Extracting Aerosol properties by the Central Laser Facility @ the Pierre Auger Observatory

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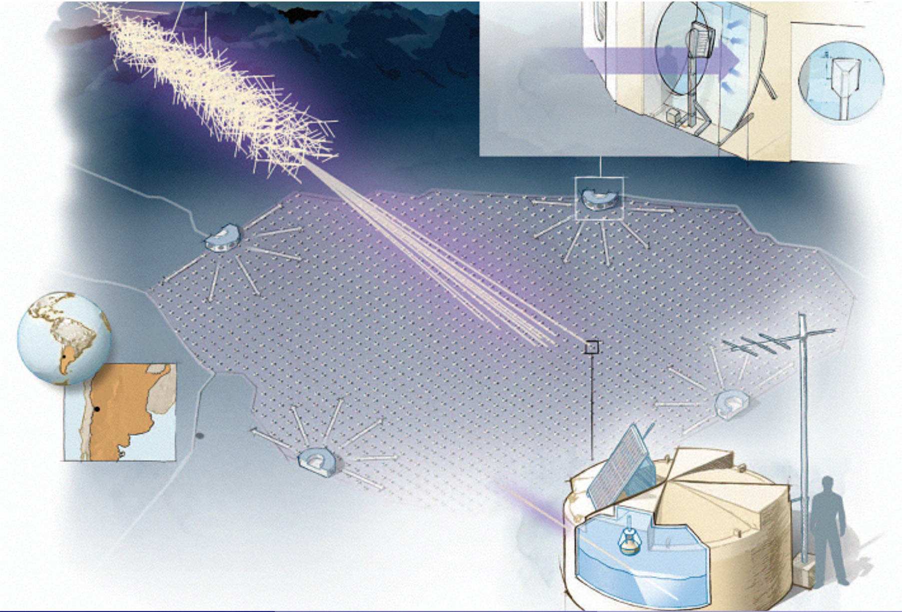
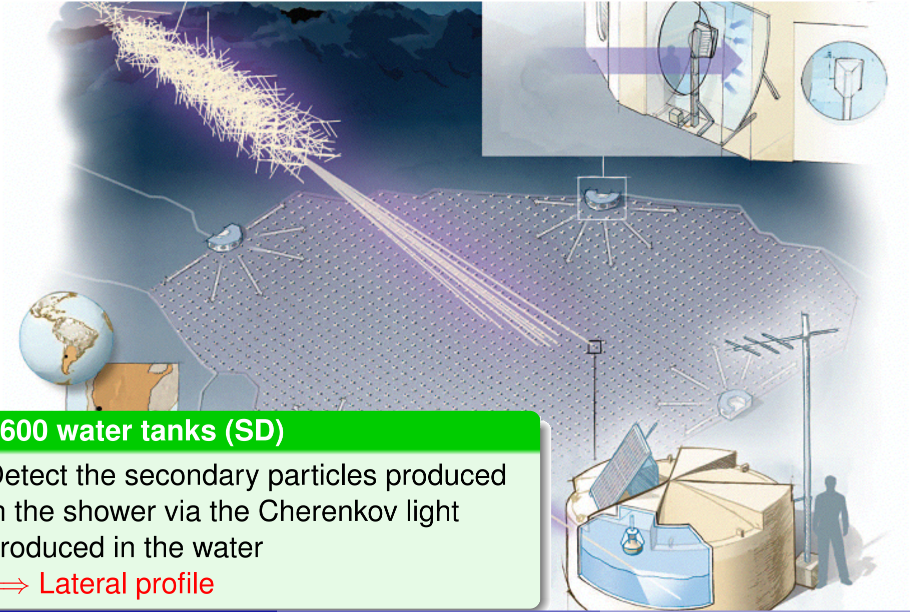
Outline

