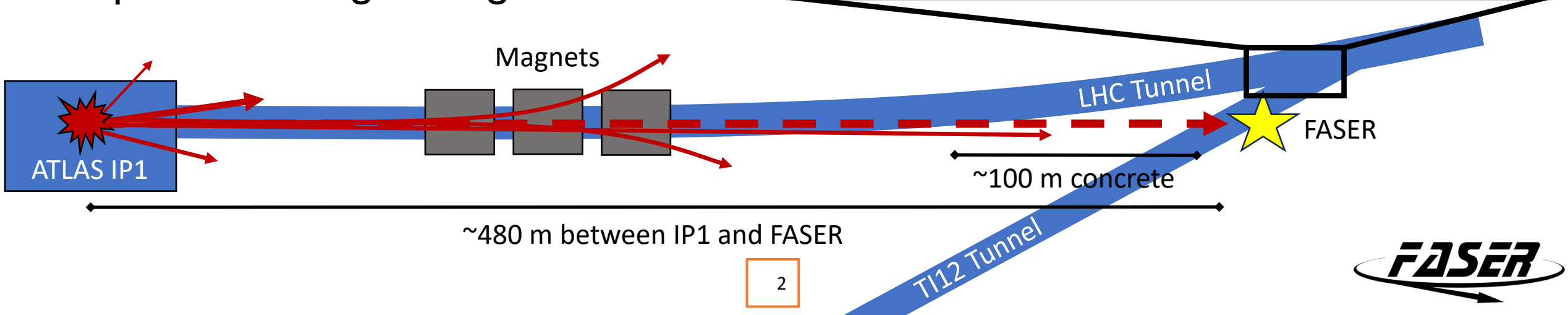
FASER 2023 Overview

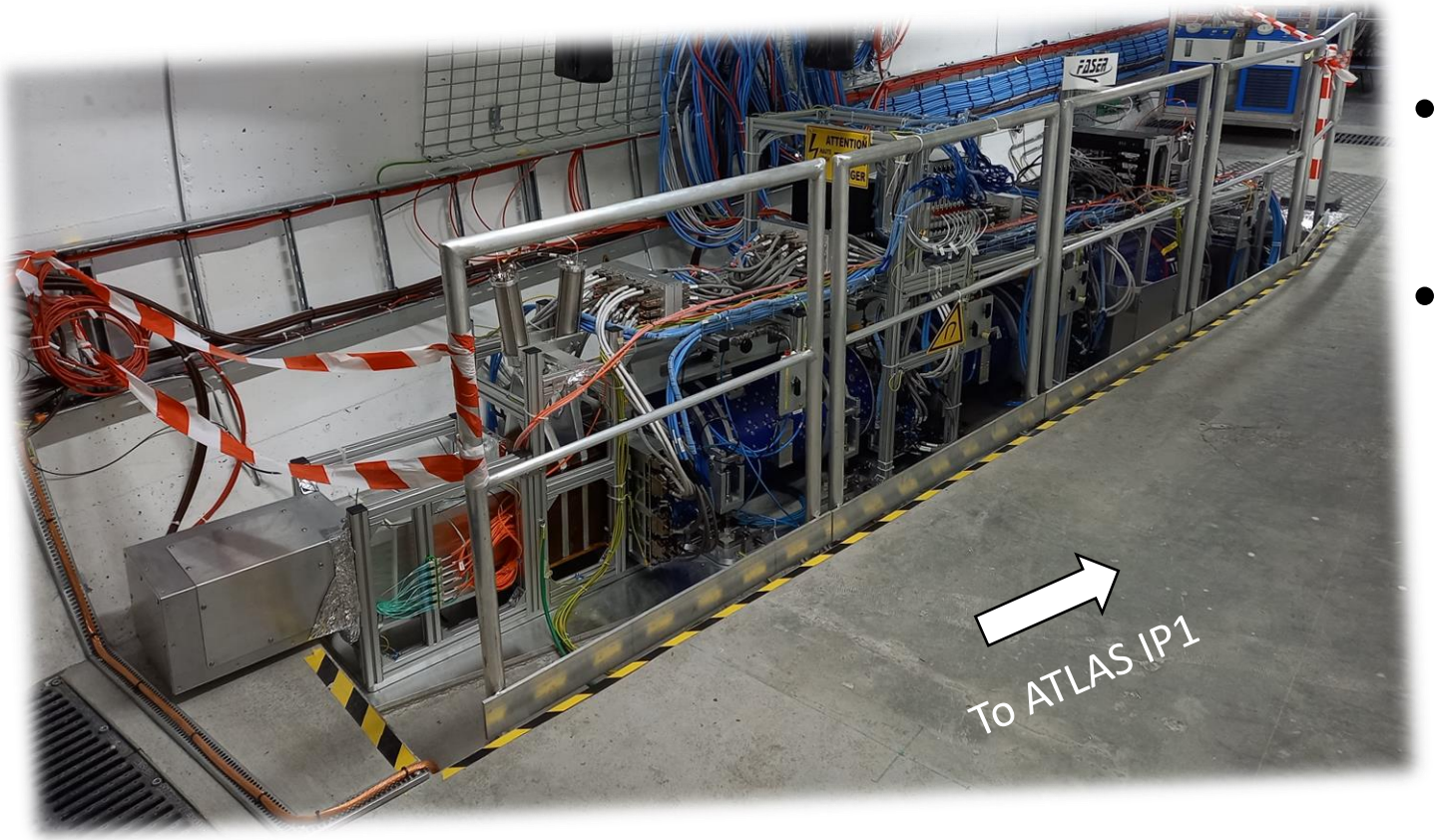
Presented by Alex Keyken, on behalf of the FASER Collaboration

LHC Forward Physics Meeting, 15/03/2024

ForwArd Search ExpeRiment

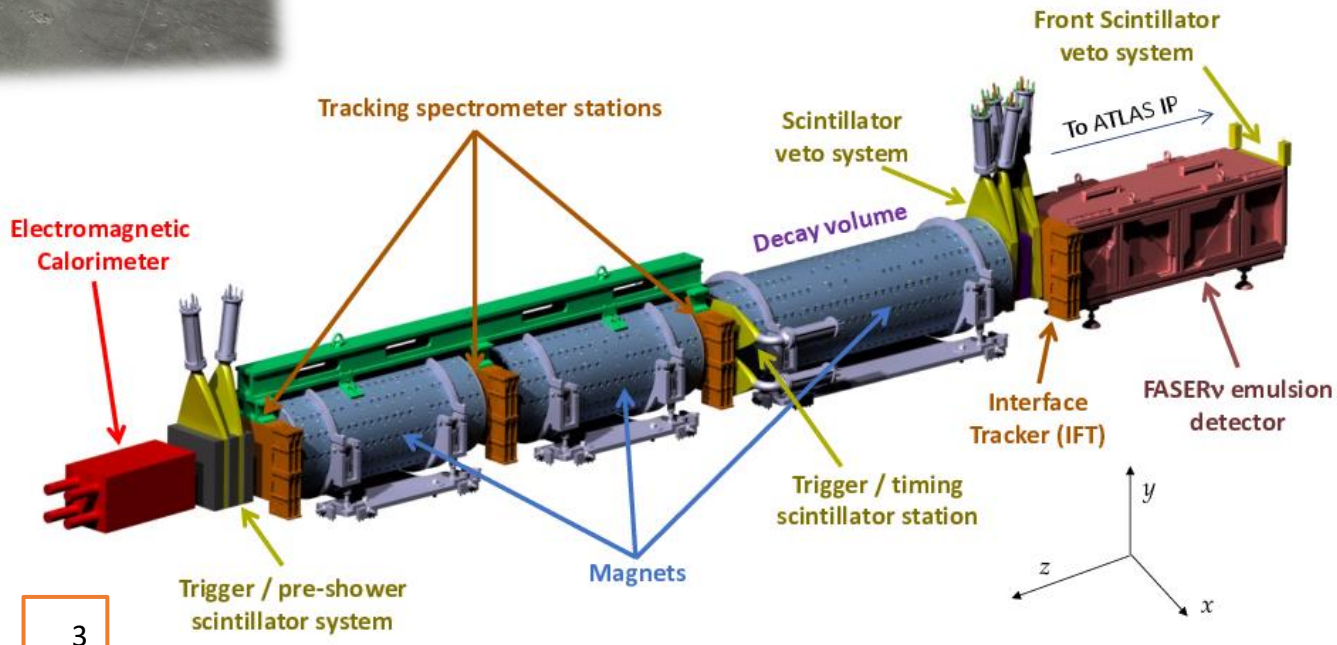
- Search for new physics and neutrinos in the very forward physics region.
- The detector location allows near background-free searches.
- ~ 7 m long detector with a < 0.21 mrad (η > 9.2) acceptance for particles originating at IP1.





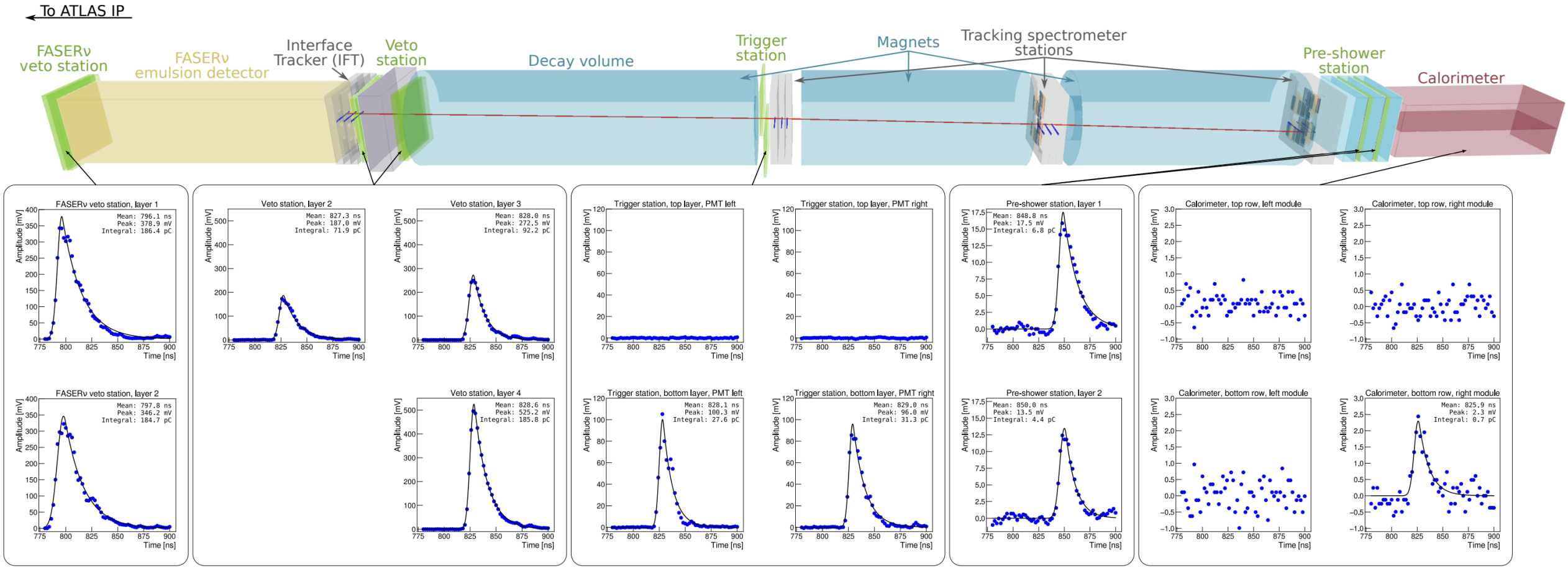
- 3 Magnets: 0.57 T permanent dipoles bending in y-plane.
- 4 Trackers (from ATLAS):
  - Spatial resolutions of 20 μm (y) and 800 μm (x).
  - Angular resolutions of 250 μrad (y) and 13 mrad (x).

- Calorimeter (from LHCb): 25 radiation lengths of alternating lead and plastic.
- 4 Scintillators: veto (~30 cm diameter), timing and pre-shower.



