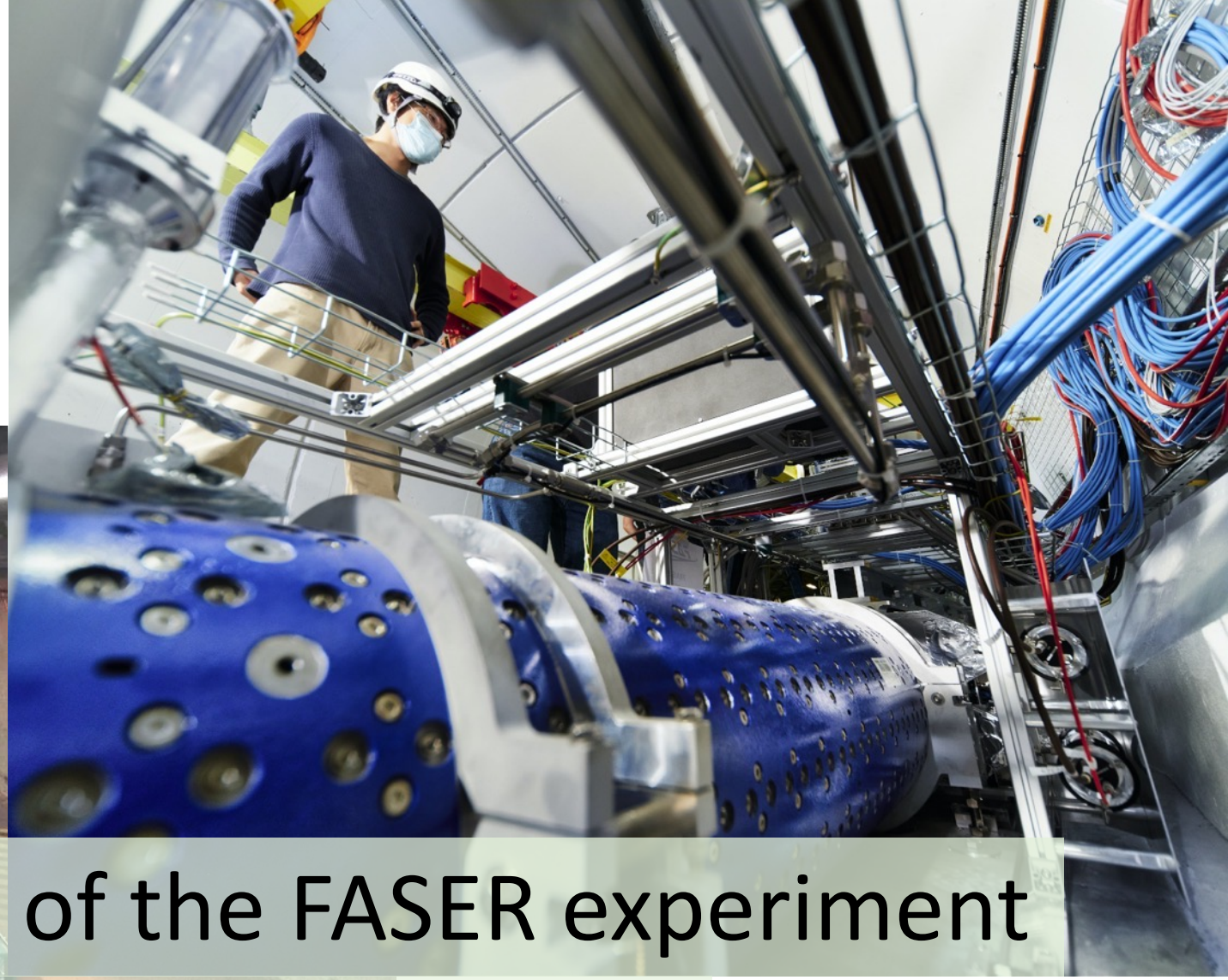
ASPEN CENTER FOR PHYSICS

2021 VIRTUAL WINTER CONFERENCE

A RAINBOW OF DARK SECTORS

MARCH 22 – APRIL 1, 2021



The recent status of the FASER experiment

Hidetoshi OTONO (Kyushu University)

HEISING-SIMONS FOUNDATION SIMONS FOUNDATION JSPS erc European Research Council

Just before starting – my gratitute to Aspen

Aspen 2018 - The Particle Frontier

Sun 25/03 | **Mon 26/03** | Tue 27/03 | Wed 28/03 | Thu 29/03 | Fri 30/03 | Sat 31/03 | All days

16:00
- **Coffee and Tea** — *Flug Forum, Aspen Center for Physics* — 16:00 - 16:30
- **ATLAS results on searches for long-lived particles** — *Hidetoshi Otono* — *Flug Forum, Aspen Center for Physics* — 16:30 - 16:50

17:00
- **CMS results on searches for long-lived particles** — *Ted Ritchie Kolberg* — *Flug Forum, Aspen Center for Physics* — 16:55 - 17:15
- **Searches for new particles at LHCb** — *J Michael Williams* — *Flug Forum, Aspen Center for Physics* — 17:20 - 17:40

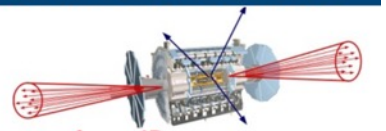
18:00
- **Coffee Break** — *Flug Forum, Aspen Center for Physics* — 17:45 - 18:15
- **Search for Light Dark Sector at BaBar** — *Chunhui Chen* — *Flug Forum, Aspen Center for Physics* — 18:15 - 18:35
- **A COmpact DEtector for eXotics at LHCb** — *Simon Knapen* — *Flug Forum, Aspen Center for Physics* — 18:40 - 19:00

19:00
- **Far Detectors Panel** — *Andrew Haas et al.* — *Flug Forum, Aspen Center for Physics* — 19:05 - 19:30

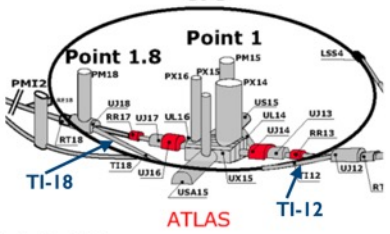
FASER: ForwArd Search ExpeRiment at the LHC

