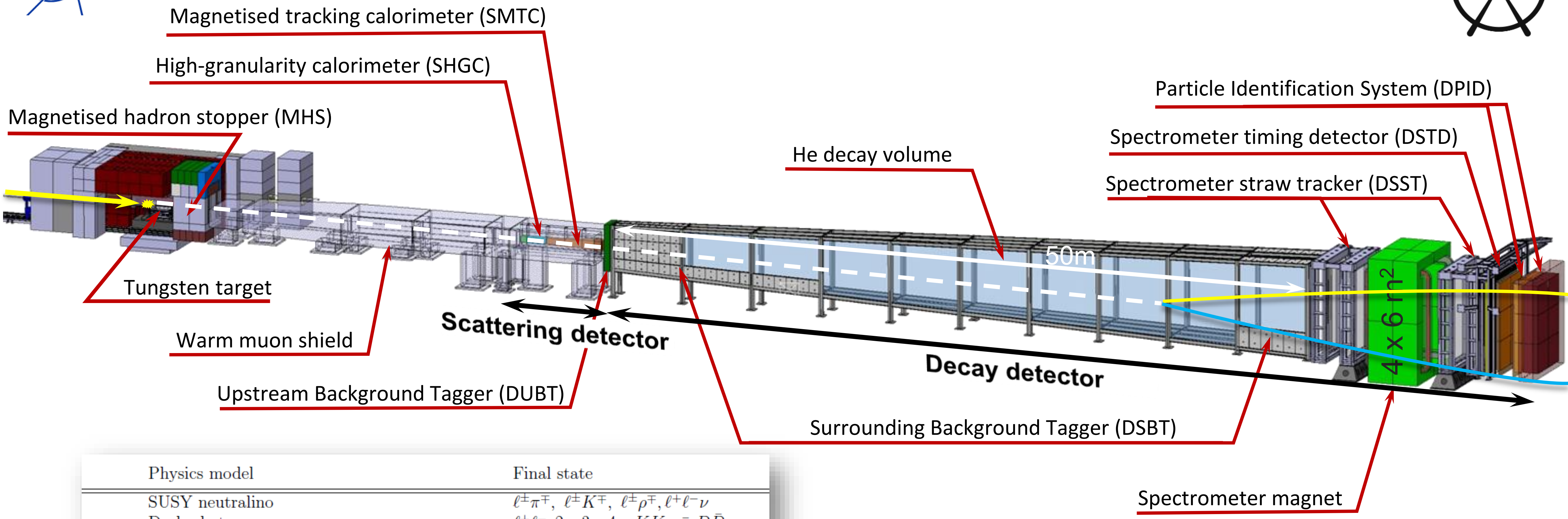
Overview of SHiP detectors

- Decay Detector current status-

Overview of SHiP detector



	Physics model	Final state
HSDS	SUSY neutralino	$\ell^{\pm}\pi^{\mp},\ \ell^{\pm}K^{\mp},\ \ell^{\pm}\rho^{\mp}, \ell^+\ell^-\nu$
	Dark photons	$\ell^+\ell^-, 2\pi, 3\pi, 4\pi, KK, q\bar{q}, D\bar{D}$
	Dark scalars	$\ell\ell, \pi\pi, KK, q\bar{q}, D\bar{D}, GG$
	ALP (fermion coupling)	$\ell^+\ell^-, 3\pi, \eta\pi\pi, q\bar{q}$
	ALP (gluon coupling)	$\pi\pi\gamma, 3\pi, \eta\pi\pi, \gamma\gamma$
	HNL	$\ell^+\ell'^-\nu, \pi l, \rho l, \pi^0\nu, q\bar{q}'l$
	Axino	$\ell^+\ell^-\nu$
	ALP (photon coupling)	$\gamma\gamma$
	SUSY sgoldstino	$\gamma\gamma, \ell^+\ell^-, 2\pi, 2K$
SND	LDM	electron, proton, hadronic shower
	ν_τ, $\overline{\nu}_\tau$ measurements	$\tau^{\pm}$
	Neutrino-induced charm production (ν_e, ν_μ, ν_τ)	$D_s^{\pm},\ D^{\pm},\ D^0,\ \overline{D^0},\ \Lambda_c^+,\ \overline{\Lambda_c}^-$

Challenge is background suppression

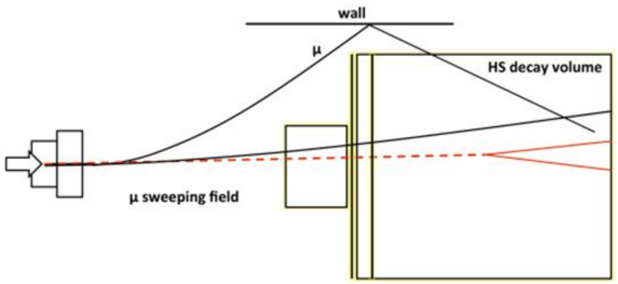
Background challenge for decay search

[See Anne-Marie's slides](#)

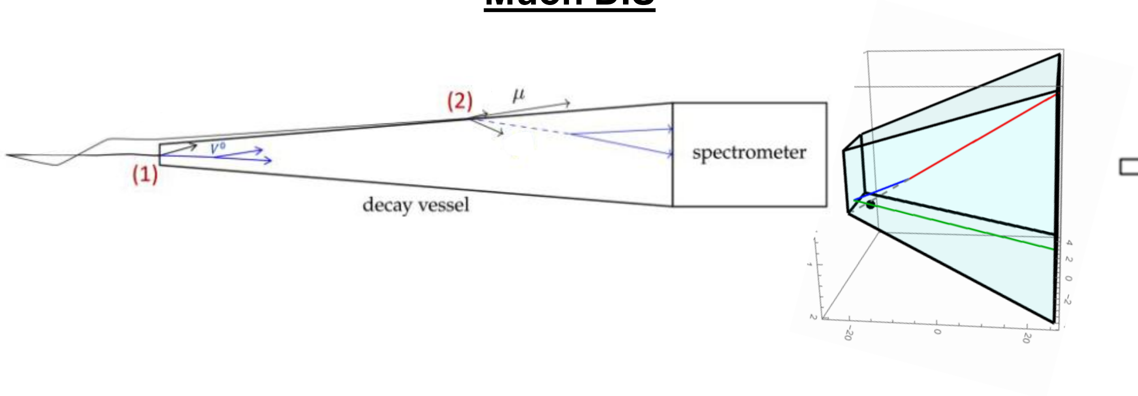
- ➔ Per spill of $4x10^{13}$ protons
  - 1.5×10^{12} neutrinos and anti-neutrinos through SHiP's fiducial volume
  - $\mathcal{O}(10^{11})$ muons above 1 GeV/c (spectrum validated in measurement at SPS with prototype target - agreement within 30%)

- ➔ Residual flux of muons and neutrinos lead to three categories of physics background:

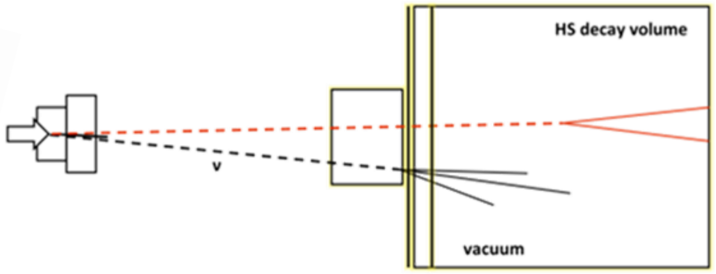
Muon combinatorial



Muon DIS

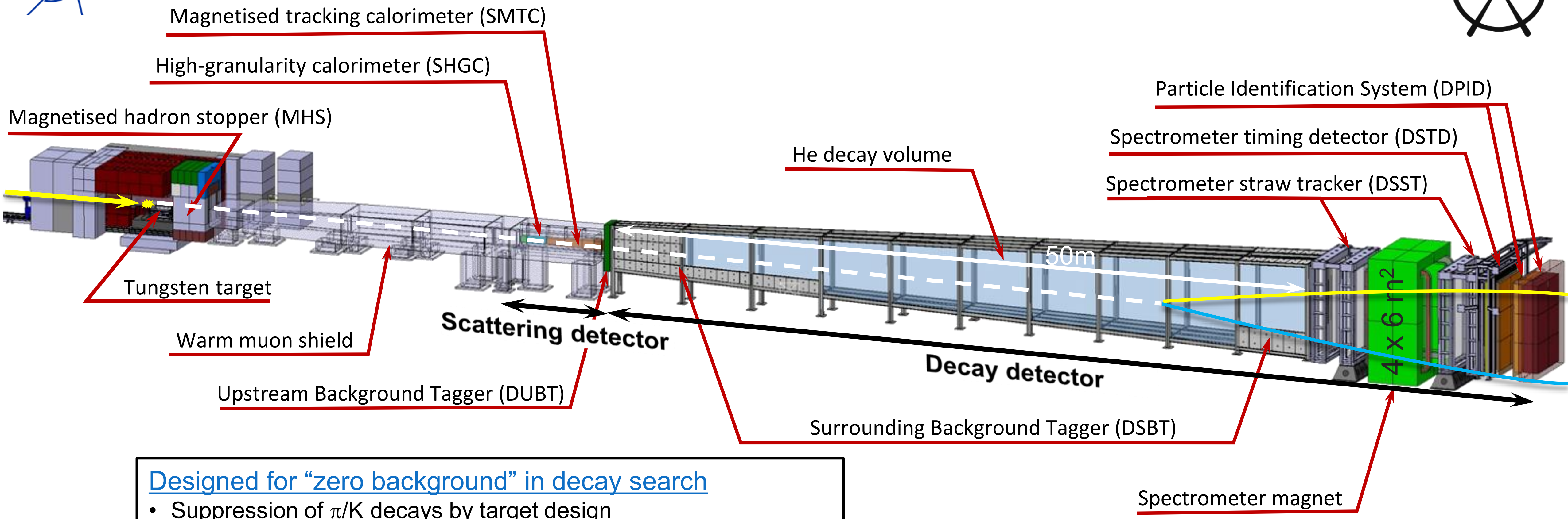


Neutrino DIS



- ⊙ Very simple and common selection for both fully and partially reconstructed modes – model independence
- ⊙ Redundant selection- Possibility to measure background with data by relaxing suppression techniques

Overview of SHiP detector



Designed for "zero background" in decay search

- Suppression of π/K decays by target design
- Suppression of muons by magnetic shield
- Suppression of neutrino by decay volume by evacuating air
- Background taggers
- Momentum and decay vertex information } by main tracker
- Impact parameter at target } by main tracker
- Coincidence timing
- Invariant mass } Not currently used in background suppression
- Particle identification } Not currently used in background suppression

Radiation to material/electronics

Radiation-to-electronics safe area:

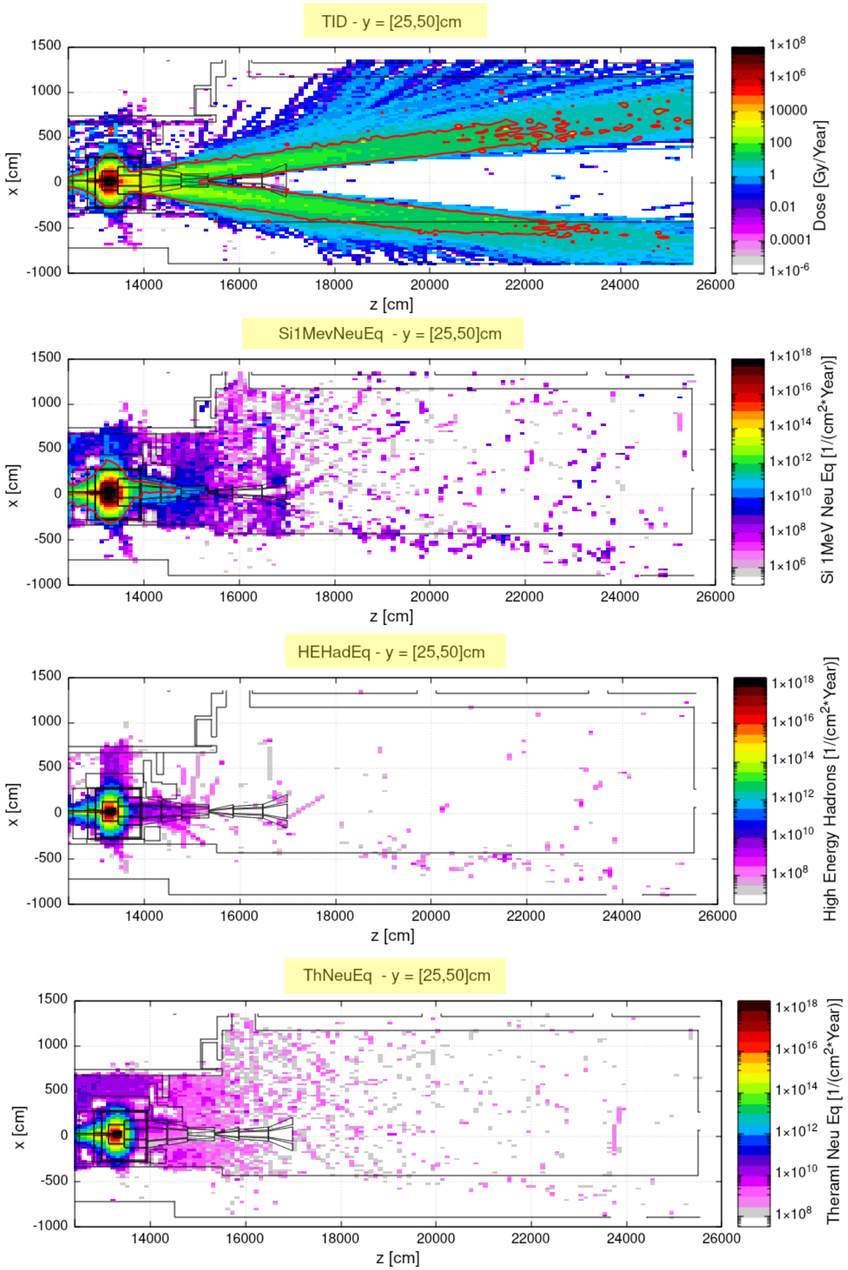
- Cumulative radiation effect at dose levels
    - <10 Gy/year
    - <1x10[11] Si 1MeV Neutron Eq/cm[2]/year

- Limits of radiation(SEU)-safe area for electronic systems:
    - <3x10[6] High Energy Hadron Eq/cm[2]/year
    - <3x10[7] Thermal Neutron Eq/cm[2]/year

Assumptions of 4×10^{19} p.o.t./year

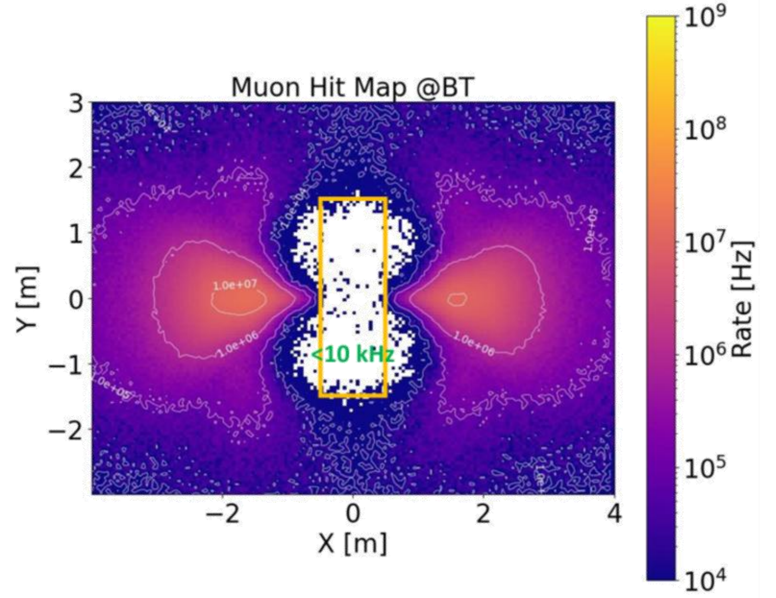
➔ Experiment location is safe

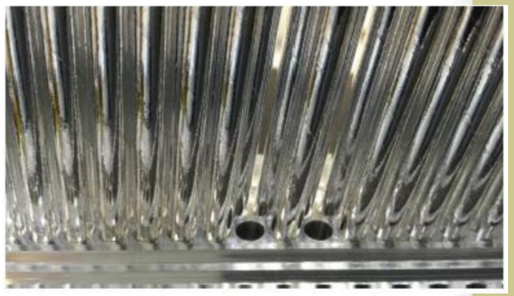
Top views

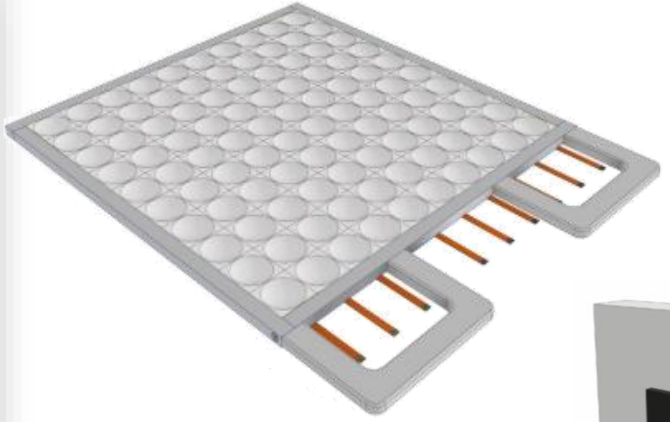


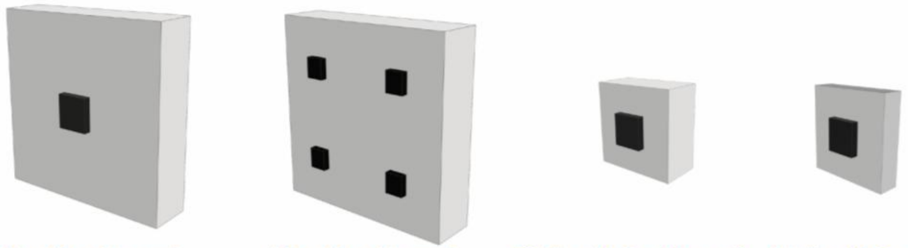
Upstream background tagger

- Tag residual muons entering decay volume and muon/neutrino inelastic scattering in end of muon shield
  - Upstream decay volume window including SBT : 1.3m x 3.1m
  - Detection efficiency >99%, pace resolution ~100 μm, time resolution <200ps
  - Particle rates up to 10 MHz per 5x5 cm2 tile in high-activity regions
  - Combination of scintillating tiles and straw (mylar) tubes



