FASER

Status and FASERν Proposal

Brian Petersen for FASER

20 November 2019
Open LHCC Session

HEISING-SIMONS FOUNDATION
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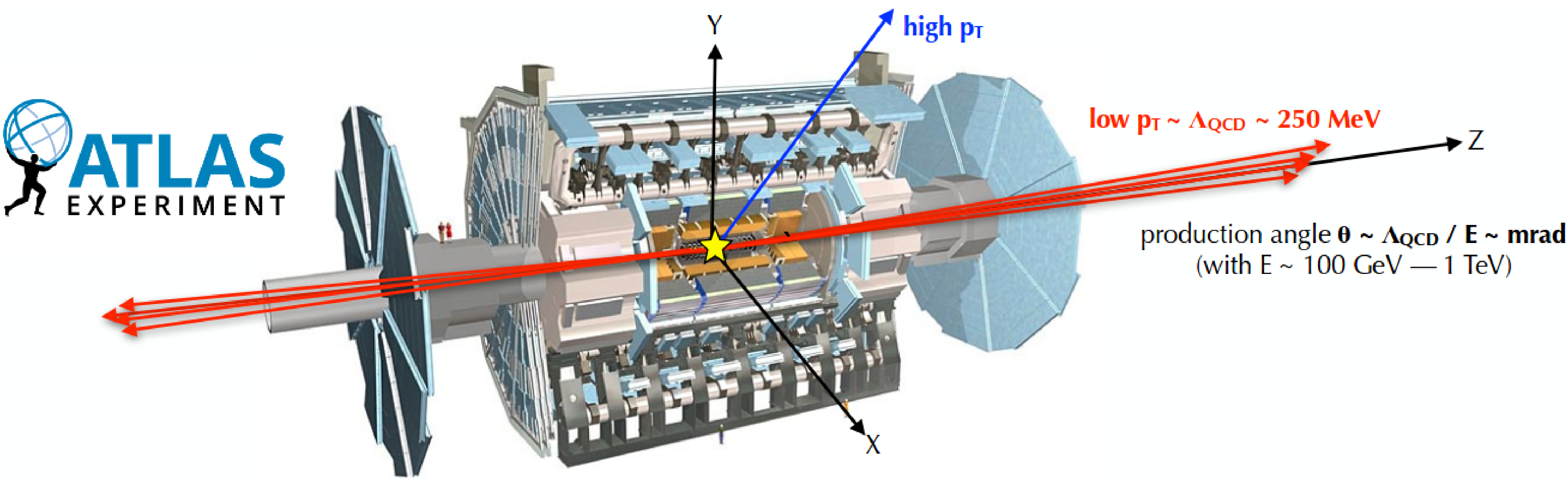
Outline

- Brief reminder of FASER
- Preparation of experimental site
- Status of detector components
- Proposal for neutrino detector (FASERν)

FASER Experiment

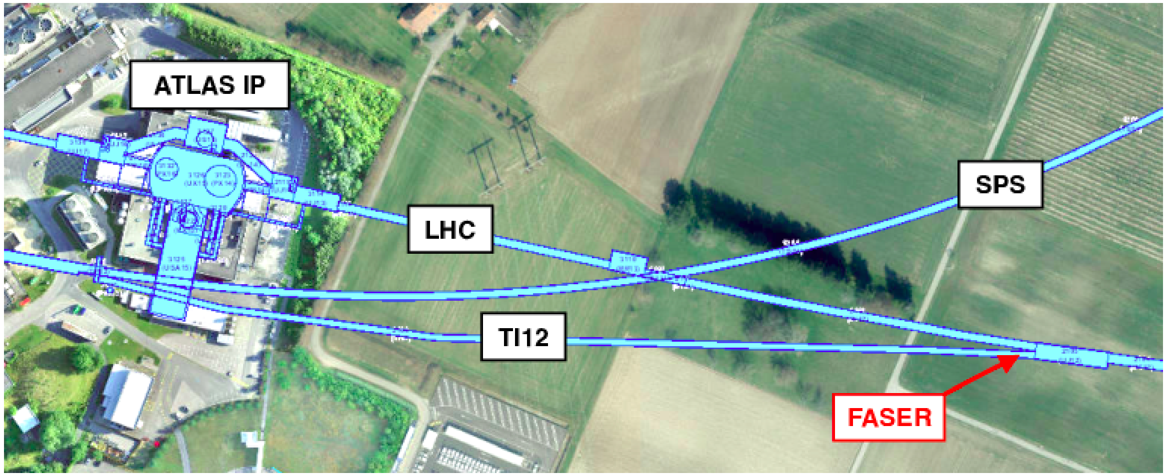
FASER Physics Case

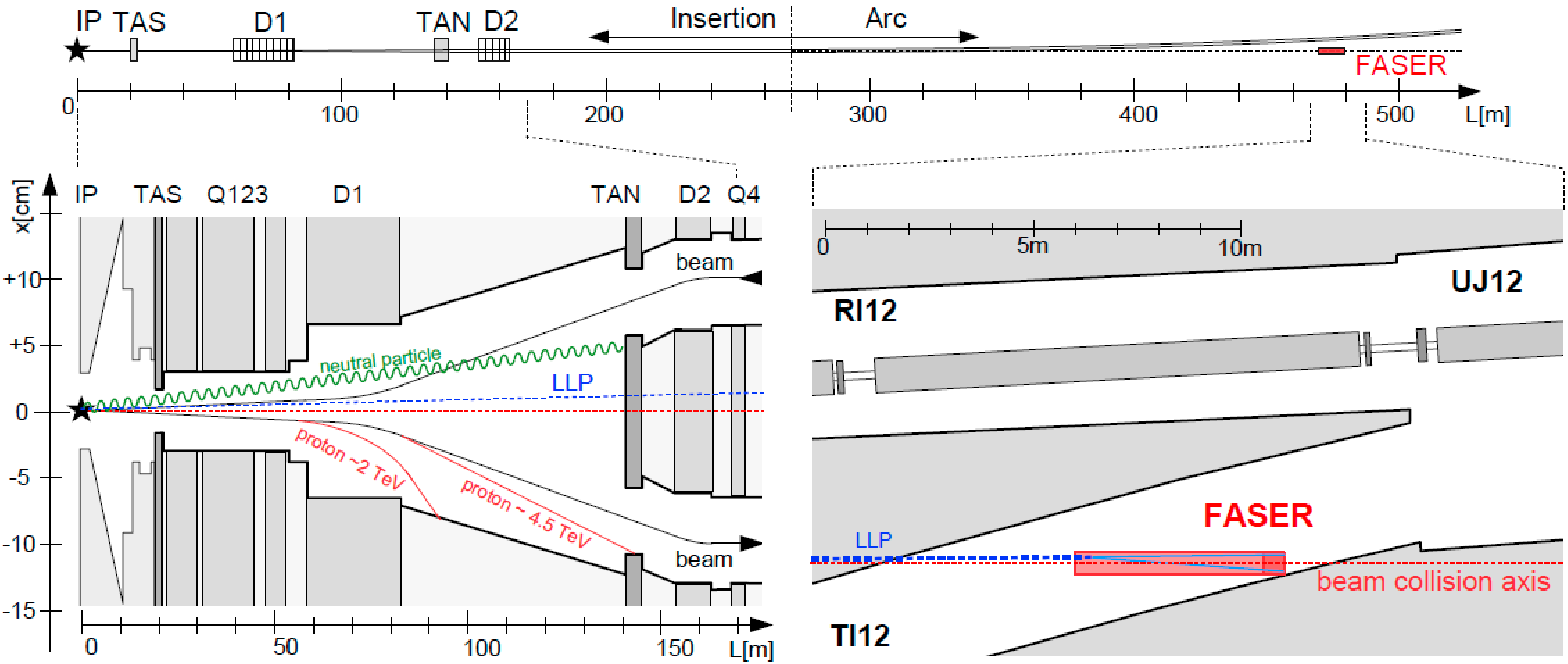
- LHC searches focus on heavy, strongly interacting particles
  - Mainly central production of high p_T particles at low rate
- FASER instead targets light and weakly coupled particles
  - Exploits large collision rate to gain sensitivity to processes with very weak couplings
    - ~10^{16} p-p collisions with 150/fb at 14 TeV
  - New light particles would mostly be produced with low p_T, thus highly collimated in forward direction



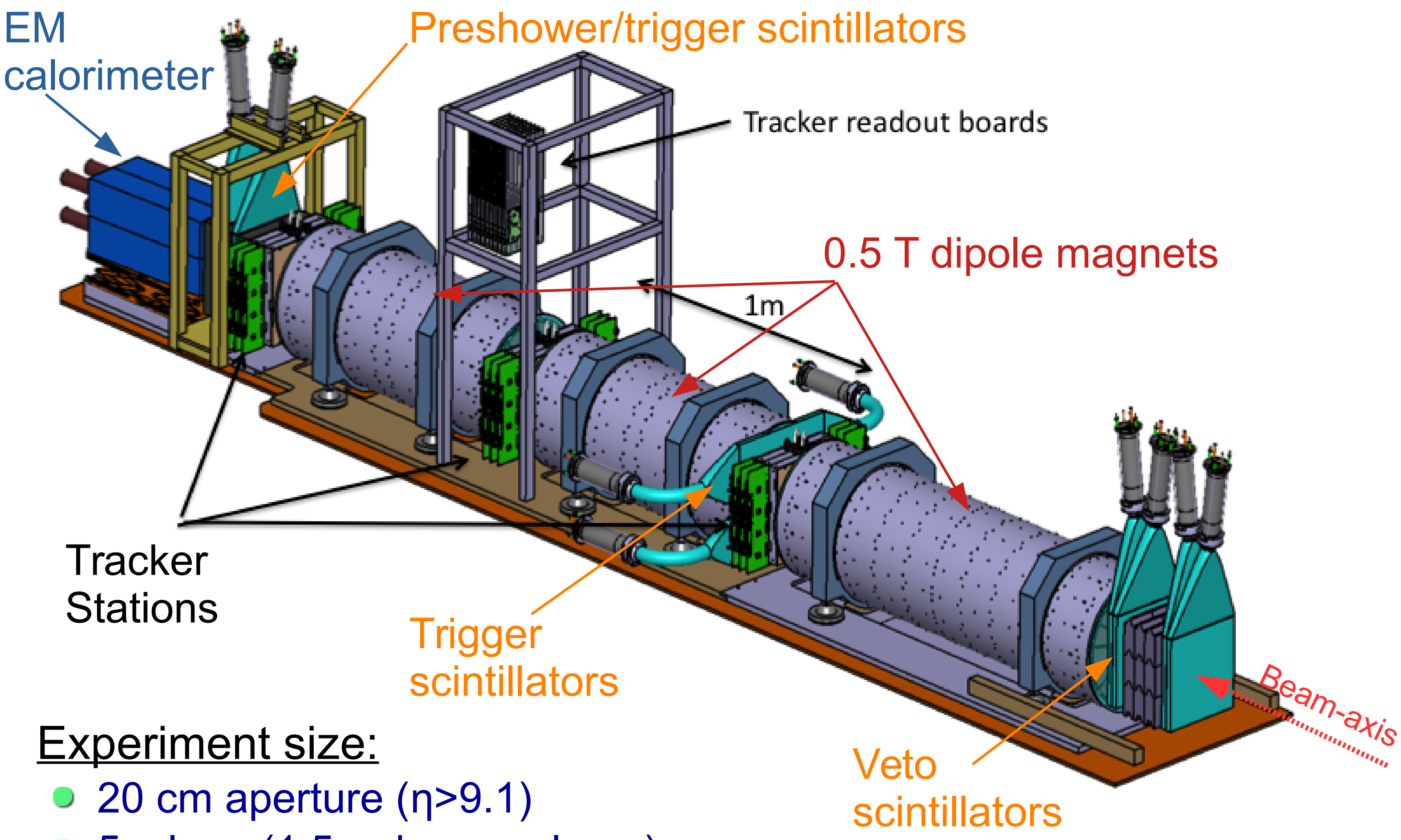
FASER Location

- Old SPS→LEP tunnel "perfect" location
  - On line-of-sight (with a little digging)
  - Shielded from IP by ~100m rock/concrete
  - Low beam backgrounds





FASER Detector

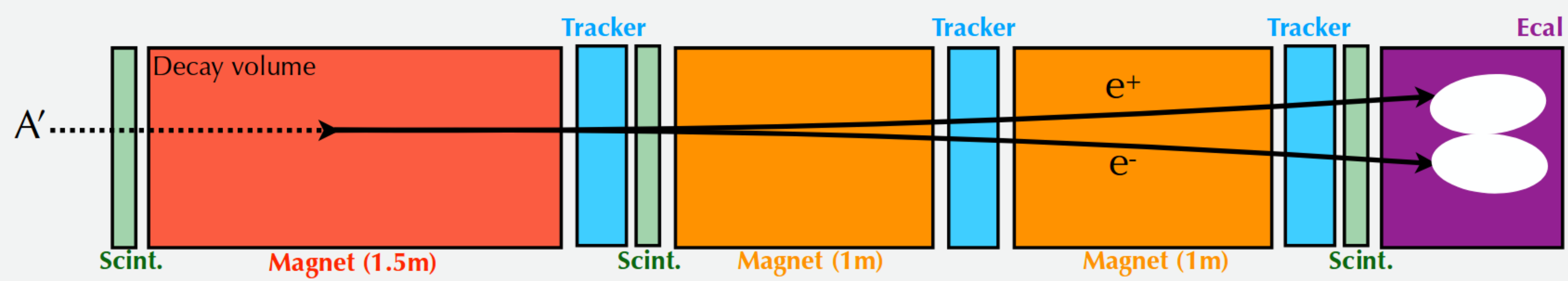


<u>Experiment size:</u>

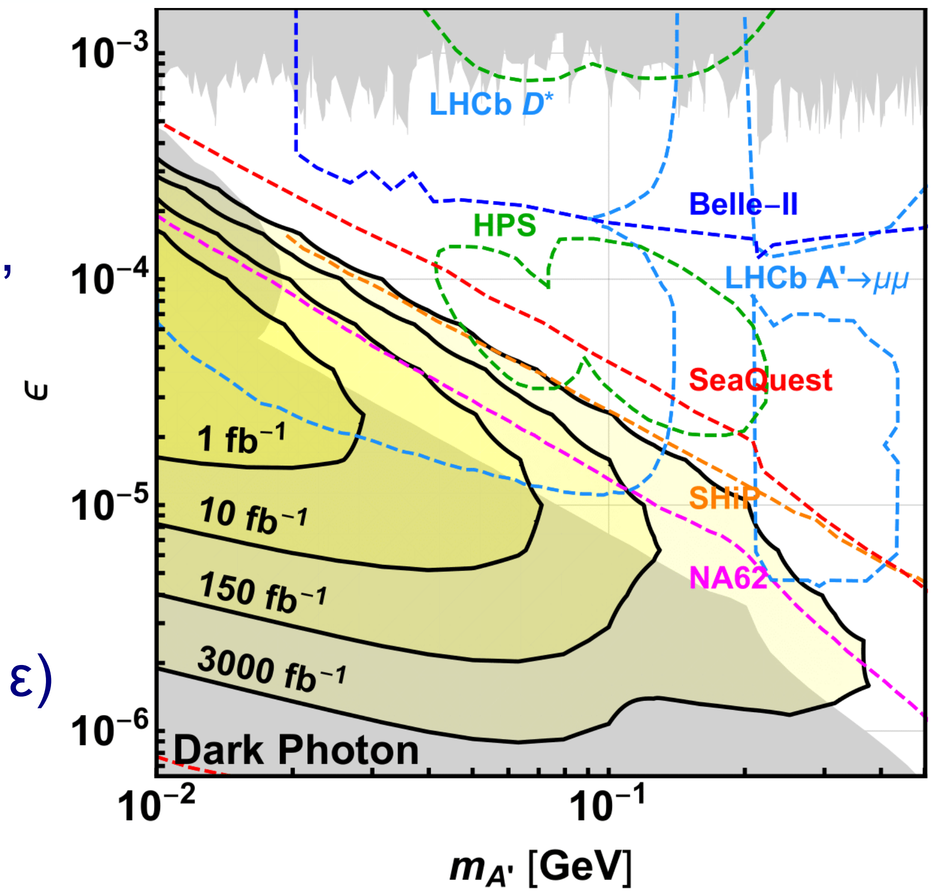
- 20 cm aperture (η>9.1)
- 5m long (1.5m decay volume)

