Small-scale structure of extensive air showers.[a]

Grigory I. Rubtsov

Institute for Nuclear Research of the Russian Academy of Sciences

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[a] work done with D. S. Gorbunov, V. A. Kuzmin and S. V. Troitsky

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Talk structure

The goal before us is to understand complexity
Albert-Laszlo Barabasi

I. Fluctuation study

- Scale dependence
- $S(600)$ and $\rho_\mu(1000)$ fluctuations

II. Public library of artificial air showers

- Library anouncement
- Possible applications

Conclusions

Fluctuation scale

- Only small fraction **($< 10^{-6}$)** of shower particles is detected by a ground array.
- Small scale fluctuation at the detector level possibly are large and can lead to **systematic errors** in energy estimation.
- Typical vertical 10^{20} eV shower contains about **20 billions** particles at the ground level: $\sim 90\%$ γ, $\sim 9\%$ e, $\sim 1\%$ μ, $\sim 3 \cdot 10^{-4}$ $hadrons$.
- Because of the huge number of particles, Monte-Carlo simulations are usually performed with some kind of **THINING**, reducing effective number of particles in calculation and **washing out small-scale fluctuations**

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Simulation

- To study the fluctuations we have simulated several **vertical** proton-induced extensive air showers with $E = 10^{18}\ eV$.
- The simulations were performed by **CORSIKA v6.2** and **CORSIKA v6.5** with QGSJET01 and QGSJET II, GHEISHA and EGS4 **without THINING**.
- The ground detector array is assumed to consist of 100 **scintillators** $(1.6m\ \times 1.6m)$ covering the area of $50km^2$.
- The $S(600)$ and $\rho_\mu(1000)$ of each shower was estimated many times with **different core locations** in the detector area.

Single detector study

- At core distance of 600 meters, an average particle density in vertical 10^{18} eV shower is 63 photons, 4 electrons and 2 muons per square meter.
- As shown by Teshima et al.[a], the magnitude of fluctuations on one detector σ^2 is nearly **proportional** to the expected average **detector response**.

[a] Teshima et al., J. Phys. G **12**, 1097 (1986).

