First FASER Physics Results & Run-3 Prsopects

Carl Gwilliam
on behalf of the FASER Collaboration

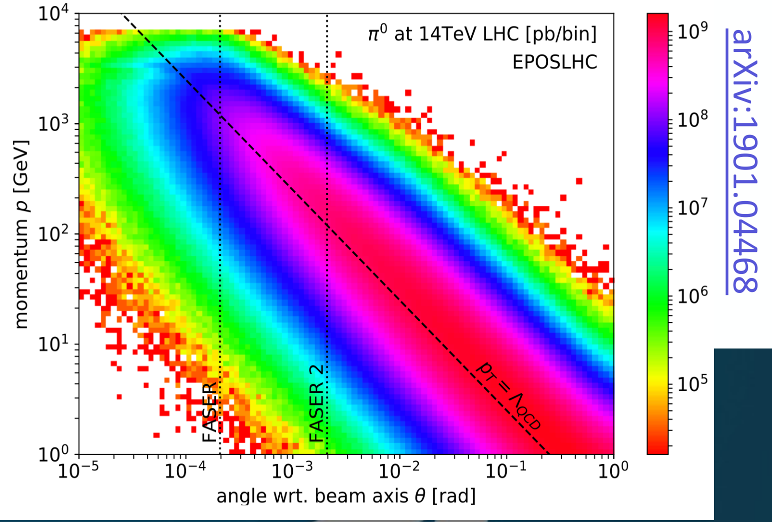
8th June 2023

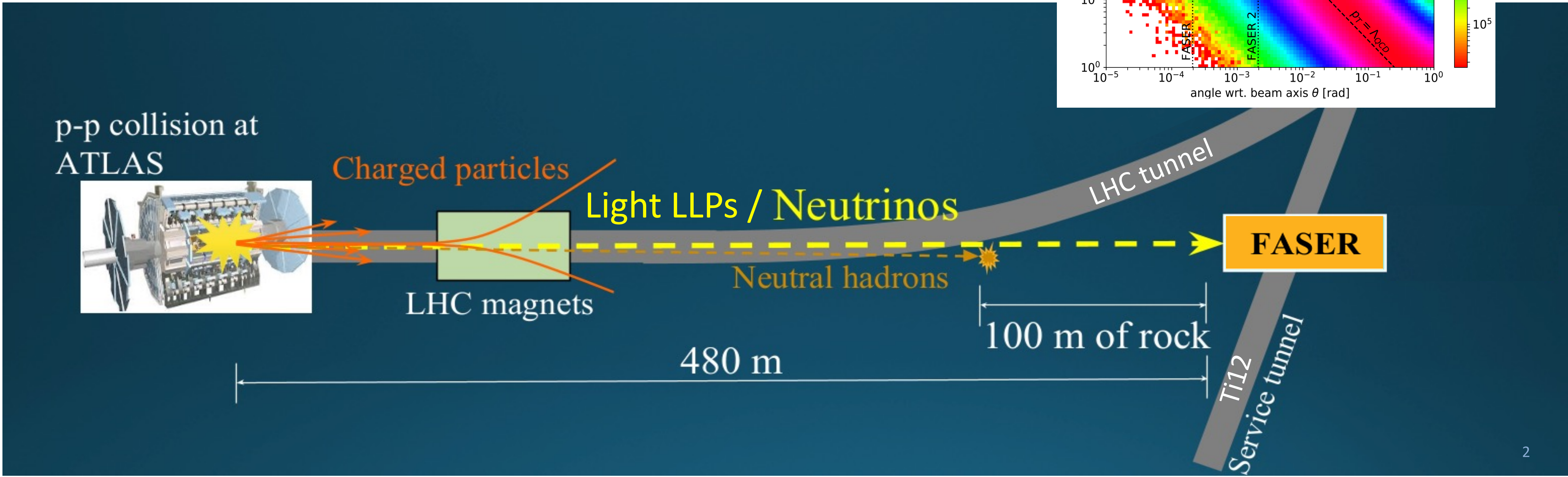
FPF Workshop

The FASER Experiment

- FASER is a relatively new forward LHC experiment to detect light and weakly interacting particles
  - Targets long-lived BSM particles (e.g. A', ALPs) and neutrinos
  - Exploiting large LHC collision rate + forward-peaked production

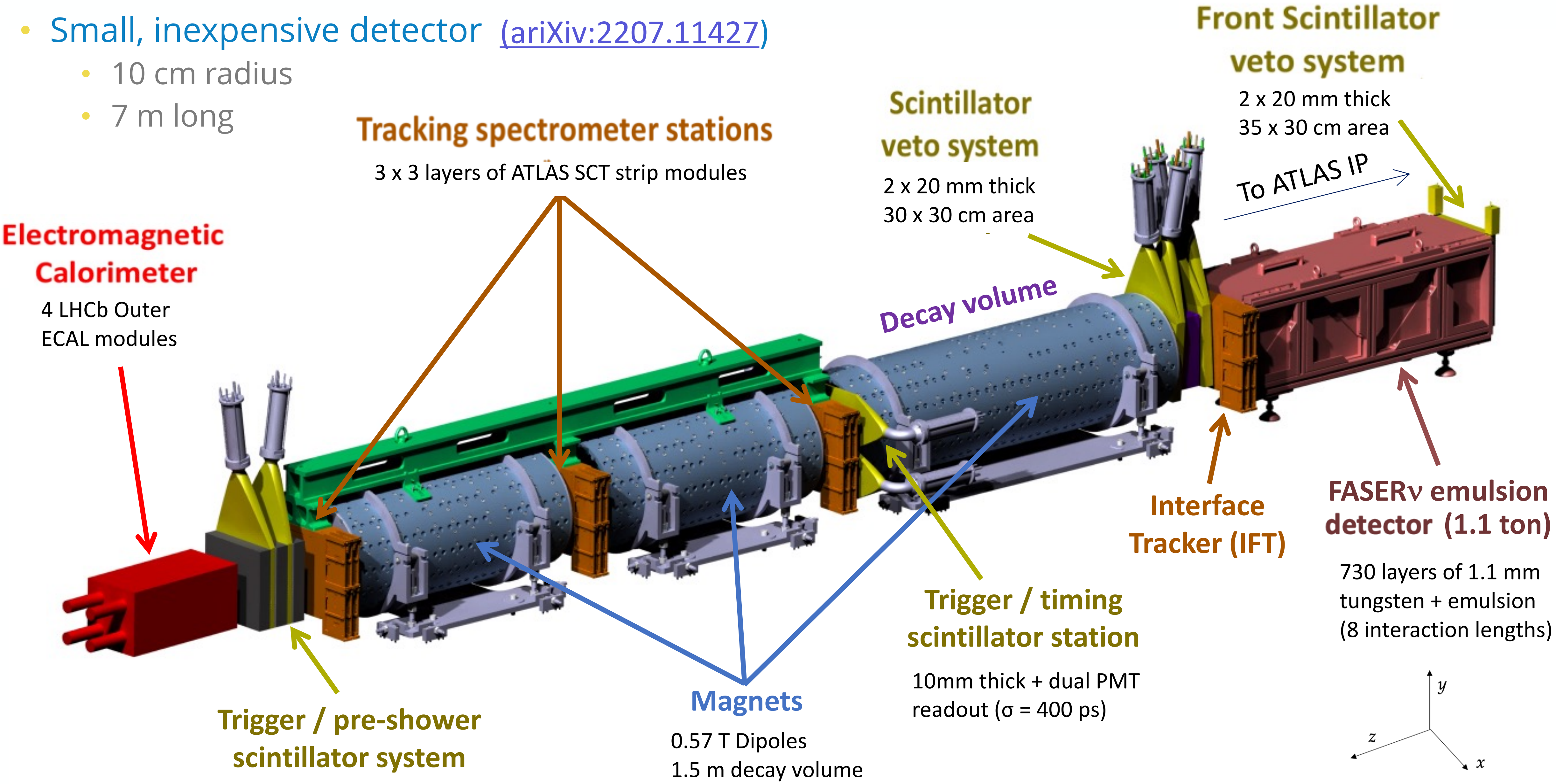
- Located 480m downstream of ATLAS interaction point
  - LHC magnets and 100 m of rock shield most background





FASER Detector

- Small, inexpensive detector (ariXiv:2207.11427)
  - 10 cm radius
  - 7 m long

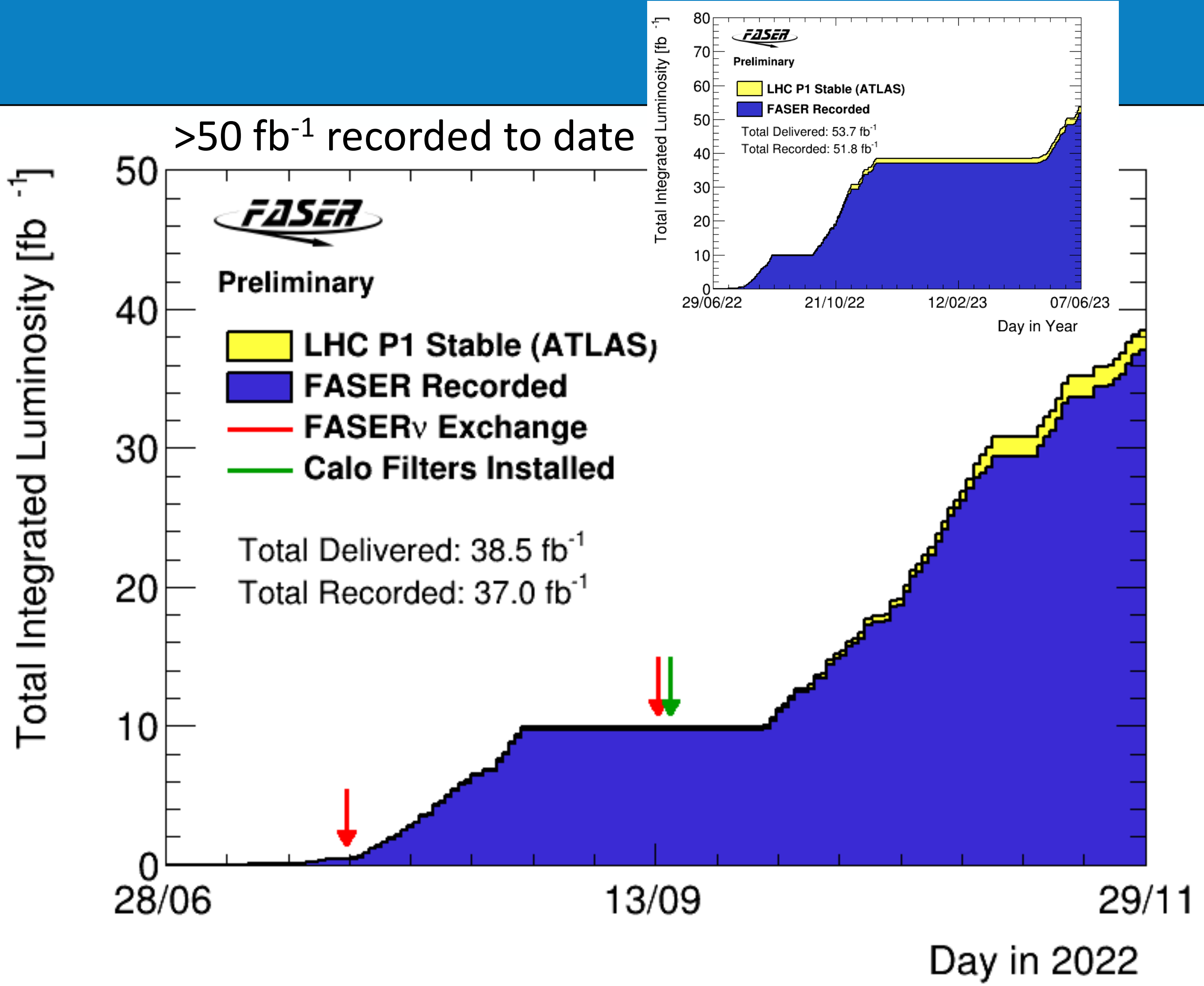


- Detector installed between March – Nov 2021, ready for LHC run 3

FASER Operations

- Successfully operated throughout 2022
  - Continuous data taking
  - Largely automated
  - Up to 1.3 kHz
- Recorded 96.1% of delivered lumi.
  - DAQ dead-time of 1.3%
  - A couple of DAQ crashes
- Emulsion detector exchanged twice
  - Needed to manage occupancy
  - First box only partially filled
- Calorimeter gain optimised for:
  - Low E (<300 GeV) before 2nd exchange
  - High E (up to 3 TeV) after this exchange

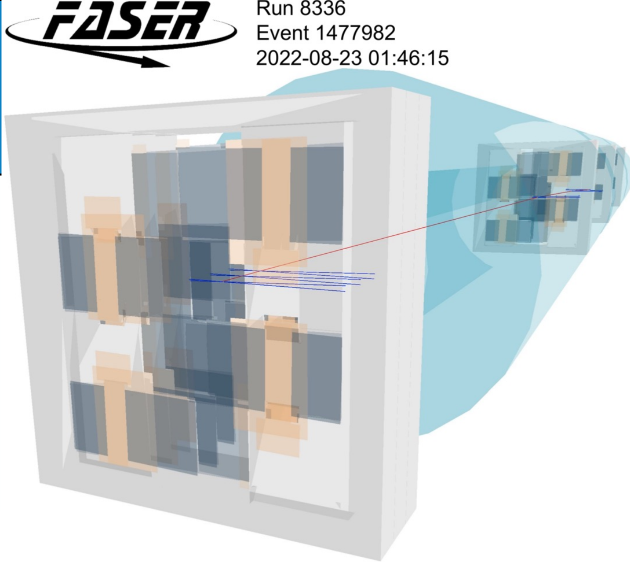
>50 fb^{-1} recorded to date

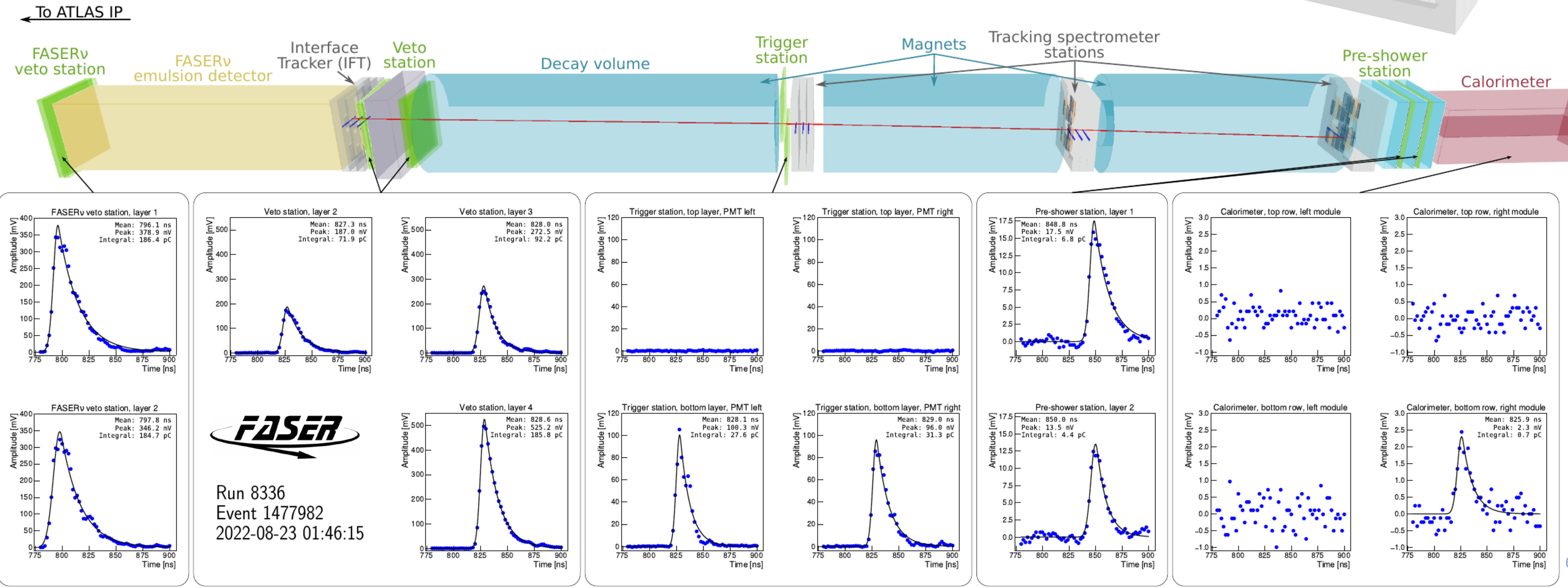


Analyses presented use 27.0 fb^{-1} or 35.4 fb^{-1}

FASER Operations (2)

- All detector components performing excellently
- More than 350M single-muon events recorded
  - Example: muon leaving track passing through full detector + scintillator/calorimeter deposits consistent with MIP



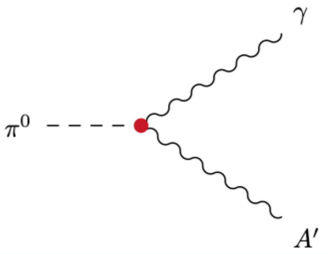


Dark Photon (A') Search

- Dark photon is a common feature of hidden sector models
  - Weakly coupling to SM via kinetic mixing (ε) with SM photon

$$\mathcal{L} \supset \frac{1}{2} m_{A'}^2 A'^2 - \epsilon\, e \sum_f q_f \bar{f} \not{A}' f$$

- MeV A's produced mainly in meson decays at LHC

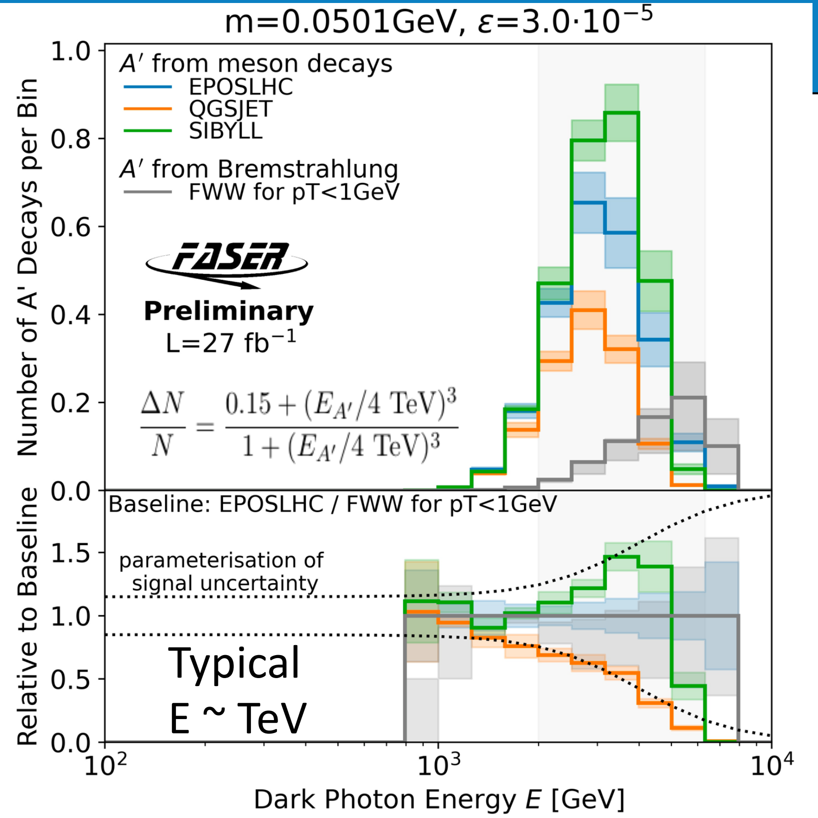


$$B(\pi^0 \to A'\gamma) = 2\epsilon^2 \left(1 - \frac{m_{A'}^2}{m_{\pi^0}^2}\right)^3 B(\pi^0 \to \gamma\gamma)$$

- FASER targets small ε, where A' has long decay length

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

  - Below $2m_\mu$, A' has 100% decay to e^+e^- pair



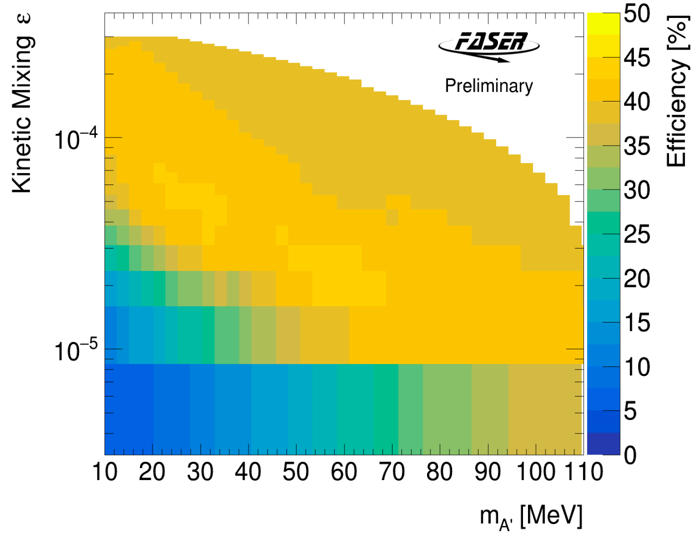
- A' → e^+e^- simulated with FORESEE*
  - π^0 and η via EPOS-LHC generator
  - Subdominant dark brem. via FWW

- Generator uncertainty dominates
  - Difference to QGSJET/SIBYLL
  - Parameterised based on A' energy

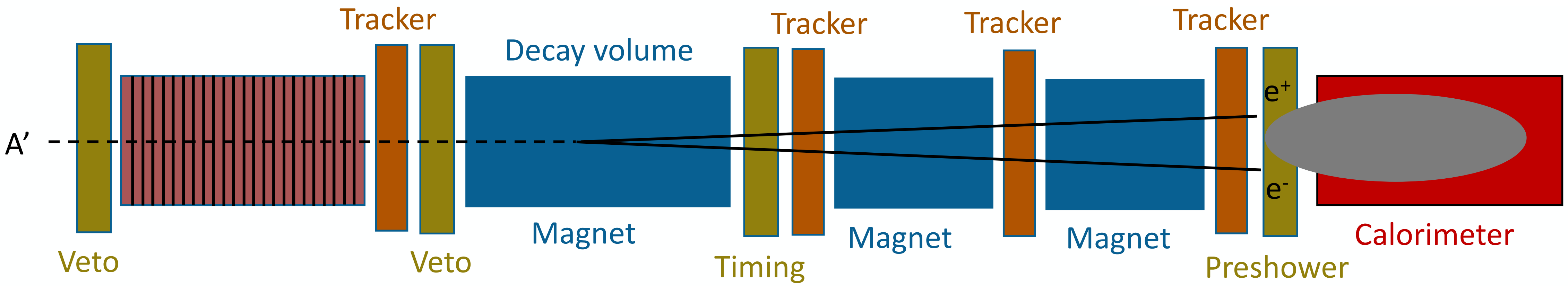
* arXiv:2105.07077

Dark Photon Selection

- Simple and robust A' → e^+e^- selection, optimised for discovery
  - Blind events with no veto signal and E(calo) > 100 GeV
  - Efficiency of ~40% across region sensitive to



1. Collision event with good data quality
4. Timing and preshower consistent with ≥2 MIPs



2. No signal (< 40 pC) in any veto scintillator
3. Exactly 2 good fiducial tracks
   - p > 20 GeV and r < 95 mm
   - Extrapolating to r < 95 mm at vetos
5. Calo E > 500 GeV

