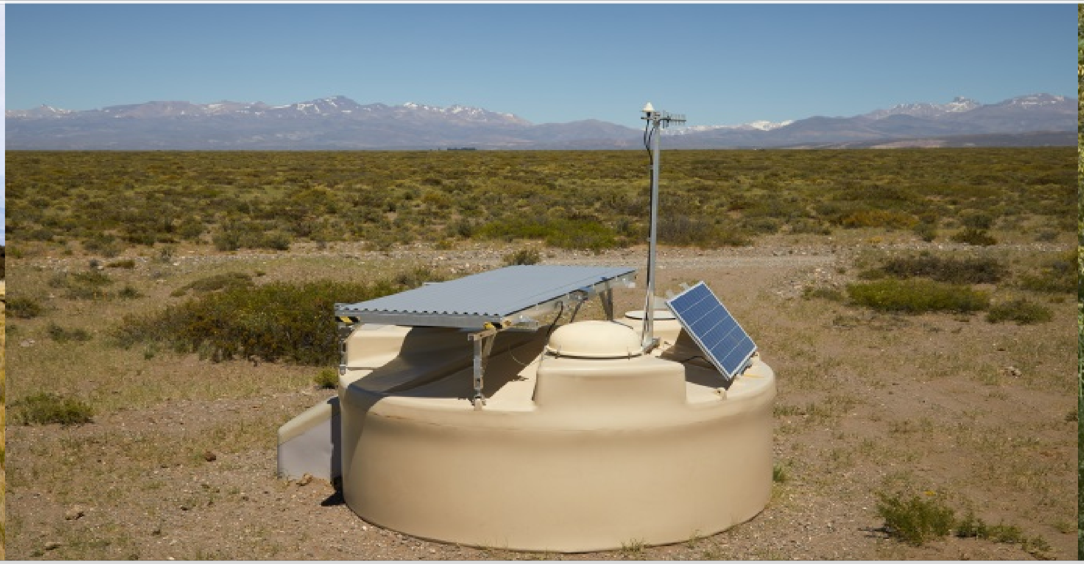
Karlsruher Institut für Technologie

PIERRE AUGER OBSERVATORY

Atmospheric Monitoring at a Cosmic Ray Observatory – a long-lasting endeavour

B. Keilhauer for the Pierre Auger Collaboration

AtmoHEAD - ATmospheric MOnitoring for High Energy Astroparticle Detectors - Anacapri, 24. – 26. September 2018



Atmospheric Monitoring Installations

Aerosols – content and properties:

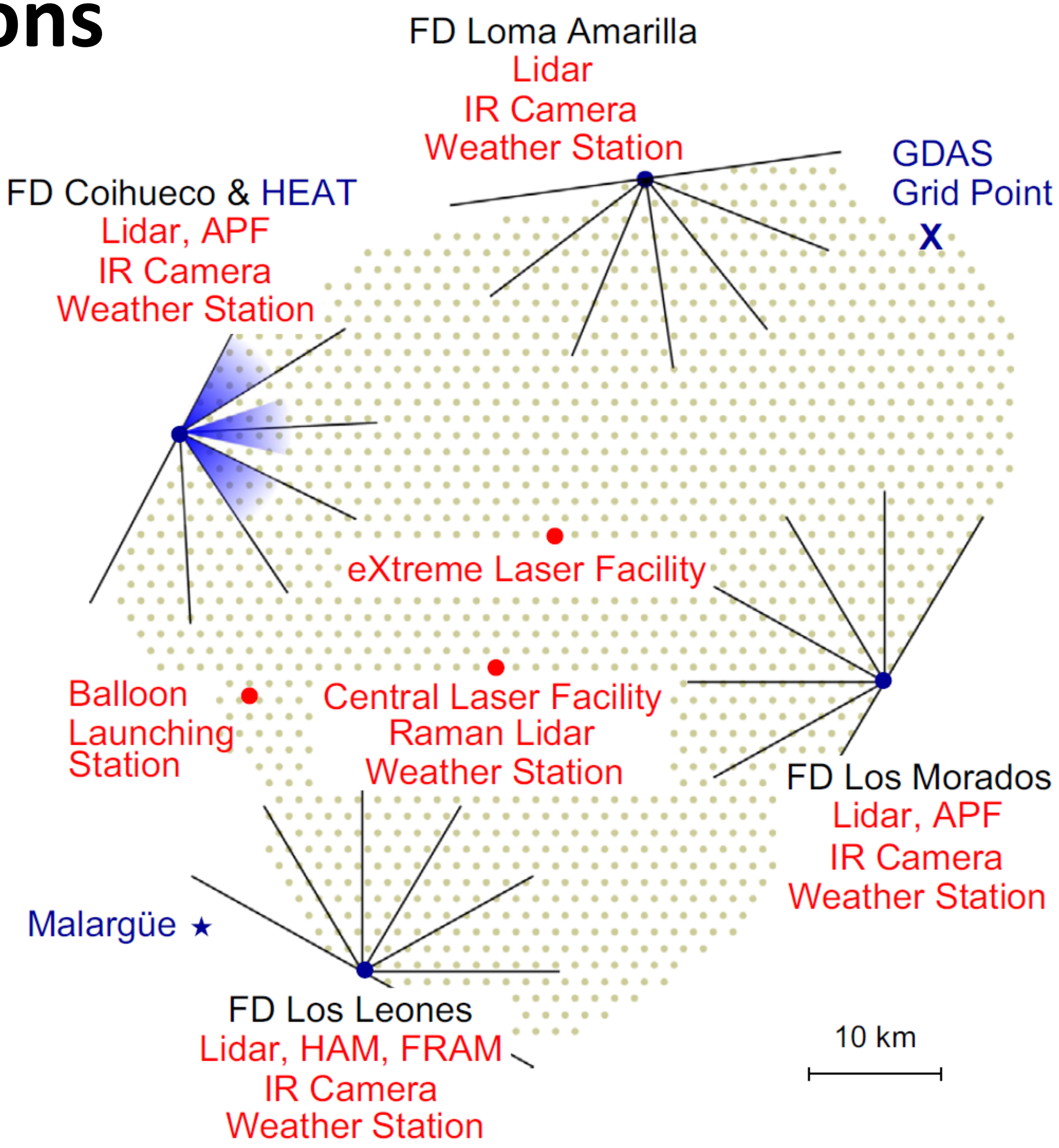
- CLF / XLF
- Elastic lidars
- Raman lidar
- Horizontal Attenuation Monitor HAM
- Aerosol Phase Function Monitor APF
- Ph(F)otometric Robotic Atmospheric Monitor FRAM

Clouds:

