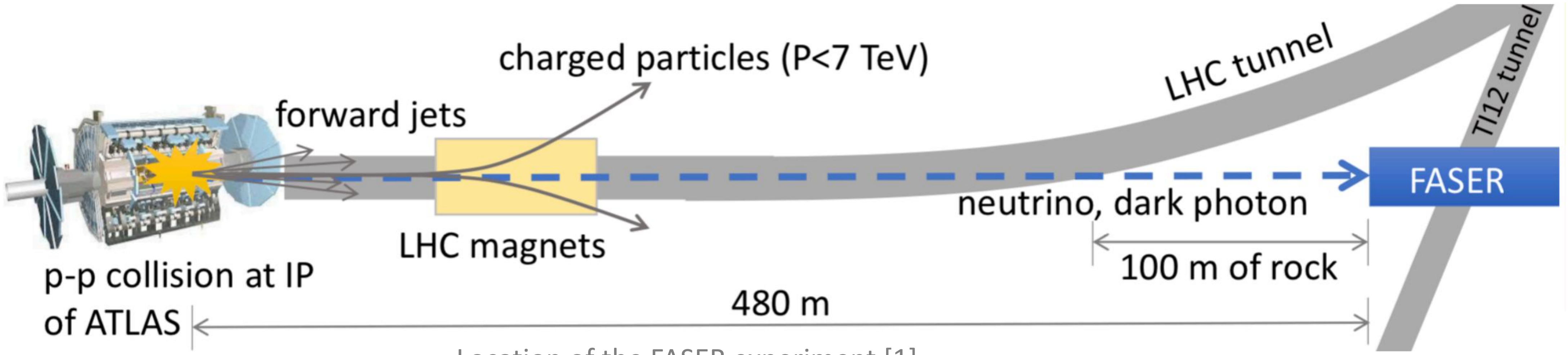
Looking for new physics at LHC: ForwArd Search ExpeRiement

Presented by: Feifei Xiao

Location: 480m from the ATLAS Interaction point (IP)



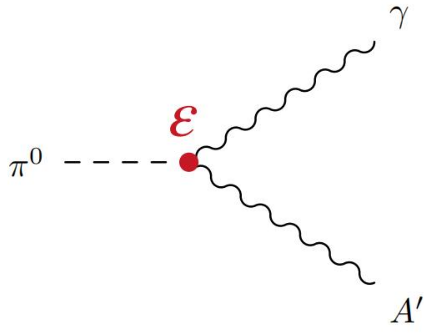
Location of the FASER experiment [1]

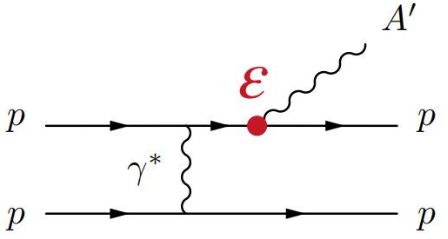
Goal of the FASER:

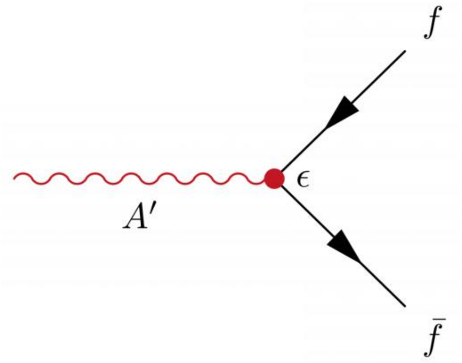
- Search for new light weakly-interacting long-lived particles (LLPs)
- Study high-energy neutrino interactions (with sub-detector FASERν)

What can LLPs be?

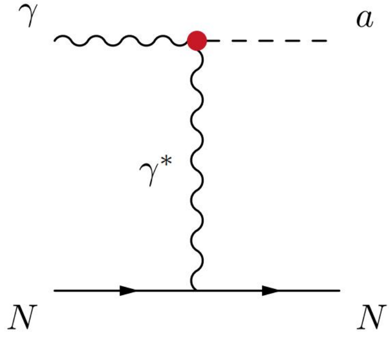
- Dark Photons







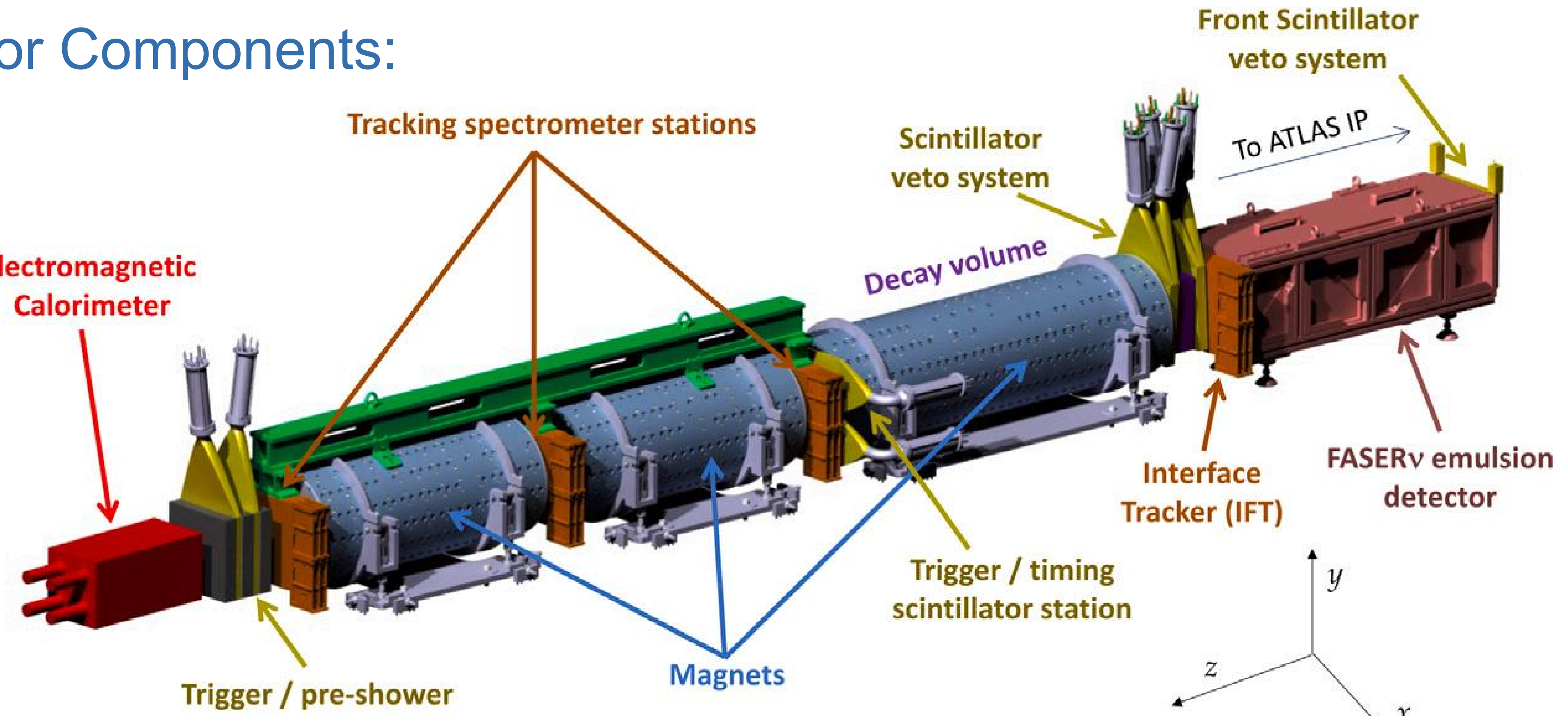
- Axion-like Particles (ALPs)



