Status of the FASER Experiment

LHC Forward Physics Meeting - 14th December 2021

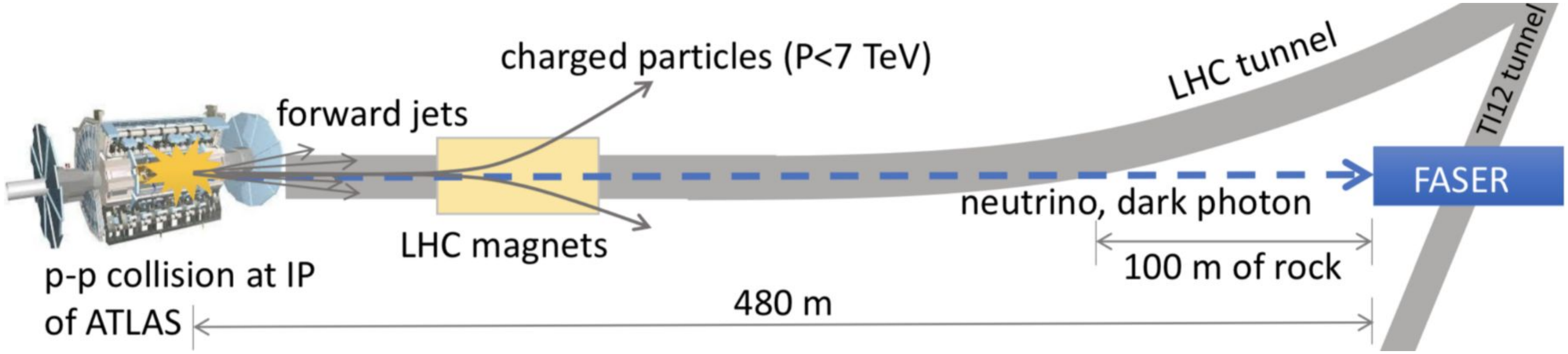
Markus Prim (University of Bonn)
on behalf of the FASER collaboration

HEISING-SIMONS FOUNDATION   SIMONS FOUNDATION   CERN

The FASER Experiment

77 collaborators,
21 institutions,
9 countries

- FASER is a small experiment at the LHC and …
  - … located 480m from IP1, in the line-of-sight and low p_T spot of ATLAS.
  - … most backgrounds are greatly reduced by accelerator magnets and ~100m rock shielding.
  - … will take data during LHC Run-3 (2022-2024).
- FASER targets light, weakly-coupled new particles at low pT
- FASER**ν** targets the measurement of neutrinos produced in pp collisions.



FASER Timeline

Technical Proposal of FASERν neutrino detector

FASER: ForwArd Search ExpeRiment at the LHC

Jonathan L. Feng, Iftah Galon, Felix Kling, Sebastian Trojanowski

FASER catches first candidate collider neutrinos

The result paves the way for studies of high-energy neutrinos at current and future particle colliders

‘84 | Aug ‘17 | Nov ‘18 | Dec ‘18 | Mar ‘19 | Jan ‘20 | Mar ‘21 | Jun ‘21

LHC Run III

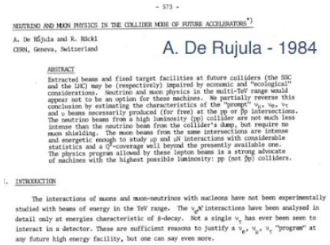
Technical Proposal

Letter of Intent

FASER: CERN approves new experiment to look for long-lived, exotic particles

The experiment, which will complement existing searches for dark matter at the LHC, will be operational in 2021

Installation of the detector in TI12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NEUTRINO AND MUON PHYSICS IN THE COLLIDER MODE OF FUTURE ACCELERATORS*)

