Light intensity studies on ELVES at the Pierre Auger Observatory

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

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(on behalf of the Pierre Auger Collaboration)

PIERRE AUGER OBSERVATORY

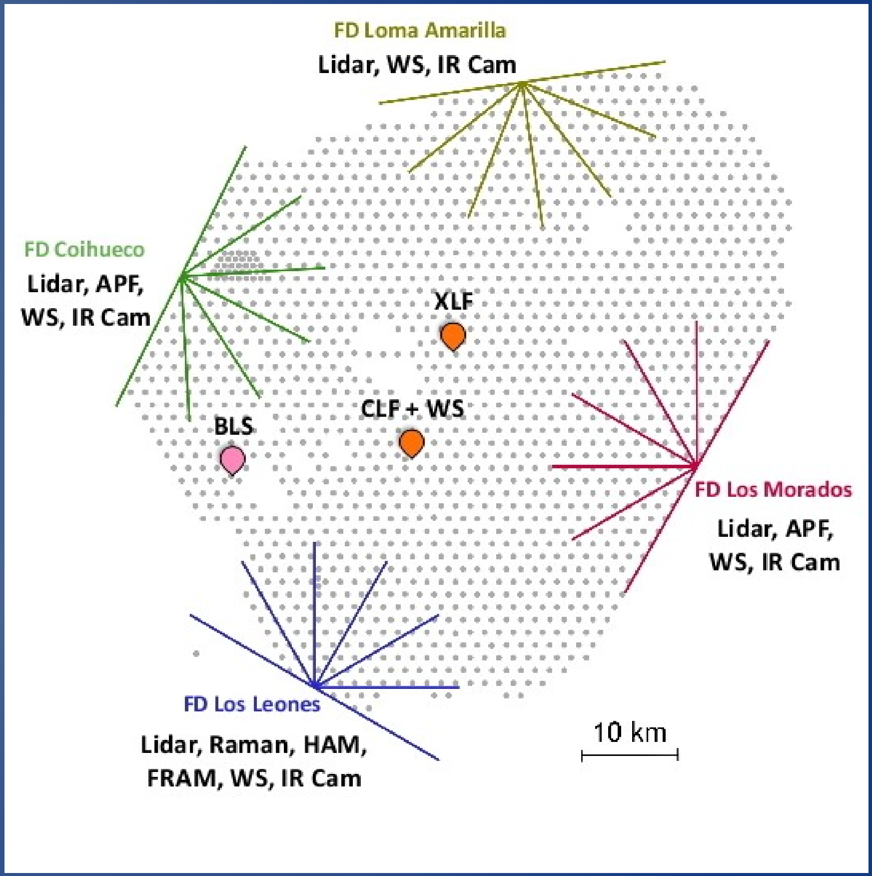
INFN Torino Istituto Nazionale di Fisica Nucleare

EGU 2016, Vienna

April 18th , 2016

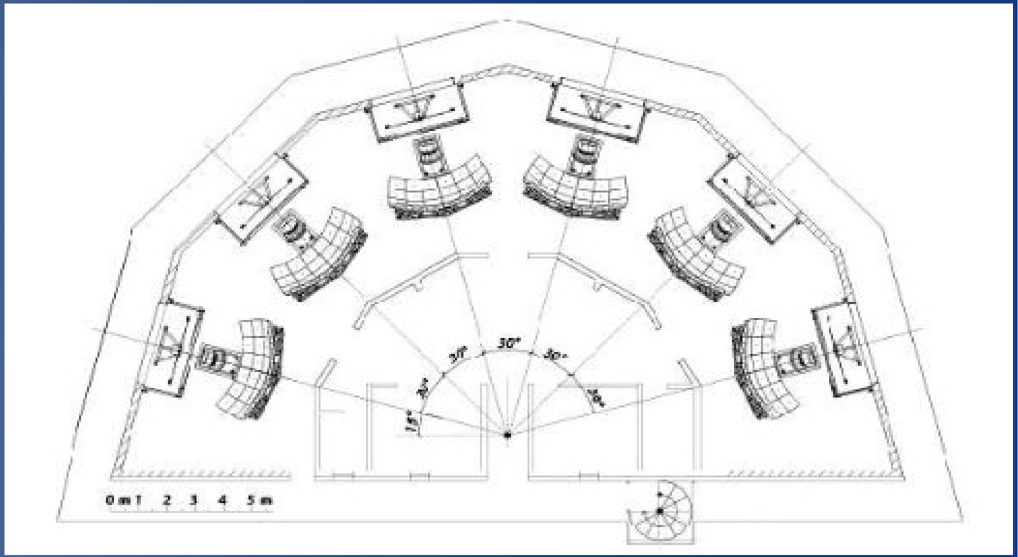
Pierre Auger Observatory

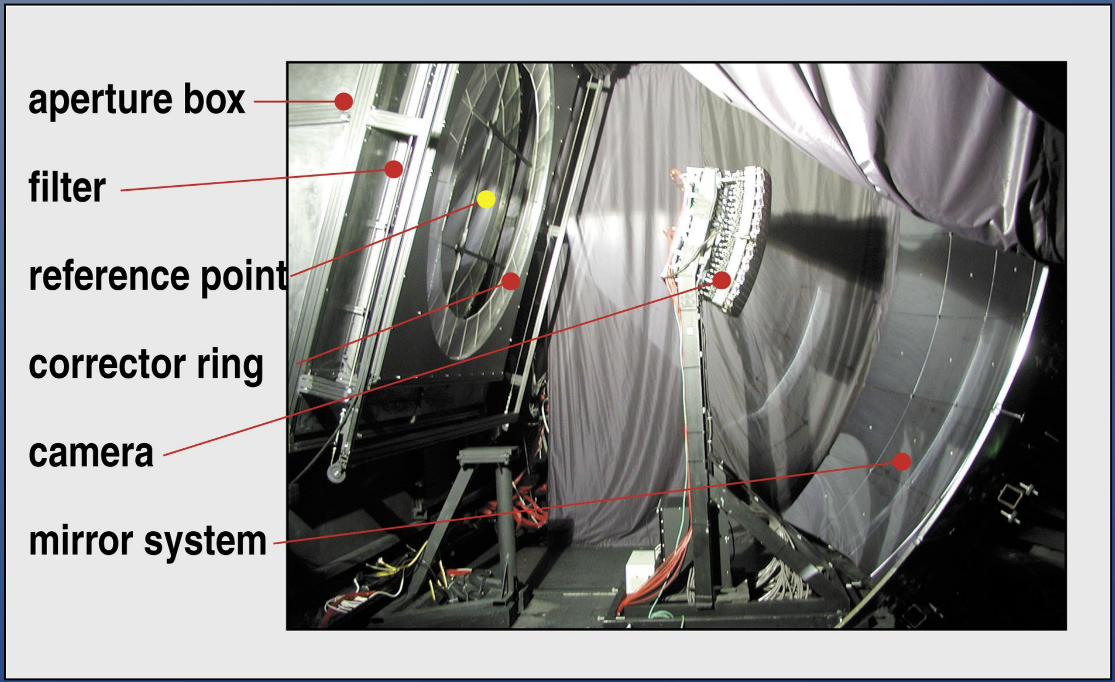
Malargüe,Mendoza, Argentina (35°28’S,69°20’W)
1600 detectors,1.5 km spacing, *1.4-1.5 km asl*
3000 km^2 effective area
12 tons of H_2O per detector
Detection of Cherenkov light from $\mu^{\pm}$,$e^{\pm}$,γ
100% duty cycle
Angular resolution <1°
Threshold Energy: $10^{18.3}$ eV
3 PMTs /detector unit
Complete since 2008

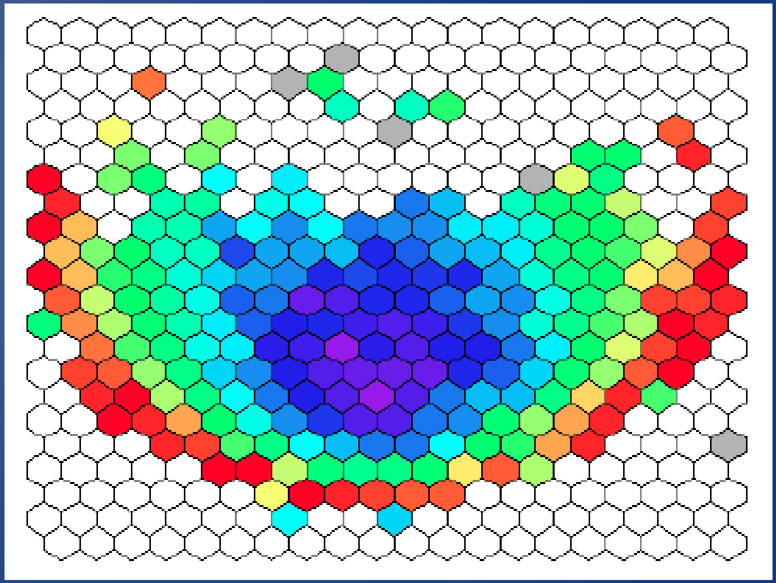


Fluorescence Detector

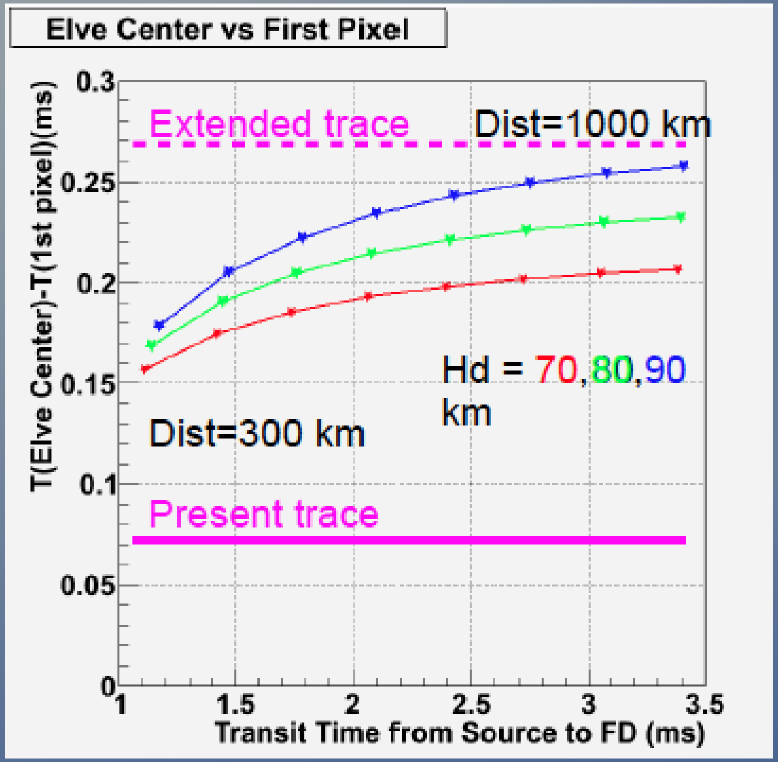
24 telescopes in 4 eyes
FD camera: 440 PMTs / telescope
Mirror area: $11m^2$
Field of View: 6x30°x30° for each FD
UV filter: 300-420 nm
Buffering 1000 time bins, 100 ns each
A 10 Mfps camera !
Duty cycle ~12% (1/2 moon cycle)
Angular resolution ~ 0.6°