$$a \to \gamma\gamma$$

- Dark higgs $\mathcal{L} \supset -\theta\,\phi^2\,|H|^2$ [2]
- Heavy Neutral Leptons $\mathcal{L} \supset -\sum y_{\alpha I}\bar{L}_\alpha H N_I$ [2]

Detector Components:

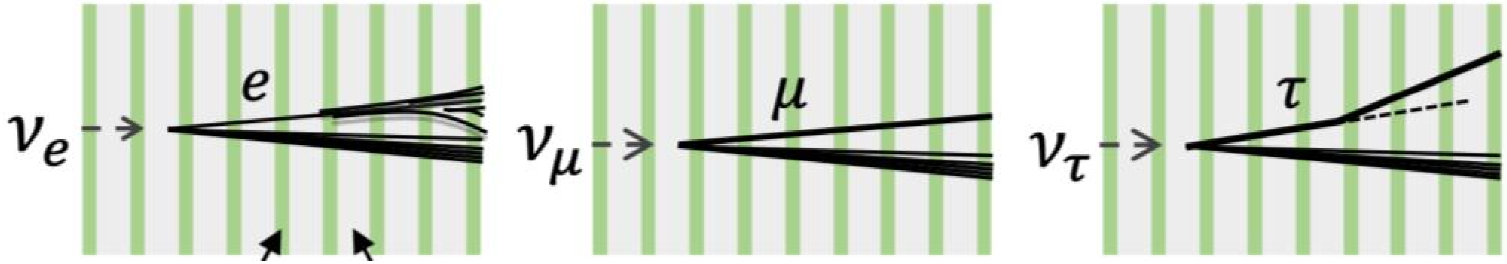


A Schematic view of the FASER detector [3]

Advantages:

- Small: 7m · 1.1m (aperture: 20cm) [4] & Inexpensive
- Low Background noise (1event $cm^{-1}s^{-1}$) & Minimal Radiation (4×10^{6} 1MeV ν cm^{-2} yr^{-1})

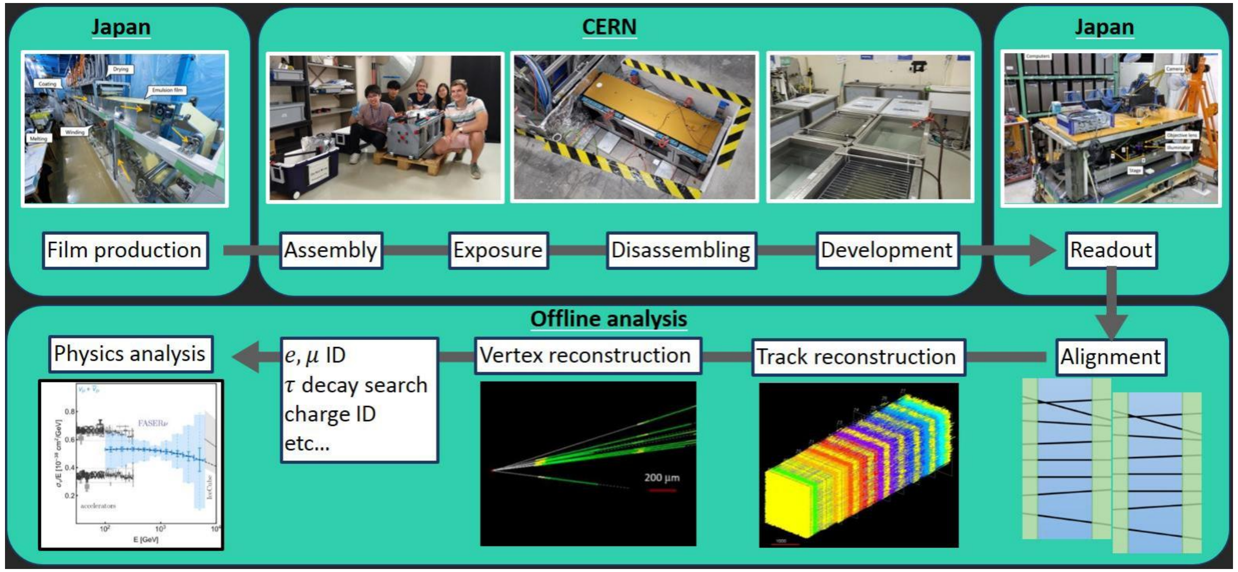
FASERν Emulsion Detector:



emulsion film tungsten plate (1.1m) [5]

- 730 layers (emulsion + tungsten)
- 1m long, 1.1 ton heavy
- Exchange emulsions every 3 months (keep track density < 30 fb^{-1})

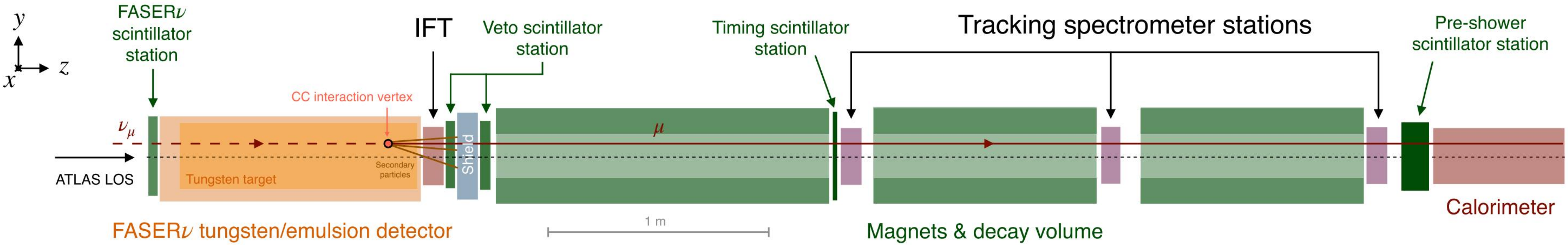
What to Measure? Technology?



