The new FASER experiment at the CERN LHC

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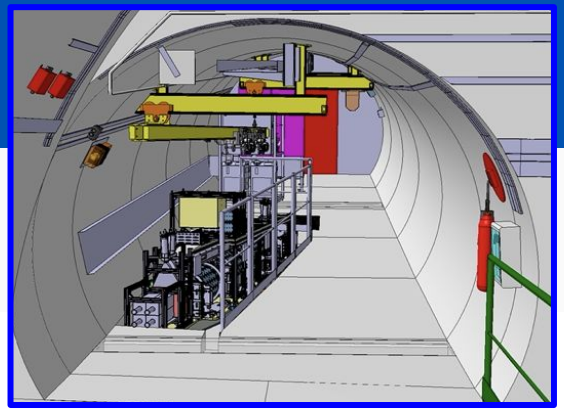
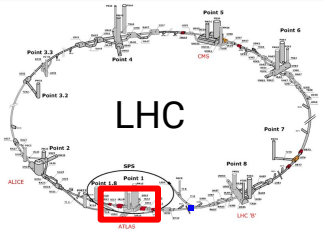
Nikhef

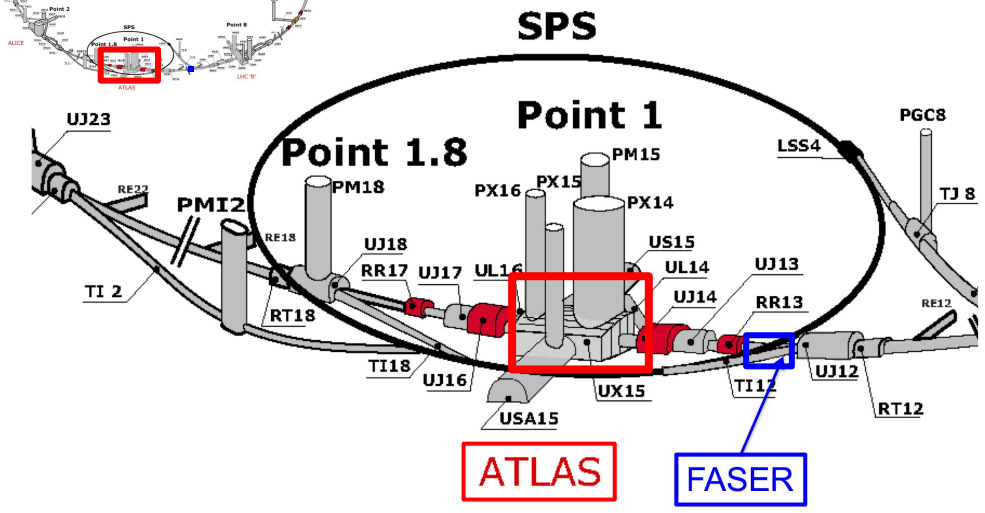
Direct search for new physics



Broadening chances of finding new physics

- ➔ Established LHC experiments focus on heavy, strongly interacting particles
- ➔ Large number of interesting models to test outside the focus of larger experiment
  - FASER targets light and weakly interacting particles
  - Low cost experiment
    - Reusing spare parts from other experiments
    - Total detector cost <2MCHF
    - Built in side tunnel TI12





Construction and Commissioning

2017

Concept born

March 2019

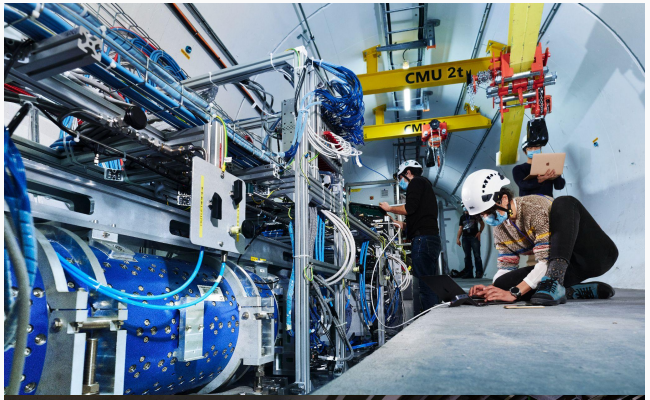
FASER approved

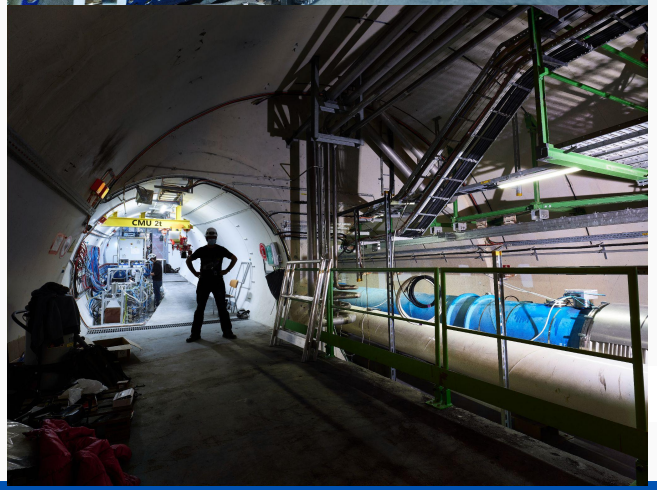
March 2021

FASER installed

July 2022

Run 3 start

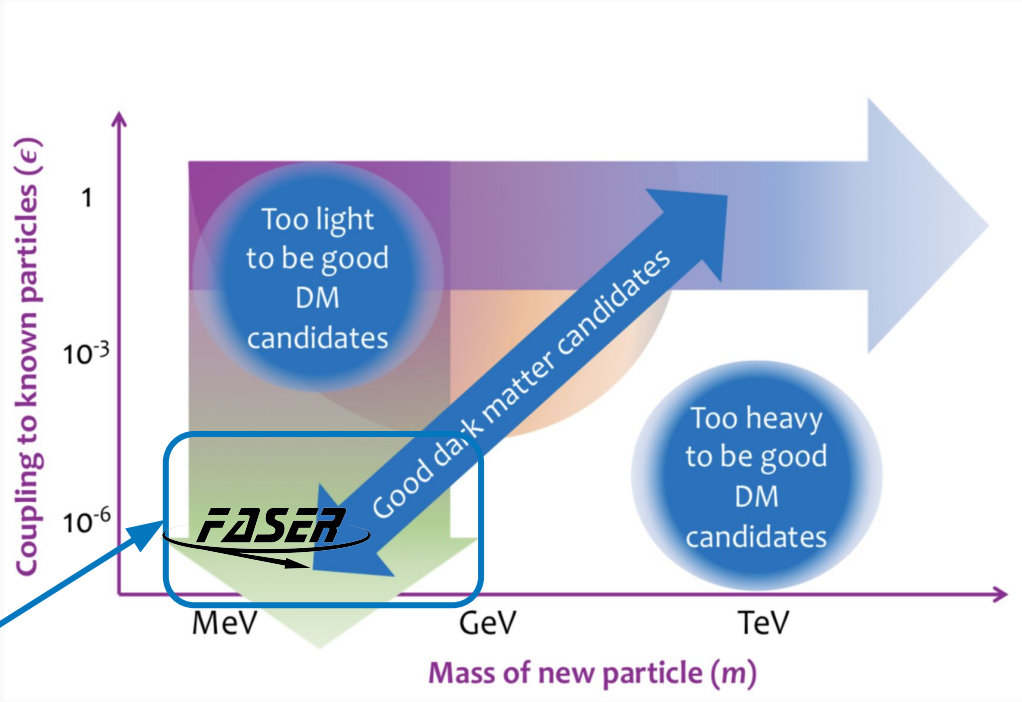




FASER philosophy

Exploit high rate of light SM particles produced in collimated beam around the LHC beam

- ➔ Inelastic pp cross-section: ~0.1 barns, N ~ 10^{16} at Run 3
- ➔ Very forward production: $\theta \sim \Lambda_{QCD}/E$ ~mRad
- ➔ Decay length: ~100 m for m ~10-100 MeV $\varepsilon \sim 10^{-5}$