Single plastic scintillator

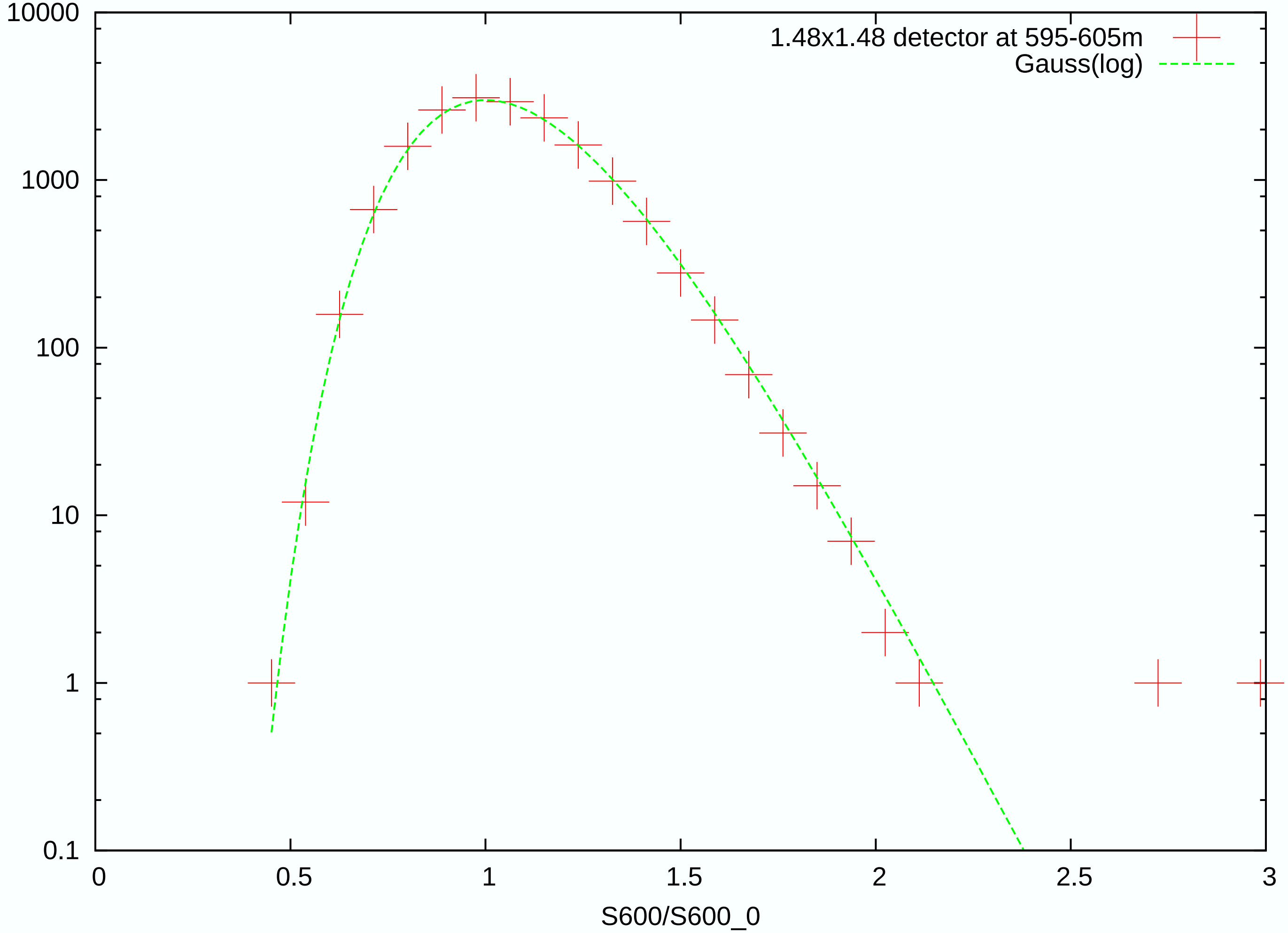

Fig. 1: 1.48x1.48m detector at [595;605m]

Single plastic scintillator 2x

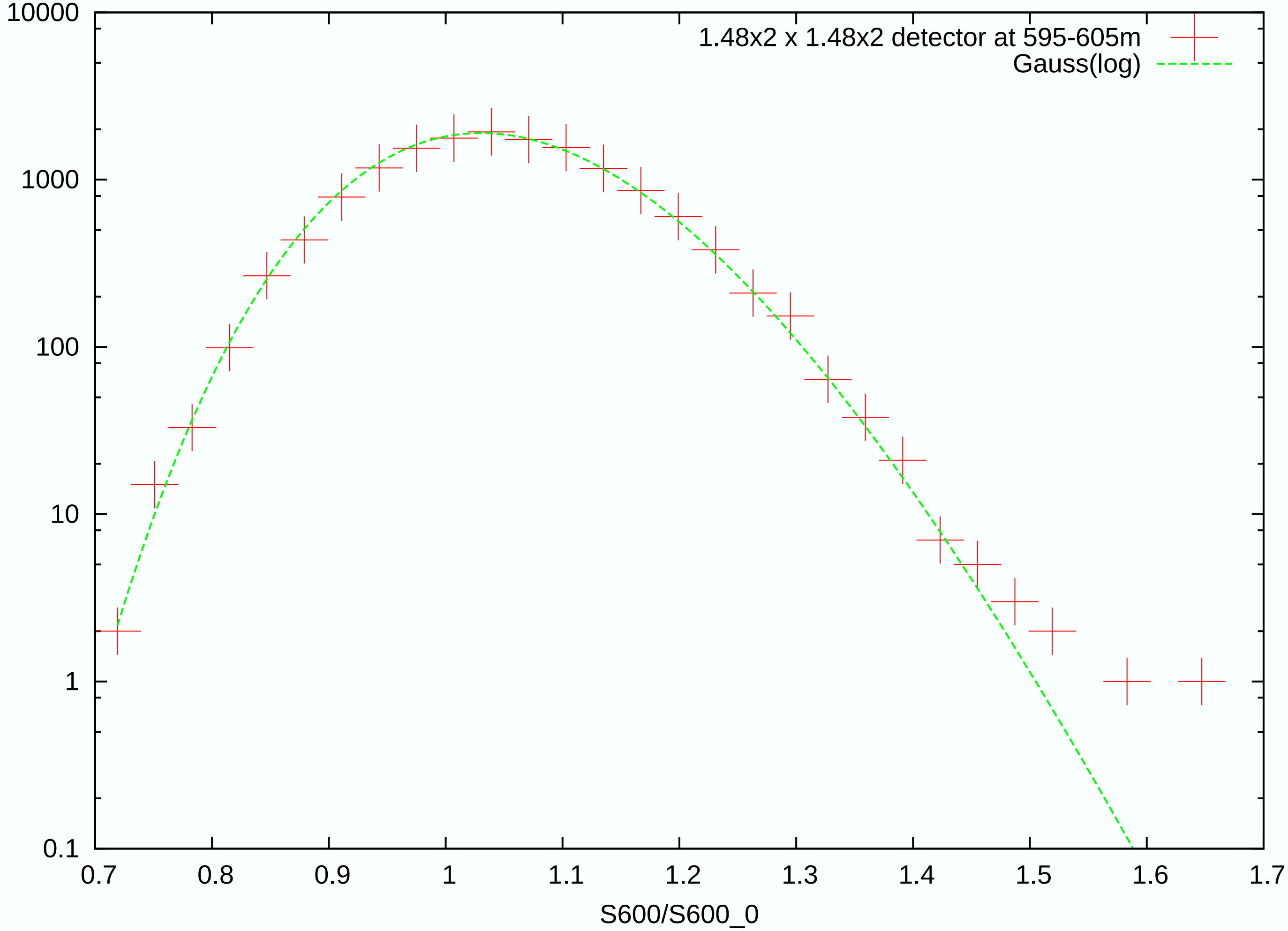

Fig. 2: 2.96x2.96m detector at [595;605m]

