

Latest Dark Sector Results from the Experiment

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On Behalf of the FASER Collaboration



The FASER Collaboration

126 Collaborators
27 Institutions
11 Countries

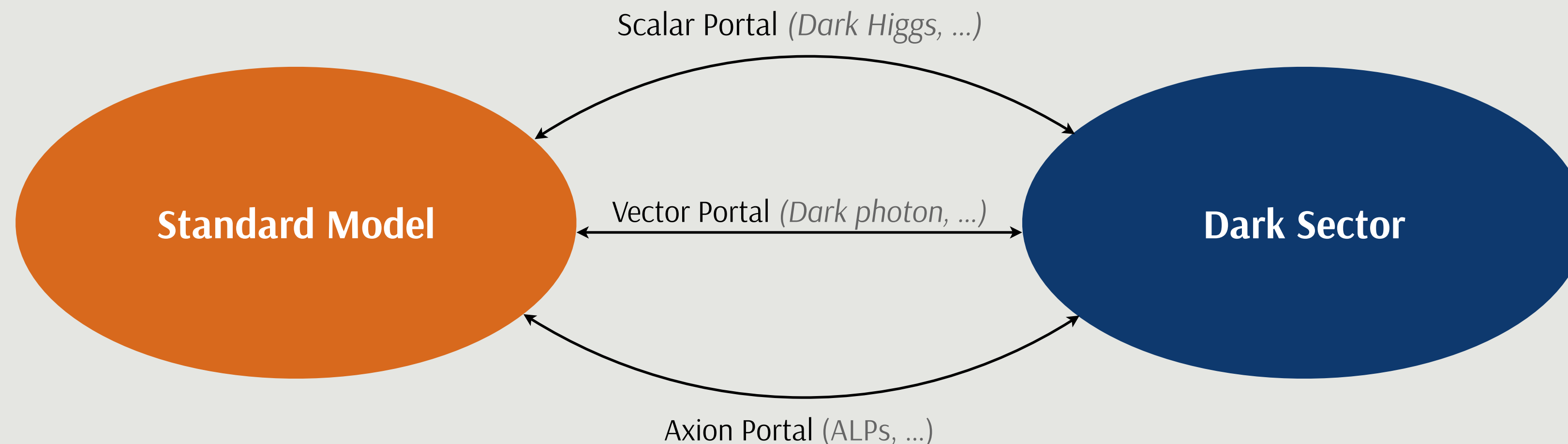
With generous support from



Accelerator Based Dark Sector Searches

- * Dark matter may be very complex, consisting of undiscovered particles and forces: a “Dark Sector”
- * Dark sectors can be probed through phenomenologically rich interaction portals
- * Accelerator experiments can produce dark sector mediator particles that decay into SM final states through these portals
- * Many of these manifest generically as long-lived particles, motivating dark sector searches at a detector like FASER

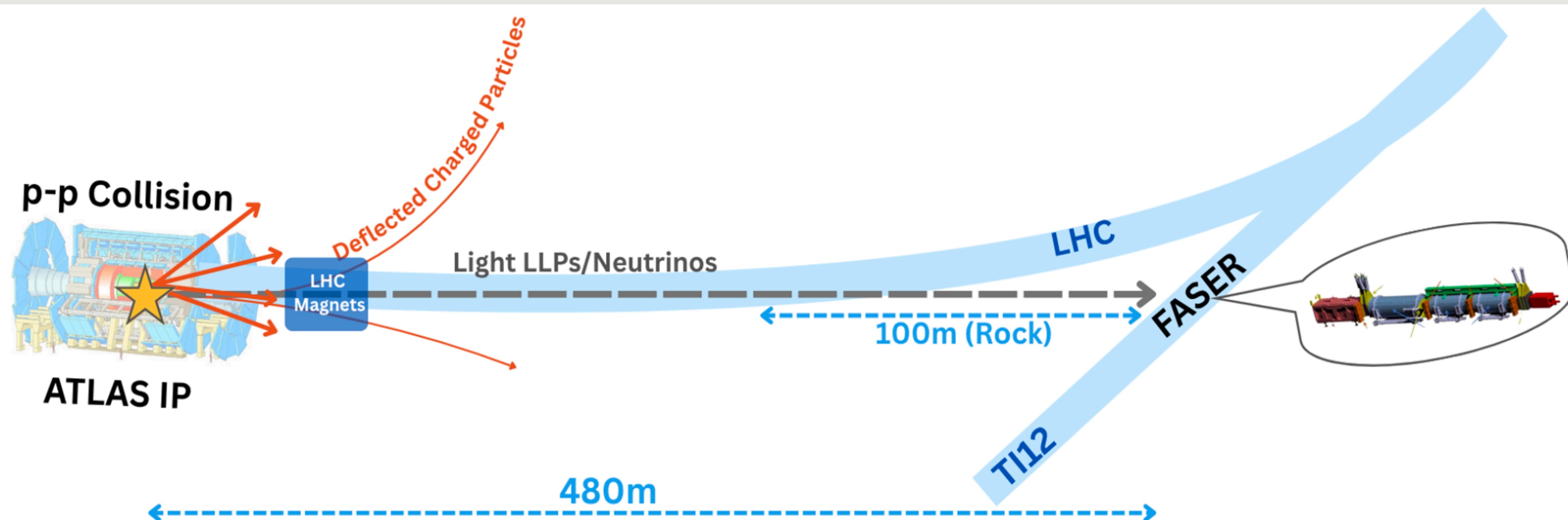
Portals



Forward Search Experiment

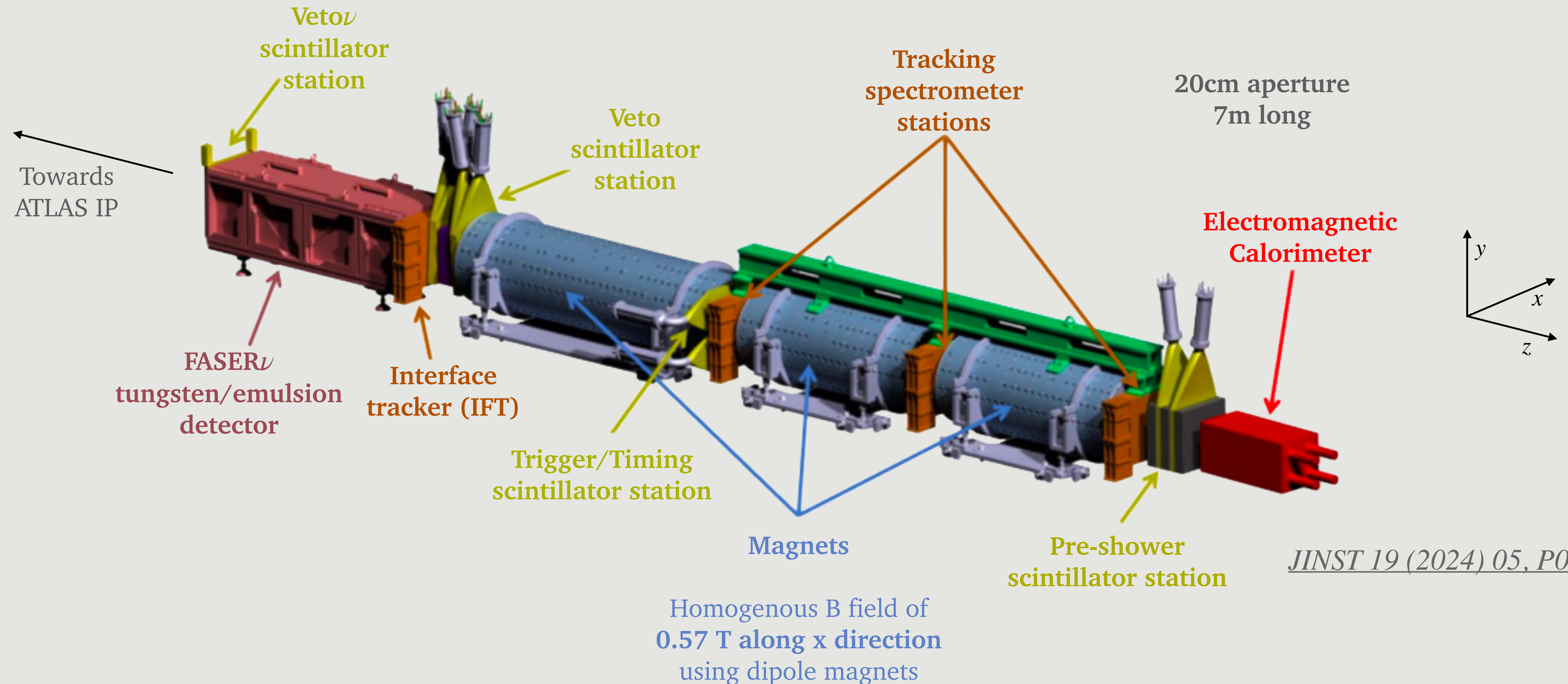
What is FASER?

- * The LHC produces an intense and collimated beam of high energy particles (light hadrons) in the far forward region which largely escape the ATLAS detector
- * FASER was purposefully designed to exploit this large forward production rate to make **neutrino measurements** and perform **dark sector searches** <- focus of this talk



Forward Search Experiment

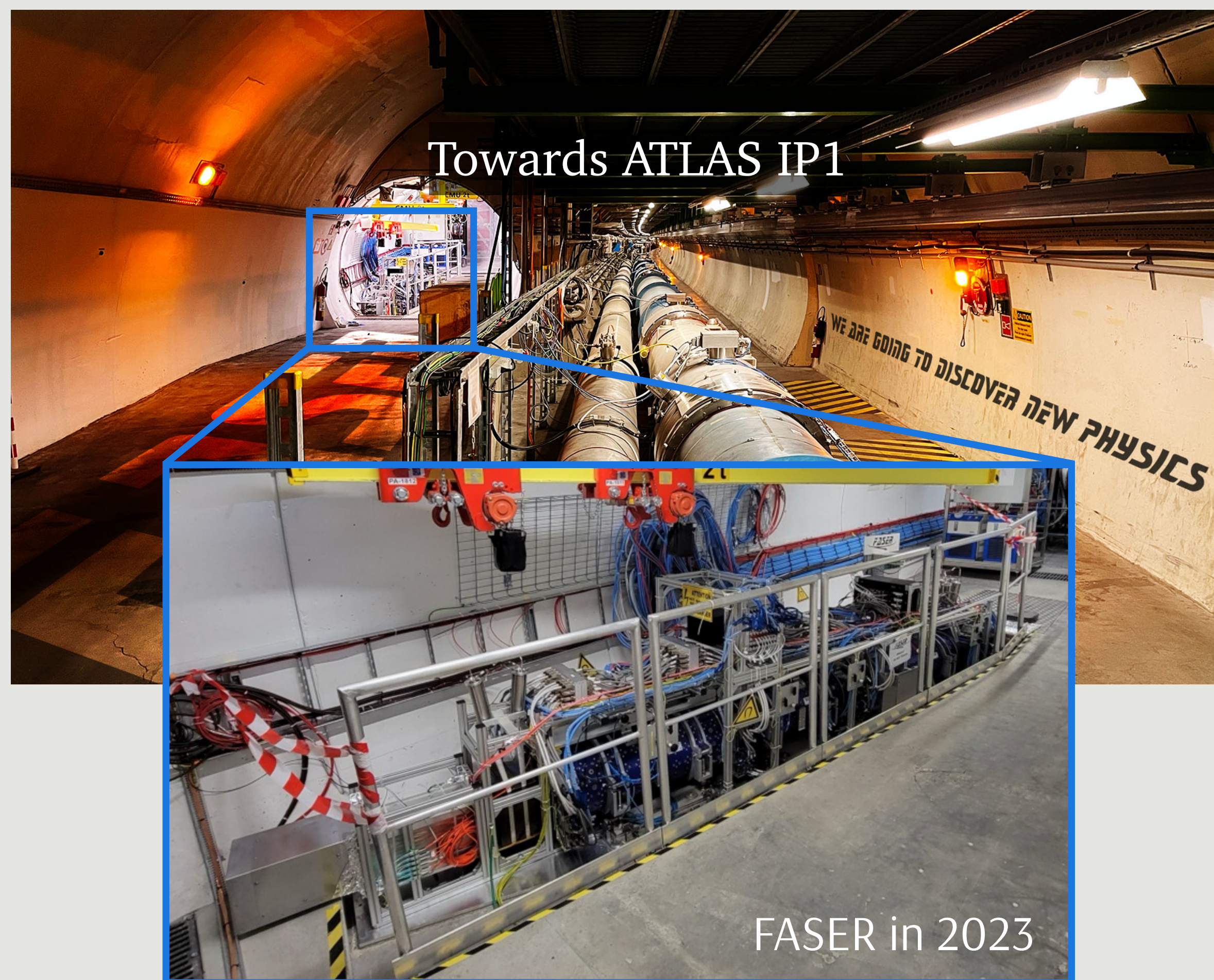
The Detector



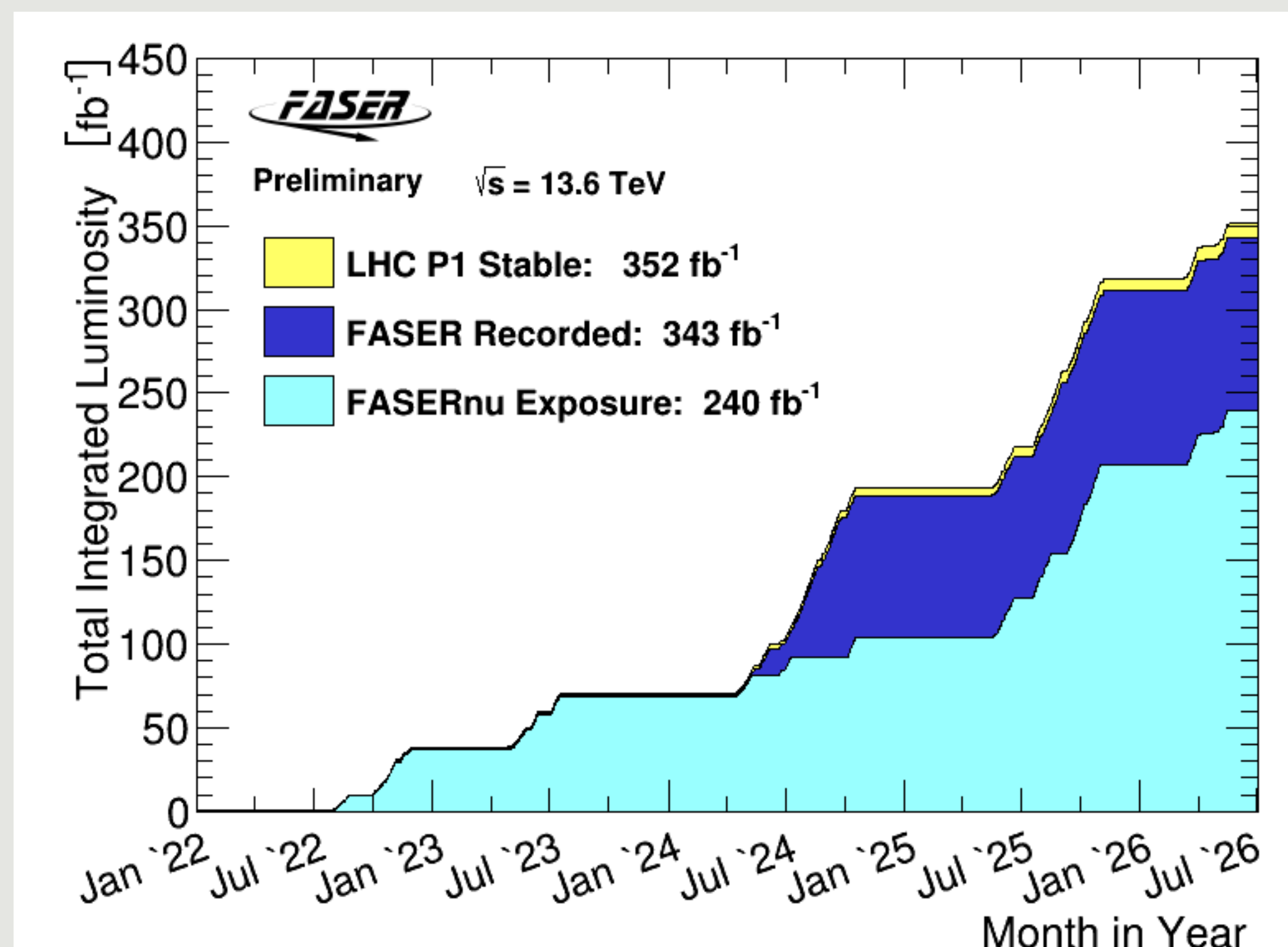
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Forward Search Experiment

