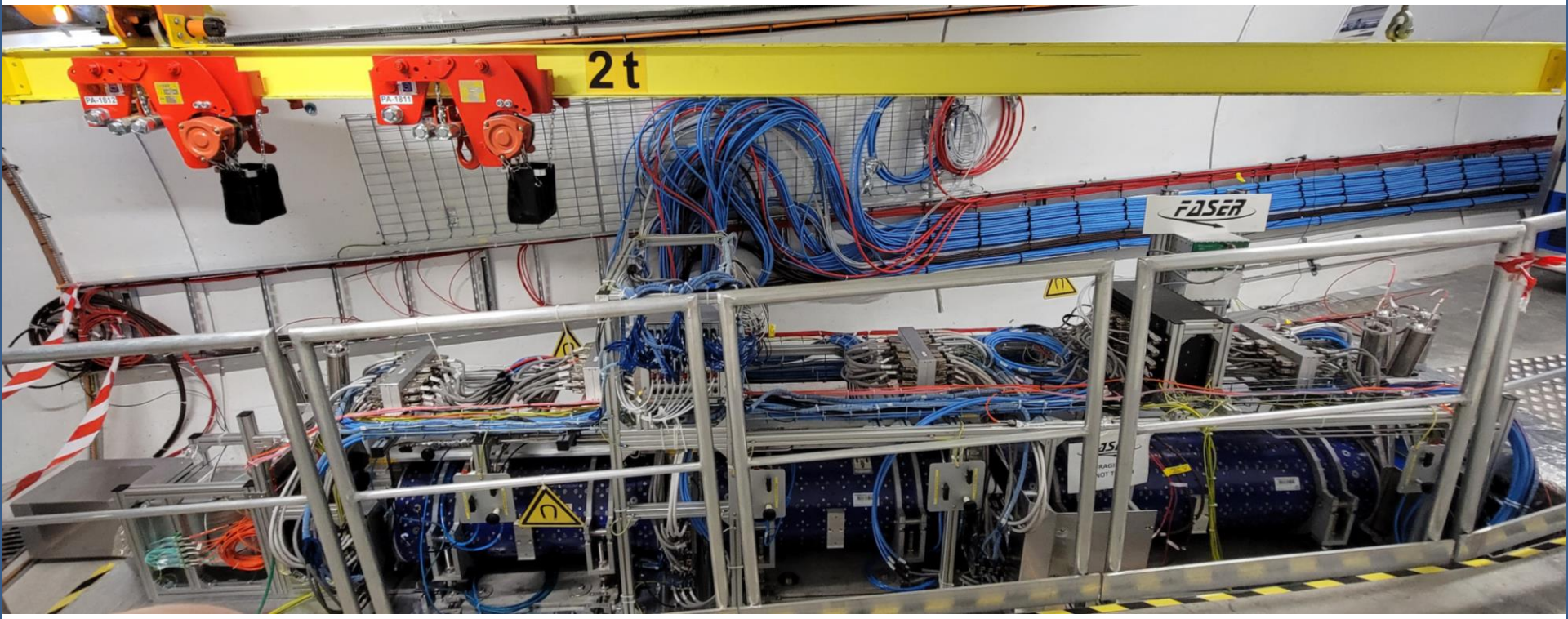
The ForwArd Search ExpeRiment



25-10-2022

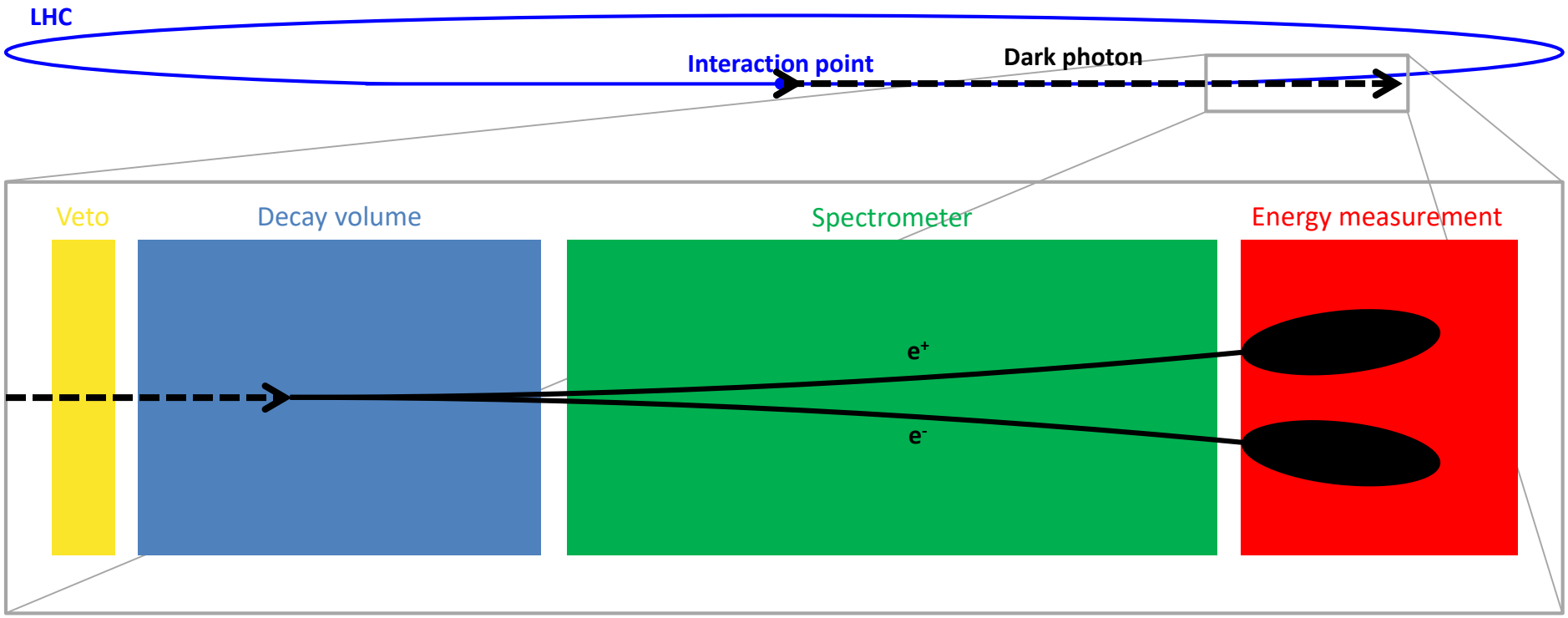
Sune Jakobsen (CERN EP-DT-TP)
on behalf of the FASER collaboration

acknowledges support from the Heising-Simons Foundation, Simons Foundation and CERN

LHC Forward Physics meeting

FASER physics

Conceptional FASER physics case – Dark photon



Signature of golden event

No signal in the veto.

Two high energy oppositely charged tracks from a common vertex in the decay volume.

Spectrometer (magnets + trackers) to separate the decay products so the tracks can be measured individually.

Large electromagnetic energy deposit (for electron final states).

FASER location

The FASER location

FASER is benefitting from existing structures

LHC interaction point 1 housing the ATLAS detector.

