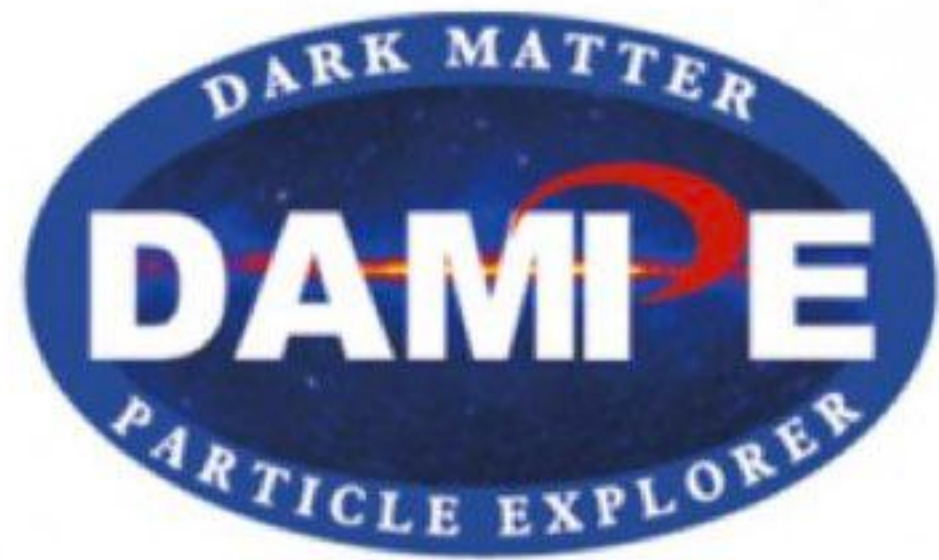




CR proton flux towards PeV energies with DAMPE

Andrii Tykhonov



UNIVERSITÉ
DE GENÈVE

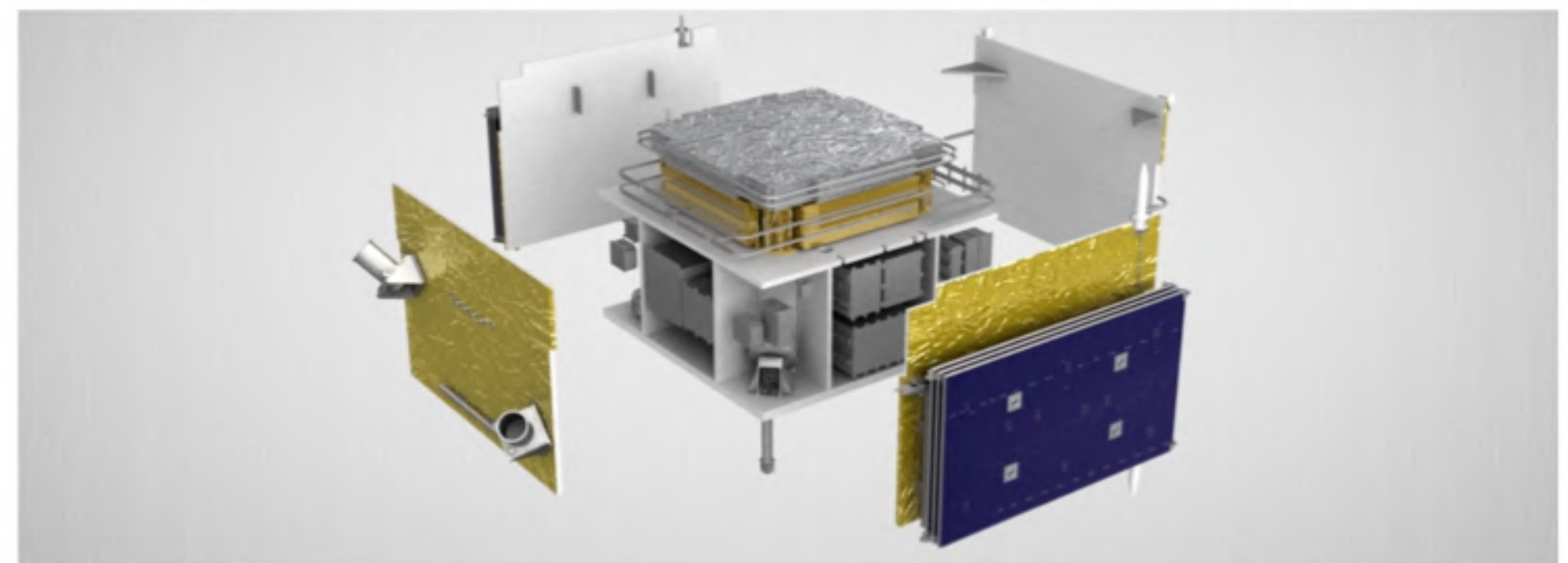
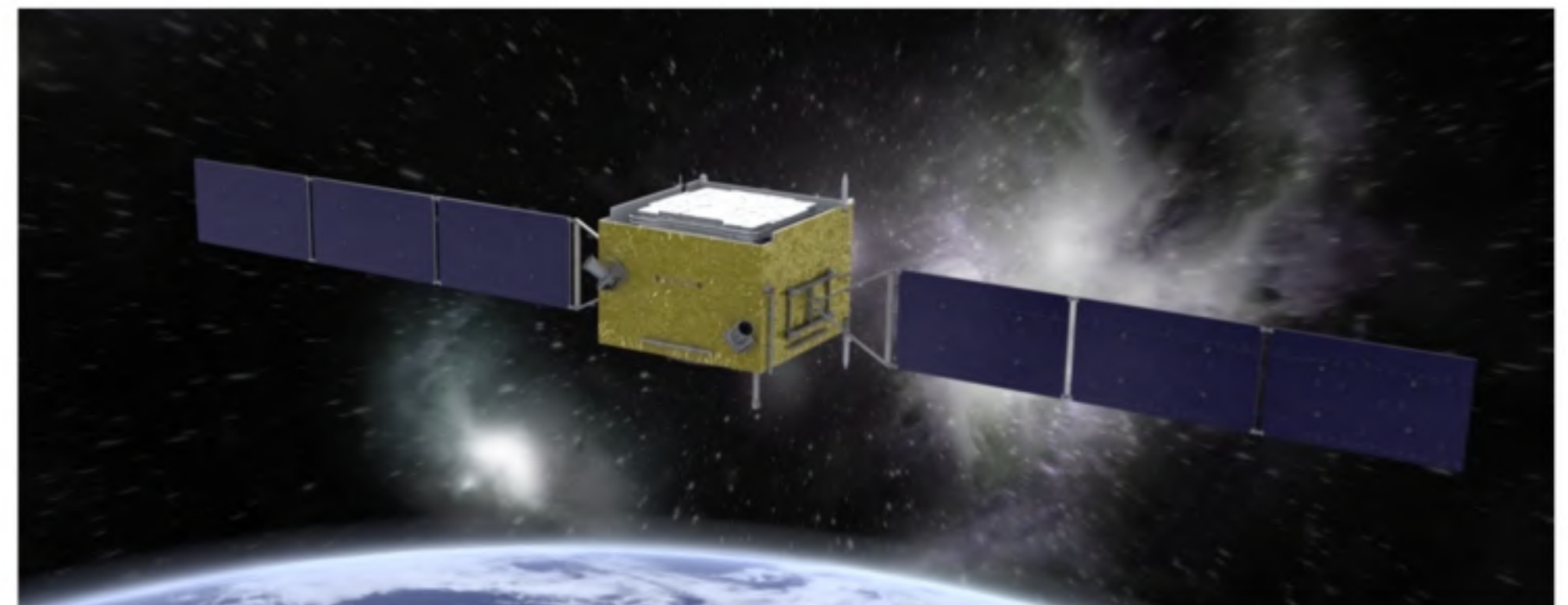


(for the DAMPE collaboration)

DArk Matter Particle Explorer (DAMPE)

- Launched in **Dec 2015**
- Orbit: sun-synchronous, **500 km**
- Period: **95 min**
- Payload: **1.4 Tonn**
- Power: **~ 400 W**
- Data: **~ 12 GByte / day**

Collaboration



DArk Matter Particle Explorer (DAMPE)

PSD

- Z identification up to *Ni* ($Z=28$)
- γ anti-coincidence signal

STK

- Position solution ~ 50 *micron*
- γ angular resolution $0.5^\circ - 0.1^\circ$ (GeV — TeV)
- Absolute Charge (Z) identification

BGO

- $31 X_0$ — thickest in space
- e/γ detection up to **10 TeV**
- p/ions up to **50 GeV — 500 TeV**

NUD

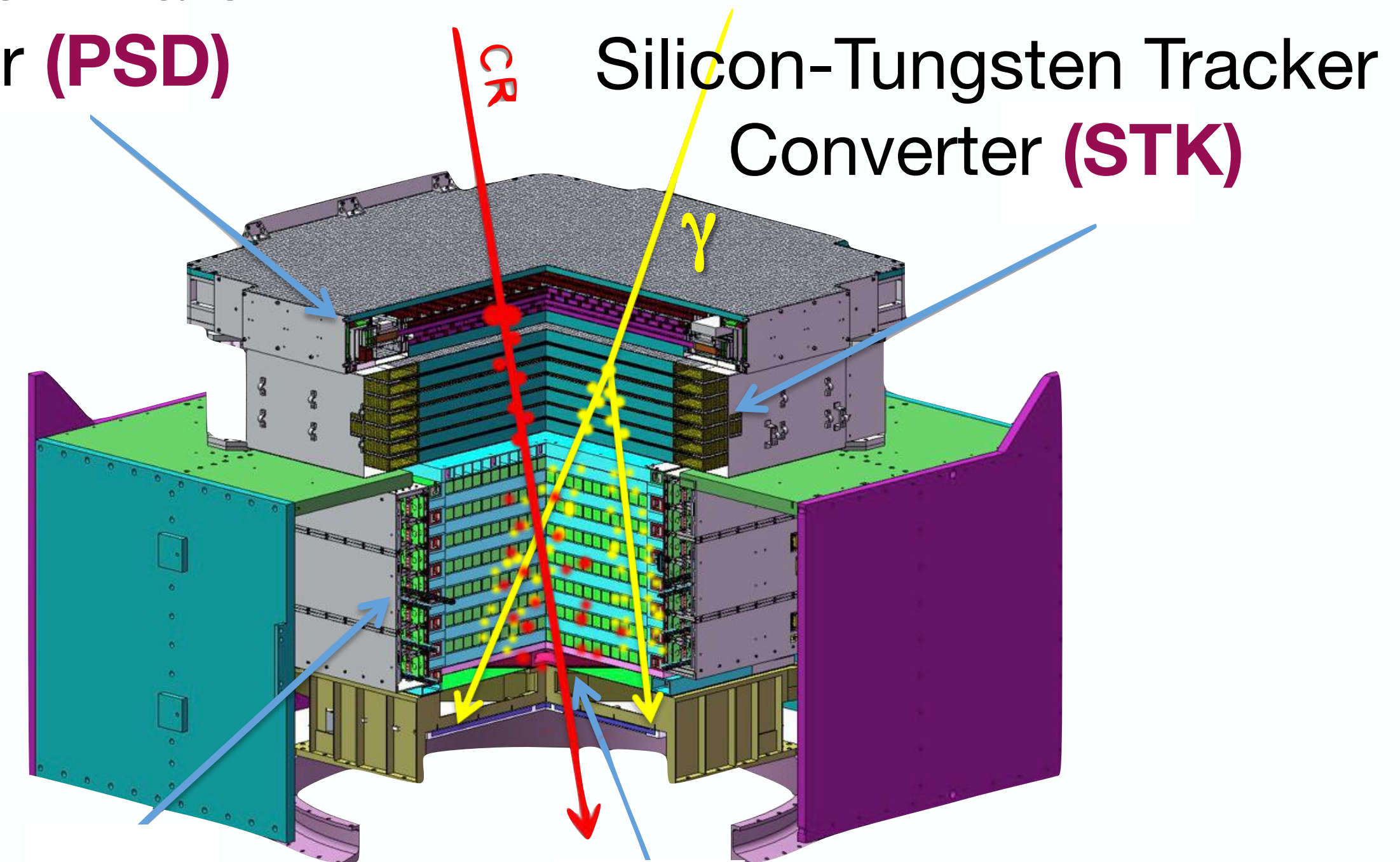
- Additional e/p rejection capability

Plastic Scintillator
Detector (**PSD**)

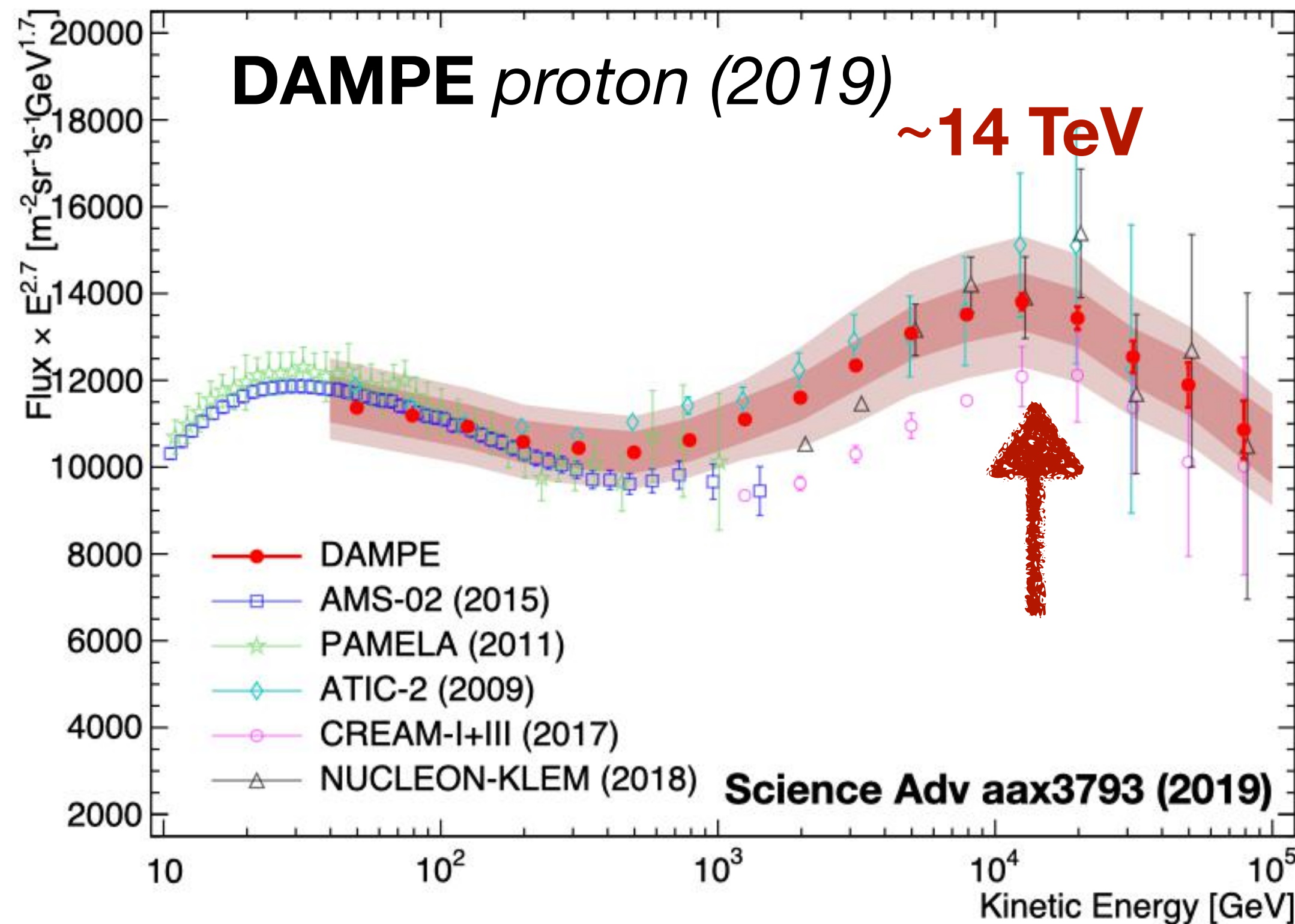
Silicon-Tungsten Tracker
Converter (**STK**)

Calorimeter (**BGO**)

