FORWARD SEARCH EXPERIMENT AT THE LHC

FASER Status

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On behalf of FASER Collaboration

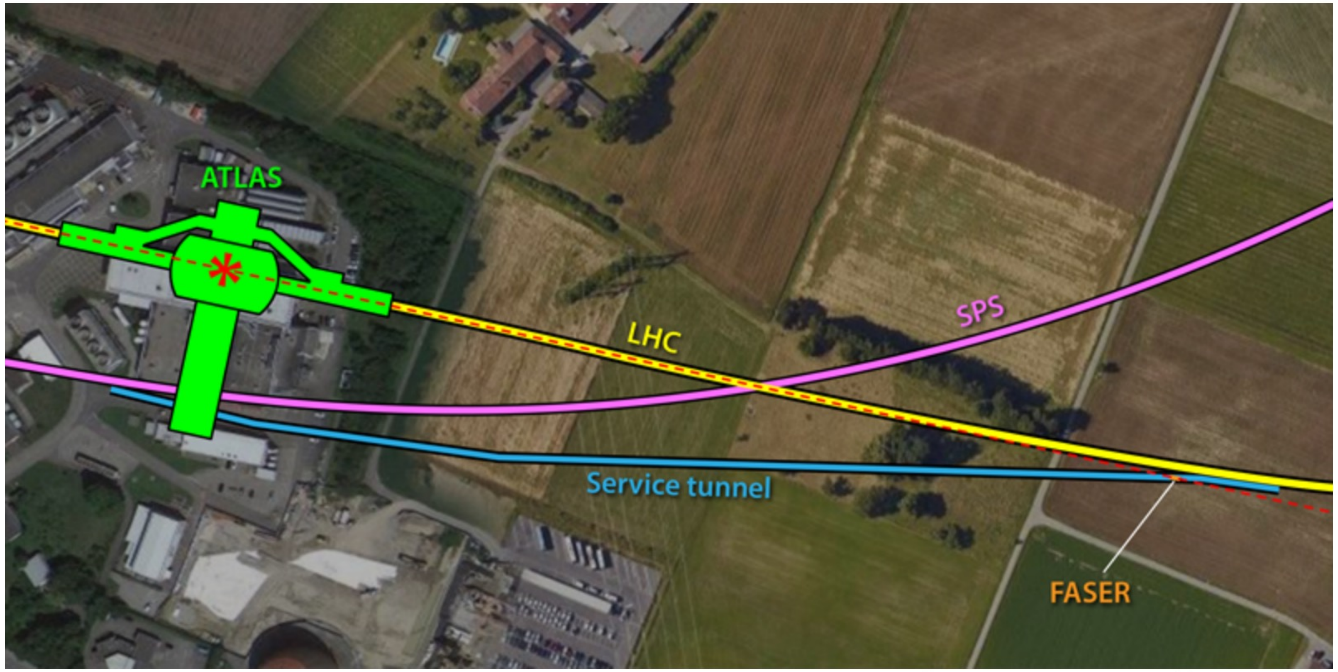
LHC Forward Physics July 2024 Workshop

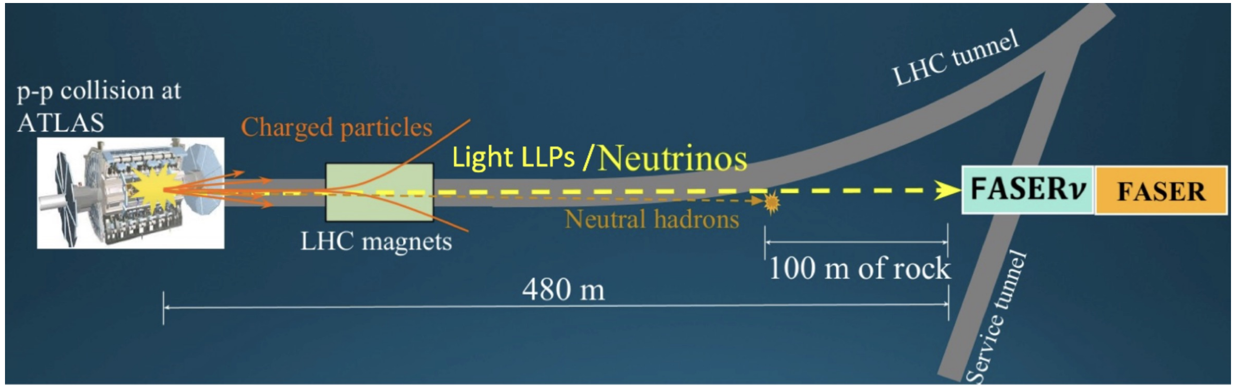
July 15, 2024

HEISING-SIMONS FOUNDATION SIMONS FOUNDATION CERN erc 科研費 KAKENHI NSF Swiss National Science Foundation

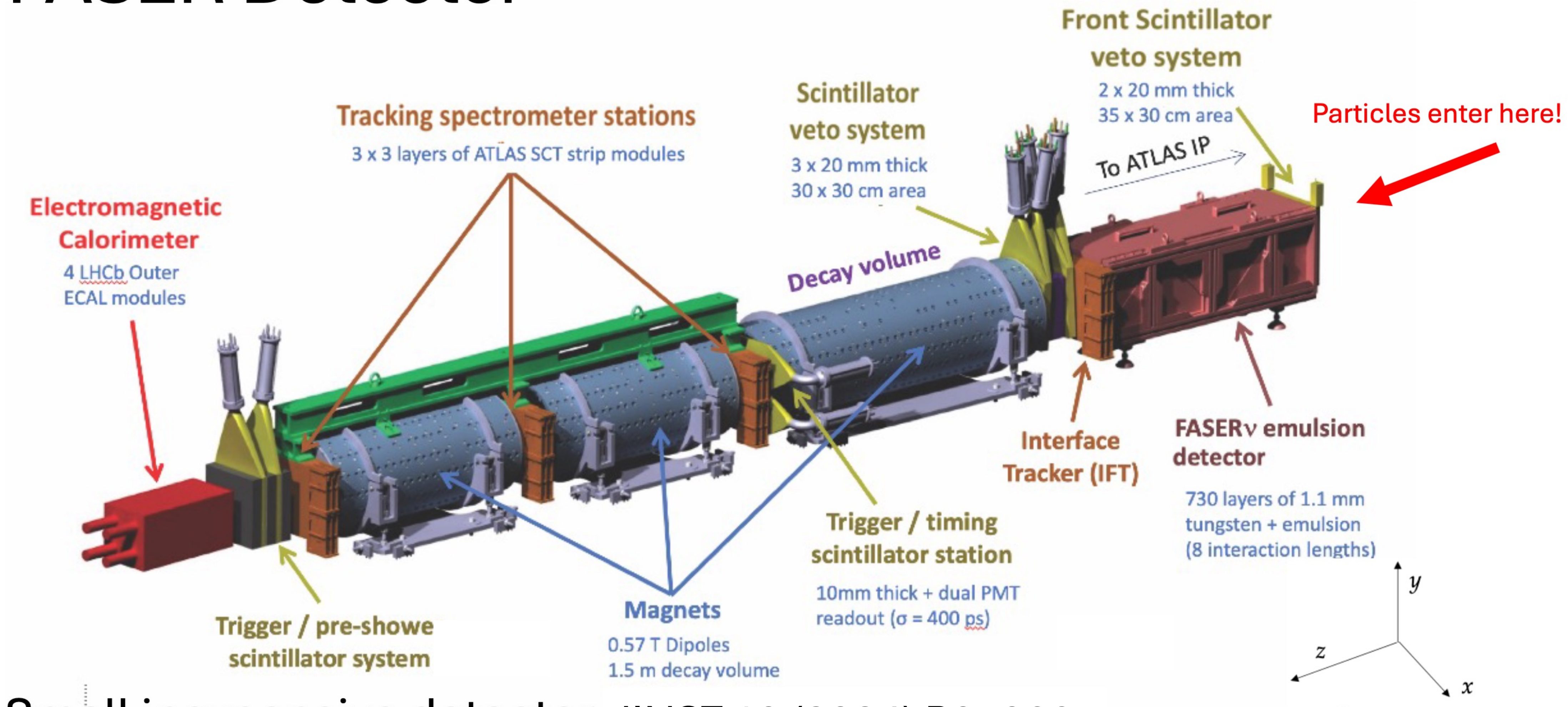
FASER: A quick introduction

- ForwArd Search ExpeRiment
  - Built between 2019-2021
  - 101 members, 27 institutes, 11 countries
- Located 480 m from ATLAS
  - Aligned with ATLAS collision axis (LOS)
- Receives particles coming from ATLAS IP in the forward direction ($\eta > 9.2$)
  - Weakly coupled, light new pactilces (dark sector)
  - Neutrinos produced in hadron decays
- Shielded by 100 m of rock



