FASER Status and Physics Prospects

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Introduction

Why building a new detector?

- LHC searches focus on high p_T regions $\longrightarrow$ heavy, strongly interacting particles
- For light and weakly interacting particles, this may be completely misguided
- Searches for new weakly interacting light particles, coupling to SM in forward region
  - Produced in decays of light mesons (e.g. π, K), abundantly present in pp collisions, primarily in large pseudorapidity

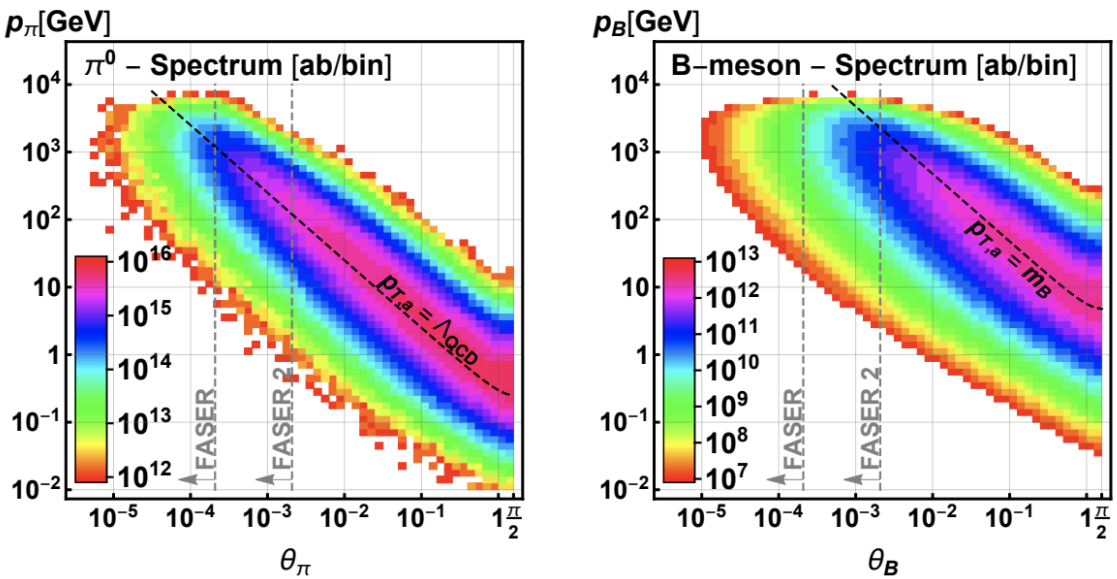
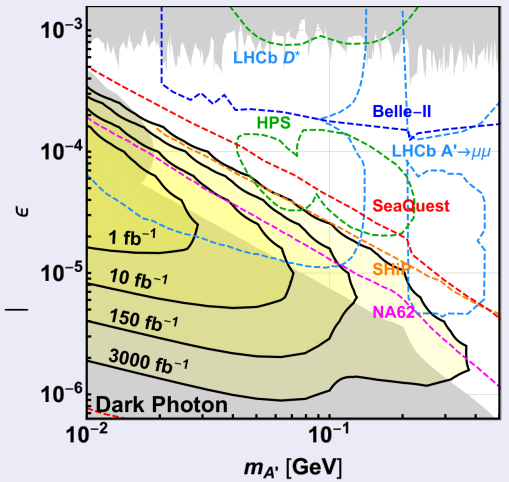


Figure: Production rates of light hadrons in pp collisions in LHC as a function of θ and p.

Physics prospects

Example of phyiscs of interest - dark photon A'

- Spin 1, couples weakly to SM fermions (εQ_f coupling, small ε) through mixing with the photon
- Mainly produced through decays of light mesons and dark bremsstrahlung
- For $m_{A'}$ below a few hundred MeV, they mainly decay into e^+e^- and $\mu^+\mu^-$ pairs
- FASER's reach for dark photons illustrated on the right



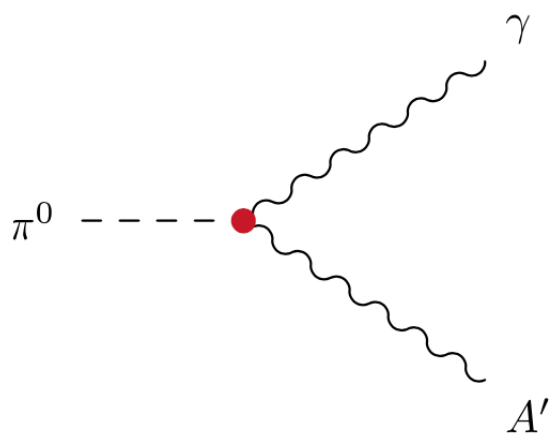


Figure: Decay of π^0 creating γ and A'.

Physics prospects

Example of physics of interest – axion-like particles (ALPs)

- Pseudoscalar SM-singlets; can appear in theories with broken global symmetries
- Produced by photon fusion, rare decays of neutral pions but mostly by Primakoff process $\gamma N \longrightarrow aN'X$ in interactions with LHC structures (high-energy photon beam dump)
- Decaying to photons