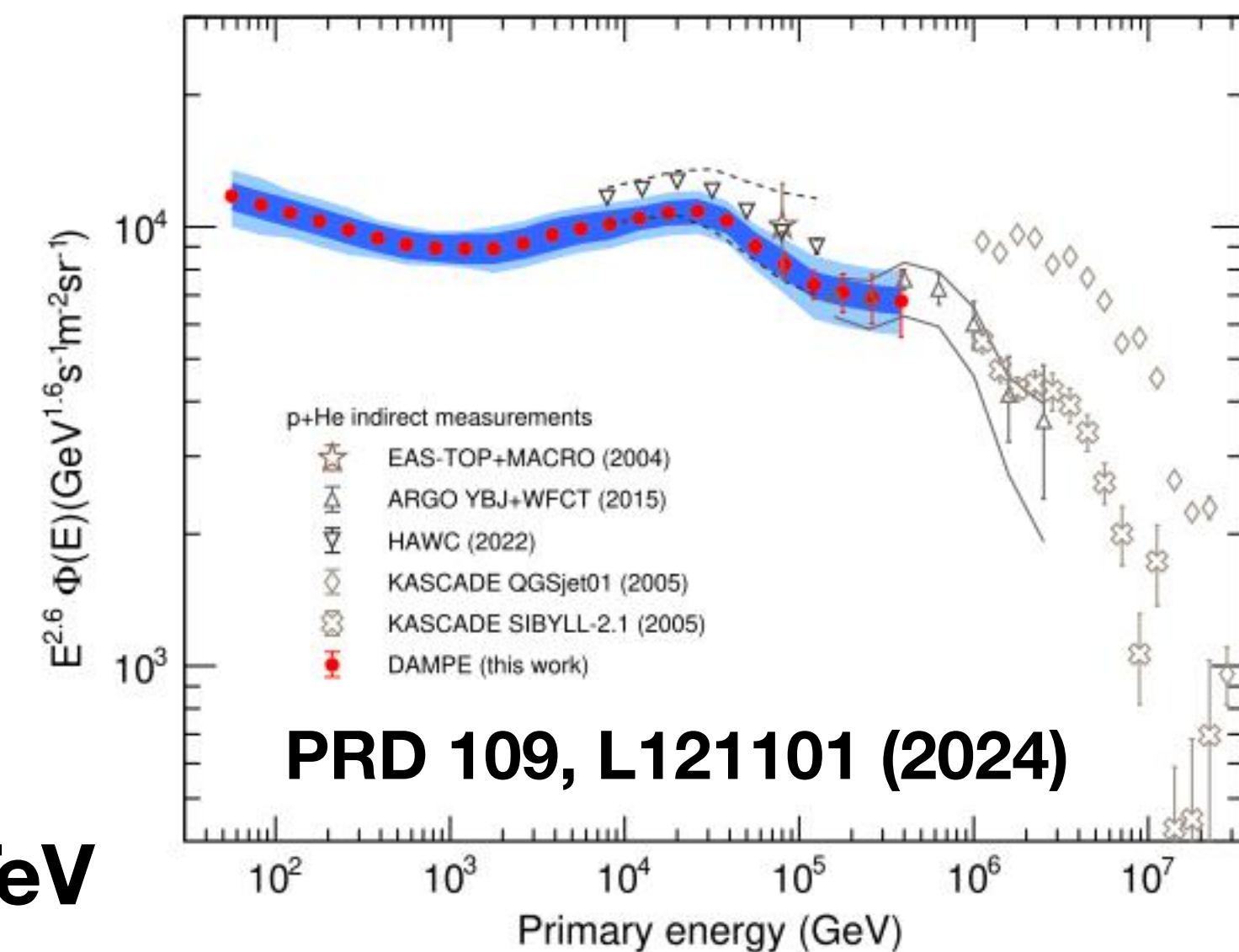
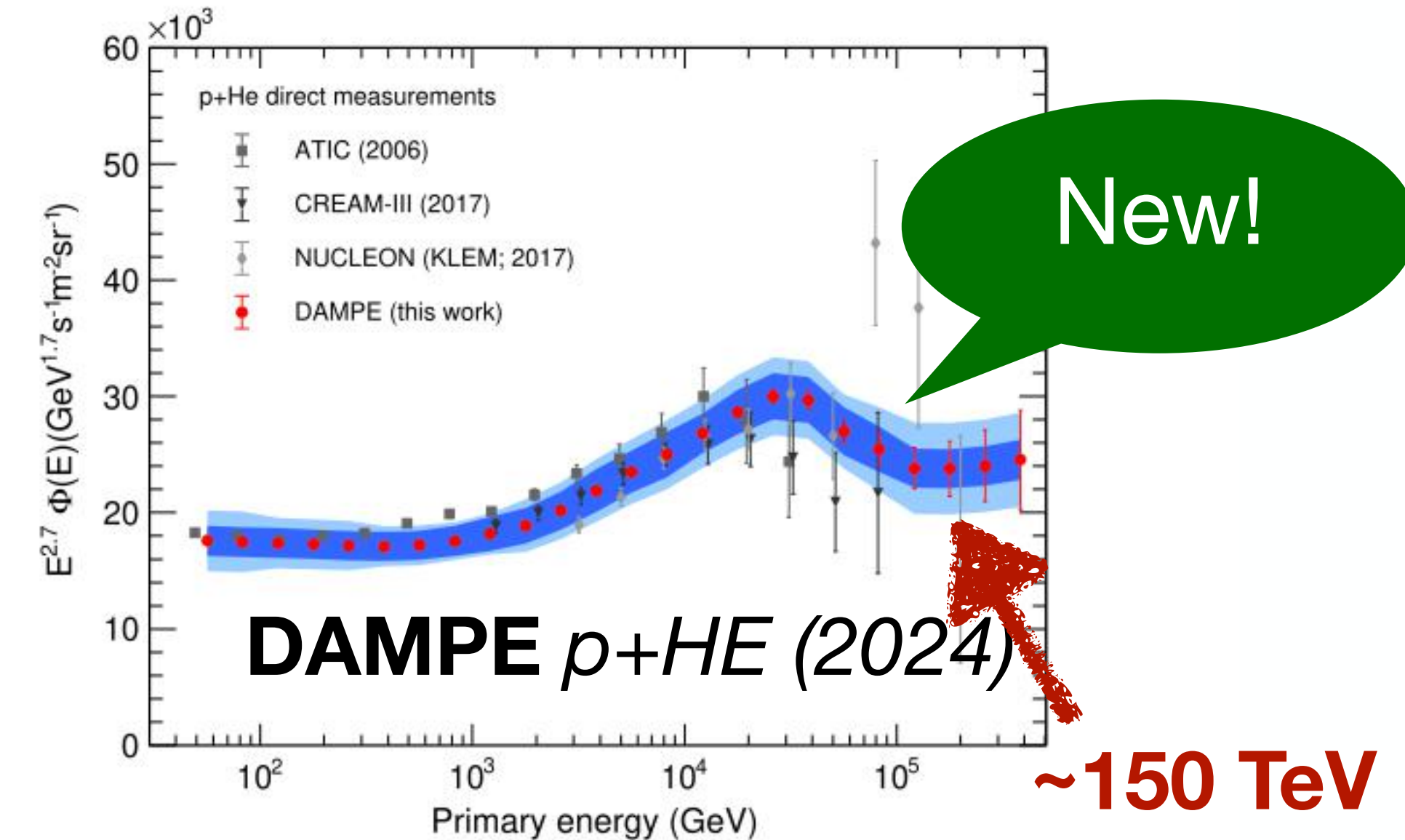
Neutron Detector
(**NUD**)



Motivation



- Proton — most abundant CR and the only CR with $Z=A$
- Previous individual CR proton measurement reaching 100 TeV
→ limited by statistics and particle ID
- p+He spectrum (2024) suggests a new hardening at ~ 150 TeV**



Challenge: track reconstruction

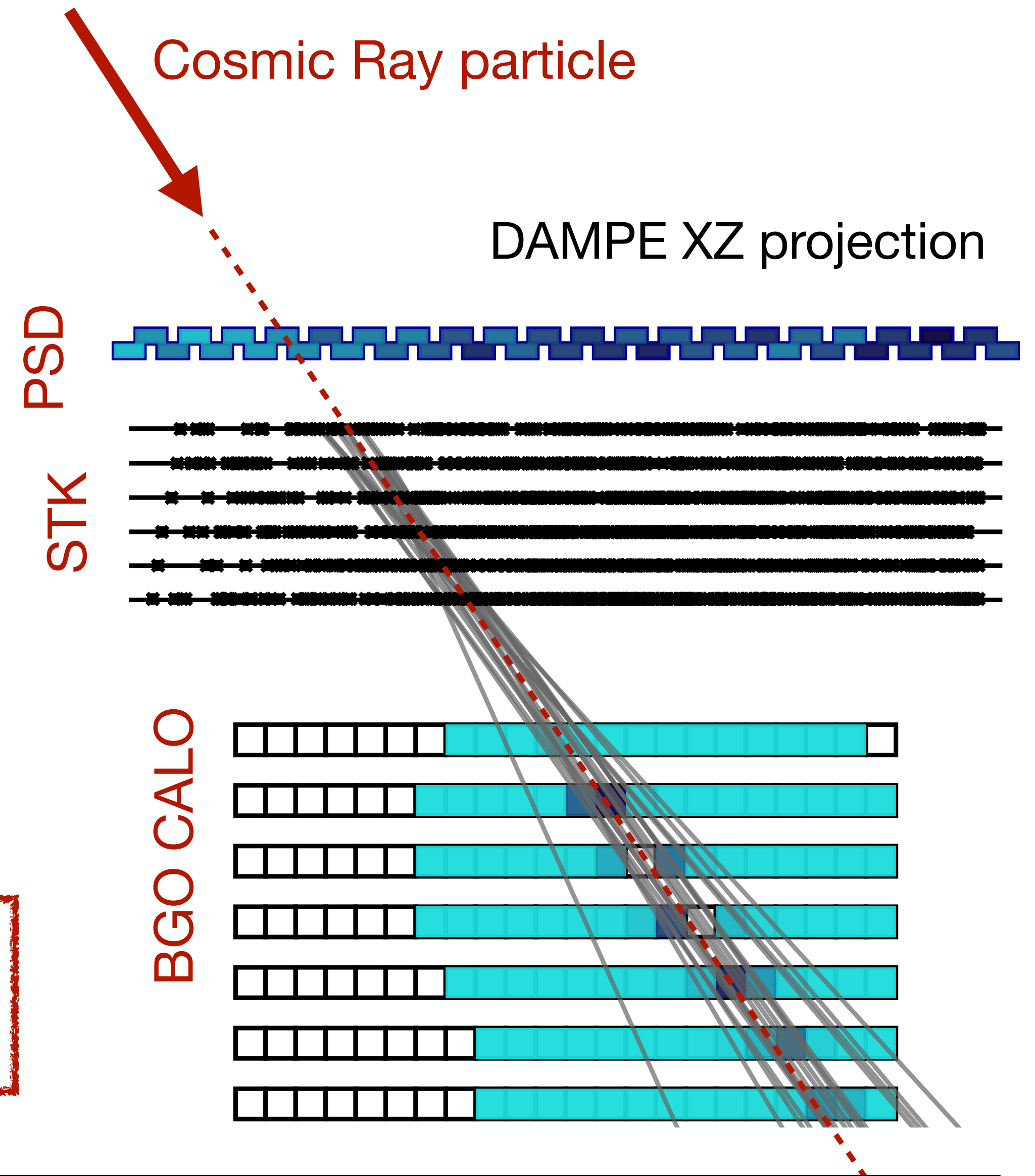
Conventional track reconstruction:

- Shower axis from CALO as a seed
- Kalman fitting
- Combinatorial track finding
- XZ and YZ fitted separately,
- ... then combined in 3D tracks

Problems:

- Selection needed to find **the ONLY** track
- Efficiency drops at high hit multiplicity

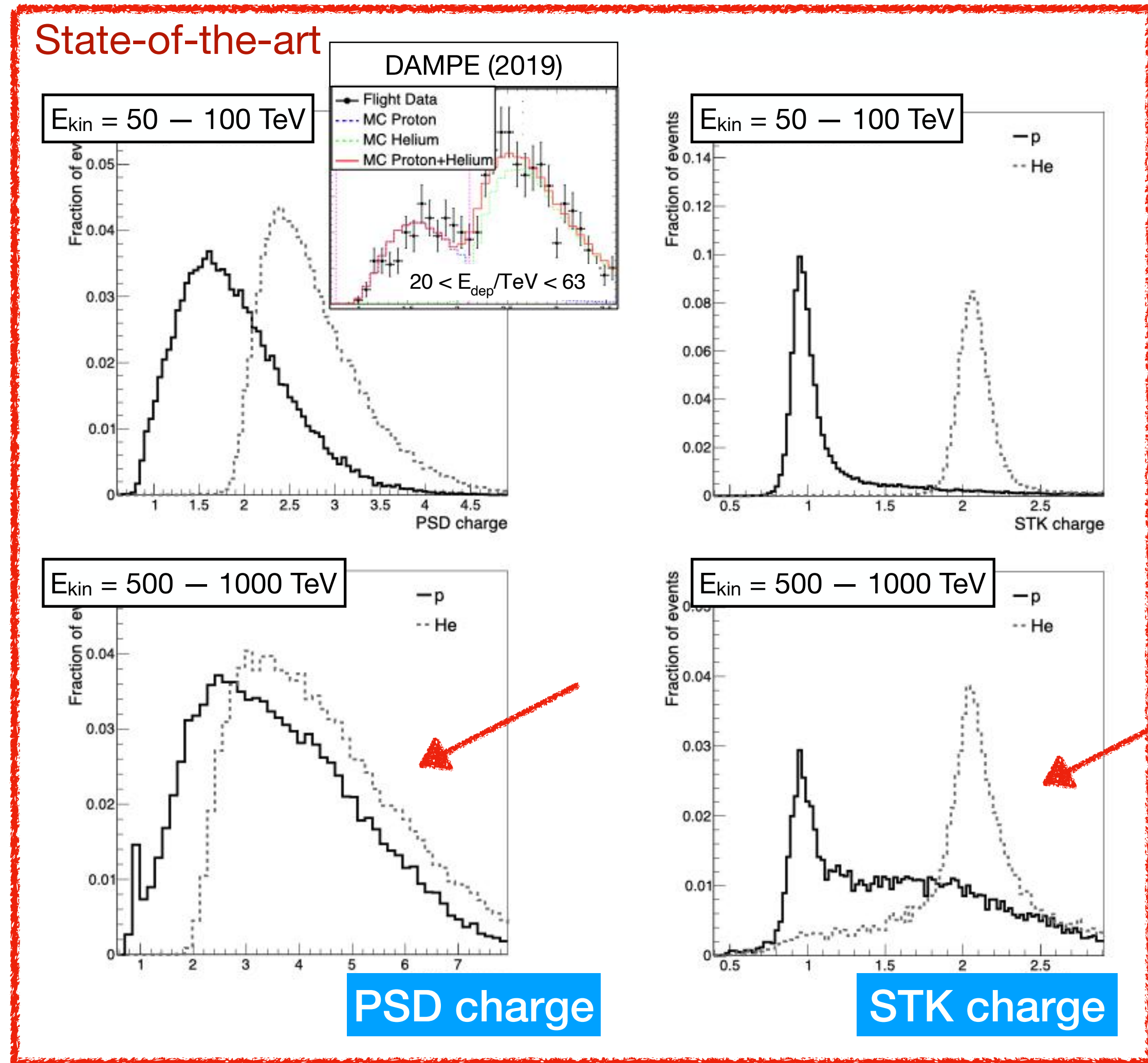
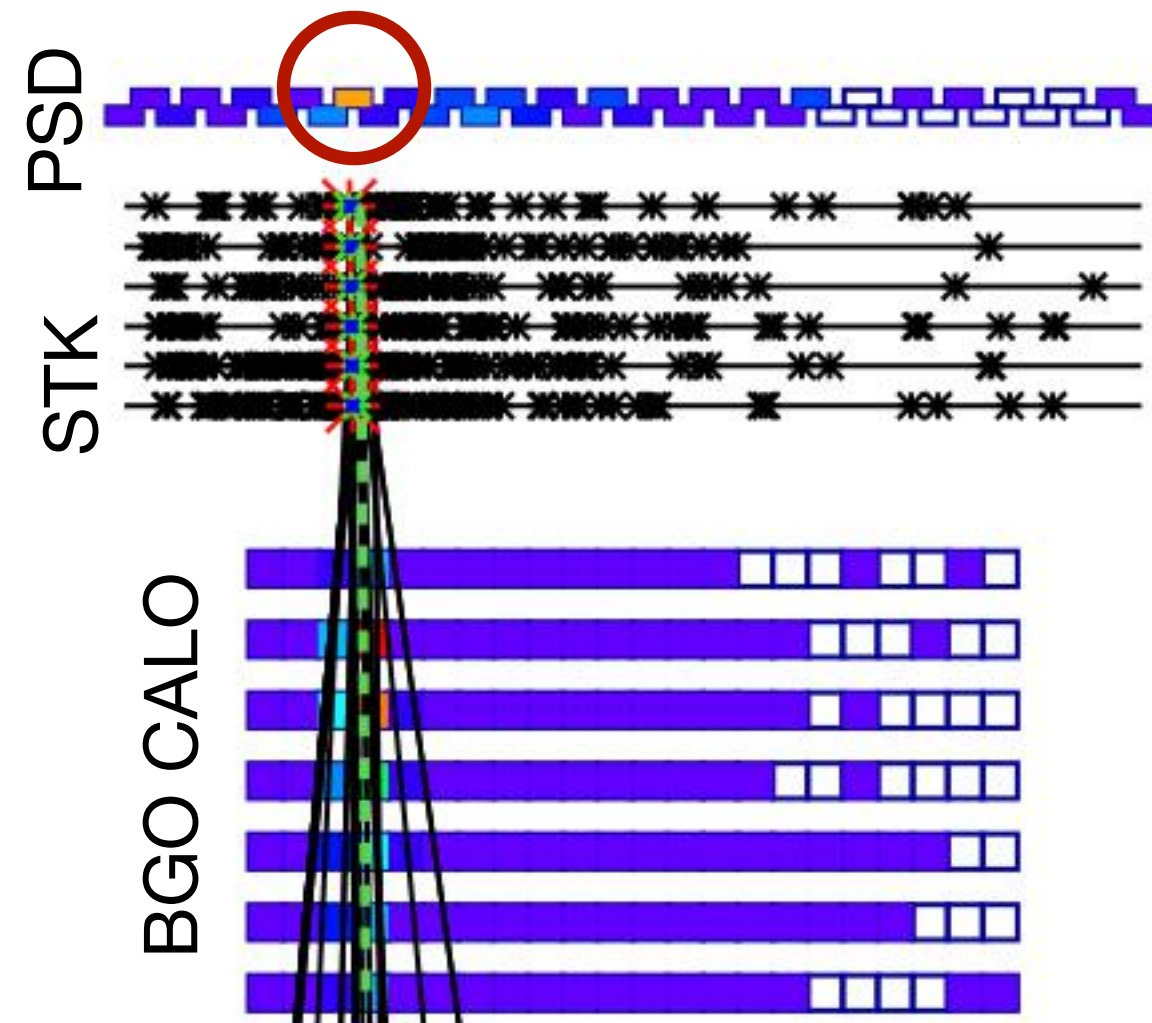
At TeV— PeV hit multiplicity increases dramatically →
Track reconstruction & identification is a key challenge!