Operations



Data recorded with >97% efficiency

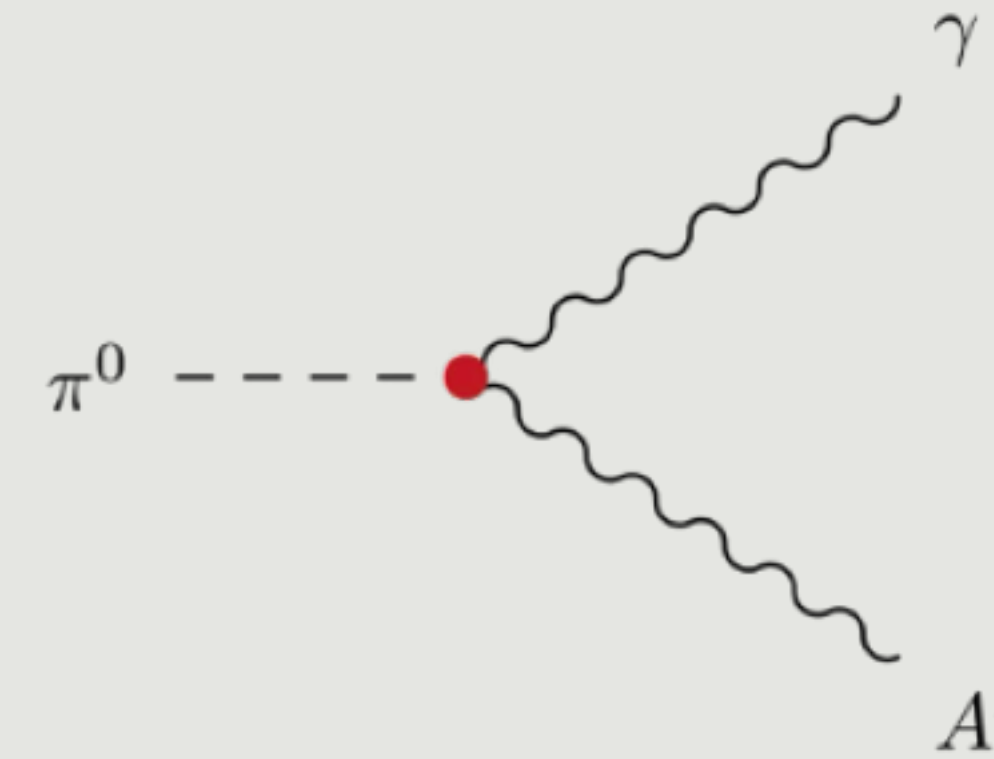


Installed just in time for run 3!

New Dark Photon Search

The Dark Photon

- * The dark photon (A') is a common benchmark for dark-sector models
- * Arises from an extension of the SM through a massive $U(1)$ gauge boson with kinetic mixing ε
- * FASER is most sensitive to MeV-scale dark photons with small ε
- * For $2m_e < m_{A'} < 2m_\mu$ the A' decays only into e^+e^- pairs, which are easy to detect!



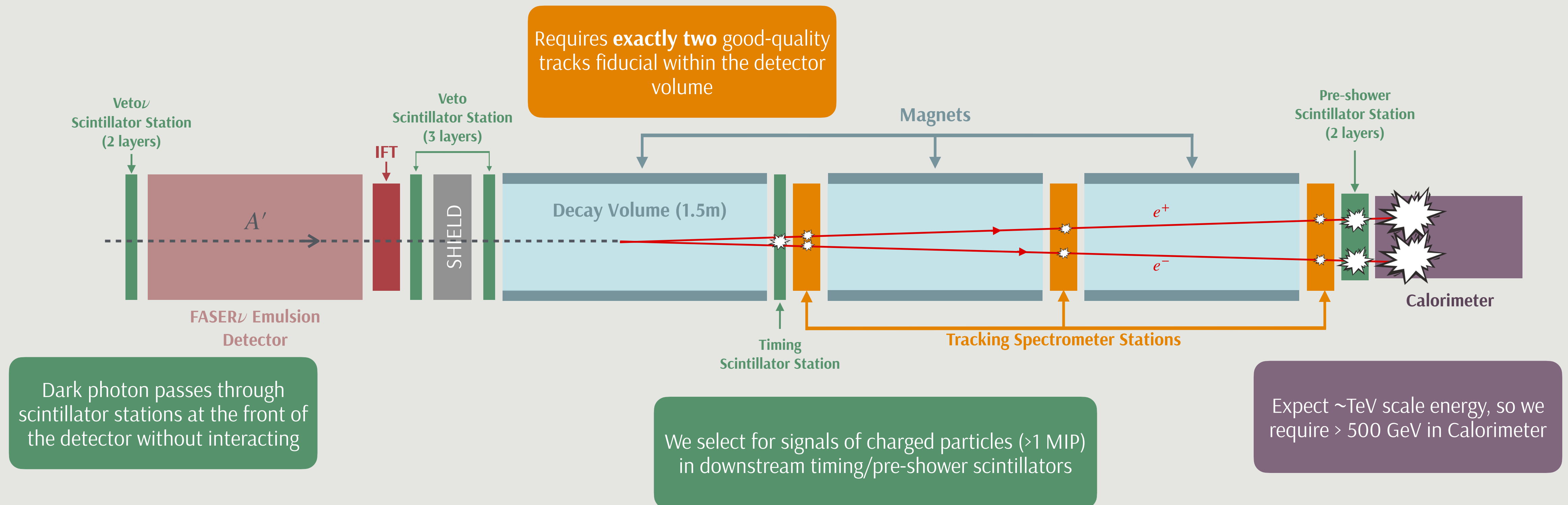
$$\mathcal{L} \supset \frac{1}{2} m_{A'}^2 A'^2 - \varepsilon e \sum_f q_f A'^\mu \bar{f} \gamma_\mu f$$

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

The lifetime of the dark photon is inversely proportional to ε^2 and $m_{A'}$

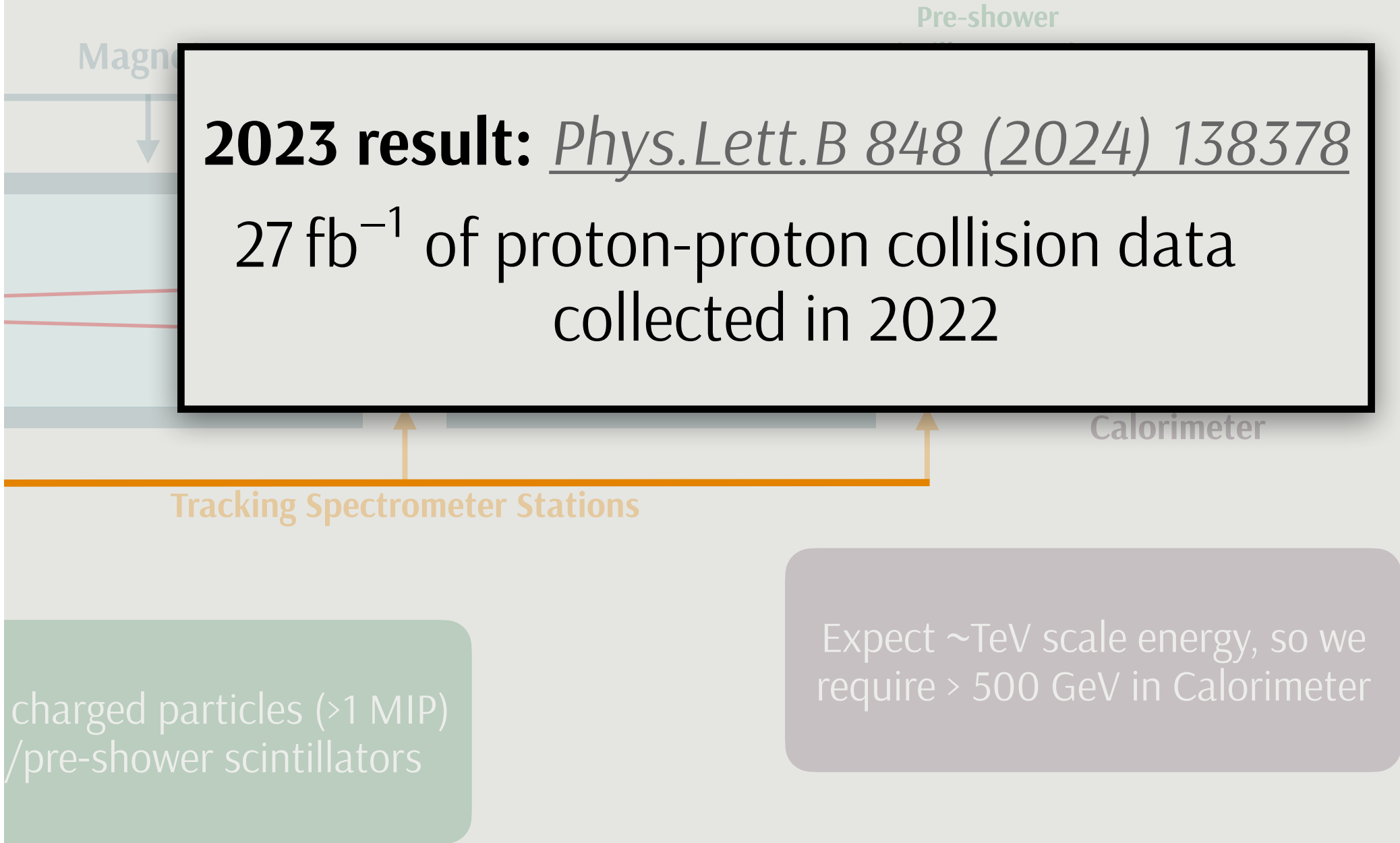
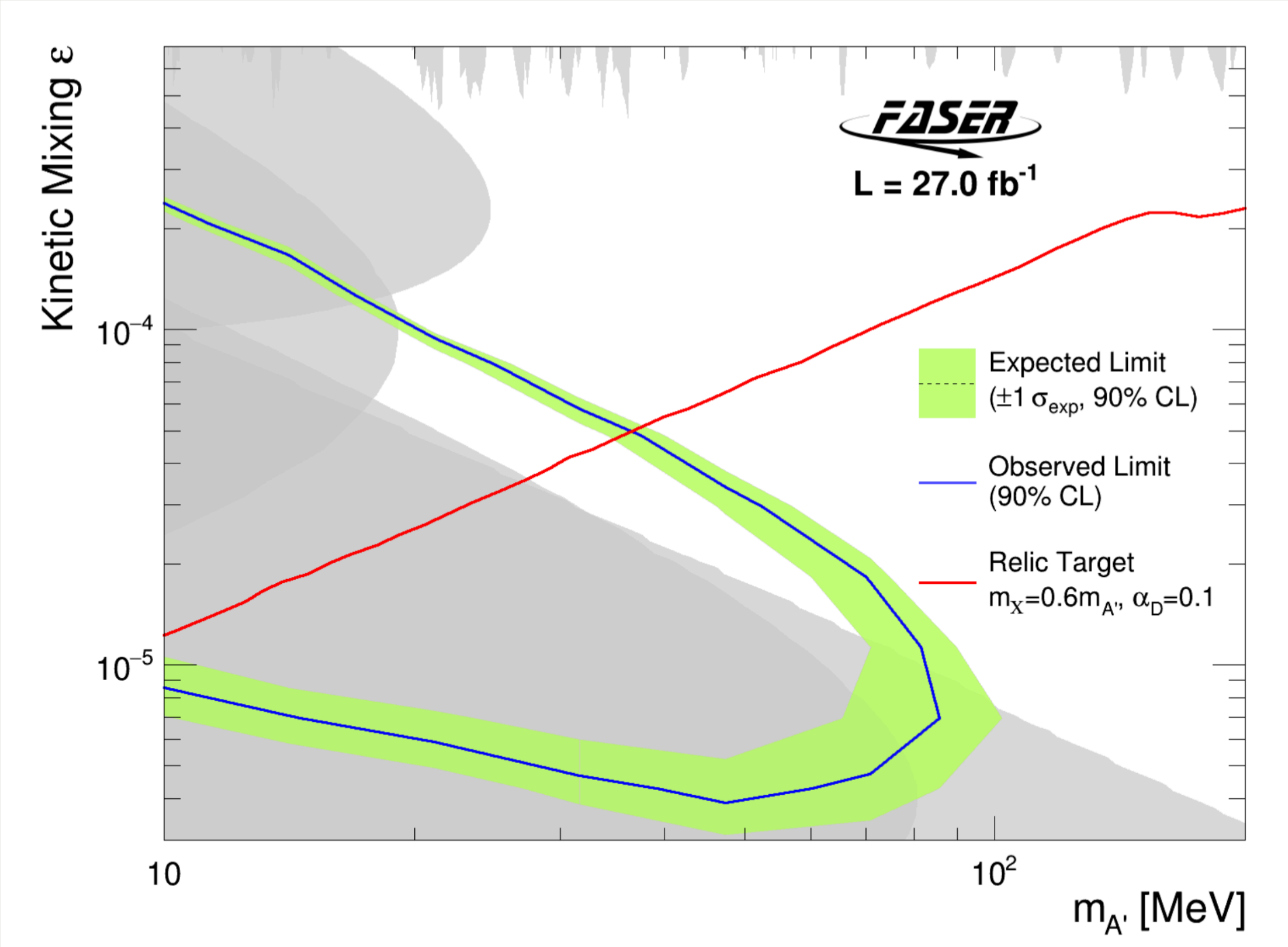
Previous Dark Photon Search

