Energy reconstruction of cosmic ray for LHAASO-KM2A

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Purpose

- The all-particle energy spectrum exhibits two interesting structures from 10^{14} to 10^{18} eV, the “knee” and the “second knee”. An explanation of these features is thought to be an important step in understanding the origin of the high-energy particles.

- A finite energy attained during the acceleration process
  leakage from the Galaxy

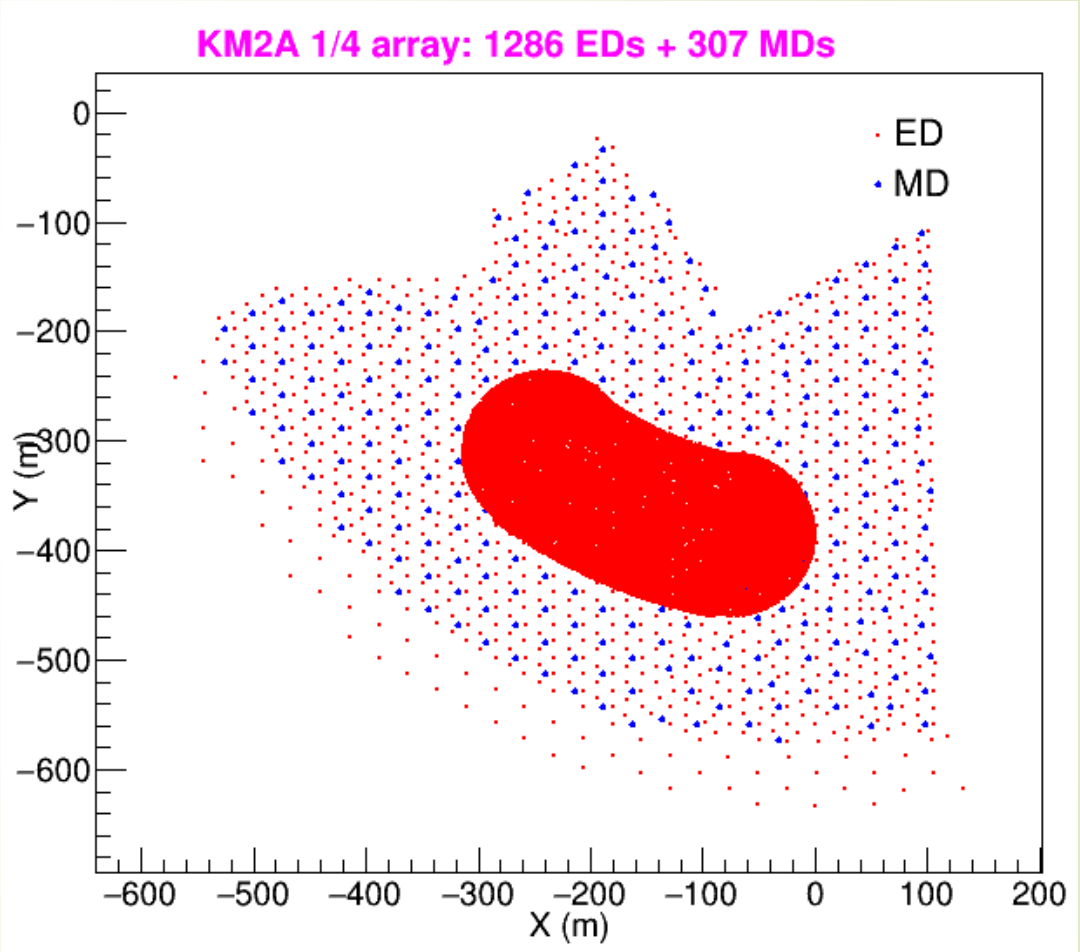
- Cosmic-ray compositions and hadronic interaction models

- A combination of electron and muon sizes is insensitive to the type of primary particle.

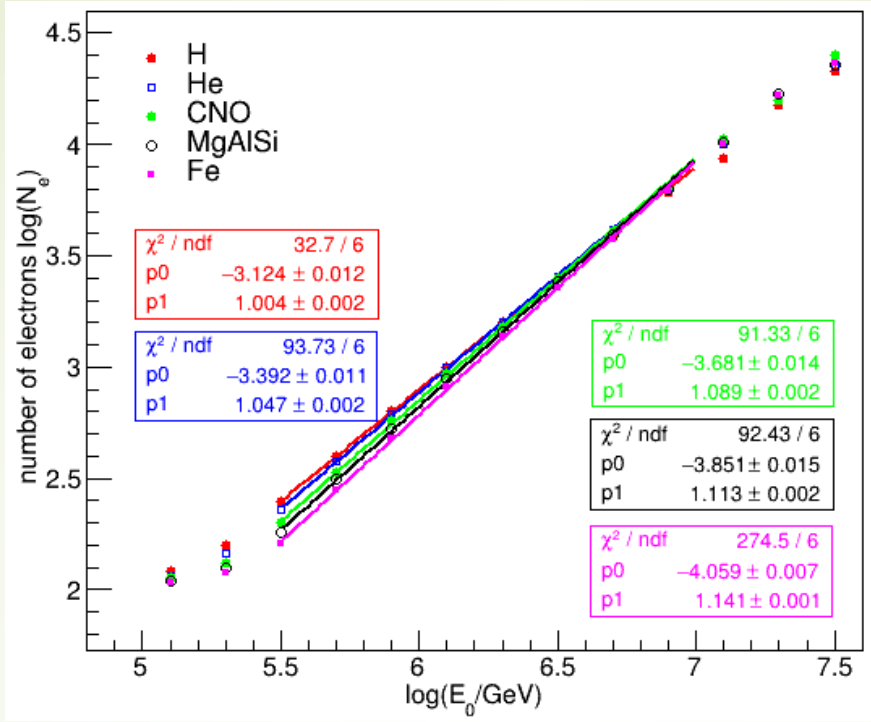
Quarter array simulation data：

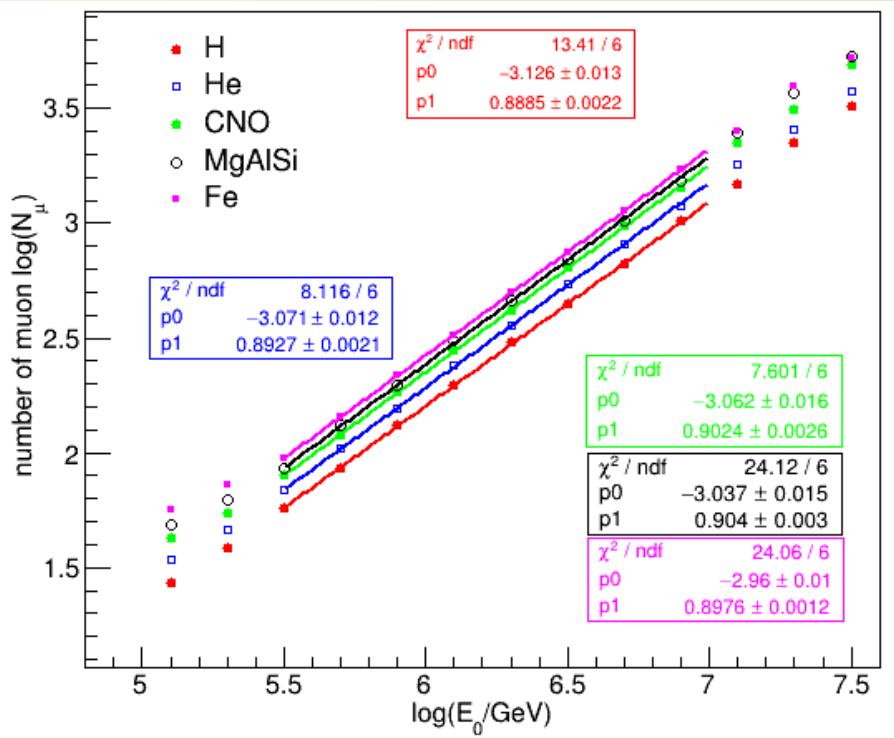
QGSII_Gheisha：
Proton He CNO MgAlSi Fe,
Theta:0-11°
Slope: -2

normalizing to Gaisser energy spectrum



Quantity and E_0

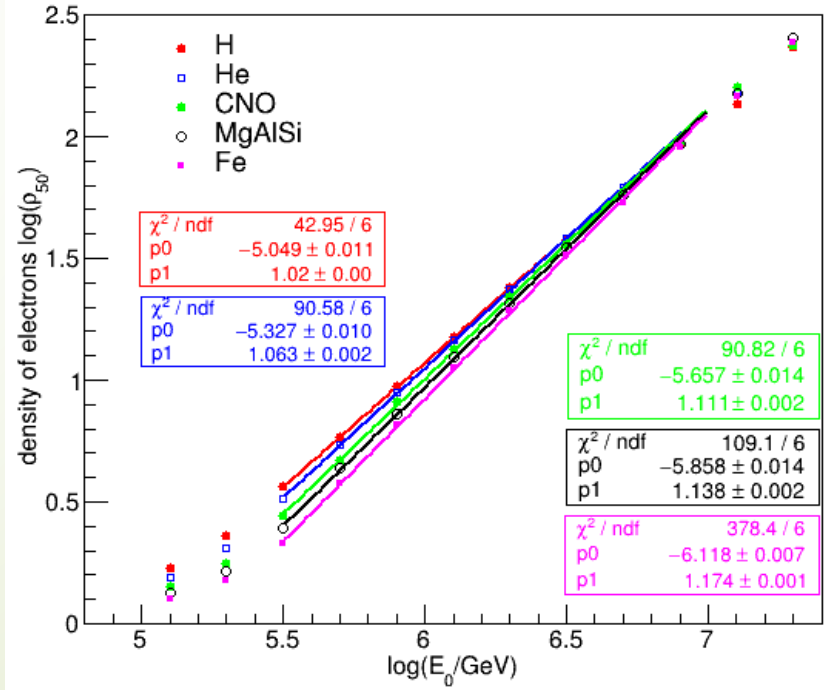




N_e: sum particle of ED with r=40-100m

N_μ: number of muons of MD with r=40-200m

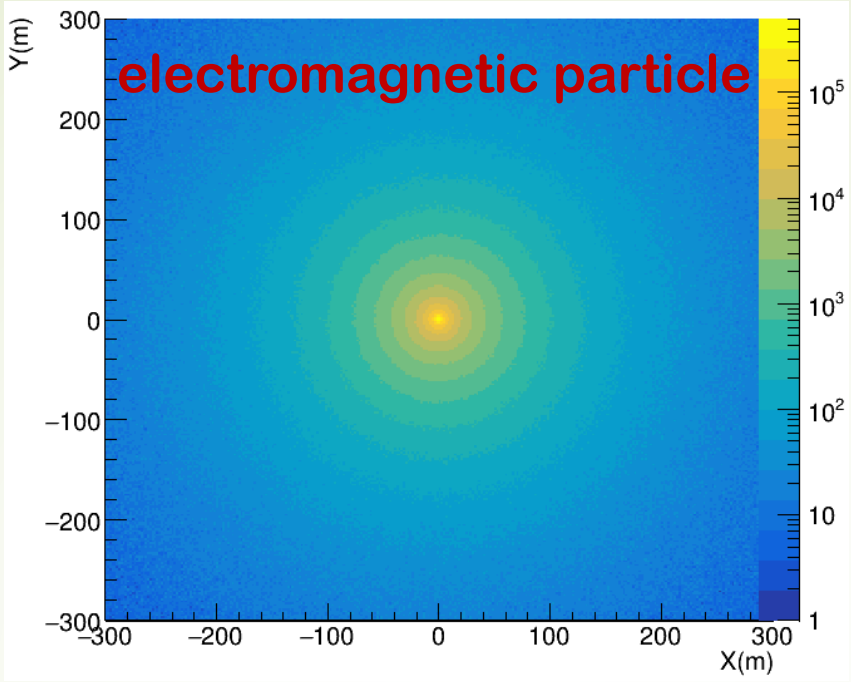
ρ_{50}: particle density at r = 50m of NKG fit

