Angular Distribution of light emission in ELVES at the Pierre Auger Observatory

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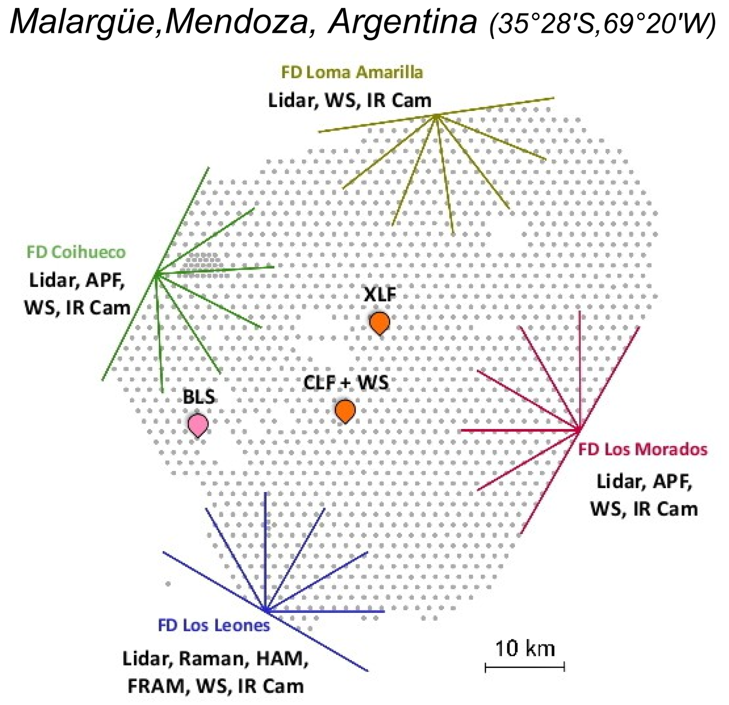
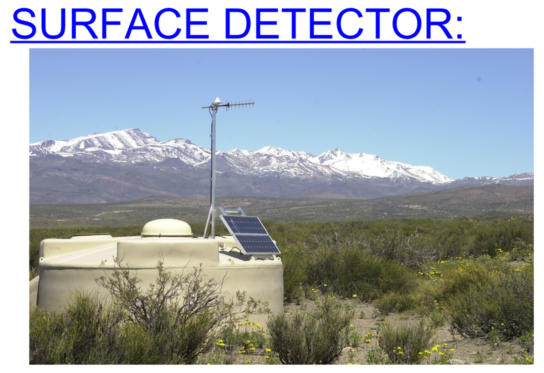
The Pierre Auger Observatory, located in Malargüe (Argentina), is the largest facility (3000 km^2) for the study of Ultra High Energy Cosmic Rays (E>0.3 EeV). The four sites of the Fluorescence Detector (FD) are continuously observing the night sky with moon fraction below 50% (13% duty cycle) with 100 ns time resolution and a space resolution below one degree. Since 2013, the Observatory has implemented a dedicated trigger for the study of ELVES events, produced by lightning activity in Northern Argentina during summer months. A network of ancillary devices (LIDARs, cloud cameras, weather stations, lightning sensors, E-field mills) complements the FD data to correct for the variation of atmospheric optical properties. This poster reports about the procedure to calculate the angular distribution of the light emission around the vertical above the lightning source. The complexity of the recorded events have required a further extension of the trace length, which has been implemented on January 2017. Prospects are given.

PIERRE AUGER OBSERVATORY

Malargüe,Mendoza, Argentina (35°28'S,69°20'W)



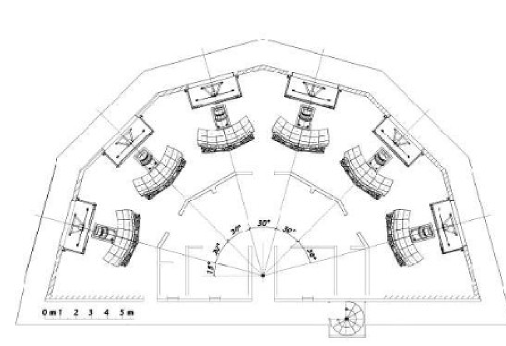
SURFACE DETECTOR:



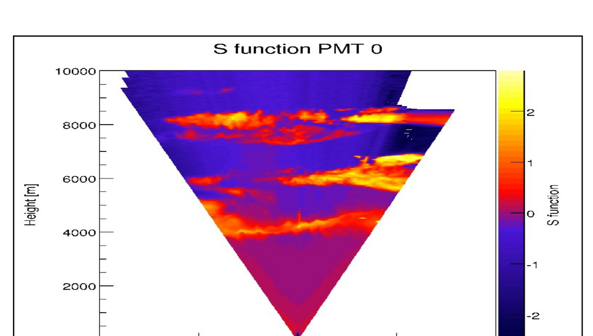
- 1600 tanks,1.5 km spacing
- 3000 km^2 effective area
- 12 tons H_2O per tank
- 100% duty cycle
- Time resolution: 25 ns
- Angular resolution <1°
- Threshold Energy: $10^{18.3}$ eV
- 3 PMTs per tank

FLUORESCENCE DETECTOR:

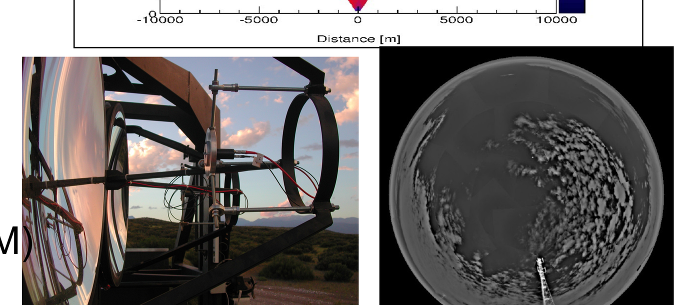
- 24(+3) telescopes in 4 eyes
- FD camera: 440 PMTs per telescope
- Wavelength range: 300-420 nm
- Mirror area: 11m^2
- Field of View: 6x30°x30° for each FD
- Duty cycle: ~12% (nights with <1/2 moon)
- Time resolution: 100 ns
- Angular resolution: ~0.6°



ATMOSPHERIC MONITORING NETWORK:



- 5 Weather Stations (WS)
- Radiosonde launch facility (BLS)
- 2 Central Laser Facilities (CLF,XLF)
- 4 elastic LIDARs, 1 Raman LIDAR
- 2 Aerosol Phase Function Monitors (APF)
- Horizontal Attenuation Monitor (HAM)
- Photometric Robotic Telescope (FRAM)
- 4 IR Cloud Cameras

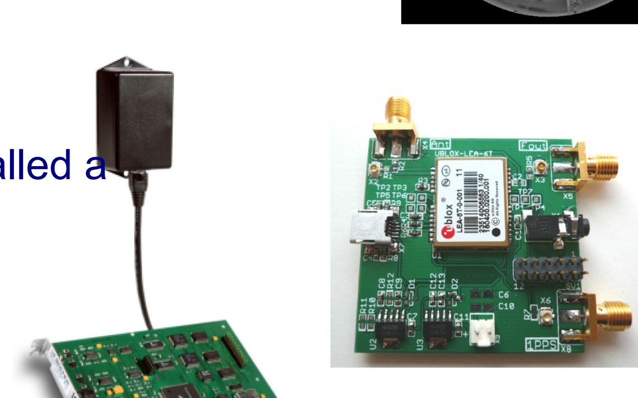


Lightning Monitoring Network

Recently the AERA group has installed a lightning network on site made of :

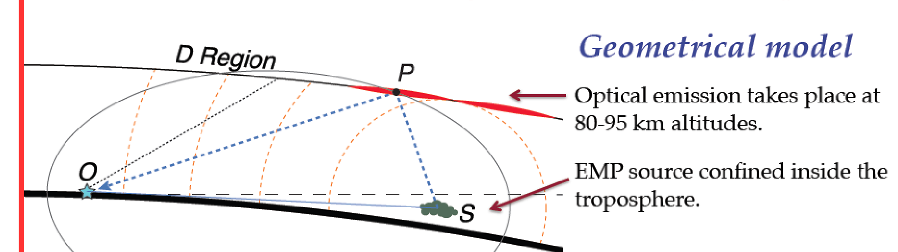
- 5 Boltek Storm trackers with GPS antenna (30 ns resolution)
Range: up to 500 km
Locations:4 FD sites+town

