Forward Search Experiment at the LHC

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on behalf of
The FASER collaboration

XXVII Epiphany conference on the future of particle physics
Cracow 7-10 January 2021

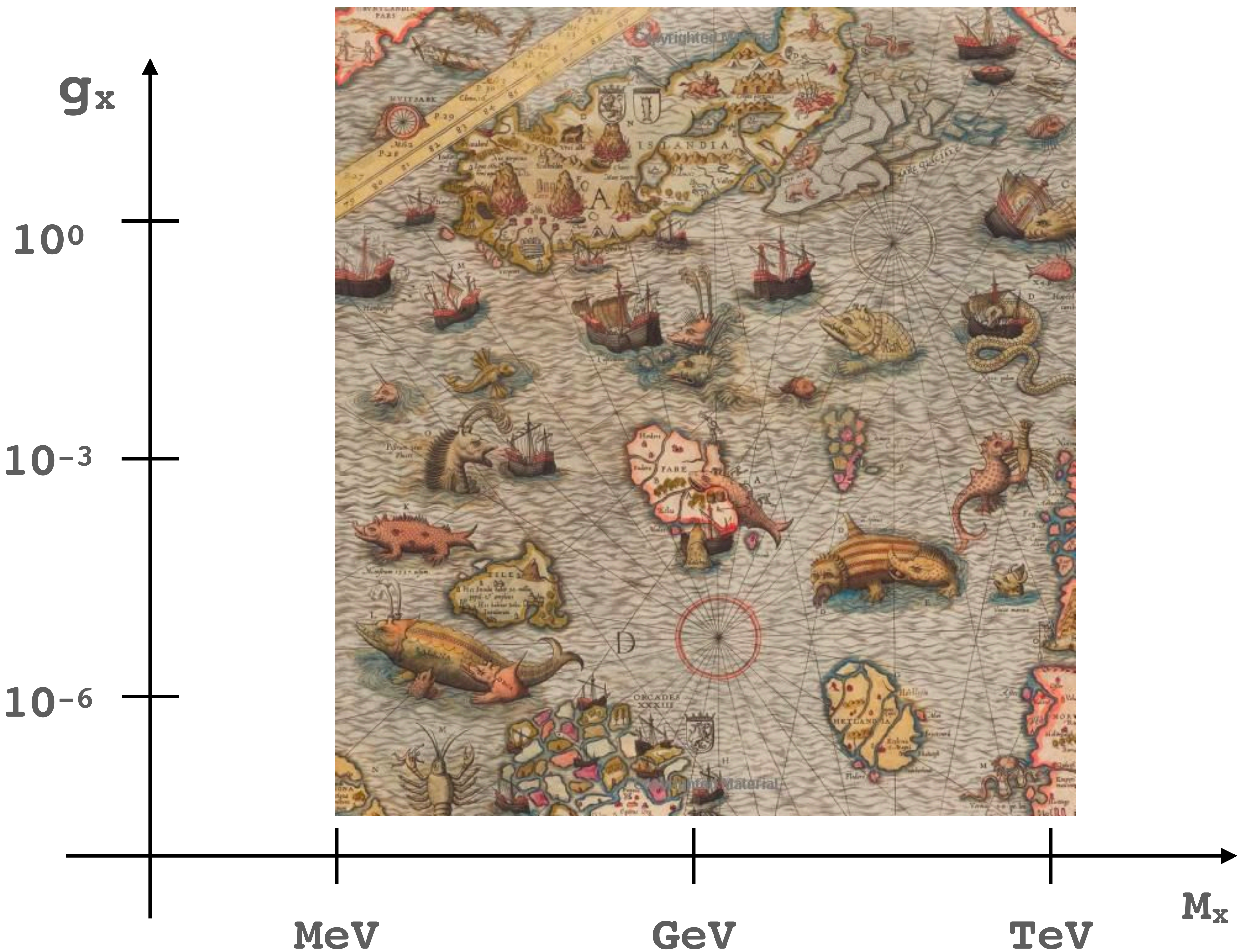
- A small experiment at the **LHC** searching for **light and weakly** interacting particles in Run-3 (**2022**)

- First concept in **2017** (Feng, Galon, Kling, Trojanowski 1708.09389), approved by CERN in **2019**, currently being installed (~2M$ largely funded by Heising-Simons and Simons Foundations)

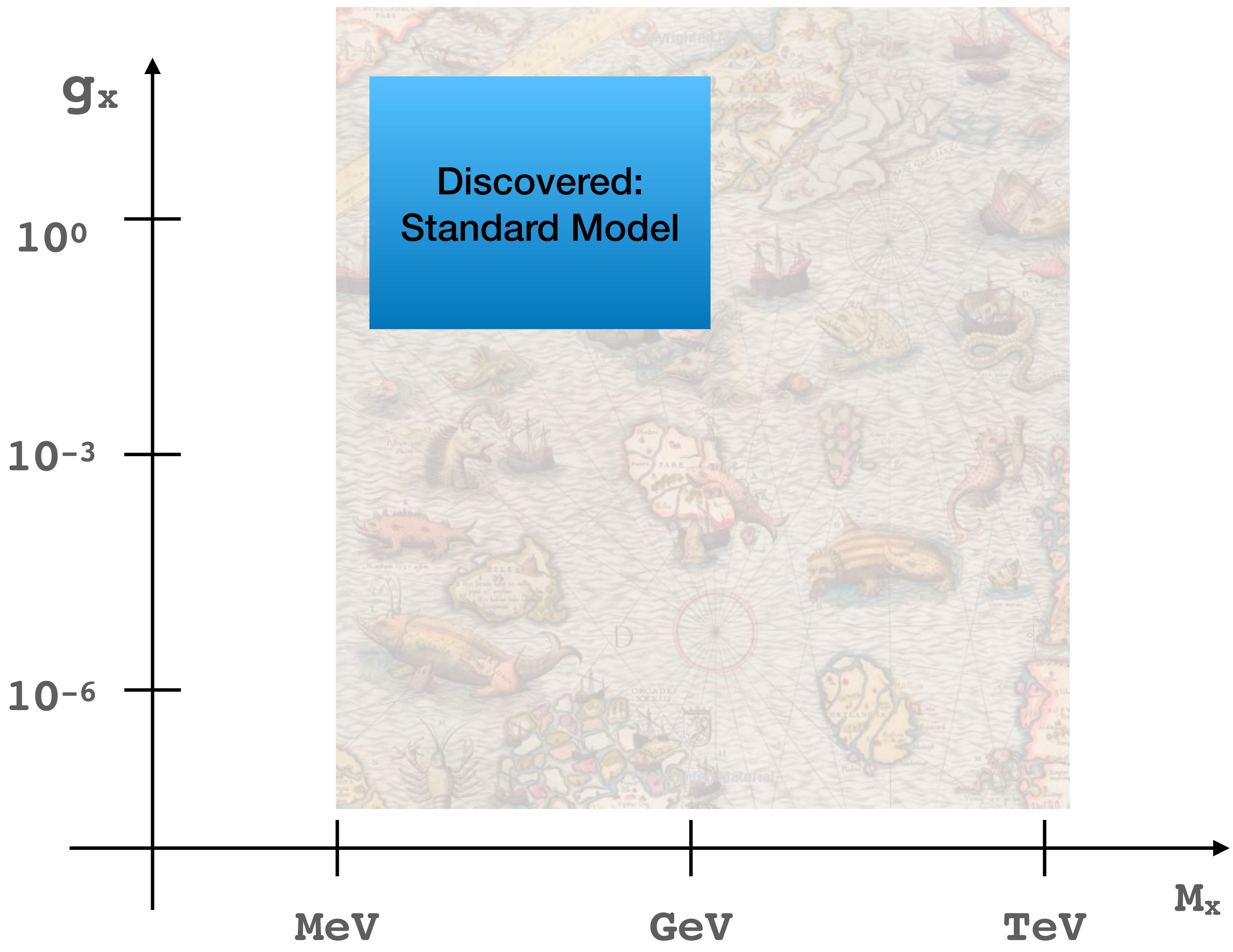
  - Detector constructed quickly and cheaply (reuse parts when possible)

- 65 collaborators, 19 institutions, 8 countries

Motivation



Motivation



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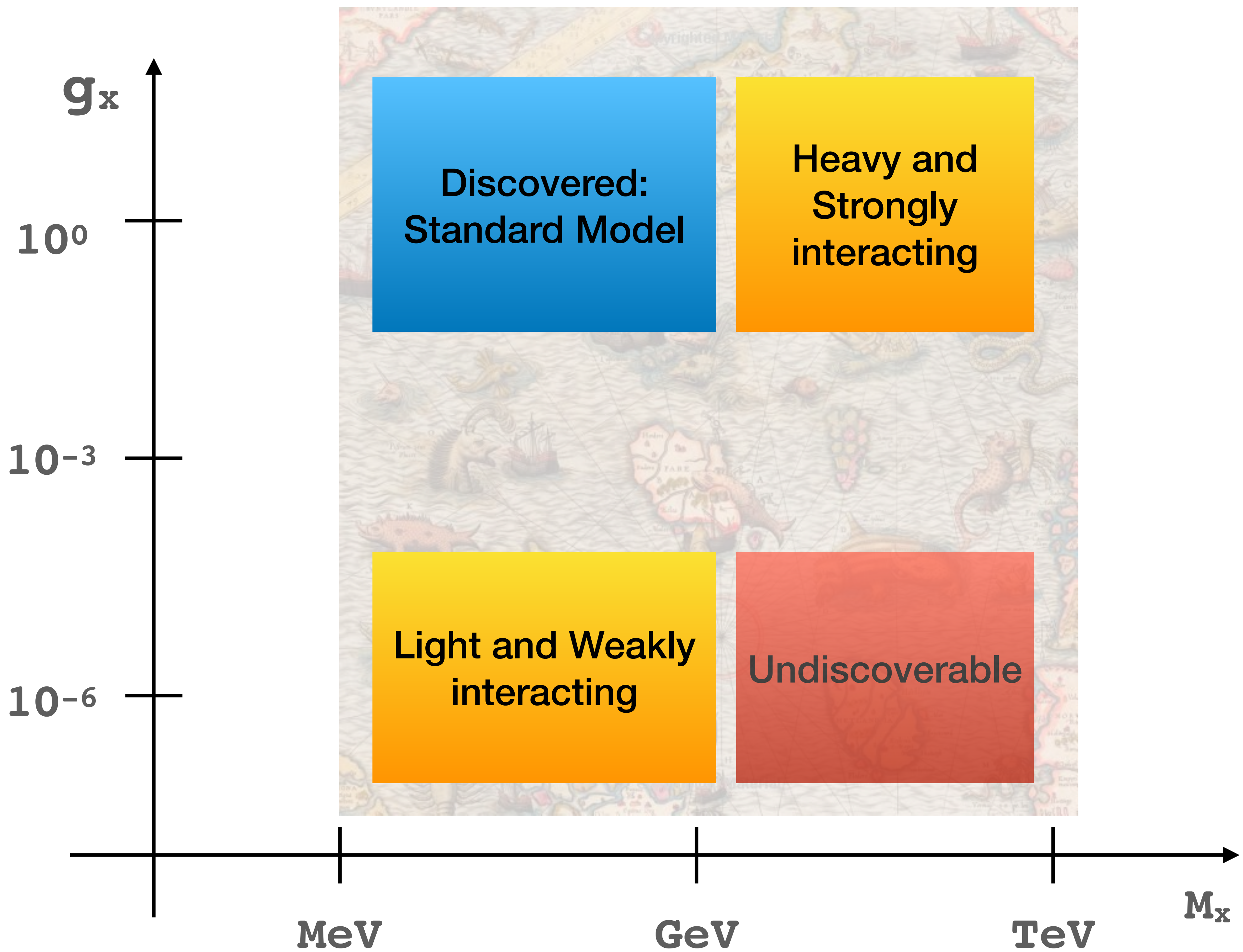


gx
10⁰
10⁻³
10⁻⁶
Discovered: Standard Model
Heavy and Strongly interacting
Light and Weakly interacting
Undiscoverable
MeV
GeV
TeV
Mx