Single plastic scintillator 4x

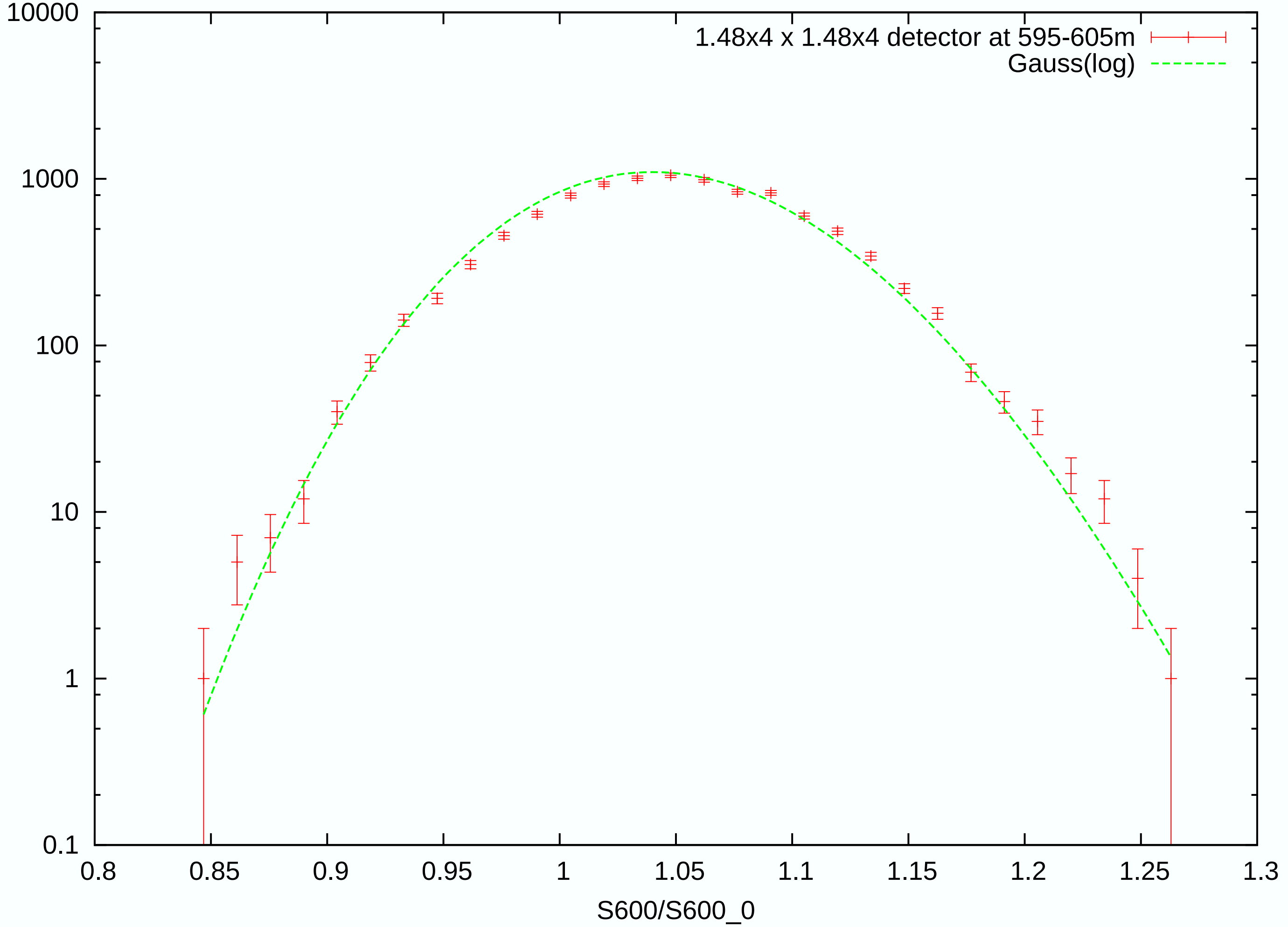

Fig. 3: 5.92x5.92m detector at [595;605m]