Original Signal Region



Previous Dark Photon Search

Original Signal Region



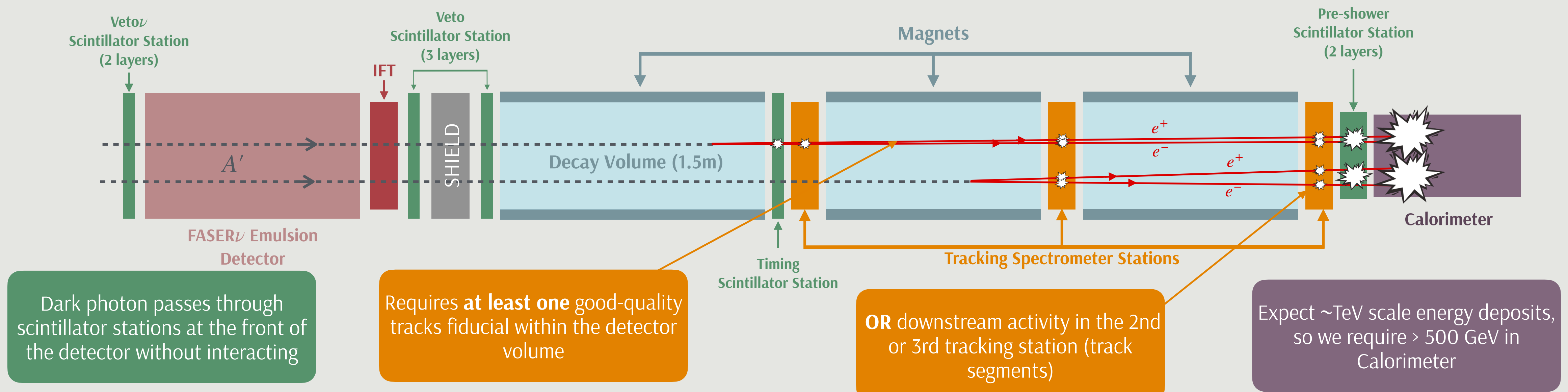
New Dark Photon Search

Two New Signal Regions

- * **One Plus Track Signal Region:** At least one good-quality track fiducial inside the detector volume —*recovers efficiency for highly collimated decays*
- * **Segment Signal Region:** Exactly zero tracks, but searches for charged particle activity in the two downstream tracking scintillators with track segments—*extends viable decay volume*

New Analysis

Significantly improved signal selection strategy (**2.5x better acceptance**)
Using 2022, 2023, 2024 data (**>6x more data**)

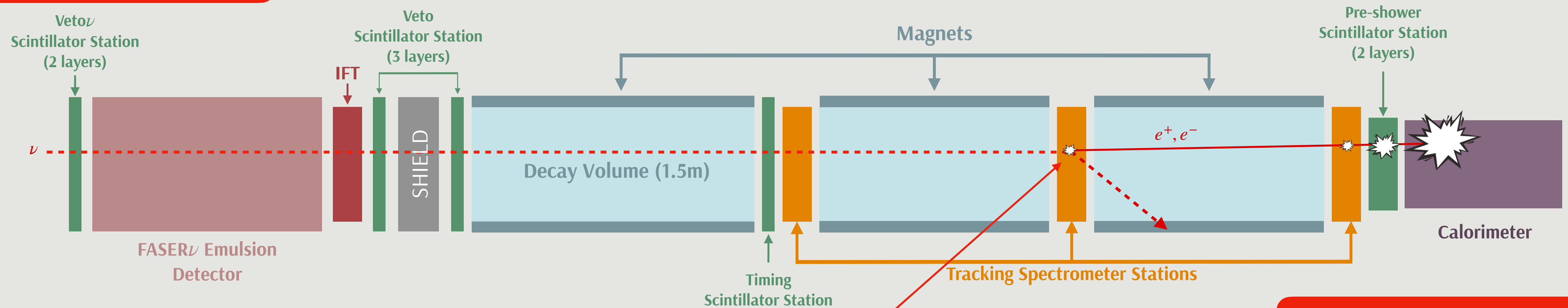


New Dark Photon Search

Backgrounds

- * **Neutrinos:** Dominant background, suppressed through energy and/or tracking requirements. Estimated through Genie MC Simulations.

Neutrinos pass through scintillator stations at the front of the detector without interacting



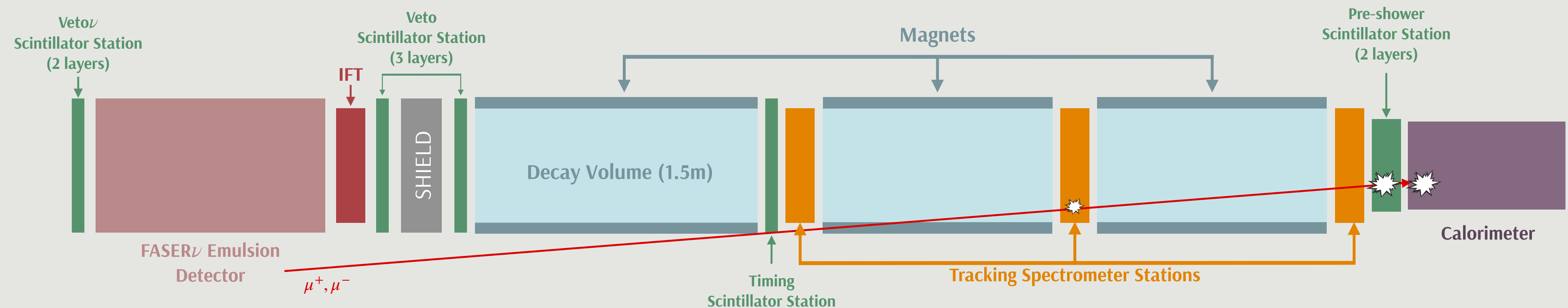
They can then interact with the detector material and produce downstream showers

The downstream neutrino showers can rarely deposit large energy

New Dark Photon Search

Backgrounds

- * **Neutrinos:** Dominant background, suppressed through energy and/or tracking requirements. Estimated through Genie MC Simulations.
- * **Geometric Muons:** Largely negligible, suppressed through energy requirements and/or fiducial requirements on tracks/track segments



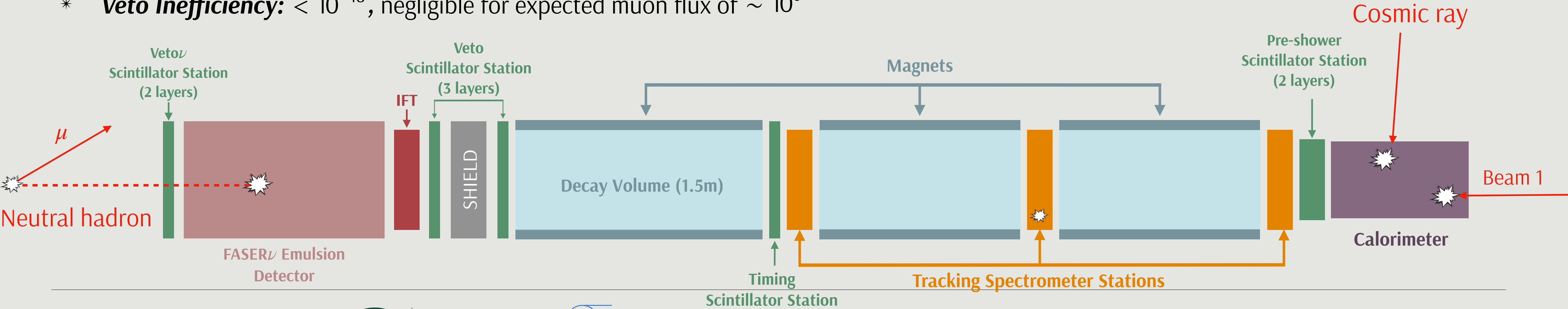
New Dark Photon Search

Backgrounds

- * **Neutrinos:** Dominant background, suppressed through energy and/or tracking requirements. Estimated through Genie MC Simulations.
- * **Geometric Muons:** Largely negligible, suppressed through energy requirements and/or fiducial requirements on tracks/track segments
- * **Neutral Hadrons:** negligible (MC simulation)
- * **Beam Background:** negligible (data estimate)
- * **Cosmic Background:** negligible (data estimate)
- * **Veto Inefficiency:** $< 10^{-18}$, negligible for expected muon flux of $\sim 10^9$

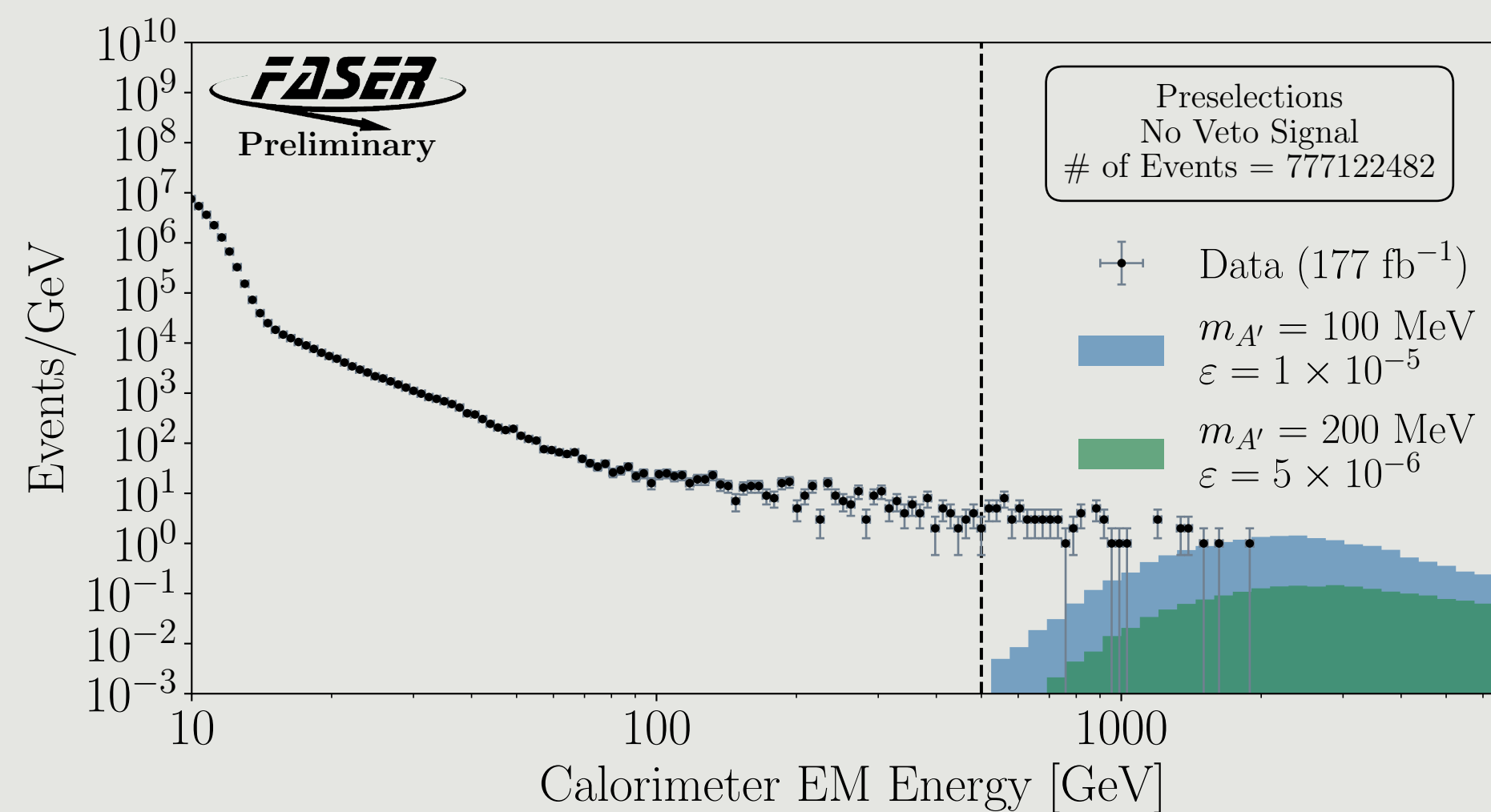
Source	Segment SR	One Track SR
Neutrinos	$0.025^{+0.014}_{-0.014}$	$0.018^{+0.007}_{-0.016}$
Geometric Muons	$0.002^{+0.001}_{-0.001}$	0
All Other	0	0

Net Contribution << 1 event

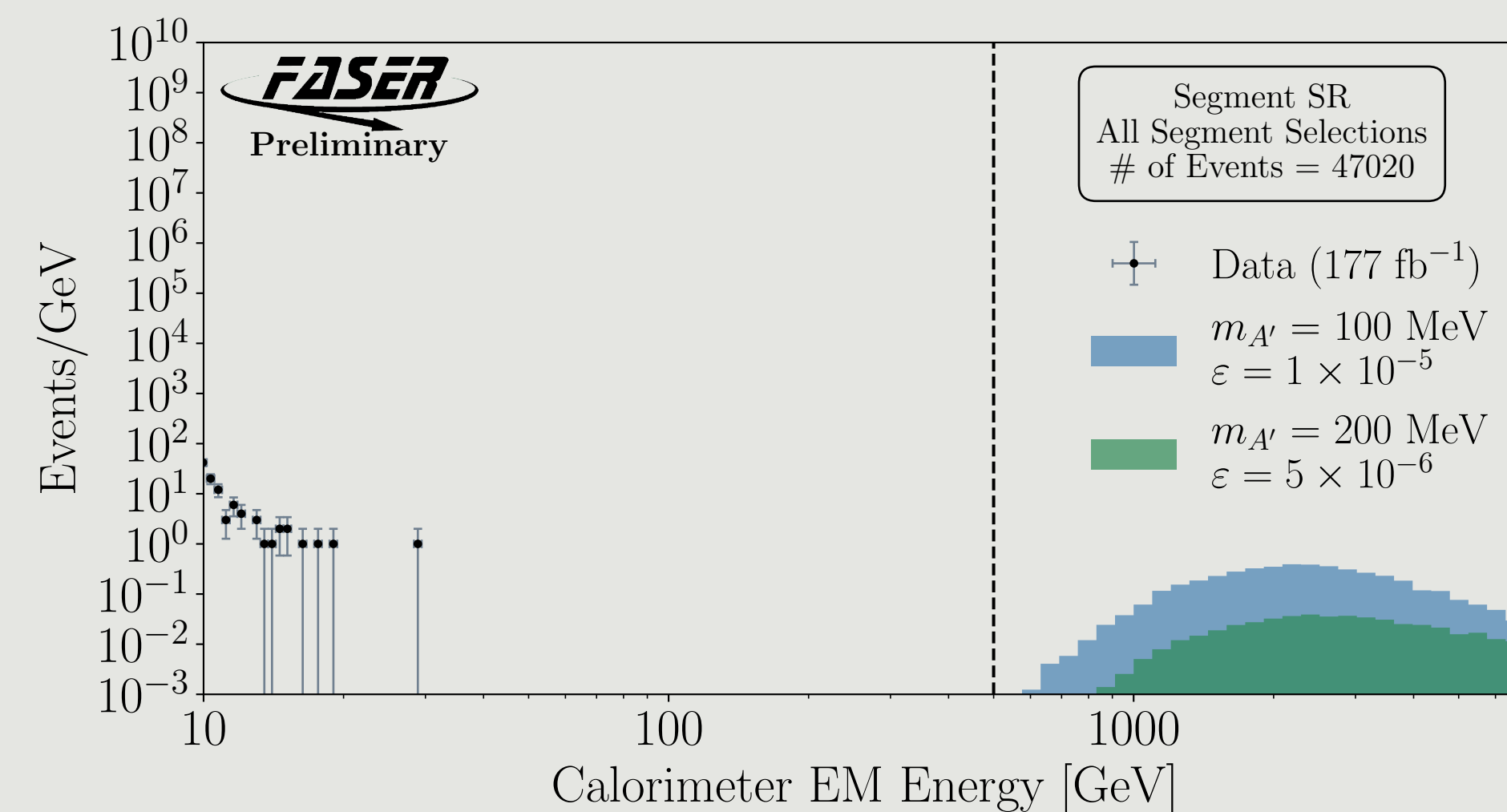
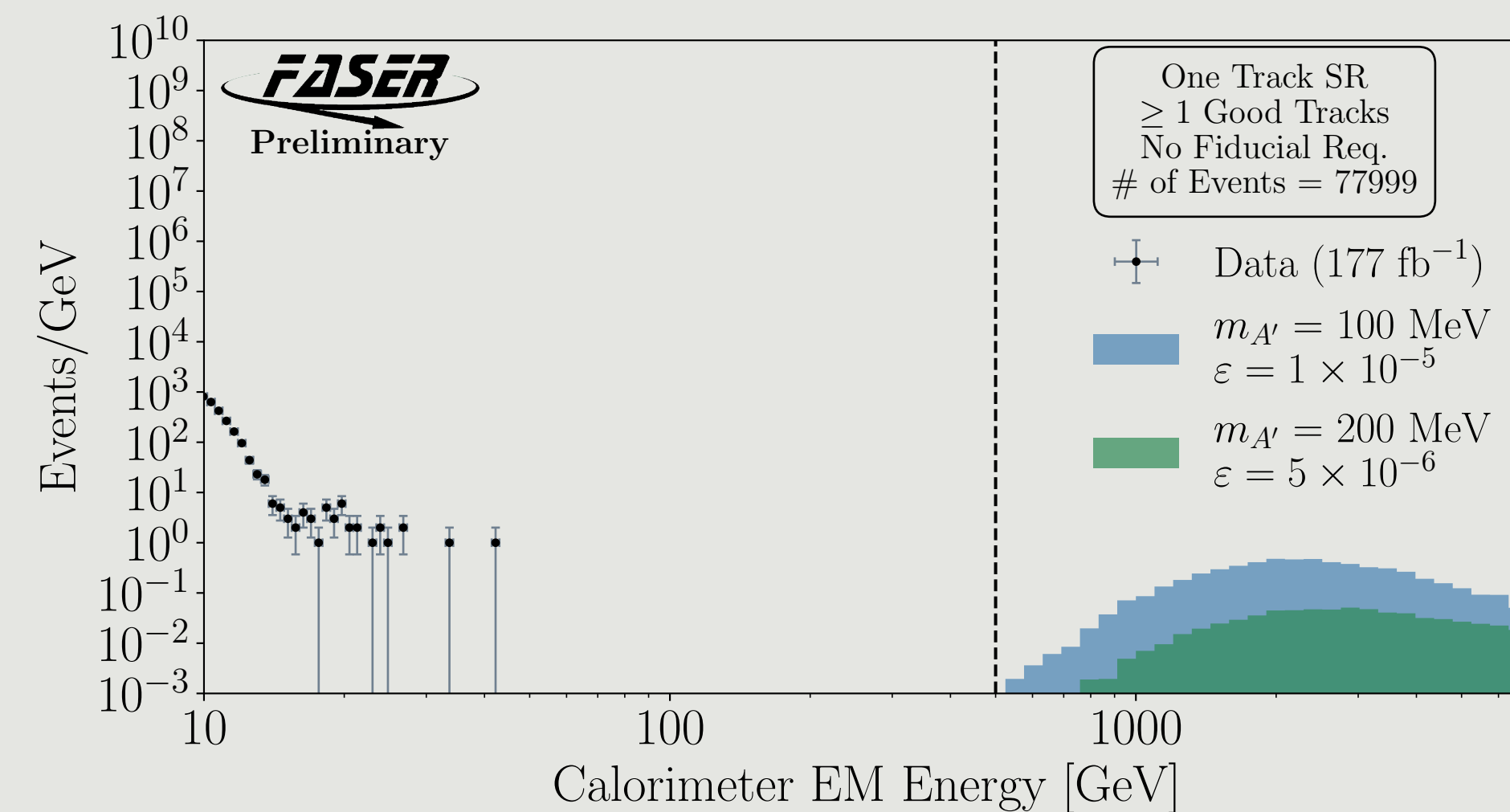


