APF Light Sources for the Auger Southern Observatory

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1: The aerosol phase function ... why Auger cares

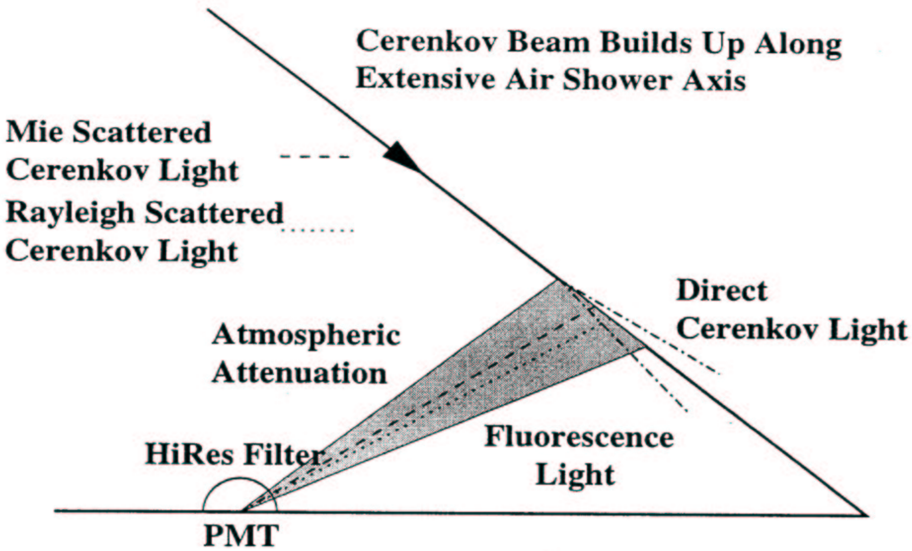
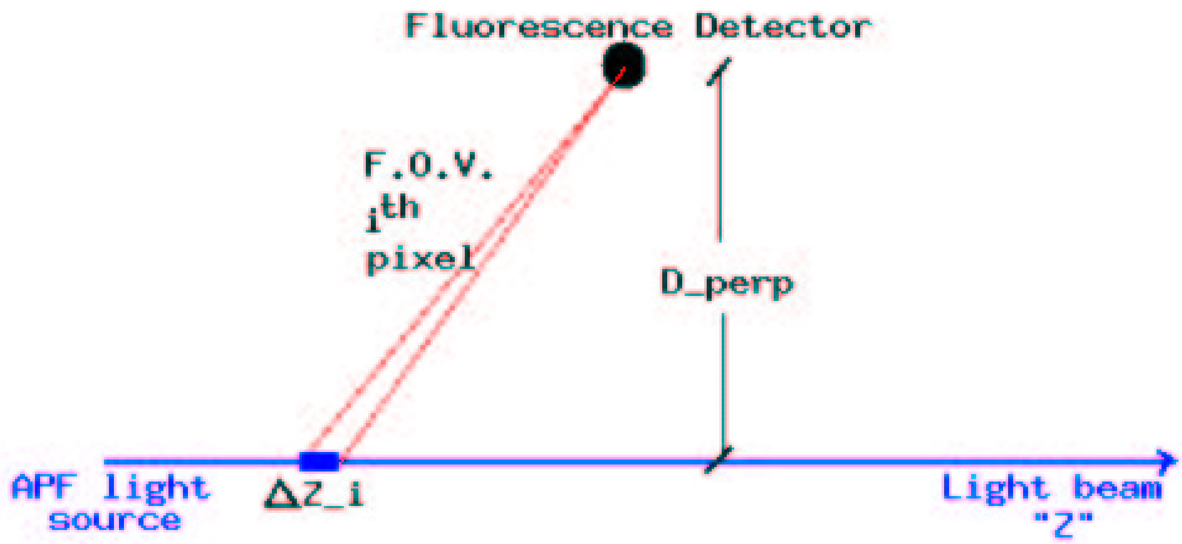


Figure 6.3: A summary of the factors that affect the light signal measured by the detector. Light is generated by the EAS and is attenuated as it travels to the detector. The actual signal measured will further depend upon detector parameters such as the transmission filter and PMT quantum efficiency. Note that most cases the light signal will be dominated by the fluorescence component.

