Modelling photon-induced showers observed by a ground array

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Problem

Our goal is to test the photonic solution of the north-south anisotropy in arrival direction of UHECR measured by AGASA detector.

We do the numerical simulations for photon-induced showers and estimate detected energy for ground array (AGASA).

Main features of photon-induced showers

- First interaction is electromagnetic — less amount of strong-interacting particles
- LPM effect — γ-nuclear interactions are supressed for $E \gtrsim 10^{20}\ eV$
- Shower fluctuations are larger
- Primary photon can interact with geomagnetic field

Interaction of primary photon with geomagnetic field

- Primary photon with energy around $10^{20}\ eV$ produce $e^+\ e^-$ pairs in geomagnetic field ($B \gtrsim 0.3G$). $P \sim \frac{E}{m_e} \cdot \frac{B_\perp}{B_{cr}}$
- Interaction leads to formation of preshower in magnetosphere
- Most particles in preshower have energies about $10^{19}\ eV$ and do not experience LPM effect
- Fluctuations in showers, originated in geomagnetic field are smaller, than in atmospheric showers.

Simulation

We assume arrival directions of primary photons with energy $10^{20}\ eV$ are uniformly distibuted over the sky. We use $\theta < 45^\circ$ cut, corresponding to AGASA acceptance. We set the geographic location of AGASA array.

To simulate photon-initiated showers we use CORSIKA 6.176β program, kindly granted by Dieter Heck and Piotr Homola. This beta version contains PRESHOWER code, simulating interaction in geomagnetic field. We use QGSJET hadronic model and EGS4 electromagnetic interaction model, which accounts for LPM effect.

Account of detector response

For each paricle, coming to the ground we calculate energy deposition using graphs, presented in the paper by Kutter [a]. For slanted arriving particles the energy deposition is assumed to be $E_{sc}(\alpha) = E_{sc}(\alpha = 0)/\cos(\alpha)$, ($alpha$ - angle of inclination) which is probably not accurate.

[a] Kutter, Auger Technical Note, GAP98-048

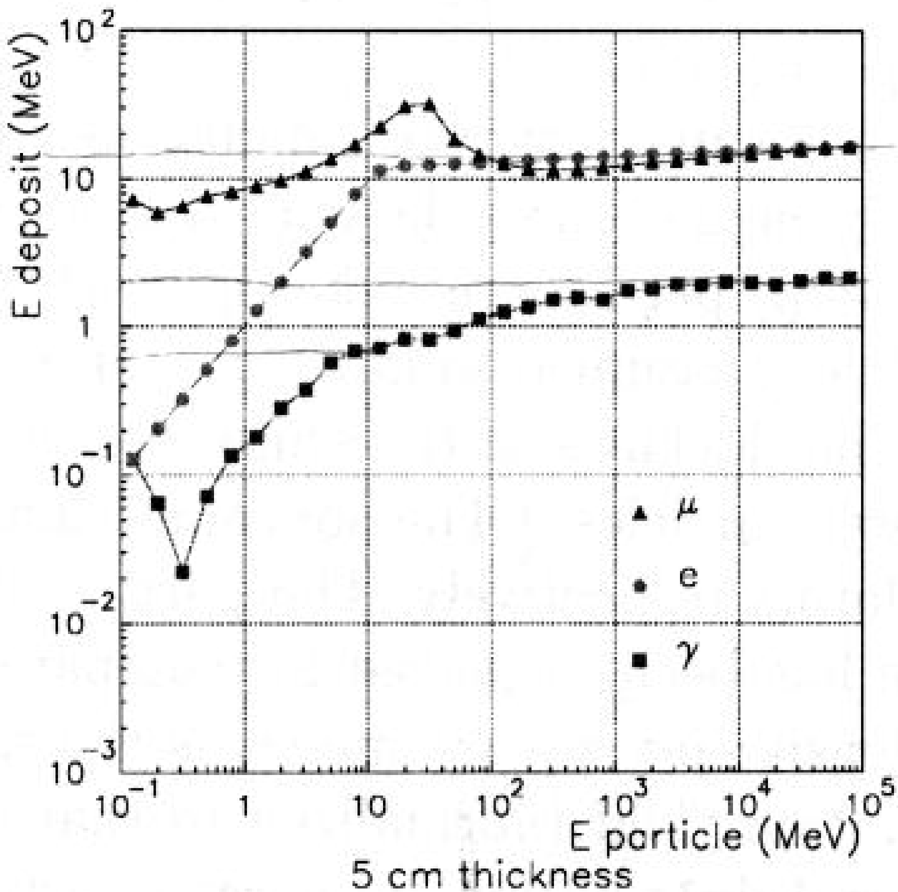

Fig. 1: Average energy deposition arrays for 5 cm thin scintillator. [b]