Challenge: charge identification

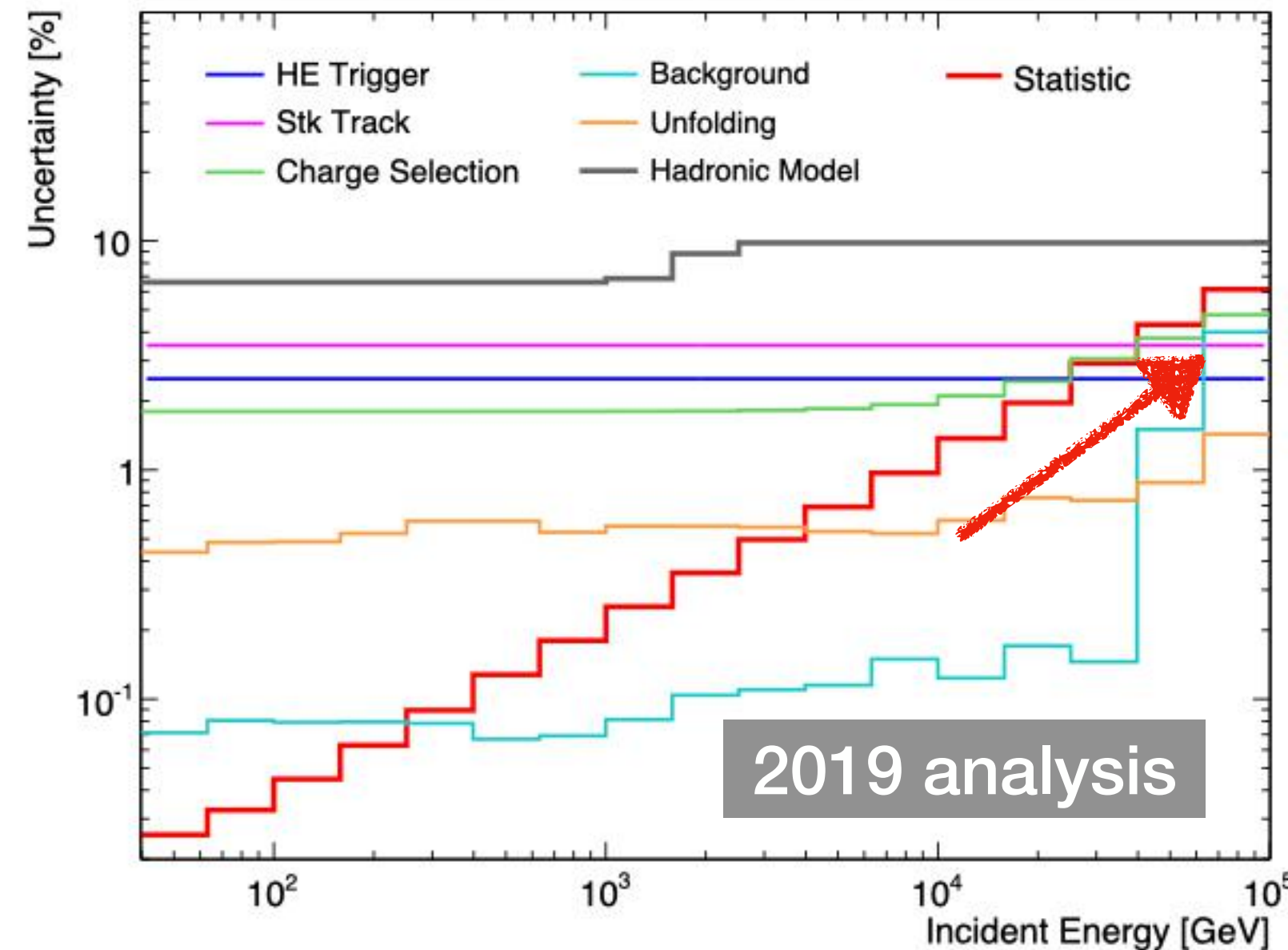
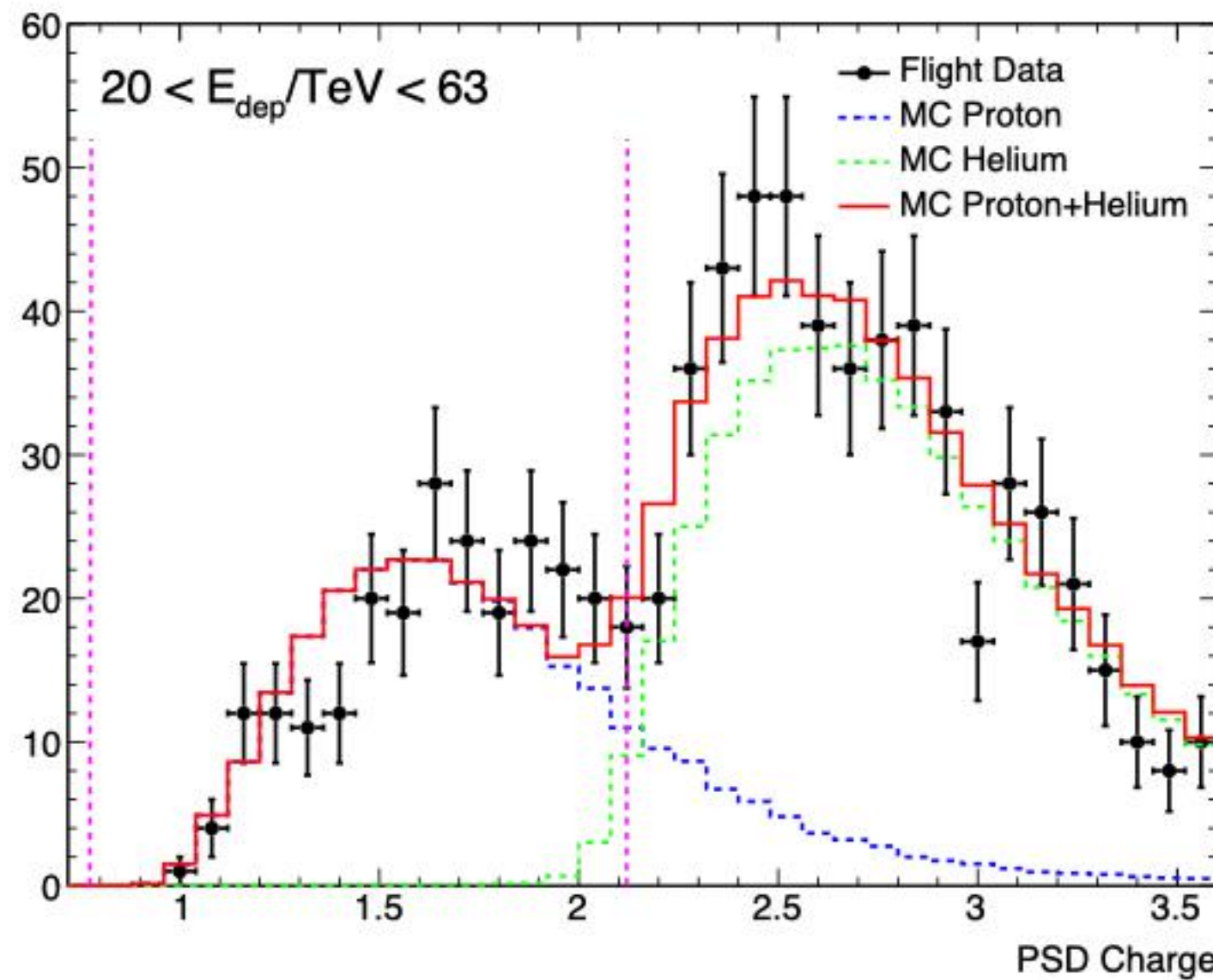
- Charge ID conventional done in PSD
- Track used as a pointer to PSD
- Tolerant to track mis-identification, however:

***p* and *He* peaks “washed out”
at high energies!**

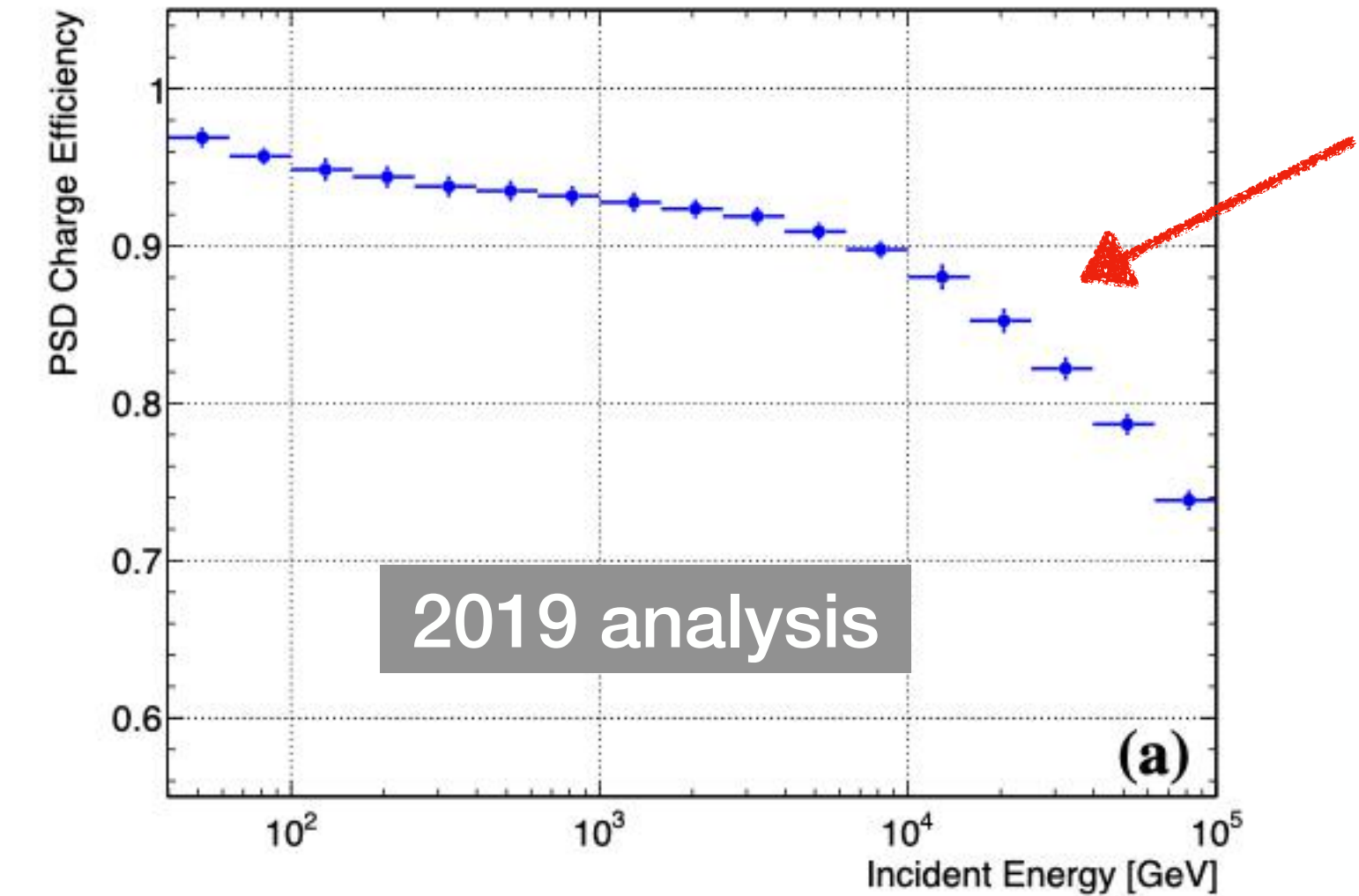


Challenge: tracking & charge ID

Statistical & Systematic errors



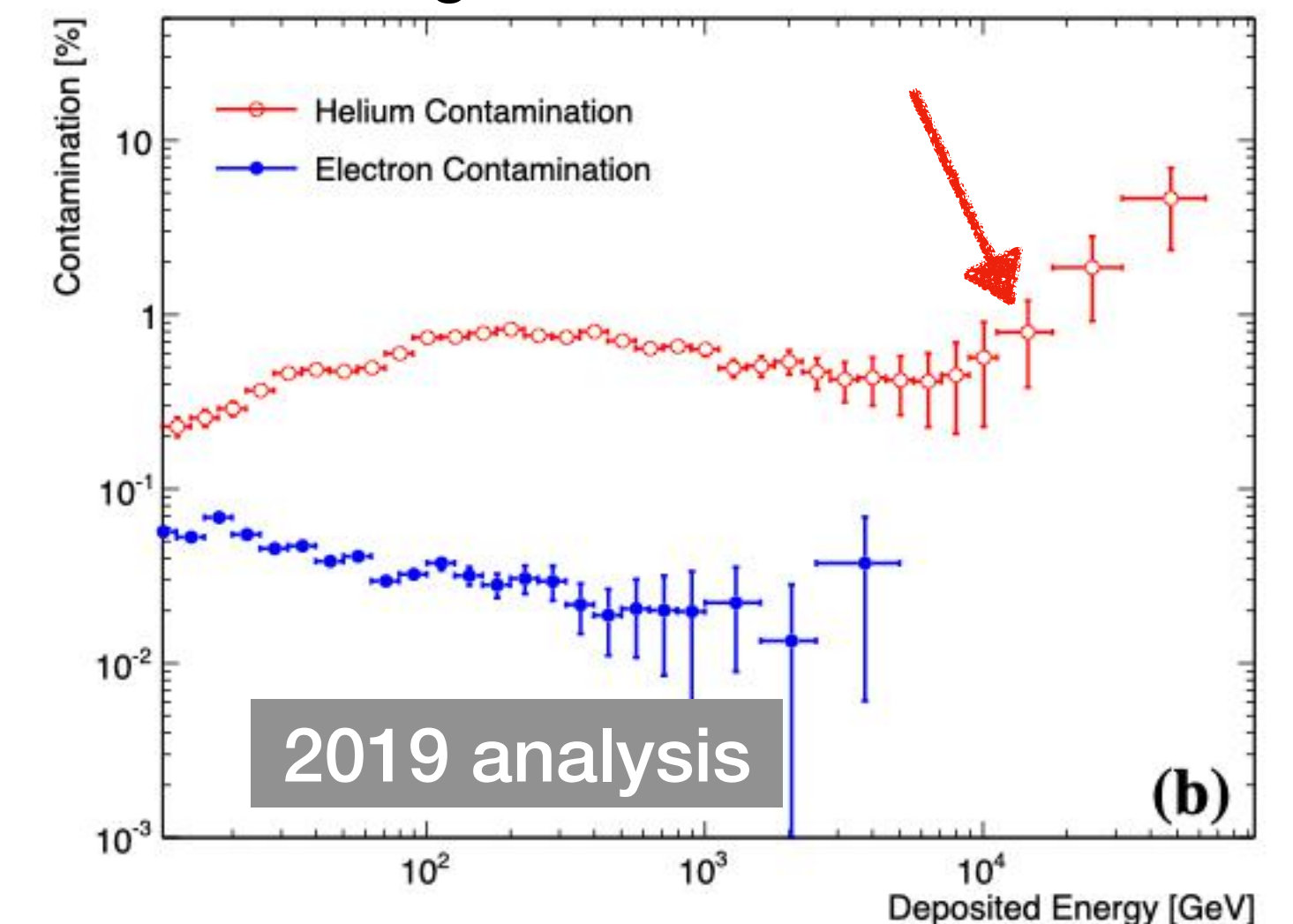
p charge selection efficiency



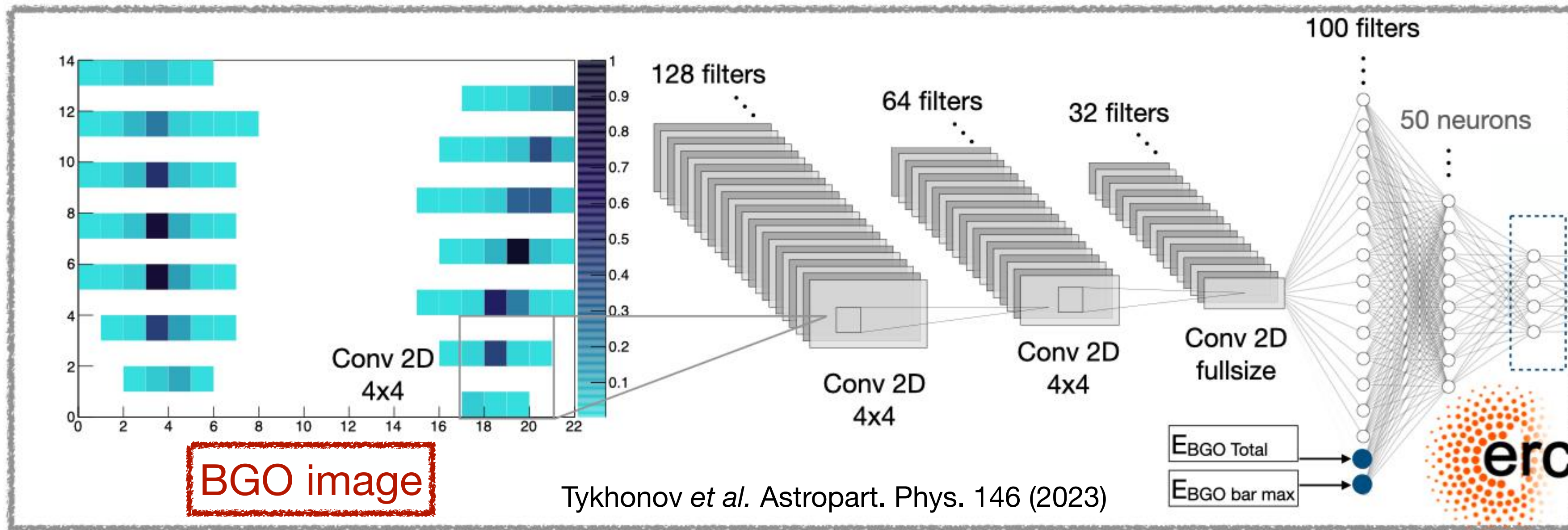
- Track reconstruction + proton charge identification + background contamination — dominating uncertainty at high energies!

New tracking algorithm required for ~ PeV measurements!

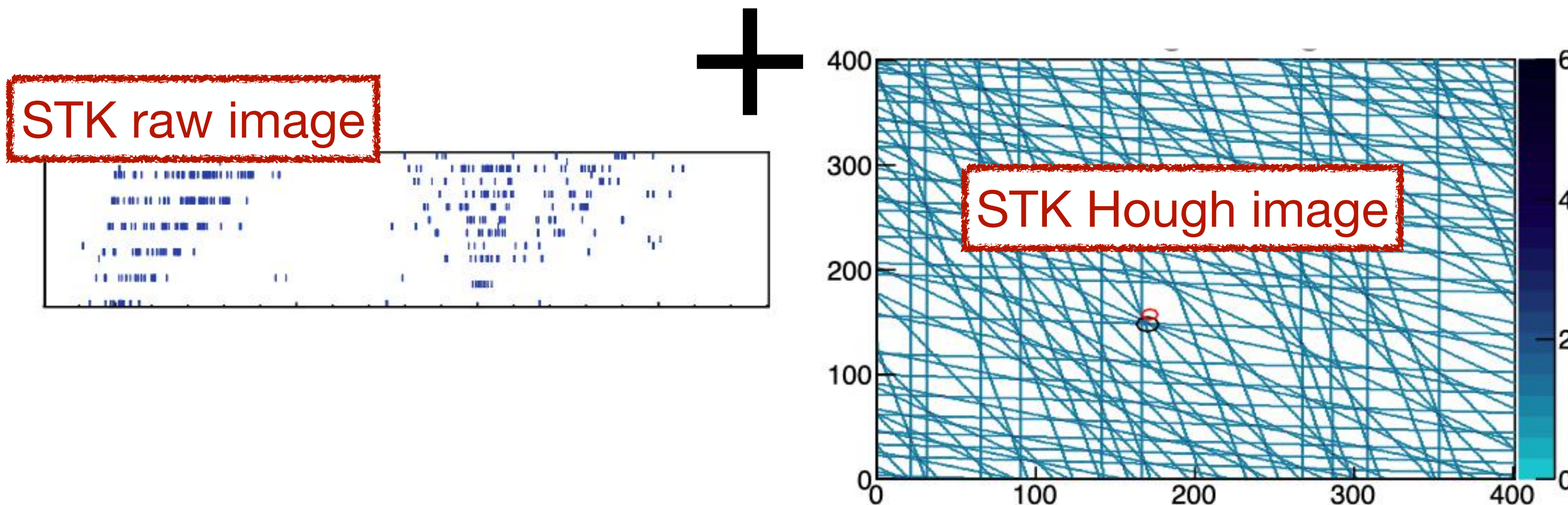
Background contamination



New track reconstruction & ML

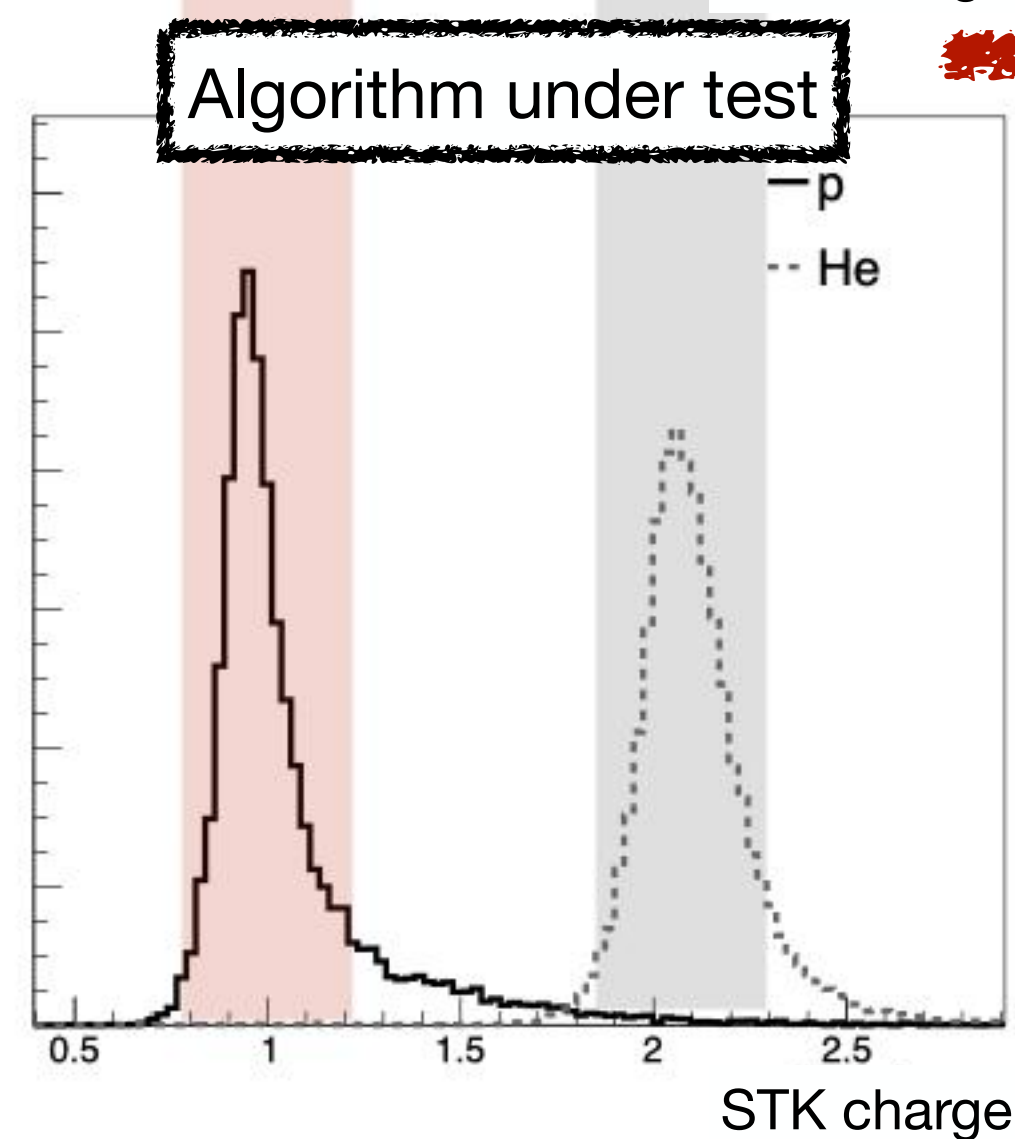
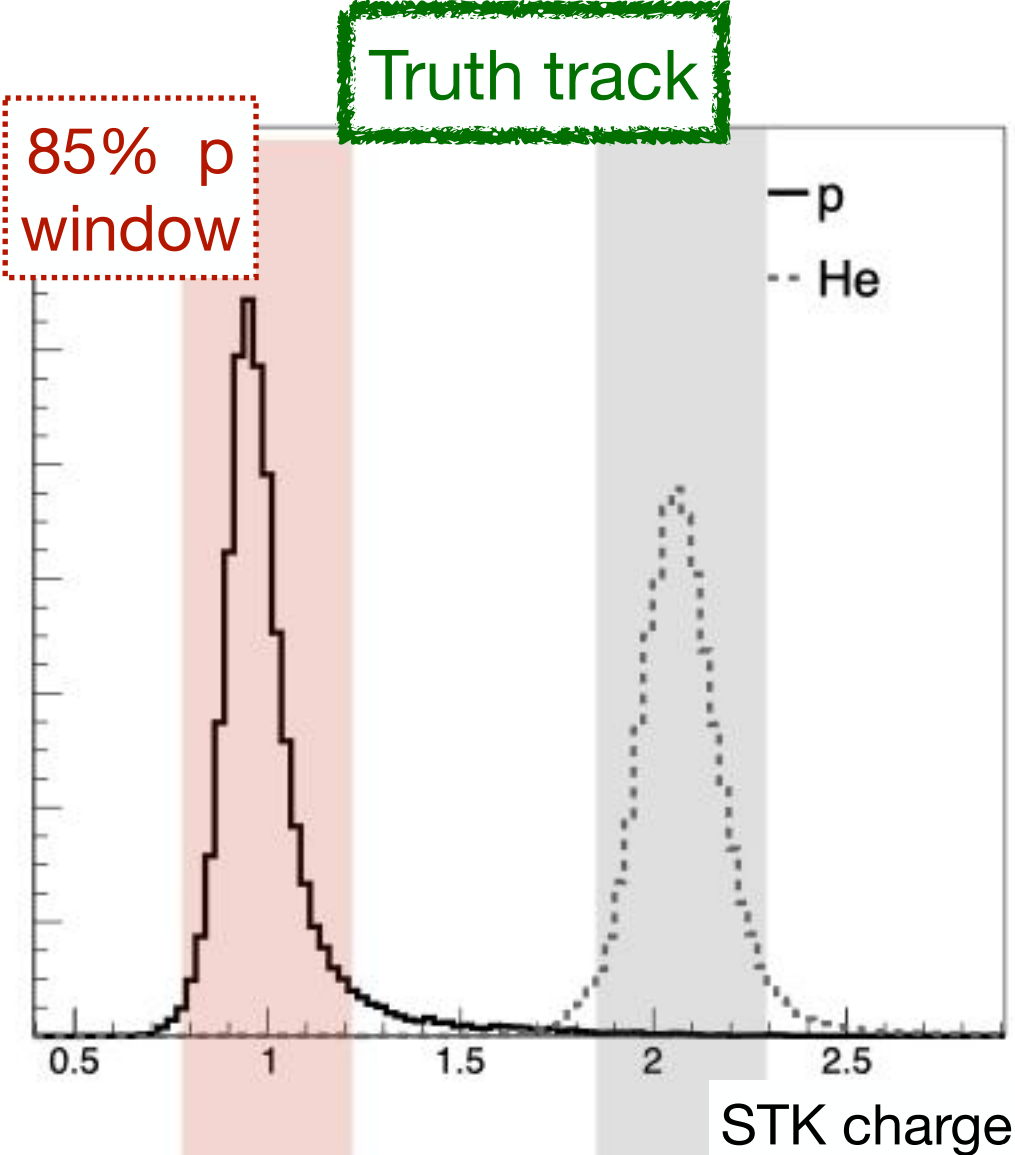


We employ **Convolutional Neural Networks (CNNs)** to boost the accuracy of track reconstruction & identification @ DAMPE

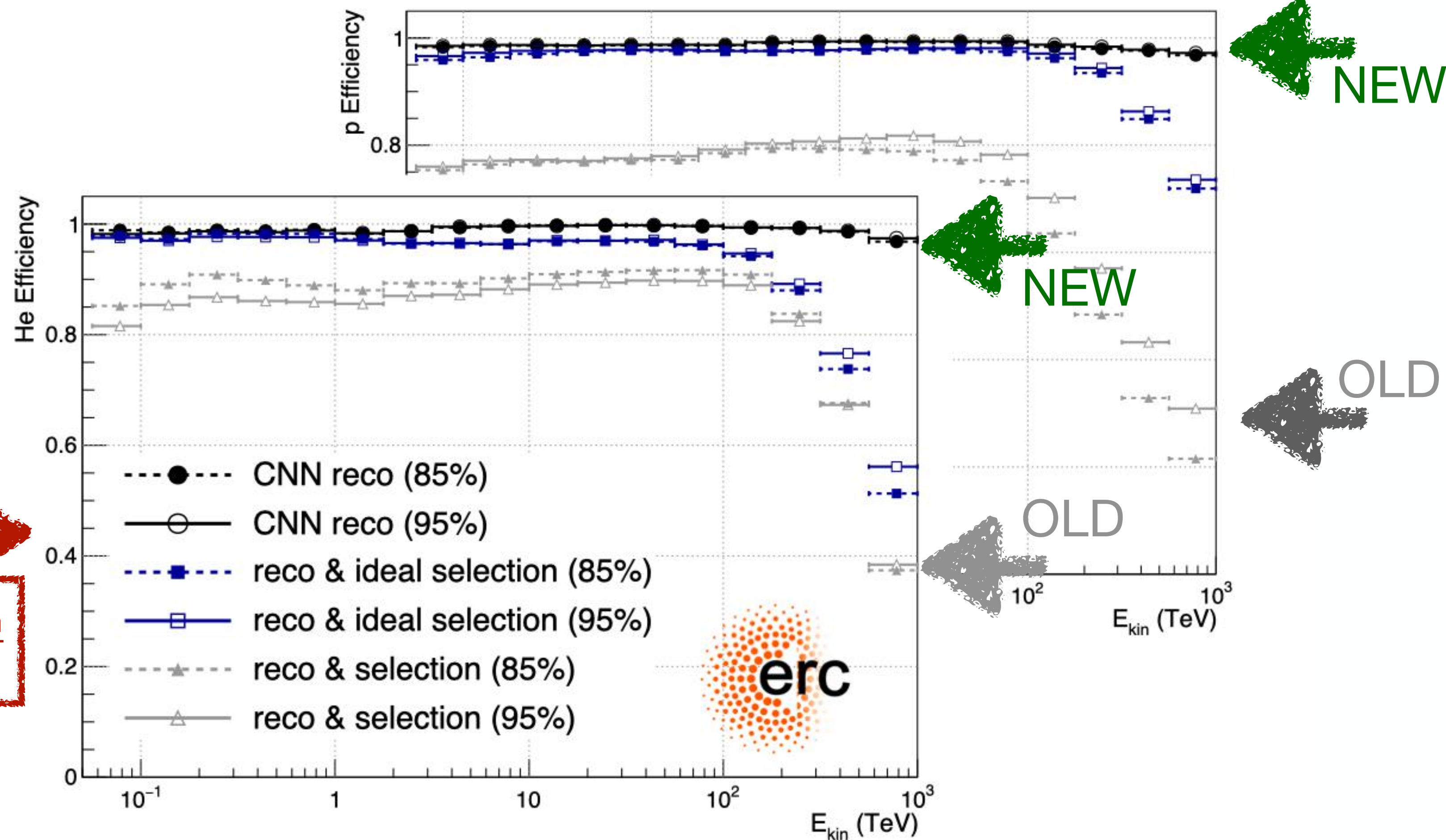


CALO & Tracker “images” used as input, regression type of problem — returns particle direction as an output (no track selection needed)

