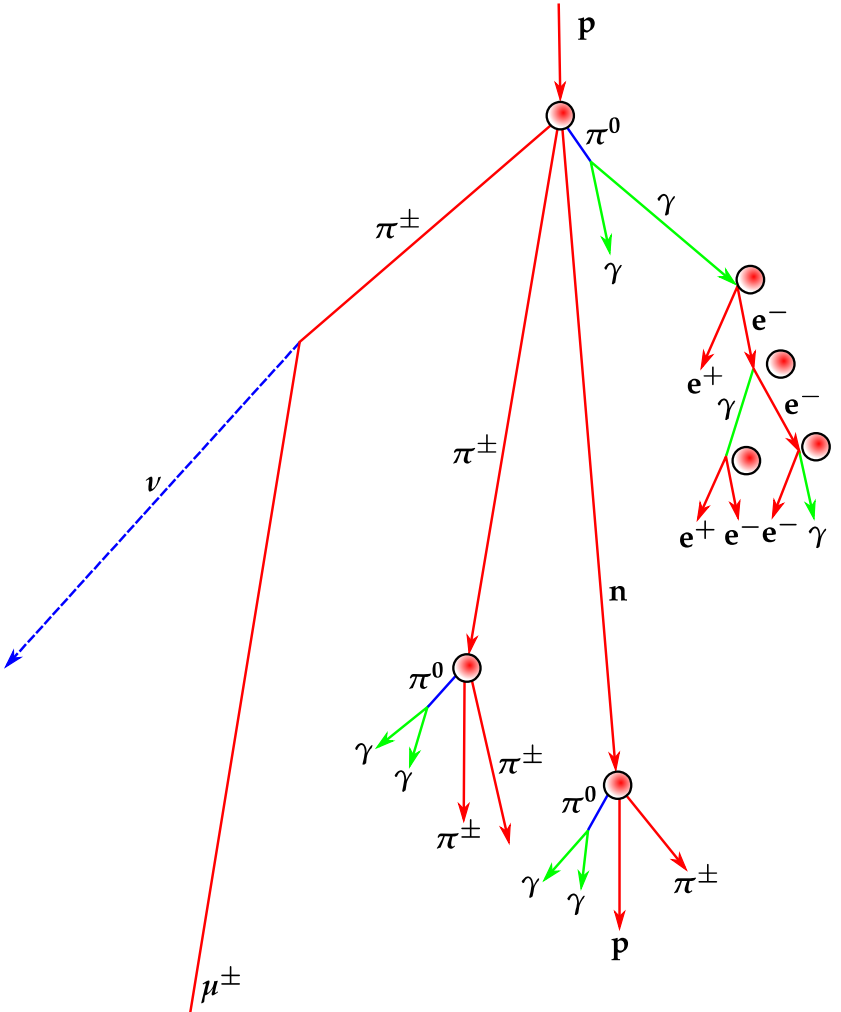


PIERRE AUGER OBSERVATORY

Measurement of the muon content in air showers at the Pierre Auger Observatory

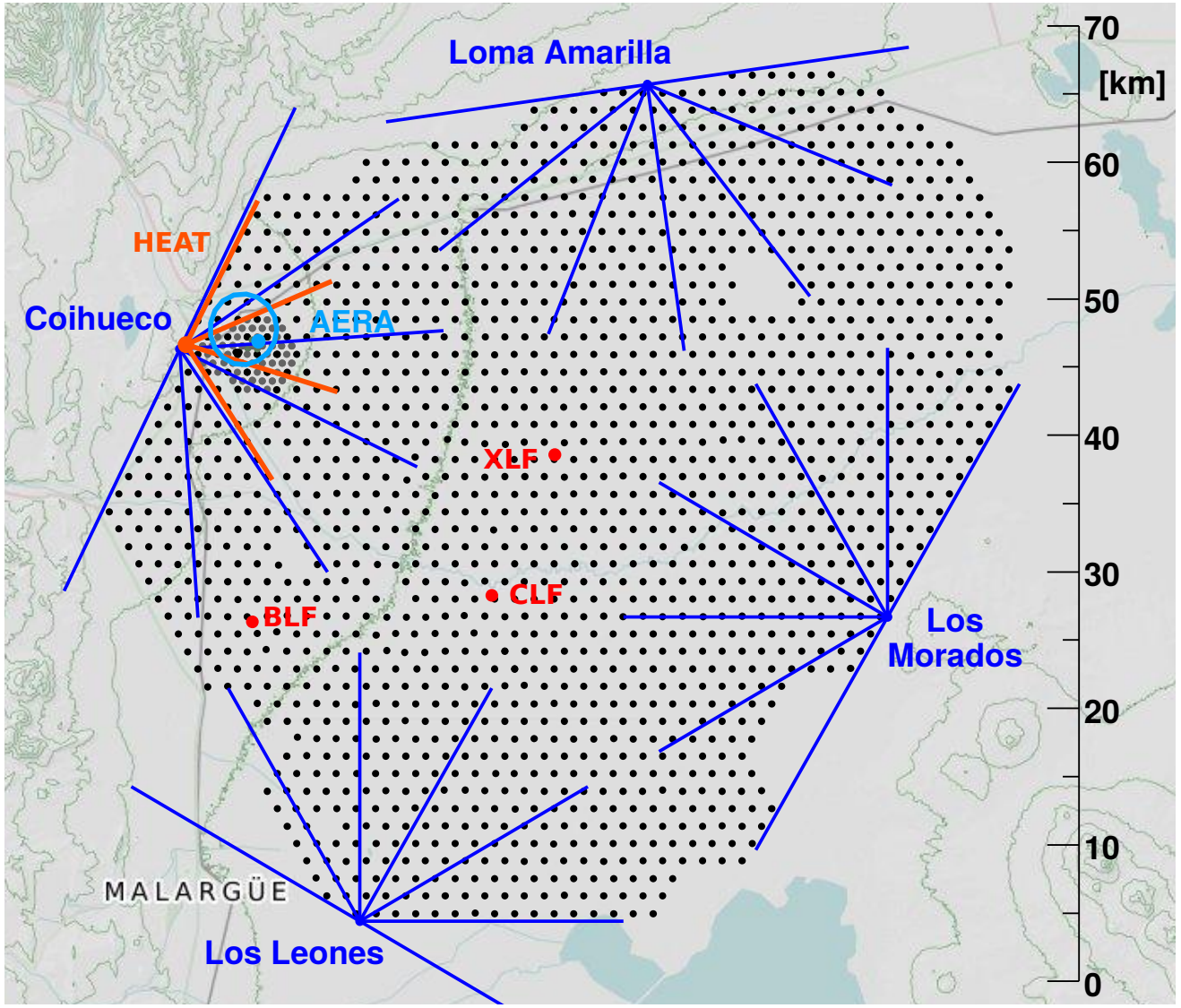
Darko Veberic

IKP, Karlsruhe Institute of Technology (KIT)

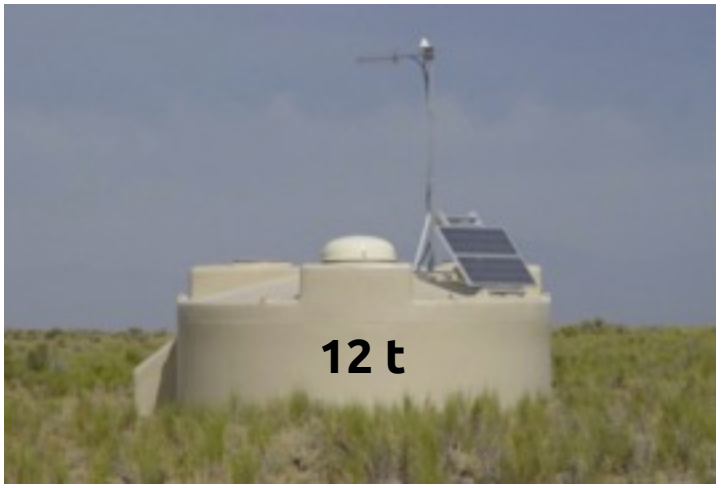
for the Pierre Auger Collaboration

http://www.auger.org/archive/authors_2015_10.html

Pierre Auger Observatory



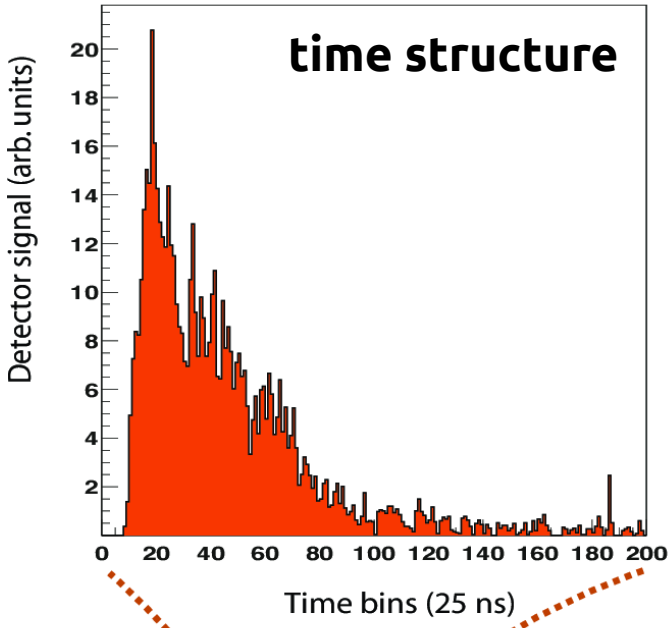
fluorescence detector

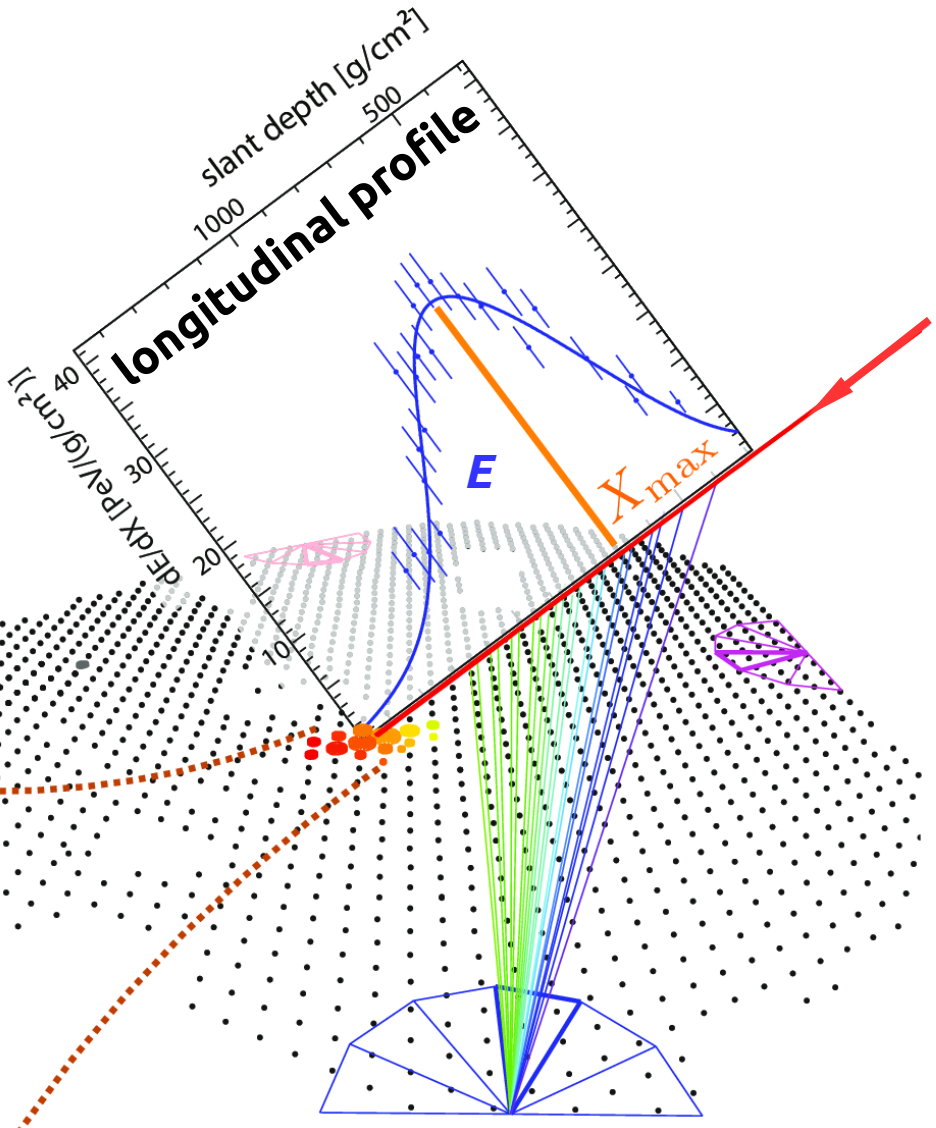


surface detector
water-Cherenkov technique

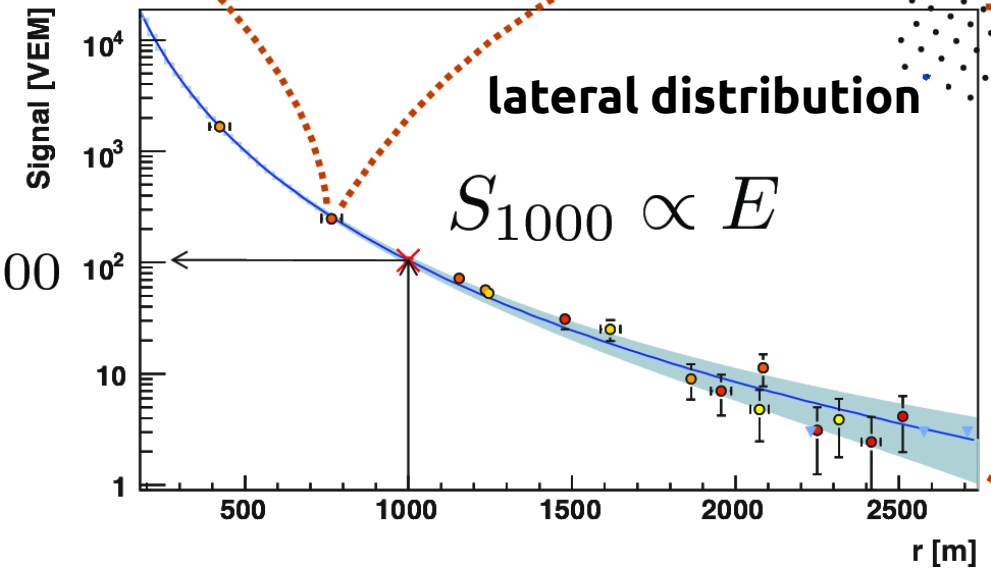
3000 km², 1660 SD stations, 27 FD telescopes
lidars, cloud monitoring, weather stations
$\langle h \rangle$ = 1450 m, X_{vert} = 860 g/cm²