Idea: search for LLP in forward direction
- large LHC event rates in forward direction
- energetic particles very forward $\theta < 1$ mrad

→ We propose small inexpensive detector downstream from IP

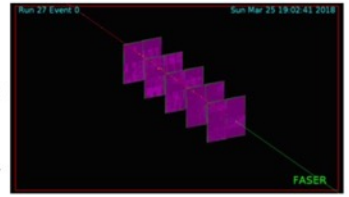


Location: along beam axis after LHC curves
- LHC Infrastructure acts as natural filter
- promising location: TI-18 /TI-12



Detector: small, cheap, operates concurrently
- physics: dark photon, dark Higgs, HNLs …
- distinct signature: 2 tracks with TeV energy
- equipped with tracking system + magnetic field (+ ECAL)

Current Developments & Next Steps
- FASER collaboration is growing
- realistic background estimate: FLUKA/measurements
- detector design & GEANT4 simulations
- explore more physics opportunities: ALPs, IDM, ν's …



Felix Kling | FASER: ForwArd Search ExpeRiment at the LHC | UCIrvine

I encountered FASER experiment on March 26th 2018, then joined in April.

Introduction

Various ideas to make use of the accelerator/infrastructure at CERN have been discussed

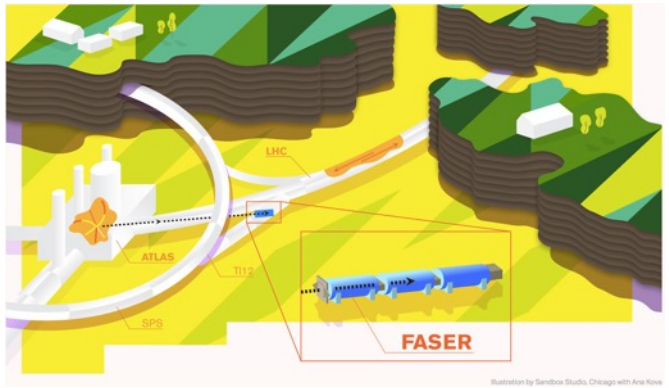
- LHC Run-3 will start in 2022, aiming to double the integrated luminosity
- HL-LHC, starting in 2027, will deliver 10 times more integrated luminosity

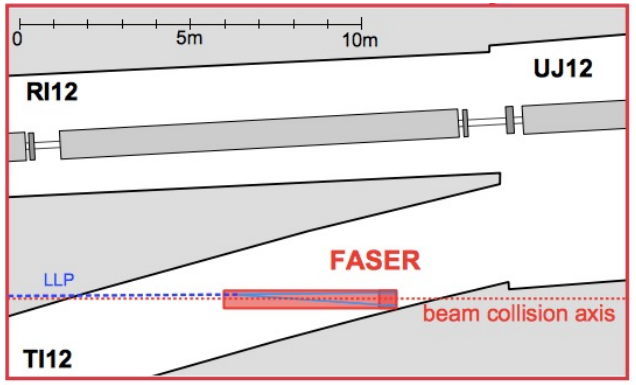
LS2 is a great opportunity to prepare for LHC-Run3 and beyond.

FASER experiment

FASER is located in an unused tunnel (TI12) 480 m downstream from the ATLAS interaction point for:

- New weakly-coupled particles in the MeV-GeV range
- All flavors of neutrinos at the TeV-energy frontier





Favorable location, except that refurbishment is needed to be an experimental site:

- Background from collision point is only high-energy muon at about 1 /cm^2/sec
- Radiation level from LHC is quite low, around 4×10^{-3} Gy/year (= 4×10^7 *1*-MeV neutron/cm^2/year)

Search for new light weakly-coupled particles

LHC collisions produce an enormous flux of light mesons in the forward direction

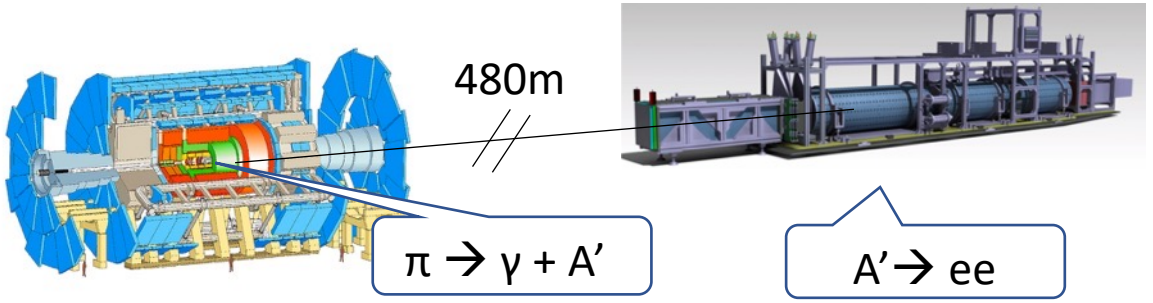
- ~ 10^{15} π^0 in the FASER angular acceptance in LHC Run-3

⇨ FASER could discover a new particle from a rare decay of the light mesons

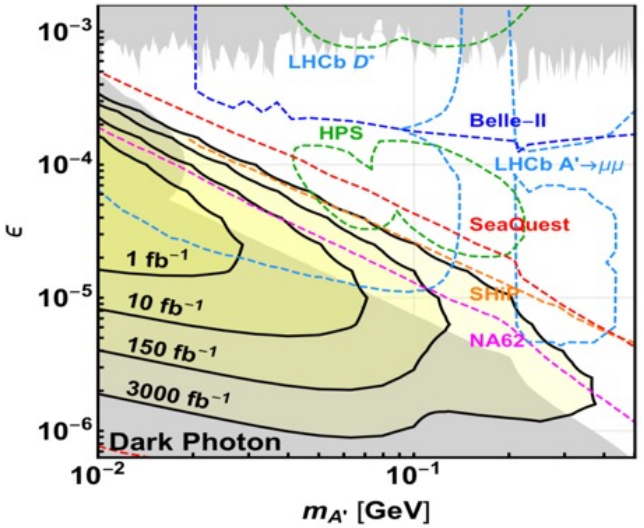
= a new weakly-coupled particle in the MeV-GeV range

Sensitive to various new particles

- Dark photon (A'): appears with a new U(1) symmetry



- Axion-like particle, heavy neutral leptons, ... (Phys. Rev. D 99, 095011 (2019))

