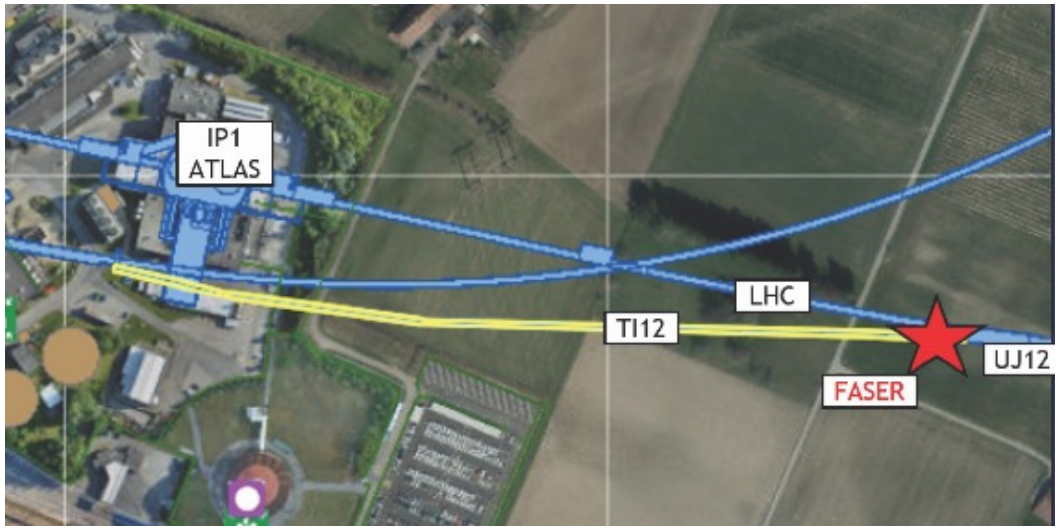
New Physics Results from the FASER Experiment

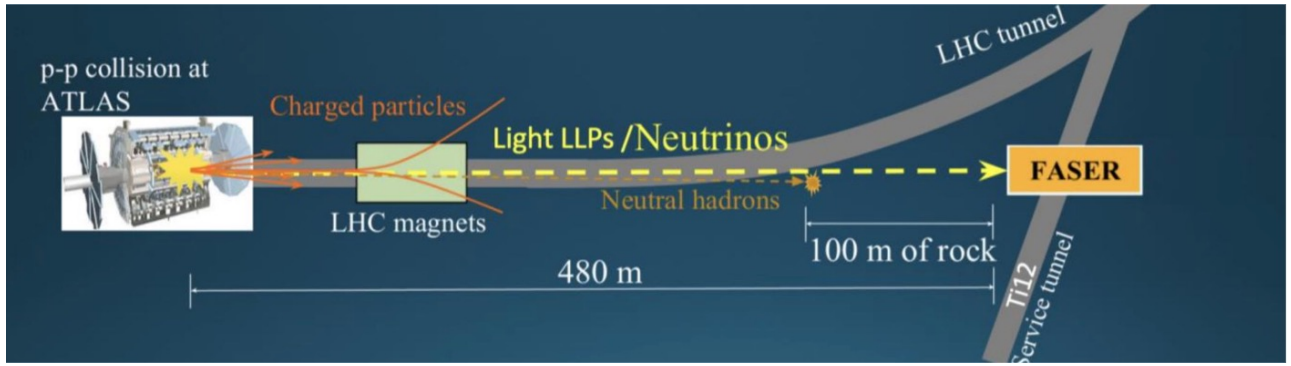
Ansh Desai
University of Oregon
on behalf of the FASER Collaboration

DPF Conference May 13th, 2024

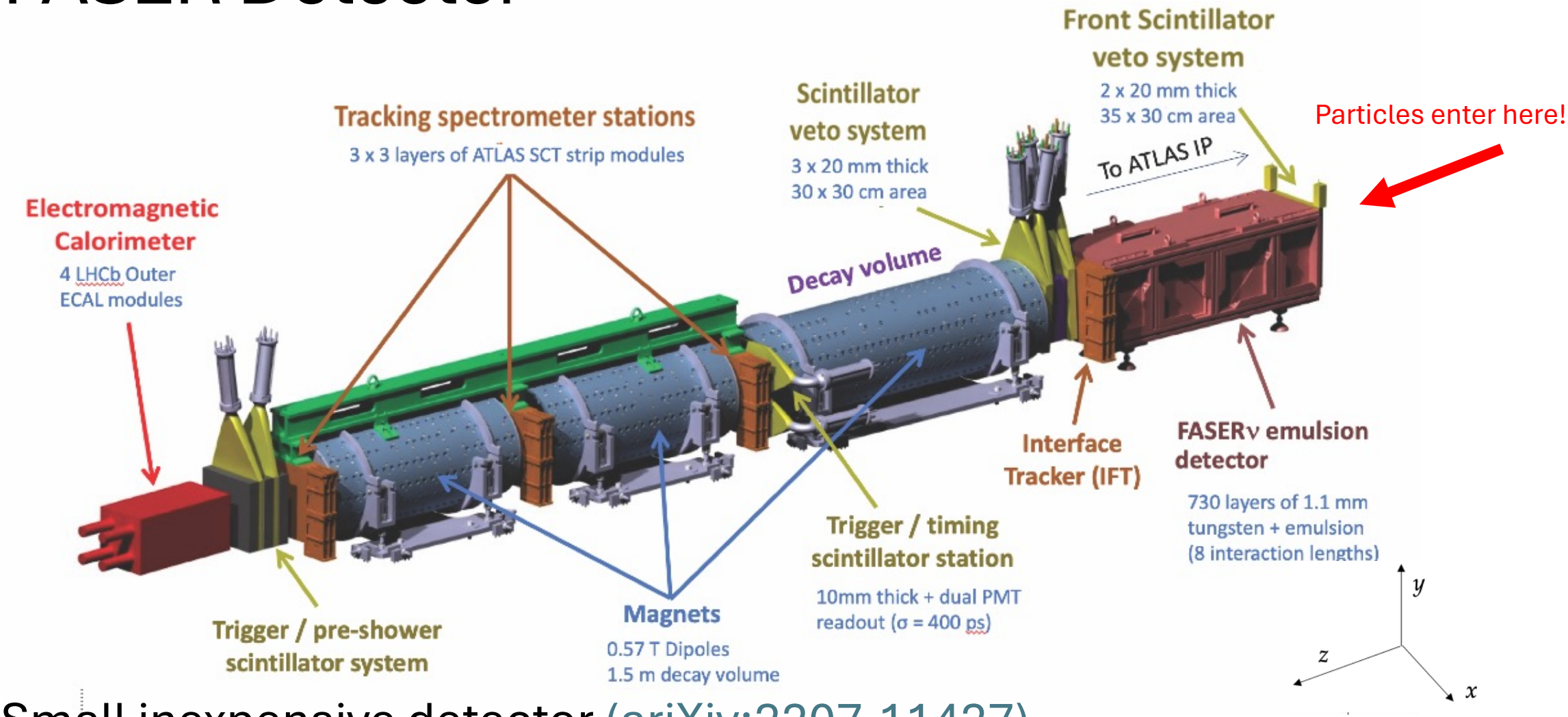
What is FASER?

