BSM Searches with FASER

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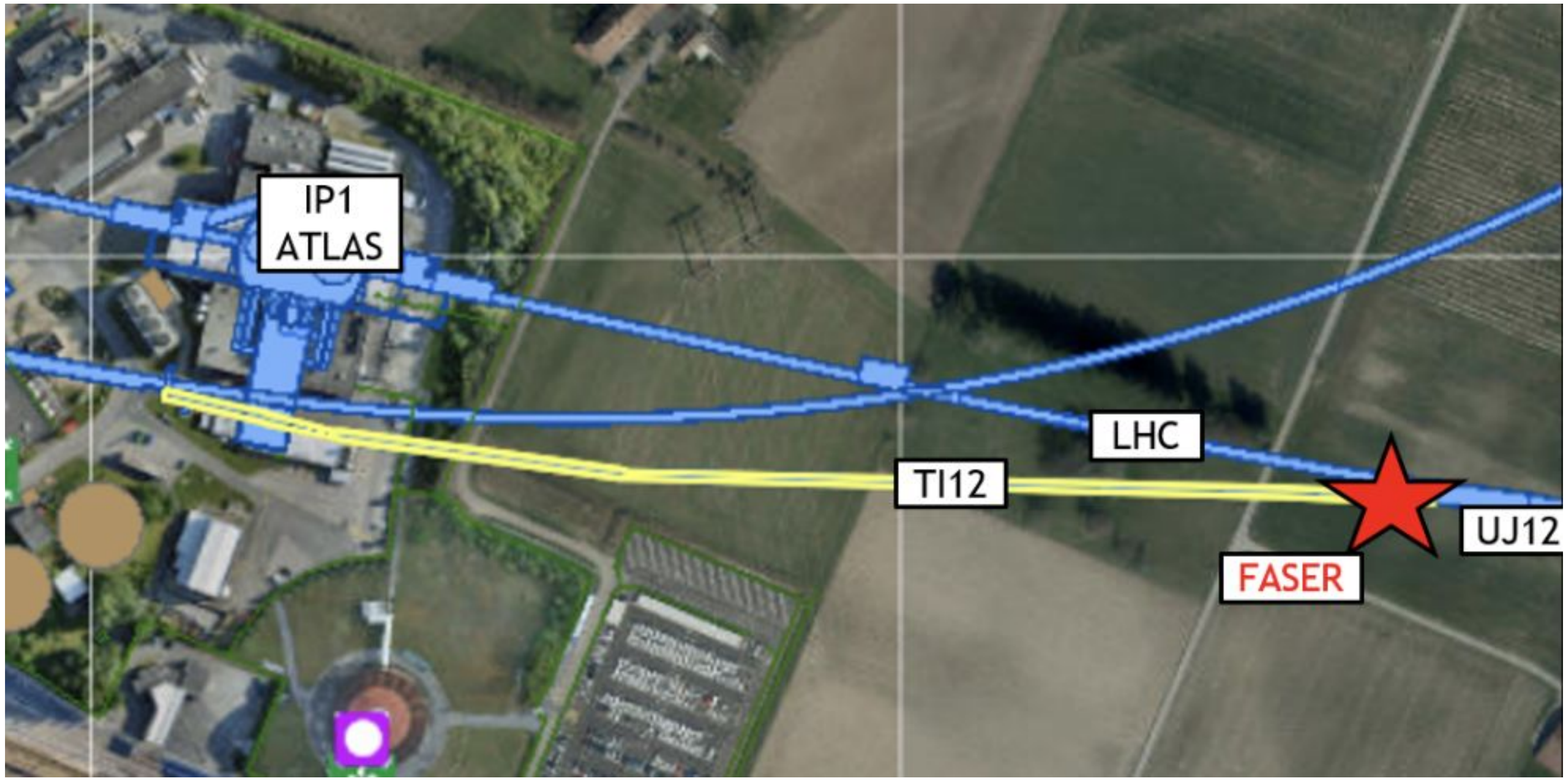
The FASER Collaboration

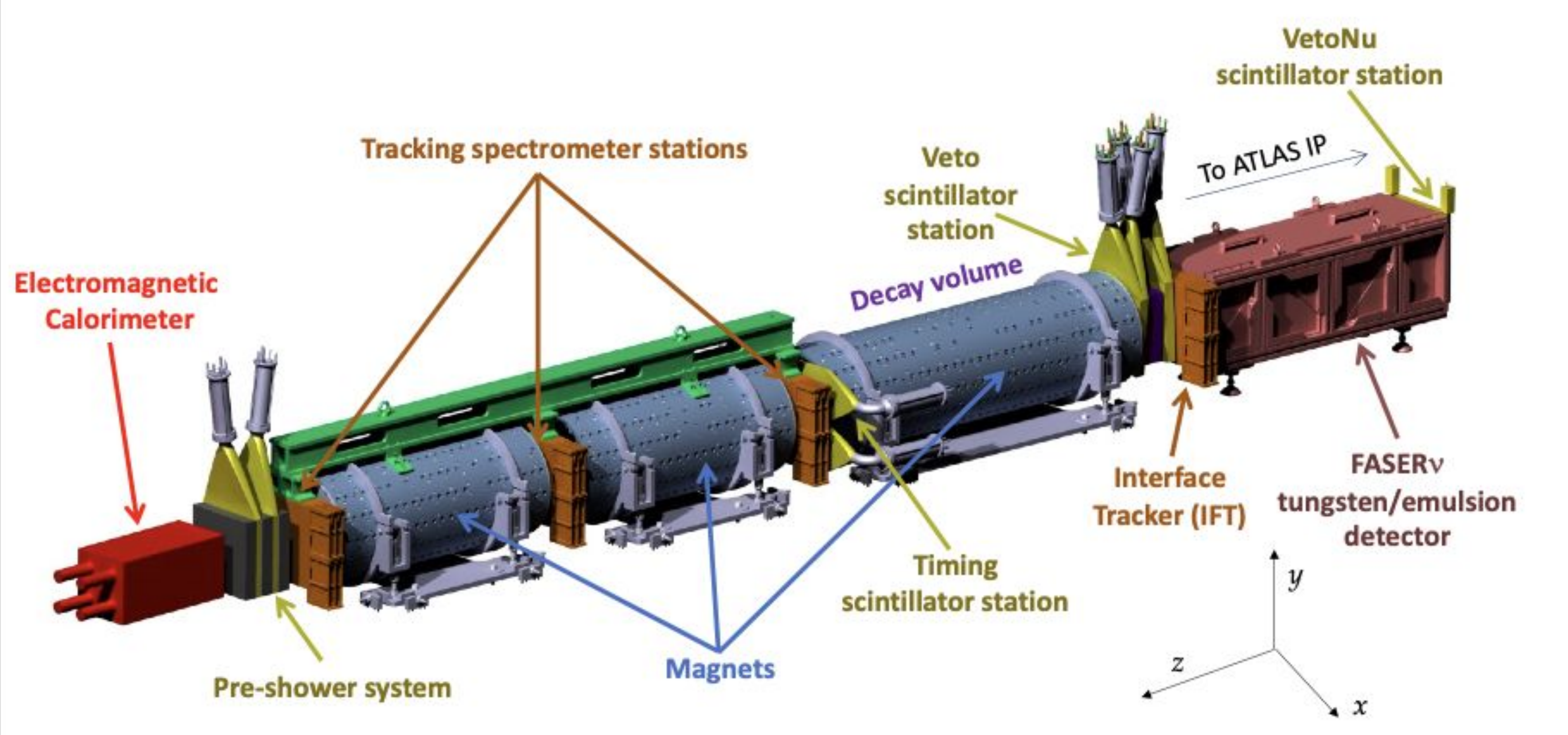
- FASER is a forward LHC experiment designed to detect light and weakly interacting particles
  - Situated 480m downstream of the ATLAS IP
  - Utilises the large LHC collision rate (and increased light particle production rate in the forward region) to:
    - Search for long-lived BSM particles such as Dark Photons (A')
    - Measure collider-produced neutrinos



- Further FASER related talks:
  - [Tomohiro: FASER Neutrino results](), [Jamie: Forward Physics Facility]()

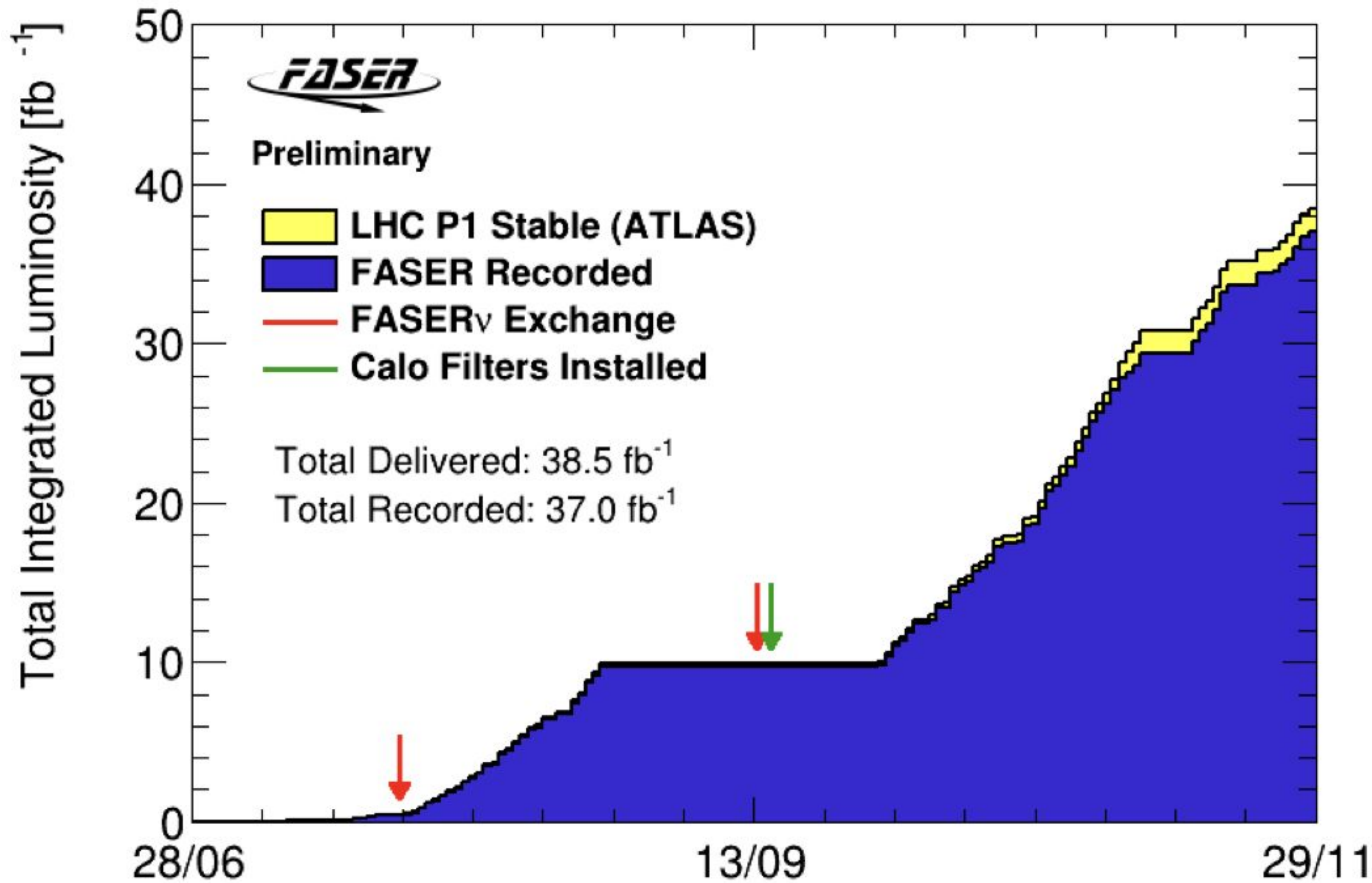
The FASER Detector (arxiv:2207.11427)