Shower Observables



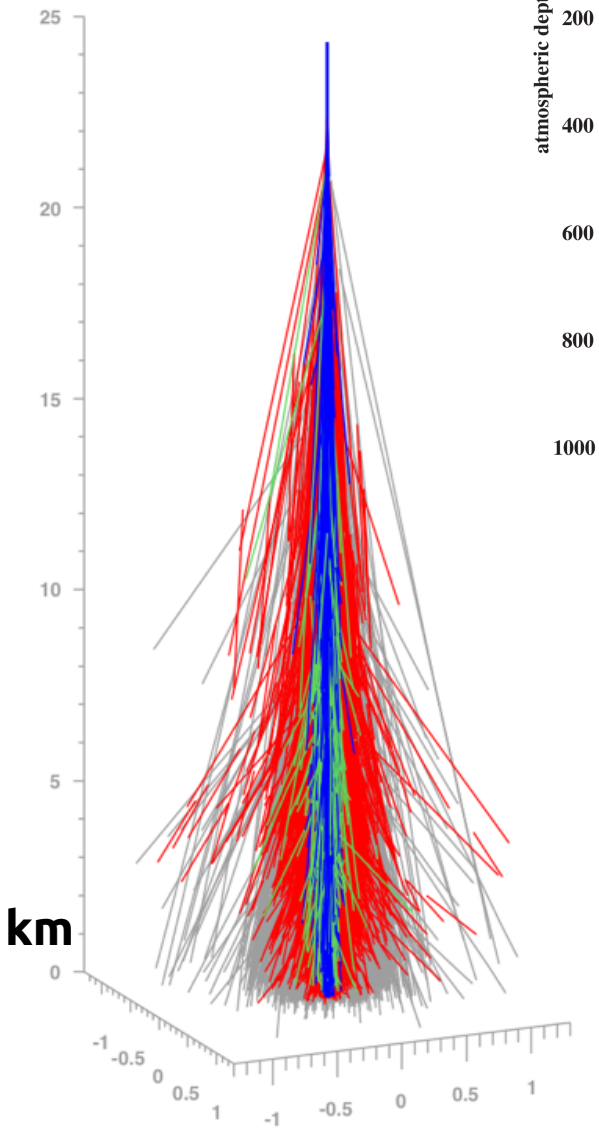


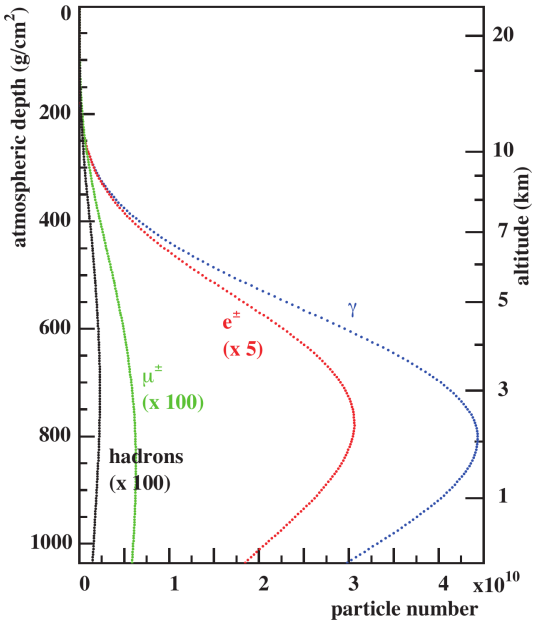
SD
~100% duty cycle

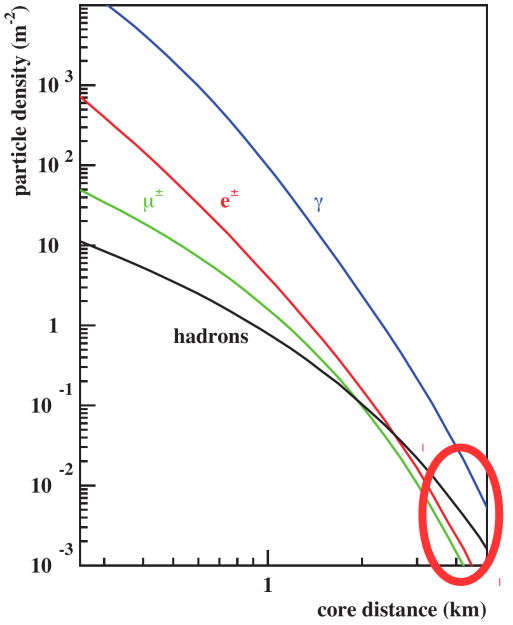


FD
10% duty cycle
(cloudless nights, low moon fraction)

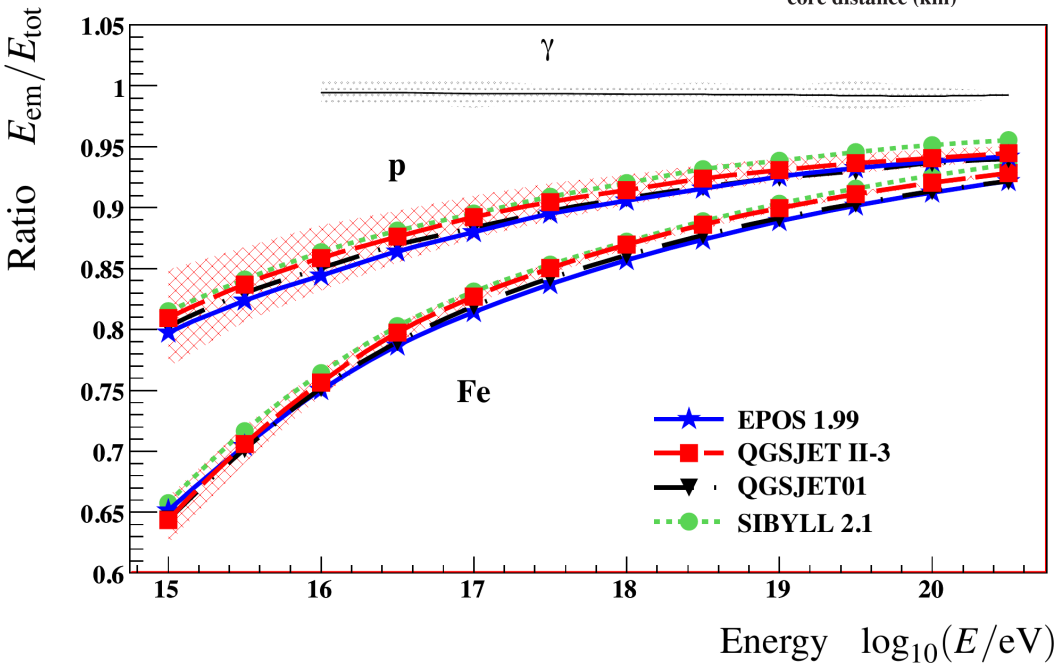
Why Muons Matter?







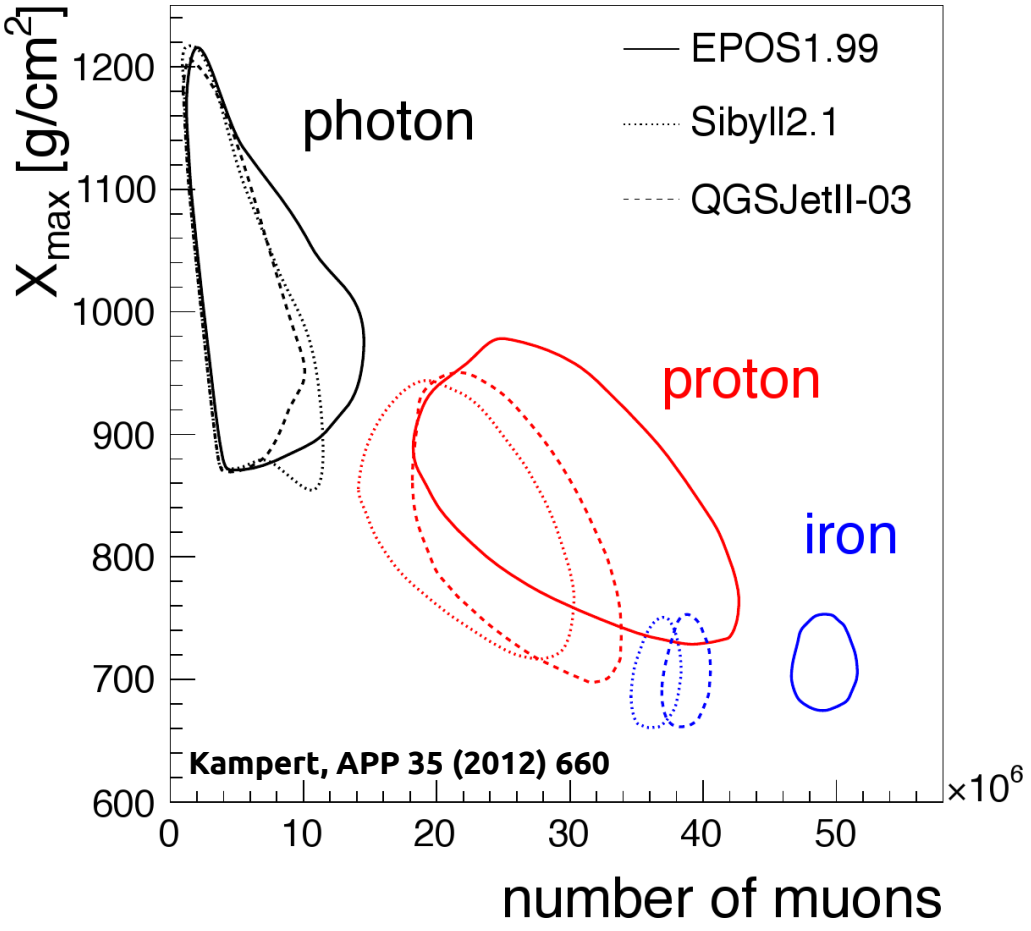
larger response to muons

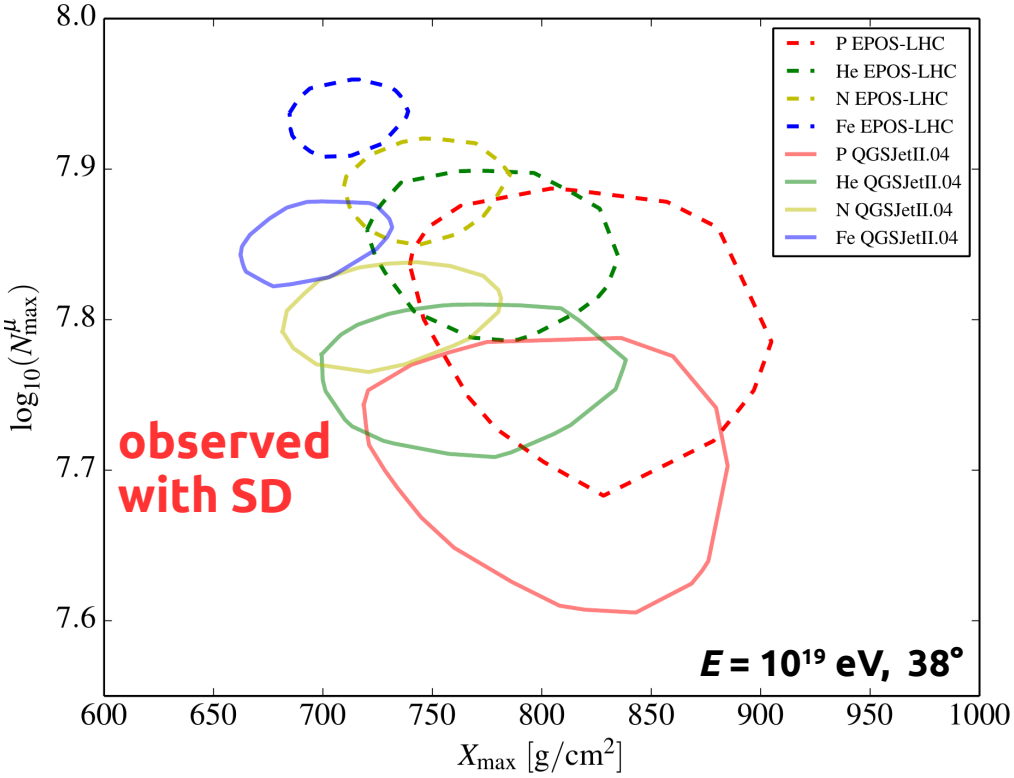


Engel, ARNPS 61 (2011) 467

Why Muons Matter!