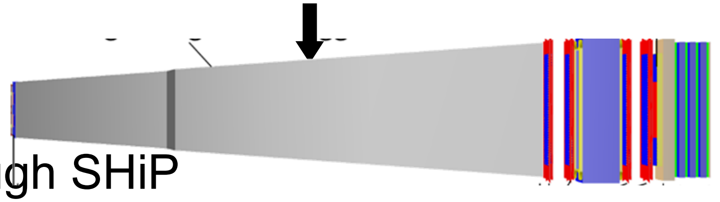






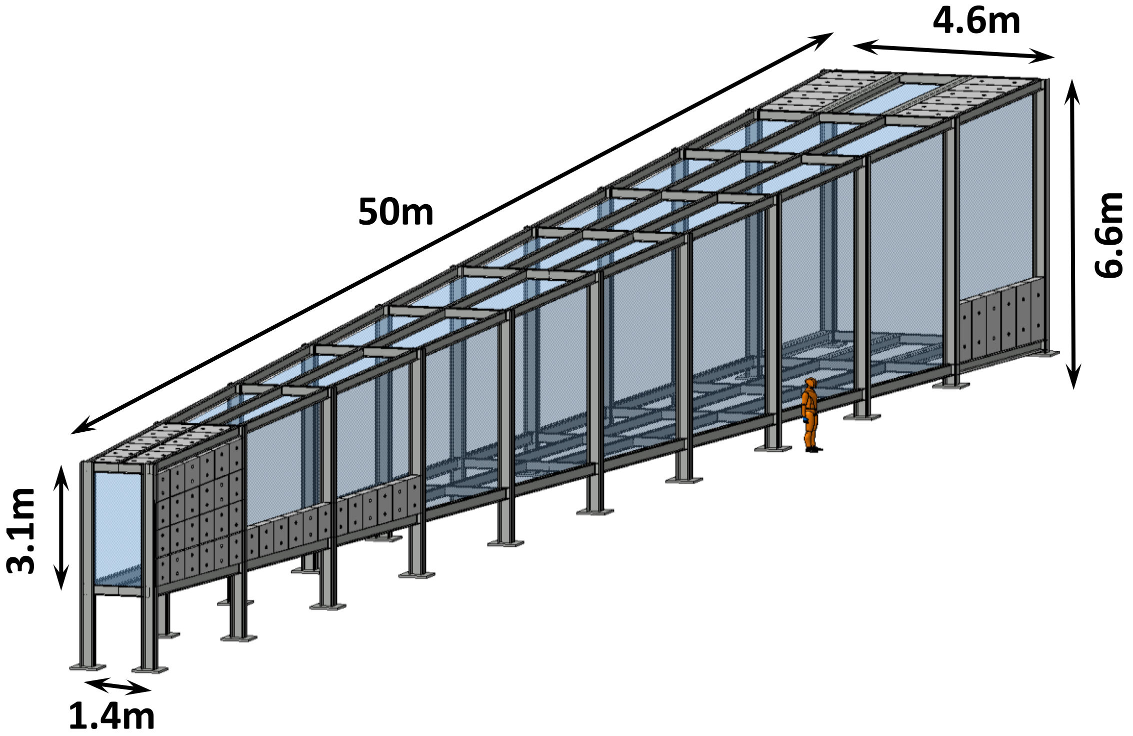
40 x 40 x 10 mm³ 6x6 mm² SiPM | 40 x 40 x 10 mm³ Four 3x3 mm² SiPM | 20.8 x 20.8 x 10 mm³ 6x6 mm² SiPM | 20.8 x 20.8 x 5 mm³ 6x6 mm² SiPM

Decay volume



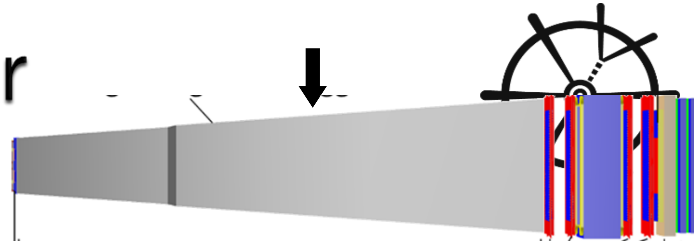
Per spill of 4x10[13] protons: 1.5 ×10[12] neutrinos and antineutrinos through SHiP

1. Suppress to <10 interactions in decay volume by evacuating the air
2. Suppress interactions in decay volume structure by surrounding scintillator veto system



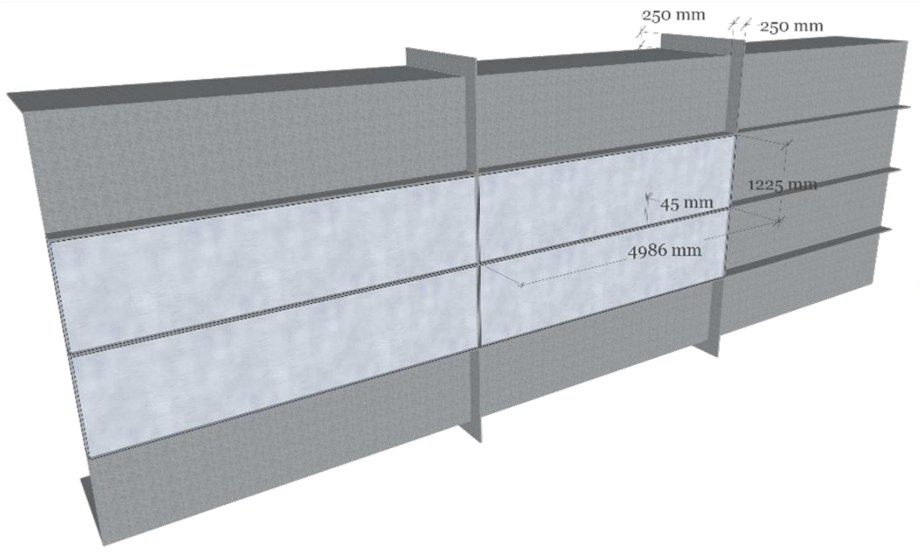
- Helium at 1atm will probably be sufficient instead of vacuum at 1mbar
  - Steel vacuum vessel replaced by soft liner ("balloon") held in place by a frame structure of aluminium
  - Submillimetre thickness of liner, total area of ~685m^2 and total volume 550m^3
  - Need for large-volume helium circulation and purification system (~99%)

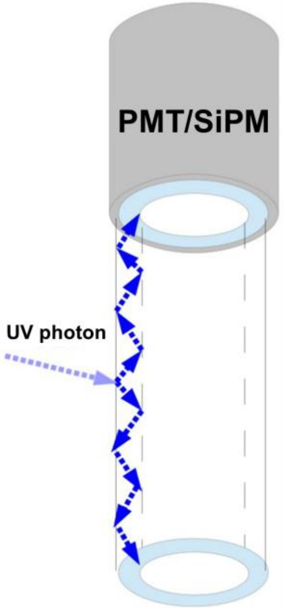
Surrounding Background Tagger

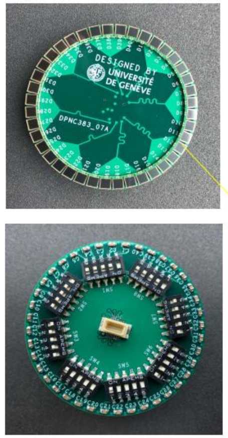


- Purpose: Tagging charged particles entering decay volume and tagging ν and μ interactions in the vacuum chamber walls
  ➔ >99% efficiency and ~1ns time resolution