A. De Rújula and R. Rückl
CERN, Geneva, Switzerland

A. De Rujula - 1984

ABSTRACT

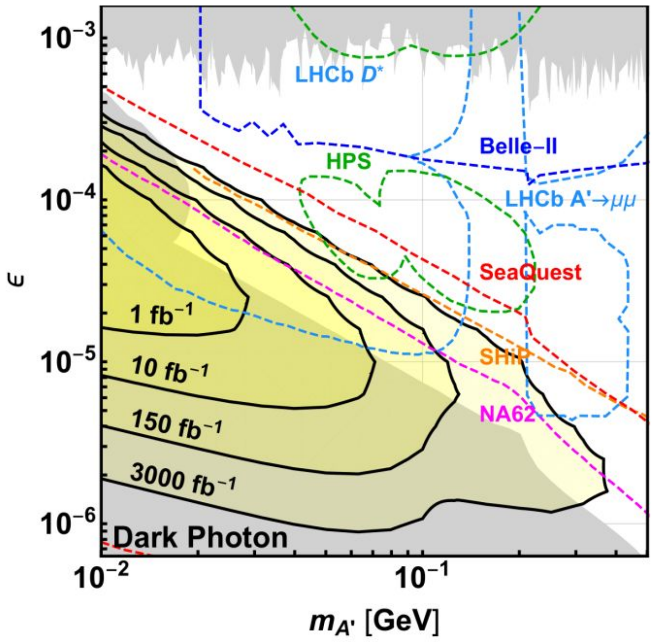
Extracted beams and fixed target facilities at future colliders (the SSC and the LHC) may be (respectively) impaired by economic and "ecological" considerations. Neutrino and muon physics in the multi-TeV range would appear not to be an option for these machines. We partially reverse this conclusion by estimating the characteristics of the "prompt" ν_μ, ν_e, ν_τ and μ beams necessarily produced (for free) at the pp or $\bar{p}p$ intersections. The neutrino beams from a high luminosity (pp) collider are not much less intense than the neutrino beam from the collider's dump, but require no muon shielding. The muon beams from the same intersections are intense and energetic enough to study μp and μN interactions with considerable statistics and a Q^2-coverage well beyond the presently available one. The physics program allowed by these lepton beams is a strong advocate of machines with the highest possible luminosity: pp (not $\bar{p}p$) colliders.

1. INTRODUCTION

The interactions of muons and muon-neutrinos with nucleons have not been experimentally studied with beams of energy in the TeV range. The $\nu_e N$ interactions have been analysed in detail only at energies characteristic of β-decay. Not a single ν_τ has ever been seen to interact in a detector. These are sufficient reasons to justify a ν_e, ν_μ, ν_τ "program" at any future high energy facility, but one can say even more.

Example Physics Case for FASER

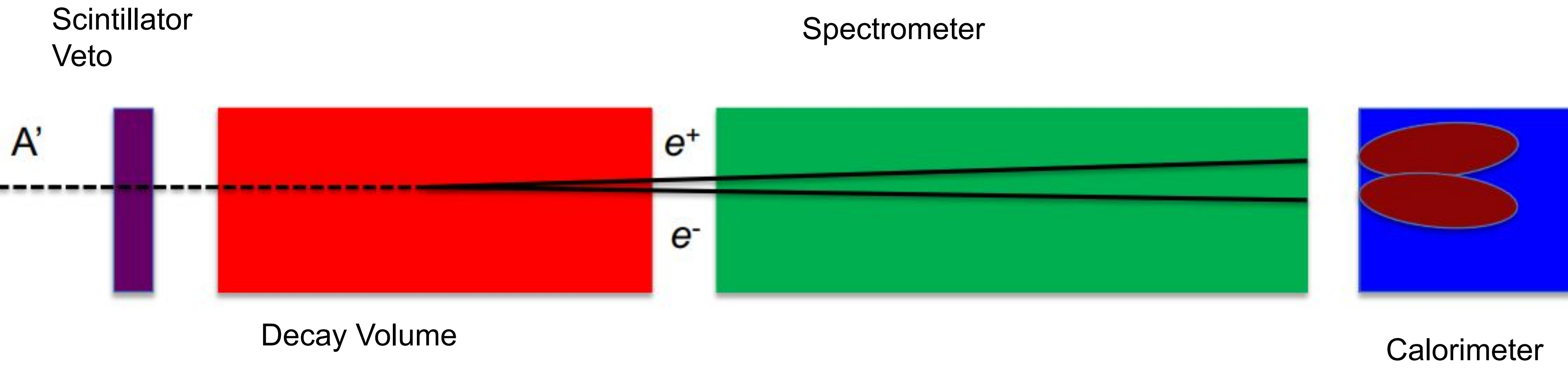
- Dark matter motivate light, weakly coupled particles, e.g. dark photons A' with mass and coupling to the SM fermions.
- Produced very rarely in Pi0 -> A' gamma decays (BF ~10^-10 in the parameter space relevant for FASER).
- Travels long distances without interacting.
- Decays into charged particle pairs.
- FASER takes advantage of the huge number of light mesons in the forward region produced at the LHC.



Assumptions:

- 0 background (striking signal topology)
- 100% efficiency (O(1) difference in efficiency has minor impact on contours)