- **CR composition measurement → origin of flux suppression (sources), proton fraction (pair-production "dip", future of astronomy with CR, predict gamma & nu flux)**

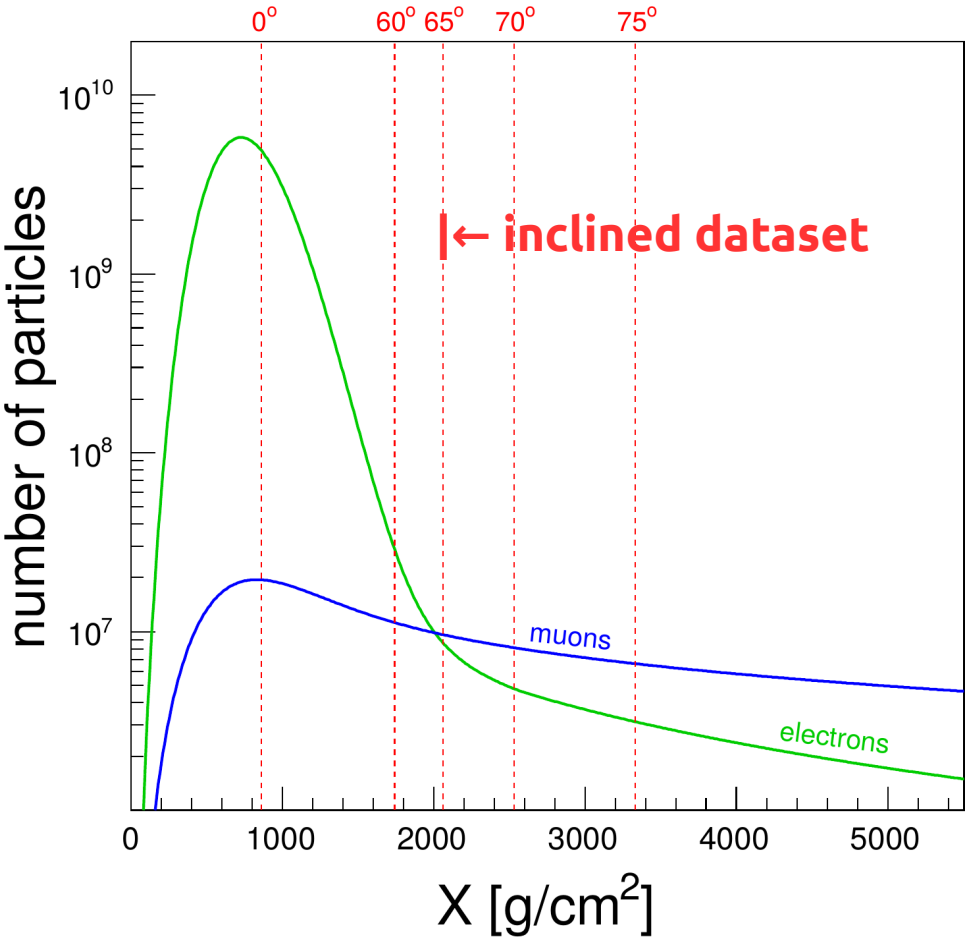


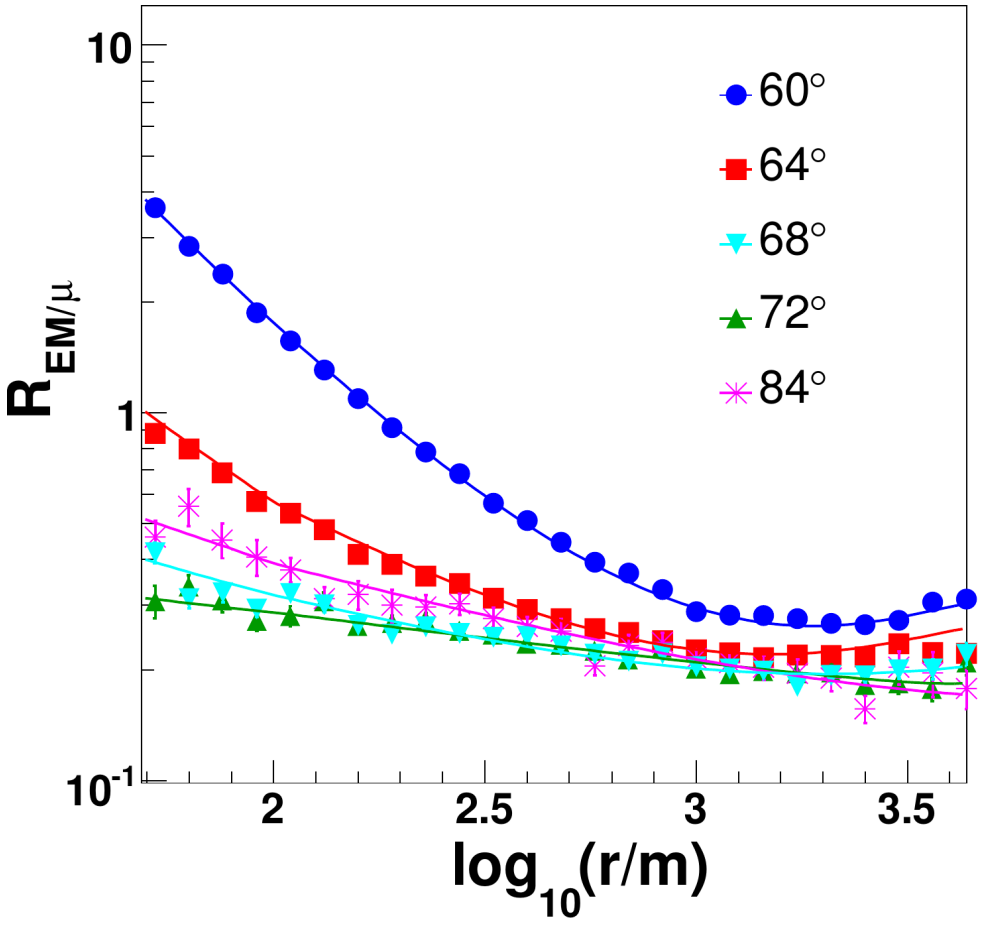


observed with FD (10% duty cycle)

- **muons probe for models of hadronic interactions**
- **AugerPrime: upgrade → shower-to-shower determination of primary mass**

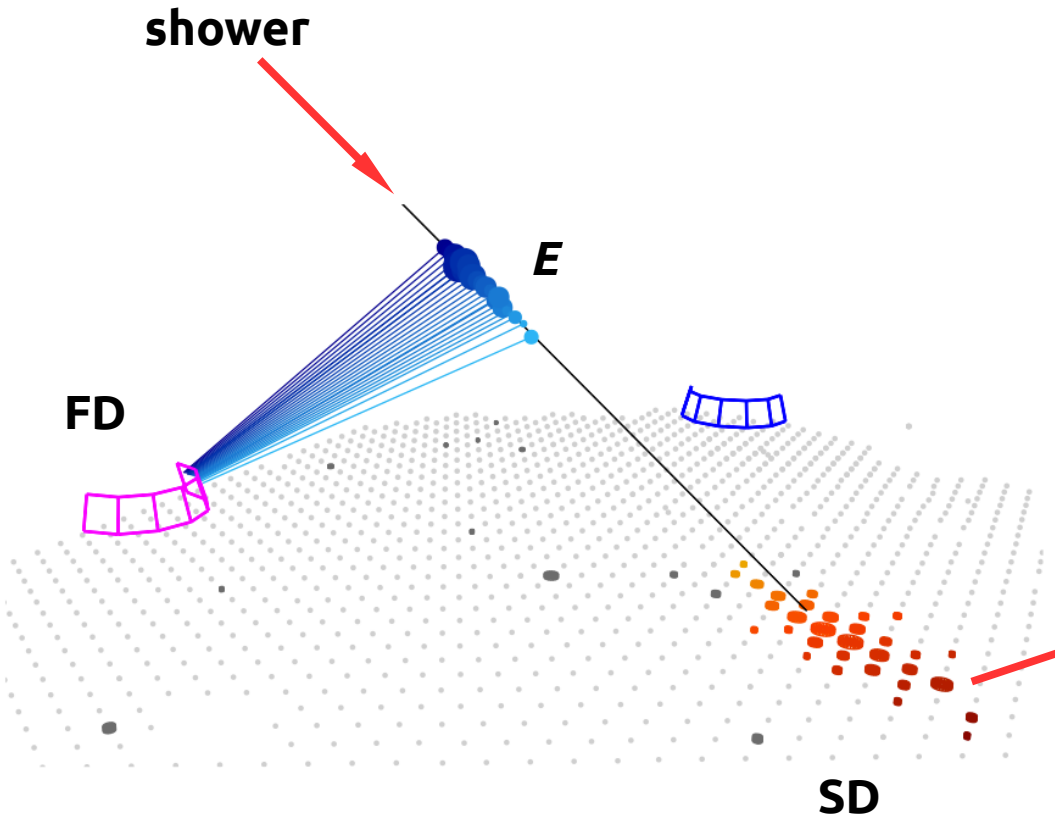
EM/μ Ratio

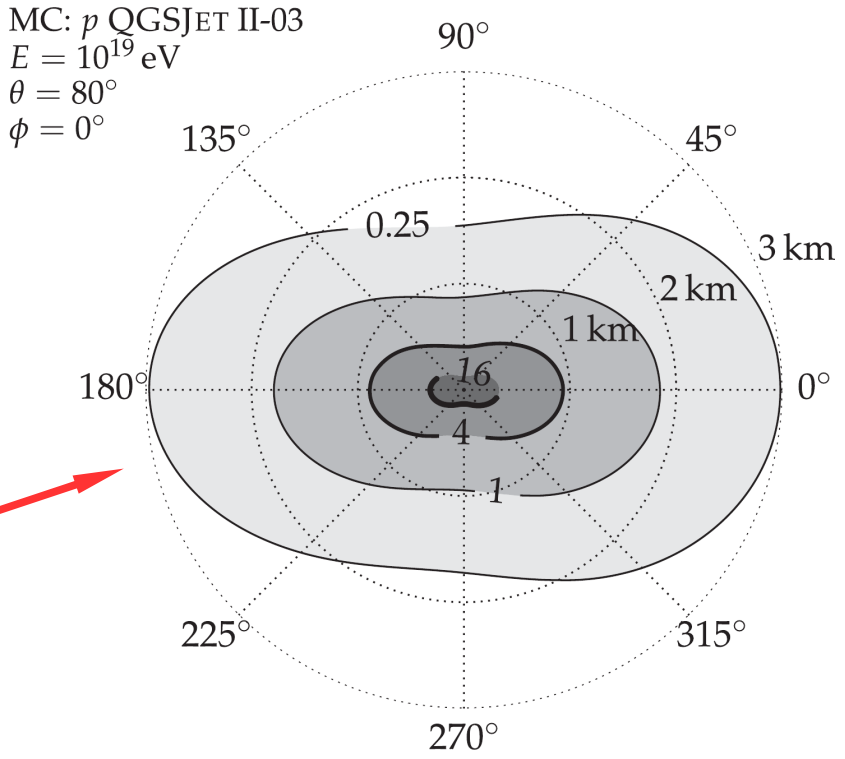




EM vanishes faster

Inclined Showers

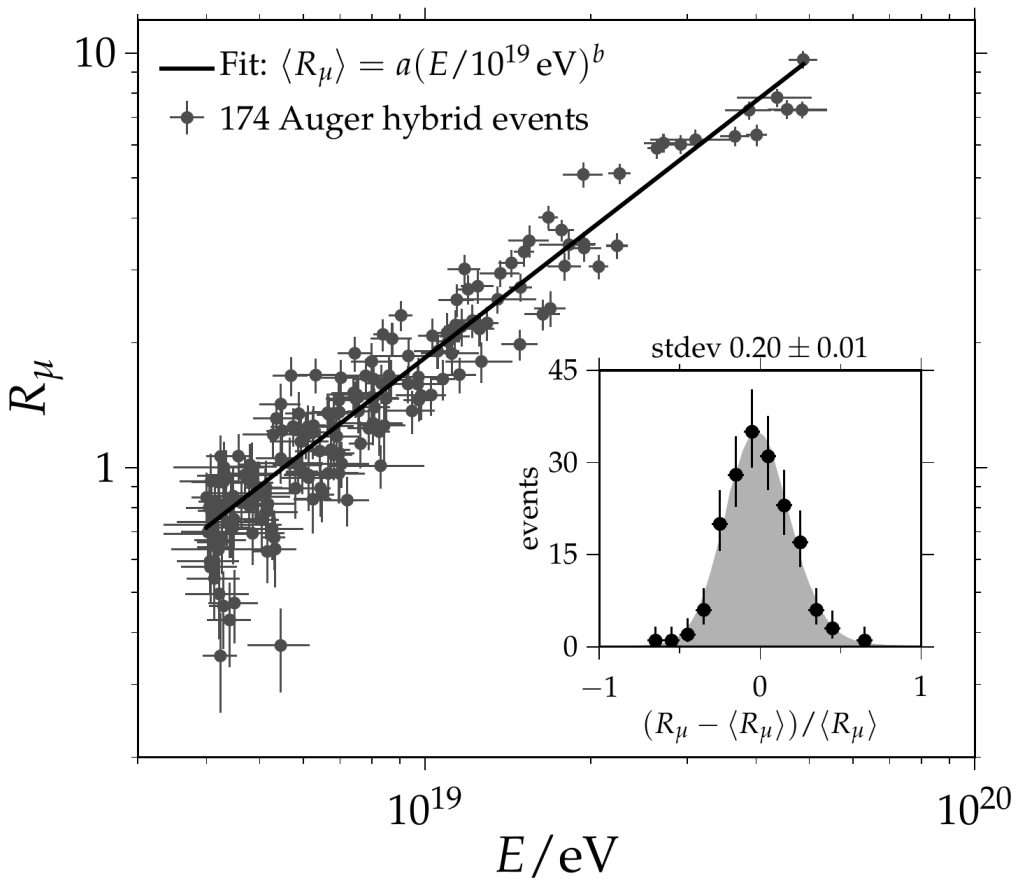


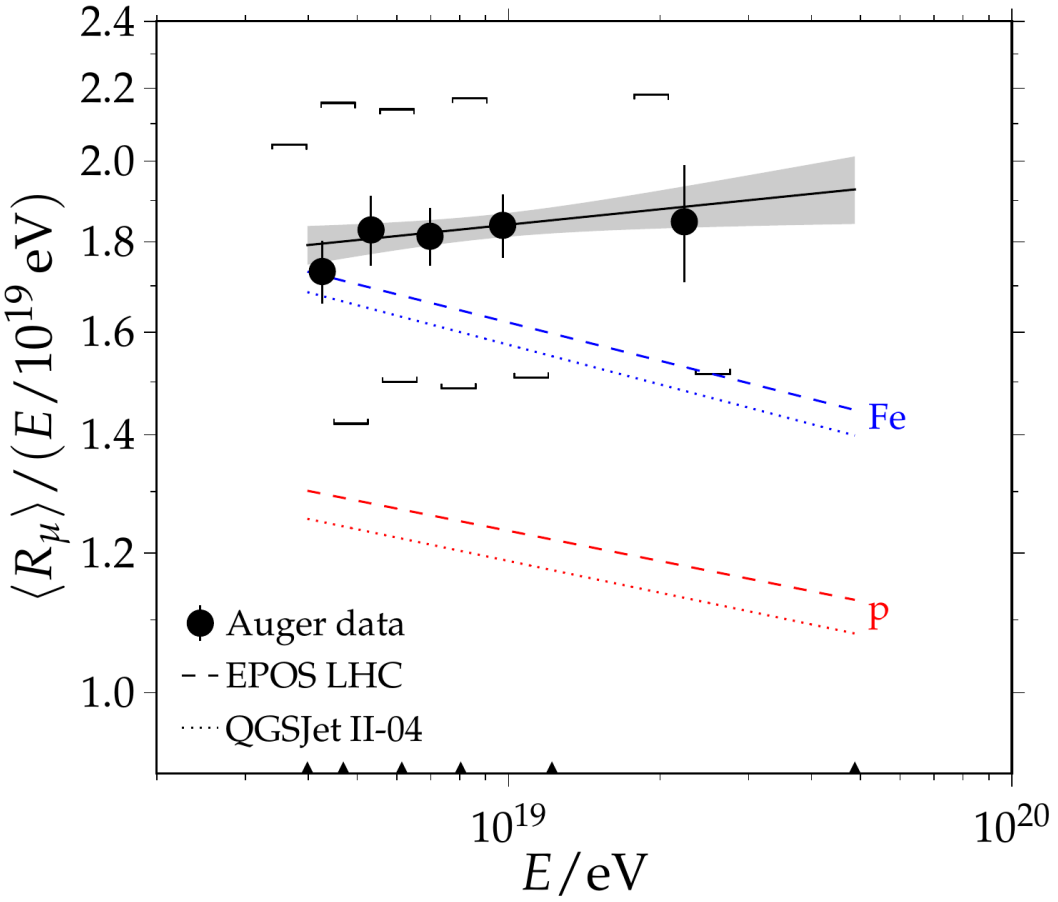


zenith and azimuthal angle dependent template (geomagnetic field)

