Pierre Auger Observatory

studying the universe's highest energy particles

Extracting the Aerosol Phase Function by the Central Laser Facility @ the Pierre Auger Observatory

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Light scattering by (spherical) particles

Rayleigh scattering: $R \ll \lambda$

$\Rightarrow$ Molecular

- total cross section: $\sigma_{\mathrm{tot}} \propto \lambda^{-4}$,
- attenuation length Λ_{m} monitored by weather stations,
- phase function: $P_{\mathrm{Ray}}(\theta) \propto 1 + \cos^2\theta$.

Mie scattering: $R \geq \lambda$

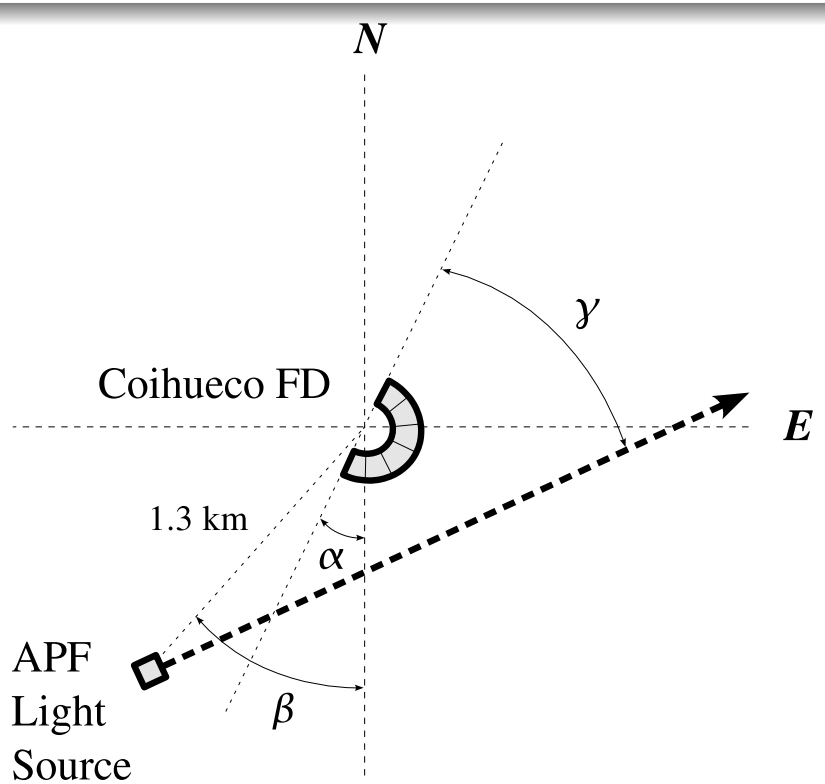
$\Rightarrow$ Aerosols (for instance, sand during a sandstorm)

- total cross section: $\sigma_{\mathrm{tot}} \propto \lambda^{-\gamma}$, with γ the Angström parameter,
- attenuation length Λ_{a} deduced from VAOD measurements,
- phase function $P_{\mathrm{Mie}}(\theta)$ from typical parametrizations or tabulated.

Up to now, the Aerosol Phase Function @ Auger

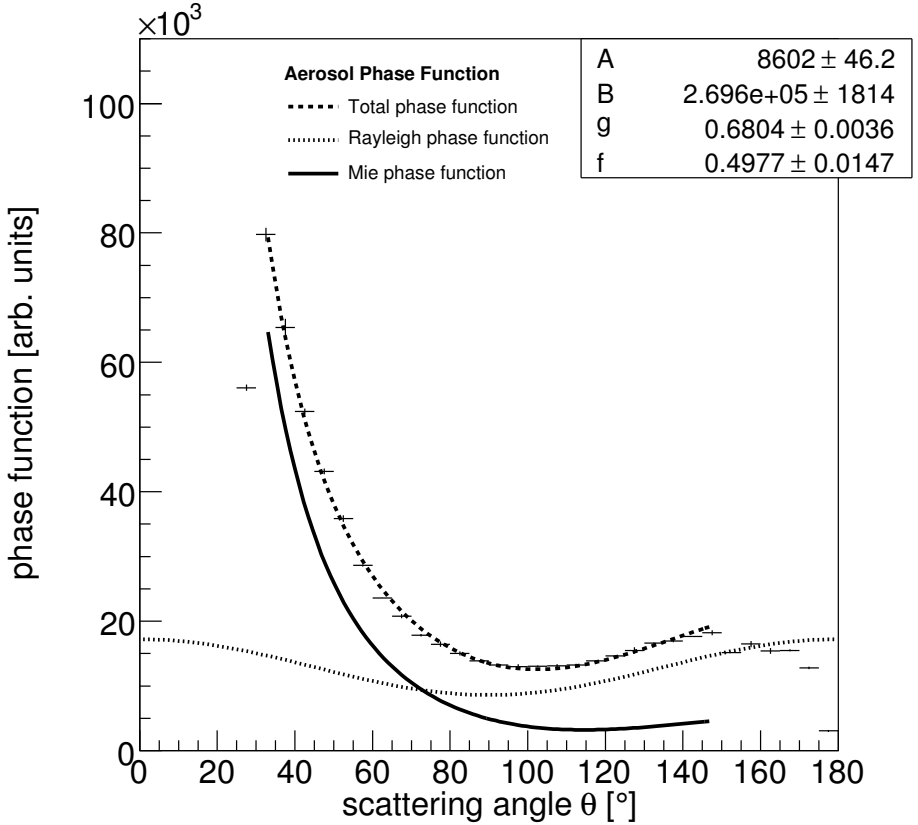
APF signal in fluorescence detectors

- 2 experimental setups located at Coihueco and Los Morados,
- collected signal as follows: $S = A \times P_{\mathrm{Ray}}(\theta) + B \times P_{\mathrm{Mie}}(\theta)$.

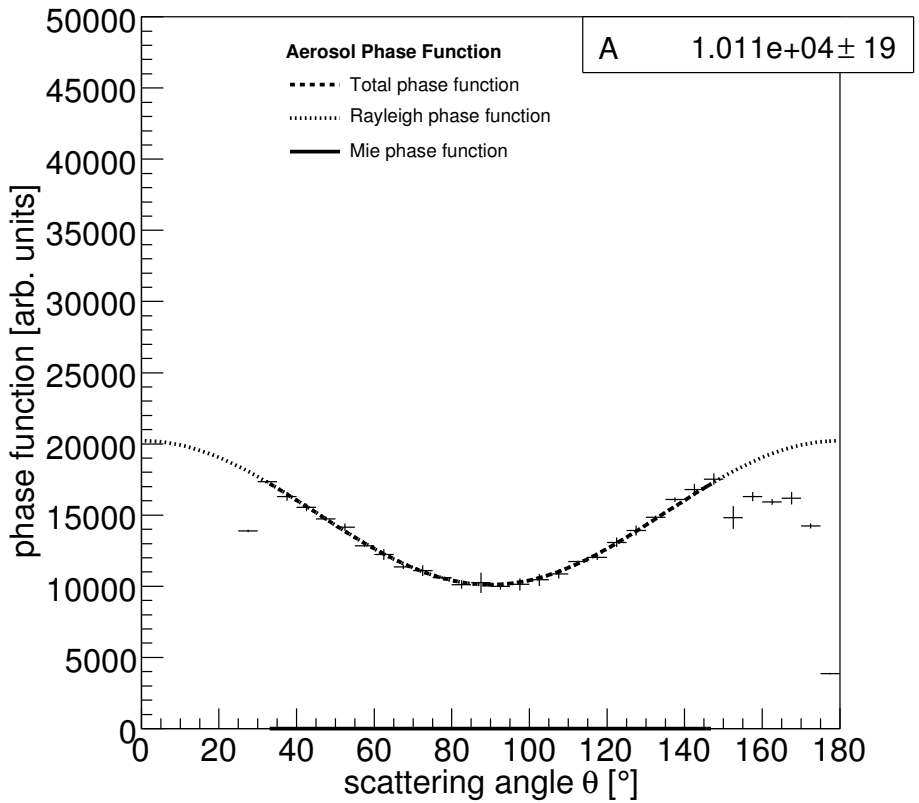


Up to now, the Aerosol Phase Function @ Auger

Typical night



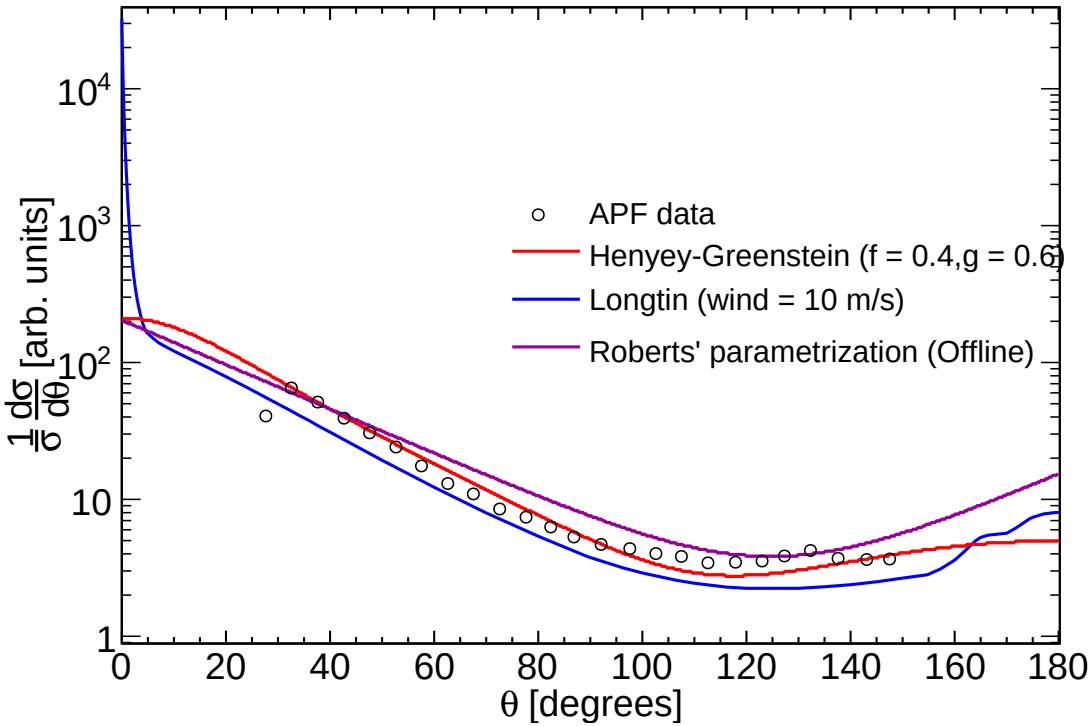
Rayleigh night



- measurements doable only between 30° and 150°,
- Rayleight night $\Longleftrightarrow$ $B = 0$ $\Longleftrightarrow$ no aerosols.