Run 8336
Event 1477982
2022-08-23 01:46:15

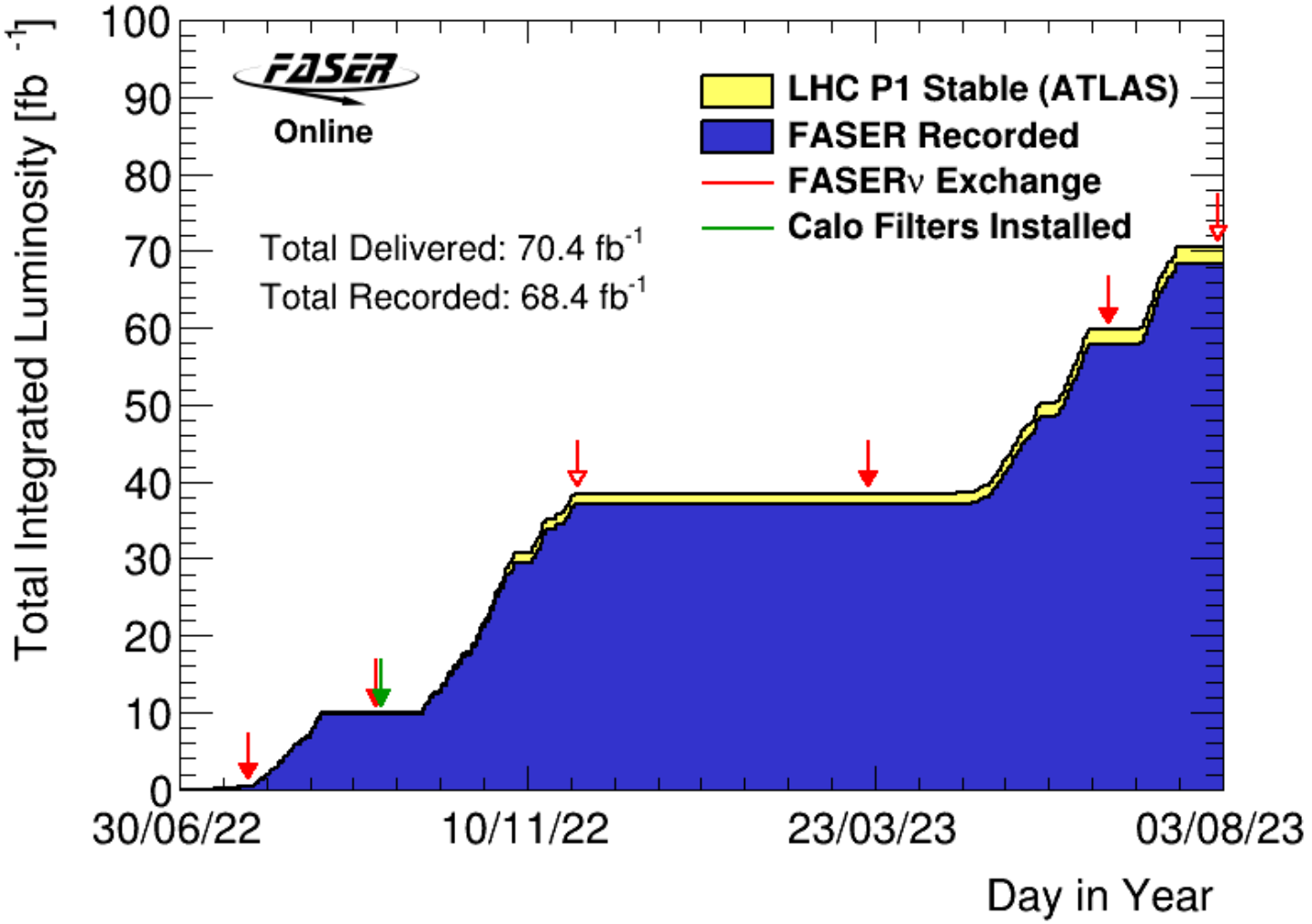
Example of 1.3 TeV muon from collision event with 6.8 TeV stable beams



Waveforms: **Veto stations** | **Trigger stations** | **Preshower** | **Calorimeter**

Data Taking

- 98% data taking efficiency since startup.
- Physics trigger rates are on average 1 kHz.
- 35 fb^{-1} collected in 2022 and 33 fb^{-1} in 2023.
- FASERν emulsion box has been replaced 4 times.



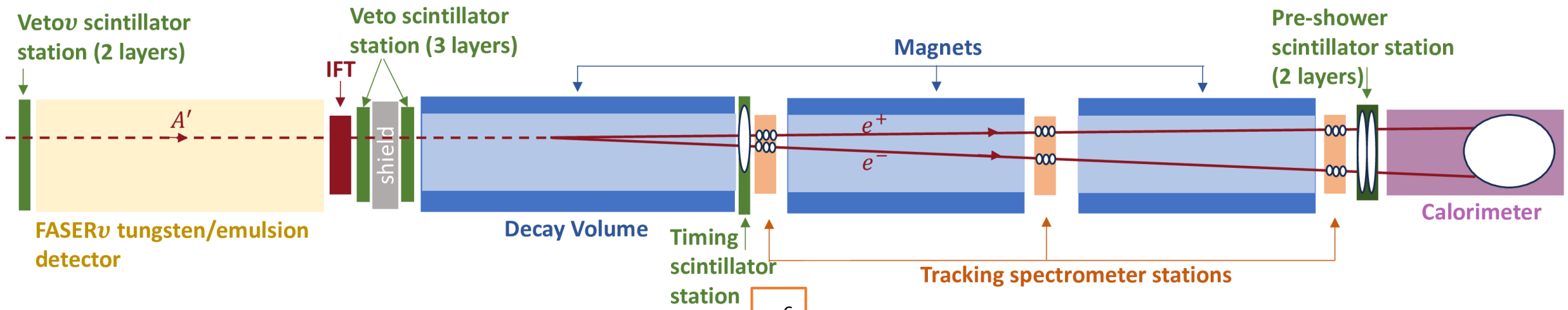
Dark Photons at FASER

Phys. Lett. B 848 (2024) 13837

- Cosmologically favoured dark photons in FASER's angular acceptance are:
  - rarely produced in π^0 decays ($m_{A'} < 135$ MeV), η decays ($m_{A'} < 548$ MeV) and dark bremsstrahlung ($m_{A'}$ up to $\mathcal{O}(2\ \mathrm{GeV})$),
  - long-lived, traveling $\mathcal{O}(100)$ m before decaying.
- For $2m_e < m_{A'} < 2m_\mu$, the dark photons then decay almost exclusively to a highly collimated e^+e^- pair.
- B-L gauge bosons are produced similarly but may decay to SM neutrinos.

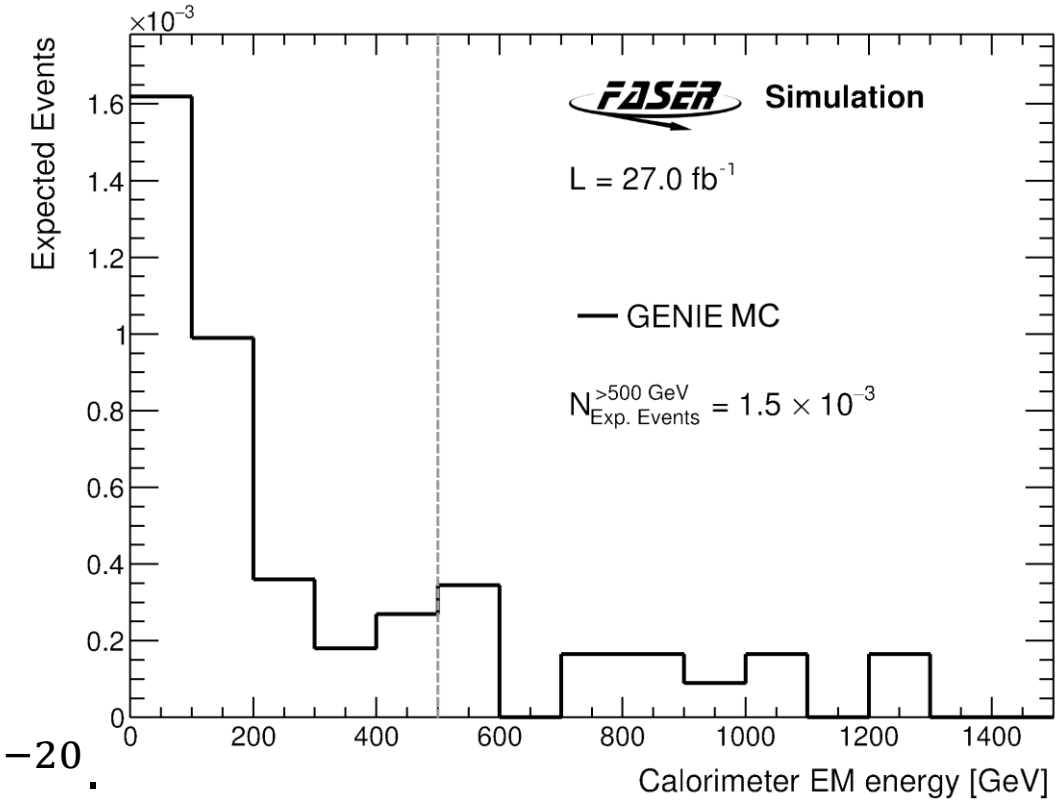
Benchmark Dark Photon: $\mathcal{L} \supset \frac{1}{2} m_{A'}^2 A'^2 - \epsilon e \sum_f q_f A'^\mu \bar{f} \gamma_\mu f$

B-L Gauge Boson: $\mathcal{L} \supset \frac{1}{2} m_{A'_{B-L}}^2 A'^2_{B-L} - g_{B-L} \sum_f Q^f_{B-L} A'^\mu_{B-L} \bar{f} \gamma_\mu f$



Dark Photon Backgrounds

- Neutrinos Interacting In Decay Volume:
  - $(1.5 \pm 0.5\,(\text{stat.}) \pm 1.9(\text{syst.})) \times 10^{-3}$ events estimated by MC.
- Neutral Hadrons:
  - Parent muon misses veto and hadrons traverse all 8 interaction lengths of FASERν.
  - Estimated to be $(8.4 \pm 11.9) \times 10^{-4}$ events.
- Veto Inefficiency:
  - The combined inefficiency of all 5 planes is $\leq 10^{-20}$.



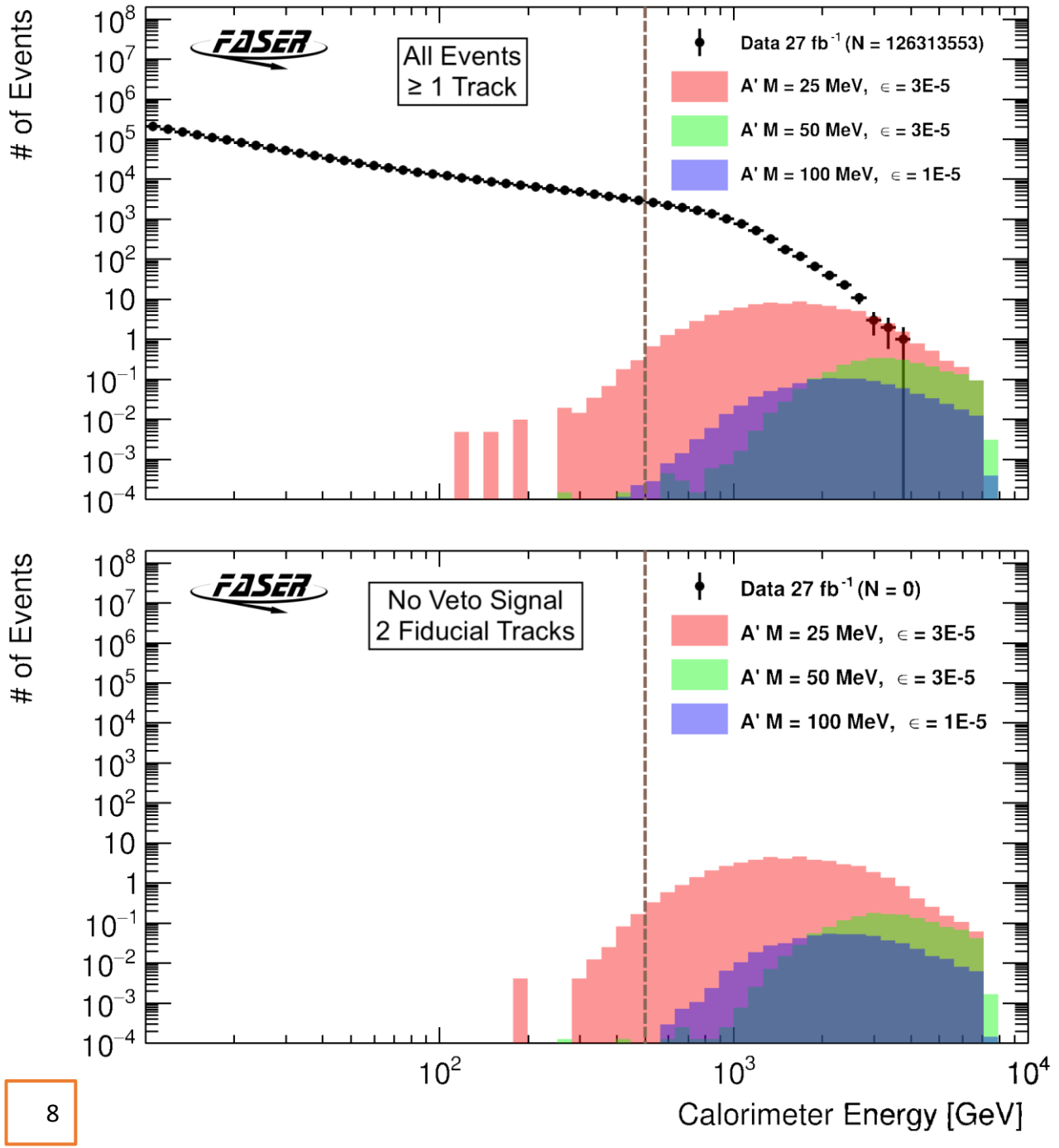
- Geometric Muons:
  - Large incidence-angle muons that miss the veto.
  - Negligible as scintillator tracks must be within fiducial volume (validated by data-driven method).
- Non-collision Background:
  - Bunch timing info distinguishes Beam-1 background, while no cosmic events satisfy a >100 GeV calo deposit or ≥1 good track.

