



# CR proton flux towards PeV energies with DAMPE

Andrii Tykhonov

(for the DAMPE collaboration)

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## **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)**

#### BGO

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

#### STK

- Position solution ~50 micron
- $\gamma$  angular resolution **0.5°**–**0.1**° (GeV TeV)
- Absolute Charge (Z) identification

#### PSD

- Z identification up to Ni (Z=28)
- y anti-coincidence signal

#### NUD

Additional e/p rejection capability lacksquare









### Motivation



- $\bullet$

 $\bullet$ 







## **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





# Challenge: tracking & charge ID



Track reconstruction + proton charge identification + background lacksquarecontamination — dominating uncertainty at thigh energies!

New tracking algorithm required for ~ PeV measurements!

#### *p* charge selection efficiency Statistical & Systematic erros Charge Efficier Background Statistic Unfolding 0.9 Hadronic Model PSD 0.8 0.7 2019 analysis 0.6 (a) 10<sup>2</sup> $10^{3}$ Incident Energy [GeV] 2019 analysis Background contamination 10<sup>3</sup> 10<sup>4</sup> mination [% Incident Energy [GeV] Helium Contamination 10 Electron Contamination 0+0+0+0101010101010101010 10-2

10-3

CR proton flux with DAMPE

10<sup>4</sup>

10<sup>3</sup>

2019 analysis

10<sup>2</sup>





## New track reconstruction & ML



Andrii Tykhonov

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













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





### **Event selection**

#### **Pre-selection**:

- Ensure well-reconstructed and fullycontained 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**



- $\bullet$



# **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,  $\sim 3\%$  effect for p at 10 GeV lacksquare**Saturation** of BGO bars at ~100 TeV CR kinetic energy: corrections derived using analytical and ML methods



CR proton flux with DAMPE



## Event counts, energy unfolding

Bayesian unfolding used to obtain event  $\bullet$ counts as a function of CR kinetic energy













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!













Good agreement with 2019 result within the analysis errors

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





## Conclusions

### Motivation

- First publication of proton flux in 2019 (30 months data)
- Classical analysis limited to ~100 TeV by ~ 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)





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### To be continued ....



# Thank You!