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(for the FASER collaboration)

Results from FASER

Dark photon search CONF note on CERN Document Server

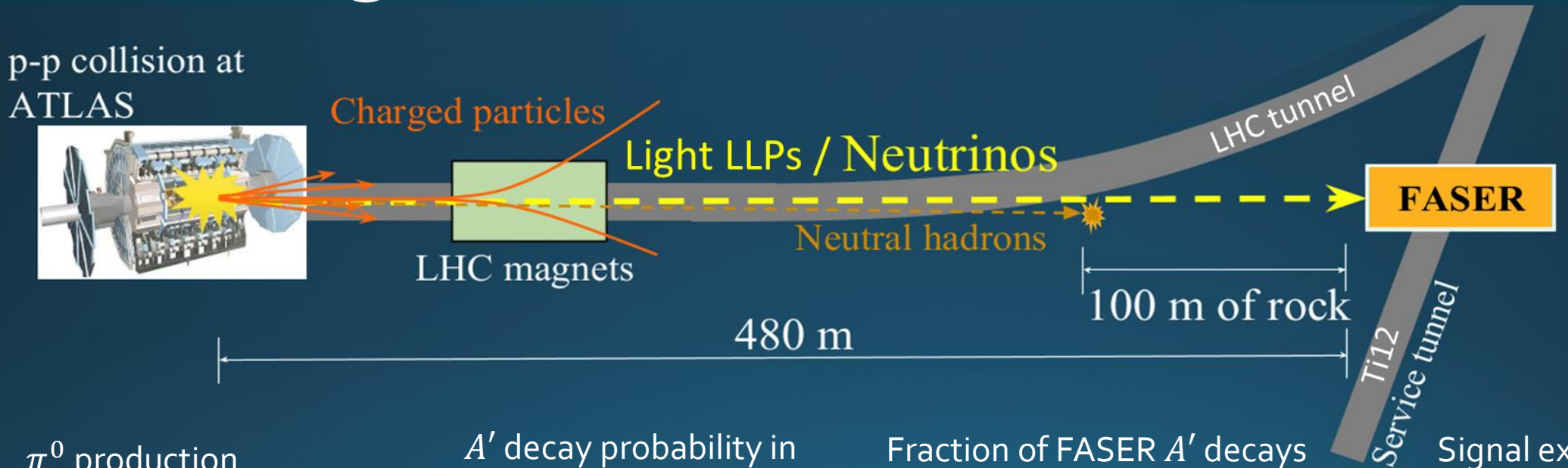
Collider neutrino direct detection paper (submitted to PRL)

Motivation: search for long-lived A'

- Dark photon coupling to Standard Model fermions:
  - $\mathcal{L} \supset \frac{1}{2} m_{A'}^2 A'^2 - \epsilon e \sum_f q_f A'_\mu \bar{f} \gamma^\mu f$
- Assuming $m'_A < 2m_\chi$, $m'_A \sim (\mathrm{MeV} - \mathrm{GeV})$ and $\epsilon \sim (10^{-6} - 10^{-3})$ give thermal relic density in range expected for dark matter
- Dark photon sources at LHC:
  - Neutral pion decay: $\pi^0 \to \gamma A'$
  - Eta meson decay: $\eta \to \gamma A'$
  - Dark bremsstrahlung: $pp \to ppA'$
- For $2m_e < m'_A < 2m_\mu$, $A' \to e^+e^-$ is ~100% of branching ratio
- Long decay length for boosted A', assuming $E'_A \gg m'_A \gg m_e$:
  - $L = c\beta\tau\gamma \approx (80\ \mathrm{m}) \left(\frac{10^{-5}}{\epsilon}\right)^2 \left(\frac{\mathrm{E'_A}}{\mathrm{TeV}}\right) \left(\frac{100\ \mathrm{MeV}}{m'_A}\right)^2$

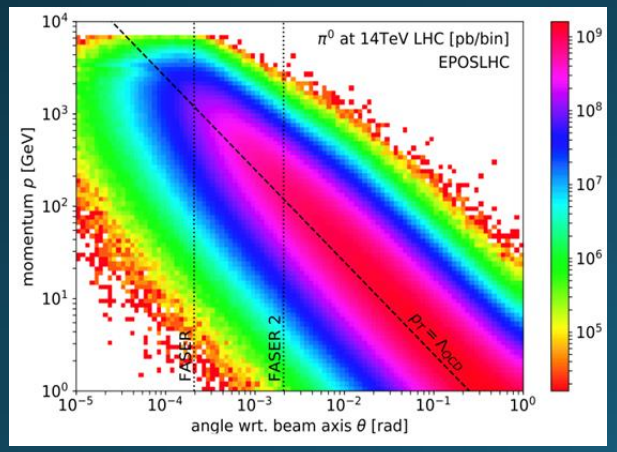
Feng, Galon, Kling and Trojanowski, *Phys. Rev. D* 97 (2018) no. 3, 035001

Looking forward in FASER

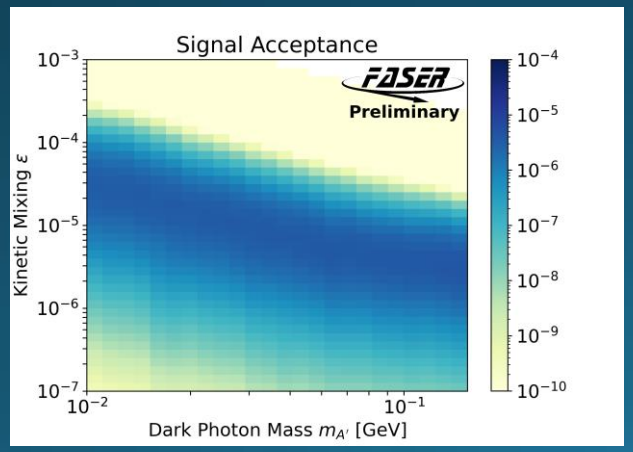


Detector subtends $\sim 10^{-8}$ of solid angle from ATLAS; rely on collimation from boost

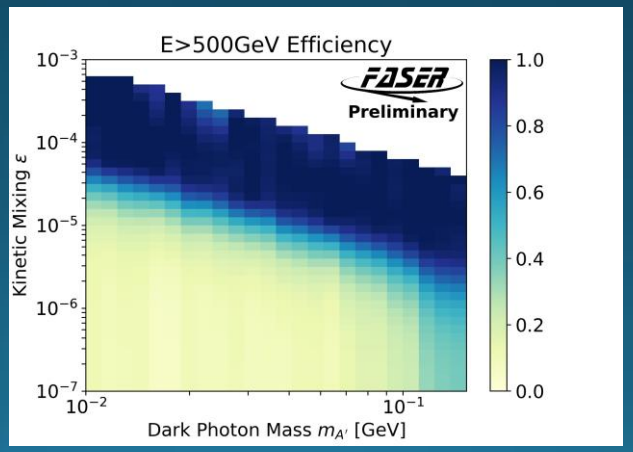
π^0 production
arXiv:1901.04468



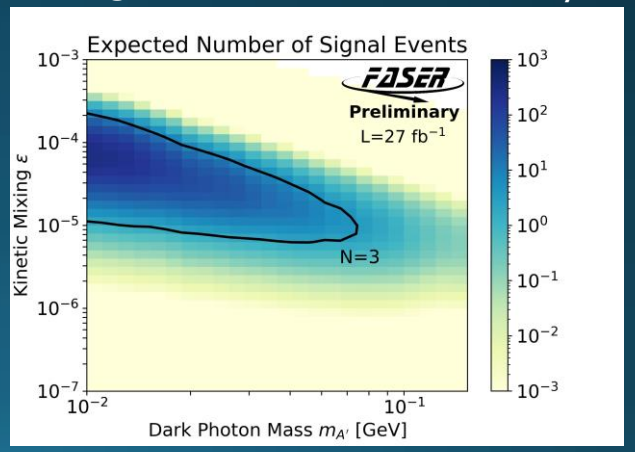
A' decay probability in 1.5 m decay volume @480 m