Auger, PRD 91 (2015) 032003

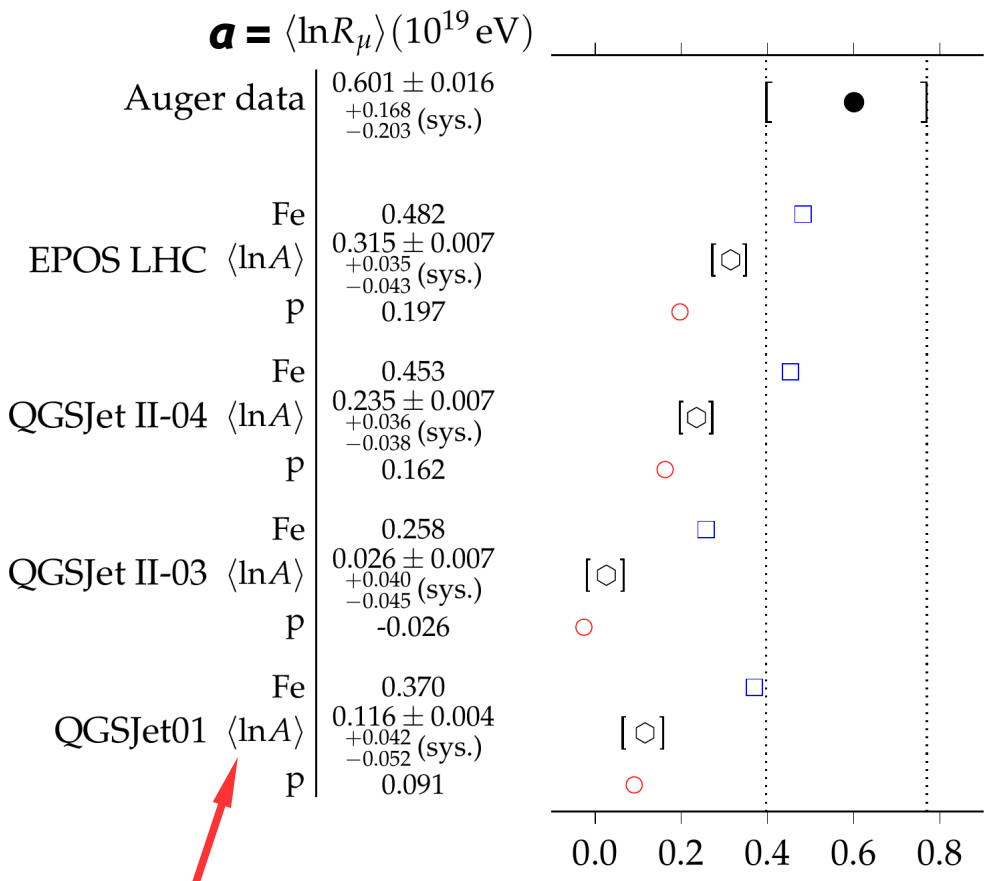
Relative Muon Number R_μ

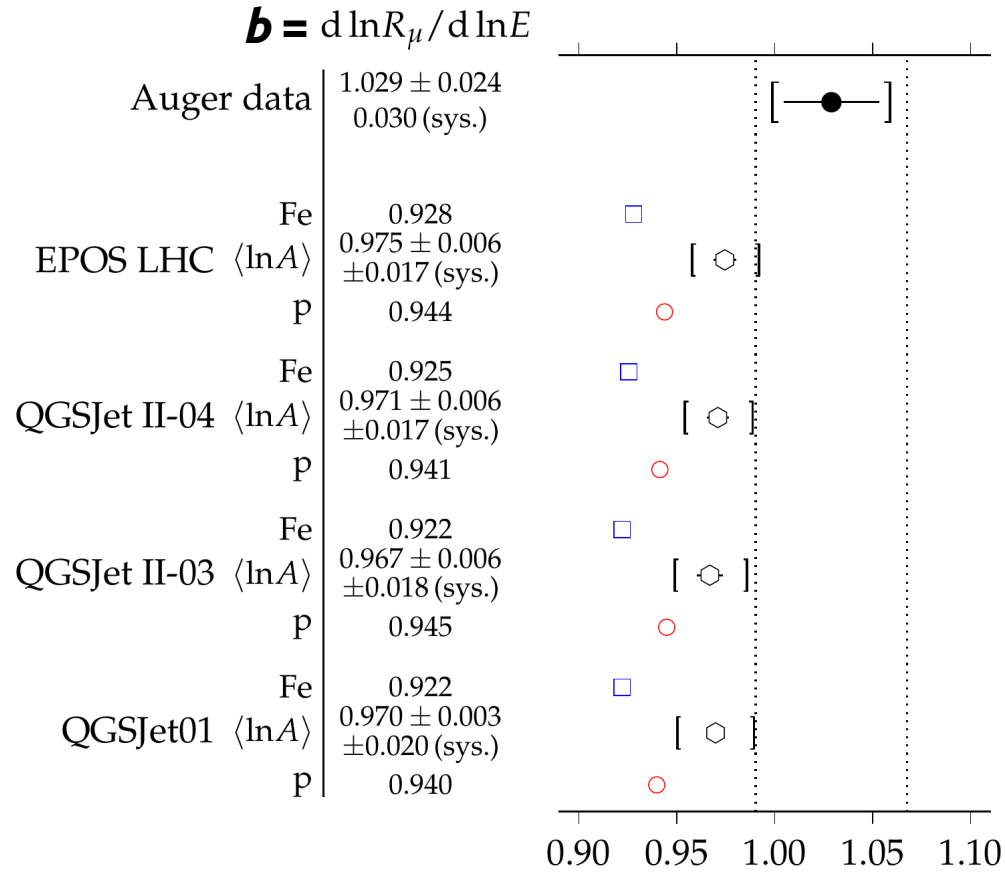




Auger, PRD 91 (2015) 032003

R_μ Parameters

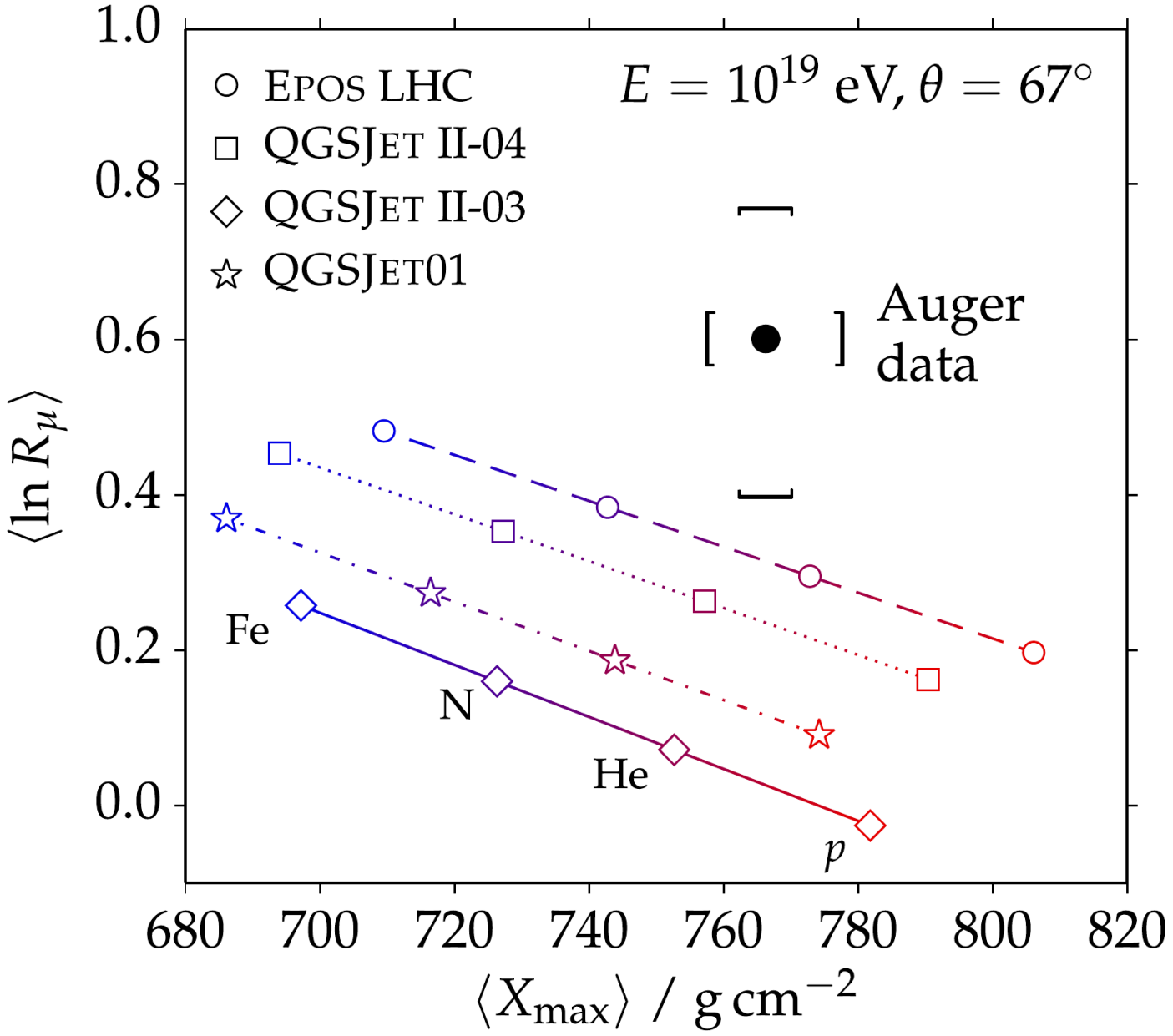




from X_{max}

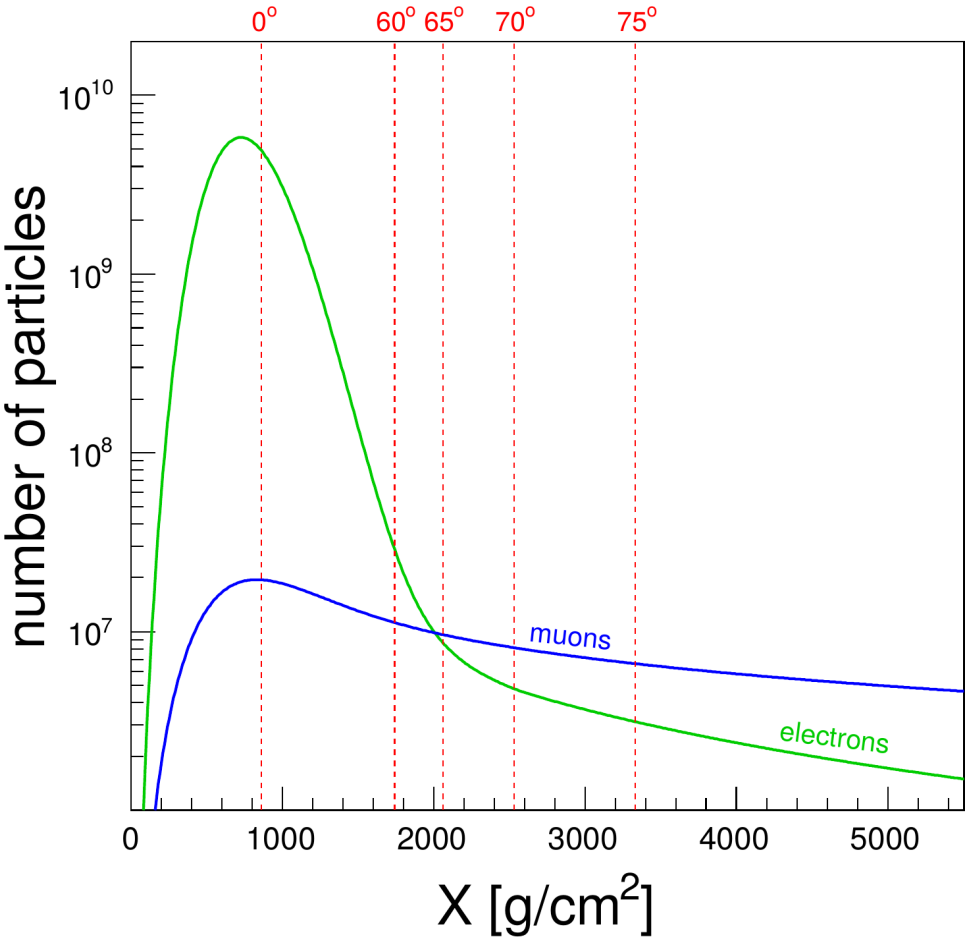
Auger, PRD 91 (2015) 032003

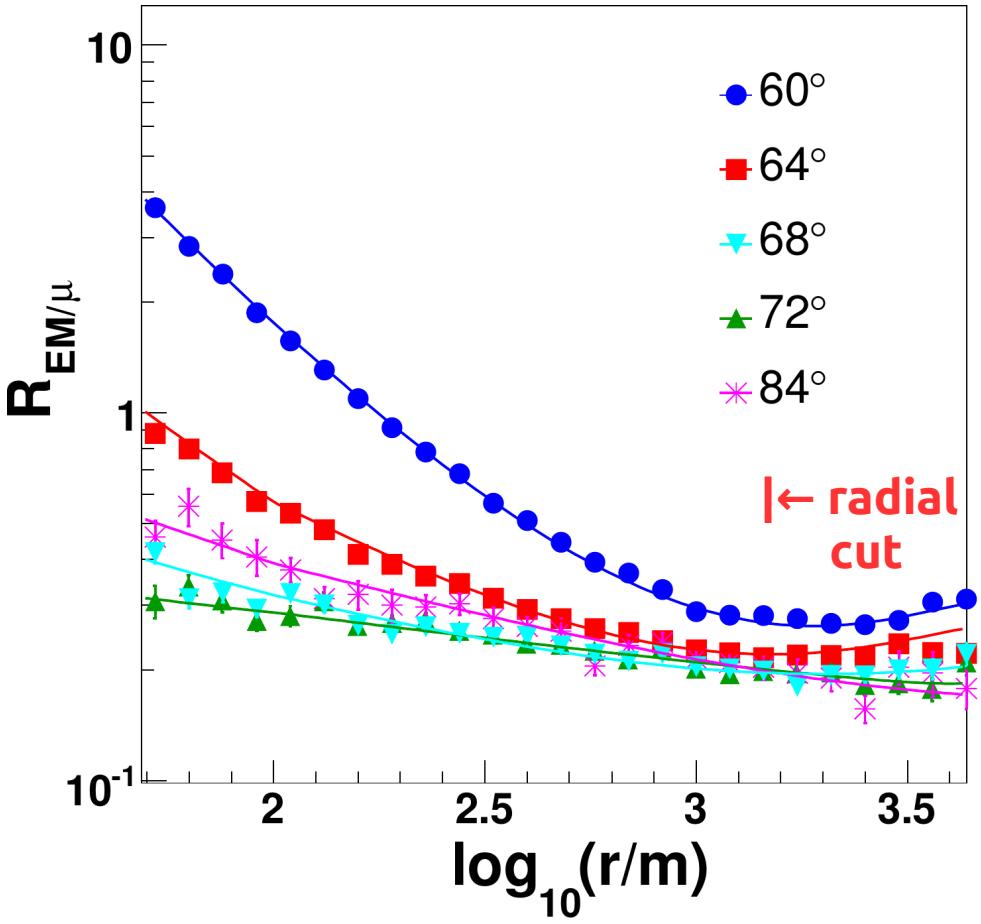
R_μ vs. X_{max}



