Recent results from the FASER experiment

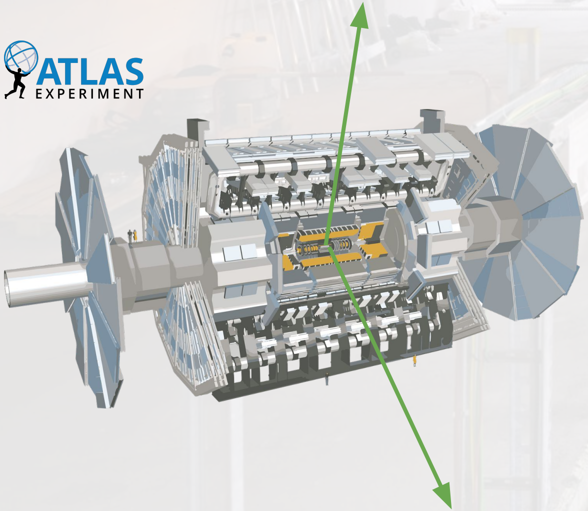
Michaela Queitsch-Maitland
(University of Manchester)

MPI@LHC 20-24th November, Manchester

The University of Manchester

Forward at the LHC

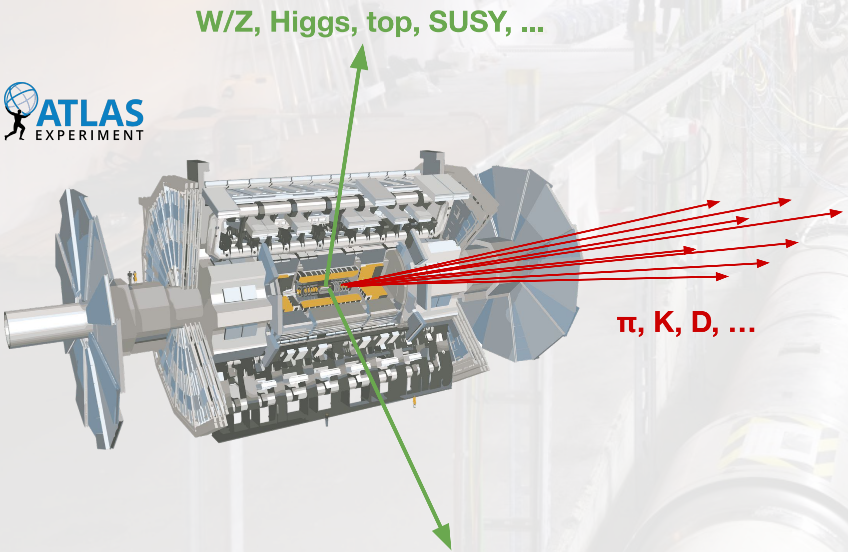
Experiments at the LHC designed to search for **heavy** and **strongly coupled** particles



Produced **isotropically** at **high p_T**

Forward at the LHC

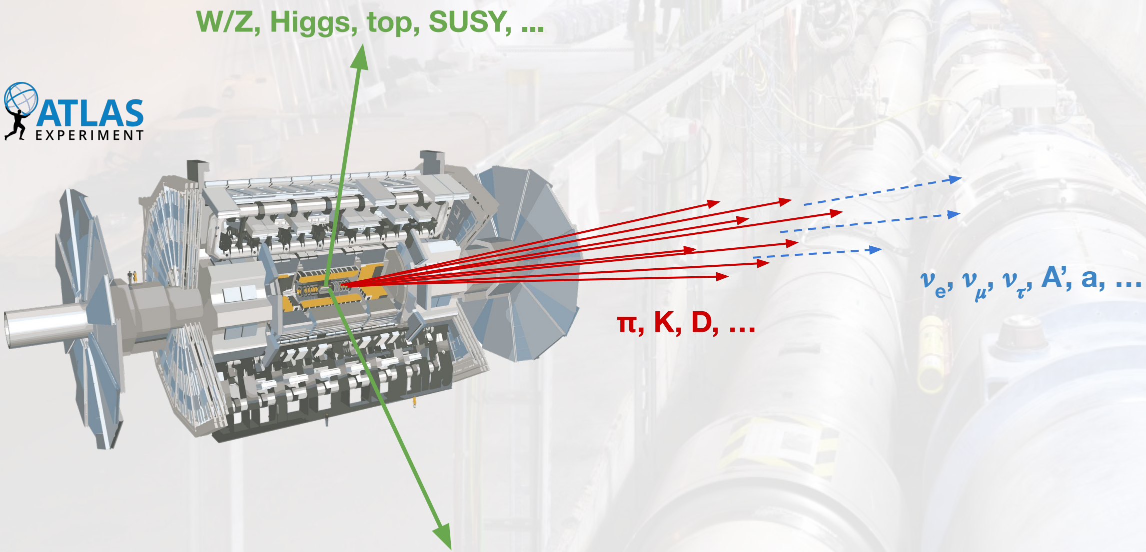
But: high rate of **light hadrons** also produced in *non-instrumented* **far-forward (low p_T)** region



1% of **pions** produced in forward ~10^{-6}% of solid angle

Forward at the LHC

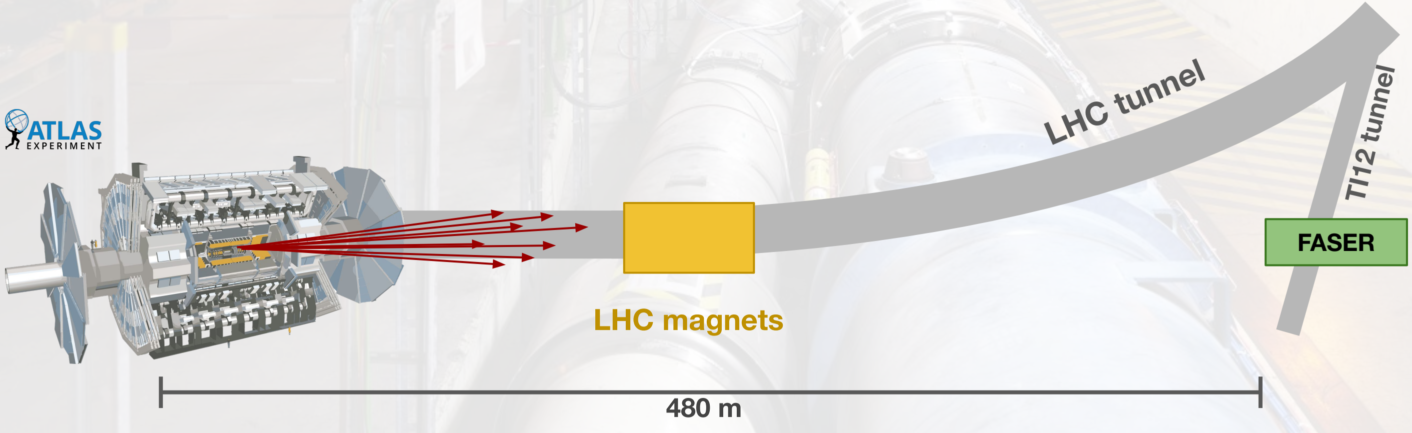
Light, **weakly coupled** particles produced in proliferation in forward region.



