Exploring Flavour Symmetries and Long-Lived Particles with the FASER Experiment

Cristiano Sebastiani (CERN)

FLASY

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11TH WORKSHOP

Flavor Symmetries and Consequences in Accelerators and Cosmology

Intro

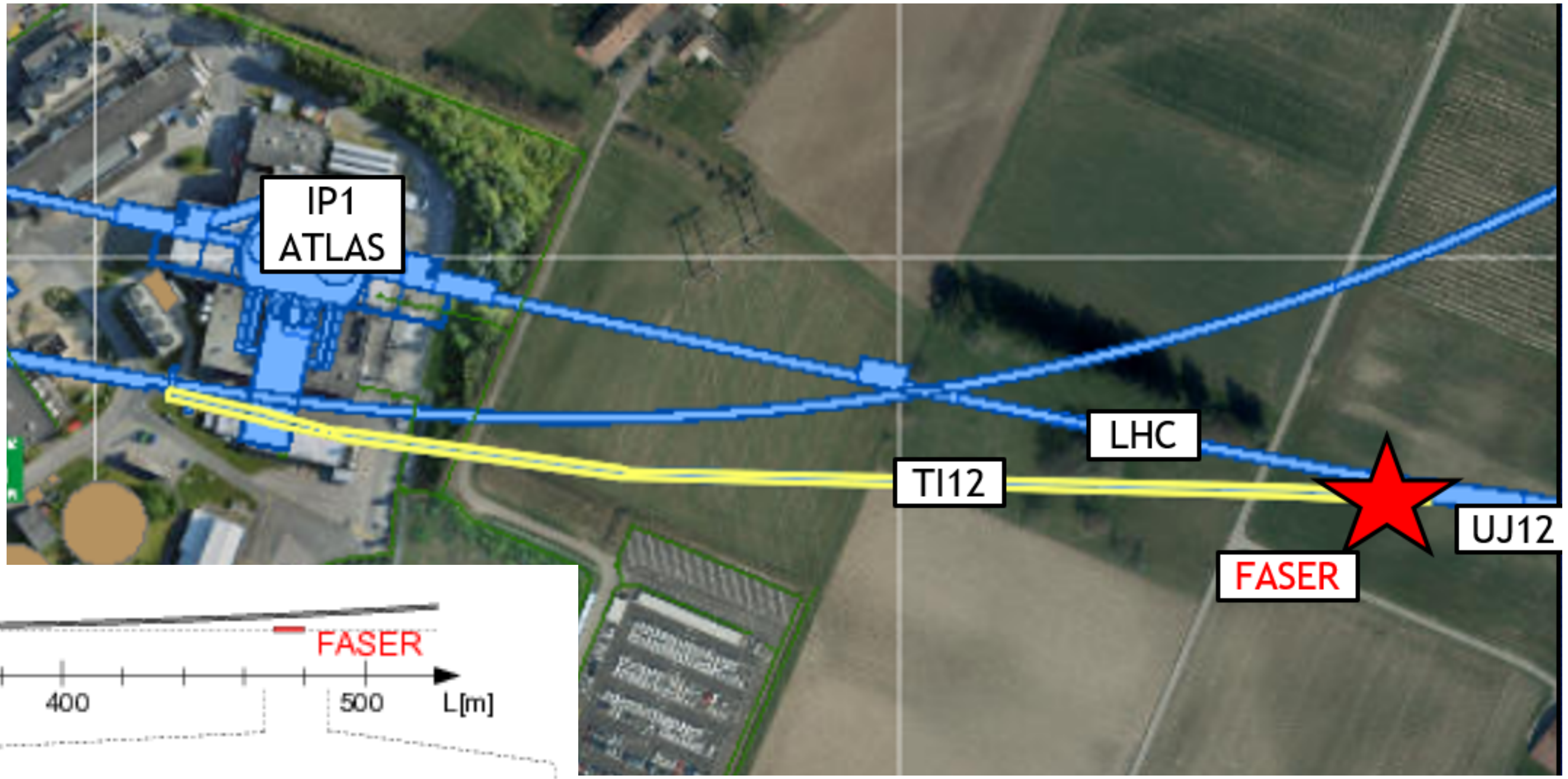
FASER is a small experiment uniquely positioned in the forward region at the LHC:

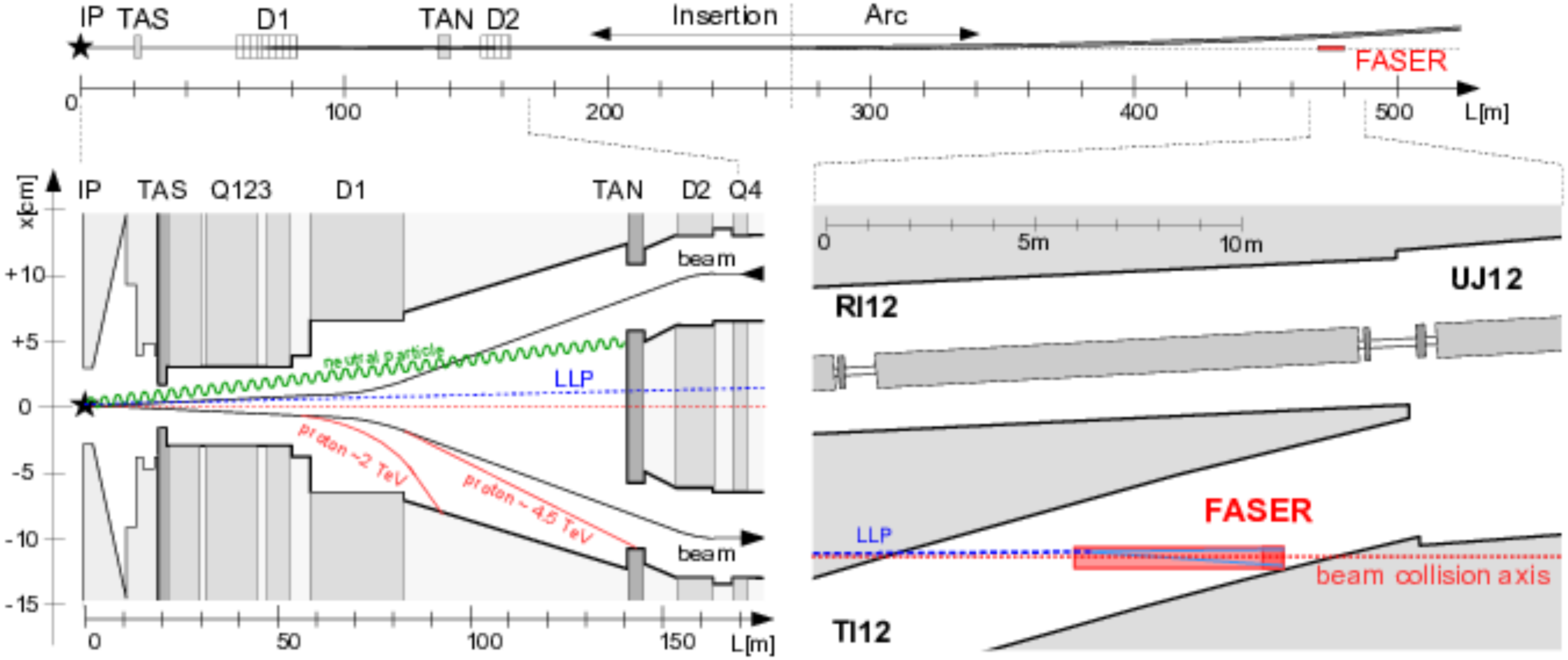
- Optimised to detect light and long-lived particles (LLPs)
- LLPs arise naturally in many models with flavour dynamics, connecting flavour physics to dark sectors and cosmology
- FASER searches for dark photons, axion-like particles and collider neutrinos, enable a broad exploration of new physics scenarios related to flavour

Most recent FASER results will be presented Today

FASER location

FASER is located 480m downstream of ATLAS, shielded with 100m of rock and concrete



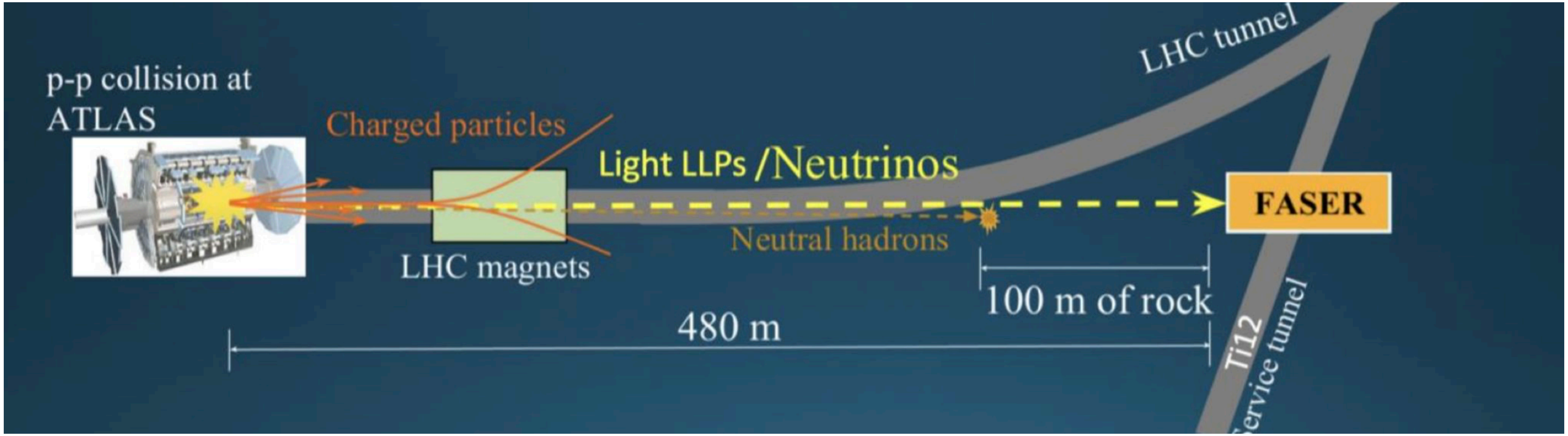


The detector is aligned with the beam collision axis line of sight

Physics

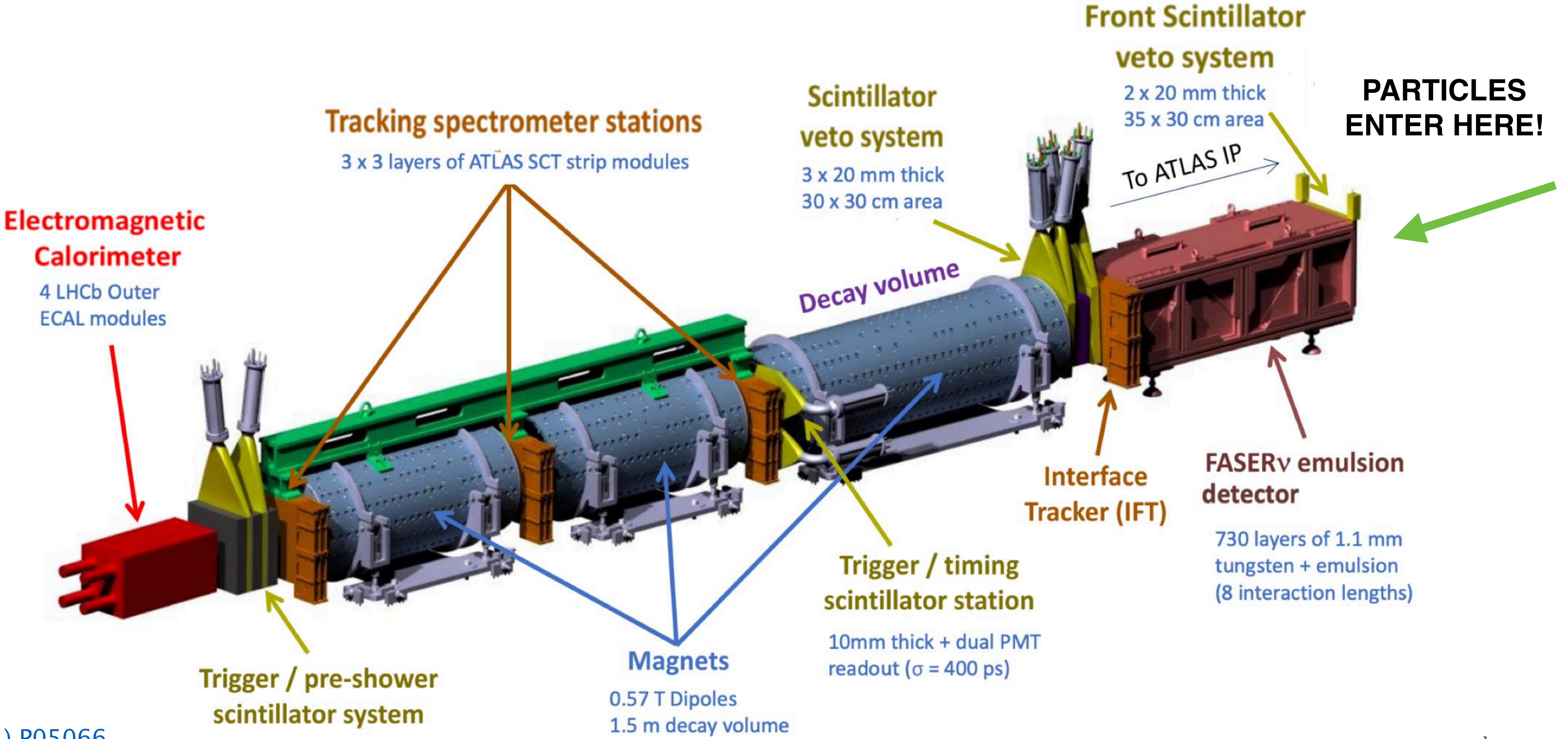
FASER exploits high LHC collision rate with highly collimated forward production of light particles:

- High flux of light particles at LHC produced in π, K, D meson decay - N~ 10^{16} pions/10^{12} neutrinos in LHC Run 3 (2022-2025)
- Energy ~ TeV, direction $\theta_{beam\text{-}axis}$ ~ mrad



Detector

~7m length with 20 cm aperture (η>9.1) and a ~1.5 m magnetised decay volume



JINST 19 (2024) P05066

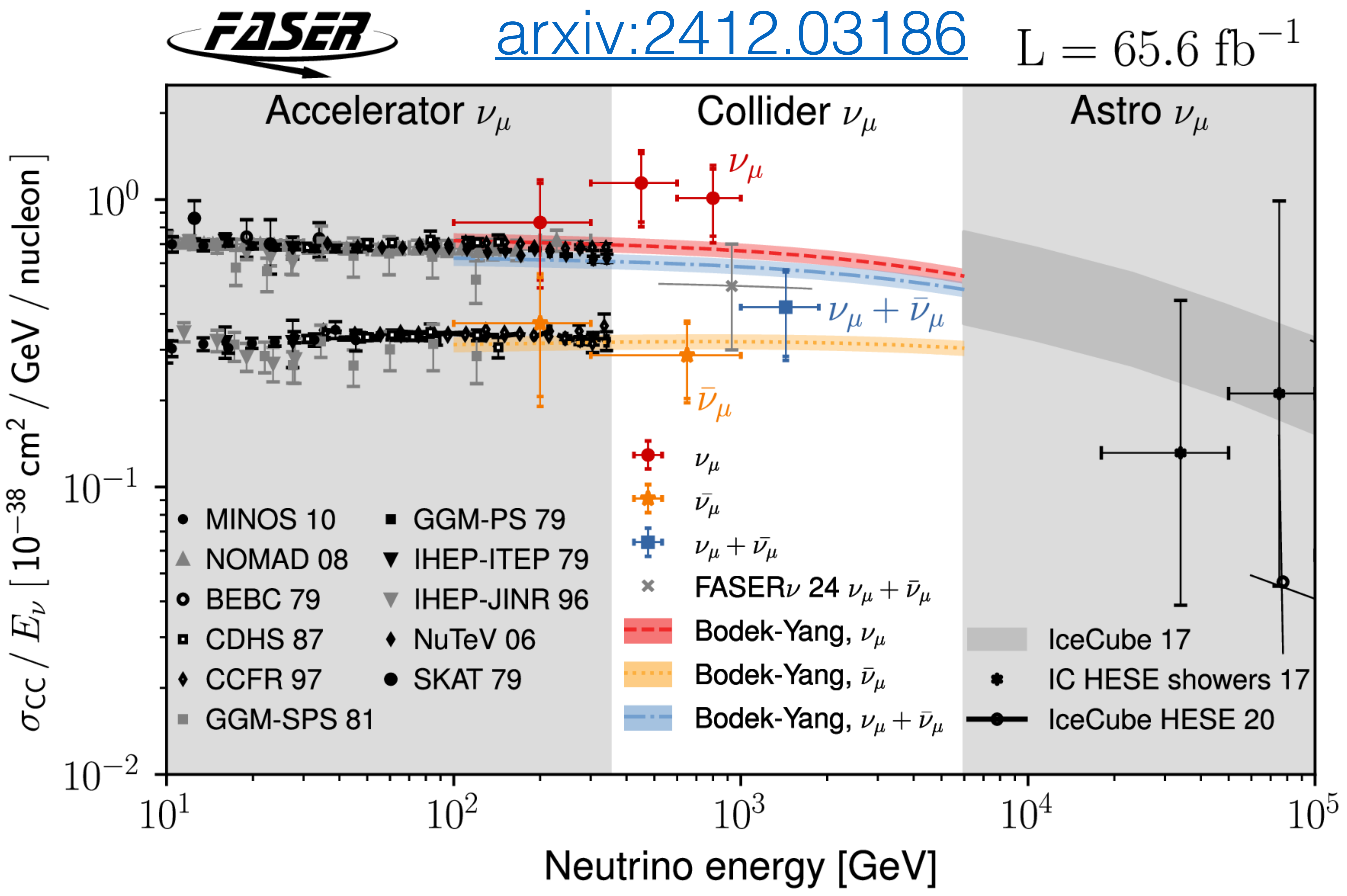
Neutrino flux at FASER

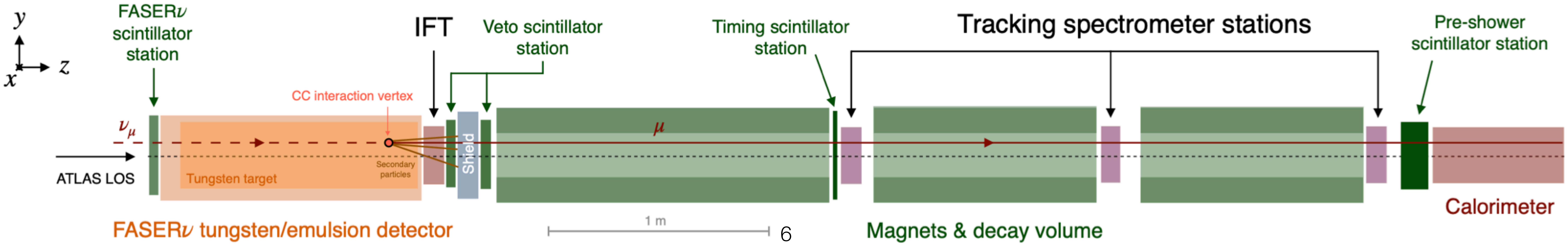
First Measurement of the Muon Neutrino Interaction Cross Section and Flux as a Function of Energy at the LHC with FASER

$$\nu_e:\ K \longrightarrow \pi e \nu_e\ ,\ D \longrightarrow K e \nu_e$$
$$\nu_\mu:\ \pi^\pm \longrightarrow \mu\nu_\mu\ ,\ K^\pm \longrightarrow \mu\nu_\mu$$
$$\nu_\tau:\ D_s \longrightarrow \tau\nu_\tau$$

Generators		FASERν at Run 3		
light hadrons	charm hadrons	$\nu_e+\bar\nu_e$	$\nu_\mu+\bar\nu_\mu$	$\nu_\tau+\bar\nu_\tau$
EPOS-LHC	–	1149	7996	–
SIBYLL 2.3d	–	1126	7261	–
QGSJET 2.04	–	1181	8126	–
PYTHIAforward	–	1008	7418	–
–	POWHEG Max	1405	1373	76
–	POWHEG	527	511	28
–	POWHEG Min	294	284	16
Combination		1675^{+911}_{-372}	8507^{+992}_{-962}	28^{+48}_{-12}

arxiv:2412.03186

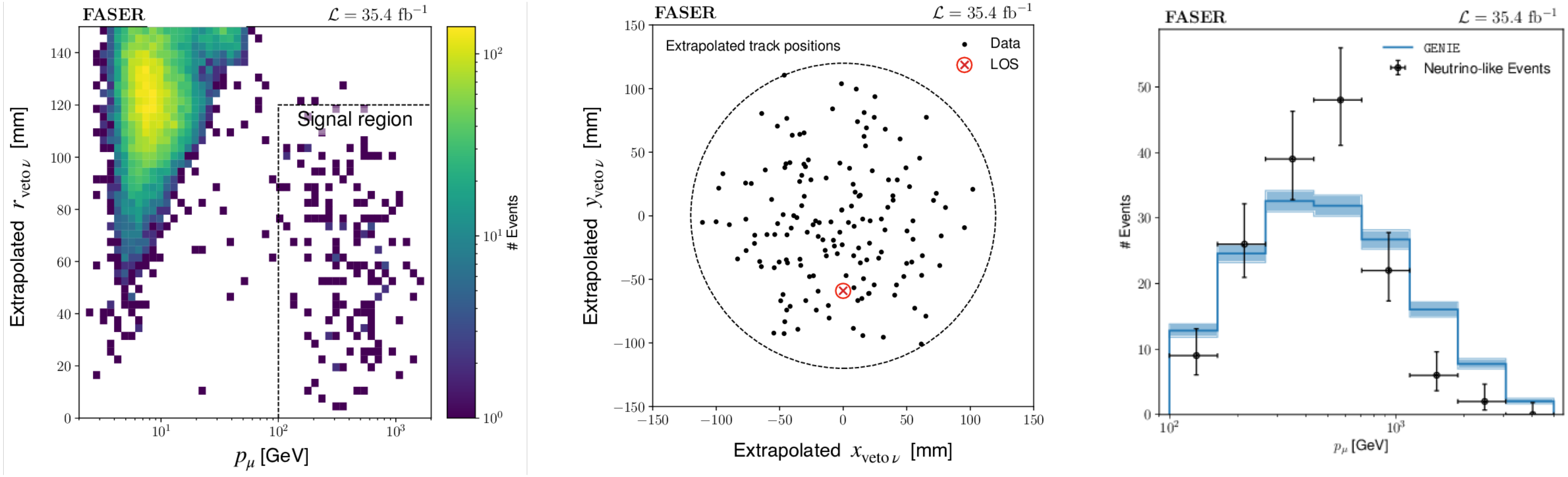




First collider neutrino observation

First direct observation of collider neutrinos!