- Characteristics
  - Liquid scintillator based: linear alkylbenzene (LAB) together with 2.0 g/l diphenyl-oxazole (PPO) as the fluorescent
  - WOMs with SiPM readout Hamamatsu S14160-3050PE (40x 3x3mm²) and surrounded by PMMA vessel
  - Thickness 20cm
  - Total quantity 125 m^3

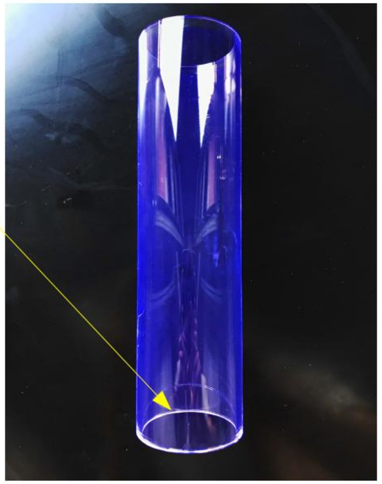


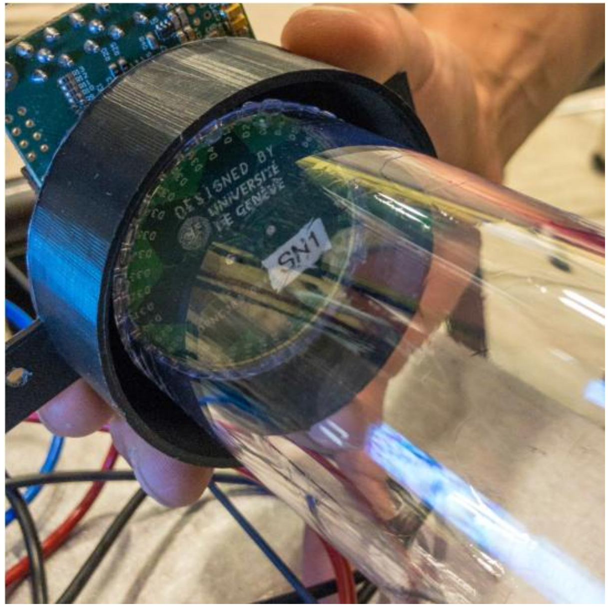




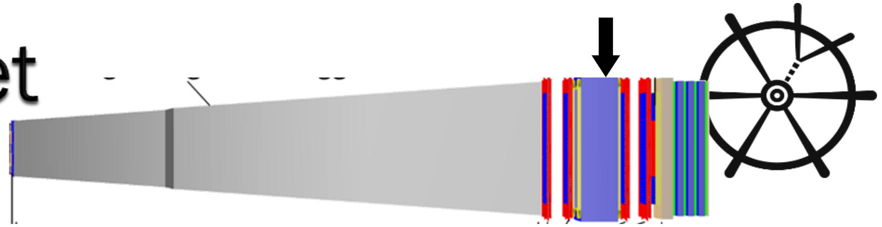
40-SiPMs array built by Geneva

WOM w/o lightguide



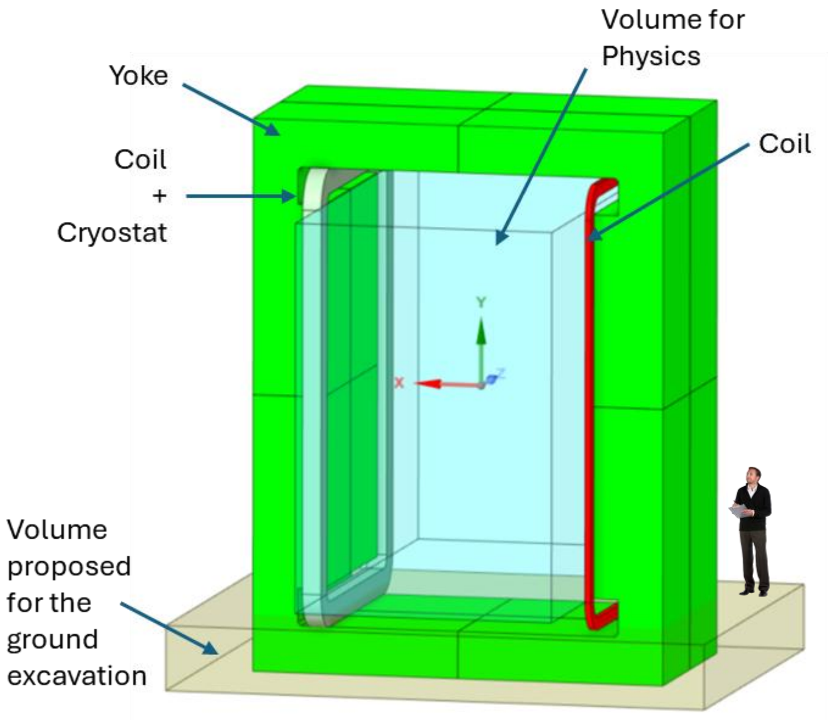


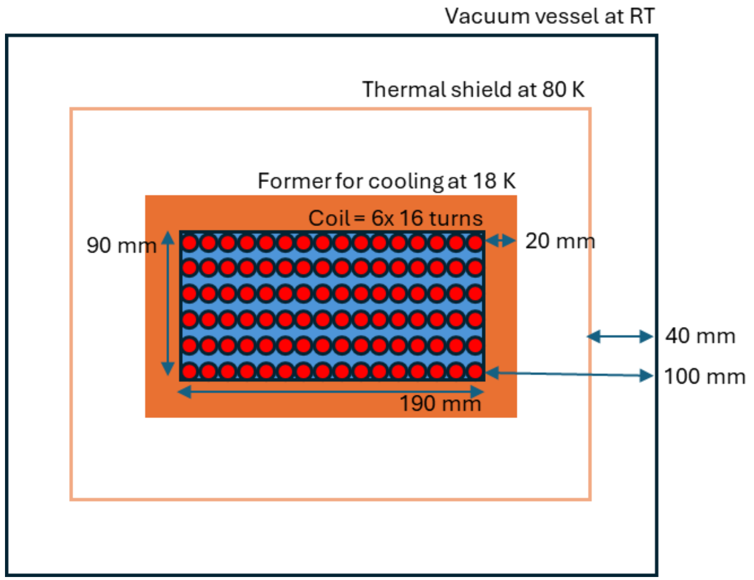
Spectrometer magnet

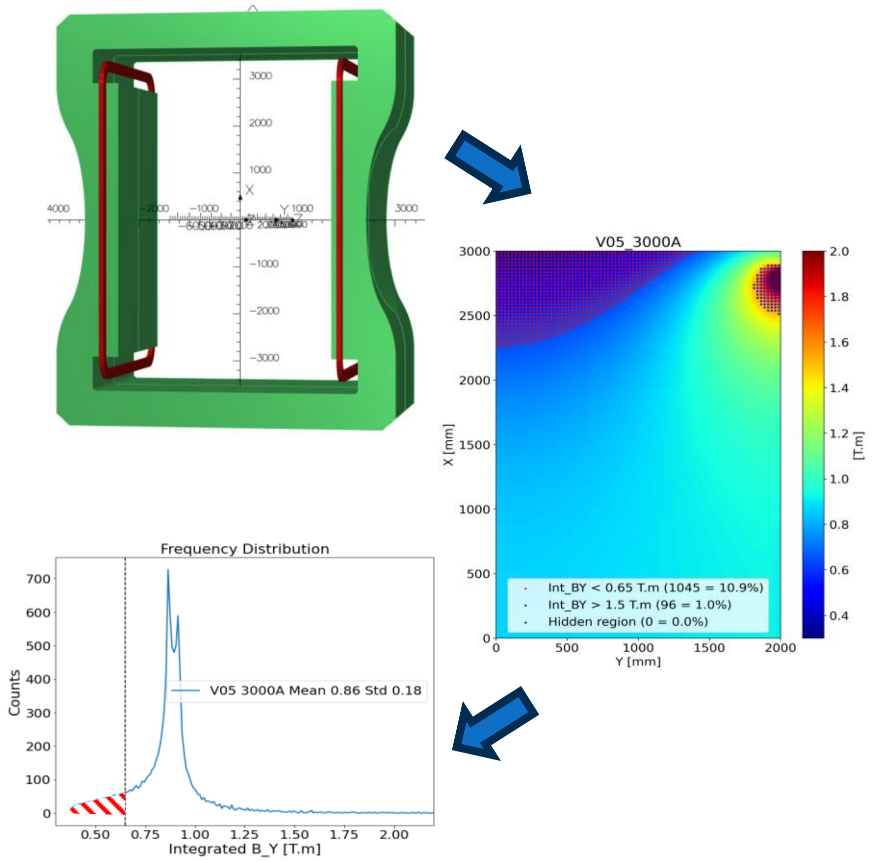


- Spectrometer requirements:
  - Physics aperture 4 x 6 m^2
  - Bending field ~0.7 Tm , nominal on axis ~0.15T