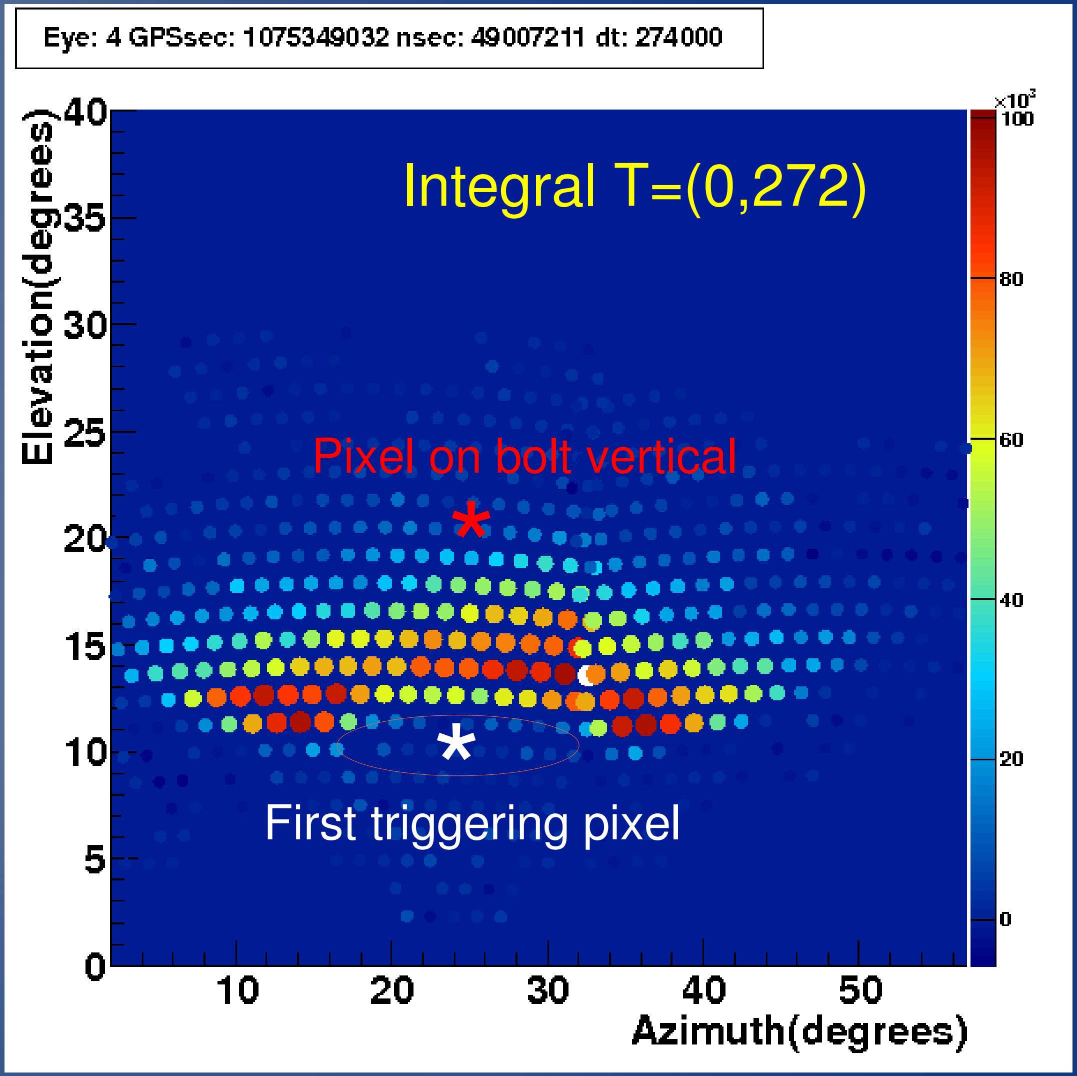






Extended readout





Statistics for 2014:

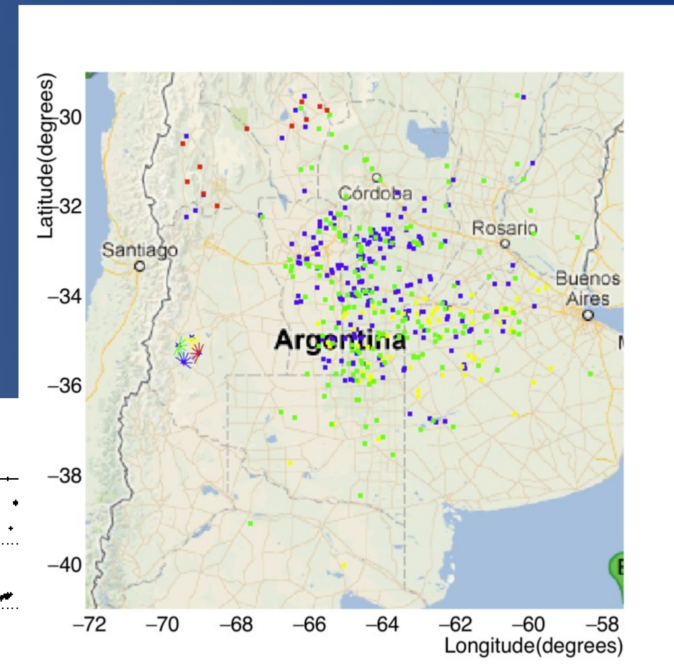
	Total	OK	1	2 (*)
LL	348	288	41	19
LM	33	20	7	6(0)
LA	145	125	11	9(3)
CO	315	232	49	34(25)

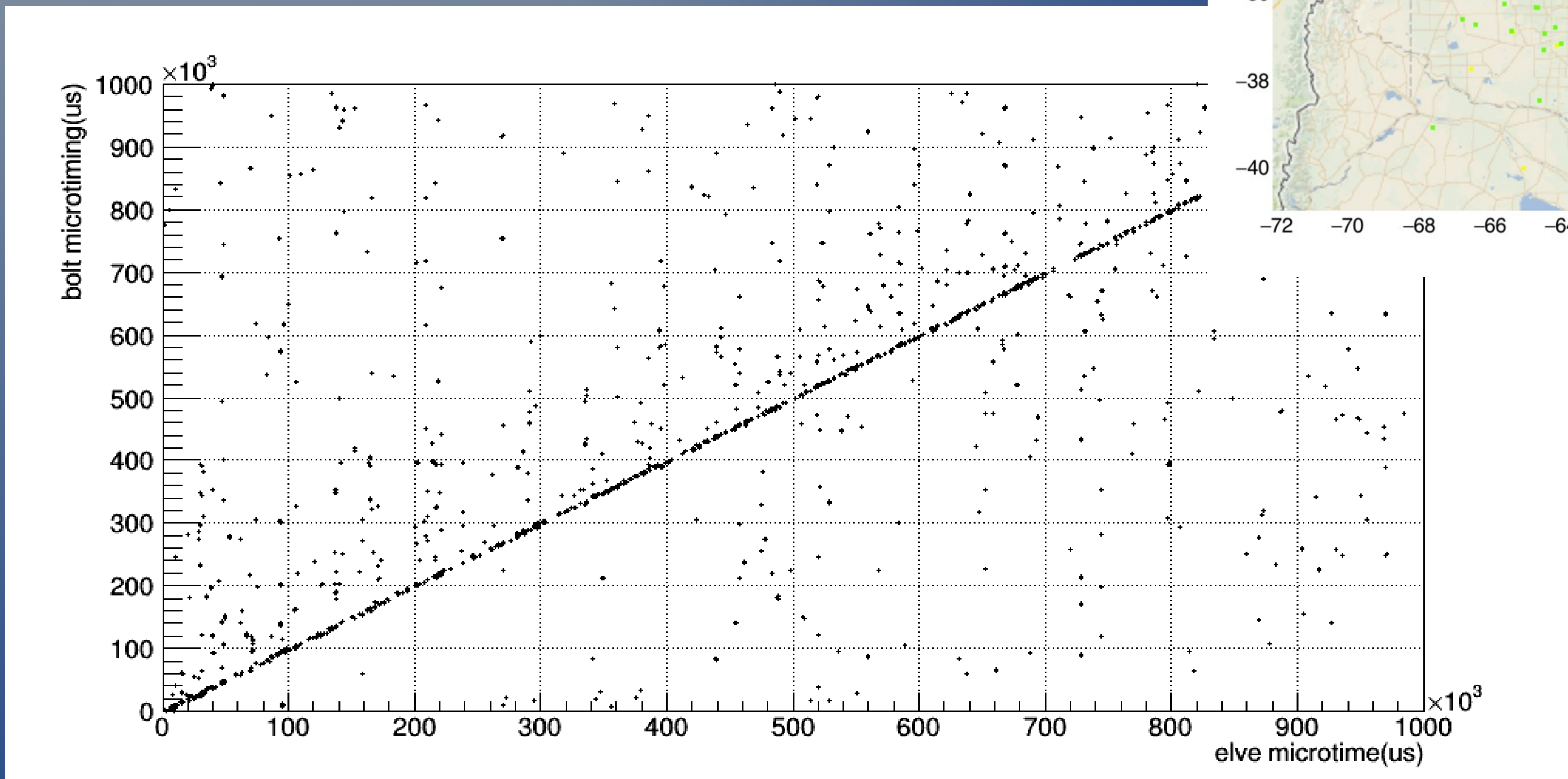
(*) XR in LL since 1/1
In LM-LA-CO since 28/1

