Some systematic effects in the energy reconstruction by ground arrays: small scale shower fluctuations and possible photonic primaries[a]

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[a]work done in collaboration with Dmitry Gorbunov and Sergey Troitsky

Energy estimation systematics

The stone which the builders rejected
Has become the chief cornerstone.
[Matthew 21:42 NIV]

Possible systematic effects:

- Small-scale shower fluctuations
- Photonic primaries

Small-scale shower fluctuations

- Small scale fluctuation at the detector level possibly are large and can lead to systematic errors in energy estimation
- Energy estimation fluctuations can be non-Gaussian
- This effect usually is not resolved, becaused simulations are performed with the THINING option.

Method

- Two vertical, proton induced showers with $E = 10^{18}\ eV$ were simulated by CORSIKA+QGSJET without THINING.
- The detector is assumed to be ground detector of 100 scintillators ($1.6m\ \times 1.6m$) covering the area of $50km^2$
- The energy of each shower was estimated many times with different core location in the detector area.

Fluctuations on one scintillator

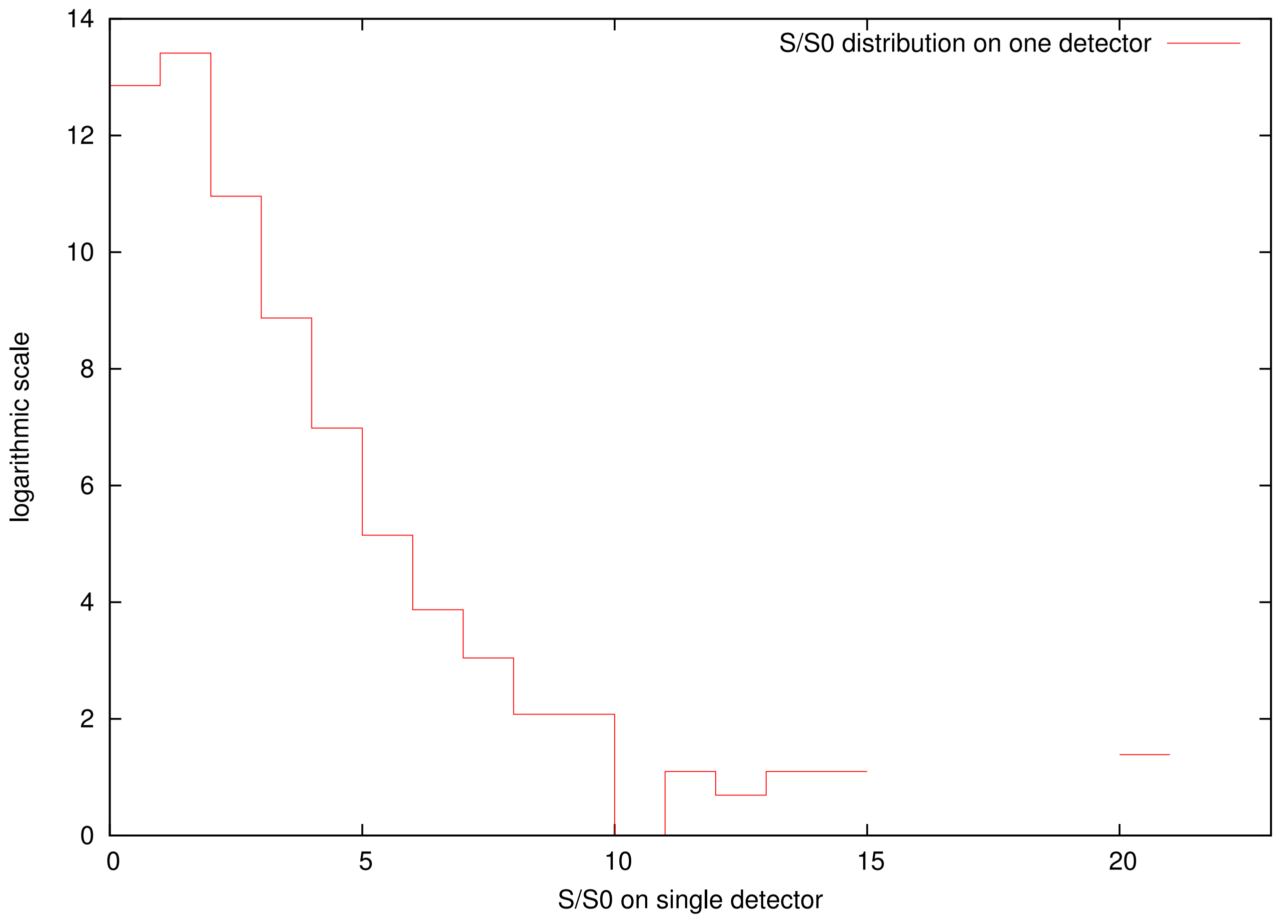

Fig. 1: S/S0 distribution on one scintillator, $r \in [300m, 1000m]$)

