中国科学技术大学
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Energy Reconstruction of Non-fiducial Electron Events in DAMPE with CNN

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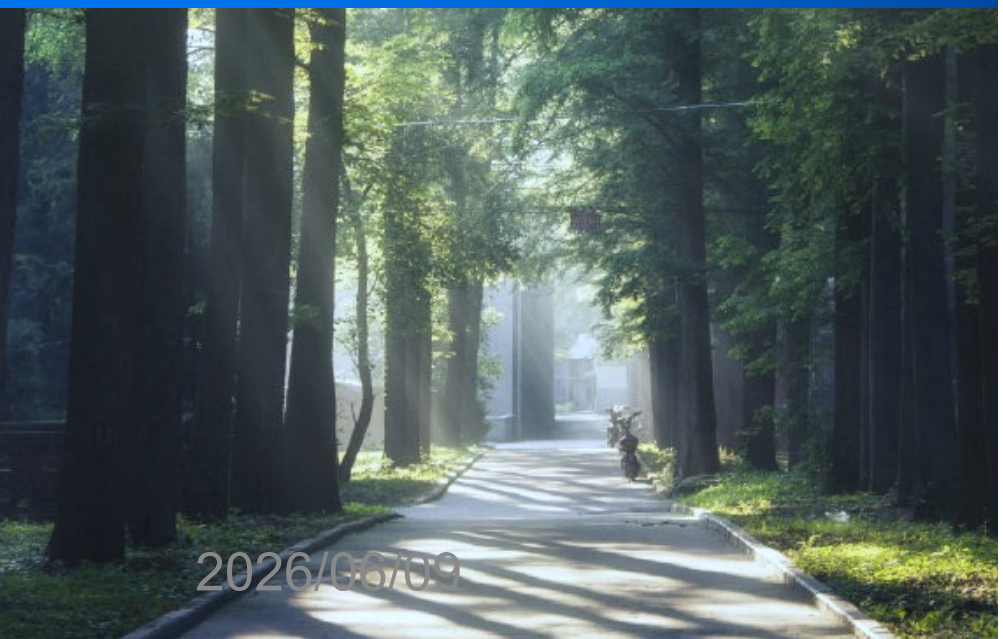
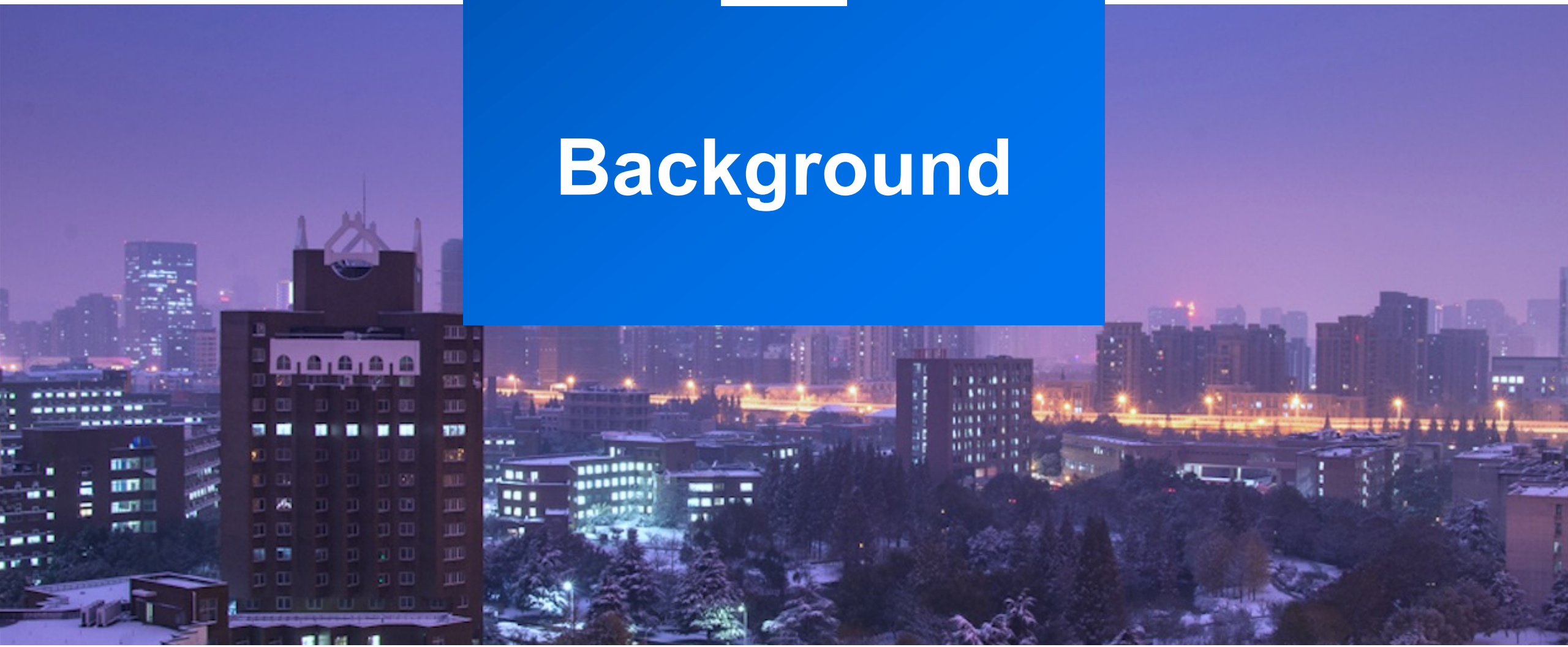
Based on arXiv:2503.10521v2