FASERν processing and analysis chain [6]

- Analyze the trajectory inside the emulsion films
  ⟶ ν flavour tagging with topological information
- Latent image formation (similar to film exposure)
- Submicron spatial resolution (~0.4μm)
- No timing resolution
- Get event number of different neutrinos. 110fb^{-1} data collected, compare data with prediction.

First direct observation of neutrino interaction at a particle collider experiment:



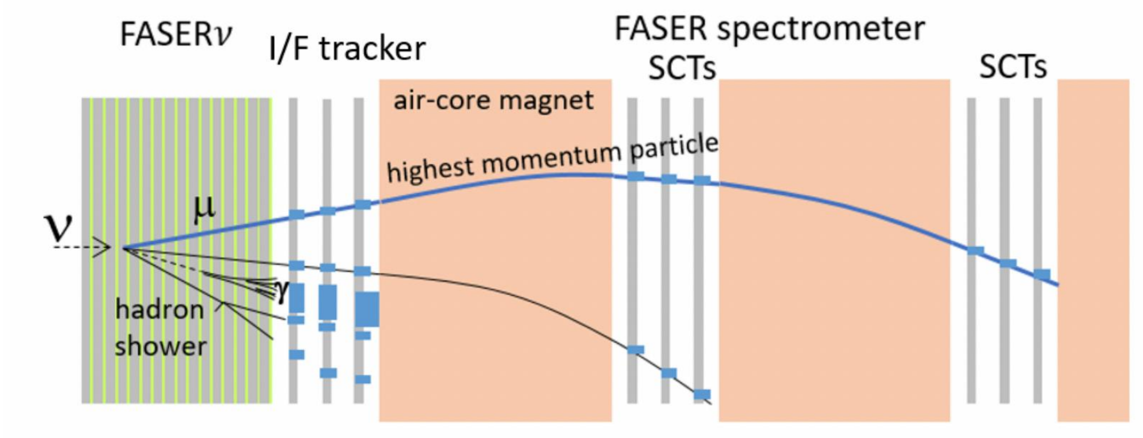
Schematic side view of the FASER detector with a muon neutrino undergoing a CC interaction in the emulsion-tungsten target [7]

Interface Silicon Tracker (IFT) [8]:

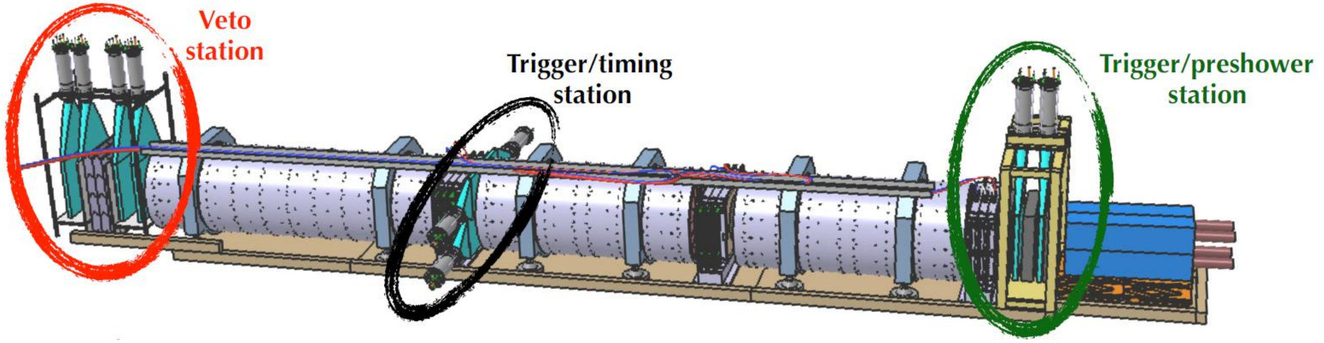
- 3-layer siliconstrip tracker
- Match tracks between FASERν and spectrometer
- ATLAS SCT barrel module (more details later)

Spectrometer & decay volume:

- Magnetic field of 0.55T
- Charge identification ⟶ determine ν or anti-ν
- More details later



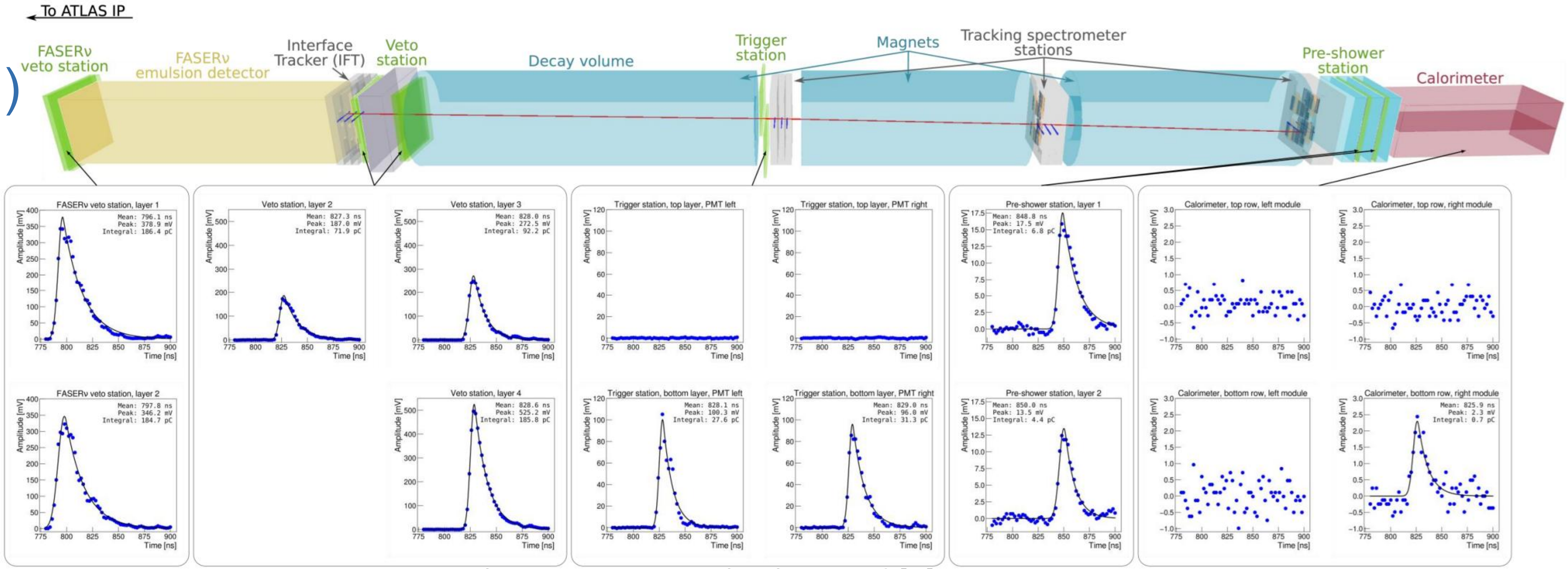
Scintillators: charged particles ⟶ scintillator ⟶ photomultiplier tubes ⟶ DAQ