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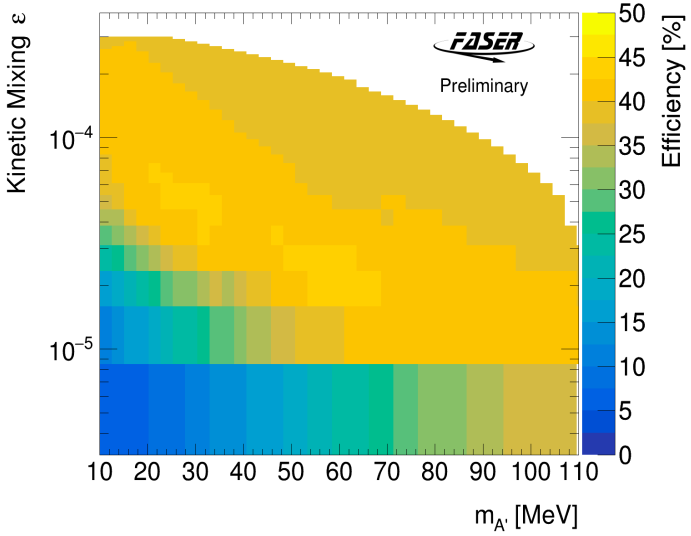

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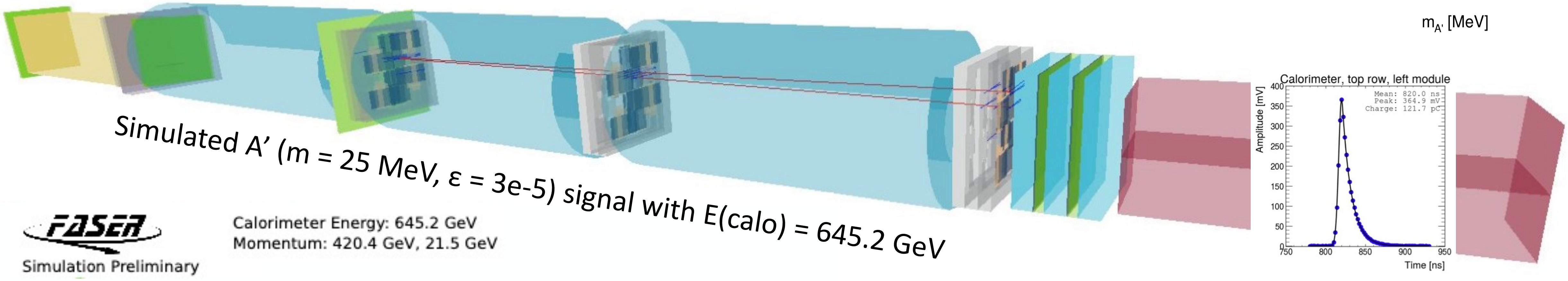

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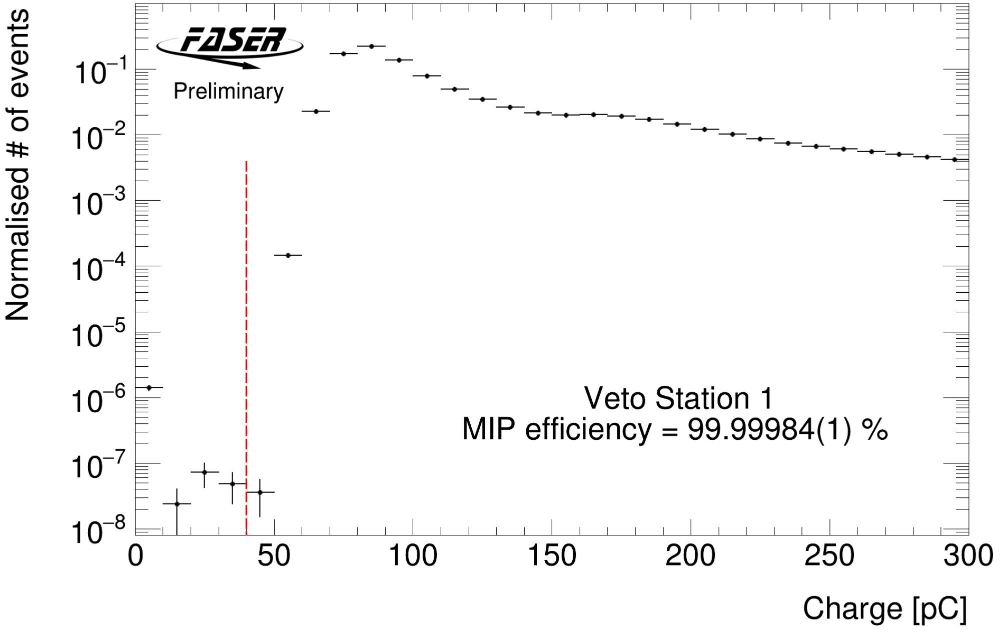
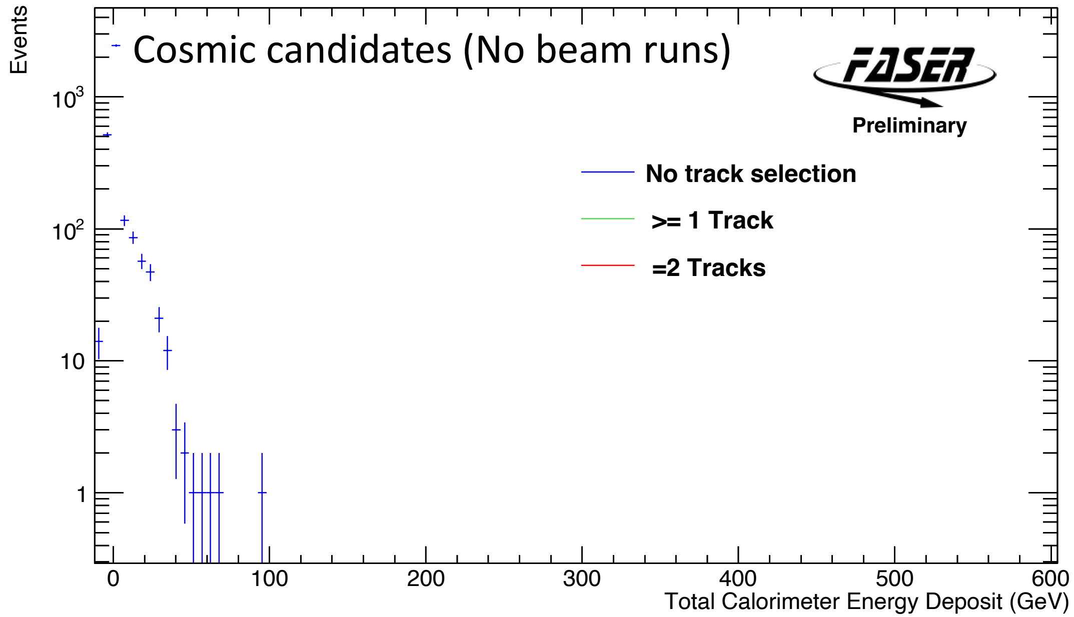
Dark Photon Backgrounds

- Veto inefficiency
  - Measured layer-by-layer via muons with tracks pointing back to vetos
  - Layer efficiency > 99.998%
  - 5 layers reduce exp. 10^8 muons to negligible level (even before cuts)
- Non-collision backgrounds
  - Cosmics measured in runs with no beam
  - Near-by beam debris measured in non-colliding bunches
  - No events observed with ≥1 track or E(calo) > 500 GeV individually





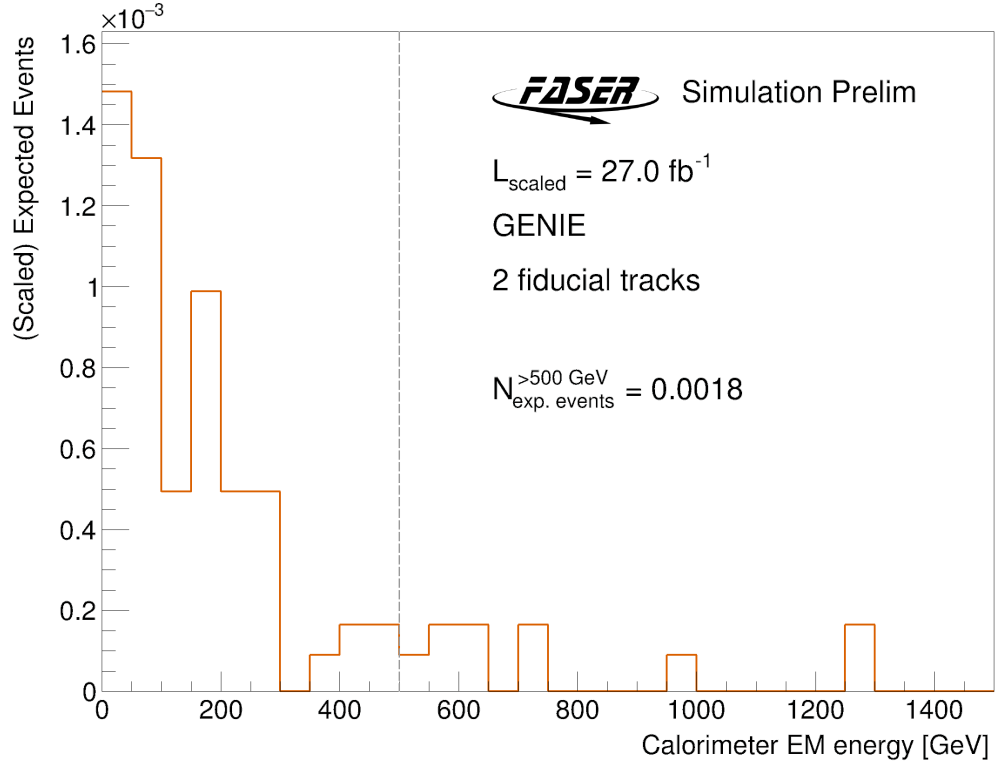
Dark Photon Backgrounds

- Main background is from neutrino interactions
  - Primarily coming from vicinity of timing detector
  - Estimated from GENIE simulation (300 ab^{-1})
    - Uncertainties from neutrino flux & mismodelling
  - Predicted events with E(calo) > 500 GeV

$$N = (1.8 \pm 2.4) \times 10^{-3}$$

- Neutral hadrons (e.g. K_S) from upstream muons interacting in rock in front of FASER
  - Heavily suppressed since:
    - Muon nearly always continues after interaction
    - Has to pass through 8 interaction lengths (FASERν)
    - Decay products have to leave E(calo) > 500 GeV
  - Estimated from lower energy events with 2 or 3 tracks and different veto conditions

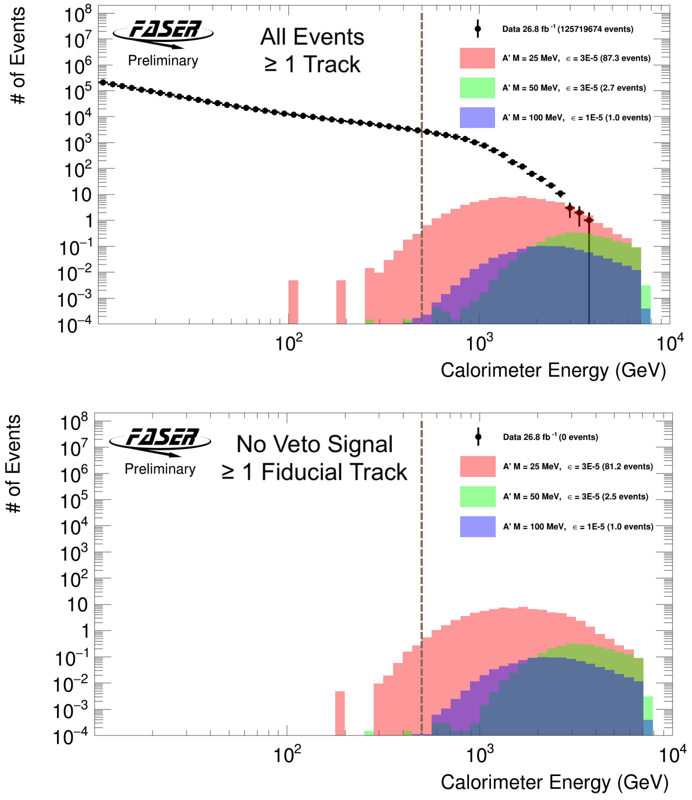
$$N = (2.2 \pm 3.1) \times 10^{-4}$$



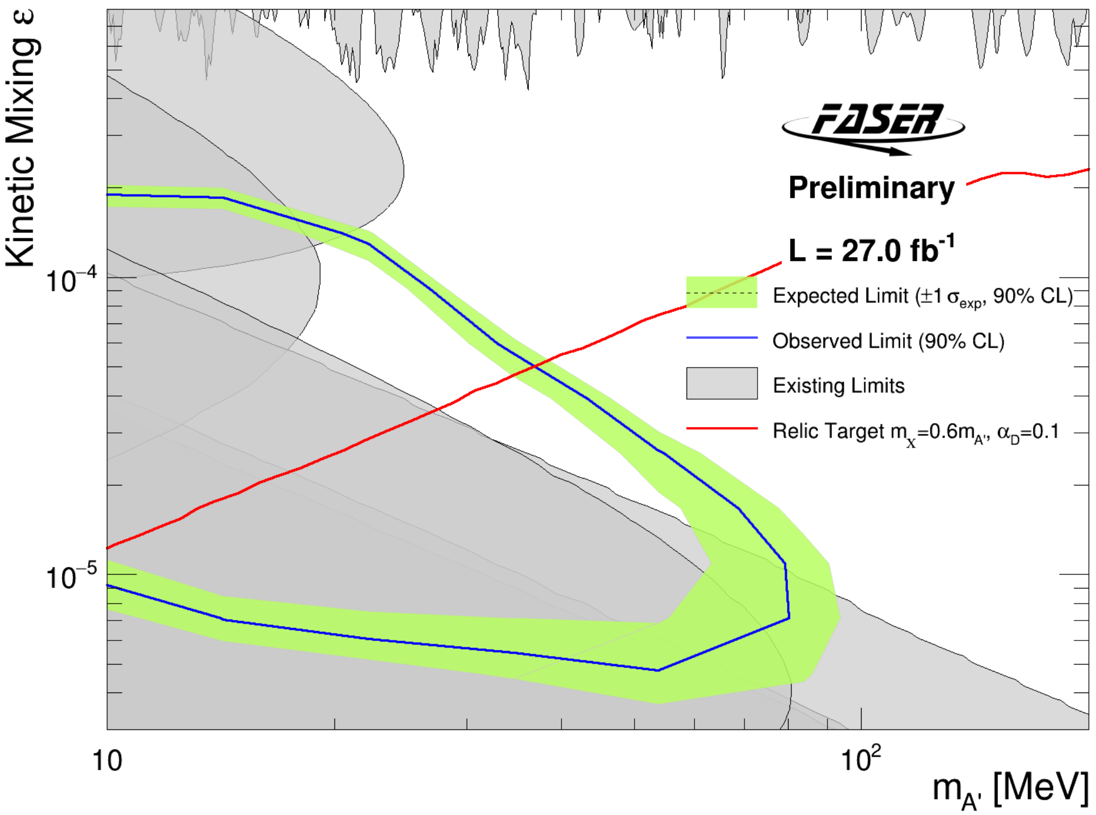
- Total background prediction

$$N = (2.02 \pm 2.4) \times 10^{-3}$$

Dark Photon Results



- No events in unblinded signal region
  - Not even any with ≥1 fiducial track



- Based on this null results, FASER sets limits in previously unexplored parameter space!
  - Probing region interesting from thermal relic target
  - Also taking into account new preliminary NA62 result (see backup)

CERN-FASER-CONF-2023-001

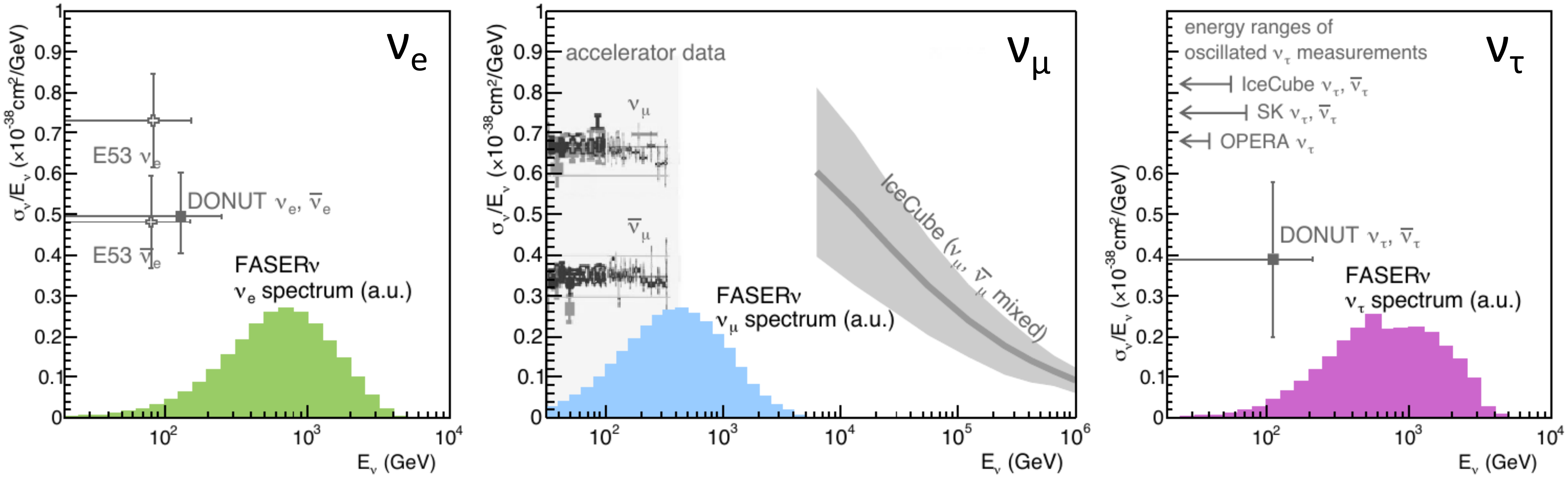
Paper now in progress

Collider Neutrinos

- Neutrinos produced copiously in decays of forward hadrons
  - Highly energetic (TeV scale) → high interaction cross section
- Extends FASER physics program into SM measurements
  - Targets measurement of highest energy man-made neutrinos
  - Energy range complementary to existing neutrino experiments

For 35 fb^{-1}	ν_e	ν_μ	ν_τ
Main source	Kaons	Pions	Charm
# traversing FASERν	~10^{10}	~10^{11}	~10^{8}
# interacting in FASERν	≈200	≈1200	≈4

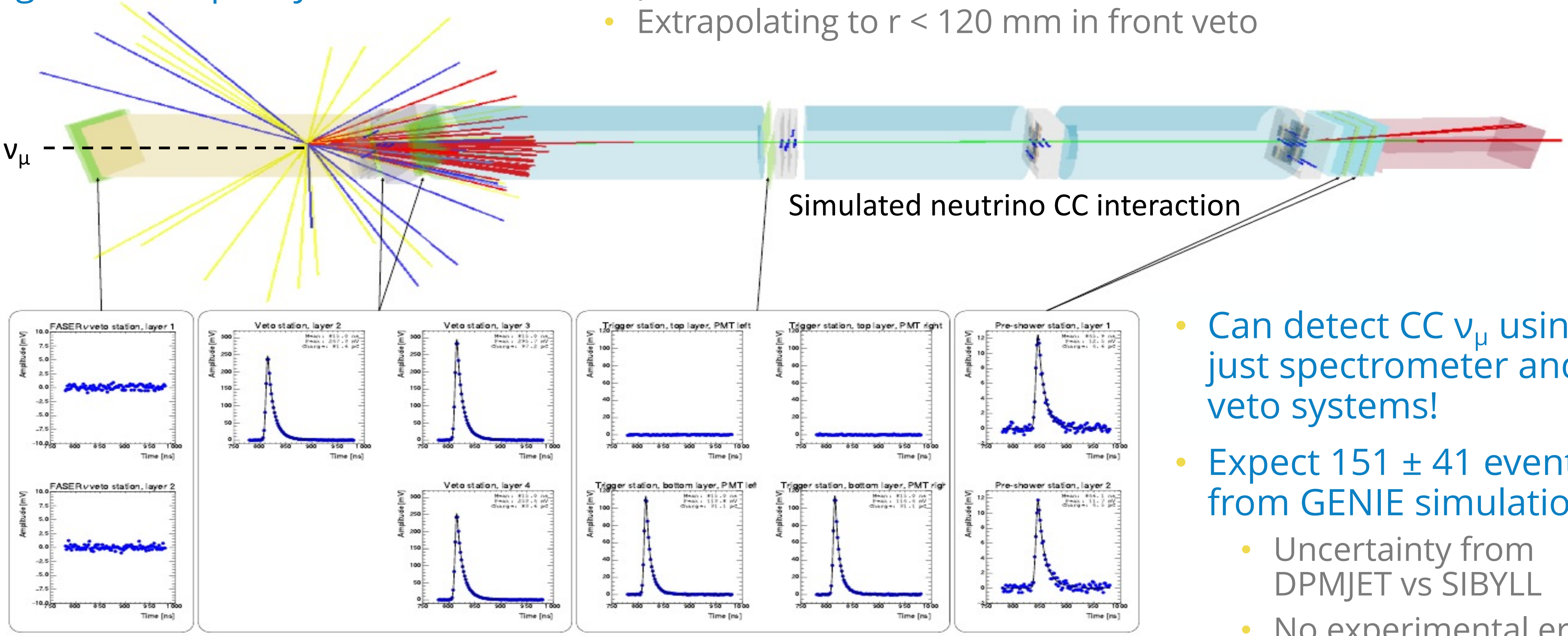
PRD 104, 113008



Study at colliders originally proposed by Rújula and Rückl in 1984!