Content

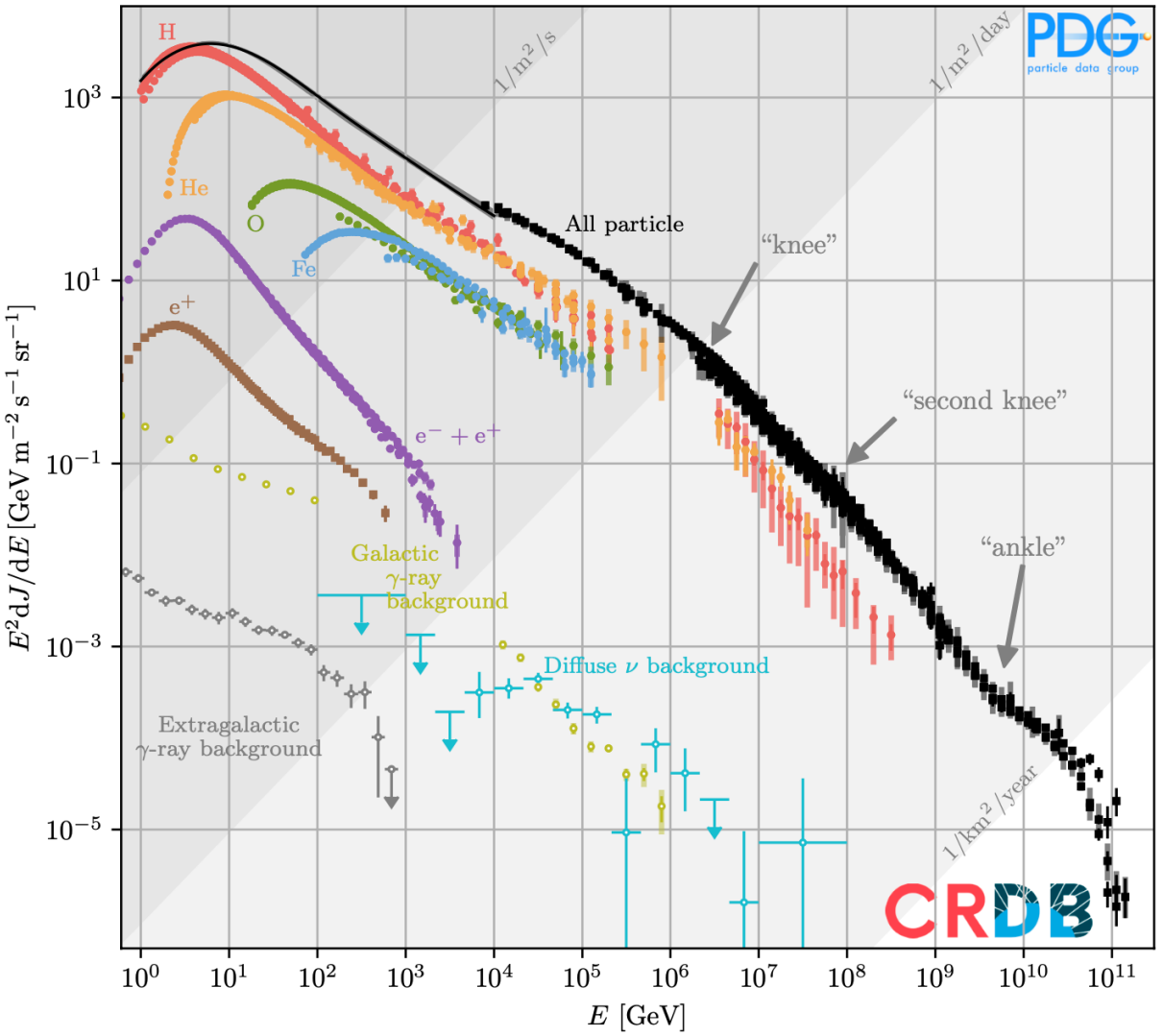


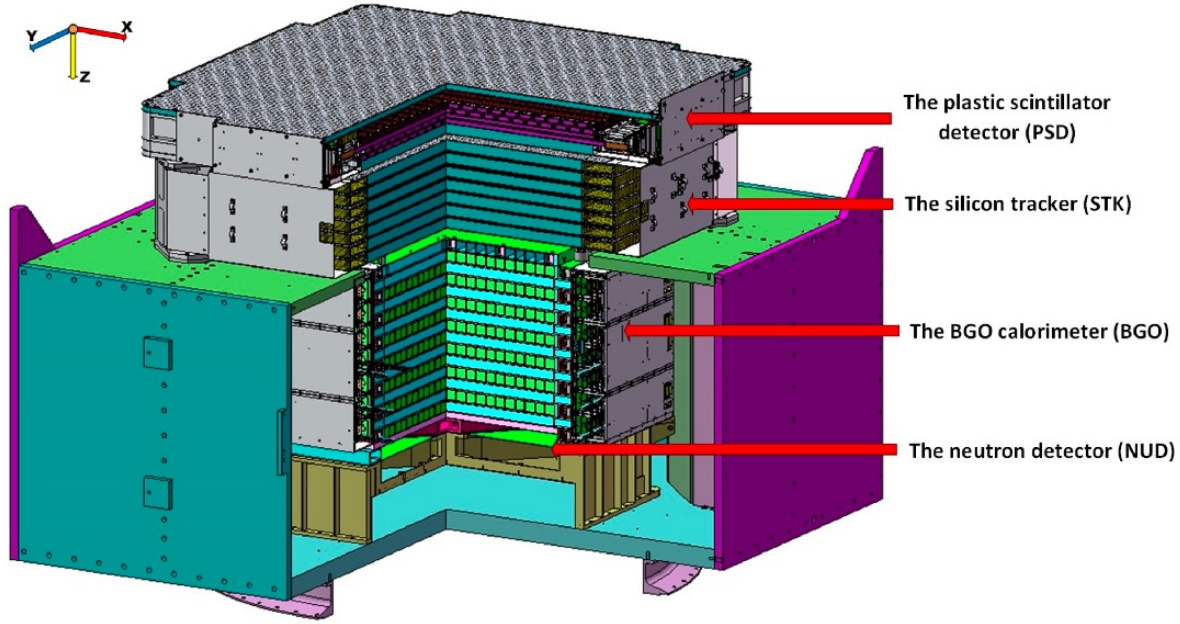
01

Background



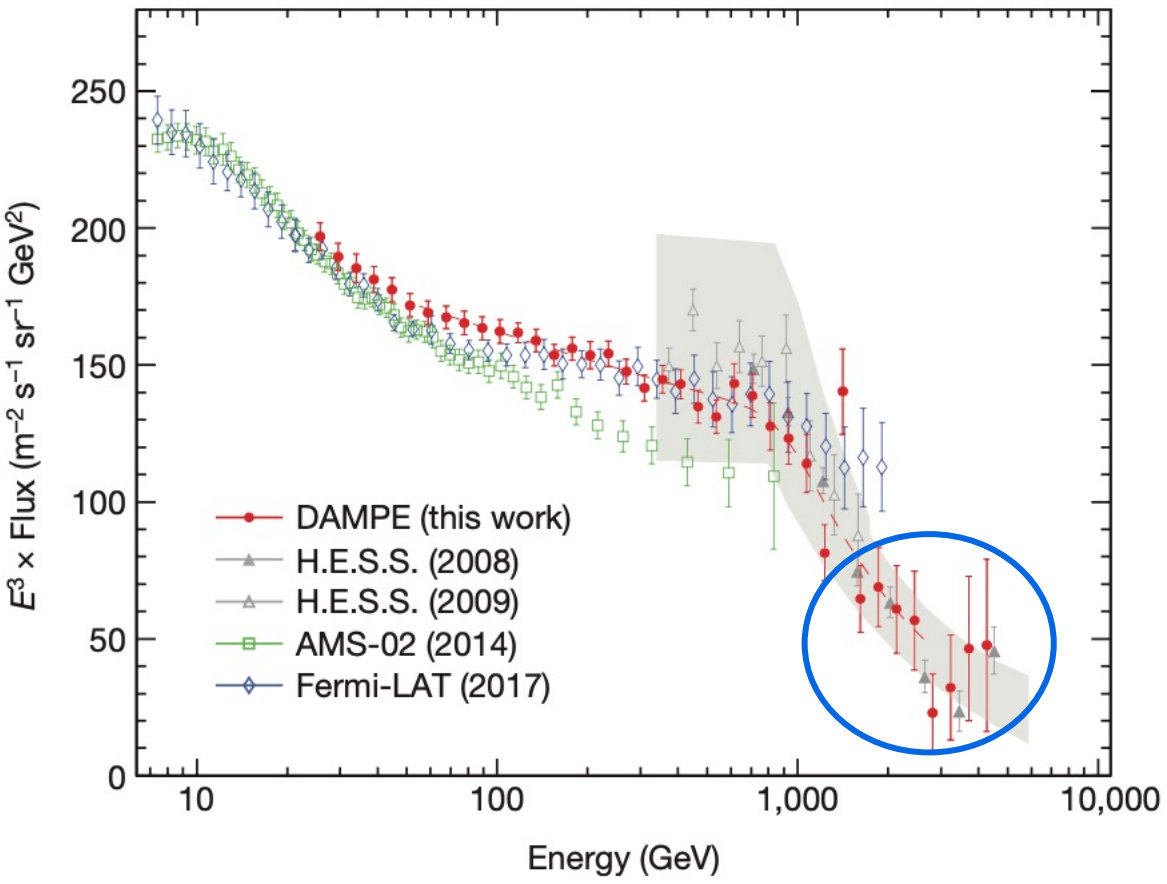
Physical Goals of DAMPE



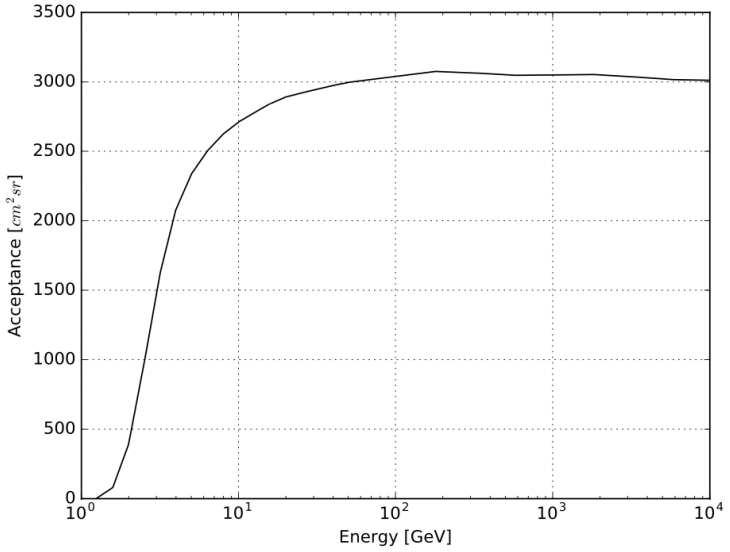


- Indirect search of dark matter particles
- Cosmic ray physics
- Gamma ray astronomy research

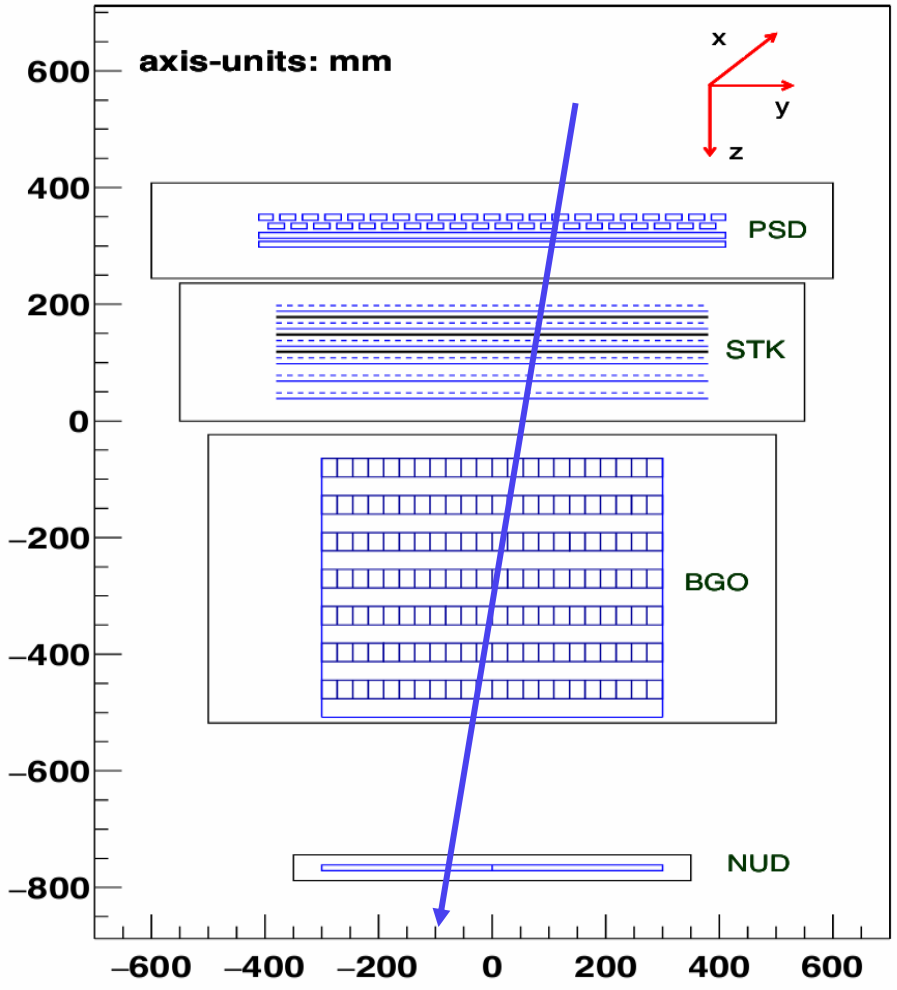
Cosmic-Ray Electrons Spectrum



- High-energy cosmic-ray electrons may enable the observation of phenomena such as dark-matter particle annihilation or decay.
- Limited event statistics lead to large statistical uncertainties in the high-energy range.
- Possible proposal: to use events rejected by geometric cuts.



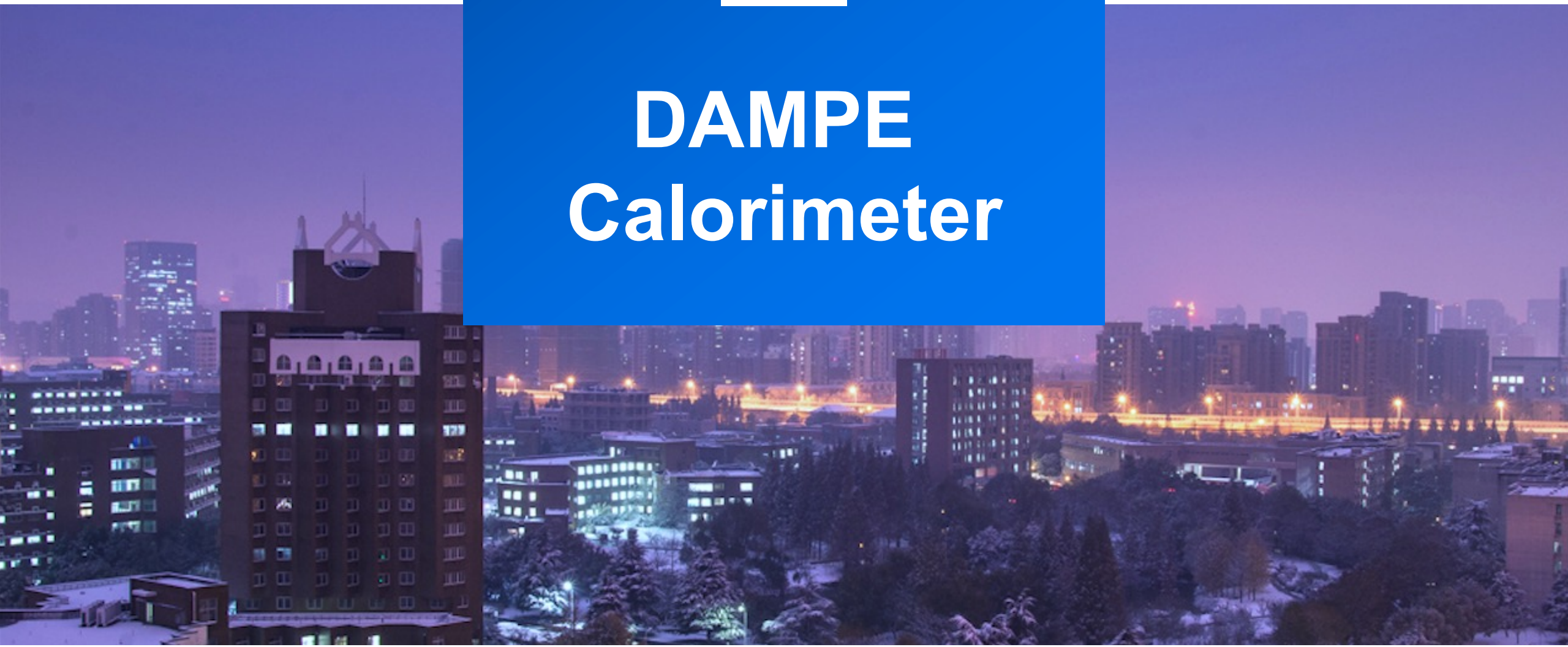
Geometric Cuts



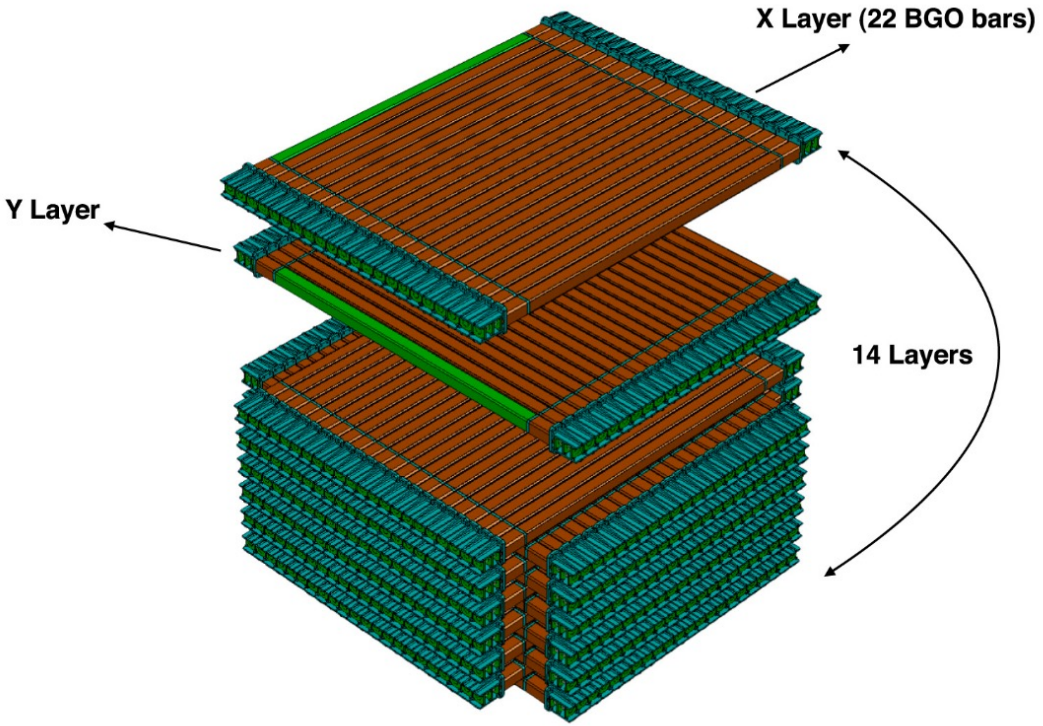
- Possible particle source for satellite: almost the whole upper hemisphere;
- Strict geometric cuts (fiducial selection) give our detectors full play to the performance;
- If we unset the geometric cuts, tradition reconstruction may not work. New method to be developed!

02

DAMPE Calorimeter



DAMPE Calorimeter



Summary of designed parameters and expected performance of the BGO calorimeter.

