Search for Weakly Interacting Particles with the FASER Experiment
Matthias Schott on behalf of the FASER Collaboration
The general idea

- **Huge cross-sections at the LHC**
  - \( N_{\text{inel}} \approx 2.3 \times 10^{16} \) inelastic pp scattering events for an integrated luminosity of 300 fb\(^{-1}\)
  - Extremely weakly-coupled and light new particles may be produced in sufficient numbers in the very forward region.

- **Such particles may be highly collimated**
  - typically produced within \( \theta \sim \Lambda_{\text{QCD}}/E \)
  - implies that \( \sim 100 \) m down-stream, such particles have only spread out \( \sim 10 \) cm in the transverse plane.
Physics Reach: Dark Photons and Dark Higgs

- Spin 1, couples weakly to SM fermions
  - Mainly from decays of light mesons, $\pi$, $\eta$, dark bremsstrahlung and hard scattering
  - Decay into electrons, muons, pions

- FASER has sensitivity to coupling strength of $\sim 10^{-5}$ for dark photon.
  - Assumption: 0 background and 100% efficiency.
  - →FASER, LHCb and Belle2 are complementary and can cover most search region of $m_{A'} < 1\text{GeV}$
Physics Reach:
Dark Photons and Dark Higgs
Physics Reach: Heavy Neutral Leptons and ALPs

- ALPs production via Primakoff process ($\gamma N \rightarrow aN$)
  - Assume only couplings to photons

- For ALP-$\gamma\gamma$ decay, magnetic field does not help separate closely spaced decay products
  - maybe pre-shower but challenging to resolve closely spaced (~1mm) high energy photons (>500 GeV)

- FASER would be able to detect ALPs with $m_a \approx \text{MeV}$ and $g_{a\gamma\gamma} \approx 10^{-4}$ GeV$^{-1}$, as those would travel up to 350m and decay then into two photons, which can be detected.
Neutrinos at FASER

- Sensitive to new physics by measuring scattering cross sections and studying each flavor
The Detector
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
  - Paper: NIMA (2022) 166825

- 4 stations commissioned and installed
  - 99.9% strips are active
  - Expected noise/gain are confirmed
  - Thermal performance as expected
  - Interlock/safety are carefully verified
- 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 $\sim 1\%$ for 1 TeV electron energy deposits
Trigger and Data acquisition

- 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 $L=2\times10^{34}$ cm$^{-2}$s$^{-1}$)
  - Clock and bunch taken from LHC
- Ethernet switch -> Servers on surface
- All components are installed and pass 1KHz test: 2021 JINST 16 P12028
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 ~50 nm
- Angular resolution ~0.35 mrad
- No Timing information

Pilot detector (29 kg) exposed in TI18 for 1 month in 2018
- Observed first collider \( \nu \) candidates (2.7\( \sigma \)) with 12.2 fb-1 data!
- Phys. ReV. D 104, L091101
Installation

Spring 2019

Autumn 2020

Winter 2021
- Full Installation Video
  - [https://faser.web.cern.ch/faser-installation](https://faser.web.cern.ch/faser-installation)
- Detector Paper
  - [arxiv: 2207.11427](https://arxiv.org/abs/2207.11427)

- Current partial (30%) FASERv
  - Frequent exchange in Run 3
  - 1st full detector July 26 (TS1)
  - 2nd full detector Sep 13 (TS2)
Test Beam @ CERN H2 beam (2021)
- Electrons (5-300 GeV), muons (200 GeV) and pions (200 GeV)
- 6 ECAL modules (inc. spares)
- Along with IFT and preshower
- Paper in preparation

Calo E resolution

Tracking resolution

σ < 30 μm
Currently data-taking

Saw first beam particles from recent 6.8 TeV beam optics tests. First particles traversing full detector, including FwdVeto and IFT.
Ongoing Mock Data Challenge (MDC) to ensure readiness for data-taking
- Test full production chain from generation all the way through to analysis
- Representative background and signal processes have been produced

Goal: demonstrate end-to-end analysis workflow
- Finalise software: determine readiness & find missing pieces
- In addition, jump start analysis effort already
Upgrade for 2023/2024

- Preshower scintillator will be replaced by hybrid pixel detector (100μm pitch, 130nm SiGe BiCMOS)
- Upgrade to enable detecting ALPs → γγ 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
Alternative Concept developed in Mainz

Idea: Use Micromegas Detectors

2111.14939.pdf
FASER - a new forward experiment at the LHC in the unused tunnel
- Search for light weakly-coupled particles in MeV-GeV range
- Probe TeV-energy neutrino in all flavors - First collider neutrino candidate is published!

- All detectors installed in TI12
- Great progress of test beam analysis and commissioning to verify expected performance

- Data Taking Ongoing
  - We are excited to get our first physics results