The study of the longitude development of muons in the air shower

Liping Wang[1,2], *Lingling Ma*[2], *Cunfeng Feng*[1]

lpwang@mail.sdu.edu.cn

1Institute of Frontier and Interdisciplinary science Shandong University, Qingdao, China

2 Key Laboratory of Particle Astrop.hysics, Institute of High Energy Physics, CAS, Beijing, China

Outline

Muon production in air shower

- ✓ The main contributions to the muon component in air showers are the decay of charged pions (π^+, π^-)and kaons (K^+, K^-, K_L^0), and other charmed particles, such as $D^\pm, D^0$,J/ψ

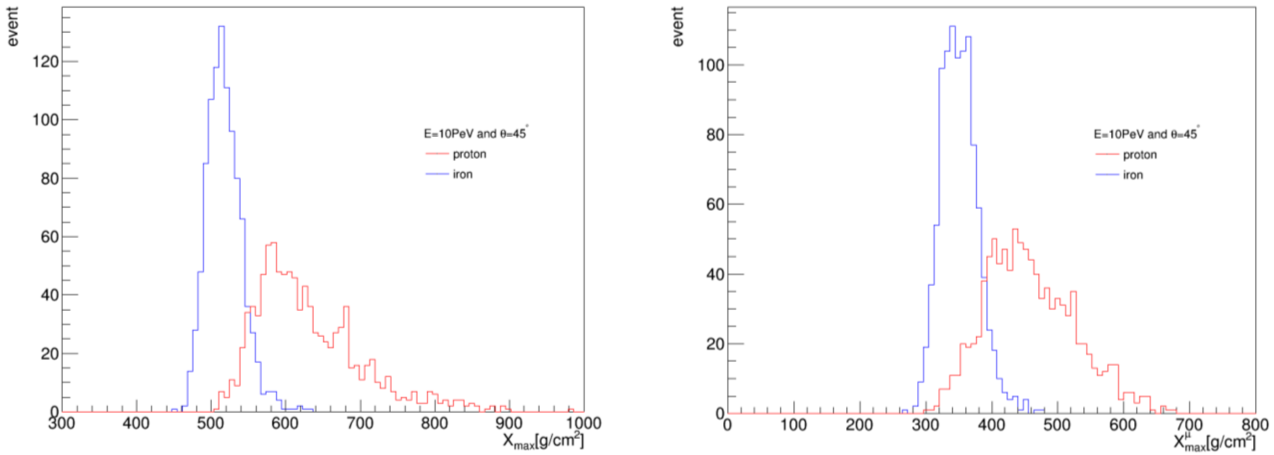
$$p + N(or\ A) \rightarrow p + N(or\ A) + n\pi^{\pm,0} + X$$

$$\pi^\pm \rightarrow \mu^\pm + (\overline{\nu_\mu})$$

- ✓ The production depth of muon can trace the positions of charged pions , so the longitude development of muons preserves the information of primary particles and plays an important role in the study of composition identification.

Purpose to study muon

- ✓ Measure the cosmic ray energy spectrum and mass composition
- ✓ Help to study the hadronic interaction models
- ✓ Provide insight on whether new physics phenomena take place



- X_{max}: the air depth of the shower maximum development
- X^μ_{max}: the depth along the shower axis where the production of muons reaches maximum

X^μ_{max} can be used to identify mass compositions of cosmic rays.

Physical Motivation

- Method 1: By tracking the trajectories of the muon
  - KASCADE-Grande (reaches up to 10^{18}eV)
- Method 2: By the arrival time of muons
  - Surface detector of Pierre Auger Observatory(reaches up to 10^{20}eV)

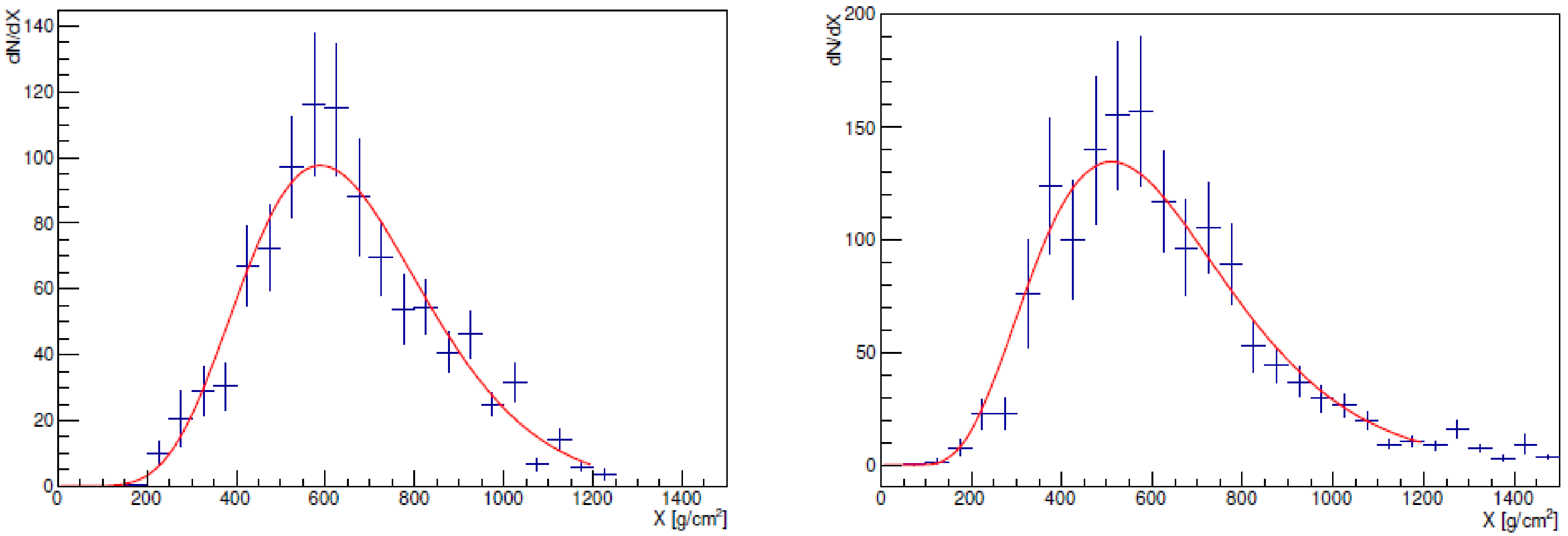
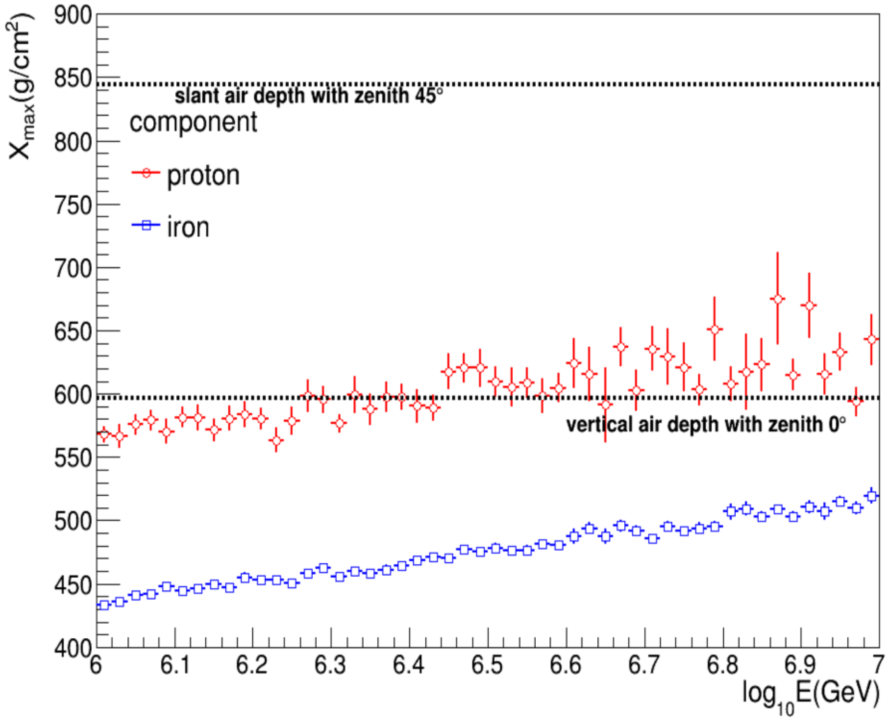


Fig. 8: Left) The reconstructed MPD distribution for a proton shower with $\theta = 48^\circ$ and $E = 10^{19.8}$ eV simulated using QGSJetII-04 model. Right) The reconstructed MPD distribution for a proton shower with $\theta = 58^\circ$ and $E = 10^{19.6}$ eV simulated using QGSJetII-04 model. The USP function fits are also shown.

We try to reconstruct the muon production depth by the arrival time of muon in 10^{16}eV

Introduction of data simulation

- **Simulation with CORSIKA (v76400)**
  - EPOS-LHC+GHEISHA
  - Altitude: 4410m (vertical air depth= $600g/cm^2$)
  - Energy: 10PeV; 5PeV; 1PeV
  - Zenith angle(θ): fixed 45°
  - MUPROD: additional information of muon

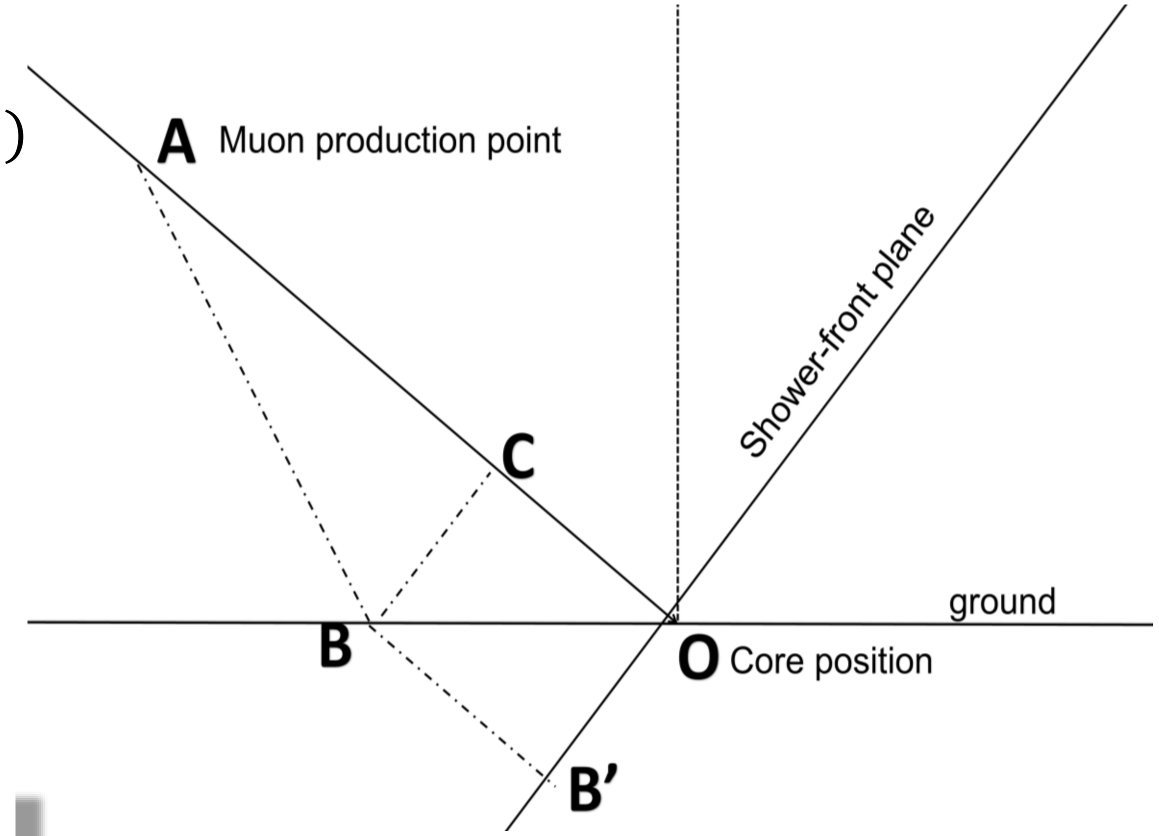


Number of shower	10PeV	5PeV	1PeV
Proton	1000	2000	2000
Iron	1000	2000	2000

*** In order to ensure the shower full development, the zenith angle is selected as 45°**

Reconstruction method of Muon Production Depth(MPD)

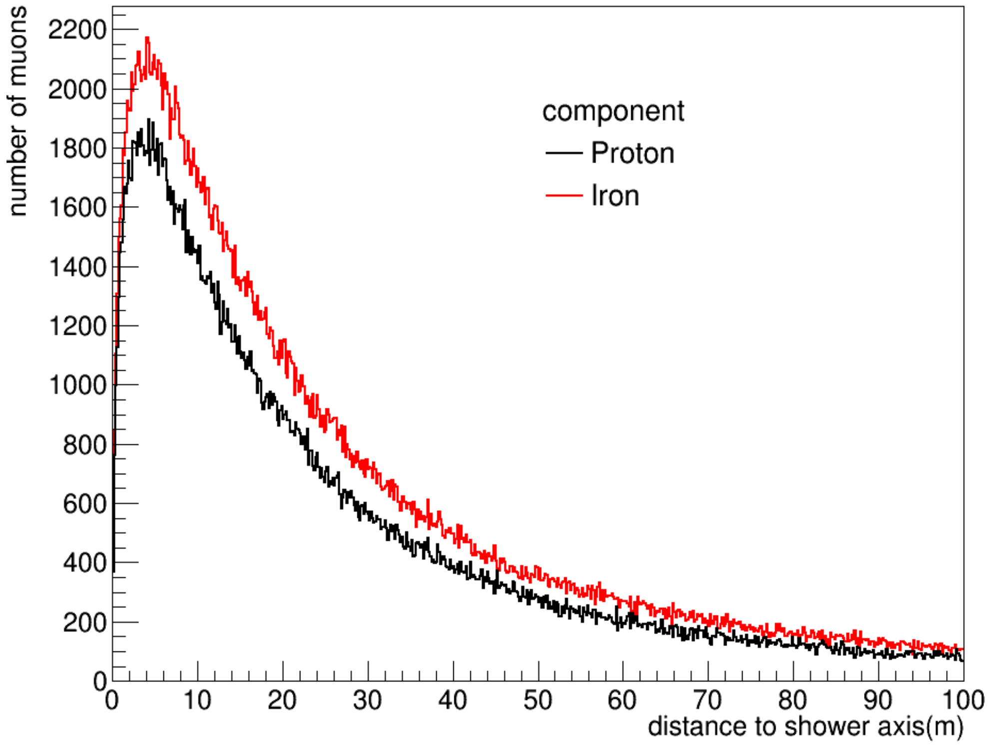
- Considering geometric delay as :$t_g = (t_{AB} - t_{AC})$
- $\overline{AB} = \sqrt{\overline{BC}^2 + (\overline{AO} - \overline{BB'})^2}$
- $\overline{AB} = \overline{AC} + c \times t_g$
- Correction by the path traveled by the parent mesons :$t_\pi \sim 3ns$

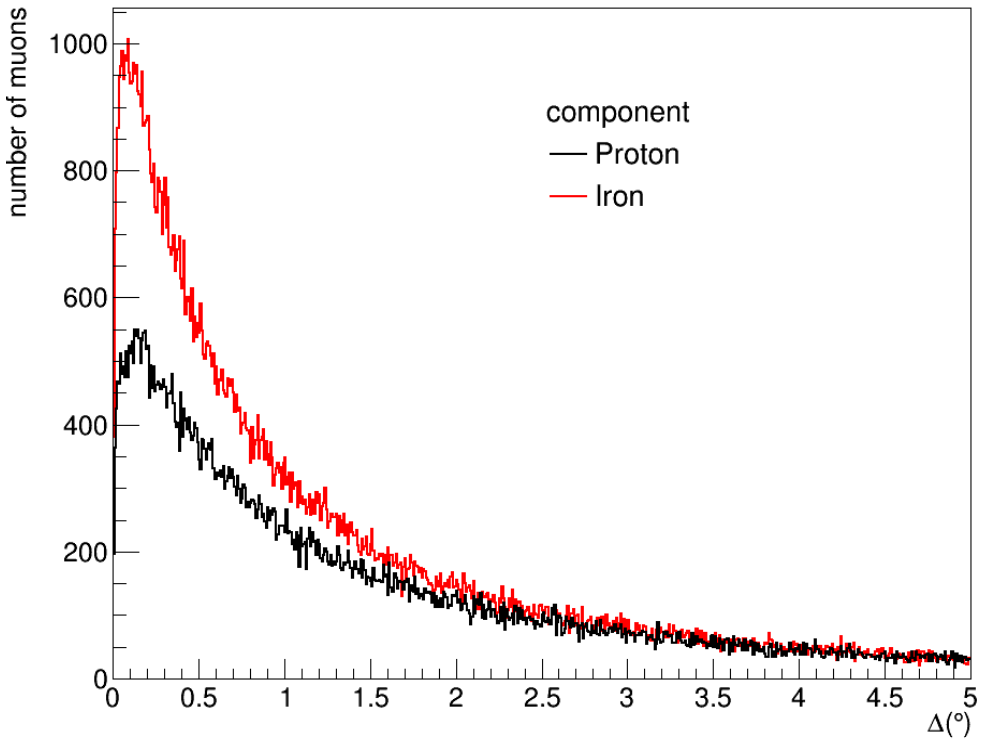


$$\overline{AO} = \frac{1}{2}\left(\frac{\overline{BC}^2}{c\times(t_g)} - c \times (t_g)\right) - c \times t_\pi$$

- The muons are produced on the shower axis
- Muons travel in straight lines at the speed of light c
- Geometric delay is dominant

Reconstruction method of Muon Production Depth(MPD)

