Applying
Extensive Air Shower Universality to Ground Detector Data

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Outline

- EAS universality at large core distances
- Ground signal parametrization based on universality
- Determining number of muons and model-independent energy scale
- Conclusion

Energy calibration of ground arrays

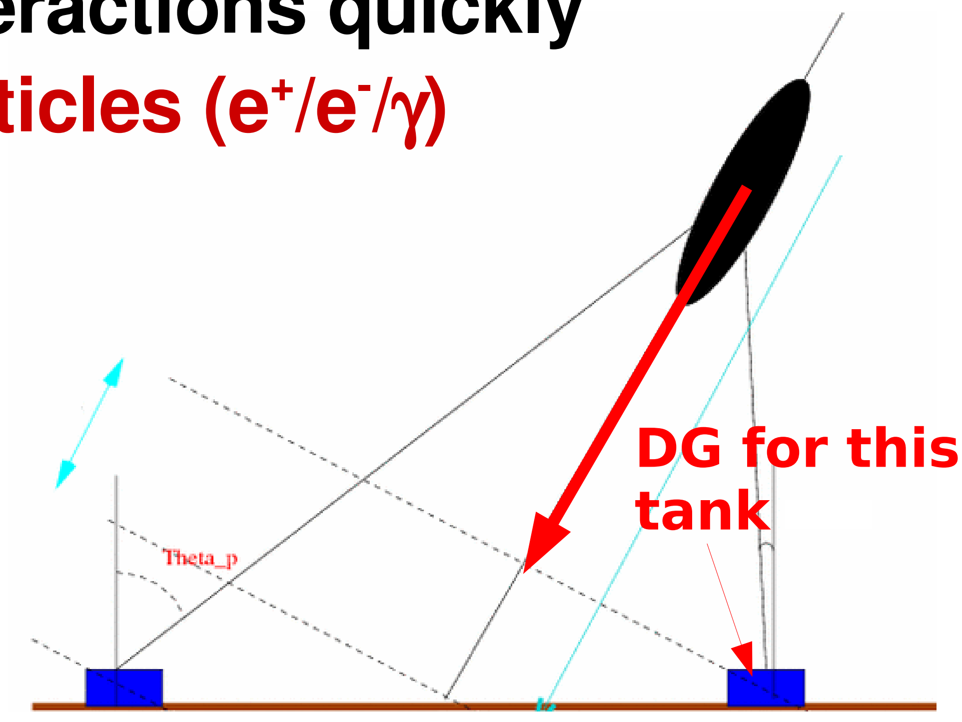
Standard procedure so far:

- **determine $S(r_{opt})$ from detector signals**
  - r_{opt} depends on experiment (detector spacing)
- **calibrate $S(r_{opt})$ – E relation with simulations**
- **large systematic uncertainties in E calibration**
  - due to unknown hadronic interaction physics

Can we circumvent these unknowns ?