A schematic view of scintillators [1]

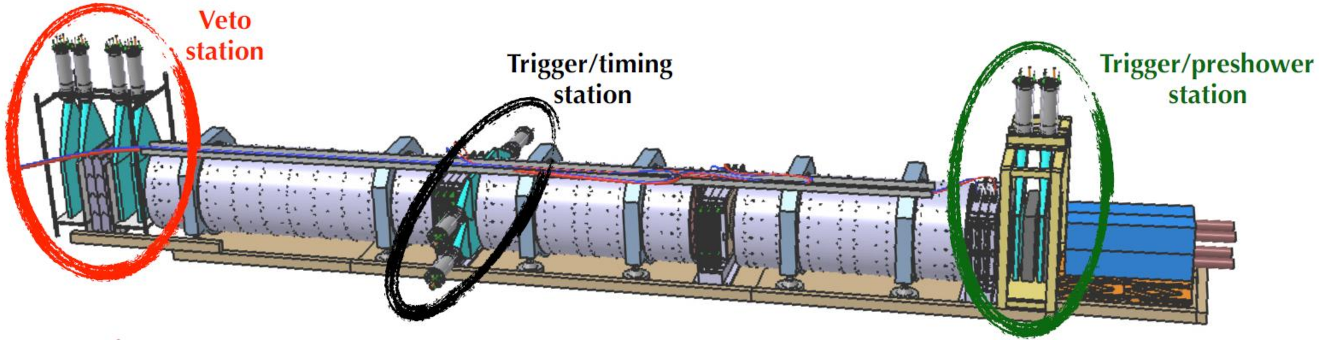
CAEN digitiser [1]

μ event: (background)



Example event: a muon background [9]

Scintillators: charged particles ⟶ scintillator ⟶ photomultiplier tubes ⟶ DAQ



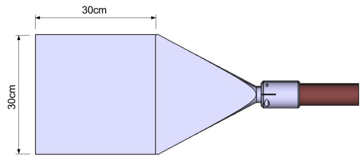
A schematic view of scintillators [1]

CAEN digitiser [1]

Veto Station component[10]

Veto station:

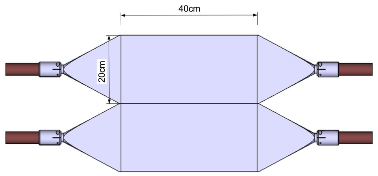
- 2 cm-thick, 30 cm × 30 cm plastic scintillators connected through light guides to PMTs
- Detect charged particles and veto these events, target efficiency per layer > 99%



Veto & Preshower Station [11]

Timing station:

- A single scintillator layer made from two 20 cm × 40 cm scintillator blocks with a thickness of 1cm.
- Detect the presence of a charged particle pair from the decay of an LLP in the decay volume of the first dipole magnet
- Timing resolution < 1ns

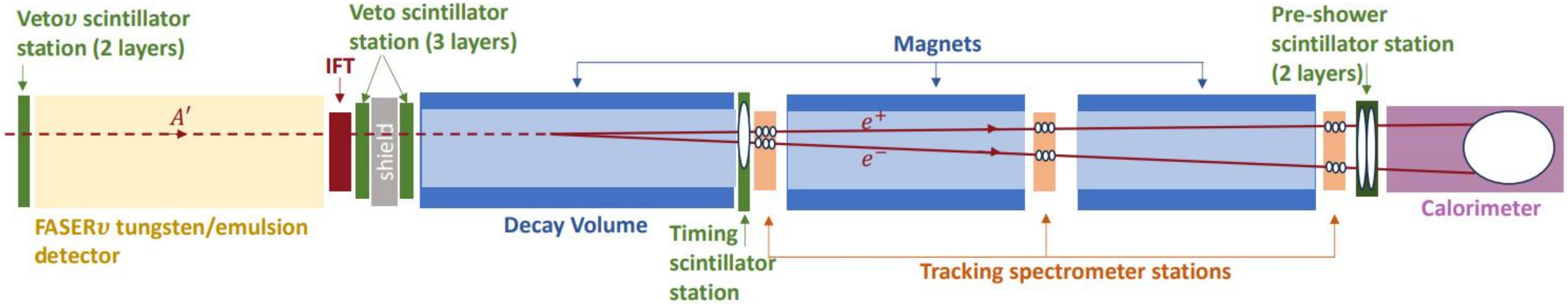


Timing Station [11]

Preshower station:

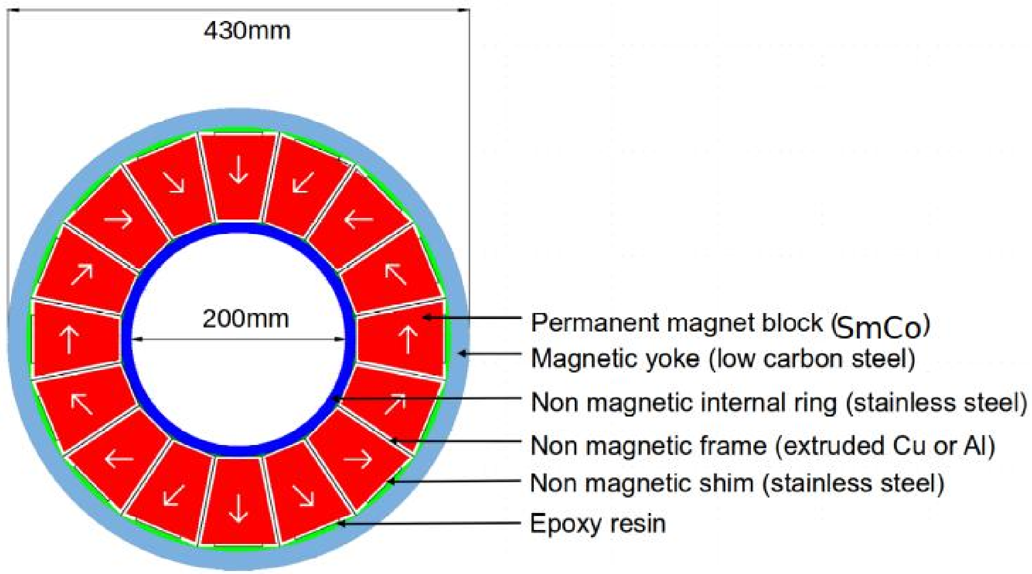
- A thin layer of radiator (about 1 radiation length of tungsten and graphite)
- Used in a coincidence with the first trigger station to reduce the rate of non-physics triggers

If a dark photon comes through:



A schematic view of a dark photon coming through [12]

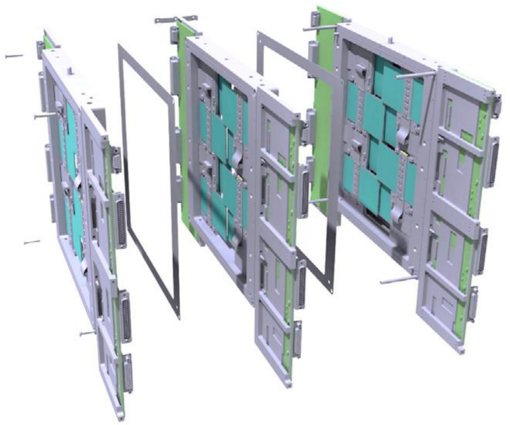
Magnets:

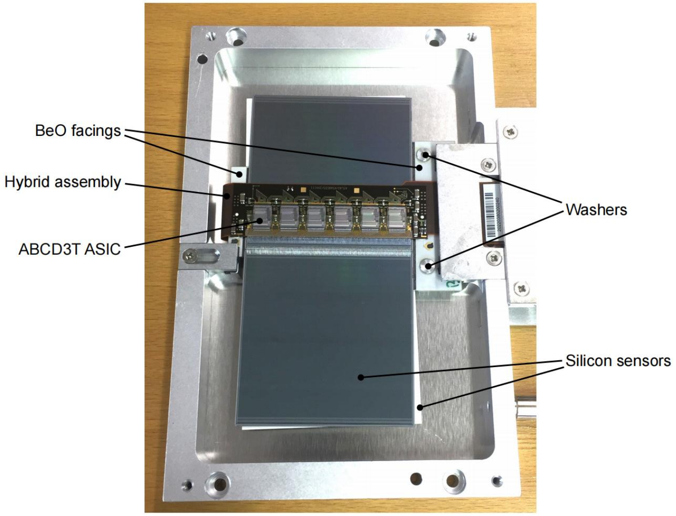


Sketch of the FASER magnet design [13]

- 0.55 T permanent dipole magnets based on the Halbach array design with SmCo magnetic material
- 1 magnet of 1.5m (decay volume)
- 2 magnets of 1m (spectrometer)
- Separate closely spaced charged particles
- No need for power supply, cooling system
- Additional μ-metal shielding is used, to minimize the potential impact of the stray field on PMTs

Tracker Overview:


Exploded CAD view of a tracker station [14]

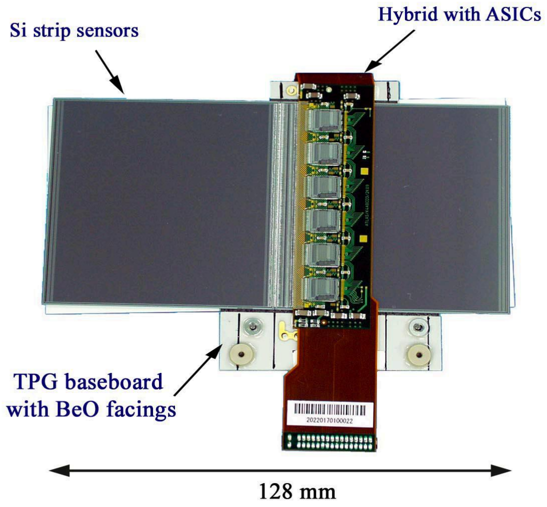


Photograph of a SCT barrel strip module [14]

- 3 stations × 3 layers × 8 spare ATLAS semiconductor tracker barrel modules
- 4 silicon microstrip detectors in pairs on two sides of a central based borad
- p in n silicon sensor (based on electron hole pair production) n-type substrate of 285μm thickness & 768 (p^+ implant) strips with at a constant pitch of 80 μm
- spatial resolution of ~17μm perpendicular to the strips, ~580μm parallel