An abandoned transfer line leading from the SPS to LHC.

From ATLAS the line of sight is crossing the abandoned transfer line: This is the location for the FASER detector.

The LHC magnets are sweeping away the majority of luminosity based background from charged particles.

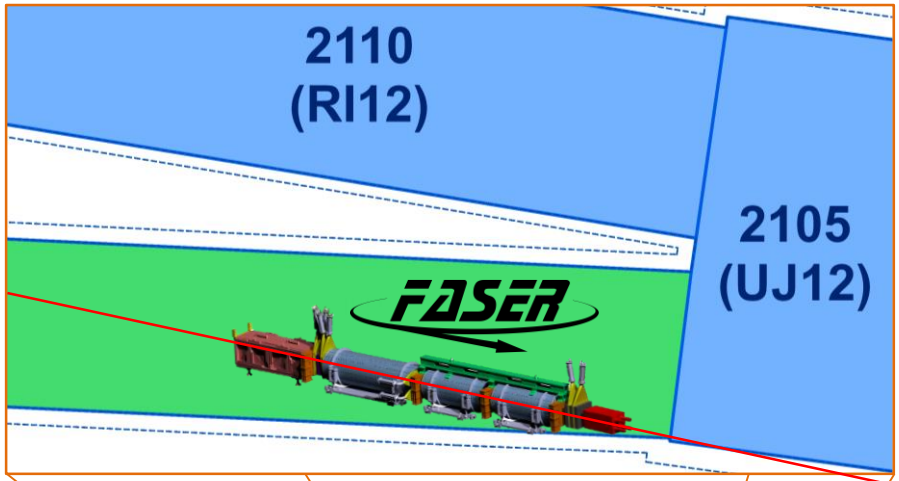
~100 m of rock shields FASER from luminosity based background (including neutrals).

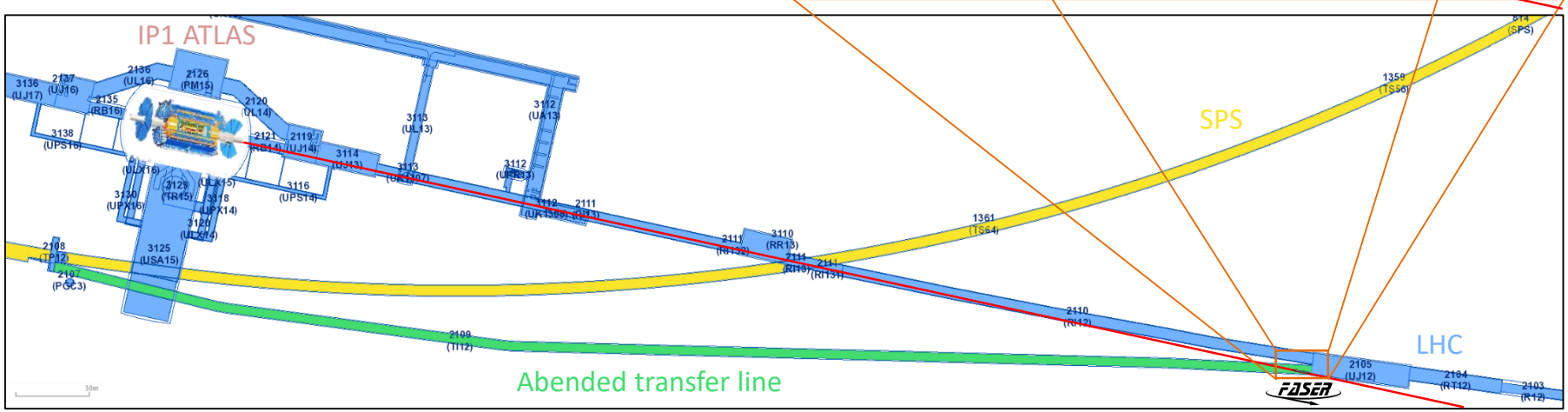
The location is separated from the LHC, which minimizes beam related background.

Forward direction

At LHC, the production of many particles are emphasized in the forward direction.

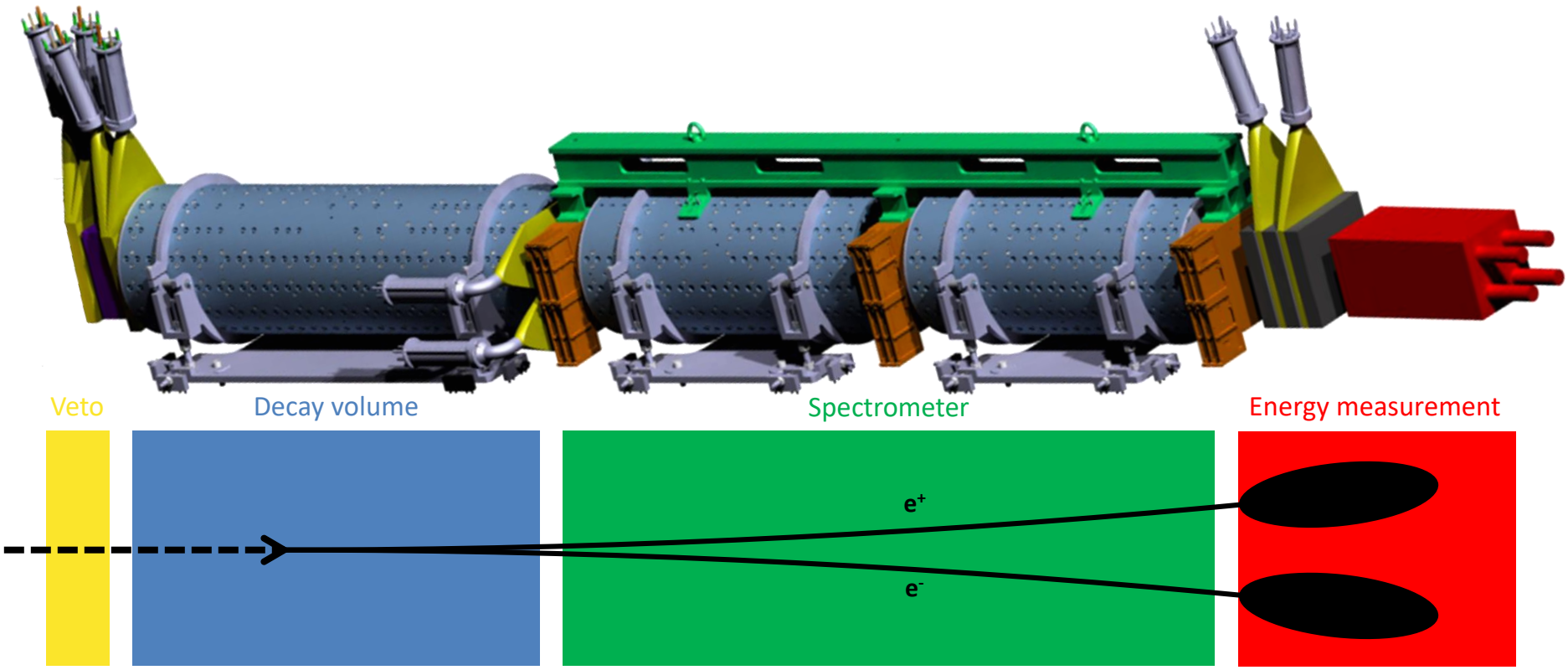
E.g. 1 % of π^0 are produced in the FASER acceptance despite it acceptance only covers 1E-8 of the solid angle.