- A (relatively) small detector composed of:
  - An emulsion based neutrino detector (FASER**ν**)
  - Multiple scintillator systems (used for either triggering, timing, or vetoing)
  - A calorimeter system (LHCb outer Calo modules)
  - 4 tracking stations (IFT and 3 spectrometer stations composed of 3x3 layers of ATLAS SCT strip modules with 0.5 B-field applied)
  - 1 decay volume (1.5m) with 0.5T B-field applied



FASER 2022 Operations

- Installed and successfully commissioned during 2021/22
  - More than 350M single-muon events recorded
  - All detector components working as expected



- Recorded $37fb^{-1}$ of data
  - Generally automated, continuous data-taking
  - Trigger rate of up to 1.3kHz
  - Dead-time of 1.3%
- Dark Photon analysis luminosity: $27fb^{-1}$
  - Lower luminosity used than the full dataset as only events where the optical fibres were installed
  - Allowing for a calorimeter gain optimised up to 3 TeV

Dark Photon Search - Theoretical Motivation

- Dark photons (A') are predicted in many hidden sector models
  - Weakly coupled to the SM via kinetic mixing (**ε**) to the SM photon

$$\mathcal{L} \supset \frac{1}{2} m_{A'}^2 A'^2 - \epsilon\, e \sum_f q_f A'_\mu \bar{f} \gamma^\mu f \ ,$$

- At the LHC, low mass A' will mainly be produced in the decays of light mesons (eg: the pion), with a branching ratio:

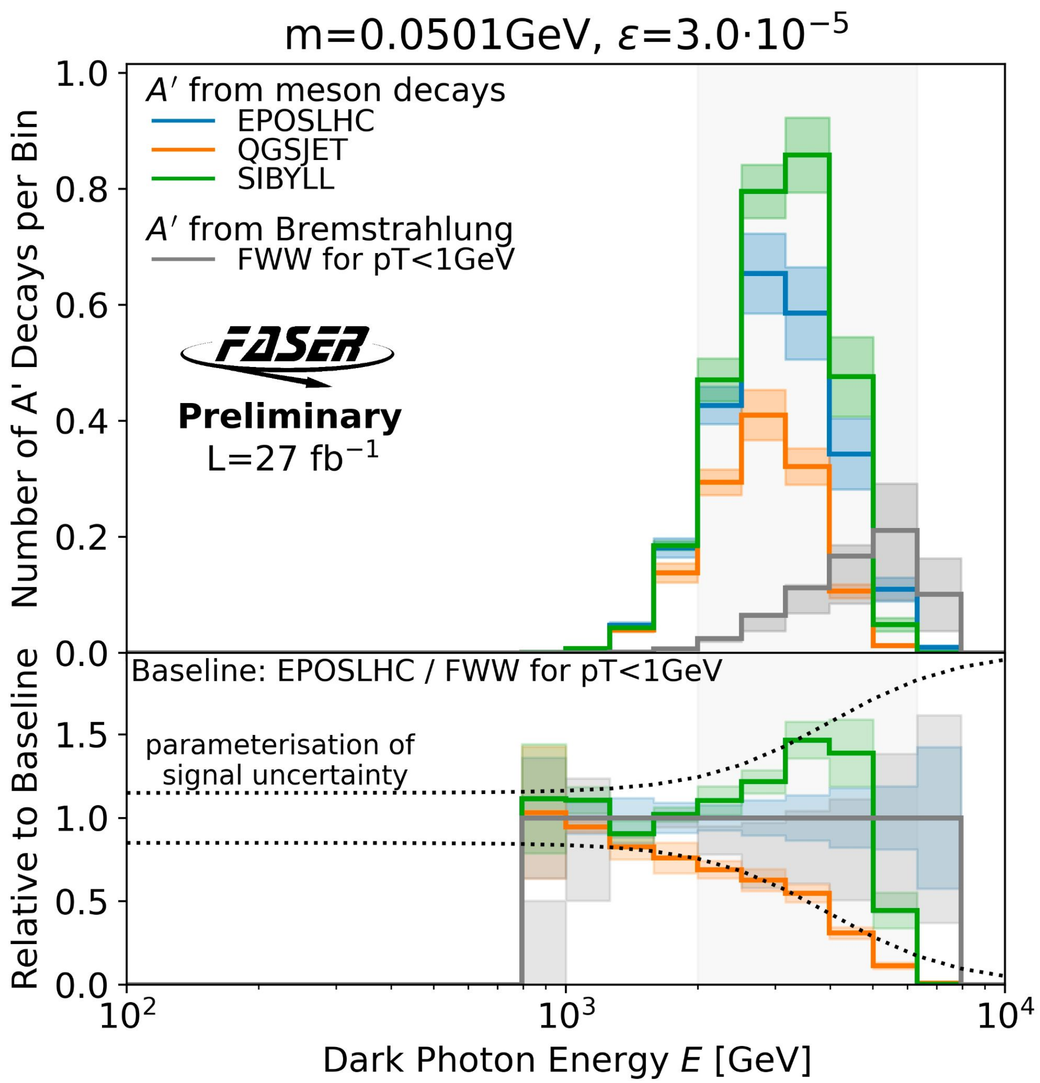
$$B(\pi^0 \to A'\gamma) = 2\epsilon^2 (1 - m_{A'}^2/m_{\pi^0}^2)^3 B(\pi^0 \to \gamma\gamma)$$

- As the lifetime is dependent upon the kinetic mixing, FASER targets long decay lengths, (therefore weak mixing) due to the distance of the detector from the IP

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

Dark Photon Search - Signal Kinematics & Modelling

- Provided m(A') < 2m(μ), the dark photon decay will always decay to an e^+e^- pair
  - Dark photon signal simulated using FORESEE
  - Generated π^0 & **η** using EPOS-LHC
    - Subdominant contributions from "dark"-bremstrahlung
  - Systematic uncertainties on the signal generation are considered (and are found to be the dominant uncertainty)
    - A parameterised (based on E(A')) difference between the nominal and QGSJET/SIBYLL is applied
  - All generators are tuned on LHCf forward pion data, and these generators bracket the LHCf data

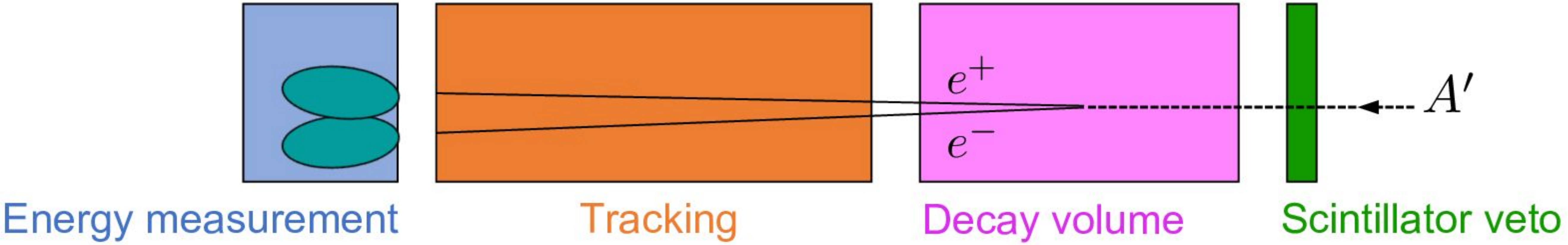


- For the phase space that FASER is sensitive to, high electron energies are expected, hence a relatively high calorimeter energy requirements

Dark Photon Search - Event Selection

- For the first result a simple analysis strategy is implemented
    - A blind analysis is performed, with a blinding criteria of no-veto signal in the veto scintillator and Ecalo > 100GeV

- Robust selection:
    - Collision event passing FASER data-quality requirements
    - No signal (< 40pC) in any veto scintilator
    - Exactly two good tracks:
        - p > 20GeV
        - r < 95mm (tracks are then extrapolated back to the veto stations and are also required to be within r <95mm)
    - Timing & preshower scintilators are consistent with 2 MIPs
    - Calo energy deposit of E > 500GeV



