Forw***A***rd ***S***earch ***E***xpe***R***iment at the LHC

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On behalf of the FASER Collaboration

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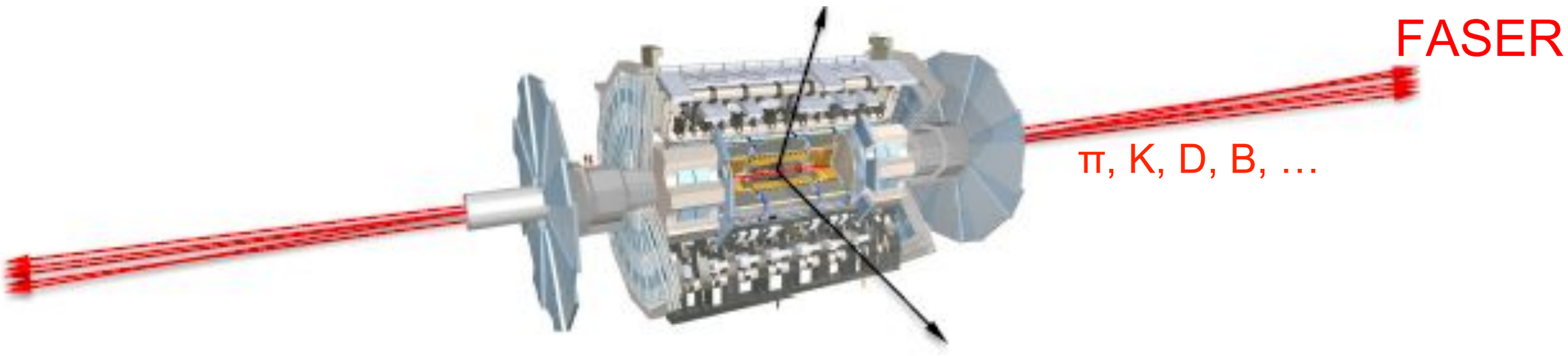
4th LLP@LHC, Amsterdam
https://twiki.cern.ch/twiki/bin/view/FASER/
Letter of Intent: LHC-I-032

Motivation

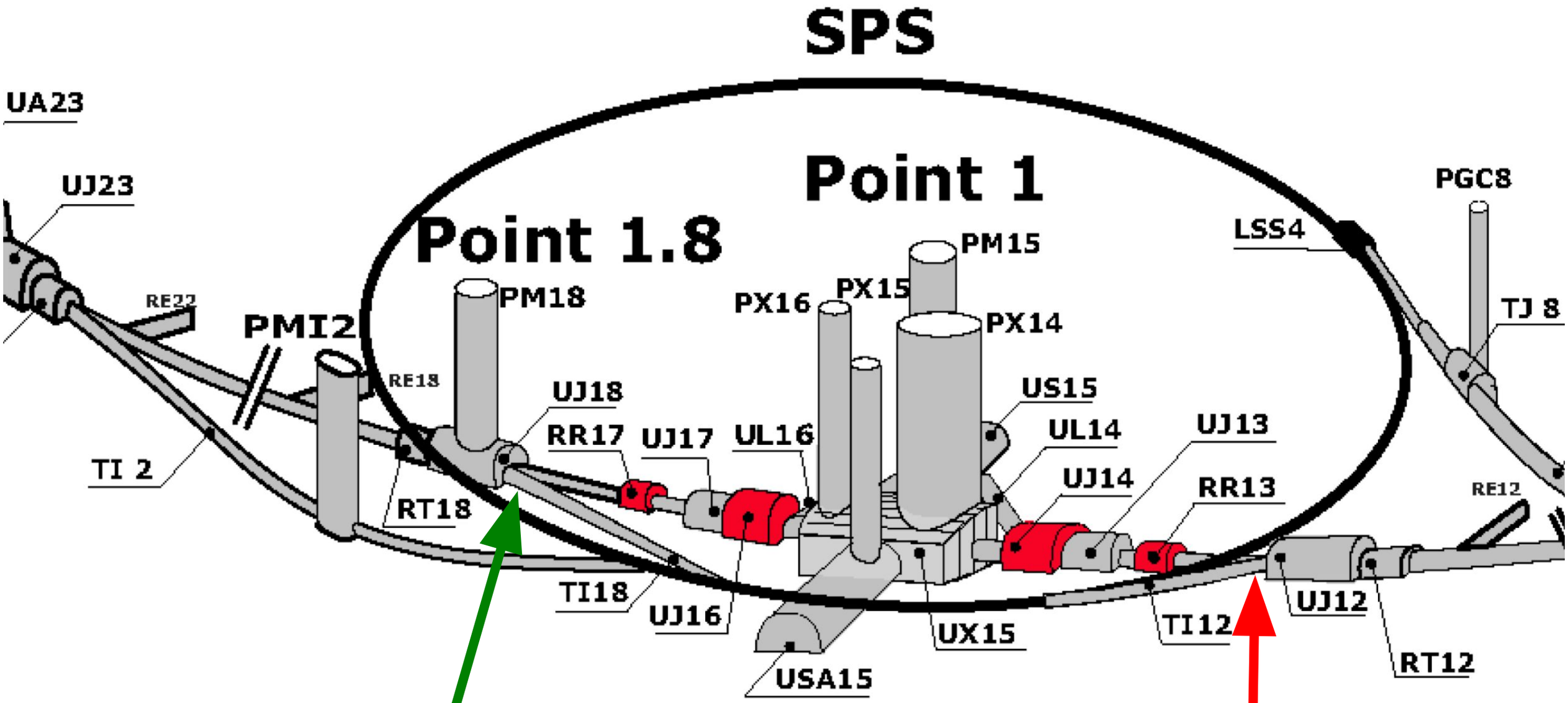
- New physics searches at the LHC have traditionally focused on high pT. This is appropriate for heavy, strongly-interacting particles
  - σ ~ fb to pb $\rightarrow$ N_π ~ 10^3 – 10^6 in 3 ab^{-1} produced ~isotropically

- However, if new particles are light and weakly interacting, this may be completely misguided. Instead should exploit
  - σ_{inel} ~ 100 mb $\rightarrow$ N_π ~ 10^{17}, $\theta_{beam\ axis}$ ~ m_π / TeV ~ 0.1 mrad

- These light, weakly-interacting particles are long-lived and collimated. This motivates a small (~0.1 m^3) and inexpensive (~1.5M CHF) experiment placed in the very forward region of ATLAS (480 m downstream).



FASER location



FASER (LoI)

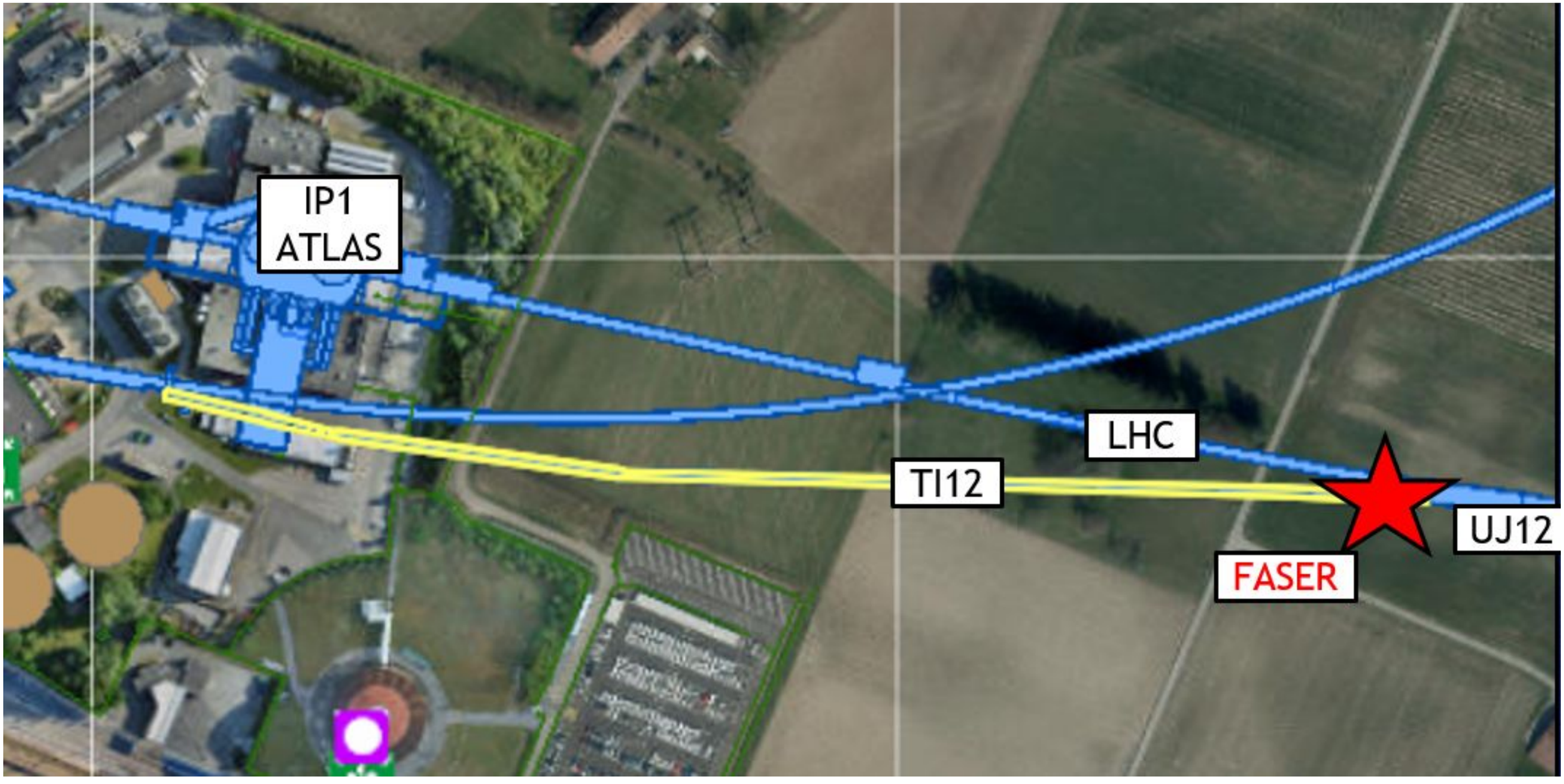
50 cm digging down with limitation of a 3.5 m long detector

ATLAS

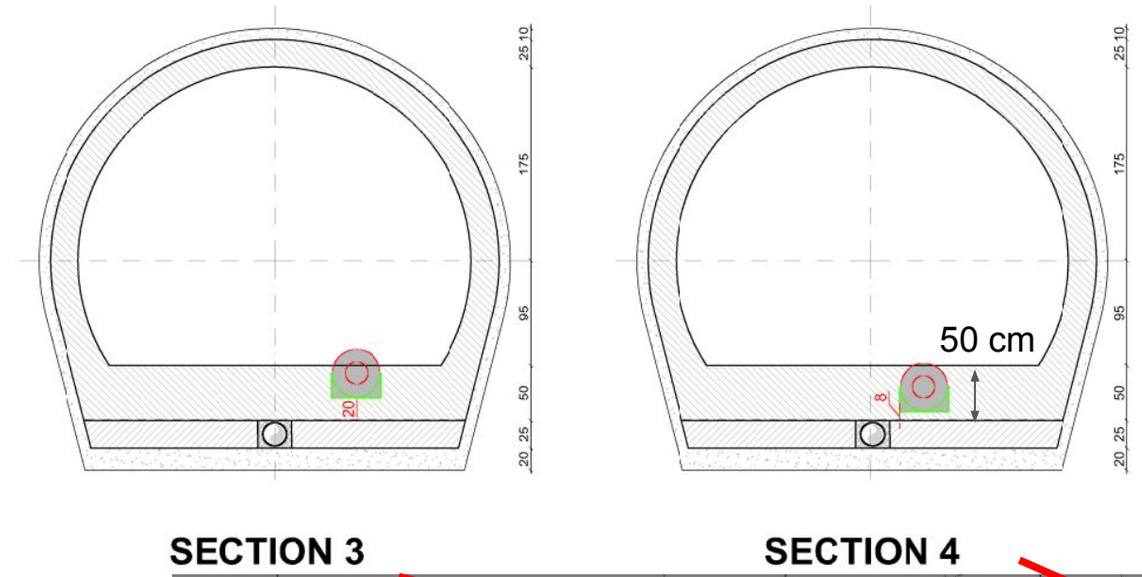
FASER (TP)