	Nrecords	Nevents	N_{1bay}	N_{2bay}
LL	965	299	250	49
LM	80	33	33	0
LA	406	144	143	1
CO	828	274	233	41

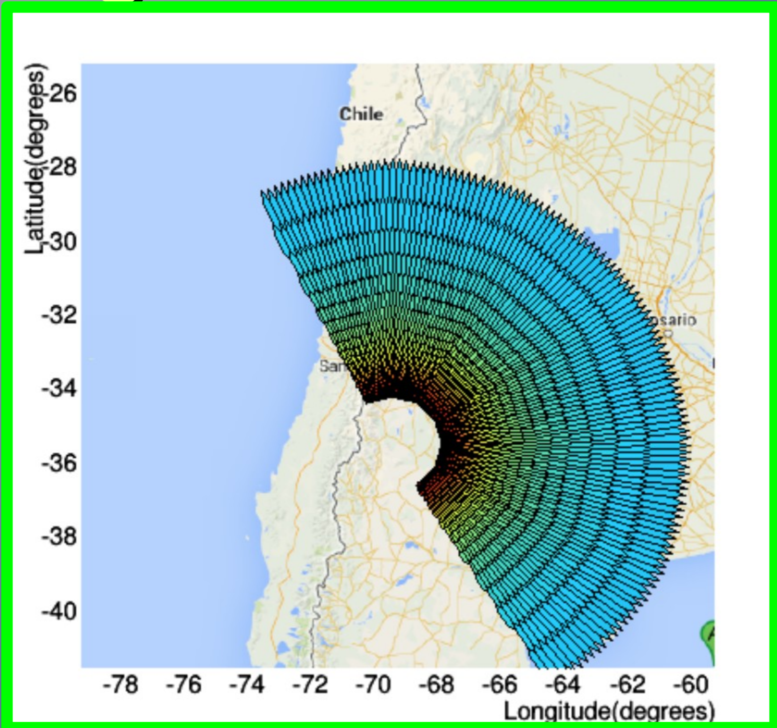
Comparison with WWLLN data

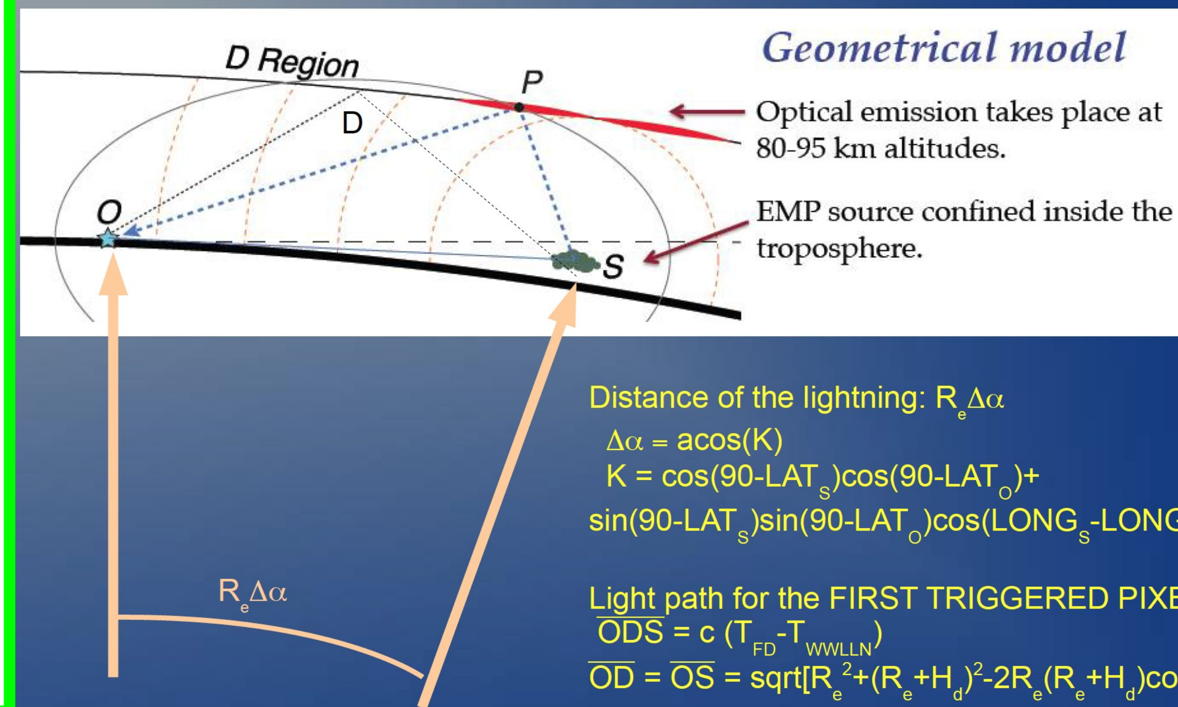
Excellent correlation with WWLLN data : ~ 50% in 2013.
We used it to check space+time resolution of our reconstruction





Light emission normalization





Distance of the lightning: $R_e \Delta\alpha$

$\Delta\alpha = \mathrm{acos}(K)$

$K = \cos(90-LAT_S)\cos(90-LAT_O)+\sin(90-LAT_S)\sin(90-LAT_O)\cos(LONG_S-LONG_O)$

Light path for the FIRST TRIGGERED PIXEL:

$\overline{ODS} = c\,(T_{FD}-T_{WWLLN})$

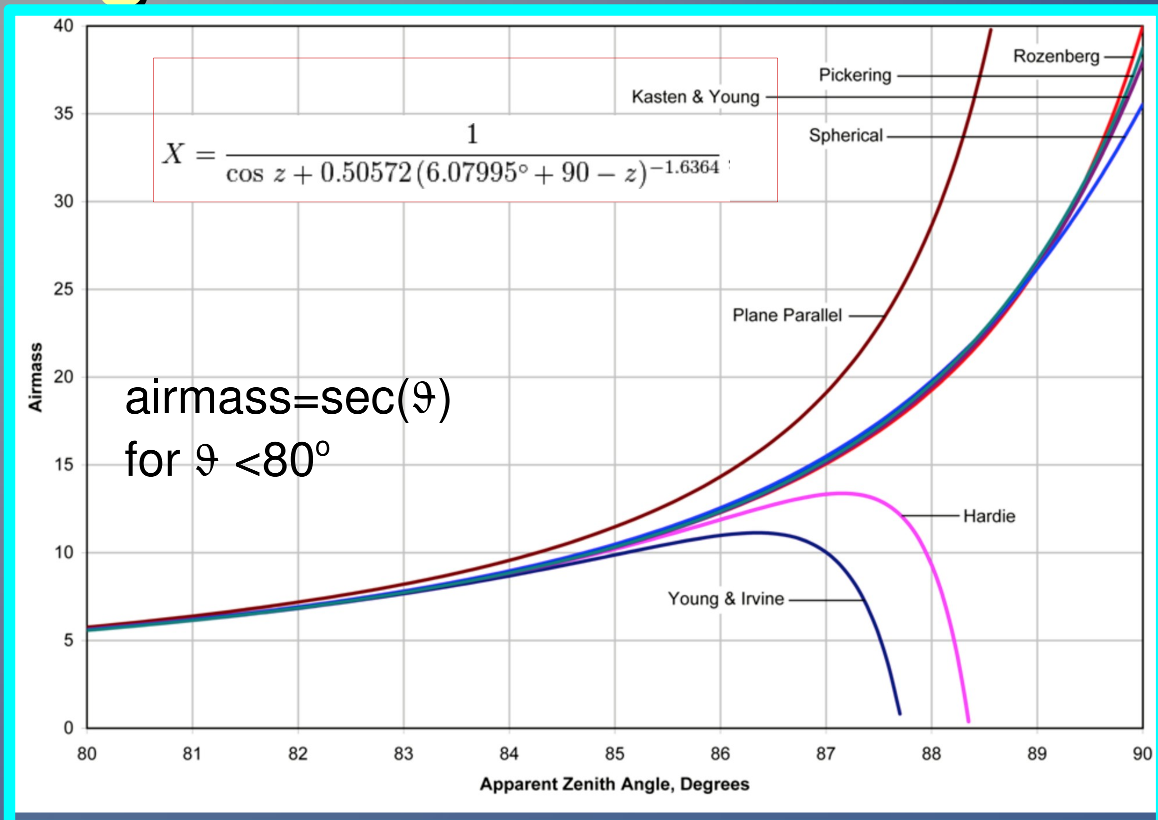
$\overline{OD} = \overline{OS} = \mathrm{sqrt}[R_e^2+(R_e+H_d)^2-2R_e(R_e+H_d)\cos(\Delta\alpha/2)]$

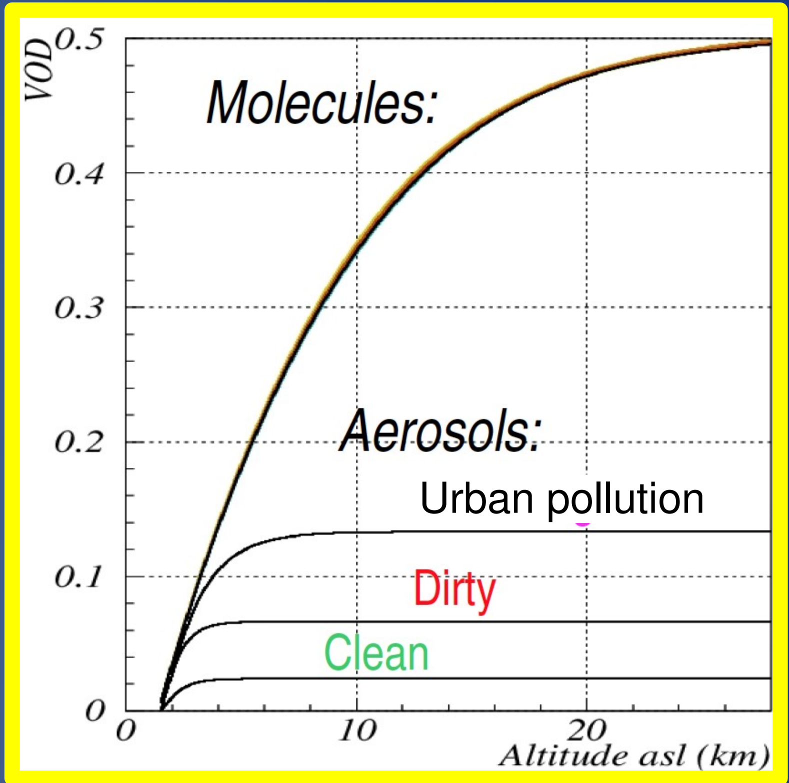
Photons detected by the FD camera are corrected for distance from the base of ionosphere (assumed at 85 km), and for the surface observed by each pixel.