Parameter	Value
Active area	60 cm × 60 cm (on-axis)
Depth (radiation lengths)	32
Sampling	≥ 90%
Longitudinal segmentation	14 layers (≃2.3 rad. lengths each)
Lateral segmentation	∼1 Molière radius

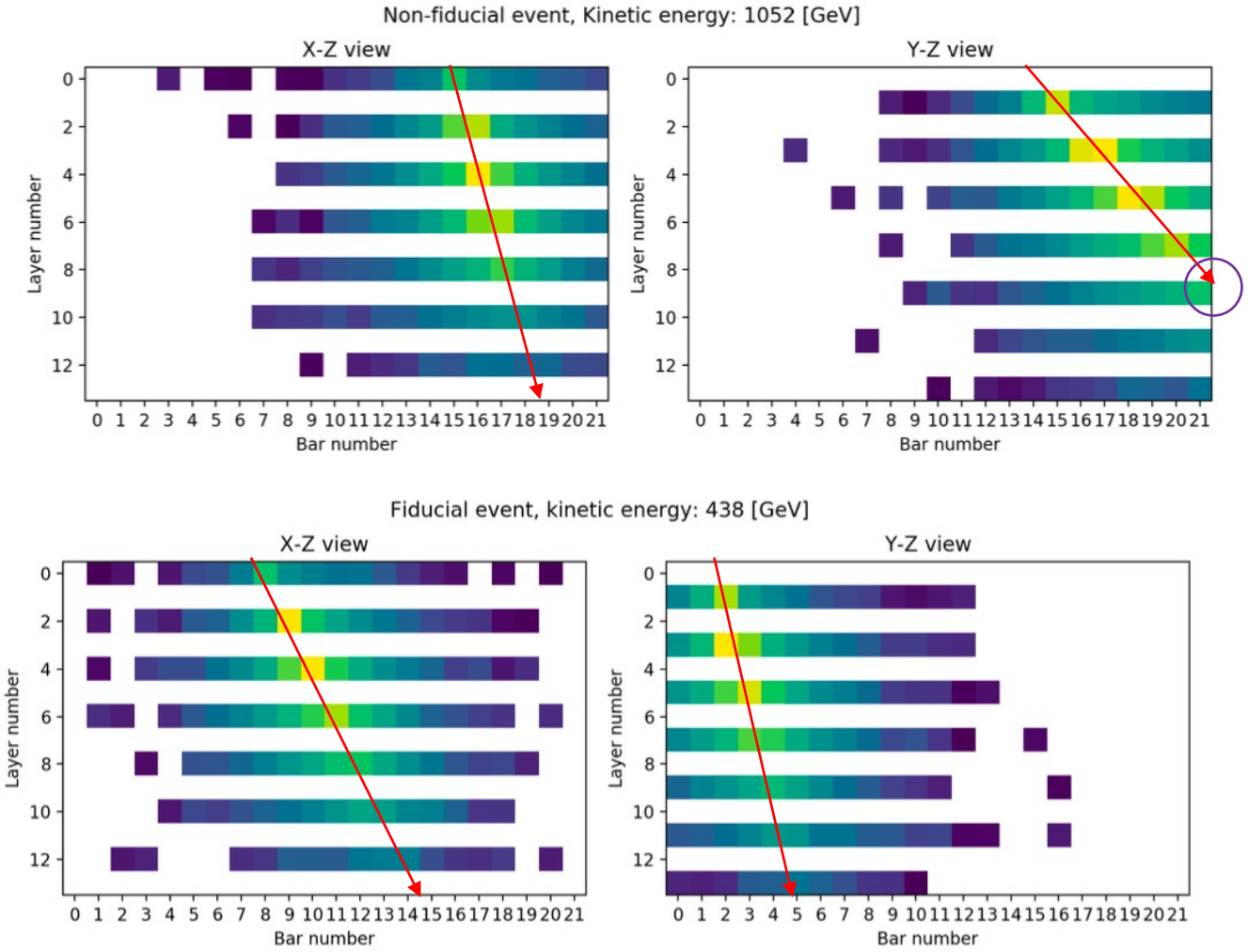
Parameter of BGO crystal

Density	7.13g/cm^3
Nuclear interaction length(λ_I)	22cm
Radiation length(X_0)	1.12cm
Moliere raidus	2.23cm
Energy loss (for MIPs)	9.2 MeV/cm

Main purposes of BGO calorimeter:

1. Measuring the energy deposition of incident particles;
2. Imaging the 3D profile of the shower development.

Non-fiducial Events



Fiducial selection in DAMPE:

- Rejecting events that enter the calorimeter from the sides;
- Rejecting events where the shower direction cannot be reconstructed;
- Ensuring that the reconstructed shower direction extrapolates to the top and bottom of BGO.

For non-fiducial events:

Only invert the last cut.

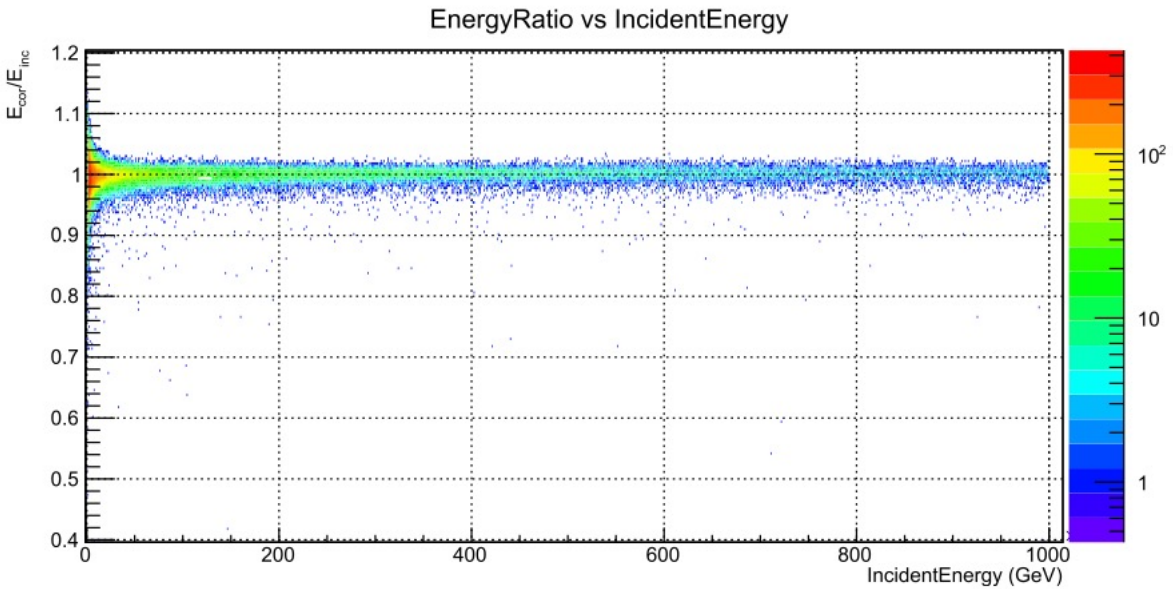
Classical Method with MC Electrons

Classical Energy Reconstruction:

- Sum total deposited energy;
- Bayes unfolding to get primary energy.

Correction Method:

Consider the character of the shower.



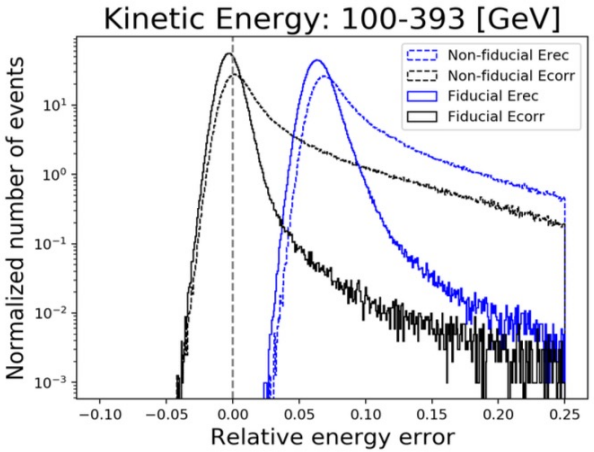
Monto Carlo:

- Geant4 (version 10.05), FTFP-BERT
- Isotropic electrons;
- Energy range: 100 GeV – 24 TeV;
- Energy distribution: E^{-3} power law;

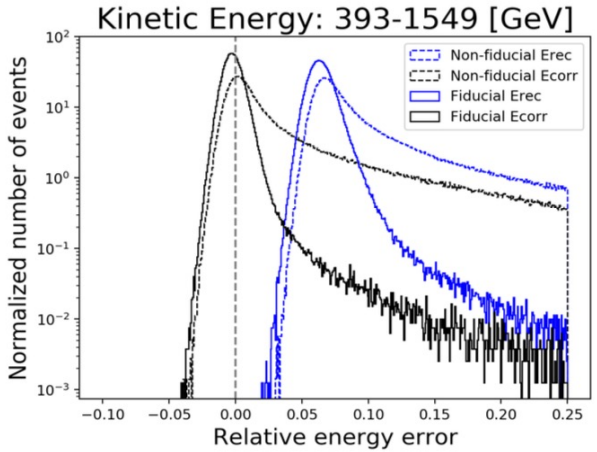
Relative Energy Error:

$$r = 1 - \frac{E}{E_{\mathrm{kin}}}$$

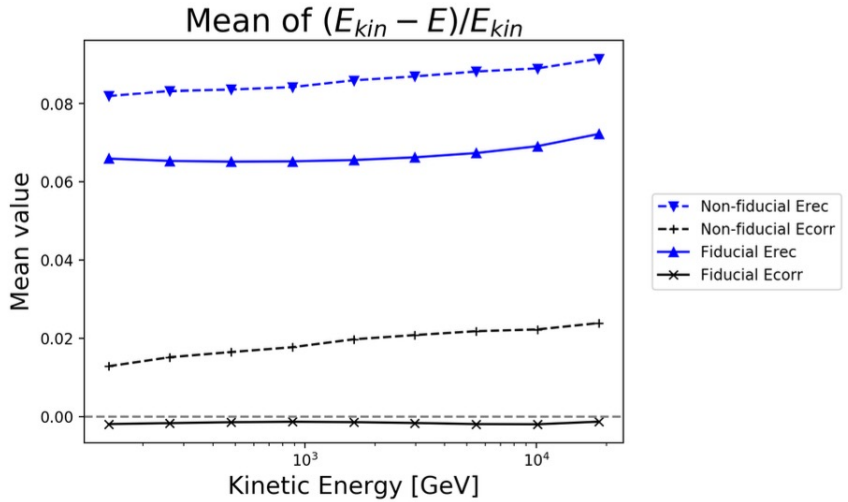
Classical Method with MC Electrons

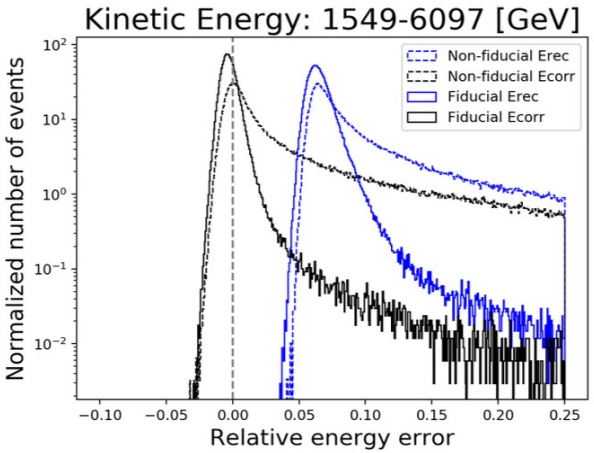


(a) 100-393 GeV

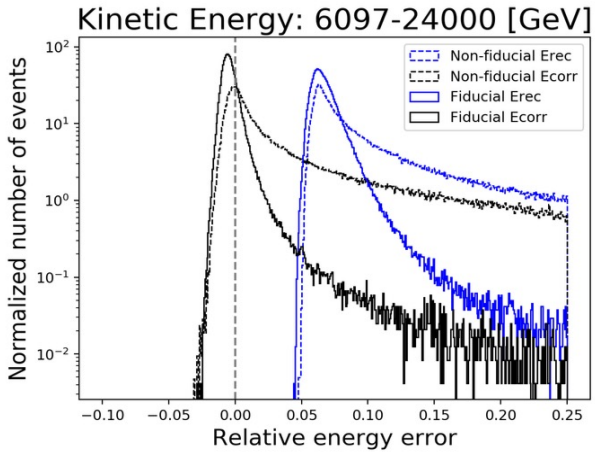


(b) 393-1549 GeV

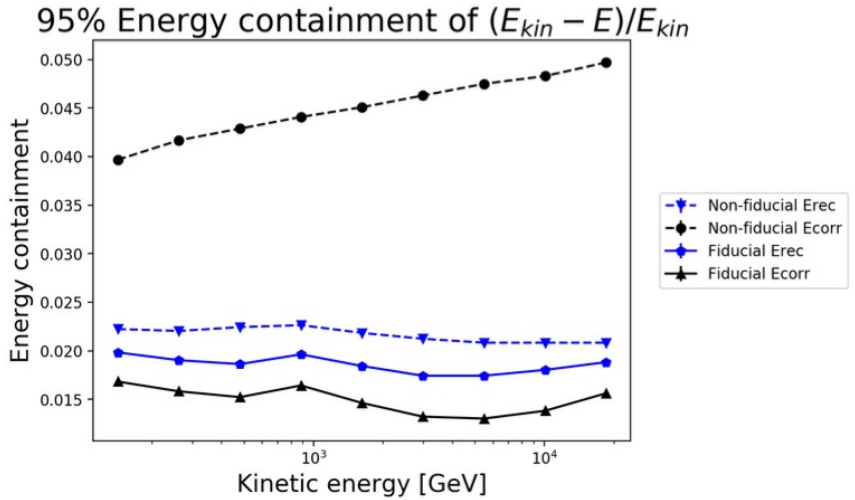




(c) 1549-6097 GeV



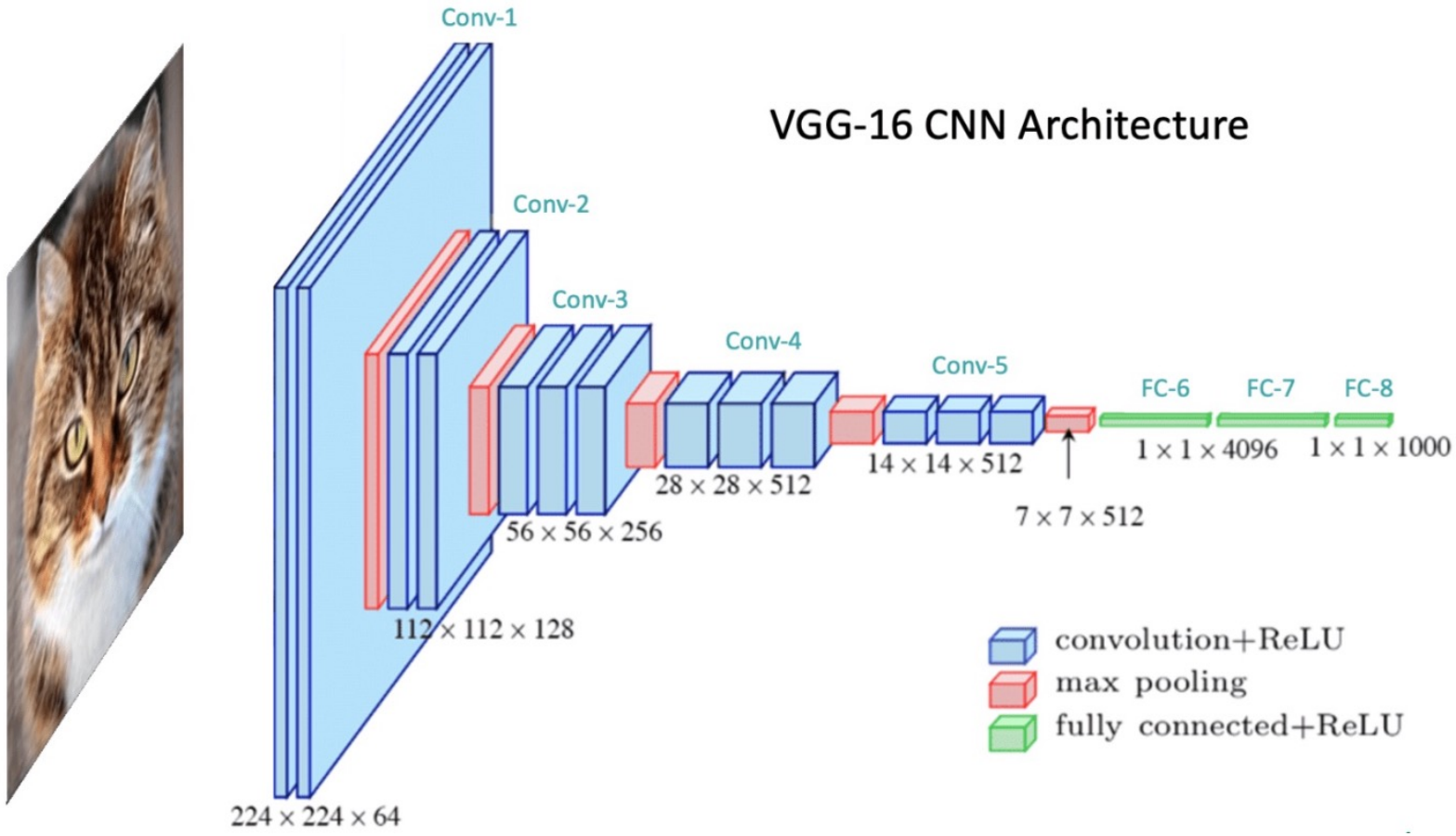
(d) 6097-24000 GeV



03

CNN Method

Convolutional Neural Network



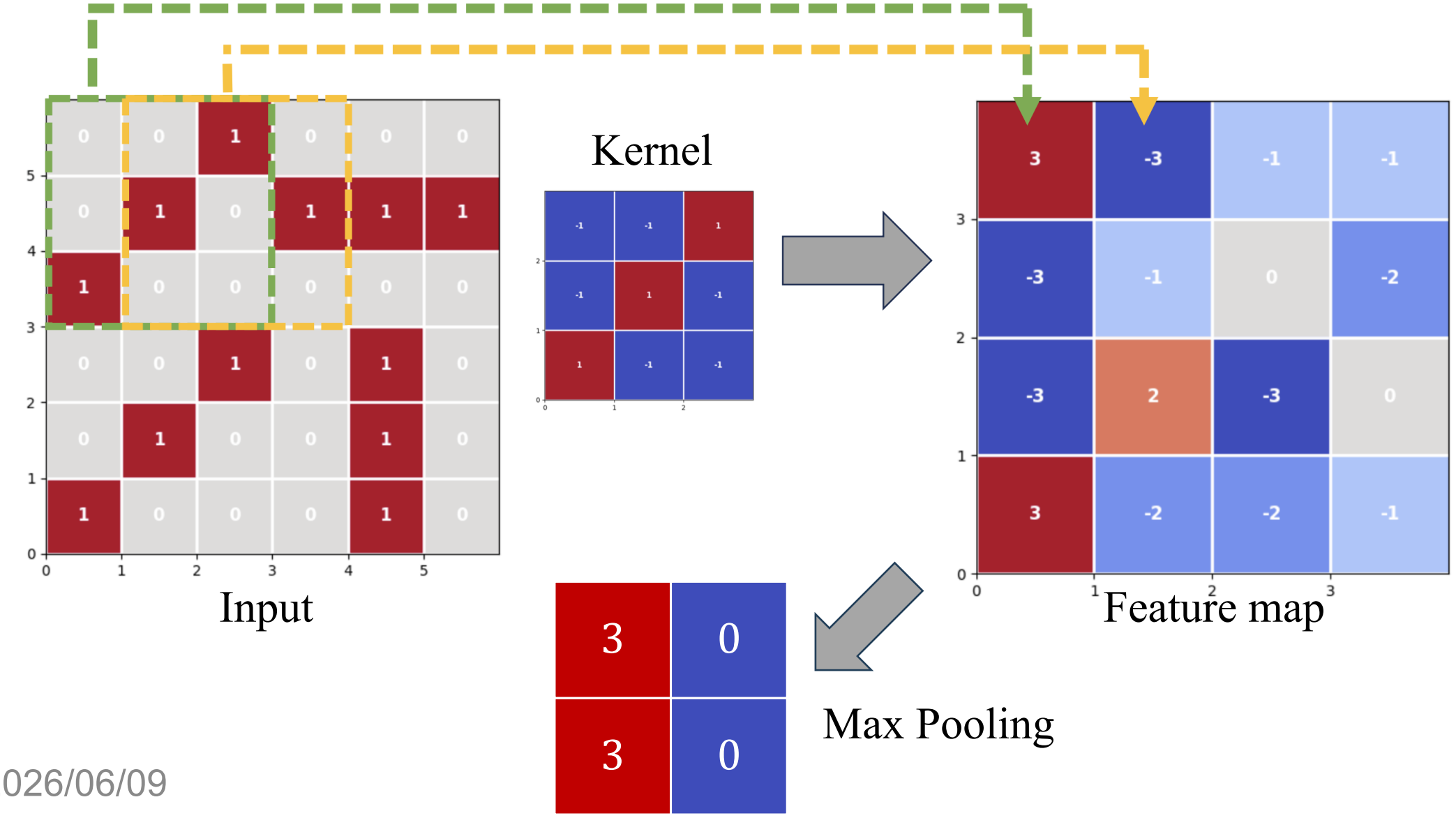
Convolution Neural Network:

- Translation invariance
- Focus on local feature
- Widely used to recognize image

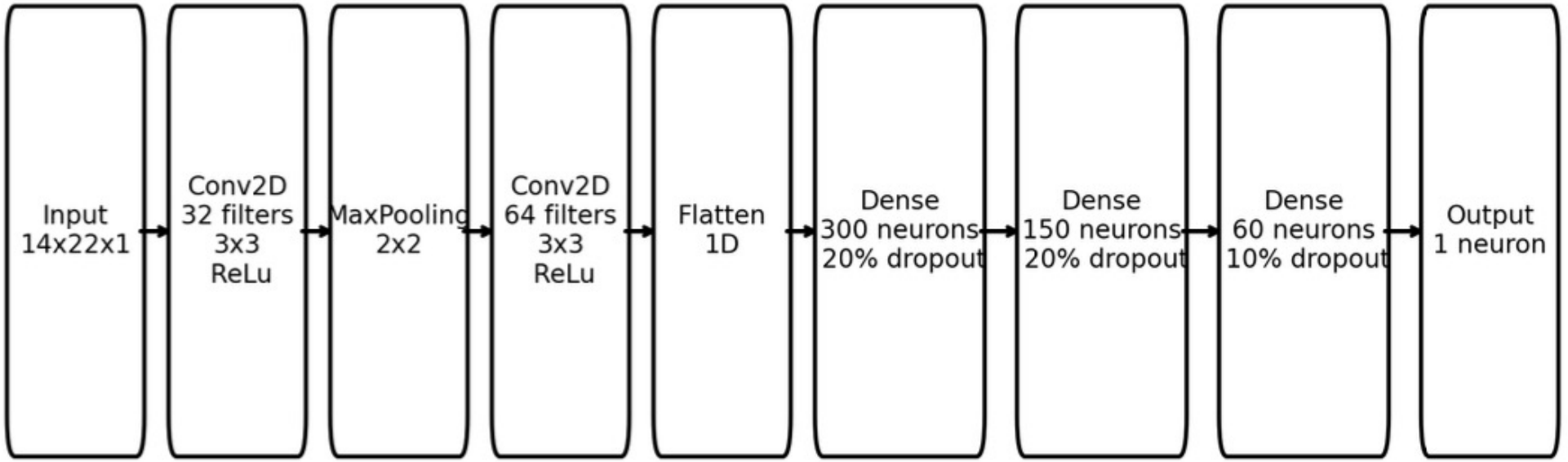
CNN for HEP:

- Reconstruction: Calibrating reconstructed energies
- Unfolding: Recover real distributions from measurements
- PID: electron, proton, pion identification
- Jet Tagging

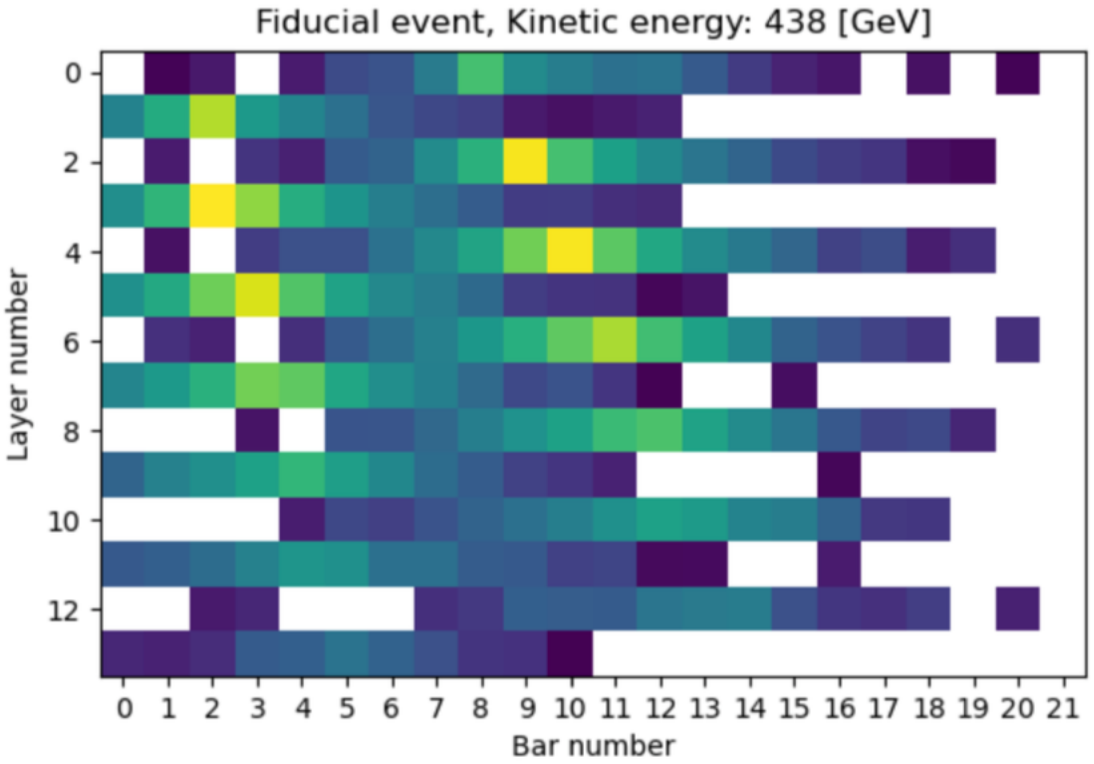
Convolution Step



CNN Model Structure



Model Details



Input format

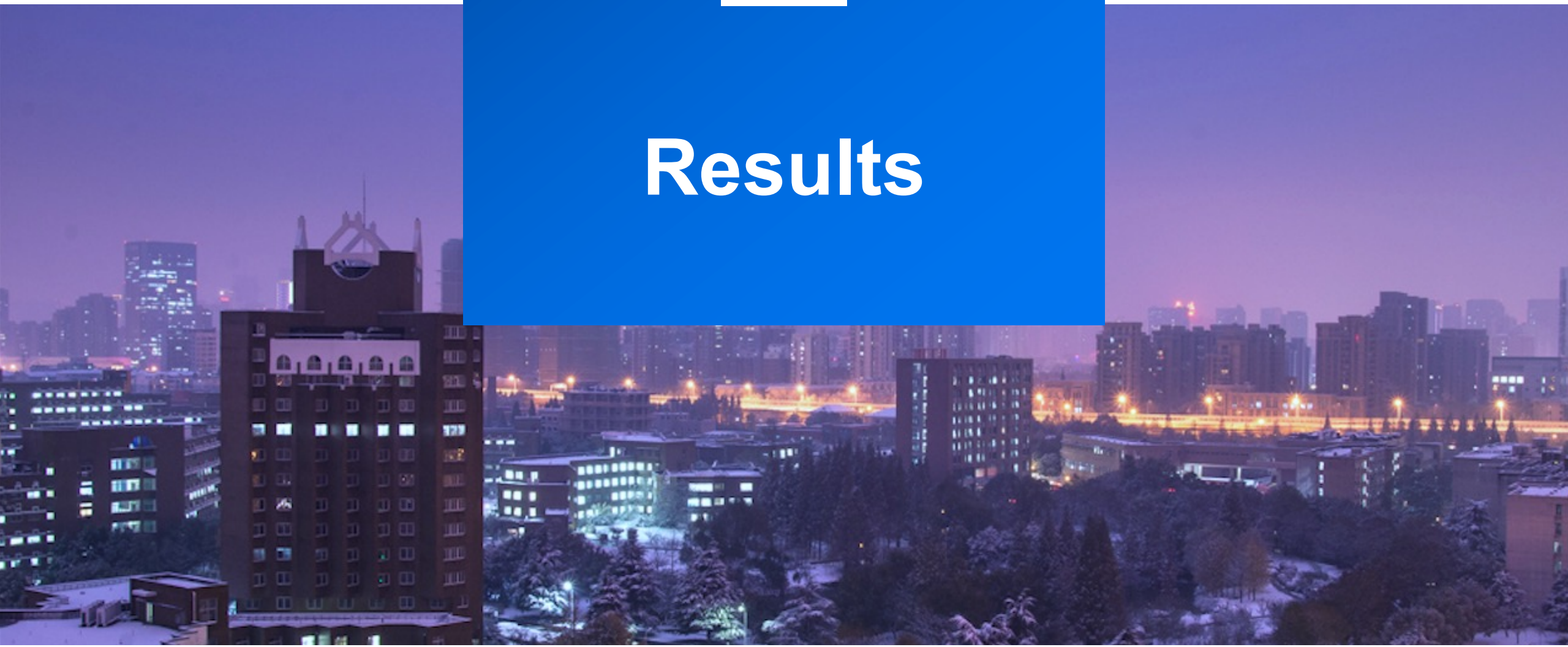
- Code: TensorFlow 2
- Convolutional kernels: 3×3
- ReLU activation function
- Dropout layers added
- Loss function: MSE