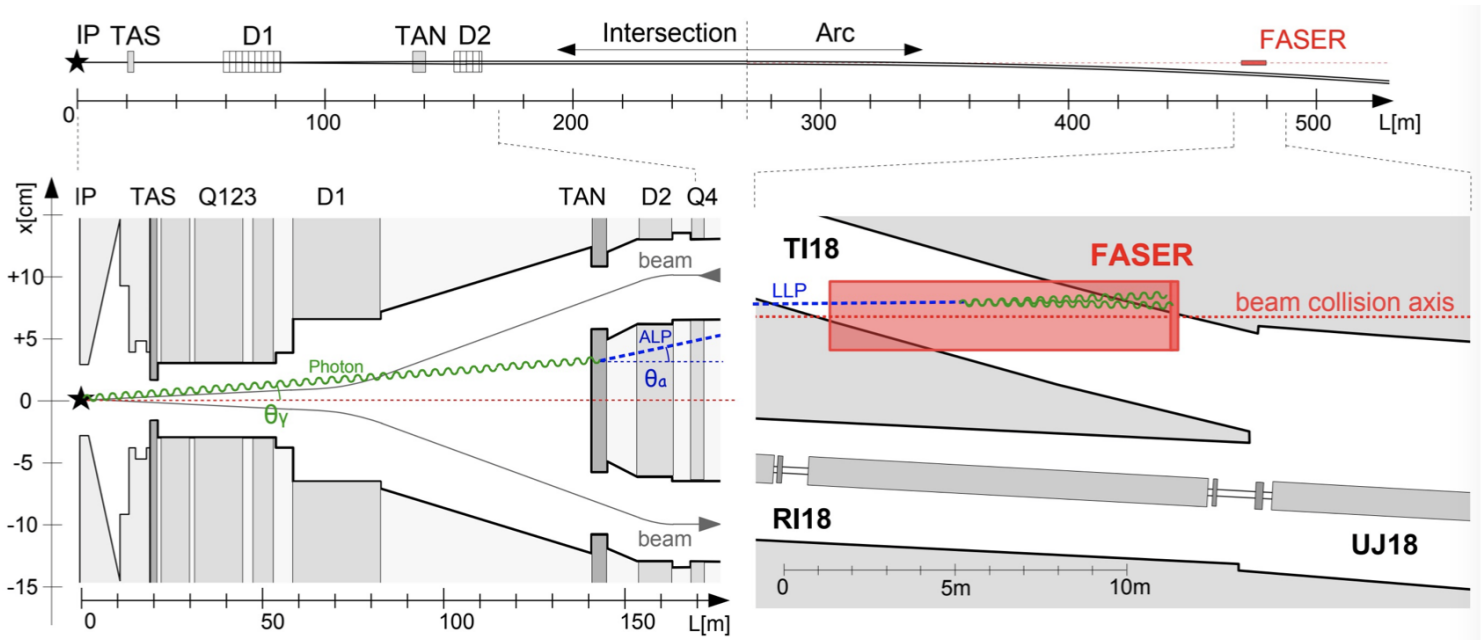


Figure: Production of ALPs in the LHC tunnel.

FASER experiment

Location

- Placed 480 m downstream of the ATLAS interaction point (IP) in unused service tunnel TI12 originally connecting SPS to the LHC
- Located on the tangent to the LHC which is touching the ring at the ATLAS IP
- Detector 20 cm in diameter which corresponds to $1 \cdot 10^{-6}$ % solid angle

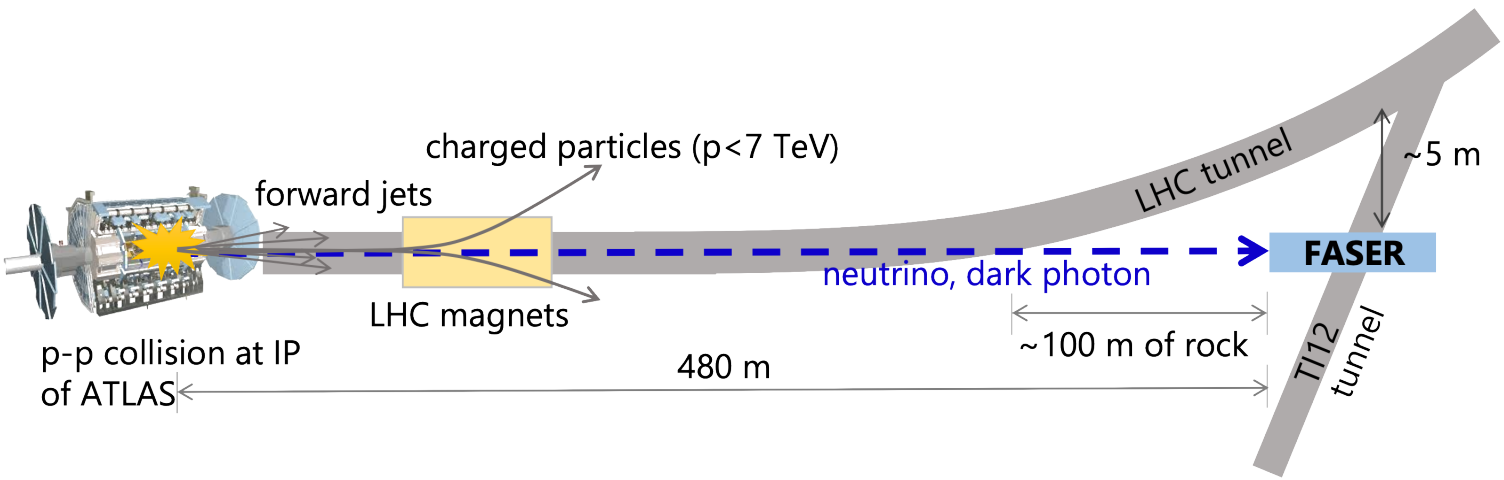


Figure: Location of FASER in the tunnel - schema is not in scale.

FASER experiment

Requirements and specifics of the detector

- Tight timeline between the experiment approval and installation, limited budget and environment of the LHC tunnel:
  - detector that can be constructed and installed quickly and cheaply
  - tried to re-use existing detector components where possible
  - tried to minimize services to simplify the installation and operations
  - aimed for the simple and robust detector (difficult access)
- A lot of challenges specific for the LHC experiments not present:
  - trigger rate $\mathcal{O}(500\,\mathrm{Hz})$ — mostly single muon events
  - low radiation
  - low occupancy
  - small event size