- 2 E-field mills
Campbell Scientific CS110

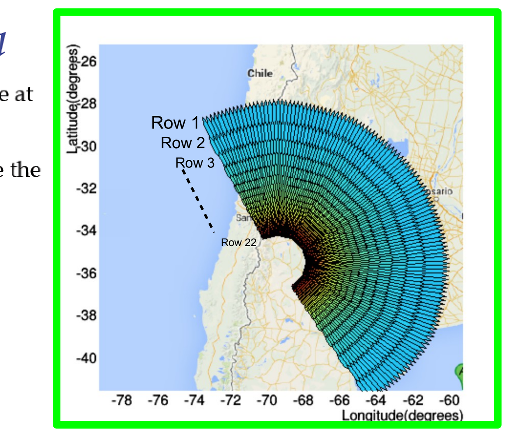


These ancillary data will allow to measure polarization and more accurate location of the closer lightning strikes.

Reconstruction of Ionospheric density of light emission



All traces are fit with (multiple) asymmetric gaussians. The integral of the bestfit function is then used to calculate the number of photons PFD(i) for each pixel. In order to obtain the surface density of light intensity Φ(i) at the base of the ionosphere, we use the expression:



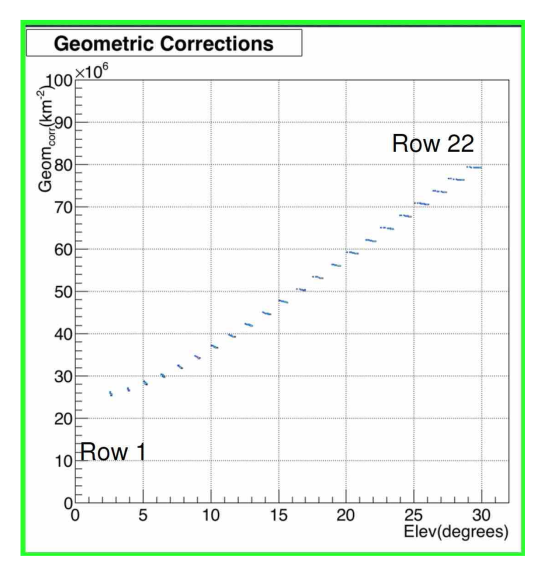
$$\Phi(i) = P_{FD}(i) * Geom\_corr * Atmo\_corr$$

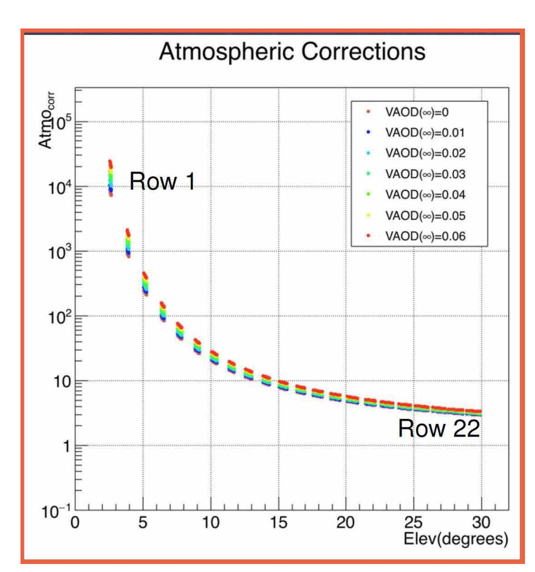
Where:

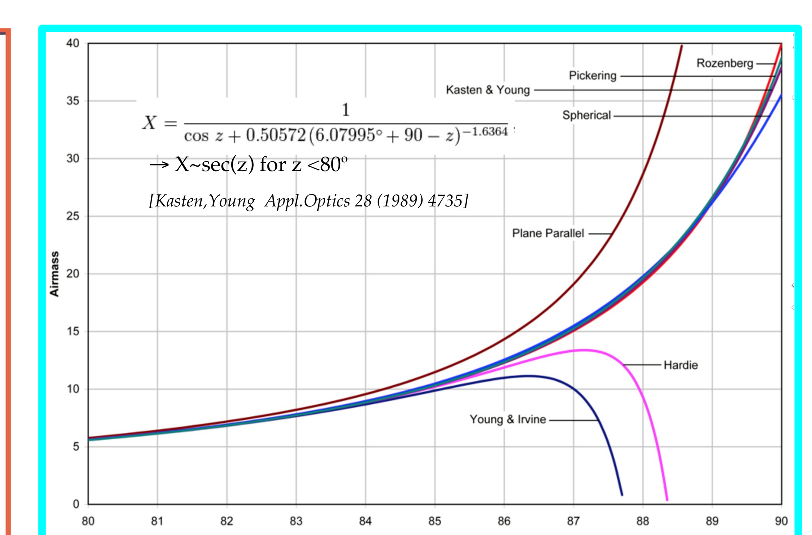
$Geom\_corr = (R^2_{PO}/A_{mirror}) / Area(h=H_o)$

$Atmo\_corr = e^{airmass(\theta)} x e^{VMOD+VAOD}$

VMOD=Vertical Molecular Optical Depth (from GDAS database)
VAOD=Vertical Aerosol Optical Depth (from hourly local LIDAR measurements).
Airmass (z=θ) accounts for earth curvature and is calculated using the Kasten&Young formula.

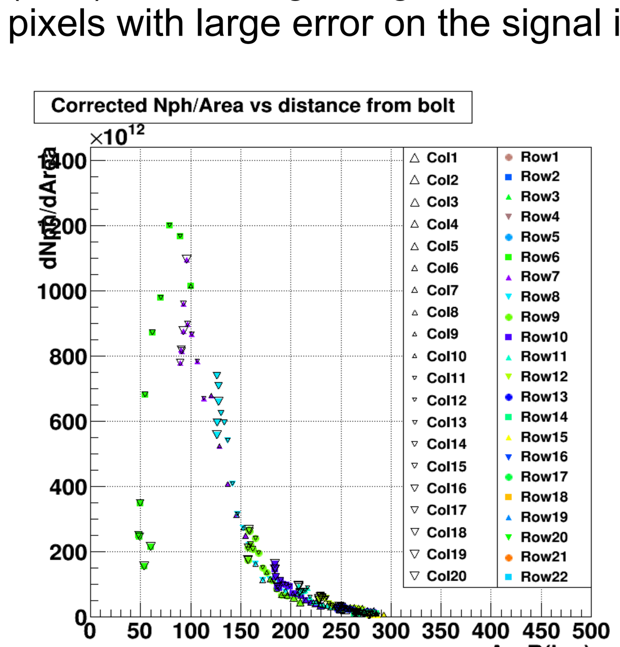


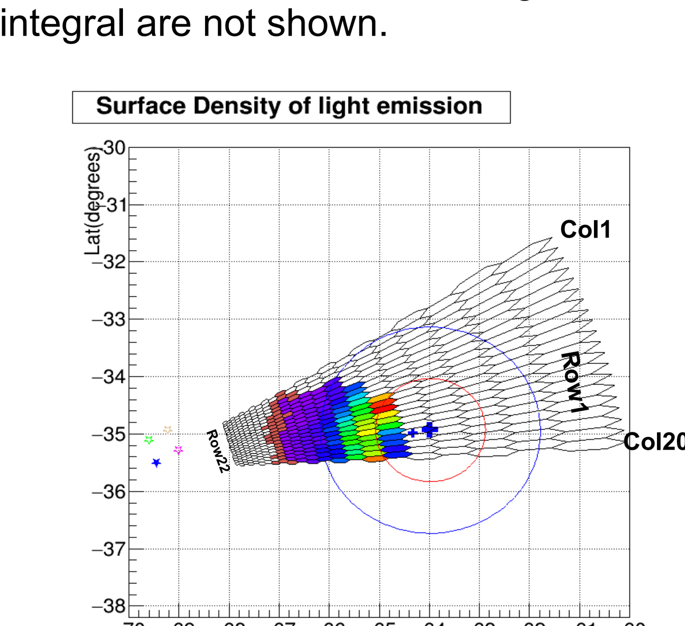




Angular Distribution of Light Emission

The reconstruction of the light emission from a typical event is shown below. The left plot show the surface density of light emission after all corrections. In the right plot, the larger blue cross indicates the best fit of the lightning position, as calculated from the data. The rings are at 100 (red) and 200 km (blue) from the lightning vertical. The stars indicate the FD buildings. The pixels with large error on the signal integral are not shown.



