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Karlsruher Institut für Technologie

A universal description of temporal and spacial distributions of ground particles in extensive air showers

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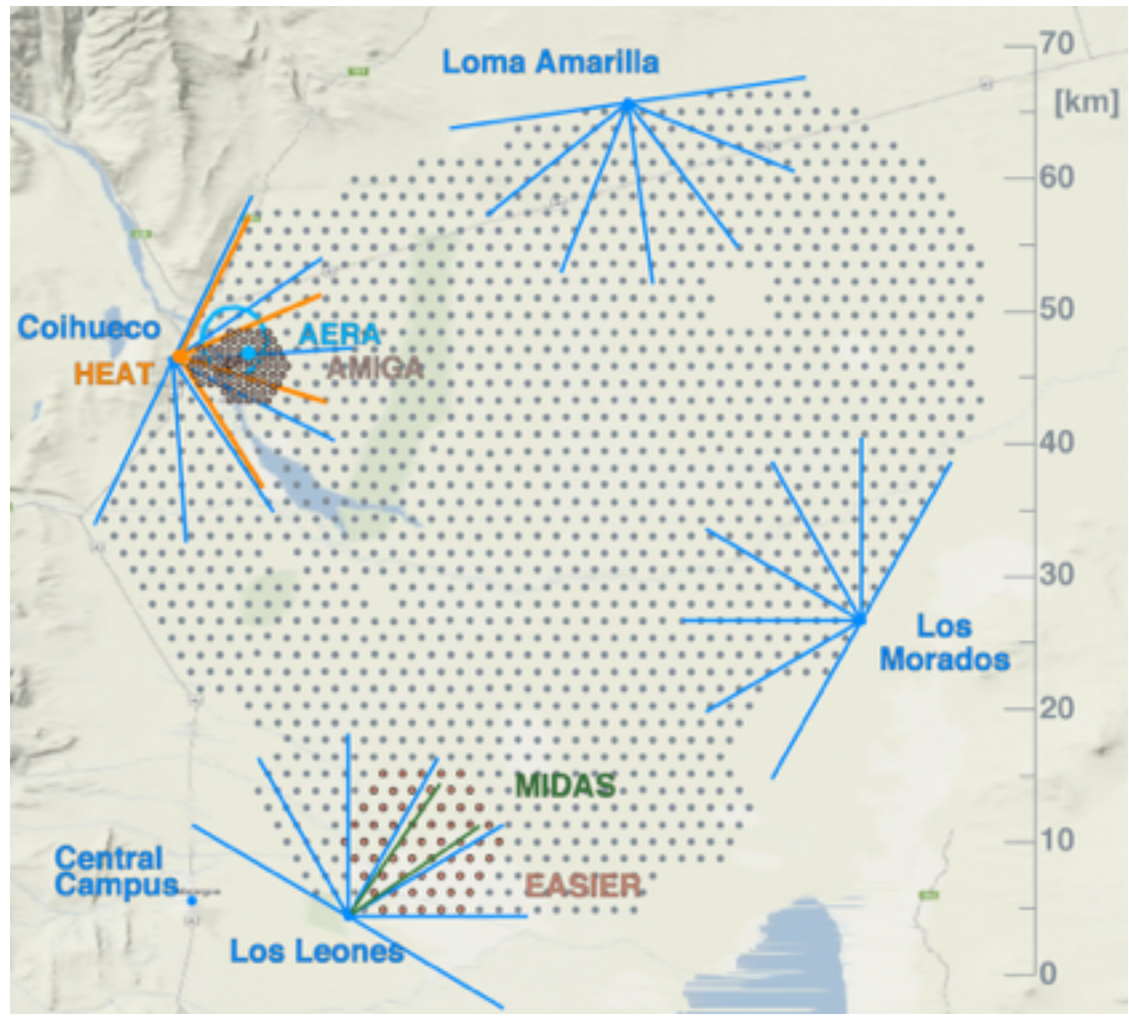
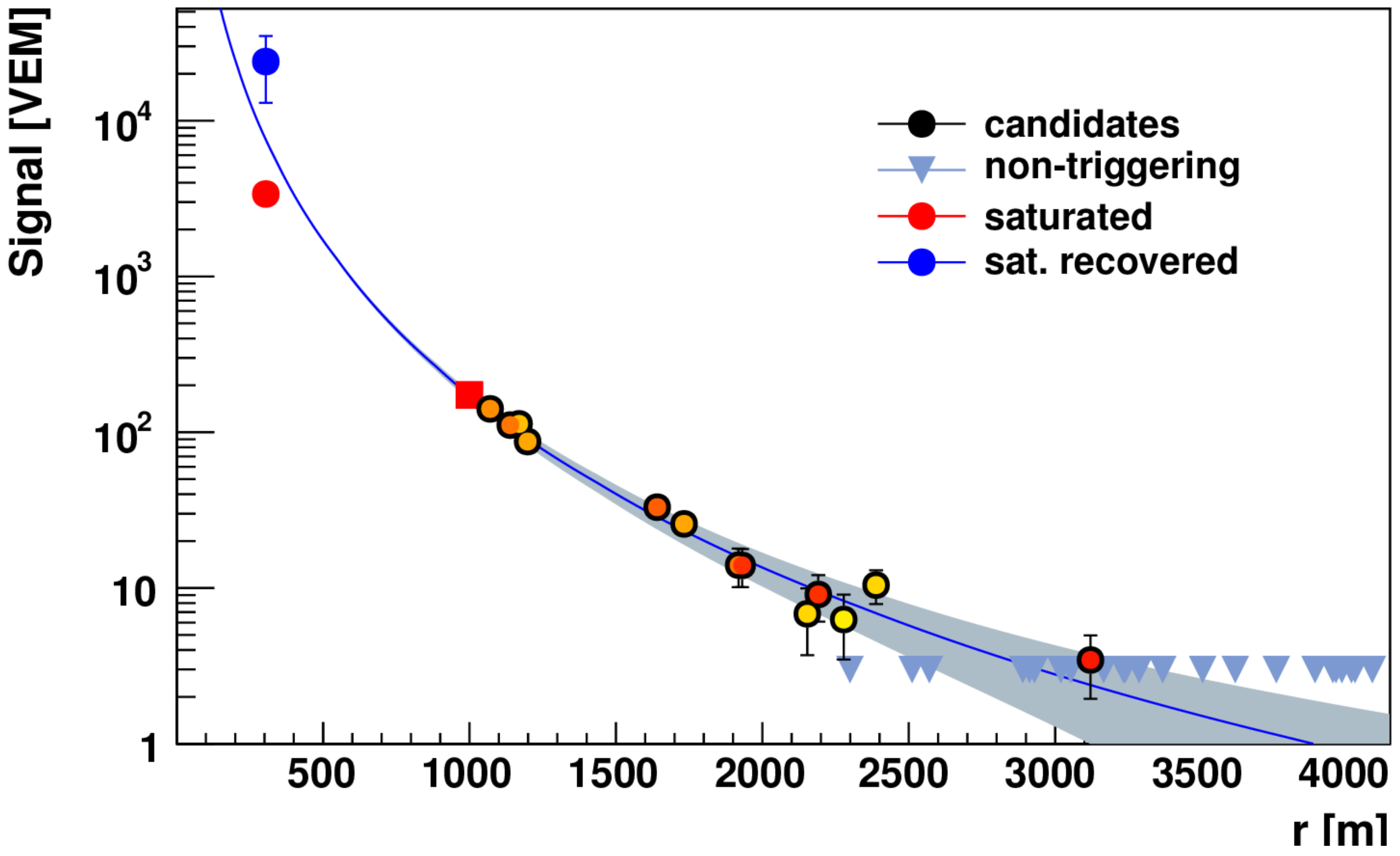
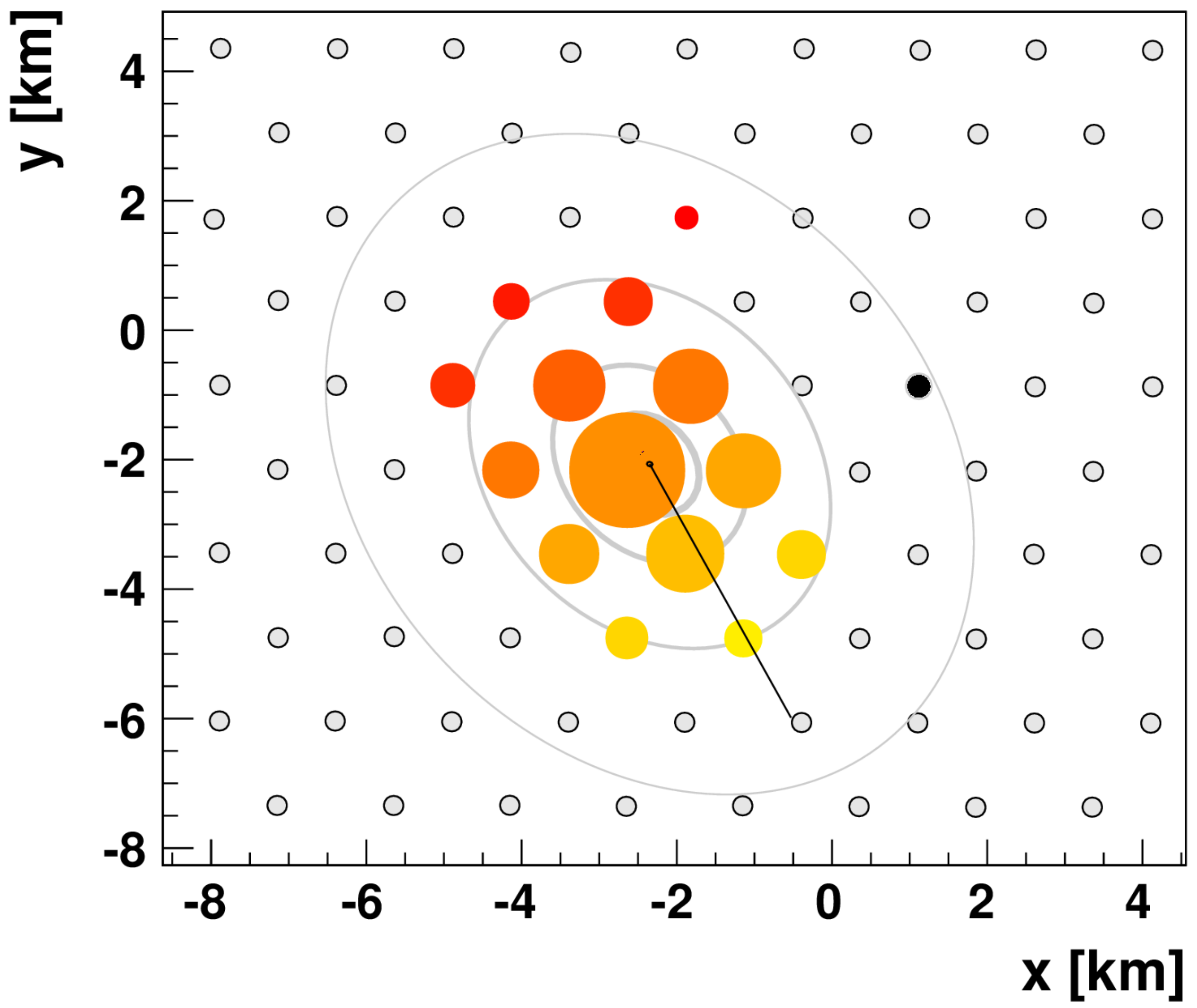
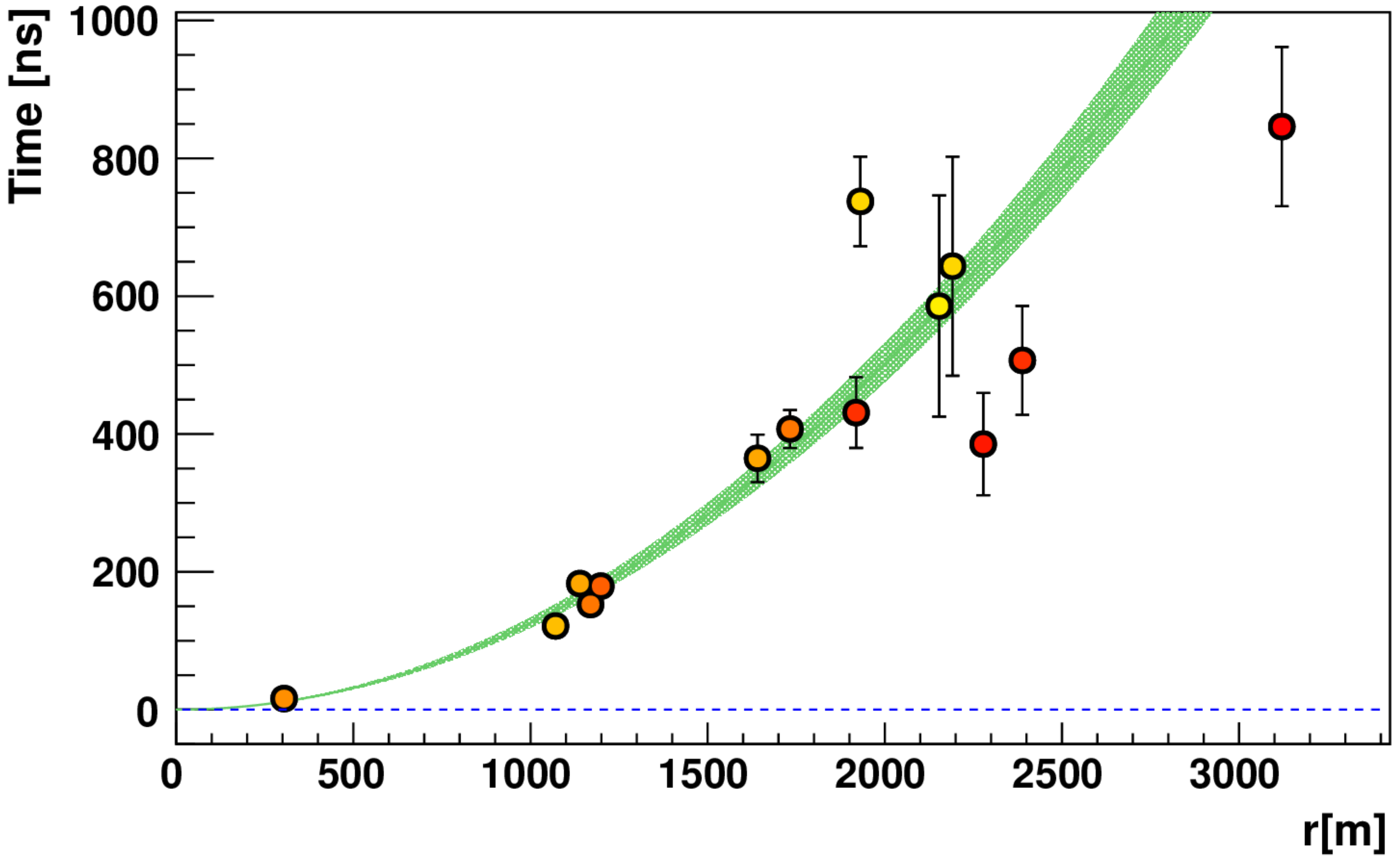
Reconstruction of surface detector data at e.g. Auger