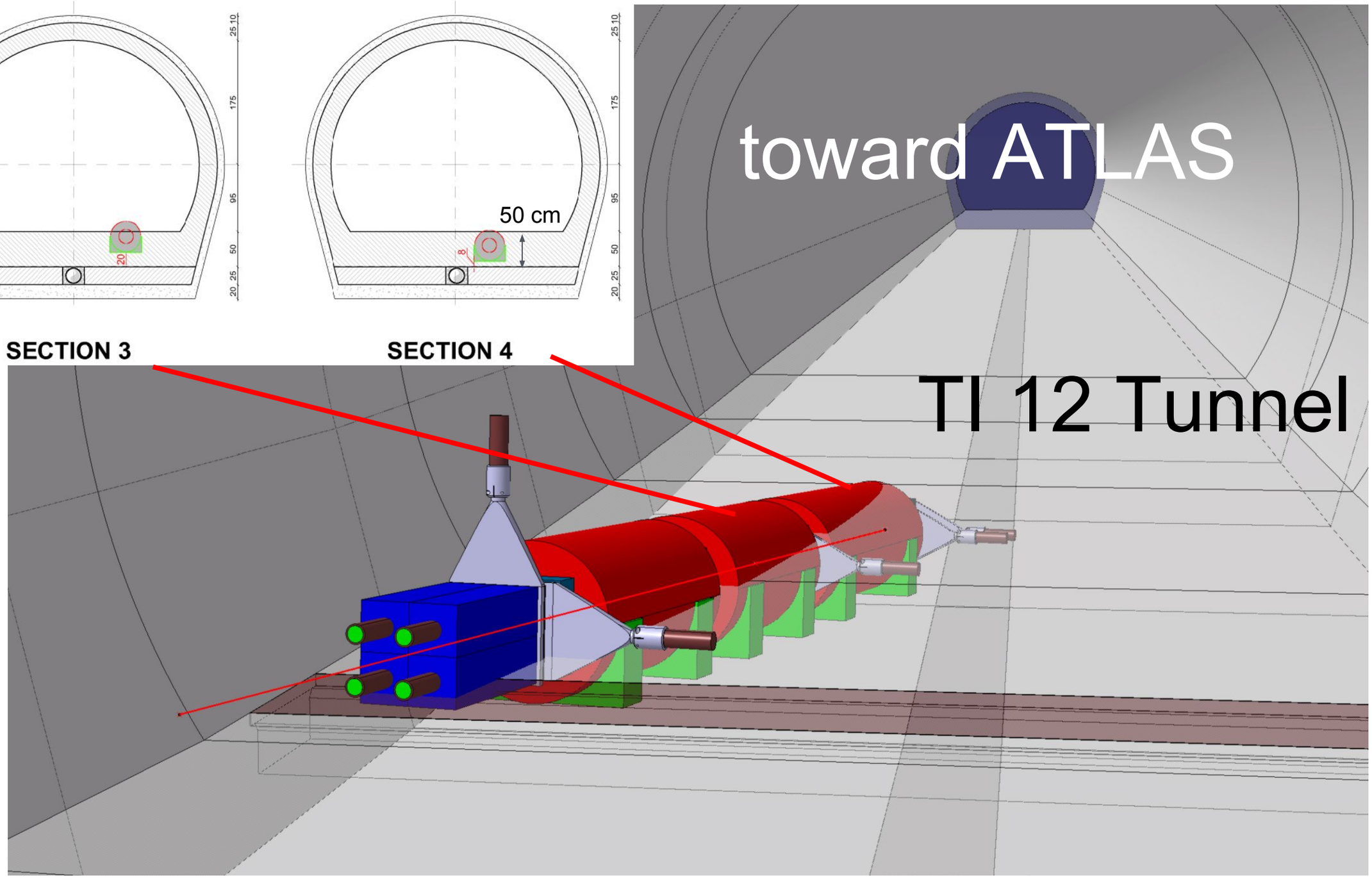
Fit 5m long detector but less service supports.

FASER location (TP)



FASER 3D model position

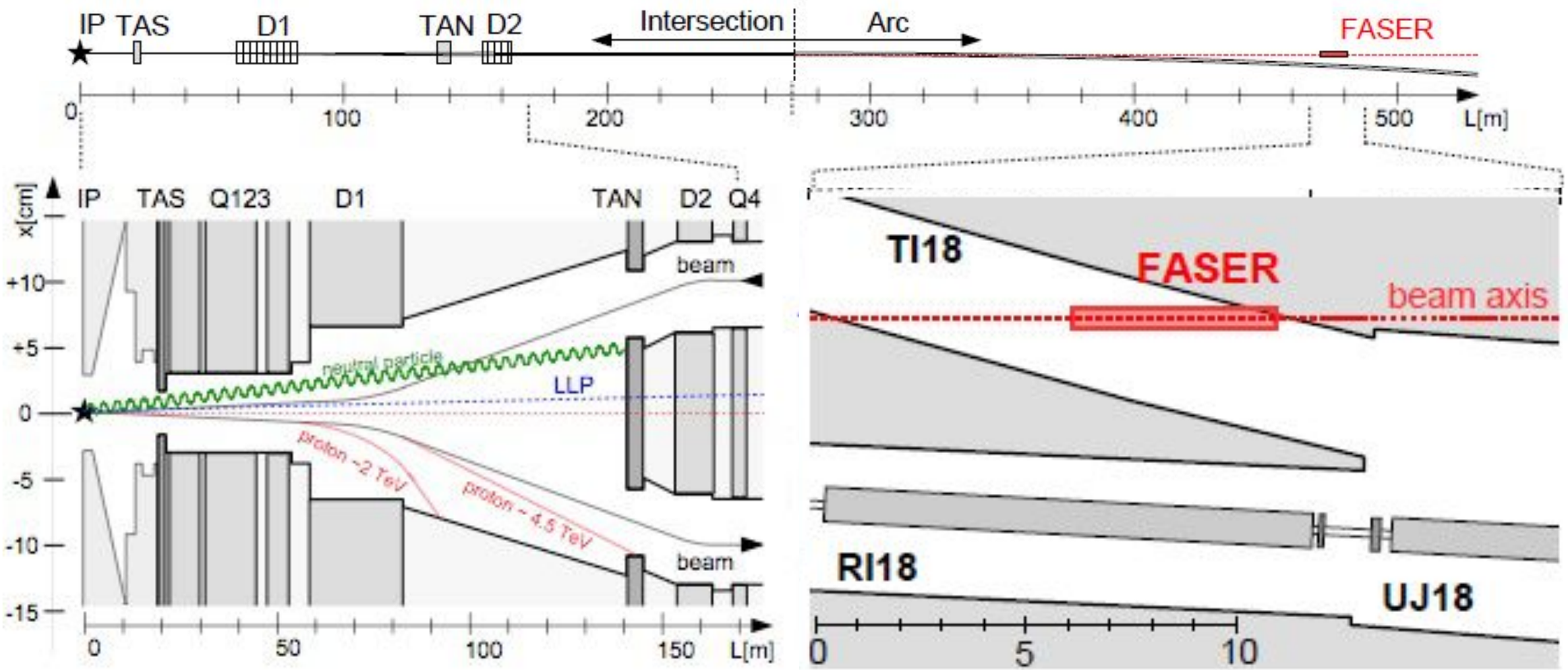




TP baseline location will be TI12. The environment in TI12 is expected to be similar to TI18. The rest of this talk will focus on LoI results while TP is still work in progress.

FASER location (LoI)

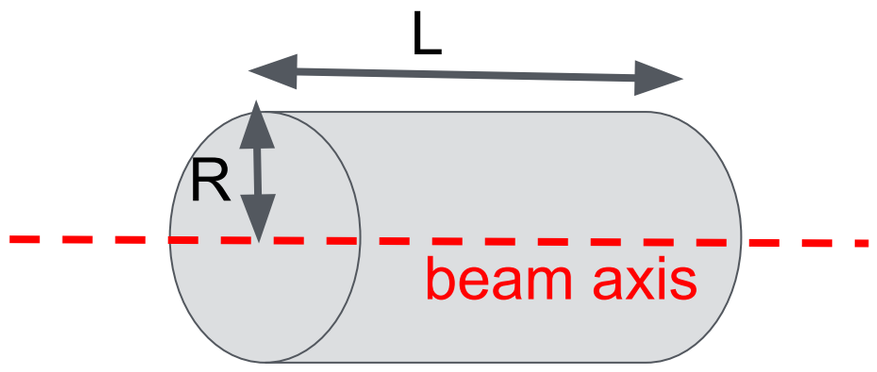
LLP starts at IP, travels through TAN and other very forward infrastructure, then leaves the LHC tunnel, travels through 90 m of rock, decays to two highly energetic (~TeV) charged tracks in FASER



• FASER will be placed on the beam collision axis (“on-axis”); if the beam crossing angle = 300 μrad, the on-axis location at FASER shifts by 7 cm.