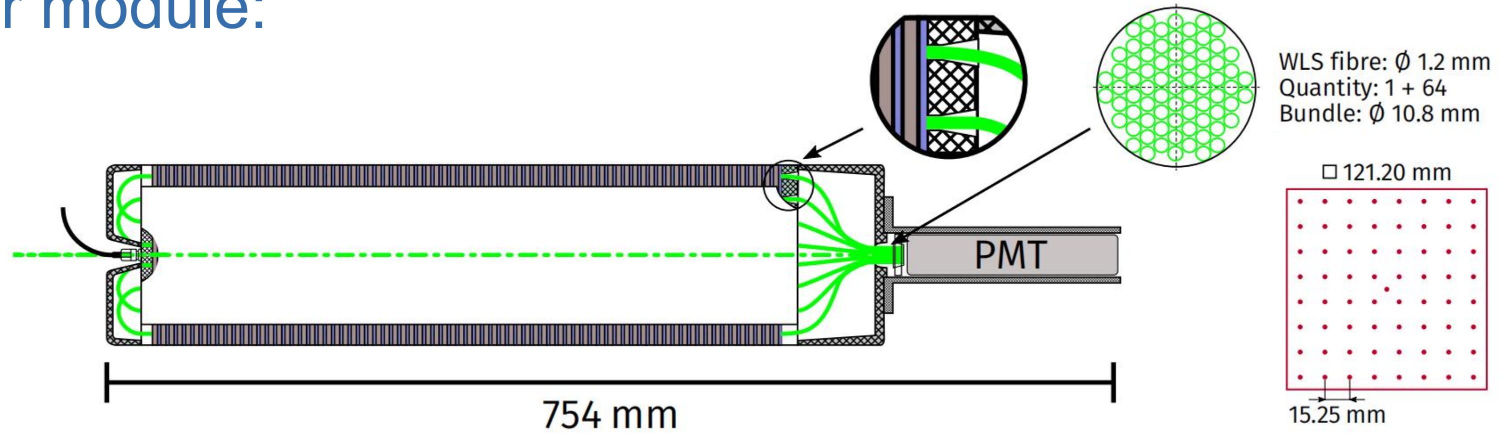
Electronics:

- ABCD3TA chip contains 128 readout channels that consist of a preamplifier, shaper and discriminator
- Double-pulse resolution < 50ns
- Trim Scan: correcting for the threshold dispersion inside the chip
- Tracker Readout Boards (TRB) get data, in short: measuring information of position, timing and charge



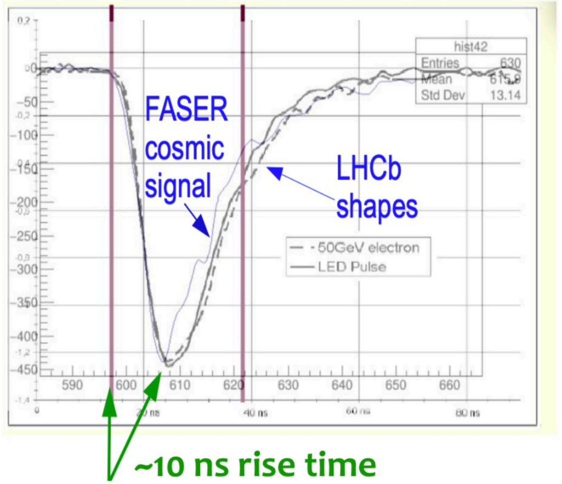
ATLAS SCT barrel module [1]

Calorimeter module:



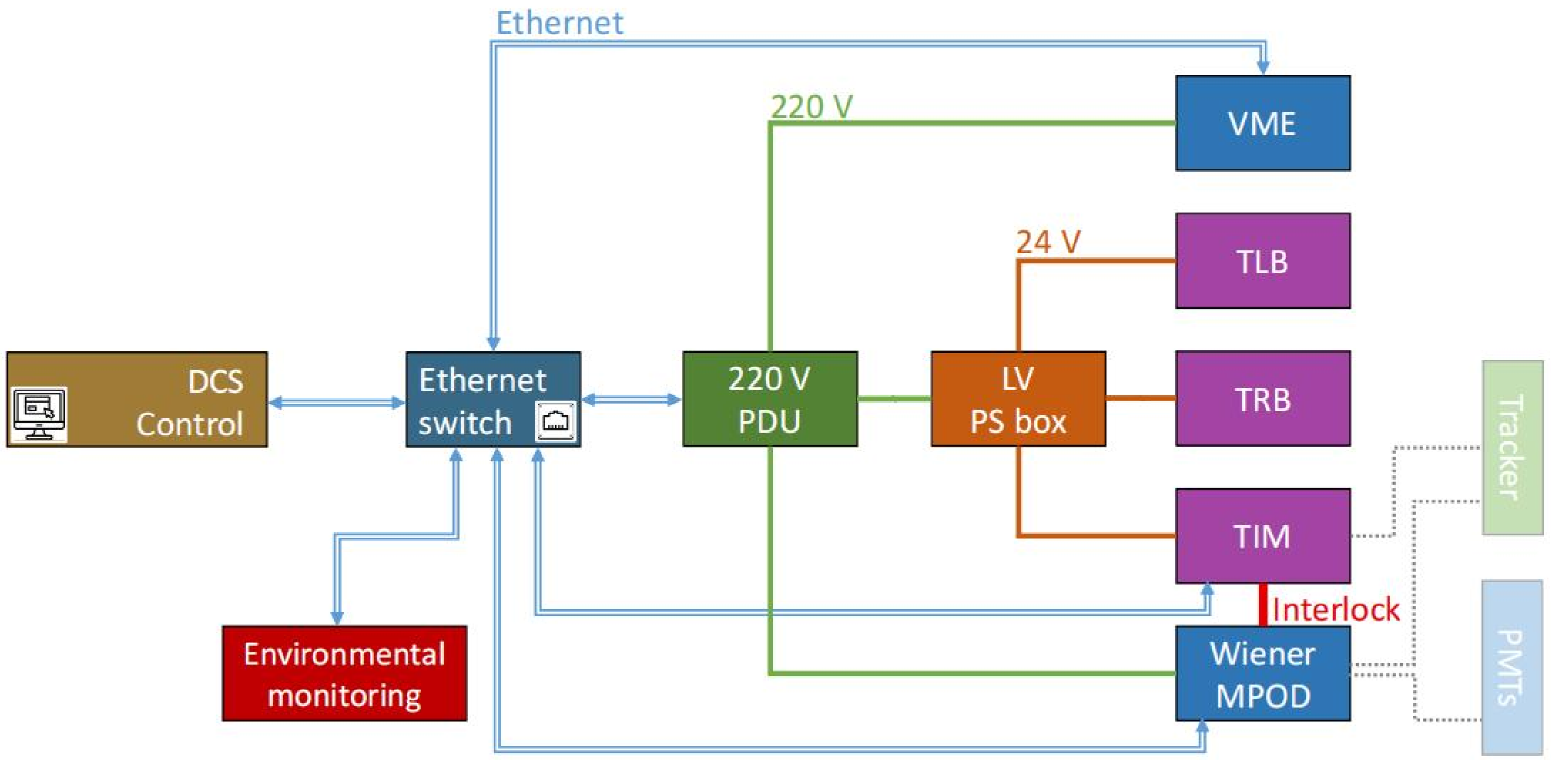
Design of a FASER calorimeter module [15]

