The FASER Experiment: Dark Photon and ALP Searches

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Introduction: The FASER Experiment

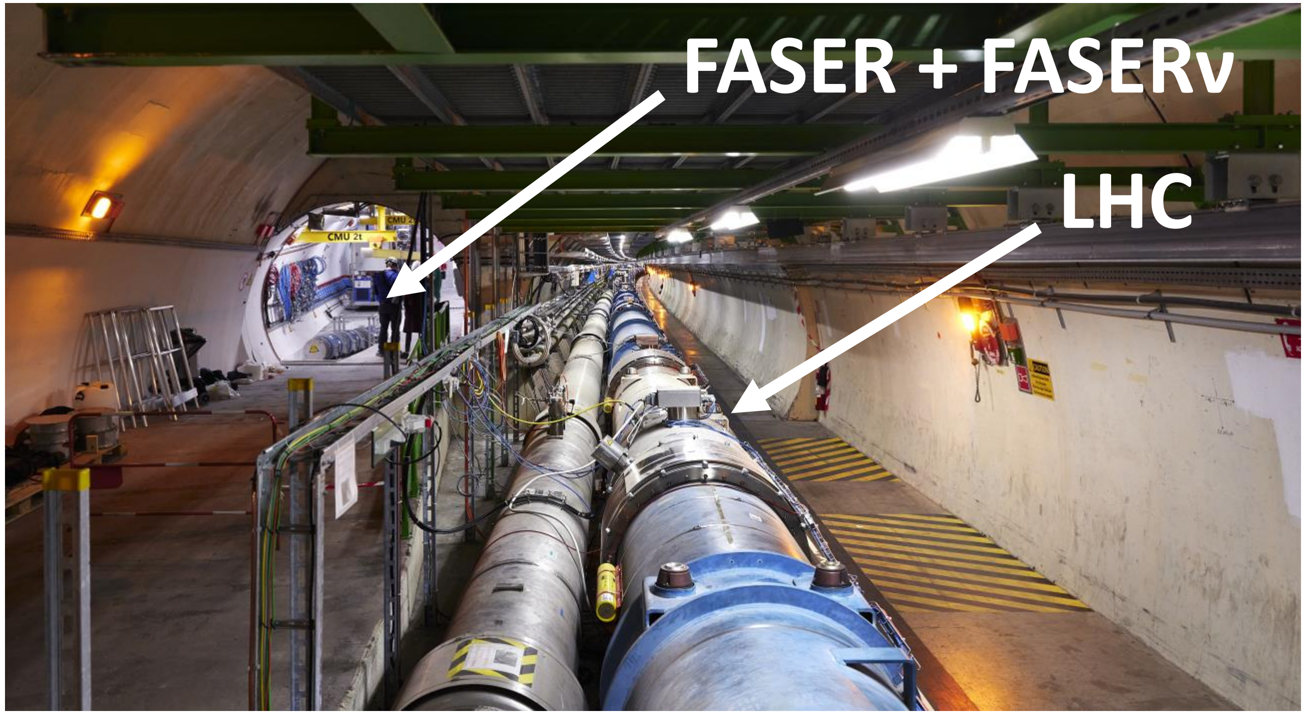
FASER is a new, small experiment designed to search for new long-lived particles (LLPs), and to study high energy neutrinos, produced at the ATLAS Interaction Point

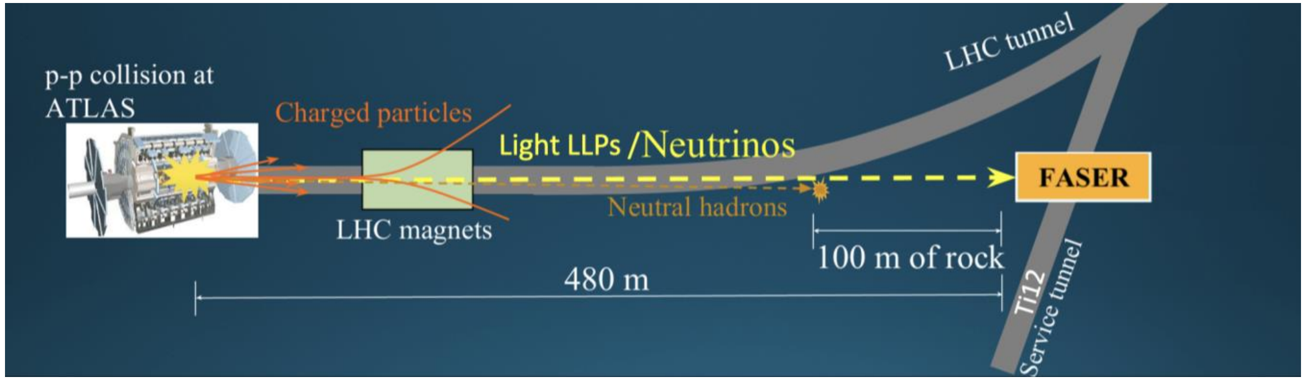
FASER targets new long-lived BSM particles including dark photons and ALPs

This talk:

Dark photon analysis – results shown at Moriond in March 23

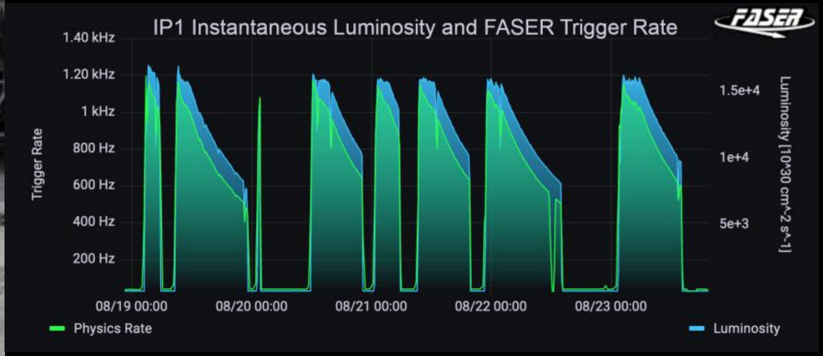
ALP analysis – ongoing, the final focus of my thesis





