2023 Results from the FASER Experiment

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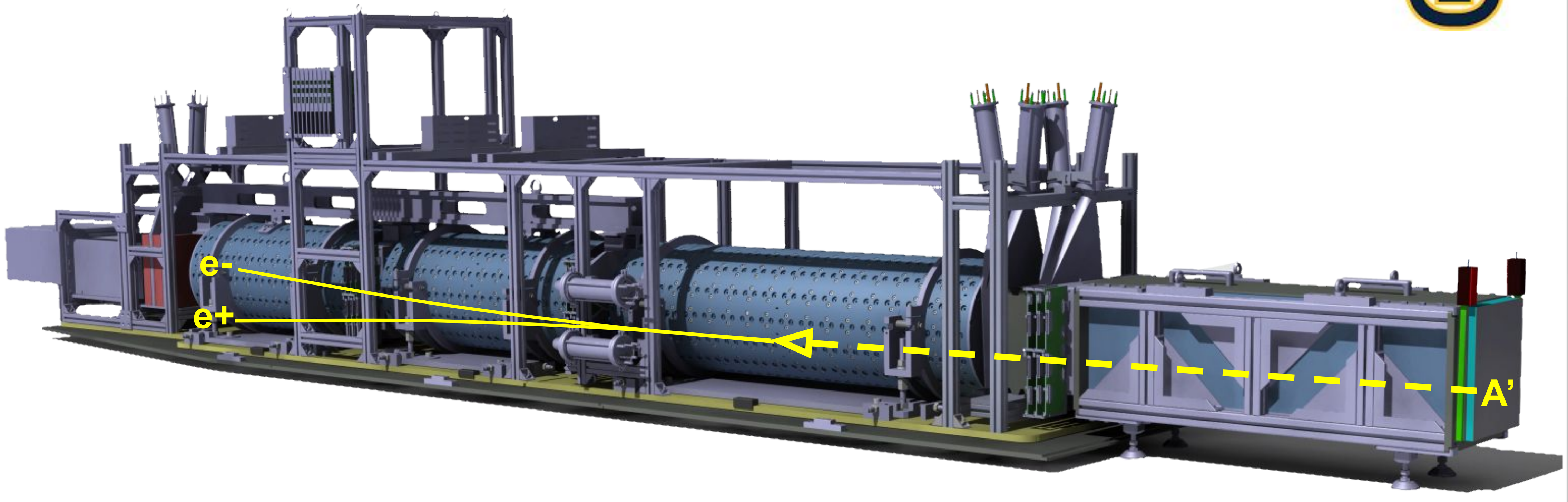
Introduction

FASER is a new experiment designed to search for light, weakly-interacting, long-lived particles (LLPs) and study high-energy neutrino interactions in the very forward region of LHC collisions. The experiment is 480 m downstream of the ATLAS interaction-point and aligned with the beam axis. ~100 m of rock provide shielding from collision related background. FASER has performed three physics analyses in 2023; a search for dark photons, an observation of ν_μ with electronic detector components, and a preliminary observation of ν_e with the FASERν emulsion detector. The dark photon search excluded an unconstrained region of parameter space motivated by dark matter. The neutrino analyses observed collider neutrinos directly for the first time, providing proof of concept for neutrino cross section measurements at collider energies. This poster describes novel physics analyses with ~30 fb^{-1} of data from LHC run 3.