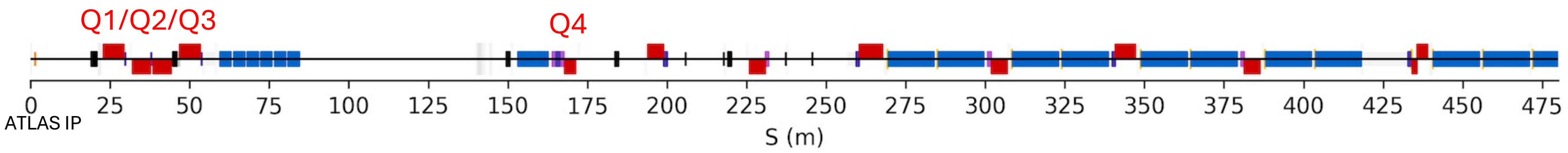


The FASER Detector

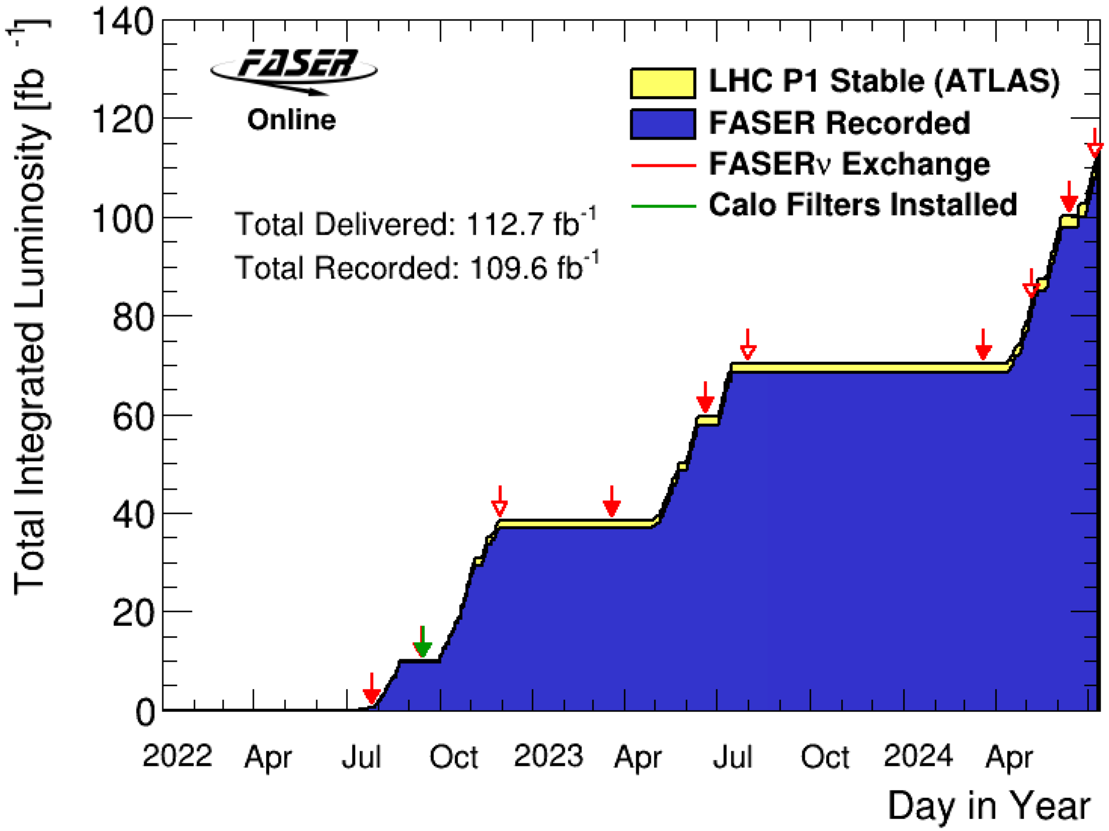


- Small inexpensive detector JINST 19 (2024) P05066
  - 10cm radius of active volume
  - 7m long

Data Taking



- LHC resumed collisions around Easter in 2024
- Updated LHC configuration in 2024
  - To protect inner triplets (Q1/Q2/Q3) from radiation
    - Triplet polarity reversed
    - Q4 magnet switched off
- Significant muon background in FASER
  - Muon background rate doubled compared to 2023
  - Higher energy (more occupancy from muon-induced radiation)
- FASERν can afford exposure ~ 3 weeks (15 fb^{-1})
- For electronic detector extra background not a major concern
  - Rate increased by ~50%

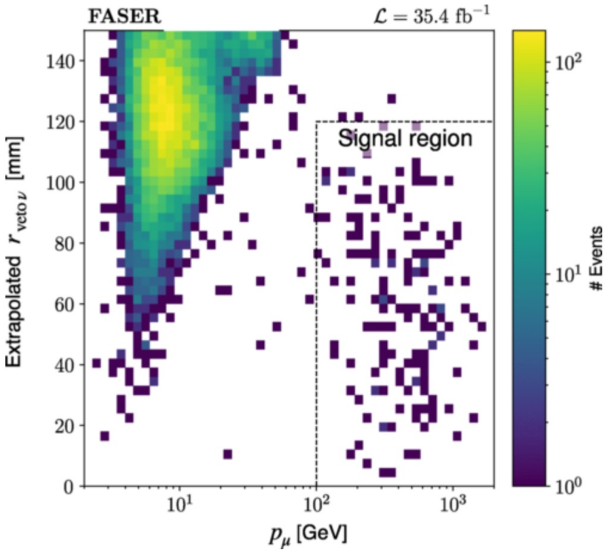


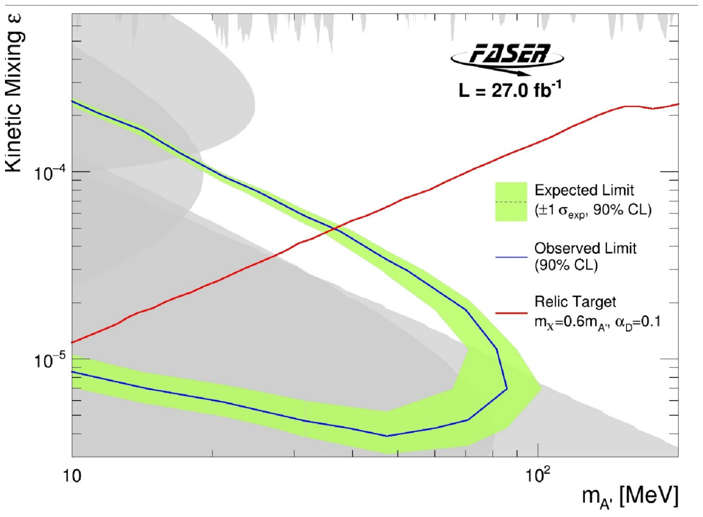
- 2022: 3 FASERν modules (F221, F222, F223)
- 2023: 2 FASERν modules (F231, F232)
- 2024: 3 FASERν modules (F241, F242, F243)

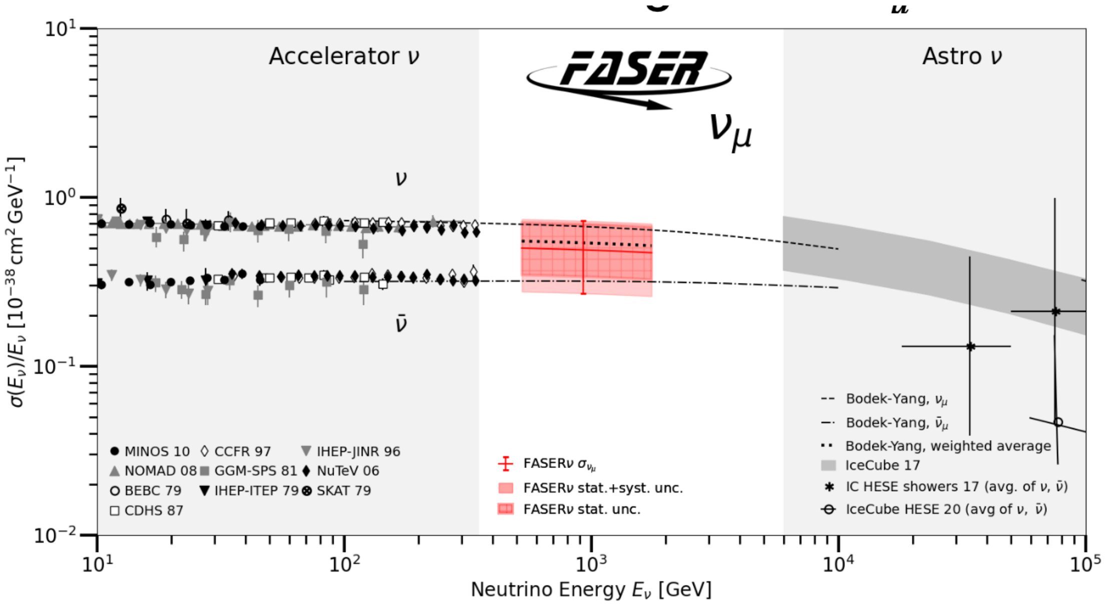
Latest results

[FASER Publications]

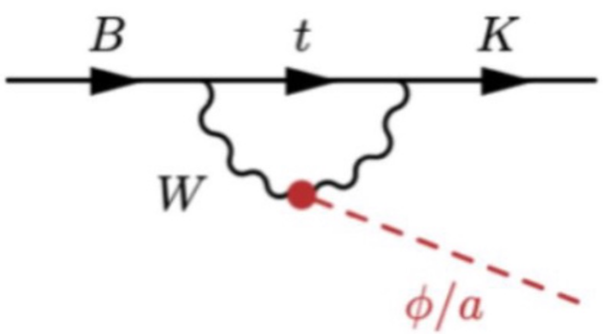
- Last FASER status presented at FPW-March-2024
- Search for Axion-like Particles in Photonic Final States with the FASER Detector at the LHC CERN-FASER-CONF-2024-001
- First Direct Observation of Collider Neutrinos with FASER at the LHC. PRL Synopsis
- Search for dark photons with the FASER detector at the LHC. PLB
- First Measurement of ν_e and ν_μ Interaction Cross Section at the LHC with FASER's Emulsion Detector. PRL



