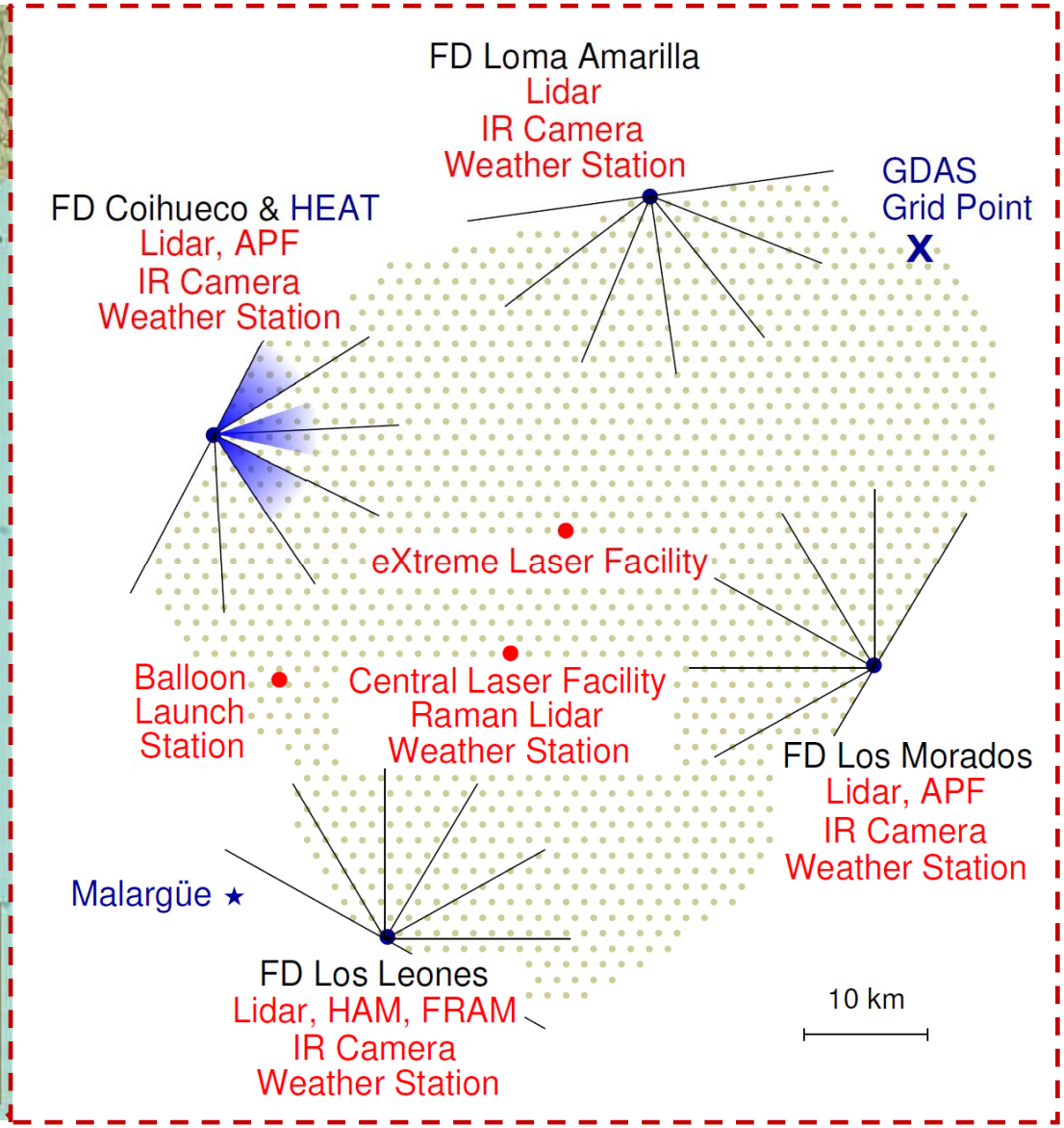
Atmospheric Monitoring at the Pierre Auger Observatory

Bianca Keilhauer for the Pierre Auger Collaboration

AtmoHEAD: Atmospheric Monitoring for High-Energy Astroparticle Detectors - Padova, 19-21 May 2014

The Pierre Auger Observatory



Main Detector Components

Surface Detectors

- 100 % duty cycle
- acceptance = geometric
- only last stage of shower development observed
- energy scale model dependent

Fluorescence Detectors

- ≈ 15 % duty cycle
- acceptance depends on distance and atmosphere
- observation of longitudinal shower development
- (almost) model independent

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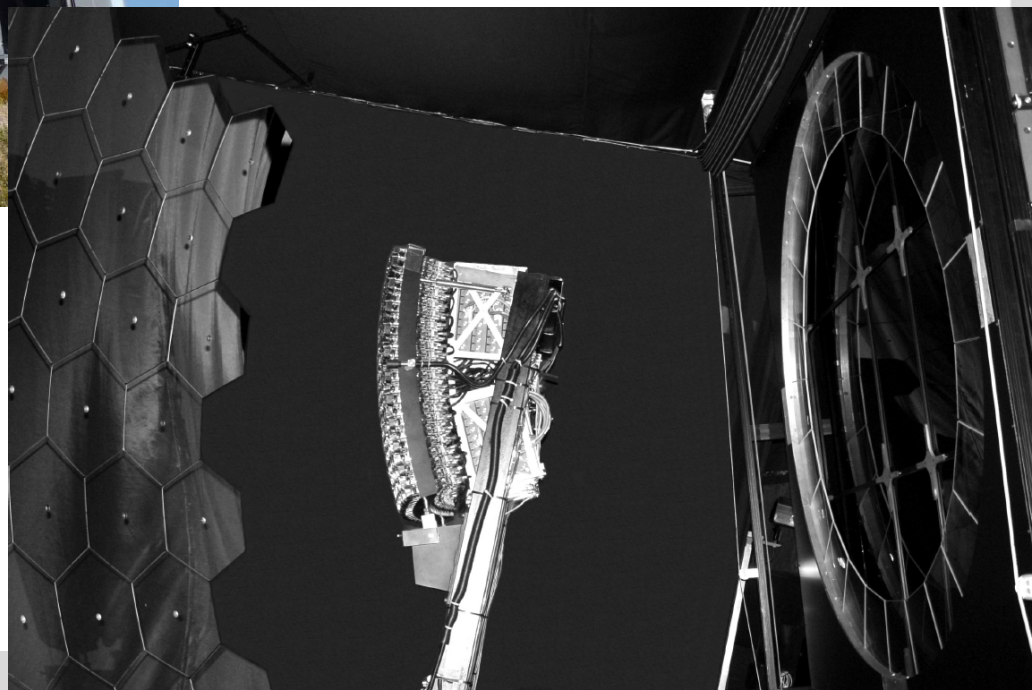
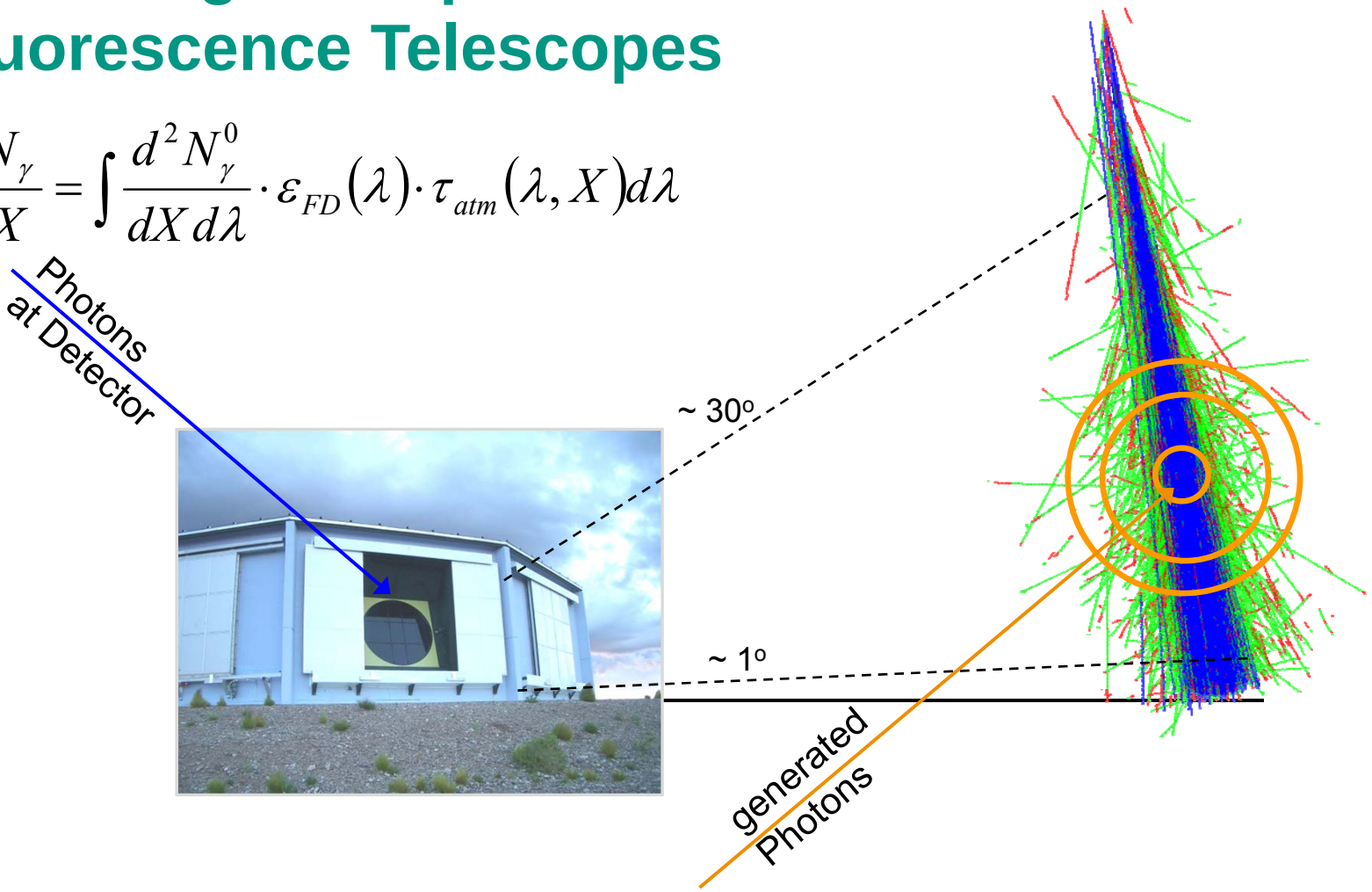