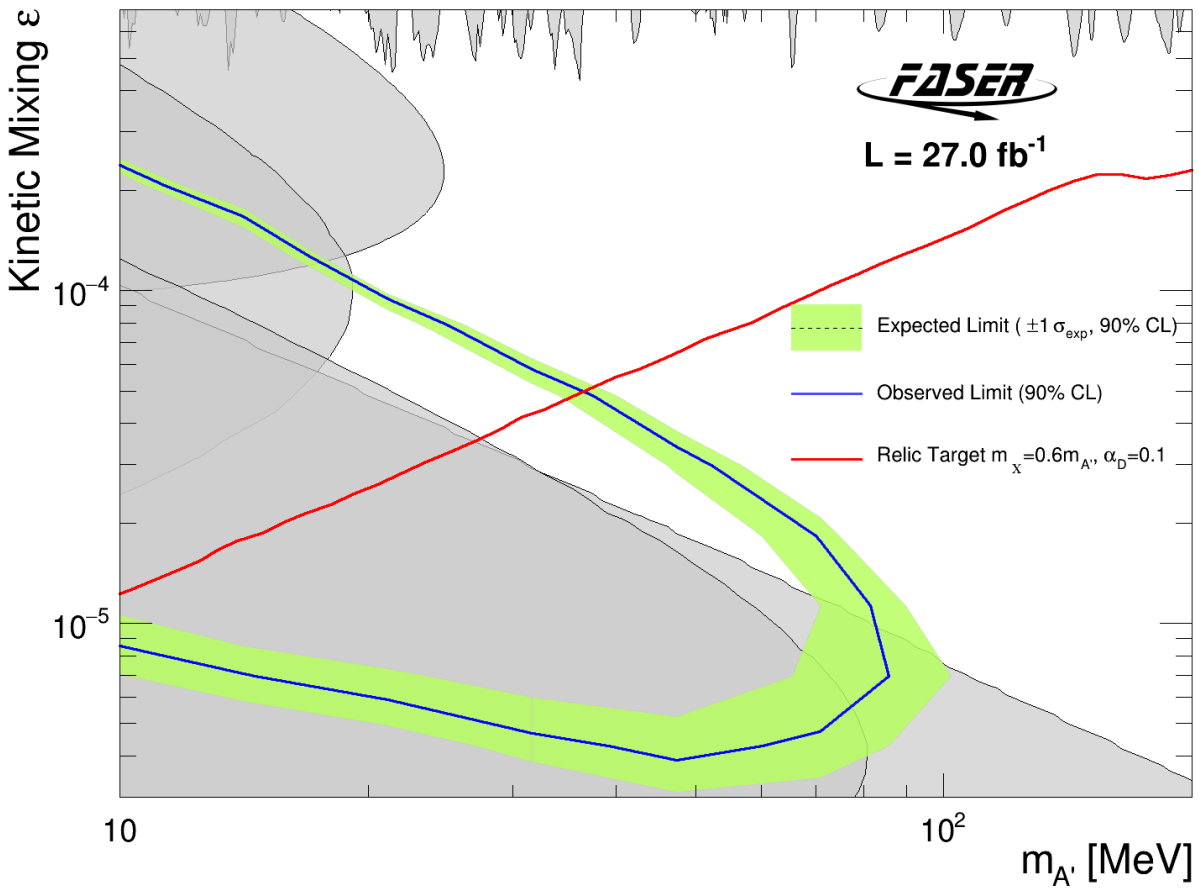
Dark Photon Results

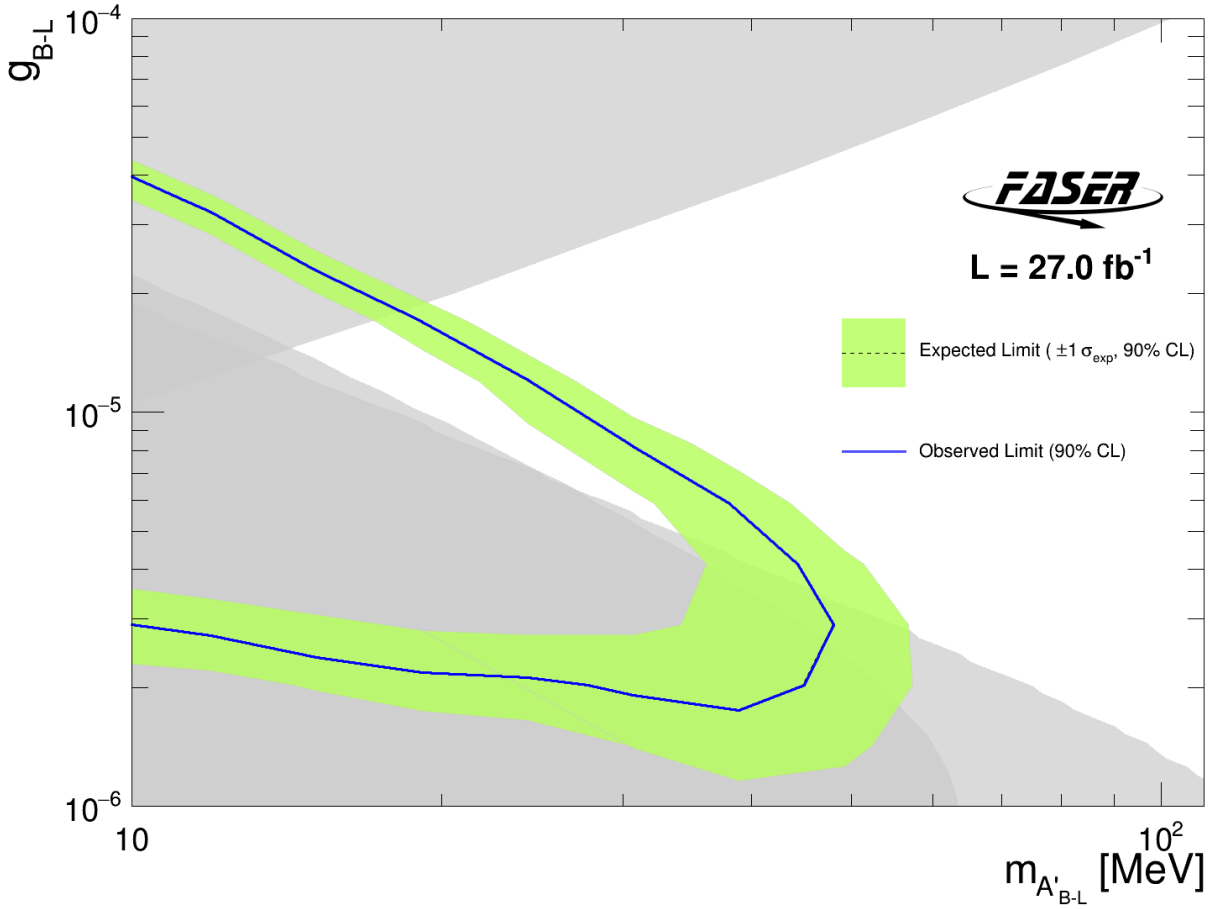
Selection Cuts:

- Event time consistent with colliding bunch.
- No veto scintillator signal.
- Two fiducial tracks (p >20 GeV).
- E >500 GeV deposited in calo.

For 27 fb^{-1}, no events are found in the signal region…



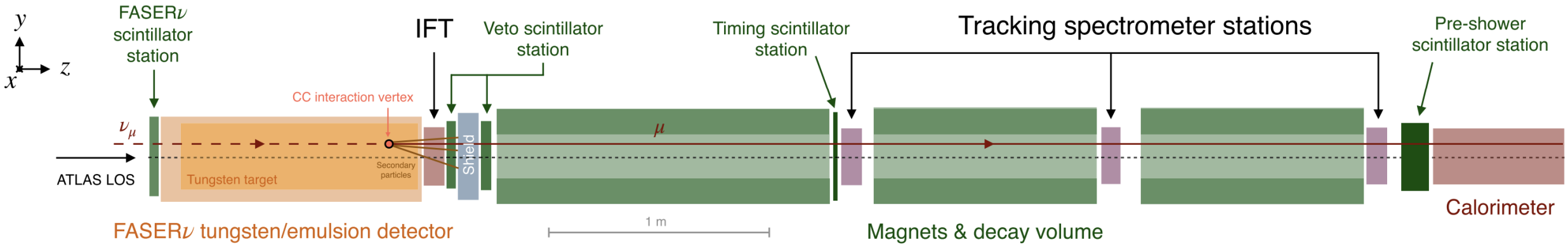




90% confidence exclusion regions for dark photons (left) and B-L gauge bosons (right). Red line represents the relic target density region that is cosmologically favored.

Collider Neutrinos at FASER

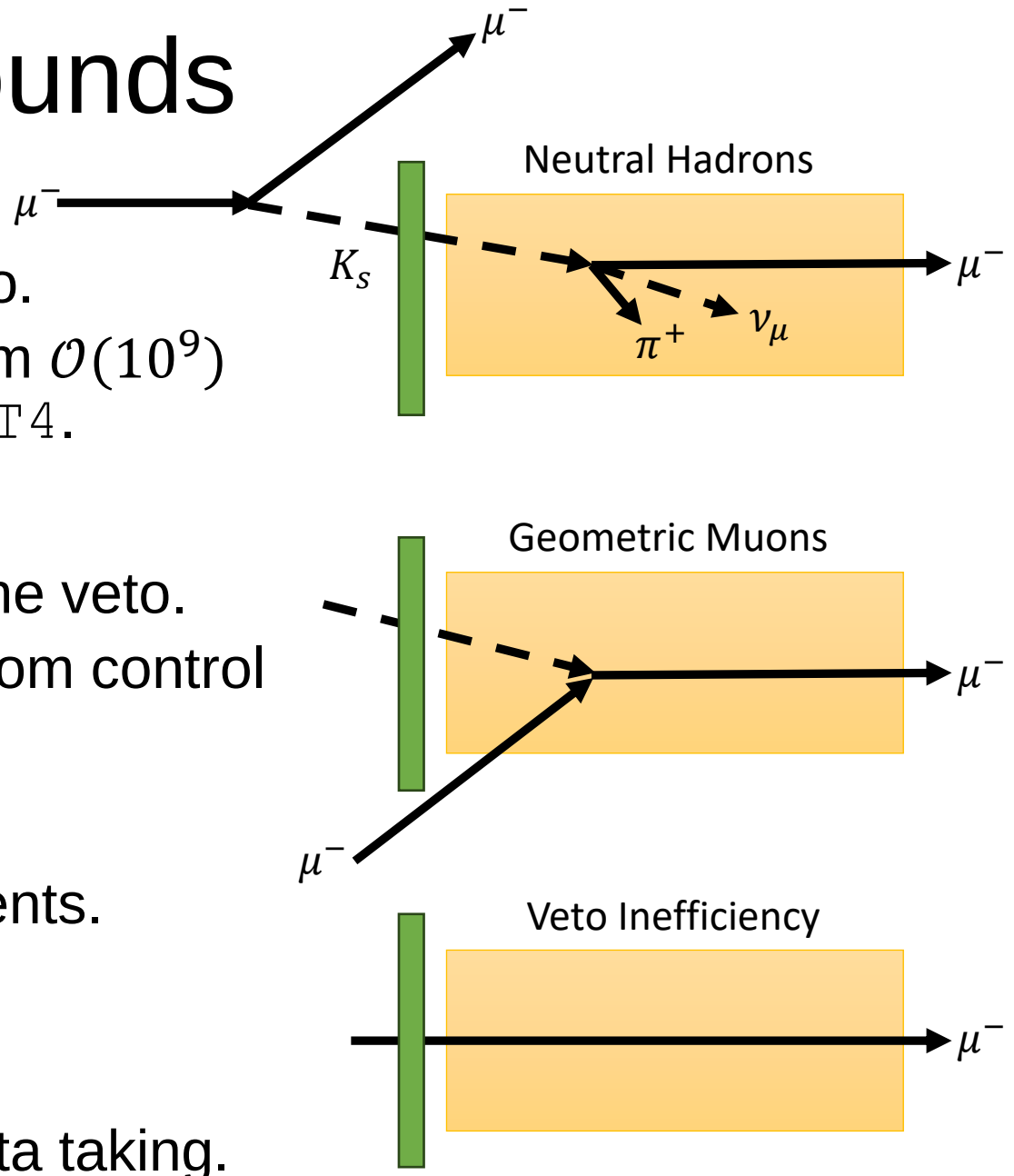
- Forward hadron decays lead to collimated beams of high energy neutrinos along LOS which had never been observed directly.
- Using the tungsten in FASERν as target, Charged-Current-interacting muon neutrino candidates leave tracks along all scintillators int the detector.
- Good tracks must leave no signal in the FASERν scintillator, have timing consistent with colliding bunches and p_μ >100 GeV.



