# Evaluation of the stereo observation performance of the Fluorescence-detector Array of Single-pixel Telescopes

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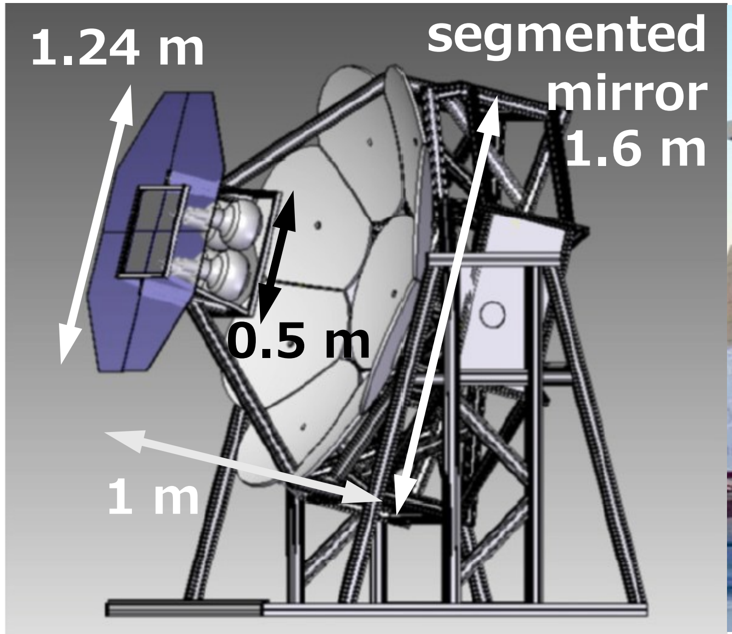
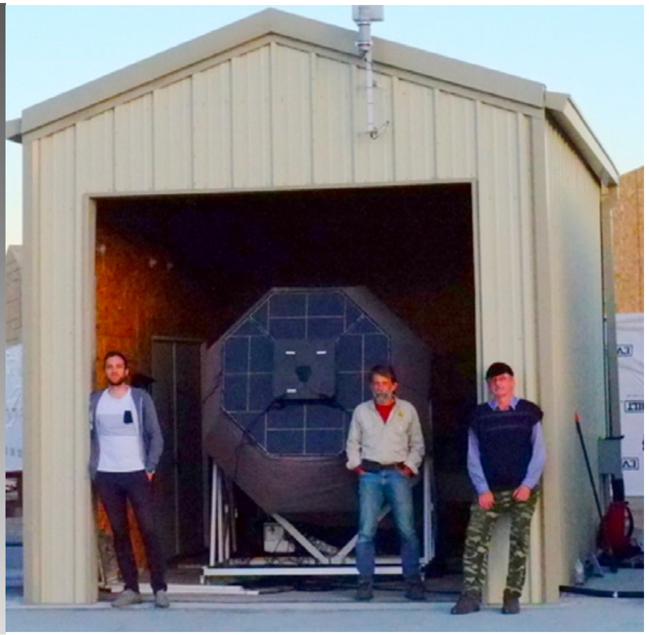
# FAST

**FAST (Fluorescence detector Array of Single-pixel Telescopes)**

- A next-generation ultra-high-energy cosmic ray experiment using air-fluorescence telescopes.
- A FAST telescope consists of **4** photomultiplier tubes (PMTs), and typically 9 mirror segments



M. Malacari et al. (2020)

Compared with conventional FDs
- **Compact**
- **Fewer PMTs**

→**Low cost**

Achieve a large detection area by deploying many telescopes

# Current FAST status

## FAST@Telescope Array(2016~)

- Observation using 3 telescopes since 2018
  Currently, observing continuously

## FAST@Pierre Auger(2019~)

- March 2026, installed 2 new prototypes
  (FAST3,4 right map)

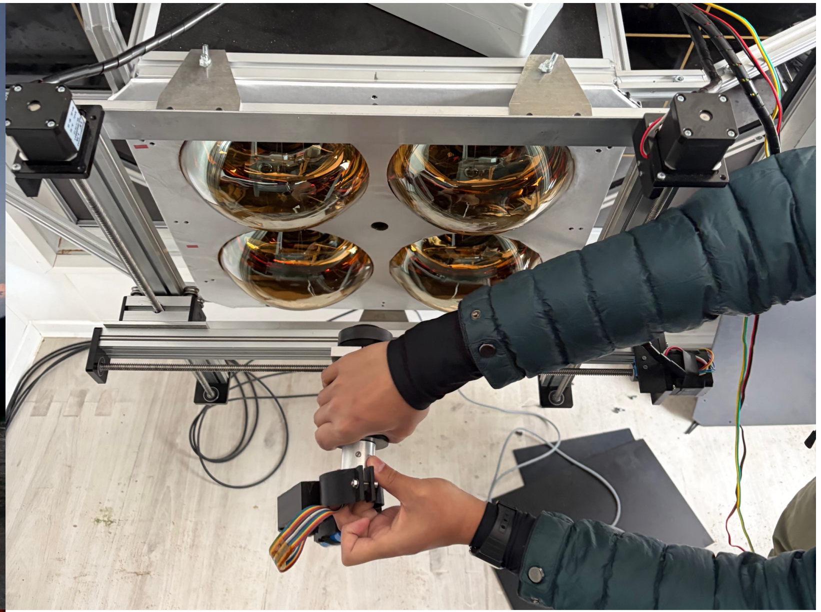

©Google

# Installation of FAST in March 2026

Installed 2 telescopes ”FAST3,4”

Czech and OMU team conducted:

- Installation & adjustment PMTs
- Measurement of PSF by drone
- Pointing determination by Sky Camera
- FoV scan by drone & Sky Camera
- Test data taking


# Evaluation of FAST performance using simulation

- The expected performance of stereo observation for the updated FAST@Auger was evaluated
- Simulation Setup

  The coordinates of each site were calculated from GPS coordinates.