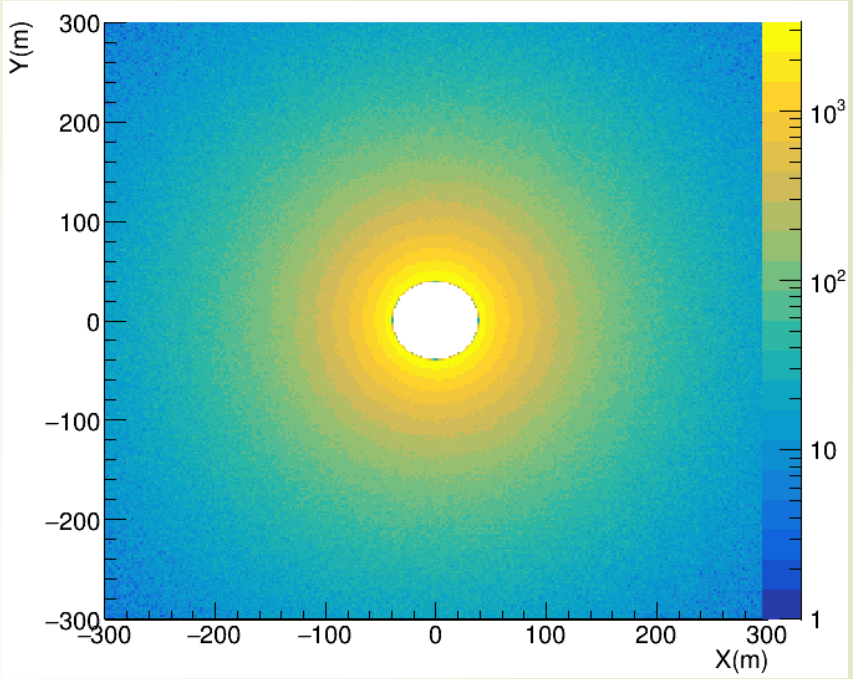


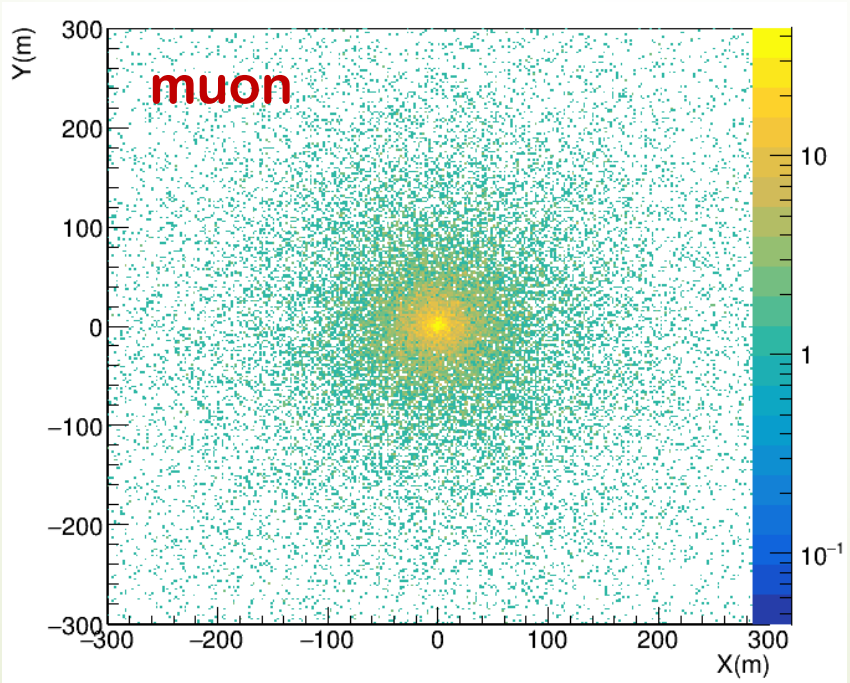
10.7PeV 9°
Proton

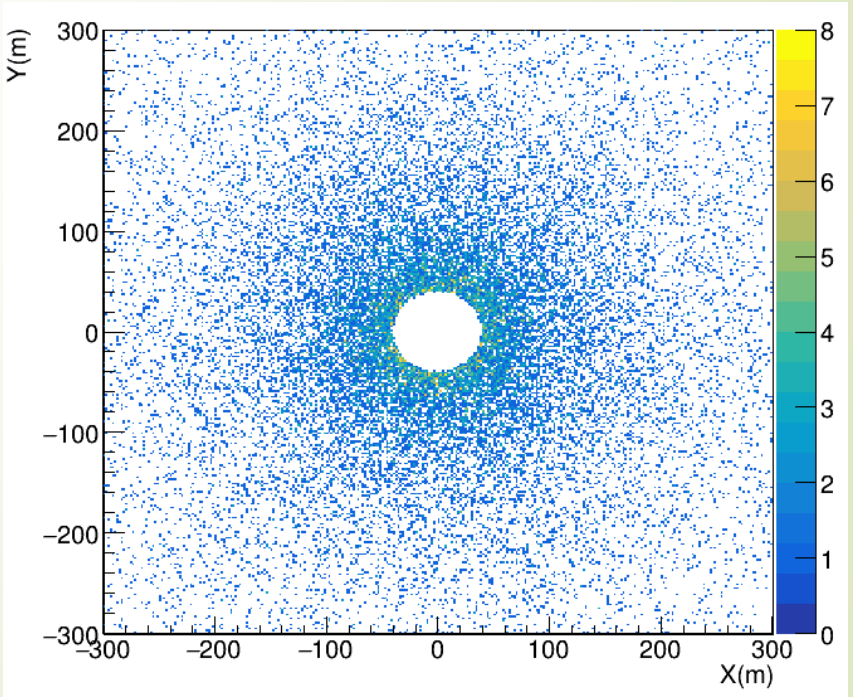
Saturation

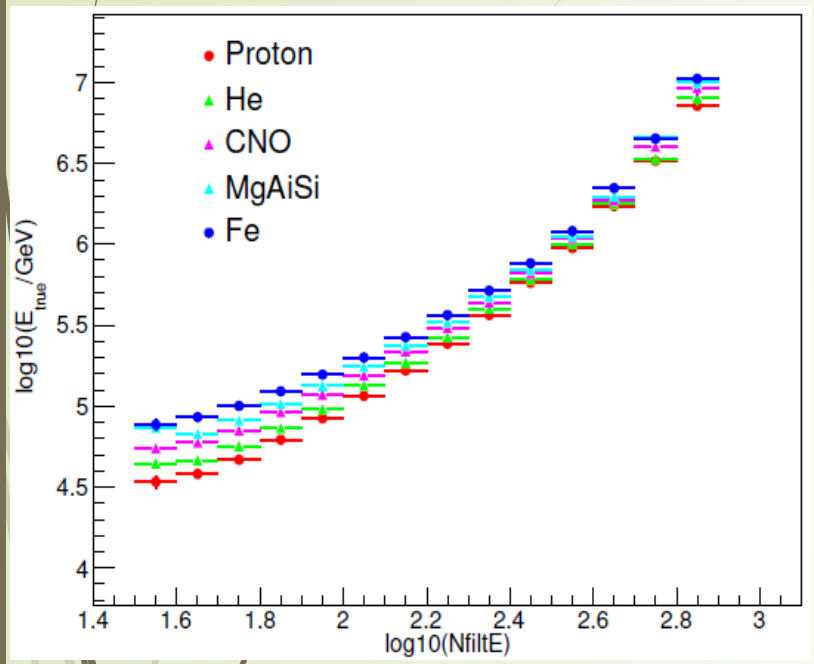
Punch-through effect

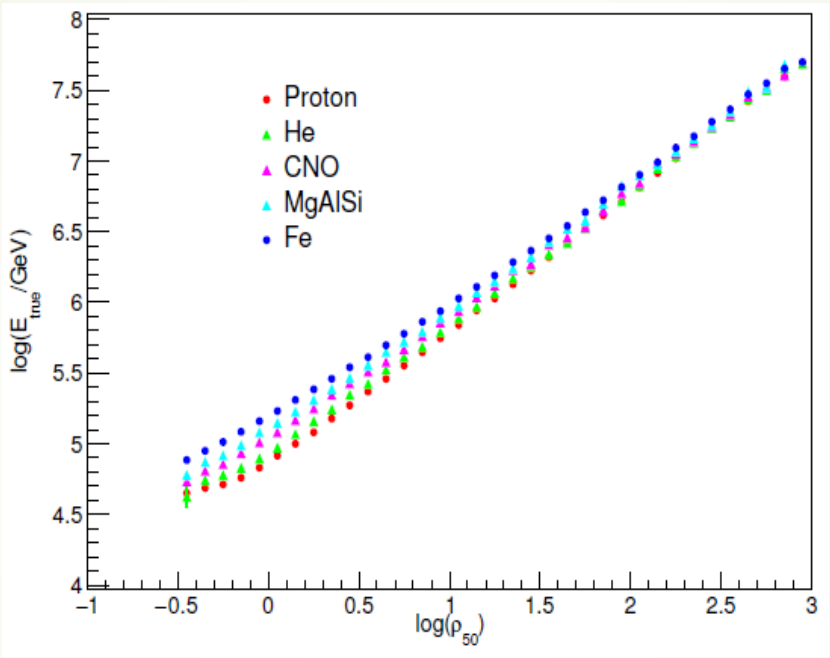


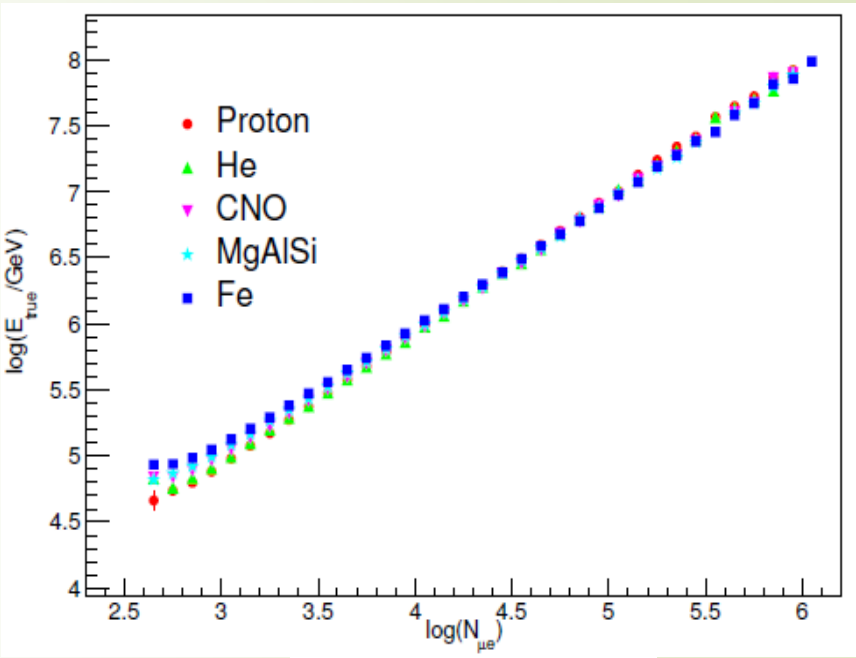








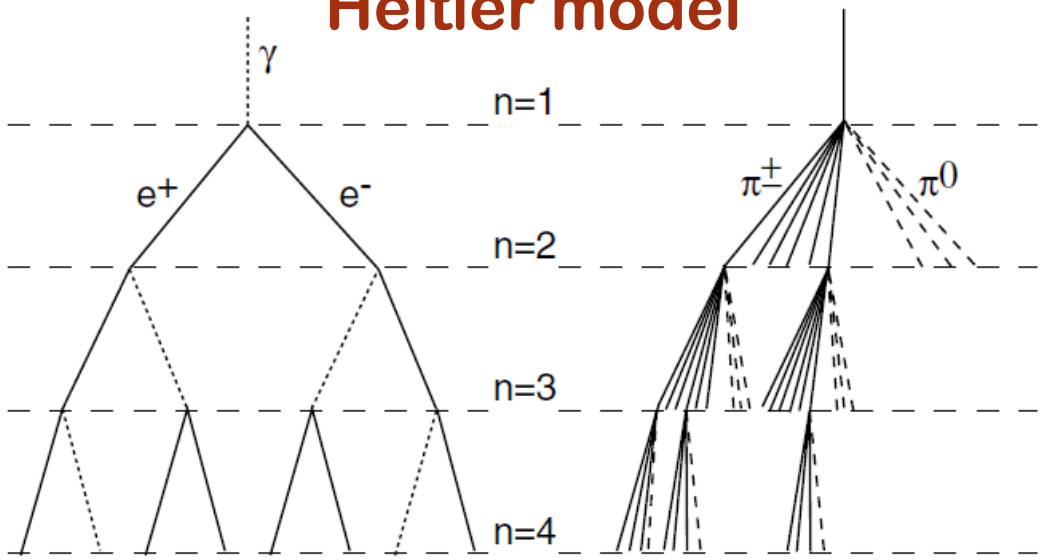




$$N_{\mu e} = \sqrt{N_{size} * N_{\mu}}$$

Energy reconstruction method 1

Heitler model



$$N_\mu = \left(\frac{E_0}{E_c^\pi}\right)^\beta A^{1-\beta} \approx 1.69 \times 10^4 \cdot A^{0.10} \left(\frac{E_0}{1\ \mathrm{PeV}}\right)^{0.90}.$$

$$N_e \approx 5.95 \times 10^5 \cdot A^{-0.046} \left(\frac{E_0}{1\ \mathrm{PeV}}\right)^{1.046}$$