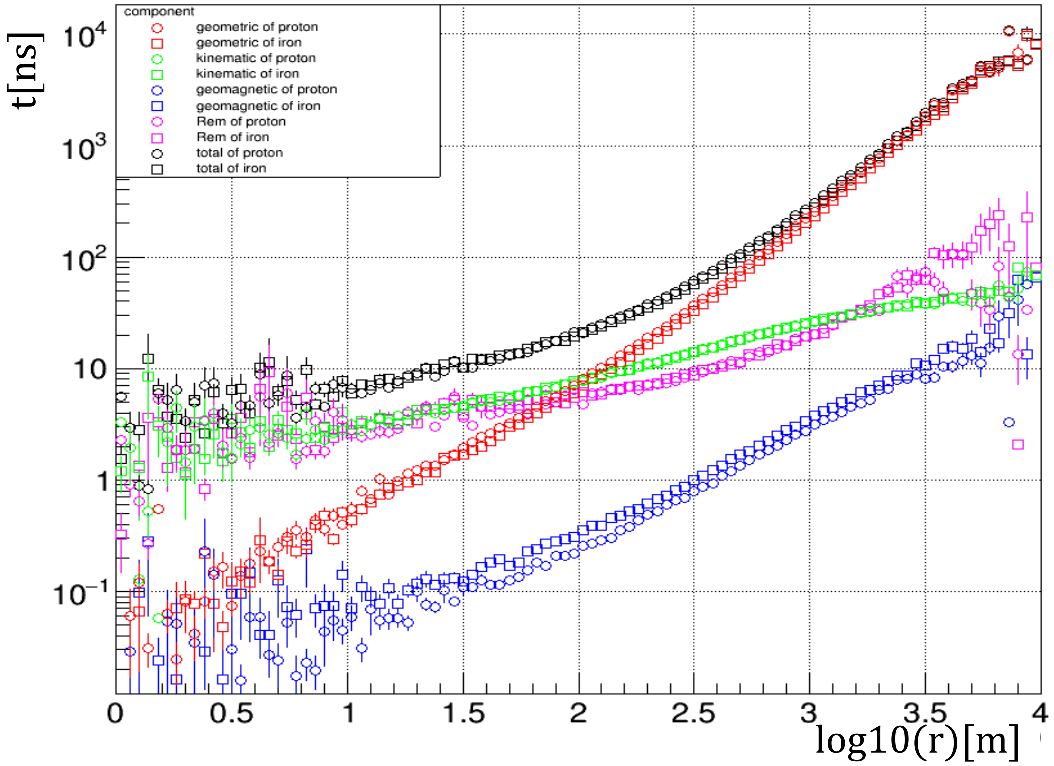




* most muons have small distance to shower axis and also lie within small Δ° (The angular difference between the production and incidence at the ground)

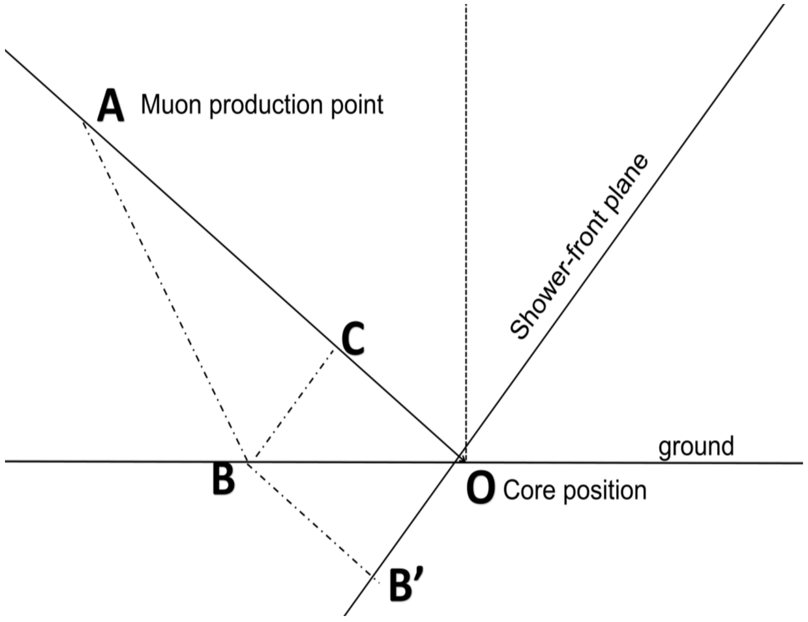
✓ **Approximation: The muons are produced on the shower axis and travel in straight lines**

Reconstruction method of Muon Production Depth(MPD)



r: distance from muon position to core on SFP

- $\mathbf{t_{total}}$: total(measurement) time delay
- $\mathbf{t_g}$: geometric delay
- $\mathbf{t_\epsilon}$: kinematic delay
- $\mathbf{t_B}$: geomagnetic delay
- $\mathbf{t_{Rem}}$: multiple scattering

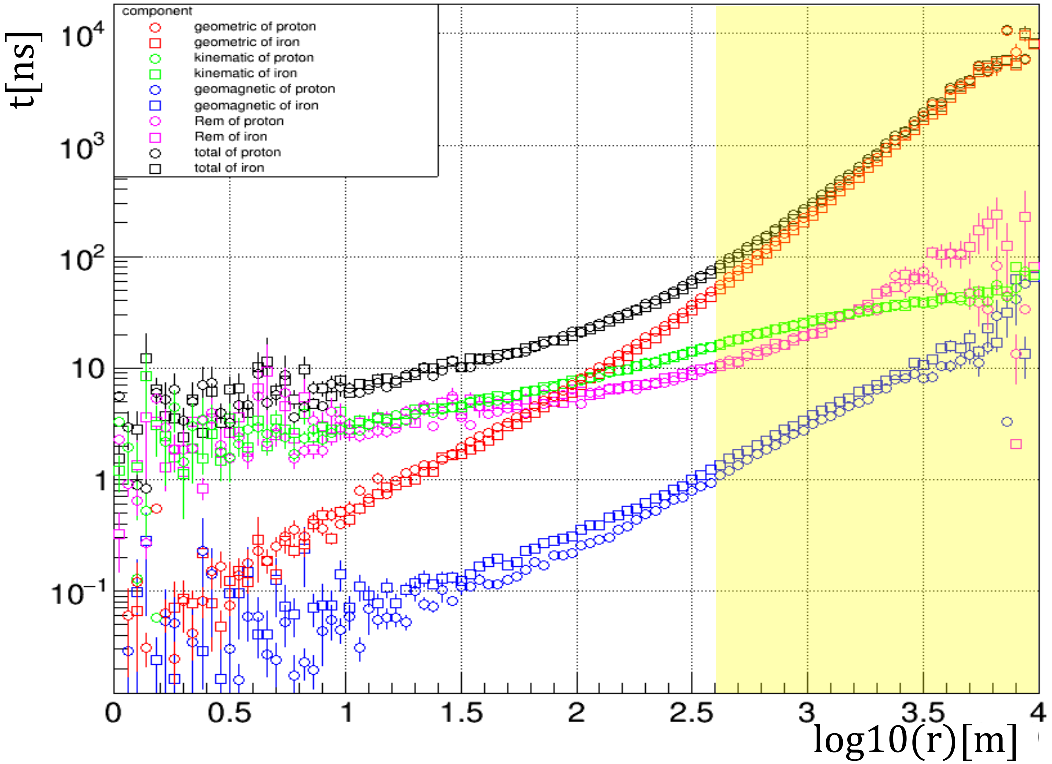


✓ **The geometric delay is dominant($v_\mu \approx c$)**

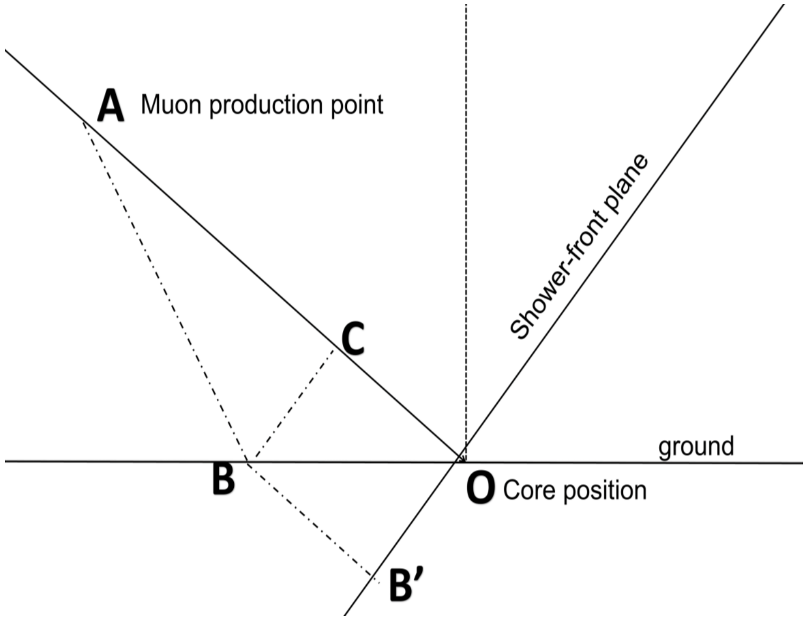
* $t_B + t_{Rem} < t_{total} \times 10\%$ when r>400m($10^{2.6}$)

* t_g is dominant when r>400m

Reconstruction method of Muon Production Depth(MPD)



- t_{total}: total(measurement) time delay
- t_g: geometric delay
- t_ϵ: kinematic delay
- t_B: geomagnetic delay
- t_{Rem}: multiple scattering



r: distance from muon position to core on SFP

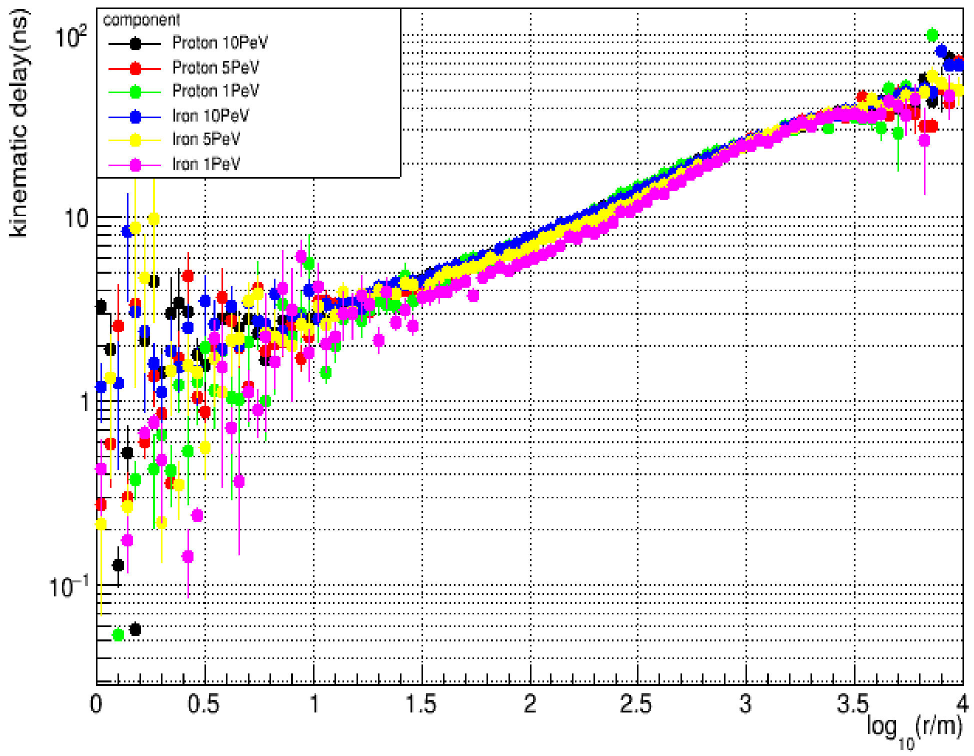
✓ **The geometric delay is dominant($v_\mu \approx c$)**

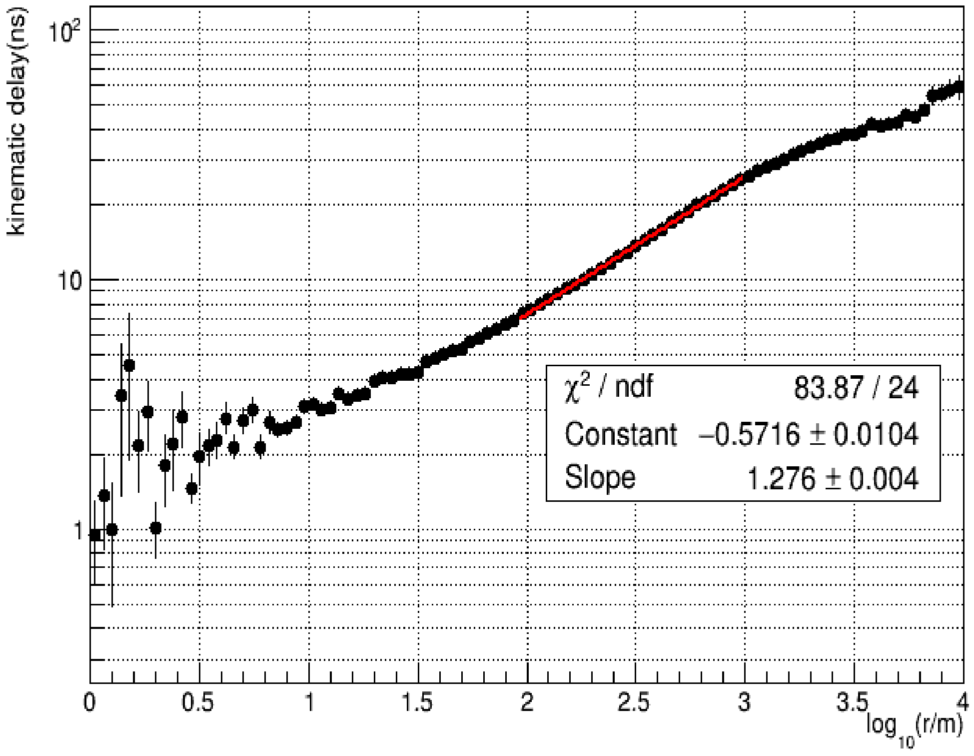
* $t_B + t_{Rem} < t_{total} \times 10\%$ when r>400m($10^{2.6}$)

* t_g is dominant when r>400m

Reconstruction method of Muon Production Depth(MPD)

◆ Correction for t_g



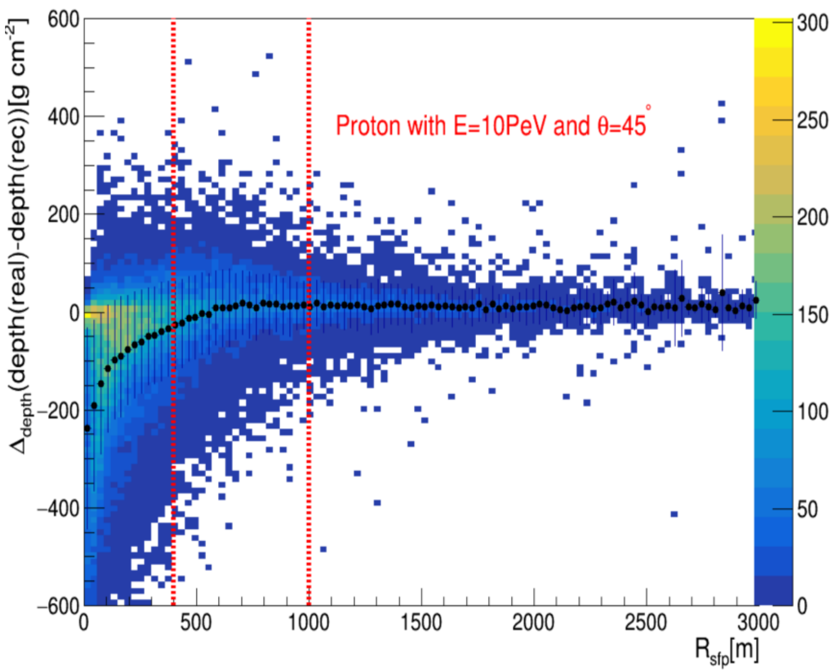


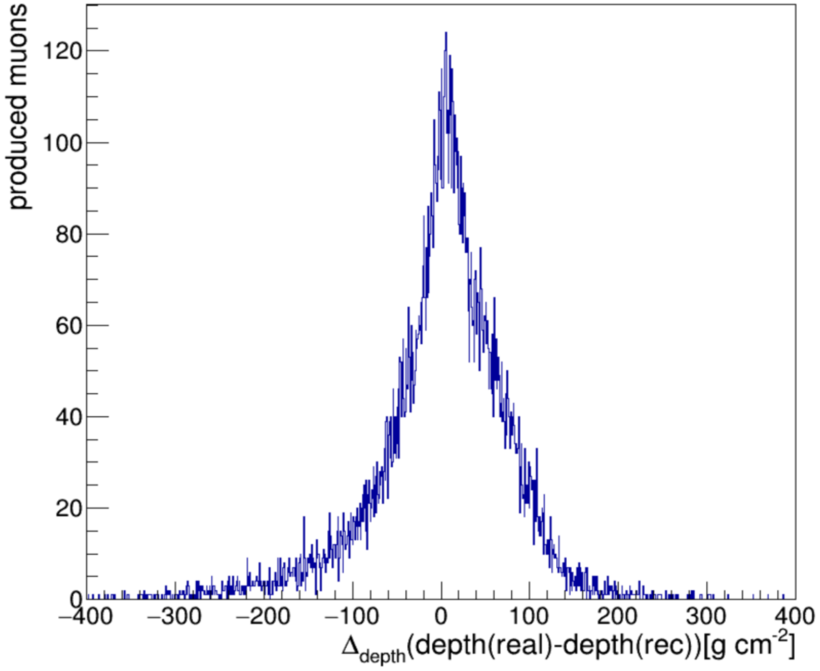
- The relationship between the t_ϵ and r of different primaries with different energy is similar
- The relationship between t_ϵ and r of different compositions and energies can be fitted with an exponential function:

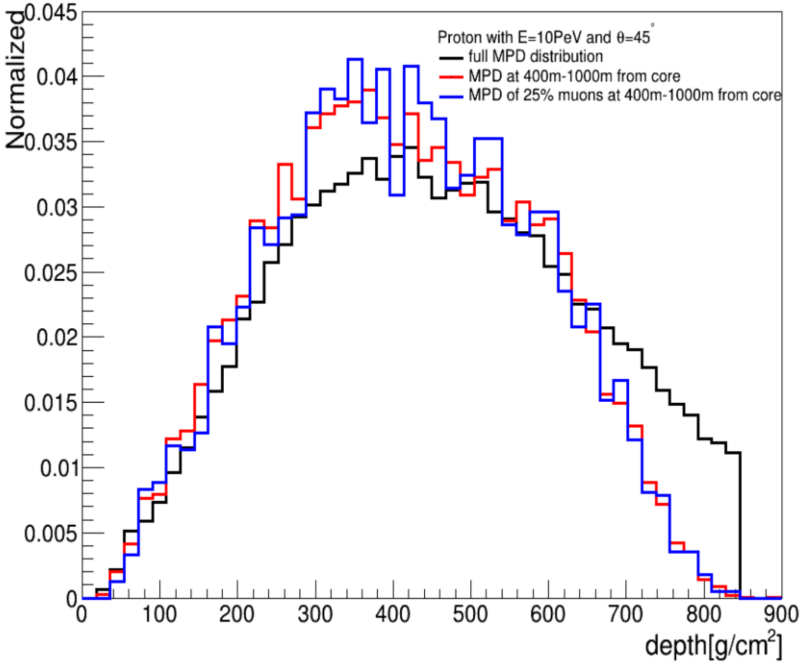
$$t_\epsilon = \exp(-0.57 + 1.276 \times log_{10}(r))$$

✓ $t_g = t_{total} - t_\epsilon$

◆ Fit the longitudinal profile of the muon



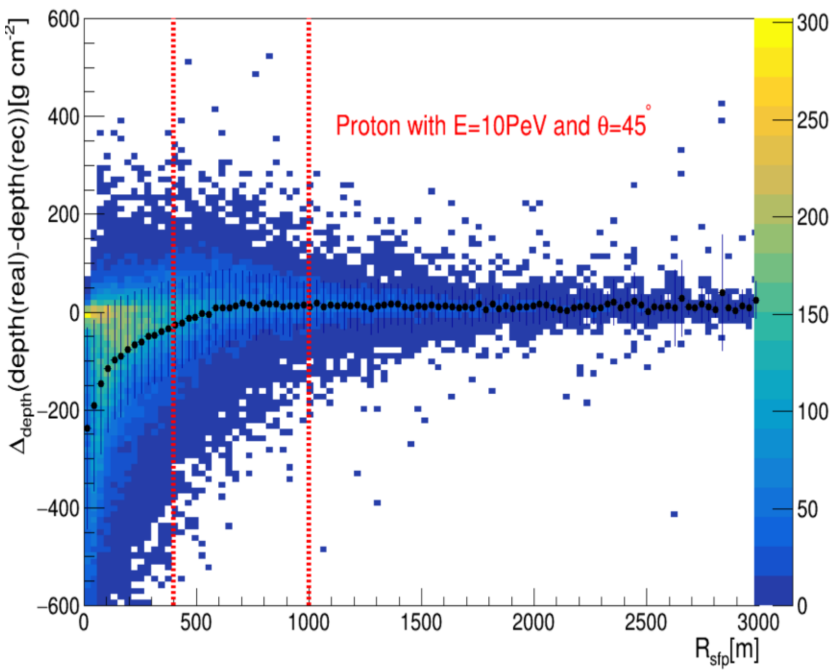


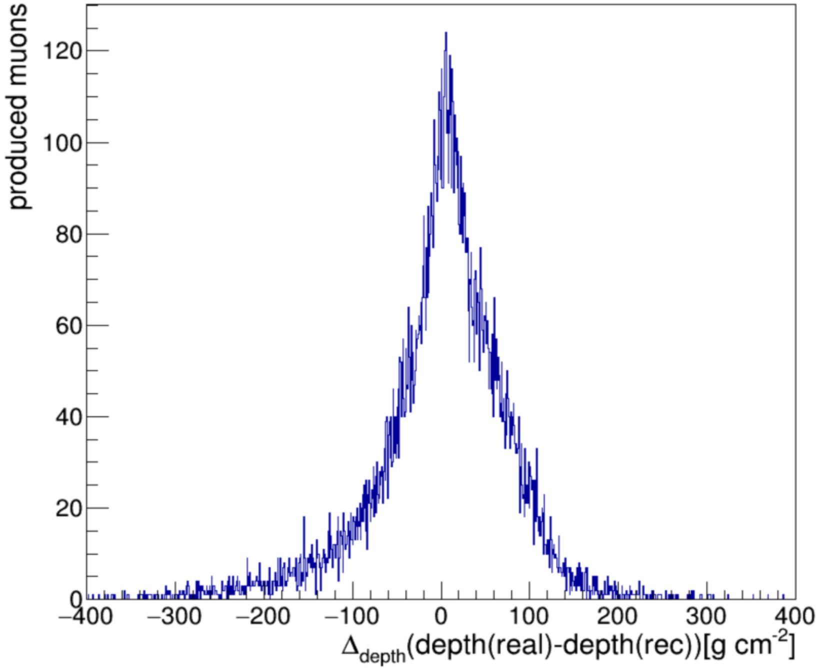


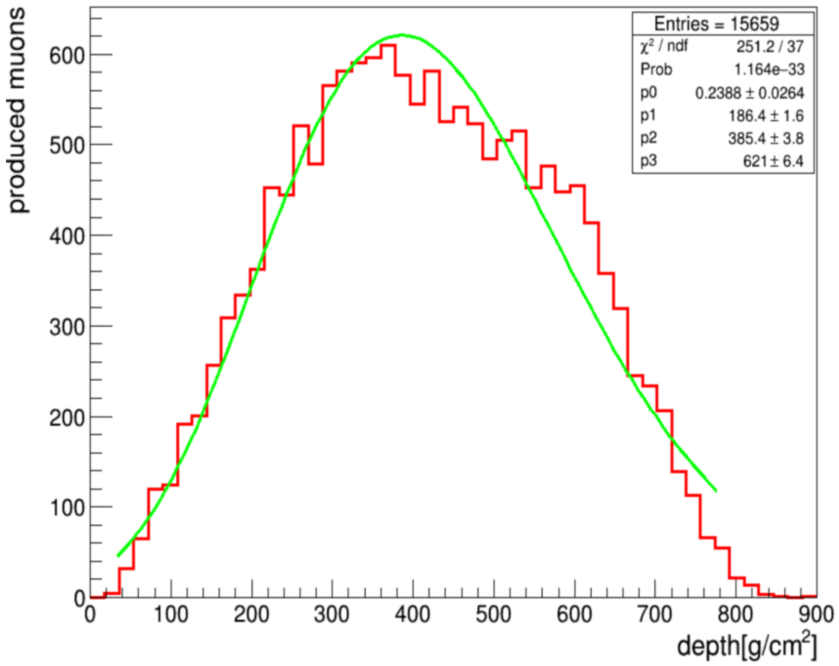
- The differences between the MPD distributions at different distance to the core and different coverage are small

Features of the muon profiles

- Fit the longitudinal profile of the muon

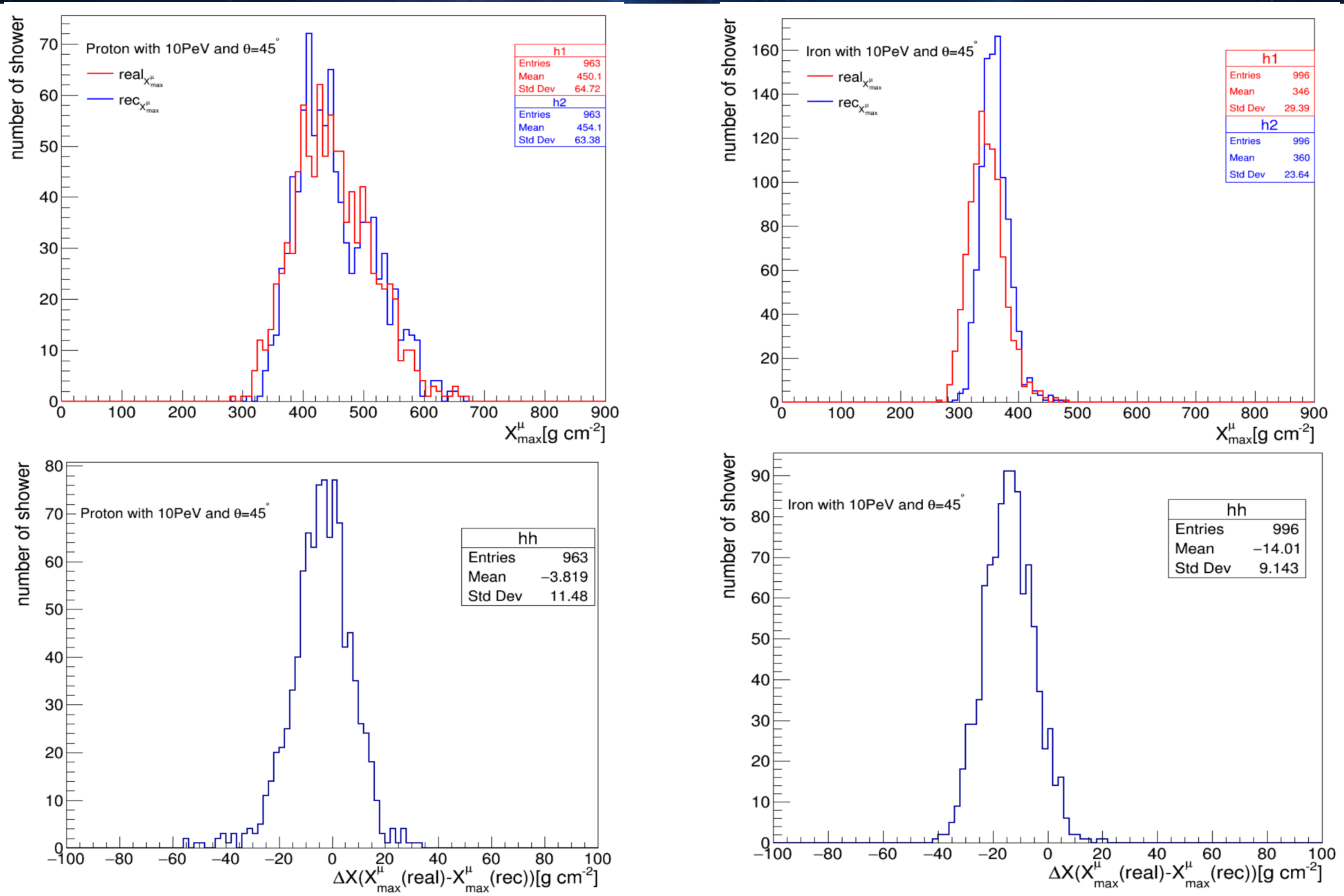




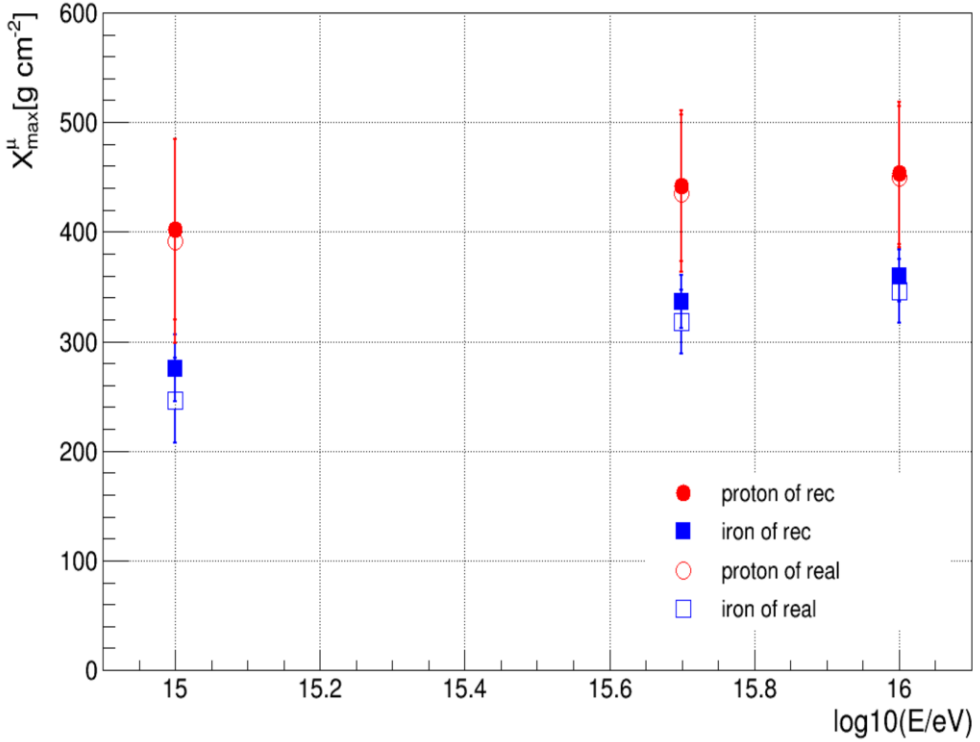


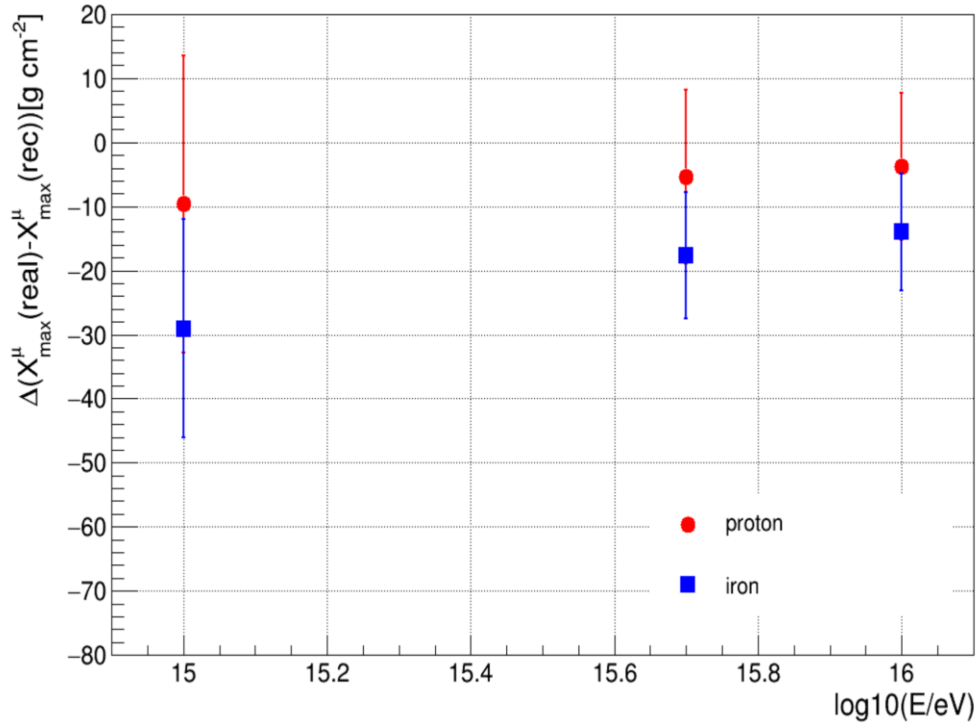
$$Fit\ formula: \frac{dN}{dX} = N_{max}\left(1 + \frac{R}{L}(X - X^{\mu}_{max})\right)^{R^{-2}} exp^{-\frac{X - X^{\mu}_{max}}{LR}}$$

Features of the muon profiles



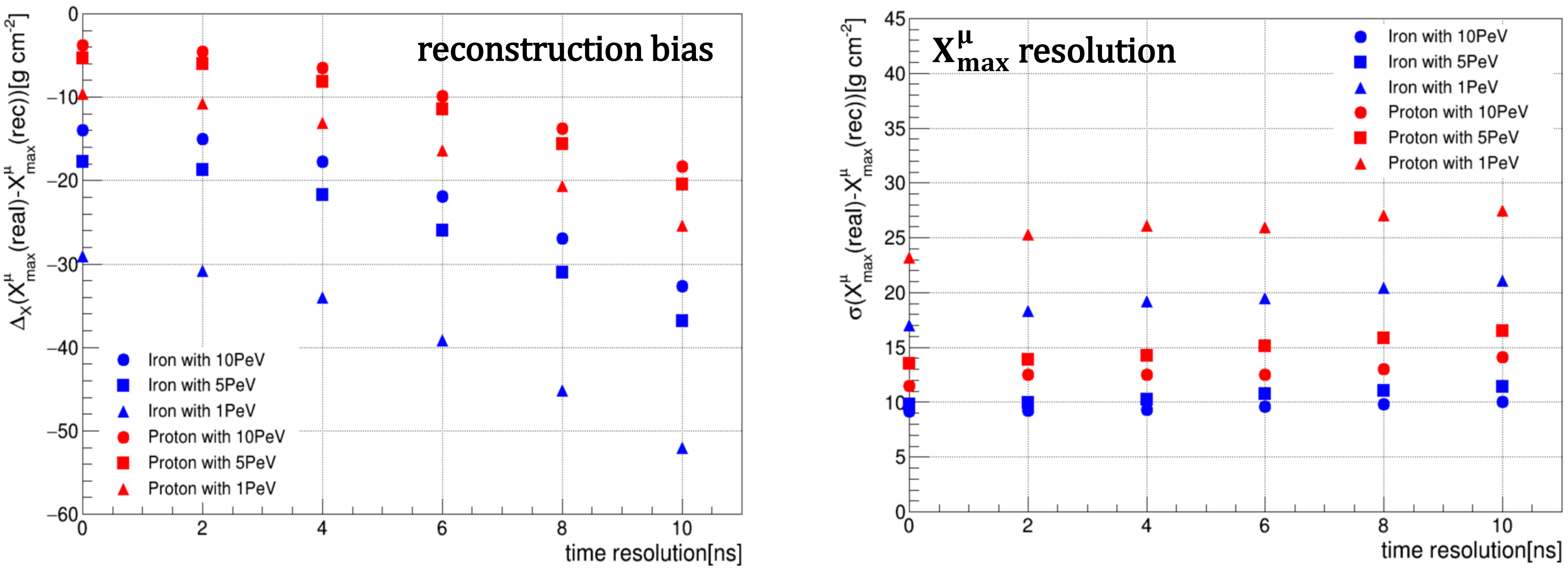
The X^{μ}_{max} study with different energies