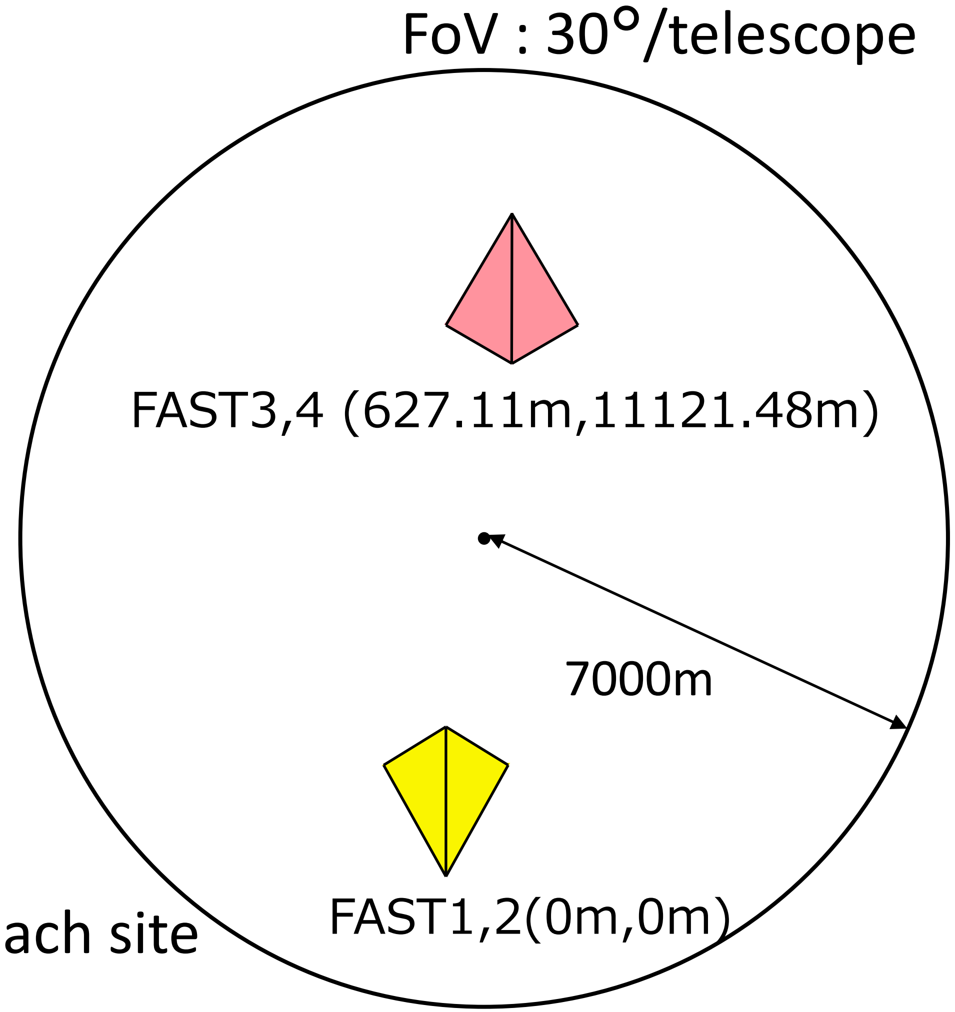
| | range | distribution |
|---|---|---|
| Energy | $10^{18.0}$~$10^{20.0}$ eV | $E^{-1}$ |
| Zenith angle | 0°~80° | sinθcosθ |
| Azimuth angle | 0°~360° | flat |

