Muons in extensive air showers with energy above 10^{17} eV according to the long standing studies at the Yakutsk array

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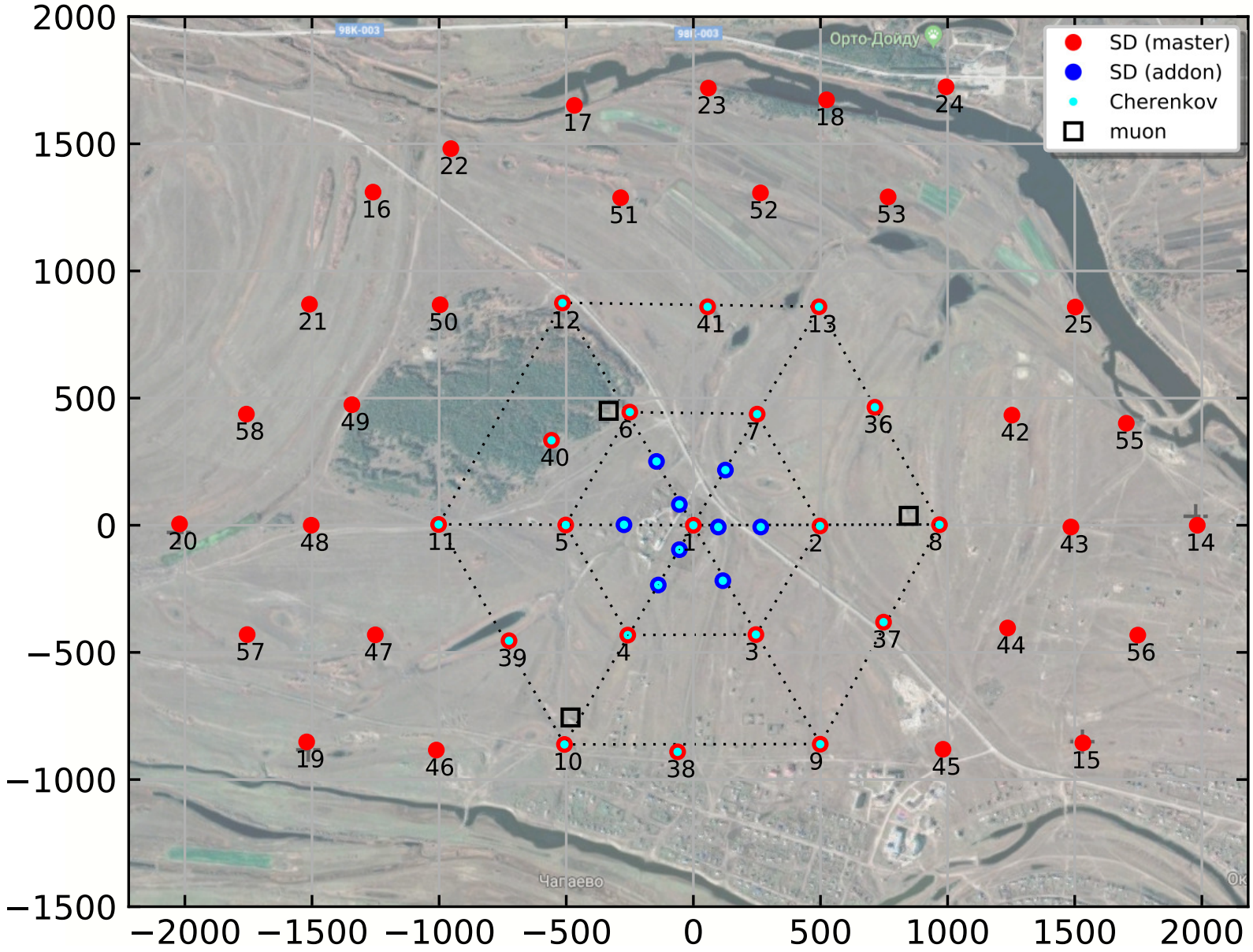
Experimental data: 1986 - 2017



Primary energy reconstruction

A revised quasi-calorimetric method

$$E_0 = \boldsymbol{E}_\gamma + \boldsymbol{E}_{\text{ion.}} + E_e + E_\mu + E_{\nu+\text{hadr.}}$$