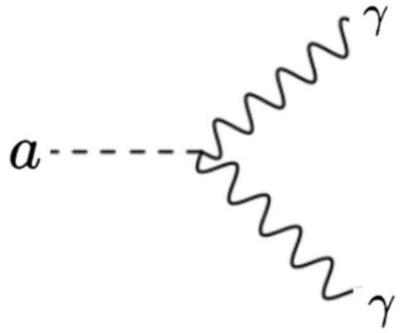


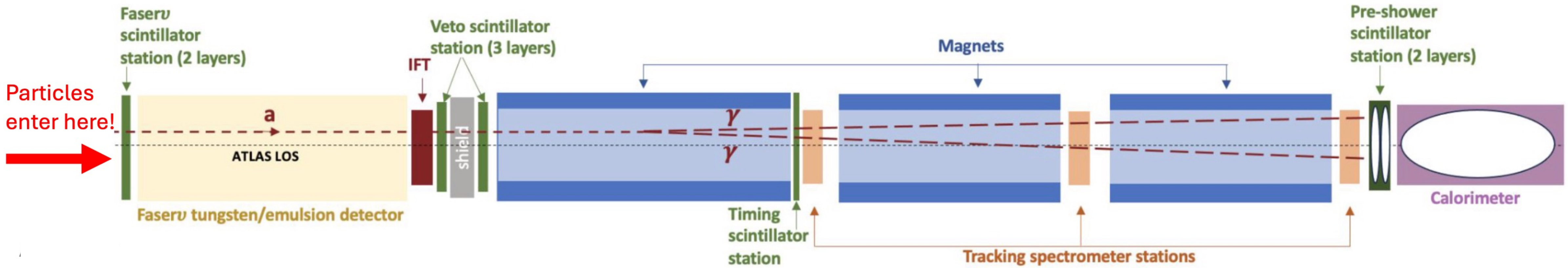


Axion-Like-Particles (ALPs)



- FASER can also probe several types of ALPs models!
  - Especially sensitive to scenarios in which the ALP couples to the $SU(2)_L$ gauge bosons
- The ALPs in our sensitivity range are dominantly produced by B^0, $B^{\pm}$ meson decays
- Once produced, the ALP decays into two high energy photons
  - These cannot be distinguished in our calorimeter
- Signal: Two photons appearing from "nothing" with ~TeV of EM energy
- Can decay anywhere in FASER spectrometer volume

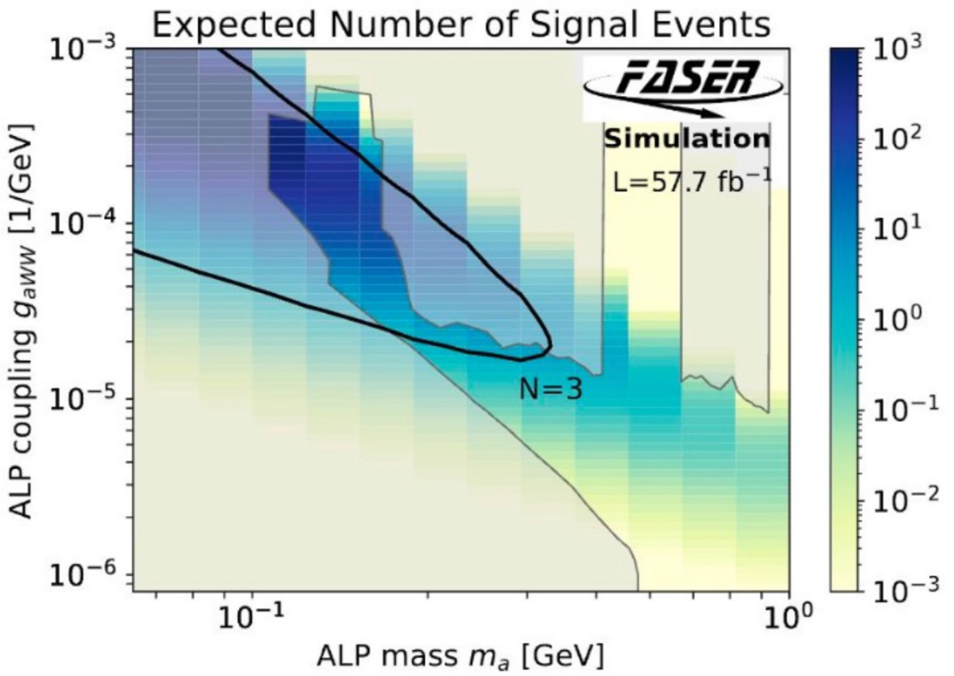




ALPs Analysis

Requirements

- No signal in any of the 5 veto scintillators
- No signal in the timing scintillator
- Evidence of EM Shower in preshower detector
- Significant energy deposit in electromagnetic calorimeter



Backgrounds

- Neutral hadrons
- Large-angle muons
- Cosmic events
- **Neutrinos**
- The main background in this analysis arises from non-negligible charge—current neutrino interactions

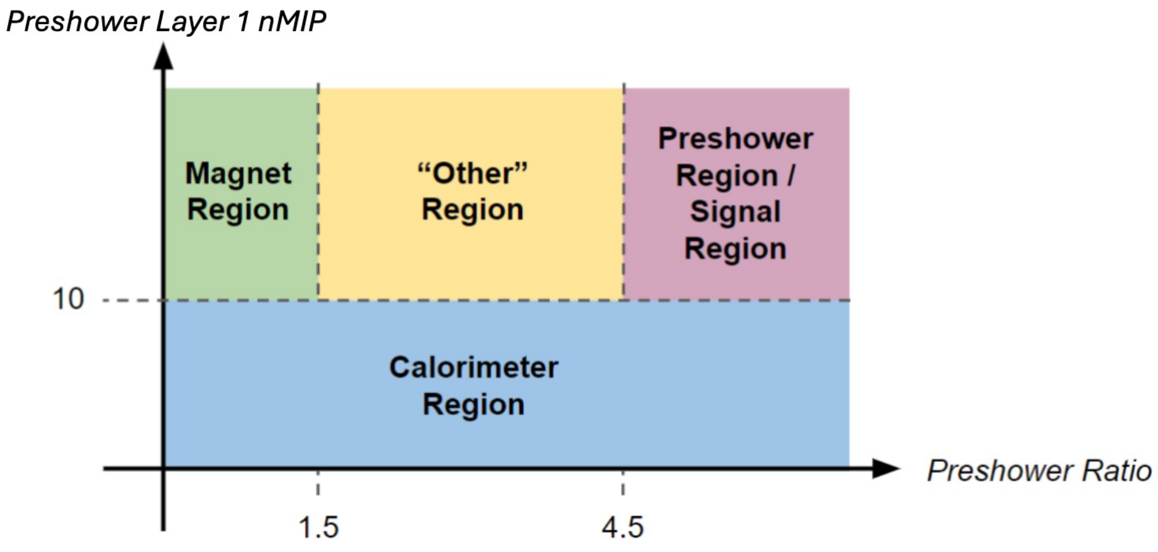
Selection	Efficiency	Cum. Efficiency
$m_a = 140$ MeV, $g_{aWW} = 2 \times 10^{-4}$ GeV^{-1}		
Veto Signal nMIP < 0.5	99.6%	99.6%
Timing Scintillator Signal nMIP < 0.5	97.8%	97.4%
Preshower Ratio > 4.5	85.7%	83.5%
Second Preshower nMIP > 10	98.6%	82.3%
Calo $E > 1.5$ TeV	91.6%	75.4%

Background Estimation: Neutrinos

- Neutrinos produced upstream of FASER through light/charm hadron decays – charged/neutral current interactions in FASER
- Evades veto, but interacts near/in preshower/calorimeter → mimics signal
- Background evaluated with MC Simulations and validated in different detector regions
- Validation regions are defined via two preshower cuts