Auger, PRD 91 (2015) 032003

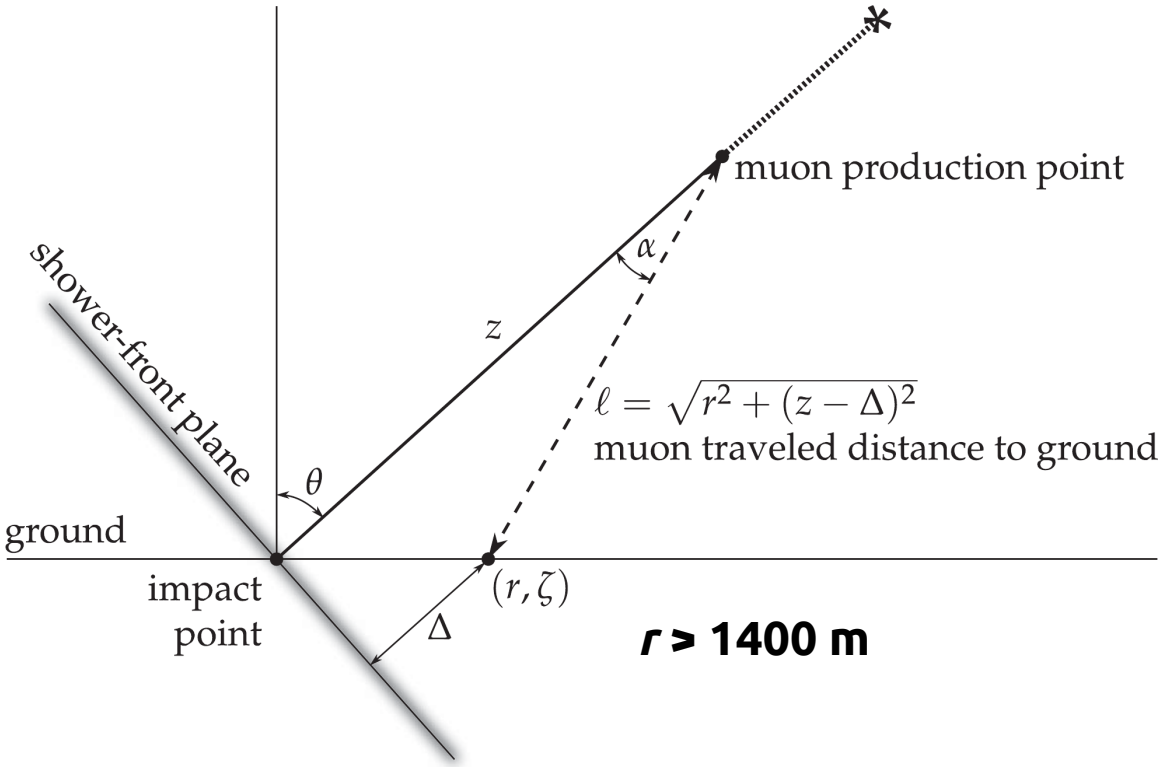
EM/μ Ratio





less EM at large distances

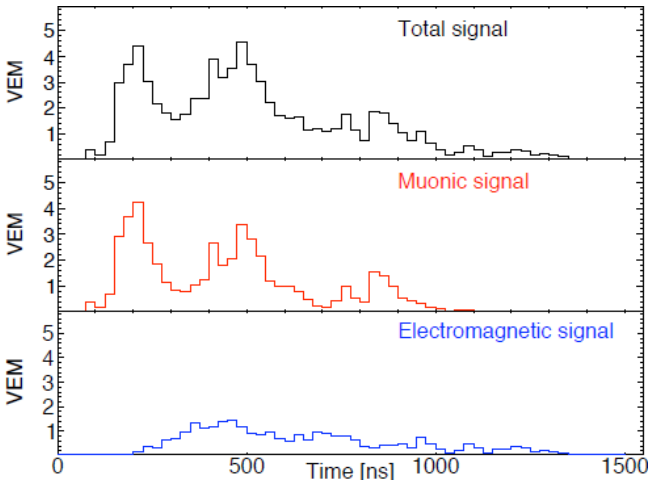
Muon Production Depth

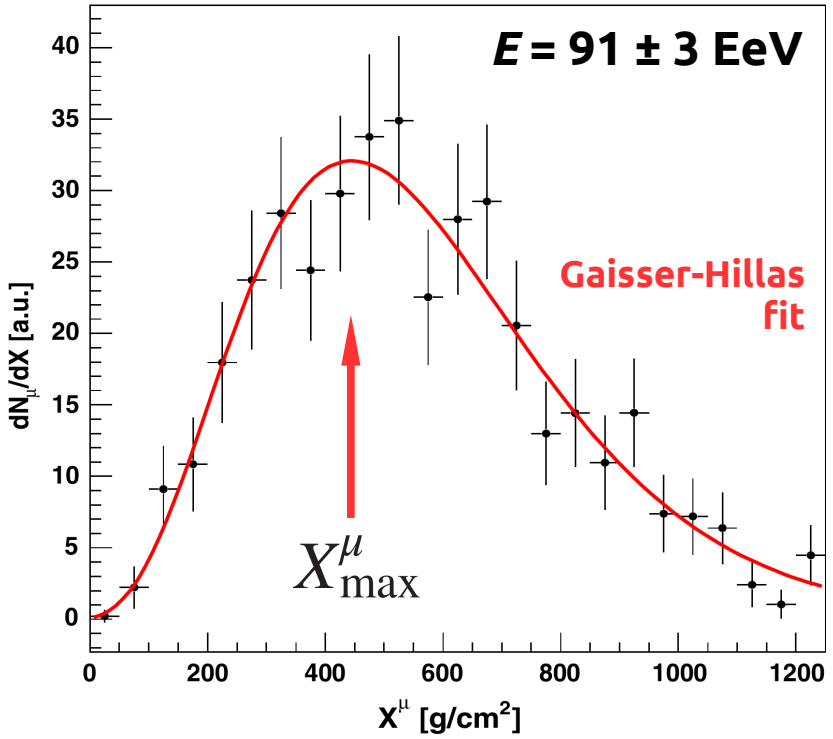


r > 1400 m

$$z \simeq \frac{1}{2}\left(\frac{r^2}{c(t - \langle t_\varepsilon \rangle)} - c(t - \langle t_\varepsilon \rangle)\right) + \Delta - \langle z_\pi \rangle$$