S BenZvi et al, Astroparticle Physics **28** *(2007) 312-320*

Usual aerosol phase functions Vs APF data



- intensity of the forward peak

$$P_{\mathrm{Mie}}(\theta = 0^{\mathrm{o}}) \propto R^2$$

- FWHM of the forward peak

$$\Delta\theta_{\mathrm{FWHM}} \propto \lambda / R$$

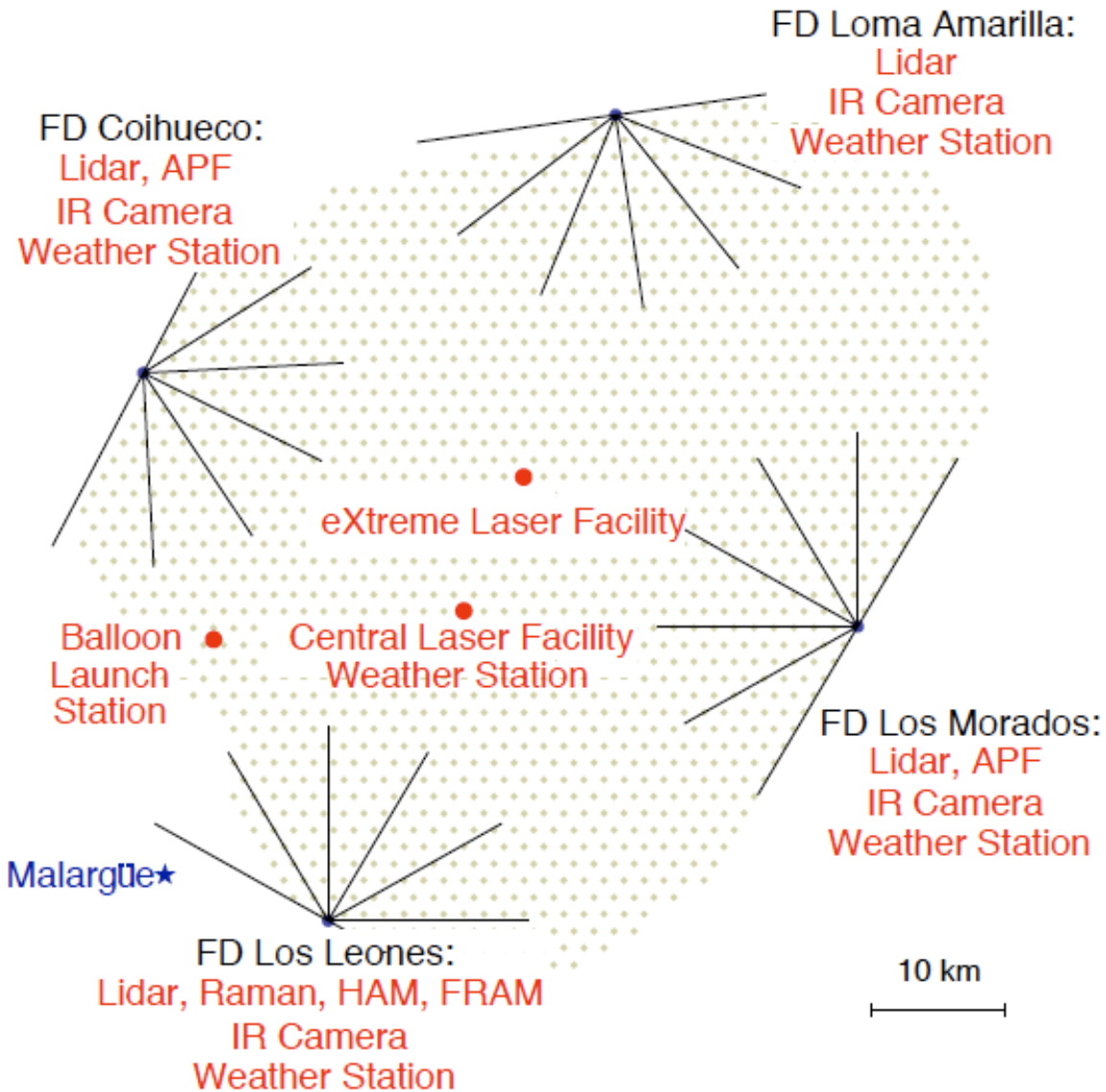
- largest aerosols affect the forward peak... but not known by APF measurements,
- consequences on the Multiple Scaterring (MS) parametrizations.

$\Longrightarrow$ uncertainty on the shower energy estimation

Outline

1. **A new way to get the APF**
   - Azimuthal ranges reached for each FD building
   - Extraction procedure of the Aerosol Phase Function (APF)
2. **Validation of the reconstruction procedure**
   - 1^{st} limit case: a Rayleigh night
   - 2^{nd} case: an Aerosol night
3. **Interesting shot sets to draw the APF**
   - Different shot sets currently fired @ Malargüe
   - Next step: new CLF shots to get the lowest scattering angles
4. **Conclusion: aerosol monitoring all along the night**

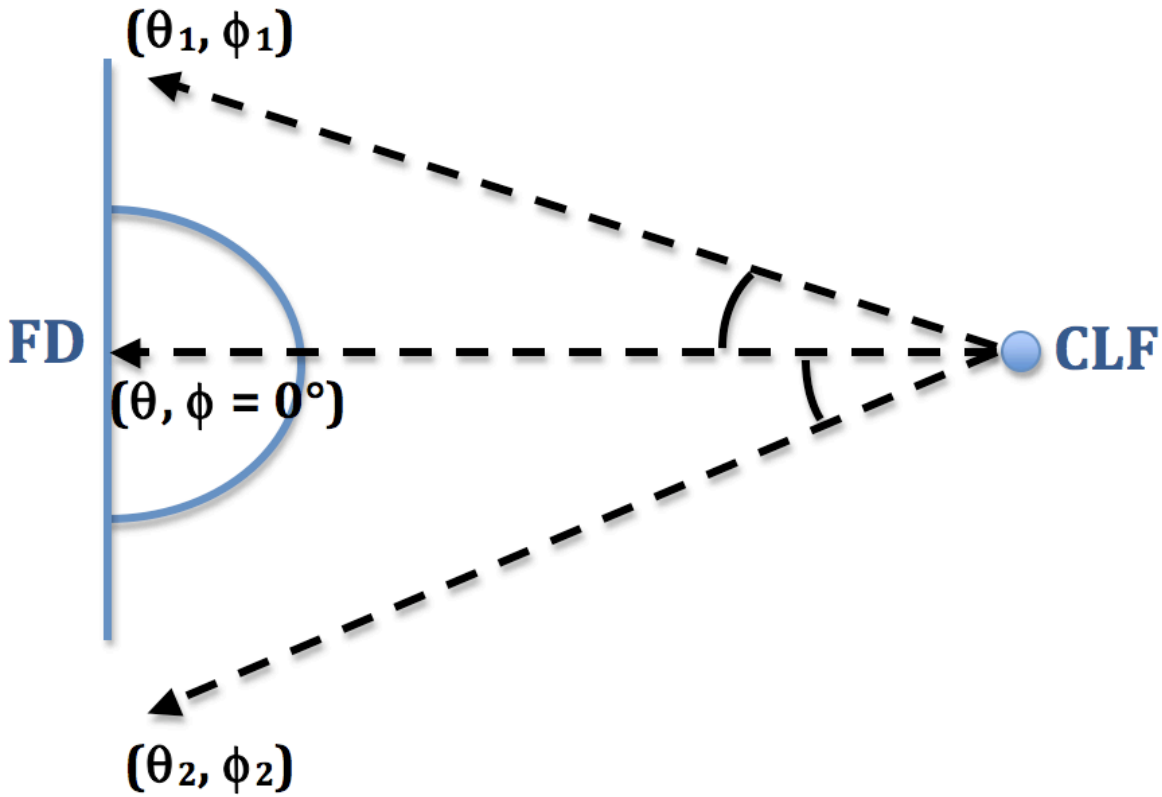
Just to remind you, the Auger array



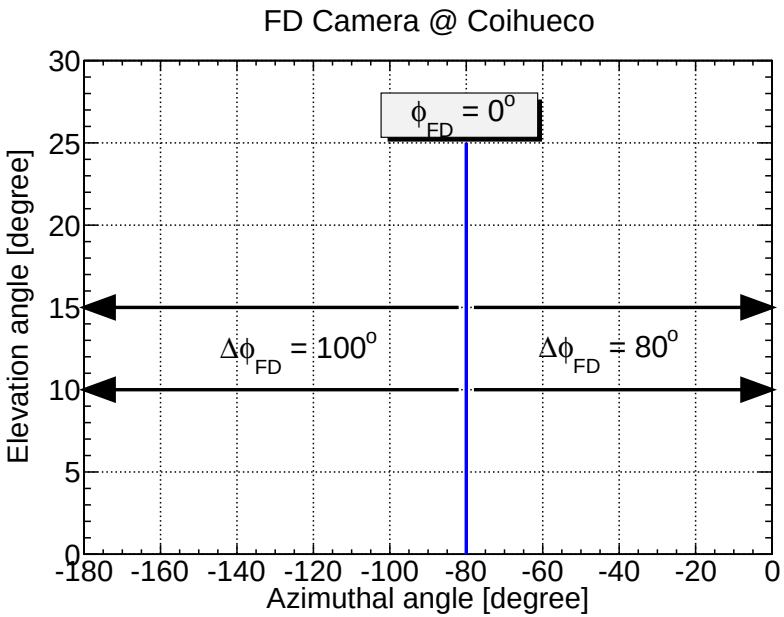
A new way to get the Aerosol Phase Function

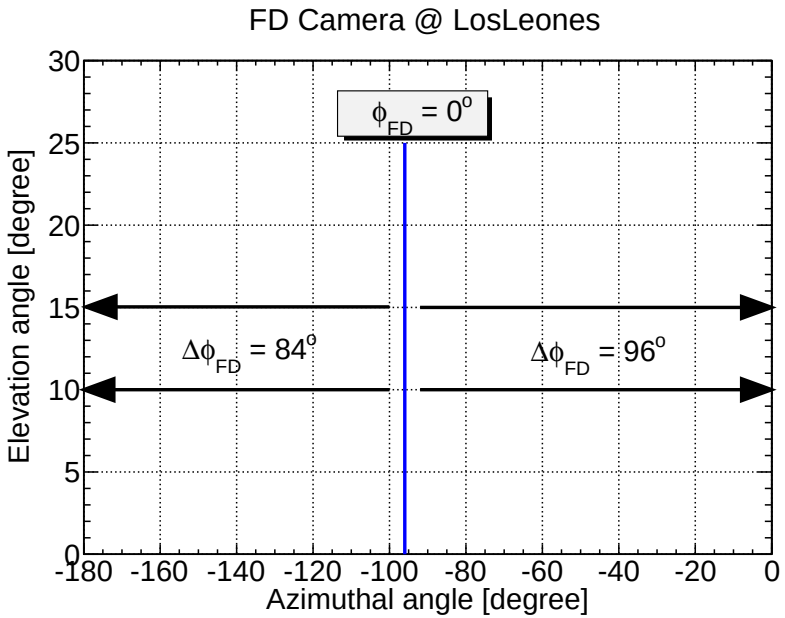
Advantages of this technique

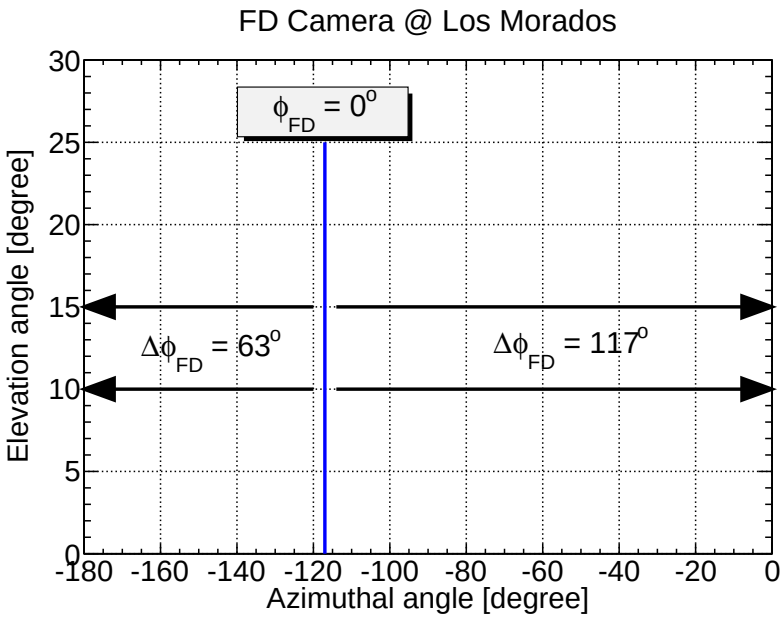
- check the uniformity of the aerosols in the whole observatory,
- the experimental setup is already made,
- monitoring of the APF doable all along the night.