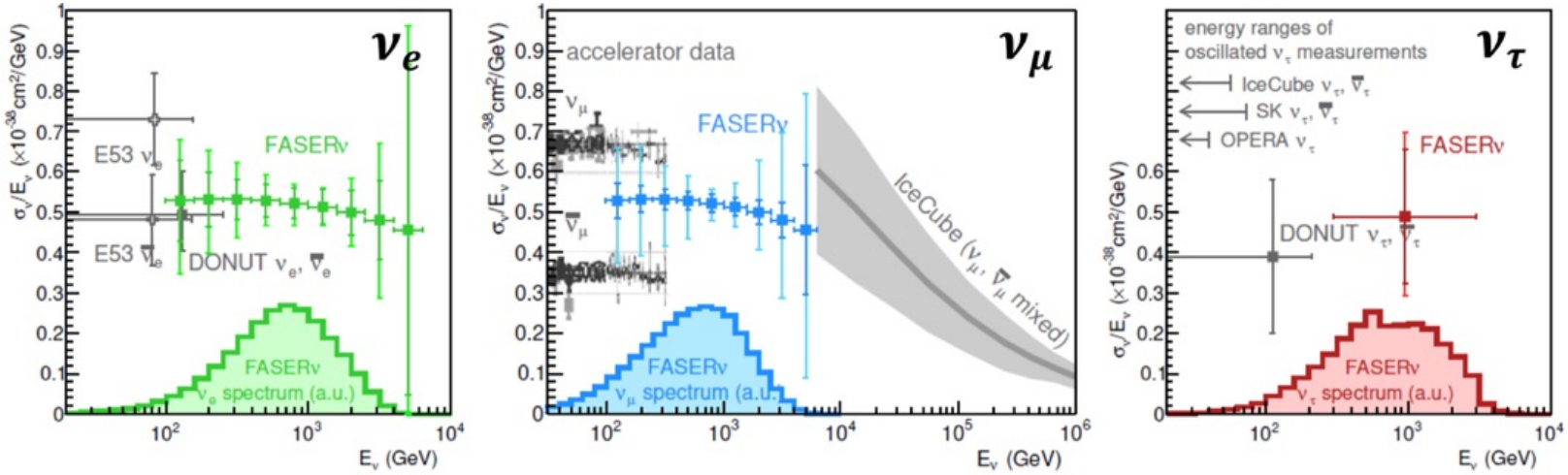


FASER is the first dedicated far-detector collider experiment for long-lived new particle searches

Exploring neutrinos at the TeV-energy frontier

The LHC collisions also produce a copious number of neutrinos at uncharted energies

- Sensitive to new physics by measuring scattering cross sections and studing the final states
- Unique data for forward hadron production, which would be useful input for prompt neutrinos in IceCube



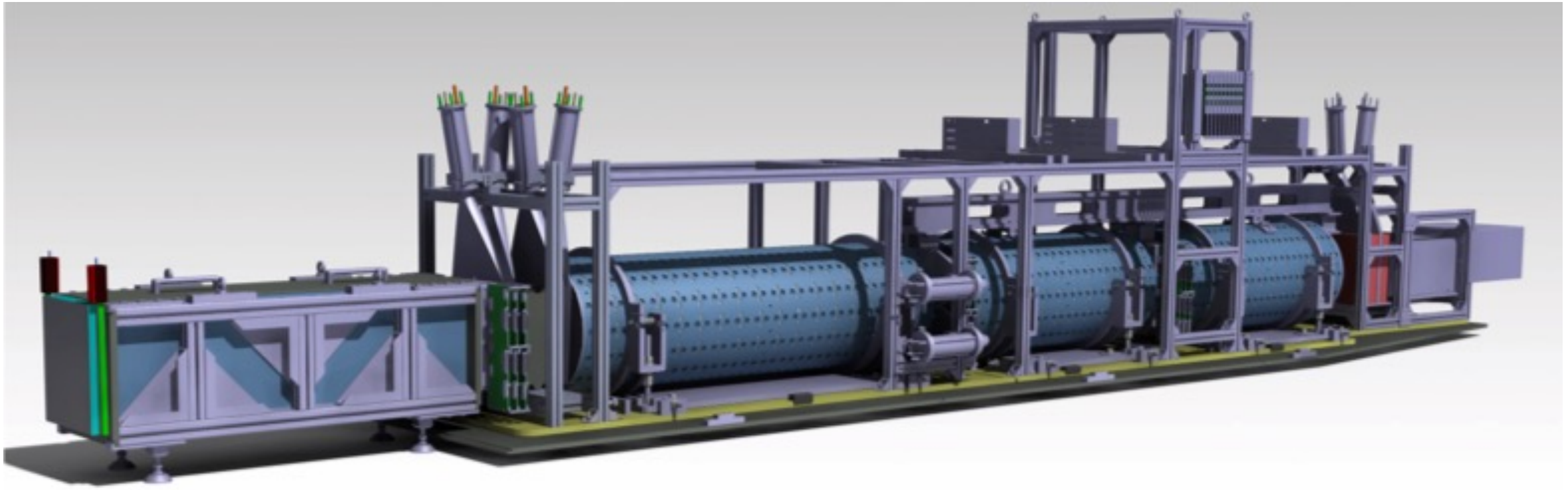
Eur.Phys.J. C80 (2020) no.1, 61

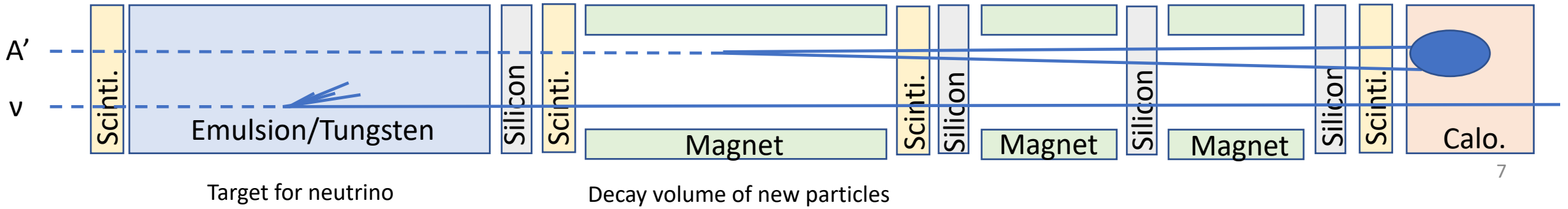
Already installed 29 kg emulsion detector in 2018, exposed to 12.2 fb^{-1} data