$$N_e^{\max} = \frac{E_0}{gE_c^e}$$

$$N_\pi = (N_{ch})^n$$

$$E_\pi = E_0/(\tfrac{3}{2}N_{ch})^n$$

$$\frac{E_{em}}{E_0} = \frac{E_0 - N_\mu E_c^\pi}{E_0} = 1 - \left(\frac{E_0}{AE_c^\pi}\right)^{\beta-1}.$$

$$n_c = \frac{\ln E_0/E_c^\pi}{\ln \frac{3}{2}N_{ch}} = 0.85 \lg\left(\frac{E_0}{E_c^\pi}\right)$$

$$N_e = \frac{E_{em}}{gE_c^e} \approx \frac{a}{gE_c^e}\left(AE_c^\pi\right)^{-b} E_0^{1+b}$$

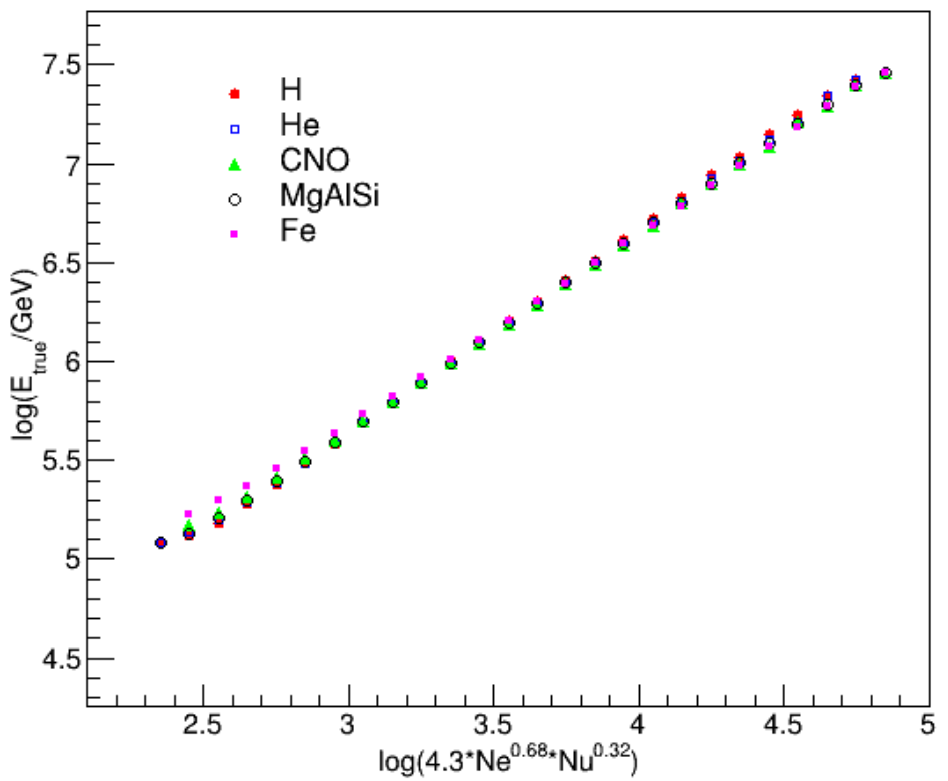
$$\ln N_\mu = n_c \ln N_{ch} = \beta \ln\left(\frac{E_0}{E_c^\pi}\right), \quad \text{with} \quad \beta = \frac{\ln N_{ch}}{\ln \frac{3}{2}N_{ch}} \approx 0.85$$