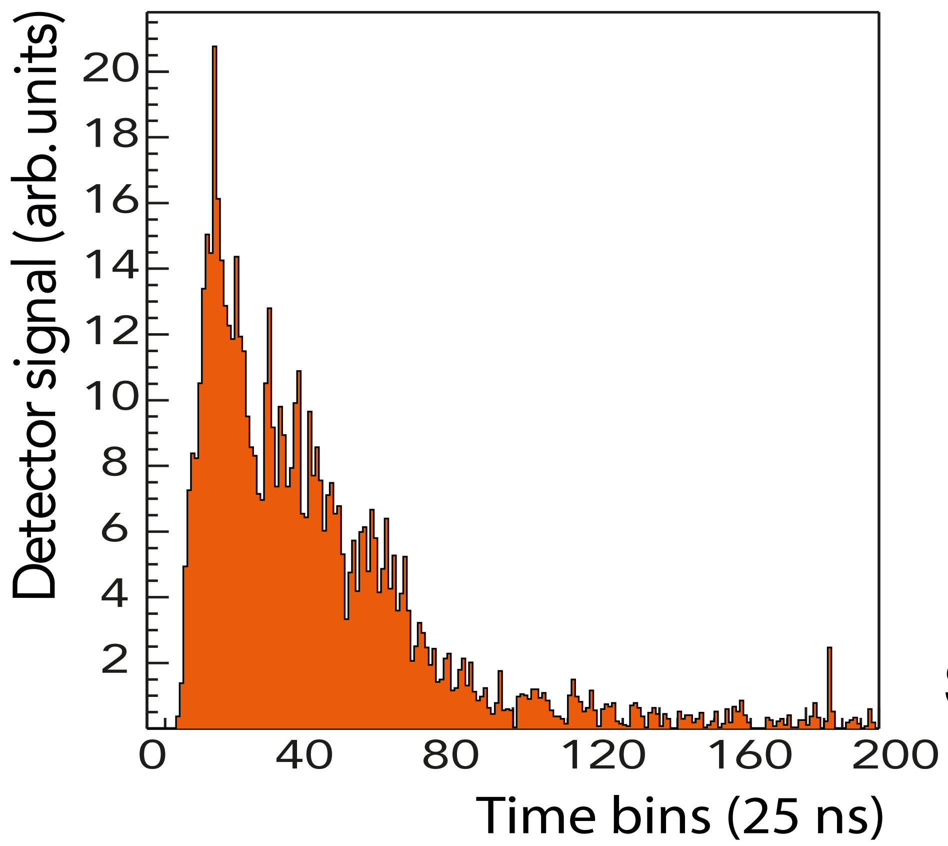






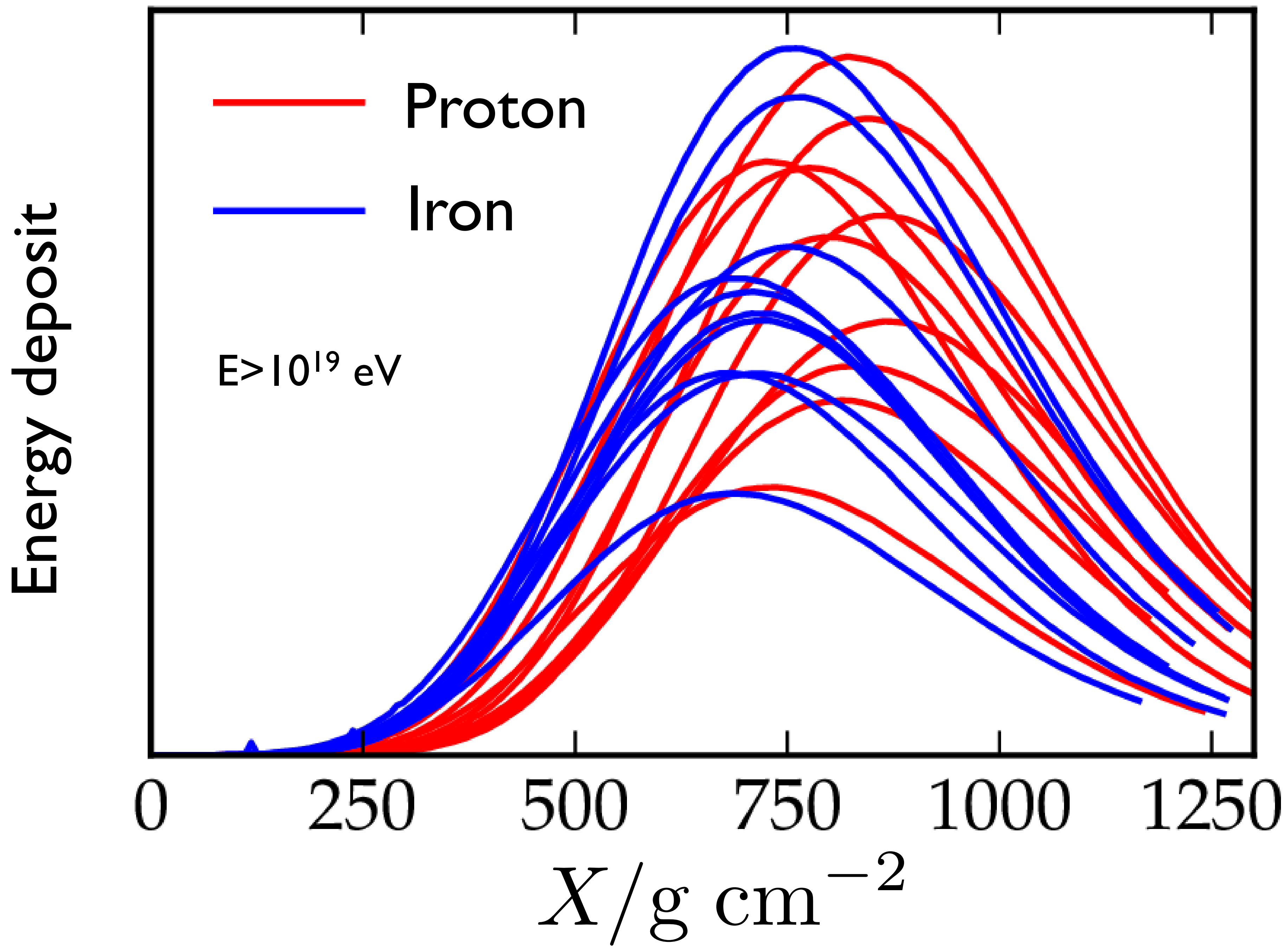


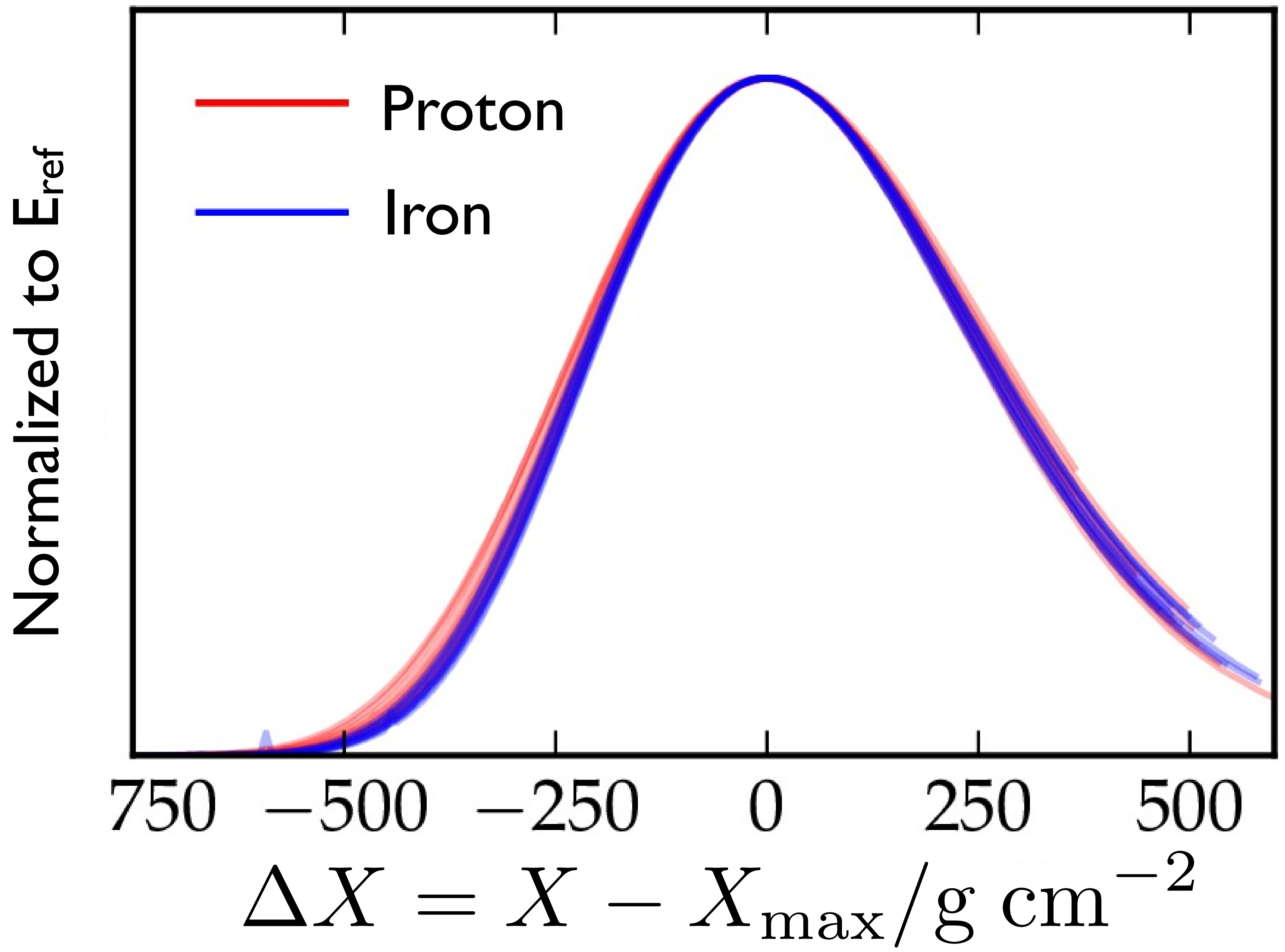
- Particle density: 1D lateral distribution
  → shower size, core position
- Arrival times: Spherical shower front
  → shower axis
- Fit parameters are connected only indirectly to mass and properties of UHE interactions,
  e.g. Rise-time, curvature, LDF slope



Rich timing information
(40 MHz sampling)
is not used in
standard reconstruction

Universal longitudinal profiles of the electromagnetic component of hadron induced showers





Longitudinal profiles depend on
- Energy E
- Distance to X_{max}: ΔX

but not on mass

Simulated energy deposit along shower axis

Large fluctuations in shower development apparent

Universal longitudinal profile

M. Ave, R.A. Vazquez, E. Zas, Astropart. Phys. 14 (2000) 109
M. Giller et al., J. Phys. G 31 (2005) 947
M. Giller, H. Stojek, G. Wieczorek, Int. J. of Modern Physics A 20 (2005) 6821
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F. Schmidt, M. Ave, L. Cazon, A. Chou, Astropart. Phys. 29 (2008) 355
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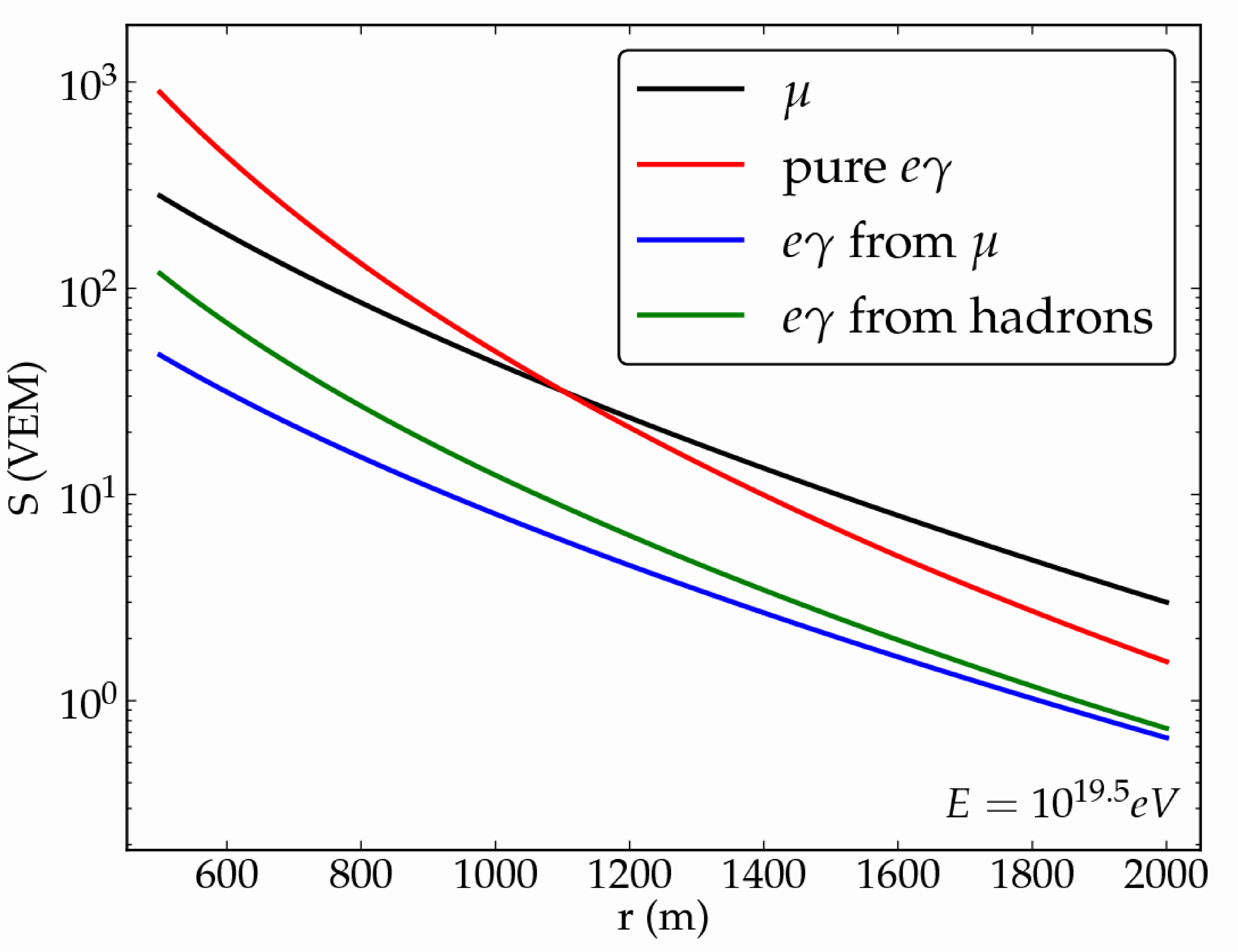
Extension to Lateral distributions of four signal components

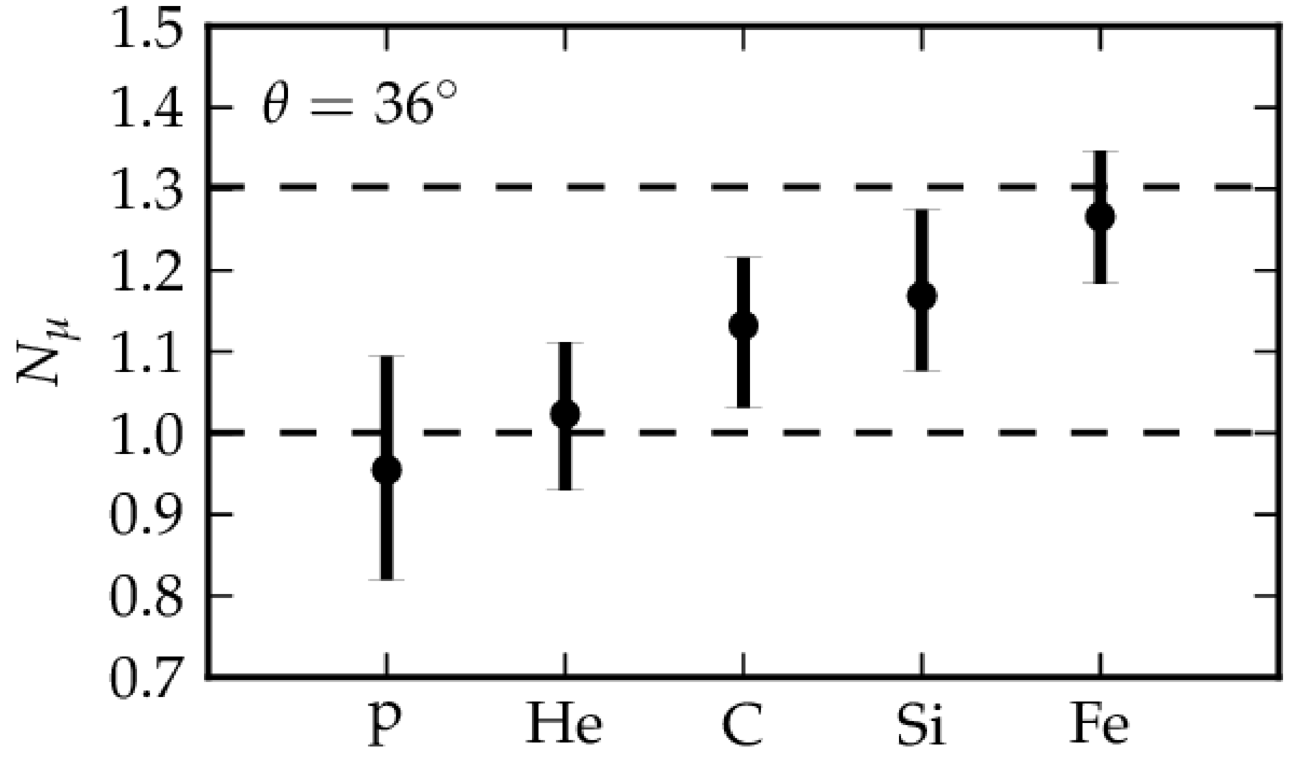
- Pure electromagnetic
- Muons
- Electromagnetic from muon decay
- Electromagnetic jets from hadrons

$$S_{\rm tot} = S_{\rm em}(DX,E) + N_\mu^{\rm rel} S_\mu^{\rm QGS}(DX,E) + N_\mu^{\rm rel} S_{\rm em}^{\mu}(DX,E) + (N_\mu^{\rm rel})^\alpha S_{\rm em}^{\rm jet}(DX,E)$$