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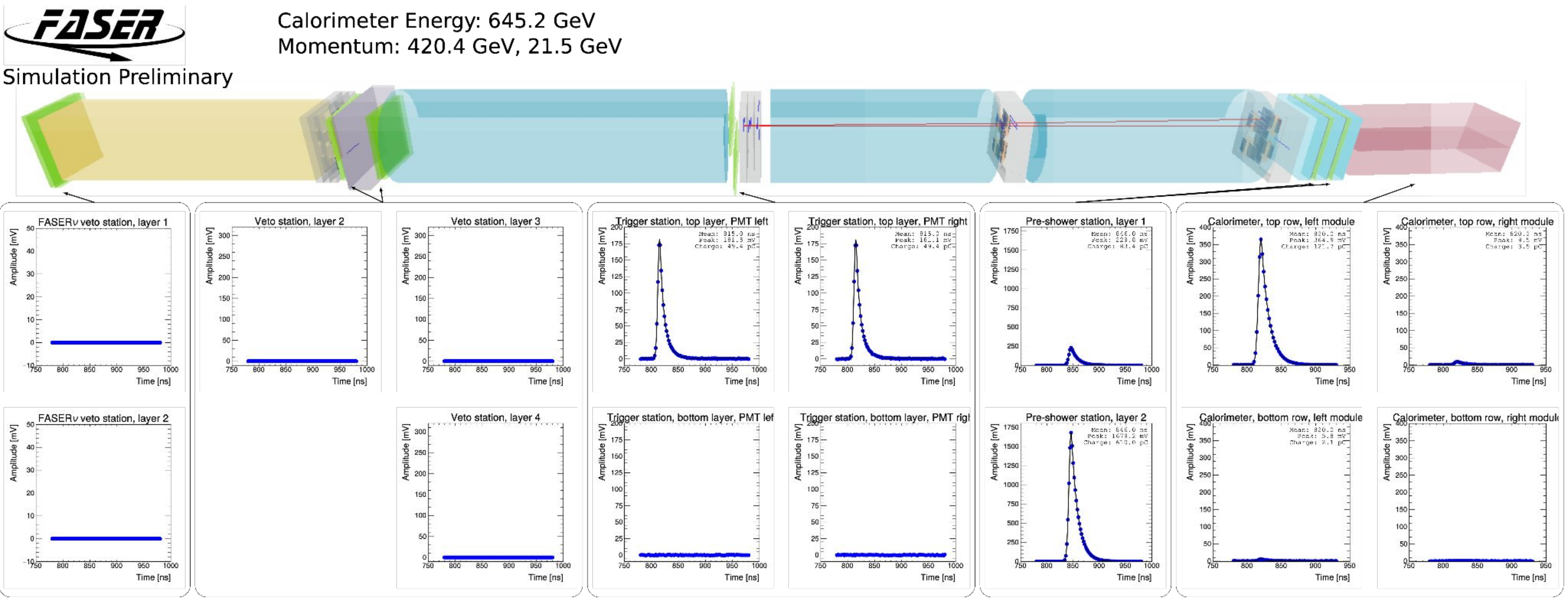

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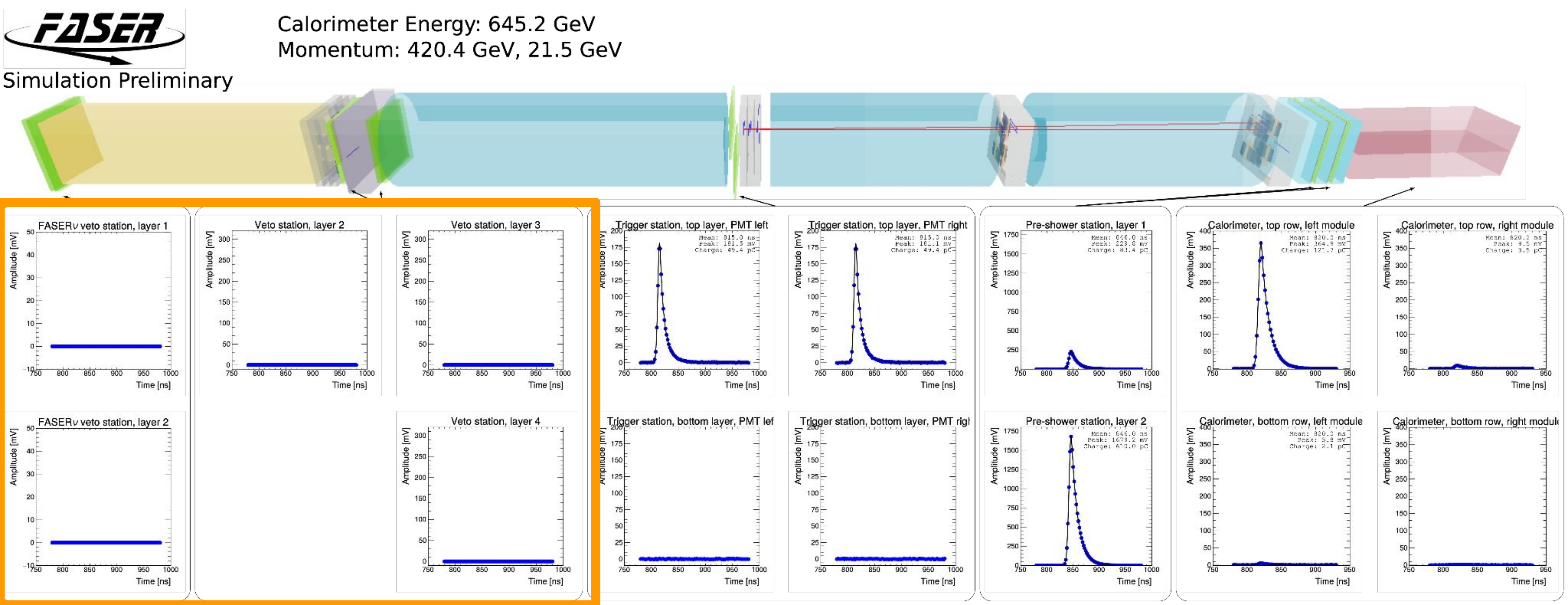

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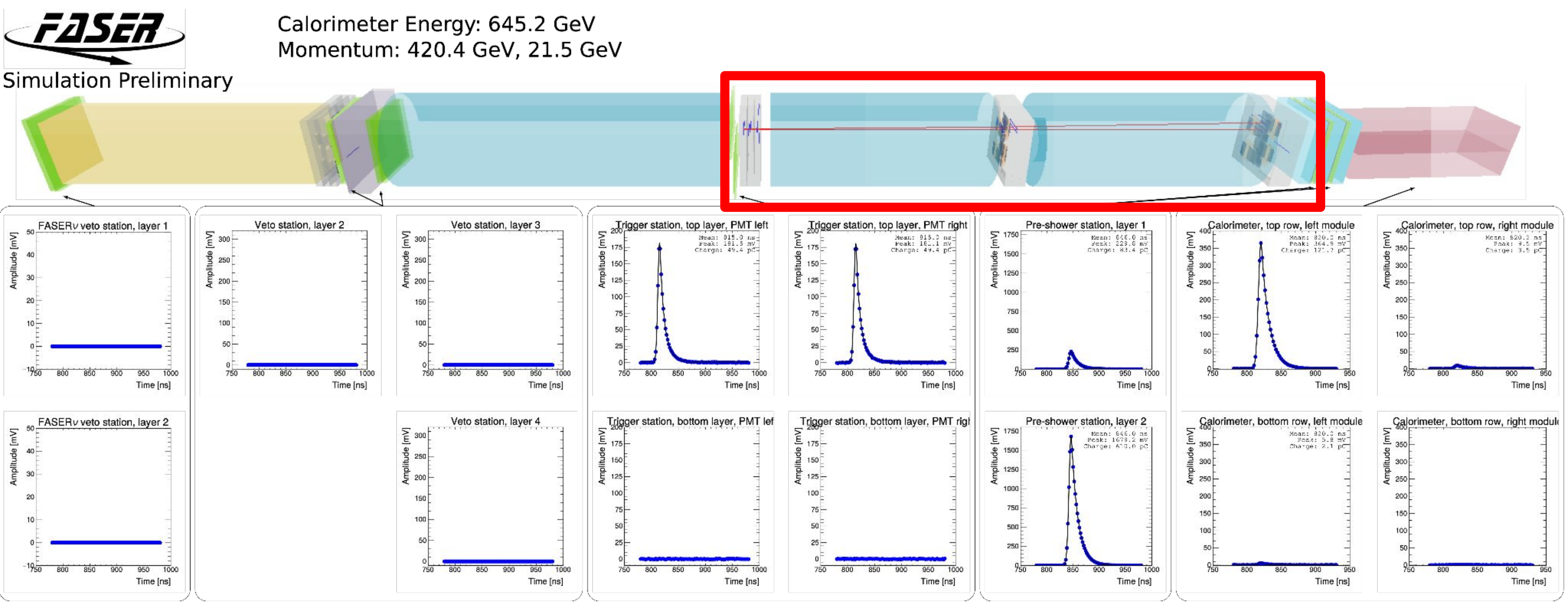

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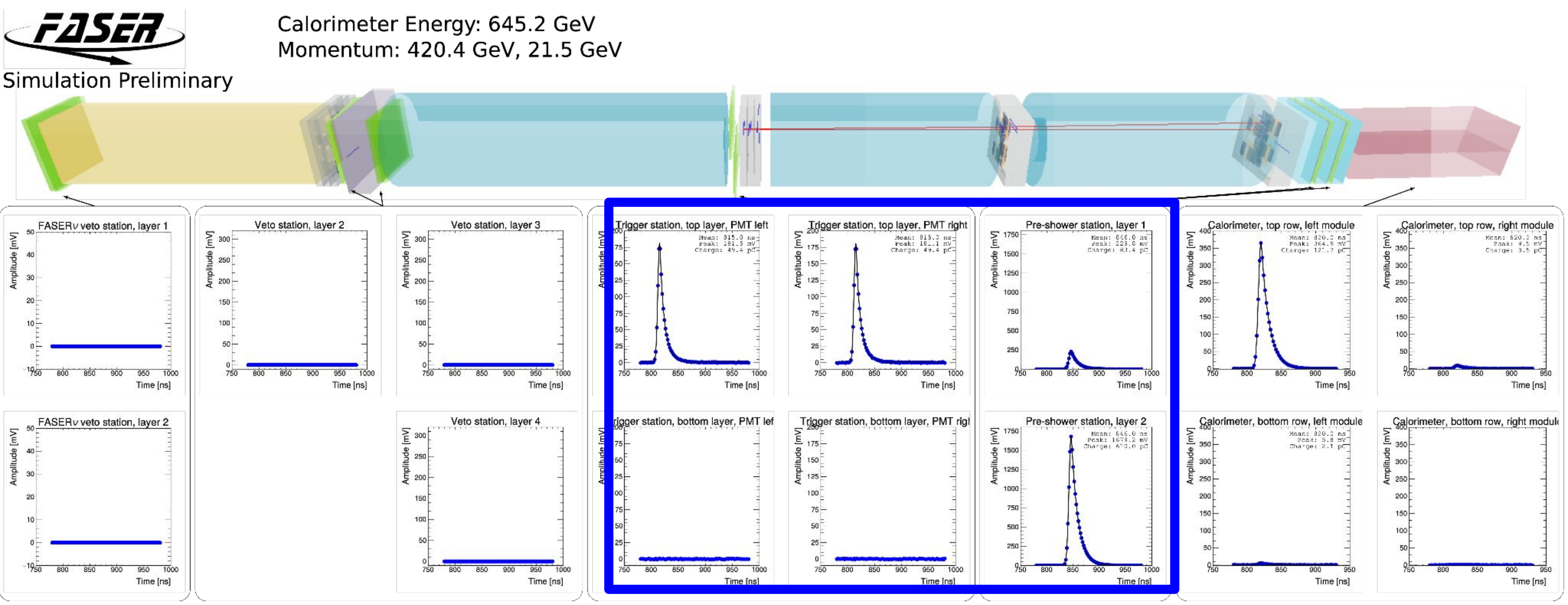

