Recent Results from FASER

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https://faser.web.cern.ch/
Forward Search ExpERiment at the LHC

- Many light particles at LHC produced in $\pi$, $K$, D meson decay
  - $N \approx 10^{16}$ pions/$10^{12}$ neutrinos in LHC Run 3 (2022-2025)
  - $E \approx \text{TeV}$ $\theta_{\text{beam axis}} \approx \text{mrad}$

- 480m downstream from ATLAS, the FASER experiment is placed directly into this beam
  - Proposed to search for long-lived particles and measure high energy neutrino nucleon interaction
  - Well shielded from ATLAS IP
Dark Photon

Spin 1, couples weakly to SM fermions

\[ \mathcal{L} \supset -\frac{e'}{2} F_{\mu
u} F^{\mu\nu} + \frac{1}{2} m'^2 X^2 \]

Mainly from decays of light mesons, \( \pi, \eta, \) dark bremsstrahlung and hard scattering
Axion-like Particles

ALPs only couple to photons

\[ \mathcal{L} = -\frac{1}{2} m_a^2 a^2 - \frac{1}{4} g_{\alpha \gamma} a \mathcal{F}^{\mu \nu} \tilde{F}_{\mu \nu} \]

Mainly produced via Primakoff process \((\gamma N \rightarrow aN)\)

\[ a \rightarrow \gamma \gamma \text{ or } \gamma e^+ e^- \]

330m
Exploring neutrinos at the TeV energy

Sensitive to new physics by measuring scattering cross sections and studying each flavor
Exploring neutrinos at the TeV energy

Sensitive to new physics by measuring scattering cross sections and studying each flavor
Detector

EM Calorimeter:

Scintillator:
- Trigger/preshower

Magnets:
0.55 T

Scintillator station:

Decay volume:
1.5 m

3 Tracker stations:

Interface tracker:

FASEr\nu:

ATLAS IP

\sim 5 \text{ m long, } 20 \text{ cm diameter}
Silicon Tracker

- Based on ATLAS SCT modules:
  - 8 modules x 3 layers x 4 stations = 96 modules
  - Resolution: 17 um x 580 um
  - Good separation for two collimated tracks

- 4 stations commissioned and installed
  - 99.9% strips are active
  - Expected noise/gain are confirmed
  - Thermal performance looks good
  - Interlock/safety are carefully verified

Paper available from NIMA (2022) 166825
Four scintillator stations are commissioned and installed
- > 99.9% efficiency, enough to trigger LLP decay inside the FASER detector
- Confirmed by in situ measurements in 2018.

Calorimeter based on LHCb ECAL module is also installed. One module has:
- 12 cm x 12 cm (25 $X_0$)
- 66 layers of (2mm lead and 4mm scintillator)
- Resolution ~1% for 1 TeV electron energy deposits
Trigger and Data acquisition

Readout electronics in TI12

- Tracker: Custom General purpose I/O (GPIO) board
- Scintillator and Calorimeter: CAEN digitiser
- Trigger: Custom GPIO board
  - 500 Hz expected rate (dominant by muon flux, 1 Hz/cm² for \( L=2\times10^{34} \text{ cm}^{-2}\text{s}^{-1} \))
  - Clock and bunch taken from LHC
- Ethernet switch -> Servers on surface

All components are installed and pass 1KHz test
Paper is published: [2021 JINST 16 P12028](https://doi.org/10.1088/1748-0221/16/12/P12028)
FASER$\nu$ Emulsion/Tungsten

Charged particle ionization recorded and can be amplified and fixed by chemical development of film

- 770 emulsions interleaved with 1-mm-thick tungsten plates (1.1 tonnes)
- Track position resolution $\sim$50 nm
- Angular resolution $\sim$0.35 mrad
- No Timing information

Pilot detector (29 kg) exposed in TI18 for 1 month in 2018

- Observed first $c$ collider $\nu$ candidates (2.7$\sigma$) with 12.2 fb$^{-1}$ data!
- *Phys. ReV. D* 104, L091101
FASER in TI12

Spring 2019

Autumn 2020

Winter 2021

LOI arXiv:1811.10243
TDR arXiv:1812.09139
Successfully Installed in TI12 March 2021

Current partial (30%) FASERν
- Frequent exchange in Run 3
- 1st full detector July 26 (TS1)
- 2nd full detector Sep 13 (TS2)

- Detector paper being finalised for publication
- In situ commissioning with cosmic events and beams since
Test Beam Summer 2021

- e (5-300 GeV)
- $\mu$ (150 GeV)
- $\pi$ (200 GeV)

