

Towards the reconstruction of air showers with the J-PET system

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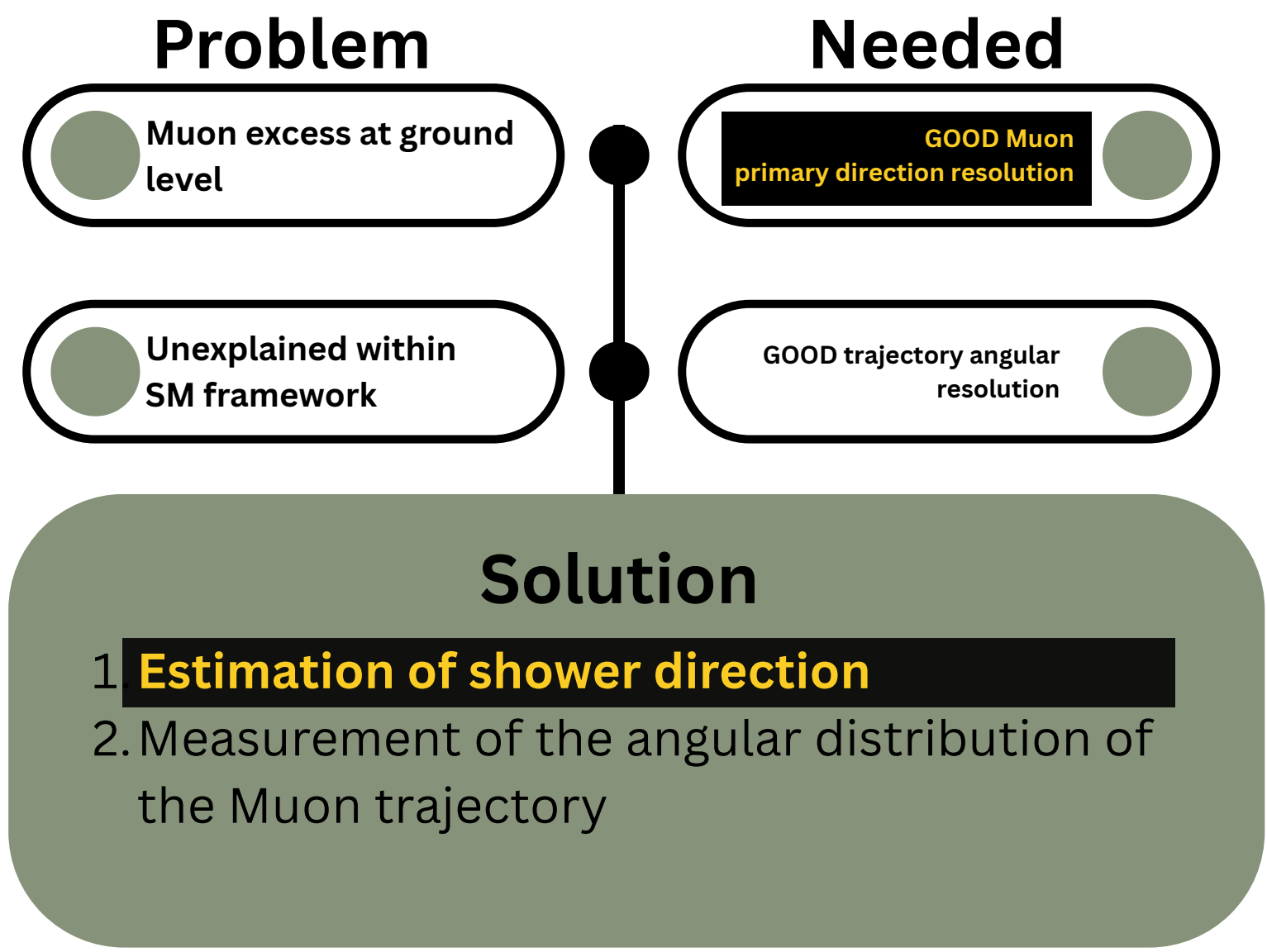
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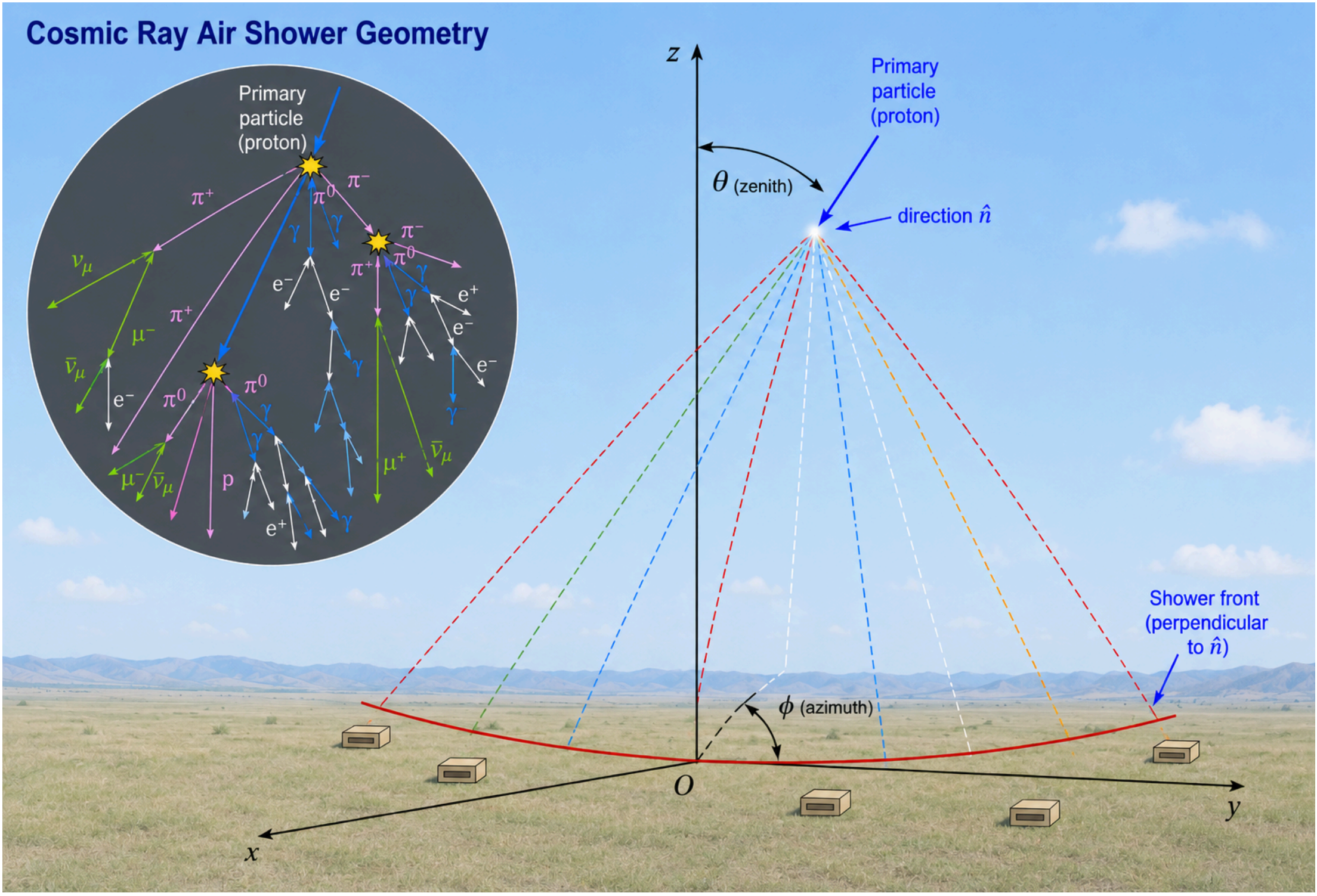
Introduction - MuPPET