- The Forward Search Experiment is an experiment at the LHC primarily designed to search for light, weakly interacting long lived particles produced at the ATLAS interaction point.
  - Neutrinos, Dark Photon
- Large signal from high LHC collision rate and forward peaked meson production
- Located 480 downstream of the ATLAS interaction point, 100m of rock and LHC magnets between the detector and ATLAS
- Small experiment -> Fast turnaround!
  - Built 2019-2021
  - First result from data in 2022
  - Data collecting is still ongoing





The FASER Detector

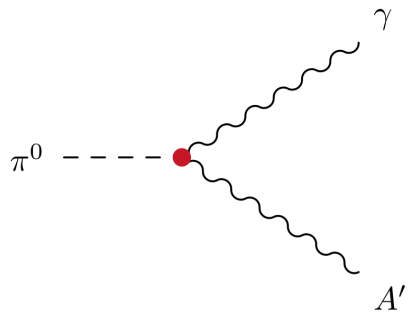


- Small inexpensive detector (ariXiv:2207.11427)
  - 10cm radius of active volume
  - 7m long


CMU 2t
CMU 2t
2t
To ATLAS
FASERnu
Calorimeter
Preshower
Tracking spectrometer
Decay volume
Veto
IFT

The Dark Photon

- Dark photons (A') are a common well-motivated feature of hidden sector models (dark U(1))
- They would potentially be weakly coupled to SM via a kinetic mixing (ε) with a SM Photon
- MeV scale dark photons would be produced mainly in light meson decays at the LHC
- FASER targets small ε highly boosted MeV-scale massive dark photons (decays most likely to e^+ e^-)

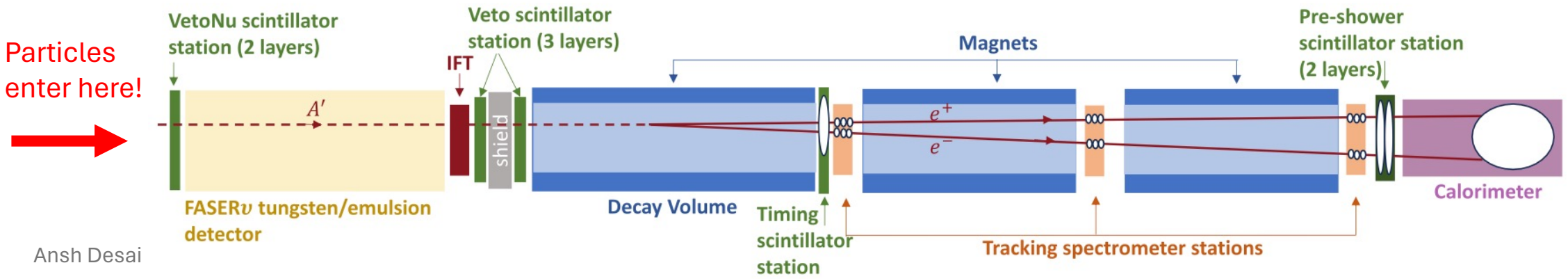


Signal

- Observed as A' → e^+ e^- appearing from nothing with ~TeV energy
- Must decay in 1.5m decay volume

Event Selection:

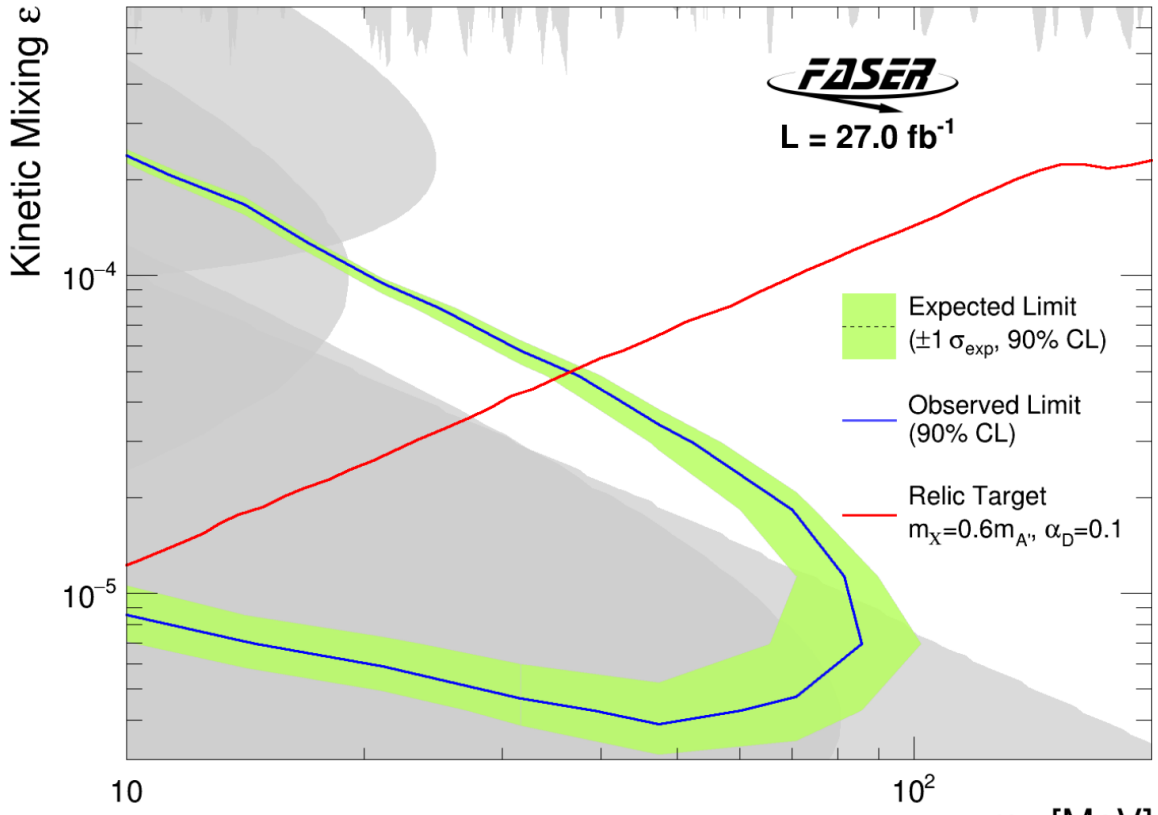
- In time with LHC Collision
- No signal in veto scintillators
- Something in downstream scintillators
- Two opposite sign tracks within fiducial volume (r < 95mm)
- Calorimeter energy > 500 GeV



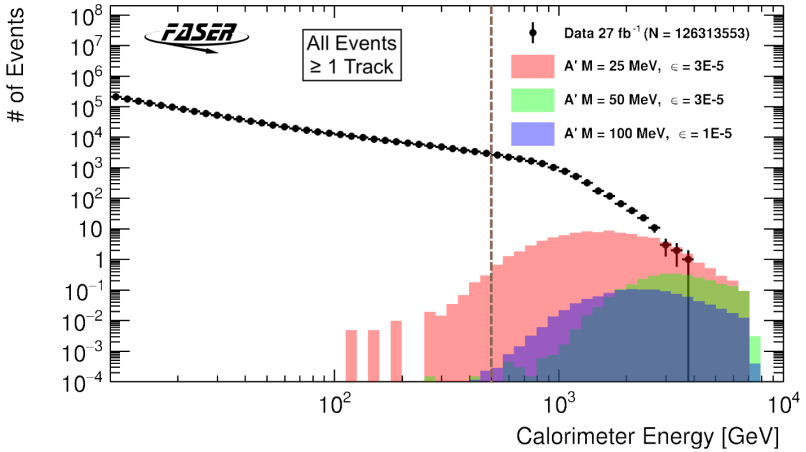
Dark Photon Results

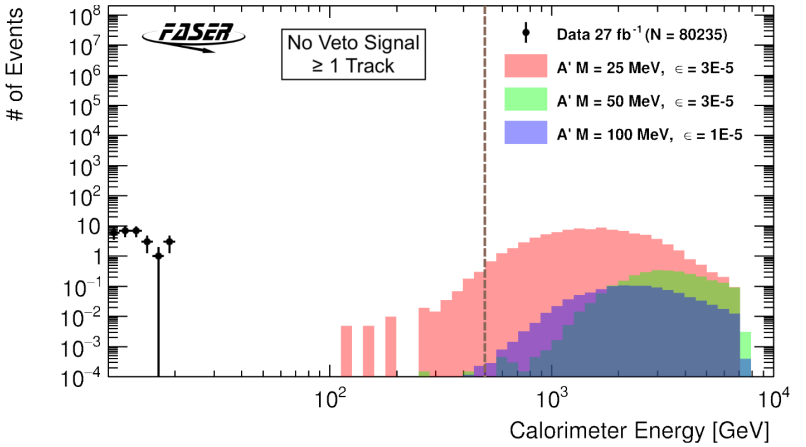
- No events observed in 27 fb^{-1} from 2022
- $(2.3 \pm 2.3) * 10^{-3}$ background events expected