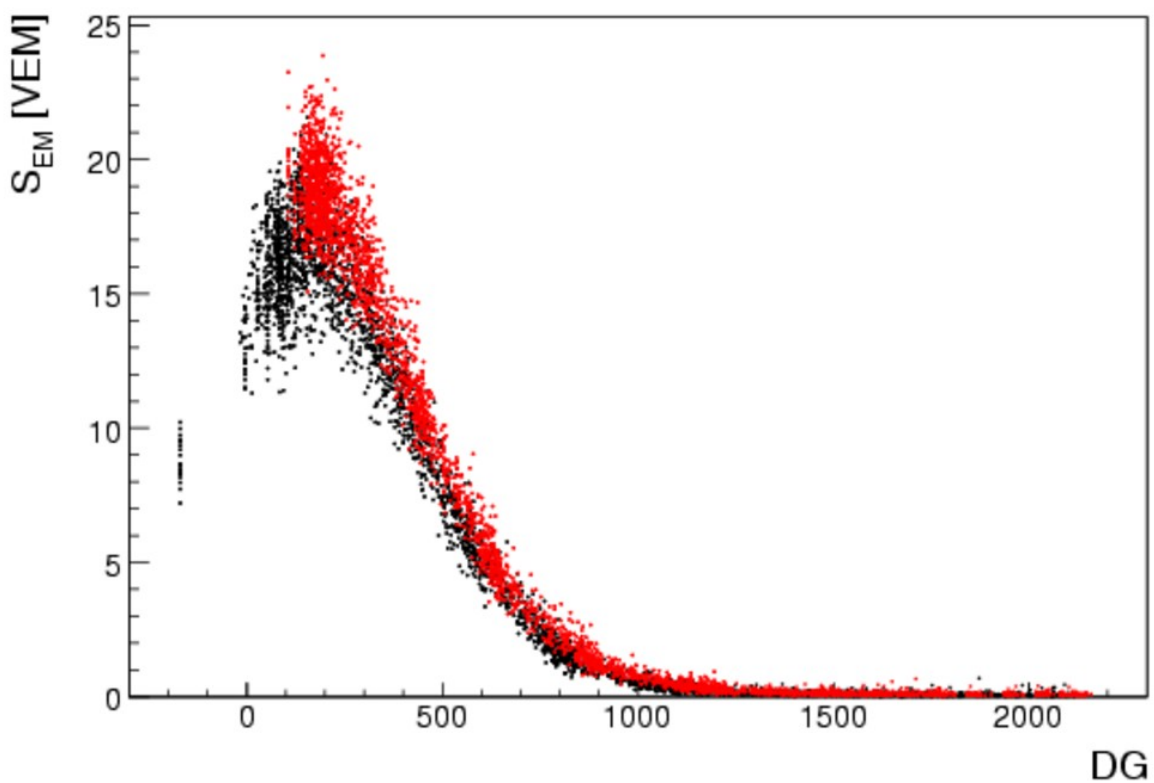
Idea of EAS Universality

- **UHECR air shower: ~10^{10} particles**
- **Details of hadronic interactions quickly washed out for EM particles ($e^+/e^-/\gamma$)**
- **Particle flux at ground only function of:**
  - energy **E**
  - zenith angle **θ**
  - distance to ground **DG** of shower maximum



Universality of EM component

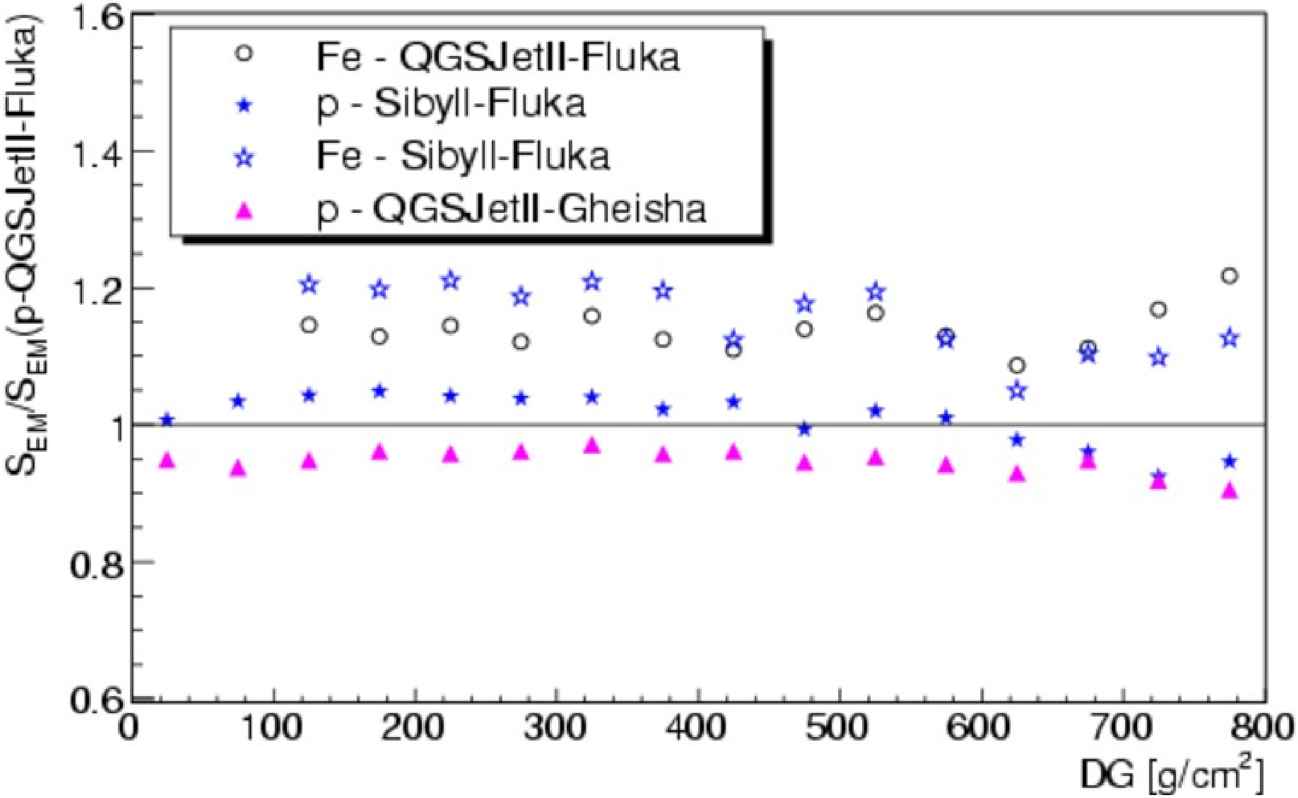
- **Evolution of signals from EM particles in water Cherenkov tank – proton / iron at 10^{19} eV**