- Found a few candidate events of TeV-neutrino interactions; being analysed for publication

<u>FASER is the first experiment to probe collider neutrinos</u>

FASER detector



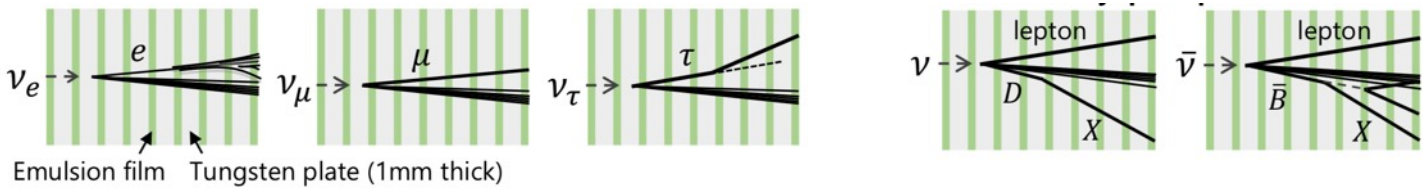


Mechanical support is ready for testing in April

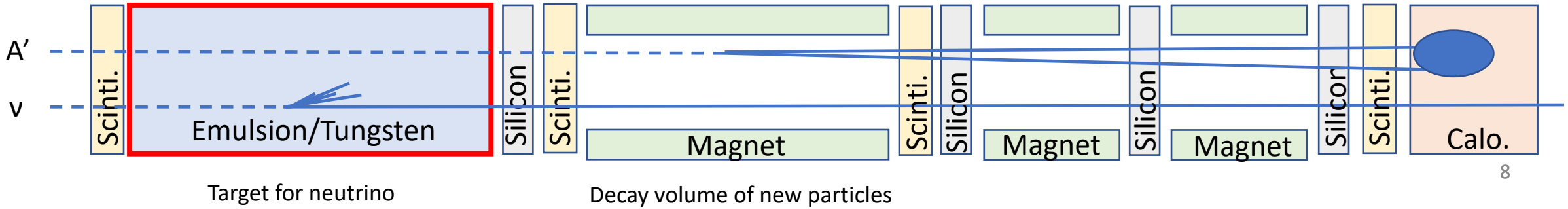
Emulsion/Tungsten detector

All flavors of neutrino interactions can be identified

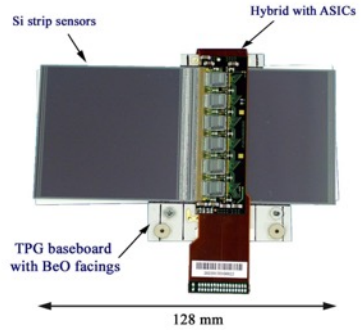
- Heavy quark production also can be distinguished



- 770 x 1-mm-thick tungsten plates, interleaved with emulsion films
- 25 x 30 cm^2, 1.1 m long, 1.1 ton detector (220 X_0 / 8 λ_{int})
  - ~10000 ν_μ, ~1000 ν_e and ~10 ν_τ expected
- 9 replacements in LHC Run-3; emulsion will be produced a few months before installation



Silicon tracker



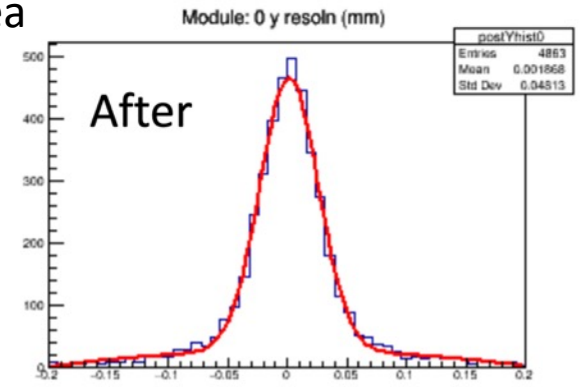
ATLAS SCT module:

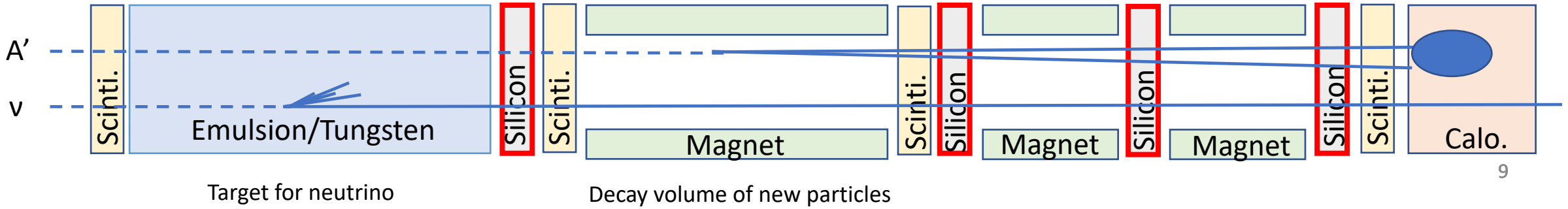
- 6cm x 12cm x 2 side (40 mrad)
- 80 um pitch/ 768 strips per side
- Resolution: 17 um x 580 um
- 6 ASICs per side

Two highly collimated tracks, e.g., from A' decay, can be separated; tracks in emulsion films can be matched

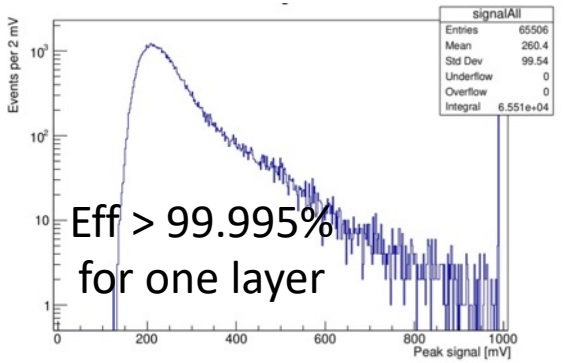
- Based on ATLAS SCT modules - 4 station x 3 layers x 8 modules = 96 modules
- 3 stations commissioned and installed
  - 99.9% strips are active
  - Expected noise/gain are confirmed
  - Thermal performance looks good
  - Interlock/safety are carefully verified
  - 25 um resolution achieved after simple correction
- 1 station for neutrino physics will be assembled in April

24 cm x 24 cm for sensitive area





Scintillation detector



Three stations (Veto/Timing/Preshower) are commissioined and installed.