Phys. Rev. Lett. 131, 031801 (2023)

Collider Neutrino Backgrounds

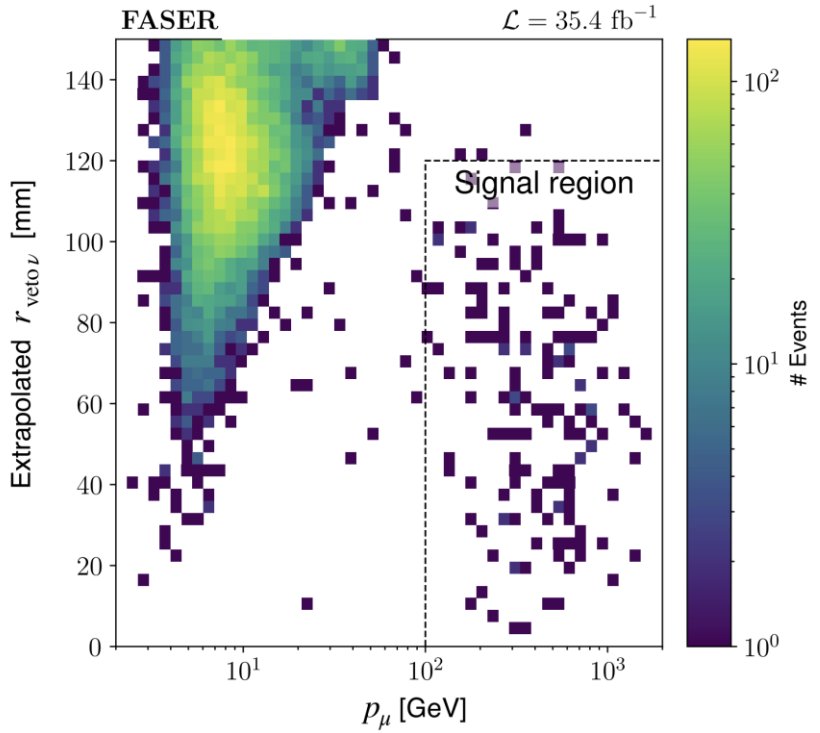
- Neutral Hadrons:
  - Neutral hadrons that interact past the veto.
  - Expected 0.11 ± 0.06 neutral hadrons from $\mathcal{O}(10^9)$ muons simulated using `FLUKA` and `GEANT4`.
- Geometric Muons:
  - Large incidence-angle muons that miss the veto.
  - Expected 0.01 ± 0.23 geometric muons from control region extrapolation.
- Veto Inefficiency:
  - Estimated to be smaller than $\mathcal{O}(10^{-7})$ events.
- Non-collision Background:
  - Cosmic events and Beam-1 background.
  - Expected negligible from non-collision data taking.

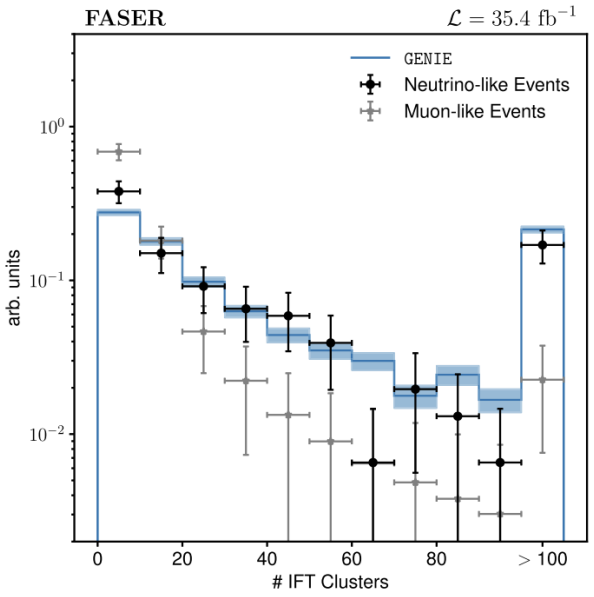


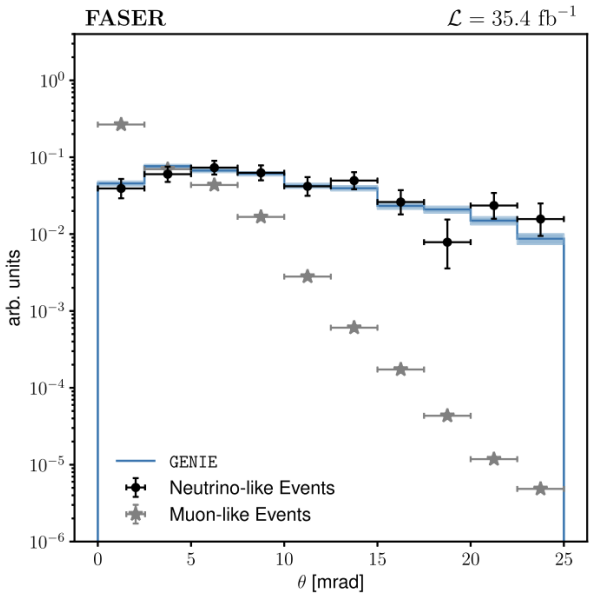
Collider Neutrino Results

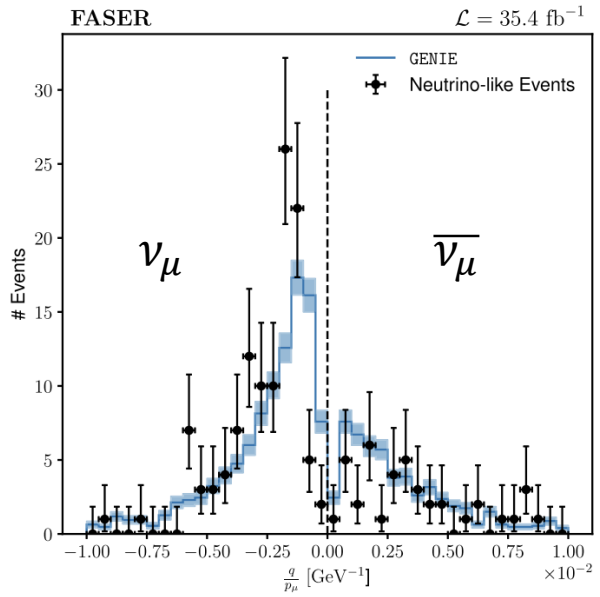
- 153^{+12}_{-13} events observed with a significance of 16σ (35.4 fb^{-1} analysed).
- Comparable to the simulation expected 151 ± 41 events*.
- Signal contains 40 anti-neutrinos.

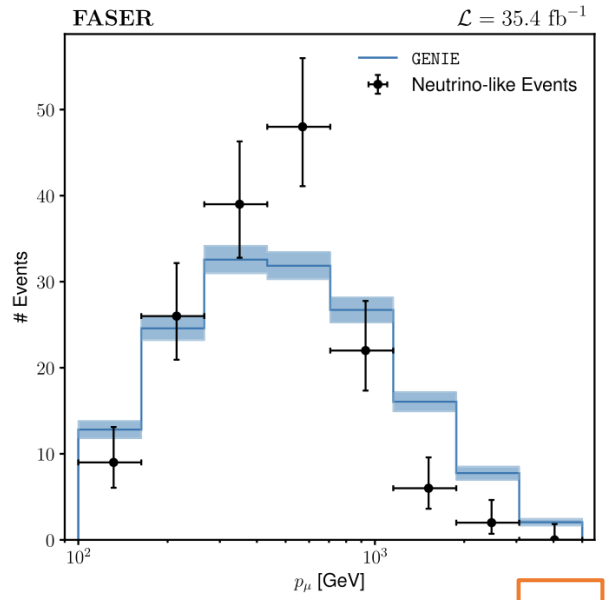
*Uncertainty due to the generator discrepancy for forward hadron production.







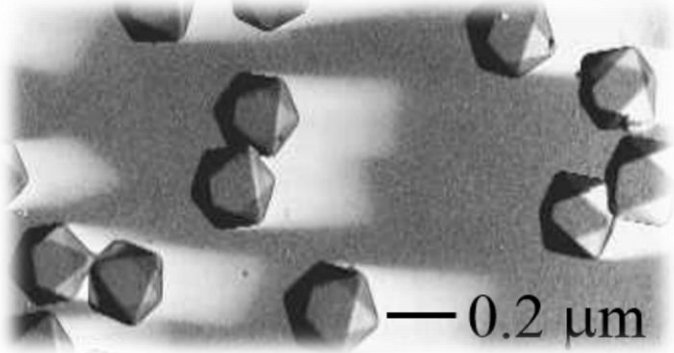


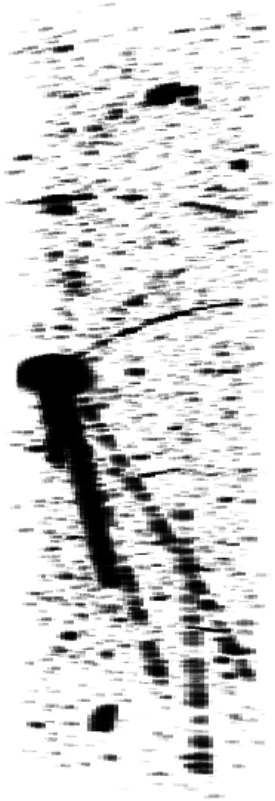


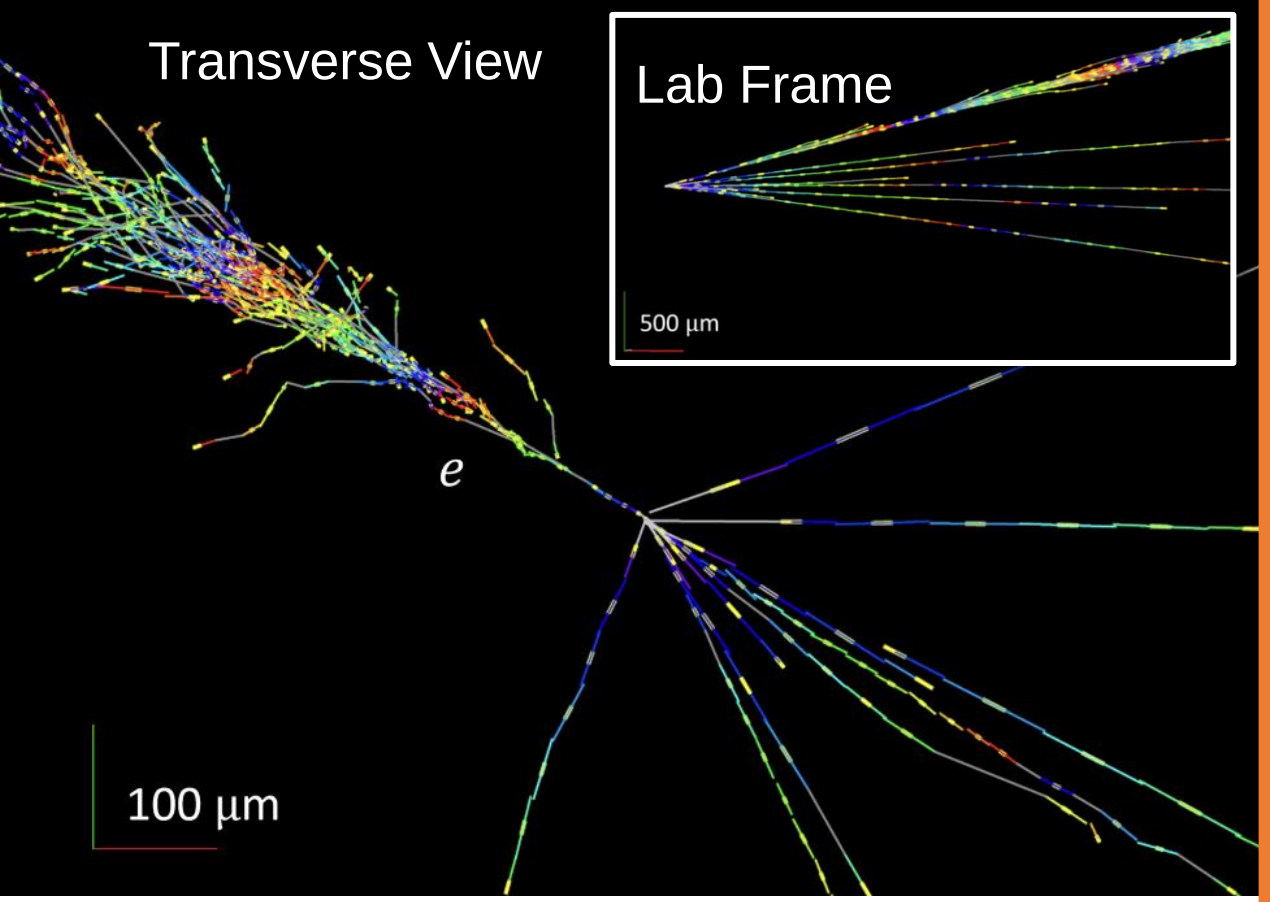
GENIE does not include experimental systematic uncertainties such as that on momentum resolution.