Operations

- Completed shifts as Run Manager and Monitoring Shifter since arriving at CERN in October



- Successful operation throughout 2022
- All detector components working very well

Calorimeter

- Concluding paper on 2021 Test Beam

Detector Paper

- ariXiv:2207.11427

Dark Photon Search: Event Selection

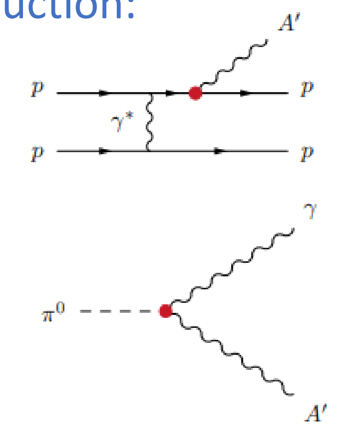
- The dark photon (A') is a common feature of hidden sector models
  - Weakly coupling to SM via kinetic mixing (ε) with SM γ

$$\mathcal{L} \supset \frac{1}{2} m_{A'}^2 A'^2 - \epsilon \, e \sum_f q_f \bar{f} \not{A}' f$$

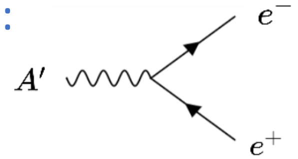
- FASER targets small ε -> long A' decay length
  - $m_{A'} < 2\, m_\mu$, A' decays 100% to e^+e^- pairs

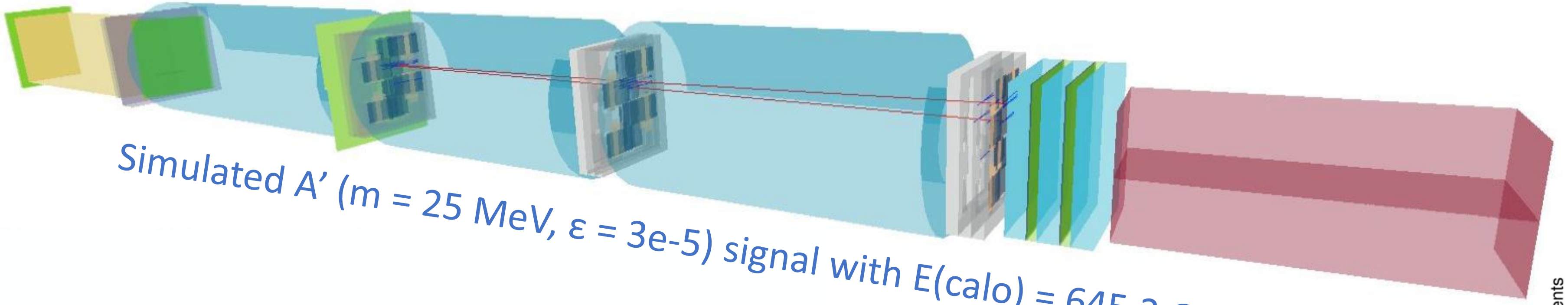
$$L = c\beta\tau\gamma \approx (80\ \text{m}) \left[\frac{10^{-5}}{\epsilon}\right]^2 \left[\frac{E_{A'}}{\text{TeV}}\right] \left[\frac{100\ \text{MeV}}{m_{A'}}\right]^2$$

A' Production:



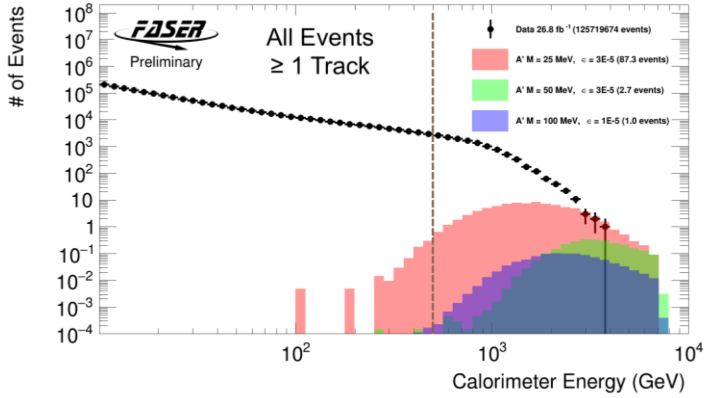
A' Decay:





Simulated A' (m = 25 MeV, ε = 3e-5) signal with E(calo) = 645.2 GeV

- A' → e^+e^- event selection optimised for discovery



> Collision event with good data quality
> No signal (< 40 pC) in any veto scintillator
> Exactly 2 good fiducial tracks
> - p > 20 GeV and r < 95 mm
> - Extrapolating to r < 95 mm at vetos
>
> Timing and pre-shower consistent with at least 2 MIPs
> Calo E > 500 GeV

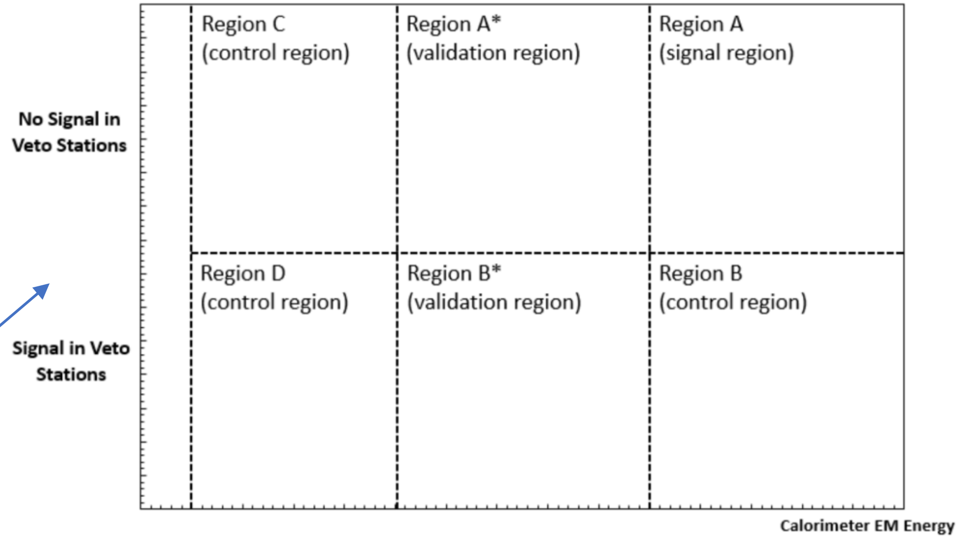
- Involved with studying the selections – particularly related to the calo