Energy estimation fluctuations, shower 1

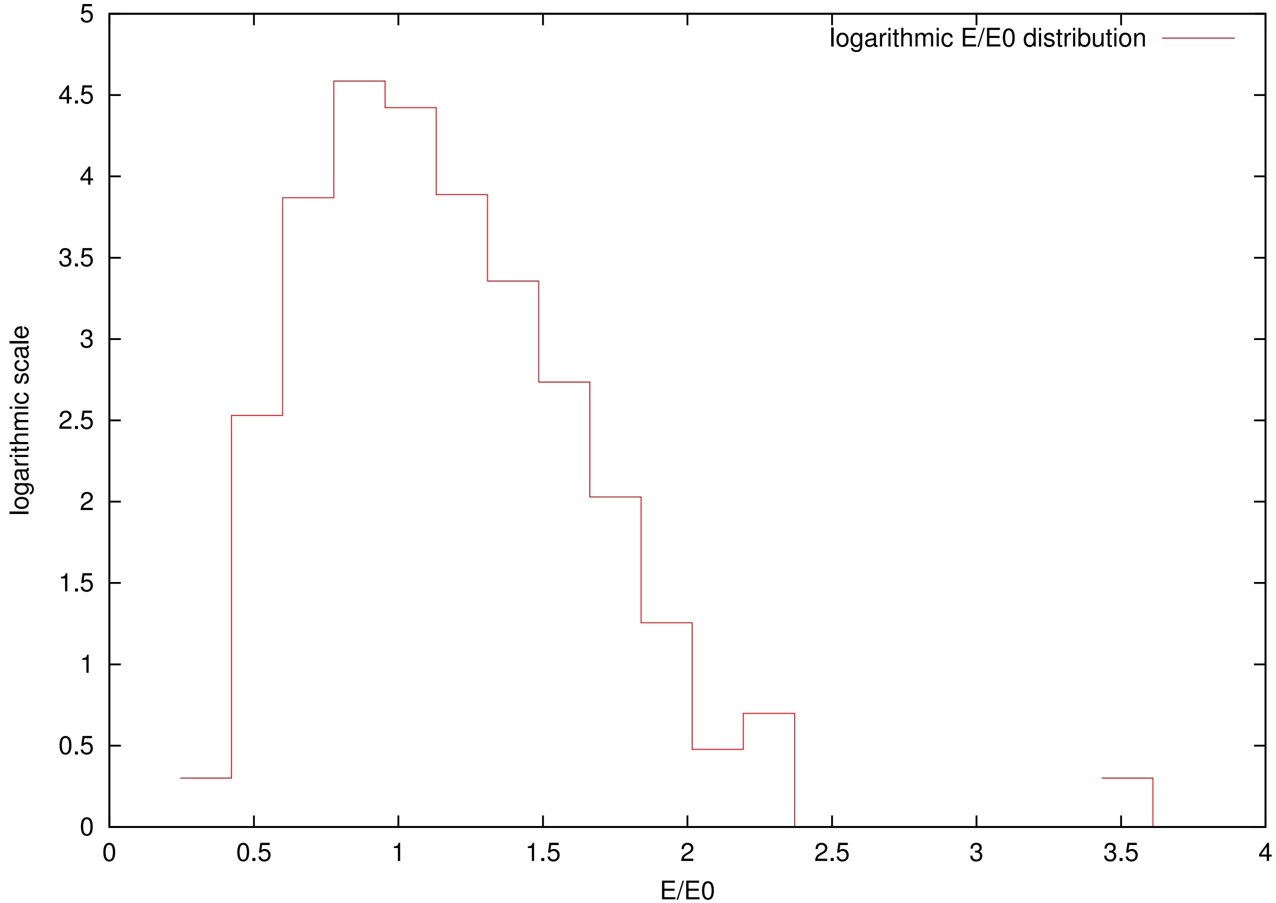

Fig. 2: E/E0 distribution ($E_0 = 10^{18}\ eV$, 83525 energy estimation acts)