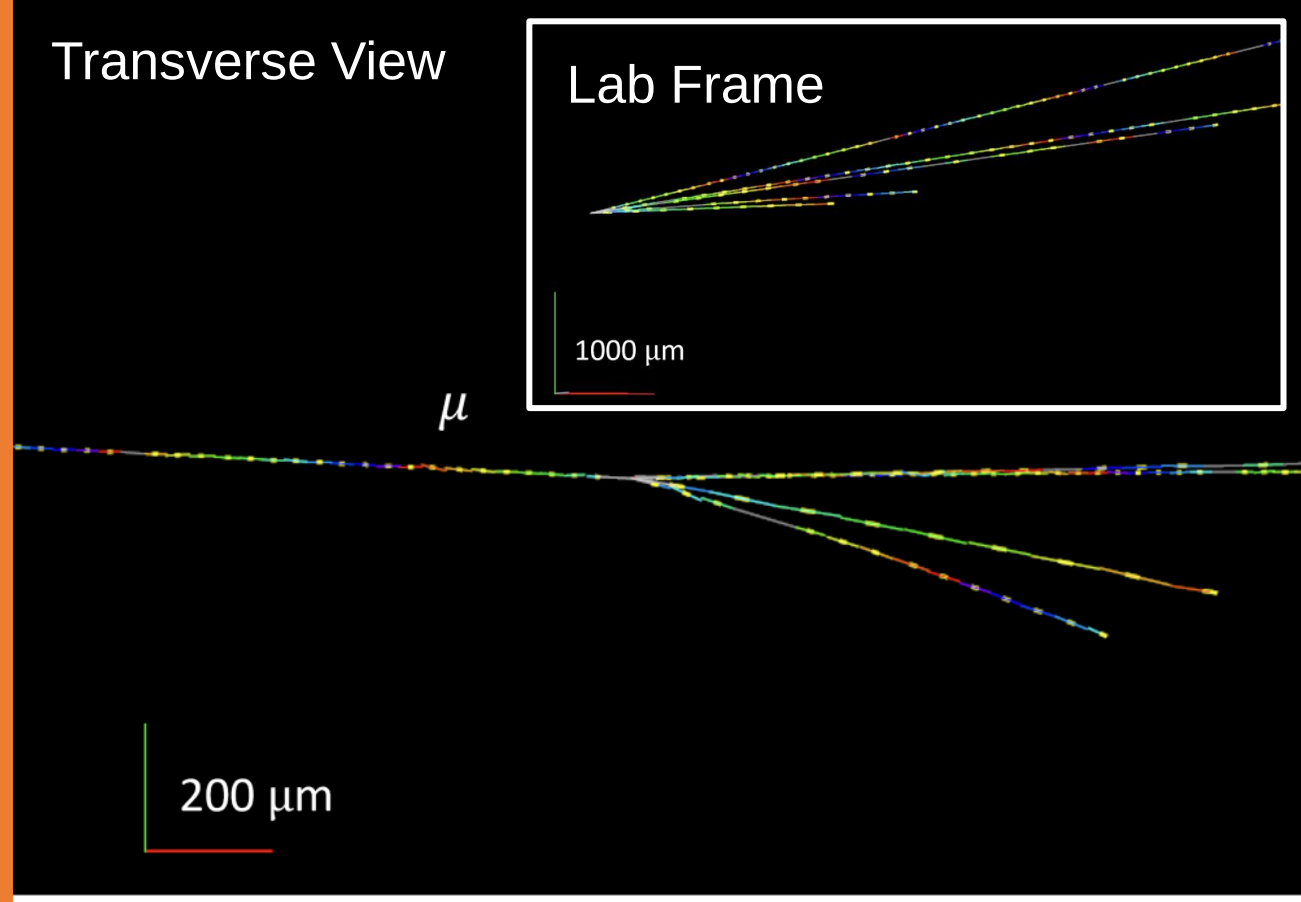
FASERν

- 1.1 ton, 1m long target mass: 730 layers of interleaved tungsten and emulsion films.
- Emulsion film contains silver bromide crystals (AgBr) which, after chemical development, record ionization quasi-permanently.
- Spatial resolution of 50 nm.
- Films saturate at ~ $5x10^5$ tracks/cm^2 and must be replaced periodically.
- First neutrino analysis uses 150 films or 68 Kg (9.5 fb^{-1} in 2022).









ν_e leave short tracks + EM shower.

Expected 0.6-5.2 CC ν_e interactions.

Observed 3 ν_e events with a background of 0.002 ± 0.003 neutral hadrons (5σ).

First collider ν_e observation!

ν_μ leave long tracks + no shower.

Expected 3.0-8.6 CC ν_μ interactions.

Observed 4 ν_μ events with a combined background of 0.51 ± 0.27 neutral hadrons and Neutral-Current ν interactions (2.5σ).

CERN-FASER-CONF-2023-002

What to Look Forward To

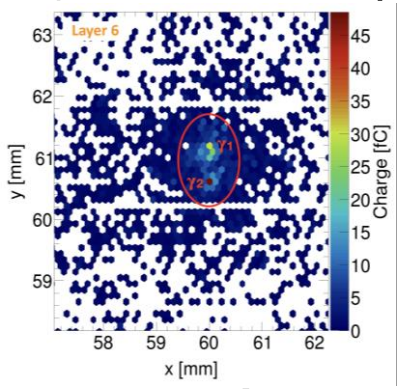
[Preshower Technical Proposal (2022)]

[FPF Facility Project Proposal (2022)]

YETS 2023 YETS 2024 HL-LHC

Preshower Upgrade

6 SiGe pixel sensor layers to allow multi-γ tracking (~100 μm resolution).

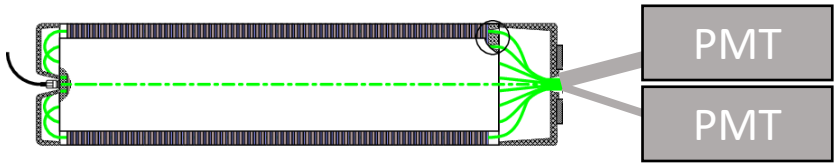


1st ALPs Results

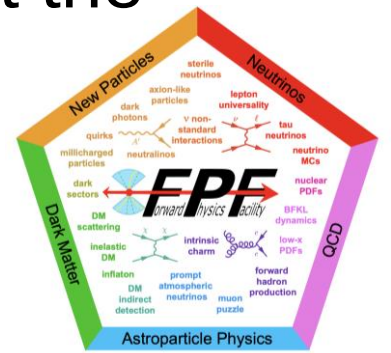
You are here

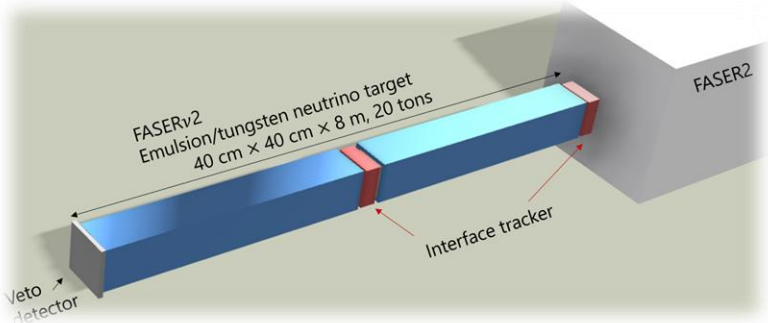
Calorimeter Readout Upgrade

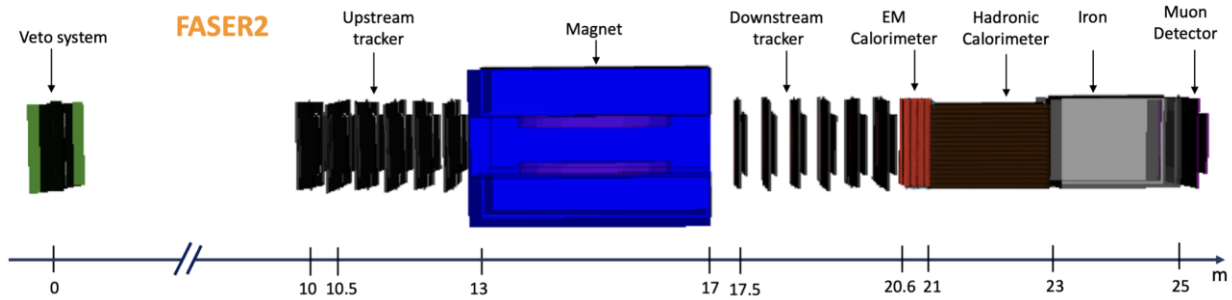
Previously operated at reduced light output.
New readout uses 2 PMTs (high and low gain).



FASER2 and FASERν2 at the FPF (awaiting approval)





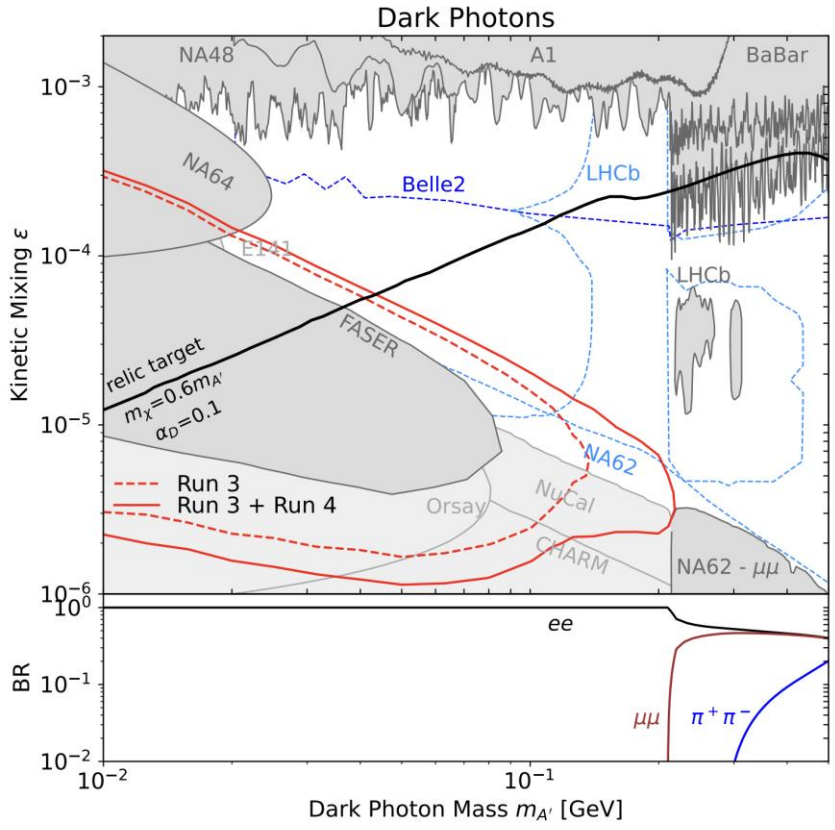


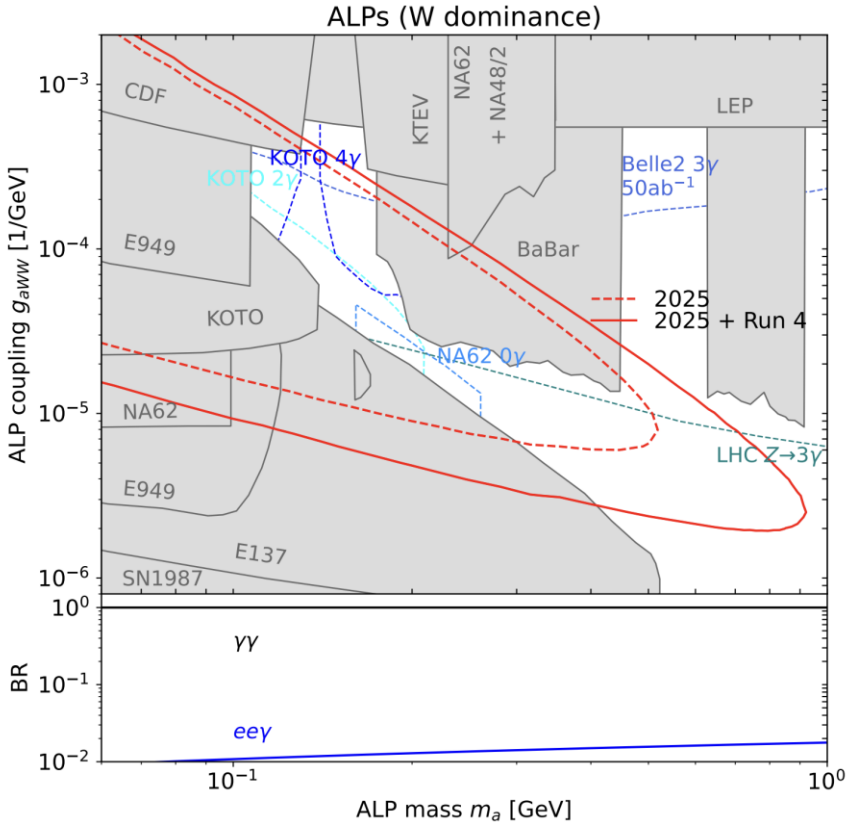
FASER approved for Run 4!