$$\frac{1}{m}\sum_{i=1}^{m}(\hat{r}_i - r_i)^2$$

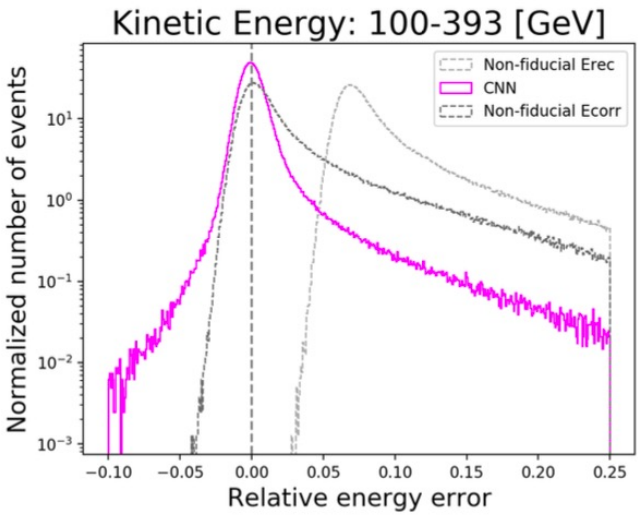
- Linear activation function for output layer

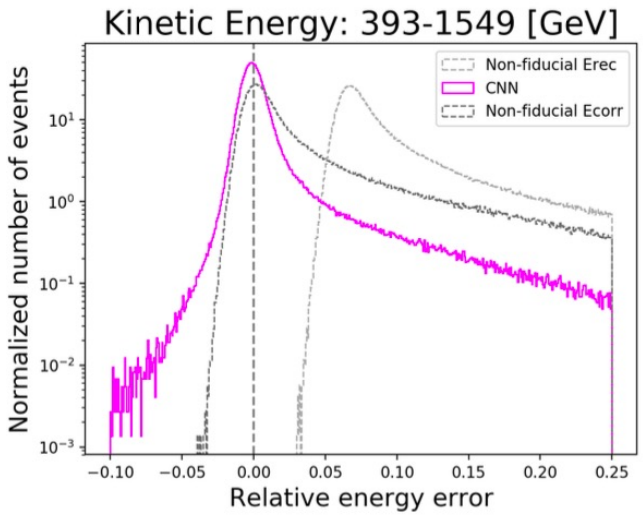
04

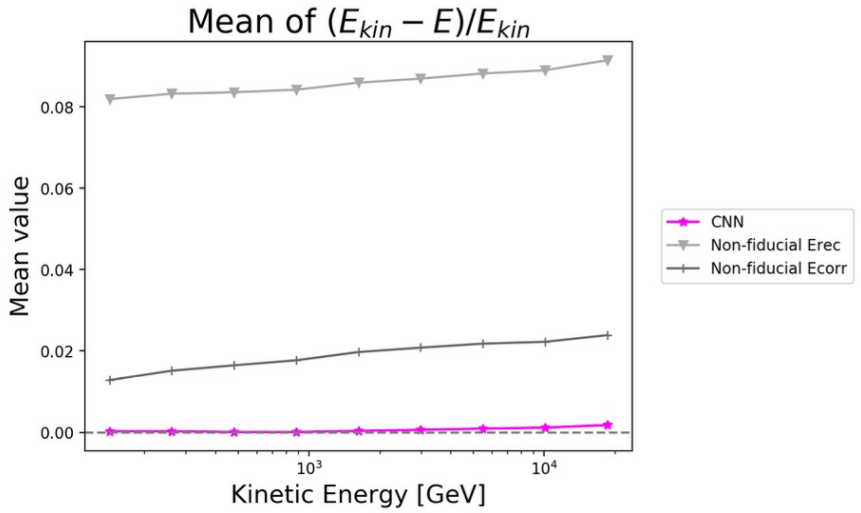
Results

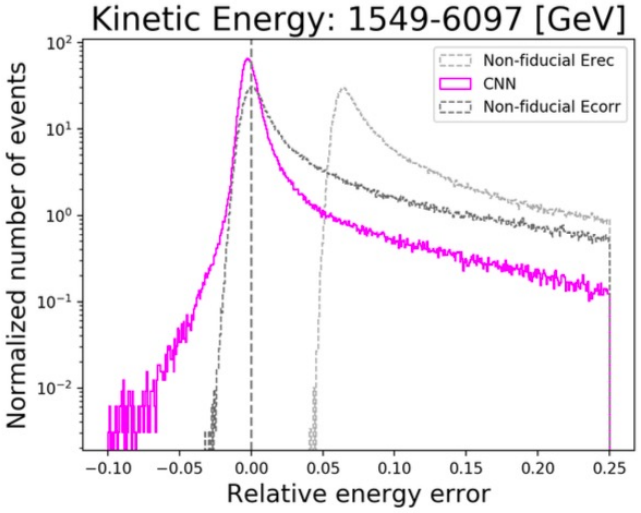


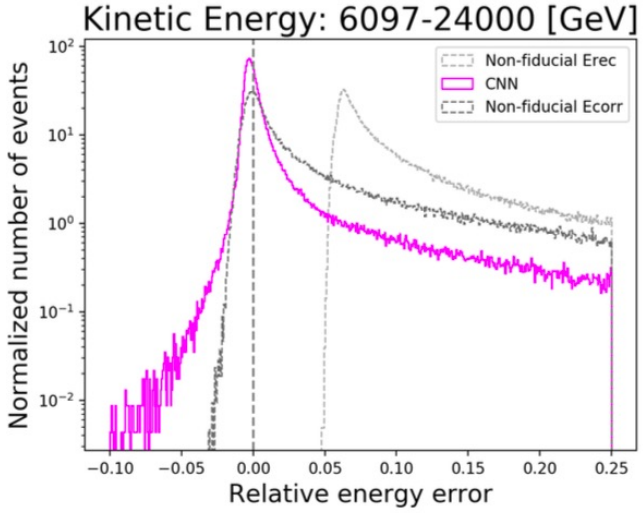
Relative Energy Error

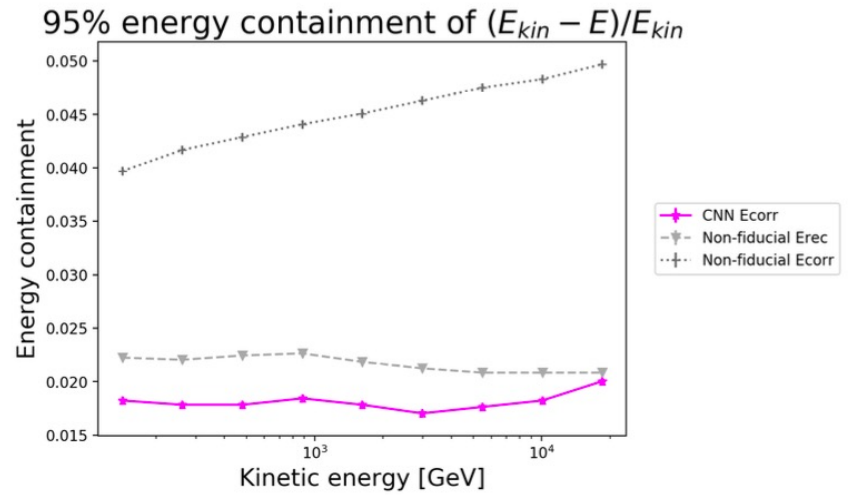




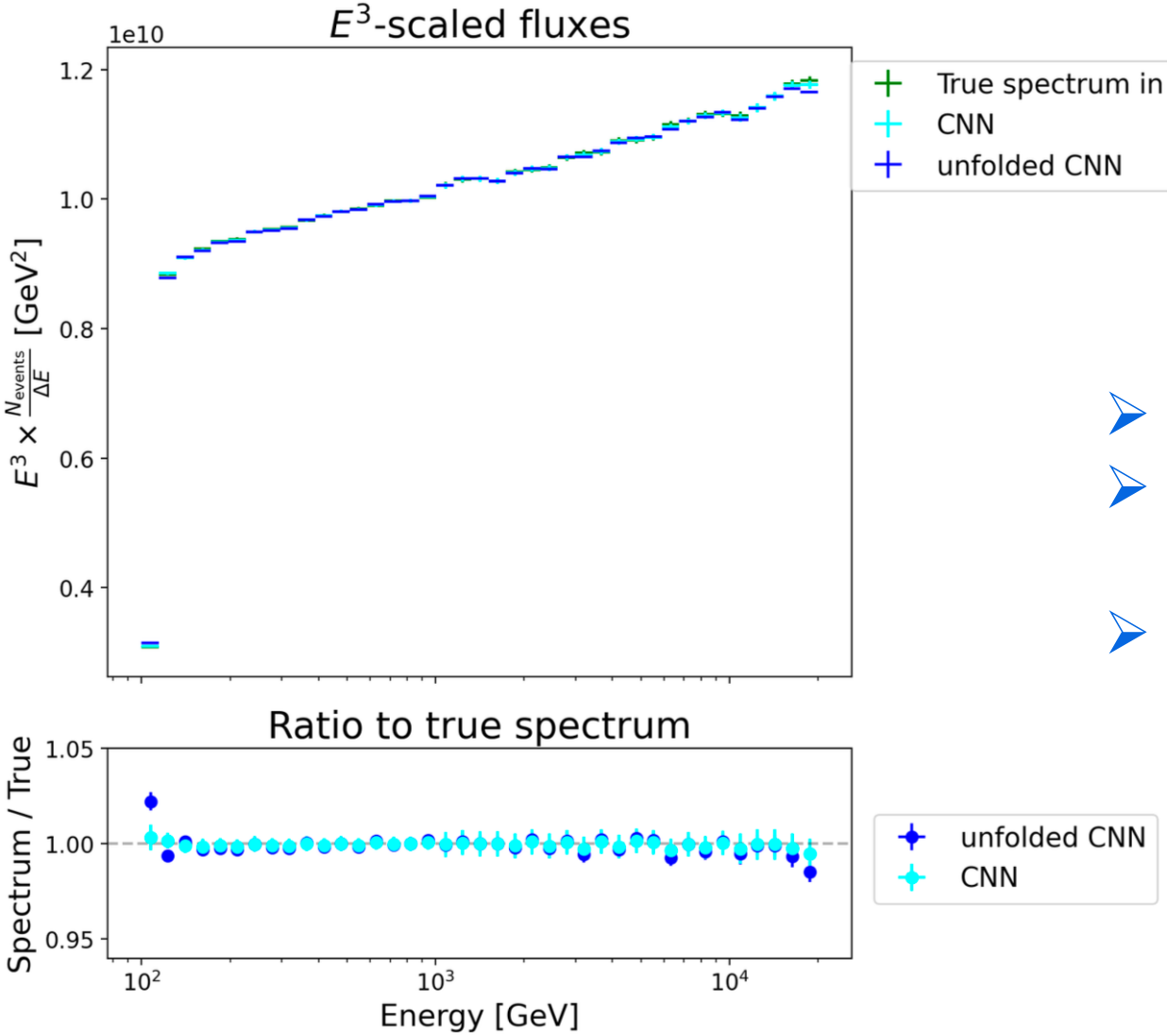






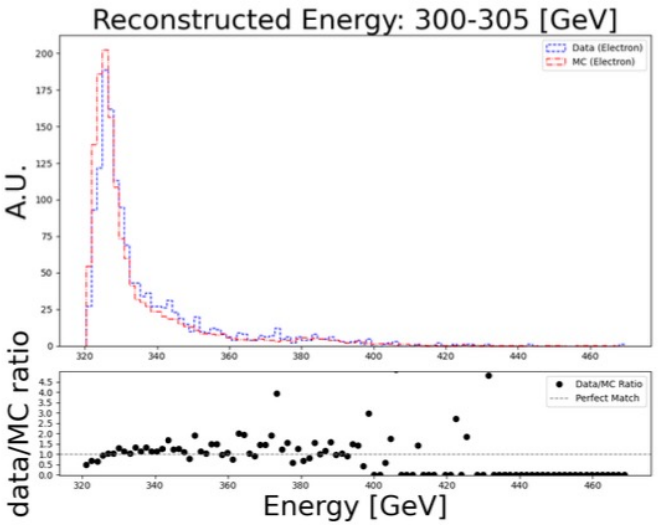


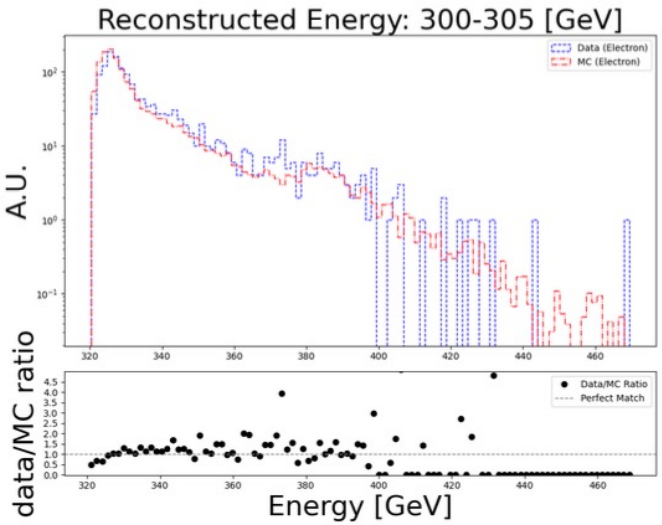
Kinetic Energy Spectrum

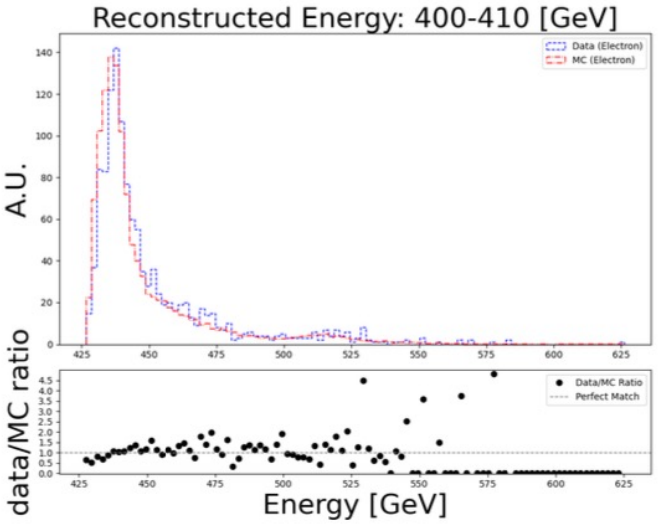


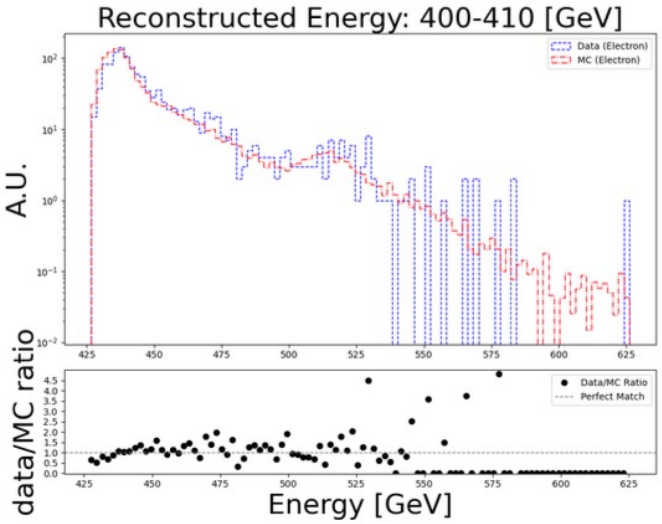
- Agree well with the kinetic energy;
- Unfolding procedure is not needed to compute electron flux;