Azimuthal ranges for each FD building







- FD locations affect our possibilities,
- in this talk, only the FD building @ Los Leones is used.

Extracting the Aerosol Phase Function (APF)

$$S_i = I_0 \times T_i \times \left[\frac{1}{\Lambda_{\mathrm{Ray}}} P_{\mathrm{Ray}}(\zeta) + \frac{1}{\Lambda_{\mathrm{Mie}}} P_{\mathrm{Mie}}(\zeta) \right] \times \Delta z_i \times \Delta\Omega_i$$

Reconstruction procedure

1. light collection in each pixel i triggered in the FD camera,
2. construction of the analogy: $(\theta_i,\phi_i) \Longleftrightarrow$ scattering angle ζ,
3. application of the corrections: Δz_i, $\Delta\Omega_i$, $T_i = \exp\left(-d_i/\Lambda_{\mathrm{att}}\right)$,
   $\Longrightarrow$ Total Phase Function (TPF)
4. subtraction of the Rayleigh Phase Function (RPF),
   $\Longrightarrow$ Aerosol Phase Function (APF)

We need to understand very precisely the kinematics of the laser to well estimate the geometrical parameters

Outline

Validation of the reconstruction procedure

From one side, simulation of laser shots

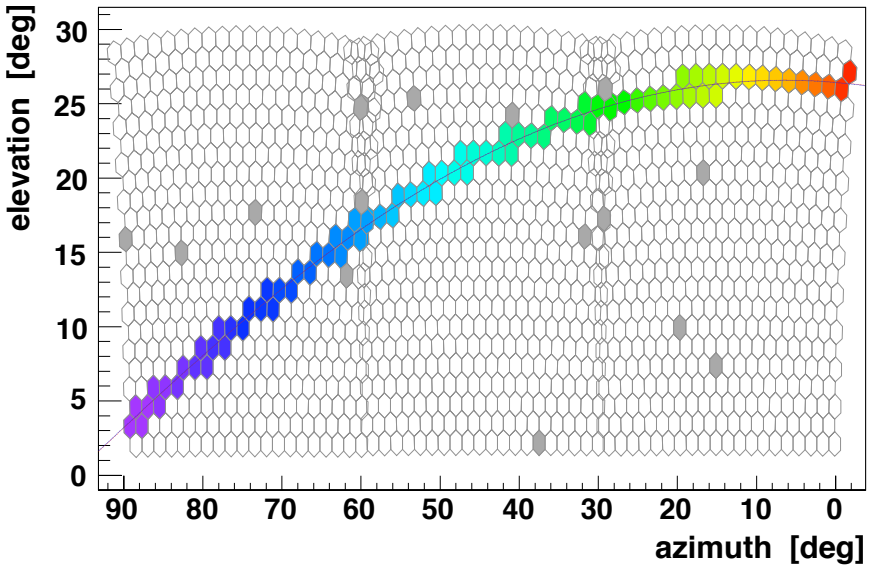
- $\overline{\text{Off}}\underline{\text{line}}$: main program of the Auger collaboration,
- simulates lasers (E, θ, ϕ) in the Auger fluorescence detector,
- as output, a file in the same format as real data.

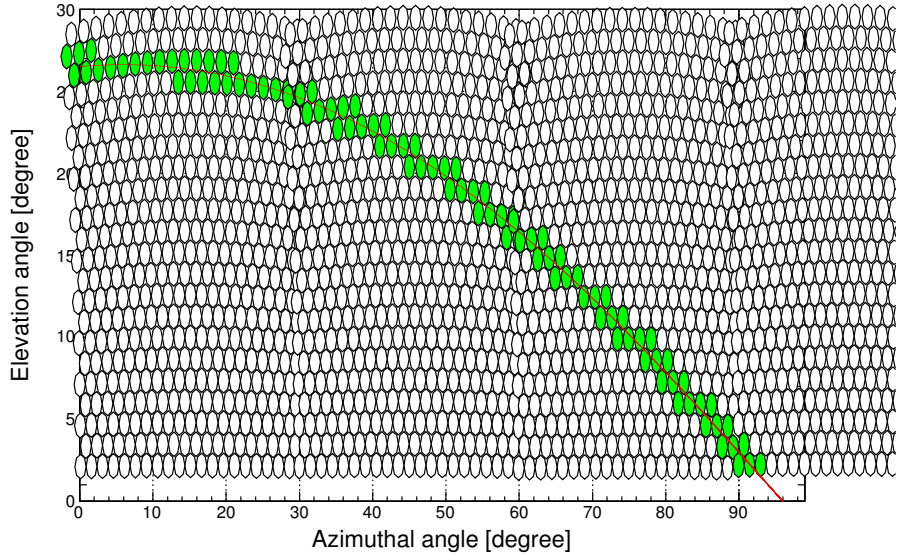
From the other side, development of my own program

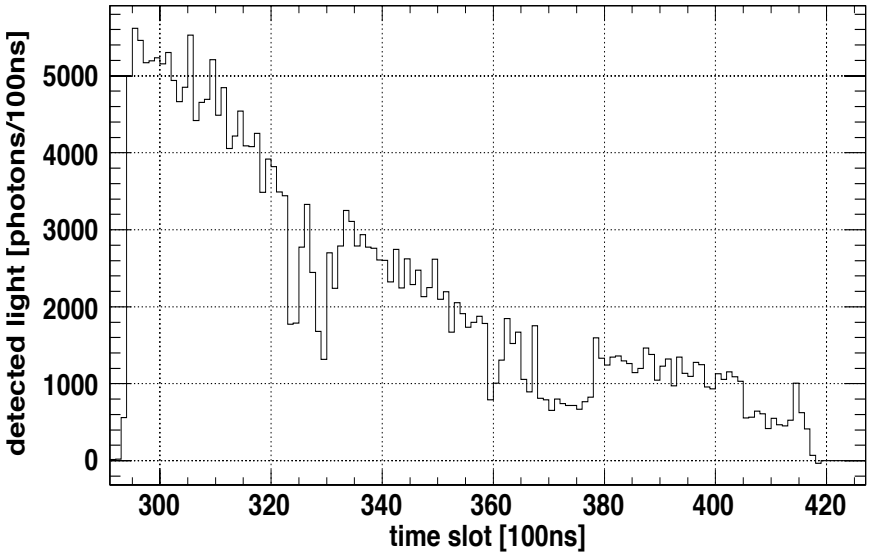
- generate a laser following the (θ, ϕ) parameters,
- estimate the parameters (Δz_i, $\Delta\Omega_i$, T_i) for each pixel,
- apply the corrections to the $\overline{\text{Off}}\underline{\text{line}}$ file
  $\rightarrow$ we get the phase function.

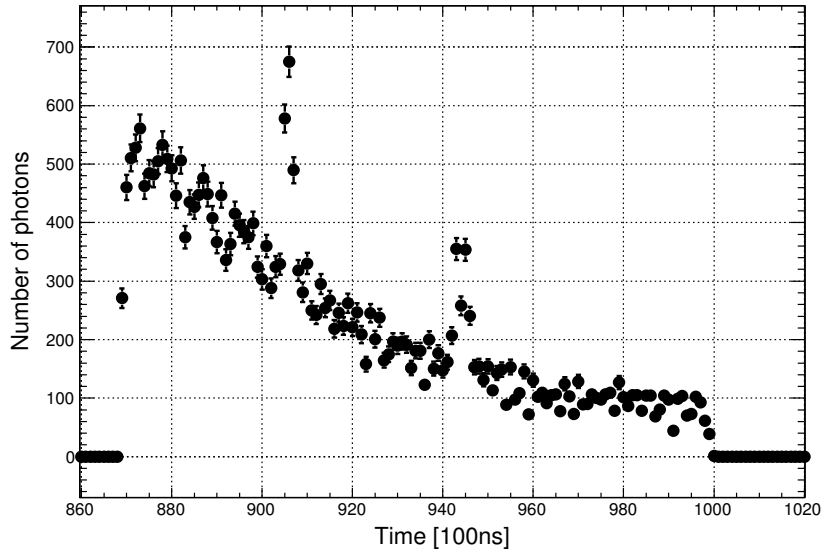
Validation done for the shot set ($\theta = 87^{\text{o}}$, $\phi_{\text{FD}} = 6^{\text{o}}$) @ Los Leones