Fraction of FASER A' decays with $E > 500$ GeV

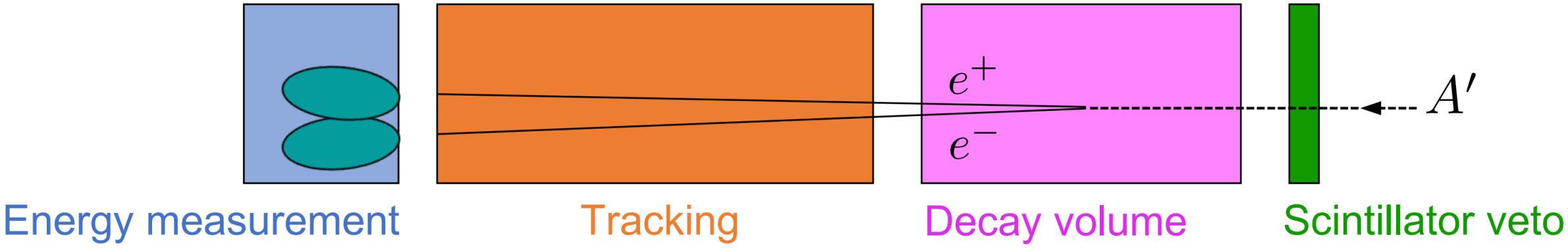


Signal expected assuming 50% selection efficiency



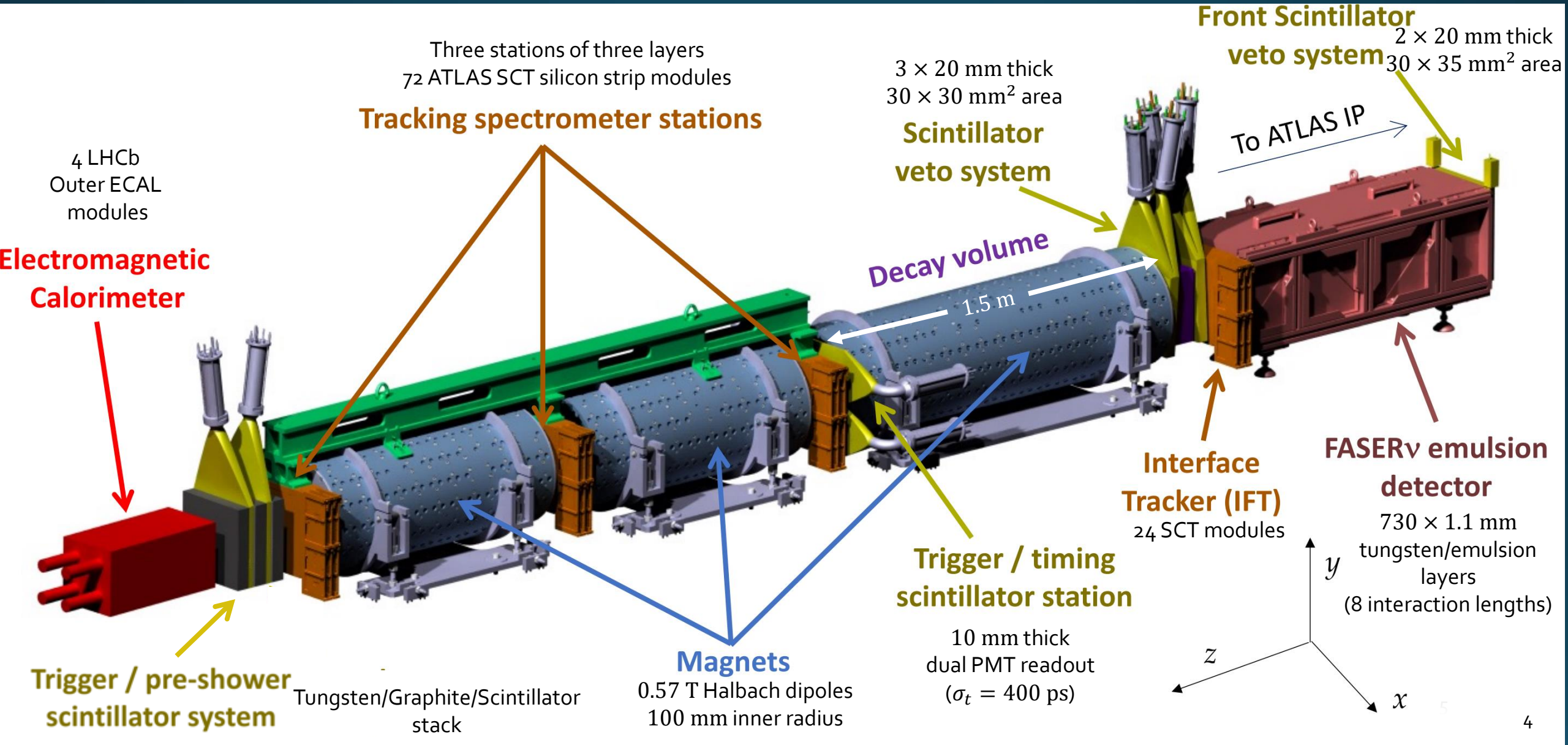
Generator level studies

$A' \rightarrow e^+e^-$ signature



- Veto entering charged particles
- Reconstruct two energetic charged tracks
- Confirm particle ID and energy with large shower in EM Calorimeter

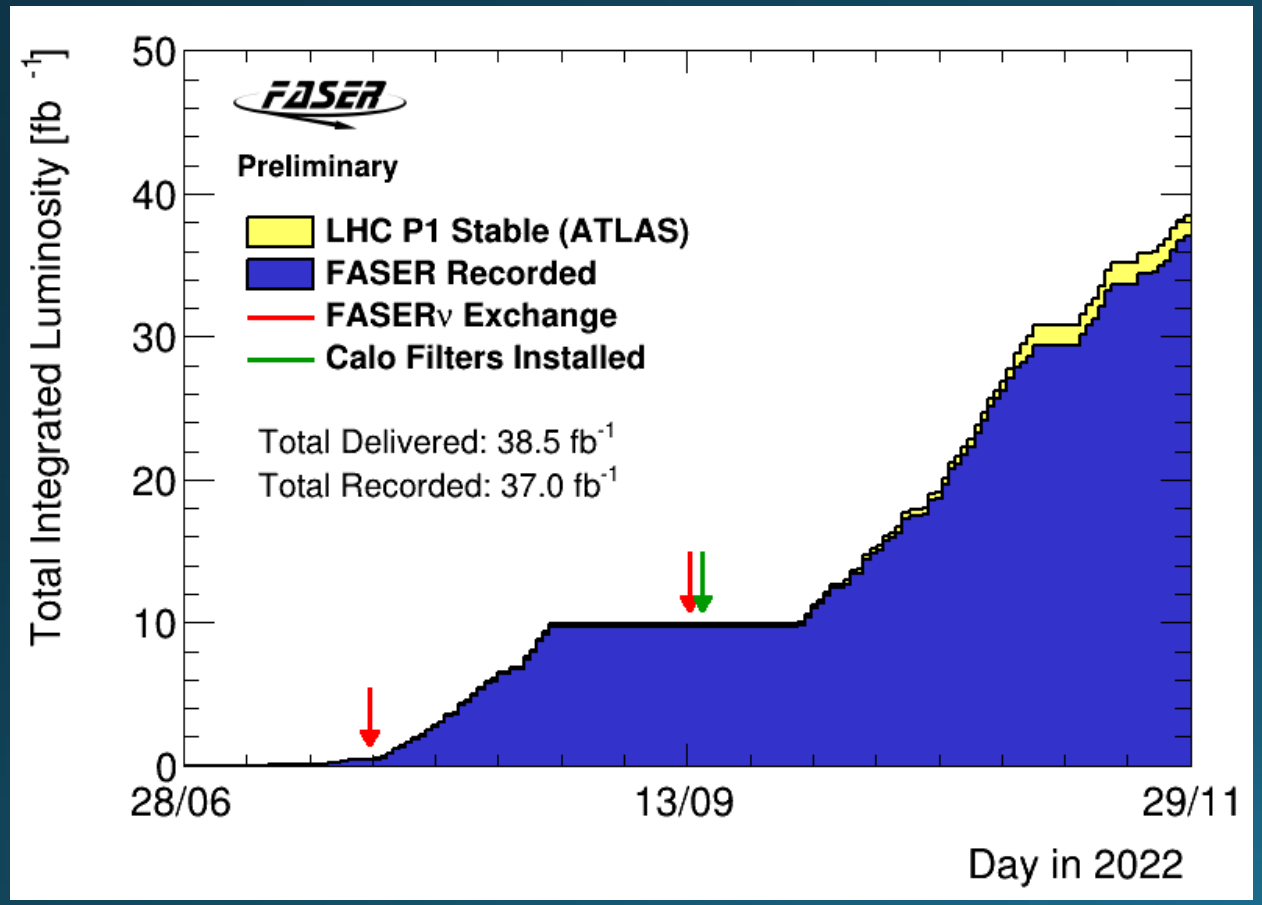
FASER Detector (arXiv:2207.11427)