153 events observed with an expected background of 0.2 +/- 1.8

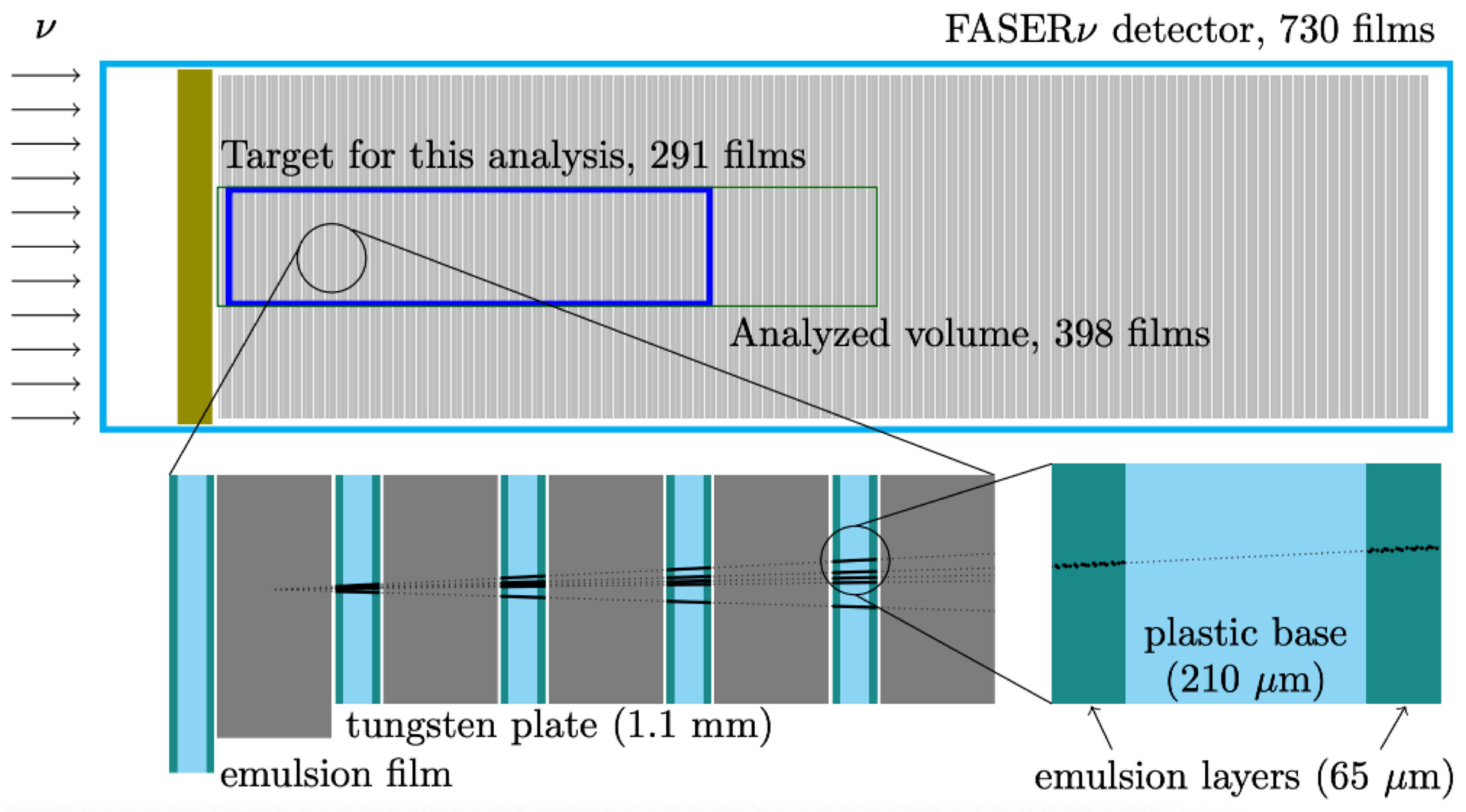


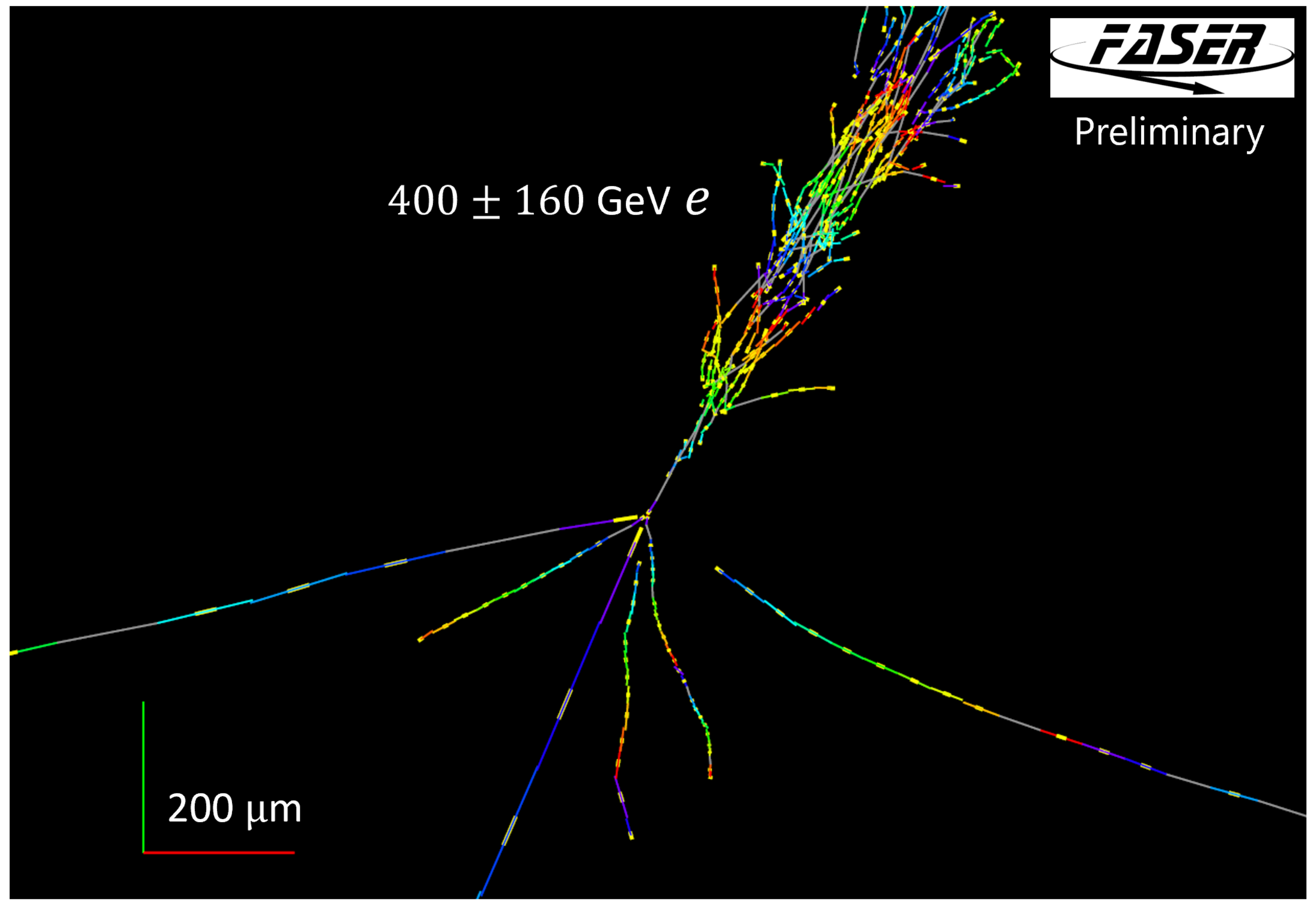
PhysRevLett.131.031801

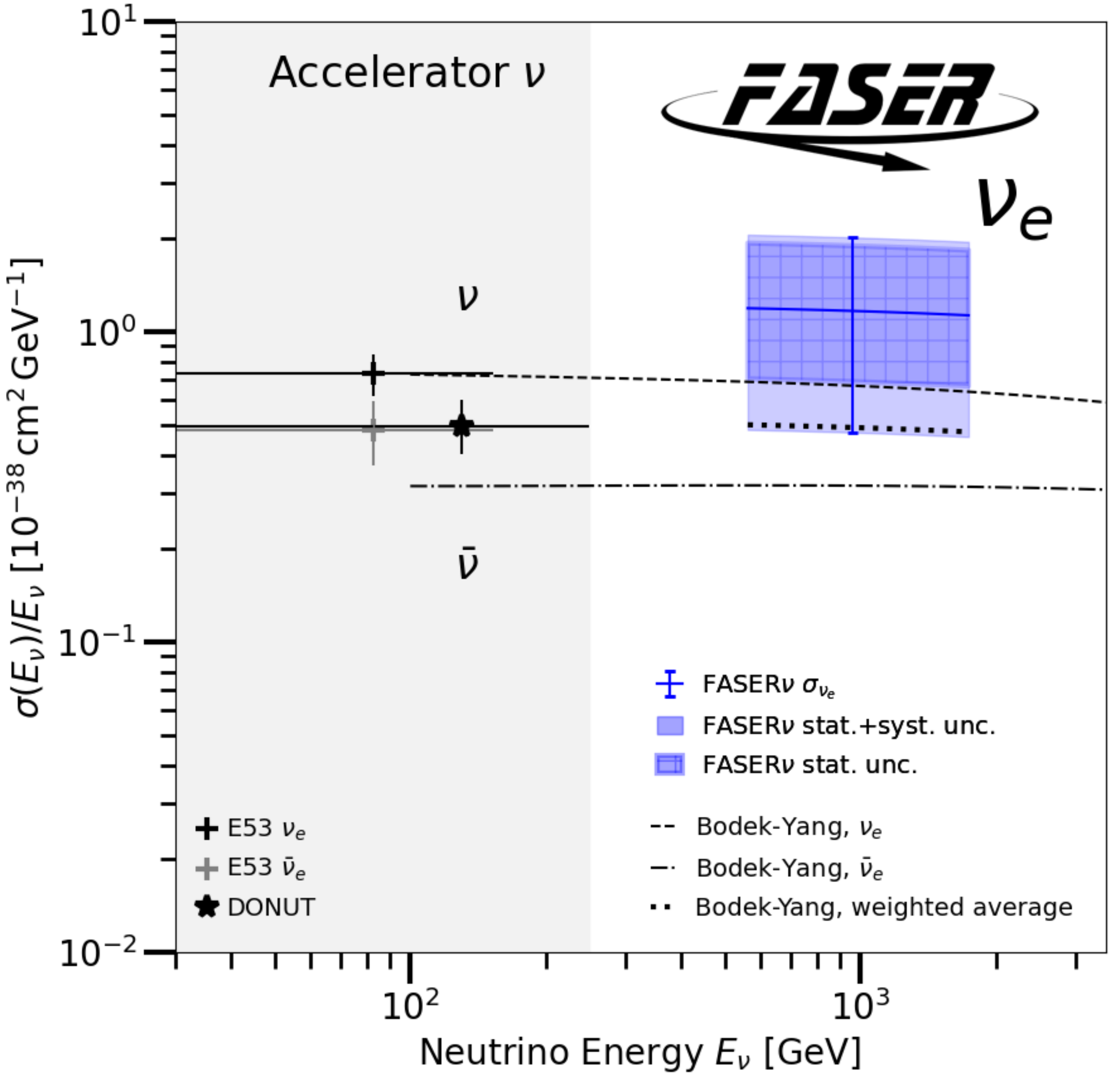
Neutrino flux at FASERν arxiv:2403.12520

First Measurement of the electron Neutrino with FASER: Only small percentage of 2022 data analysed for emulsion-based neutrino measurements yet!

- up of 730 layers of interleaved tungsten plates and emulsion films (0.34 mm), with a total target mass of 1.1 tonnes
- Position resolution 0.30μm
- Data collected between July 26th and September 13th 2022 (9.5 fb-1 delivered)
- Analysed target mass of 128.6 kg



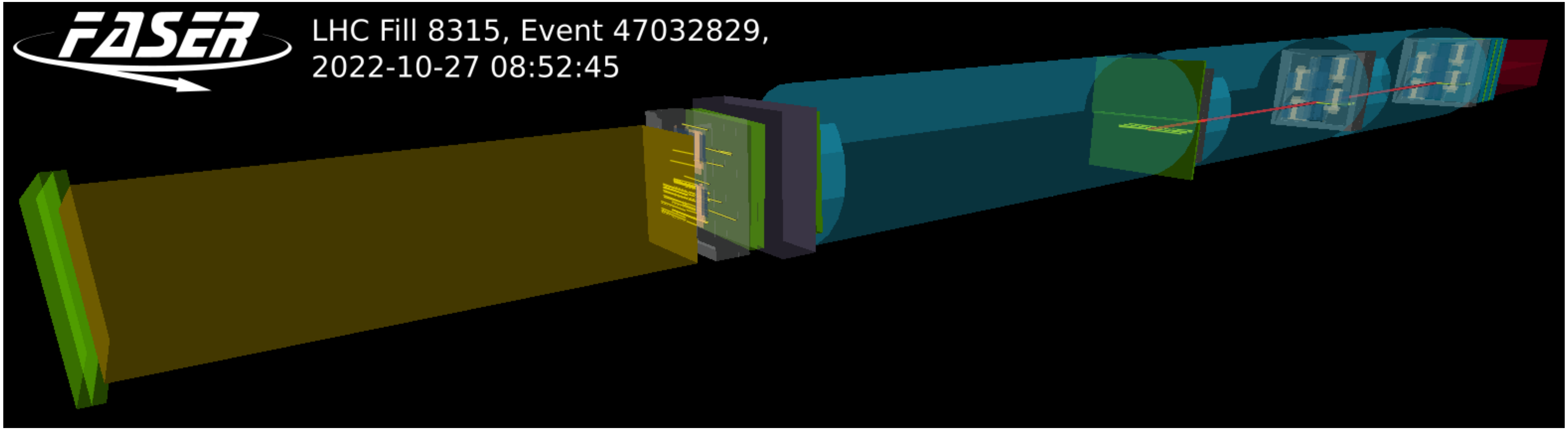


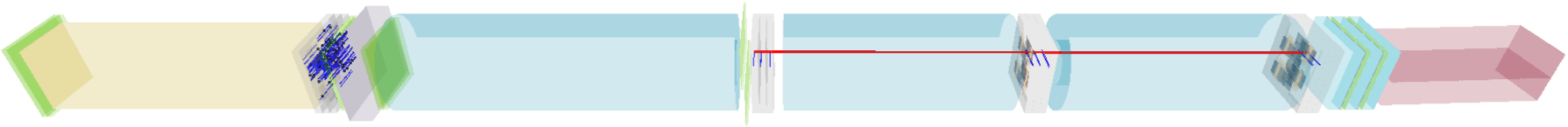


Electron neutrino events observed: 4 (5.2σ)

Event display

Event display of a neutrino interaction candidate in which secondary particles produced in the CC interaction produce activity in the IFT





