Aerosol horizontal homogeneity studies with elastic lidars at the Pierre Auger Observatory

Roberto Mussa

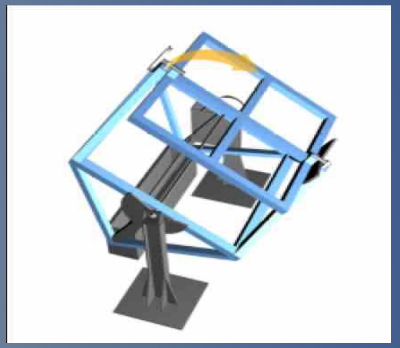
(for the Pierre Auger Collaboration)

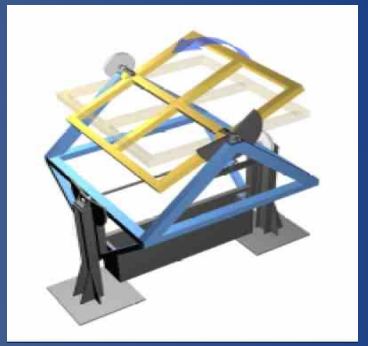
Outline

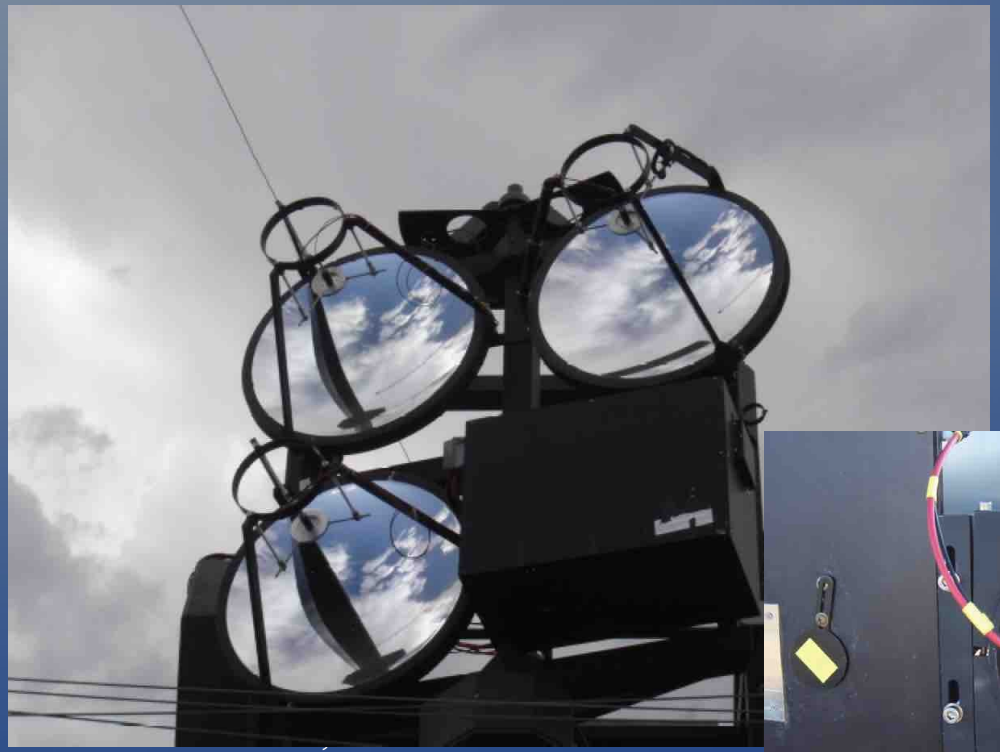
- Elastic lidars hardware
- Horizontal shots
- Overlap function studies
- Quality of exponential fit : χ^2/N_{dof}
- Short vs Long Range consistency
- Azimuthal asymmetries
- Molecular α_0 with ERA5 DB
- Results on $\alpha_{0,aer}$

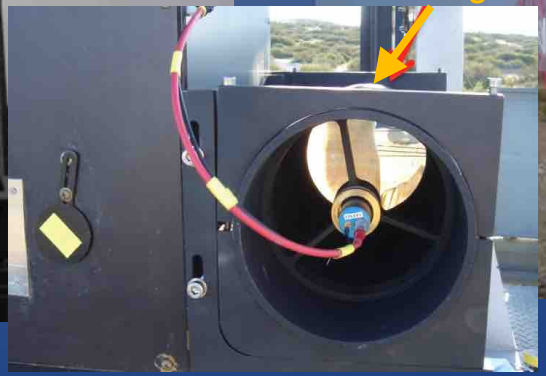
LIDAR : mechanics

Alt-altazimuthal motorized mount
Encoder controlled steering
Aligned to the axis of each FD
Fully retractable cover
Short range mirror added in LA+CO







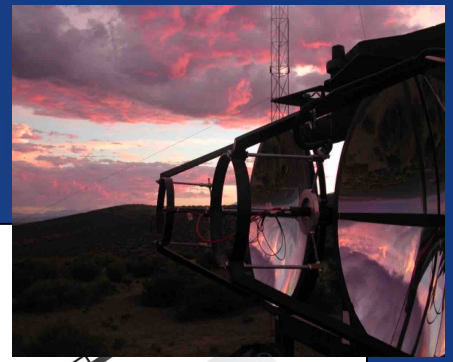


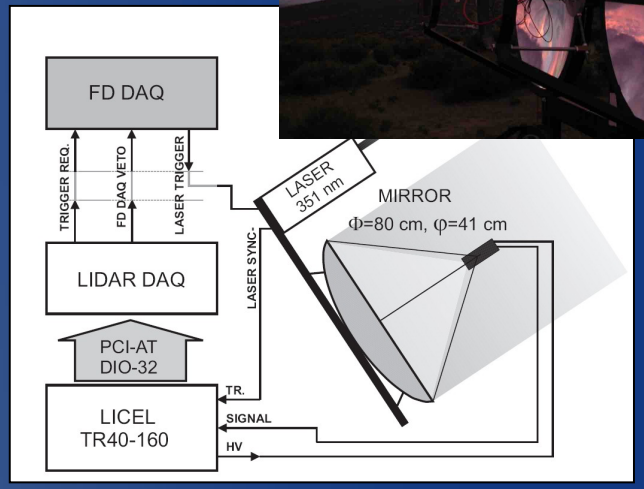
LIDAR: photonics

LASER Photonics DC30-351

Laser Type: Nd:YLF
Main wave length: 351 nm
Pulse Energy: 0.1 mJ
Pulse width: 15 ns
Repetition rate: 0.333 kHz

PMT: Hamamatsu R7400 U-03
HV: 770-900 V
FWHM single photon: 2 ns
photocathode diameter: 8 *mm,*
peak wavelength: 420 *nm* (at 25*°C*),
UG1 filter (PMT entrance window)





DATA ACQUISITION Licel TR40-160 (3 channels)

A/D converter

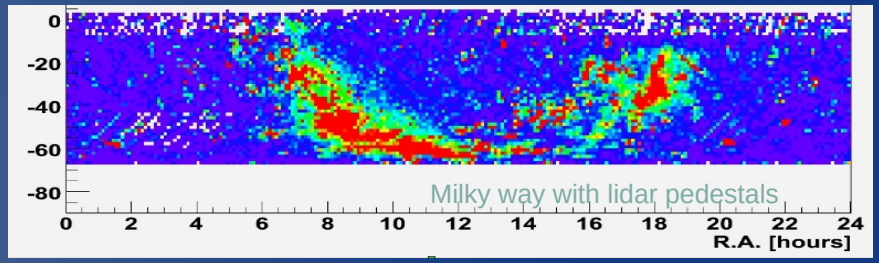
Resolution:**12 bit**
Sampling frequency: **40 MHz**
→ Spatial resolution: **3.75 m**
Trace length: **16k (60 km)**

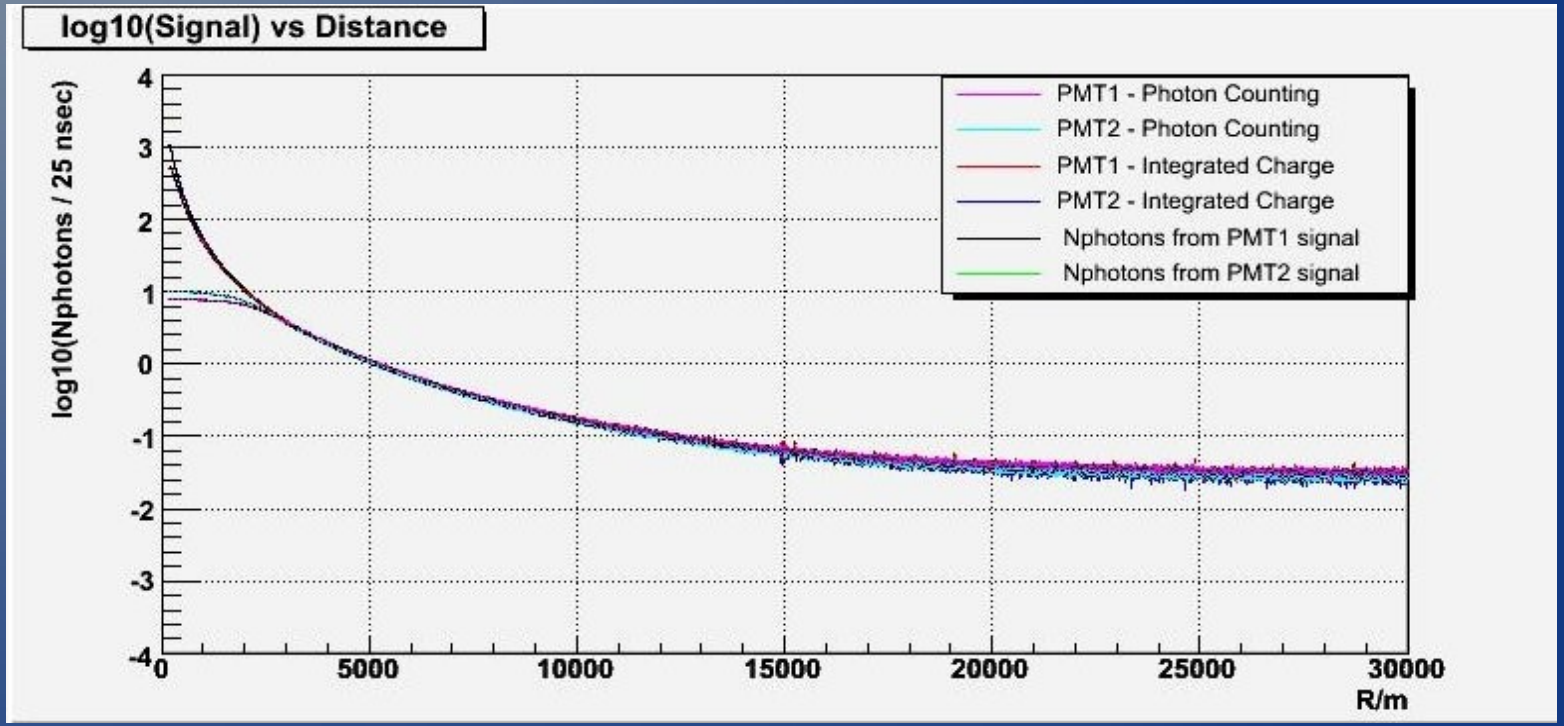
High speed discriminator

Frequency: **250 MHz**
Configurable threshold level
(64 levels between 0 and –100 mV)

LIDAR: signals

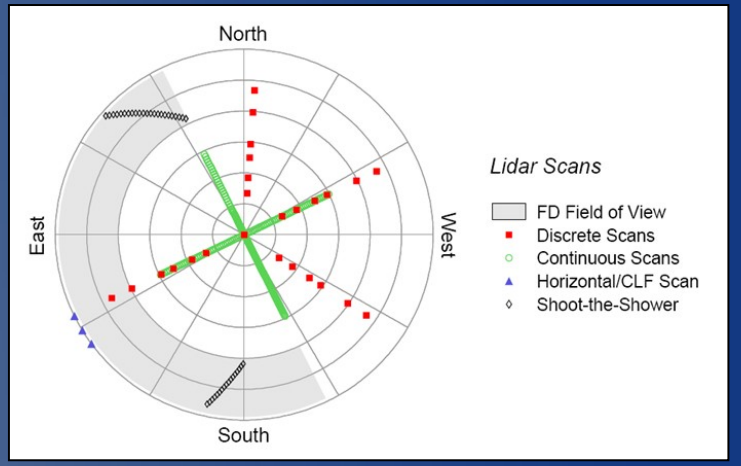
Signal is the sum of 1000 shots in 3 seconds
Dynamic range : almost 5 orders of magnitude
Lower limit: sky background (stars, airglow)
Range: *almost* 30 km





LIDAR : sky scans

Every hour, each Lidar performs this set of scans:



Horizontal Shots

Horizontal homogeneity
Aerosol extinction at ground

Continuous Scans

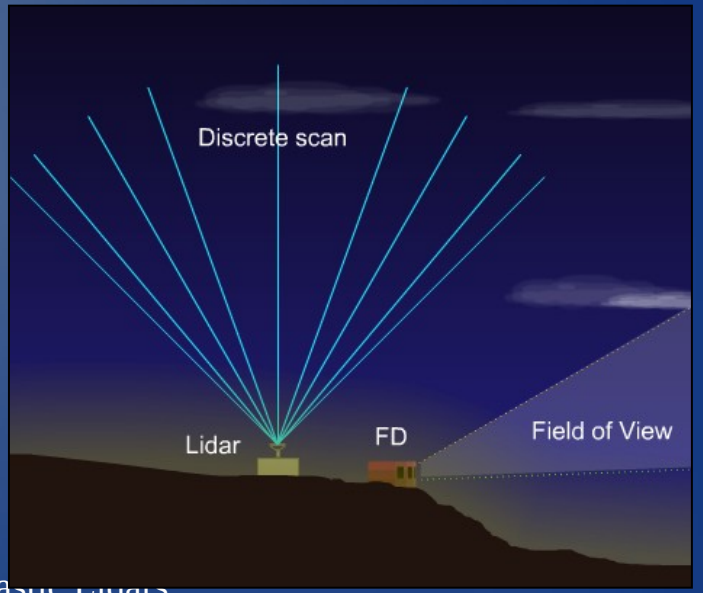
Cloud coverage
Cloud characterization

Discrete Scans

Vertical Aerosol optical depth (VAOD) with multiangle inversion technique

Vertical Shots

VAOD with Fernald inversion technique

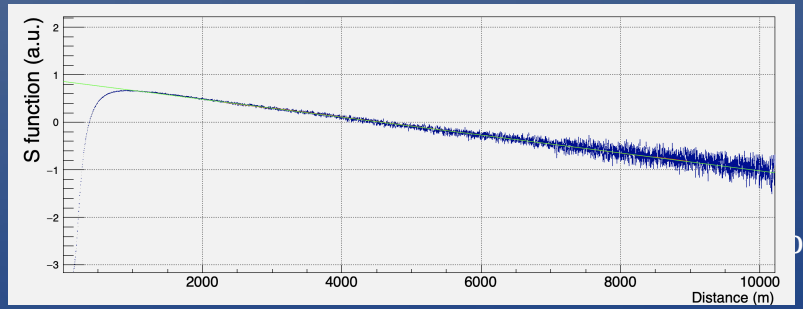


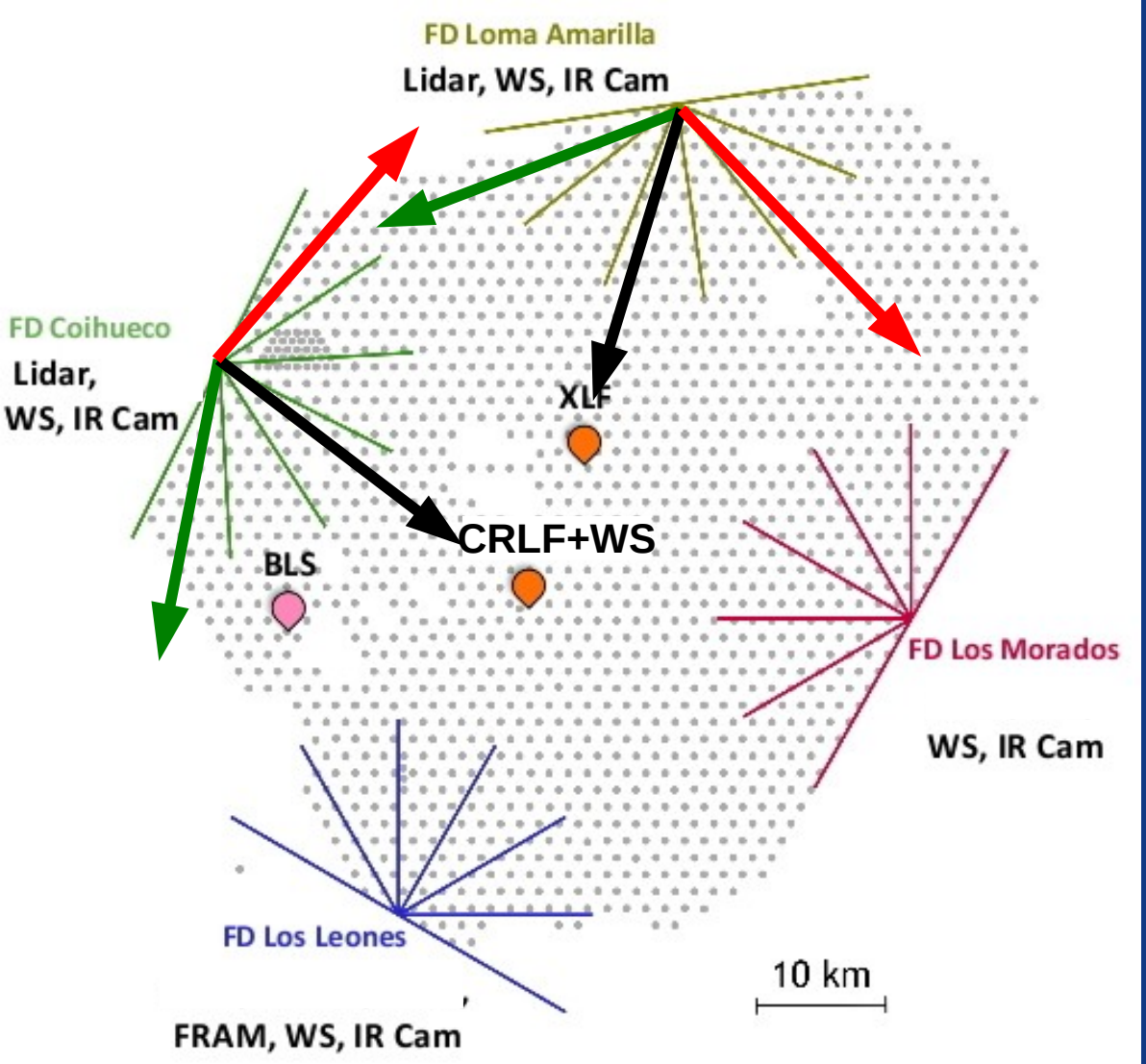
Horizontal shots

Sequences of 2-3 k shots in 3 azimuths to check horizontal homogeneity of aerosols

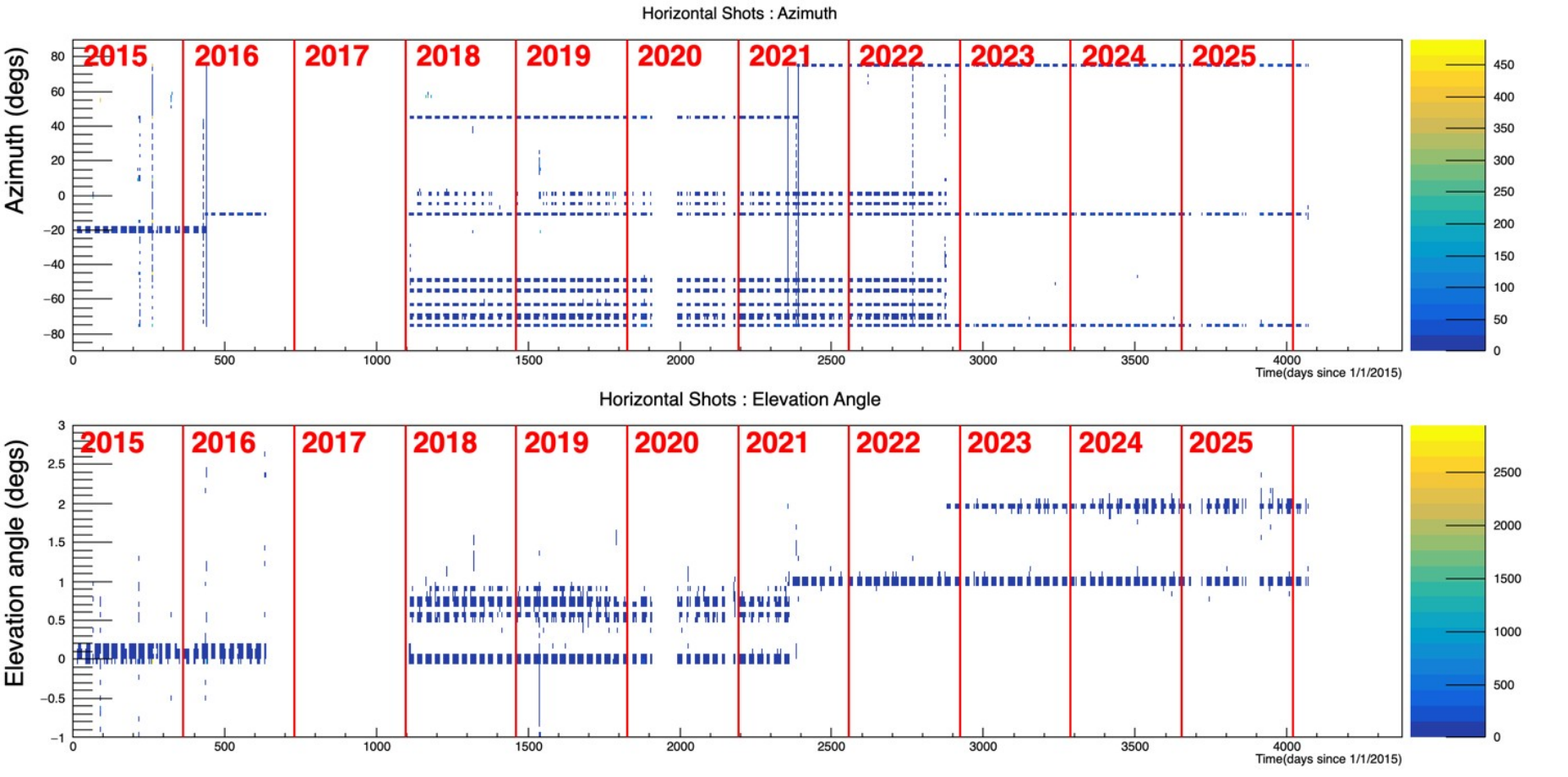
Loma Amarilla
- Azi,Elev: (-75;1),(-24.5;0),(35;1)
- Fit of α_0 in range [1.5-6] km

Coihueco
- Azi,Elev: (-75.5;1), (-75.5;2), (-10.5;1), (-10.5;2), (75;1), (75;2)
- Fit of α_0 in range [2.25-9] km

