Rigidity and Energy Reconstruction of Cosmic Rays using machine learning method

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Outline

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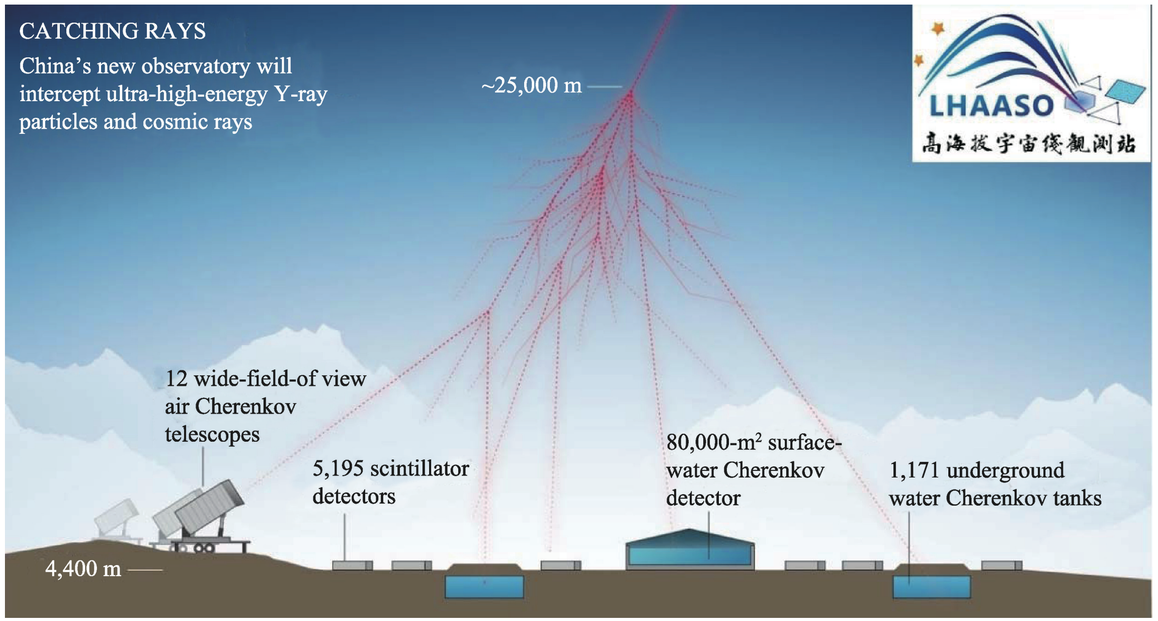
- Method
- Result
- Summary & Outlook

Introduction



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LHAASO KM2A detectors

ED hits, MD hits …

Machine Learning

Regression

Particle Info:

Energy

Rigidity

…

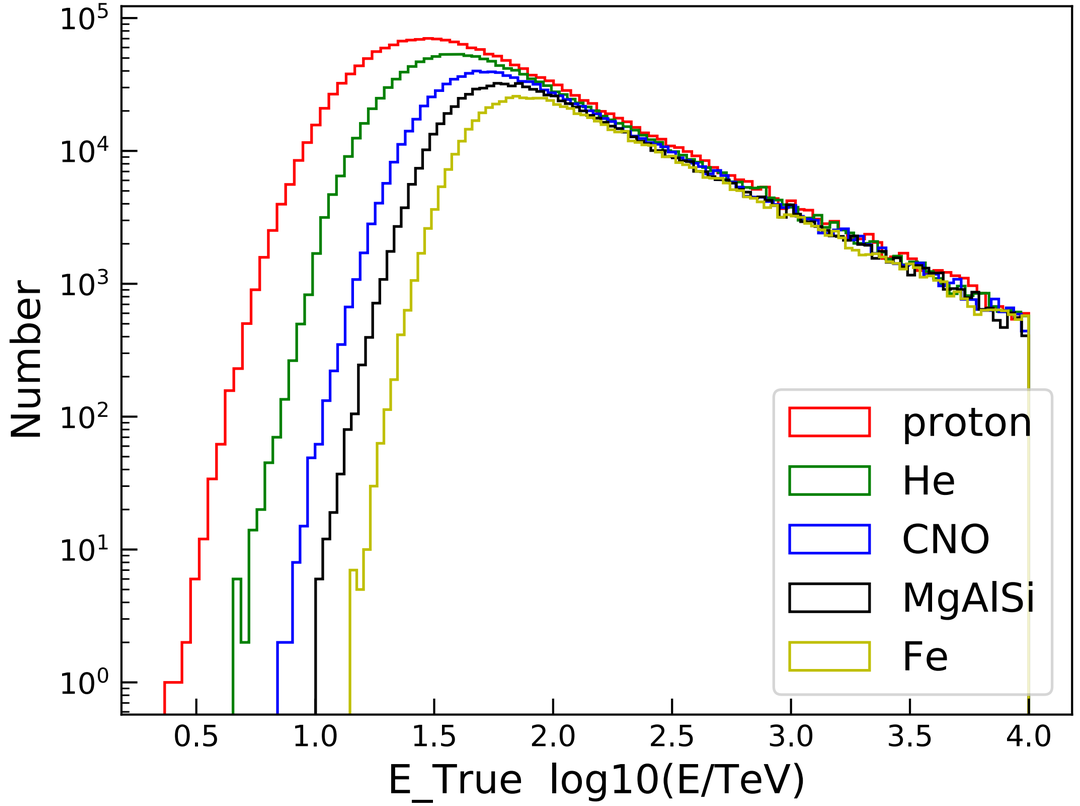
Introduction

MC: KM2A Full Array

To reconstruct energy & rigidity without particle identification !

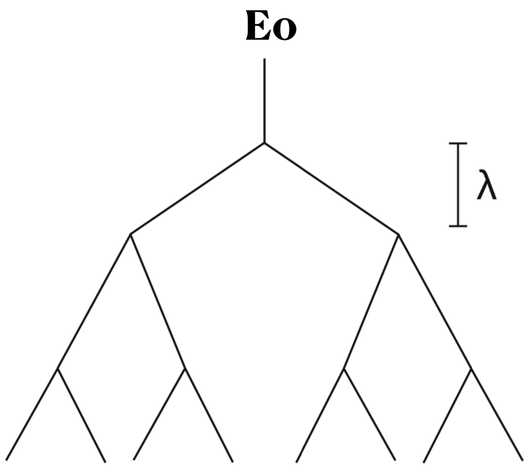
Selection Cuts:

1. zenith < 40 deg
2. NtrigE >= 20
3. NfiltE >= 20
4. NpE3 > 0
5. NuM3 > 0
6. dr > 0