- **At 1000m from shower core**
- **``Flat tank'' approximation -> no θ-dependence**
- **Not including muon decay products**
- **CORSIKA simulations with QGSJetII / Fluka**

Universality of EM component

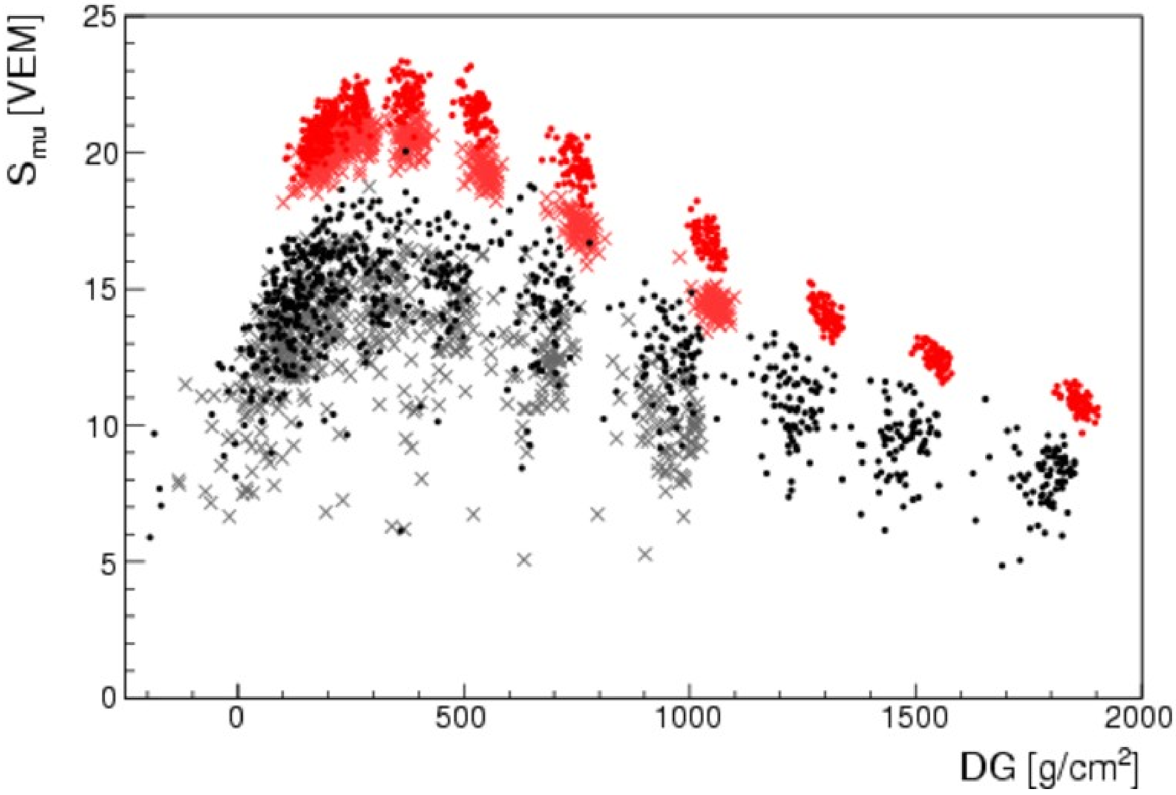
- ~12% difference b/w p/Fe - universality violation
- independent of shower evolution