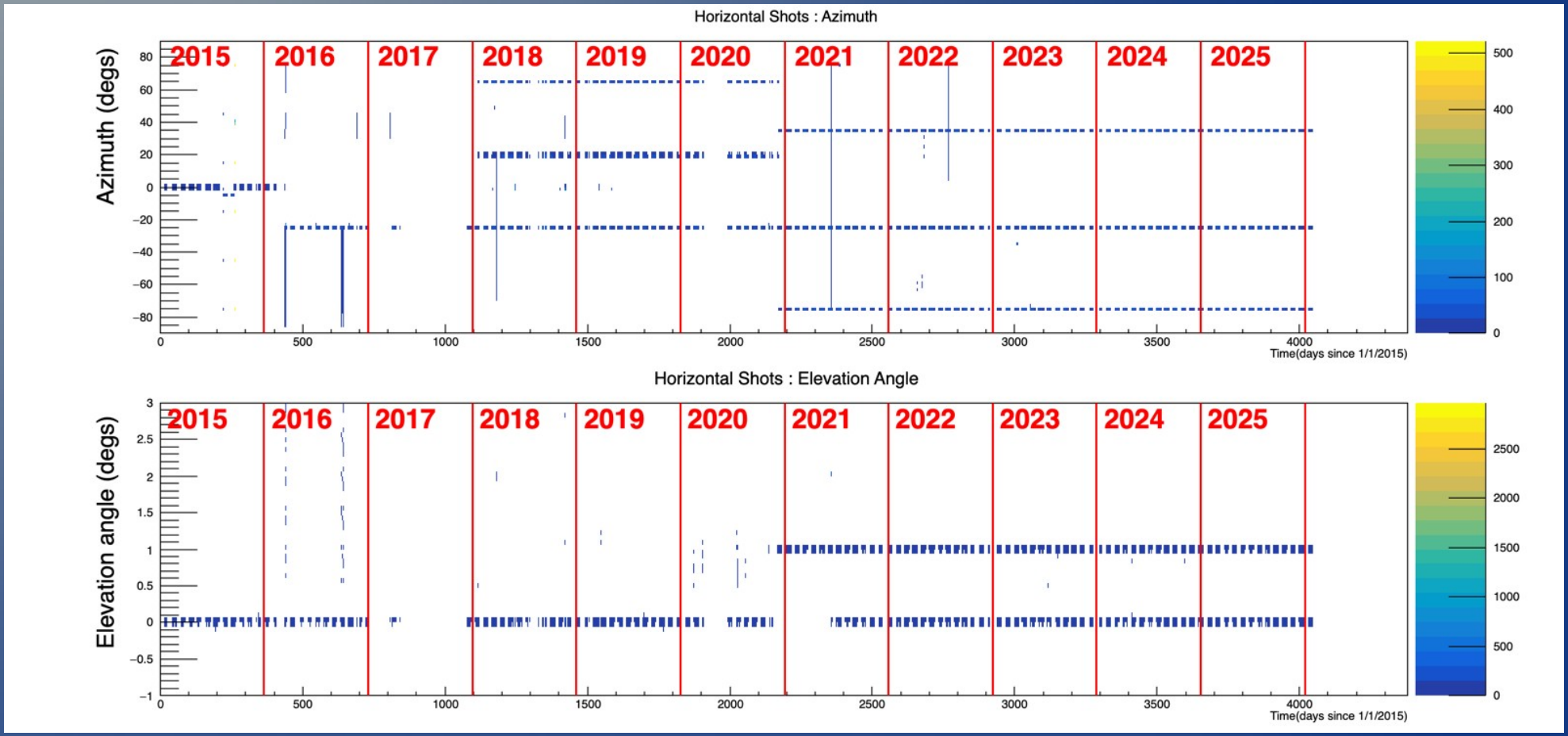




Direction of horizontal shots at the Coihueco site

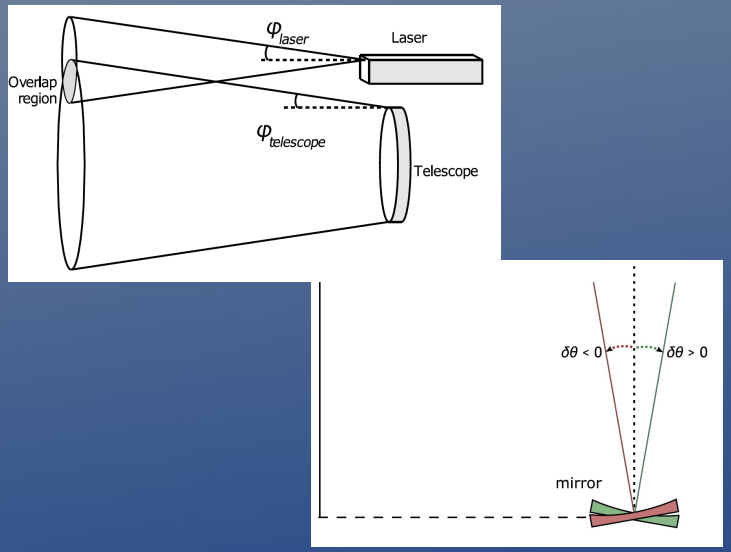


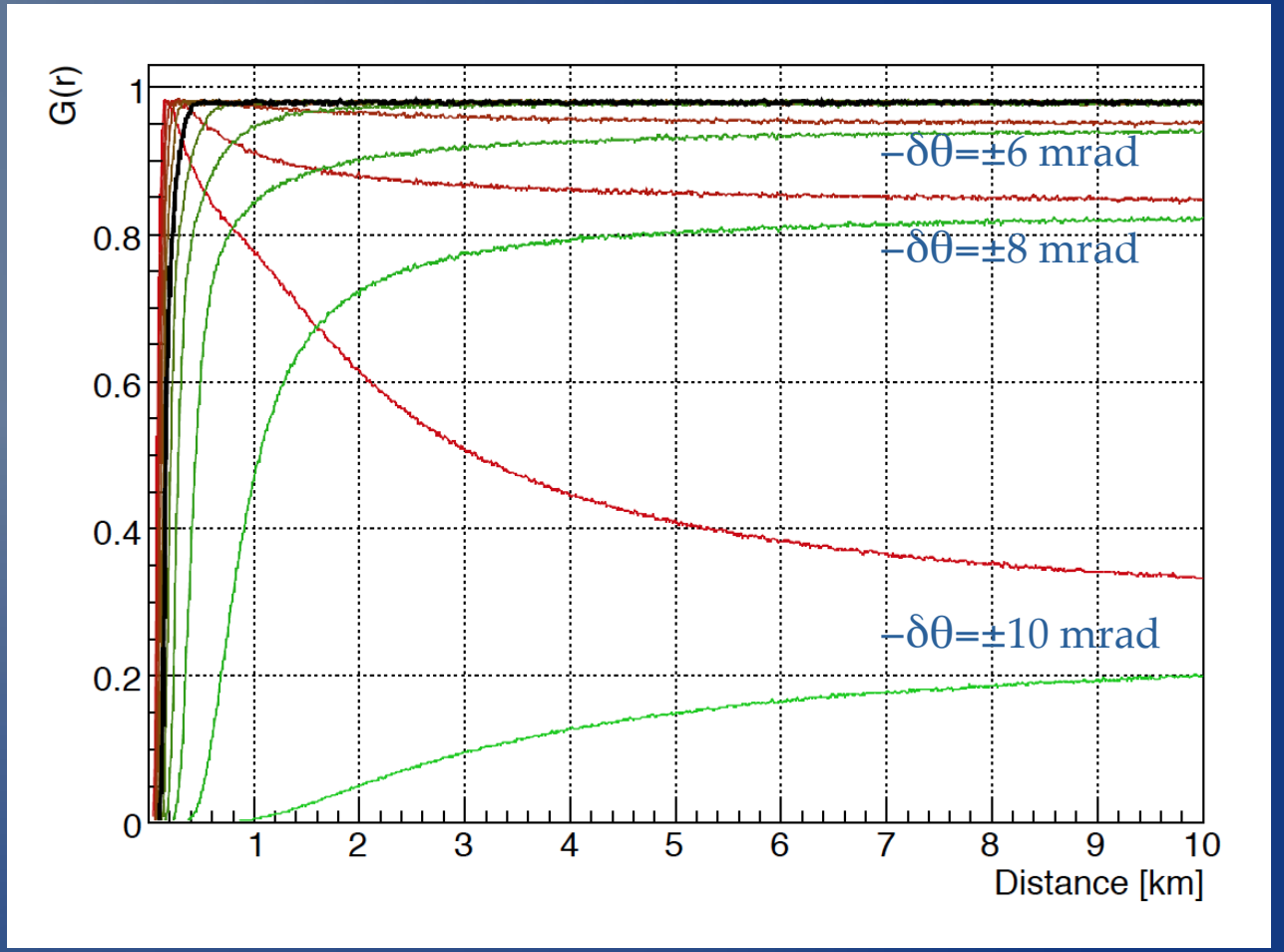
Direction of horizontal shots at the Loma Amarilla site



Overlap function

The overlap function describes the lidar return in the region where not all the laser spot is in the field of view of the focusing mirror. Ideally.
For the long range mirror:
G(1 km) ~ 1

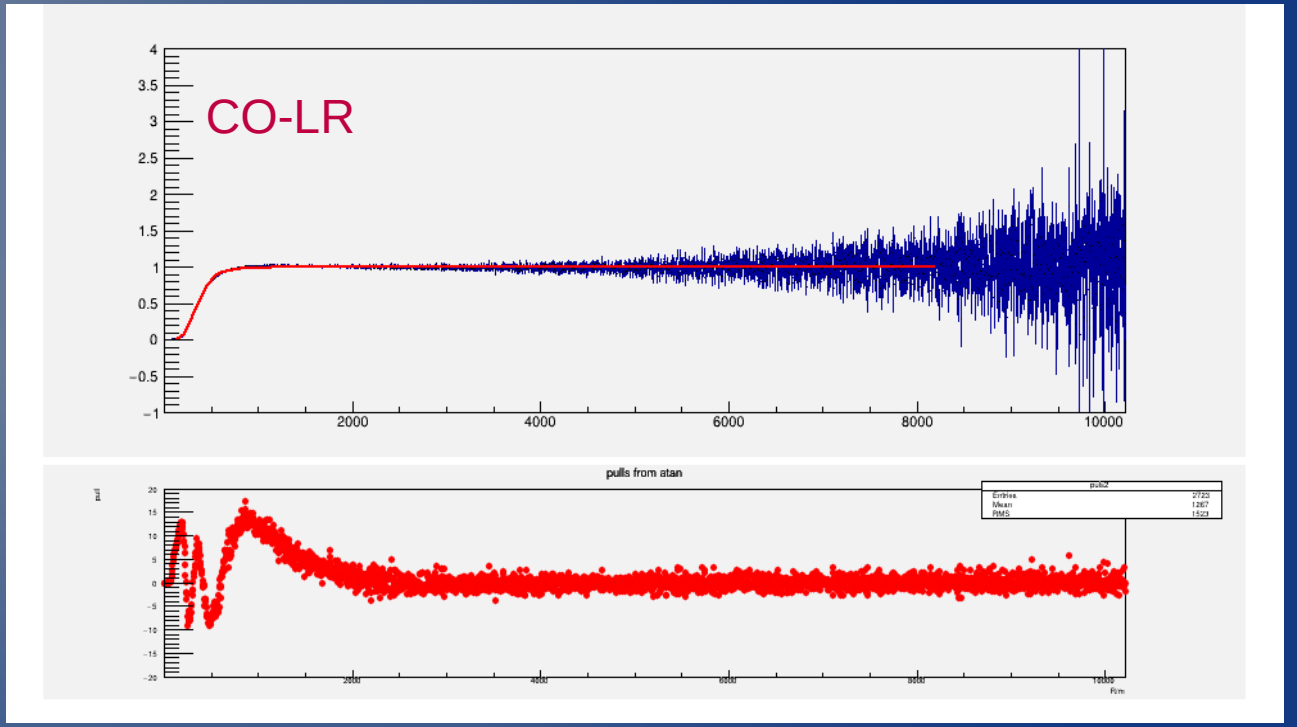




Overlap function

A correct parametrization of G(r) allows to improve accuracy in detecting low lying aerosols, in multi-angle analysis.

Horizontal shots are used to model and describe G(r) with the minimal number of parameters.



$$G(r) = [(\arctan(Z+P_2*Z^2+P_3*Z^3)+\pi/2)/\pi]^4$$

$$\text{with } Z = P_1*(r-P_0)$$

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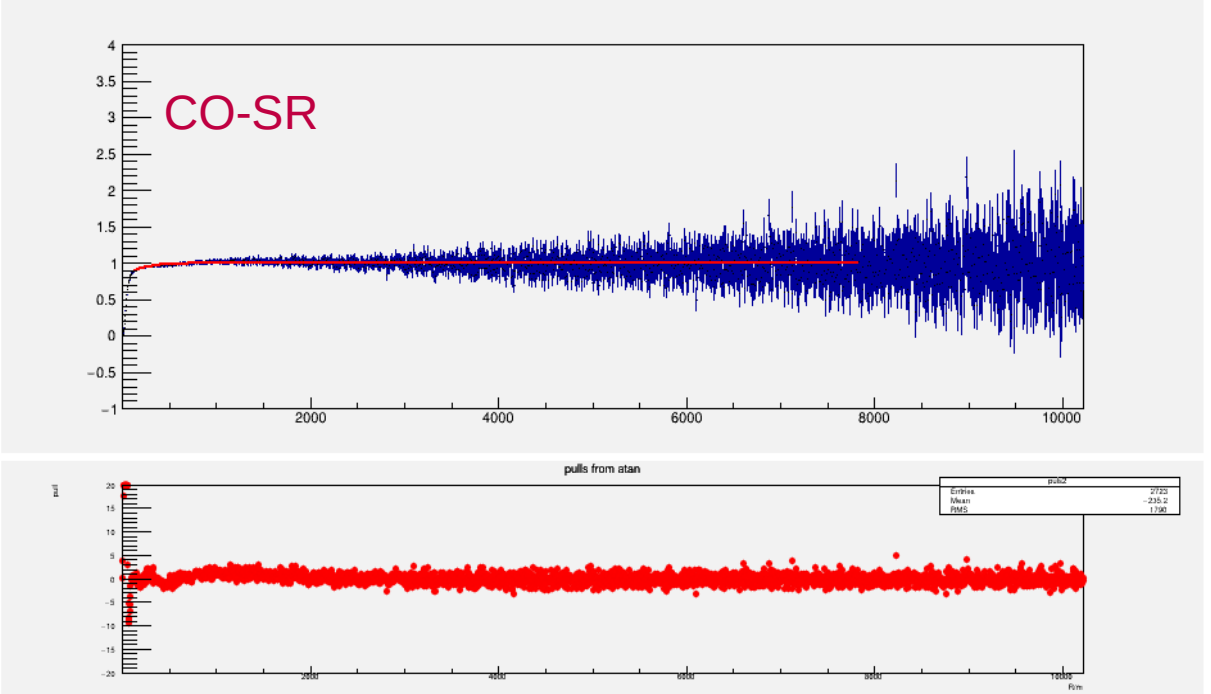

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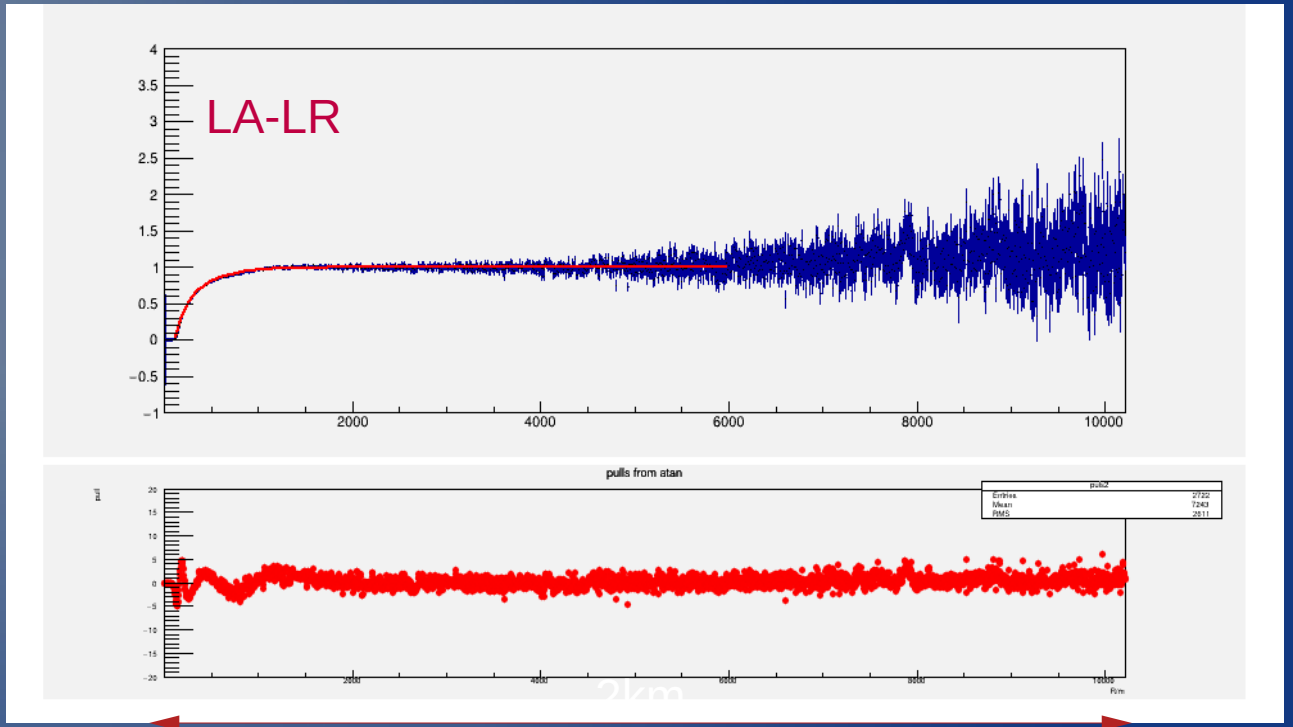