The Pierre Auger Observatory



The Pierre Auger Observatory

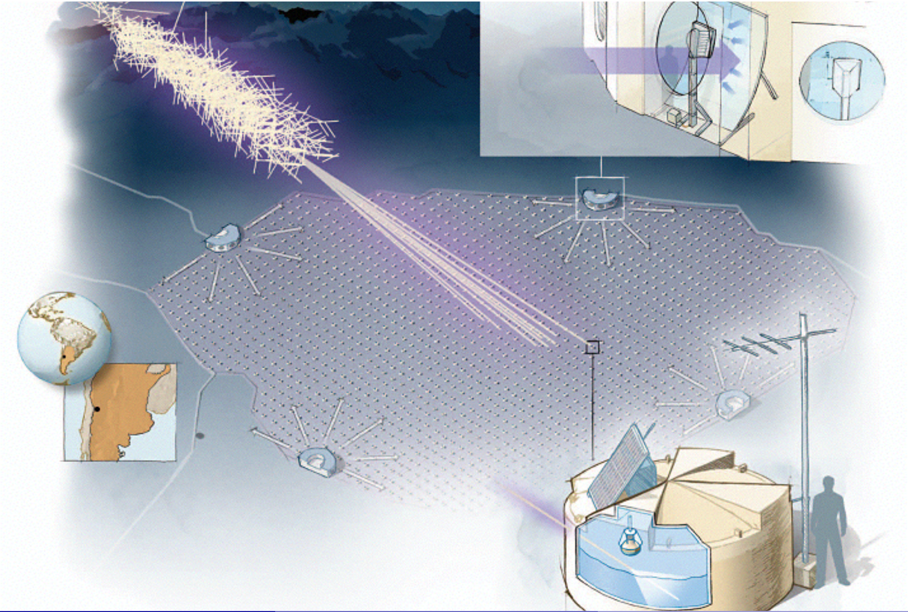


1600 water tanks (SD)

Detect the secondary particles produced in the shower via the Cherenkov light produced in the water

$\Longrightarrow$ Lateral profile

The Pierre Auger Observatory



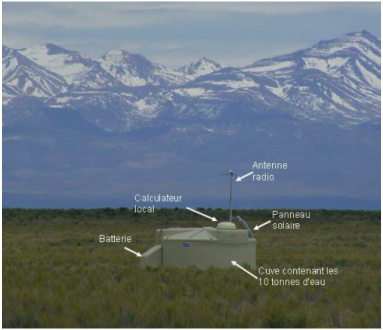
The Pierre Auger Observatory

24 fluorescence telescopes (FD)

Detect the light coming from the N_2 desexcitation ($300 - 400$ nm) induced by the $e^{\pm}$ from the shower

$\Longrightarrow$ Longitudinal profile

A ground array with 1600 water tanks *(SD)*

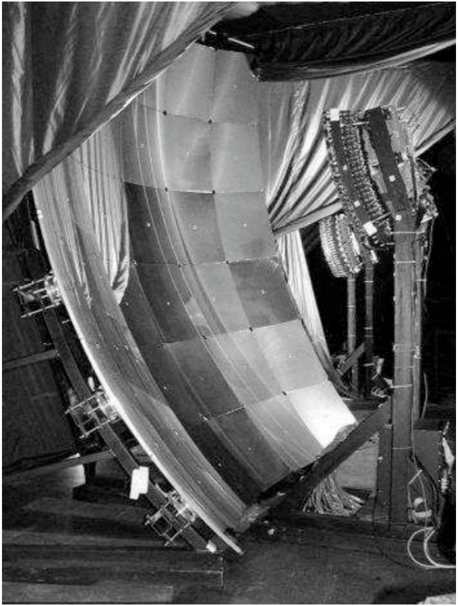


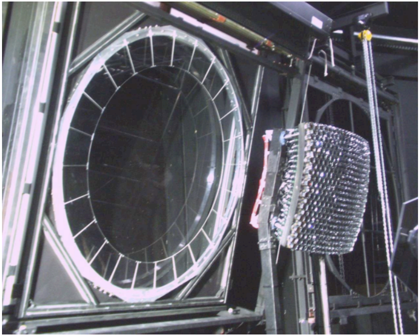
- tank filled with 12 tons of water,
- 3 photo multipliers tubes (PMT) per tank,
- charged particles detection by the Cherenkov effect.

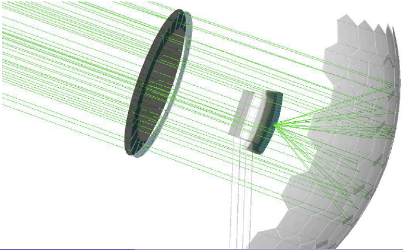
24 telescopes around the ground array *(FD)*

- the secondary particles ionize the atmosphere,
- emission of fluorescence light seen by the telescopes in UV.

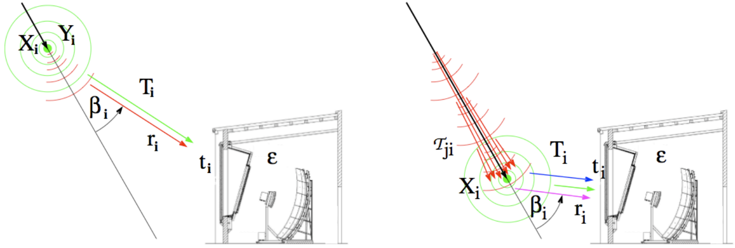
Description of a fluorescence telescope



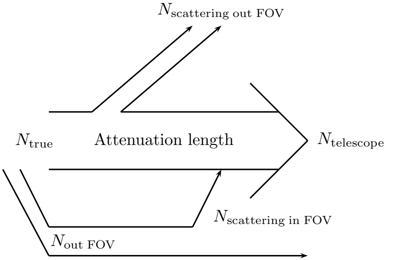




Light detection and atmosphere effect



(a) *direct light contribution* (b) *scattered light contribution*



$$N_{\text{true}} = N_{\text{telescope}} + N_{\text{scattering out FOV}} - N_{\text{scattering in FOV}}$$