FASER Sensitivity – An Example

Ex: pp → A′(→ e⁺e⁻) + X, with E(A′)~TeV



- Dark photon signature:
  - Two very-high energy, oppositely-charged tracks originated from a common vertex in the decay volume, pointing back to the IP
  - No signal in the scintillator veto
  - Energy deposit in calorimeter
- Sensitivity
  - All production channels considered
  - Reach limited by decay length (high ε) and production rate (low ε)
  - Sensitivity with just 1/fb in 2021



FASER Collaboration

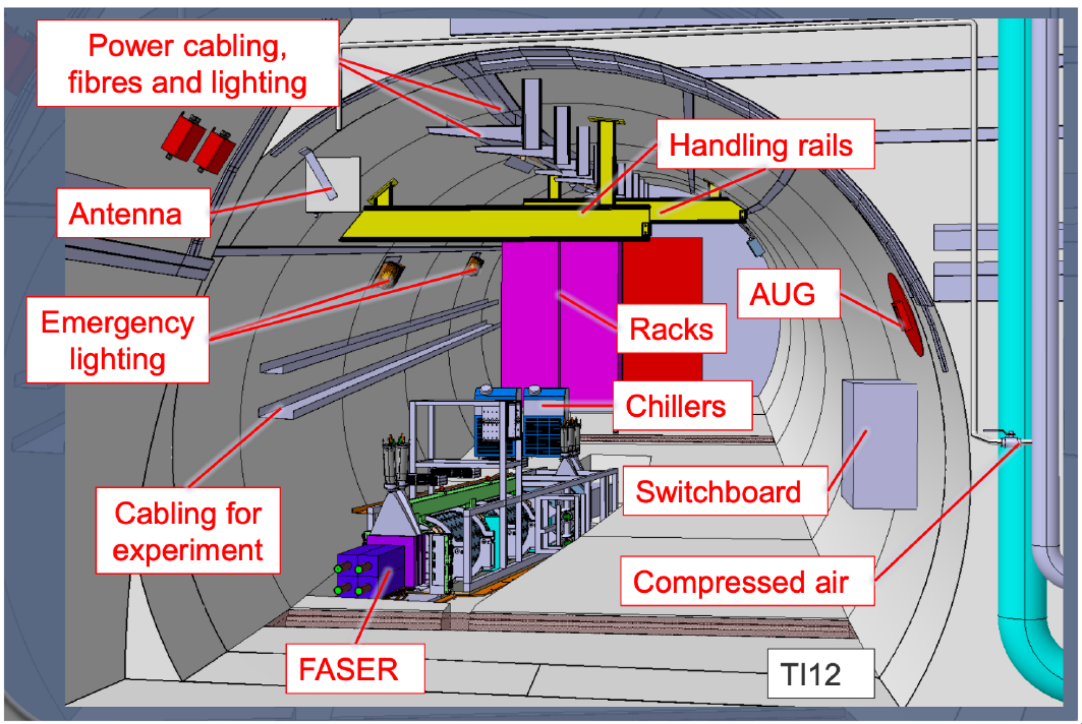
50 collaborators, 18 institutions, 8 countries

Largely funded by two private foundations (& CERN hostlab support)

Status of FASER Site

TI12 Work During LS2

- Significant work in LS2 to prepare TI12 for FASER services and installation
  - Includes lowering floor by 50cm



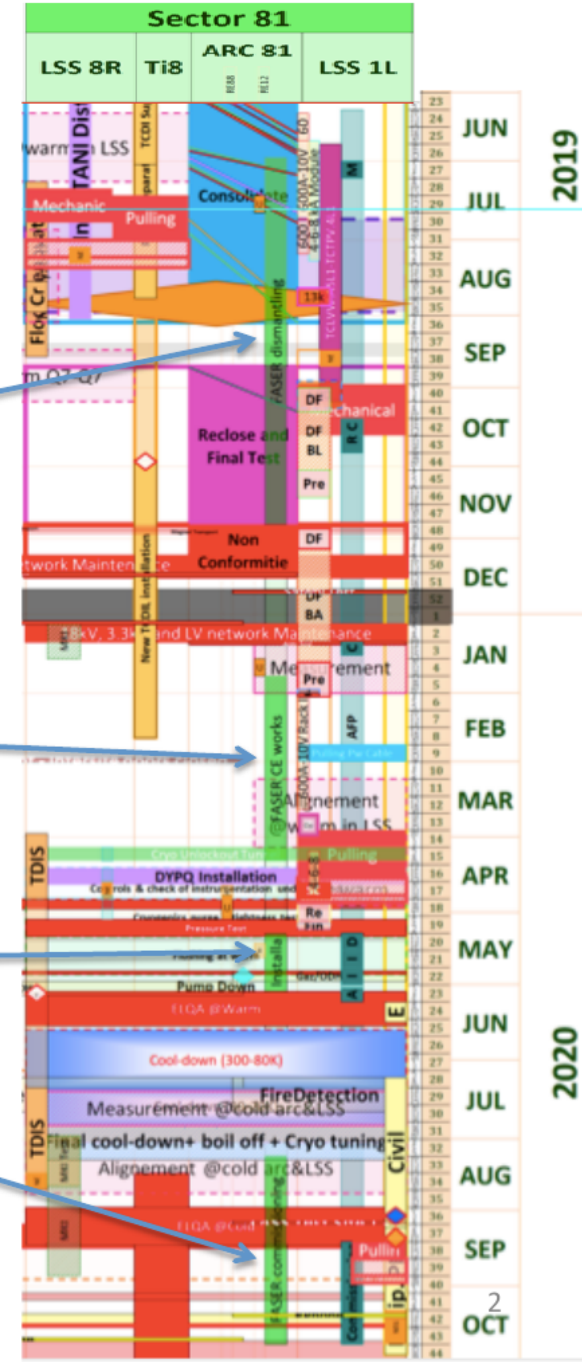
- Tight schedule, but fits with other LS2 activities

Clean-up and prep. of TI12

Civil-engineering

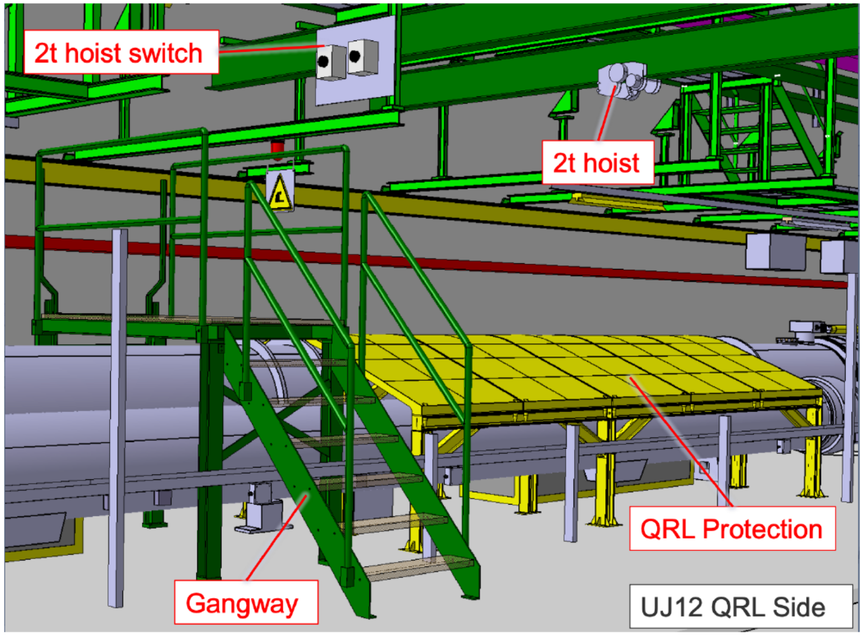
Installation

In situ com-missioning when access



Cleanup and Preparation

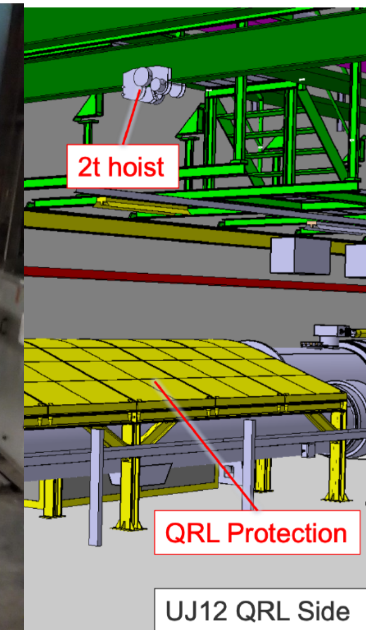
- Junction cavern (UJ12) next to TI12 prepared for FASER
  - New gang-way for easy access
  - TI12 sealed off with dust-proof tent
  - Hoist installed over LHC
  - Protective shield to be installed in next weeks

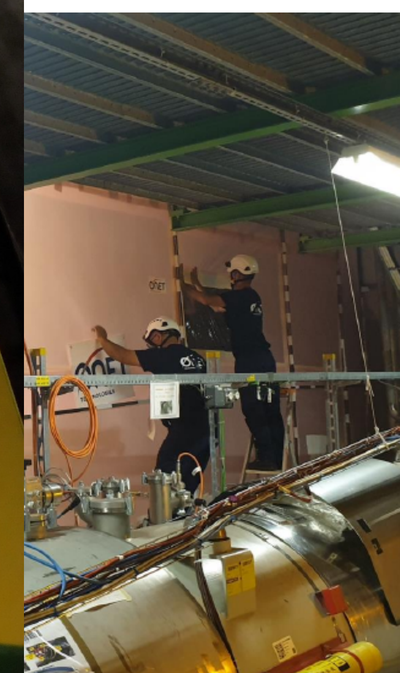


Cleanup and Preparation

- Junction cavern UJ
  TI12 prep F
  - Nev
  - T

Hot of the press
Protection Installed
this morning

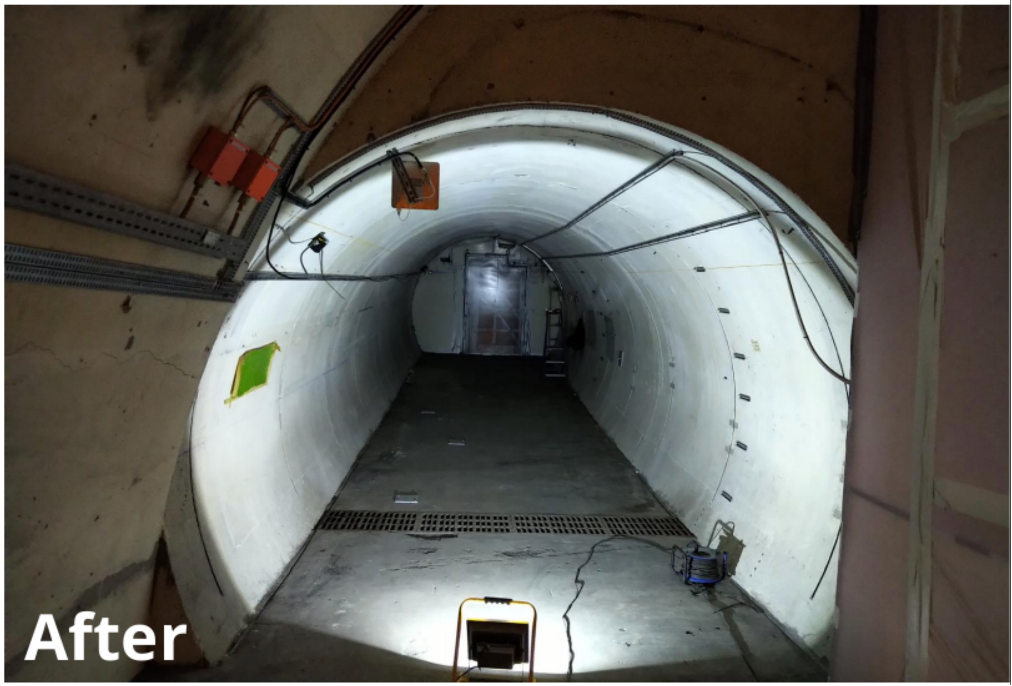




Cleanup and Preparation

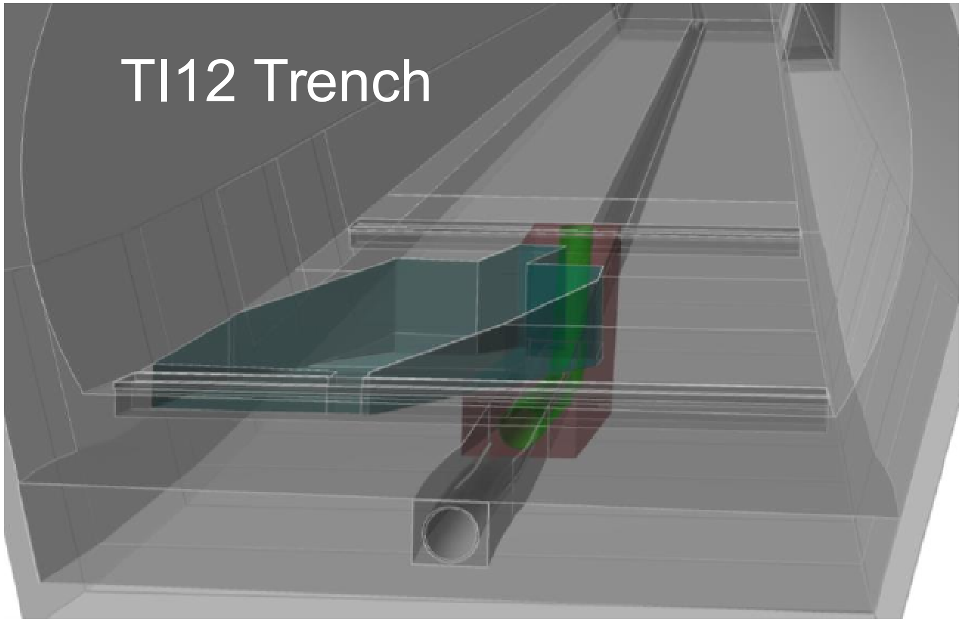
- TI12 has been cleared out
  - Unused ventilation and cable trays have been removed
  - GSM cable replace with antenna

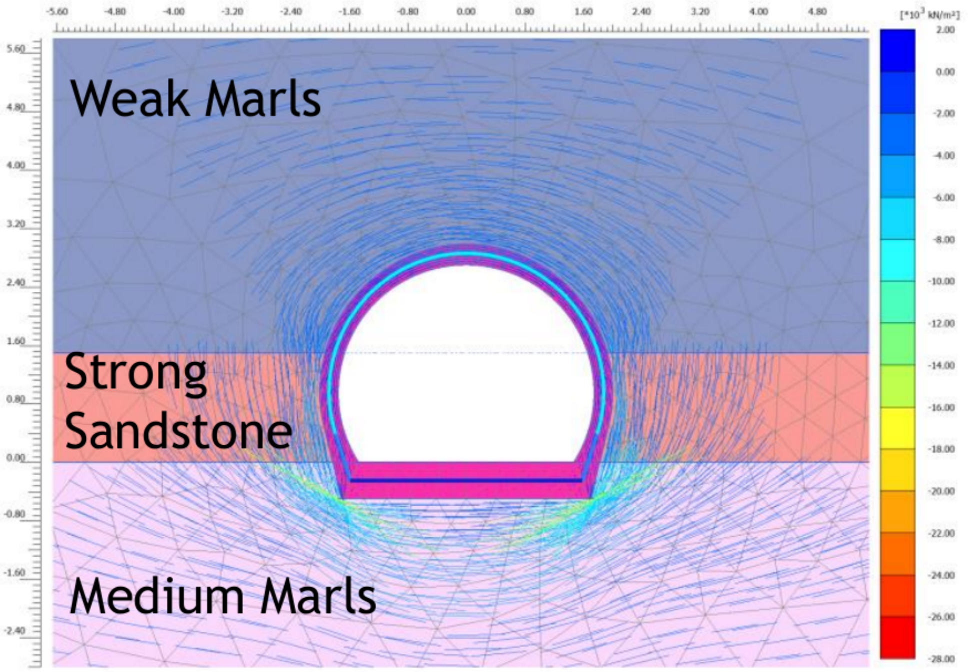
Many thanks to the excellent work by many different groups at CERN