From C.R. Wilkinson, *HiRes* thesis (1998)

- Through scattering in the air, some air Cherenkov light appears as a background in the fluorescence data.
- The observed light from an extensive air shower will also include a contribution of multiple-scattered light.
- To estimate the multiple-scattered and air Cherenkov light **scattered on aerosols we need the aerosol extinction length, $\Lambda^a(z,\lambda)$, and the aerosol phase function, $\frac{1}{\sigma^a}(\frac{d\sigma^a}{d\Omega})$.**

2: APF Light Source Geometry

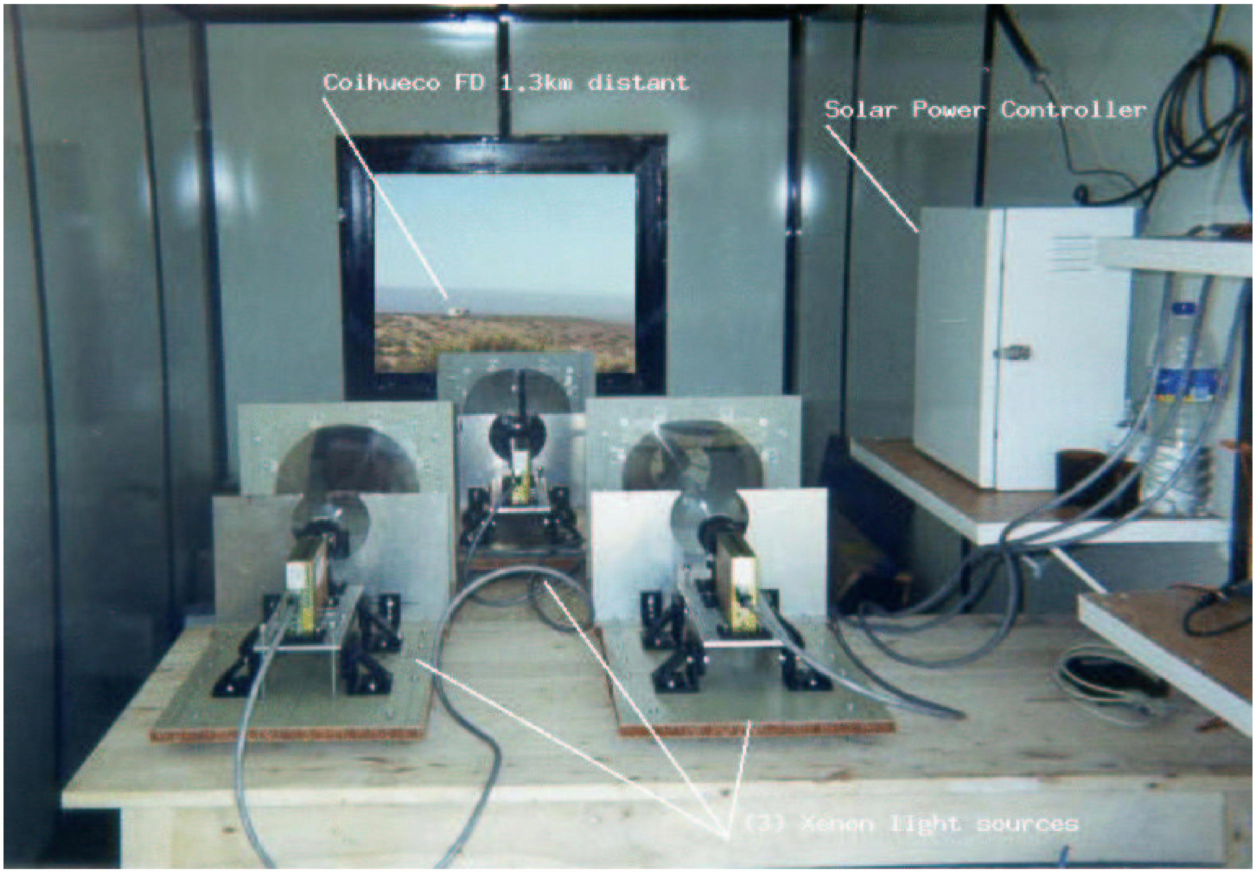


- As the Auger fluorescence detectors view $\sim 180°$ in azimuth, even a fixed direction light beam crossing the fluorescence field of view allows $\frac{1}{\sigma^a}(\frac{d\sigma^a}{d\Omega})$ to be determined.
- The FD signal, S_i, from the APF light source is:

$$S_i \;=\; I_0 \cdot T \cdot \left(\frac{1}{\Lambda^m(z)}[\frac{1}{\sigma^m}(\frac{d\sigma^m}{d\Omega})] \;+\; \frac{1}{\Lambda^a(z)}[\frac{1}{\sigma^a}(\frac{d\sigma^a}{d\Omega})] \right)_i \cdot \Delta z_i \cdot \Delta\Omega_i \cdot \epsilon_i$$