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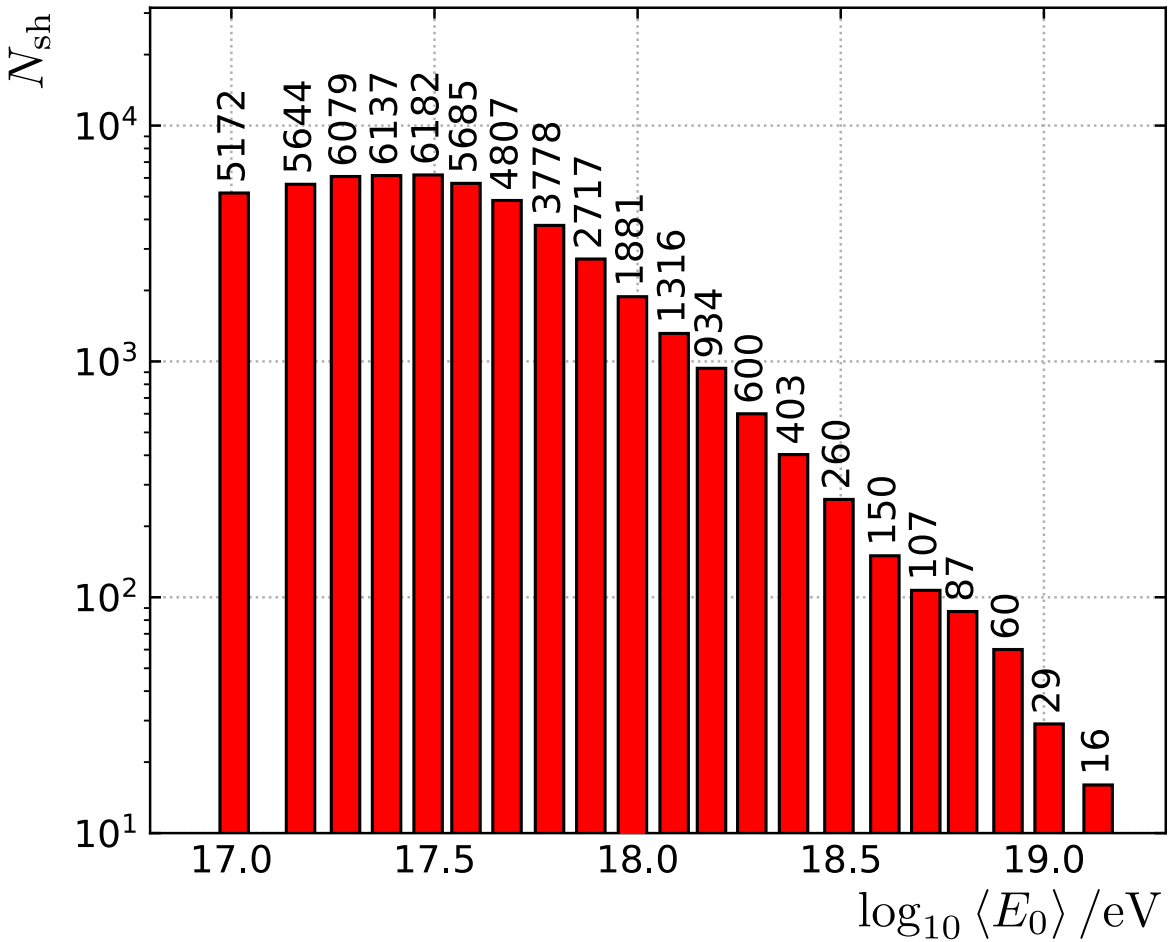