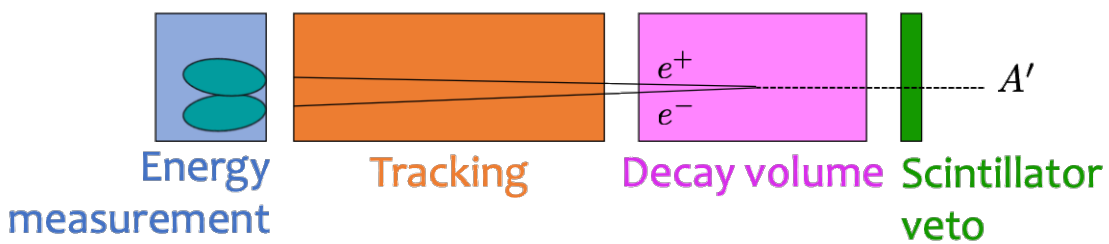
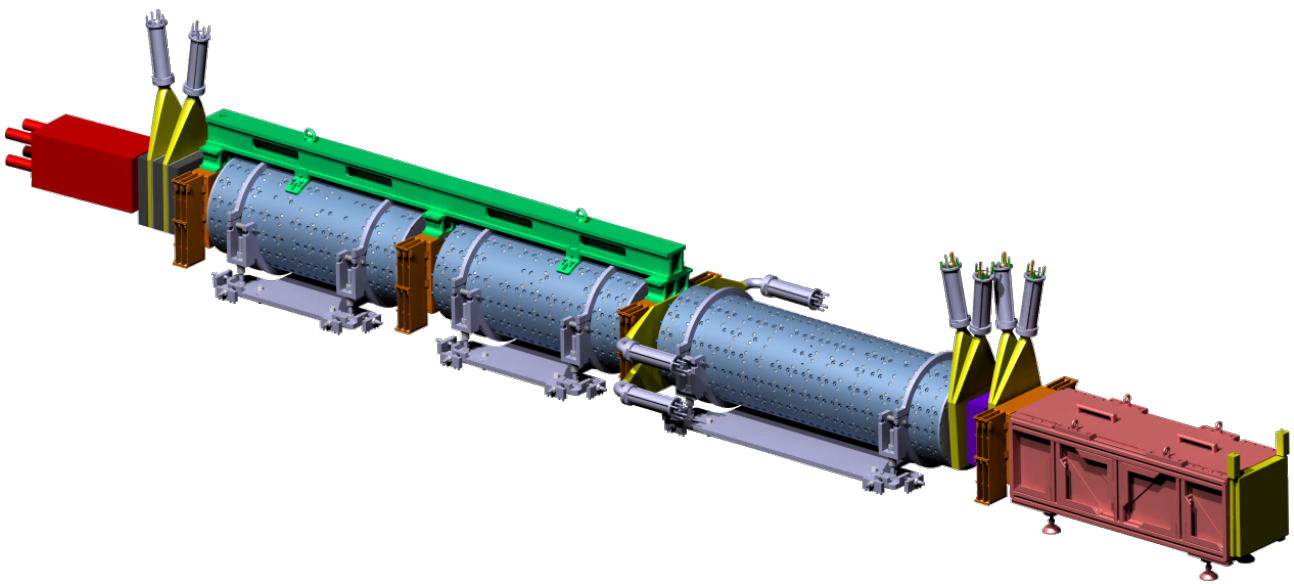


Figure: The main detector subsystems.

Detector design

FASER

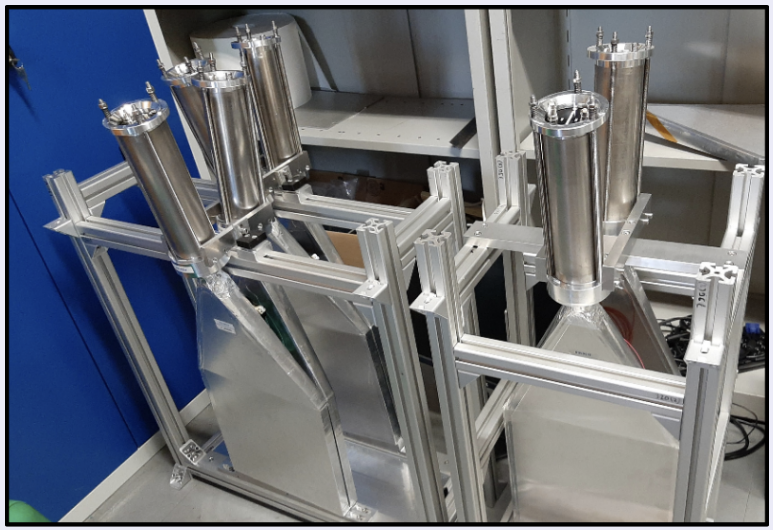
- ∼7 meters long detector
- Consists of several key components
  - scintillators
  - FASERν
  - tracker
  - permanent magnets (0.55 T, 1.5 m long decay volume)
  - calorimeter
  - TDAQ