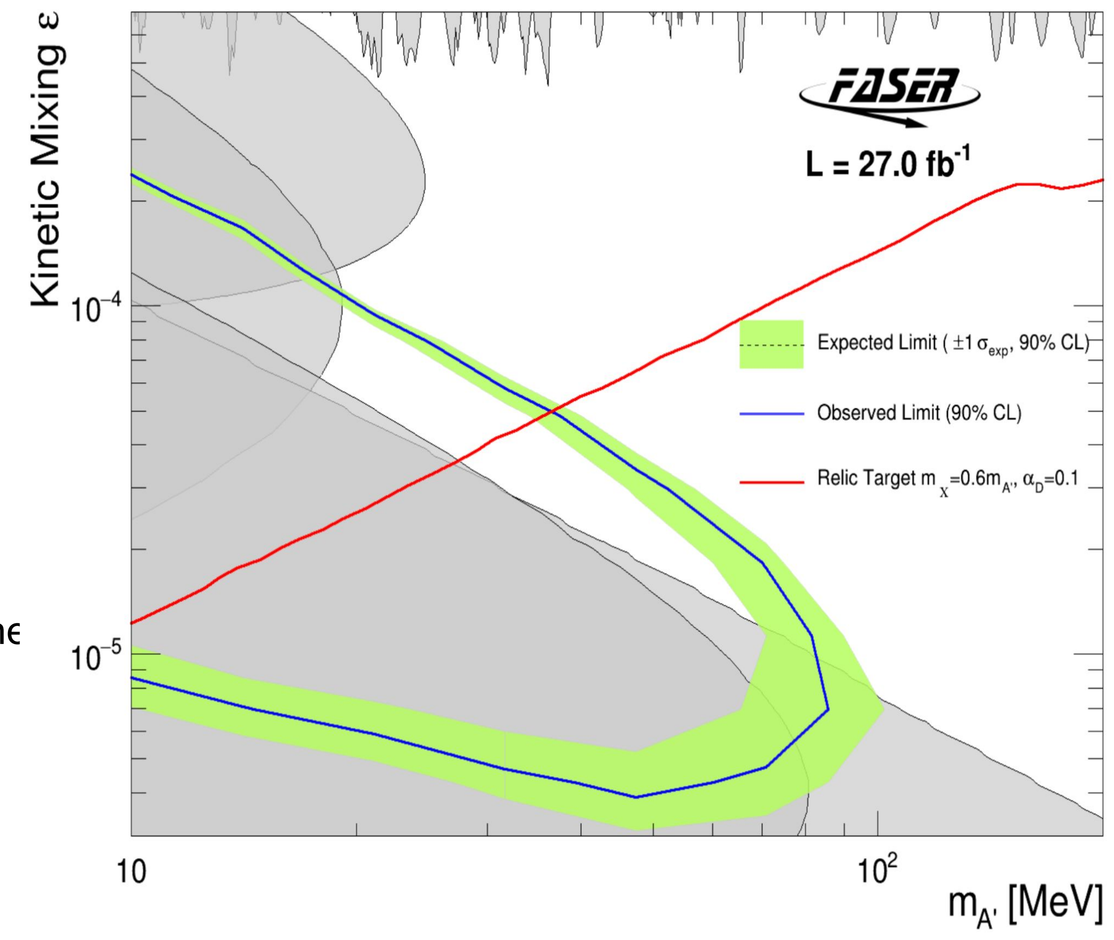