Measuring Principle of EAS with Fluorescence Telescopes

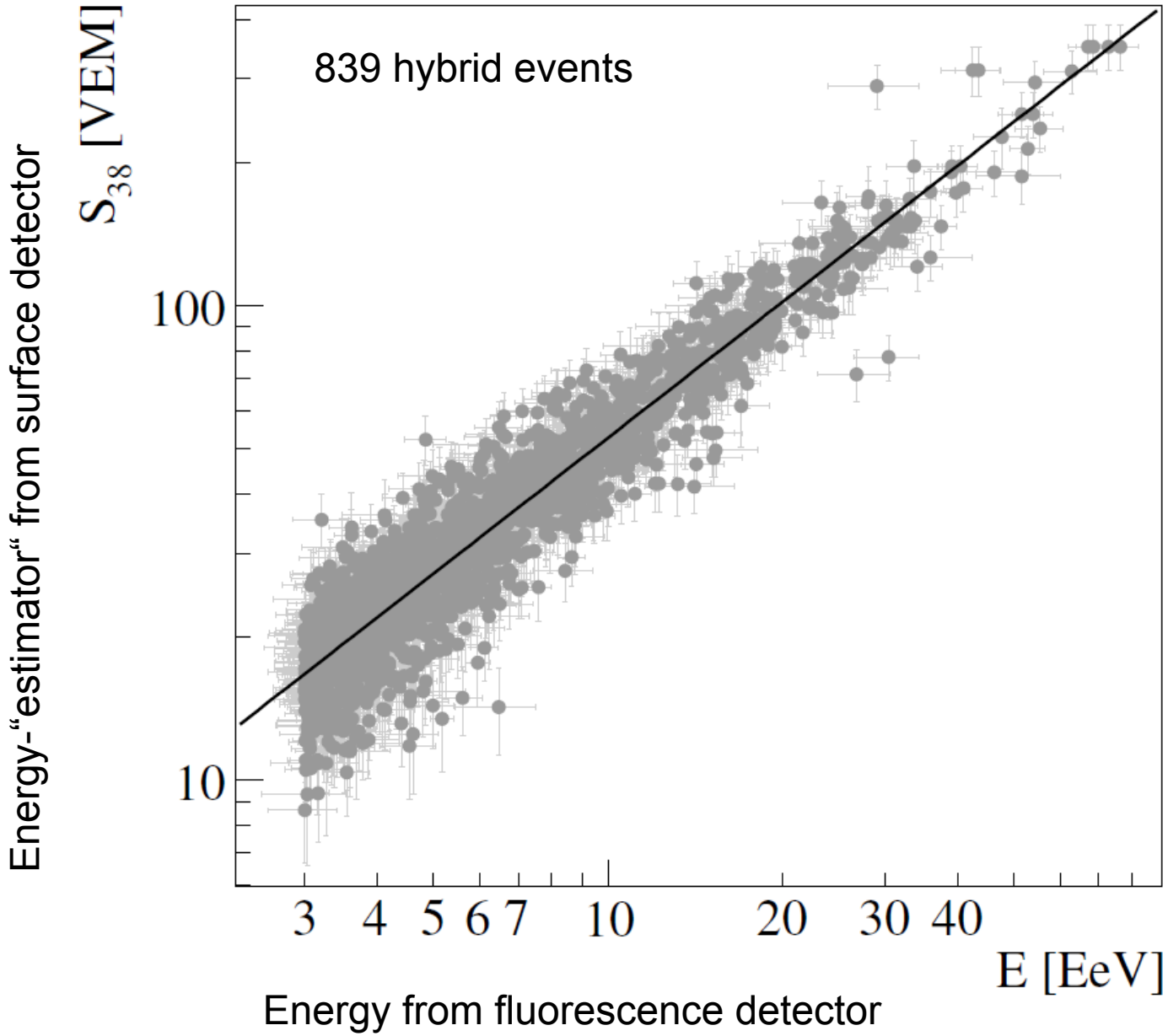
$$\frac{dN_\gamma}{dX} = \int \frac{d^2 N_\gamma^0}{dX\, d\lambda} \cdot \varepsilon_{FD}(\lambda) \cdot \tau_{atm}(\lambda, X) d\lambda$$



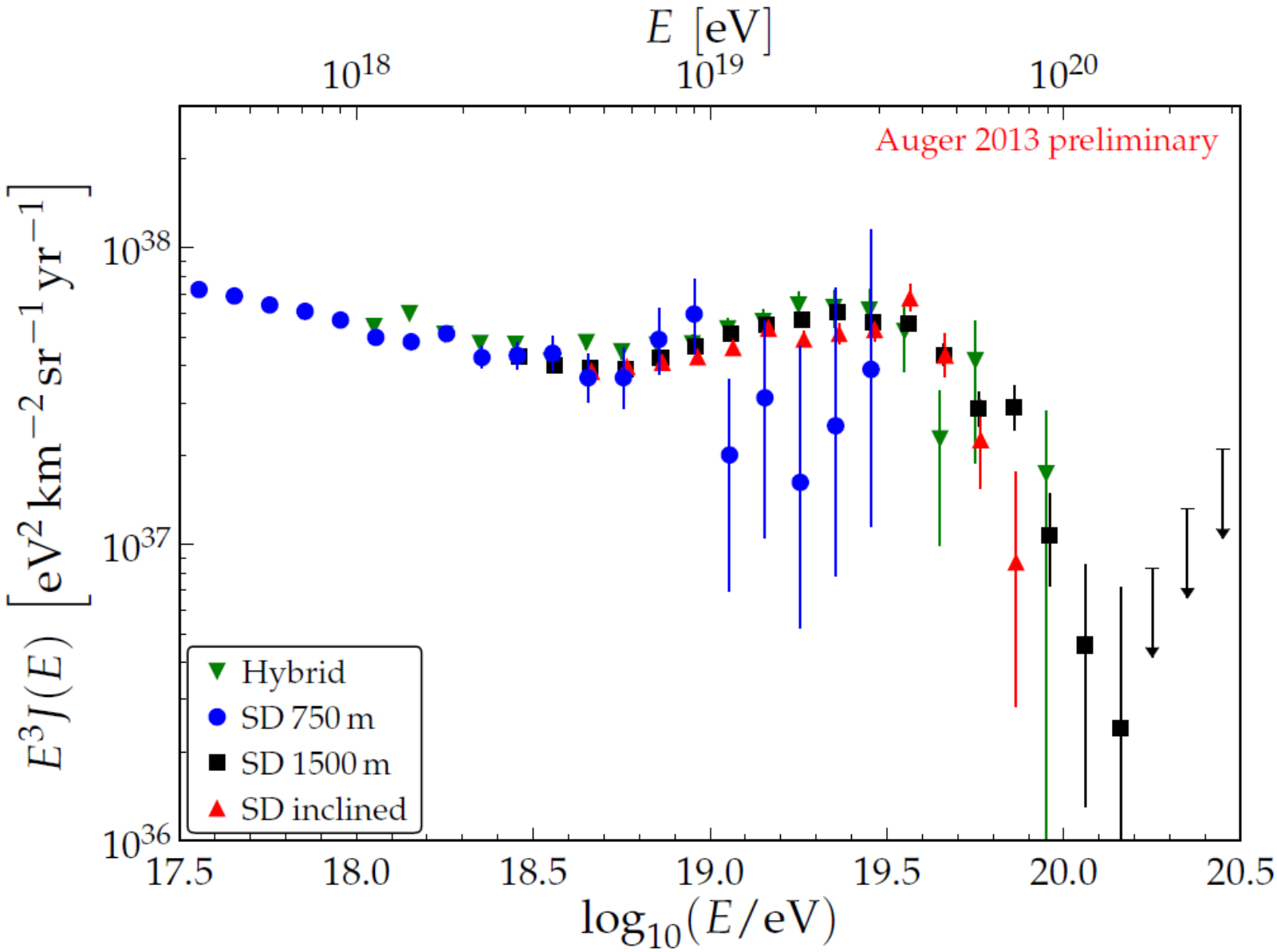
$$\frac{d^2 N_\gamma^0}{dX\, d\lambda} = \int Y(\lambda, P, T, u, E) \cdot \frac{dN_e(X)}{dE} \cdot \frac{dE_{dep}}{dX} dE$$

