Reconstruction accuracy of the surface detector of the Pierre Auger Observatory

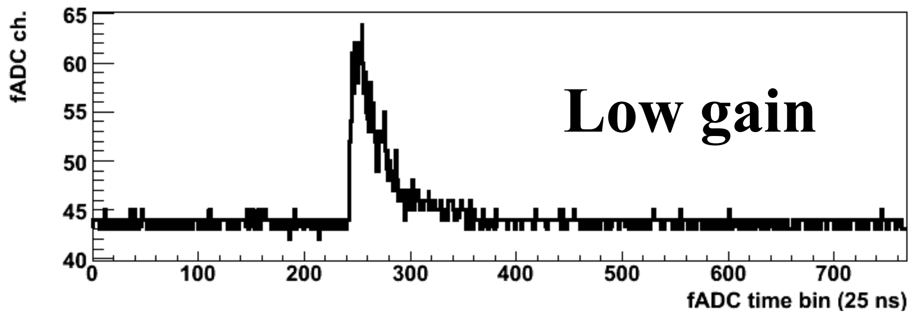
PIERRE AUGER OBSERVATORY

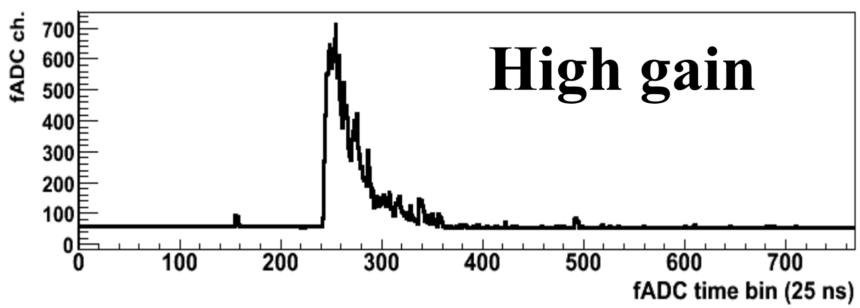
The Pierre Auger Collaboration
Simone Maldera

Auger Surface Detector

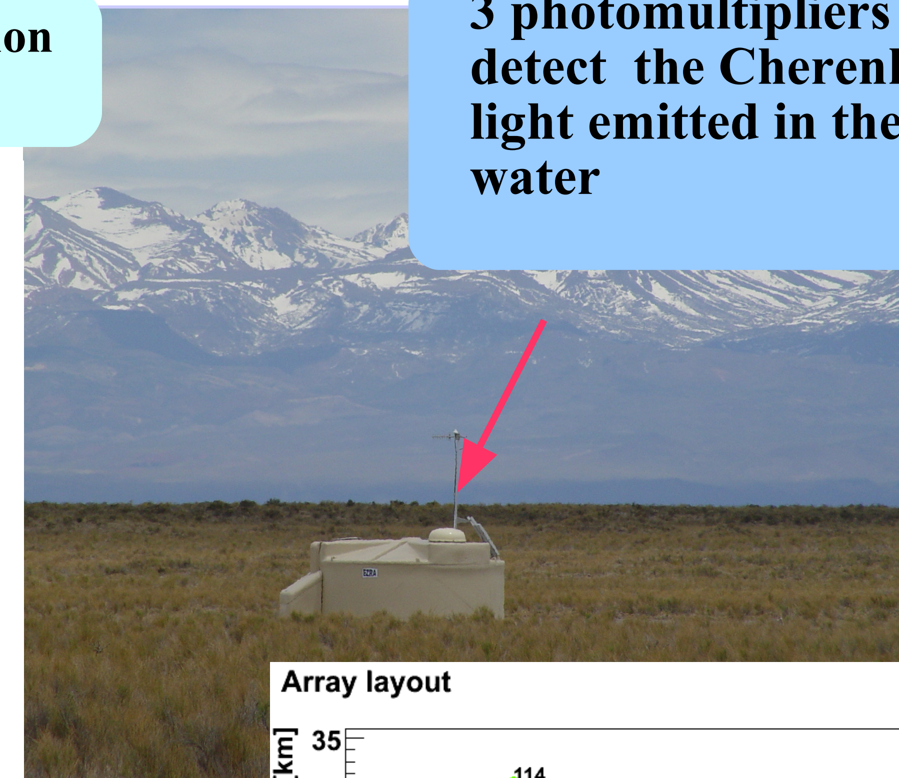
calibration: VEM = Vertical Equivalent Muon

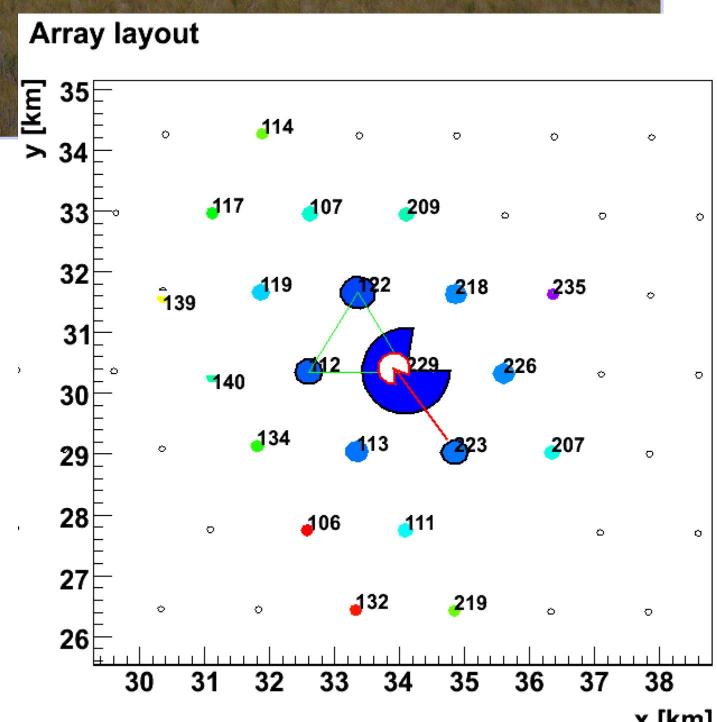
1 VEM ~ 100 pe/PMT





3 photomultipliers detect the Cherenkov light emitted in the water





Arrival direction : time of flight

Energy estimator : particle density at 1000 m : S(1000)