Neutrinos of all flavours, and **BSM** particles

ForwArd Search ExpeRiment (FASER)

- FASER is a new, small, experiment at the LHC:
  - In TI12 located **480 m** from the ATLAS interaction point
    Aligned with the ATLAS collision **Line of Sight**
  - **Low background** environment: LHC magnets deflect charged particles (e.g. muons); shielded by 100 m of rock/concrete
  - **Maximal neutrino flux**



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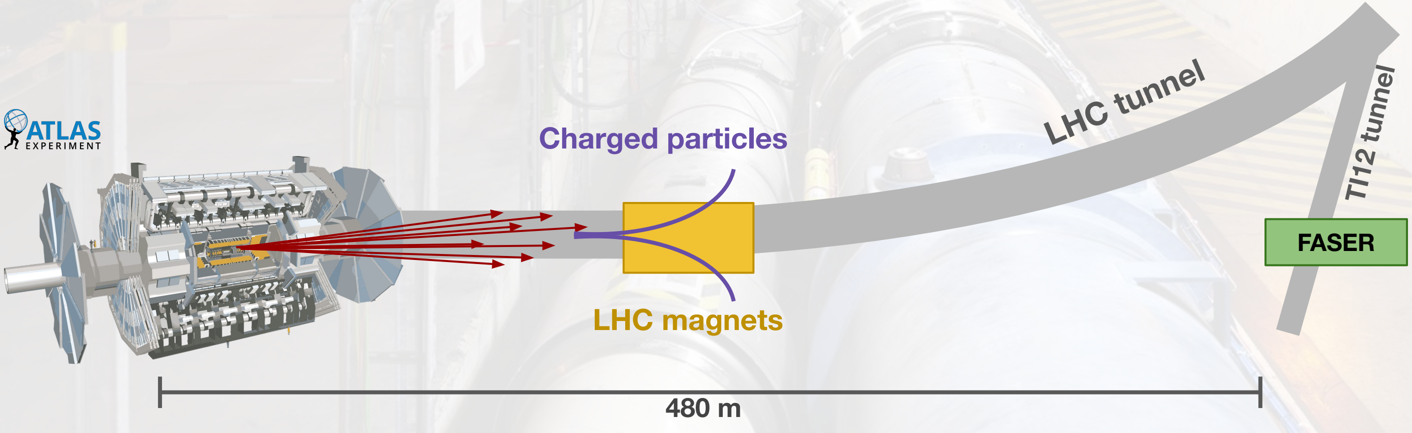

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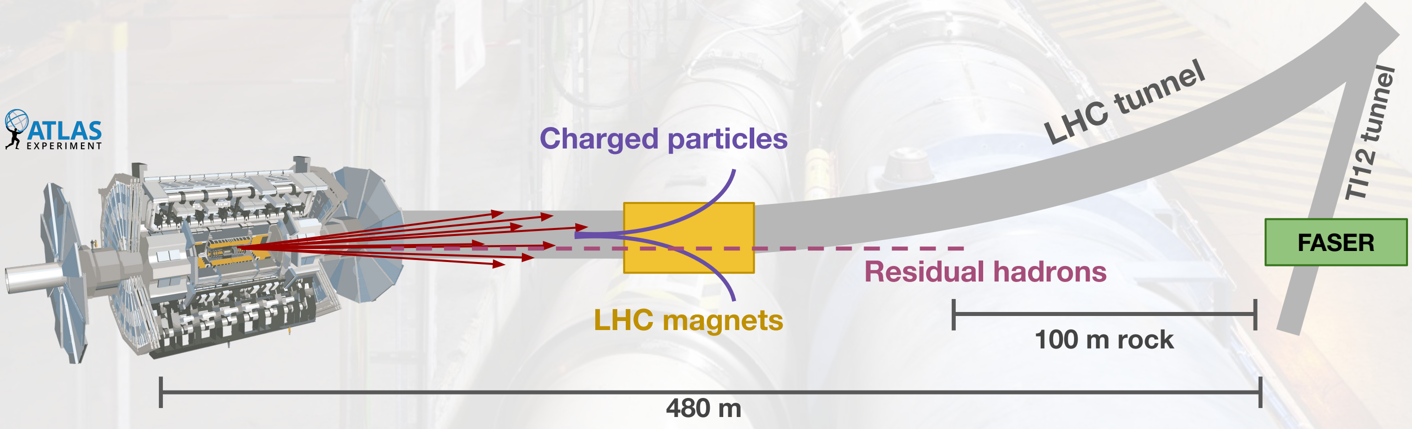

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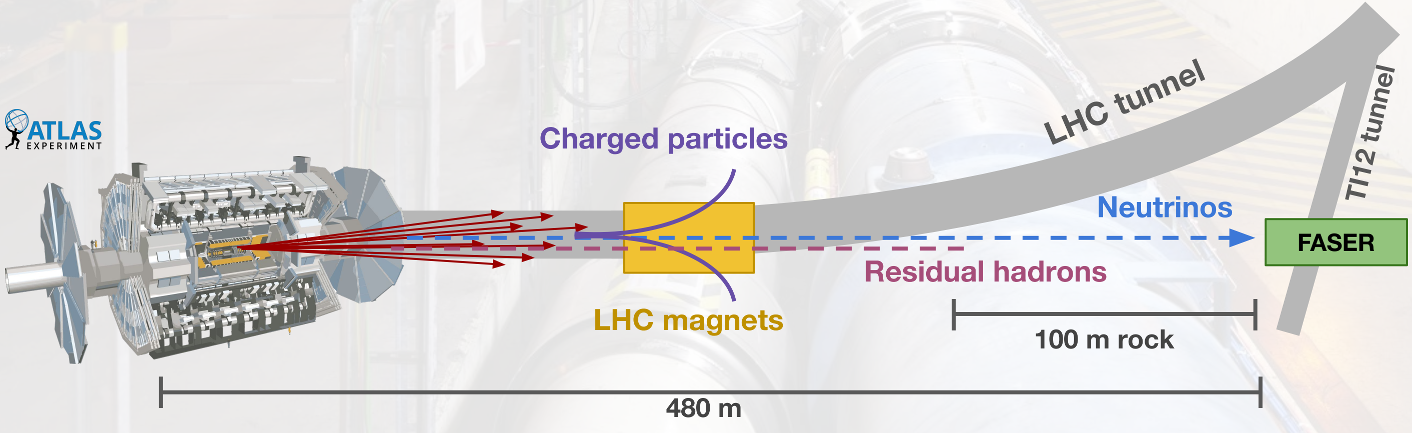
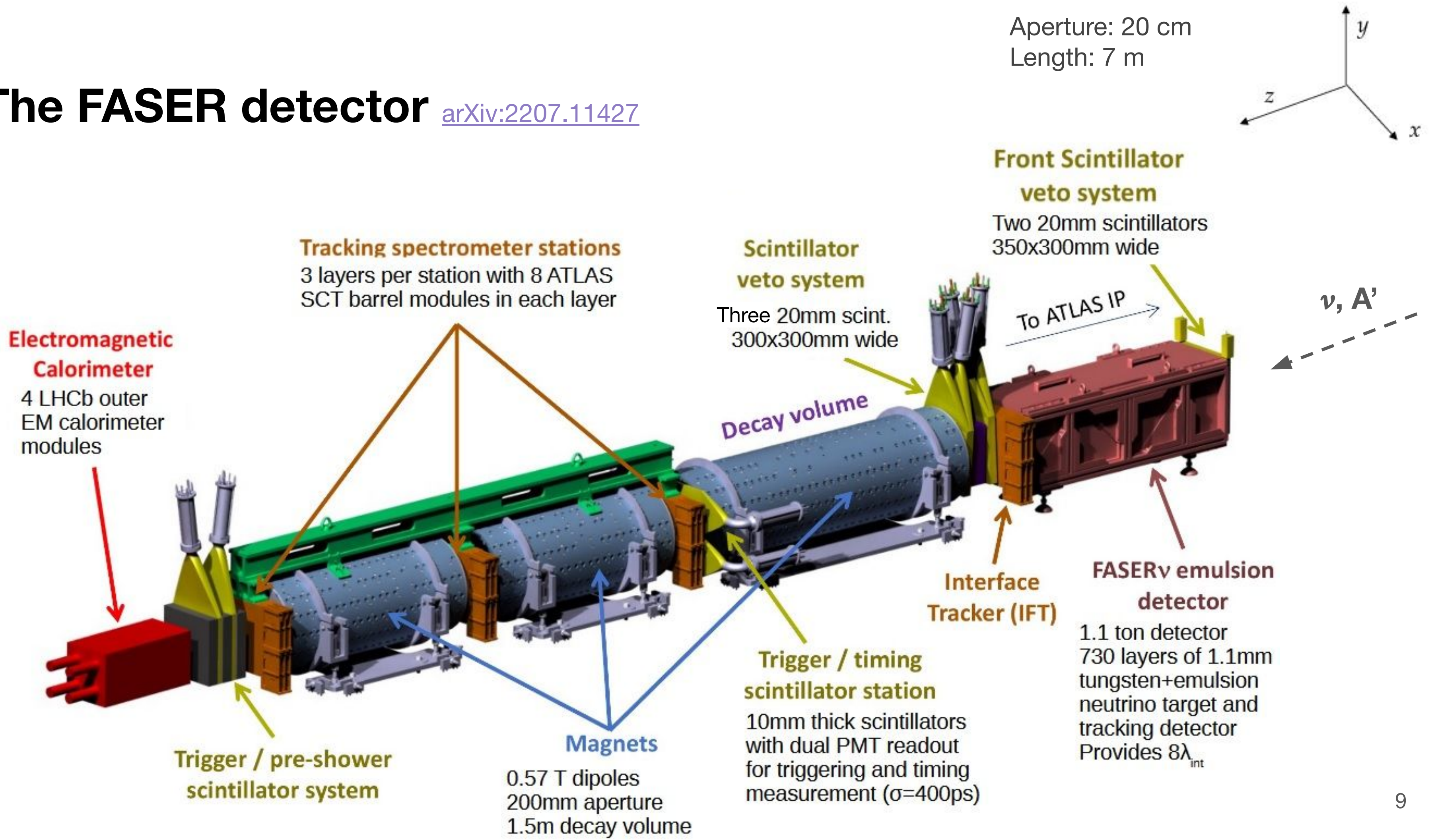


