First Observation of Collider Neutrinos with FASER

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FASER collaboration
• FASER (The ForwArd Search ExpeRiment) is a new experiment at LHC (in operation since 2022)
• The target of FASER includes dark matter and collider neutrino (FASErν)
• An introduction has been given last year:
  • Tomohiro: Looking forward to New Physics and Neutrinos with FASER at LHC
• We report the latest physics results from FASER:
  • Dark photon search, Hao Pang: 9:50, 18th Nov
  • Collider neutrino search: This report
• Neutrinos are copiously produced at collider, but they have never been directly detected
  • Small cross section, high background, forward produced …

• Collider neutrinos have exciting features compared with other neutrino sources
  • Compared to cosmic neutrino, collider neutrino can be largely produced
  • Compared to reactor and beam dump neutrino, collider neutrino has much higher energy
  • The source of collider neutrino can be charm/bottom decay
  • Neutrinos with all flavors can be produced from collider (not from oscillation)
- FASER is an experiment aims to detect light, long-lived particles produced at the LHC collisions. These particles tend to fly in a very forward direction, which is the blind area for traditional spectrometers.
- FASER is located at the beam axis line-of-sight (LOS) from the ATLAS collision point (IP1).
- Installation started by 2021. Data taking started by 2022, will run during the Run3.
• FASER is a light weight detector (7m long, 20cm diameter)
• Comprised of an emulsion (with tungsten), scintillators, tracking stations and an electromagnetic calorimeter
• Main detecting volume in 0.6T magnetic filed
• The major part of FASERν includes 730 alternate layers of emulsion film and tungsten plate
  • Act as the target of neutrino interaction and vertex tracker
Observation of Collider Neutrinos with Electronic Detector
• The result about collider neutrino search based on electronic detectors of FASER has been published [PhysRevLett.131.031801]
• The information from the emulsion is not utilized
• Track propagating through the entire length of the FASER detector is served as candidate (consistent with $\nu_\mu$ CC interaction)
• Dataset collected between 2022.7-11 ($35.4 f b^{-1}$) is used, with collision energy 13.6TeV
• Expected number of events is: $151 \pm 41$
• Signal is selected with high momentum $\mu$ ($p > 100 \text{GeV}$) and passing through the center of veto scintillator ($r < 120 \text{ mm}$)

• Several backgrounds are investigated
  • High momentum $\mu$: vetoed by scintillator
  • Neutral hadrons: estimated by simulation
  • Geometric backgrounds: estimated by sideband

• $153^{+12}_{-13}$ neutrino events after unblinding
  • 99% originate from $\nu_\mu$ CC interaction
  • 40 events with positively charged track $\rightarrow \bar{\nu}_\mu$ observed!
The first direct observation of collider neutrinos!
- 16\(\sigma\) deviations above the background-only hypothesis
- Expected to be the most energetic neutrino ever detected from an artificial source!
  - Estimated energy significantly above 200 GeV
- Published at PRL [PhysRevLett.131.031801]
Observation of Collider Neutrinos with Emulsion Detector
• Although with slower workflow, emulsion of serves not only the target of neutrino interaction but also a tracker with excellent position resolution
  • Three neutrino flavors can be identified
• A investigation has been conducted with a subset of the emulsion
• Not matched with tracks from electronic detector
• Dataset collected between 2022.7-9 (9.5 fb$^{-1}$) is used, with collision energy 13.6TeV
Main background arises from neutral hadrons produced by $\mu$ from the collision
- Estimated by simulation
- $0.51 \pm 0.27$ for $\nu_\mu$, $0.002 \pm 0.003$ for $\nu_e$

Energy of neutrinos can also be estimated by emulsion tracks
- Resolution: $\sim 20\%$ for $E_e$ and $\sim 25\%$ for $P_\mu$

4 vertexes $\nu_\mu$ and 3 vertexes for $\nu_e$ are observed
- With energy and azimuthal angle requirements
• First preliminary result with the FASERν emulsion detector (CERN-FASER-CONF-2023-002)

• First observation of collider electron neutrino
  • $5\sigma$ for $\nu_e$, $2.5\sigma$ for $\nu_\mu$

• Demonstrate the ability to carry out neutrino studies with the FASERν emulsion detector
  • Will be improved with longer range used
• Summary

• FASER is a young forward experiment at LHC

• FASER aims to search for light, long-lived particles, including possible new particles and collider neutrinos

• With electronic detector, FASER made the first observation of collider neutrinos with relatively high energy

• With emulsion detector, FASERv achieved the first observation of collider electron neutrinos

• Better performance is expected with more emulsion films analyzed, matching emulsion and electronic detector, upgrading analysis method…
• A totally new physics domain has been presented, and we just only the first page...

• FASER experiment
  • Main Page, publication and presentation
  • You may also have a virtual tour

• FASER will be upgraded to a more powerful version: FASER2

• A greater plan is under discussion: FPF (Forward Physics Facility)

Thank You!
CLHCP 2023
BACK UP
Jinfeng Liu (Tsinghua University)
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• Geometric background estimation

Side band candidate

FASER

$\mathcal{L} = 35.4$ fb$^{-1}$

Sideband: $90$ mm $< r_{IFT} < 95$ mm, # IFT Clusters $\leq 8$

- fit: $0.2 \pm 4.1$ events with $p_\mu > 100$ GeV
- No $r_{veto}$ selection
- $r_{veto} < 120$ mm

$\log_{10}$ # Events vs $p_\mu$ [GeV]
• Muon background estimation

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<thead>
<tr>
<th>Category</th>
<th>Events</th>
<th>Expectation</th>
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<tbody>
<tr>
<td>Signal</td>
<td>153</td>
<td>$n_\nu + n_b \cdot [p_1 \cdot [p_2 + n_{\text{had}} + n_{\text{geo}} \cdot f_{\text{geo}}$</td>
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<tr>
<td>$n_{10}$</td>
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<td>$n_b \cdot (1 - p_1) \cdot p_2$</td>
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<tr>
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<td>$n_b \cdot (1 - p_1) \cdot (1 - p_2)$</td>
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