The μ PPET project addresses the longstanding muon puzzle by constructing a phenomenological model of hadronic interactions that accounts for QCD corrections from polarisation effects [1]. A central challenge is reconstructing muon trajectories relative to the primary cosmic ray direction. Modular Array will provide time synchronisation of the shower. In this work, we present early-stage progress towards the simulation and analysis foundation of the μ PPET reconstruction pipeline. Using the J-PET framework and its calibration methodology [4], a GEANT4-based description of the array response to air-shower secondaries is under development alongside the analysis of cosmic muon data, with attention to extracting energy related observables from timestamps. We studied the potential of this configuration, and this foundational work is intended to support subsequent studies of shower geometry.

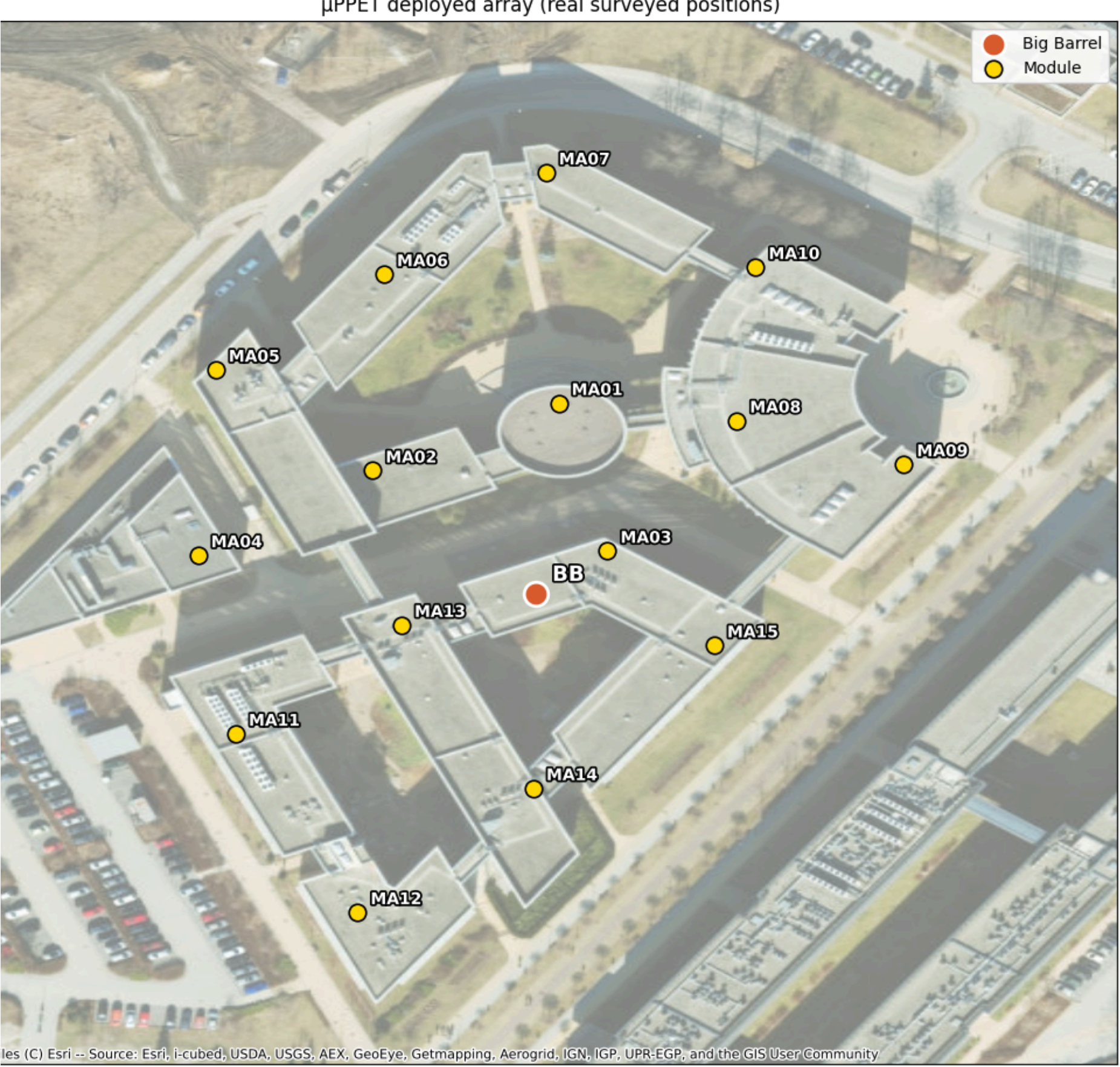
Motivation → Muon Puzzle



$$\chi^2_{n-k}(\mathcal{D} \mid \theta) = \sum_i^n \frac{(D_i - f(X_i, \{\theta_i, \dots, \theta_k\}))^2}{\sigma_i}$$