The FASER detector

The FASER detector - Overview



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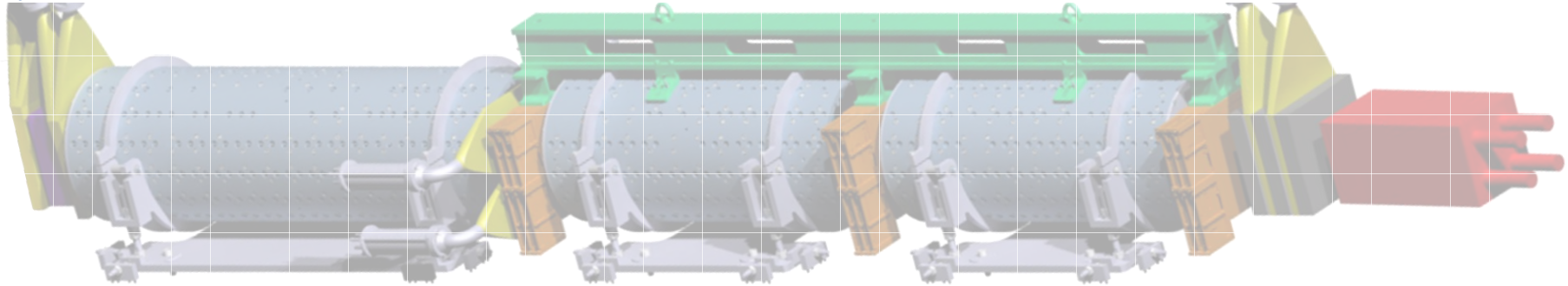
FASER Detector paper: arxiv: 2207.11427

The FASER detector – Magnets



The 3 FASER magnets

1 magnet for the decay volume (length 150 cm).

2 magnets for the spectrometer (length 100 cm).

Magnet design

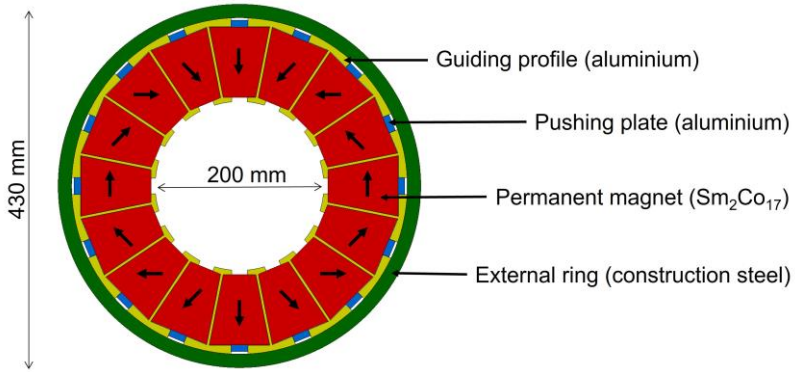
Design and construction at CERN.

Permanent dipole magnet based on the Halbach design array.

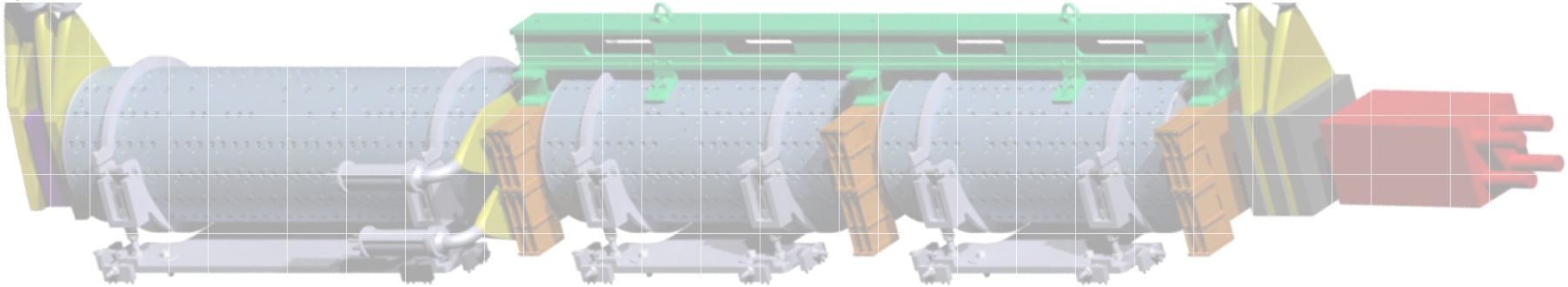
No need for infrastructure (power and cooling).

0.55 T magnetic field.

20 cm round aperture.



The FASER detector – Tracker



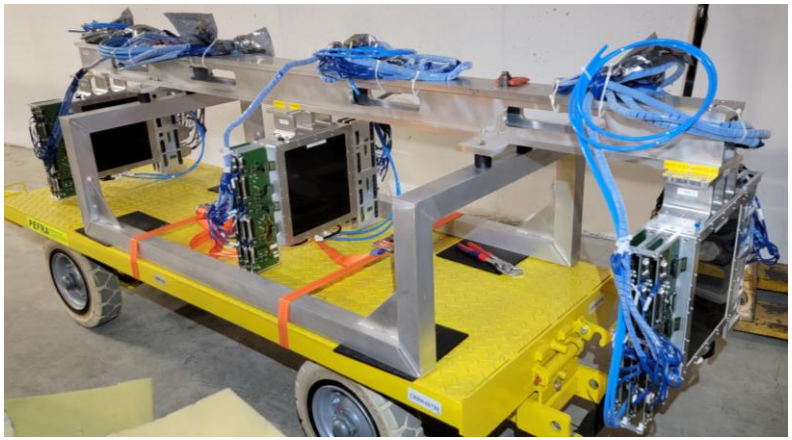
3 tracker stations as part of the spectrometer.

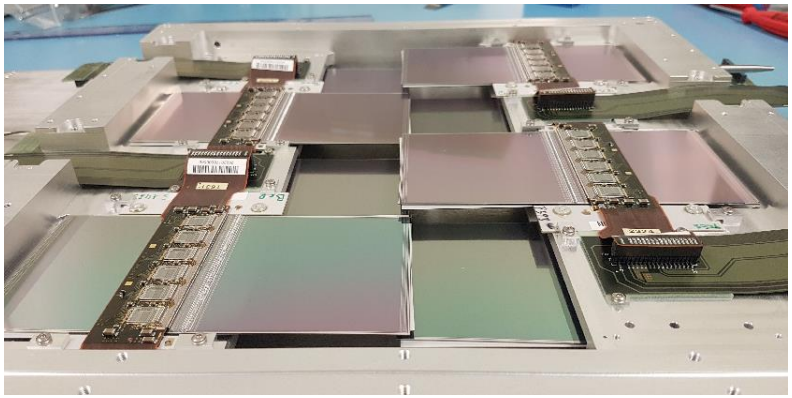
Support and relative alignment is provided by a backbone structure.