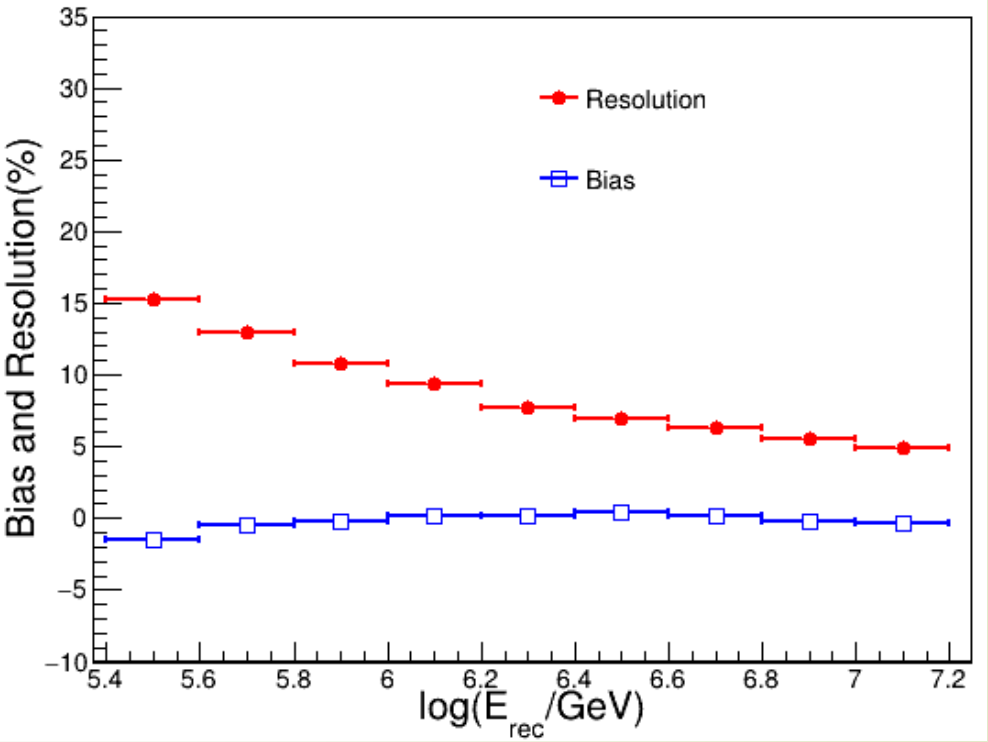
$$N_\mu = A(E_0/(AE_c^\pi))^\beta$$

Energy reconstruction method 1

$$N_{em} = N_e^{0.68} * N_\mu^{0.32}$$

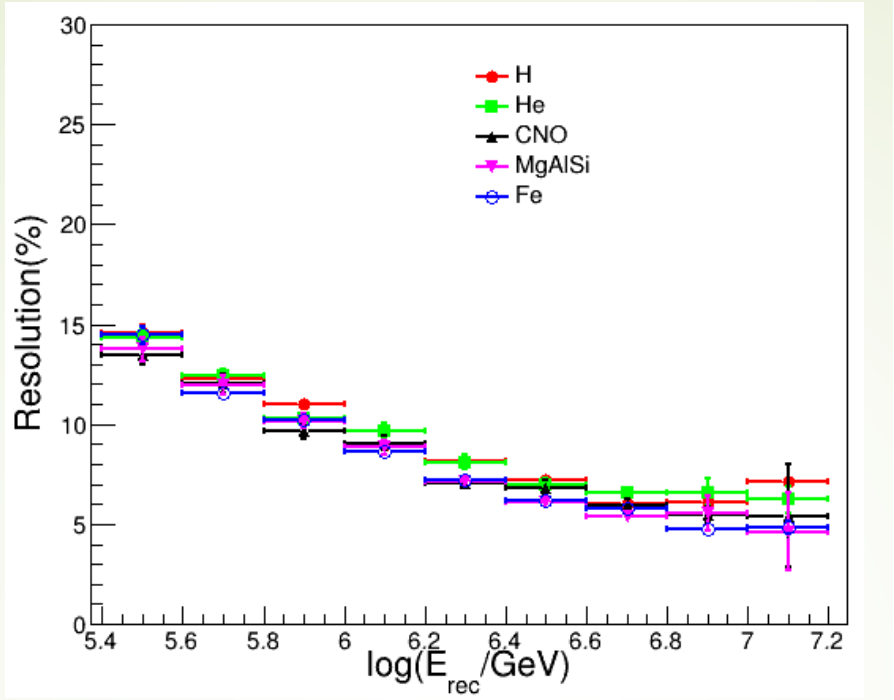
$$\log10(E)=a+b*\log10(N_{em})$$

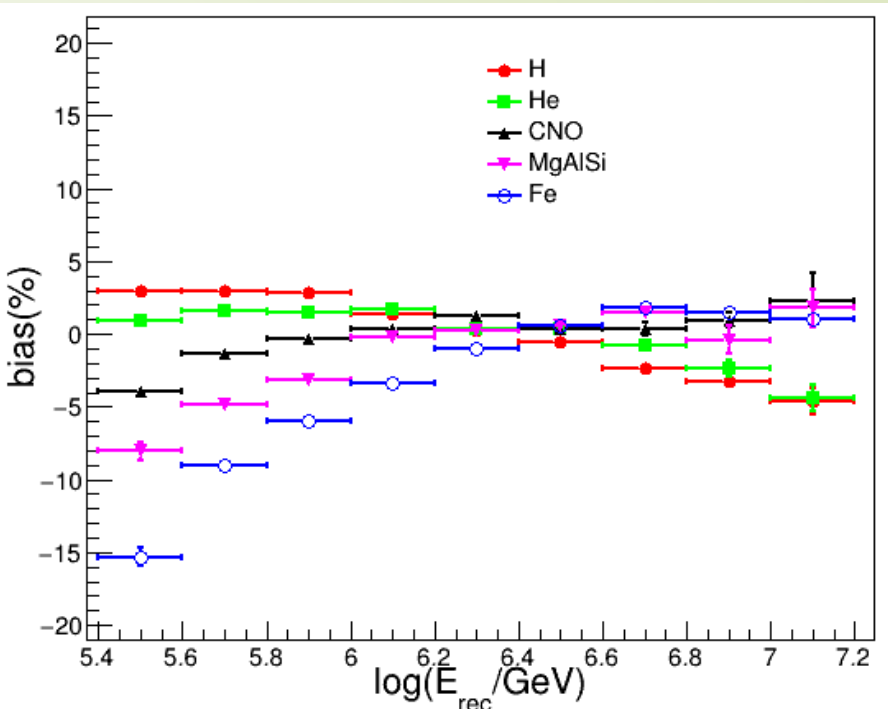




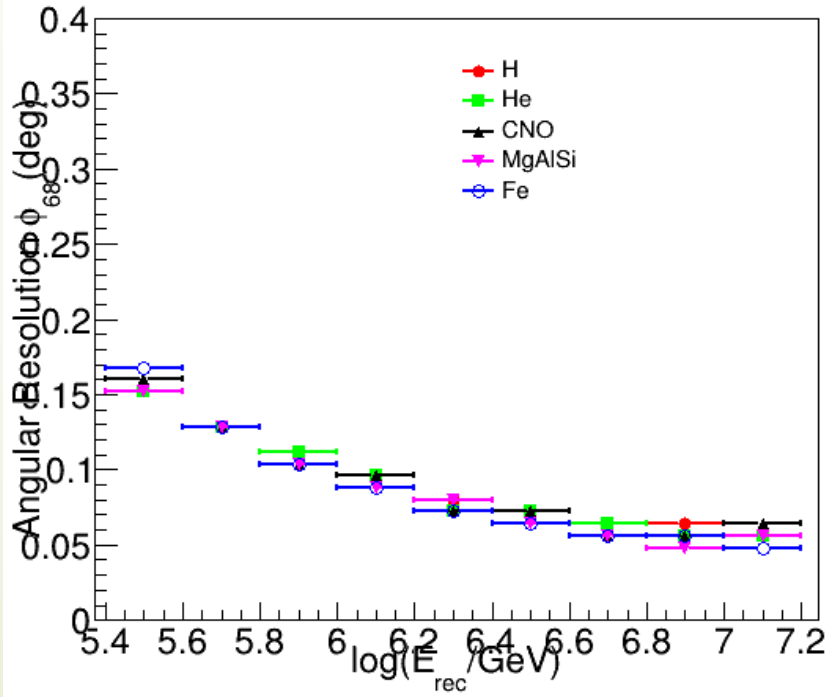
$$(E_{rec} - E_{true})/E_{true}$$

Energy resolution