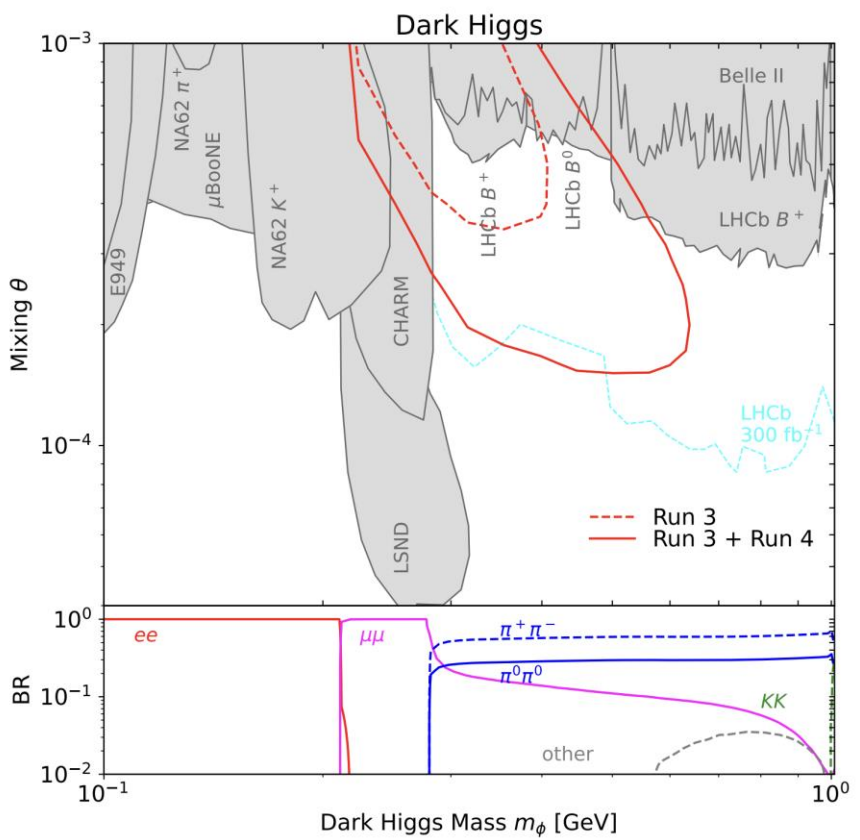
[FASER Run 4 Letter of Intent (2023)]

What to Look Forward To… For Run 4

(assuming 250 fb^{-1} in Run 3 and 680 fb^{-1} in Run 4)

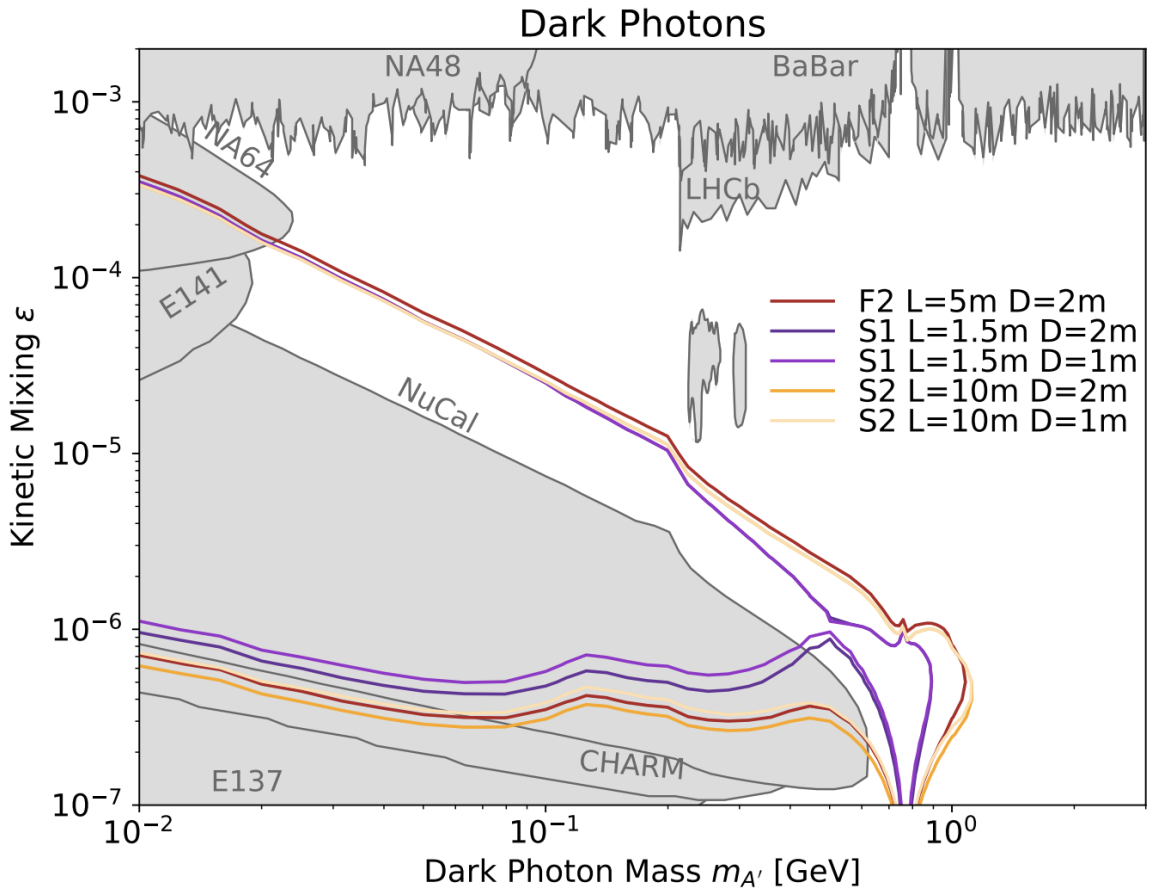


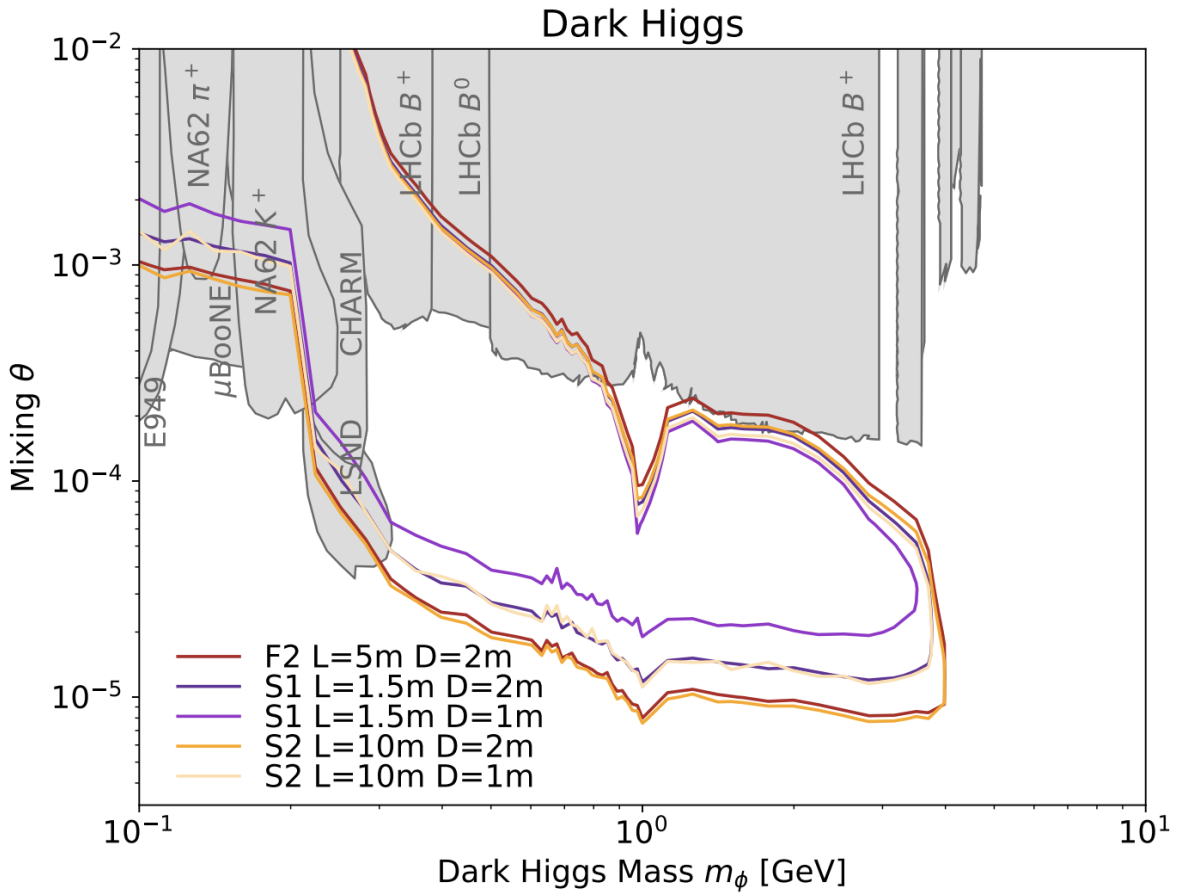




FASER2 at the Forward Physics Facility

awaiting approval

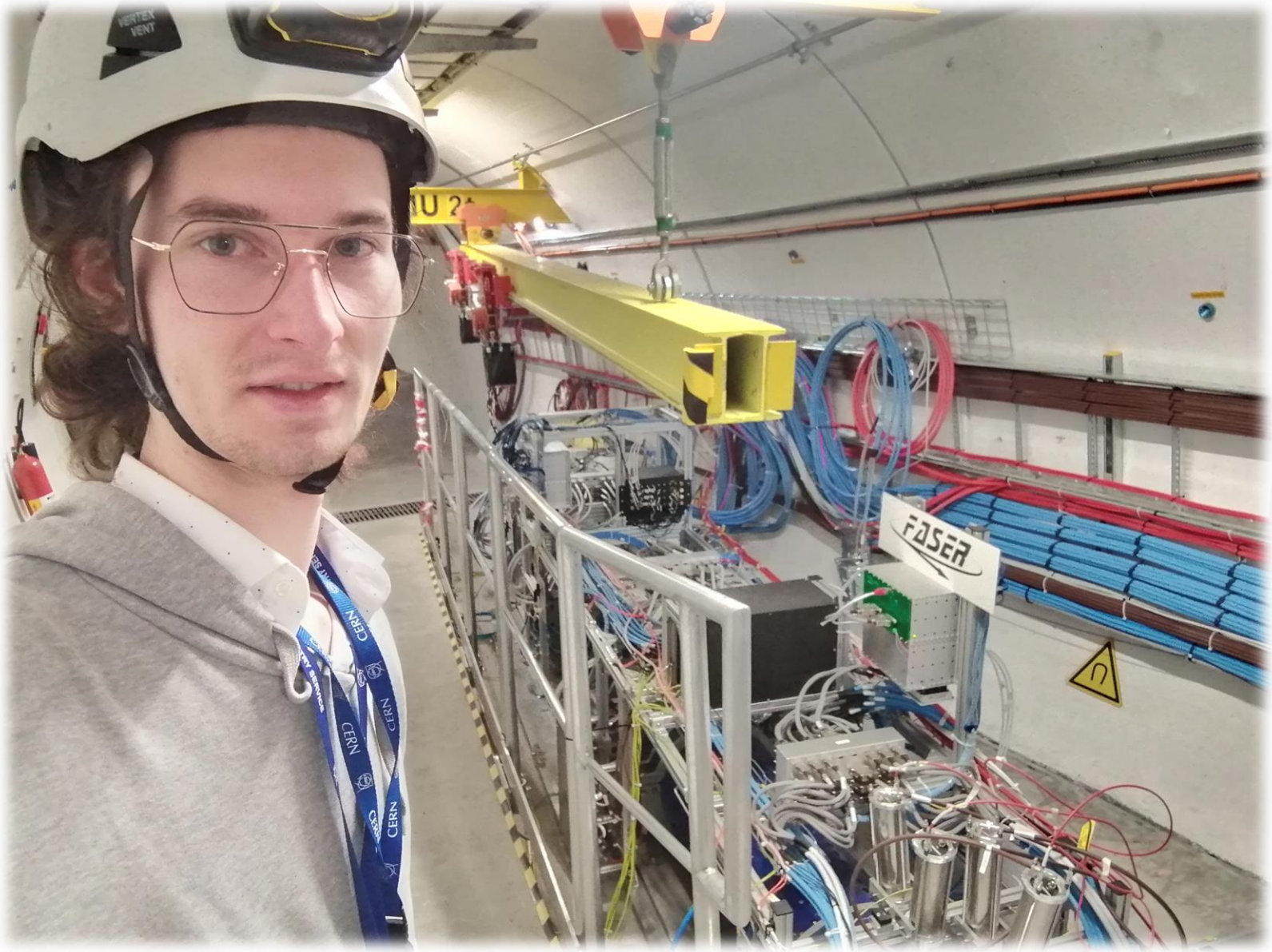




Scenario	Distance to IP [m]	Available Length [m]	Decay Volume Length [m]	Available Diameter [m]	Decay Volume Diameter [m]
Original (F2)	480	15	5	2	2 (/ 1 / 0.5)
Alcoves (S1)	500	5	1.5 (/ 2)	1.5 (/ 2)	2 / 1 (/ 0.5)
New Cavern (S2)	620	25	10 (/ 15 / 20)	2	2 / 1 (/ 0.5)