- Avoid edge effects of unfolding.

Application in Flight Data

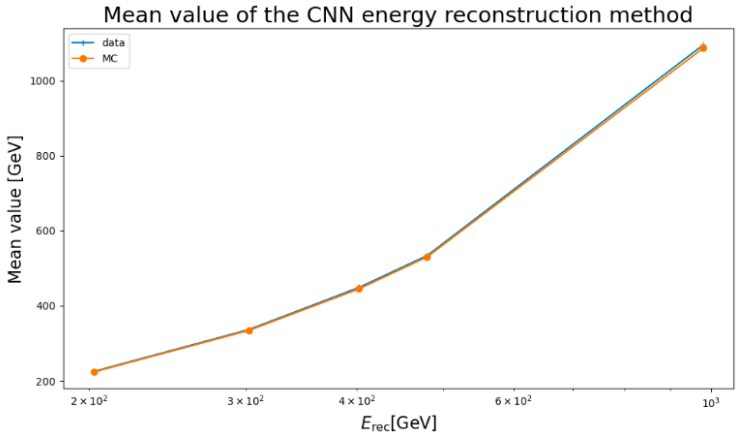


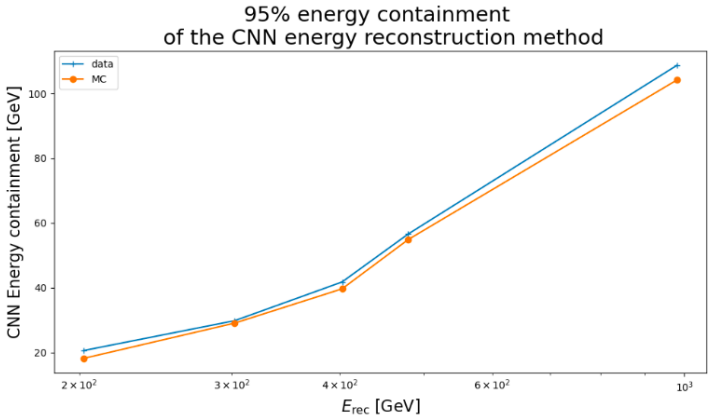






- Set narrow E_{rec} range due to inaccessible kinetic energy;
- The qualitative behavior of the CNN is similar between data and MC.





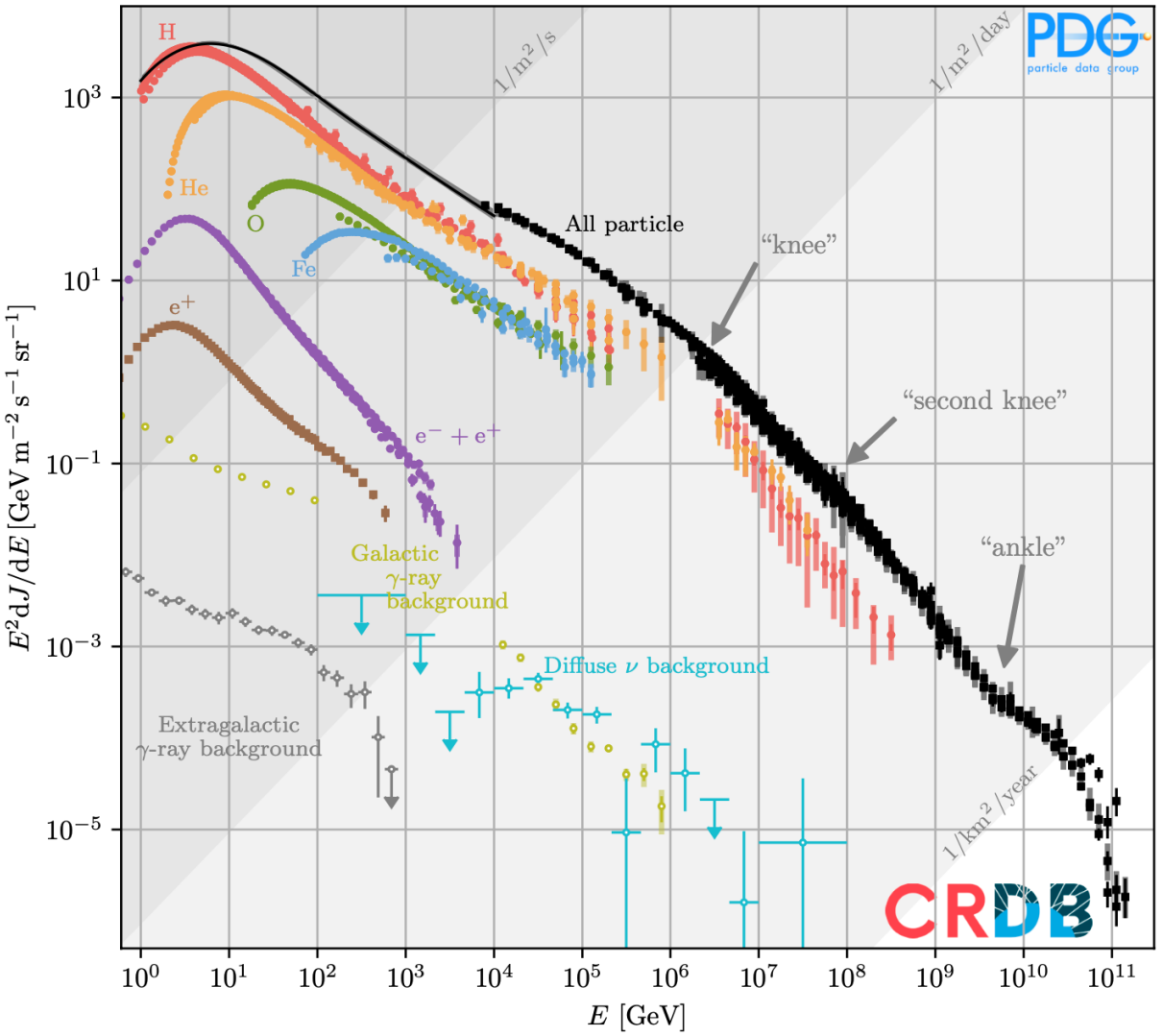
Summary

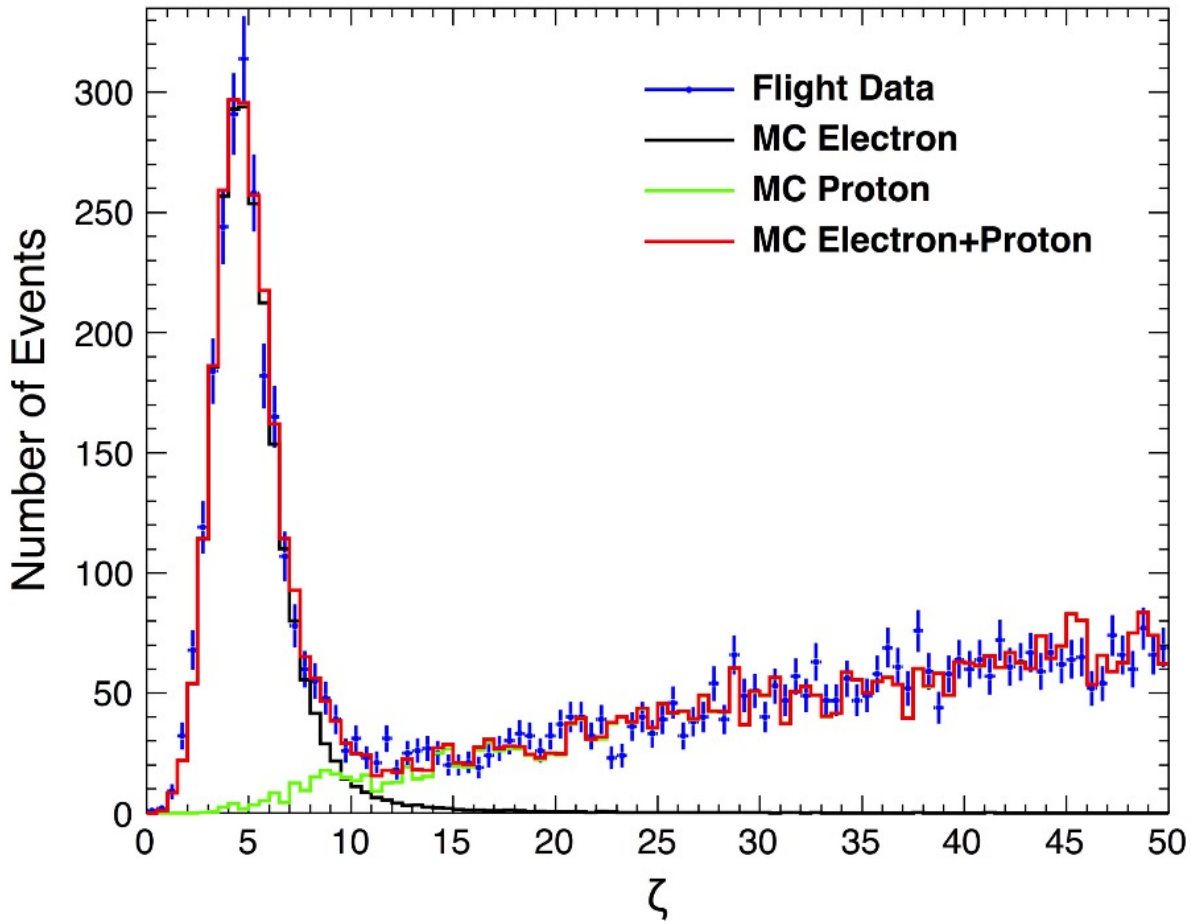
- ✓ Loose fiducial cuts help enhance the acceptance;
- ✓ Traditional energy reconstruction performs badly on non-fiducial events;
- ✓ The paper takes an attempt to improve the energy reconstruction with CNN;
- ✓ No more need of unfolding method with this CNN method;
- ✓ A significant progress in accuracy and precision of estimating the initial energy.

THANKS!