Observing Neutrino Candidates in FASER

1. Collision event with good data quality
4. Exactly 1 good fiducial (r < 95 mm) track
   - p > 100 GeV and θ < 25 mrad
   - Extrapolating to r < 120 mm in front veto

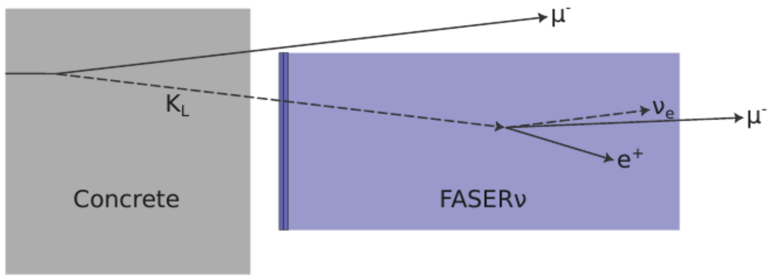


- Can detect CC ν_μ using just spectrometer and veto systems!
- Expect 151 ± 41 events from GENIE simulation
  - Uncertainty from DPMJET vs SIBYLL
  - No experimental errors
    - Currently not trying to measure cross section

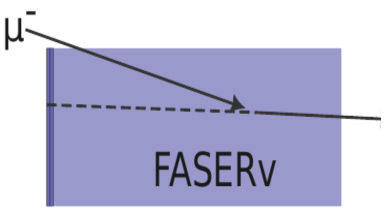
2. No signal (<40 pc) in 2 front vetos
3. Signal (>40 pC) in other 3 vetos
5. Timing and preshower consistent with ≥1 MIP

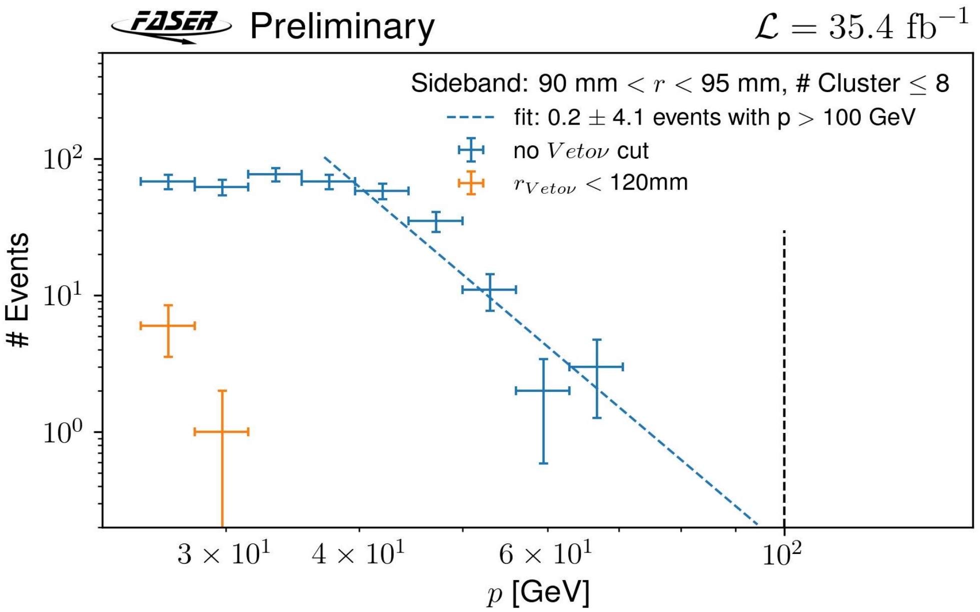
Neutrino Backgrounds

- Neutral hadrons estimated from 2-step simulation
  - Expect ~300 neutral hadrons with E>100 GeV reaching FASERν
    - Most accompanied by μ but conservatively assume missed
  - Estimate fraction of these passing event selection
    - Most are absorbed in tungsten with no high-momentum track
  - Predict N = 0.11 ± 0.06 events



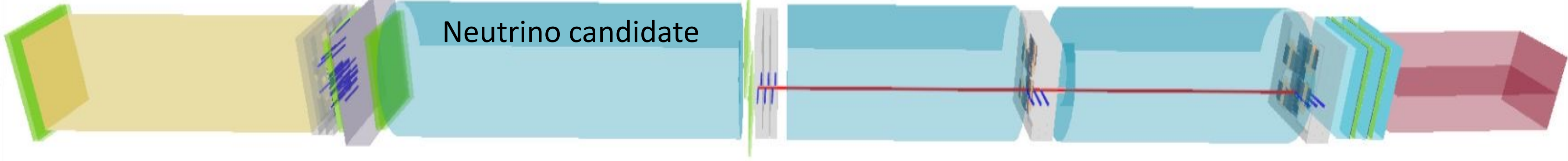
- Scattered muons estimated from data SB
  - Take events w/o front veto radius requirement and single track segment in first tracker station with 90 < r < 95 mm
    - Fit to extrapolate to higher momentum
  - Scale by # events with front veto cut
    - Use MC to extrapolate to signal region
  - Predict N = 0.08 ± 1.83 events
    - Uncertainty from varying selection





- Veto inefficiency estimated from final fit
  - Fit events with 0 (SR) and also 1 (1st or 2nd) or 2 front veto layers firing
  - Find negligible background due to very high veto efficiency

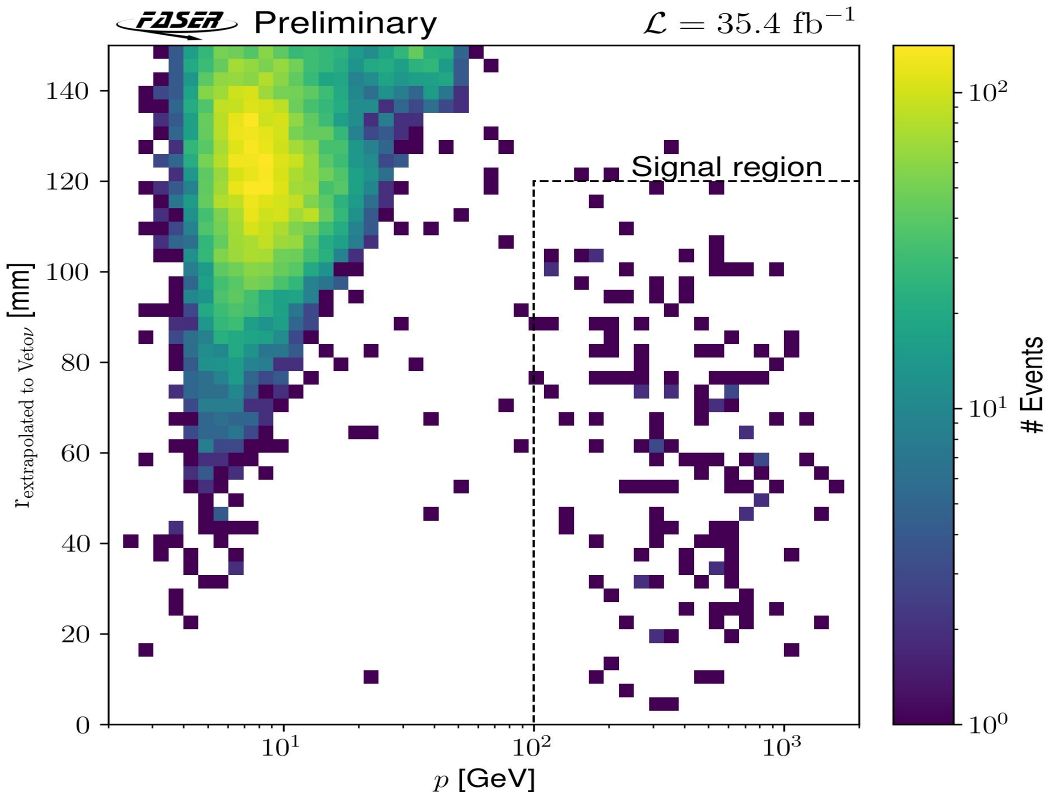
Neutrino Results

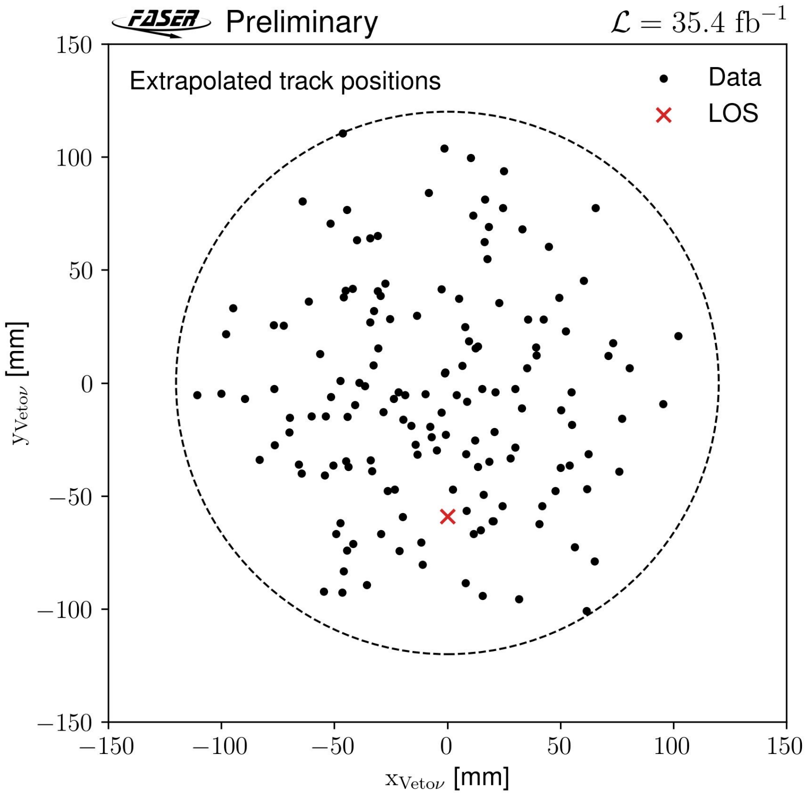


preliminary
Run 8943
Event 47032829
2022-10-27 08:52:45

- Upon unblinding find 153 events with no veto signal
  - Just 10 events with one veto signal
- First *direct* detection of collider neutrinos!
  - With signal significance of 16σ
  - Accepted by PRL arXiv:2303.14185

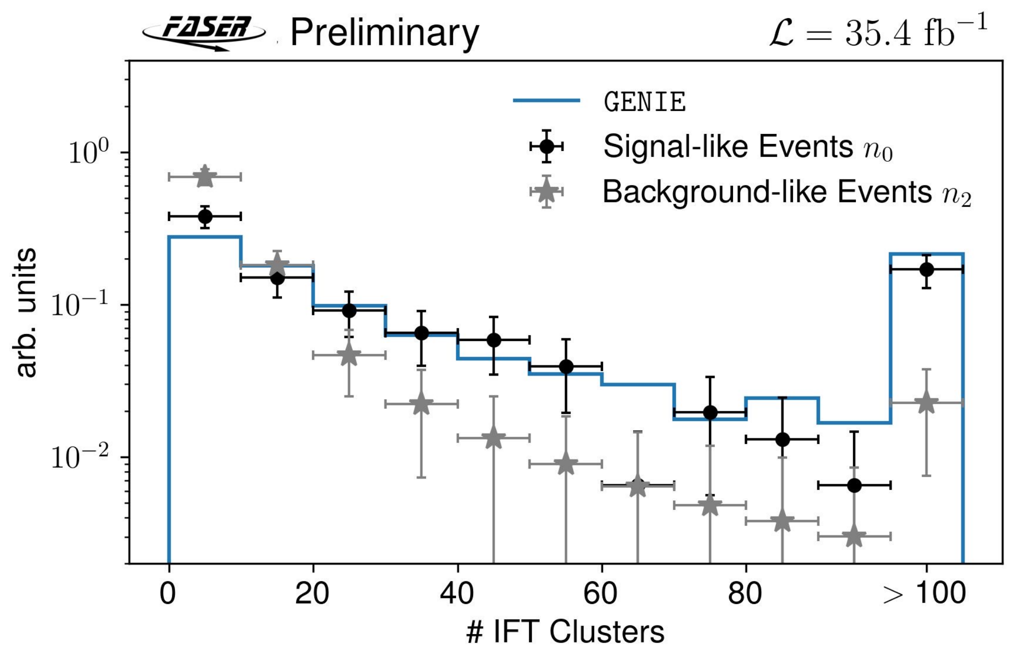
Candidate	Events
n_0	153 (151 ± 41)
n_{10}	4
n_{01}	6
n_2	64014695

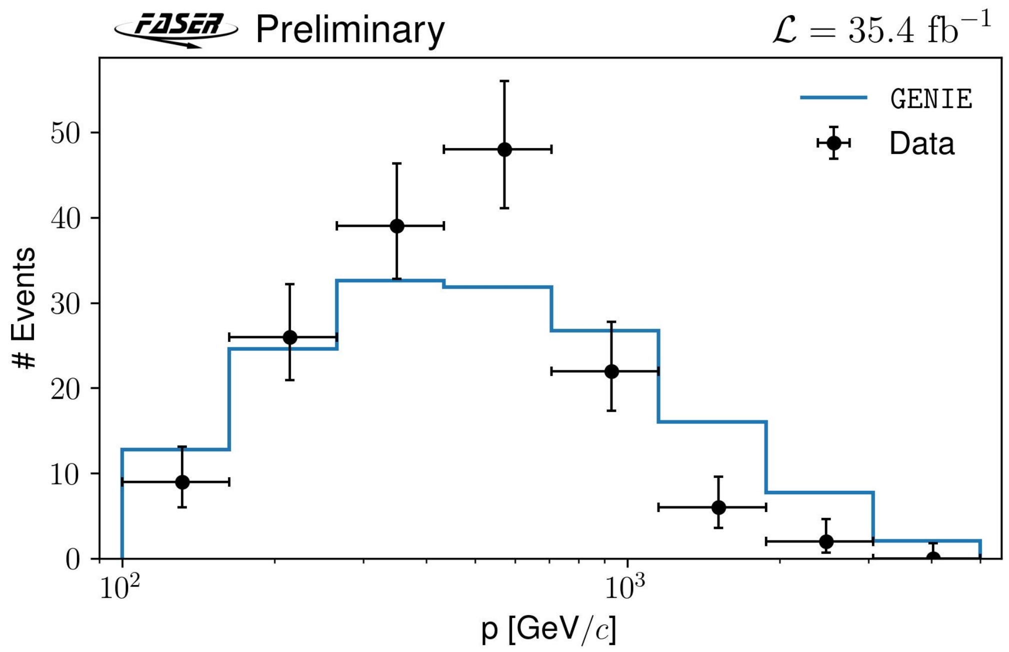


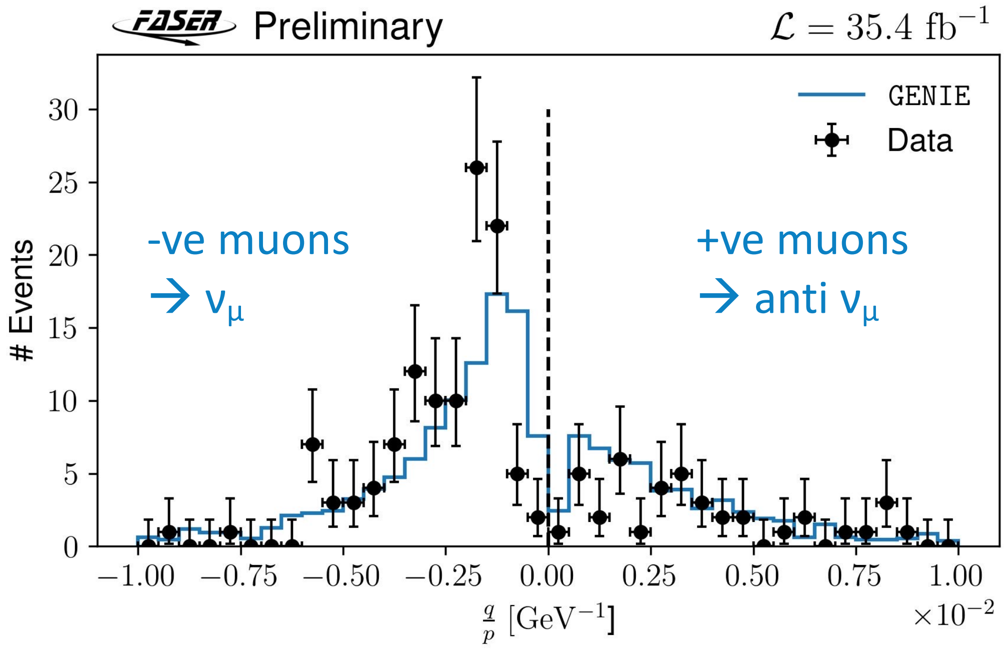


Neutrino Characteristics

- Candidate neutrino events match expectation from signal
  - High occupancy in front tracker station
  - Most events have high μ momentum
  - More ν_μ than anti- ν_μ
- Note: no acceptance corrections nor any systematic uncertainties in these plots

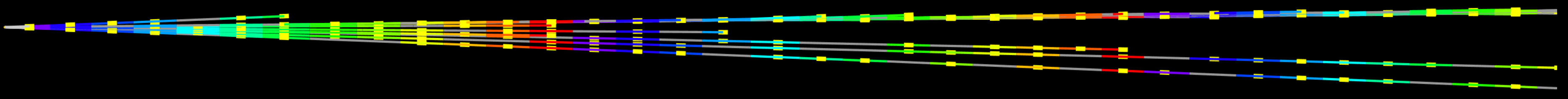


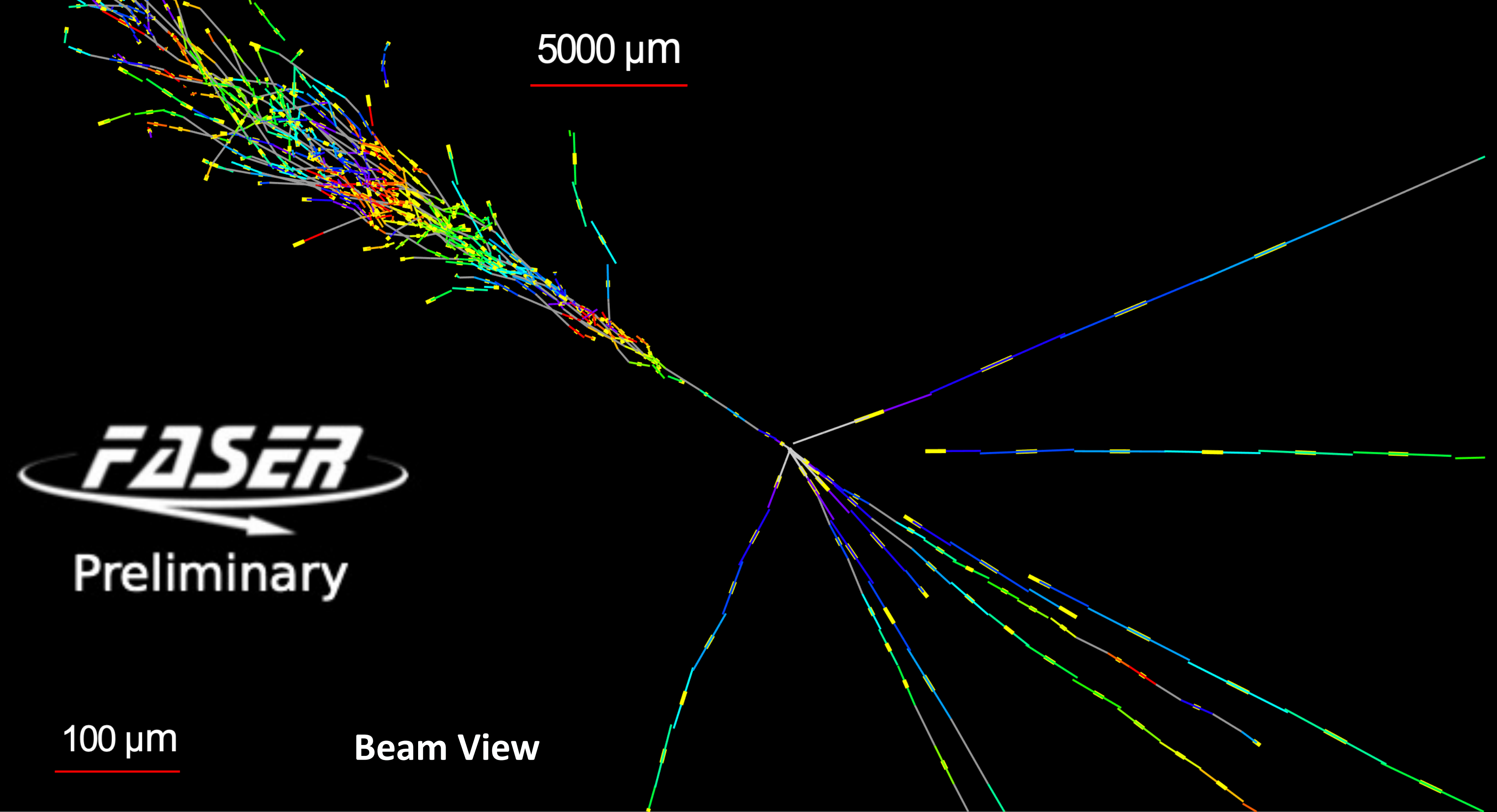




Neutrinos in FASERν

- Analysis of FAESRν emulsion detector underway
  - Have multiple candidates including highly νe-like CC event



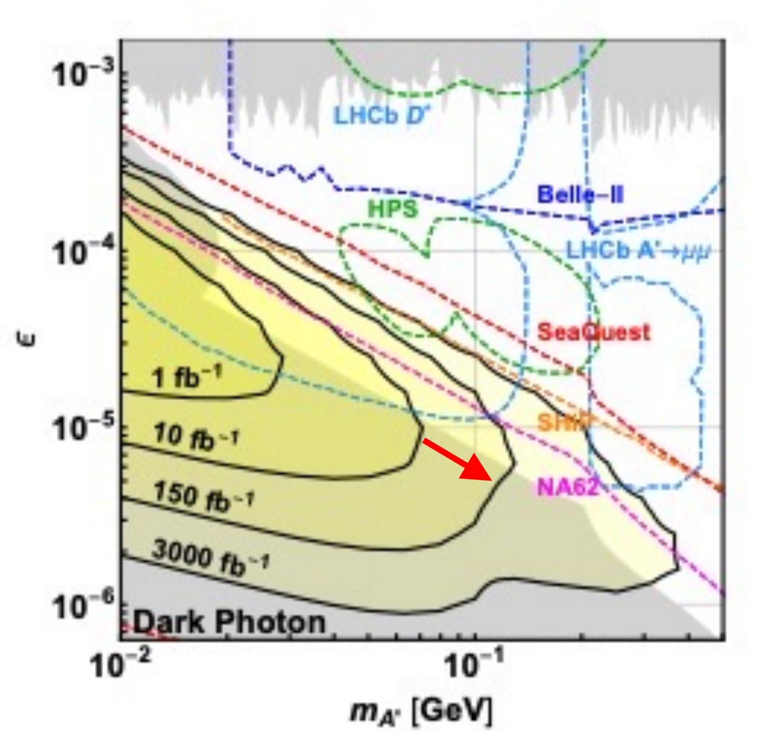


- Vertex with 11 tracks
  - 615 μm inside tungsten
- e-like track from vertex
  - Single track for $2X_0$
  - Shower max @ $7.8X_0$
  - θ_e = 11 mrad to beam
- Back-to-back topology
  - 175° between e & rest

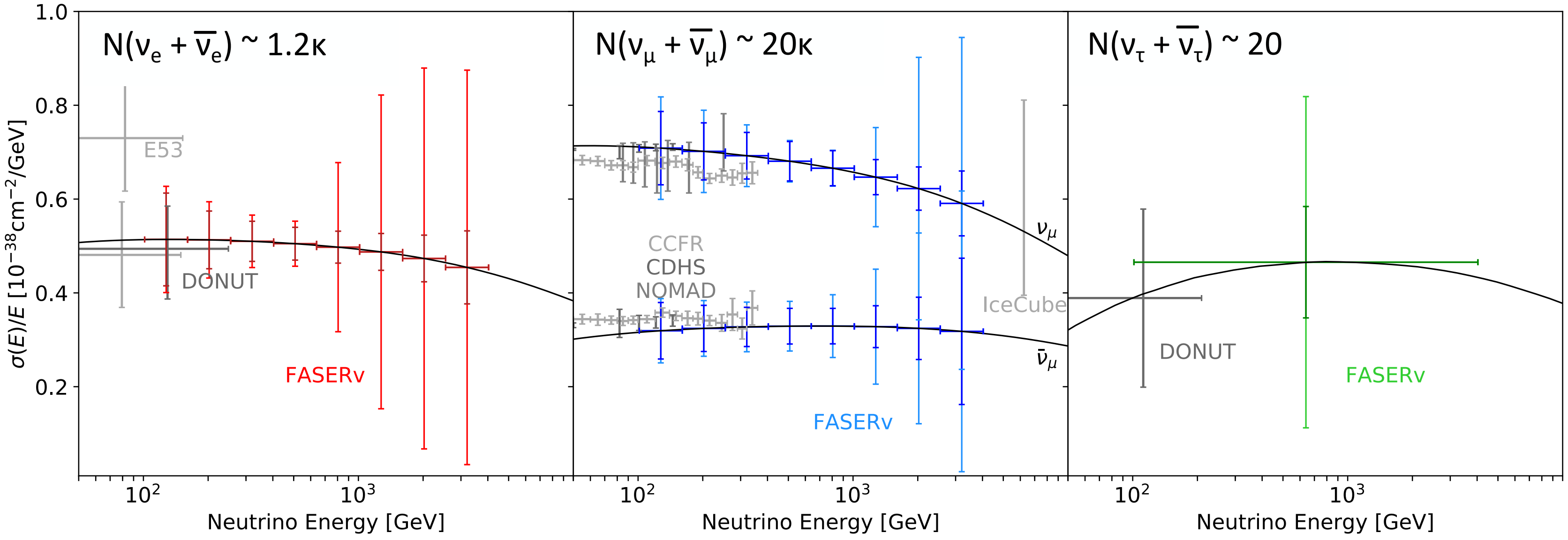
Plenty still to come in Run 3 …

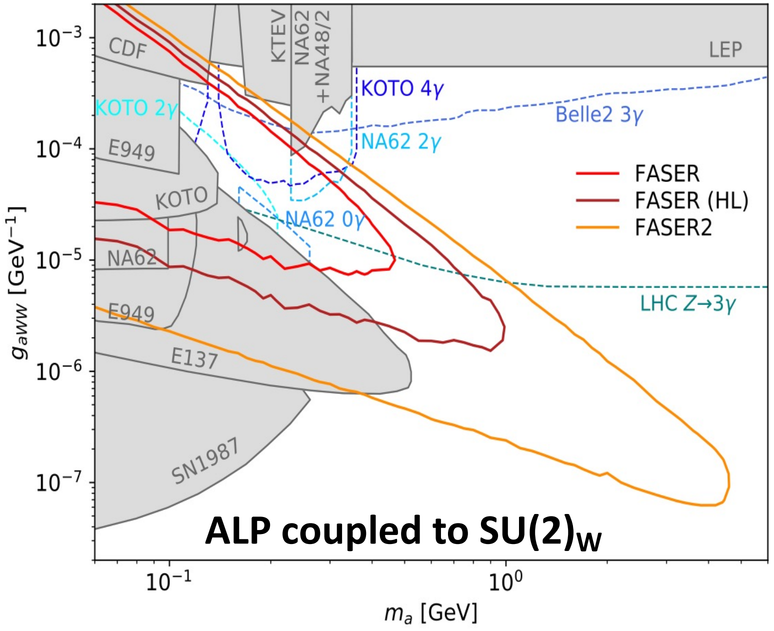
- LLPs
  - Significant increase in A′ reach
  - ALPs analysis in progress
  - Several other models:
    - B-L, U(1)B, Up-Philic etc