Interaction model: EPOS-LHC

Composition: p, He, N, Fe 25% each

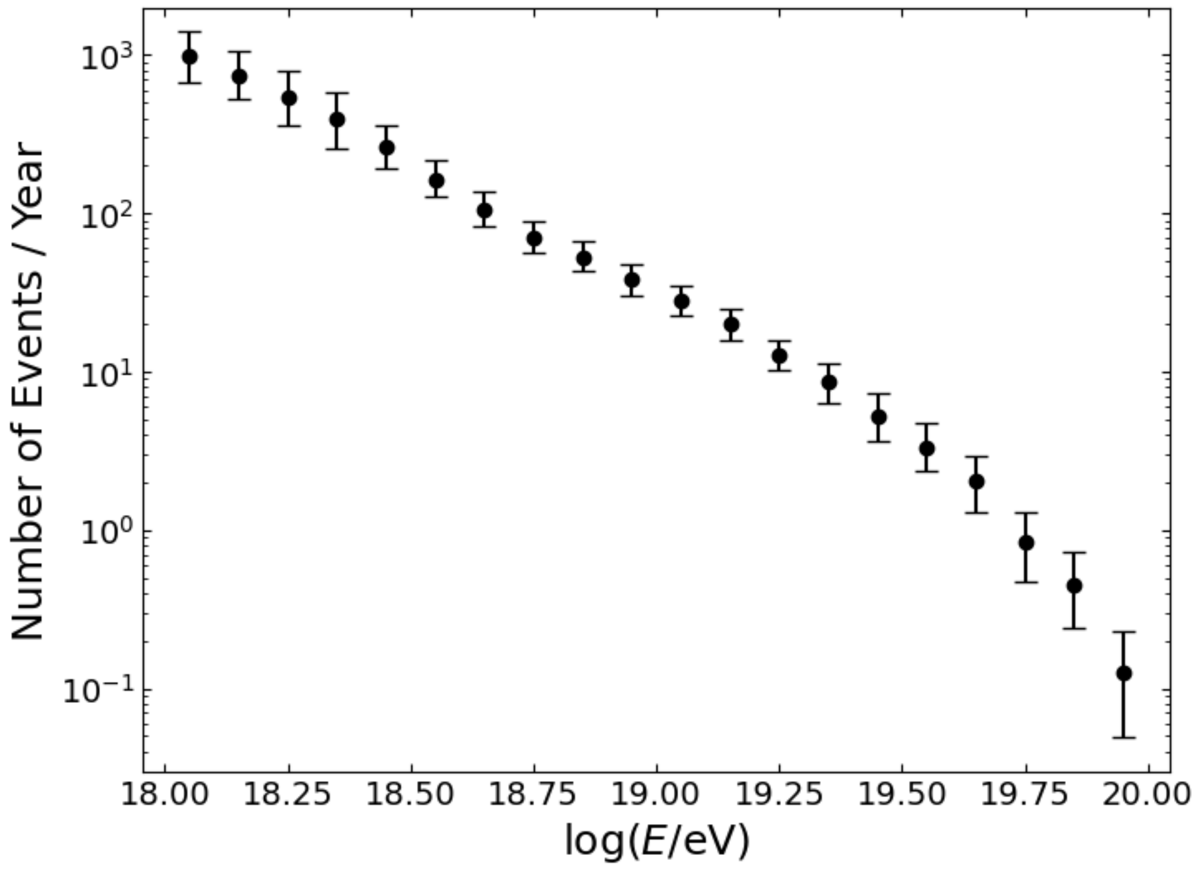
- Stereo Trigger

  →the presence of at least one PMT with a S/N ratio≥5 at each site



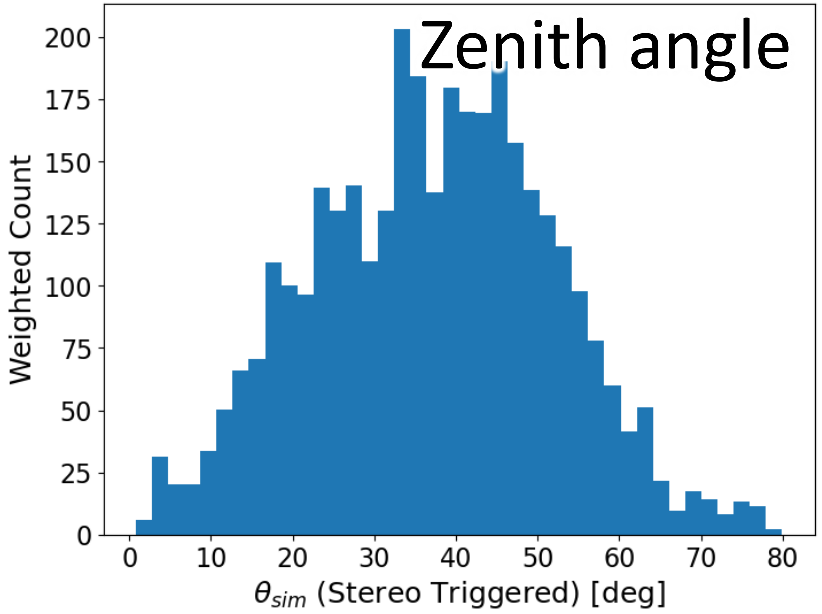
# Expected number of events per year

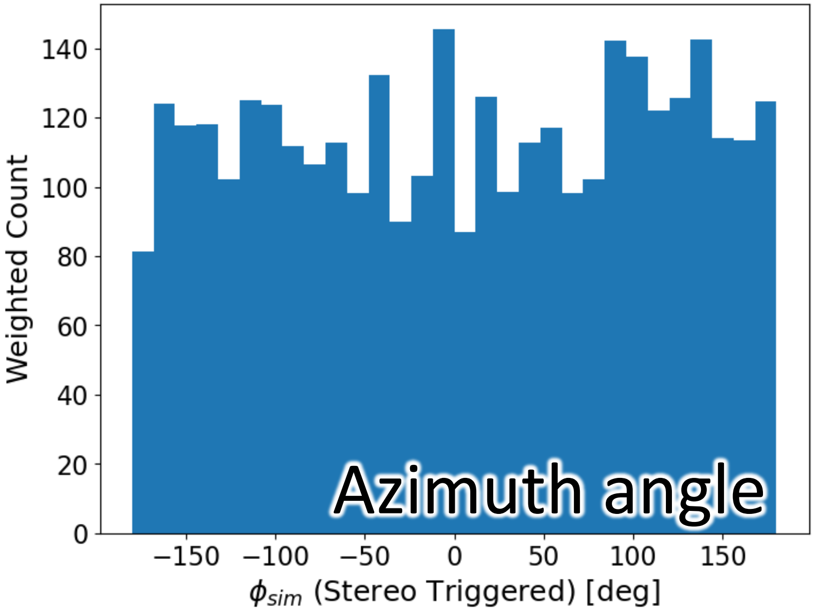
- Used the energy spectrum reported from the Pierre Auger Observatory (https://arxiv.org/abs/2109.13400)