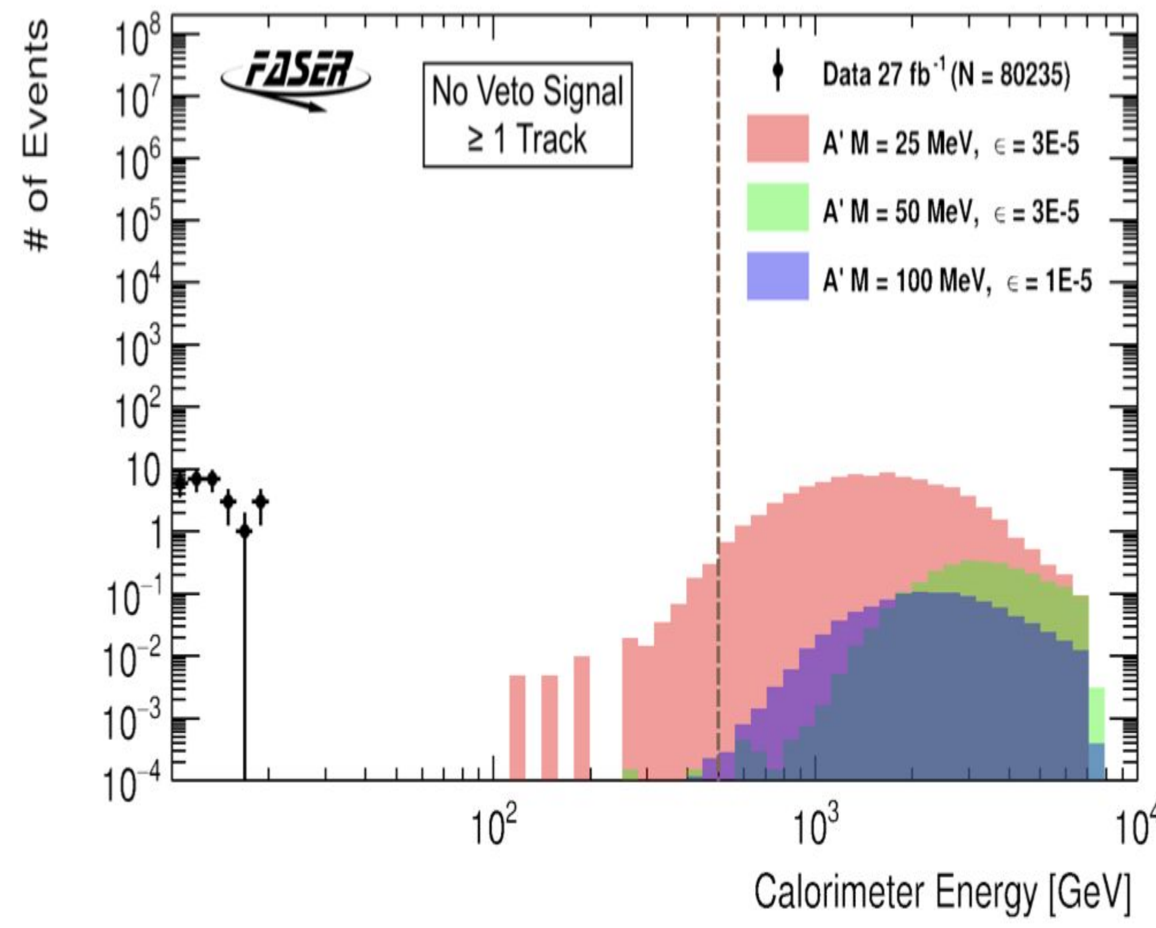
Dark photon search [1]