Single muon detector

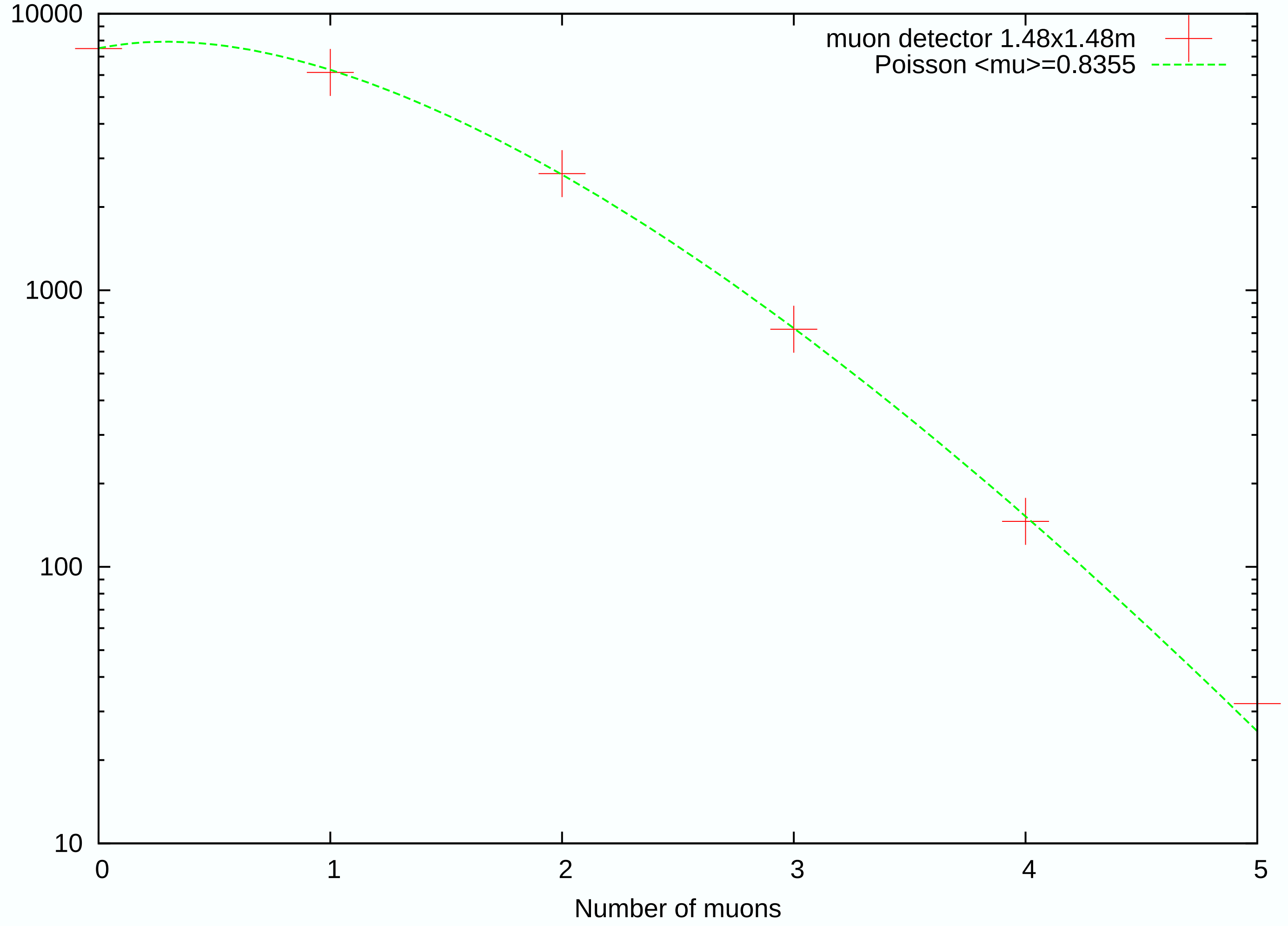

Fig. 3: 1.48x1.48m detector at [595;605m]