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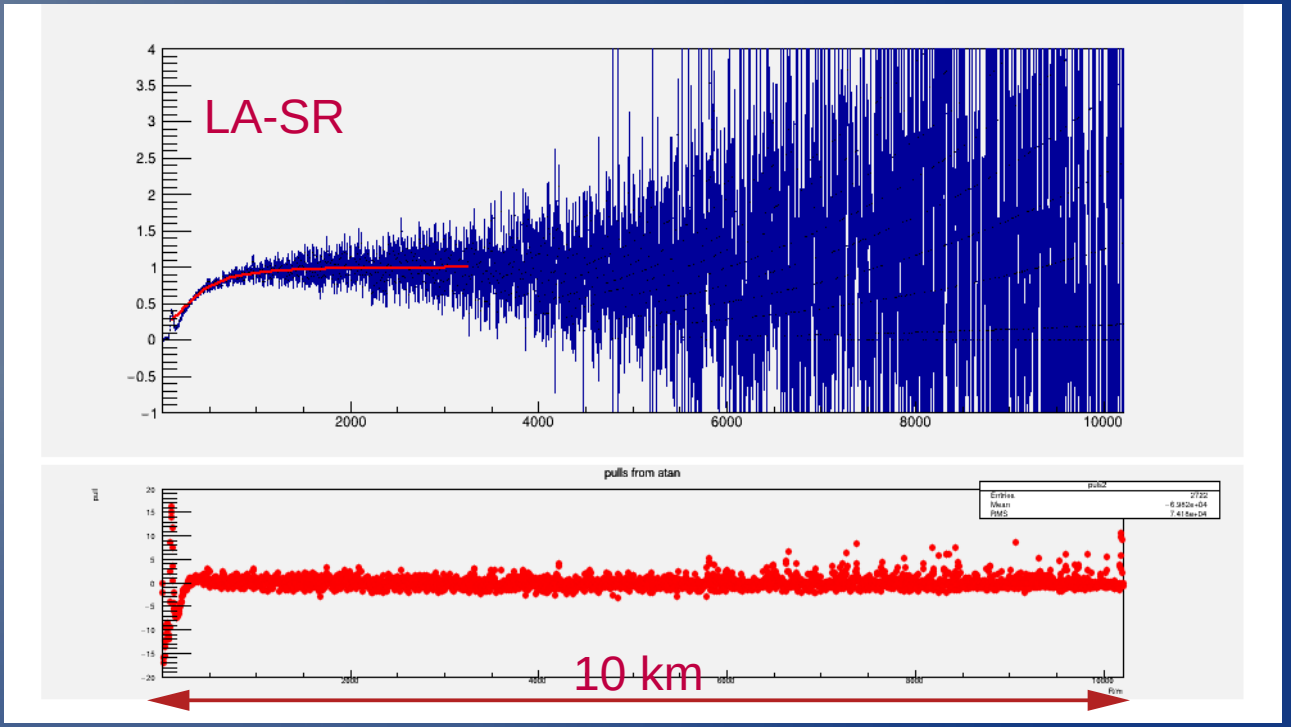

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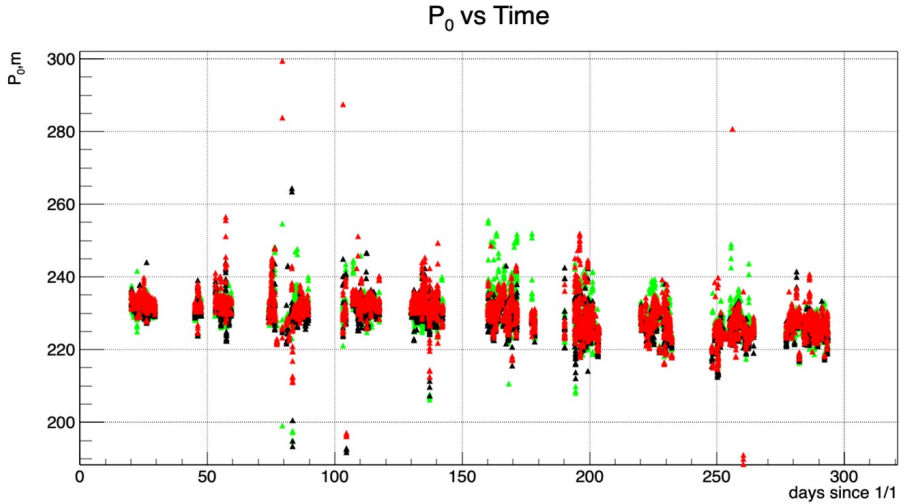
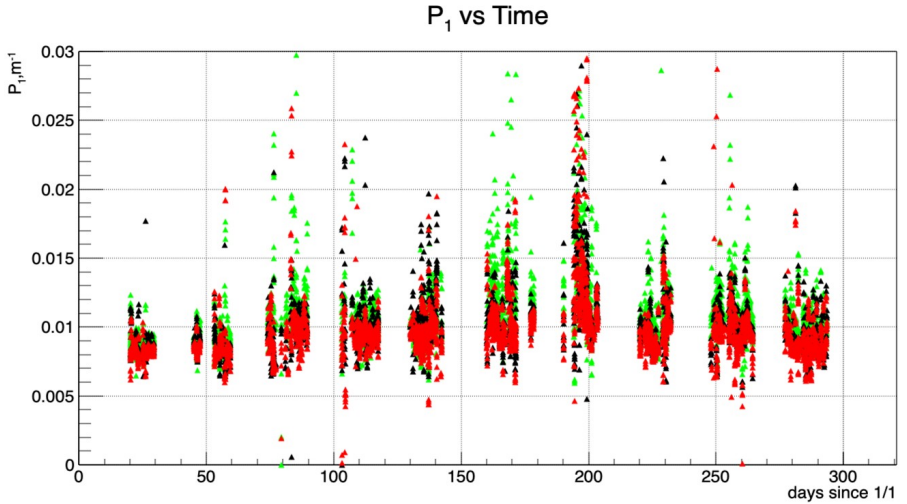
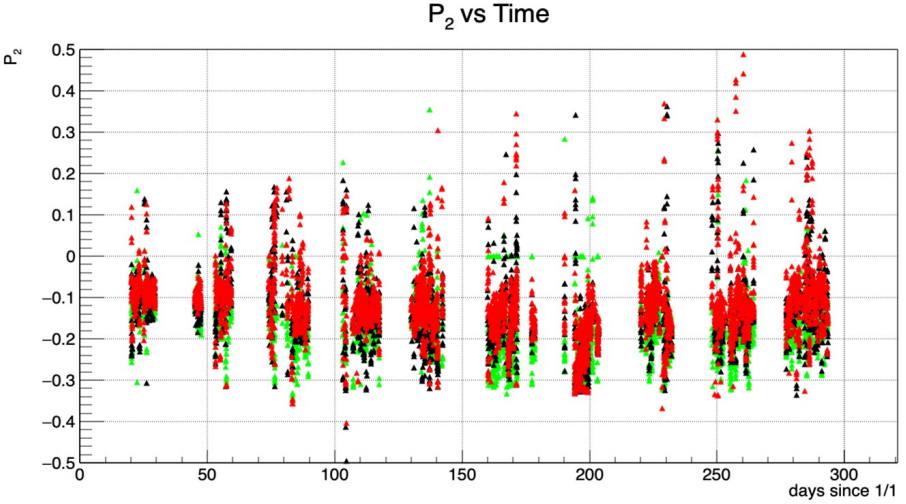
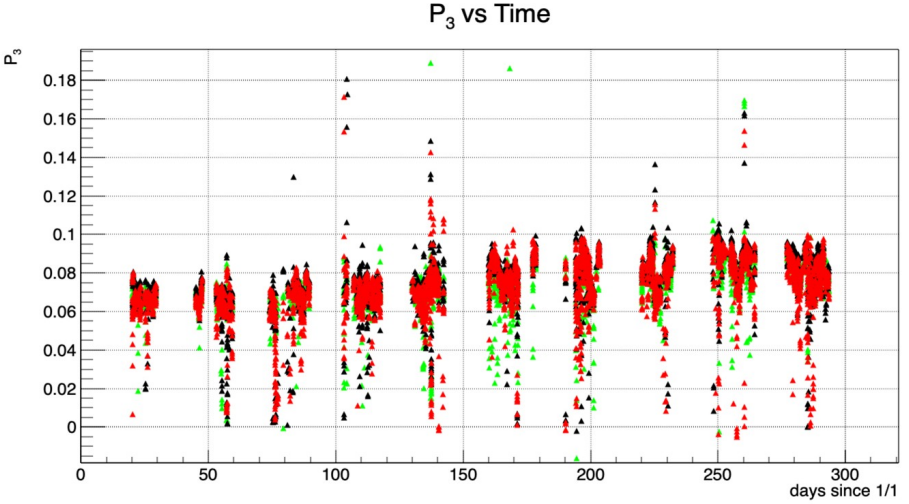
Overlap function: variation of P_i at Coihueco-LR (2023)