2017: Feng, et al. idea paper
2018-19: Proposal, funding and approval
2019-20: Construction and testing on surface
2020-21: Installation underground
2021-22: Commissioning with cosmics
2021: Test beam
2022: Collision data from LHC Run 3

Slide credit: C. Gwilliam

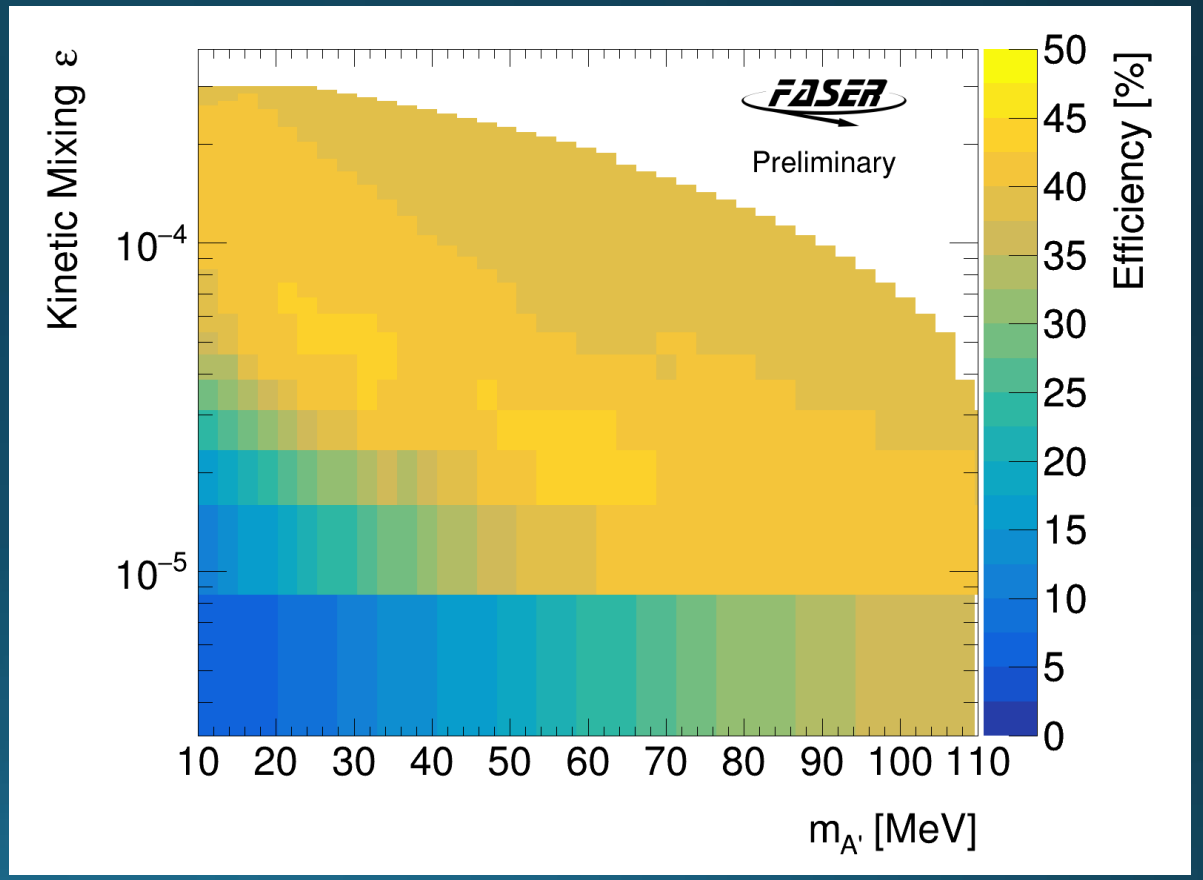
Operations and data set



- Detector performed almost flawlessly in 2022
  - Automated, continuous data-taking
  - Trigger rates up to 1.3 kHz
  - DAQ deadtime: 1.3%
  - Recorded 96.1% of delivered luminosity
  - Over 350M single muon events
- Calorimeter gain optimized for TeV energies after second emulsion exchange (green arrow)
  - 27.1/fb used for dark photon search

$A' \rightarrow e^+e^-$ selection

- Events with no veto activity and $E_{\text{calo}} > 100$ GeV blinded until selection finalized.
- Simple selection optimized for discovery:
  - Collision event with good data quality
  - No signal (> 40 pC) in any veto
  - Timing and preshower consistent with ≥ 2 minimum ionizing tracks
  - Exactly two good fiducial tracks:
    - $p > 20$ GeV and $r < 95$ mm
    - Extrapolate to $r < 95$ mm at vetos
  - $E > 500$ GeV in EM calorimeter



Selection efficiency ~ 40% over region of sensitivity

Dark photon backgrounds

- Veto inefficiency
  - Negligible
- Muon-induced neutral hadrons
  - Estimated from three-track sample, ignoring muon and removing photon conversions
- Geometric muon background
  - Negligible
- Neutrino interactions in detector material
  - Estimated from GENIE sample, corrected for material missing in simulation
  - Small, but dominant background
- Non-collision (cosmic or beam) background
  - Negligible