Single muon detector 4x

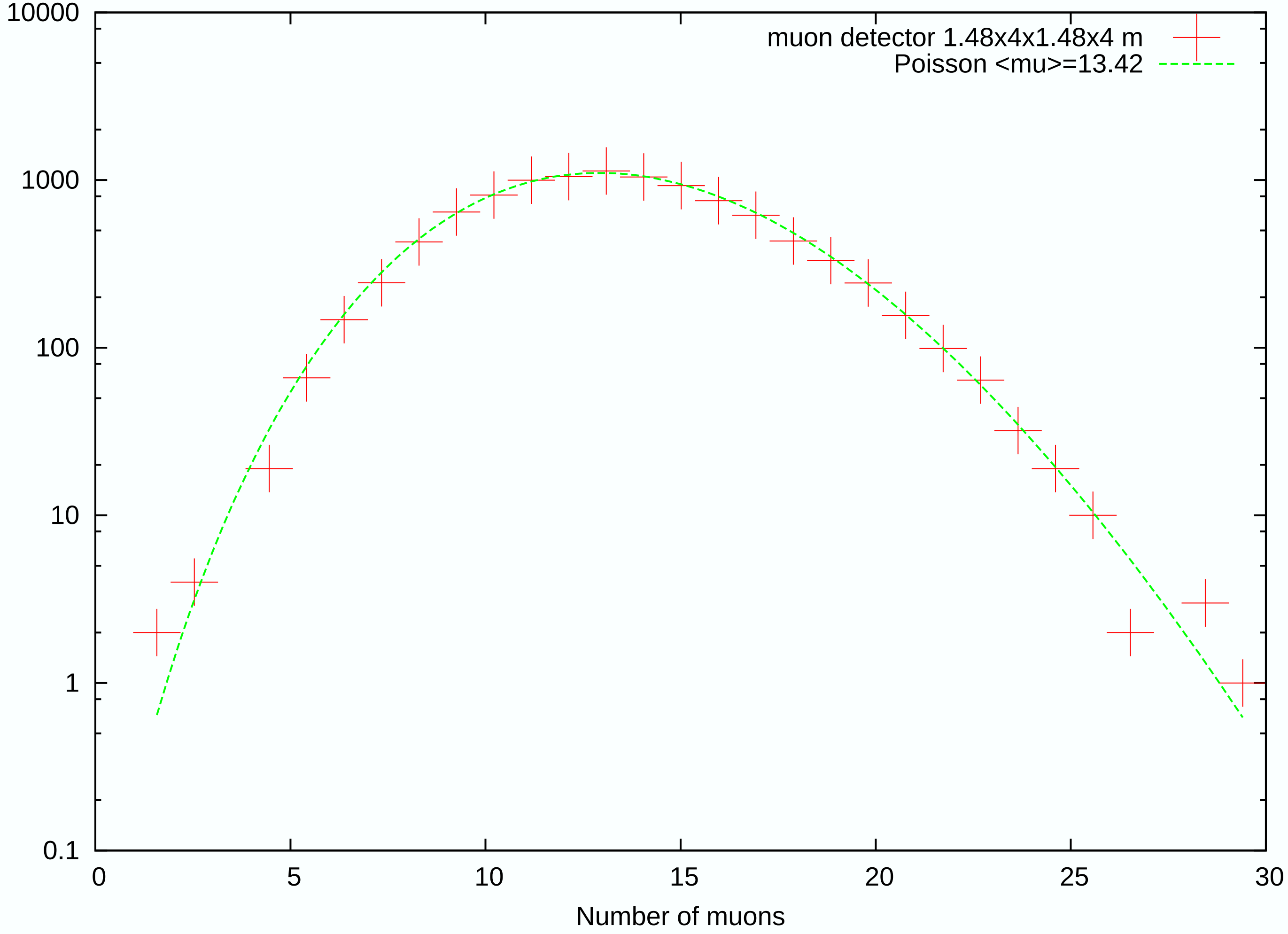

Fig. 5: 5.92x5.92m detector at [595;605m]

Single muon detector 10x

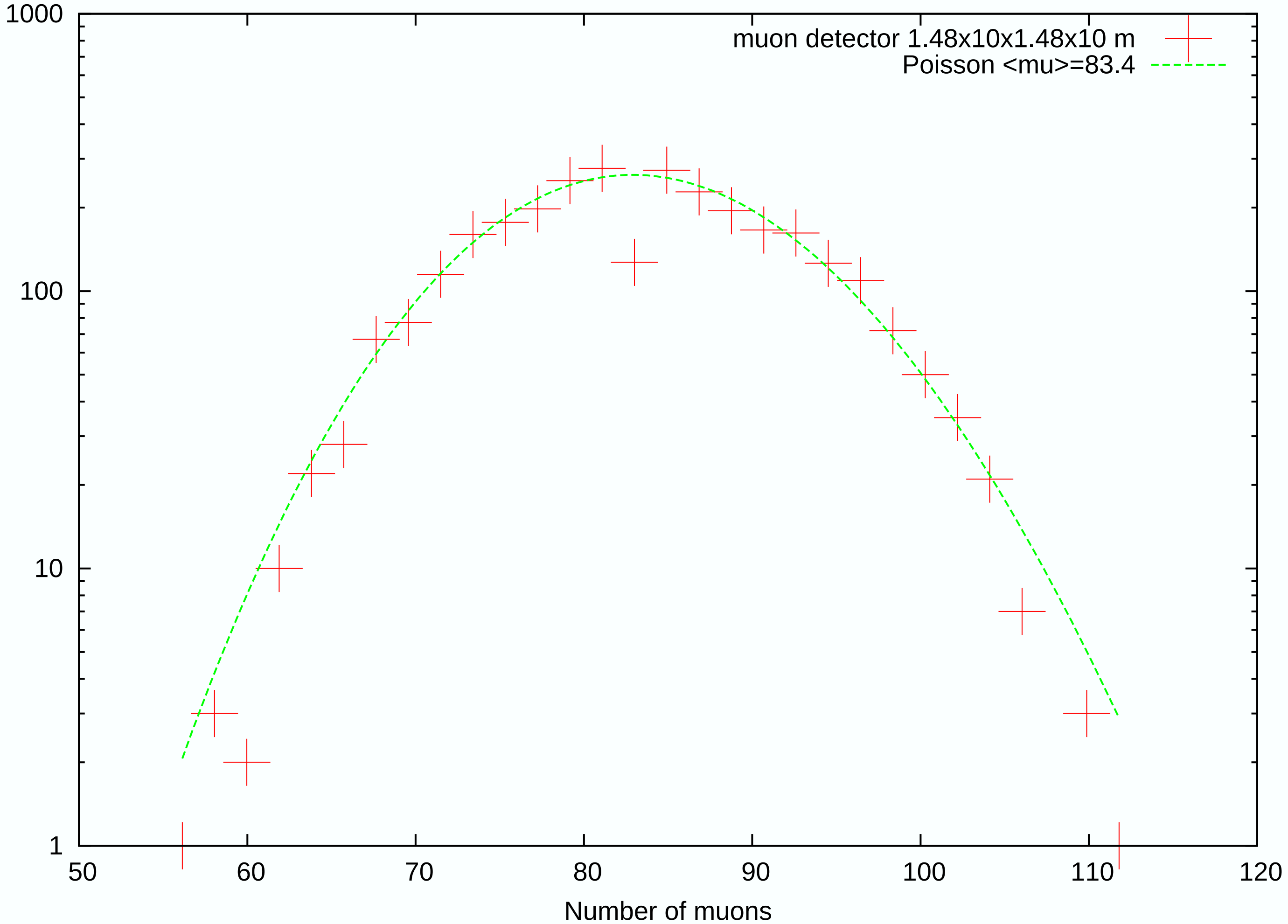

Fig. 6: 14.8x14.8m detector at [595;605m]