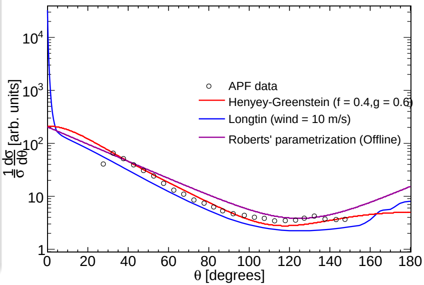
- multiple scattering contribution depends on aerosols *strongly*...
- ... but up to now in Auger, implemented *only* in ”hard”

Light scattering by particles in the atmosphere

Rayleigh scattering: $R \ll \lambda$

$\Rightarrow$ Molecular (N_2 , O_2, ...)

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



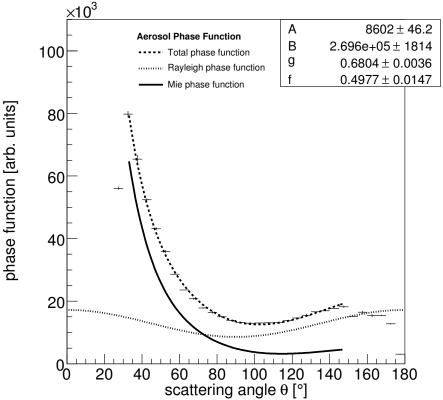
Mie scattering: $R \geq \lambda$

$\Rightarrow$ Aerosols (including dust or sand)

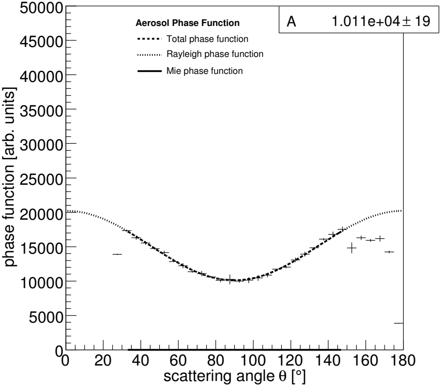
- total cross section: $\sigma_{\text{tot}} \propto \lambda^{-\gamma}$, with γ the Angström parameter,
- attenuation length Λ_{a} deduced from VAOD measurements,
- phase function $P_{\text{Mie}}(\theta)$ from typical parametrizations or tabulated.

Up to now, the Aerosol Phase Function @ Auger

Typical night



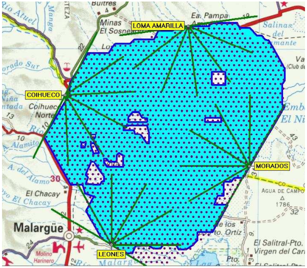
Rayleigh night



- measurements doable only between 30^o and 150^o,
- Rayleigh night $\iff$ no aerosols.

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

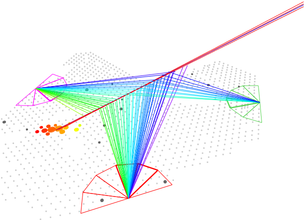
A hybrid detector



Hybrid measurements

- calibration: $\mathrm{Signal(SD)} \Longleftrightarrow \mathrm{E_{calo}(FD)}$,
- lower dependence to the hadronic models not know at UHE,
- full acceptance for $\mathrm{E} \geq 3 \times 10^{18}$ eV.

A hybrid detector



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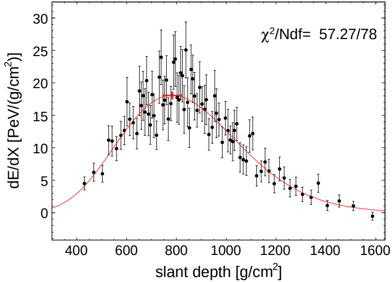

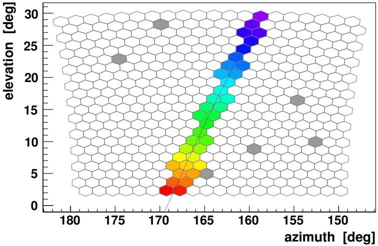

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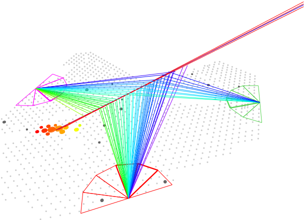