Angular Resolution

computed on an event by event basis

θ , Φ and σ_θ , σ_Φ

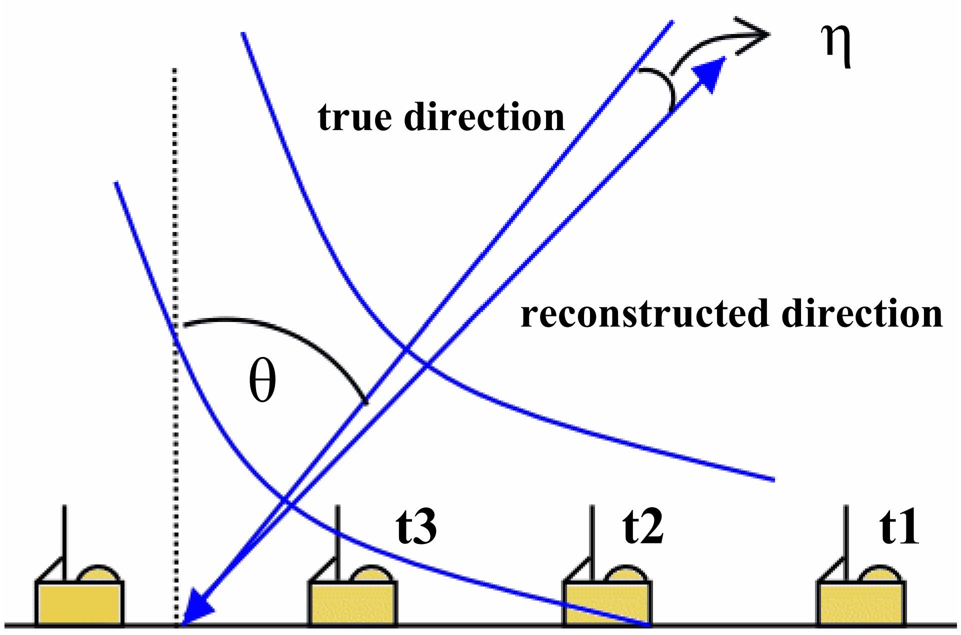
from fit of arrival time of the first particle in the tank.

based on:

◊ Parabolic shower front Model

◊ semi-empirical model for the uncertainty in the time measurement in each detector.

(C. Bonifazi, et al astro-ph 0705.1856)



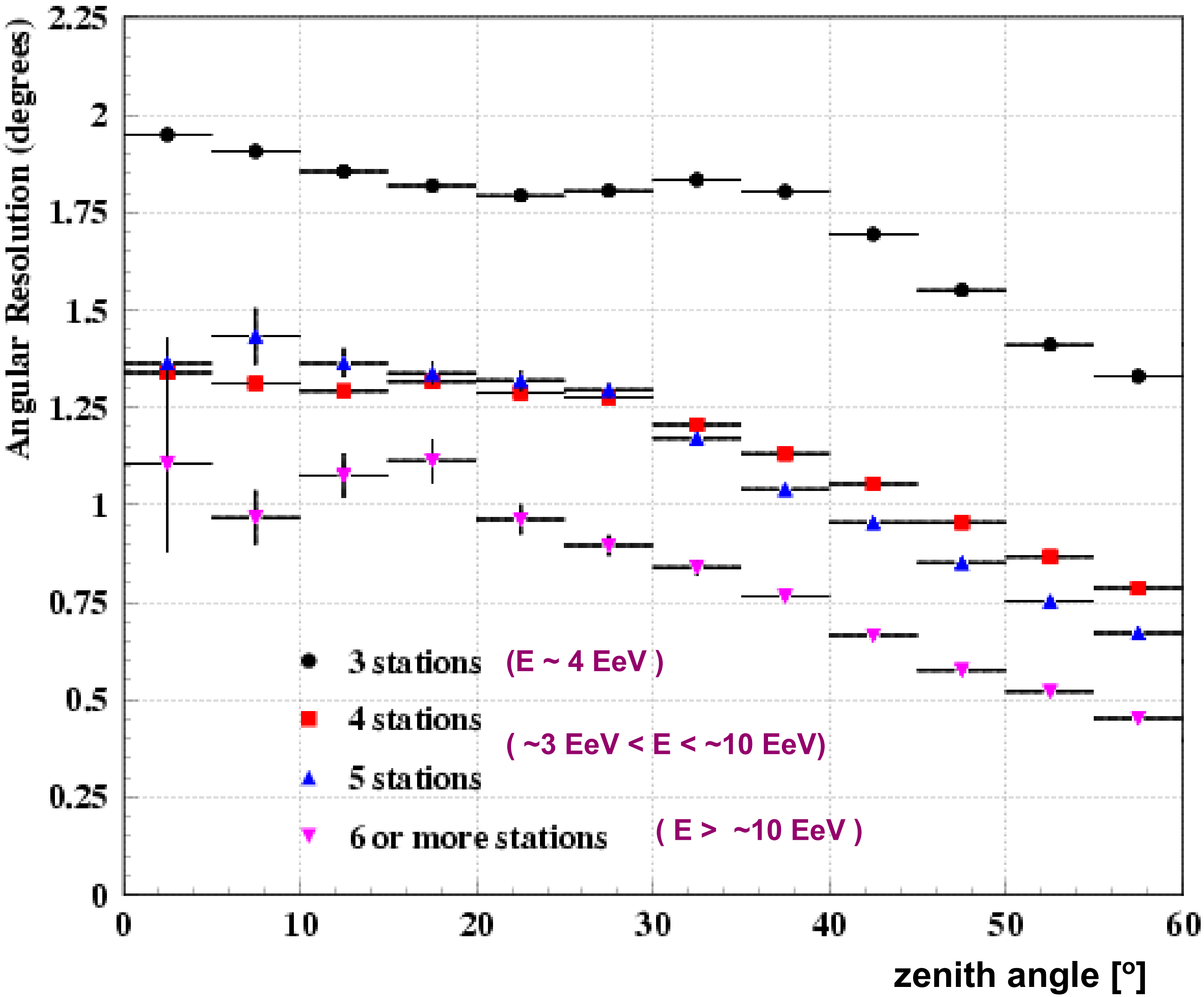
space-angle uncertainty computed from σ_θ and σ_Φ as:

$$F(\eta) = \frac{1}{2}[\sigma_\theta^2 + \sin^2(\theta)\sigma_\phi^2]$$

Angular Resolution: angular radius that would contain 68% of the showers coming from a point source.

$$AR = 1.5\sqrt{F(\eta)}$$

Angular resolution on an event by event basis

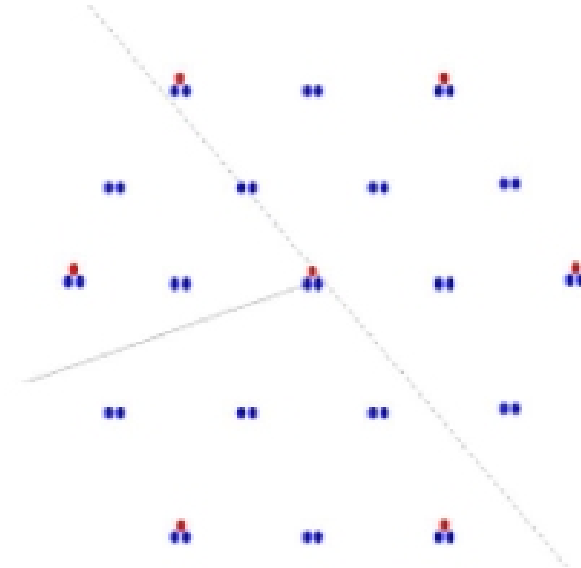


◊ improves with the event multiplicity and zenith angle

for events with 6 or more stations and θ>20º

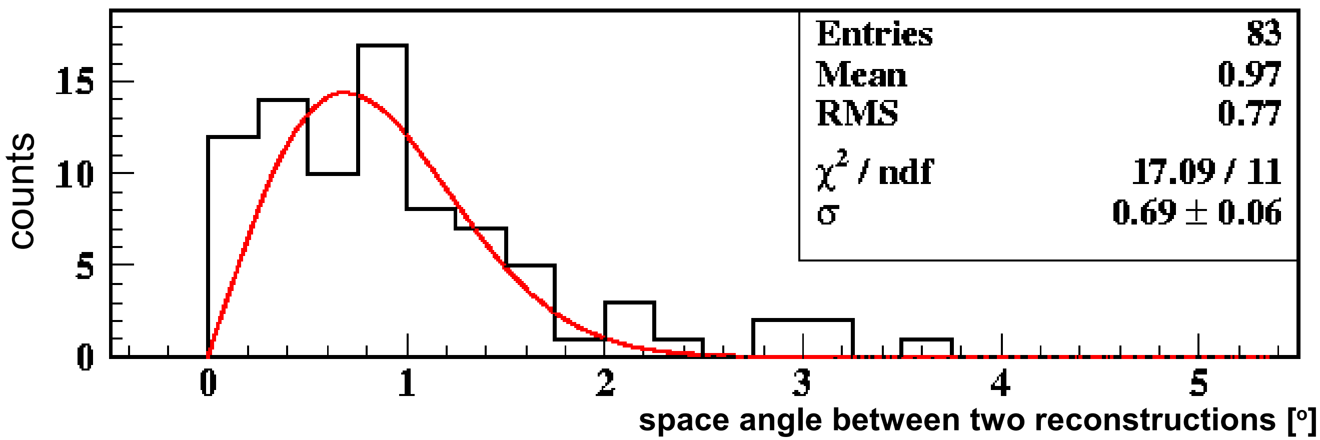
AR < 0.9º

check on Angular resolution (I): "twin" tanks



We reconstructed the same showers twice, each time using one of the pairs of stations located 11 m apart.

5 or more stations [0°< θ< 60°]



The space angle difference between the two reconstructions is distributed as:

$$dp = e^{-\frac{\eta^2}{2\sigma^2}} d\left(\cos(\eta)\right)$$

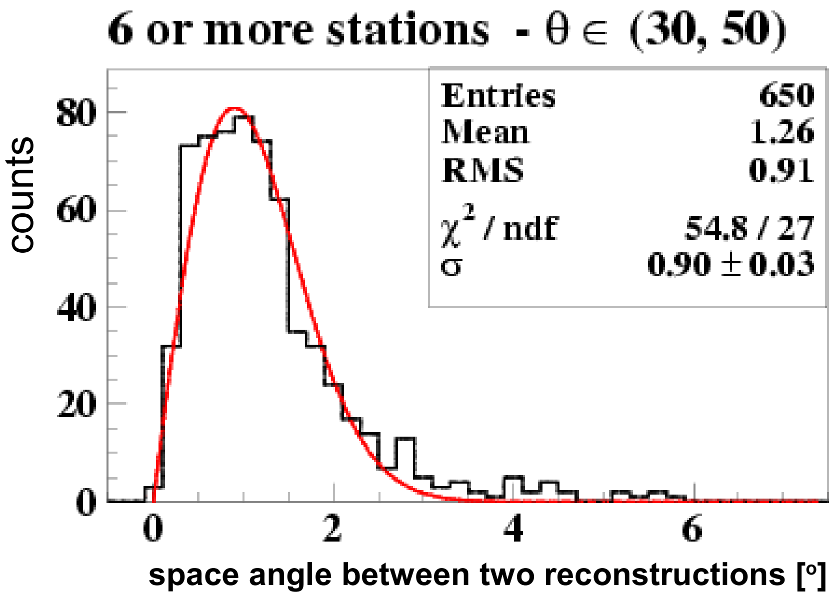
#	AR doublets [°] $1.5\frac{\sigma}{\sqrt{2}}$	AR SD-only [°]
3	1.14 ± 0.02	1.52 ± 0.02
4	0.87 ± 0.05	0.92 ± 0.03
5	0.73 ± 0.06	0.68 ± 0.04