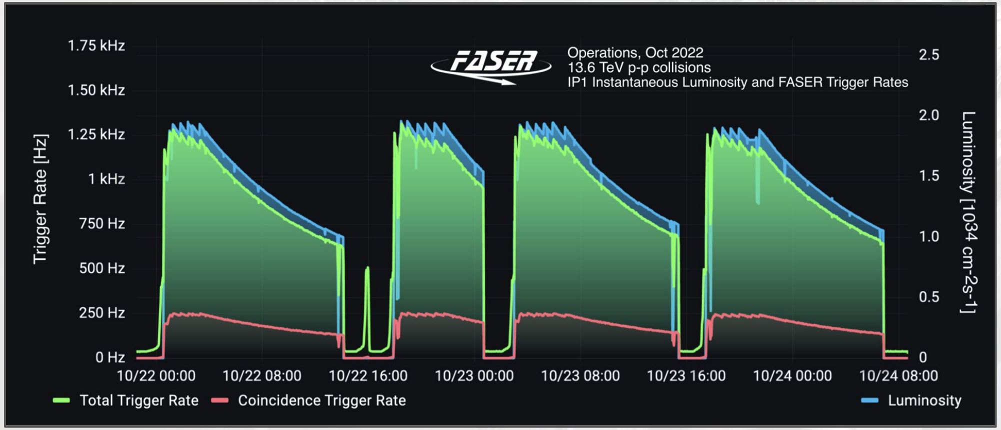
Aperture: 20 cm
Length: 7 m

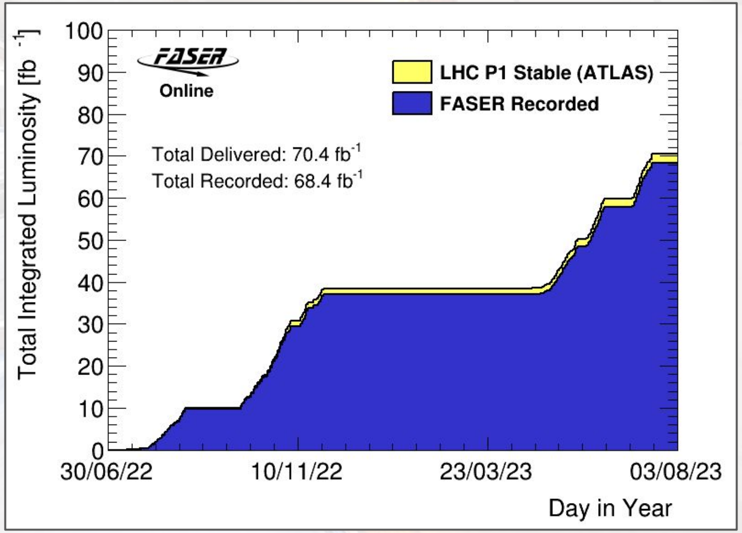
The FASER detector arXiv:2207.11427



FASER operations

- Detector was constructed and installed 2019–2021.
- Successfully collected 35 fb^{-1} in 2022 and 33 fb^{-1} in 2023.
- Data taking efficiency > 97%.

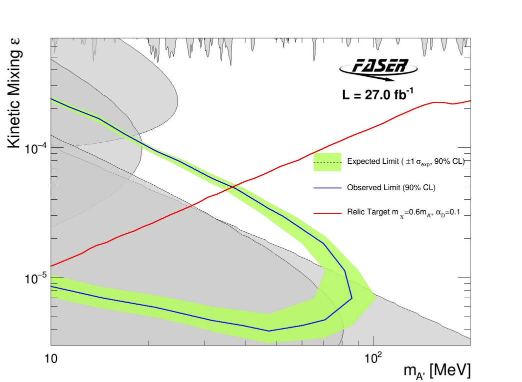




ForwArd Search ExpeRiment (FASER)