Energy Calibration

R. Pesce for the Pierre Auger Collaboration, Proc. 32nd ICRC Beijing, China, **2** (2011) 214–217; arXiv:1107.4809.

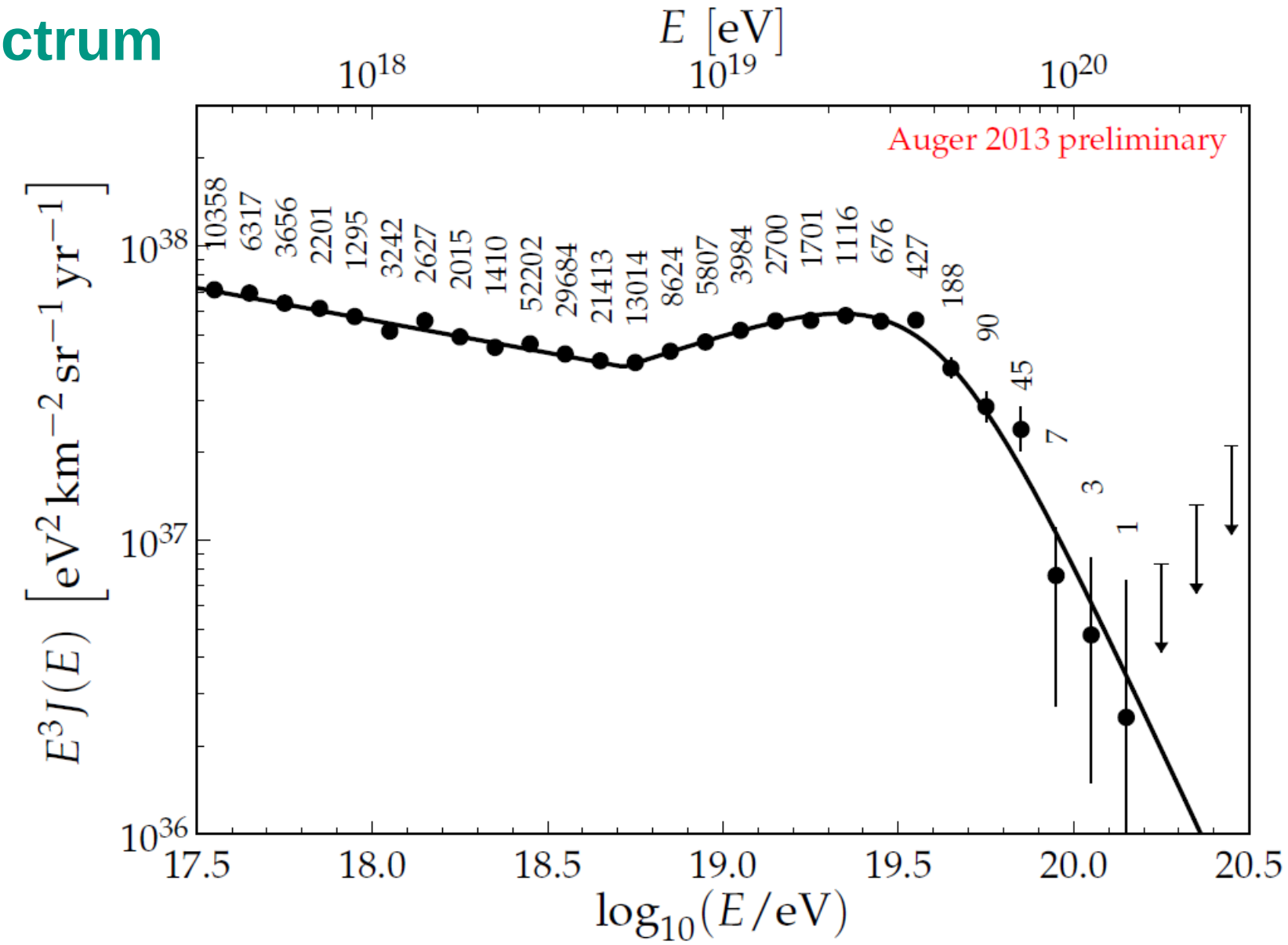


Flux spectra

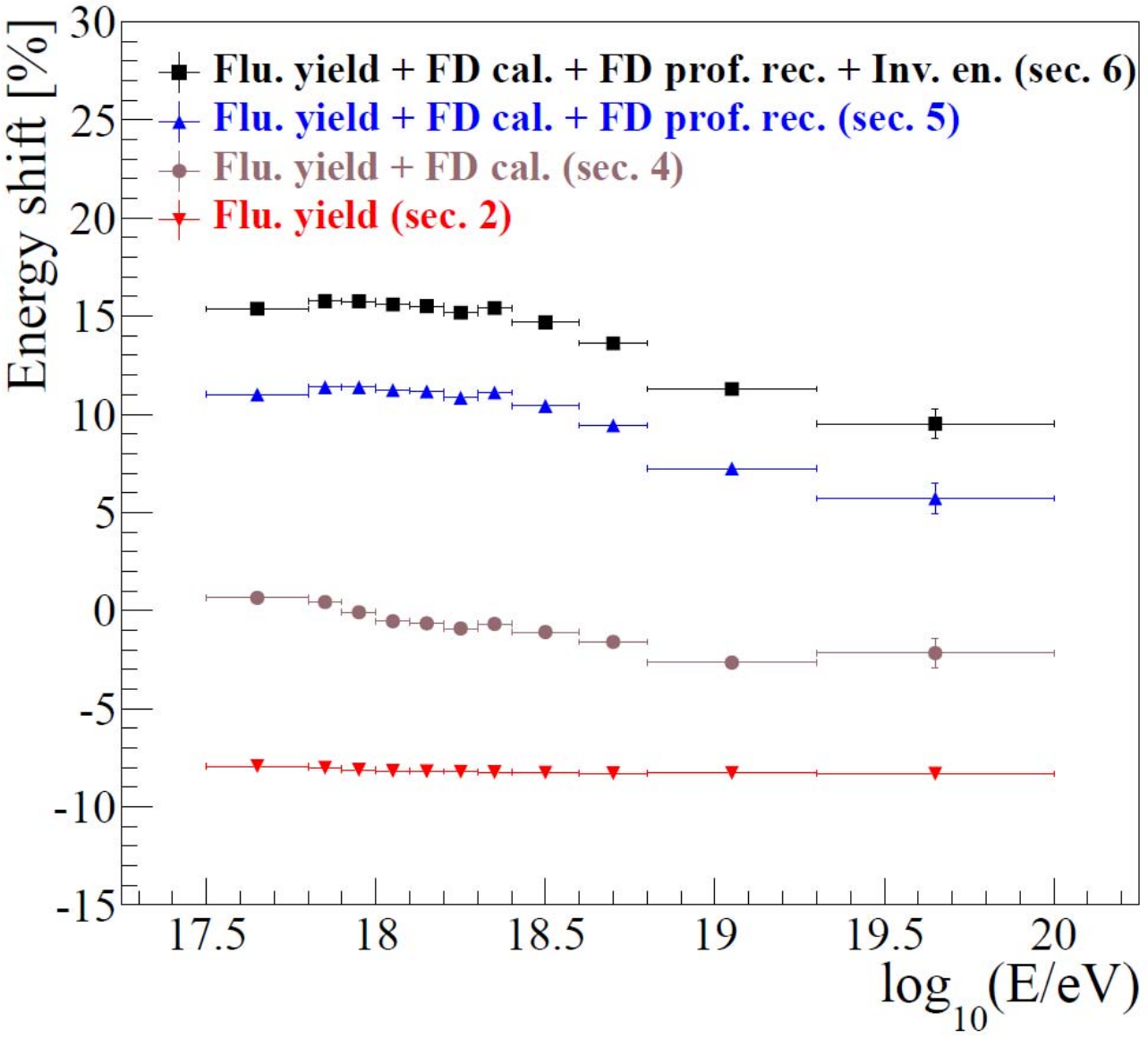


Combinded Spectrum

A. Schulz *et al.* Energy spectrum measured at the Pierre Auger Observatory
33RD INTERNATIONAL COSMIC RAY CONFERENCE, RIO DE JANEIRO 2013
ICRC 2013



Energy Scale

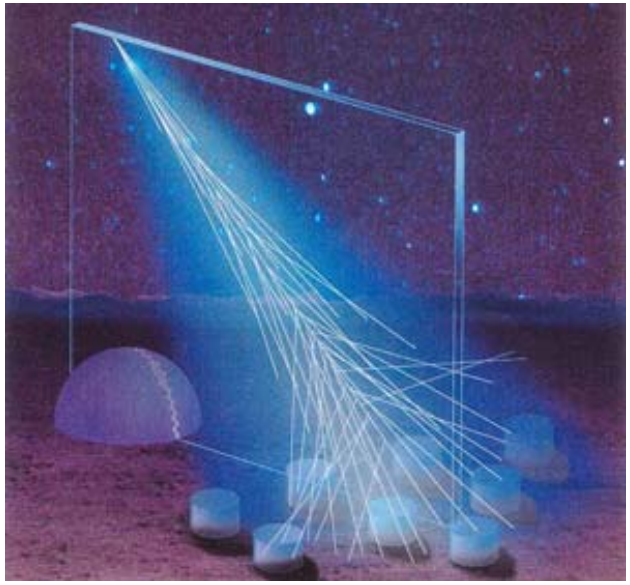


Energy Scale shift and uncertainties

Changes in FD energies at 10^{18} eV	
Absolute fluorescence yield (sec. 2)	**-8.2%**
New optical efficiency	4.3%
Calibr. database update	3.5%
Sub total (FD calibration - sec. 4)	**7.8%**
Likelihood fit of the profile	2.2%
Folding with the point spread function	9.4%
Sub total (FD profile reconstruc. - sec. 5)	**11.6%**
New invisible energy (sec. 6)	**4.4%**
Total	**15.6%**

Systematic uncertainties on the energy scale	
Absolute fluorescence yield	3.4%
Fluor. spectrum and quenching param.	1.1%
Sub total (Fluorescence yield - sec. 2)	**3.6%**
Aerosol optical depth	3%÷6%
Aerosol phase function	1%
Wavelength depend. of aerosol scatt.	0.5%
Atmospheric density profile	1%
Sub total (Atmosphere - sec. 3)	**3.4%÷6.2%**
Absolute FD calibration	9%
Nightly relative calibration	2%
Optical efficiency	3.5%
Sub total (FD calibration - sec. 4)	**9.9%**
Folding with point spread function	5%
Multiple scattering model	1%
Simulation bias	2%
Constraints in the Gaisser-Hillas fit	3.5% ÷ 1%
Sub total (FD profile rec. - sec. 5)	**6.5% ÷5.6%**
Invisible energy (sec. 6)	**3%÷1.5%**
Stat. error of the SD calib. fit (sec. 7)	**0.7%÷1.8%**
Stability of the energy scale (sec. 7)	**5%**
Total	**14%**

Atmospheric Influences



Ground-based weather stations

- measured: mainly temperature T, pressure p, humidity u, wind
- every 5 min. a set of data
- transfer to database within a few days



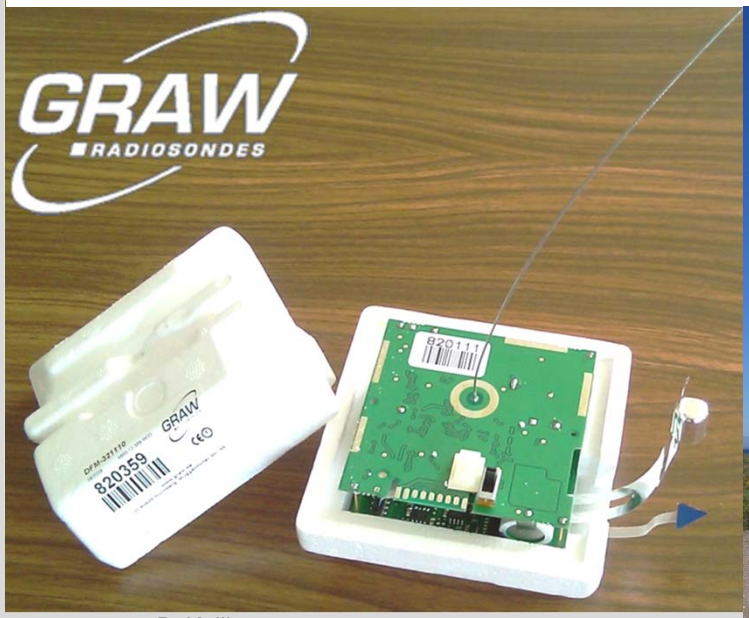


Atmospheric State Variables

- measured: mainly temperature T, pressure p, and humidity u
- derived variables: density ρ, atmospheric depth X, and vapour pressure e

