

# Poster 2



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

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on behalf of LHAASO collaboration

# Introduction



## Motivation:

1.  $p + N(\text{or } A) \rightarrow p + N(\text{or } A) + n\pi^{\pm,0} + X; \pi^{\pm} \rightarrow \mu^{\pm} + (\bar{\nu}_{\mu})$
2. Longitude development of muons preserves the information of primary particles and plays an important role in study of composition identification
  - Measure the cosmic ray energy spectrum and mass composition around knee region
  - Helps to study the hadronic interaction model

## Data Sample:

- EPOS-LHCR; QGSJET-III-01;SIBYLL 2.3e (corsika 7.8)
- Altitude: 4424m (LHAASO)
- Zenith:  $10^{\circ}$ - $30^{\circ}$  ( $X \sim 609-693 \text{ g/cm}^2$ )
- Energy: 1PeV-63PeV
- Index:  $-1$

	1-10PeV	10-16PeV	16-50PeV	50-63PeV
Iron	3000	600	600	600
Proton	3000	600	600	600

# Reconstruction of muon production depth

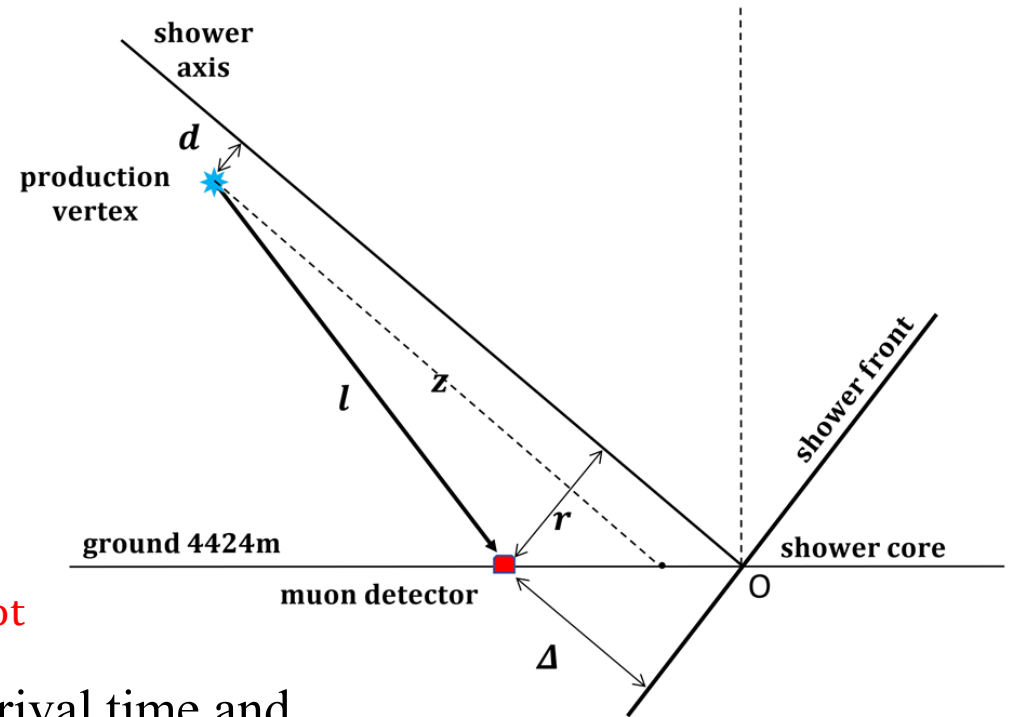


## Basic Assumptions in Muon Production Depth Reconstruction:

- Muon propagation path is collinear with its parent particle
- Muon travels in a straight line at the speed of light

## Geometric method:

- $$z = \frac{1}{2} \left( \frac{(r-d)^2}{ct_g} - ct_g \right) + \Delta * \frac{r-d}{r}$$
- Geometrical delay time:  $ct_g = l - \left( z - \Delta \cdot \frac{r-d}{r} \right) \propto t_{tot}$
- Total delay time  $t_{tot}$ : difference between the muon arrival time and the shower-core arrival time