J-PET system → MuPPET array

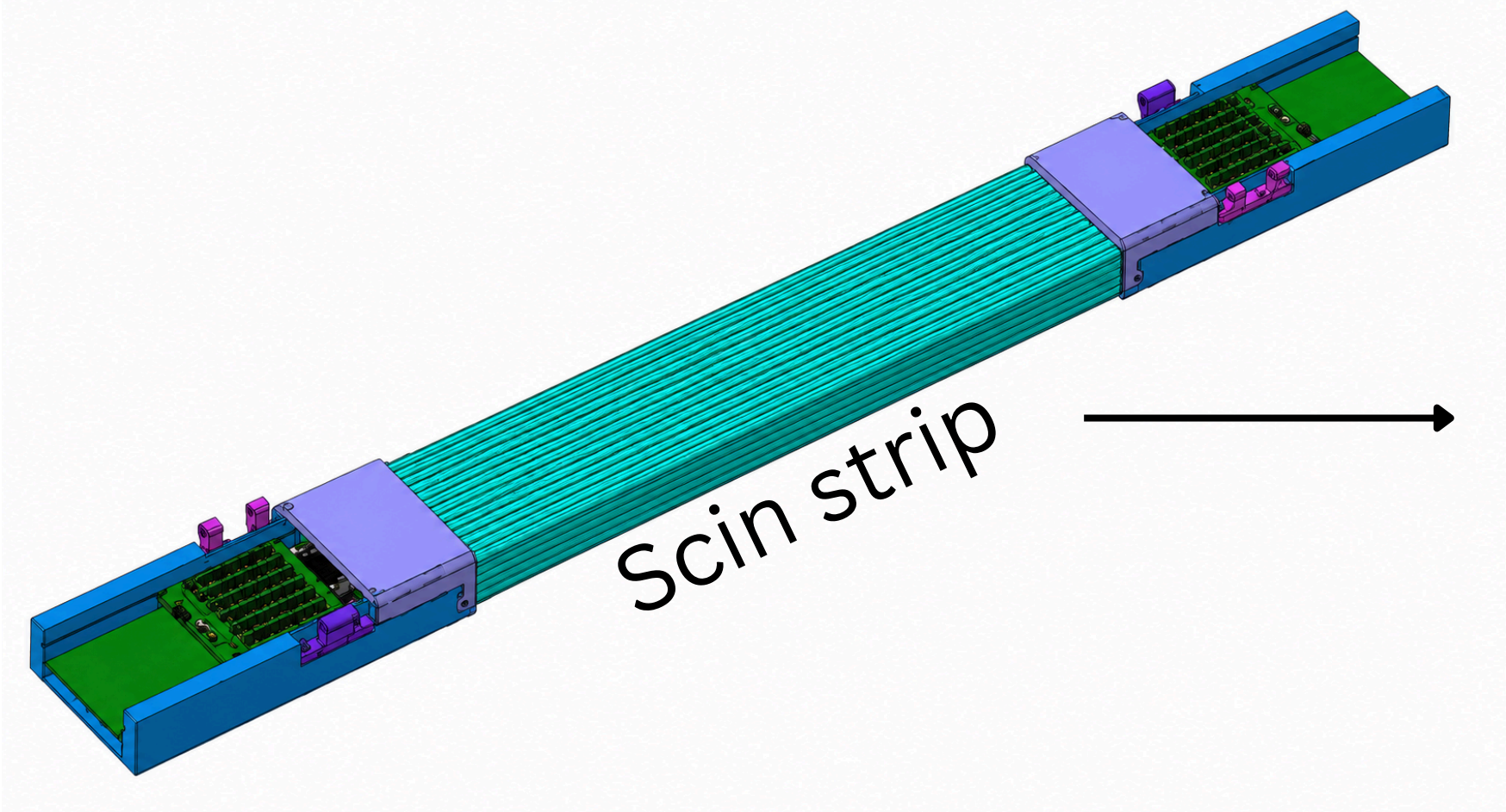


Schema

- Shower generation by CORSIKA
- Shower information: the **FIVE** parameters
 - θ, φ — the direction of the axis (where the shower came from in the sky)
 - core position (x, y) — where the axis hits the ground
 - $t_{\text{core}} (t_0)$ — when the shower front passes the core
- Zenith residuals $(\theta_{\text{reco}} - \theta_{\text{true}})$ are fitted with Cauchy/Lorentzian estimator
- σ vs. $\log_{10}(E/\text{GeV})$ with uncertainties - angular resolution