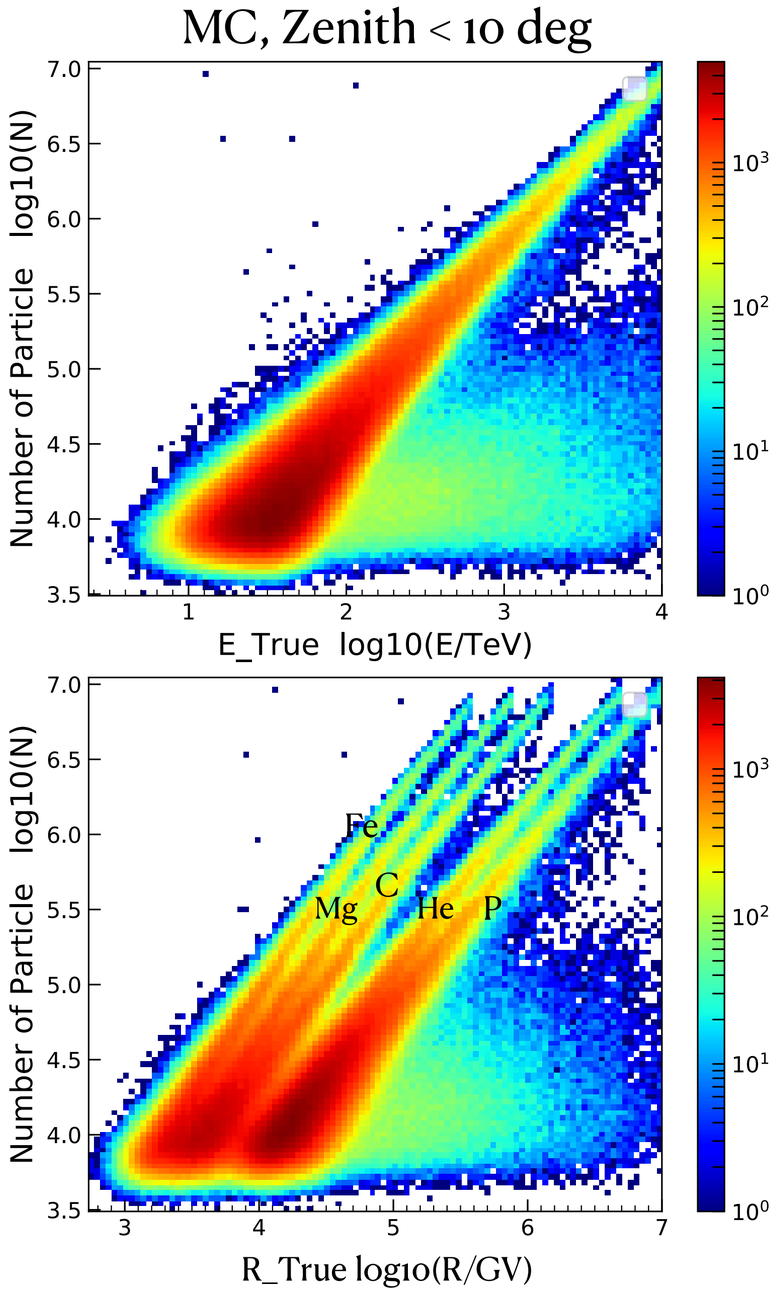


Introduction

Heitler's Toy Model



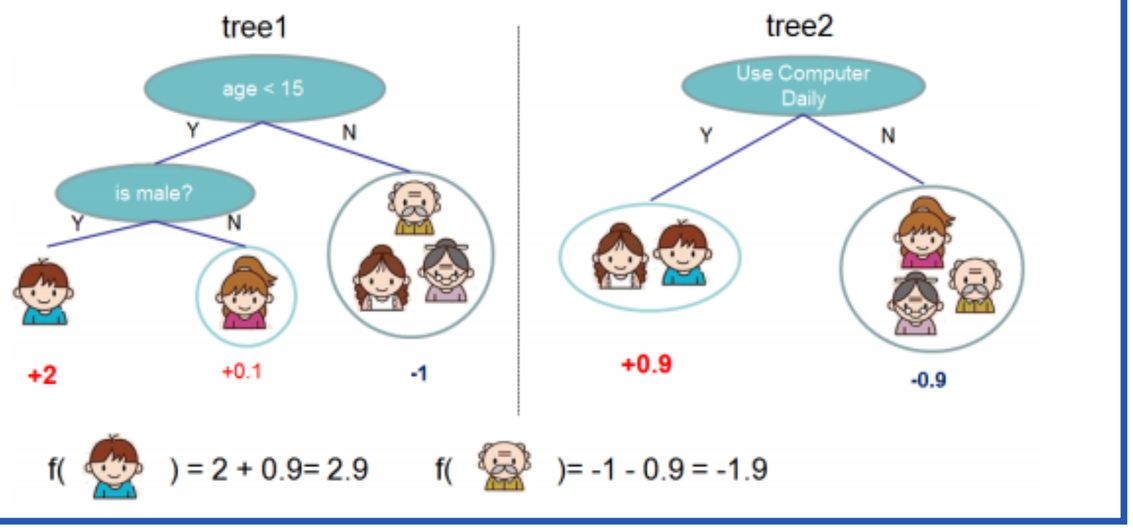
$$N(X_{max}) = E_0/E_c \ , \ X_{max} = \lambda \frac{ln(E_0/E_c)}{ln2}$$