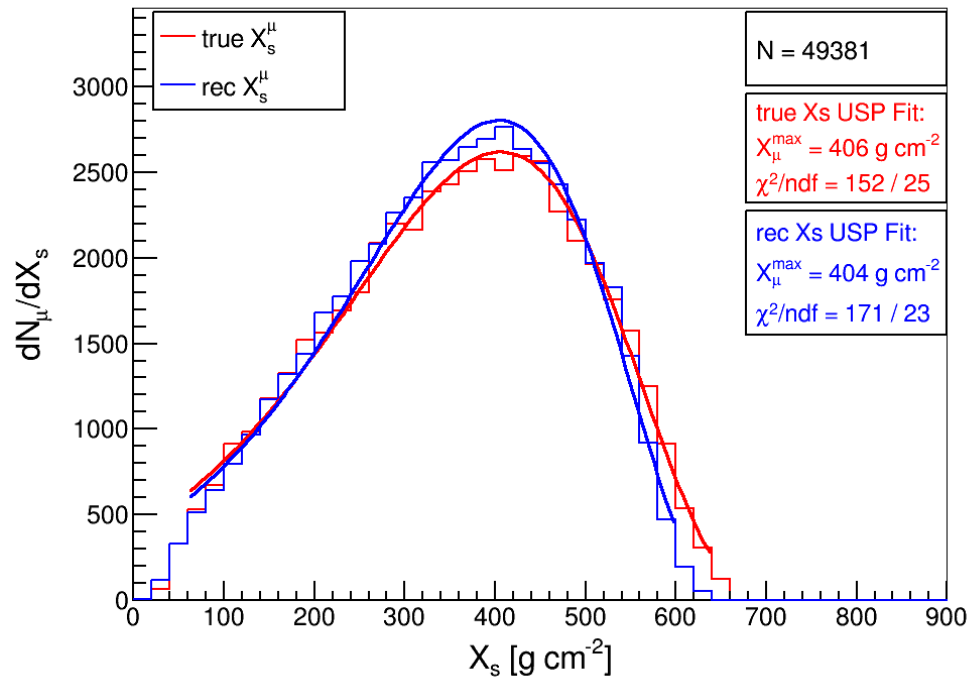
# Measurement of the $X_{\max}^{\mu}$ of muons



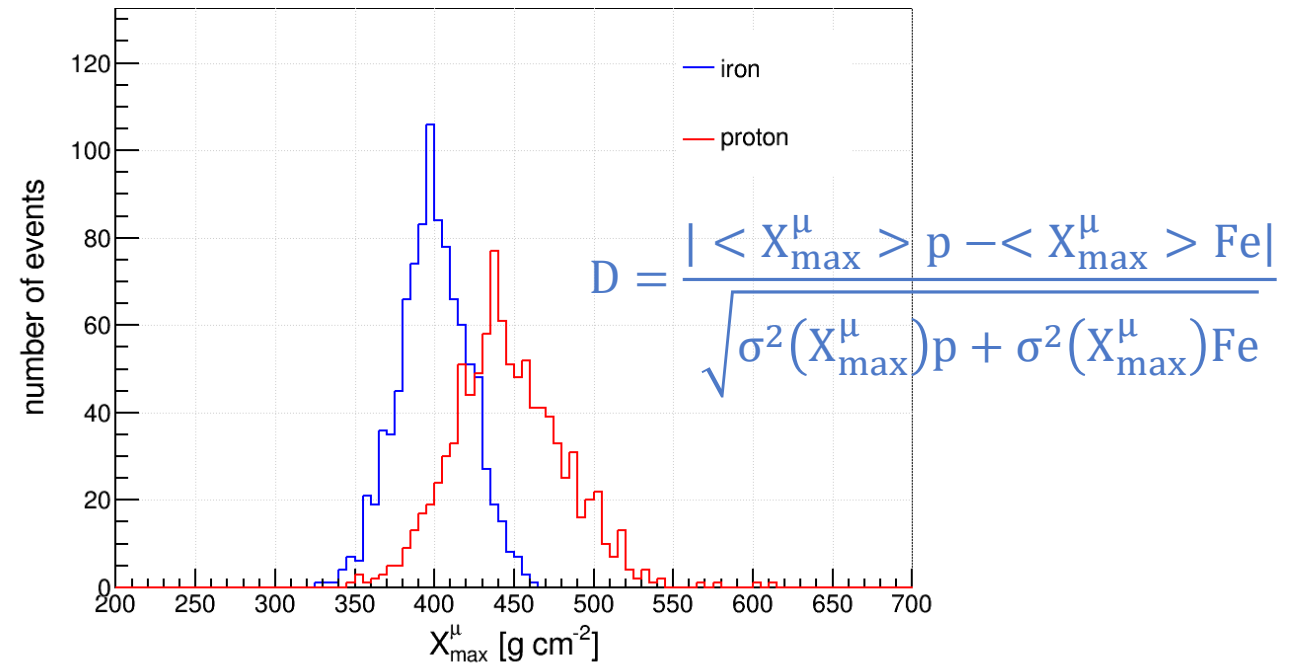
USP function:

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

$X_{\max}^{\mu}$ : Maximum depth of muon production;

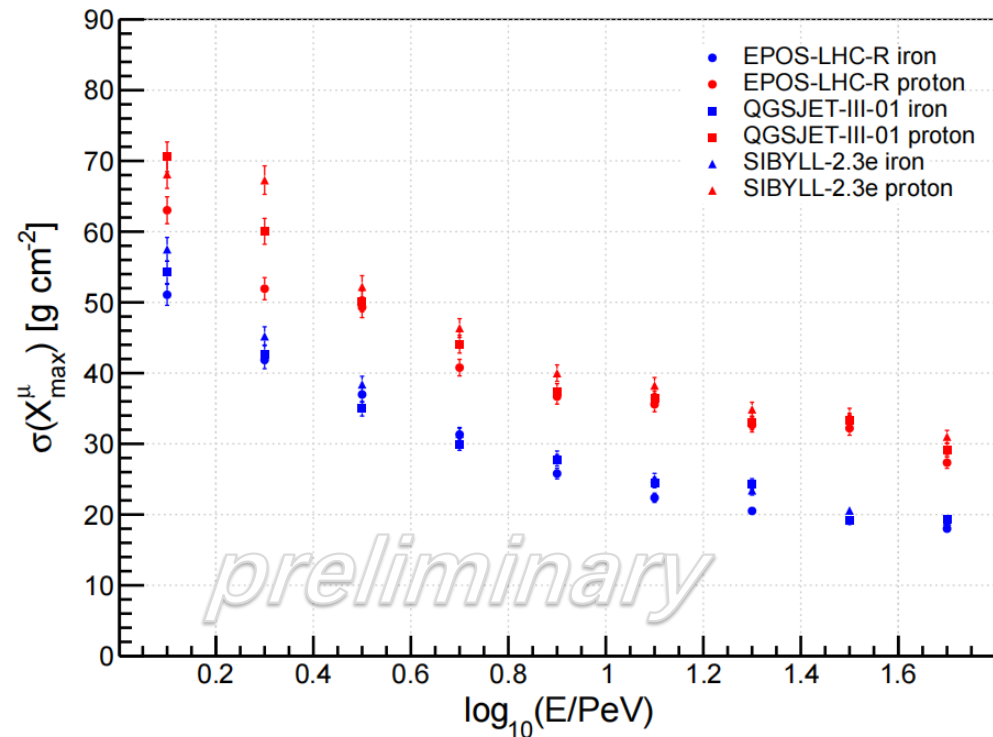
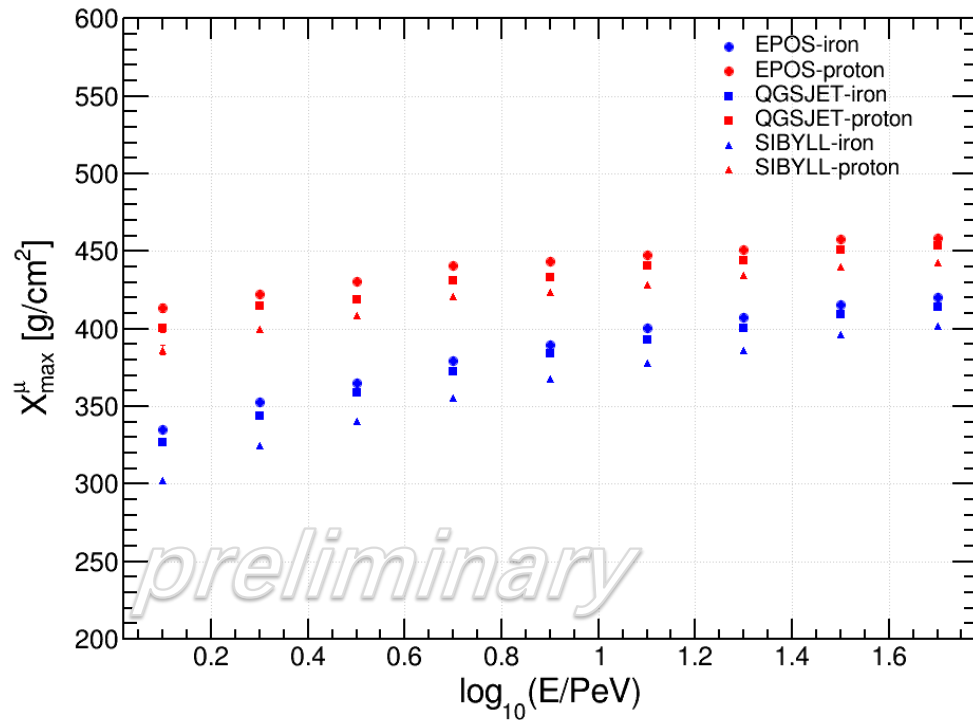
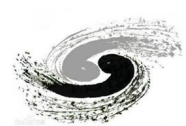