Signals for different primaries/models relative to proton-QGSJetII

Universality of μ component ?

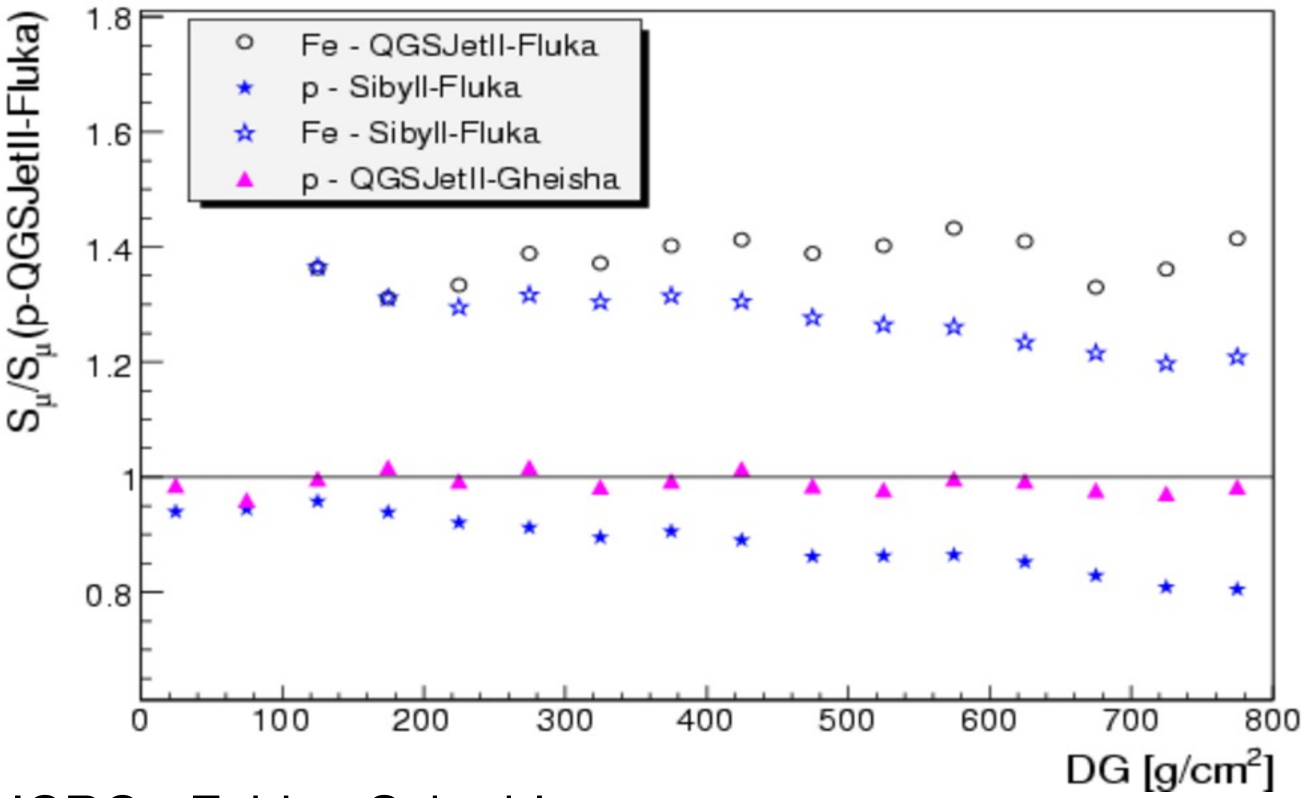
- **Again water Cherenkov signals at 1000m**
- **Strong primary/model dependence**