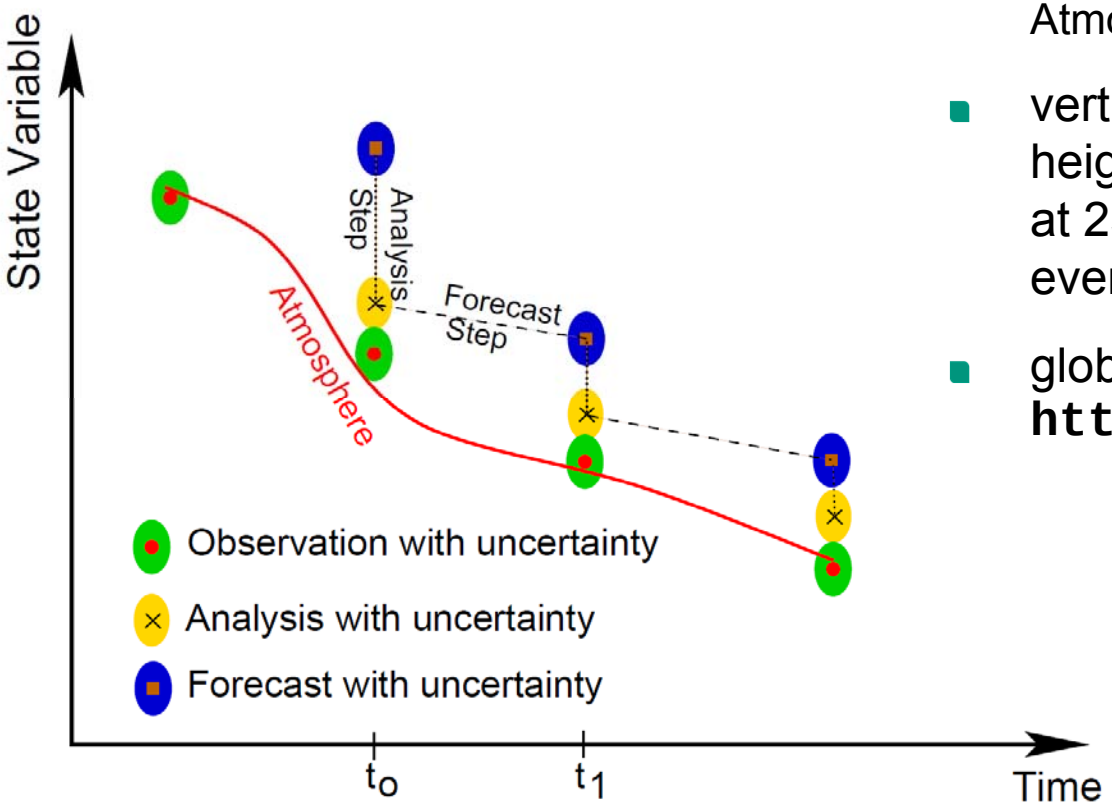
profiles from radio soundings

- intermittent launches
- 331 successful profiles until Dec. 2010
- 1st ascent in Aug. 2002
- now dedicated campaigns



Highschool and university project of Nebraska-Lincoln (UNL)
15 September 2012
maximal altitude about 95 000 feet (≈ 30 km a.s.l.)

Global Data Assimilation System - GDAS



- global atmospheric model developed at NCEP

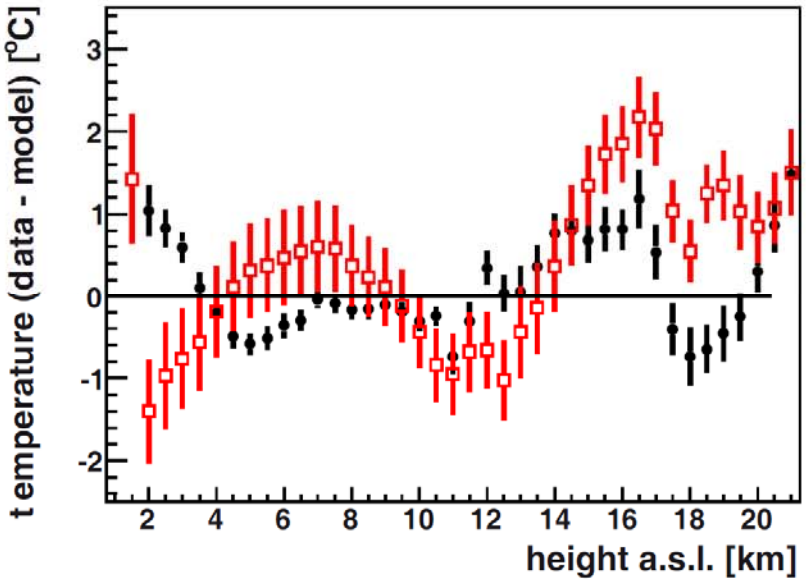
  National Centers for Environmental Prediction (NCEP) at NOAA – National Oceanic and Atmospheric Administration

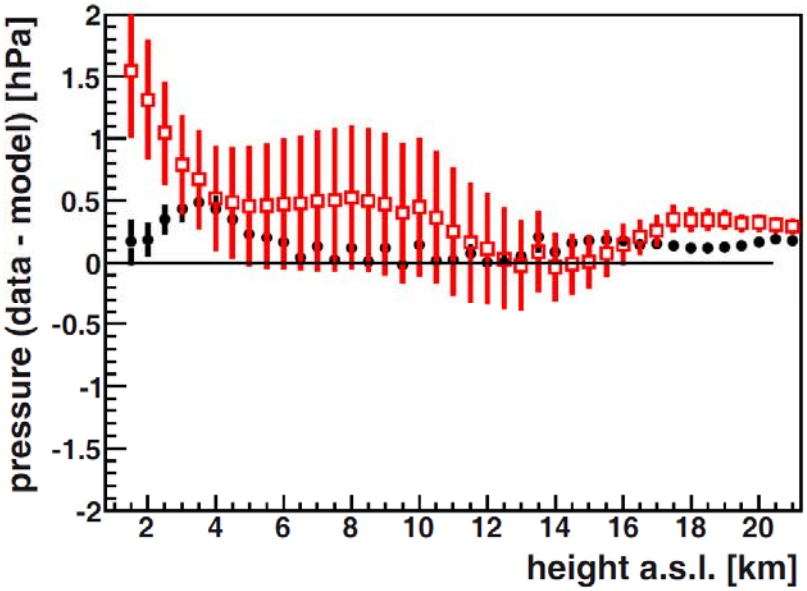
- vertical atmospheric profiles for height, temperature, humidity at 23 constant pressure levels every 3 hours since Dec. 2004

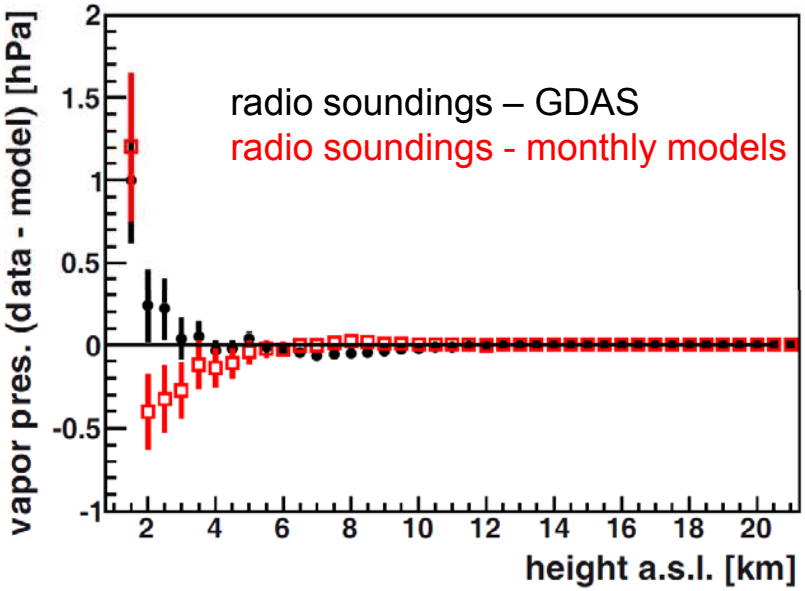
- global data publicly available at **`http://ready.arl.noaa.gov`**