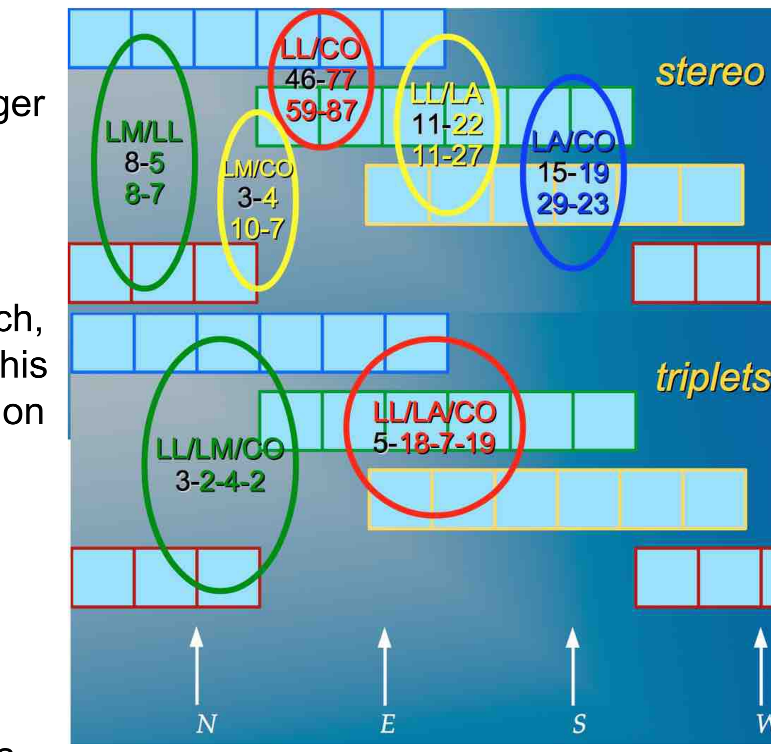


Bibliography:

PIERRE AUGER COLLABORATION: http://www.auger.org
- R.Mussa et al. (for the Auger Collaboration) EPJ Plus 127,94 (2012)
- A.Tonachini, Proceedings ICRC2011, Beijing, August 2011
- A.Tonachini, Proceedings TEPA2012, Moscow, July 2012

ELVES candidates in the period 2013-2016

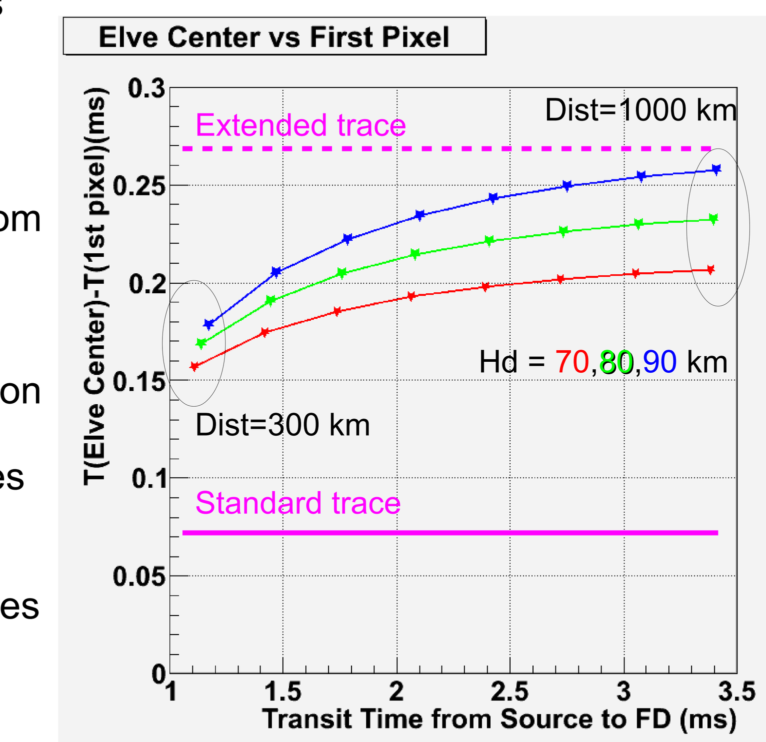
The Observatory is taking ELVES data with a dedicated trigger since 2013. A summary of stereo and triplet events seen in these 4 years is shown on the right. Since January 2014, a special extended readout scheme allows to record Elves events, identified by their peculiar topology (a rapidly expanding ring) adding two consecutive pages of 100 μs each, to the first one if they arrive within a 205 μs time window. This allows to observe the signal from the the ionospheric region on the vertical of the causative lightning.