Reasonable energy resolution confirmed
First beam particles in May 2022

- Saw first beam particles from recent 6.8 TeV beam optics tests!
- First particles traversing full detector, including Fwd Veto and IFT
- Good readiness confirmed toward Run 3
Preshower upgrade for 2023/2024

- Preshower scintillator will be replaced by hybrid pixel detector (100μm pitch, 130nm SiGe BiCMOS)
- Upgrade to enable detecting ALPs→ $\gamma\gamma$ searches (2 photon separation by ~200μm)
- Installation by the end of 2023, and data-taking from 2024
- Approved by CERN. See TDR [CERN-LHCC-2022-006](https://cern.ch/)

![hexagonal pixels](Image)

![Prototype chip](Image)

![W-Si Detector](Image)
Forward Physics Facility toward HL-LHC

A new dedicated facility ~600 m to west of ATLAS (IP1)

Rich and broad physics programs:
- Extending BSM dark sector searches
- Neutrino physics
- New inputs for QCD and astrophysics

- Very preliminary cost: ~40 MCHF (62% civil engineering/38% service)
- Experiments on top

Snowmass White paper arXiv:2203.05090
Summary

● **FASER** - a new forward experiment at the LHC in the unused tunnel, TI12
  ○ Give access to light weakly-coupled particles in MeV-GeV range
  ○ Probe TeV-energy neutrino in all flavors - First collider neutrino candidate is published!

● **Ready for data taking in LHC Run 3 from 2022:**
  ○ All detectors installed in TI12
  ○ Great progress of test beam analysis and commissioning to verify expected performance

● **Upgrade toward enhancing forward physics program**
  ○ Near term preshower upgrade for ALP search
  ○ Longer term Forward Physics Facility enabling broad physics programs
    ■ Tight timeline for construction
    ■ More discussions in Seattle Snowmass Community Summer Study July 17-26 2022

http://seattlesnowmass2021.net/
Backup
Detector

**EM Calorimeter:**
- 66 scintillator + lead planes
- \( \sim 25 \times 0 \)

**Scintillator:**
- Trigger/preshower

**3 Tracker stations:**
- Each has 3 layer of 8 silicon strip modules
- Measure track trajectory
- More details in NIMA166825(2022)

**Scintillator station:**
- 3 layers of 8 silicon strip modules (SCT)

**Interface tracker:**
- Trigger/timing
- More details in INST16,P12028 (2021)

**Magnets:**
- 0.55 T

**Decay volume:**
- 1.5 m

**FASERν:**
- 770 emulsion + tungsten plate
- \( \sim 8\lambda \)
- Measure track trajectory, neutrino flavor

**ATLAS IP**

- Veto charged particles

\(~5 \text{ m long, 20 cm diameter}\)
Beam Backgrounds

- FLUKA simulations and in situ measurements have been used to assess the backgrounds expected in FRASER.
- FLUKA simulations studied particles entering FASER from:
  - IP1 collisions, off-orbit protons hitting beam pipe aperture, beam-gas interactions
- Expect a flux of high energy muons (E>10 GeV) of $0.5 \text{ cm}^{-2}\text{s}^{-1}$ at FASER for $2 \times 10^{34}\text{cm}^{-2}\text{s}^{-1}$ luminosity from IP1 collisions.

Large muon charge asymmetry at FASER due to LHC bending magnets.
BSM particles can be detected in various ways

- Giving access to wide range of models

Neutrinos can be used to search for BSM effects

- Production
- Propagation
- Interaction
FASER2

scaled up version of FASER2 with ~100 x active area

- Veto: similar scintillator-based
- Magnets: Superconducting w/ \( B = 1 \) T
- Tracker: much larger using e.g. SiFI/SiPM
- Calo/Muon: enhanced PID & position resol.

|       | FASER | FASER2 |
|-------|-------|--------|
| R [m] | 0.1   | 1      |
| DV [m] | 1.5  | 10     |
| TS [m] | 2.6  | 10     |
FASER2 Physics

- Wide LLP program probing many models
- Dark vectors, (pseudo) scalars, ALPs, HNLs, …
- Extended sensitivity to higher mass
FASERν2

- ~20t emulsion + tungsten detector
- Focus on ντ

FLArE: Forward Liquid Argon Experiment

- ~10t LAr TPC
- DM scatters + ν physics
Other experiments

AdvSND
- Off-axis ν detector
- Forward charm prod. + low-x gluon PDF

FORMOSA: FORward MicrOcharge SeArch
- Scintillator/tungsten detector
- For milli-charged particles