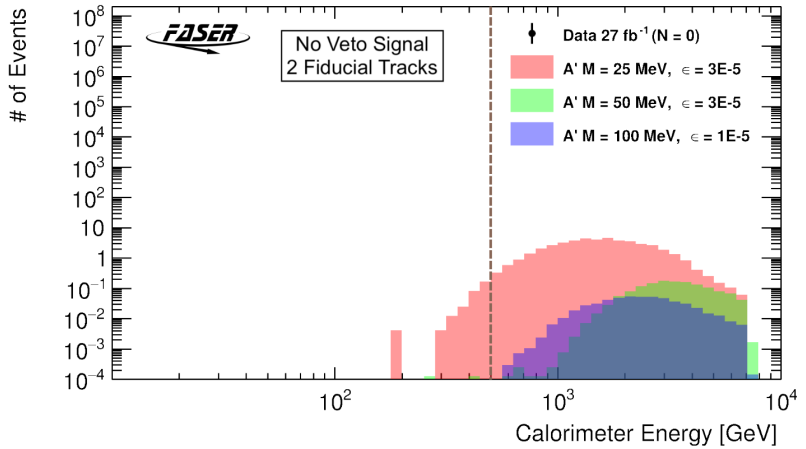
Dark Photon



Published: [PLB 848 (2024) 138378]

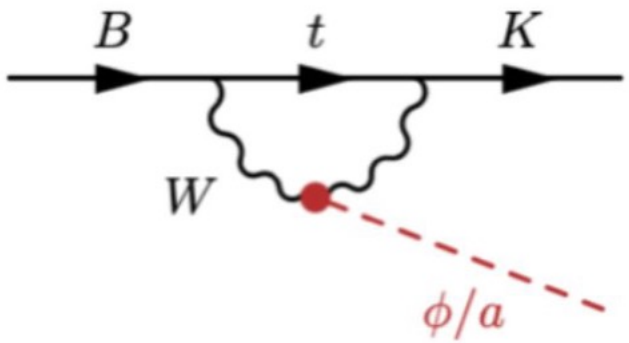


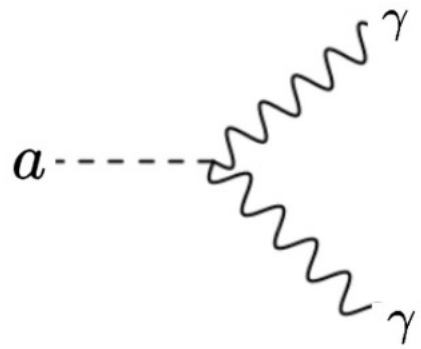


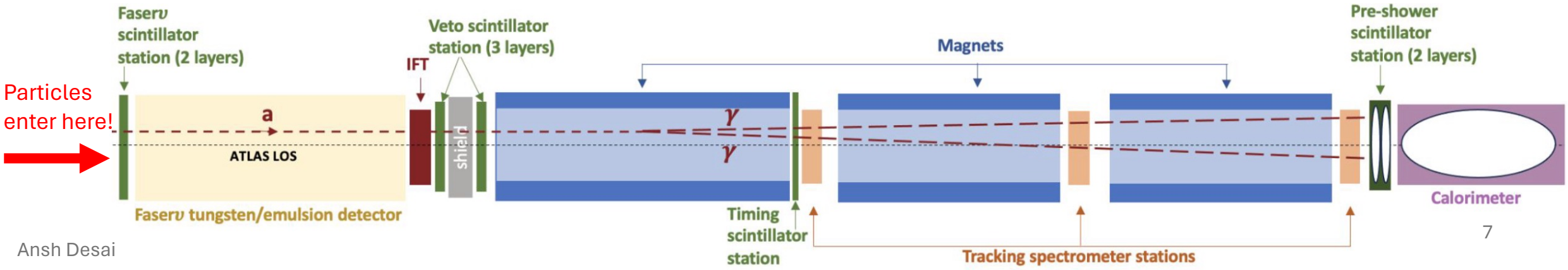


Axion-Like-Particles (ALPs)