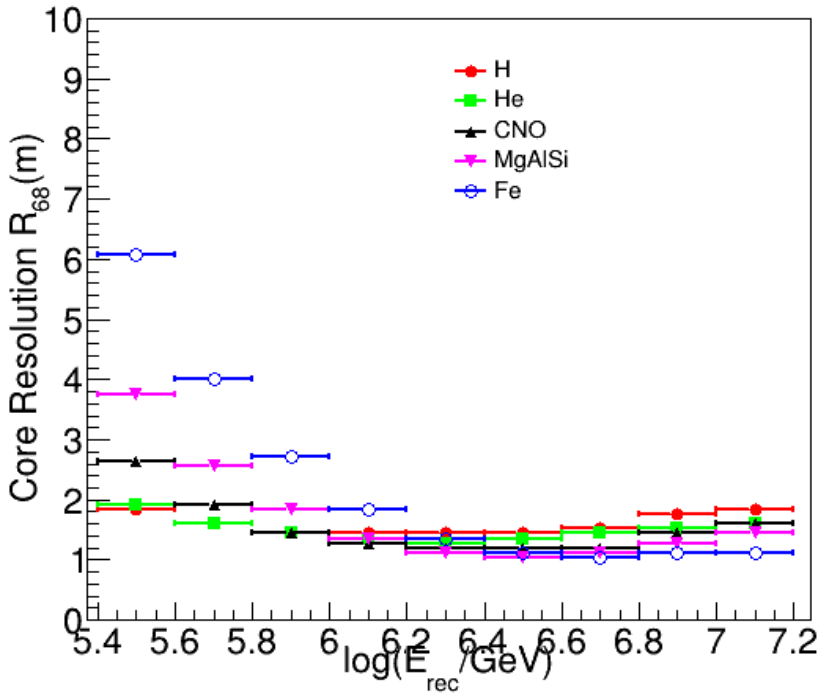




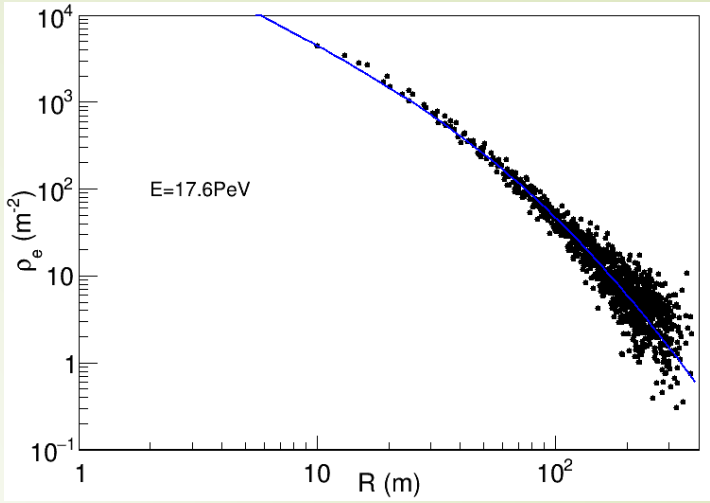
Angular Resolution

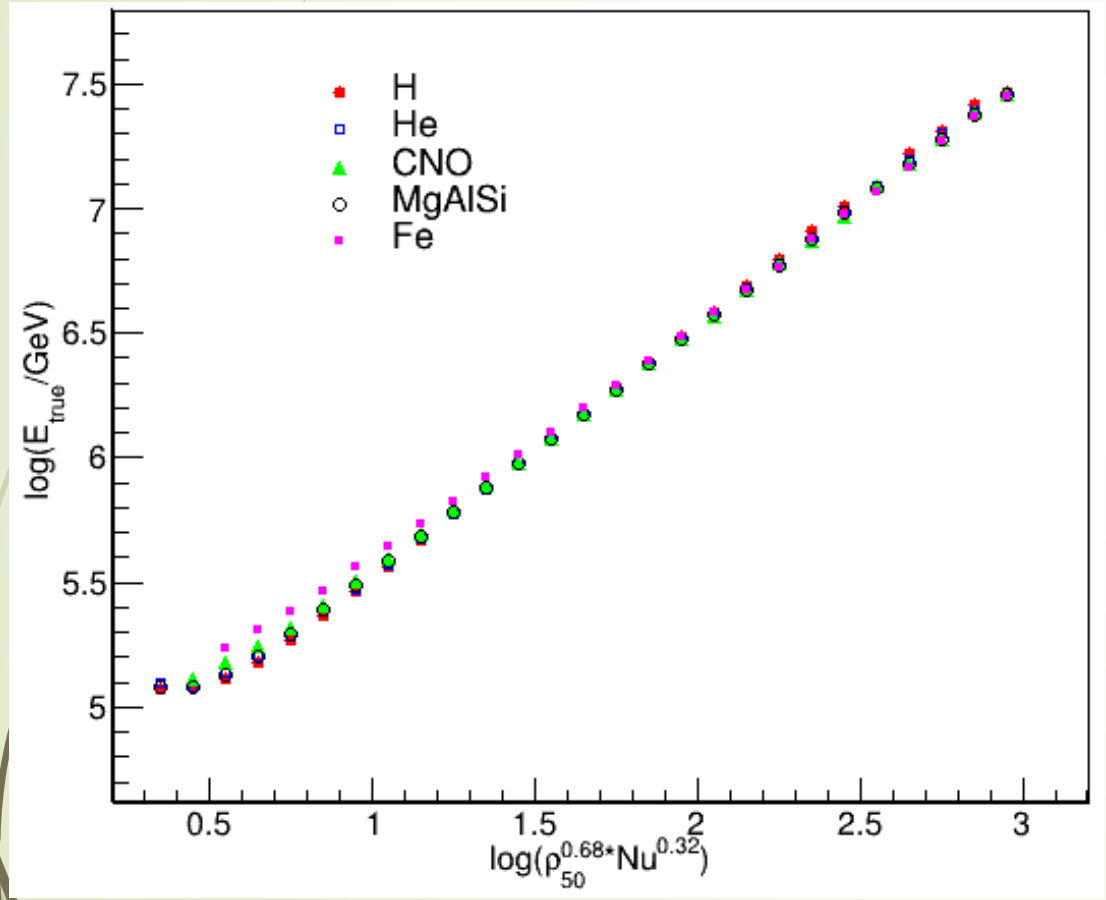


Core Resolution @68%



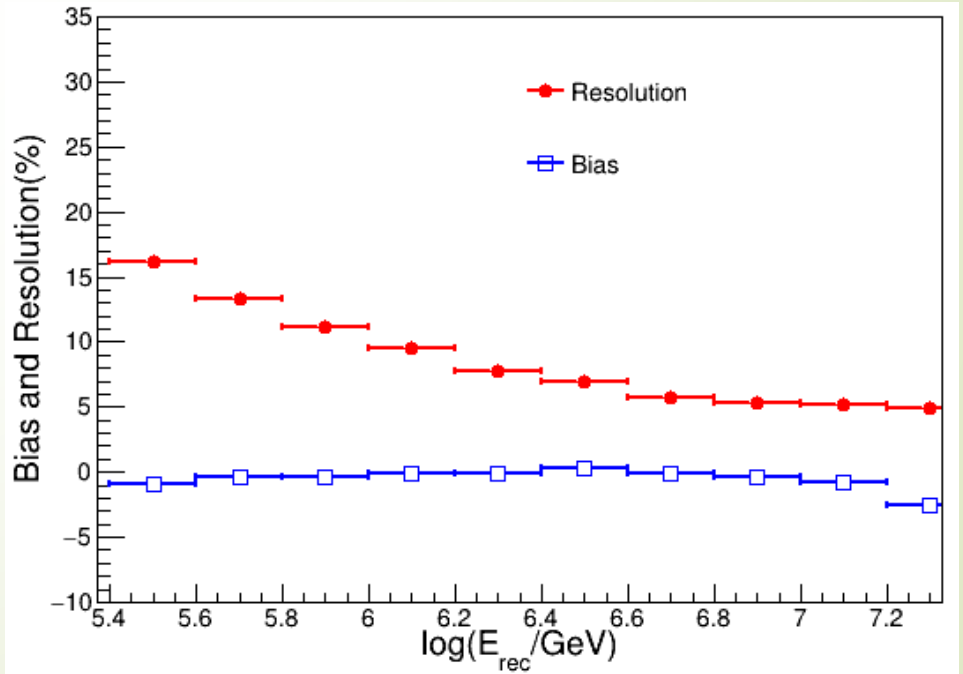
Energy reconstruction method 2



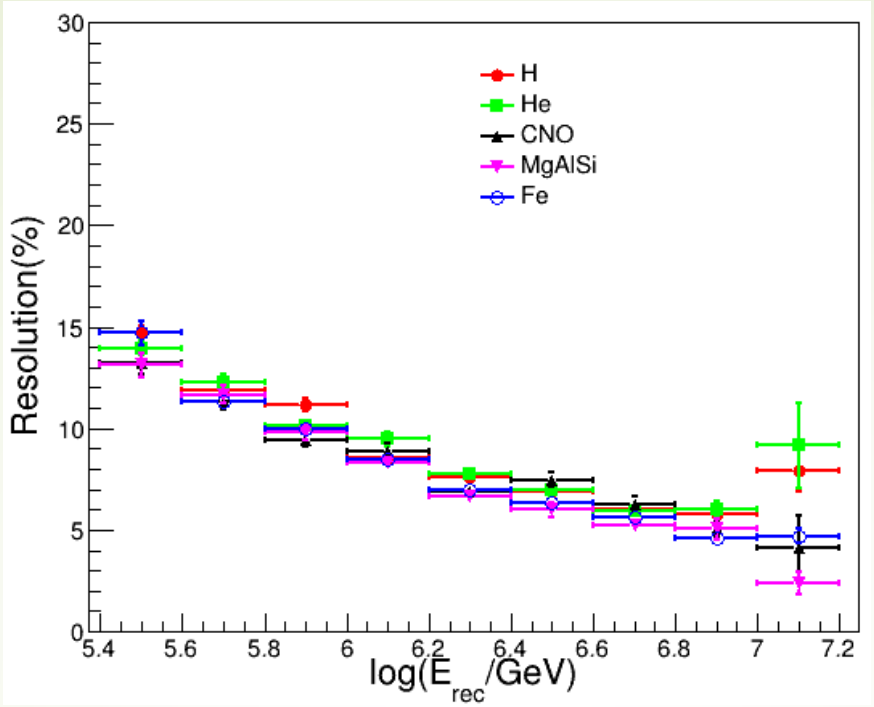


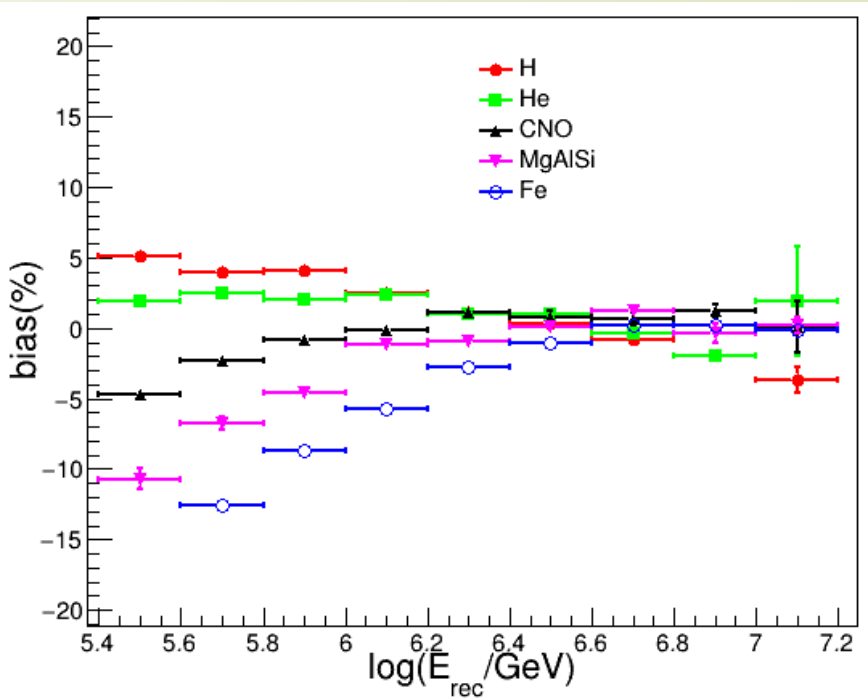
$$N_{em} = \rho_{50}^{0.68} * N_{\mu}^{0.32}$$

log10(E)=a+b*log10(N_{em})