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

$$Geom\_corr = (R^2_{PO}/A_{mirror}) / Area(h=H_d) \quad ; \quad Atmo\_corr = \exp((OD_{mol}+OD_{aer})*airmass(\theta))$$

Light emission normalization





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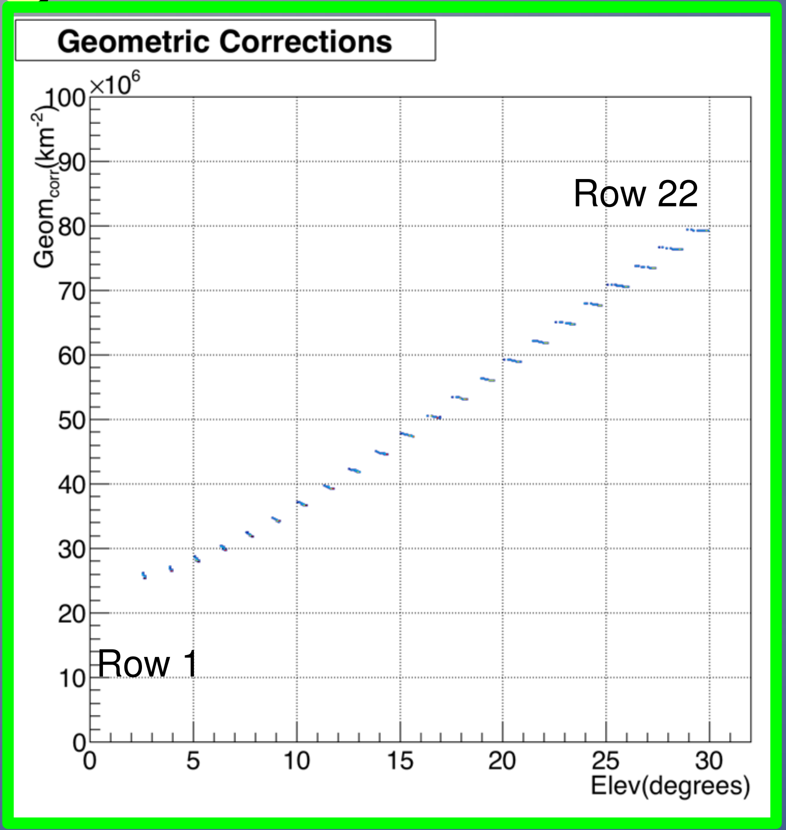
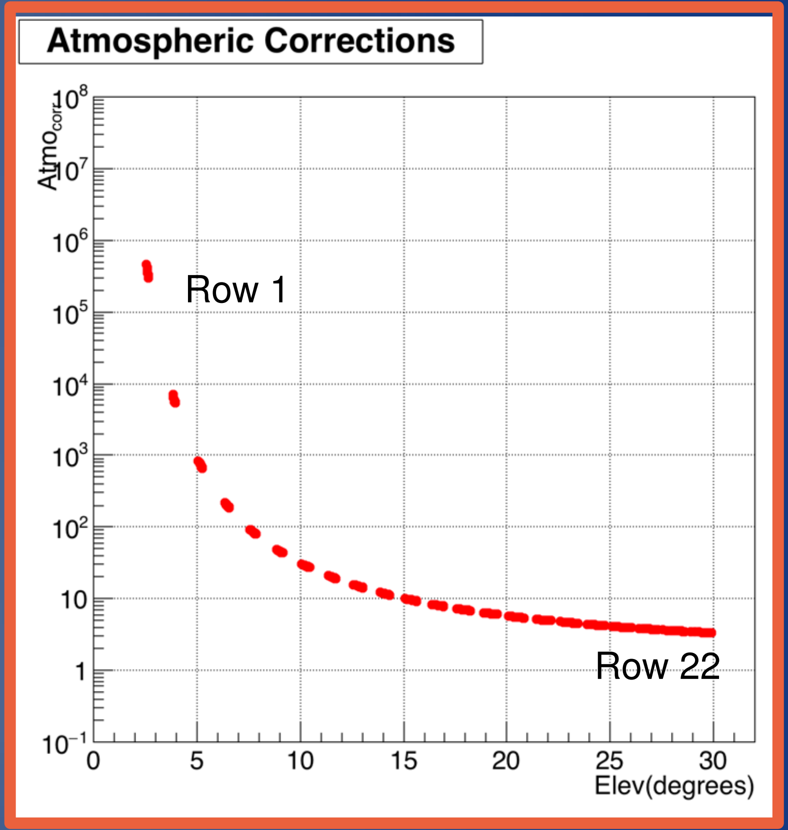
Atmospheric optical depth OD is calculated from Vertical Molecular (by weather stations, radiosondes, GDAS) and Aerosol profiles (hourly LIDAR measurements).

Airmass is calculated from *Kasten, F.; Young, A. T. (1989).. Applied Optics 28: 4735–4738*.

Light emission normalization





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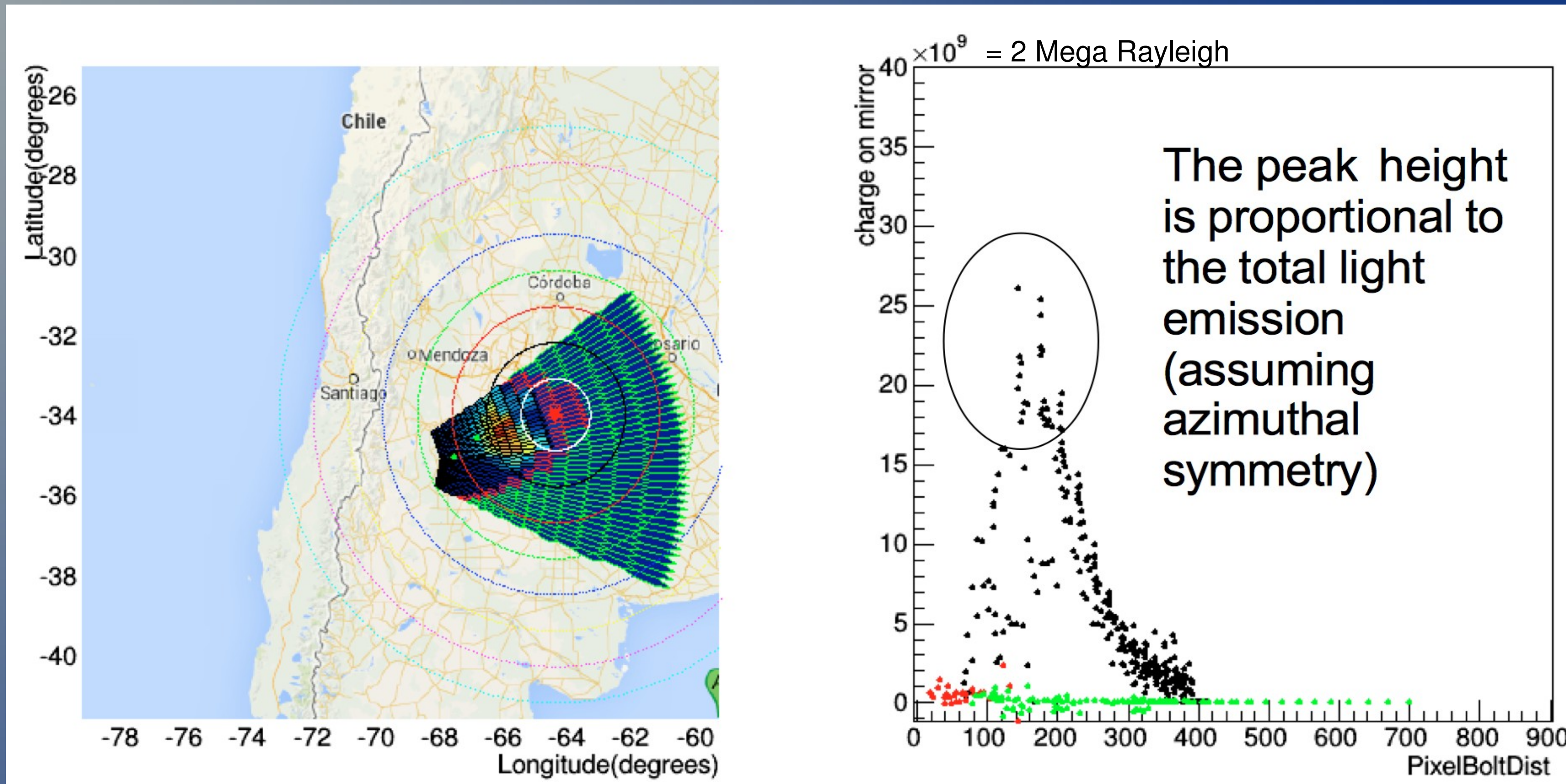
Large Atmospheric corrections are optical depth OD is calculated from Vertical Molecular (by weather stations, radiosondes, GDAS) and Aerosol profiles (hourly LIDAR measurements).