1st limit case: a Rayleigh night



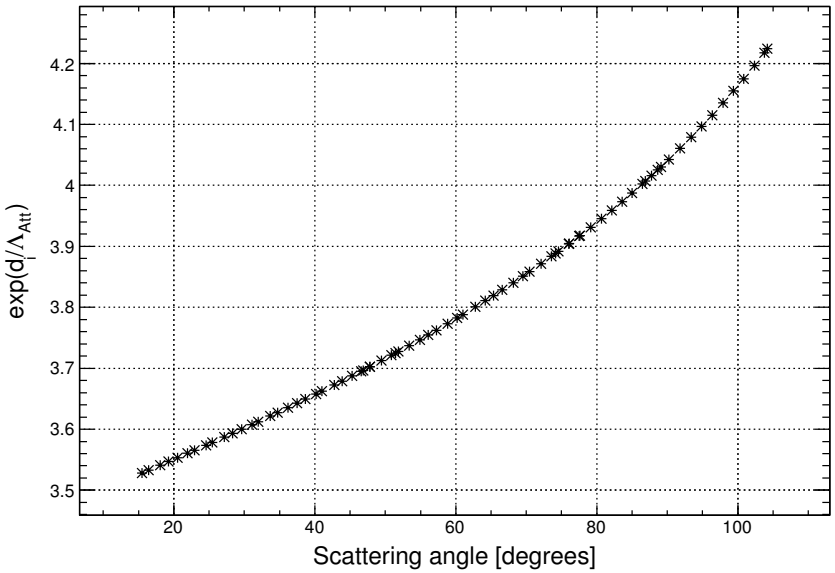




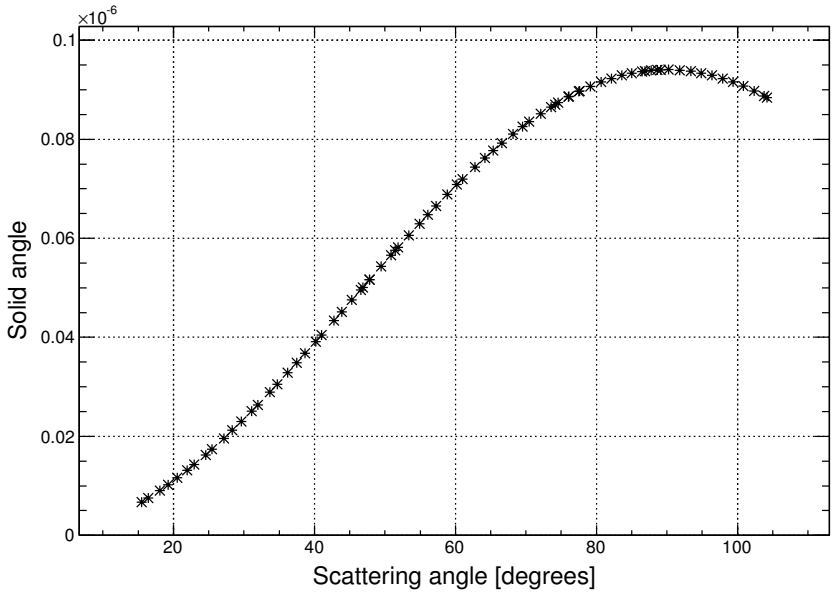


Corrections affected to each triggered pixel on the FD camera

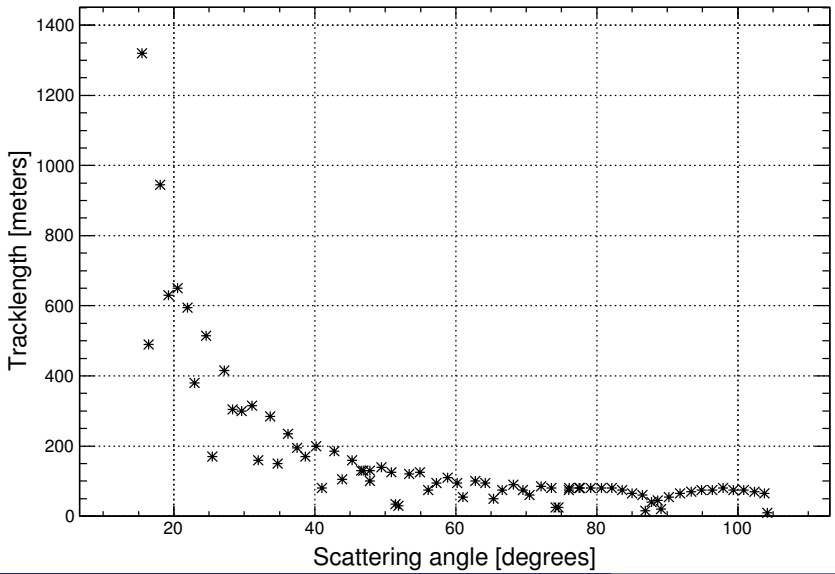
Attenuation



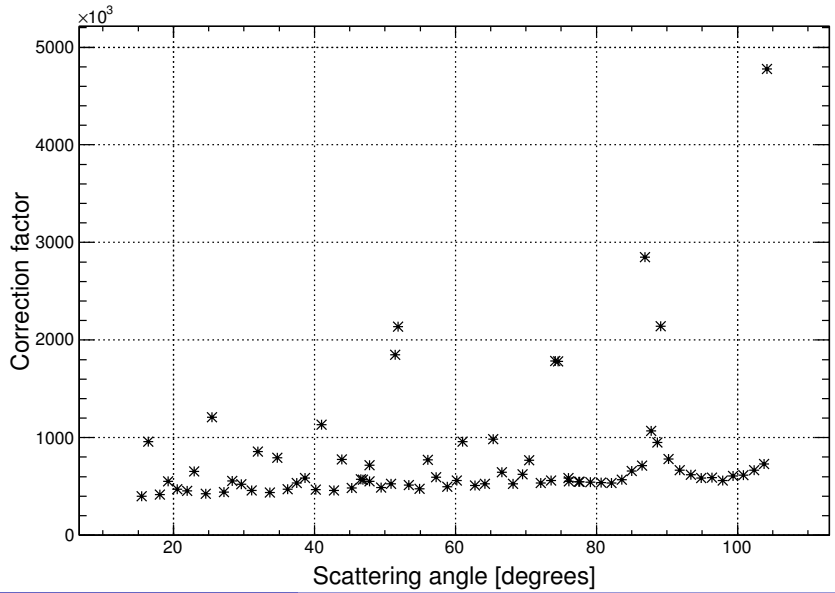
Solid angle



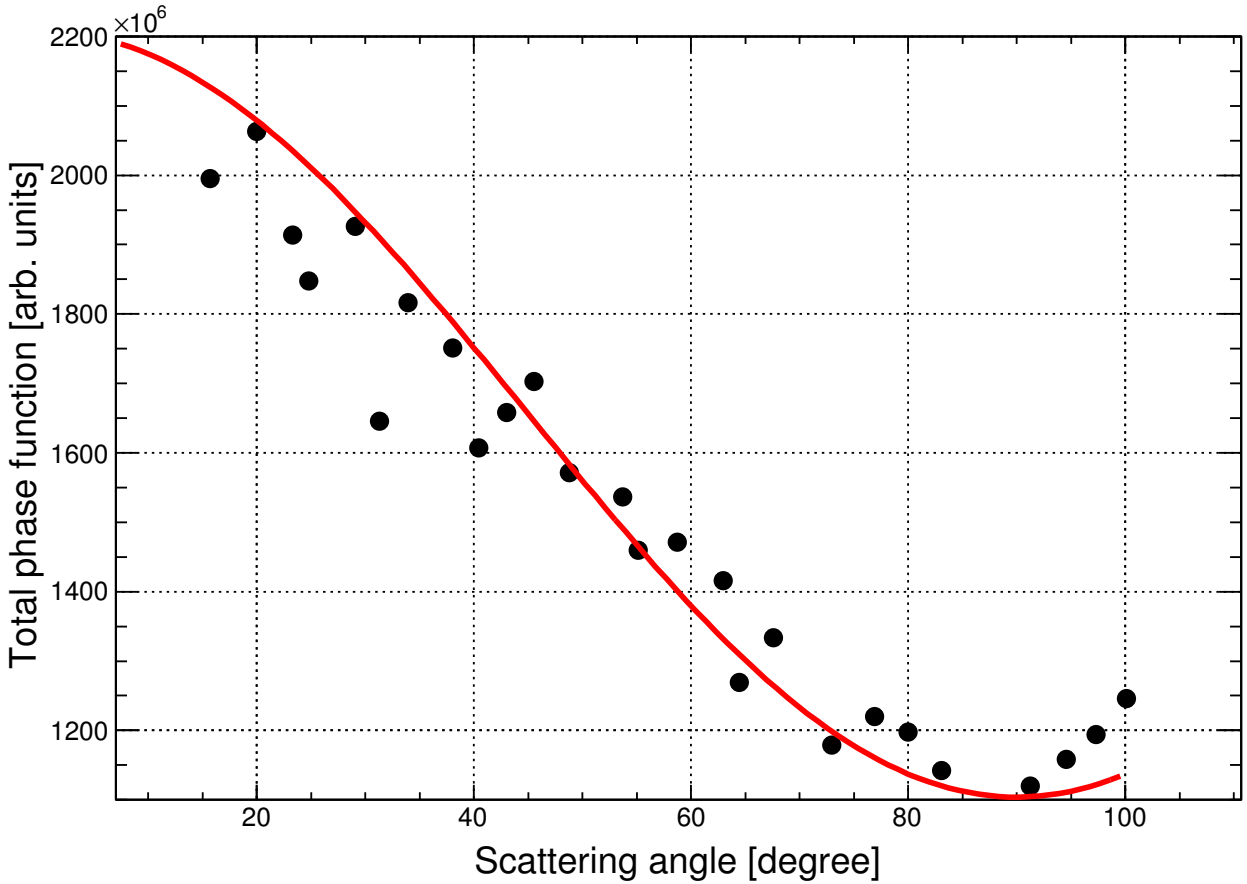
Tracklength



Global correction factor



Reconstruction of the Rayleigh phase function

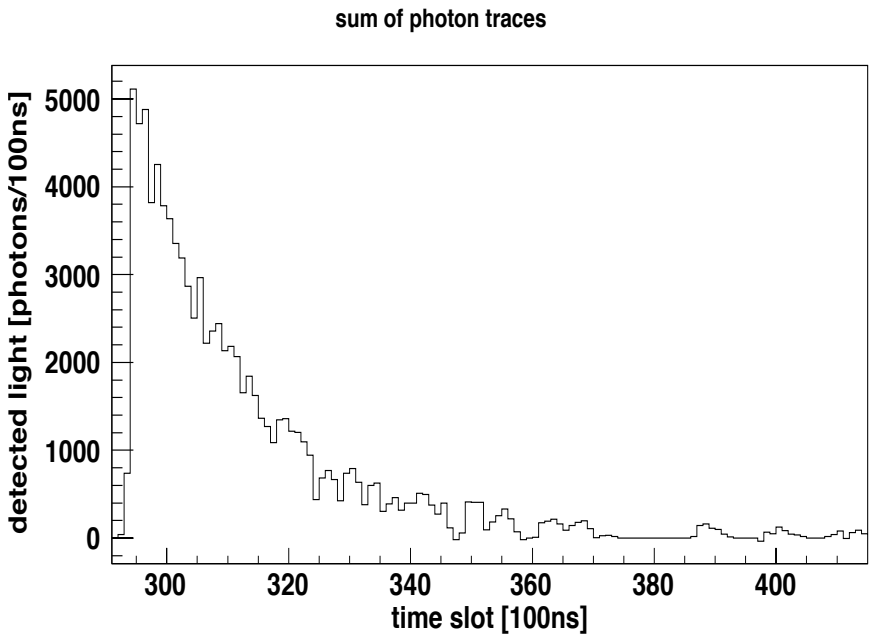


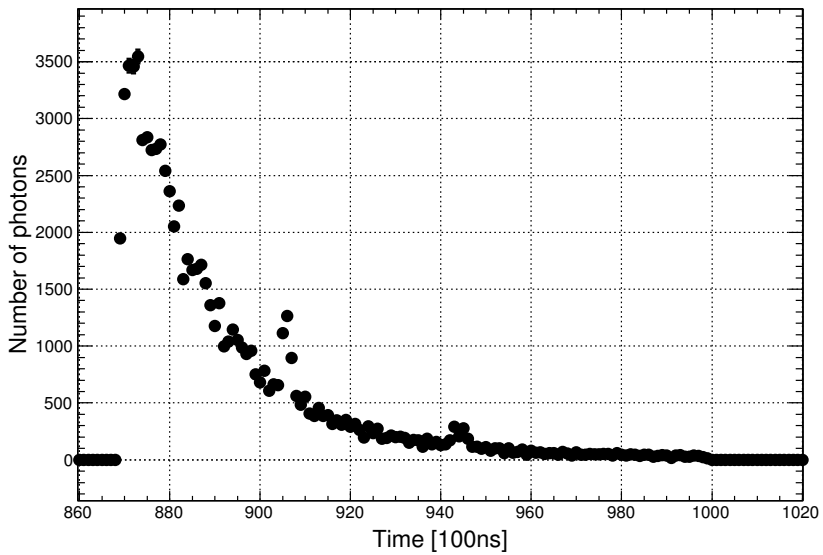
- overlap between the $(1 + \cos^2 \zeta)$ function and our reconstruction,
- high sensitivity to the position of the laser on the FD camera.