Benchmark Model	FASER
Dark Photons	✓
$B-L$ Gauge Bosons	✓
$L_i - L_j$ Gauge Bosons	—
Dark Higgs Bosons	—
Dark Higgs Bosons with hSS	—
HNLs with e	—
HNLs with μ	—
HNLs with τ	✓
ALPs with Photon	✓
ALPs with Fermion	—
ALPs with Gluon	✓
Dark Pseudoscalars	—



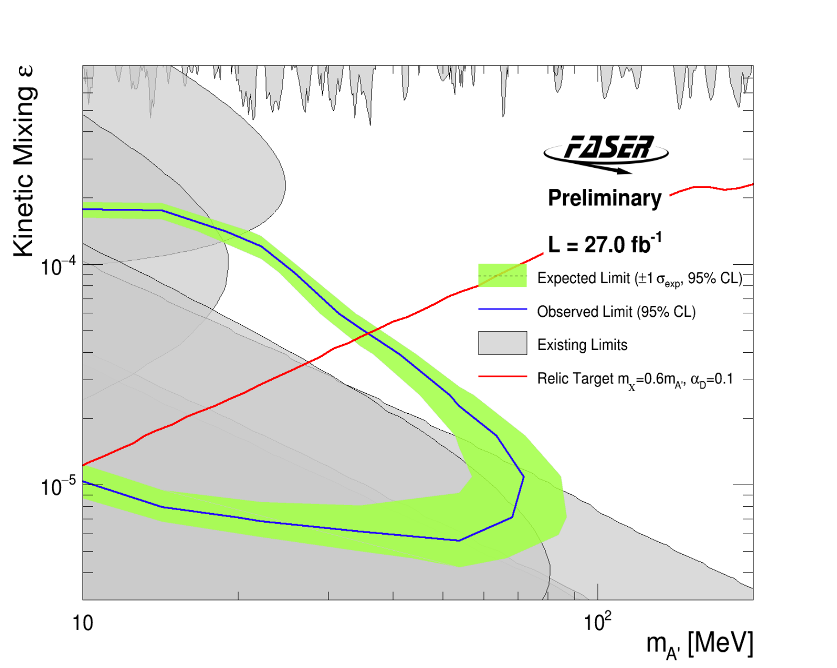
- Neutrinos
  - First emulsion results, probing ν_e in addition to ν_μ
  - Differential cross-section/flux measurements for all flavours

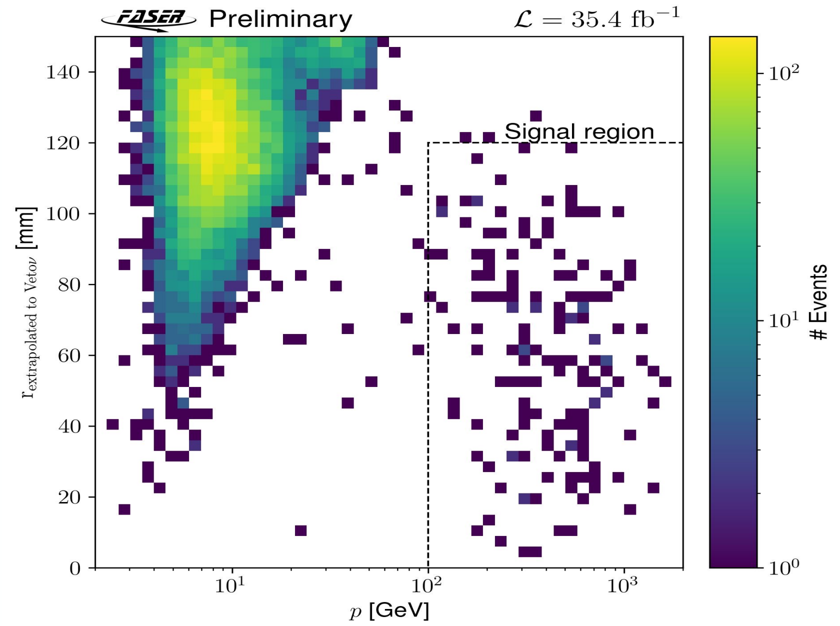


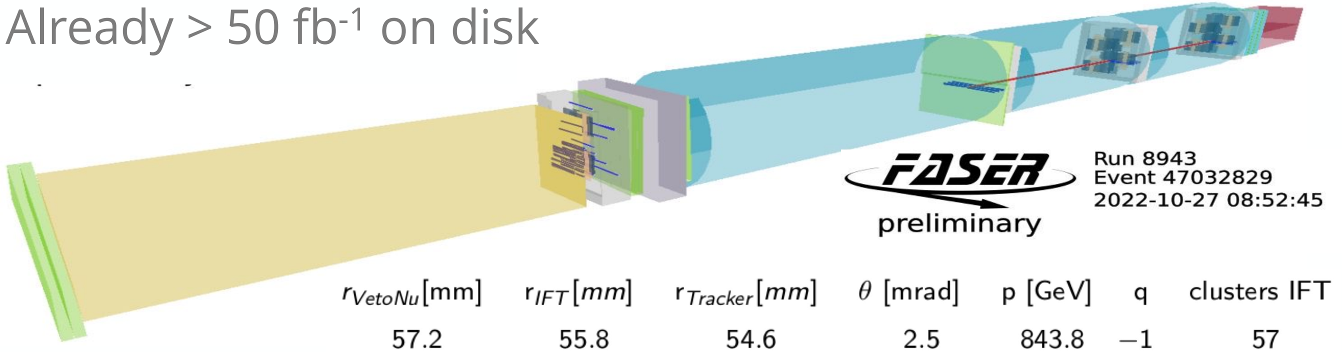


Summary

- FASER successfully took data in first year of Run 3
  - Running with fully functional detector and very good efficiency
- Excluded A' in region of low mass and kinetic mixing
  - Probes new territory in interesting thermal-relic region
- Reconstructed ~150 ν_μ CC interactions in spectrometer
  - First *direct* detection of collider neutrinos!
  - Opens new window for high-energy ν study
- More searches and neutrino measurements to come
  - Including first results from emulsion detector
- Looking forward to up to 10x more LHC run-3 data
  - Already > 50 fb^{-1} on disk







r_{VetoNu}[mm]	r_{IFT}[mm]	$r_{Tracker}$[mm]	θ [mrad]	p [GeV]	q	clusters IFT
57.2	55.8	54.6	2.5	843.8	−1	57

Acknowledgements

- FASER is supported by

SIMONS FOUNDATION

HEISING-SIMONS FOUNDATION

NSF

CERN

erc

Swiss National Science Foundation

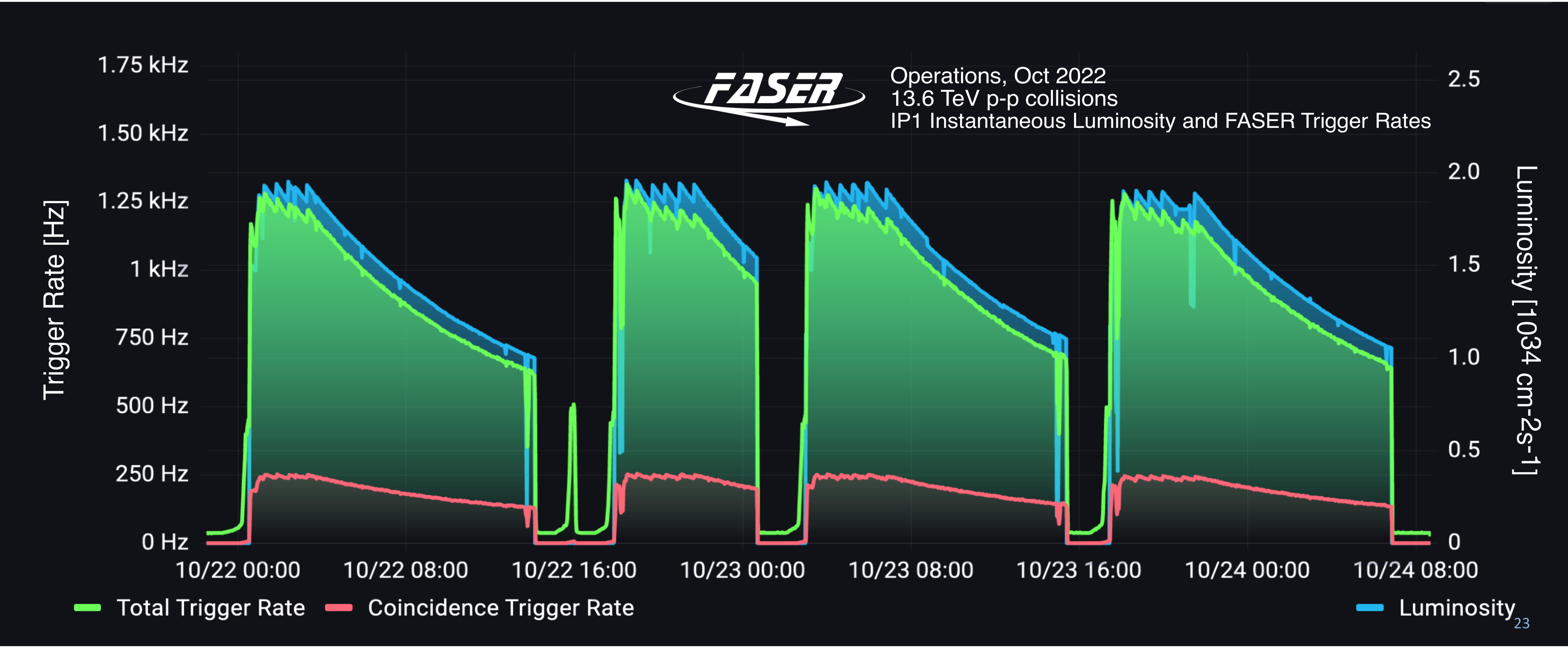
科研費 KAKENHI

- And would additionally like to thank
  - LHC for the excellent performance in 2022
  - ATLAS for providing luminosity information
  - ATLAS for use of ATHENA s/w framework
  - ATLAS SCT for spare tracker modules
  - LHCb for spare ECAL modules
  - CERN FLUKA team for background sim
  - CERN PBC and technical infrastructure groups for excellent support during design construction and installation

Backup Slides

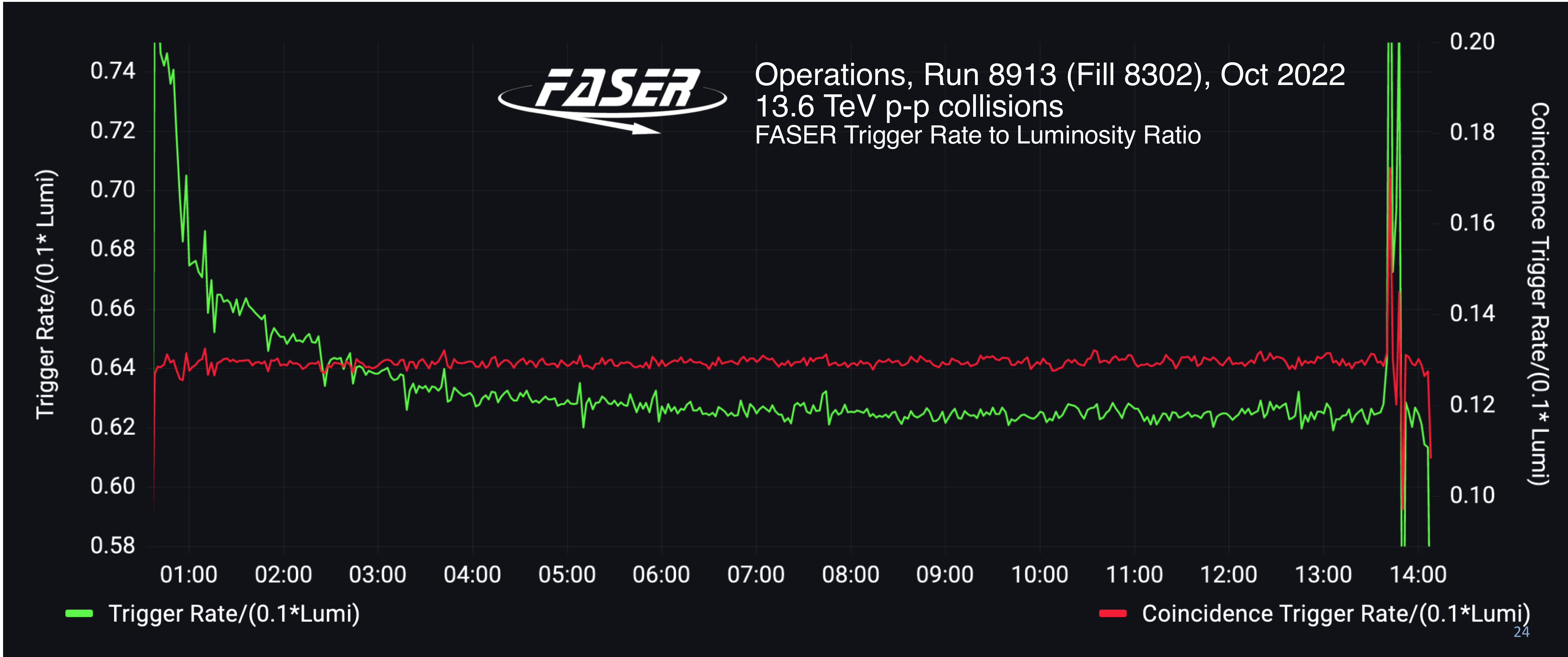
Detector Performance: Trigger + DAQ

- DAQ running smoothly up to 1.3 kHz with deadtime only 1.3%
  - Only two stops in data-taking due to DAQ failures



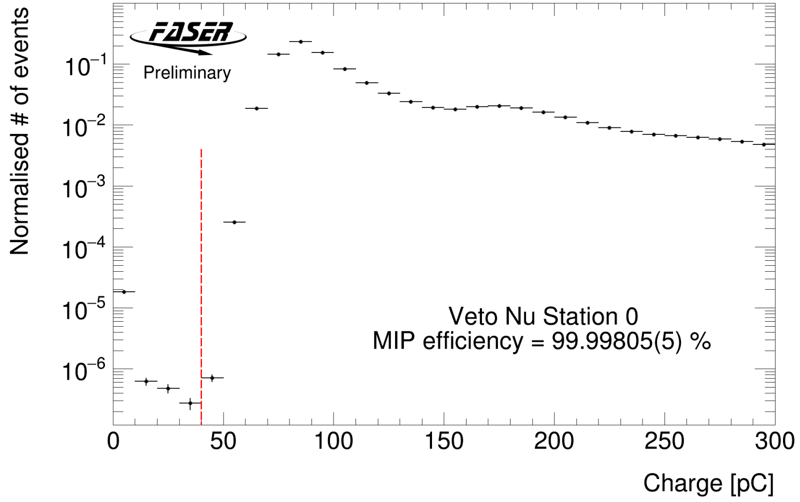
Detector Performance: Trigger + DAQ (2)

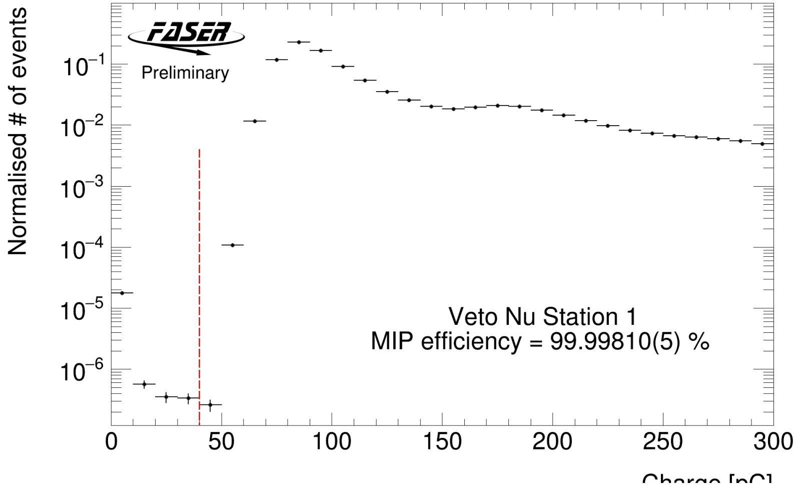
- Total trigger rate falls off faster than luminosity profile during run
  - But coincidence trigger rate flat wrt lumi

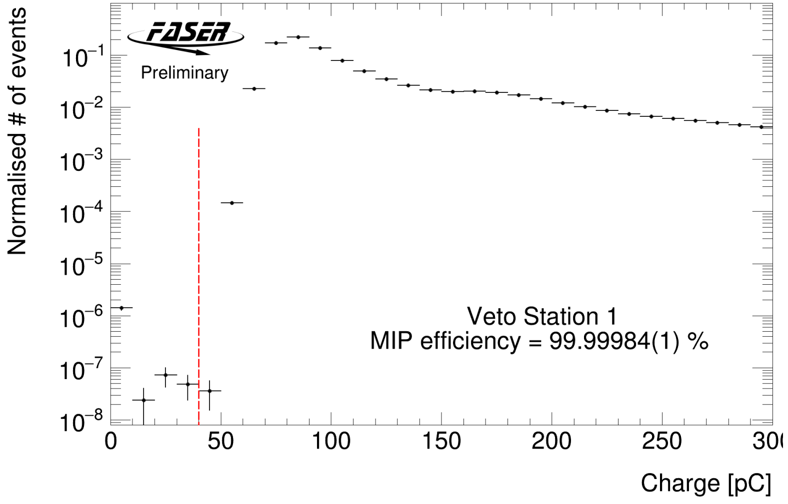


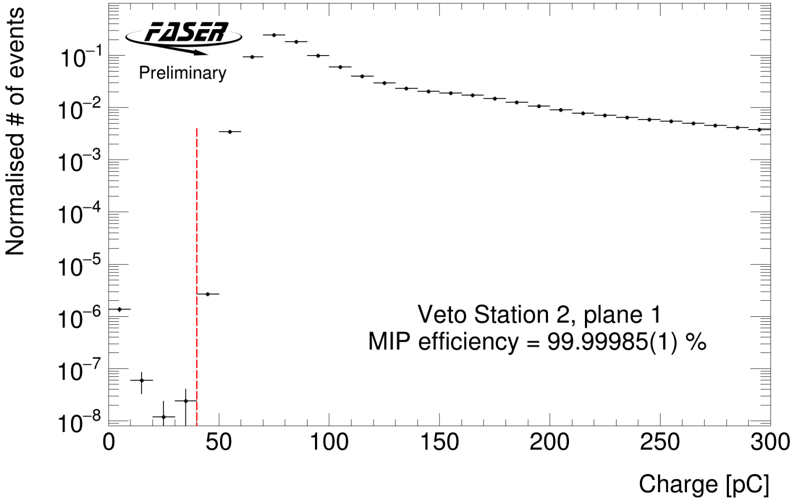
Detector Performance: Veto Scintillators

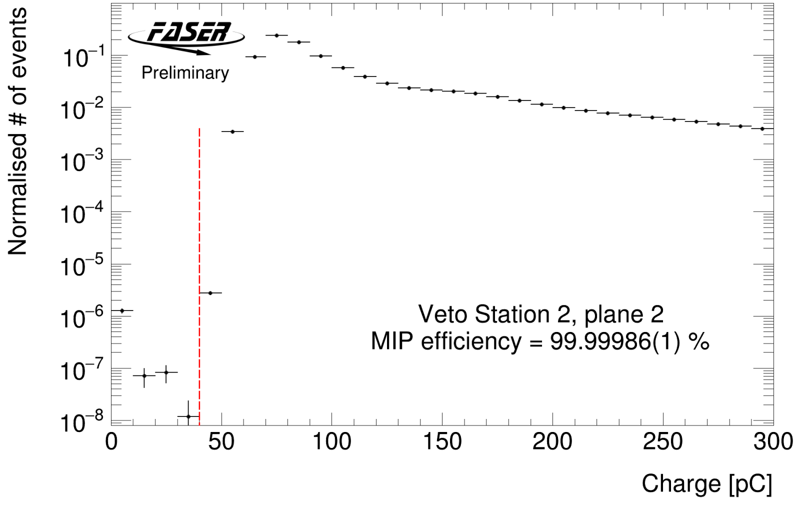
- Veto efficiency measured extrapolating tracks triggered by timing scint. to corresponding layer
  - No requirement on other scintillator layers
  - Layer efficiencies found to be uncorrelated
  - All layers found to have inefficiencies < 2 x 10^{-5}