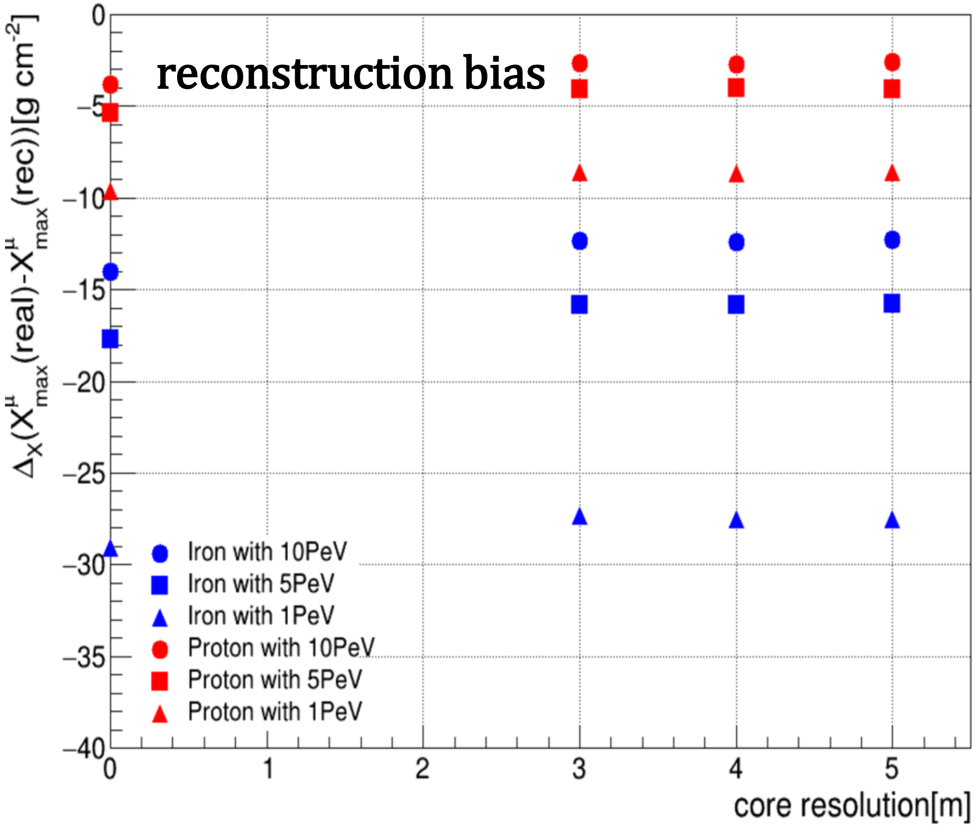
- The reconstruction bias of X^{μ}_{max} for Proton is smaller than that for Iron
- The X^{μ}_{max} resolution improves with energy increasing
- X^{μ}_{max} can be used to identify mass compositions of cosmic rays.

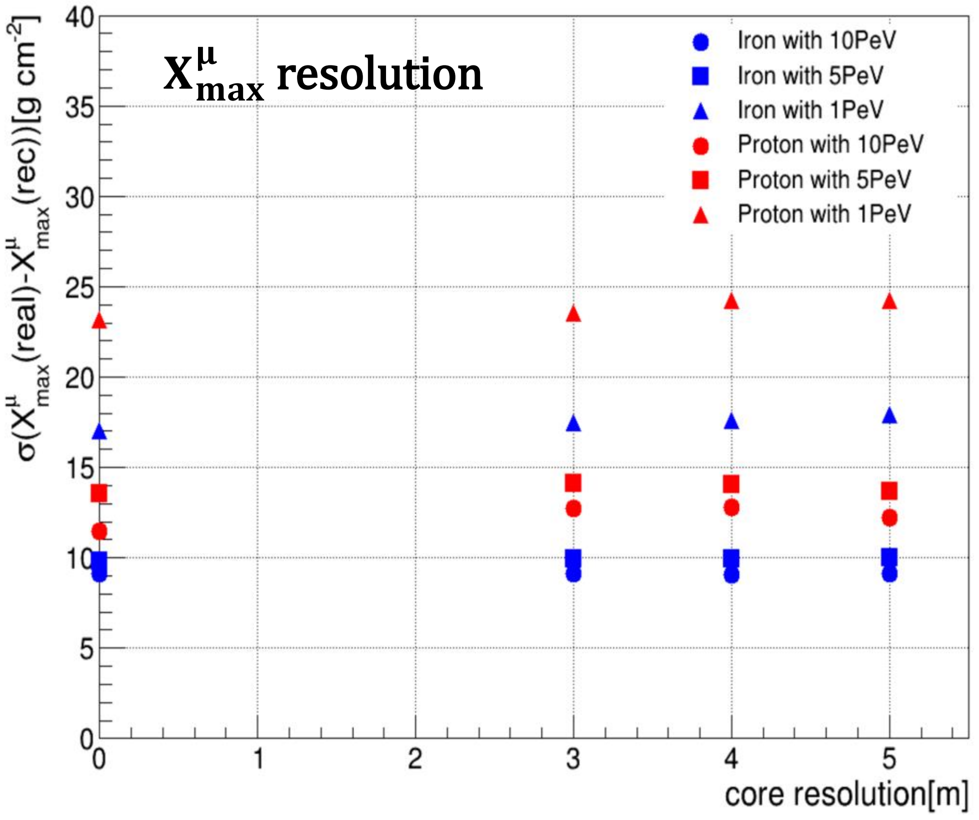
The X_{max}^{μ} study with different time resolution



- The time resolution can affect reconstruction bias of X_{max}^{μ}
- The time resolution has little influence on X_{max}^{μ} resolution

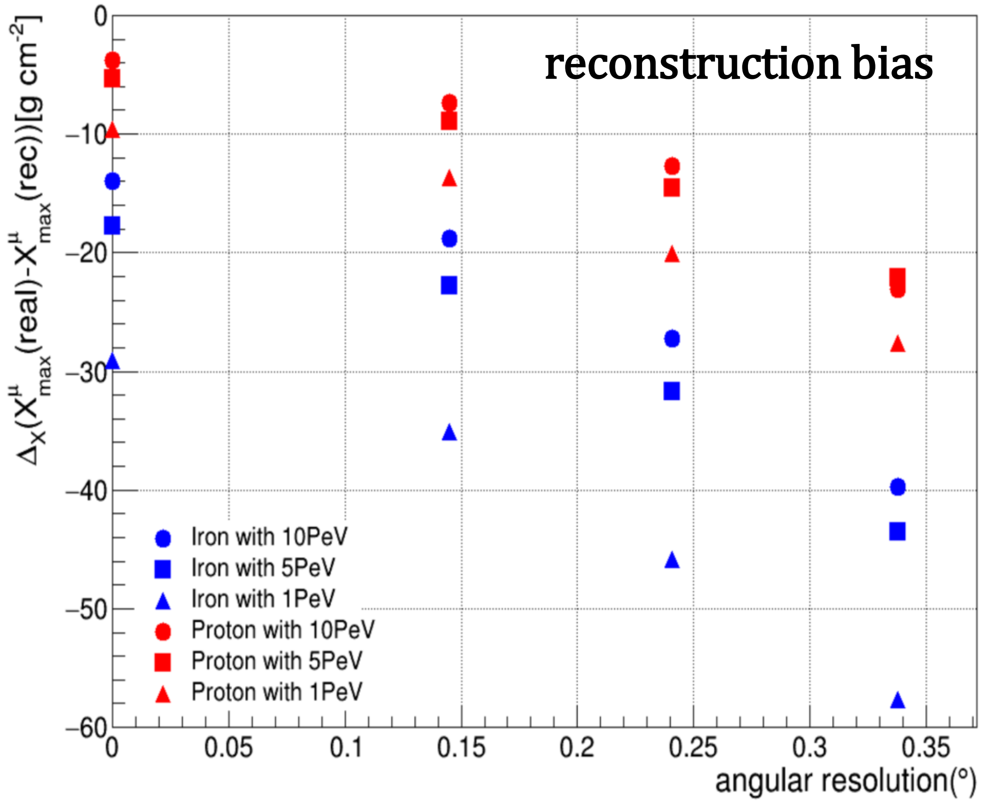
The X_{max}^{μ} study with different core resolution

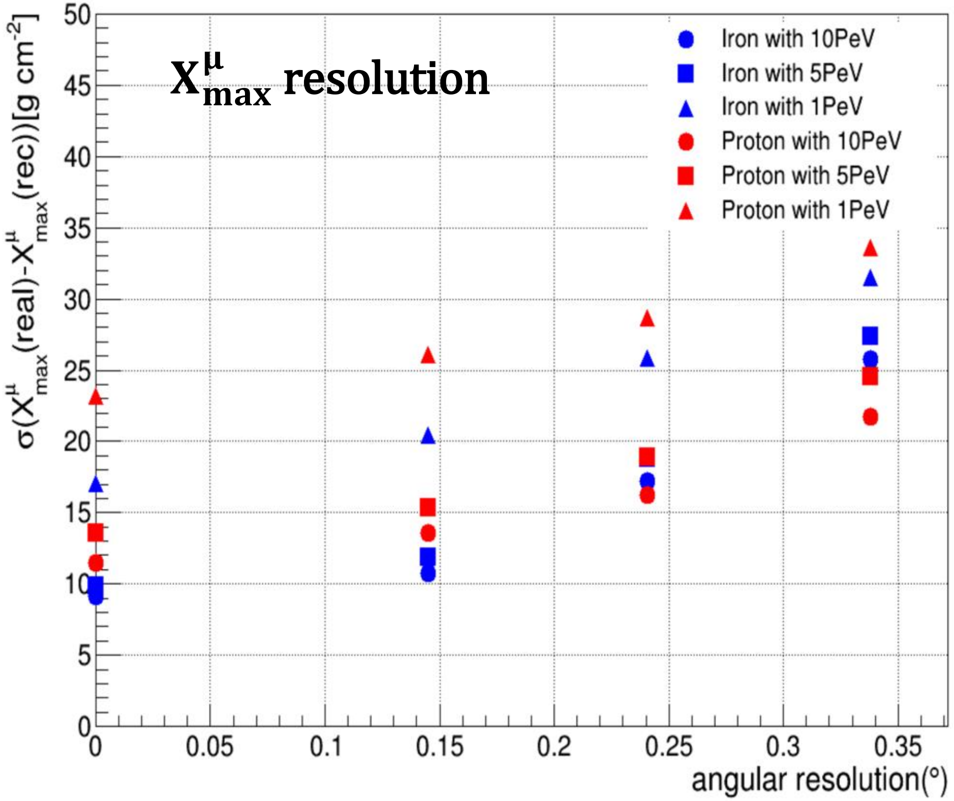




- The core resolution has little influence on the reconstruction of MPD

The X_{max}^{μ} study with different angular resolution





- The angular resolution has a great impact on the reconstruction of MPD

Summary and Next plan

Summary

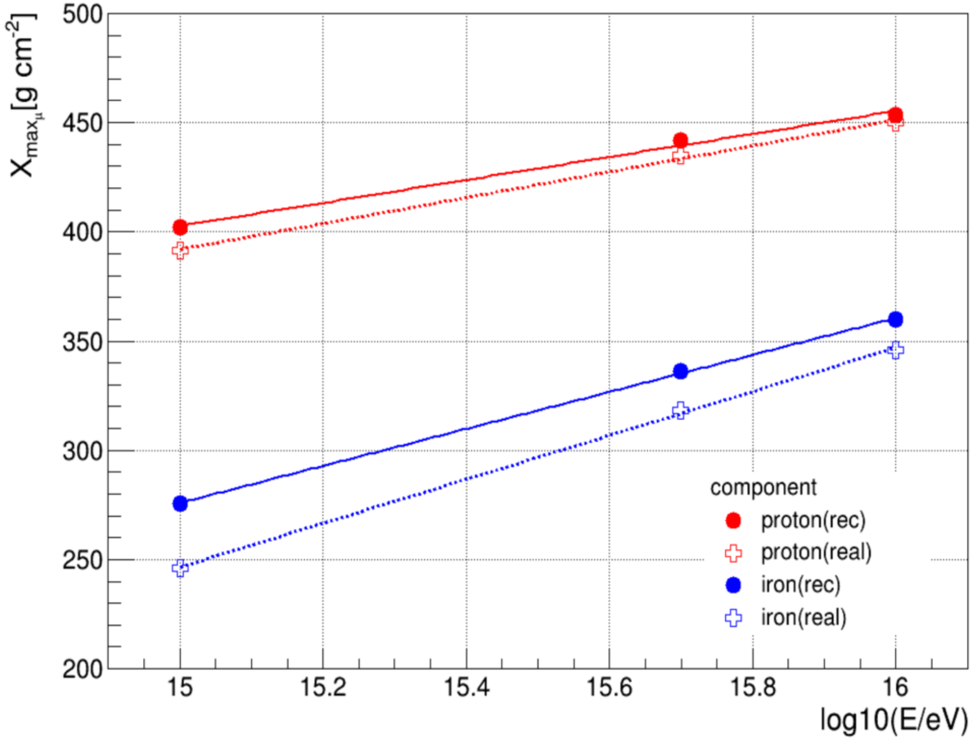
- The longitude development in the air shower and X^{μ}_{max} can be reconstructed according to the geometry effect
- The time resolution and core resolution have little influence on the X^{μ}_{max} resolution
- The time resolution and angular resolution also affect on the reconstruction bias of X^{μ}_{max}

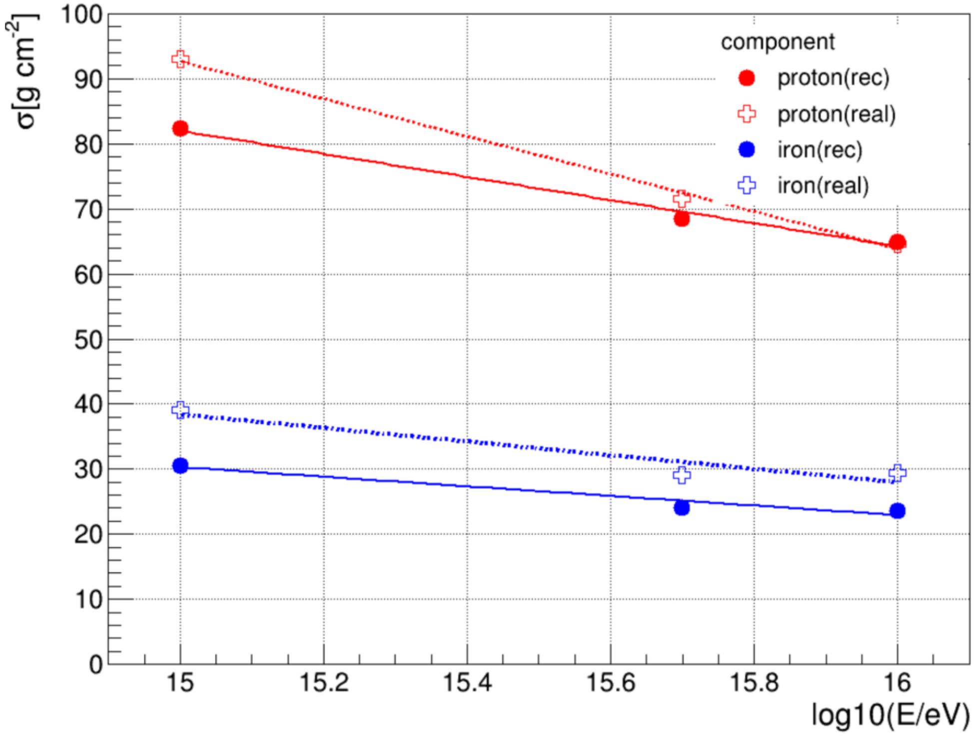
Next plan

- The well performance muon detector in LHAASO will be used to measure the MPD
- Identify mass compositions of cosmic rays by X^{μ}_{max}
- Measure <lnA> by the X^{μ}_{max} and it’s fluctuations