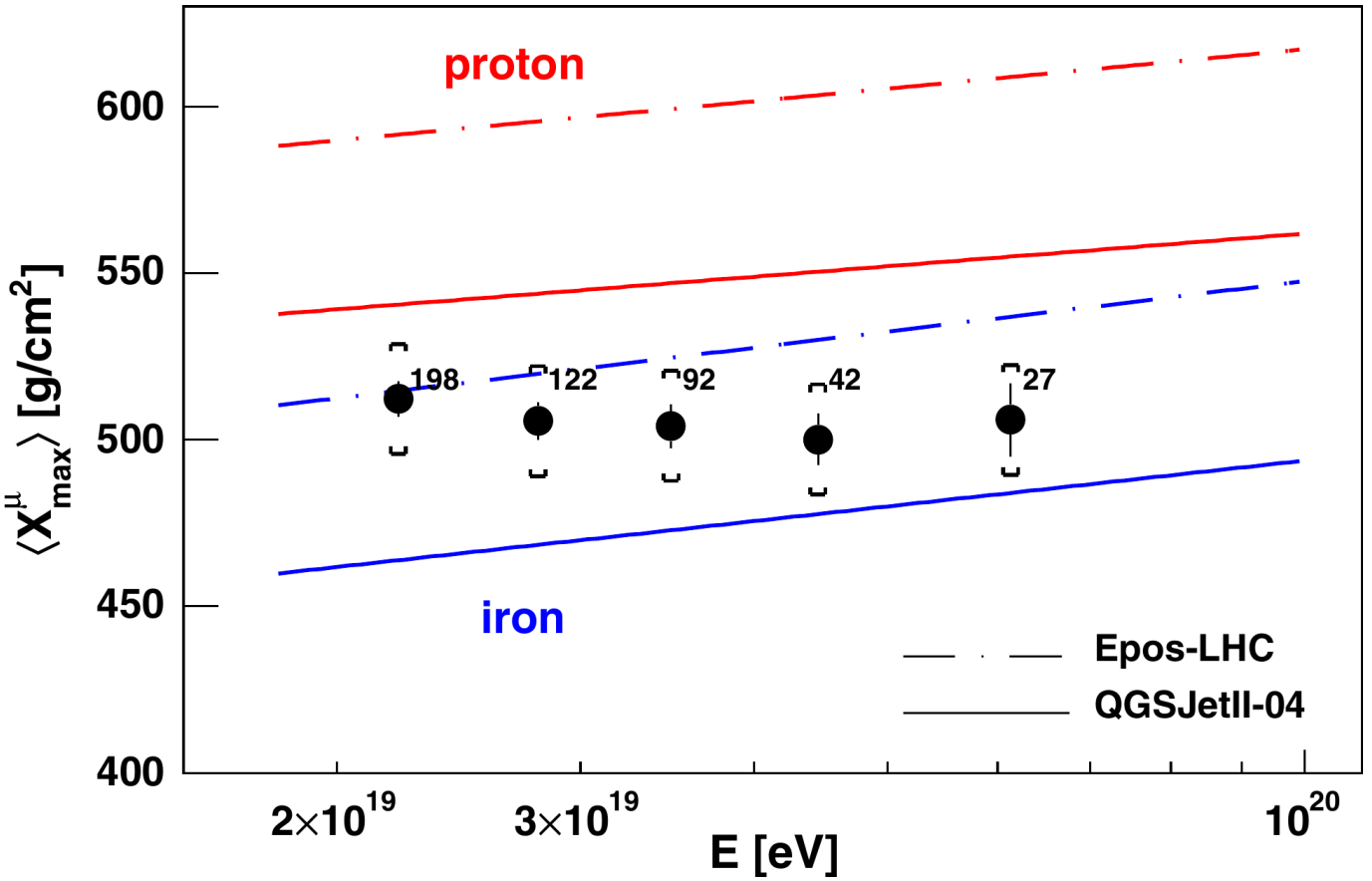
per event



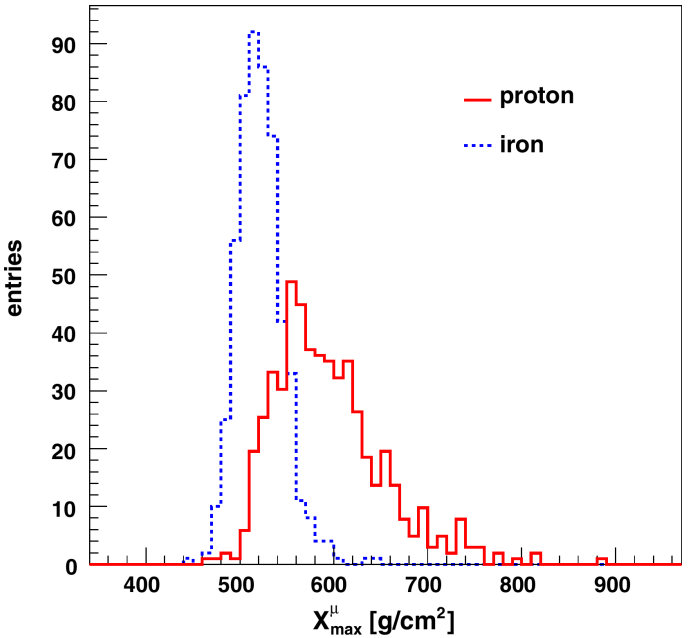


Auger, PRD 90 (2014) 012012

Muon Production Depth

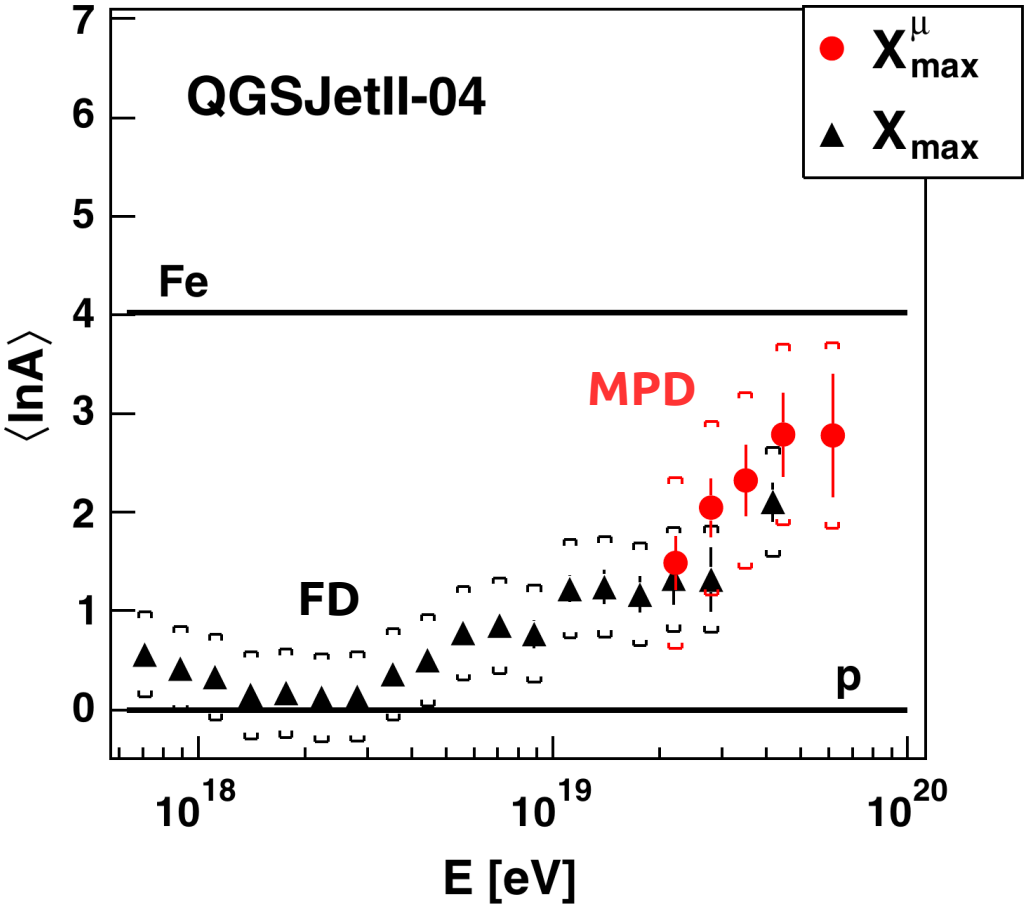


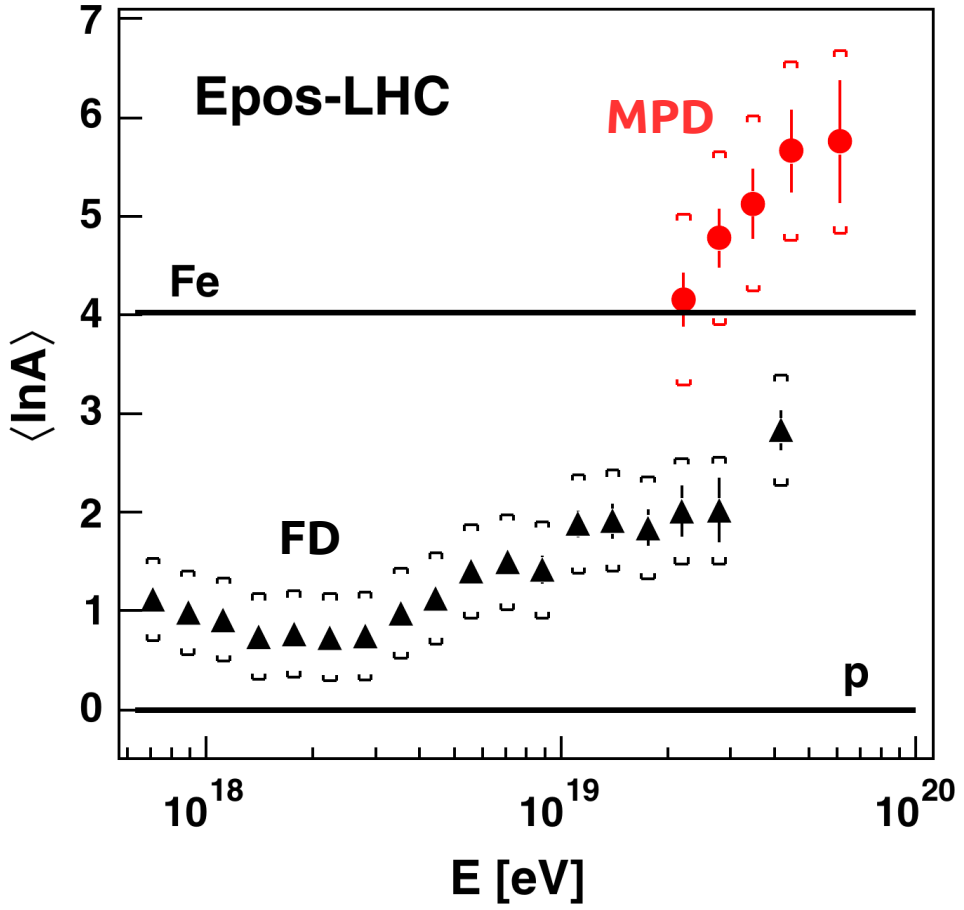
MC distributions



Auger, PRD 90 (2014) 012012

Muon Production Depth



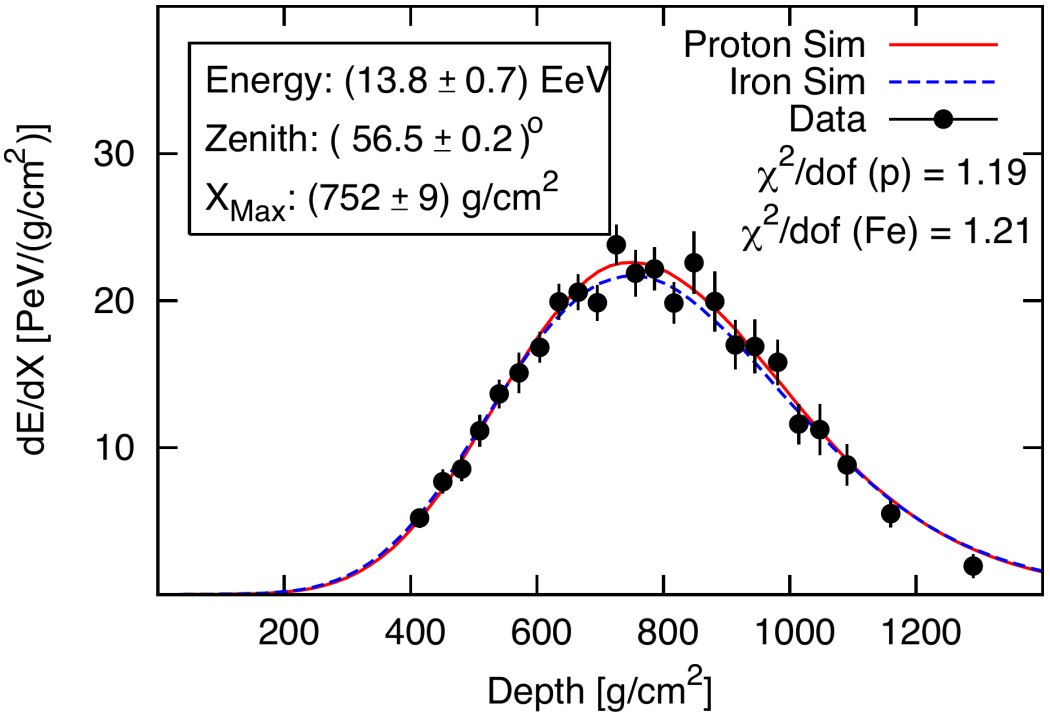


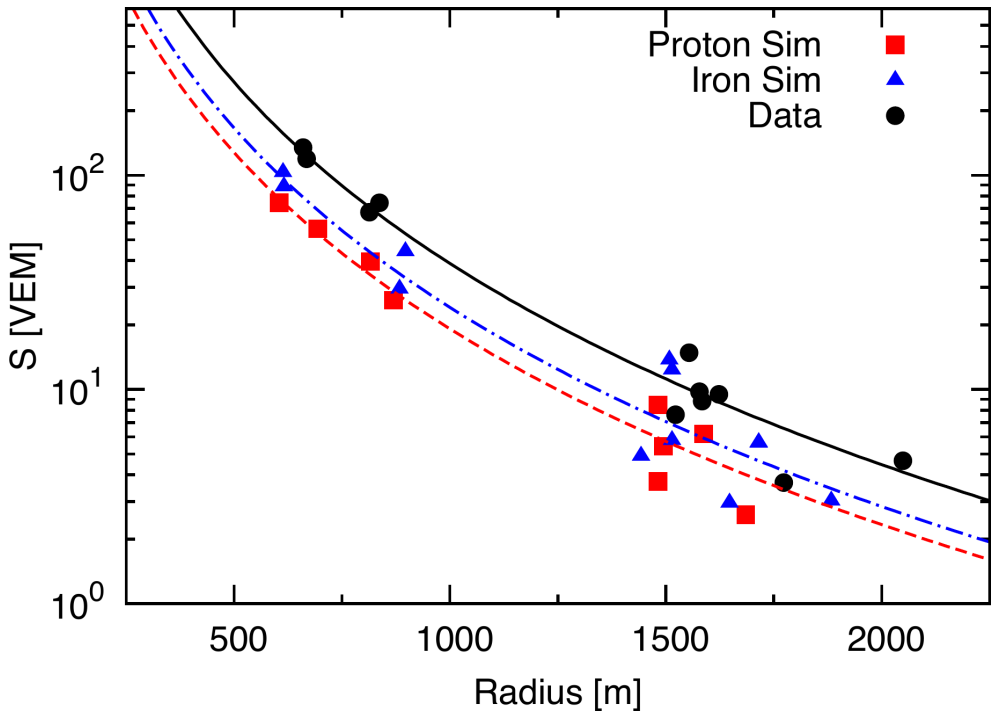
Auger, PRD 90 (2014) 012012

Top-down