New track reconstruction & ML



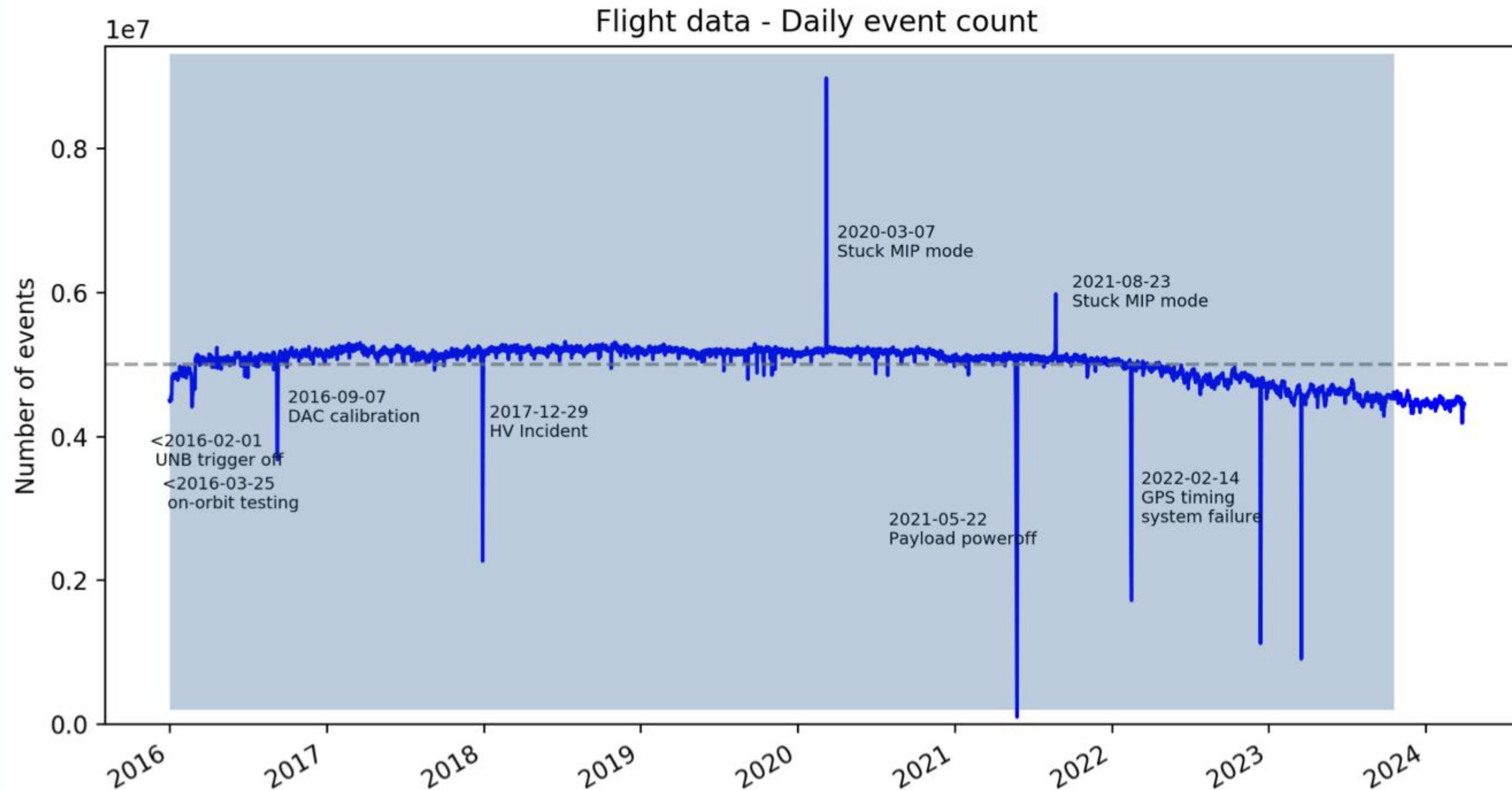
$$\text{Eff} = \frac{N_{\text{algorithm}}}{N_{\text{true}}}$$



Tykhonov *et al.* Astropart. Phys. 146 (2023)

CNN tracking efficiency = **98-99%** up to 500 TeV (**> 96%** @ PeV)

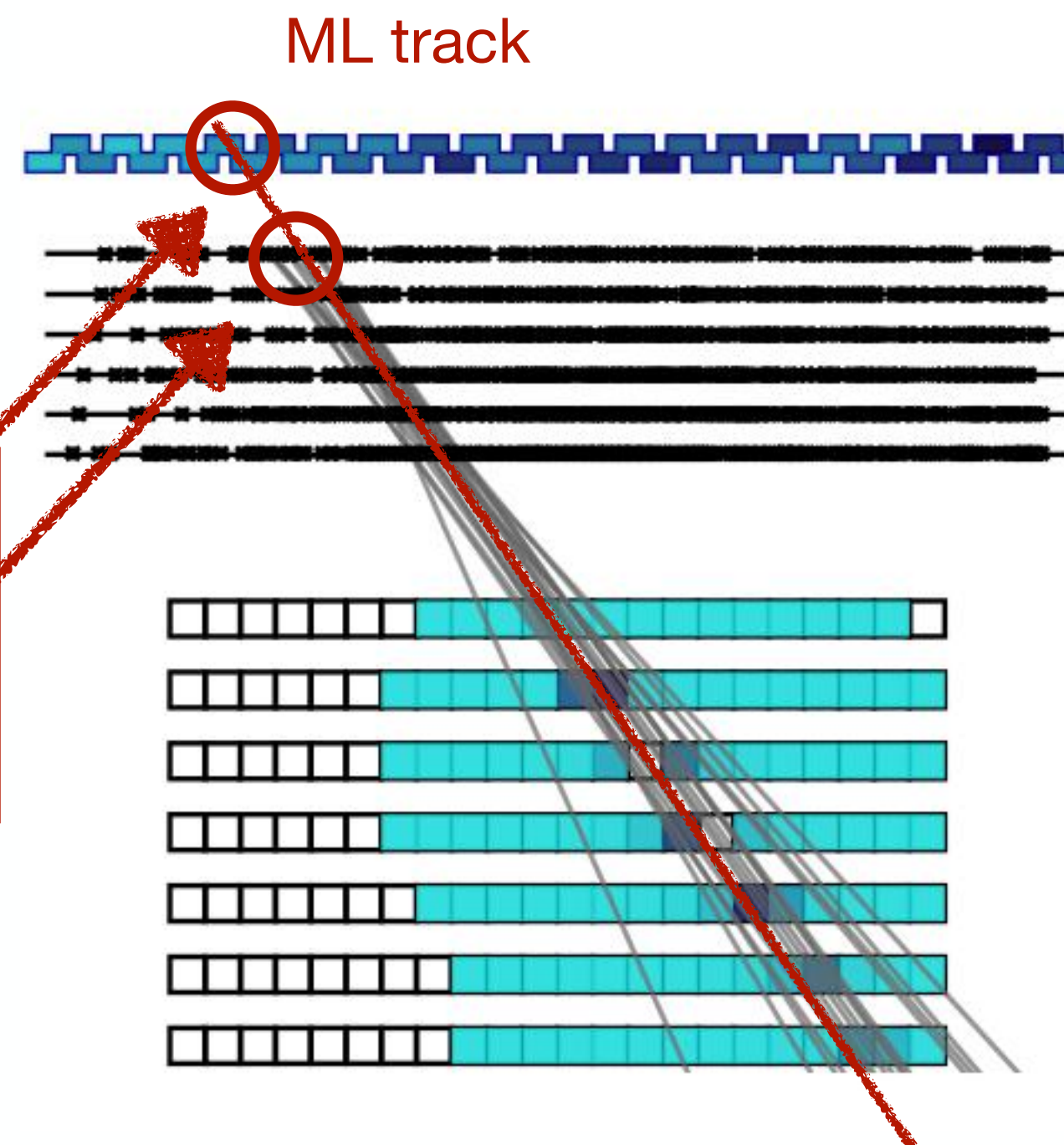
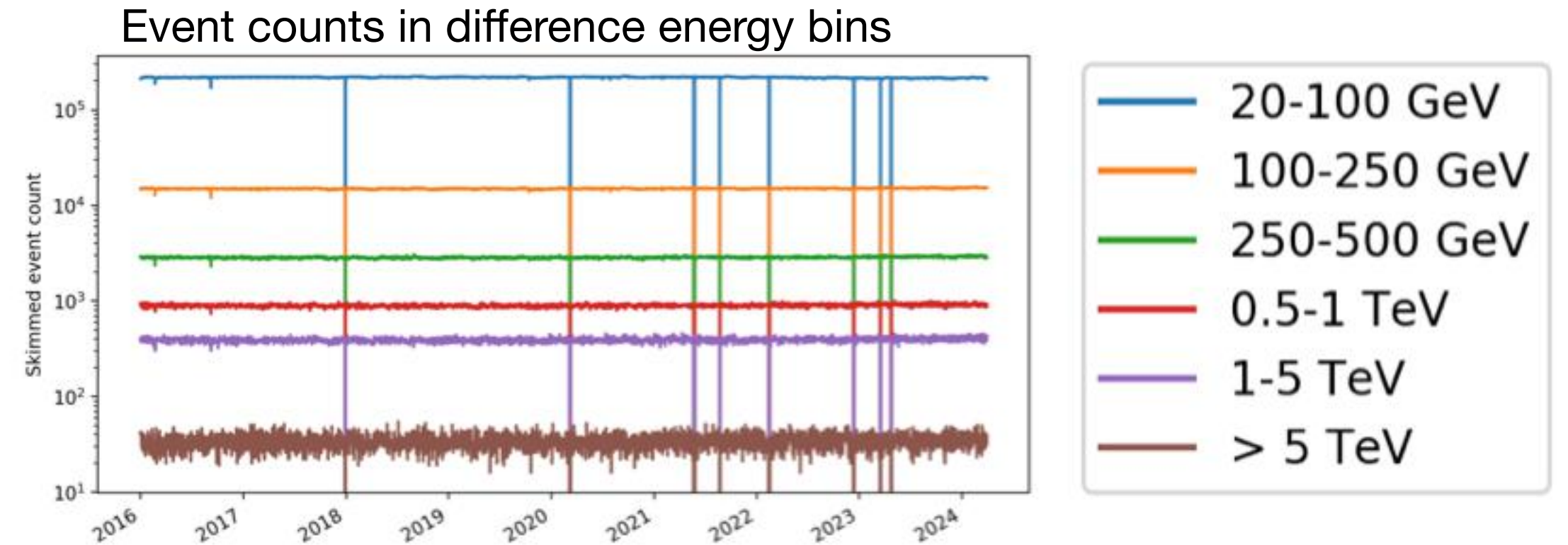
Data



- **92 months of data**
- **14 billion events**
- **Livetime:**
183698199 seconds
(76%)

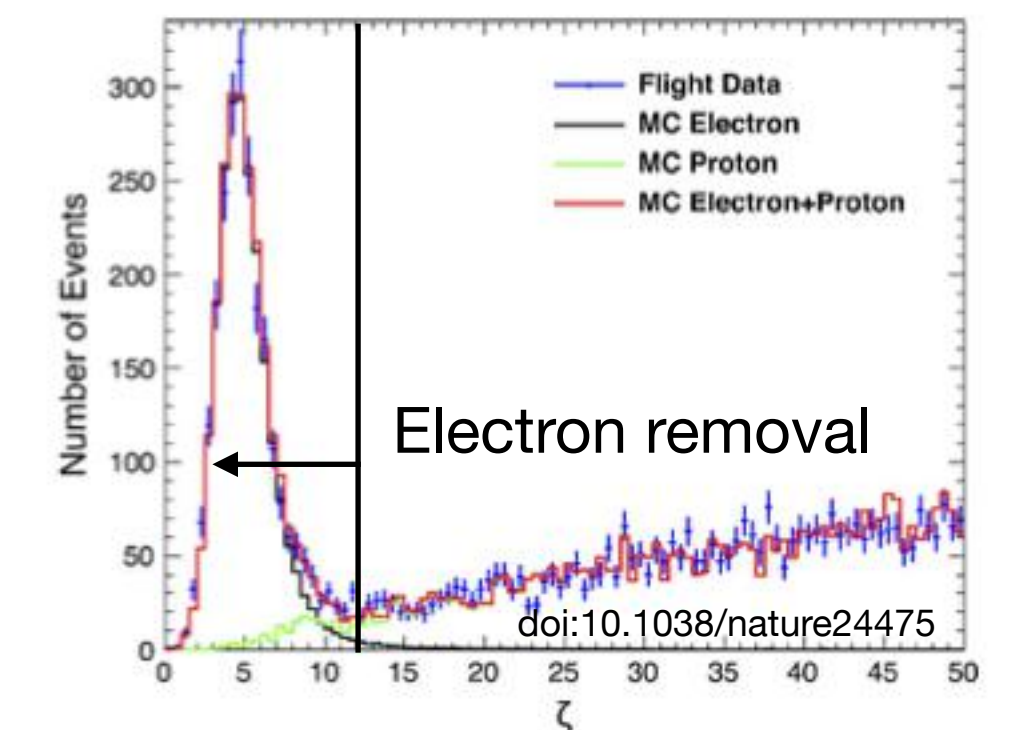
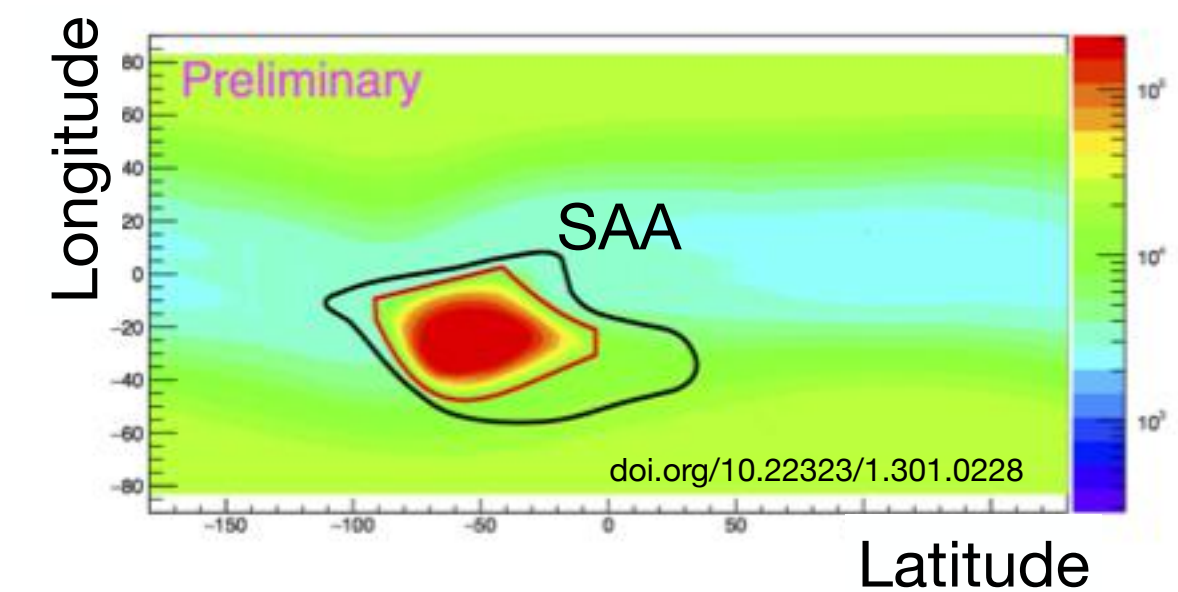
Event selection

- **Pre-selection:**
 - Ensure well-reconstructed and fully-contained events in the detector
- **Selection:**
 - High-energy trigger
 - Deposited energy > 20 GeV
 - Removal of SAA region
 - Electron removal (ζ classifier)
 - ML track reconstruction