Dark Photon Analysis: Background and Uncertainty

- This is a low-background analysis, the main sources are:
  - Neutrino interactions
  - Veto inefficiencies
  - Non-collision beam background and cosmics
  - Neutral hadrons from upstream muons

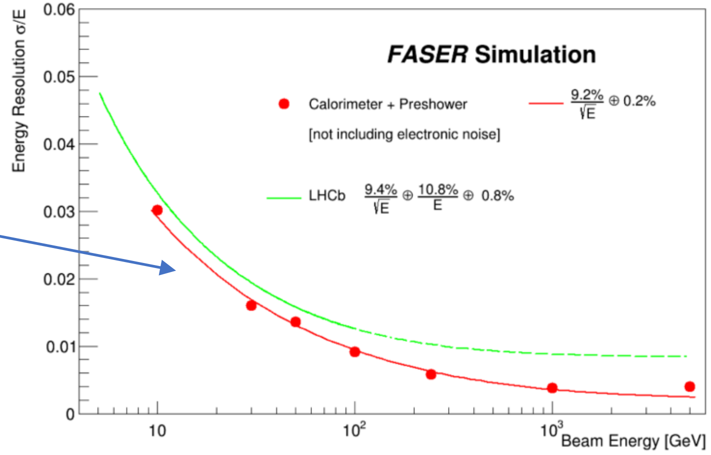
Total background prediction:
$N = (2.02 \pm 2.4) \times 10^{-3}$

- I validated these background predictions with data
  - Data-driven ABCD method



- The main systematics to be taken into account:
  - MC generator uncertainties
  - Uncertainty on the luminosity from ATLAS
  - Modelling of detector response in MC
  - **Calorimeter energy scale calibration**

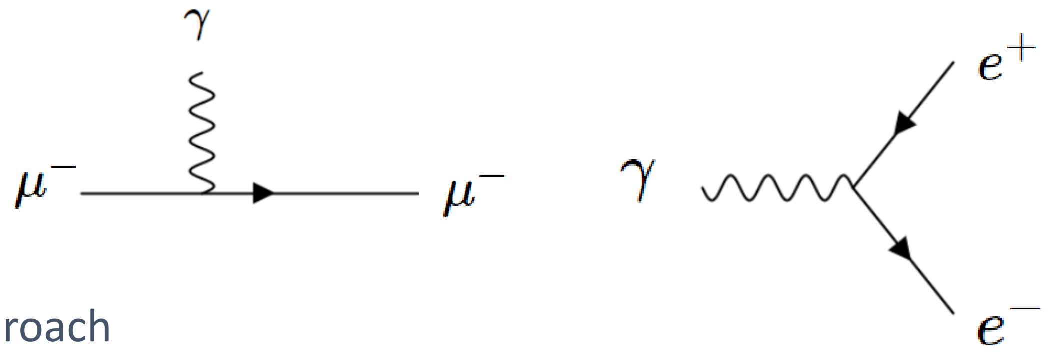
My work on the Test Beam showed a difference in energy resolution between data and MC