dataset: 411 high-quality hybrid events

in MC find matching FD profile → **compare lateral signal on the ground**

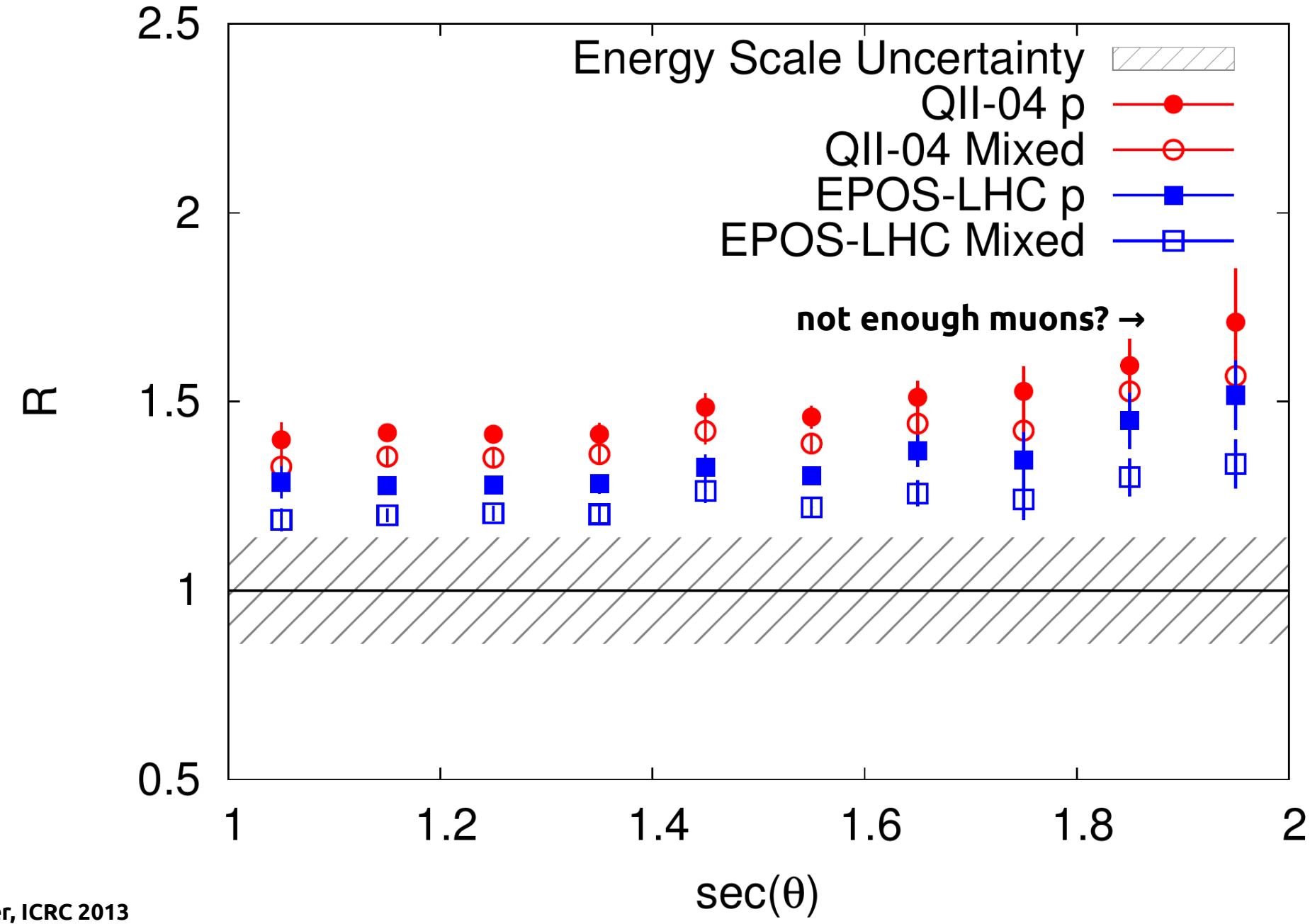




defines rescaling *R*

Auger, ICRC 2013

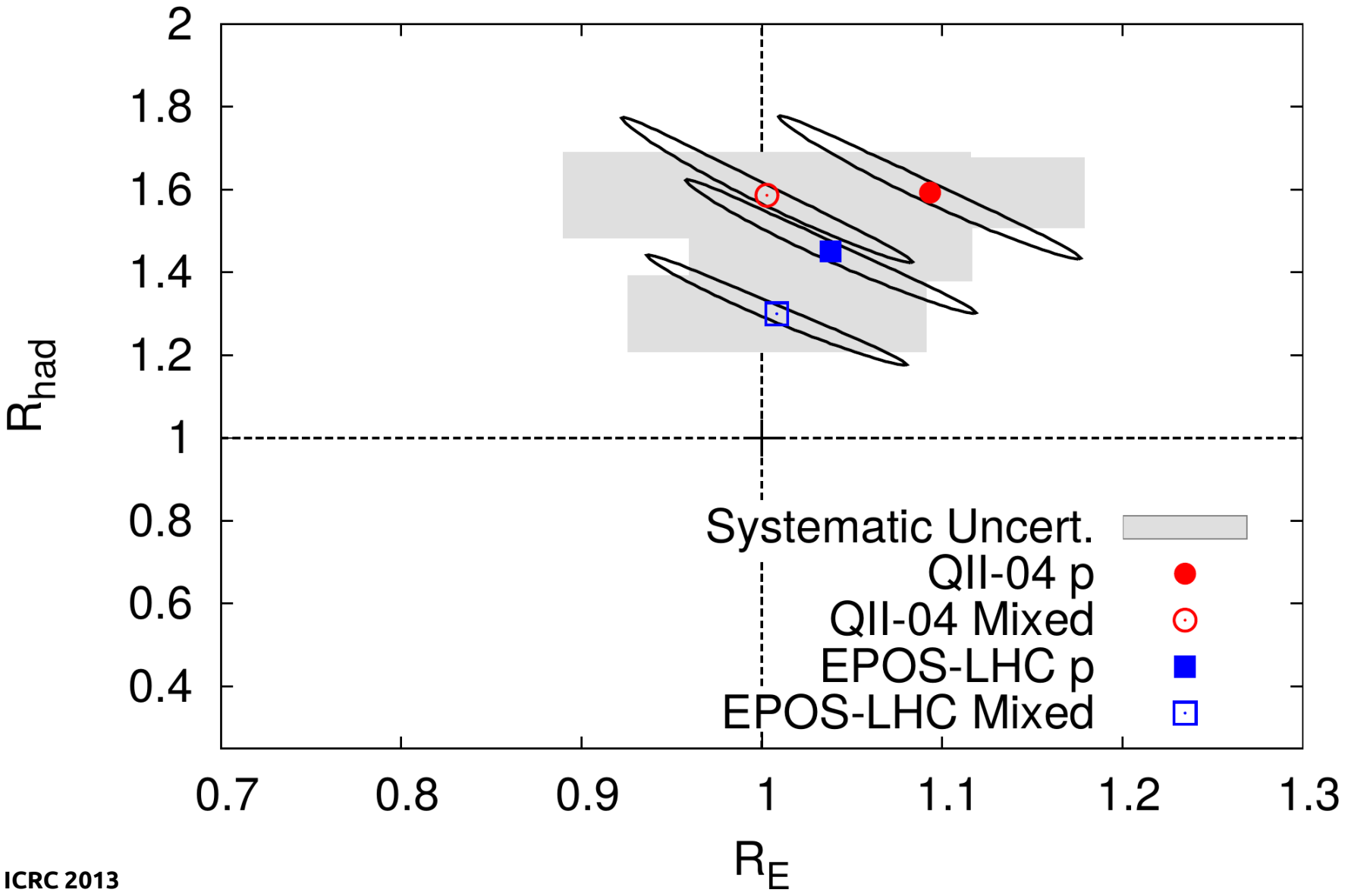
Top-down



Auger, ICRC 2013

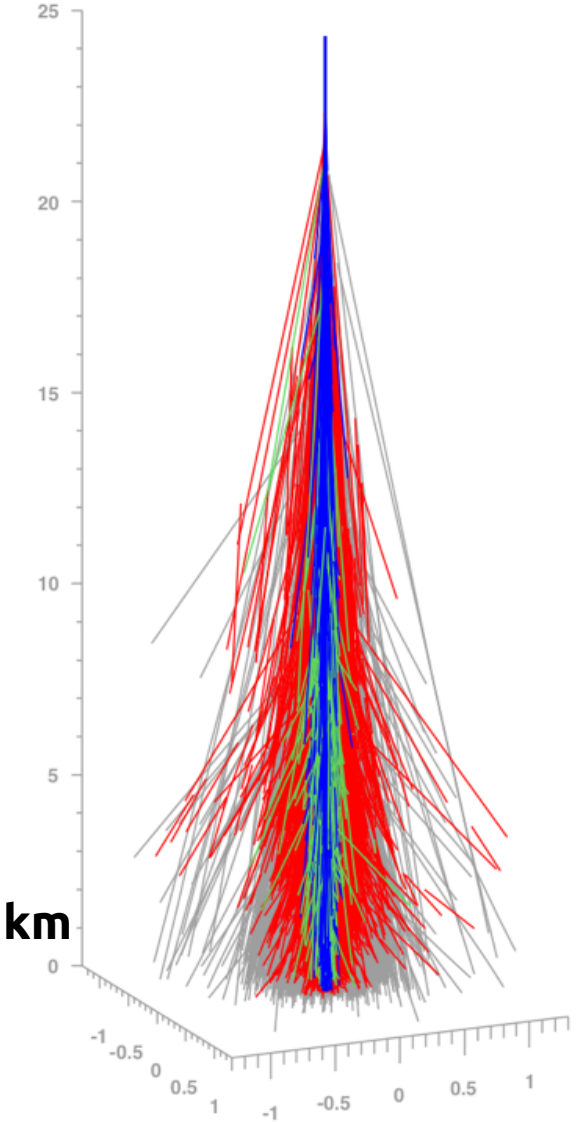
Top-down

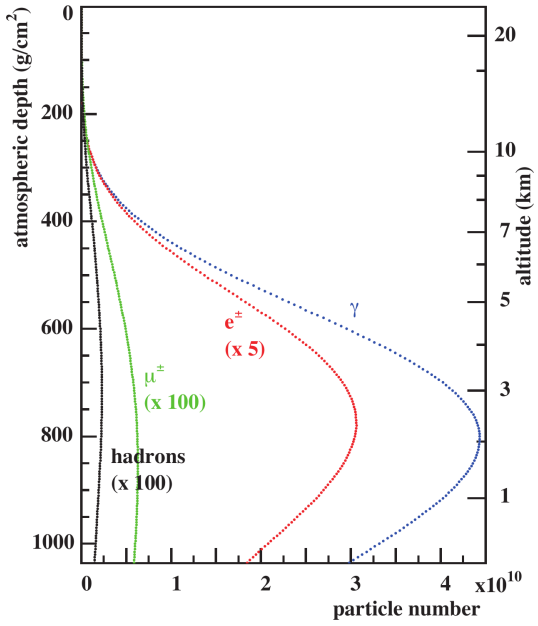
Furthermore, in MC use energy and "muon" (hadronic) rescaling: R_E and R_{had}