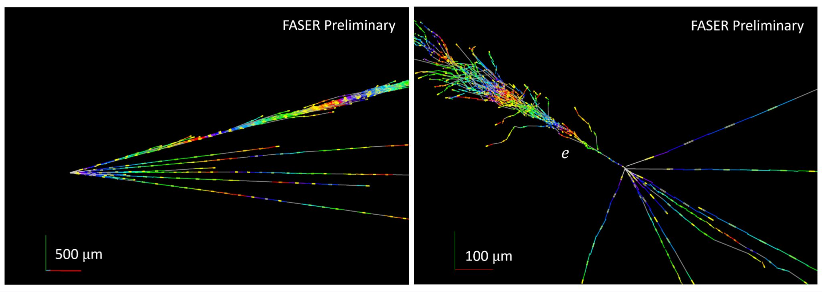
FASER physics

Weakly interacting new particles
- Dark photons
- ALPs
- Dark Higgs



arXiv:2308.05587

Collider neutrinos



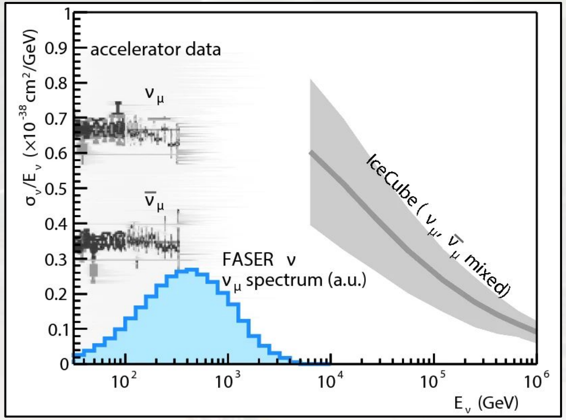
Focus of this talk

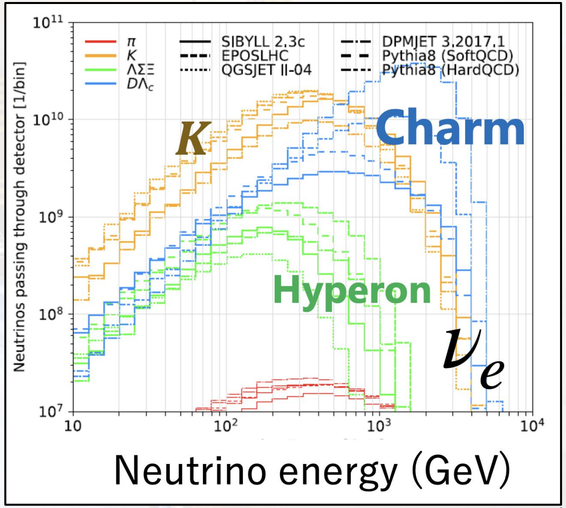
Why study collider neutrinos?

1. Neutrino interactions (all flavours) at **unexplored TeV energies**

2. Probe of **forward hadron production**, novel inputs for:
   - QCD (gluon PDFs at low-x, intrinsic charm)
   - Astroparticle physics (collider counterpart of high-energy cosmic rays interactions: cosmic ray muon puzzle)

3. Probe of **hadron structure** (proton/nuclear PDFs)





Forward hadron production and nuclear PDFs

Neutrino **production** at the ATLAS IP probes **forward hadron production**

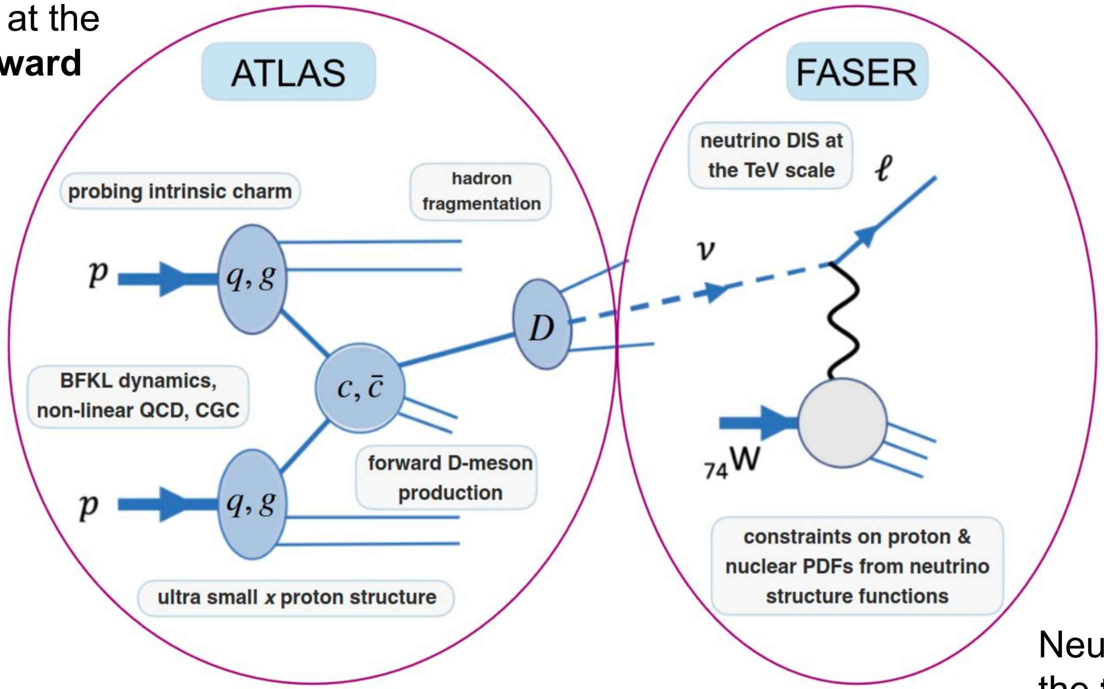


Figure adapted from: [J. Phys. G 50 (2023) 3, 030501]

Neutrino **interaction** with the **target** (Deep Inelastic Scattering) probes the **proton/nuclear PDF**

Neutrinos at FASER

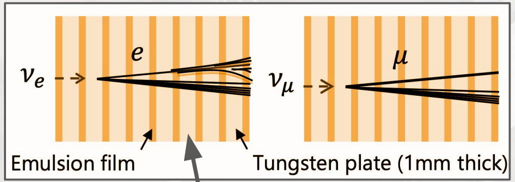
Two methods of detecting collider neutrinos with FASER:

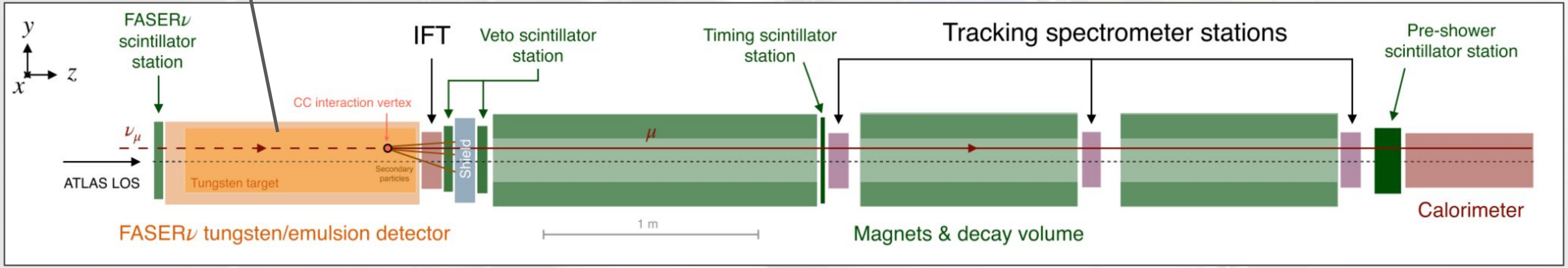
1) Emulsion detector:

- detect **all neutrino flavours**
- excellent spatial resolution
- slow (each film must be scanned, digitised, and processed)

2) Electronic spectrometer:

- fast analysis (only using electronic components of detector)
- separate anti-neutrino/neutrino (muon charge)
- can study **only muon neutrinos**