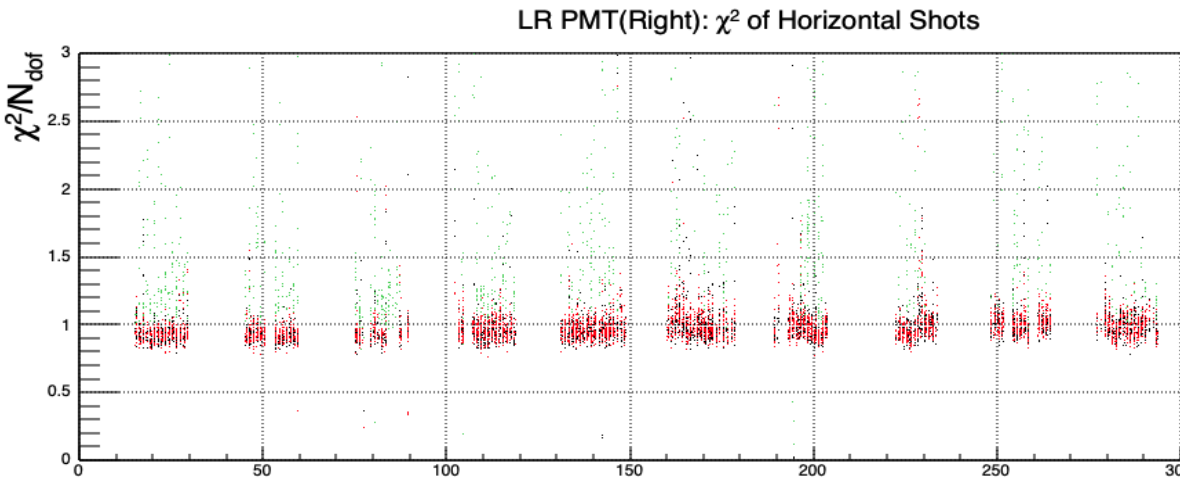


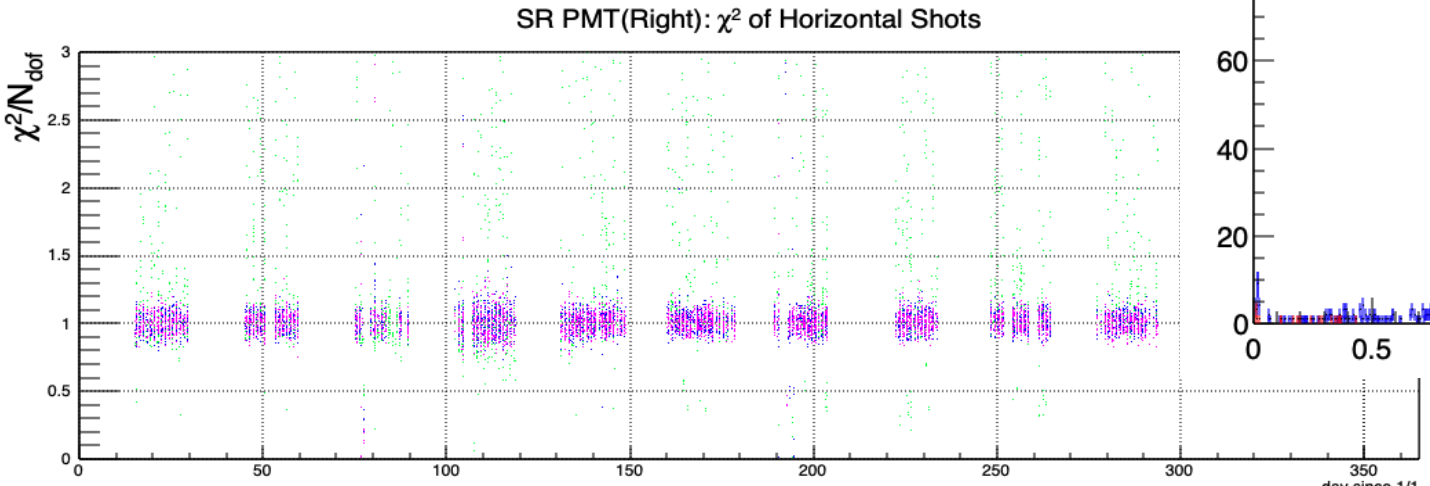


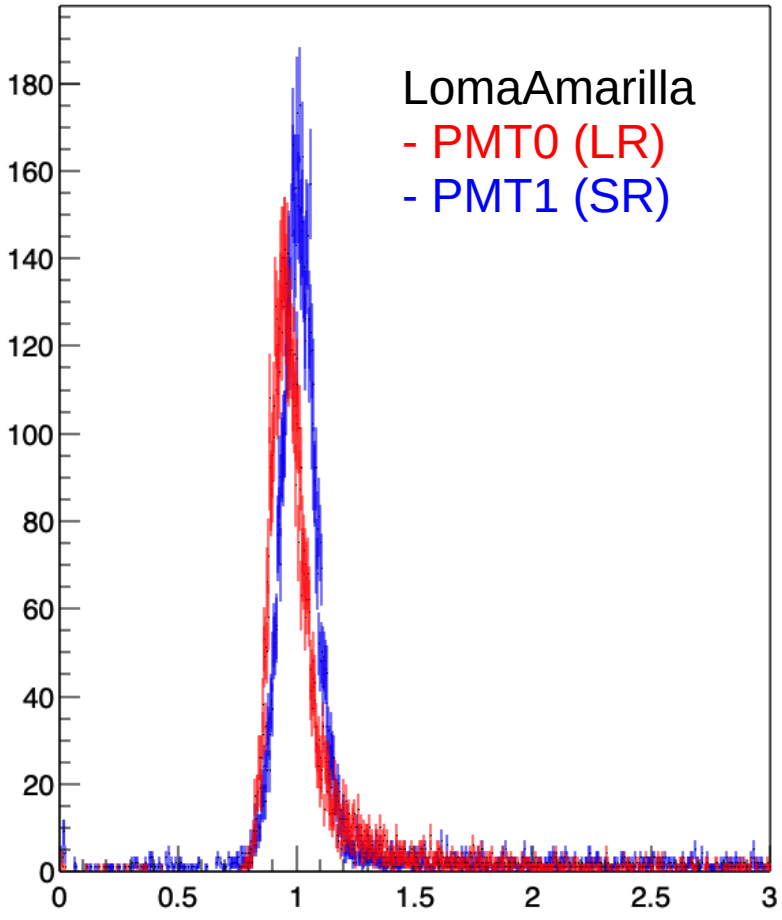




Quality of exponential fit : χ^2/N_{dof}







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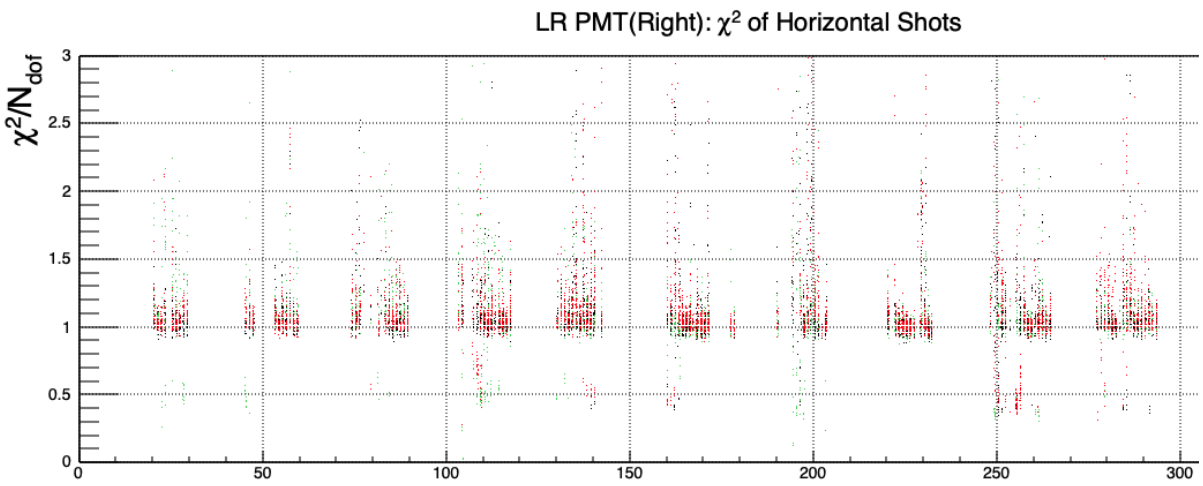
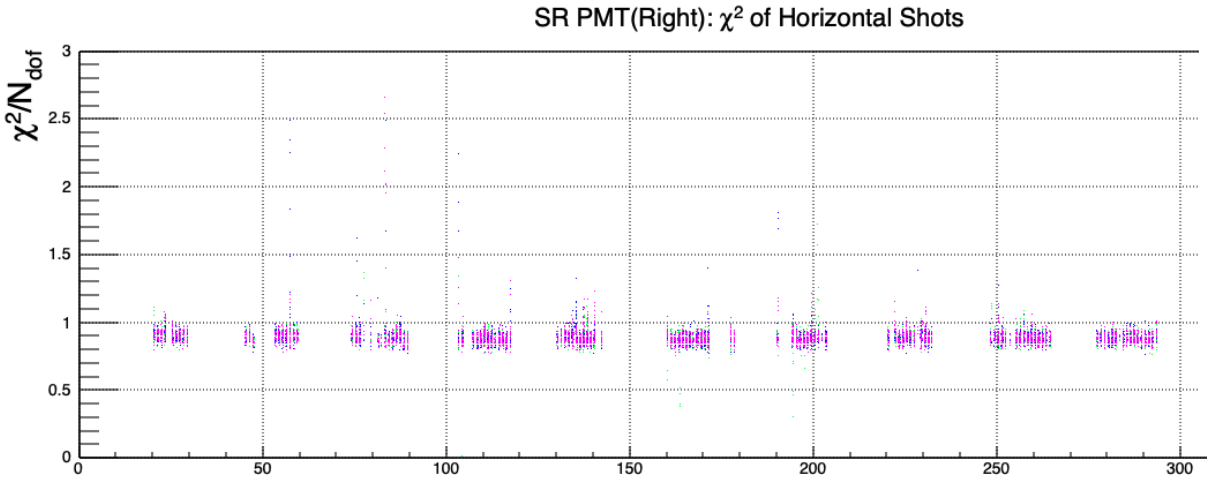
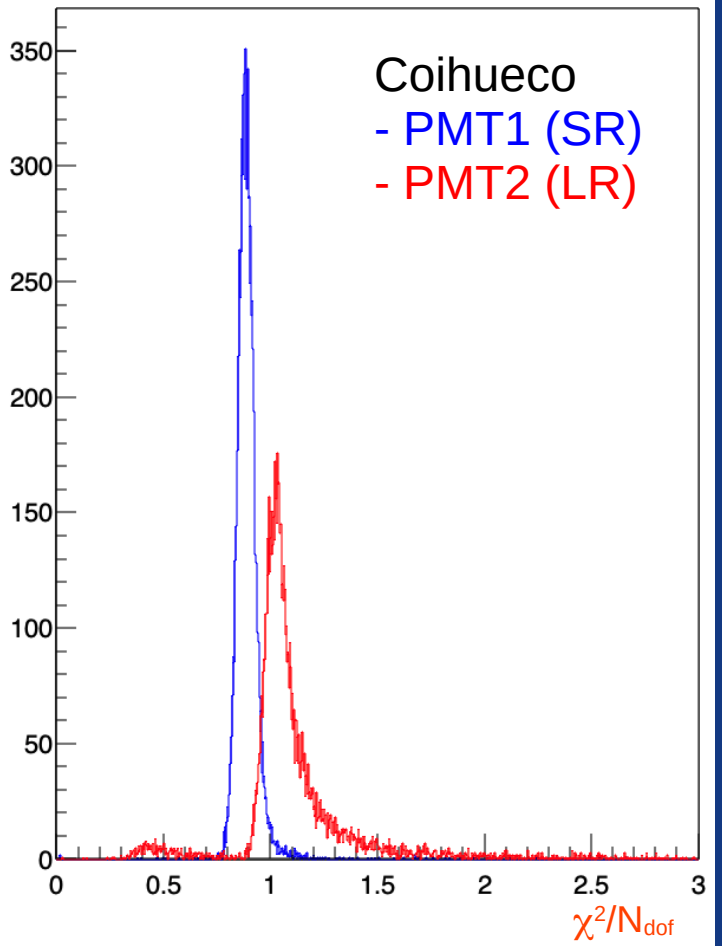
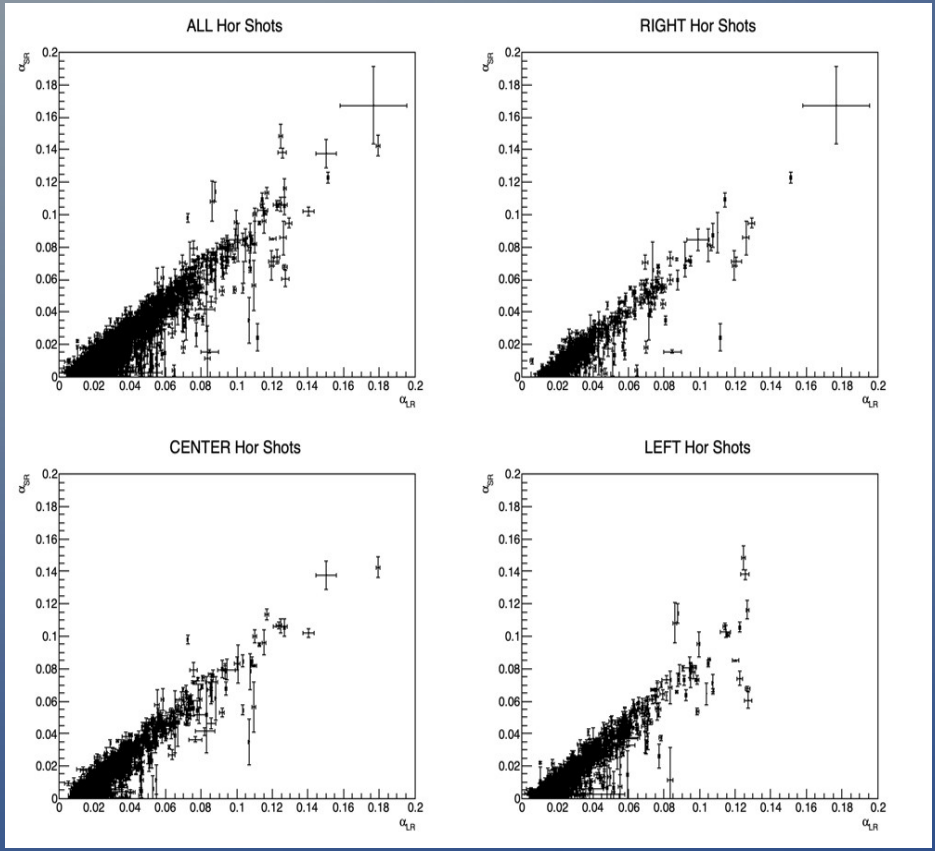


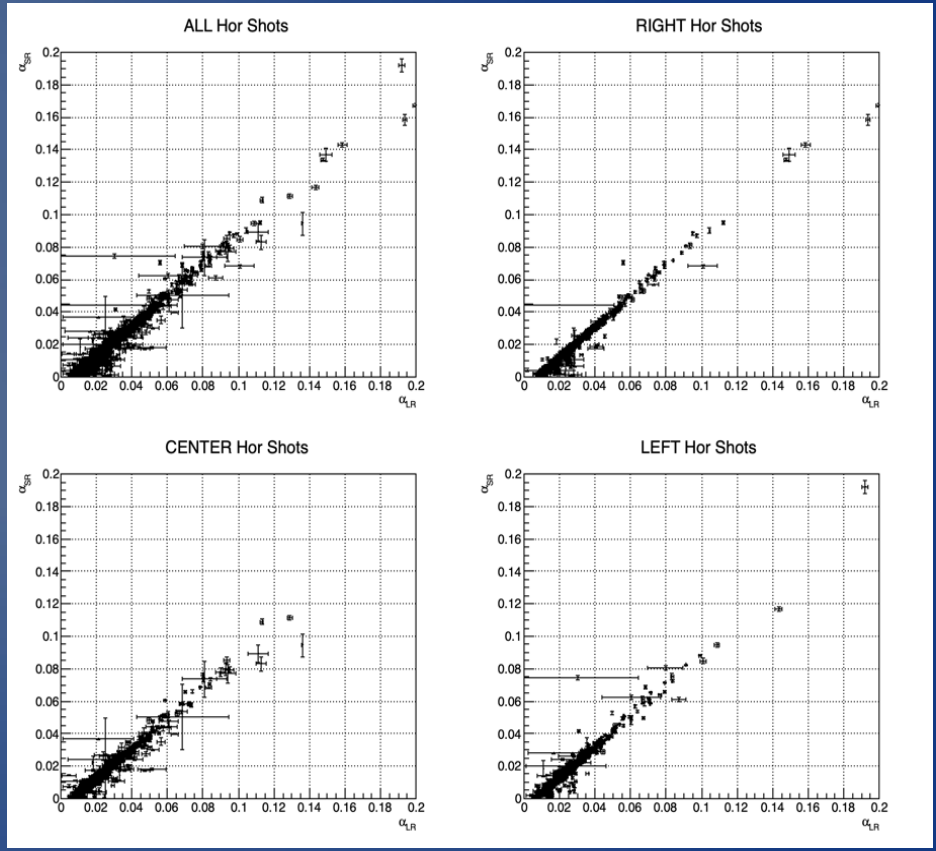




Short vs Long Range



Loma Amarilla (2024)



Coihueco (2024)