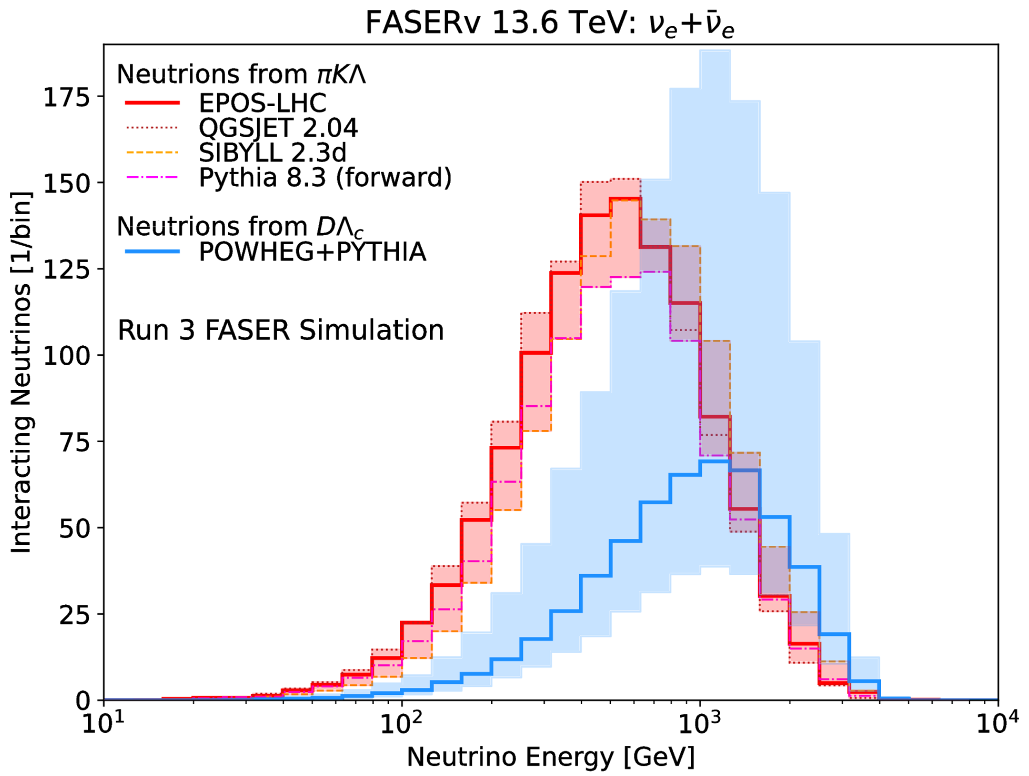
For 57.7 fb^{-1}

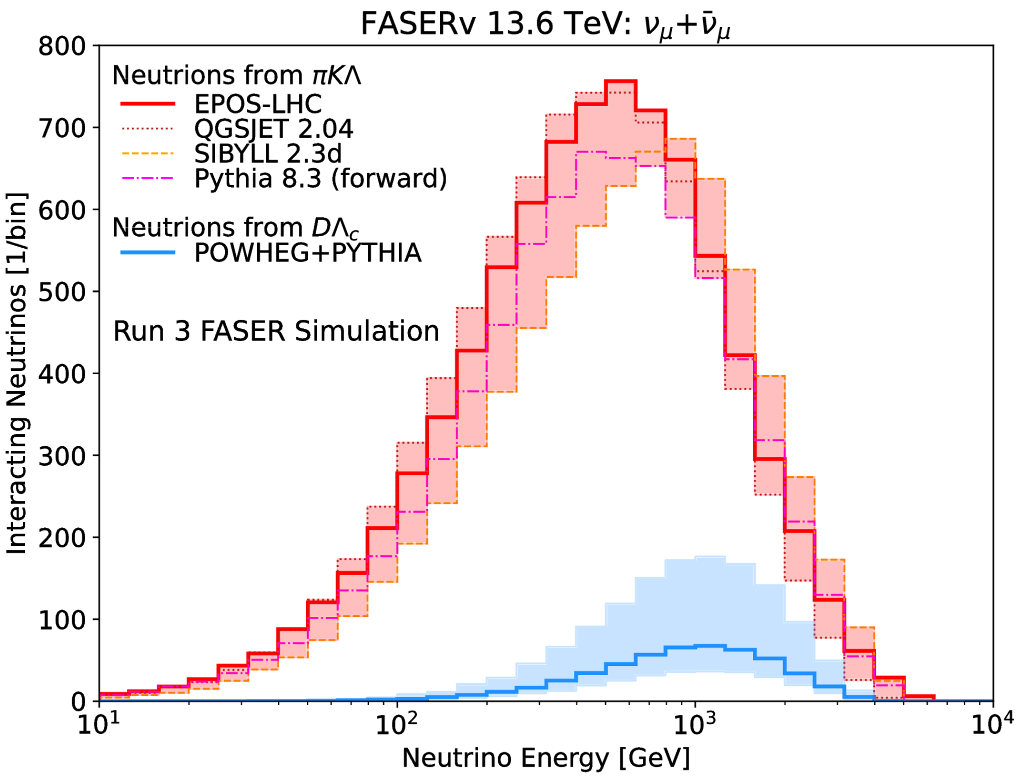
	> 1.5 TeV signal region
Light	$0.23^{+0.01}_{-0.11}$ (flux) $\pm$ 0.11 (exp.) $\pm$ 0.04 (stat.)
Charm	$0.19^{+0.32}_{-0.09}$ (flux) $\pm$ 0.06 (exp.) $\pm$ 0.03 (stat.)
Total	**0.42 $\pm$ 0.38 (90.6%)**



Background Estimation: MC Samples and Uncertainties

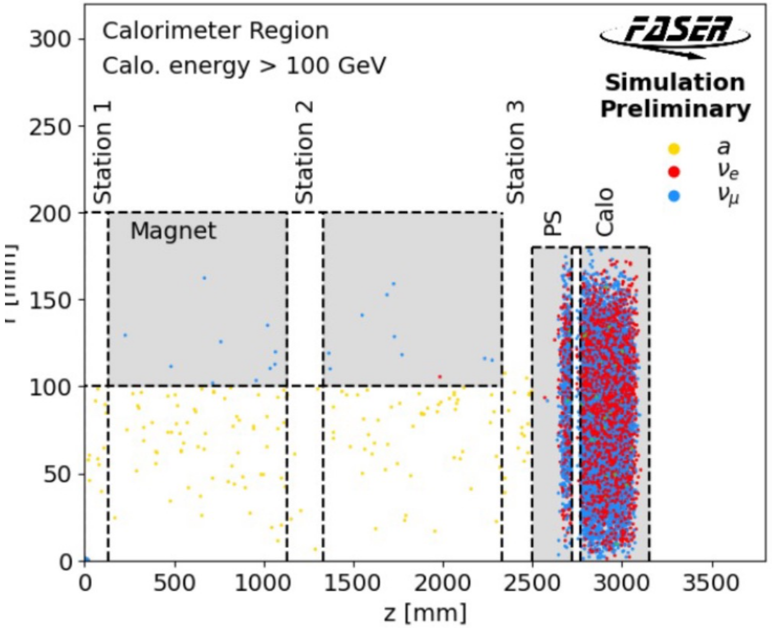
- Neutrino rate predictions for FASER PRD
  - Light flavor hadron decays
    - Central value: Predictions from EPOS PRC
    - Uncertainty: spread from SIBYLL 2.3d PRD , QGSJET 2.04 PRD and Pythia 8.3 arXiv with a dedicated tune)
  - Charm decays
    - Central value: NLO prediction implemented in POWHEG JHEP
    - Uncertainty: from scale variations

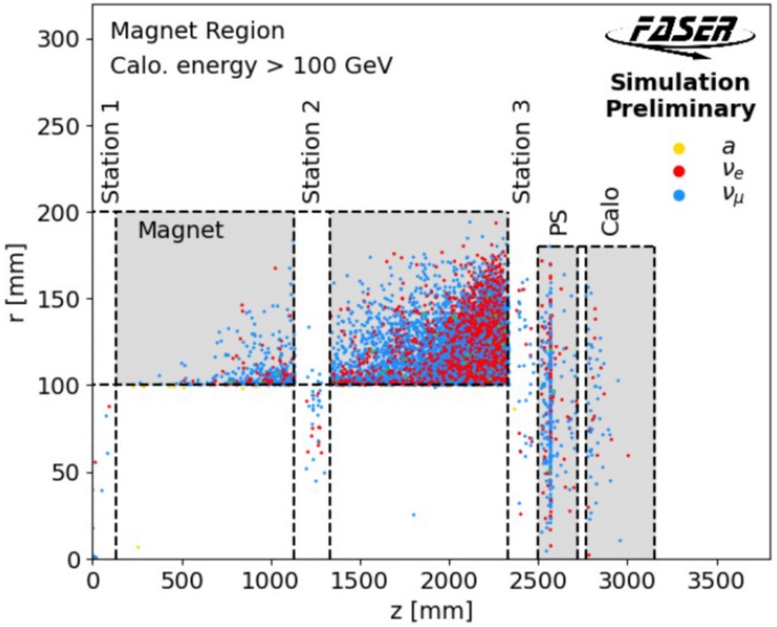


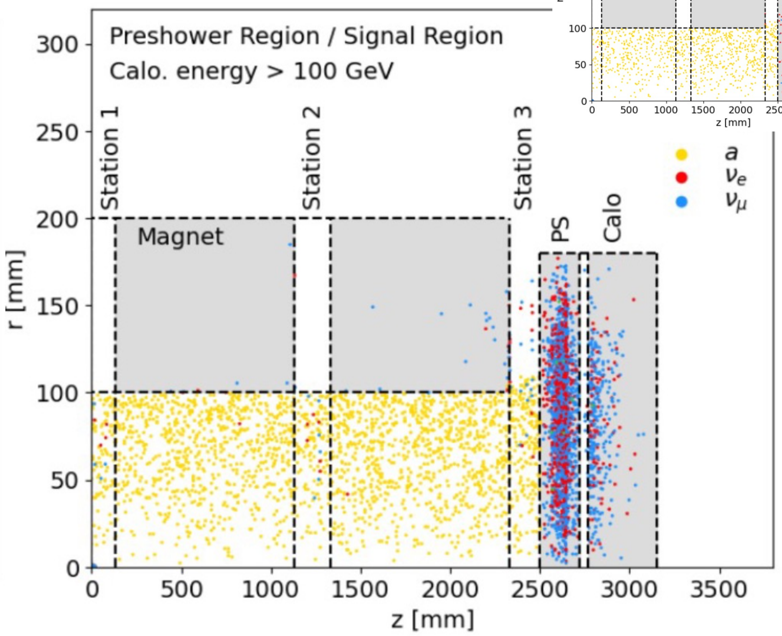


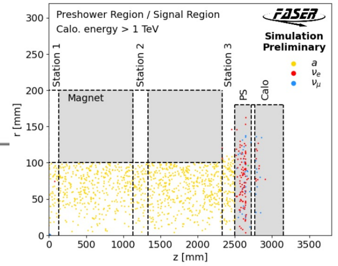
Background Estimate Validation

- Distribution of neutrino interaction vertices and decay vertex of representative ALP signal model with $m_a = 120$ MeV and $g_{aWW} = 10^{-4}$ GeV-1
- Magnet and calorimeter regions have high efficiency (80%) and purity (>90%) for neutrino events
- Preshower Region’s efficiency is < 40%