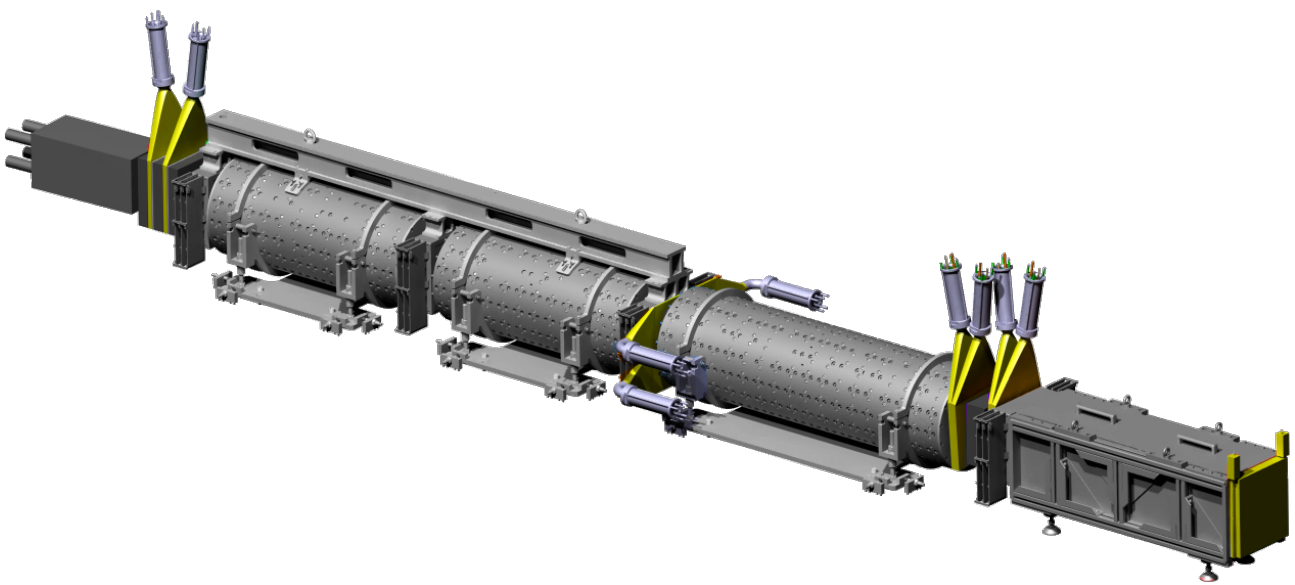


Detector design

Scintillators

- Four scintillator stations – used for triggering, veto, timing of the event $\mathcal{O}(1)$ ns and as a preshower for the calorimeter
  - 1 scintillator before FASERν
  - 1 before the first tracking station
  - 1 trigger/timing station after the first magnet
  - 1 preshower station
- Read out with PMTs and CAEN digitizer

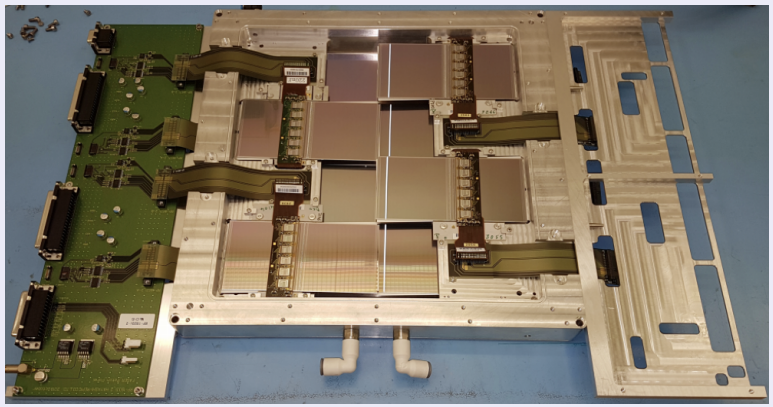


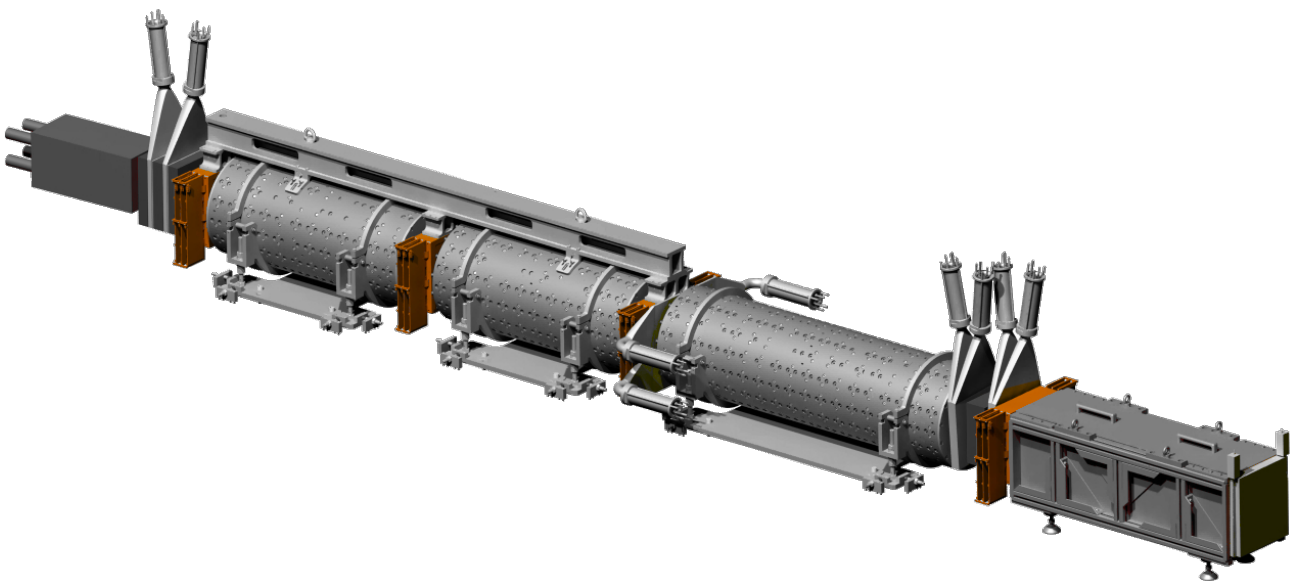


Detector design

Tracker

- Consists of three tracking stations + interface tracker
  - Each station has three layers
  - Each layer has 8 silicon strip double-sided modules (originally for ATLAS)
- strip pitch 80 μm with 40 mrad stereo angle
  - $\sim$ 20 μm resolution in precision coordinate
  - $\sim$ 550 μm in the other coordinate
- Tracker paper arxiv:2112.01116

