Karlsruhe Institute of Technology

PIERRE AUGER OBSERVATORY

Analysis of the lateral distribution of air showers at Augers SD-array

SAT - Obertrubach-Bärnfels, 03.-11. Okt. 2018

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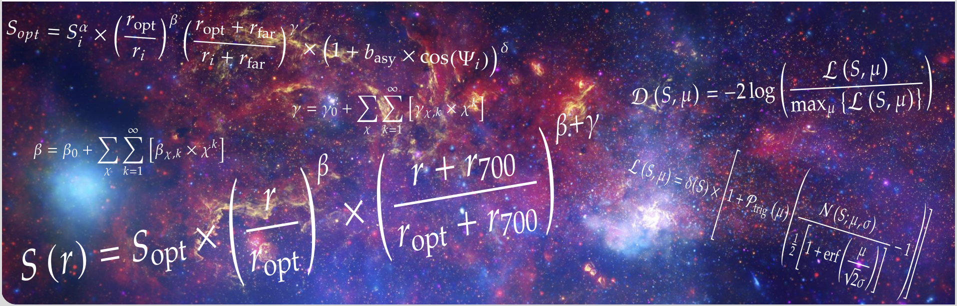
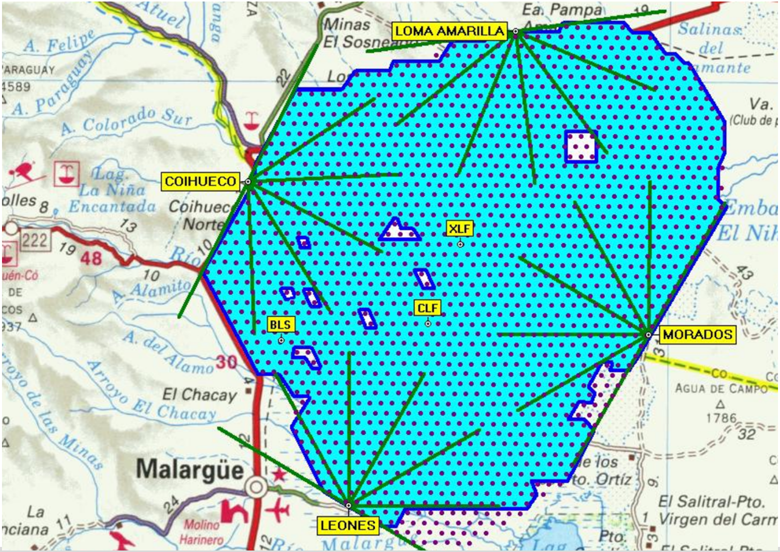
INSTITUTE FOR NUCLEAR PHYSICS



About the Pierre Auger Observatory

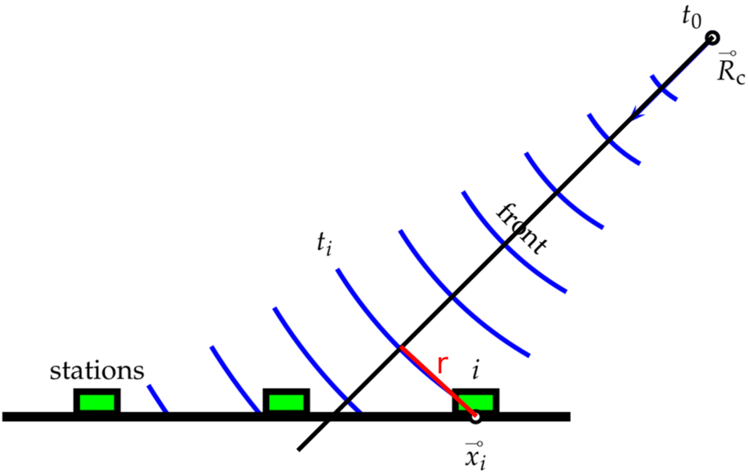
- area of 3000km^2 near the city of Malargüe in Mendoza Province
- hybrid detector of over 1600 water cherenkov detectors, 24 fluorescence telescopes + 150 radio antennas & Upgrades

Map of the Detector Site



Pictures of SD-tanks

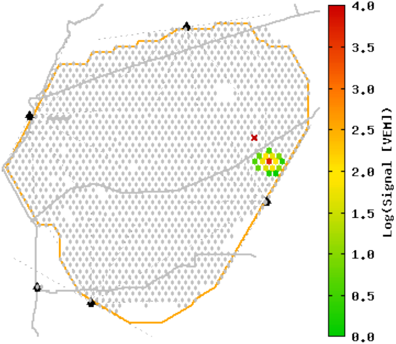
What's the Setting?