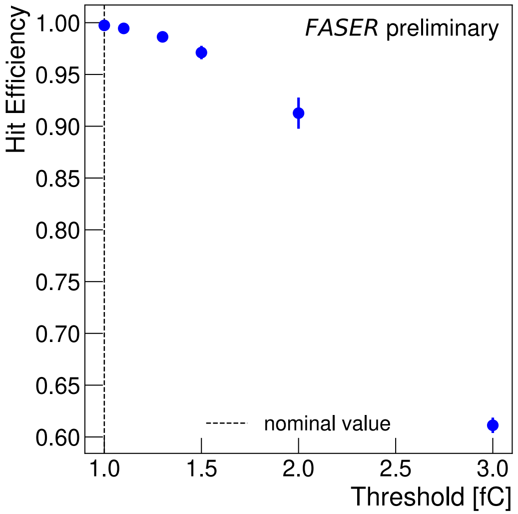


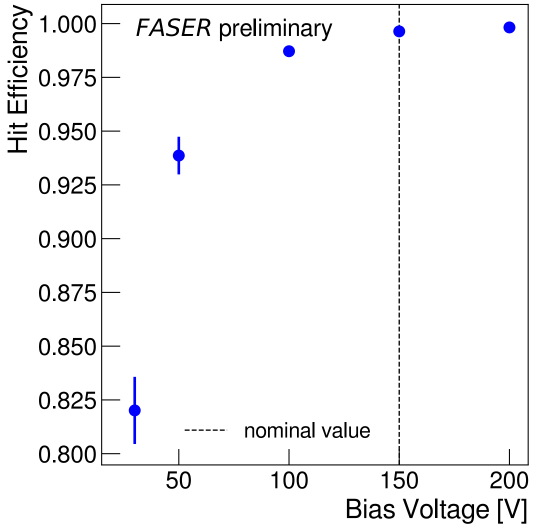




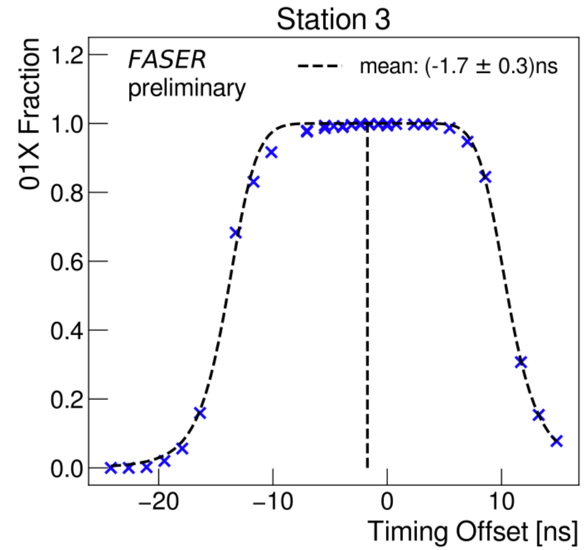
Detector Performance: Tracker

- Hit efficiency 99.64% @ 150 V bias and 1 fC threshold

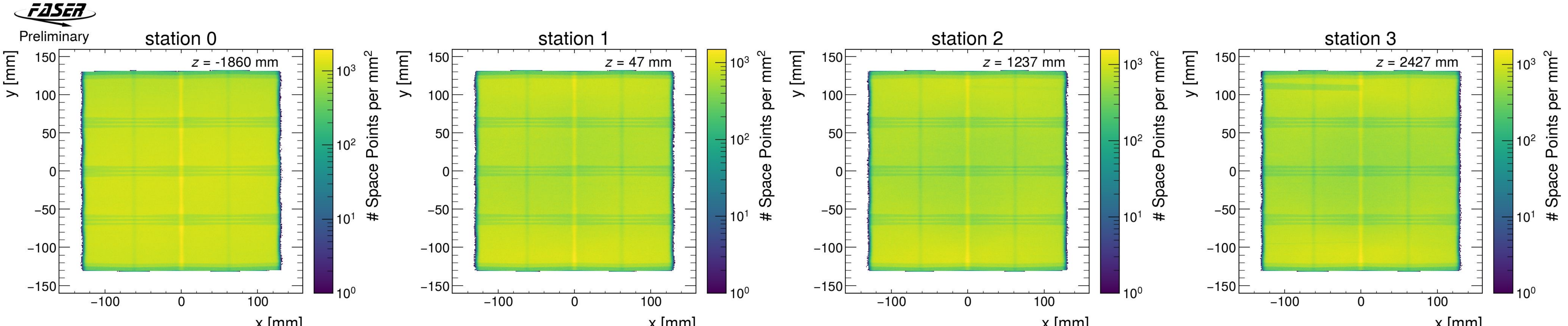




- Tracker fully timed in wrt LHC clock

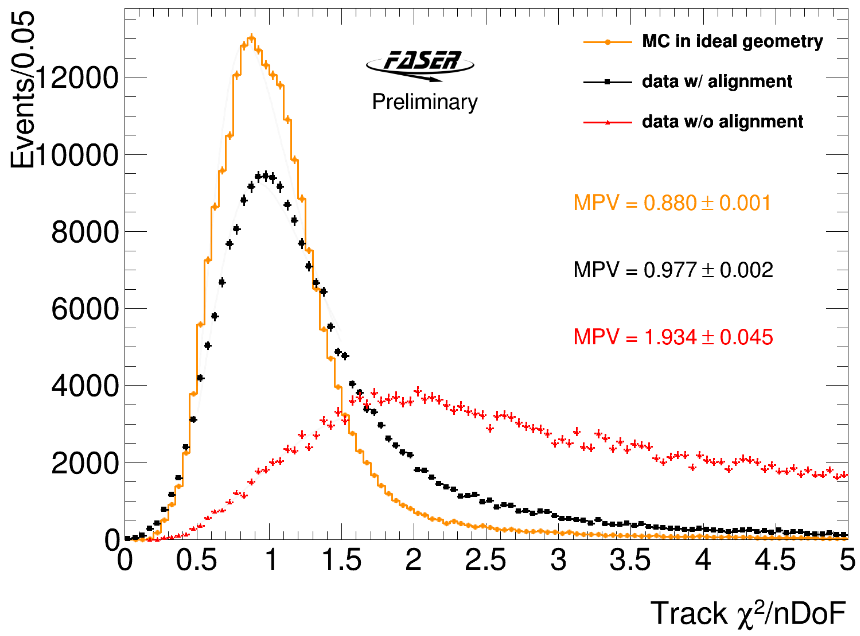


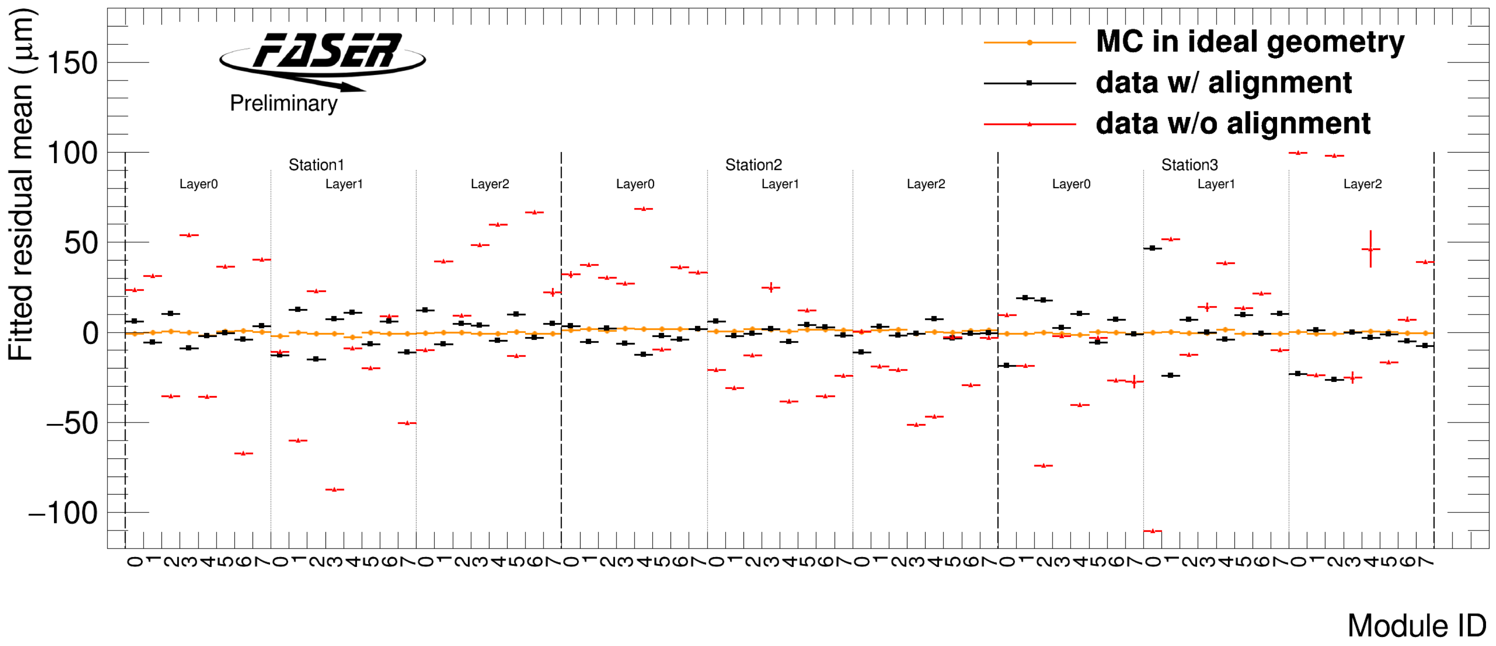
- <0.5% dead/noisy strips (inefficiency at edges expected)

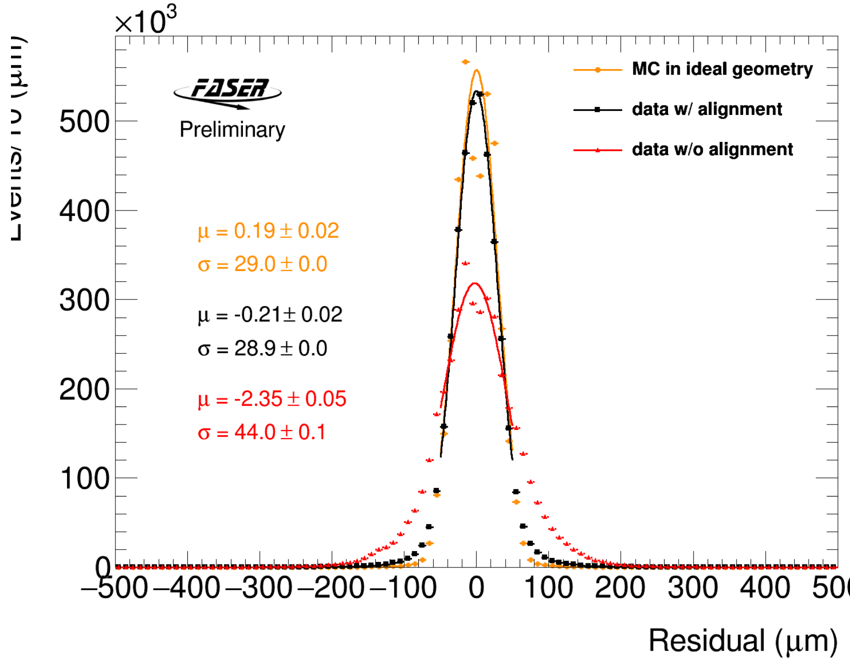


Detector Performance: Alignment

- Tracker aligned using iterative local χ^2 method
  - Validated using simulation with misalignment
- Currently only aligning two most sensitive parameters
  - Vertical shift and in-plane rotation
- Aligned residuals close to ideal geometry simulation

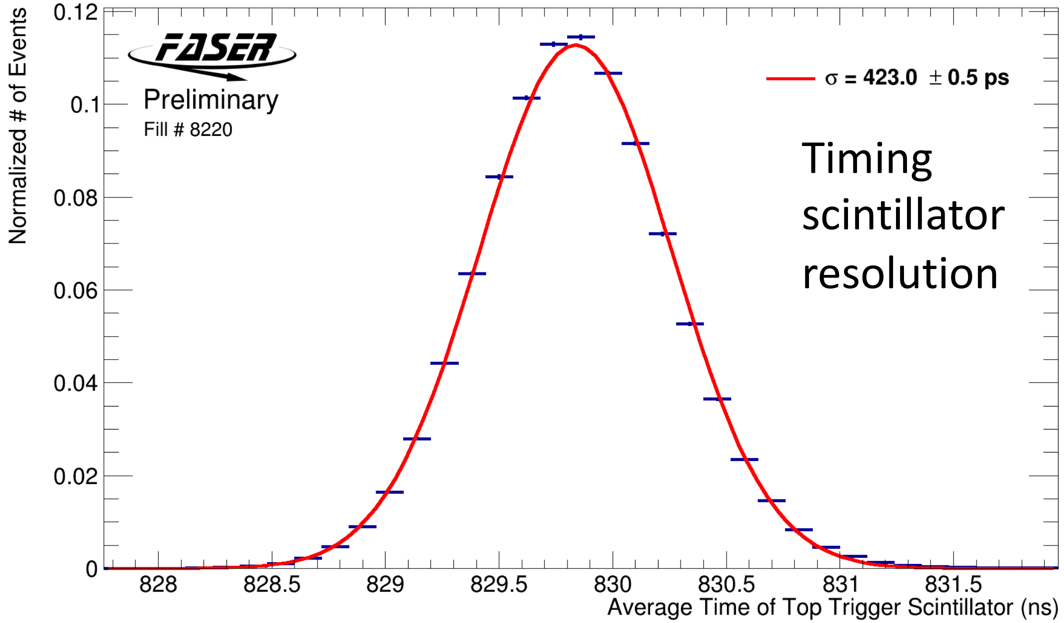


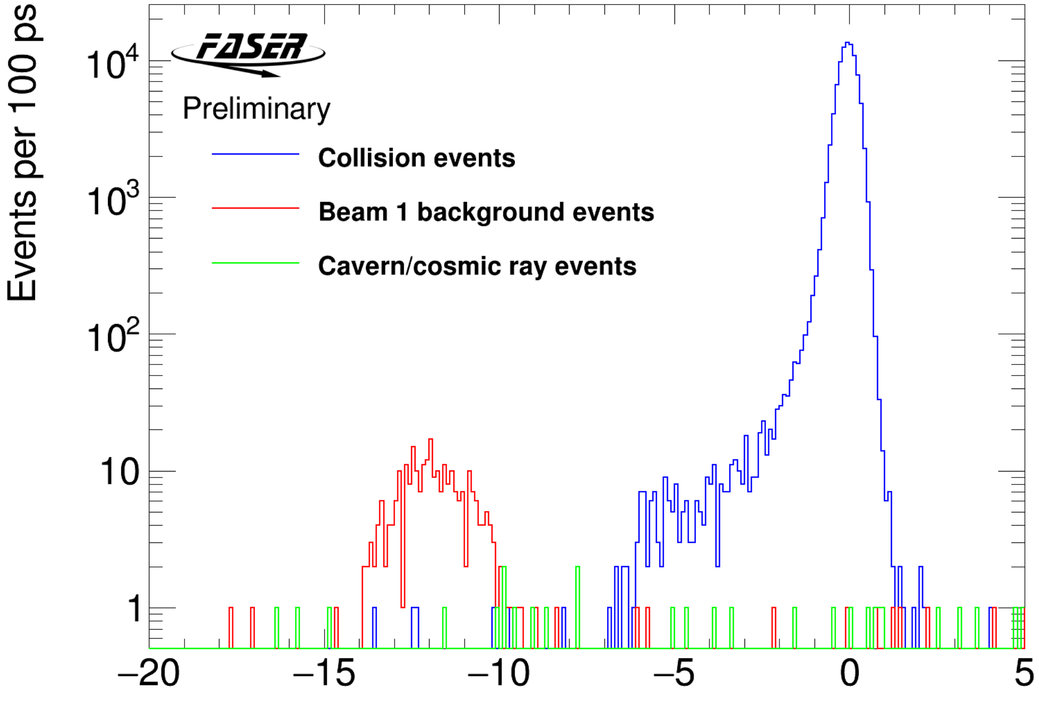




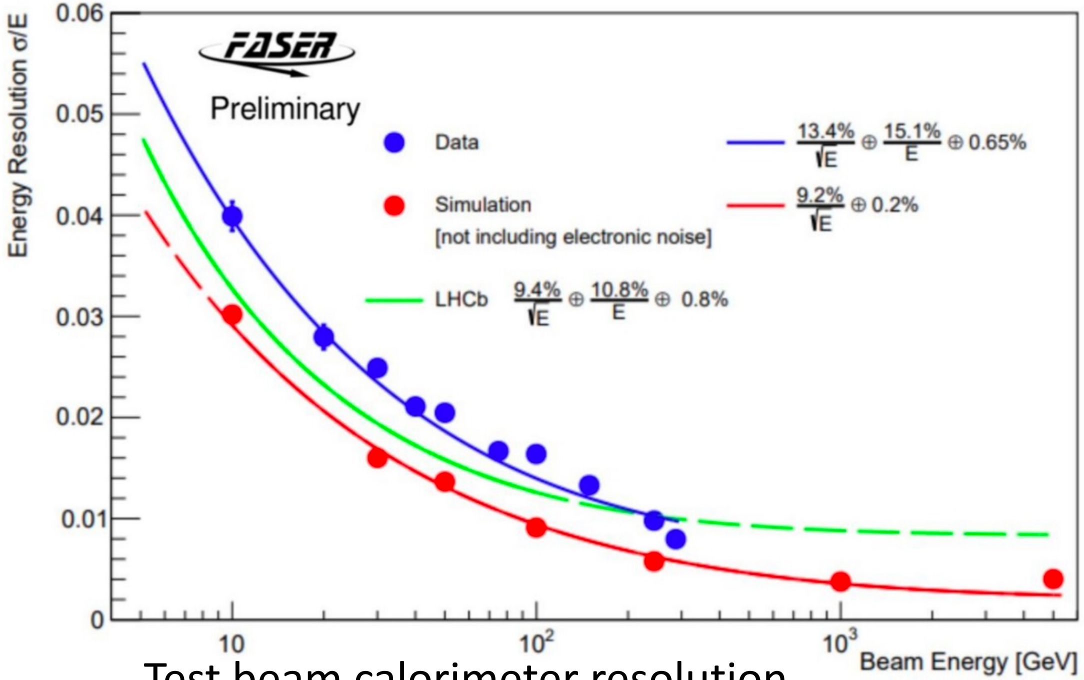
Detector Perf.: Timing and Calo

- Calorimeter resolution measured in test beam
  - Better than 1% at high energy
- Precision timing of both scintillator and calorimeter
  - Not used in current analyses





Calo timing for different events

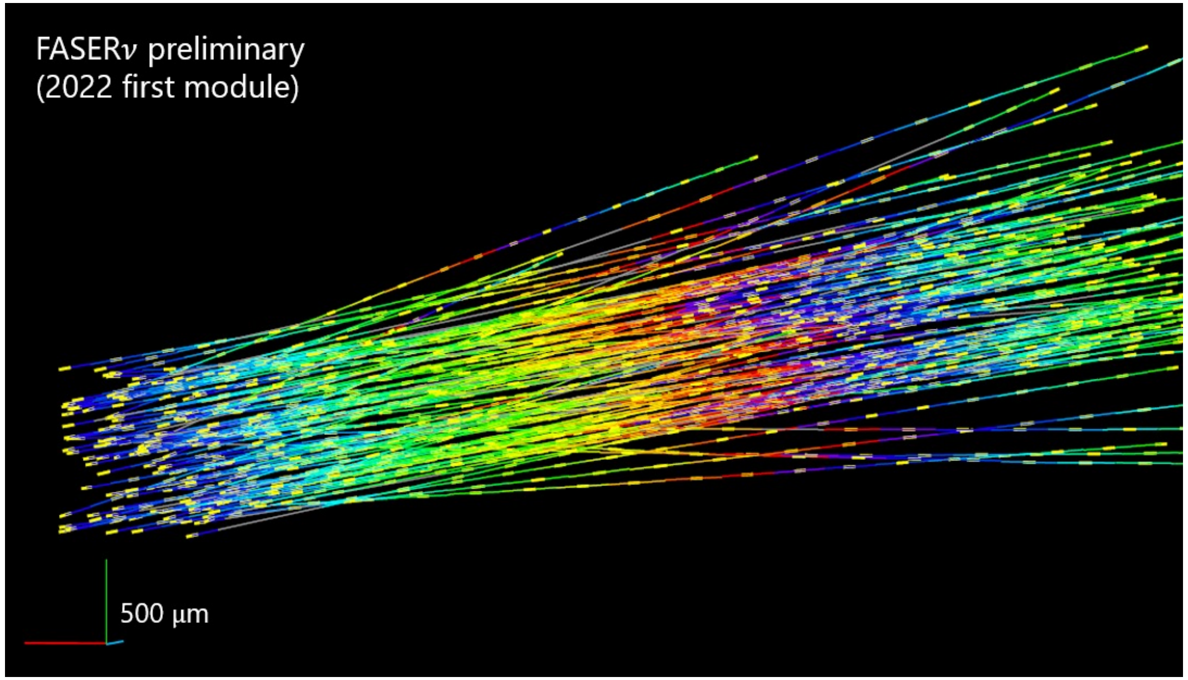


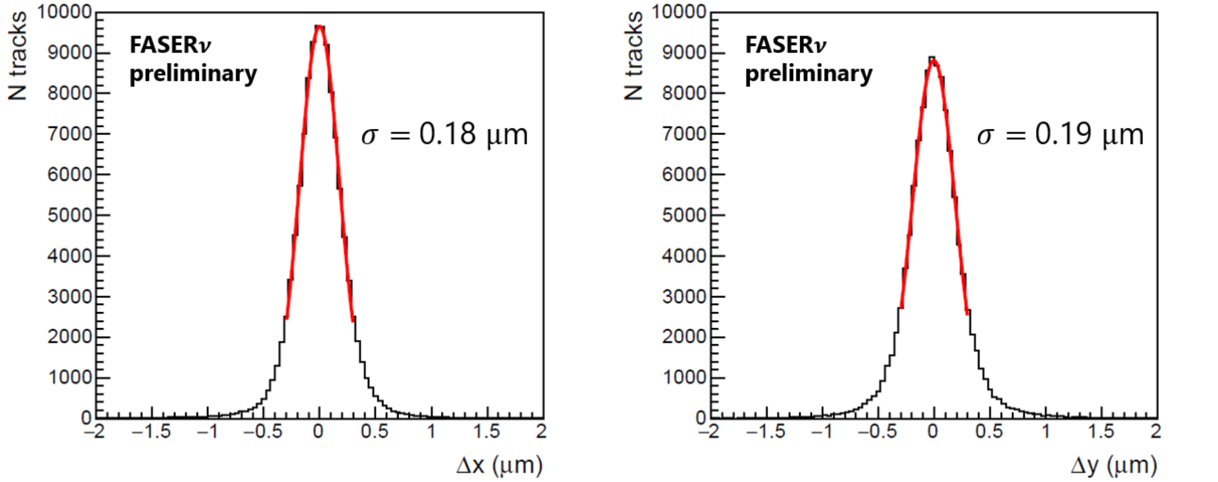
Test beam calorimeter resolution

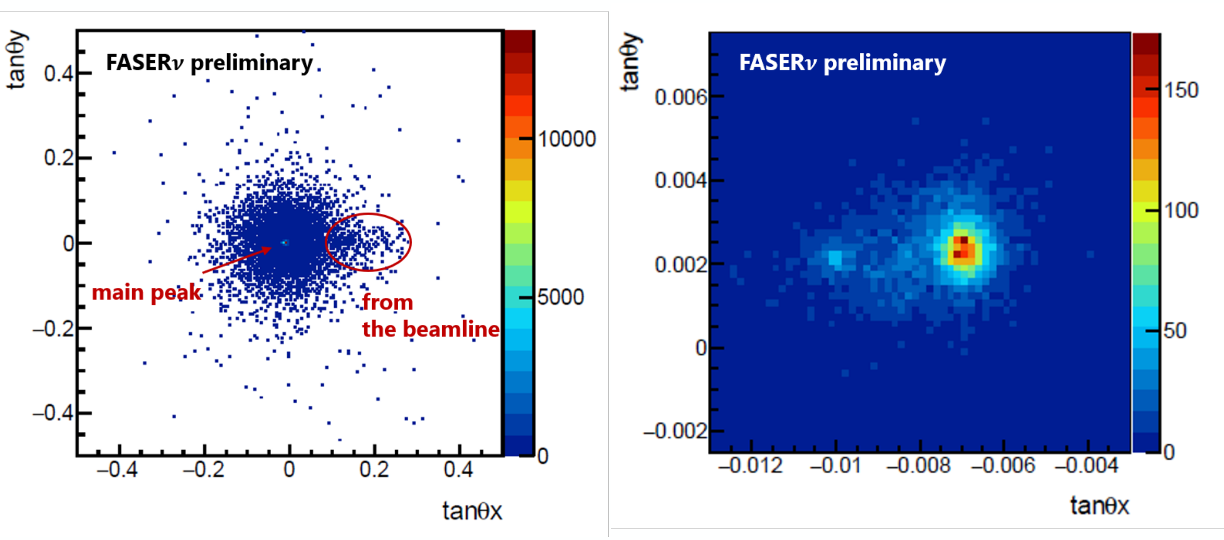
Detector Performance: Emulsion

- Track multiplicity and angular distribution measured in initial partial FASERν emulsion
  - Consistent with FLUKA simulation