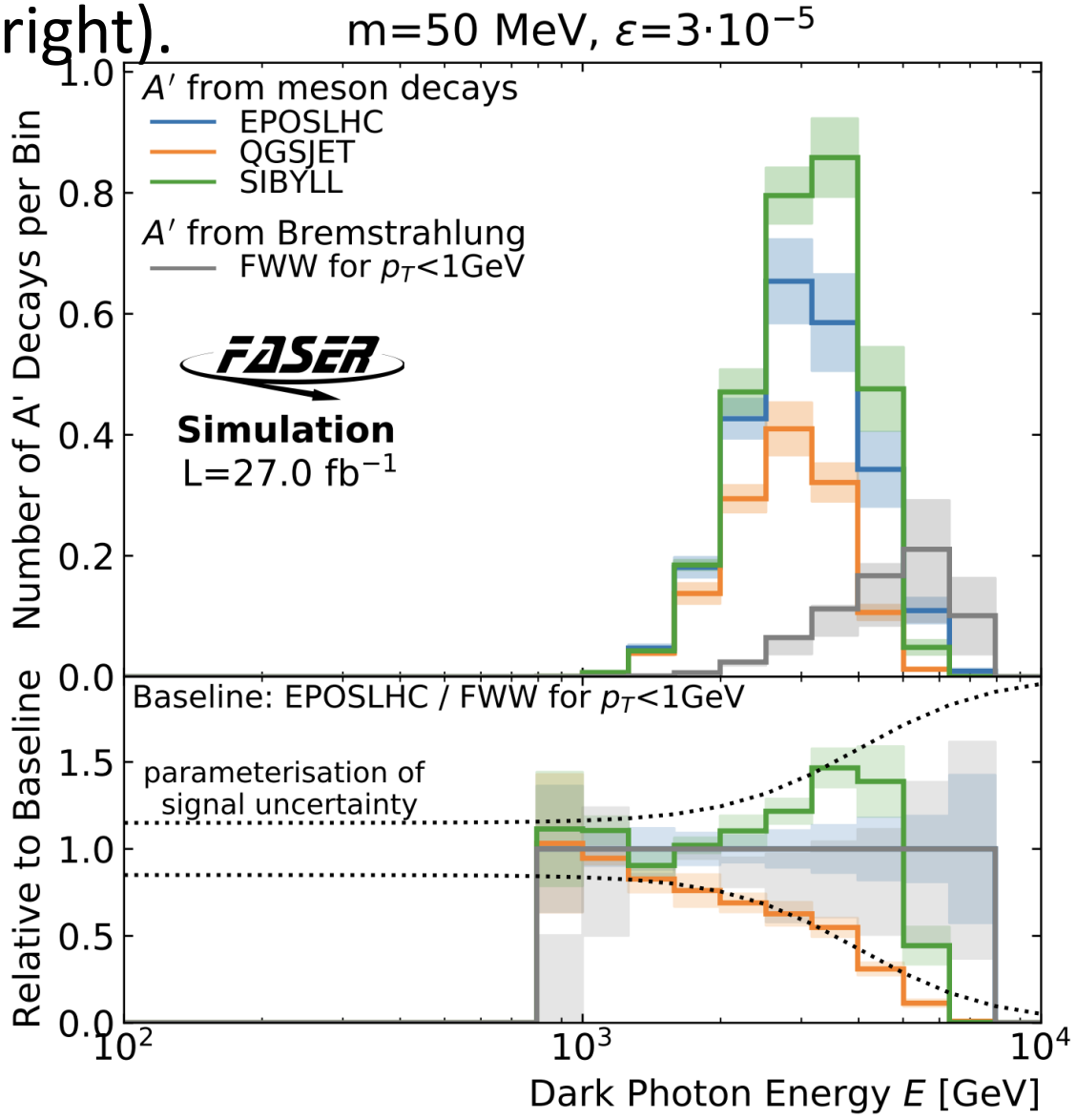
Summary

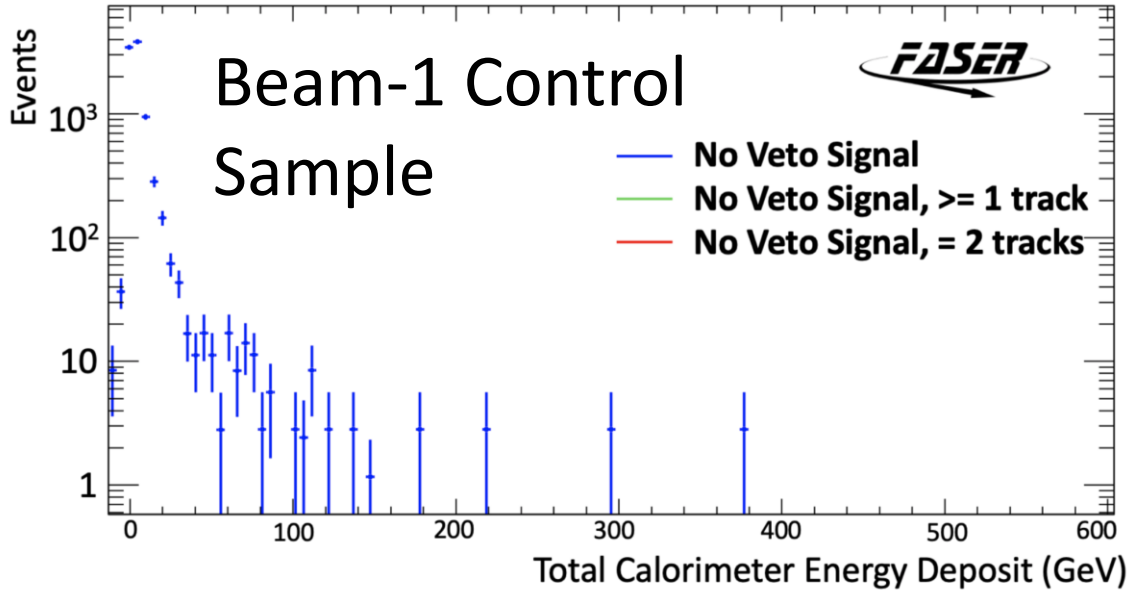
- Smooth data taking since detector start-up with 98% efficiency.
- Dark photon search produces 90% confidence exclusion regions for the Benchmark Dark Photon and B-L Gauge Boson models.
- FASER and FASERν observe ~150 collider neutrinos, including:
  - the first direct observation of collider ν_e,
  - the highest energy neutrinos detected from an artificial source.
- Various analysis on-going, including ALPs and ν flux measurements.
- Calorimeter and preshower upgrades will improve data taking in Runs 3 and 4.

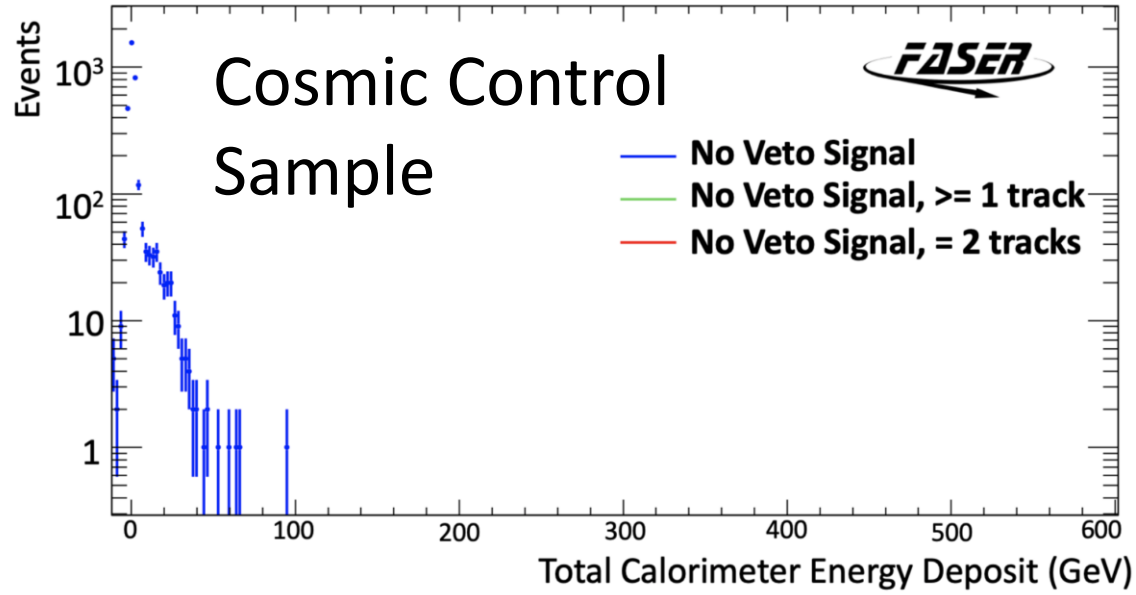


Thank you for your attention :)

Dark Photons: energy-dependent generator model uncertainty estimation (left) and non-collision background control samples after various selections (right).





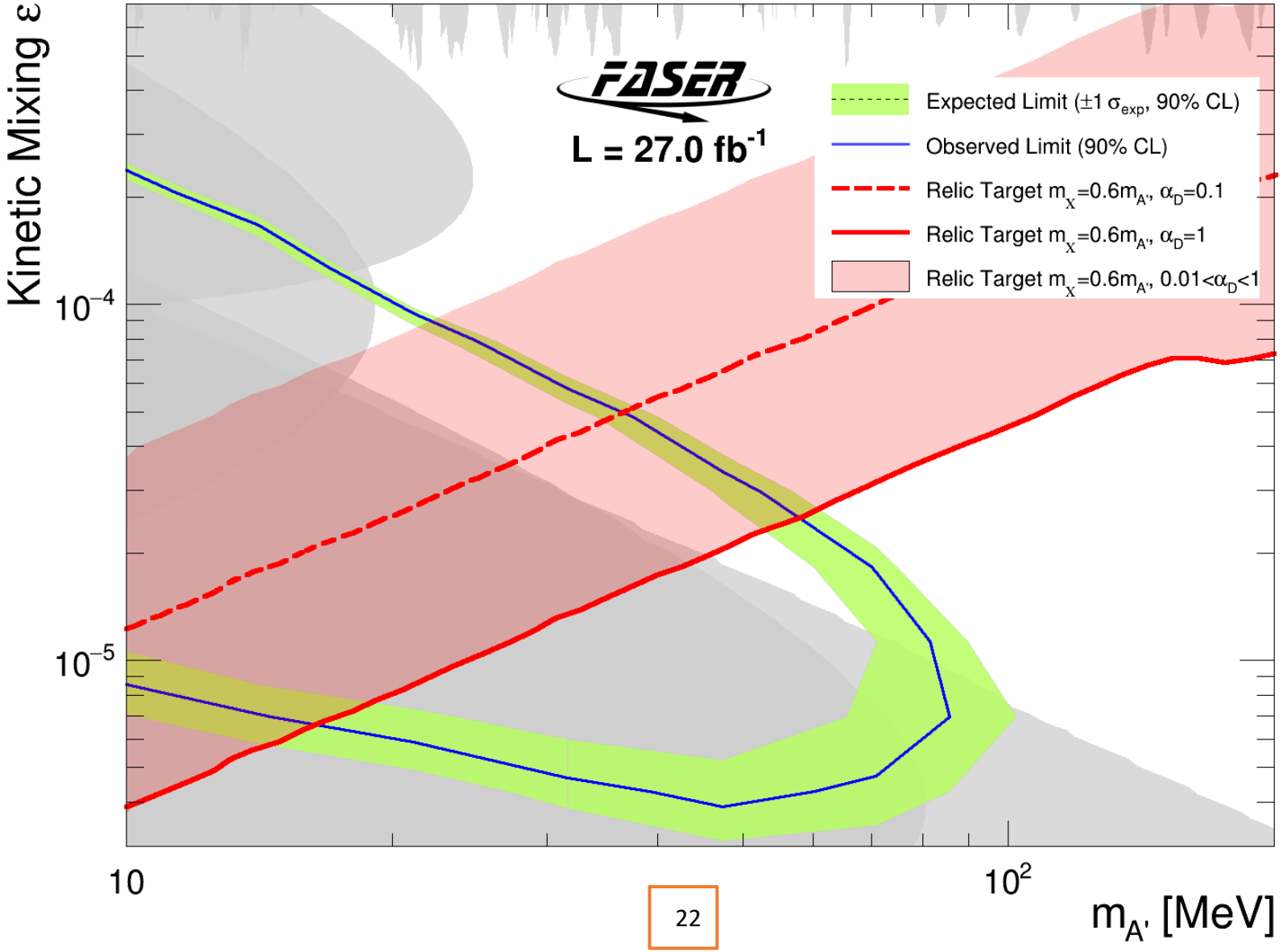


Dark Photons: events remaining after applying different selection criteria (bottom) and all selection criteria applied(right).

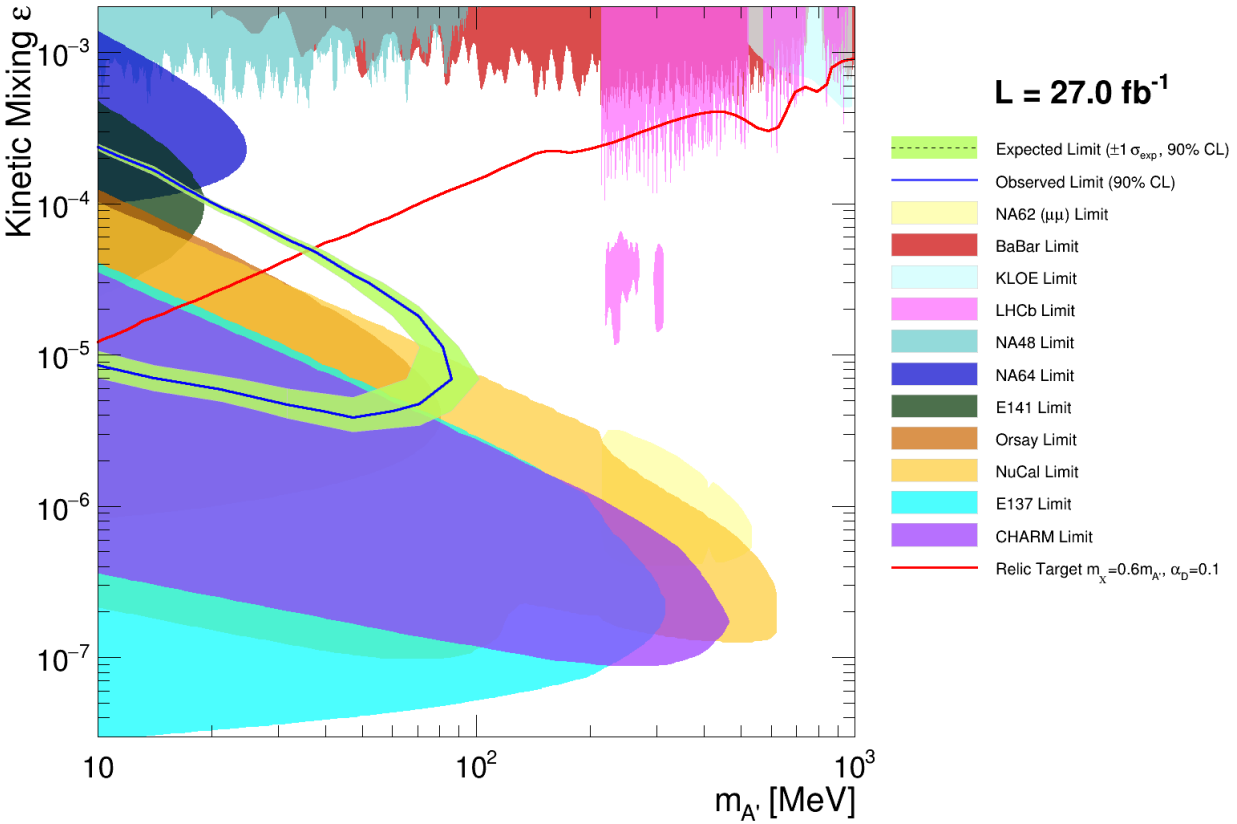
Cut	Data	
	Events	Efficiency
Good collision event	151231009	–
No Veto Signal	1250092	0.827%
Timing + Preshower Signal	332549	0.220%
≥ 1 good track	22224	0.015%
$= 2$ good tracks	0	0.000%
Track radius < 95 mm	0	0.000%
Calo E > 500 GeV	0	0.000%