Dark Photon Discovery Potential

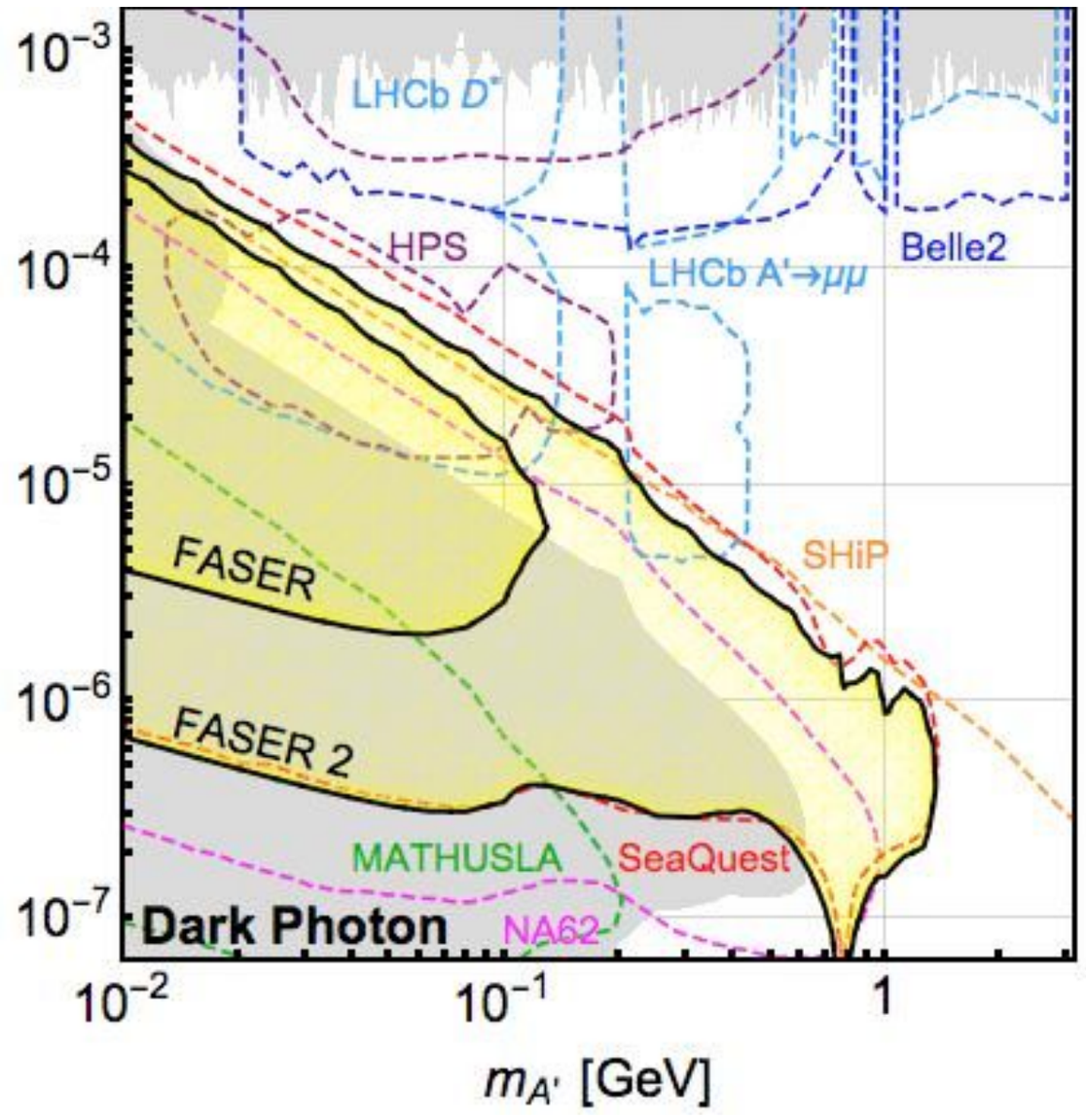
- FASER
  - Collect data during Run 3 (150 fb^{-1})
  - Decay volume: R=10 cm, L=1.5 m
- FASER 2
  - Collect data during HL-LHC (3 ab^{-1})
  - Decay volume: R=1 m, L=5 m



Decay Volume

FASER is complementary to other proposed experiments. FASER covers more parameter space for new particles produced in pion decays

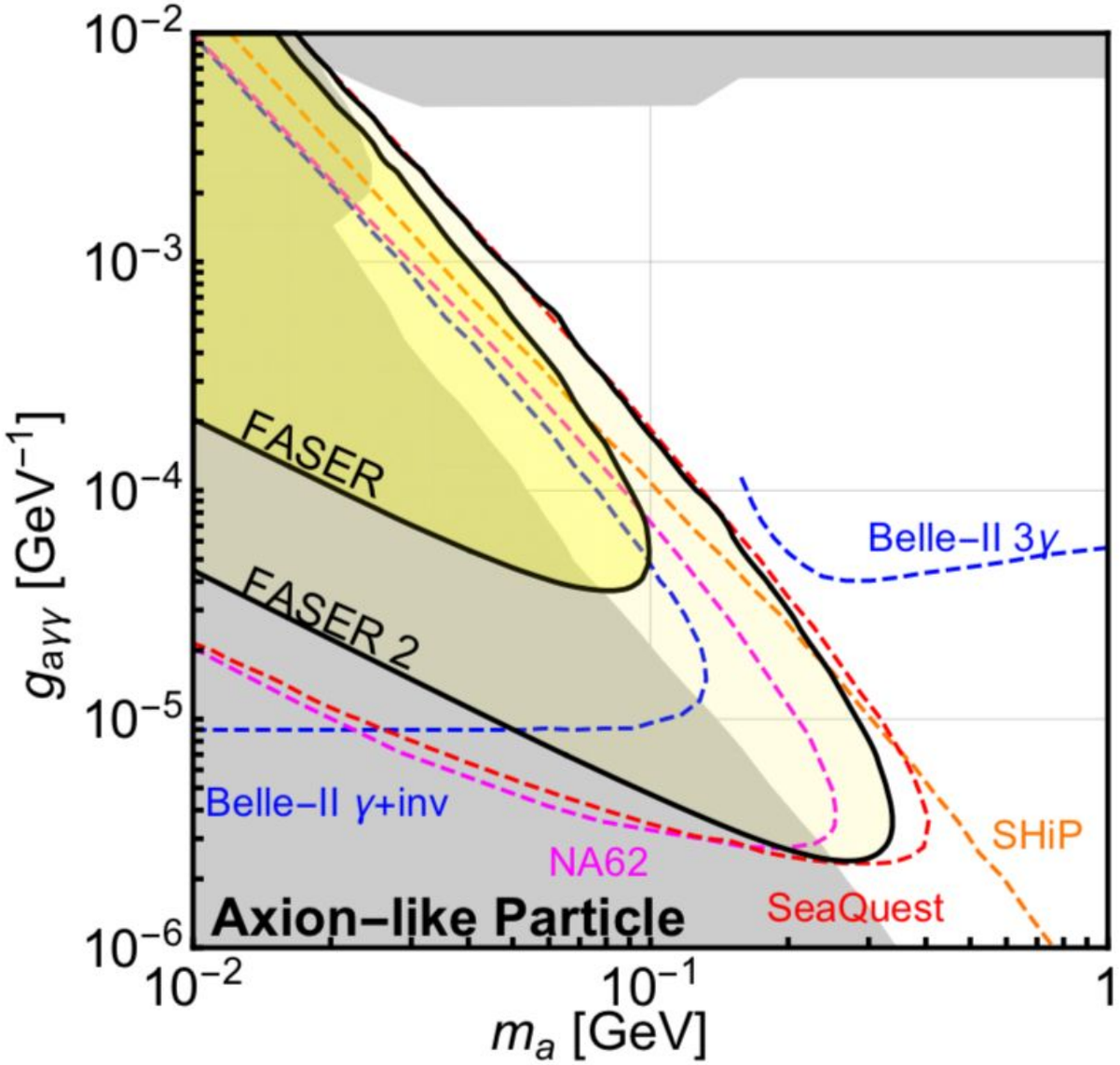
A' as a DM-SM mediator



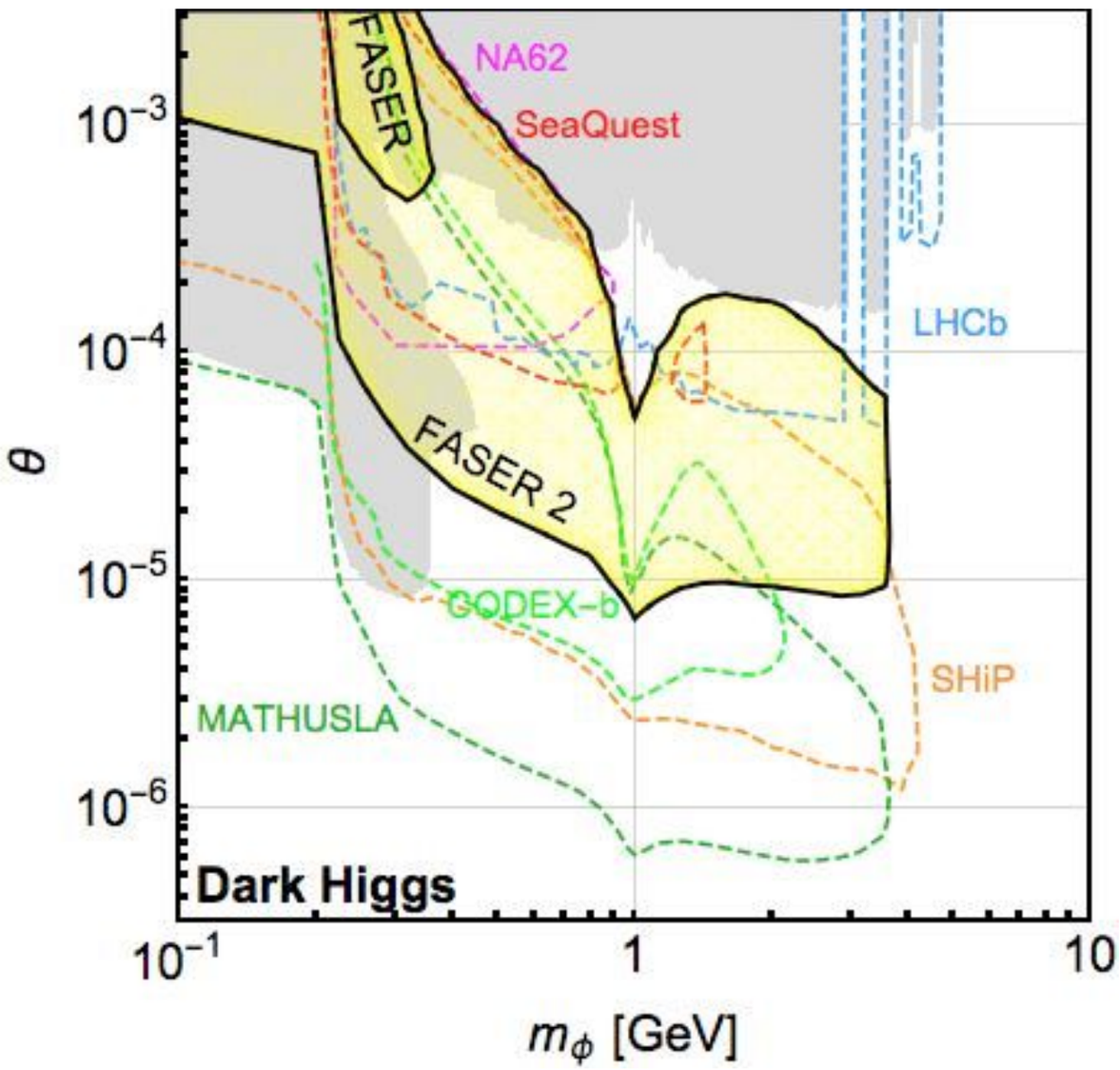
$$\mathcal{L} \supset \frac{1}{2} m_{A'}^2 A'^2 + \epsilon e j_{EM}^{\mu} A'_{\mu}$$