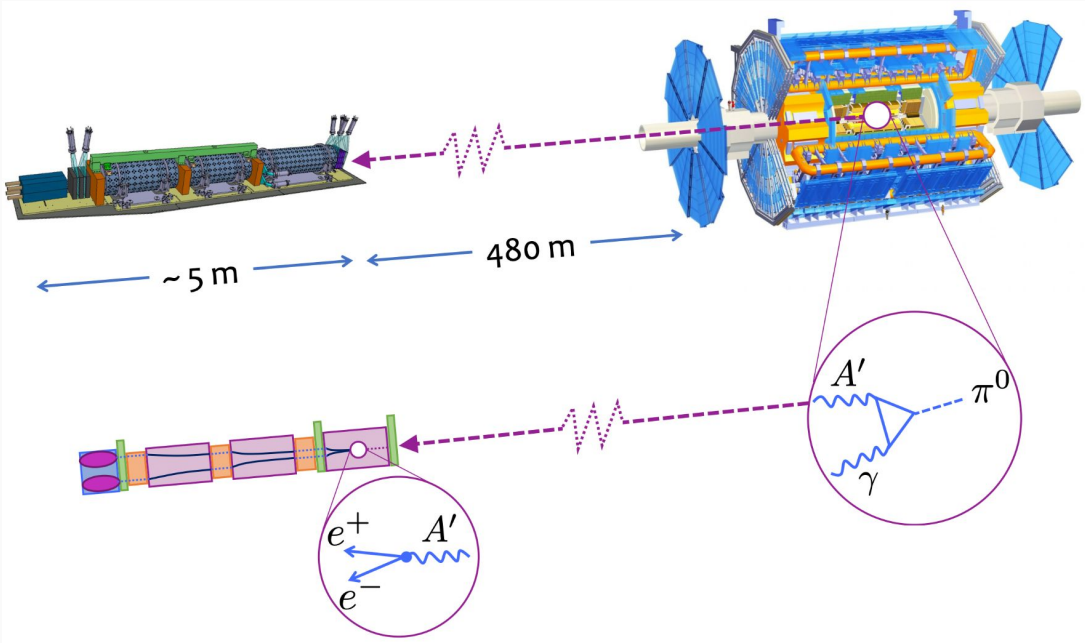
Phasespace where FASER is sensitive

Physis process

Target Dark photons A’ as benchmark physics process

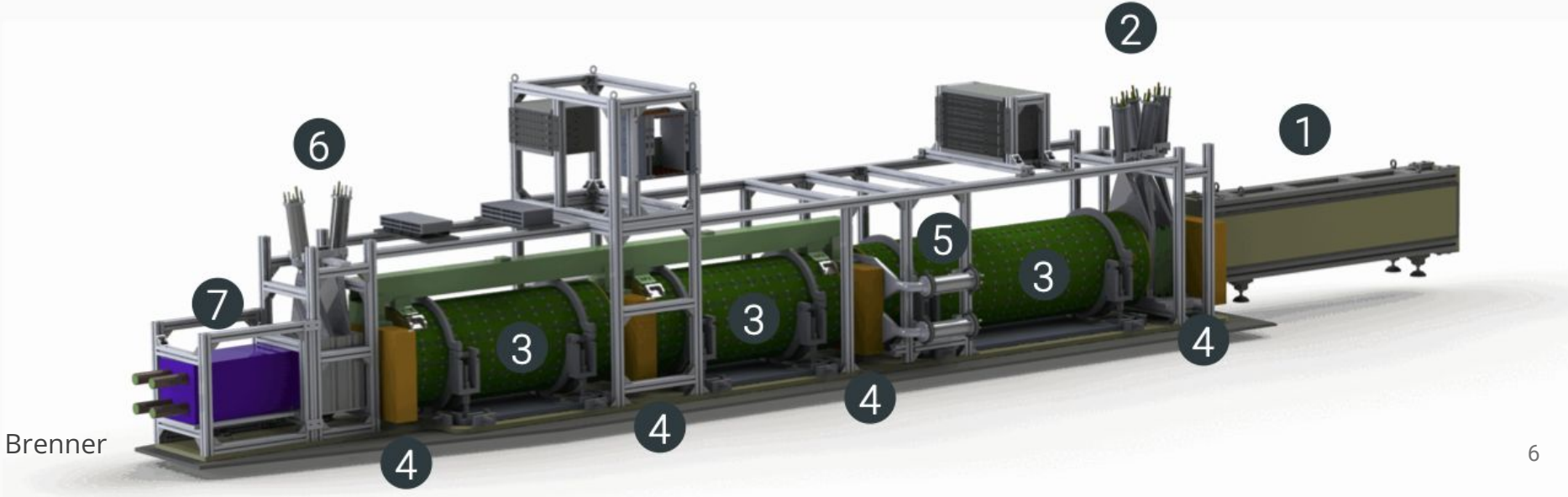
- ➔ Produced via kinetic mixing from e.g. π^0 decays
- ➔ BF ~ 10^{-10}
- ➔ Detected in decay to e^+e^- in FASER decay volume
- ➔ Sensitive to other LLPs and decay modes as well

Physics potential: Phys. Rev. D 99, 095011



Detector overview

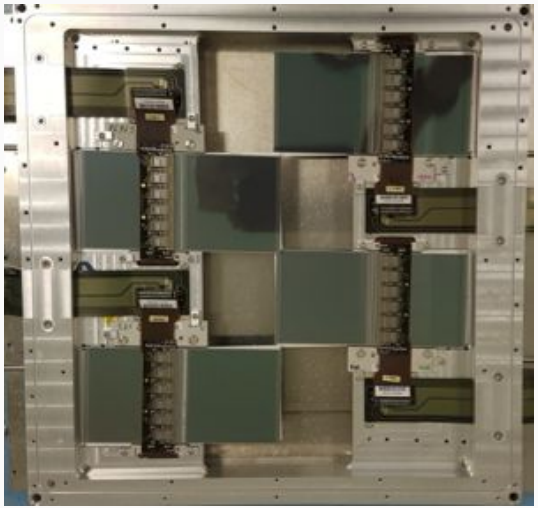
1. FASERν neutrino detector
2. Veto scintillators
3. Dipole magnet (0.6 T)
4. Tracker stations
5. Scintillator (precise timing)
6. Scintillator based preshower
7. Calorimeter

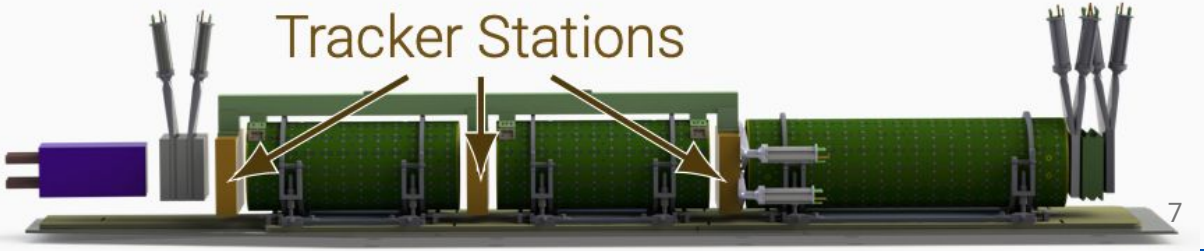


Tracker

Made from spare Si strip detector (SCT) modules from ATLAS

- ➔ Each module tested and best quality modules used
- ➔ Consists of 3 tracker stations with each 3 layers consisting of 8 modules
  - 72 modules with O(10^5) channels in total
- ➔ Extensive testing on the surface shows expected performance
  - 25 μm resolution
  - <0.1% defect strips

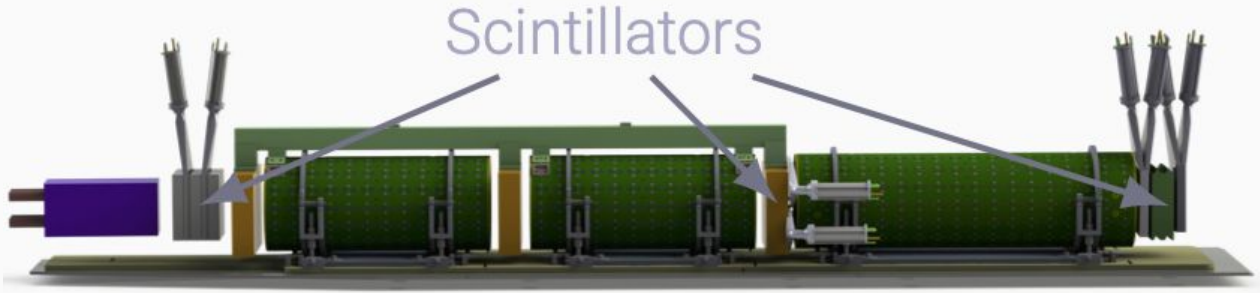




Scintillators

Trigger capabilities in 3 scintillator stations

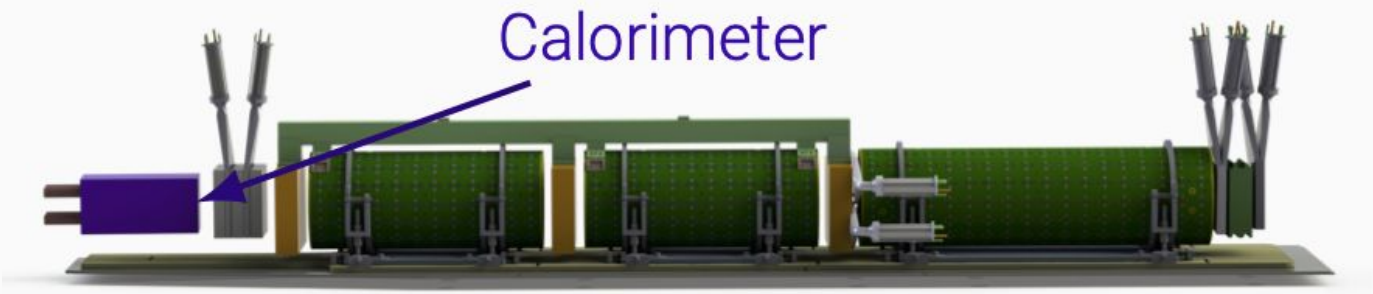
- ➔ High efficiency veto station for vetoing charged particles
- ➔ Efficiency generally measured to be >99.995% for a single layer
  - Based on cosmic data
  - Used a tracker station and three scintillators