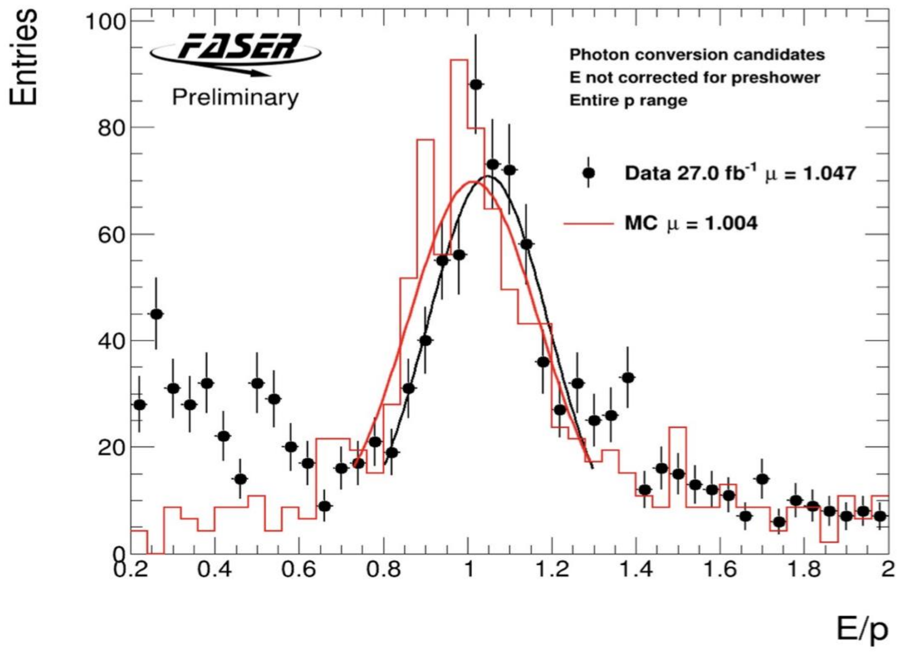
From FASER detector paper

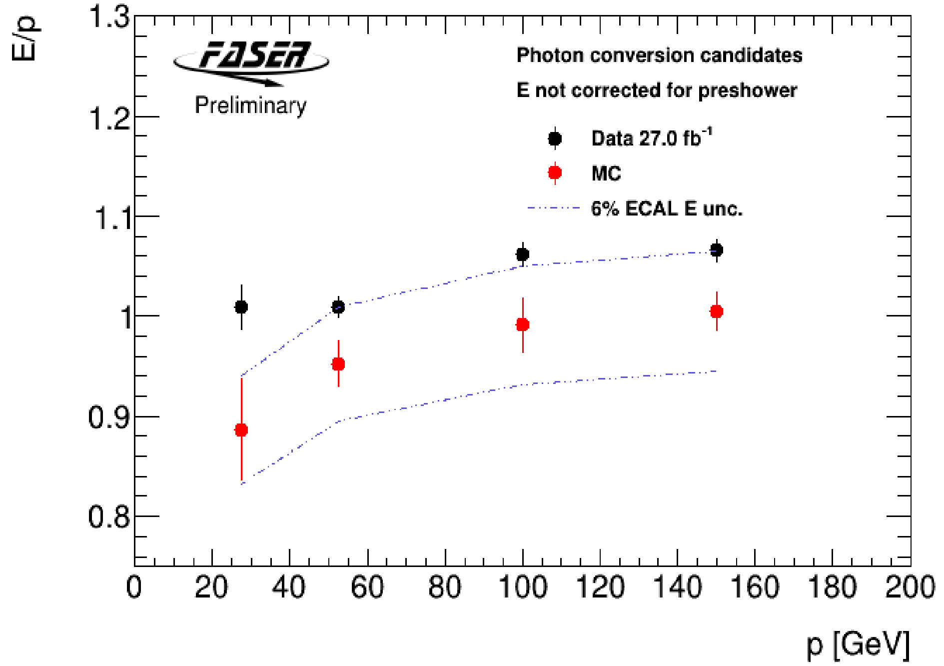
Dark Photon Analysis: Calorimeter Systematics

- The Test Beam gave a bottom-up estimate of 6% uncertainty
  - MC was calibrated to account for this



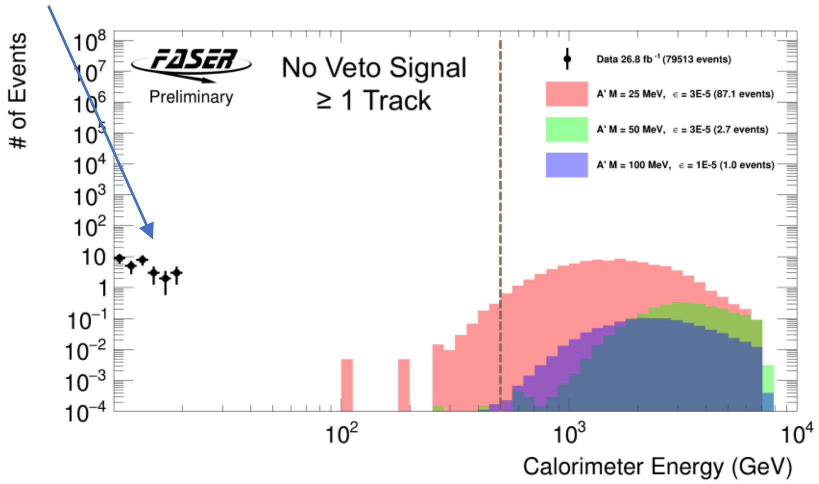
- I carried out a validation of this calibration using a top-down approach
  - Comparison of E/p distributions of isolated photon conversion events