proton / iron
QGSJetII / SibyII

Universality of μ component

- **Primary/model dependence in**
  signal normalization, *not* evolution !



μ signals relative to proton QGSJetII

Signal parametrization

- **Based on universality:**
  - S_{EM} known *(given DG)*
  - S_{μ} evolution known
  - **μ signal normalization N_{μ} unknown**

    -> to be determined from data
  - **DG** given by **mean depth of showers $\langle X_{max} \rangle$**

$$S(E, \theta, DG) = S_{EM}(E, \theta, DG) + N_{\mu} \cdot S_{\mu,ref}(\theta, DG)$$

Reference: proton-QGSJetII at 10^{19} eV

Determining N_μ from data

- **Use isotropy of cosmic ray flux**

constant intensity method:

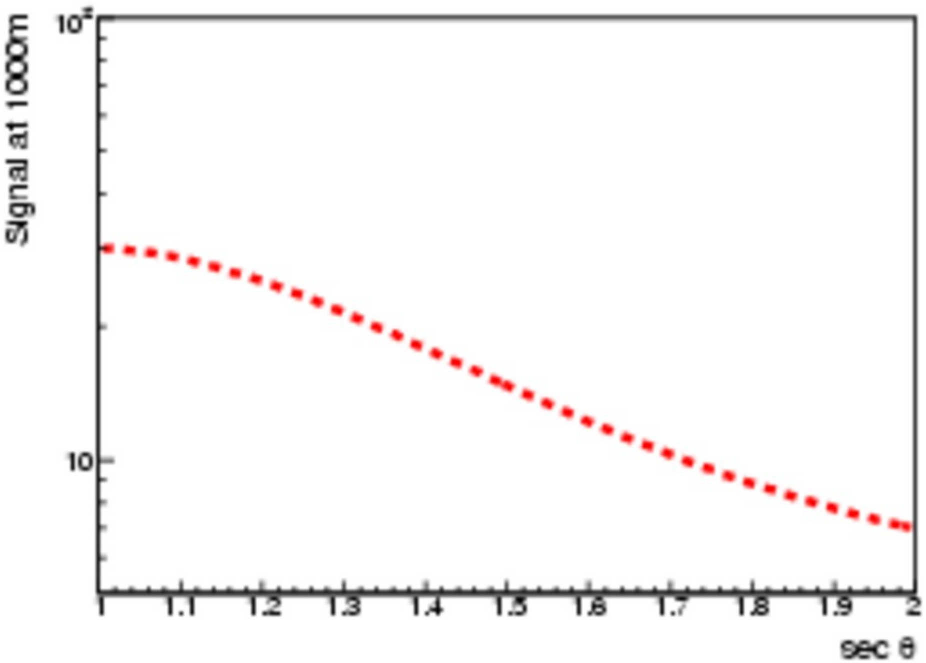
N_{events}(>E) is equal in equal exposure bins in θ

- **Showers at different zenith angles probe different DG -> discern S_{EM} from S_μ**