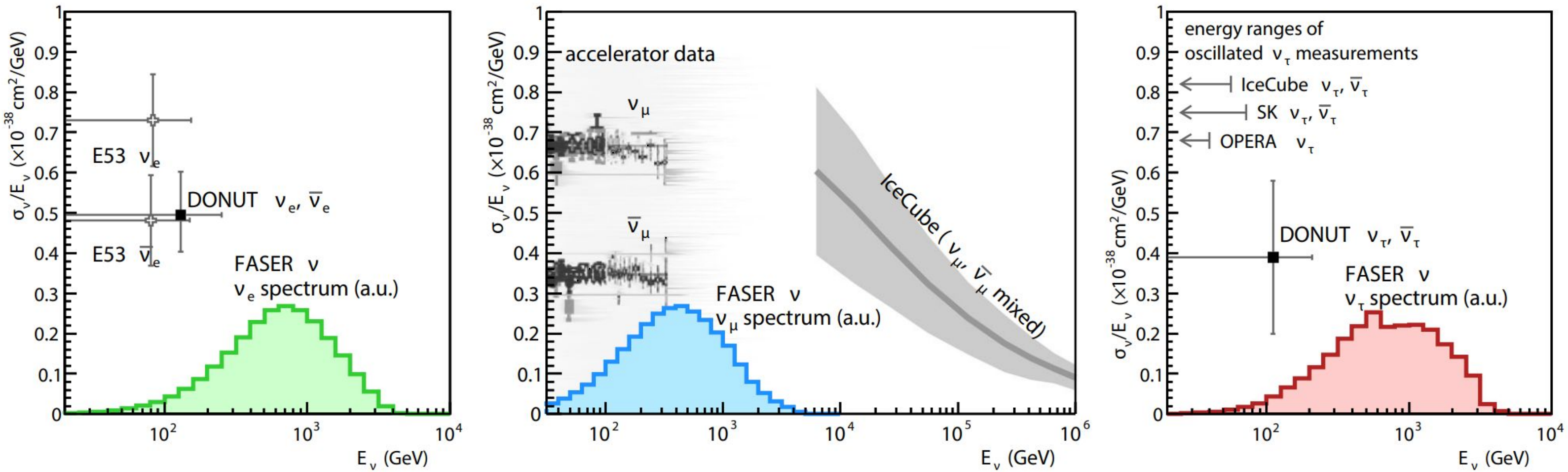
Dark Photon Signature Expected at FASER



- FASER is designed to measure the signal sketched above
  - no signal in the veto scintillator
  - two high energy oppositely charged tracks from a common vertex in the decay volume
  - magnets need to separate the decay products so the tracks can be measured individually
  - large energy deposit in the ECAL (for electron final states)

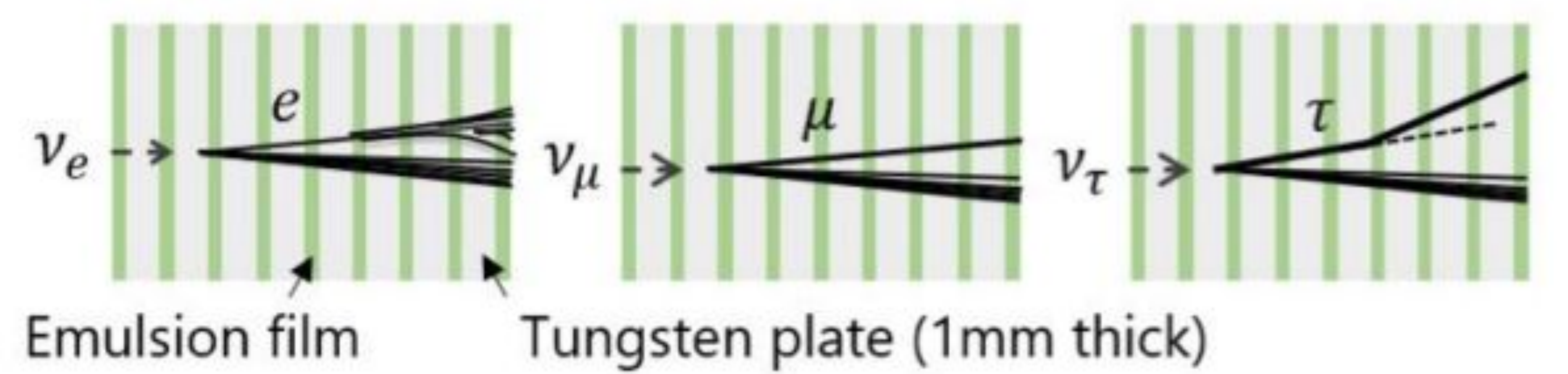
FASERν - neutrino flavours

- Primary goal: first cross-section measurements of different flavors at TeV energies
- Neutral current measurements could constrain non-standard interactions [Phys. Rev. D 103, 056014]
- search for sterile neutrinos, measurement of charm and strange PDFs