- Excellent hit resol (0.2 μm) after layer alignment





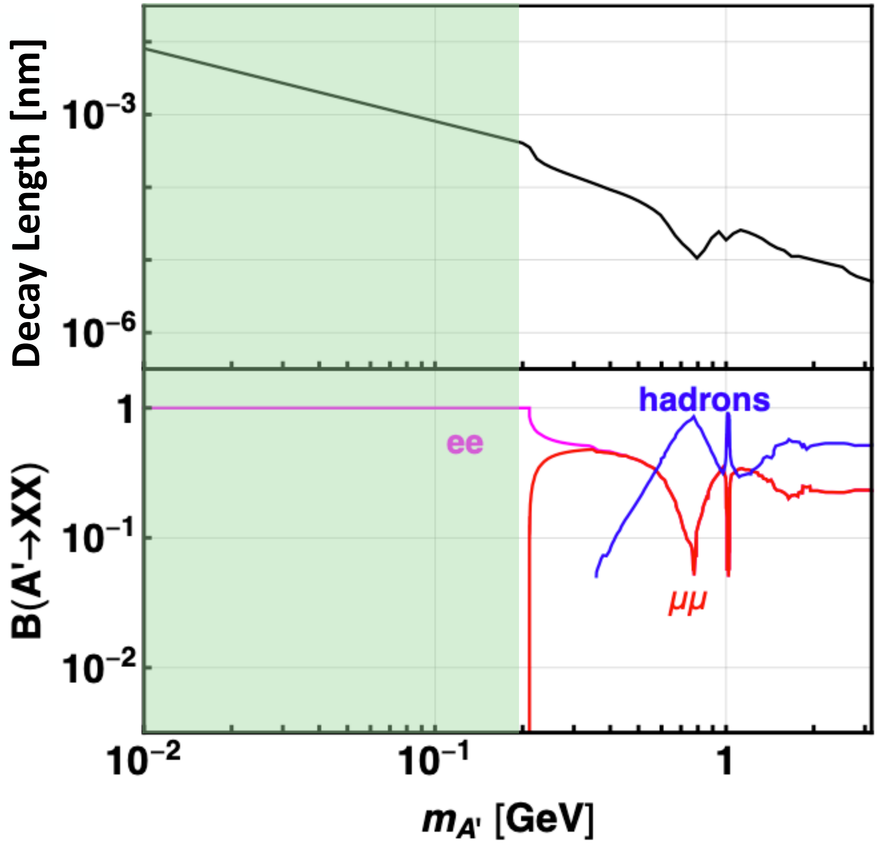


Dark Photon Search

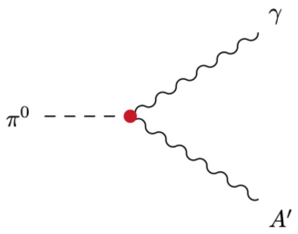
- Several new physics models propose a hidden sector
  - With a mediator acting as a portal to the SM

$$\mathcal{L} \supset \frac{1}{2} m_{A'}^2 A'^2 - \epsilon\, e \sum_f q_f \bar{f} \not{A}' f$$

- One of best motivated is extra U(1) symmetry
  - Gives rise to additional vector field: dark photon (A'), weakly coupling to SM via kinetic mixing (ε) with SM γ



- MeV A's produced mainly in meson decays at LHC



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

- FASER targets small ε, where A' has long decay length

$$\bar{d} = c\,\frac{1}{\Gamma_{A'}}\,\gamma_{A'}\beta_{A'} \approx (80\ \mathrm{m})\ B_e \left[\frac{10^{-5}}{\epsilon}\right]^2 \left[\frac{E_{A'}}{\mathrm{TeV}}\right]$$

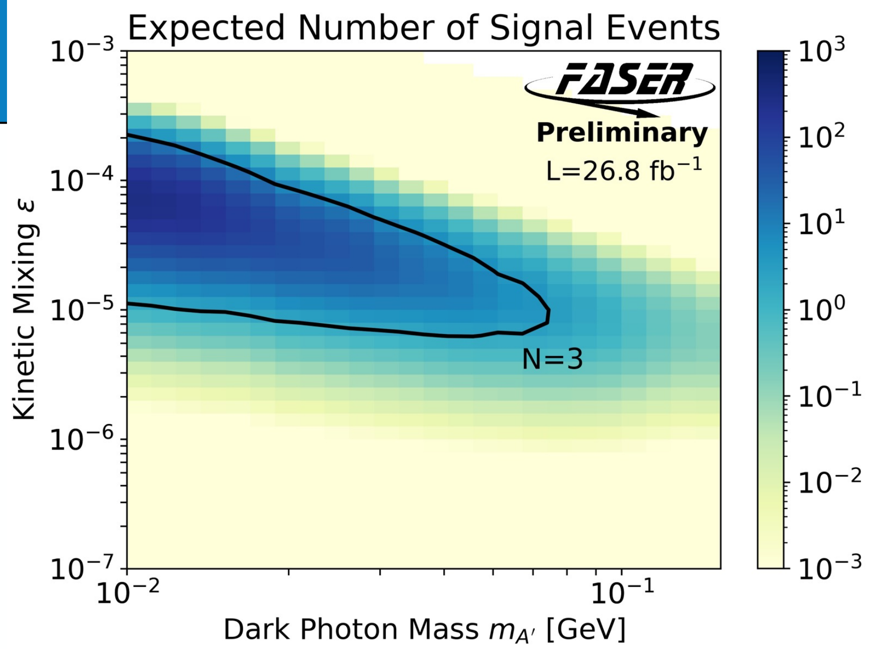
  - Below $2m_\mu$ A' has 100% decay to e^+e^- pair

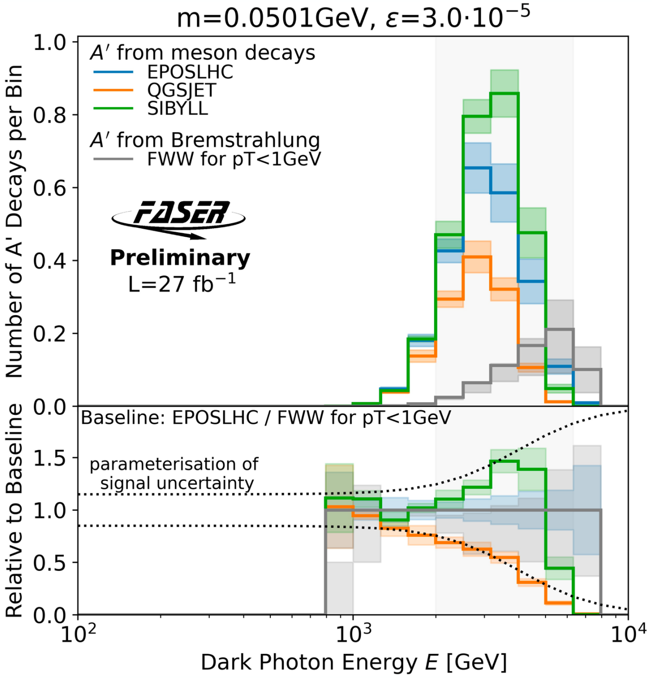
Dark Photon Signal

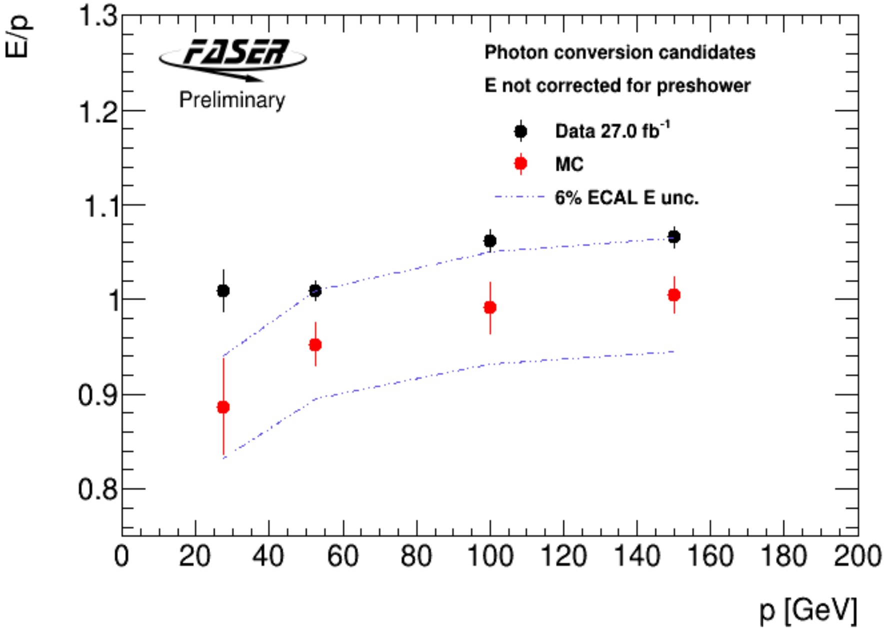
- A′ → e^+e^- decays in FASER volume simulated with FORESEE
  - π^0 and η via EPOS-LHC generator
  - Subdominant dark bremstrahlung via FWW
- Generator uncertainty from difference to QGSJET/SIBYLL
  - Parameterised based on A′ energy

$$\frac{\Delta N}{N} = \frac{0.15 + (E_{A'}/4\ \mathrm{TeV})^3}{1 + (E_{A'}/4\ \mathrm{TeV})^3}$$

- Experimental uncertainties
  - Tracking efficiency
    - 15% for close-by tracks
    - Estimated from overlay
  - Calo E scale
    - 6% at 500 GeV
    - Cross-checked with E/p
  - Momentum scale/resol.
    - 5% each
    - Negligible effect







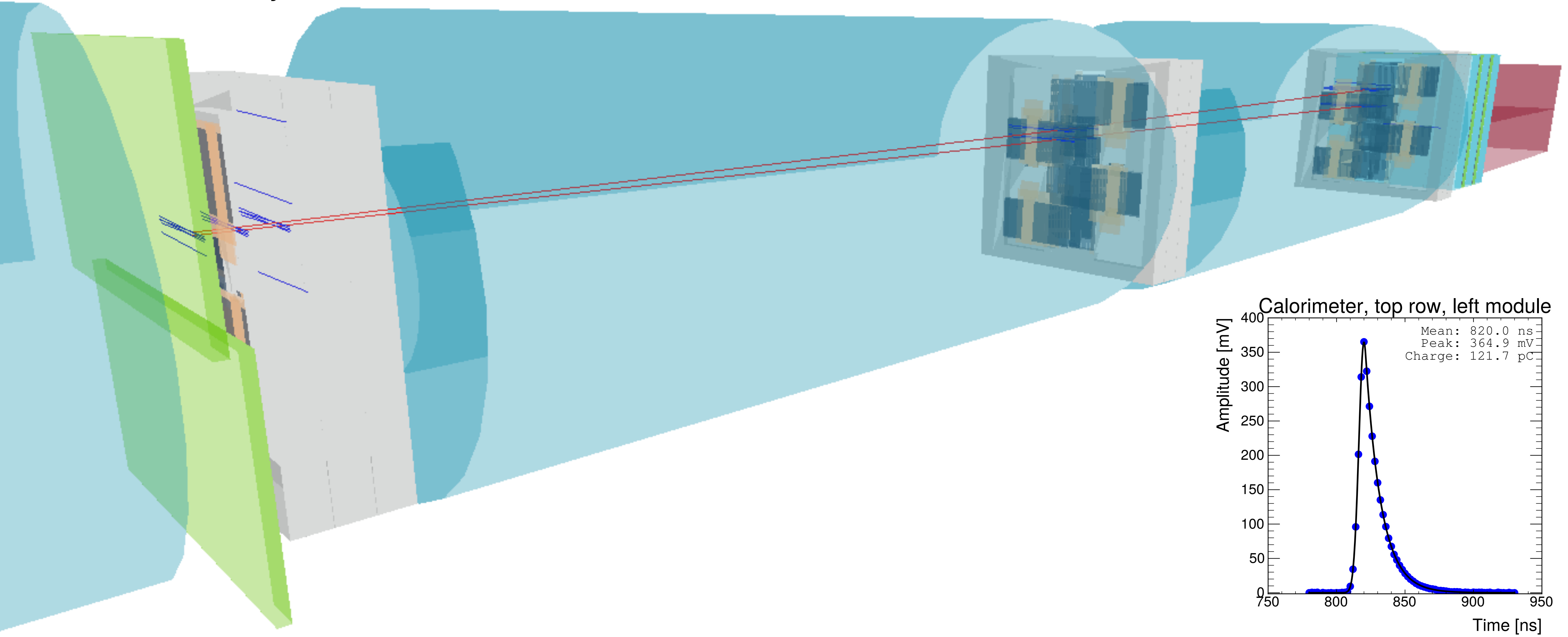
Dark Photon: Event Display (1)

FASER

Simulation Preliminary

Calorimeter Energy: 645.2 GeV
Momentum: 420.4 GeV, 21.5 GeV

- Simulated dark photon event



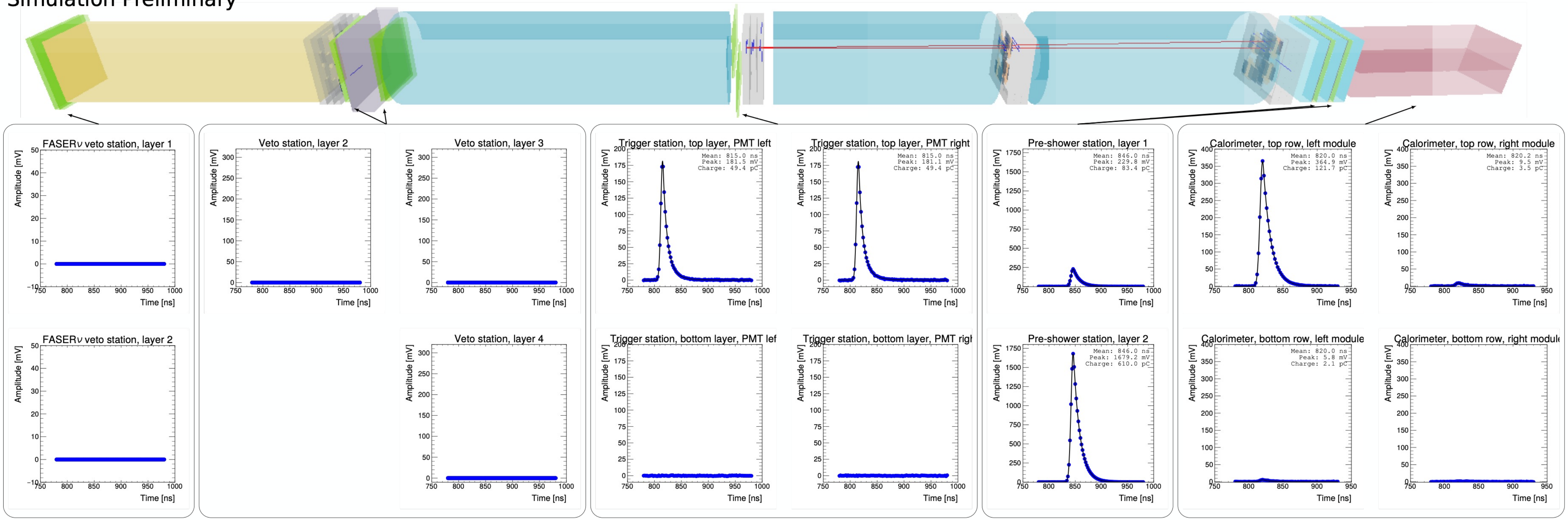
Dark Photon: Event Display (2)

- Simulated dark photon event

FASER

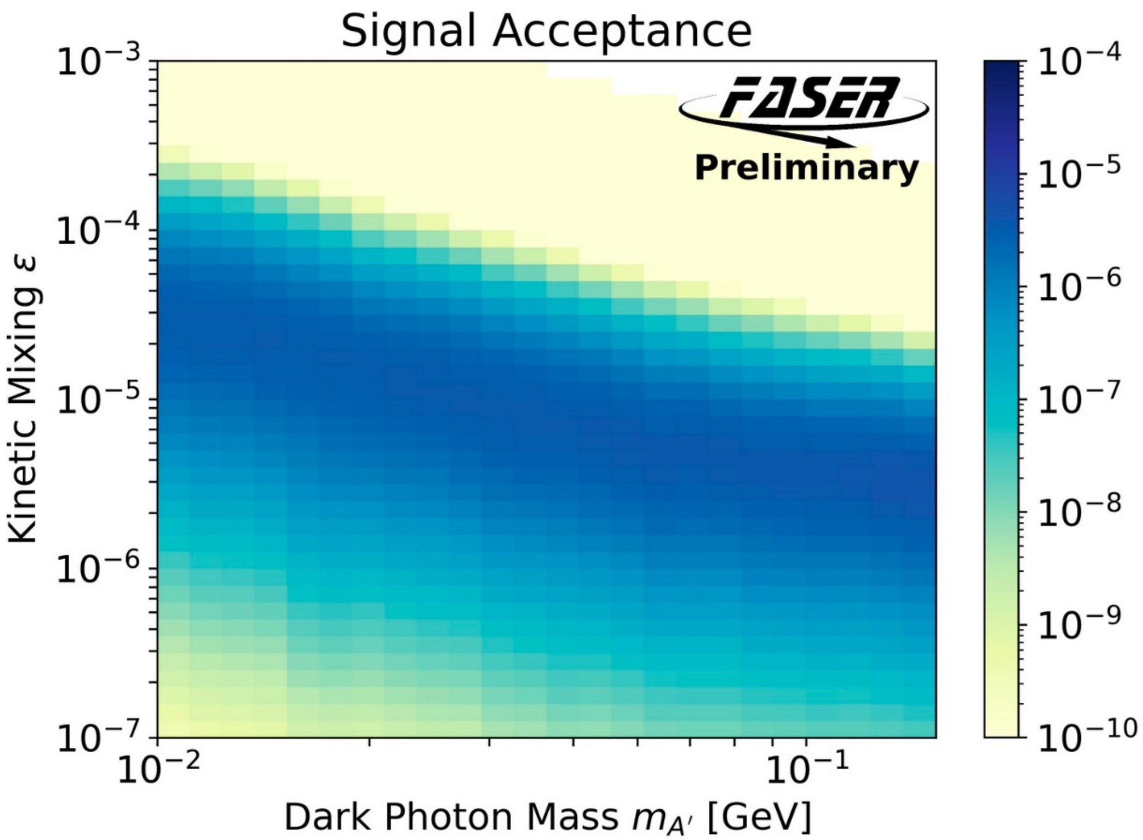
Calorimeter Energy: 645.2 GeV
Momentum: 420.4 GeV, 21.5 GeV

Simulation Preliminary



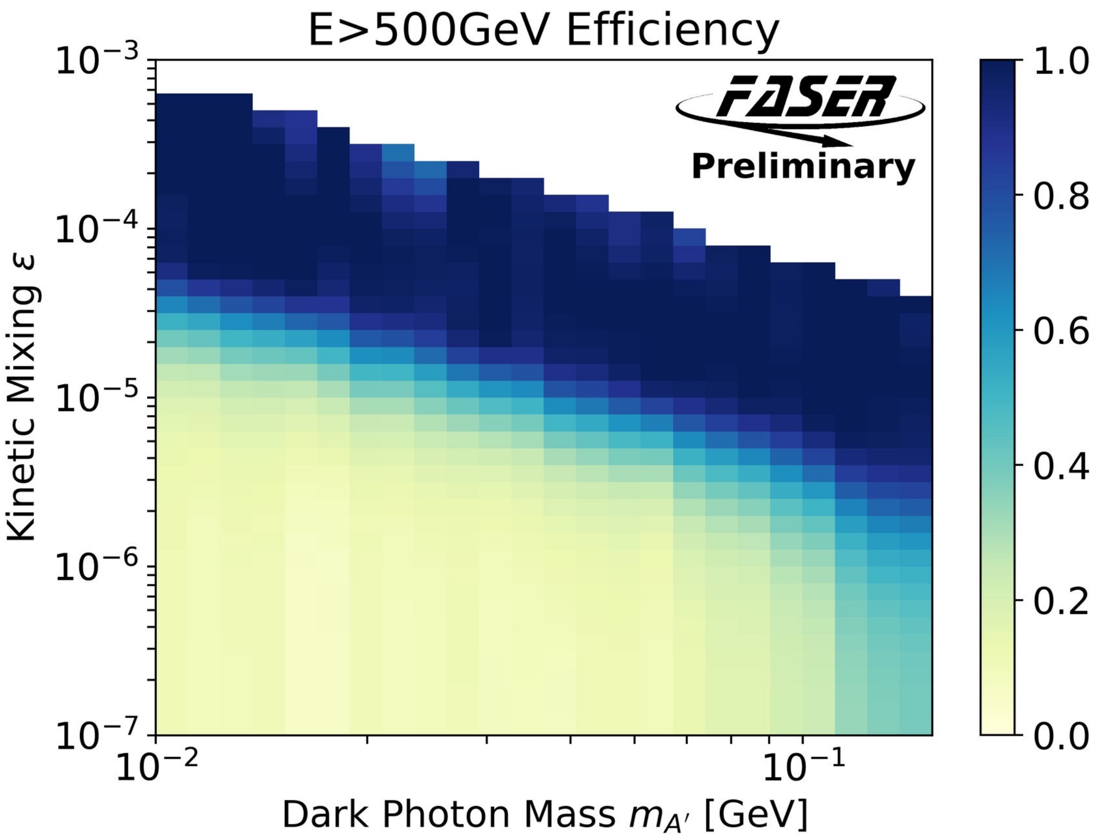
Dark Photon: Signal Acceptance x Efficiency

- Signal acceptance for A' produced in IP1
  - And decaying in FASER decay volume