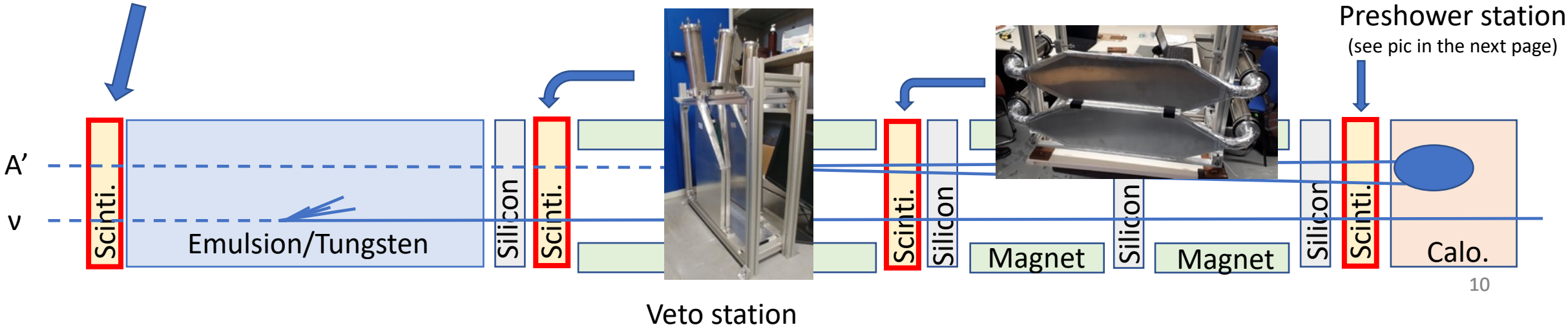
⇨ Veto station: 3 layers of scintilators achieve veto inefficiency of better than 10^{-8} – zero background!

- 5 x 10^8 muons from the interection point to FASER detector in LHC-Run3

⇨ Timing station: 1 nsec resolution confirmed, synchronized with the collision at every 25 ns

⇨ Preshower station: 2 layers of scintillators with tungsten (2 X_0) and graphite (to absorb back splash)

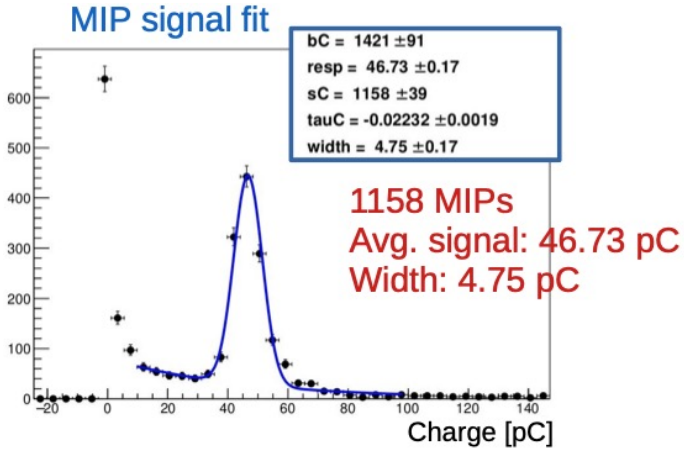
One station for neutrino physics is in progress.



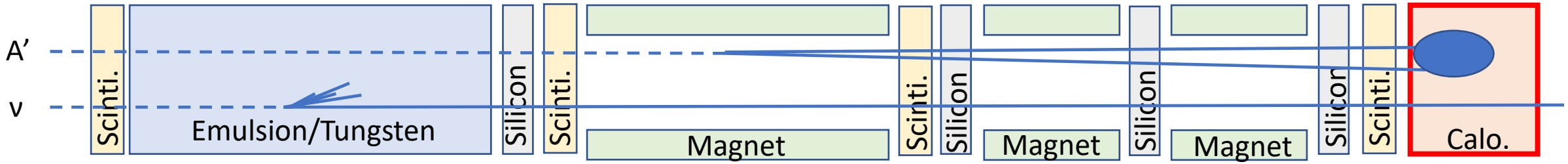
Electromagnetic Calorimeter

Electron, e.g., A'→ ee, and gamma, e.g., ALP -> γγ, separated from muon

- Based on LHCb ECAL module; one module has:
  - 12 cm x 12 cm (25 X_0)
  - 66 layers of (2mm lead and 4mm scintillator)
  - Energy resolution: 1% at 1 TeV
    - Beam test scheduled this autumn
- 4 modules used for FASER – 24 cm x 24 cm
  - Successfully installed in March



- To separate 2 gammas, upgrade of preshower station based on Pixel detector being considered



