Karlsruher Institut für Technologie

Double Doctoral degree in Astrophysics DDAp

UNIVERSIDAD NACIONAL DE SAN MARTÍN

Hybrid Universality Air Shower Reconstruction

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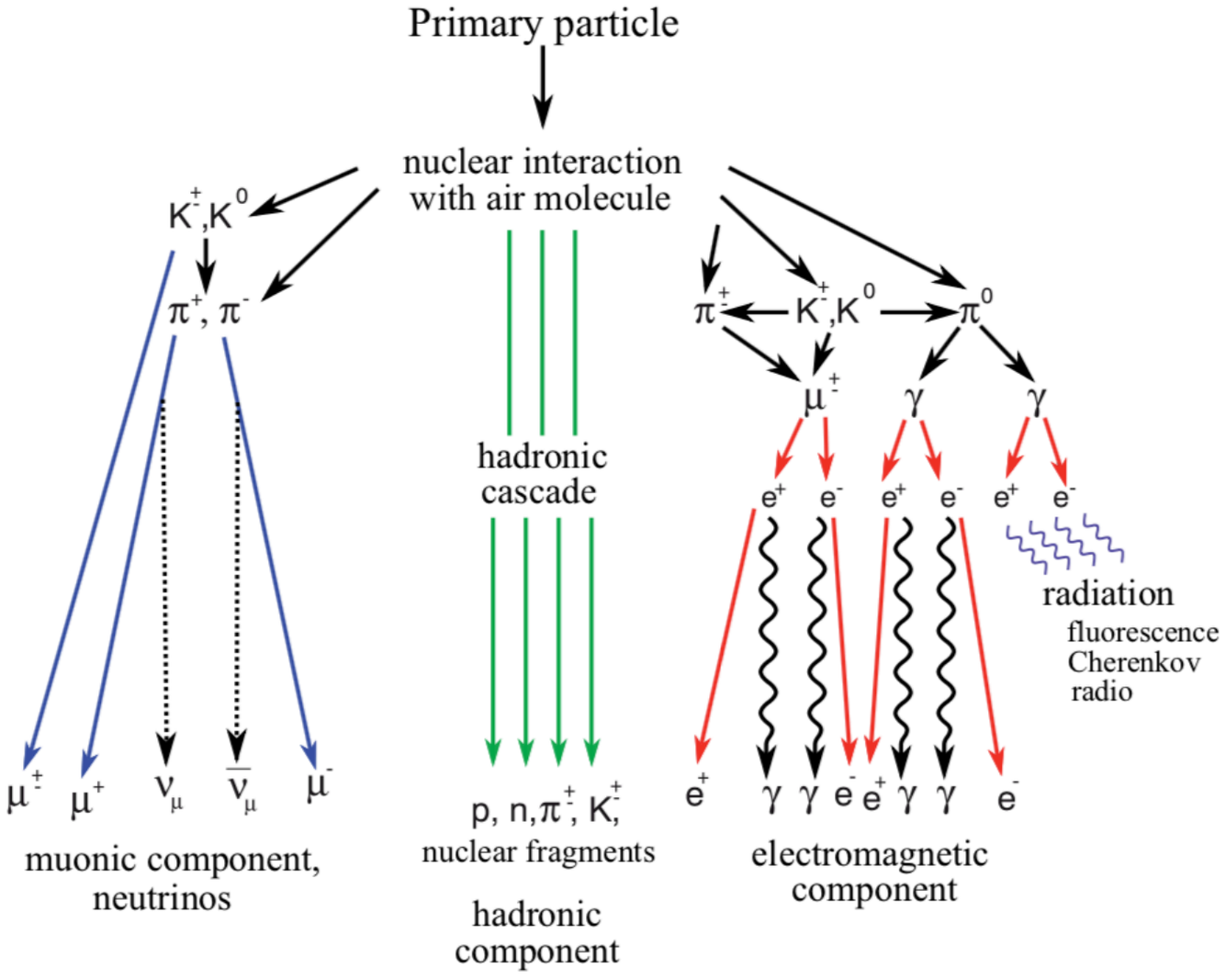
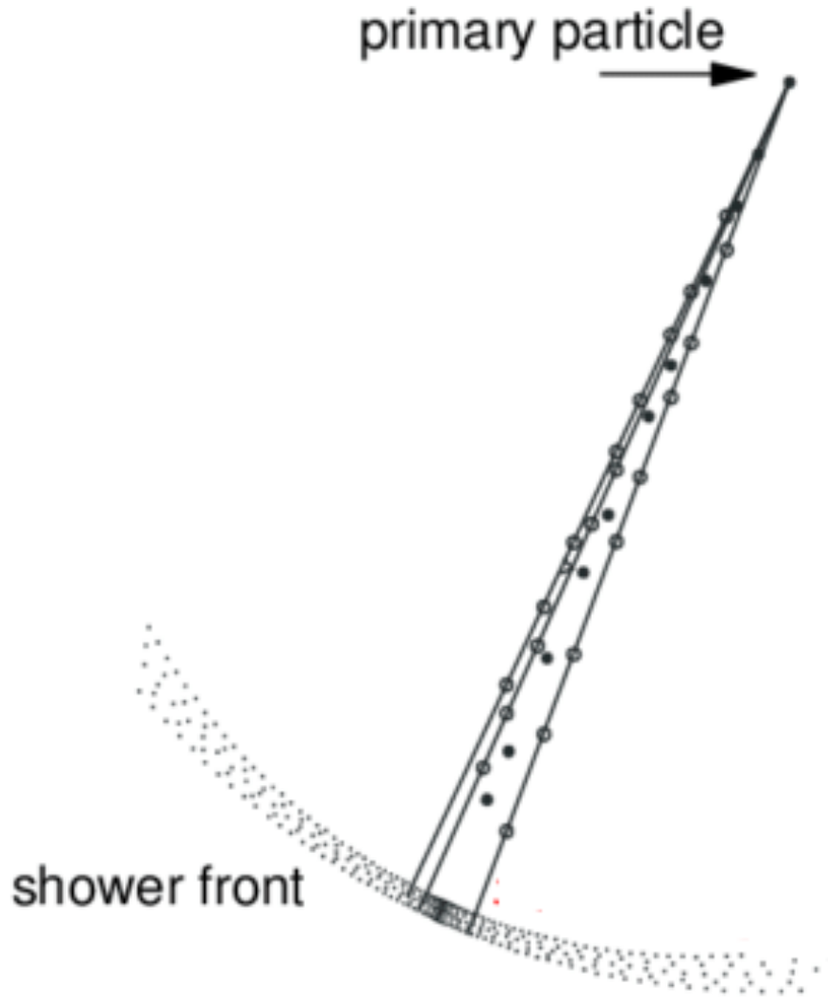
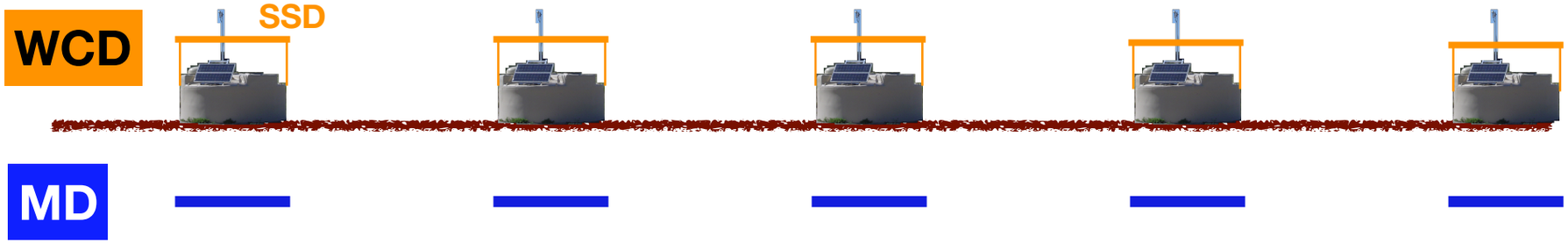
IKP (KIT) **ITeDA (UNSAM)**

Extensive Air Showers



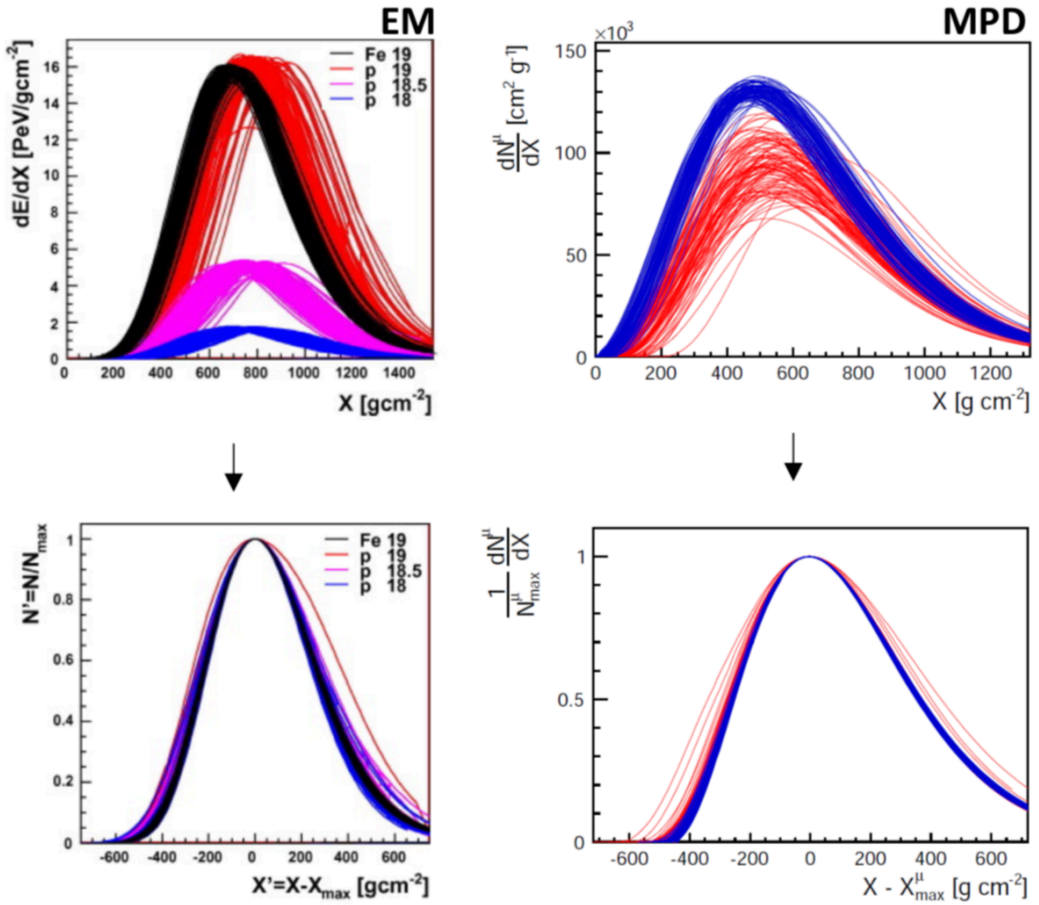


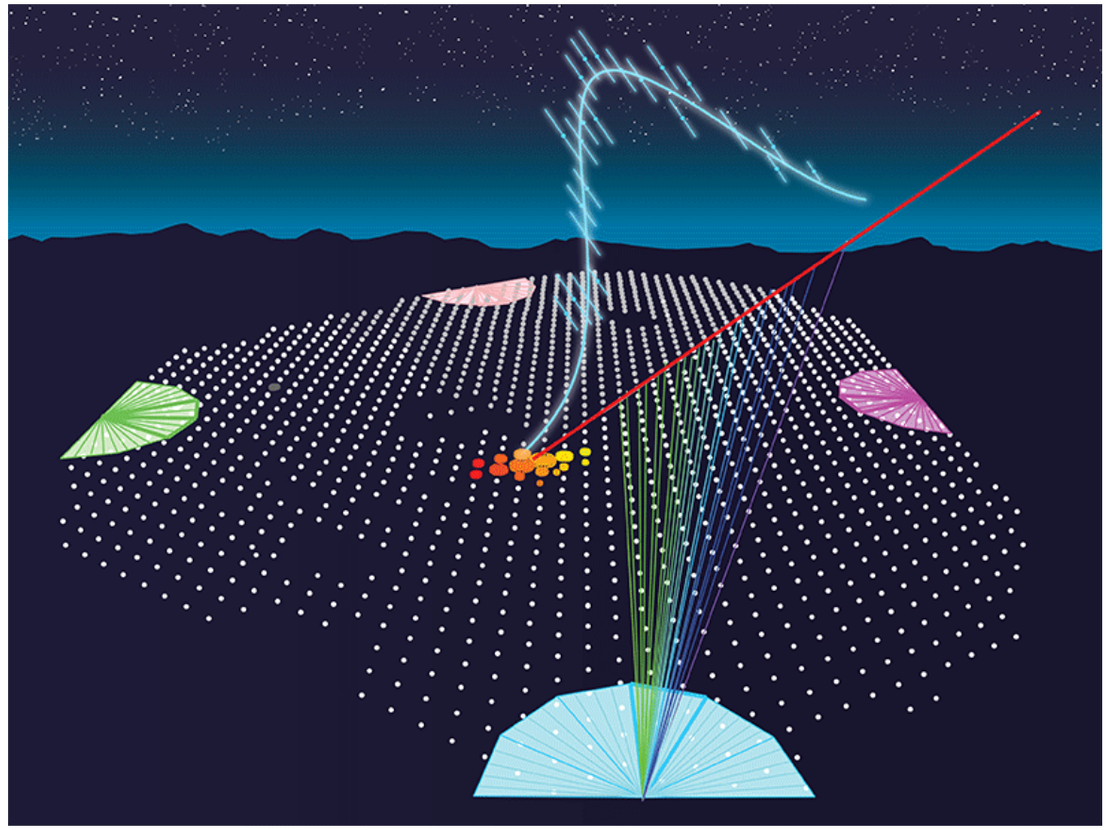


Shower Components:

- Muon
- EM Pure
- EM Muon
- EM Hadron

Principles of Shower Universality





1. Normalized longitudinal profile of an air shower is equivalent for each primary

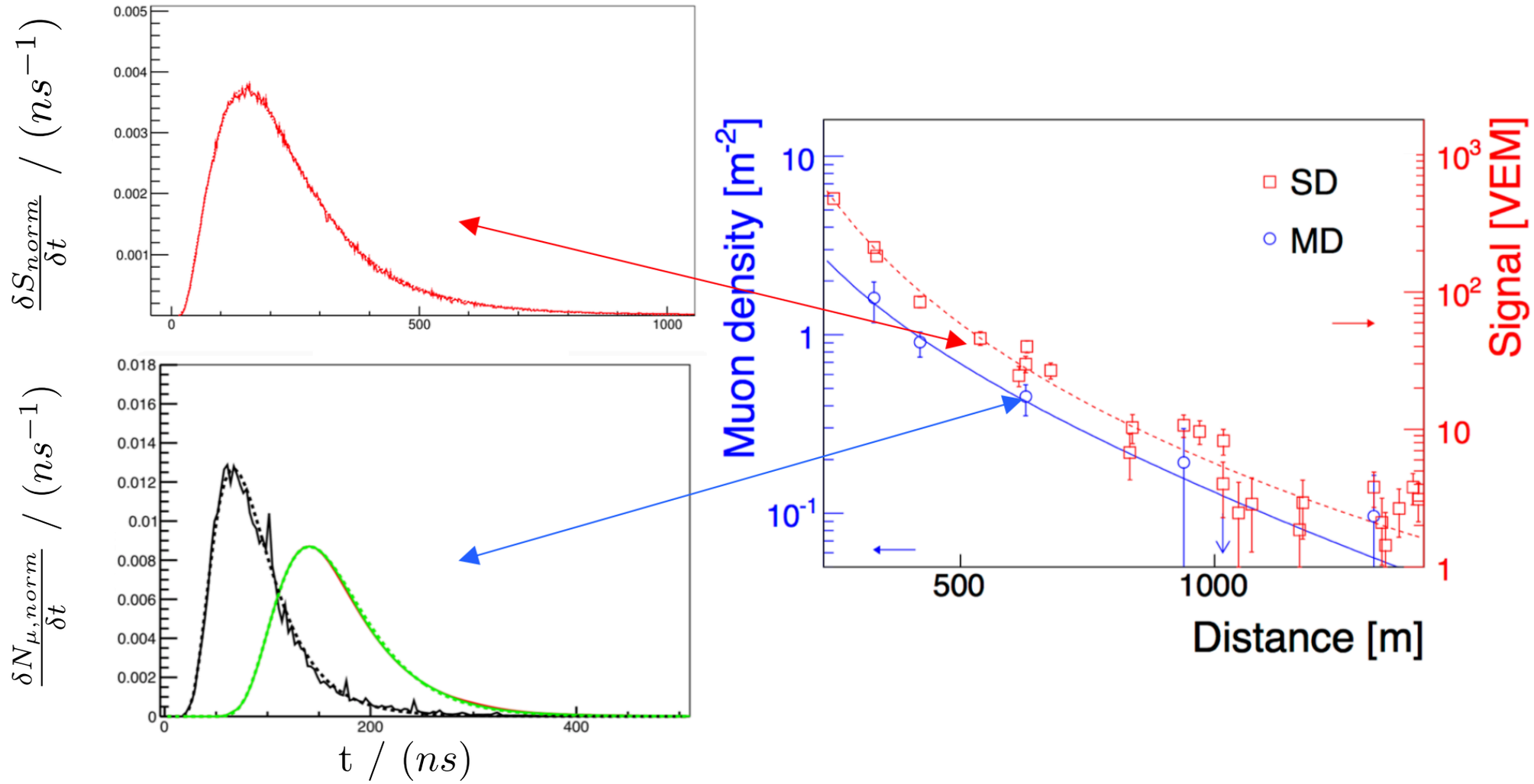
2. Showers with the same shower “age” have the same fractional rate of change with increasing depth

$$X' = X - X^{(\mu)}_{max}$$

$$N' = N/N^{(\mu)}_{max}$$

Principles of Shower Universality

Objective: 1-to-1 mapping of shower particle **signal** & **time** distribution at any known stage of the shower development to E, $X^{(\mu)}_{max}$, R_μ and geometry



Previous Universality model/ reconstruction

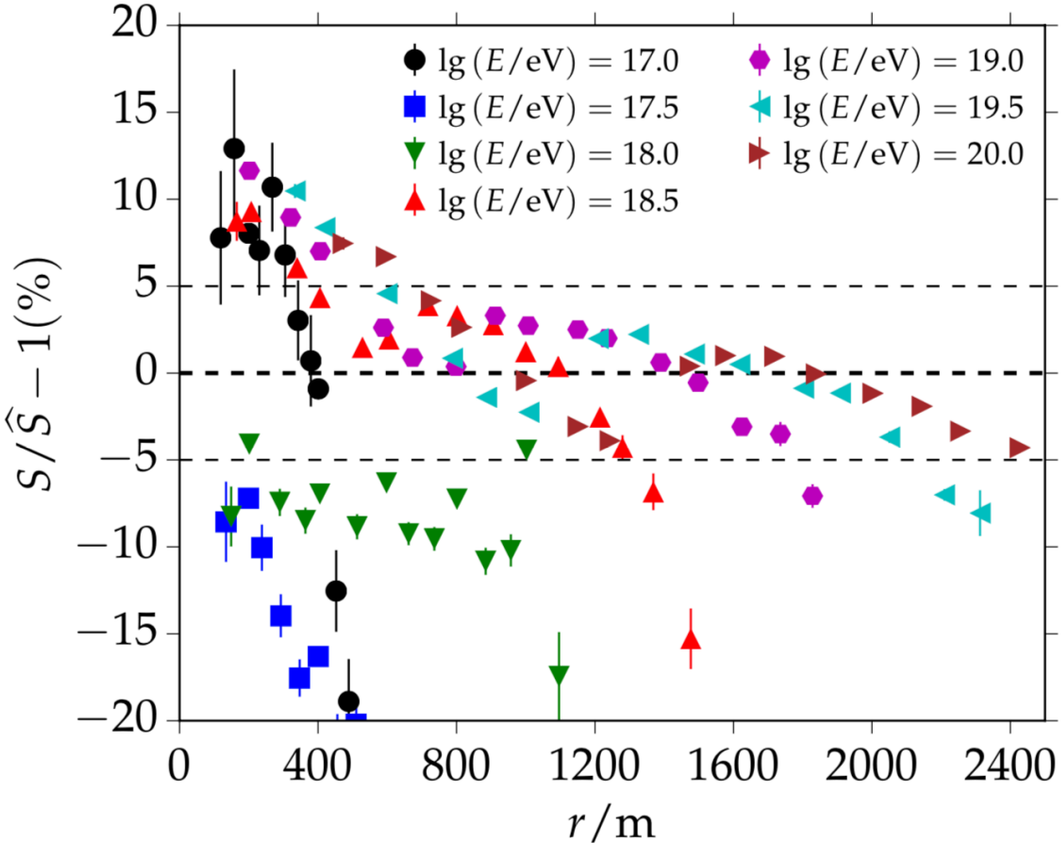
Many detectors, many Universality models. Why?

- SSD: provides accurate indirect measurement of particle components
- MD: direct muon counting, sets minimum muon limit for WCD & SSD

} **towards Hybrid Universality**

Tasks:

- ☒ use below lg(E/eV) < 18.5
- ☒ Universality Model for MD
- ☒ account for MPD
- ☒ SSD model
- ☒ hybrid reconstruction



Signal Model

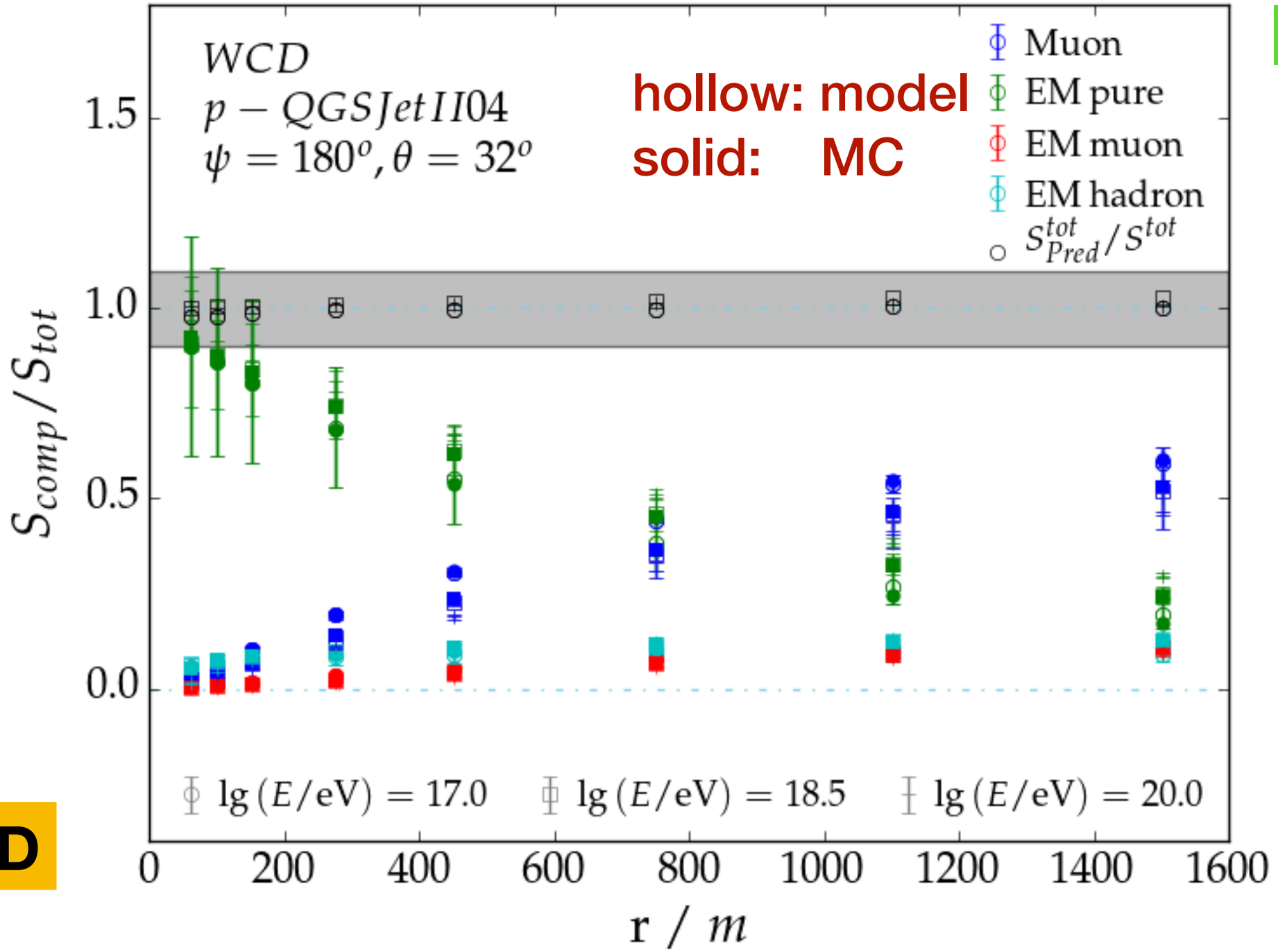
Ansatz:

$$S_{tot} = \sum_{comp=1,..,4} S_{ideal}^{comp}(r, \Delta X, E) \cdot f_{conv}^{comp}(r, \Delta X, \psi, \theta) \cdot f_{atm}^{comp}(r, \rho_{ground}^{air}) \cdot f_{mod}^{comp}(r, \psi, \theta) \cdot f_{N^{\mu}}^{comp}(r, R_{\mu})$$

- **C**onvert S_{ideal} into S_{real}
- **A**ccount for atmospheric fluctuations
- **P**arametrize asymmetries between upstream/ downstream particles
- **O**ptimize parametrization to account for shower-to-shower fluctuations