Neutrino Signature Expected at FASERν

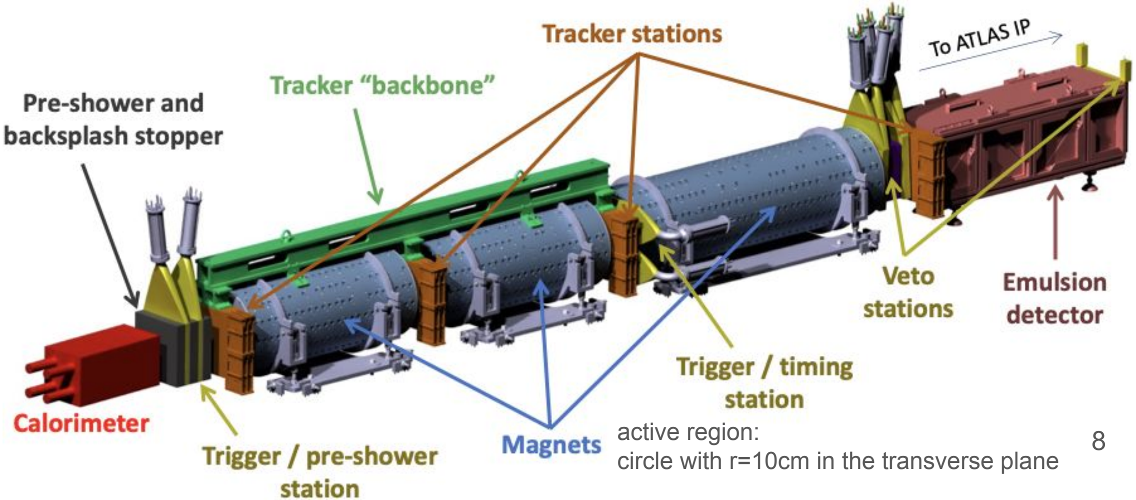
- The different neutrino flavors leave district signatures in the emulsion detector.



The FASER Experiment

- Three 0.55 T permanent dipole magnets to separate charged particles from LLP decays.
- Veto, timing, and pre-shower scintillator stations to ensure LLPs decay inside of the decay volume or emulsion detector and triggering.
- Three tracking stations and an interface tracker to measure position and momenta of charged particles. [https://arxiv.org/abs/2112.01116]
- Electromagnetic calorimeter to measure particle energy and discriminate electrons from muons and triggering

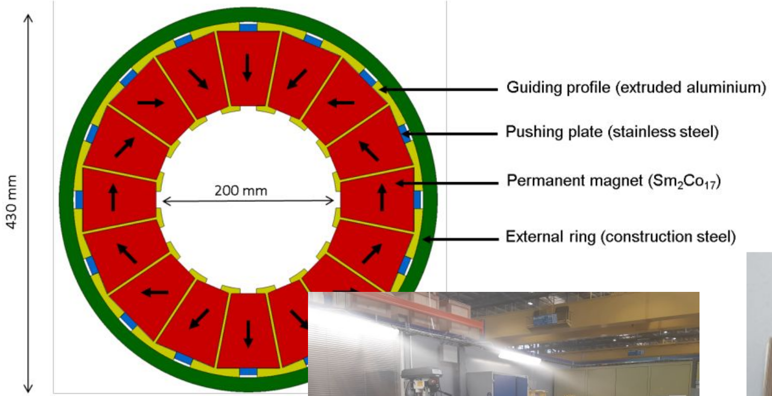
- Tungsten/emulsion detector to detect all three neutrino flavors.
- Trigger with an expected rate of 500-1000 Hz, dominated by muons originating from collision in IP1. [https://arxiv.org/abs/2110.15186]



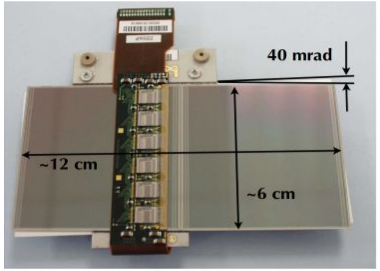
active region:
circle with r=10cm in the transverse plane

FASER Magnets and Tracker

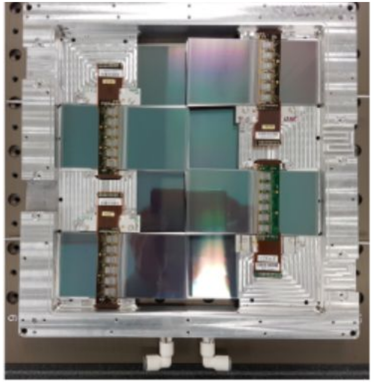
- Many thanks to the CERN magnet group designing and constructing the magnets.
- 0.55T permanent dipole magnets based on the Halbach array design.



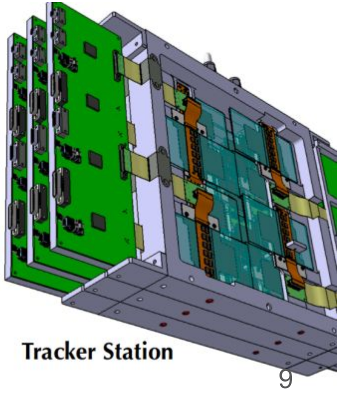
- 3 Tracking Stations + Interface Tracker, each containing 3 layers of double-sided silicon micro-strip sensors.
- 80µm strip pitch, 40mrad stereo angle (17µm / 580µm resolution), precision measurement in bending (vertical) plane
- 24cm x 24cm sensitive area per layer
- Many thanks to the ATLAS SCT collaboration for providing the modules.