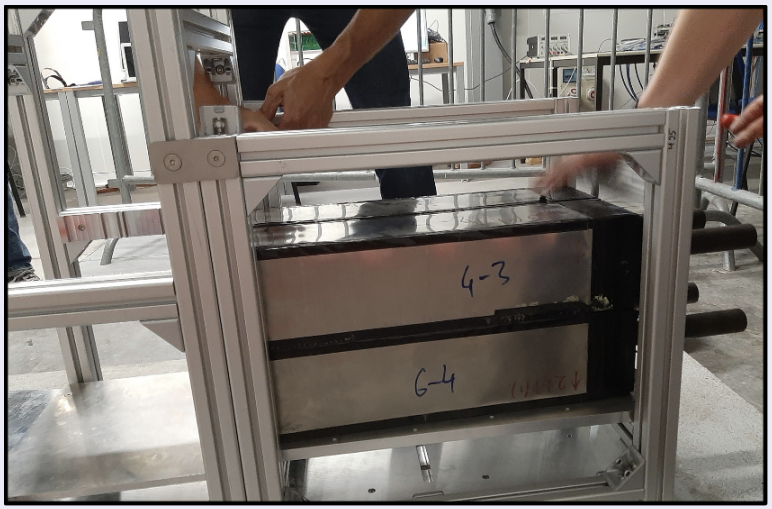


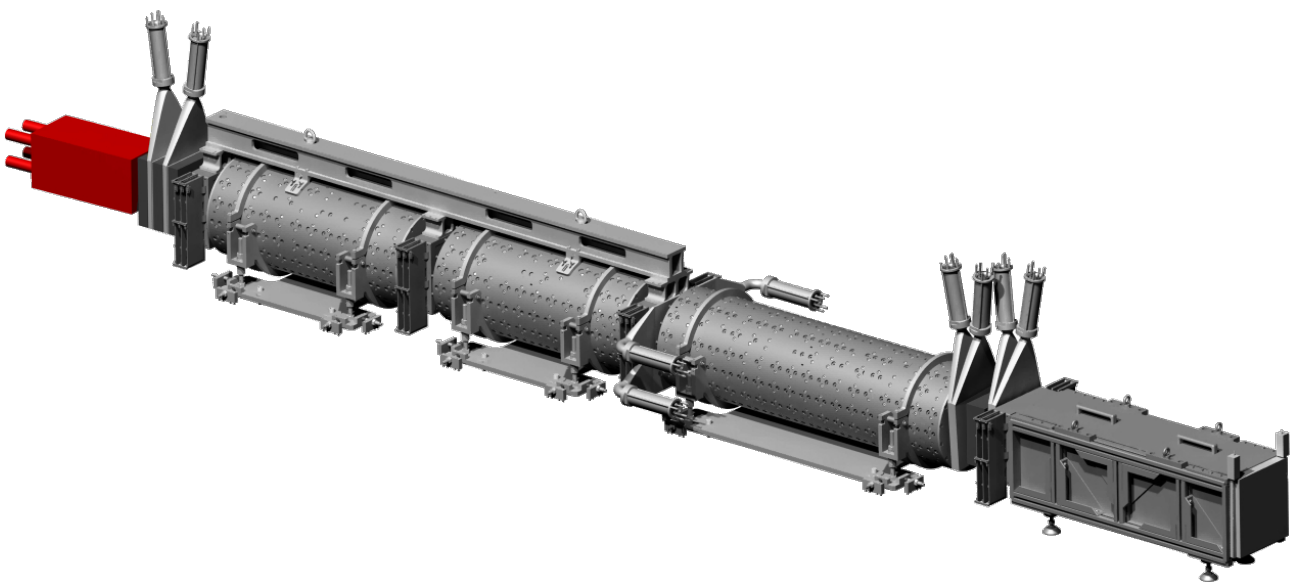


Detector design

Calorimeter

- Uses four spare LHCb outer ECAL modules.
- Electromagnetic calorimeter designed to stop highly energetic photons and electrons, identify them and measure their energies
  - 25 radiation lengths long
  - lead/scintillator calorimeter
- Energy resolution ∼1% for TeV deposits

