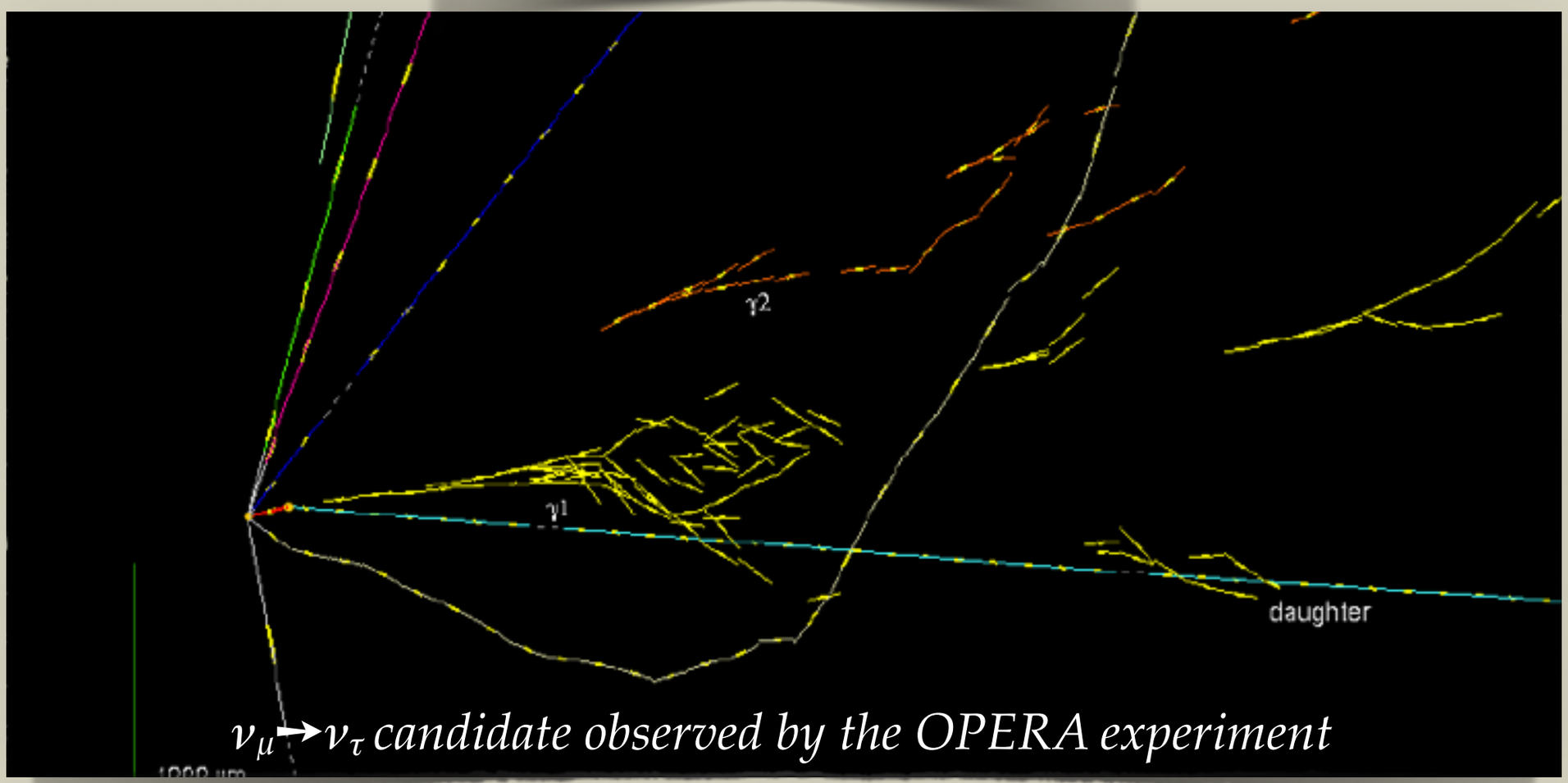
- Energy spectrum of different neutrino flavors @beam dump

Tau Neutrino Physics

- High neutrino flux expected
- ν_τ: the less known particle in the Standard Model