  - I_0 is the light source intensity
  - $T \;\approx\; e^{-lightpath/\Lambda_{tot}} \;\approx\; 1$ for typical *lightpaths*
  - Δz_i, $\Delta\Omega_i$ and ϵ_i are the track length, detector solid angle and efficiency for the i^{th} FD pixel
  - for *cylindrical* geometry: $\Delta z_i \cdot \Delta\Omega_i \;\approx\; \frac{Area \cdot \Delta\theta}{D_{perp}}$ independent of "i" (where $Area$ and $\Delta\theta$ are the telescope physical and angular acceptances)

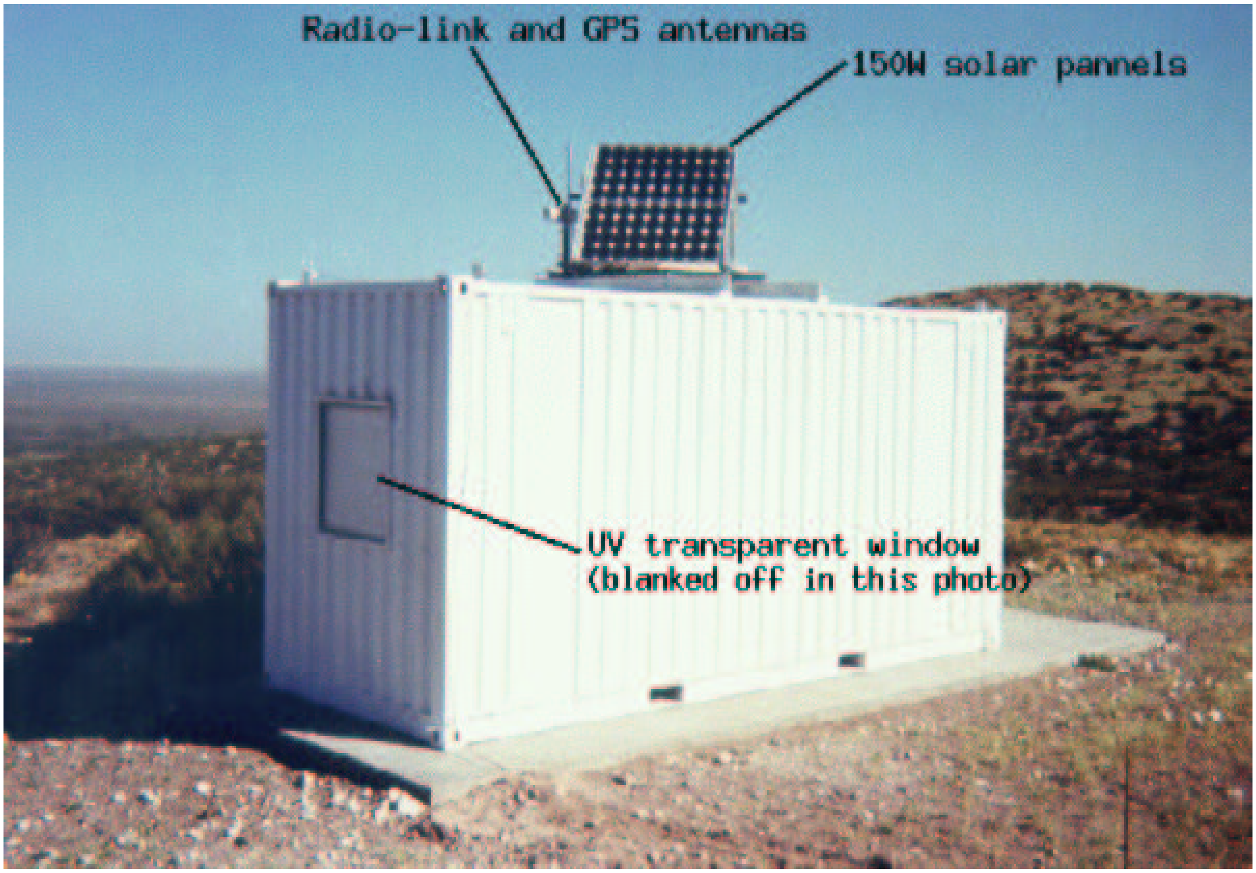
3: The first Auger APF light source



The APF light source includes three separate light sources at ∼330nm, 360nm and 390nm.