$$R_{\mu} = \frac{S_{\mu}}{S_{\mu}^{ref}}$$

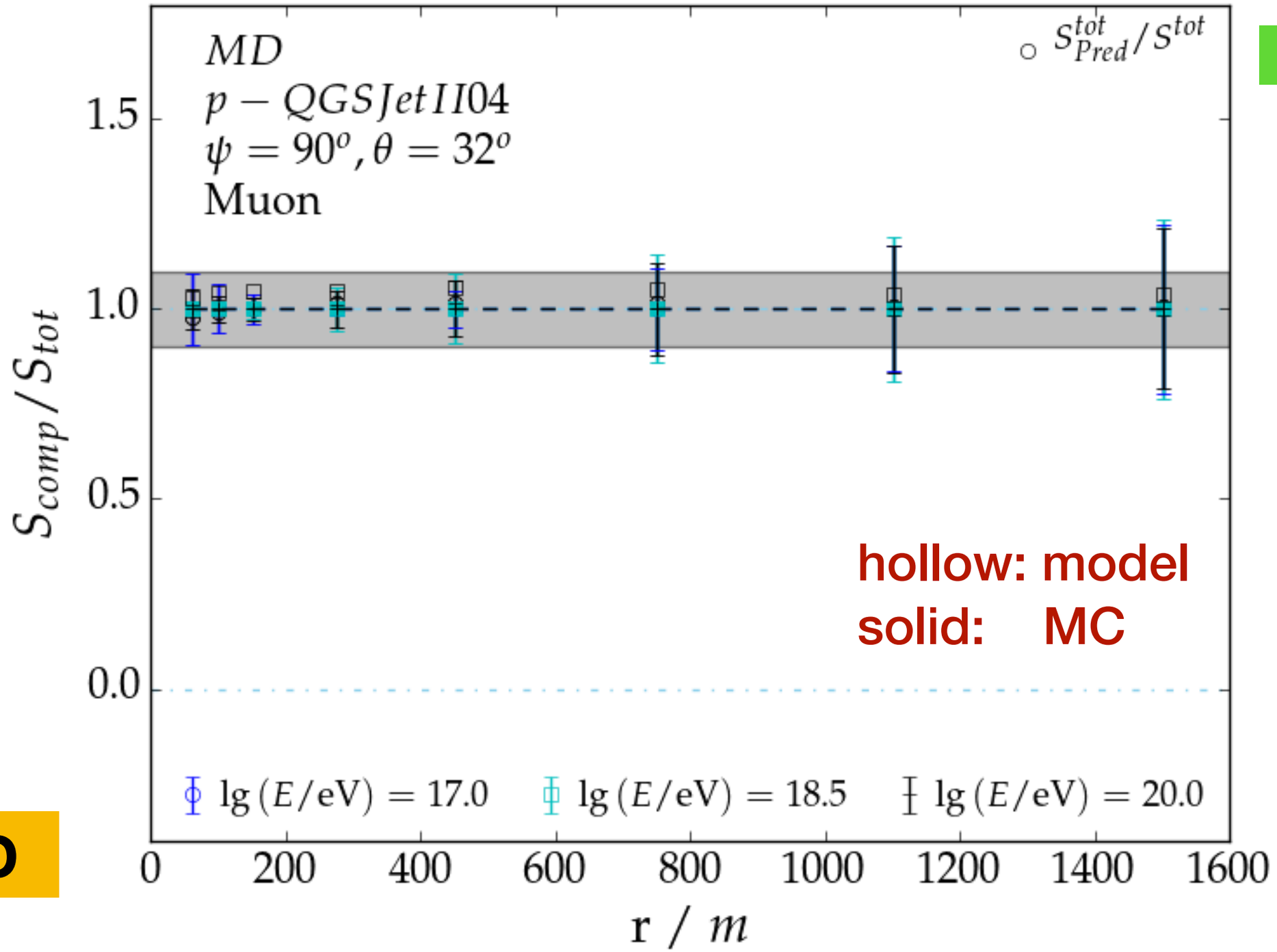
Signal Model - Validation



±5%

WCD

Signal Model - Validation



±5%

MD

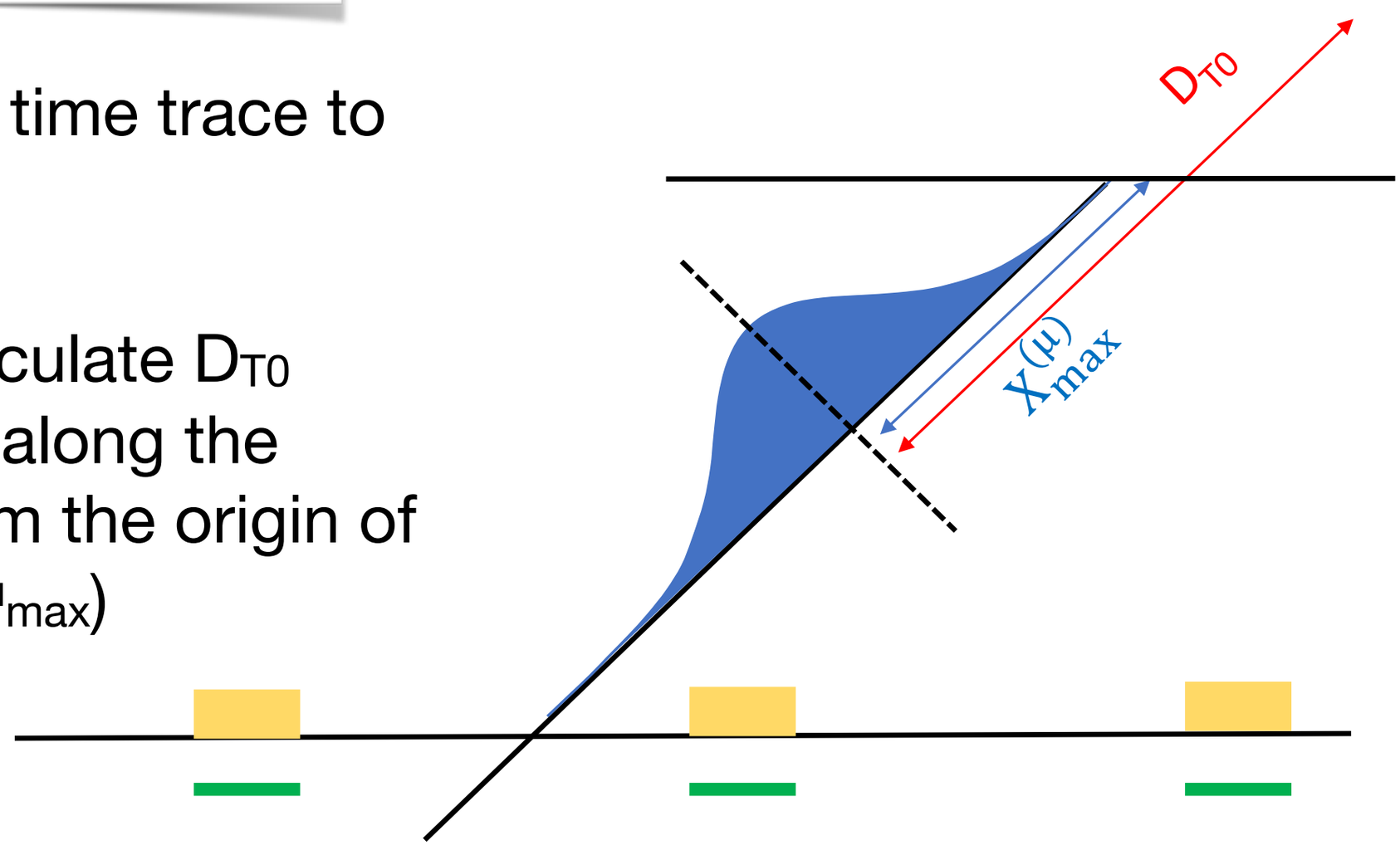
Time Model

Ansatz:

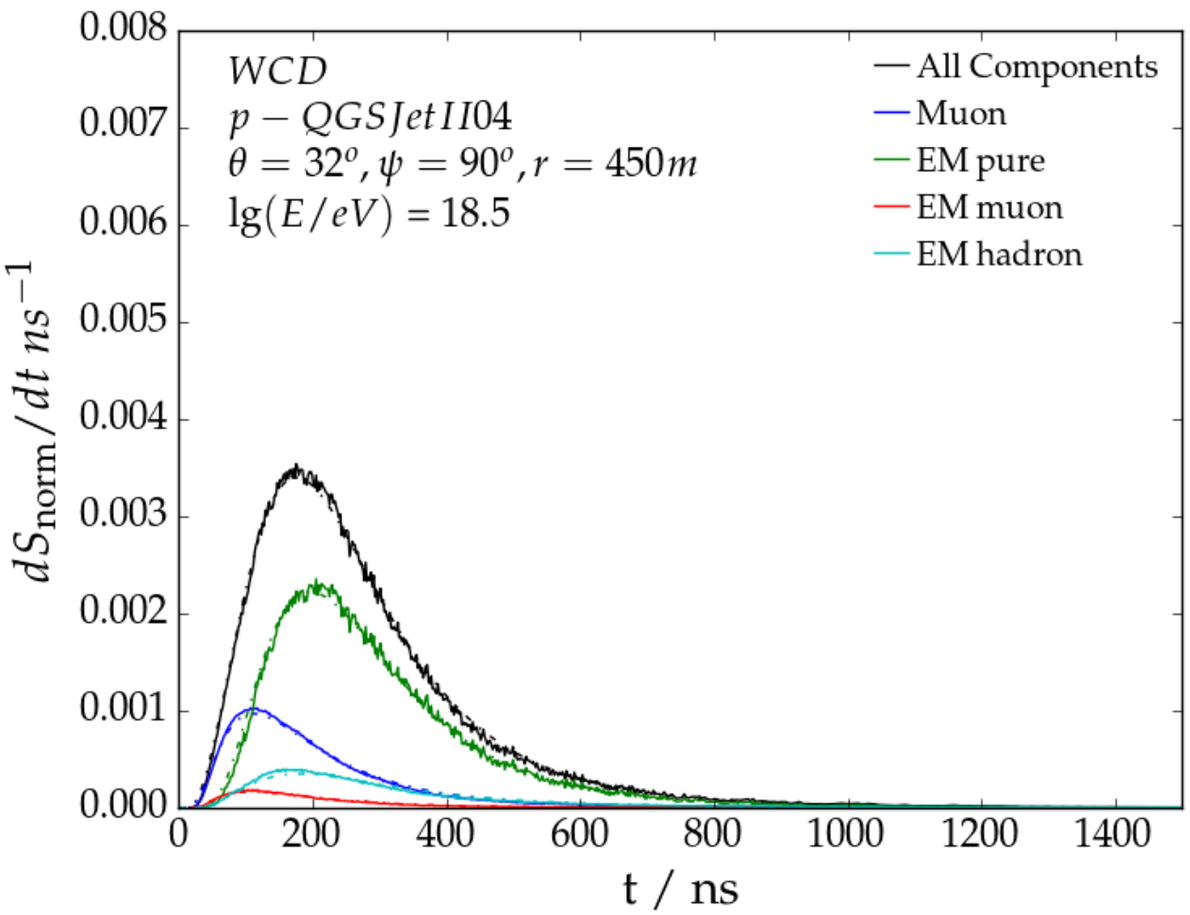
$$\frac{dS}{dt}(t) = \frac{1}{\sqrt{2\pi}(t-t_0)s} e^{-\frac{(ln(t-t_0)-m)^2}{2s^2}}$$

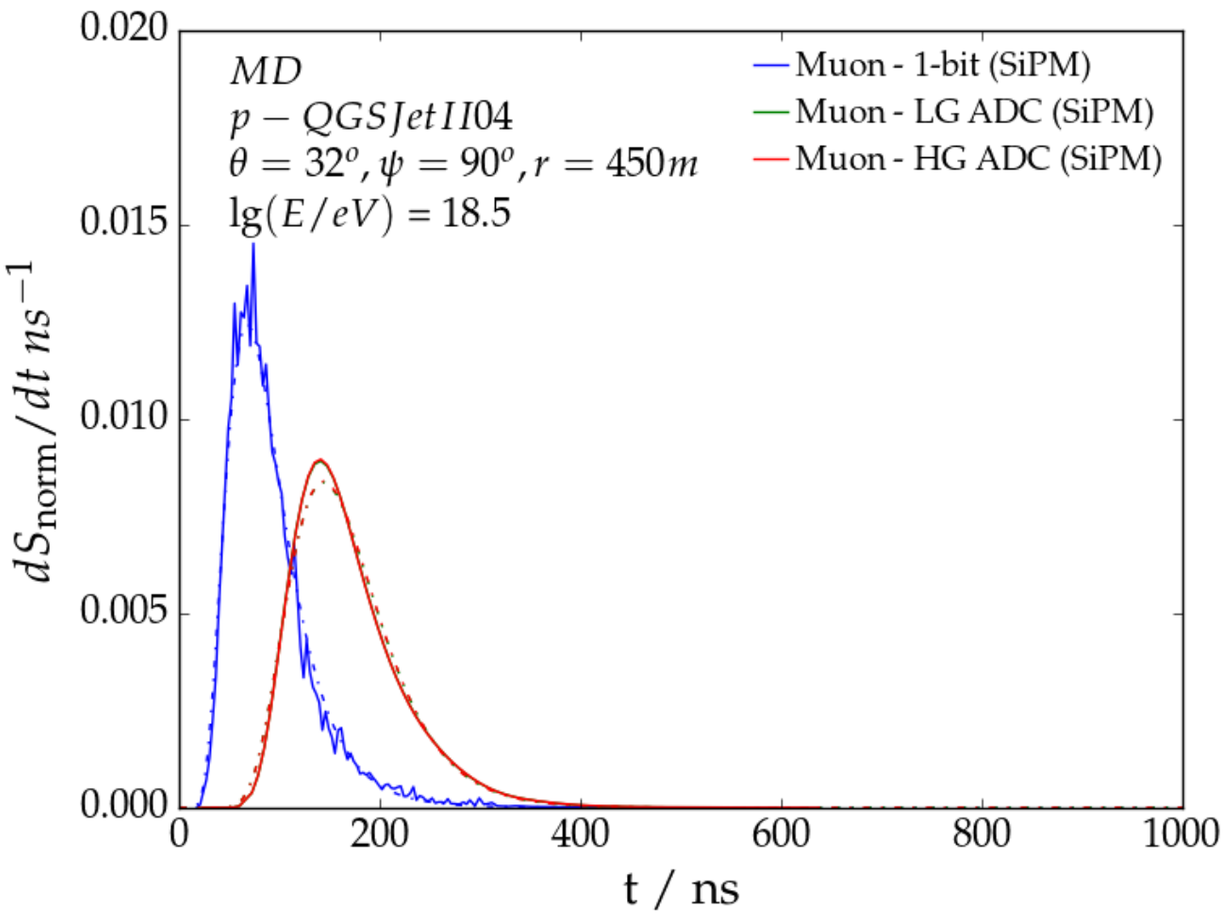
- using complete time trace to obtain (t_0, m, s)

- t_0 is used to calculate D_{T0} (distance in *km* along the shower axis from the origin of times to X_{max}/$X\mu_{max}$)