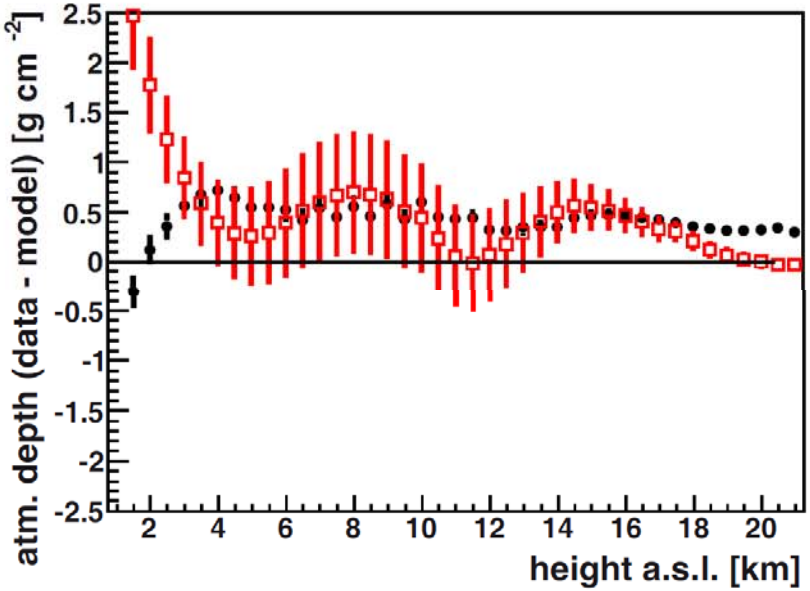
Astrophys. Space Sci. Trans. 6(2010)27

GDAS – comparison with local measurements



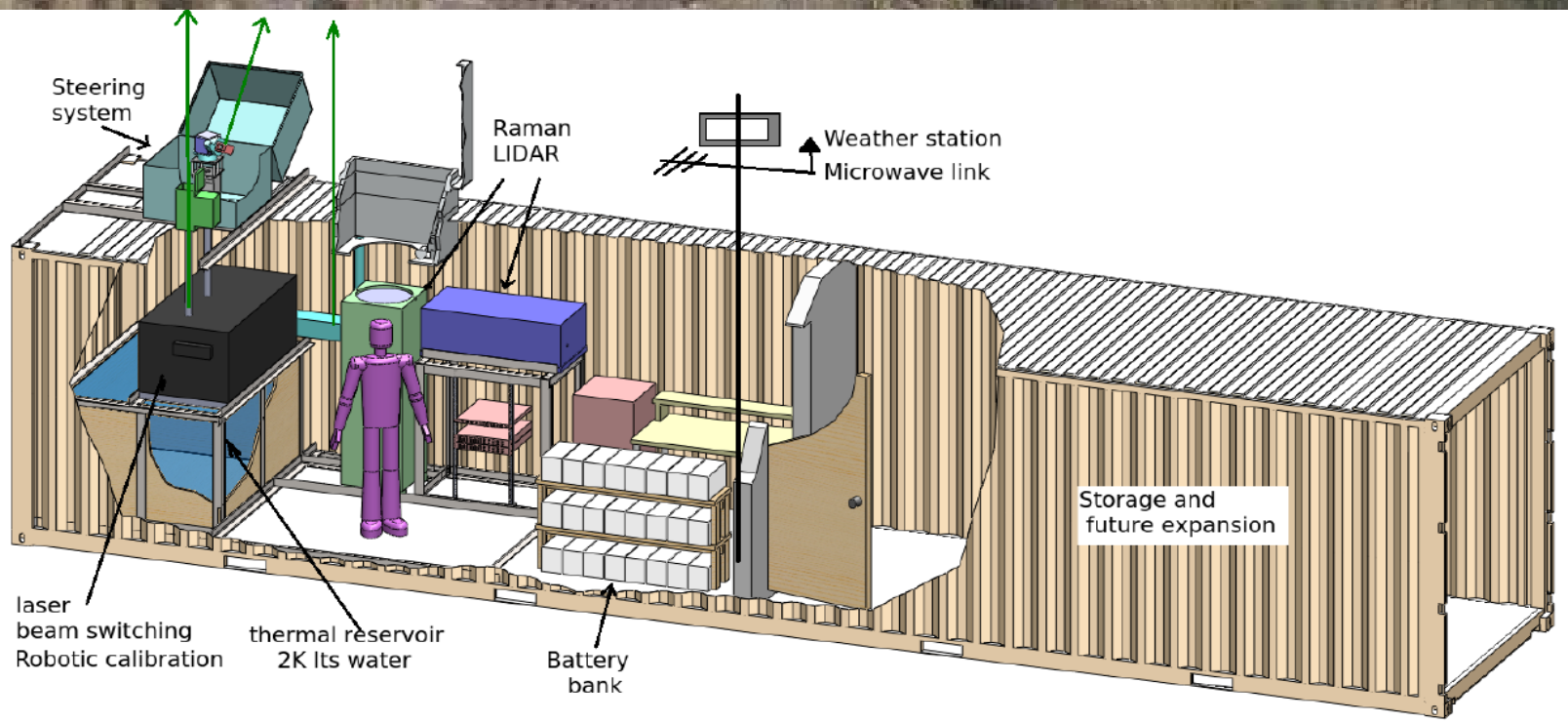




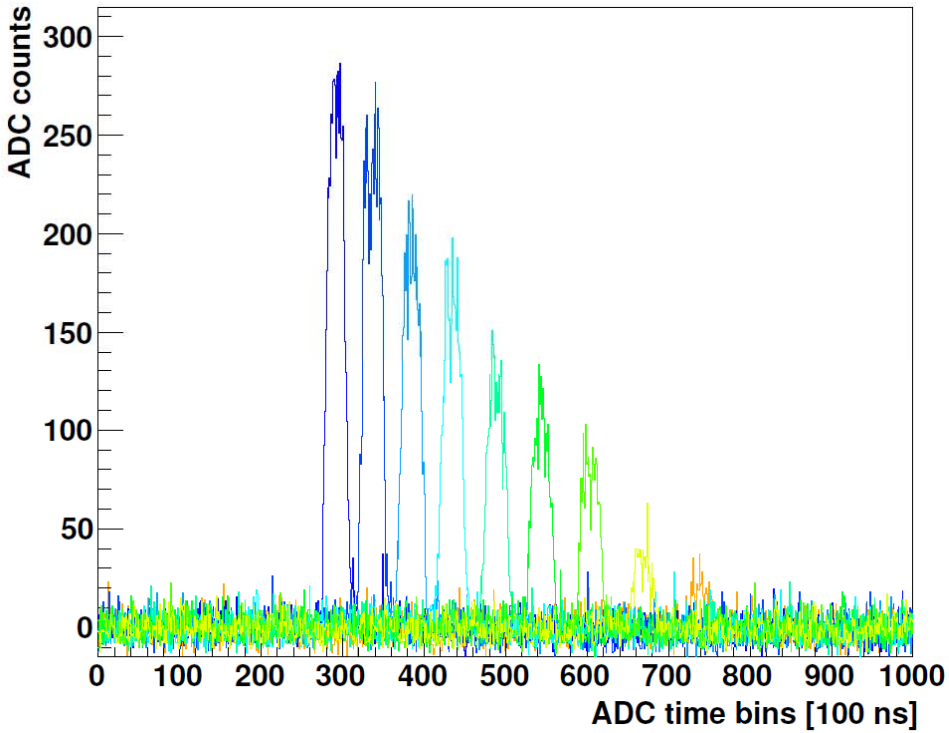


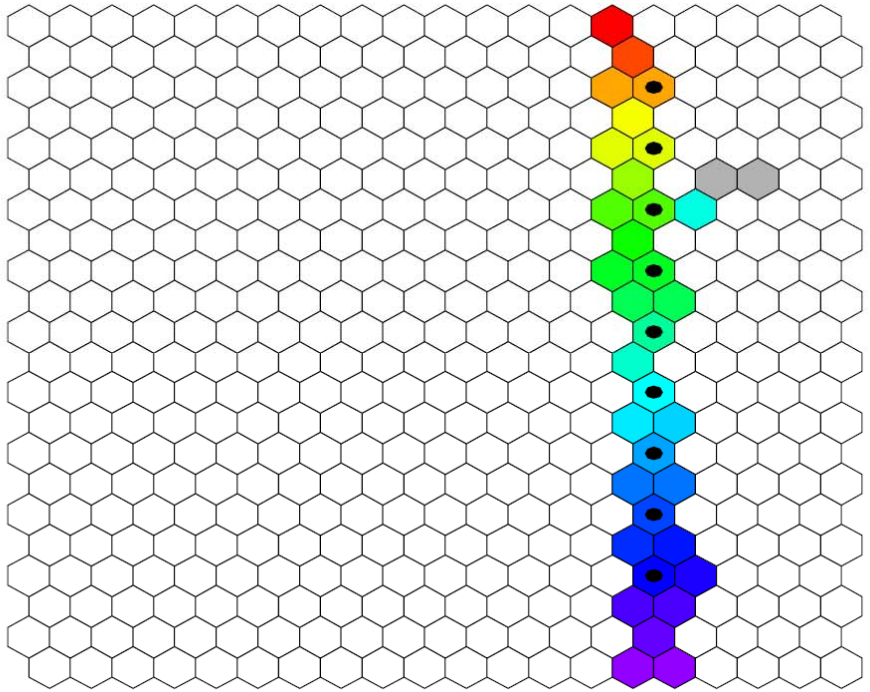
P. Abreu et al./Astroparticle Physics 35 (2012) 591–607

New Central Laser Facility with Raman lidar



CLF shot seen at FD Los Leones





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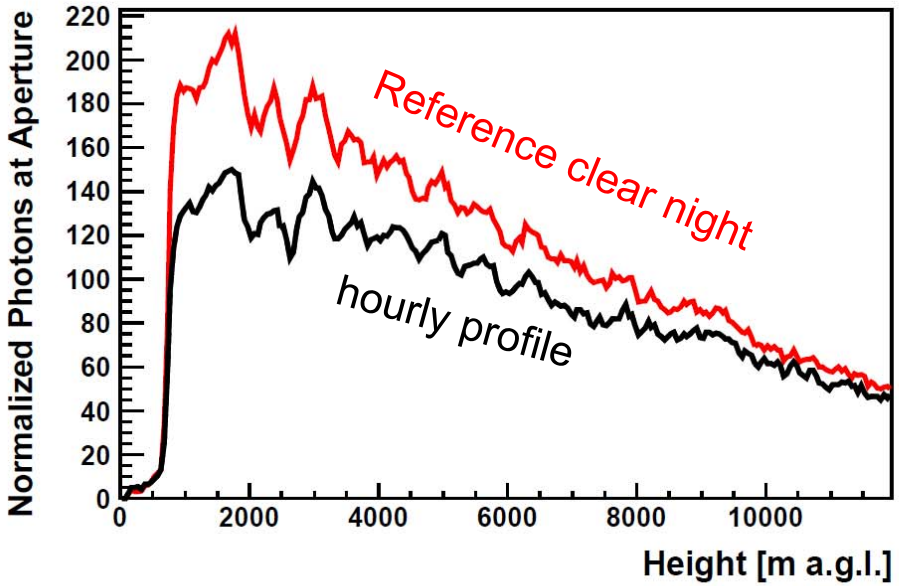
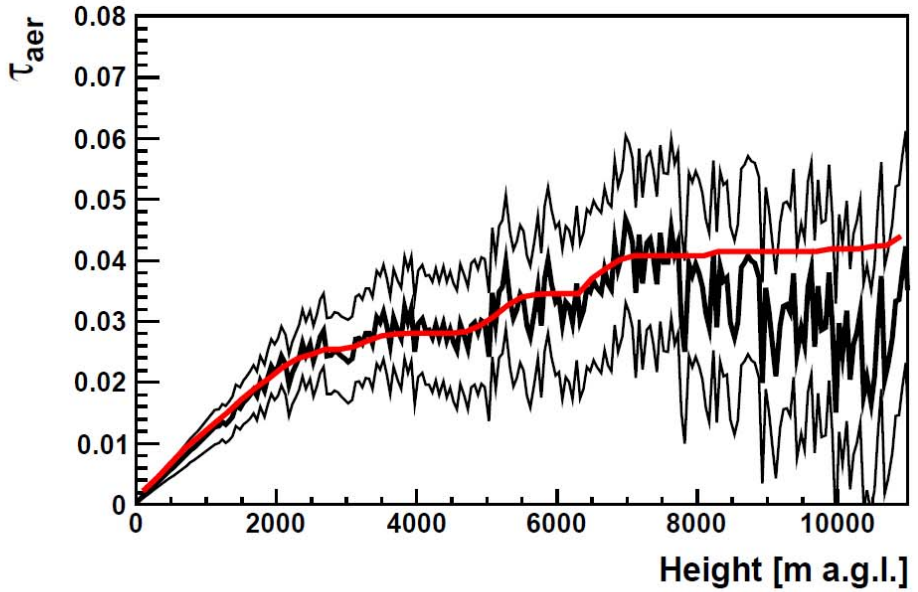
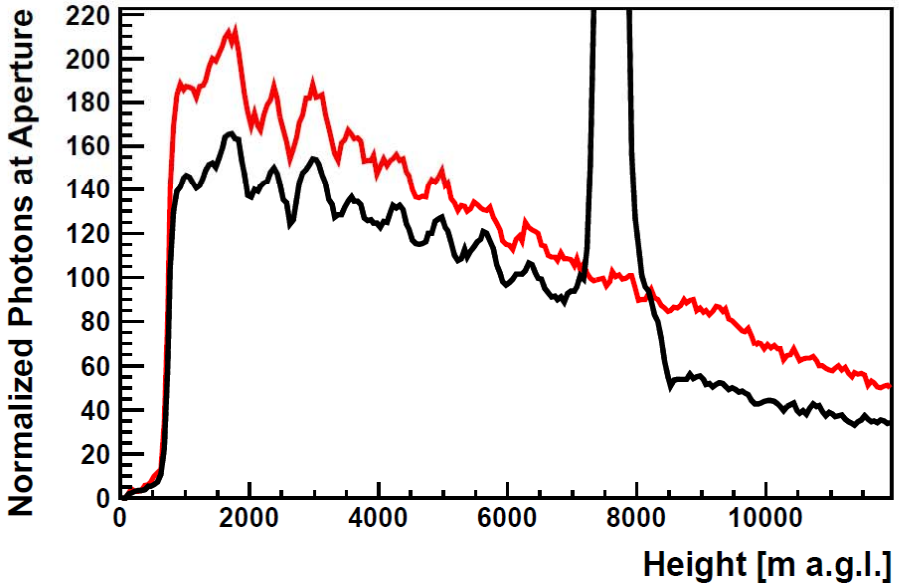
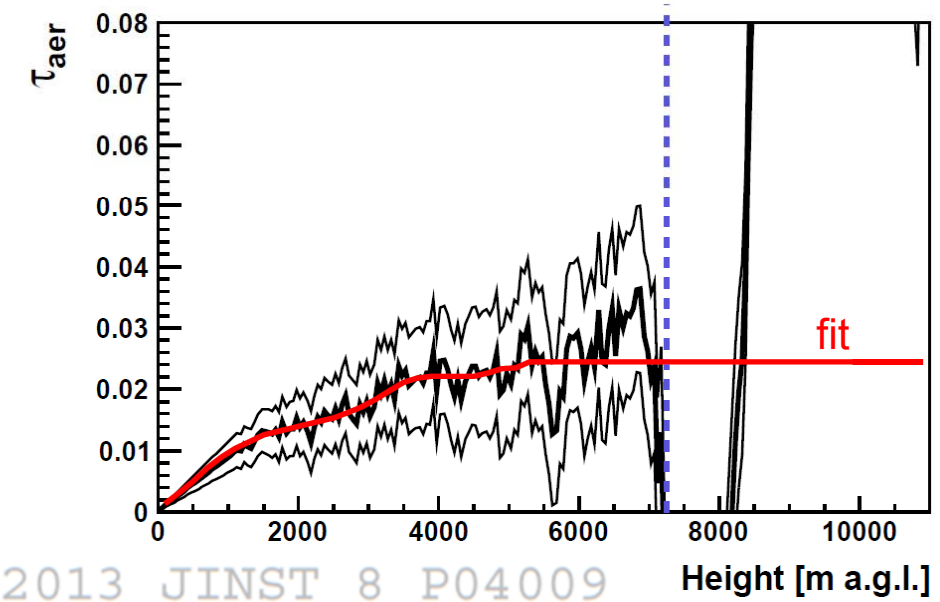
From light profiles to Vertical Aerosol Optical Depth