TI12 Civil Engineering

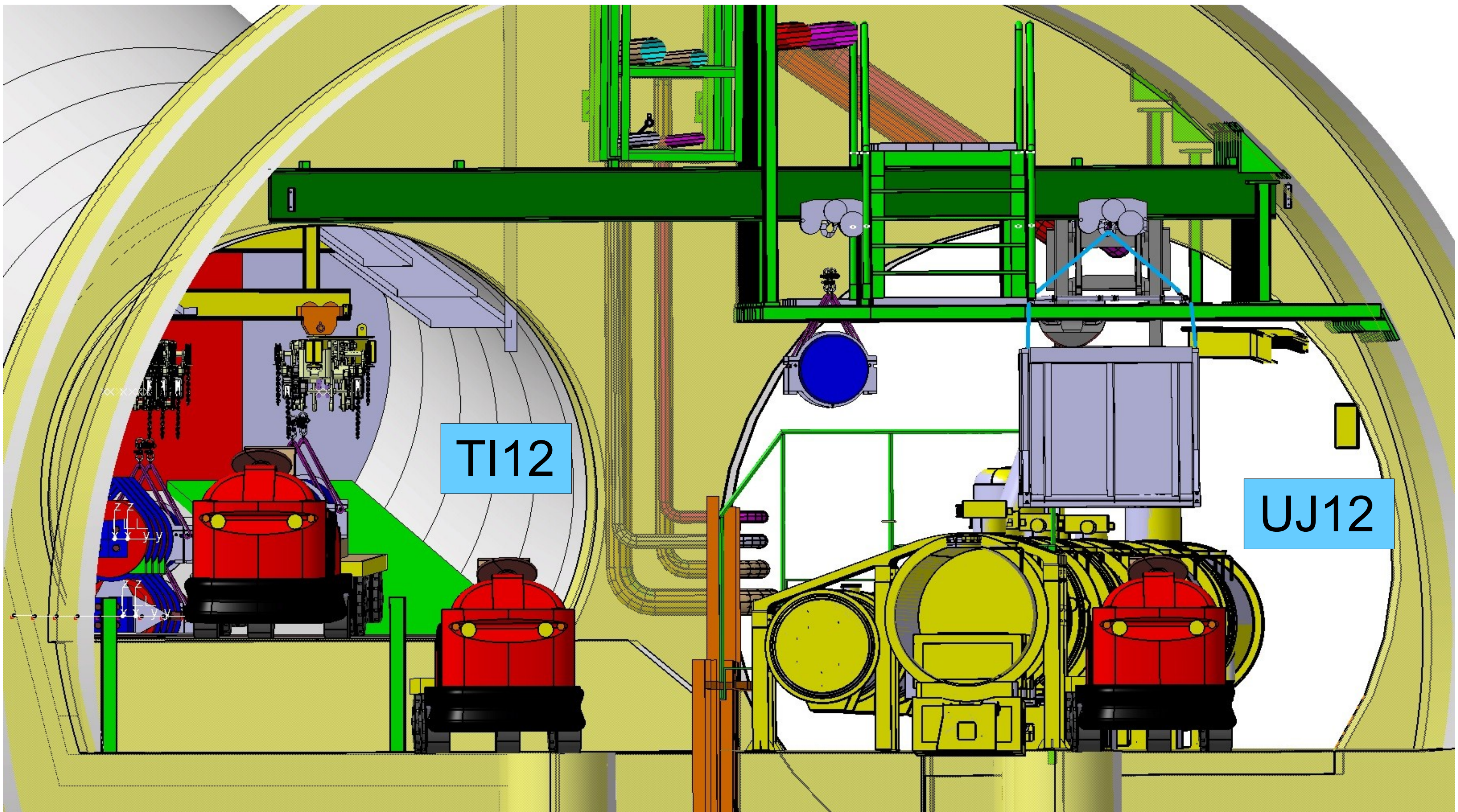
- Floor to be lowered by 50cm to center FASER on axis
- Studies show safe to dig out floor – drain to be moved
- Design finished and expect to award contract very soon
  - Work to start end of January





FASER Installation

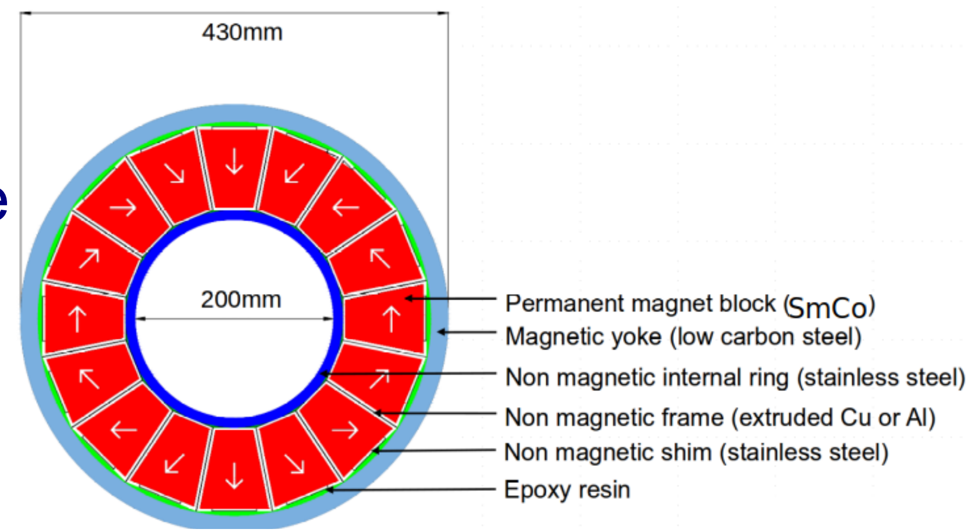
- Detailed planning of installation under way
  - Services (TI12 hoist, power, fibers, dry air) in April/May
  - FASER components second half of May



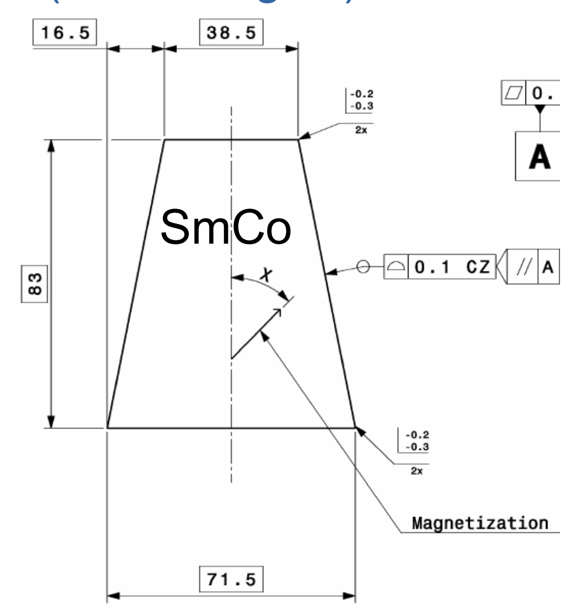
Detector Status

Spectrometer Magnets

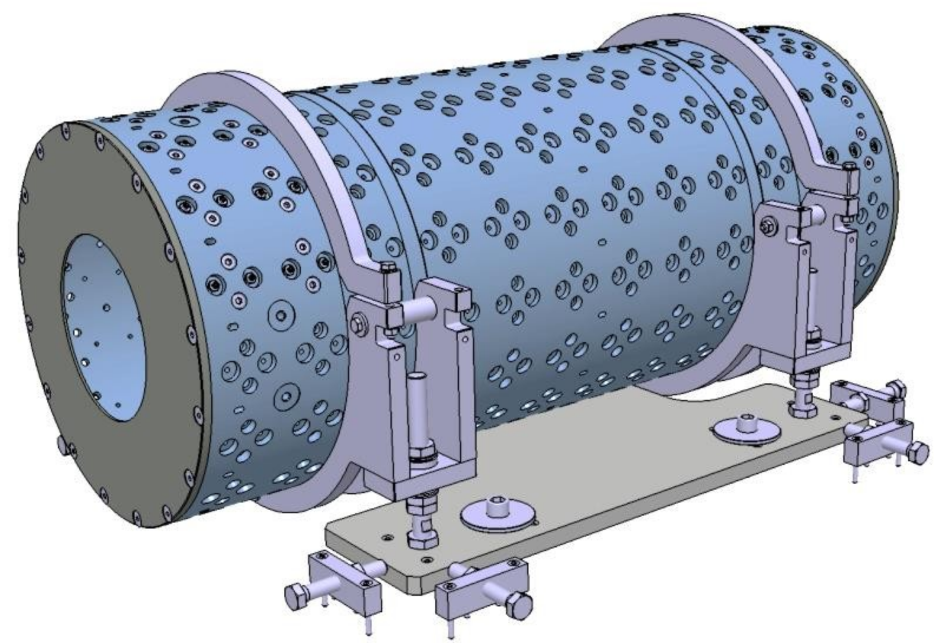
- Permanent magnets based on Halbach array design
  - Minimizes size and infrastructure
- Being constructed at CERN by the TE-MSC-MNC group
- Assembly test in December
  - On track for completion for May



Magnet block specification (5 field angles)

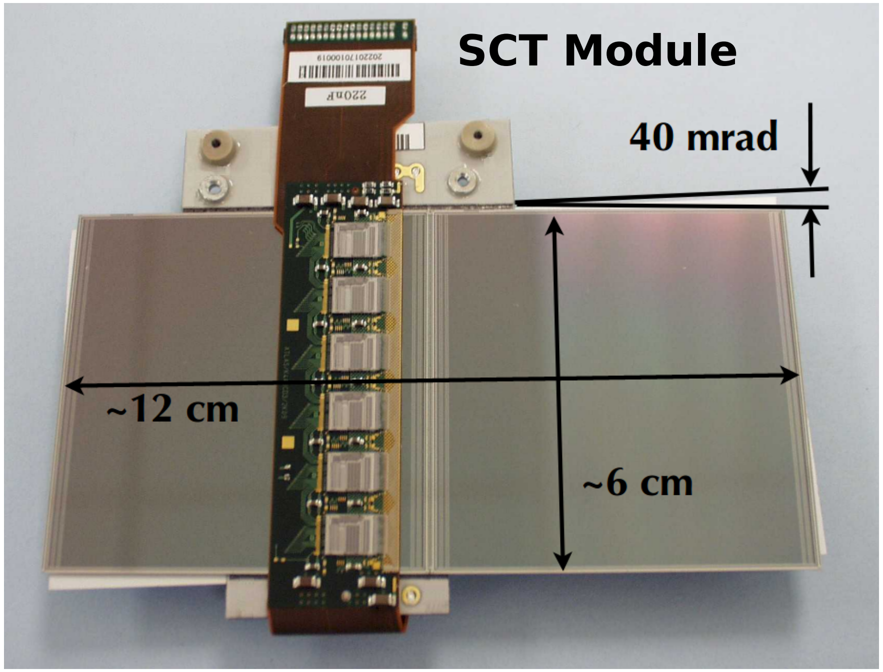


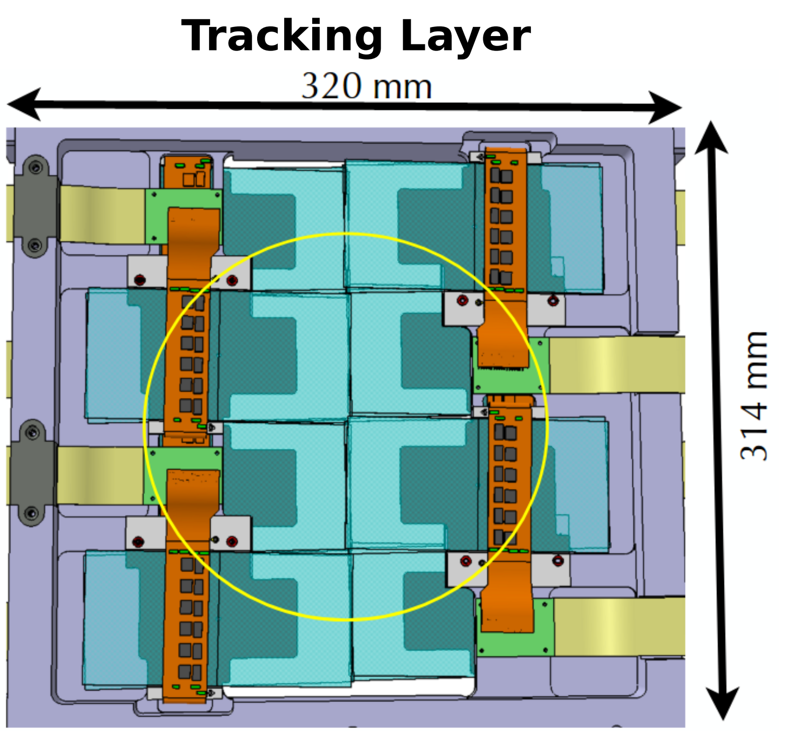
Magnet with support structure

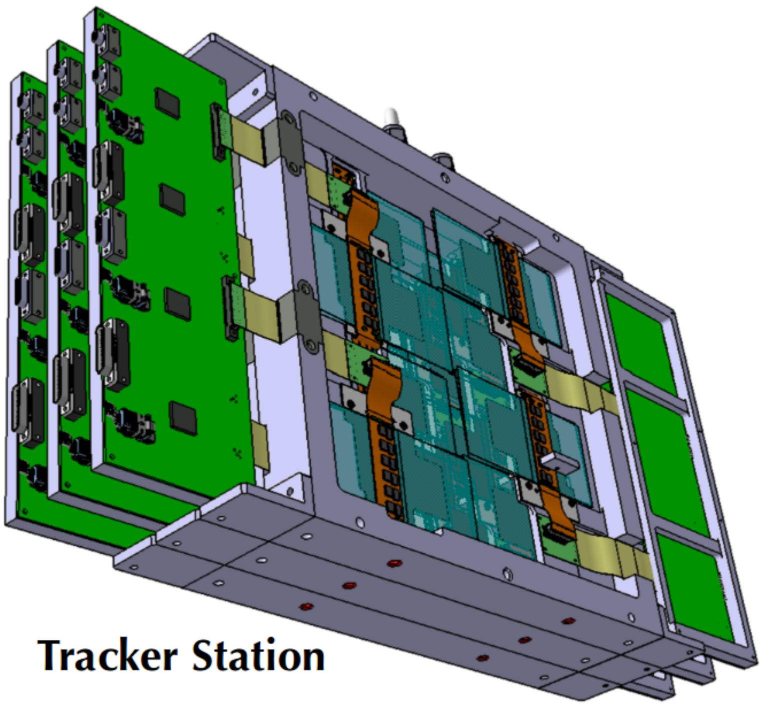


Tracking Stations

- 3 tracking stations with 3 tracking layers
  - "Simple" water cooling (low radiation)
- Each layer uses 8 spare ATLAS strip modules (SCT)
  - Generously donated by ATLAS SCT
- 80 SCT modules tested and confirmed good for FASER