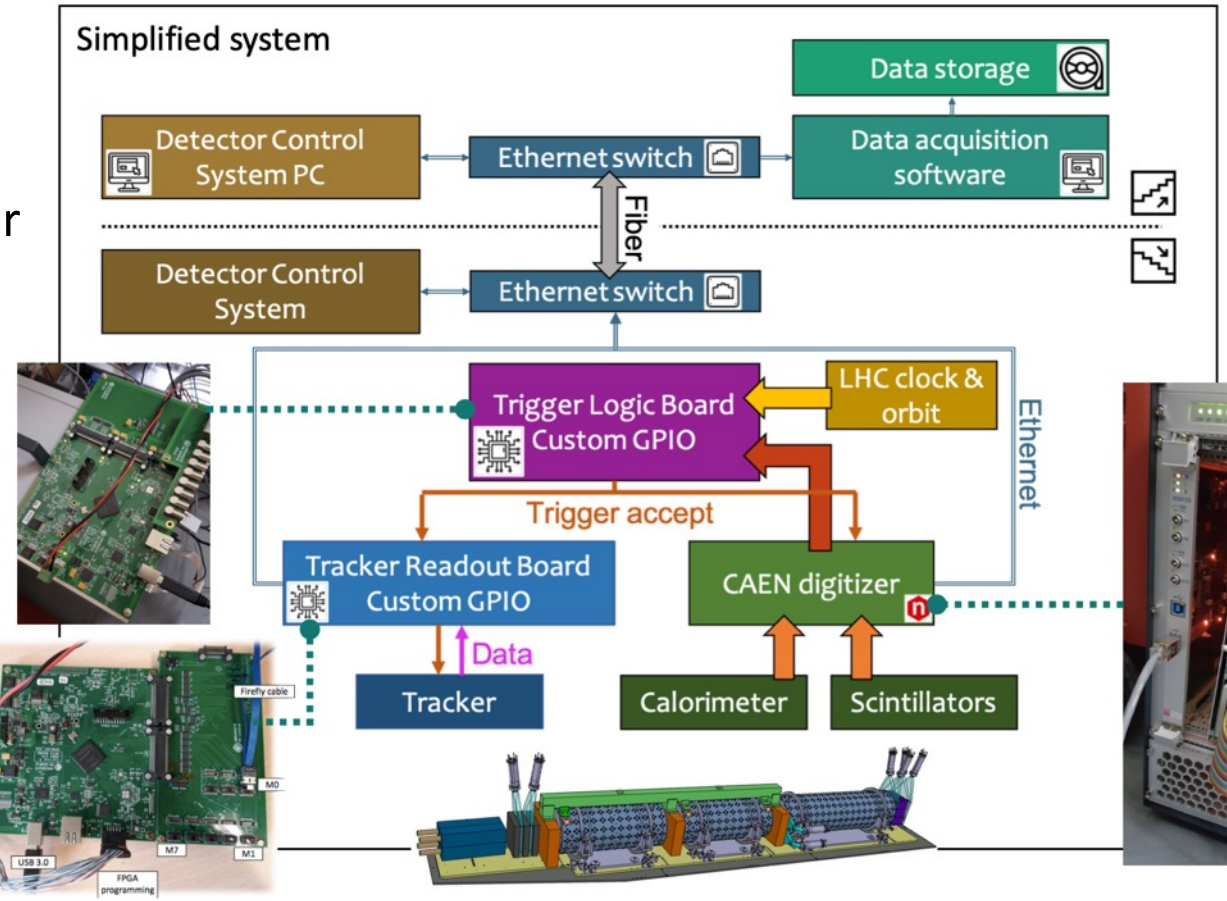
Trigger and Data acquisition

Readout electronics in TI12

- Silicon tracker: Custom GPIO board
- Scintillator and Calorimeter: CAEN digitiser
- Trigger: Custom GPIO board
  - 500 Hz expected rate
  - Clock and bunch taken from LHC
- Ethernet switch -> Servers on surface

All components are installed

- High rate test at 1 kHz successful
- Monitoring tool in place
  - Status of the detector and data taking