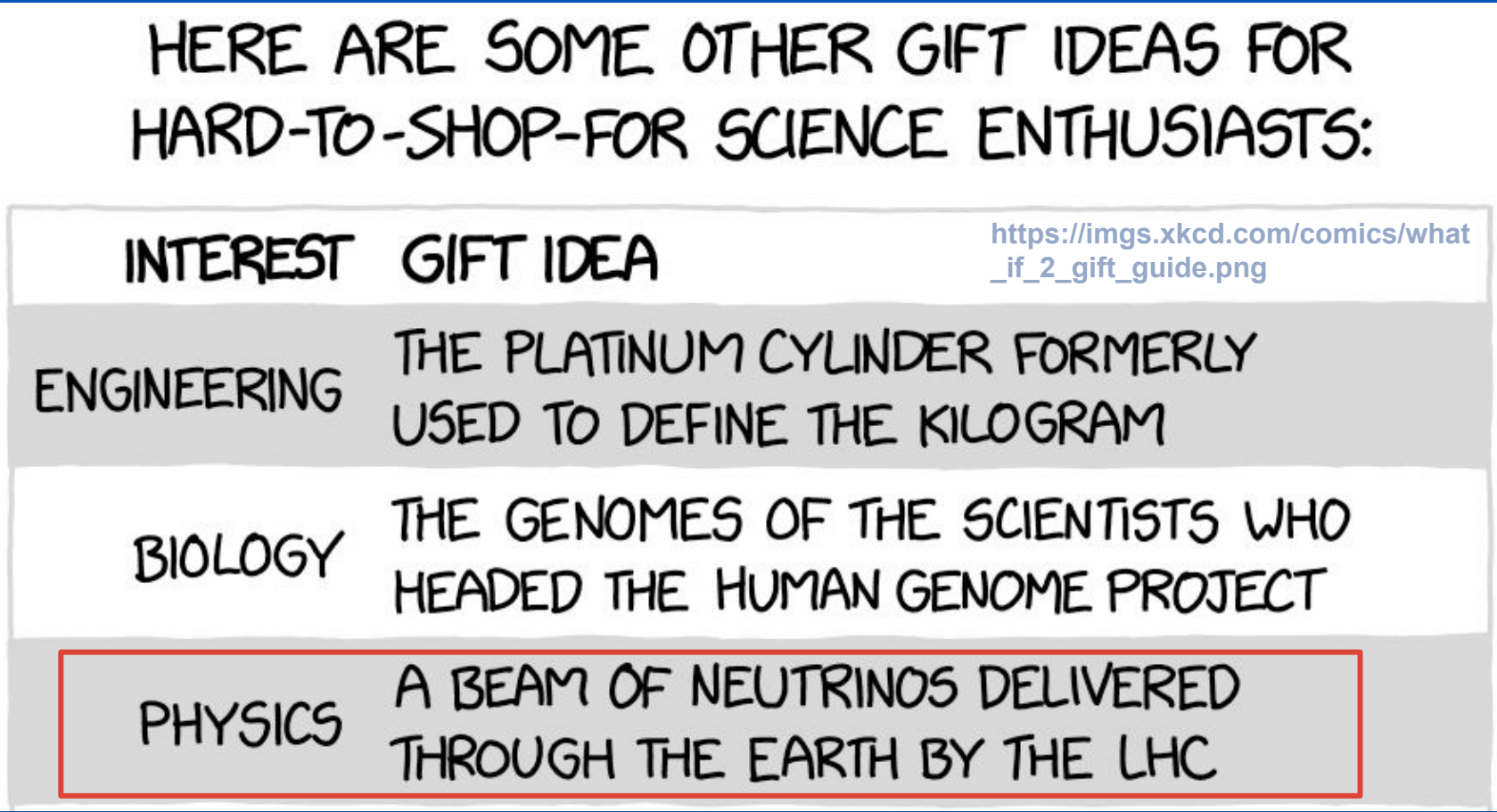
Calorimeter

Made from four calorimeter modules from LHCb outer ecal

- ➔ Readout using PMTs from LHCb with custom voltage divider base
- ➔ Consists of 66 layers of lead/scintillator
  - ◆ 25 radiation lengths in total
- ➔ Calibrated using LED calibration
- ➔ Energy resolution ~ 1% for TeV deposits



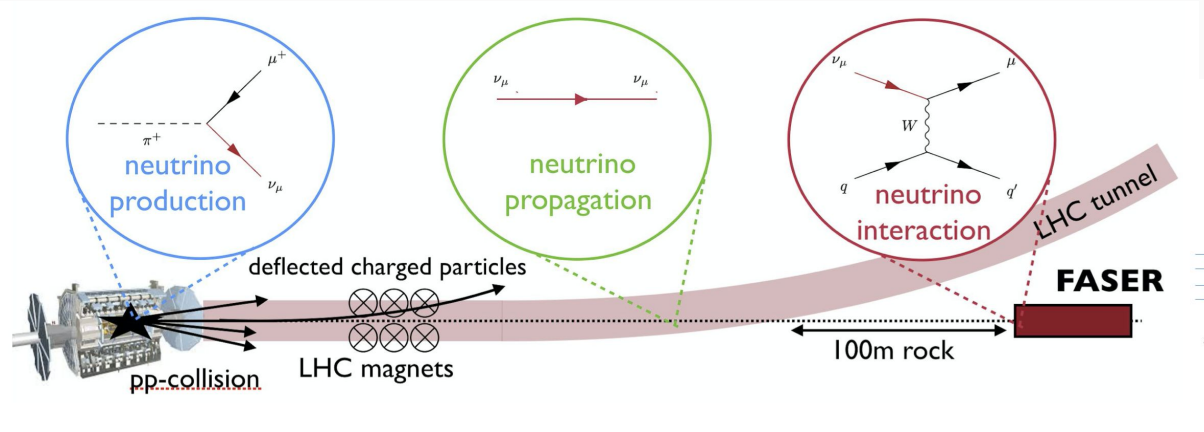
FASERν

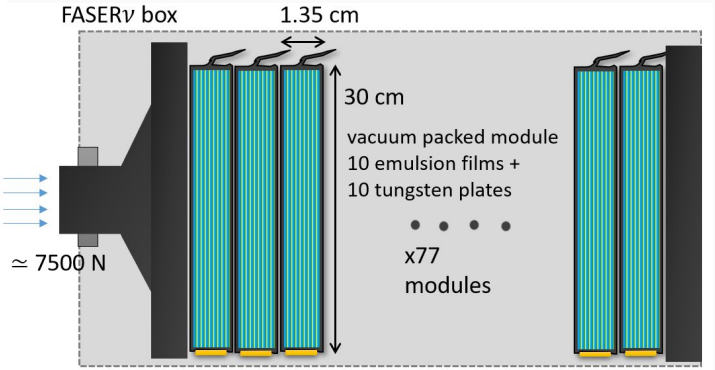

HERE ARE SOME OTHER GIFT IDEAS FOR HARD-TO-SHOP-FOR SCIENCE ENTHUSIASTS:
INTEREST
GIFT IDEA
https://imgs.xkcd.com/comics/what_if_2_gift_guide.png
ENGINEERING
THE PLATINUM CYLINDER FORMERLY USED TO DEFINE THE KILOGRAM
BIOLOGY
THE GENOMES OF THE SCIENTISTS WHO HEADED THE HUMAN GENOME PROJECT
PHYSICS
A BEAM OF NEUTRINOS DELIVERED THROUGH THE EARTH BY THE LHC

FASERν

Neutrinos are produced in abundance in the Standard Model

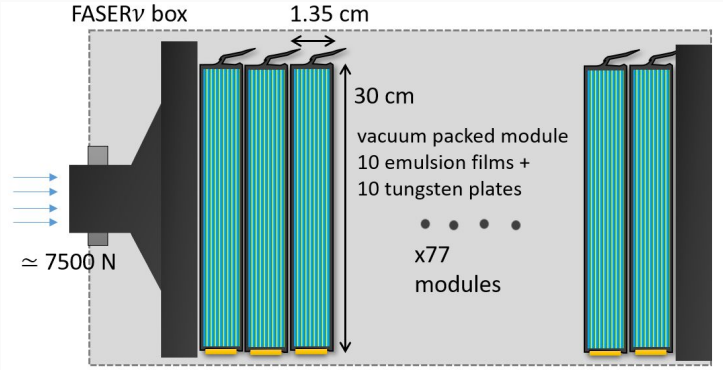
- ➔ Goal to measure neutrino cross-section in collider energy range 100 GeV - few TeV
- ➔ Additional detector at front of FASER
  - ~1 ton tungsten-emulsion stack





FASERν details

- Emulsion film made up of ~80μm emulsion layer on either side of 200μm thick plastic
- Emulsion gel active unit silver bromide crystals (diameter 200nm)
- Charged particle ionization recorded and can be amplified and fixed by chemical development of film
- Track position resolution ~50nm angular resolution ~0.35mrad
- But no time resolution!



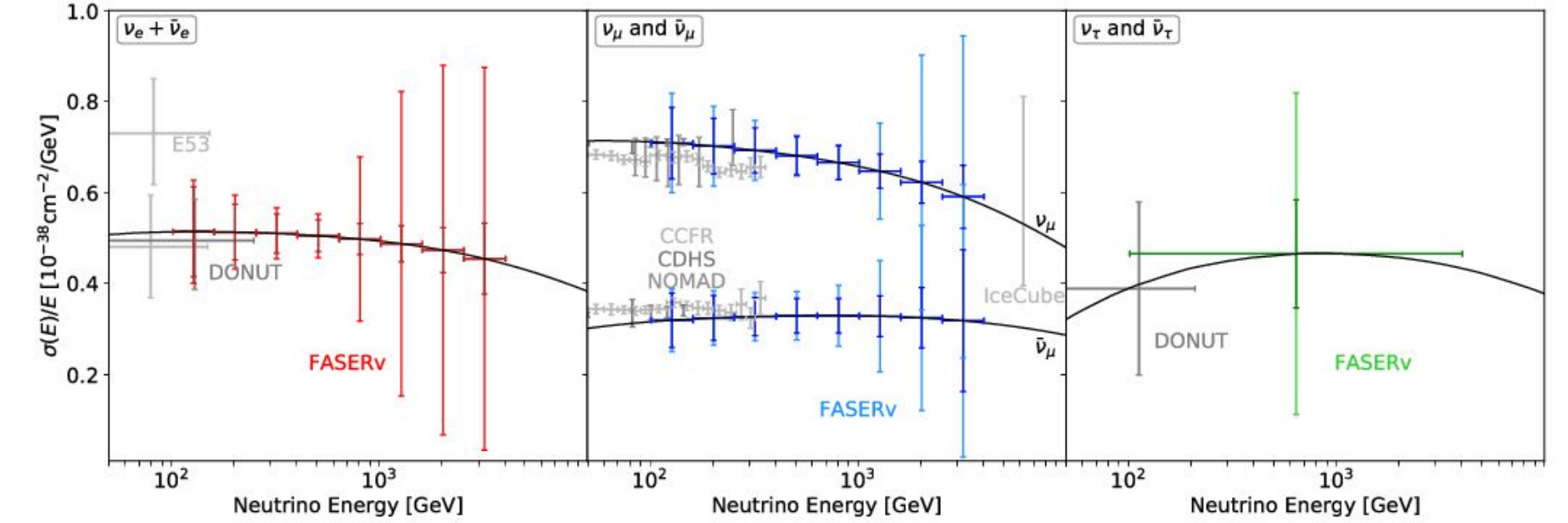
FASERν goals

A huge number of neutrinos produced in the LHC collisions (hadron decay) traverse the FASER location covering an unexplored neutrino energy regime.

➔ Primary physics goal – cross section measurements at high energy.
➔ Emulsion box exchanged every 10-50 fb−1.
➔ Uncertainty from neutrino production important

To provide inclusive charged current neutrino cross-section measurements, constraints on neutrino production in (forward) hadronic interaction models, valuable input to simulation tools related to neutrino event shape and kinematic.

