4th International UHECR Workshop

on the Highest Energy Cosmic Rays and their Sources

Study of the chemical composition with muon content

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Outline

What is the primary of an observed event?

energy-related parameters of a shower — E-parameters

composition-related parameters of a shower — $\mathbf{c}$-parameters

Both parameters are reconstructed with some errors

The probability distribution that the primary particle which produced an actual shower with the observed E-parameters equal to E_{obs} would rather produce a shower with these parameters equal to E_{rec}:

$$g_E(E_{\text{rec}}, E_{\text{obs}})$$

The probability distribution that a shower with measured C-parameters equal to $\mathbf{c}$ could produce detector readings corresponding to $\mathbf{c}'$:

$$g_c(\mathbf{c}', \mathbf{c}).$$

Steps

1. for each primary one generates a library of simulated showers : the same direction, $E_s \sim E_{obs}$, e.g. $0.5E_{obs} < E_s < 2E_{obs}$
2. following the experimental procedure for each event one finds E_{rec}
3. one assigns to each simulated shower a weight $w_1 = g_E(E_{\rm obs}, E_{\rm rec})$
4. one assigns to each simulated shower an additional weight $w_2 = (E_s/E_{obs})^{\alpha}$ to mimic the real power-law spectrum

Output:

The distribution of the parameters $\mathbf{c}$ for the showers consistent with the real one by E-parameters is given by

$$f_A(\mathbf{c}) = \frac{1}{\mathcal{N}} \sum_i g_c(\mathbf{c}, \mathbf{c}_{iA}) w_{1,iA} w_{2,iA}$$

Results

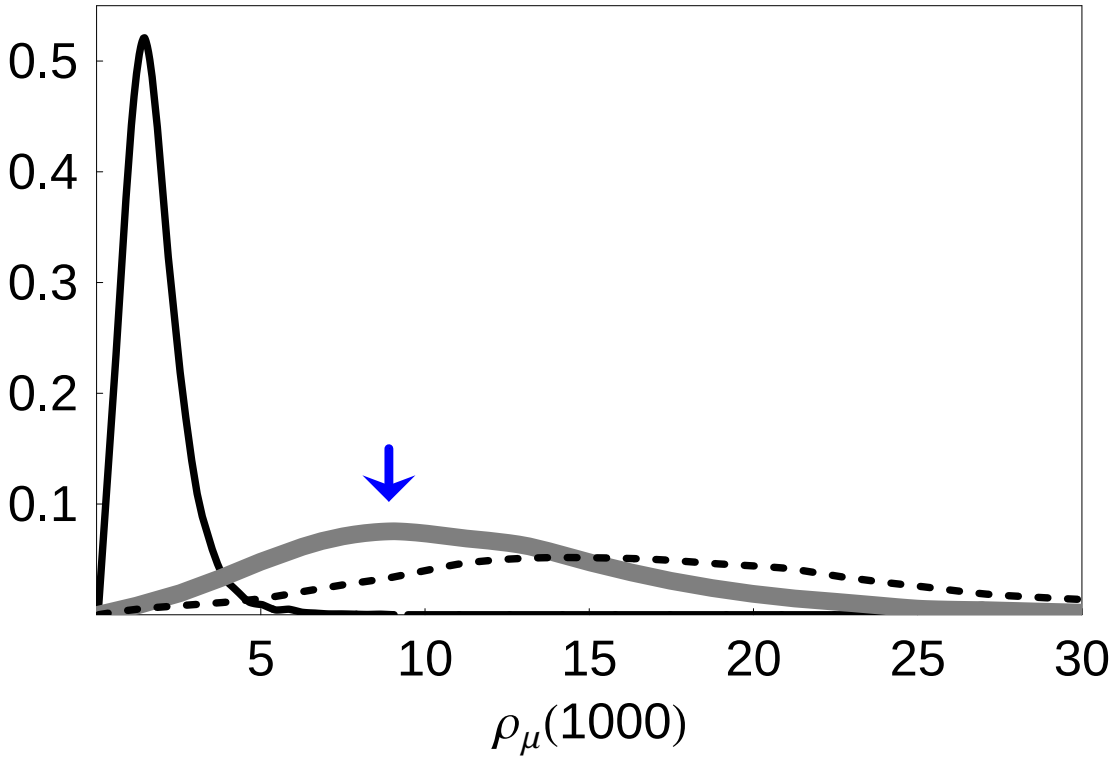
If the event is unlikely being initiated by the primary A, one can estimate of the probability it could be initiated by the primary A:

$$p_{A_1} = F_A(\mathbf{c}_{\rm obs}) \equiv \int\limits_{f_A(\mathbf{c}) \le f_A(\mathbf{c}_{\rm obs})} f_A(\mathbf{c}) d\mathbf{c}$$

one can test the hypothesis that the primary was either A_1 or A_2. Then $p_{A_1} + p_{A_2} = 1$ and

$$p_{A_{1,2}} = \frac{f_{A_{1,2}}(\mathbf{c}_{\rm obs})}{f_{A_1}(\mathbf{c}_{\rm obs}) + f_{A_2}(\mathbf{c}_{\rm obs})}$$

The highest energy AGASA event $2.46 \cdot 10^{20}$ eV



Distributions of muon densities f_A of simulated events: thin dark line, $A = \gamma$; thick gray line, $A = p$; dashed line, $A =$Fe.

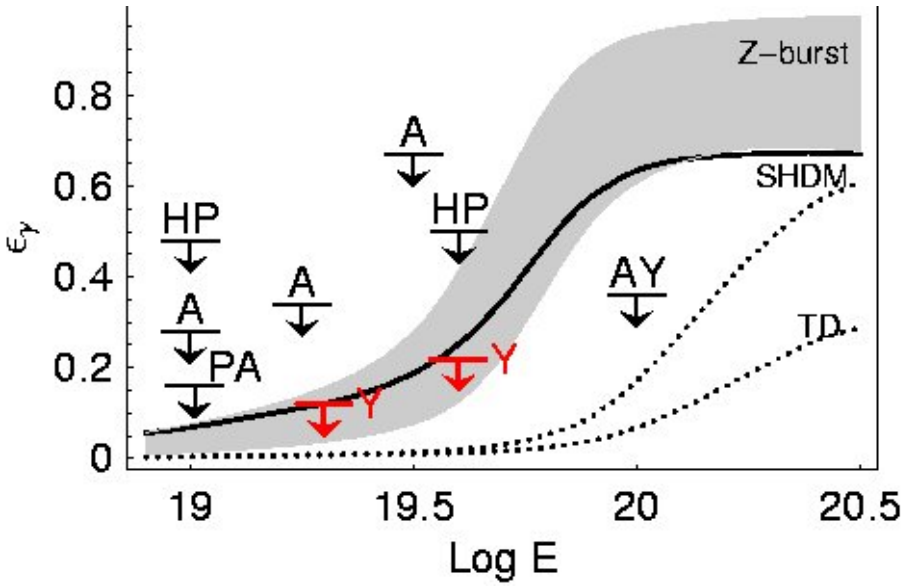
Ground array: Yakutsk 10-20 km^2

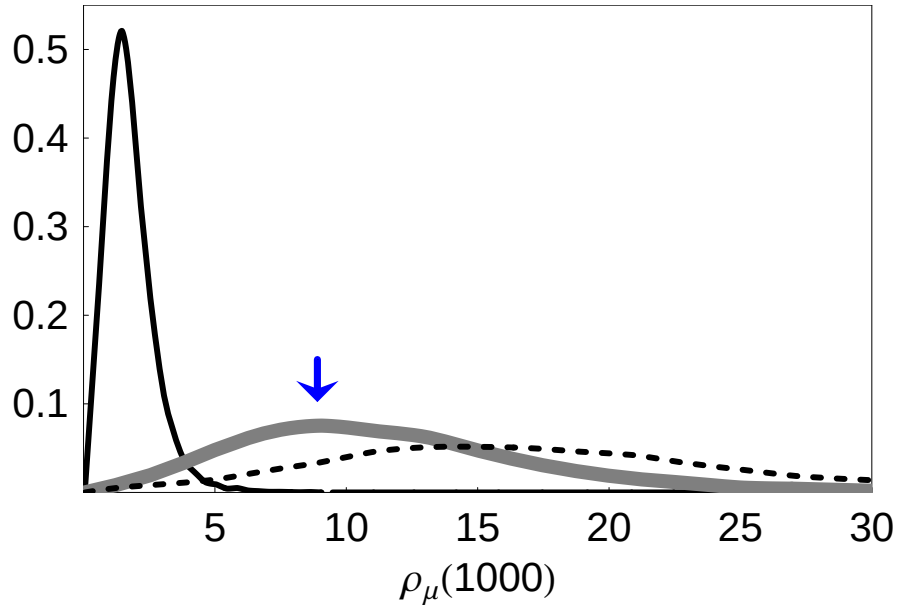




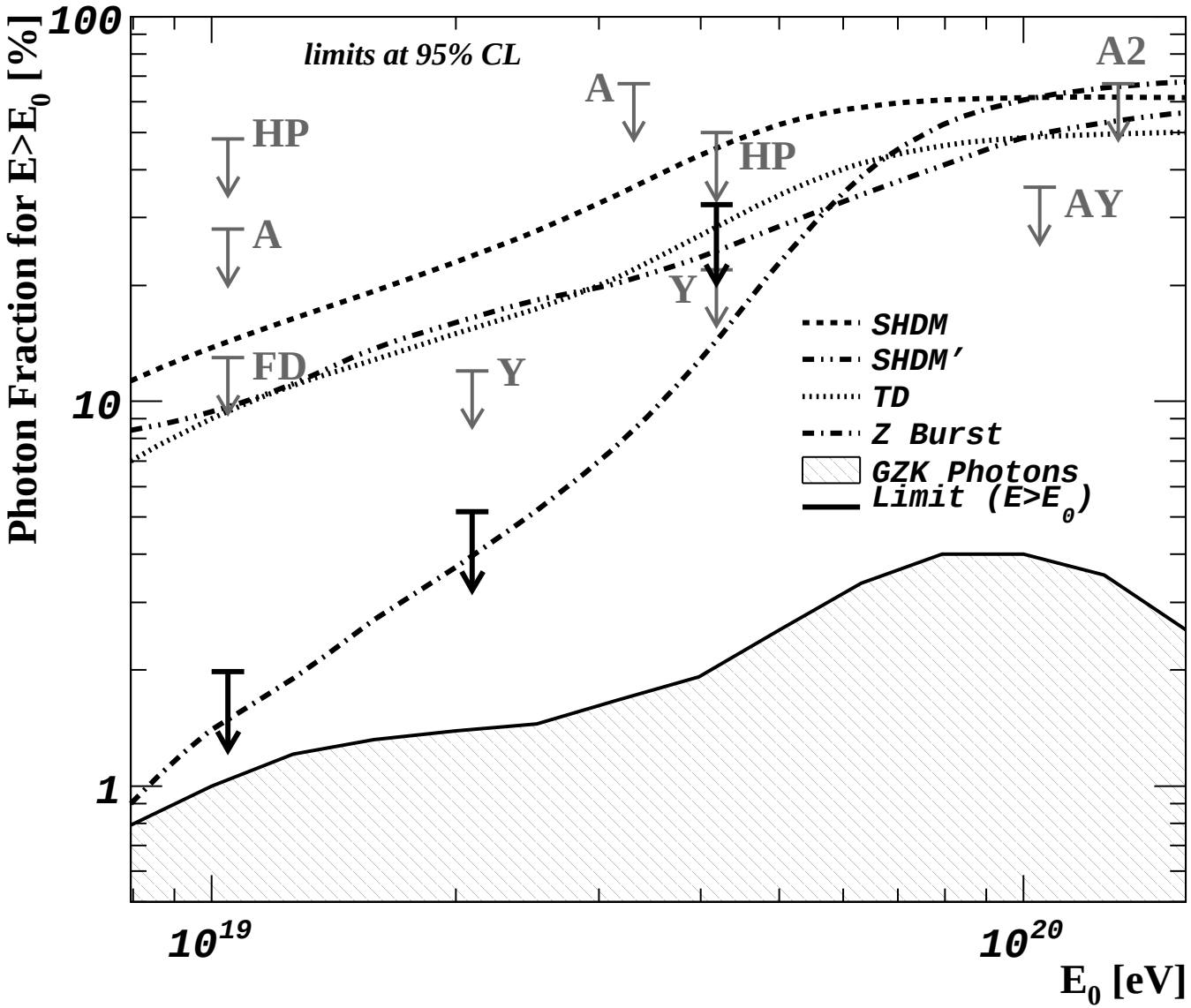

Chemical composition: results

- no horizontal showers — no neutrinos!
- no muon-pour showers — no photons!
- most probably protons or nuclei
- lack of muons in simulated showers
- . . .