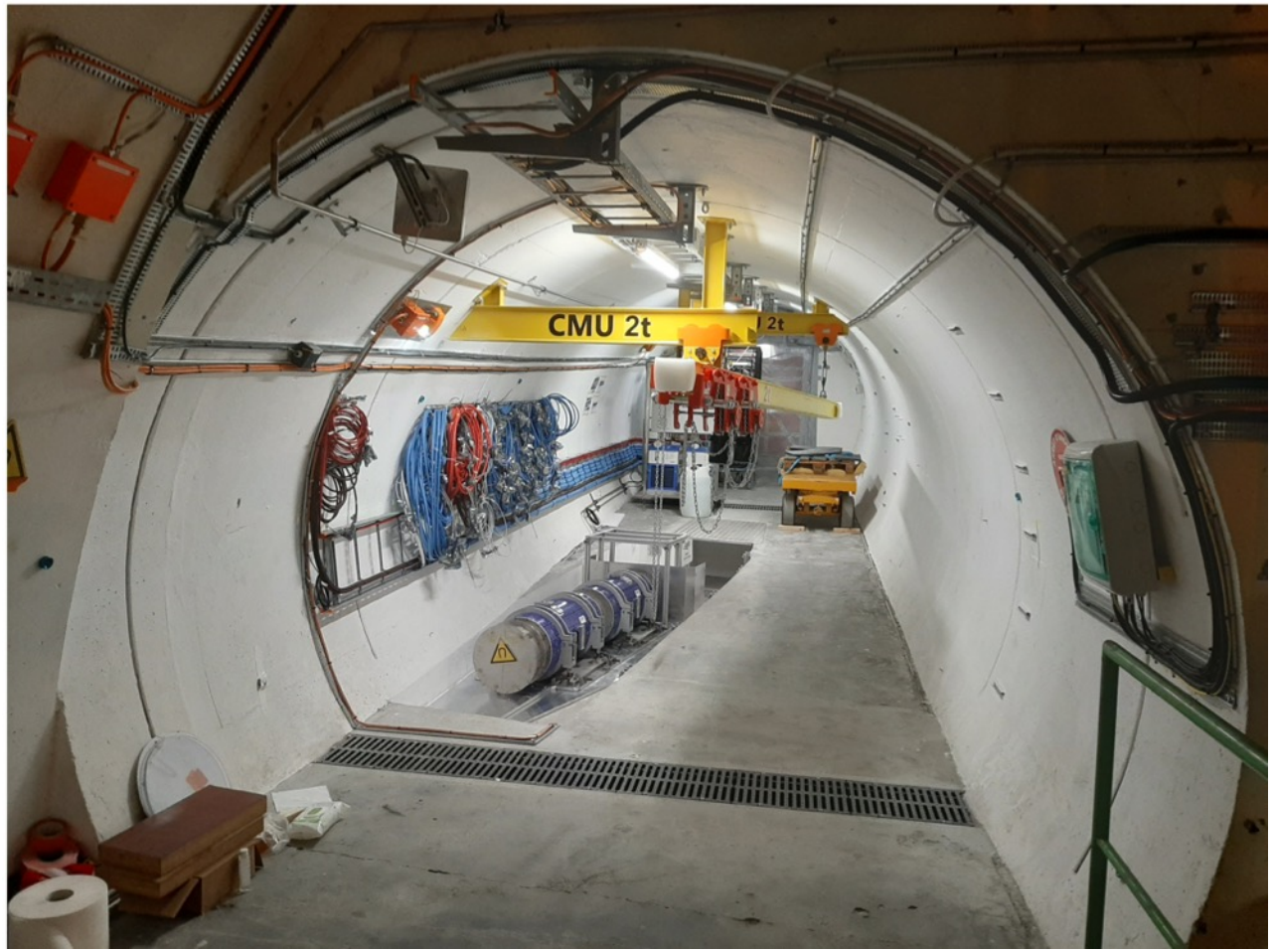


Refurbishment of TI12 completed in 2020

2020 winter

2019 spring

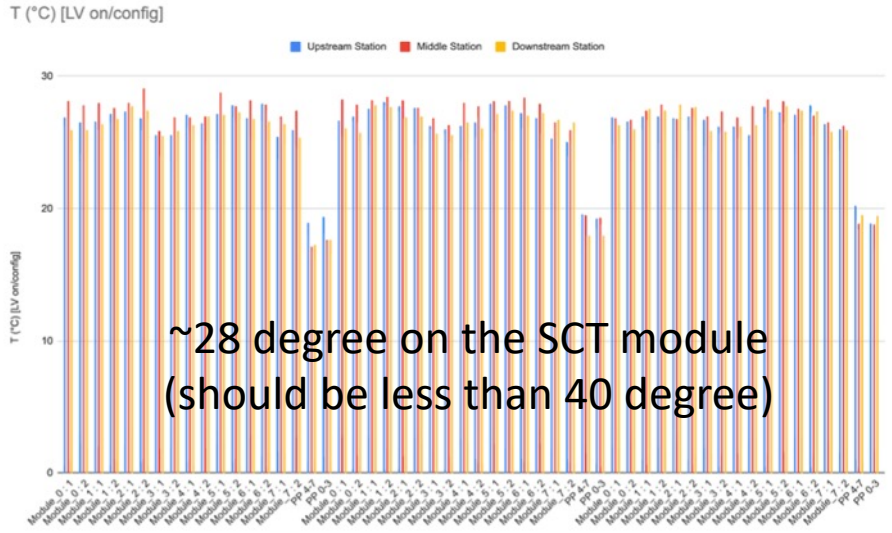
2020 autum



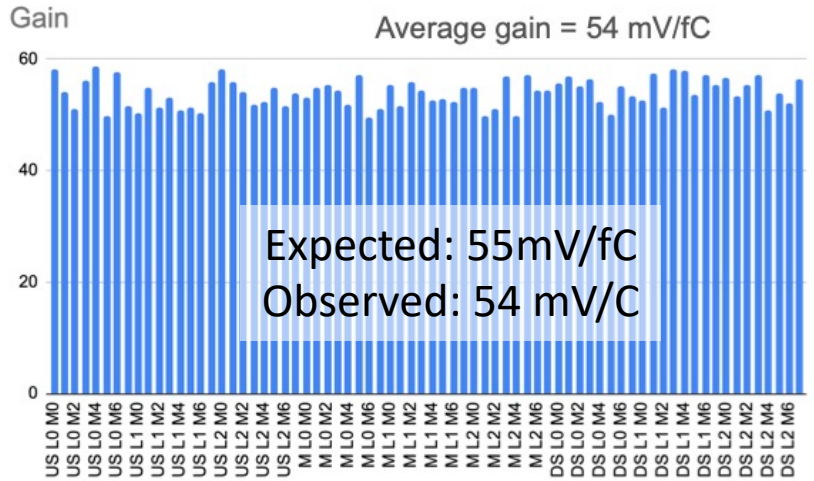
Thanks a lot to CERN for their support for FASER!!

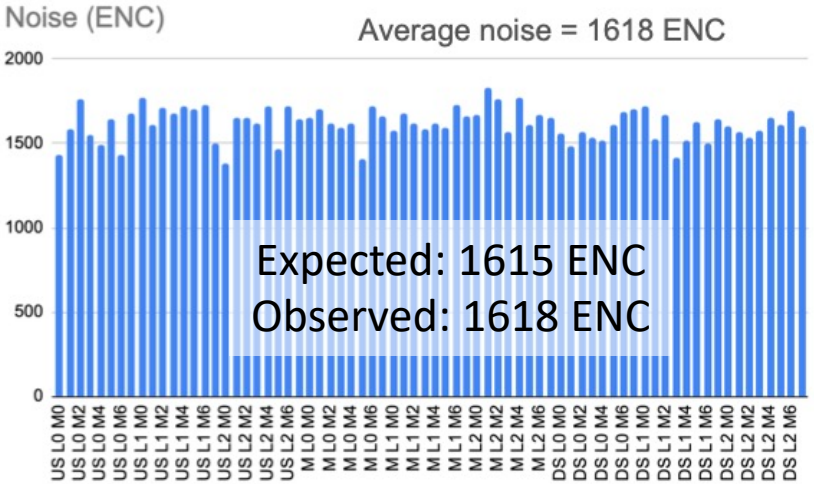
On March 24th,
ALL equipment for the new particle searches are installed.