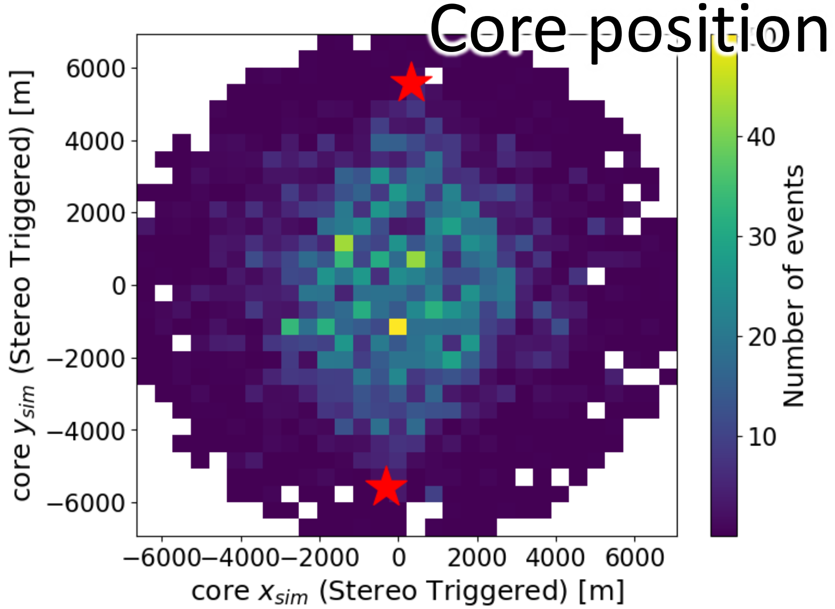


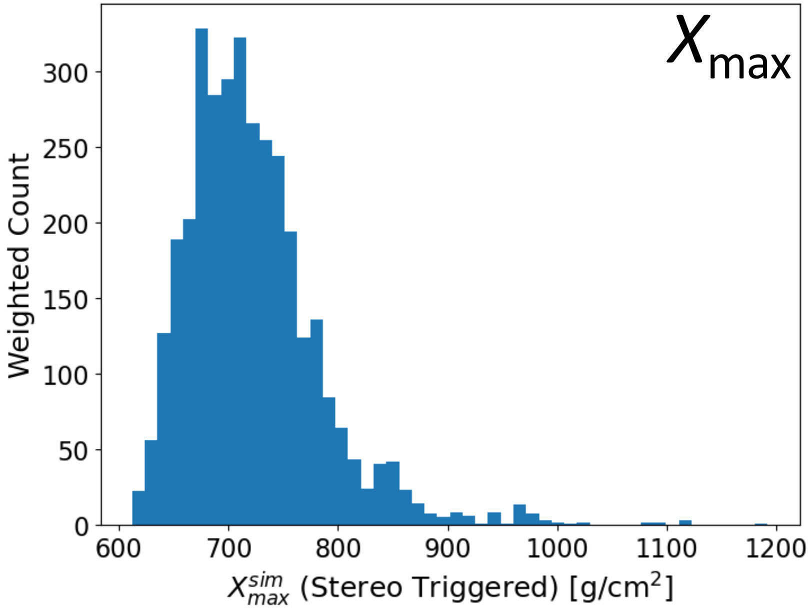

- With duty cycle 10%, approximately 350 events/yr for energies above $10^{18}$ eV.
  （>$10^{19}$ eV, approximately 8 events/yr）

# Expected shower parameters



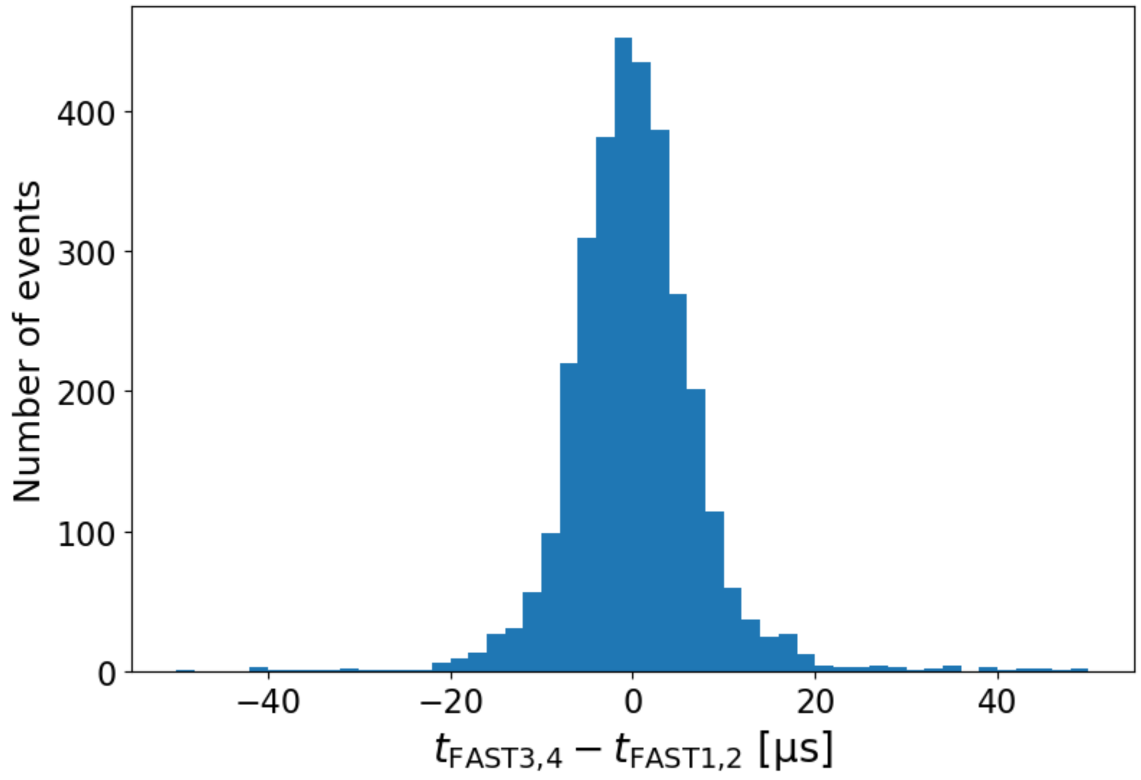




★:Telescopes Position

# Comparison of signal times across the stations

- Compared centroid times of max S/N ratio pixel between 2 sites.
- Time differences match expected delay (~11.2 km distance)