Loma Amarilla : Short vs Long Range

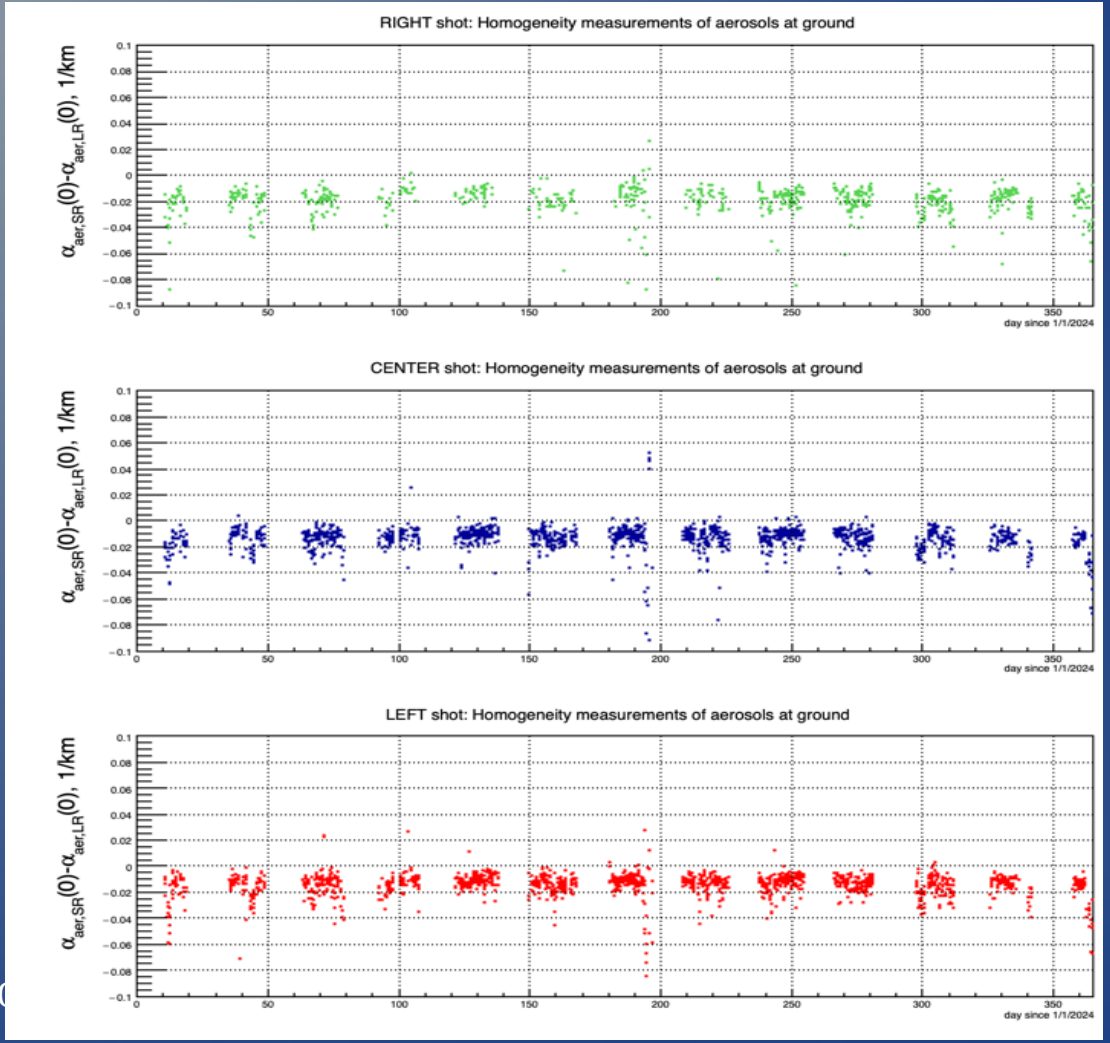
α_{LR}-α_{SR} ~0.01km^{-1}

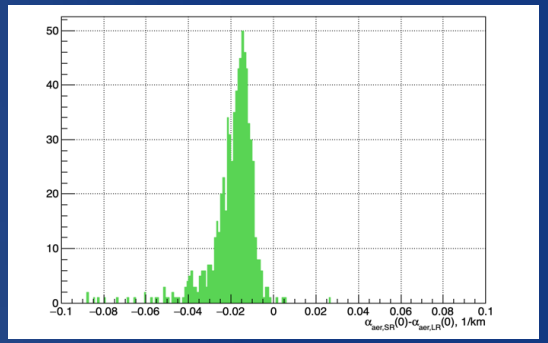
Right shots

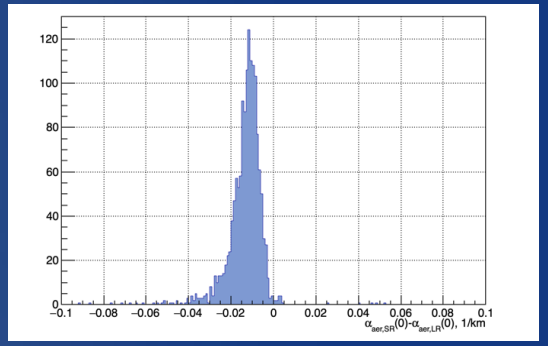
Central shots

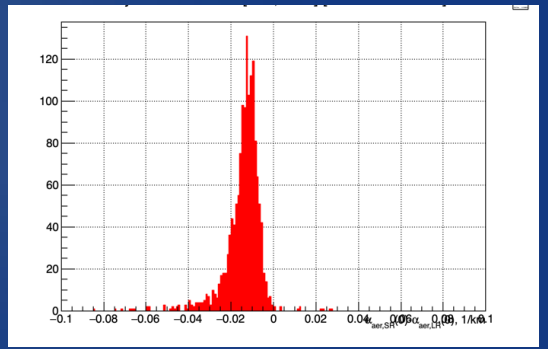
Left shots

Constant in time,
no seasonal effects









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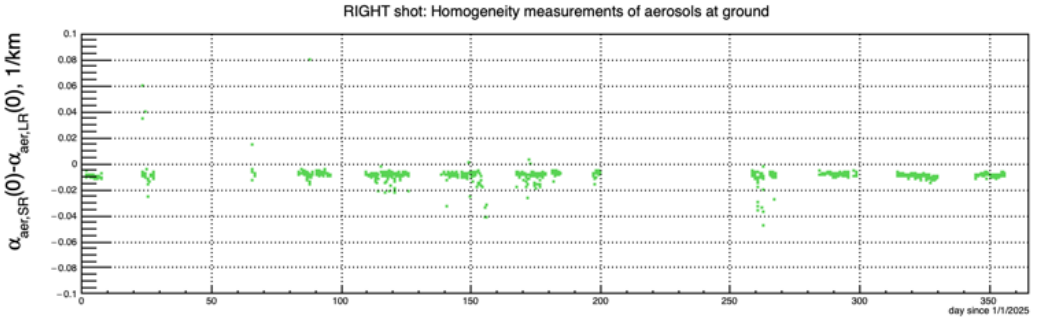
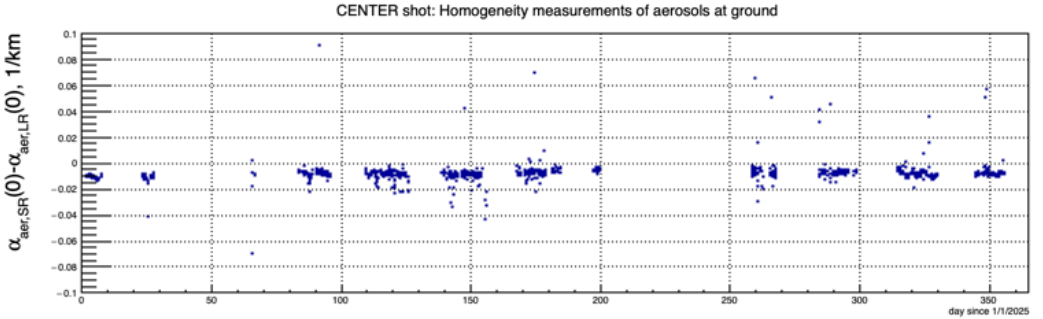
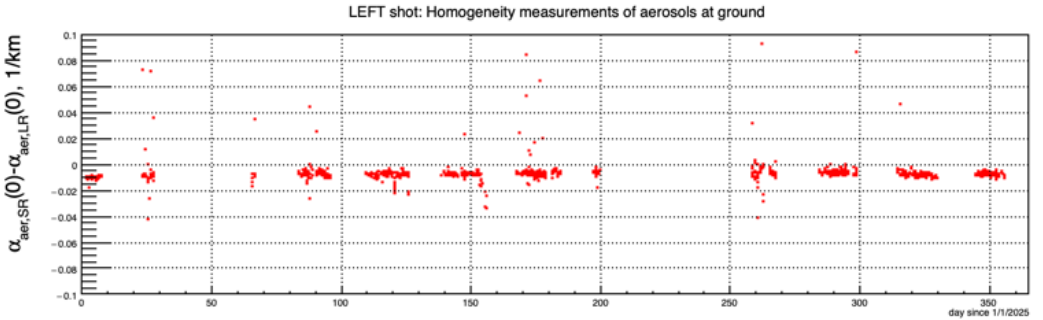
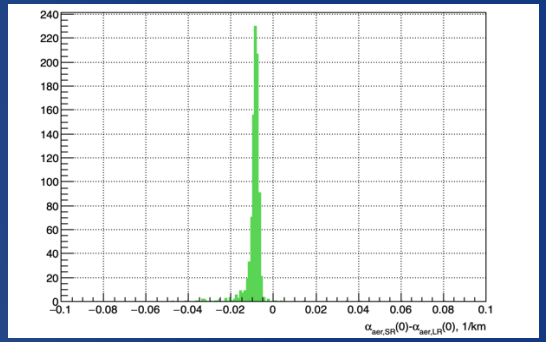
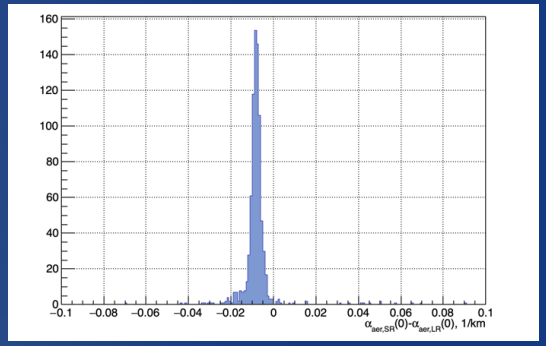
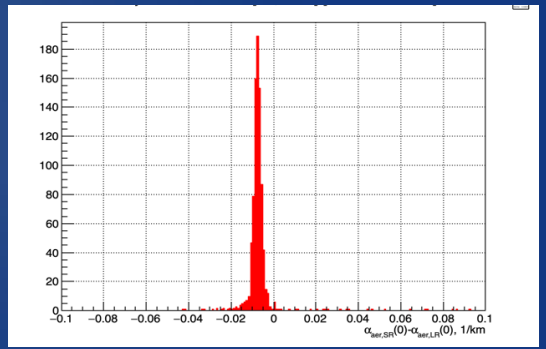






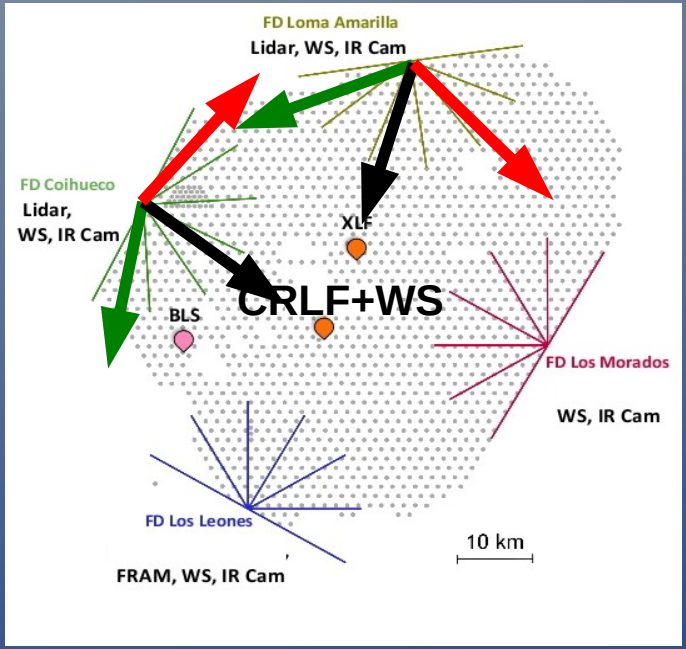


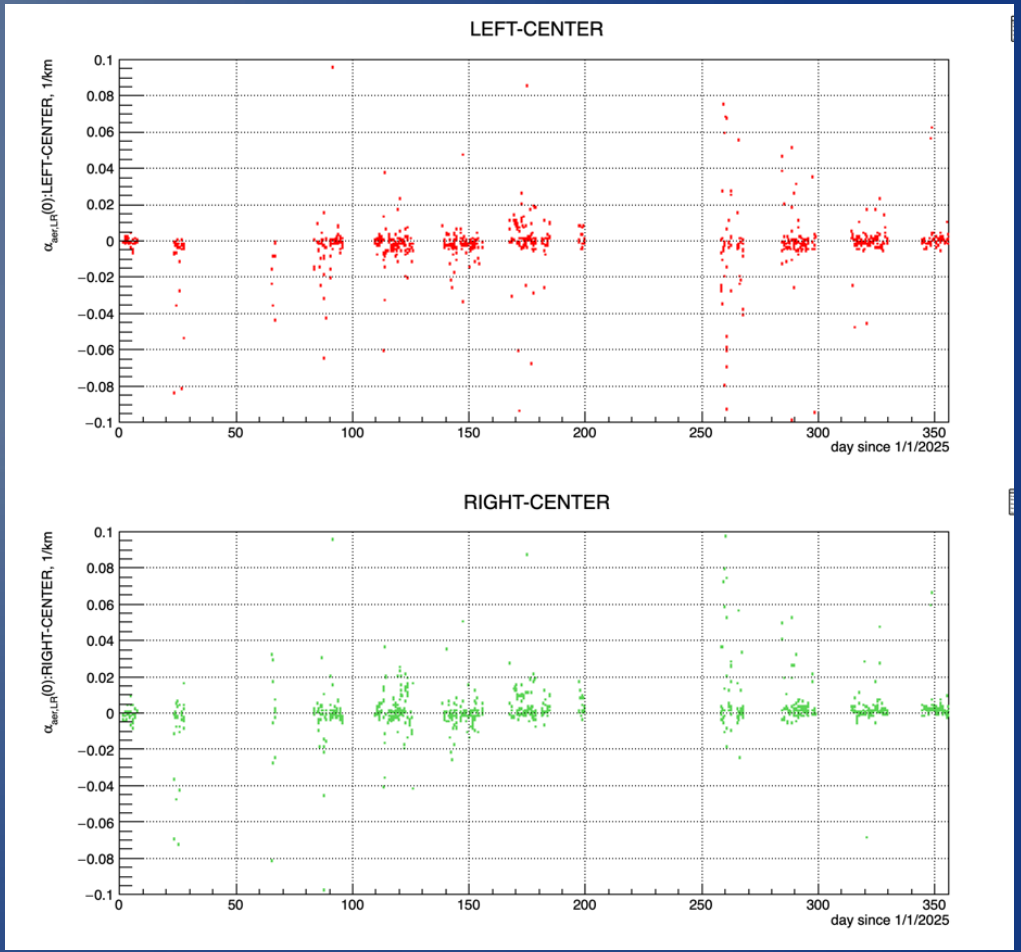




Azimuthal asymmetries (Coihueco)