A couple of quick results

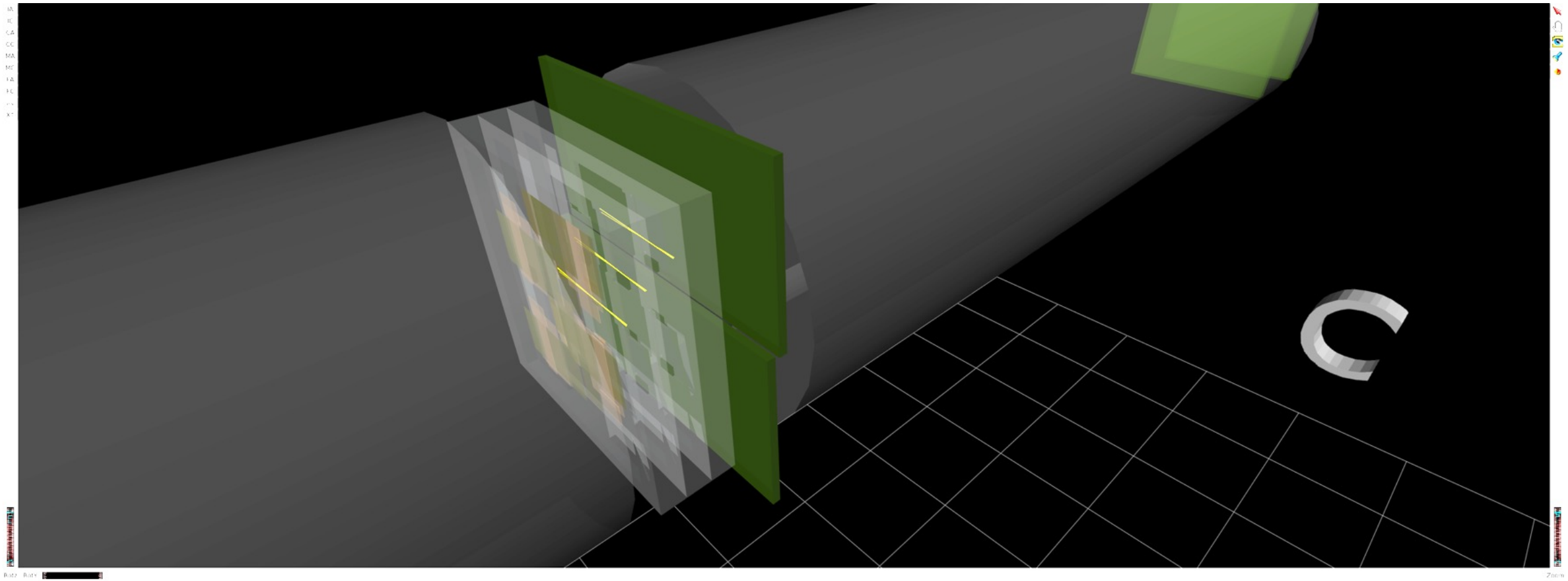


Masked channels	Upstream station	Middle station	Downstream station
Dead	7	7	28
Noisy	6	6	44
Total	13 (0.04%)	13 (0.04%)	72 (0.2%)



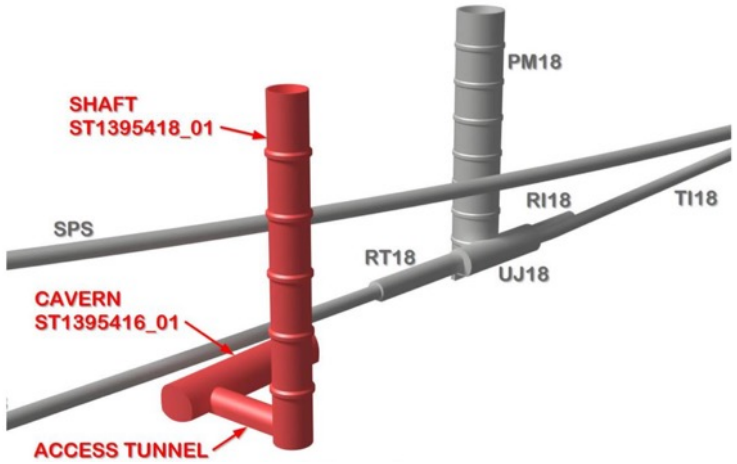


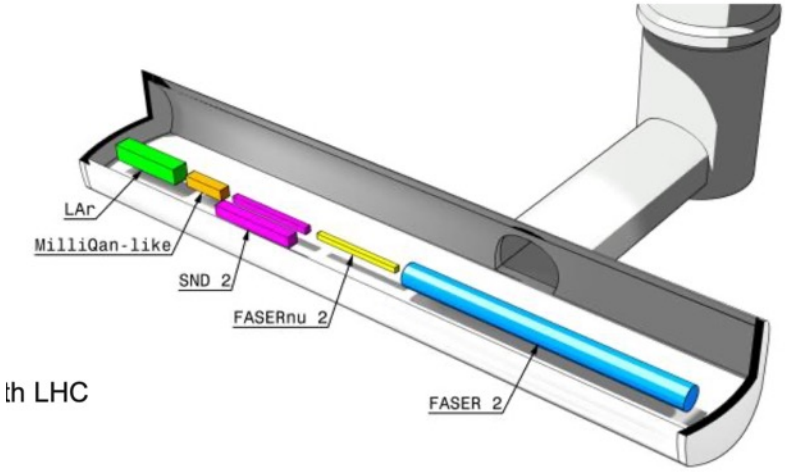
A cosmic-ray event in TI12



Toward HL-LHC

Civil enginering study for a new facility called the Forward Physics Facility (FPF) has started





th LHC

Benchmark Model	Underway	FPF
BC1: Dark Photon	FASER	FASER 2
BC1': $U(1)_{B-L}$ Gauge Boson	FASER	FASER 2
BC2: Dark Matter	–	FLArE
BC3: Milli-Charged Particle	–	FORMOSA
BC4: Dark Higgs Boson	–	FASER 2
BC5: Dark Higgs with hSS	–	FASER 2
BC6: HNL with e	–	FASER 2
BC7: HNL with μ	–	FASER 2
BC8: HNL with τ	FASER	FASER 2
BC9: ALP with photon	FASER	FASER 2
BC10: ALP with fermion	FASER	FASER 2
BC11: ALP with gluon	FASER	FASER 2

FPF plans to house several experiments:

- Enhance physics reach of FASER
- Extend reach to probe dark matter, milli-charged particles

FPF Kickoff Meeting held 9-10 Nov 2020, https://indico.cern.ch/event/955956

2nd FPF Workshop, 27-28 May 2021, https://indico.cern.ch/event/1022352, all welcome!

Conclusion

FASER is a new forward experiment at the LHC in the unused tunnel, TI12.

- Refurbishment of TI12 to be an experimental site was completed in Winter 2020.

Aiming to start data taking in LHC Run-3 from 2022 for:

- discovery of a light weakly-coupled particle in MeV-GeV range
  - All detectors have been installed in TI12 as of March 2021
  - Already starting to collect cosmic-ray data
- probe all flavors of neutrinos at the TeV-energy frontier
  - Design and strategy are all defined
  - All detectors will be ready by Autumn 2021

Towards HL-LHC, dicussion for Forward Physics Facility started both for

- BSM physics (weakly-coupled particles, milli-charged particles, dark matter…)
- SM physics (neutrinos, QCD, astrophysics)