$$N_\mu^{\rm rel} = \frac{S_\mu(DX,r,E)}{S_\mu^{\rm QGS}(DX,r,E)}$$

determined by lateral distribution and thus correlated to S_{1000}



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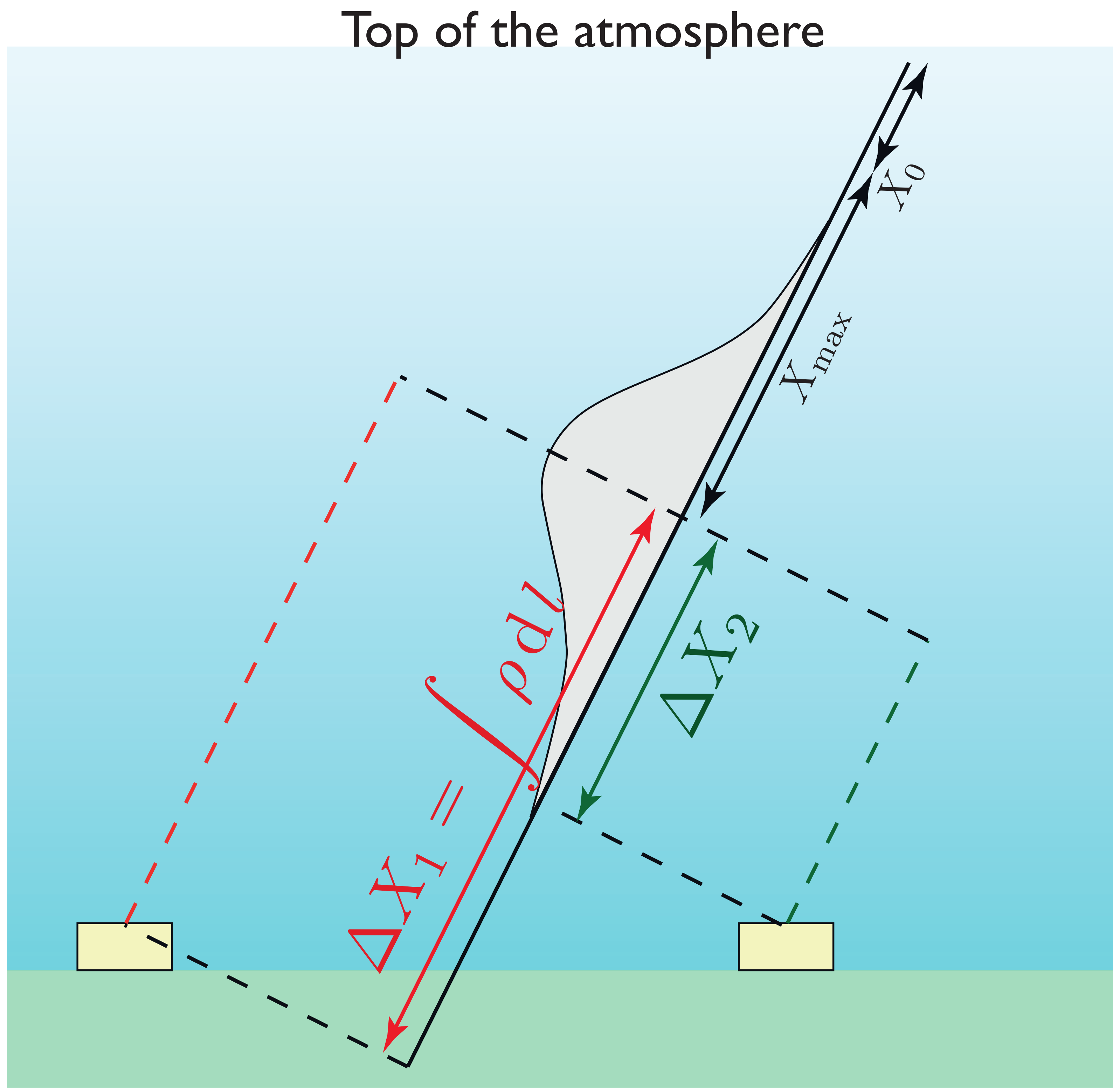
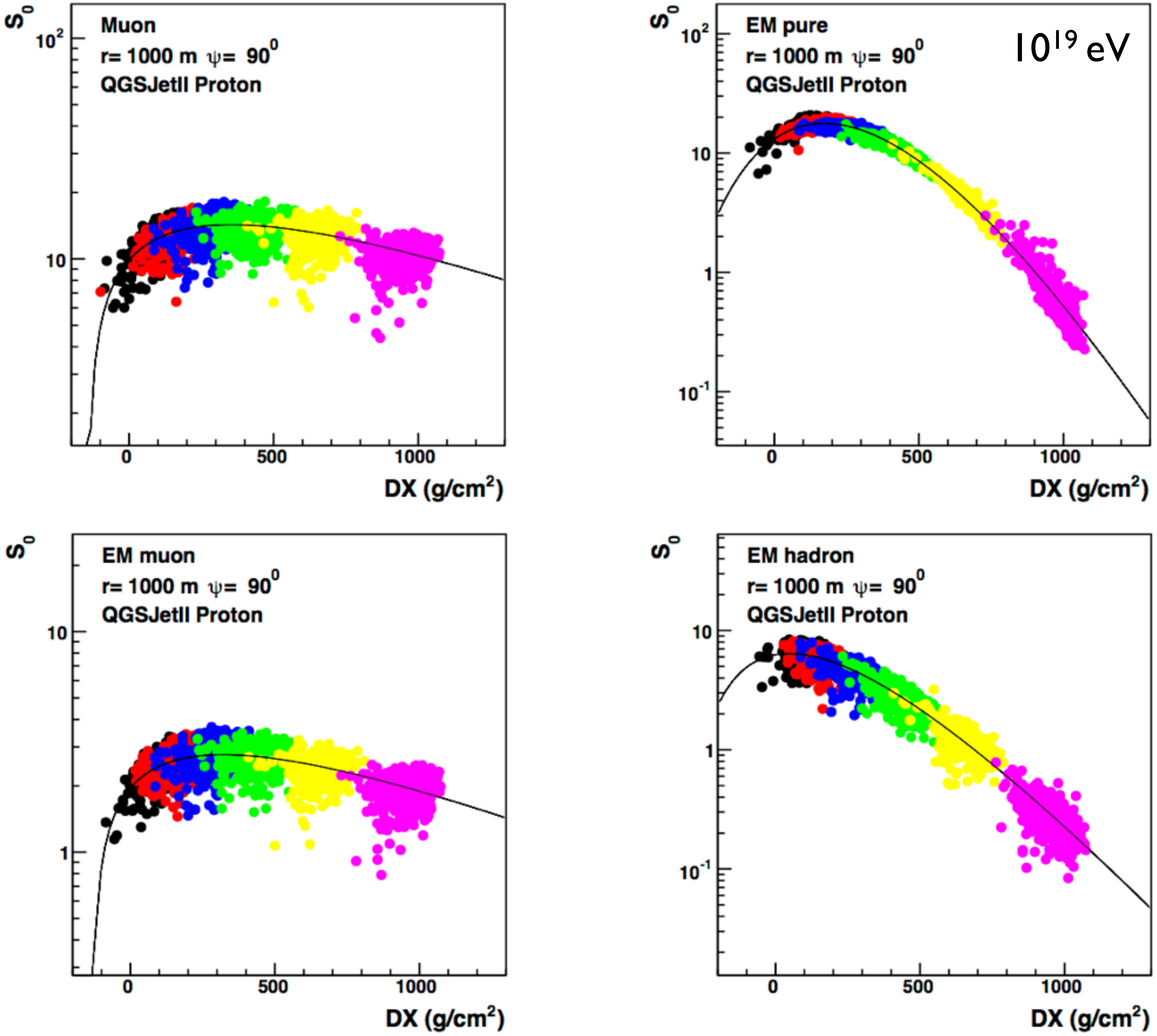
Signal contribution at 1000m





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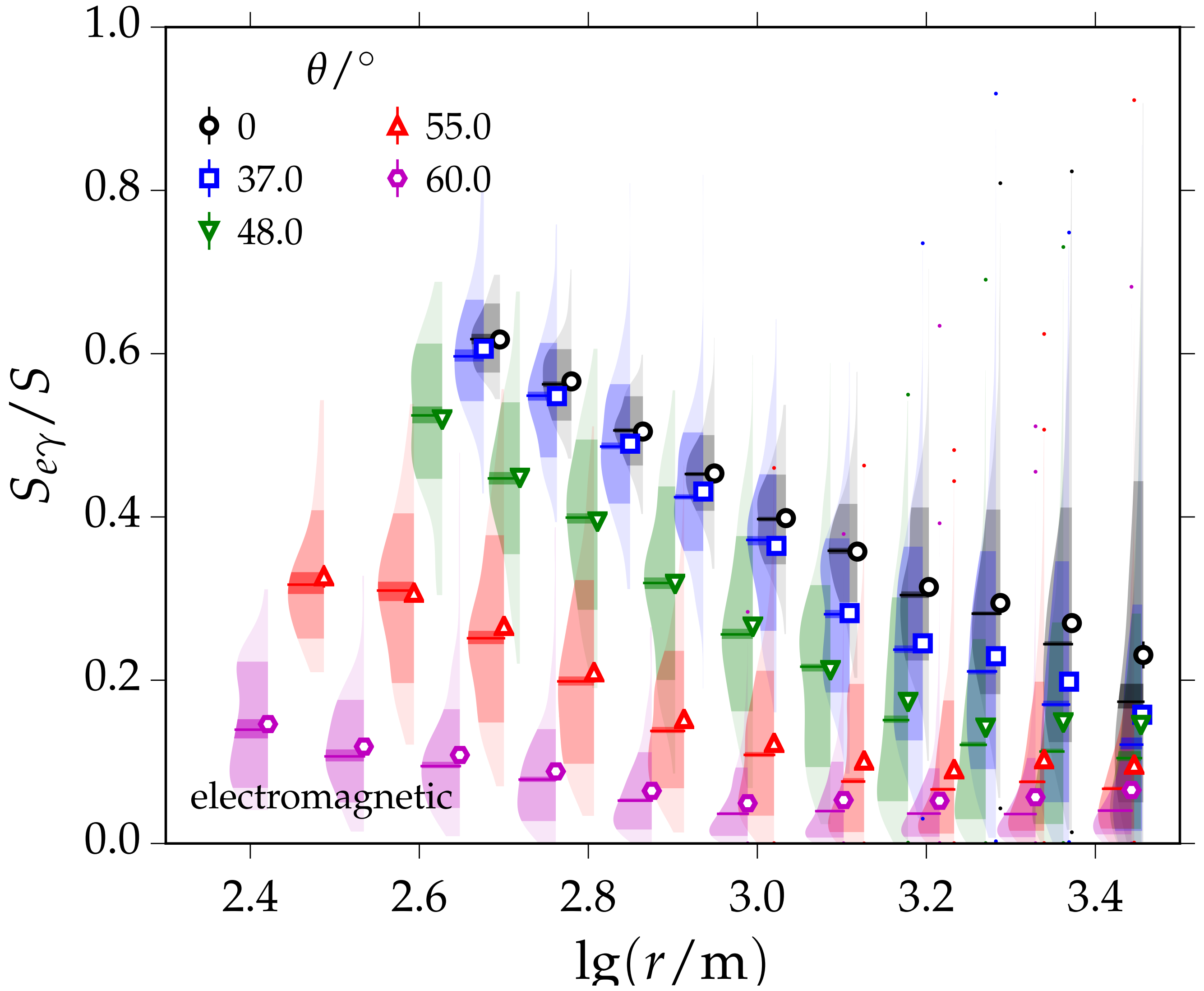
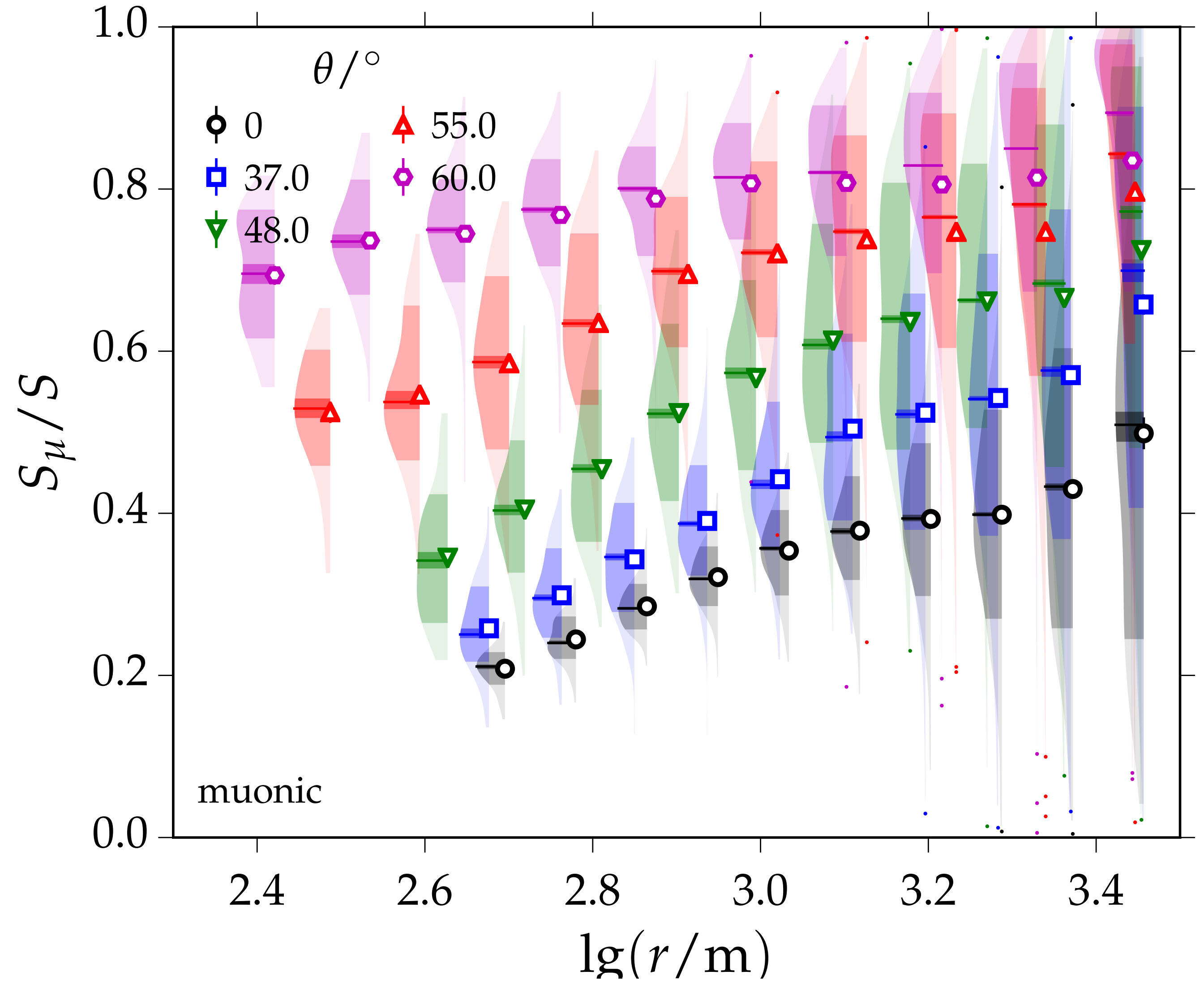
Relative signal contribution of individual components