New Dark Photon Search

Data



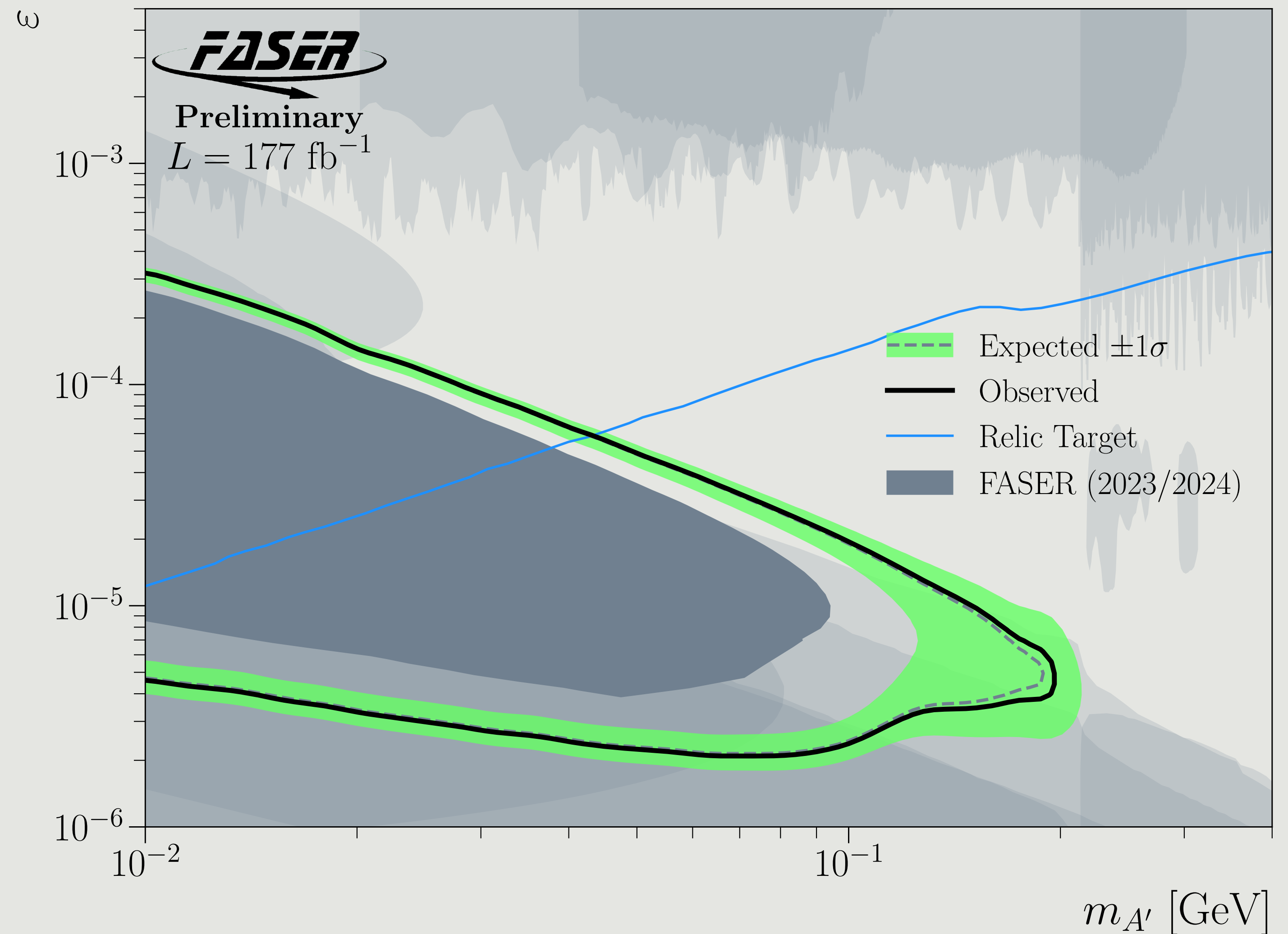
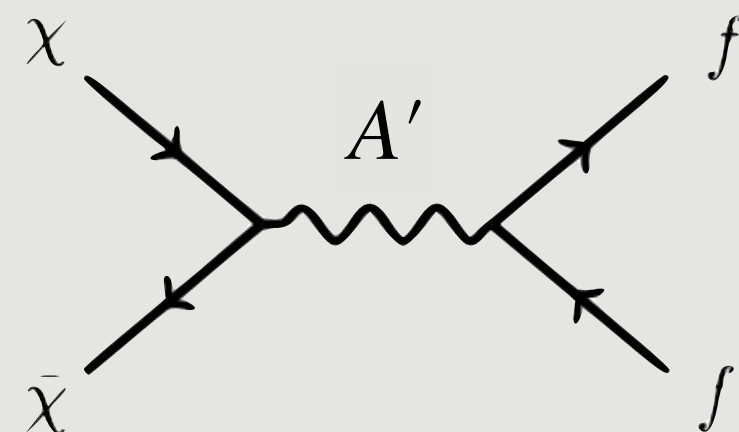
Combined analysis using 177 fb^{-1} of
data from 2022, 2023, 2024
Zero events seen after all selections



New Dark Photon Search

Results

- * Set significantly stronger constraints compared to previous result
- * Dark photons are of particular interest because they can allow for obtaining the correct relic density via thermal freeze-out
- * These results can be complementary to direct detection searches! Ex. a model where the dark photon is coupled to a scalar dark matter field χ
- * We show an example thermal relic contour in blue for coupling $\alpha_D = 0.1$ and mass ratio $m_\chi / m_{A'}$
- * These values guarantee the dark photon decays visibly into SM species, and DM annihilates via $\chi\chi \rightarrow A' \rightarrow ff$
- * For this model the region **below the line** would produce an overabundance of DM and be **excluded cosmologically**

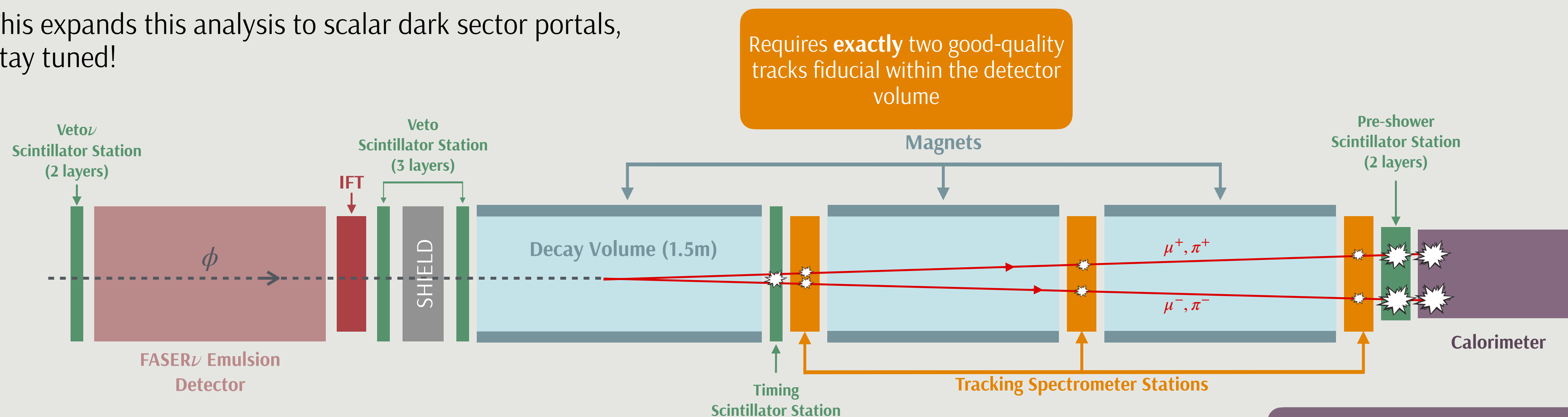


New Dark Photon Search

Coming Soon!

- * **Two Track Signal Region:** Two track search with reduced energy (< 500 GeV) – targeting $\pi^+\pi^-$ and $\mu^+\mu^-$ final states, orthogonal to previous two signal regions
- * This expands this analysis to scalar dark sector portals, stay tuned!

Paper in prep. with all three signal regions



Dark sector particle passes through scintillator stations at the front of the detector without interacting

We select for signals of charged particles (>1 MIP) in downstream timing/pre-shower scintillators