- LHCb outer ECAL modules, 66 layers of interleaved 2mm lead plates and 4mm scintillator, 64 wavelength shifting fibers delivering the scintillation light to a single PMT
- Measure the electromagnetic energy, electron and photon identification
- ~1% energy resolution
- Calibration using ^{137}Cs source and cosmic-ray test stand
- Resolution degrades at energies above 1 TeV due to leakage out of the back of the calorimeter



FASER cosmic signal comparison [1]

Detector Control and Safety System:



The DCS control hierarchy [15]

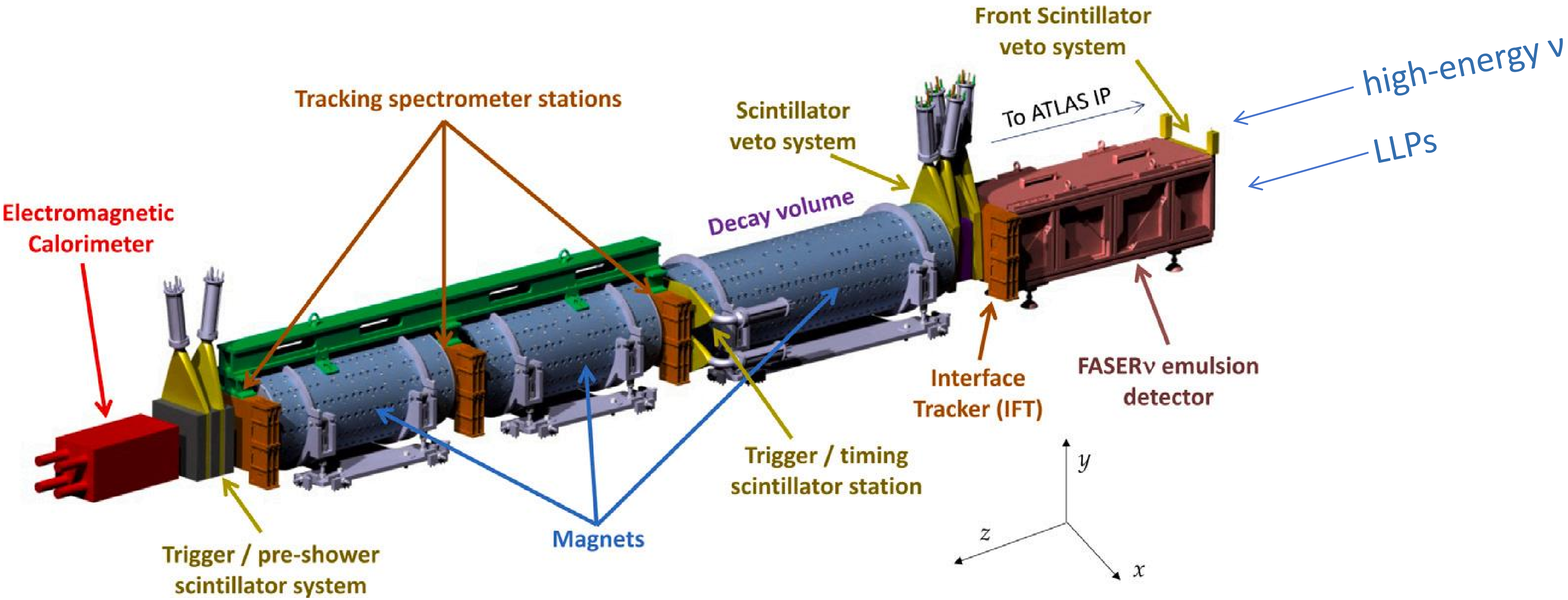
Cooling system:

- simple water chiller ~15 ℃ to cool ASICs
- dry air system to avoid condensation on the electronics due to the cooling [14]

Safety Interlock:

- monitor temperture and humidity data
- control and monitor power supplies
- software system: turn off individual detector components
- hardware system: shut down power supplies

FASER has two sub-detectors: the main FASER detector and the FASERν detector



The FASER detetor makes use of emulsion detectors, scintillators, photomultiplier tubes, silicon strip trackers, etc. Thanks to the donation of ATLAS and LHCb Collaboration, it has mature SCT and ECAL modules. More than 105 fb^{-1} data collected so far, and new generation of FASER has been proposed.

[1] https://indico.uu.se/event/766/attachments/1122/1560/Uppsala_FASER_MQueitschMaitland_011020.pdf

[2] https://indico.cern.ch/event/783977/contributions/3455126/attachments/1894349/3124893/faser_poster_dm_at_ lhc_2019.pdf

[3] Inada T, FASER Collaboration. Early performance of the tracking detector for the FASER experiment[J]. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 2024: 169547

[4] Ariga A, Ariga T, Boyd J, et al. Letter of intent for FASER: ForwArd Search ExpeRiment at the LHC[J]. arXiv preprint arXiv:1811.10243,2018.

[5] https://indico.global/event/7282/contributions/67857/attachments/32781/61683/FASERnu_ISVECRI2024_Sato_v2. pdf

[6] https://indico.cern.ch/event/1291157/contributions/5904124/attachments/2899129/5083552/20240718_Dmitrievsky _FASERnu.pdf

[7] Abreu H, Anders J, Antel C, et al. First direct observation of collider neutrinos with FASER at the LHC[J]. Physical review letters, 2023, 131(3): 031801.

[8] https://indico.global/event/470/contributions/13319/attachments/3676/5726/LakeLouise2022_DaikiHayakawa.pdf

[9] https://indico.cern.ch/event/1216905/contributions/5448276/attachments/2702823/4691466/JAtkinson_NuFACT2023_ObservationAndResultsOfTheFASERnuDetector.pdf

[10] https://indico.global/event/774/contributions/21311/attachments/9159/13901/20210526_tariga_FASERnu_Pheno_v2.pdf

[11] https://faser.web.cern.ch/about-the-experiment/detector-design/scintillators

[12] https://indico.cern.ch/event/1460367/contributions/6240690/attachments/3002176/5290909/FASER_Ariga_NeutrinosAtCERN2025.pdf