LHC collisions produce large amounts of π^0 and η^0. Dark sector models predict there is a chance, characterized by the kinetic mixing parameter ε, that these mesons can decay into a massive dark photon (A'). ε also parametrizes the probability for the A' to decay into the standard model. The A' decay length is $\mathcal{O}(100)$ m, this makes it suitable for detection at FASER.

Analysis: The A' can decay in the FASER decay volume to a very collimated, high momentum, e+e− pair. These decay products can then leave signals in the trackers and a large energy deposit in the calorimeter. The analysis required two good quality reconstructed charged particle tracks, more than 500 GeV of energy in the calorimeter, and no signal in the veto stations.

Results: The dark photon analysis used 27.0 fb^{-1} of data. The estimated background is $2.3 \pm 2.3 \times 10^{-3}$ events. The background is dominated by neutrino interactions in the detector. No events were observed passing the selection. Exclusion limits are set at 90% confidence level, excluding signal parameter space in the cosmologically favored region ε ~ 10^{-5} – 10^{-4}, $m_{A'}$ ~ MeV – GeV.





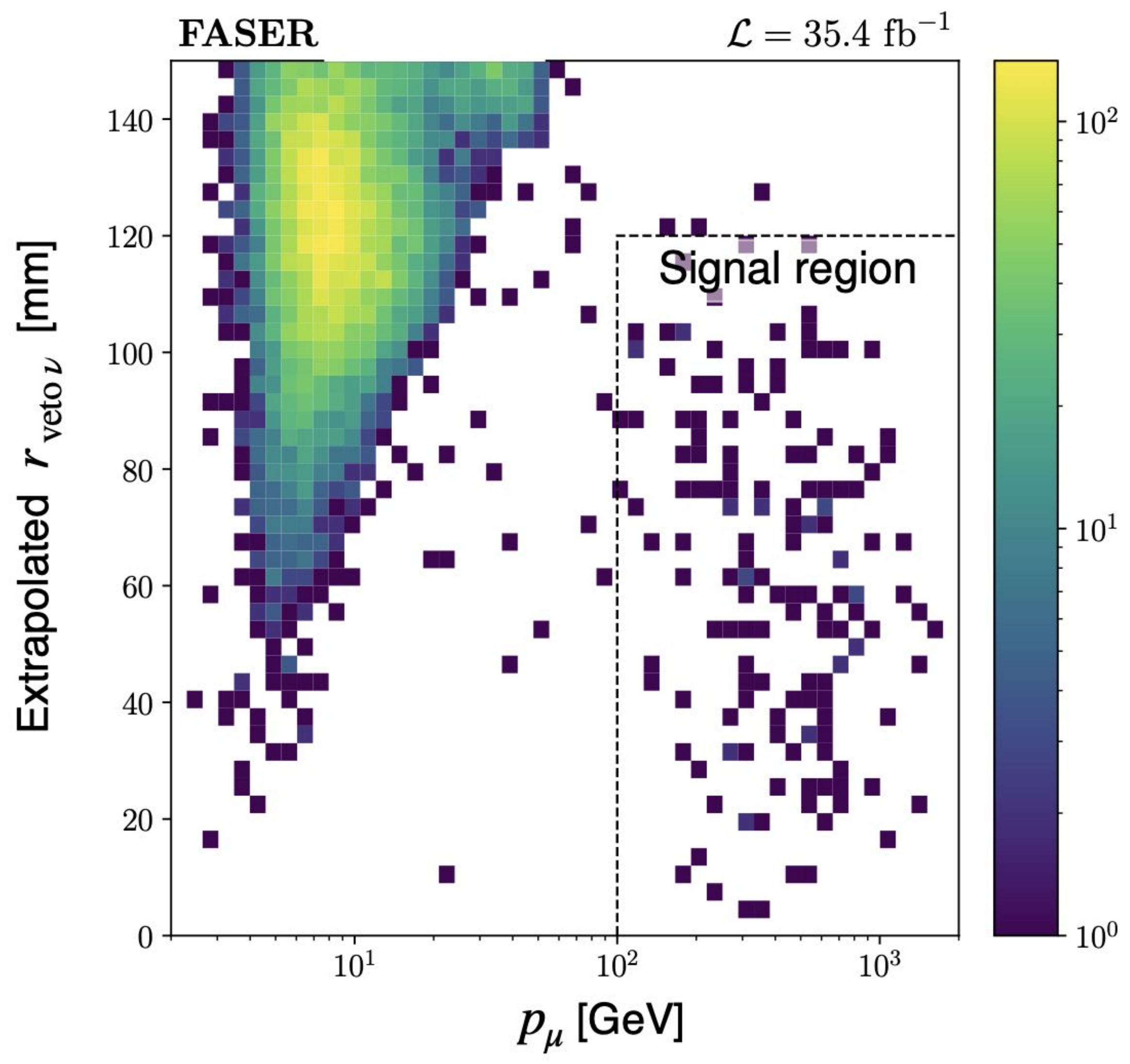
(Left) 90% confidence level exclusion contours in the A' parameter space. The red line shows the region of parameter space that yields the correct dark matter relic density with the benchmark choice of parameters, $m_\chi = 0.6 m_{A'}$ and $\alpha_D = 0.1$. (Right) Energy distribution for events that have no signal in veto stations and at least one good track.