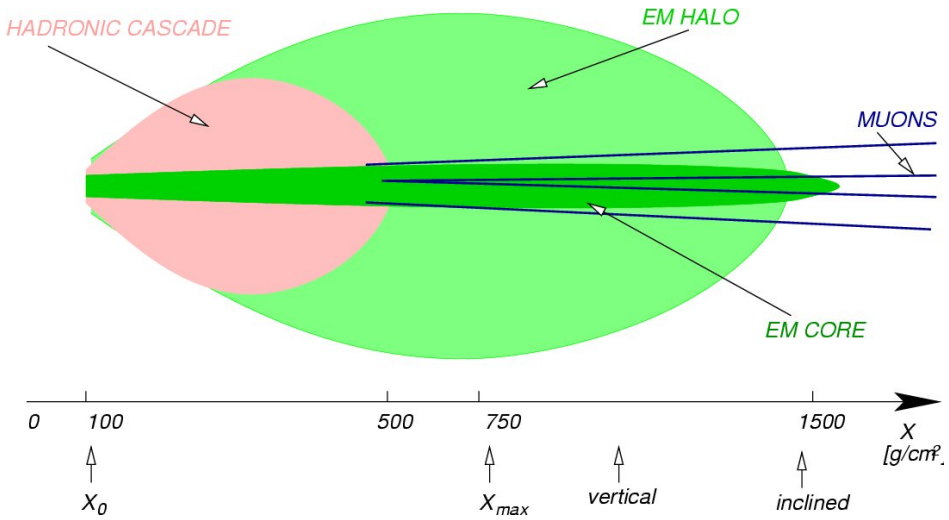
Limits on photons: PAO and Yakutsk

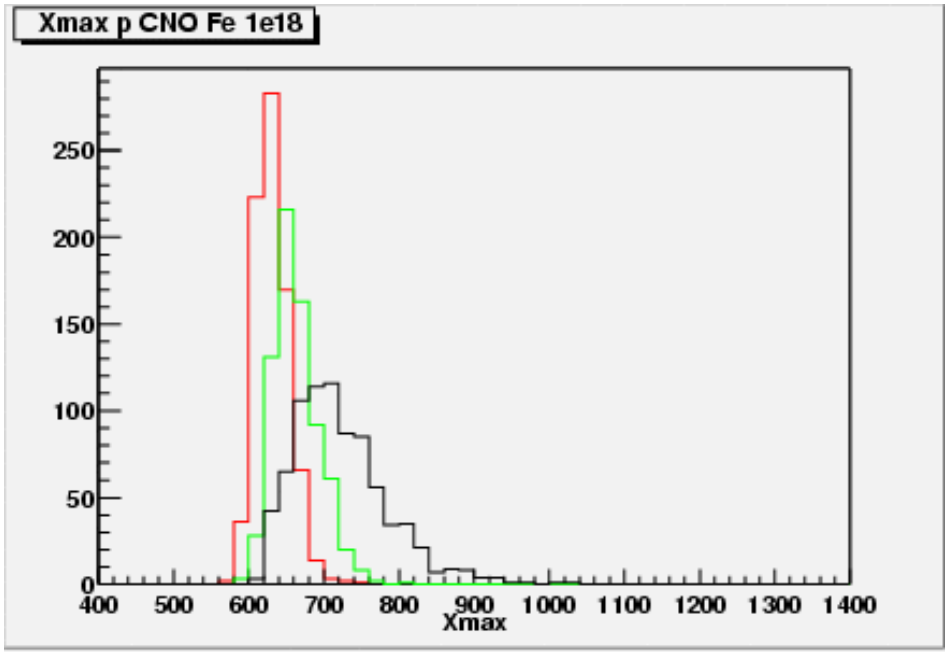


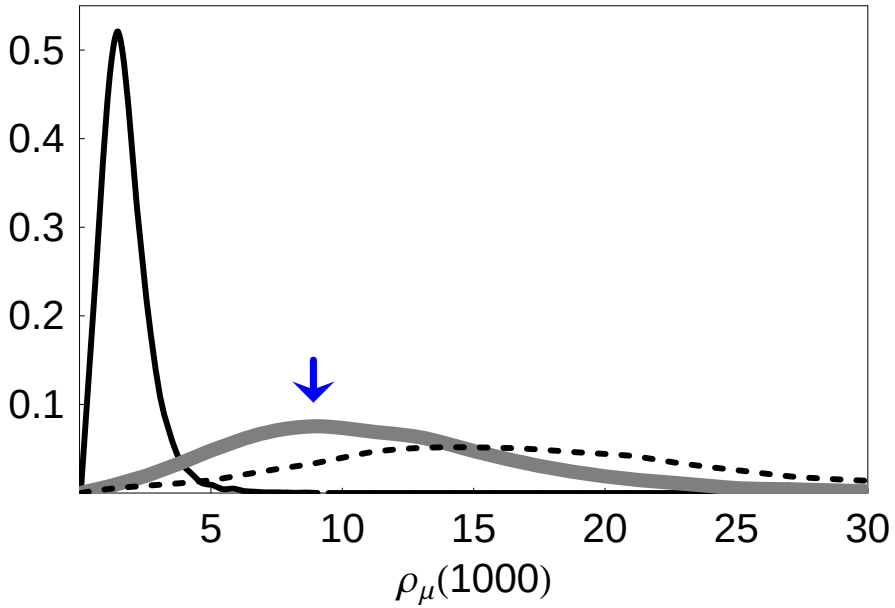
Main uncertainty: ENERGY