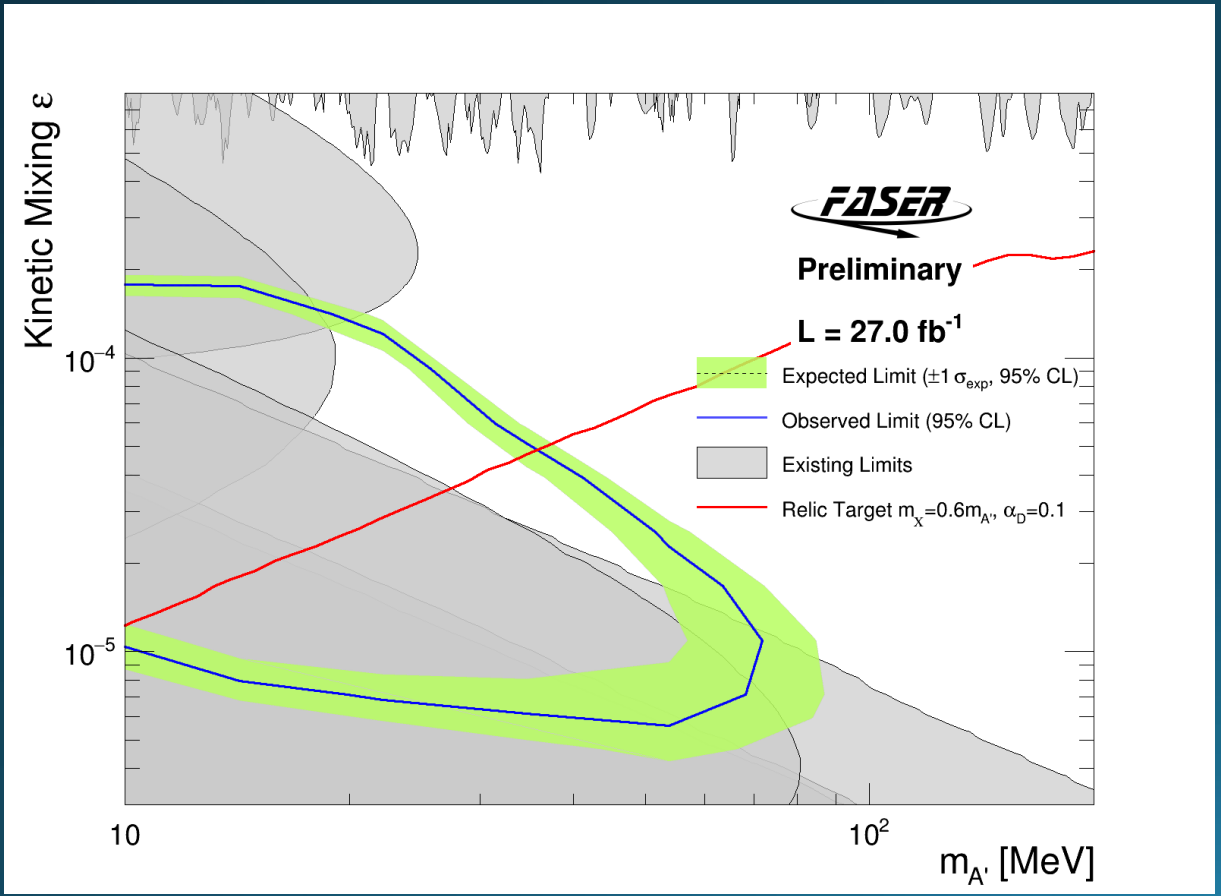
Scintillator	Efficiency
NuVeto-0	0.9999805(5)
NuVet0-1	0.9999810(5)
Veto-0	0.9999985(1)
Veto-1	0.9999984(1)
Veto-2	0.9999986(1)

Process	Background Estimate
Veto inefficiency	Negligible
Neutral hadron & geometric muon background	$(0.22 \pm 0.31) \times 10^{-3}$
Neutrino interactions	$(1.8 \pm 2.4) \times 10^{-3}$
Non-collision background	Negligible
Total background	$(2.0 \pm 2.4) \times 10^{-3}$

See https://cds.cern.ch/record/2853210/files/CERN-FASER-CONF-2023-001.pdf for more details and validation studies

$A' \rightarrow e^+e^-$ result

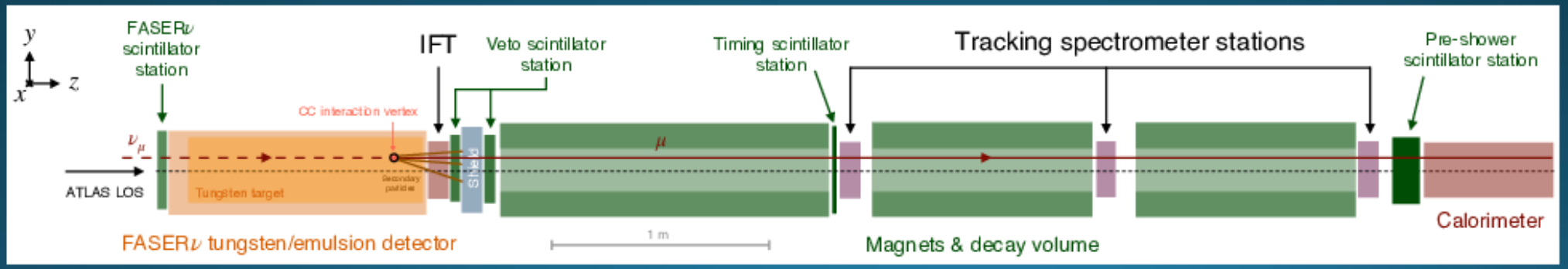
- 95% CL excluded region based on 0 events passing selection
  - 0 events with even 1 fiducial track



Source	Systematic Uncertainty	Typical Effect on Signal Yield
Theory, Statistics and Luminosity		
A' cross section	$\frac{0.15 + (E_{A'}/4\ \mathrm{TeV})^3}{1 + (E_{A'}/4\ \mathrm{TeV})^3}$	15-45%
Luminosity	2.2%	2.2%
MC statistics	$\sqrt{\sum W^2}$	1-2%
Tracking		
Momentum scale	5%	< 0.5%
Momentum resolution	5%	< 0.5%
1-track efficiency	3%	3%
2-track efficiency	15%	15%
Calorimetry		
Energy scale	6%	< 1%

Collider neutrino search

- Copious meson production makes the LHC an intense source of the world's highest energy man-made neutrinos
  - De Rujula and Ruckl (1984)
- FASERν emulsion detector will study in detail
- Active electronic detector can find ν_μ and $\bar{\nu}_\mu$ CC interaction signal above background:
  - Long, high-momentum fiducial track
  - No activity in forward veto station
  - Blinded analysis (35.4/fb luminosity used for neutrino search)