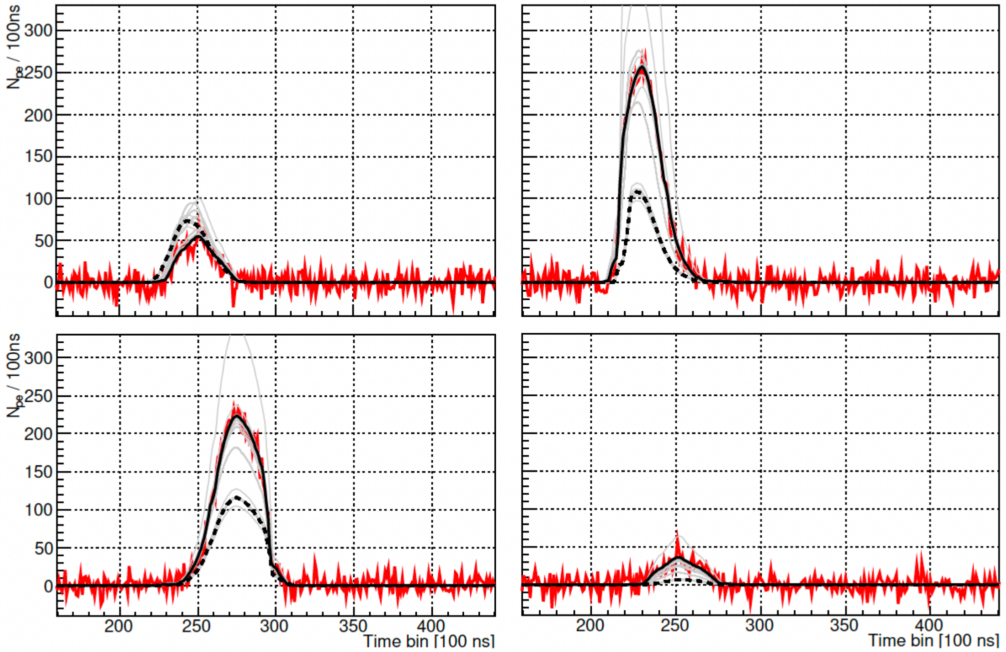



Standard deviation: 9.56 μs

- Future Work : Compare with actual data to verify stereo trigger conditions

# Reconstruction Method

- FAST has fewer pixels than conventional FDs
  →"bottom-up" approach is difficult
- Use "top-down" method
  - Compare observed PMT waveforms with simulated waveforms
    →Reconstruct shower parameters for waveform consistency




$$\ln \mathcal{L}(\vec{x}|\vec{a}) = \sum_{k}^{N_{\text{pix}}} \sum_{i}^{N_{\text{bins}}} \ln\left(P_k(x_i|\vec{a})\right)$$

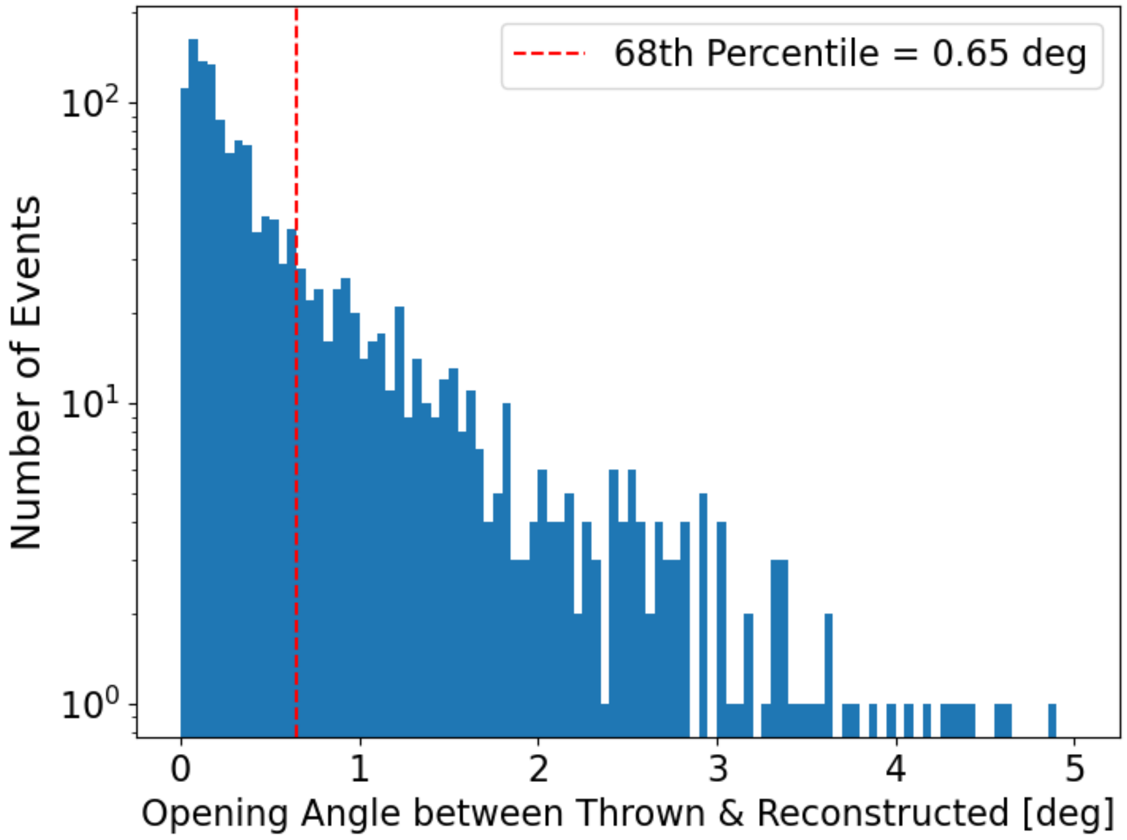
$$P(x_i|\mu_i,\sigma) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left[-\frac{(x_i-\mu_i)^2}{2\sigma^2}\right]$$