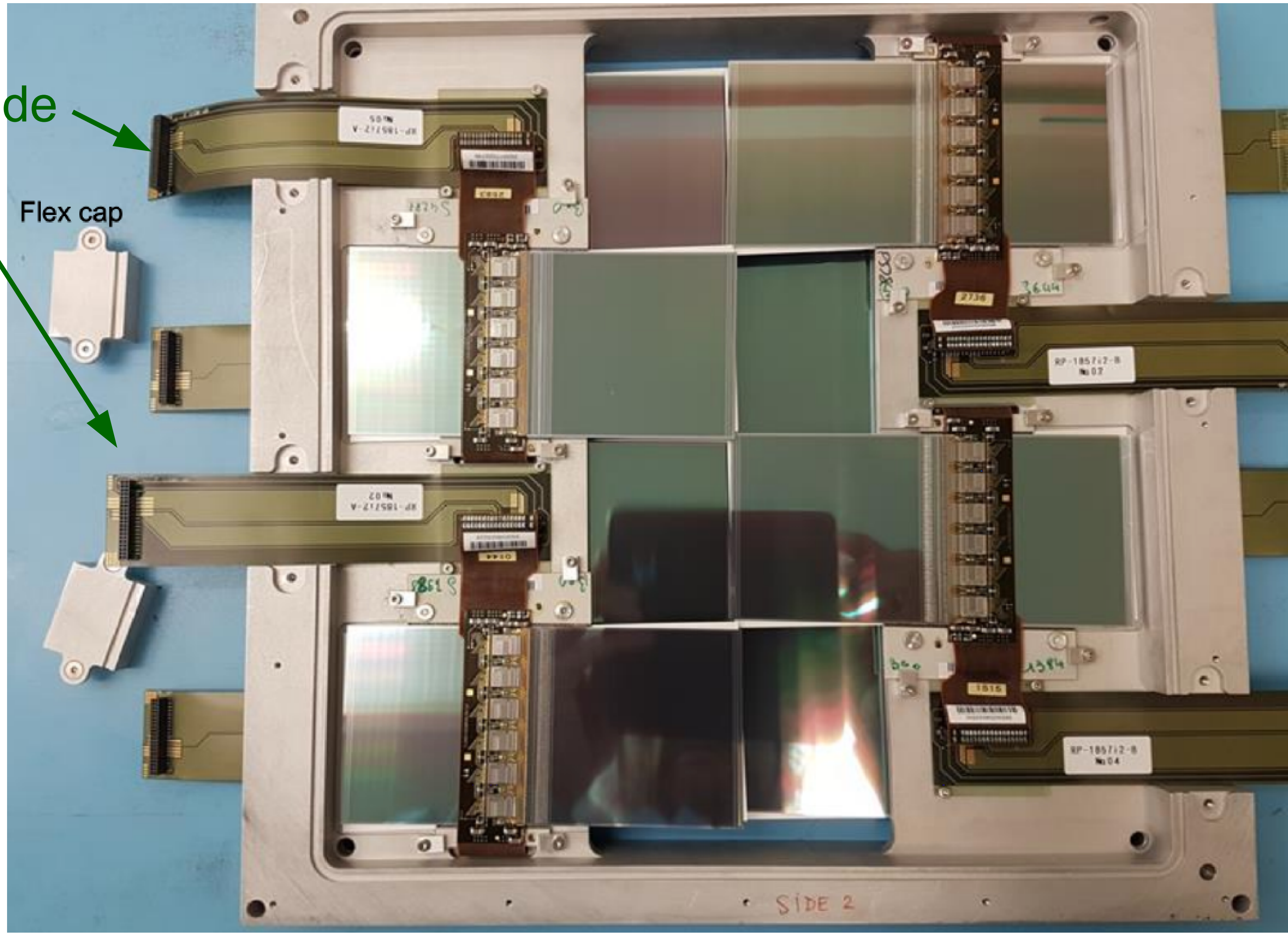






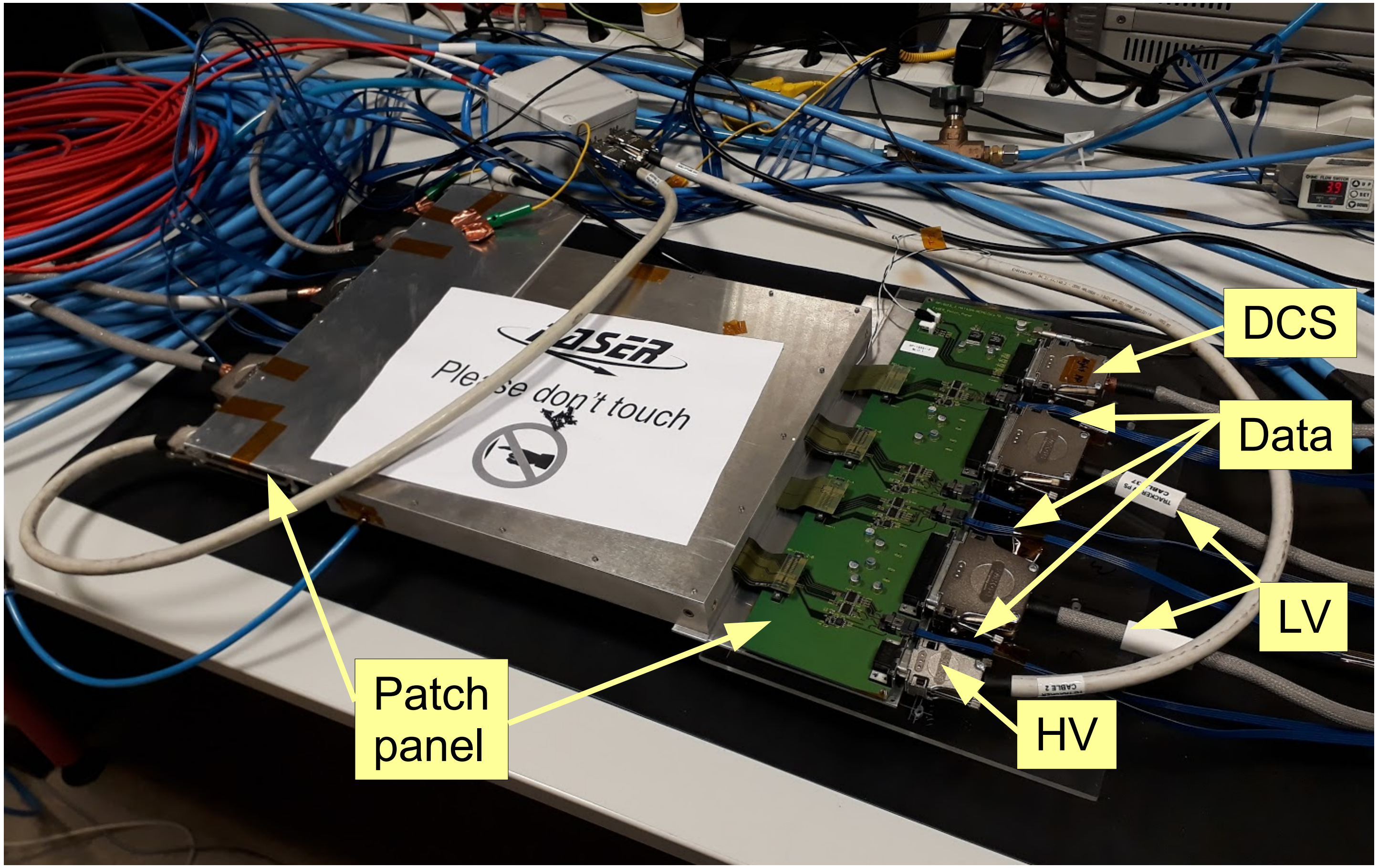
Prototype Tracking Layer

First prototype layer produced and mounted in September



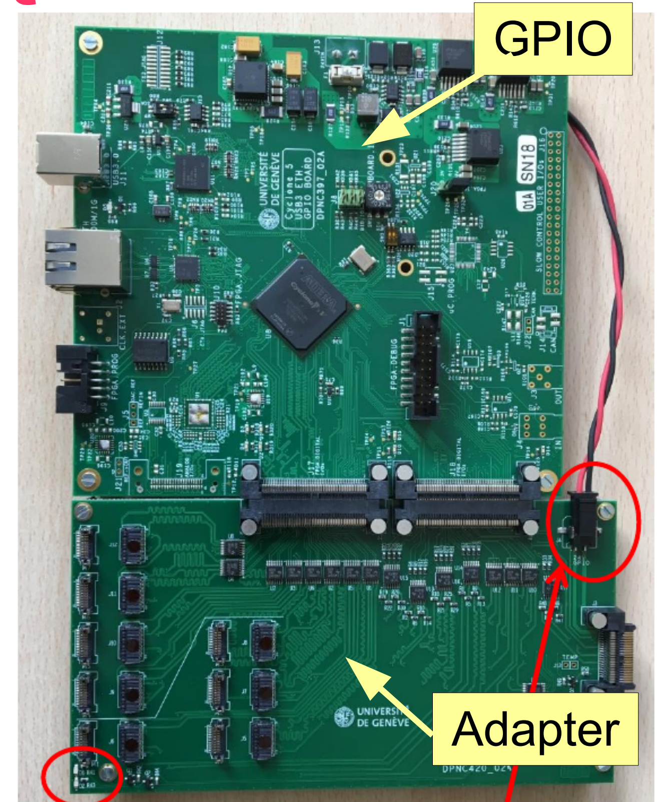
Prototype Testing

- Prototype layer under active testing
  - Thermal properties confirmed → frame production started
  - Noise tests still to be completed before launching final production of flex cables and patch panels
- Full set of layer/station assembly in January-March



Tracker Readout

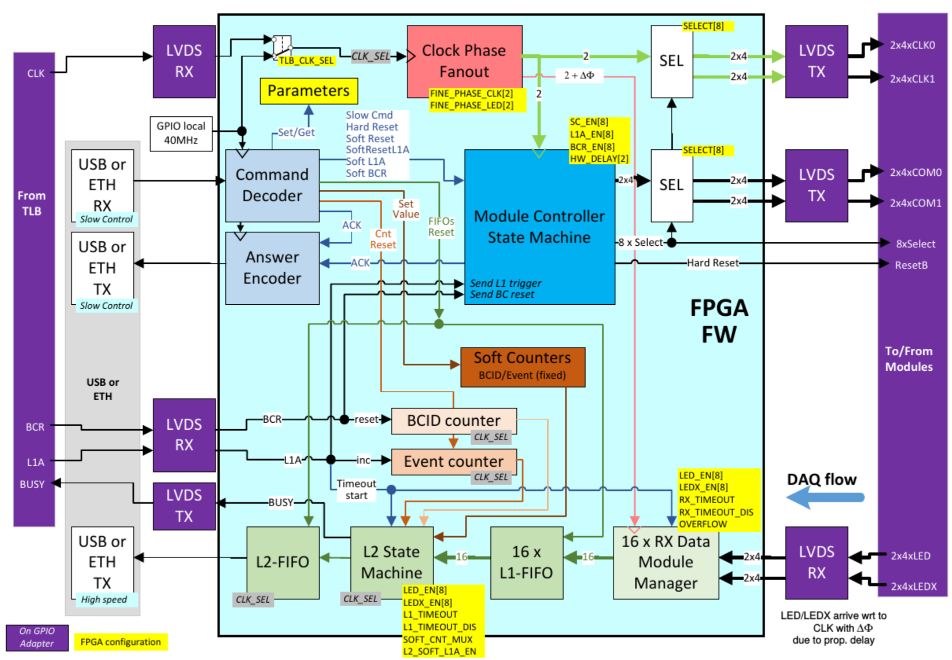
- Readout based on generic FPGA board with adapter board (1 per layer)
- Boards all produced and tested
  - Crate backplane still to be made
- First firmware implemented and tested
  - Kept as simple as possible
  - Ethernet interface to come in next weeks
- Successfully used in prototype testing

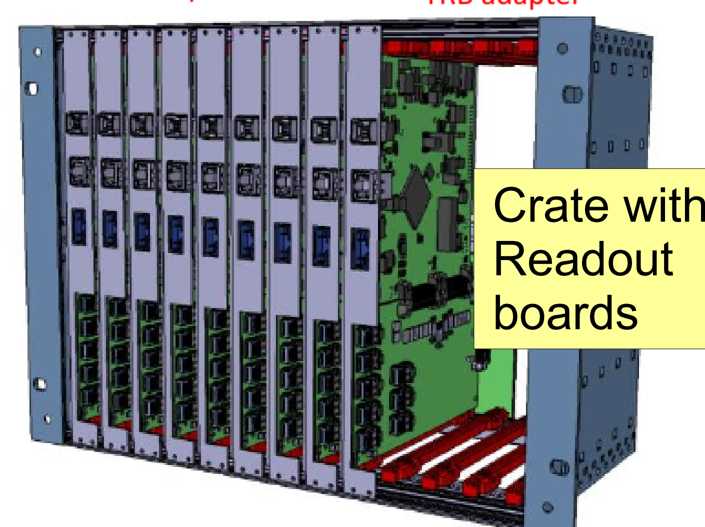


2 front panels LEDs

24V discrete wire to TRB adapter

Firmware schematic



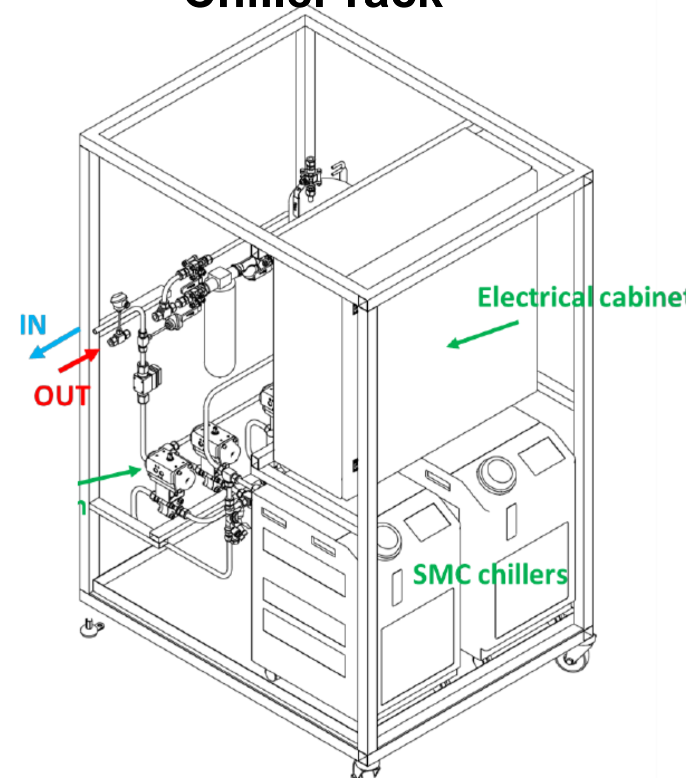


Tracker Monitoring, Cooling and Power

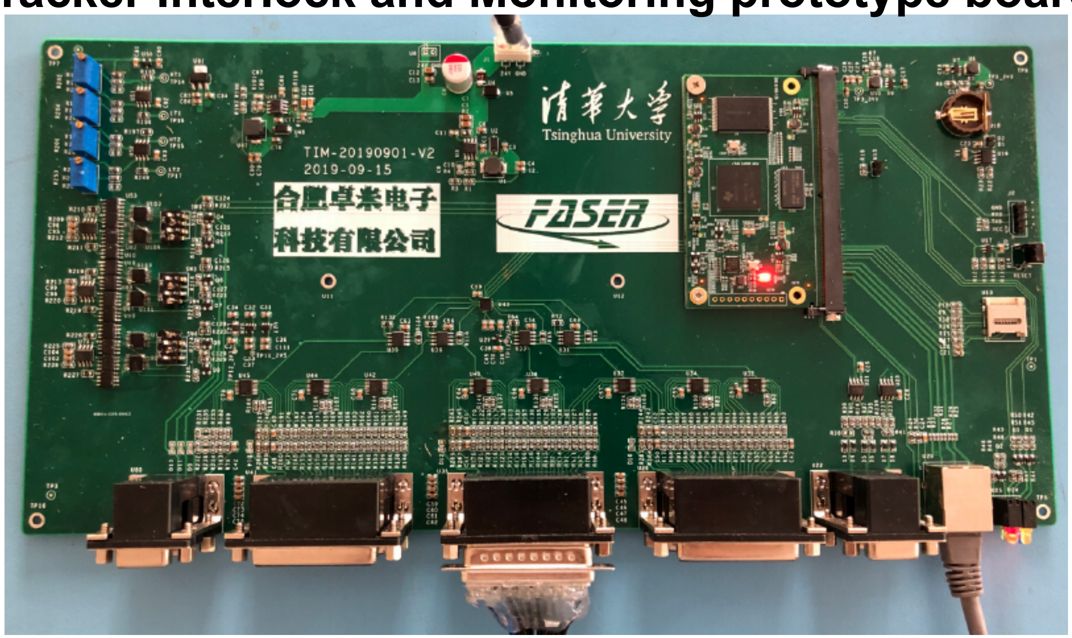
- Powering based on Wiener system
  - Delivery expected end of year
- Water cooling of tracker stations using redundant chillers (10-15°C)
  - System being designed and implemented by EN/CV
- Custom board for temperature and humidity monitoring/interlock
  - Final board version imminent