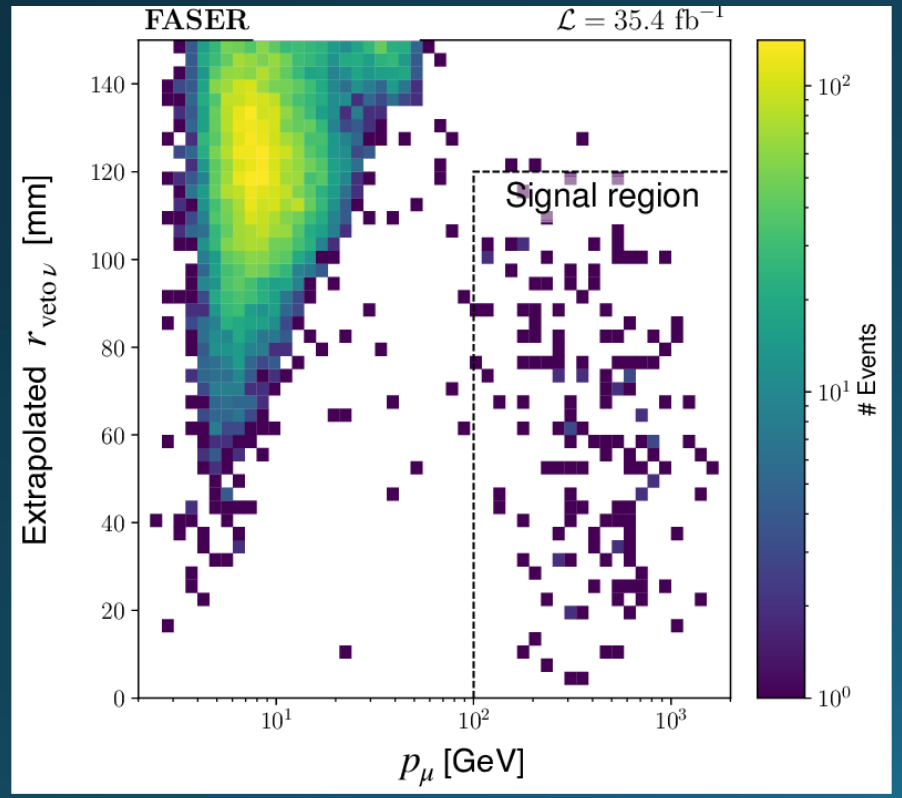
Expected backgrounds

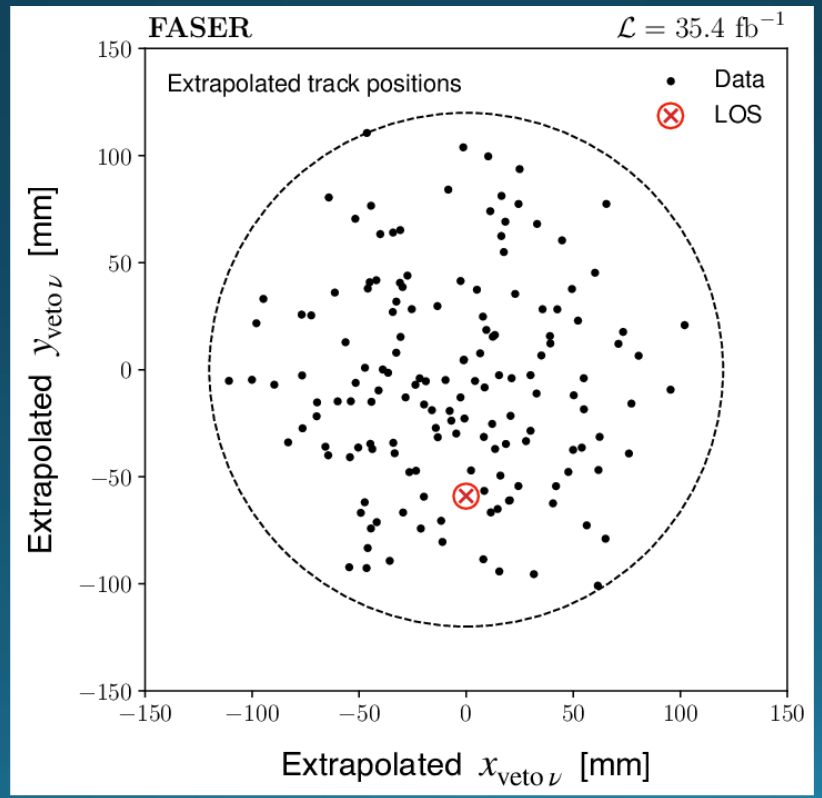
- Veto inefficiency
  - Measured using singles rate in forward veto (only one of two layers fire)
  - Negligible
- Muon-induced neutral hadrons
  - $n_{had} = 0.11 \pm 0.06$ (stat) estimated from simulation
  - Conservative; ignores likely veto signal from parent muon
- Geometric muons (leakage around veto)
  - $n_{geo} = 0.08 \pm 1.83$ (stat) extrapolated from side-band

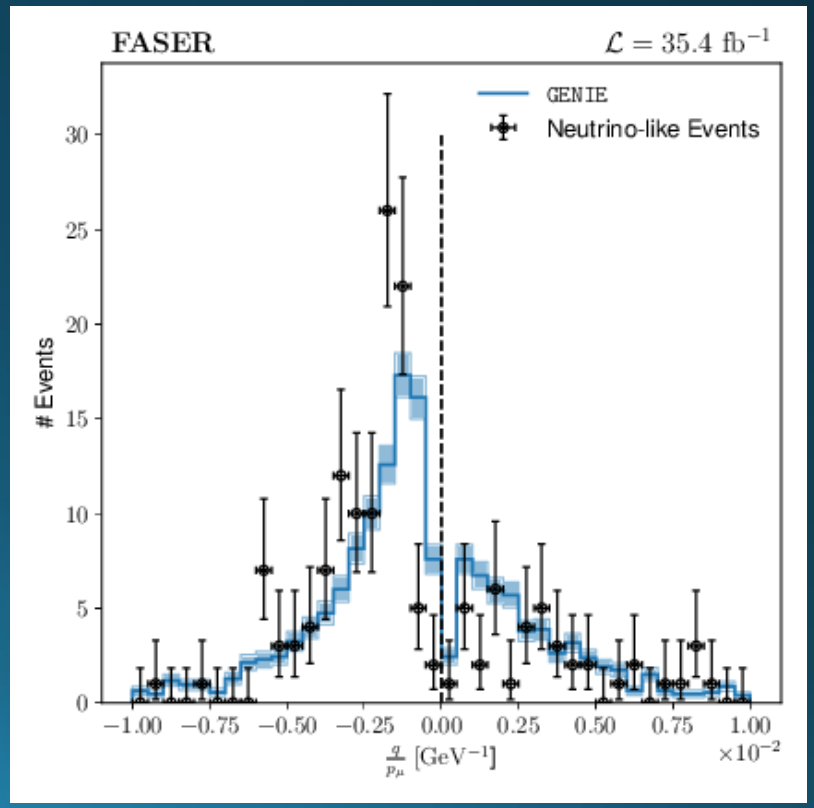
Please see https://arxiv.org/pdf/2303.14185.pdf for details

Collider neutrino results

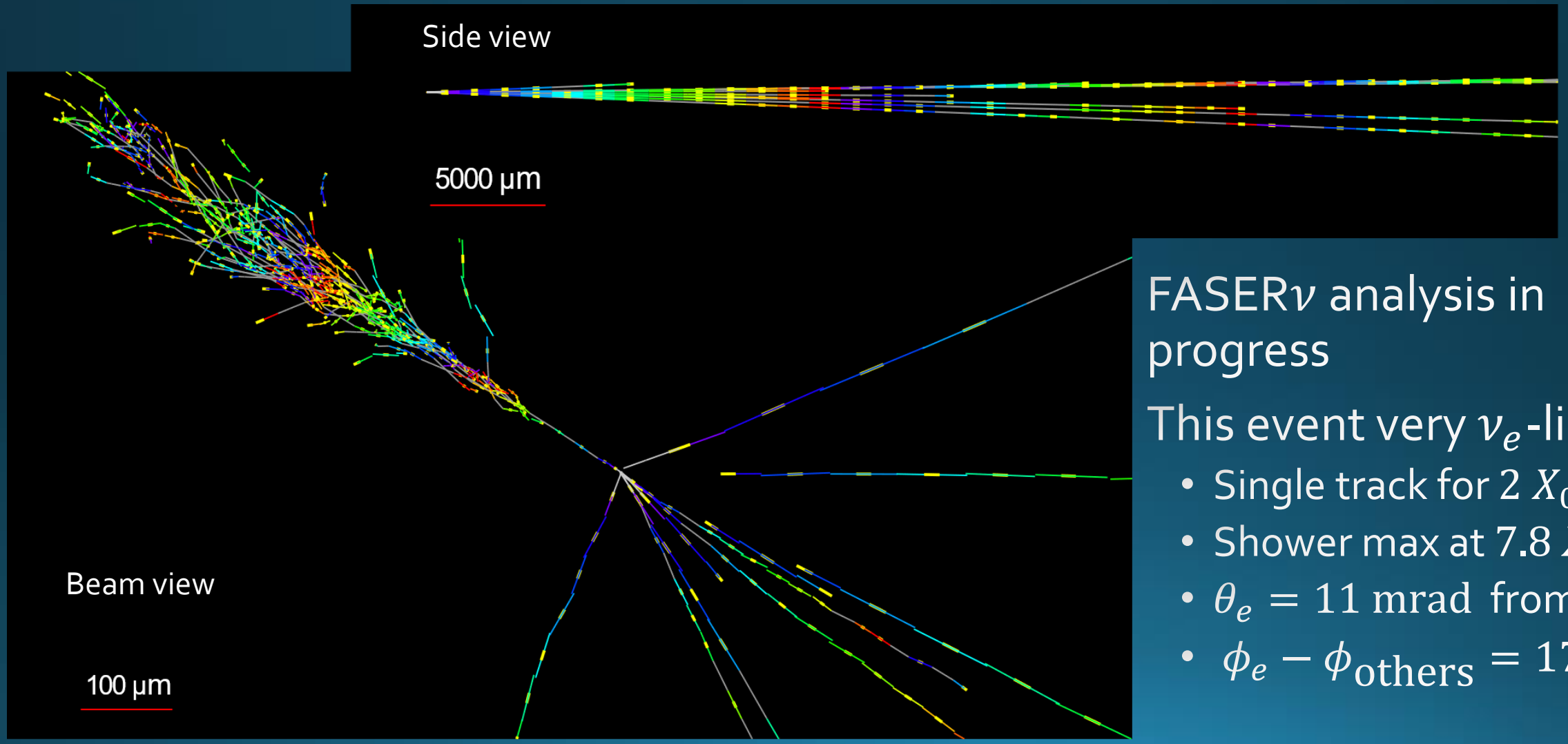
- 153^{+12}_{-13} neutrino-like events observed over backgrounds
  - "No signal" hypothesis excluded at 16 σ
  - Clear evidence of both ν_μ and $\bar{\nu}_\mu$ interactions with $E_\nu > 200$ GeV
  - No attempt to measure cross section, but luminosity-normalized prediction agrees well with data.