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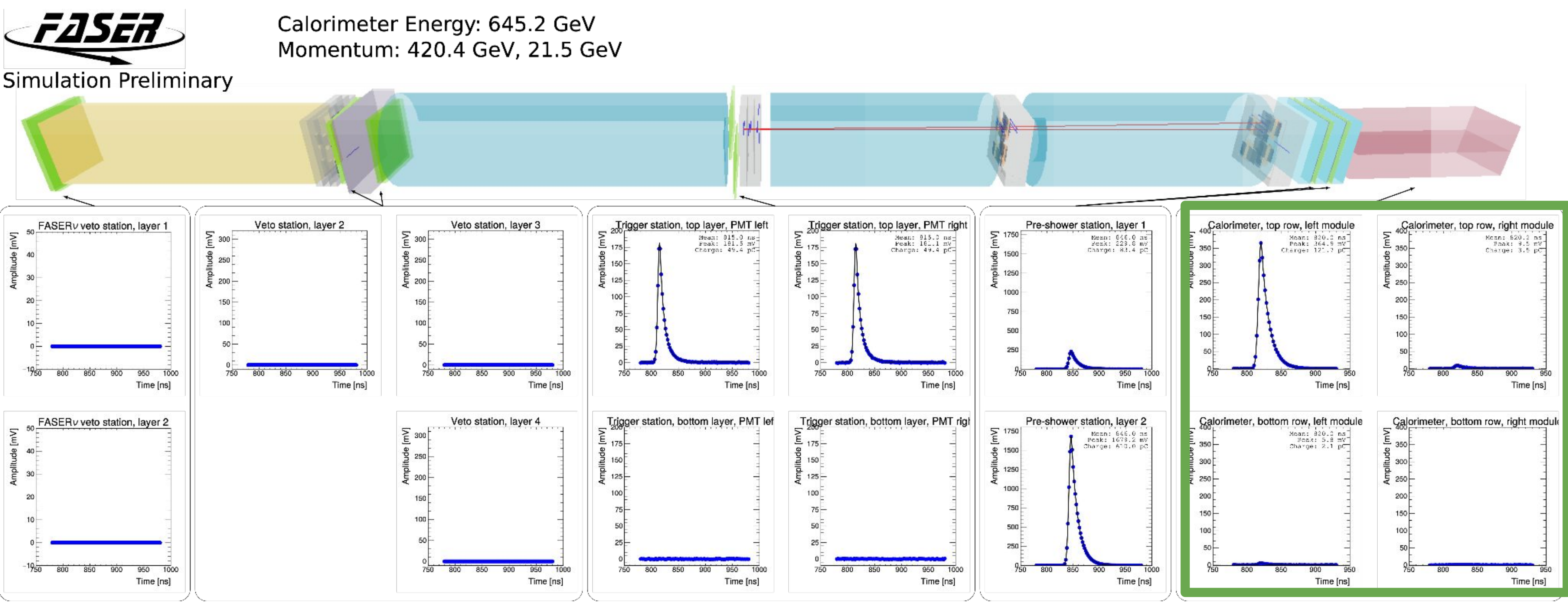

Dark Photon Search - Background Sources

- There are 4 potential background sources that are considered:
  - Veto inefficiency
  - Non-collision backgrounds (Cosmics, Beam debris)
  - Neutrino background
  - Neutral Hadron background

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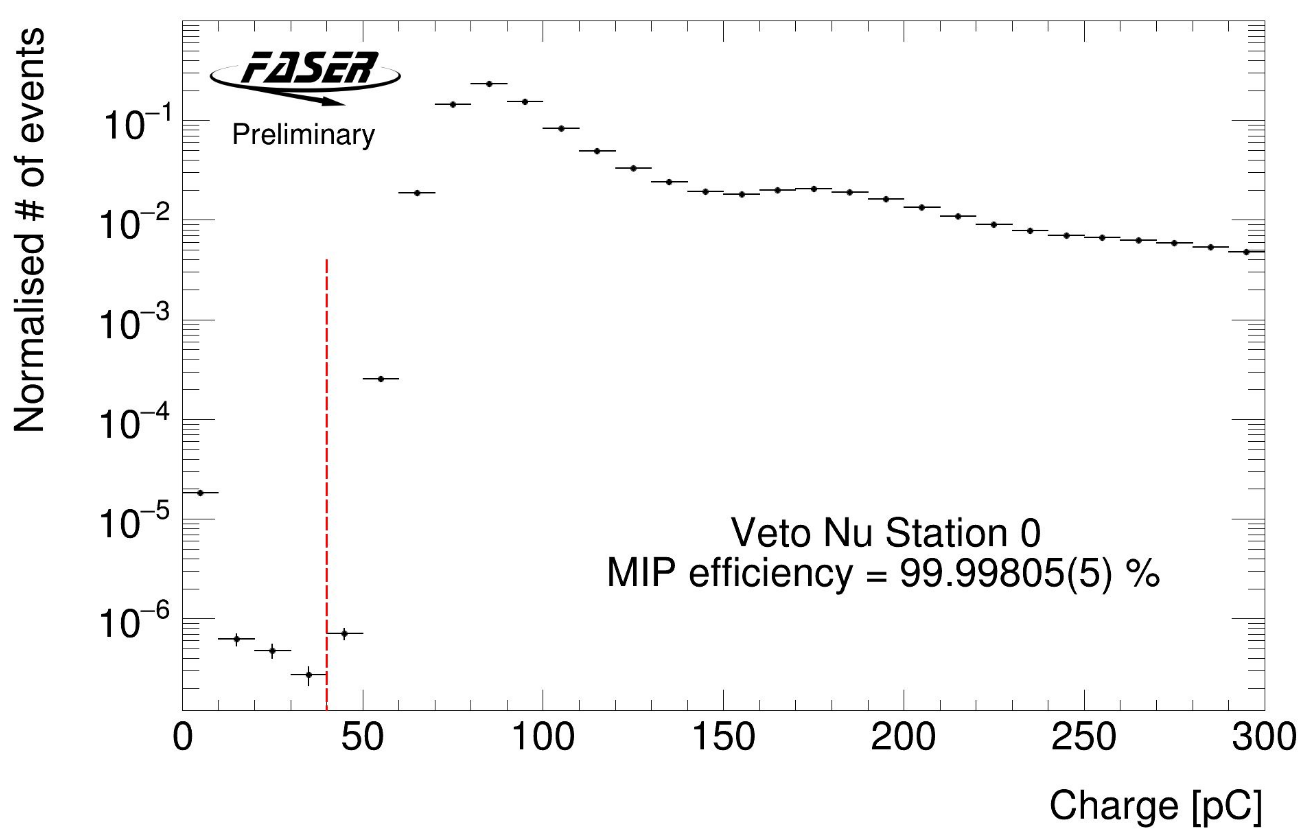

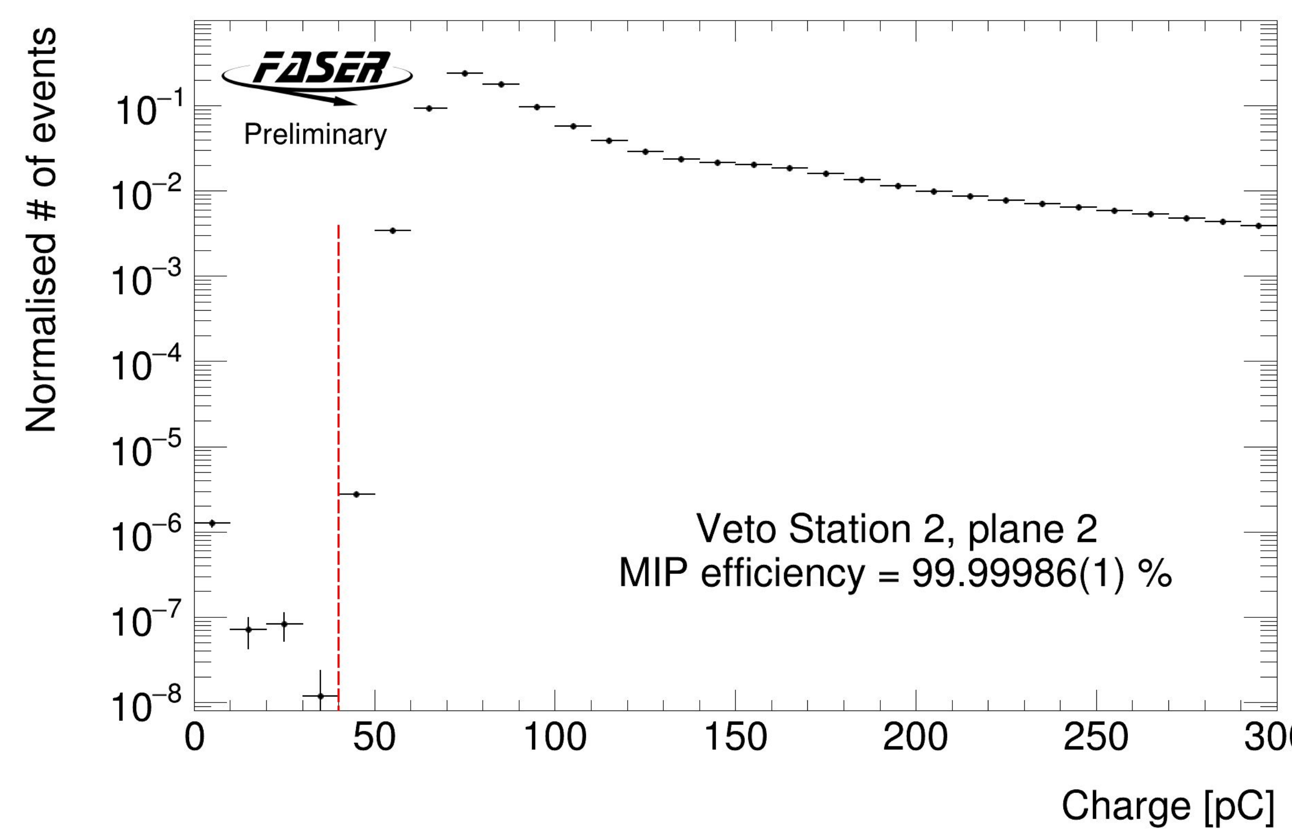

- The inefficiency is measured (layer-by-layer in the scintillators) with muons with tracks which point back to the veto layers
- 5-layer veto reduces 10^8 muon sample to a negligible level before applying selections: <u>0 expected events</u>