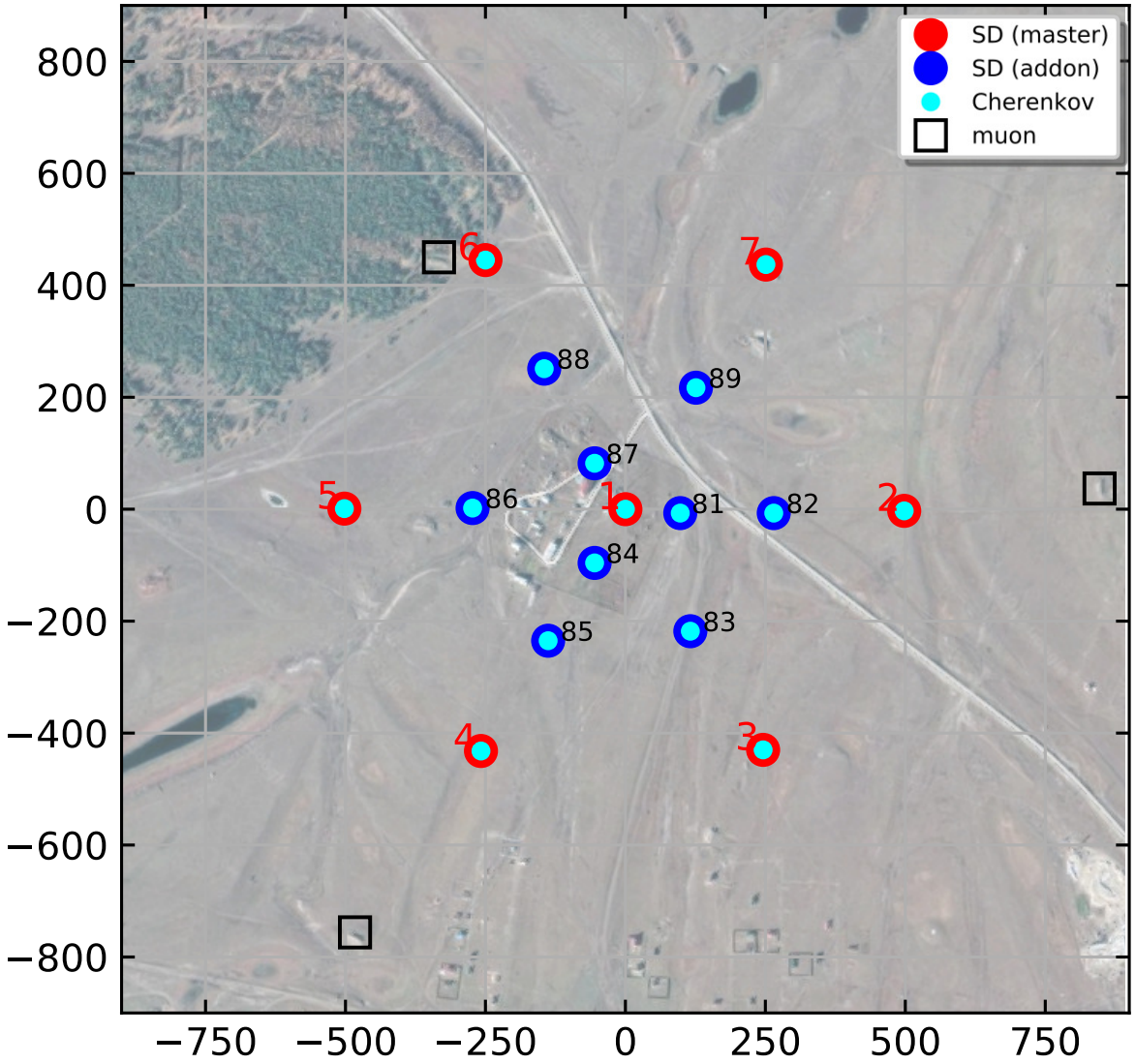
$$E_0 = (3.76 \pm 0.3) \times 10^{17} \cdot \rho_s(600)^{1.02 \pm 0.02}$$