SCT module



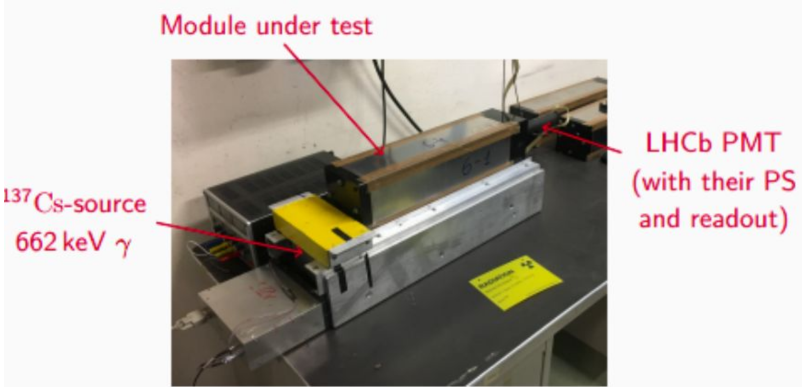
Tracking layer



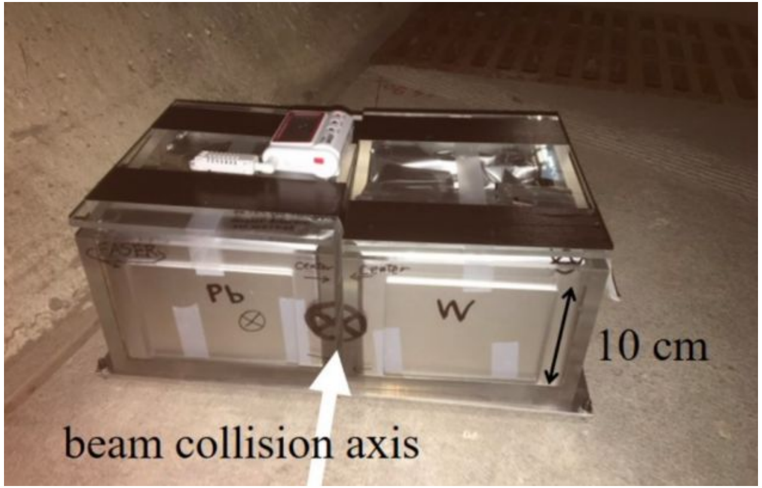
Tracker Station

FASER Calorimeter and Emulsion Detector

- 66 layers of lead/scintillator, light out by wavelength shifting fibers, 25 radiation lengths long
- Readout by PMT (no longitudinal shower information), only 4 channels in full calorimeter
- Dimensions: 12cm x 12cm – 75cm long (including PMT)
- Provides ~1% energy resolution for 1 TeV electrons
- Many thanks to LHCb for letting us use these.

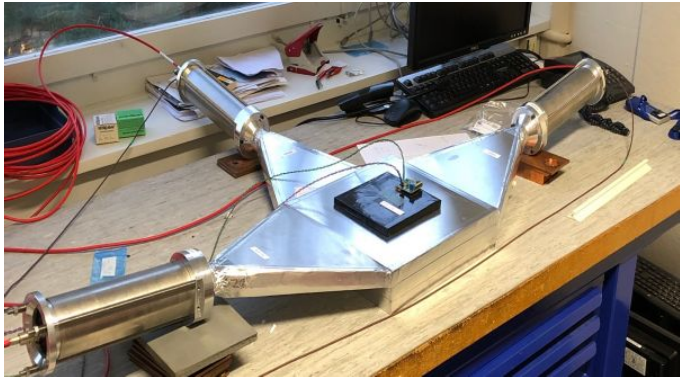


- Pilot detector consisted of 2 halves: Pb (1 mm x 100 layers) and W (0.5 mm x 120 layers)
- Successfully collected 12.2 fb^-1 of data
- Performance demonstrated with first physics publication [PhysRevD.104.L091101]

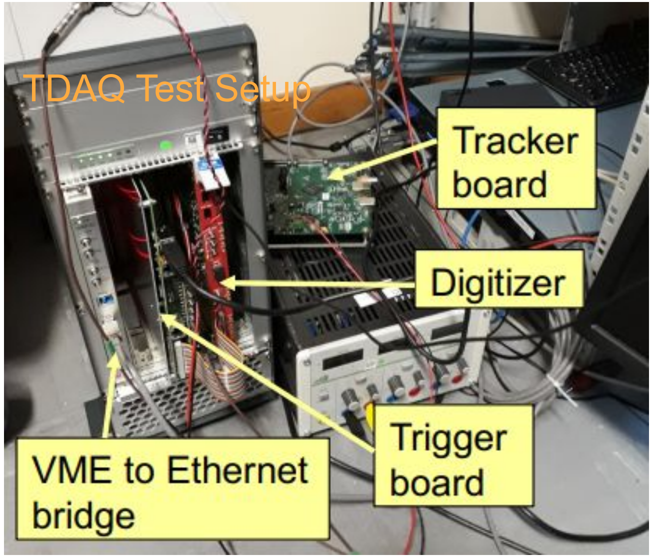


FASER Scintillators and TDAQ

- Scintillators used for vetoing incoming charged particles - Very high efficiency needed (O(10^8) incoming muons in 150/fb)
- Timing measurement, 1ns resolution
- Simple pre-shower for the calorimeter
- Many thanks to the CERN scintillator lab for producing the scintillators and light guides.