Teaser: ν_e candidate in FASERν



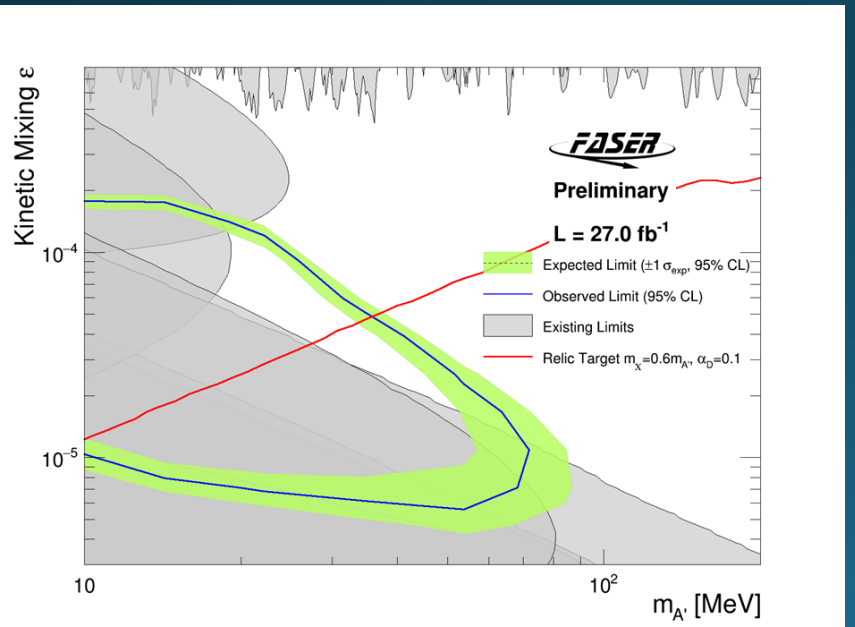
FASERν analysis in progress

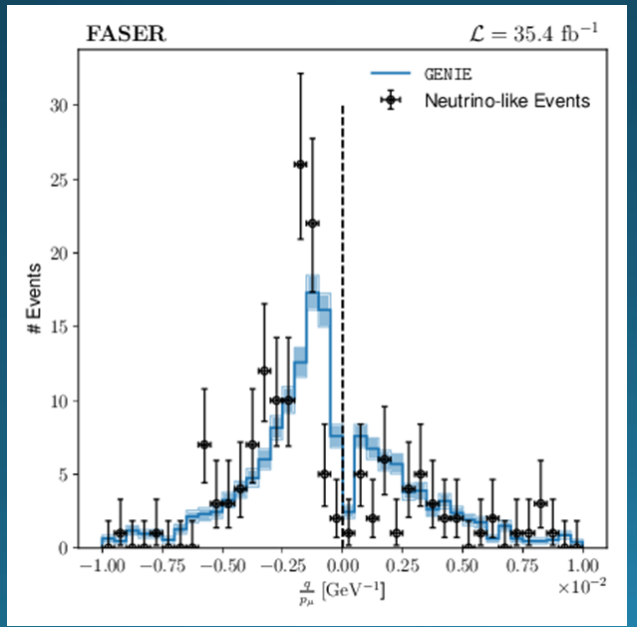
This event very ν_e-like

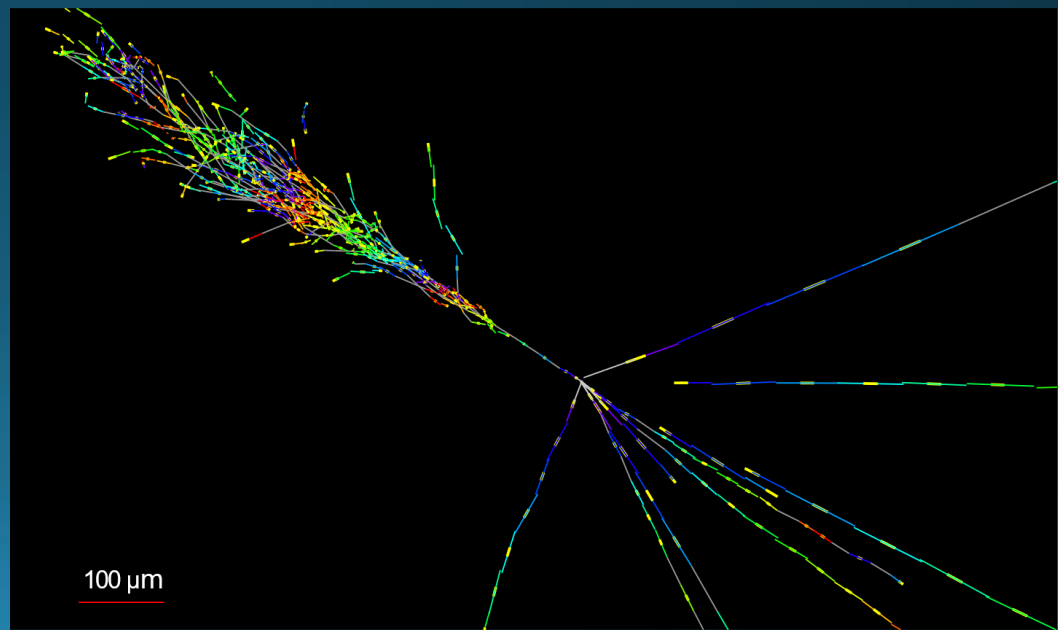
- Single track for 2 X_0
- Shower max at 7.8 X_0
- $\theta_e = 11$ mrad from beam
- $\phi_e - \phi_{\text{others}} = 175°$

Summary

- FASER had a very successful start to Run-3
- A' exclusion in interesting thermal relic region
- First direct detection of 153 collider neutrino interactions
- High-resolution neutrino studies with FASERν underway
- Much more data to come!