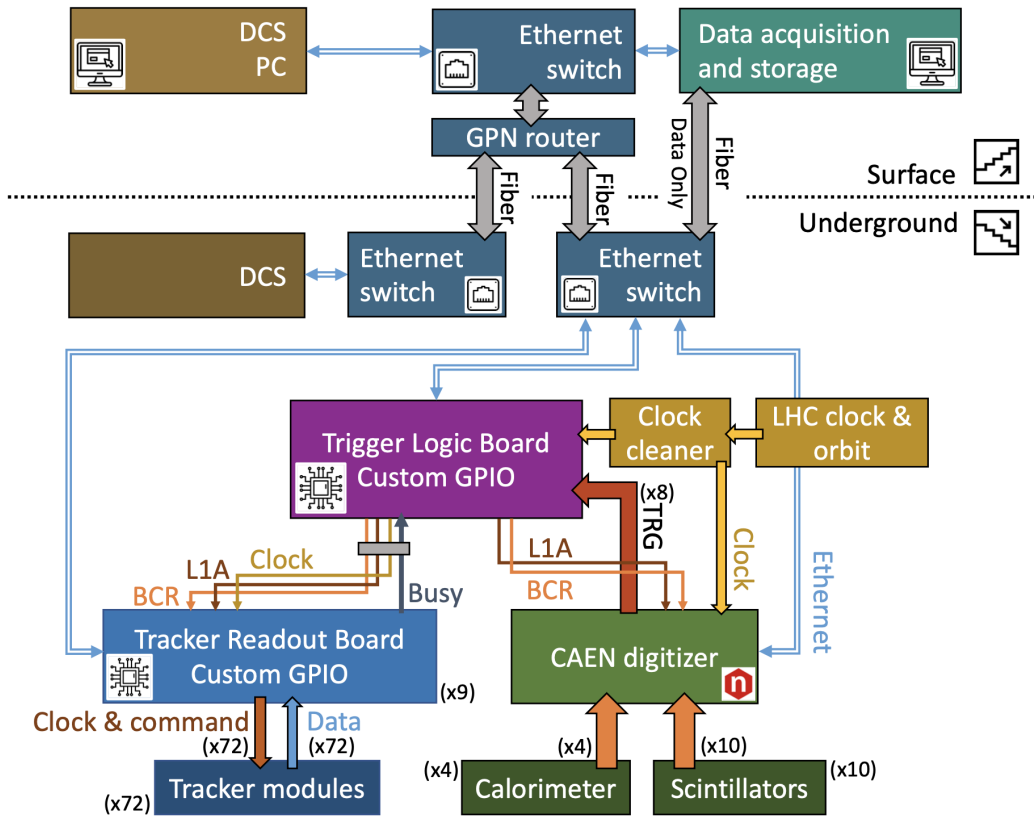




Detector design

TDAQ

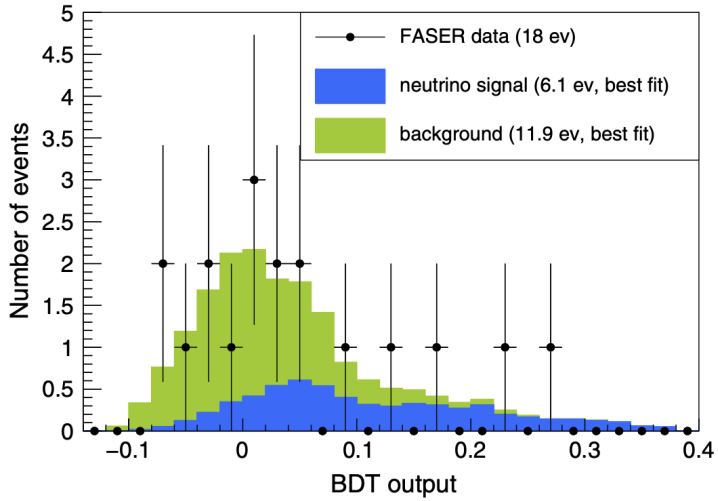
- Scintillators and calorimeter used for triggering
- Expected trigger rate of 500-1000 Hz
  - dominated by muons from the ATLAS IP
  - ∼5 Hz of energetic signatures deposited in calorimeter
- TDAQ electronics placed in TI12
- TDAQ paper arxiv:2110.15186

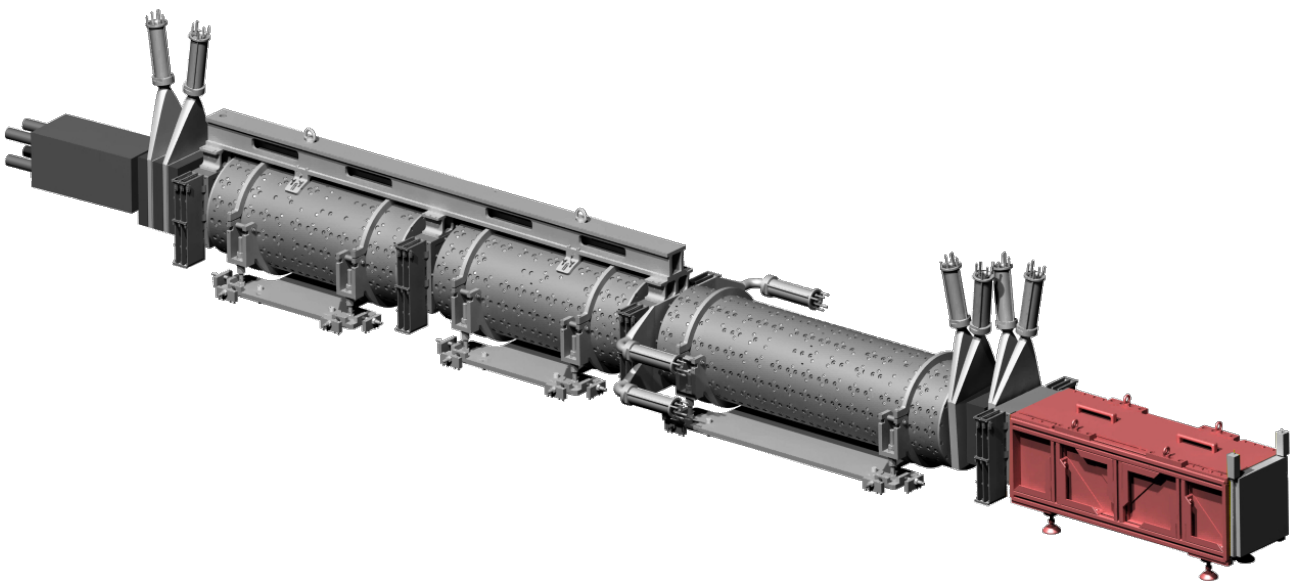


Detector design

FASERν

- FASER subdetector aiming for the first-ever detection of collider neutrinos
- Emulsion detector – 770 emulsions interleaved with 1-mm-thick tungsten plates (total target mass of 1.1 tonnes)
- A small FASERν pilot detector, installed into the LHC tunnel for 1 month in 2018 LHC running, detected several ν candidate events (PhysRevD.104.L091101)

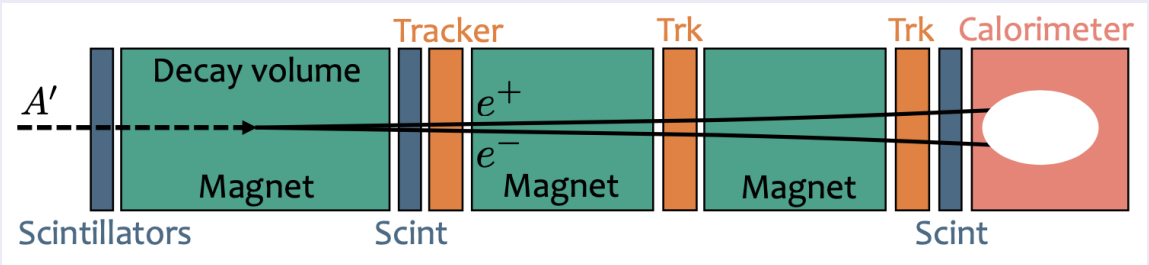




What is FASER looking for?

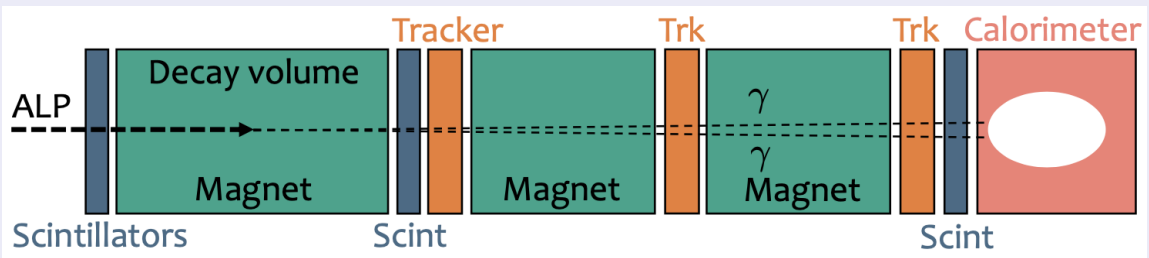
A' signature

- Two charged particles with opposite charge whose total momentum points to ATLAS IP