- Note: FASER solid angle coverage only ~10^{-8}

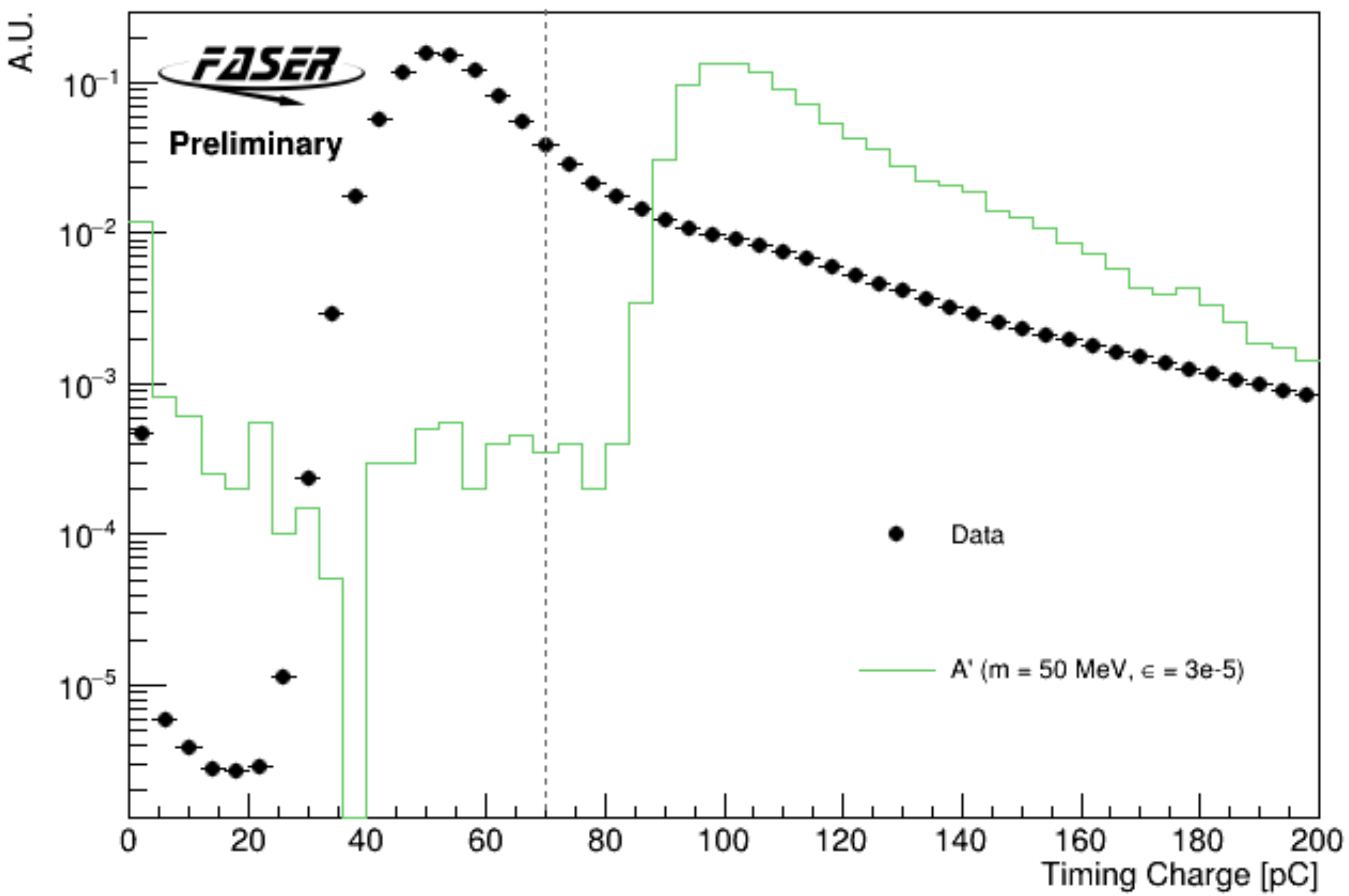
- Efficiency of calorimeter E > 500 GeV
  - For A' decaying in FASER decay volume



- Efficiency of other selections ~40%

Dark Photon: Timing Scintillator Selection

- Timing cut of 70 pC is ~100% efficiency for signal
  - Supresses a large fraction of data, which are predominantly single-track events



Dark Photon: Cut Flow

- Efficiency of analysis selection for data and example signal
  - Note the data was preselected to have ≥ 1 track (no quality cuts) in the event
- Overall signal efficiency ≈ 40 %
  - While reducing background to 0

Cut	Data		Signal ($\varepsilon = 3 \times 10^{-5}$, $m_{A'} = 25.1\,\text{MeV}$)	
	Events	Efficiency	Events	Efficiency
Good collision event	151750788	—	95.3	99.7%
No Veto Signal	1235830	0.814%	94.0	98.4%
Timing/Preshower Signal	313988	0.207%	93.0	97.3%
$\geq$ 1 good track	21329	0.014%	85.2	89.2%
$=$ 2 good tracks	0	0.000%	44.5	46.6%
Track radius $<$ 95 mm	0	0.000%	40.4	42.3%
Calo energy $>$ 500 GeV	0	0.000%	39.7	41.6%

Dark Photon: Neutral Hadron Background

- Select 3-track events where muon produces two other particles
  - A minority of these are neutral hadrons (Ks) + continuing muon (assumed to have highest momentum)
- Look at number of 3 track events with 100 < Ecalo < 500 GeV
  - Compared to number of 2 track events (muon missed) that don't pass the veto with Ecalo < 100 GeV
- Use this to estimate # events with Ecalo > 500 GeV where muon is not seen
  - Assuming E spectrum of neutral hadron is same whether muon is seen or not
- However, most of these are γ conversions in veto material that would fail event selection
  - Removed by E/p < 0.5 for two-track system (i.e. without muon)
  - But this biases Ecalo → use simulated two-track p_Z to estimate events with Ecalo > 100 or 500 GeV
- From 3-track events in data strong evidence that most Ks decay in FASERν and fire veto
  - Hence scale the neutral hardon events with Ecal > 500 GeV by fraction of 3-track events decaying after veto → $(2.2 \pm 3.1) \times 10^{-4}$

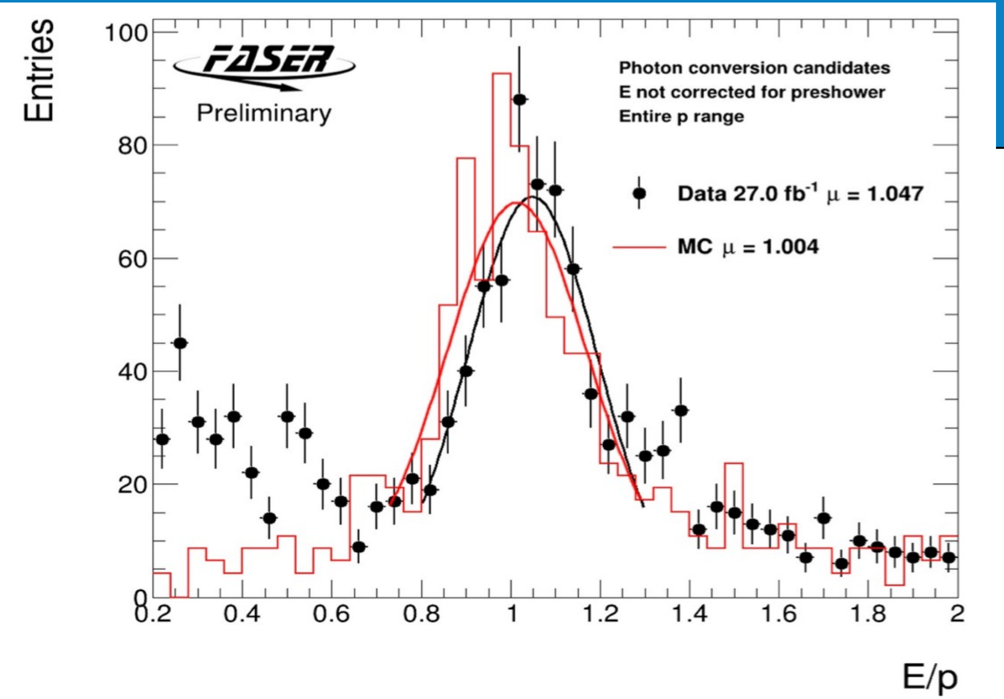
Dark Photon: Systematic Uncertainties Summary

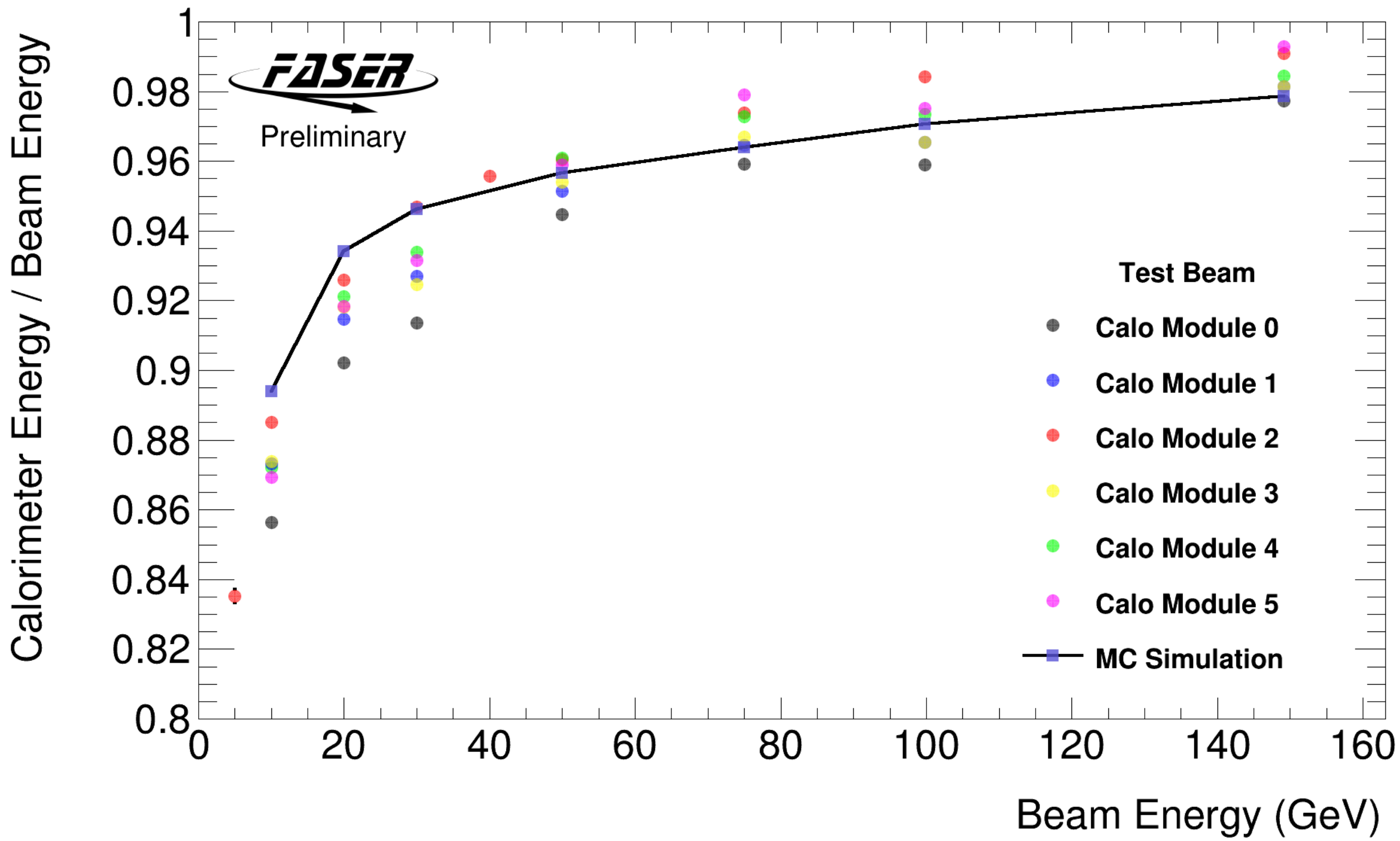
- Complete list of systematic uncertainties and their impact on the signal yield
  - Numbers in parenthesis are the effect on signal in previous unexcluded FASER reach

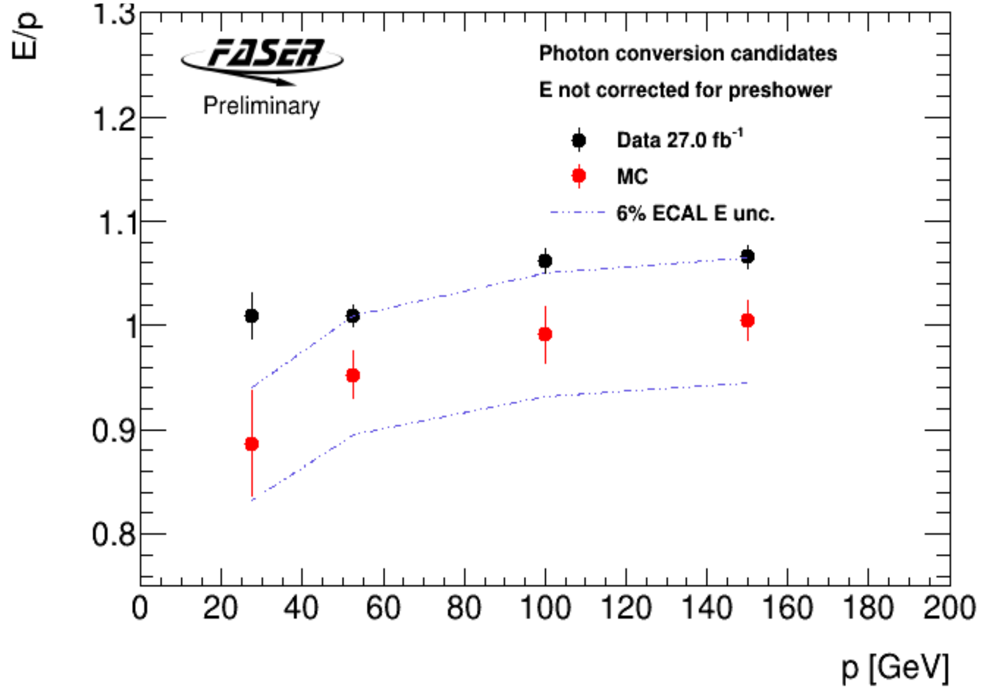
Source	Value	Effect on signal yield
Theory, Statistics and Luminosity		
Dark photon cross-section	$\frac{0.15+(E_{A'}/4\text{TeV})^3}{1+(E_{A'}/4\text{TeV})^3}$	15-65% (15-45%)
Luminosity	2.2%	2.2%
MC Statistics	$\sqrt{\sum W^2}$	1-3% (1-2%)
Tracking		
Momentum Scale	5%	$< 0.5\%$
Momentum Resolution	5%	$< 0.5\%$
Single Track Efficiency	3%	3%
Two-track Efficiency	15%	15%
Calorimetry		
Calo E scale	6%	0-8% ($< 1\%$)

Dark Photon: Calo Energy Scale

- Calorimeter energy scale and uncertainty evaluated based on test beam data and in-situ MIP calibration
  - Validated using conversion events (μ with e^+e^- pair)
  - E/p in data and MC agrees within 6%

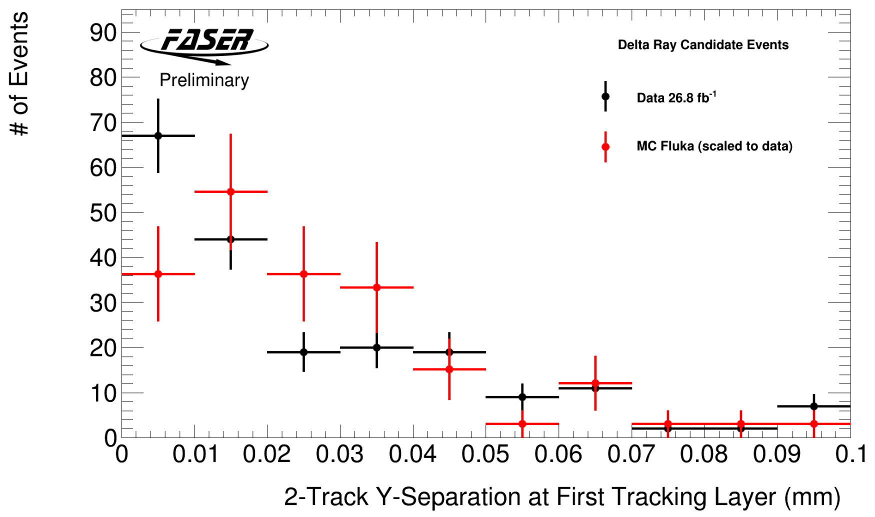






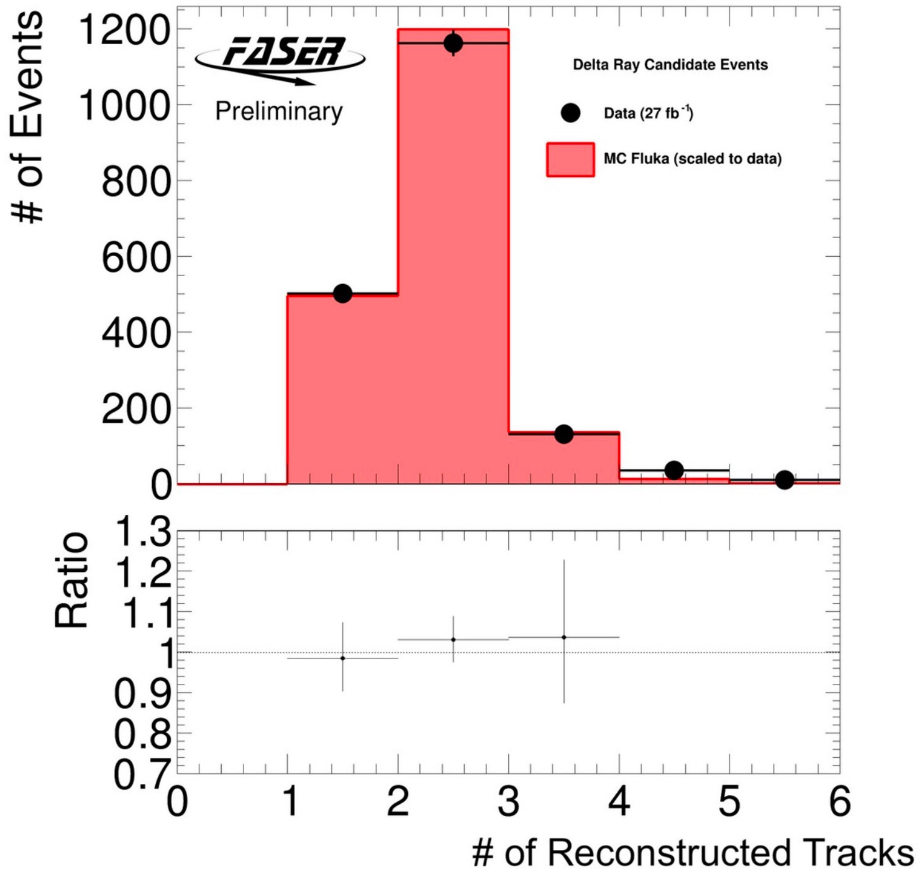
Dark Photon: Tracking Systematics

- Single track efficiency studies in muons events with track segments found in each station
  - 98.4% in data with data/MC agreement at 1.5% level
- Tracking efficiency lower for two close by tracks (~60%) → studied in two ways:
  1. Overlaying hits from 2 single track events in either data or MC and measuring efficiency to find 2 tracks
     - Correct MC by ~15% difference and conservatively apply full correction as a MC systematic
  2. Conversions and delta-ray events where require 1 less track than needed (i.e. 3 or 2 respectively)
     - With additional track segments + preshower/calo signals consistent with additional EM signal



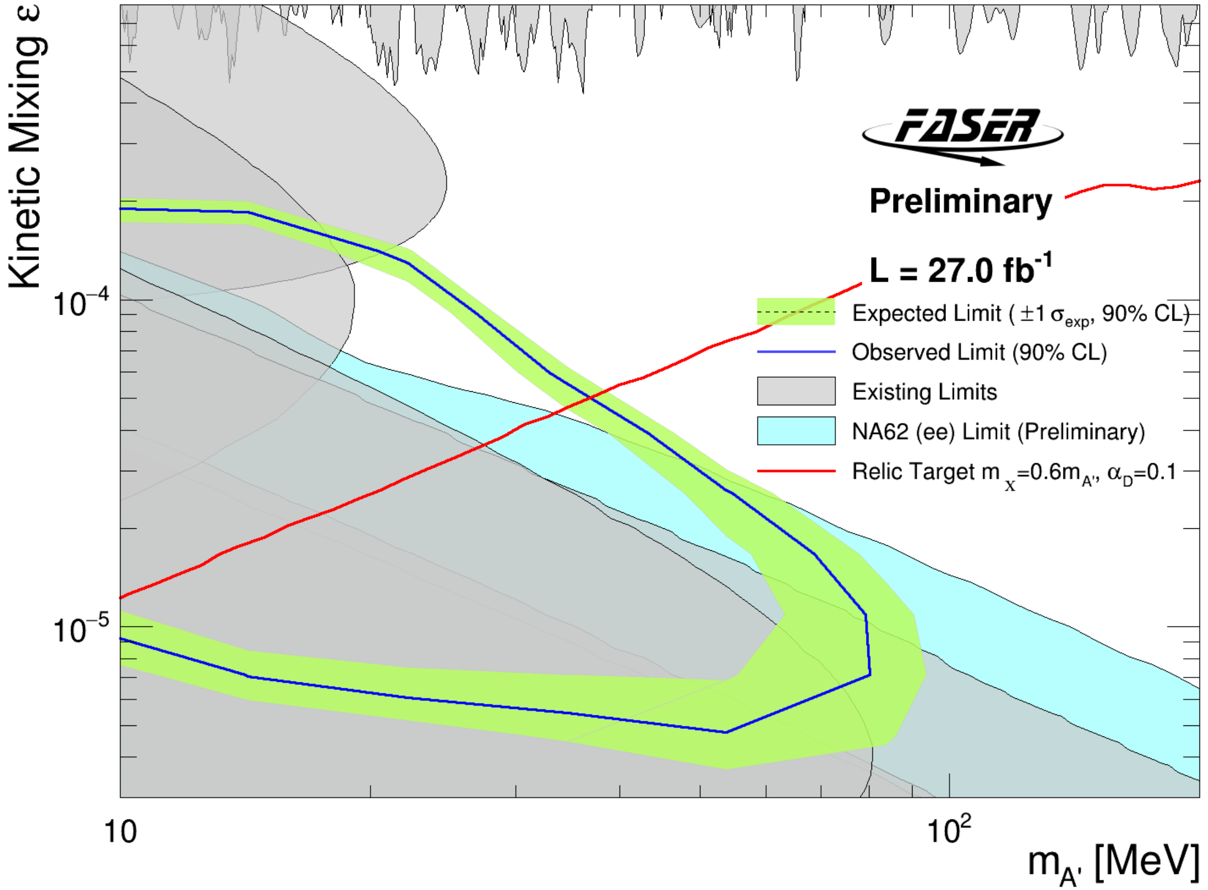
Two-track separation in delta-ray like events