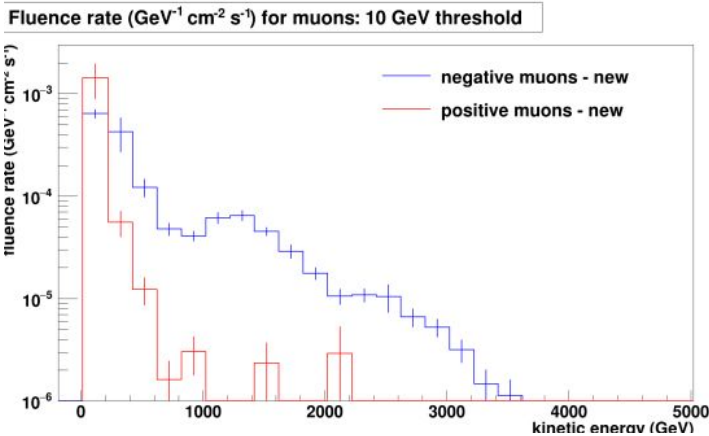


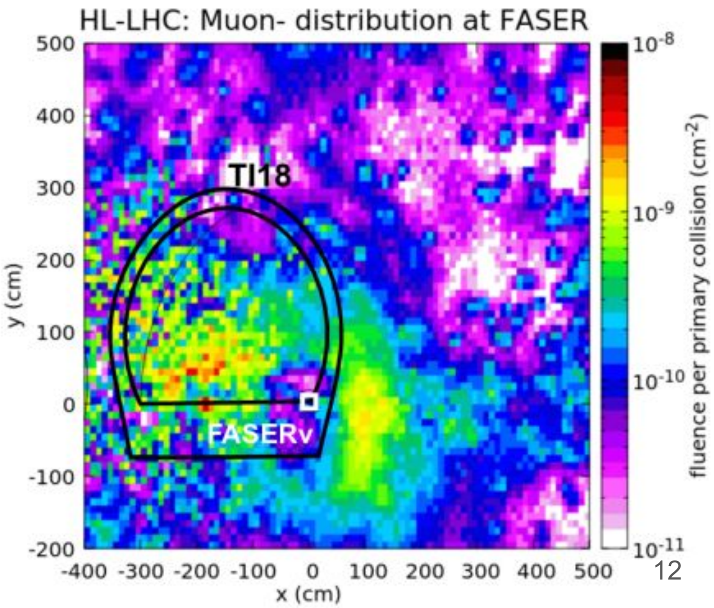
- Trigger rate 500-1000 Hz
- Maximum bandwidth ~15MB/s
- Event size ~24KB
- Readout and trigger logic electronics located in the TI12 tunnel.



Background Estimation

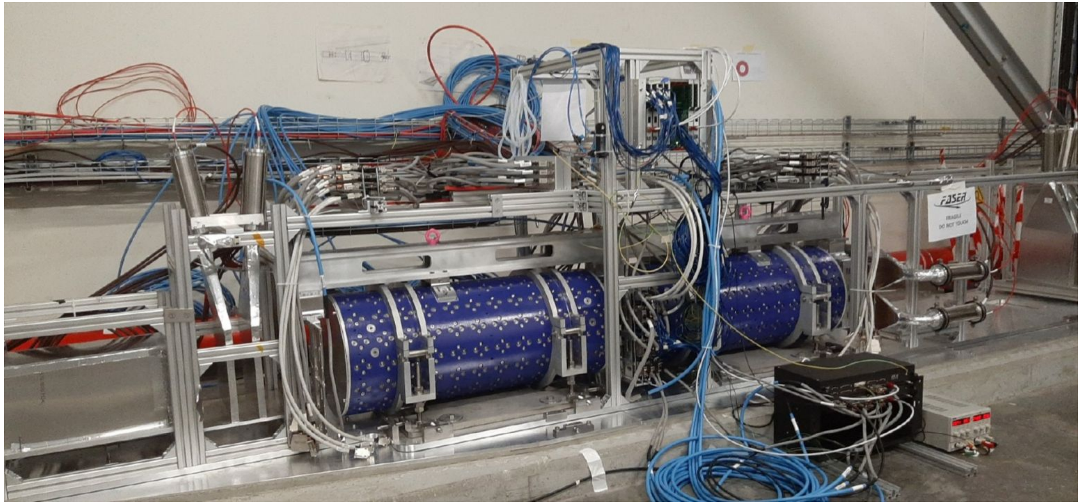
- The FLUKA simulations were performed for particles originating from
    - IP1 collisions (shielded by 100m of rock)
    - off-orbit protons hitting the beam pipe aperture in dispersion suppressors close to FASER
    - beam-gas interactions
- The muon flux of high energy muons (E>10GeV) is 0.4cm^-2 s^-1 for 2e24cm^-2s^-1 luminosity from IP1 collisions. **Confirmed by in situ measurements in 2018.**