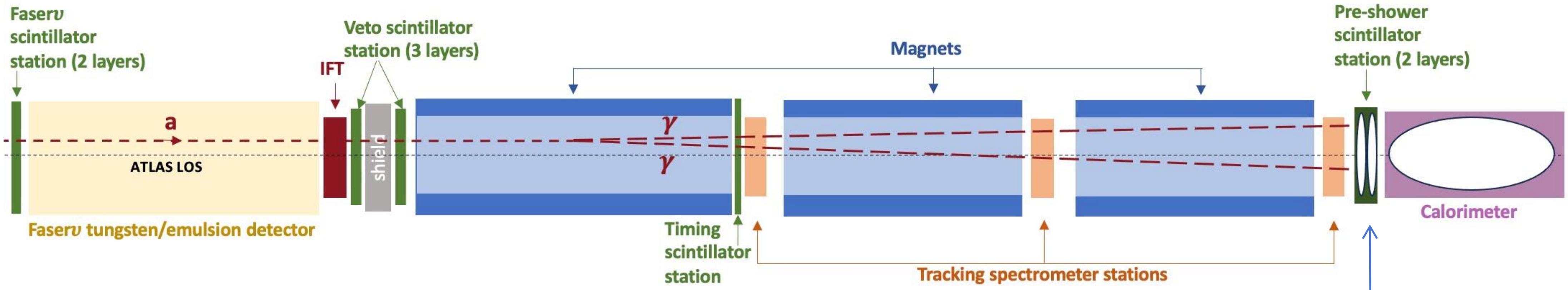
[13] https://faser.web.cern.ch/index.php/about-the-experiment/detector-design/magnets

[14] Abreu H, Antel C, Ariga A, et al. The tracking detector of the FASER experiment[J]. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 2022, 1034: 166825.

[15] Abreu H, Mansour E A, Antel C, et al. The FASER detector[J]. Journal of Instrumentation, 2024, 19(05): P05066.

BACK UP

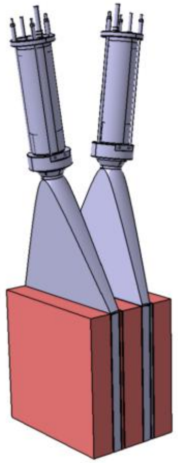
What about a ALP comes through:



A schematic view of an axion-like particle coming through [16]

Current detector has irreducible background from neutrino interactions in preshower

- Preceded with 3 mm-thick layer of radiators (tungsten) to create a simple preshower detector to distinguish two close-by energetic photons & deep inelastic scattering of high-energy neutrinos
- A 5 cm-thick low-Z absorber material (graphite) is placed in front of each layer of tungsten and between the final scintillator module and the calorimeter reduce backsplash from the calorimeter and preshower radiator into the last tracking station



Preshower station [15]

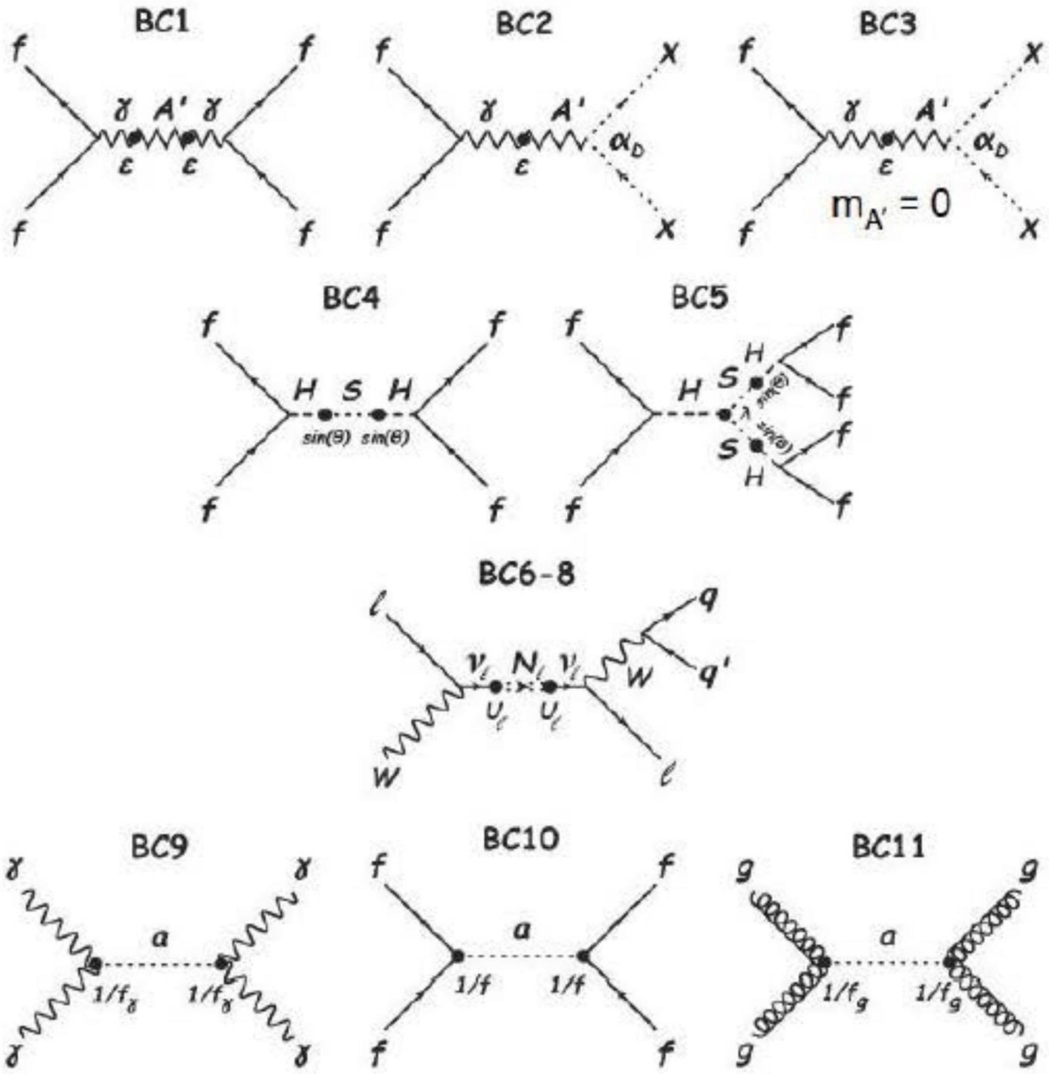
Different BSM Particles:

Dark Photons, Dark Matter & millicharged particles

Dark Scalars

Heavy Neutral Leptons

Axion-Like Particles



Feynman Diagram of BSM [16]

References:
[16] https://indico.cern.ch/event/1451530/contributions/6186586/attachments/3009676/5306062/FASER-LHCbWorkshop-6.2.25.pdf