Experimental data selection: 1986 - 2017



- $E_0 \geq 10^{17}$ eV
- $\theta \leq 38.7°$
  $\langle\cos\theta\rangle \simeq 0.90$
- 1 km around the center:
  6 *Trigger-500* triangles +
  6 *Trigger-1000* triangles
- $\sigma(\text{axis}) \leq 30$ m
  Trigger-500
- $\sigma(\text{axis}) \leq 50$ m
  Trigger-1000
- **52044 events with muons**

Experimental data selection: 1986 - 2017

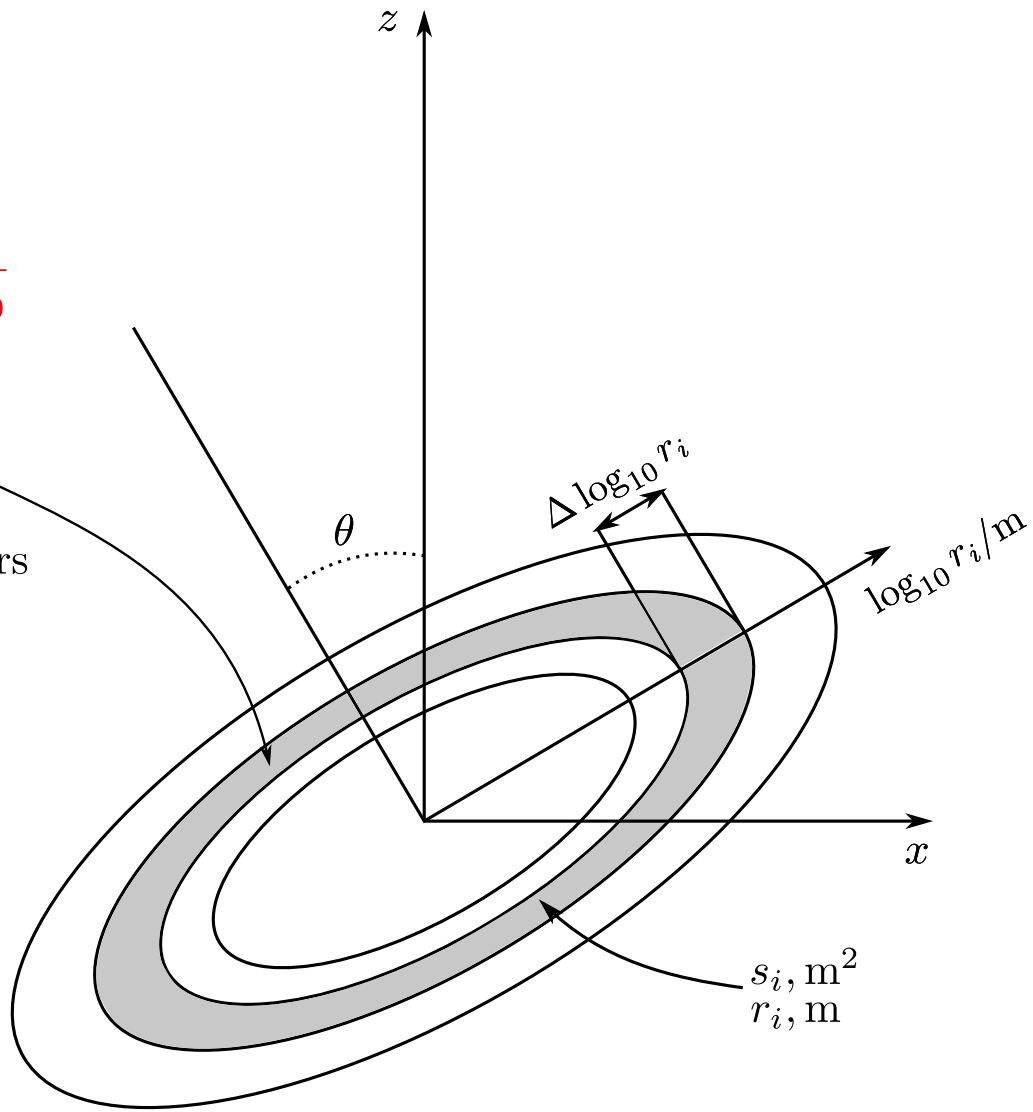


- 3 muon detectors $s = 20$ m^2
- 500 m, 100 m from the center
- $\epsilon_{\text{thr.}} \simeq 1$ GeV

Mean muon LDF for $\langle E_0 \rangle$:

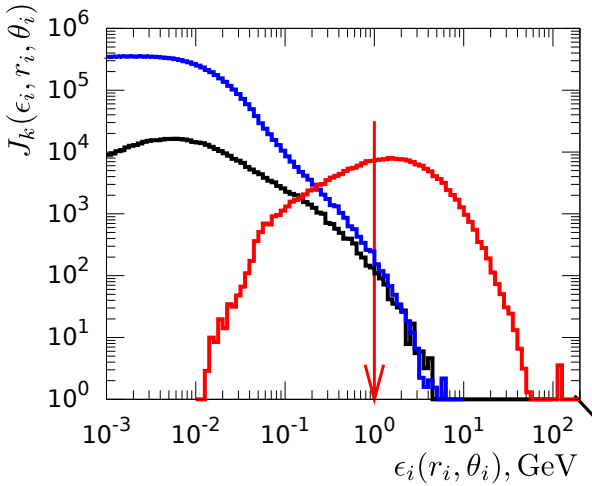
$$\langle \rho_\mu(r_i) \rangle = \sum_{n=1}^{N_1} \frac{\rho_{\mu,n}(r_i)}{N_1 + N_0}$$

N_1 — fired detectors
N_0 — “mute” detectors

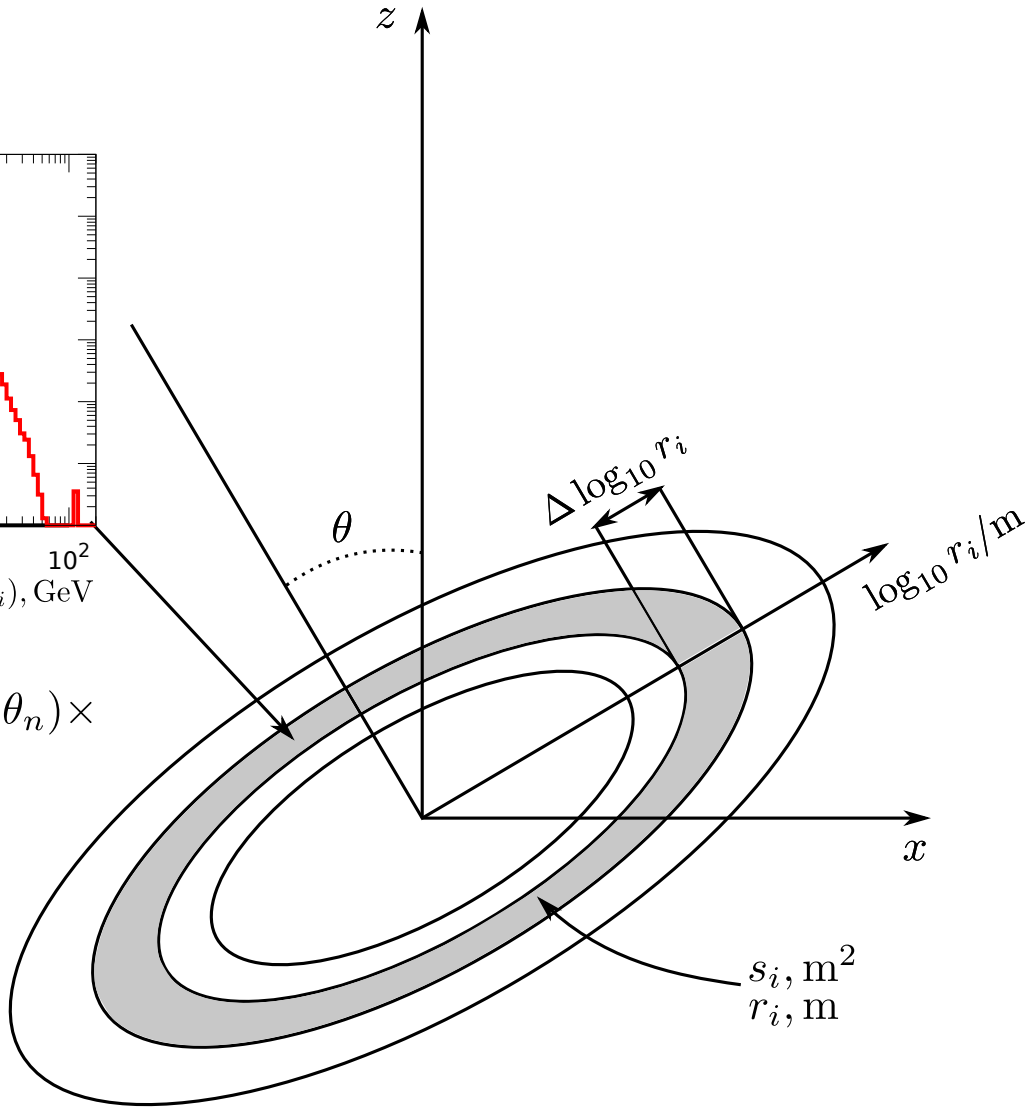