[b] Kutter, Auger Technical Note, GAP98-048

Then we fit the ground scintillation energy profile $S(r)$, where r is a distance to the shower axis, with AGASA empirical lateral distribution function.

$$S(r) \sim \left(\frac{r}{R_M}\right)^{-1.2} \left(1 + \frac{r}{R_M}\right)^{-\eta-1.2} \left\{1 + \left(\frac{r}{1000m}\right)^2\right\}^{-0.6} \quad (1)$$

where $\eta = 3.97 - 1.79(\sec\theta - 1)$, $R_M = 91.6m$. [c]

From the fit we calculate $S(600)$ and normalize it to vertical $S(600)$ using attenuation function

$$S_\theta(600) = S_0(600) exp\left[-\frac{X_0}{\Lambda_1}(\sec\theta - 1) - \frac{X_0}{\Lambda_2}(\sec\theta - 1)^2\right] \quad (2)$$

where $X_0 = 920g/cm^2$, $\Lambda_1 = 500g/cm^2$ and $\Lambda_2 = 594g/cm^2$.

[c]Takeda et al, Energy determinating in the AGASA experiment, arXiv:astro-ph/0209422

Results

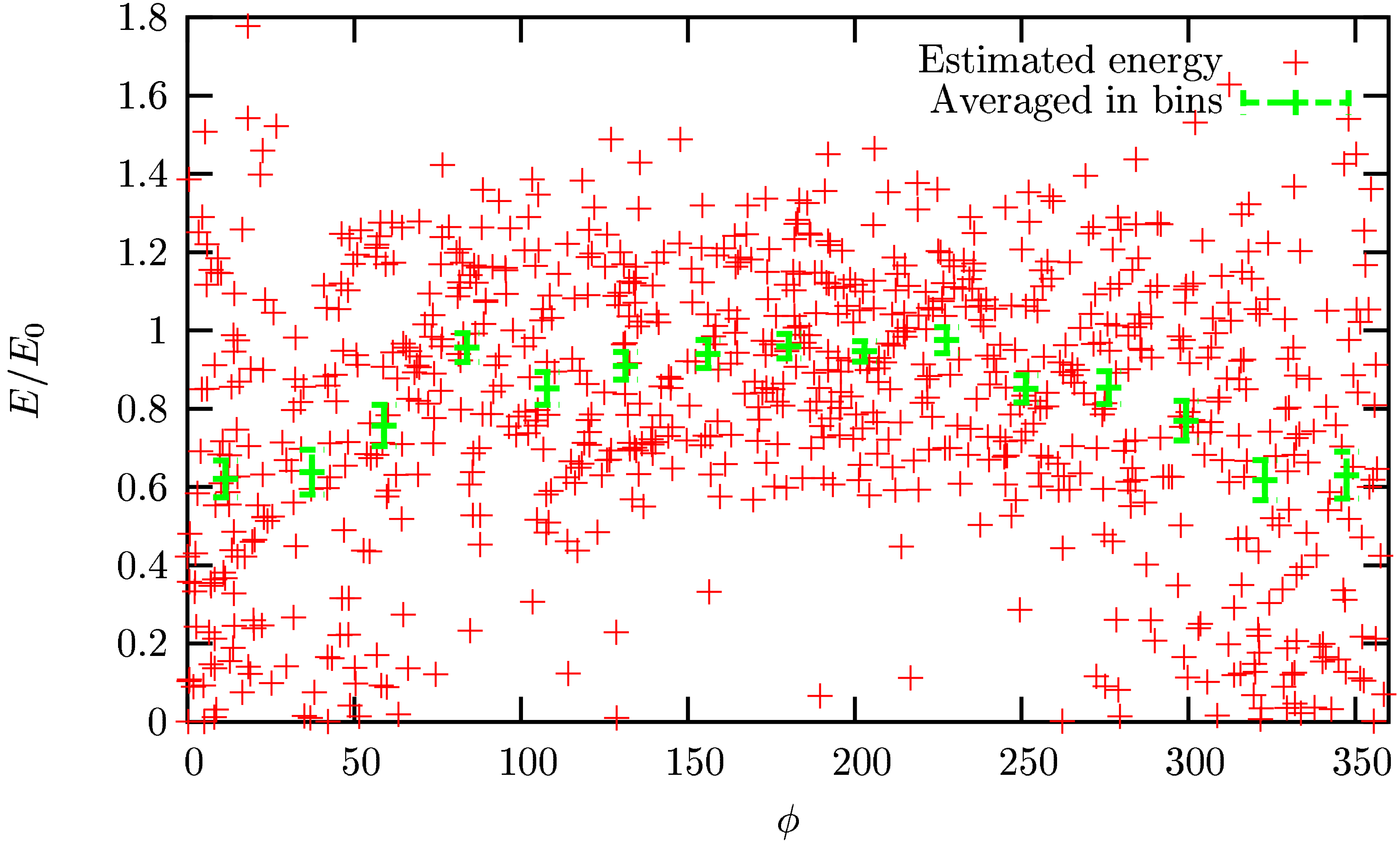

Fig. 2: Estimated energy dependence on azimuthal angle.

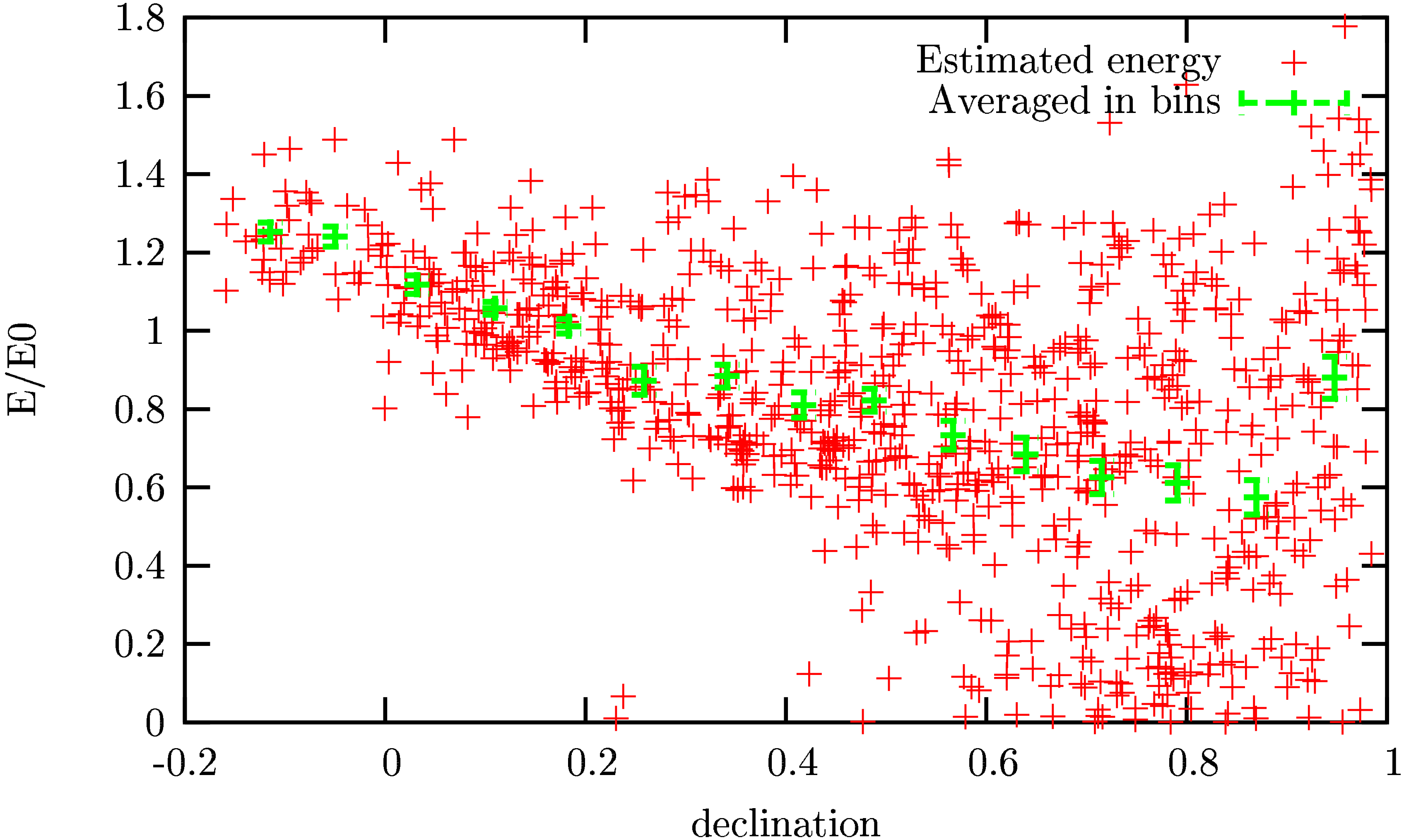

Fig. 3: Estimated energy dependence on declination.