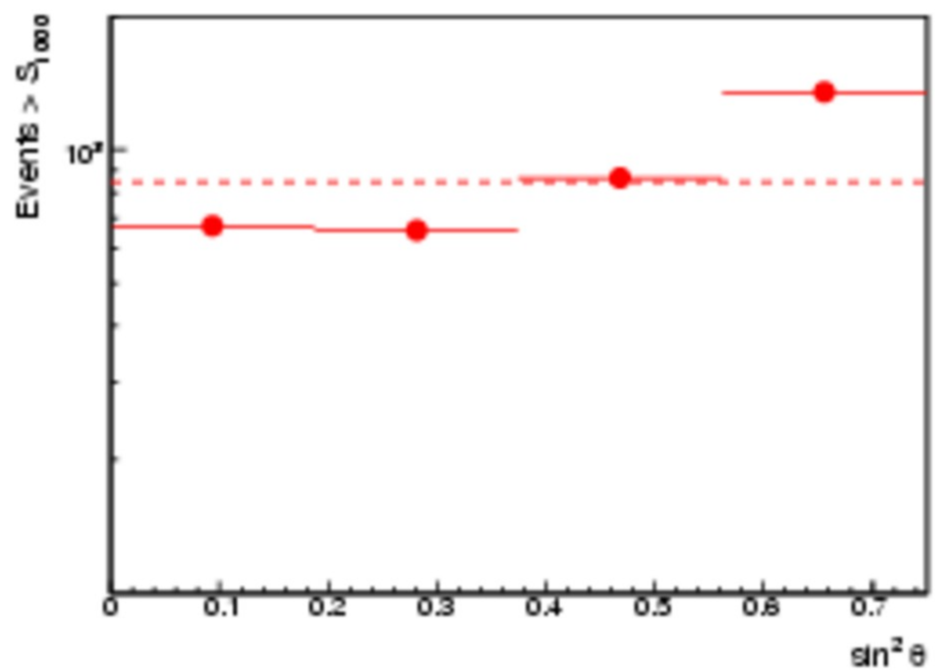
Constant intensity method

- **N_μ = 0.5:** too small ...

Energy fixed at 10^{19} eV



Signal at 1000m vs sec θ

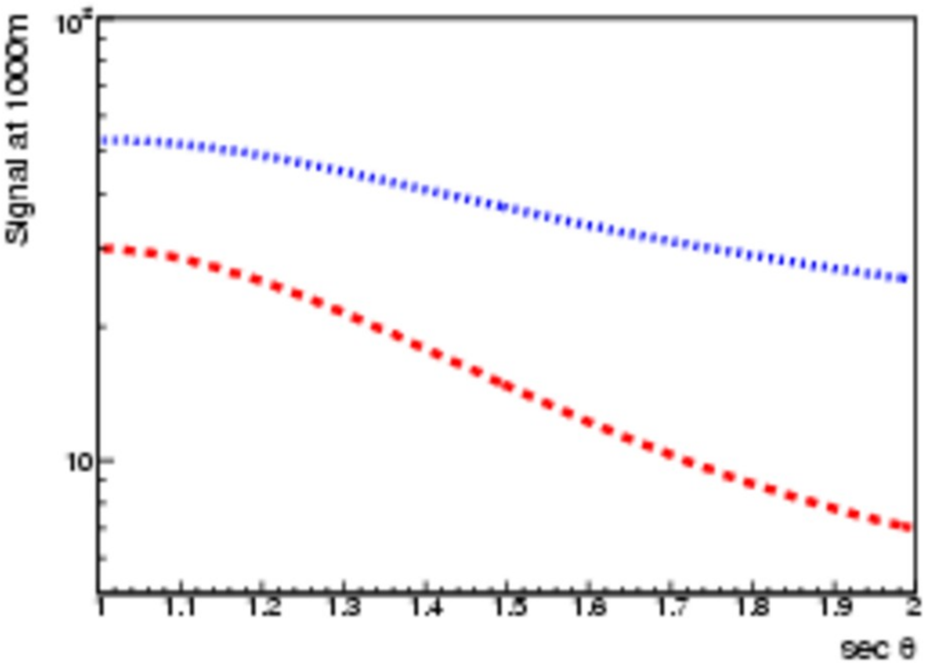


N_{events}(> S) in equal exposure bins ($\sin^2\theta$)