Dark-photon search

PLB.2023.138378

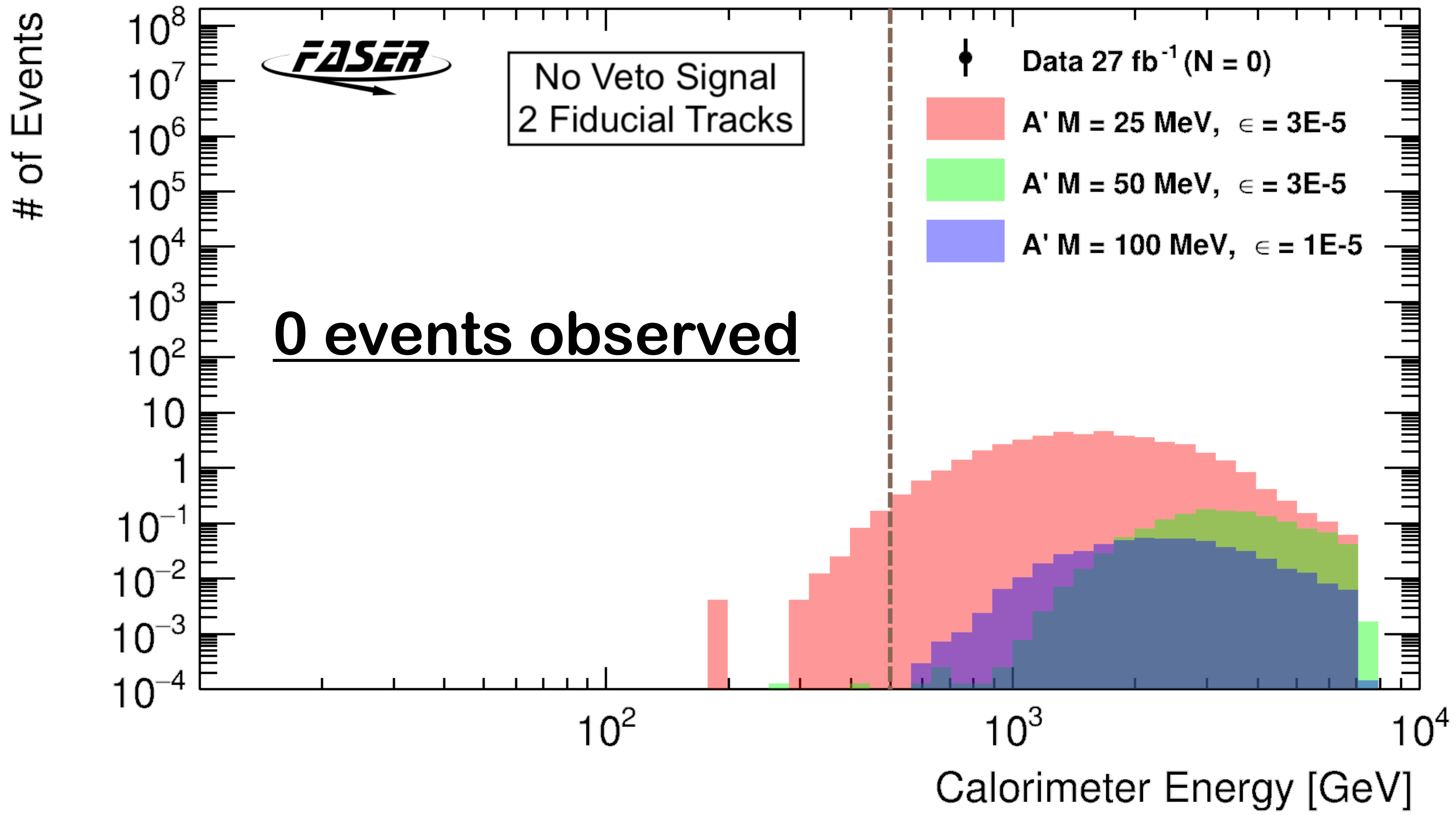
First FASER search for light dark photons decaying to electrons (2022 dataset 27/fb)

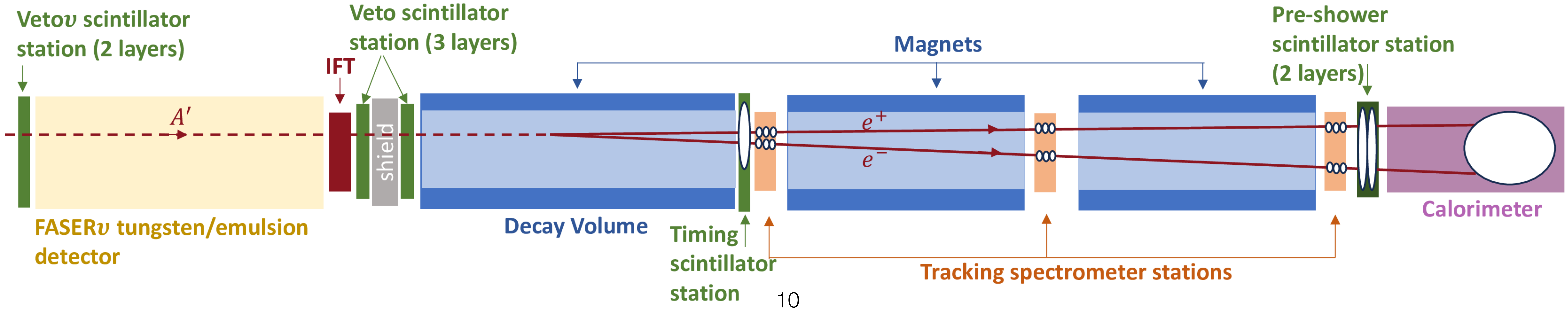
Signature:

- No signal in vetoes
- 2 tracks with momentum p > 20 GeV
- 2 MIPs in pre-shower scintillators with associated EM Calo deposit >500 GeV

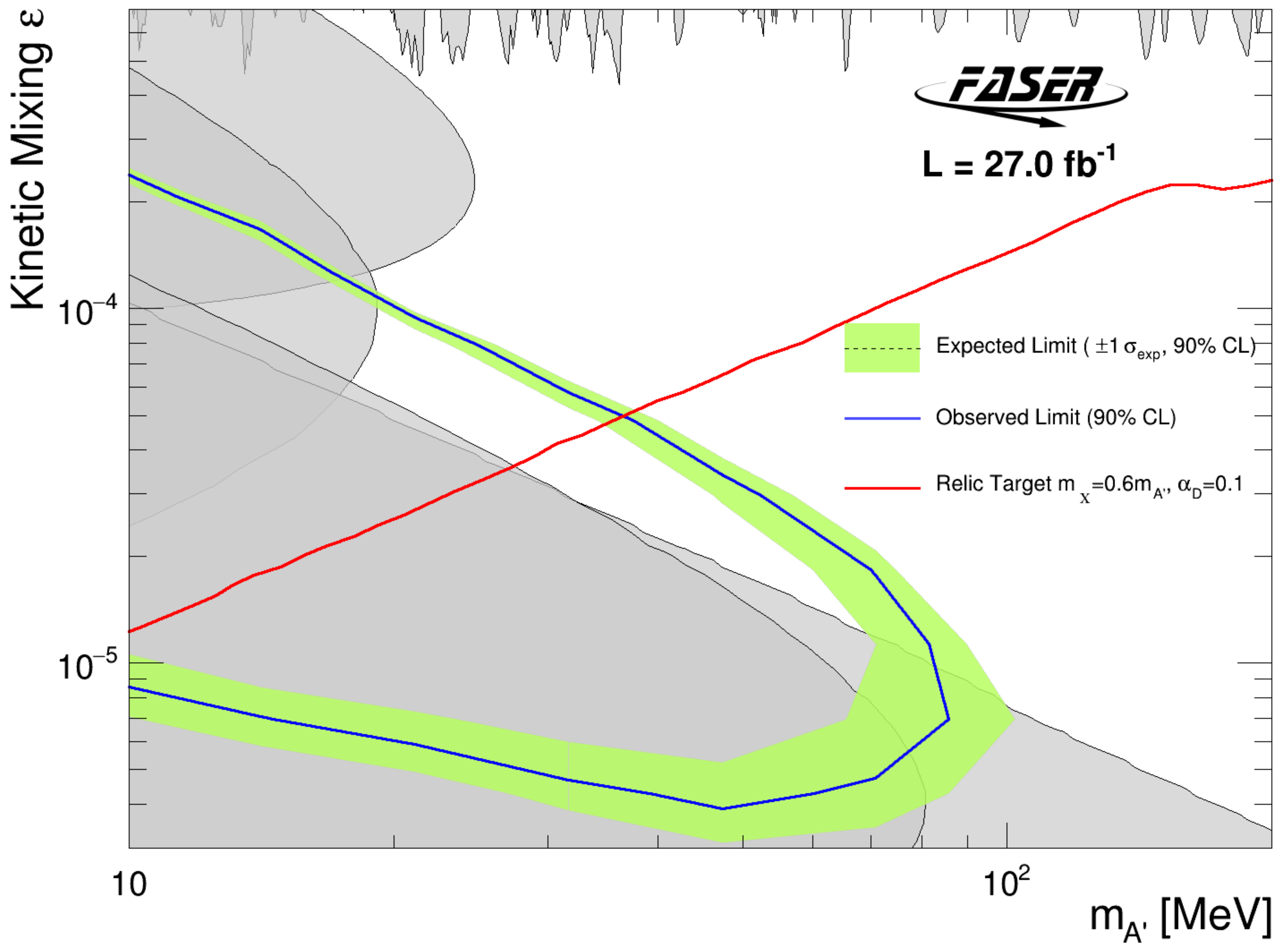
Background free analysis:

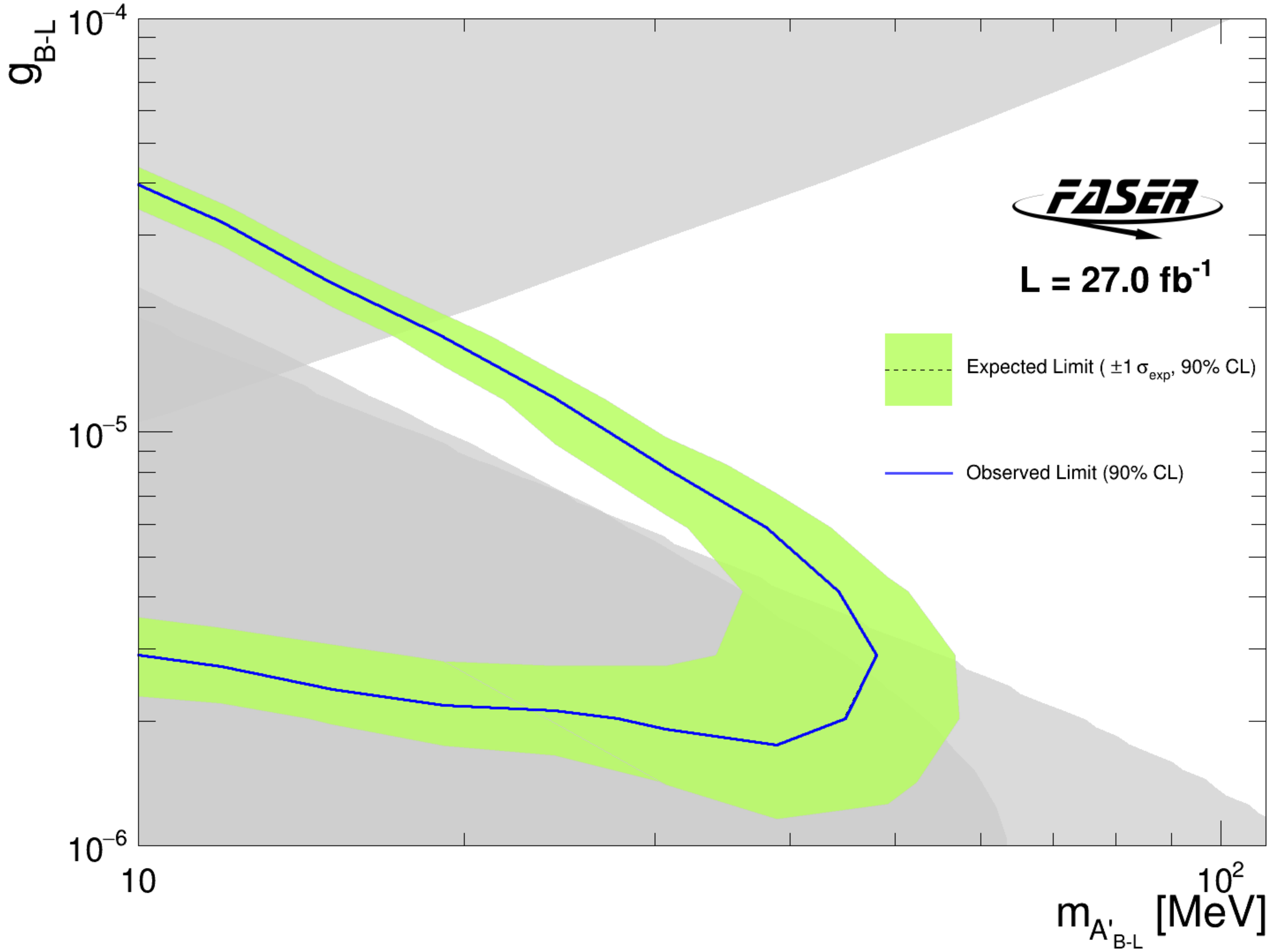
- Neutral hadrons (8.4 ± 11.9)x10-4 expected events
- Neutrinos (1.5 ± 1.9)x10-4 expected events