Acknowledgements

- Financial support for FASER comes from:

- We also thank:
  - LHC for successful 2022 run
  - ATLAS for accurate luminosity data
  - ATLAS SCT for donated tracker modules
  - ATLAS for Athena software framework
  - LHCb for donated ECAL modules
  - CERN FLUKA team for simulations
  - CERN PBC and technical infrastructure teams for excellent support during design, construction and installation

Supplemental material

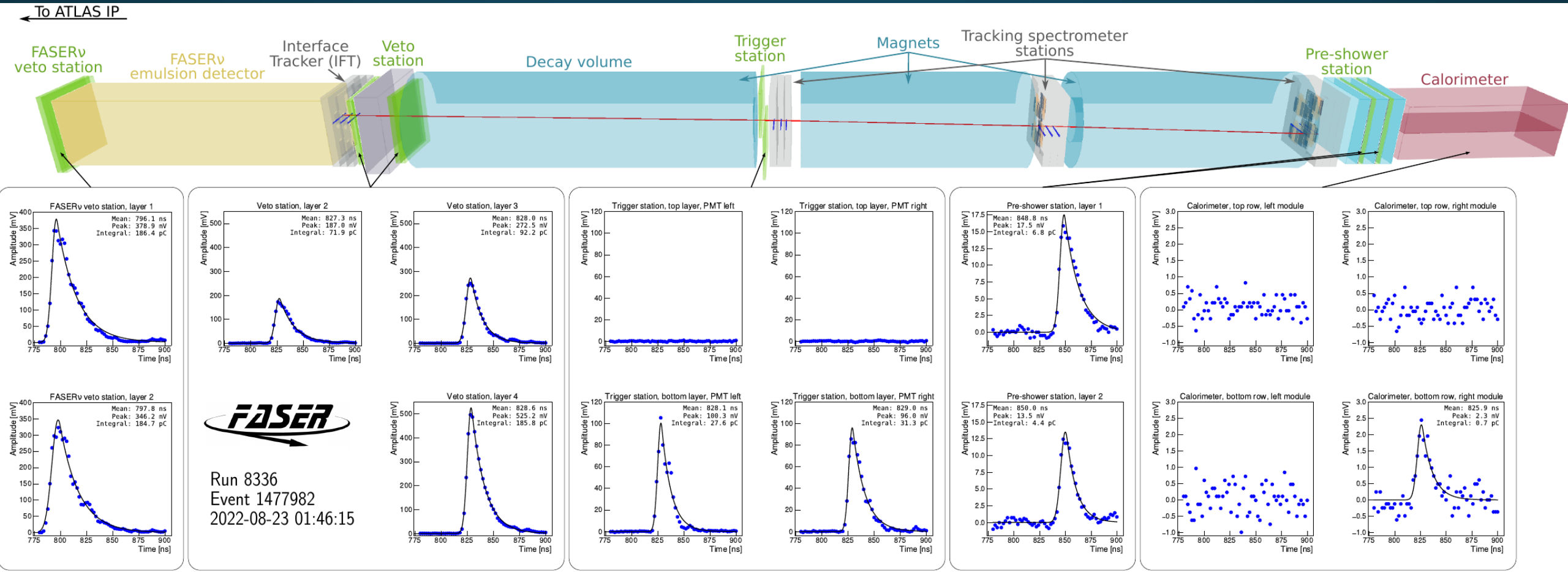
Backup

FASER collaboration

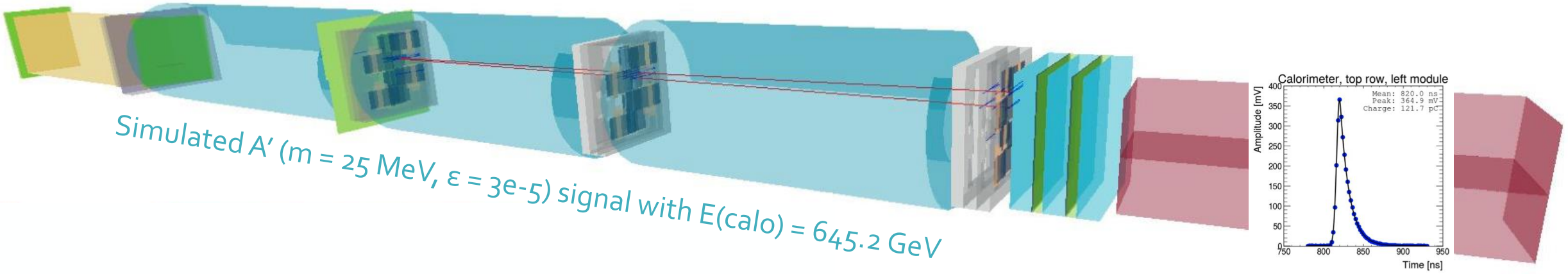
- 87 members from 24 institutes in 10 countries

Example single muon event

- Record silicon strip hits in tracker modules
- PMT waveforms from scintillators and ECAL modules