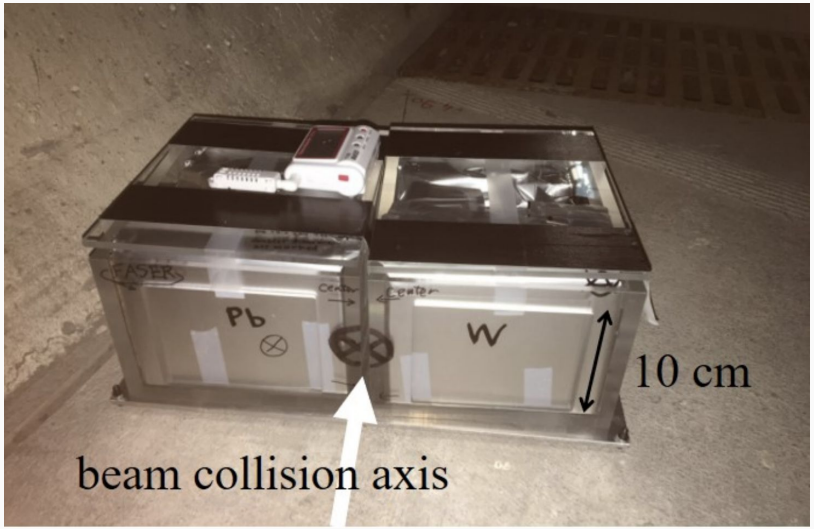
FASERν projected results



FASERν (Run 3) to measure ~1000s *νe*, ~10 000s *νμ* and ~10s *ντ* neutrinos in 250 fb^{-1} data.

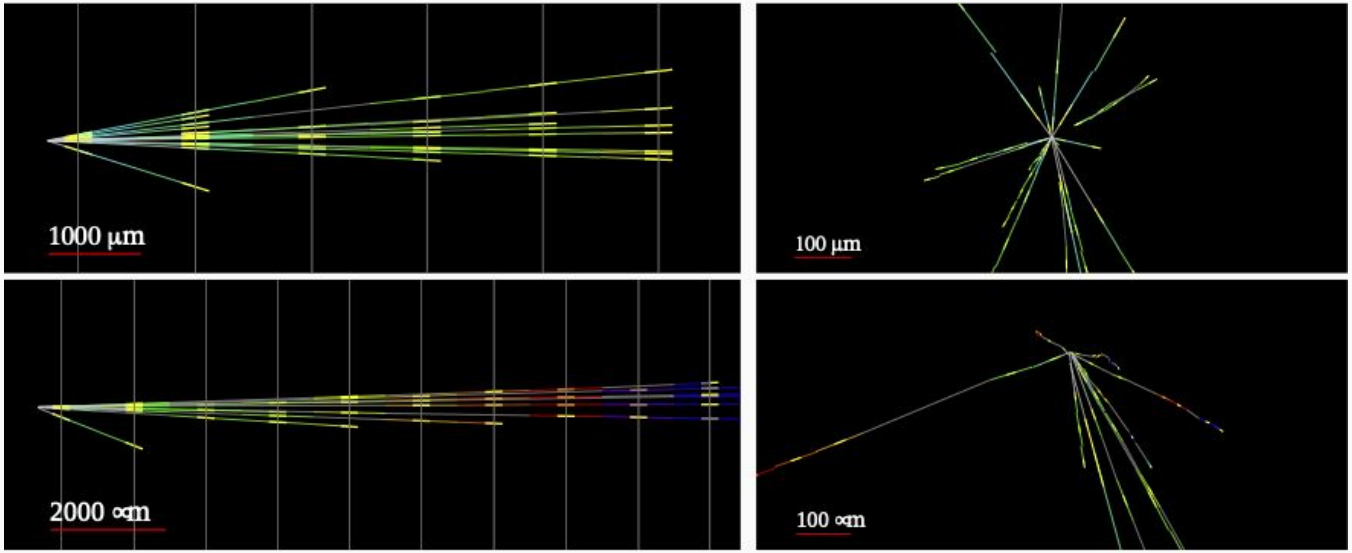
FASERν prototype results

- ~30 kg prototype built and installed at the right distance from ATLAS IP
  - Collected ~4 weeks of collision data in 2018
  - Exposed to 12 fb^{-1}
- Using BDT to classify between signal and background events
  - Background consists of neutral hadrons produced from muon interactions in the rock in front of the detector



FASERν prototype results

- ➔ Determined 6 neutrino candidates with 3.3 events expected
- ➔ 2.7 sigma significance of rejecting the no-neutrino hypothesis

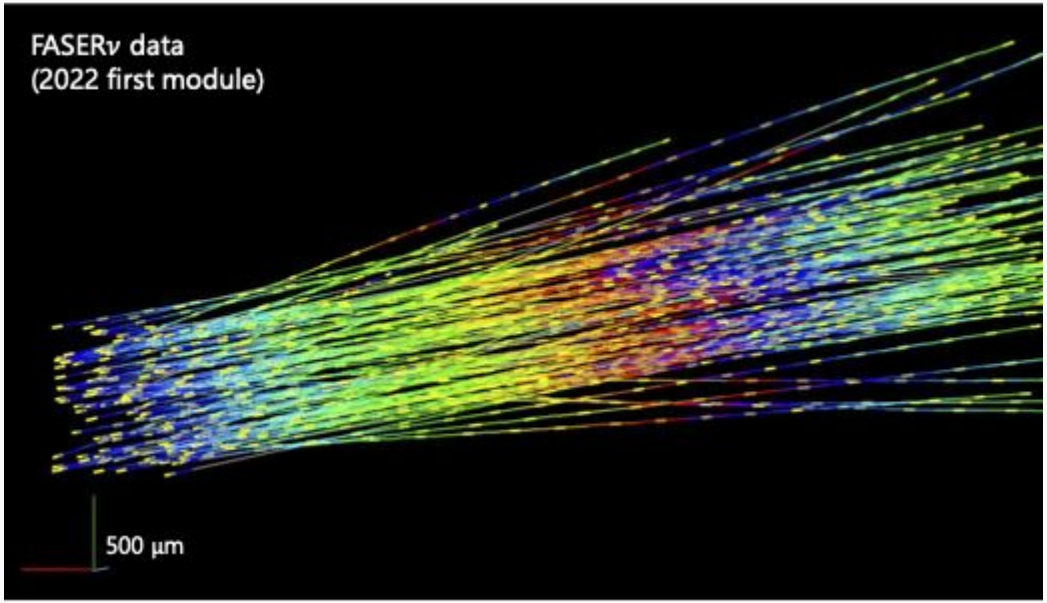


More details: First neutrino interaction candidates at the LHC (arXiv:2105.06197)

FASERν results

➔ 3 FASERv emulsion installations so far: 1st box of 0.5 fb−1, 2nd box of 10 fb−1 and 3rd box of 30 fb−1 exposure.

Reconstructed > 1 GeV tracks in 1mm x 1 mm of 20 emulsion layers of first installed module (0.5 fb^{-1}). Measured track density of $1.2 \times 10^4/cm2$.



FASERν prototype results

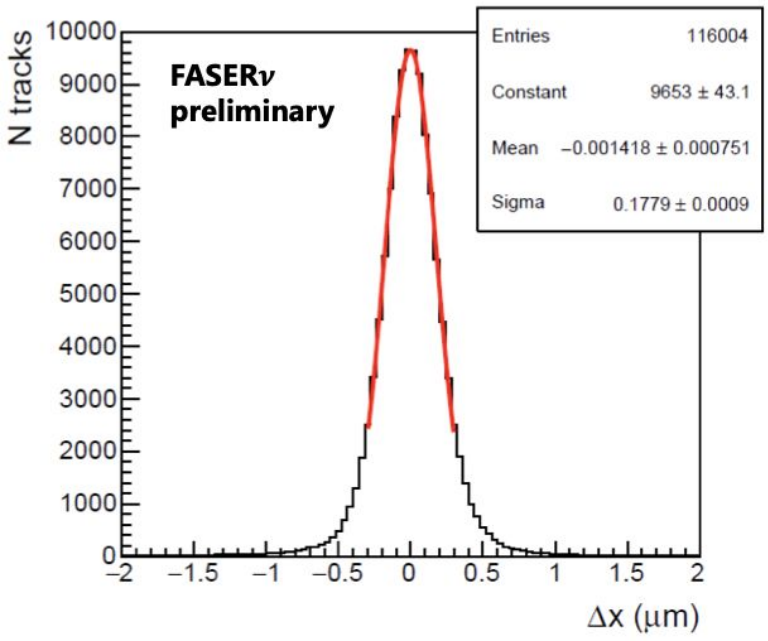
➔ 3 FASERv emulsion installations so far: 1st box of 0.5 fb−1, 2nd box of 10 fb−1 and 3rd box of 30 fb−1 exposure.

Track measurements of first module of 0.5 *fb*−1 showed excellent track resolution.