Dark-photon exclusion PLB.2023.138378





New parameter space is probed by FASER

Result for $U(1)_{B-L}$ model

ALP search

[JHEP 01 (2025) 199]

First FASER search for light ALPs decaying to photons (2022-2023 dataset 57.7/fb)

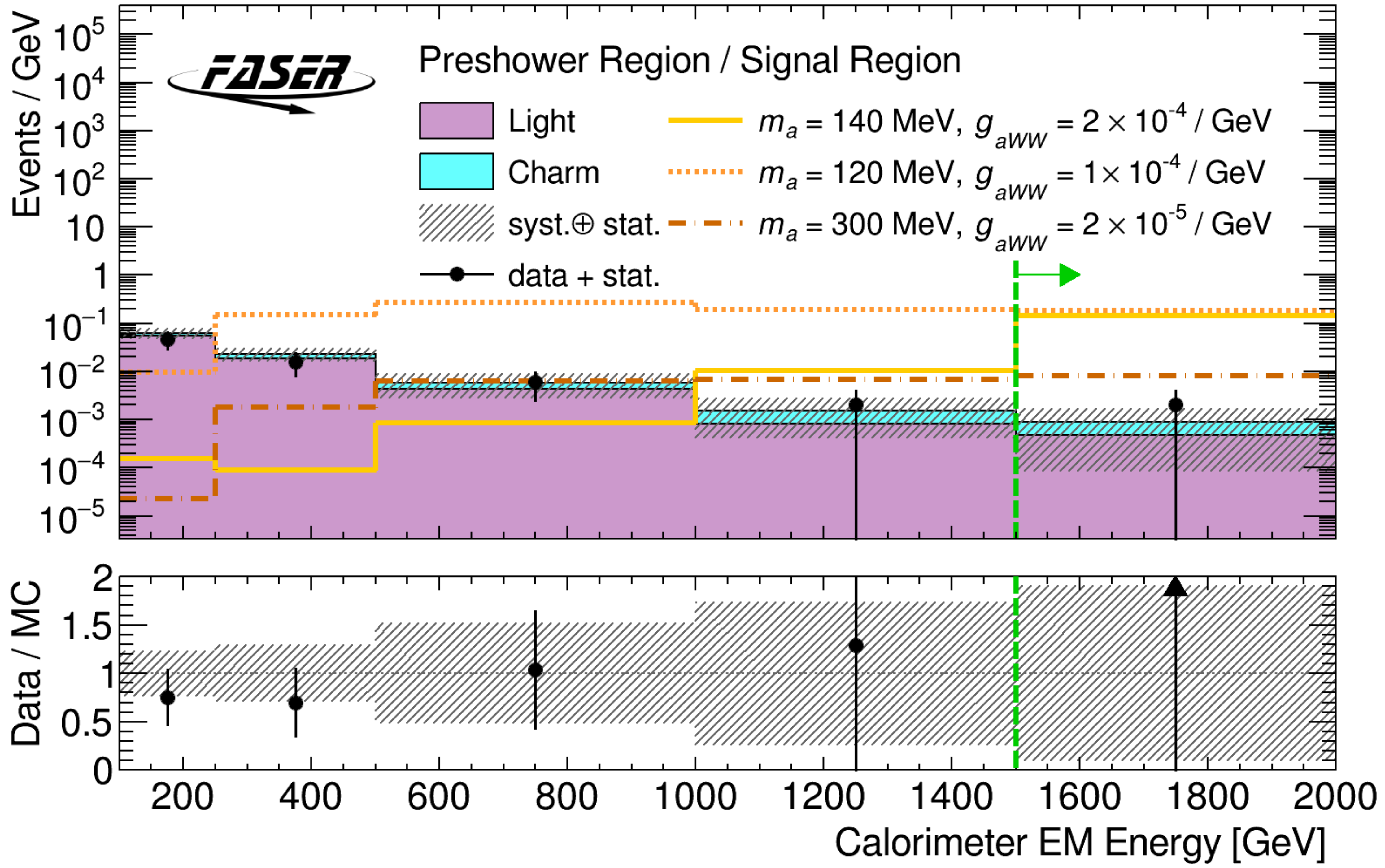
Signature:

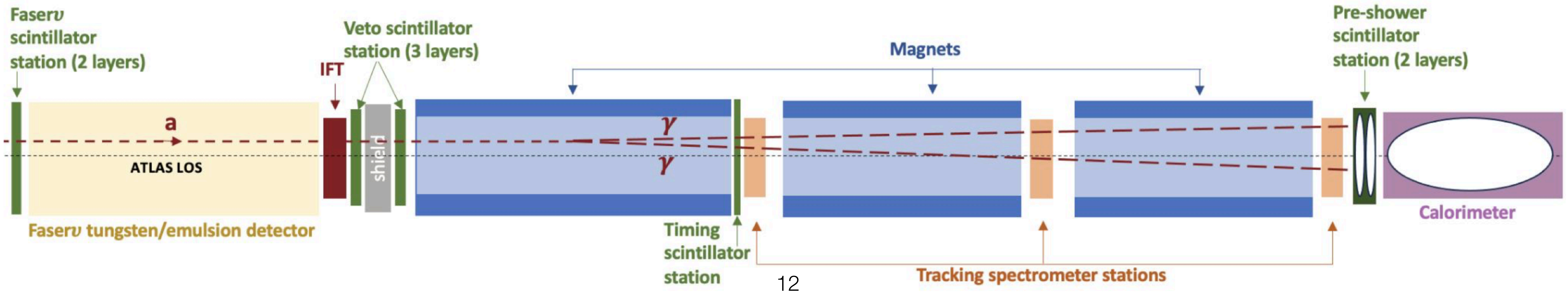
- No signal in vetoes, timing scintillator and tracking stations
- Signal in the pre-shower and large energy deposit in calorimeter (>1.5 TeV)

Small background:

- neutrino interactions in the pre-shower exp events (0.42 ± 0.38)

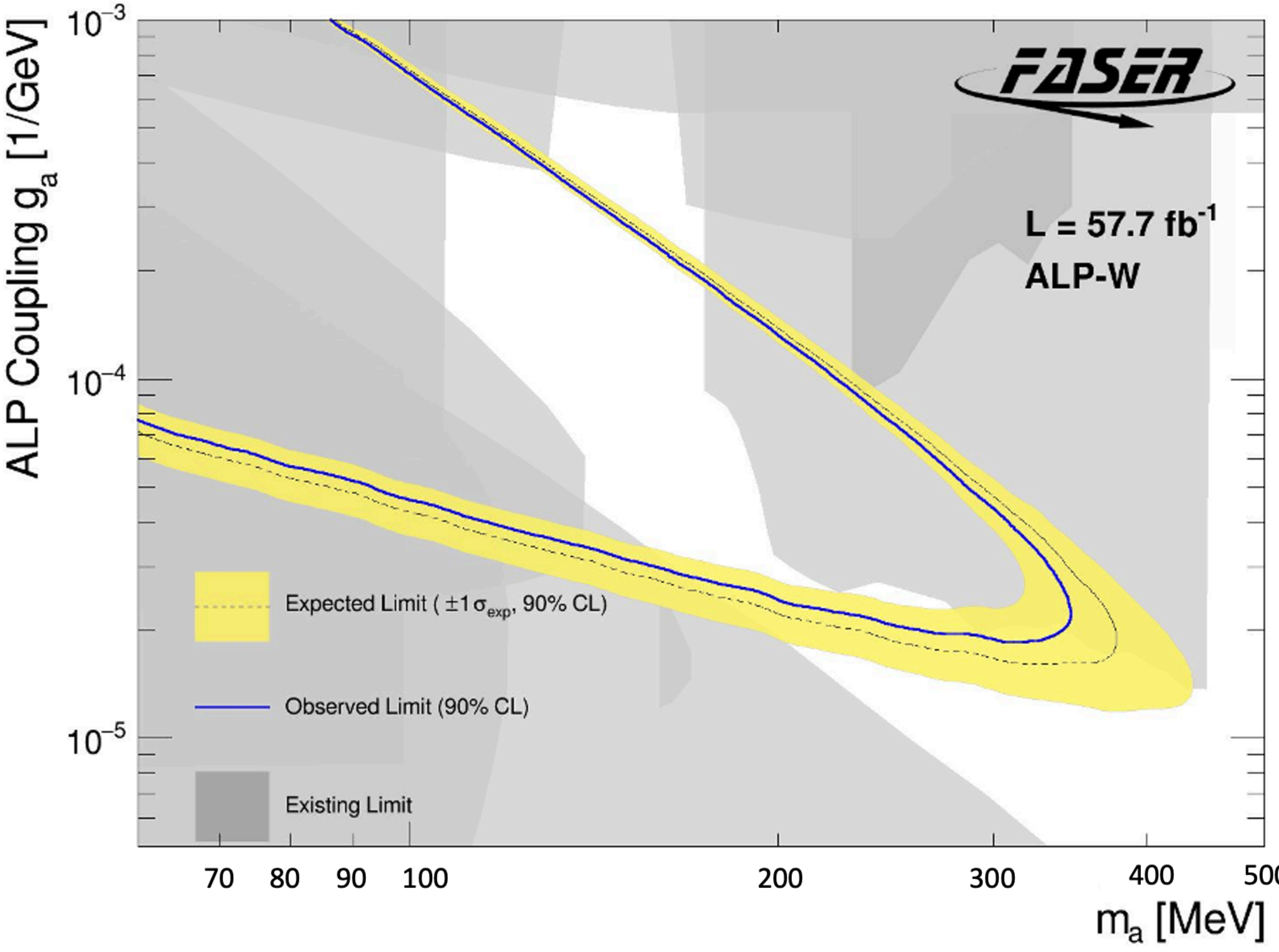
Current system cannot resolve 2 high energy photons