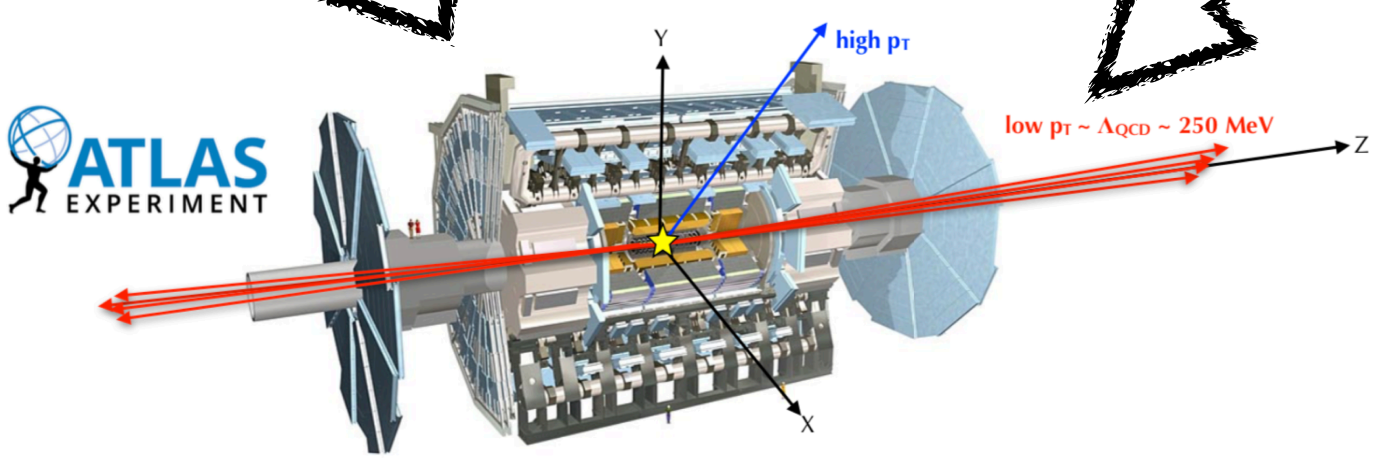
Motivation

Heavy and Strongly interacting

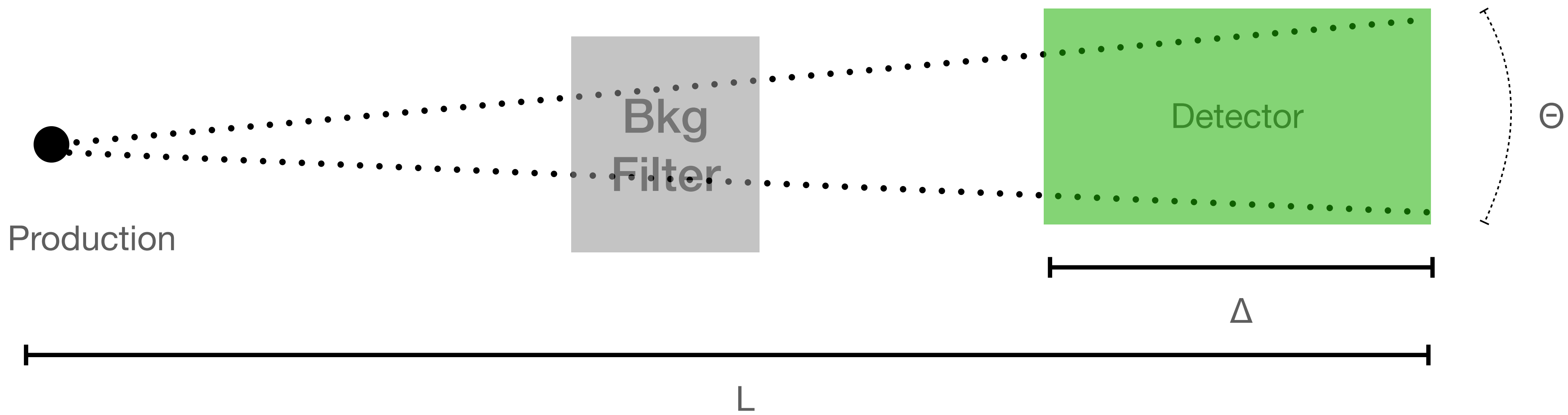
- High pT signature
- Isotropic
- ATLAS / CMS

Light and Weakly interacting

- Light: Can be produced in light hadron decays
- Weakly interacting:
  - Need large event rate to see them
  - Can travel macroscopic distance before decaying



Detecting Light and Weakly interacting Long Lived Particles



* for backgrounds ~0, sensitivity is driven by yield

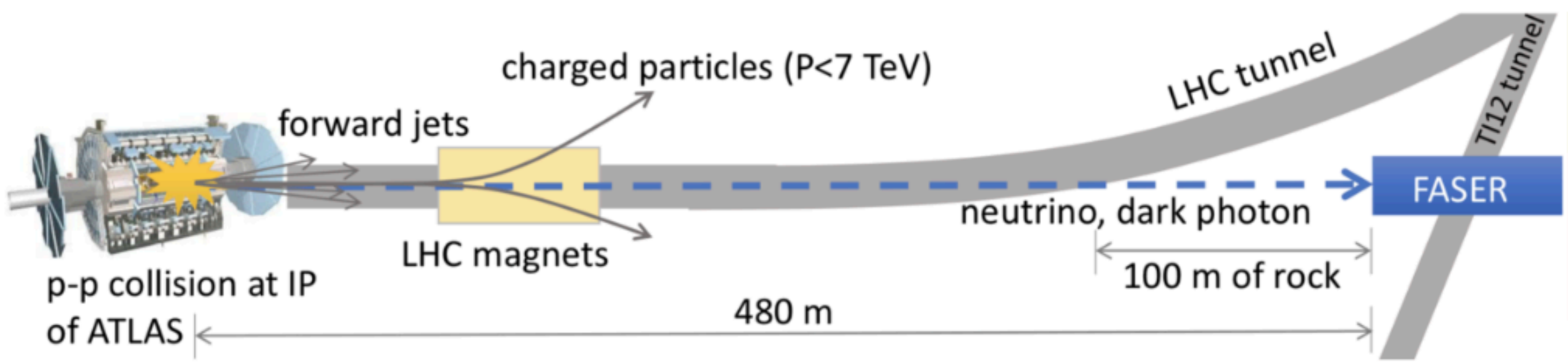
Factors driving sensitivity

- **Production:** Luminosity and Cross section
- **Detection:** *A(L,p,Θ)*
  - Propagation within detector geometric acceptance
  - Decay within detector: d~p/m c. τ, P(decay)~exp[(Δ-L)/d] - exp[-L/d]

* For d >> L, P(decay) ~ exp[-L/d]

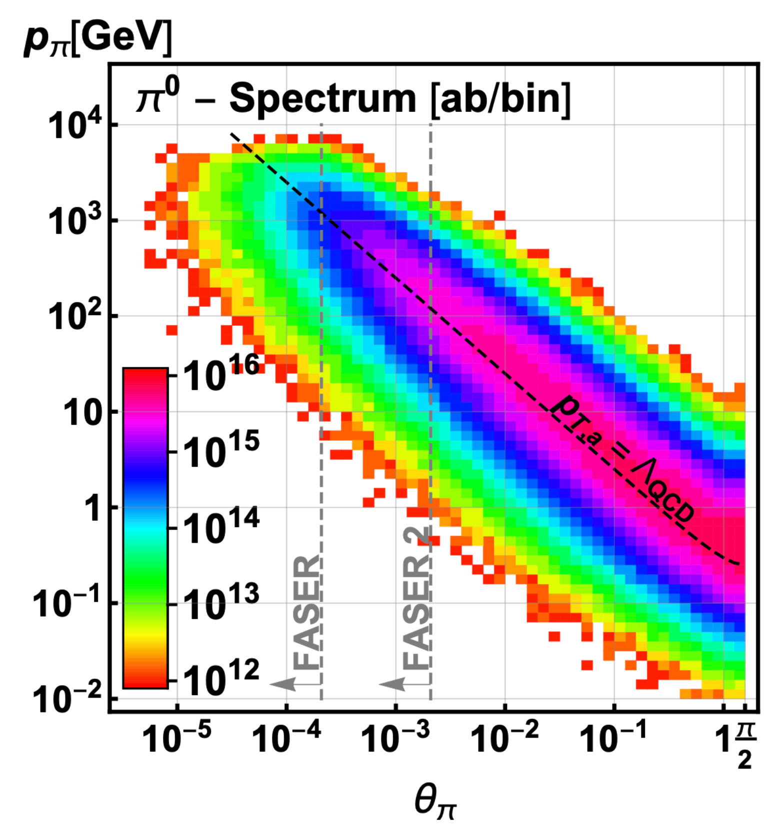
Weakly interacting Long Lived Particles with FASER

- FASER is located along the beam *collision axis line of sight 480m from the ATLAS interaction point (IP1)*



production angle **$\theta \sim \Lambda_{QCD} / E \sim$ mrad**
(with E ~ 100 GeV — 1 TeV)