Mean muon LDF (CORSIKA)

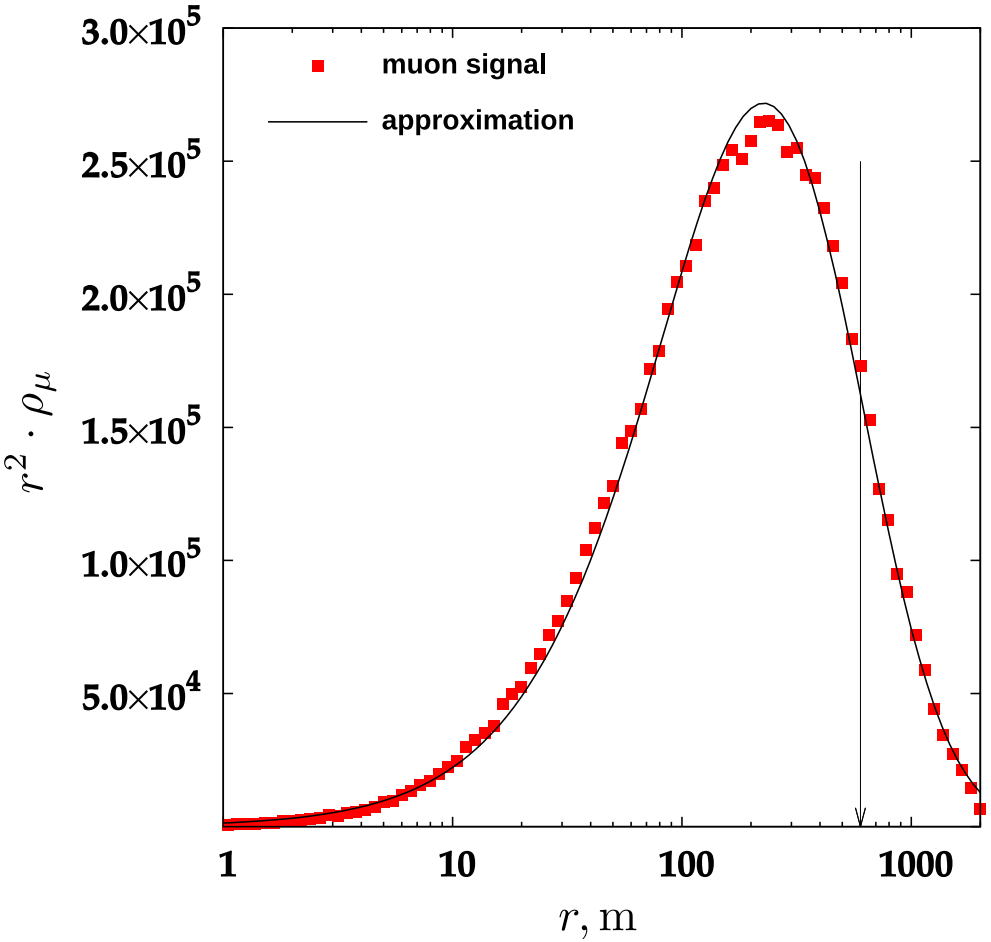
[poster #3.1]



$$\rho_s(r_i) = \sum_{k=1}^{3} \sum_{n=1}^{N_k} u_k(\epsilon_n, \theta_n) \times$$
$$\times J_k(\epsilon_n, r_i, \theta_n)$$