- The APF light sources provide a near-horizontal, pulsed light beam directed across the field of view of a near-by fluorescence detector.
- Three sources provide experimental cross checks as well as the potential to measure wavelength variations in the aerosol phase function.

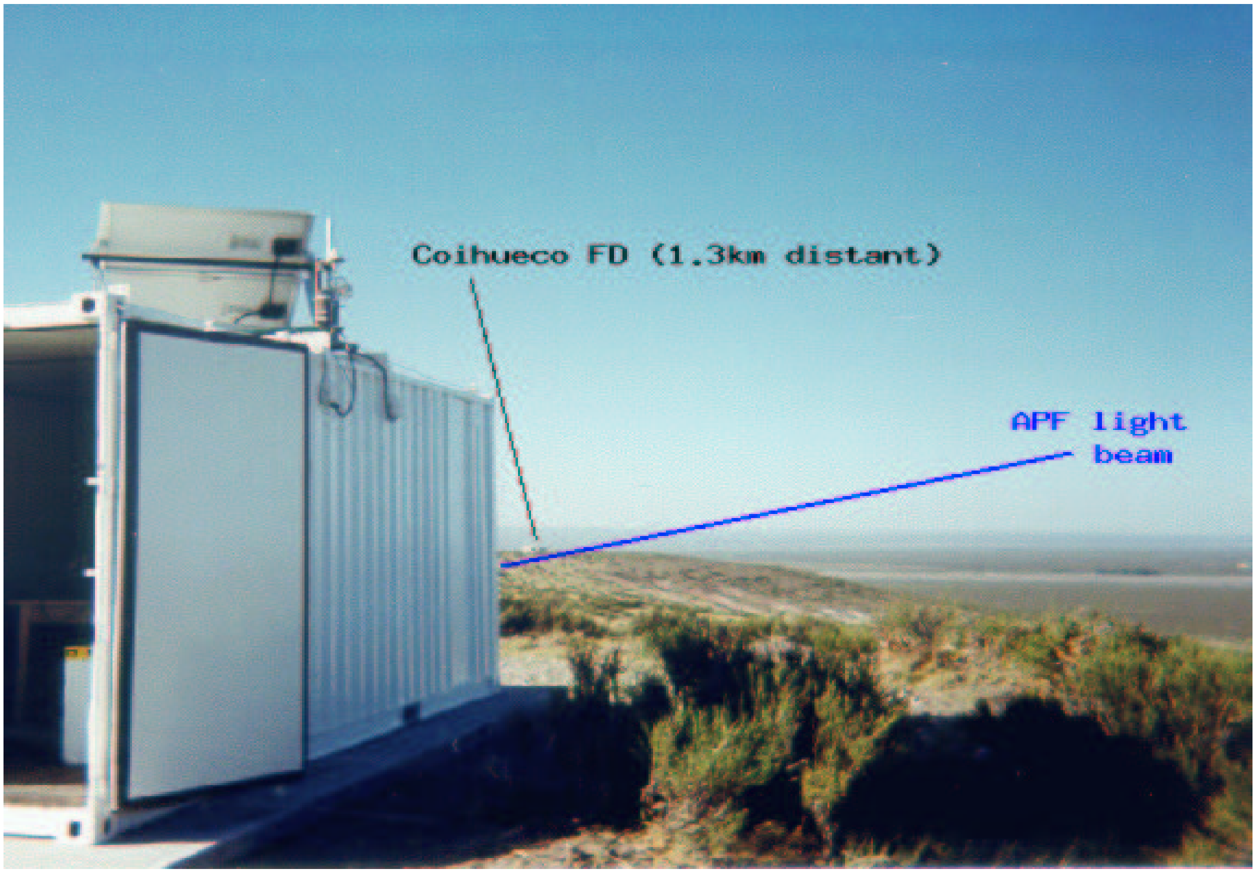
4: APF light source enclosure



The (3) xenon sources are mounted in a refurbished 20-foot shipping container.

- The light beams exit through a UV transmitting window.
- One light source is enabled at any given time.
- Computer control is at the Coihueco FD building $\sim$ 1.3km distant.

5: Light path of APF light sources



- Hourly during FD operation, an ADC/relay system enables a 1Hz GPS pulser, a 12V to 24V inverter to power the xenon flash lamps and then sequentially enables one light source at a time to provide light pulses in the field of view of the Coihueco telescopes.
- Eight 8-bit ADCs monitor the correct operation of the relay-switched components.
- Solar panels provide 12V power.