2nd case: an Aerosol night

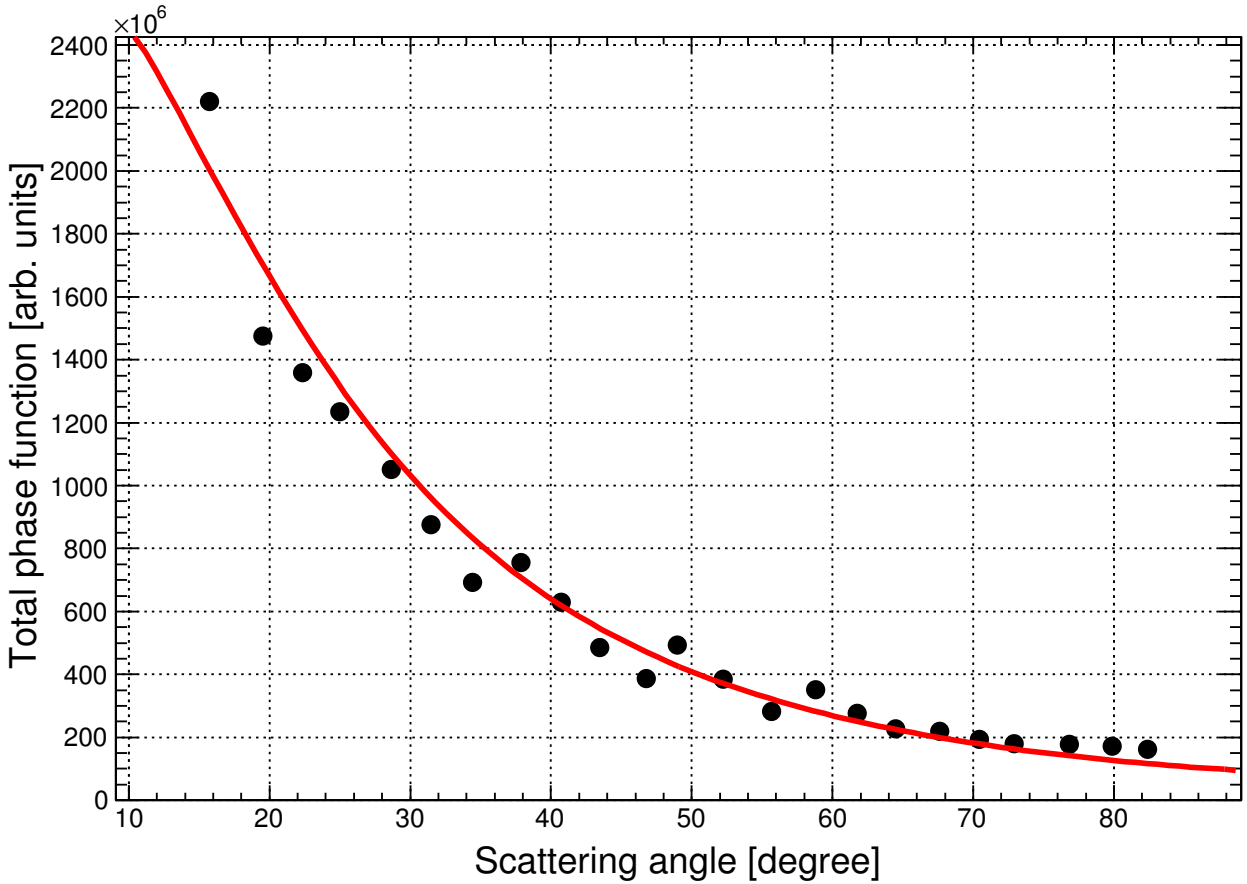
Adding an aerosol population in the atmosphere

- a Henyey-Greenstein function $\rightarrow (g = 0.6,\ f = 0.4)$,
- attenuation length fixed at 20 km.





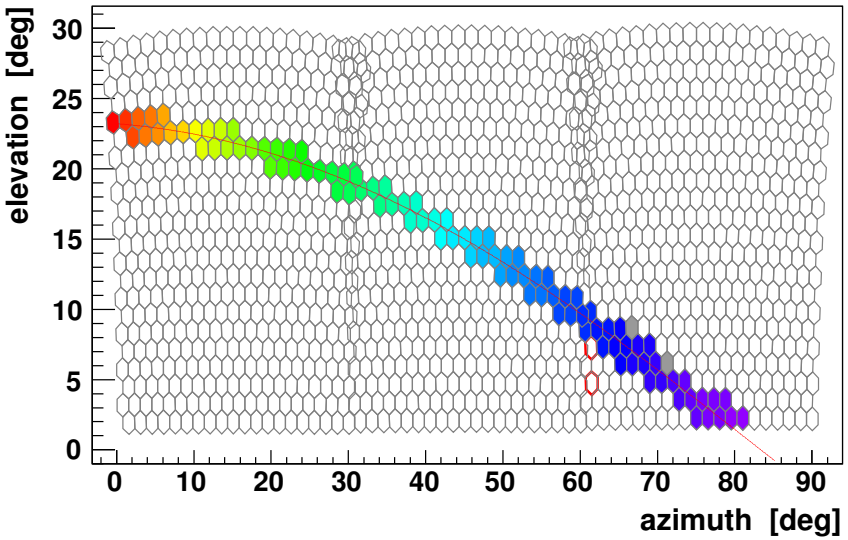
Extraction of the Aerosol phase function

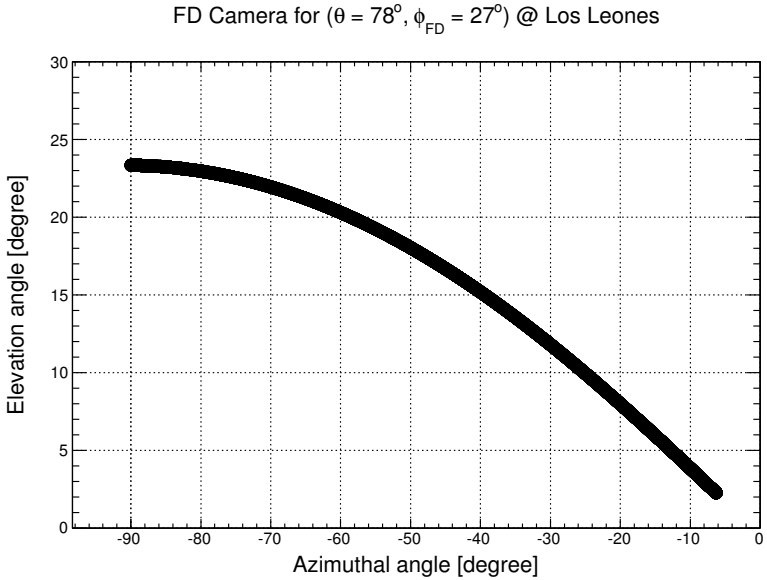


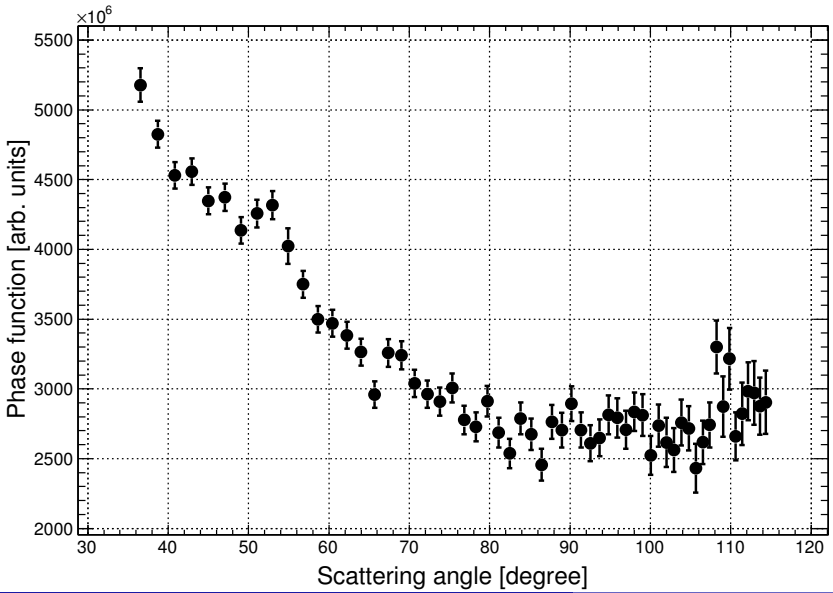
- good overlap with the original Henyey-Greenstein.