Energy estimation fluctuations, shower 2

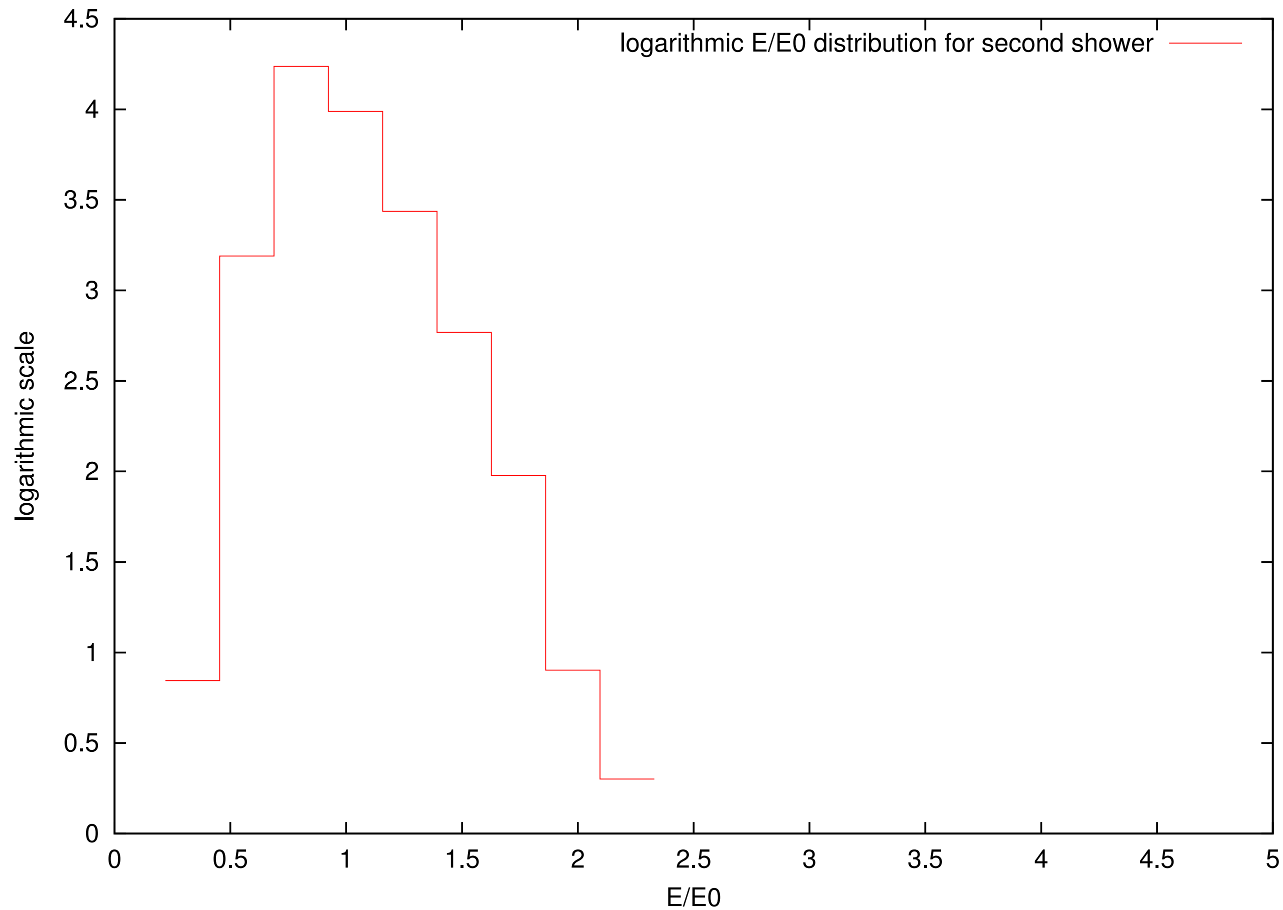

Fig. 3: E/E0 distribution ($E_0 = 10^{18}\ eV$, 31996 energy estimation acts)

Small-scale fluctuations - Results

- Small-scale fluctuations may lead to non-Gaussian error in energy estimation
- The error is not large enough to have an effect on overall energy spectrum

Possible photonic primaries

- Energies of events at AGASA and YAKUTSK experiments were estimated in assumption of hadronic primaries.
- Muon content can be used to set a constraint on the fraction of photon-induced events

Method

- Let's assume that primary particles are photons. For each published AGASA and Yakutsk event with $E > 10^{20}\ eV$ we estimate the energy of primary gamma ray, consistent with observed S_{600}.
- For this purpose we generate photon-induced showers within broad range of energies with arrival direction corresponding to particular event. Then we select only showers, giving S_{600} value consistent with experiment.
- For the set of selected showers we caclulate distribution of primary energy and muon density $\rho_\mu(1000)$.