Backup

Fiducial e/p Discrimination

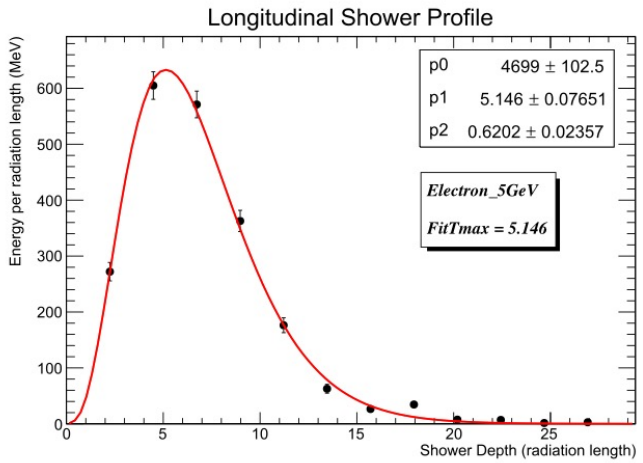




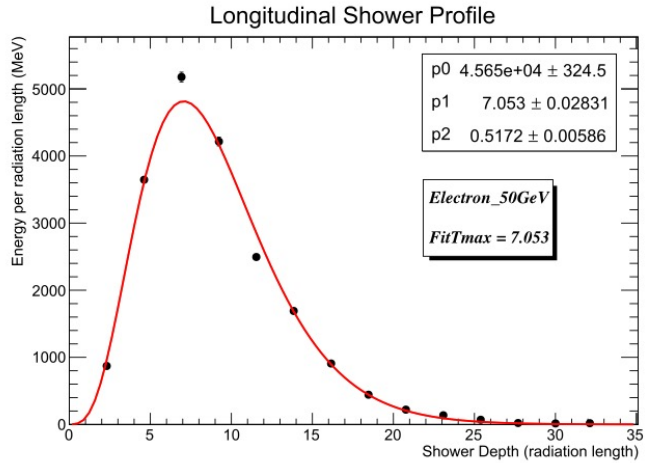
Longitudinal Shower Profile

$$\frac{dE(t)}{dt} = E_0 \cdot \frac{(\beta t)^{\alpha-1} \cdot \beta \cdot e^{-\beta t}}{\Gamma(\alpha)}$$

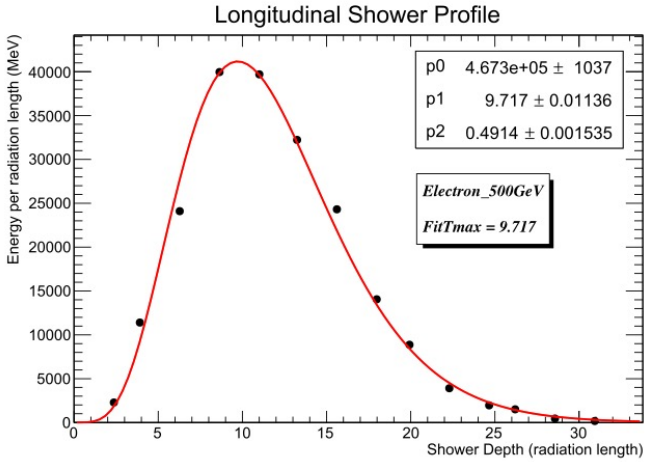
α: shape parameter;
β: scaling parameter



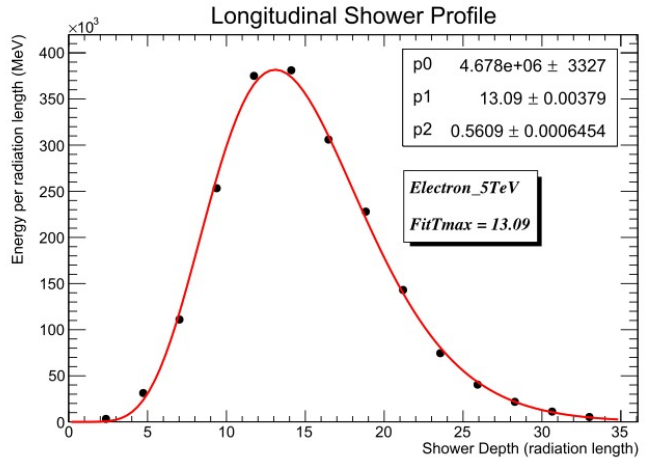
(a) 5 GeV MC electron



(b) 50 GeV MC electron

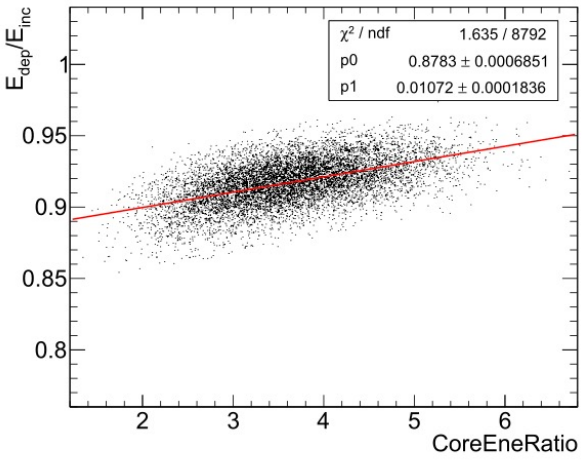


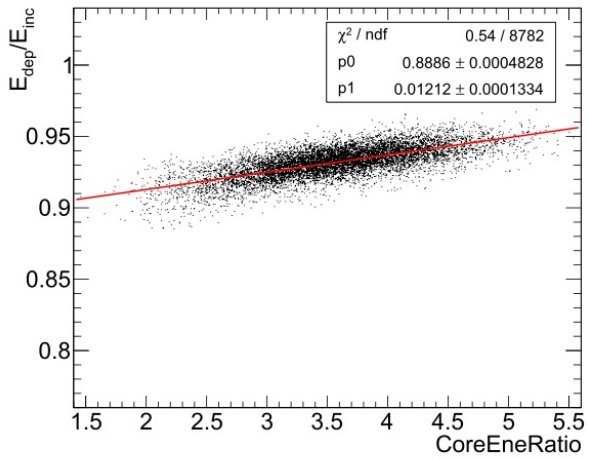
(c) 500 GeV MC electron

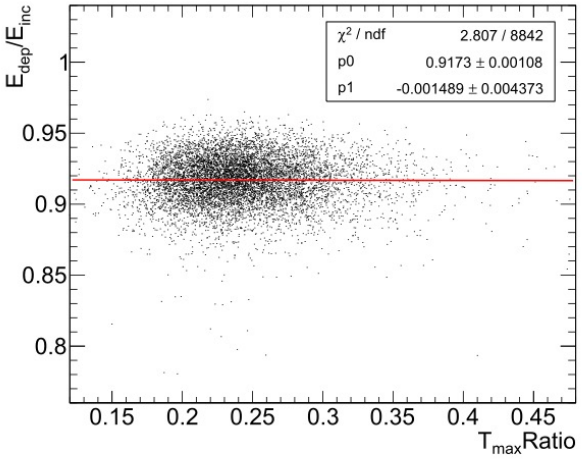


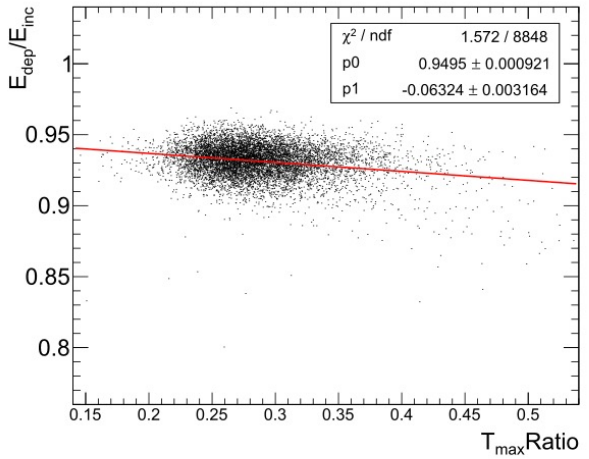
(d) 5 TeV MC electron

Electromagnetic Showers Energy Correction









(a) 10 GeV MC electron (b) 100 GeV MC electron

Lateral correction:

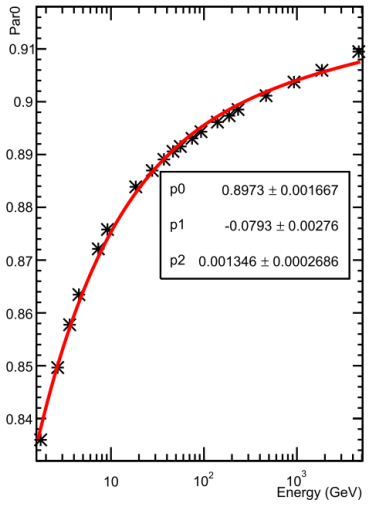
$$CoreEneRatio = \frac{\sum MaxBarE_i}{\sum LayerE_i - \sum MaxBarE_i} \cdot \frac{1}{\cos\theta}$$

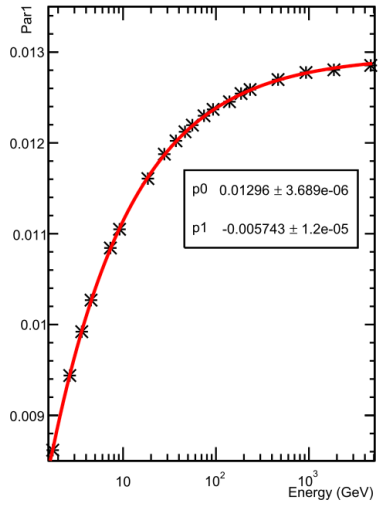
Longitudinal correction:

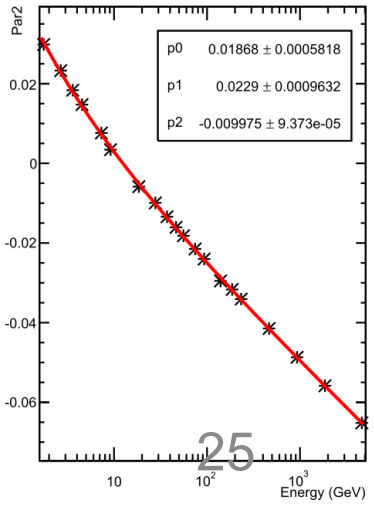
$$T_{max} = \frac{\alpha - 1}{\beta},\ T_{max}Ratio = \frac{T_{max}}{T_{total}}$$

Energy correction function:

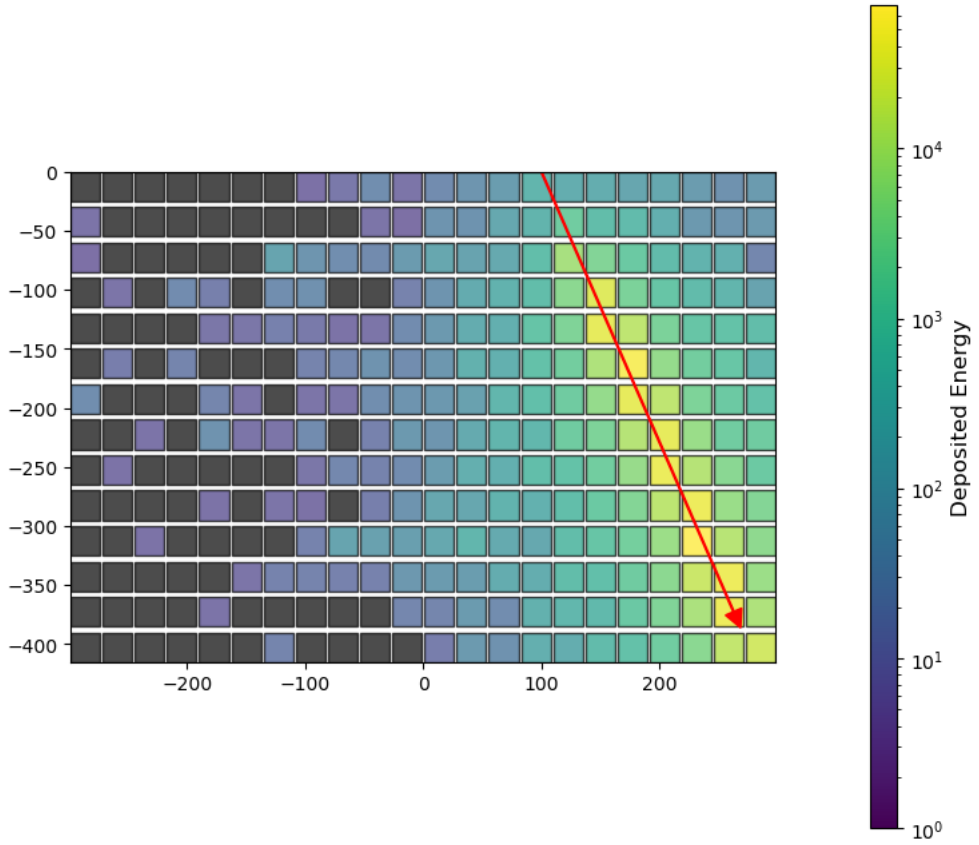
$$\frac{E_{dep}}{E_{inc}} = p_0 + p_1 \cdot CoreEneRatio + p_2 \cdot T_{max}Ratio$$