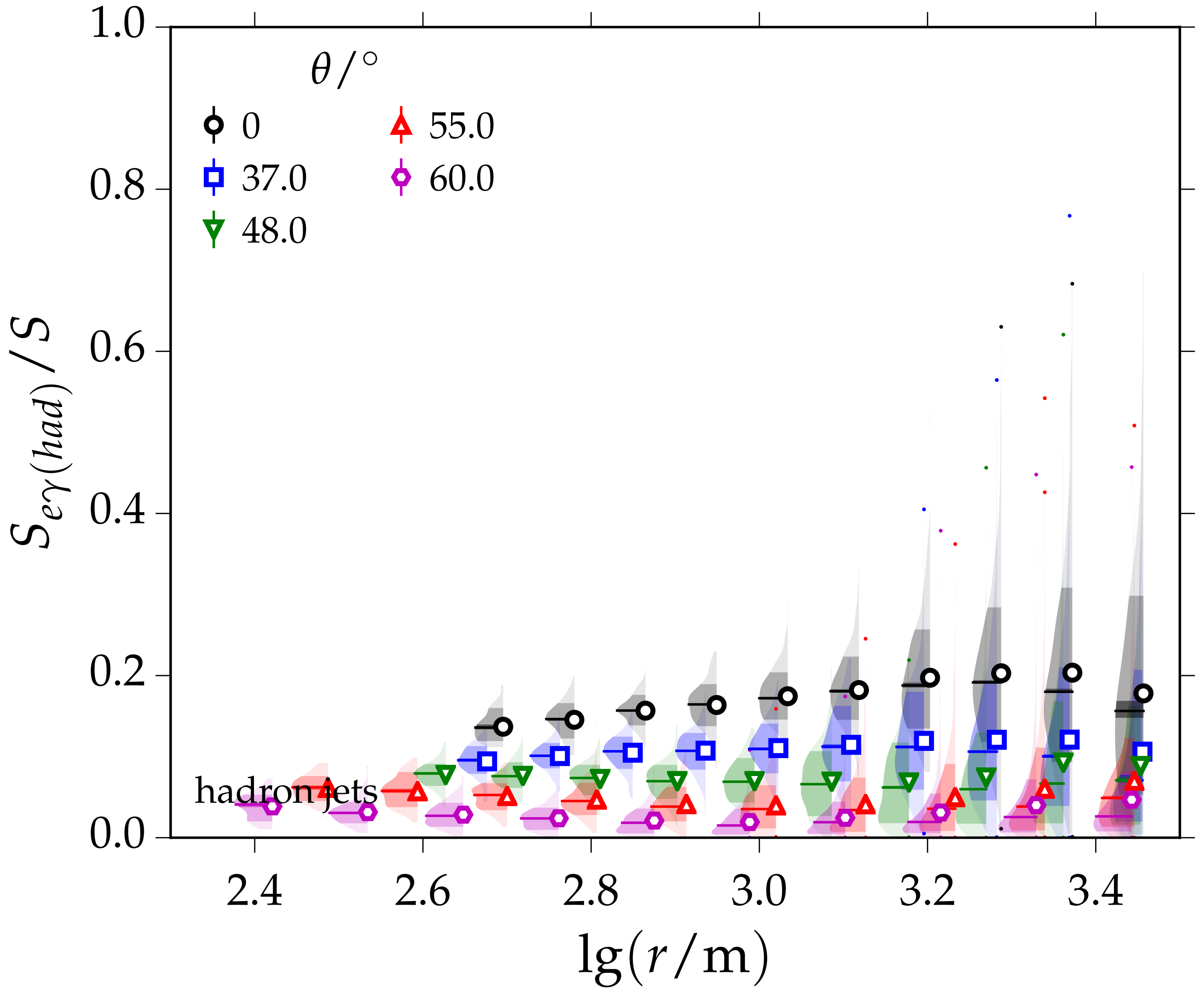
e/γ



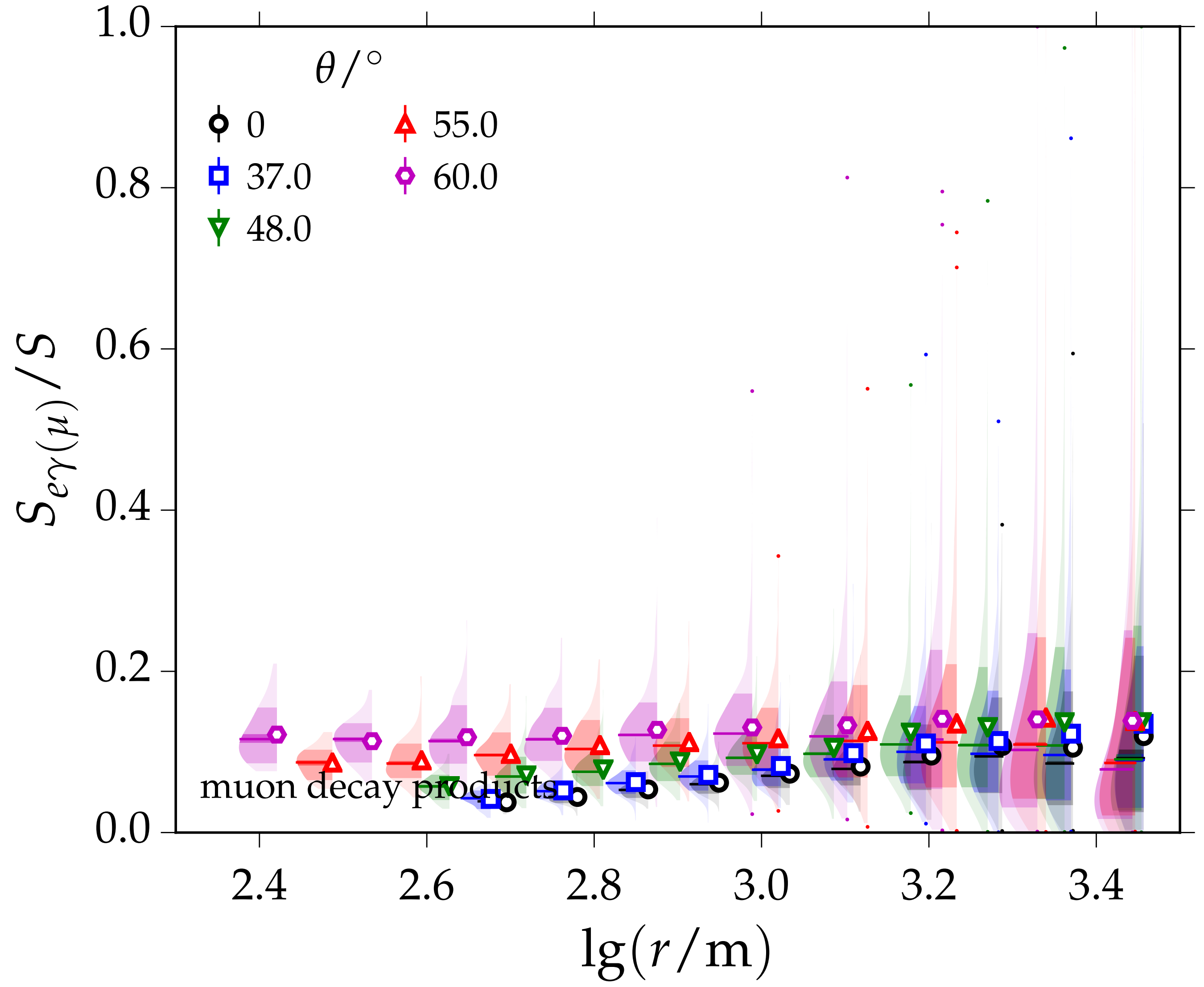
μ component



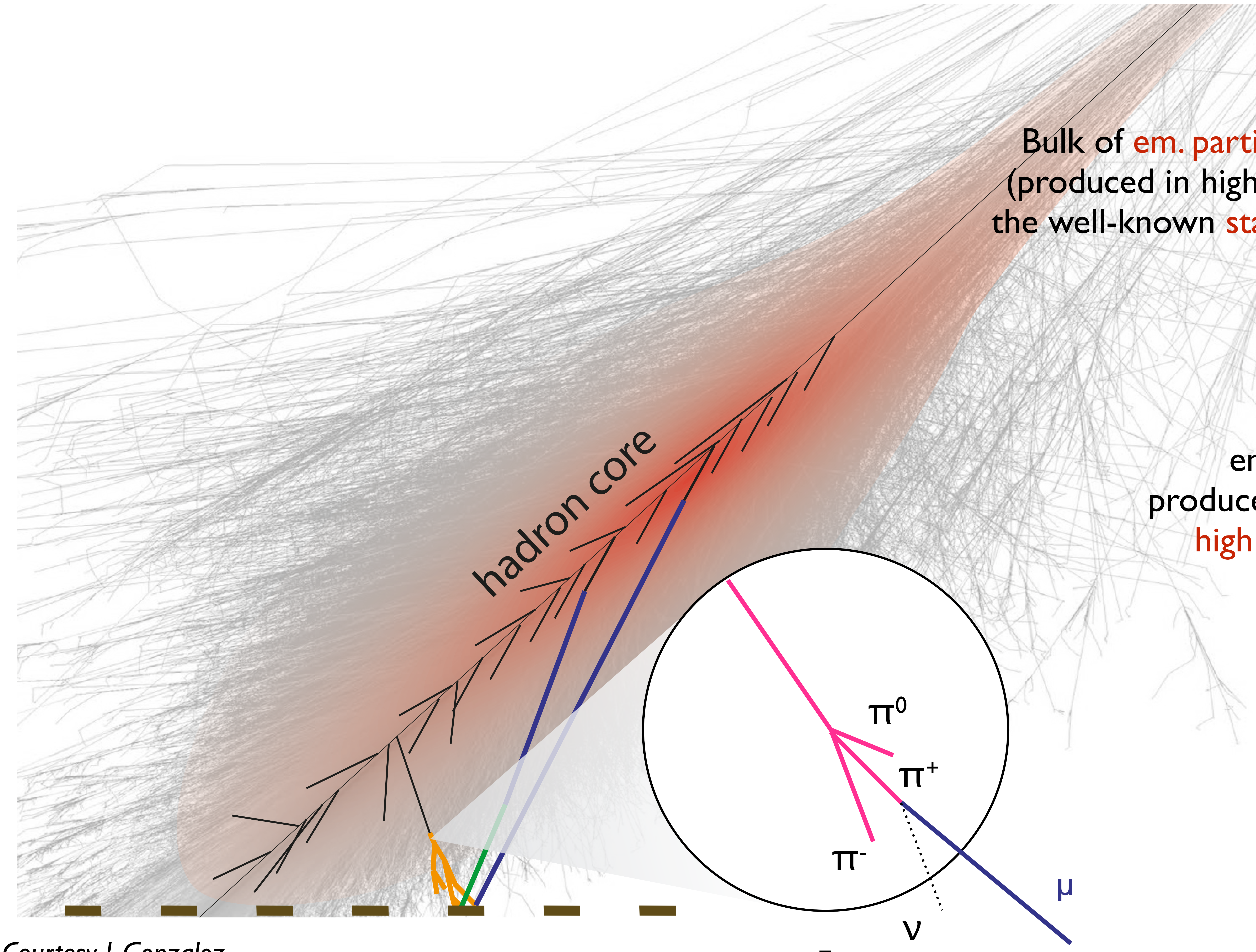
hadron jet



μ decay products



Four-component universality model



Bulk of em. particles from high-energy π^0 decay (produced in high energy interactions) diffuses in the well-known standard electromagnetic cascade

em. particles from low-energy π^0 produced in low-energy interactions at high $p_{T,}$ muons and em. particles are directly correlated

μ
e/γ
e/γ from μ decay
e/γ from late hadrons

Courtesy J. Gonzalez

Parameterization of the time dependence

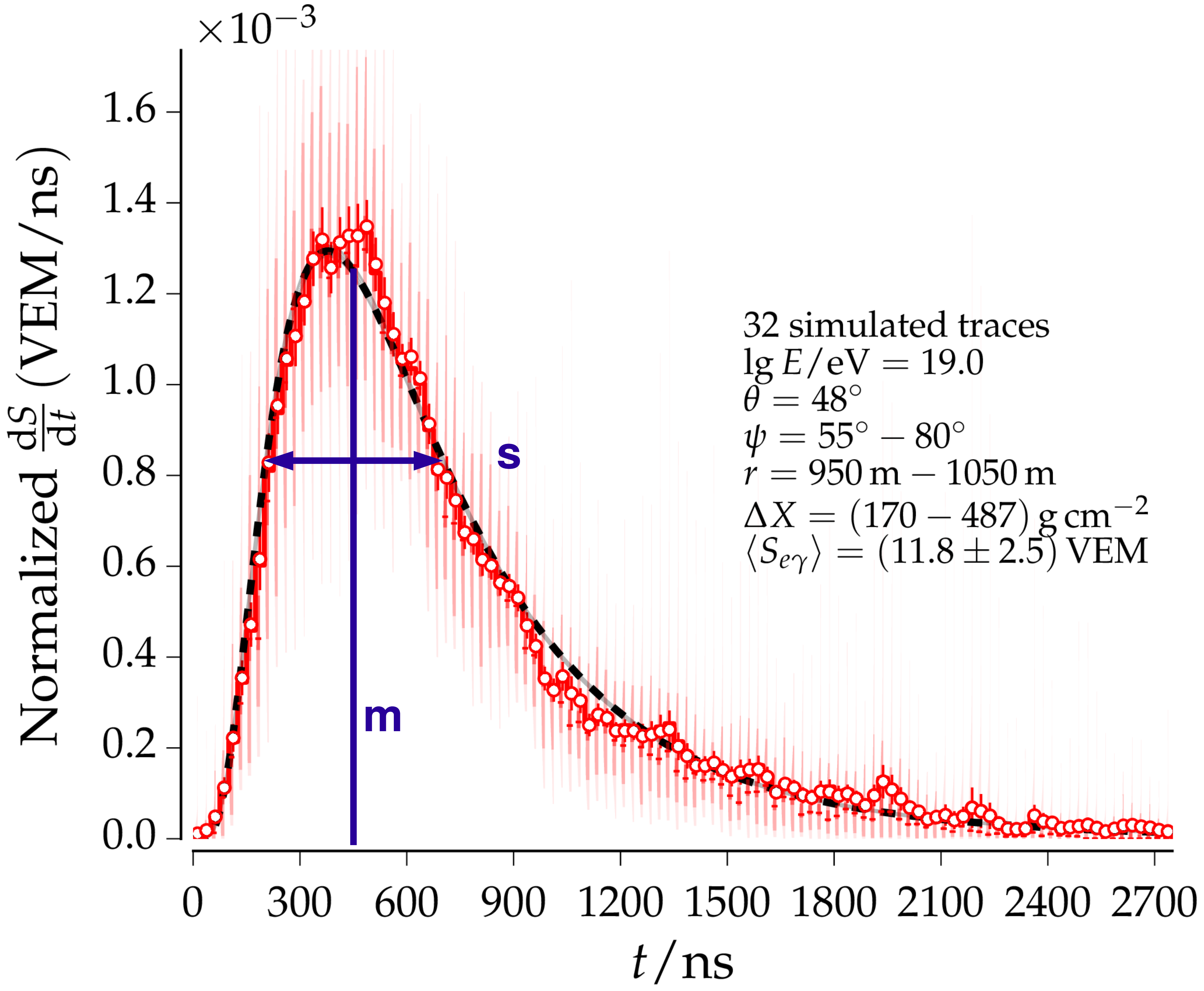
- Time-dependent detector response modeled by log-normal distribution (for each signal component)

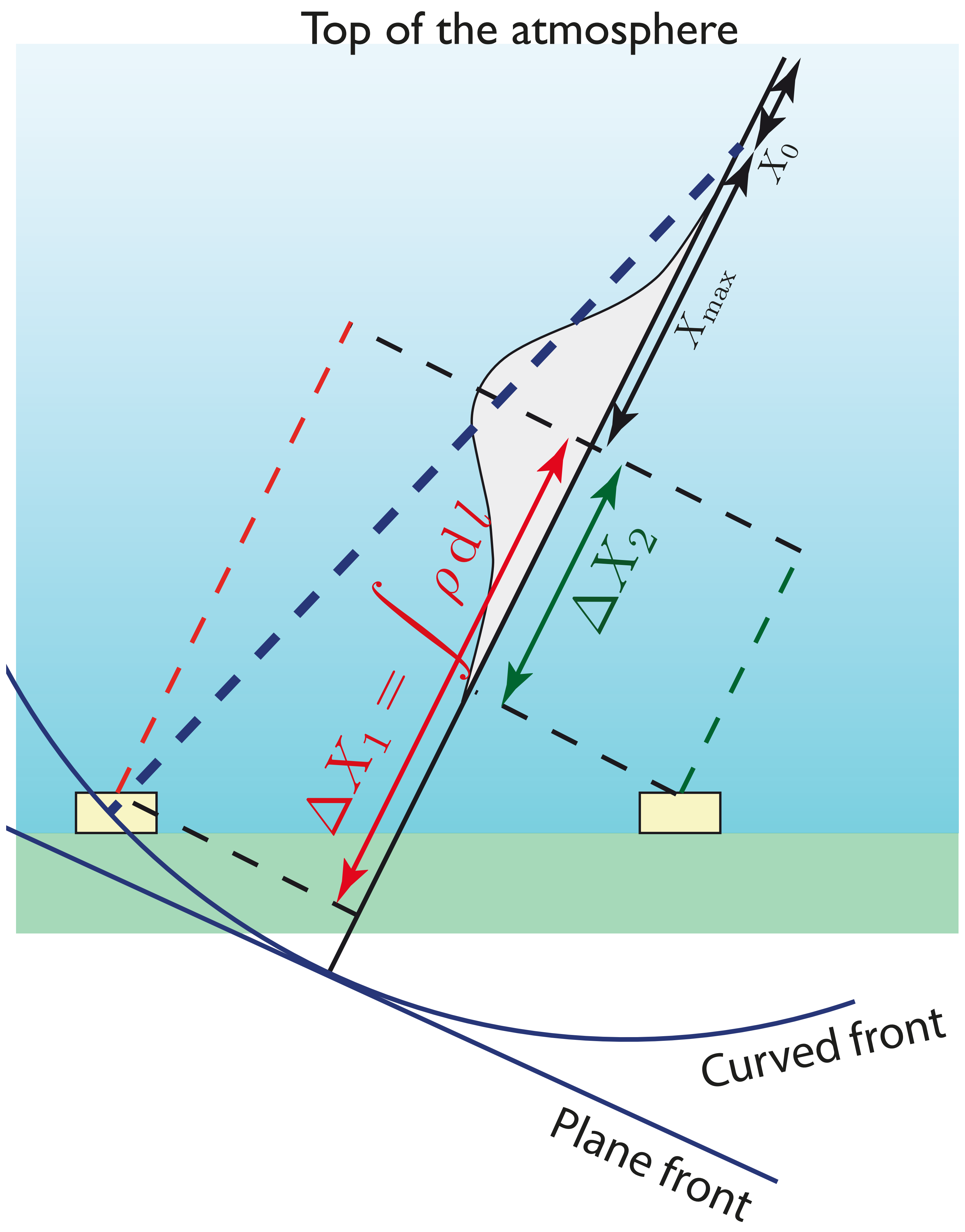
- Start time t_0 given by first interaction X_0 (spherical front)

- Time shape (*m*ean/*s*pread) depends on ΔX and position in shower plane: $S(t) = f(t, t_0, DX, r, \psi)$

- Time structure is universal (no dependence on N_μ)