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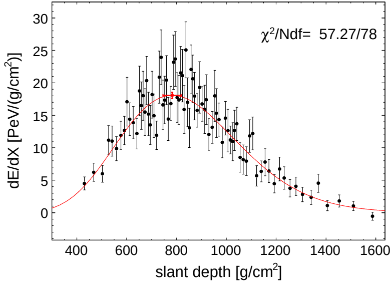
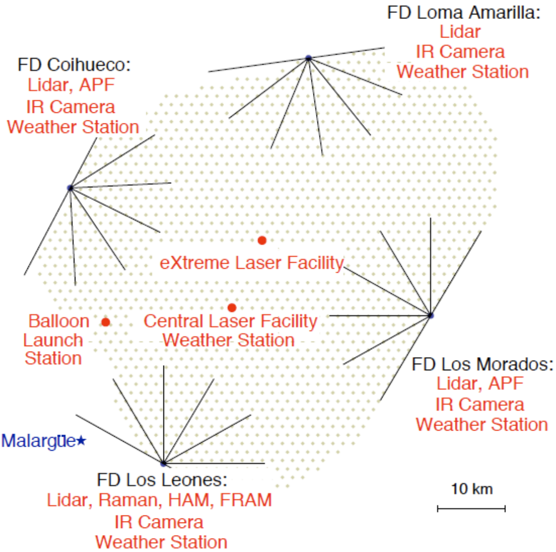
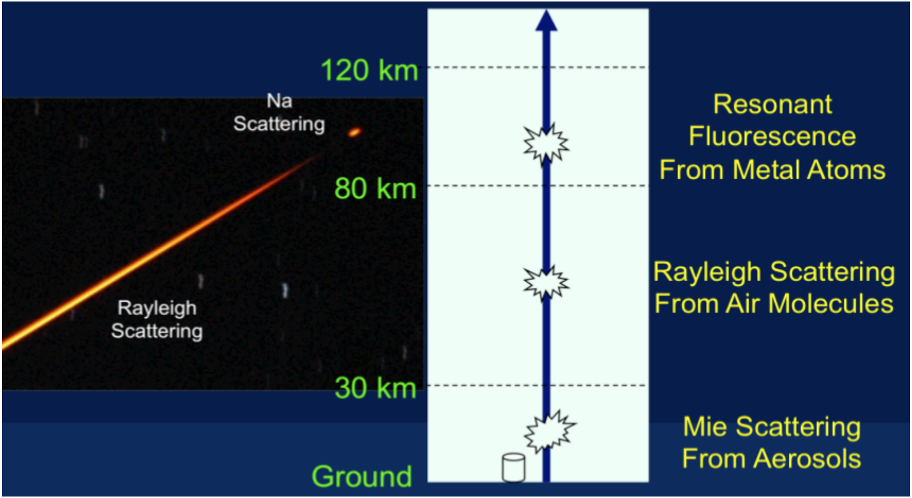


Outline

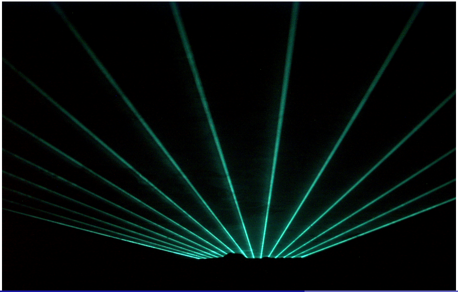
Different setups dedicated only to the Atmospheric monitoring



LIDAR: *LI*ght *D*etection *A*nd *R*anging

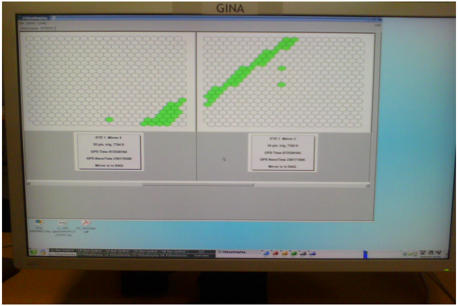


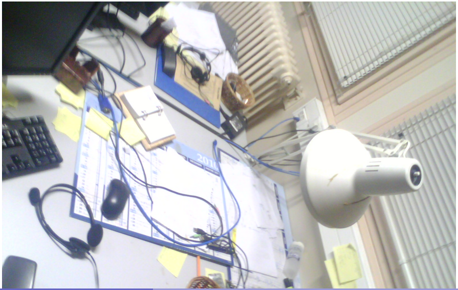
The Central Laser Facility *(CLF)*



- energy per pulse around 6.5 mJ, over 7 ns,
- wavelength fixed @ 355 nm (fluorescence band),
- zenithal: $\theta_{\mathrm{CLF}} \in [0^o\,,\,90^o]$
- azimuthal: $\phi_{\mathrm{CLF}} \in [0^o\,,\,360^o]$