Detector design

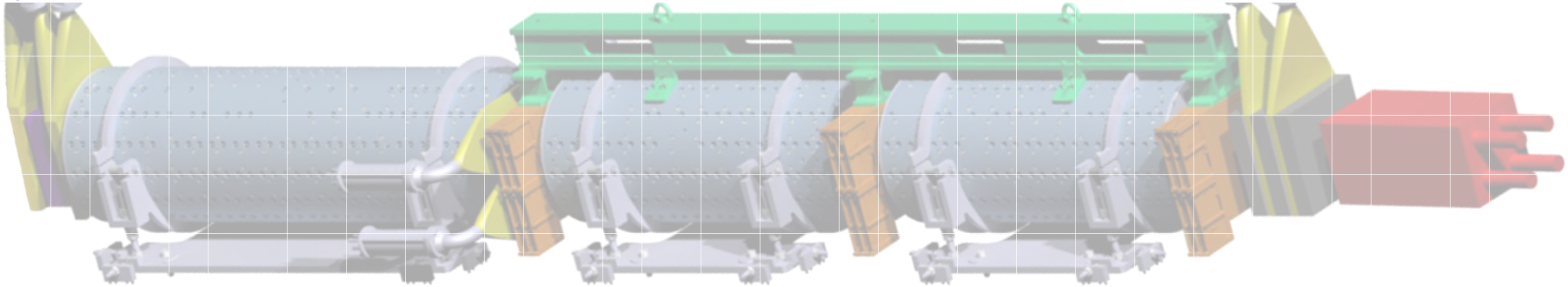
- Based on silicon strip tracking modules from ATLAS.
- 8 modules is used for a tracking plane.
- Each station has 3 tracking planes.
- Resolution in the bending direction: ~20 µm.
- Resolution in the non-bending direction: ~550 µm.
- Water cooled (no need for very low temperature as there is only little radiation).
- Dry gas can be flushed through the station to prevent condensation.

FASER Tracker paper: NIMA 166825 (2022)





The FASER detector – Veto, timing and trigger



Veto station

Purpose: Suppress event with incoming standard model particles. (e.g. 1E8 muons in Run3).

2 pairs of 2 cm x 30 cm x 30 cm plastic scintillators.

4 classical photomultiplier tubes (Hamamatsu H6410) with 2 layers of mu-metal for magnetic shielding.

Classic fishtail light guide with tilts to optimize the relative photomultiplier positions.

Trigger and timing station

Purpose: Trigger and provide accurate timing of the event.

2 units of 1 cm x 40 cm x 20 cm plastic scintillators.

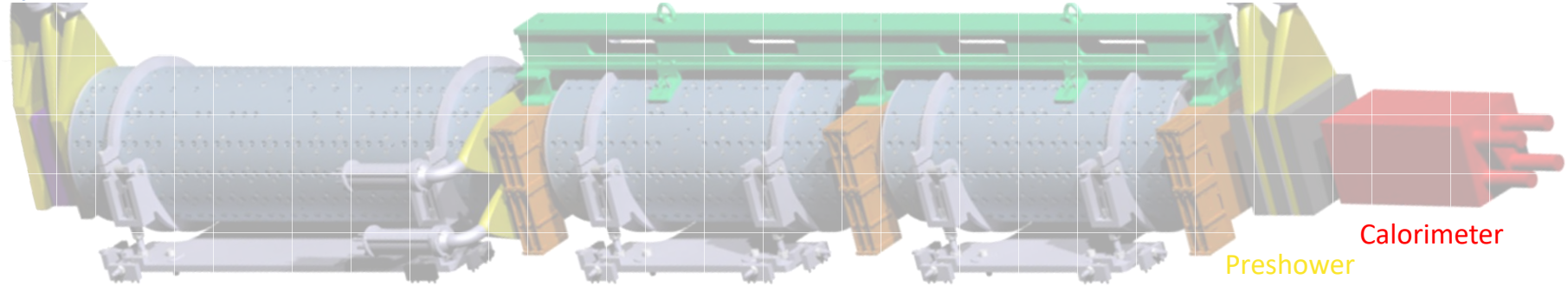
Same photomultipliers and mu-metal as for the veto station.

Classic fishtail light guide with 90 degree bent to fit in the detector space.

Performance

The scintillator efficiencies have been measured with cosmic rays and collisions data and are well within specifications.

The FASER detector – Preshower and calorimeter



Preshower station

Purpose: Trigger and particle identification.

Detector identical to veto station.

3 mm tungsten radiator installed in front of each scintillator.

50 mm graphite installed in front of each scintillator and the calorimeter to reduce backsplash.

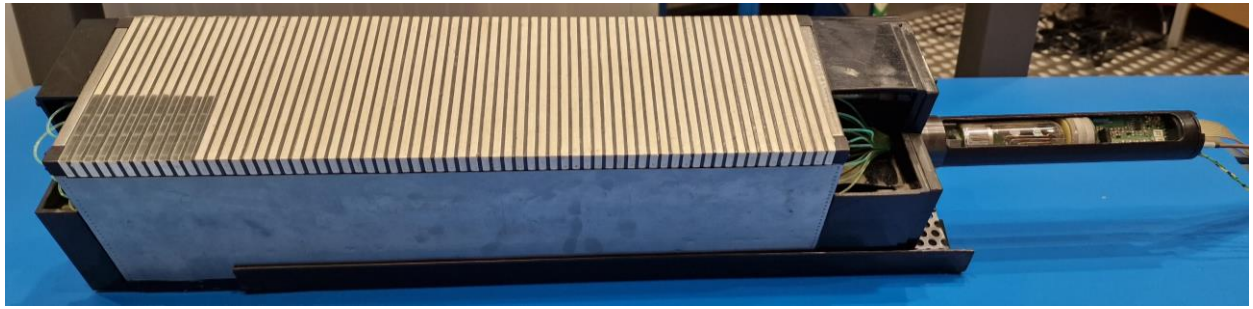
Calorimeter

Based on 4 LHCb outer ECAL modules.

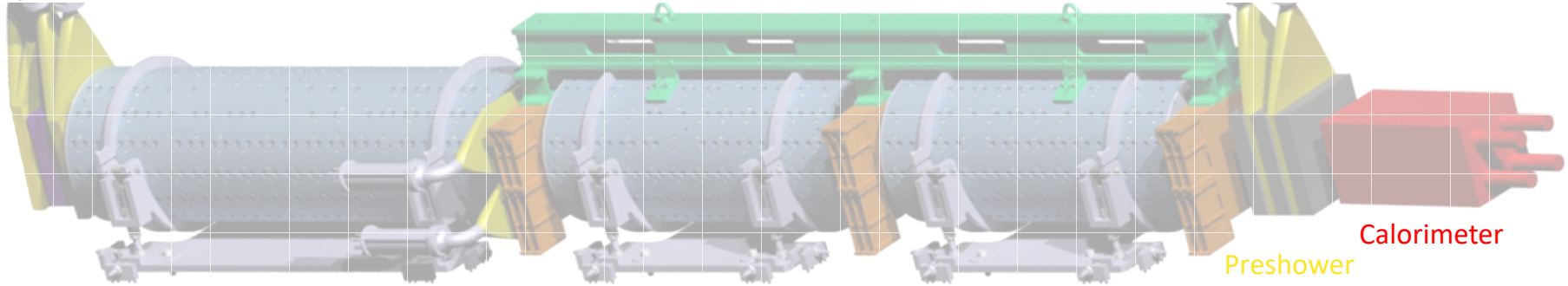
Shashlik-type with interleaved plastic scintillator (4 mm) and lead (2 mm).