Corrected light emission versus distance from Lightning Strike



Red star: WWLLN bolt location

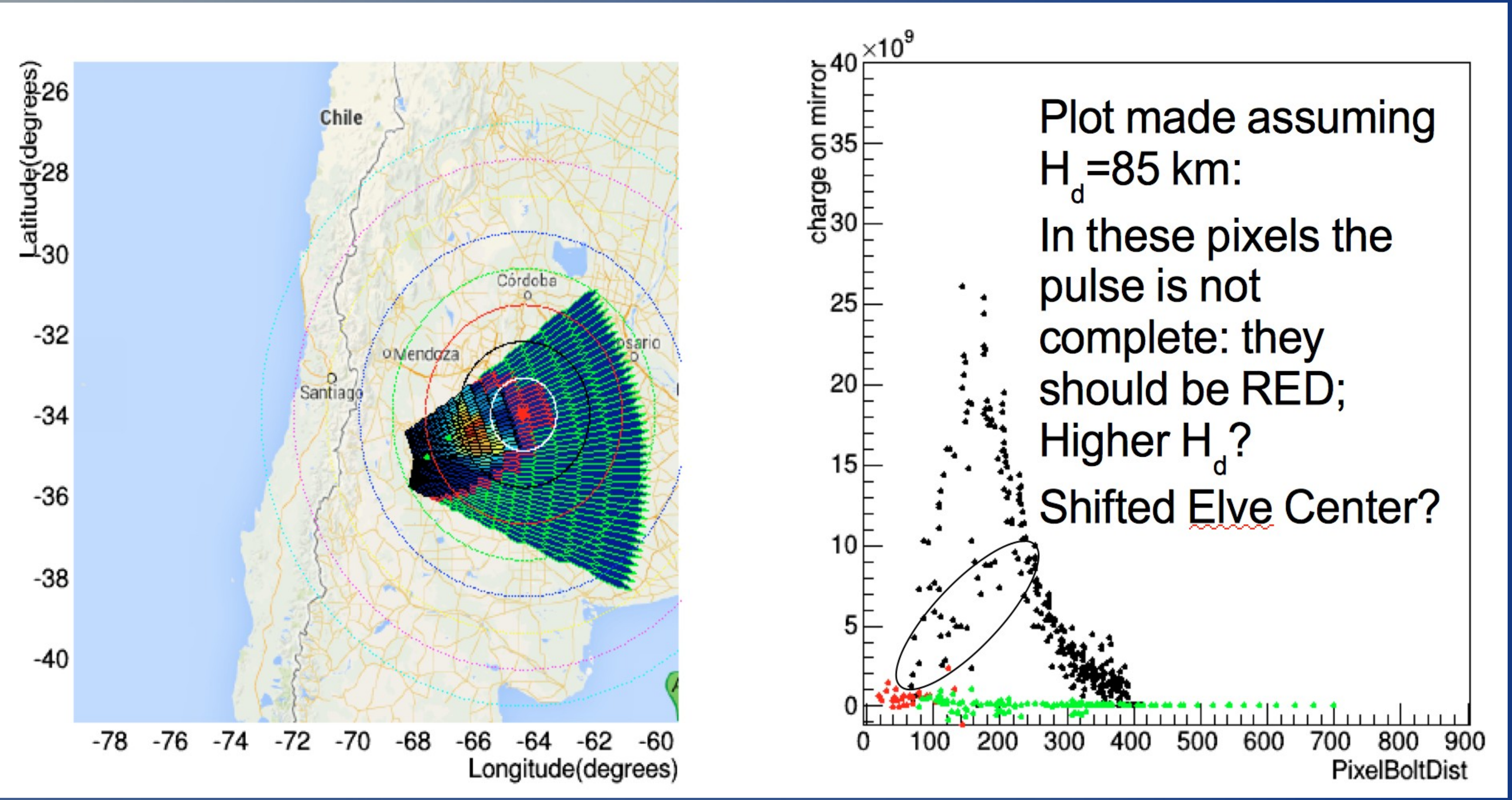
The colors indicate the ionospheric surface density of light emission

Circles at 100,...,800 km

Elve pulse containment: Full, Partial, Zero

In Green pixels the light emitted will arrive AFTER our time window (272 microseconds)

Corrected light emission versus distance from Lightning Strike



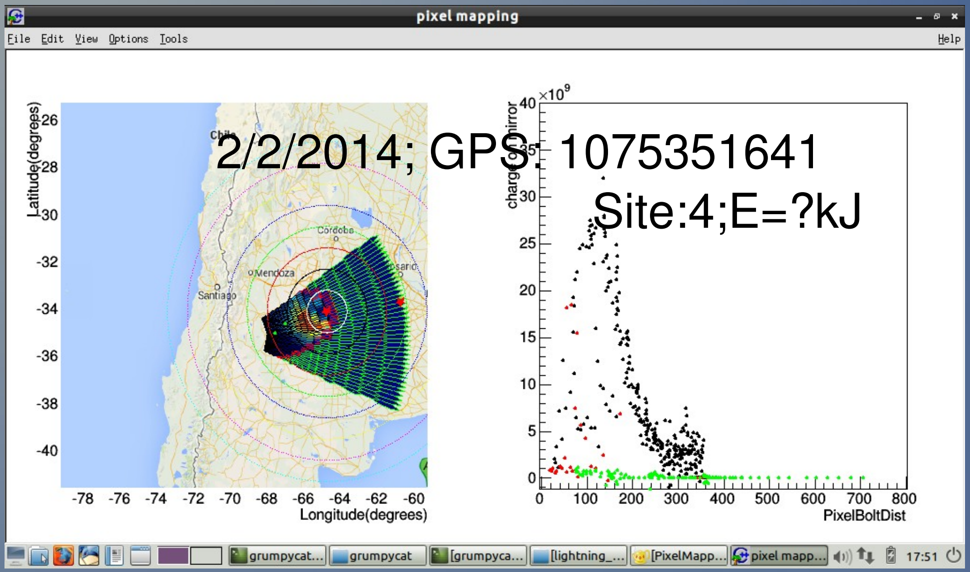
Red star: WWLLN bolt location

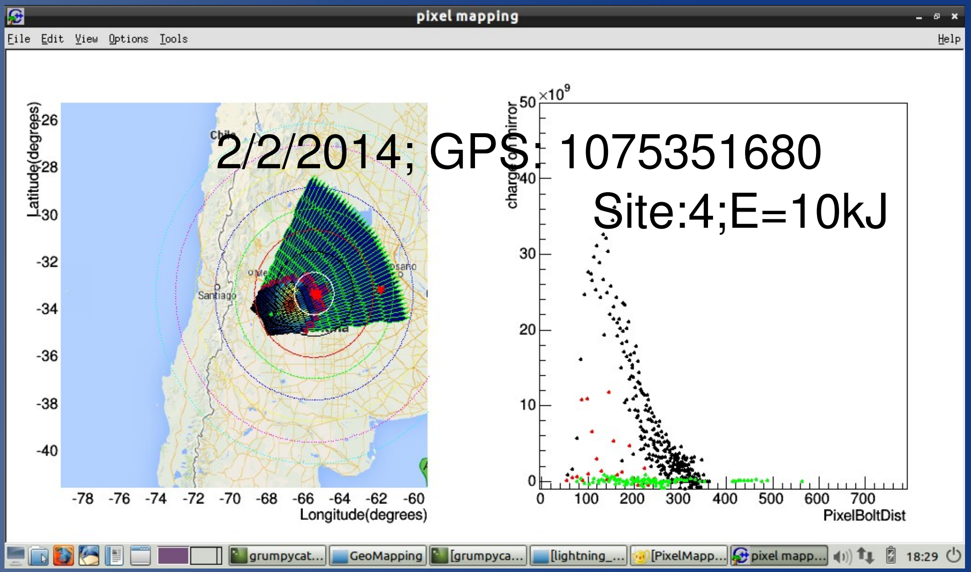
Circles at 100,...,800 km

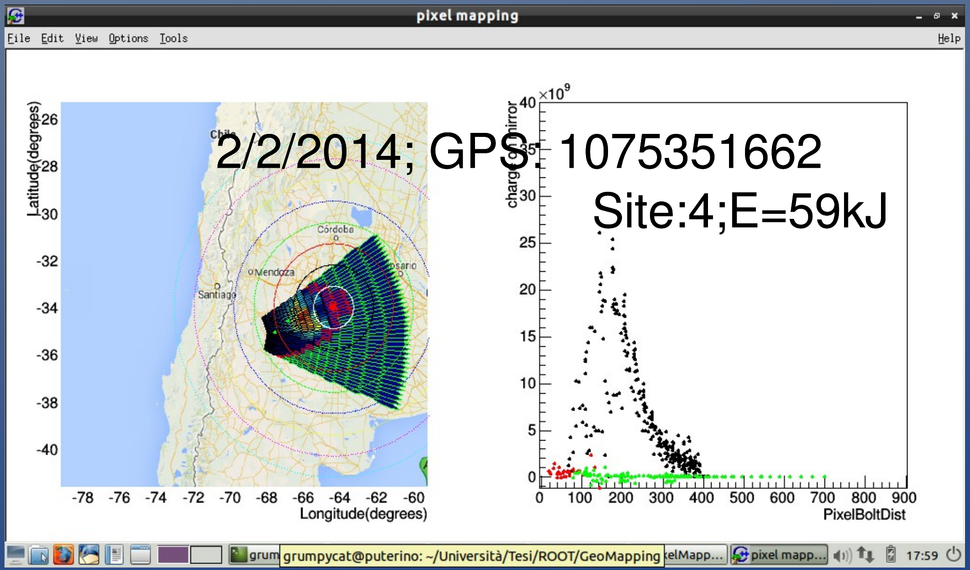
Elve pulse containment: Full, Partial, Zero

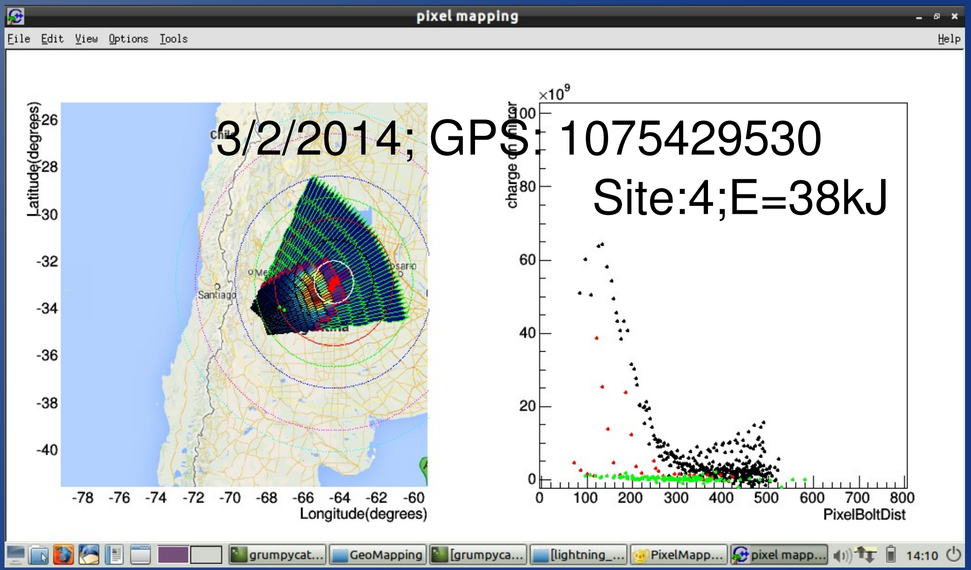
In Green pixels the light emitted will arrive AFTER our time window (272 microseconds)