Shower information:

- Azimuthal $0 - 60^\circ$, zenith 0 to 90°
- x - y plane is the ground, z is vertical
- Energy range: $\log_{10}(E/\text{GeV})$ 6-8

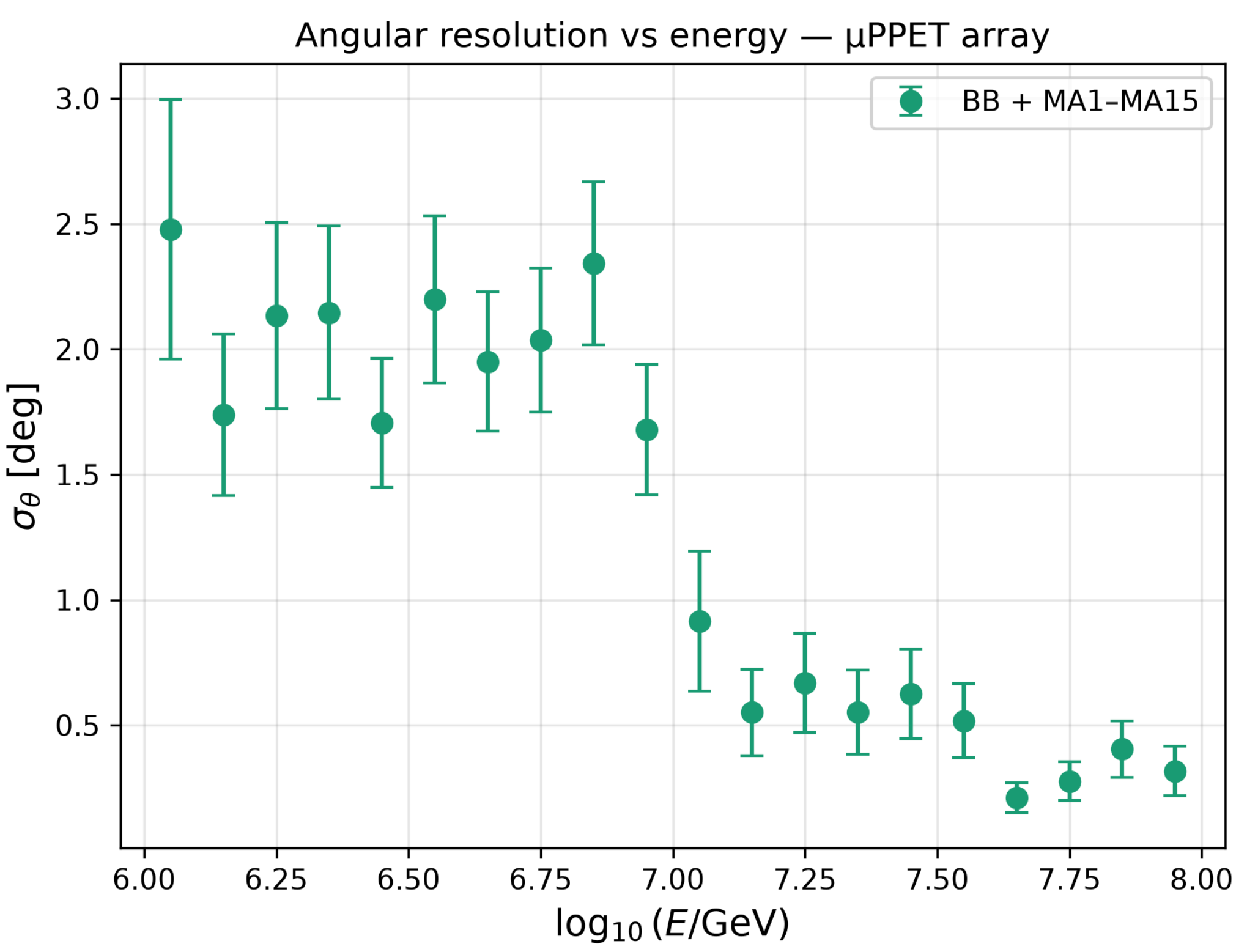
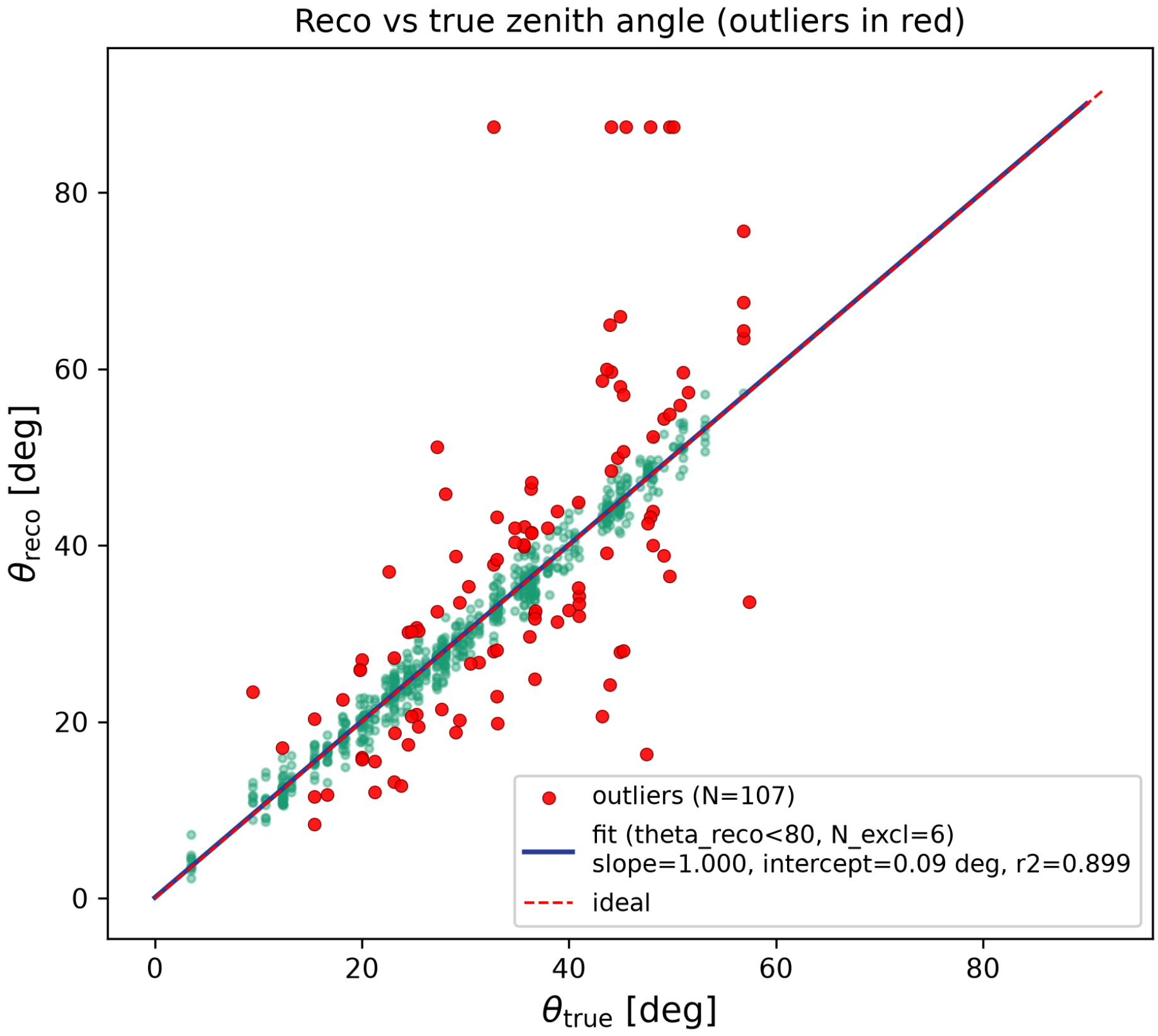
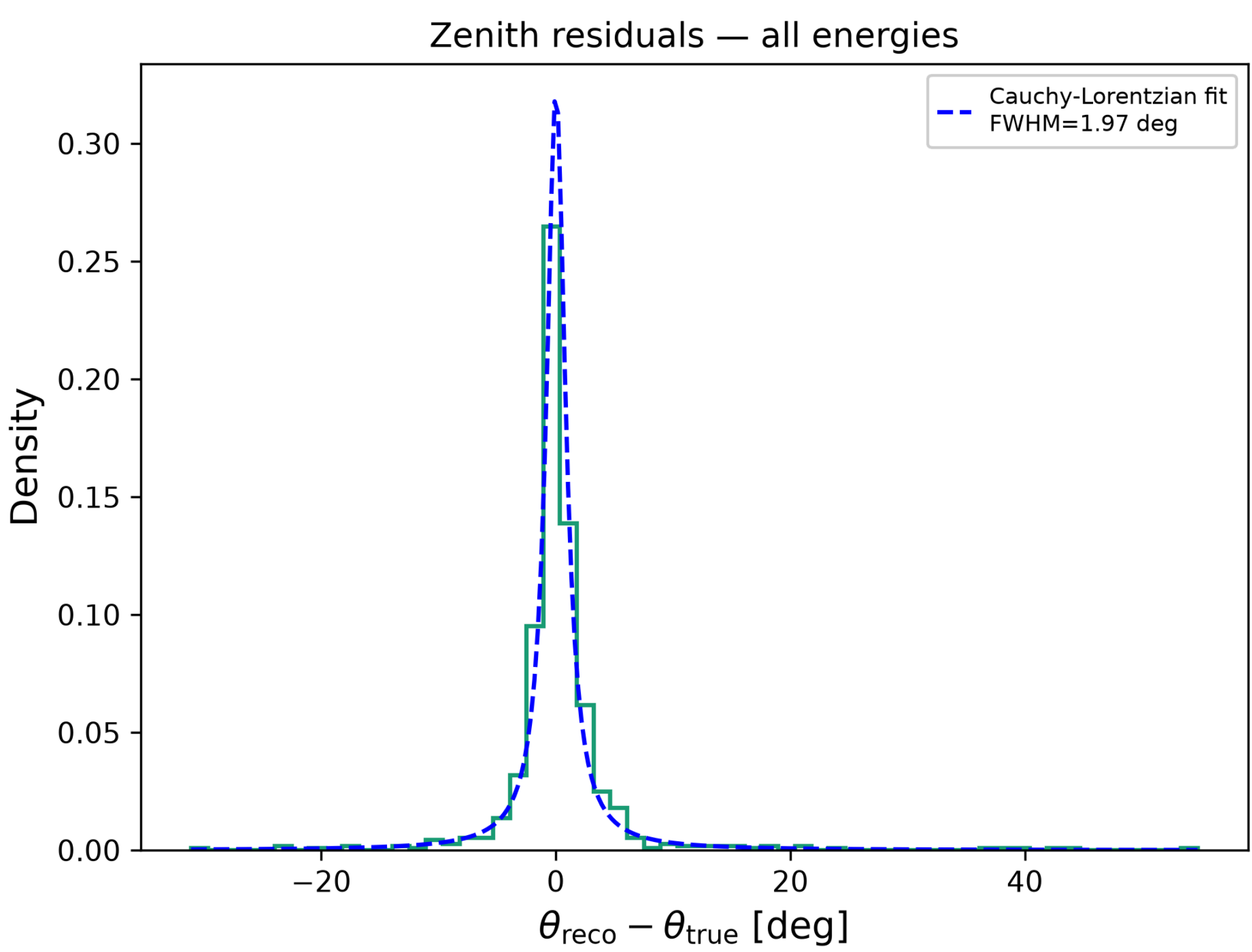


JPET detector (modular units + Big Barrel) will be used as Modular array (MA) for its high detector resolution which will leverage the angular resolution of Muon trajectory to converge the results better to desired accuracy level.

Detector information:

- Units of Modular Array will contain two plastic scintillators caged in each box.
- Stations are clock synchronised.
- Dimension: $0.7 \times 1.9 \times 50.0$ cubic cm.
- Architecture: FPGA controlled Central Master connected to units.

Results



Conclusion

- A reconstruction for the shower front generated and validated for CORSIKA-simulated proton showers across the μ PPET array (Big Barrel + 15 Modular J-PET stations)
- Analysis focussed on $\sim 10^6$ GeV to investigate the region of most interest
- These results provide a benchmark as a baseline for future reconstruction frameworks particularly a GNN-based

References

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Acknowledgments

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