Example of the top-down reconstruction applied to a Monte-Carlo event

F. Bradfield, 2025

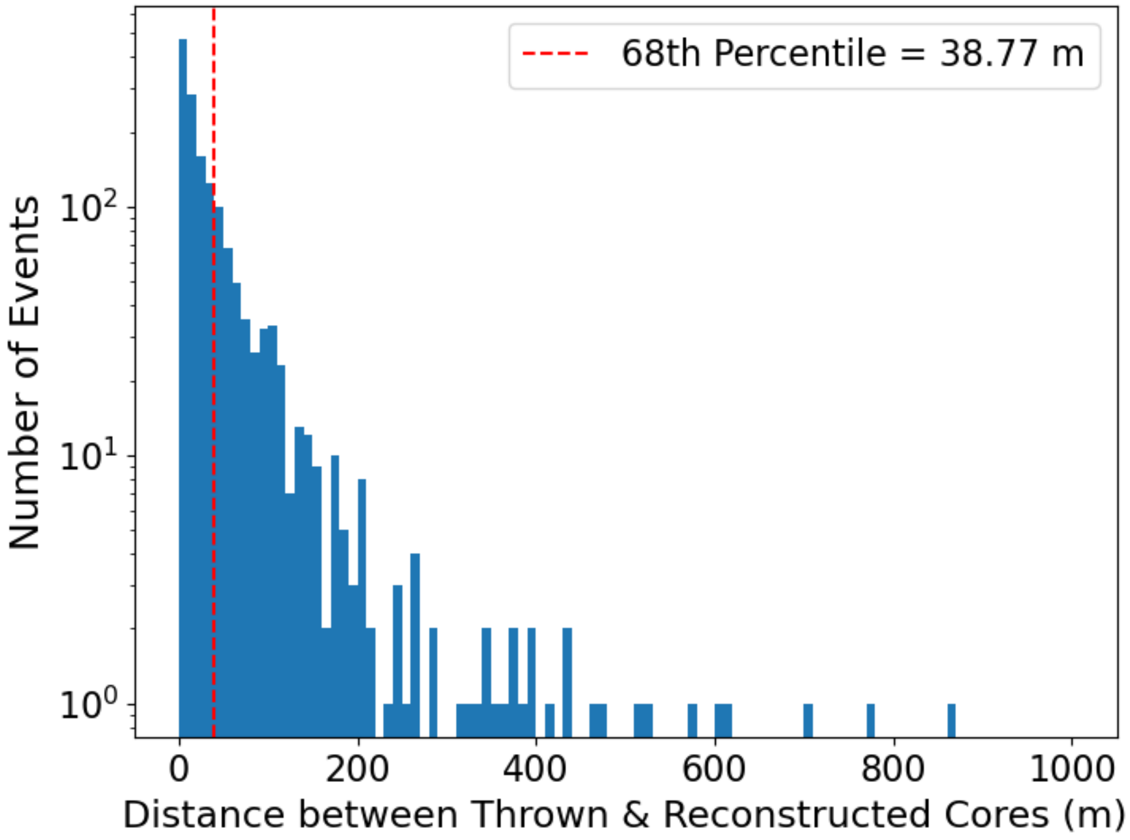
# Reconstruction results : Geometry

## Angular resolution




0.65° (68 percentile)