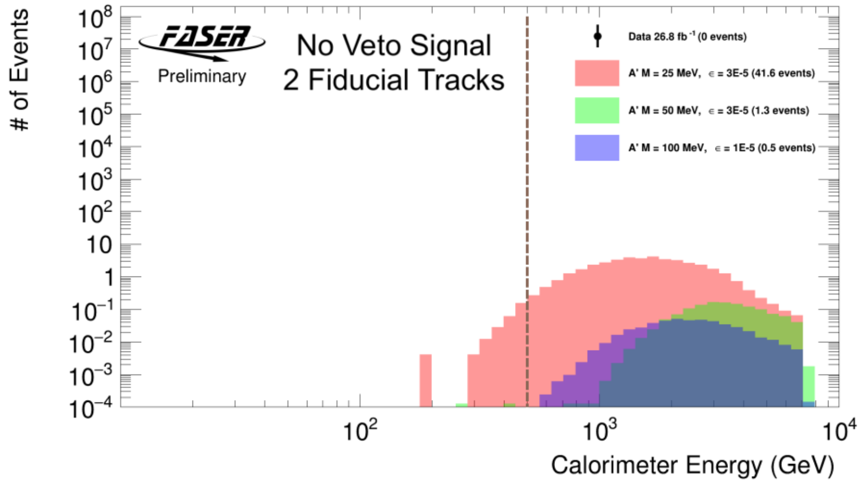


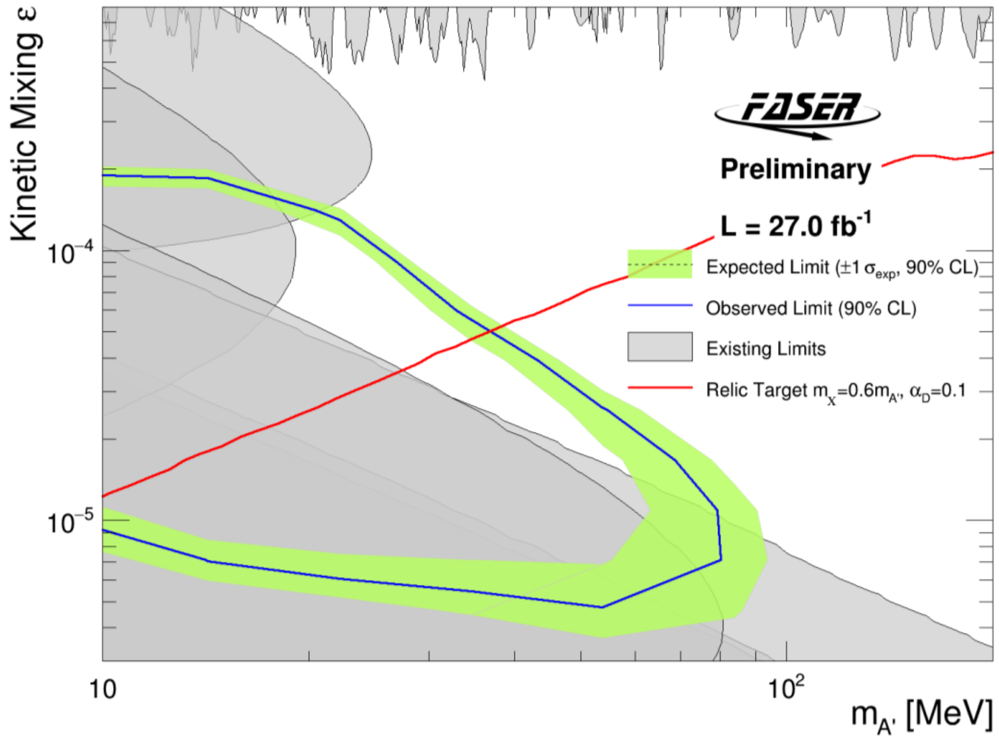
Dark Photon Analysis: Results

- Small number of events with at least one track



- No events in unblinded signal region
  - When looking for 2 fiducial tracks





- Based on this null result, FASER is able to set limits in previously unexplored parameter space!
  - Public conf note:

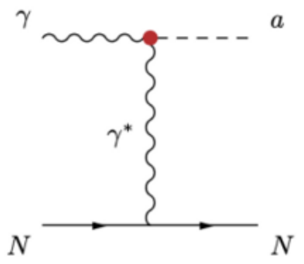
    CERN-FASER-CONF-2023-001

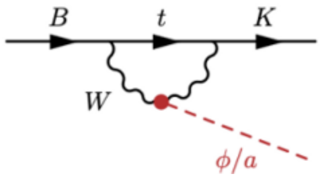
ALP Search

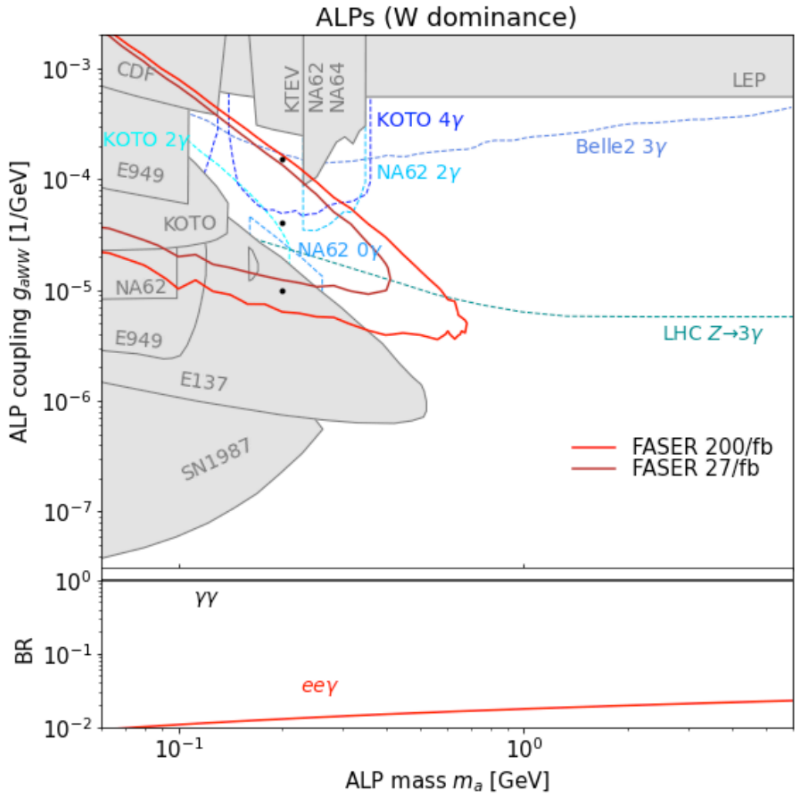
- Axion-like particles (ALPS, a) are weakly interacting, pseudoscalar particles that can have coupling g between the SM and a dark sector

$$\mathcal{L} \supset -\frac{1}{2} m_a^2 a^2 - \frac{1}{4} g_{a\gamma\gamma}\, a F^{\mu\nu} \widetilde{F}_{\mu\nu}$$

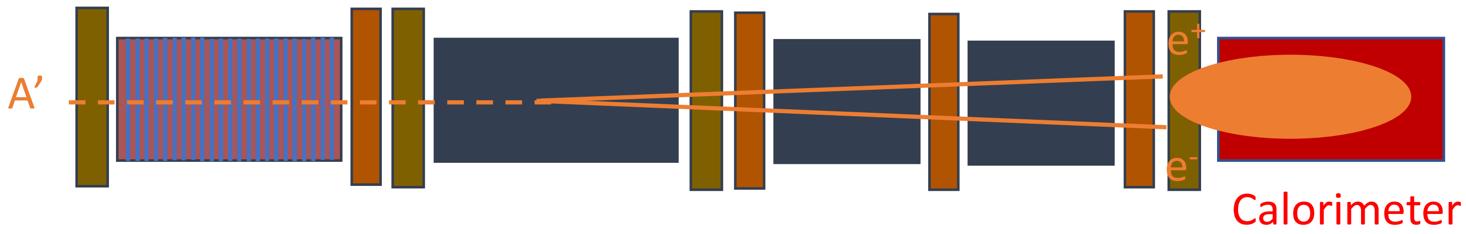
ALP Production:

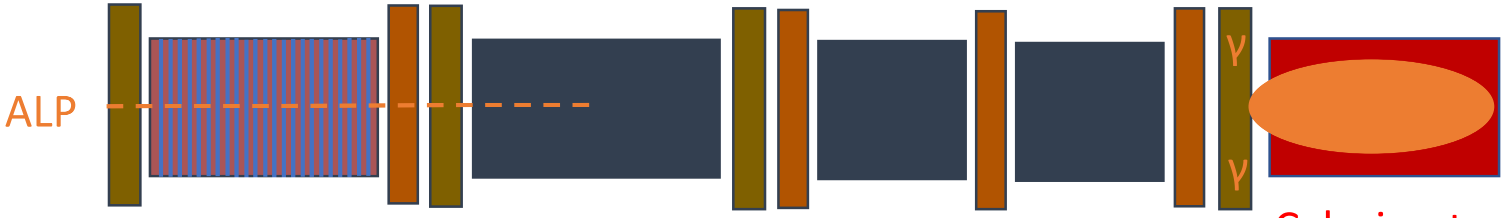




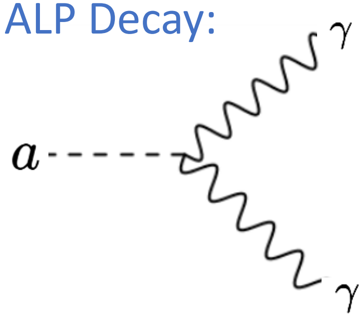


- Very different signature compared to A'
  - No tracks!



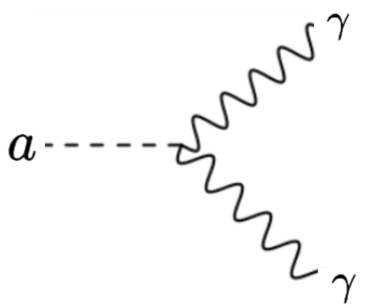


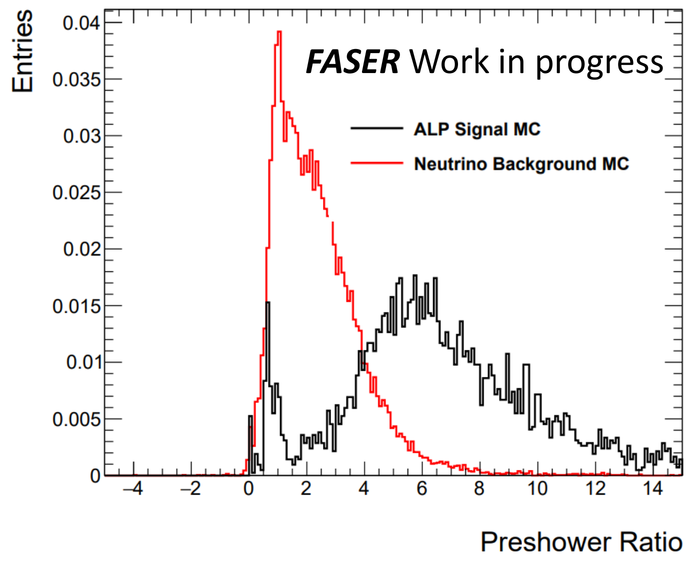
ALP Decay:

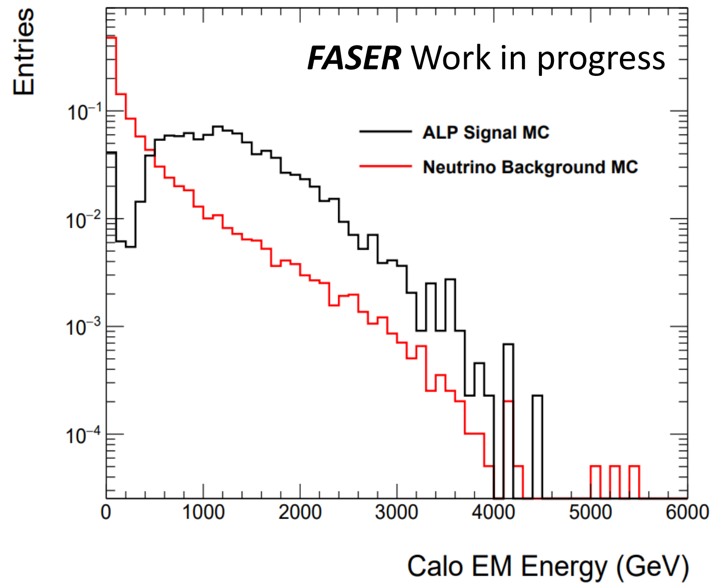


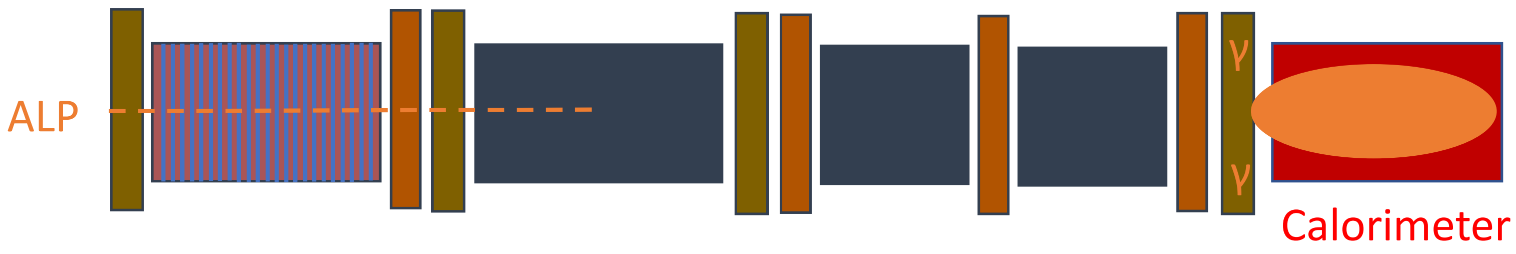
ALP Search (2)

- The main handles will be preshower and calorimeter signals
  - The calorimeter has been the focus of my simulation and test beam studies so far
- We already have some reach with the 27 fb^{-1} used in the A' analysis
  - This extends even further as Run 3 continues
- Already began to establish a baseline selection
  - Likely to be a non-zero background analysis looking for 0-track events