Muon Production Depth distribution @ one event



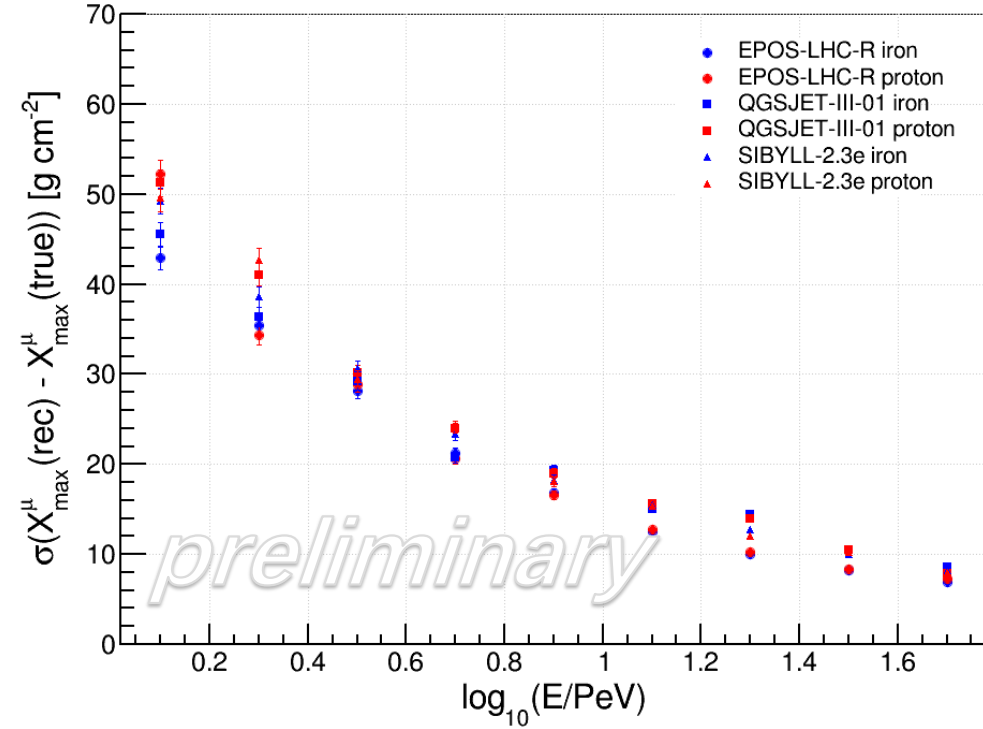
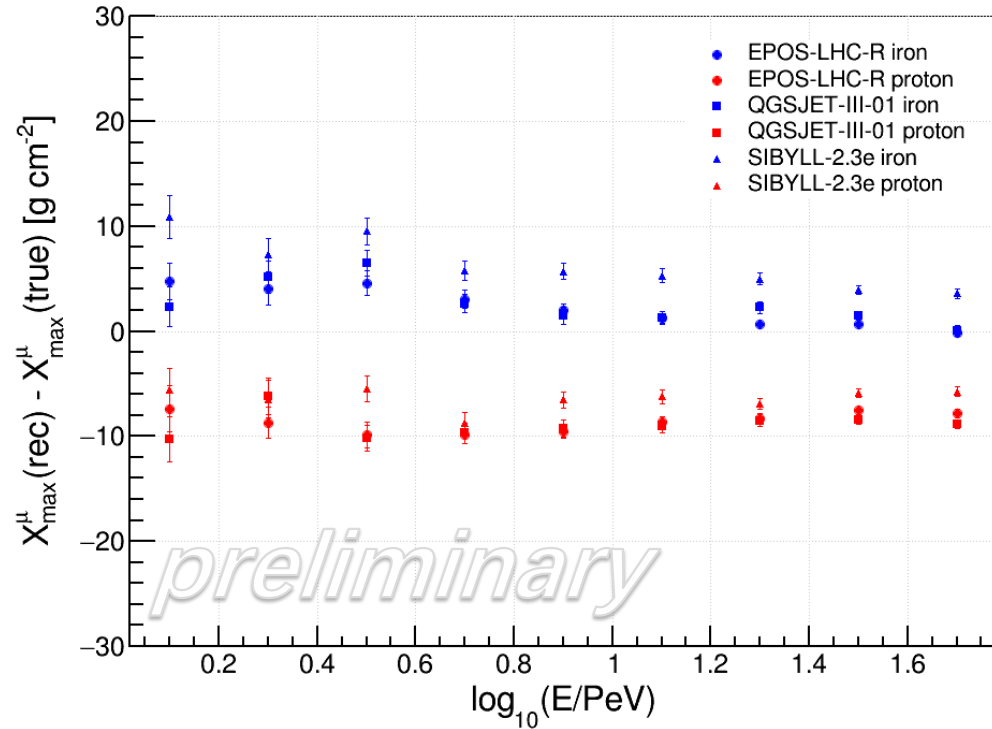
$X_{\max}^{\mu}$  distribution of Proton and Fe @10PeV