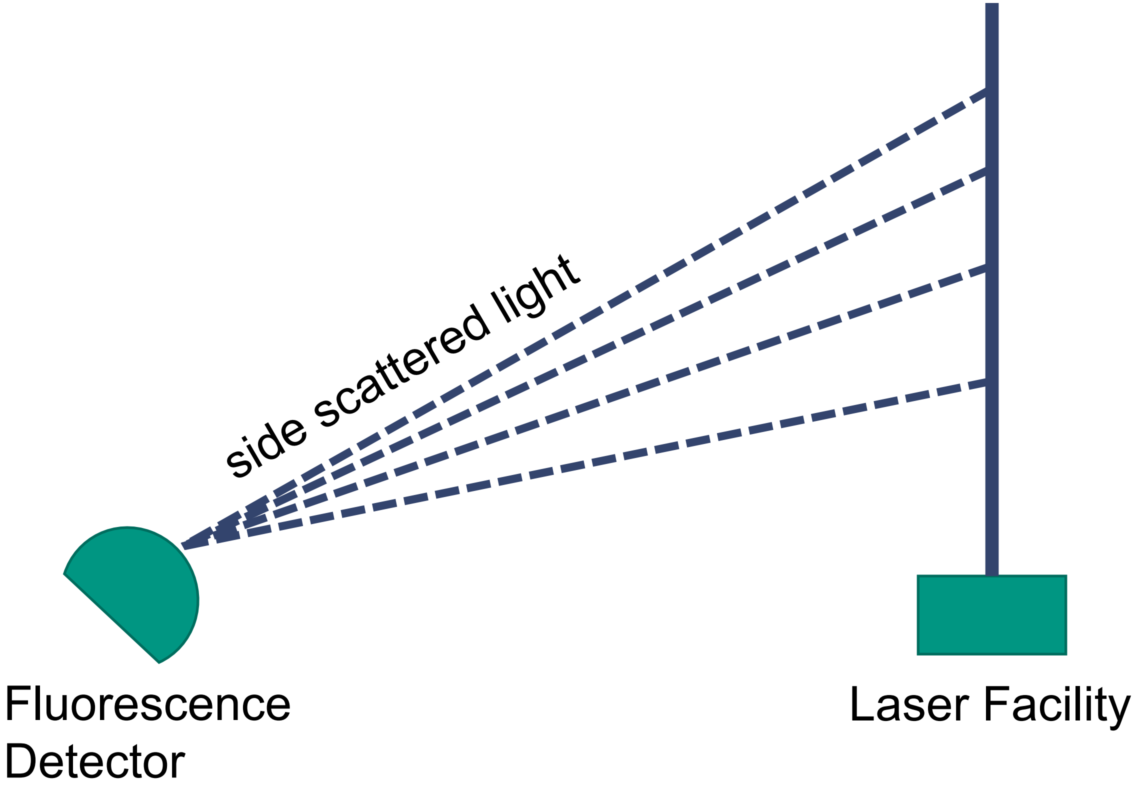
- IR Cameras
- Elastic lidar
- CLF / XLF

State variables:

- Weather stations
- Formerly: radio soundings



CLF / XLF



- vertical aerosol optical depth VAOD profiles

CLF / XLF

Operating scheme:

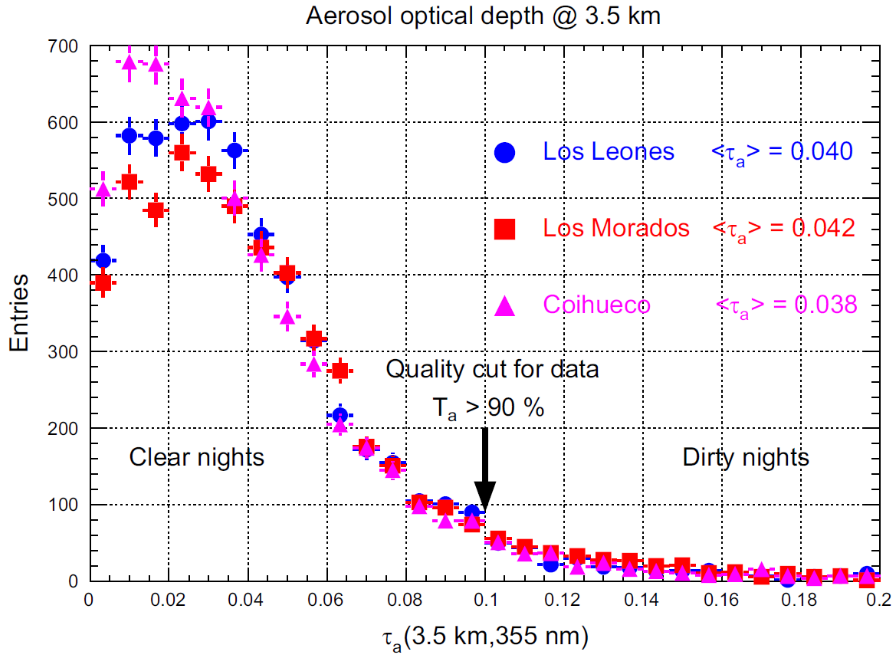
- During FD data taking
- 50 vertical laser shots every 15 min.
- Fully automated operation
- Check of data output by FD shifters

Data output

- Hourly averages of VAOD profiles
- CLF data since 2004
- XLF data since 2009
- Standard aerosol information of cosmic ray event reconstruction

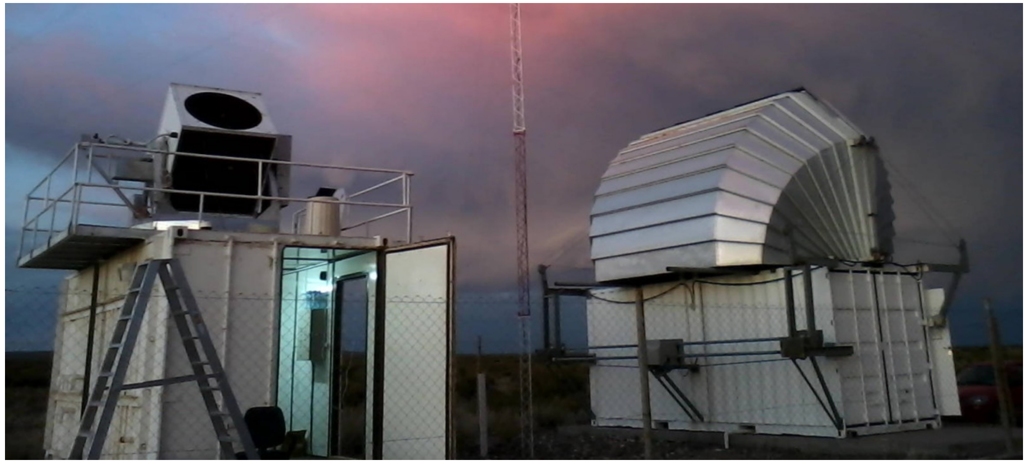
Challenges:

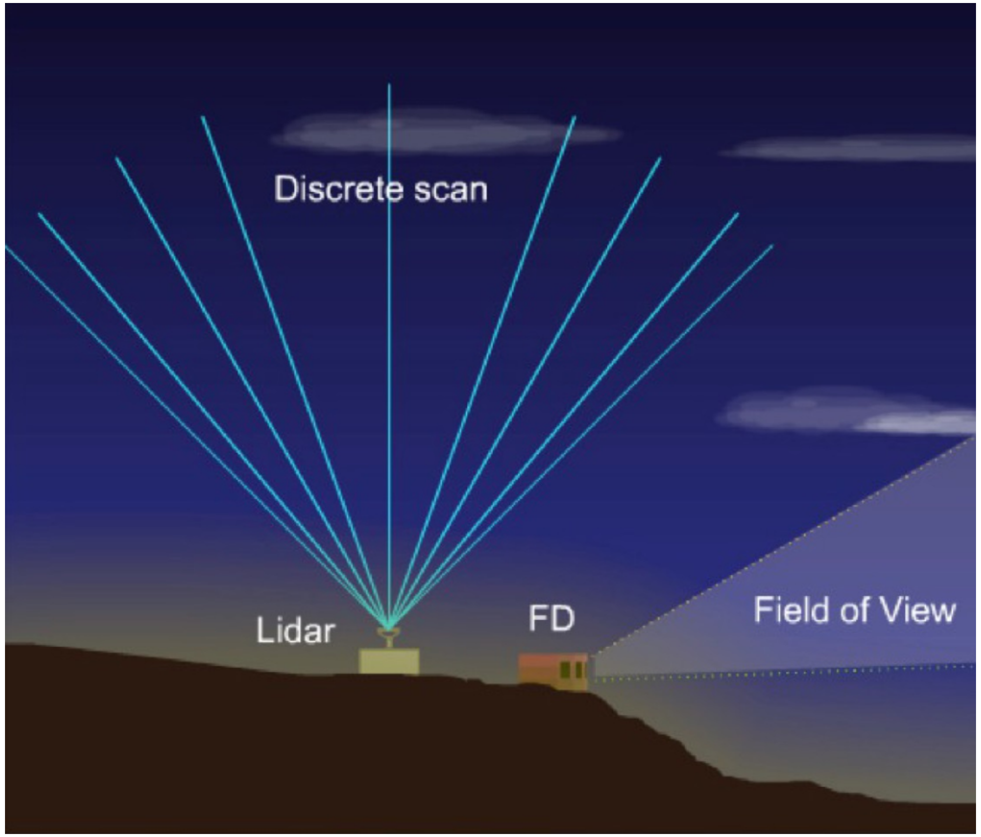
- Regular maintenance
- High costs of spare parts
- Sophisticated data analysis which is done quite manually



Data from Jan 2004 to Dec 2010

Elastic lidars





- ➢ Cloud base heights
- ➢ vertical aerosol optical depth VAOD profiles

Elastic lidars

Operating scheme:

- During FD data taking
- discrete and continuous scanning patterns
- FD shifters need to start, check, and finish data taking
- Scanning patterns are automated

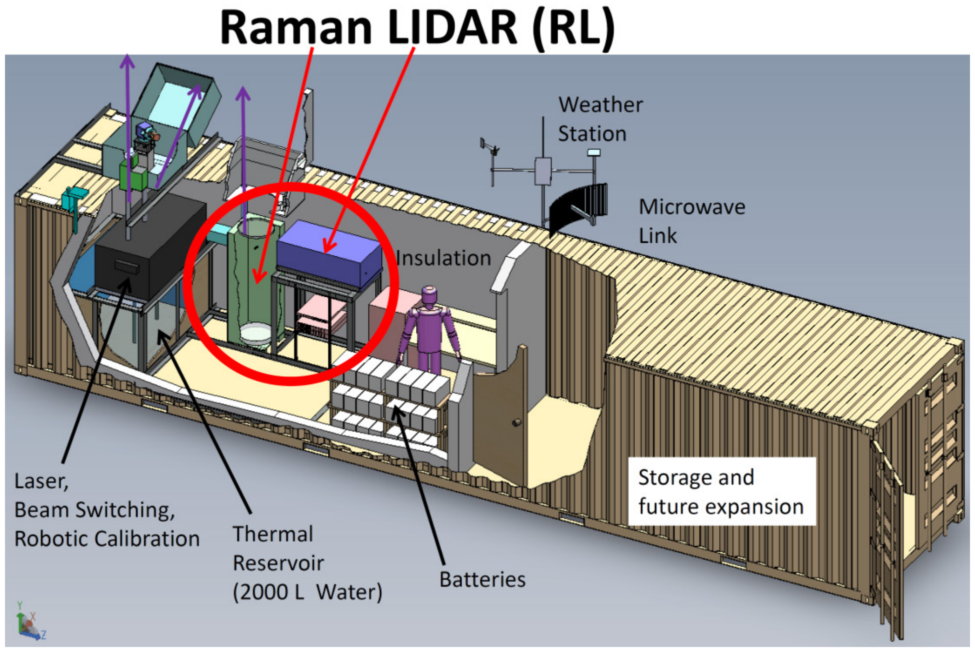
Data output

- Currently only cloud base heights
- VAOD profiles possible, typically behind FOV of FD telescopes
- Standard cloud base height information of cosmic ray event reconstruction

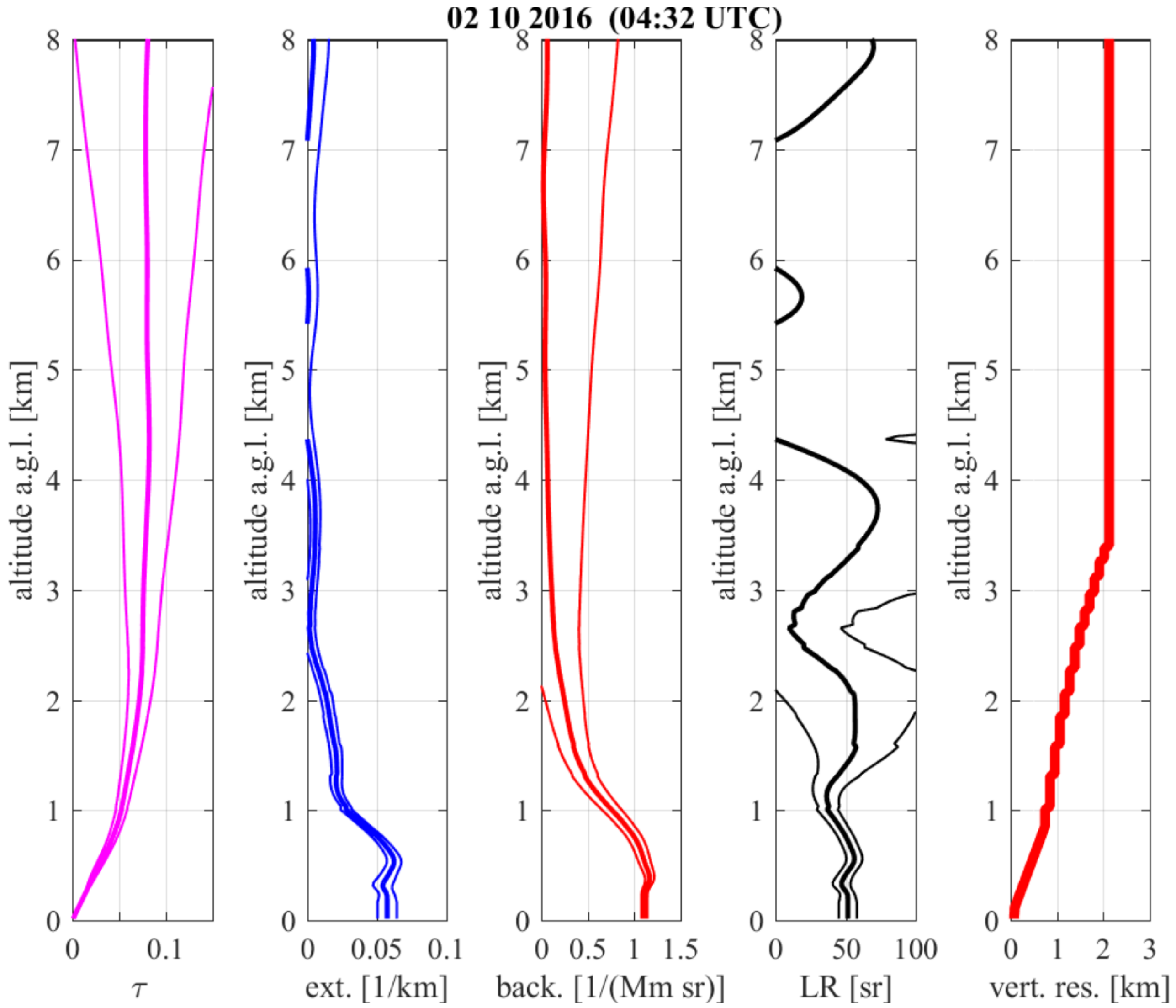
Challenges:

- Delicate allignment of optical system
- Lidar scans either behind FOV of FD or a balance between FD taking and lidar scans has to be found
- Regular maintenance
- High costs of spare parts
- Sophisticated data analysis which is done quite manually

Raman lidar



integrated in the CLF



- vertical aerosol optical depth VAOD profiles

Raman lidar

Operating scheme:

- During FD data taking
- 3 windows of 15 min: before, during, and after FD data taking

⇒ 15 min veto for FD data taking in FOV

- Fully automated operation
- Check of data output by L'Aquila group

Data output

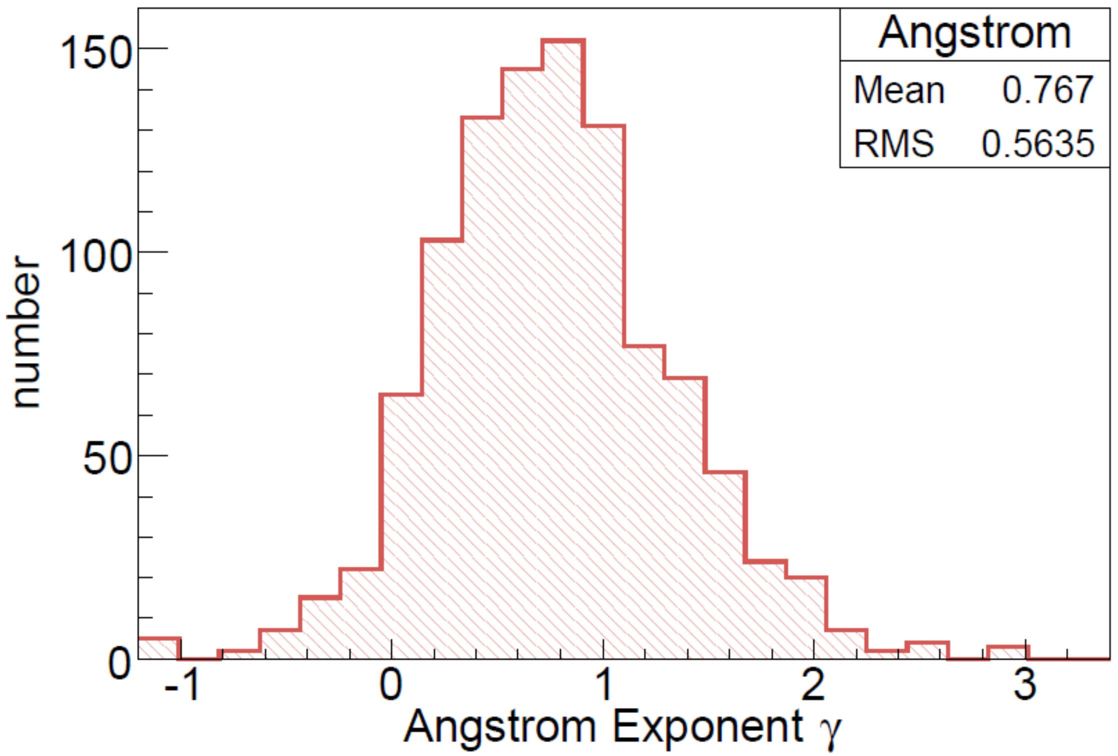
- VAOD profiles
- data since 2013
- Currently used for cross-checks with CLF

Challenges:

- Regular maintenance
- High costs of spare parts
- Sophisticated data analysis which is done quite manually

Horizontal Attenuation Monitor HAM

- high intensity discharge lamp at Coihueco
- CCD camera at FD Los Leones, about 45 km distance
- 5 wavelengths between 350 nm and 550 nm