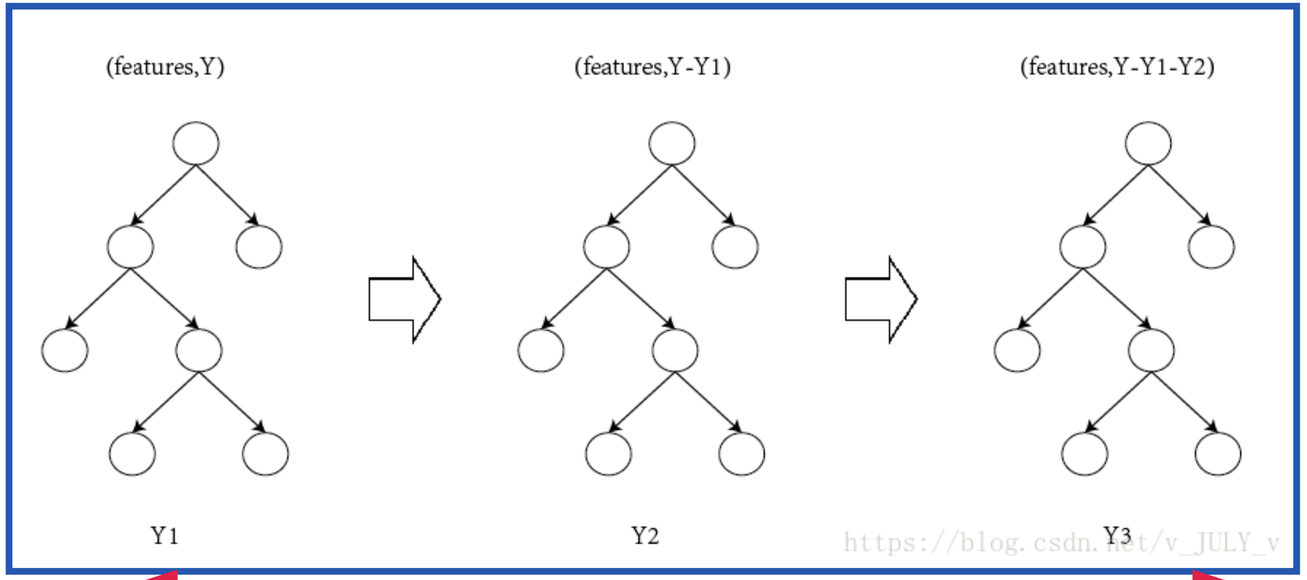
Algorithm — XGBoost

- XGBoost： eXtreme Gradient Boosting Decision Tree
- Tianqi Chen, 2016

Illustration: successive trees are better



Final prediction = Y1 + Y2 + Y3 + ... + Yn



arxiv: 1603.02754

Features

1. Theta: reconstructed zenith
2. Size: total number of particles of EM shower
3. Age: age of EM shower
4. rho(50)
5. NfiltE: total number of hits of ED after filter out noise
6. NfiltM: total number of hits of MD after filter out noise
7. NhitE: number of hit of ED
8. NhitM: number of hit of MD
9. NpE1: number of particles of ED with r < rwind + 50, dt: -50, 100
10. NpE2: number of particles of ED with r < 40 ~ 100, dt: -50, 100
11. NuM1: number of muons of MD with r = 15, rwind + 100, dt: -50, 100
12. NuM2: number of muons of MD with r = 15, rwind + 300, dt: -50, 100
13. NuM3: number of muons of MD with r = 40, 200, dt: -50, 100
14. dr