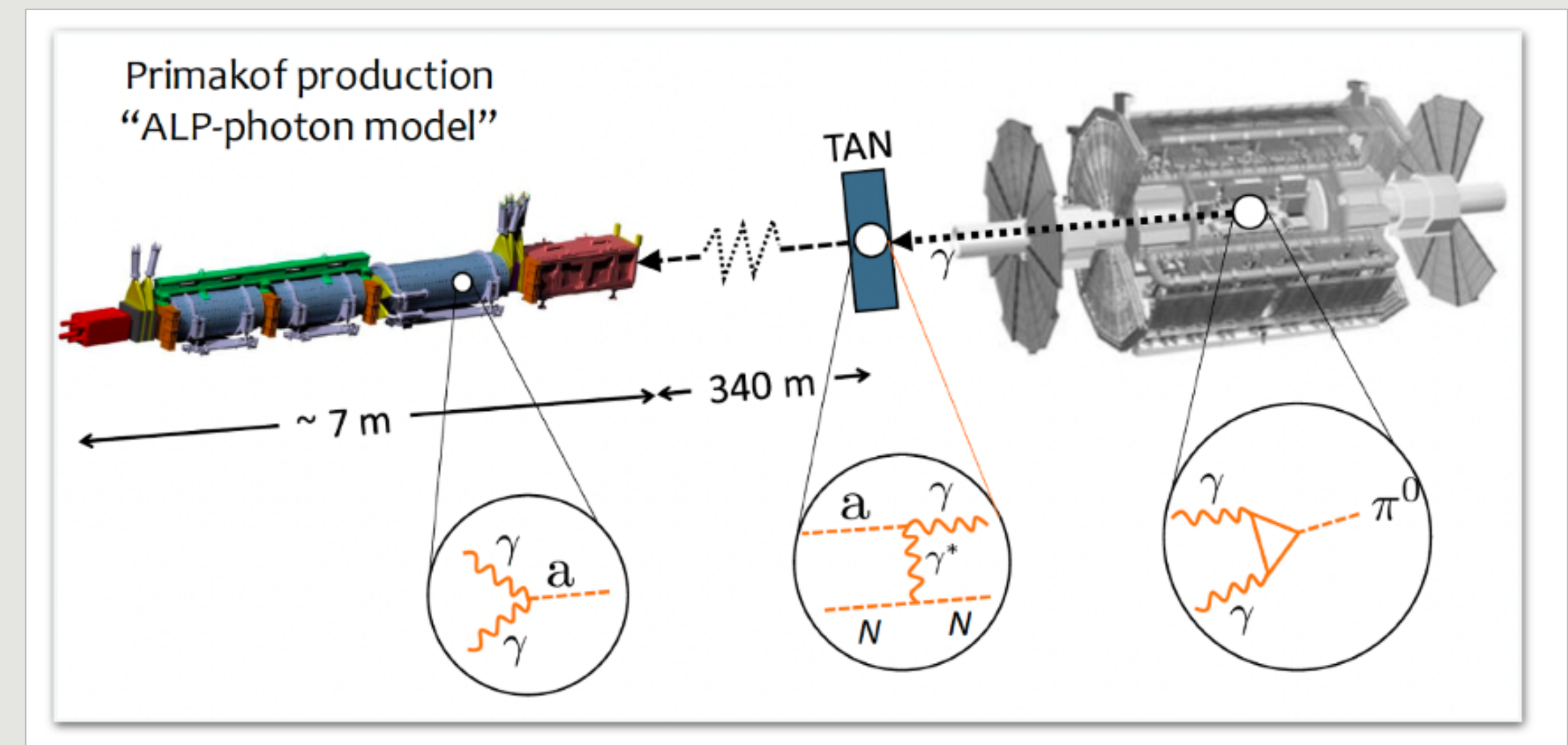
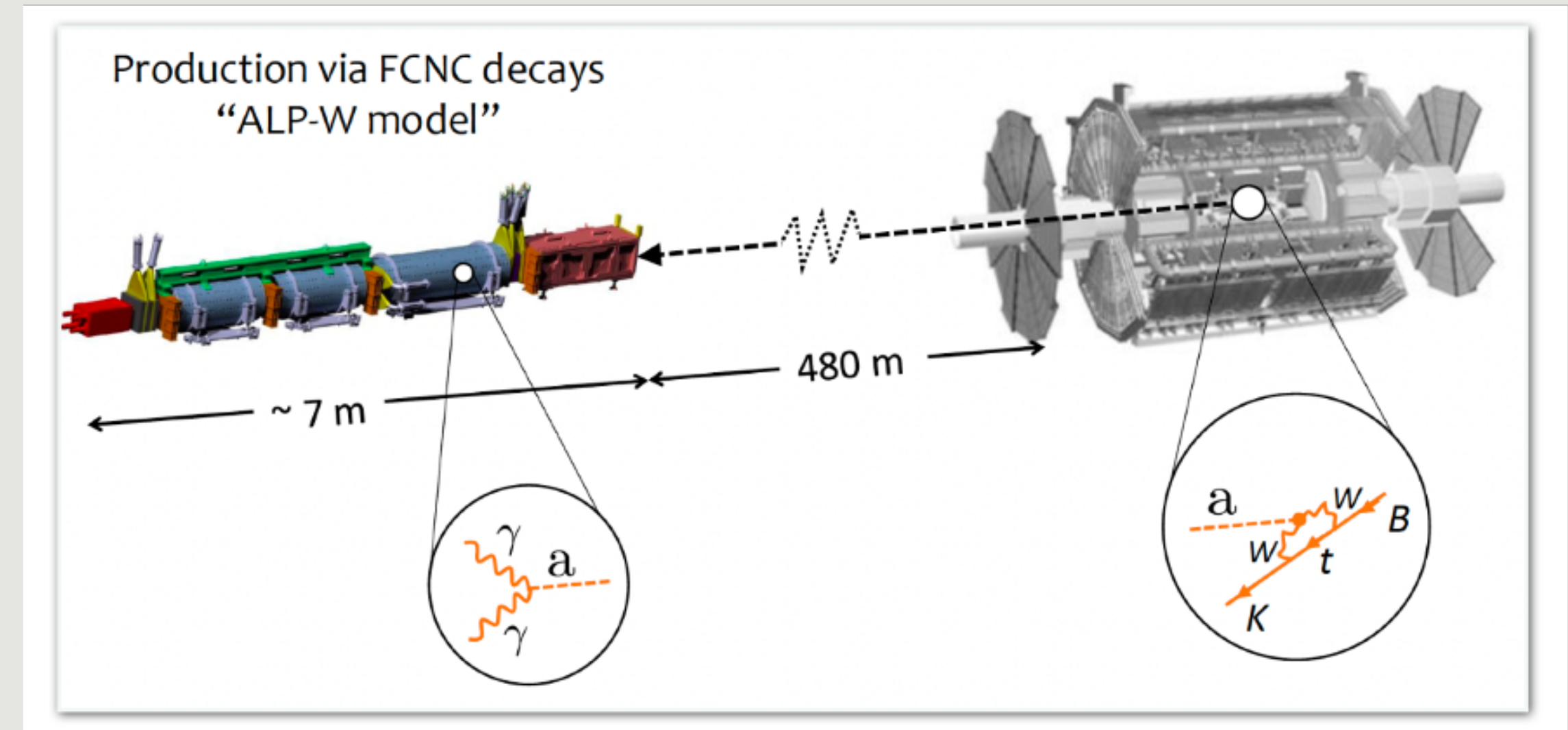
For $\mu^+\mu^-$, $\pi^+\pi^-$ we expect only a fraction of energy to be deposited, so we require < 500 GeV

ALPs Search

Axion-Like-Particles

- * FASER is sensitive to several ALP models, mostly produced through B-meson decays
- * Once these ALPs are produced, they decay into pairs of high energy photons
- * ALP-W Model:

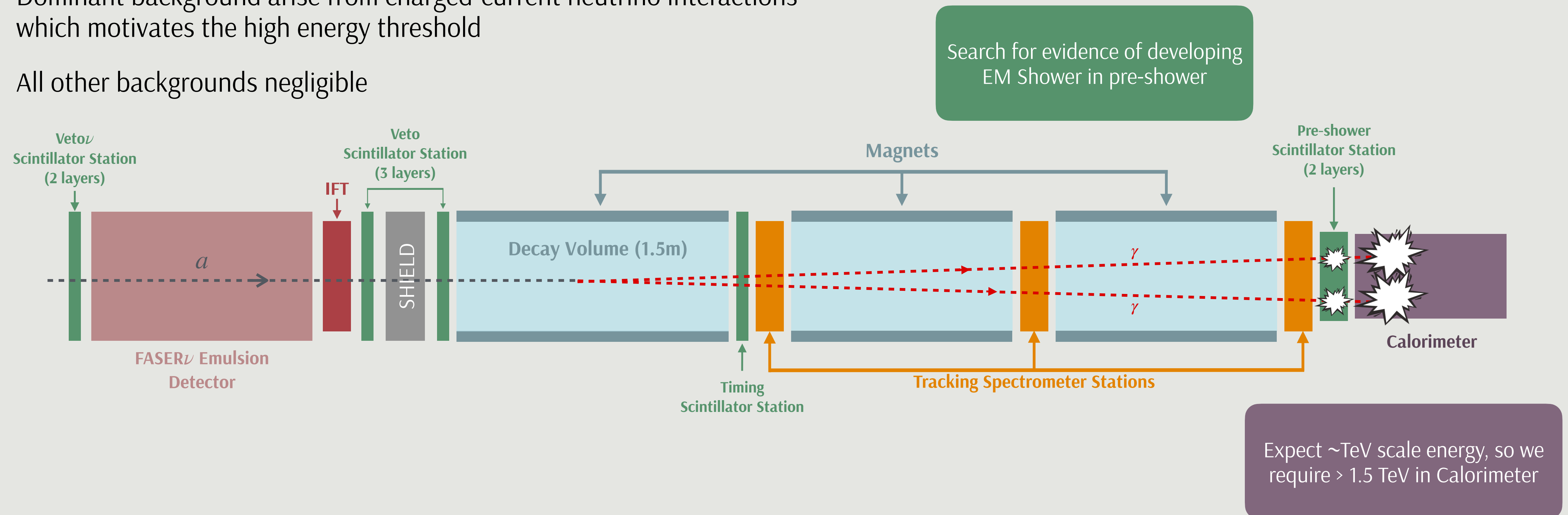
$$\mathcal{L} \supset -\frac{1}{2} m_a^2 a^2 - \frac{1}{4} g_{aWW} a W_{\mu\nu}^a \tilde{W}^{a,\mu\nu}$$



ALPs Search

ALPs Analysis

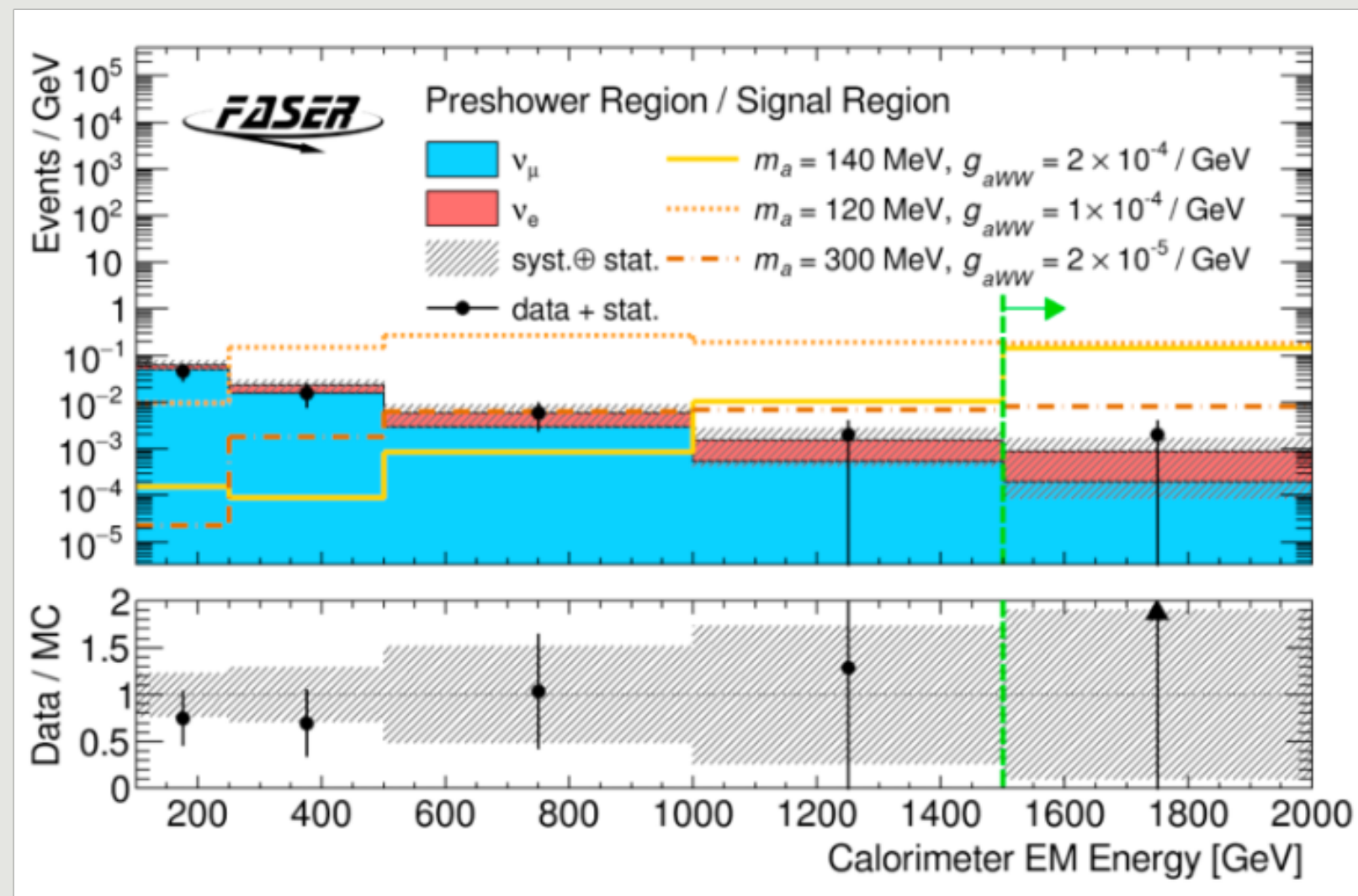
- * Simple analysis selection using only scintillators, preshower and calorimeter
- * Analyzed 57.7 fb^{-1} of data collected during 2022 and 2023
- * Dominant background arise from charged-current neutrino interactions – which motivates the high energy threshold
- * All other backgrounds negligible



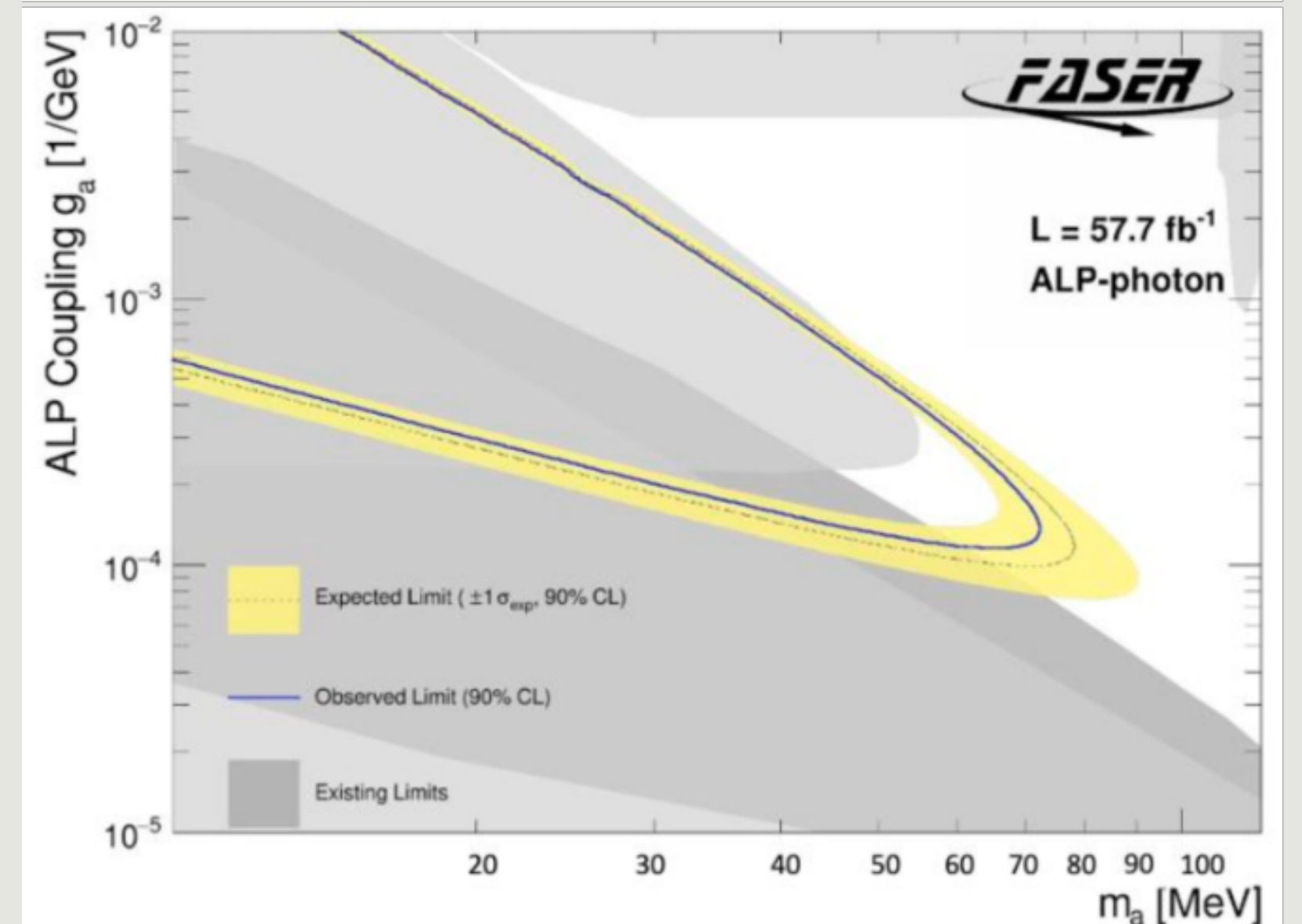
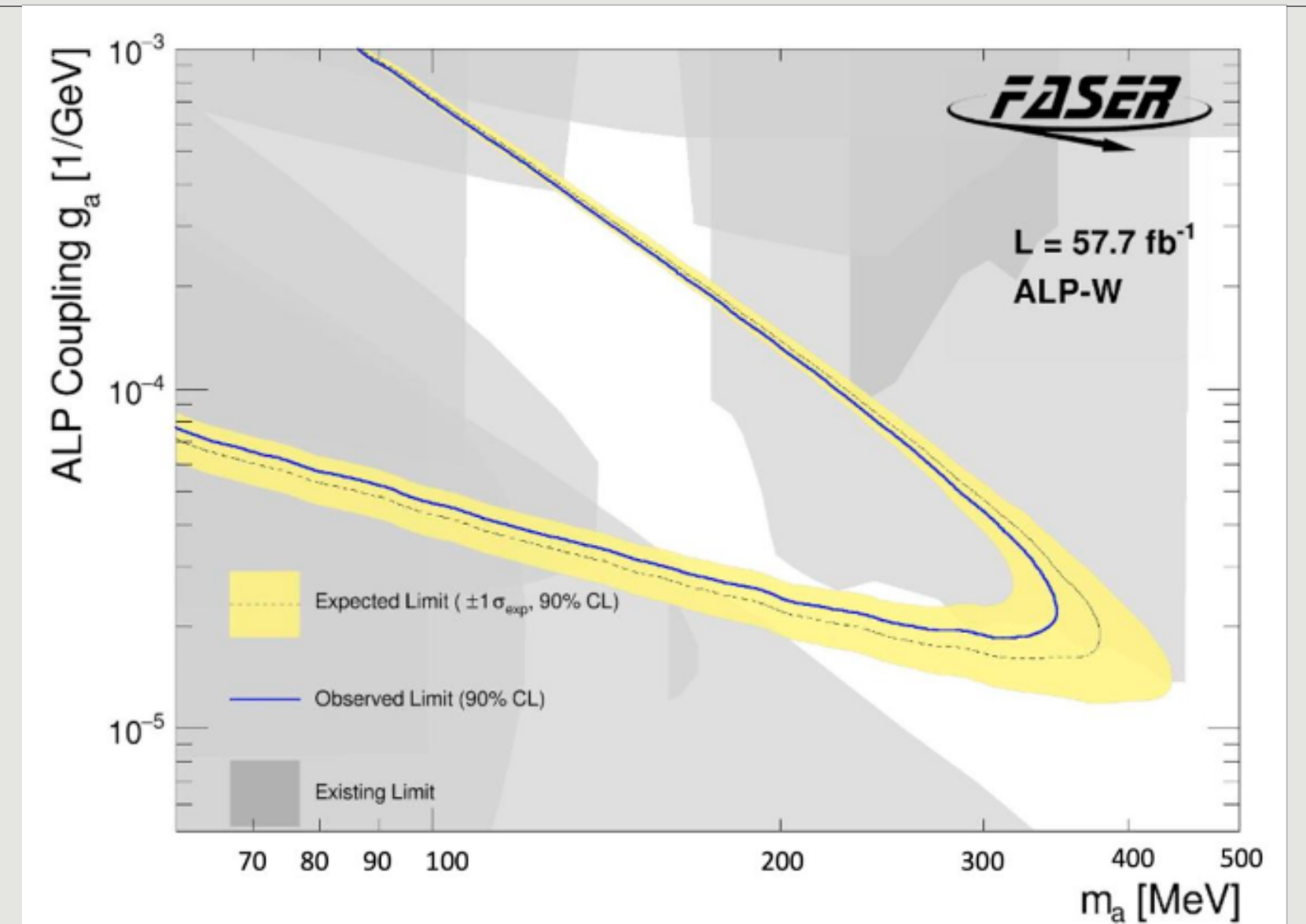
ALPs Search