6: A simple APF simulation

- Studies have been done with a simplified model

- The model conforms to measured quantities, but some telescope details (*e.g.* small variations in pixel efficiencies), multiple scattered light, ... were **not** included

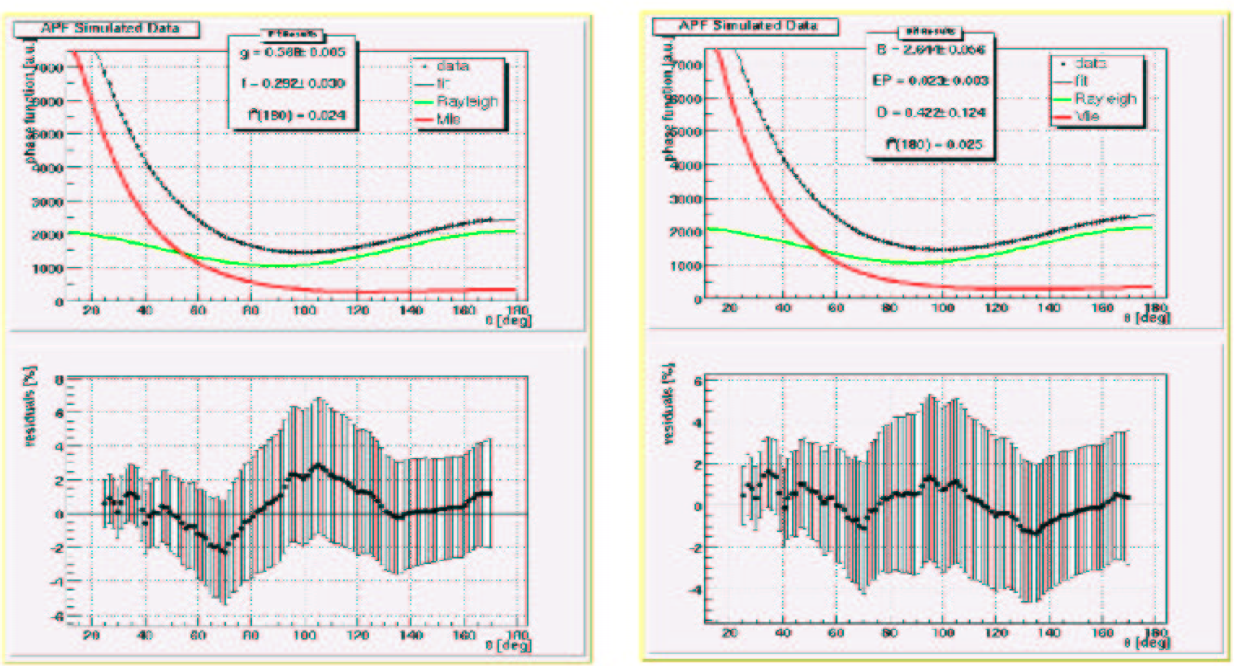
- In the analysis small corrections were applied to the model above (Slide 3):
  1. Cylindrical geometry is almost correct ... in practice the simulated signals were corrected by actual "$\Delta z_i \cdot \Delta\Omega_i$" *versus* approximate "$\frac{Area \cdot \Delta\theta}{D_{perp}}$"
  2. No correction for light attenuation is almost correct ... in practice the simulated signals were corrected by $e^{lightpath(\theta)/\Lambda_{tot}}$ where: $lightpath(\theta)$ is the total light travel distance (for a given scattering angle) and Λ_{tot} is the horizontal attenuation length **at the height of the fluorescence detector**
  3. The aerosol signal is almost correct ... but it is actually proportional to ALBEDO/Λ^a where ALBEDO < 1 means that some of the aerosol light is absorbed (*versus* all scattered). [The simulation used ALBEDO = 0.9]