σ_{inel}(13 TeV) ~ 75 mb → **N_{inel} (Run3, 150 fb^{-1}) ~10^{16}**

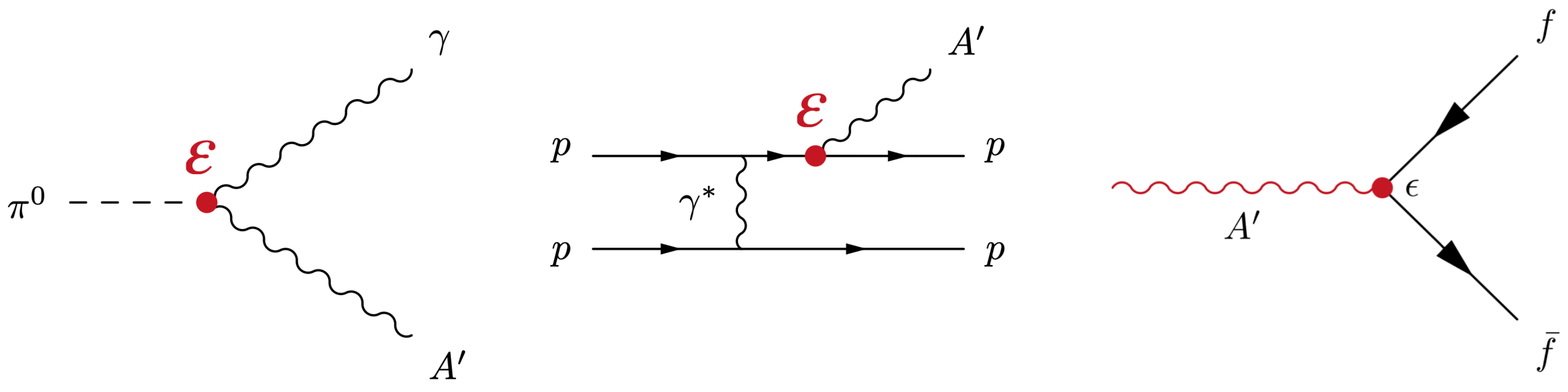


LLP produced in π, K, D, B decays

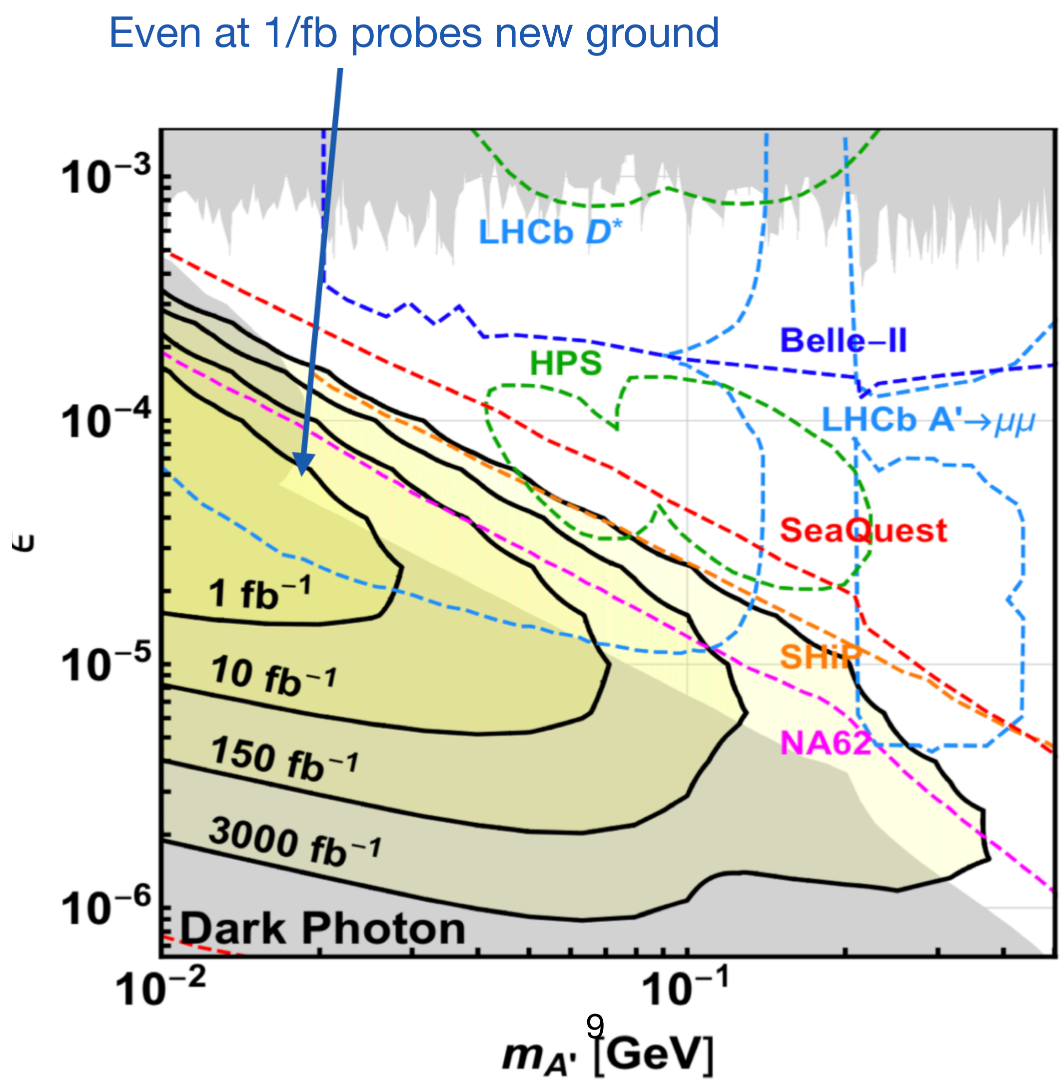
At FASER, expect during Run-3 (150 fb^{-1})

$$\sim 2.3 \times 10^{17}\ \pi^0,\ \sim 2.5 \times 10^{16}\ \eta,\ \sim 1.1 \times 10^{15}\ D,\ \sim 7.1 \times 10^{13}\ B$$