The angular resolution obtained is in agreement with the event by event estimation

check on Angular resolution (II): Hybrid data

comparison between hybrid and SD only reconstruction

(Hybrid resolution ~0.9° (σ ~ 0.6°) subtracted in quadrature).



$$AR = 1.5\sqrt{\sigma^2 - 0.6^2}$$

#	AR_{hybr} [°]	$AR_{SD\text{-}only}$ [°]
3	1.71 ± 0.05	1.54 ± 0.01
4	1.49 ± 0.07	1.03 ± 0.01
5	1.3 ± 0.1	0.92 ± 0.02
6	1.0 ± 0.1	0.62 ± 0.01

Provides an absolute check on the reference system.

FD mirrors pointing checked with stars and reconstructed laser shots (< 0.3°)

S(1000) as energy estimator and its uncertainty

Building an energy estimator for a Ground Array

Sampled signals have to be used to estimate:

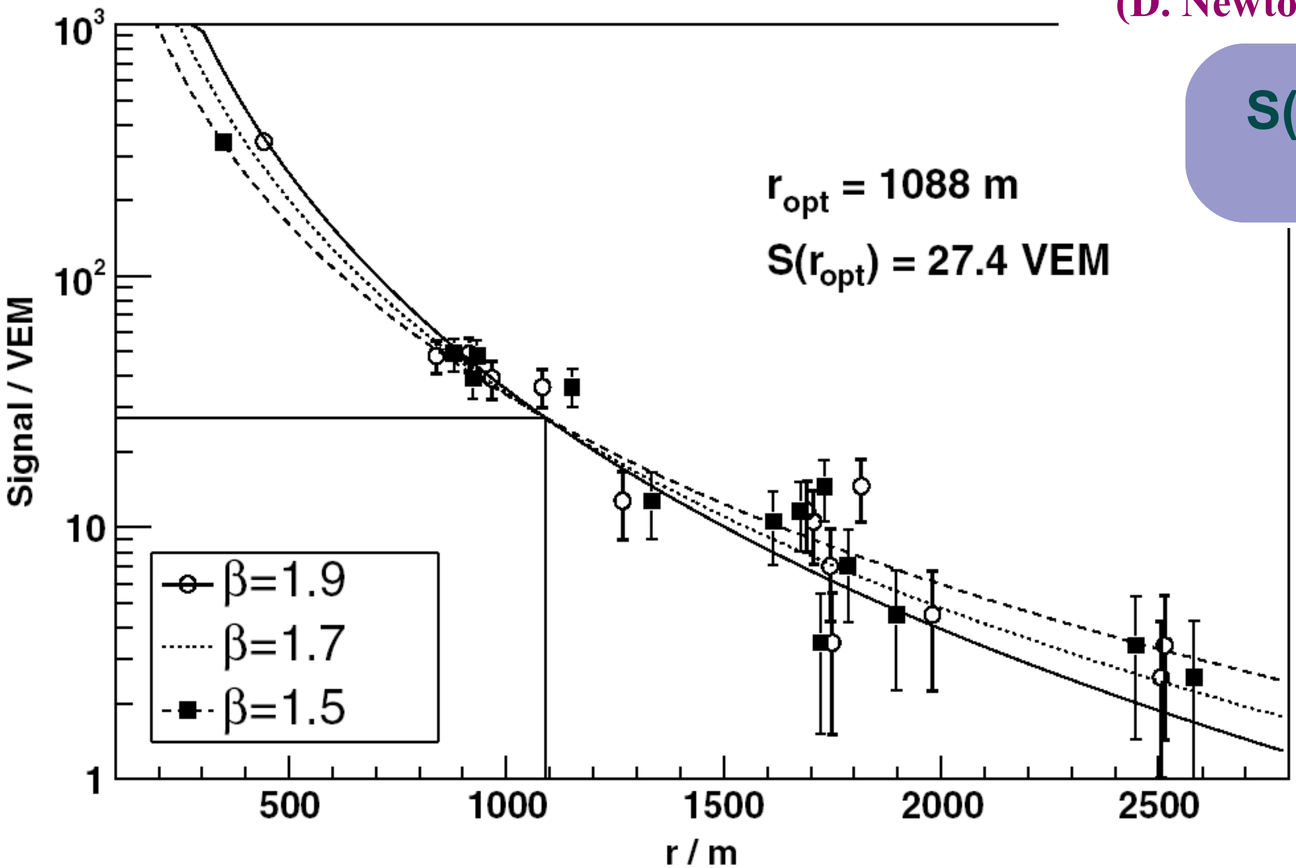
Core Position and $S(R_{ref})$ with R_{ref} a reference distance

For every event there is an $R_{optimum}$ for which S fluctuations (due to the unknown LDF shape) are minimized

$< R_{optimum} > = 1000$ m Non Sat. Events

$< R_{optimum} > = 1600$ m Sat. Events

(D. Newton et al Astrop. Phys. 26 (2007) 414-419)



S(1000) will be our energy estimator

reconstruction: S(1000) from fit of NKG-like LDF

ß slope of the LDF:

$\beta=\beta(\theta,S(1000))$

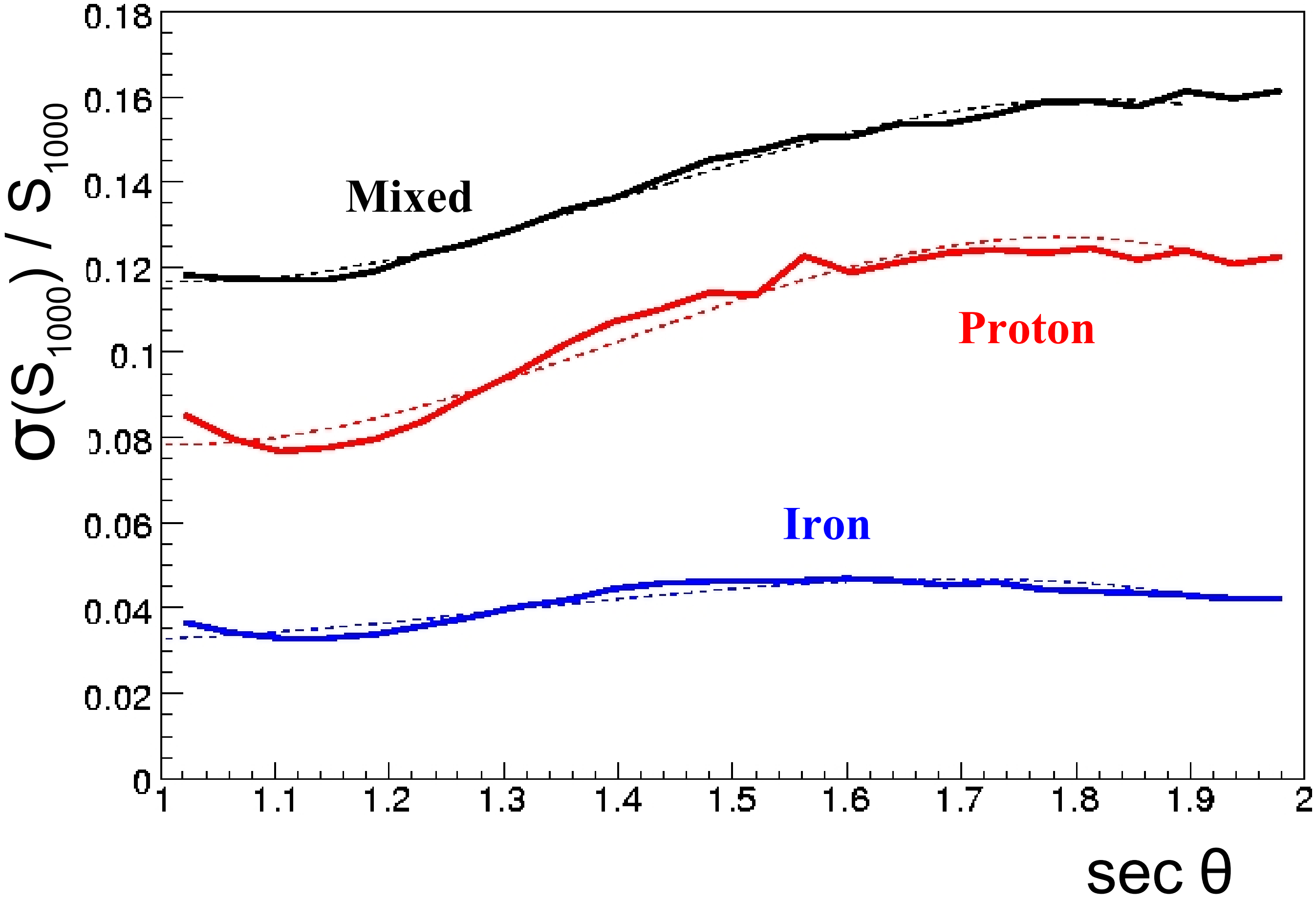
$\sigma_\beta=\sigma_\beta(S1000)$

parametrized from data

uncertainties of the energy estimator

Shower-To-Shower: fluctuations of S(1000) for fixed primary energy and composition

caused by shower physics



Model and energy independent

shower to shower fluctuations of S(1000) at the level of 10%

uncertainties of the energy estimator

reconstruction uncertainties:

Statistical:

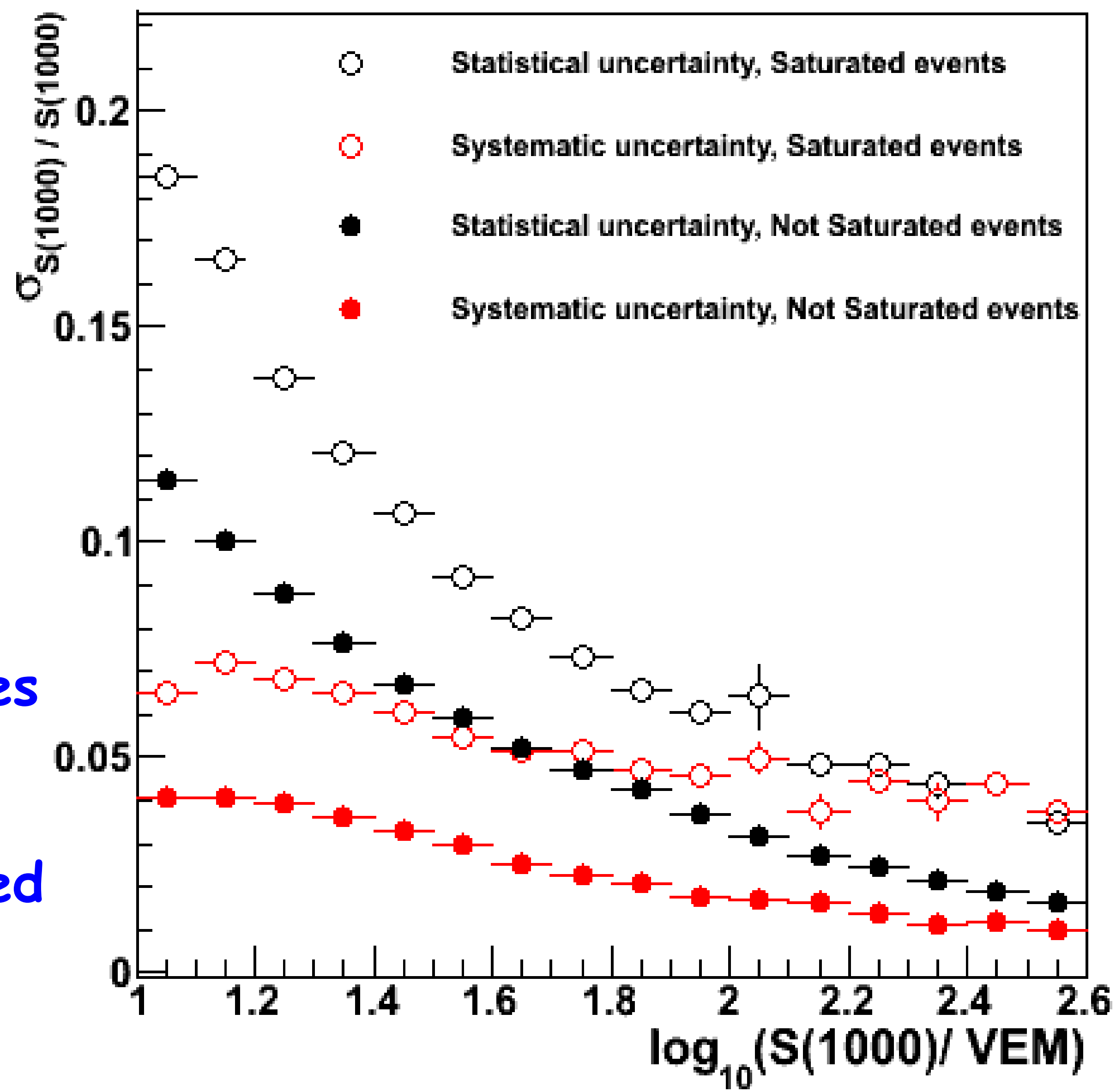
sampling fluctuations in signal sizes (finite area of detectors)

obtained from the LDF fitting uncertainties

Systematic:

caused by the uncertainty in the shape of the LDF on an event by event basis

event reconstructed N times with LDF slope (β) sampled from a Gaussian distribution centered around the predicted value and $\sigma = \sigma_\beta$



uncertainties of the energy estimator

reconstruction uncertainties:

Statistical:

sampling fluctuations in signal sizes (finite area of detectors)

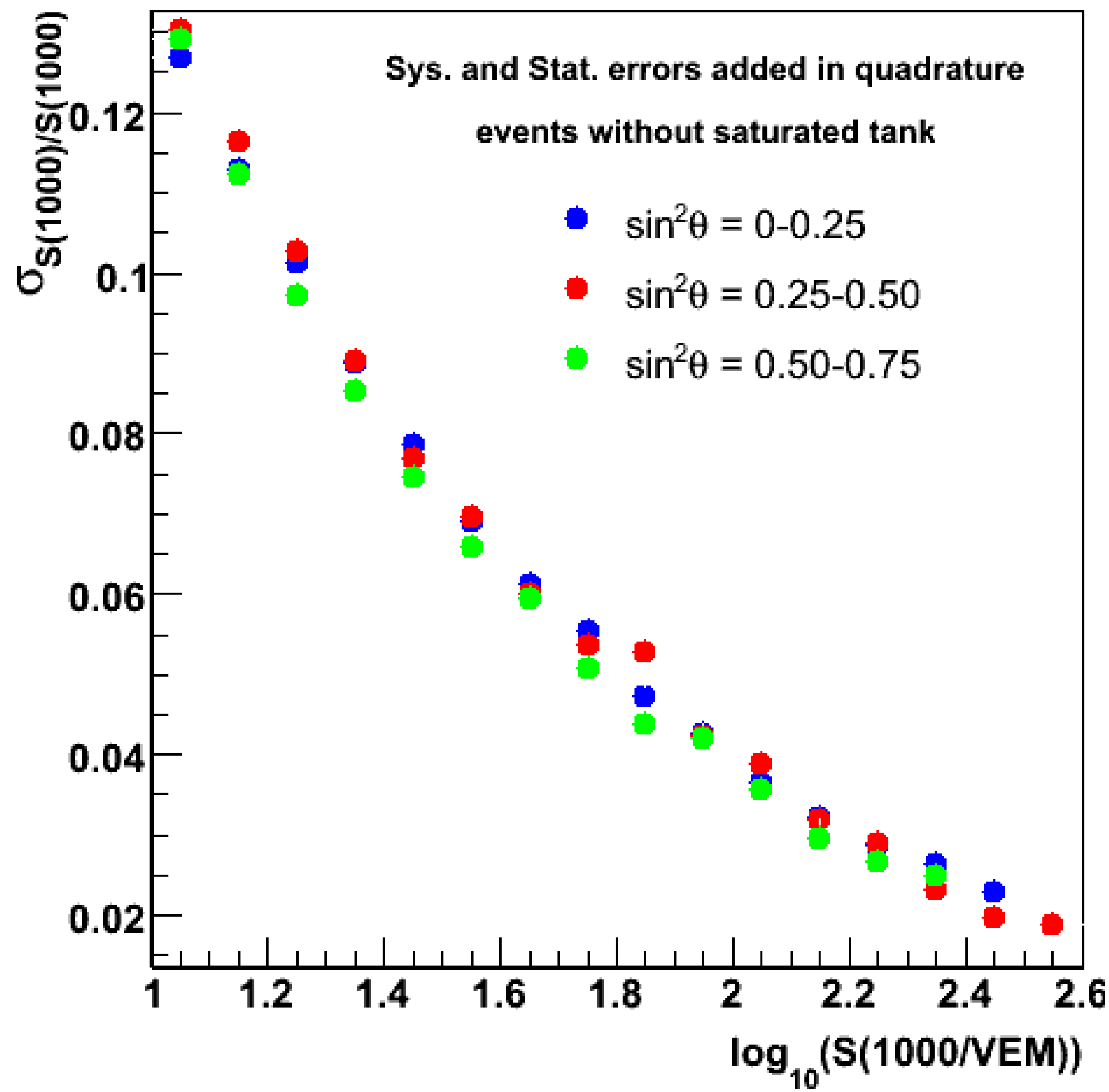
obtained from the LDF fitting uncertainties