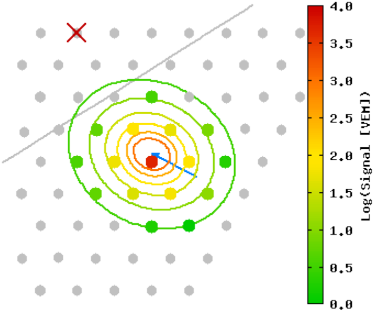


Auger Data

properties

- ID: 32112000 (26.03.2015) • $E = 38.8 \pm 2.0$EeV • $\theta = 34.5 \pm 0.2$deg





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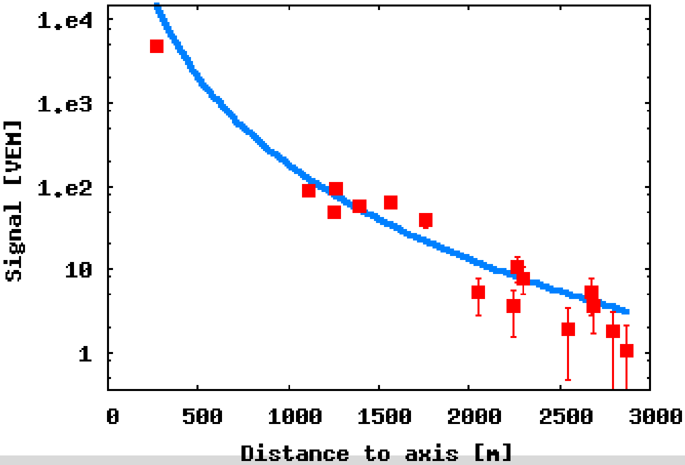


My Work

1. implemented state of reconstruction

2. goals of my analysis

3. preliminary results

Implemented LDF

describes the **lateral distribution of signal** S

$$S(r) = S_{\text{opt}} \times \left(\frac{r}{r_{\text{opt}}}\right)^{\beta} \times \left(\frac{r + r_{700}}{r_{\text{opt}} + r_{700}}\right)^{\beta+\gamma} \tag{1}$$

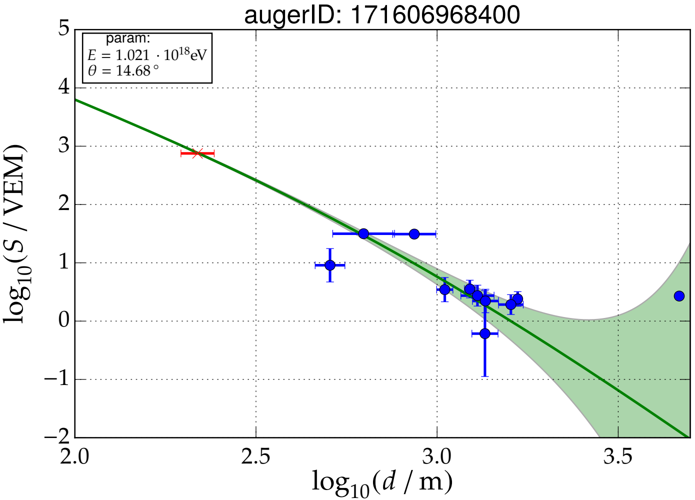
and uncertainty

$$\sigma_S(\theta) = \underbrace{\left[0.32 + 0.42\sec(\theta)\right]}_{f_s(\theta)} \times \sqrt{S} \tag{2}$$

energy estimator

$$E \propto S \tag{3}$$

Plot of the LDF in log-log-scale



Overfitted Slope Parameters

$$\beta = (-3.720 + 0.0967s) + (+1.740 - 0.2420s) \times \sec(\theta) + (-0.274 + 0.0349s) \times \sec^2(\theta) \quad (4)$$

and

$$\gamma = (-1.870 - 0.1830s) + (+0.490 - 0.0650s) \times \frac{1}{a+1} - 0.272(\cos(\theta))^{4.64} \times \frac{1}{\exp[18.01(s-1.95)] + 1} \quad (5)$$