2024 ALPs Results

- * 1 observed event, compatible with background estimation of 0.44 ± 0.39 neutrino events (modeled from Genie MC)
- * World leading constraints for several ALP models
- * ALP-W and ALP-photon models shown here, others in backup
- * New ALPs search combining 2022, 2023 2024 data should be out soon!



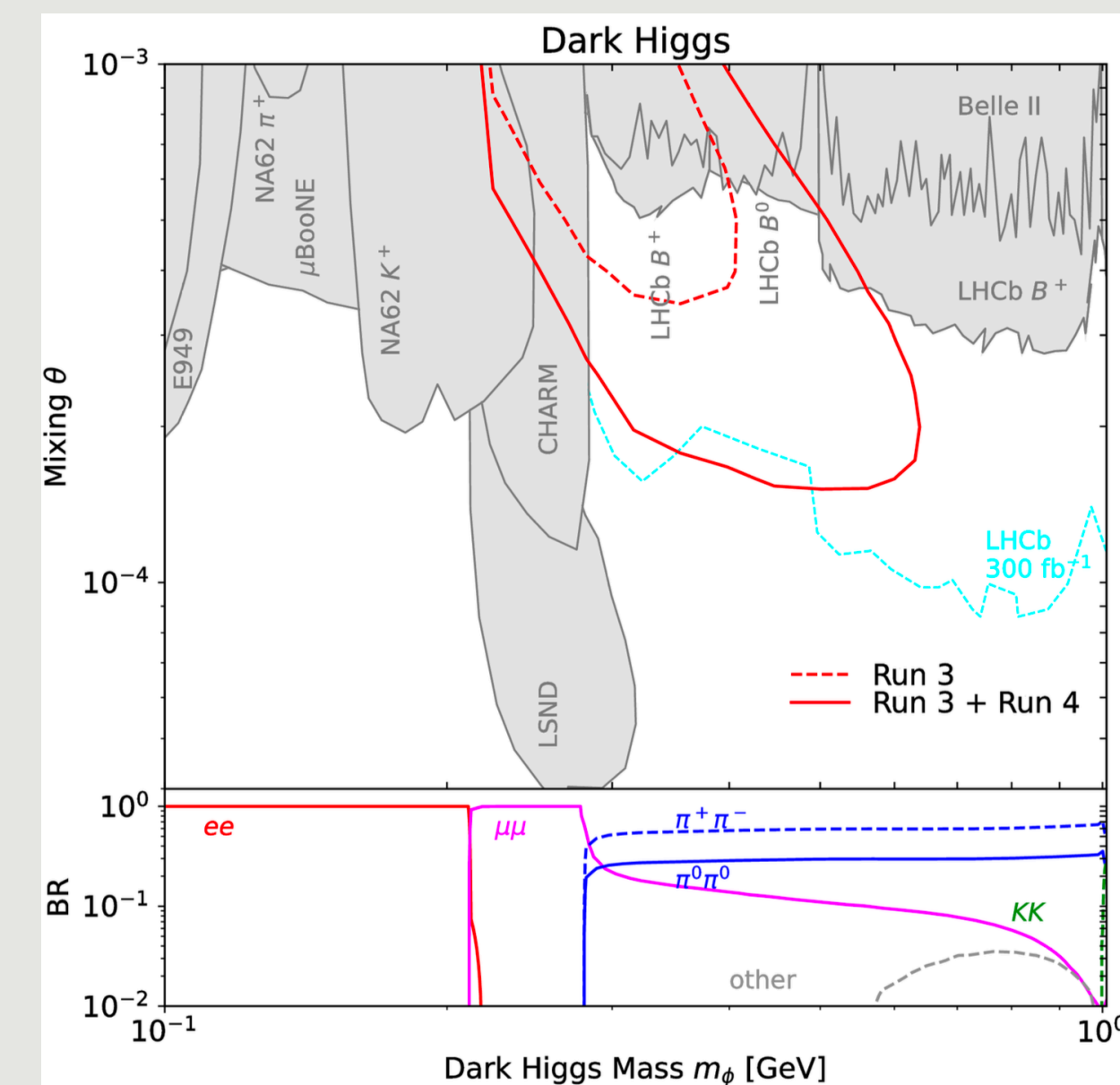
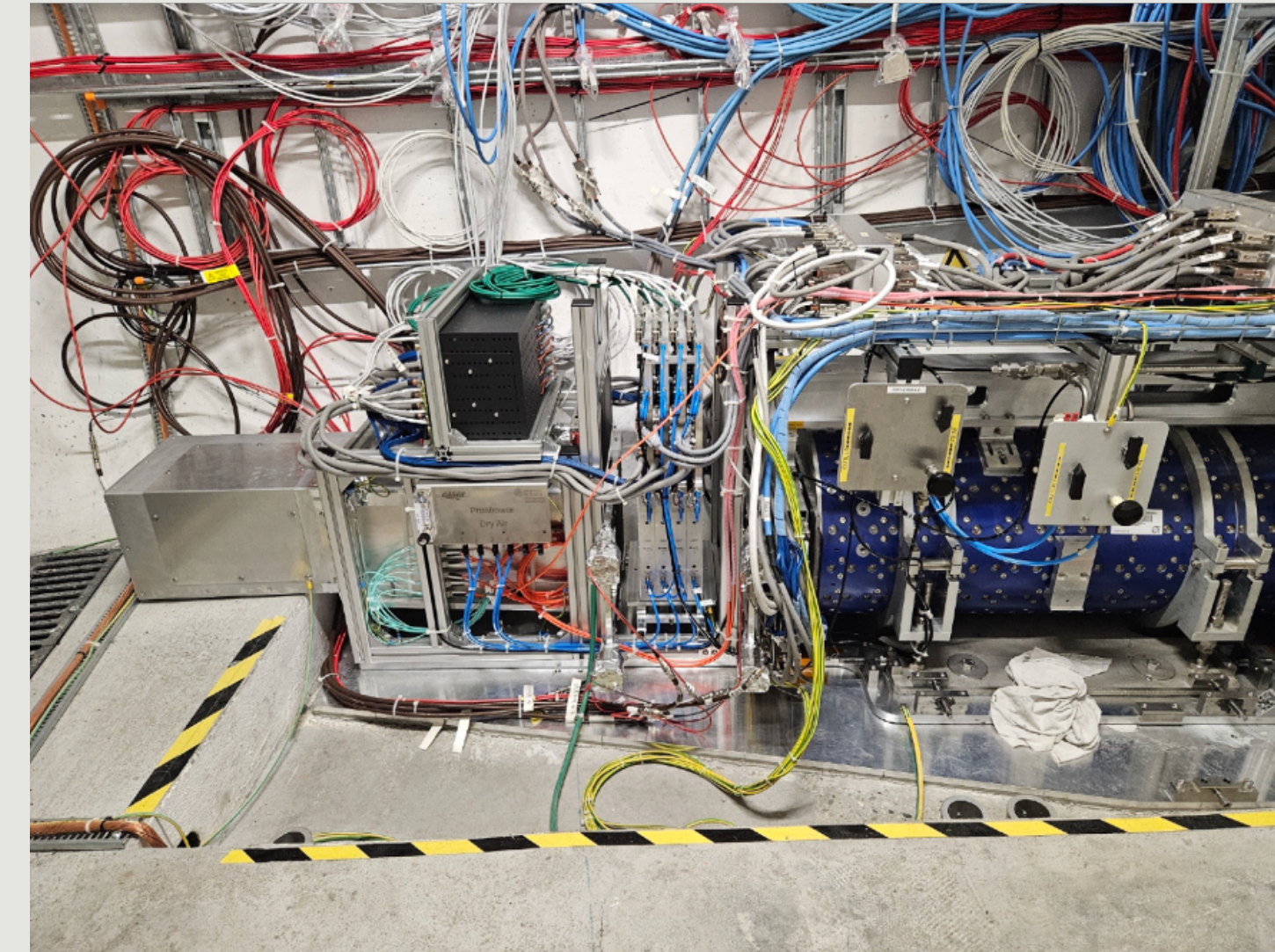
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Future

What's Next for FASER?

- * Analysis of 2025 and 2026 data with new high granularity preshower detector – enables precise measurement of EM showers
- * FASER is approved for the HL-LHC with several detector upgrades being considered
- * With the increased statistics FASER will gain significant sensitivity to many dark sector models



Summary

- * FASER has the unique ability to probe several dark sector models, providing a complementary approach to traditional indirect/direct detection methods
- * In addition to exciting neutrino results, FASER has produced world-leading results for several dark sector models
- * FASER has operated successfully throughout all of LHC Run 3, and will produce more exciting physics results during LHC Run 4 with upgraded detectors



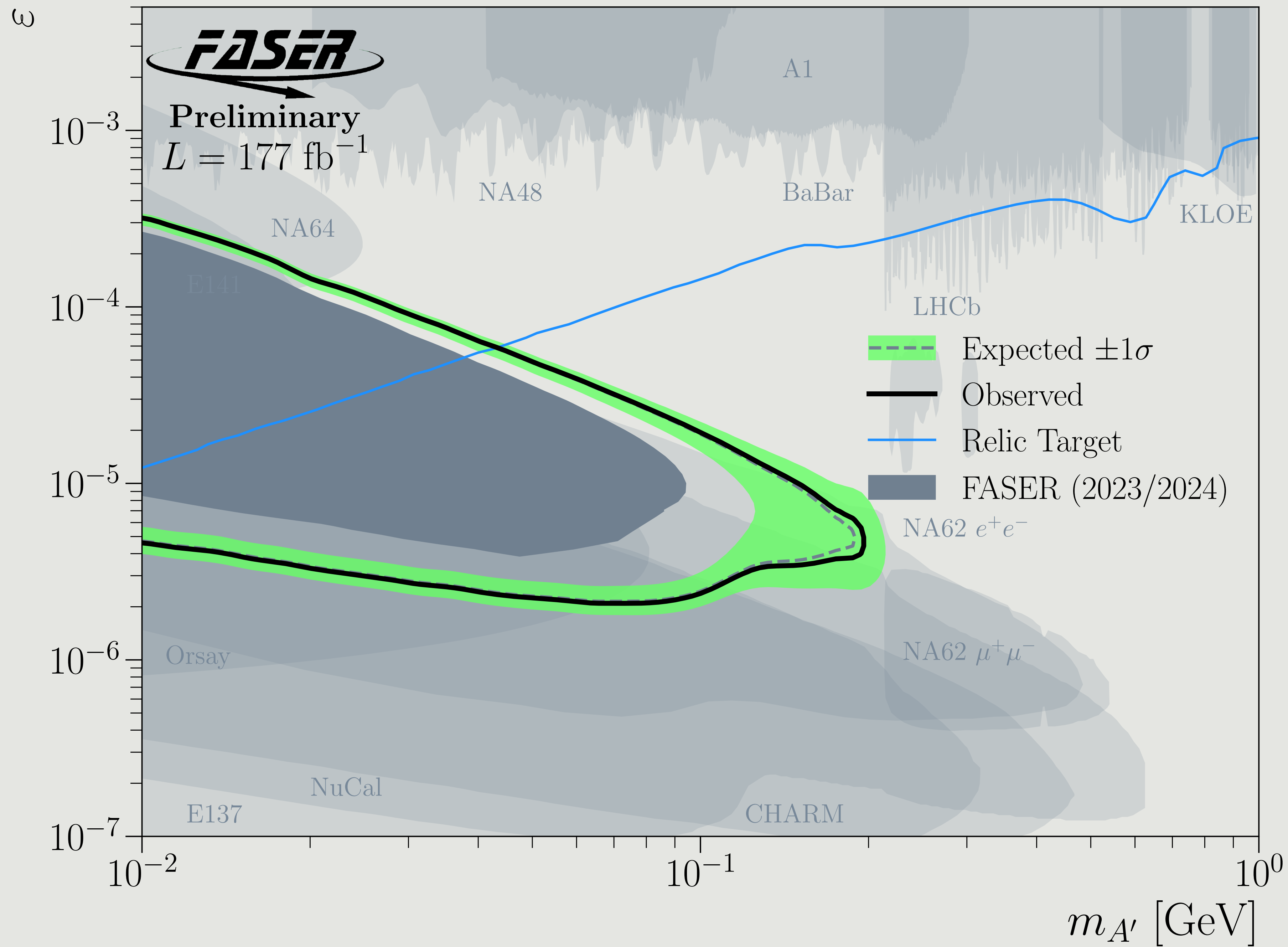
Thank you for your attention!