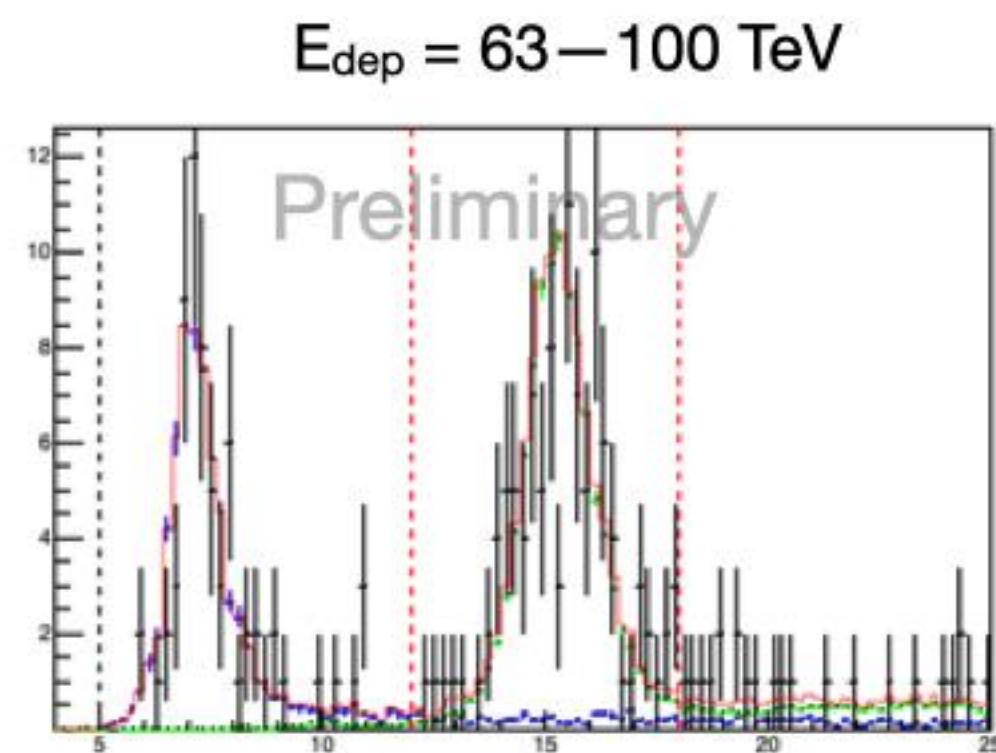
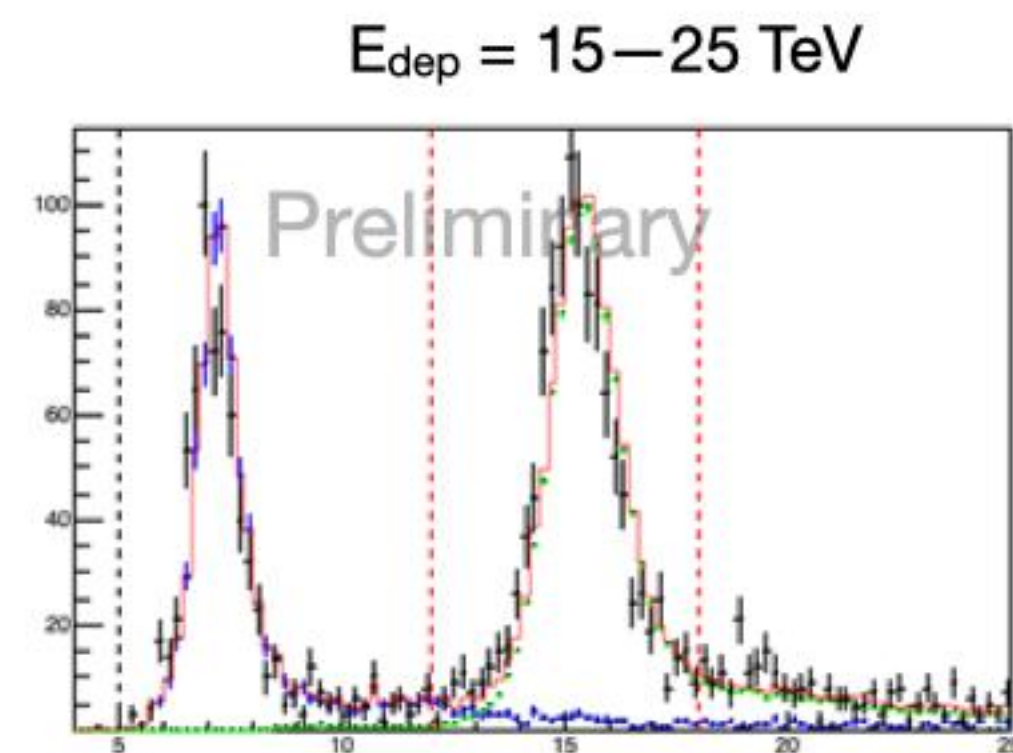
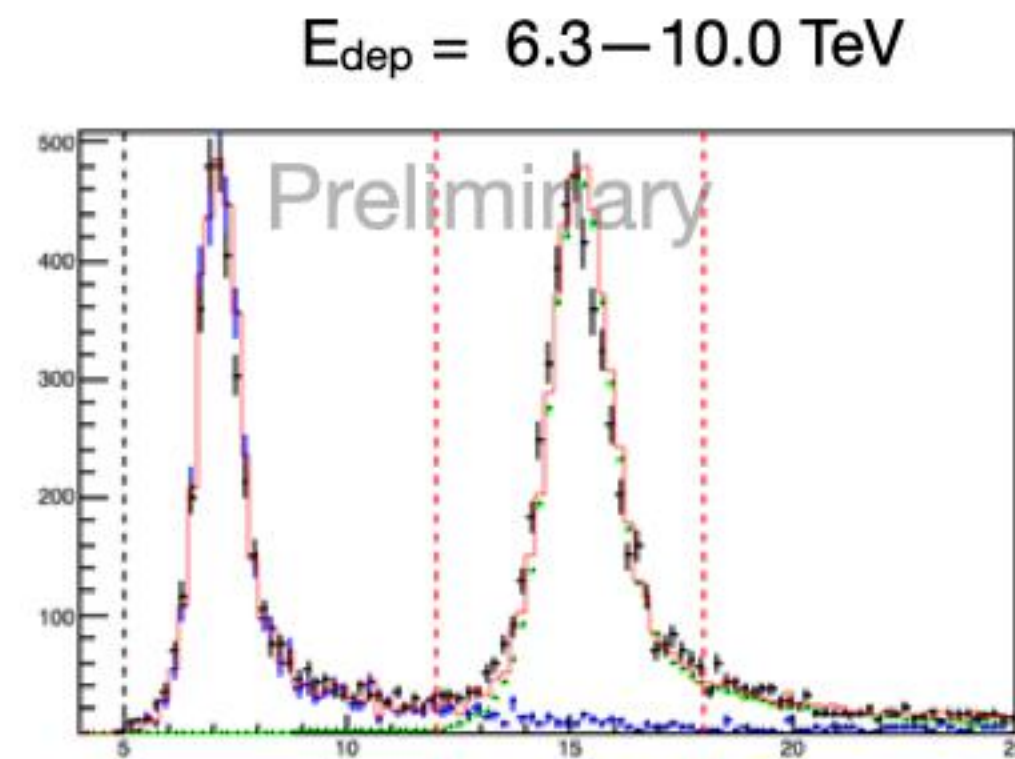
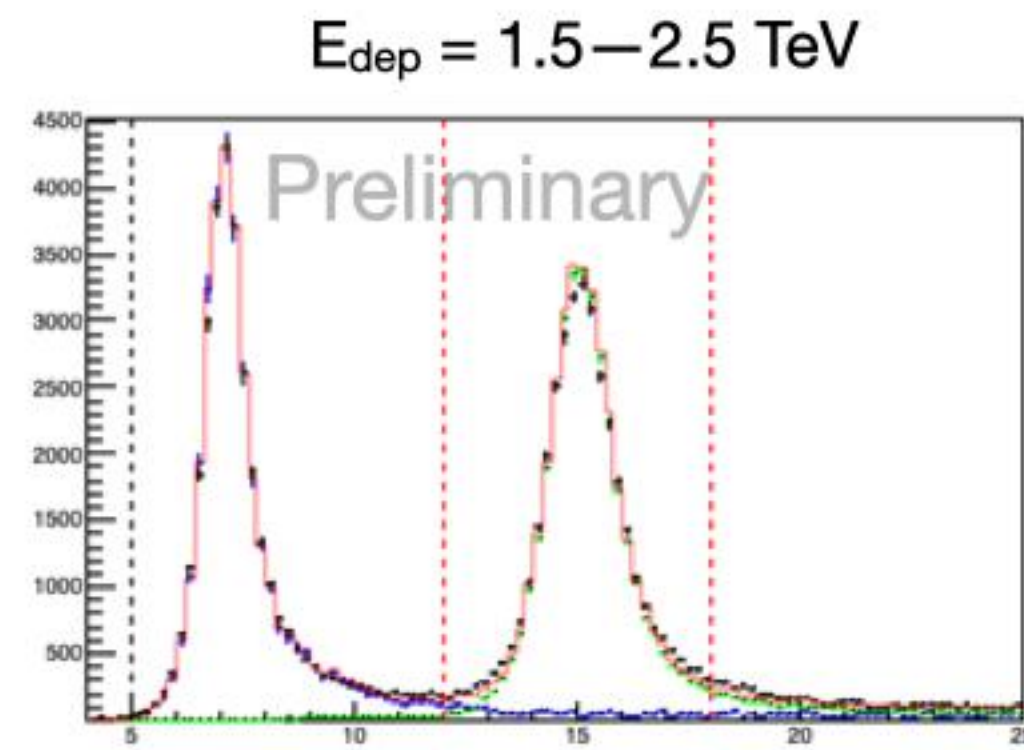


Combined charge selection =

- PSD charge if CR interacts before STK
- STK charge if CR interacts after PSD

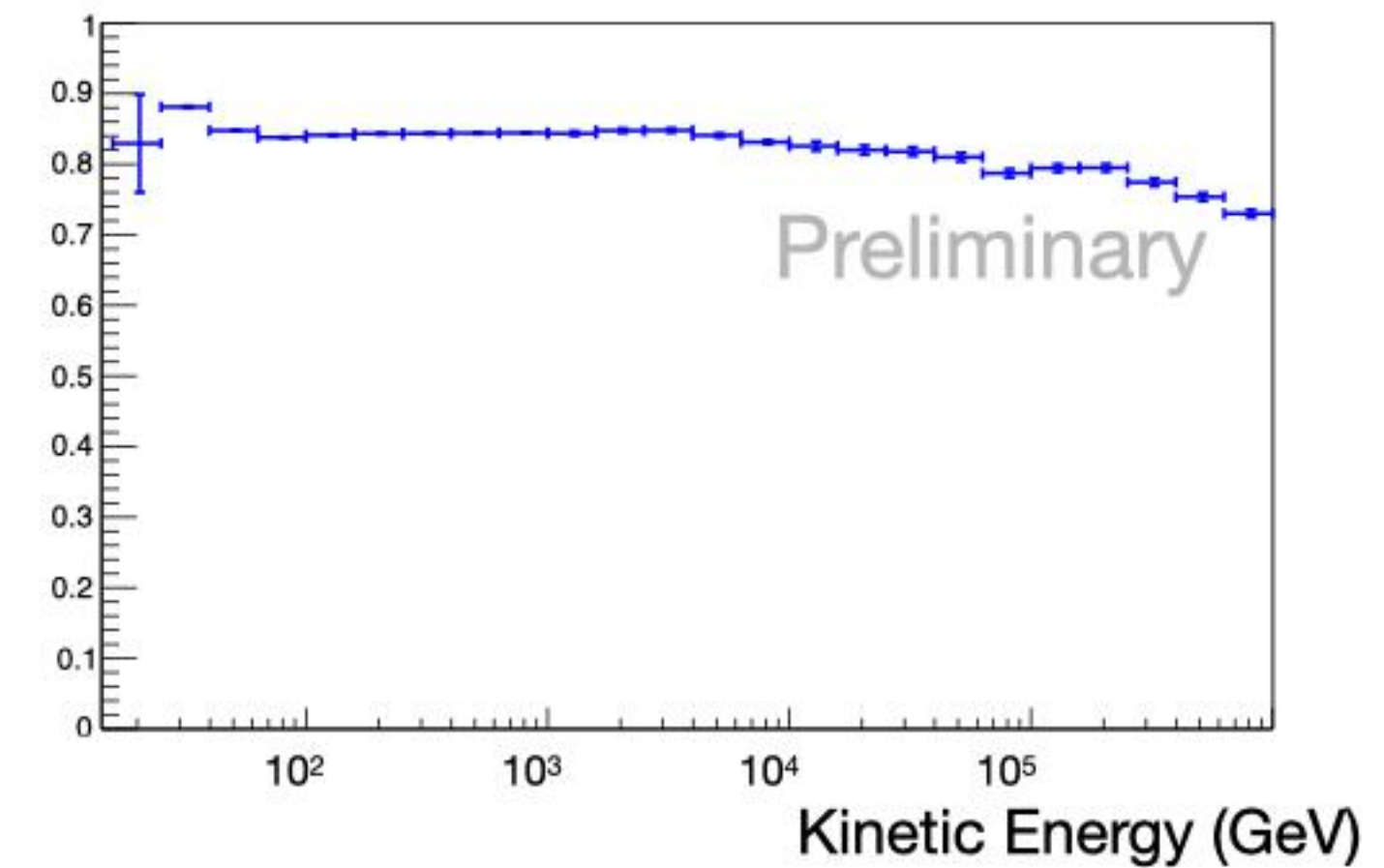


Charge selection

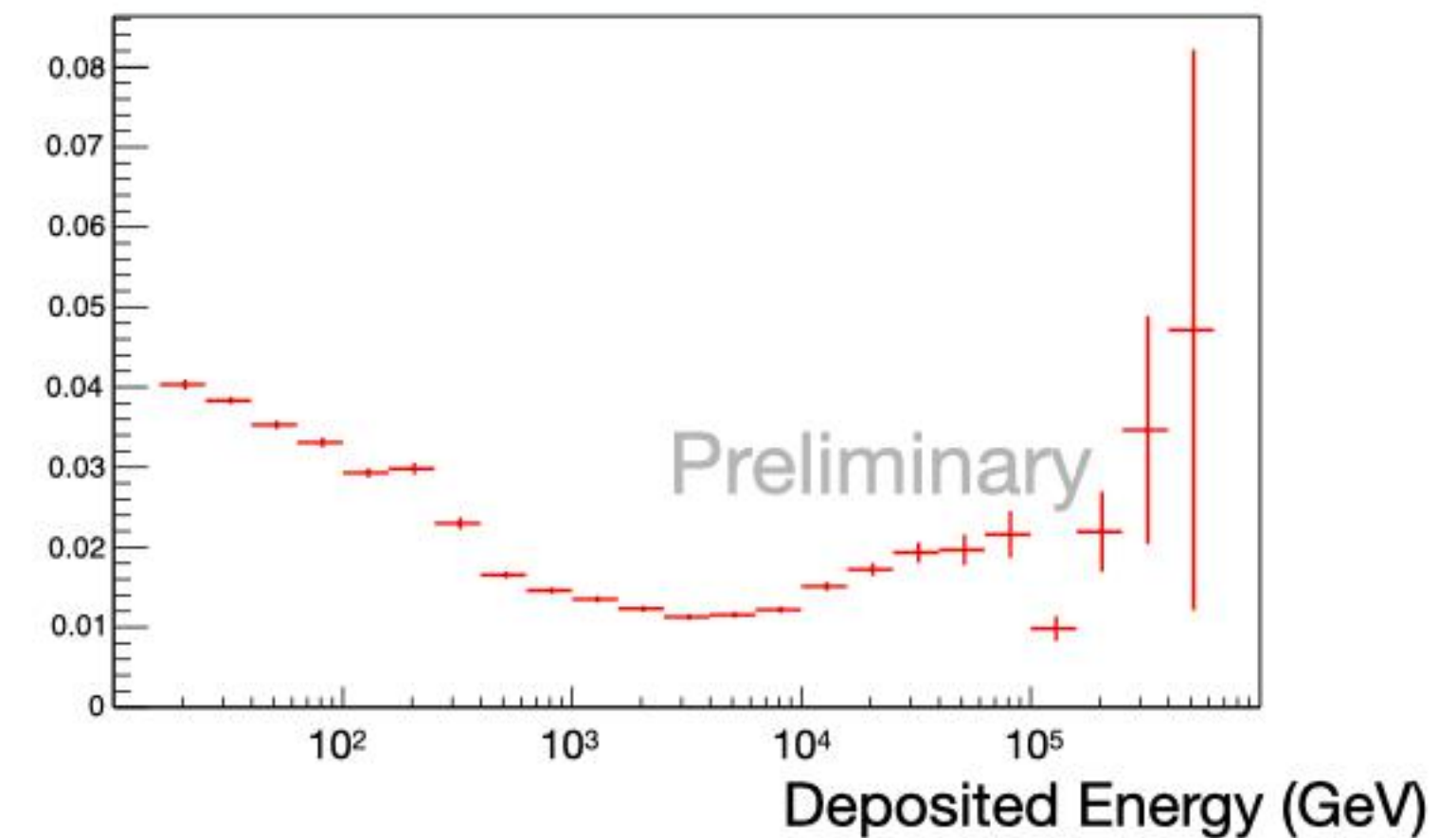


Combined charge (arbitrary units)