Simulation

- Simulations are preformed with CORSIKA v6201 with QGSJET01c and PRESHOWER code.
- EGS4 model is used for elecromagnetic interactions
- Thining level is $2 \cdot 10^{-6}$
- Electrons are tracked down to $7MeV$, gammas — to $0.5MeV$.

Example: an AGASA event

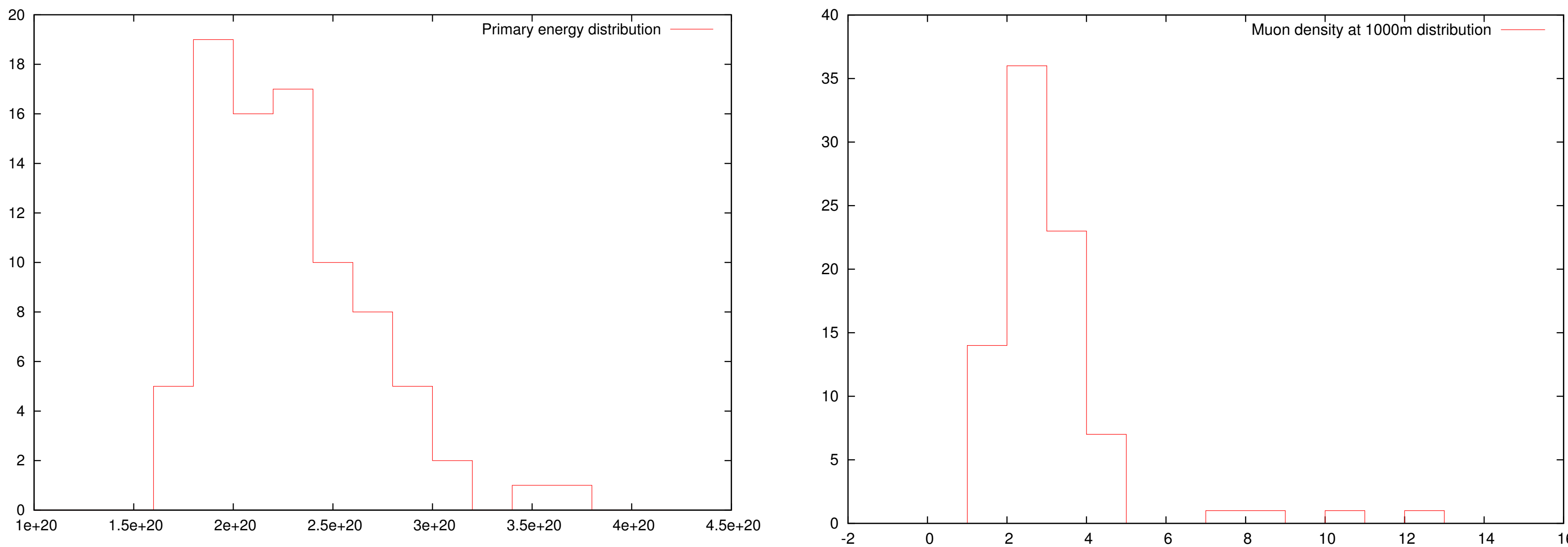

Fig. 4: Energy and $\rho_\mu(1000)$ distribution for primary photons simulated for AGASA event ($E_{AGASA} = 2.13 \cdot 10^{20} eV$)

AGASA events

N	$E/10^{20}$	θ	ϕ	ρ^{μ}_{1000}	$H_{\perp}$	E_{γ}	$\rho^{\mu}_{\gamma\ 1000}$	Prob(γ)
1	2.46	36.5	79.2	8.9	0.367	1.70	3.1	0.11
2	2.13	22.9	55.5	10.7	0.278	2.28	3.1	0.097
3	1.5	44.2	23.0	8.7	0.177	1.17	1.03	0.031
4	1.34	35.1	2.35	5.9	0.423	0.99	1.63	0.075
5	1.05	33.7	292	12.6	0.285	0.83	1.37	0.028
6	1.04	35.6	100	9.3	0.408	0.78	1.37	0.034
7	1.01	39.9	72.1		0.357	0.71		
8	1.44	14.2	27.5		0.242	1.89		
9	1.2	27.2	34.2		0.216	1.34		
10	1.22	23.4	260		0.347	1.22		
11	1.21	22.2	79.4		0.332	1.26		

Table 1: Table of highest energy AGASA events.