THANK YOU

◆ Measure the mass of cosmic rays by the reconstructed muon profile

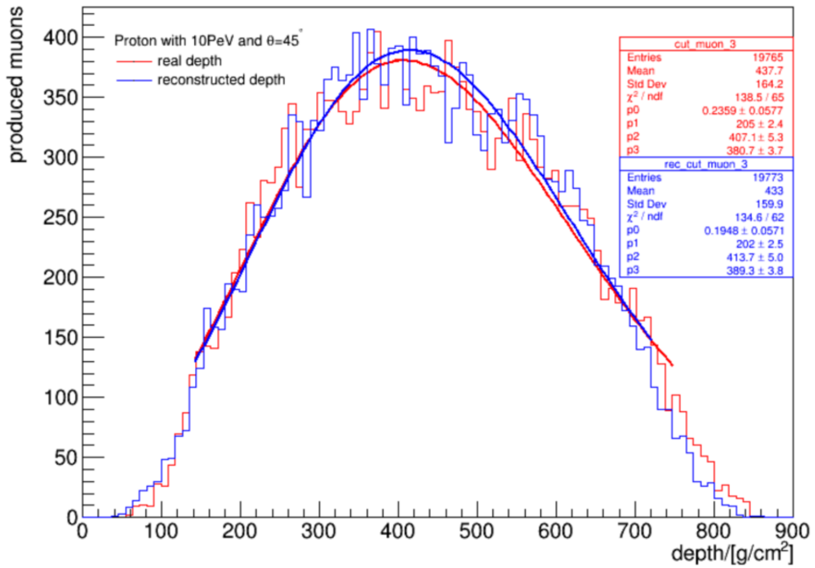


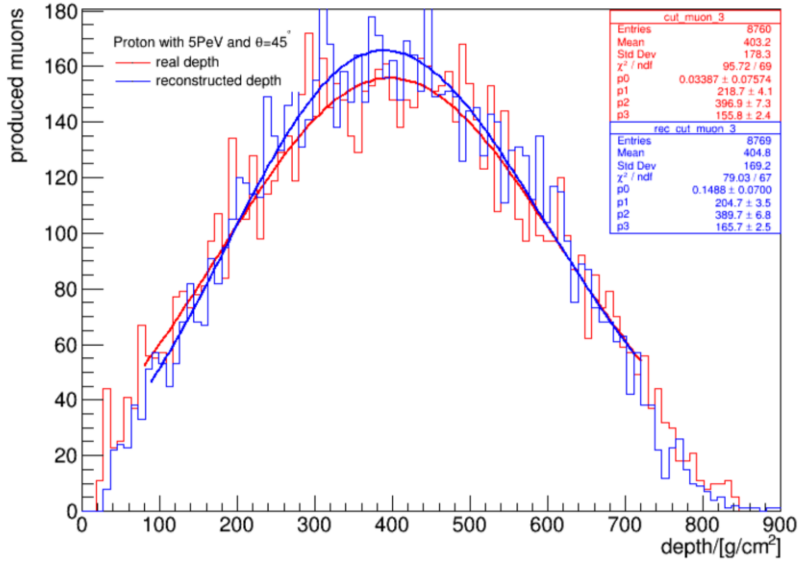


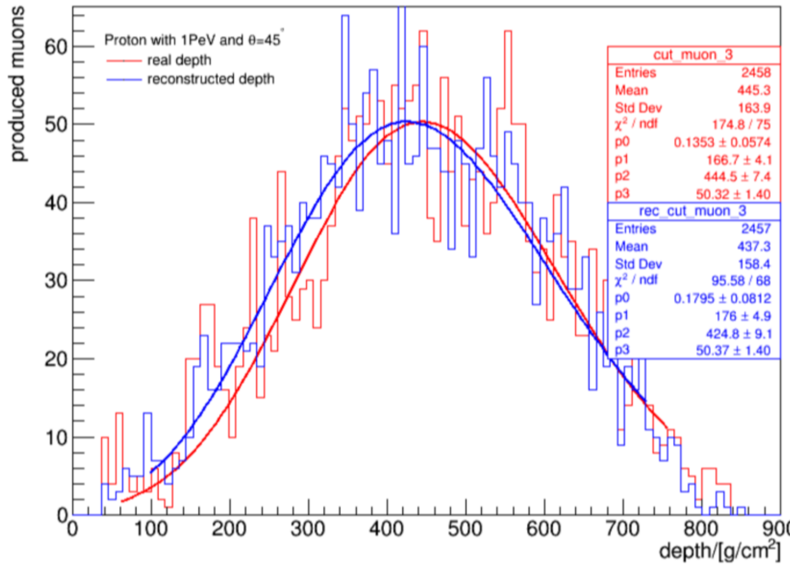
* Measure $< lnA >$ by learning the longitudinal development of muons

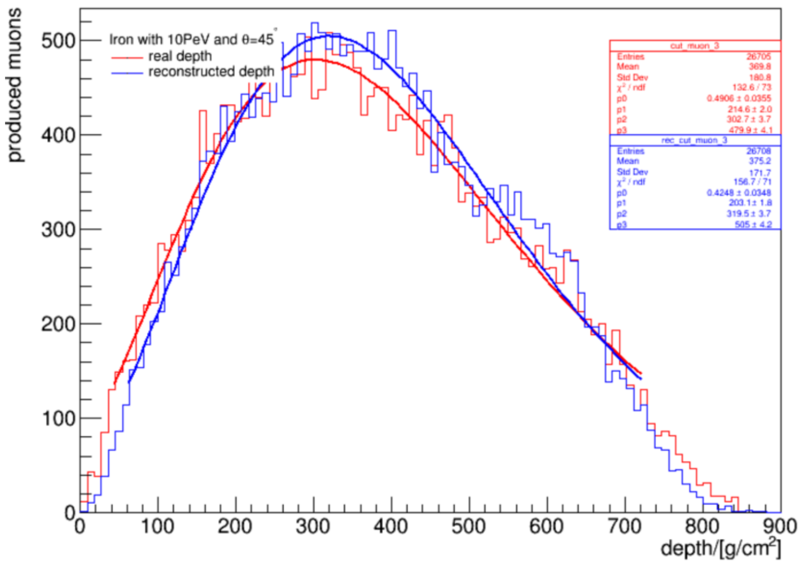
* Identify mass compositions of cosmic rays.

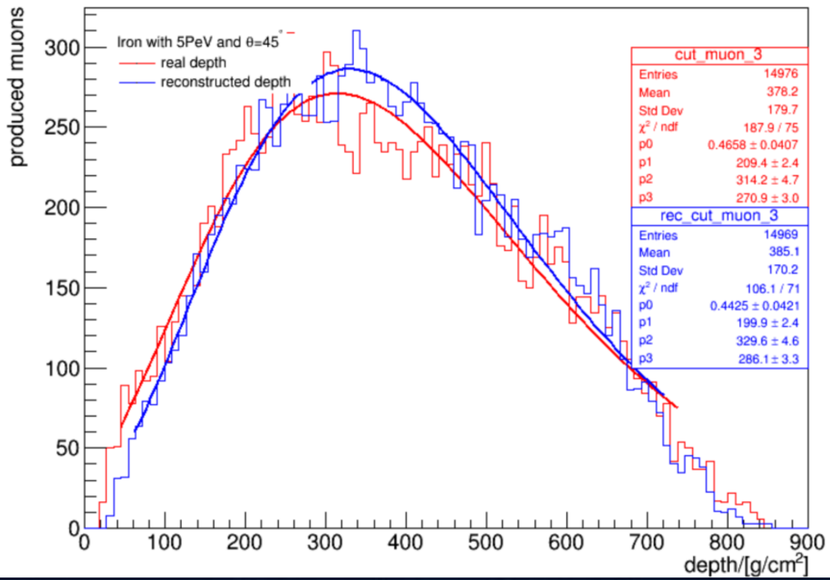
BACK UP

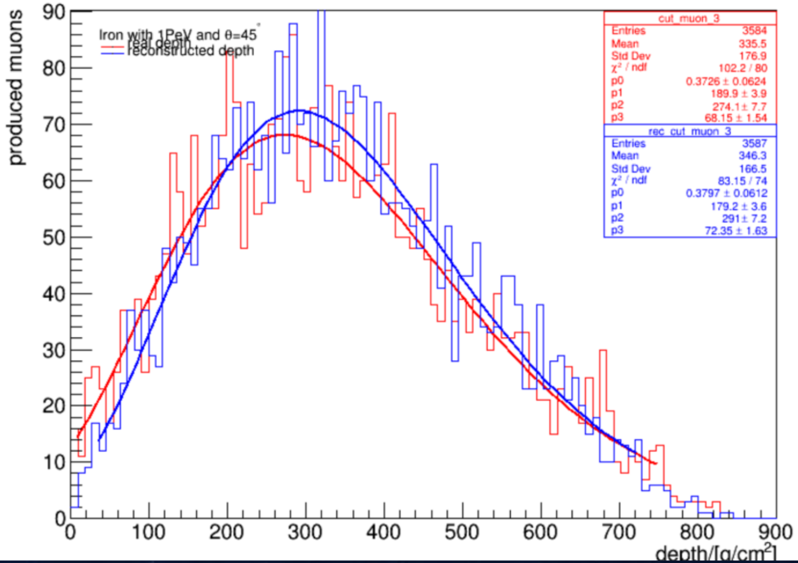

Proton with 10PeV and θ=45°
real depth
reconstructed depth
cut_muon_3
Entries 19765
Mean 437.7
Std Dev 164.2
χ² / ndf 138.5 / 65
p0 0.2359 ± 0.0577
p1 205 ± 2.4
p2 407.1 ± 5.3
p3 380.7 ± 3.7
rec_cut_muon_3
Entries 19773
Mean 433
Std Dev 159.9
χ² / ndf 134.6 / 62
p0 0.1948 ± 0.0571
p1 202 ± 2.5
p2 413.7 ± 5.0
p3 389.3 ± 3.8
produced muons
depth/[g/cm²]


Proton with 5PeV and θ=45°
real depth
reconstructed depth
cut_muon_3
Entries 8760
Mean 403.2
Std Dev 178.3
χ² / ndf 95.72 / 69
p0 0.03387 ± 0.07574
p1 218.7 ± 4.1
p2 396.9 ± 7.3
p3 155.8 ± 2.4
rec_cut_muon_3
Entries 8769
Mean 404.8
Std Dev 169.2
χ² / ndf 79.03 / 67
p0 0.1488 ± 0.0700
p1 204.7 ± 3.5
p2 389.7 ± 6.8
p3 165.7 ± 2.5
produced muons
depth/[g/cm²]

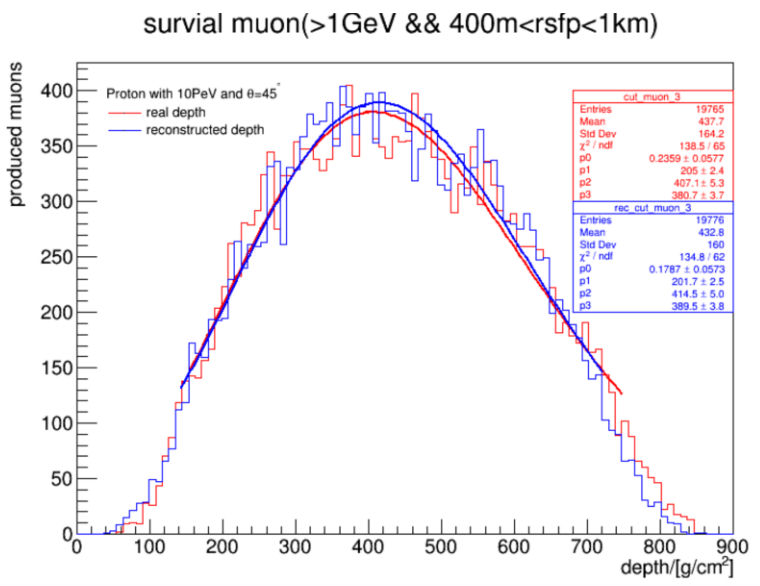

Proton with 1PeV and θ=45°
real depth
reconstructed depth
cut_muon_3
Entries 2458
Mean 445.3
Std Dev 163.9
χ² / ndf 174.8 / 75
p0 0.1353 ± 0.0574
p1 166.7 ± 4.1
p2 444.5 ± 7.4
p3 50.32 ± 1.40
rec_cut_muon_3
Entries 2457
Mean 437.3
Std Dev 158.4
χ² / ndf 95.58 / 68
p0 0.1795 ± 0.0812
p1 176 ± 4.9
p2 424.8 ± 9.1
p3 50.37 ± 1.40
produced muons
depth/[g/cm²]

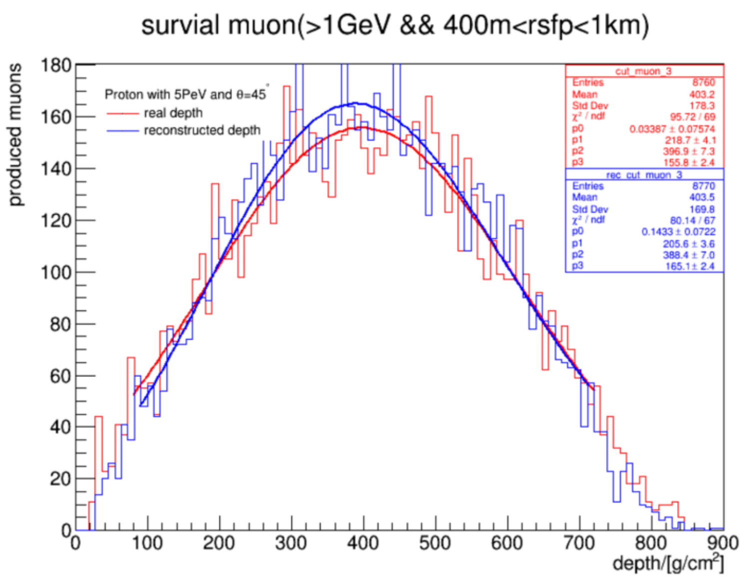

Iron with 10PeV and θ=45°
real depth
reconstructed depth
cut_muon_3
Entries 26705
Mean 369.8
Std Dev 180.8
χ² / ndf 132.6 / 73
p0 0.4906 ± 0.0355
p1 214.6 ± 2.0
p2 302.7 ± 3.7
p3 479.9 ± 4.1
rec_cut_muon_3
Entries 26708
Mean 375.2
Std Dev 171.7
χ² / ndf 156.7 / 71
p0 0.4248 ± 0.0348
p1 203.1 ± 1.8
p2 319.5 ± 3.7
p3 505 ± 4.2
produced muons
depth/[g/cm²]

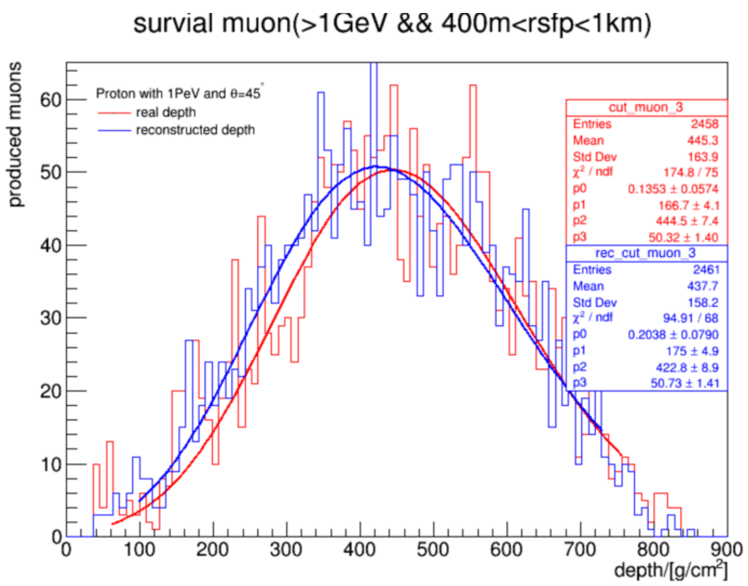

Iron with 5PeV and θ=45°
real depth
reconstructed depth
cut_muon_3
Entries 14976
Mean 378.2
Std Dev 179.7
χ² / ndf 187.9 / 75
p0 0.4658 ± 0.0407
p1 209.4 ± 2.4
p2 314.2 ± 4.7
p3 270.9 ± 3.0
rec_cut_muon_3
Entries 14969
Mean 385.1
Std Dev 170.2
χ² / ndf 106.1 / 71
p0 0.4425 ± 0.0421
p1 199.9 ± 2.4
p2 329.6 ± 4.6
p3 286.1 ± 3.3
produced muons
depth/[g/cm²]

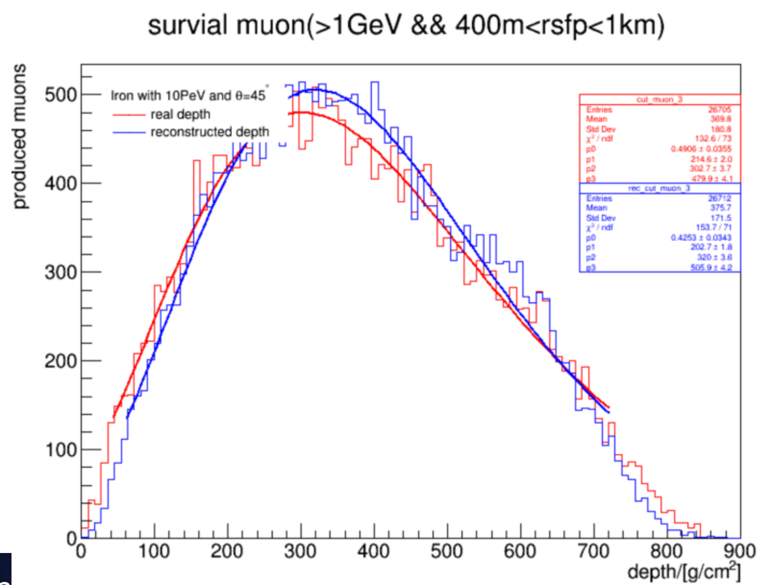

Iron with 1PeV and θ=45°
real depth
reconstructed depth
cut_muon_3
Entries 3584
Mean 335.5
Std Dev 176.9
χ² / ndf 102.2 / 80
p0 0.3726 ± 0.0624
p1 189.9 ± 3.9
p2 274.1 ± 7.7
p3 68.15 ± 1.54
rec_cut_muon_3
Entries 3587
Mean 346.3
Std Dev 166.5
χ² / ndf 83.15 / 74
p0 0.3797 ± 0.0612
p1 179.2 ± 3.6
p2 291 ± 7.2
p3 72.35 ± 1.63
produced muons
depth/[g/cm²]