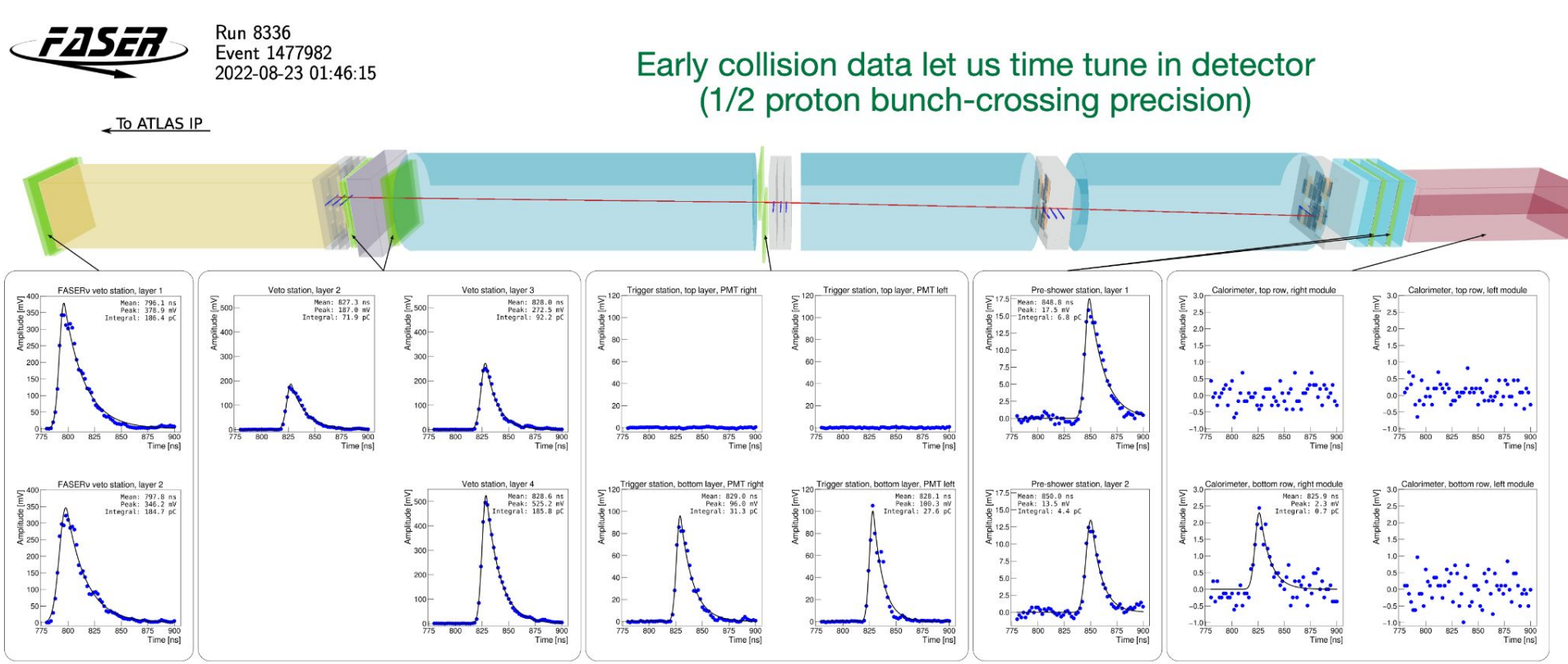
Measured track resolution in

Δx of ~0.2 μm in agreement with

sub-μm target resolution

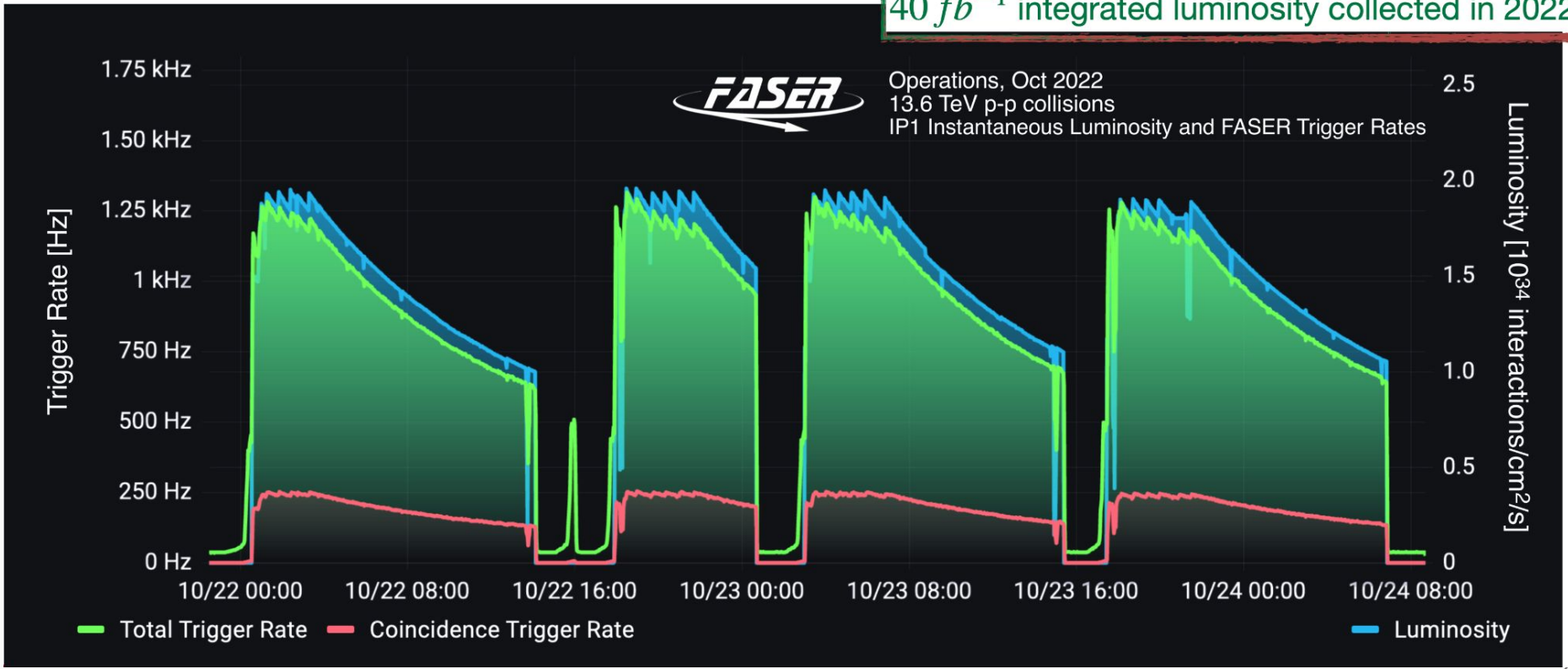


FASER first Run 3 results



FASER top physics rate

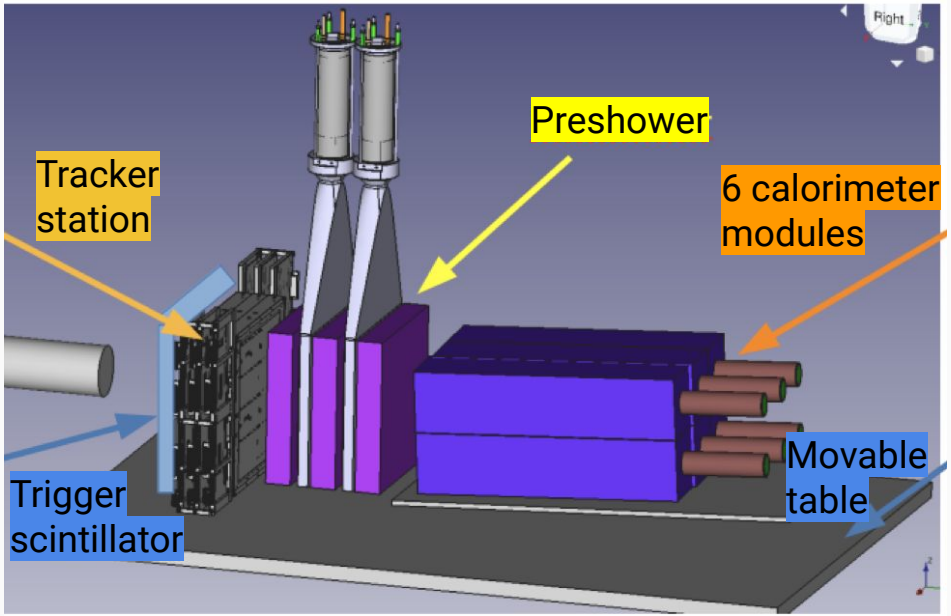
$40\ fb^{-1}$ integrated luminosity collected in 2022



FASER data analysis

Summer 2021 Test Beam Data Analysis

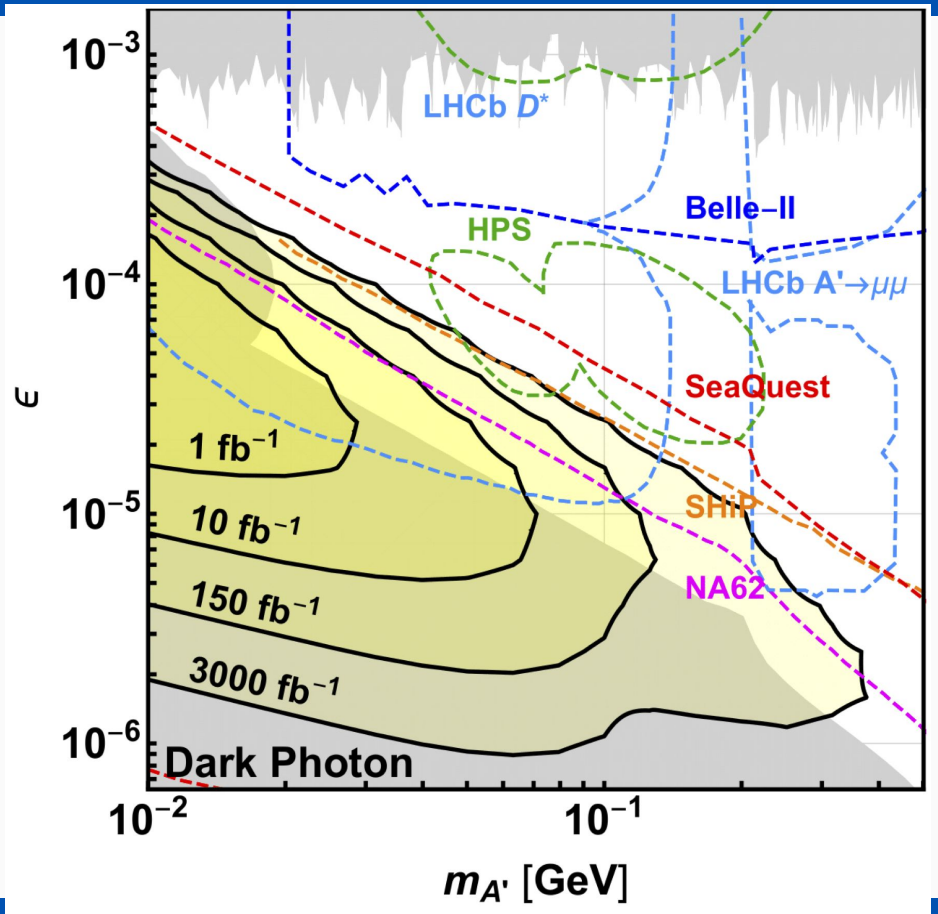
- ➔ Dedicated Test Beam at CERN SPS last year to obtain calibration data for calorimeter modules.
- ➔ Test Beam data also used to study tracker alignment, data vs simulation, particle identification capabilities.