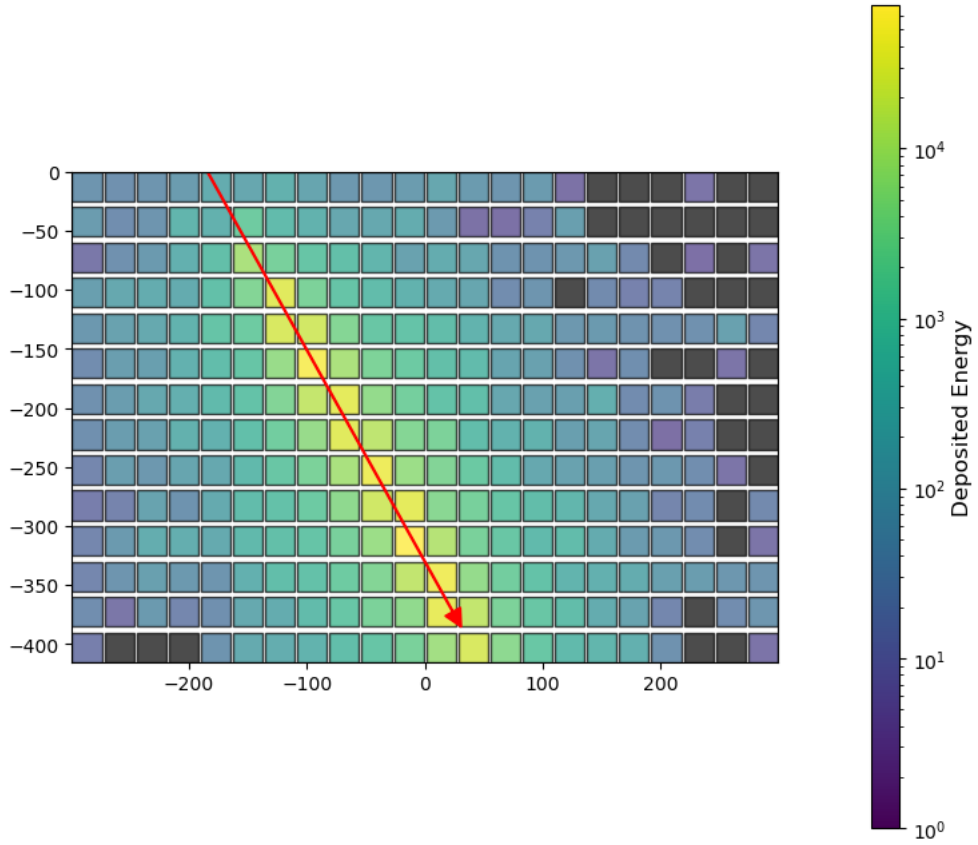




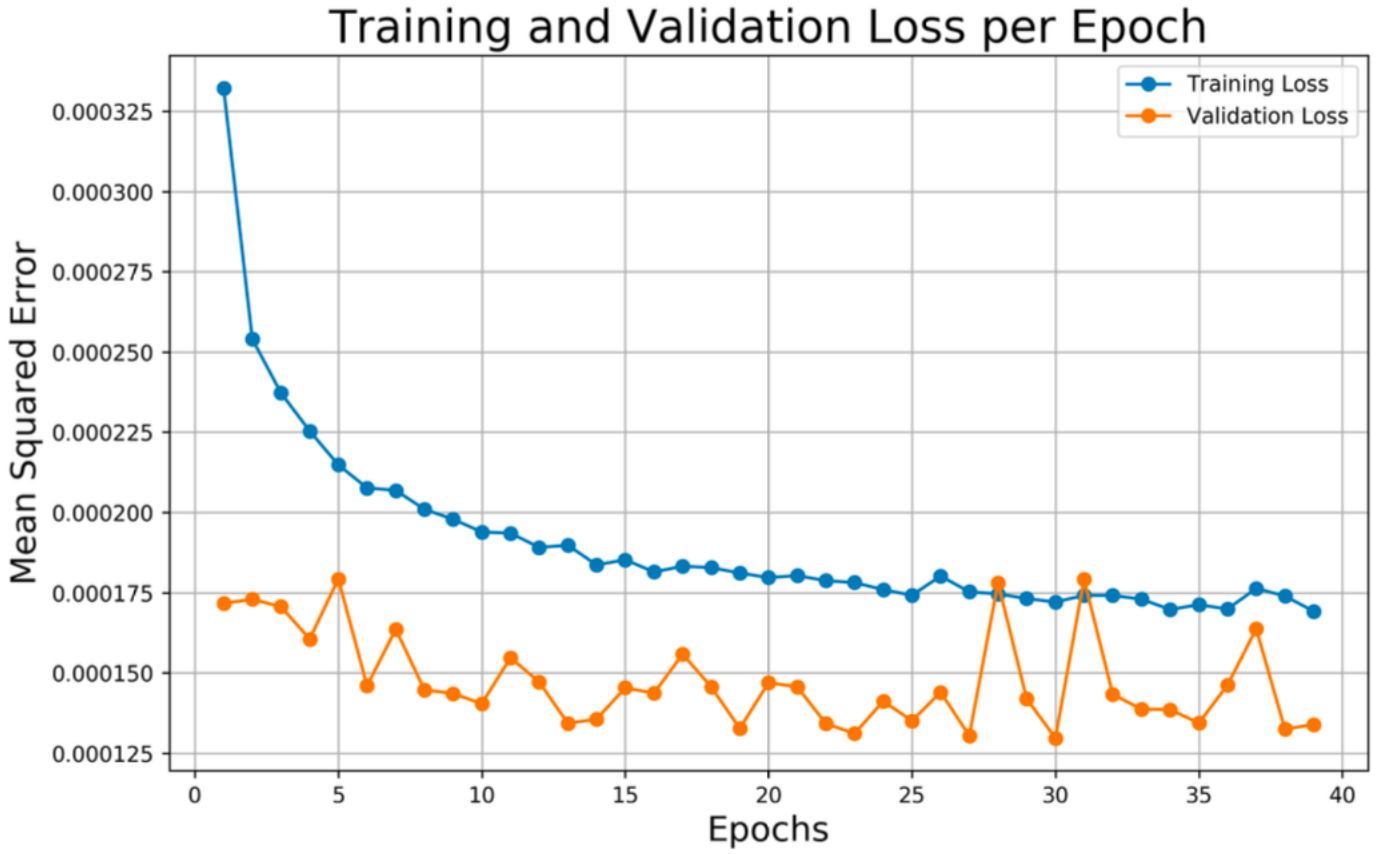


Discussion on Input

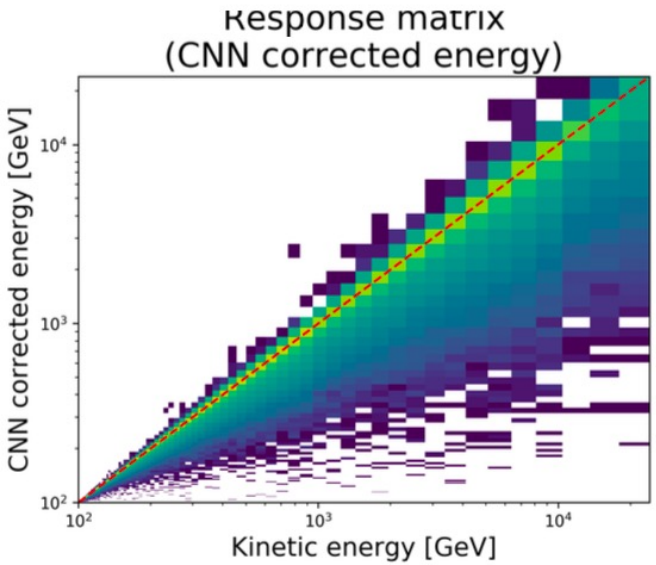


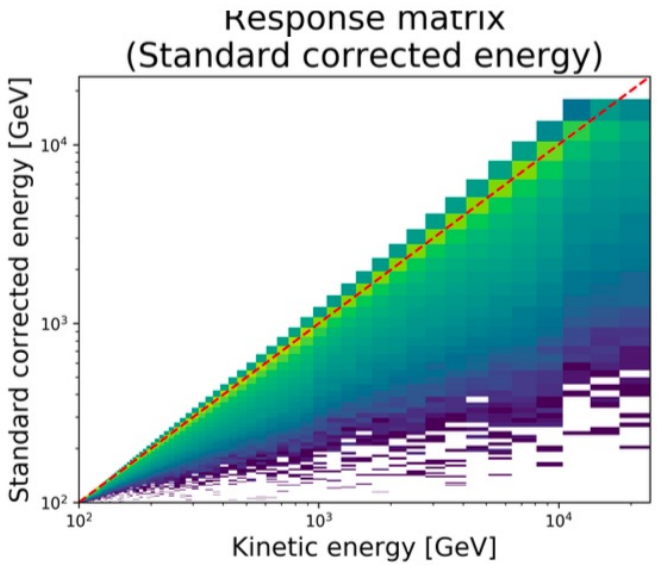


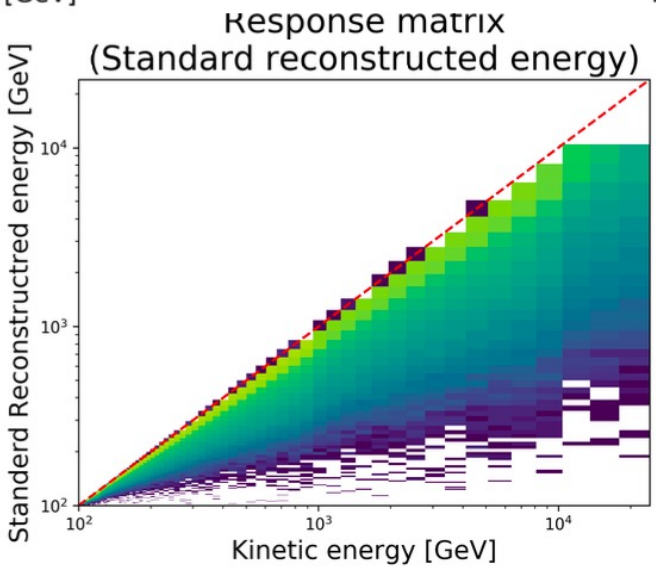
Training and Validation Loss



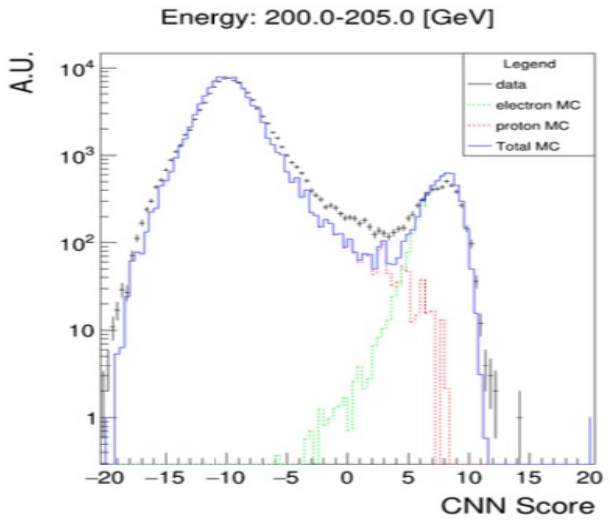
Response Matrix

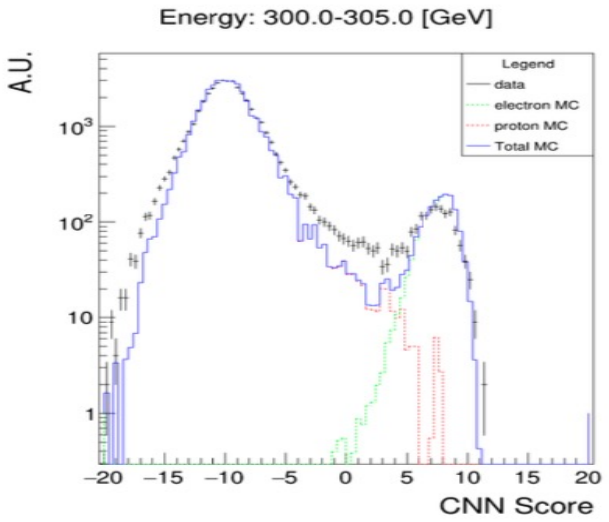


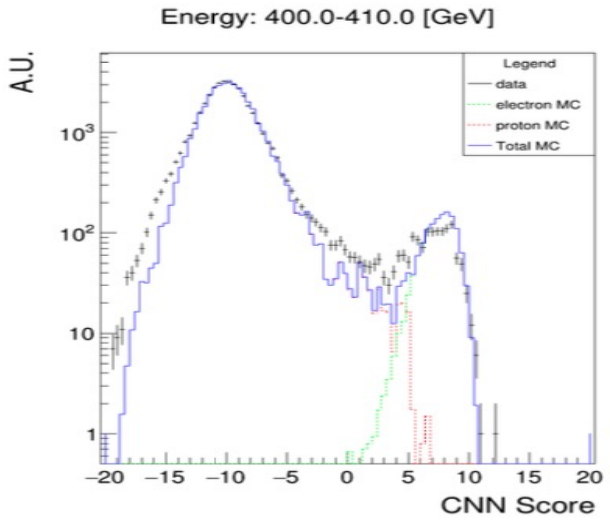


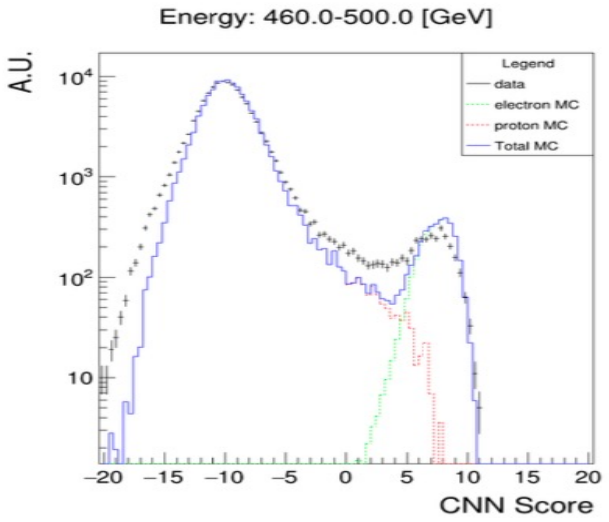


Electron Sample Selection









- Set narrow E_{rec} range due to inaccessible kinetic energy;
- Separate electrons from protons background with another CNN;
- Remove the sigmoid of the output layer to check CNN score.

arXiv:2102.05534v2

Energy range [GeV]	proton MC	electron MC	data
200–205	279	4763	4793
300–305	63	1508	1429
400–410	63	1246	1215
460–500	254	3045	2988
960–1000	49	401	434

Counts of CNN Score larger than 4