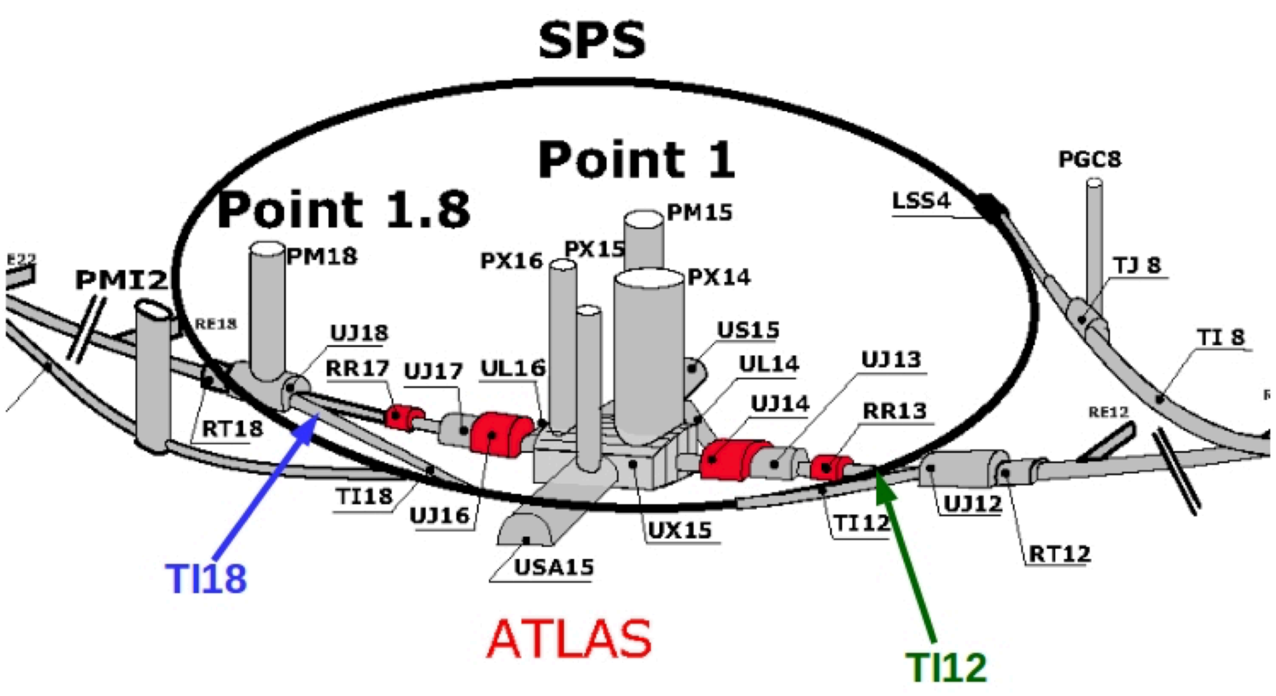
Physics Potential

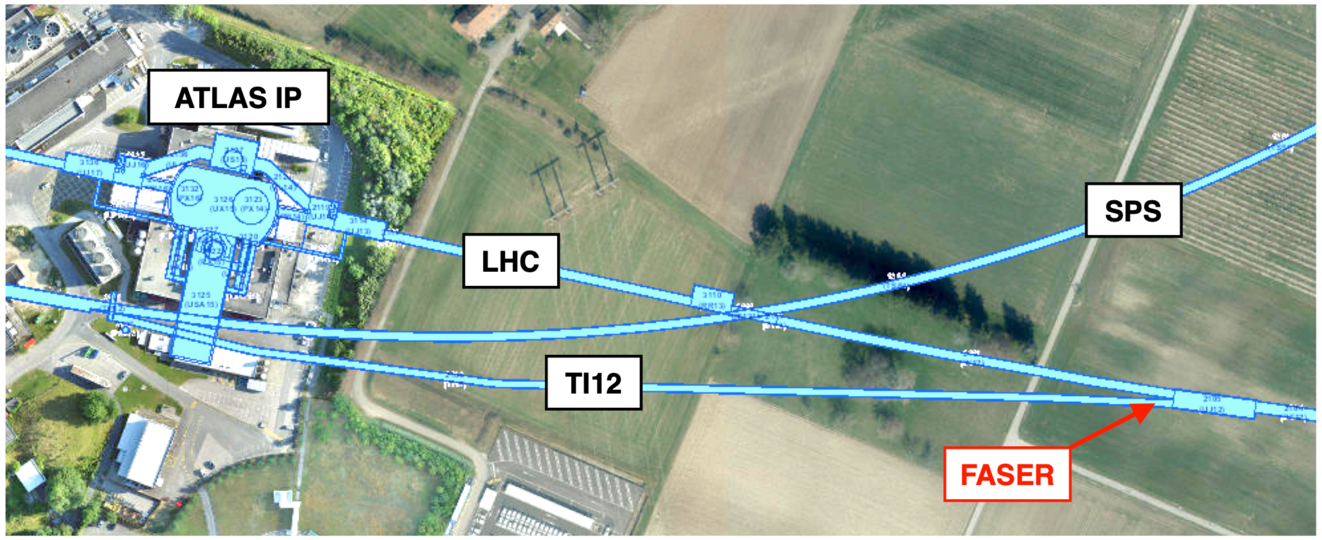


Example: Dark Photon

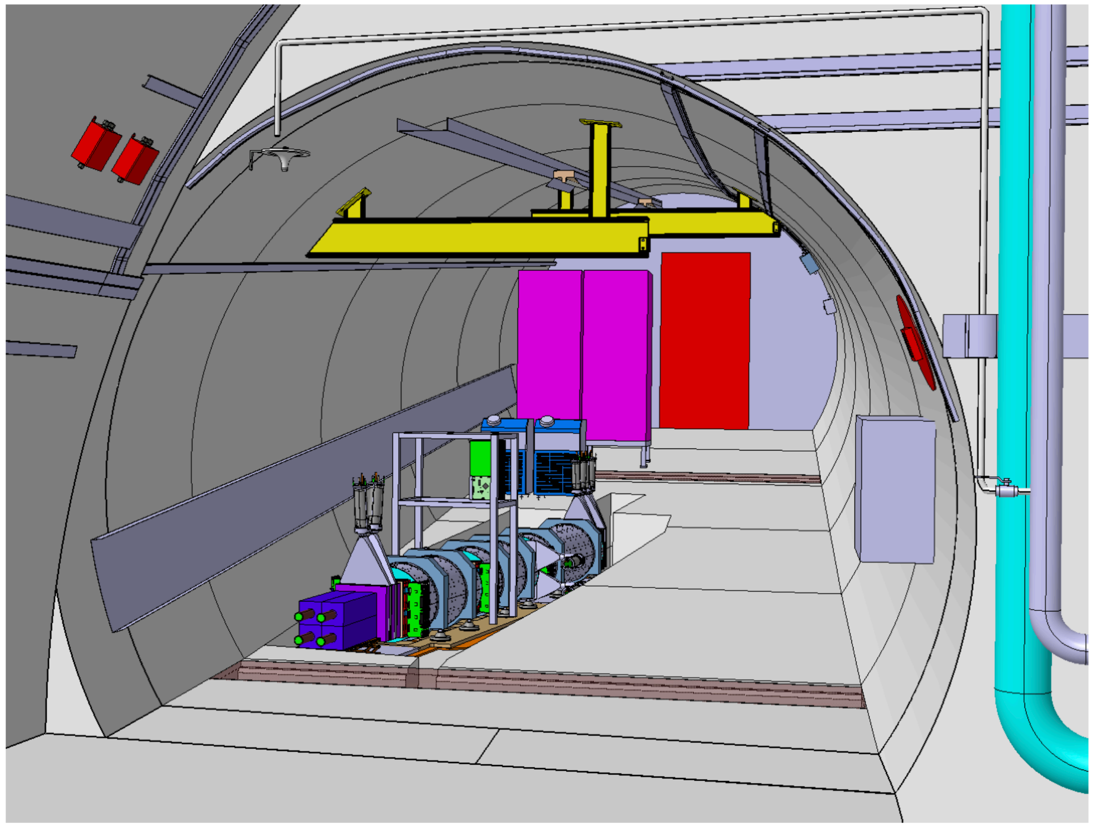


FASER Location



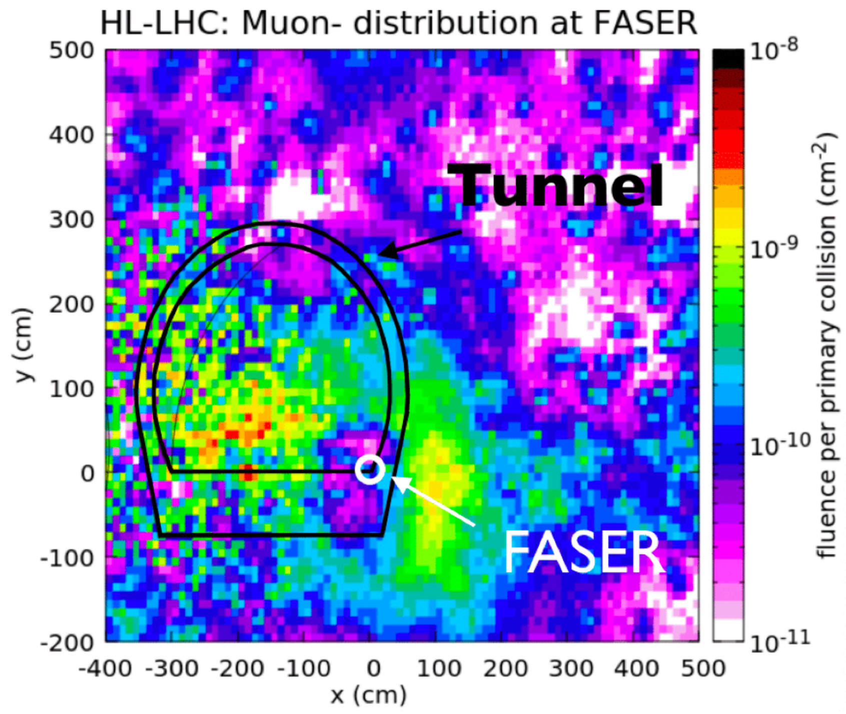


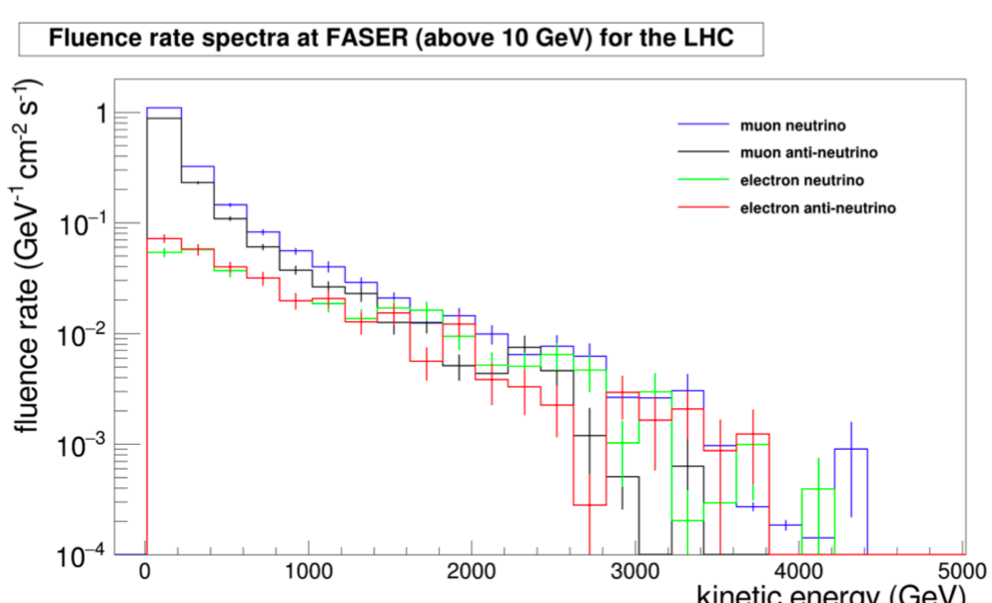
TI12: Old SPS-Lep Tunnel
Shielded by ~ 100m rock



Backgrounds

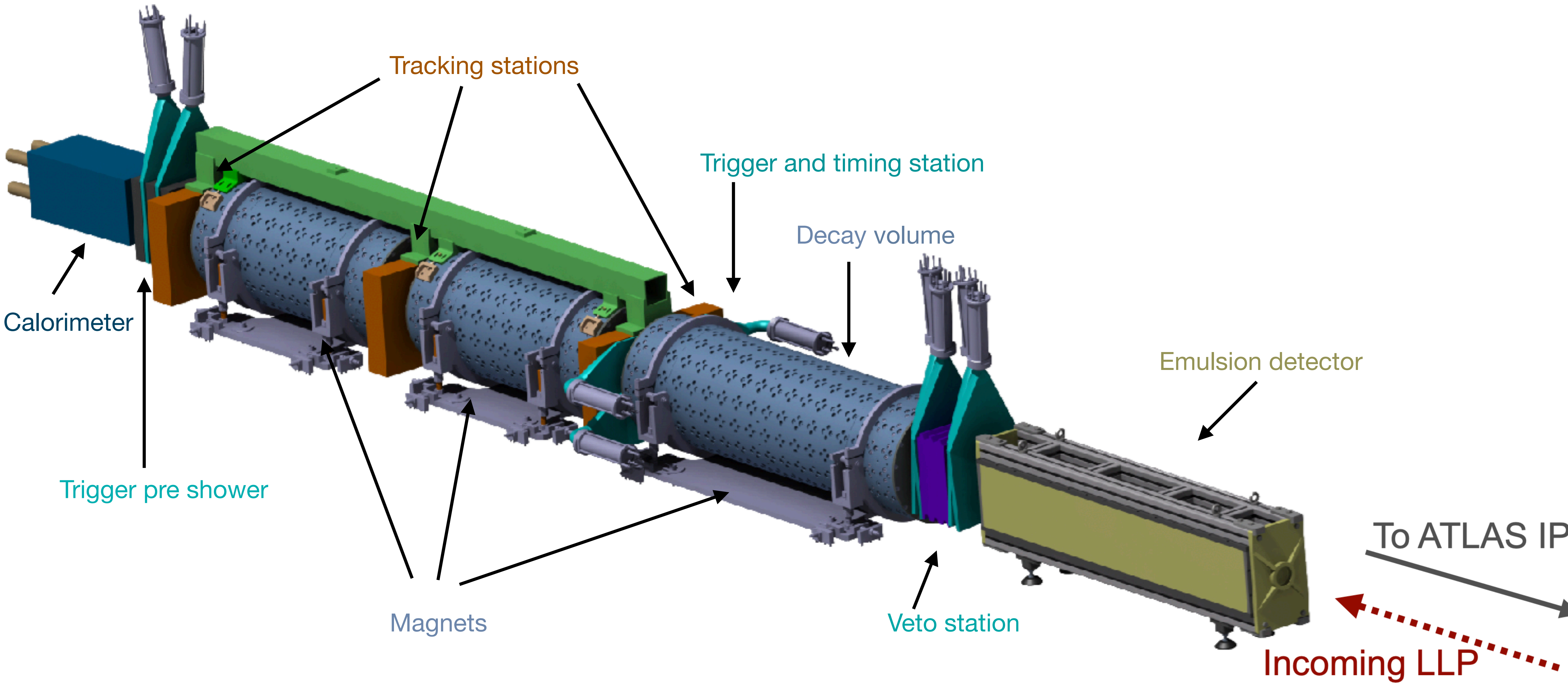
- Simulation and *in-situ measurements*
  - *IP1* collisions (shielded by 100m of rock)
    - Off-orbit protons
    - Beam gass interactions
  - Low particle flux due to LHC optics
  - Low radiation



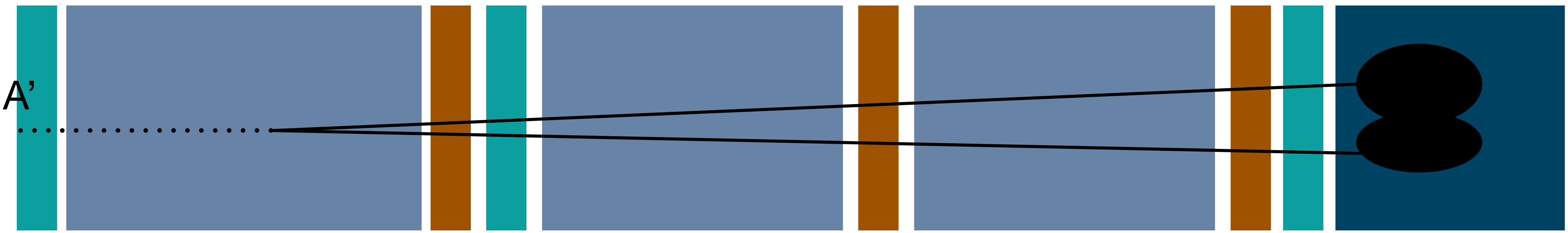


Muons (@L=$2x10^{-34}$ cm^{-2} s^{-1})	
Energy threshold [GeV]	Charged Particle Flux [cm^{-2} s^{-1}]
10	0.40
100	0.20
1000	0.06

Detector Layout



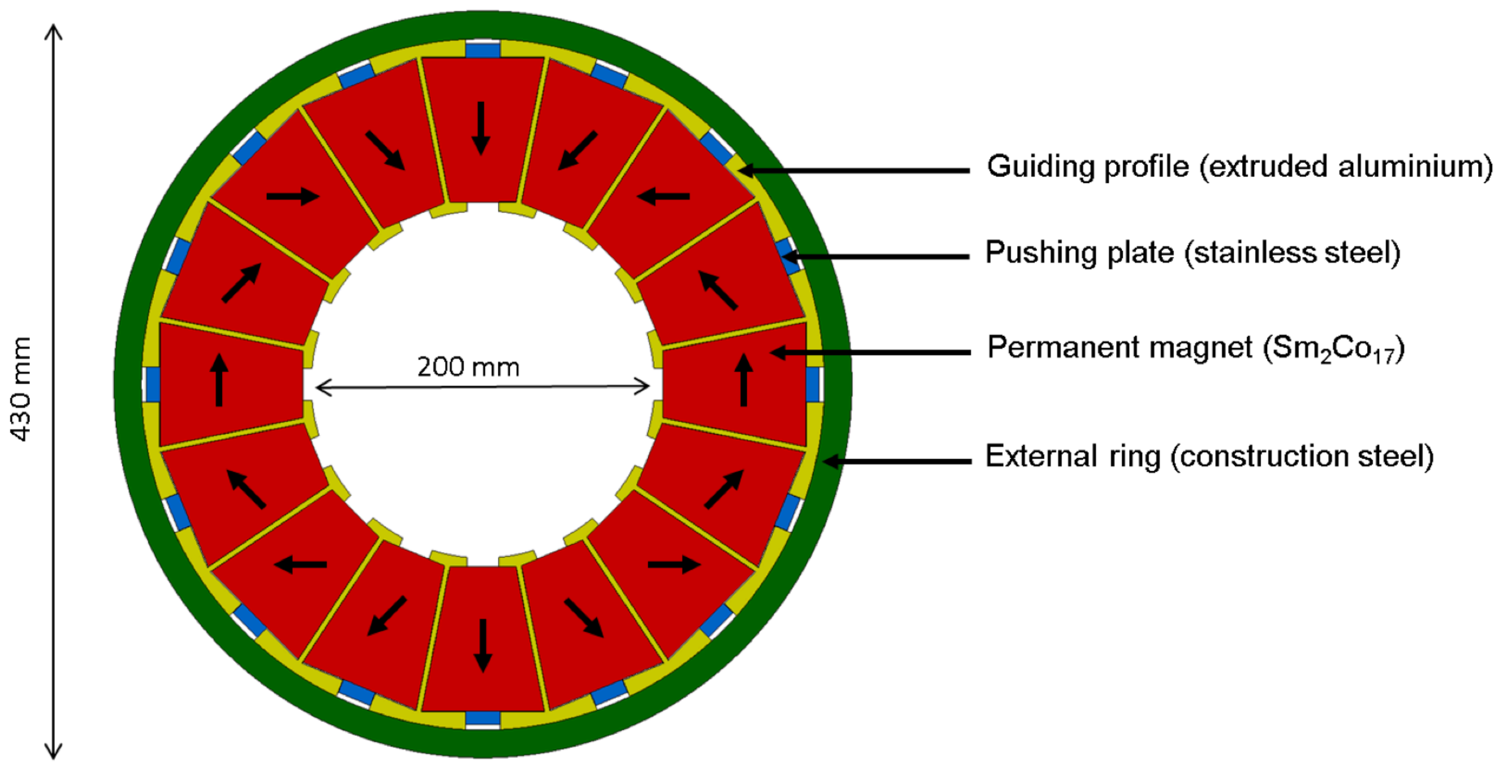
Signal Signature

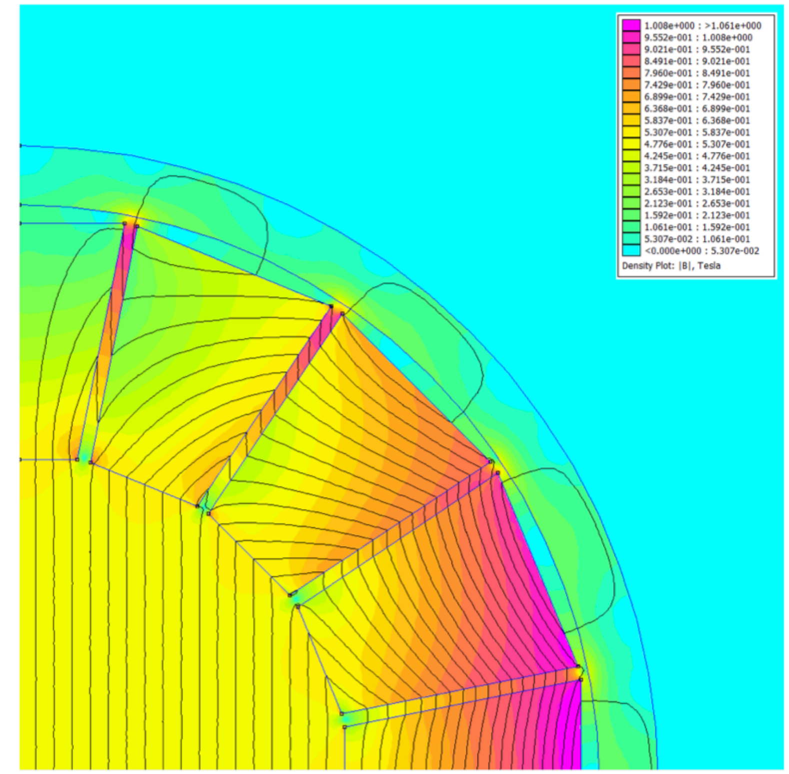


A’ —> ee

- No signal in the veto scintillator, and signal in the two trigger scintillators
- Two opposite charge tracks consistent with a common vertex and pointing to IP1 (magnets separate the tracks)
- EM shower (too close to be resolved for A’ case)