Muon signal approximation



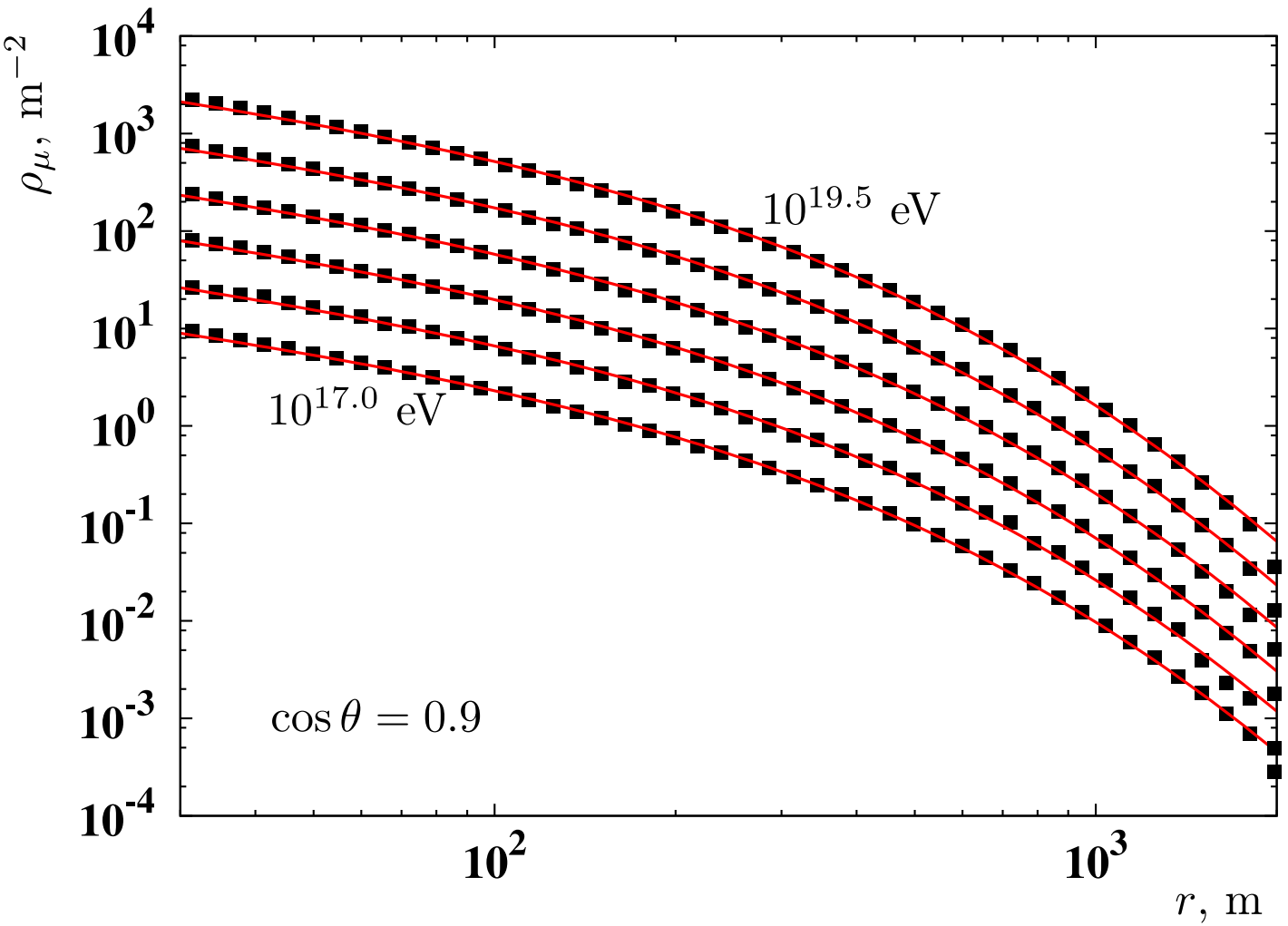
$$\rho_\mu(r) = f_\mu(r) \times \left(\frac{2000+600}{2000+r}\right)^{6.5},$$