Good agreement between neutrino MC prediction and data in validation regions

Calorimeter	
MC	62.7 ± 19.7 (31.4%)
Data	74

Magnet	
MC	43.5 ± 18.2 (41.9%)
Data	34

Preshower	
MC	17.8 ± 5.1 (28.8%)
Data	15

Uncertainties

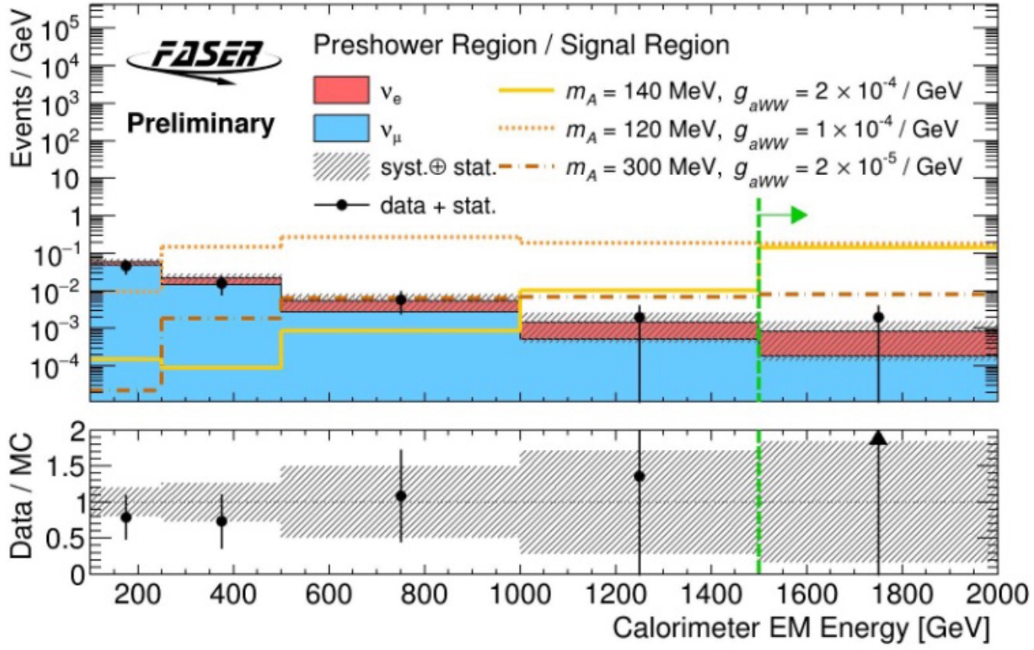
- 3 primary sources of systematic uncertainty on the expected signal in this analysis + statistical uncertainty
- **Modeling of flux of SM particles from LHC <- Dominant source (60%)**
- Detector response to simulation – Calorimeter, Preshower layers
- Luminosity uncertainty: from ATLAS

Signal Sample	Flux	Stat.	Luminosity	Calorimeter	Second Preshower Layer	Preshower Ratio
$m_a = 140$ MeV $g_{aWW} = 2 \times 10^{-4}$ GeV^{-1}	59.4%	1.8%	2.2%	3.6%	0.6%	7.9%
$m_a = 120$ MeV $g_{aWW} = 10^{-4}$ GeV^{-1}	57.3%	3.5%	2.2%	16.3%	0.6%	6.9%
$m_a = 300$ MeV $g_{aWW} = 2 \times 10^{-5}$ GeV^{-1}	58.0%	2.9%	2.2%	15.8%	0.6%	8.4%

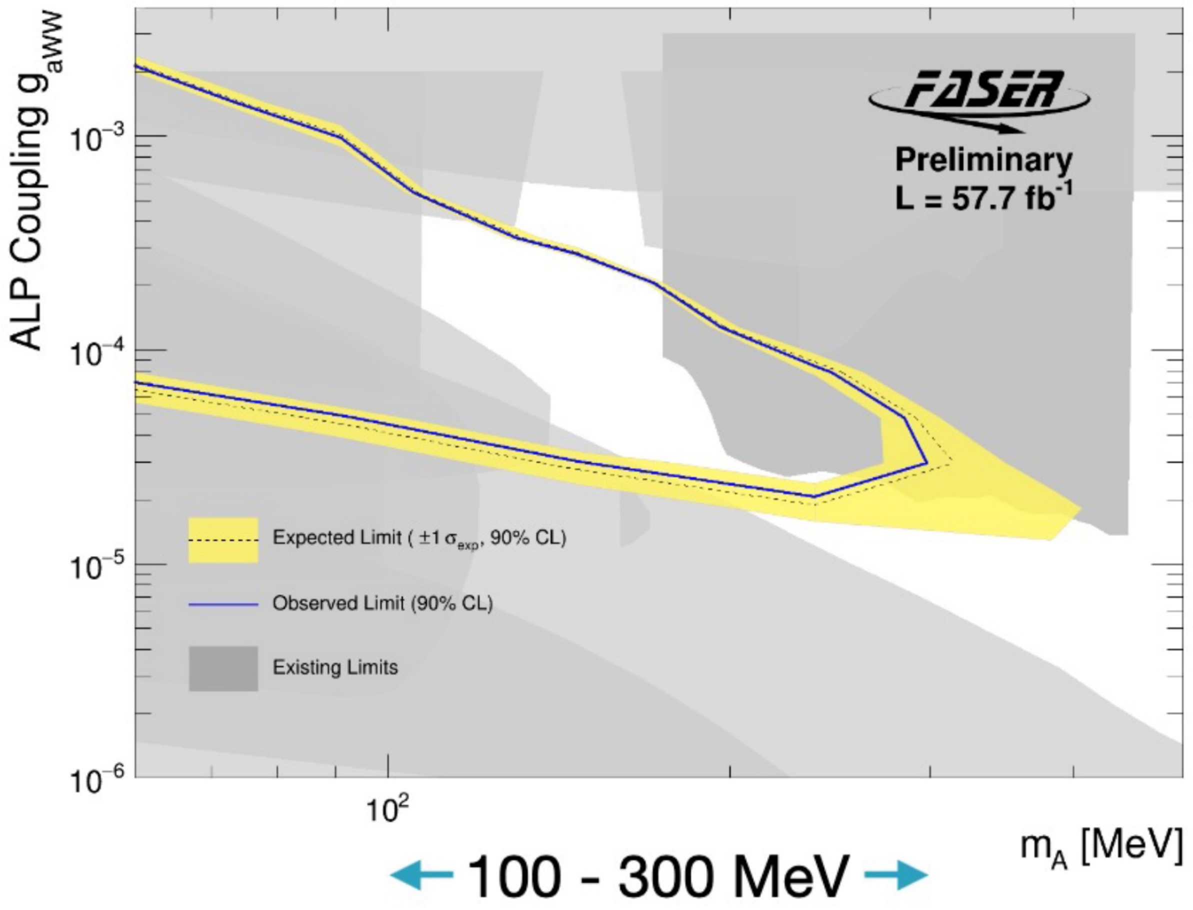
Unblinded Results

- In 57.7 fb^{-1} of data we saw **1 event** in unblinded signal region
- Expected background: 0.42 ± 0.38 events
- Preshower deposits consistent with EM Shower
- Calorimeter energy of **1.6 TeV**