Time Model - Validation

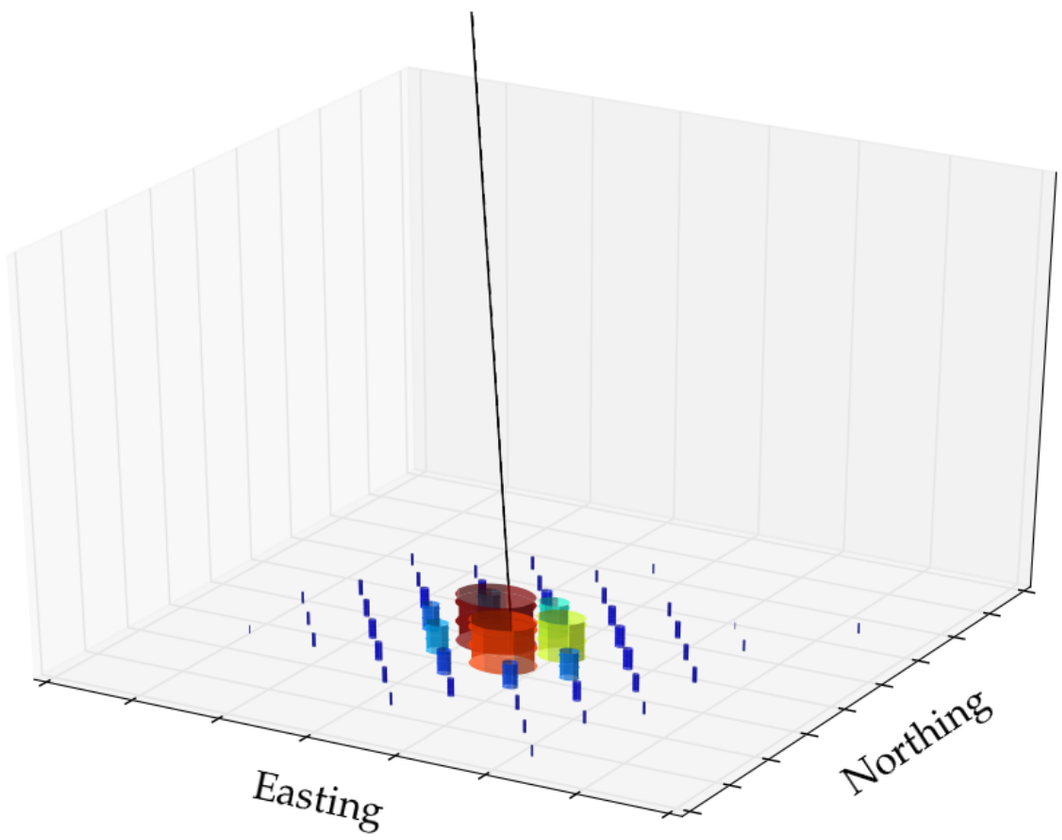




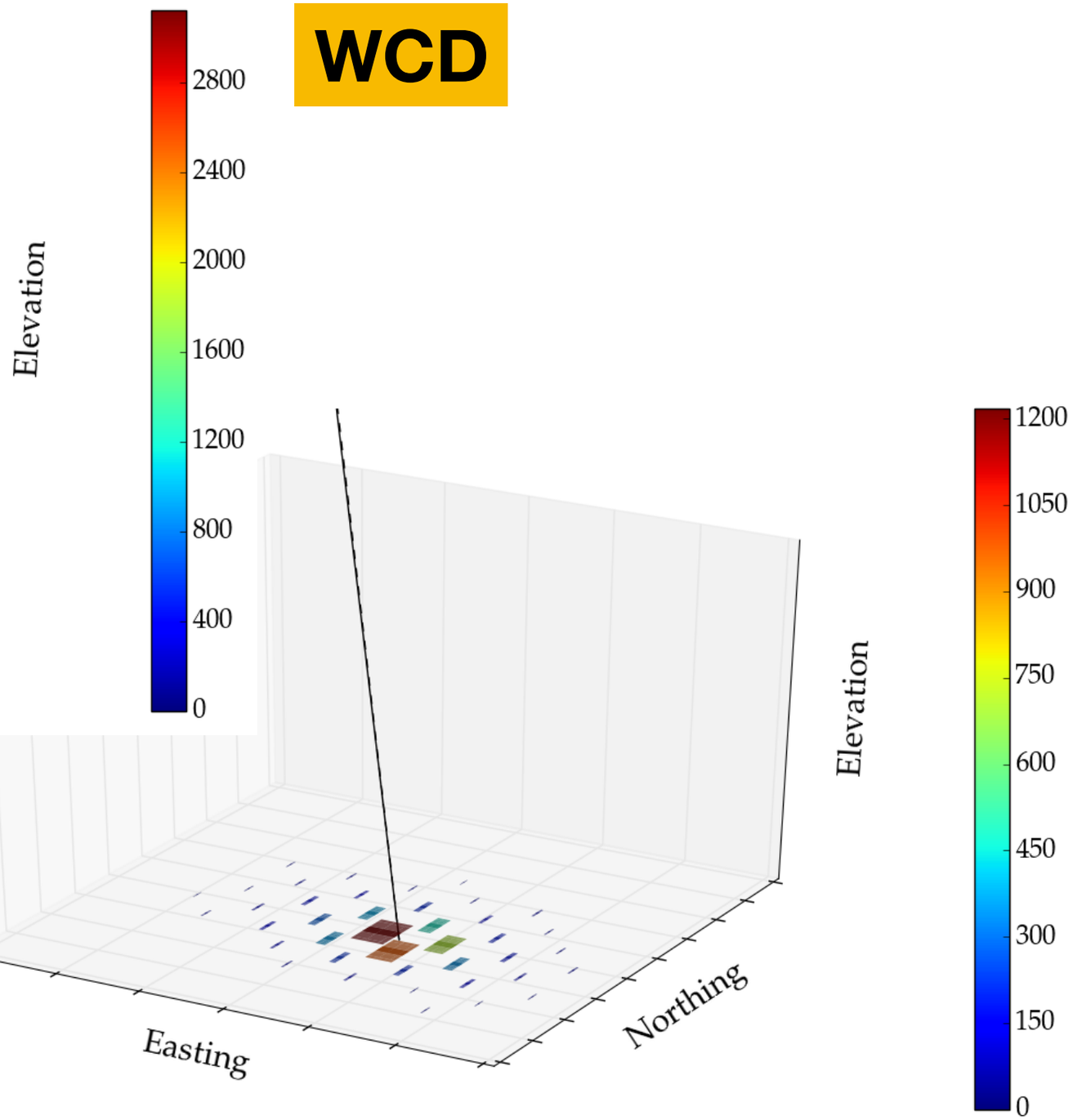
WCD

MD

Hybrid Universality Reconstruction

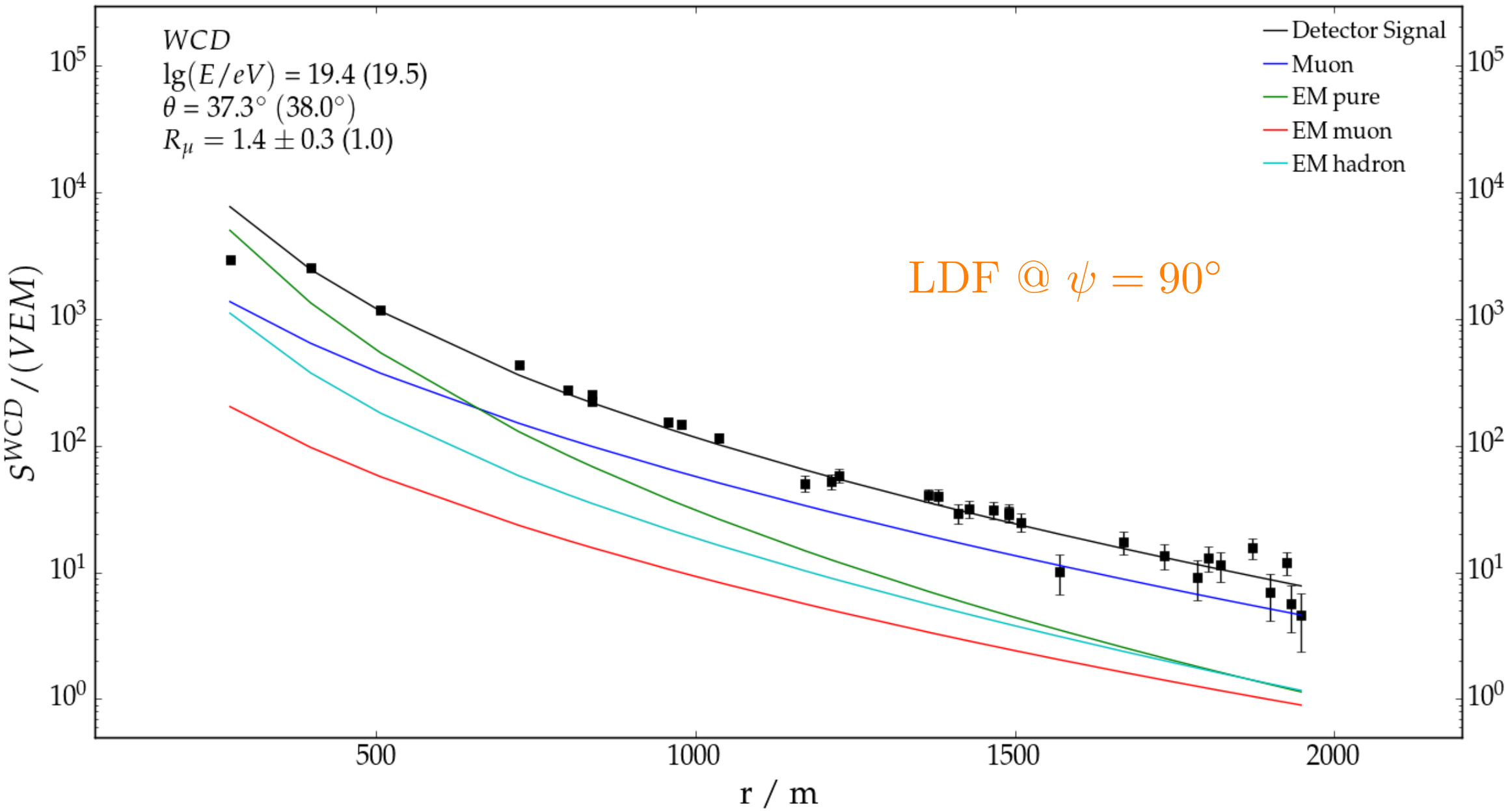


MD

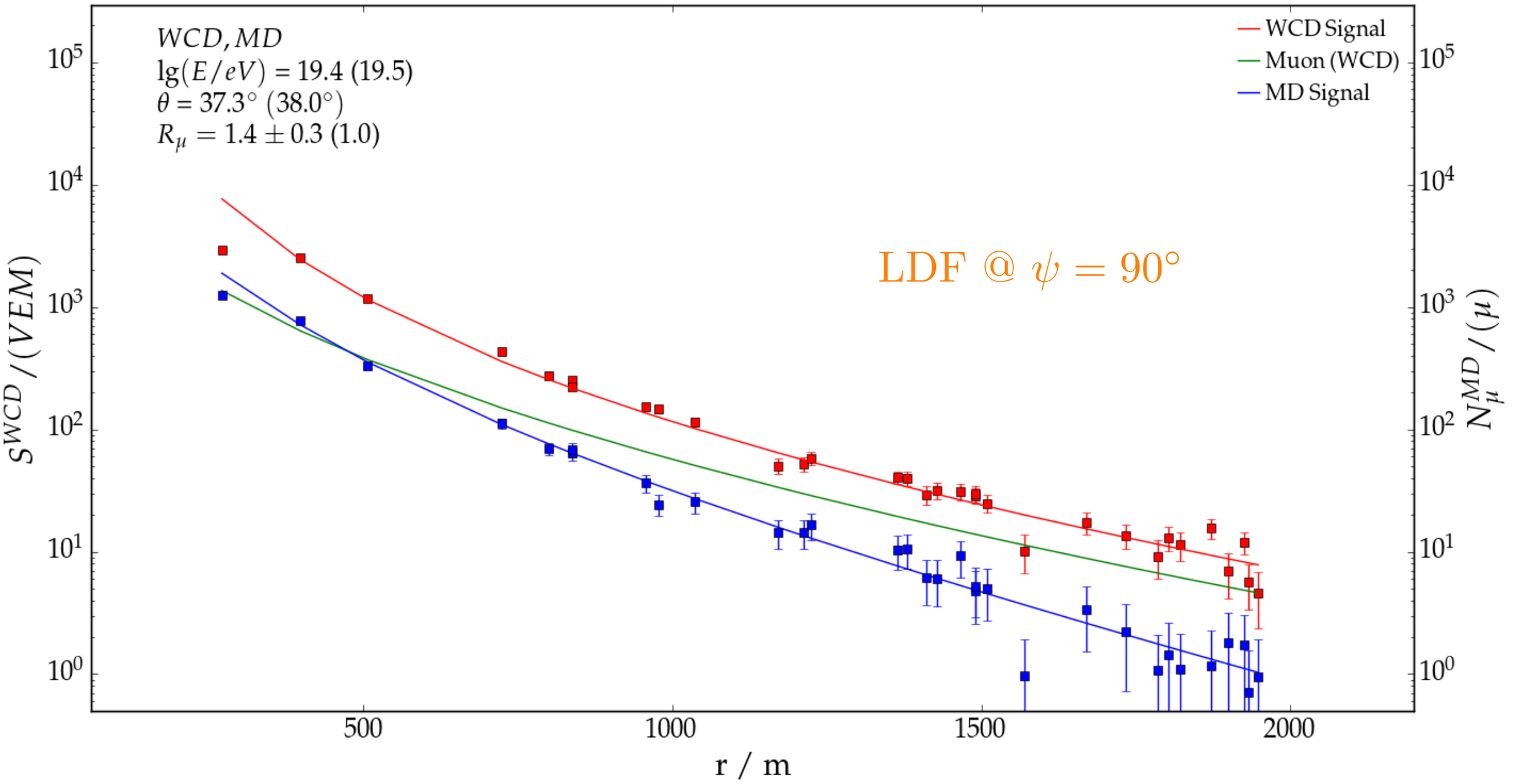


WCD

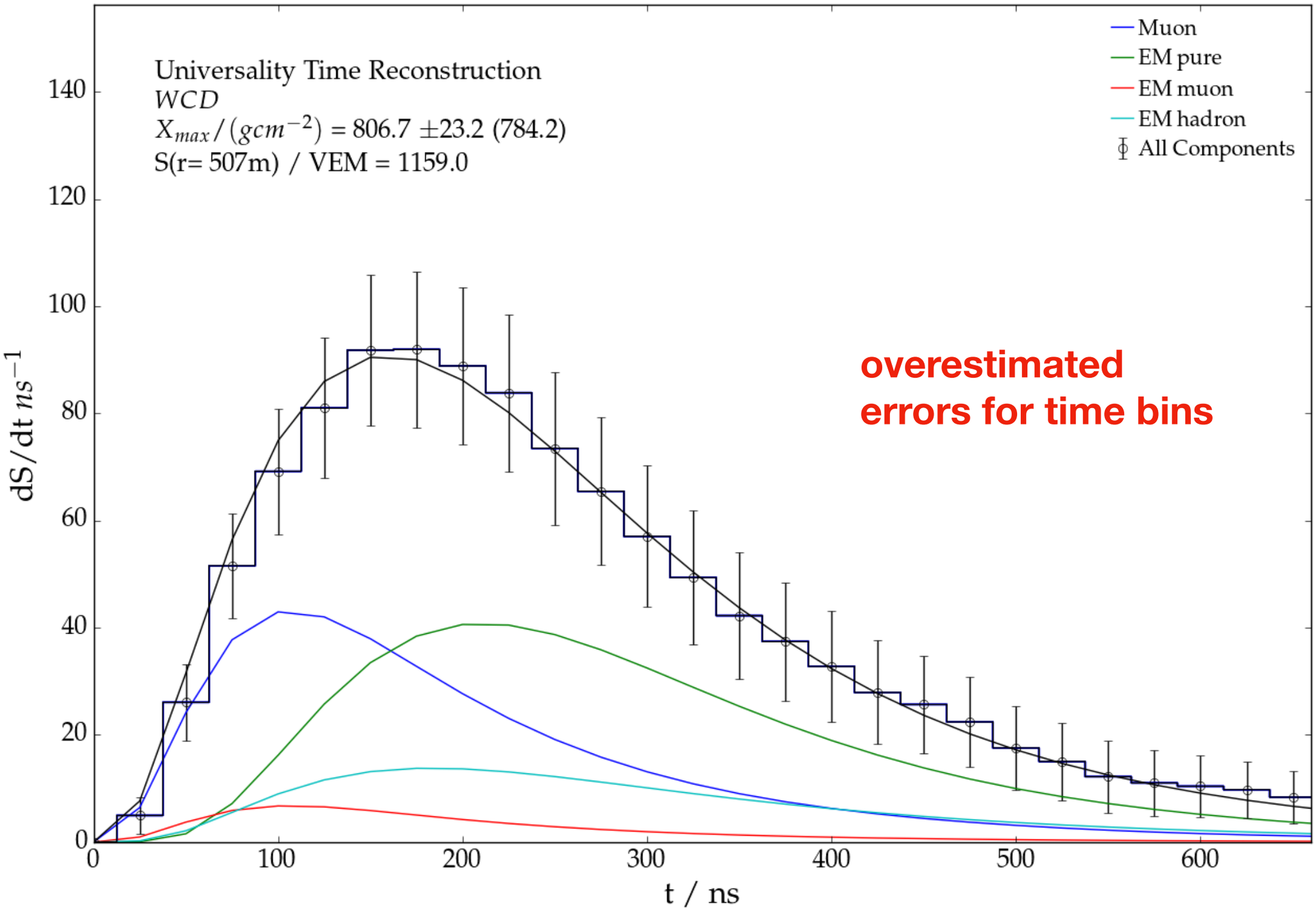
Hybrid Reconstruction: Signal



Hybrid Reconstruction: Signal

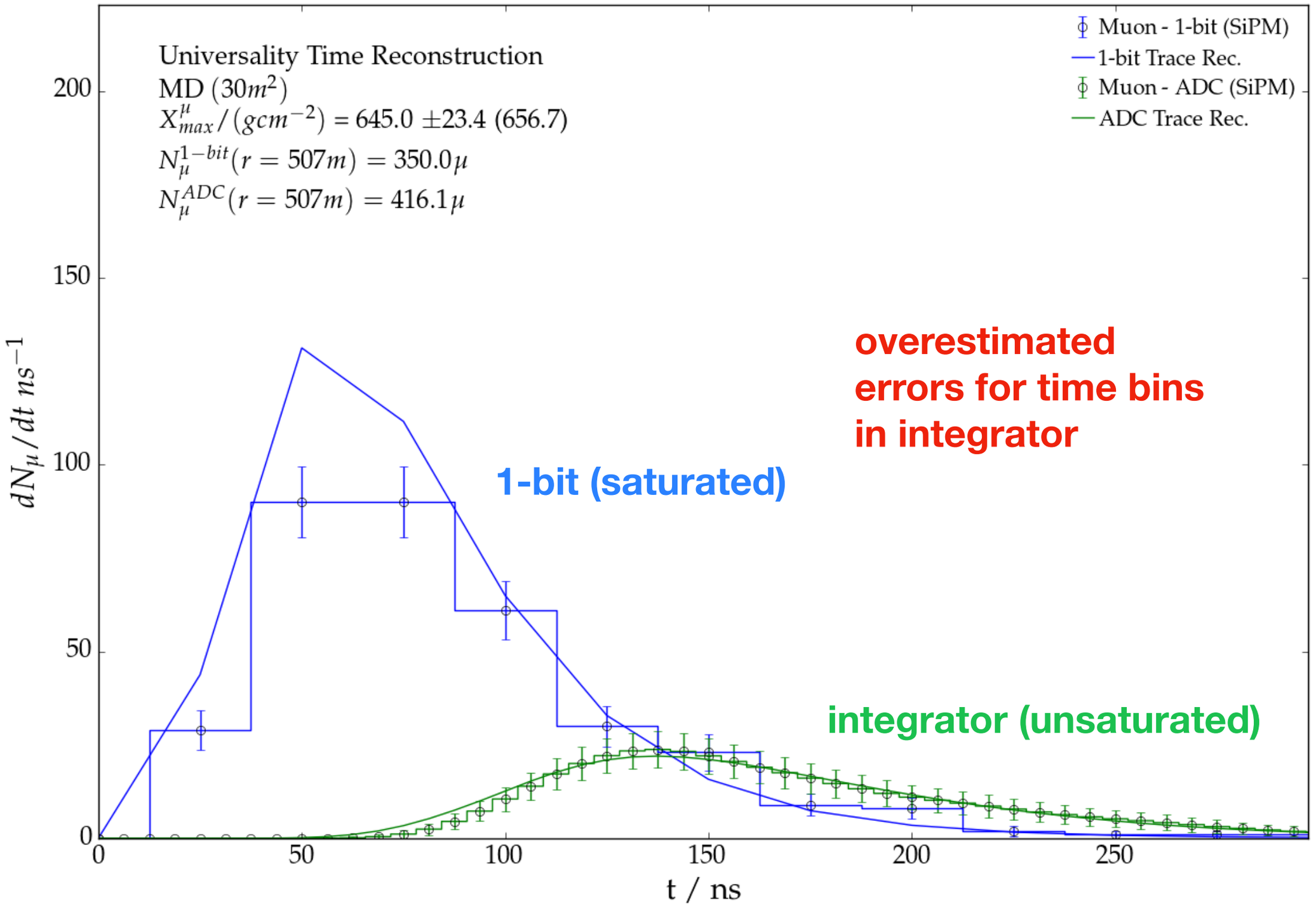