- 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







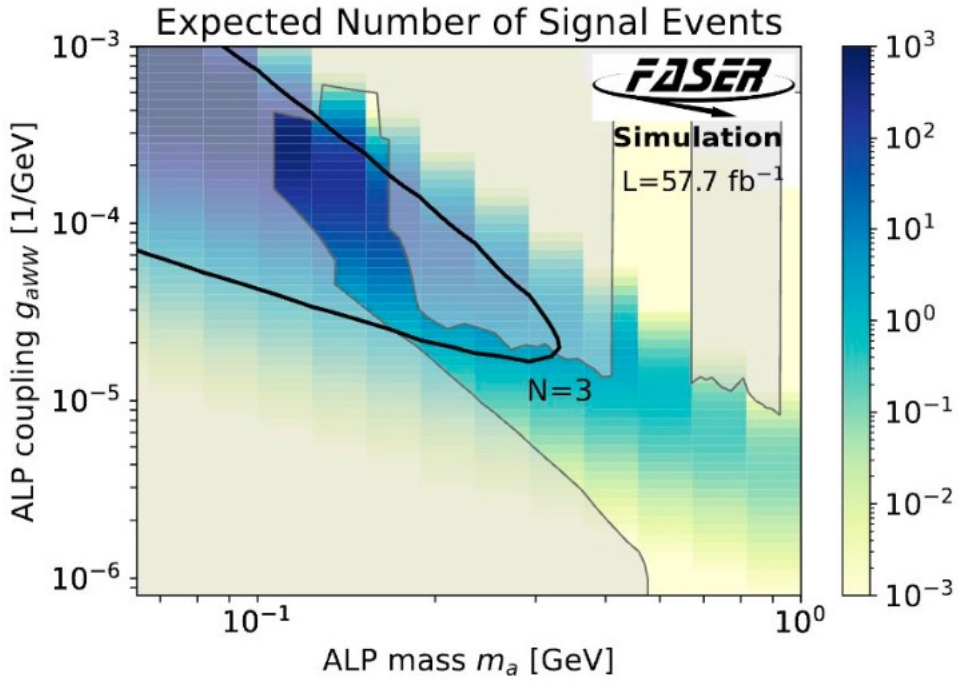
ALPs Analysis

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%

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

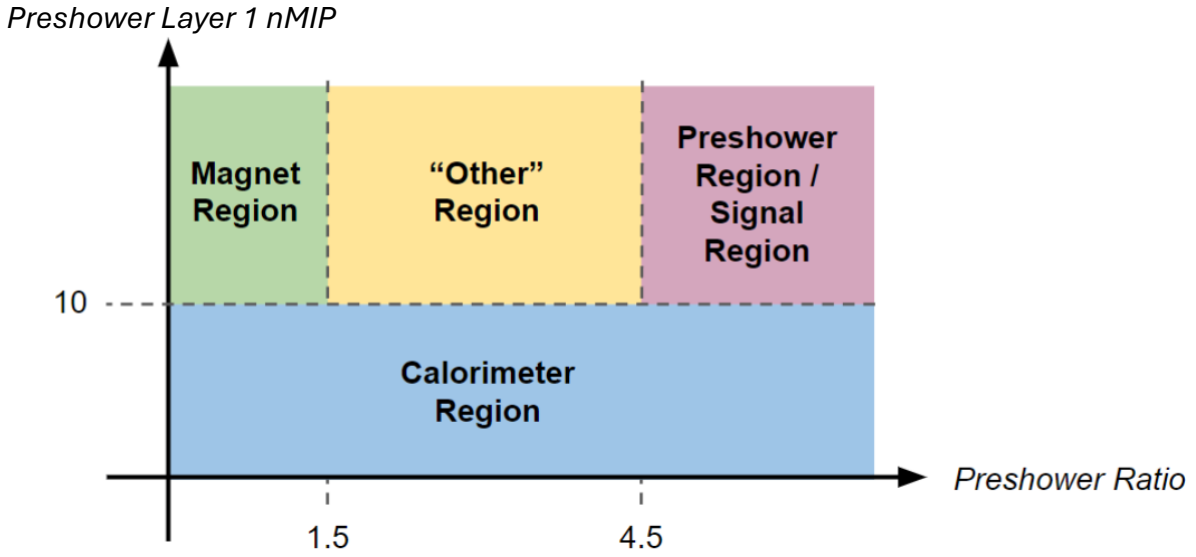
Signal Sample	Flux	Stat.	Luminosity	Calorimeter	Second Preshower Layer	Preshower Ratio
$m_a = 140$ MeV $g_{aWW} = 2 \times 10^{-4}$ GeV^{-1}	59.4%	1.8%	2.2%	3.6%	0.6%	7.9%
$m_a = 120$ MeV $g_{aWW} = 10^{-4}$ GeV^{-1}	57.3%	3.5%	2.2%	16.3%	0.6%	6.9%
$m_a = 300$ MeV $g_{aWW} = 2 \times 10^{-5}$ GeV^{-1}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

Background Estimation: Neutrinos

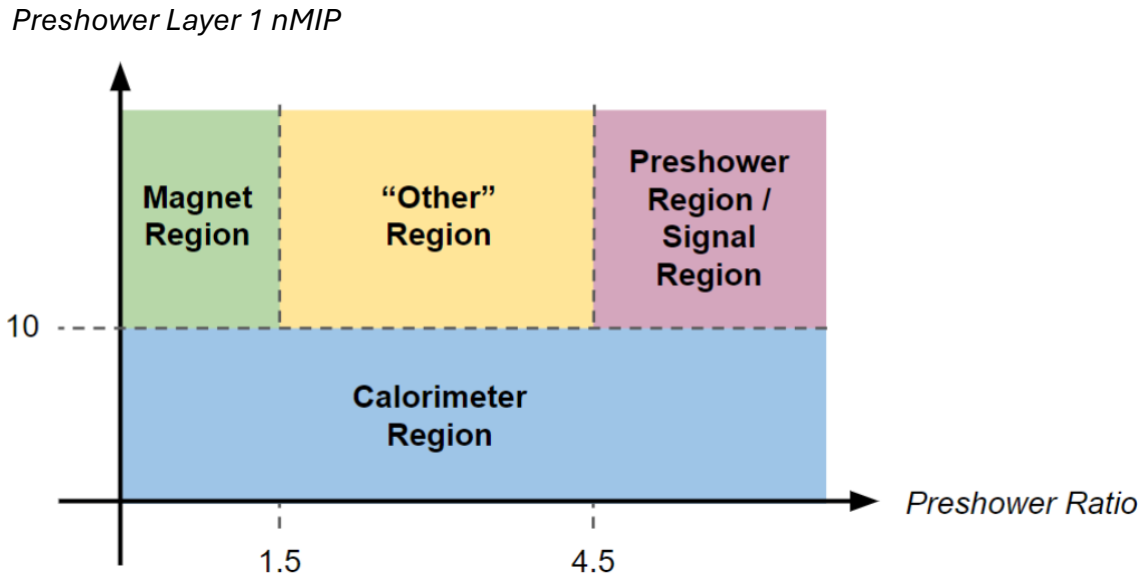
- Neutrinos produced upstream of FASER through light/charm hadron decays – charged/neutral current interactions in FASER
- Evades veto, but interacts near/in preshower/calorimeter → mimics signal
- Background evaluated with MC Simulations and validated in different detector regions
- Validation regions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