Unblinded Signal Region



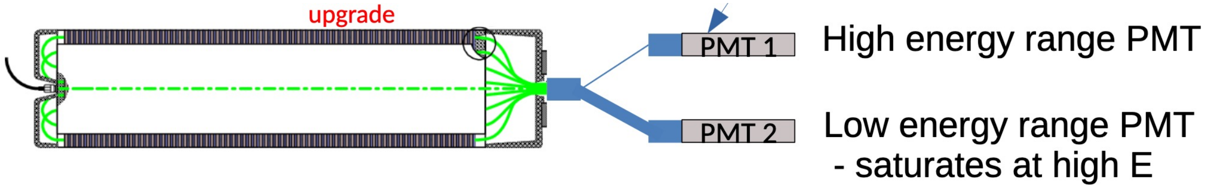
Observed Limit

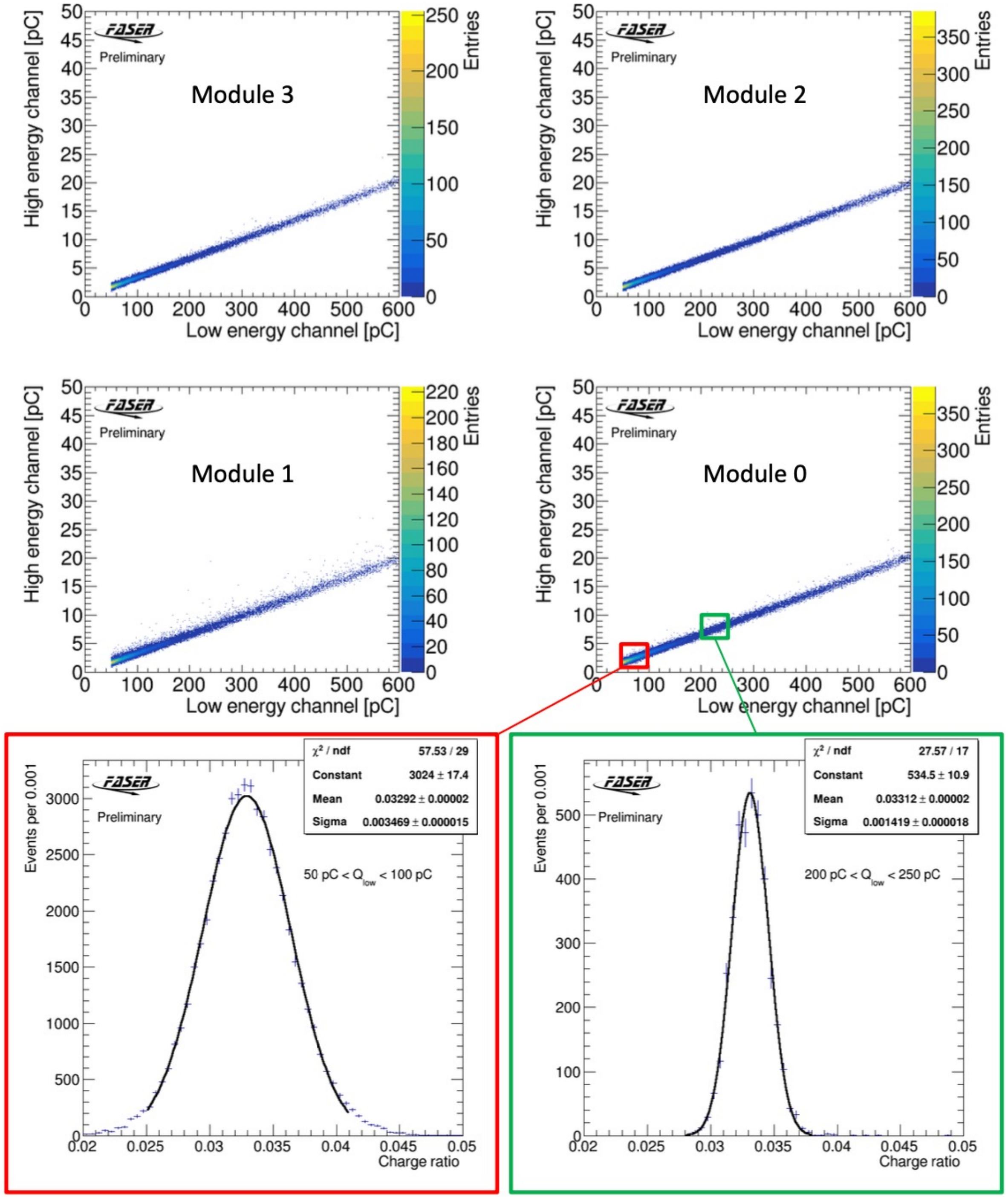


Conf note: CERN-FASER-CONF-2024-001

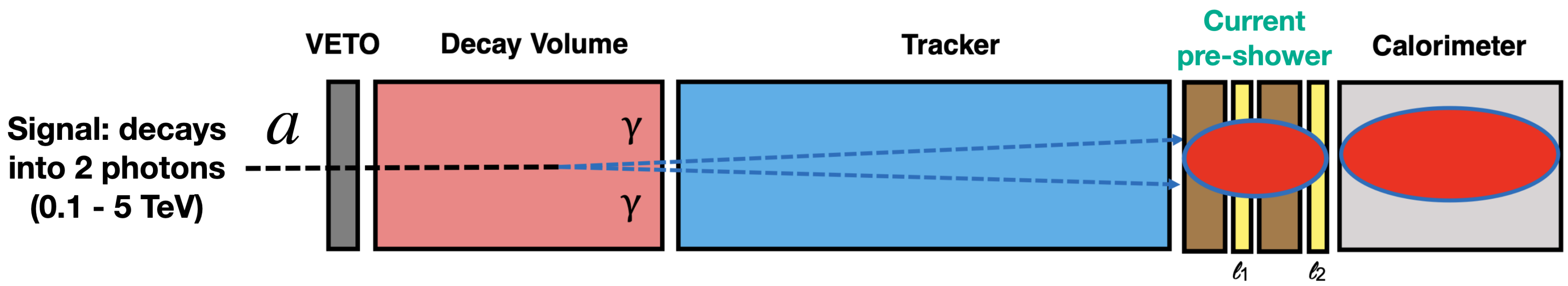
Upgrade I (YETS 2023)

- Calorimeter readout upgrade
- Dual channel readout
  - Split signal optically using fiber bundle into two PMTs
- Split light 1:30 between PMTs
  - Low energy range: 0.1-100 GeV
  - High energy range: 3-3000 GeV
    - Overlap region 3-100 GeV for cross calibration
- Increased dynamic range allowing detailed studies of MIPs and better energy calibration
- Early performance looks promising

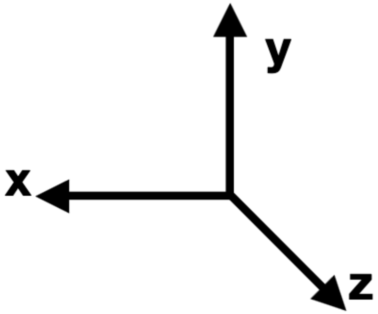


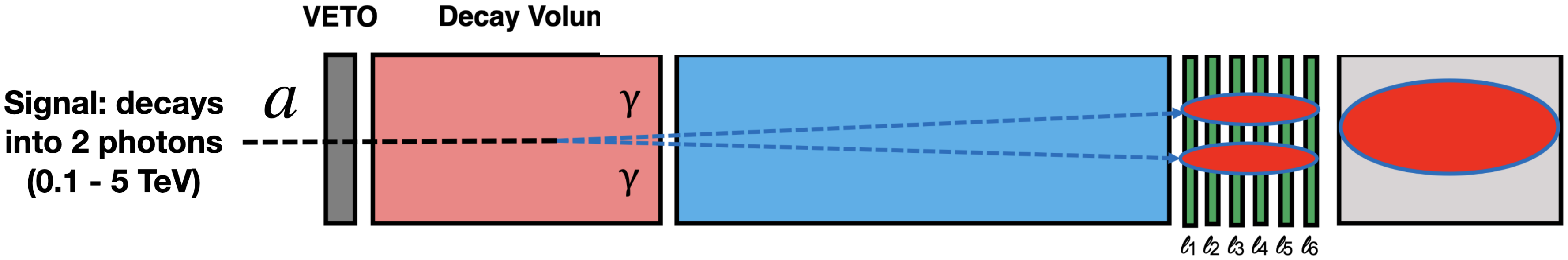


Preshower

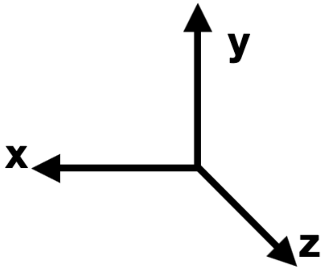


No X-Y granularity: unable to resolve di-photon events !



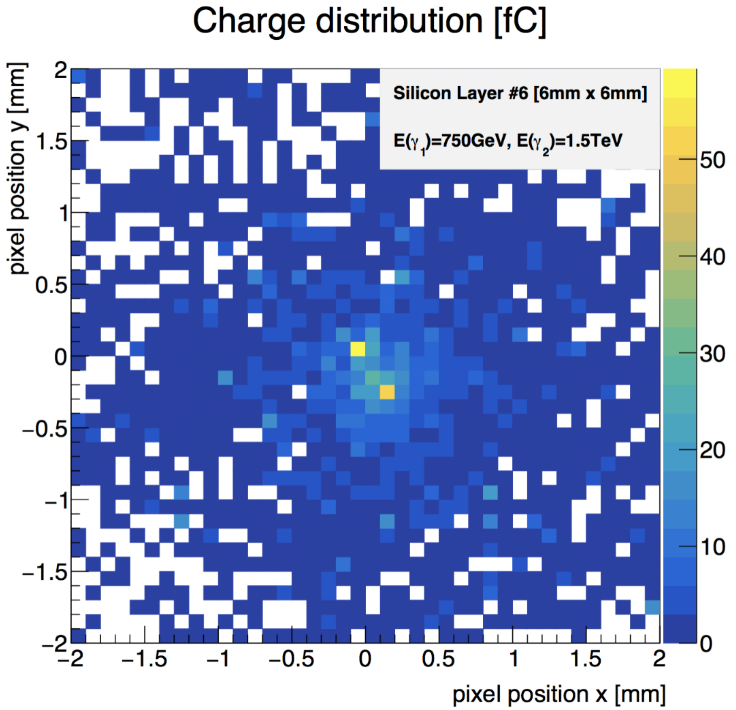


Fine X-Y granularity, high dynamic range



Upgrade II (YETS 2024)