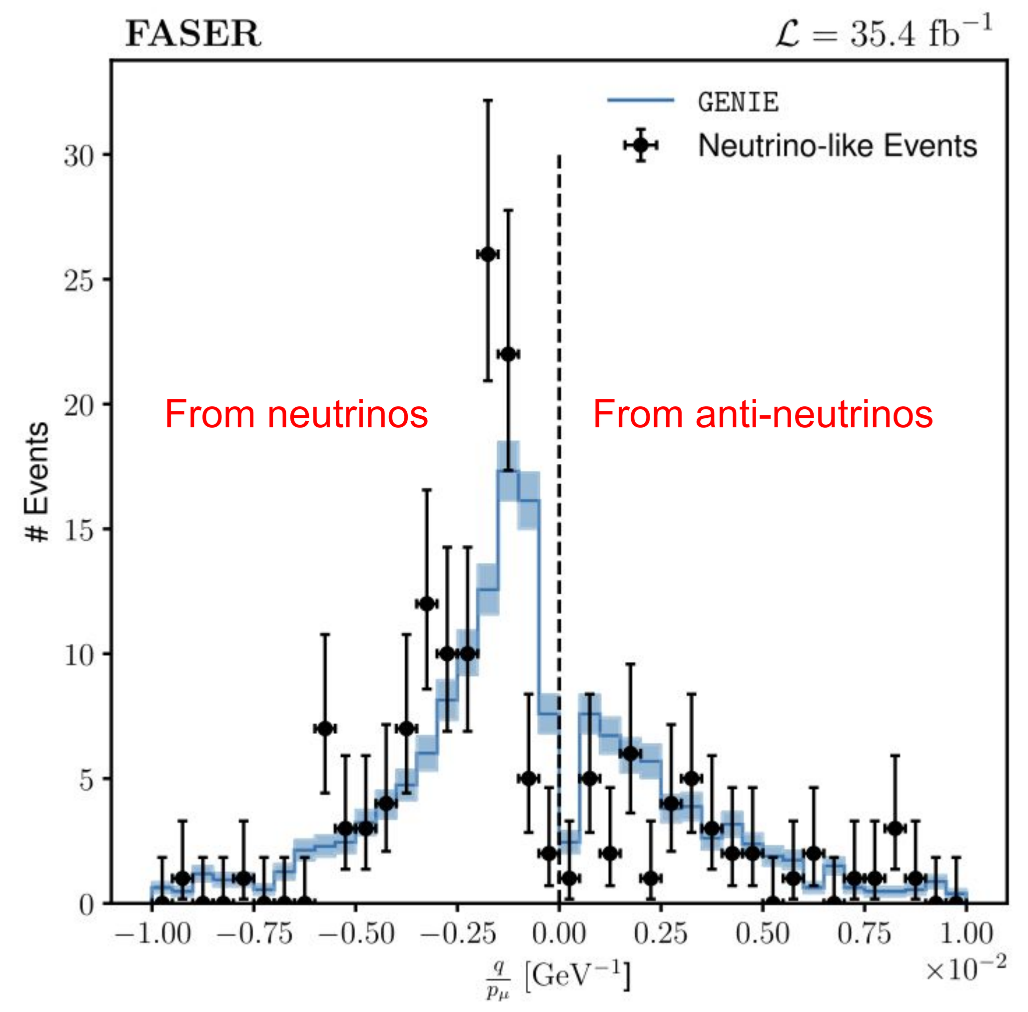
Electronic neutrino detection of ν_μ and $\bar{\nu}_\mu$ [2]

Neutrinos have never been directly observed at a collider despite their abundant production via hadron decay. FASER detects neutrinos electronically with it's scintillators and trackers, using tungsten in the FASERν box as a target. FASER presented the first direct observation of collider neutrinos at Recontres de Moriond, 2023.

Analysis: ν_μ and $\bar{\nu}_\mu$ charged current interactions occur in the tungsten. These interactions produce a high-momentum muon that can be reconstructed in the three stations of the FASER tracking spectrometer. The main requirements for definitive observation are no signal in the FASERν veto scintillators and a signal consistent with one muon downstream with a track momentum > 100 GeV. The chosen analysis strategy is designed to be independent of the simulation of the detector response and therefore does not measure the neutrino interaction cross section

Results: Using 35.4 fb^{-1} of collected data, 153^{+12}_{-13} signal events were observed with 16 σ significance. The observed yield includes both ν_μ and $\bar{\nu}_\mu$. The relevant backgrounds come from neutral hadrons produced in the upstream rock, and scattered muons from FASERν, which contribute 0.11 ± 0.06 events and 0.08 ± 1.83 events respectively. In addition to being the first collider neutrinos ever observed, the neutrinos detected here are expected to be the most energetic ever detected from a human source, with energies in the range 360 GeV – 6.3 TeV. This range fills a gap in observed neutrino energies between fixed target experiments and astroparticle data. A future analysis will correct the observed yield for detector effects to obtain a cross section measurement.





(Left) Signal region in extrapolated radius $r_{veto\,\nu}$ and p_μ. (Right) Distribution of charge-muon momentum ratio, for which no systematic uncertainties related to detector effects are included in the GENIE MC predictions.

Emulsion neutrino detection with FASERν [3]