$$f_\mu(r) = \rho_\mu(600) \times \left(\frac{600}{r}\right)^{0.75} \times$$

$$\times \left(\frac{r_0+600}{r_0+r}\right)^{b_\mu - 0.75}.$$

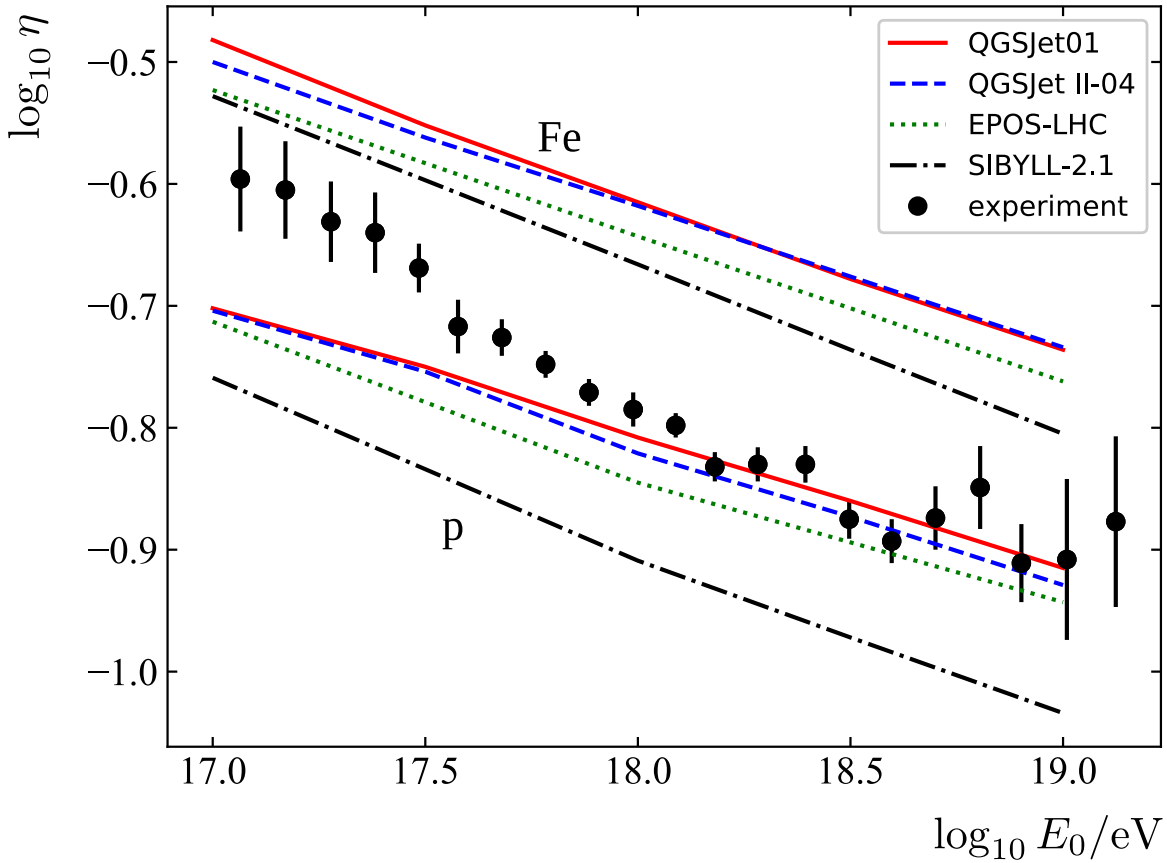
QGSJET II-04, P, $\cos\theta = 0.95$

Muon signal approximation



QGSJET01, $\cos\theta = 0.9$

Comparing model predictions to experiment



$$\eta = \rho_\mu(300)/\rho_s(300)$$

- easily derived from experimental LDF at $E_0 \geq 10^{17}$ eV
- sensitive to CR composition

Conclusions

- Both theoretical and experimentally derived mean LDFs are well described by chosen approximation
- Muon fraction at 300 m is highly sensitive to CR mass composition
- QGSJet01 & QGSJet II-04 give predictions closest to experiment if we accept the hypothesis that CR mass composition changes from $\langle \log A \rangle \simeq 2.5$ to protons in energy range $(1 - 30) \times 10^{17}$ eV

Thank You!