Outline

Shot set: ($\theta = 73^{o}$, $\phi_{\mathrm{FD}} = 25^{o}$) @ Los Leones

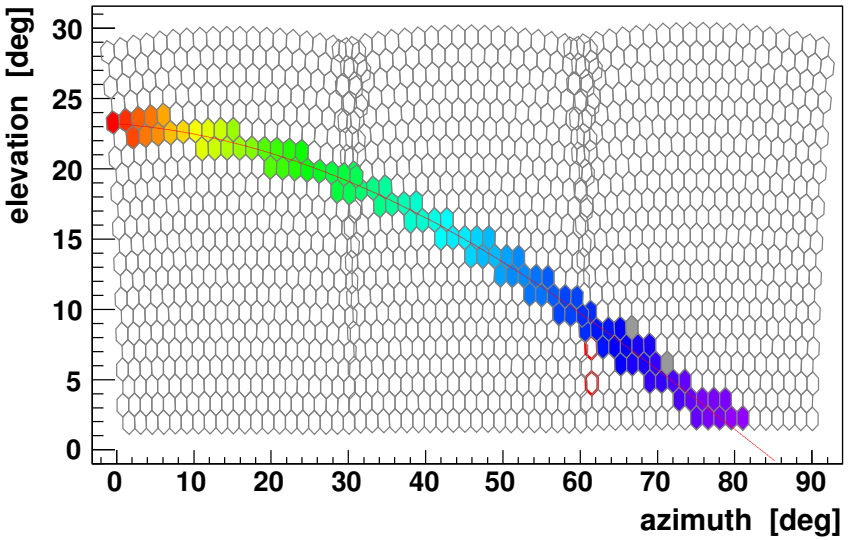


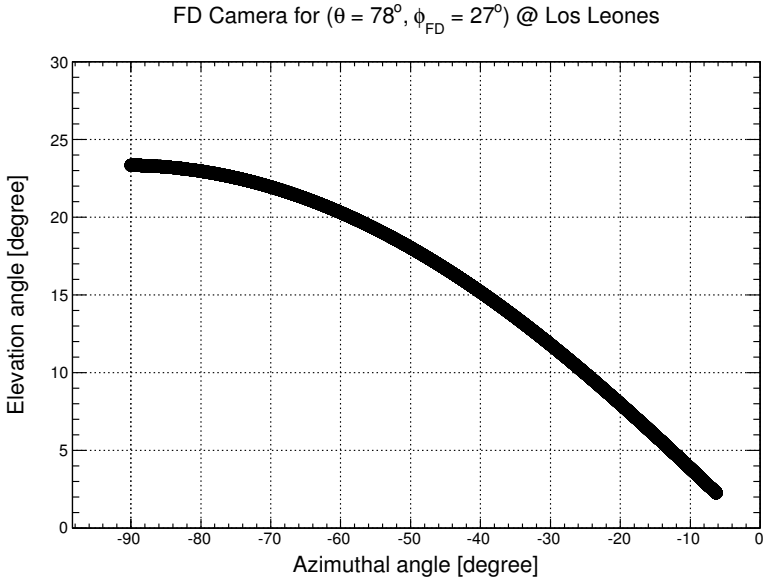


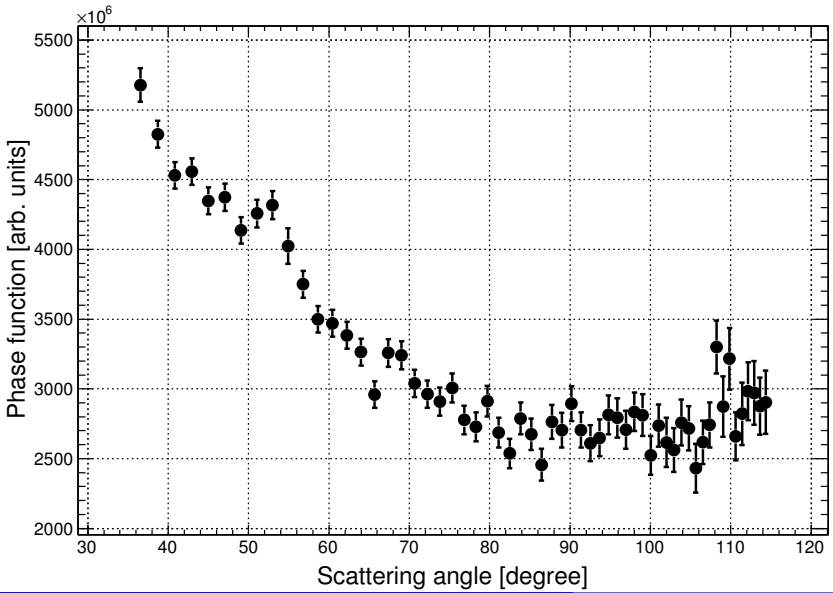


$$35^{o} \leq \text{Scattering Angle} \leq 115^{o}$$

Shot set: ($\theta = 78^{o}$, $\phi_{\mathrm{FD}} = 27^{o}$) @ Los Leones

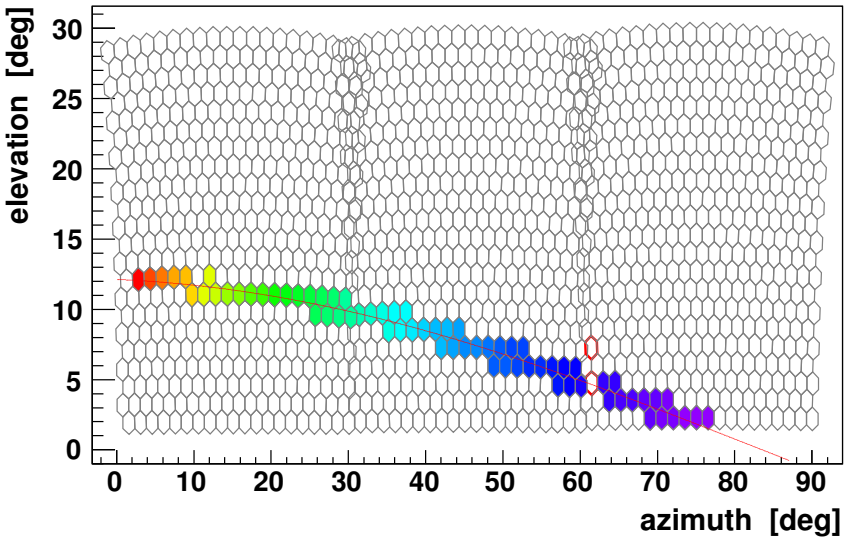


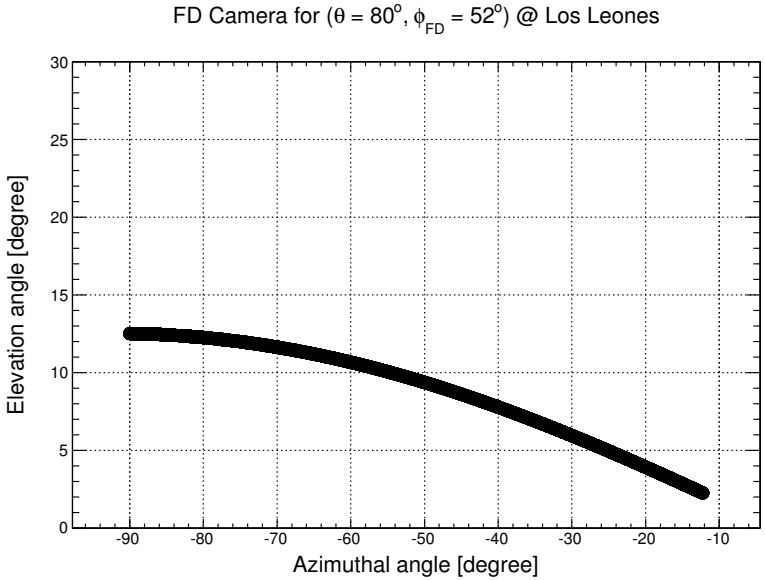


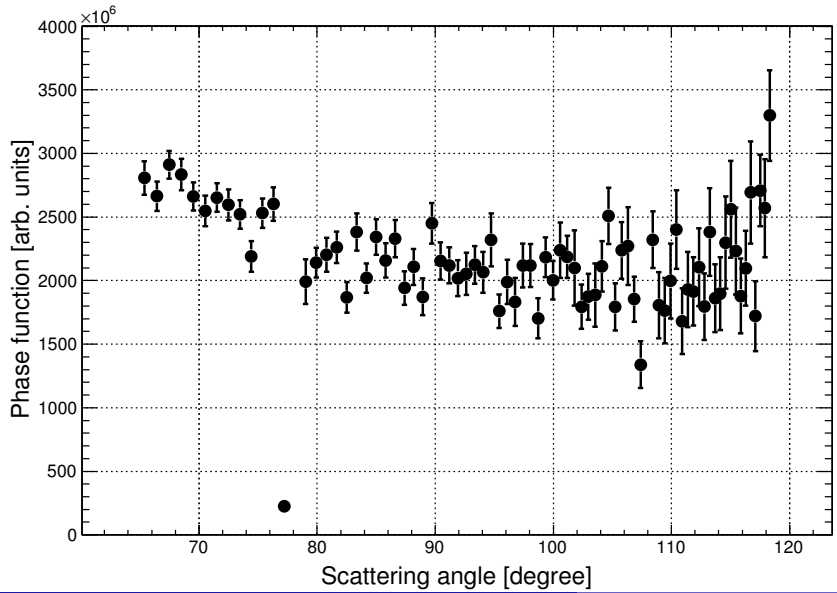


$$35^{o} \leq \text{Scattering Angle} \leq 115^{o}$$

Shot set: ($\theta = 80^{o}$, $\phi_{\mathrm{FD}} = 52^{o}$) @ Los Leones

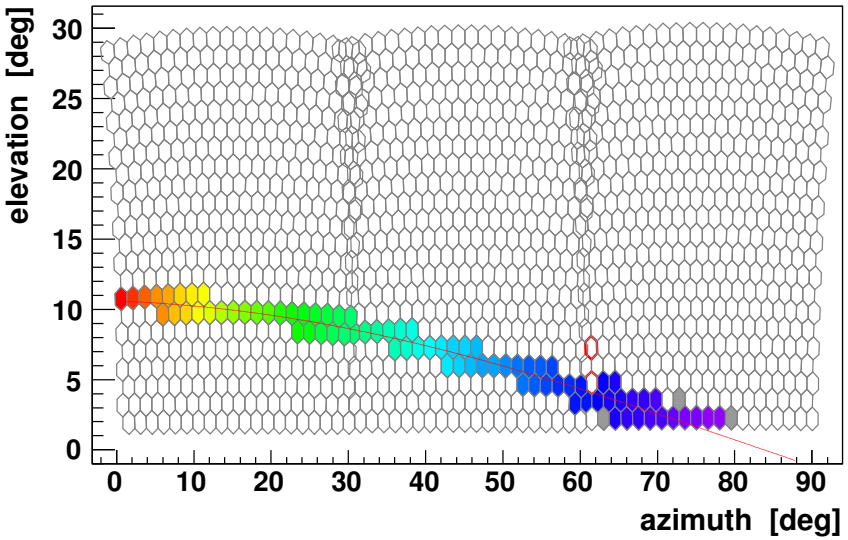


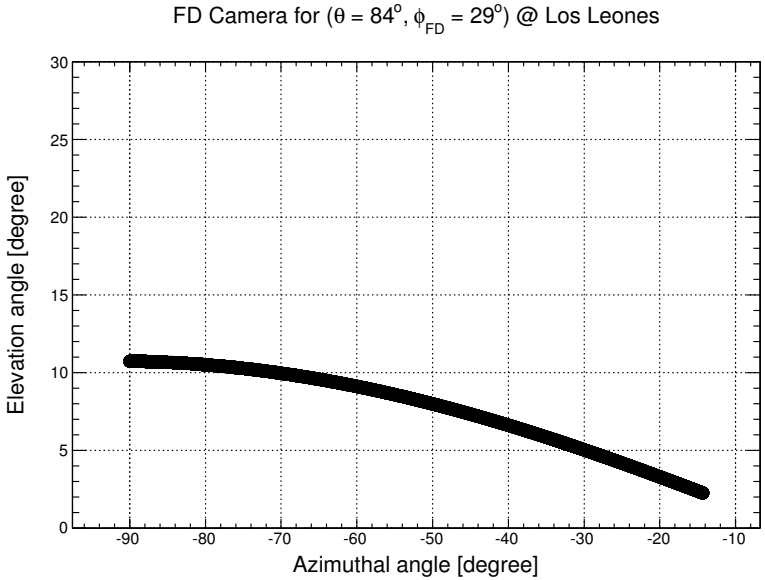