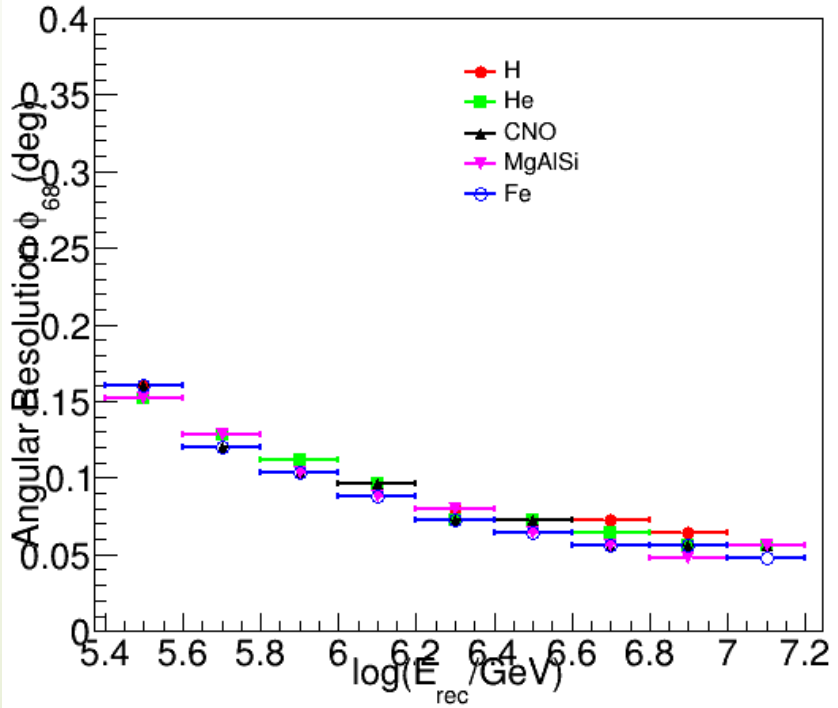


Energy resolution

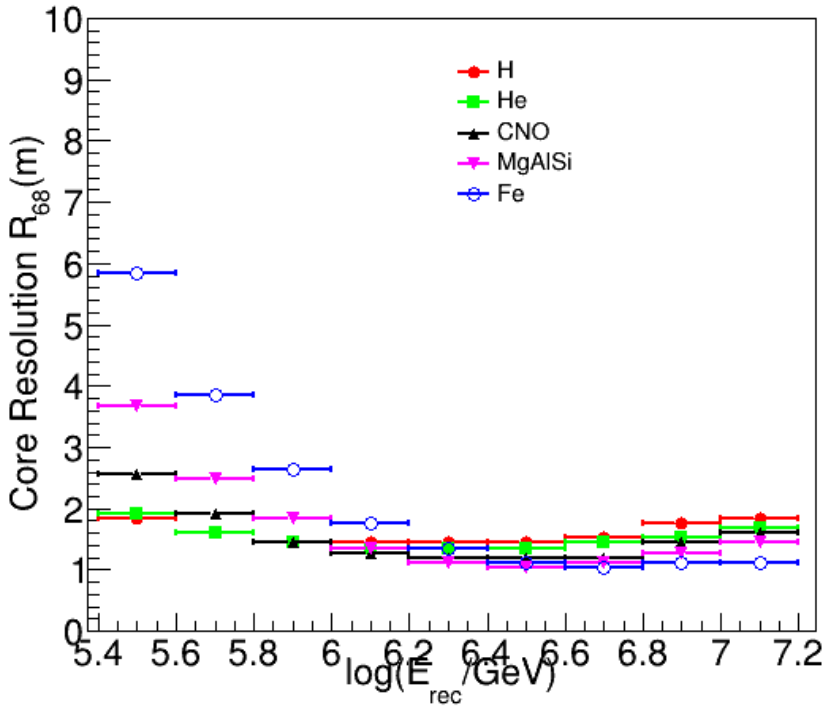




Angular Resolution



Core Resolution @68%

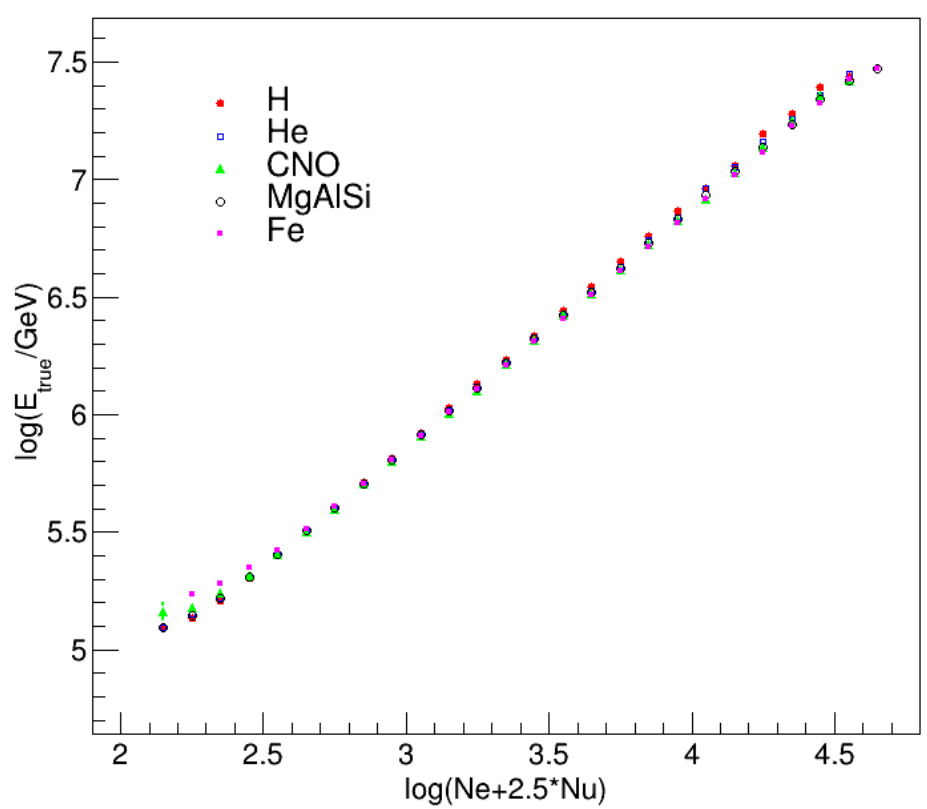


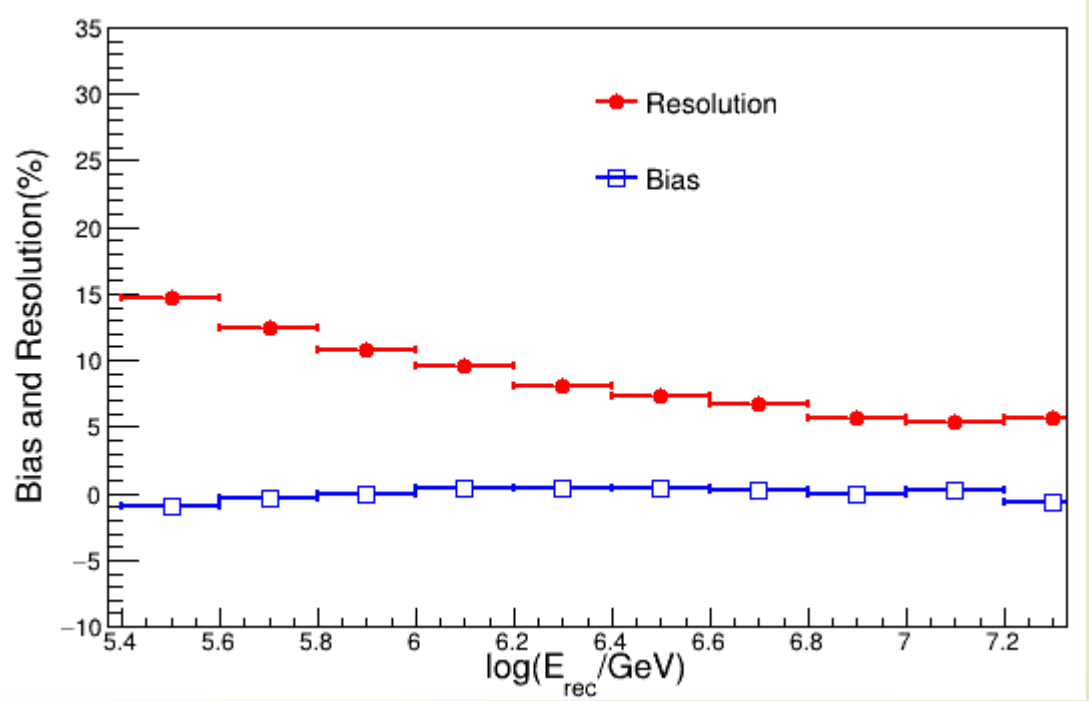
Energy reconstruction method 3

$$E_0 = E_e + E_h$$

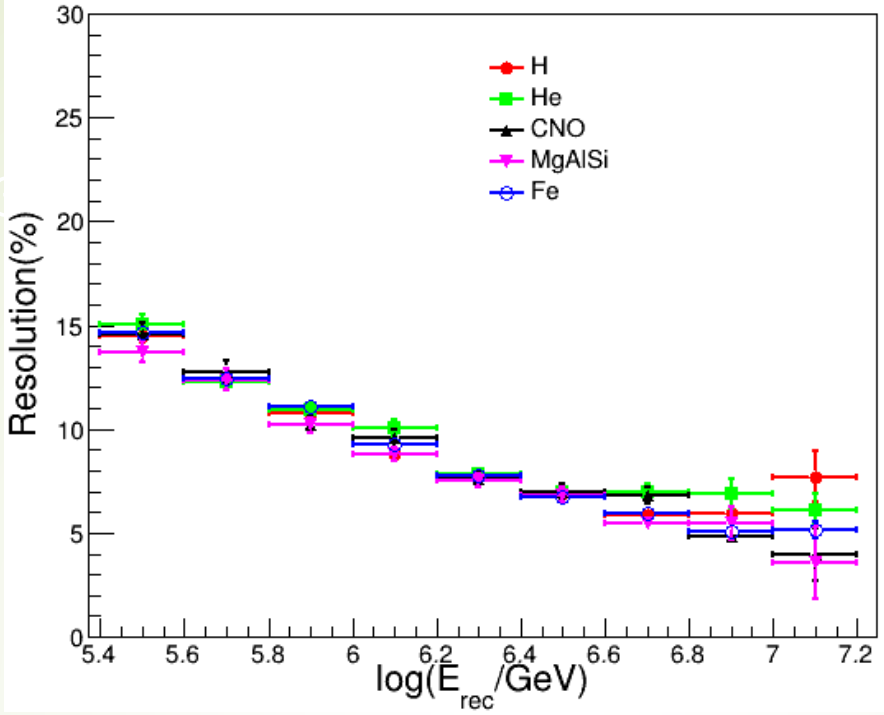
$$N_{em} = N_e + 2.5 * N_\mu$$

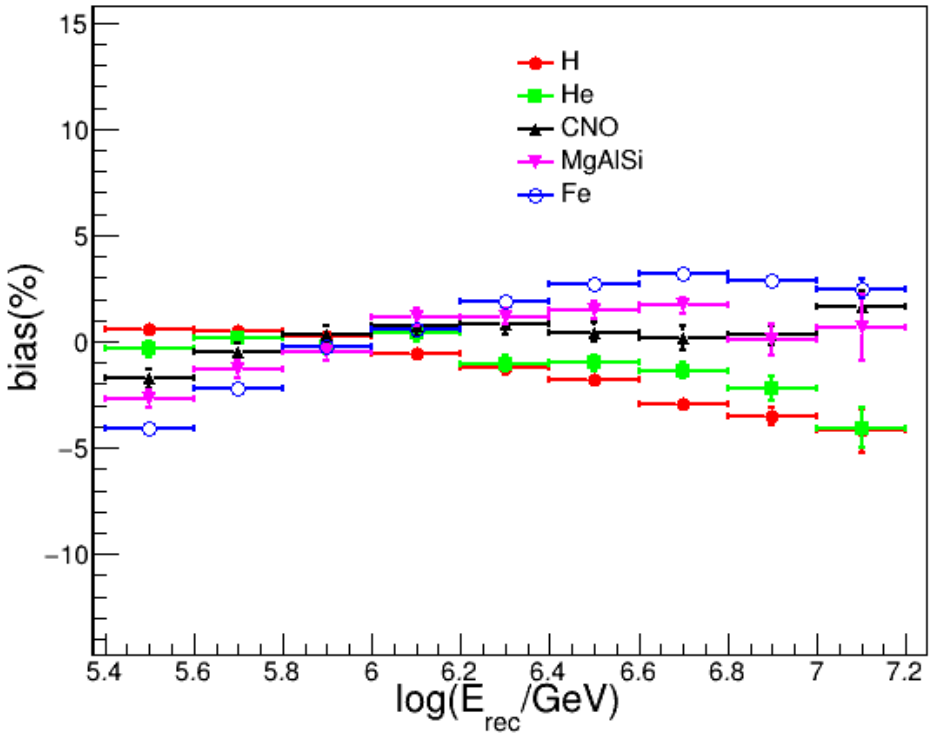
$$\log10(E)=a+b*\log10(N_{em})$$



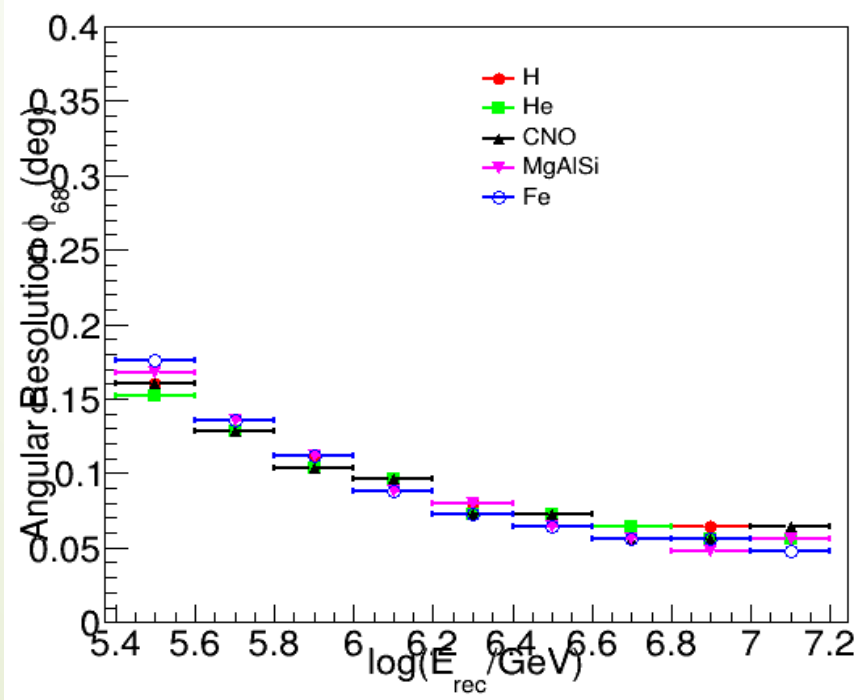


Energy resolution

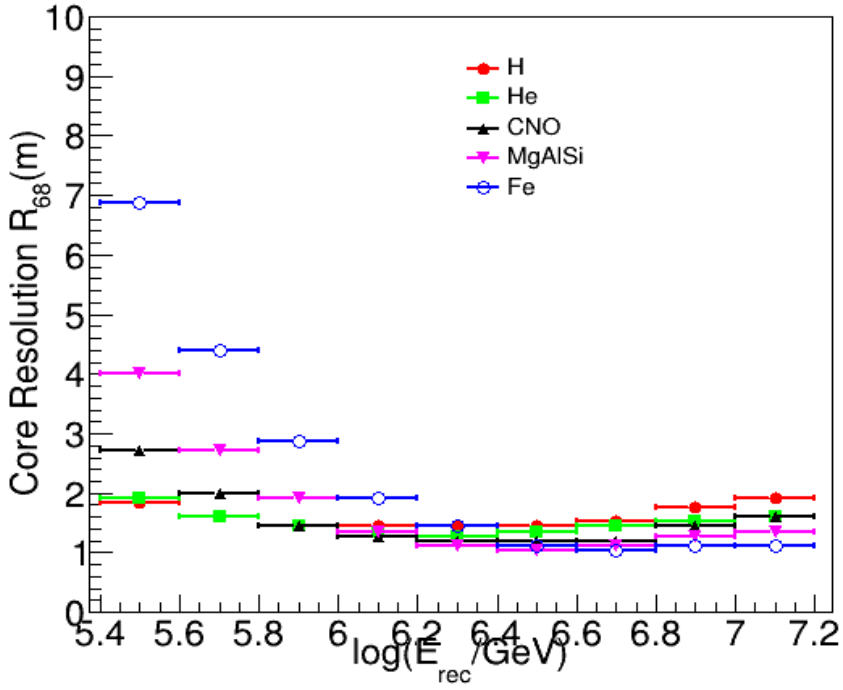




Angular Resolution