Magnets

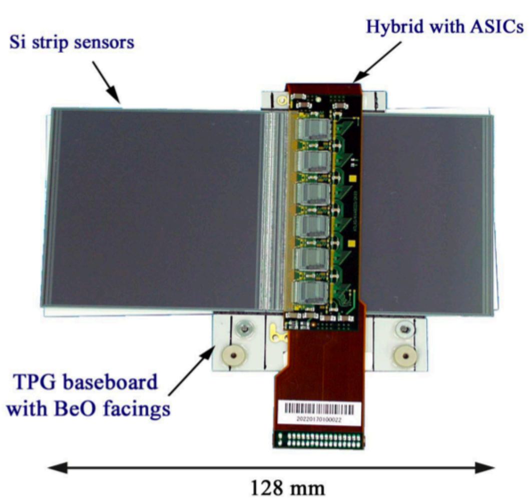




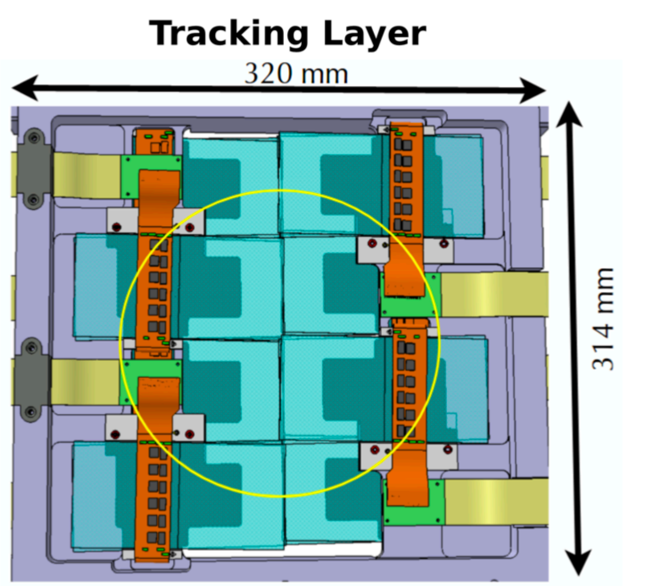
- B=0.55 T, 1.5m (decay volume) 2x1m (spectrometer)
- Permanent dipole magnets with Halbach design
  - Minimize services
  - Thin enough to allow line of sight to the IP without too much digging
- Designed and Constructed by the CERN magnet group

Tracking detector

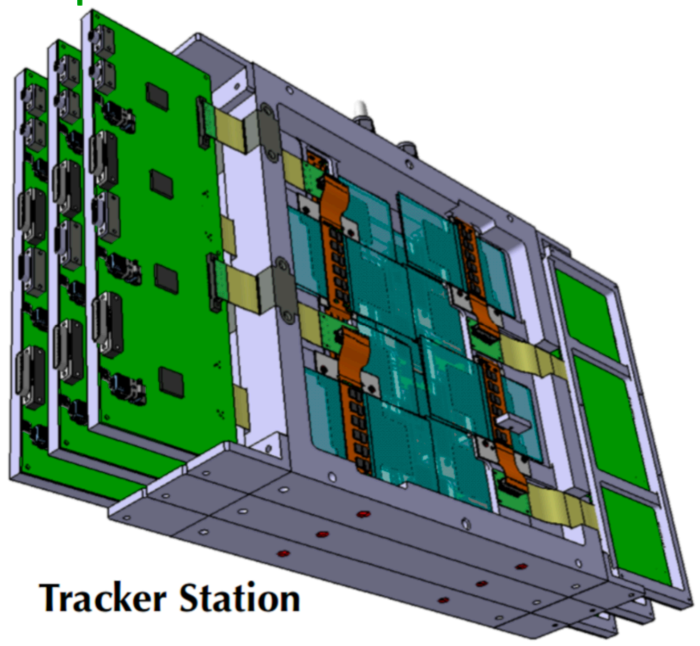
- Separate efficiently two very close tracks
    - Tracking system: 3 tracking stations with 3 tracking layers each
    - 8 ATLAS SCT spare modules per layer (**Thanks ATLAS SCT!**)
    - 80um pitch, 40mrad stereo angle, 1536 channels per module 17um/580um resolution (precision in the bending plane)
-