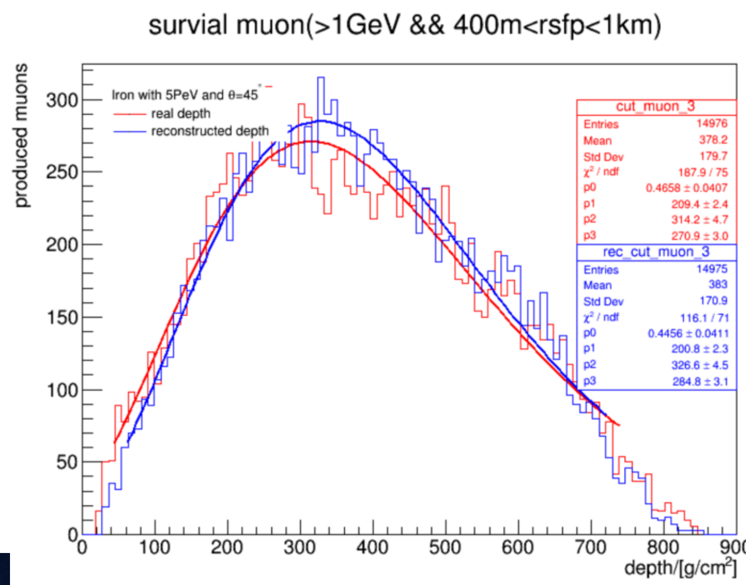
BACK UP

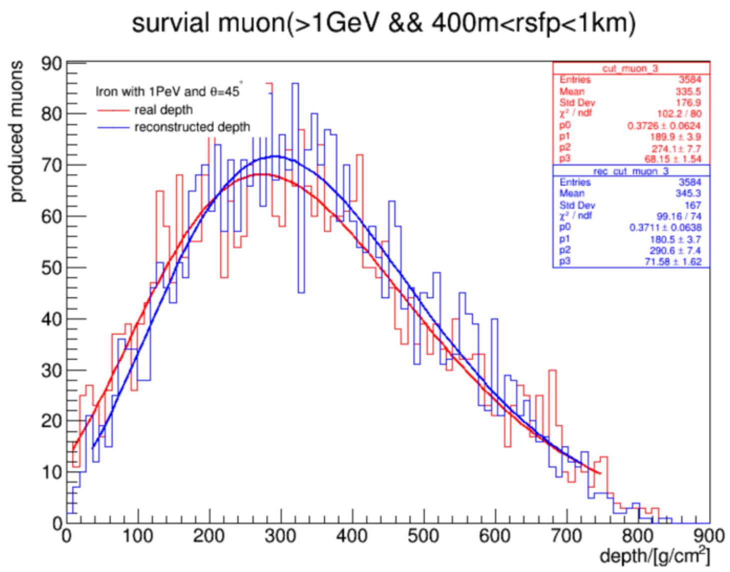

survial muon(>1GeV && 400m<rsfp<1km)
Proton with 10PeV and θ=45°
real depth
reconstructed depth
produced muons
depth/[g/cm²]
cut_muon_3
Entries 19765
Mean 437.7
Std Dev 164.2
χ² / ndf 138.5 / 65
p0 0.2359 ± 0.0577
p1 205 ± 2.4
p2 407.1 ± 5.3
p3 380.7 ± 3.7
rec_cut_muon_3
Entries 19776
Mean 432.8
Std Dev 160
χ² / ndf 134.8 / 62
p0 0.1787 ± 0.0573
p1 201.7 ± 2.5
p2 414.5 ± 5.0
p3 389.5 ± 3.8


survial muon(>1GeV && 400m<rsfp<1km)
Proton with 5PeV and θ=45°
real depth
reconstructed depth
produced muons
depth/[g/cm²]
cut_muon_3
Entries 8760
Mean 403.2
Std Dev 178.3
χ² / ndf 95.72 / 69
p0 0.03387 ± 0.07574
p1 218.7 ± 4.1
p2 396.9 ± 7.3
p3 155.8 ± 2.4
rec_cut_muon_3
Entries 8770
Mean 403.5
Std Dev 169.8
χ² / ndf 80.14 / 67
p0 0.1433 ± 0.0722
p1 205.6 ± 3.6
p2 388.4 ± 7.0
p3 165.1 ± 2.4


survial muon(>1GeV && 400m<rsfp<1km)
Proton with 1PeV and θ=45°
real depth
reconstructed depth
produced muons
depth/[g/cm²]
cut_muon_3
Entries 2458
Mean 445.3
Std Dev 163.9
χ² / ndf 174.8 / 75
p0 0.1353 ± 0.0574
p1 166.7 ± 4.1
p2 444.5 ± 7.4
p3 50.32 ± 1.40
rec_cut_muon_3
Entries 2461
Mean 437.7
Std Dev 158.2
χ² / ndf 94.91 / 68
p0 0.2038 ± 0.0790
p1 175 ± 4.9
p2 422.8 ± 8.9
p3 50.73 ± 1.41

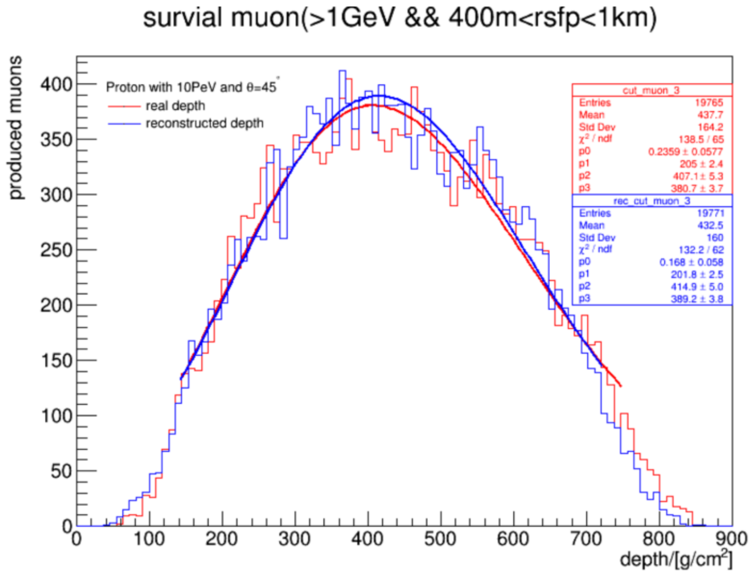

survial muon(>1GeV && 400m<rsfp<1km)
Iron with 10PeV and θ=45°
real depth
reconstructed depth
produced muons
depth/[g/cm²]


survial muon(>1GeV && 400m<rsfp<1km)
Iron with 5PeV and θ=45°
real depth
reconstructed depth
produced muons
depth/[g/cm²]
cut_muon_3
Entries 14976
Mean 378.2
Std Dev 179.7
χ² / ndf 187.9 / 75
p0 0.4658 ± 0.0407
p1 209.4 ± 2.4
p2 314.2 ± 4.7
p3 270.9 ± 3.0
rec_cut_muon_3
Entries 14975
Mean 383
Std Dev 170.9
χ² / ndf 116.1 / 71
p0 0.4456 ± 0.0411
p1 200.8 ± 2.3
p2 326.6 ± 4.5
p3 284.8 ± 3.1

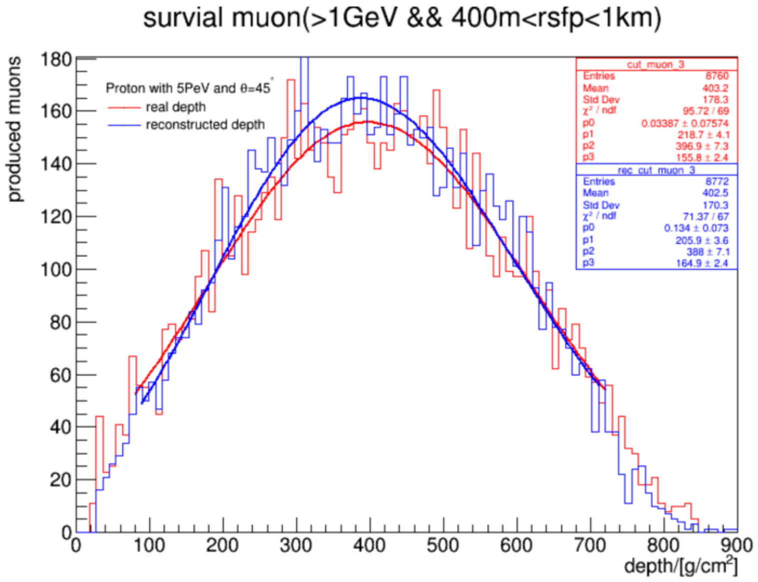

survial muon(>1GeV && 400m<rsfp<1km)
Iron with 1PeV and θ=45°
real depth
reconstructed depth
produced muons
depth/[g/cm²]

5m

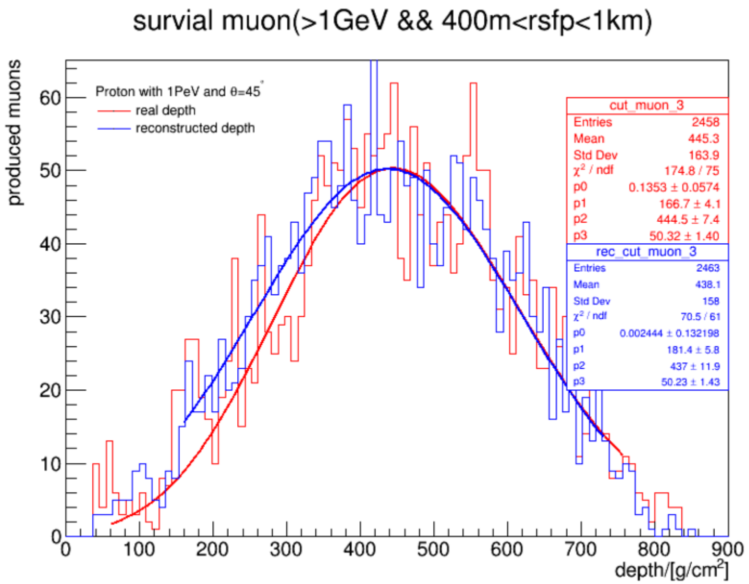
BACK UP



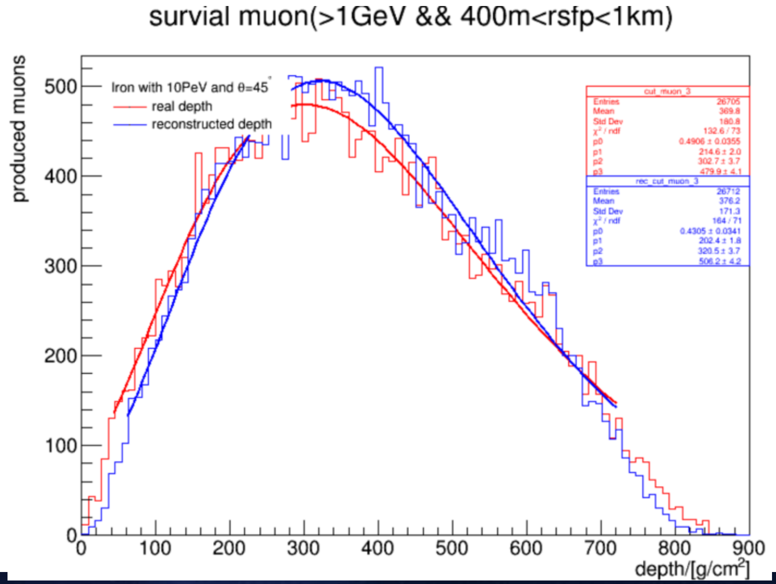
survial muon(>1GeV && 400m<rsfp<1km)
Proton with 10PeV and θ=45°
real depth
reconstructed depth
produced muons
depth/[g/cm²]
cut_muon_3
Entries 19765
Mean 437.7
Std Dev 164.2
χ² / ndf 138.5 / 65
p0 0.2359 ± 0.0577
p1 205 ± 2.4
p2 407.1 ± 5.3
p3 380.7 ± 3.7
rec_cut_muon_3
Entries 19771
Mean 432.5
Std Dev 160
χ² / ndf 132.2 / 62
p0 0.168 ± 0.058
p1 201.8 ± 2.5
p2 414.9 ± 5.0
p3 389.2 ± 3.8



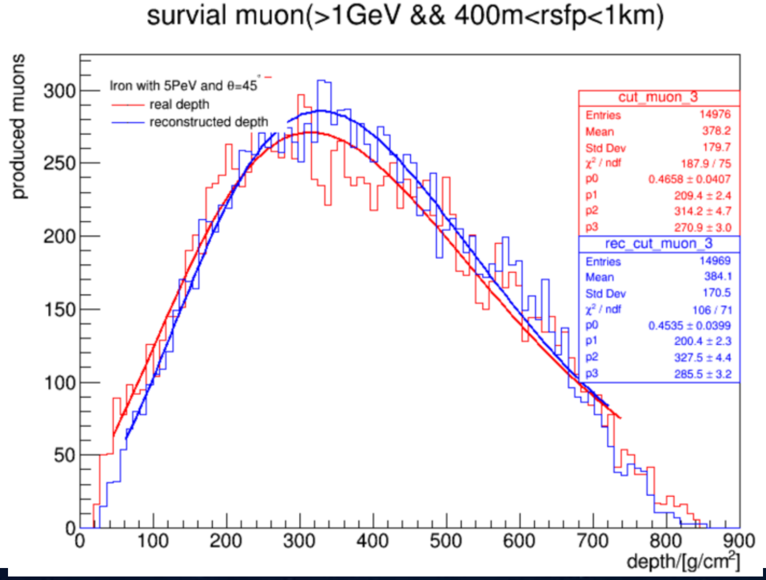
survial muon(>1GeV && 400m<rsfp<1km)
Proton with 5PeV and θ=45°
real depth
reconstructed depth
produced muons
depth/[g/cm²]
cut_muon_3
Entries 8760
Mean 403.2
Std Dev 178.3
χ² / ndf 95.72 / 69
p0 0.03387 ± 0.07574
p1 218.7 ± 4.1
p2 396.9 ± 7.3
p3 155.8 ± 2.4
rec_cut_muon_3
Entries 8772
Mean 402.5
Std Dev 170.3
χ² / ndf 71.37 / 67
p0 0.134 ± 0.073
p1 205.9 ± 3.6
p2 388 ± 7.1
p3 164.9 ± 2.4



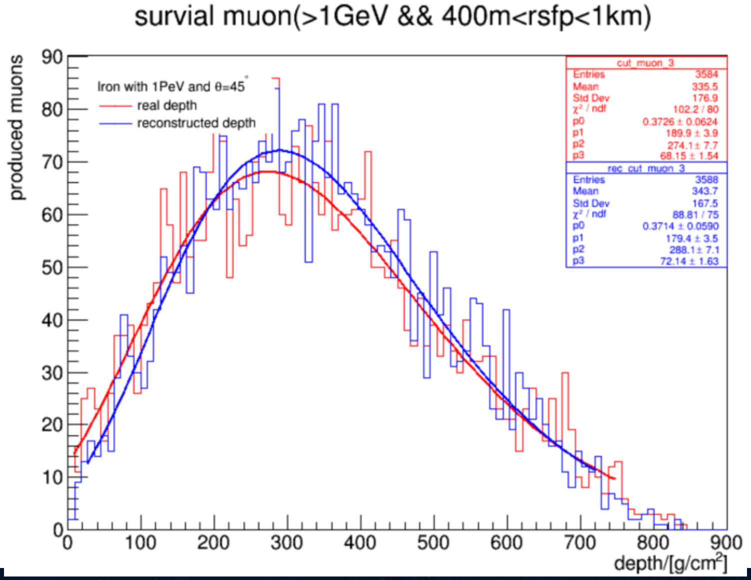
survial muon(>1GeV && 400m<rsfp<1km)
Proton with 1PeV and θ=45°
real depth
reconstructed depth
produced muons
depth/[g/cm²]
cut_muon_3
Entries 2458
Mean 445.3
Std Dev 163.9
χ² / ndf 174.8 / 75
p0 0.1353 ± 0.0574
p1 166.7 ± 4.1
p2 444.5 ± 7.4
p3 50.32 ± 1.40
rec_cut_muon_3
Entries 2463
Mean 438.1
Std Dev 158
χ² / ndf 70.5 / 61
p0 0.002444 ± 0.132198
p1 181.4 ± 5.8
p2 437 ± 11.9
p3 50.23 ± 1.43



survial muon(>1GeV && 400m<rsfp<1km)
Iron with 10PeV and θ=45°
real depth
reconstructed depth
produced muons
depth/[g/cm²]
cut_muon_3
Entries 26705
Mean 369.8
Std Dev 180.8
χ² / ndf 132.6 / 73
p0 0.4906 ± 0.0355
p1 214.6 ± 2.0
p2 302.7 ± 3.7
p3 479.9 ± 4.1
rec_cut_muon_3
Entries 26712
Mean 376.2
Std Dev 171.3
χ² / ndf 164 / 71
p0 0.4305 ± 0.0341
p1 202.4 ± 1.8
p2 320.5 ± 3.7
p3 506.2 ± 4.2