Example: e/γ component



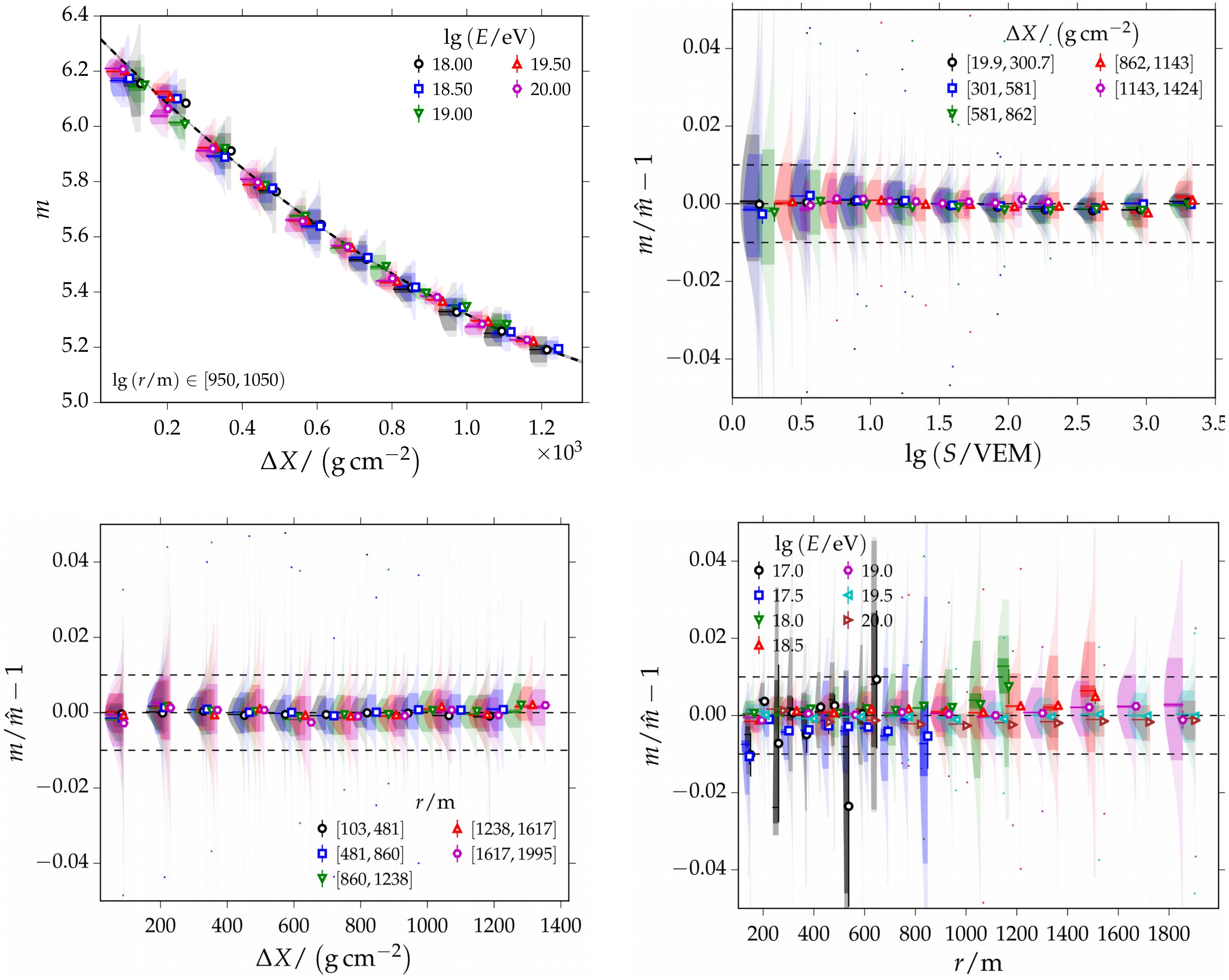


Parameter dependencies

Parameters m and s depend on

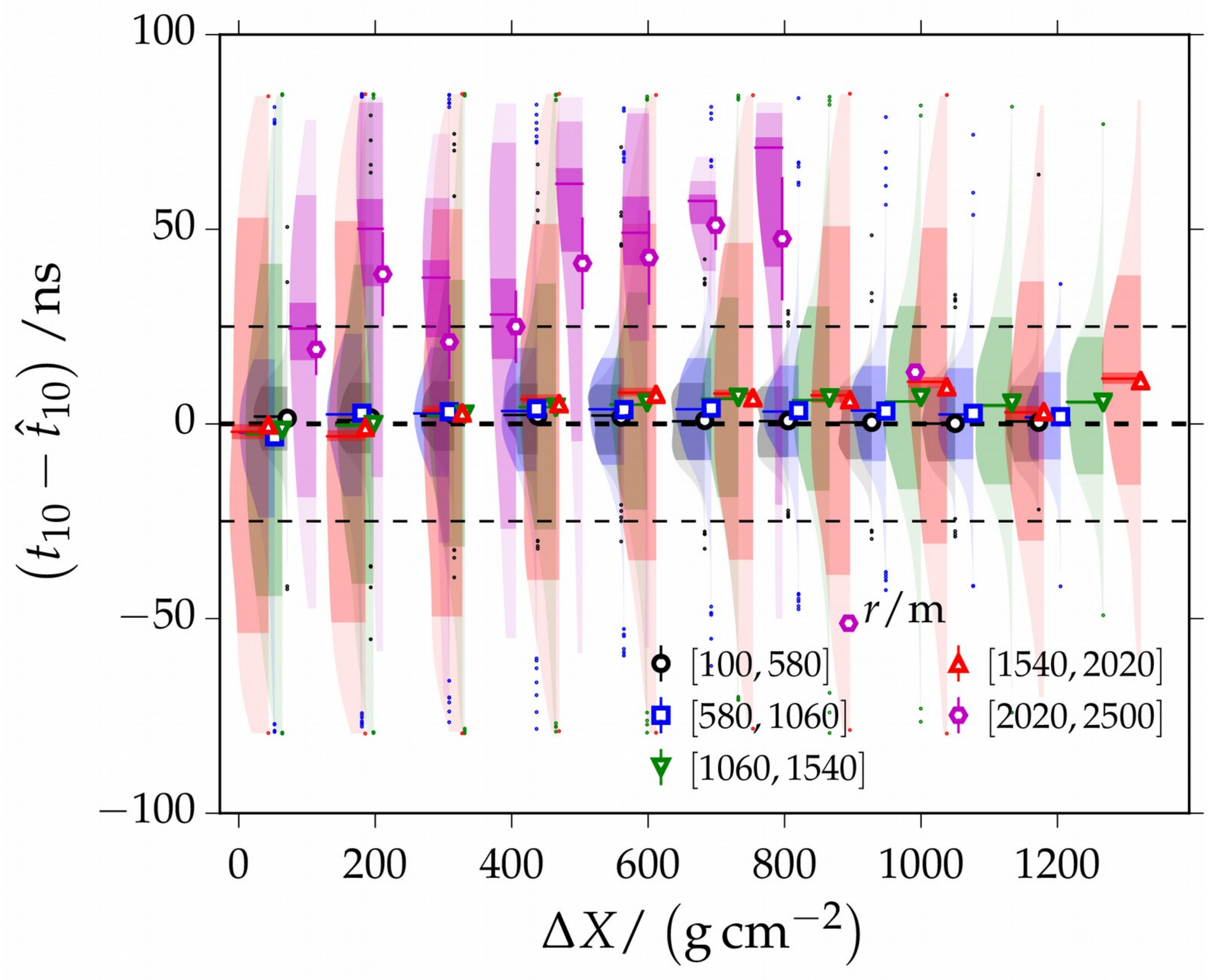
- Energy *E*
- Distance to X_{max}: ΔX
- Core distance *r*
- Shower geometry θ, ϕ

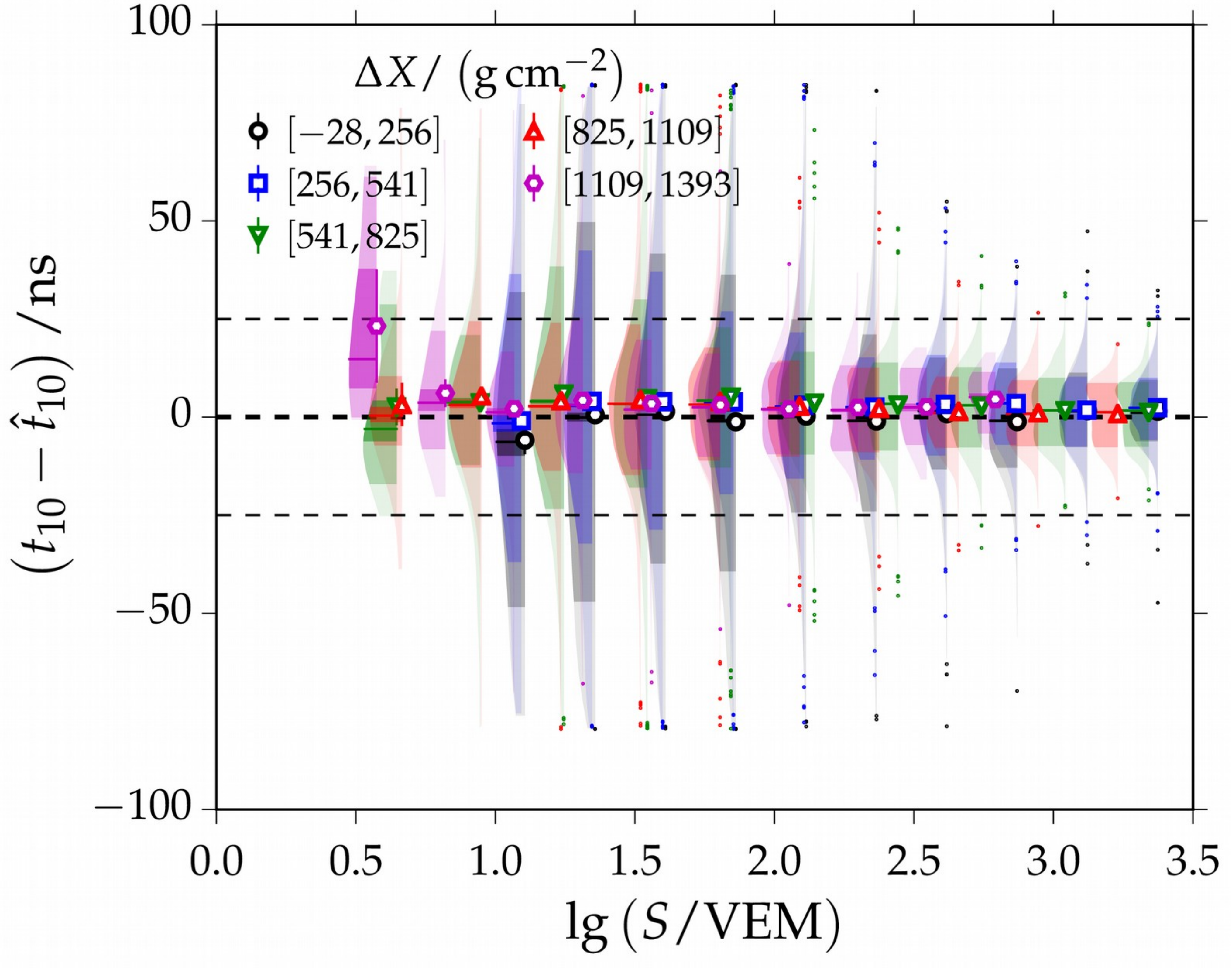
No energy, ΔX nor core distance dependent bias apparent