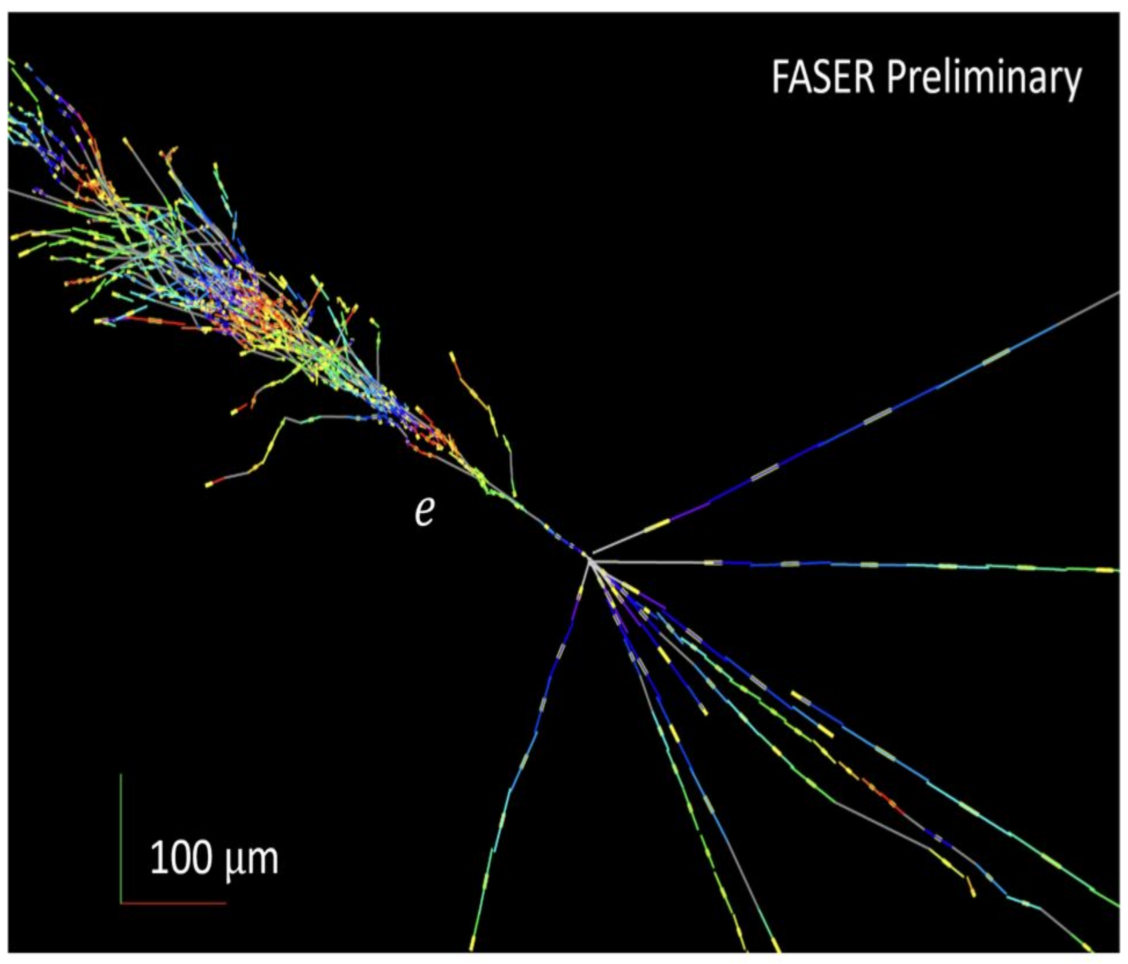
FASER also detects neutrinos with its dedicated emulsion detector, FASERν. The 1.1 ton detector is made of 730 layers where each layer consists of a 1.1mm tungsten sheet and subsequent emulsion film.