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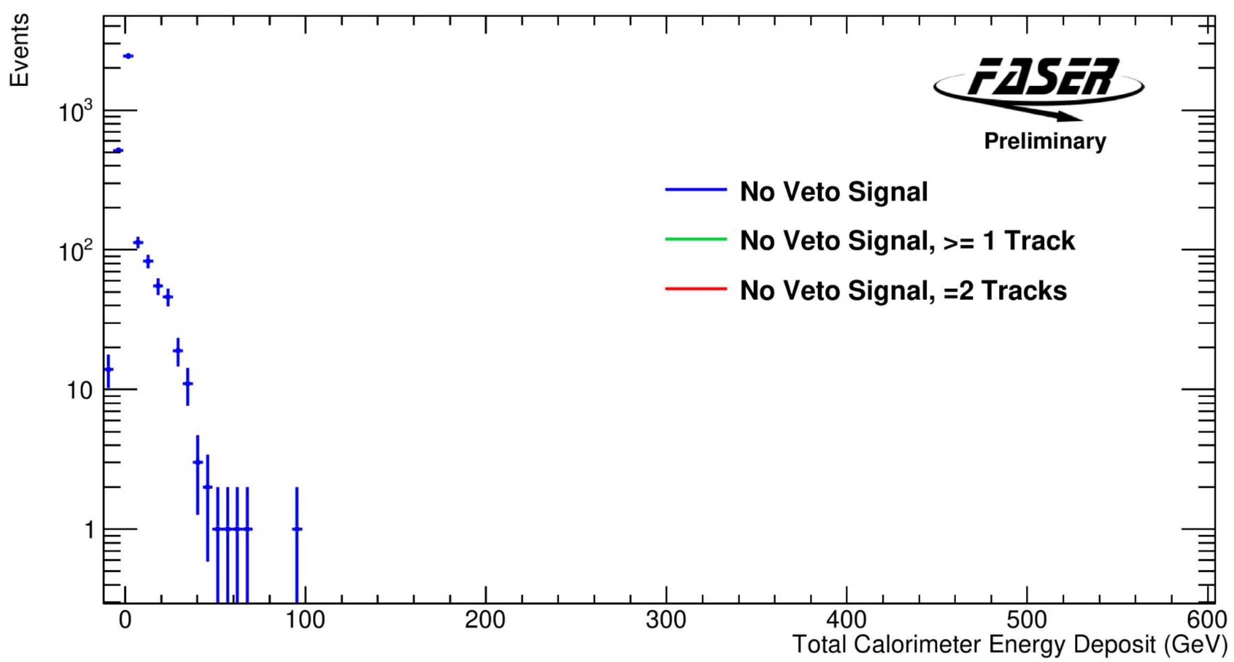

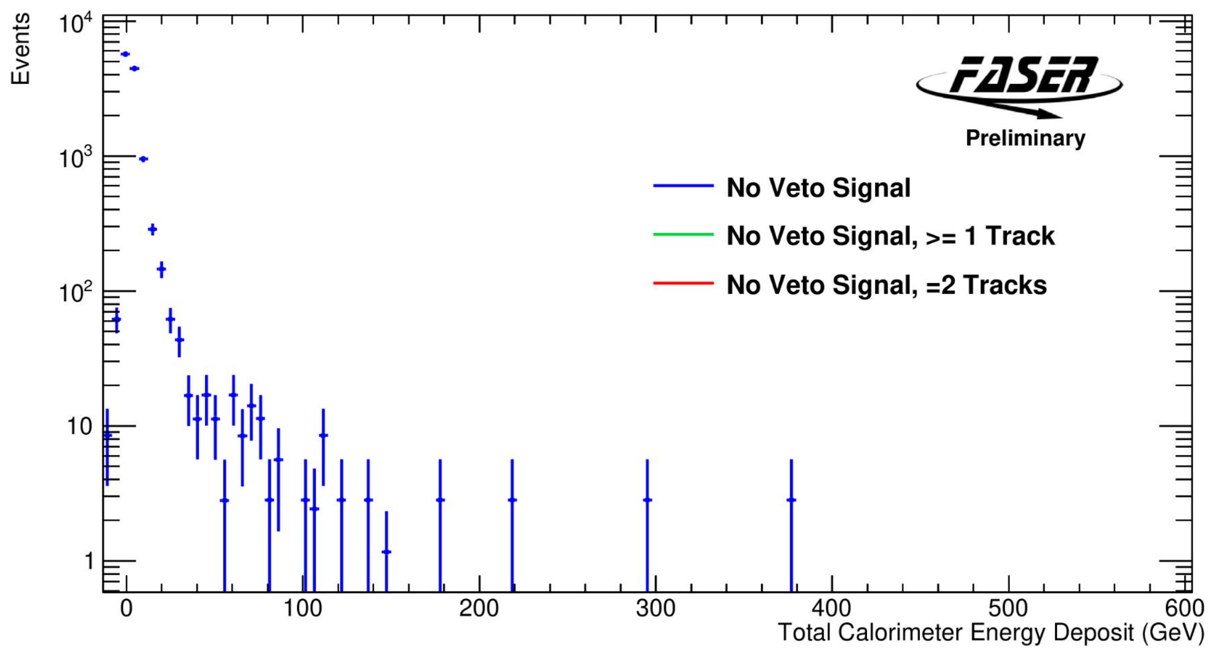

- Cosmics: measured in runs without beam (left), beam debris measured in non-colliding bunches
  - <u>No events observed</u> with ≥1 track or ECalo > 500 GeV

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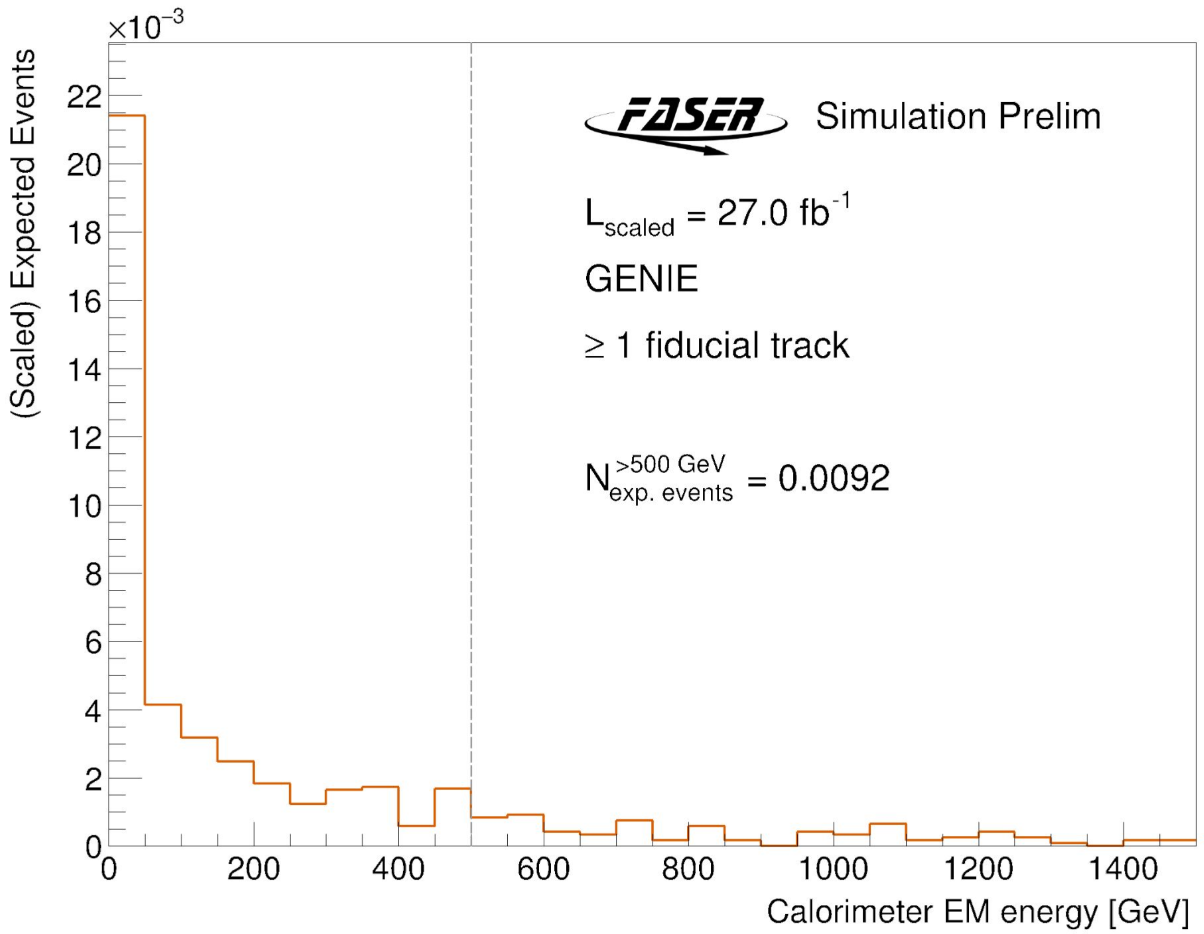