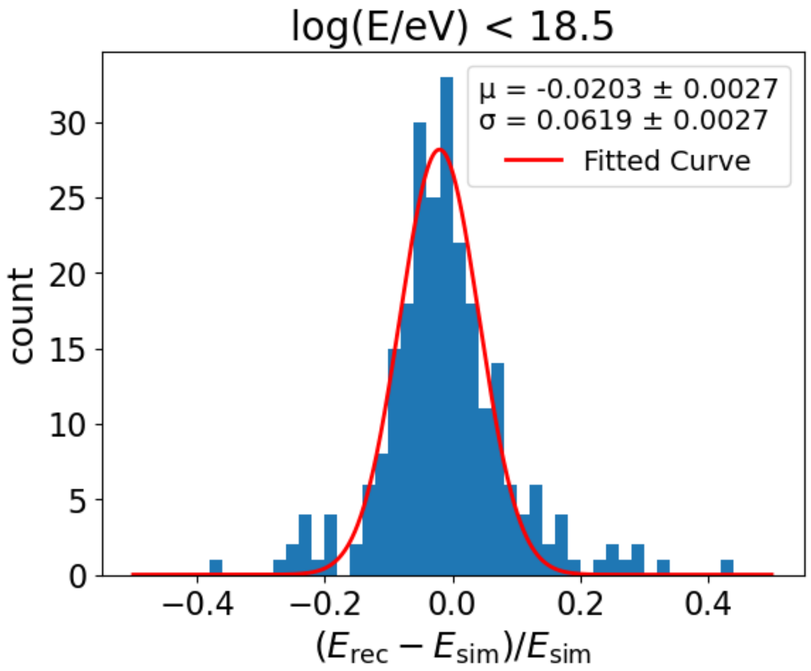
## Core position resolution



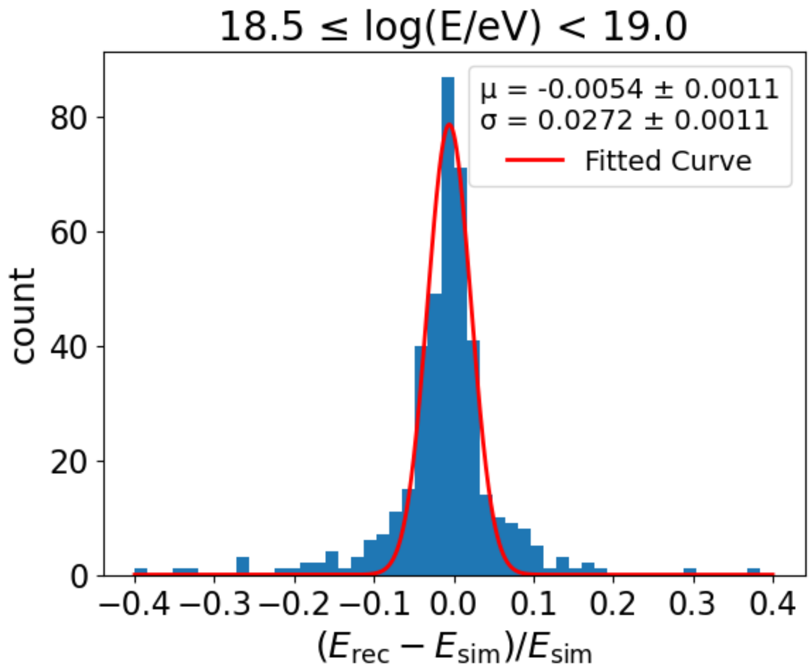

38.77 m (68 percentile)

# Reconstruction results : Energy

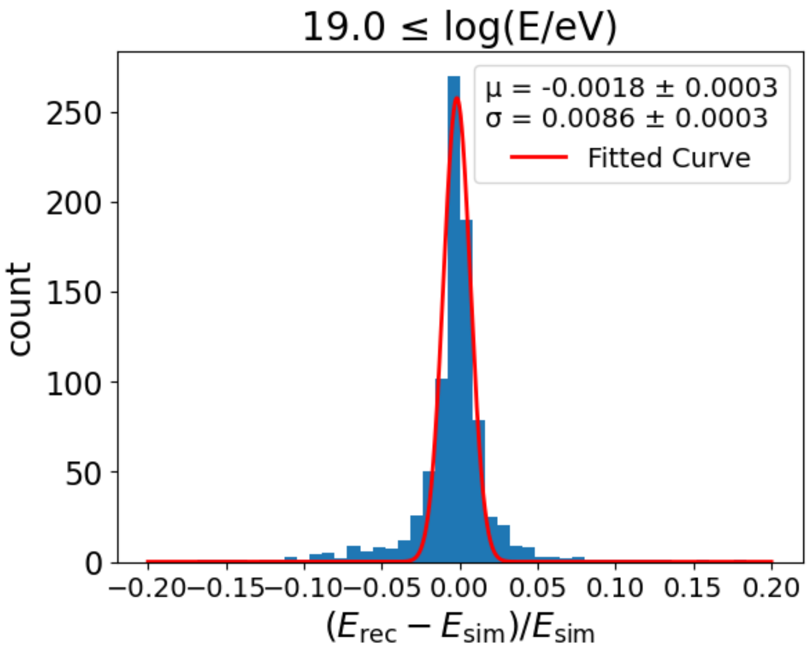
- Comparison for three energy ranges




bias:-2.03±0.27%
resolution:6.19±0.27%



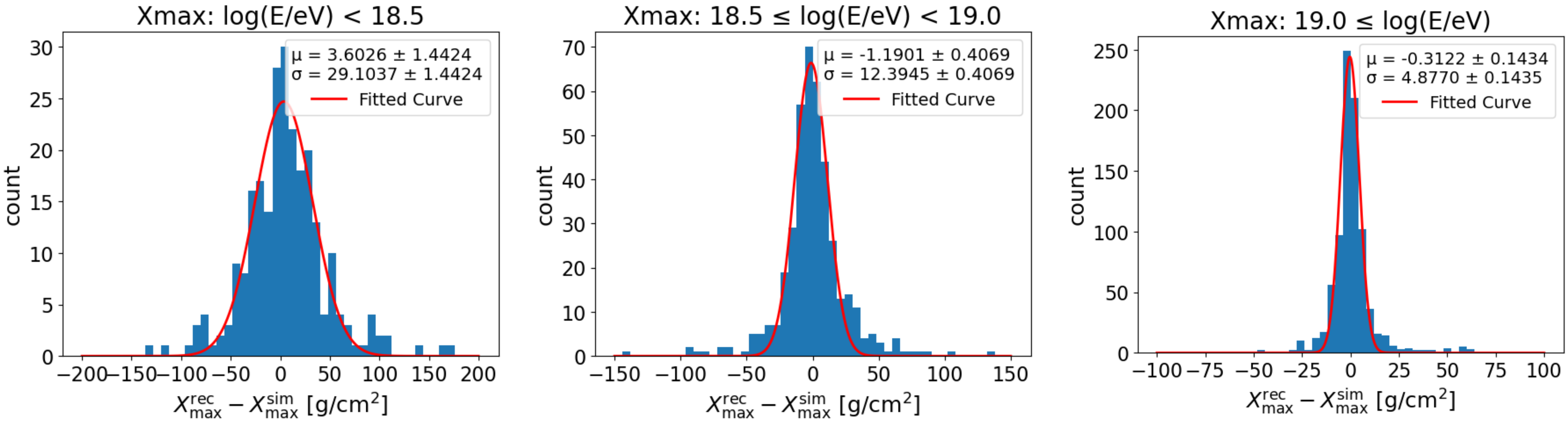

bias:-0.54±0.11%
resolution:2.72±0.22%




bias:-0.18±0.03%
resolution:0.86±0.03%

# Reconstruction results : $X_{max}$

- Comparison for three energy ranges




| | | |
|---|---|---|
| bias:3.60±1.44 g/cm$^2$ | bias:-1.19±0.41 g/cm$^2$ | bias:-0.31±0.14 g/cm$^2$ |
| resolution:29.10±1.44 g/cm$^2$ | resolution:12.39±0.41 g/cm$^2$ | resolution:4.88±0.14 g/cm$^2$ |

- These values are idealized scenario; actual will be worse.