Backup

New Dark Photon Search

Dark Photon Systematics

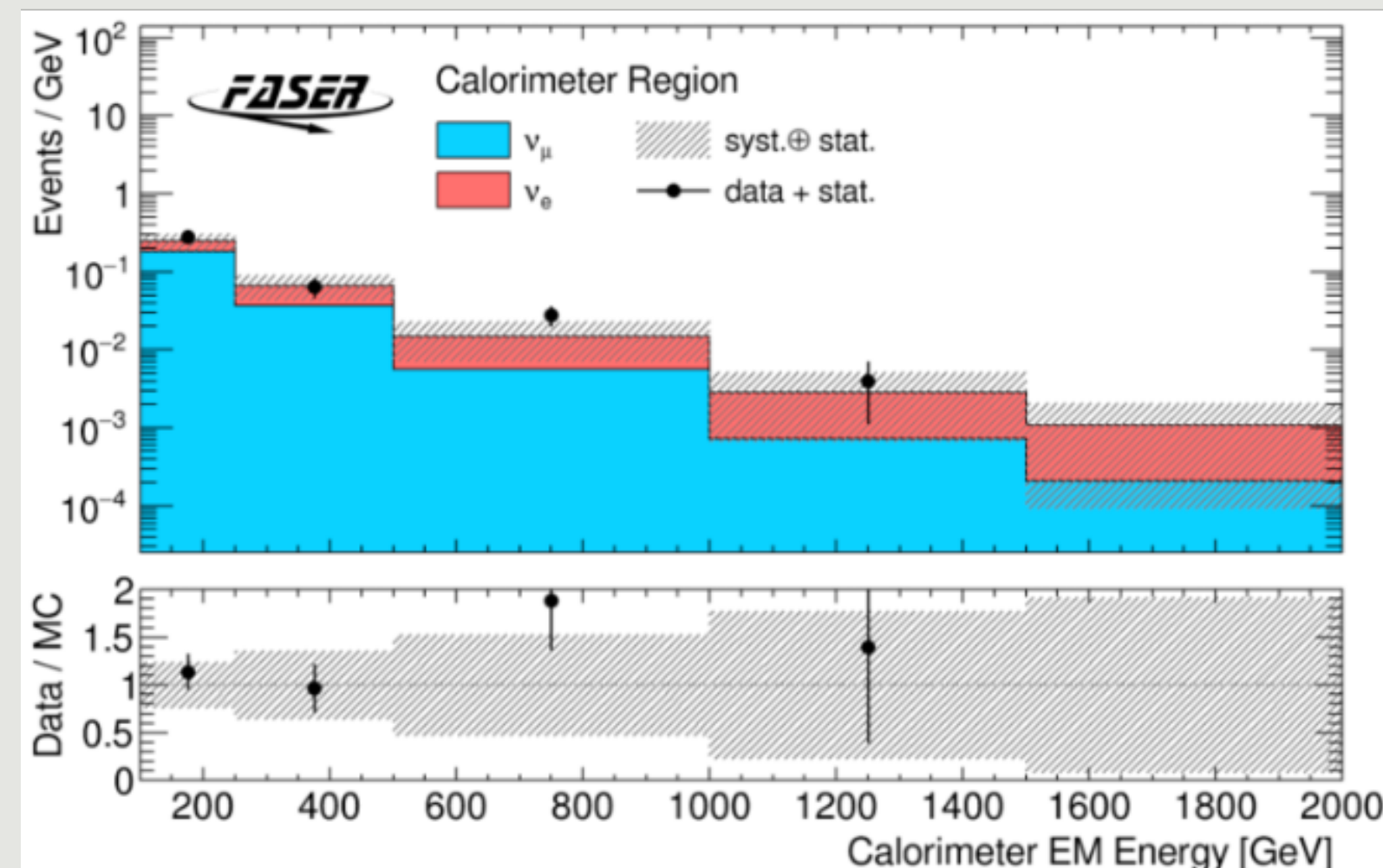
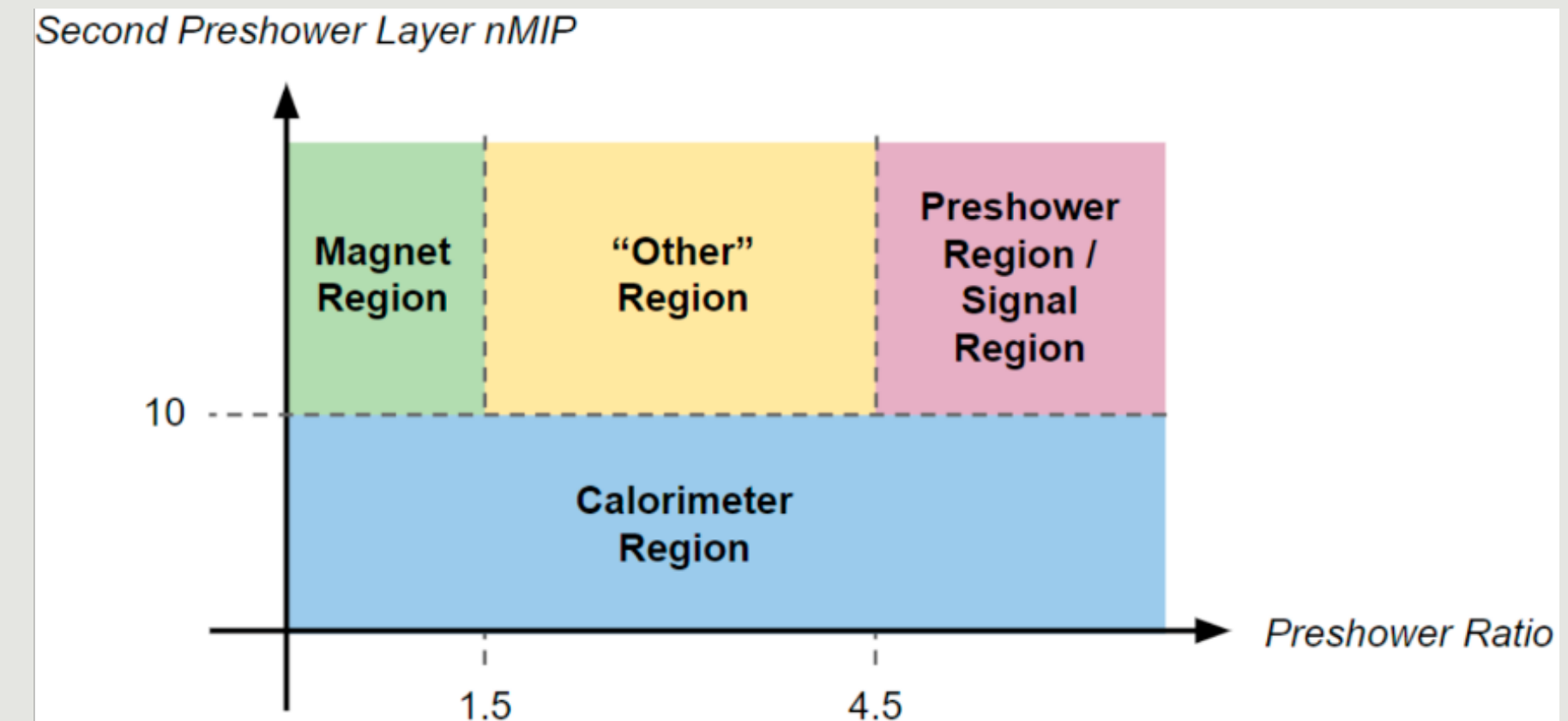
Source	Value	Effect on Signal Yield
Dark Photon Generation (from mesons)	15%	15% (8%)
Dark Photon Generation (from dark Bremsstrahlung)	22%	22% (40%)
Luminosity	1.9%	1.9%
Momentum Scale	5%	<0.5%
Momentum Resolution	5%	<0.5%
Single Track Efficiency	0.47%	0.47%
Two Track Efficiency	~1% (3.5%)	~1% (3.5%)
Segment Efficiency	6.07%	6.07%
Calo Energy Scale	5.46%	3% (11%)



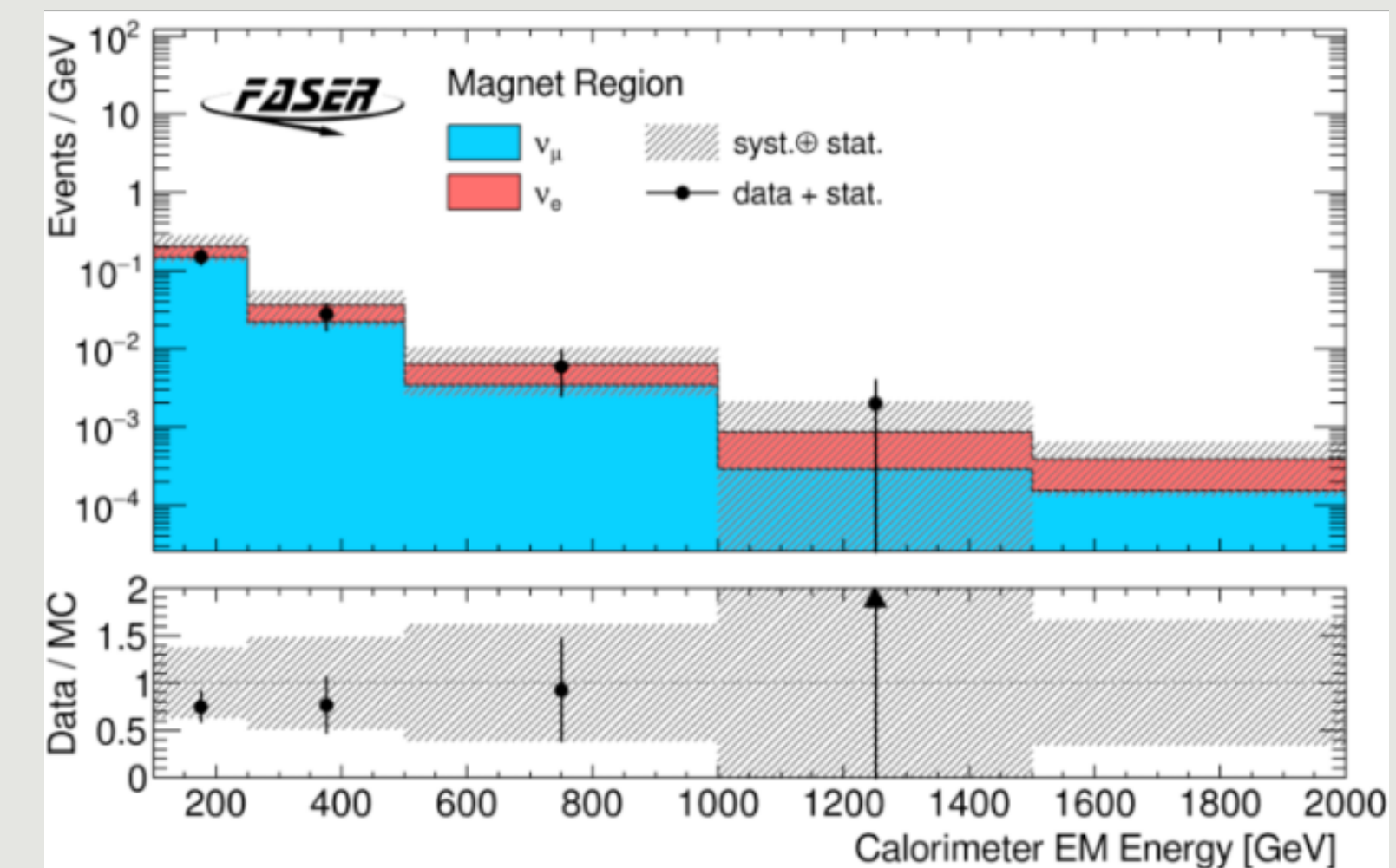
ALPs Search

ALPs Background Modeling

- * Largest background comes from neutrino interactions and the preshower and the calorimeter
- * MC modeling was done using flux predictions from [2402.13318](https://arxiv.org/abs/2402.13318)
- * Validated by isolating different neutrino interaction regions using the preshower detector