Axion-Like Particle and Dark Higgs

Similar to QCD axion



Dark Higgs-DM portal

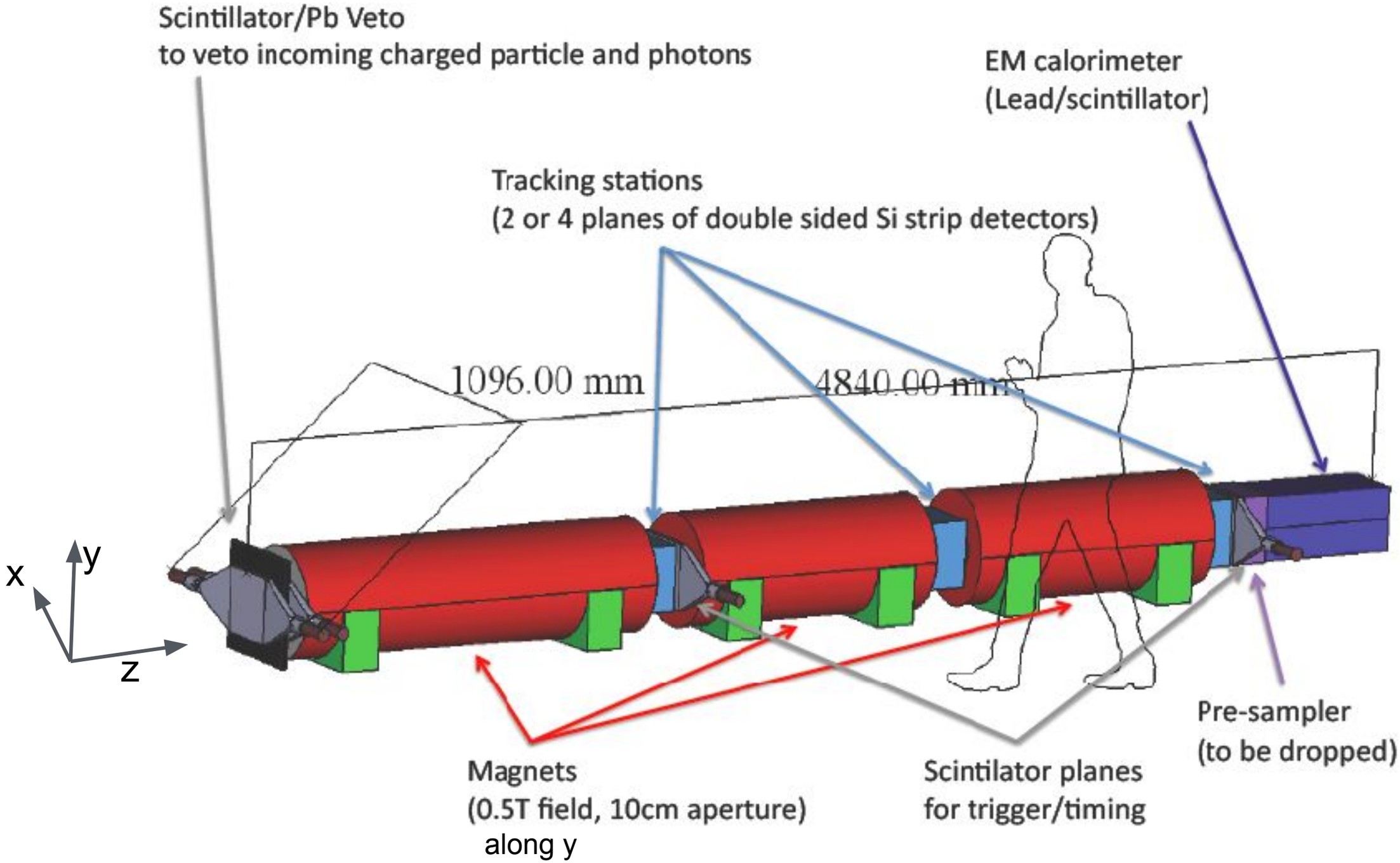


$$\mathcal{L} \supset \frac{1}{2} m_a^2 a^2 + g_{a\gamma\gamma}\, a F^{\mu\nu} \widetilde{F}_{\mu\nu}$$

$$\mathcal{L} \supset -m_\phi^2 \phi^2 - \sin\theta \frac{m_f}{v} \phi \bar{f} f - \lambda v h \phi\phi$$

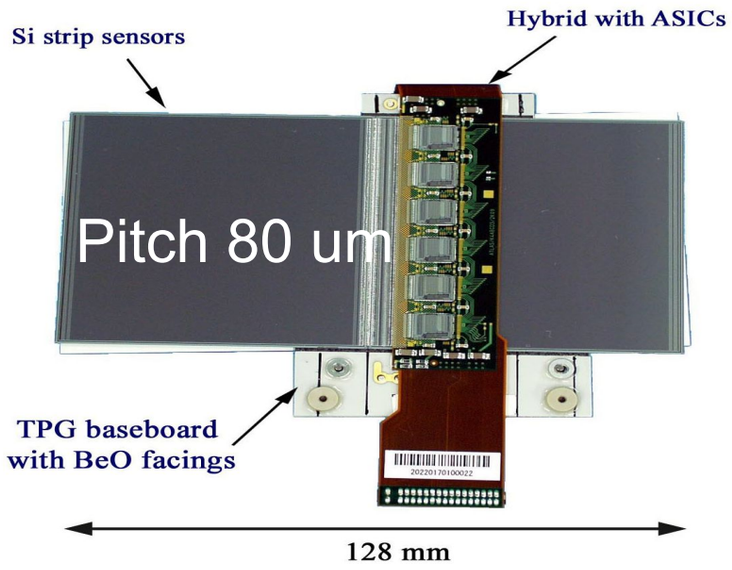
Detector Layout (LoI)

Target signal: two oppositely charged tracks with ~TeV energies that emanate from a common vertex inside the detector and have a combined momentum that points back to the IP



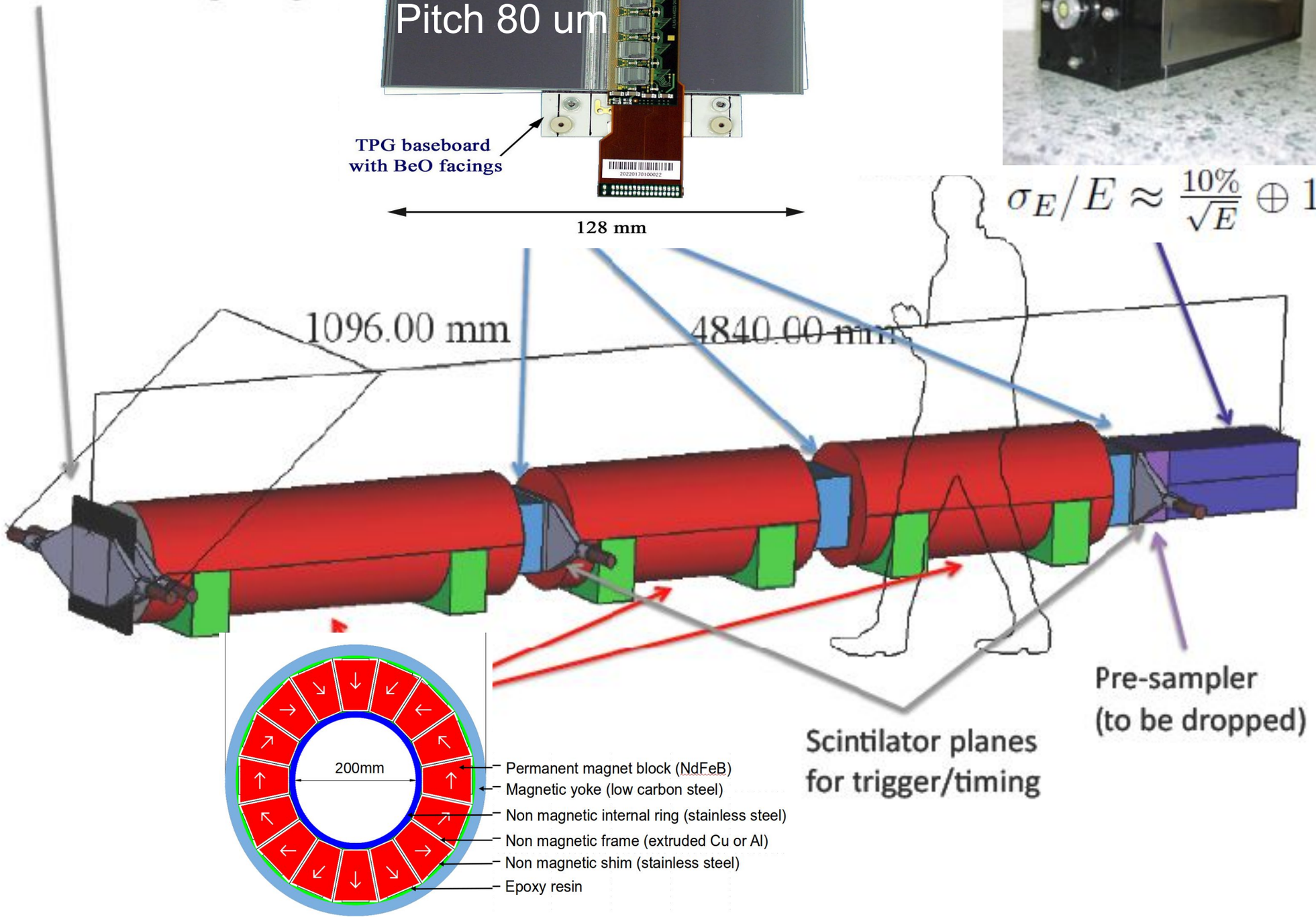
Detector Technology

ATLAS SCT module



LHCb ECAL module 25 X_0

$$\sigma_E/E \approx \frac{10\%}{\sqrt{E}} \oplus 1\%$$



Background - FLUKA simulation

- **The signal is striking:** two opposite-sign, high energy (E > 500 GeV) charged particles that originate from a common vertex in a small, empty decay volume, point back to the IP through 90 m of rock, and are consistent with bunch crossing timing.