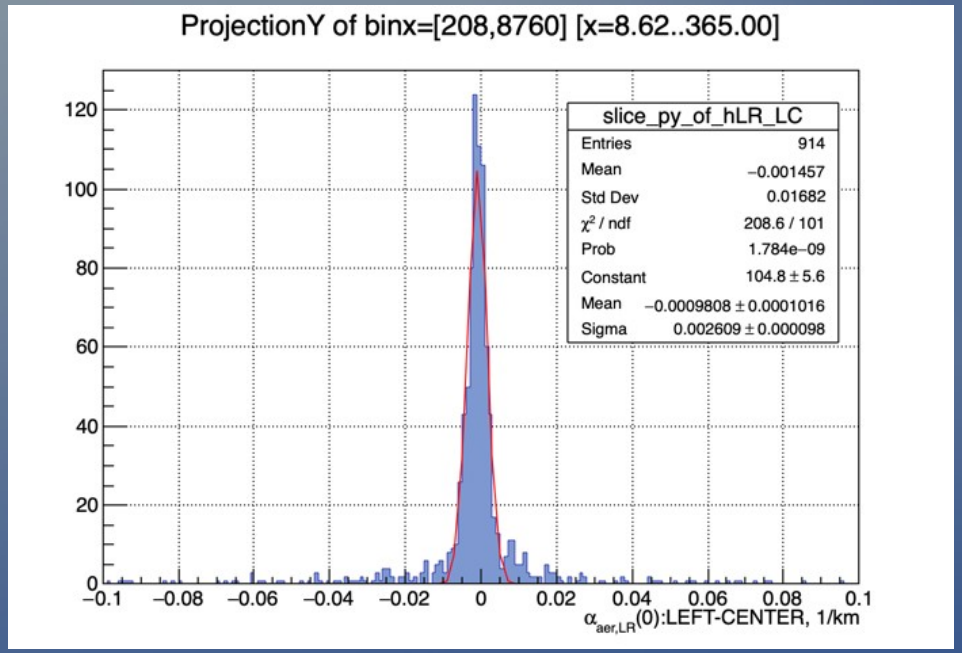
Answer to the basic systematic question: how often is it safe to assume that aerosol profiles are homogeneous in different direction?



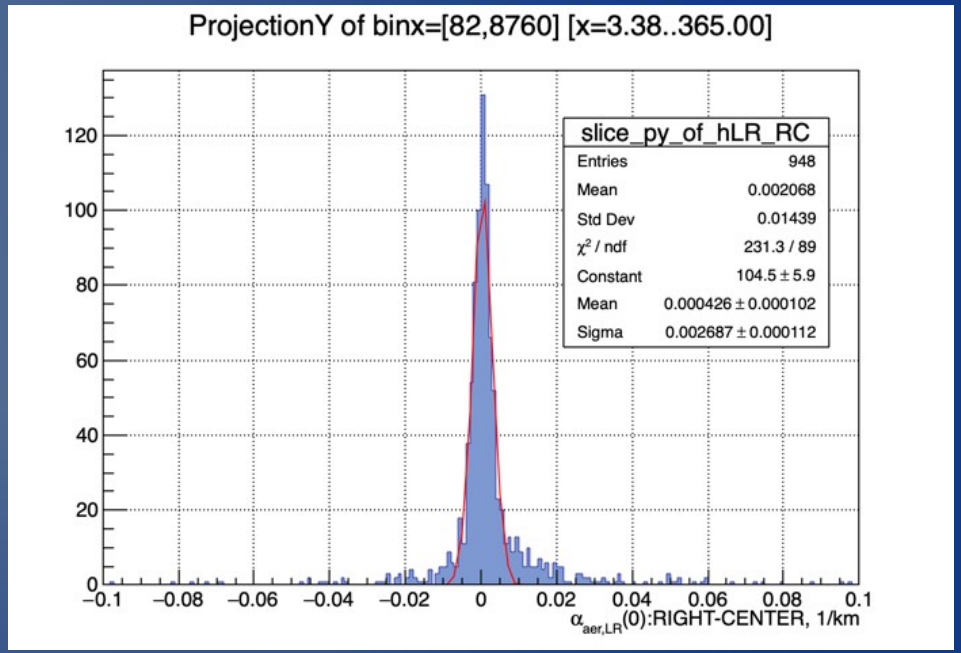


Azimuthal asymmetries (Coihueco)

$\Delta_{LC}=\alpha_{Left}-\alpha_{Center}$



$\Delta_{RC}=\alpha_{Right}-\alpha_{Center}$



Gaussian fit $\sigma(\Delta_{LC})=0.0025$ km^{-1} Gaussian fit $\sigma(\Delta_{RC})=0.0025$ km^{-1}

Non gaussian tails: 22% of the hours have $|\Delta_{LC}|>3\sigma$, or $|\Delta_{RC}|>3\sigma$

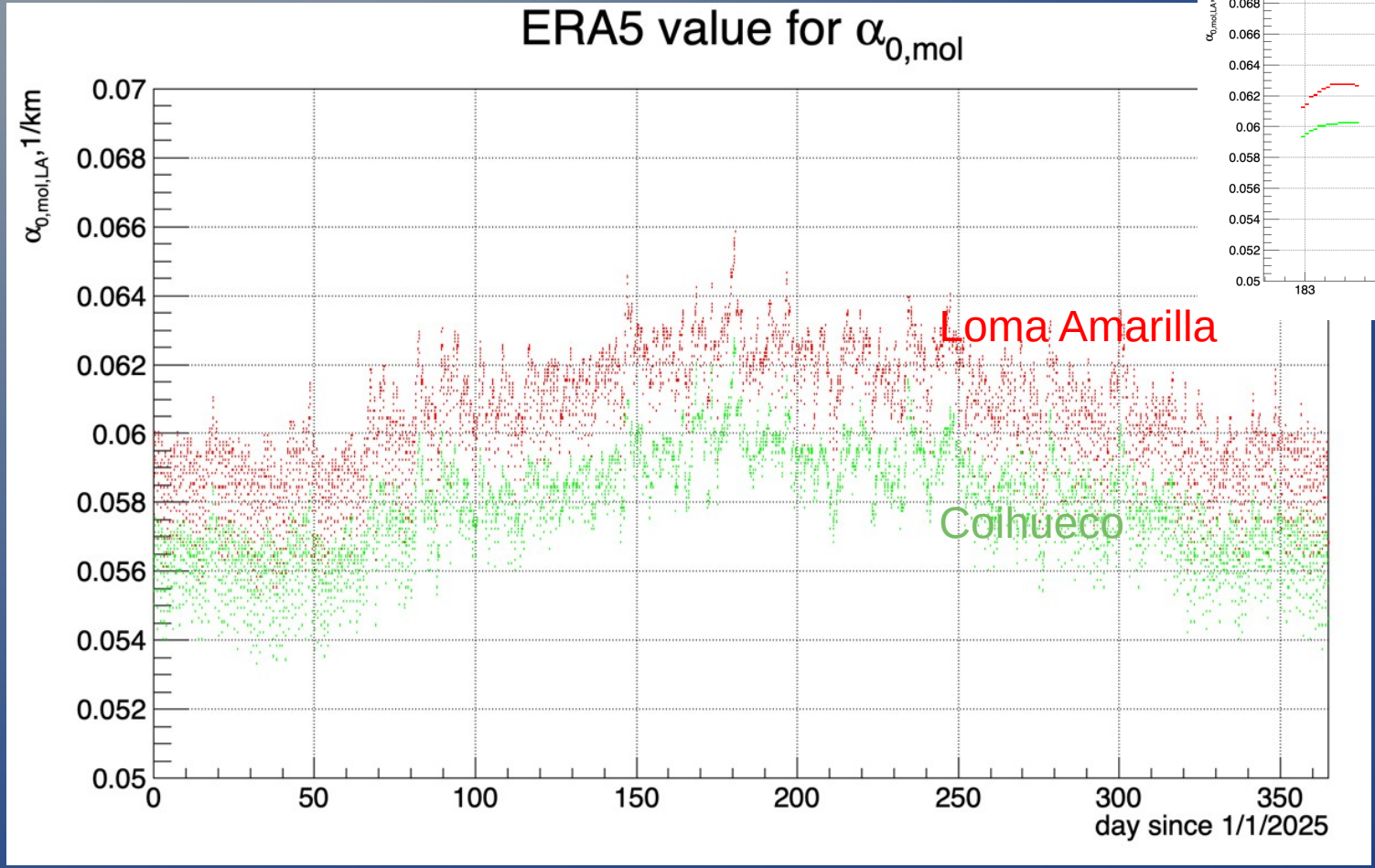
Molecular atmosphere retrieval from ERA5

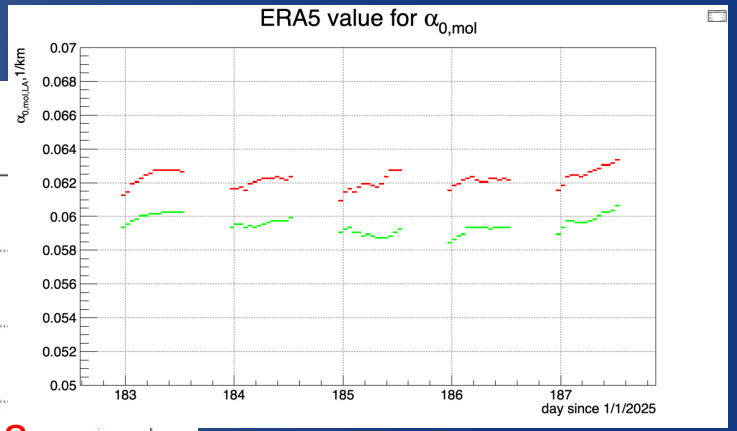
ERA5 provides hourly values of temperature, pressure, and dewpoint at ground.
https://cds.climate.copernicus.eu/

	Long	Lat	Alt
1	-35.00	-69.5	1482.85
2	-35.00	-69.25	1378.35
3	-35.25	-69.5	1431
4	-35.25	-69.75	2018.53
5	-35.00	-69.75	1939.96

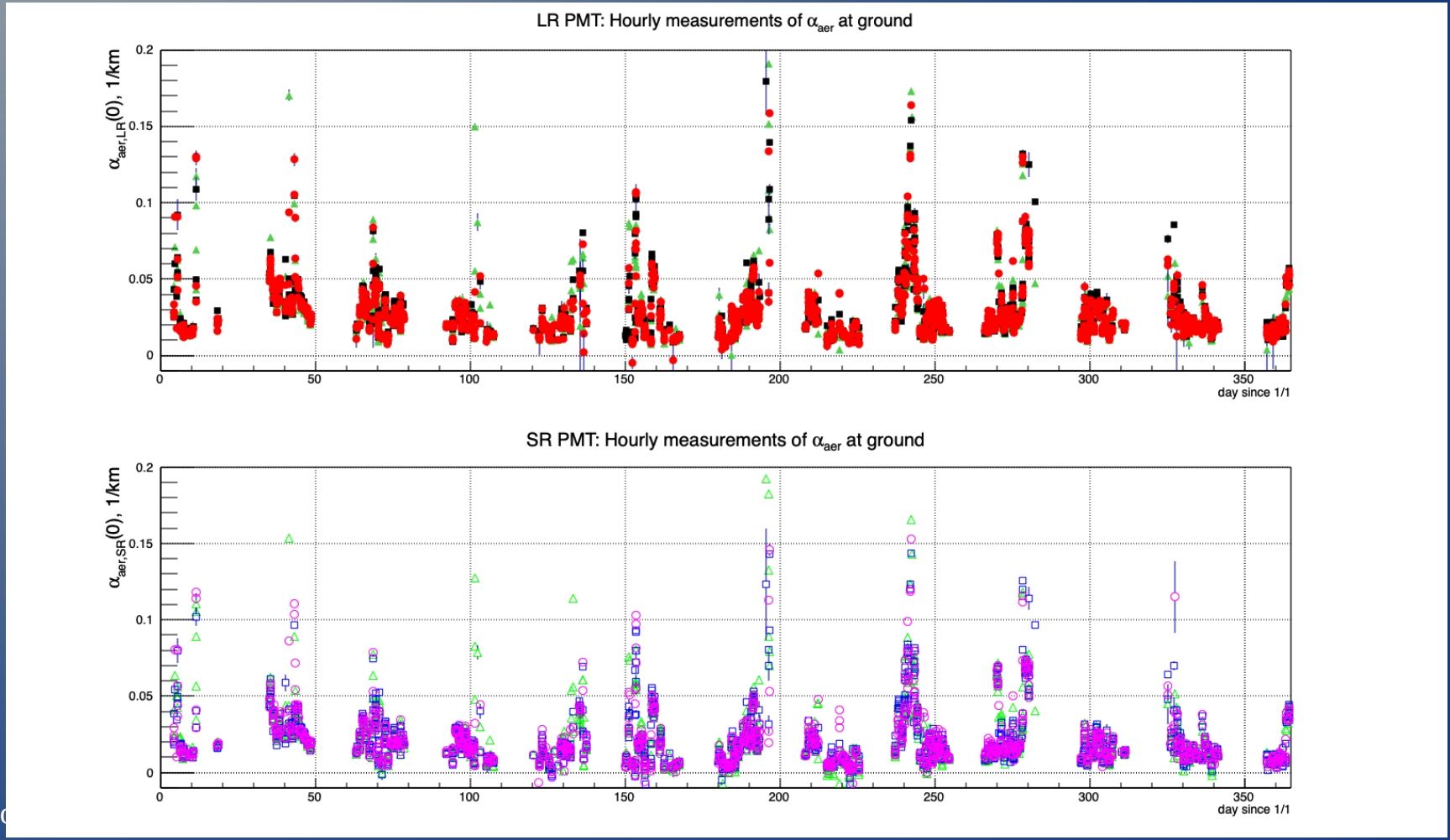
For Loma Amarilla we use point 2.
For Coihueco : average the values from points 1,3,4,5