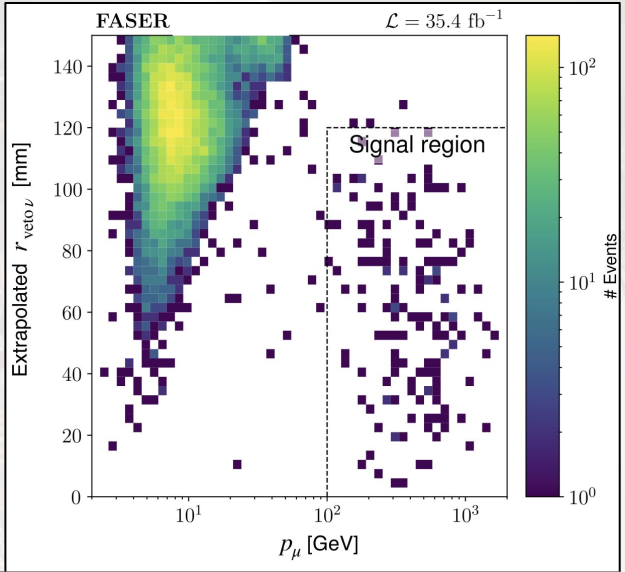


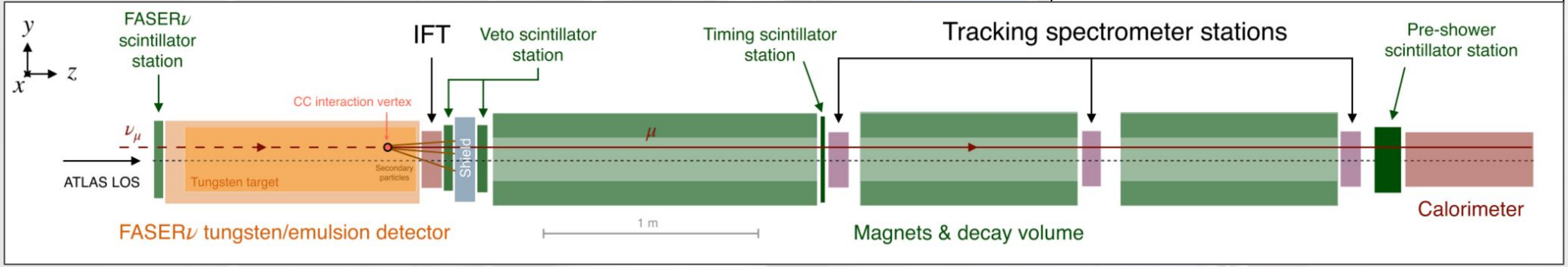


PhysRevLett.131.031801

First direct observation of collider neutrinos

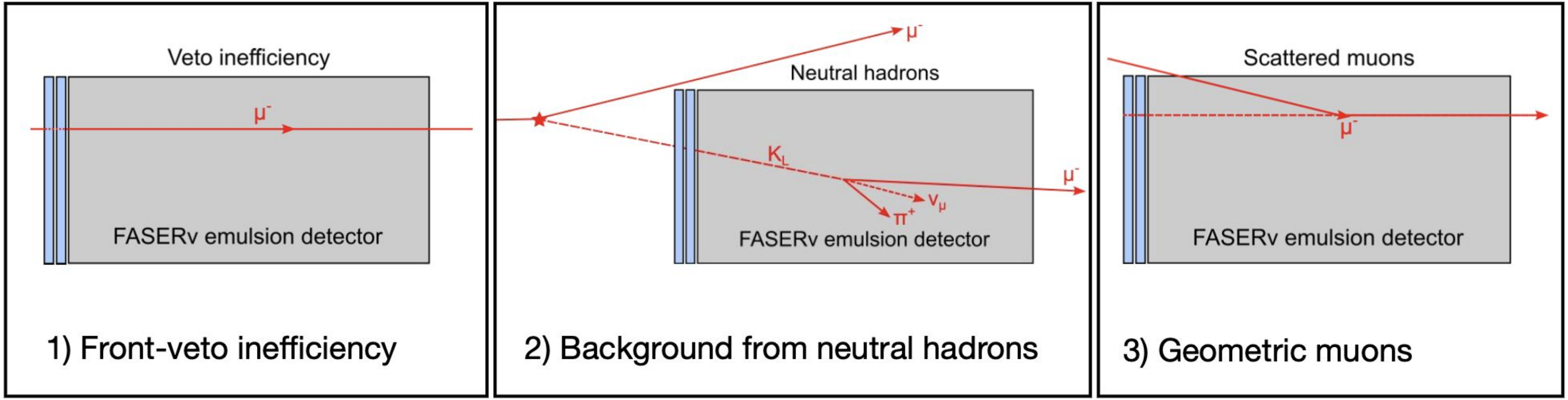
- Measure CC muon (anti-)neutrino interactions using electronic components of detector
- Signature selection:
  - No hits in **FASERν scintillator** station
  - Track in spectrometer with **p > 100 GeV**
  - Track within **r < 120 mm** when extrapolated back to FASERν scintillator





First direct observation of collider neutrinos

3 background sources:



Estimated in **data** comparing hit difference in 1st/2nd layer

Inefficiency is ~10^{-7}, so expect to be **negligible**

Estimated in simulations. Majority of hadrons absorbed in tungsten or parent muon hits veto.

Expect **0.11 ± 0.06 events**

Estimated from control region

Expect **0.08 ± 1.83 events**

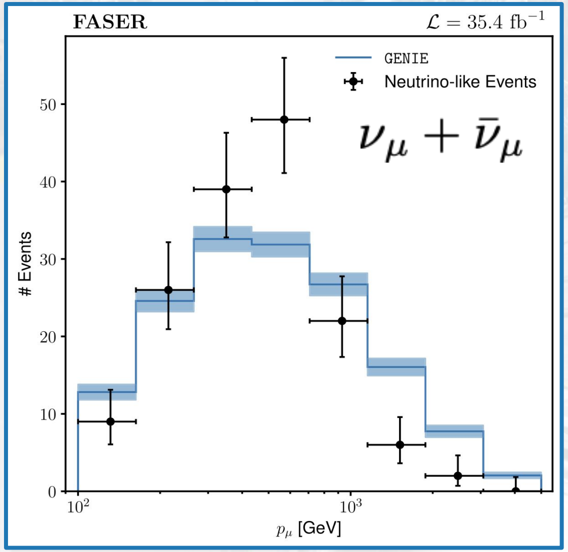
PhysRevLett.131.031801

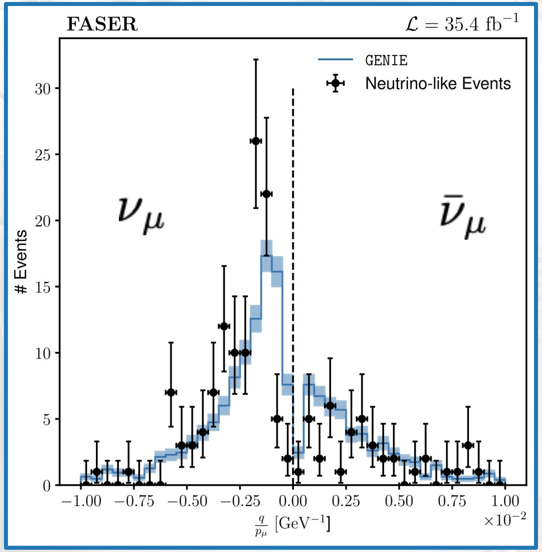
First observation of collider electron neutrinos

Observation with more than **16 sigma significance**:

$$n_\nu = 153^{+12}_{-13}(\text{stat})\,^{+2}_{-2}(\text{bkg}) = 153^{+12}_{-13}(\text{tot})$$