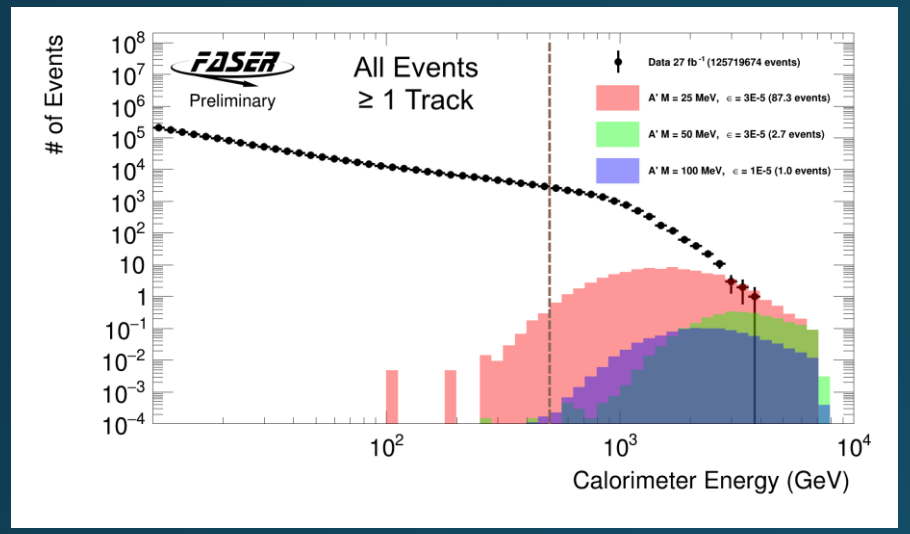


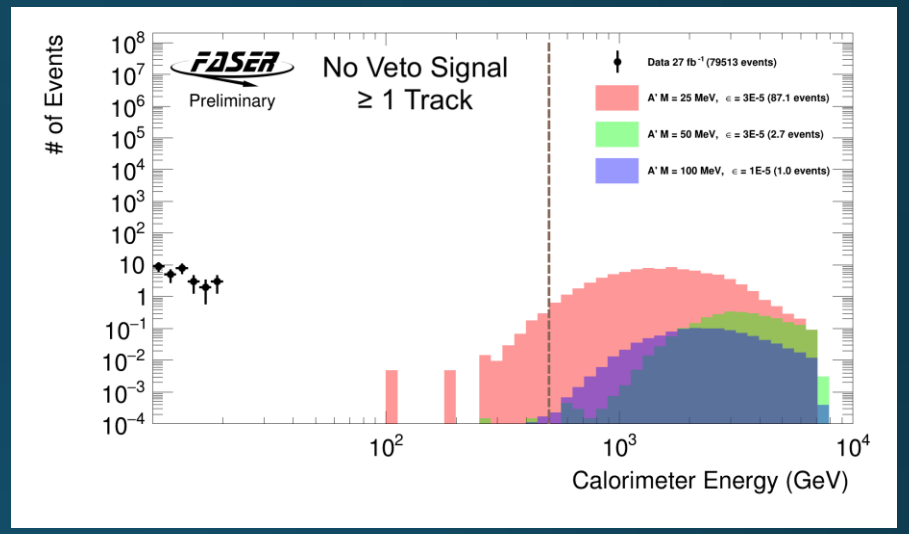
Simulated $A' \rightarrow e^+e^-$

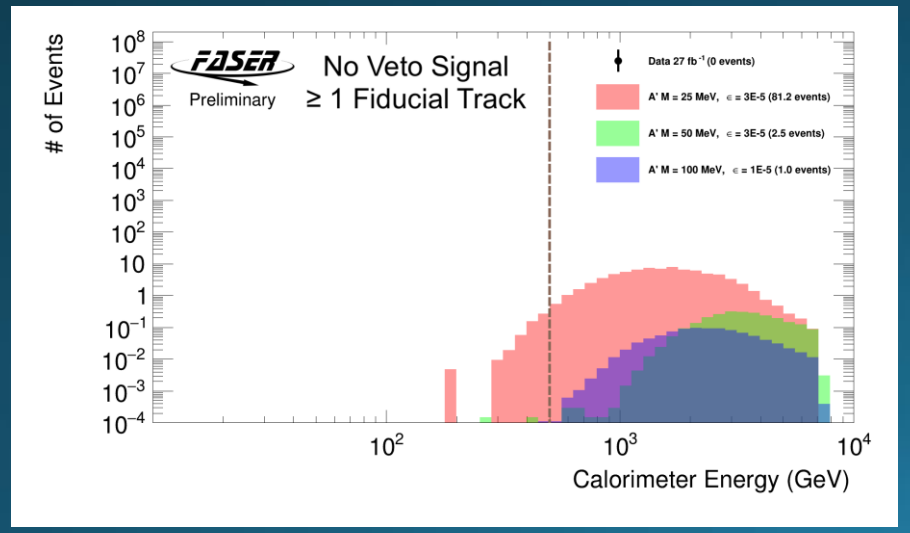


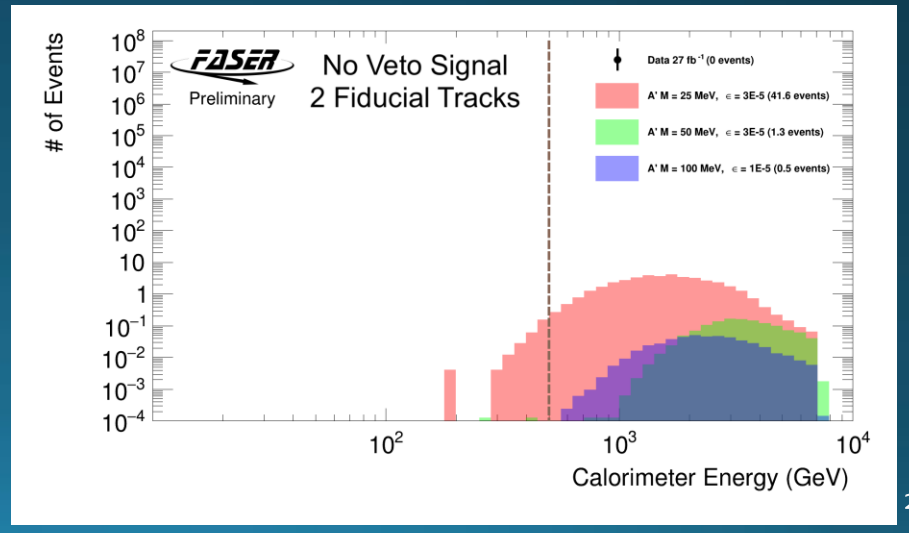
Simulated A′ (m = 25 MeV, ε = 3e-5) signal with E(calo) = 645.2 GeV

$A' \rightarrow e^+e^-$ cut flow: calorimeter energy

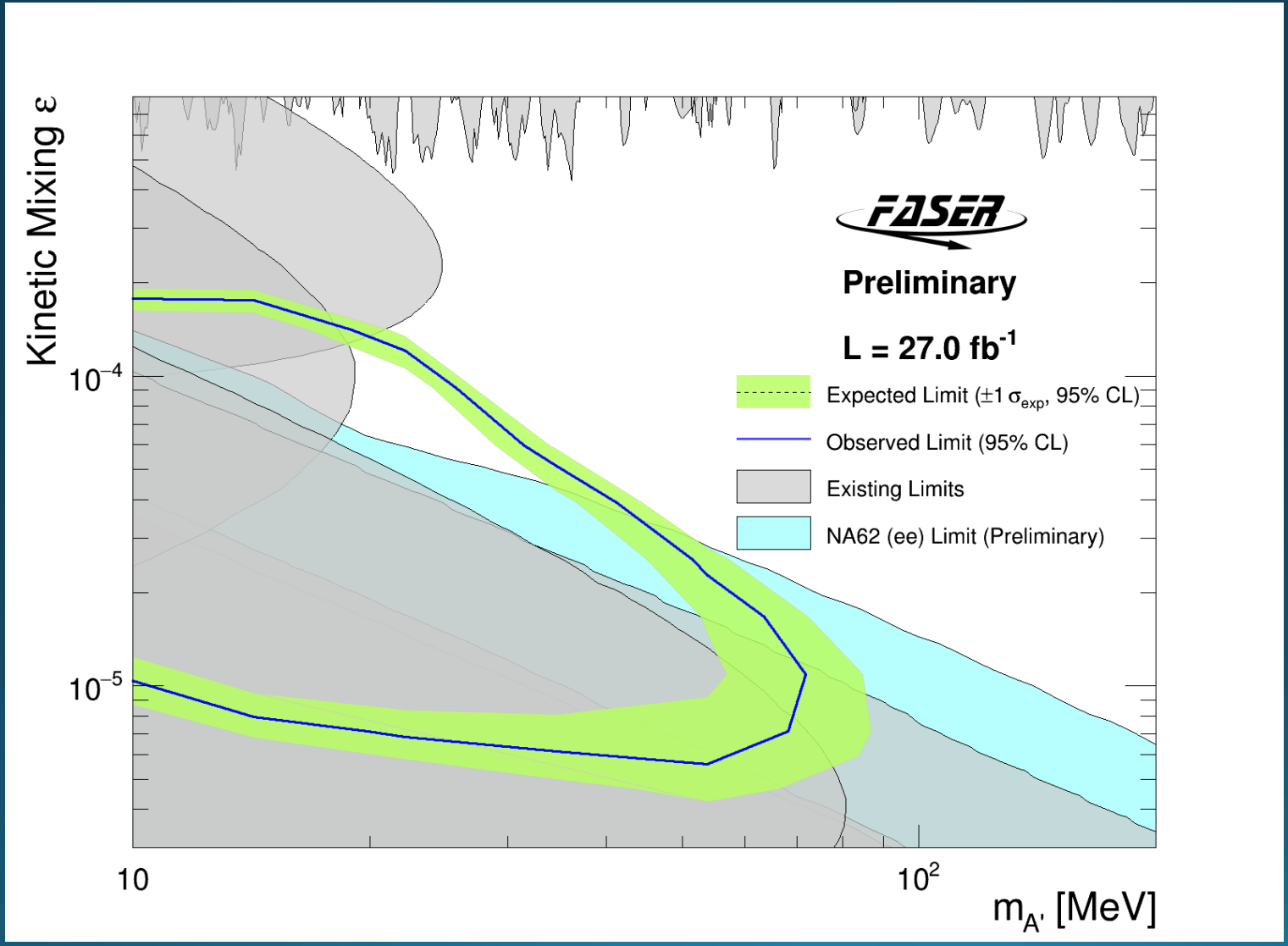








FASER and NA-62 result from Moriond



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