THE SHiP PROJECT

SEARCH FOR HIDDEN PARTICLES

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on behalf of Napoli Group

University & INFN Napoli
Italy

December 19th, 2016

Activities Of The Napoli Group

- A. Alexandrov
- A. Buonaura
- S. Buontempo
- R. De Asmundis
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- A. Di Crescenzo
- G. Galati
- A. Iuliano
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- P. Strolin
- V. Tioukov
- E. Voevodina

- **Activities:**

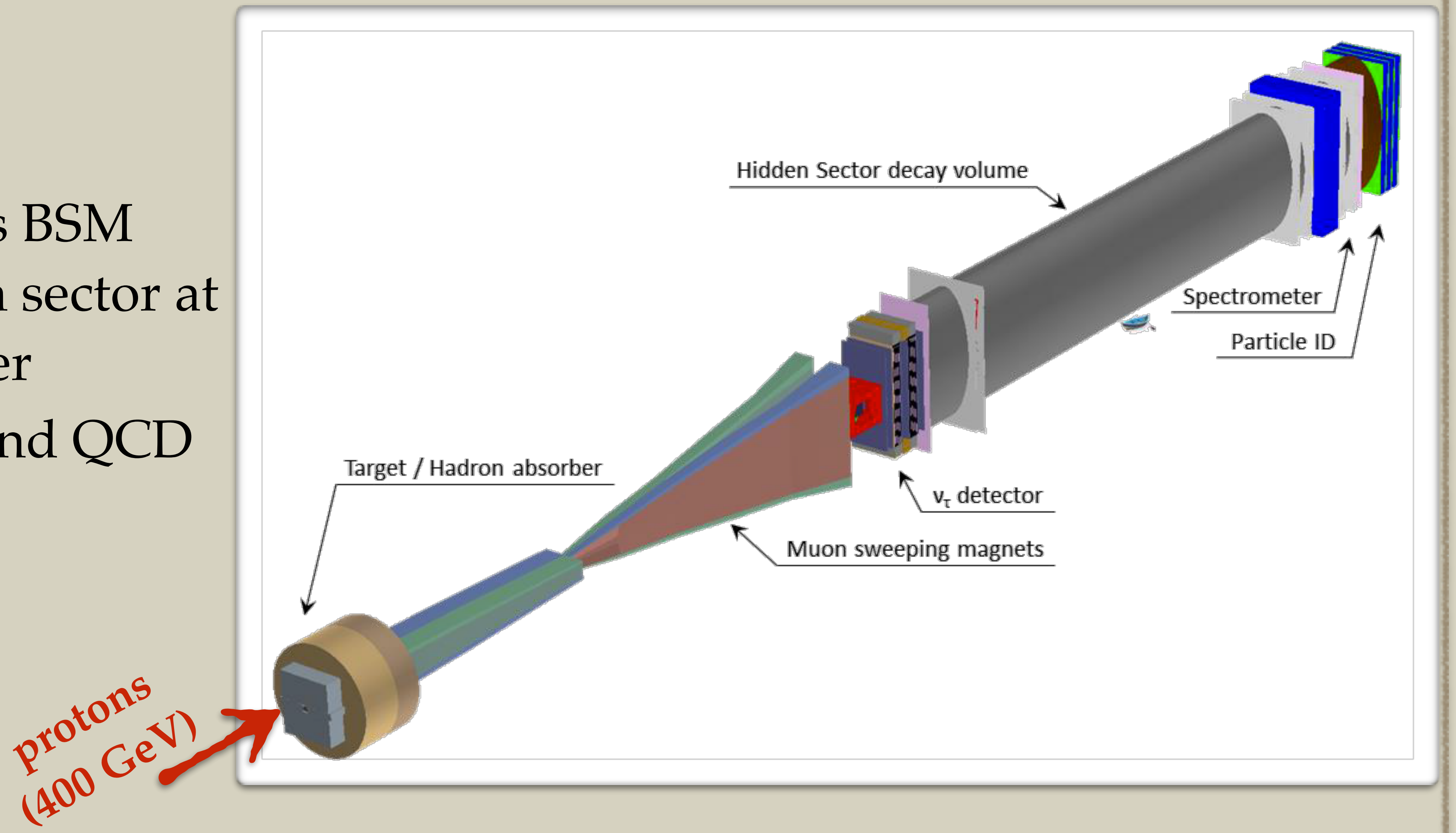
1) Optimization of the Neutrino Detector
2) Neutrino studies and Dark Matter search
3) Test the detector component with particle beams
4) Design of a detector for charm production measurements
5) Design of RPC tracking system in the Muon Spectrometer

The SHiP Experiment

- Beam dump facility at CERN SPS
- **Motivation**:
  - Find answer to open questions in Particle Physics: neutrino masses and oscillations, baryon asymmetry of the Universe, Dark Matter

Main goals:

- Explore the physics BSM through the hidden sector at the intensity frontier
- Neutrino physics and QCD measurements



Status Of The Project

- April 2015 **Technical proposal** [1] submitted to **SPSC,** together with the Physics Proposal [2]
- January 2016 Positive recommendation by SPSC

and antineutrino measurements and valuable QCD studies. Furthermore it would extend the hidden sector search to scattering of dark matter particles. The facility could accommodate additional detectors extending the range of dark matter searches. The SPSC supports the motivation for the search for hidden particles, which will explore a domain of interest for many open questions in particle physics and cosmology, and acknowledges the interest of the measurements foreseen in the neutrino sector. SHiP could therefore constitute a key part of the CERN Fixed Target programme in the HL-LHC era.

From SPSC Review Jan 2016

decision, coincides with the expected revision of the EU HEP strategy. The Committee **also notes** the plans of the incoming CERN Management to set up a working group to prepare the future of the CERN Fixed Target programme after LS2, as input to the next EU strategy update. In this context the SPSC **recommends** that the SHiP proponents proceed with the preparation of a Comprehensive Design Report (CDR), and that this preparation be made in close contact with the planned Fixed Target working group.

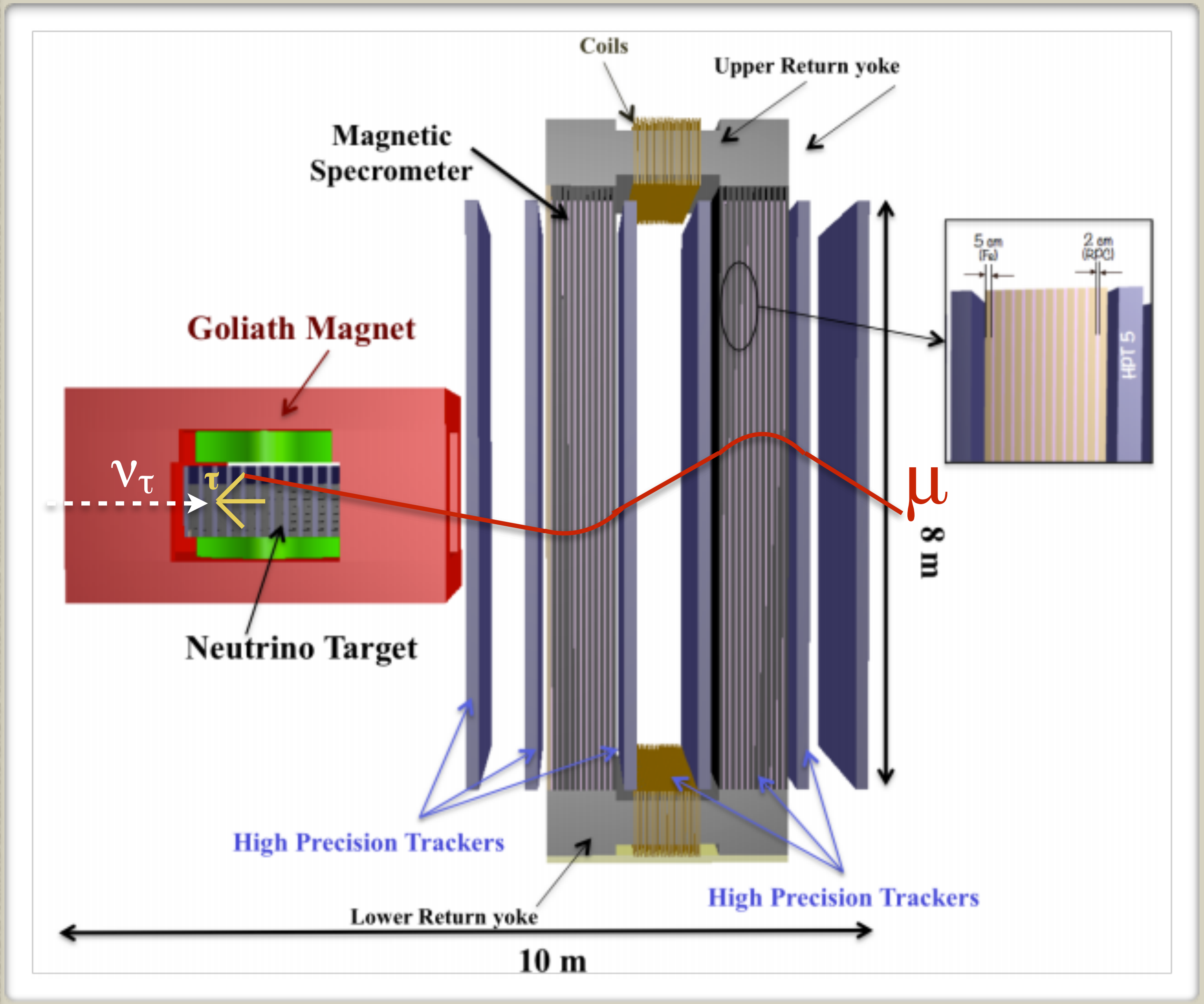
- March 2016 **Physics Beyond Colliders (PBC)**: working group set-up at CERN
  SHiP preparatory phase within the working group
- September 2016 First PBC Workshop at CERN

Comprehensive Design Report expected in 2018 for the approval by **European HEP strategy**

(1) CERN-SPSC-2015-016/SPSC-P_350 *arXiv:1504.04956 (hep-ph)* (2) Rep. Prog. Phys. 79 (2016) 12

The Neutrino Detector

(*A.Buonaura*)



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*

The Neutrino Target

(*A.Buonaura*)

Neutrino target

- Made by ~1000 unitary cells
- Emulsion Cloud Chamber (ECC) brick: lead plates and Nuclear Emulsions

↓

Definition of neutrino interaction and tau lepton decay vertex with μm resolution

- Compact Emulsion Spectrometer: air gaps and Nuclear Emulsions

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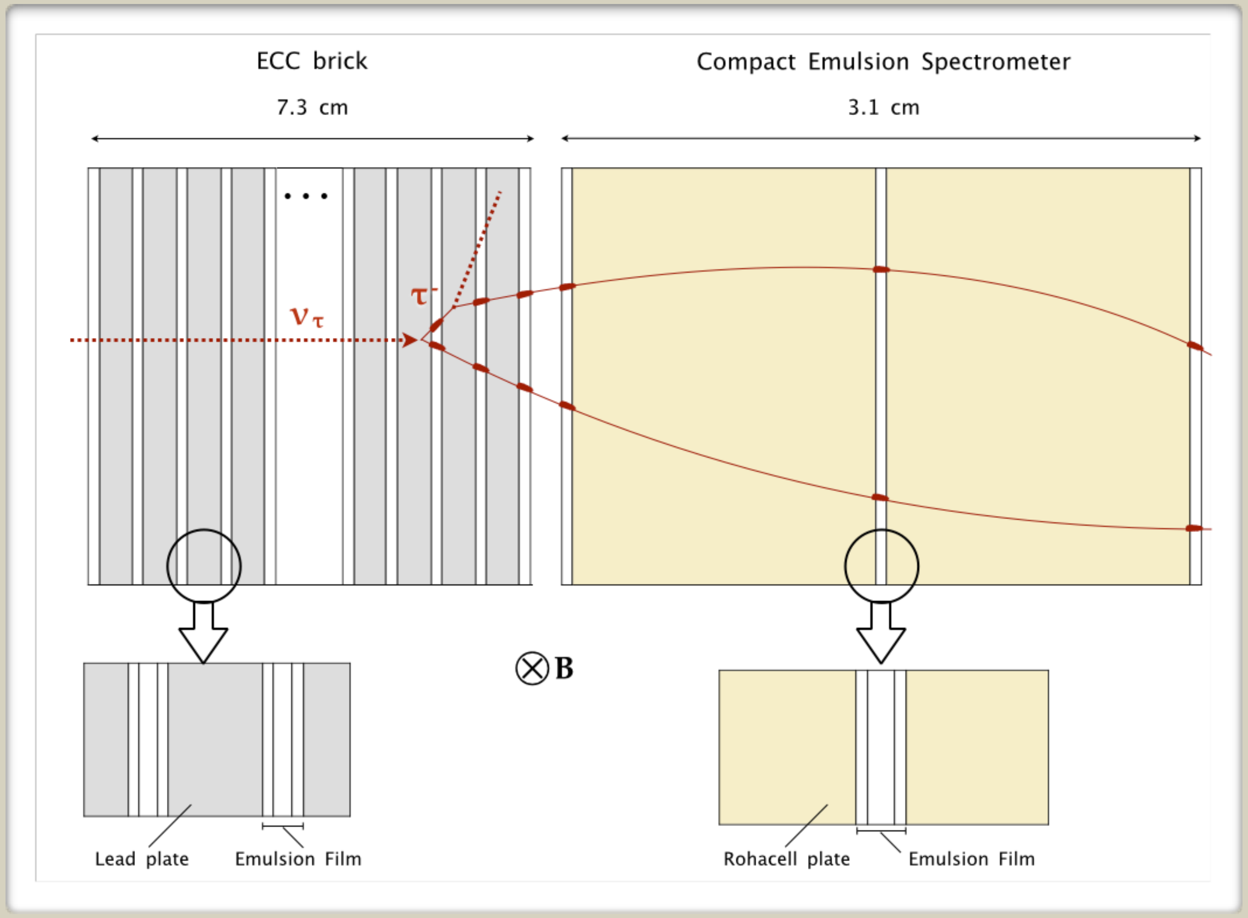
Electric charge measurement of τ lepton decay products, ν_τ/anti-ν_τ separation



Physics goals:

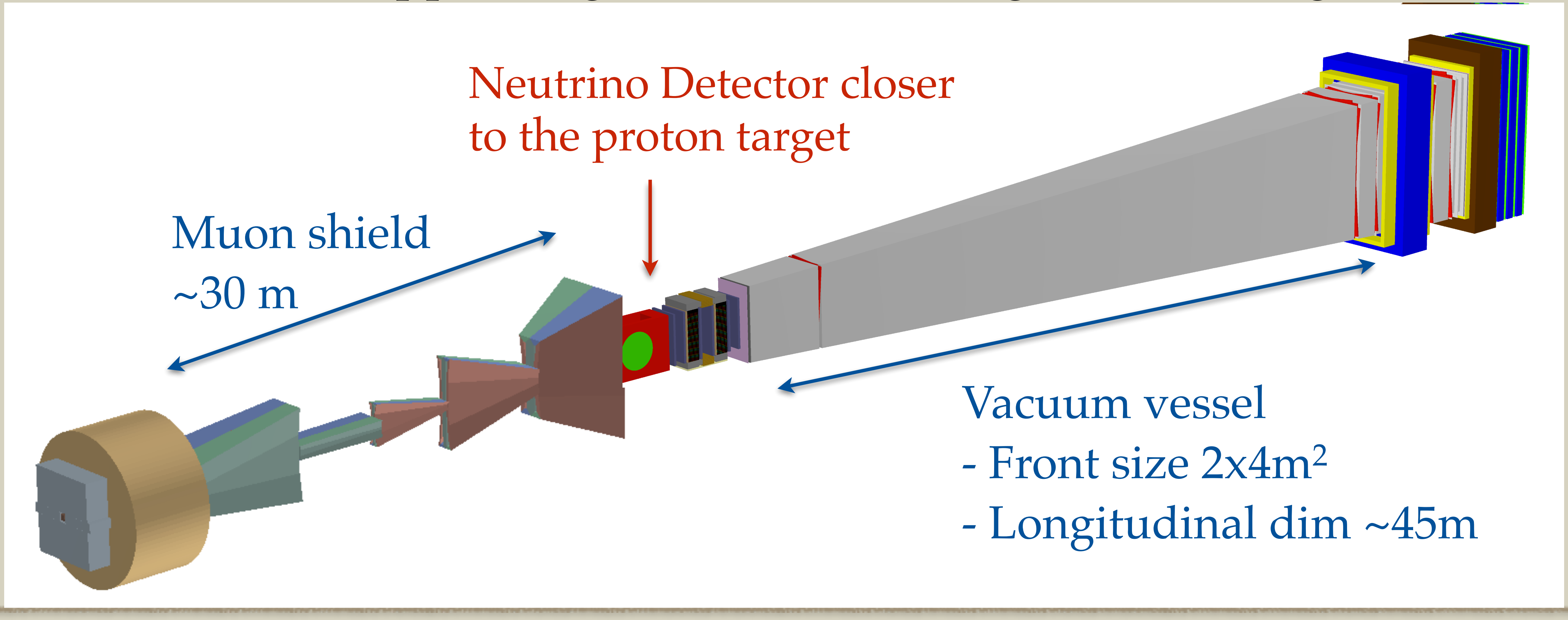
- First observation of anti-ν_τ
- ν_τ / anti-ν_τ cross-section measurement
- First evaluation of F_4 and F_5 structure functions
- Measurement of the strange quark content through charm production in neutrino scattering

Detector Optimization

- Conical shape of vacuum vessel: reduction of frontal size, get closer to the target → Re-design of the Neutrino Detector
- Effect of magnetising the hadron stopper
  - Can shorten the muon shield and reduce the amount of iron by a factor~2
  - Substantial gain in acceptance for e.g. HNL (+30%)

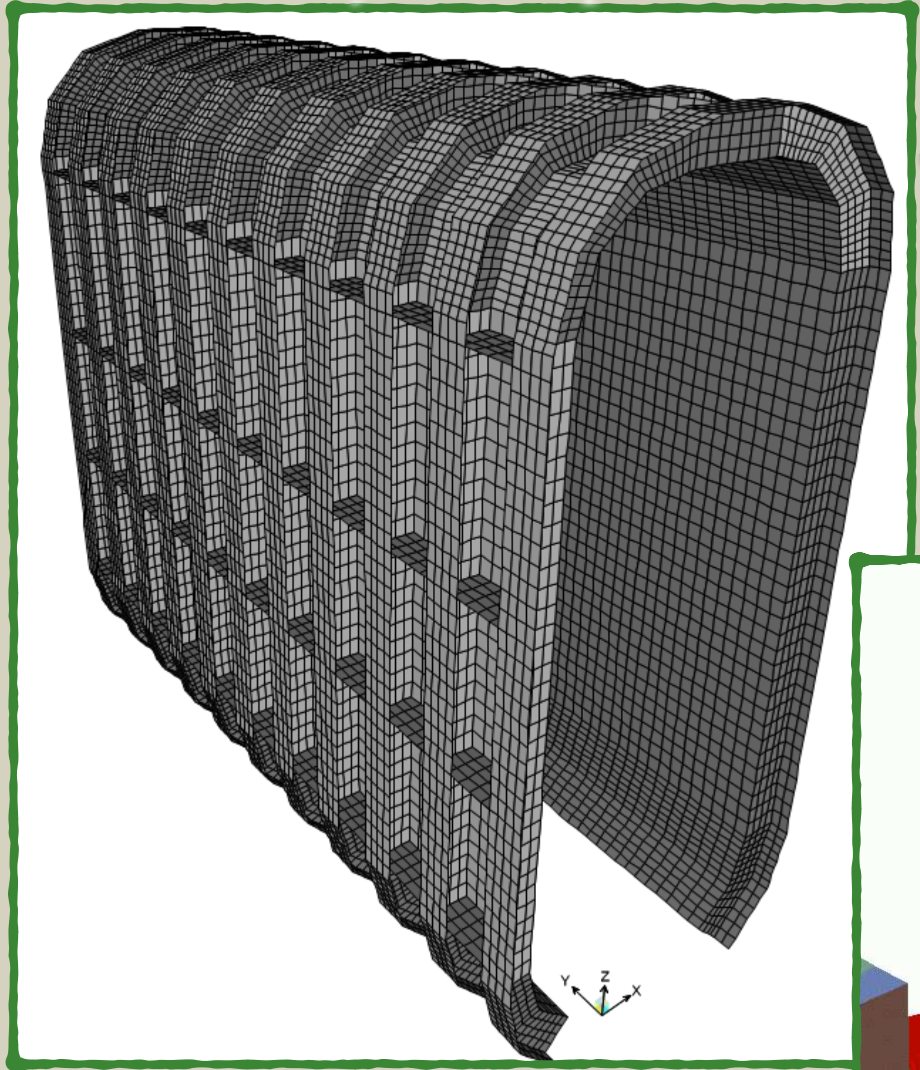
New Layout

Hadron stopper magnetized + re-arrangement of magnets



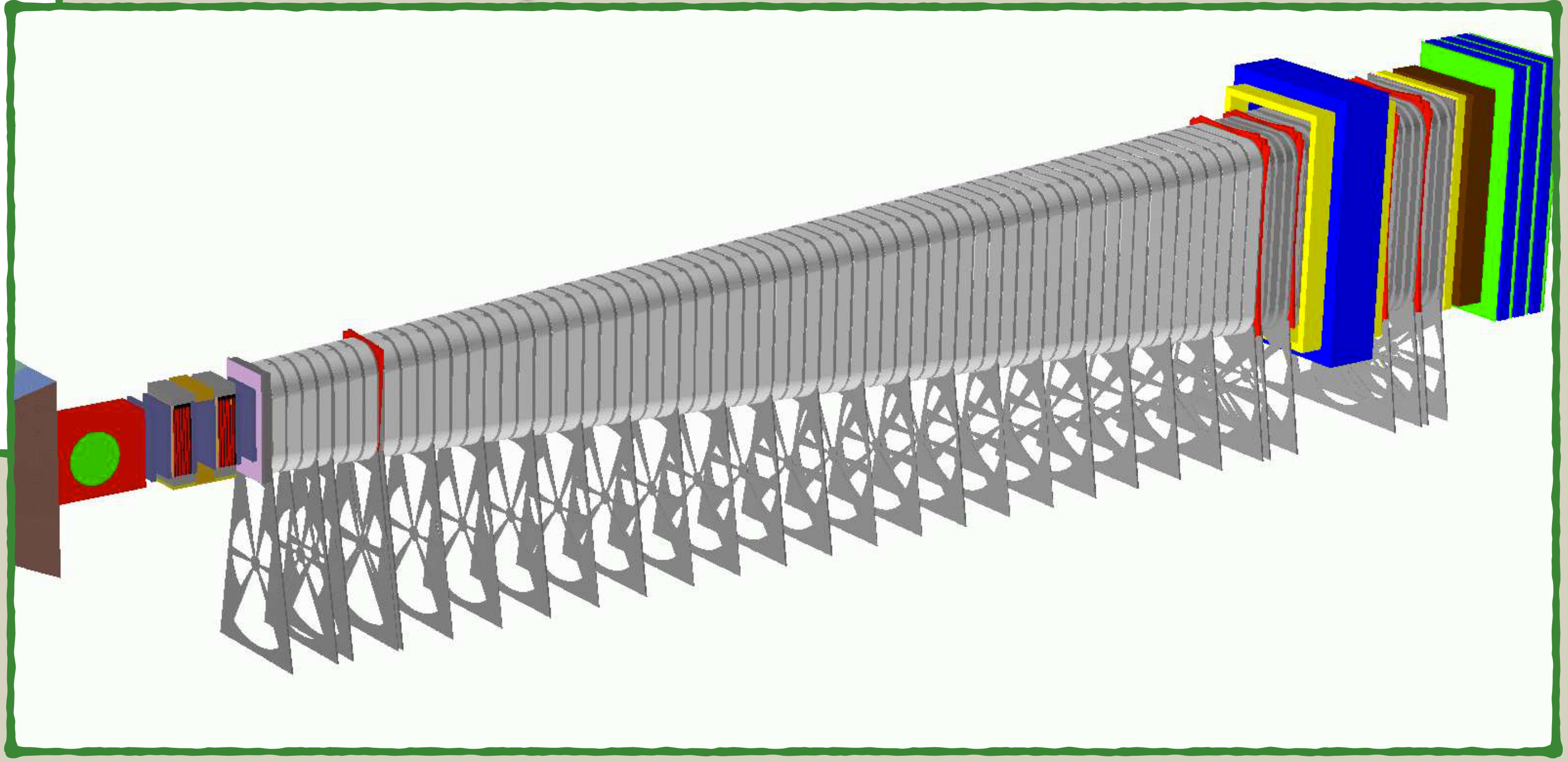
Design Of Vacuum Vessel

- Proposal from A. Prota, Dept. of Structures for Engineering and Architecture - University of Naples Federico II



Steel structure with a calendered sheet coupled with welded stiffening elements

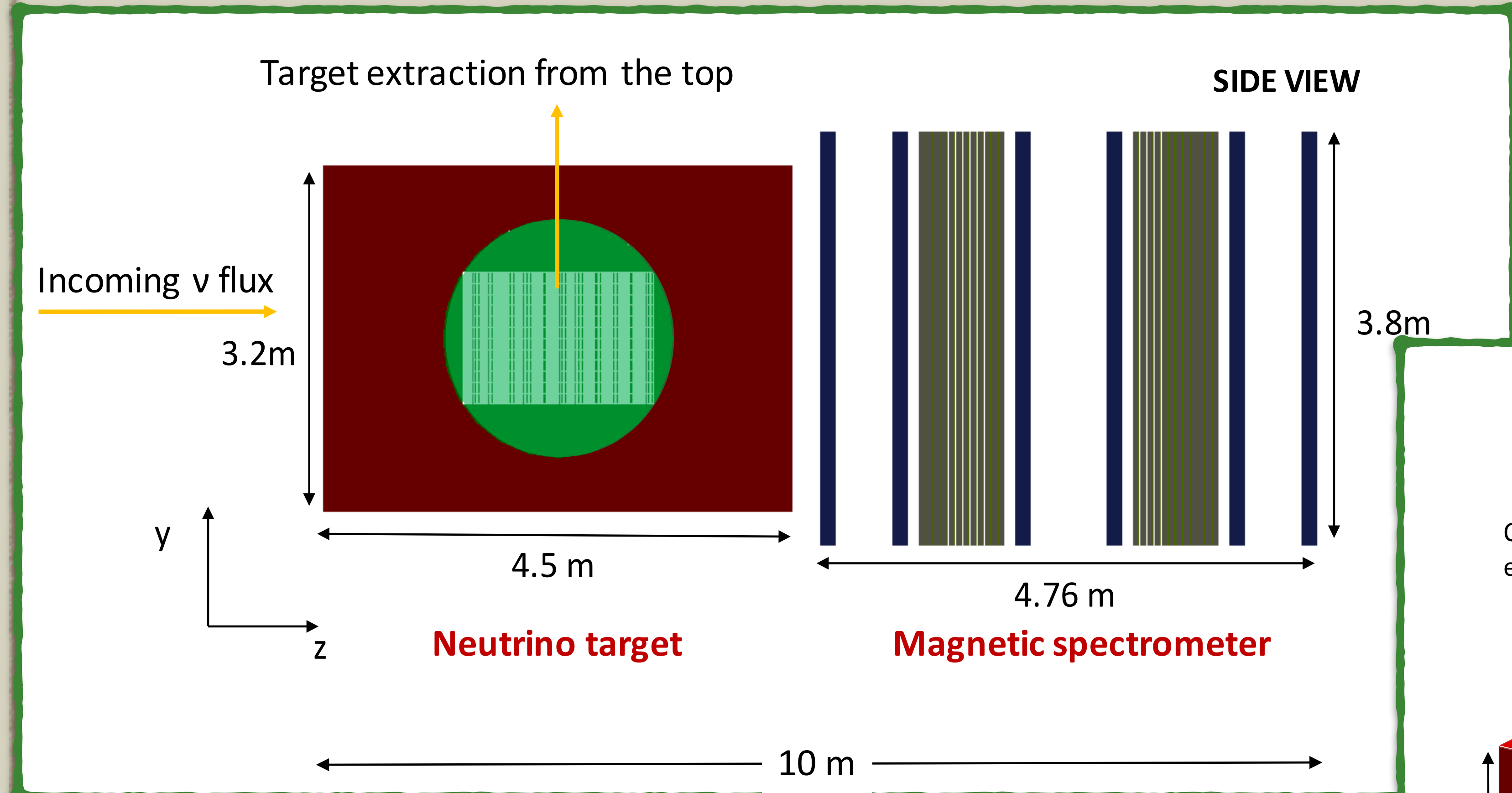
Implementation in SHiP Simulation Software