FASER projections

- ➔ Collecting data for full Run 3
- ➔ Continuously running
  - ◆ Also when beam is off
  - ◆ To test remote operation and monitoring
- ➔ Successful triggers with scintillator coincidence
- ➔ Tracker performance matching surface tests
- ➔ Automated DQ/monitoring

FASER is covering large unexplored section of phase-space



Summary

- ➔ FASER has been installed in the LHC tunnel and is running for Run 3
- ➔ Commissioning in tunnel has gone smoothly
- ➔ First physics results from neutrino pilot run published

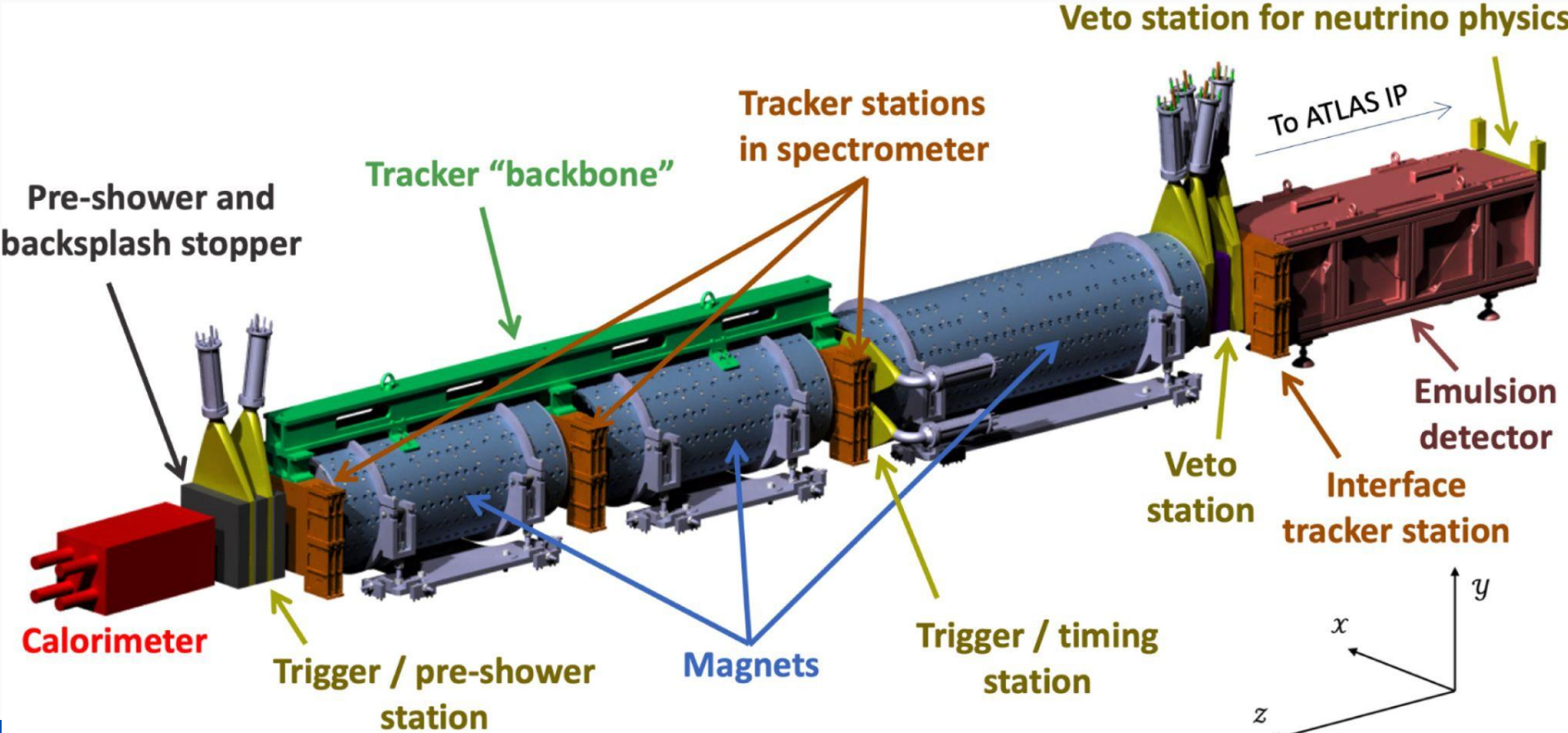
Around 40 fb−1 integrated lumi of data collected in 2022, with sensitivity to dark photons in unconstrained regions of parameter space.

- ➔ Getting ready to provide first physics analysis results for next year's winter conferences.
- ➔ Already thinking about possible upgrades → Listen to Juan Rojo's talk next!

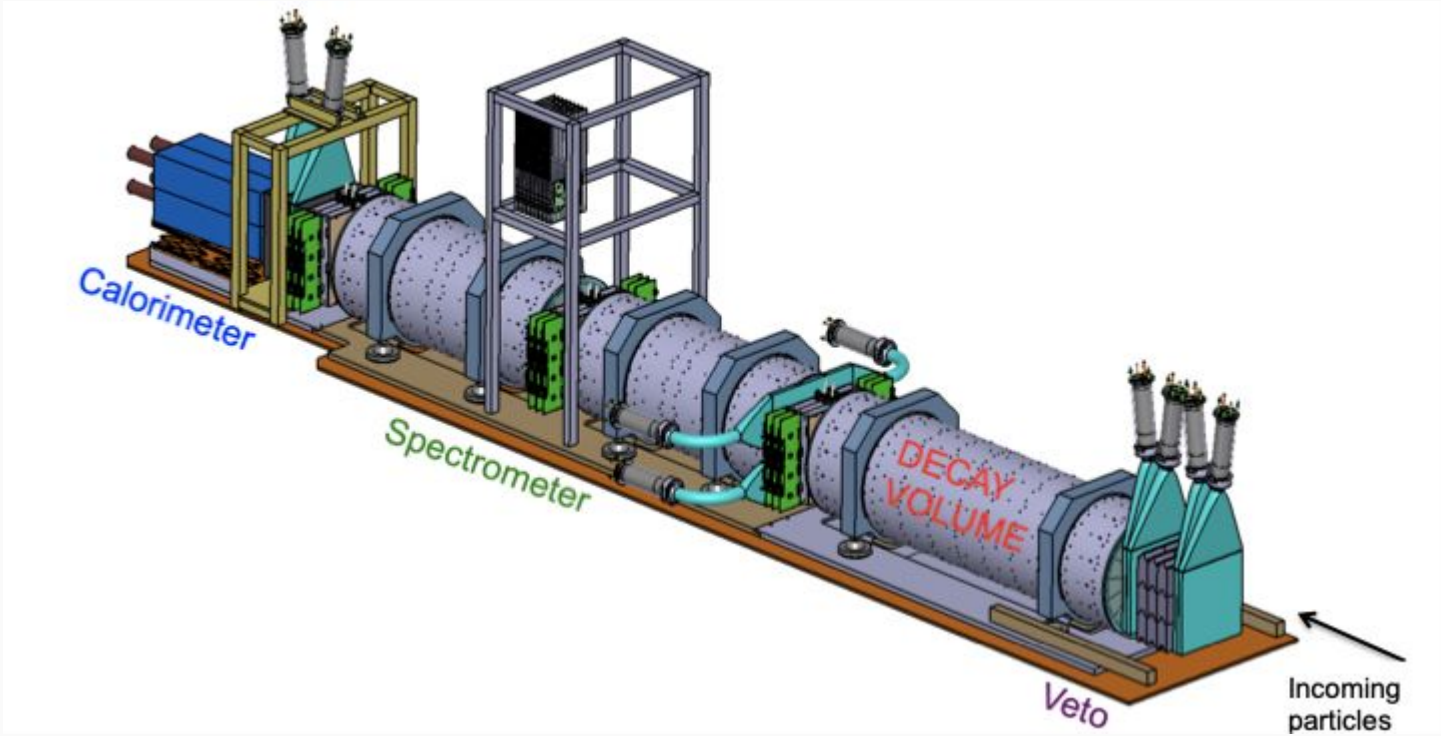
Thanks to the Heising-Simons foundation, Simons Foundation and CERN for their support