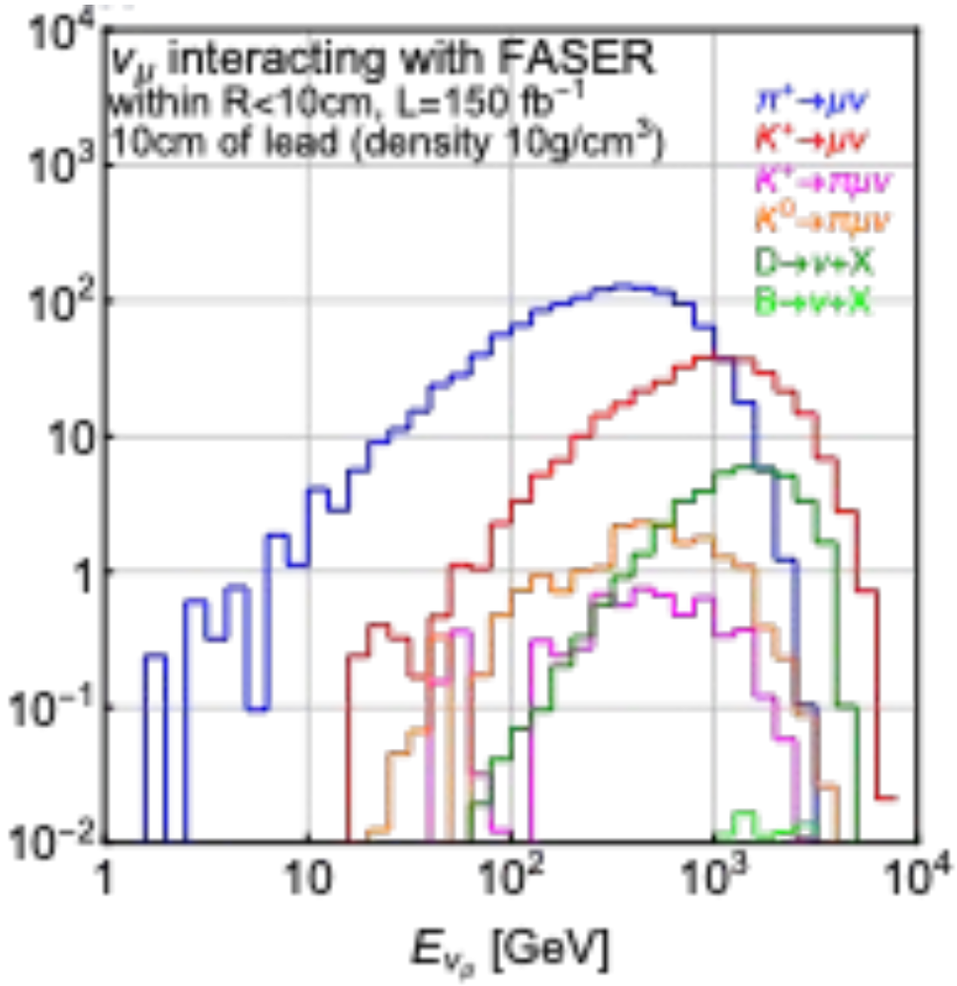
- **Muons coming from IP**

70 Hz (>100 GeV) at L=2x10^{34}cm^{-2}s^{-1}

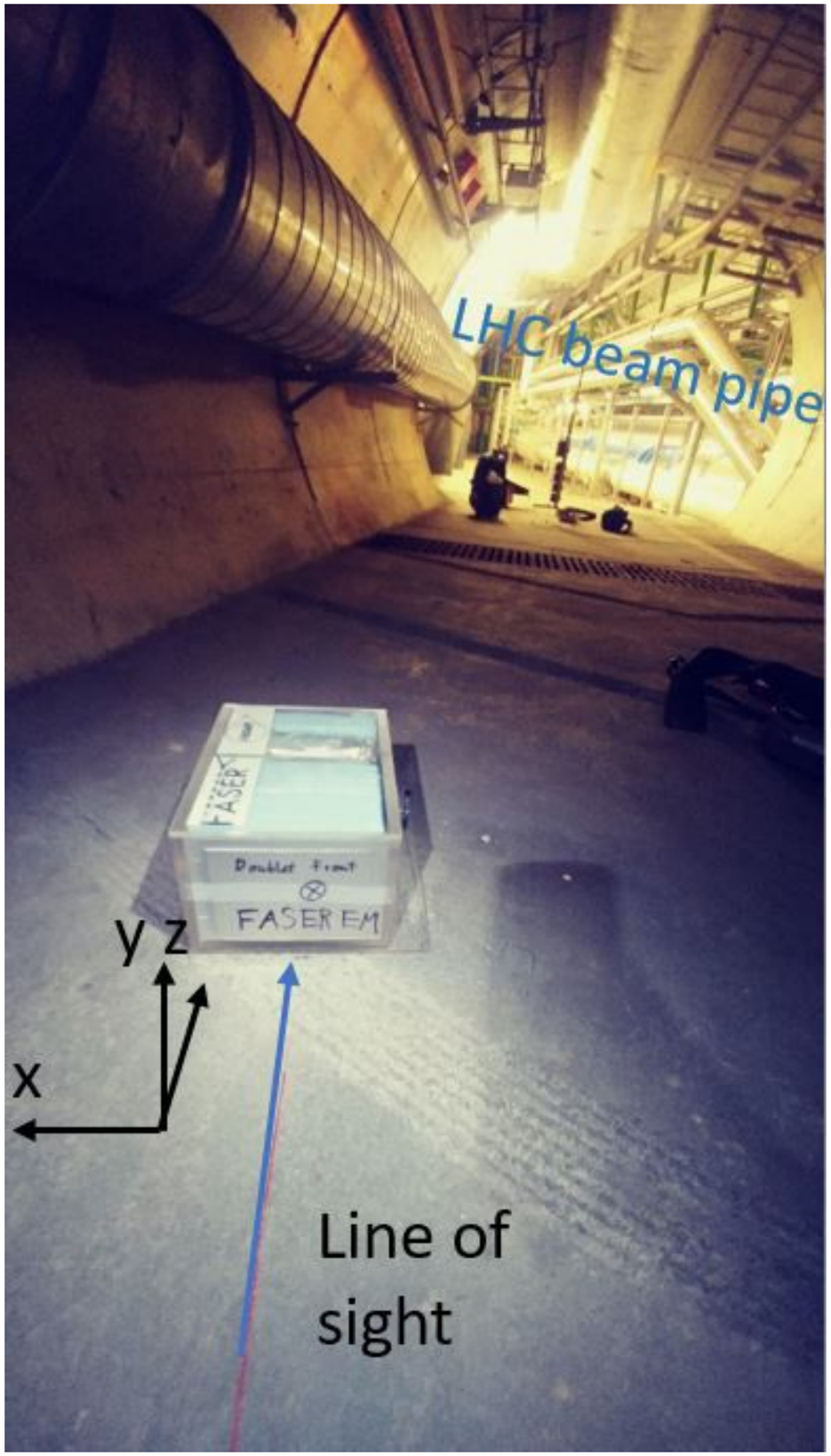
Process	Number
μ	540M
$\mu + \gamma_{\text{brem}}$	41K
$[\mu + (\gamma_{\text{brem}} \to e^+e^-)]$	[7.4K]
μ + EM shower	22K
μ + hadronic shower	21K

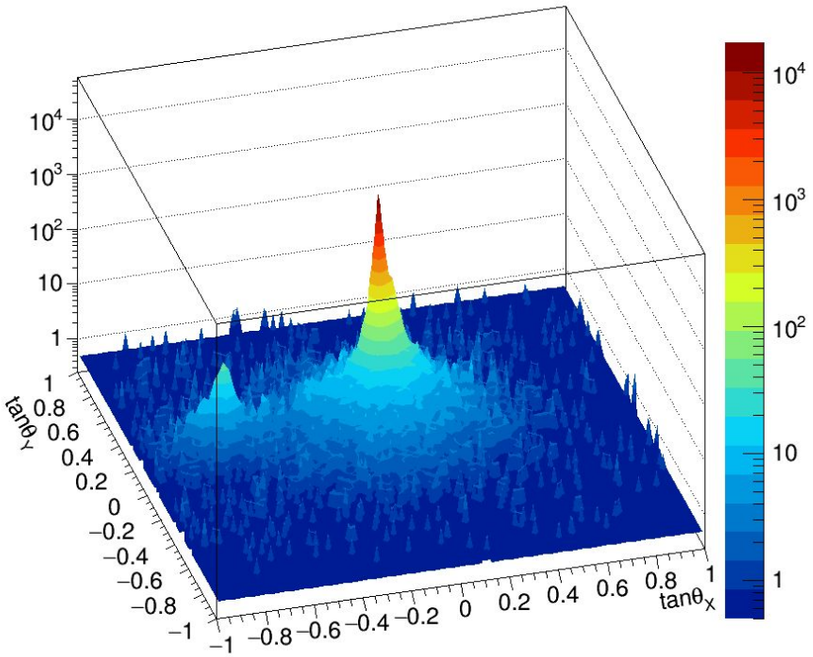
- **Neutrino-induced events: low rate**

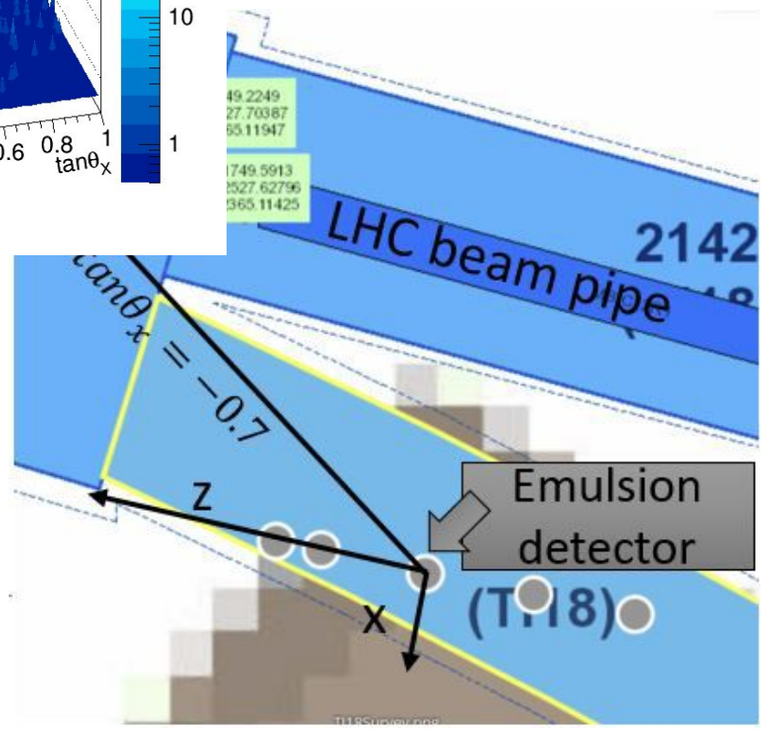
a few ~100 GeV events at 150 fb^{-1}



In-situ background measurements in TI18







- First measurements already performed
  - Emulsion detectors
  - BatMon (Battery-operated radiation monitor)
- First results promising - consistent with FLUKA
- Data analysis and TI12 measurements on-going

Growing FASER Collaboration

First paper arXiv:1708.09389 by J. Feng, I. Galon, F. Kling, S. Trojanowski

Now 20 members, 12 institutes

Collaboration is growing. Welcome to join us!

九州大学
KYUSHU UNIVERSITY

名古屋大学
NAGOYA UNIVERSITY

Weizmann Institute of Science

UNIVERSITÄT BERN

Summary

- FASER is an opportunity for a small and inexpensive experiment to search for a full range of light and weakly-interacting particles, complementing other experiments.

- Currently pursuing funding options and seeking CERN approval
  - Positive feedback for Letter of Intent from LHCC
  - Working on Technical Proposal for LHCC approval in November

- If successful, a possible timeline and plan is
  - Install FASER in LS2 (2019-20) for Run 3 (150 fb^{-1})
    - Decay volume R = 10 cm, L = 1.5 m, requires lowering floor by 50cm
    - Target dark photons, ALPs, etc.
  - Install FASER 2 in LS3 (2023-25) for HL-LHC (3 ab^{-1})
    - Decay volume R = 1 m, L = 5 m, requires some extension of existing tunnel
    - Full physics program: dark photons, B-L, ALPs, dark Higgs, HNLs, etc.