# Summary

- March 2026, two additional telescopes were installed at the Auger site.
- Currently, 3 telescopes at the TA site, and 4 telescopes at the Auger site.
- Investigated the stereo observation performance of all four FAST telescopes using simulations.
  - Expected shower parameters, reconstruction accuracy, etc

## Future Work

- Evaluate reconstruction accuracy (for impact parameter, etc.)
- Incorporate the actual characteristics of components into the simulation.
- Compare simulations to actual data
  - background noise
  - Trigger time difference etc. → Use for stereo trigger development for real telescopes
- Investigate performance of deployment at three locations (future plan)

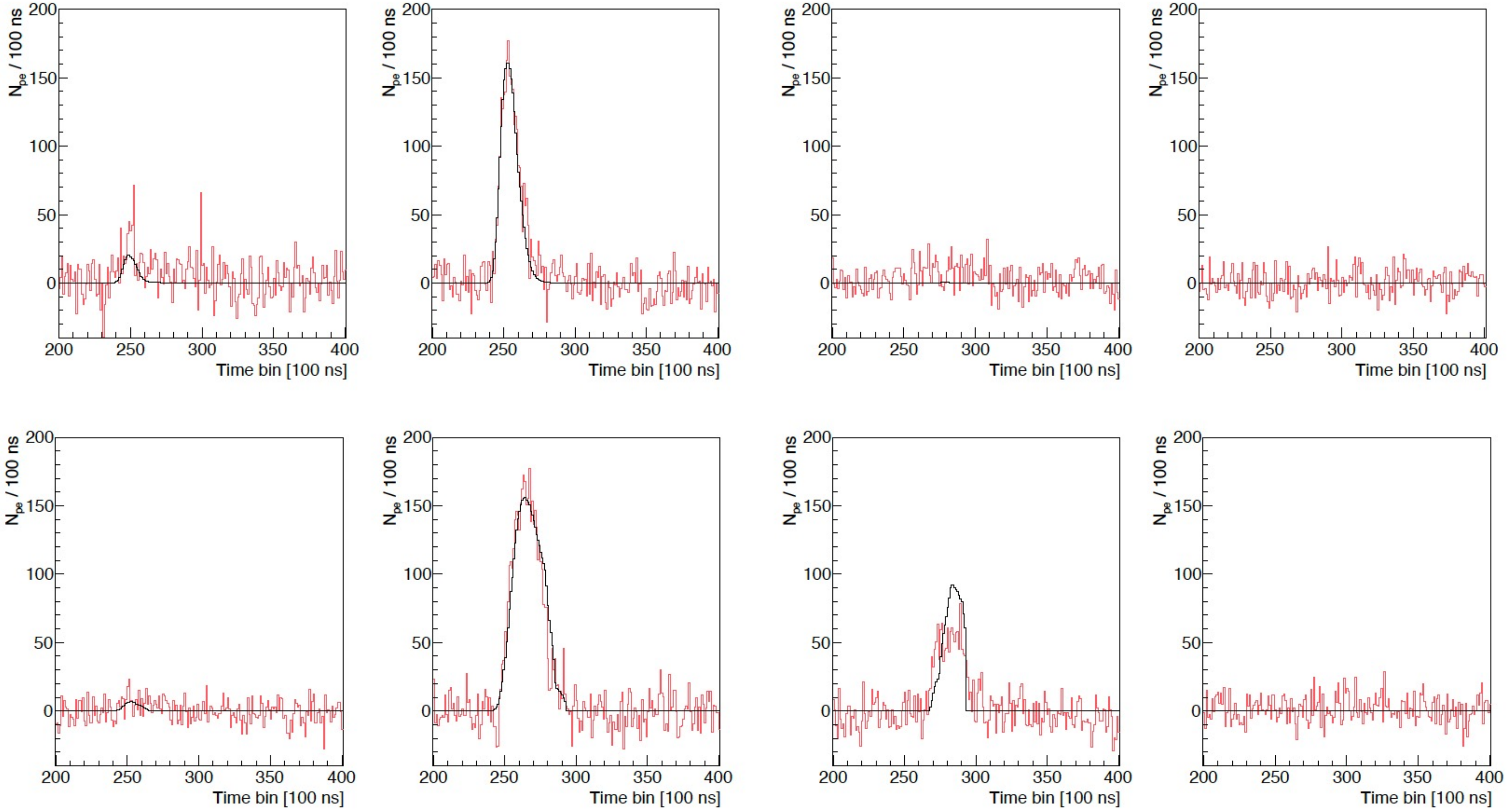
# Appendix

# Reconstruction Settings

- Reconstruct geometry, energy and $X_{max}$
- Analyze restricted to events with $X_{max}$ within telescope FoV.
- The initial values for the fitting are the smeared true values.

| **Parameter** | **Gaussian Smeared** |
|---|---|
| Core position | 100 m |
| Angle | 1.0° |
| Energy [logE/eV] | 0.1 |
| $X_{max}$ | 100 g/cm$^2$ |

# Reconstruct real event




T. Albury, 2018