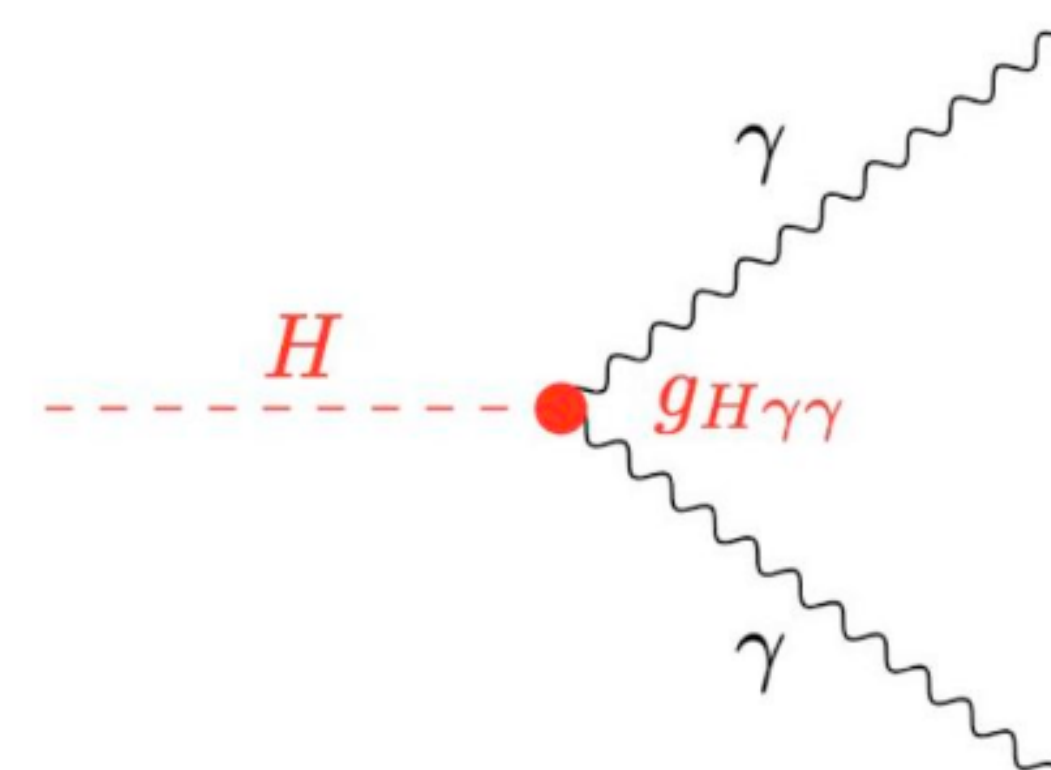
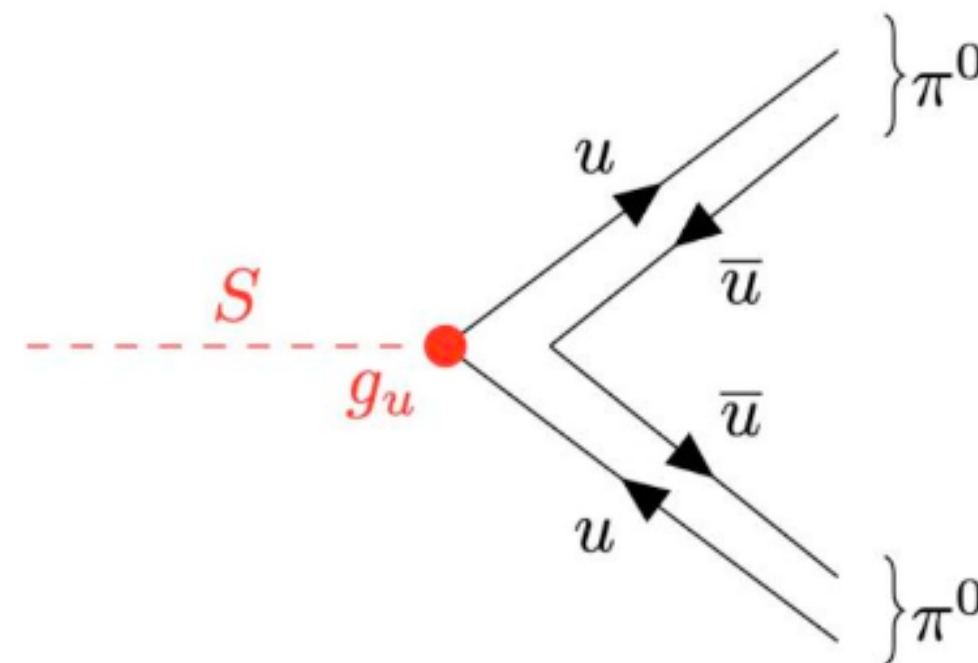
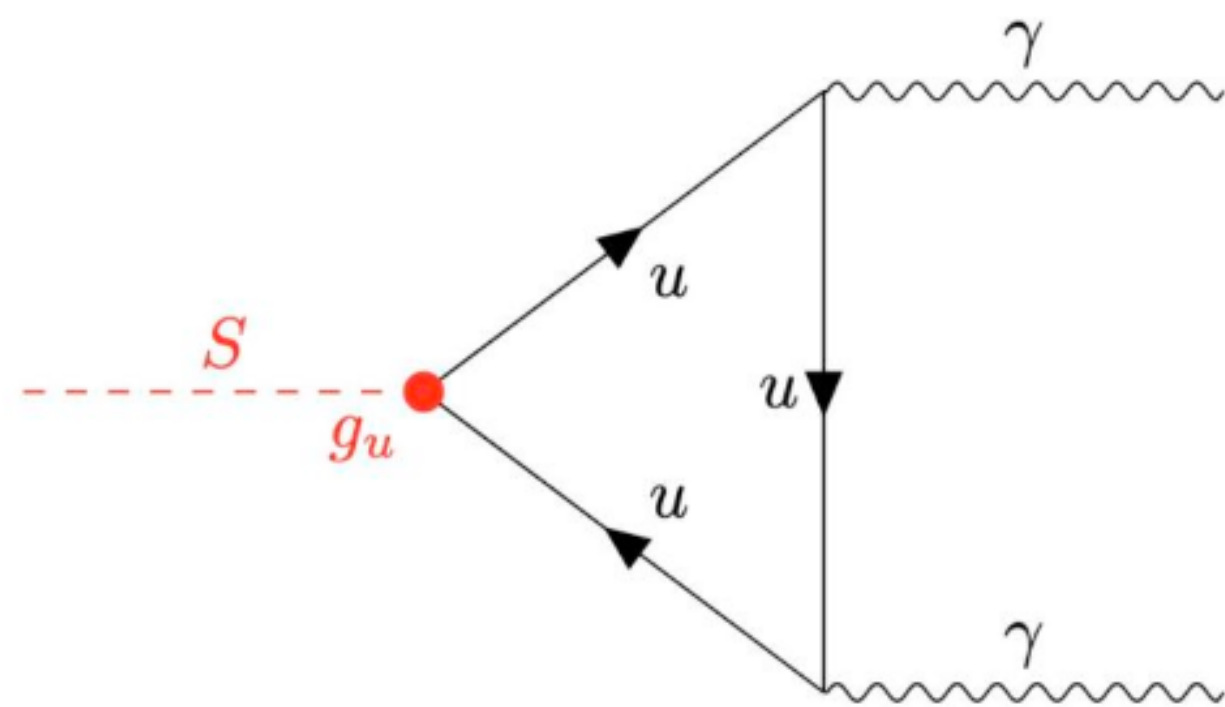
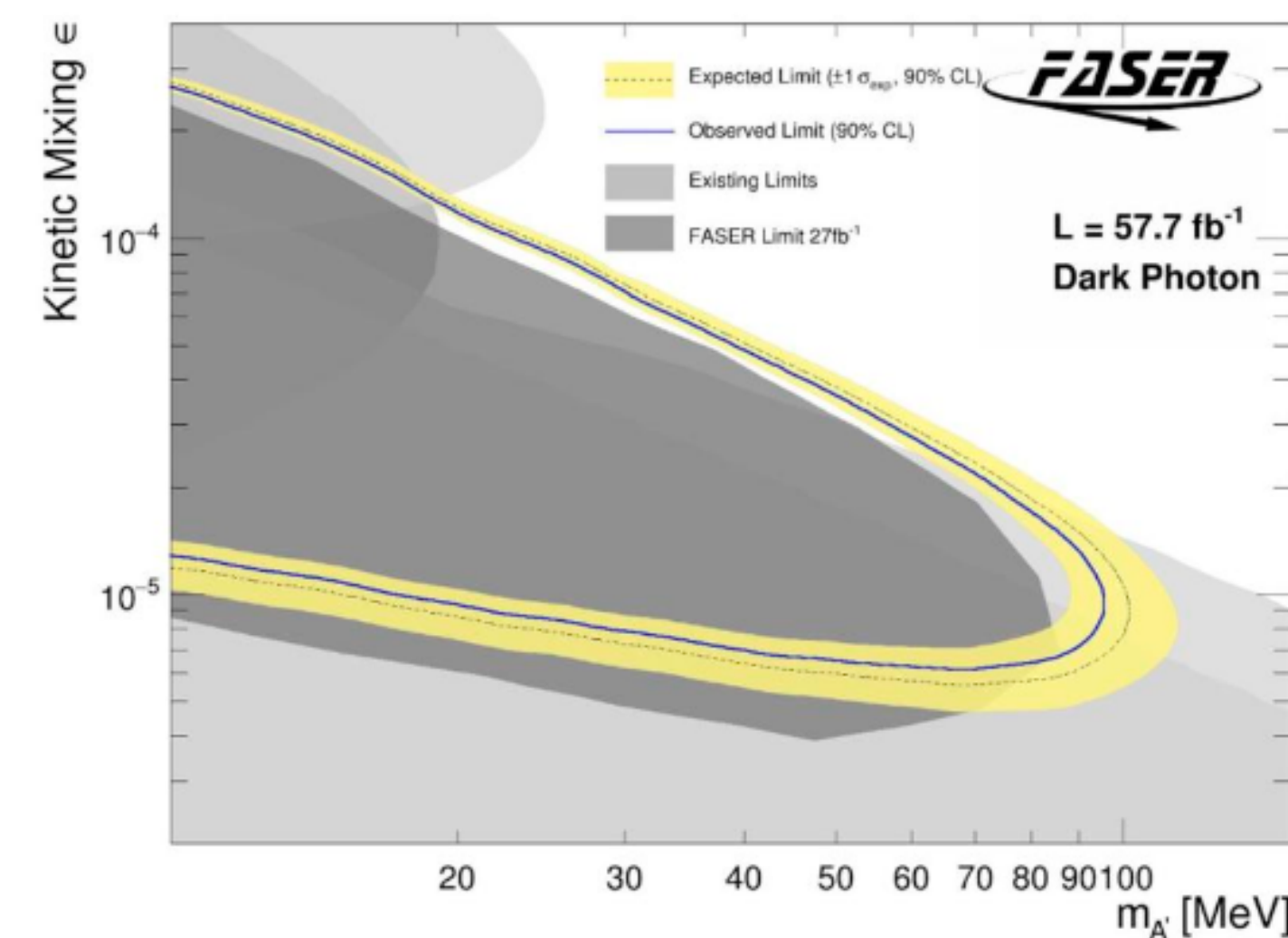
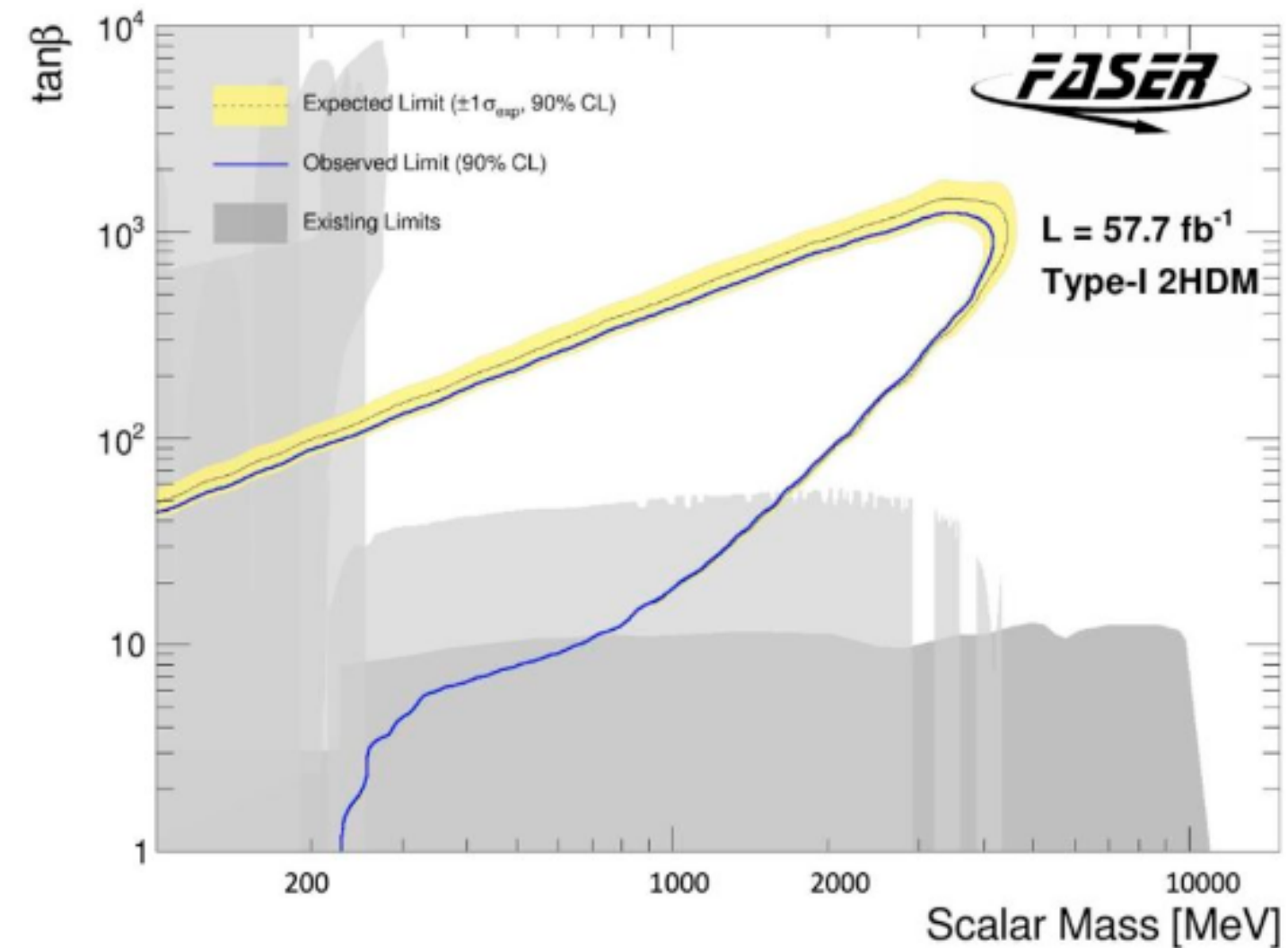
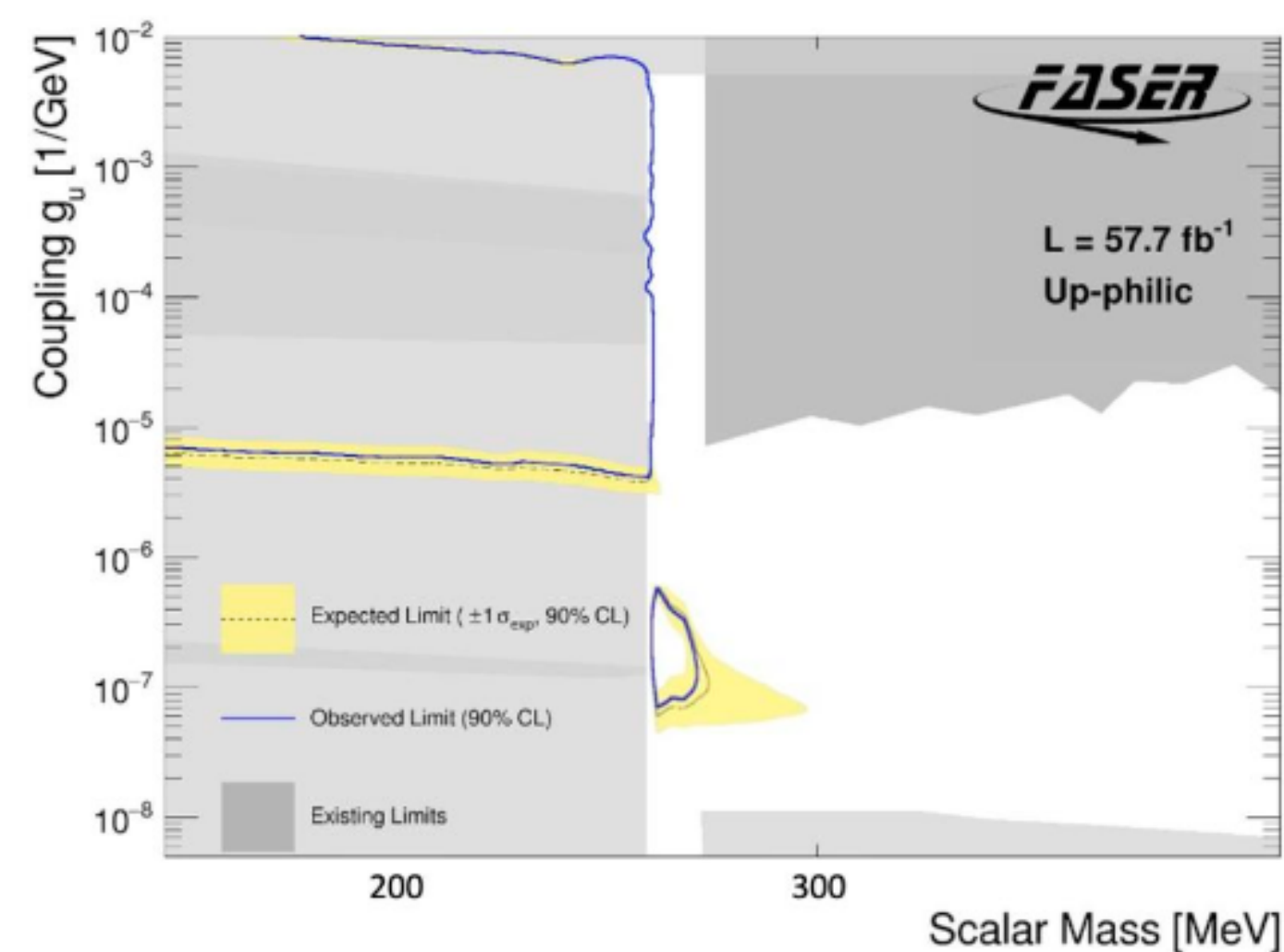


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2024 ALPs Search Interpretations

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