Back-up

FASER schematic



FASER schematic

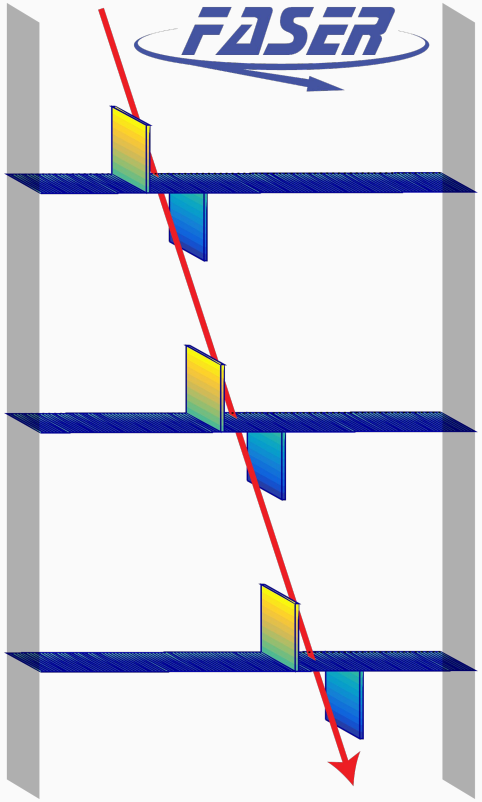


FASER offline development

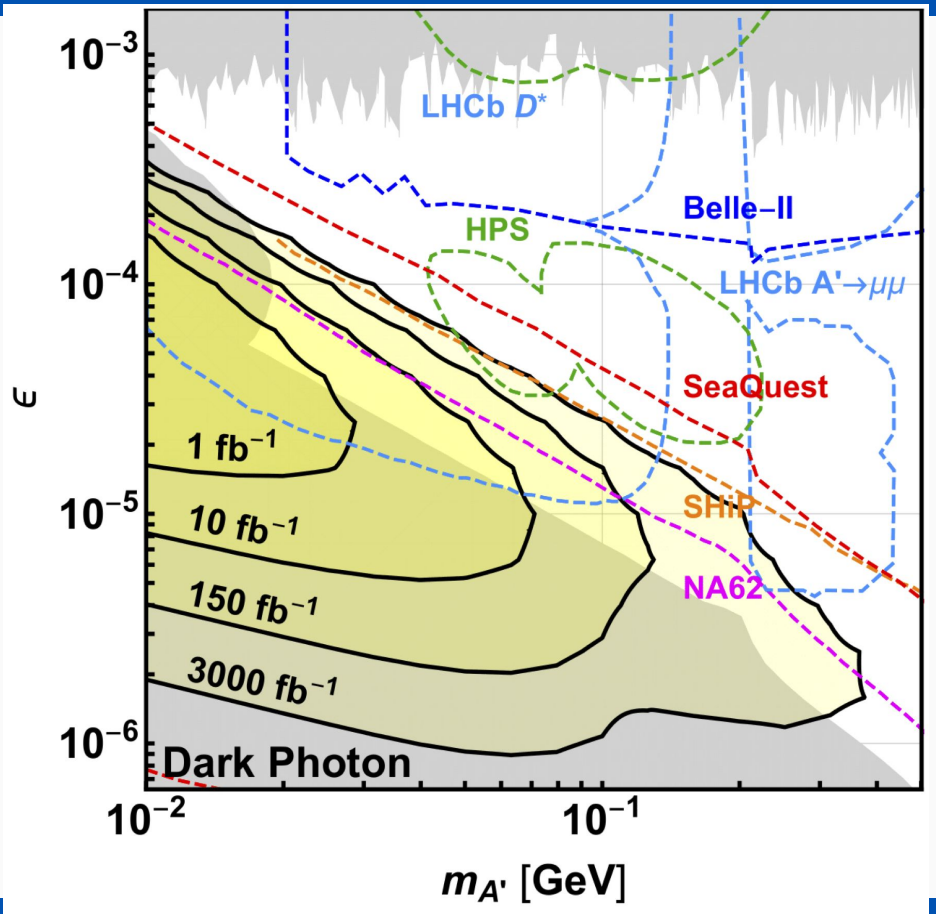
- ➔ Detector simulation well advanced
  - ◆ Recently added cosmic generator
  - ◆ FaserNu detector geometry included
- ➔ Reconstruction code development
  - ◆ ACTS-based tracking code making progress
  - ◆ Fast segment finder for cosmics also developed
- ➔ Automated production system
  - ◆ Implementing light-weight job scheduling with Redis rq
- ➔ IFT (FaserVersion = FASER-02) is fully working
  - ◆ Submission of calibration jobs, reco, monitoring, streaming

FASER cosmics

- ➔ Single station tracks
  - Go through three layers of the station
  - Triggered by nearby scintillator
  - Rate around 1/min
- ➔ Double station tracks
  - Couple per day
- ➔ Triple station tracks
  - Expected to be very rare
  - First candidates observed



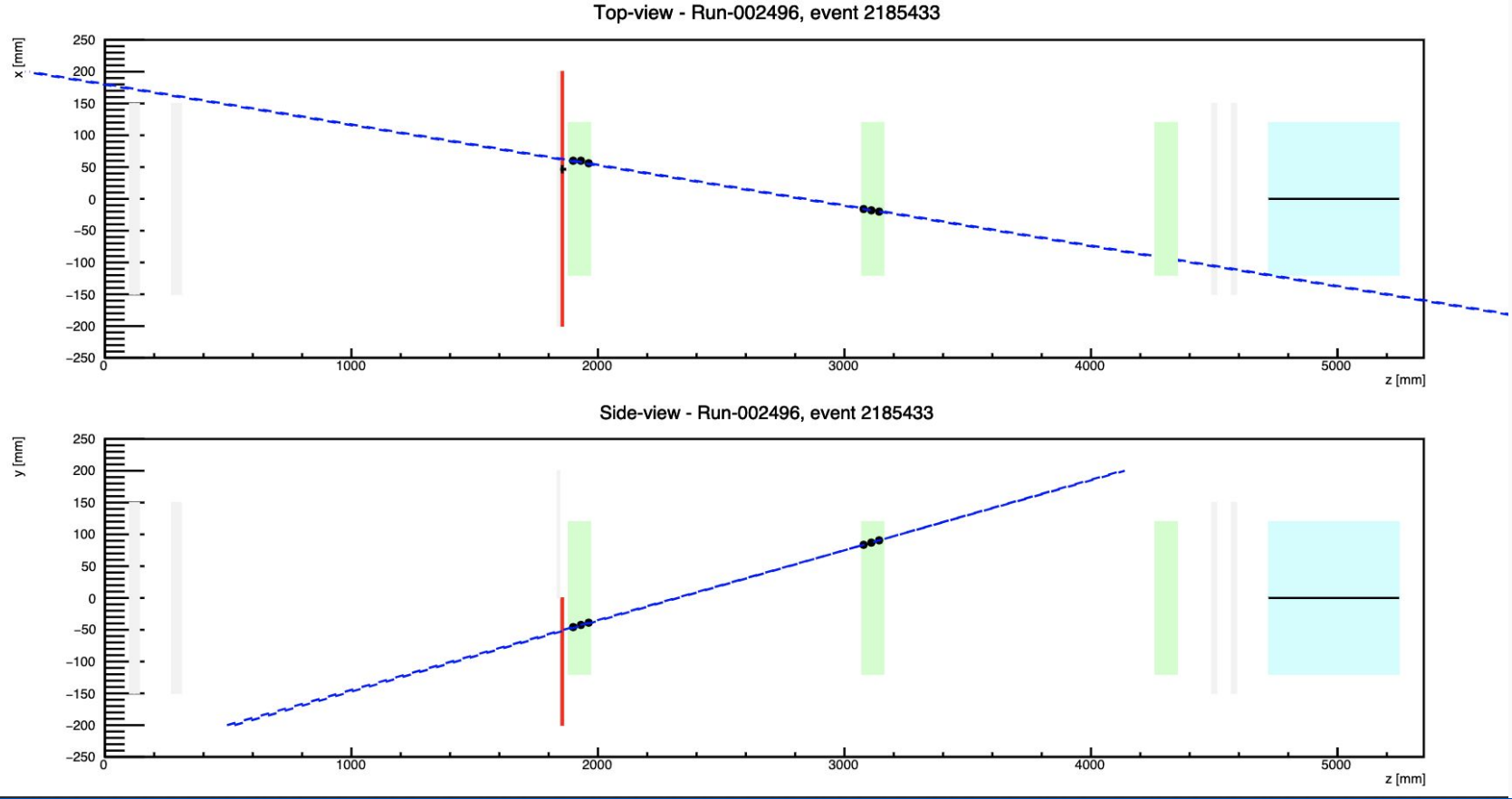
Faser projections



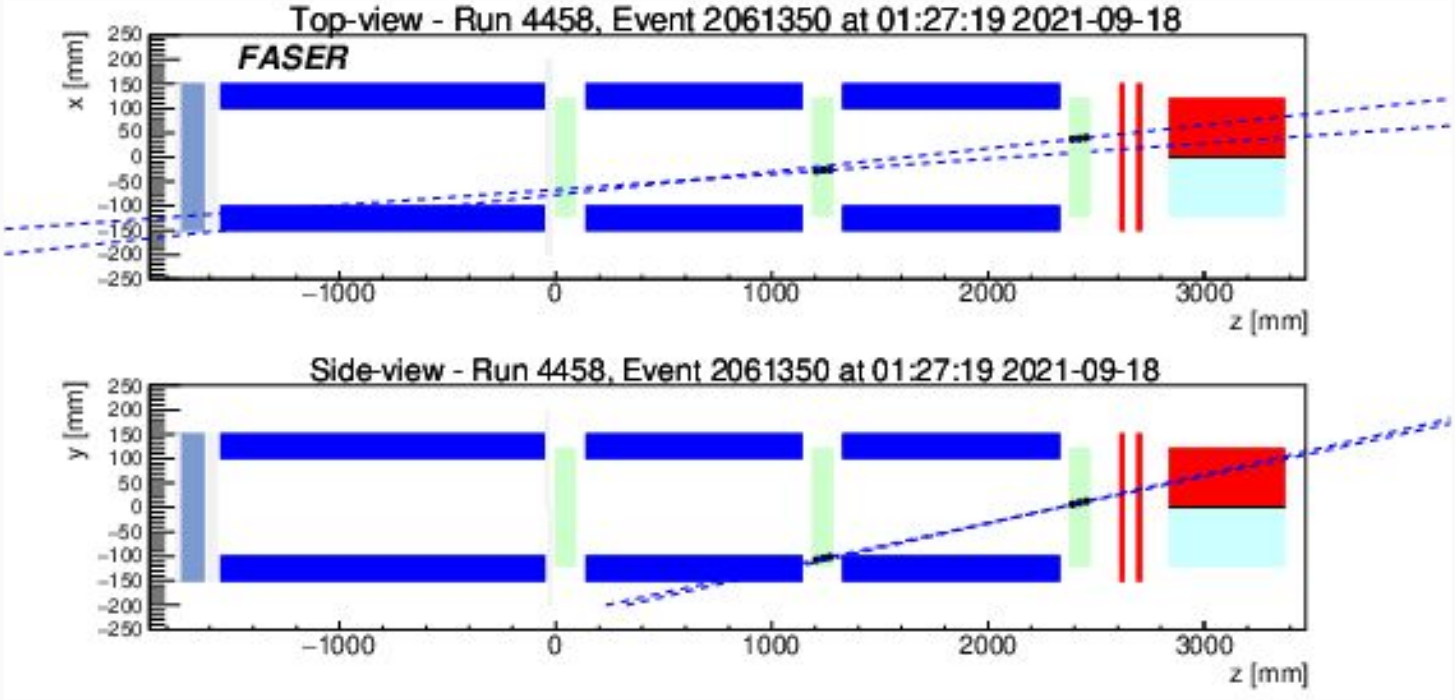
FASER takes advantage of the the huge number of light mesons (π_0, η,..) that are produced at the LHC, predominantly in the very forward direction.