Core distance dependence

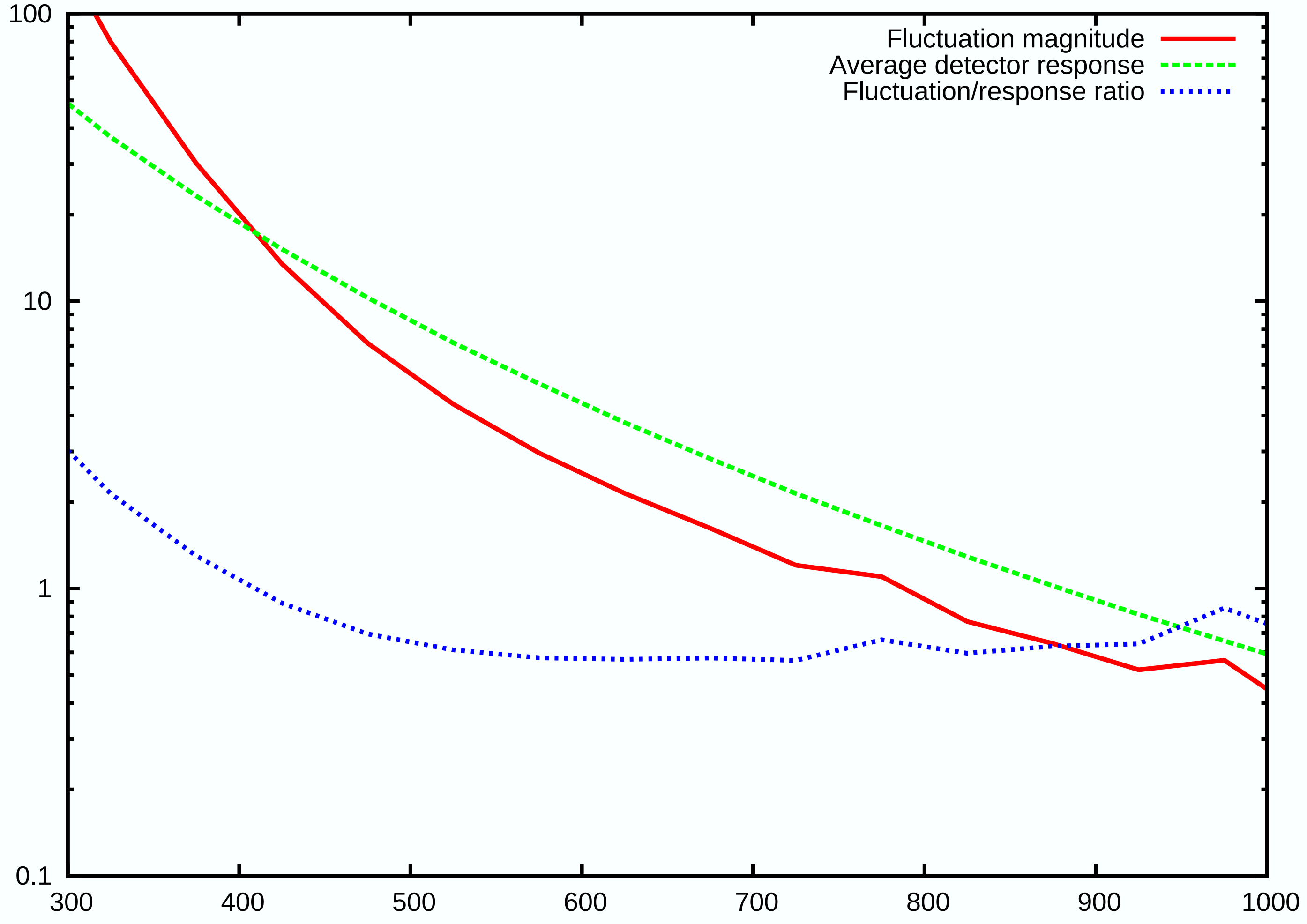

Fig. 7: Core distance dependence of σ^2

S(600) estimation

- The readings of detectors at core distance from 300 to 1500 meters were **fit by empirical profile** used by AGASA experiment.
- To ensure fit **quality** we followed the procedure, proposed by AGASA: if $\chi^2/N > 1.5$, the worst detector is excluded.
- The procedure is repeated continuously and allows to exclude large deviations, cause by one detector with large fluctuation.
- One detector was excluded in 14% cases, two detectors — in 2% cases, three or more — in 0.4% cases.