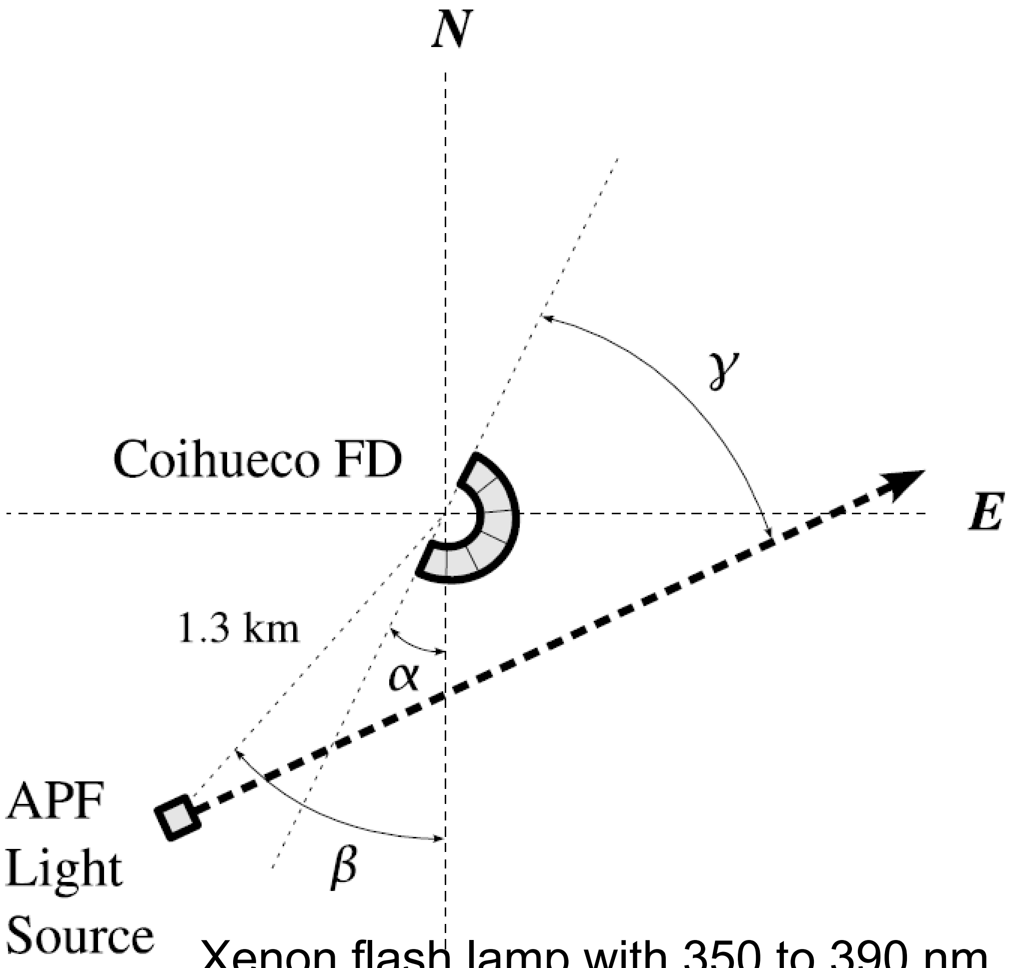


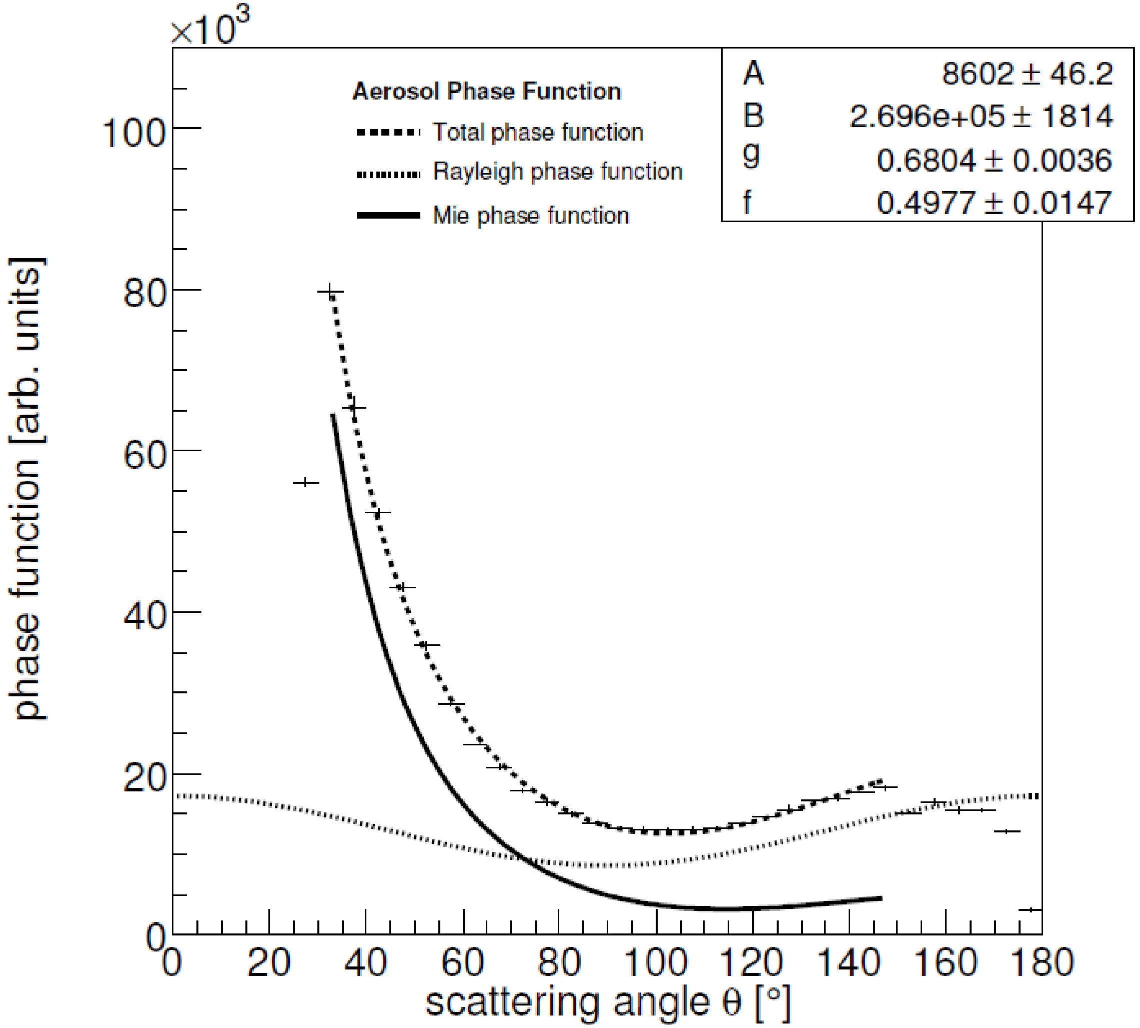
Data from Jul 2006 to Feb 2007

Data output

- Ångstrom exponent
- $$\tau(\lambda) = \tau_0 \cdot \left(\frac{\lambda_0}{\lambda}\right)^{\gamma}$$
- averaged γ factor is used in the cosmic ray event reconstruction

Aerosol Phase Function Monitor APF





Xenon flash lamp with 350 to 390 nm
Scattering angle 30° - 150°

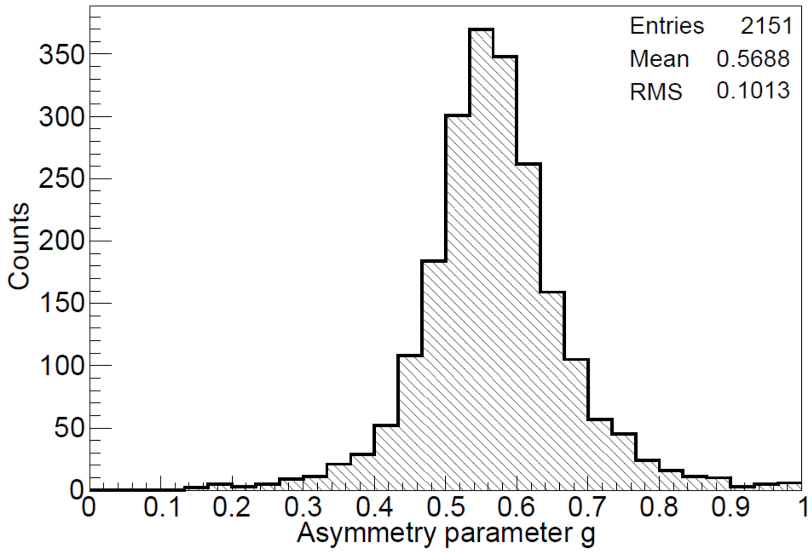
Aerosol Phase Function Monitor APF

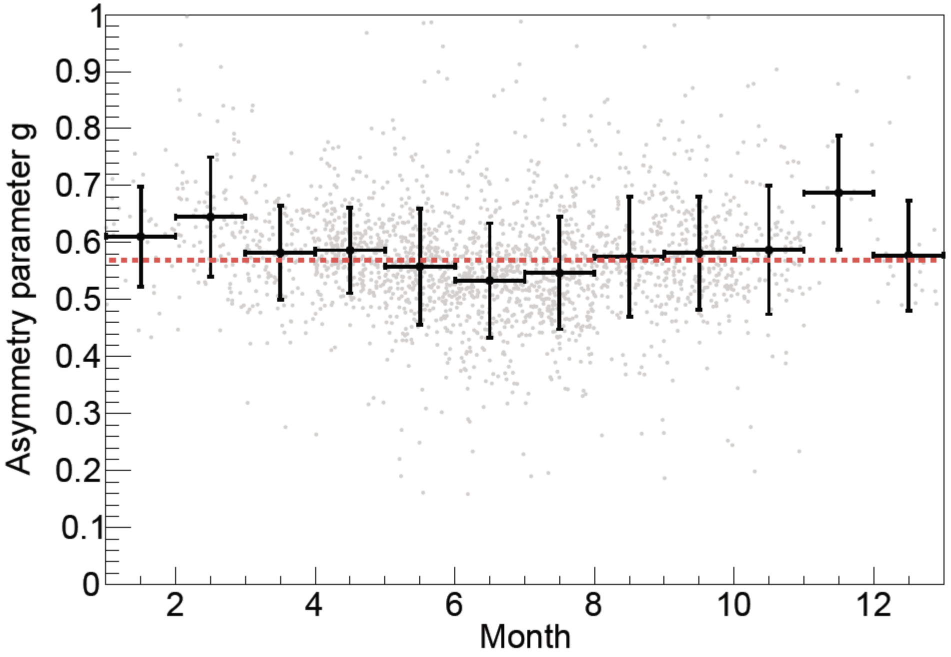
Operating scheme:

- During FD data taking
- At 2 FD sites
- Fully automated operation

Data output

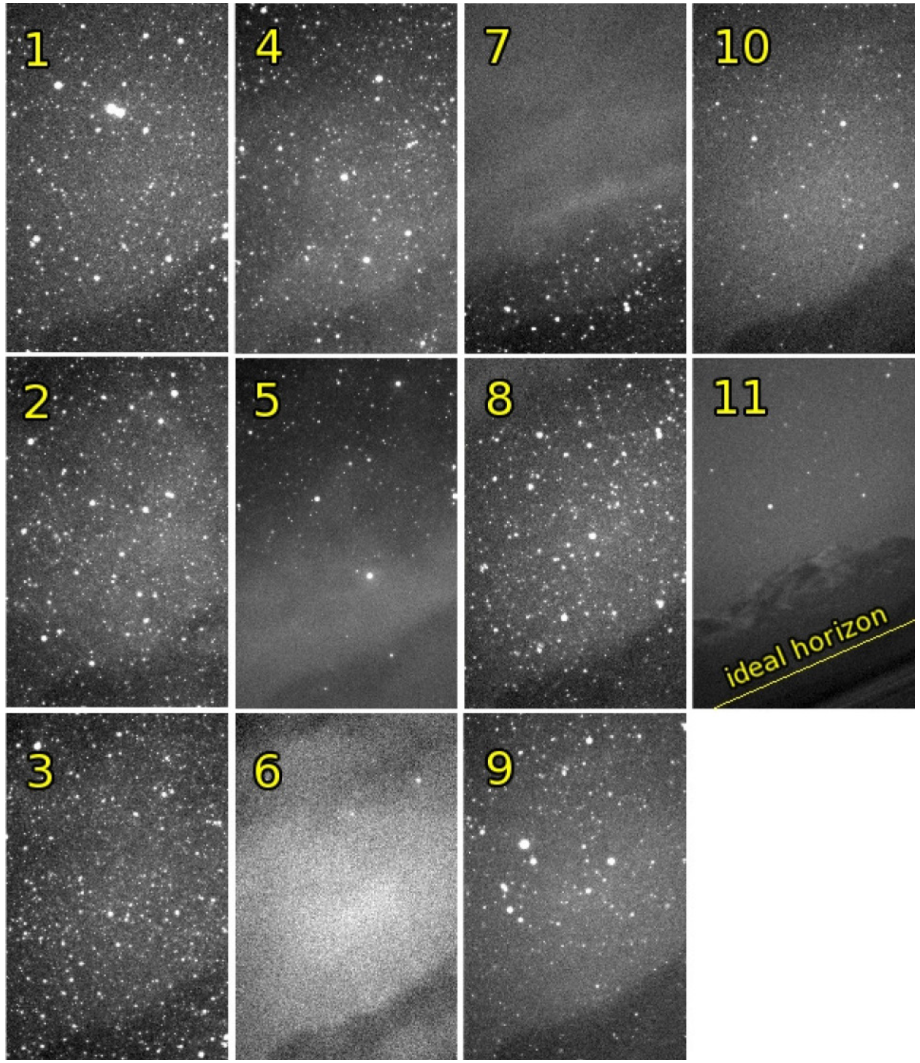
- Horizontal scattered light between 30° and 150°
- Average value for g, describes the asymmetry of scattering, derived
- This averaged g factor is used in the cosmic ray event reconstruction





Data from 2011 to 2015

Ph(F)otometric Robotic Atmospheric Monitor FRAM



- ➢ Integral extinction

Ph(F)otometric Robotic Atmospheric Monitor FRAM

Operating scheme:

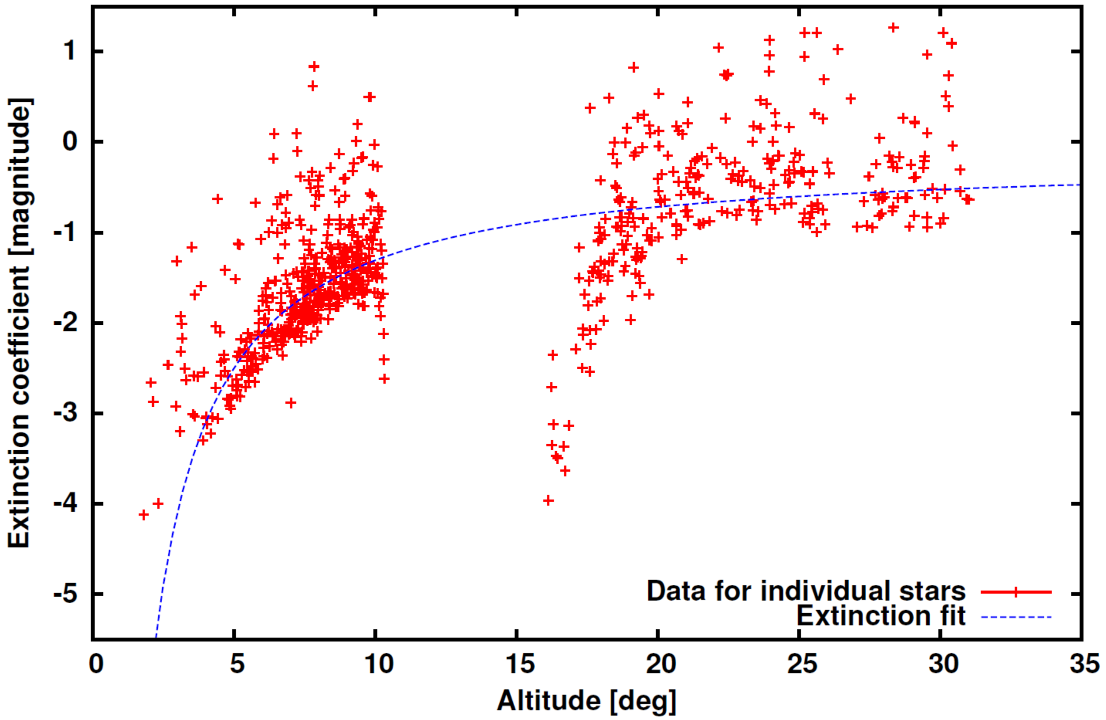
- During FD data taking
- Fully automated operation
- Continuous data taking and particular triggers for ‚shoot-the-shower'
- Check of data output by Prague group