7: 2-parameter and 3-parameter fits

- Two **Mie** scattering *phase function* parameterizations were compared (fitted) to the data:
  1. **2-parameter** form:
  $$f^a(\mu) = \frac{1-g^2}{4\pi}\left(\frac{1}{(1+g^2-2g\mu)^{3/2}} + f\frac{3\mu^2-1}{2(1+g^2)^{3/2}}\right)$$
  2. **3-parameter** form:
  $$f^a(\theta) = \frac{1}{2\pi}\left(\frac{e^{-B\theta} + E'e^{-D(\pi-\theta)}}{(\frac{1+e^{-B\pi}}{1+B^2}) + \frac{E'(1+e^{-D\pi})}{1+D^2}}\right)$$
- **Rayleigh** scattering phase function from theory
- The relative fractions of Rayleigh (molecular) and MIE (aerosol) are set by $1/\Lambda^m$ and $ALBEDO/\Lambda^a$
- The horizontal attenuation lengths (Λ^m and Λ^a) are known from local T,P and horizontal backscattered LIDAR shots.
- For 2-parameter fits there is some sensitivity to ALBEDO ... else it must be an input (*e.g.* ALBEDO = 0.9)
- The overall intensity (normalization) is an additional parameter. For stable light sources and known/stable detector efficiencies this is essentially constant ... and thus can be averaged over many hours/nights of APF light source operation!

8: Initial (simulation based) observations

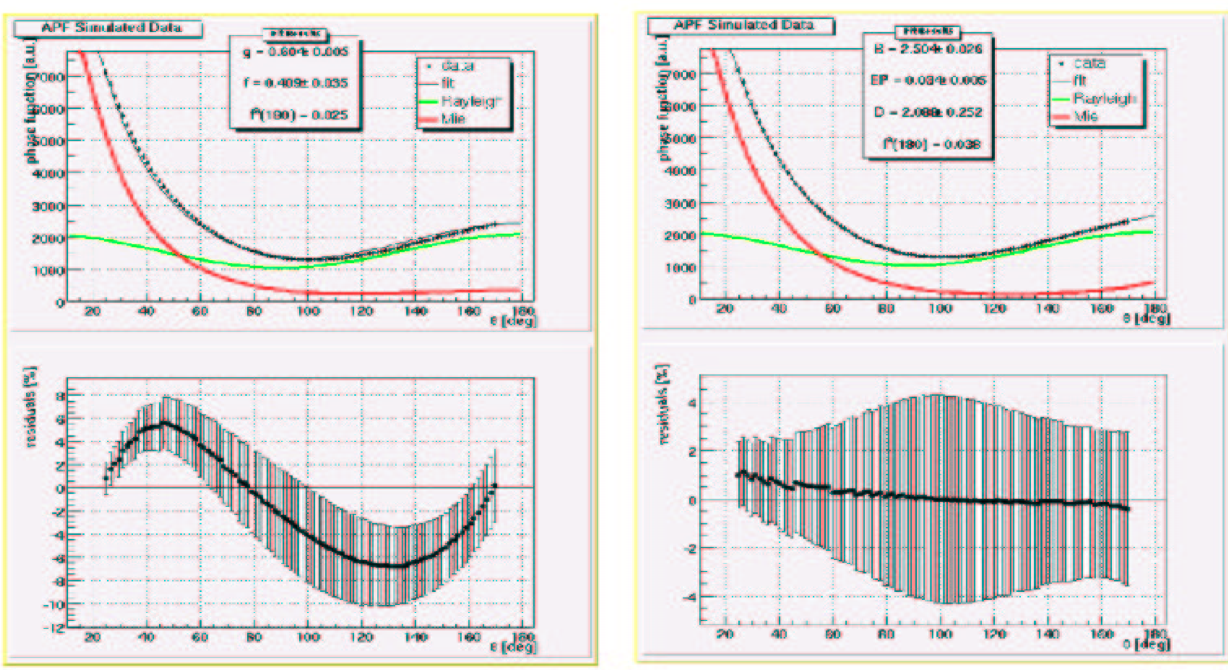
- **Cross check:** 2-parm (or 3-parm) Mie phase functions input to the simulation resulted in similar output parameters from fits to the simulated data
- For some (Elbert) input phase functions both 2-parm and 3-parm fits were stable and reproduced the simulated data. **In this instance a fit for the ALBEDO** *[2-parm phase function model]* **reproduced the input value** ... with an uncertainty < 0.05



2- and 3- parameter fits (left and right figures respectively and both for Elbert input) **have comparable residuals**

9: Initial (simulation based) observations (con't)

- For some (Longtin) input phase functions only the 3-parm fit provides a description of the data ... but with little sensitivity to the ALBEDO
- Clearly the APF analysis is insensitive to radical (upward) variations (from smooth extrapolations) for $\theta < 20°$ and for $\theta > 170°$ ... *e.g.* from large aerosol particulates. **One indication (of radical upward variations) is a reduced value for the *fitted* ALBEDO**!



2- and 3- parameter fits (left and right figures respectively and both for Longtin input) **have very different residuals**