Lightning at short and medium distance: no correlation with WWLLN energy









Events from large distance: Study of Stereo Events

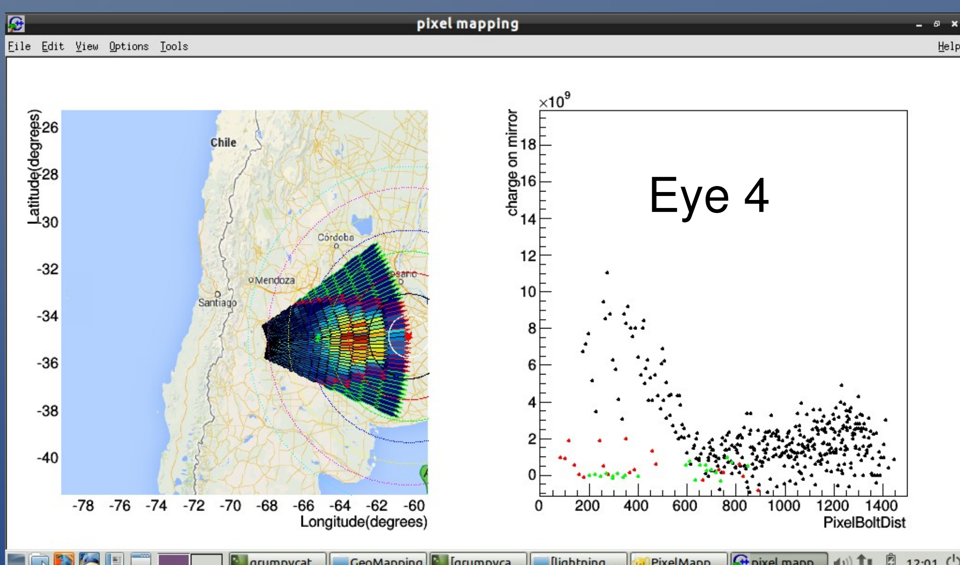
- Large atmospheric corrections are the biggest challenge for elves from far lightning

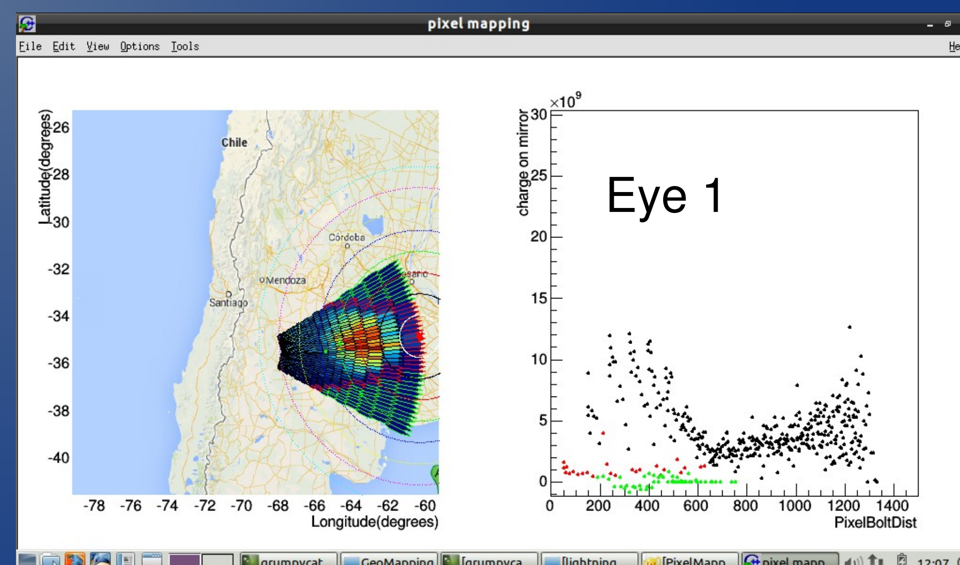
- WWLLN information is not needed to determine lightning location

- Normalization of light emission can be double checked

- We can do better studies of exotic behaviors, excluding local cloud effects

- We can improve time and space resolution using amplitude information





Summary and prospects

We studied the Surface Density of Light Emissions from Elve Events collected in 2014 and 2015 in Auger Observatory

A special trigger allows to extend the standard traces, in order to study the light emission from the vertical above the lightning , where we expect to see a decrease in light intensity.

After performing Geometry and Atmospheric corrections we can compare our results with WWLLN measurement of lightning Energy to check correlations with light emission

Hints of a possible displacement between the center of light emission and the vertical above lightning are observed. Further studies are underway.

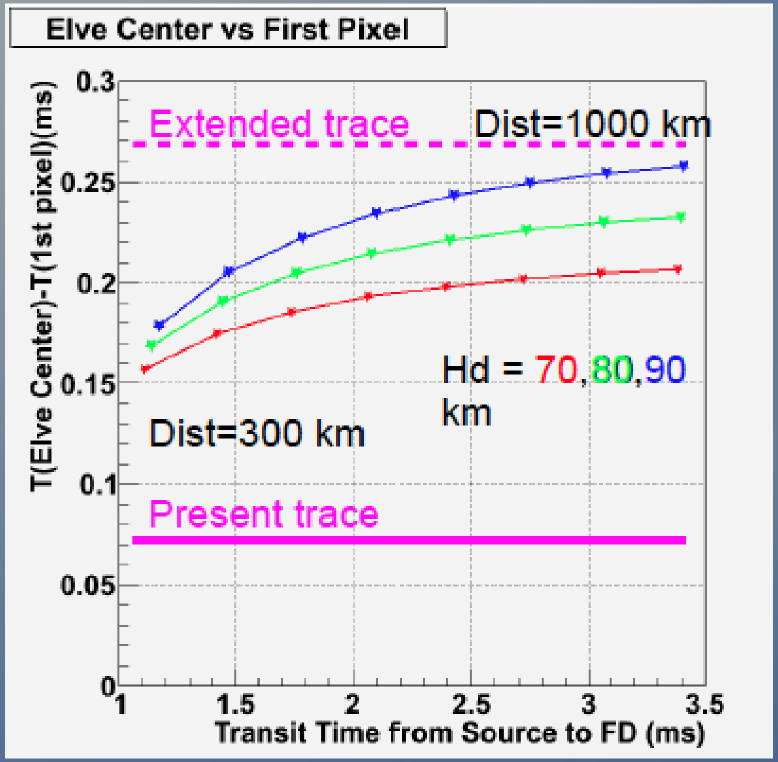
The Auger Observatory is currently being upgraded to continue operations until 2023.
A proposal is under way to extend operations through the whole moon cycle, with reduced PMT gain, which will allow to double ELVES statistic per year.

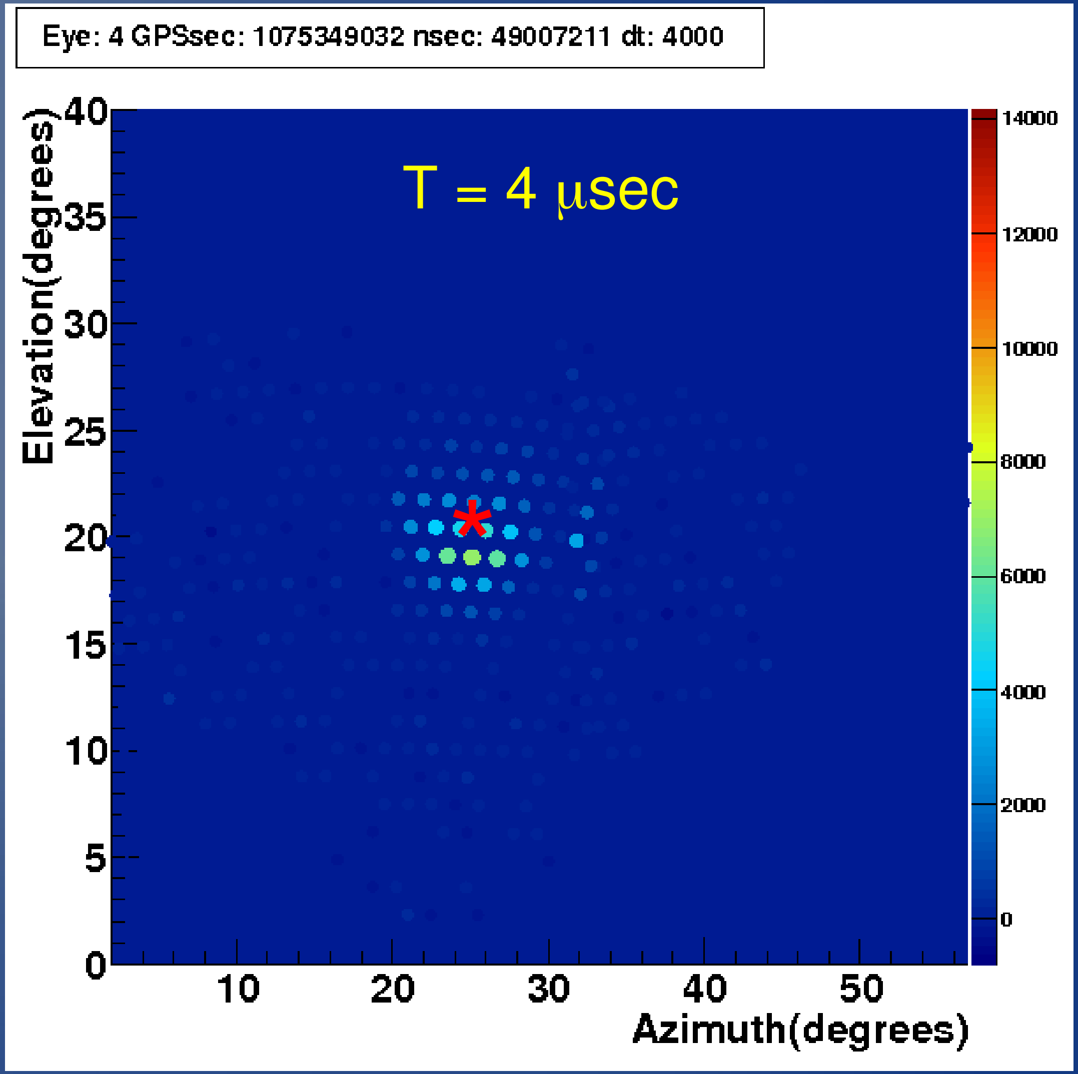
A public web page with all elves data is in preparation at INFN Torino

More ionospheric studies are ongoing at the Observatory: stay tuned!