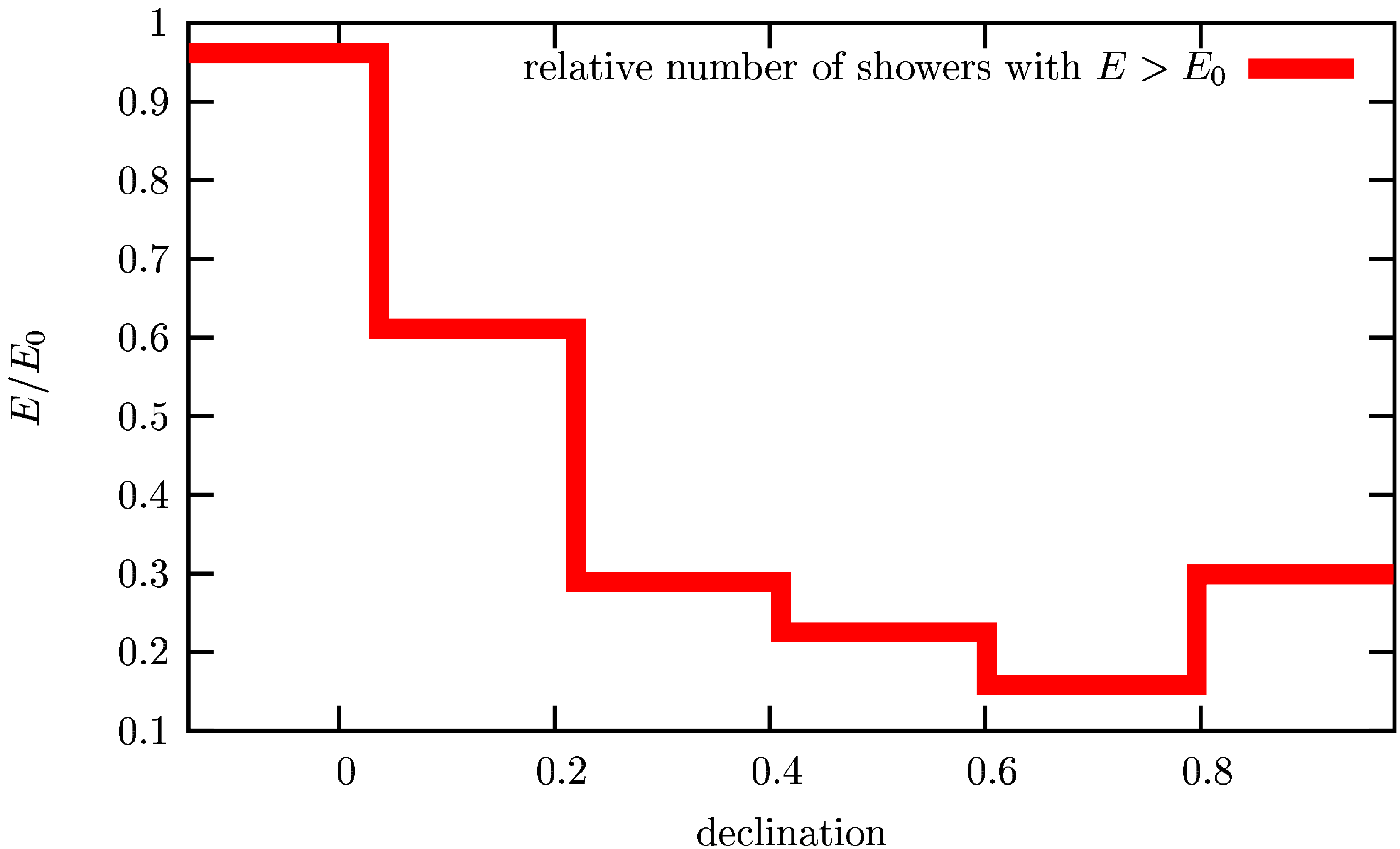

Fig. 4: Relative number of particles with detected energy larger than primary.

Conclusion

If primary particles are photons — ASASA should observe north-south anisotropy.

The energy of part of events with photons is estimated wrong by AGASA. Depending on overall normalization factor two cases are possible:

- Energies of south events is overestimated, and this really may solve cut-off problem.
- Energies of south events is estimated correctly, and energies of north events are underestimated. Then flux of UHECR is even higher.