- New-technology proposal from TE-MSC / SHiP
  - Design with MgB_2 sub-cables from HL-LHC WP6a, operate with gaseous helium at 20K with cryocoolers (HFM WP 4.6) ➔ ~1/20 power reduction expected

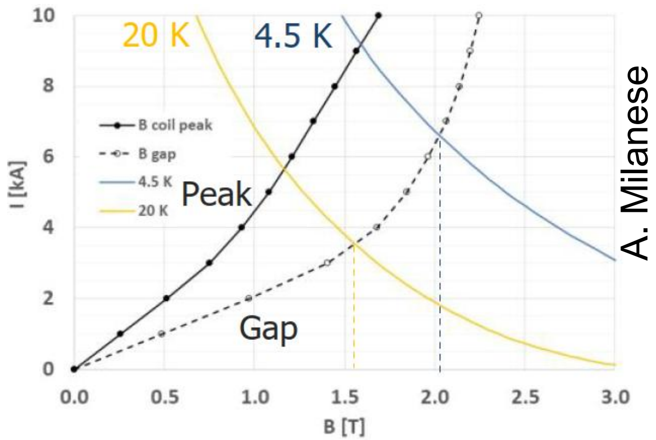






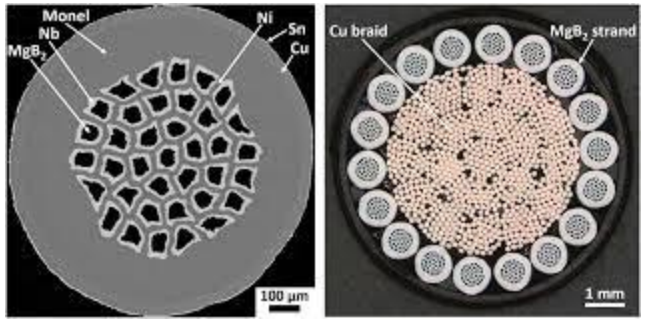
"Energy-Efficient Superferric Dipole"

- Under investigation with demonstrator
  - ✓ Prototype phase 1 (LHe@4.5K) and 2(Ghe@20-30K) : thermal cycling, no training, no performance change after quench test
  - ➔ Phase 3 (preparation ongoing): Test with warm yoke and coil at 20 K integrated in dedicated cryostat with indirect cooling
  - ➔ Next steps: optimisation of cooling configuration and current leads, and study of final coil configuration and support

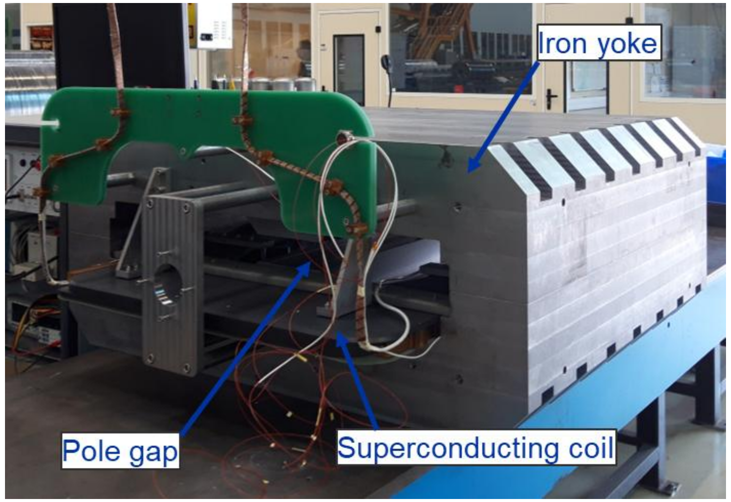


Prototype for phase 3 (2025)

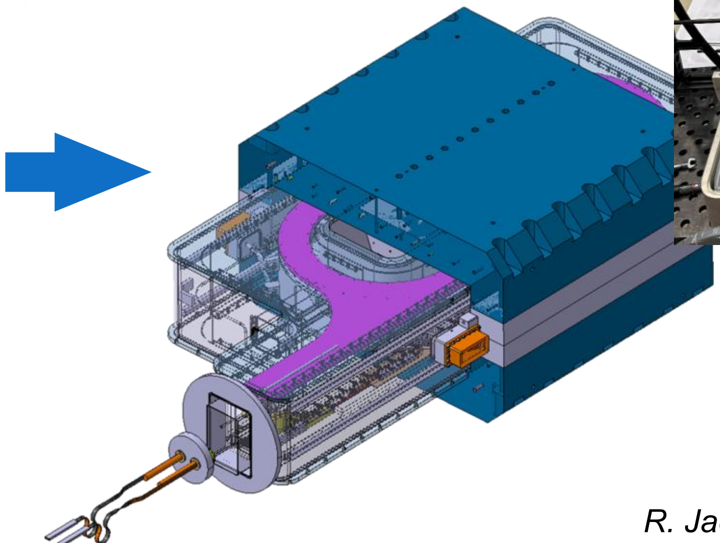
HL-LHC superconducting link sub-cable

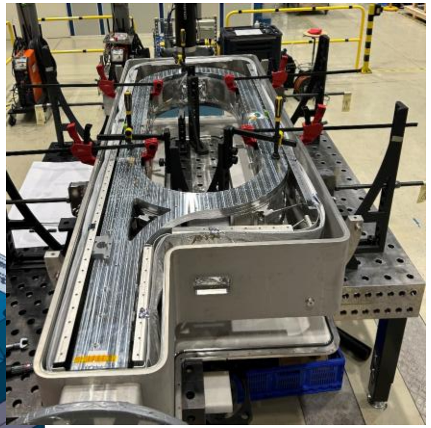


Prototype for phase 1 and 2 (2023-24)

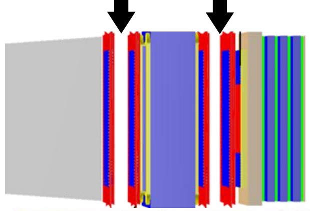


To optimize cryostat design and transfer of Lorentz loads, electromagnetic design of prototype includes two racetrack-type coils



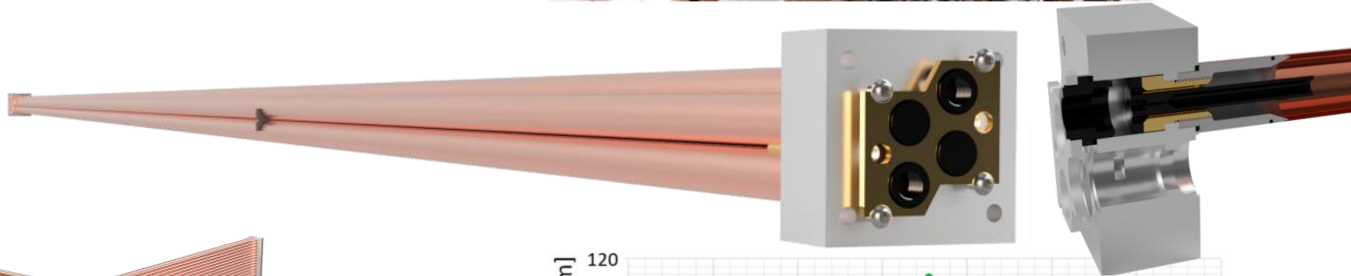


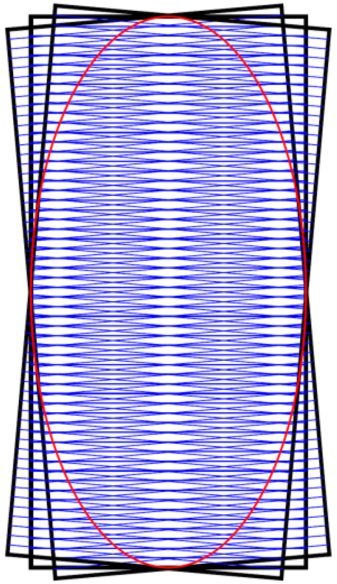
Straw Tracker

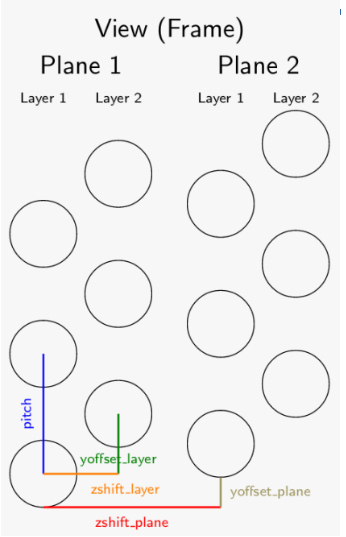


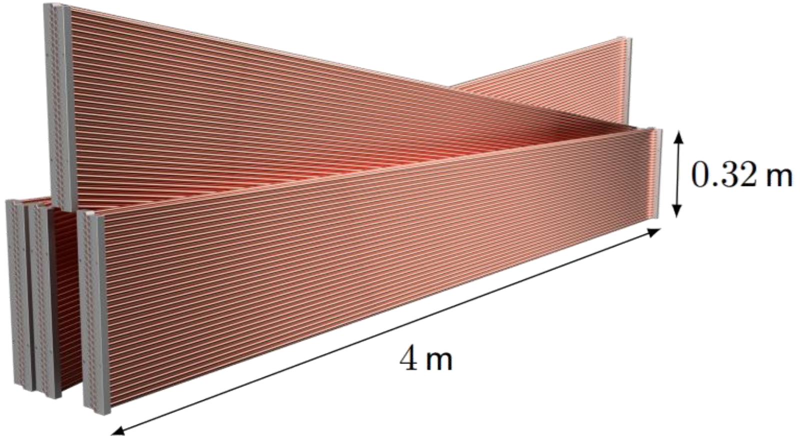
- Purpose: Track reconstruction and momentum, reconstruction of origin of neutral particle candidate. Match hits in timing detector