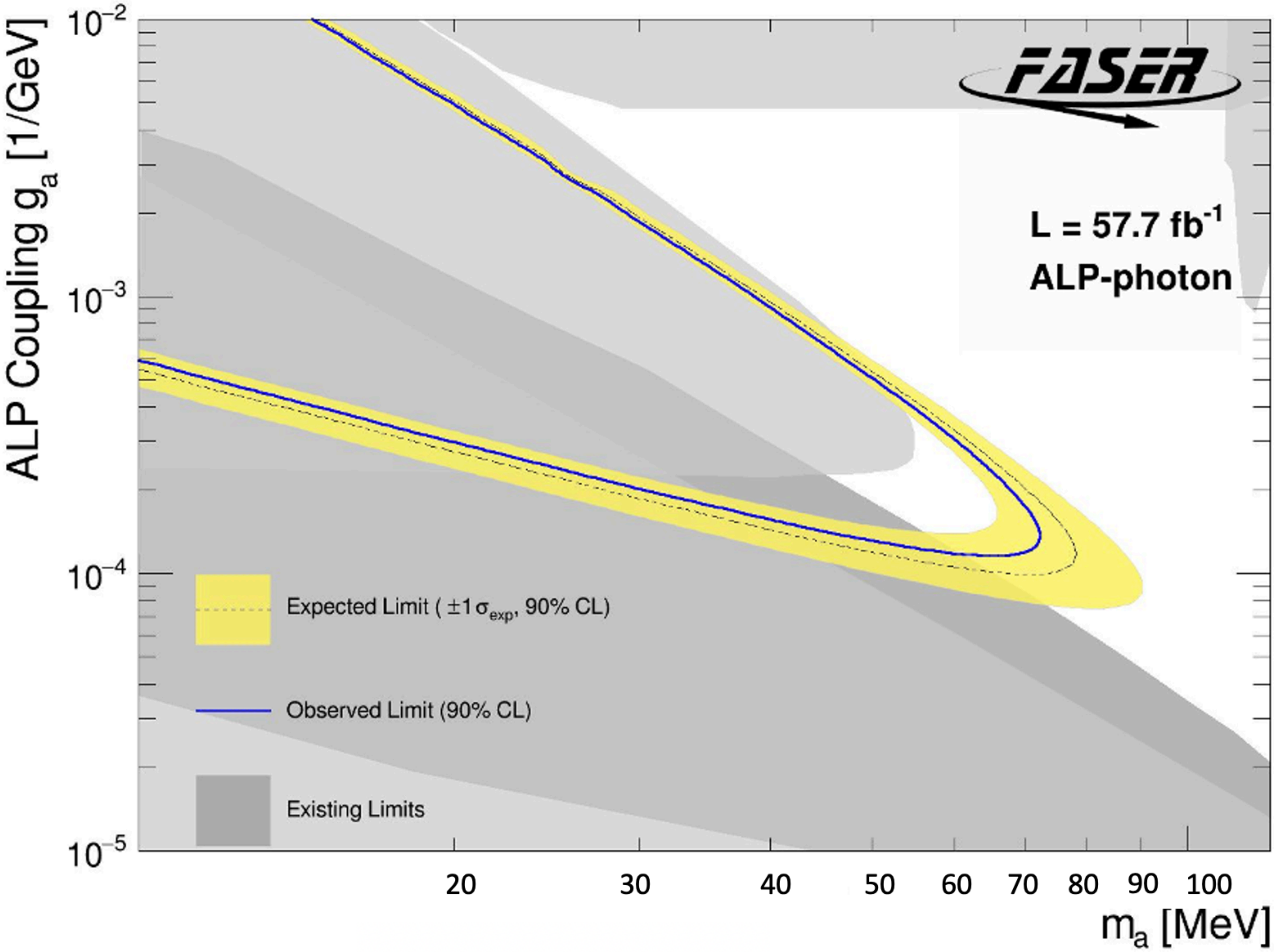


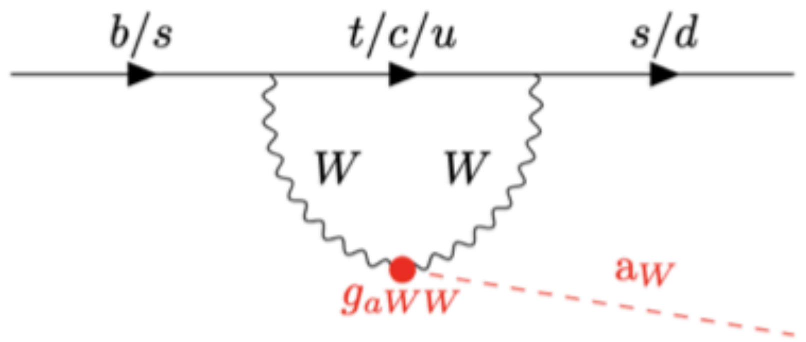


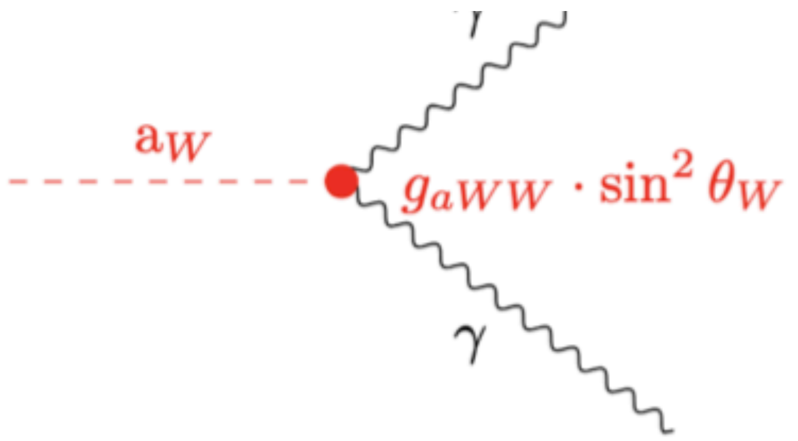
ALP exclusion

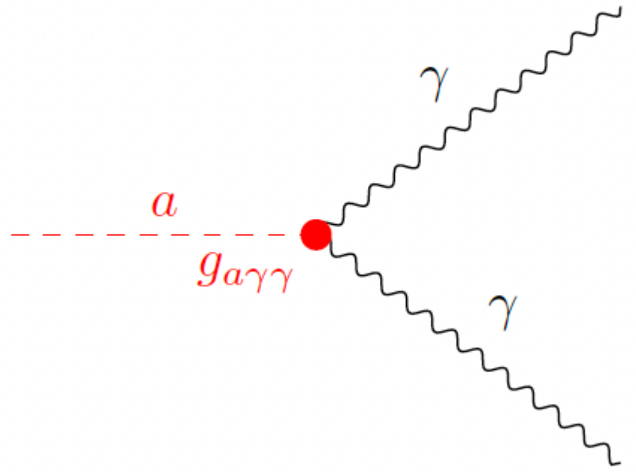
[CERN-EP-2024-262]