Yakutsk events, preliminary

N	$E/10^{20}$	θ	ϕ	ρ^{μ}_{1000}	$H_{\perp}$	E_{γ}	$\rho^{\mu}_{\gamma\ 1000}$	Prob(γ)
1	1.44	48	180	20.3	0.53	1.57	2.03	0.025
2	1.38	60	230	11.9	0.551	5.84	7.77	0.64
3	1.02	46	16	7.9	0.335	0.87	1.06	0.036

Table 2: Table of highest energy Yakutsk events.

Constraint on γ fraction, preliminary

Preliminary constraint on gamma fraction for ultra high energy cosmic rays($E > 10^{20}$) using AGASA and Yakutsk data:

$\gamma/N < 0.53$ (95 % C.L.)

Reconstructed AGASA spectrum

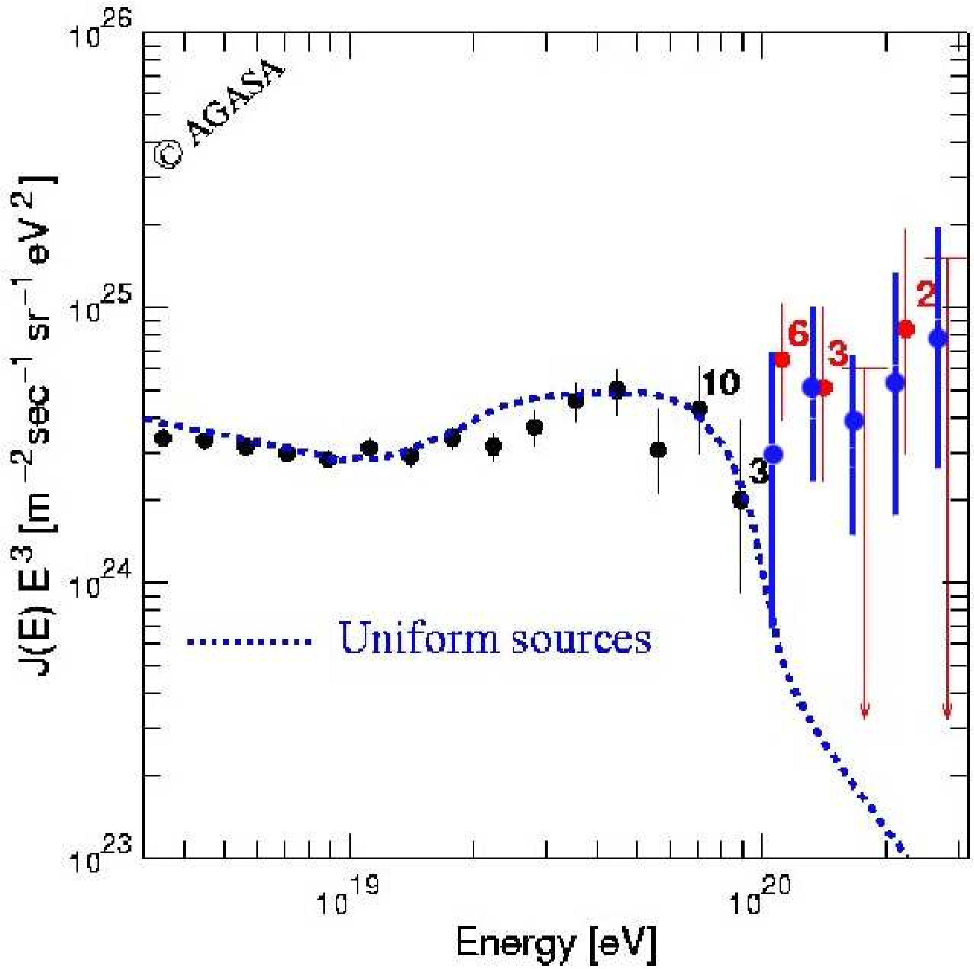

Fig. 5: AGASA spectrum in the assumption of photonic primaries

Conclusions

- Small-scale fluctuations lead to small, but non-Gaussian error in energy estimation
- The AGASA spectrum doesn't change significantly in the assumption of primary photons.
- The muon content data may give a constraint on the fraction of primary ultra-high-energy photons