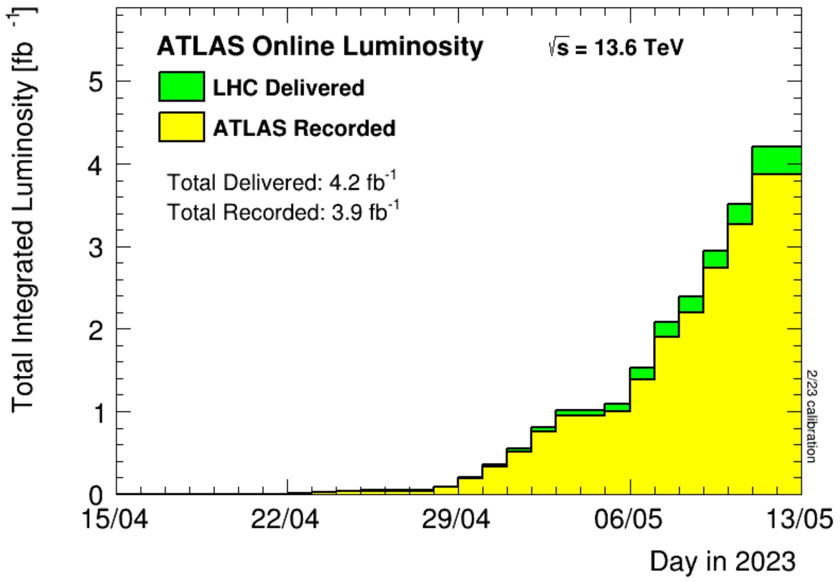


Summary

Operations
- FASER successfully took data in first year of Run 3
  - Running with fully functional detector and very good efficiency
  - Operating well for the start-up of 2023 LHC running
  - Run 3 2022: 27.0 fb^{-1} used for Dark Photon Analysis
  - Already delivered 4.2 fb^{-1} to IP1 so far this year

Dark Photon Analysis
- Study of potential backgrounds and systematic uncertainty in the calo
- Results excluded A' in region of low mass and kinetic mixing

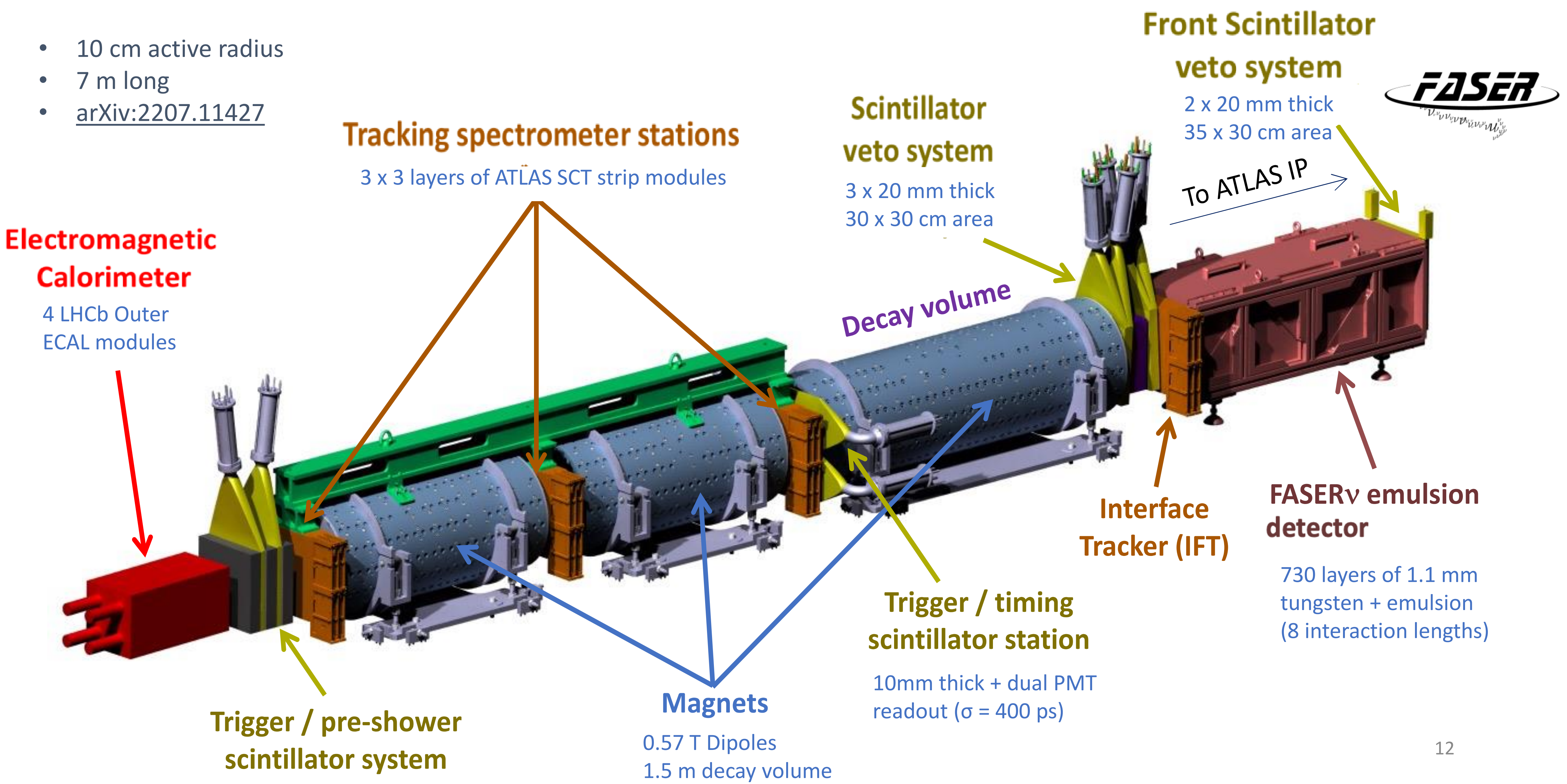
ALP Analysis
- Study of baseline selection underway for a 0-track analysis
- Comparison of signal MC with background estimates
- This will form the final focus for my thesis