Systematic:

caused by the uncertainty in the shape of the LDF on an event by event basis

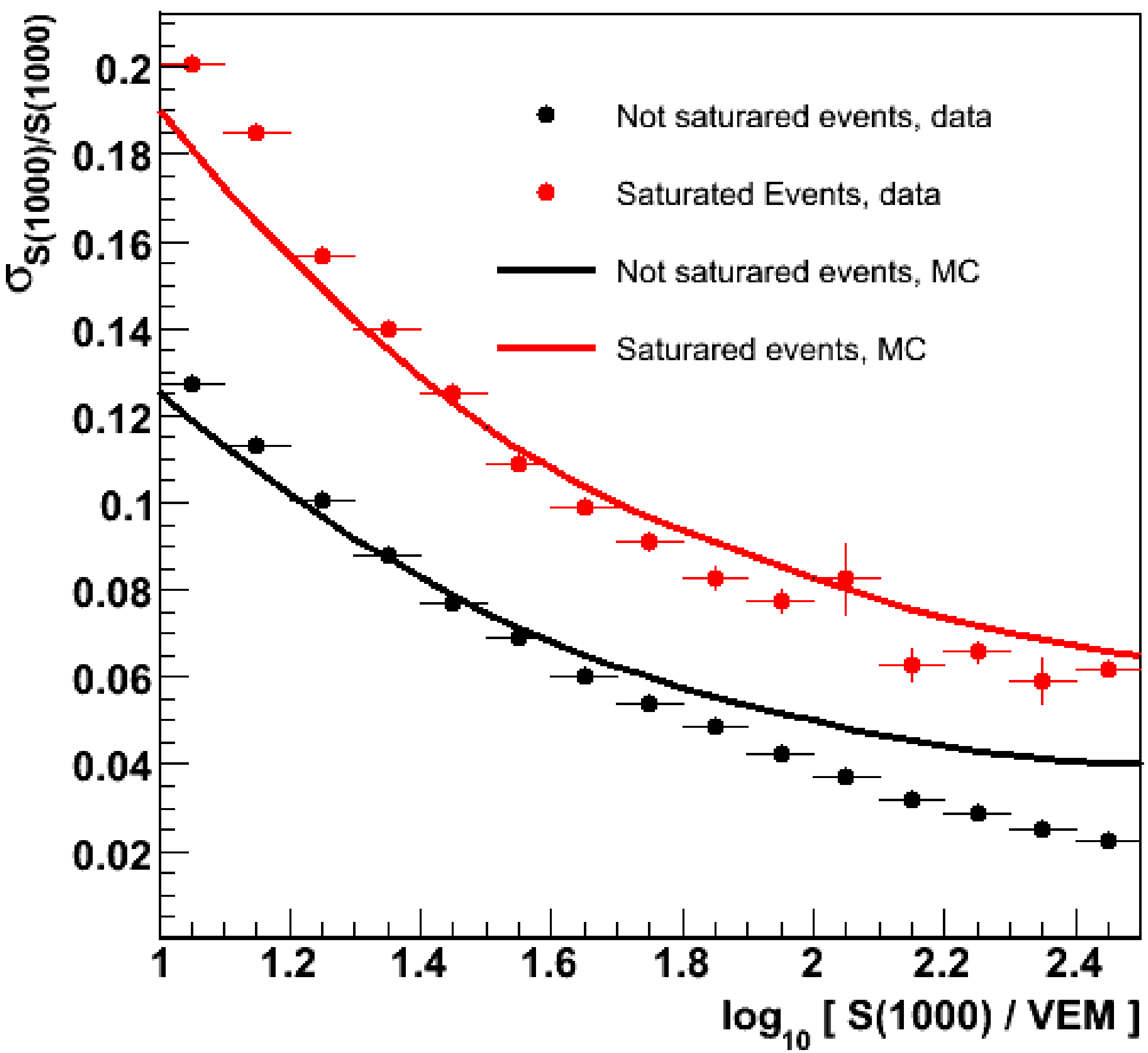
event reconstructed N times with LDF slope (β) sampled from a Gaussian distribution centered around the predicted value and $\sigma = \sigma_\beta$

no dependence on zenith angle



Check on the S(1000) uncertainty estimation

- Full MC simulations (Corsika-Proton-QGSJetII)