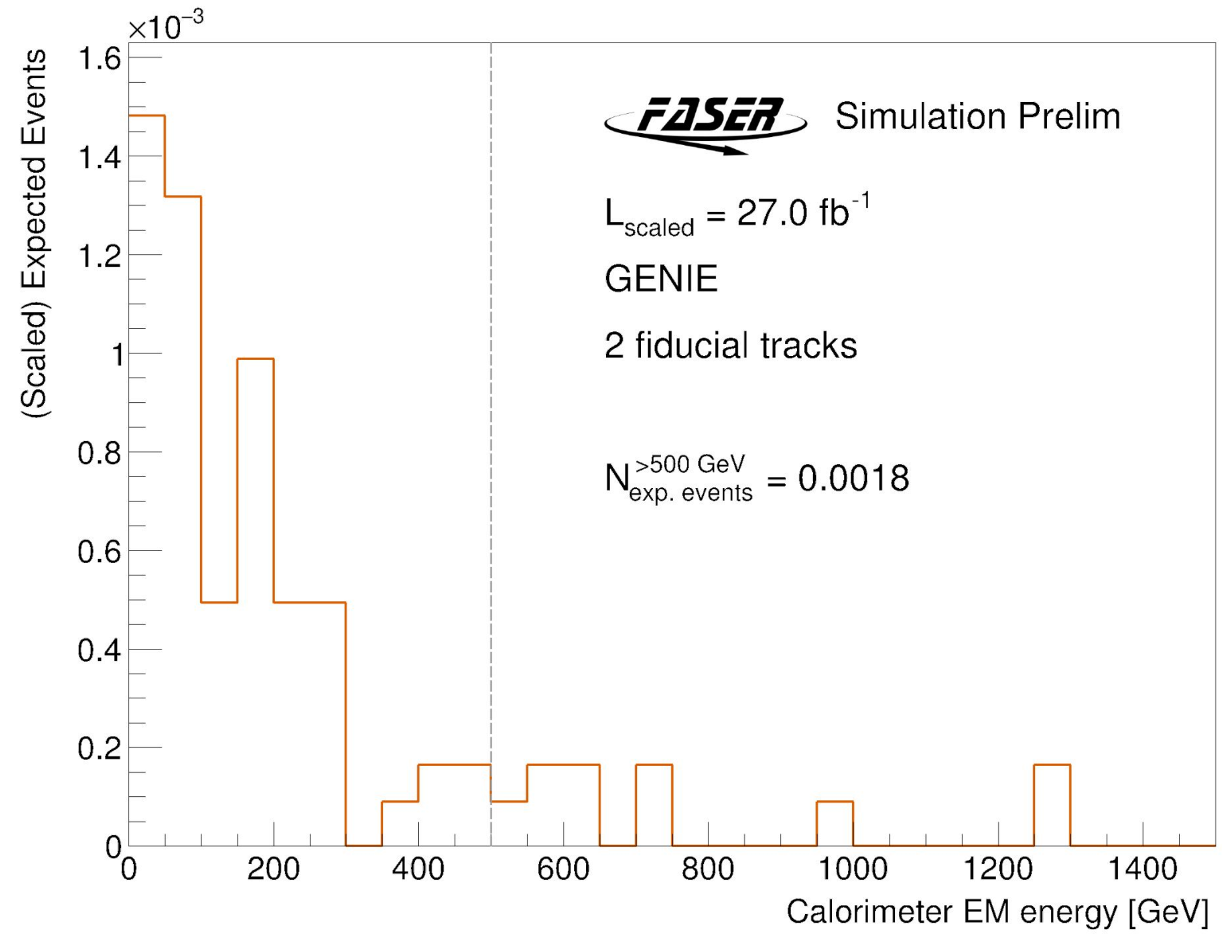

- The neutrino background is the main background in the analysis
  - Estimated using GENIE simulation (300ab^{-1}, with uncertainties from neutrino flux and mismodelling included)
  - <u>1.8 x 10^{-3} expected events</u>

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- Neutral hadron background arises from upstream muons interacting in the rock in front of FASER
  - Estimated with FLUKA SIM of muons interacting in the final 10m of rock in front of FASER
  - This background is heavily suppressed:
    - The muon generally always continues and passes through FASER (hence is vetoed in the veto scintillator)
    - The hadron must pass through 8 interactions lengths before decaying
    - The decay products must have a high energy
  - From the generated sample, a negligible amount of neutral hadrons pass the full selection, hence an extrapolation is performed using events with 2/3 tracks and differing veto conditions. Expectation = $2.2\text{x}10^{-4}$
- An ABCD method is also used to validate this (with consistent results)

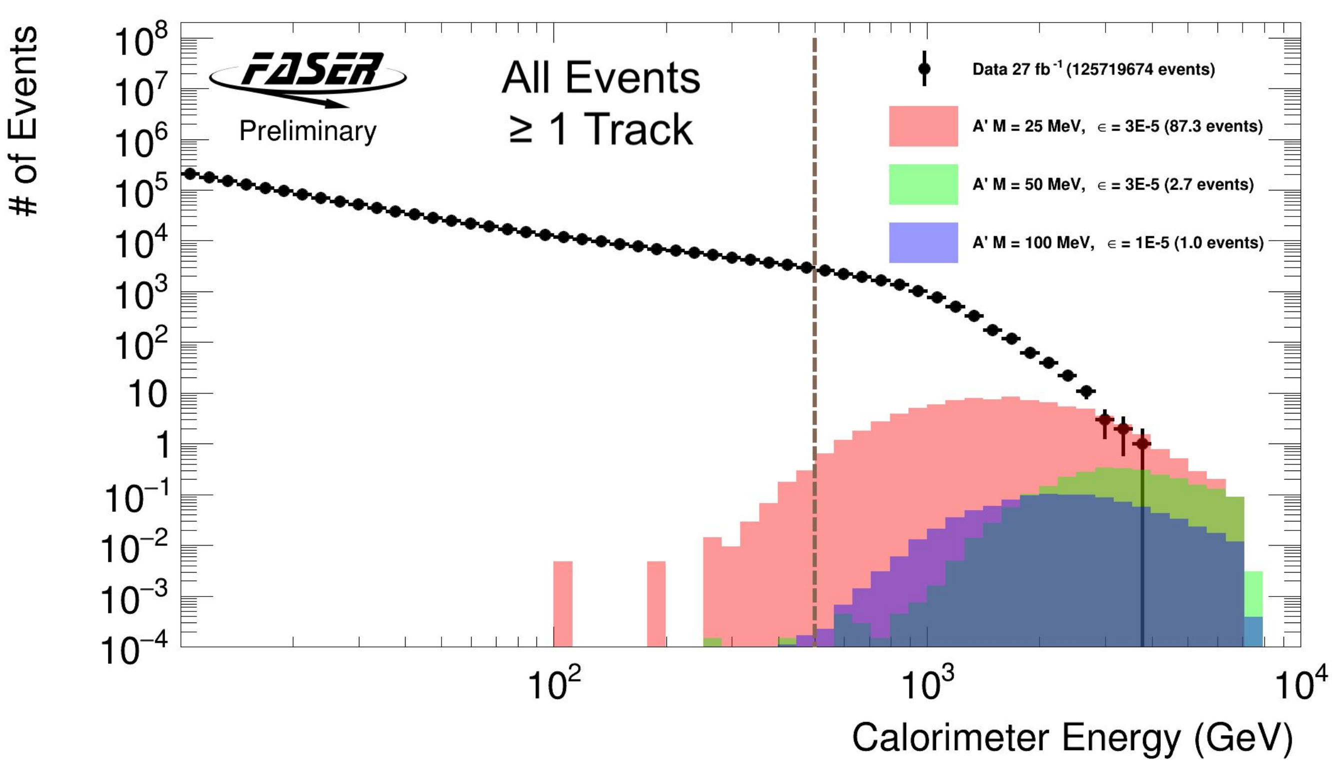
Dark Photon Search - Results

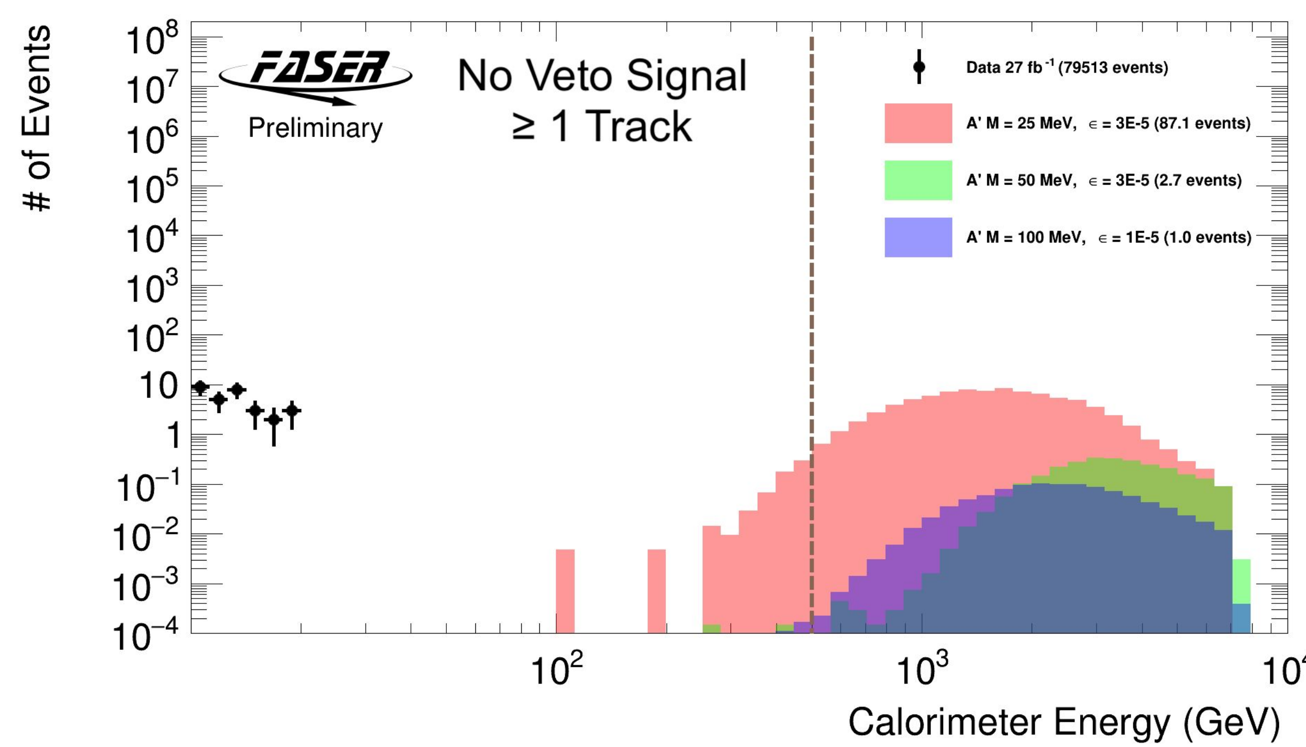
- After considering all backgrounds the total expected number of background events are found to be 2.02×10^{-3}

Background	Central Value	Error (%)
Background due to veto inefficiency	-	-
Background from neutral hadrons or muons missing veto	0.22×10^{-3}	0.31×10^{-3} (141%)
Neutrino background	1.8×10^{-3}	2.4×10^{-3} (133%)
Non-collision background	-	-
Total	$\mathbf{2.02 \times 10^{-3}}$	$\mathbf{2.4 \times 10^{-3}}$ **(119%)**

TABLE V. Summary of the different background estimates.

- After the background predictions were finalised, the unblinding was performed, with 0 events found passing the selections (0 events were found passing the ≥ 1 track requirement!)