Backup Slides

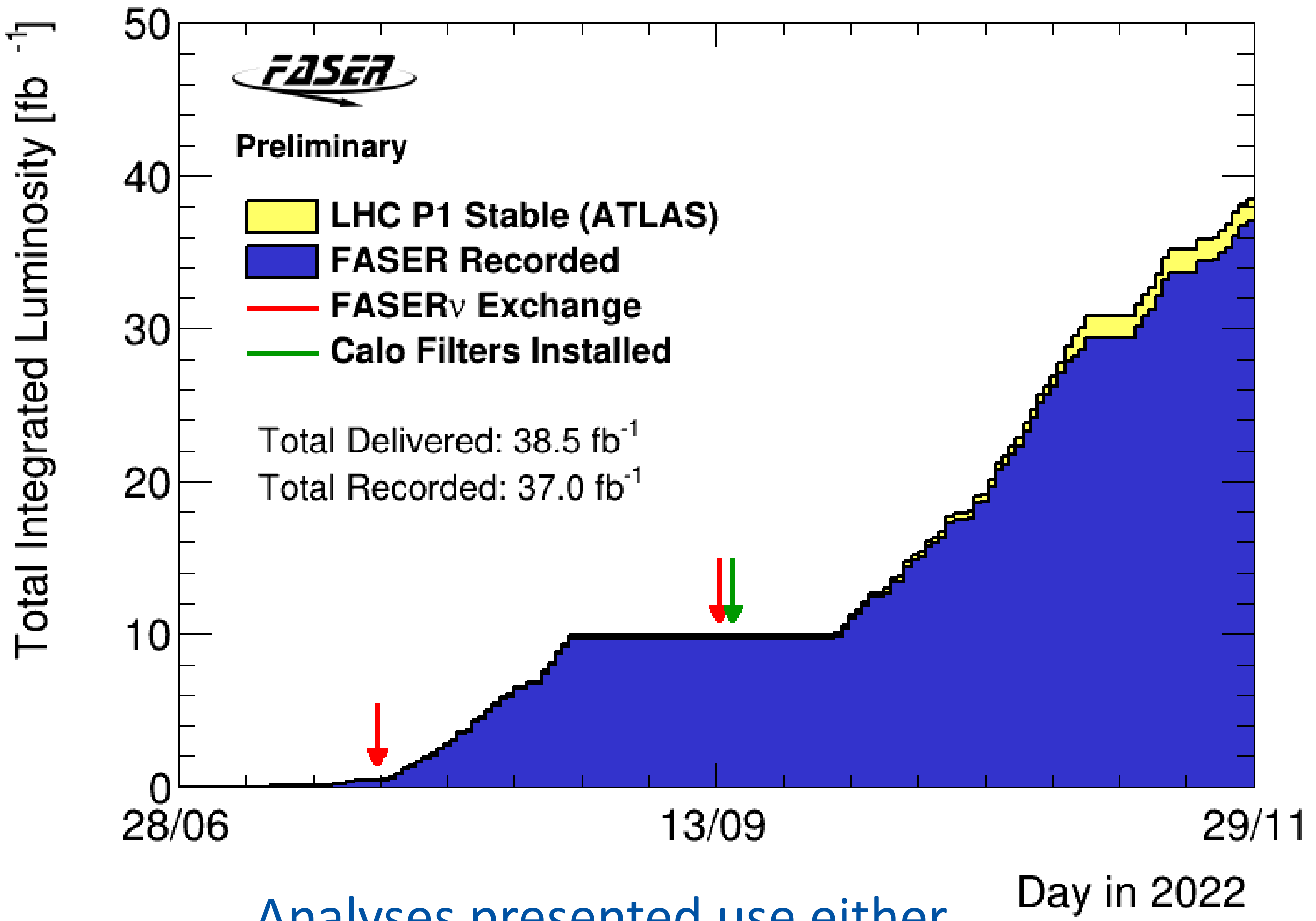
The FASER Detector

- 10 cm active radius
- 7 m long
- arXiv:2207.11427



FASER Operations

- Successful operation throughout 2022
  - Continuous and largely automatic data taking
  - Up to 1.3 kHz trigger rate
- Recorded 96.1% of delivered luminosity
  - DAQ deadtime 1.3%
  - A couple of DAQ crashes
- Emulsion detector exchanged twice
  - To manage occupancy
  - First box only partially filled
- Calorimeter gain optimised for:
  - Low energy (< 300 GeV) before second exchange
  - High energy (up to 3 TeV) after this exchange



Analyses presented use either $35.4\ \text{fb}^{-1}$ or $27.0\ \text{fb}^{-1}$

Acknowledgements

- FASER is supported by:

SIMONS FOUNDATION

HEISING-SIMONS FOUNDATION

NSF

CERN

erc

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科研費 KAKENHI

- Additional thanks to:
  - LHC for the excellent performance in 2022
  - ATLAS for providing luminosity information
  - ATLAS for use of ATHENA s/w framework
  - ATLAS SCT for spare tracker modules
  - LHCb for spare ECAL modules
  - CERN FLUKA team for background sim
  - CERN PBC and technical infrastructure groups for excellent support during design construction and installation

FASER Collaboration

- 87 members across 24 institutes from 10 countries

FASER Publications

- The FASER Detector: arXiv:2207.11427
- The FASER W-Si High Precision Preshower Technical Proposal: CERN Document Server
- The tracking detector of the FASER experiment: NIM 166825 (2022)
- The trigger and data acquisition system of the FASER experiment: JINST 16 P12028 (2021)
- First neutrino interaction candidates at the LHC: PRD 104 L091101 (2021)
- Technical Proposal of FASERν neutrino detector: arXiv:2001.03073
- Detecting and Studying High-Energy Collider Neutrinos with FASER at the LHC: EPJC 80 61 (2020)
- Input to the European Strategy for Particle Physics Update: arXiv:1901.04468
- FASER's Physics Reach for Long-Lived: PRD 99 090511 (2019)
- Letter of Intent: arXiv:1812.09139
- Technical Proposal: arXiv:1811.10243