Chemical composition: methods

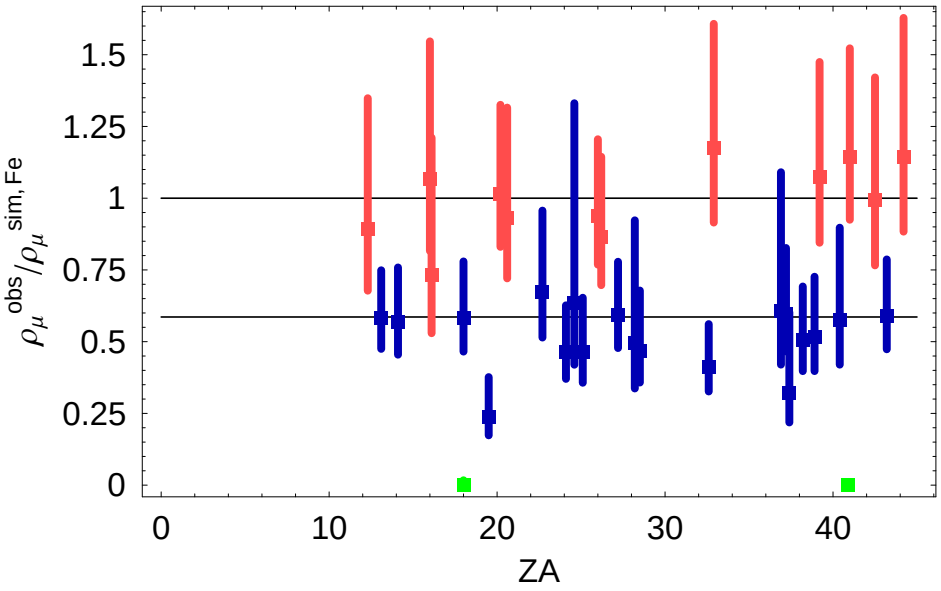
- muon component
- X_{max}
- inclined, horizontal showers
- structure of a shower front
- ...