The Central Laser Facility *and* My FD shift

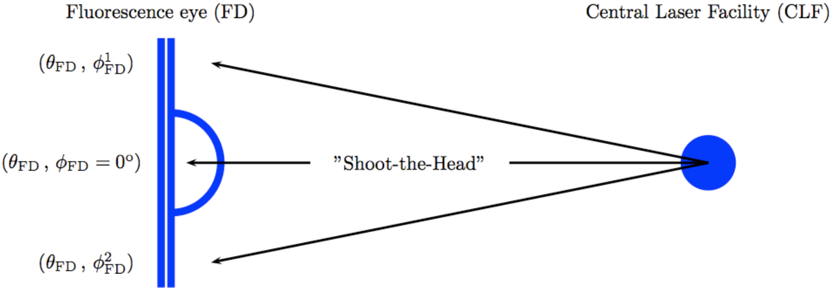




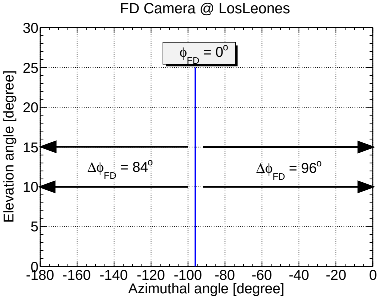
A new way to get the Aerosol Phase Function

Advantages of this technique

- check the uniformity of the aerosols in the whole observatory,
- monitoring of the APF doable all along the night,
- other aerosol parameters as the attenuation length (!)



Azimuthal ranges for the FD camera @ Los Leones



Number of time slots @ Los Leones [100 ns]

90 - Zenithal angle for laser shot [degree] \ Azimuthal angle for laser shot [degree]	0	1	2	3	4	5	6
6	24	24	26	30	35	42	50
5	20	21	23	27	33	42	53
4	16	17	20	25	33	45	63
3	12	14	17	25	37	59	105
2	8	11	17	30	56	82	96
1	5	8	26	47	61	75	88

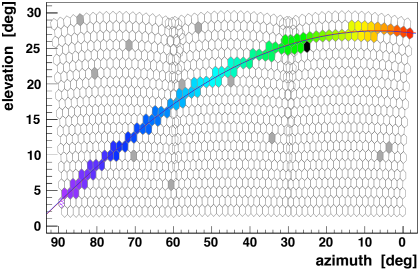
Lowest scattering angles @ Los Leones [degree]

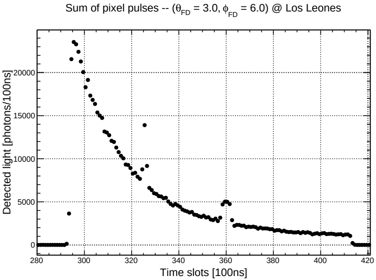
90 - Zenithal angle for laser shot [degree] \ Azimuthal angle for laser shot [degree]	0	1	2	3	4	5	6
6	8	8	9	9	10	11	12
5	7	7	8	8	9	10	11
4	6	6	7	8	9	10	11
3	5	5	6	7	8	10	11
2	5	5	6	7	9	10	12
1	4	4	6	9	11	14	16

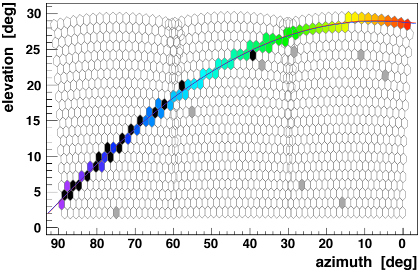
Largest scattering angles @ Los Leones [degree]

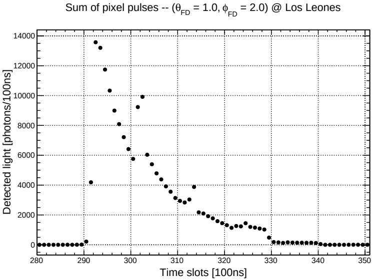
90 - Zenithal angle for laser shot [degree] \ Azimuthal angle for laser shot [degree]	0	1	2	3	4	5	6
6	36	37	38	40	44	48	53
5	35	36	38	41	45	51	57
4	34	35	38	43	49	57	68
3	33	35	40	47	58	73	97
2	32	36	45	61	83	95	96
1	31	42	77	93	94	95	96