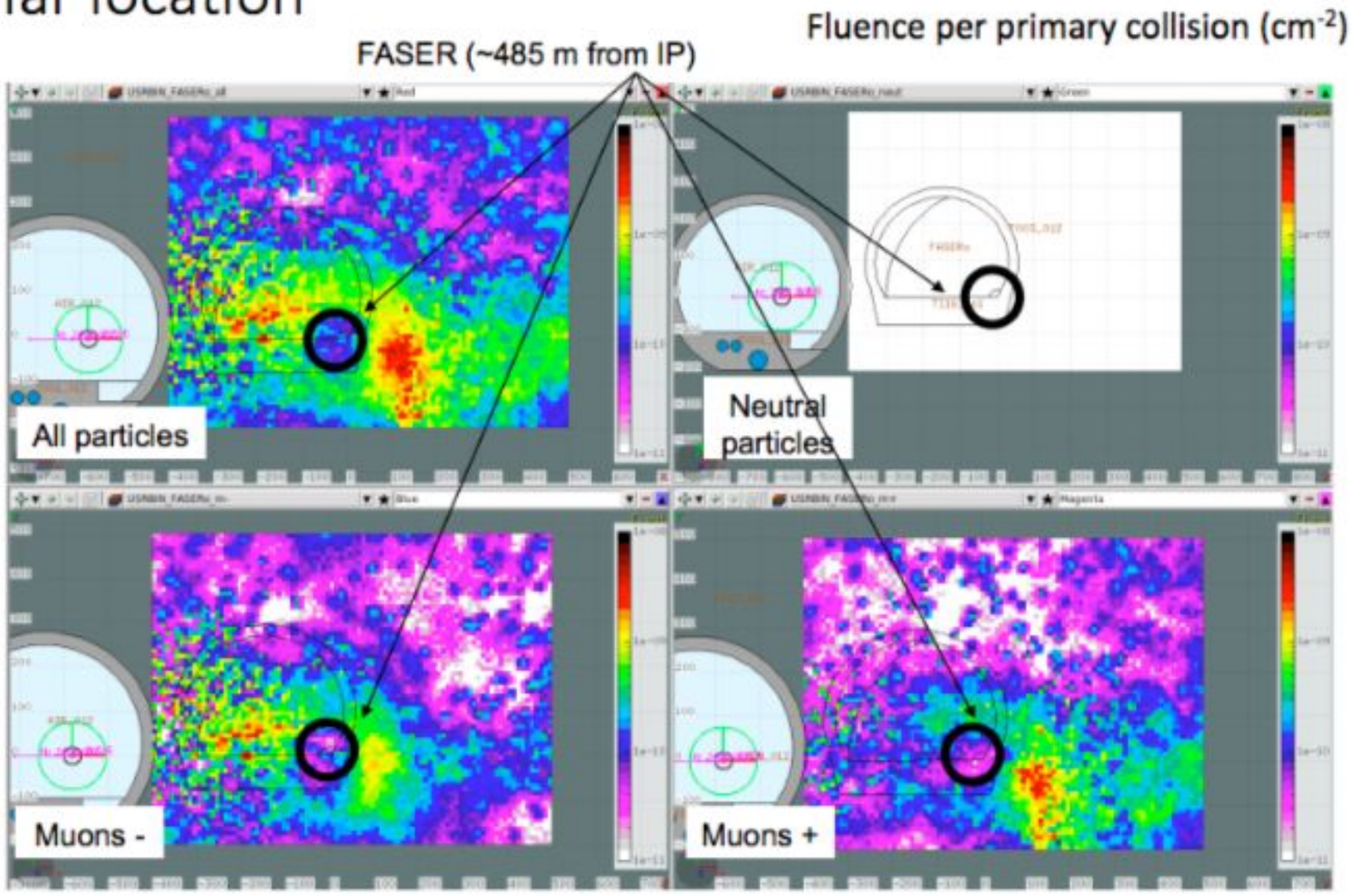
Backup

FLUKA Simulation

For HL-LHC conditions Luminosity: $5x10^{34}$ $cm^{-2}s^{-1}$ Cross section p-p collision: 85 mb Pile-up: 140 events/bunch crossing

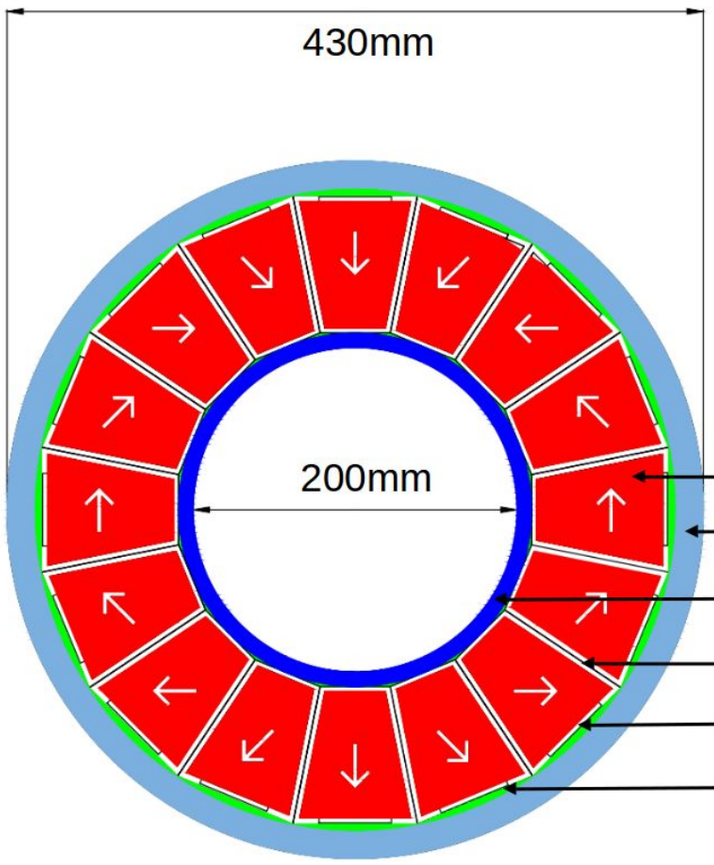
Particle type	Fluence rate ($cm^{-2}s^{-1}$)	Fluence per bunch crossing per cm^2
$\mu+$	0.18	$6.1x10^{-9}$
$\mu-$	0.40	$1.3x10^{-8}$
n	$\sim10^{-7}$	$\sim10^{-14}$
γ	$\sim10^{-4}$	$\sim10^{-12}$
π	$\sim10^{-5}$	$\sim10^{-12}$

Particle distribution around FASER inside TI18: far location



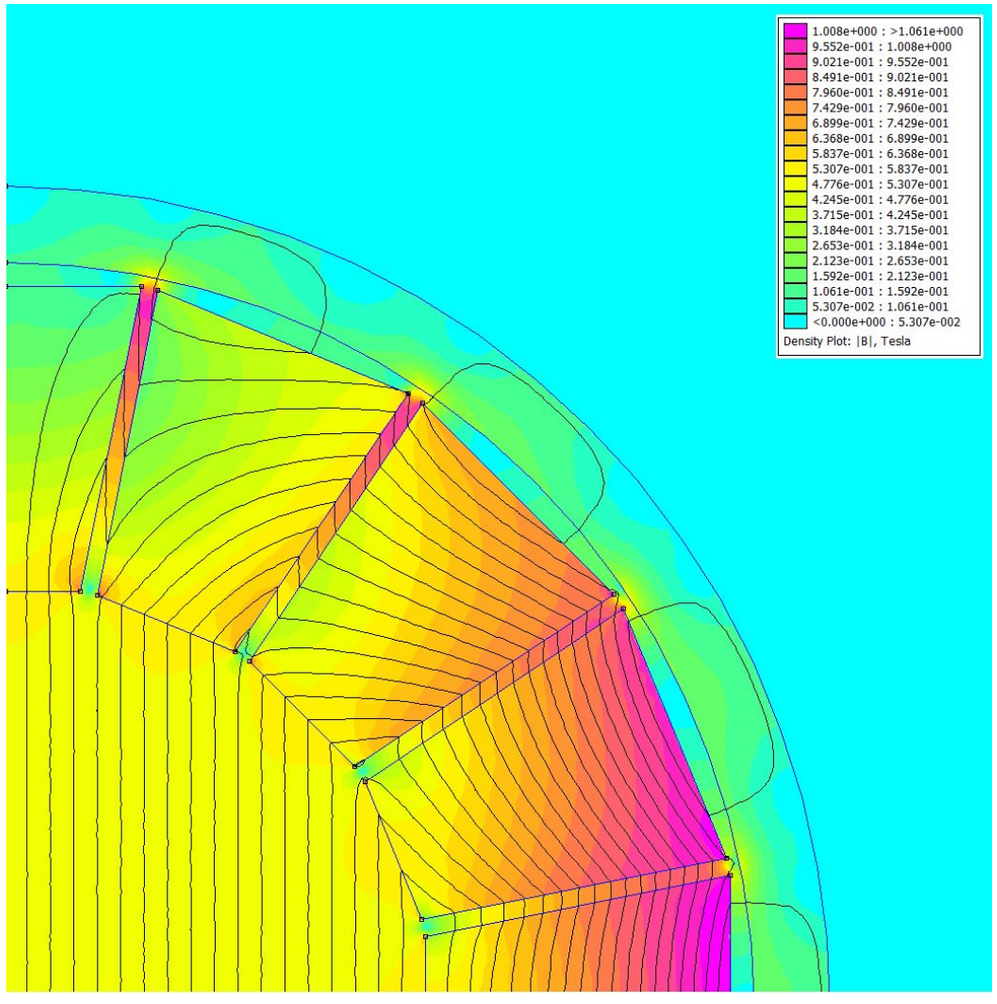
The FLUKA team are working on updating the above plots reducing the muon energy threshold from 100 GeV to 10 GeV, and also showing the flux distribution for neutrinos (also down to 10 GeV).