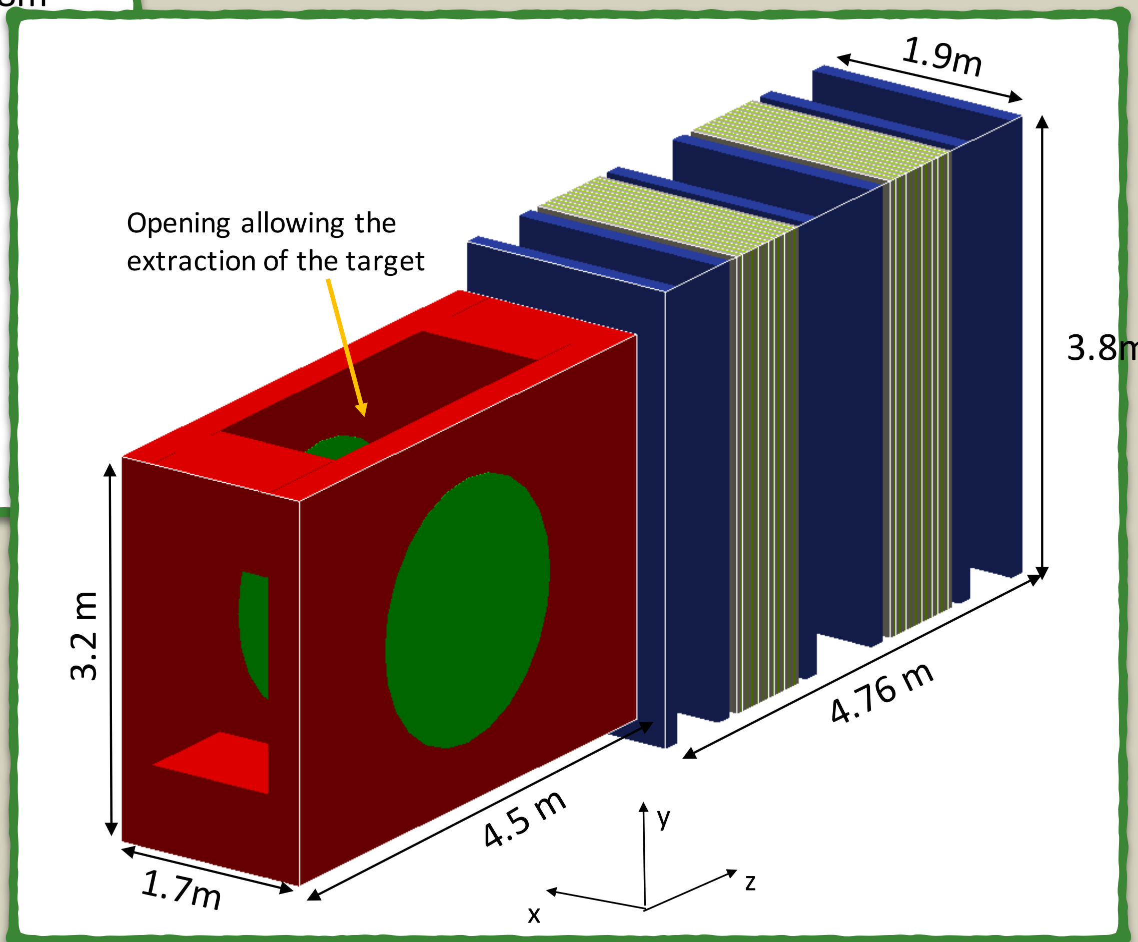


New Layout Of Neutrino Detector

(A.Buonaura)

- Reduction of transverse size of Neutrino Detector to fit in the muon-free region
- Detector layout optimized to have a number of neutrino interactions >= those in the TP





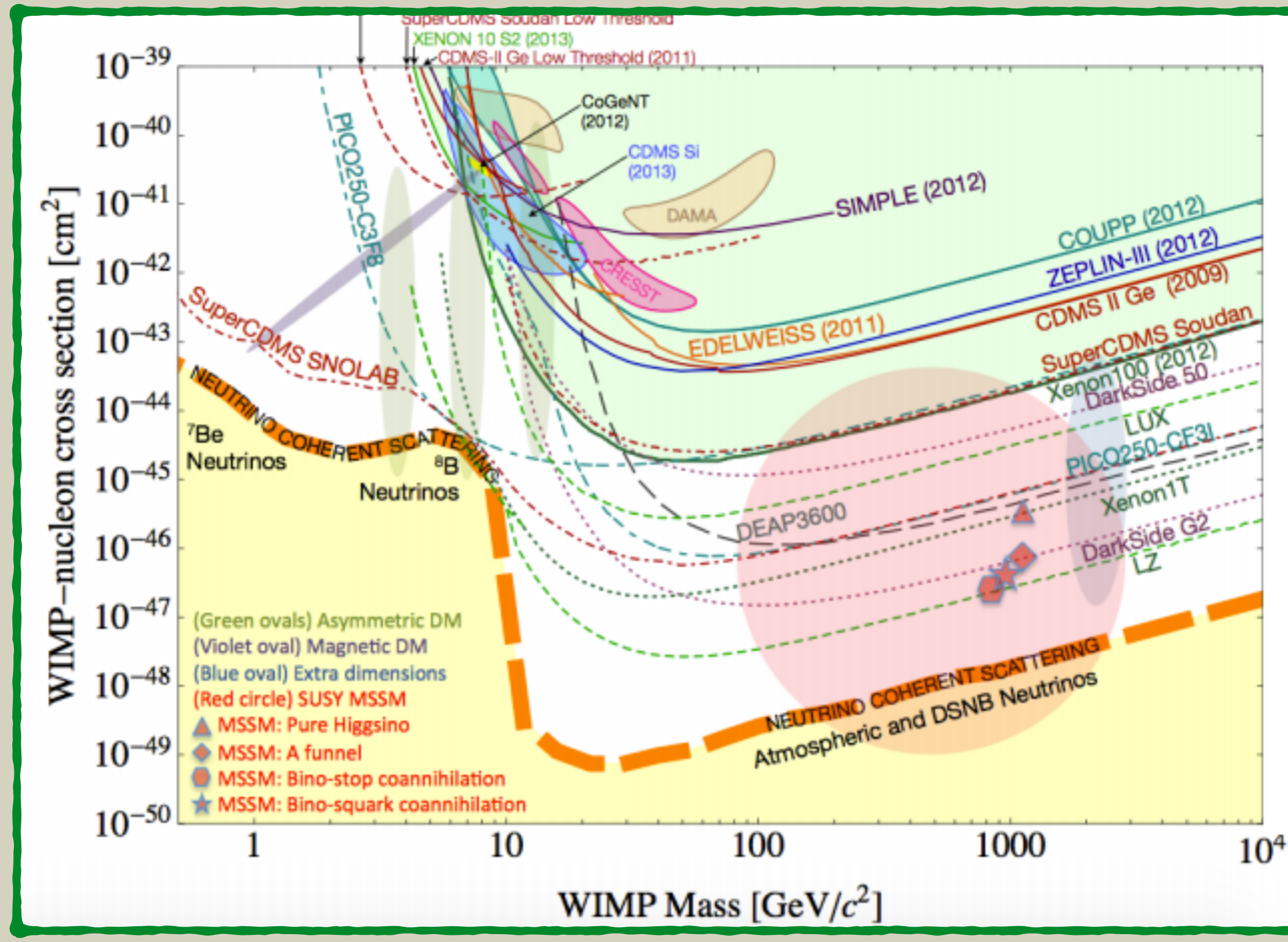
- Bipolar magnet with horizontal field

Search For Light Dark Matter Scattering

- Direct detection Dark Matter experiments have limited sensitivity for WIMP masses below few GeV/c2

Large classes of theoretical models can make the observed relic density with sub-GeV DM:

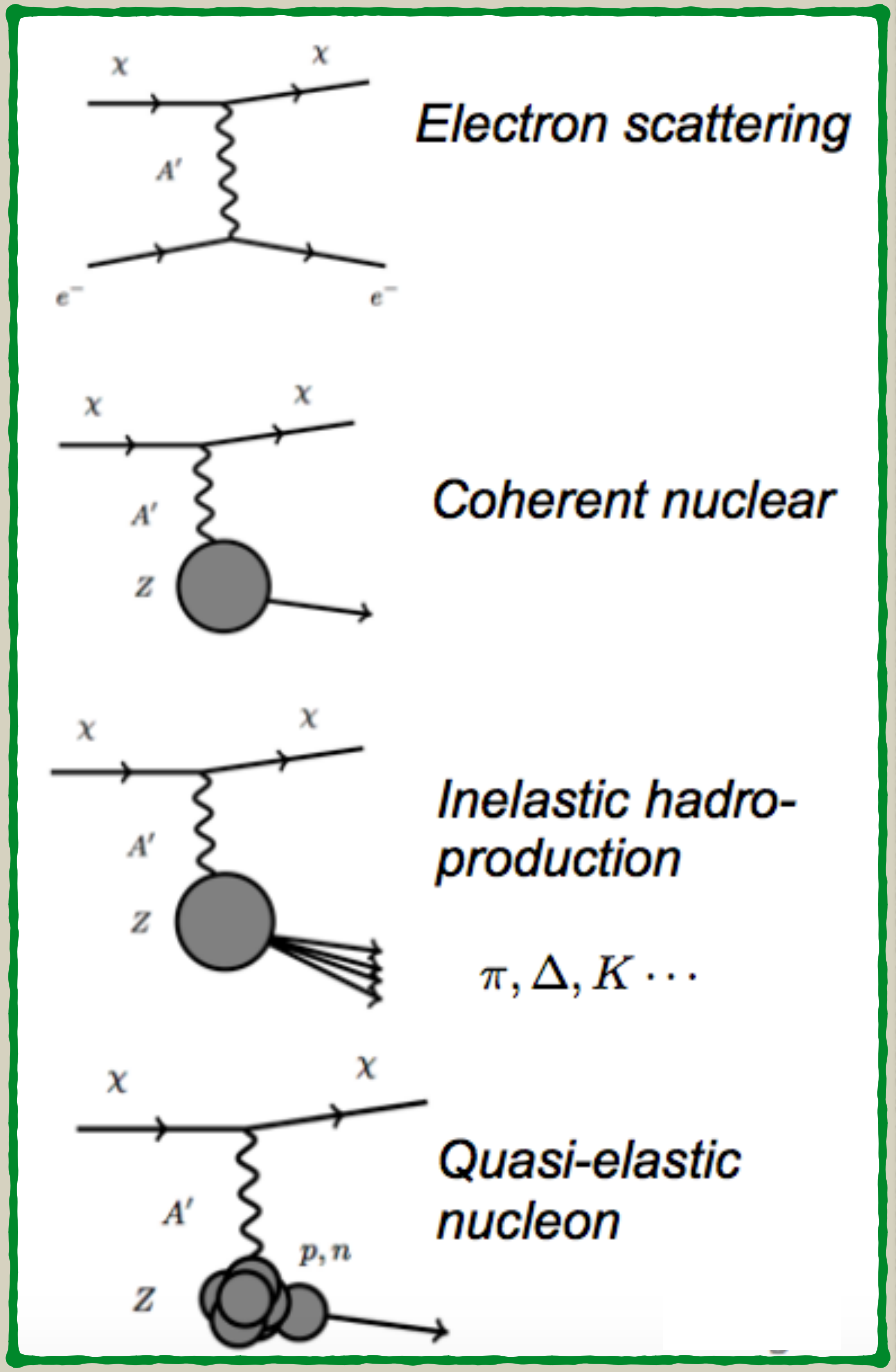
- Hidden-sector models
- Supersymmetry
- Strongly Interacting DM (SIMP)
- Extra dimensions

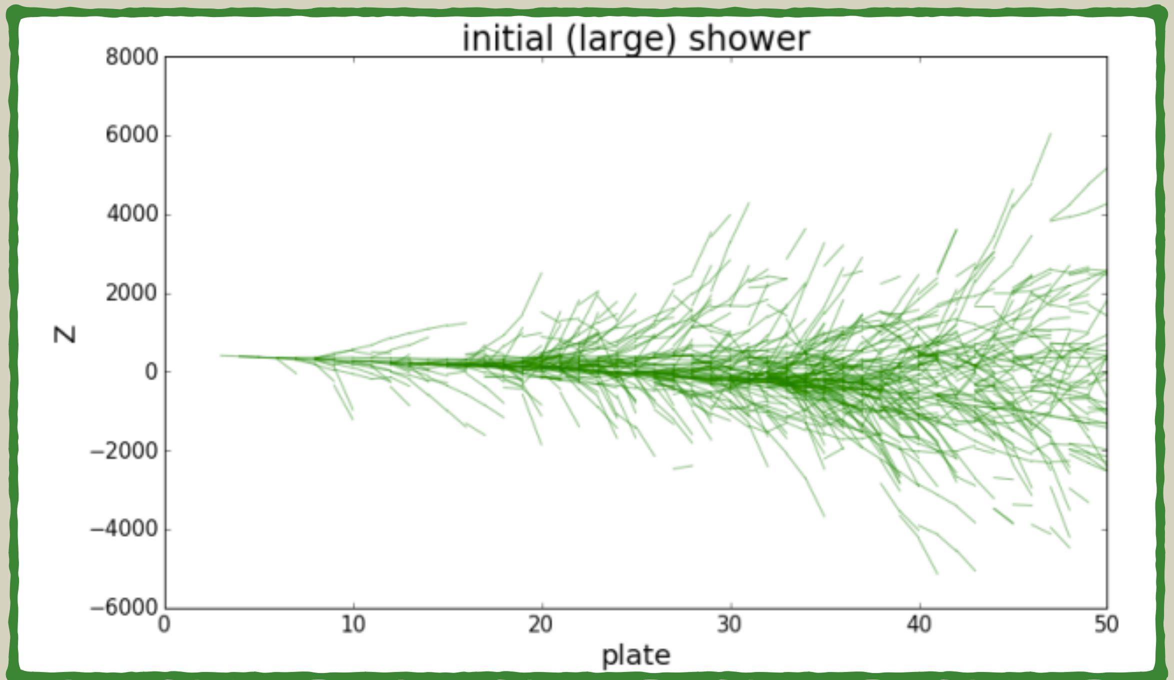


Essential to explore the sub-GeV mass range for DM

LDM@SHiP

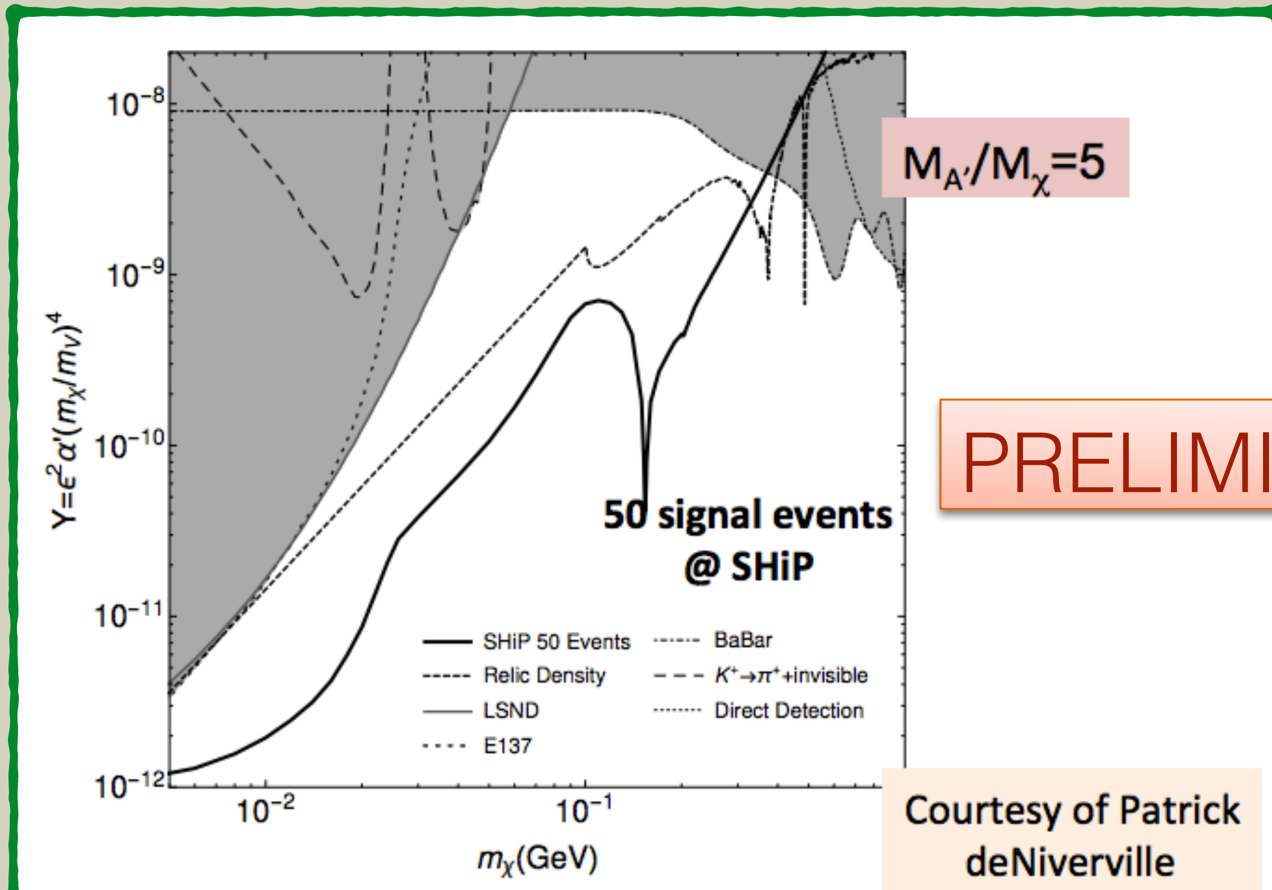
- LDM (χ) can be generated in a **beam-dump**, for example in decays of HS mediators, e.g. dark photons $A' \rightarrow \chi\chi$
- $>10^{20}$ photons expected in SHiP for 2×10^{20} p.o.t. can be used as a LDM beam
- Detect LDM via its **scattering** on atomic electrons of the emulsion target
- Use micrometric accuracy of the emulsion to determine the vertex
- Use the **emulsion target** (emulsion films+lead plates) as a sampling calorimeter to measure angle and energy of the shower