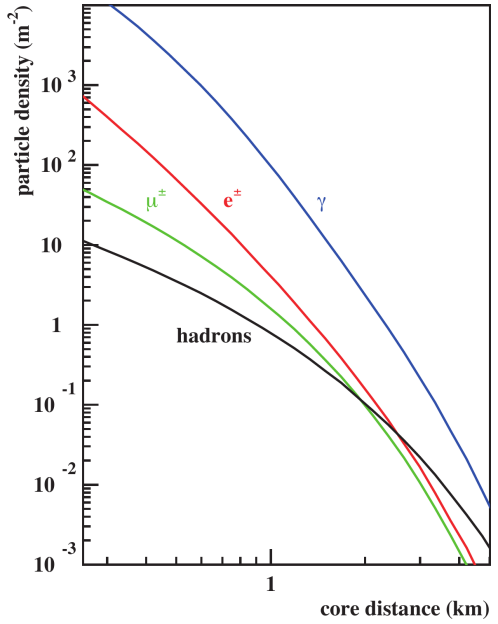


Auger, ICRC 2013

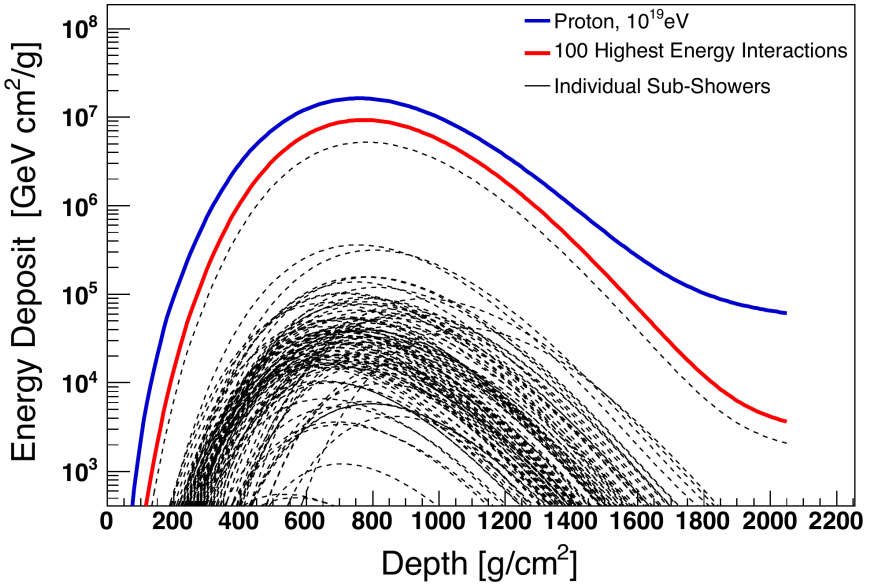
Hadronic Interactions

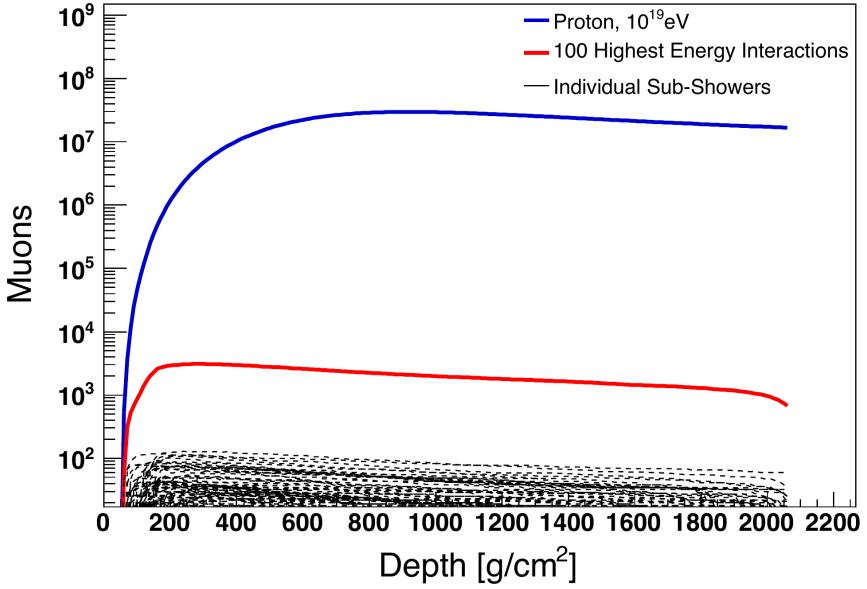






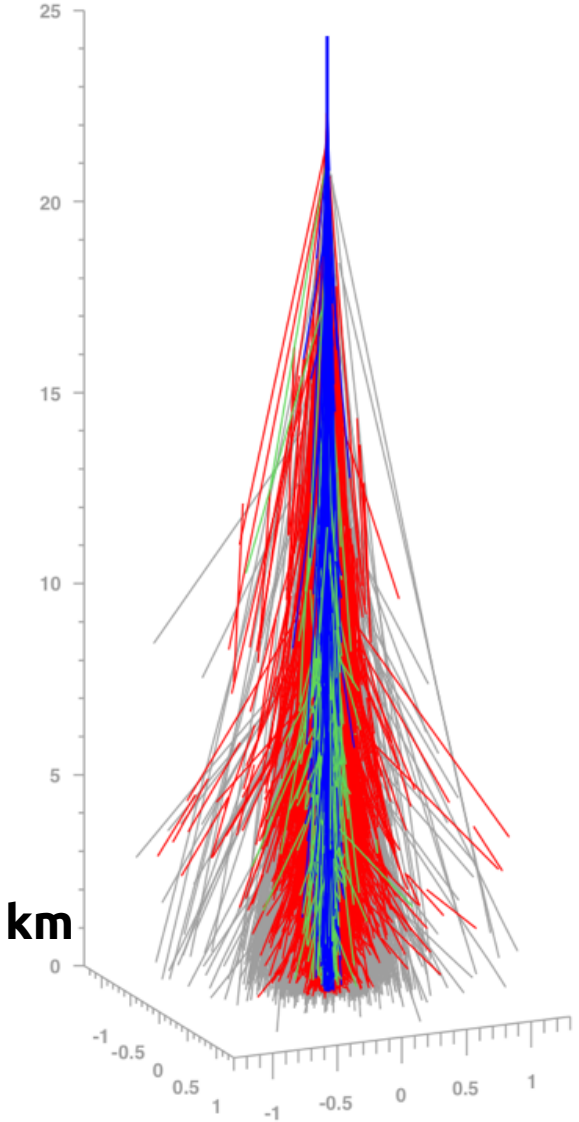
Engel, ARNPS 61 (2011) 467

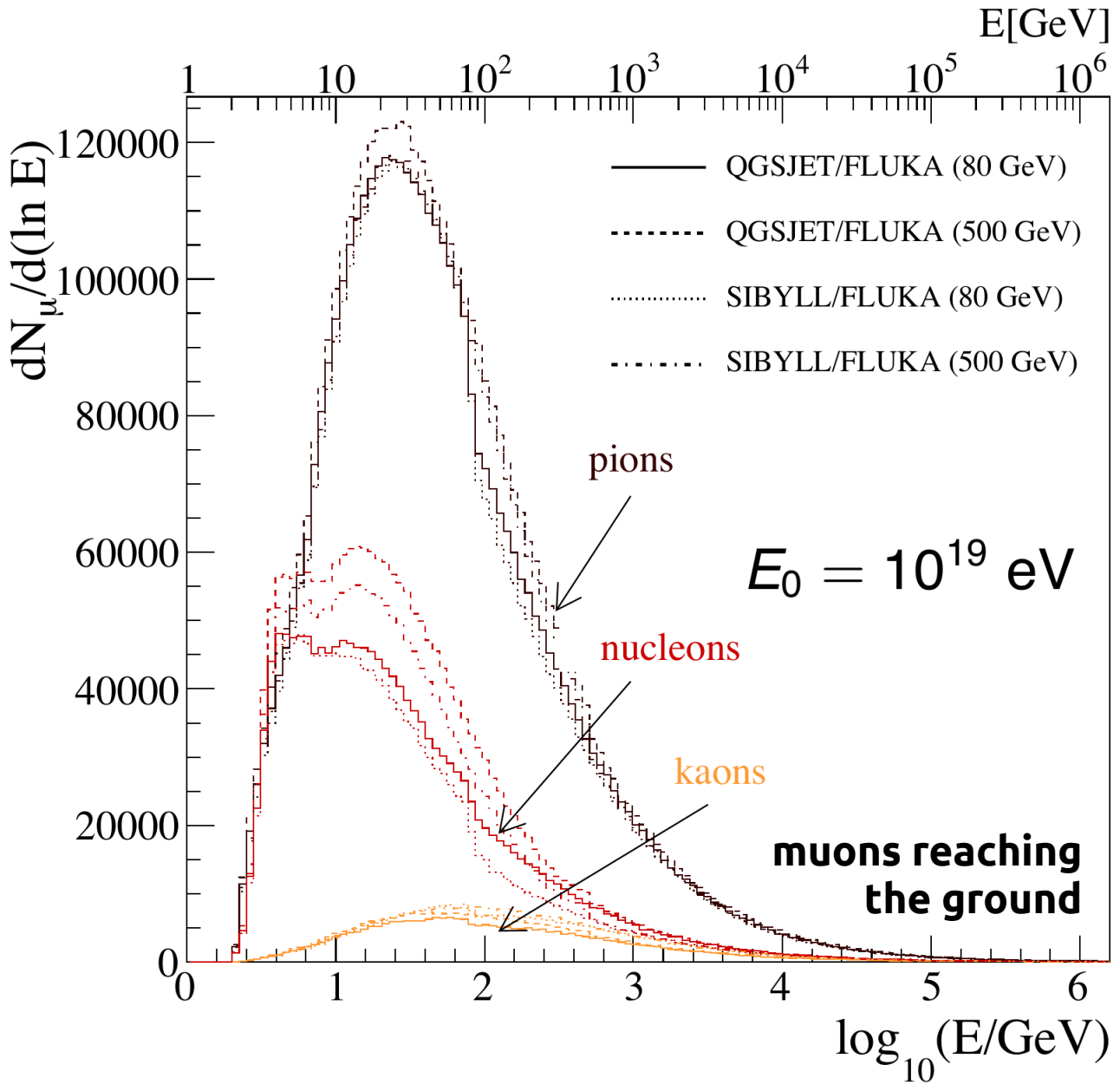




Engel, APS 2012

Muon “Grandparents”





Mariş, ICRC 2009

Change in EM Transfer

- **Baryon-antibaryon pair production:**
  Grieder, ICRC 1973; Pierog & Werner, PRL 101 (2008) 171101
- **Leading particle effect for pions:**
  Drescher 2007, Ostapchenko

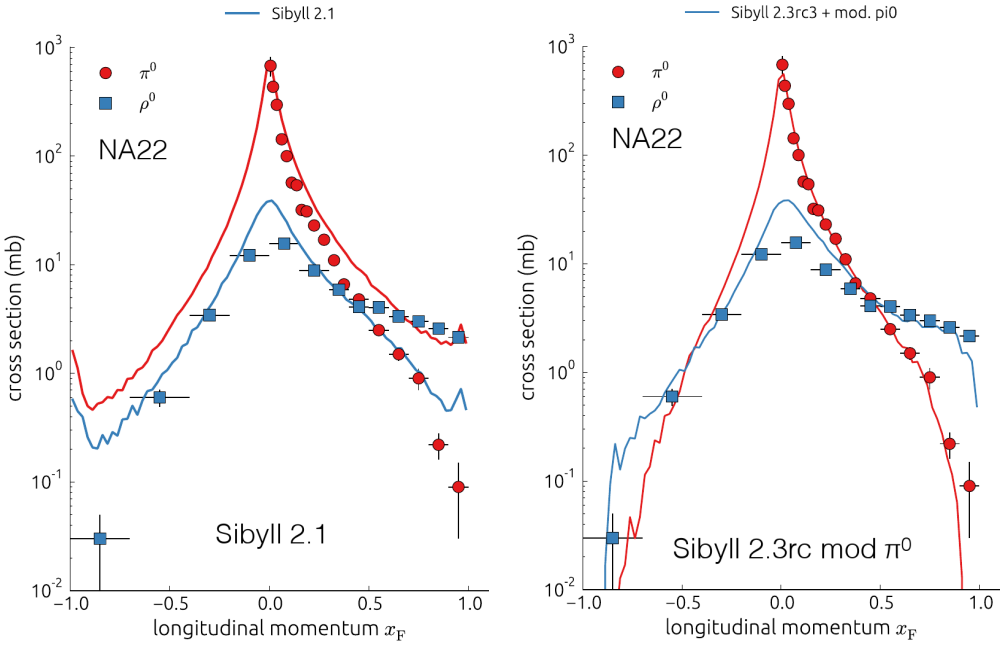
$$\pi^+ p \rightarrow \pi^0 \rightarrow 2\gamma$$

EM shower

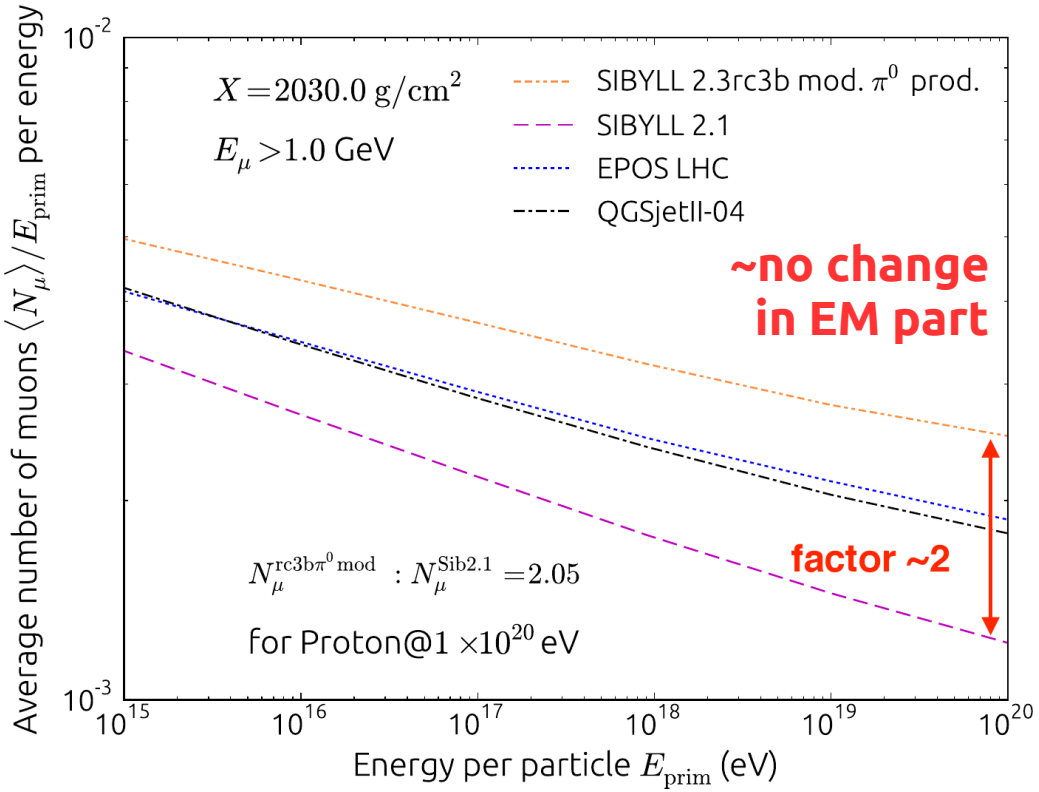
$$\pi^+ p \rightarrow \rho^0 \rightarrow \pi^+ \pi^-$$

muons

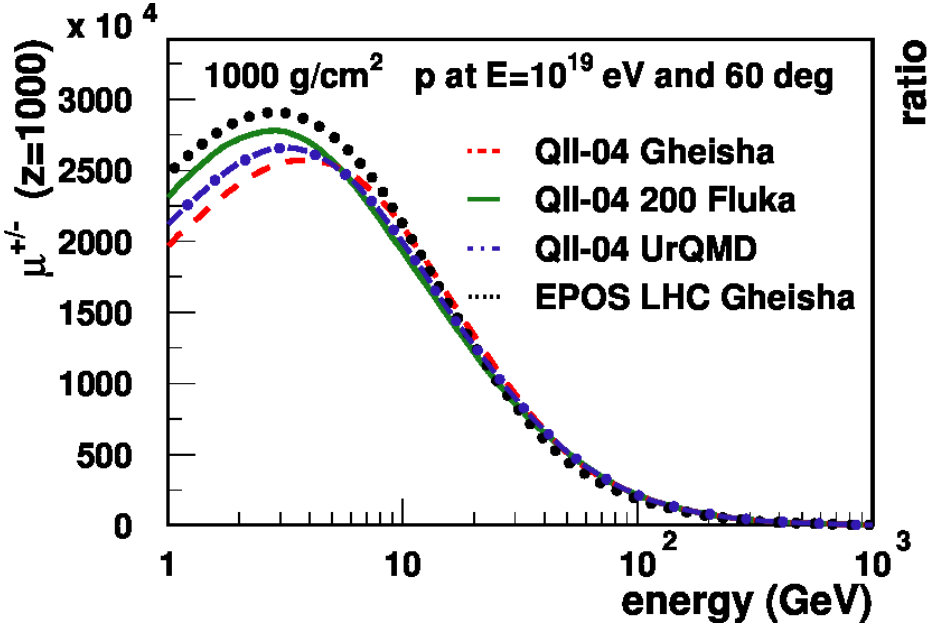
Engel, HAP Composition 2015

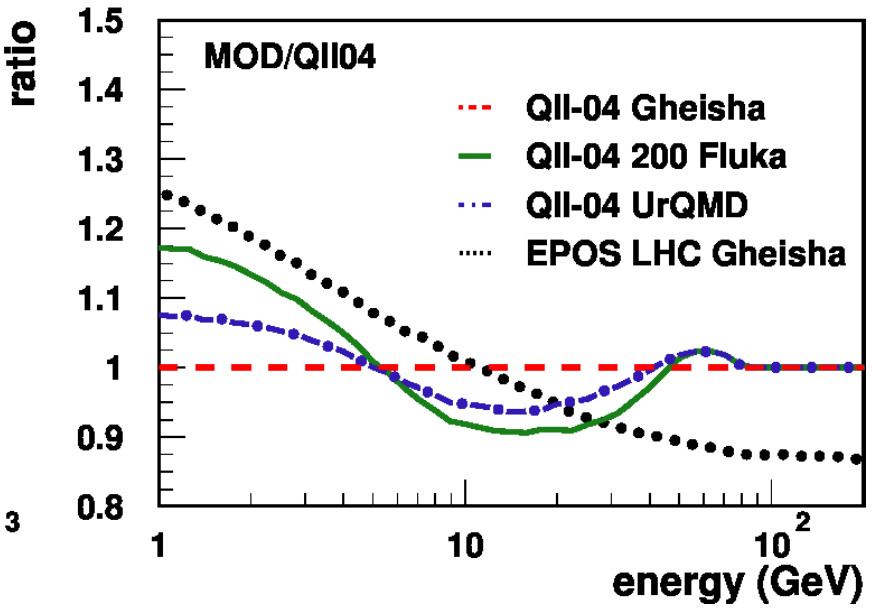


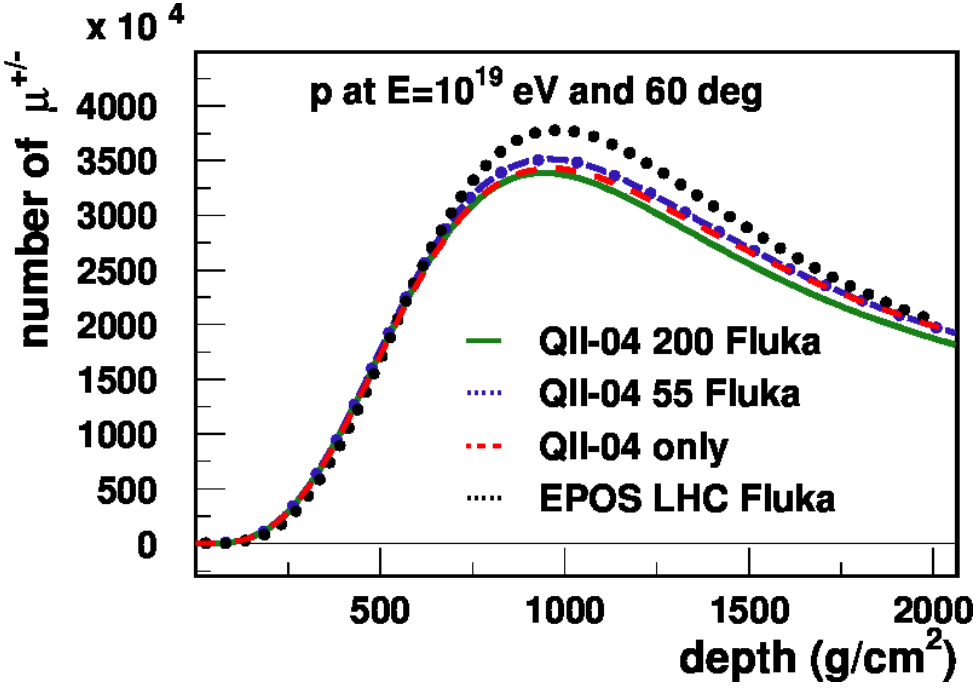
Riehn, HAP Composition 2015



Current Level of Accuracy







Pierog 2015

diffs. in low-energy models start to matter

Steven Saffi, Uni. Adelaide, 2014

Thank you!

Backup