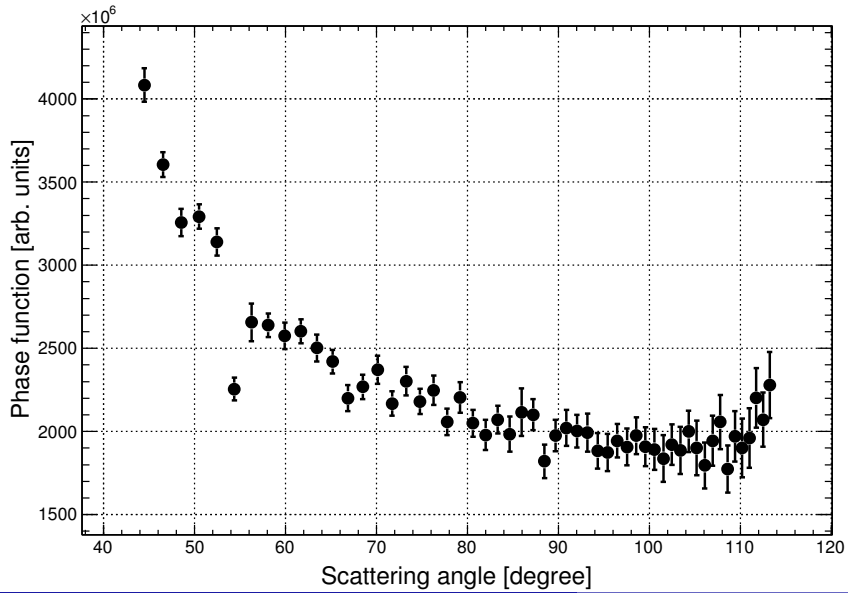


$$65^{o} \leq \text{Scattering Angle} \leq 120^{o}$$

Shot set: ($\theta = 84^{o}$, $\phi_{\mathrm{FD}} = 29^{o}$) @ Los Leones

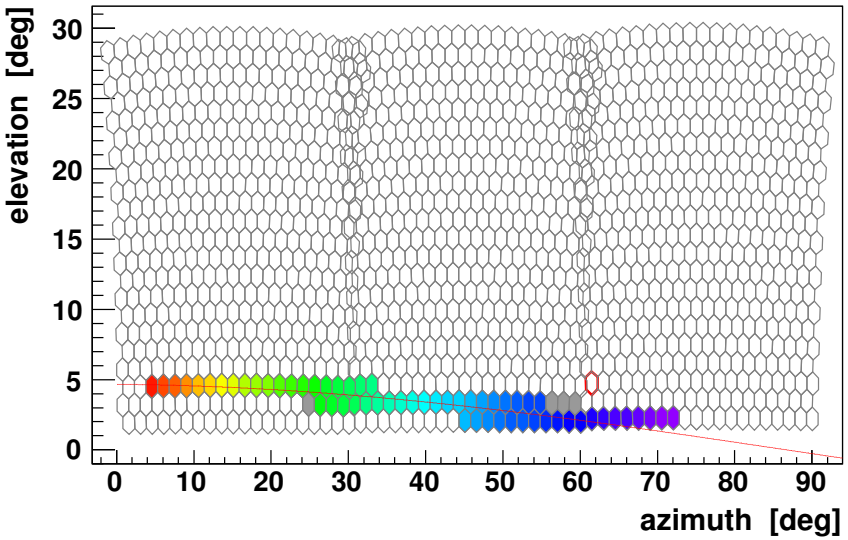


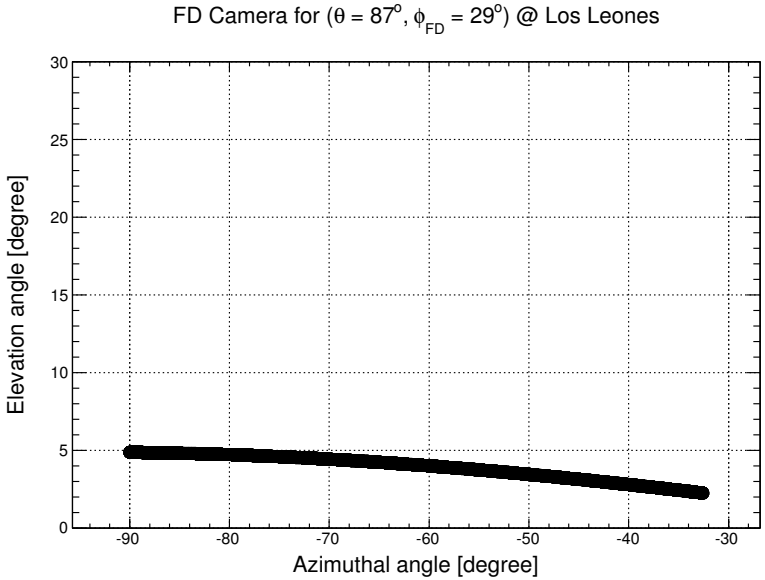


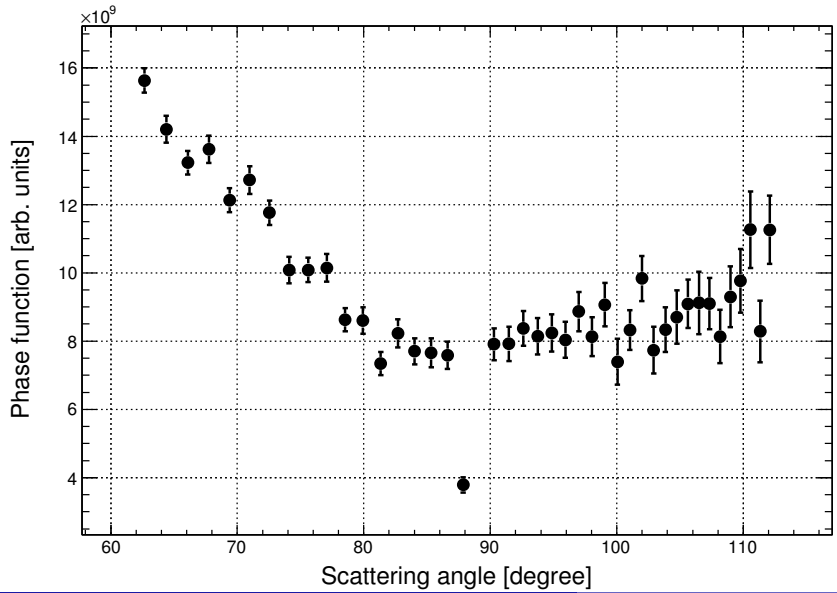


$$40^{o} \leq \text{Scattering Angle} \leq 115^{o}$$

Shot set: ($\theta = 87^{o}$, $\phi_{\mathrm{FD}} = 29^{o}$) @ Los Leones

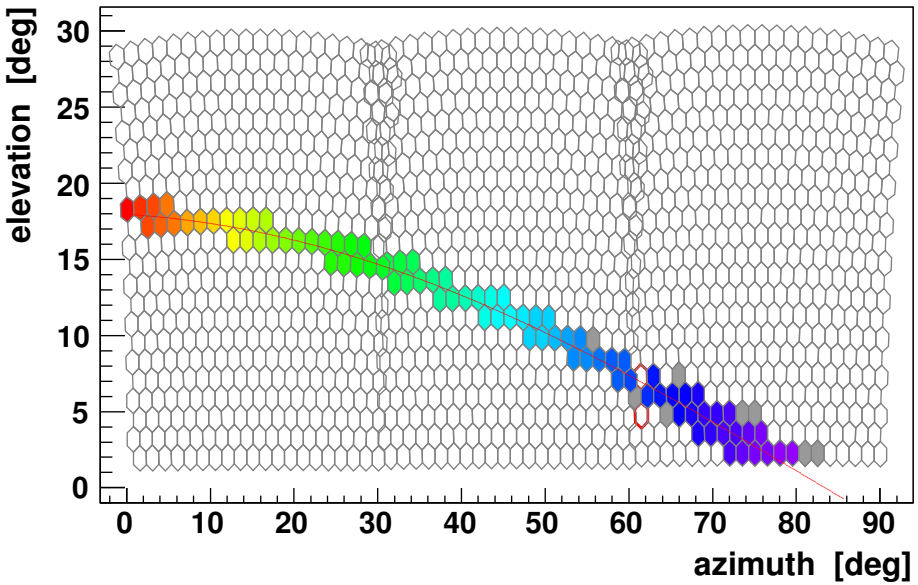


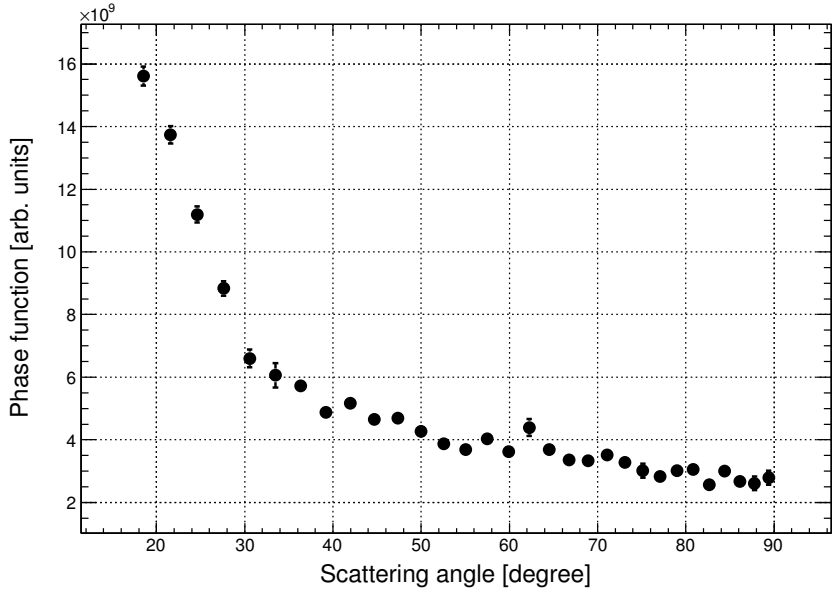


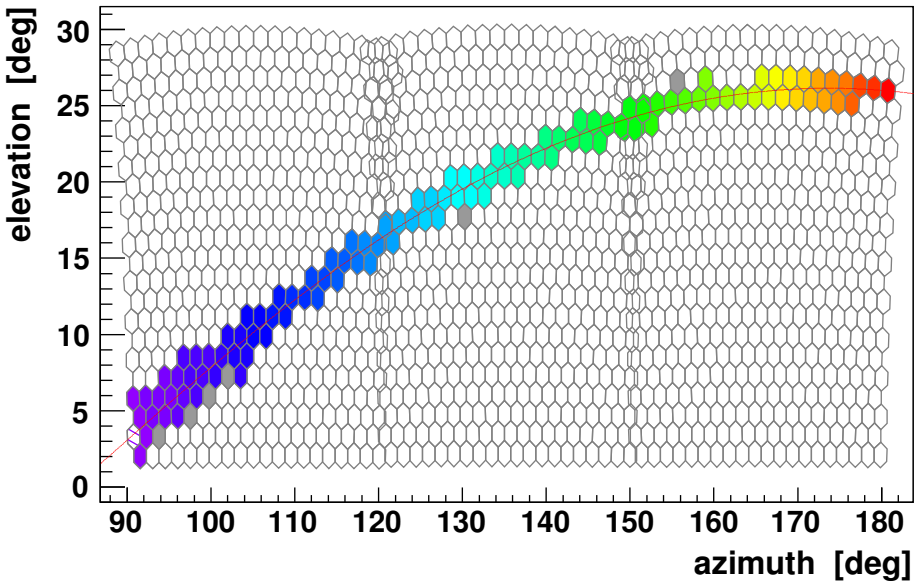


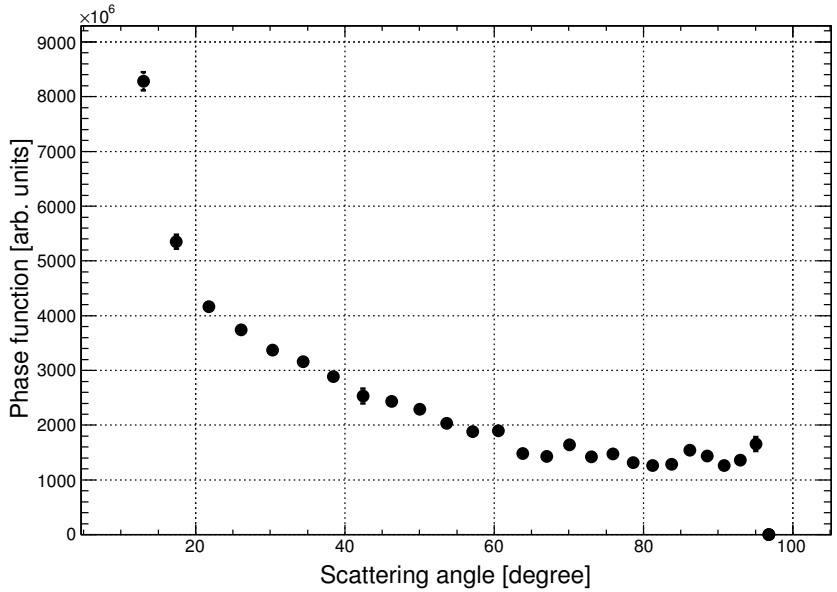
$$60^{o} \leq \text{Scattering Angle} \leq 110^{o}$$