Trigger at 28 μs

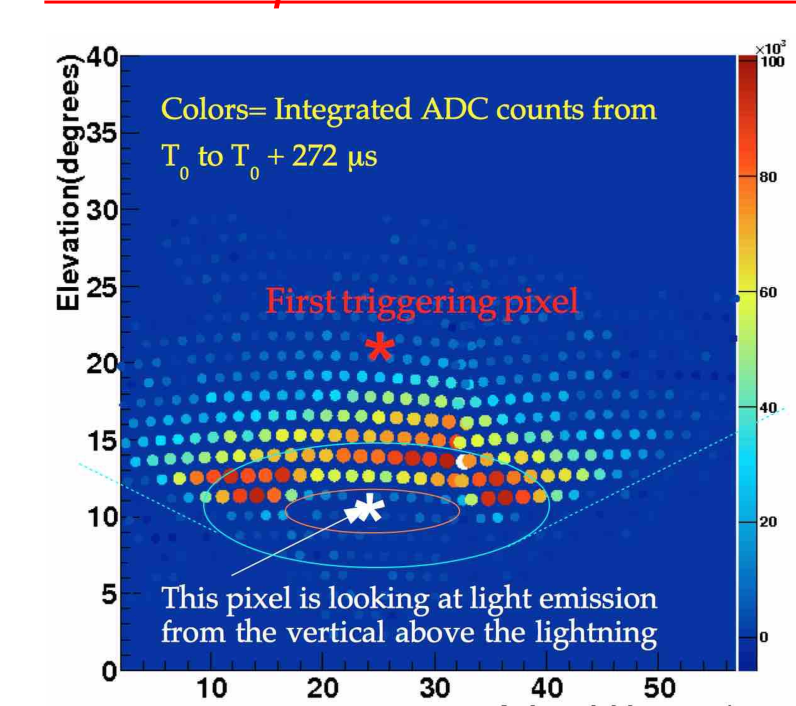
Page 1	Page 2	Page 3

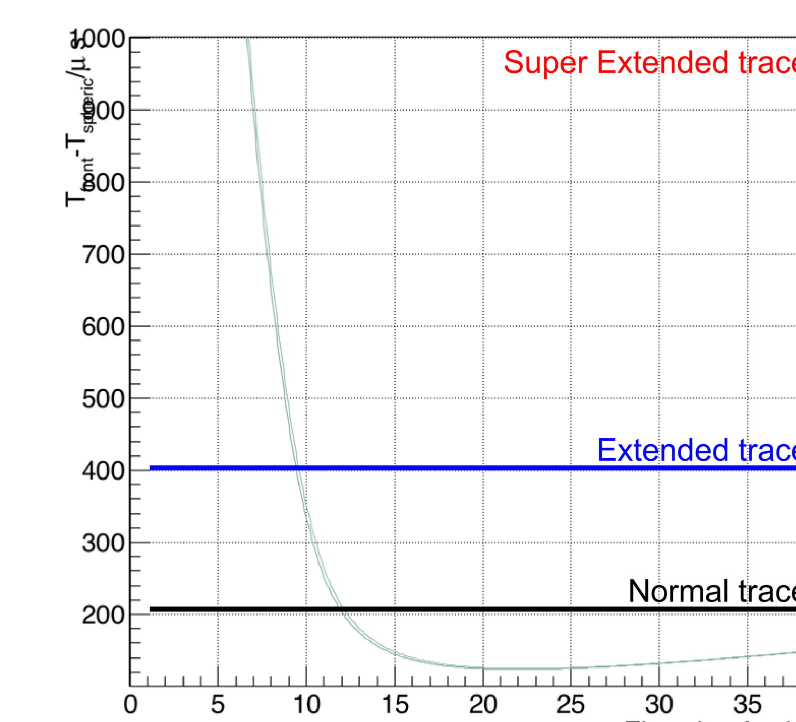
In this three year period we harvested 2240 elves candidates in total, of which 1793 are seen by a single eye (mono), 395 by two eyes (stereo) and 52 are observed by three eyes (triplets). A fraction of the events (28%) has less than three pages. This inefficiency is usually due to the presence of clouds in the lower rows, that prevent to see the emission from the region above the lightning.



The study of the angular distribution of the light emission around the vertical axis of the lightning stroke yields insights on the maximum velocity reached by the electrons in the return stroke of the lightning, according to most models. Anisotropies in the azimuthal distribution of light intensity are expected as effects of the Earth geomagnetic field, or of the passage of gravity waves at the base of the ionosphere. Local anisotropies in the distribution of aerosols may also distort the observed angular distribution.

NEW! Super-extended Readout





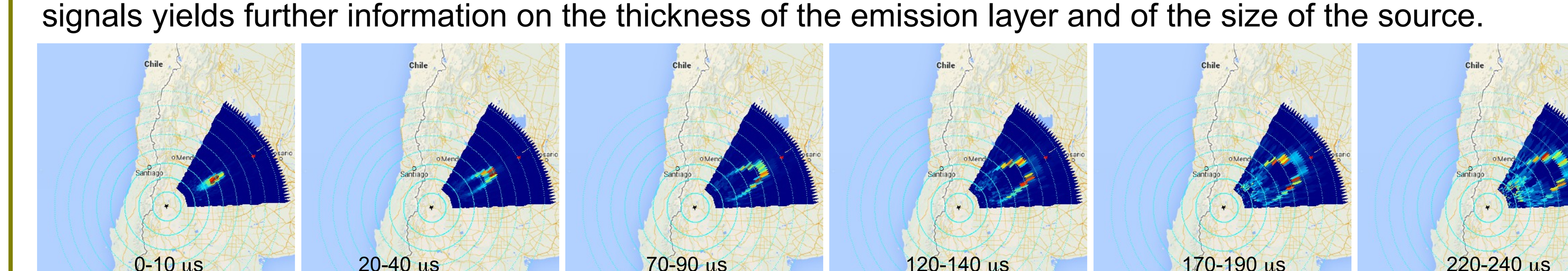
In January 2017, we further extended the readout window, to acquire longer traces (up to 8 consecutive pages after the first one). No changes were made on the trigger condition. During the first two months of data taking we observed 255 events (195 mono, 52 stereo, 8 triplets).
The number of follower pages depends on sky conditions and total light intensity. The raw distribution of number of contiguous pages from the first period of data taking is given in the table below.

28 μs = trigger

	Page 1	Page 2	Page 3	+ Page 4				Page 9
Fraction of events:	1.5%	4.0%	7.7%	12%	17%	22%	20%	7.3%	7.7%

Study of Time Evolution: Data vs Models

The event appears like a rapidly expanding superluminal front which propagates towards the lightning source, starting from a point at the same distance from source and observer. The time evolution of the corrected signals yields further information on the thickness of the emission layer and of the size of the source.



Our ELVES data recordings are being compared with the simulations based on Stanford's 3D EMP model, in collaboration with R.Marshall (CU Boulder). The sequence below shows a simulated ELVES event in the FD The colors indicate the integrated photon flux in 10 us (frame 1) and 20 us (frames 2-6).