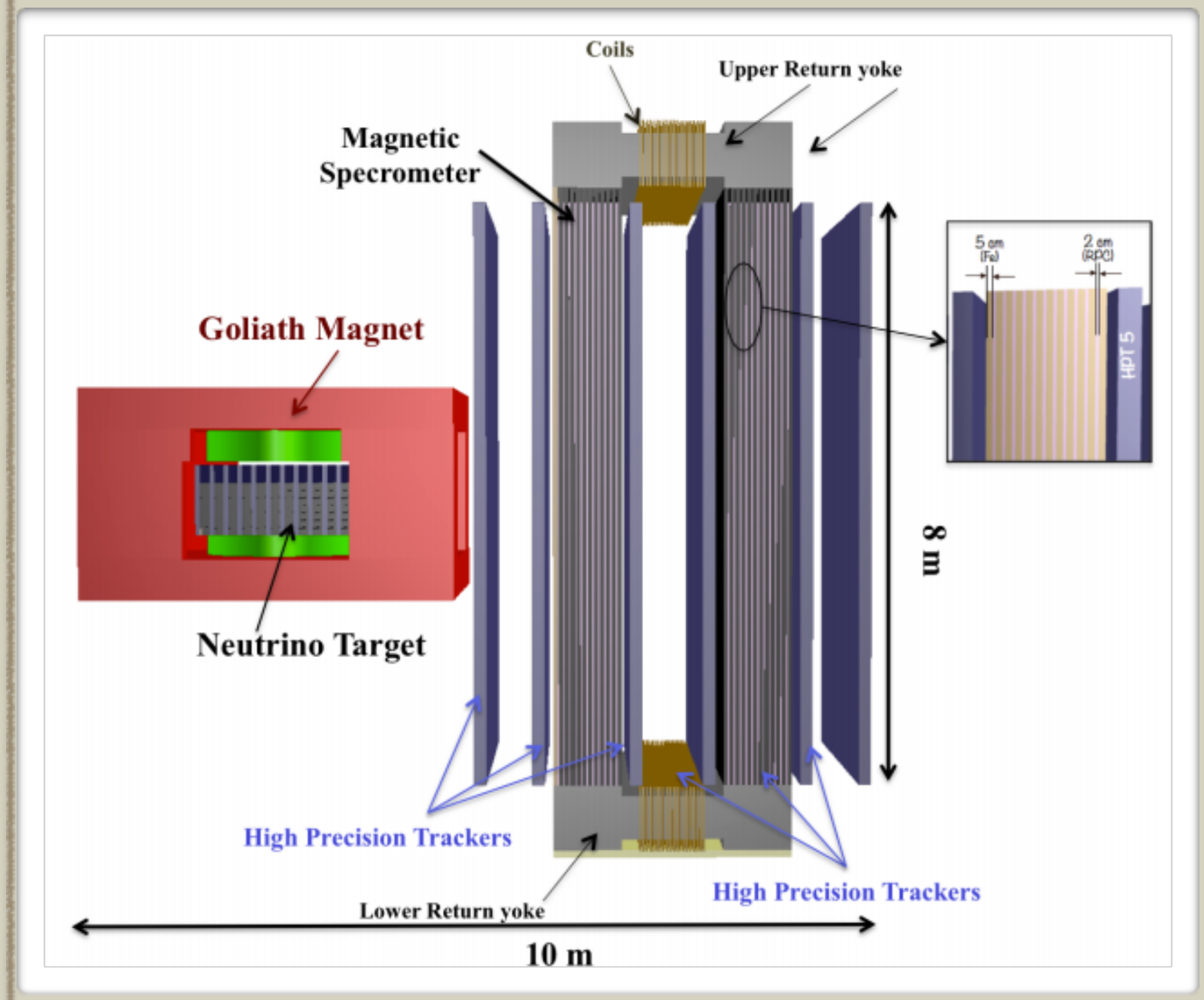
<u>DONUT</u>: 9 observed ν_τ candidate events (leptonic number not measured)
<u>OPERA</u>: discovery of $\nu_\mu \rightarrow \nu_\tau$ oscillations in appearance mode

$\bar{\nu}_\tau$ not detected yet!



$\nu_\mu \rightarrow \nu_\tau$ candidate observed by the OPERA experiment

Neutrino Detector



Requirements:

- High spatial resolution to observe the τ decay (~1 mm)
  - → *EMULSION FILMS*
- Electronic detectors to give "time" resolution to emulsions
  - → *TARGET TRACKER PLANES*
- Magnetized target to measure the charge of τ products
  - → *DIPOLAR MAGNET*
- Magnetic spectrometer to perform muon identification and measure its charge and momentum
  - → *MUON SPECTROMETER*