4 classical photomultiplier tubes (Hamamatsu R7899-20) used for readout.

A filter in front of the photomultiplier tube is used to move the range to the TeV scale.



The FASER detector – Trigger and acquisition system



Underground

Trigger Logic Board: Core of the TDAQ system, distributes clocks and L1A and manage trigger signals.

CEAN digitizer: Readout of all photomultiplier tubes. 14 bit ADC and readout window of up to 1.2 µs.

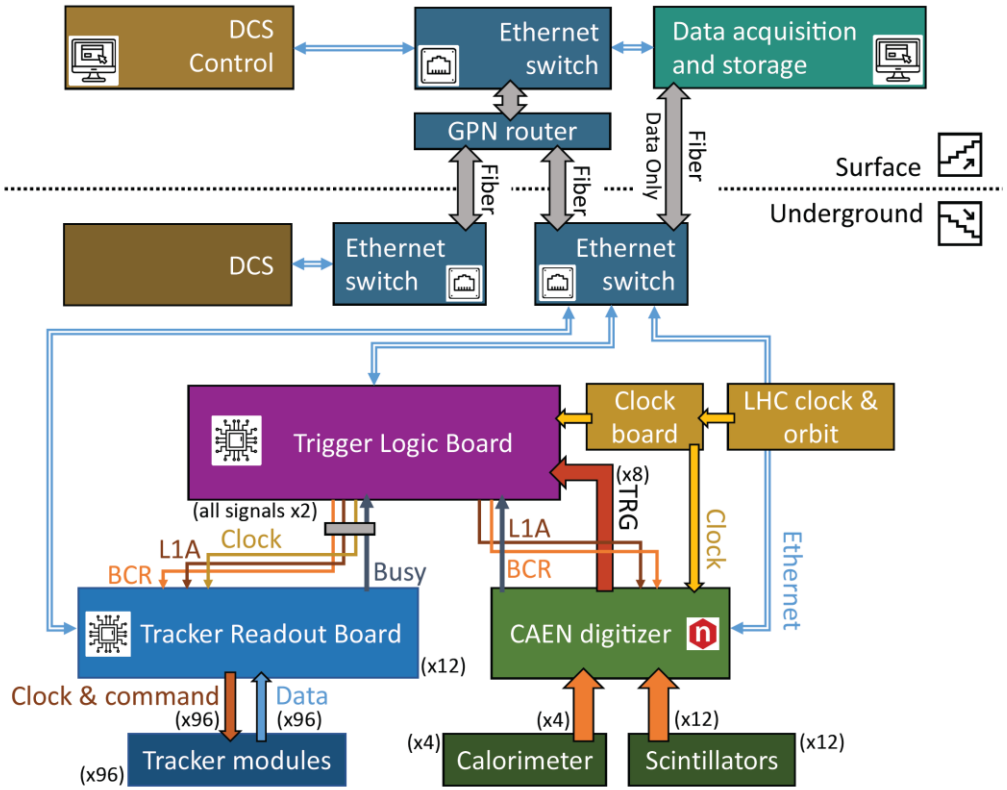
Tracker Readout Board: Readout of the SCT modules.

Surface

Data acquisition and storage.

Detector Control System.

No control room (all remote).



FASER DAQ paper: JINST 16 P12028

FASER test beam

FASER test beam

Main purpose: Calibration of calorimeter.

Secondary purpose: Experience with combined running of the detector system.

Experimental setup: Full "mini FASER"

FASER trigger scintillators (for FASERν).

One tracking station.

Full FASER preshower.

6 calorimeter modules (with and without filters).

Beam line SPS H2

Electron beam at various energies (main beam).

Muon beam.

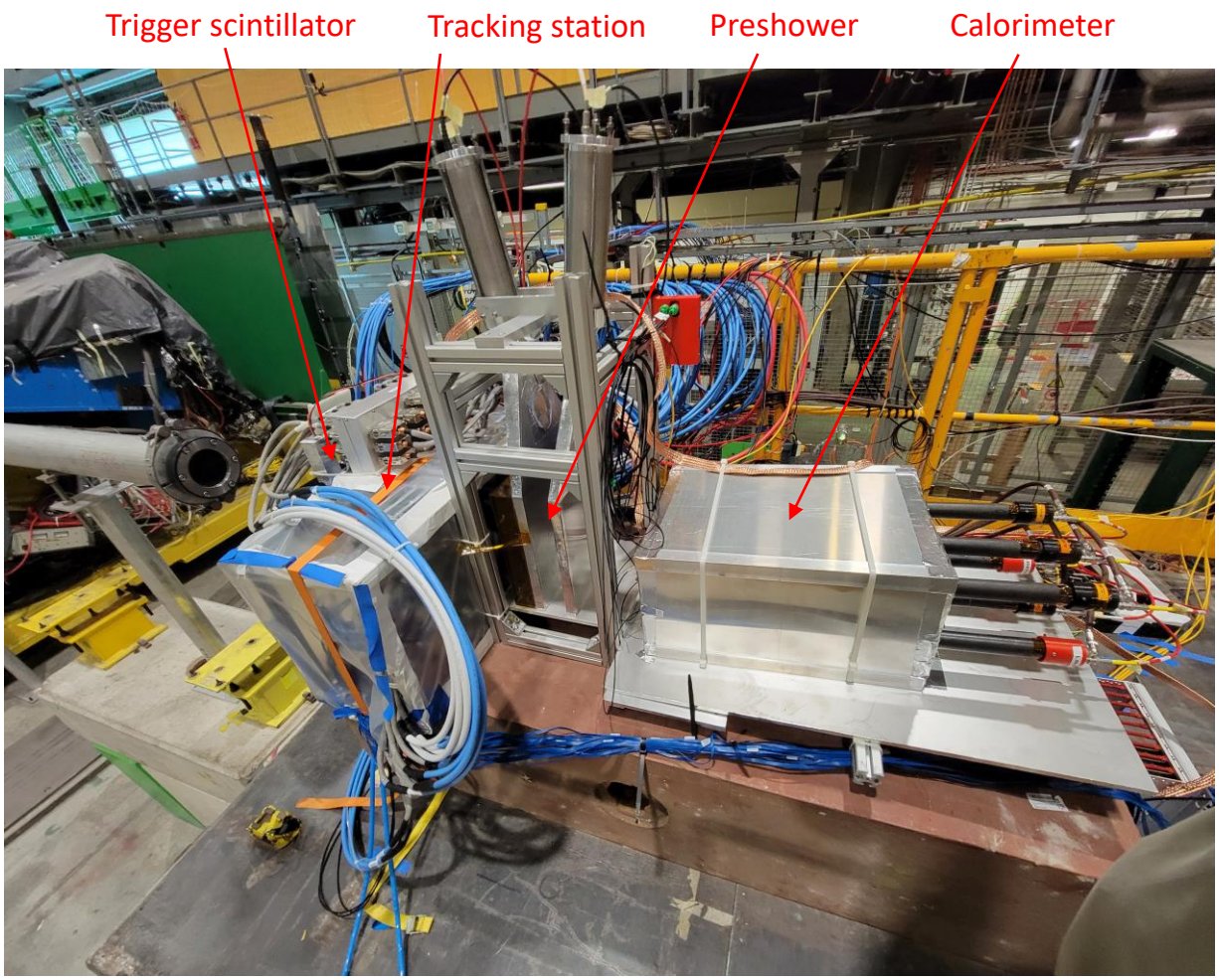
Pion beam.