Charge selection efficiency

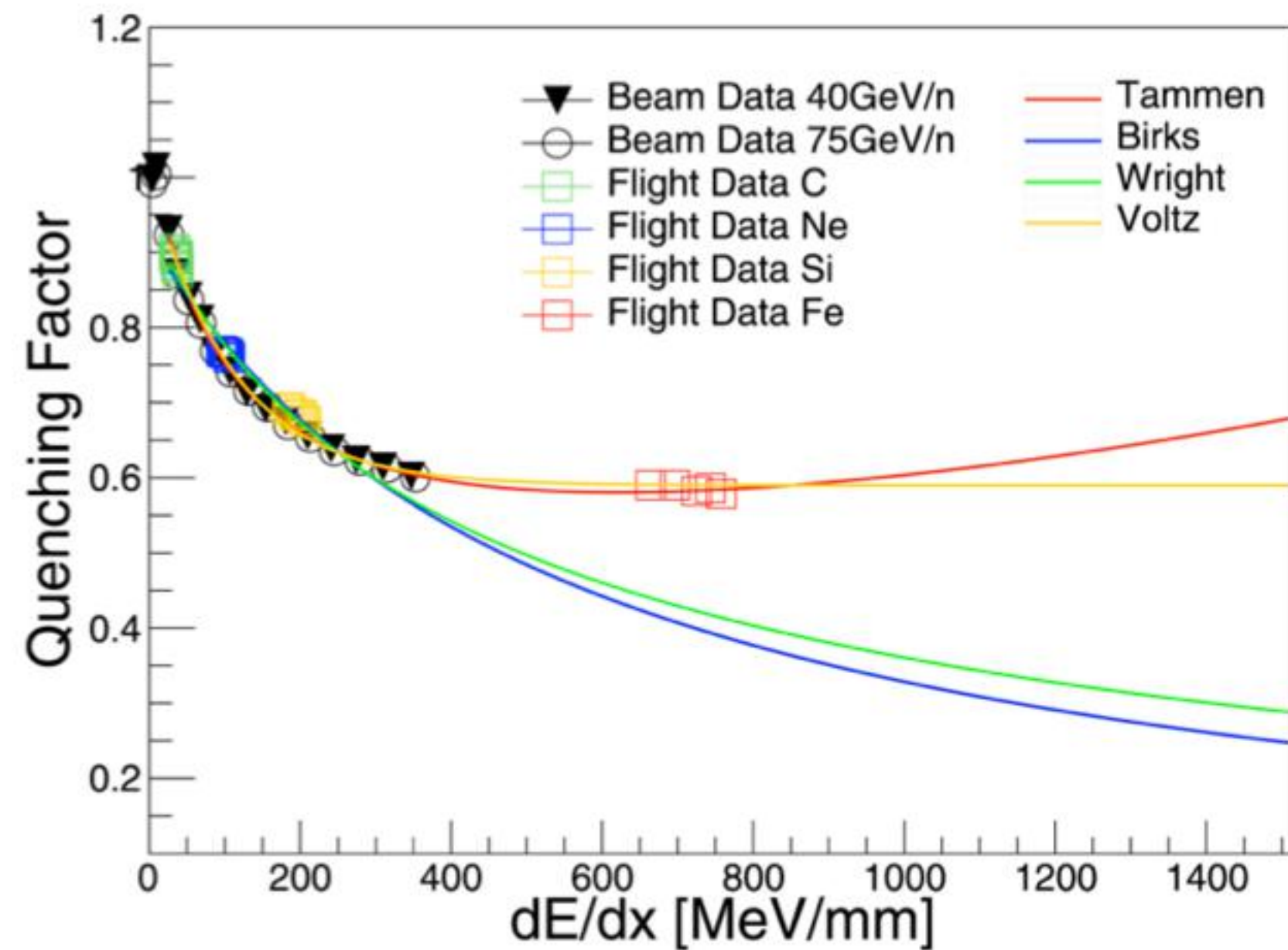


Residual *He* background fraction



- He background below ~4% up to ~ 500 TeV
- Charge selection efficiency above 80% up to 100 ~TeV, 73% at ~PeV

BGO quenching and saturation corrections



Y. Wei et al., Transactions on Nuclear Science, 67/6 (2020), Y.-F. Wei et al. NIMA 922 (2019), Z.-F. Chen et al. NIMA 1055 (2023)

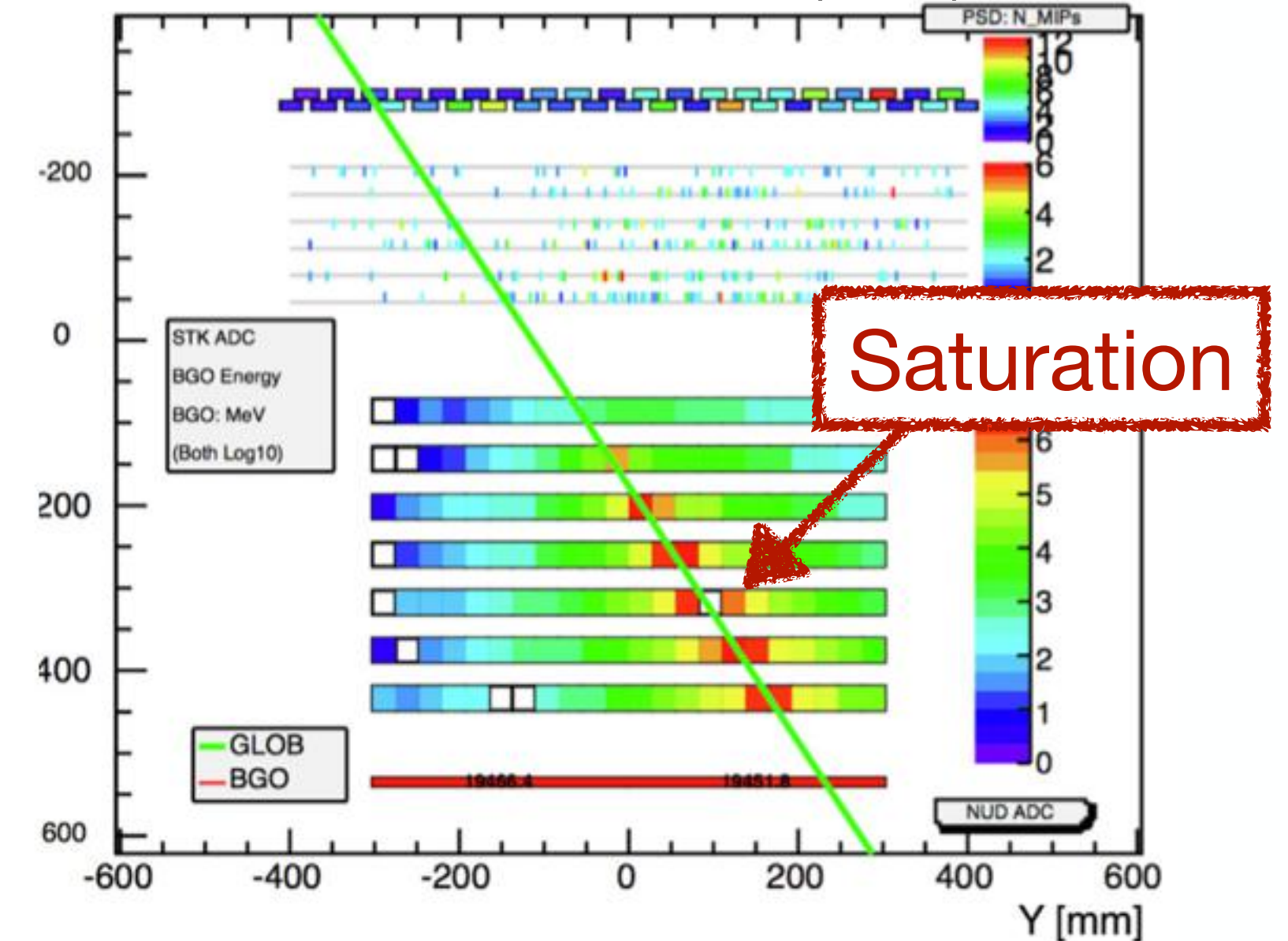
Quenching — nonlinear fluorescence response of BGO for large ionization

- correction derived from beam test and flight data
- implemented in the detector simulation, ~3% effect for p at 10 GeV

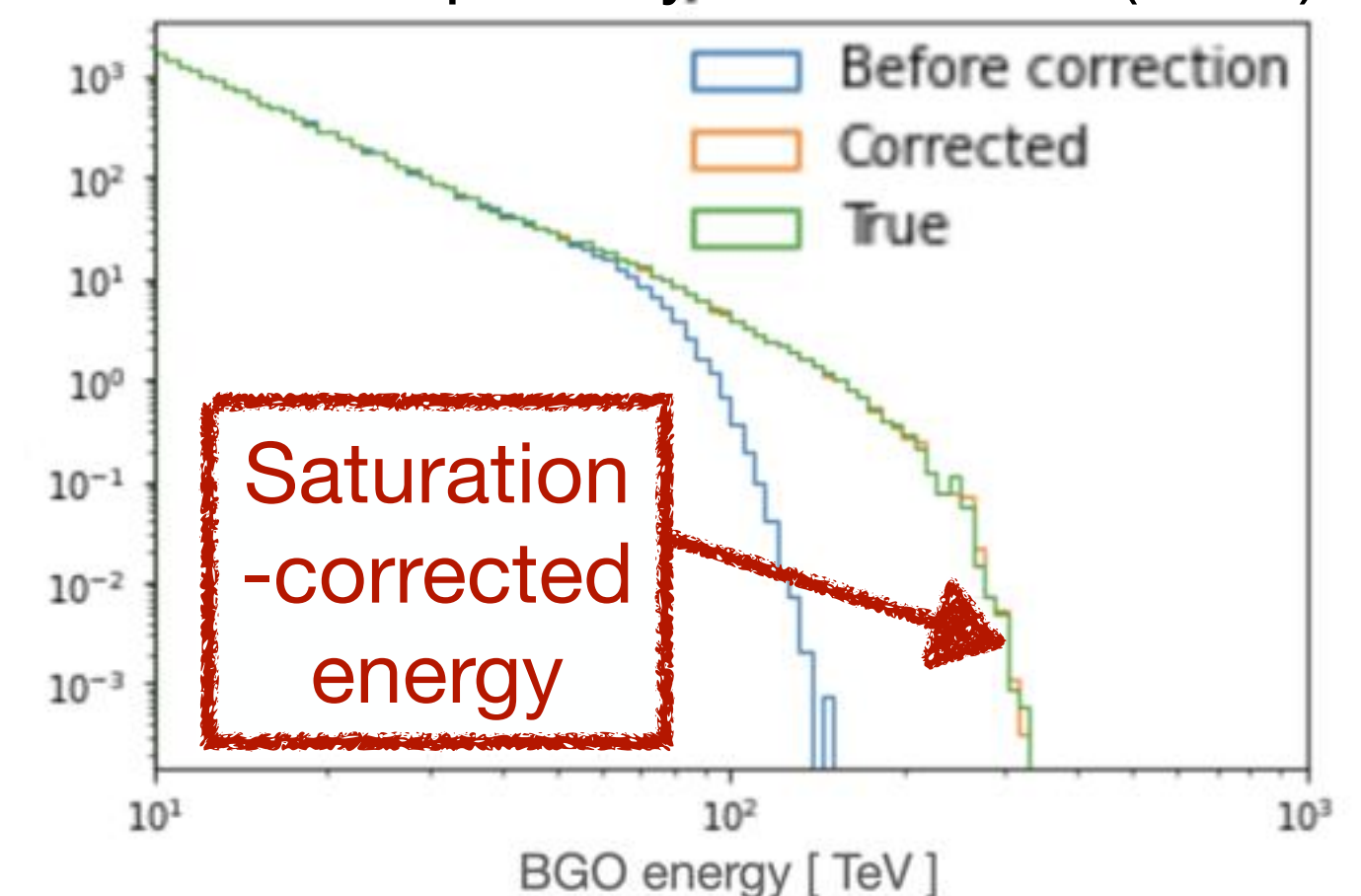
Saturation of BGO bars at ~100 TeV CR kinetic energy:

- corrections derived using analytical and ML methods

C. Yue et al. NIM, A 984 (2020) 164645



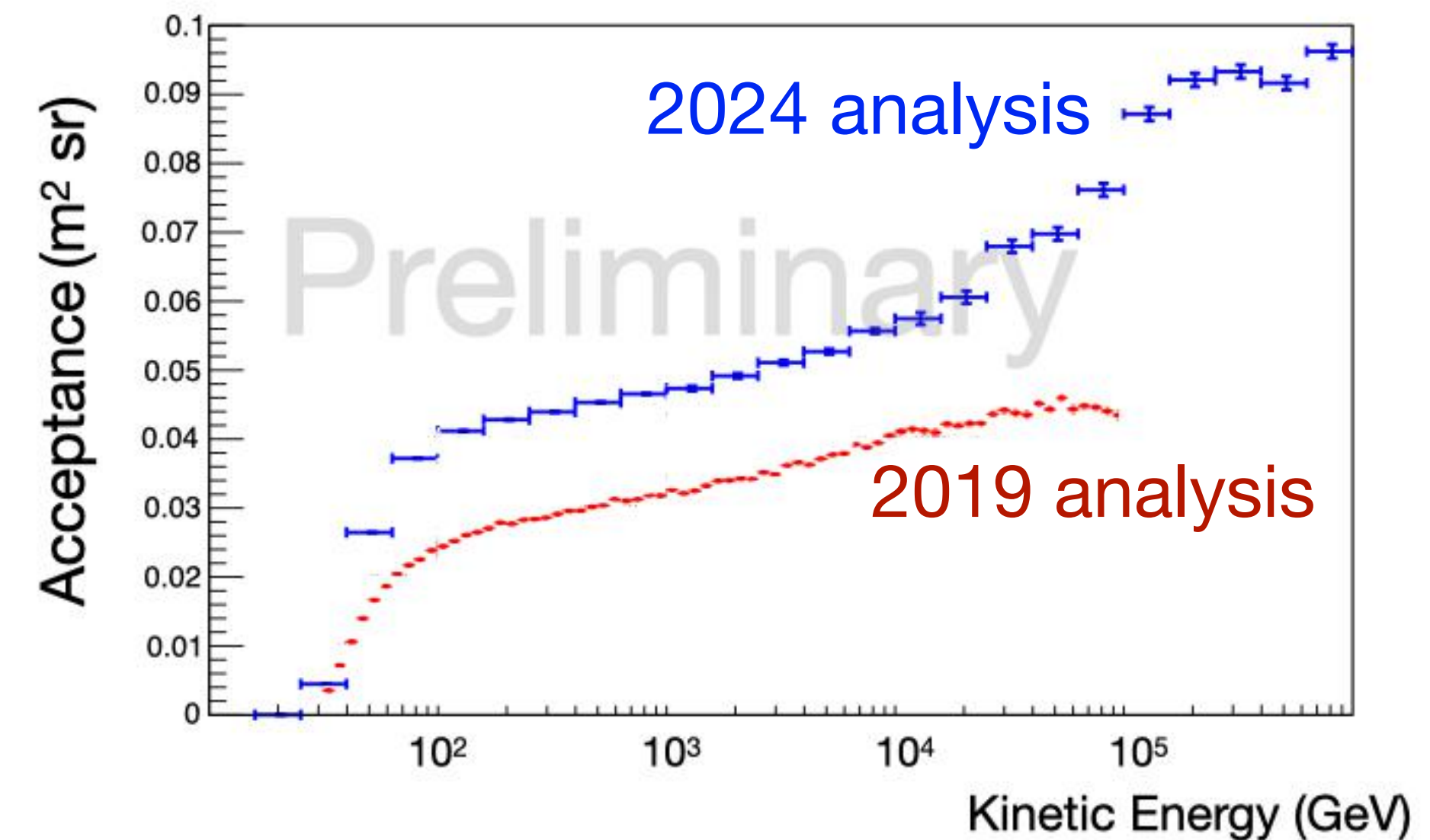
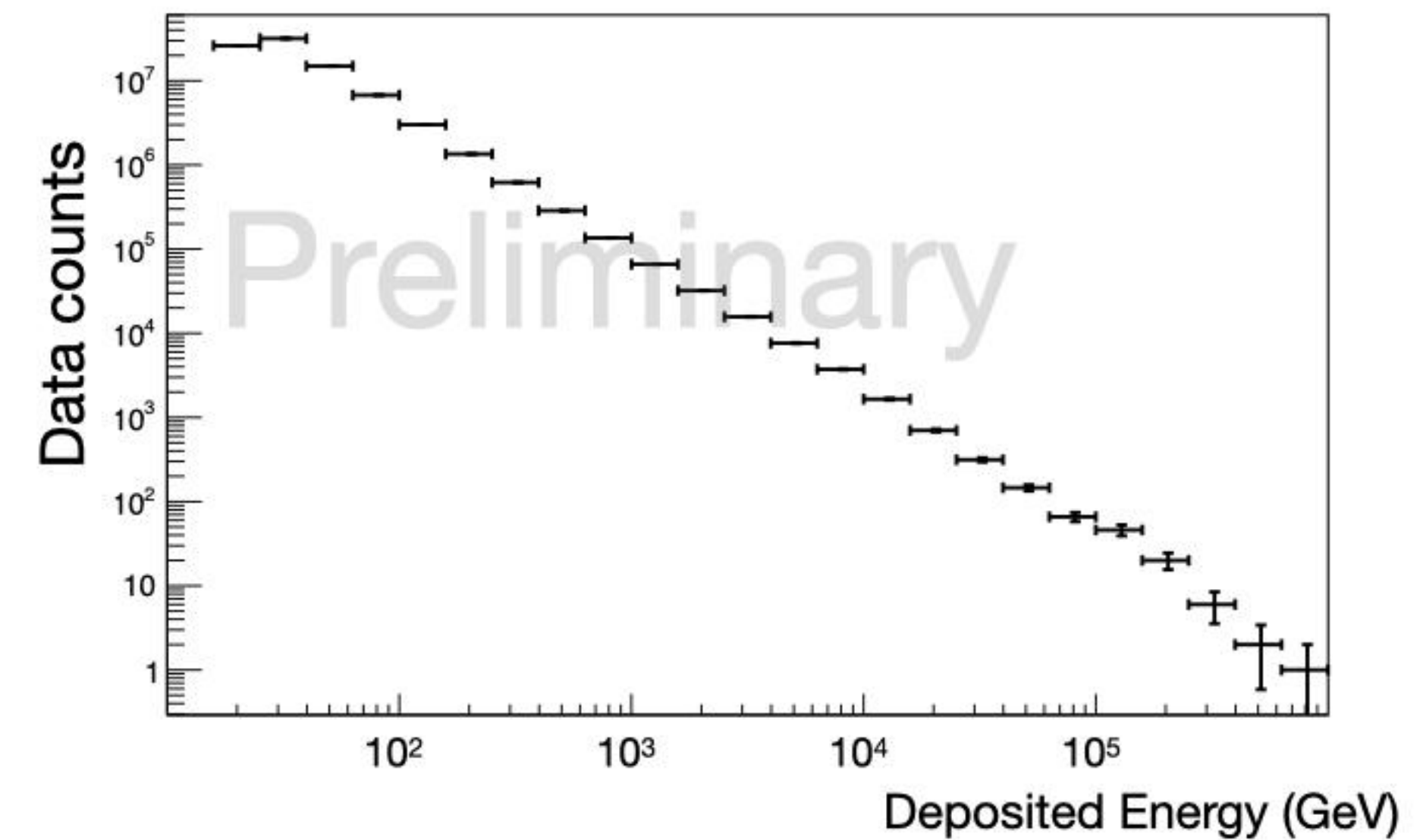
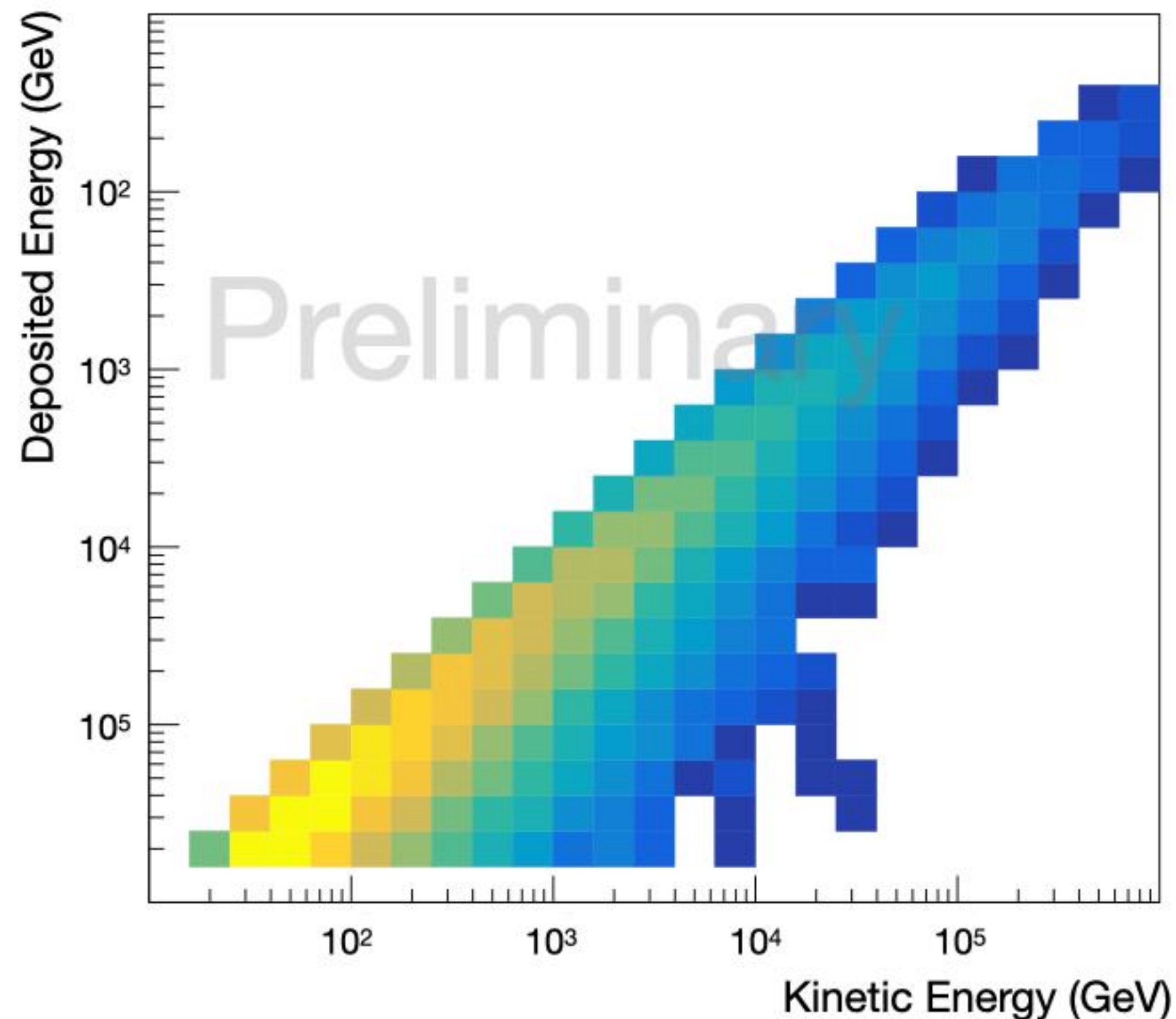
M. Stolpovskiy et al. JINST (2022)



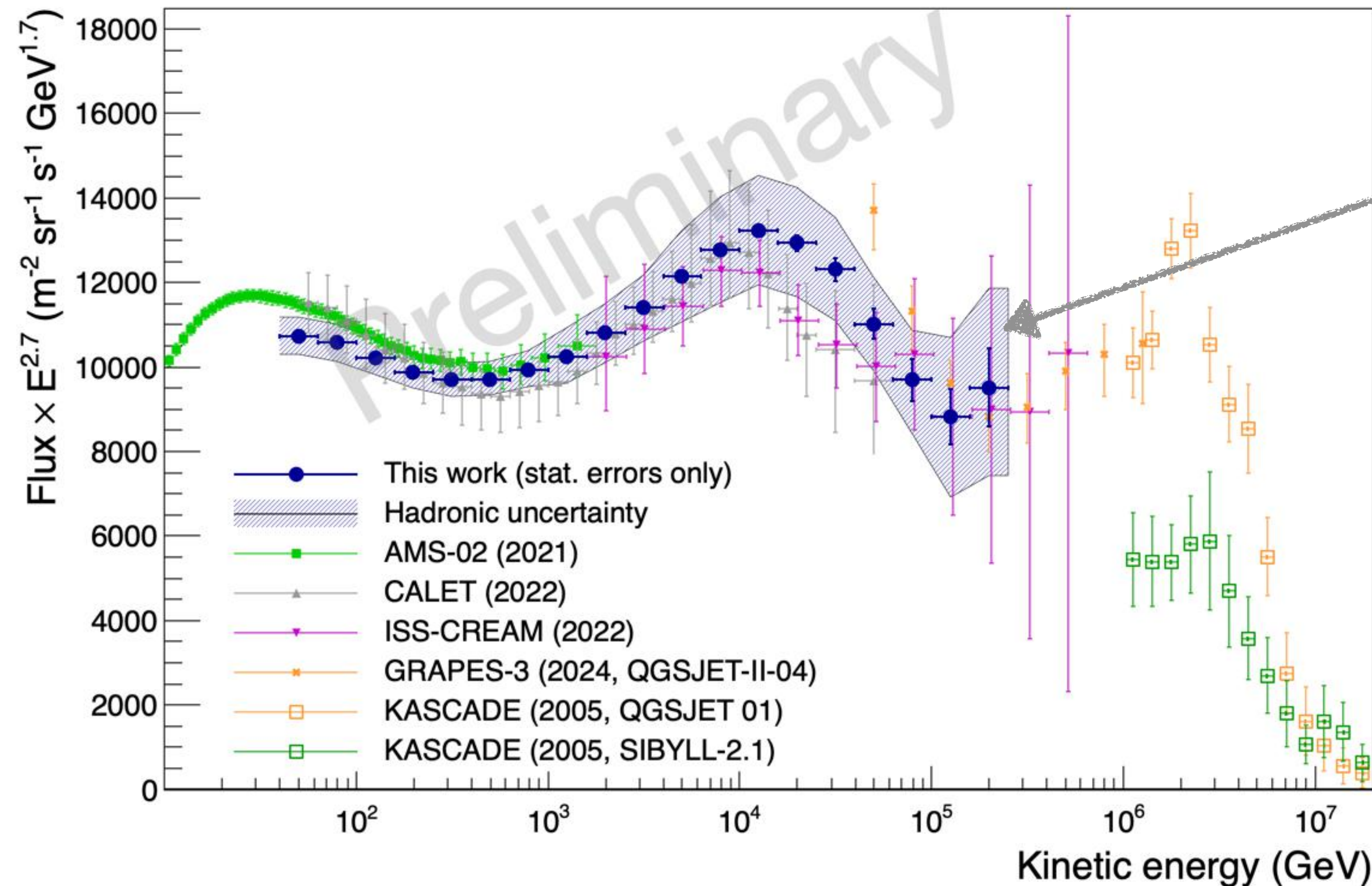
Event counts, energy unfolding

- Bayesian unfolding used to obtain event counts as a function of CR kinetic energy

$$P(E_{\text{true},j}|E_{\text{meas},i}) = \frac{P(E_{\text{meas},i}|E_{\text{true},j}) P(E_{\text{true},j})}{\sum_k P(E_{\text{meas},i}|E_{\text{true},k}) P(E_{\text{true},k})}$$



Flux

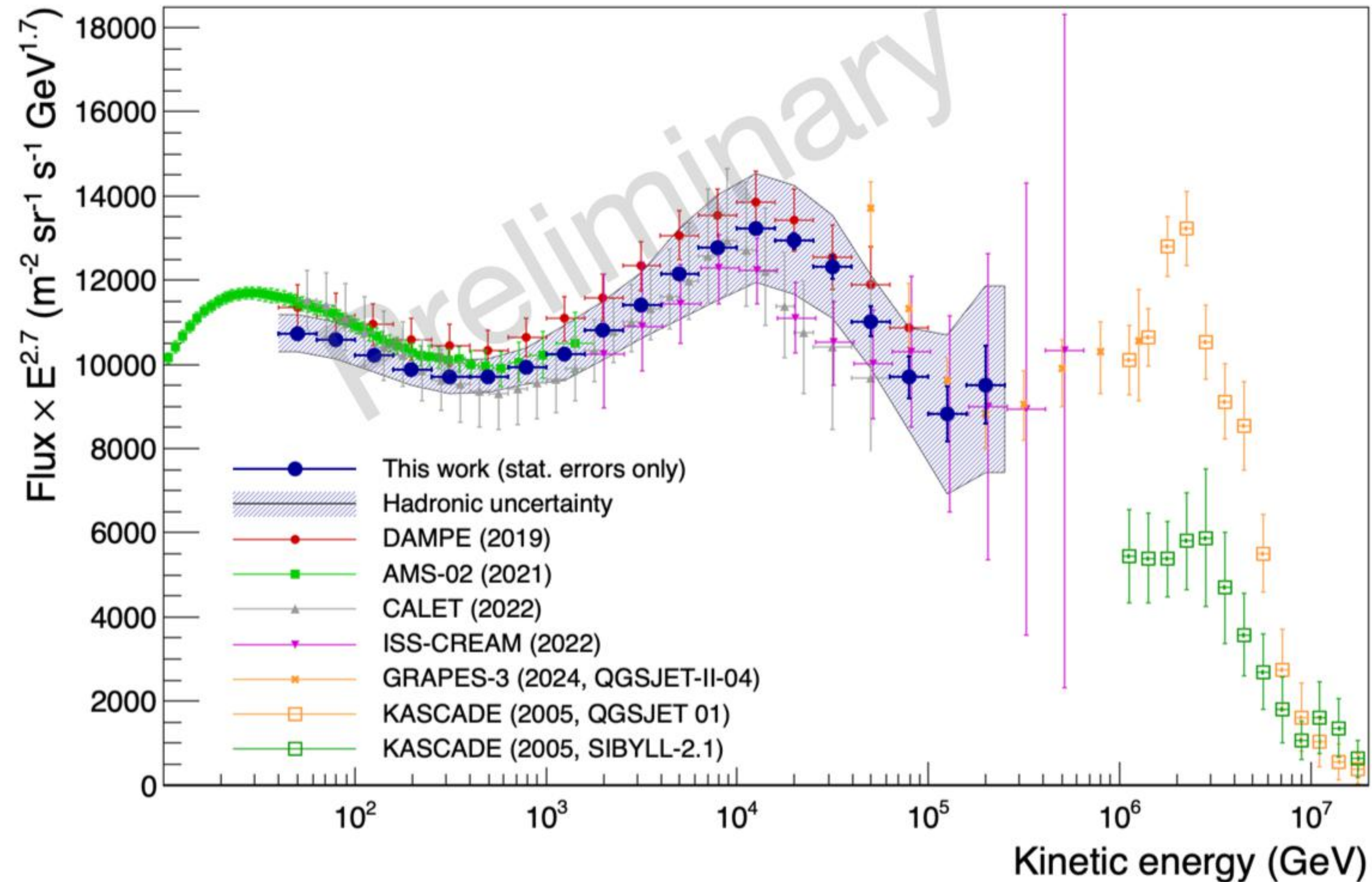


Hadronic errors:

- Estimated from Geant4 vs FLUKA comparison
- Mostly affect normalization
- Minor effect on flux shape

Dedicated work on hadronic measurements & corrections, see **XSCRC2024: Cross sections for Cosmic Rays @ CERN** this October!

Flux



Good agreement with 2019 result within the analysis errors

Estimation of systematics in process, dominating factors: charge selection for PSD-interacting events, BGO saturation, quenching, ...

Motivation

- First publication of proton flux in 2019 (30 months data)
- Classical analysis limited to ~ 100 TeV by $\sim$ particle ID
- Hints of new feature in combined p+He at ~ 150 TeV



New result

- 92 months of data
- Based on ML tracking
- Increased acceptance and improved particle ID
- Careful systematics study in process
- Dedicated work on hadronic measurements & corrections (first results soon)

Motivation

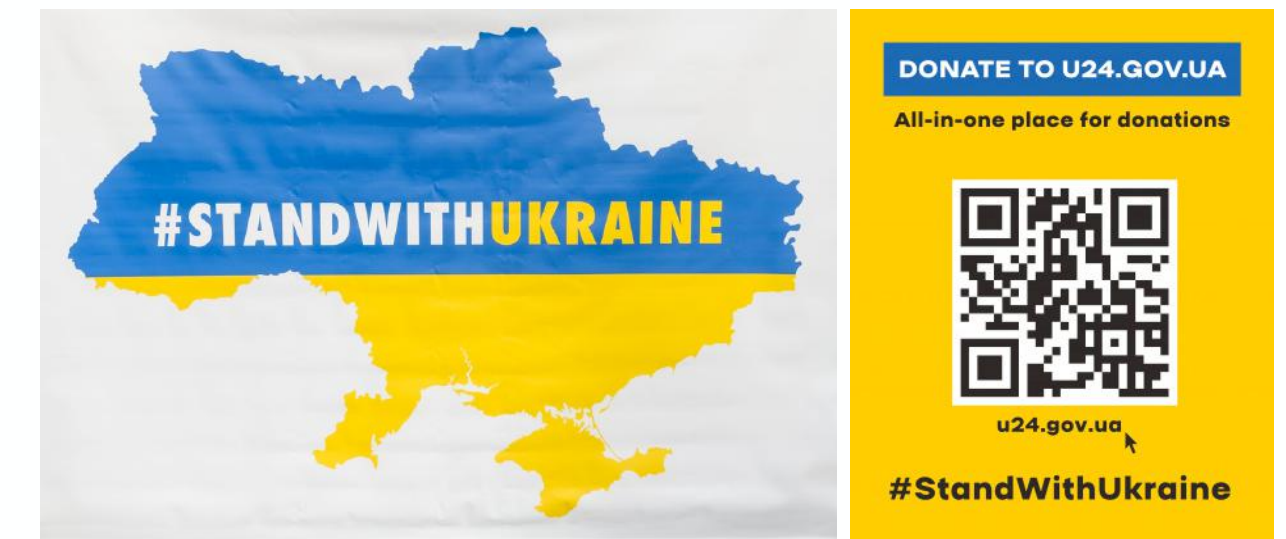
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New result

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To be continued



Thank You!