LDM PROSPECTS@SHIP

- With 50 signal events SHiP would be able to probe even beyond relic density in minimal hidden-photon model provided that the background from neutrino interactions is kept under control



50 signal events of the LDM scattering correspond to ***2.5t*** *of lead (cylinder with 0.52m radius and 2.1m length) and 2×10^{20} pot. Selection efficiency is assumed to be 50%.*

Note: Background estimated for **10t** of lead

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

Dominant background comes from neutrino interactions: ν_e quasi-elastic, elastic, resonant scattering

→ *Signal excess >3σ (in the hypothesis of dominant statistical error)*

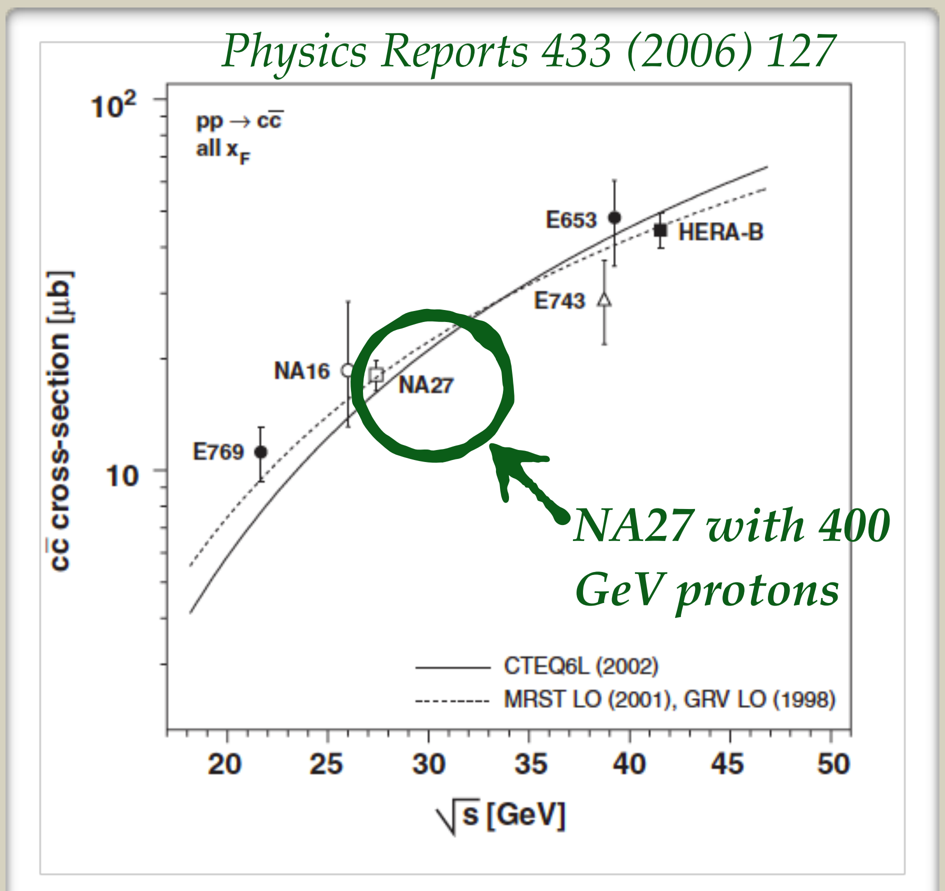
Detailed simulation and detector optimization in progress

Design Of An Experiment For Charm Cross-Section Measurement

- Charm production in **proton interactions** and in **hadron cascades** in the SHiP target crucial for Hidden Sector normalization and ν_τ cross-section measurements

From SPSC Review Jan 2016

> further theoretical studies of expected signals and comparisons with alternative search programmes. The Committee **encourages** the proponents to define a programme of measurements concerning production of charm in a SHiP-like target, important for normalisation purposes. The SPSC **also encourages** the proponents to further explore the



- Inclusive cc cross-section measurement from NA27

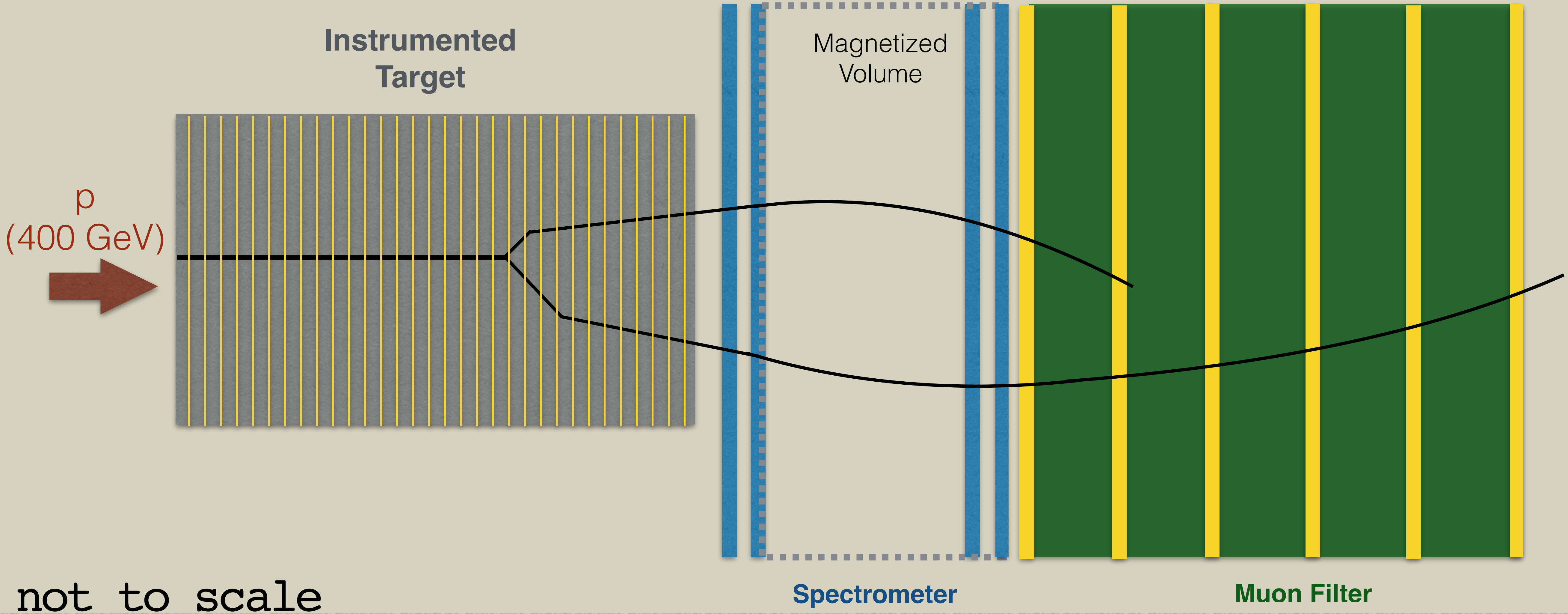
$$\sigma_{c\bar{c}} = 18.1 \pm 1.7\ \mu\text{barn}$$

- Lack of experimental data for differential cross-section and charm production in hadron cascades
- Large theoretical uncertainties
- Large systematical uncertainties in MC estimations

Conceptual Design - Napoli

Design of a hybrid detector for **double-differential** cross-section measurement **(*$d^2\sigma/dEd\theta$*)**

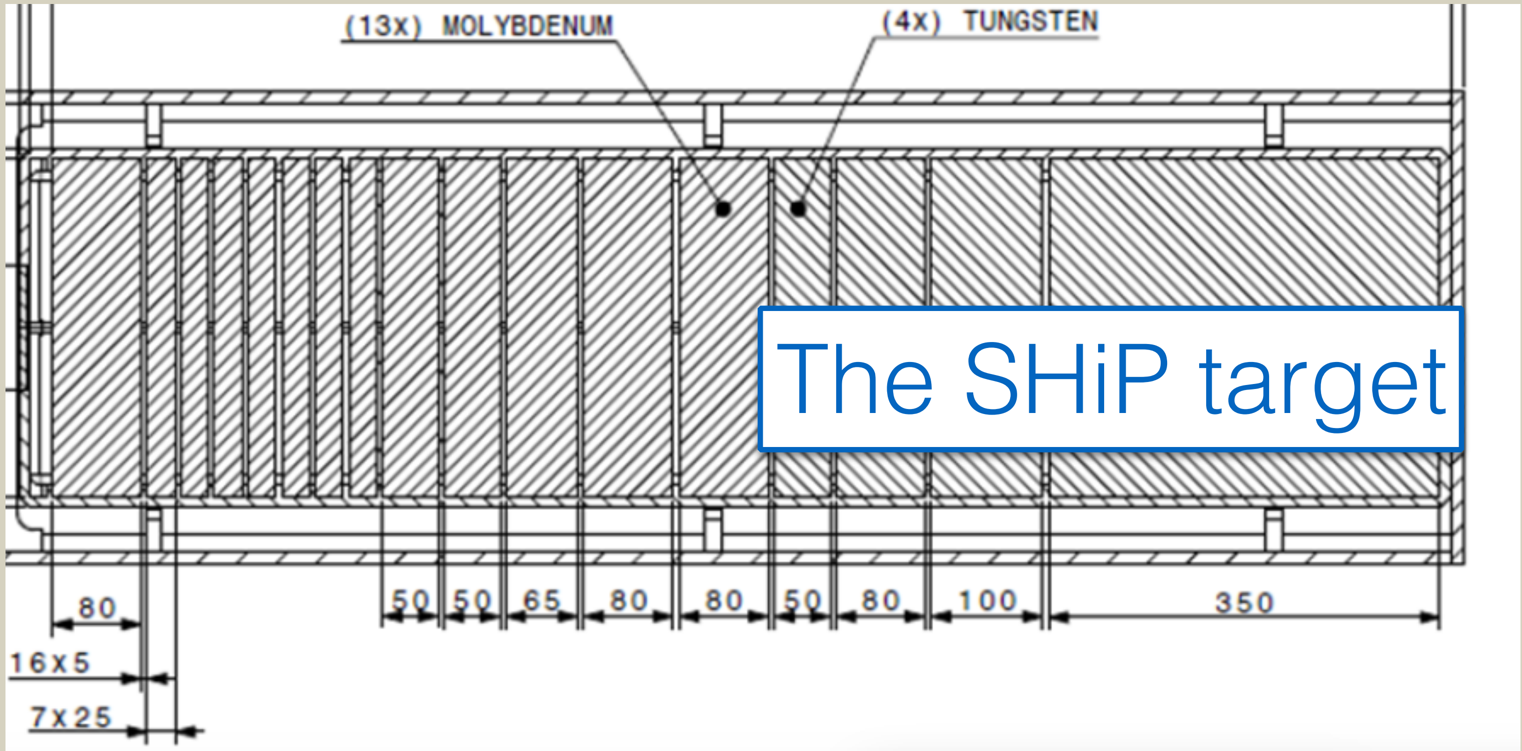
- Proton collisions in Mo/W target instrumented with **nuclear emulsions**
- Use of **nuclear emulsions** as tracking detector
  - identification of hadronic and leptonic charm decay modes
  - volume of sensitive layers << target volume
- Measurement of charm daughters charge and momentum with **Spectrometer**
- Muon identification with **Muon Filter**



not to scale

The Target

- Replica of the SHiP target with smaller section: 10x10 cm^2
- Exactly the same TZM, W distribution



Target Instrumentation

- Nuclear emulsions used as micrometric tracking device to identify charm production and decay
- Charm average decay length ~ 3.3 mm

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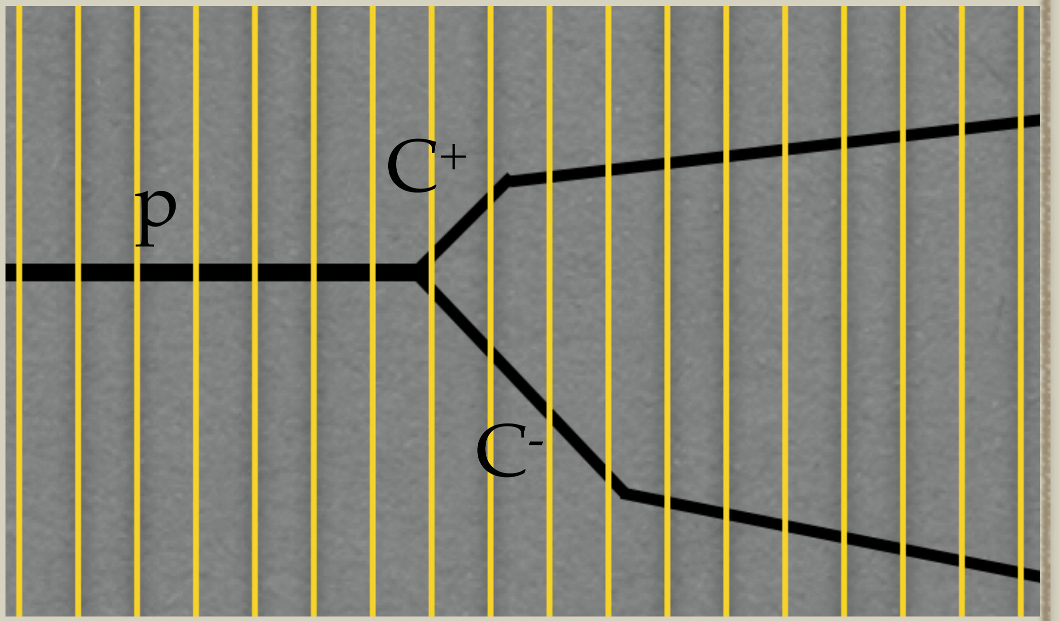
- Emulsion Cloud Chamber (ECC) technique employed: sampling of target material (TZM/W) every 3 mm
- Build ECC chambers to study the charm production in different sections of the target