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Further devices for aerosol properties

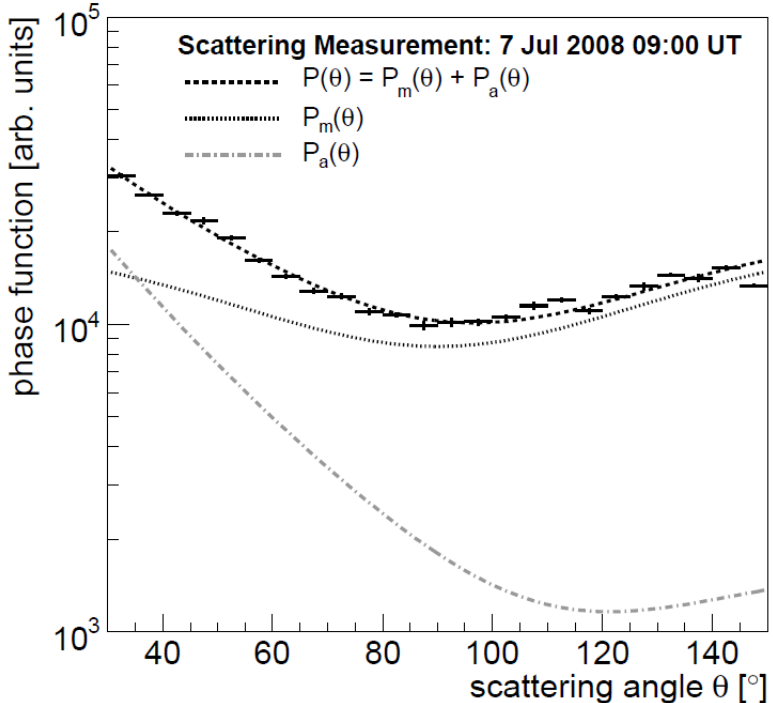
- HAM – Horizontal Attenuation Monitor

$$\tau_a(h,\lambda) = \tau(h,\lambda_0) \cdot \left(\frac{\lambda_0}{\lambda}\right)^{\gamma}$$

average at Auger side: $\gamma \approx 0.7 \pm 0.5$

- APF – Aerosol Phase Function monitor

$$P_a(\theta) = \frac{1-g^2}{4\pi} \cdot \left(\frac{1}{(1+g^2-2g\cos\theta)^{3/2}} + f\frac{3\cos^2\theta - 1}{2(1+g^2)^{3/2}}\right)$$



average at Auger side: $g \approx 0.56 \pm 0.10$

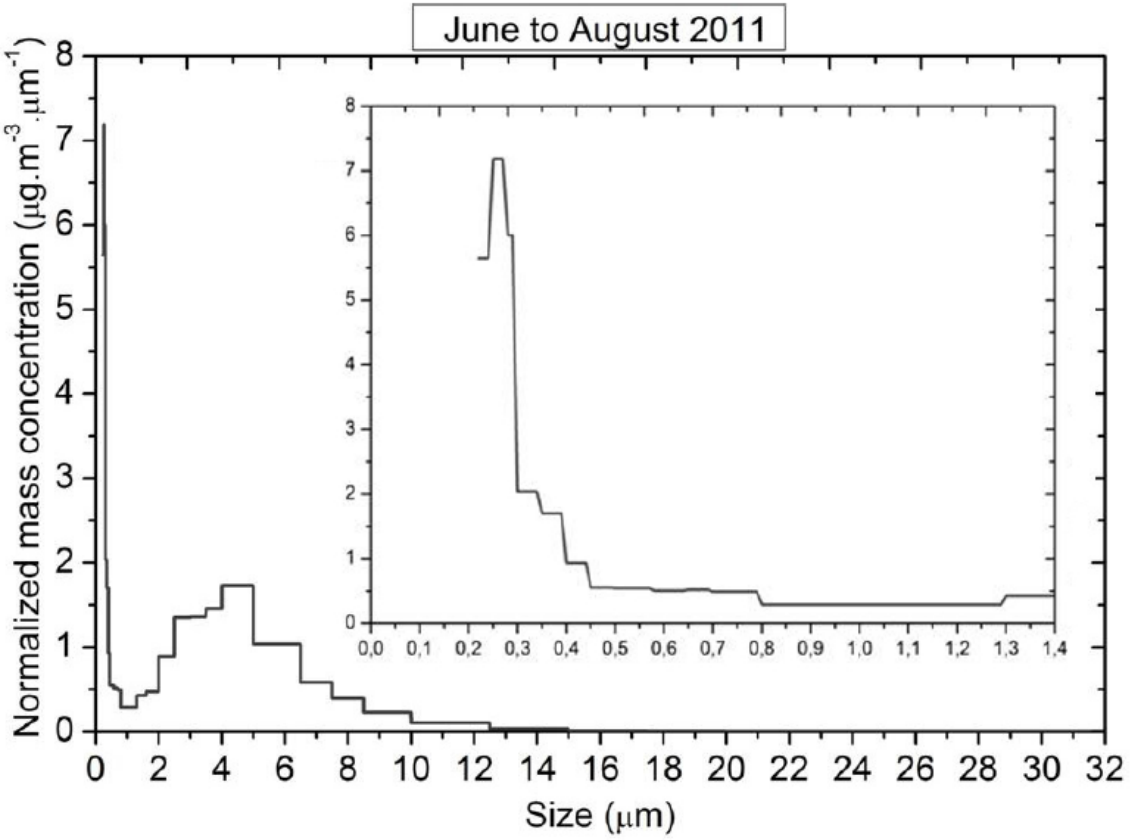
J. Abraham *et al.* Astropart. Phys. 33 (2010) 108

Further devices for aerosol properties

- Aerosol concentration, size, and elemental composition

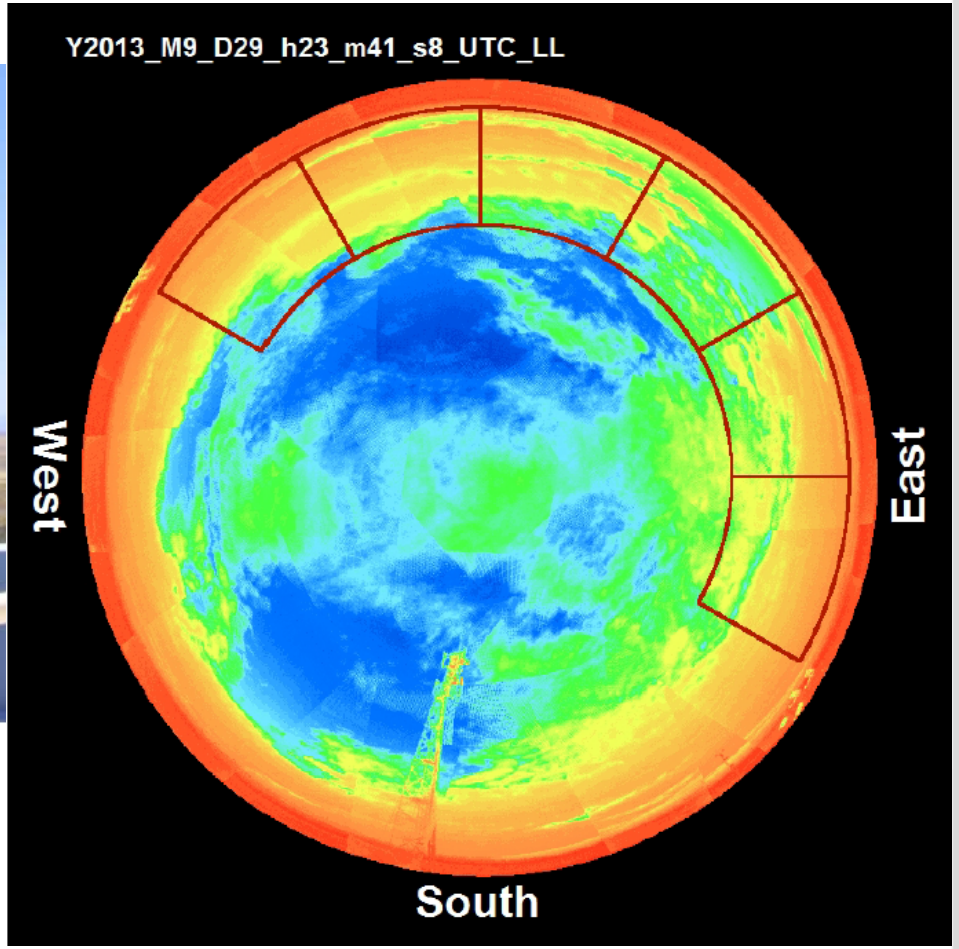
Andersen-Graseby 240 instrument @ Coihueco