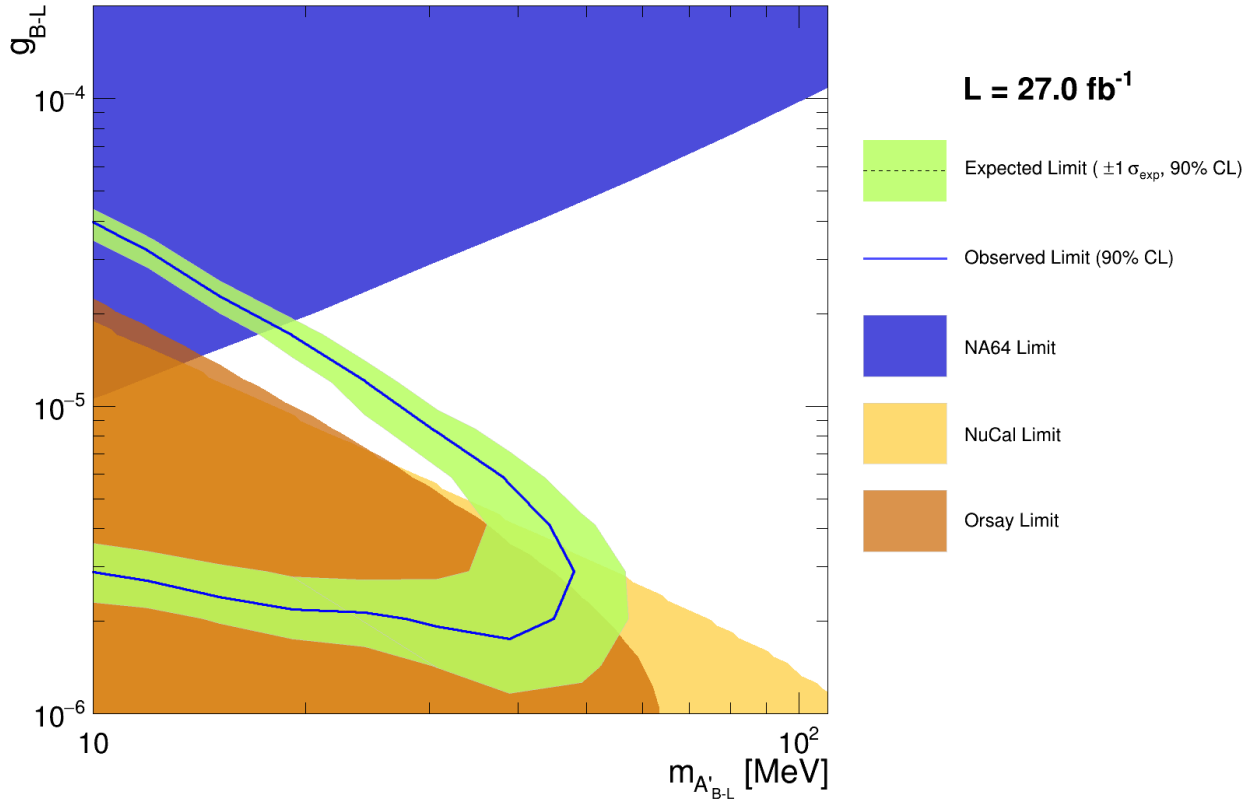
Description	**Value**
Pre-selecton	
Time consistent with a colliding bunch identifier Timing scintillator trigger	
Scintillator	
Timing station: Top or Bottom Scintillator charge OR Top and Bottom charge	 > 70 pC > 30 pC
Each Pre-shower scintillator charge Each Veto scintillator charge	>2.5 pC <40 pC
Tracking	
Exactly 2 Good Tracks Momentum χ^2/NDF Number of tracker layers on track Number of tracker hits on track	 > 20 GeV < 25 ≥ 7 ≥ 12
Fiducial selection	
Track extrapolated to all scintillators and tracking stations	 < 95 mm
Calorimeter	
Calorimeter energy (sum of four channels)	> 500 GeV

Dark Photons: exclusion plot with a cosmic relic target band, corresponding to different values of the model-dependent parameters m_χ and α_D.

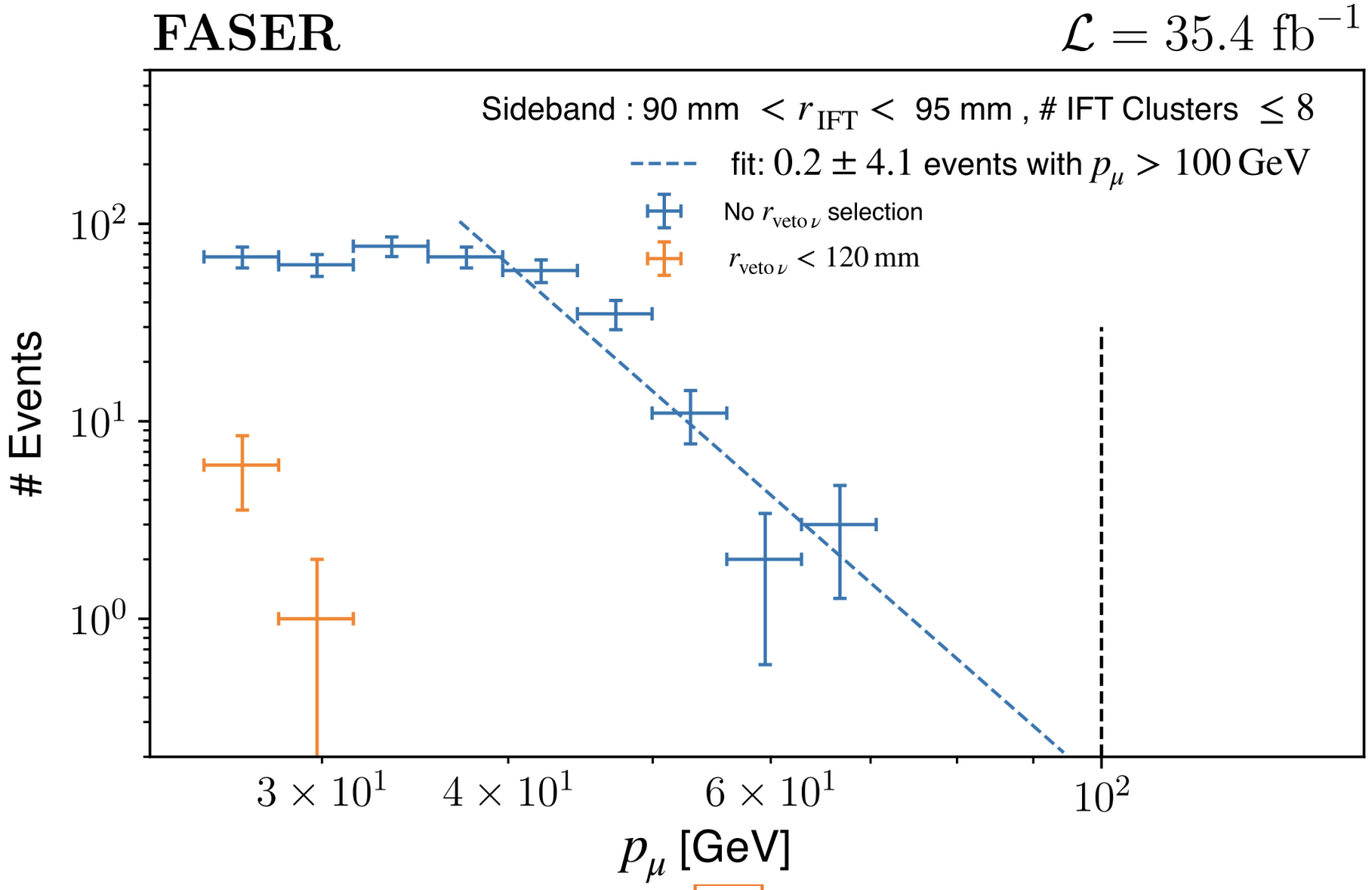


Dark Photons: FASER comparison with exclusion regions set by other experiments.

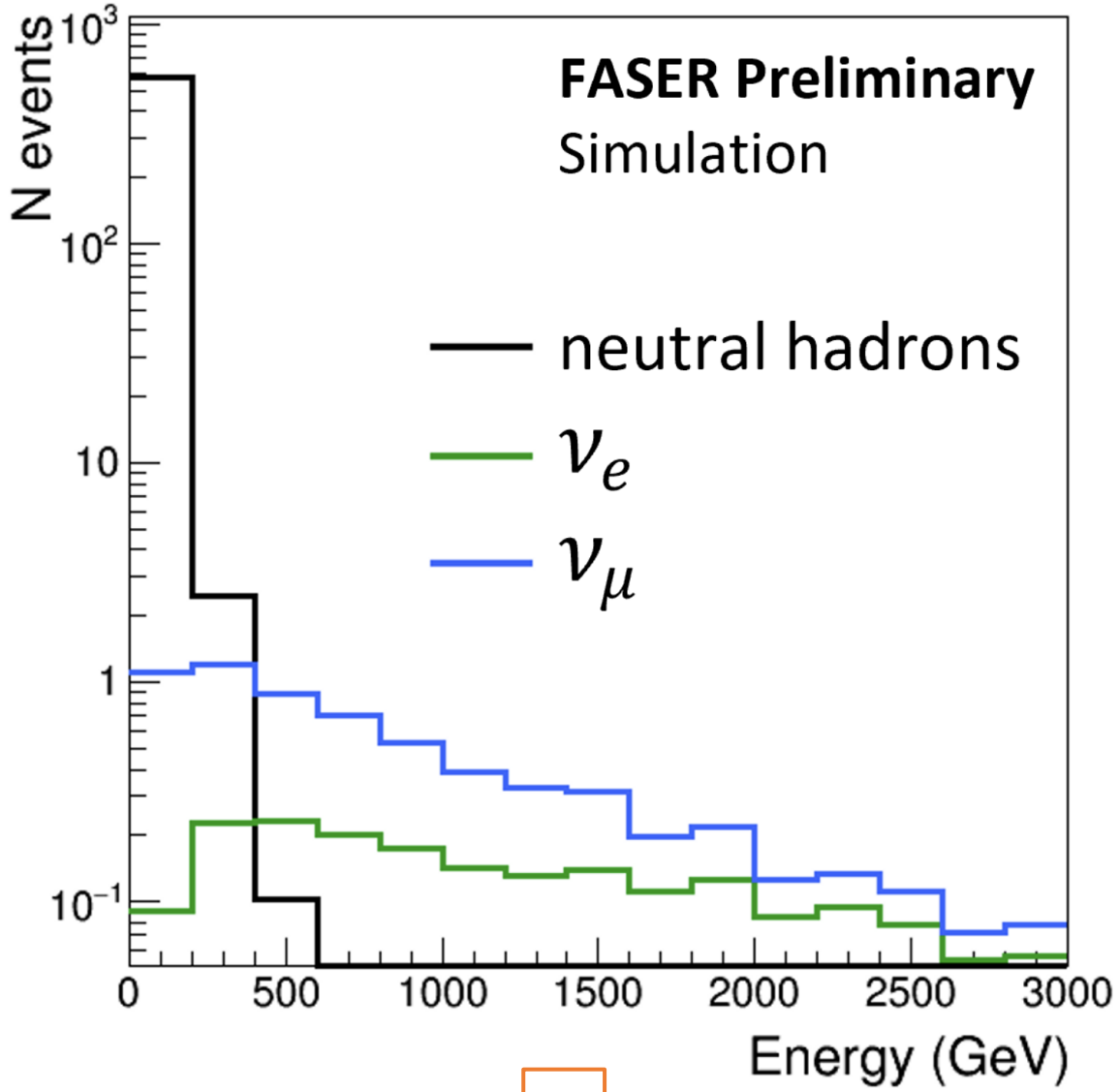




Collider Neutrinos: geometric muon background estimation using control region data.



FASERν: 2 fb^{-1} MC energy spectra of neutral hadrons and neutrinos entering the detector.



FASERν: ν_e (top) and ν_μ (bottom) MC and data comparison of track multiplicity, collision axis angle, momentum and azimuthal angle.