Data output

- Extinction data for ‚double bump' events
- Ångstrom exponent
- Recently AOD
- Data since 2006

Challenges:

- Regular maintenance
- Sophisticated data analysis which is done quite manually



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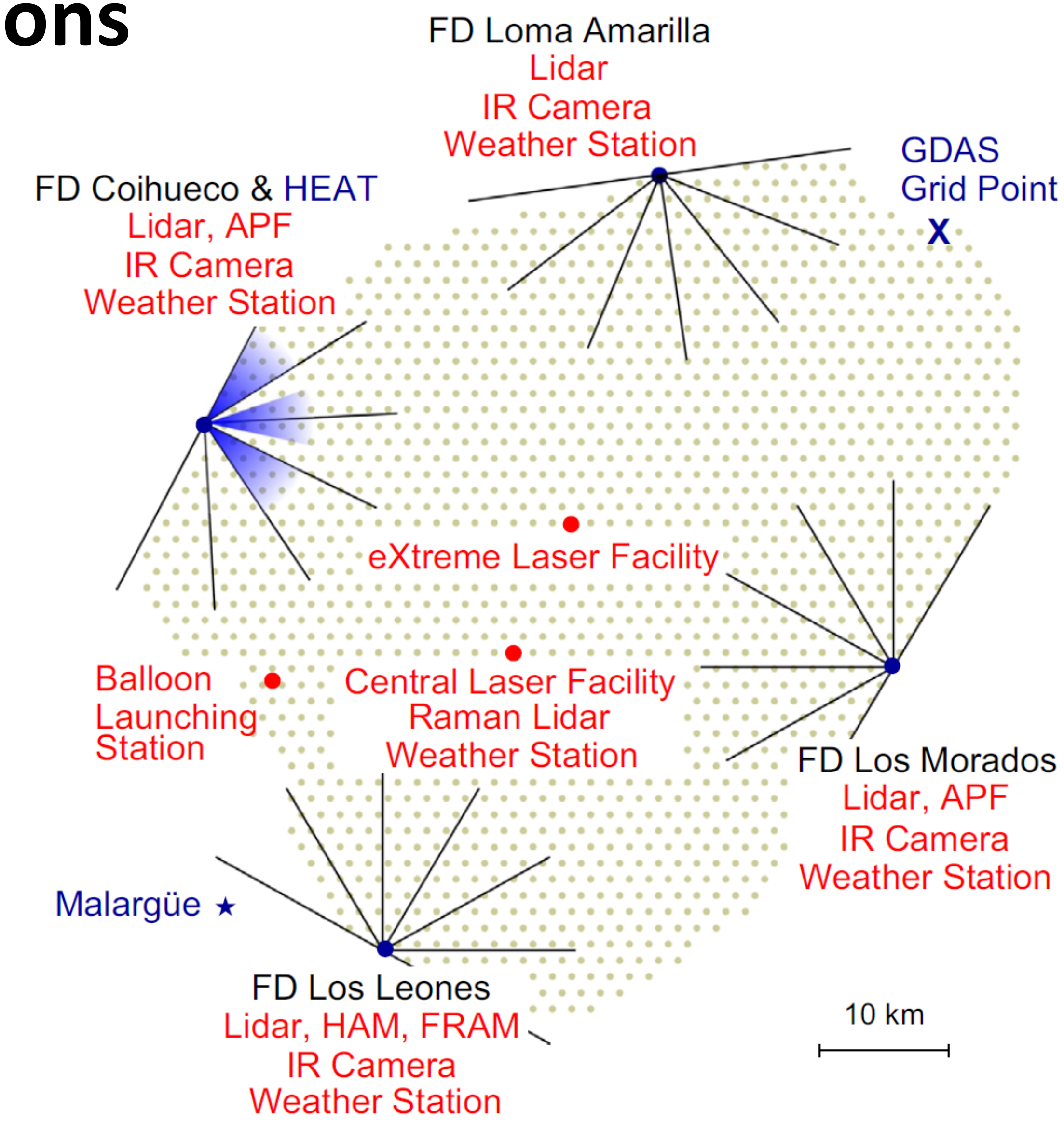
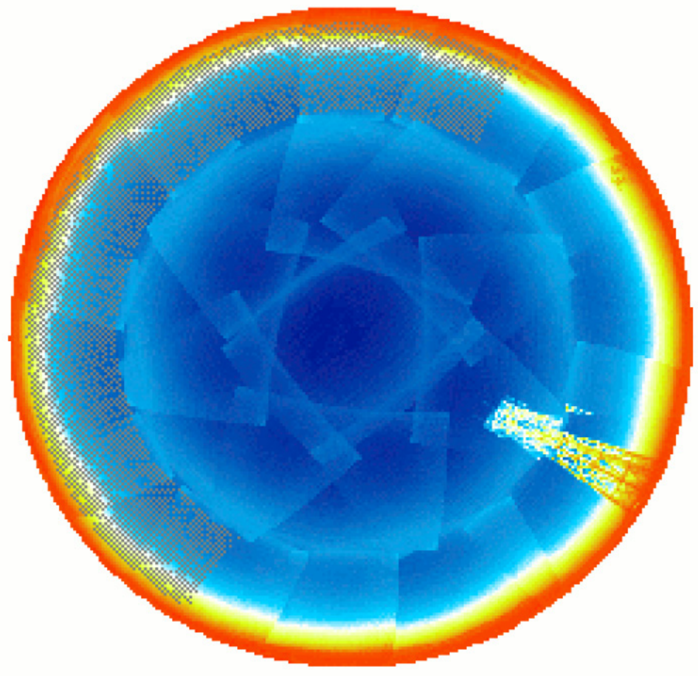
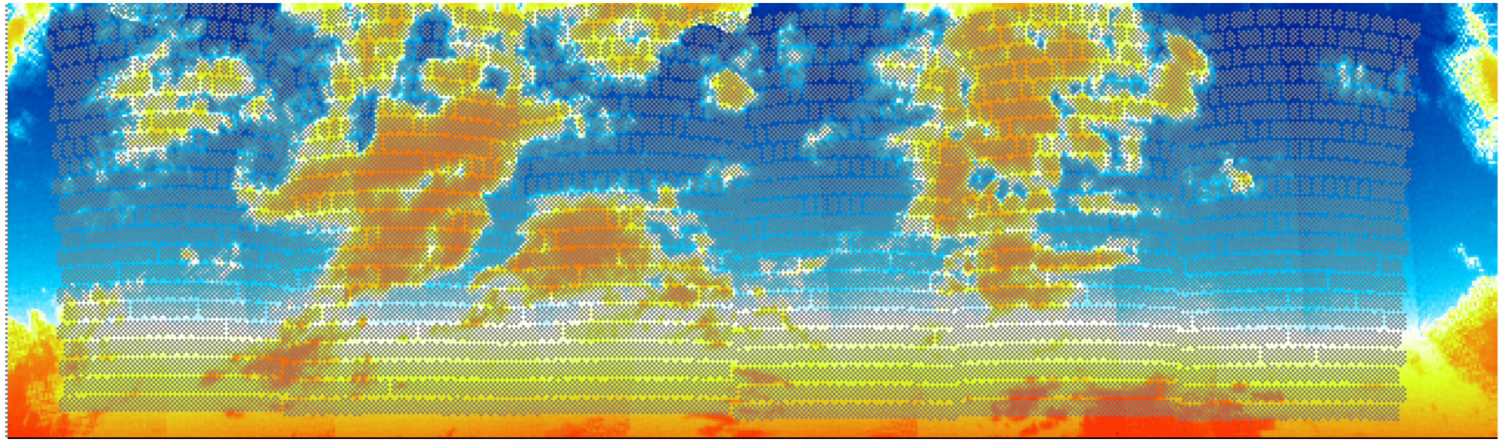