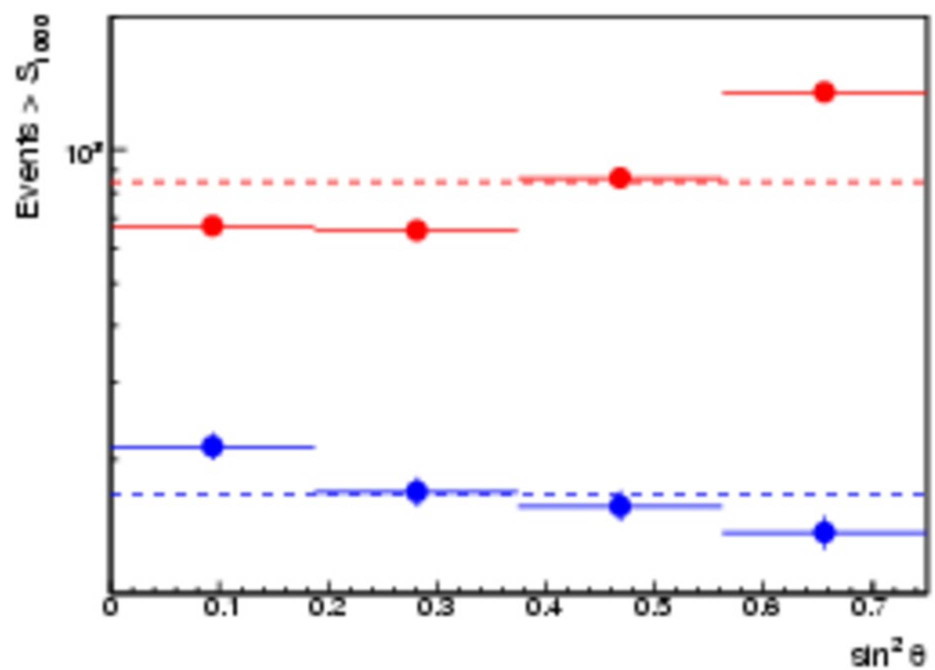
Constant intensity method

- **N_μ = 2.0:** **too large ...**

Energy fixed at 10^{19} eV



Signal at 1000m vs sec θ

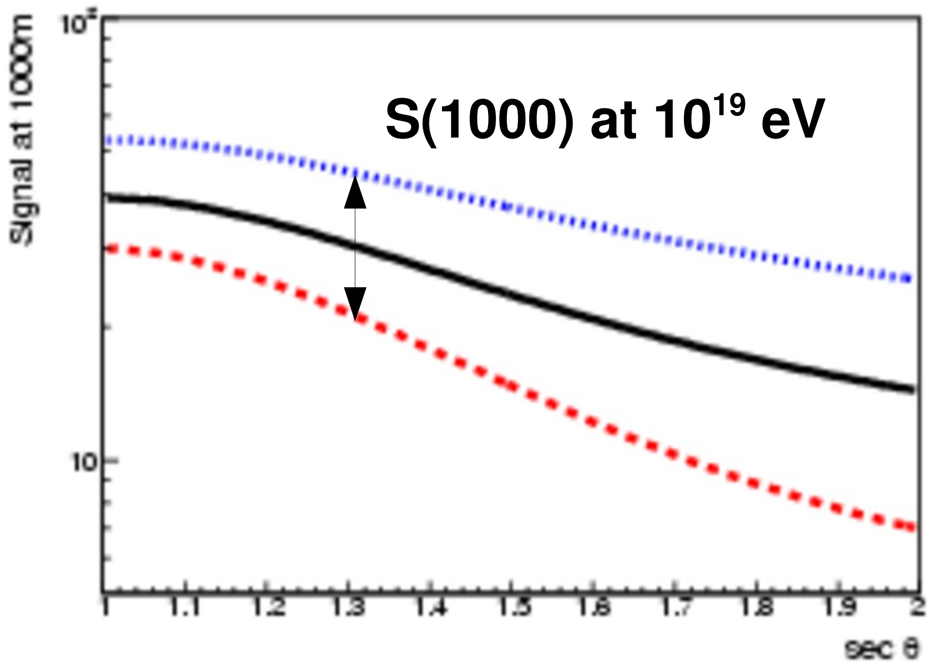


N_{events}(> S) in equal exposure bins ($\sin^2\theta$)