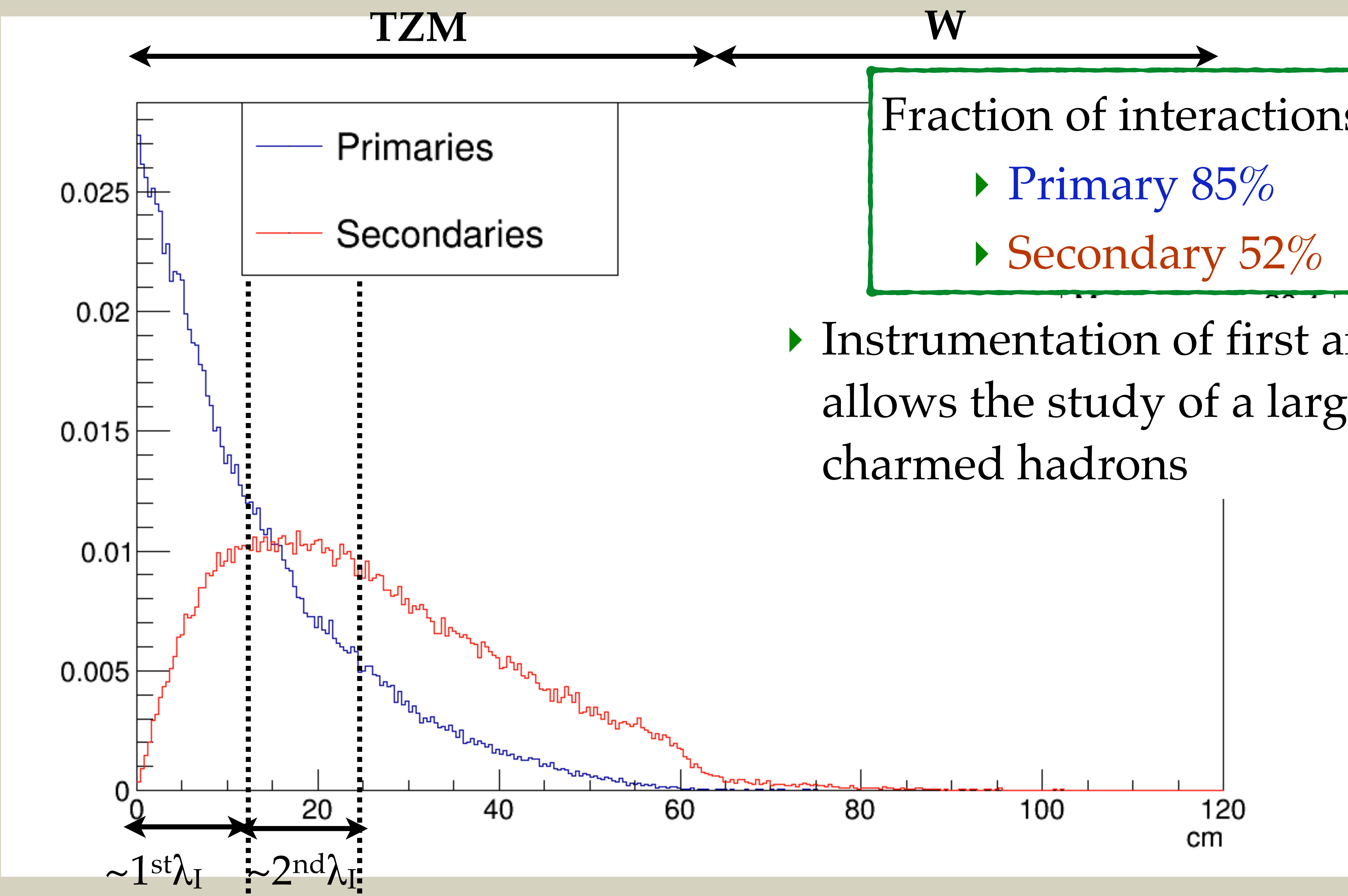
Charmed Hadron Production

(*A. Iuliano*)

- Position distribution along beam axis of charm production vertices in the target

PRIMARY PROTON INTERACTIONS

CASCADE PRODUCTION



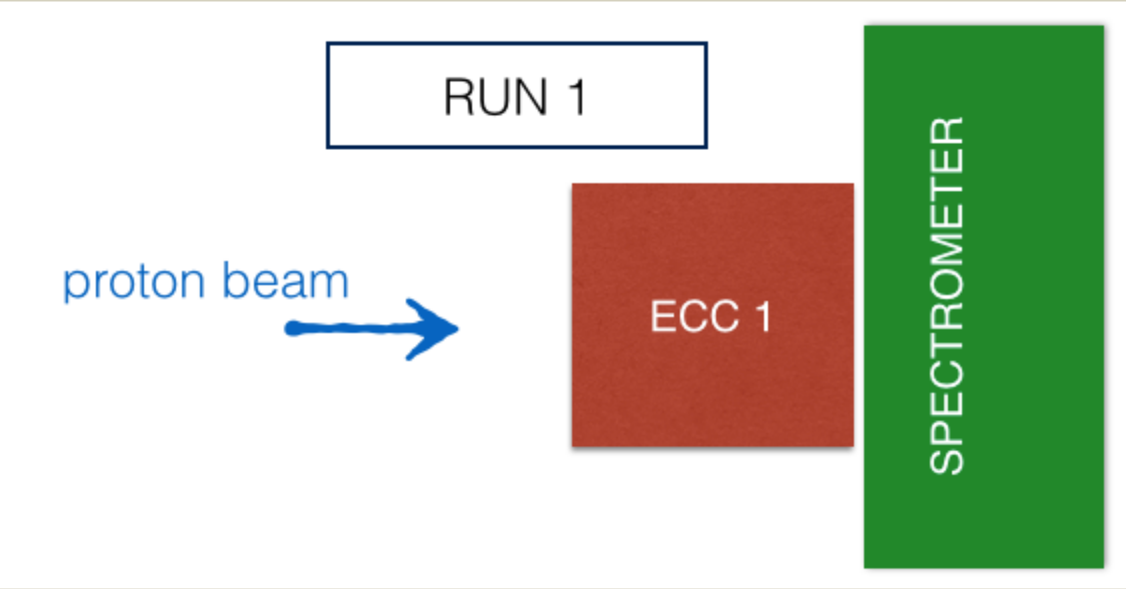
Fraction of interactions within $2\lambda_I$

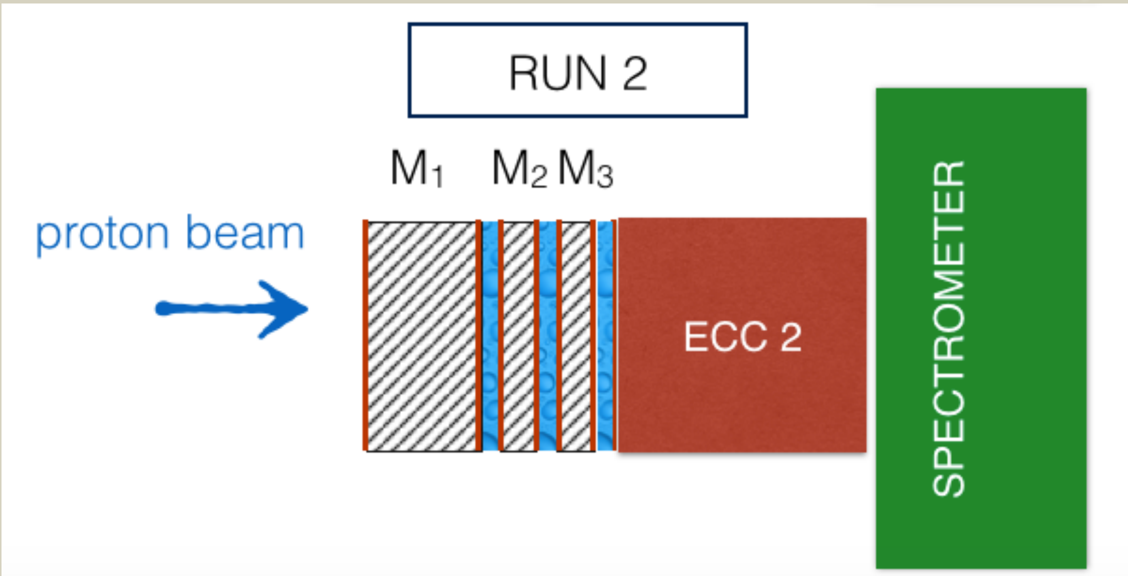
- Primary 85%
- Secondary 52%

- Instrumentation of first and second λ_I allows the study of a large fraction of charmed hadrons

RUN CONFIGURATION

(A. Iuliano)





- Number of integrated pot per run driven by the maximum number of tracks that can be integrated in emulsion films

Exposure needed to observe **10k** charmed pairs

300 x ECC1 x 1.6 x 10^5 pot

220 x ECC2 x 1.2 x 10^5 pot

Total number of integrated pot = 8 x 10^7

Total emulsion surface = 250 m^2

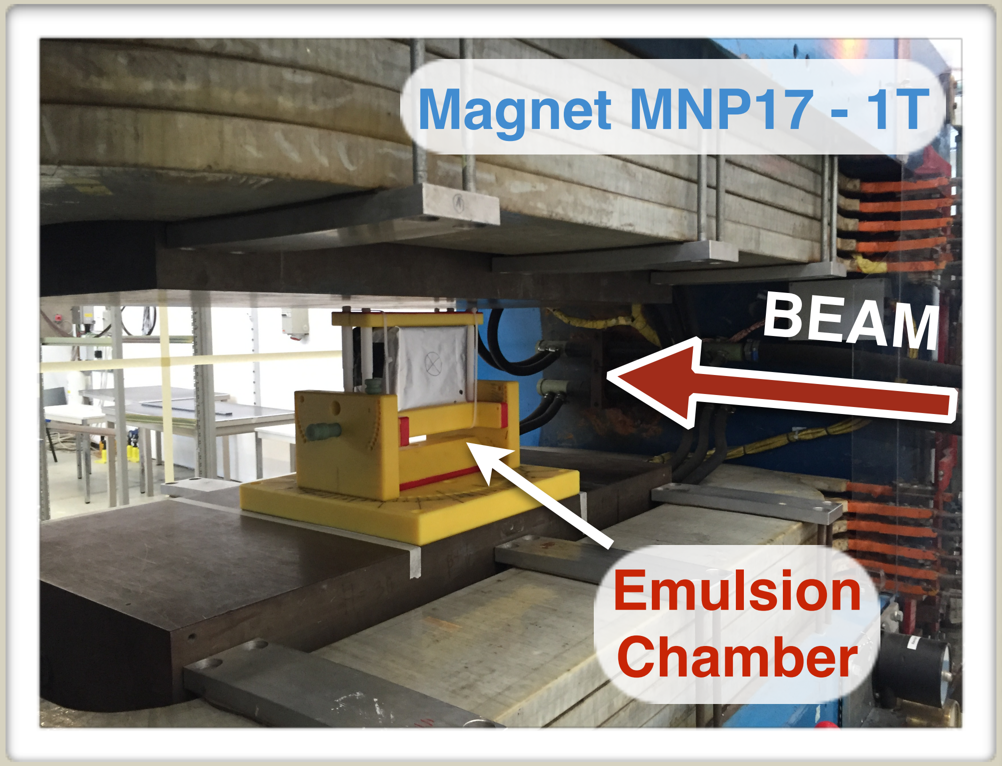
Experiment Planned For 2018

TEST BEAM ACTIVITIES

- SHiP test beam @CERN with nuclear emulsions performed in August/ September 2016
- Goals:

  1) Measurement of particles charge and momentum with the Compact Emulsion Spectrometer

  2) Matching between emulsions and Micromegas



- Facilities:
  - Emulsion laboratory & dark room @CERN
  - T9 beam line (PS - East Area), MNP-17 magnet
  - SPS - North Area, Goliath Magnet

- Groups involved: **Napoli-Emulsion** group**, RD51** groups, Nagoya, Ankara, Lebedev groups

Conclusions

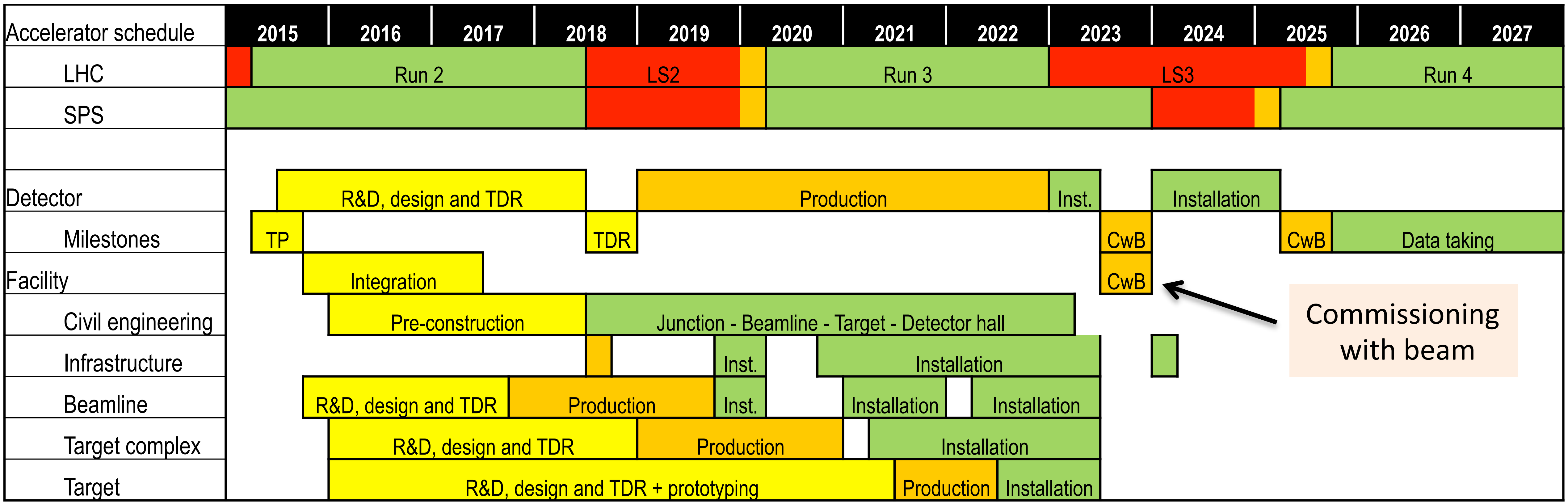
- **Napoli group leading the following activities:**
  1) Optimization of the Neutrino Detector
  2) Neutrino studies and Dark Matter search
  3) Test the detector component with particle beams
  4) Design of a detector for charm production measurements
  5) Design of RPC tracking system in the Muon Spectrometer