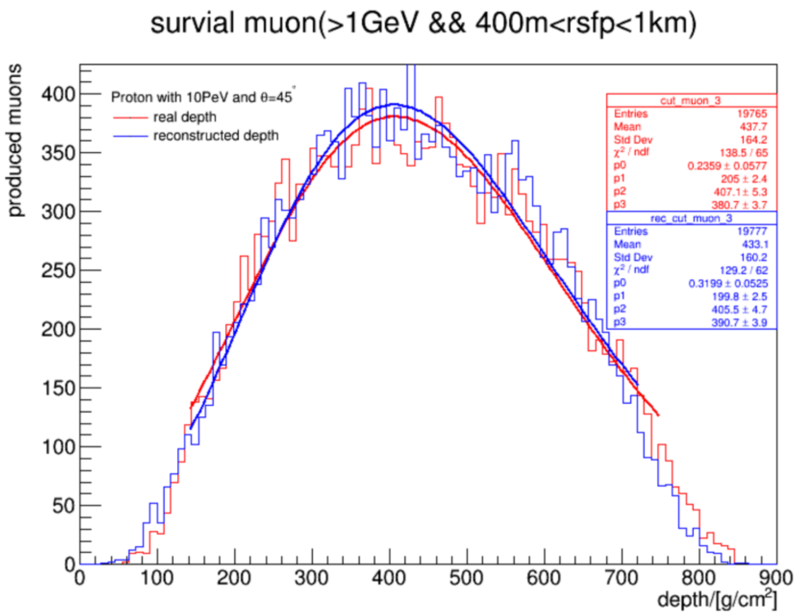


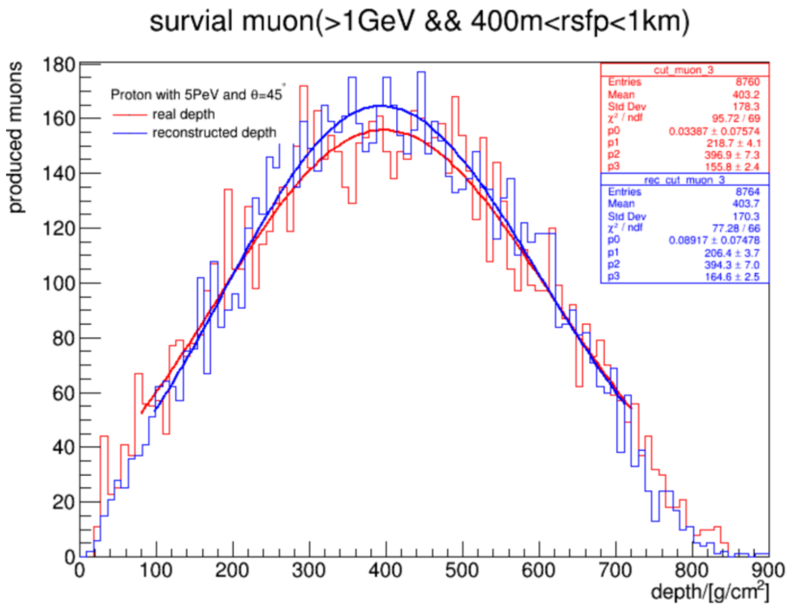
survial muon(>1GeV && 400m<rsfp<1km)
Iron with 5PeV and θ=45°
real depth
reconstructed depth
produced muons
depth/[g/cm²]
cut_muon_3
Entries 14976
Mean 378.2
Std Dev 179.7
χ² / ndf 187.9 / 75
p0 0.4658 ± 0.0407
p1 209.4 ± 2.4
p2 314.2 ± 4.7
p3 270.9 ± 3.0
rec_cut_muon_3
Entries 14969
Mean 384.1
Std Dev 170.5
χ² / ndf 106 / 71
p0 0.4535 ± 0.0399
p1 200.4 ± 2.3
p2 327.5 ± 4.4
p3 285.5 ± 3.2

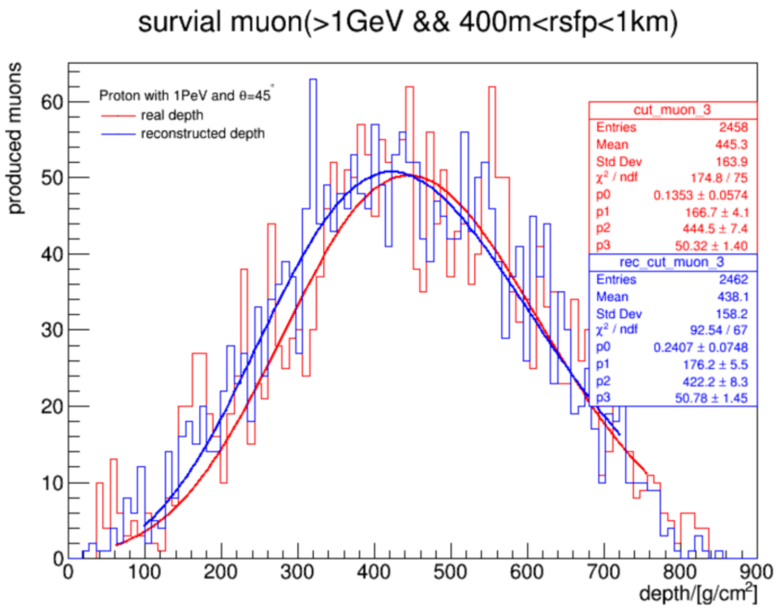


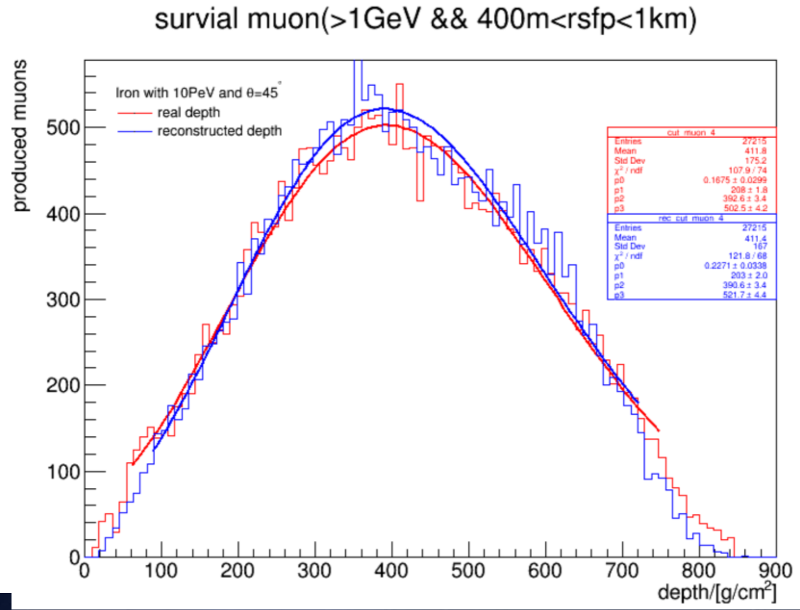
survial muon(>1GeV && 400m<rsfp<1km)
Iron with 1PeV and θ=45°
real depth
reconstructed depth
produced muons
depth/[g/cm²]
cut_muon_3
Entries 3584
Mean 335.5
Std Dev 176.9
χ² / ndf 102.2 / 80
p0 0.3726 ± 0.0624
p1 189.9 ± 3.9
p2 274.1 ± 7.7
p3 68.15 ± 1.54
rec_cut_muon_3
Entries 3588
Mean 343.7
Std Dev 167.5
χ² / ndf 88.81 / 75
p0 0.3714 ± 0.0590
p1 179.4 ± 3.5
p2 288.1 ± 7.1
p3 72.14 ± 1.63

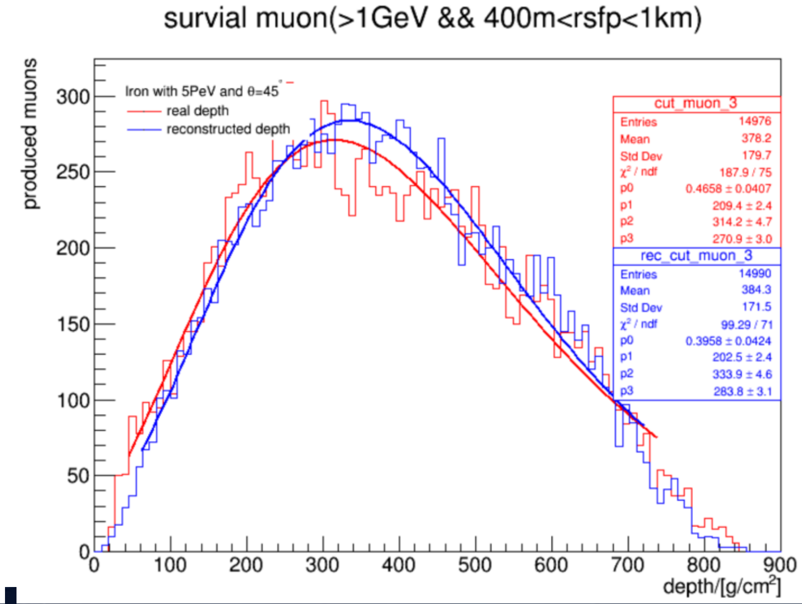
BACK UP

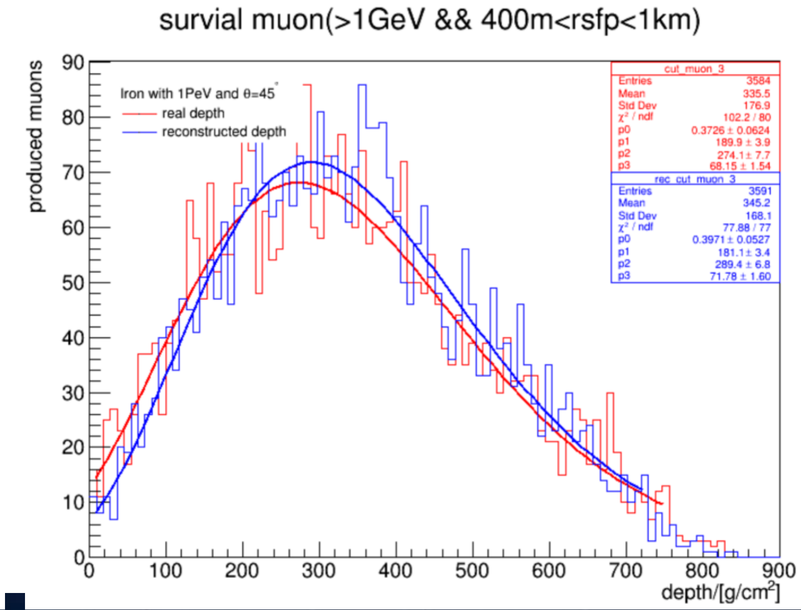

survial muon(>1GeV && 400m<rsfp<1km)
produced muons
Proton with 10PeV and θ=45°
real depth
reconstructed depth
cut_muon_3
Entries 19765
Mean 437.7
Std Dev 164.2
χ² / ndf 138.5 / 65
p0 0.2359 ± 0.0577
p1 205 ± 2.4
p2 407.1 ± 5.3
p3 380.7 ± 3.7
rec_cut_muon_3
Entries 19777
Mean 433.1
Std Dev 160.2
χ² / ndf 129.2 / 62
p0 0.3199 ± 0.0525
p1 199.8 ± 2.5
p2 405.5 ± 4.7
p3 390.7 ± 3.9
depth/[g/cm²]


survial muon(>1GeV && 400m<rsfp<1km)
produced muons
Proton with 5PeV and θ=45°
real depth
reconstructed depth
depth/[g/cm²]

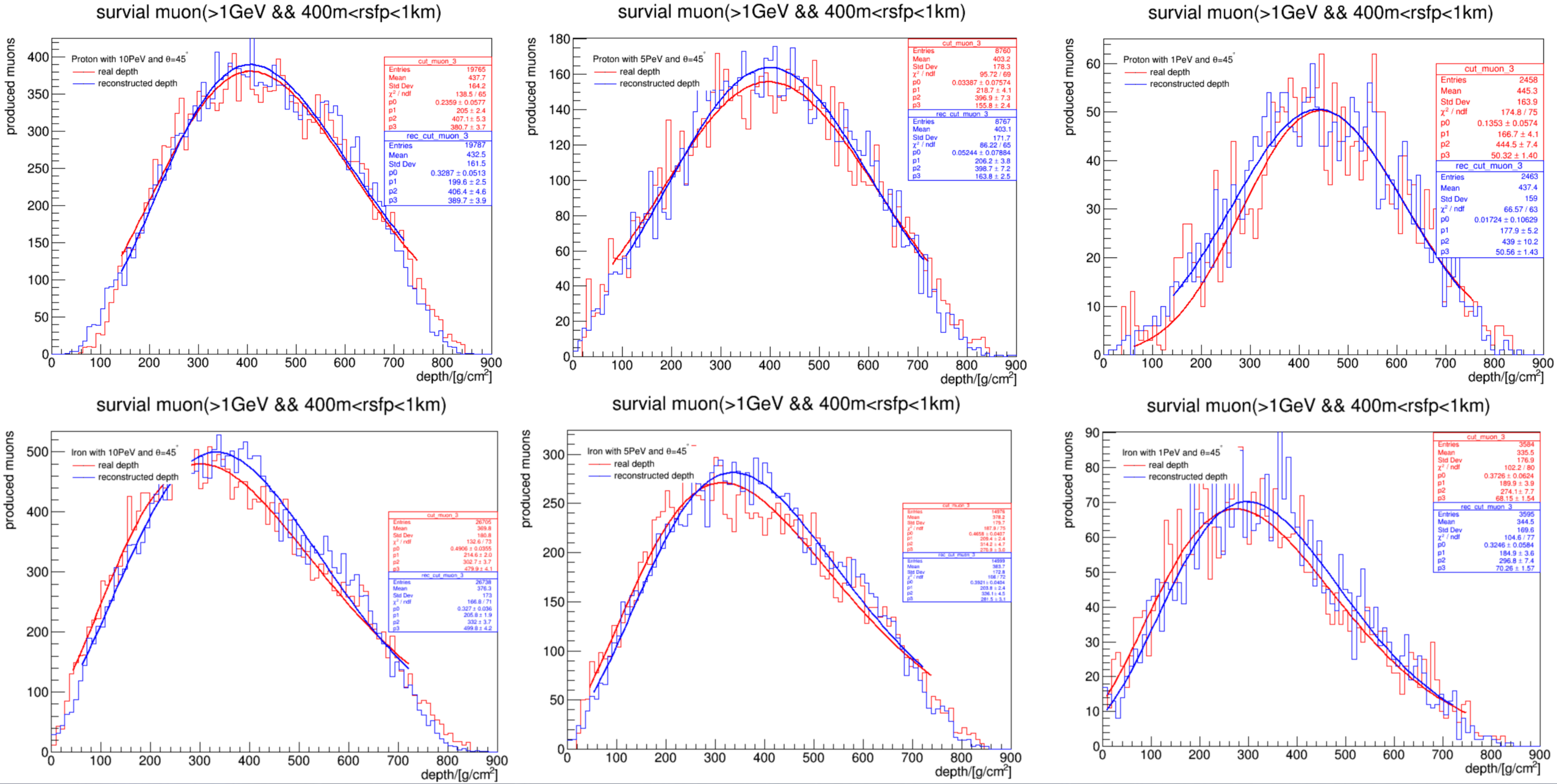

survial muon(>1GeV && 400m<rsfp<1km)
produced muons
Proton with 1PeV and θ=45°
real depth
reconstructed depth
cut_muon_3
Entries 2458
Mean 445.3
Std Dev 163.9
χ² / ndf 174.8 / 75
p0 0.1353 ± 0.0574
p1 166.7 ± 4.1
p2 444.5 ± 7.4
p3 50.32 ± 1.40
rec_cut_muon_3
Entries 2462
Mean 438.1
Std Dev 158.2
χ² / ndf 92.54 / 67
p0 0.2407 ± 0.0748
p1 176.2 ± 5.5
p2 422.2 ± 8.3
p3 50.78 ± 1.45
depth/[g/cm²]


survial muon(>1GeV && 400m<rsfp<1km)
produced muons
Iron with 10PeV and θ=45°
real depth
reconstructed depth
depth/[g/cm²]


survial muon(>1GeV && 400m<rsfp<1km)
produced muons
Iron with 5PeV and θ=45°
real depth
reconstructed depth
cut_muon_3
Entries 14976
Mean 378.2
Std Dev 179.7
χ² / ndf 187.9 / 75
p0 0.4658 ± 0.0407
p1 209.4 ± 2.4
p2 314.2 ± 4.7
p3 270.9 ± 3.0
rec_cut_muon_3
Entries 14990
Mean 384.3
Std Dev 171.5
χ² / ndf 99.29 / 71
p0 0.3958 ± 0.0424
p1 202.5 ± 2.4
p2 333.9 ± 4.6
p3 283.8 ± 3.1
depth/[g/cm²]

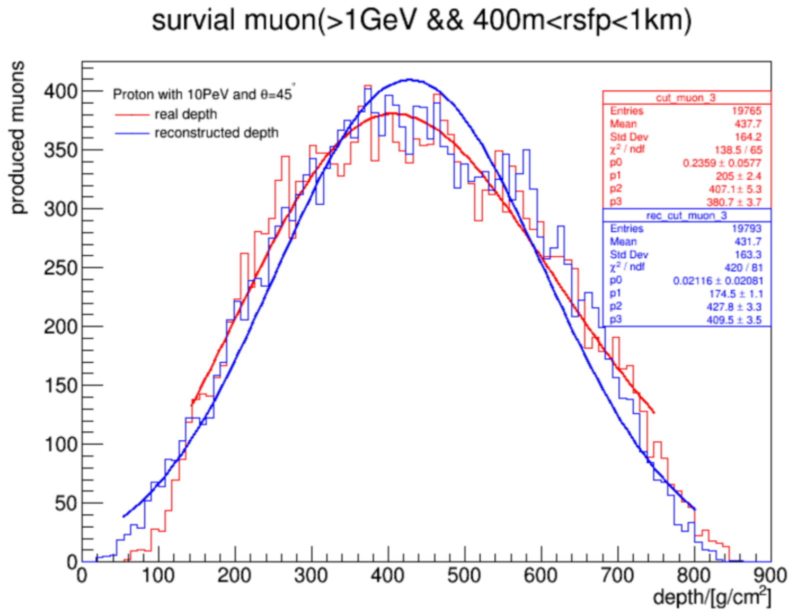

survial muon(>1GeV && 400m<rsfp<1km)
produced muons
Iron with 1PeV and θ=45°
real depth
reconstructed depth
depth/[g/cm²]