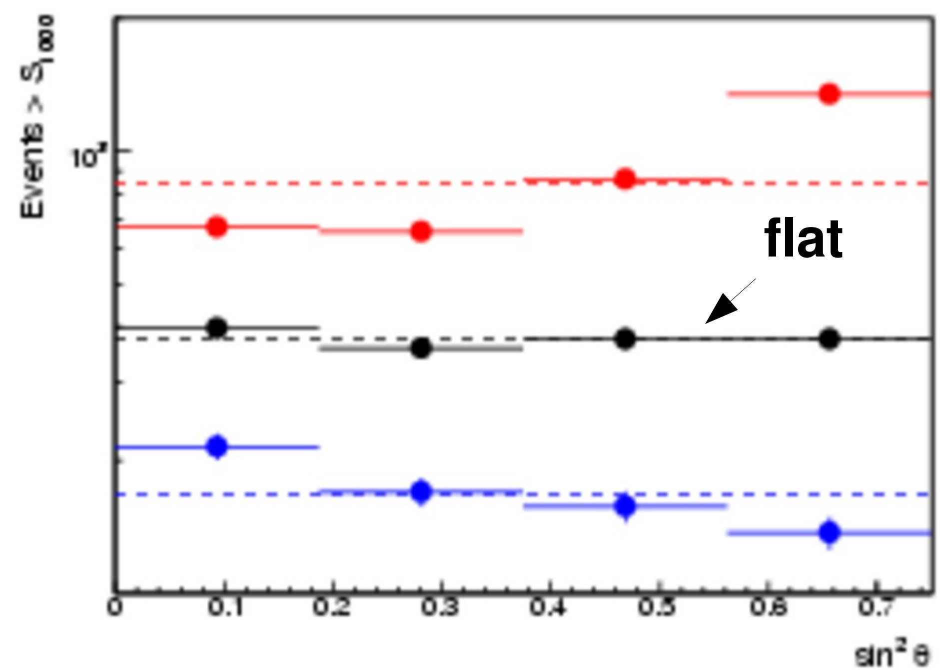
Constant intensity method

- N_μ = 1.0: right ...

Energy fixed at 10^{19} eV



Signal at 1000m vs sec θ



N_{events}(> S) in equal exposure bins ($\sin^2 \theta$)

N_μ and the ground detector energy scale

- N_μ determined from data yields

model- and primary-independent ground detector energy scale:

$$\text{Ground signal}\,(E,\theta) = S_{EM}(E,\theta) + N_{\mu,exp}(E)\cdot S_{\mu,ref}(\theta)$$

- based on universality
  - **systematic error in N_μ around 0.1** due to universality violation and uncertainty on $\langle X_{max}\rangle$
  - statistical error for Auger-like data set ~0.1

Validation with hybrid events

- **Combination of fluorescence tel. and ground array: independent event-by-event energy and X_{max}**
- **Directly measure S_μ (relying on known S_{EM}):**

$$S_{\mu,i} = S_i - S_{EM}(E_i,\theta_i,X_{max,i})$$

- **probe muon signal evolution S_μ(DG)**
- **measure N_μ at different θ:**
  - consistency check of universality
- **Caveat: have to rely on fluorescence energy scale**

Conclusions

- **EM signal and muon signal evolution universal**
- **Muon normalization can be inferred from data**
- **Method yields model- and primary-independent energy scale for ground detectors**
- **Measured N_μ places constraints on hadronic interaction models**
- **New model EPOS under investigation**
- ***Application to Auger data presented by R. Engel, #605***