Physics Planning Group (Members as defined in "Mandate" document)

Chair:	**Physics Coordinator**	N. Serra (Zurich)
	CDR Conveners	
	Hidden sector signals and models	K. Petridis (Bristol)
	Hidden sector background and signal selection	M. Patel (Imperial)
	Tau neutrino and Light Dark Matter	A. Di Crescenzo (Naples)

Back-up Slides

PROJECT SCHEDULE

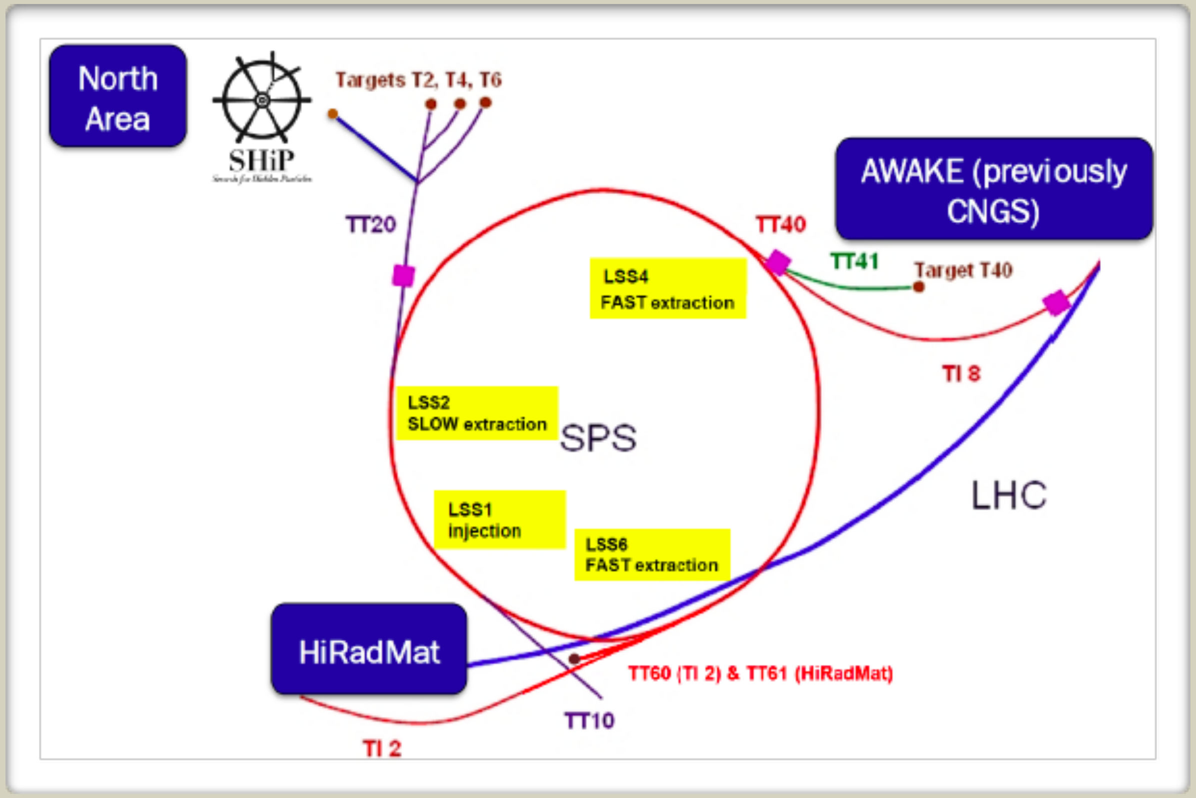


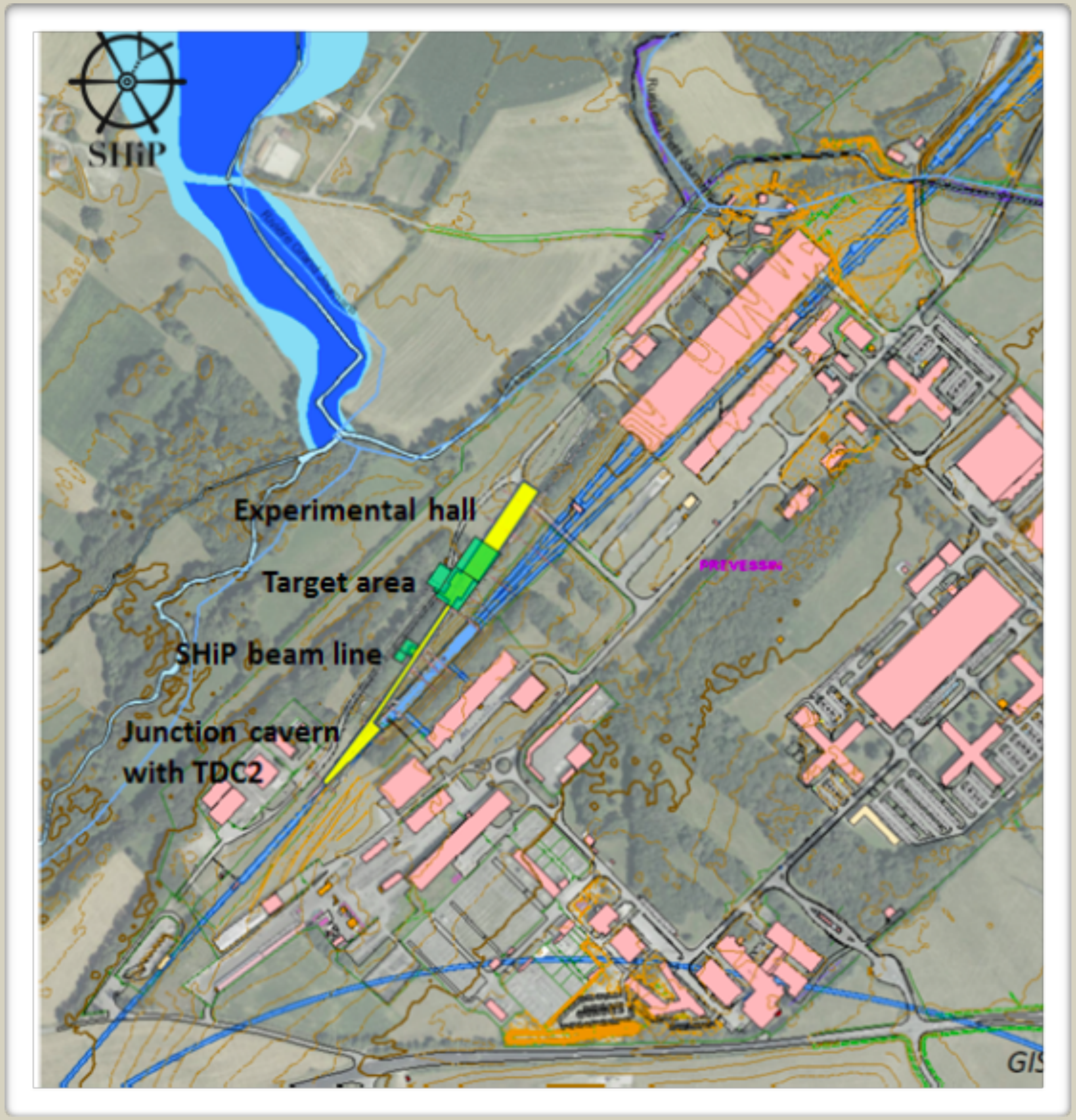
- **Form SHiP Collaboration** — **December 2014 ✔**
- **Technical Proposal** — **April 2015 ✔**
- Technical Design Report — 2018
- Construction and Installation — 2018-2023
- Commissioning — 2023
- Data taking and analysis — 2026

THE FIXED-TARGET FACILITY AT SPS

complex

High-intensity proton beam: 4x10^{19} pot/yr, 5 years run



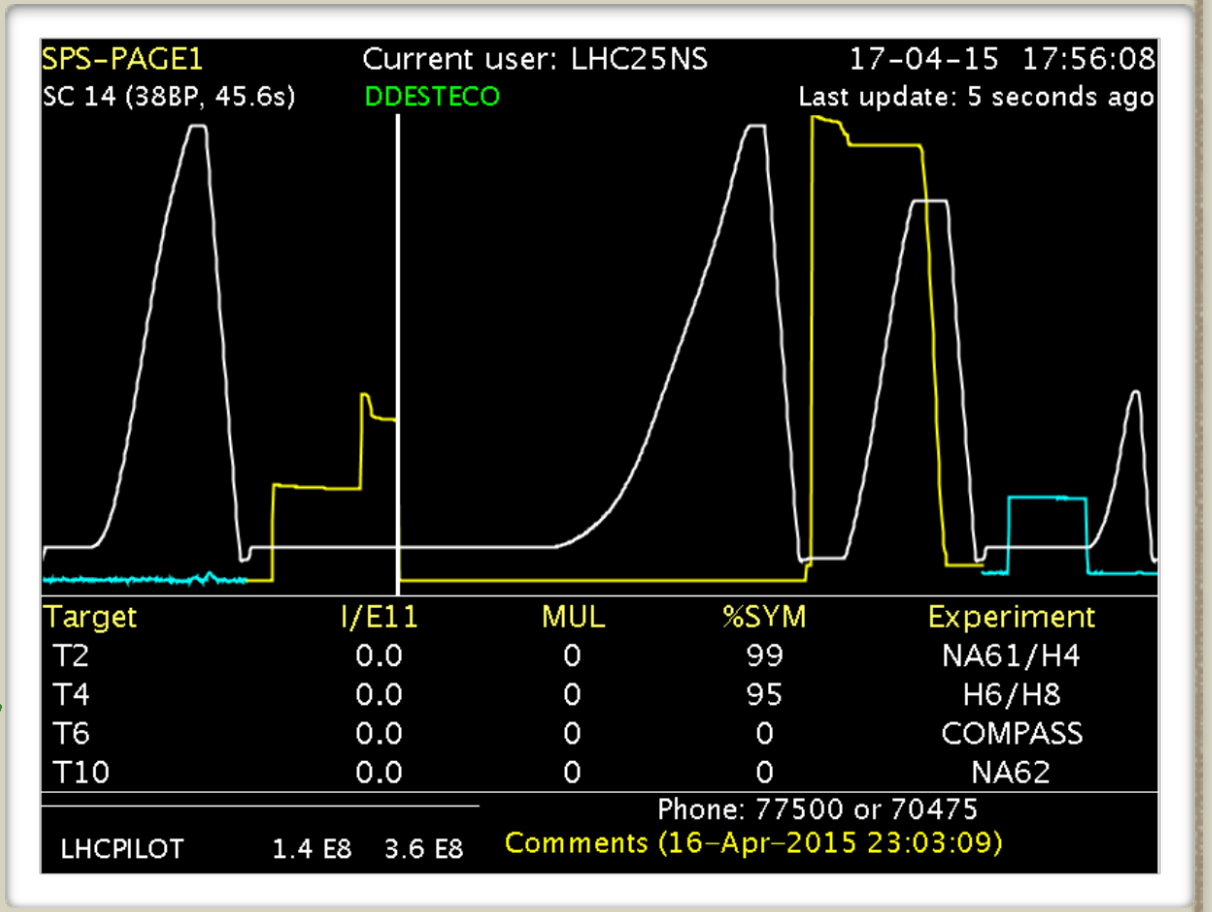


Location: Prevessin North Area site

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

R&D At Cern For Proton Extraction

- Deployment of the new SHiP cycle
- Extraction loss characterisation and optimisation
  - Reduce p density on septum wires
  - Probe SPS aperture limits during slow extraction
- Development of new TT20 optics
  - Change beam at splitter on cycle-to cycle basis
- Characterisation of spill structure
- R&D and development of laminated splitter and dilution (sweep) magnets