Thank you!

Extended readout

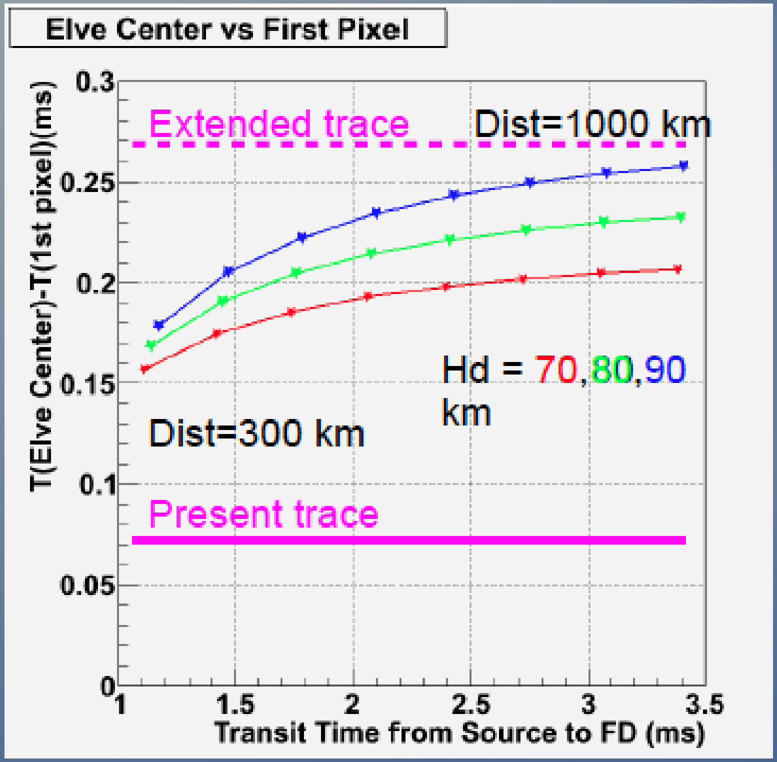


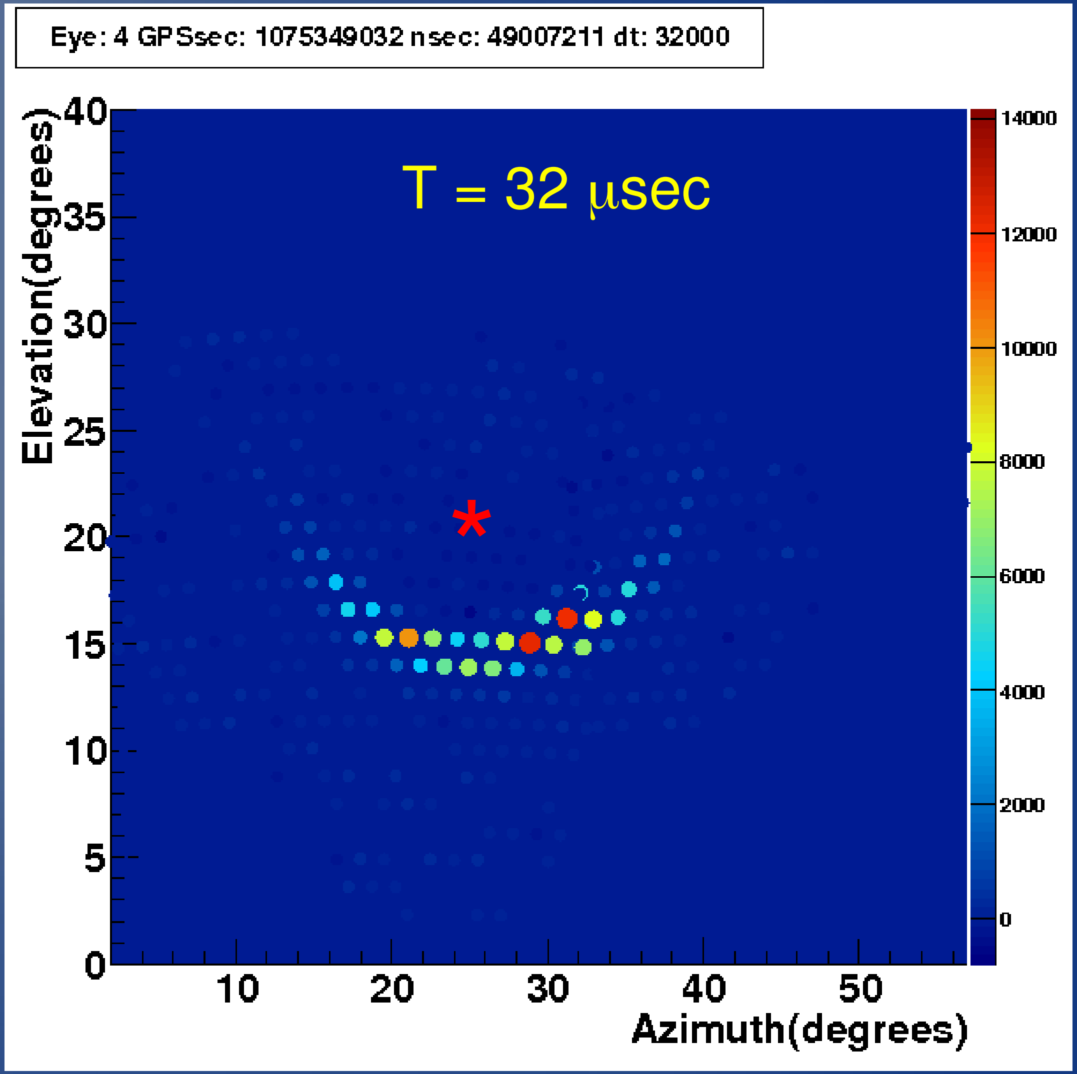


	Total	OK	1	2
LL	334	276	39	19
LM	32	21	6	5(0)
LA	145	125	11	9(3)
CO	307	224	49	34(25)

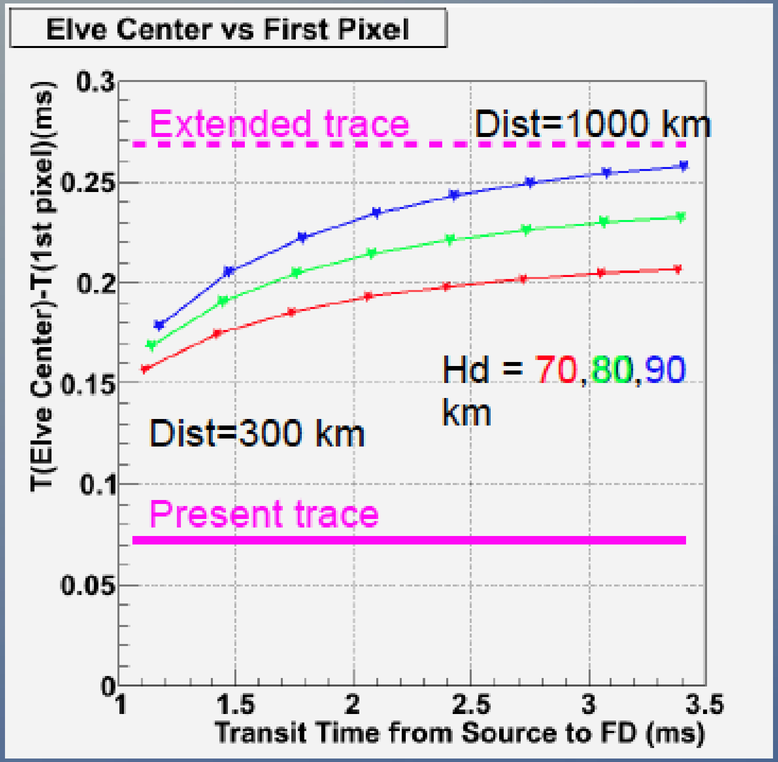
790 total records, 145 (18%) have only 1 or 0 followers