ATLAS SCT barrel module

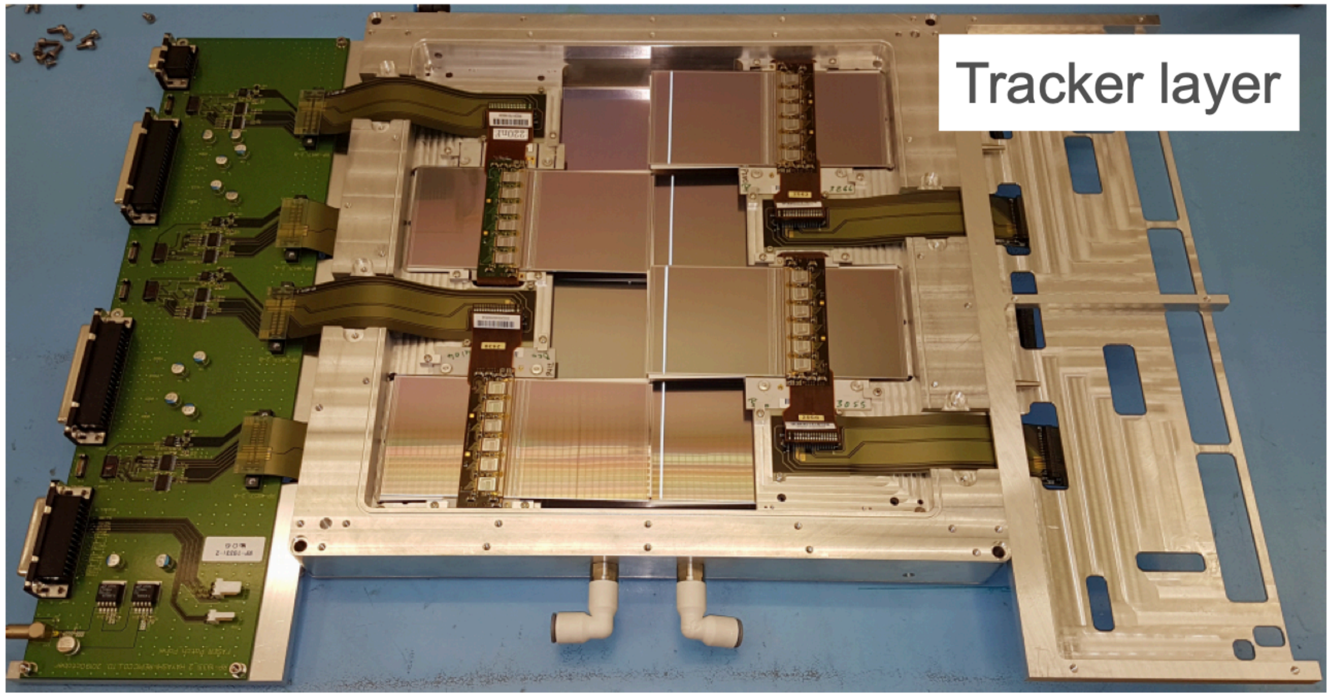


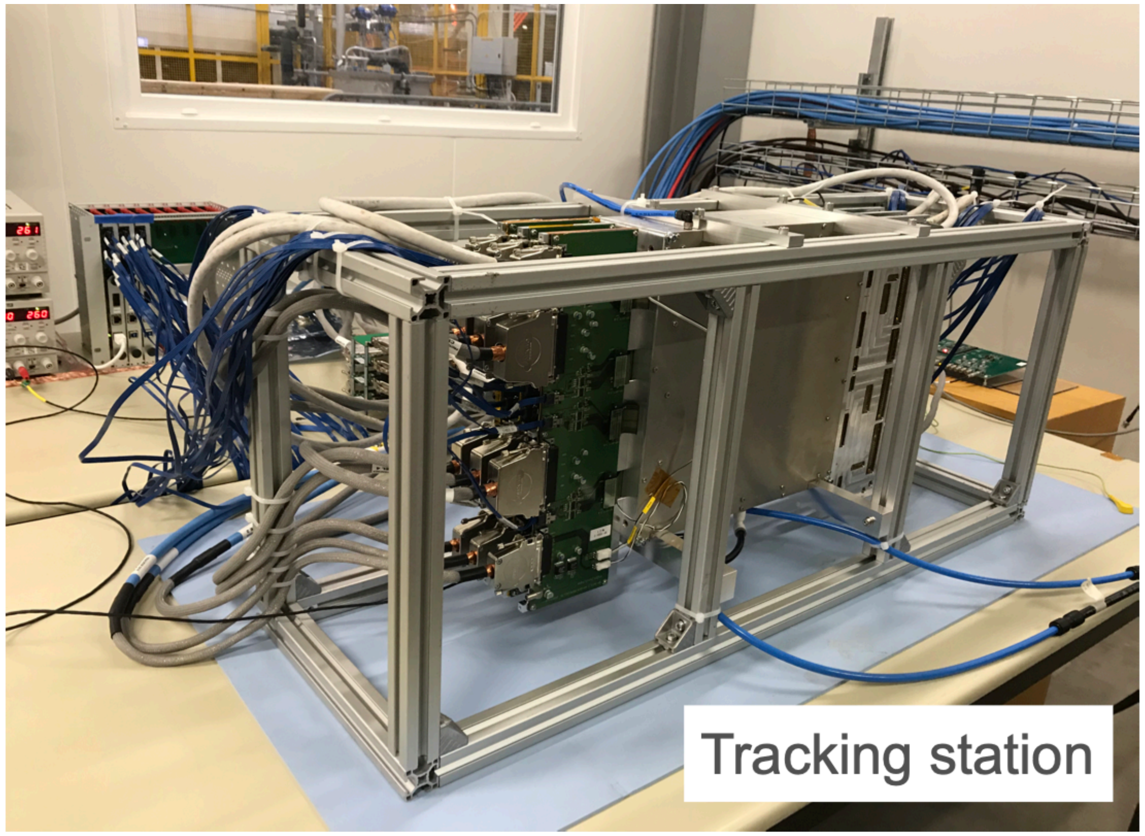
Flex cables

Patch panels


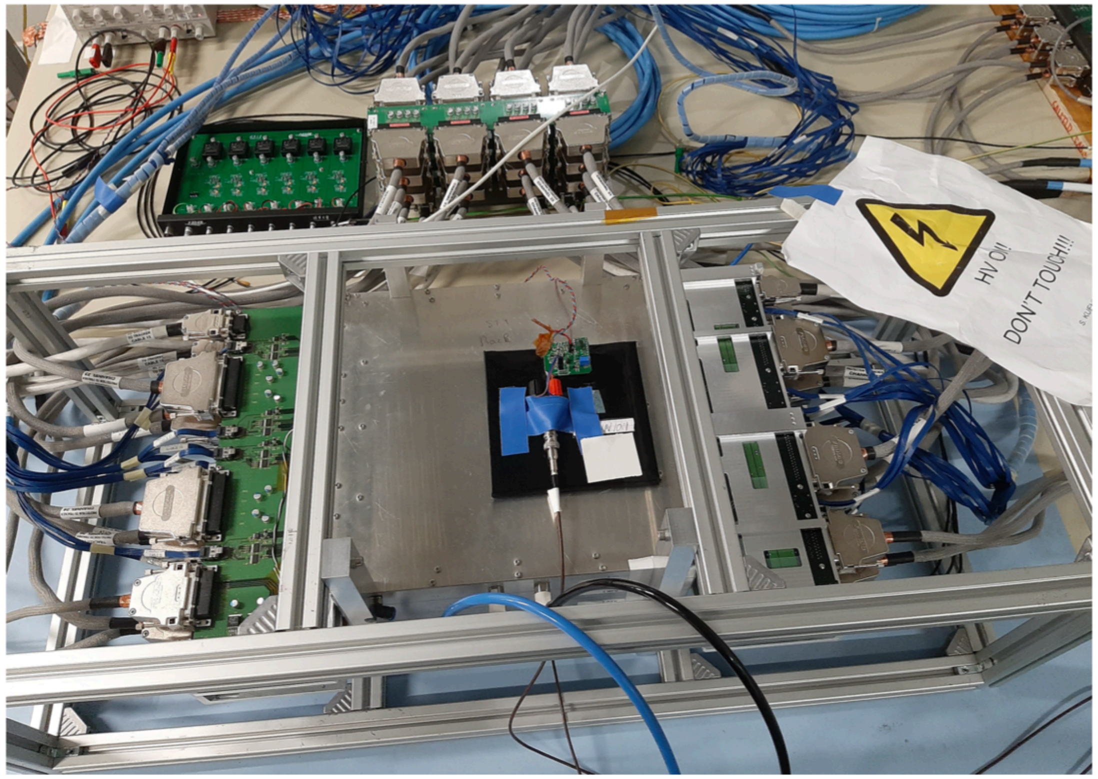
Tracking detector

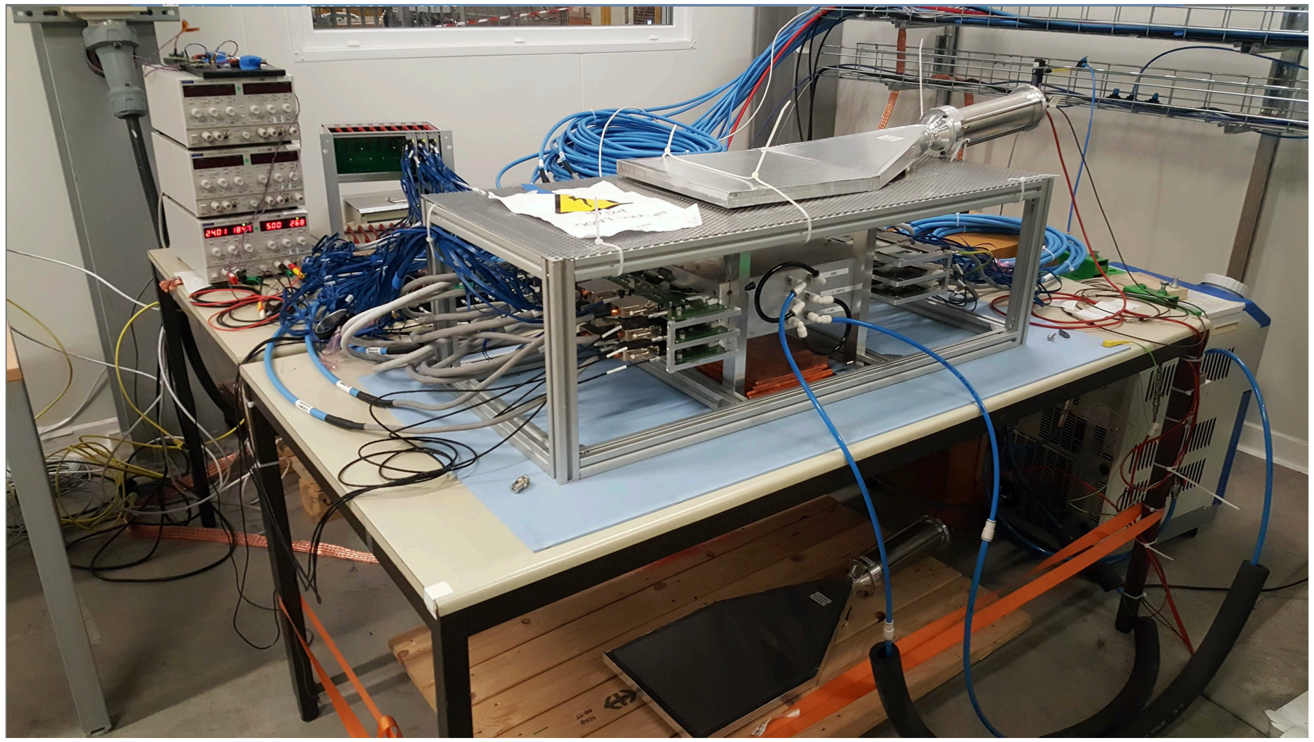
- Low radiation - Can be operated at room temperature but need water cooling to remove 360W from the detector ASICS
- Not using ATLAS readout (too complex), custom flex cable, patch panel and FPGA based readout module (a few meters from the detector)





Tracking cosmic test-bench

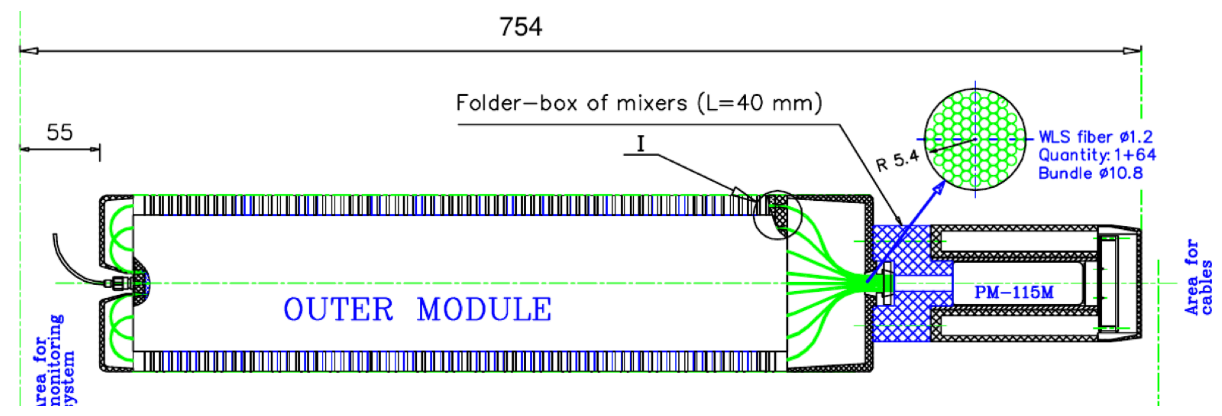




- Cosmic data taking with one station at the time
  - Operational experience, tracking efficiency and local resolution and alignment, offline studies
- Top/bottom scintillator for trigger
- FASER TDAQ

EM calorimeter

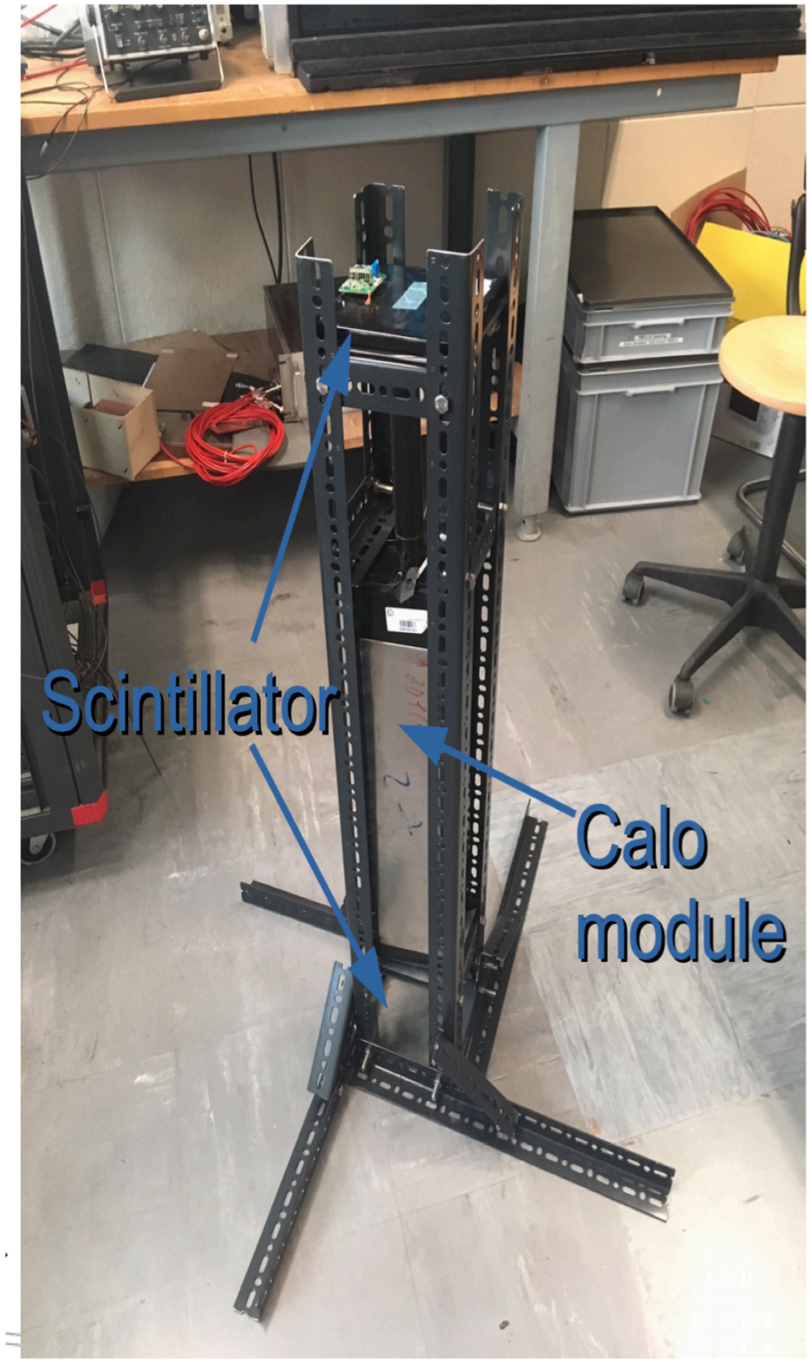
- Measure the EM energy
- Electron/photon identification
- Trigger



- 4 spare EM calo modules from LHCb (**Thanks LHCb!**)
- 66 layers (2mm Pb+4mm plastic scintillator) 25 x_0
- Dimensions: 12cm x 12cm x 75cm including PMT
- 1% resolution for 1 TeV electrons