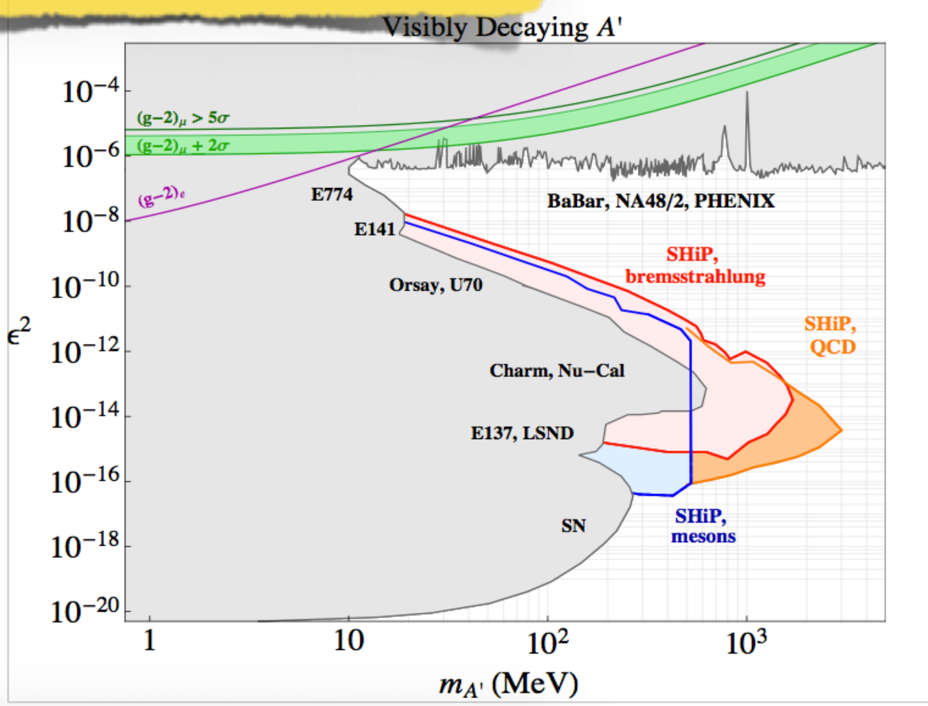


Successful test in April 2015

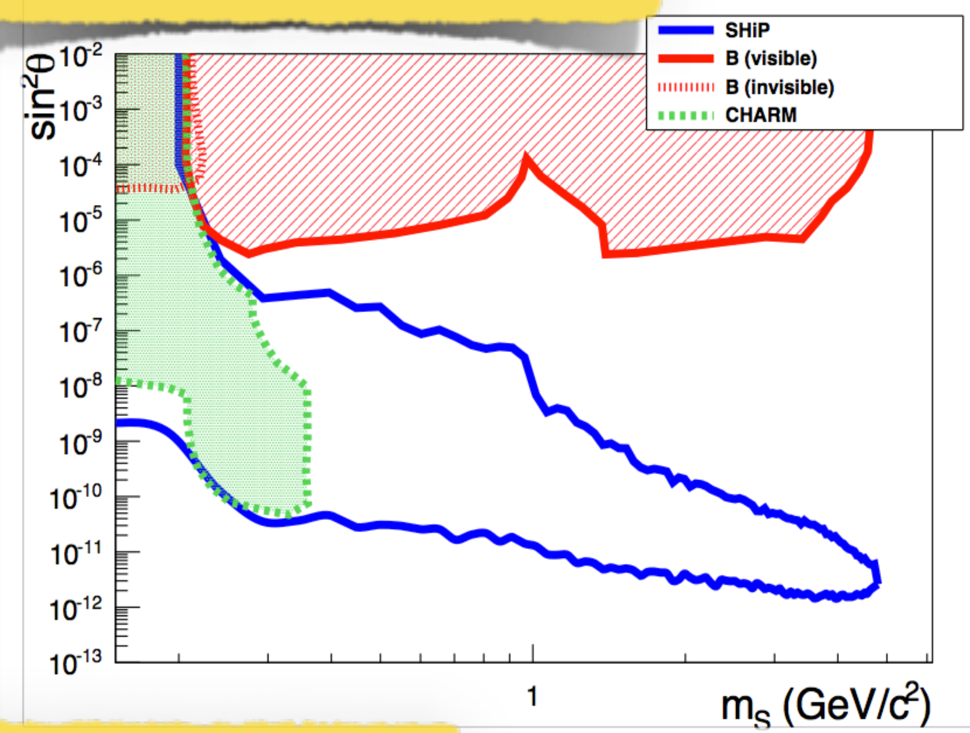
SENSITIVITIES

Based on 2x10[20] pot @400 GeV
in 5 years

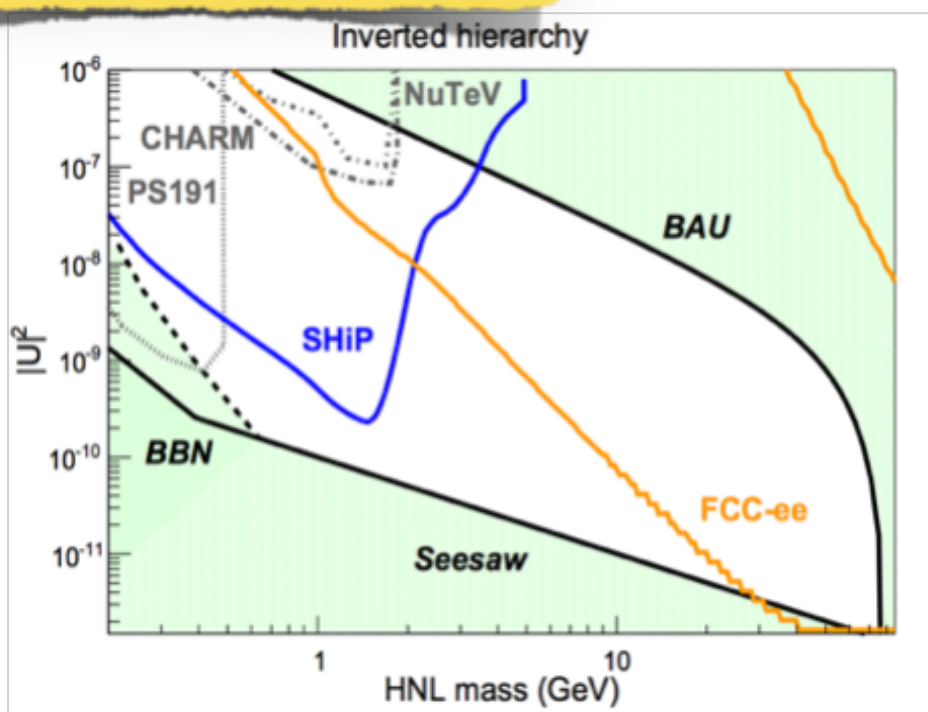
VECTOR PORTAL



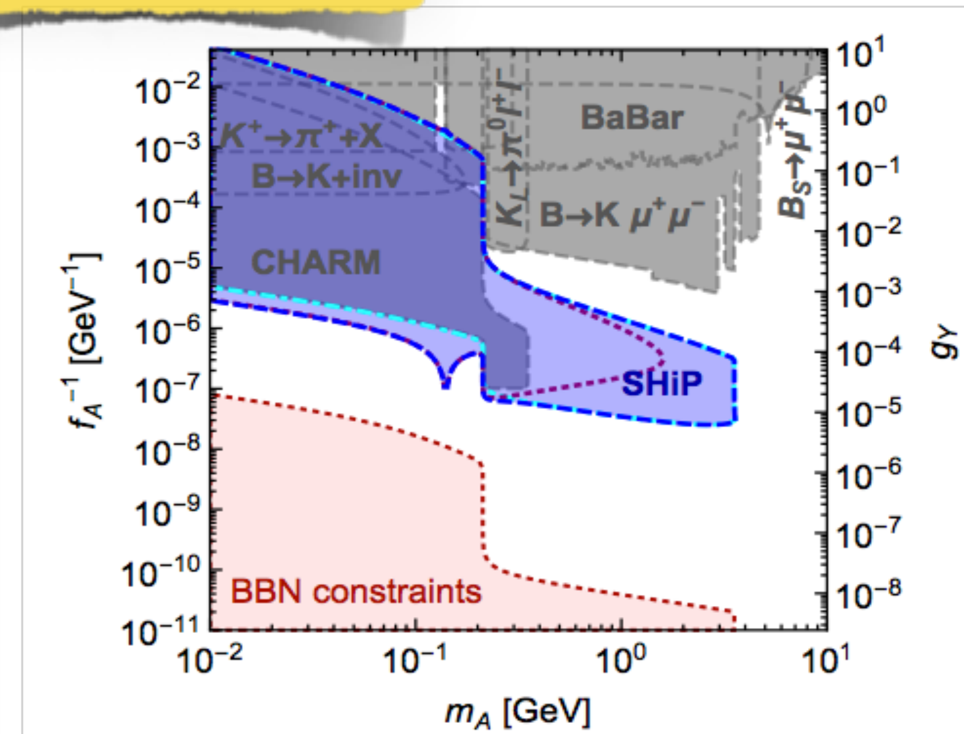
SCALAR PORTAL



NEUTRINO PORTAL



AXION PORTAL



ν_τ Physics

- ν_τ and $\bar{\nu}_\tau$ produced in the leptonic decay of a D^-_s meson into τ^- and $\bar{\nu}_\tau$, and the subsequent decay of the τ^- into a ν_τ
- Number of ν_τ and $\bar{\nu}_\tau$ produced in the beam dump

$$N_{\nu_\tau+\bar{\nu}_\tau} = 4N_p \frac{\sigma_{c\bar{c}}}{\sigma_{pN}} f_{D_s} Br(D_s \to \tau) = 2.85 \cdot 10^{-5} N_p$$

- Main background source: charm production in ν_μ^{CC} ($\bar{\nu}_\mu^{CC}$) and ν_e^{CC} ($\bar{\nu}_e^{CC}$) interactions, when the primary lepton is not identified

- Geometrical, location and decay search efficiencies considered
- Expectations in 5 years run ($2\text{x}10^{20}$pot)

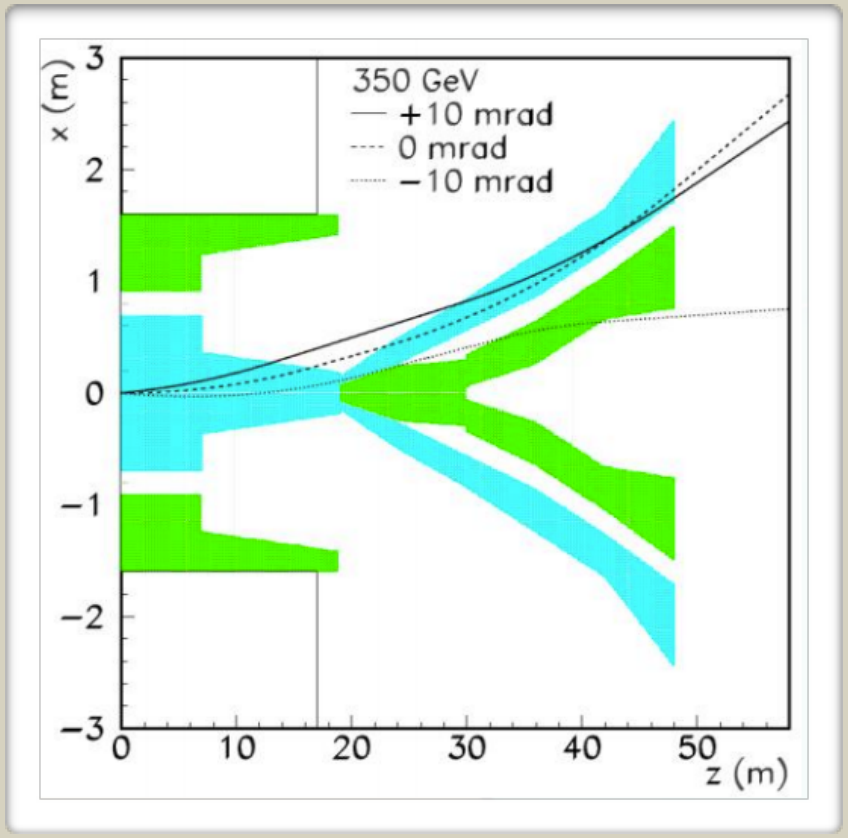
SIGNAL EXPECTATION BACKGROUND R = S/B RATIO

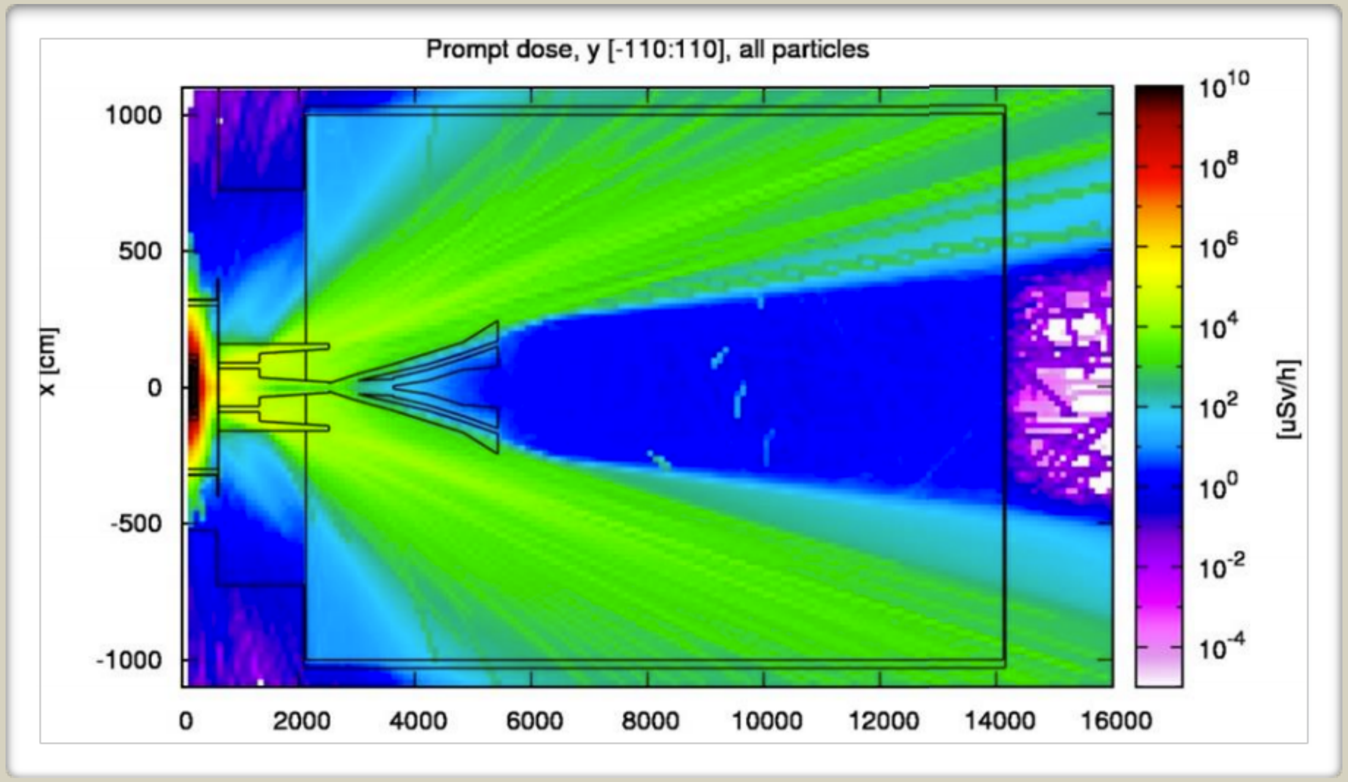
decay channel	ν_τ			$\bar{\nu}_\tau$		
	N^{exp}	N^{bg}	R	N^{exp}	N^{bg}	R
$\tau \to \mu$	570	30	19	290	140	2
$\tau \to h$	990	80	12	500	380	1.3
$\tau \to 3h$	210	30	7	110	140	0.8
total	1770	140	13	900	660	1.4

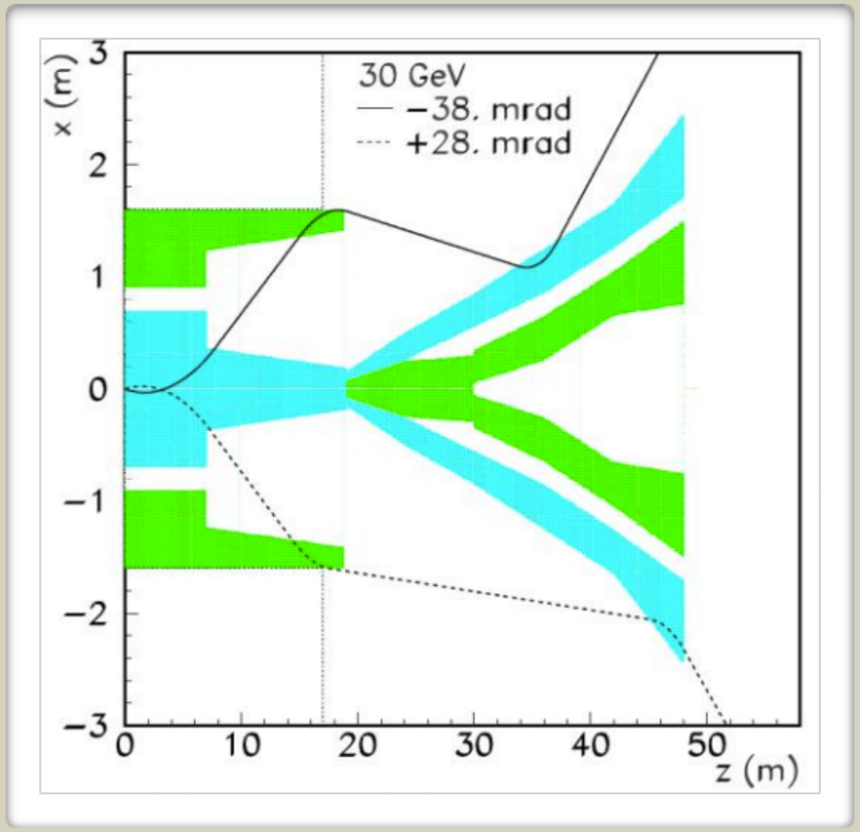
Active Muon Shield

- Muon flux driven by the HS background and emulsion-based neutrino detector
- Active muon shield based entirely on **magnet sweeper** with a total field integral B = 86.4 Tm