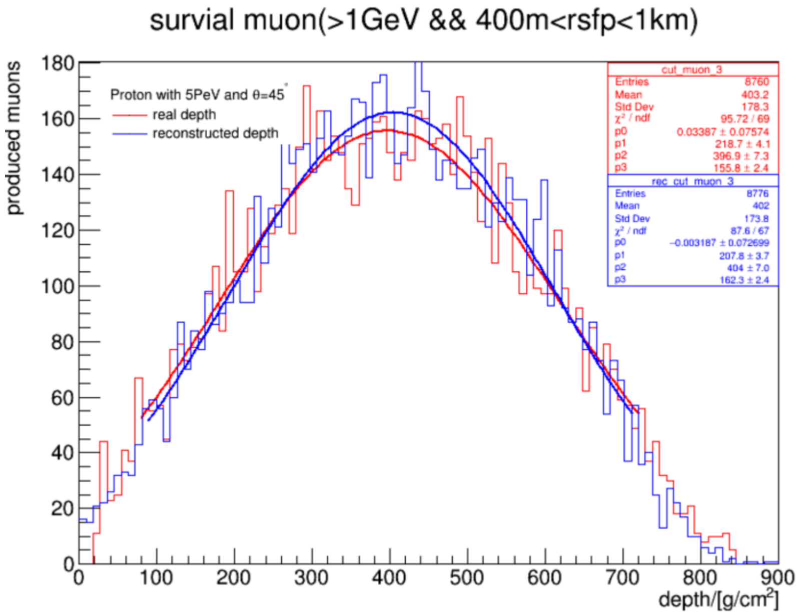
BACK UP

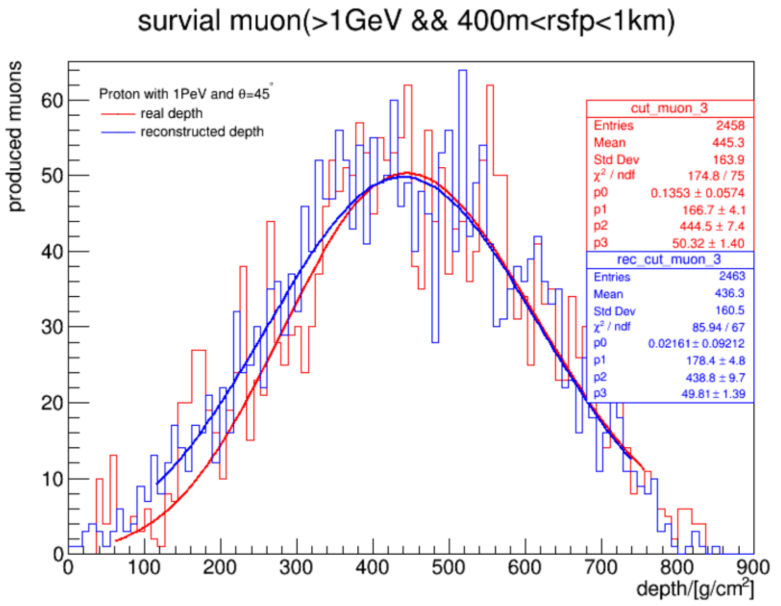

survial muon(>1GeV && 400m<rsfp<1km)
Proton with 10PeV and θ=45°
real depth
reconstructed depth
cut_muon_3
Entries 19765
Mean 437.7
Std Dev 164.2
χ² / ndf 138.5 / 65
p0 0.2359 ± 0.0577
p1 205 ± 2.4
p2 407.1 ± 5.3
p3 380.7 ± 3.7
rec_cut_muon_3
Entries 19787
Mean 432.5
Std Dev 161.5
p0 0.3287 ± 0.0513
p1 199.6 ± 2.5
p2 406.4 ± 4.6
p3 389.7 ± 3.9
produced muons
depth/[g/cm²]
survial muon(>1GeV && 400m<rsfp<1km)
Proton with 5PeV and θ=45°
real depth
reconstructed depth
cut_muon_3
Entries 8760
Mean 403.2
Std Dev 178.3
χ² / ndf 95.72 / 69
p0 0.03387 ± 0.07574
p1 218.7 ± 4.1
p2 396.9 ± 7.3
p3 155.8 ± 2.4
rec_cut_muon_3
Entries 8767
Mean 403.1
Std Dev 171.7
χ² / ndf 86.22 / 65
p0 0.05244 ± 0.07884
p1 206.2 ± 3.8
p2 398.7 ± 7.2
p3 163.8 ± 2.5
survial muon(>1GeV && 400m<rsfp<1km)
Proton with 1PeV and θ=45°
real depth
reconstructed depth
cut_muon_3
Entries 2458
Mean 445.3
Std Dev 163.9
χ² / ndf 174.8 / 75
p0 0.1353 ± 0.0574
p1 166.7 ± 4.1
p2 444.5 ± 7.4
p3 50.32 ± 1.40
rec_cut_muon_3
Entries 2463
Mean 437.4
Std Dev 159
χ² / ndf 66.57 / 63
p0 0.01724 ± 0.10629
p1 177.9 ± 5.2
p2 439 ± 10.2
p3 50.56 ± 1.43
survial muon(>1GeV && 400m<rsfp<1km)
Iron with 10PeV and θ=45°
real depth
reconstructed depth
survial muon(>1GeV && 400m<rsfp<1km)
Iron with 5PeV and θ=45°
real depth
reconstructed depth
survial muon(>1GeV && 400m<rsfp<1km)
Iron with 1PeV and θ=45°
real depth
reconstructed depth

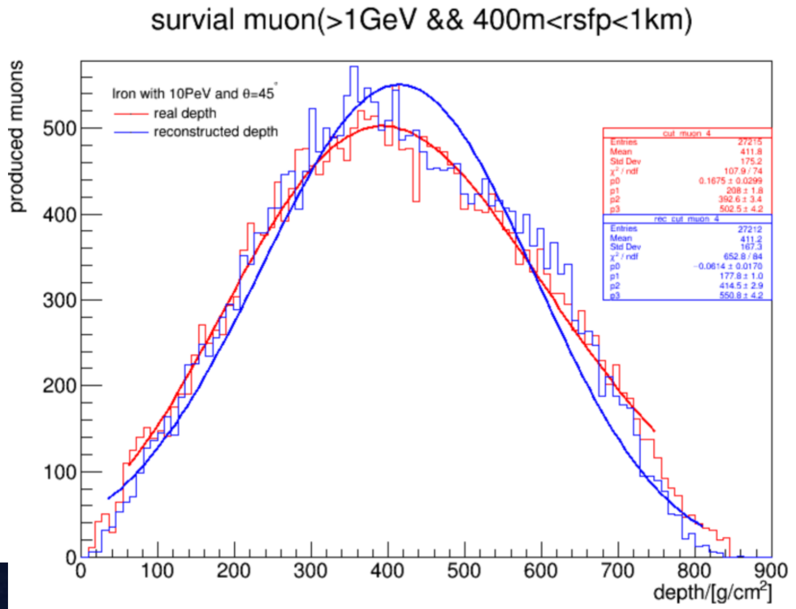
0.338

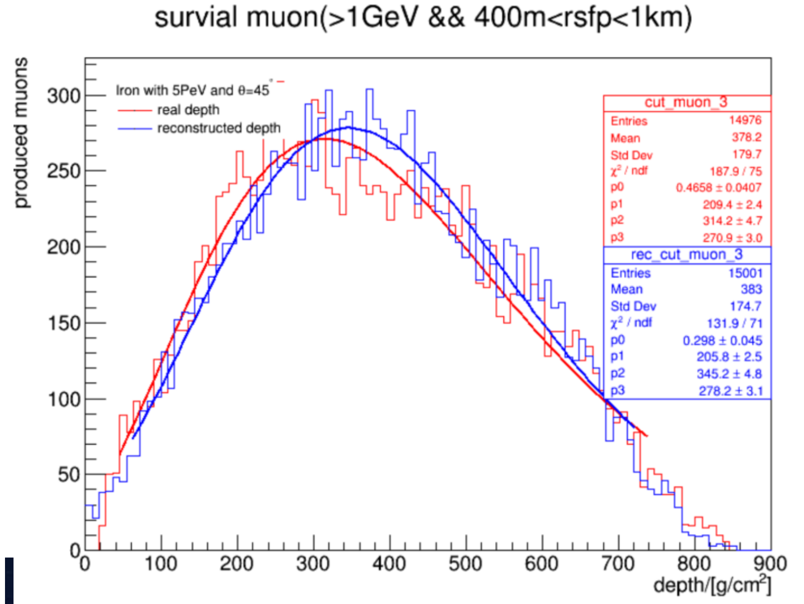
BACK UP

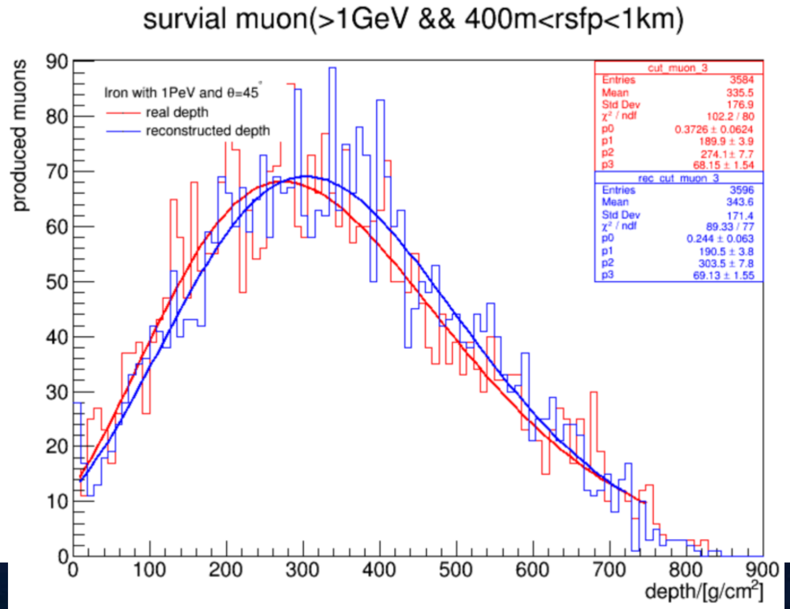

survial muon(>1GeV && 400m<rsfp<1km)
Proton with 10PeV and θ=45°
real depth
reconstructed depth
cut_muon_3
Entries 19765
Mean 437.7
Std Dev 164.2
χ² / ndf 138.5 / 65
p0 0.2359 ± 0.0577
p1 205 ± 2.4
p2 407.1 ± 5.3
p3 380.7 ± 3.7
rec_cut_muon_3
Entries 19793
Mean 431.7
Std Dev 163.3
χ² / ndf 420 / 81
p0 0.02116 ± 0.02081
p1 174.5 ± 1.1
p2 427.8 ± 3.3
p3 409.5 ± 3.5
produced muons
depth/[g/cm²]

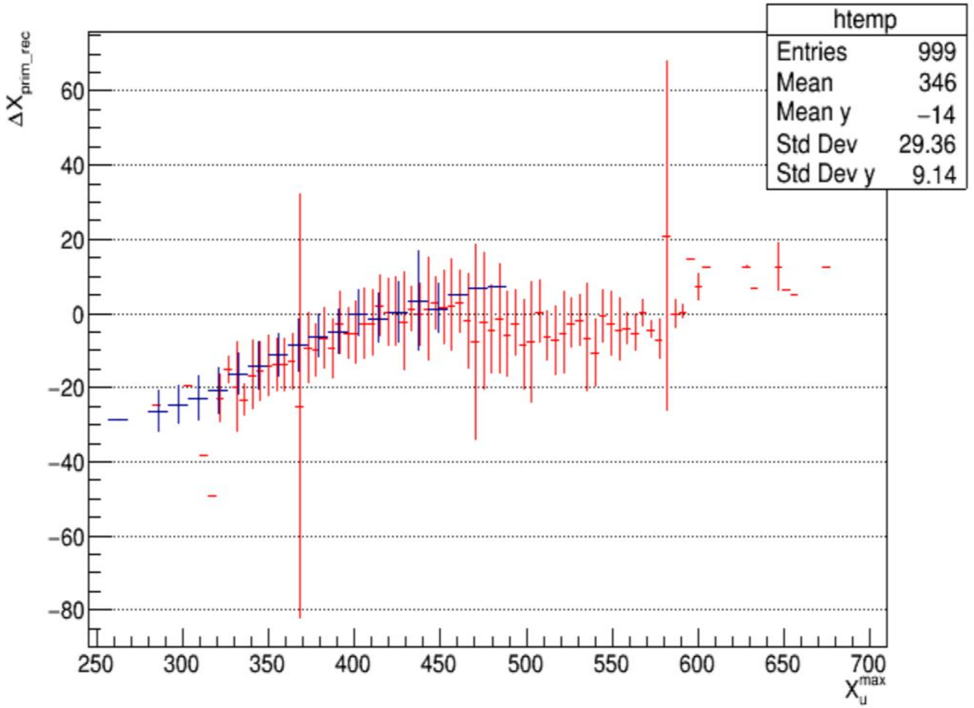

survial muon(>1GeV && 400m<rsfp<1km)
Proton with 5PeV and θ=45°
real depth
reconstructed depth
cut_muon_3
Entries 8760
Mean 403.2
Std Dev 178.3
χ² / ndf 95.72 / 69
p0 0.03387 ± 0.07574
p1 218.7 ± 4.1
p2 396.9 ± 7.3
p3 155.8 ± 2.4
rec_cut_muon_3
Entries 8776
Mean 402
Std Dev 173.8
χ² / ndf 87.6 / 67
p0 −0.003187 ± 0.072699
p1 207.8 ± 3.7
p2 404 ± 7.0
p3 162.3 ± 2.4
produced muons
depth/[g/cm²]

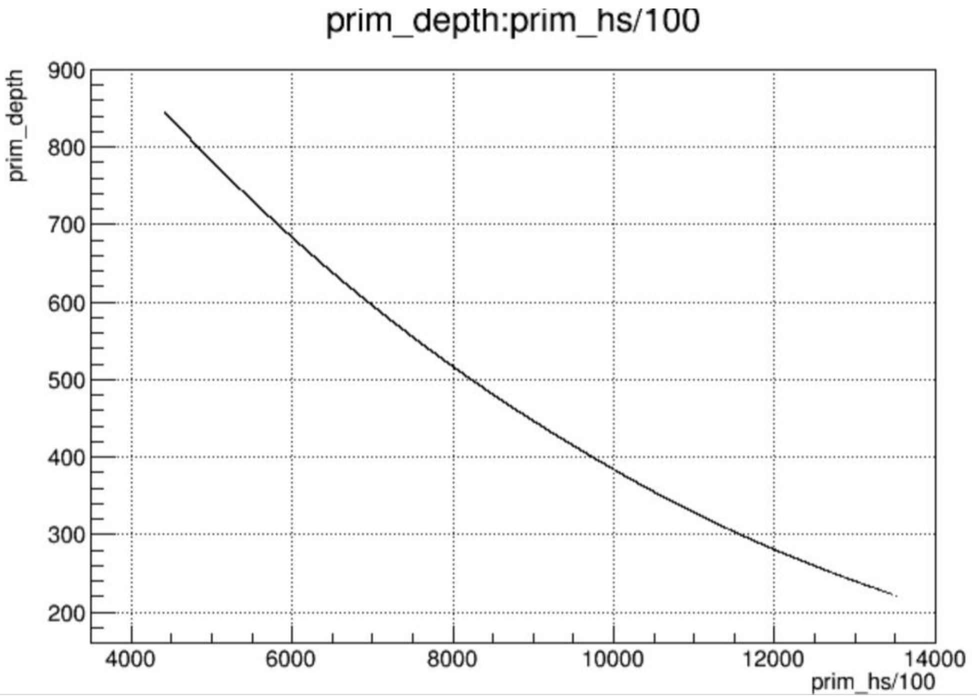

survial muon(>1GeV && 400m<rsfp<1km)
Proton with 1PeV and θ=45°
real depth
reconstructed depth
cut_muon_3
Entries 2458
Mean 445.3
Std Dev 163.9
χ² / ndf 174.8 / 75
p0 0.1353 ± 0.0574
p1 166.7 ± 4.1
p2 444.5 ± 7.4
p3 50.32 ± 1.40
rec_cut_muon_3
Entries 2463
Mean 436.3
Std Dev 160.5
χ² / ndf 85.94 / 67
p0 0.02161 ± 0.09212
p1 178.4 ± 4.8
p2 438.8 ± 9.7
p3 49.81 ± 1.39
produced muons
depth/[g/cm²]


survial muon(>1GeV && 400m<rsfp<1km)
Iron with 10PeV and θ=45°
real depth
reconstructed depth
cut_muon_4
rec_cut_muon_4
produced muons
depth/[g/cm²]


survial muon(>1GeV && 400m<rsfp<1km)
Iron with 5PeV and θ=45°
real depth
reconstructed depth
cut_muon_3
Entries 14976
Mean 378.2
Std Dev 179.7
χ² / ndf 187.9 / 75
p0 0.4658 ± 0.0407
p1 209.4 ± 2.4
p2 314.2 ± 4.7
p3 270.9 ± 3.0
rec_cut_muon_3
Entries 15001
Mean 383
Std Dev 174.7
χ² / ndf 131.9 / 71
p0 0.298 ± 0.045
p1 205.8 ± 2.5
p2 345.2 ± 4.8
p3 278.2 ± 3.1
produced muons
depth/[g/cm²]


survial muon(>1GeV && 400m<rsfp<1km)
Iron with 1PeV and θ=45°
real depth
reconstructed depth
cut_muon_3
rec_cut_muon_3
produced muons
depth/[g/cm²]


htemp
Entries 999
Mean 346
Mean y −14
Std Dev 29.36
Std Dev y 9.14
ΔX prim_rec
X u max
60
40
20
0
−20
−40
−60
−80
250 300 350 400 450 500 550 600 650 700


prim_depth:prim_hs/100
prim_depth
prim_hs/100
900
800
700
600
500
400
300
200
4000 6000 8000 10000 12000 14000