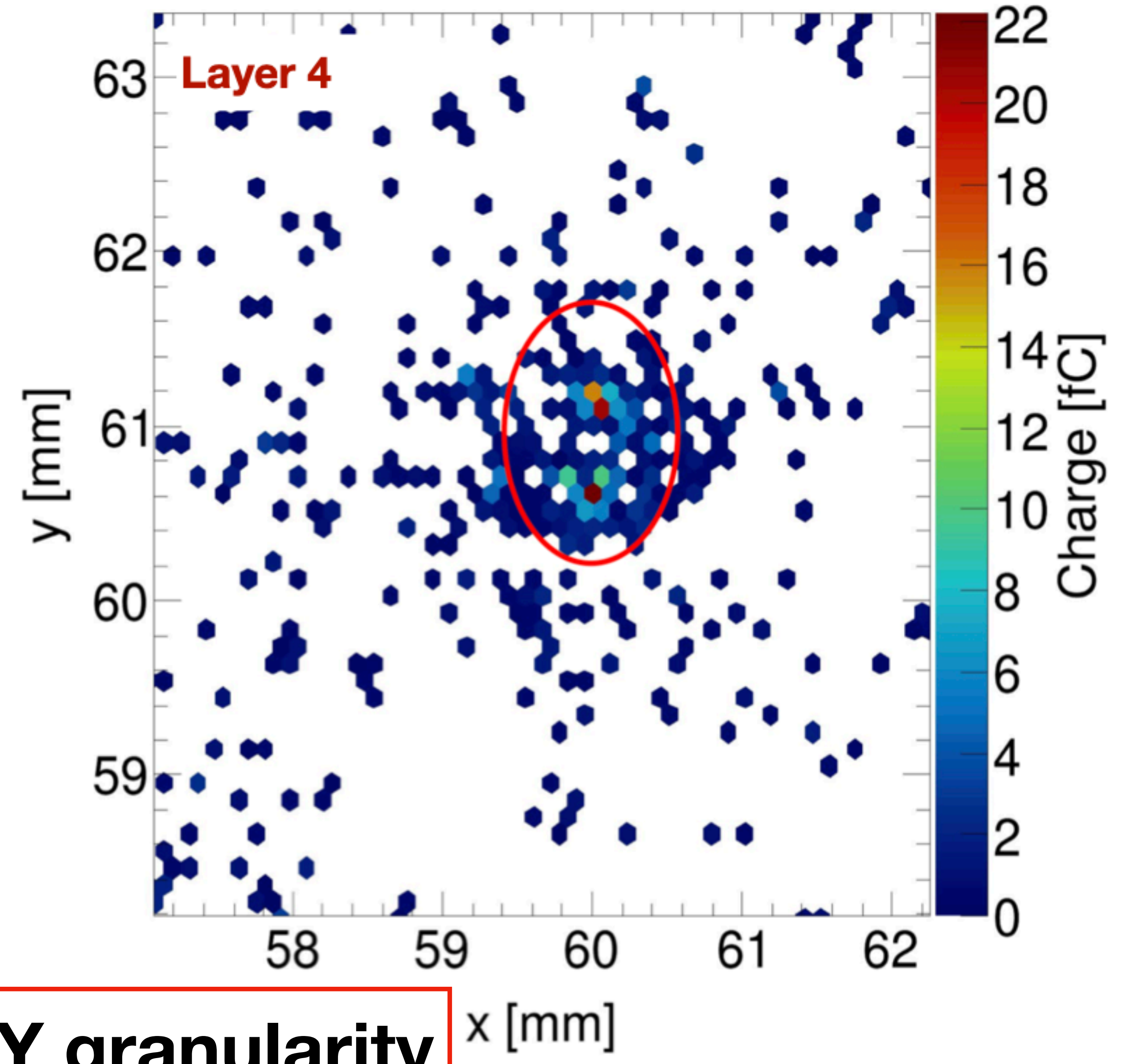


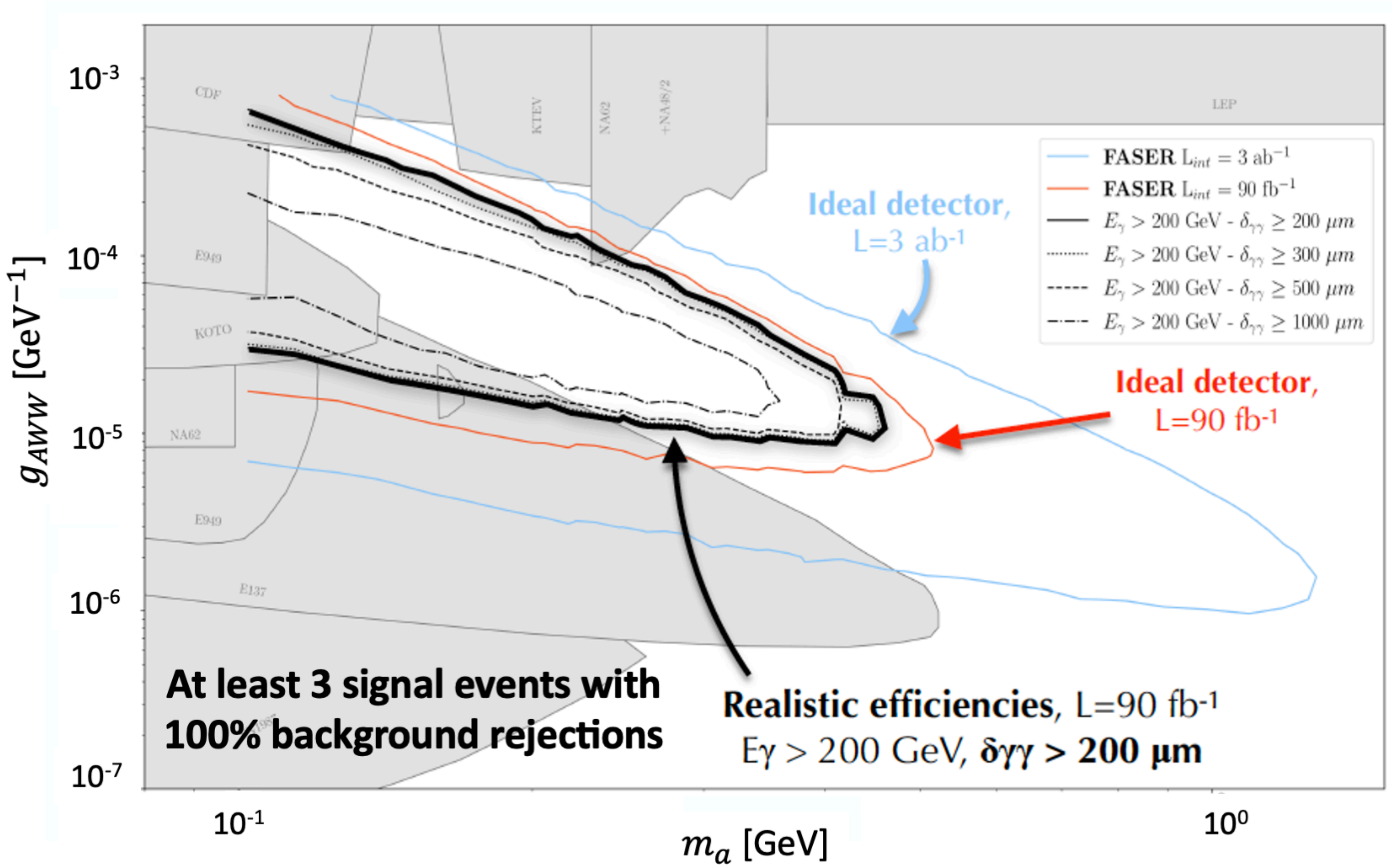
Produced through primakoff process

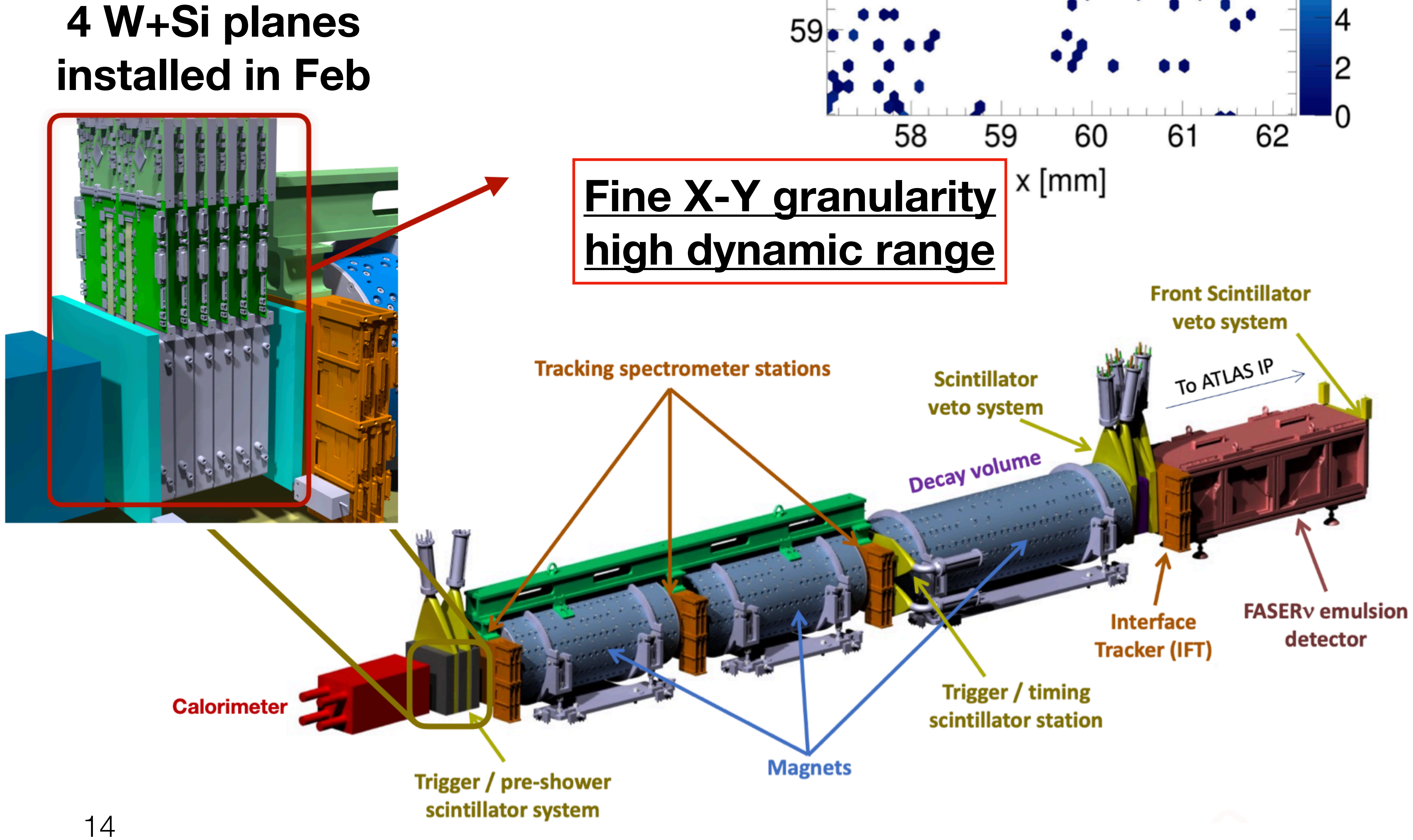
What next in Run3?

FASER upgraded in early 2025:

- New high-resolution W-Si pixel preshower detector installed
  - Enables multi-γ tagging and increase ALP searches' reach
- New muon ID detector installed after calorimeter using old preshower
  - Allows for muon / pion discrimination (→ LLP models with pions)







Summary

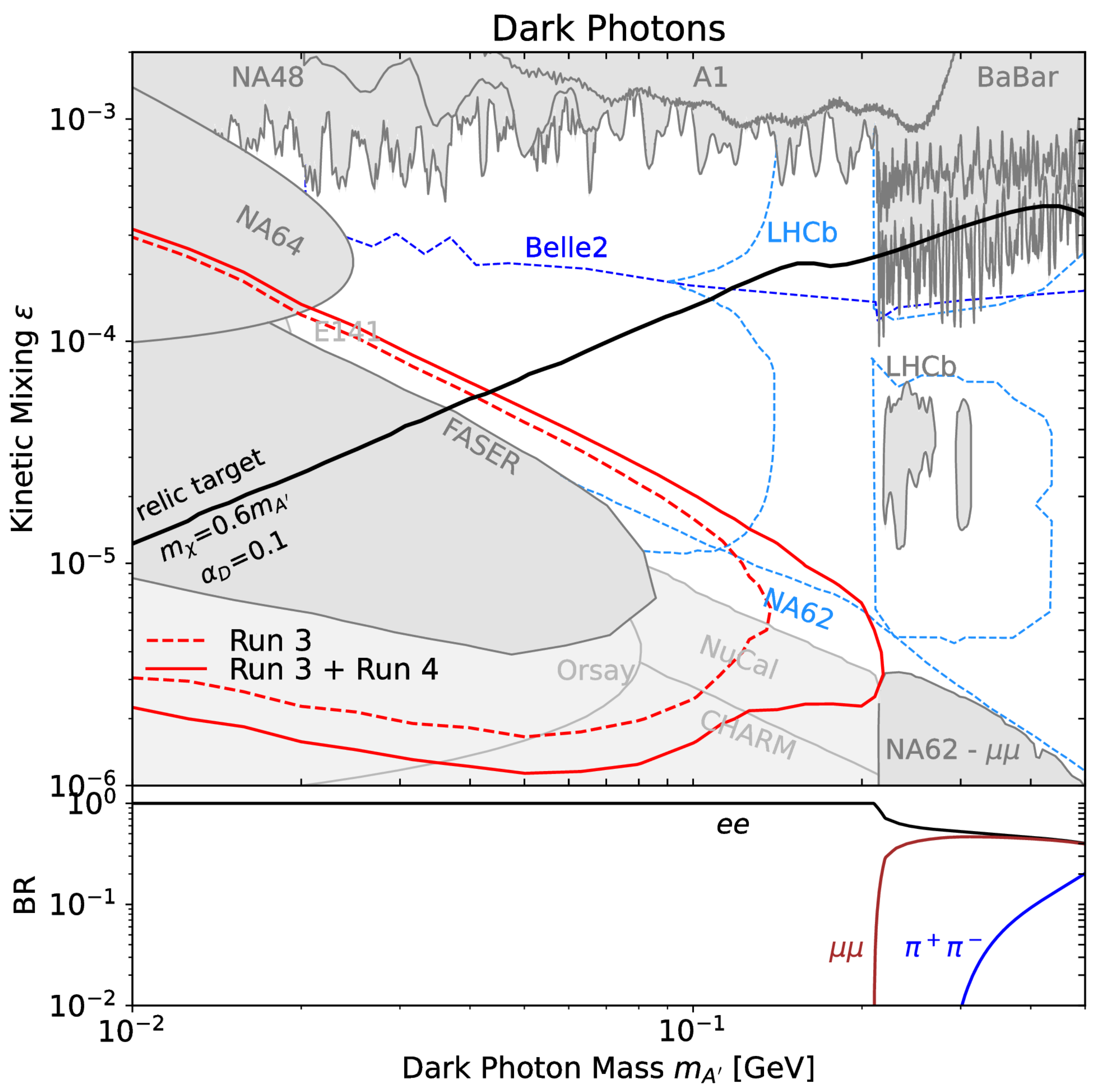
FASER successfully took data in the first 3 years of Run3:

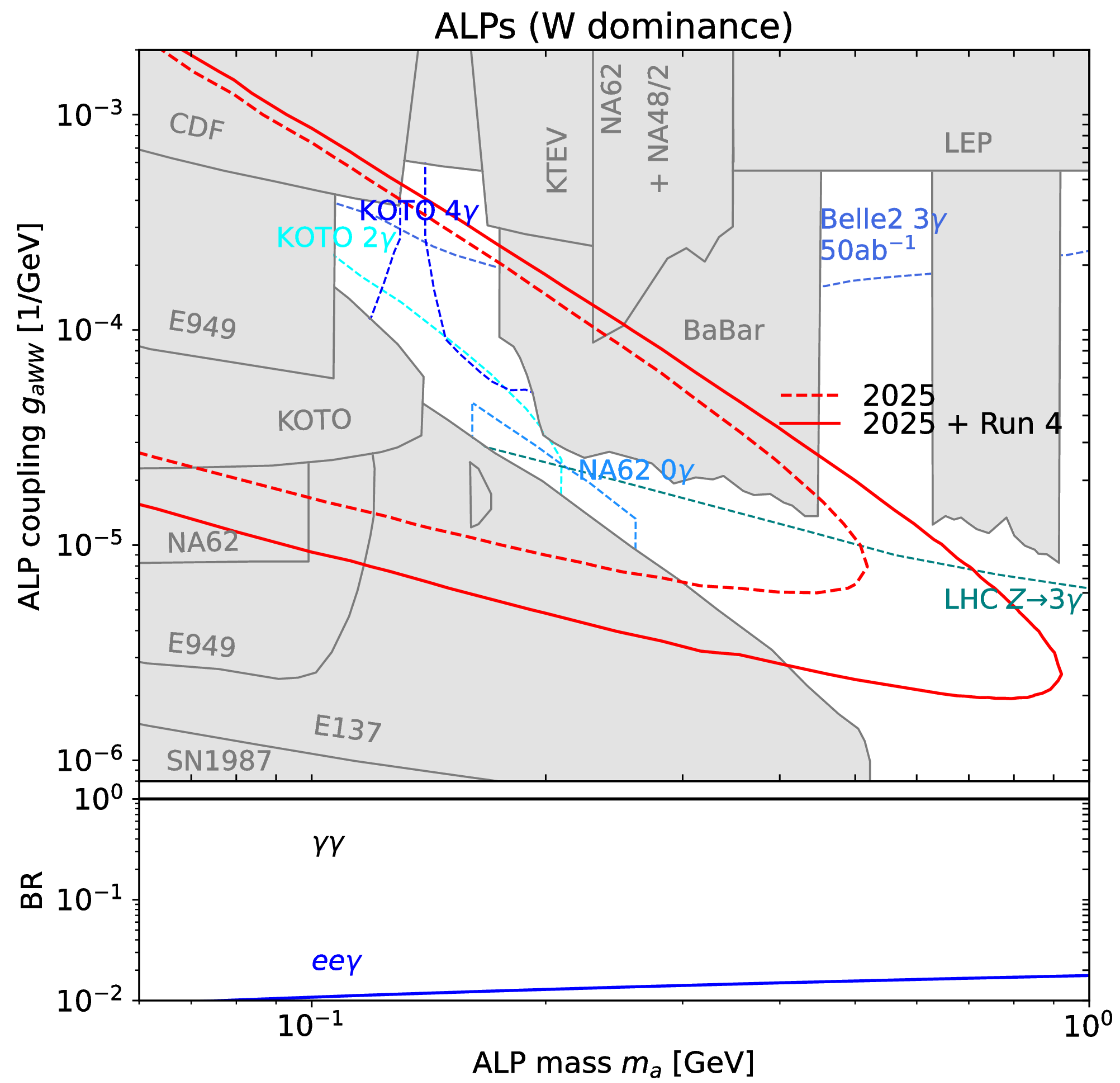
- Set world-leading constraints on dark photons and ALPs

- First-ever detection of collider-produced neutrinos, opening a new window on high-energy neutrino physics

- Synergies with ATLAS, LHCb, and flavour factories will further strengthen our understanding of the connections between flavour, dark sectors, and cosmology

- Run-4 operations approved! The future is FORWARD

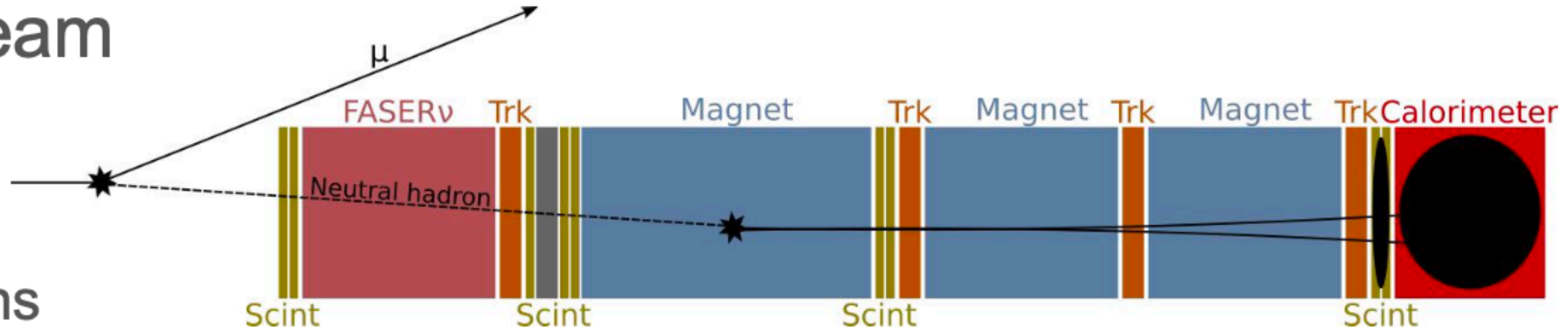




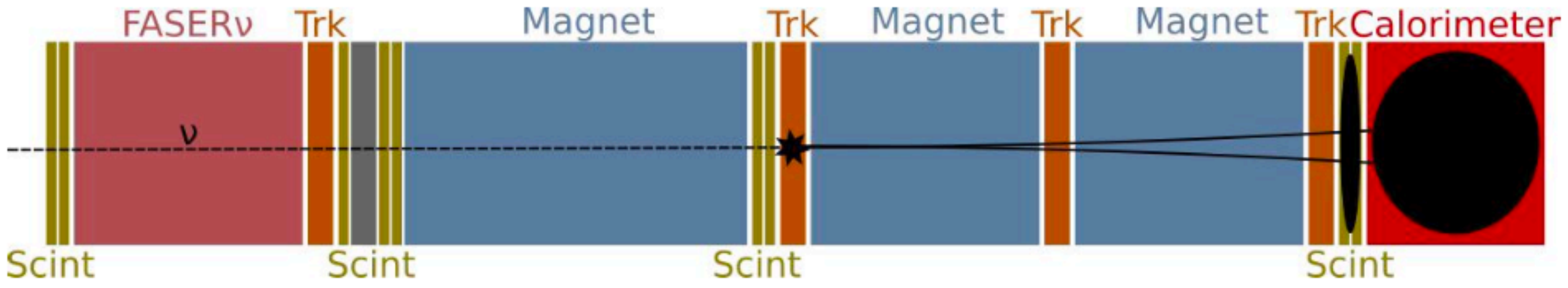
BACKUP

Dark Photon Dominant Background

- Neutral hadrons (e.g. Ks) from upstream muons interacting in rock
  - Data driven estimate from lower energy 3-track/2-track and different veto conditions
  - **$(8.4 \pm 11.9)\text{x}10^{-4}$** expected events