- Realistic **design** of sweeper magnets in progress
- **Challenges**: flux leakage, constant field profile, modeling magnet shape
- Rate reduction: from 10^{10} to 10^4 muons/spill
- **Negligible flux** in terms of detector occupancy







Hidden Sector Detector Concept

Aim: Reconstruction of HS decays in all possible final states

- Long decay volume protected by various Veto Taggers
- Magnetic Spectrometer followed by the Timing Detector
- Calorimeters and Muon systems

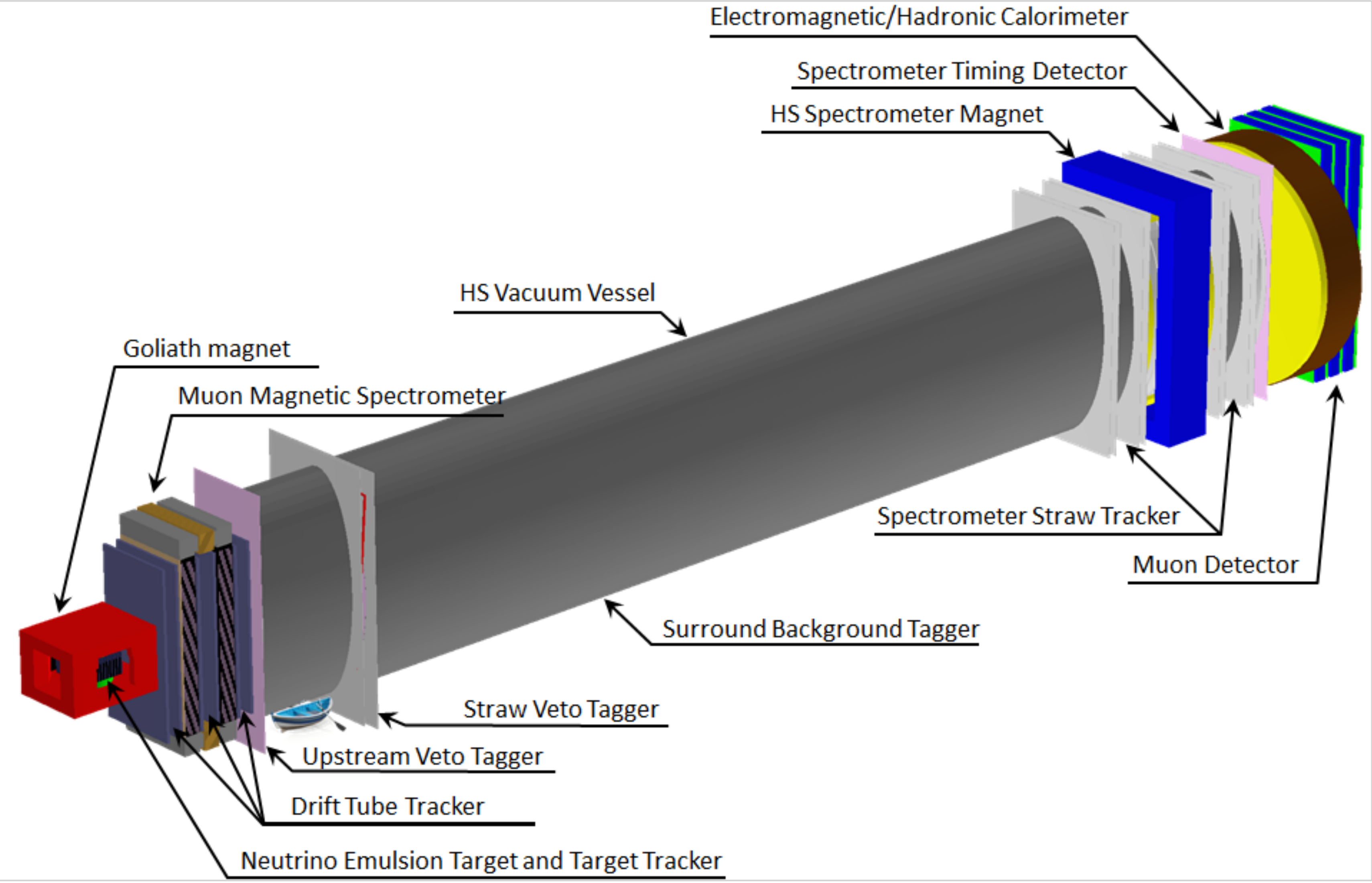
$\sigma_p/p \sim 0.5\% \oplus 0.02\% \times p$

$\sigma E/E \sim 6\%/\sqrt{E}$

$\sigma t \sim 100\text{ps}$

Challenges

- Large vacuum vessel
- 5 m long straw tubes
- High resolution timing detector

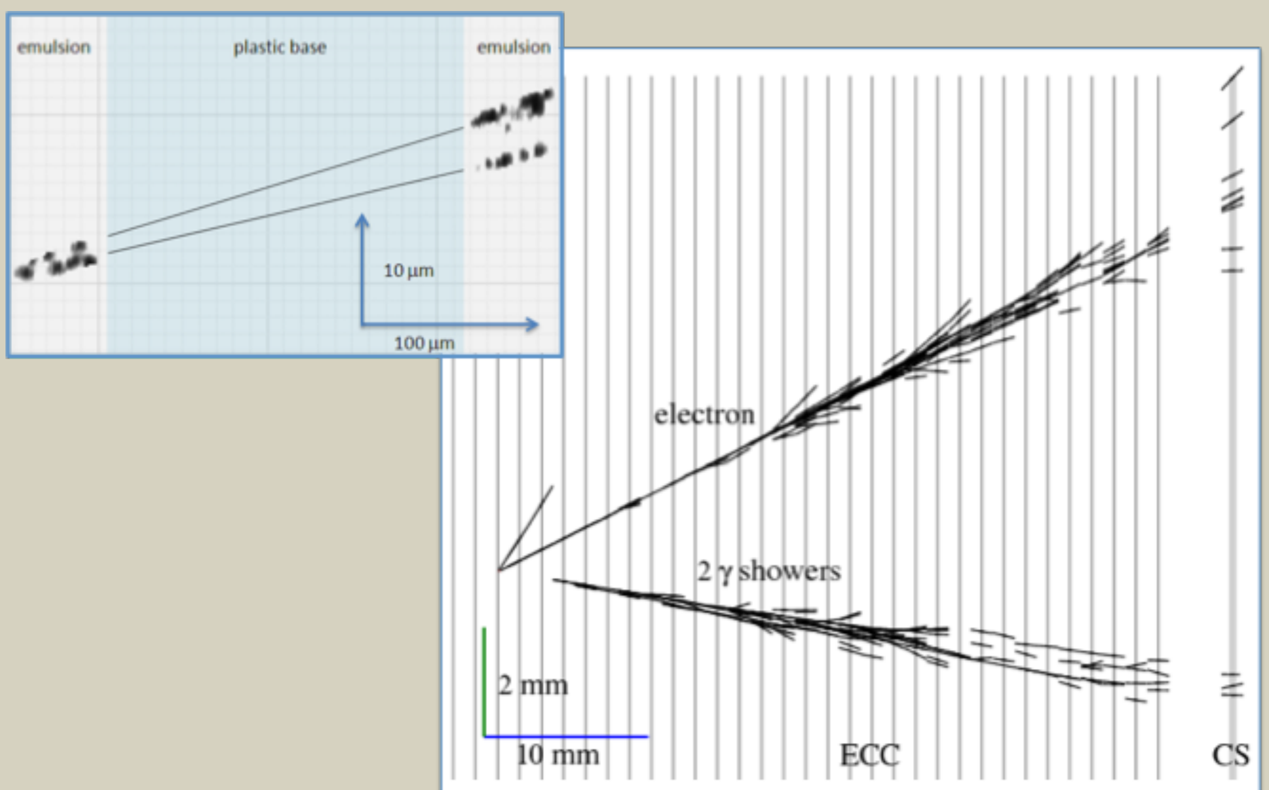


Lepton Flavour Identification

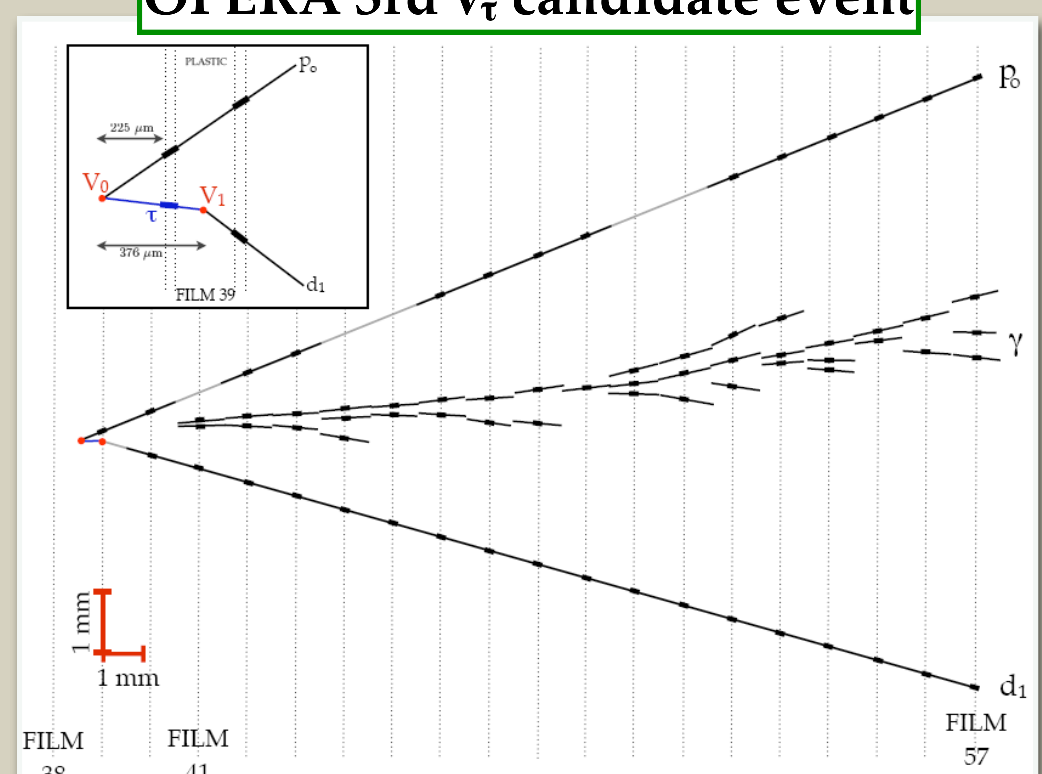
Emulsion Cloud Chamber technique

Lead plates (high density material for the interaction) interleaved with **emulsion films** (tracking devices with **μm resolution**)

- ***ν_μ identification:*** muon reconstruction in the magnetic spectrometer
- ***ν_e identification:*** electron shower identification in the brick
- ***ν_τ identification:*** disentanglement of τ production and decay vertices

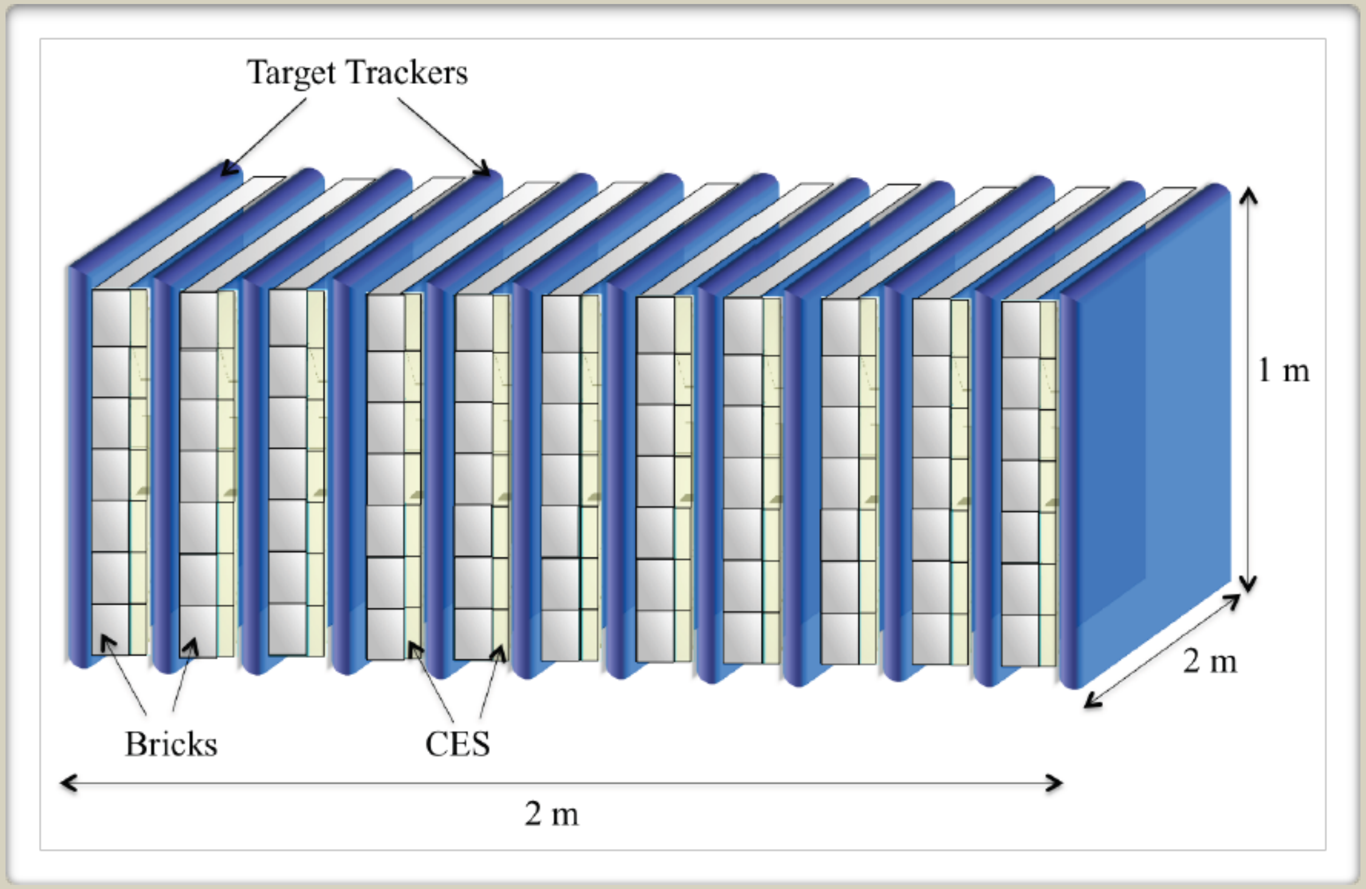


OPERA 3rd ν_τ candidate event



Event Time Stamp

Target tracker (TT)



Features:

- Provide Time stamp
- Link track information in emulsions to signal in TT
- Link muon track information in ν target to μ magnetic spectrometer

Requirements in 1T field:

- 100 μm position resolution on both coordinates
- high efficiency (>99%) for angles up to 1 rad

Possible options:

- Scintillating fibre trackers
- Micro-pattern gas detectors (GEM, Micromegas)

Detector layout:

- 12 target planes interleaving the 11 brick walls at a few mm distance
- Transverse size of about 2 x 1 m^2