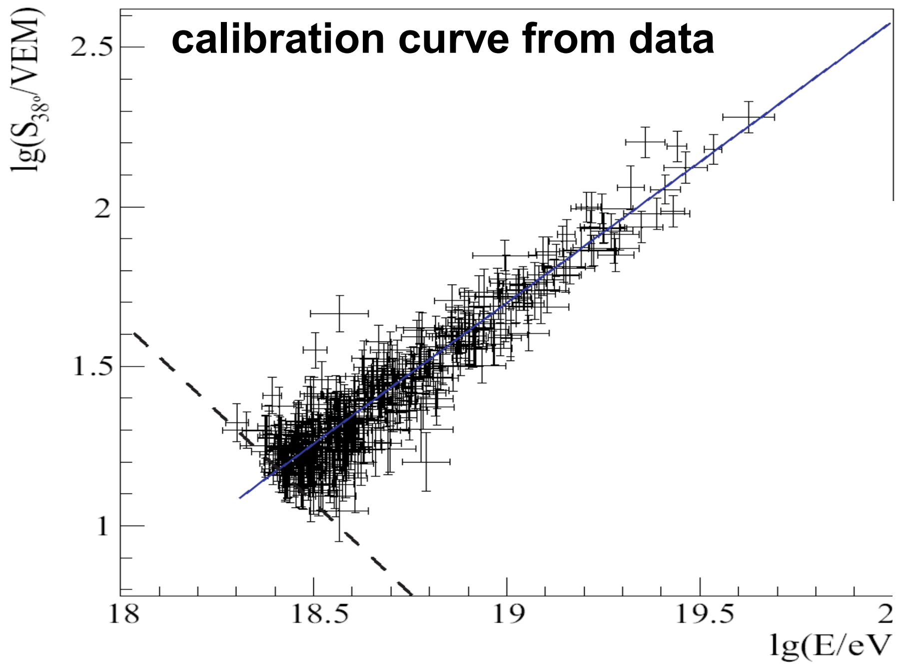
- $S(1000)_{True}$ computed simulating a ring of 18 tanks at 1000 m.
- The distribution of: $\log(S(1000)_{Rec}/S(1000)_{True})$ is fitted to a log normal distribution for each S(1000).

$\sigma_{S(1000)}/S(1000)$ form MC is compared with data

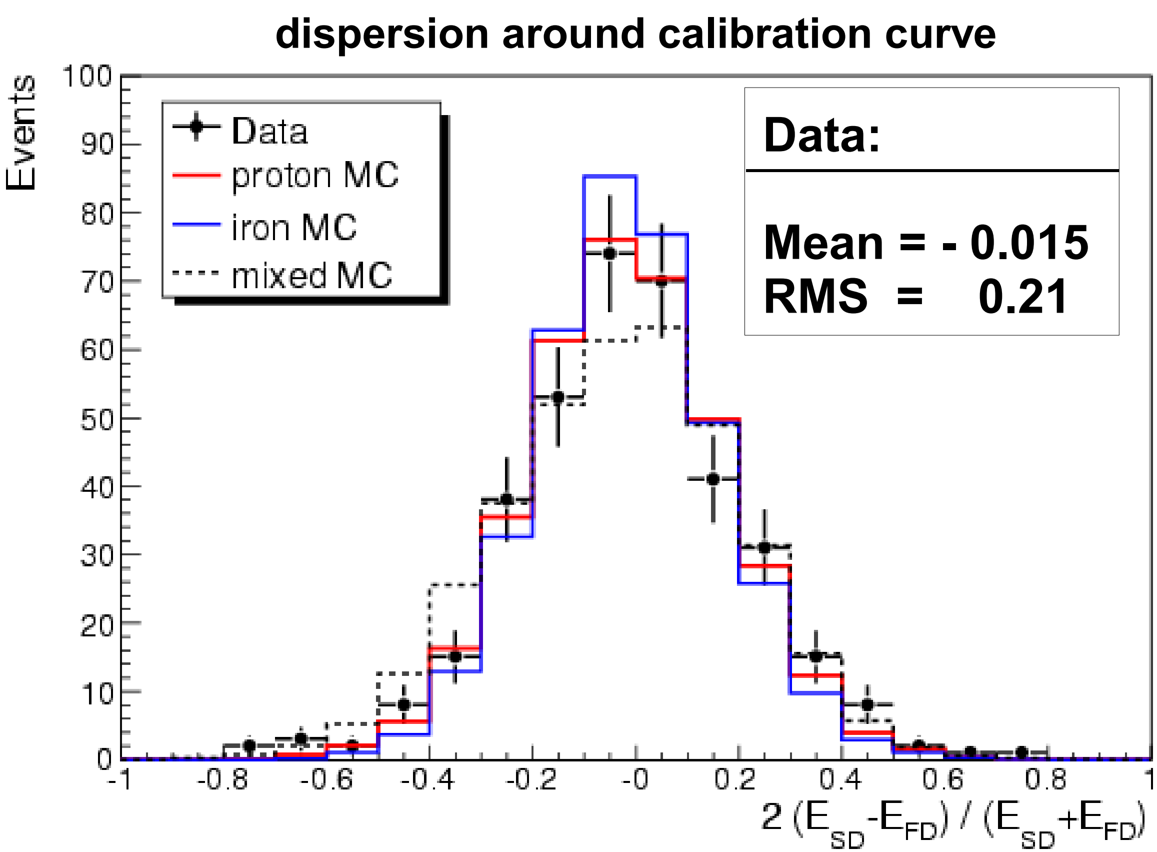
agreement between estimation from data and MC

Checks with Hybrids

we reproduce the dispersion around the calibration curve using the S(1000) fluctuations and FD energy resolution



- the dispersion around the calibration curve is related to the combined uncertainties of SD and FD
- using S(1000) uncertainties (sh-to-sh and reconstruction) and the 14% FD energy resolution we reproduce the observed dispersion with simple simulation



We understand the combined uncertainties of FD-SD.

Conclusions

Angular Resolution

- The angular resolution is experimentally determined event by event
- checked using doublets and hybrid data.
- It is better than 2 deg for E< 4 EeV,

  1.2 deg 3<E<10 EeV and 0.9 deg for E>10 EeV (θ>20^o)

S(1000) accuracy

- Uncertainties are estimated on an event by event basis
- $\frac{\sigma_{S(1000)}}{S(1000)} \sim$ 4% (8%) at the highest energies for events without (with) saturated stations.
- At the highest energy the uncertainties of the energy estimator are dominated by shower to shower fluctuations.