The *Balloon-the-Shower* programme of the Pierre Auger Observatory

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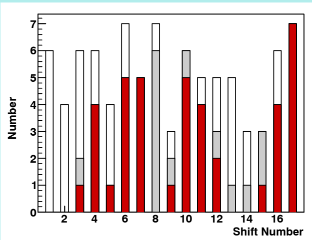
I. Introduction

- hybrid detector for **high-energy cosmic rays** composed of surface water-Cherenkov tanks and fluorescence telescopes
- almost calorimetric measurement of E by fluorescence detector (FD) [1]
- energy calibration based on hybrid data; FD energy is transferred to all surface detector events [2]
- unpredictable changes of atmospheric conditions → **sophisticated monitoring system** is required [3]
- events of particular interest, **very high-energy events,** should be **reconstructed with highest possible precision**
  ⇒ **provide information of atmospheric conditions at the time of (≈ directly after) the event**

II. *Balloon-the-Shower (BtS)*

- *BtS* replaces regularly scheduled meteorological radio soundings
- all hybrid air shower events are reconstructed online
- every 15 min., events passing the following cuts are selected:
  - relative uncertainty of energy $\sigma_E / E < 0.2$
  - uncertainty of position of shower maximum $\sigma_{X_{max}} < 40$ g cm^{-2}
  - X_{max} well contained in the observed track
  - further quality cuts concerning the fit to shower profile
  - energy threshold $E_{min} \approx 2 \cdot 10^{19}$ eV
- these events trigger automatically a text message (SMS) which is sent to an on-site technician who performs a launch of a weather balloon (1 SMS per 15 min. at most)

III. Statistics



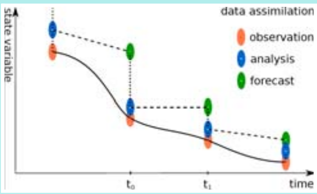
White bars: Expected *BtS* triggers for the 17 shifts between 01/2009 and 05/2010

Grey bars: Generated SMS only for those expected events. There were more SMS sent than shown because some of the events that the online script selects have reconstructed parameters that did not pass one of the cuts during offline reconstruction.

Red bars: Events that were covered by a balloon launch.

- in total, 39 successful launches after SMS alert
- these cover 51 selected air shower events
- for further analysis, 69 reconstructed FD event profiles used

IV. Global Data Assimilation System (GDAS)



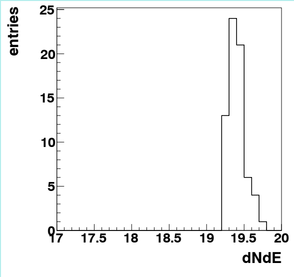
Schematic principle of data assimilation:
continuous line – real time course of a state variable
dotted line – analysis step
dashed line – forecast step

- global atmospheric model developed at NCEP[1]
- vertical atmospheric profiles for height, temperature, humidity at constant pressure levels every 3 hours since Dec. 2004
- global data publicly available at `http://ready.arl.noaa.gov`
- good description of local atmospheric conditions for the site of the southern Pierre Auger Observatory as measured with meteorological radio soundings [4]

[1] National Centers for Environmental Prediction (NCEP) at NOAA – National Oceanic and Atmospheric Administration

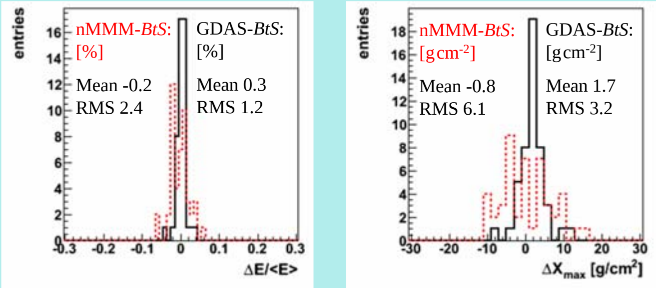
V. Event Reconstruction

- using the Offline Software Framework [5]
- including full atmosphere-dependent fluorescence calculation [6,7] based on AIRFLY data [8]



Energy distribution of all 51 high-energy events which passed the quality cuts, reconstructed with actual atmospheric profiles from the *BtS* programme.

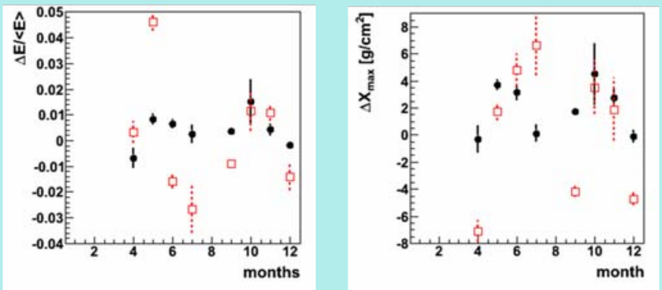
- comparison between reconstructions using models [3,4] and using *BtS* atmospheric profiles



Difference between reconstructed events using monthly models (nMMM) and using *BtS* atmospheric profiles in red and using GDAS compared with *BtS* in black. Left: Energy. Right: Position of shower maximum.

→ **very good E reconstruction, for X_{max} small offset with GDAS due to small offset in pressure compared with *BtS* atmosphere**

- study of systematics



Reconstruction results **in dependence on the month of year**, colours as above. Left: Difference in E. Right: Difference in X_{max}.

→ **No dependence on month for E reconstruction. Small seasonal dependence for X_{max} reconstruction for nMMM-*BtS* while neglecting Sept. results (only 2 entries) - possibly caused by slight difference between actual and modelled water vapour.**

References

[1] Pierre Auger Collab. The fluorescence detector of the Pierre Auger Observatory. Nucl. Instr. Meth. A620 (2010) 227; arXiv:0907.4282 [astro-ph]

[2] Pierre Auger Collab. The Cosmic Ray Energy Spectrum and Related Measurements with the Pierre Auger Observatory. Proc. 31st ICRC, Lodz, Poland (2009); arXiv:0906.2189 [astro-ph]

[3] Pierre Auger Collab. A study of the effect of molecular and aerosol conditions in the atmosphere on air fluorescence measurements at the Pierre Auger Observatory. Astropart. Phys. 33 (2010) 108

[4] D. Epperlein et al. Investigation of Applying a Global Atmospheric Model to the Southern Site of the Pierre Auger Observatory. Auger technical note GAP-2010-074 (2010)

[5] S. Argiro et al. The Offline Software Framework of the Pierre Auger Observatory. Nucl. Instr. Meth. A580 (2007) 1485; arXiv:0707.1652 [astro-ph]

[6] F. Arqueros et al. Air fluorescence relevant for cosmic-ray detection – Summary of the 5th fluorescence workshop, El Escorial 2007. Nucl. Instr. Meth. A597 (2008) 1; arXiv:0807.3760 [astro-ph]

[7] B. Keilhauer, M. Unger. Fluorescence emission induced by extensive air showers in dependence on atmospheric conditions. Proc. 31st ICRC, Lodz, Poland (2009); arXiv:0906.5487 [astro-ph]

[8] M. Ave et al. Temperature and humidity dependence of air fluorescence yield measured by AIRFLY. Nucl. Instr. Meth. A597 (2008) 50.

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