Outcome

Very successful.

Next to no detector down time.

All desired energies scanned.



FASER installation

FASER installation and status

Preparation of location.

Infrastructure

- Power.
- Fibers, clocks and Ethernet.
- Racks.
- Cooling.
- Cranes.

Detector installation

- Mounting plate: Support all and can move the full detector (for change of crossing angle).
- Magnets.
- Tracker stations.
- Scintillator modules.
- Calorimeter.

January 2019

April 2020

November 2020

FASER operation

FASER operation

The FASER detector has been fully commissioned.

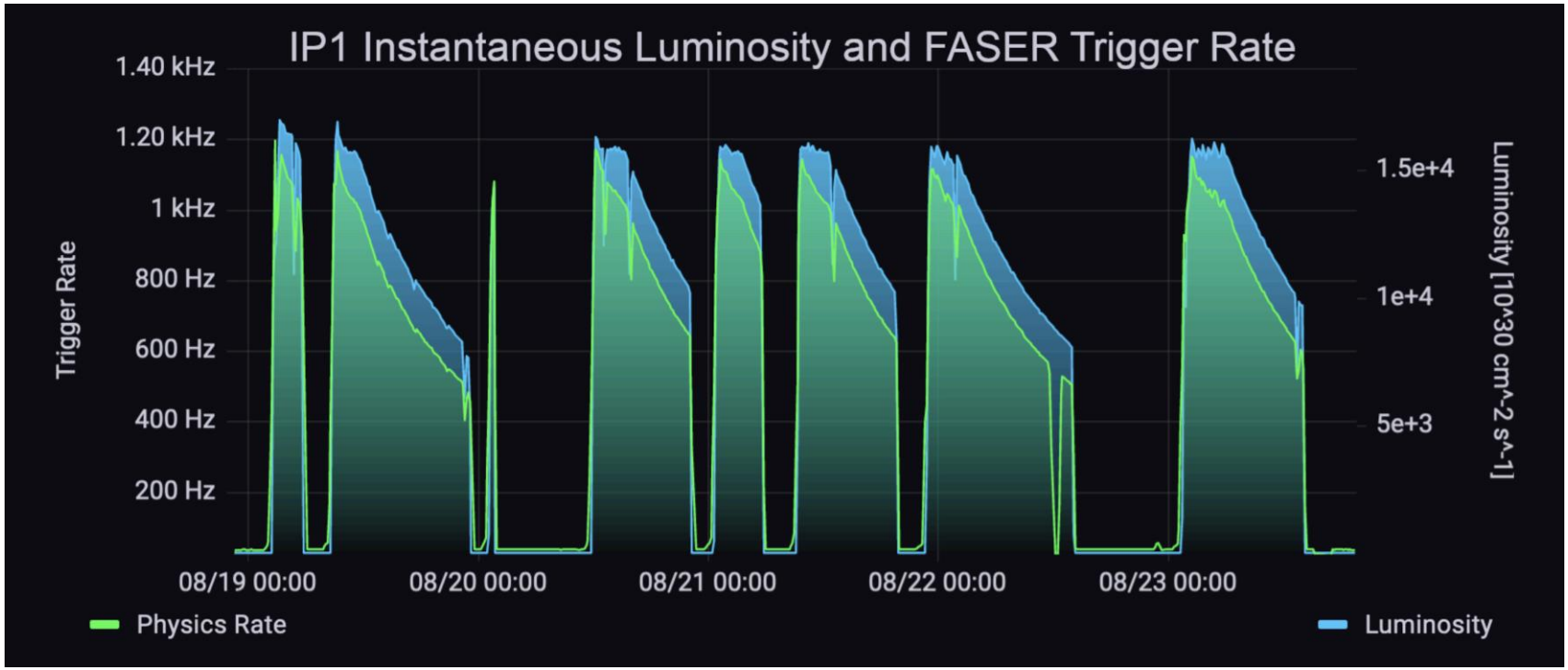
Since July 2022 FASER has been collecting $\sqrt{s}$ = 13.6 TeV collision data

No problems observed.

The maximum trigger rate is ~1.2kHz (nearly 2x the expectation), but this is not a problem for physics.

Over L_{INT} = 20 fb^{-1} data have been recorded.

Many performance studies are ongoing.



FASER operation – Event display

Collision event with a muon traversing FASER

Run 8336.

Event 1477982.

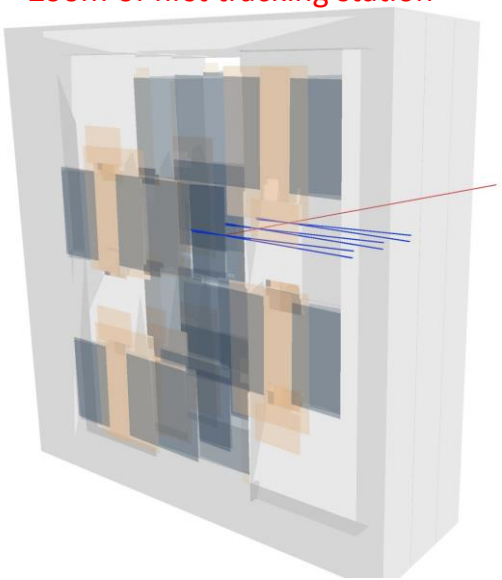
Time: 2022-08-23 01:46:15.