Laser shots selection @ Los Leones









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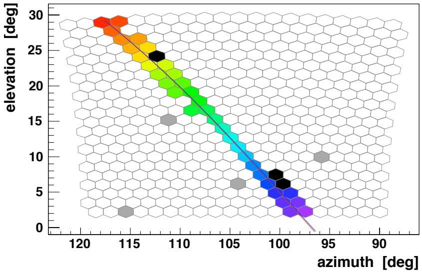
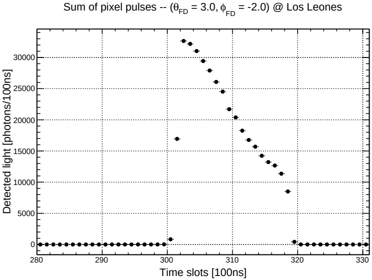




A new approach to extract the recorded signal in the FD camera

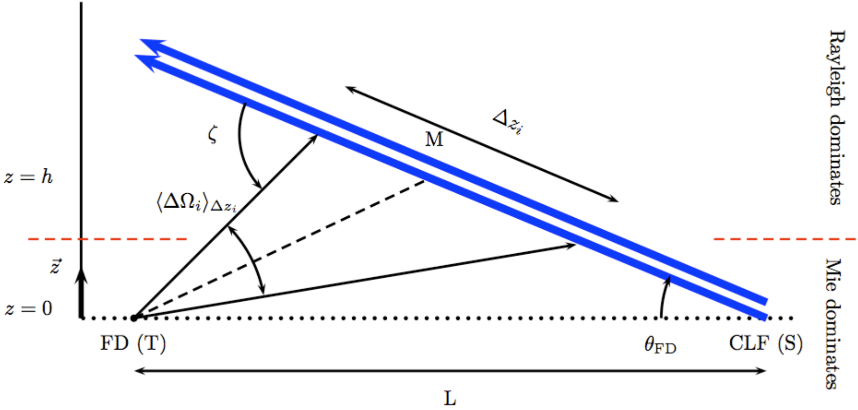
- these shots were fired for the first time during my shift...
- remark: the accuracy on the FD azimuthal angle is only $\pm 0.2^o$

$\Longrightarrow$ *Now*, new CLF shots will be fired in the automatical CLF run for the next FD shifts

Outline

Signal collected by the ith pixel in the FD camera

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



$\Lambda_X(h)$: attenuation lengths, or mean free paths

$\Longrightarrow$ probability of the traveled length before a scattering

$$\Lambda_X(h) = 1/(N(h) \times \sigma_{tot})$$

Molecular attenuation length

$$\Lambda_{Ray}(h) = \Lambda^0_{Ray} \times \exp\left(h/h^0_{Ray}\right), h^0_{Ray} \simeq 8.0 \text{ km @ Malargüe level}$$

$\rightarrow$ *estimated by the weather stations (temperature, pressure)*

Aerosol attenuation length

$$\Lambda_{Mie}(h) = \Lambda^0_{Mie} \times \exp\left(h/h^0_{Mie}\right), h^0_{Mie} \simeq 1.4 - 2.9 \text{ km @ Malargüe}$$

$\rightarrow$ *estimated by vertical CLF shots and LIDARS*

$T_{\mathrm{X}}(h)$: attenuation factors

$\Longrightarrow$ fraction of photons not yet scattered at the end of the travel

Toy case: Λ_{X} is constant

$$T_{\mathrm{X}}(h) = \mathrm{exp}\left[-(\ell_1 + \ell_2)/\Lambda_{\mathrm{X}}\right]$$

True case: Λ_{X} changing

$$T_{\mathrm{X}}(h) = \mathrm{exp}\left[\frac{h^0_{\mathrm{X}}/\Lambda^0_{\mathrm{X}}}{\sin\theta_{\mathrm{FD}}}\left(\mathrm{e}^{-h/h^0_{\mathrm{X}}} - 1\right)\right] \times \mathrm{exp}\left[\frac{h^0_{\mathrm{X}}/\Lambda^0_{\mathrm{X}}}{\cos(T\vec{M}, \vec{z})}\left(\mathrm{e}^{-h/h^0_{\mathrm{X}}} - 1\right)\right]$$

$P_{\mathrm{X}}(\zeta)$: phase function

$\Longrightarrow$ probability of the scattering angle @ scattering

$$P_{\mathrm{X}}(\zeta) = (1/\sigma_{\mathrm{X}}) \times (\mathrm{d}\sigma_{\mathrm{X}}/\mathrm{d}\Omega)(\zeta)$$