Shot set: ($\theta = 87^{o}$, $\phi_{\mathrm{FD}} = \phi_{1,2}$) @ Los Leones



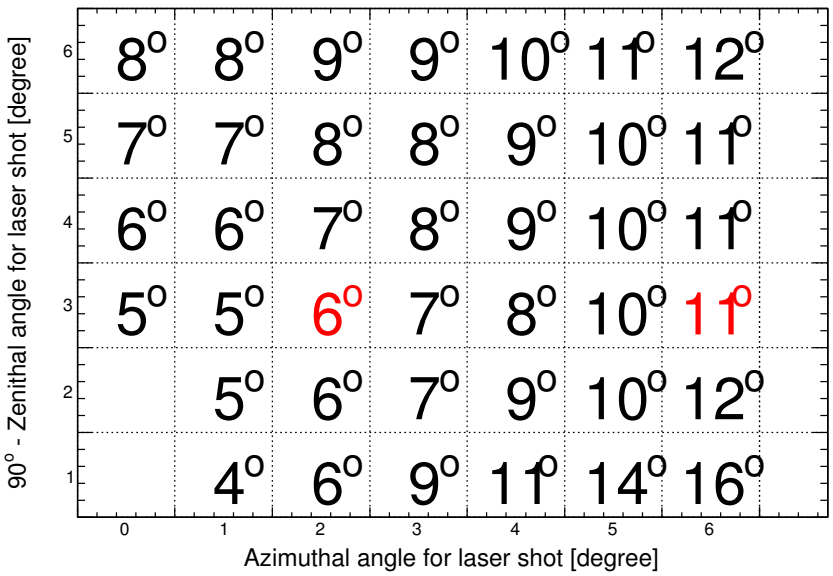




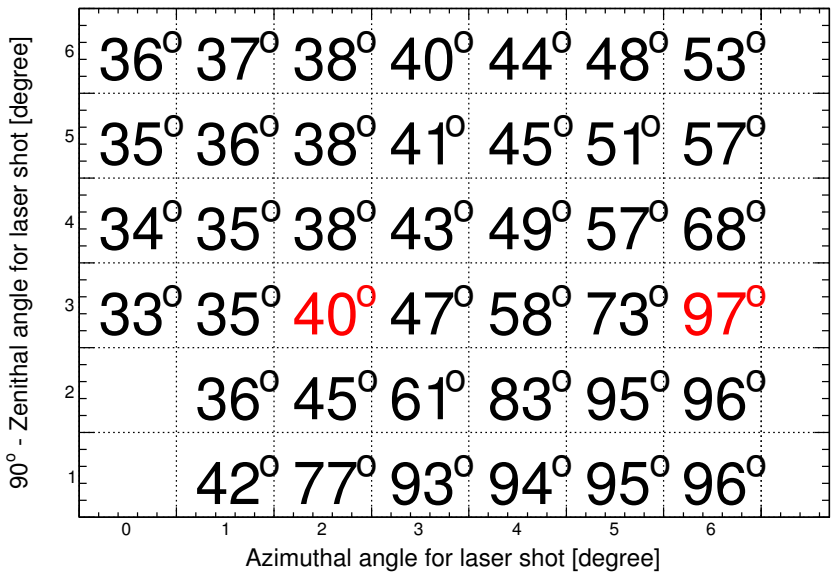


Next step: new CLF shots to get the lowest scattering angles

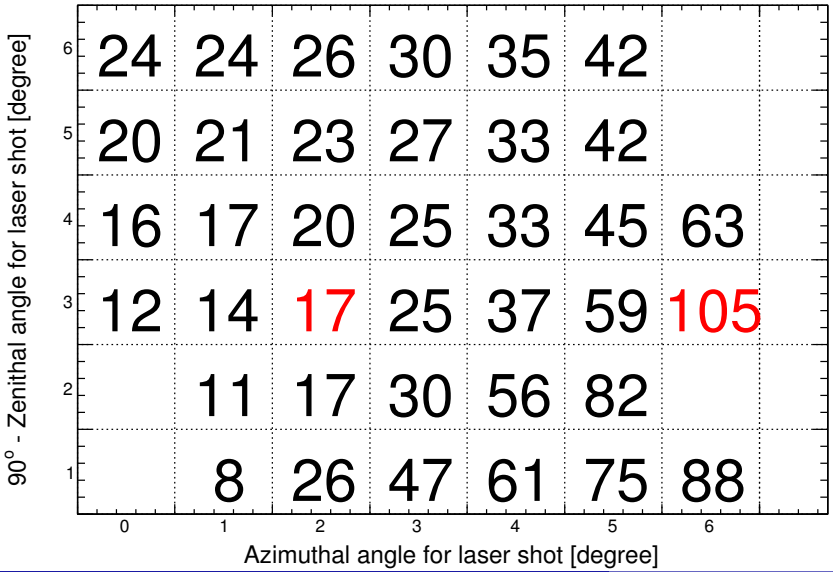
Lowest scattering angles @ Los Leones [degree]



Largest scattering angles @ Los Leones [degree]

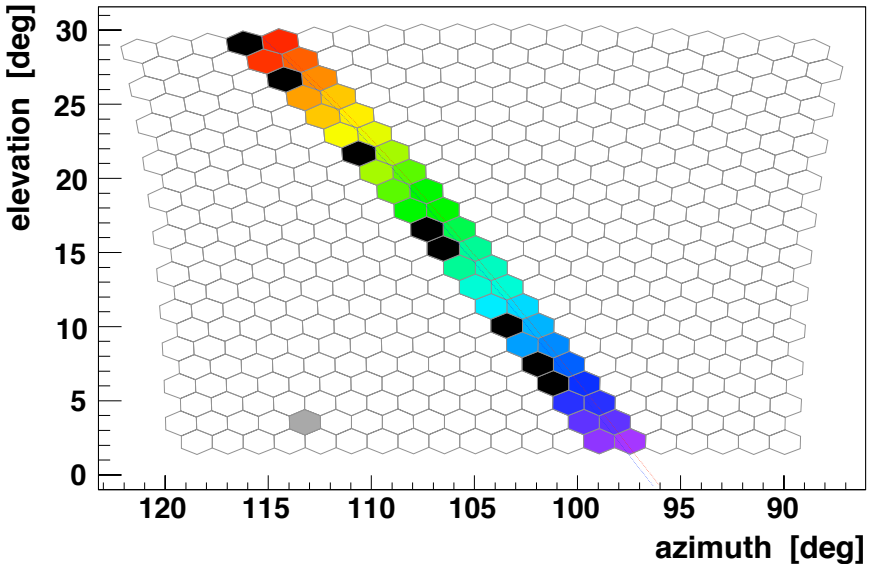


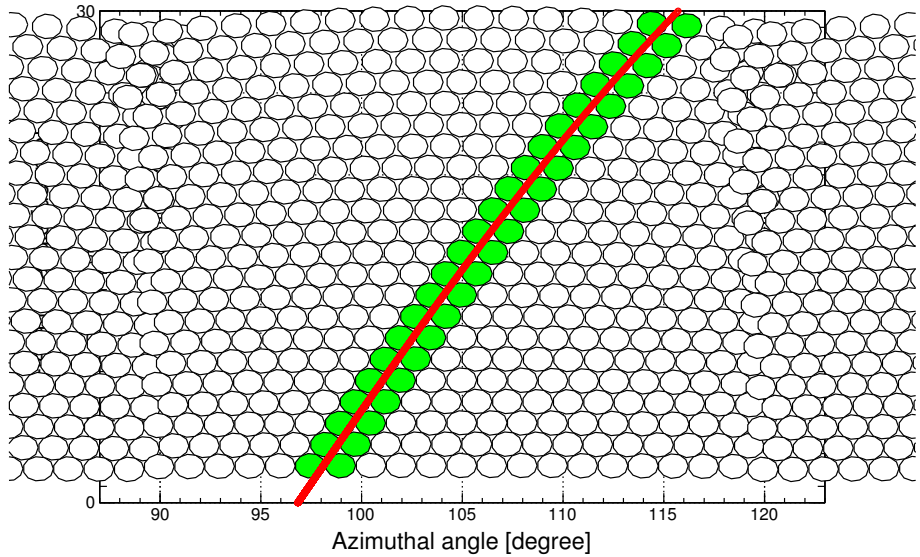
Number of time slots [100 ns]

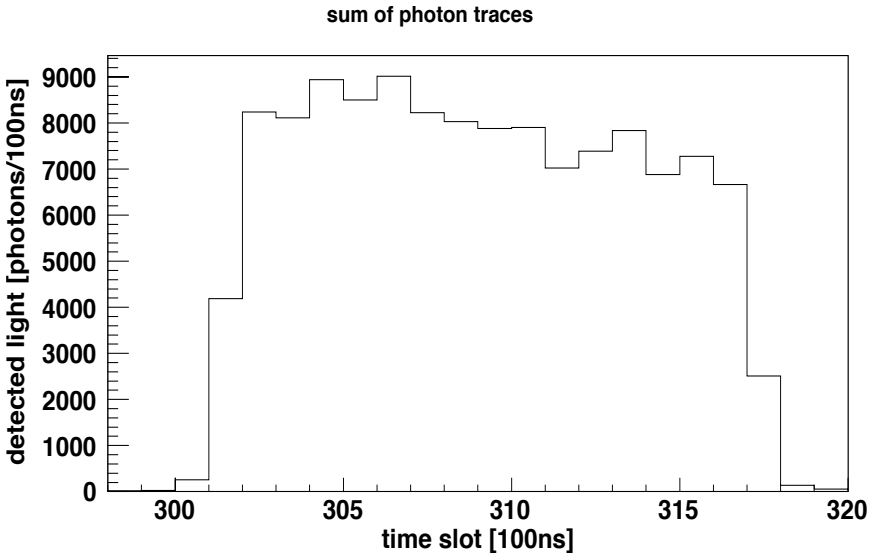


dilemma between the low scattering angle reached and the time spread for the collected light profile

A HOT shot set: ($\theta = 87^{o}$, $\phi_{\mathrm{FD}} = 2^{o}$) @ Los Leones







work in progress...

Outline

Aerosol monitoring all along the night

Proposal

- need of $\simeq 10 - 20$ shots for each (θ, ϕ_{FD}),
- procedure repeated every hours ?

$\Longrightarrow$ Monitoring of the aerosols *(complementary to the VAOD meas.)*

Better knowledge of the MS parametrization

1. aerosol phase function, from this method
2. aerosol attenuation length, from this method *(cross check with the VAOD ?)*
3. the vertical aerosol scale ?

$\Longrightarrow$ Production of monitored MS parameters for the shower reconstruction