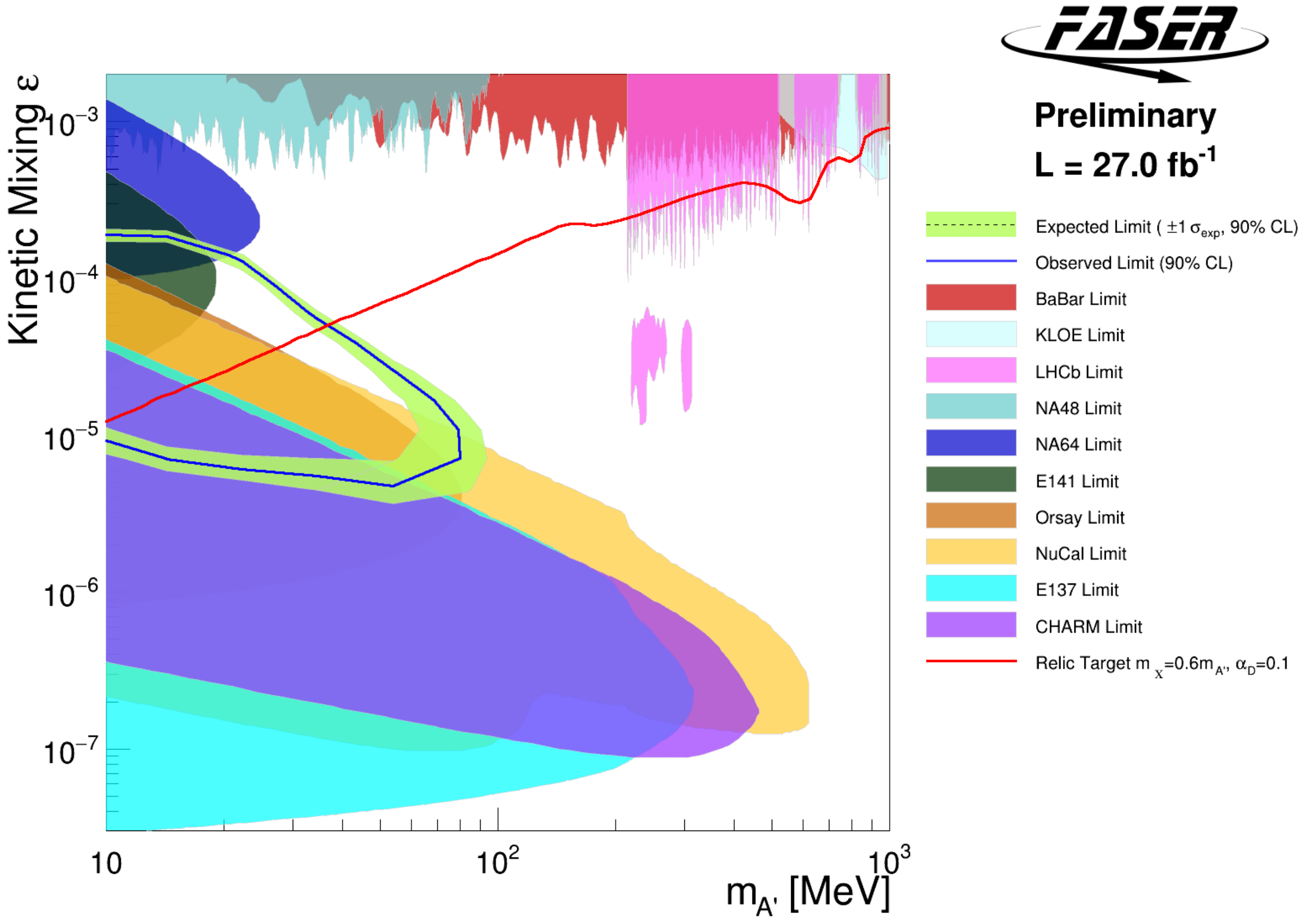
Tracks in delta-ray like events



Dark Photon: Additional Limits

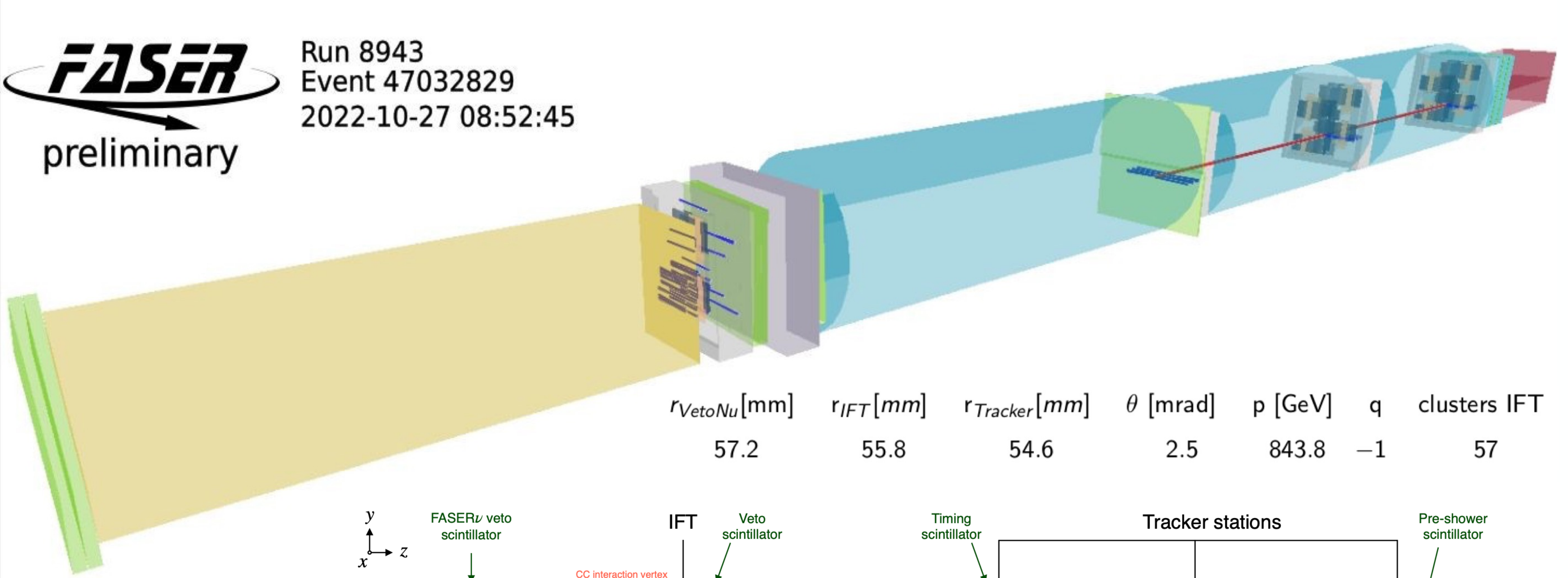
- Limits including recent prelim NA62 results
  - Partially overlaps with FASER exclusion
- Alternative limit plot showing individual previous limits available from DarkCast





- Note FASER limits very similar at 95% CL and 90% CL

Neutrinos: Event Display



r_{VetoNu}[mm]	r_{IFT}[mm]	$r_{Tracker}$[mm]	θ [mrad]	p [GeV]	q	clusters IFT
57.2	55.8	54.6	2.5	843.8	−1	57

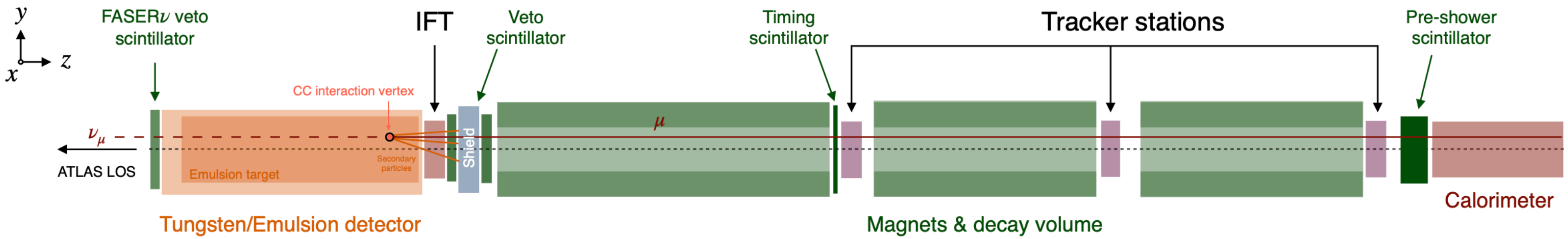
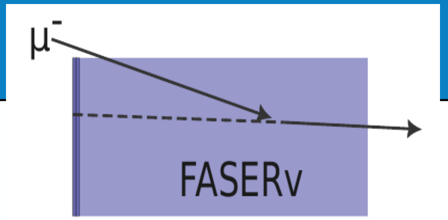
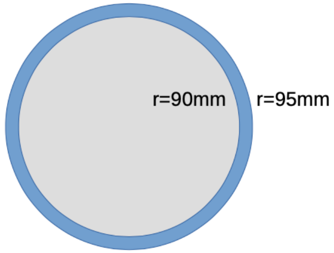


FIG. 1. Illustration of the FASER detector with a muon neutrino undergoing a CC interaction in the emulsion target.

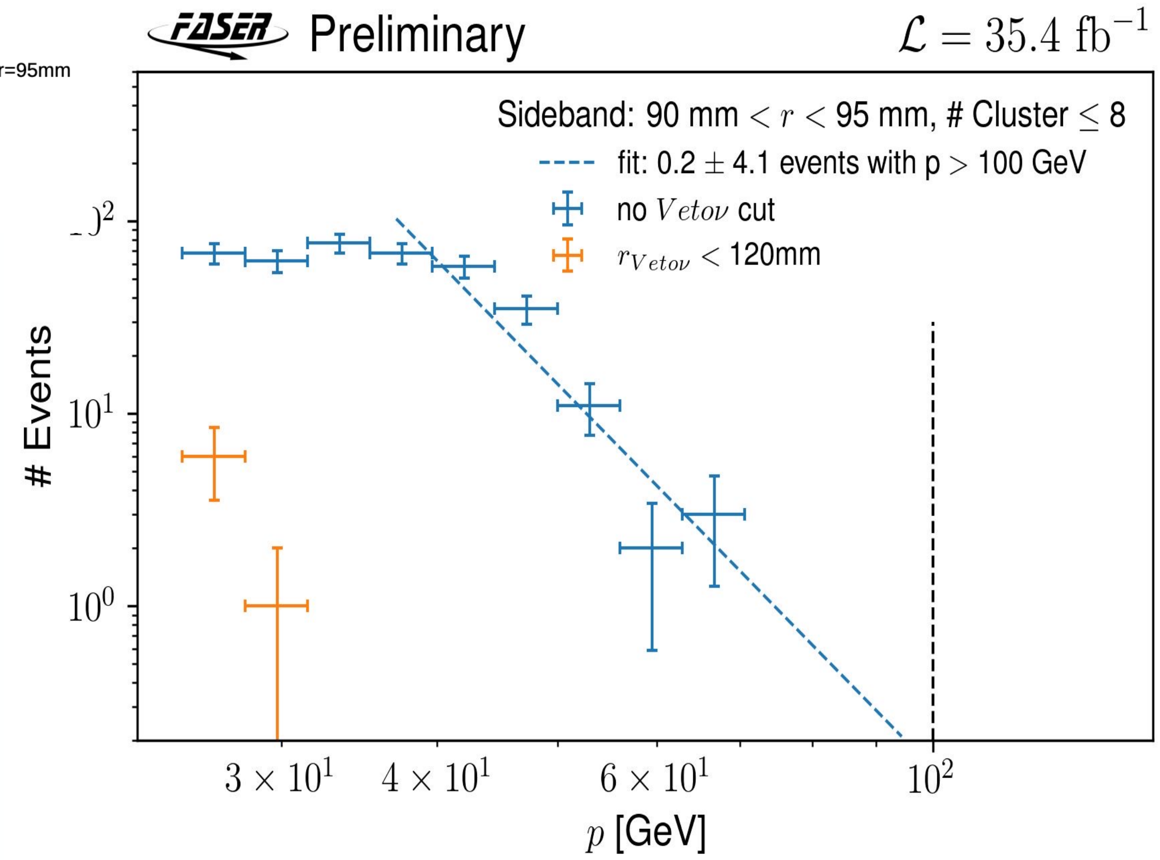
Neutrinos: Geometric Background



- Measure geometric background by counting # events in SB and scale to SR
- SB defined to enhance muons missing FASERν veto that still give a track in the spectrometer
  - Single IFT segment in 90 < r < 95 mm anulus
  - Loosened momentum requirement
  - No FASERν veto radius requirement
  - Negligible neutrino background

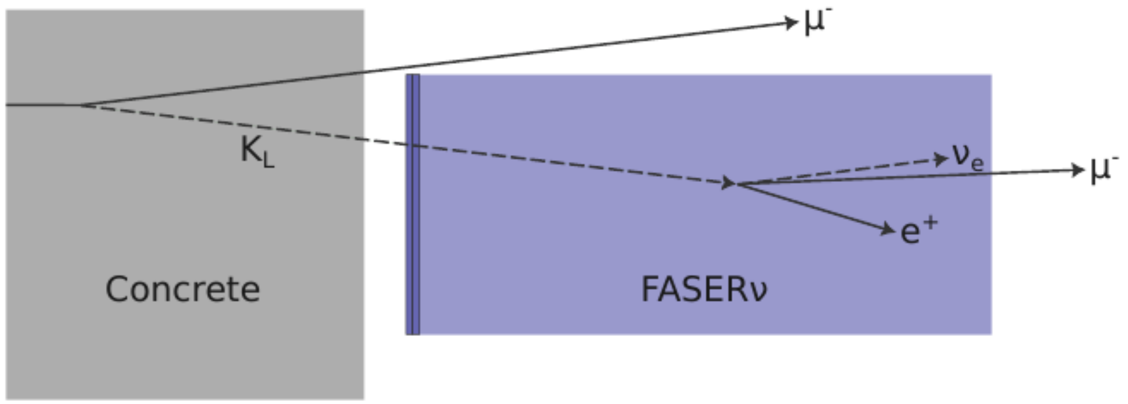


- Fit mom. to extrapolate to p > 100 GeV
- Scale to rate of events with r_{VetoNu} < 120 mm
  - 0 events so use 5.9 events as 3σ upper limit
- Scale from anulus to full acceptance
  - Using large angle muon simulation
- Expect 0.08 ± 1.83 events



Neutrinos: Neutral Hadron Background

- Simulated 10^9 μ^+ and μ^- events
  - Start from FLUKA Spectra
  - G4 propagation through last 8 m of rock
  - Number of hadrons with p > 100 GeV reaching FASER ≈ 300.
- Estimate fraction of these passing event selection
  - Simulate kaons (Ks/Kl) and neutrons with p > 100 GeV following expected spectra
  - Most are absorbed in tungsten with no high-momentum track → only small fraction pass



- Scale neutral hadrons produced by muons reaching FASER by fraction passing selection
  - Predicts N = 0.11 ± 0.06 events

Neutrinos: fit

- Fit to events with 0, 1 or 2 front veto hits
  - Splitting those were 1 hit is in 1st/2nd layer
- Construct likelihood as product of Poissions
  - With additional 3 Gaussian constraints for Neutral hadron background, Geometric background and the extrapolation factor

$$\mathcal{L} = \prod_i^4 \mathcal{P}(n_i|\nu_i) \cdot \prod_j^3 \mathcal{G}_j$$

obs exp

- Determine number in each category
  - Along with inefficiencies of 2 forward vetos, which are found to be close to expected vals.

Inefficiencies:
6 / 9 x 10^{-8}

1 - p1 = 99.999994(3)%
1 - p2 = 99.999991(4)%

n_0: A neutrino enriched category from events that pass all event selection steps.

n_{10}: Events for which the first layer of the FASERν scintillator produces a charge of >40 pC in the PMT, but no signal with sufficient charge is seen in the second layer.

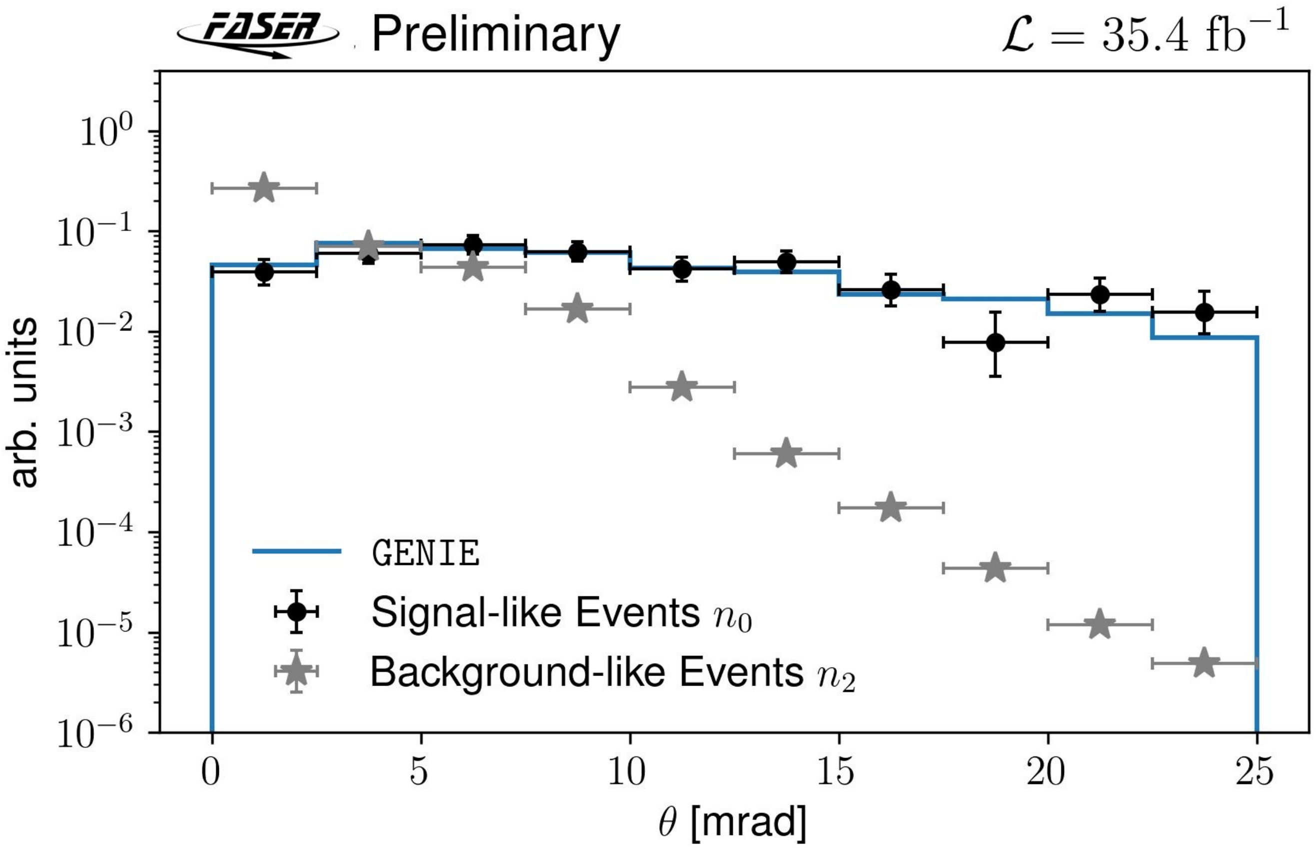
n_{01}: Analogous events for which more than 40 pC in the PMT was observed in the second layer, but not in the first layer.

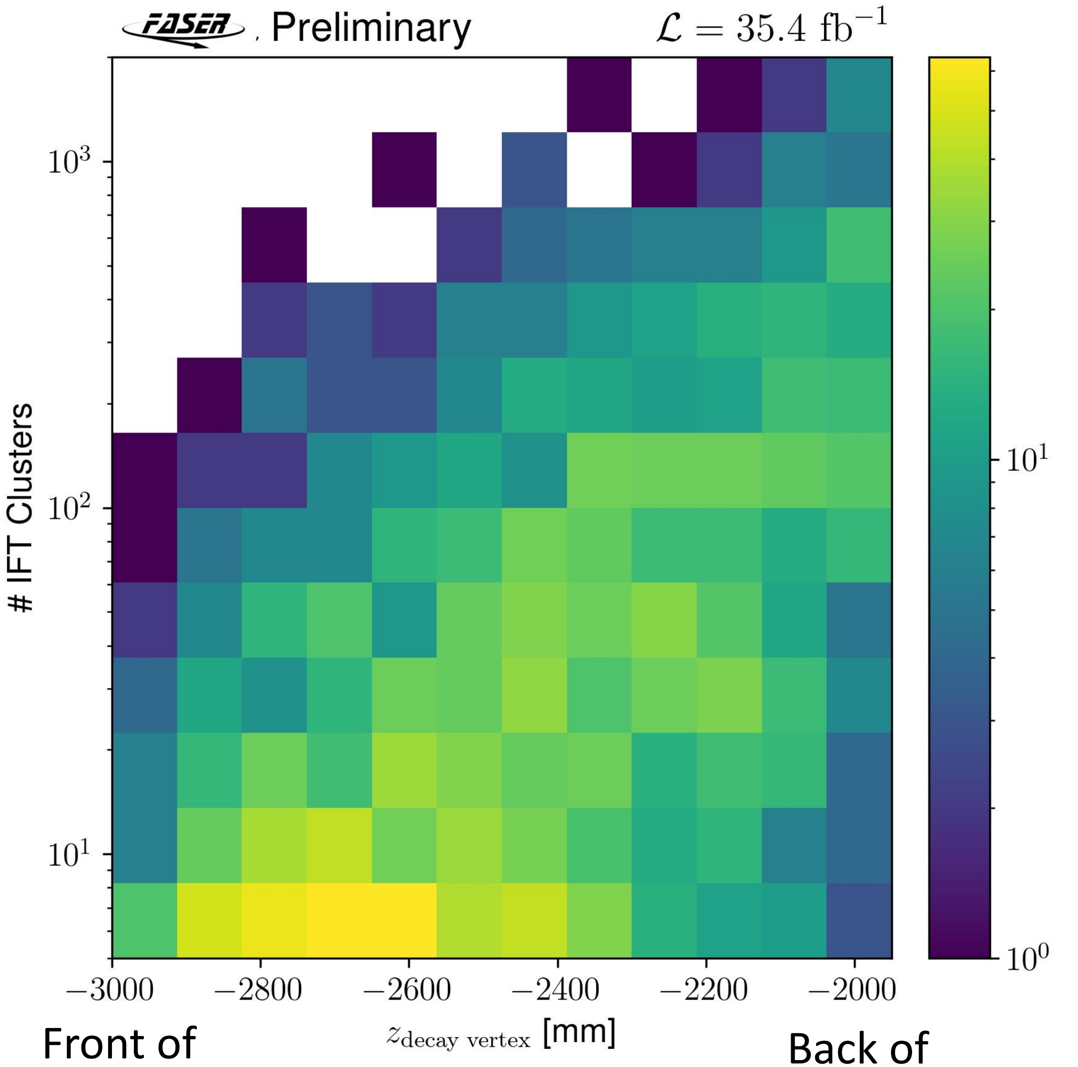
n_2: Events for which both layers observe more than 40 pC of charge.

Category	Events	Expectation
n_0	153	$\nu_\nu + \nu_b \cdot p_1 \cdot p_2 + \nu_{\rm had} + \nu_{\rm geo} \cdot \eta_{\rm geo}$
n_{10}	4	$\nu_b \cdot (1 - p_1) \cdot p_2$
n_{01}	6	$\nu_b \cdot p_1 \cdot (1 - p_2)$
n_2	64014695	$\nu_b \cdot (1 - p_1) \cdot (1 - p_2)$

Neutrinos: Additional Distributions

- Number of clusters in IFT depends on interaction point
  - Further forward interactions have less clusters
- Neutrino tracks have larger angular range
  - Compared to n_2 background events





Front of emulsion

Back of emulsion

FASER Collaboration

- 87 members across 24 institutes from 10 countries

CERN
UNIVERSITÉ DE GENÈVE
KYUSHU UNIVERSITY
UC IRVINE
UNIVERSITÄT BERN
Technion Israel Institute of Technology
NAGOYA UNIVERSITY
UNIVERSITY of WASHINGTON
JOHANNES GUTENBERG UNIVERSITÄT MAINZ JG|U
מכון ויצמן למדע WEIZMANN INSTITUTE OF SCIENCE
KEK
UNIVERSITY OF OREGON
UNIVERSITÄT BONN
INFN
清華大學 Tsinghua University
MANCHESTER 1824 The University of Manchester
ROYAL HOLLOWAY UNIVERSITY OF LONDON
UNIVERSITY OF LIVERPOOL
CHIBA UNIVERSITY
UNIVERSITY OF SUSSEX
Nikhef
DESY.
JINR
UNIVERSITÀ DEGLI STUDI DI NAPOLI FEDERICO II

FASER Publications

- The FASER Detector: arXiv:2207.11427
- The FASER W-Si High Precision Preshower Technical Proposal: CERN Document Server
- The tracking detector of the FASER experiment: NIM 166825 (2022)
- The trigger and data acquisition system of the FASER experiment: JINST 16 P12028 (2021)
- First neutrino interaction candidates at the LHC: PRD 104 L091101 (2021)
- Technical Proposal of FASERν neutrino detector: arXiv:2001.03073
- Detecting and Studying High-Energy Collider Neutrinos with FASER at the LHC: EPJC 80 61 (2020)
- Input to the European Strategy for Particle Physics Update: arXiv:1901.04468
- FASER's Physics Reach for Long-Lived: PRD 99 090511 (2019)
- Letter of Intent: arXiv:1812.09139
- Technical Proposal arXiv:1811.10243