Molecular atmosphere retrieval from ERA5

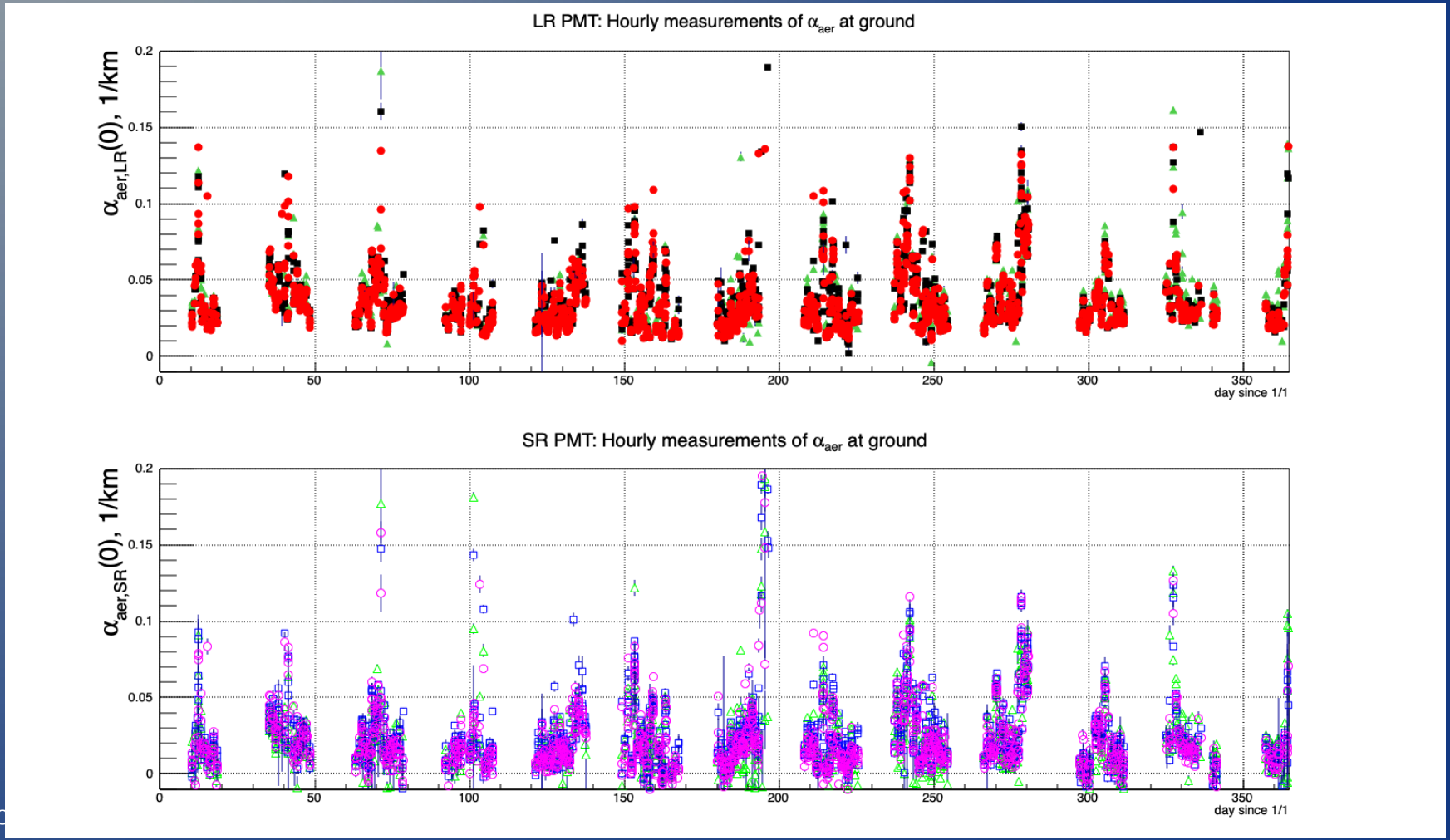




Coihueco 2024: $\alpha_{0,aer}$ vs time Results

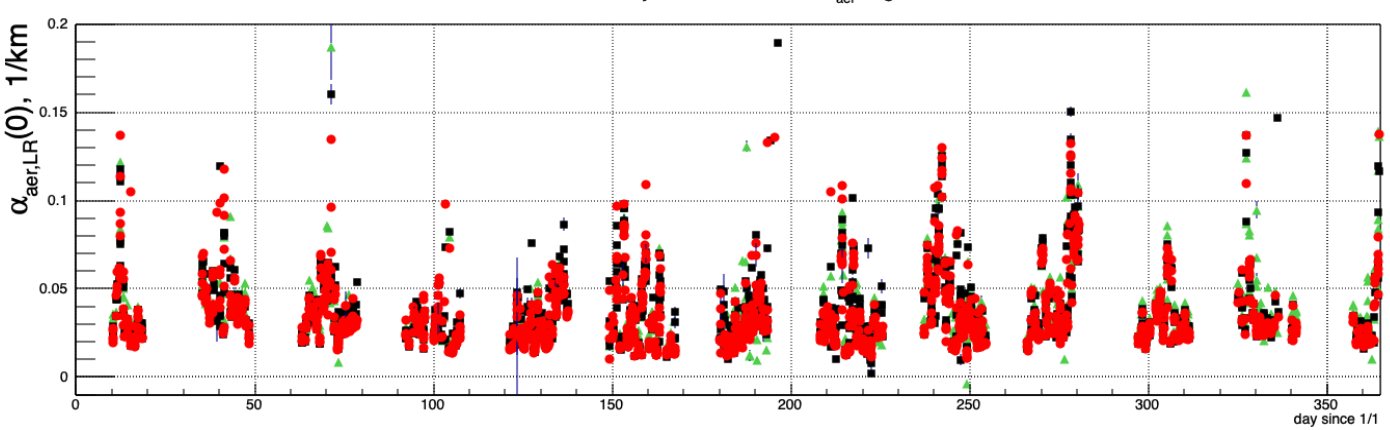


Loma Amarilla 2024: $\alpha_{0,aer}$ vs time Results

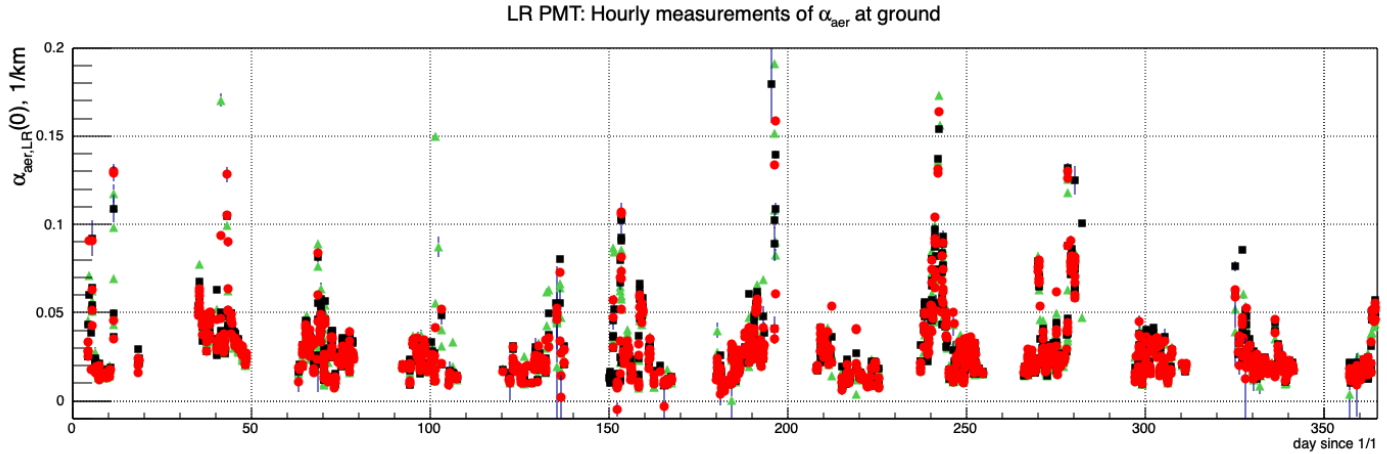


LA vs CO 2024: $\alpha_{0,aer}$ vs time Results

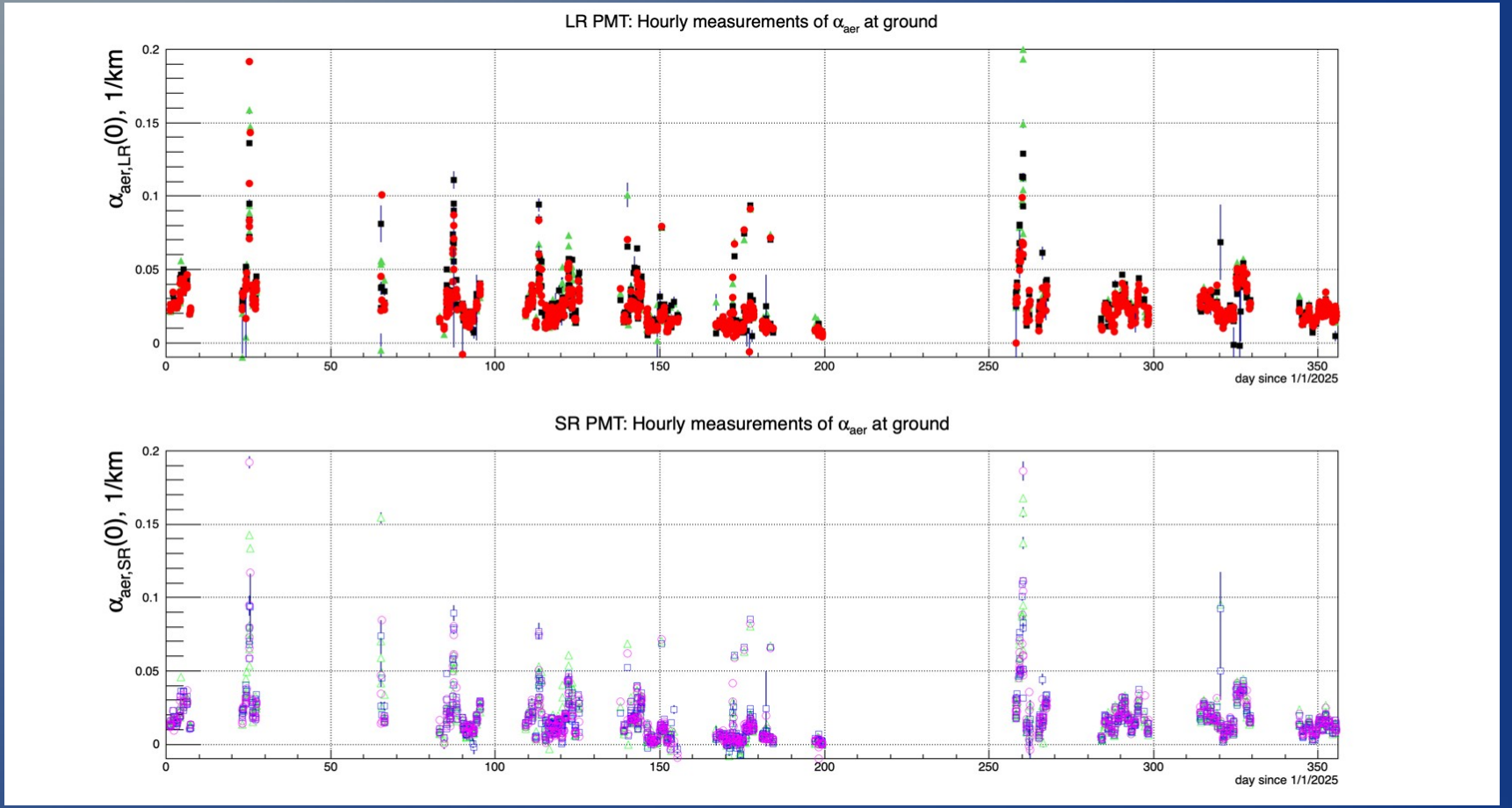
LA



CO



Coihueco 2025: $\alpha_{0,aer}$ vs time Results



Summary and prospects

Horizontal shots with elastic lidars have been used since their installation to measure ground level aerosols information, vetoing FD operations for less than 1% of the data taking time .

Such data are also useful to measure the overlap between mirror FoV and laser beam, allowing to measure the vertical aerosol profiles (using the multiangle technique) also before the region of full overlap.

Data from the short range mirrors in LA and CO are compared with the standard ones and in both sites we observe a shift of about 0.01 km^{-1} between the two measurements

Since 2018, we increased the variety of horizontal shots with the two elastic lidars of Loma Amarilla and Coihueco to study the azimuthal homogeneity of ground level aerosols: in about 20% of the events significant azimuthal asymmetries.

Recently, the ERA5 database has been made public, to provide more accurate hourly information on the molecular atmospheric parameters. Work is in progress to correct all previous data with more accurate molecular corrections.