Validation of the time model

Time quantiles for muons

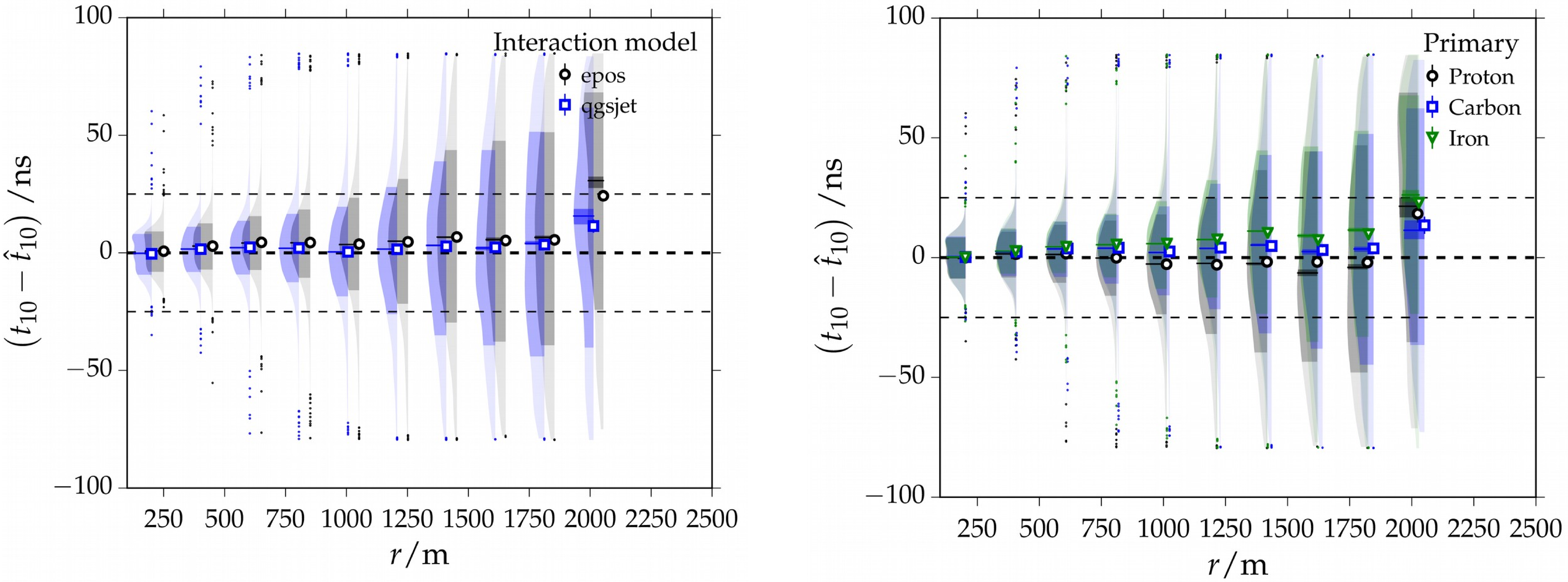




No bias for different Δ*X* nor signal size

Validation of the time model

Time quantiles for muons



No bias for different primaries nor interaction models used

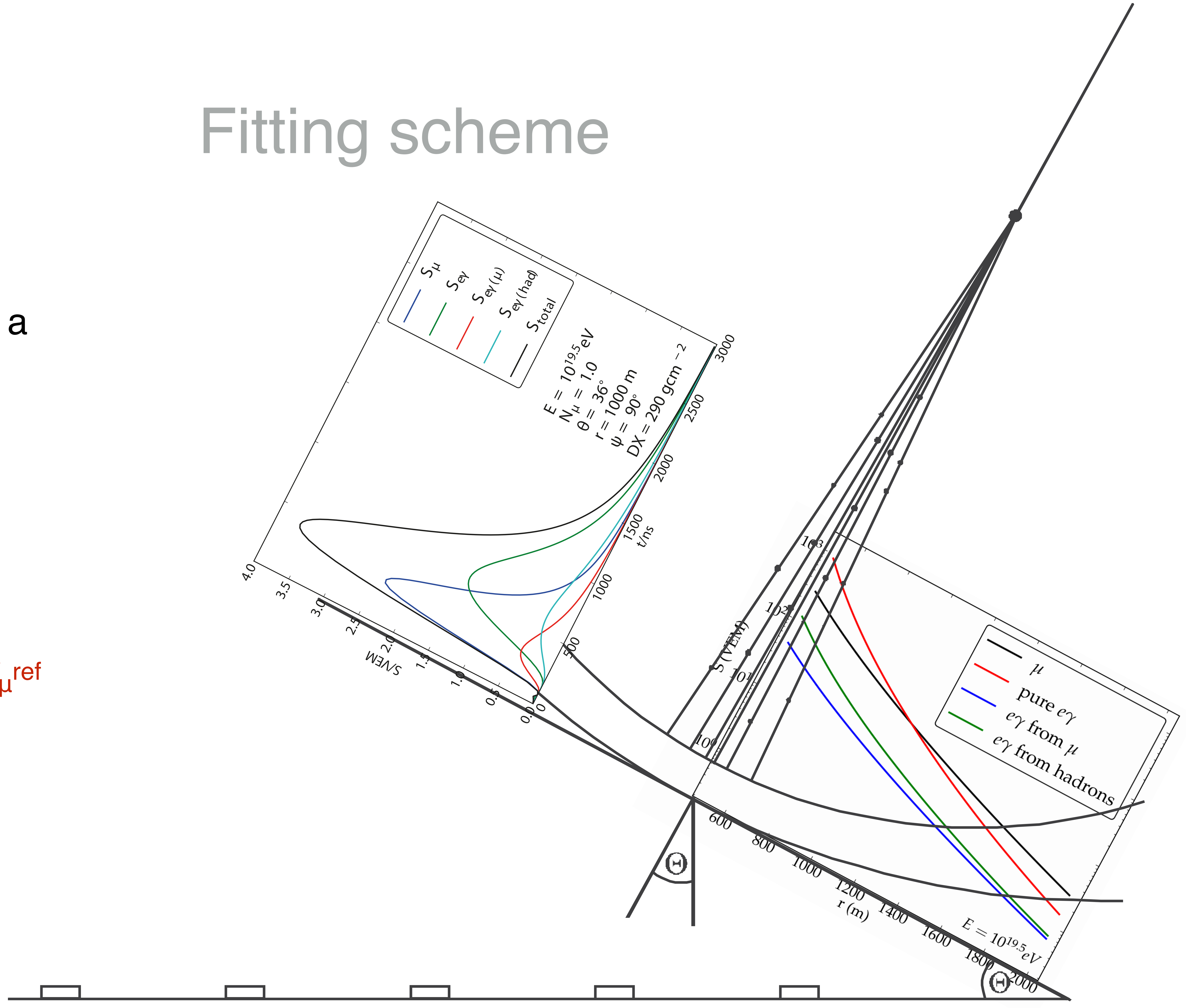
Fitting scheme

Parameterizations used in a likelihood procedure

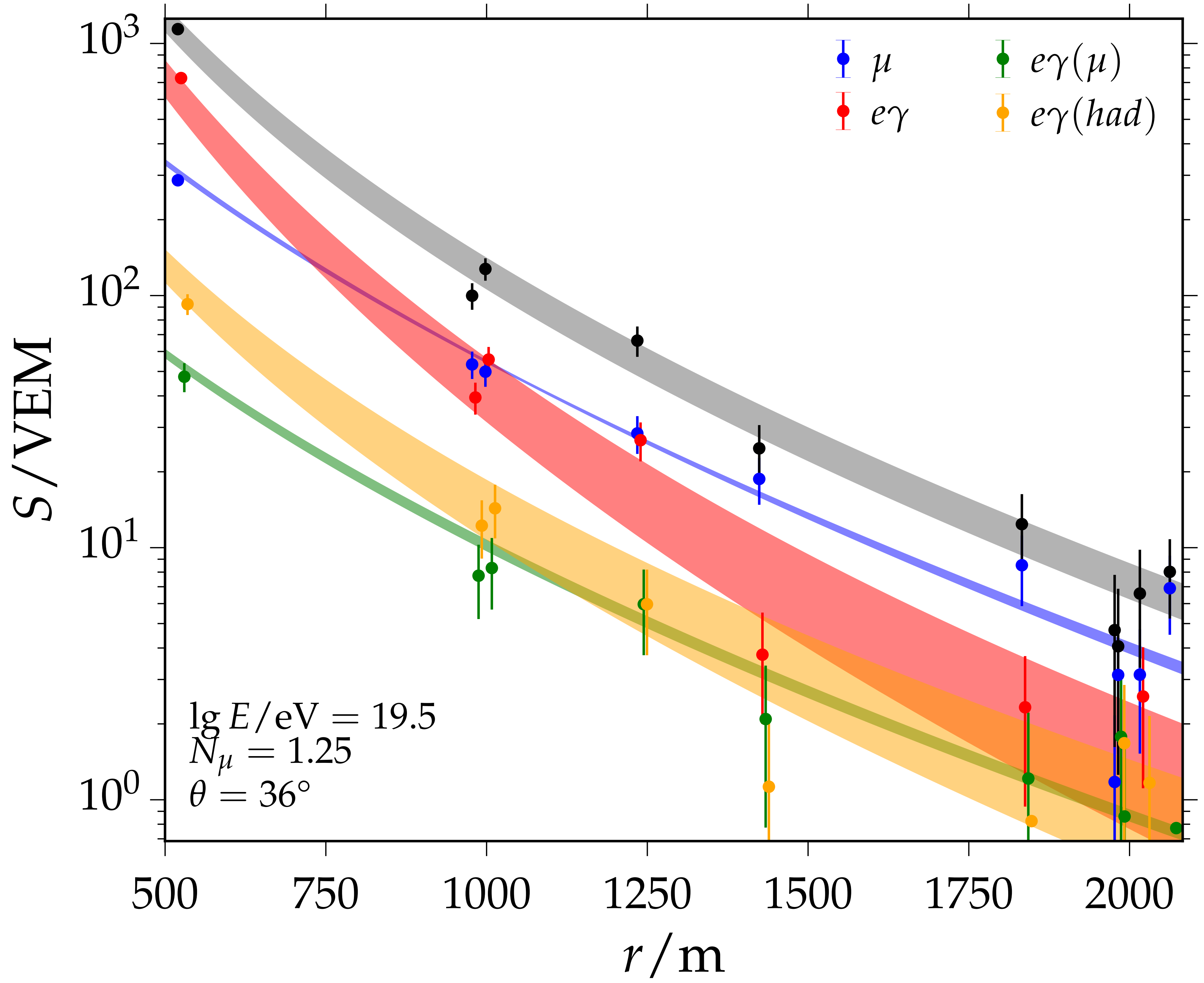
- Signal size S
- Start time t_0
- Shape m, s

as a function of

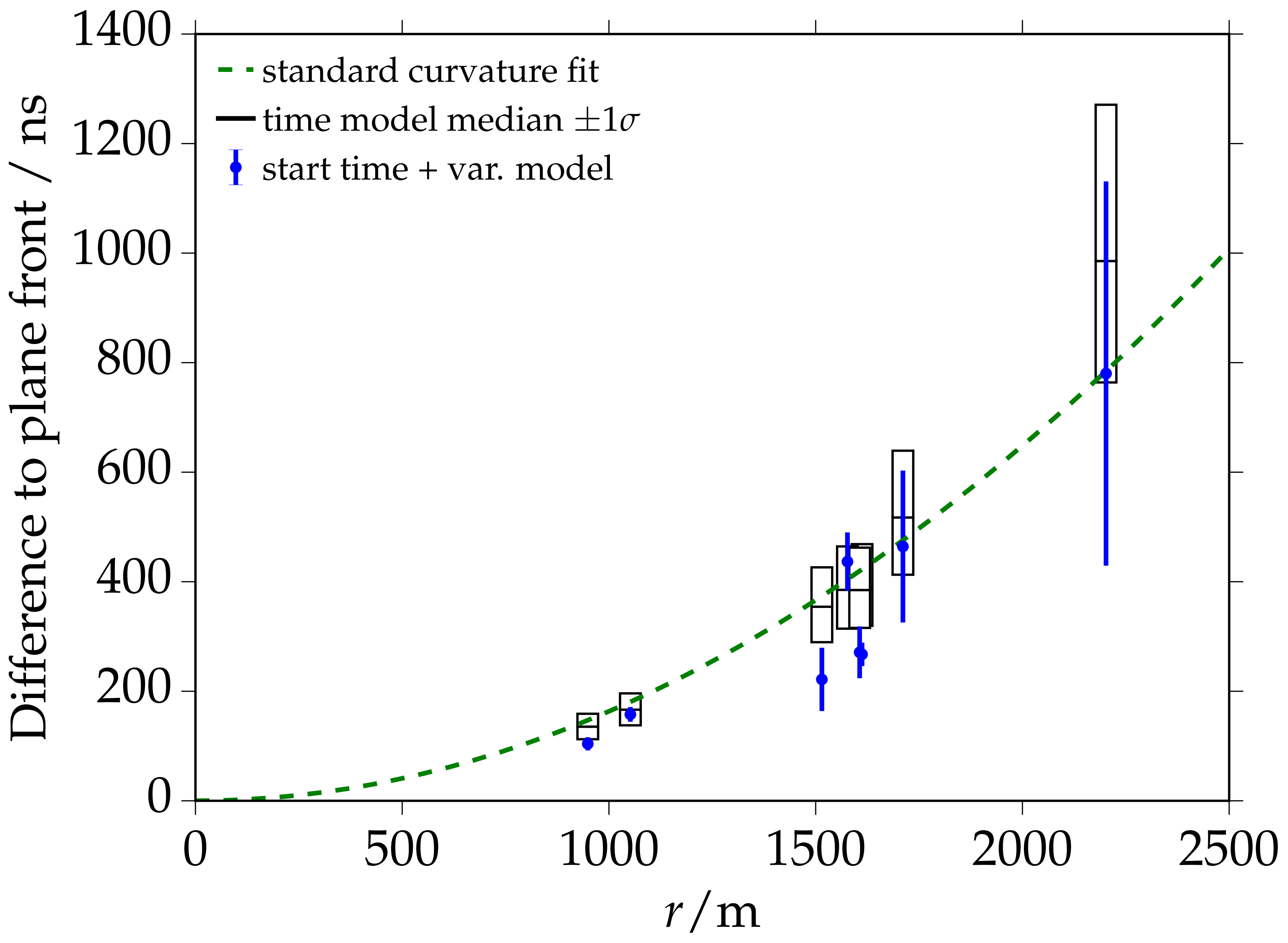
- Energy E
- Relative muon number N_μ^{ref}
- Distance to X_{max}: ΔX
- Shower geometry θ, ϕ

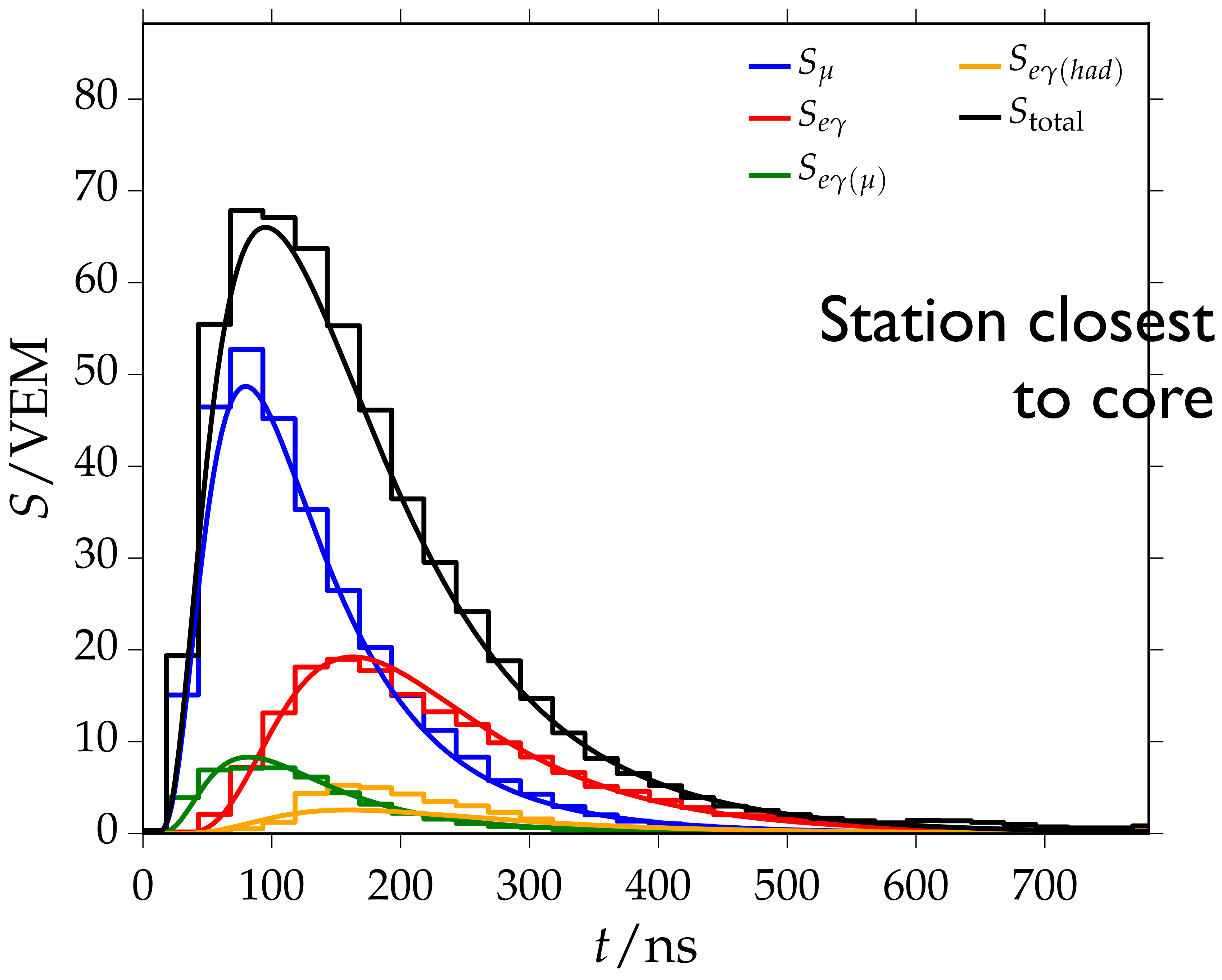


Fitting of a single event



Colored bands indicate corrections for up- and downstream asymmetry, e.g. different ΔX, ground screening, detector response