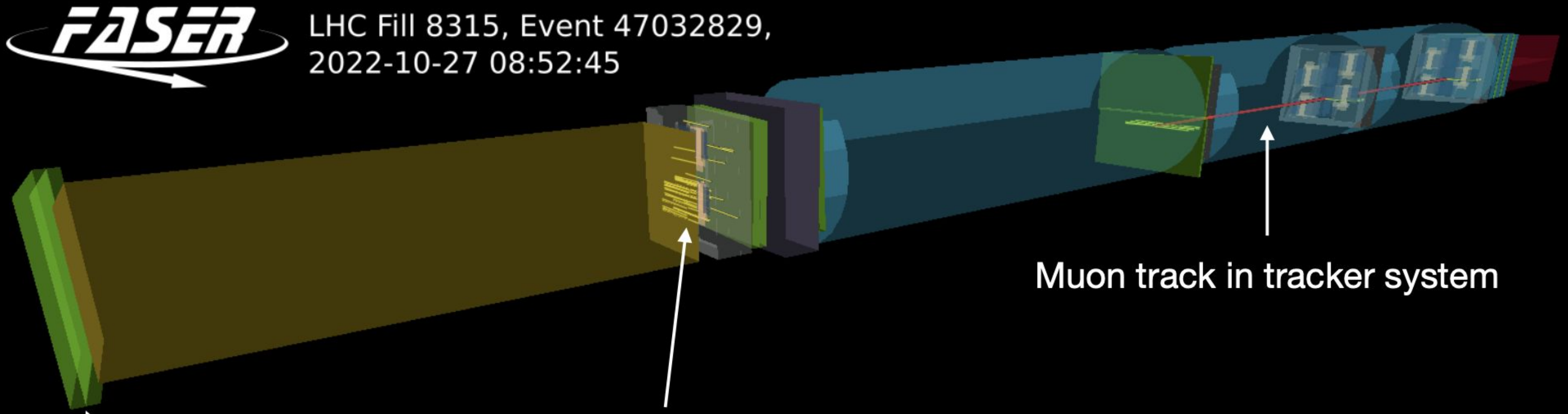
Compatible with **expectation: 151 ± 41**
(from mean/envelope of DPMJET and SIBYLL predictions)





NB: GENIE errors do not include systematic uncertainties on detector effects

Muon neutrino candidate event



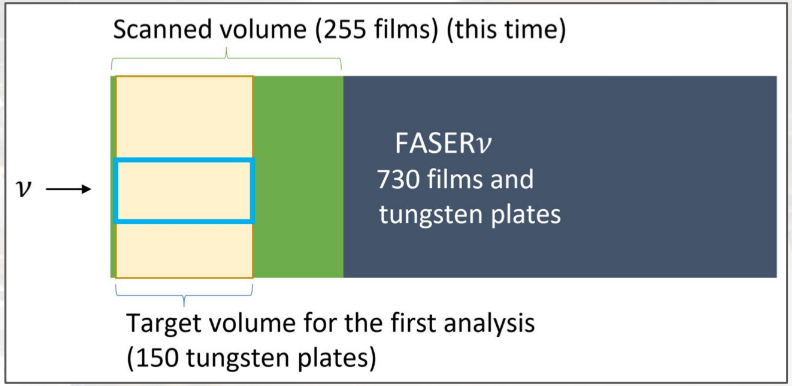
Muon track in tracker system

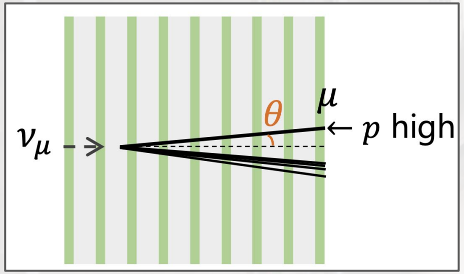
Activity in IFT (interface tracker)
from the remnants of the CC interaction

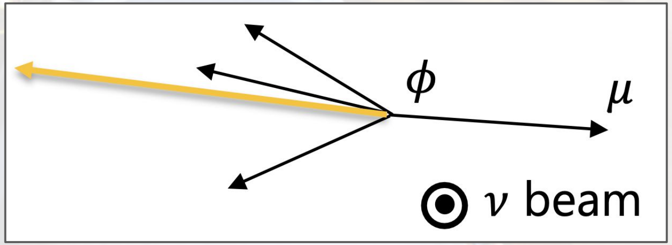
No signal in front veto

First observation of collider electron neutrinos

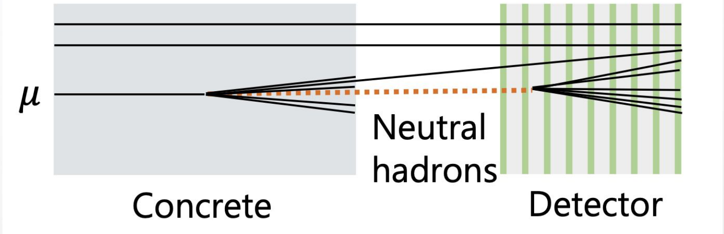
- Analysis of first 150 emulsion detector tungsten plates from 2022 data (9.5 fb^{-1})
  - (68 kg target mass equivalent)
- CC neutrino candidates selected from vertices with at least 5 tracks:
  - **Electrons:** short track, EM shower
  - **Muons**: long track, no secondary particles
- Large angular separation between lepton and CC remnants.





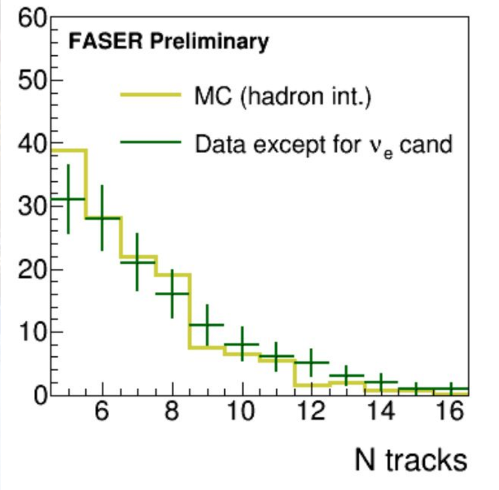


First observation of collider electron neutrinos



Backgrounds:

- **Neutral hadron** interactions estimated from simulations, validated with data
- **Neutral current** (NC) muon neutrino interactions, estimated in simulation



Total background expectation:

- **Electron: 0.002 ± 0.003**
- **Muon: 0.5 ± 0.3**

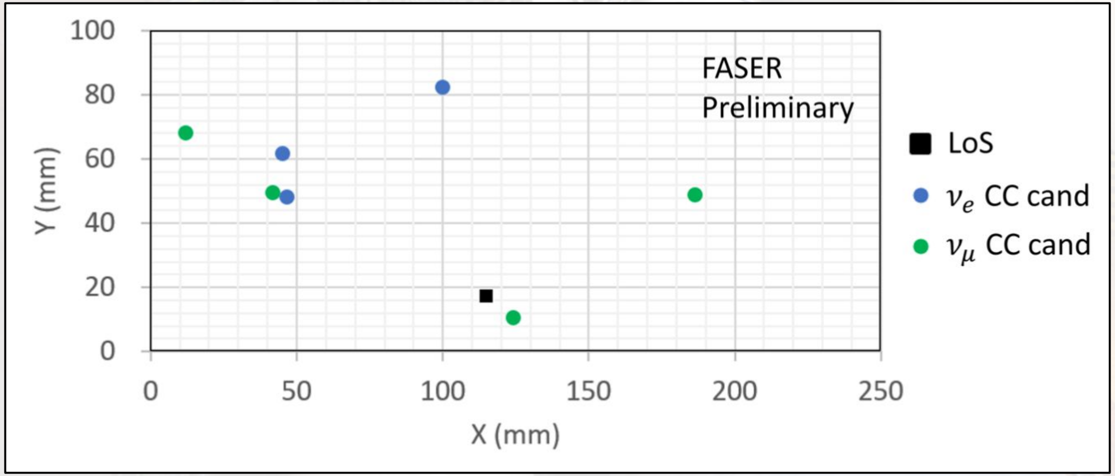
First observation of collider electron neutrinos