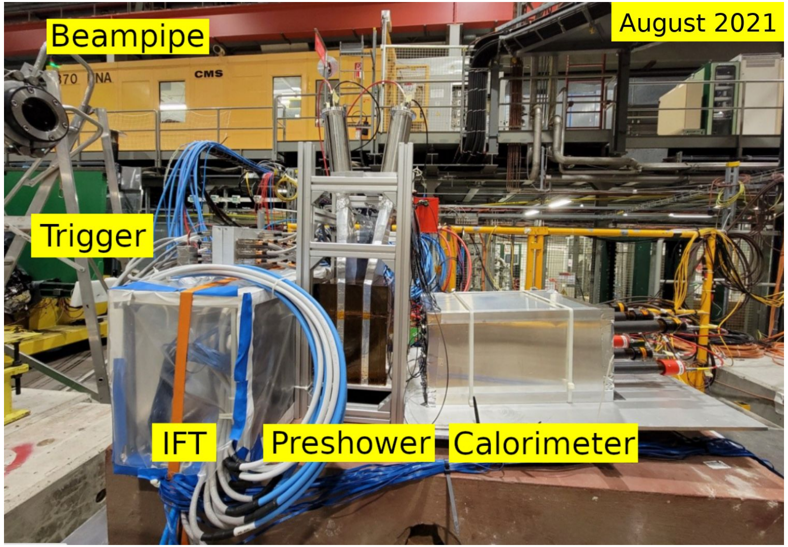
Commissioning & Surface dry run

- Full detector commissioning in the FASER lab located in EHN1 (neutrino platform) at the Prevessin site in late summer 2020.
- Assembly of the upper frame with one tracking station, calorimeter, all scintillators, and two magnets on a baseplate mock-up.



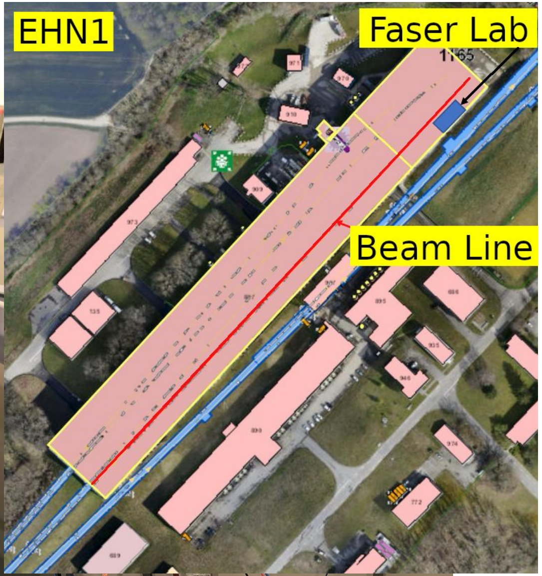
FASER Test Beam

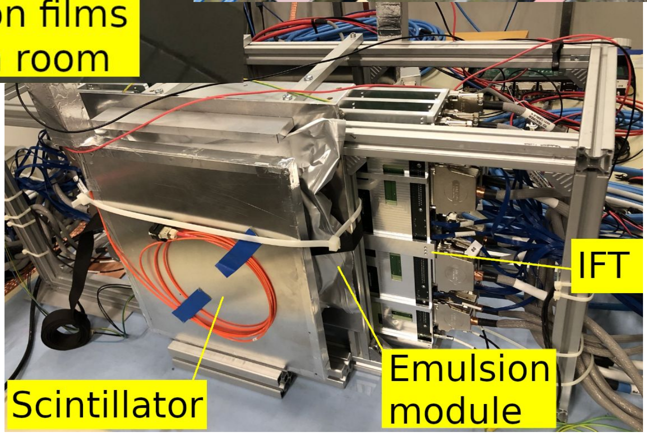
- Testbeam campaign carried out July 28th to August 4th with the CERN SPS.
- 5-300 GeV electron beams, 200 GeV muon beam, 200 GeV pion beam.
- Goal: characterization of overall performance, energy calibration of preshower and calorimeter.
- Setup:
  - two trigger scintillators
  - 3-layer tracker station (IFT)
  - preshower scintillator station
  - 6 calorimeter modules
- Recorded over 150 millions events
- Analysis of this data is still ongoing



Test of Emulsion Module

- Combined test of …
  - … a emulsion module (20 emulsion films + tungsten plates)
  - … 3-layer tracking station (IFT)
  - … two scintillators
- to study the matching of tracks in the emulsion detector and the IFT.
- We utilize the muon beam from SPS which can be detected from our lab (~6m away)





The FASER Experiment - Installation in TI12

August 2018, old LEP transfer line

April 2021, BSM search detector fully installed

April 2021, test installation of FASERν with testbox

- FASER fully installed (the last part, the IFT, was installed in November)
- FASERν emulsion detector will be installed just before the start of Run-3

In situ commissioning

- In situ commissioning ongoing since April 2021 using internal calibration circuit and cosmic rays to ensure a high fraction of operational channels, low noise occupancy, and uniform threshold distribution.
- Developing operational experience, improving monitoring and validate data processing workflows.
- Cosmics are used to test the full detector system, including trigger, DAQ, and the tracker stations. The cosmic rate is very low for horizontal cosmics.