Wiener MPOD crate

Chiller rack



Tracker Interlock and Monitoring prototype board



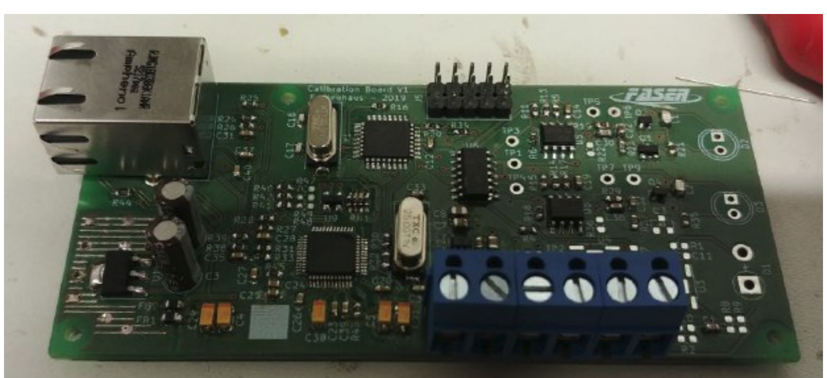
Scintillator Stations

- Scintillator plates, PMTs and digitizer procured and at CERN
  - Use CAEN digitizer card (V1730)
  - Characterization of PMTs with LED pulses on-going
- Light-guide production and assembly at CERN is on-going
- LED-based pulsing system implemented
  - Also used for calorimeter

Hamamatsu H6410 PMT

Light-guide machining

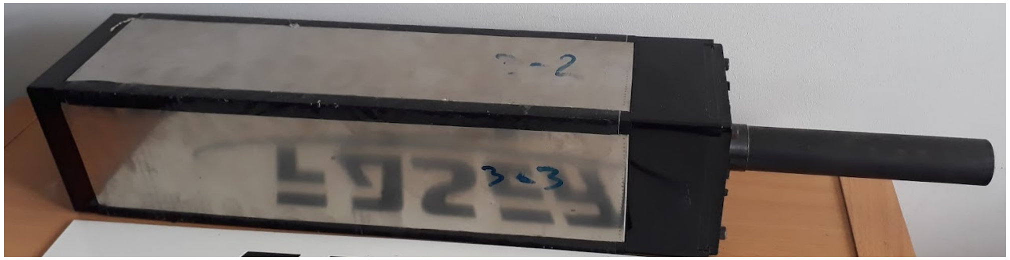
LED calibration board



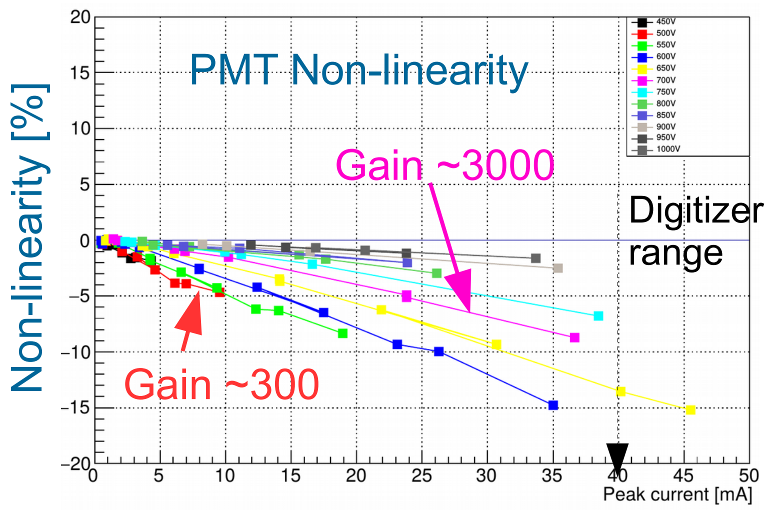
Calorimeter

- Calo. built from four spare LHCb outer ECAL modules
  - Many thanks to LHCb for lending us these modules
- Testing lab with LED pulser and cosmic ray test stand setup in building 21
- Used to characterize and determine HV working point
  - Low gain needed to have sufficient range for largest signals

Calorimeter Module

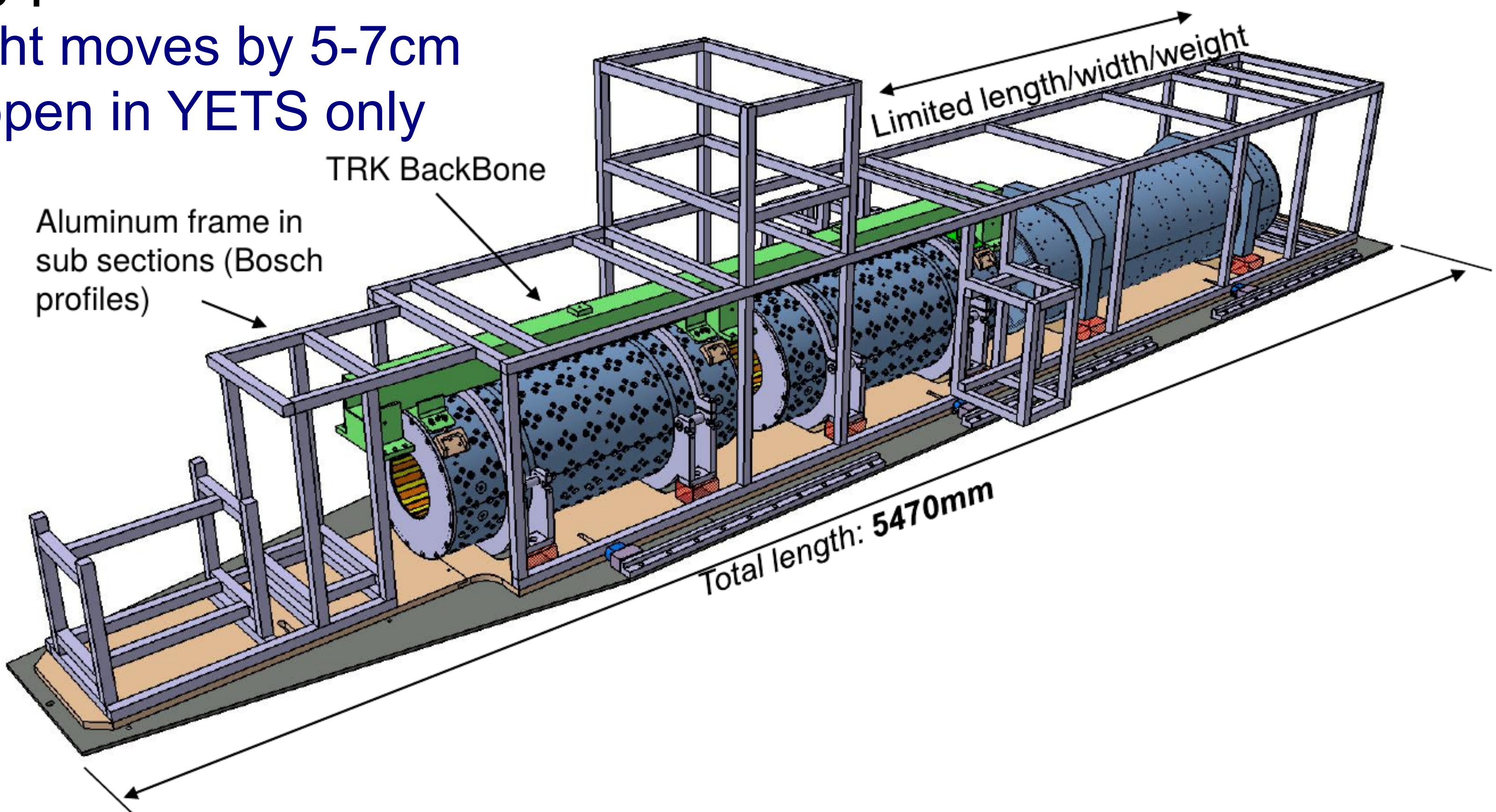


Cosmic ray test stand



Support Structure

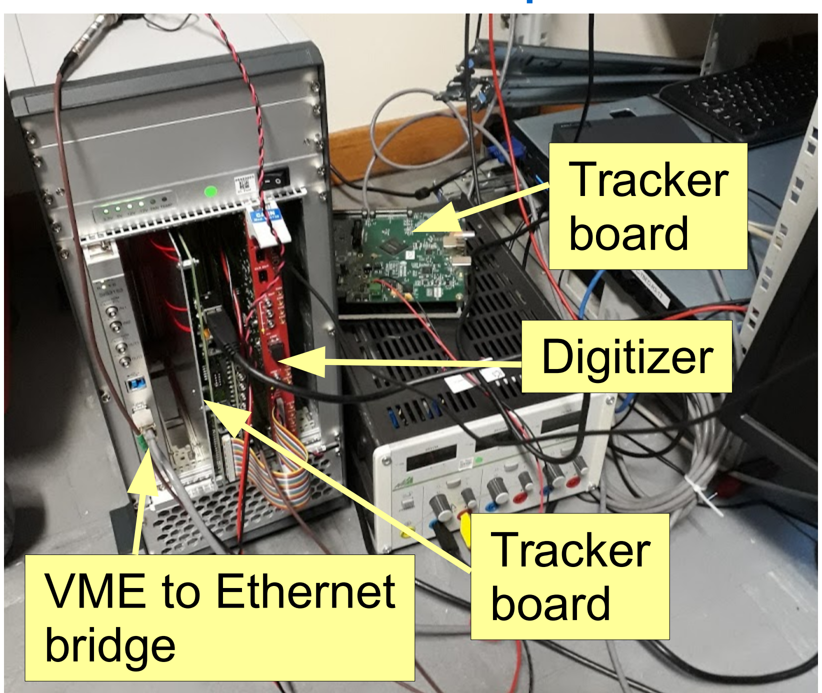
- Detector support structure well-developed
  - Internal review this Friday
  - Production to be launched right after
- Main constraint is to keep three tracking station well-aligned (O(100μm))
- Whole assembly can be moved in case of change in crossing plane/direction
  - Line-of-sight moves by 5-7cm
  - Would happen in YETS only



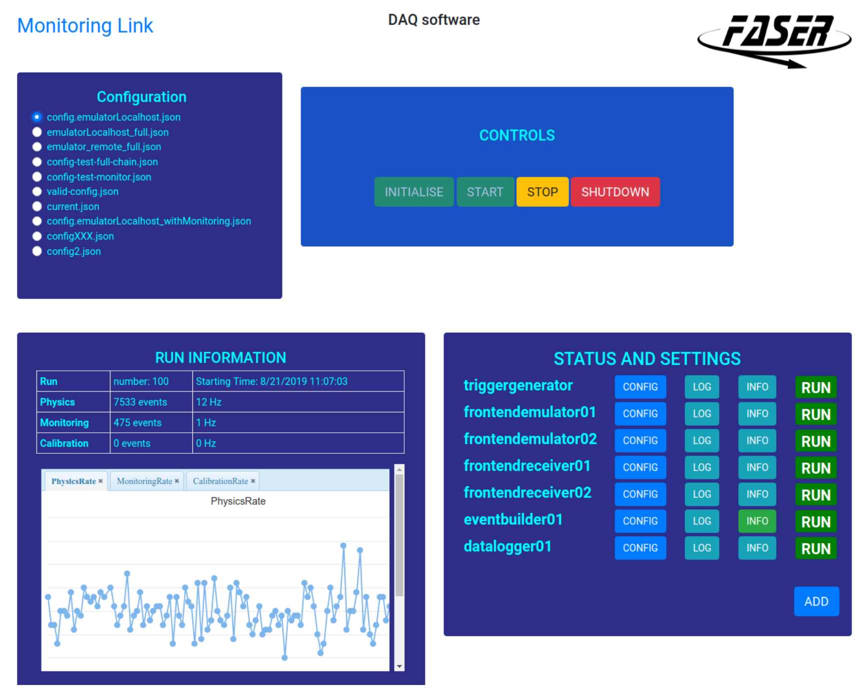
Trigger/DAQ

- Trigger system based on CAEN digitizer and trigger board based on same FPGA board as tracker readout
  - Initial firmware version complete and under test in lab
- DAQ based on new light-weight framework developed by CERN EP-DT team for small experiments
  - Expect ~500 Hz of triggers (muons) and ~15 MB/s data rate
  - Integration with readout boards on-going

TDAQ test setup

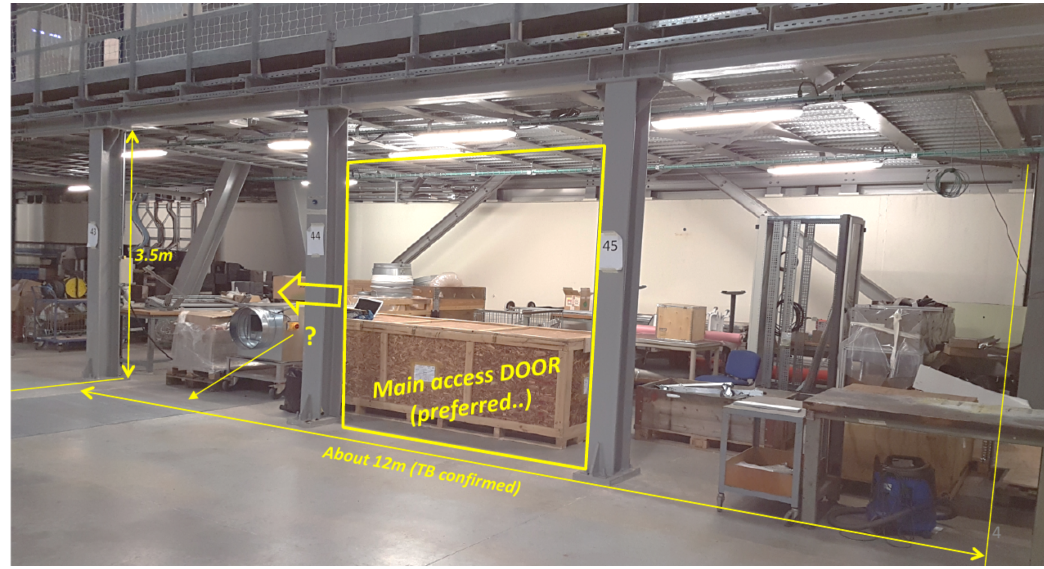


Web-based run-control



Commissioning and Installation

- Plan to do installation dry run and integration tests on surface before TI12 installation
  - Test of mechanical assembly and alignment/survey
  - Full scale test of powering, cooling, monitoring and readout