Observe in data:

$3\ \nu_e$ candidates → 5σ significance
(0.6–5.2 expected)

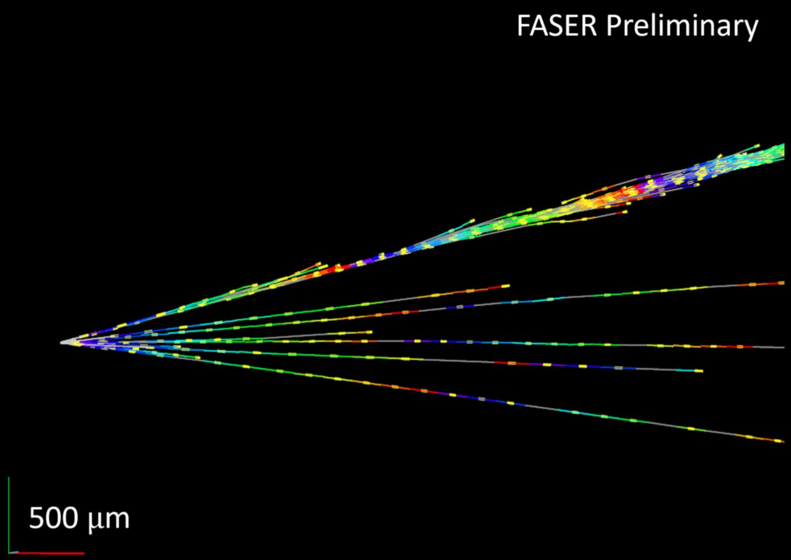
$4\ \nu_\mu$ candidates → 2.5σ significance
(3.0–8.6 expected)

Vertex positions of electron/muon neutrino CC candidate events

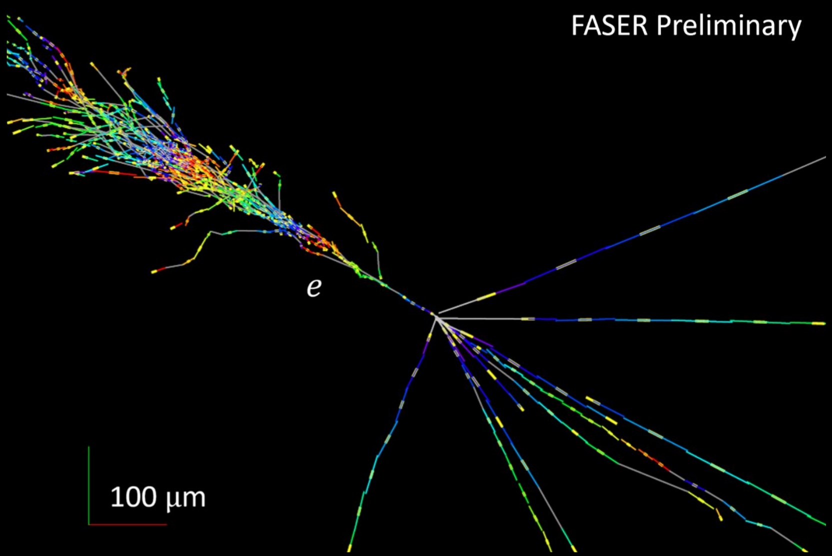


Electron neutrino candidate event

Lab view



Transverse plane

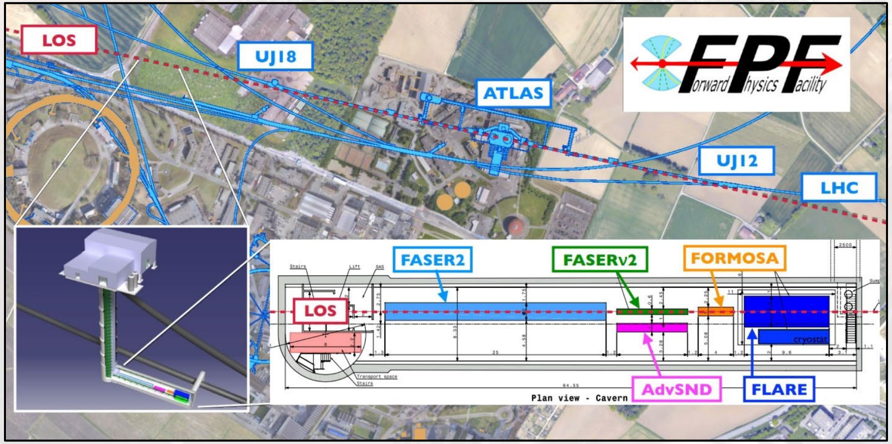


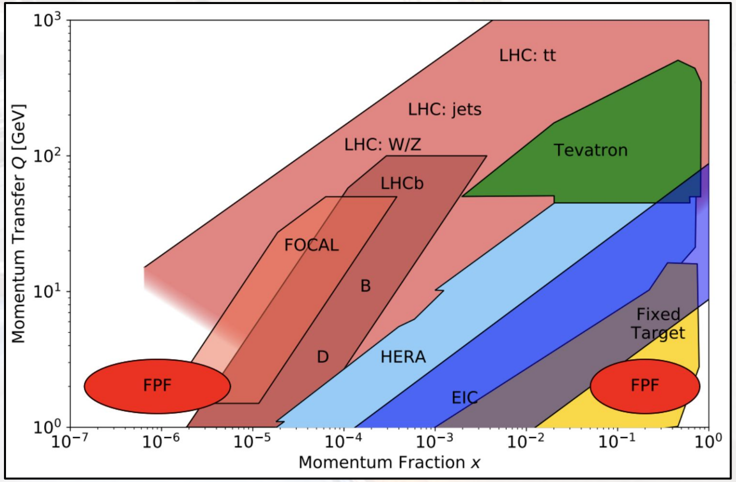
Further forward (to the future)

Forward Physics Facility (FPF):

- Proposed facility for the HL-LHC that could house a suite of experiments.

- Extend LHC’s physics potential for BSM physics searches, neutrino physics, and **QCD**.





Further reading: J. Phys. G 50 (2023) 3, 030501, Phys. Rept. 968 (2022) 1-50, arXiv:2309.09581

Looking forward to more physics

- FASER can probe **forward hadron production** and **hadron structure** by studying neutrinos produced at the LHC
- Taken the first steps towards this with **first observation of collider electron and muon neutrinos at a collider**
- More results on the way with data from 2023 and full emulsion detector dataset to be analysed!