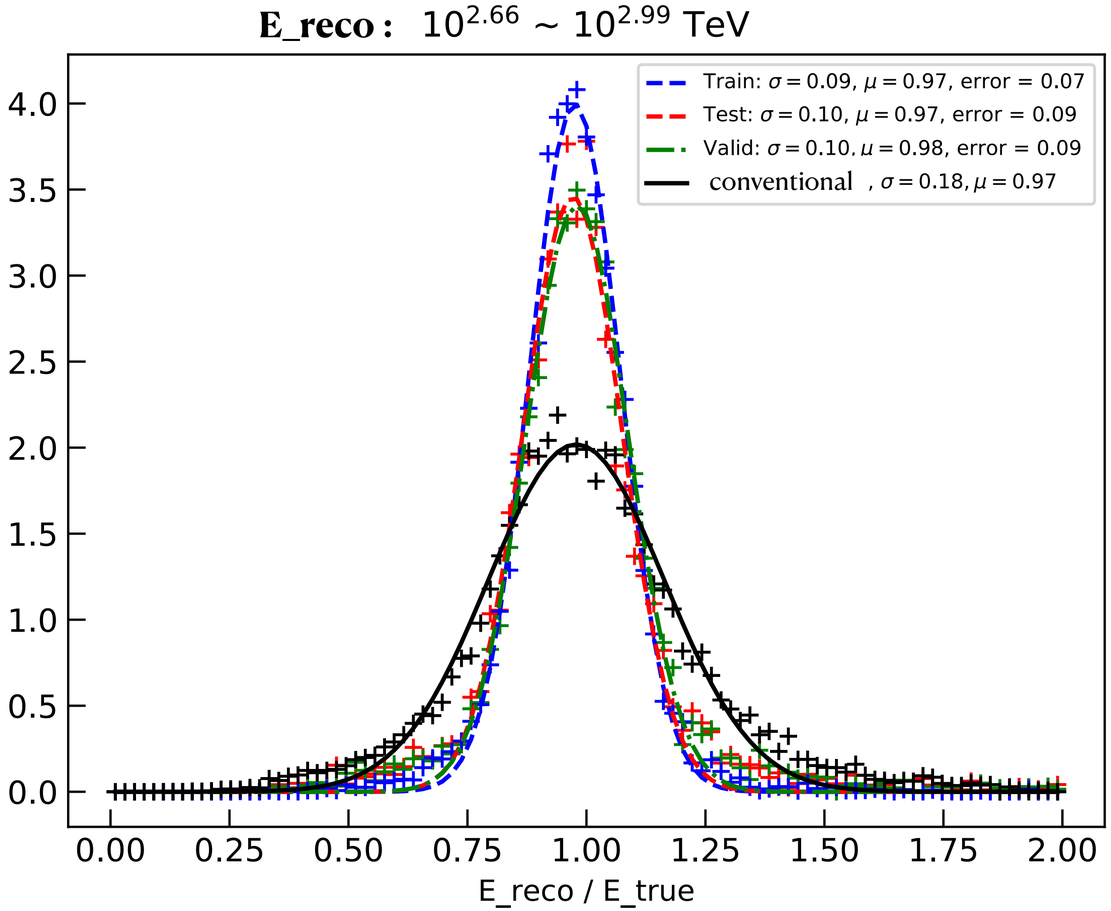
$$\rho(r)=\frac{N_{\text{size}}}{2\pi r_{\text{m}}^2}\frac{\Gamma(4.5-s)}{\Gamma(s-0.5)\Gamma(5-2s)}\left(\frac{r}{r_{\text{m}}}\right)^{s-2.5}\left(1+\frac{r}{r_{\text{m}}}\right)^{s-4.5},$$

Energy Reconstruction

$Conventional\ Method:\ \ lg(E_{reco}) = A \times lg(NpE3 \times NuM3)$

Train set : Valid set: Test set = 3 : 1 : 1

Zenith: 0 ~ 10 deg
Gaiser's model weight for different species



Energy Reconstruction

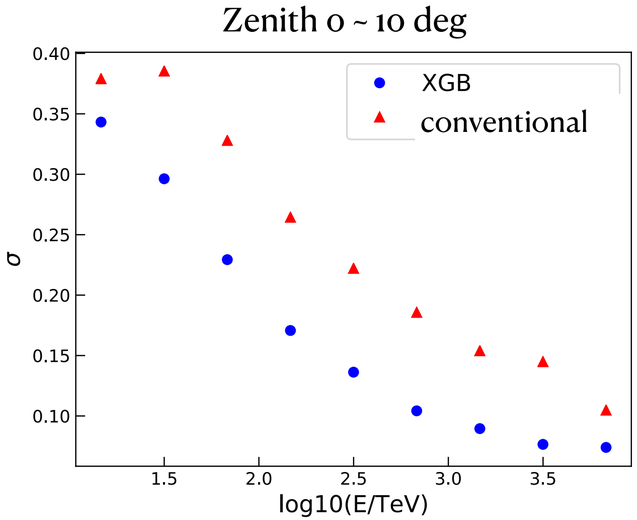
Hyperparameters:

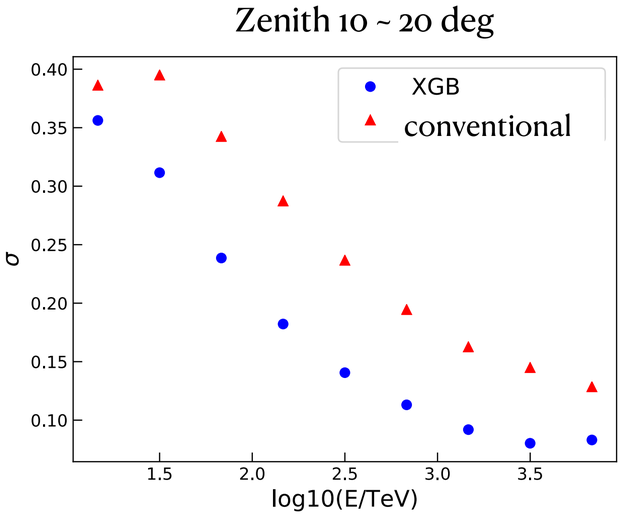
max_depth, n_estimators, learning rate

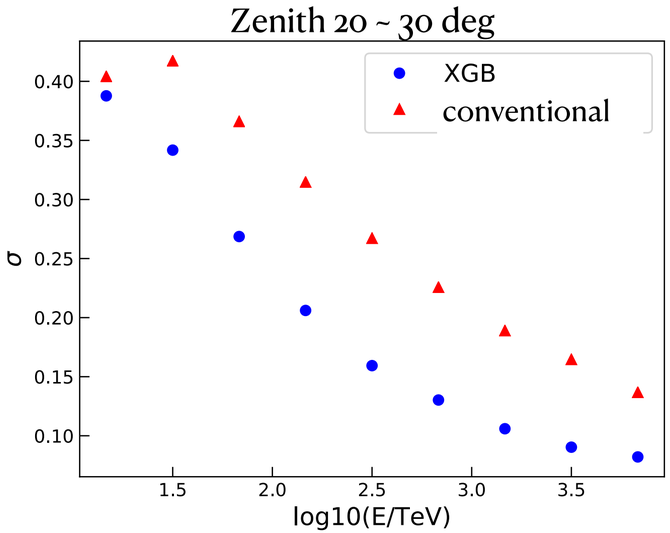
1. Zenith 0 ~ 10 deg: 11, 100, 0.05
2. Zenith 10 ~ 20 deg: 13, 100, 0.05
3. Zenith 20 ~ 30 deg: 12, 100, 0.05
4. Zenith 30 ~ 40 deg: 13, 100, 0.05

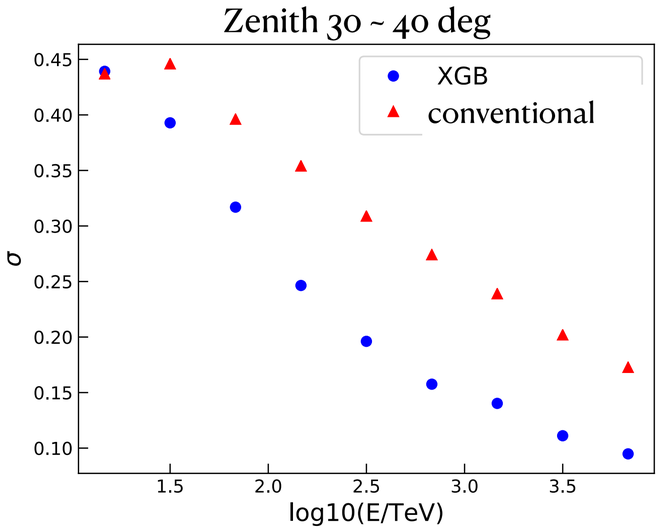
ML method Result:

- Resolution less than 15% > PeV
- Bias < 5%





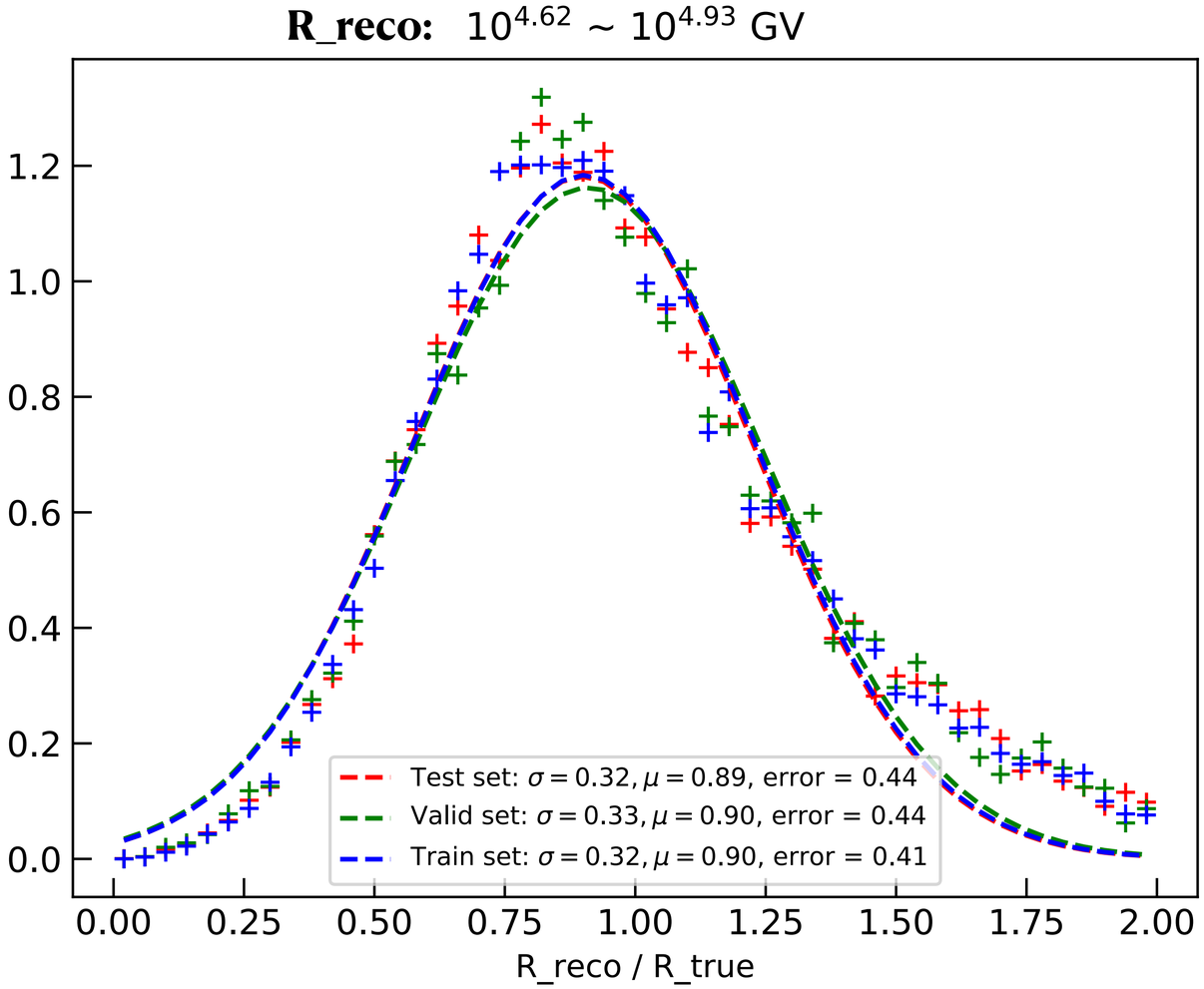




Rigidity Reconstruction

Train set : Valid set: Test set = 3 : 1 : 1

Zenith: 0 ~ 10 deg
Gaiser's model weight for different species



Rigidity Reconstruction

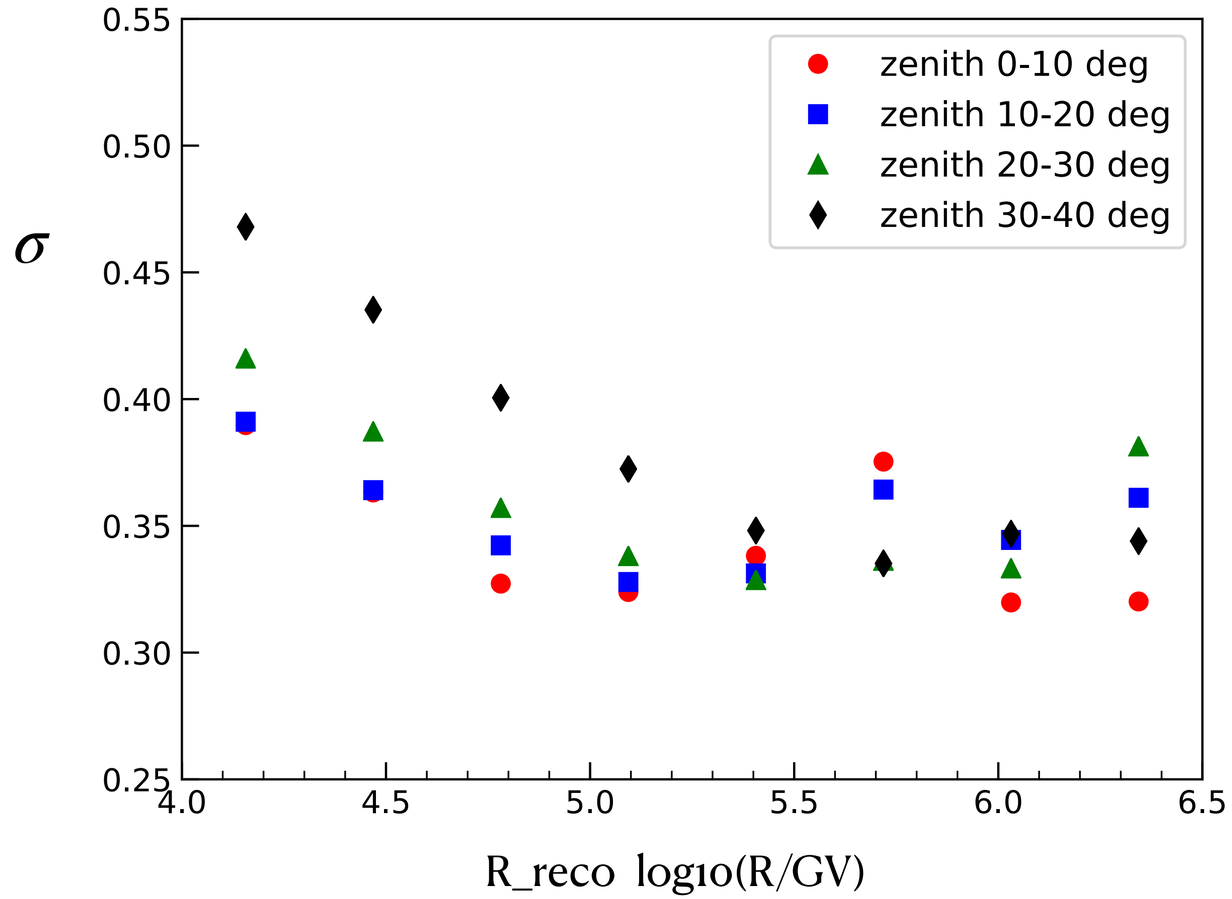
Hyperparameters:

max_depth, n_estimators, learning rate

1. Zenith 0 ~ 10 deg: 7, 150, 0.1
2. Zenith 10 ~ 20 deg: 7, 100, 0.3
3. Zenith 20 ~ 30 deg: 8, 200, 0.1
4. Zenith 30 ~ 40 deg: 9, 200, 0.1

Result:

- Resolution about 0.3 ~ 0.45
- Bias < 11%



Summary & Outlook

- ML Energy reconstruction resolution is around 0.07 ~ 0.40
- Rigidity reconstruction resolution is around 0.3 ~ 0.45
- Add more features from WFCTA & WCDA in future

谢谢！