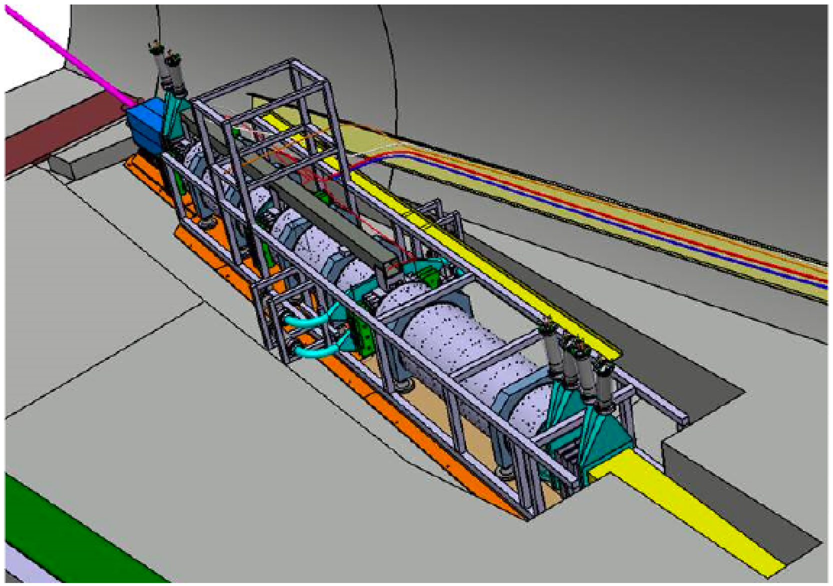
- Will take place in ENH1 (Prevessin)
  - Detailed planning on-going
  - *Magnets and tracker stations on critical path for the tests*

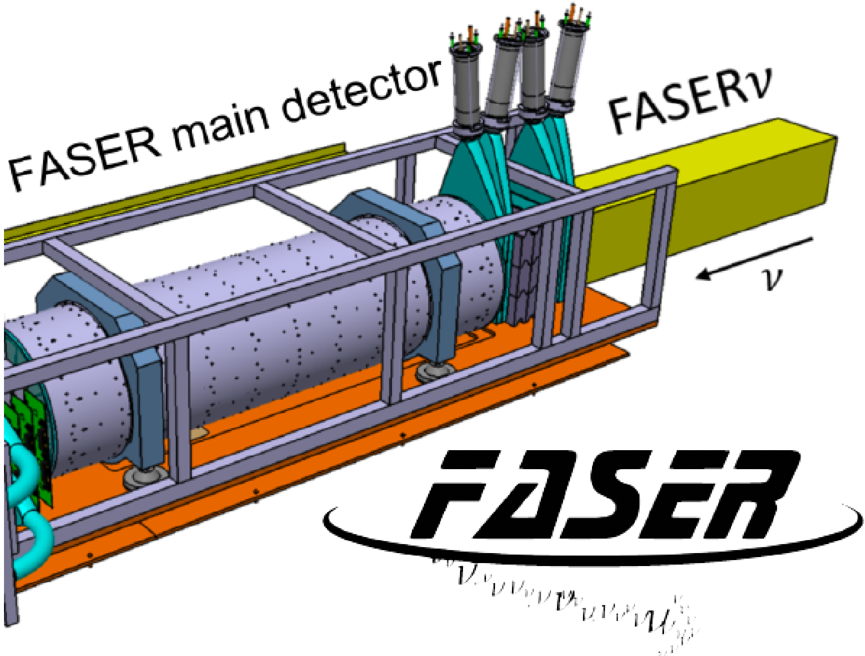
	Nov	Dec	Jan	Feb	Mar	April	May
Prepare ENH1							
Install Det. Support							
Install Calo/Scin & TDAQ							
(Partial) System Commissioning							
Installation in TI12							

FASERν Proposal

Neutrinos in FASER

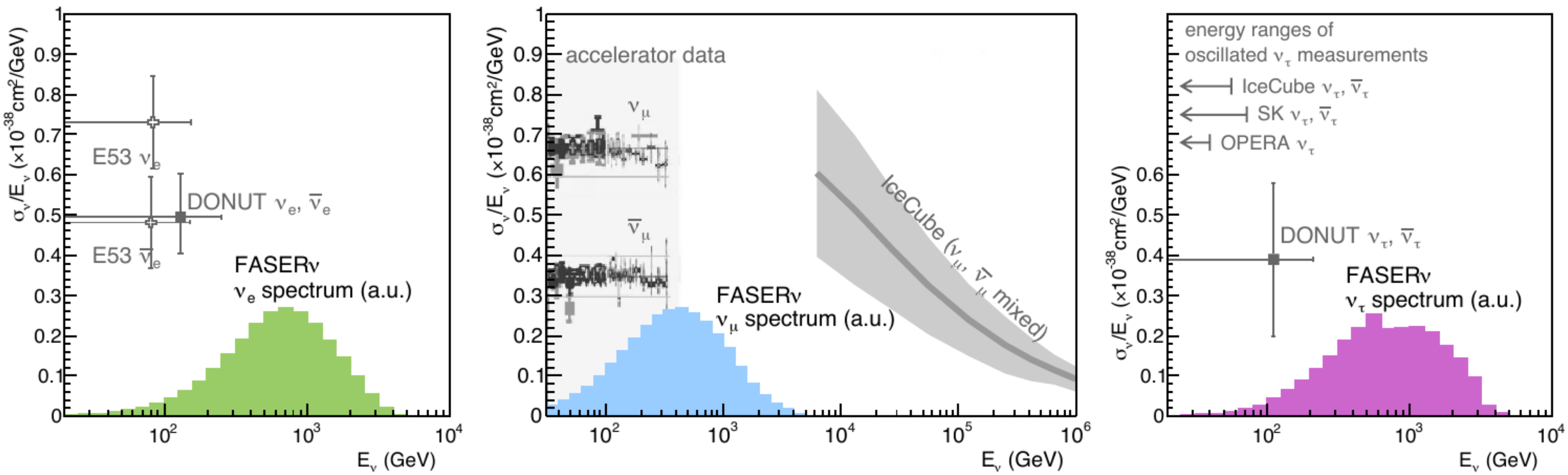
- Neutrino measurements in FASER studied since LoI
  - 10^{12} high energy neutrinos will pass through FASER in Run 3
- Propose to extend FASER with dedicated neutrino detector
  - Physics case: arXiv:1908.02310
  - Technical Proposal submitted to LHCC for review
- 1.2 t tungsten-emulsion detector in front of FASER
  - Trench was already included in civil engineering plans
  - Initially standalone detector
  - Combination with rest of FASER under study





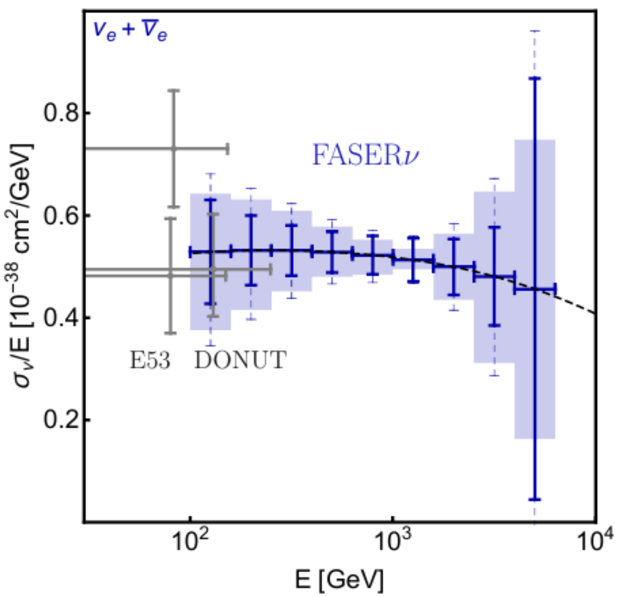
FASERν Physics case

- Extends FASER physics program with SM measurements
- Neutrino energy spectrum in FASER complementary to existing neutrino experiments
  - Measurement at highest man-made neutrino energies

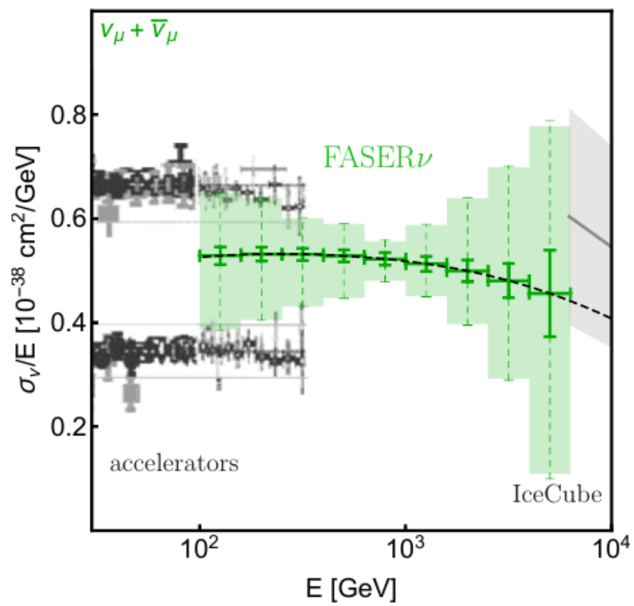


FASERν Physics case

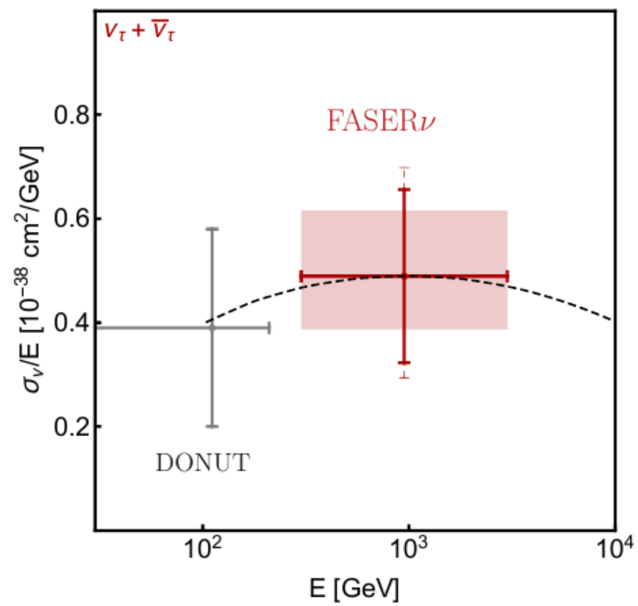
- Extends FASER physics program with SM measurements
- Neutrino energy spectrum in FASER complementary to existing neutrino experiments
  - Measurement at highest man-made neutrino energies
- Primary measurement is neutrino cross sections:



~1300 ν_e, mostly from kaon decays



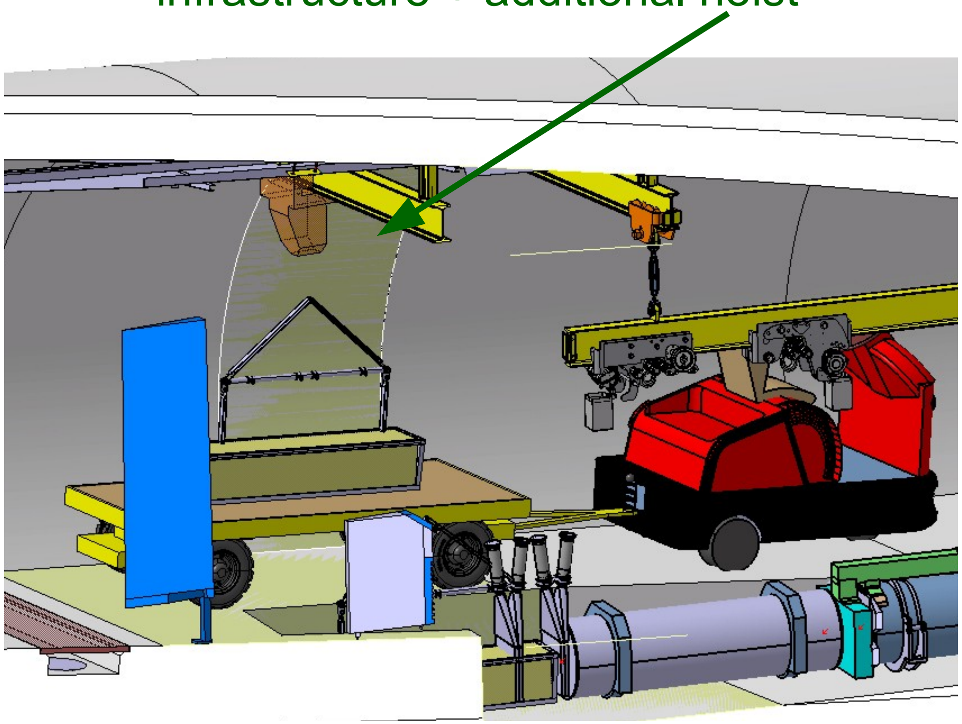
~20000 ν_μ, mostly from pion decays



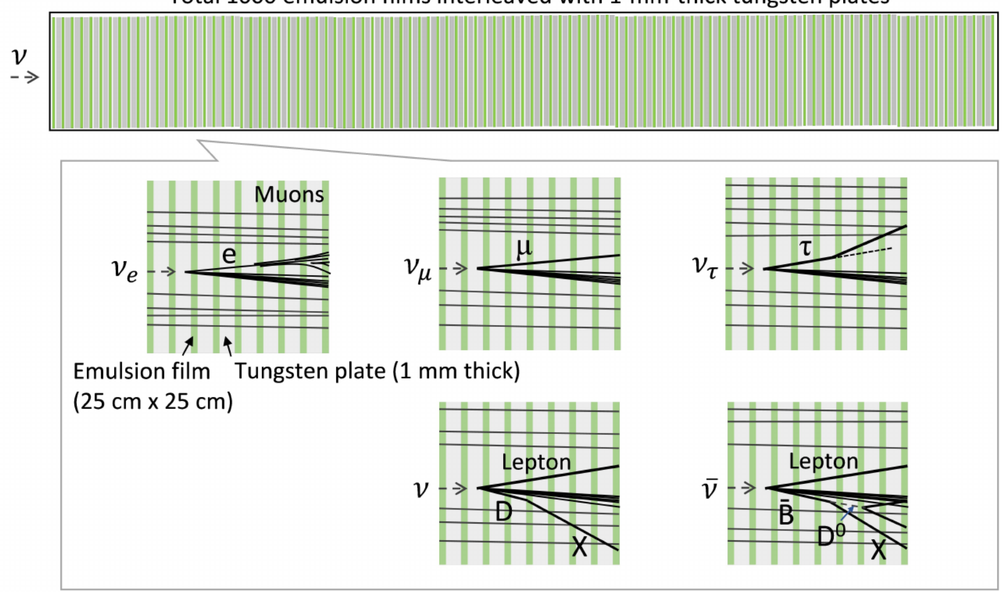
~20 ν_τ, mostly from charm decays

FASERν Detector

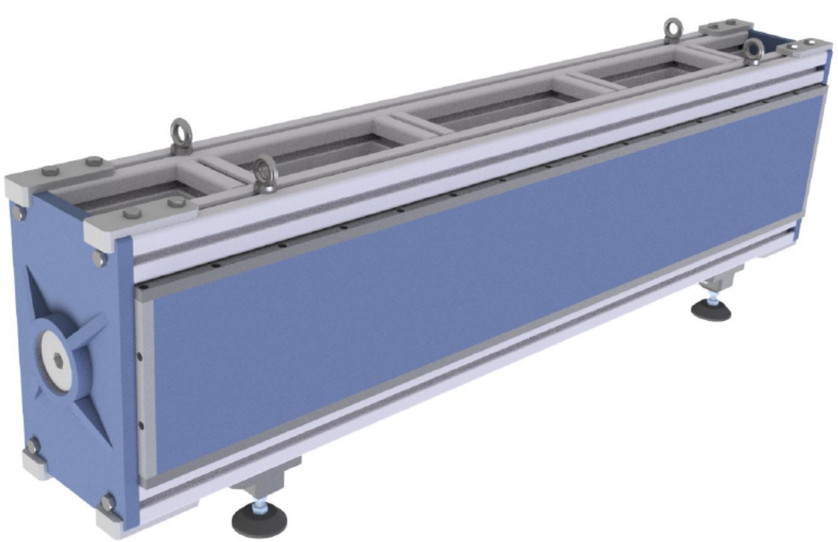
- Emulsion detector with tungsten target
  - 1000 1mm tungsten plates interleaved with emulsion film
  - Fine-grained detector allows to distinguish neutrino types from various backgrounds
- Challenges:
  - Need to replace emulsion every 20-50/fb to keep track density acceptable ($<10^6/cm^2$)
    - Detector to be replaced as single object during technical stops
    - Benefit from FASER transport infrastructure + additional hoist