Run 3 (0.15/ab) will produce a huge number of π_0s in FASER angular acceptance. Even with large suppression ($\epsilon^2 \sim 10^{-8} - 10^{-10}$ for relevant region of parameter space) can still have very large number of dark photons produced. **LHC can be a dark photon factory!**

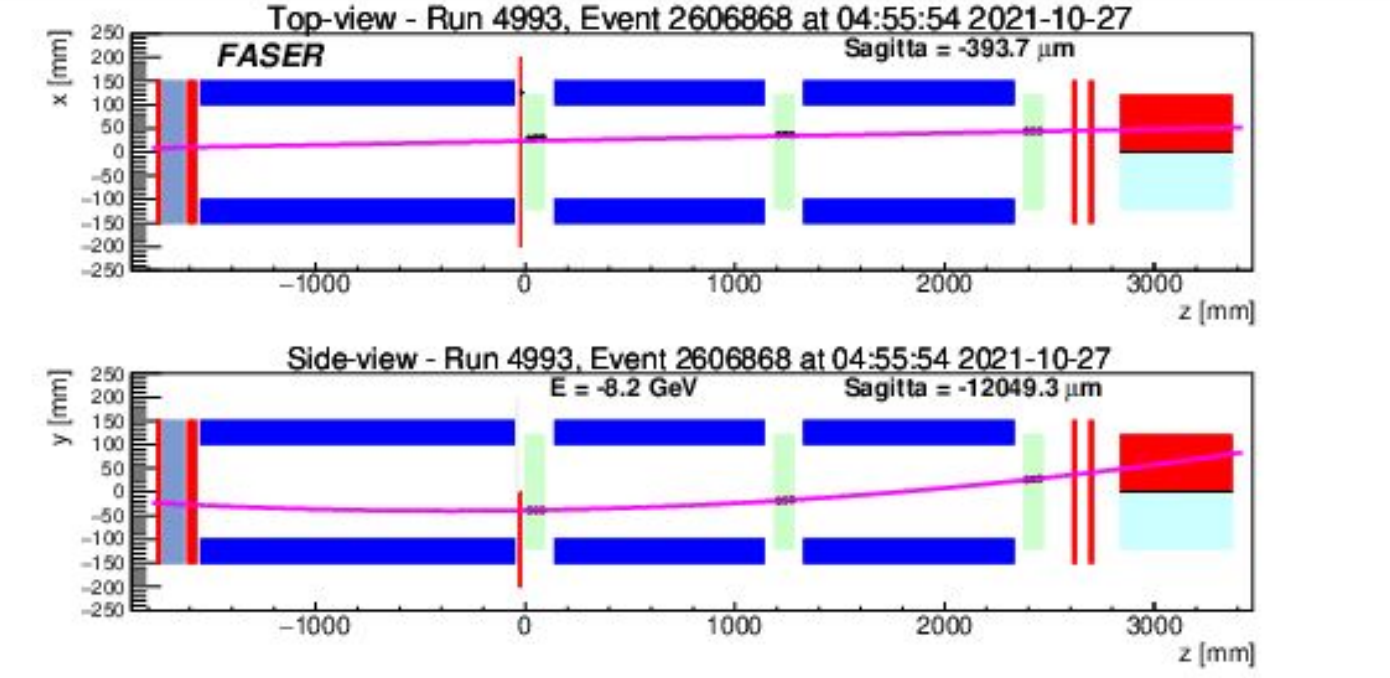
FASER cosmics



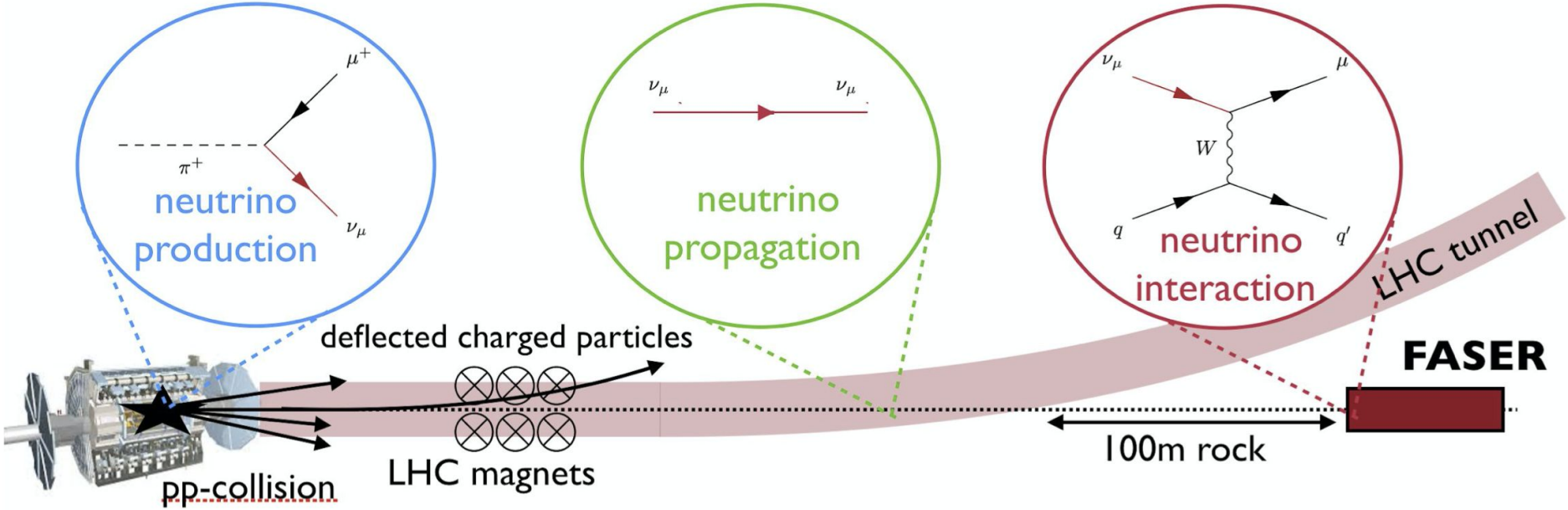
FASER cosmics



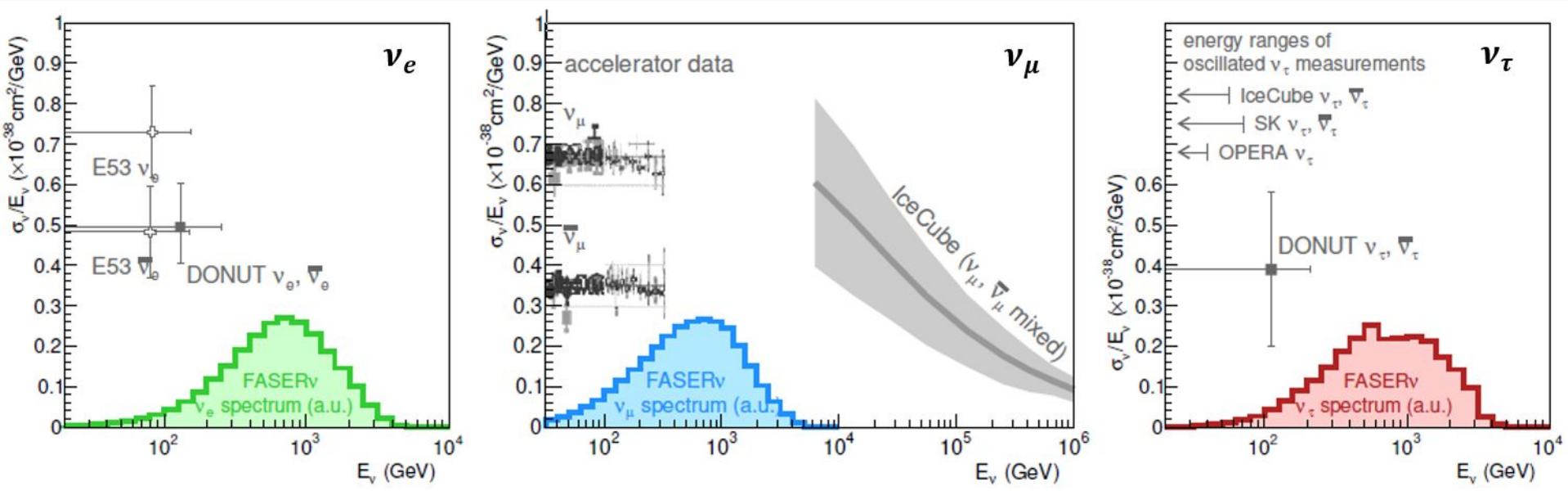
FASER data


Top-view - Run 4993, Event 2606868 at 04:55:54 2021-10-27
FASER
Sagitta = -393.7 μm
x [mm]
z [mm]
Side-view - Run 4993, Event 2606868 at 04:55:54 2021-10-27
E = -8.2 GeV
Sagitta = -12049.3 μm
y [mm]
z [mm]

FASERnu


μ^+
π^+
ν_μ
neutrino production
ν_μ
ν_μ
neutrino propagation
ν_μ
μ
W
q
q'
neutrino interaction
LHC tunnel
deflected charged particles
FASER
pp-collision
LHC magnets
100m rock

FASERnu


ν_e
E53 ν_e
E53 $\bar{\nu}_e$
DONUT ν_e, $\bar{\nu}_e$
FASERν
ν_e spectrum (a.u.)
σ_ν/E_ν ($\times 10^{-38}$ cm^2/GeV)
E_ν (GeV)
ν_μ
accelerator data
ν_μ
$\bar{\nu}_\mu$
IceCube (ν_μ, $\bar{\nu}_\mu$ mixed)
FASERν
ν_μ spectrum (a.u.)
σ_ν/E_ν ($\times 10^{-38}$ cm^2/GeV)
E_ν (GeV)
ν_τ
energy ranges of
oscillated ν_τ measurements
IceCube ν_τ, $\bar{\nu}_\tau$
SK ν_τ, $\bar{\nu}_\tau$
OPERA ν_τ
DONUT ν_τ, $\bar{\nu}_\tau$
FASERν
ν_τ spectrum (a.u.)
σ_ν/E_ν ($\times 10^{-38}$ cm^2/GeV)
E_ν (GeV)