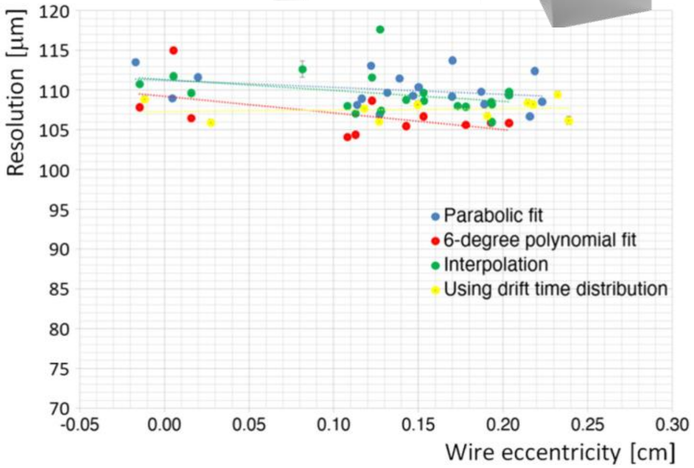
- Technology developed for the NA62 experiment
  - ➔ Horizontal orientation of tubes ➔ mechanical challenge
  - ➔ Lower rate allows increasing straw diameter (highest rate ~O(10) kHz)
- Characteristics
  - 4 x 6 m^2 sensitive area
  - 4m long 20mm diameter 36μm thick PET film coated with 50nm Cu and 20nm Au operated at 1 bar, produced and tested
  - Four stations, each with four views Y-U-V-Y, ~9600 straws





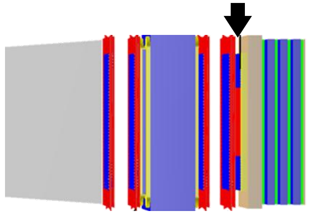


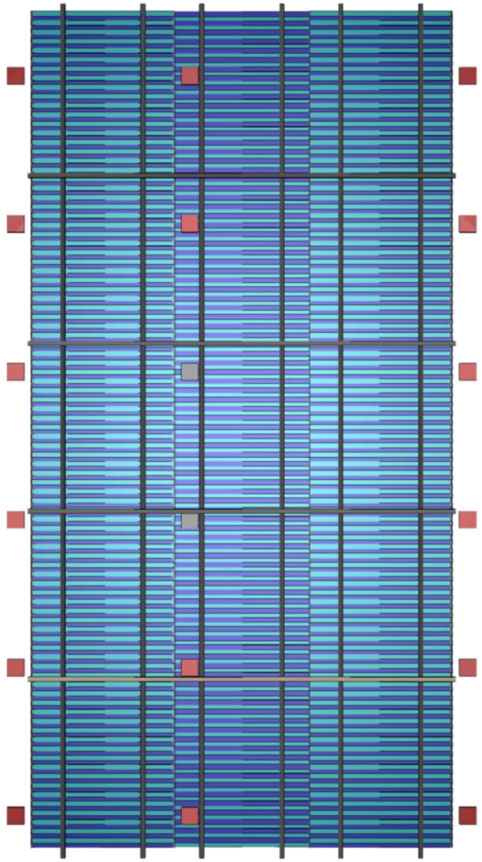




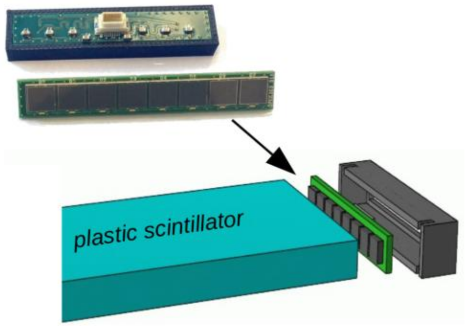
Test beams confirm 120μm hit resolution with hit efficiency >99%

Timing Detector

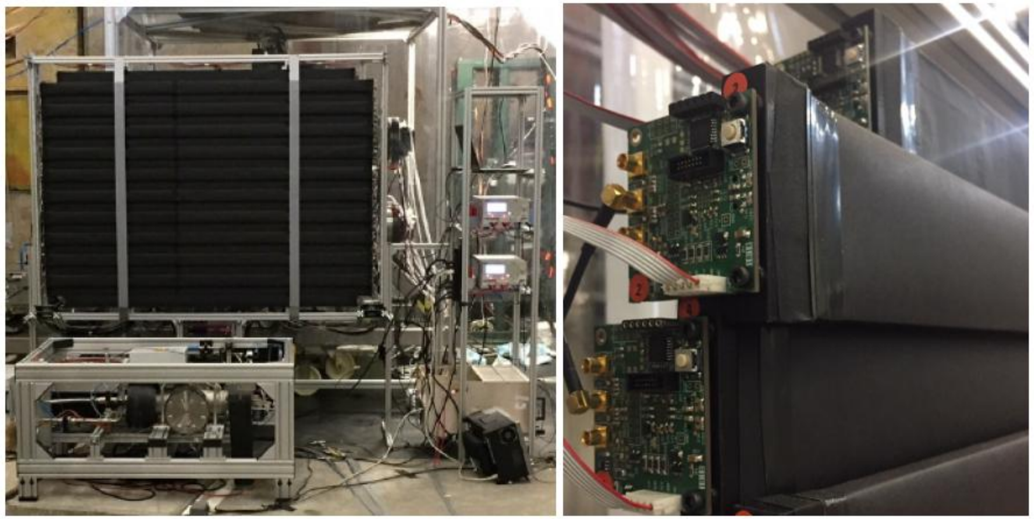


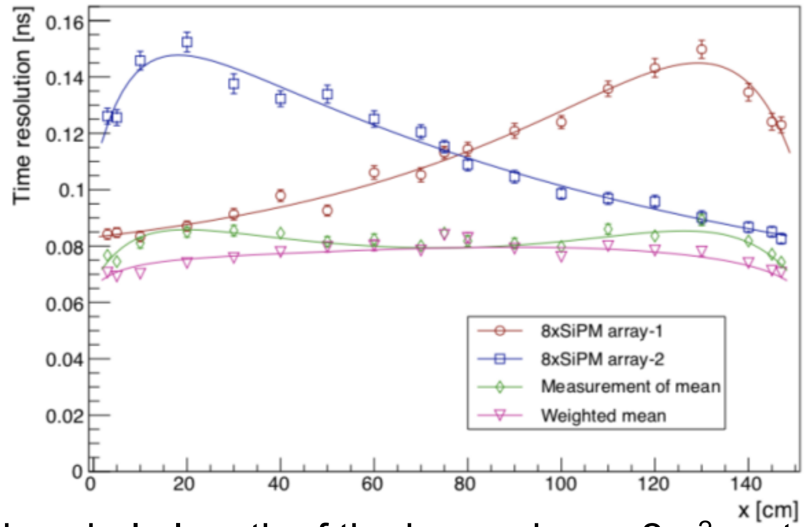


- Purpose: Provide precise timing (<100 ps) of each track to reject combinatorial background
- Plastic scintillator characteristics
  - Three-column setup with EJ200 plastic bars of 135cm × 6cm × 1cm, providing 0.5cm overlap
  - Readout on both ends by array of eight 6×6 mm^2 SiPMs, 8 signals are summed
  - 330 bars and 660 channels
  - ➔ Timing alignment



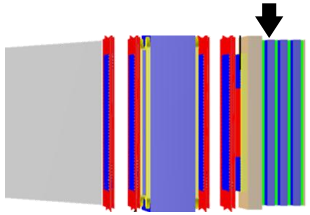
22x 168cm bar (44 channels) prototype tested at PS