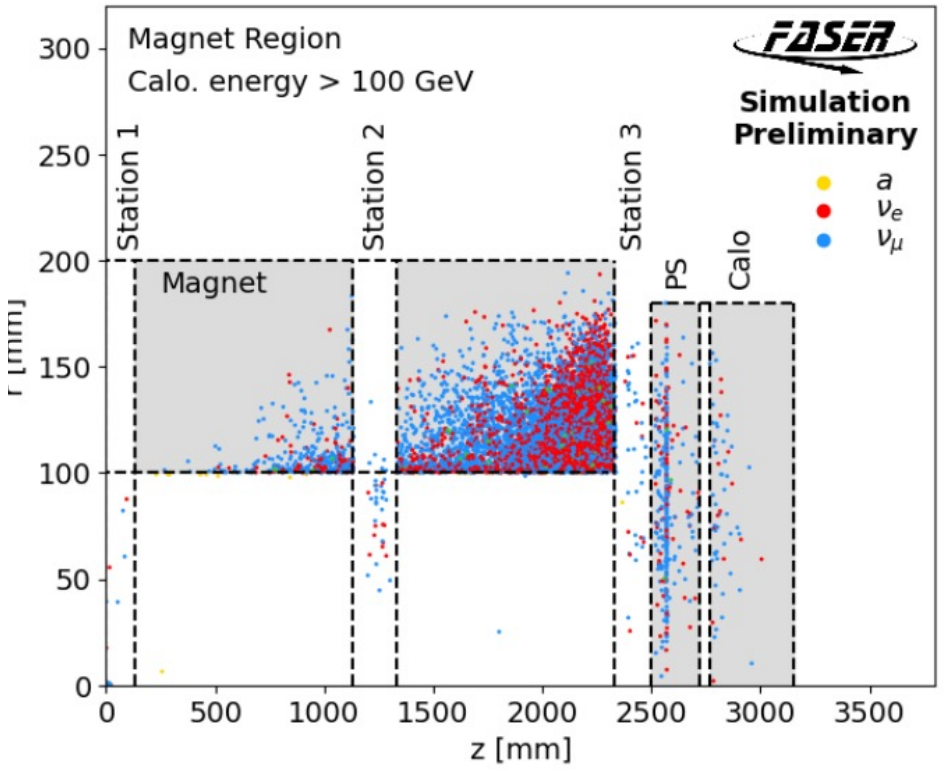
For 57.7 fb^{-1}

> 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%)**



Validation Region: Magnet Region



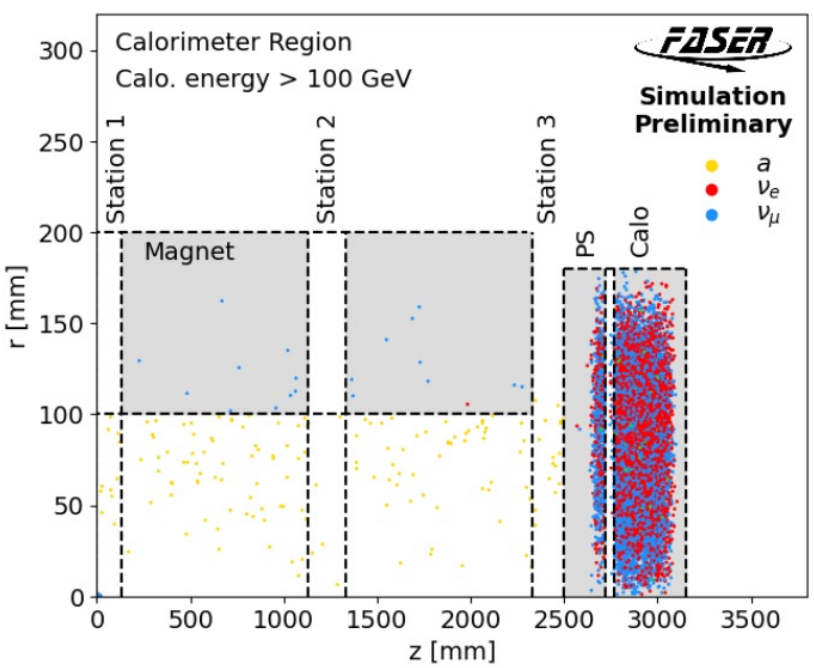


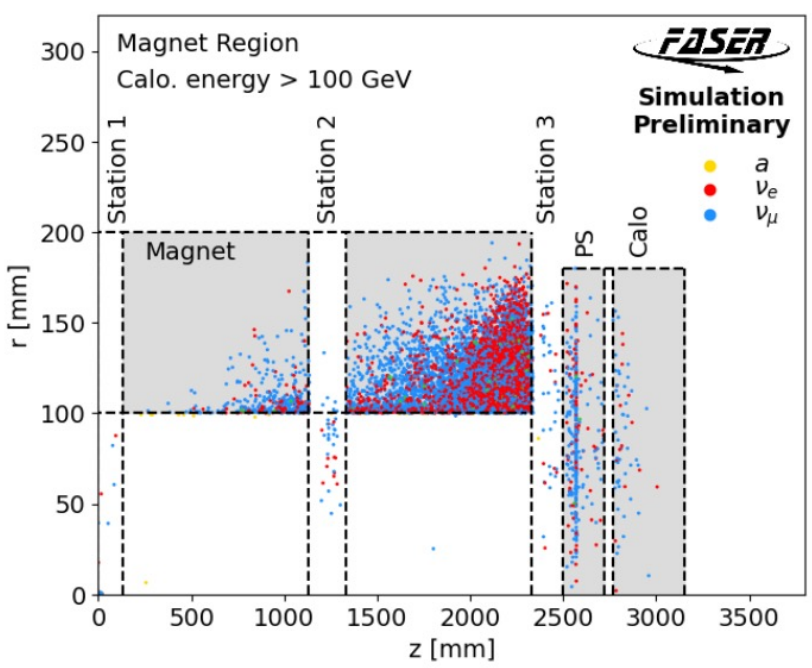
- These regions were validated by looking at neutrino interaction vertices and ALPS decay vertices using MC samples
- To check if estimates were reasonable, we compared MC simulations to data and found good agreement