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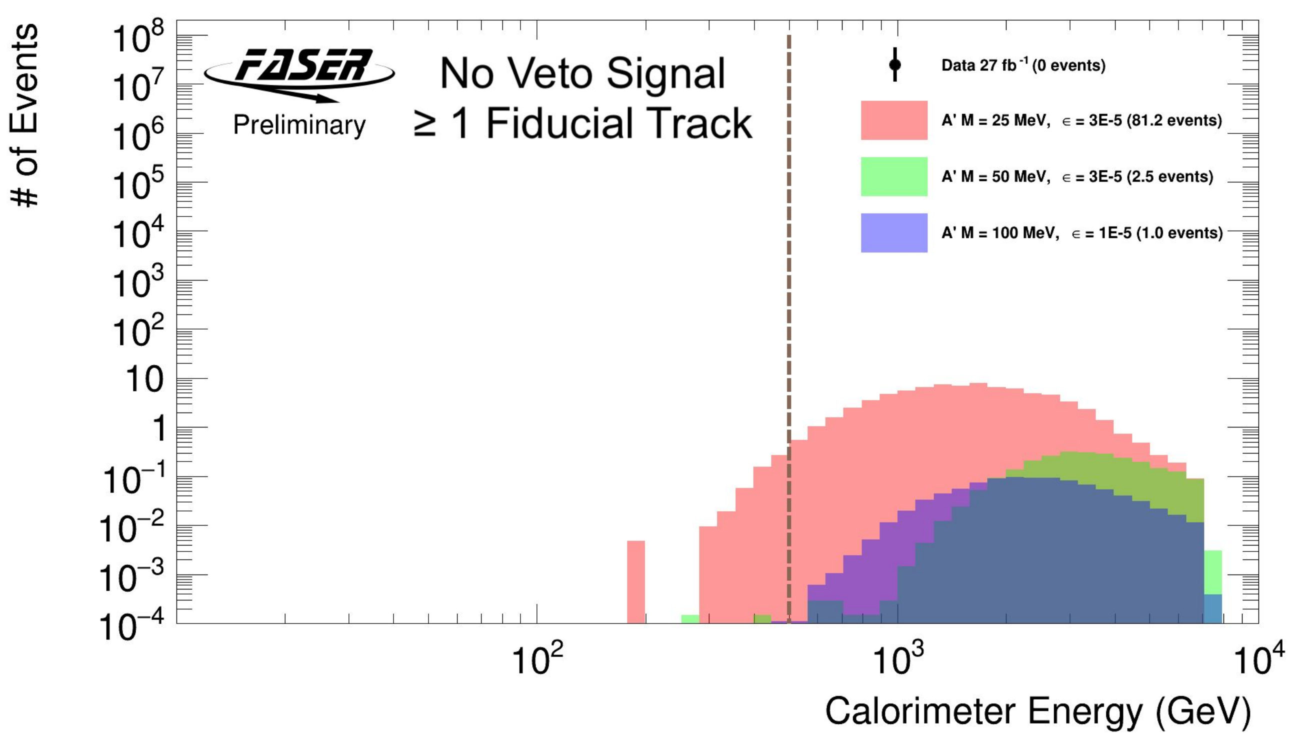
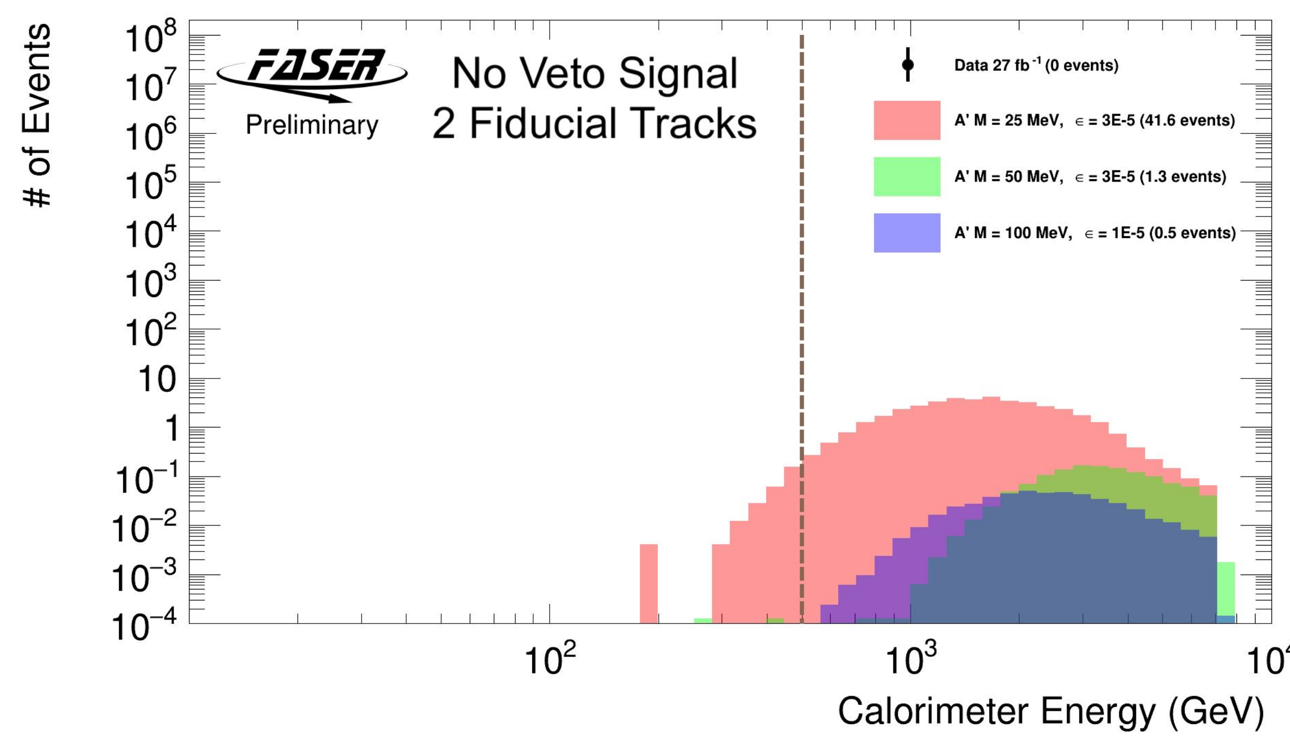
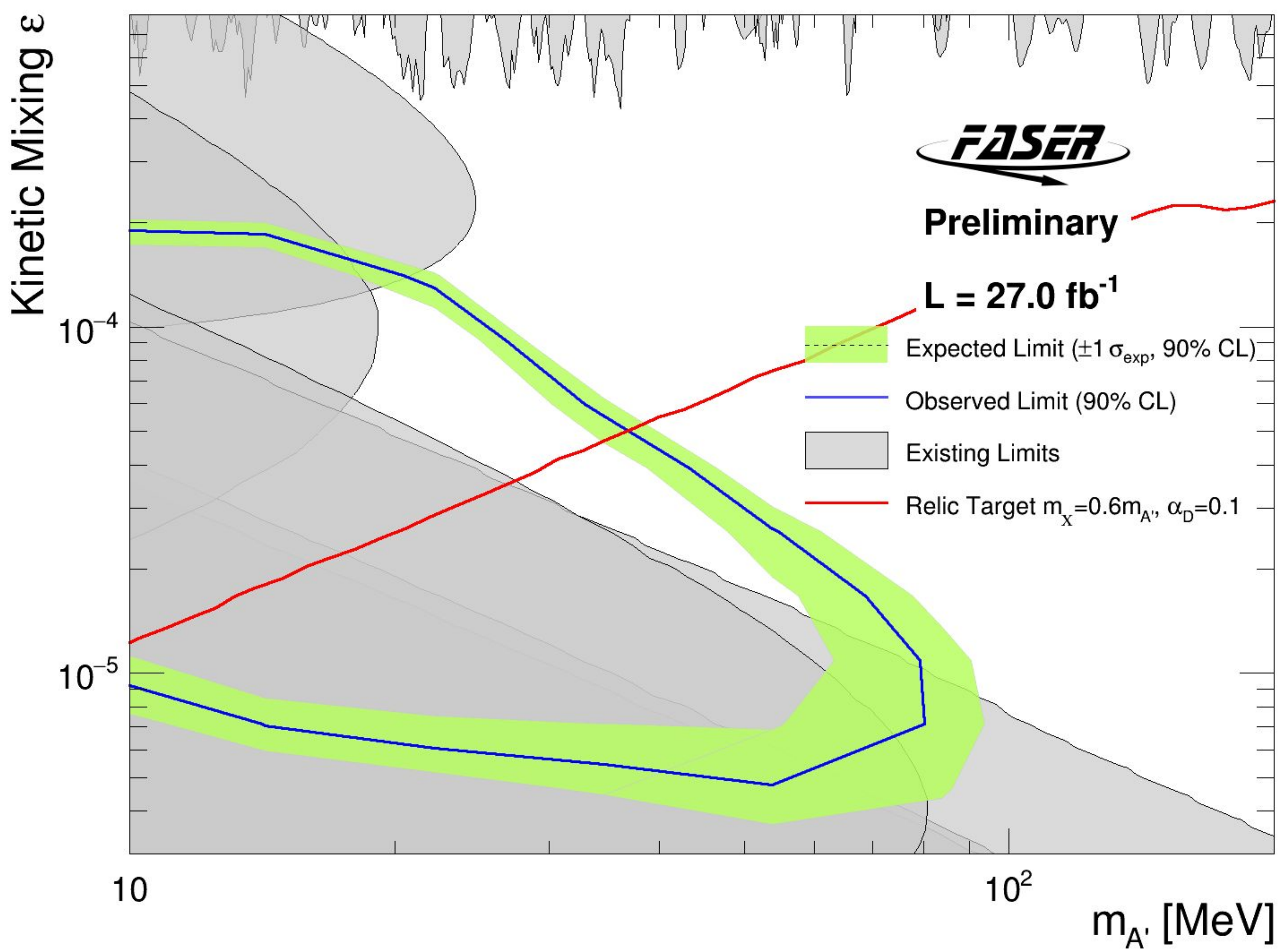




Dark Photon Search - Results

- From this null result, FASER can place (90% CL) limits in previously unprobed phase space
  - Probing region relevant for thermal relic target & region uncovered by the recent NA62 result (overlay in backup)