Magnet

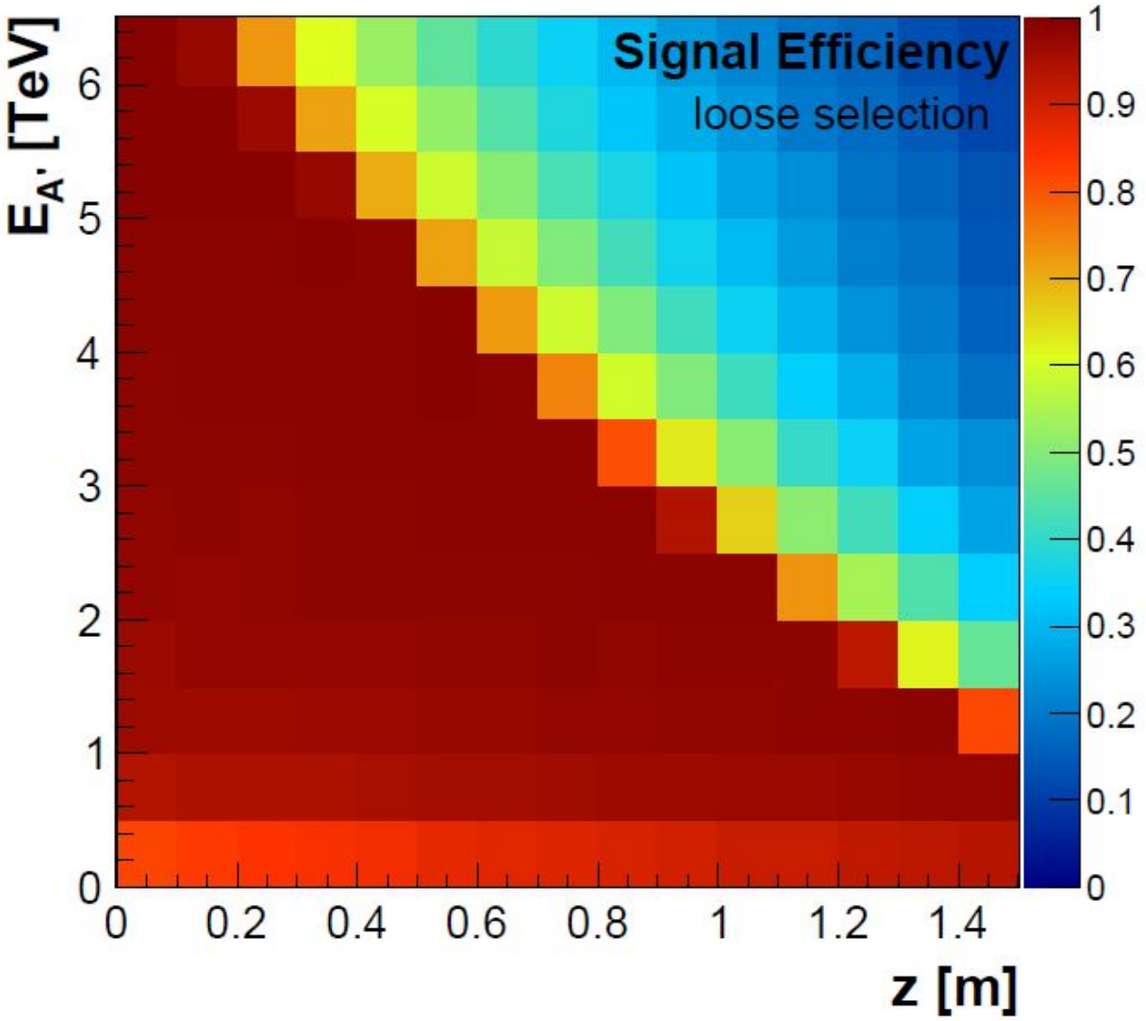


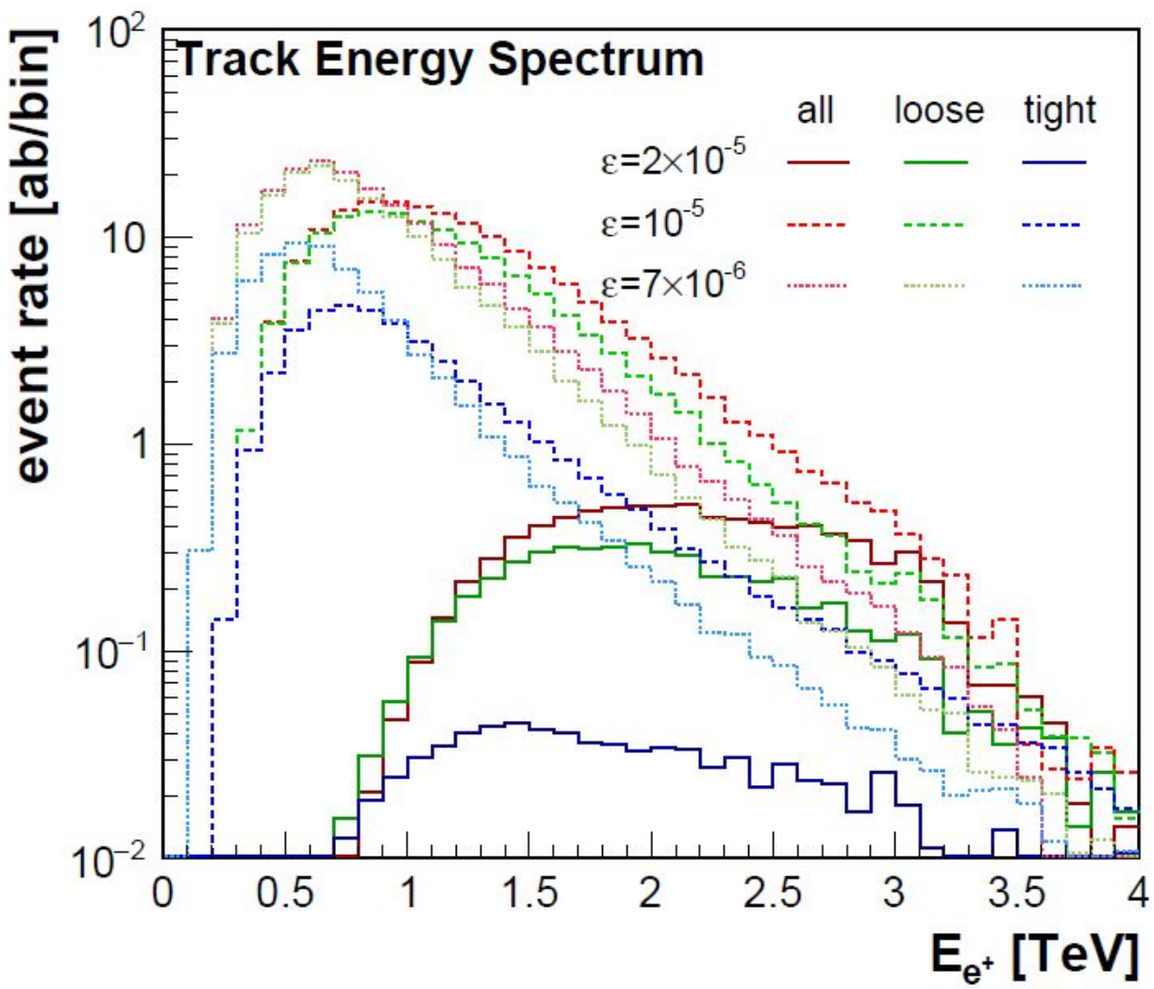
Permanent magnet block (NdFeB)
Magnetic yoke (low carbon steel)
Non magnetic internal ring (stainless steel)
Non magnetic frame (extruded Cu or Al)
Non magnetic shim (stainless steel)
Epoxy resin

Parameter	Value	Unit
Magnetic material	NdFeB	
Central Field	0.6	T
Aperture	200	mm
Outer diameter	430	mm
Field homogeneity	±2	%
Temperature dependence	-0.12	%/K
Weight / meter	≈1000	kg/m