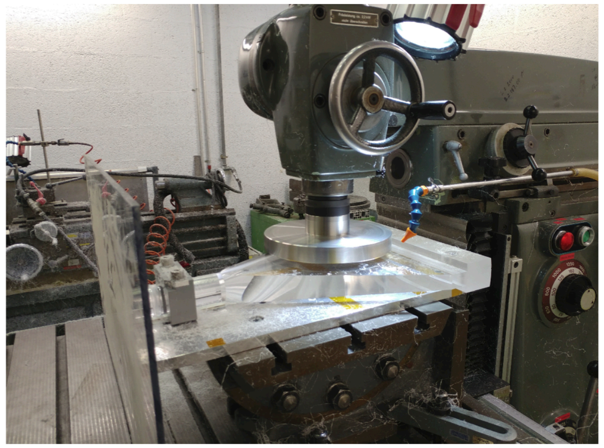
EM calorimeter - cosmic test bench

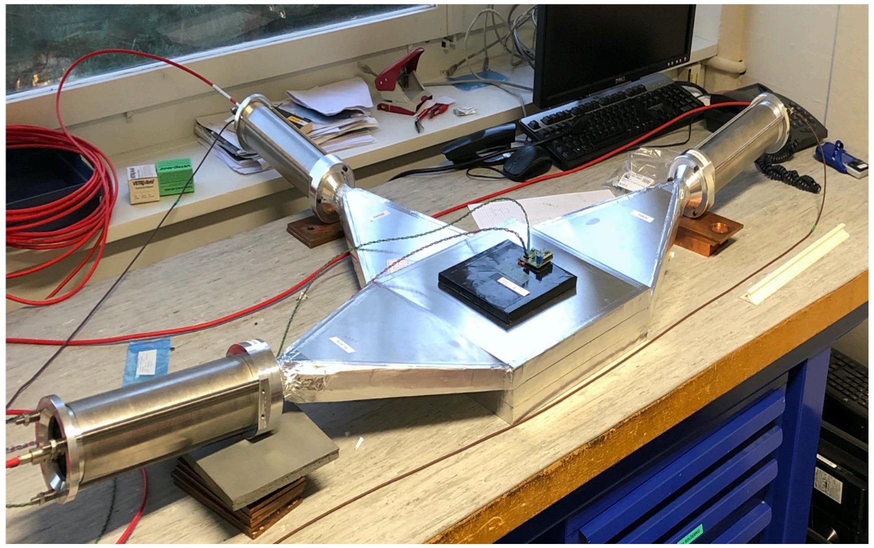
- Cosmics to test calorimeter response and to calibrate PMT
    - Top/down scintillator to trigger on cosmic muon
    - Close to final readout
- Good agreement with expected response

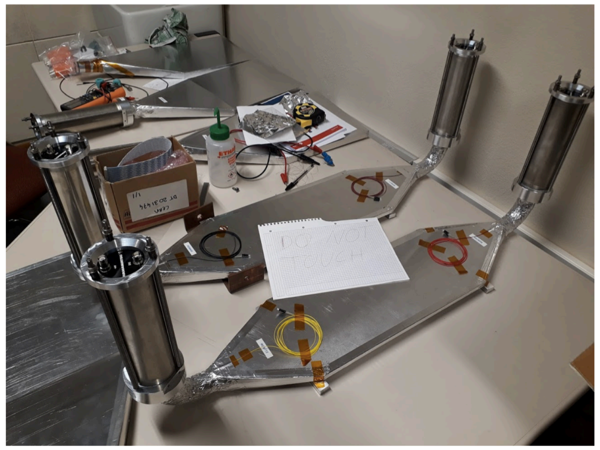


Scintillators

- **Veto** incoming charged particles: Requires very high efficiency O(10^8 muons in 150/fb)
  - Efficiency > 99.9% measured with cosmic
- **Trigger**
- **Timing measurement** ~ 1ns resolution



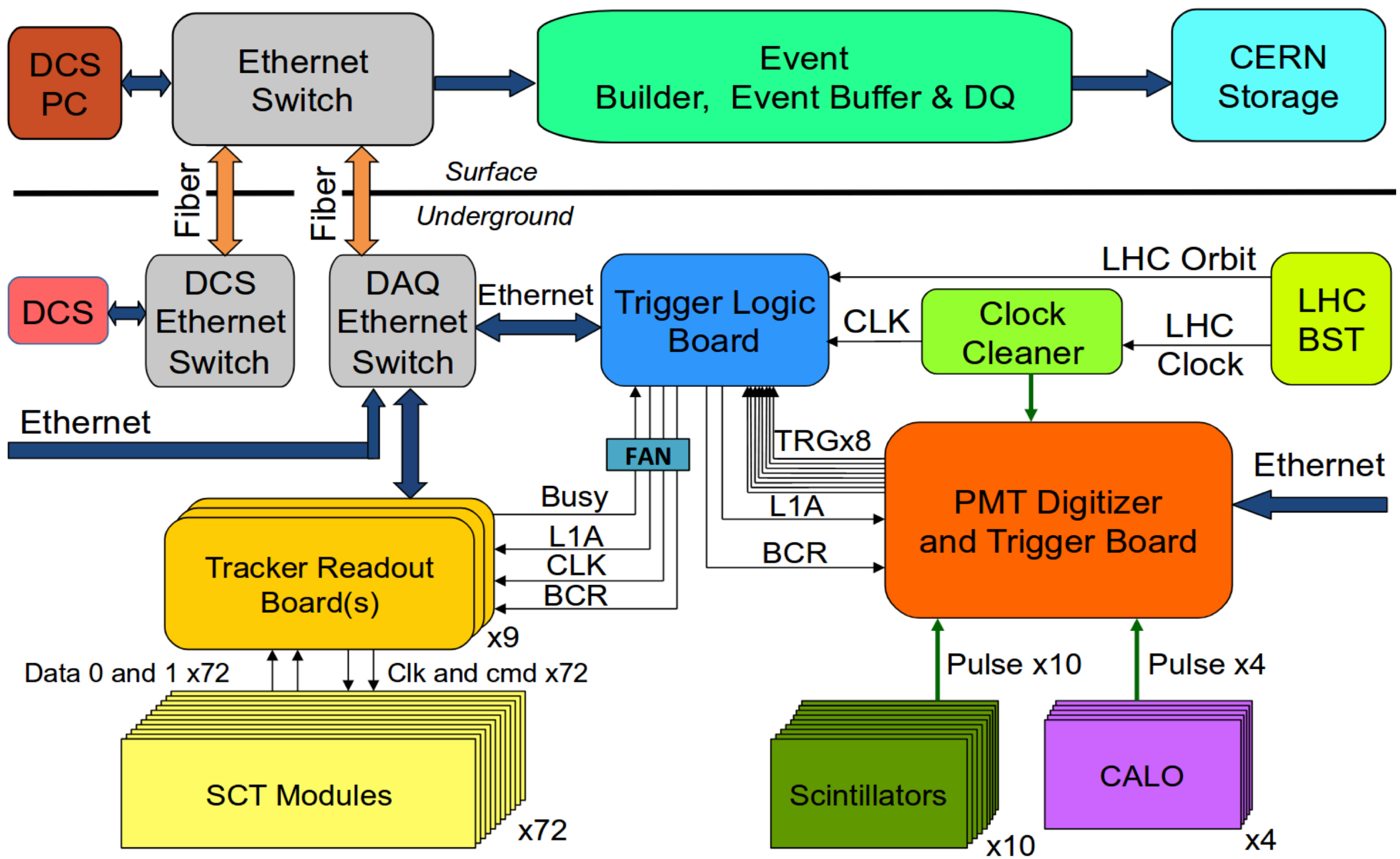




Trigger, Data Acquisition and Offline SW

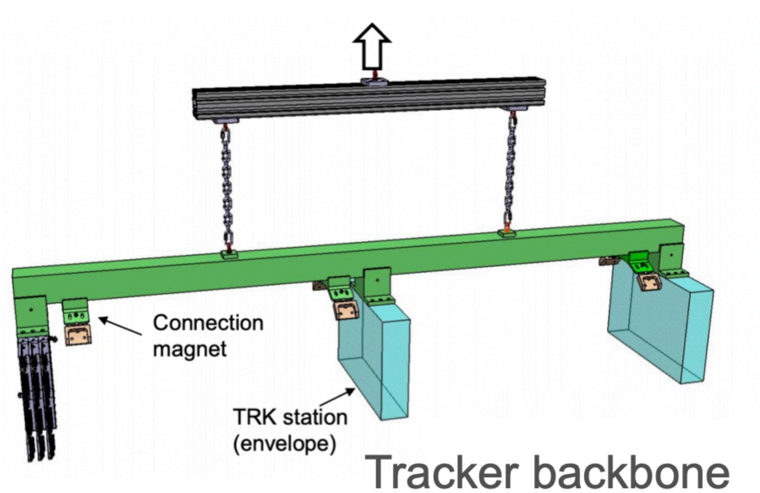
- **Trigger:** OR from Scintillators and calorimeter
  - Plan is to trigger on all particles
  - Max trigger rate ~500Hz from muons
- **Trigger Logic Board:** FPGA board (same as tracker readout board with different firmware/adapter card)
- **DAQ:** Event size ~25KB dominated by PMT waveforms, Bandwidth 15MB/s
- **Trigger and Readout Electronics at TI12, Event builder and DAQ sw runs at PC on surface**
- **DAQ software:** Based on DAQling (small experiment DAQ software by CERN)
- **Offline:** Based on Calypso (open source Athena)