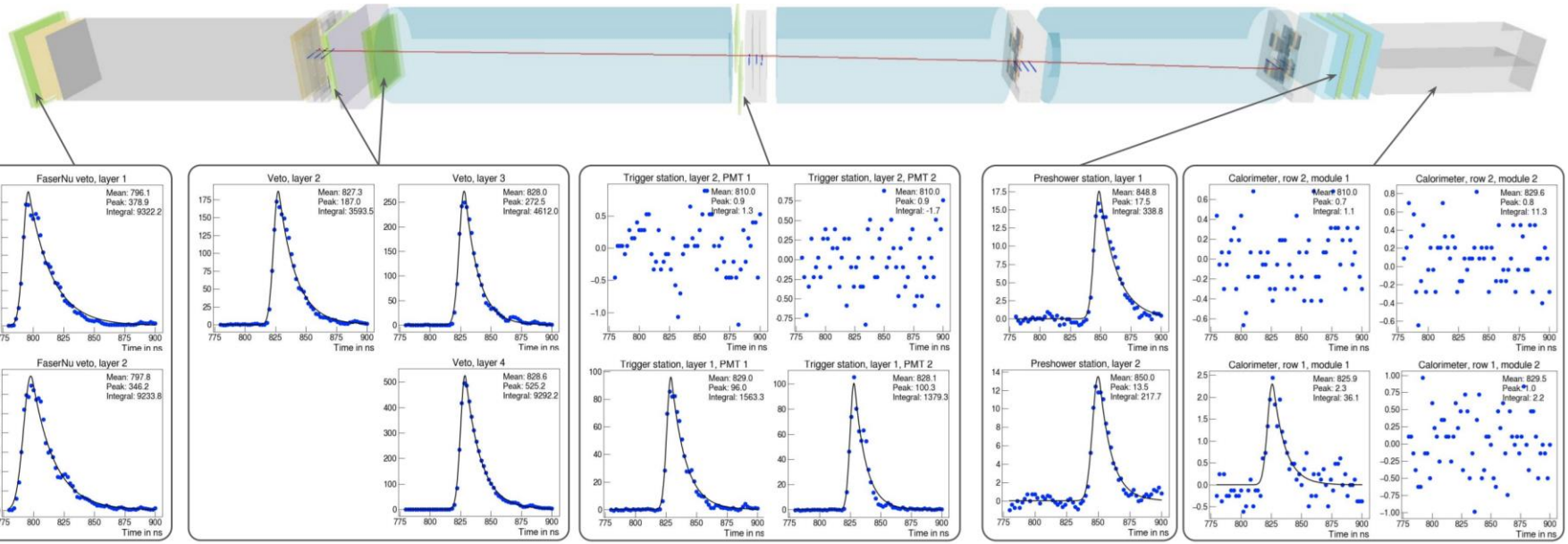
Waveforms shown for signals in scintillators and calorimeter modules.

Silicon strips with signals used to reconstruct the track in the tracking stations.

Measured momentum of 21.9 GeV.

Zoom of first tracking station



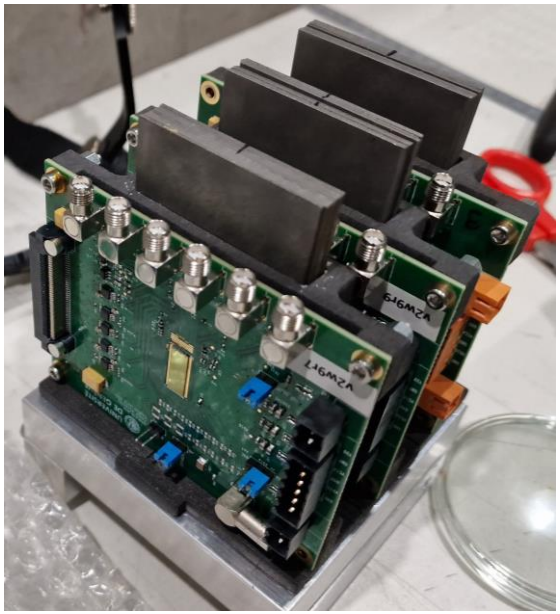


Short term FASER upgrades

Approved upgrade: Tungsten-silicon high precision preshower

Main purpose: Extend the sensitivity to long-lived particles decaying into photons

Main method: Distinguish very close together spaced photos



Detector design

6 layers of 1 radiation length tungsten.

Monolithic silicon pixel detector.

Hexagonal pixels with 100 µm pitch.

Current status

Several test beams with promising results.

Installation schedule

End of 2023.

FASER preshower technical proposal: [CDS 2803084]

Potential upgrade: Extent range of calorimeters

Main purpose: Extend the range of the calorimeters to avoid uncertainty from filter installation.

A Dark Photon signal would give TeV level energy deposit in the calorimeter.

Currently the high range of the calorimeters are achieved by introducing a filter between the calorimeter and the photomultiplier tube.

With the filters installed, the muon MIP signal for calibration is very small.

Main method: Split the light output of the calorimeter over several photomultiplier tubes.

Detector design

Replace the current photomultiplier with a fiber bundle (after a light mixer).

Split the fiber bundle into 3 bundles with e.g. 1, 8 and 60 fibers in each.

Use a separate photomultiplier tube for each bundle.

The combined range should now be almost a factor 60 larger, which should cover the full desired range.

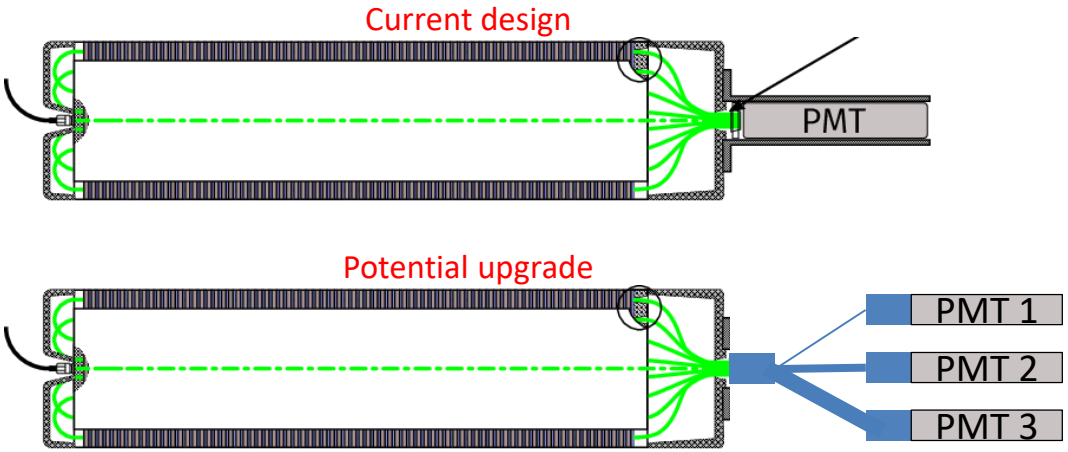
Current status

Conceptional design.

Procurement for prototype.

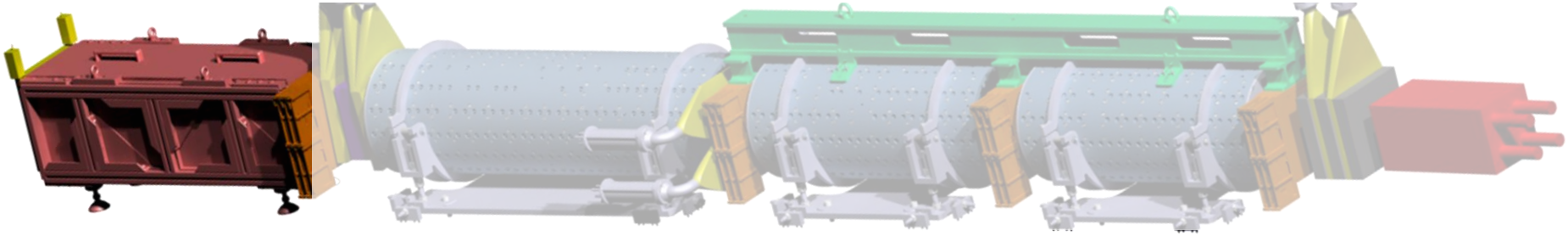
Installation schedule

2023.