ALP signature

- Two photons whose total total momentum points to ATLAS IP
  - cannot be resolved with current detector $\longrightarrow$ detector upgrade



Installation and Commissioning

- Detector installed in TI12 tunnel in March 2021
- In situ commissioning since then
- Combined cosmic running, noise runs, and calibrations
- Gained valuable operations experience, and many detector performance studies ongoing

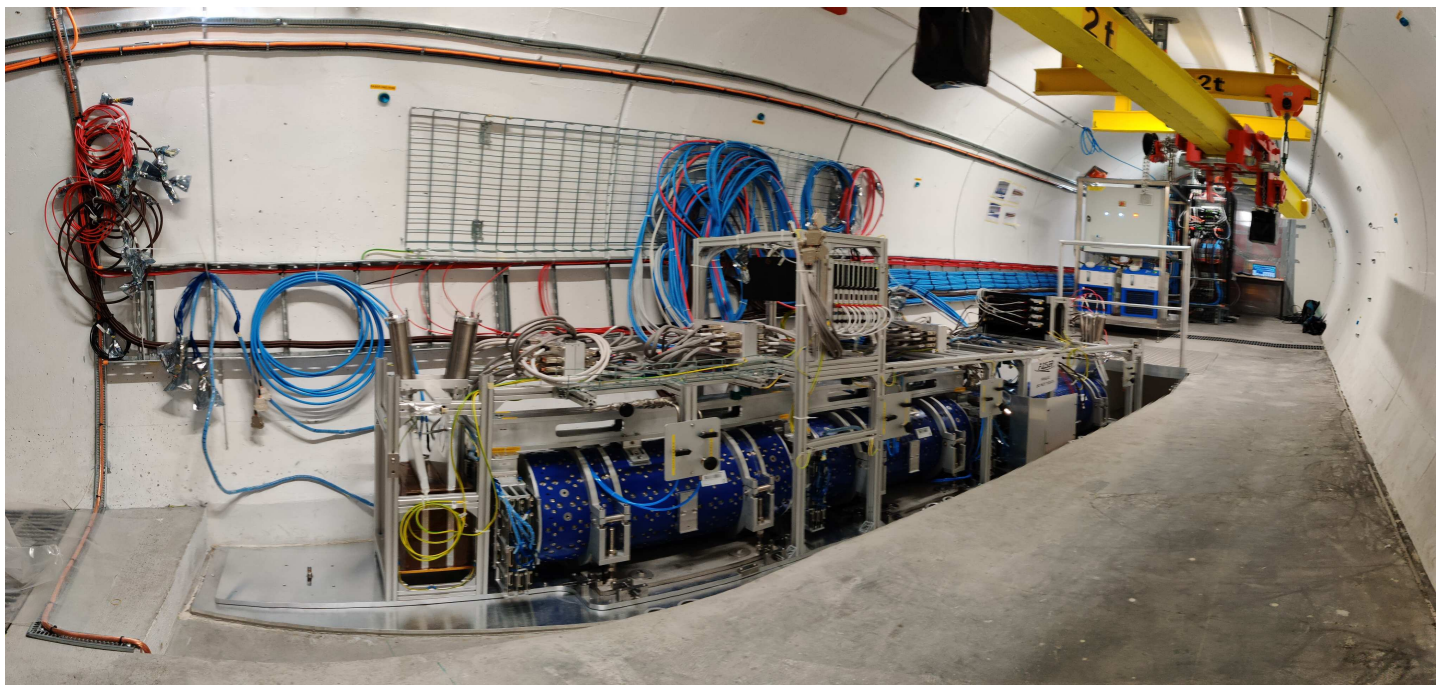
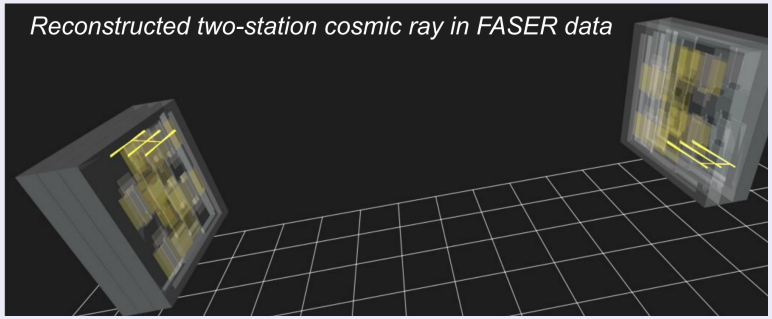


Figure: FASER installed in the tunnel TI12.

Commissioning

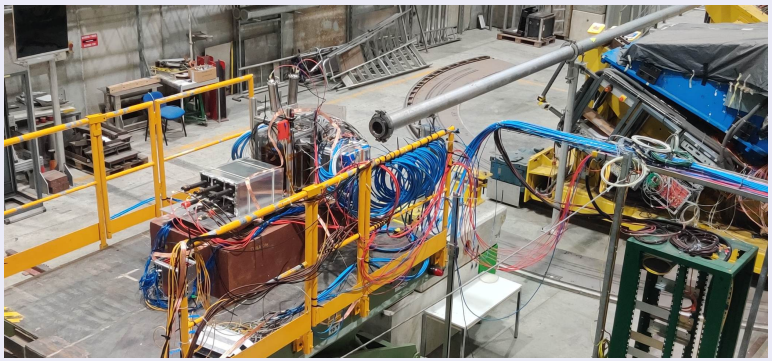
Commissioning with cosmic muons

- Used for commissioning most of the time for tracker planes
- Also most of the time since FASER installation in TI12