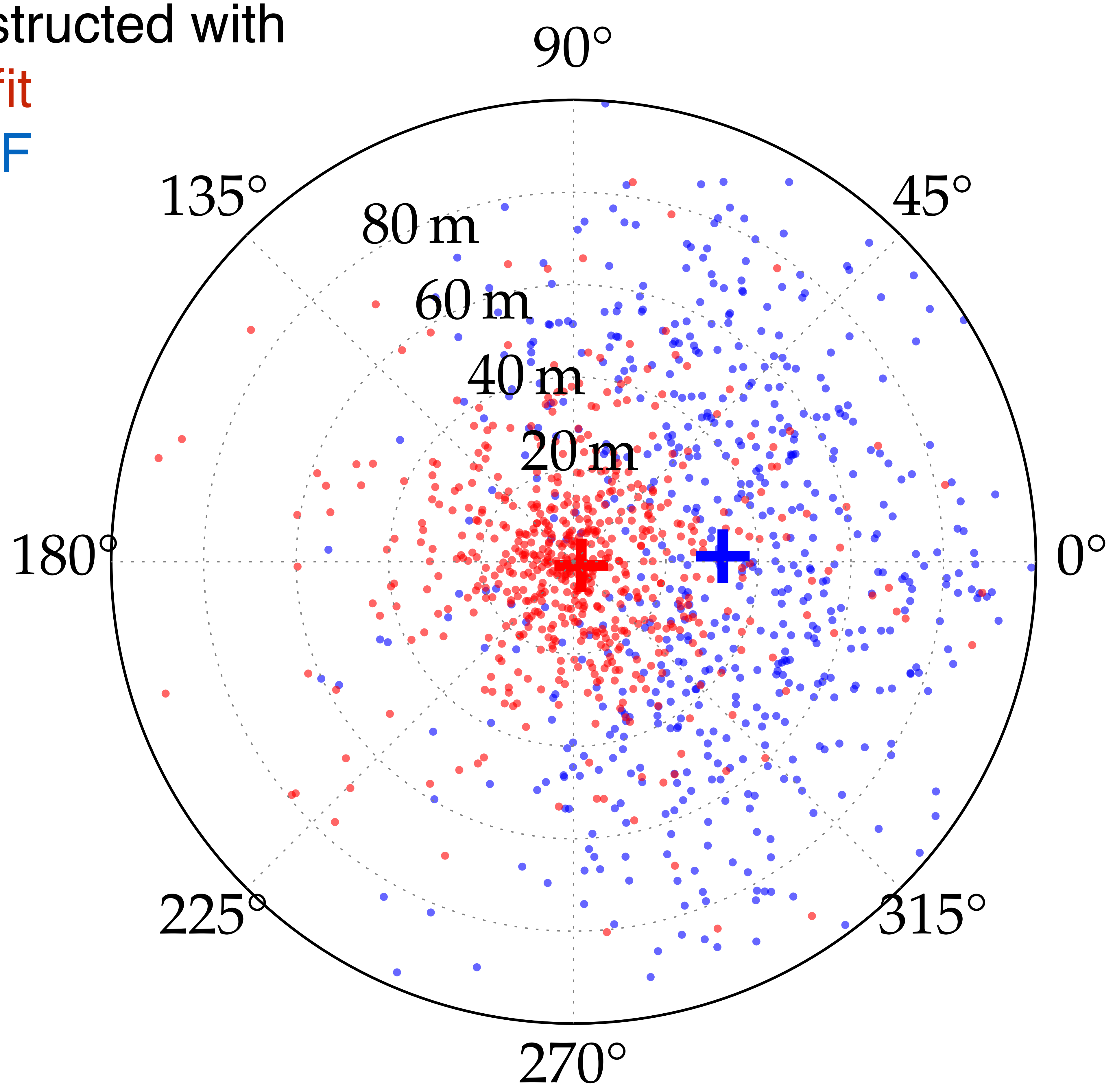


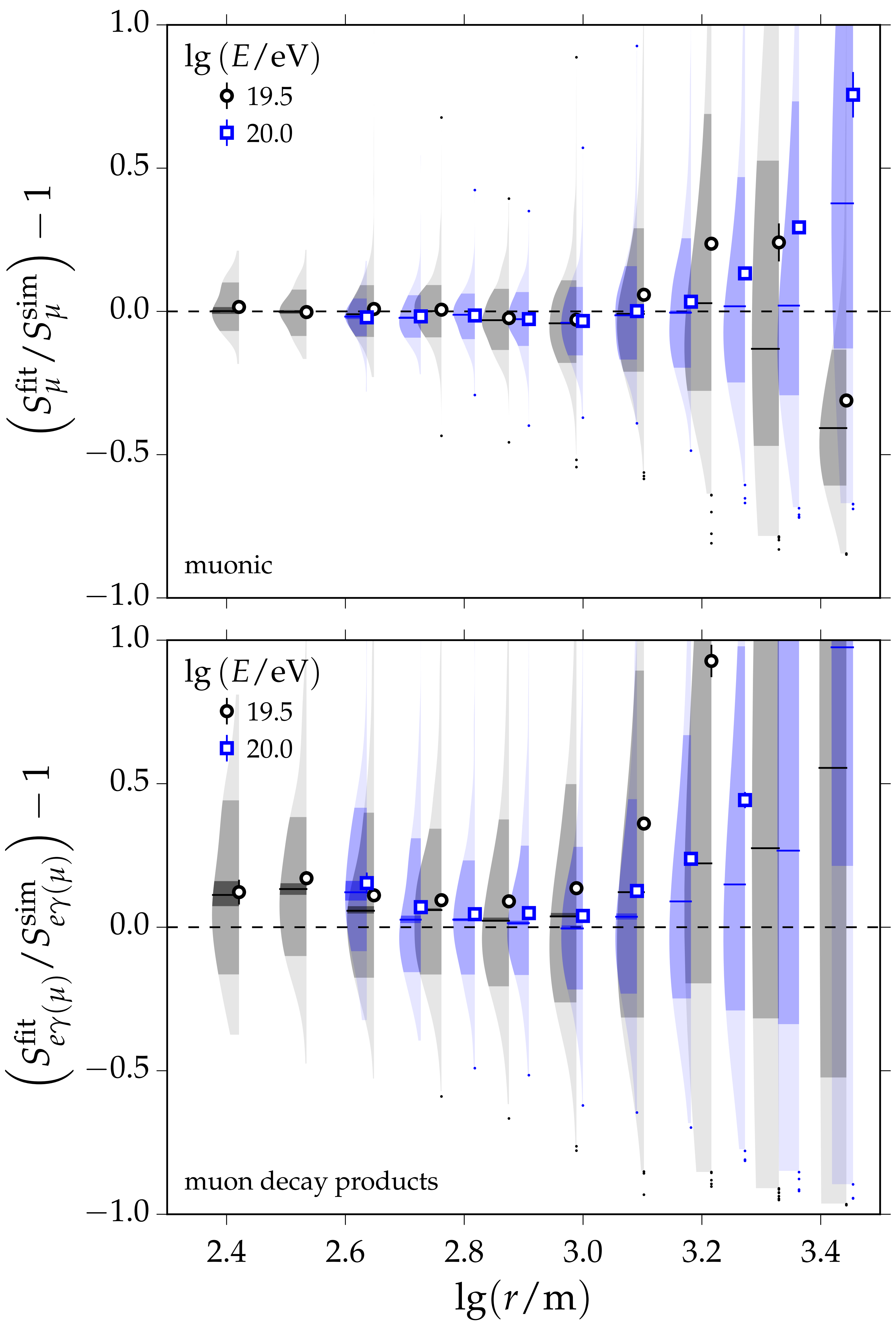


Reconstruction performance

Events reconstructed with
- Universality fit
- Standard LDF

θ=38°
lg(E/eV)=19.5

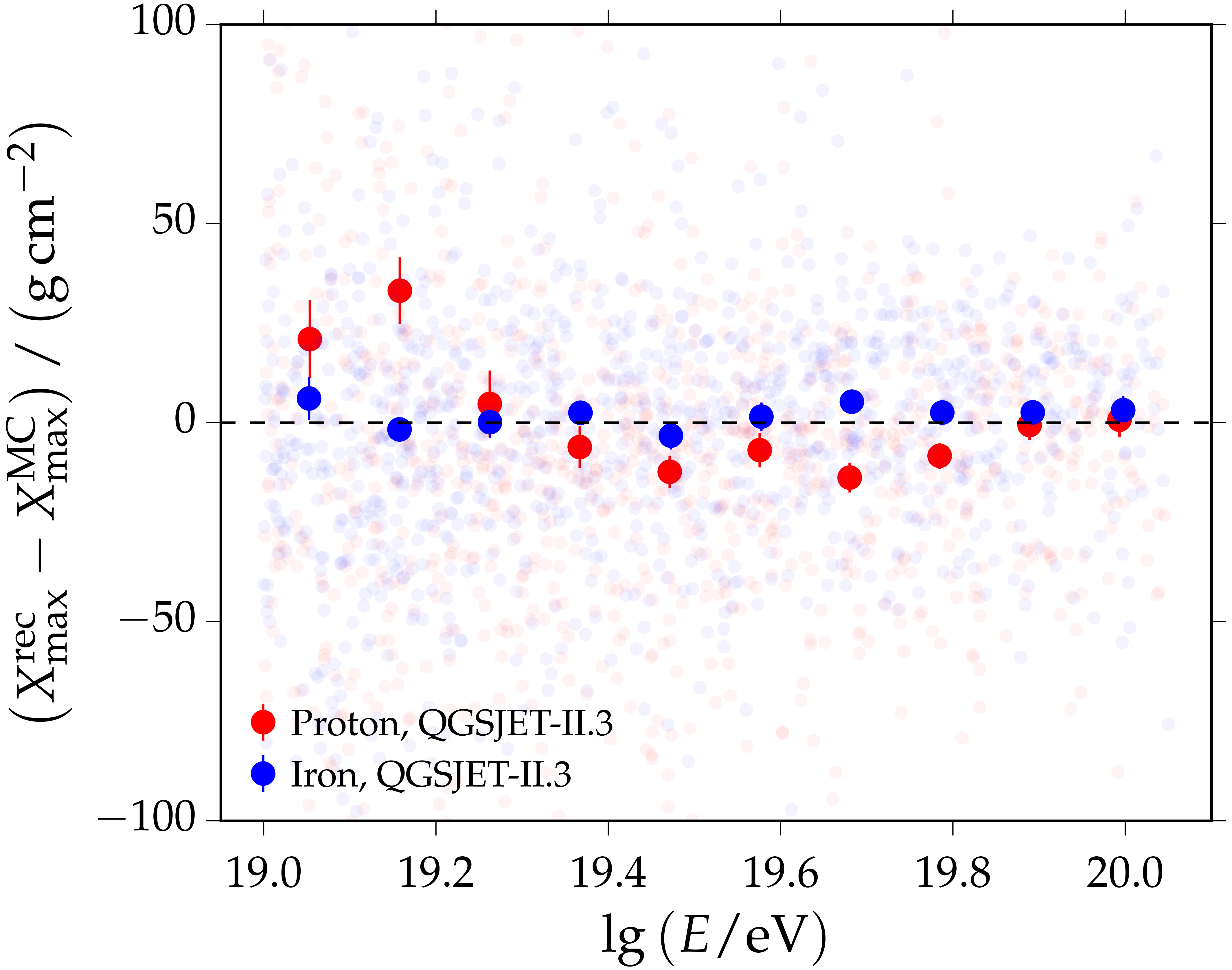


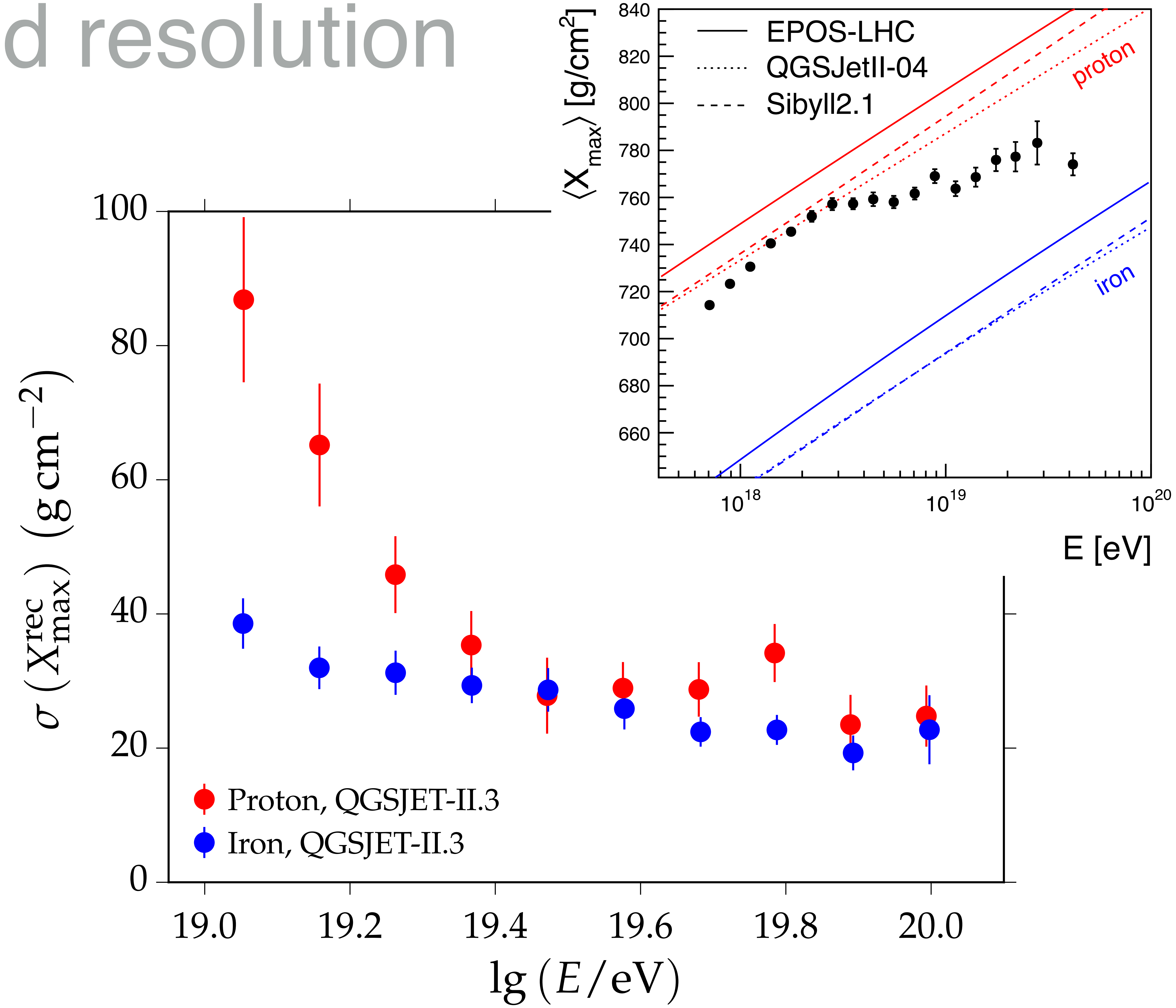


μs

μ decay products

X_{max} bias and resolution

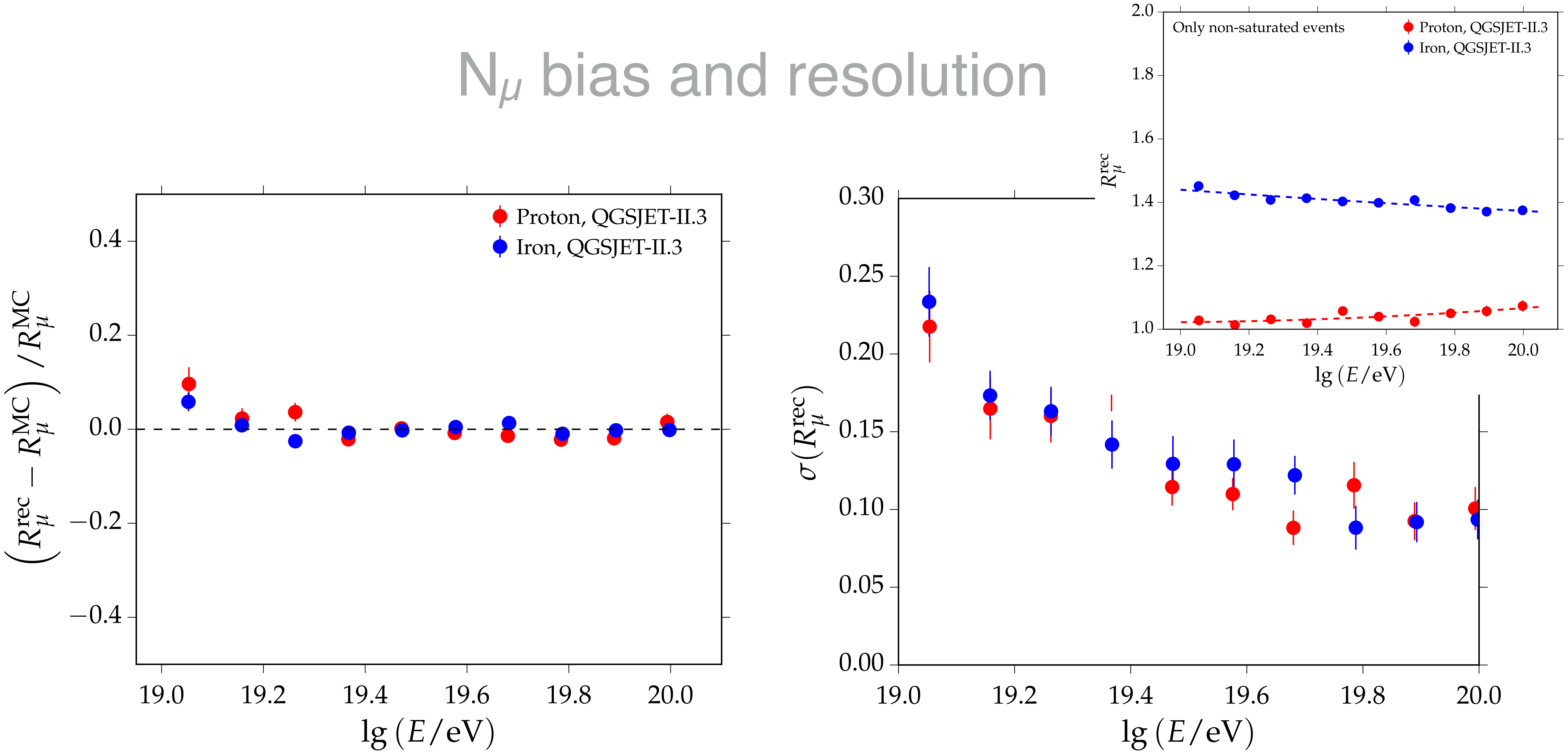




Largest systematic uncertainty: Energy scale

+10% shift in energy → ΔX_{max} = -10 g/cm^2

N_μ bias and resolution

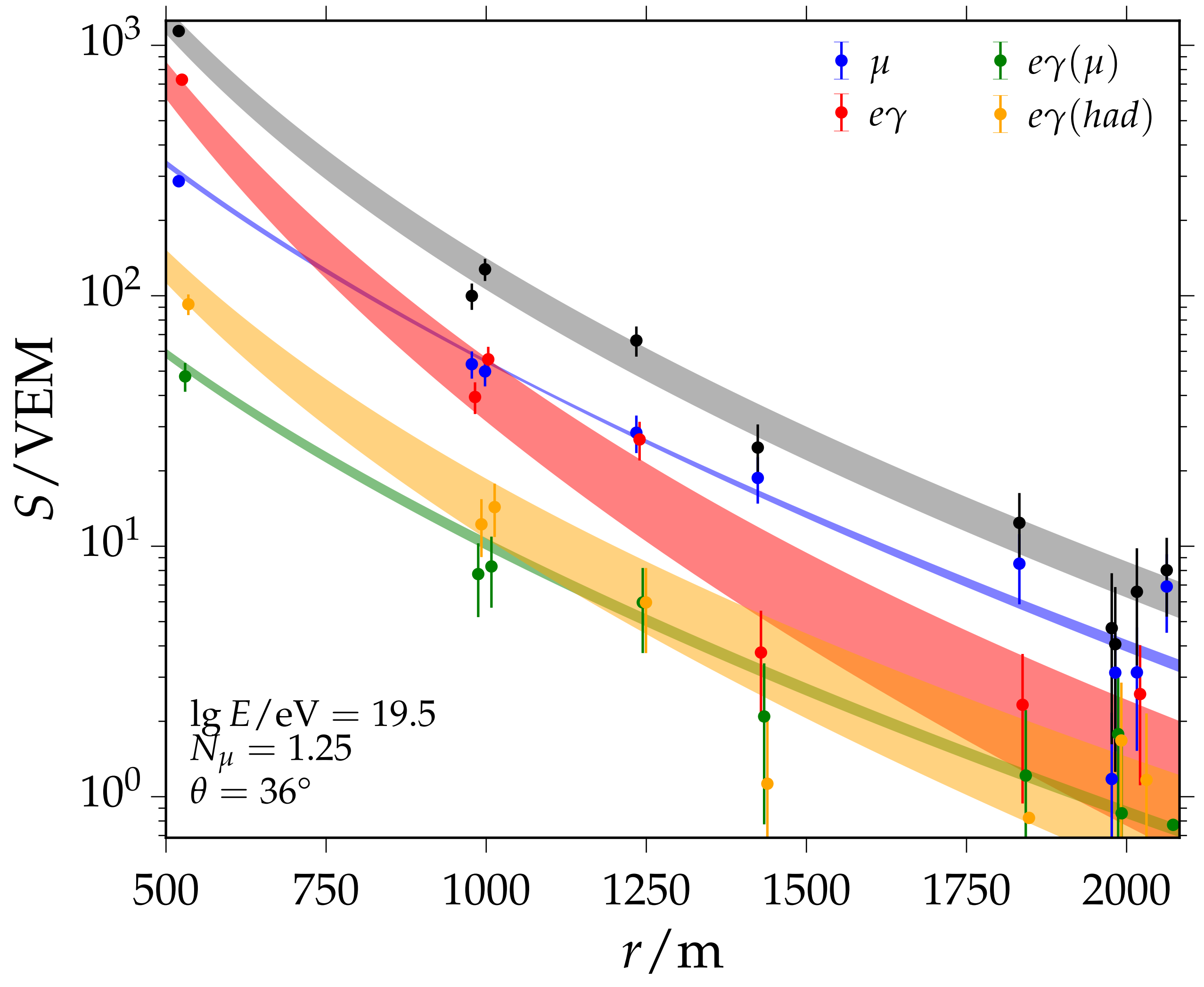


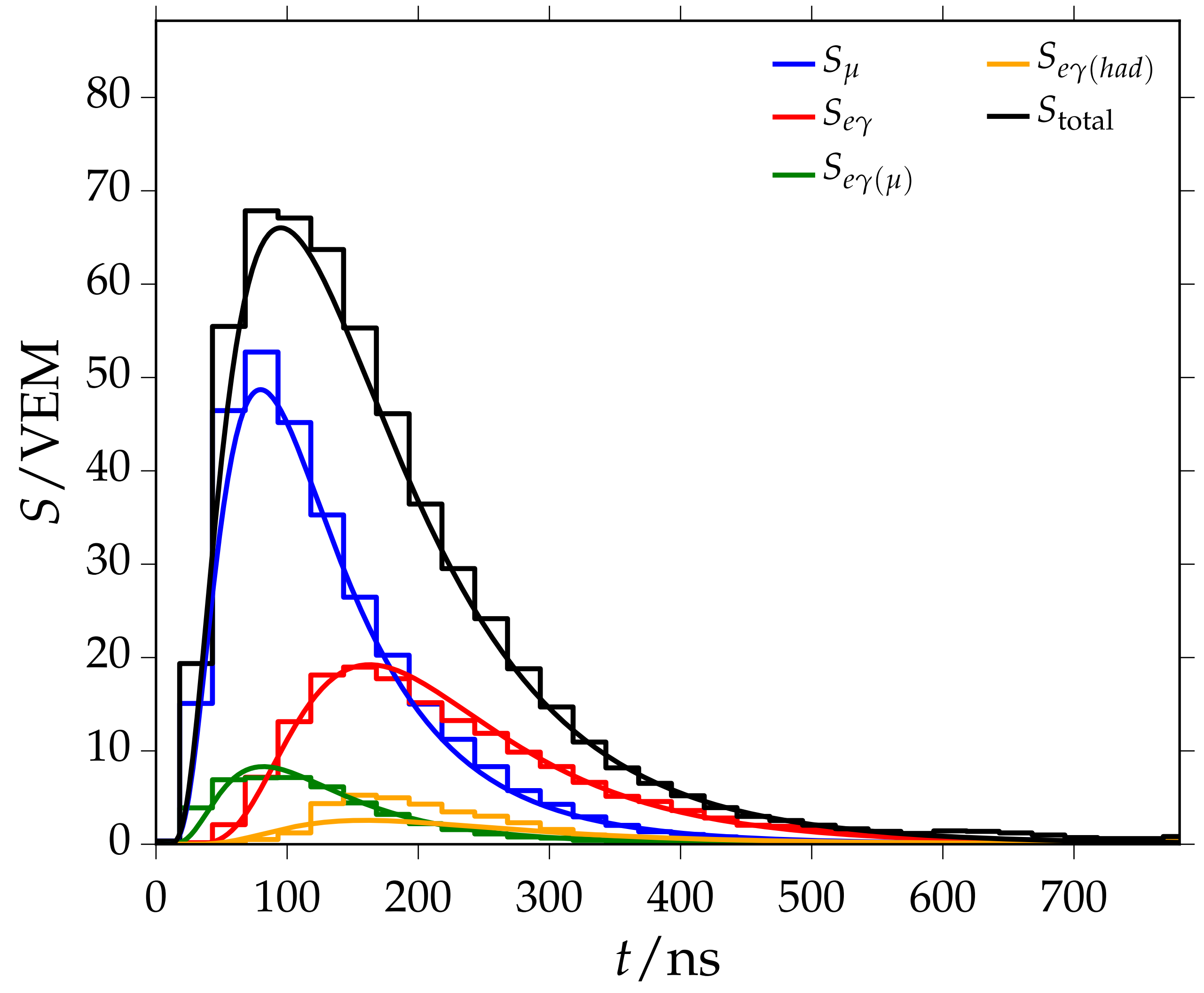
Largest systematic uncertainty: Energy scale

+10% shift in energy → ΔN_μ = -0.15

Summary

- Signals and time structure well described by shower universality
- Few parameters: N_{μ}, E, X_{max}, X_0 (+geometry)
- Reconstruction using only the time-dependent signal of ground based detectors