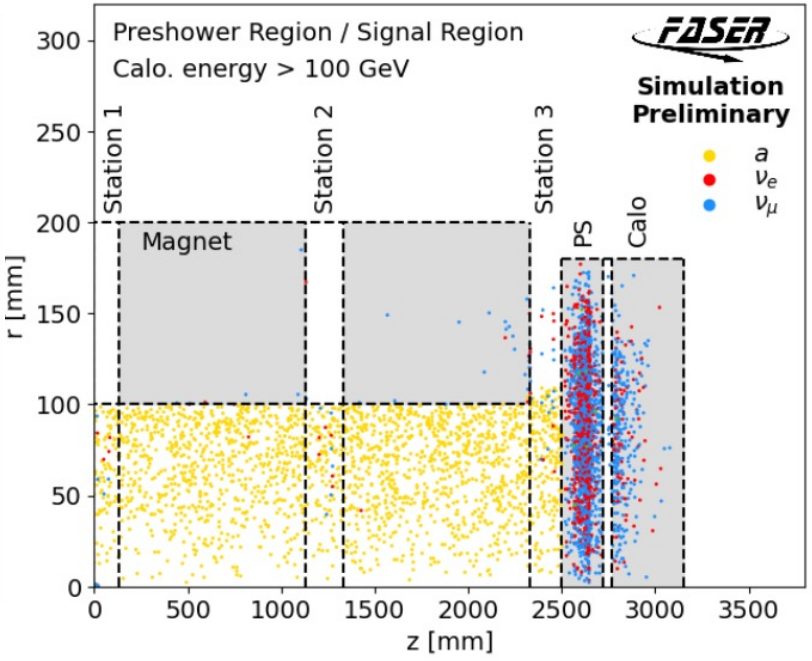
Magnet	
MC	43.5 ± 18.2 (41.9%)
Data	34

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

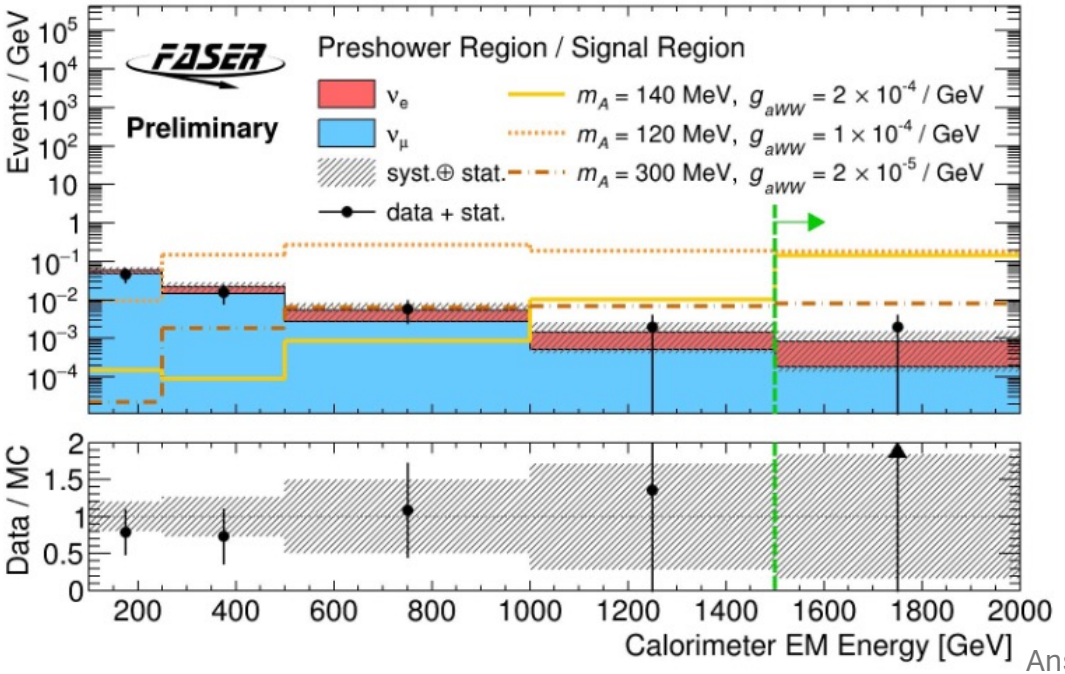
Magnet	
MC	43.5 ± 18.2 (41.9%)
Data	34

Preshower	
MC	17.8 ± 5.1 (28.8%)
Data	15

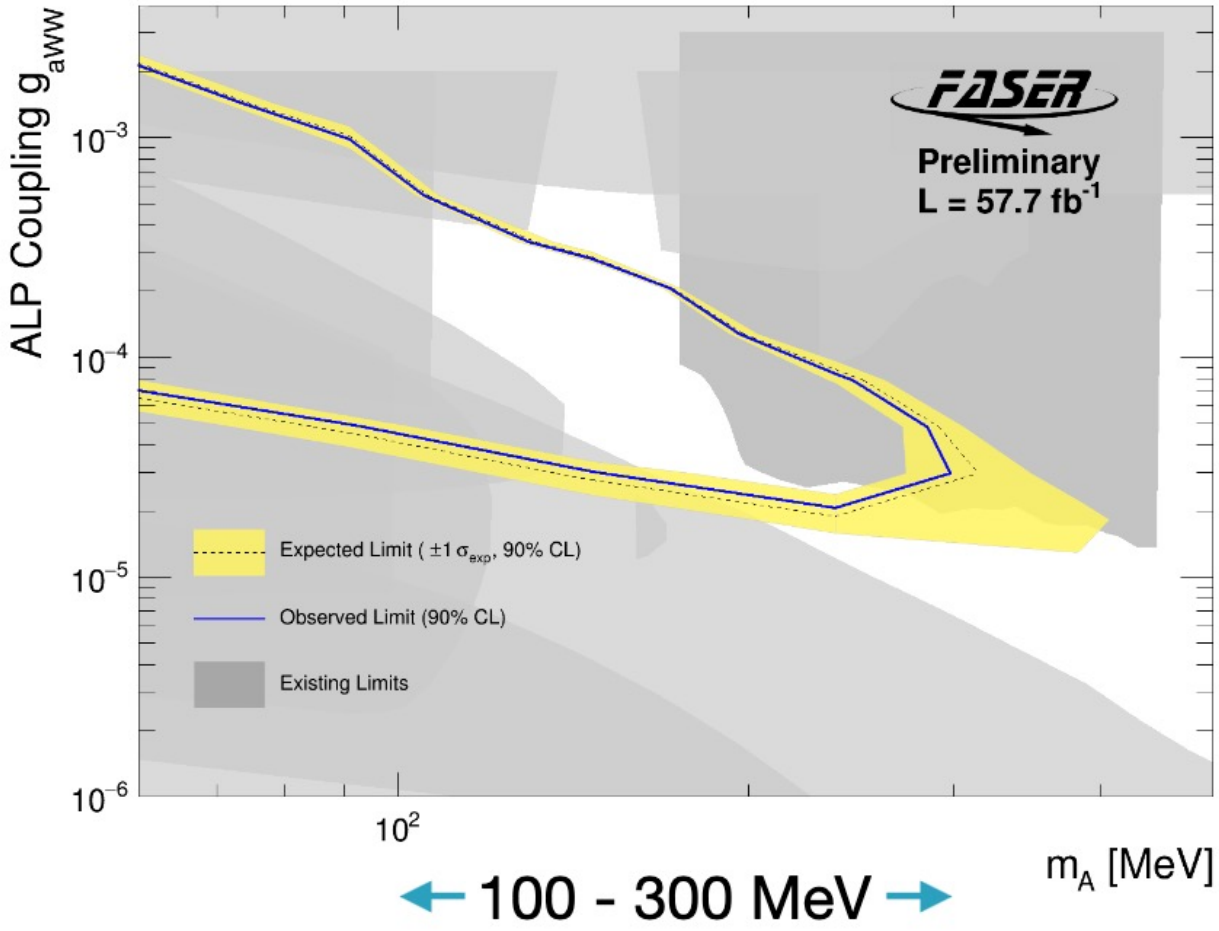
Unblinded Results

- 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



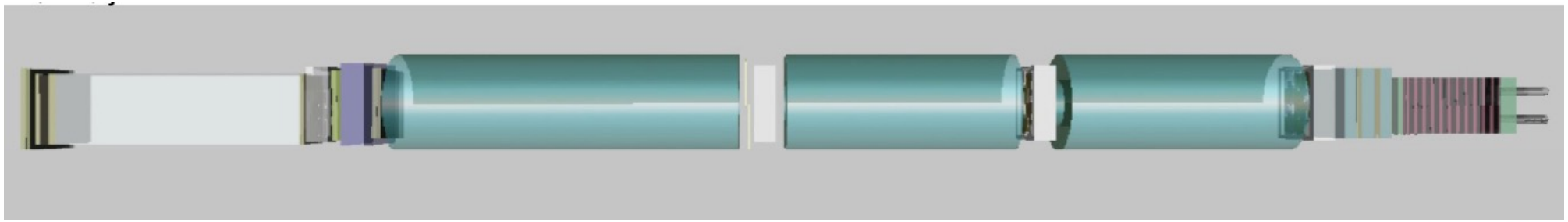
Observed Limit



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

Summary

- FASER explored new regions in the dark photon parameter space PLB 848 (2024) 138378
- FASER has probed new ALPs parameter space at mass and coupling previously unexplored by previous experiments
- A conference note on the ALPS analysis has been published, and a paper is forthcoming
- FASER expects to collect much more data in Run 3 and 4 allowing for more powerful searches for dark photons, ALPs, and other new physics models
- Thank you for listening!



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

The FASER Collaboration

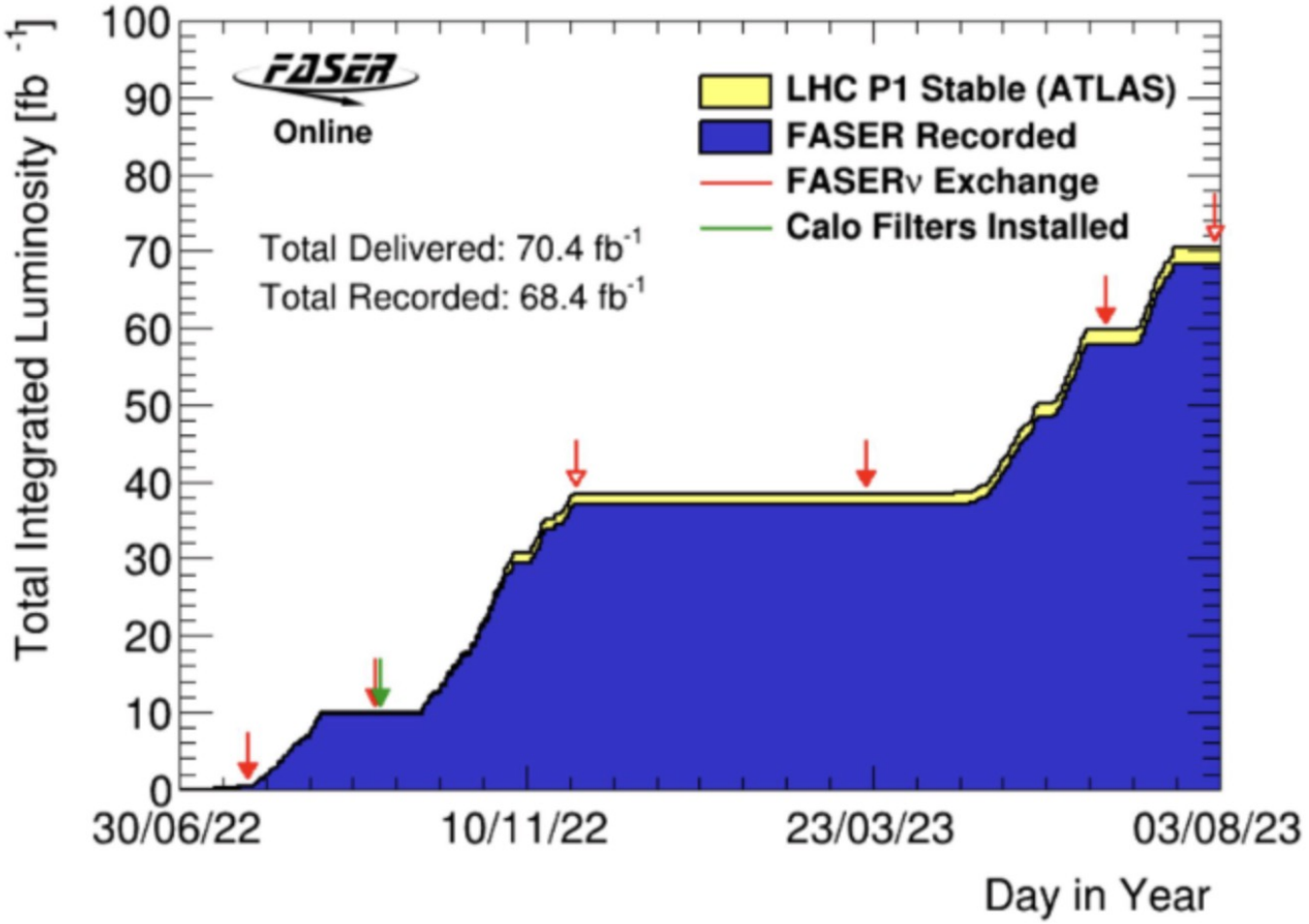
96 collaborators, 26 institutions, 10 countries