Laser Aerosol spectrometer and Dust Monitor Grimm 1.109

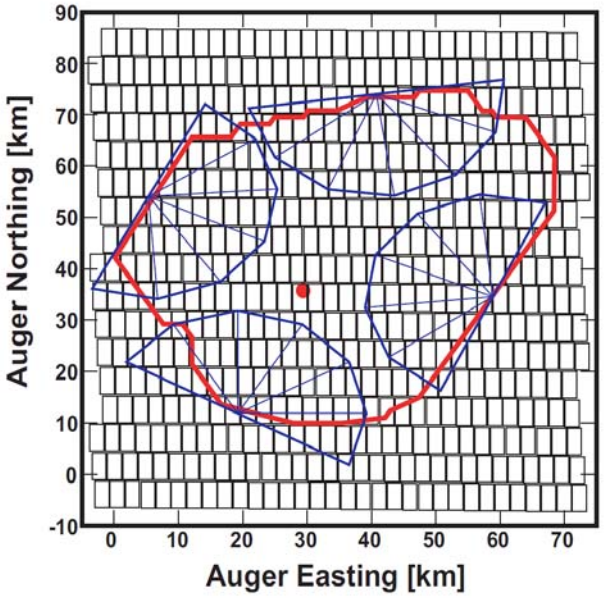


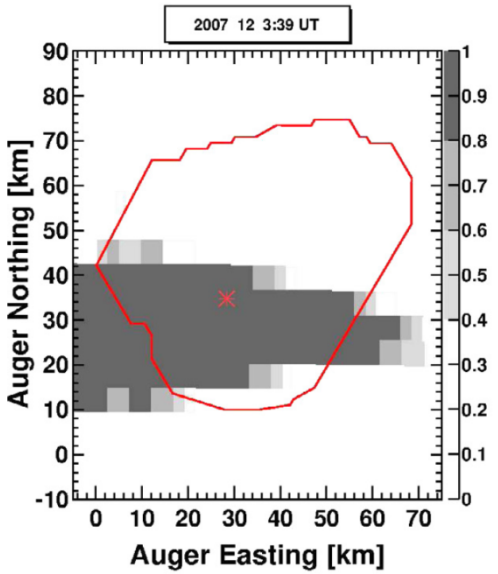
Infrared Cloud Cameras

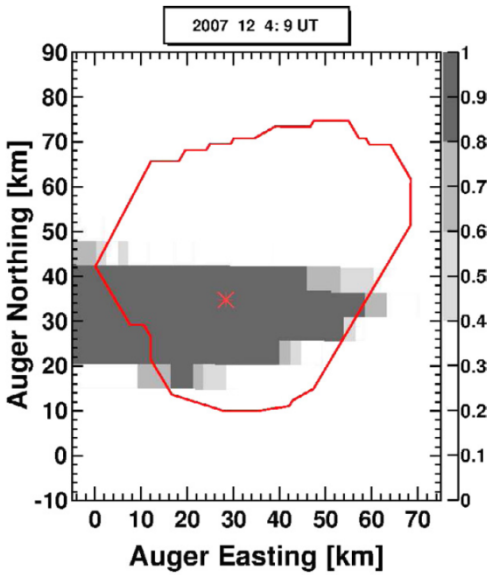
Gobi-384 radiometric microbolometer array infrared(IR) camera

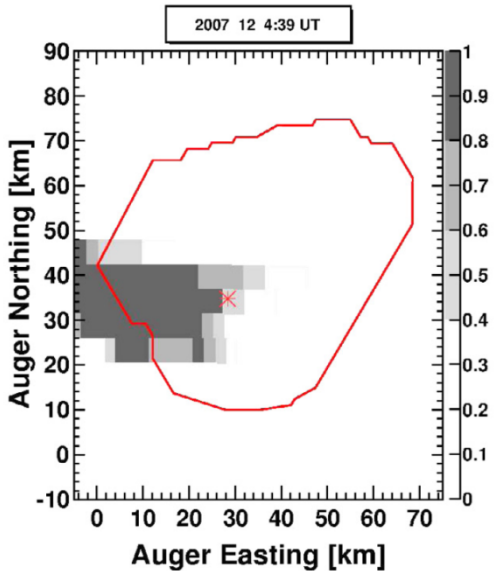


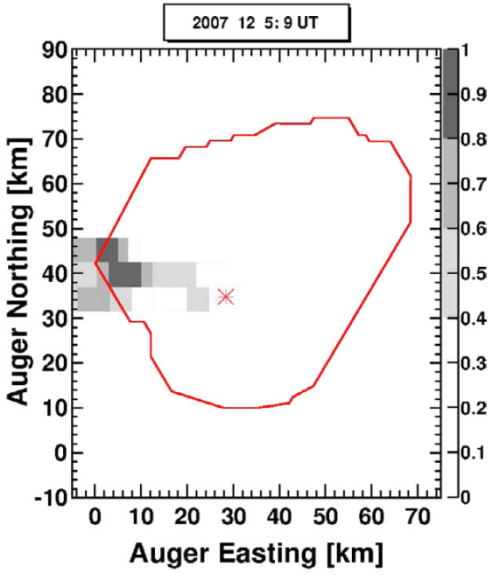
Cloud Identification with GOES-12











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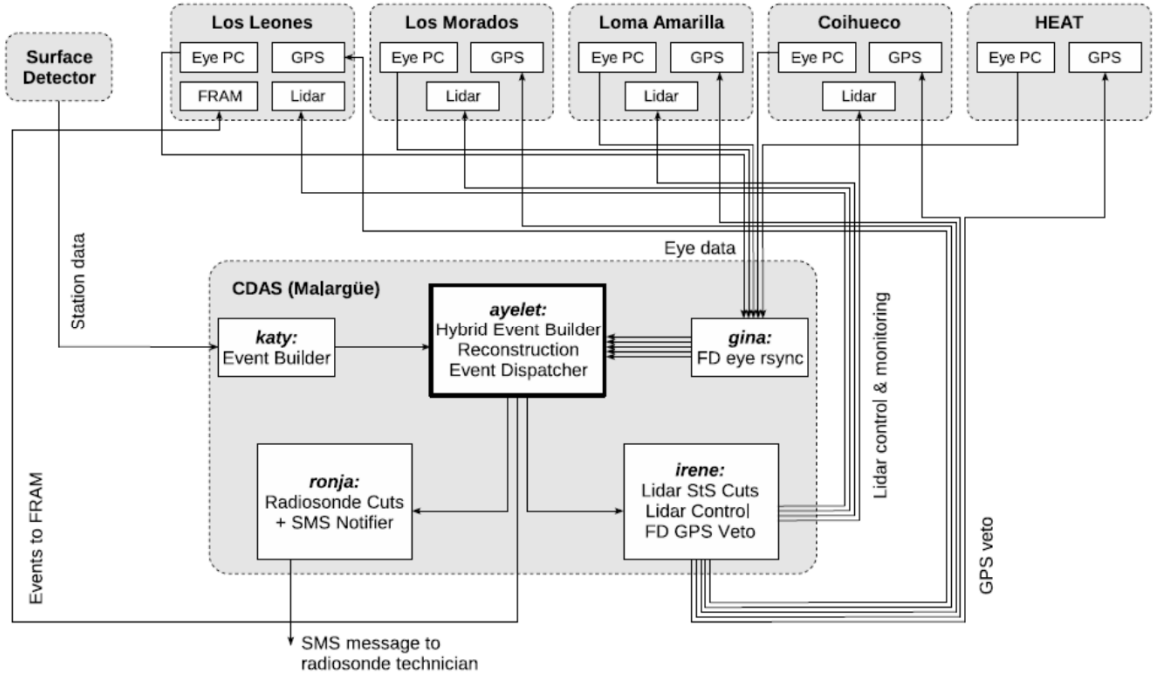
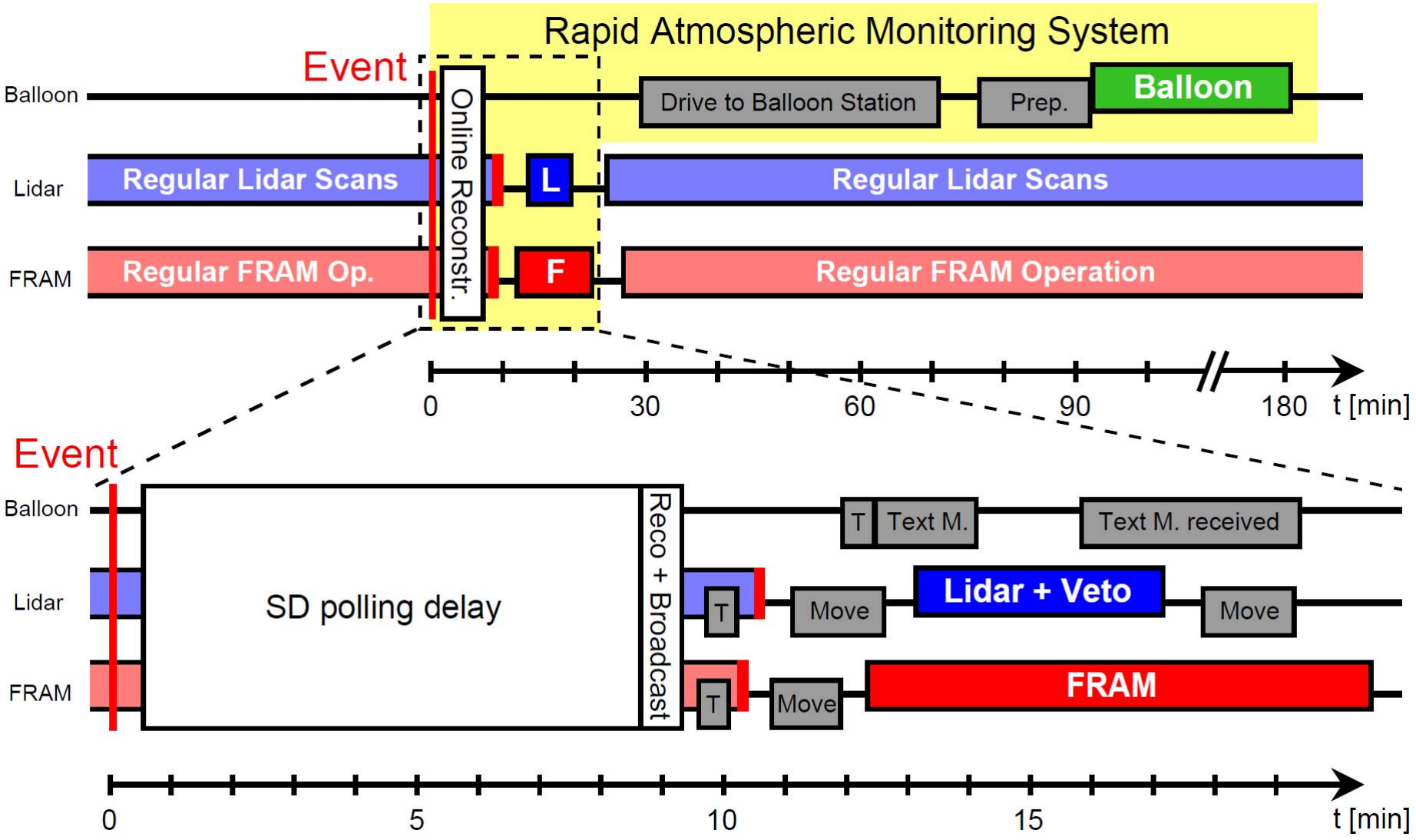
Rapid Atmospheric Monitoring