FASERν

FASERν



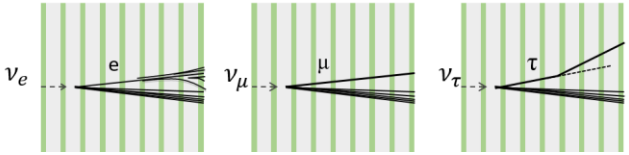
Main purpose: Probe forward neutrino physics at LHC.

Main method

Accumulate events over time.

Replace a few times per year.

Distinguishing neutrino flavors with FASERν



Detector design

Emulsion films separated with 1 mm thick tungsten (25 cm x 30 cm).

770 tungsten-emulsion layers (1.1 m).

Detector location: In front of FASER

Muon charge identification with FASER spectrometer.

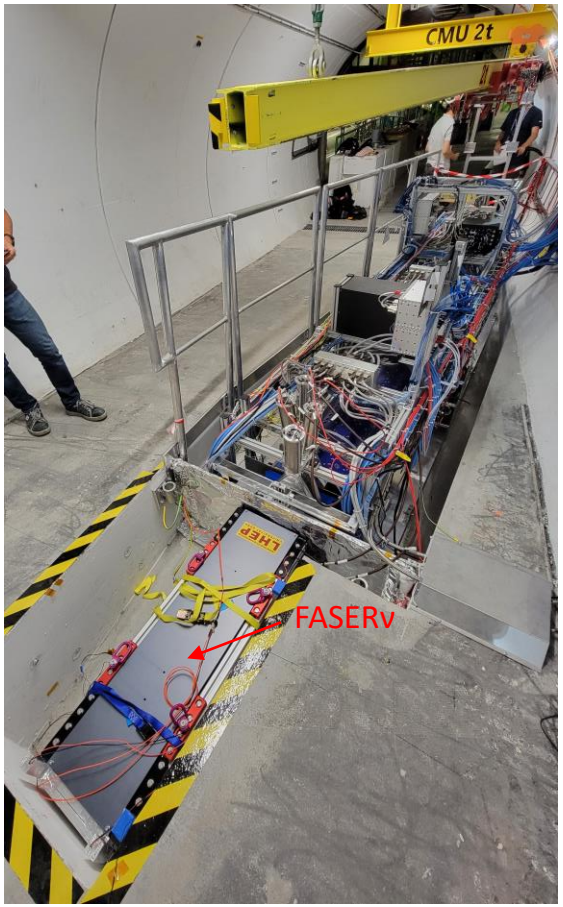
Improve energy resolution.

Current status

1st FASERν box (1/3 of nominal emulsion), installed March -> 26/7, L_{INT} ~ 0.5 fb^{-1} of collision data - to be used for commissioning of the FASERν workflow.

2nd FASERν box installed 26/7 -> 14/9 and L_{INT} ~ 10.5 fb^{-1} of collision data.

3rd FASERν box installed on 14/9 to be removed on 29/11 (expect L_{INT} ~20 fb^{-1}).



Summary

Summary

FASER is a small and cheap experiment installed in the LHC during LS2, to take data in Run 3

- Targeting light, weakly-coupled new particles at low p_T.
- FASERν: Probe forward neutrino physics at LHC.

Detector designed to be affordable and fast to construct and install

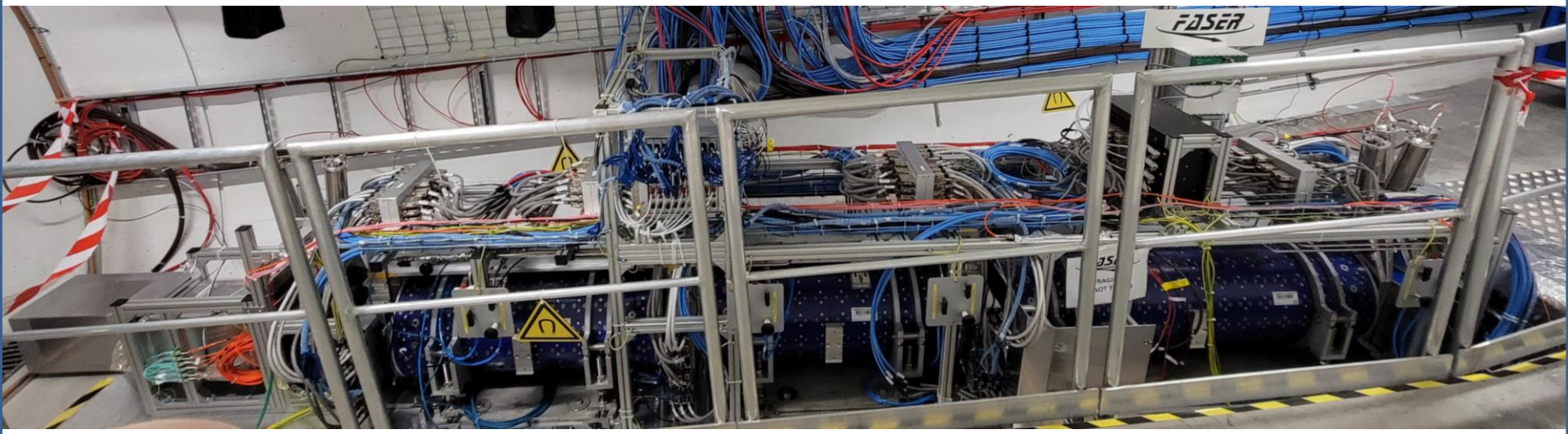
- Utilizing spare modules from existing experiments.
- Minimizing services needed where possible.

Current status: Fully operational

- More than L_{INT} = 20 fb^{-1} of data collected.
- First physics results expected early next year.

Upgrades of preshower approved and of calorimeter under consideration

Potential major upgrade: FASER2 as part of Forward Physics Facility for HL-LHC.



FASER collaboration

81 collaborators, 22 institutions, 9 countries

CERN
UNIVERSITÉ DE GENÈVE
KYUSHU UNIVERSITY
UC IRVINE
UNIVERSITÄT BERN
Technion Israel Institute of Technology
NAGOYA UNIVERSITY
UNIVERSITY of WASHINGTON
JOHANNES GUTENBERG UNIVERSITÄT MAINZ
JG|U
מכון ויצמן למדע WEIZMANN INSTITUTE OF SCIENCE
KEK
UNIVERSITY OF OREGON
UNIVERSITÄT BONN
INFN
清華大學 Tsinghua University
MANCHESTER 1824 The University of Manchester
ROYAL HOLLOWAY UNIVERSITY OF LONDON
UNIVERSITY OF LIVERPOOL
CHIBA UNIVERSITY
UNIVERSITY OF SUSSEX
DESY.
JINR