# Features of the $X_{\max}^{\mu}$



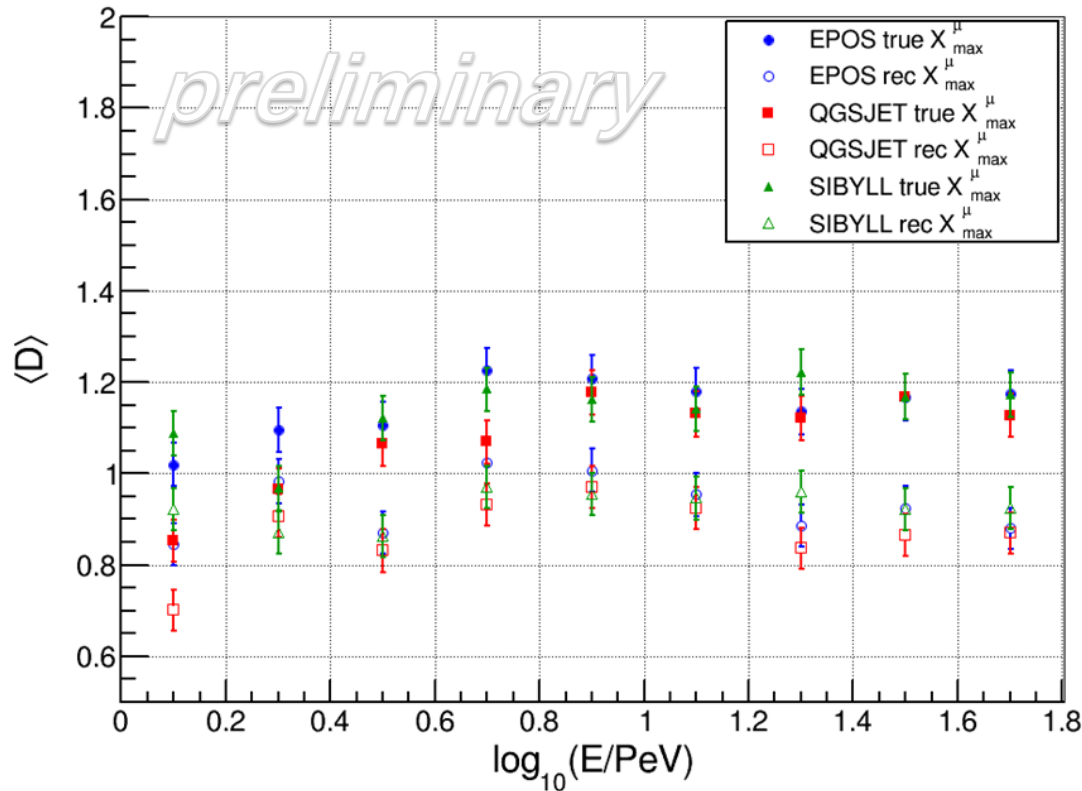
- $X_{\max}^{\mu}$  **increases with energy**, while its **uncertainty ( $\sigma(X_{\max}^{\mu})$ ) decreases**, showing similar trends for proton and iron primaries.
- Both  $\langle X_{\max}^{\mu} \rangle$  and  $\sigma(X_{\max}^{\mu})$  are **composition-sensitive**.

# Reconstruction performance of $X_{\max}^{\mu}$



- For both Proton and Fe, the bias **remains within  $\pm 10$  g/cm<sup>2</sup>** above 1 PeV, and decreases with energy.
- The **resolution is better than 50 g/cm<sup>2</sup>** above 1 PeV, and also decrease with energy.
- The reconstruction method does is **insensitive to** hadronic interaction models.

# Composition discrimination



$$\text{Proton-Fe discrimination: } D = \frac{|\langle X_{\text{max}}^{\mu} \rangle_{\text{p}} - \langle X_{\text{max}}^{\mu} \rangle_{\text{Fe}}|}{\sqrt{\sigma^2(X_{\text{max}}^{\mu})_{\text{p}} + \sigma^2(X_{\text{max}}^{\mu})_{\text{Fe}}}}$$

**Systematic errors** are combined from:

- Arrive time resolution is set to 6.7 ns.
- Zenith angle resolution is set to 0.05 degree.
- Shower core location resolution is set to 1 m.

**The reconstruction of  $X_{\text{max}}^{\mu}$  based on LHAASO is ongoing, more results will be presented.**

- True:  $D \approx 1.1$ ; Rec:  $D \approx 0.9$  @1-63PeV.
- Although  $D$  is reduced after reconstruction, proton and iron can still be distinguished

## Thanks for your attention!