Hybrid Reconstruction: Time



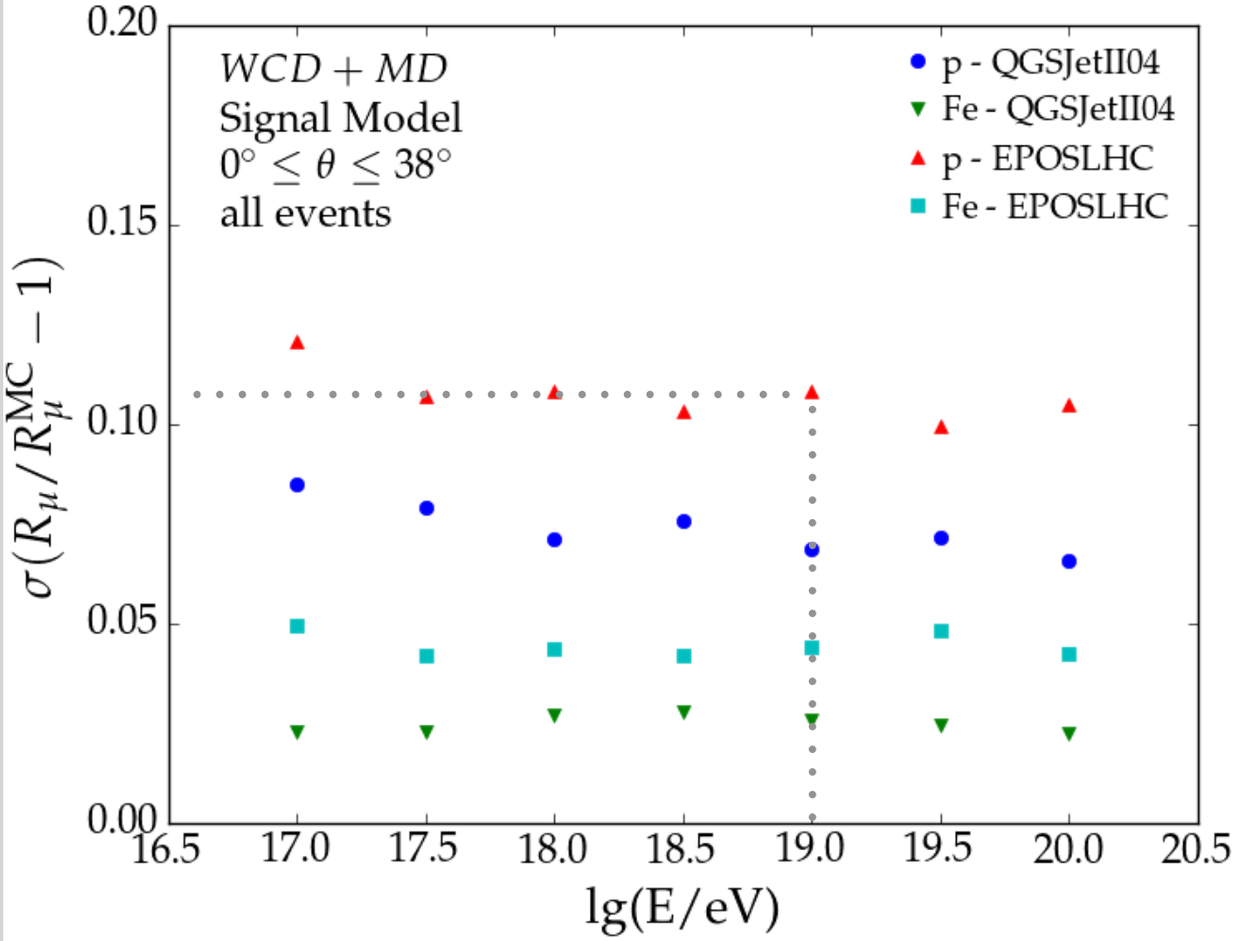
overestimated errors for time bins

Hybrid Reconstruction: Time

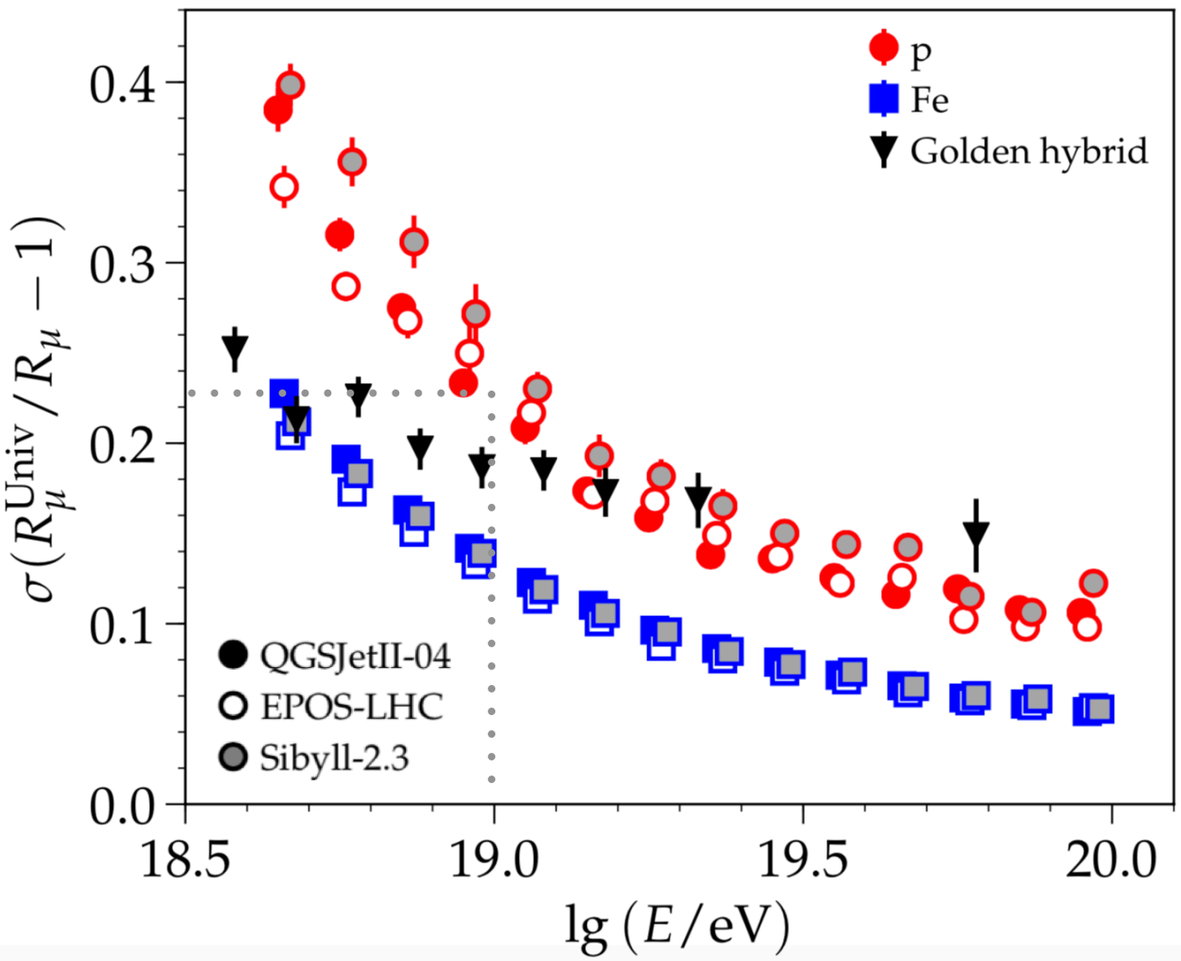


Hybrid Reconstruction: R_μ

Infill



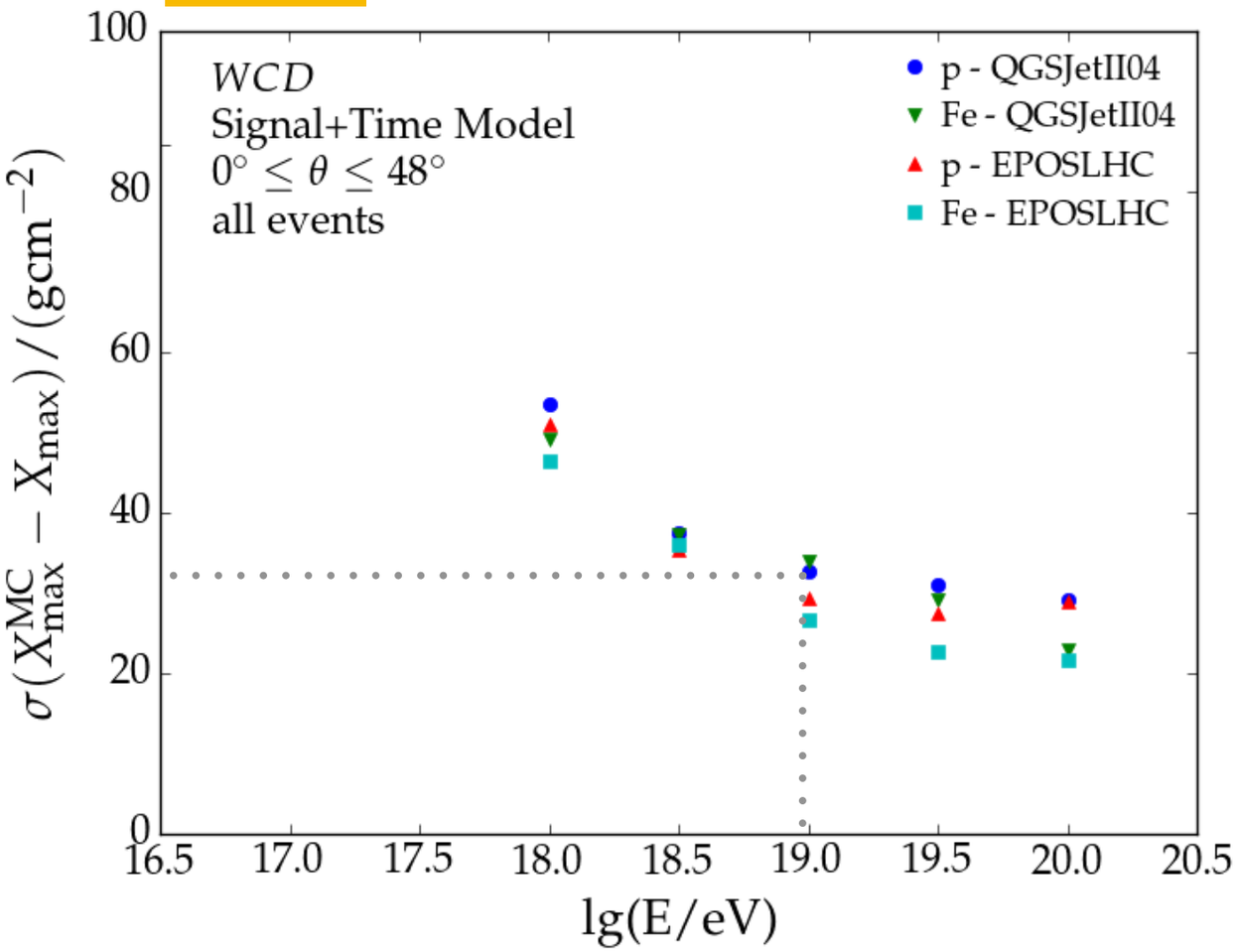
Standard Array



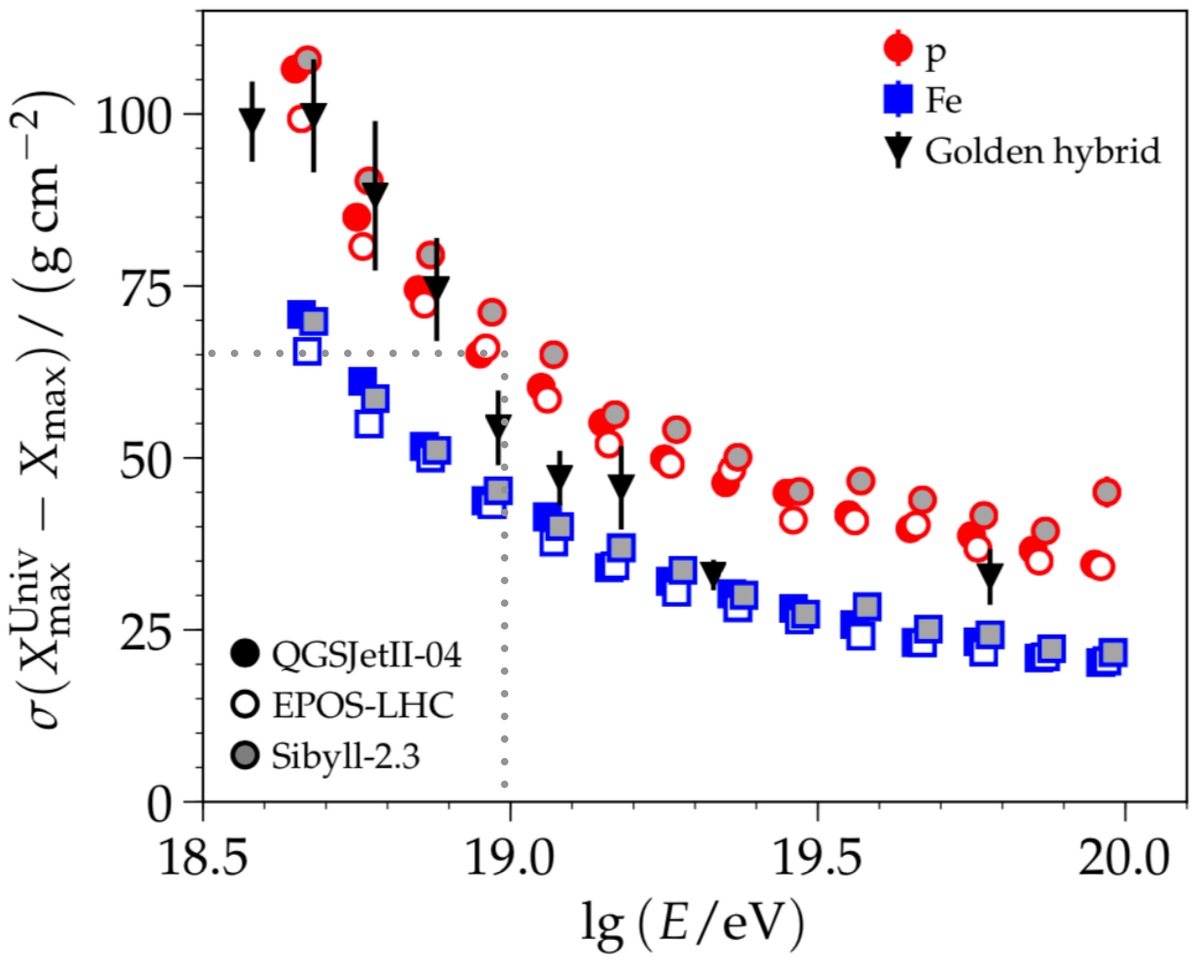
Muon content resolution improved by x2 @ 10^{19}eV