- Neutrinos interacting in the Timing scintillator station or the first tracking station
  - GENIE simulation (300 ab^{-1}) following input flux estimate method in [PRD 110 (2024) 1, 012009]
  - **$(1.5 \pm 2.4)\text{x}10^{-4}$** expected events

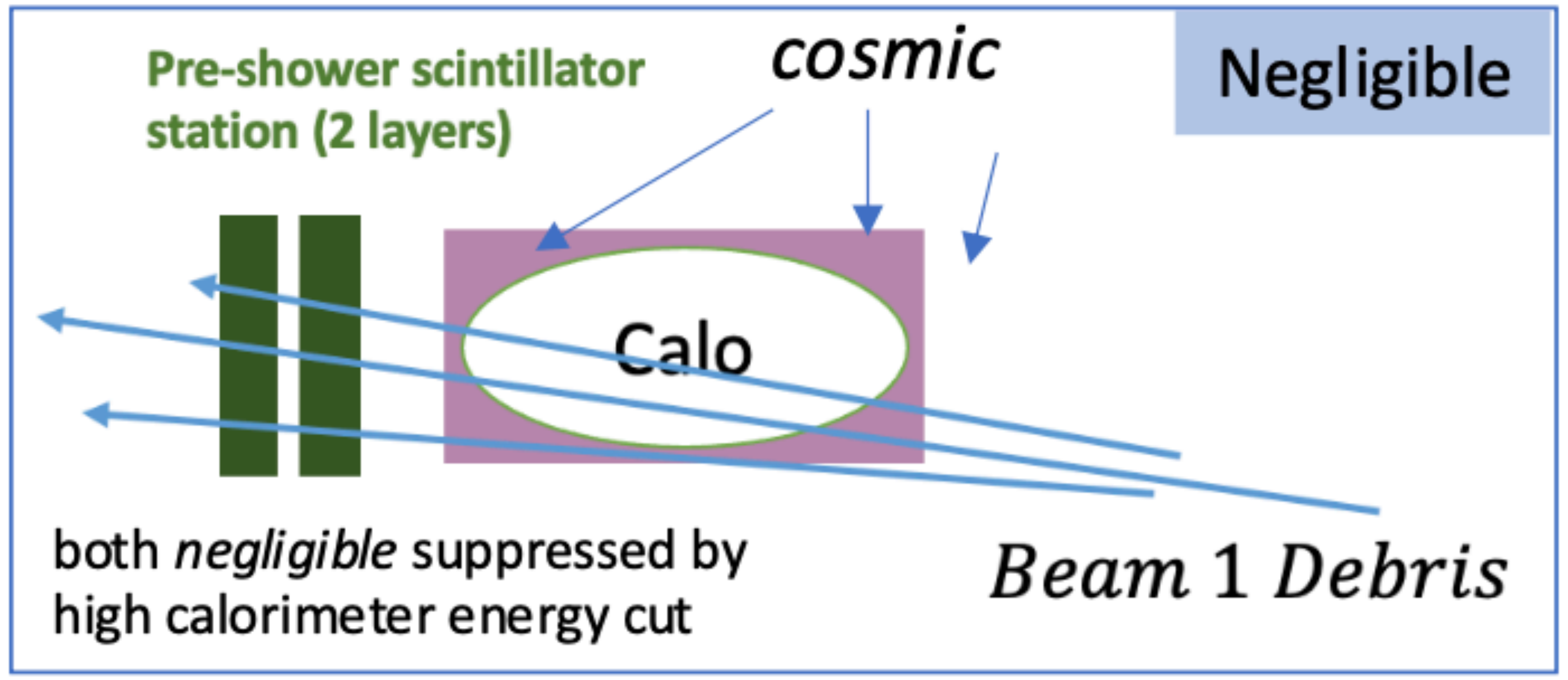


- Veto scintillators inefficiencies, Large-angle muons entering in the active detector, Non-collision events
  - Negligible

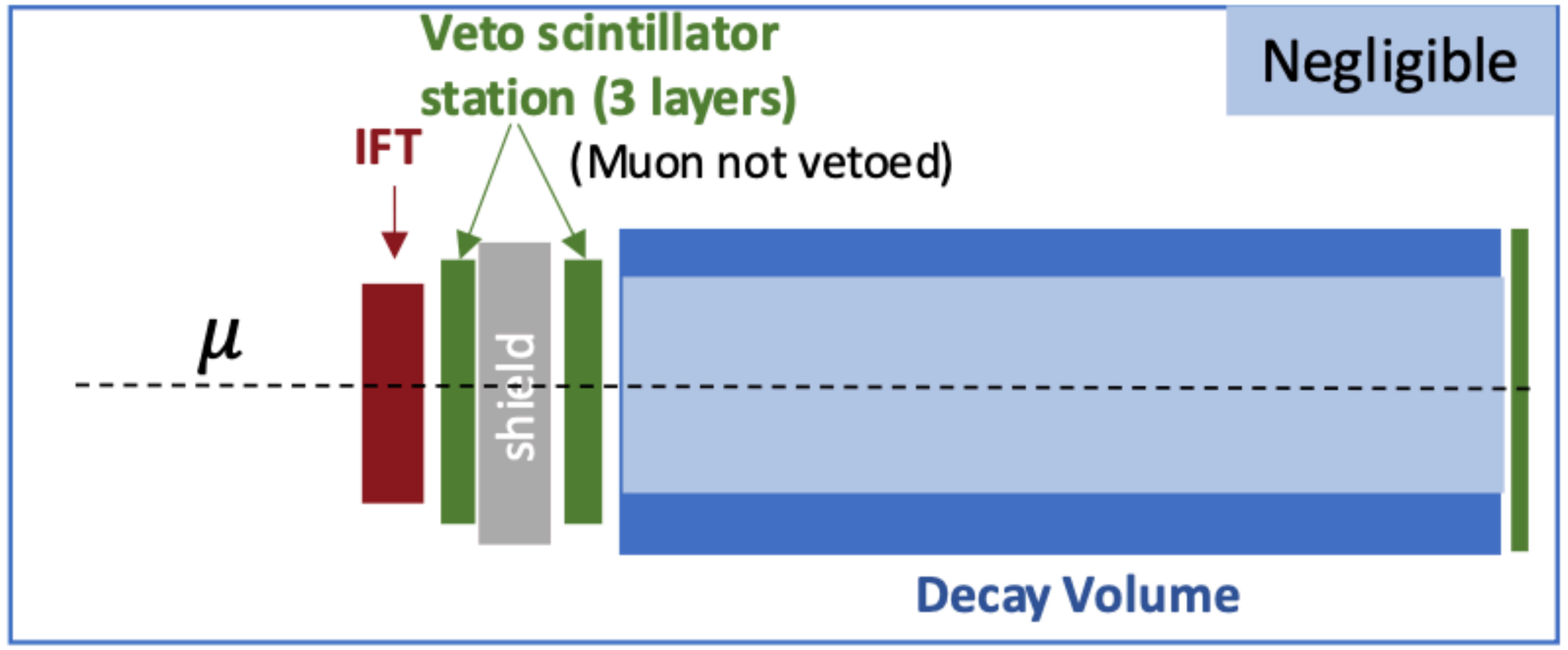
Background

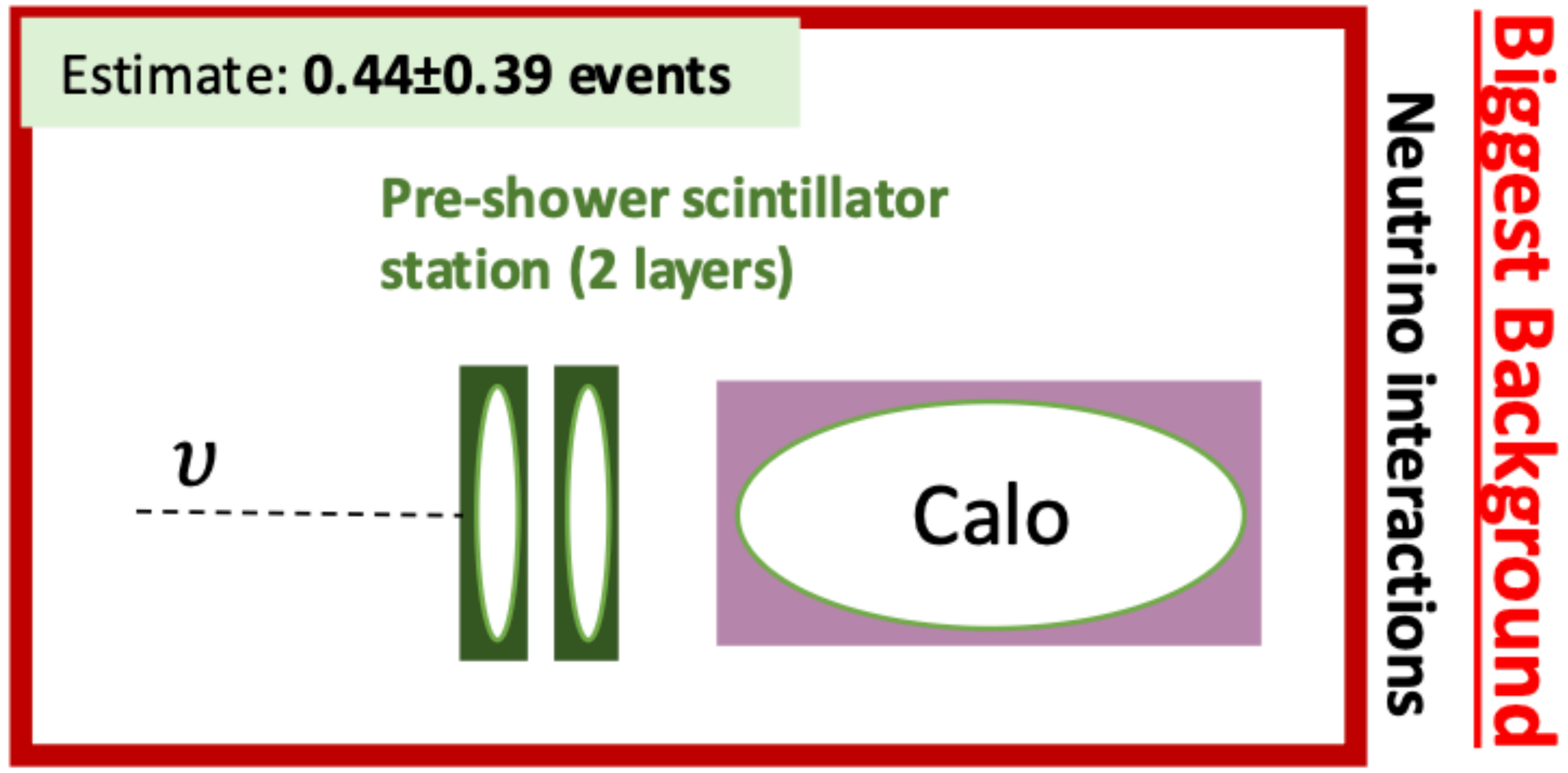
The total background estimate was: 0.44±0.39 events
With the main background coming from charged-current neutrino interactions

Non-collision background



Veto inefficiency:





Neutral hadron background