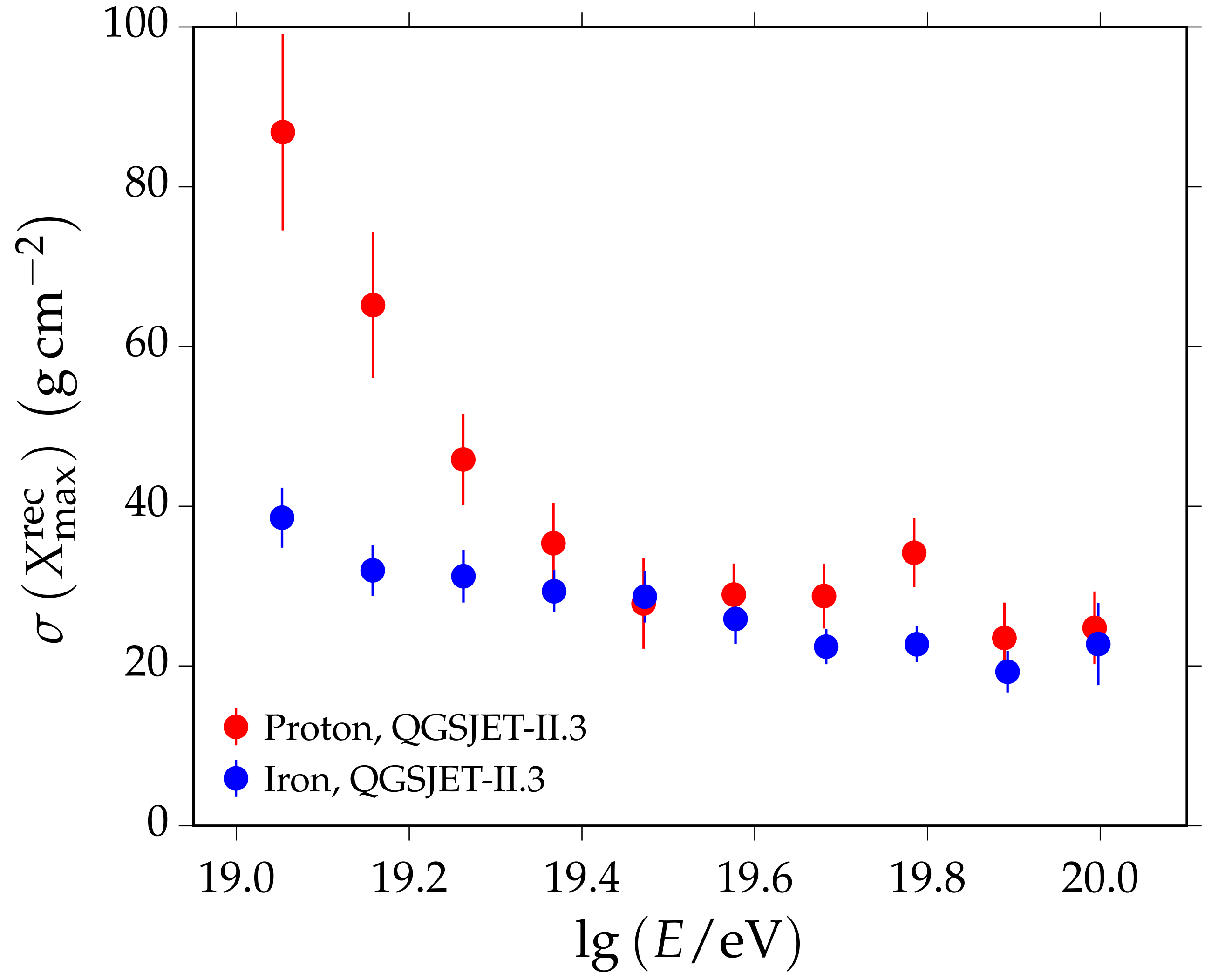




Outlook

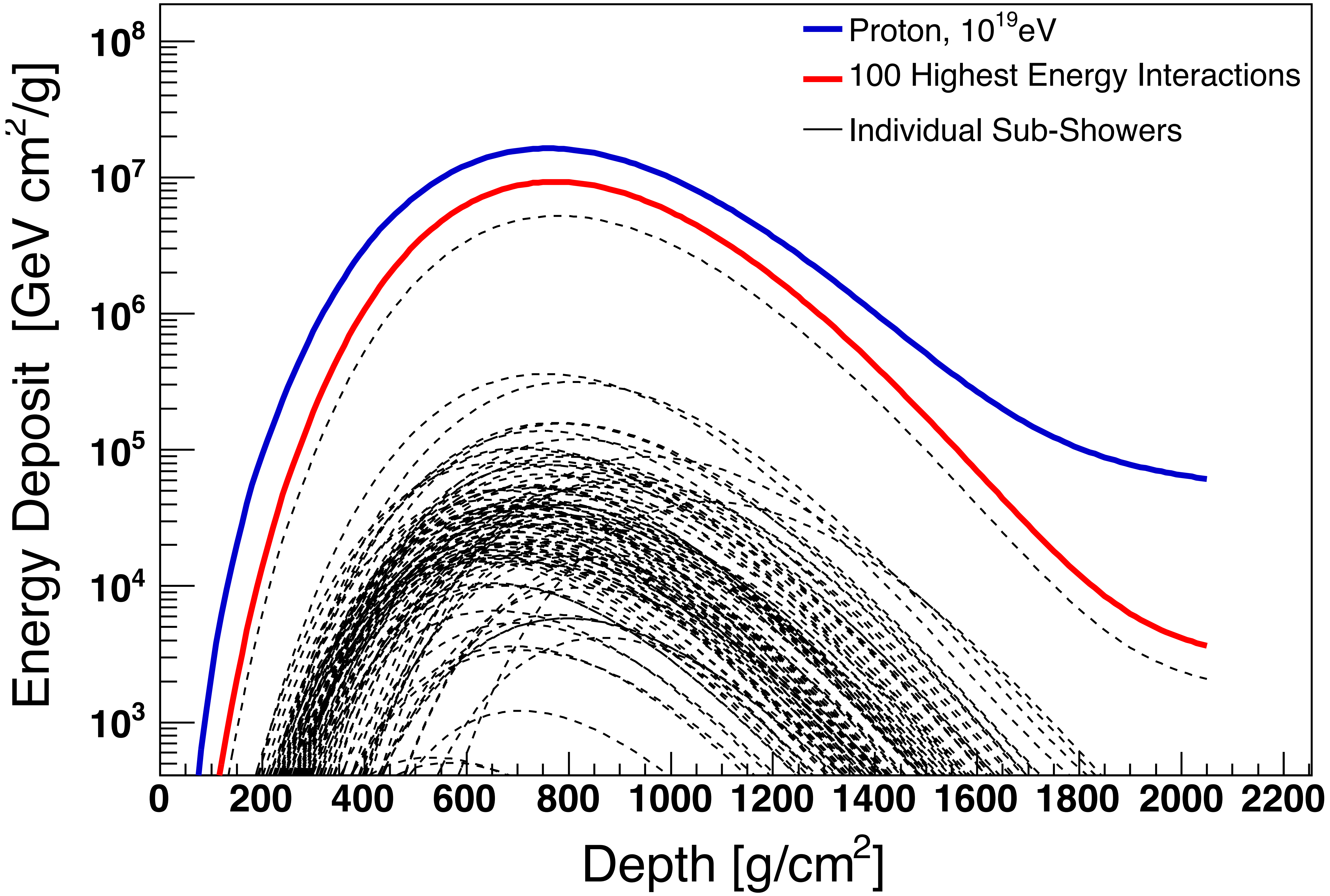
- Composition sensitive parameters *at 100% duty cycle*
- Mass composition at the highest energies
- Mass-dependent search for correlations to astrophysical sources
- Applicable to other surface detector arrays
- Additional muon measurements will reduce (N_{μ}, E) correlation

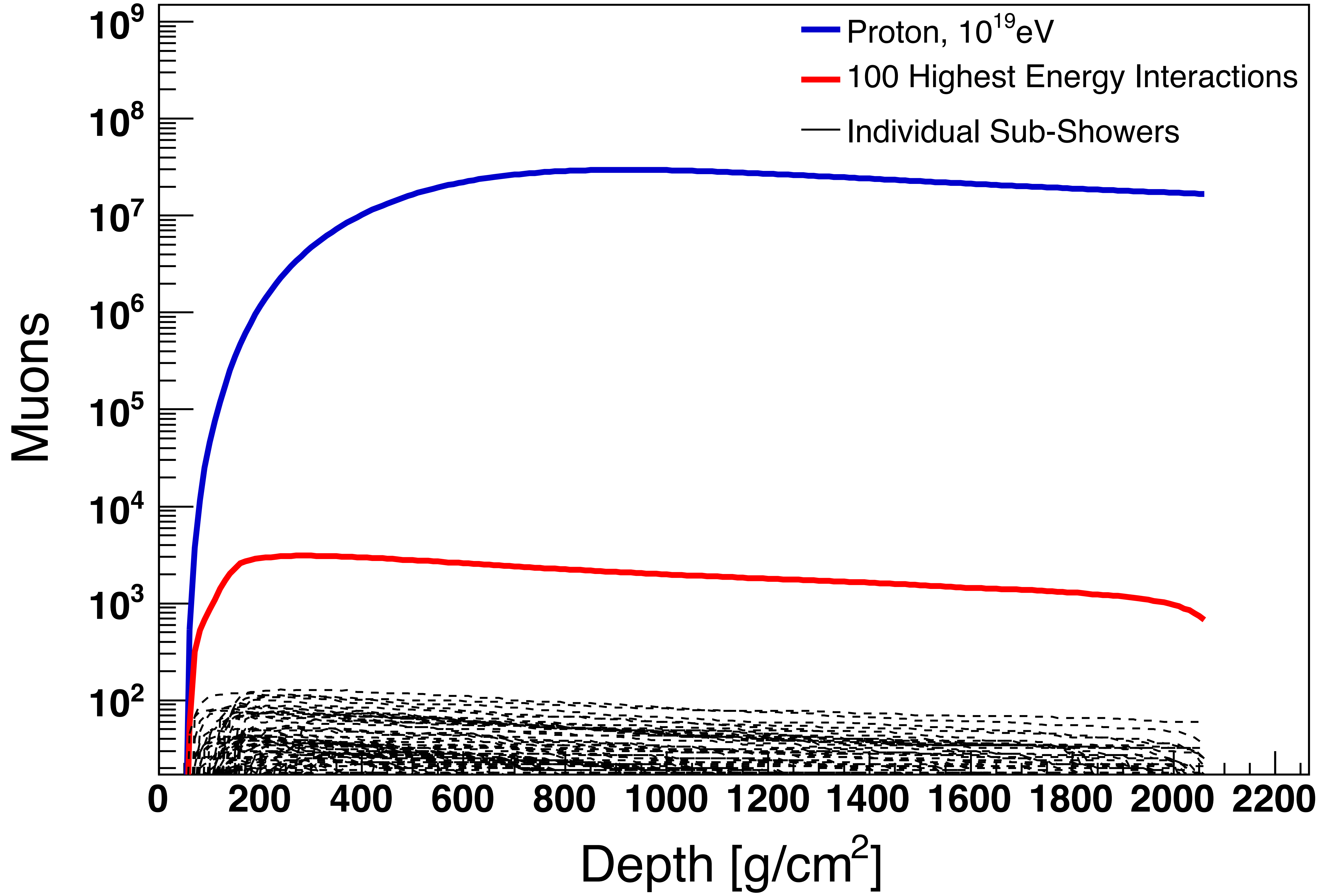
See R. Engel on the Auger upgrade PoS686 and M. Josebachuili on AMIGA POS409



Muonic component in air showers

R. Ulrich APS 2010





X_{max} is dominated by first interaction
Muons are produced late in the shower cascade

- Number of generations ~6 at 10^{19} eV
- Amplified sensitivity to hadronic interactions

May allow to disentangle particle physics and composition using hybrid events (coincident measurement of SD and FD)