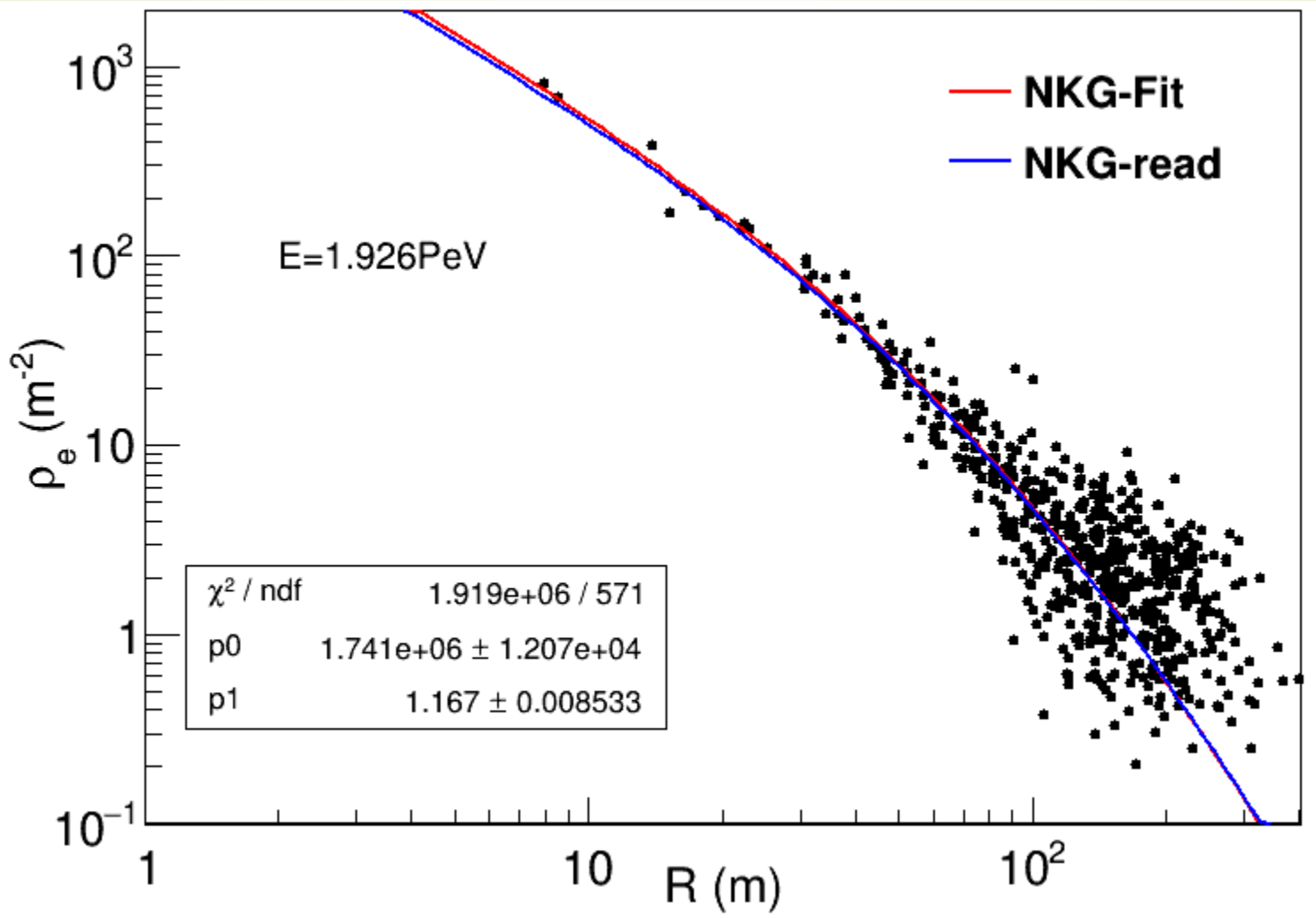


Core Resolution @68%



- ✓ A new combination of electron and muon sizes （method 3） which will be shown to be insensitive to the type of primary particle.
- ✓ The cosmic ray all-particle energy spectrum between 10^{14} to 10^{17} eV using LHAASO-KM2A full array.

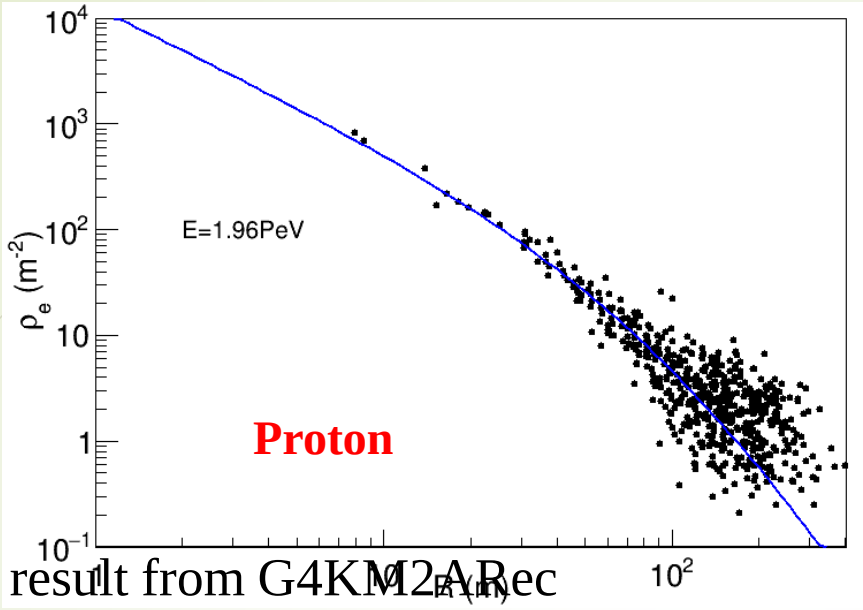
Thanks

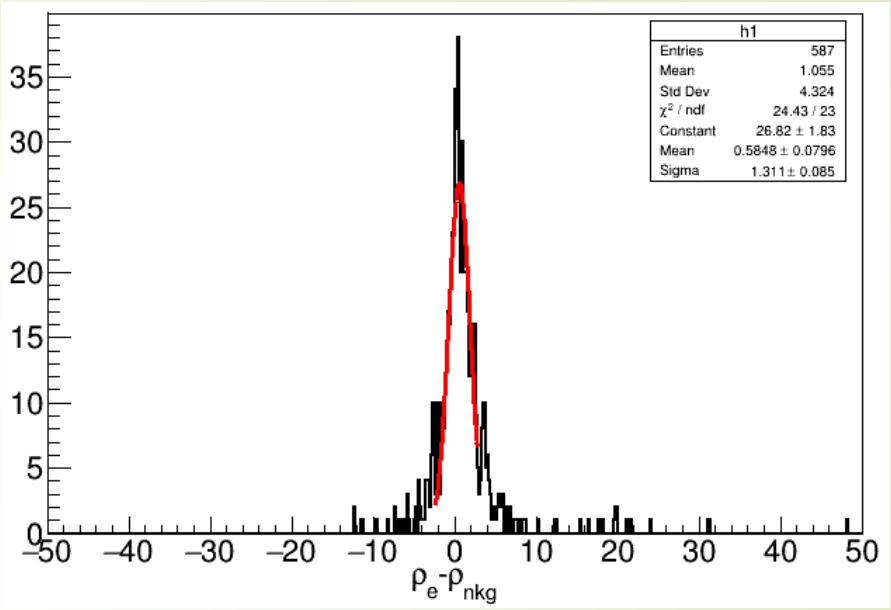

NKG-Fit
NKG-read
E=1.926PeV
χ^2 / ndf 1.919e+06 / 571
p0 1.741e+06 ± 1.207e+04
p1 1.167 ± 0.008533
ρ_e (m^{-2})
R (m)
10^3
10^2
10
1
10^{-1}
1
10
10^2