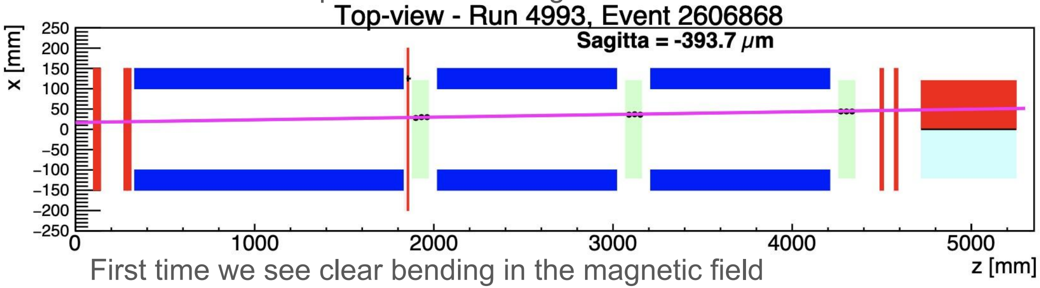
track rate	one station	two stations	three stations
expected	0.011 Hz	1 / (28 hours)	1 / (82 days)
observed	0.012 +- 0.001 Hz	1 / (33.5 +- 8.9 hours)	Not yet observed

In situ commissioning with the LHC Pilot Beam

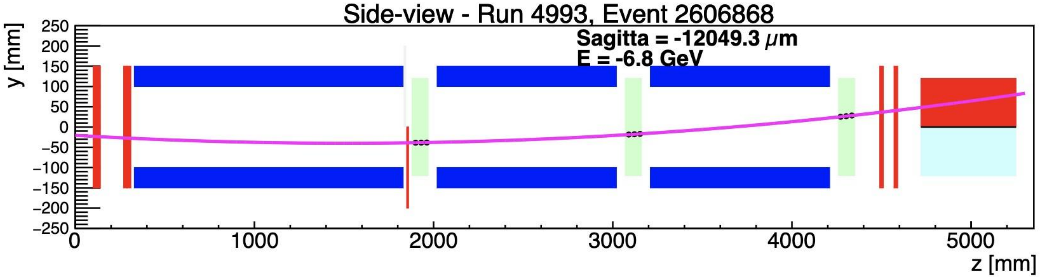
- Data recorded during pilot beam tests in the last two weeks in October.
- Beam splash events, generated by driving the beam into closed collimators producing large shower of muons, are seen.

- Observed:
  - Multi-muon events during splashes from ATLAS.
  - Single muon events during stable beams and collimator insertion in beam
  - Beam background from incoming beam (beam 1 from LHCb)

First time we see particles traversing the full detector

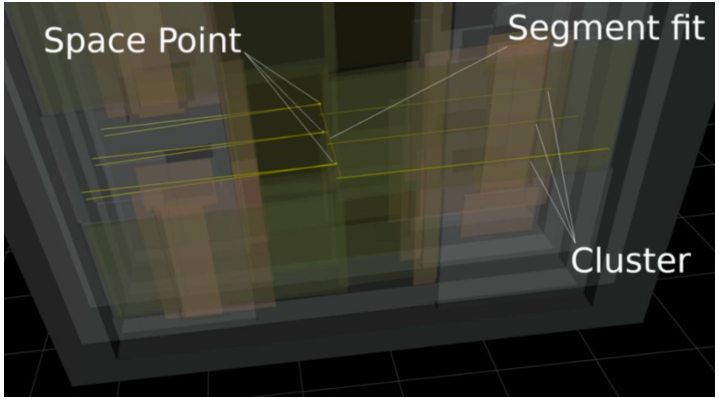


First time we see clear bending in the magnetic field



Offline Software

- A lot of parallel work on the offline software is performed in preparation for Run-3 physics.
- Improved ECAL simulation (different physics models, comparison with LHCb and testbeam data).
- Improved geometry description with passive material.
- Work on ACTS tracking and alignment ongoing.
- First studies for FASER**ν** simulation.



Summary & Outlook

- FASER is a new and inexpensive experiment at the LHC complementing the current physics program with searches in the boosted low pT region.
- Sensitivity to light, weakly interacting new particles; neutrino physics programme.
- Installation successful and in situ commissioning ongoing.
- Performance of the detector components tested with cosmic data, test beam data, and LHC pilot beams.
- We are ready for data-taking in 2022.