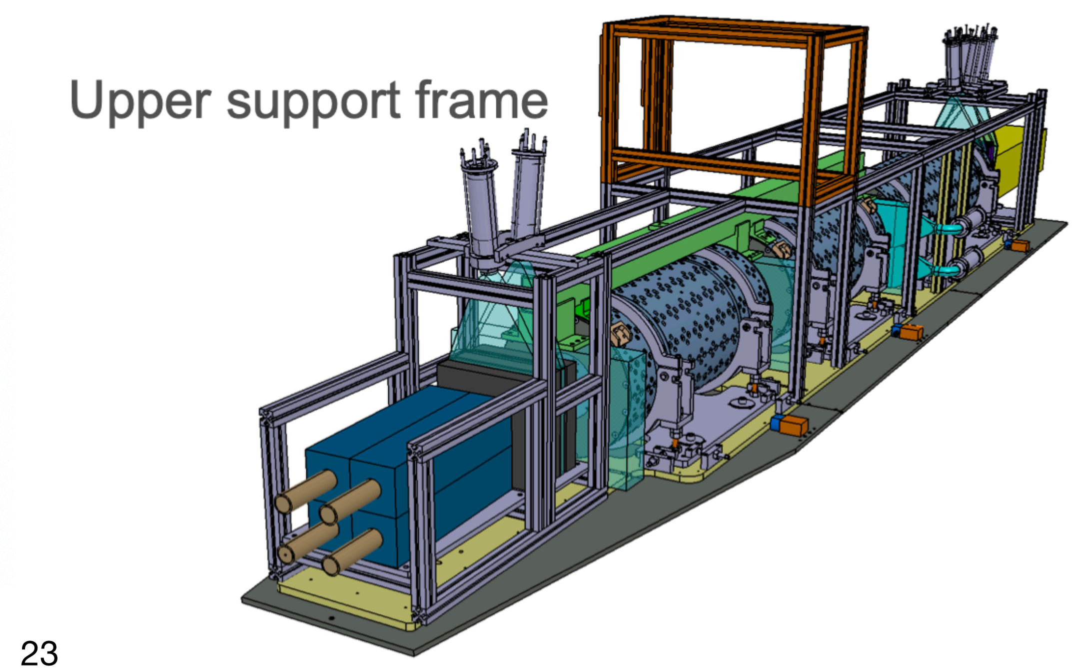
TDAQ/Control architecture



Detector support

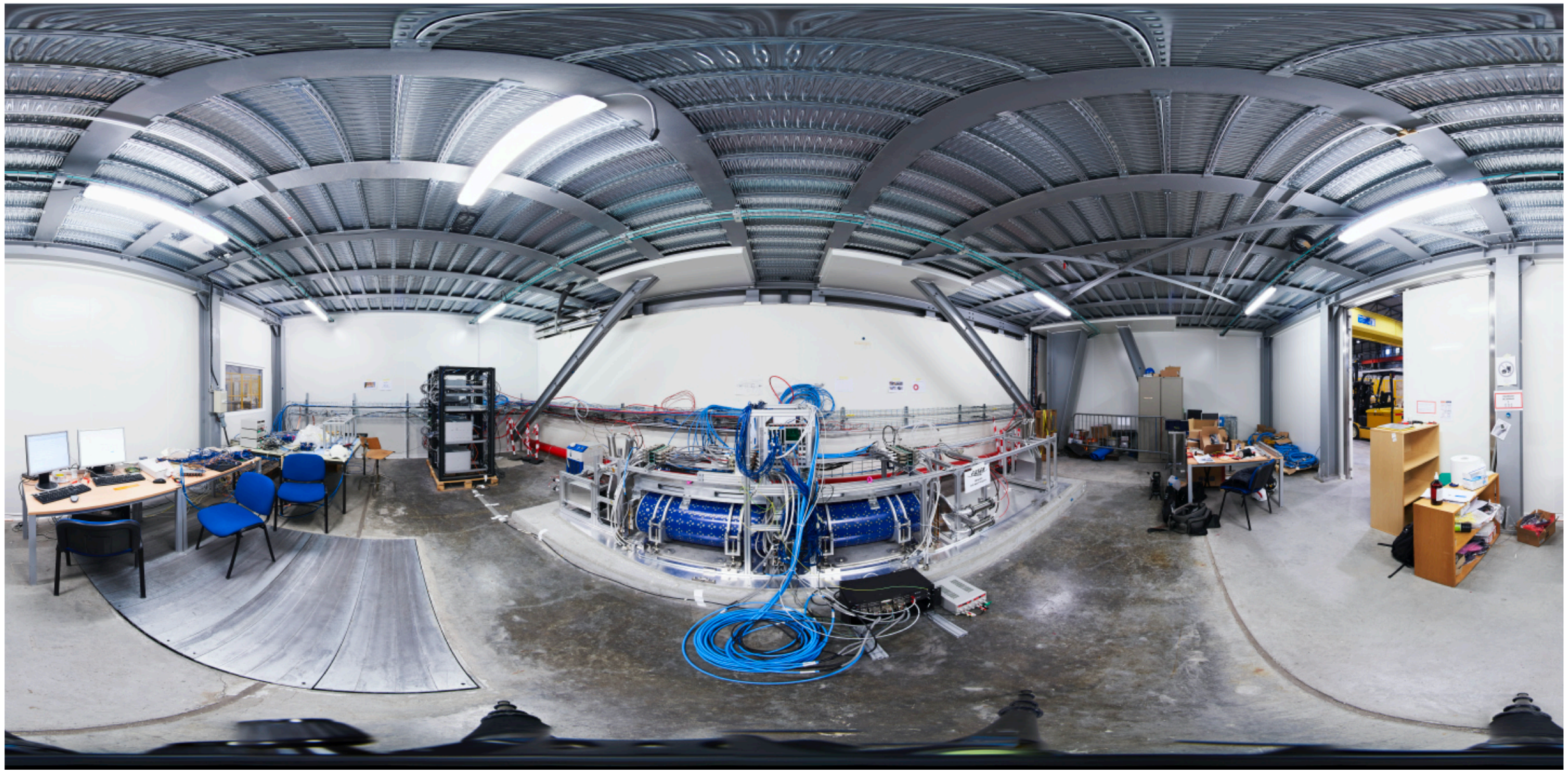
- Keep tracking stations aligned within 100um
- Align magnets to Beam Collision Line of Sight
- Allow detector to follow changes in Beam Collision Line of Sight due changes in crossing angle
- Tracker is connected through backbone mounted on magnets
- Baseplate securing magnets





Dry run on surface

- Detector assembled and run on surface
  - 1 / 3 tracking stations, without decay volume magnet



Detector installation @ TI12

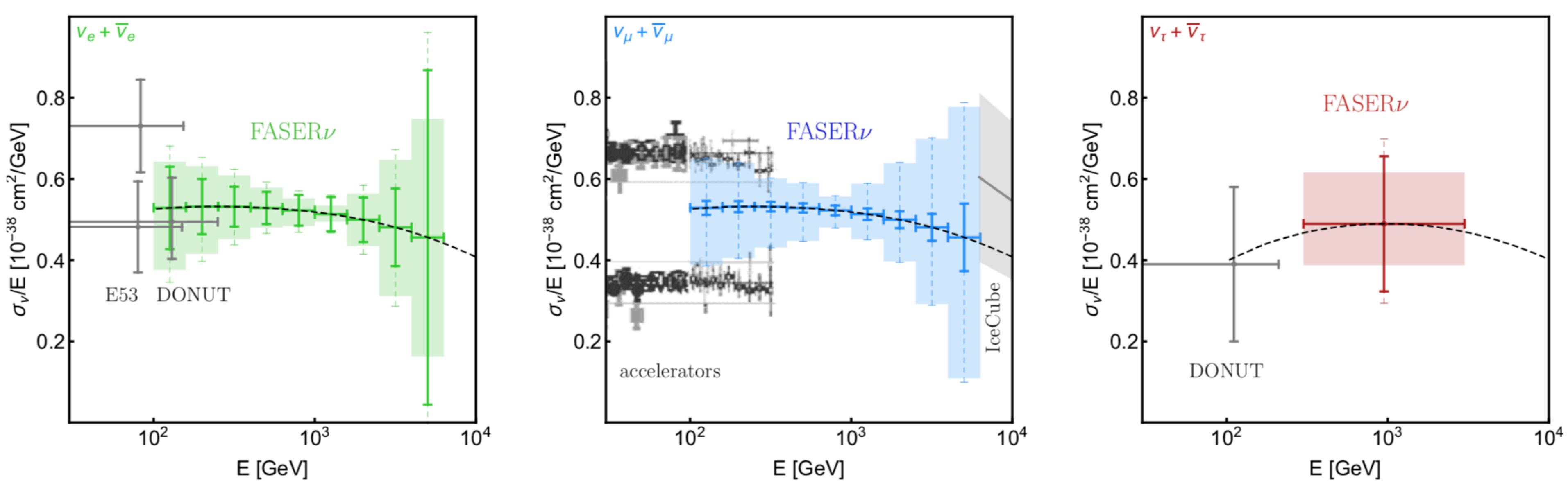
- Cooling
- Magnets
- Electronics and Power supply
- Detector baseplate



FASER ν

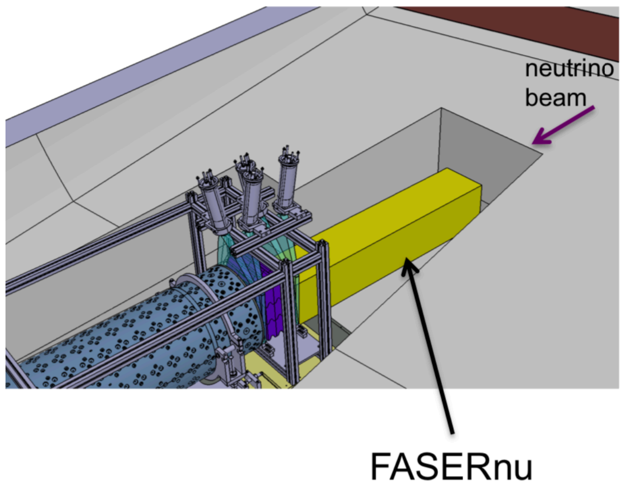
- Huge number of highly energetic neutrinos are produced at the LHC (hadron decays)
- A neutrino detector placed at the FASER cavern can probe a new energy regime for neutrinos —> Cross section measurement at high energy
- FASER ν is an emulsion detector placed in front of the main detector

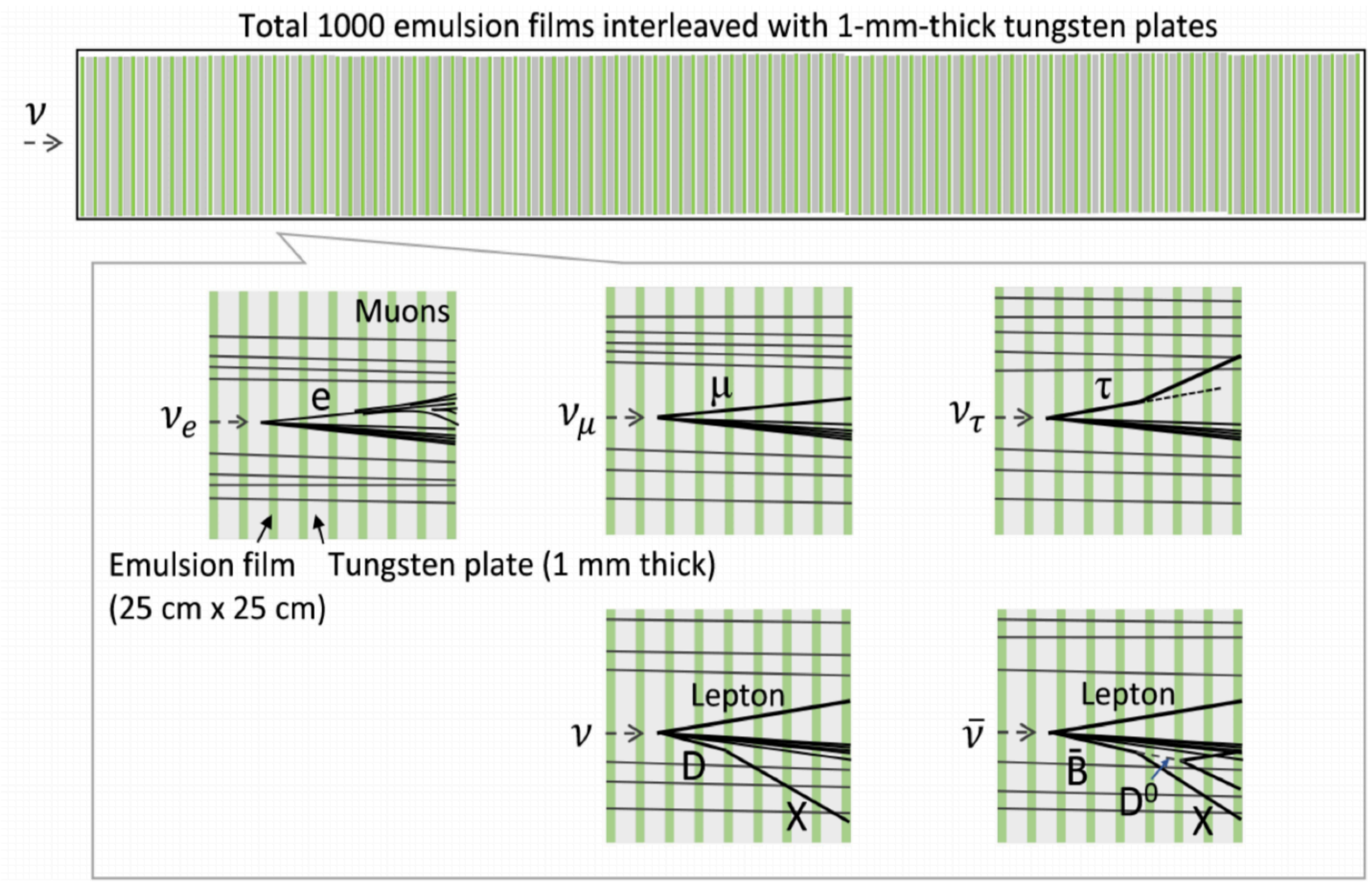
150/fb @ 14 TeV	ν_e	ν_μ	ν_τ
Main production	K decay	Pi decay	D decay
Reach FASER ν	$O(10^{11})$	$O(10^{12})$	$1O(10^{9})$
Interact	~1.3 K	~20K	~20



FASER ν

- 1.3m x 25cm x 25cm detector
- 1000 x 1mm tungsten plates (1.2 tn) interleaved with emulsion film
- Track position resolution 50nm, angular resolution 0.35mrad
  - needs to be replaced ~30-50/fb





Summary

- FASER is a small experiment looking for LLPs produced at the LHC, will collect data from 2022+ (Run-3)
  - Targets NP weakly interacting long-lived particles
  - Collider Neutrinos at high energy regime
  - Fast: Proposal (2018), Approval (2019), Installation (2020)
  - Affordable: Reuse parts from other experiments where possible
- Construction of FASER on time - will be ready for data taking 2022!

CERN

SIMONS FOUNDATION

HEISING-SIMONS FOUNDATION

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- More info:
  - FASER LOI: 1811.10243
  - FASER TP: 1811.10243
  - FASER Physics: 1811.12522
  - FASER nu LOI: 1908.02310
  - FASER nu TP: 2001.03073