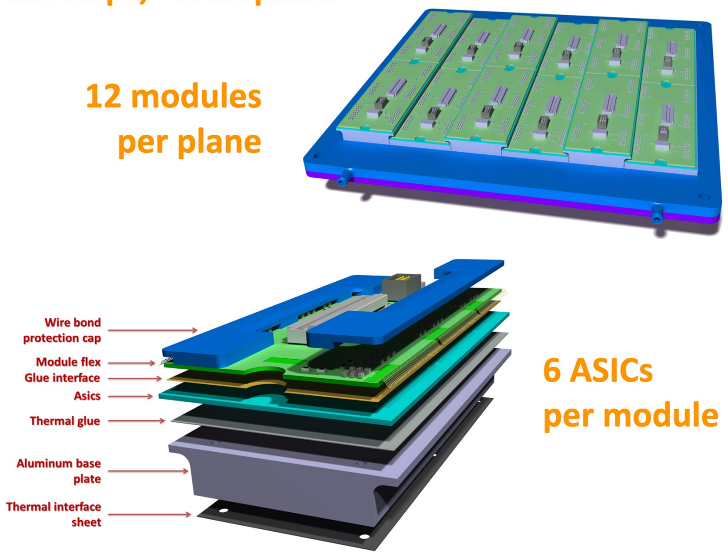
- Preshower upgrade
  - Allows to resolve high energy photons separated by $200\mu m$
    - Will allow to get rid of neutrino background in ALPs search
      - Lower the requirement on calorimeter Et
  - On track for installation in EYETS 2024



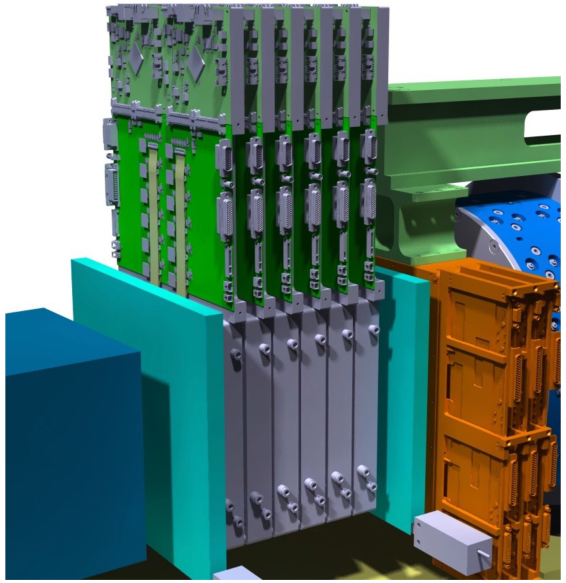
Upgraded preshower detector

432 chips, ≈11M pixels

12 modules per plane

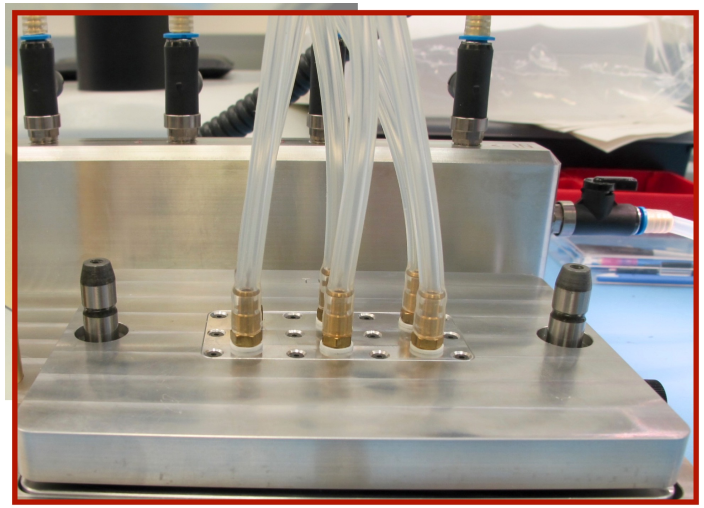


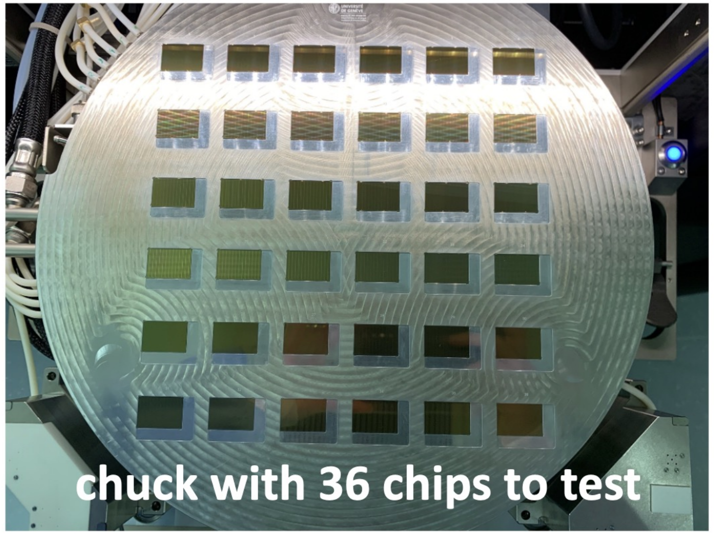
6 ASICs per module



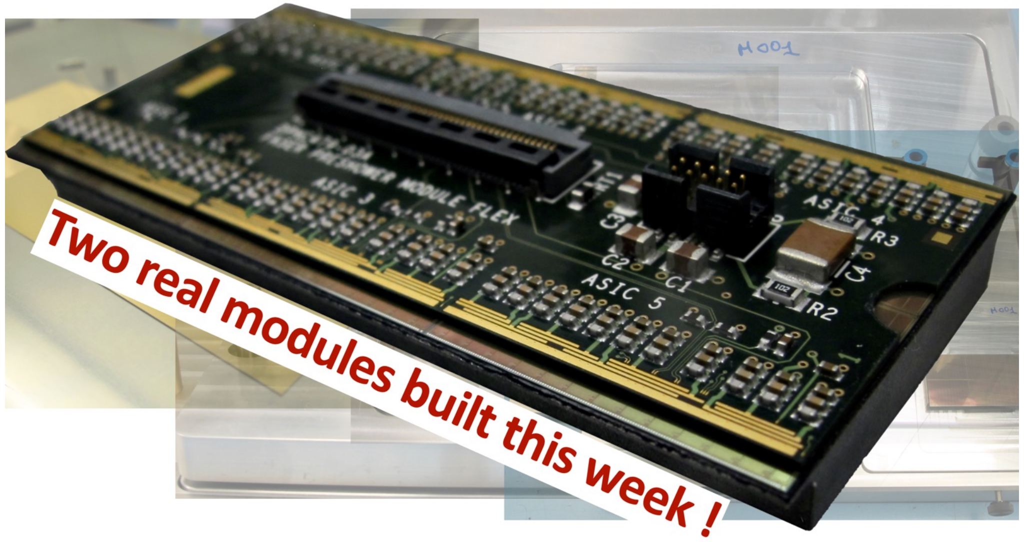
Upgraded preshower detector

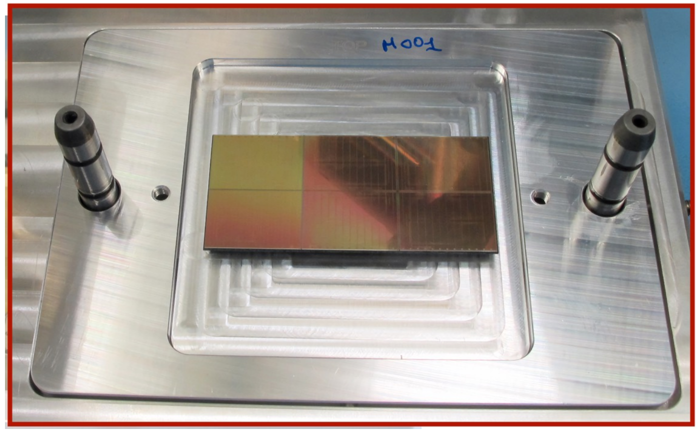
- Introducing X-Y granularity to resolve multiple γs
- 6 detector planes + 2 scintillators
  - ↳ $2 \times (1.70\ X_0$ of W + Si plane)
    $+4 \times (0.65\ X_0$ of W + Si plane)
- Technical proposal: CERN-LHCC-2022-006
- Production phase started!
  - ↳ Test wafer (no postprocessing) received in April
  - ↳ 7 diced wafers (417 chips) collected on May 17th
  - ↳ expecting 13 more in a couple of weeks
- Still on track for installation during EYETS2024