International laboratory covered by a cooperation agreement with CERN

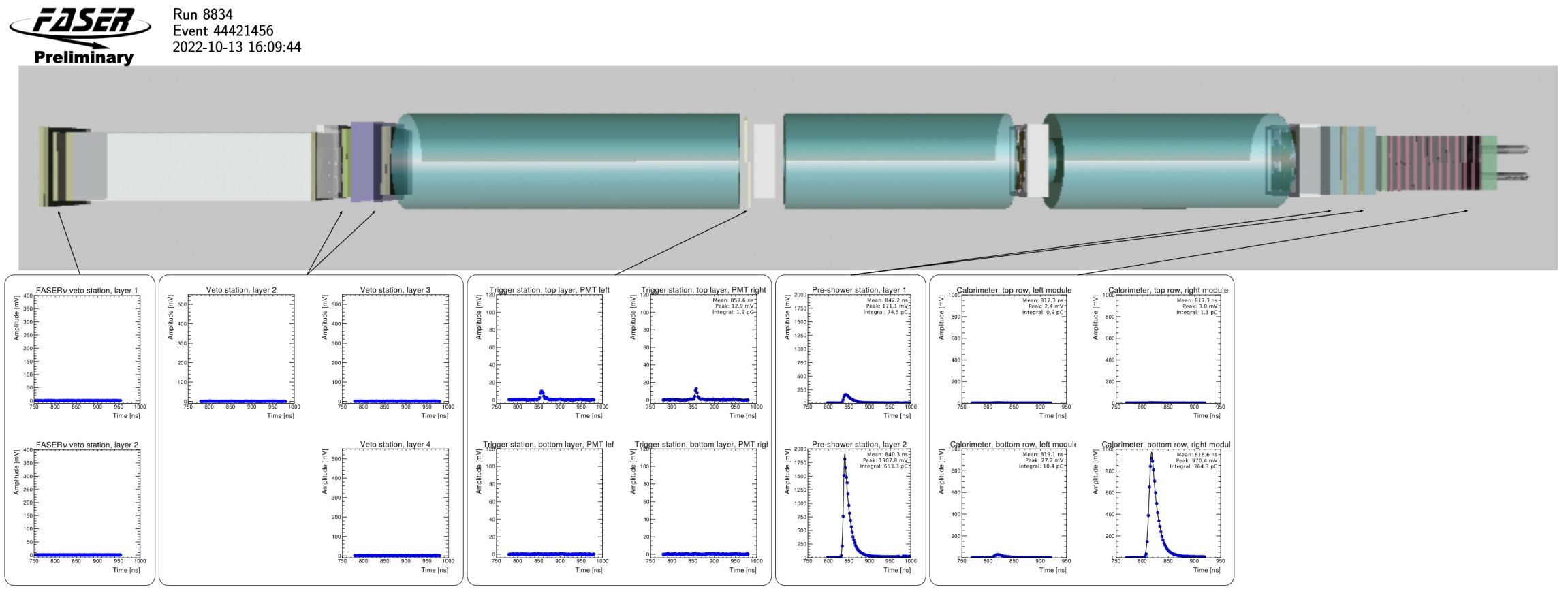
Backup

Luminosity

- The ALPs analysis used 57.7 fb^{-1} of data from 2022-2023 (LHC Run 3)

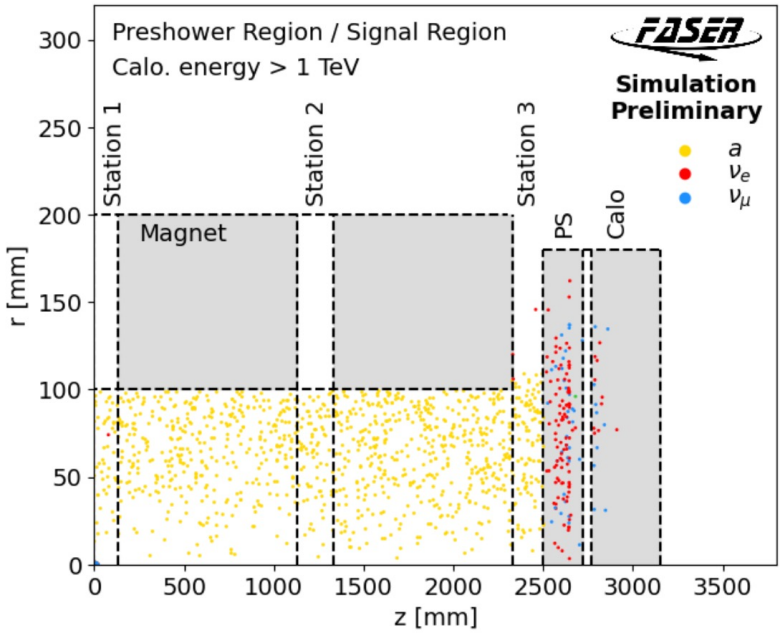


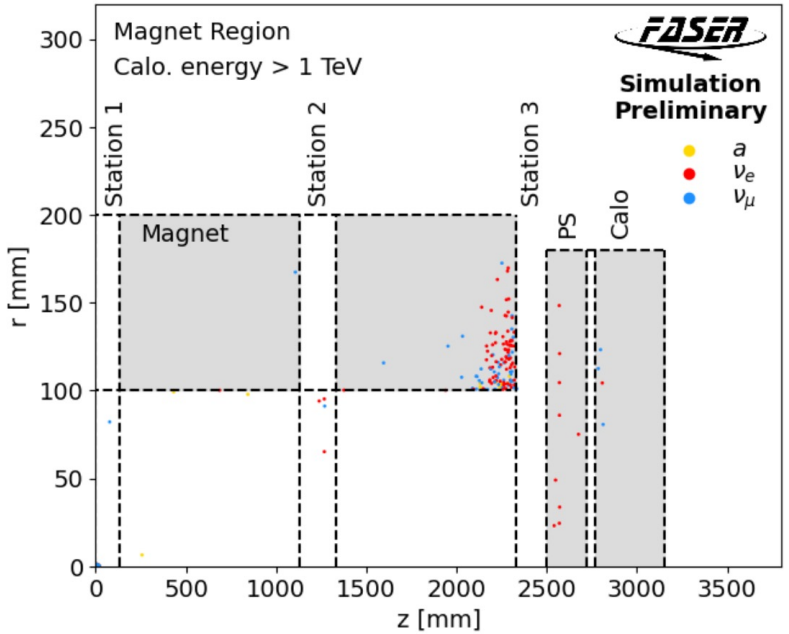
Event Display

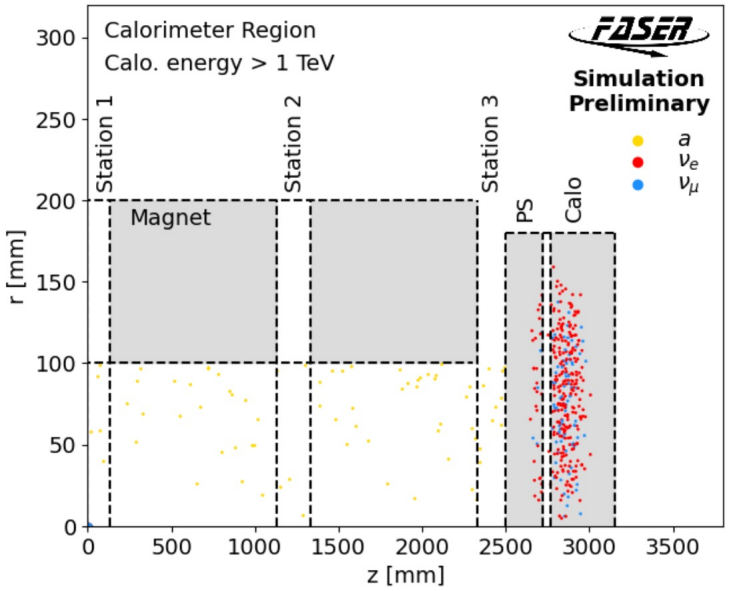


- This event had reconstructed energy equivalent to 1.6 TeV
- Preshower signal consistent with EM Shower