FASERν detector structure

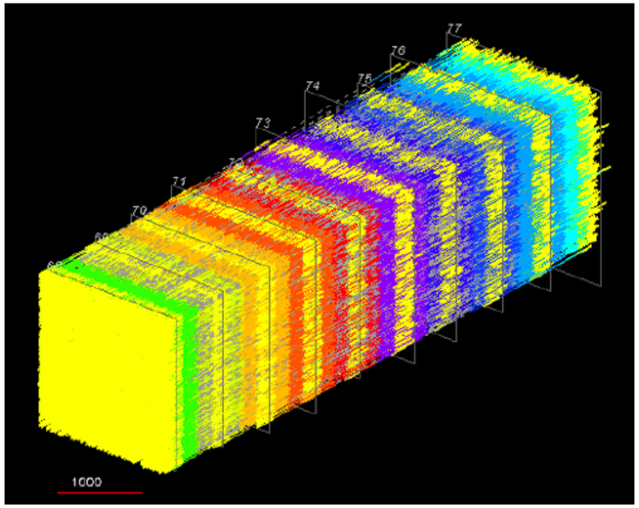


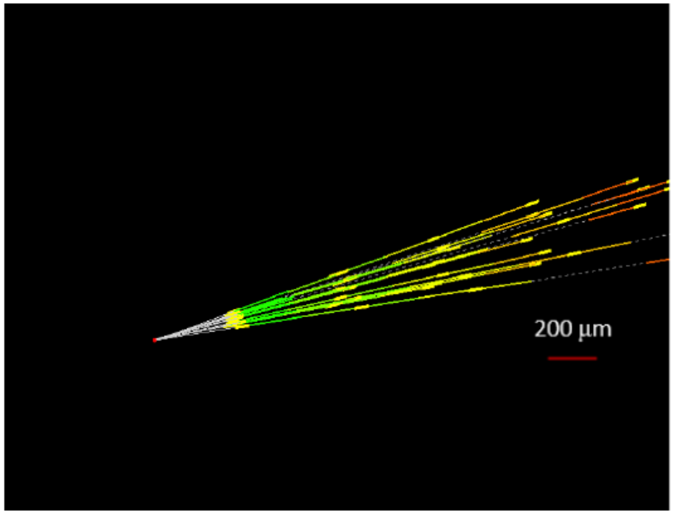
FASERν detector support



Pilot Neutrino Detector

- 30 kg emulsion detector was installed in TI18 in 2018
  - Part of FASER background measurement
- 12.5/fb of data collected
  - ~30 neutrino interactions expected in detector
- 68% of the emulsion films have been digitized
  - Neutrino candidates have been reconstructed
  - Further analysis on-going



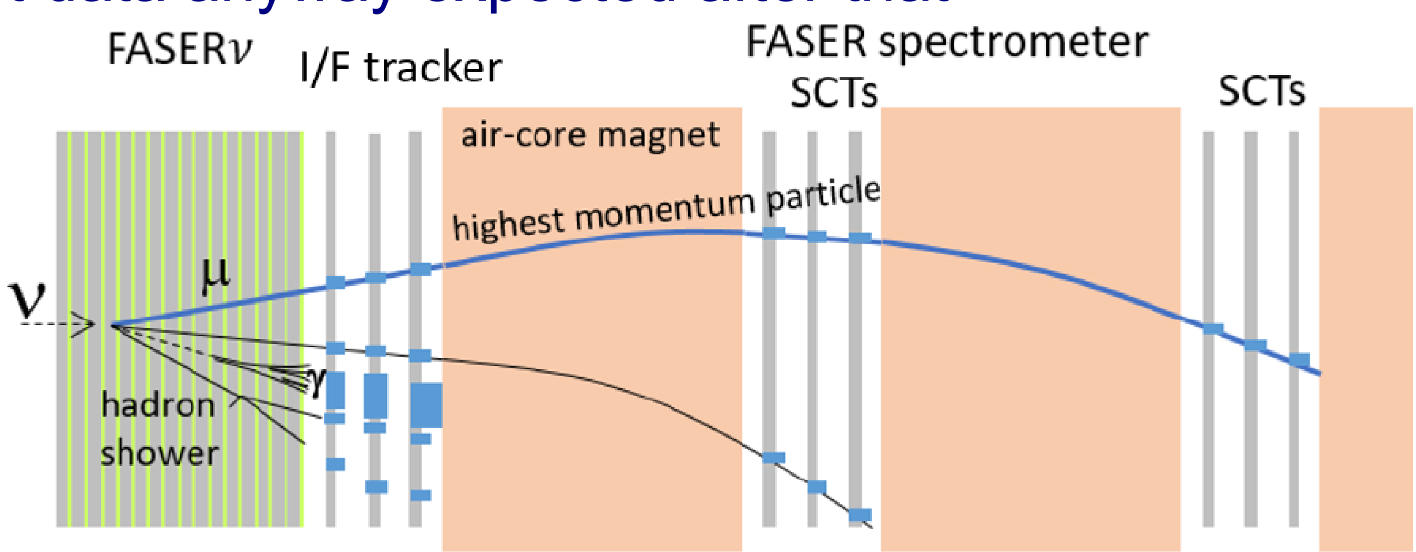


Linking FASERν with FASER

- Possibility to connect FASERν with rest of FASER for:
  - Charge identification
  - Improved energy resolution
  - Better background rejection

Simulation studies on-going to quantify possible gains

- Would require interface detector in front of FASER
  - Precision tracker to link FASERν and FASER tracks
  - Most likely a fourth station of spare ATLAS SCT modules
- To not jeopardize FASER schedule, this would only be installed in 2021/22 YETS
  - Most data anyway expected after that



Summary

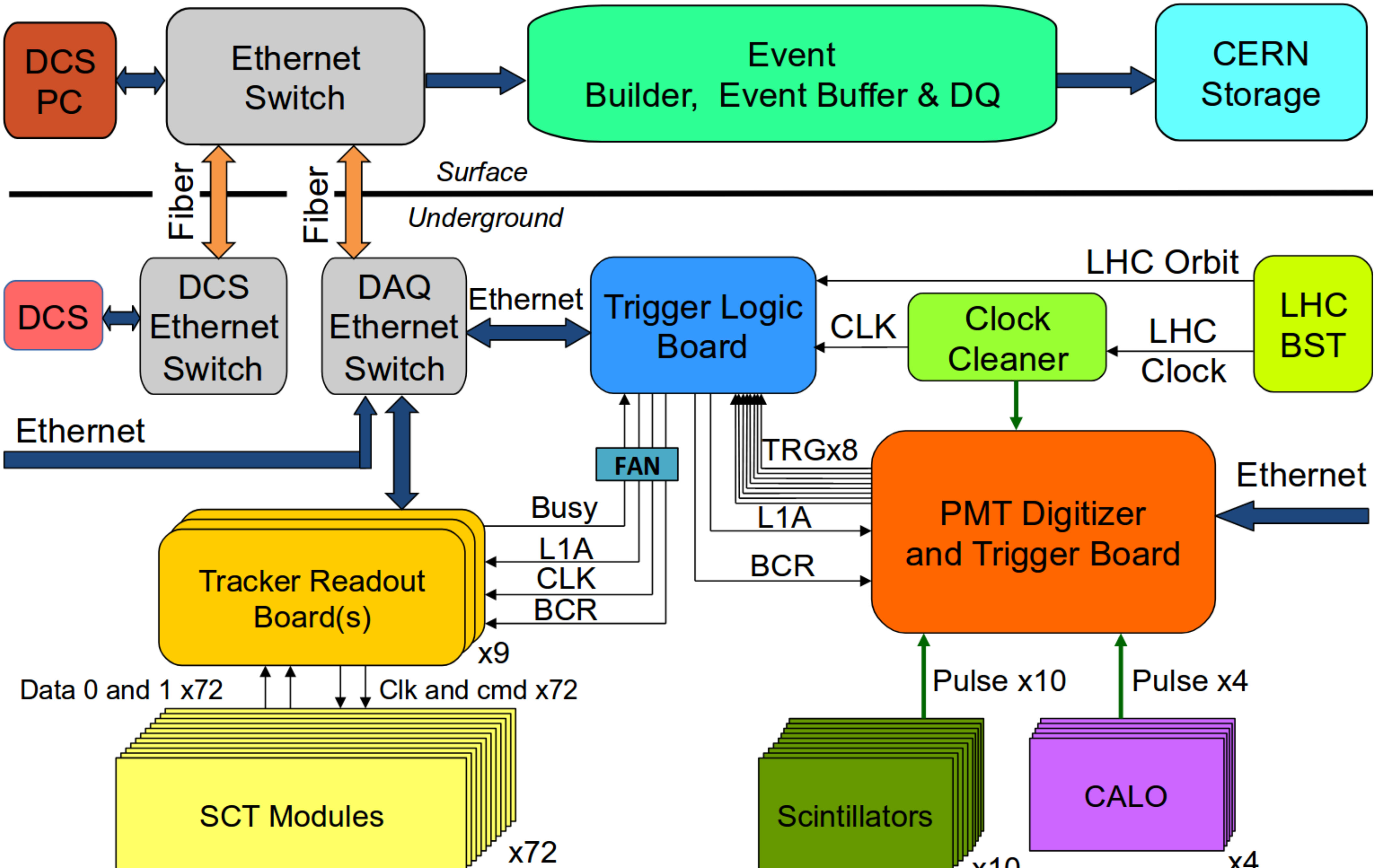
Summary and Outlook

- FASER experiment is progressing well
  - TI12 tunnel has been cleared out
  - Civil engineering work is being contracted out
  - All detector parts ordered/in production or final prototyping
- Full scale dry-installation/run planned for March-April
- On schedule for installation in May
  - Little contingency left for tracker and magnets
- A proposal to extend FASER with neutrino detector has been submitted to the LHCC
  - Would allow measurement of neutrino cross section in new energy range and first neutrinos to be seen at the LHC
  - Initially a standalone emulsion-tungsten detector, but possibility to connect to FASER spectrometer under study

Many thanks to LHCC for their support as well as to the PBC and CERN technical teams

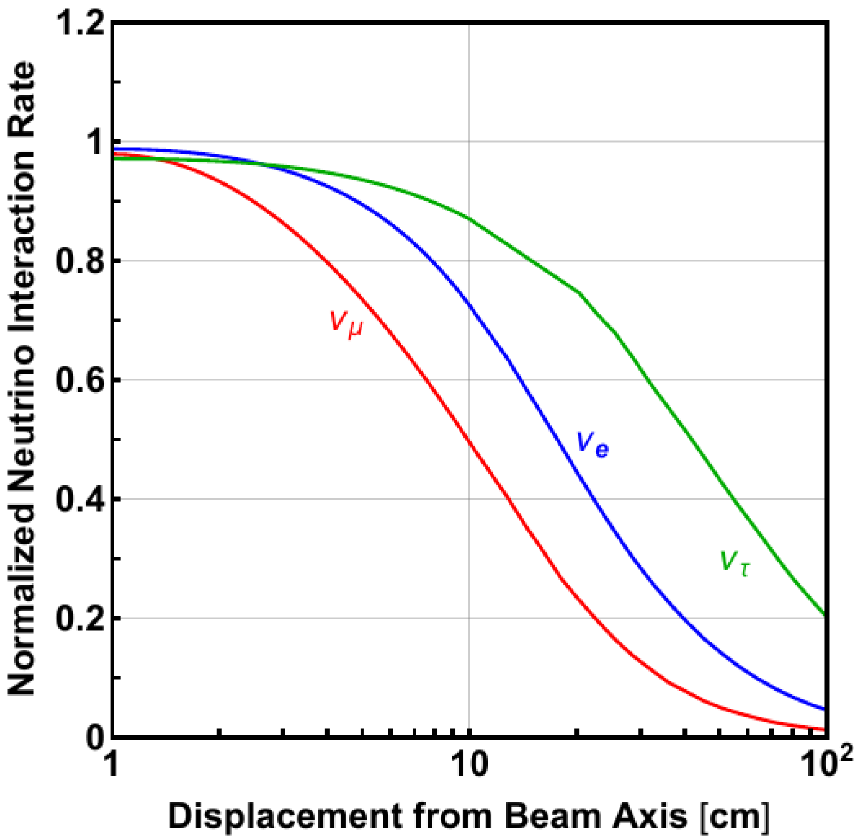
Backup

TDAQ Overview



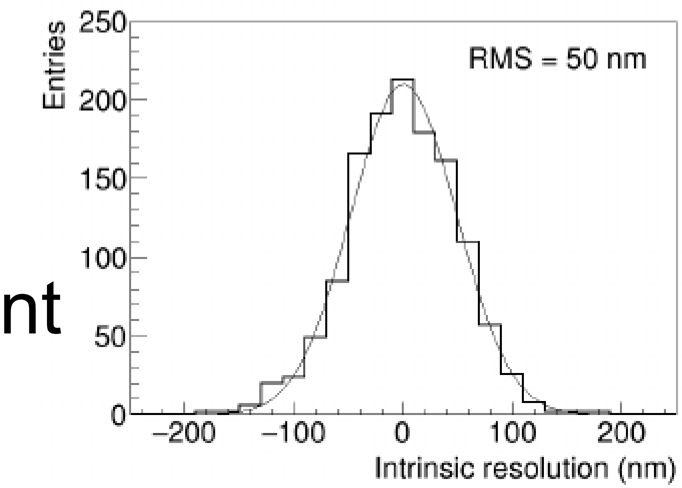
Neutrino Detector Location

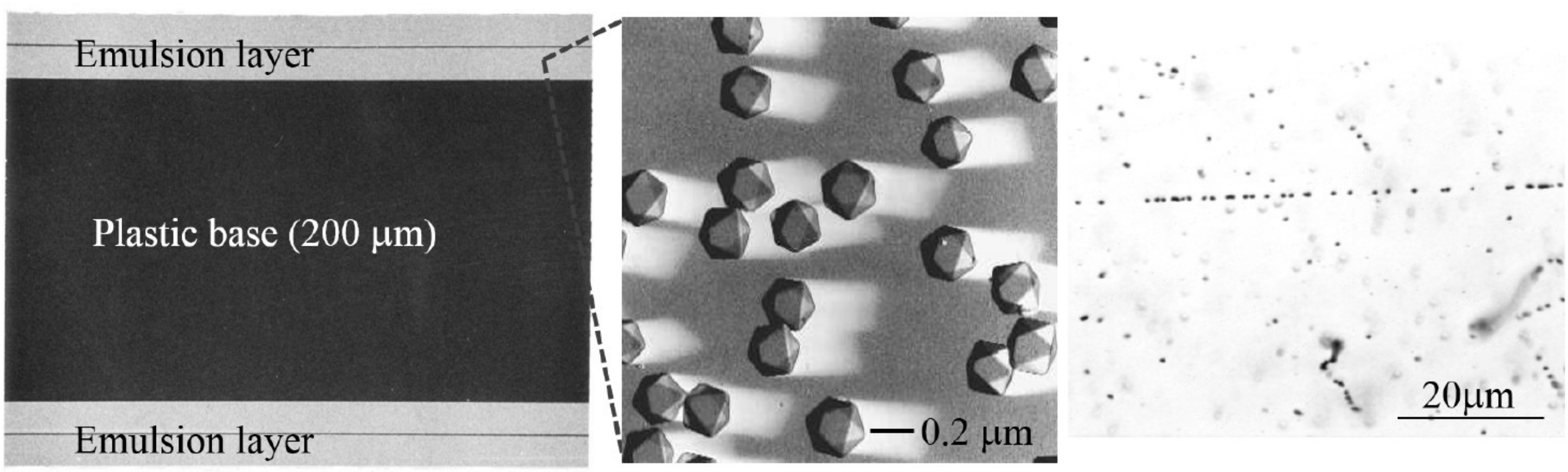
- Having FASER on beam-axis maximizes flux and energy of neutrinos in detector
  - Effect smaller for electron and tau neutrinos since source hadrons (kaons and charm) typically have higher p_T