- Atmospheric observations shortly after detection of EAS of interest
- Fast online-reconstruction
- Participating instruments: lidar, radio soundings, FRAM
- programme started in spring 2009



2012 JINST 7 P09001

Rapid Atmospheric Monitoring



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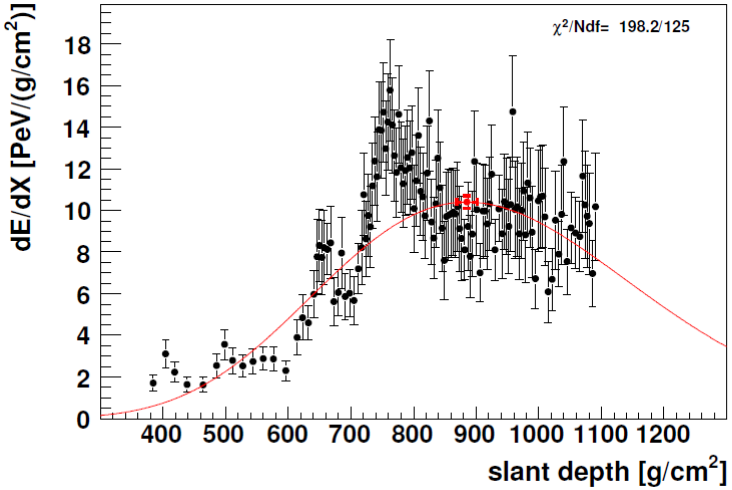
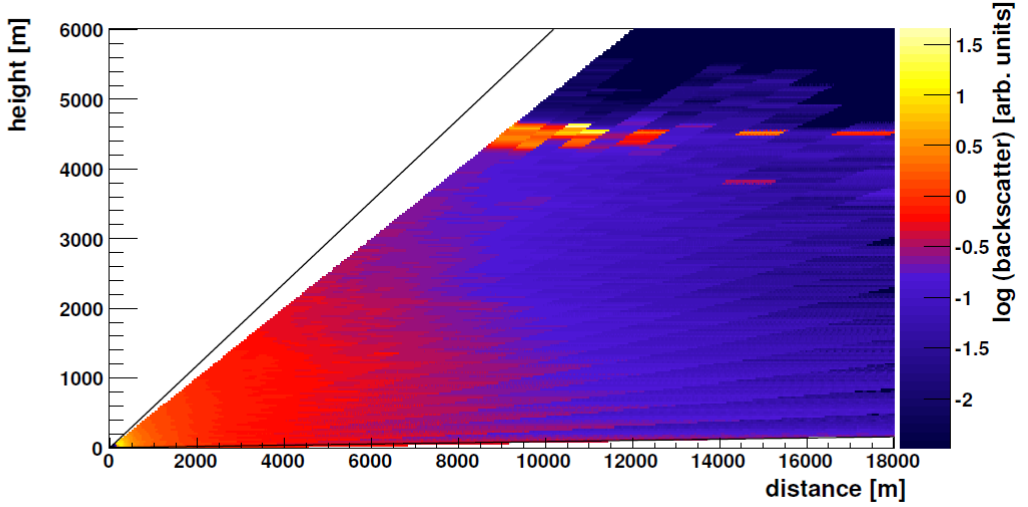
Lidars





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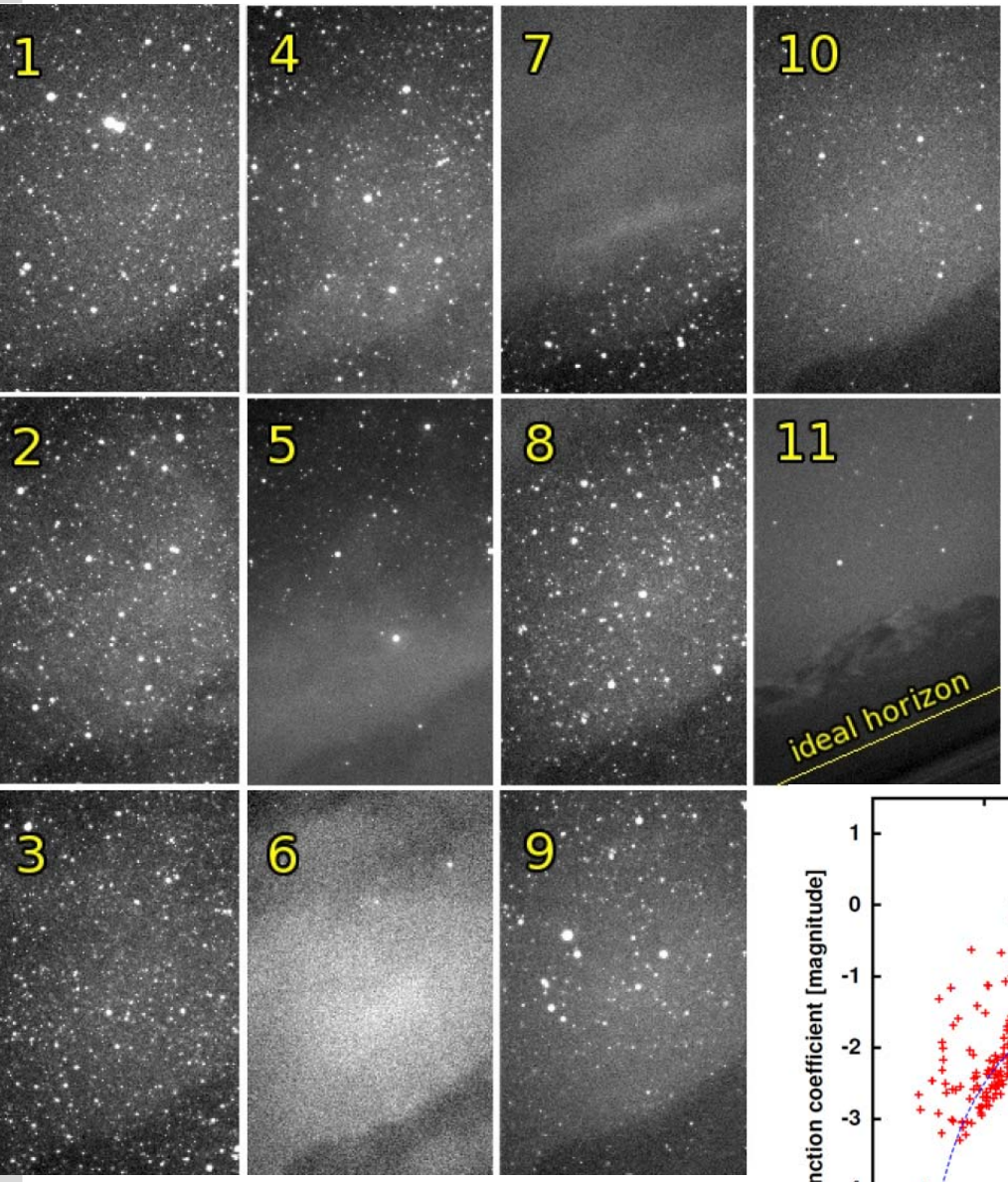
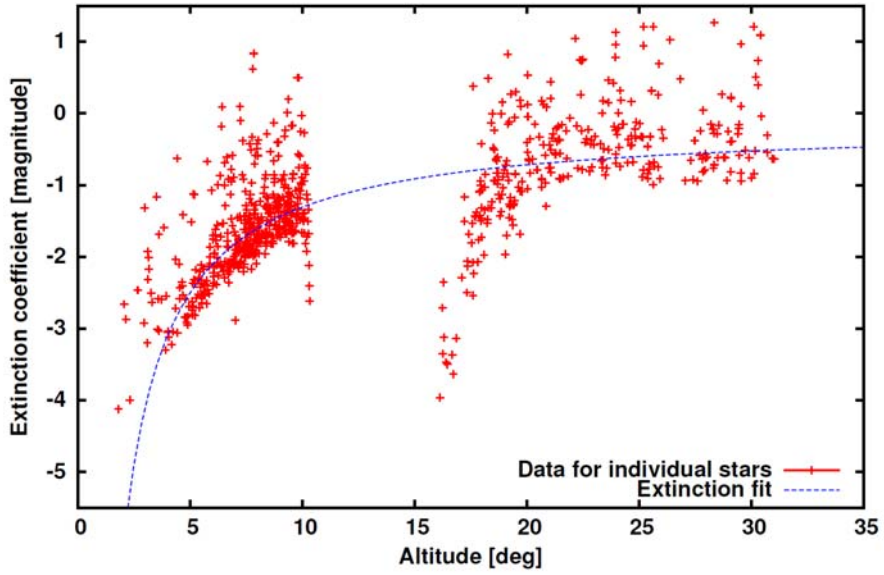
FRAM – (F/Ph)otometric Robotic Atmospheric Monitor





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Instrument Summary

Category	Variable	Frequency	Instrument(s)
State	At ground: Pressure, Temp., Wind, Humidity	5 min	Weather Stations
	Profile: Pressure, Temp., Humidity	3 hours	GDAS[a]
Aerosols	Vert. Optical Depth(z)	hourly	CLF, XLF + FD
	Phase Function	hourly	2 APF units
	Ångström Coefficent	hourly	FRAM (HAM)
Clouds	Presence in FD pixels	15 min	4 Cloud Cameras
	Behind FD sites	15 min	4 lidar stations
	Along select tracks	avg. 1/night	FRAM, lidar
	Above CLF/XLF	hourly	CLF, XLF + FD

Summary

- Actual atmospheric profiles must be known for a reliable EAS reconstruction
- Many devices are installed at the Pierre Auger Observatory
- Many data of atmospheric conditions are available for area Malargüe
- EAS reconstruction reaches a higher level of precision