Hybrid Reconstruction: X_{max}

Infill



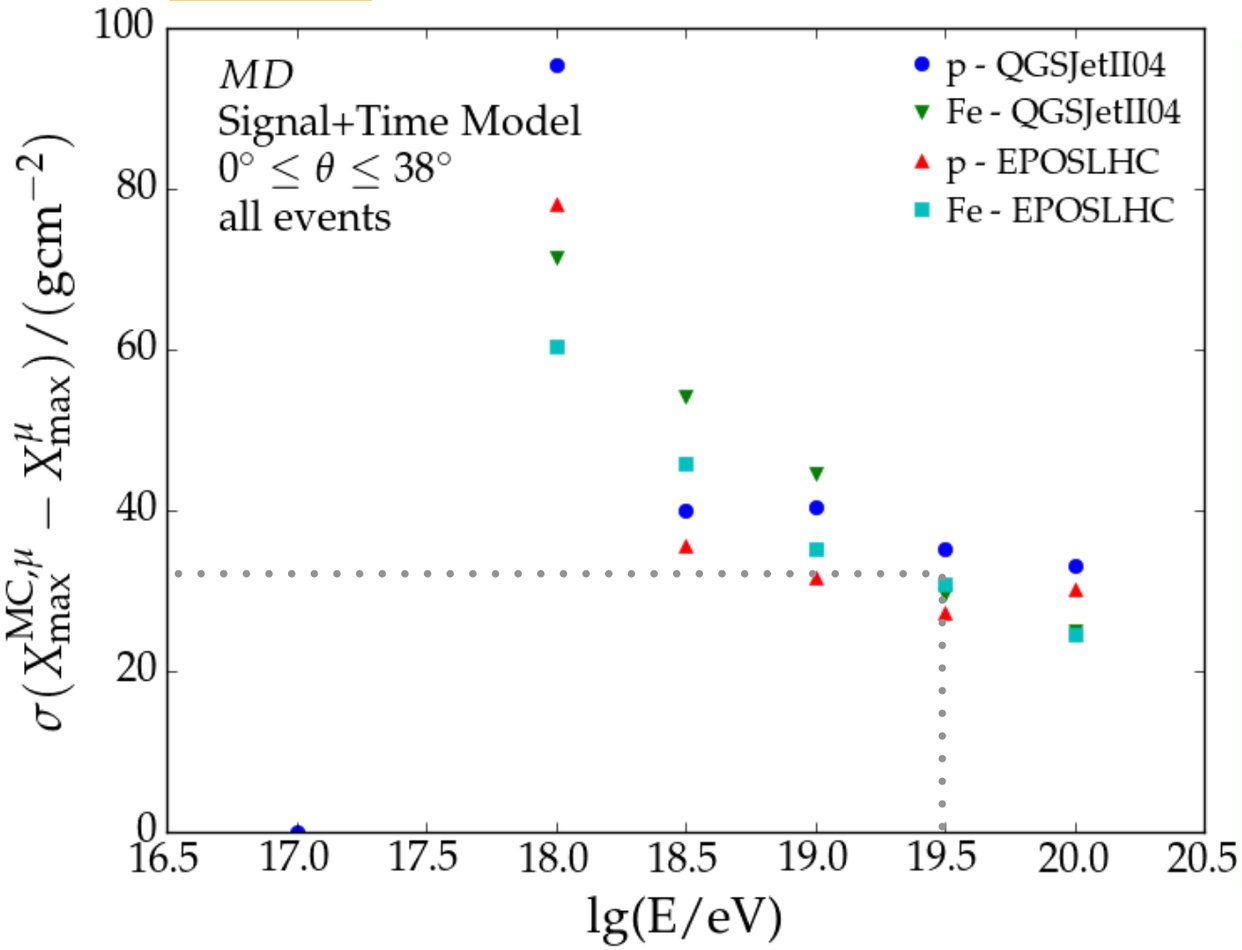
Standard Array



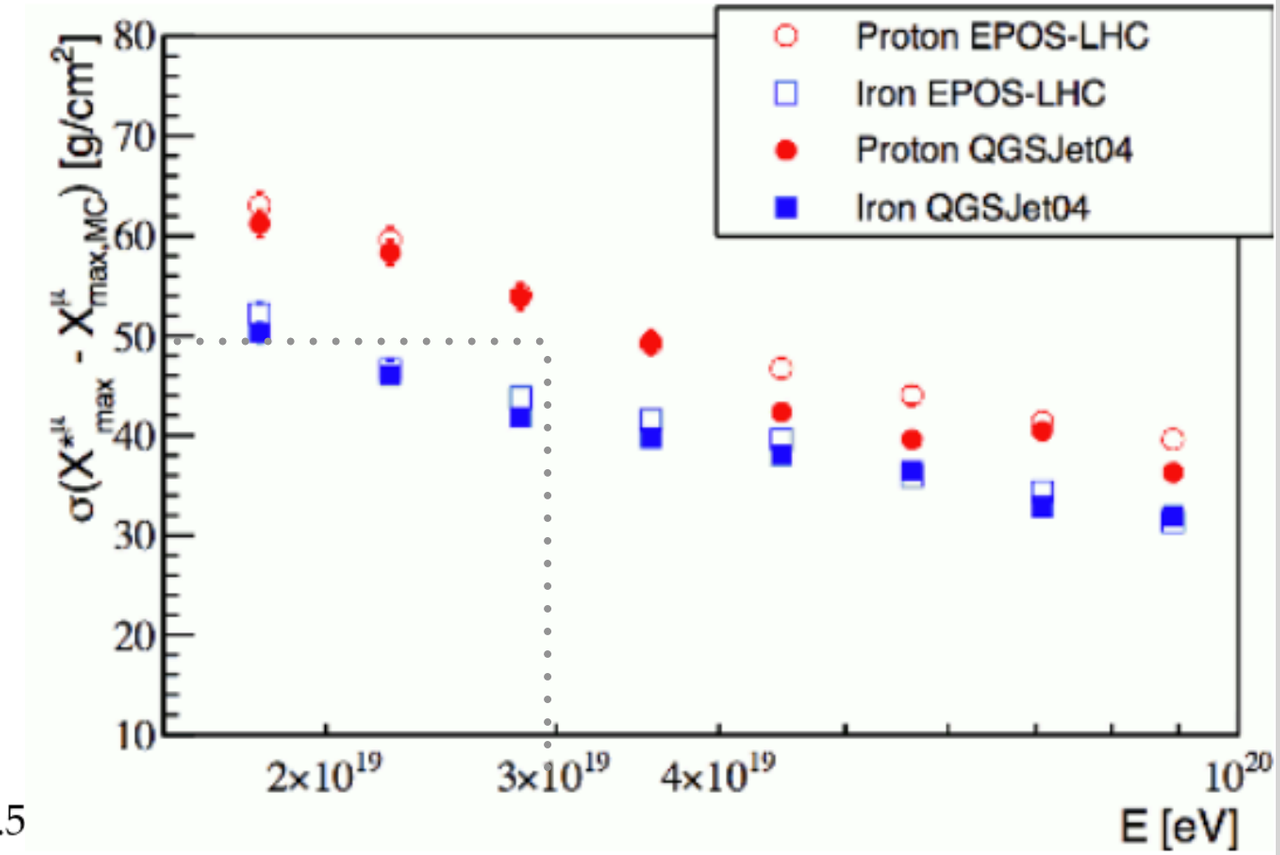
X_{max} resolution reduced from ~65gcm^{-2} to ~32gcm^{-2} @ 10^{19}eV

Hybrid Reconstruction: $X\mu_{max}$

Infill



Standard Array



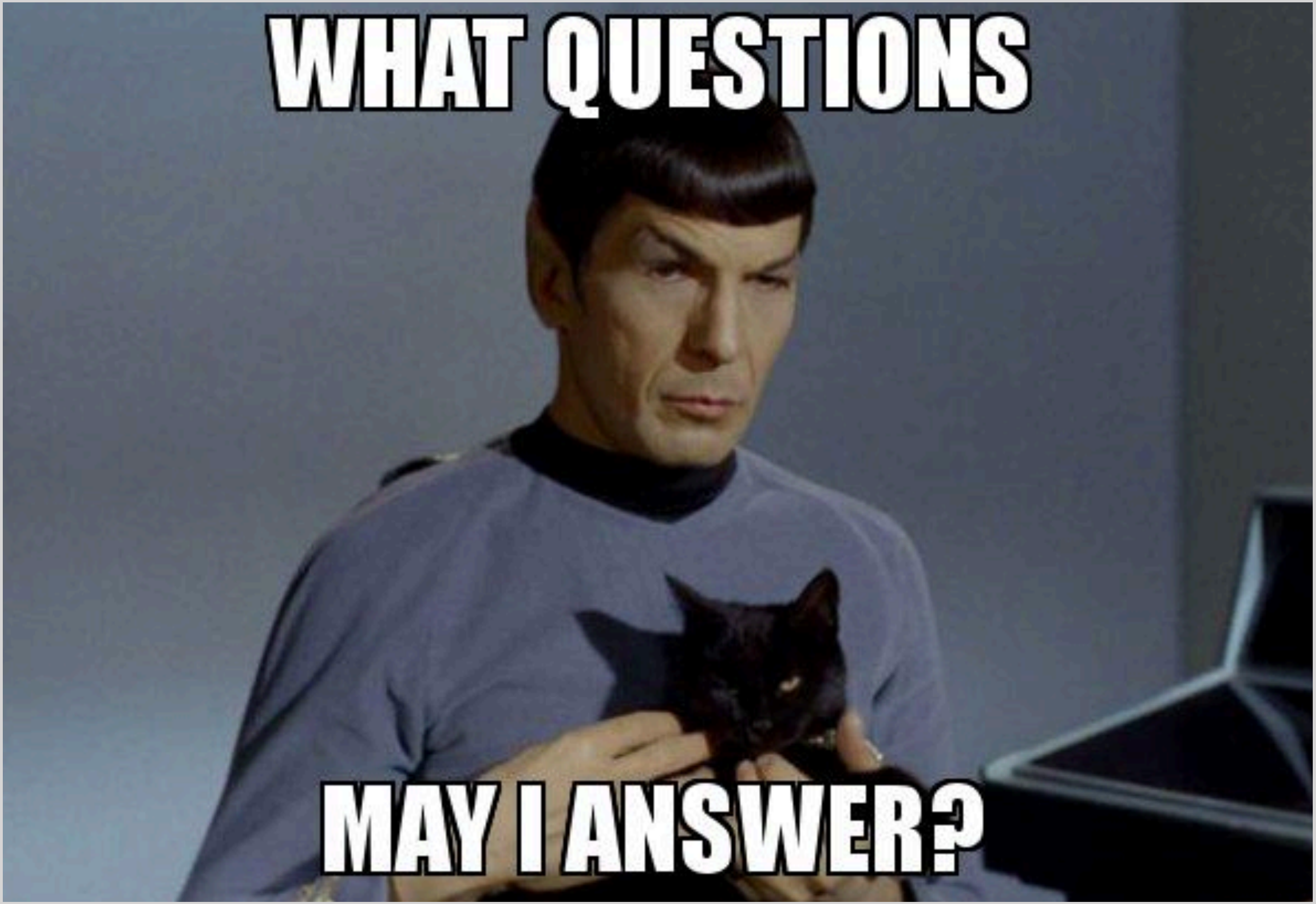
$X\mu_{max}$ resolution reduced from ~50gcm^{-2} to ~32gcm^{-2} @ 10^{19}eV

Summary & Outlook

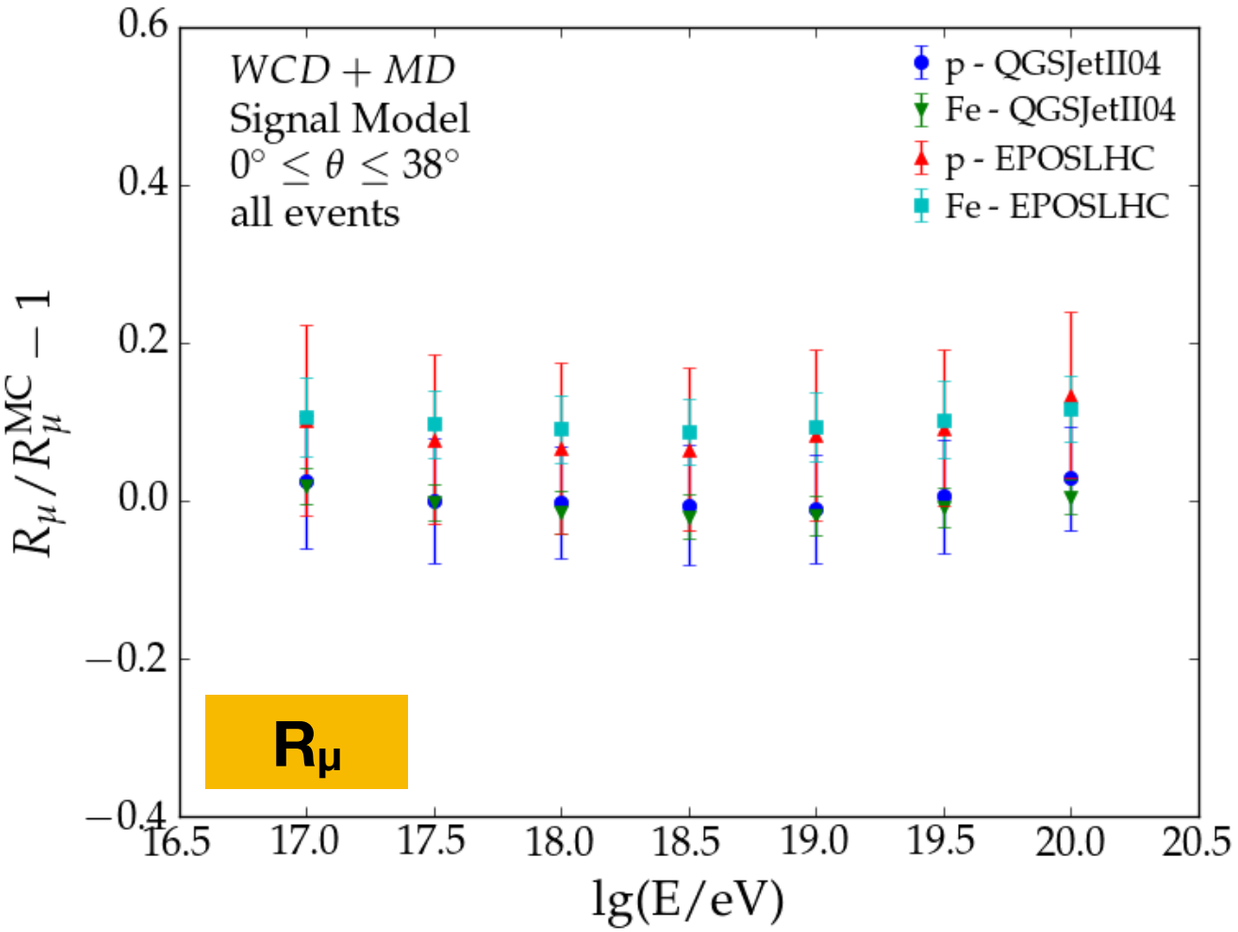
- ☑ use Universality down to lg(E/eV) = 17.0 **±5%**
- ☑ Universality Model for MD **±10%**
- ☑ account for MPD
- ☑ prototype hybrid reconstruction