Acknowledgements

FASER is supported by:

HEISING-SIMONS FOUNDATION

SIMONS FOUNDATION

CERN

erc

Swiss National Science Foundation

科研費 KAKENHI

NSF

We also thank:

– LHC for the excellent performance
– ATLAS Collaboration for providing luminosity information
– ATLAS SCT Collaboration for spare tracker modules
– ATLAS for the use of their ATHENA software framework
– LHCb Collaboration for spare ECAL modules
– CERN FLUKA team for the background simulation
– CERN PBC and technical infrastructure groups for the excellent support

Additional slides

FASER Collaboration

89 collaborators, 25 institutions, 10 countries

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UNIVERSITÉ DE GENÈVE
KYUSHU UNIVERSITY
UC IRVINE
UNIVERSITÄT BERN
Technion Israel Institute of Technology
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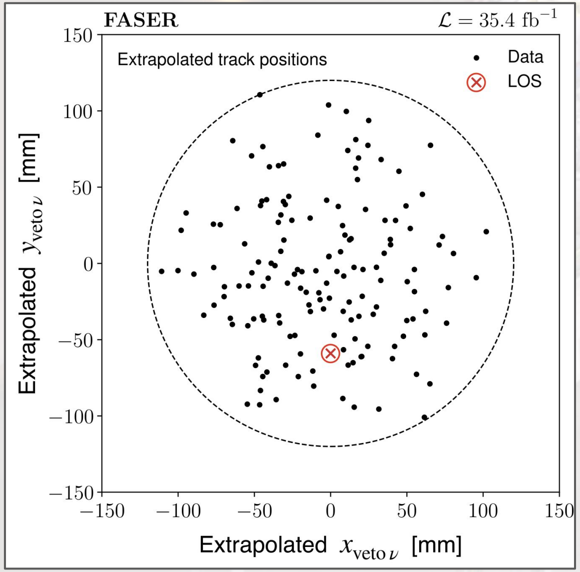
CMU 2t
CMU 2t
2t
To ATLAS
FASERnu
IFT
Veto
Decay volume
Tracking spectrometer
Preshower
Calorimeter

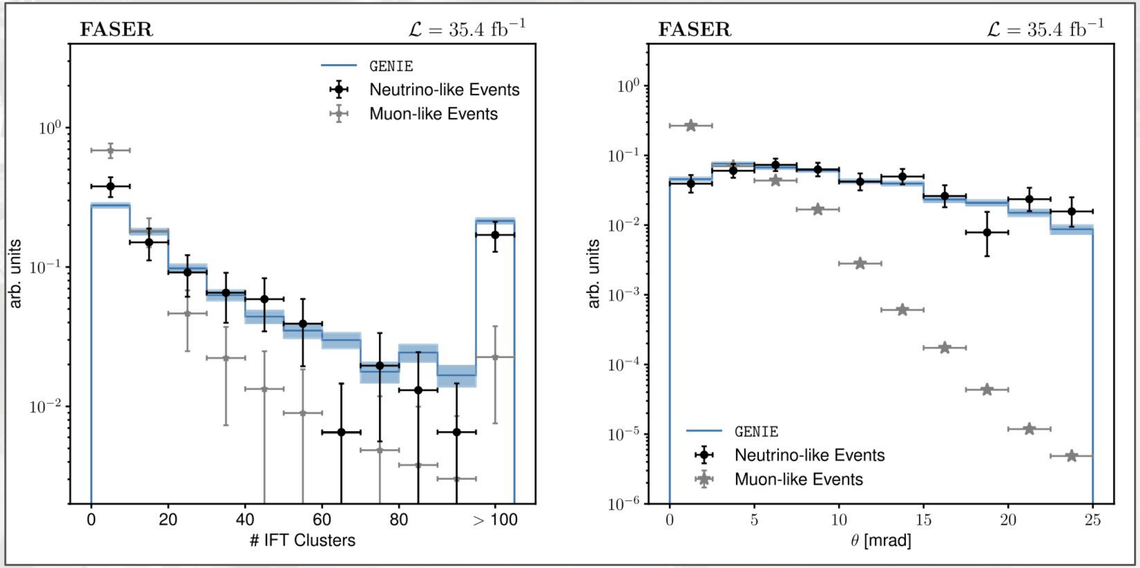
Neutrinos passing through FASER

For 35 fb^{-1}	ν_e	ν_μ	ν_τ
Main source	**Kaons**	**Pions**	**Charm**
# traversing FASERν	$\sim 10^{10}$	$\sim 10^{11}$	$\sim 10^{8}$
# interacting in FASERν	≈200	≈1200	≈4

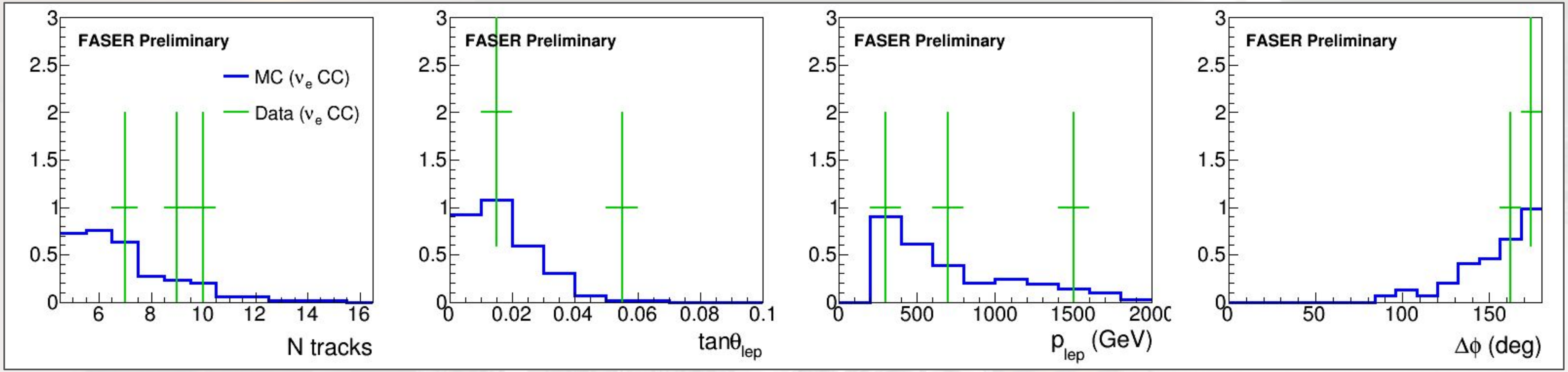
[PRD 104, 113008]

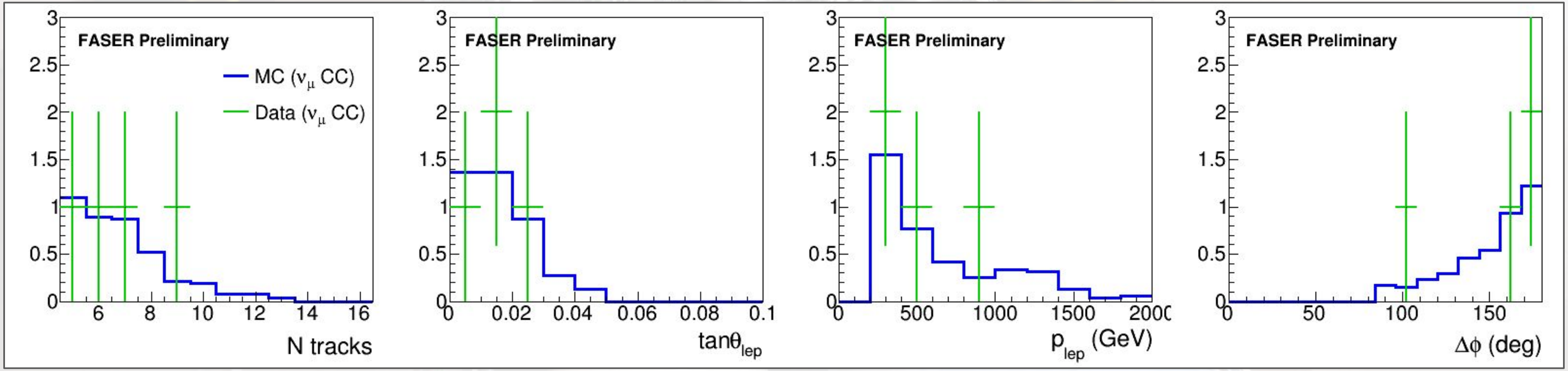
Electronic neutrino analysis distributions





FASERν selected CC candidate events





FPF BSM physics overview