Molecular phase function: Rayleigh *(MPF)*

$$P_{\mathrm{Ray}}(\zeta) = \frac{3}{16\pi}\left[1 + \cos^2\zeta\right]$$

$\rightarrow$ *known analytically ;-))*

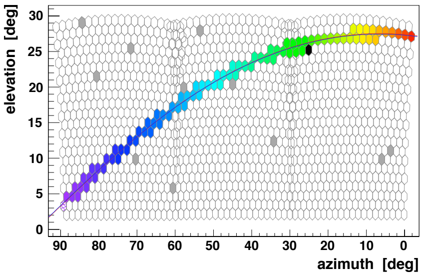
Aerosol phase function: Henyey-Greenstein *(APF)*

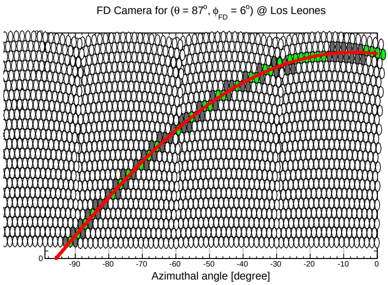
$$P_{\mathrm{Mie}}(\zeta|g,f) = \frac{1-g^2}{4\pi}\left[\frac{1}{(1+g^2-2g\cos\zeta)^{3/2}} + f\,\frac{3\cos^2\zeta - 1}{2\,(1+g^2)^{3/2}}\right]$$

$\rightarrow$ *g: asymmetry of the phase function*

$\rightarrow$ *f: strength of the backward peak*

Parameters estimation with one example





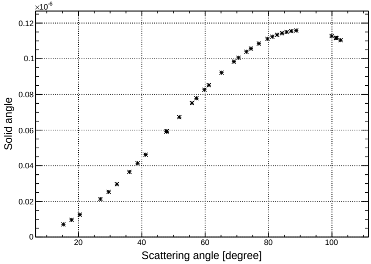
Reconstruction of the laser shot with our own program

- laser shot axis in *red*,
- rejected pixels in *gray*, pixels used in the reconstruction in *green*.

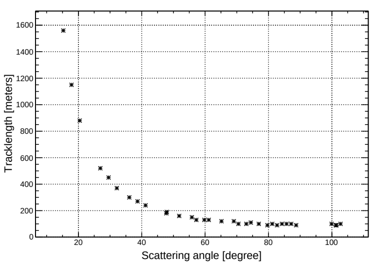
$\Longrightarrow$ A new reconstruction method pixel-by-pixel

Parameters estimation with one example

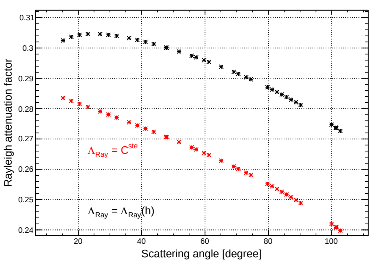
Solid angle



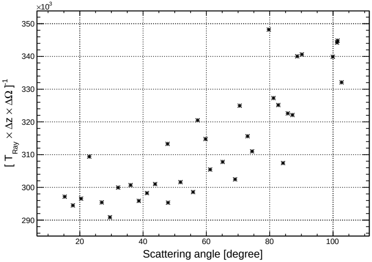
Tracklength



Rayleigh attenuation factor

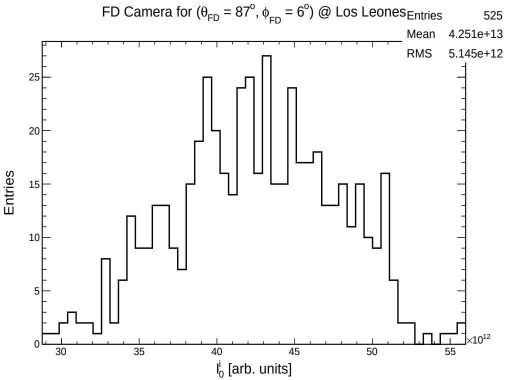


Global correction factor



Rayleigh night: estimation of the source factor I_0

$$S_{i|\mathrm{Ray}} = I_0 \times \langle T_{\mathrm{Ray}} \rangle_{\Delta z_i} \times \left[\frac{1}{\langle \Lambda_{\mathrm{Ray}} \rangle_{\Delta z_i}} P_{\mathrm{Ray}}(\zeta) \right] \times \Delta z_i \times \langle \Delta\Omega_i \rangle_{\Delta z_i}$$



$\Longrightarrow$ Each ith pixel gives a I_0^i value: $\mathrm{I}_0 = \langle I_0^i \rangle$

Extracting procedure of the Aerosol Phase Function

Reconstruction procedure

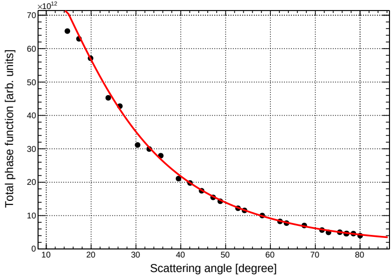
1. light collection in each pixel i in green is extracted: S_i,
2. for each ith pixel, S_i is divided by the correction factors and by its source factor I_0: we get $S_i \rightarrow S_i'(g,\ f,\ \Lambda^0_{\mathrm{Mie}},\ h^0_{\mathrm{Mie}})$,
3. a 4-parameter fit can be applied to estimate the aerosol parameters.