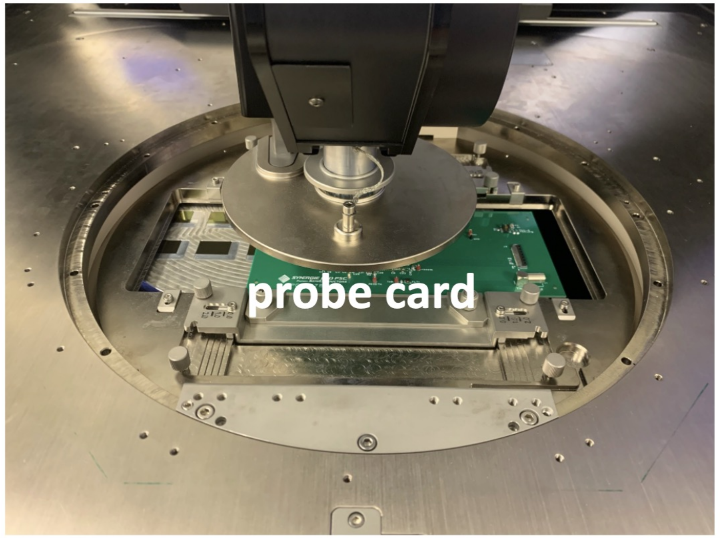




- Week of June 25

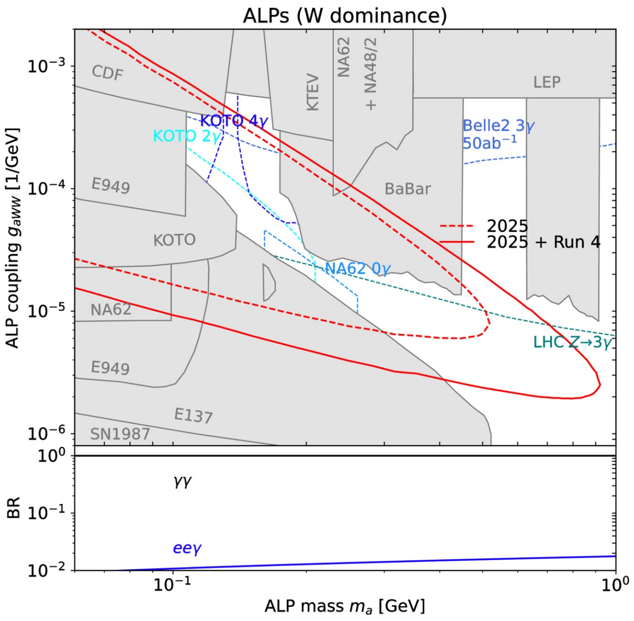


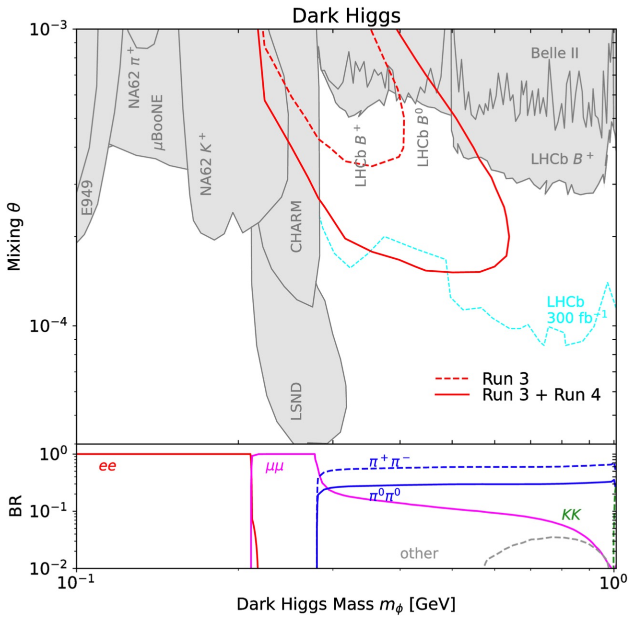




Future prospects: Run 4

- FASER has been approved to run in Run 4
  - Large dataset with upgraded FASER at HL-LHC
- Currently exploring possible neutrino detectors to replace the emulsion detector in Run 4
  - several options with different physics capabilities under study
- Predicted reach for FASER's dark photon and ALP searches with combined Run3 + Run4 datasets
  - Assuming 250 (680) *fb*$^{-1}$ for Run 3 (4)





Summary

- FASER has been efficiently collecting data
- Many interesting new results published
- Upgrade tasks for 2025 are well on track
  - Preshower upgrade
    - Multi photon tagging and enhanced ALPs seraches
  - Calorimeter upgrade
    - Extended range and improved energy scale
- Regular on going discussions about FASER in Run4 of HL-LHC

FASER COLLABORATION

101 collaborators, 27 institutions, 11 countries

CERN
UNIVERSITÉ DE GENÈVE
KYUSHU UNIVERSITY
UC IRVINE

UNIVERSITÄT BERN
Technion Israel Institute of Technology
NAGOYA UNIVERSITY
UNIVERSITY of WASHINGTON

JOHANNES GUTENBERG UNIVERSITÄT MAINZ JG|U
מכון ויצמן למדע WEIZMANN INSTITUTE OF SCIENCE
CHIBA UNIVERSITY
UNIVERSITY OF OREGON

DESY.
INFN
ISS
International laboratory covered by a cooperation agreement with CERN
清華大學 Tsinghua University
ROYAL HOLLOWAY UNIVERSITY OF LONDON

UNIVERSITÀ DEGLI STUDI DI NAPOLI FEDERICO II
UNIVERSITY OF LIVERPOOL
UNIVERSITY OF SUSSEX

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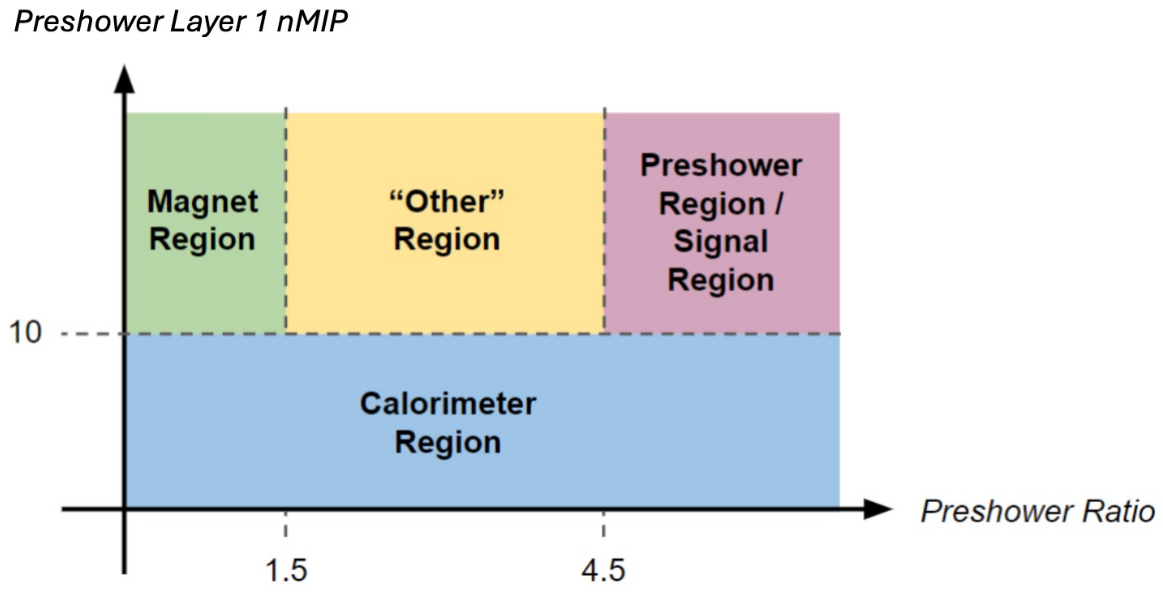
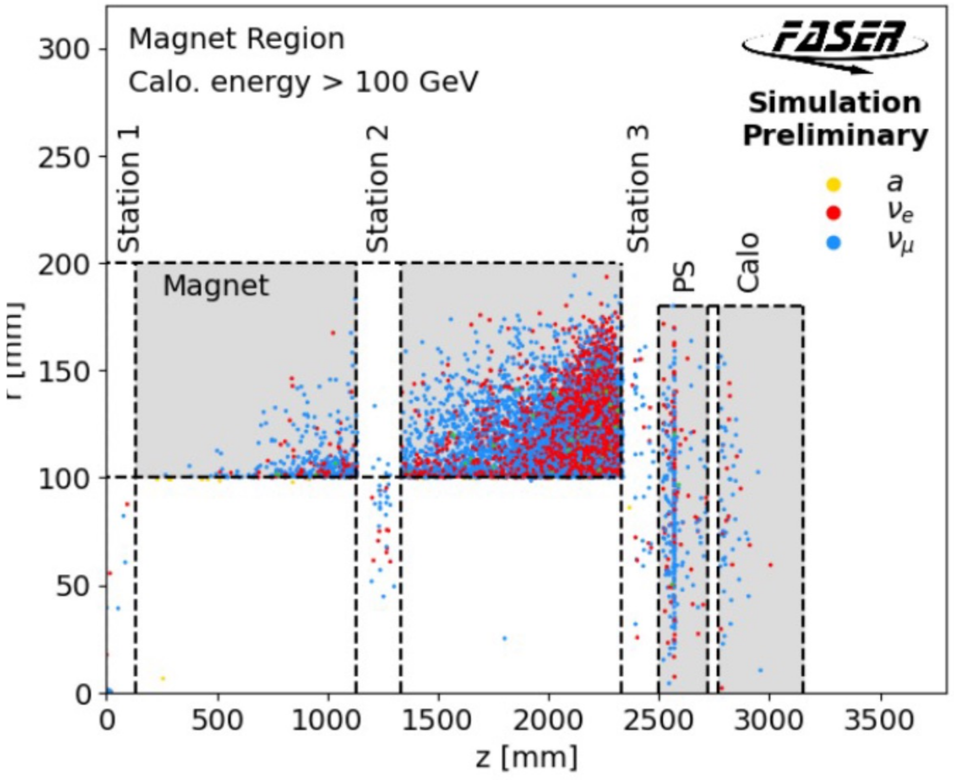
UNIVERSITÄT BONN
ETH zürich
MANCHESTER 1824 The University of Manchester

Validation Region: Magnet Region





- These regions were validated by looking at neutrino interaction vertices and ALPS decay vertices using MC samples
- To check if estimates were reasonable, we compared MC simulations to data and found good agreement

Magnet	
MC	43.5 ± 18.2 (41.9%)
Data	34