S(600) fluctuations

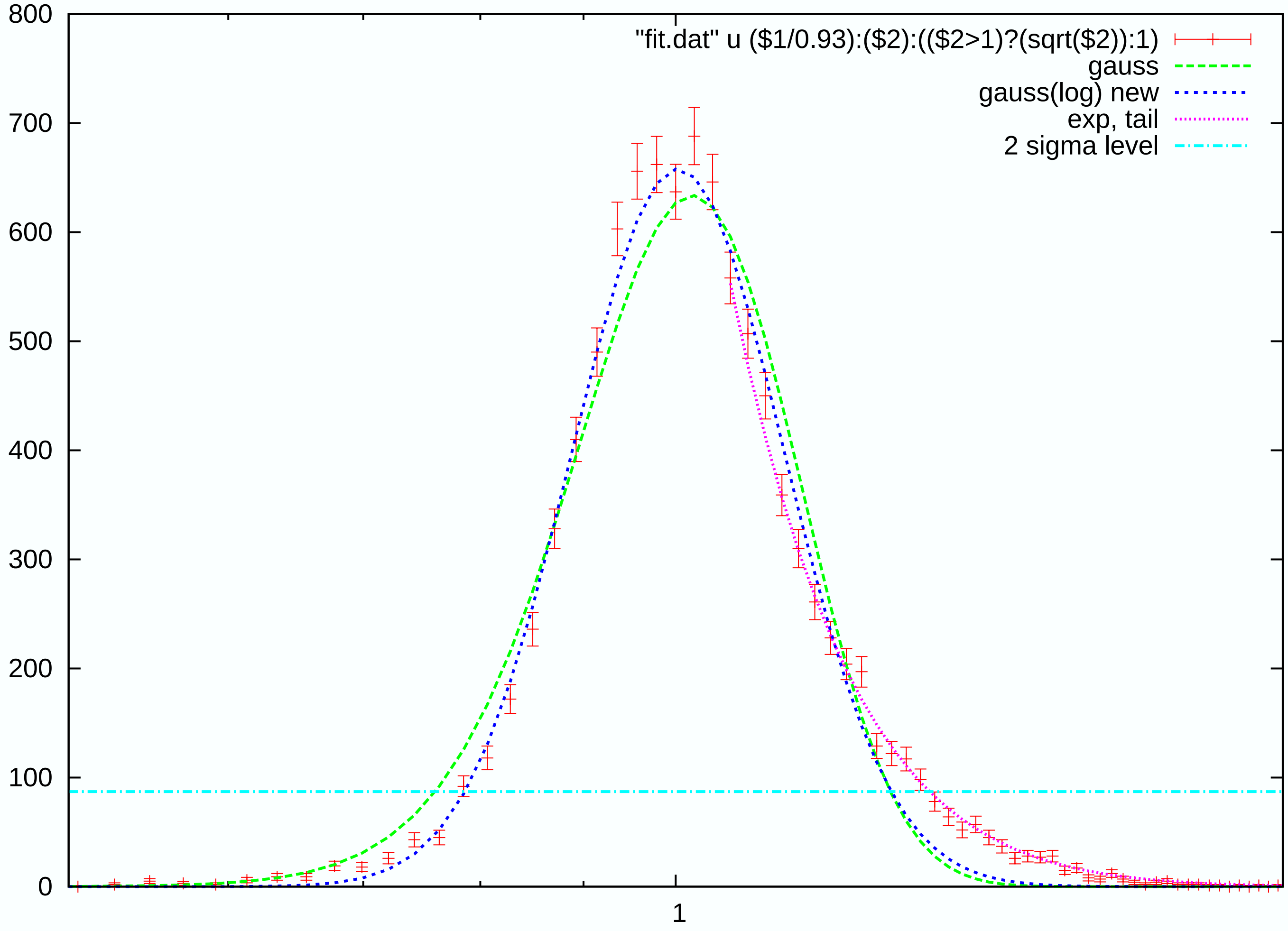

Fig. 8: $S(600)/S(600)_0$

$\rho_\mu(1000)$ fluctuations

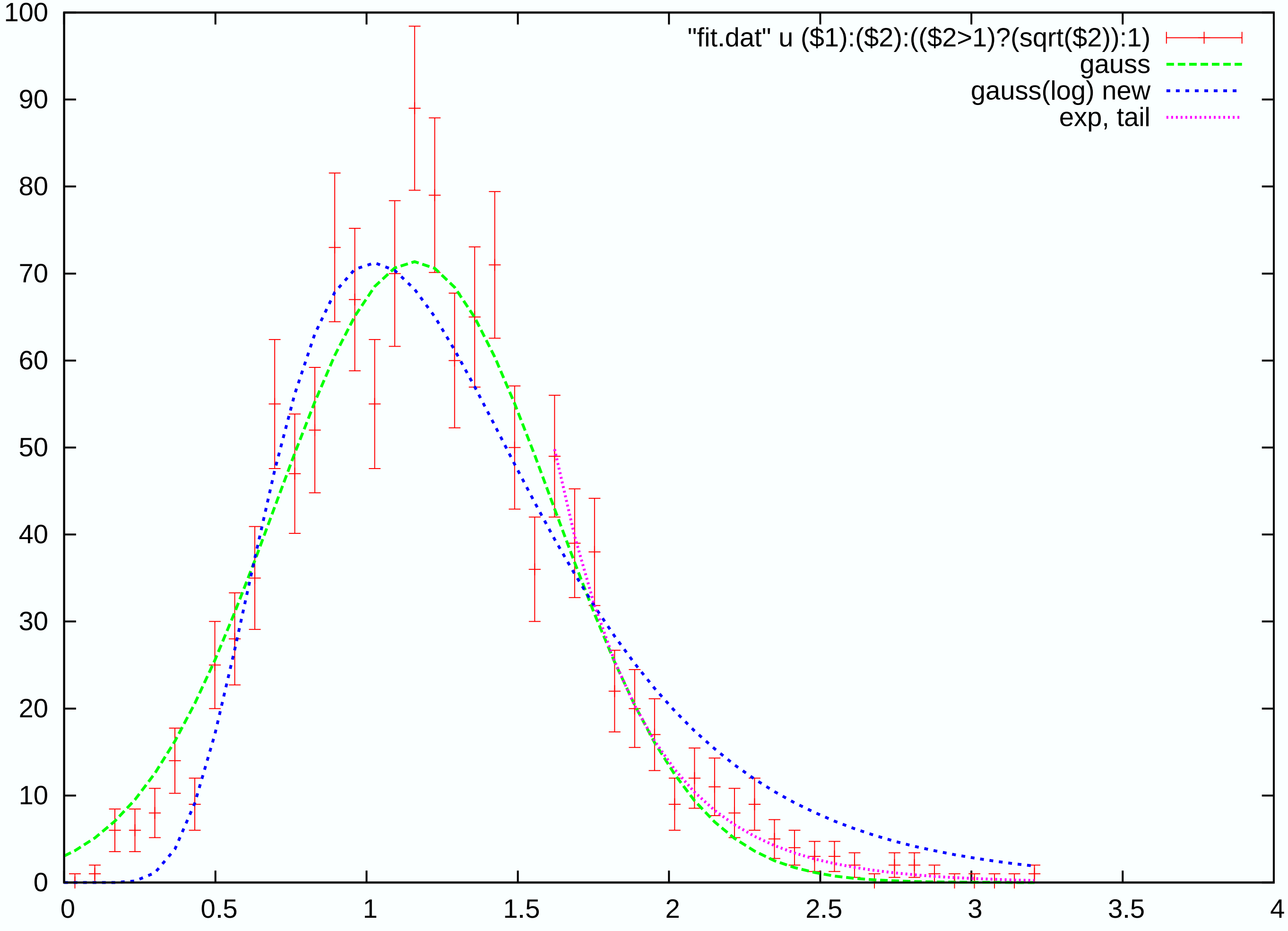

Fig. 9: $\rho_\mu(1000)/\rho_\mu(1000)_0$

II. Public library anouncement

Livni - the public database of artificial extensive air showers

- Showers, generated by CORSIKA without thinning are now available to scientists and collaborations
- The library currently contain 13 showers, with primary energies 10^{17}—10^{18} eV, different zenith angles and interaction models
- QGSJET, QGSJET II, GHEISHA and EGS4 models are currently used for simulation of library showers, more to come

Current status of Livni

$E_{primary}$	Type	θ	CORSIKA, QGSJET	Size,Gb	Cuts(h,μ,e,γ)
10^{17}	p	0	6.2001, I	4.4	0.3 0.3 0.003 0.003
10^{17}	p	0	6.0311, I	7	0.3 0.3 0.003 0.003
10^{17}	p	30	6.2001, I	1.5	0.3 0.3 0.003 0.003
10^{17}	p	45	6.2001, I	0.25	0.3 0.3 0.003 0.003
10^{17}	p	45	6.2001, I	0.35	0.3 0.3 0.003 0.003
10^{17}	γ	30	6.2001, I	5.9	0.3 0.3 0.003 0.003
$3.2 \cdot 10^{17}$	p	0	6.2001, I	17	0.3 0.3 0.003 0.003
$3.2 \cdot 10^{17}$	p	45	6.2001, I	2.2	0.3 0.3 0.003 0.003
10^{18}	p	0	6.0311, I	67	0.3 0.3 0.003 0.003
10^{18}	p	0	6.2001, I	62	0.3 0.3 0.003 0.003
10^{18}	p	0	6.2041, I	98	0.3 0.05 0.0005 0.0005
10^{18}	p	0	6.5001, II	109	0.3 0.05 0.0005 0.0005
10^{18}	p	45	6.2001, I	14	0.3 0.3 0.003 0.003

Livni: Possible applications

- Estimate experimental uncertanties for specific ground detectors
- Test new experimental techniques
- Analyse shower structure
- Crash-test thinning and “unthinning” procedures
- Base for an open discussion on the topic

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We are open for collaboration

Livni: Accessing the library

- Shell access is provided to library server with a read access to datafiles
- Shell access may be used to run custom readout scripts
- Example readout script is provided in C++. Fortran script is available in a CORSIKA package

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Registration is open on the Workshop!

Conclusions

- Fundamental scale of fluctuations is smaller than 1 meter
- Small-scale fluctuations lead to **log-Gaussian** error in $S(600)$ and to Gaussian error in $\rho_\mu(1000)$. The difference may be important for Auger comparison with AGASA or TA
- There is an exponential tale in the $S(600)$ estimation error.

Conclusions

- Fundamental scale of fluctuations is smaller than 1 meter
- Small-scale fluctuations lead to **log-Gaussian** error in $S(600)$ and to Gaussian error in $\rho_\mu(1000)$. The difference may be important for Auger comparison with AGASA or TA
- There is an exponential tale in the $S(600)$ estimation error.
- Enjoy the shower library!