Test beam at CERN

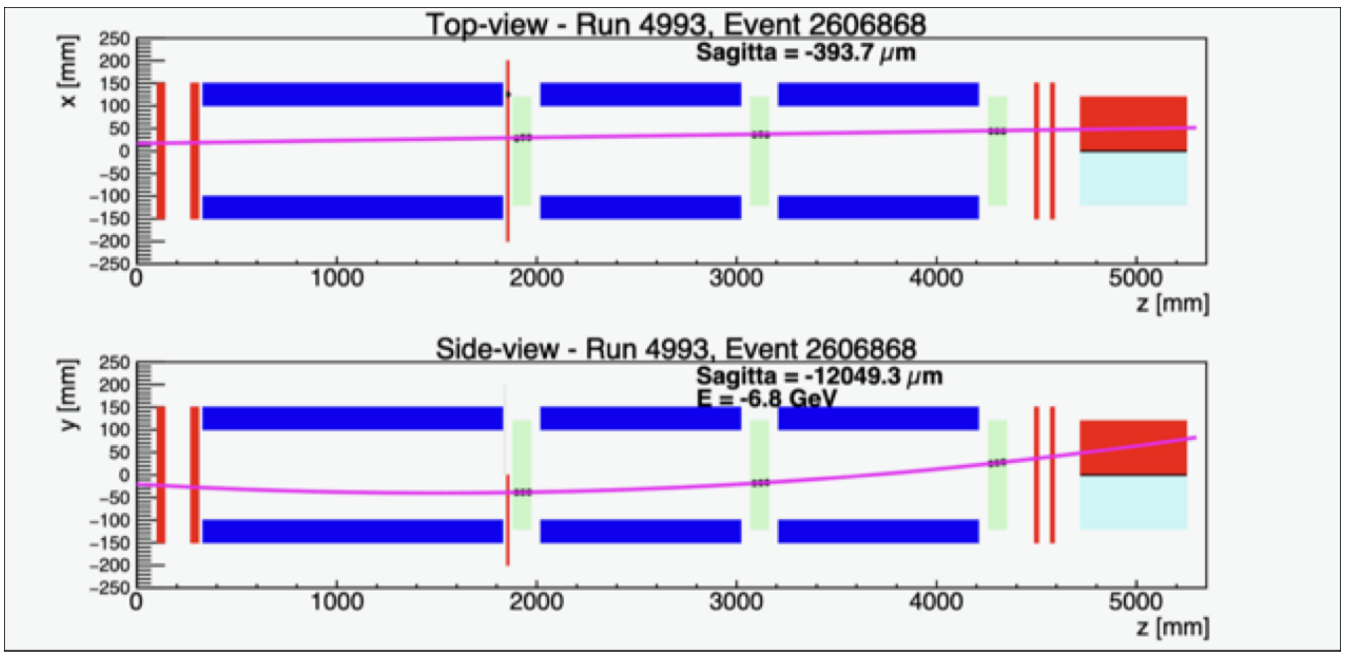
- July 28^{th} – Aug 4^{th} 2021
- Test beam at CERN in SPS North area
- Primary goal was to calibrate the calorimeter with high energy electron beam
- $150 \cdot 10^6$ events collected using electron, muon and pion beams
- See the poster *"First Results of the 2021 FASER Calorimeter Test Beam"* by Charlotte Cavanagh on this conference



Commissioning

The first LHC beams

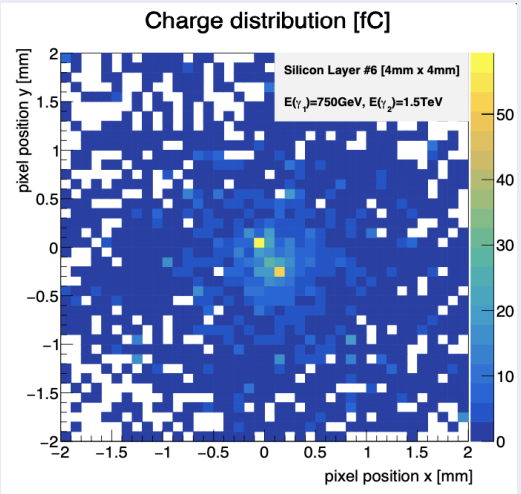
- In Oct 2021 the LHC carried out a 2 week pilot beam test, with 450 GeV beams circulated and collided
- FASER saw beam related activity during various operations (beam splash, collimator alignment, single beam and colliding beams)
- Data used to time in the trigger, and for performance and background studies
- First time we saw particles traversing the full detector

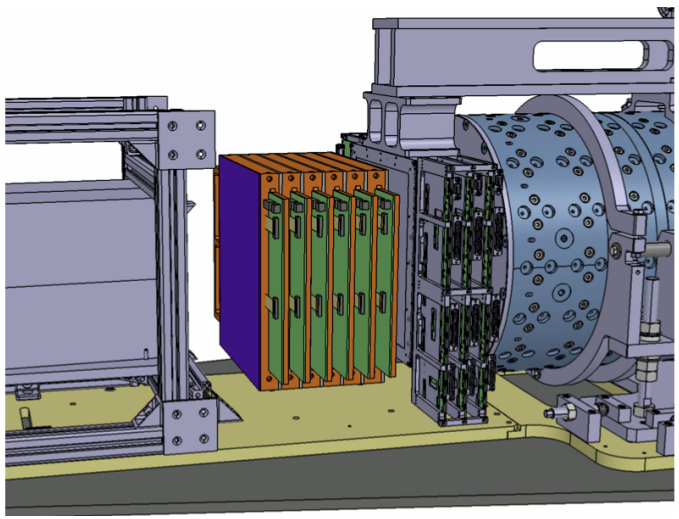


What's next?

Pre-shower upgrade

- Current pre-shower is designed to separate high energy photons separated by 200 μm
- Upgrade to enable detecting ALPs
  - 2γ searches, by allowing to reconstruct 2 very closely spaced high energy photons
- Existing pre-shower will be replaced with a high-resolution silicon pre-shower detector using monolithic pixel ASICs
  - hexagonal pixels of $65\mu m$ side
- Planned to be ready for 2024 data taking





Outlook

- Waiting for the first beams in Run 3 and the first data
  - discovery potential or putting constrains on current theories
  - the first collider-originated neutrino measurements
- Preparing upgrade for FASER preshower detector do be able to distinguish two-photon events
- Studies started for a bigger FASER2 detector, as part of the proposed Forward Physics Facility (FPF) arxiv:2109.10905

Thank you for your attention!