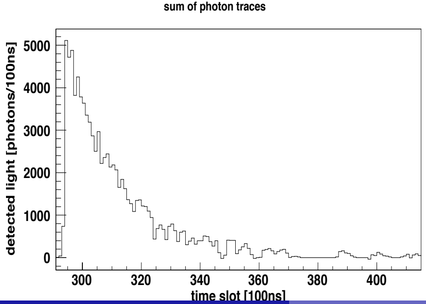
We simulate expected profiles for each parameter configuration, then a χ^2 test is runned to estimate the optimized parameters

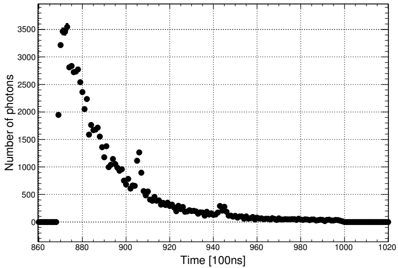
Validation of the geometrical reconstruction

A typical night @ Los Leones

- aerosols: H-G ($g = 0.6$, $f = 0.4$),
- aerosol attenuation length fixed at 20 km,
- vertical aerosol scale fixed at 1.4 km.



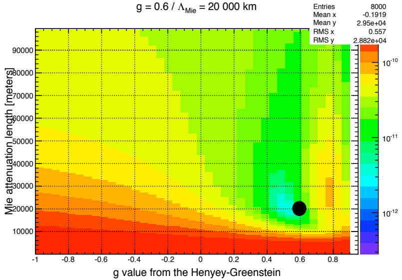


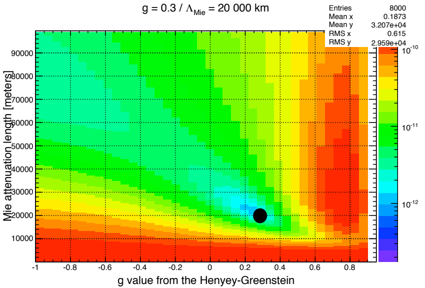


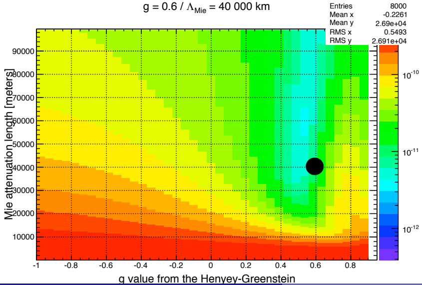
Aerosol parameters estimation by a (3)-parameter fit @ Los Leones

- the shot (3^o, 6^o) does not draw the aerosol backward peak
  $\rightarrow f$ value is fixed at 0.4
- the asymmetry parameter : $g_{H-G} \in [-1, 1]$,
- the aerosol attenuation length : $\Lambda^0_{Mie} \in \ ]0, 100\,000]$,
- the vertical aerosol scale : $h^0_{Mie} \in \ ]0, 5000]$.

First results from the 3-parameter fit (Preliminary)







- not very sensitive to the vertical aerosol scale (shots at low altitude),
- systematic effect on the g estimation ?

And with the data...

$\emptyset$

Outline

Conclusions

- selection of laser shots done and they are scheduled for the next *runs*,
- after the Higgs tracking, here it is the big aerosols tracking.

To Do list

- *in the next days*, systematics (?) and first try of the method on CLF data set for laser shots (3^o,$\pm 6^o$),
- *in the next weeks*, development of our own APF parametrization derived from the Ramsauer approach *(see JRJC'09 proceeding)*,
- *in the next months*, make the link with the Multiple Scattering parametrizations in $\overline{\text{Off}}\underline{\text{line}}$ (collaboration with a MS code already developed).

$\Longrightarrow$ On the way of a **complete** aerosol monitoring *(complementary to other atmospheric measurements @ Auger)*

A workshop to promote interdisciplinary science at the Auger observatory.

Interdisciplinary Science @ the Auger Observatory:

from Cosmic Rays to the Environment

A workshop to promote interdisciplinary science at the Pierre Auger Observatory in Western Argentina

18-19th April 2011

Centre for Mathematical Sciences
University of Cambridge

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