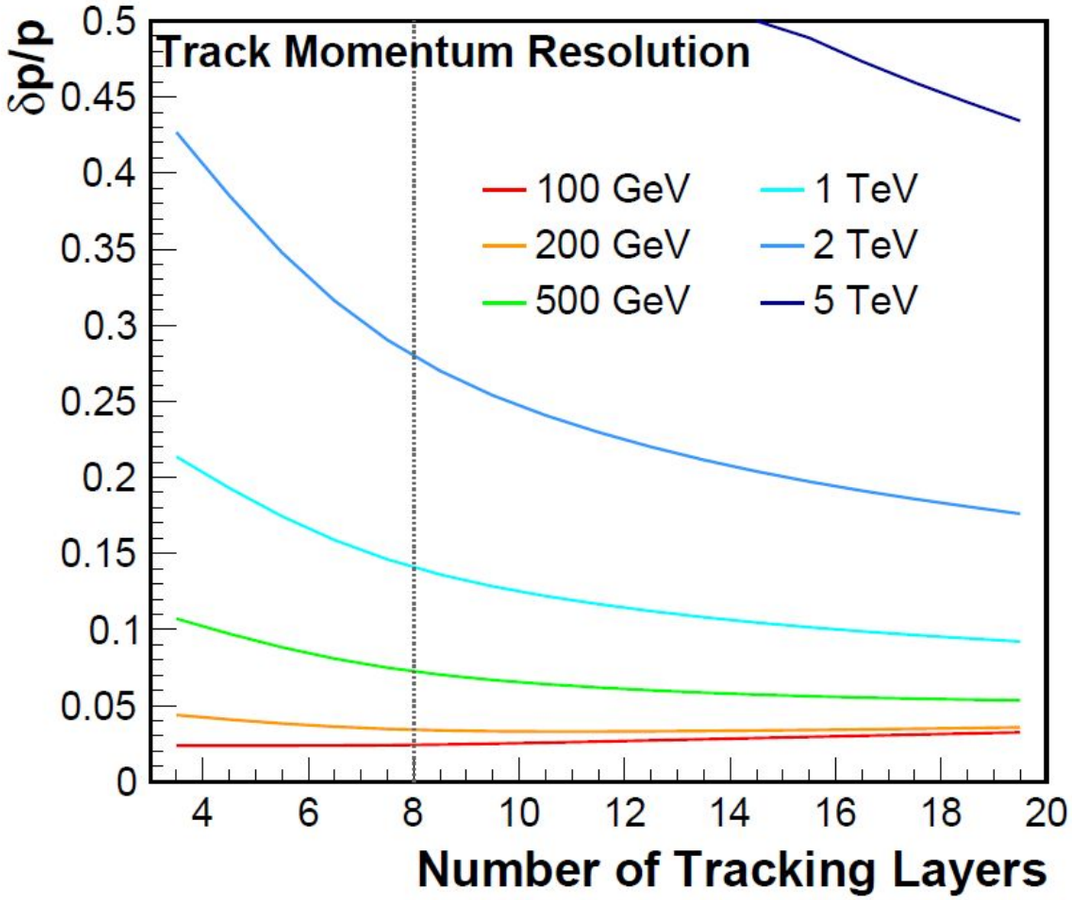


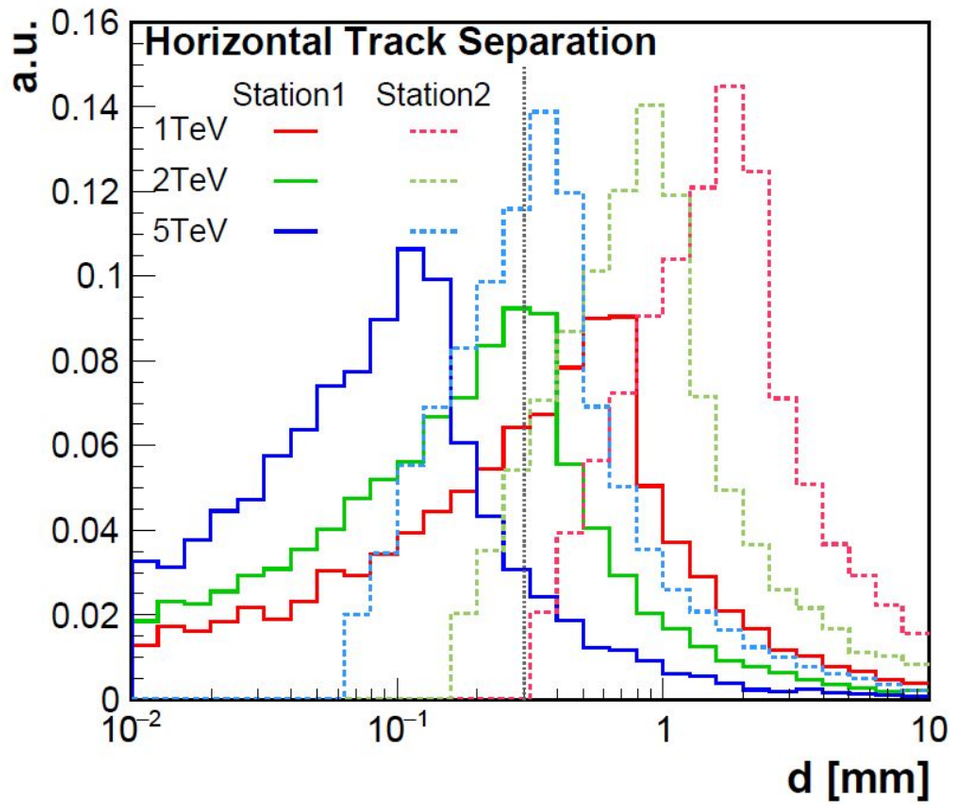
Tracking Spectrum



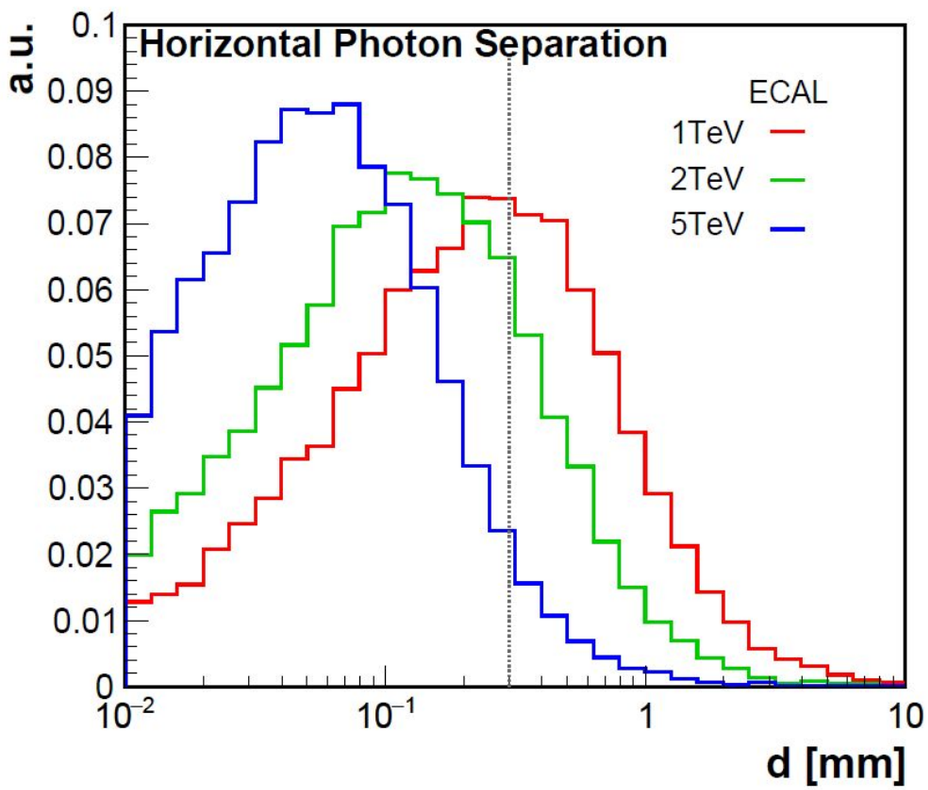


Track separation and momentum resolution

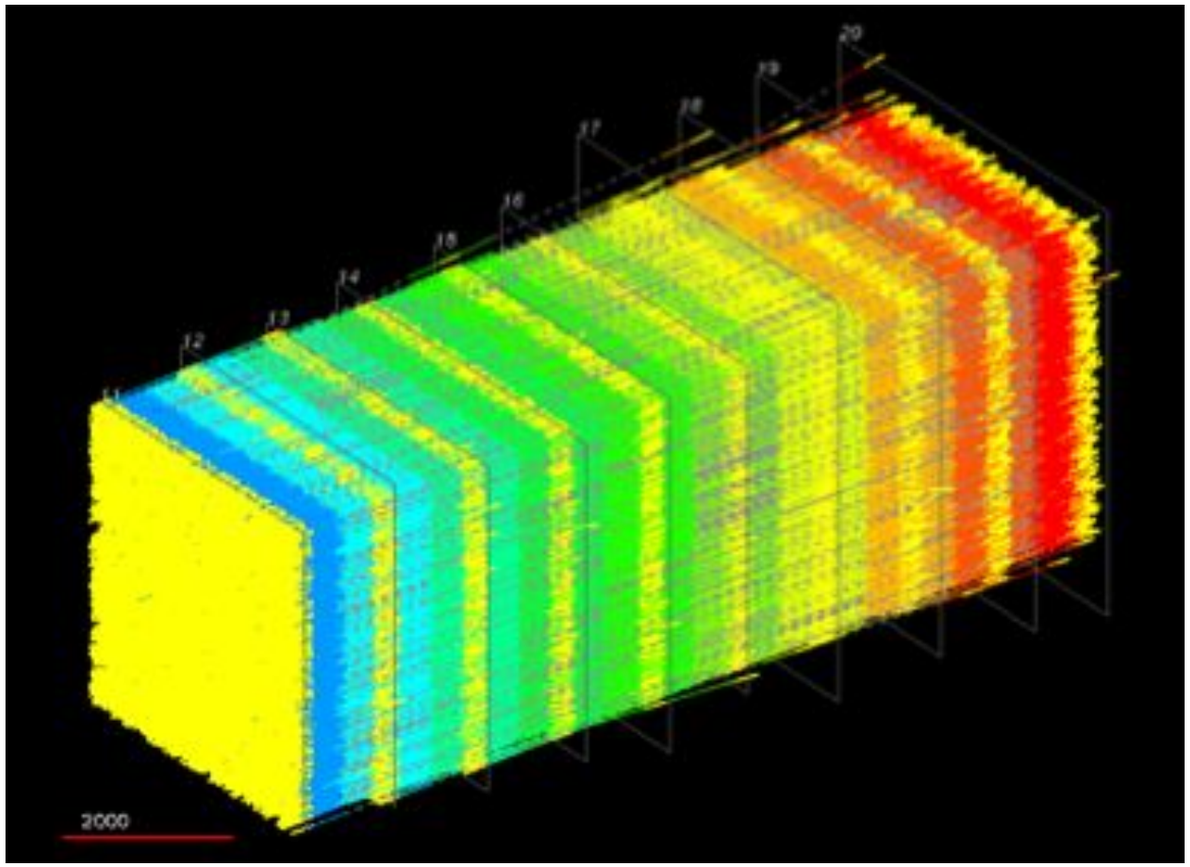


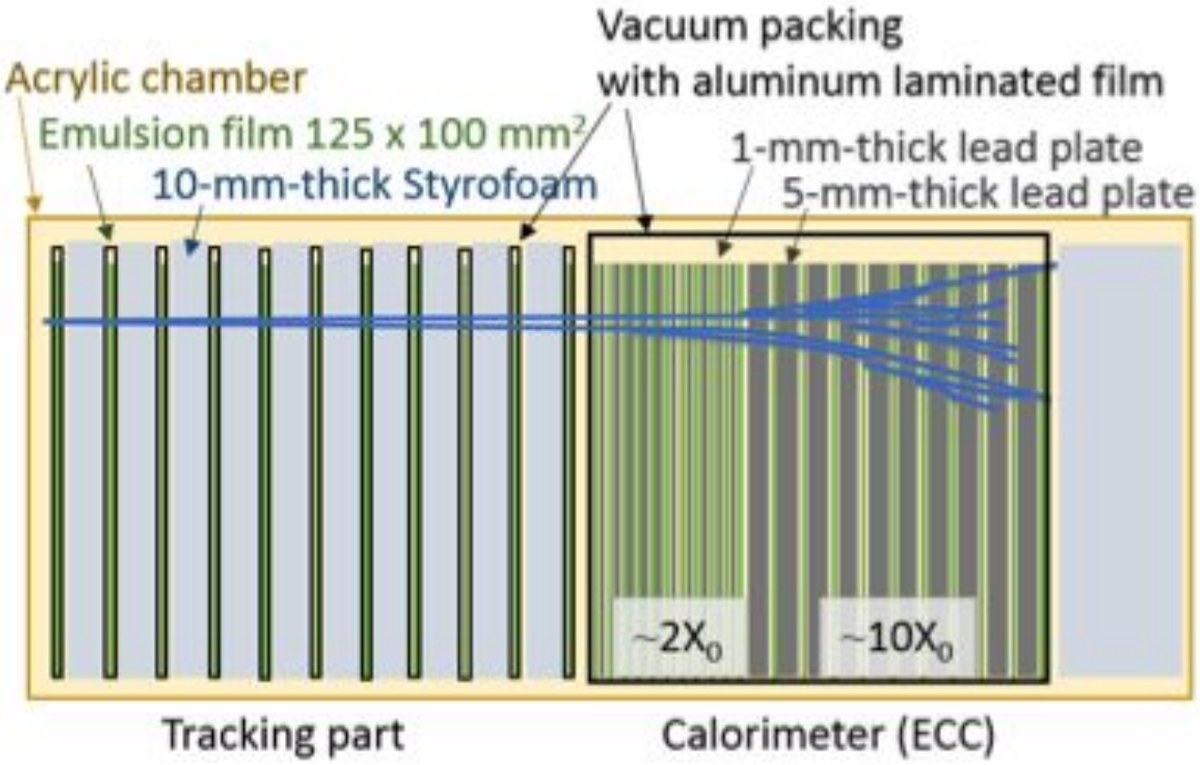


A conservative estimate of the separation required to FASER's choice create isolated clusters in a silicon strip detector

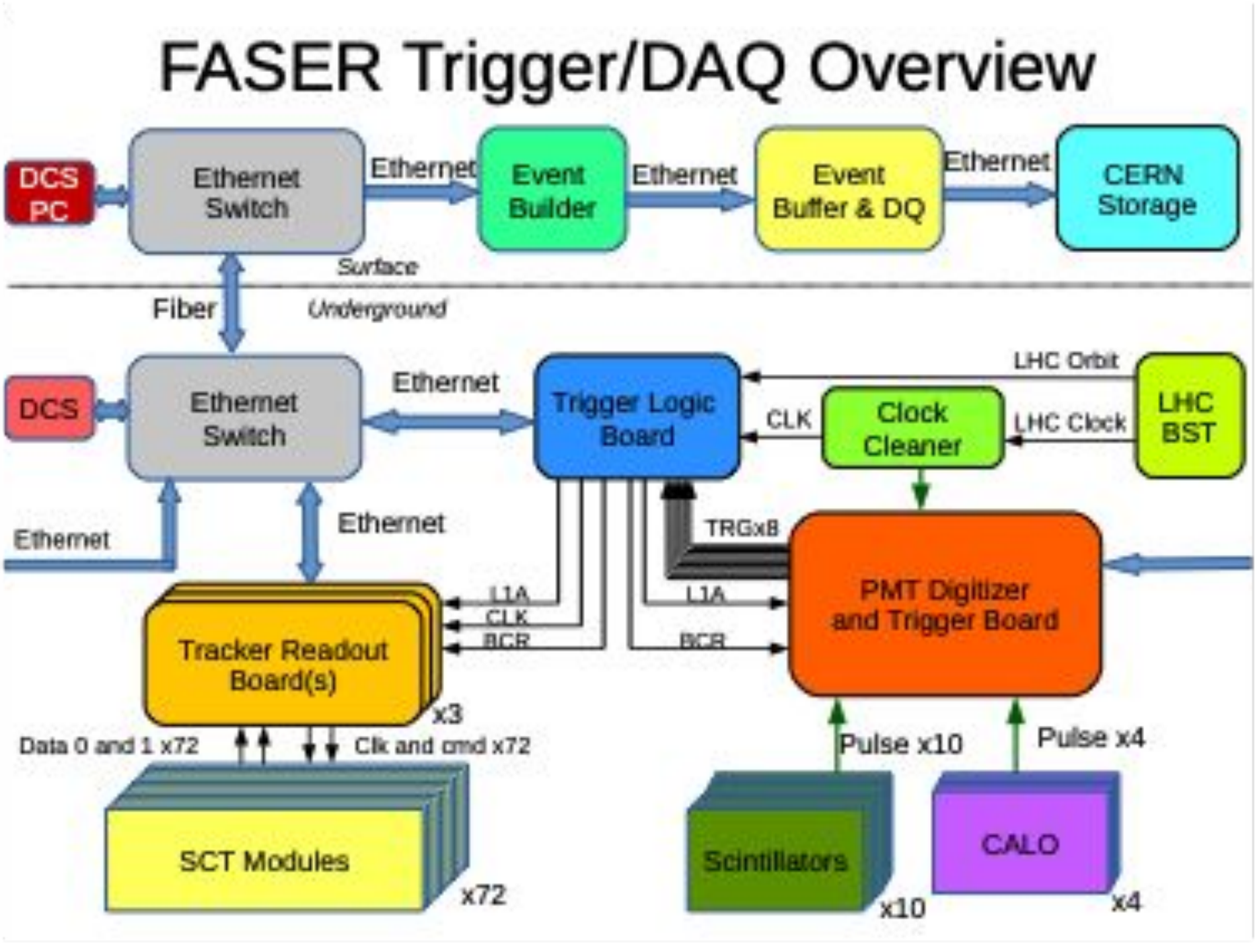


FASER Emulsion





	Energy cutoff	Flux / 14 fb^{-1}
Emulsion	E > 0.5 GeV	1.8 x 10^5 /cm^2
FLUKA	E > 100 GeV	1.4 x 10^5 /cm^2

FASER TDAQ

~500 Hz Trigger Rate at $L = 2 \times 10^{34}$ cm^{-2} s^{-1}