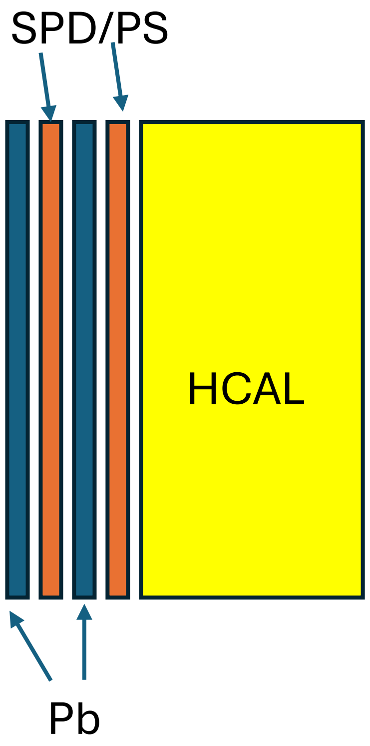


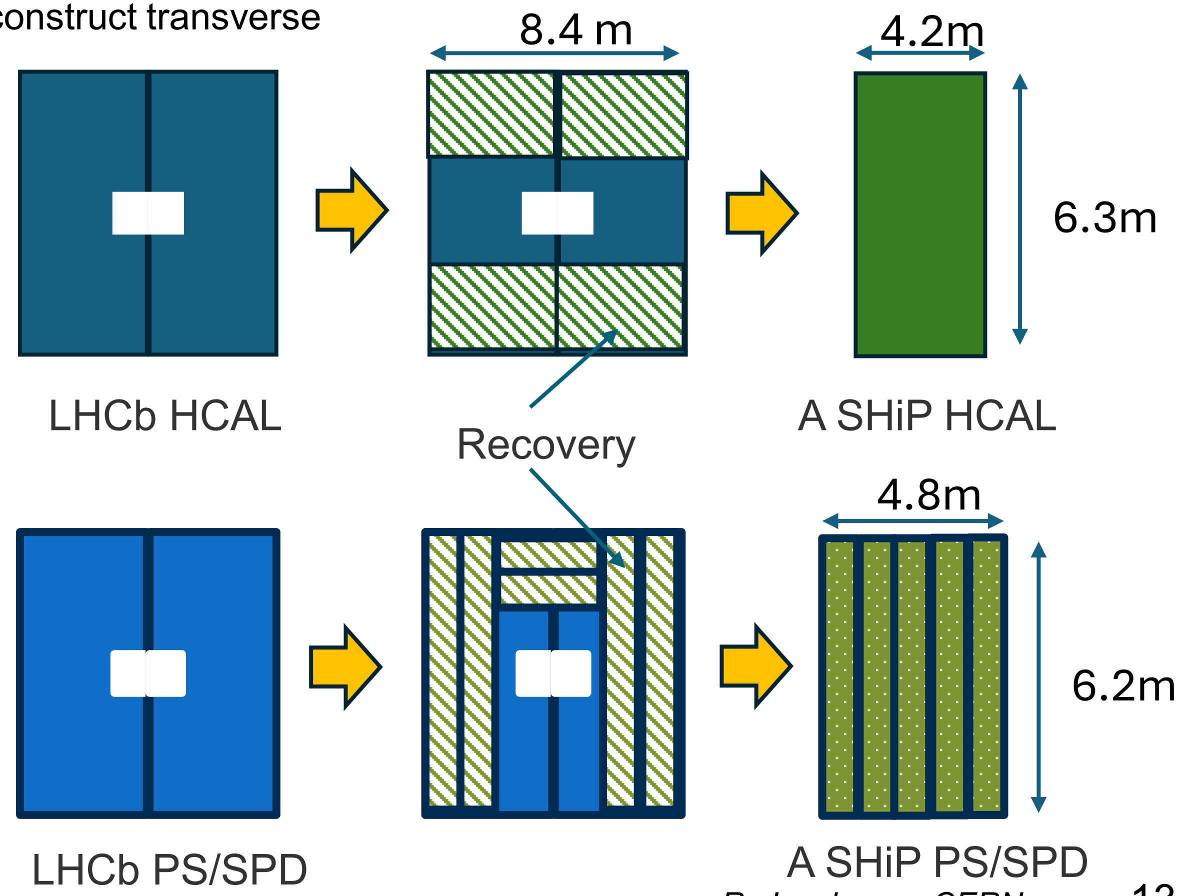
Resolution demonstrated to be ~80 ps along the whole length of the bar and over 2m^2 prototype

Particle Identification System

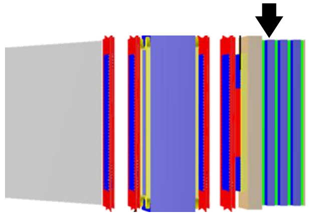


- Purpose: e / γ / π / μ identification, π^0 reconstruction, photon directionality for ALP→ $\gamma\gamma$ with ~5mrad (coincidence timing)
- Characteristics
  - Initial configuration of SHiP with recuperation & refurbishment of LHCb SPD/PS/HCAL – need new mechanics and electronics
  - HCAL is CERN property. Clermont-Ferrand owns PS, SPD by Barcelona.
  - Future High-Precision Layers: two - three layers at different depth to reconstruct transverse shower barycentre,

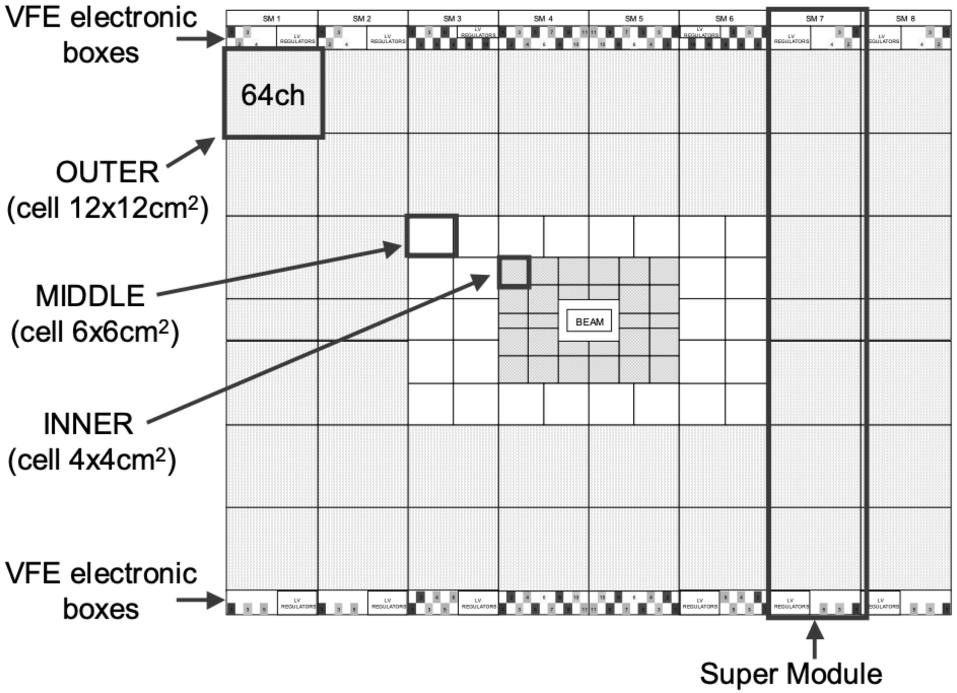




Particle Identification System

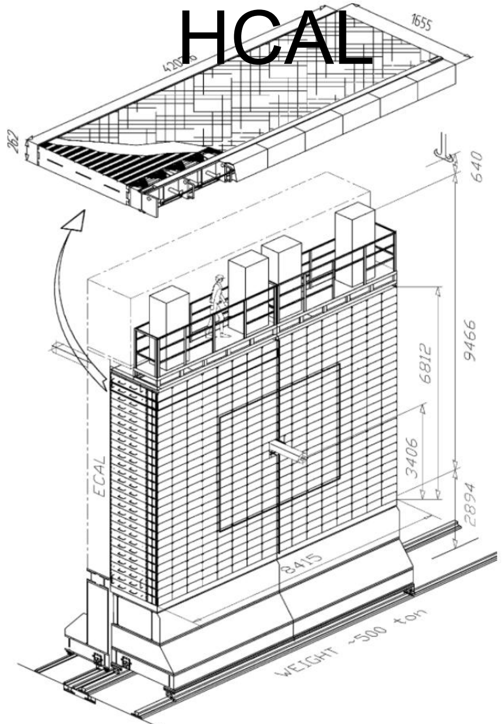


SPD/PS



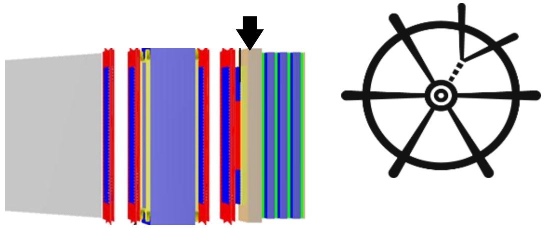
- Sensitive area about 7.6 m wide x 6.2 m high, with 11,904 pad channels ➔ Use 12x12cm2 pads resulting in 4160 channels
- SPD and PS are separated by a 12 mm lead converter ($2.5X_0$); PS / SPD cell sizes are projective to the LHCb ECAL towers.
- Scintillator pads. The active readout uses WLS fibres, clear fibres, compact 64-channel MaPMTs
- Needs entirely new mechanics