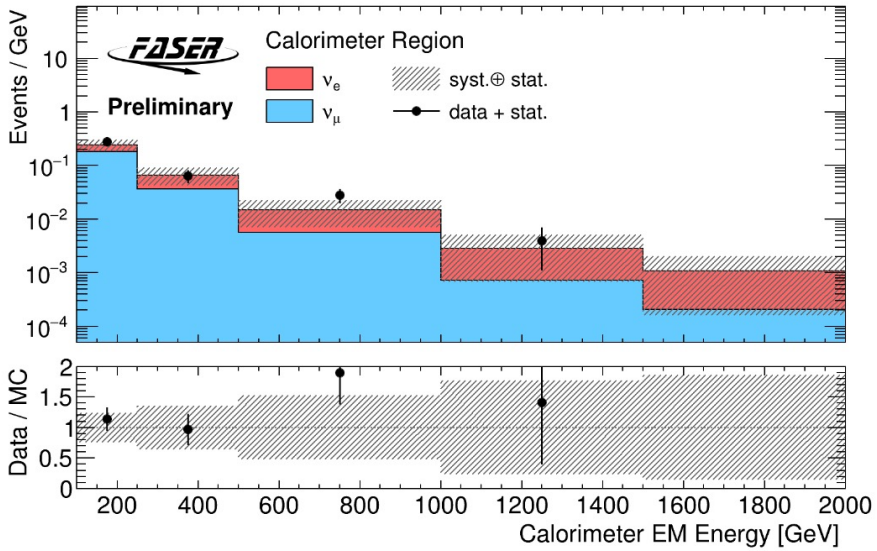
Control Regions 1 TeV Plots

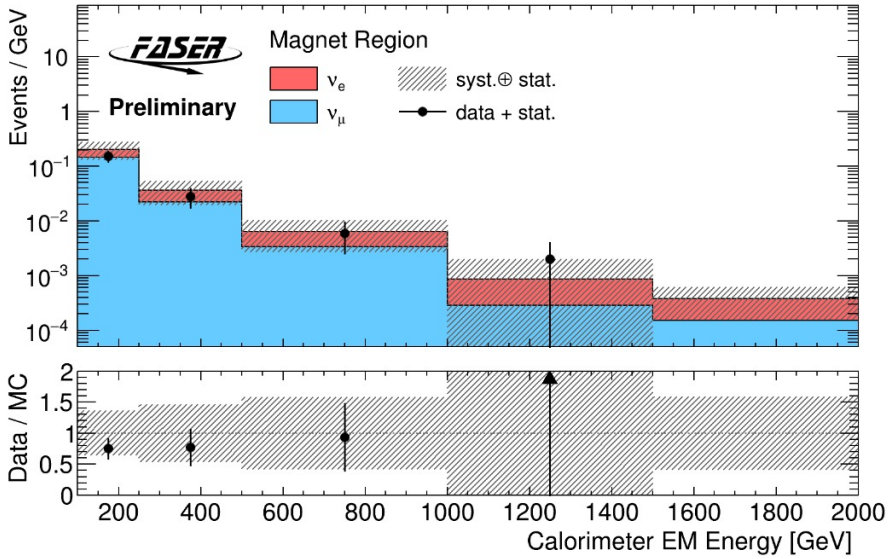


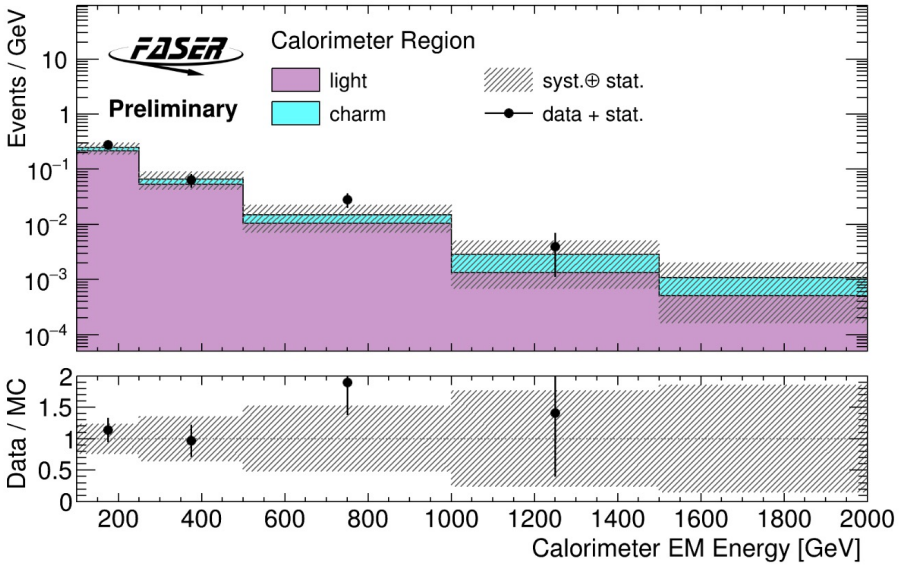


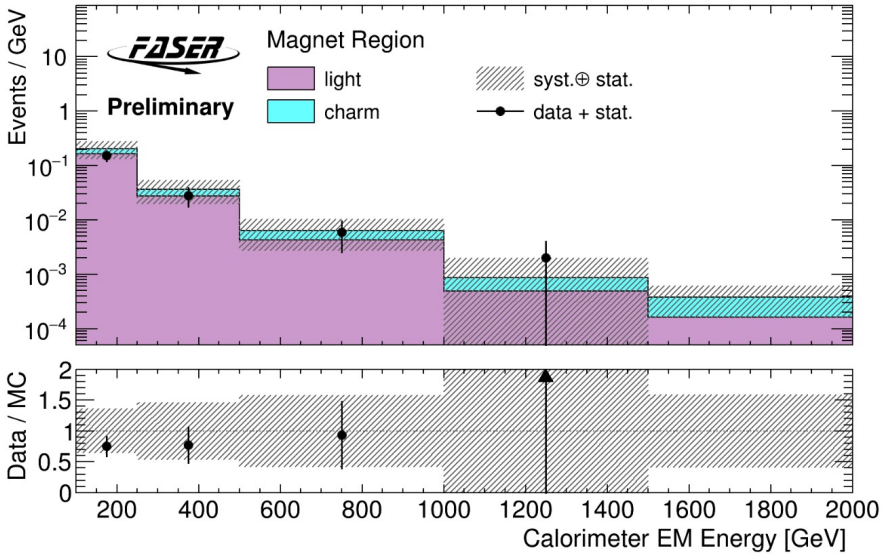


Control Region Plots









Trigger and Data Quality
Selecting events with calorimeter triggers
Calorimeter timing (> -5 ns and < 10 ns)
Baseline Selection
Veto/VetoNu Scintillator to have no signal (< 0.5 MIPs)
Timing Scintillator to have no signal (< 0.5 MIPs)
Signal Region
Preshower Ratio to have EM shower in the Preshower (> 4.5)
Second Preshower Layer to have signal (> 10 MIPs)
Calorimeter to have a large deposit (> 1.5 TeV)

Background Estimation: Other

- Veto Inefficiency: measured per layer efficiency of below 10^{-5}, with estimated # of muons ~10^{8} → negligible
- Large angle muons: Checked with MC → negligible
- Neutral hadron background: suppressed by muon angle and high calorimeter energy. Previously found to be negligible in dark photon analysis, and for the same reasons as found then → negligible
- Non collision background: no events above 100 GeV observed when running over the same amount of time as 2022 + 2023 data → negligible
- Beam Gas Background (LHC Beam 1) -> Events caused by this are well separated from collisions -> timing cut eliminates these → negligible

Alternate Limits Plot