Infrared cloud cameras



Hemisphere picture



Clouds in the FOV of a FD

- Cloud cover

Infrared cloud cameras

Operating scheme:

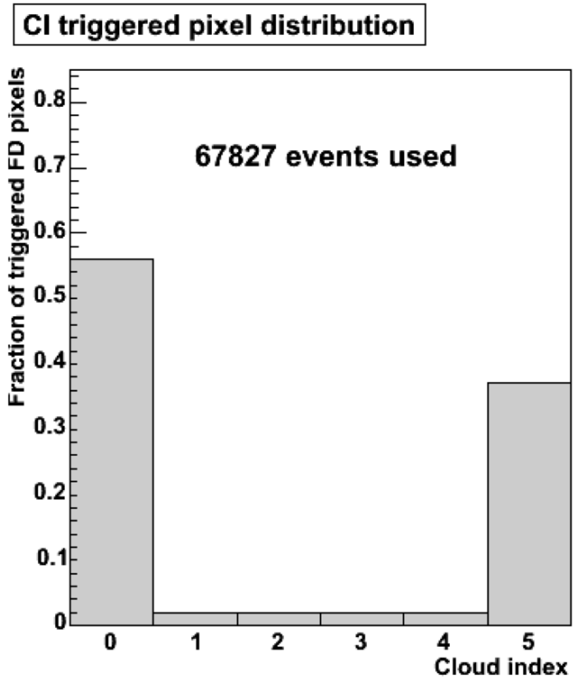
- During FD data taking
- Fully automated operation
- Every 15 min. full hemisphere
- Every 5 min. in FOV of FD

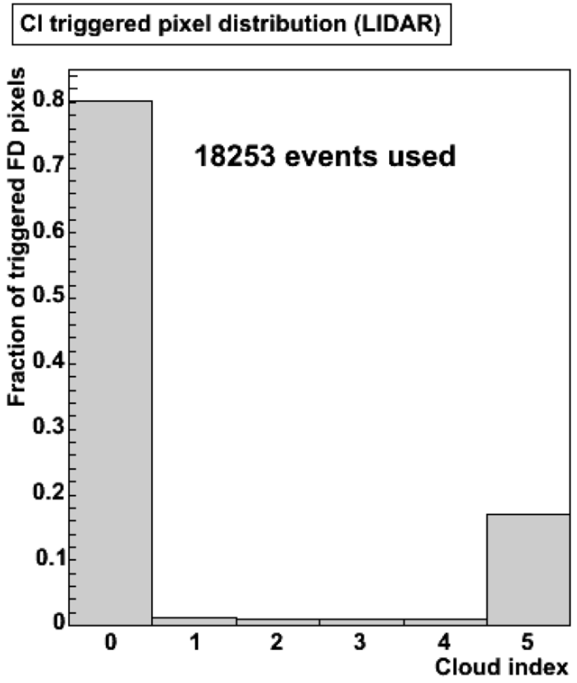
Challenges:

- Regular maintenance
- Sophisticated data analysis which is done quite manually

Data output

- Standard cloud cover information of cosmic ray event reconstruction
- Data since 2004





Weather Stations

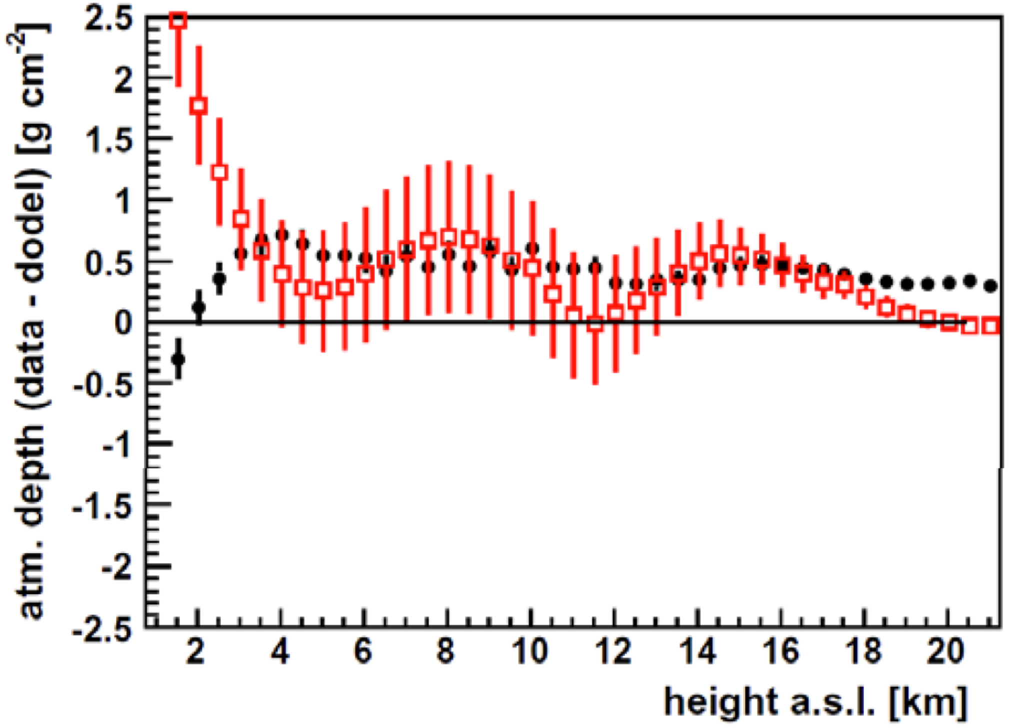
- At each of the four FD sites and at the CLF
- Atmospheric state variables

Data output

- Every 5 min. T, p, u, wind information
- Derived data density, atmospheric depth, water vapour
- Fully automated scripts to process the data for use in the cosmic ray event reconstruction

Radio Soundings – Atmospheric Profiles

- 331 radio soundings of state variables
- Data between 2002 and 2010
- Used to validate GDAS



Data of GDAS

- Every 3 hours
- At 23 constant pressure levels
- Fully automated scripts to process the data for use in the cosmic ray event reconstruction

Impact on the Energy Reconstruction

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%**

Conclusion

- Observatories run for many years up to few decades
- Atmospheric monitoring systems have to be designed for long-term operations, for low staff assignment during continuous operation, and for low maintenance effort
- In the designing phase of an observatory, the requirements for the atmospheric monitoring have to be defined carefully:
  - What data are needed in what precision, format, and which time intervalls?
  - How fast have these data to be available for cosmic ray data analyses?
  - How much of redundancy is aimed for?
  - Is the planning, installation, and design of analyses procedures of atmospheric monitoring systems fast enough to meet the needs of the observatory?
- It is recommended to rely on robust, most simple, and sufficiently automized atmospheric monitoring systems for use at cosmic ray observatories, because of their long-term operation at typically quite remote sites.