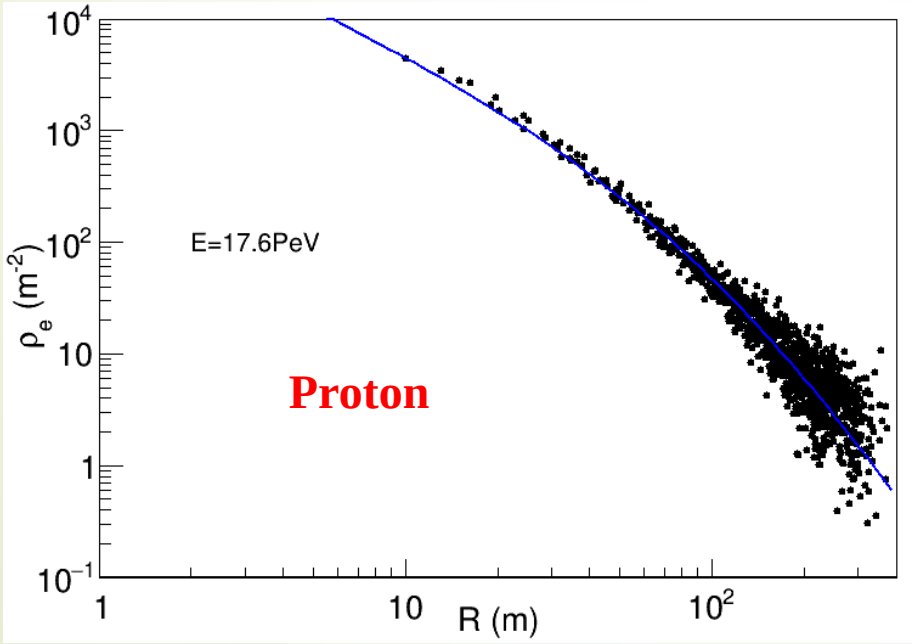
Proton

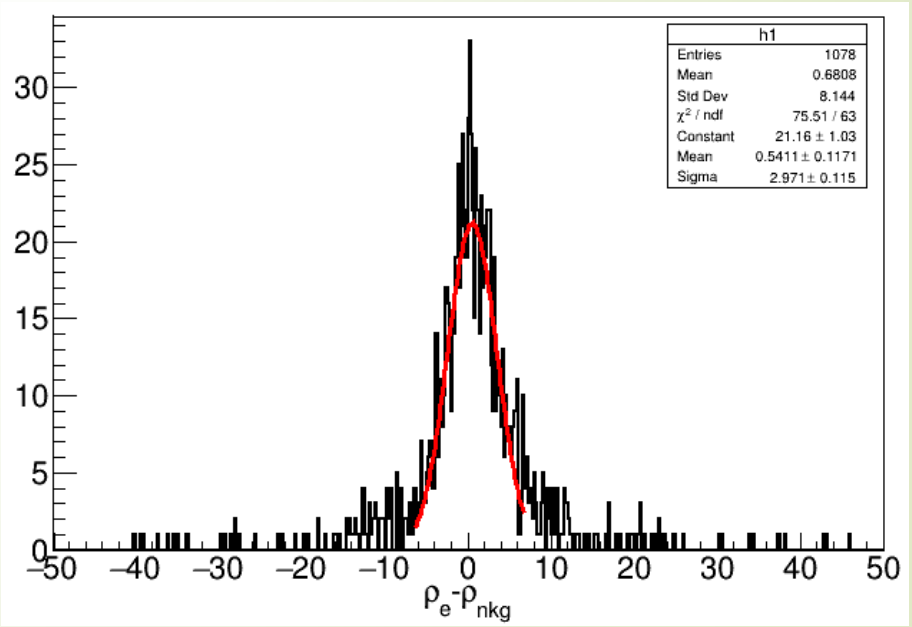
Blue line: NKG fit result from G4KM2ARec

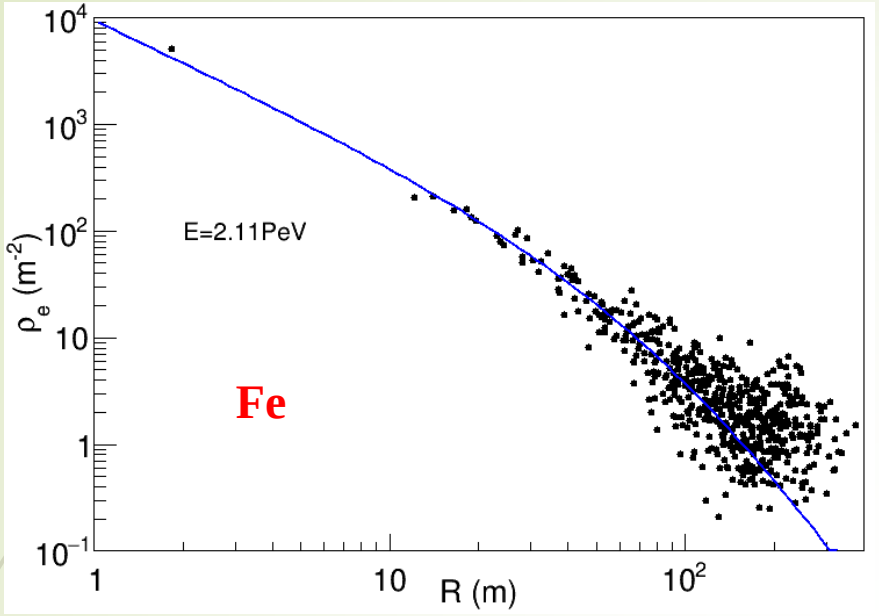
Black dot: density of one ED

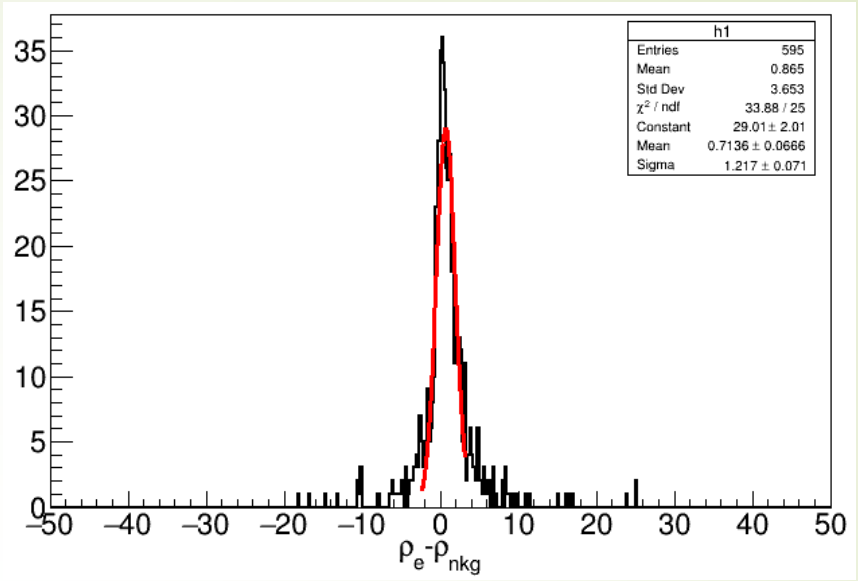


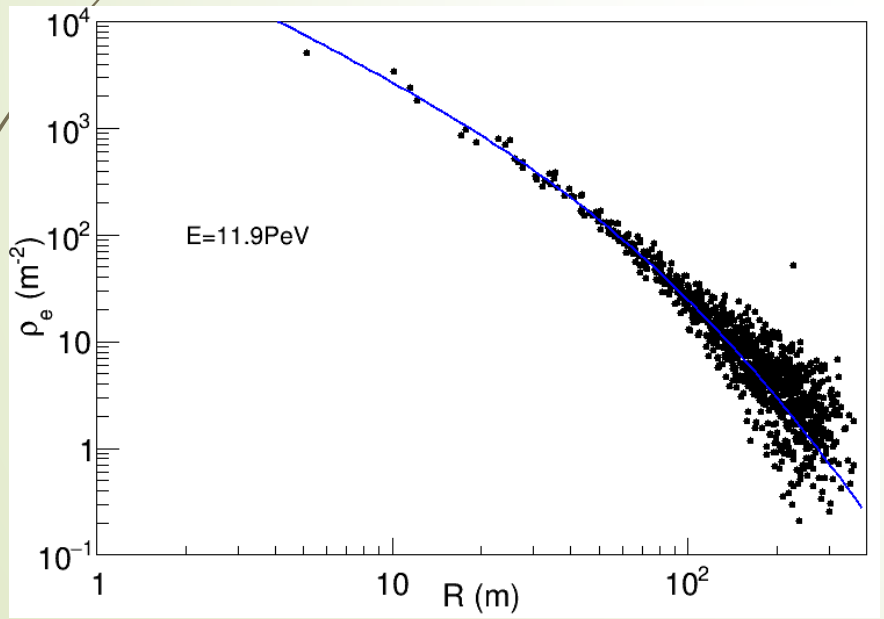


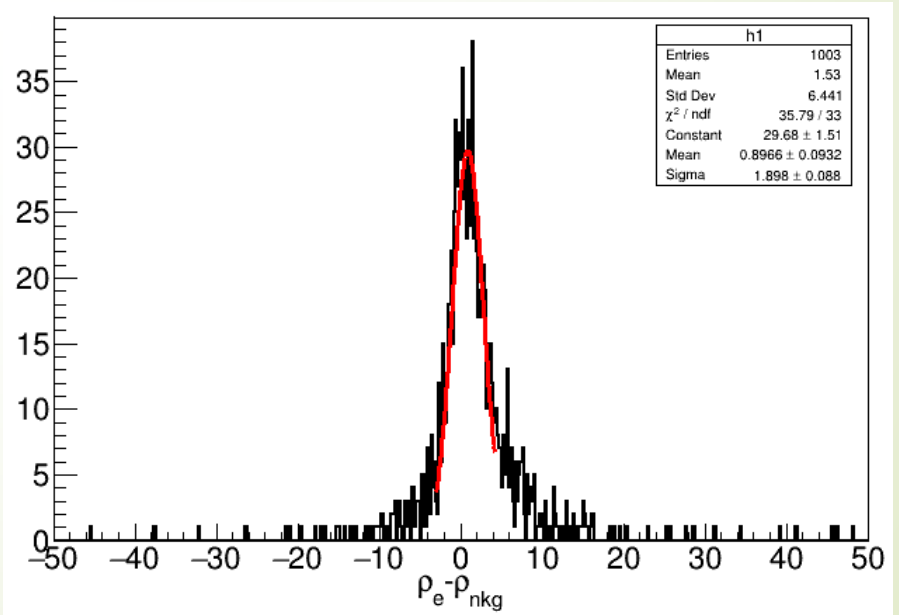





E=2.11PeV
Fe
ρ_e (m^{-2})
R (m)


h1
Entries 595
Mean 0.865
Std Dev 3.653
χ^2 / ndf 33.88 / 25
Constant 29.01 ± 2.01
Mean 0.7136 ± 0.0666
Sigma 1.217 ± 0.071
ρ_e-ρ_{nkg}


E=11.9PeV
ρ_e (m^{-2})
R (m)


h1
Entries 1003
Mean 1.53
Std Dev 6.441
χ^2 / ndf 35.79 / 33
Constant 29.68 ± 1.51
Mean 0.8966 ± 0.0932
Sigma 1.898 ± 0.088
ρ_e-ρ_{nkg}