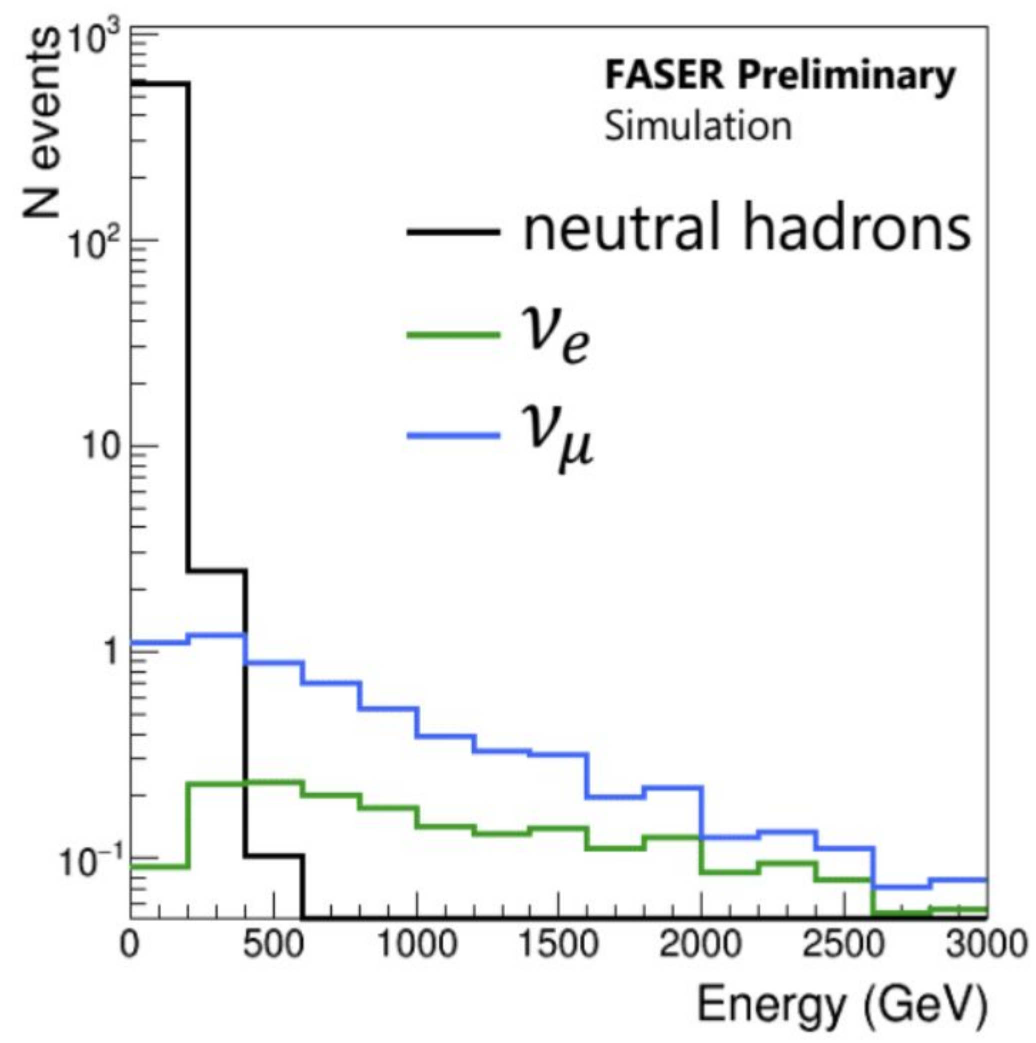
Analysis

Neutrinos interact with the tungsten, and the outgoing interaction products are recorded in the emulsion layers. The emulsion is read out by the Hyper Track Selection system. Candidate charged current neutrino interaction vertices are selected by looking for events with at least 4 converging tracks that have a minimum distance of 5 μm, and the absence of a charged parent track. Energy, momentum and angle cuts are made on reconstructed muon and electron candidates.

Results

The first analysis included 150 of the 730 plates with 9.5 fb^{-1} of data. The expected number of neutrino signal events satisfying the selections are in the ranges 0.6–5.2 (for ν_e CC) and 3.0–8.6 for (for ν_μ CC), where the range covers the predictions of the different event generators. The expected background is 0.002 ± 0.003 events and 0.5 ± 0.3 events for electrons and muons respectively. The background is dominated by neutral hadrons. Three ν_e vertices and four ν_μ vertices were selected. The muon neutrino interaction candidates were identified with 2.5 σ. The selected electron neutrino interaction candidates were observed with 5.1σ and have reconstructed electron energies of 1.5 TeV, 700 GeV, and 400 GeV, the highest-energy ν_e interactions detected by accelerator-based experiments.





(Left) Event displays in the transverse plane of one of the ν_e CC candidate events. (Right) The expected spectra of neutral hadrons, ν_e and ν_μ.

[1] **FASER** Collaboration., "Search for Dark Photons with the FASER detector at the LHC," arXiv:2308.05587 [hep-ex]
[2] **FASER** Collaboration., "First Direct Observation of Collider Neutrinos with FASER at the LHC," Phys. Rev. Lett. **131** (2023) no. 3, 031801, arXiv:2303.14185v2 [hep-ex].
[3] **FASER** Collaboration, "Observation of high-energy electron neutrino interactions with FASER's emulsion detector at the LHC," CERN-FASER-CONF-2023-002 https://cds.cern.ch/record/2868284

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