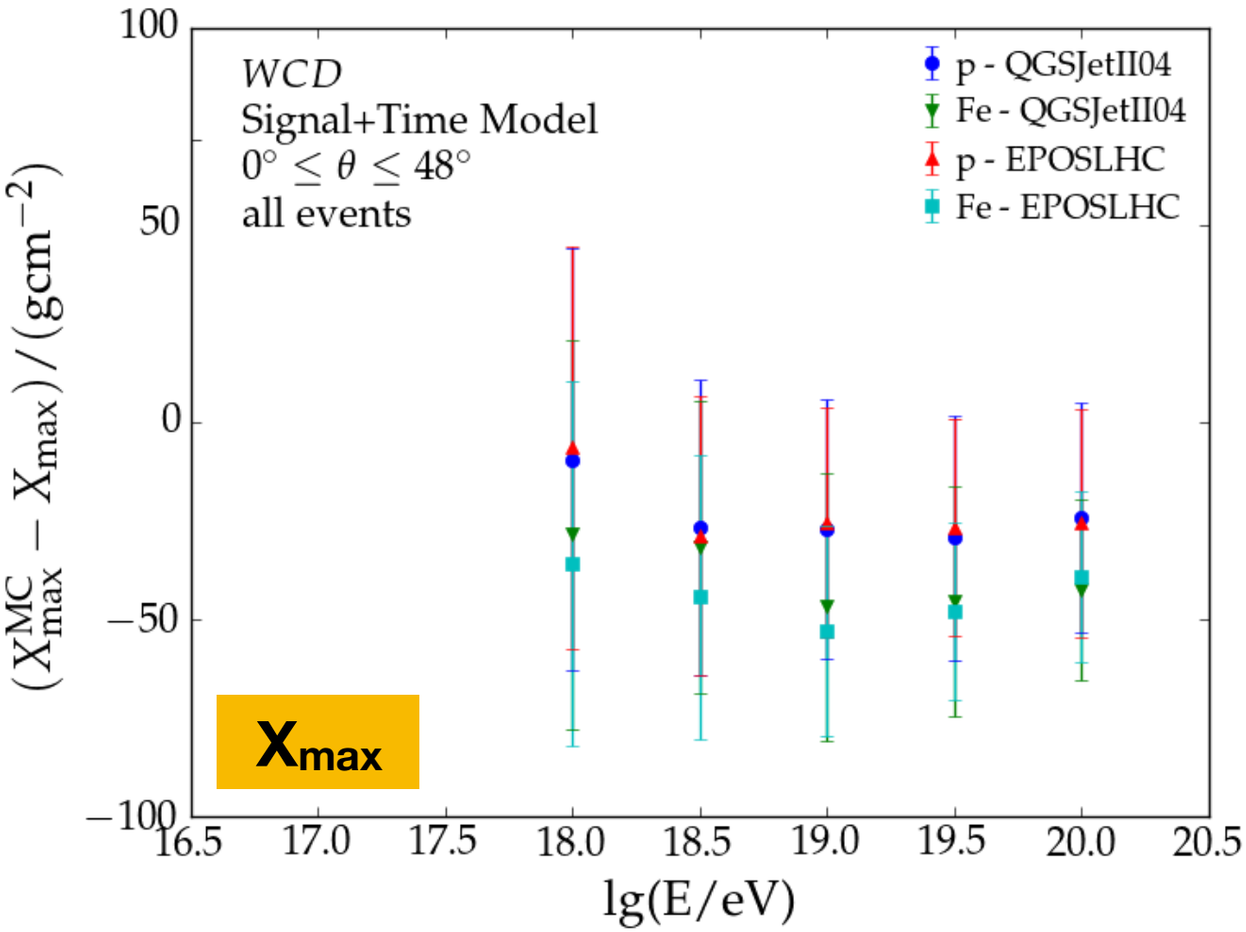
Currently in Universality pipeline:

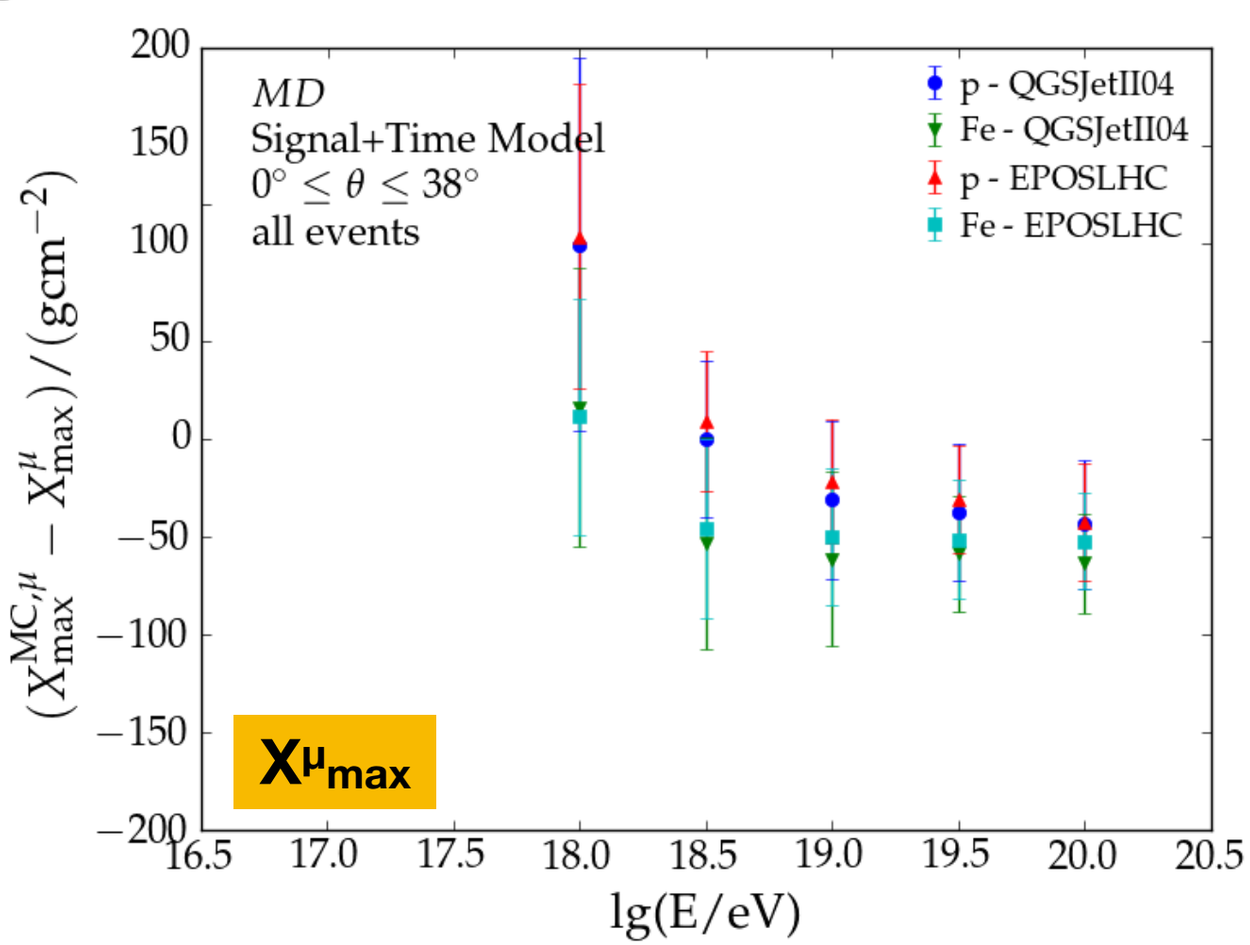
- optimizing reconstruction method…
- towards data…


WHAT QUESTIONS
MAY I ANSWER?

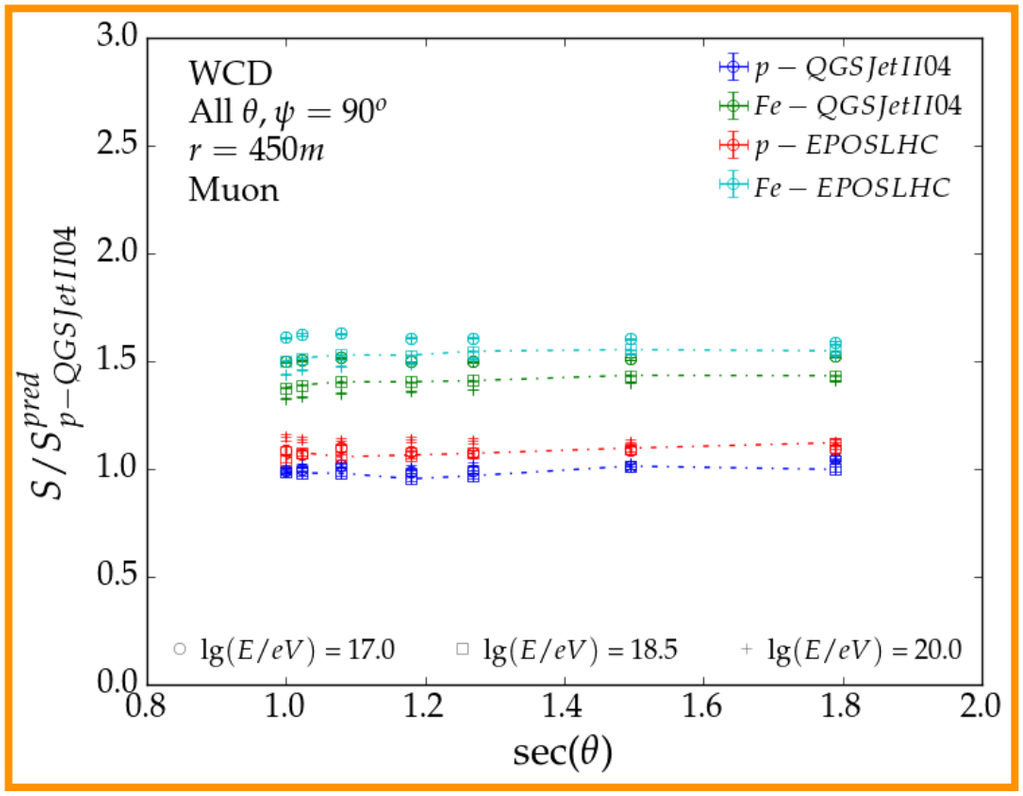
Backup

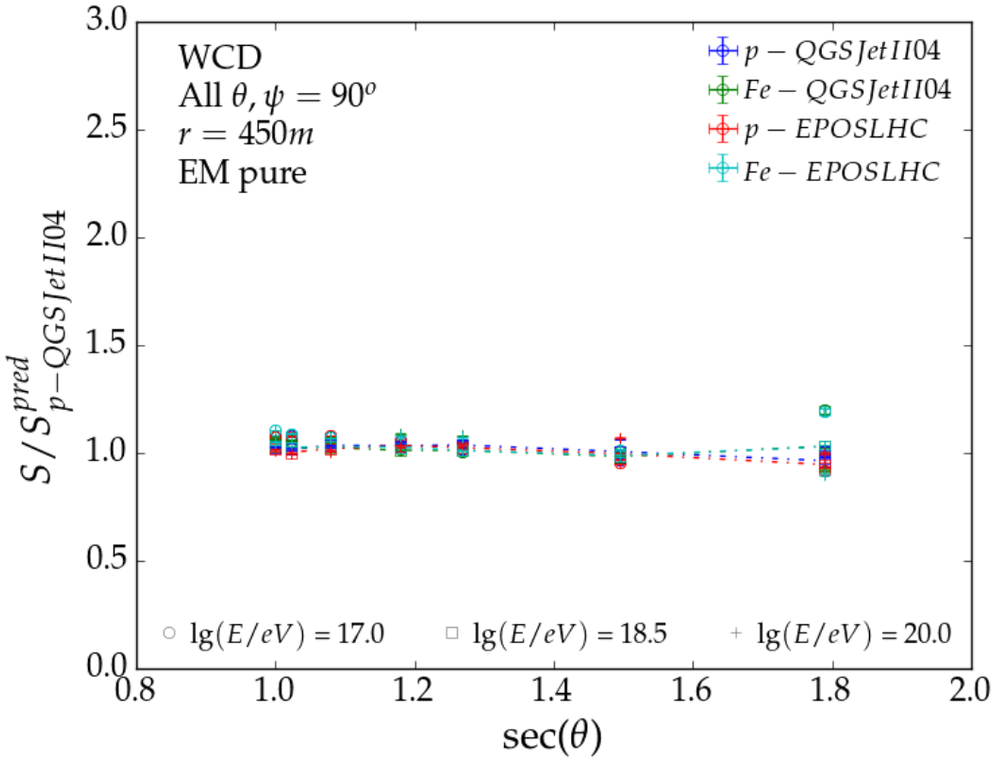

WCD + MD
Signal Model
0° ≤ θ ≤ 38°
all events
p - QGSJetII04
Fe - QGSJetII04
p - EPOSLHC
Fe - EPOSLHC
Rμ
$R_\mu / R_\mu^{MC} - 1$
lg(E/eV)