Dark Photon Search - Outlook

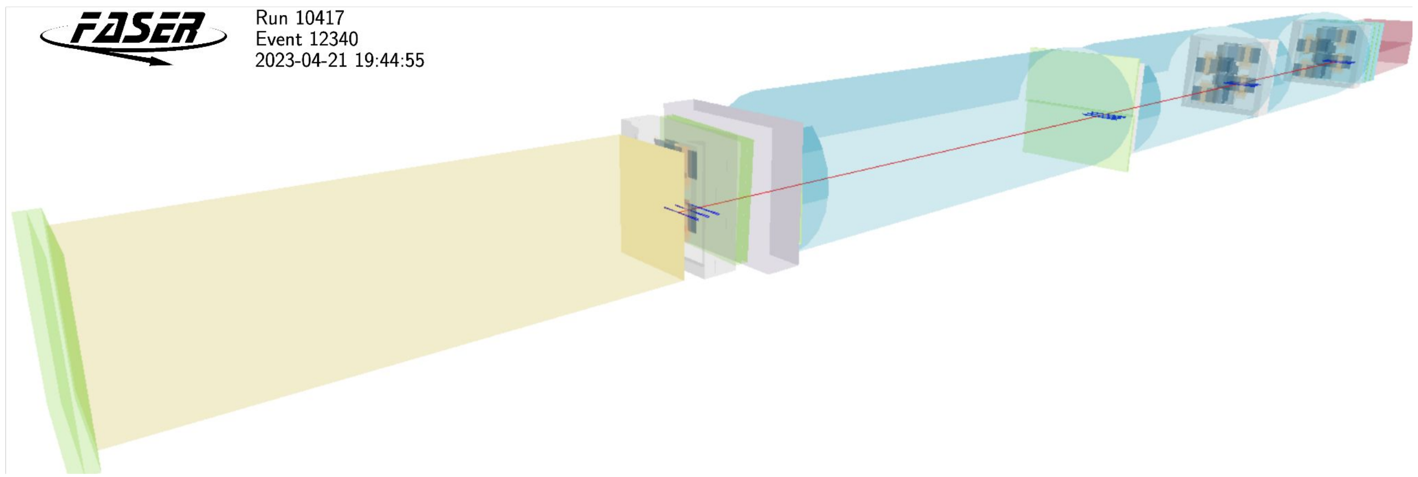
- Presented the results of the first BSM search performed by FASER
    - Limits placed in interesting (and uncovered) regions of parameter space with respect to the thermal relic target

- Currently presented results are from our preliminary CONF note, with the final results (including small analysis improvements) to be finished in the next months
    - Will also include an interpretation in a B-L model
    - Final paper documenting this search is expected by the end of July

- We are already planning on the reinterpretation of our results and we plan to implement RECAST (not just for this result but generally for our BSM searches)
    - We will also obviously provide the standard HEPDATA
        - Limit results
        - Acceptance x efficiency
        - Cutflow examples
    - We will also put the result into DarkCast

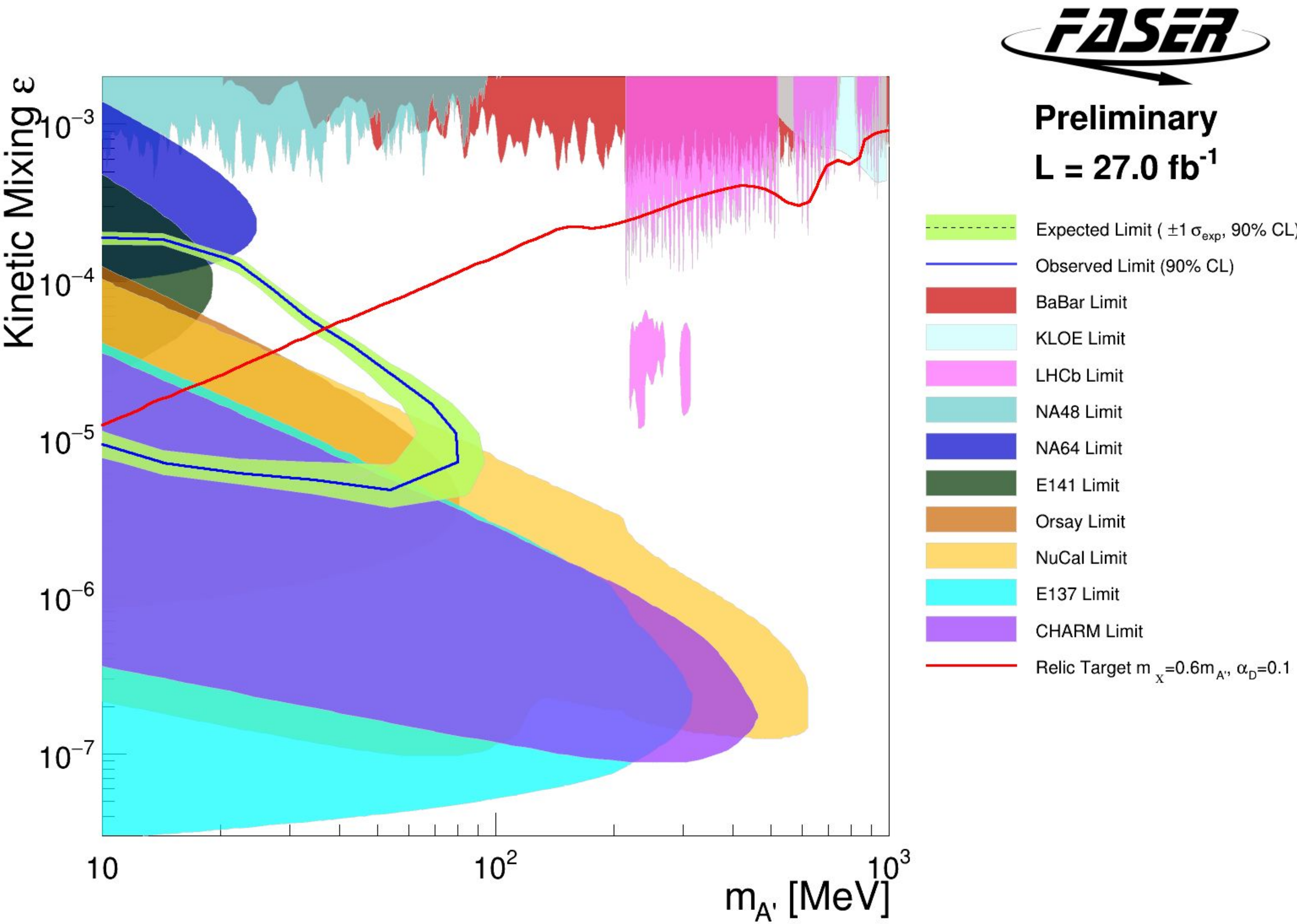
FASER - Outlook & Ongoing Work

- We expect x10 more data for the full Run 3 dataset
  - We will search for several other models including ALPs → $\gamma\gamma$
  - 2023 data taking is proceeding well, with 20 fb^{-1} of data already collected



  - Proposed large upgrade to FASER is being discussed in the context of the Forward Physics Facility

With many thanks to:
NSF
SIMONS FOUNDATION
HEISING-SIMONS FOUNDATION
CERN


FASER
Preliminary
L = 27.0 fb^-1
Expected Limit (±1 σ_exp, 90% CL)
Observed Limit (90% CL)
BaBar Limit
KLOE Limit
LHCb Limit
NA48 Limit
NA64 Limit
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Orsay Limit
NuCal Limit
E137 Limit
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Relic Target m_X=0.6m_A', α_D=0.1
Kinetic Mixing ε
m_A' [MeV]
10^-3
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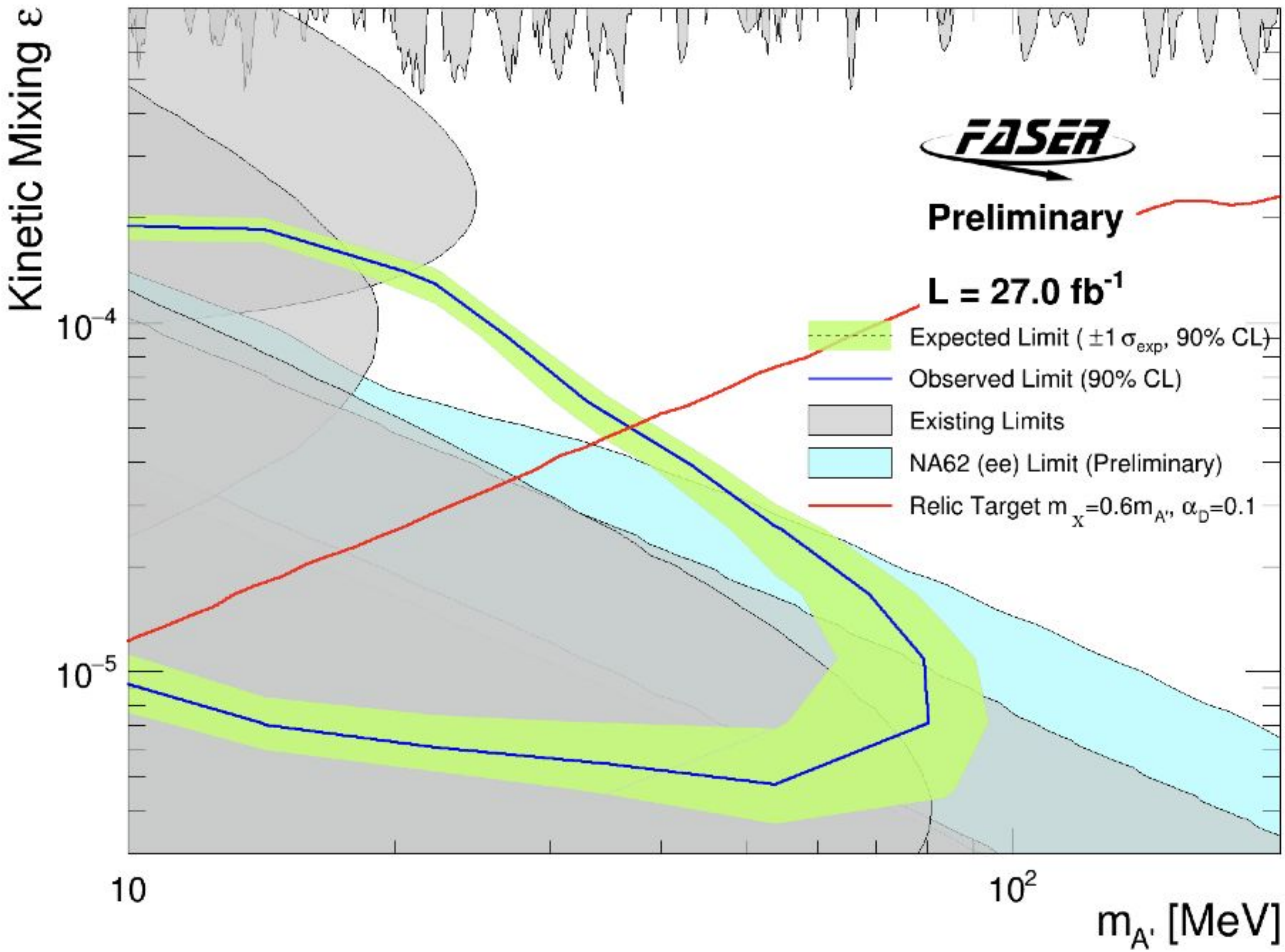
10^-6
10^-7
10
10^2
10^3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