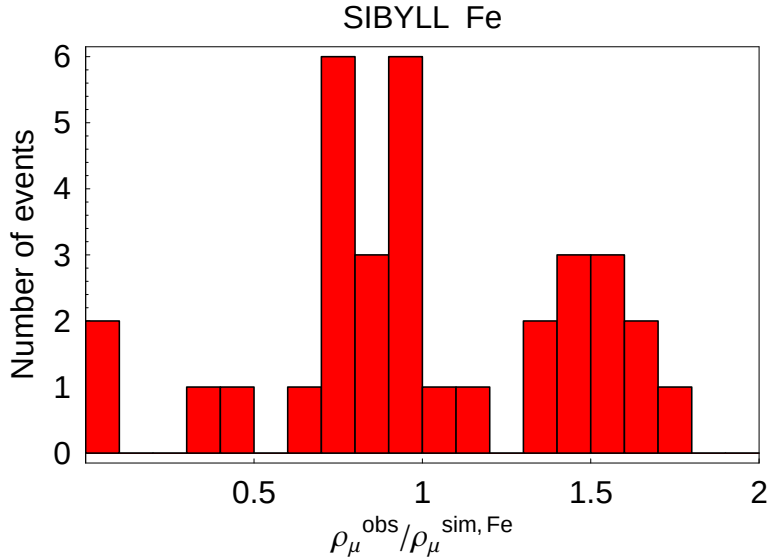






Chemical composition: measurement of ρ_μ

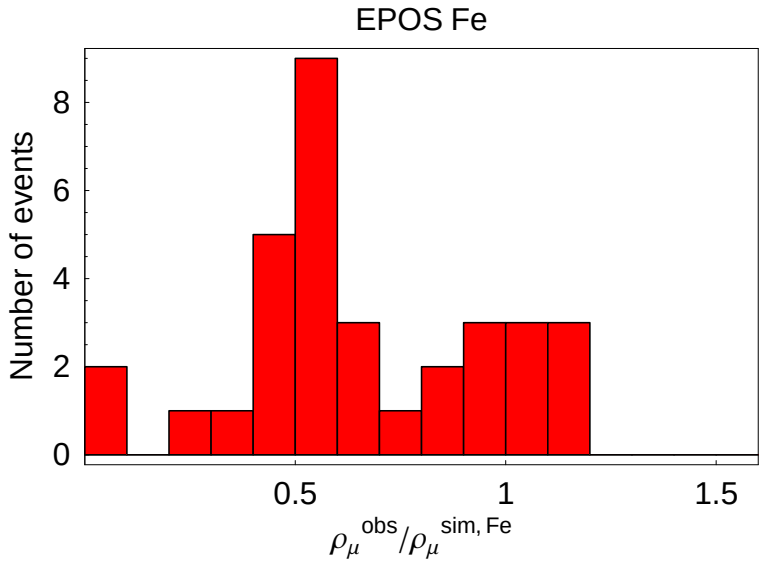




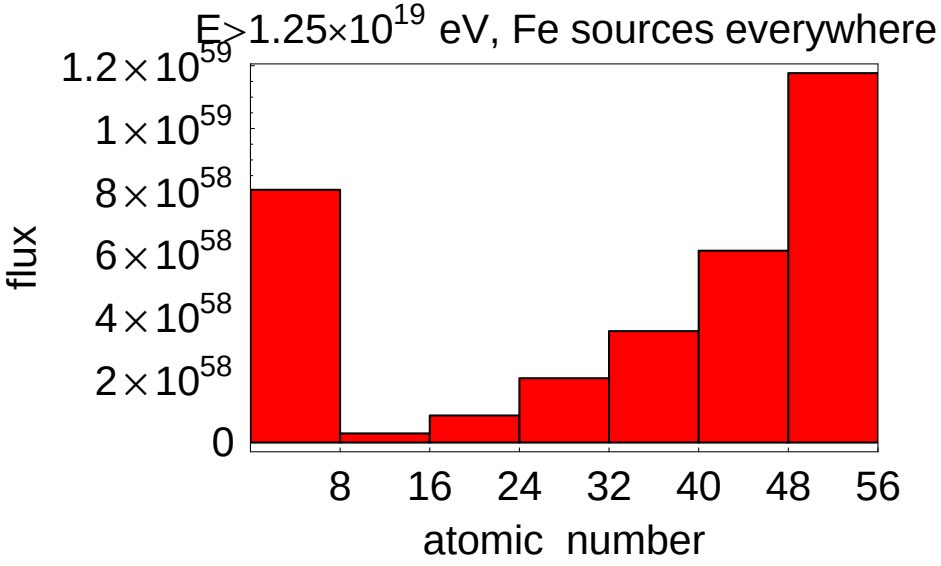
$$E > 10^{19}\ \text{eV}\ :$$

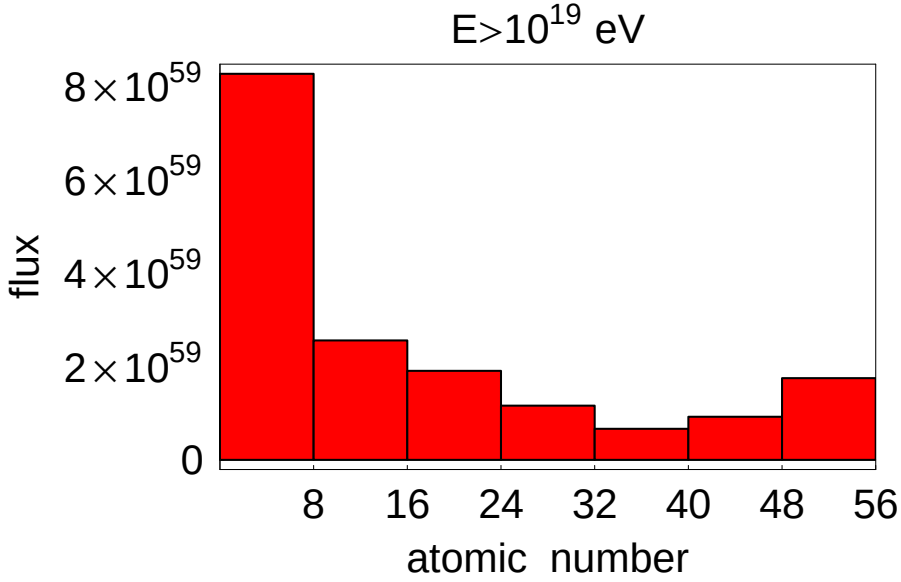
$$0.29 \leq \varepsilon_{\text{Fe}} \leq 0.68 \quad (95\%\text{CL})\,.$$

A.Glushkov *etal*.
arXiv:0710.5508



Heavy irons: Yakutsk





Energy normalization to... HiRes

galactic-CR-like composition in the sources BUT NO p and He

Scan over parameter space:

$E_{max} \propto Z$, z_{min}, α, B_{extr}, IR

accepted sets: consistent @ 5% or better

other nuclei: $\rho_\mu(A) = \rho_\mu(p) \cdot A^\beta$

D.G., O.Kalashev, G.Rubtsov, S.Troitsky in preparation