HCAL



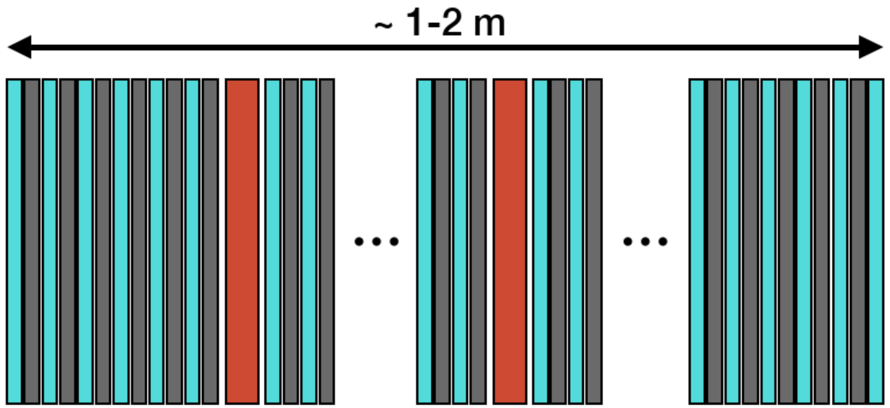
- $8.4 \times 6.8\text{m}^2$ and instrumented depth 1.22m ($5.6\ \lambda_I$)
- WLS fibres along tile edges and PMT readout, Readout subdivided into two zones, inner and outer, with square cells of size $13\times 13\ \text{cm}^2$ in the inner zone and $26 \times 26\ \text{cm}^2$ in the outer zone
- Two symmetric halves, each built from 26 stacked horizontal modules with 1488 readout cells total.
- One module weights about 9.5 t

PID system High-Precision Layers

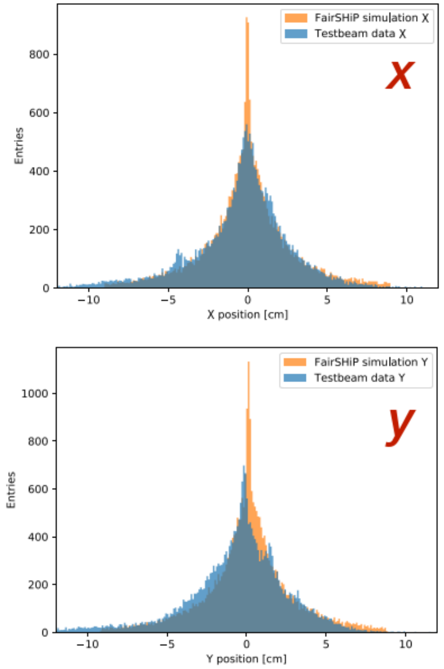


- HPL with resolution of ~200μm (μRWELL, GEM, RPC or SciFi detectors) to provide photon angular resolution.

➔ 3 mrad for 20 GeV, 5 mrad for 10 GeV and 9 mrad for 6 GeV photor



2.1 X_0



Electronics, online, computing

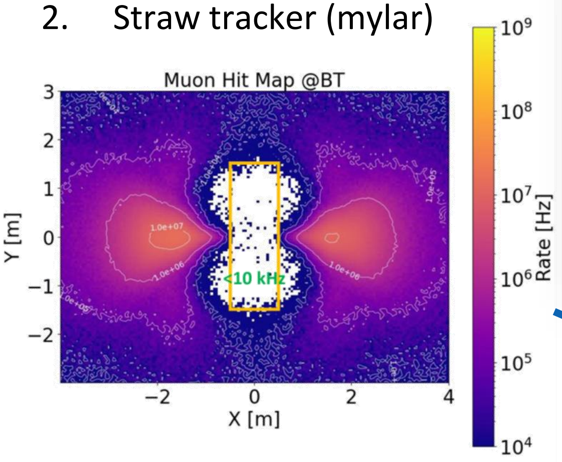
➔ See talks by Jihane, Dominique, Federico, Enrico, Oliver

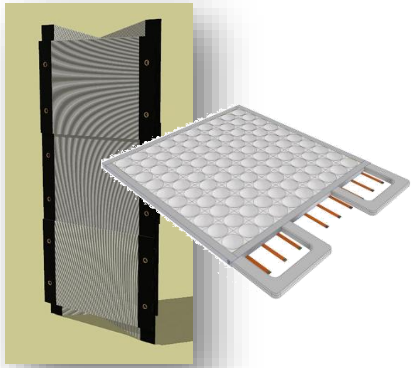
Summary detector technologies

Upstream Background Tagger (eff >99%)

- σ_{space} ~100 μm, σ_{time} ~200 ps

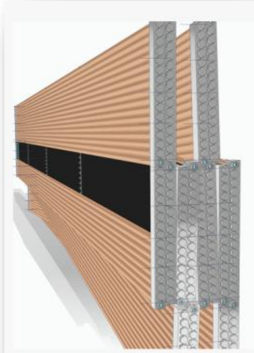
1. Scintillating tiles + SiPM
2. Straw tracker (mylar)





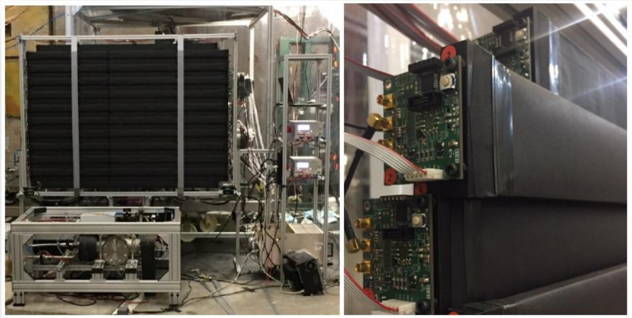
Spectrometer Straw Tracker

- σ_{space} ~120 μm
- Mylar straws



Spectrometer Timing Detector

- <100 ps
- Scintillating bars + SiPM

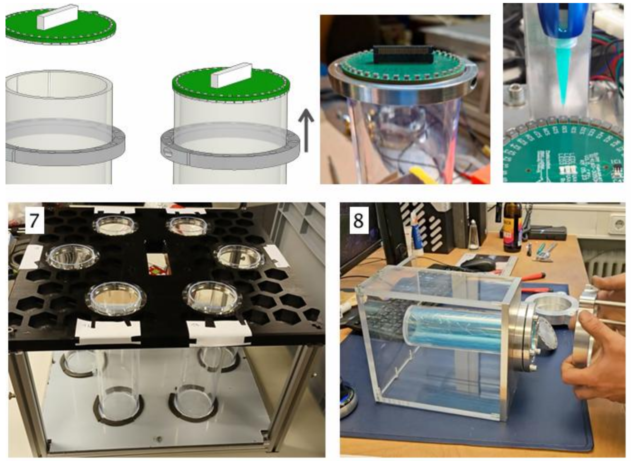


Decay volume

- He balloon

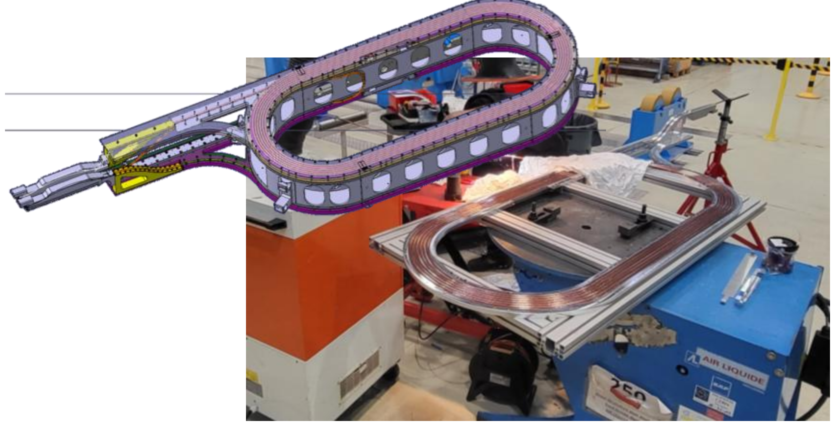
Surrounding Background Tagger

- σ_{space} ~$\mathcal{O}$(cm), σ_{time} < ns ps
- Liquid scintillator + WLS optical modules



Spectrometer magnet

- 4m x 6m, 0.7 Tm
- Super-ferric technology (MgB_2@20-30K)



PID system

- LHCb PS/SPD, HCAL
- PID + shower axis <5mrad
- High-precision layer with GEMs, RPCs, or SciFi