Emulsion Detector

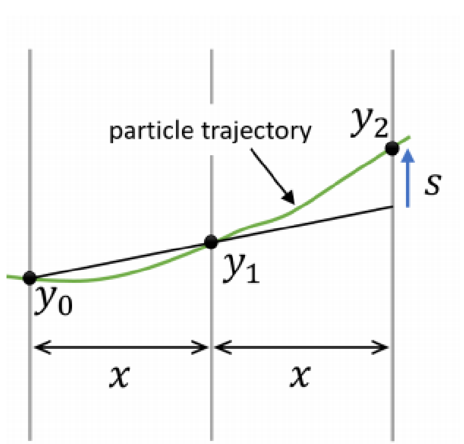
- Emulsion is 3D tracking device with exception intrinsic resolution
- Temperature stability important to keep relative alignment constant over full exposure period





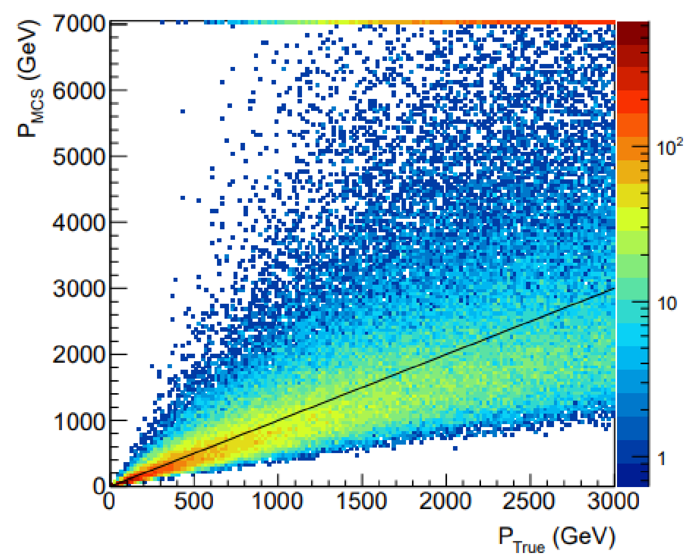
Track Momentum Reconstruction

- High granularity, high precision tracking allows momentum measurement using multiple columb scattering estimate
- Expect sub-micron alignment of layers thanks to large rate of high energy muons



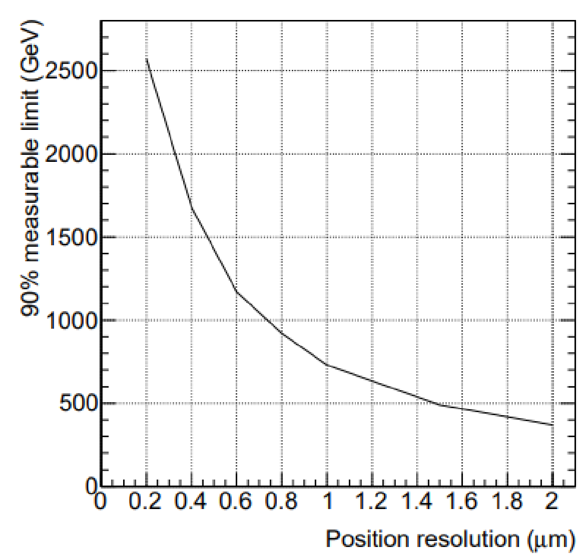
$$(s^{\mathrm{RMS}})^2 = \left(\sqrt{\frac{2}{3}}\frac{13.6(\mathrm{MeV})}{\beta P}x\sqrt{\frac{x}{X_0}}\right)^2 + \left(\sqrt{6}\,\sigma_{\mathrm{pos}}\right)^2$$

Reco momentum vs truth



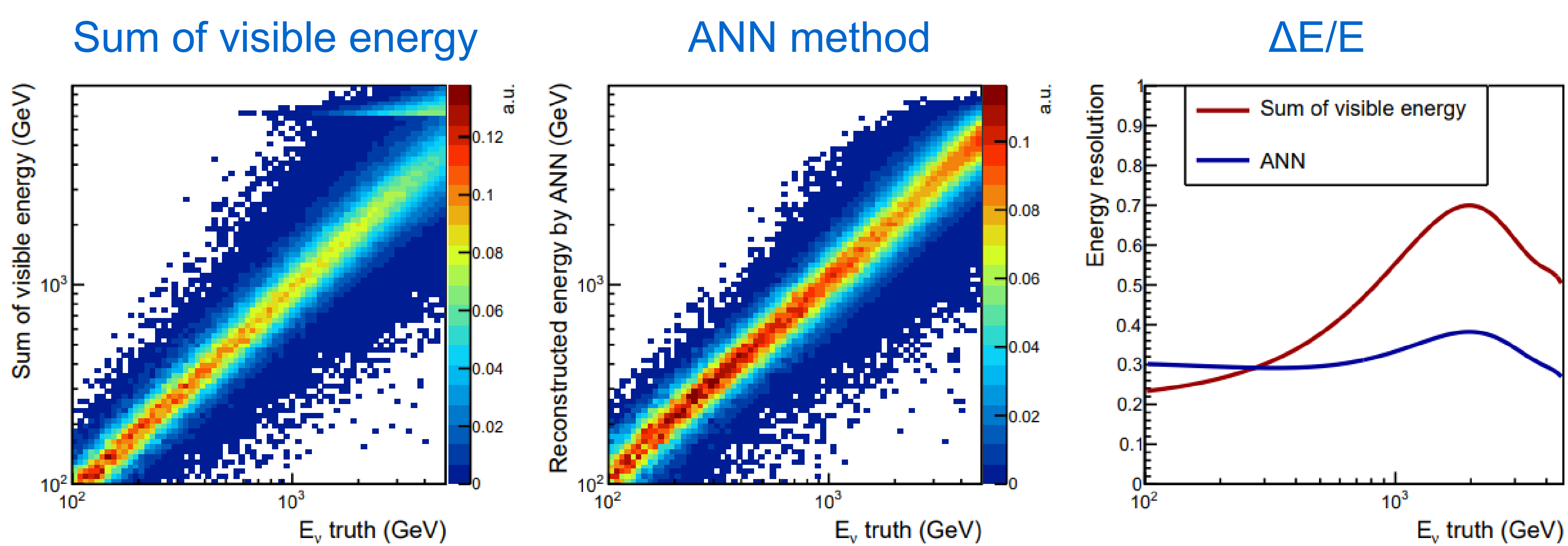
Assumes 0.4μm resolution and 100 traversed layers

Max momentum vs position res.

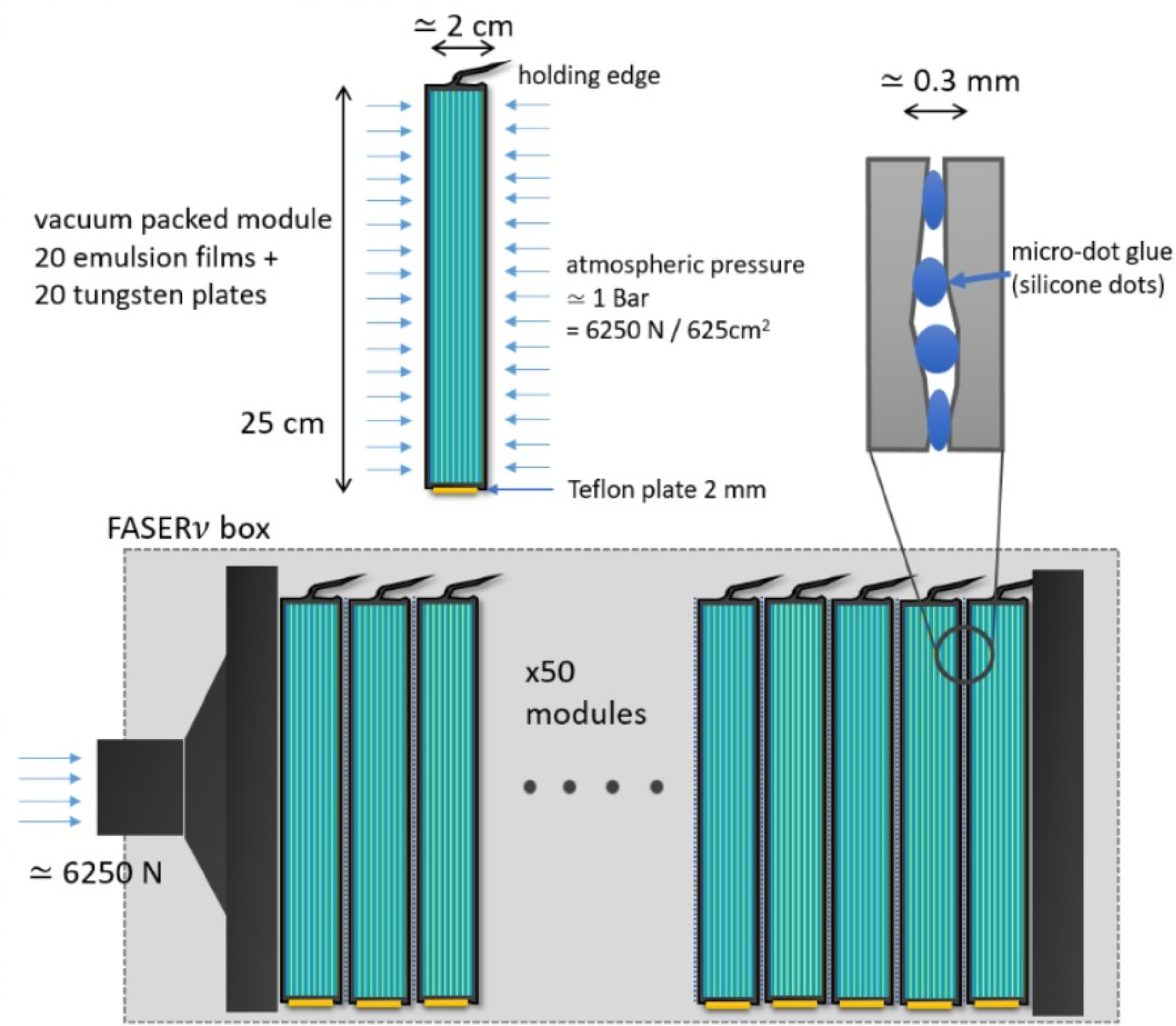


Neutrino Energy Reconstruction

- Neutrino energy can be estimated from sum of visible energy
- Improved resolution under study using ANN to also combine with angular information

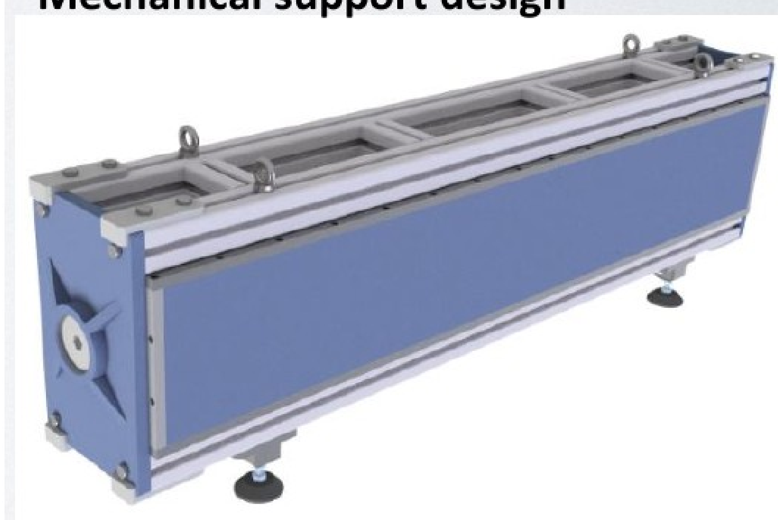


Emulsion Detector Structure



Vacuum-packed module

Mechanical support design



Emulsion Detector Sequence

At CERN

Detector assembling → Exposure → Disassembling → Development → Full area Readout

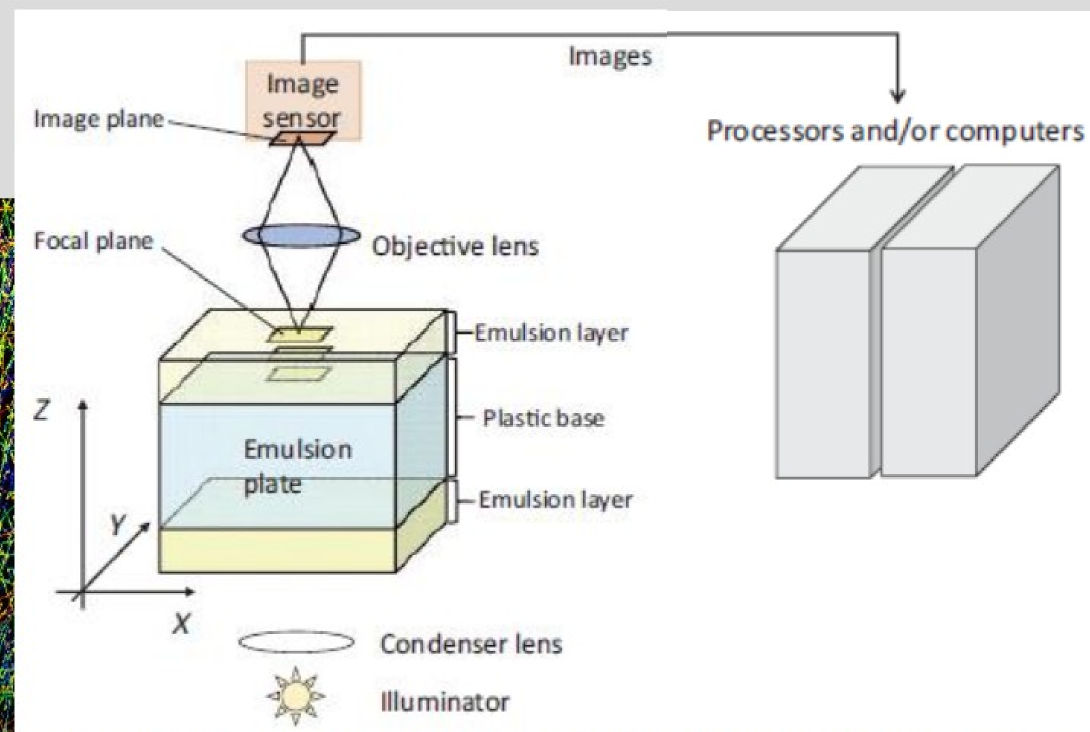
↓

Readout (in Japan), off-line analysis

Alignment → Track reconstruction → Vertex reconstruction → μ / e ID → Search for tau/charm decays

↓

Kinematical analysis



Emulsion Readout System