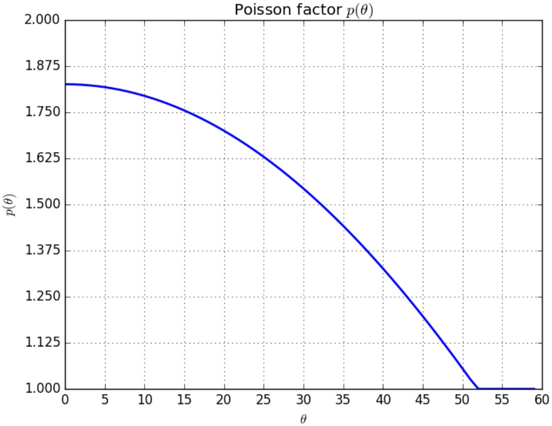
with

$$a = \exp\left[(19.6 - 2.10s) \times (\cos^2(\theta) - (0.483 + 0.005s))\right] \quad (6)$$

Particle ↔ Signal

Signals S dependence on number of particles n via *Poisson factor* p :

$$S = p \times n \tag{7}$$



Maximum Likelihood Function $\mathcal{L}$

Likelihood of LDF-expectation μ_i against effective number of particles n_i per tank i:

$$\mathcal{L} = \prod_i \left[f_{\text{Zero}} \times f_{\text{Poi}} \times f_{\text{Std}} \times f_{\text{Sat}}\right](n_i, \mu_i) \quad (8)$$

with

$$\text{Zero Signal} \quad : \quad f_{\text{Zero}} = \sum_{n=0}^{n_{\text{th}}} f_{\text{Poi}}(n, \mu_i) \quad (9)$$

$$\text{small Signal} \quad : \quad f_{\text{Poi}} = \frac{\mu_i^{n_i} e^{-\mu_i}}{n_i!} \quad (10)$$

$$\text{large Signal} \quad : \quad f_{\text{Std}} = \frac{1}{\sqrt{2\pi}\sigma_i} \exp\left(-\frac{(n_i - \mu_i)^2}{2\sigma^2}\right) \quad (11)$$

$$\text{Saturated Stations} \quad : \quad f_{\text{Sat}} = \int_{n_i}^{\infty} f_{\text{Std}}(n, \mu_i)\, dn \quad (12)$$

Goals of my Analysis

renew

- inspect new LDF parameterizations
- renew likelihood $\mathcal{L}_{\text{new}}$

introduce

- trigger probabilty $\mathcal{P}_{\text{trig}}\,(\mu)$
- azimuth Ψ_i asymmetry

What's the Asymmetry?

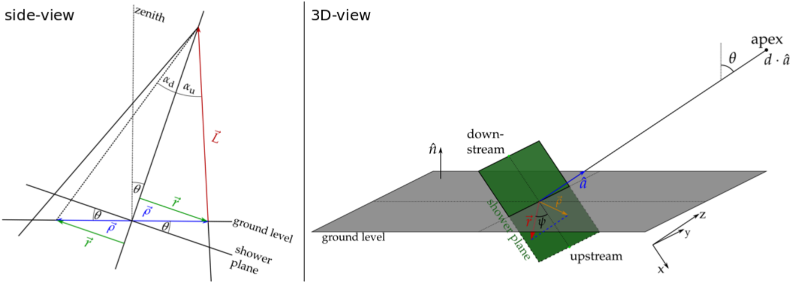


Figure: from: *"Asymmetries of the Lateral Distribution of Particles on the Ground"*, by L.Armbruster, BachelorThesis June 2018, IKP at KIT

New LDF-ansatz

NKG-type LDF:

$$S_i = S_{\text{opt}} \times \left(\frac{r_i}{r_{\text{opt}}}\right)^{\beta} \left(\frac{r_i + r_{\text{far}}}{r_{\text{opt}} + r_{\text{far}}}\right)^{\gamma} \times (1 + b \tan(\theta) \cos(\Psi)) \tag{13}$$

new parameterizations

$$\beta = \beta_0 + \sum_{\chi} \sum_{k=1}^{\infty} \left[\beta_{\chi,k} \times \chi^k\right], \quad \gamma = \gamma_0 + \sum_{\chi} \sum_{k=1}^{\infty} \left[\gamma_{\chi,k} \times \chi^k\right] \tag{14}$$

Normalized and simplified maximum likelihood function:

$$\mathcal{L}_{\text{new}}(S, \mu) = \overbrace{\delta(S) \times \left[1 - \mathcal{P}_{\text{trig}}(\mu)\right]}^{\text{zero}} + \overbrace{\mathcal{P}_{\text{trig}}(\mu)\, \mathcal{N}(S; \mu, \sigma)}^{\text{signal}} \tag{15}$$

Preliminary Results and New Approaches

results

- $\surd$ implement new NKG-type LDF
- X find new likelihood and compare deviances
- X introduce trigger probability
- X introduce asymmetry

new approaches

- test different likelihood with ToyMC
- compare different triggers & combined trigger probability
- define asymmetry parameter for different radii on real data
- ...