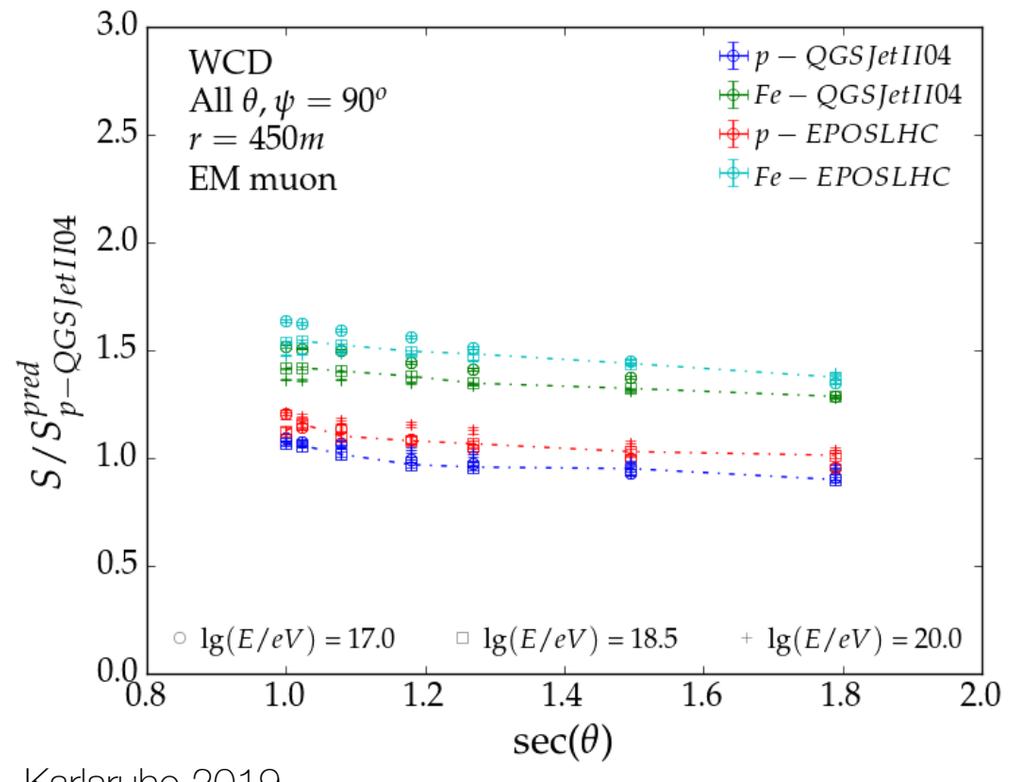

WCD
Signal+Time Model
0° ≤ θ ≤ 48°
all events
p - QGSJetII04
Fe - QGSJetII04
p - EPOSLHC
Fe - EPOSLHC
Xmax
$(X_{max}^{MC} - X_{max}) / (gcm^{-2})$
lg(E/eV)

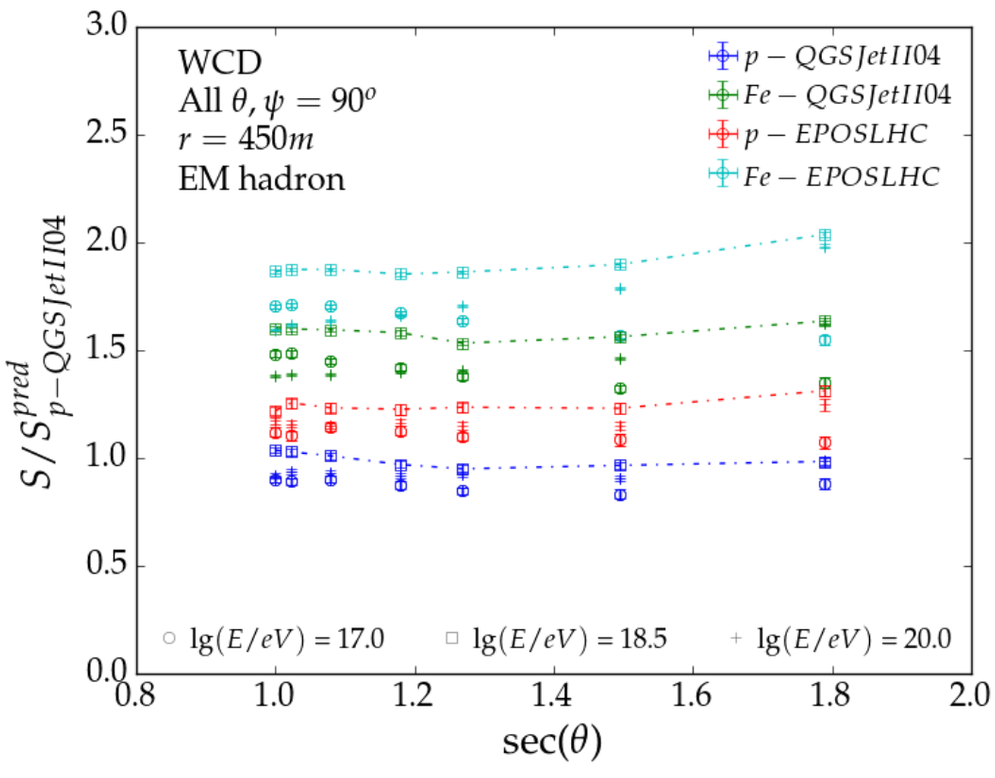

MD
Signal+Time Model
0° ≤ θ ≤ 38°
all events
p - QGSJetII04
Fe - QGSJetII04
p - EPOSLHC
Fe - EPOSLHC
Xμmax
$(X_{max}^{MC,\mu} - X_{max}^{\mu}) / (gcm^{-2})$
lg(E/eV)

R_μ

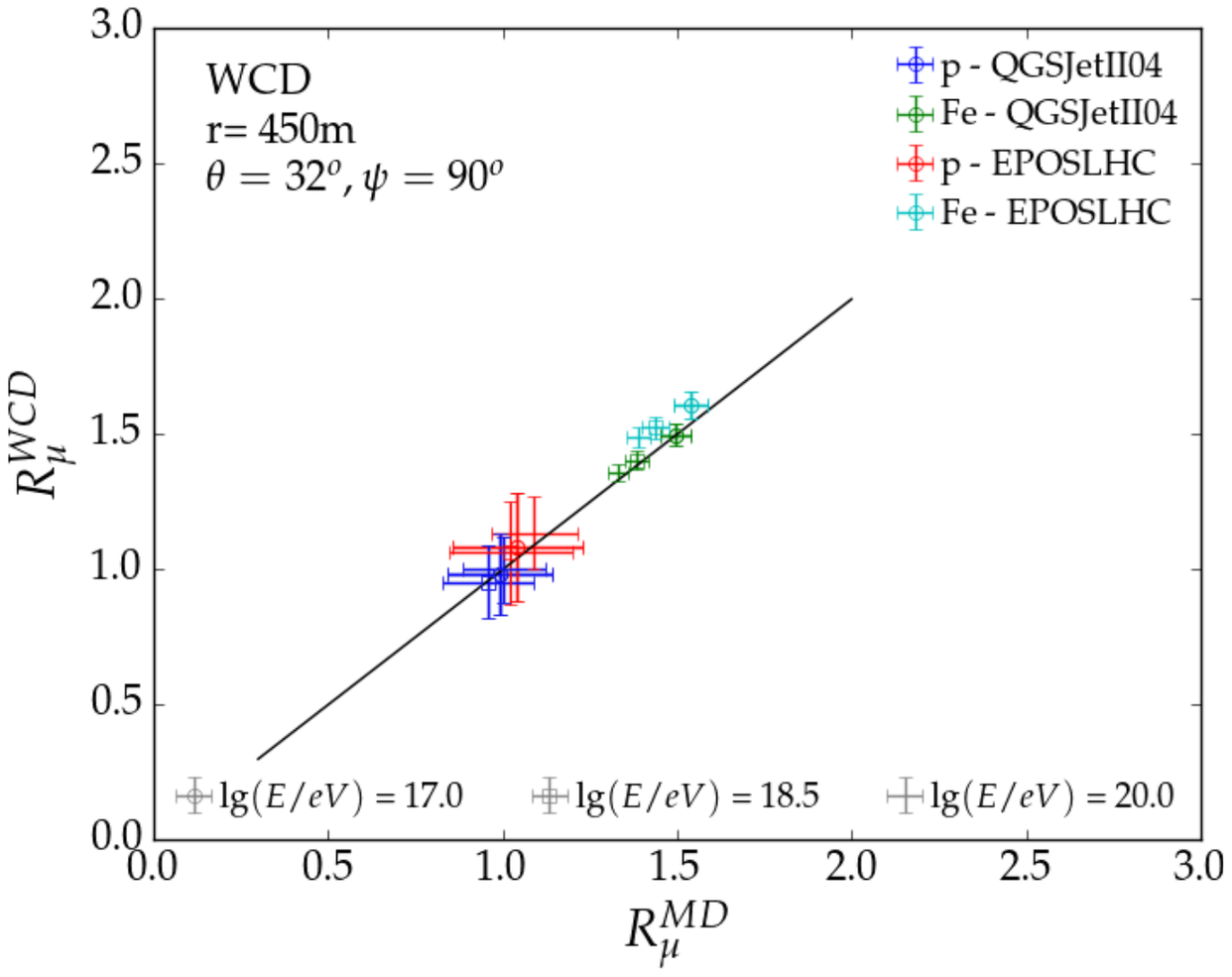

WCD
All $\theta, \psi = 90^o$
$r = 450m$
Muon
$p - QGSJetII04$
$Fe - QGSJetII04$
$p - EPOSLHC$
$Fe - EPOSLHC$
$\lg(E/eV) = 17.0$
$\lg(E/eV) = 18.5$
$\lg(E/eV) = 20.0$
$S/S^{pred}_{p-QGSJetII04}$
$\sec(\theta)$

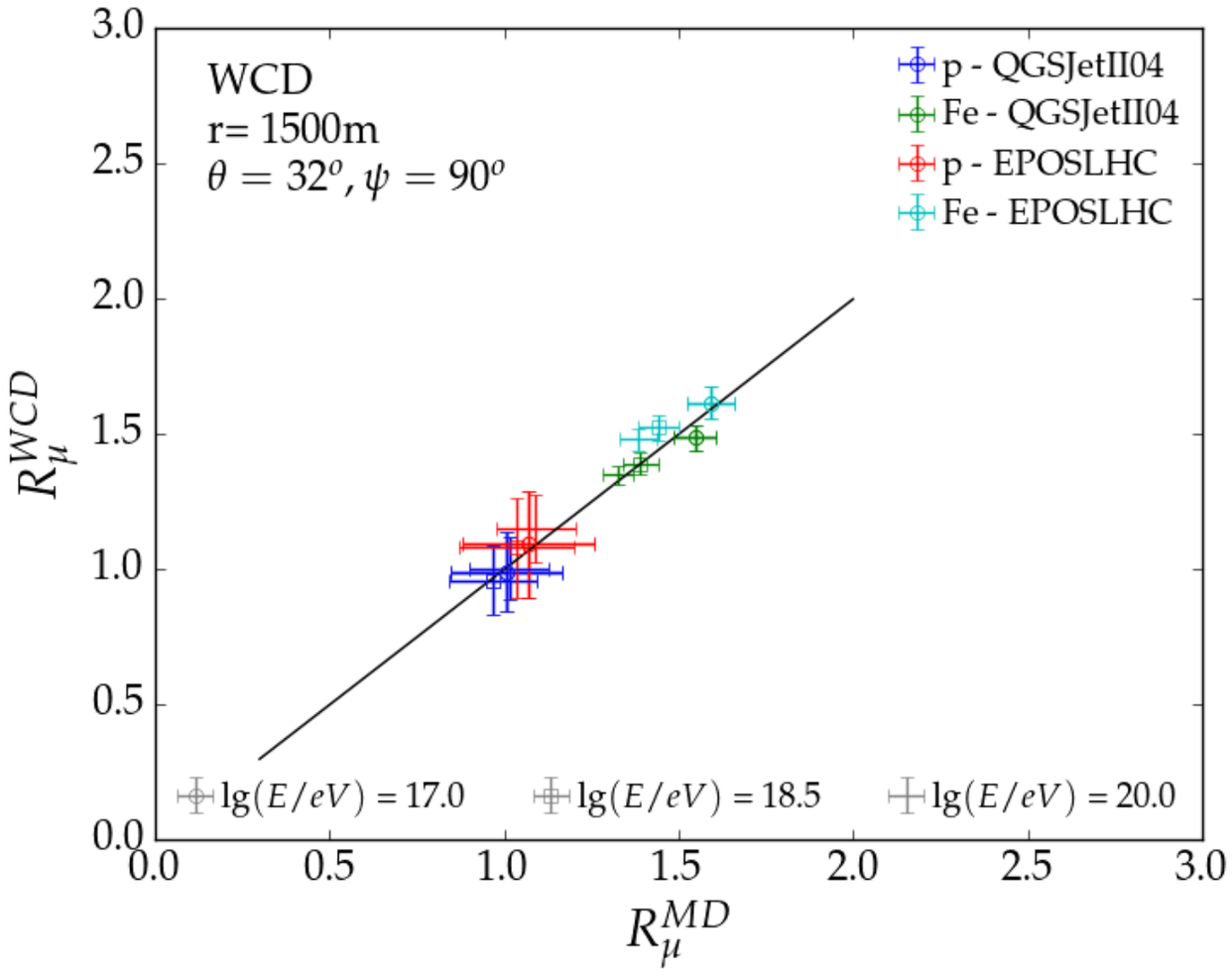

WCD
All $\theta, \psi = 90^o$
$r = 450m$
EM pure
$p - QGSJetII04$
$Fe - QGSJetII04$
$p - EPOSLHC$
$Fe - EPOSLHC$
$\lg(E/eV) = 17.0$
$\lg(E/eV) = 18.5$
$\lg(E/eV) = 20.0$
$S/S^{pred}_{p-QGSJetII04}$
$\sec(\theta)$


WCD
All $\theta, \psi = 90^o$
$r = 450m$
EM muon
$p - QGSJetII04$
$Fe - QGSJetII04$
$p - EPOSLHC$
$Fe - EPOSLHC$
$\lg(E/eV) = 17.0$
$\lg(E/eV) = 18.5$
$\lg(E/eV) = 20.0$
$S/S^{pred}_{p-QGSJetII04}$
$\sec(\theta)$


WCD
All $\theta, \psi = 90^o$
$r = 450m$
EM hadron
$p - QGSJetII04$
$Fe - QGSJetII04$
$p - EPOSLHC$
$Fe - EPOSLHC$
$\lg(E/eV) = 17.0$
$\lg(E/eV) = 18.5$
$\lg(E/eV) = 20.0$
$S/S^{pred}_{p-QGSJetII04}$
$\sec(\theta)$

R_μ (WCD vs MD)


WCD
r= 450m
$\theta = 32^o, \psi = 90^o$
p - QGSJetII04
Fe - QGSJetII04
p - EPOSLHC
Fe - EPOSLHC
$\lg(E/eV) = 17.0$
$\lg(E/eV) = 18.5$
$\lg(E/eV) = 20.0$
R_μ^{WCD}
R_μ^{MD}
0.0
0.5
1.0
1.5
2.0
2.5
3.0


WCD
r= 1500m
$\theta = 32^o, \psi = 90^o$
p - QGSJetII04
Fe - QGSJetII04
p - EPOSLHC
Fe - EPOSLHC
$\lg(E/eV) = 17.0$
$\lg(E/eV) = 18.5$
$\lg(E/eV) = 20.0$
R_μ^{WCD}
R_μ^{MD}
0.0
0.5
1.0
1.5
2.0
2.5
3.0