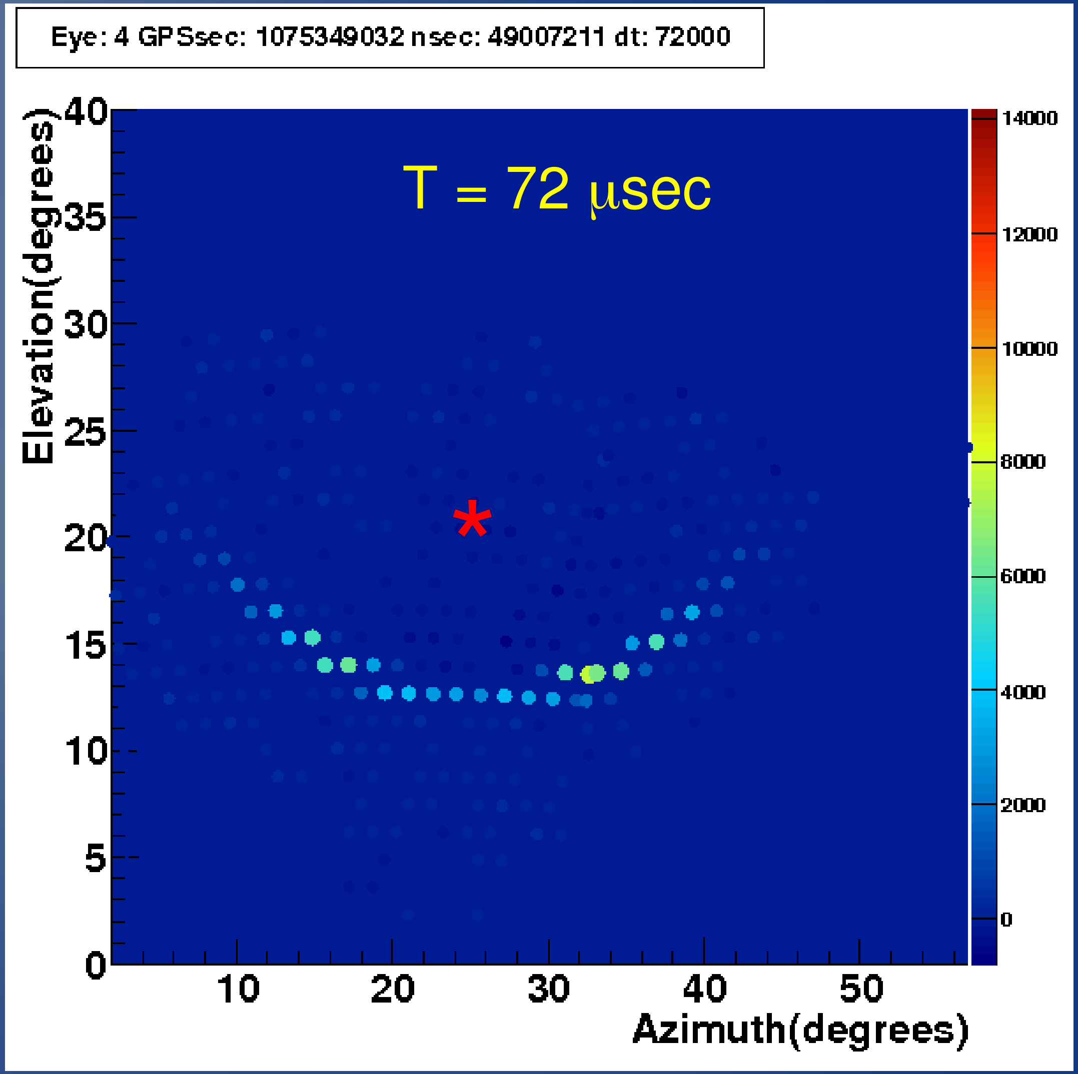
Extended readout



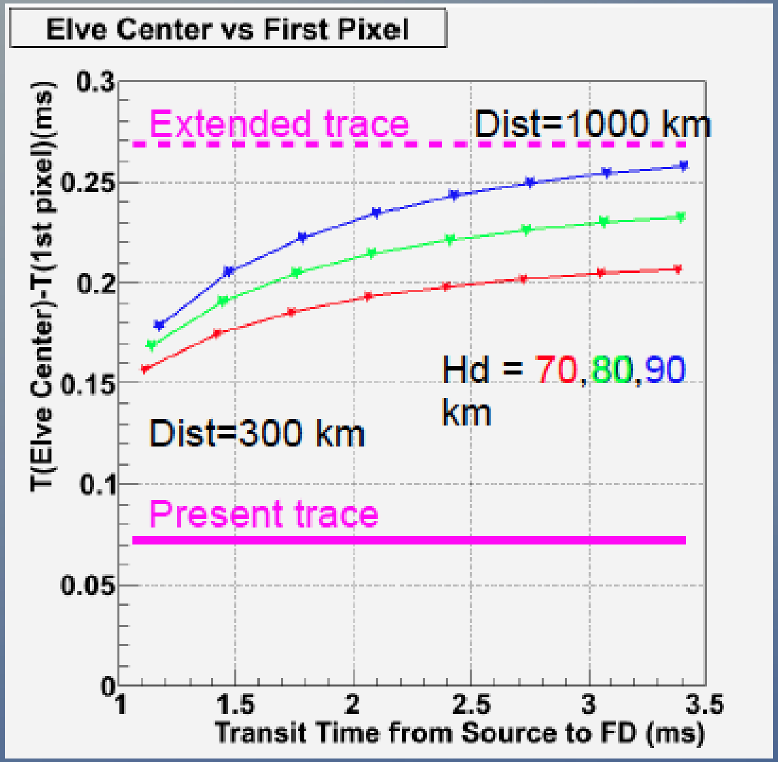


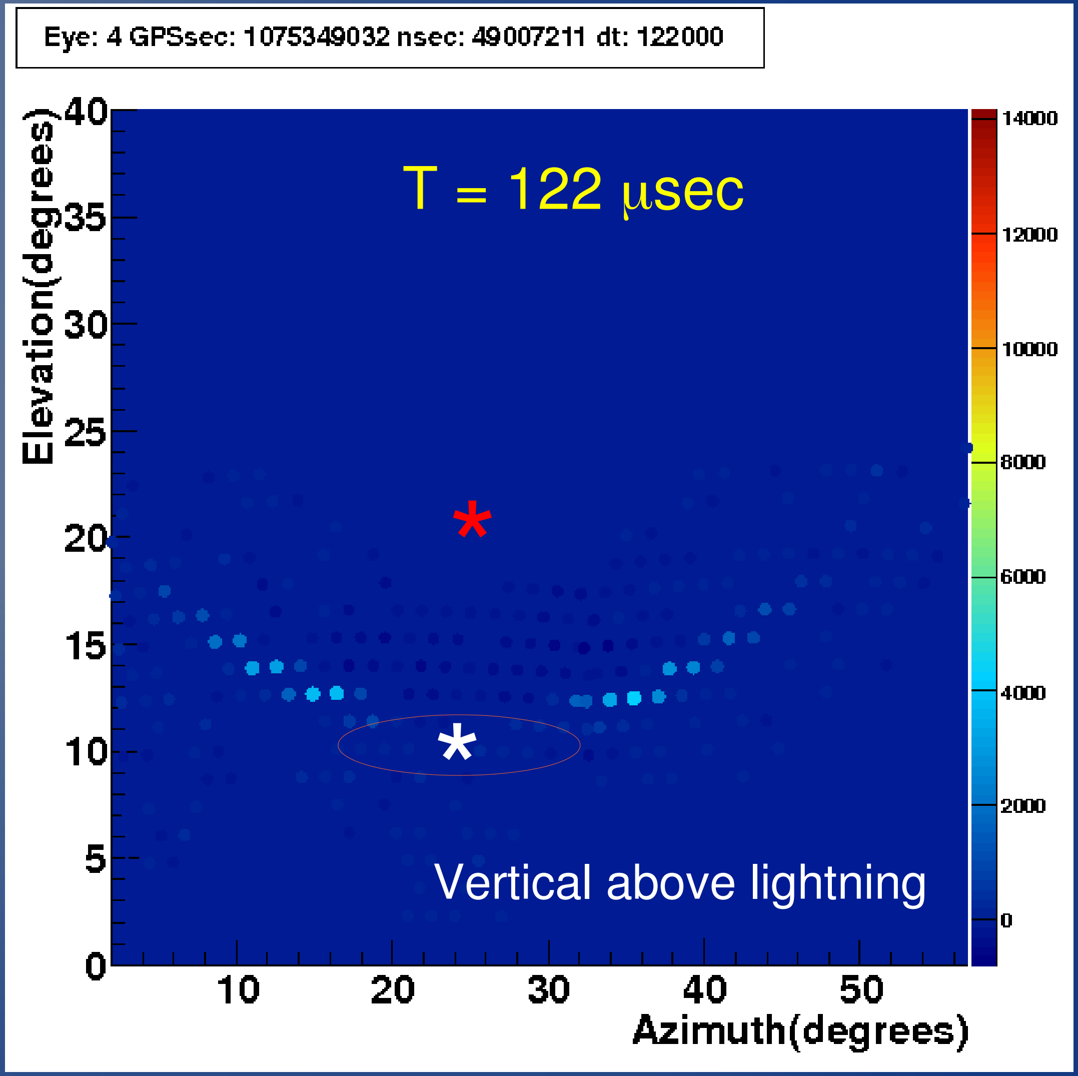
Extended readout





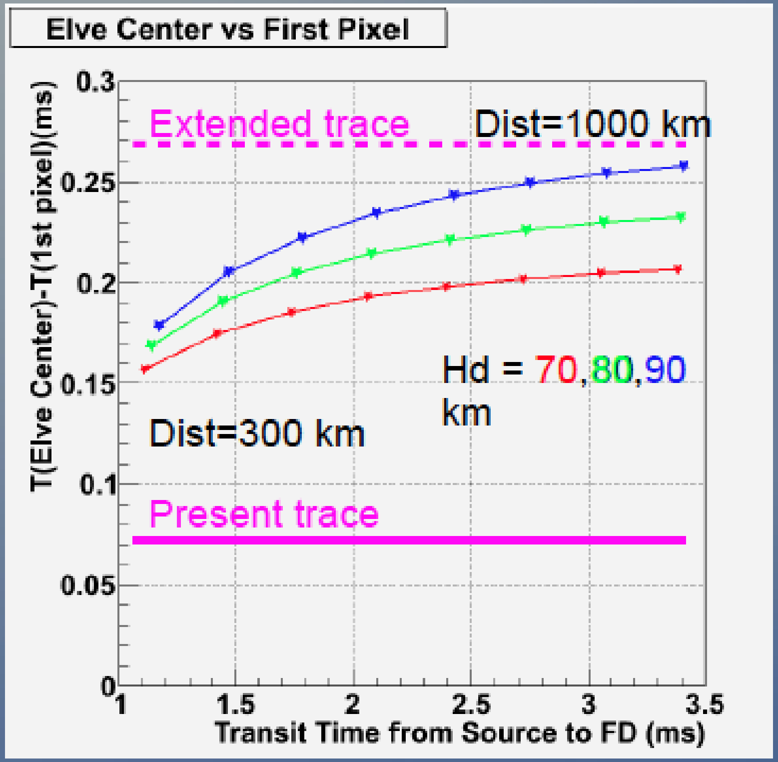
Extended readout

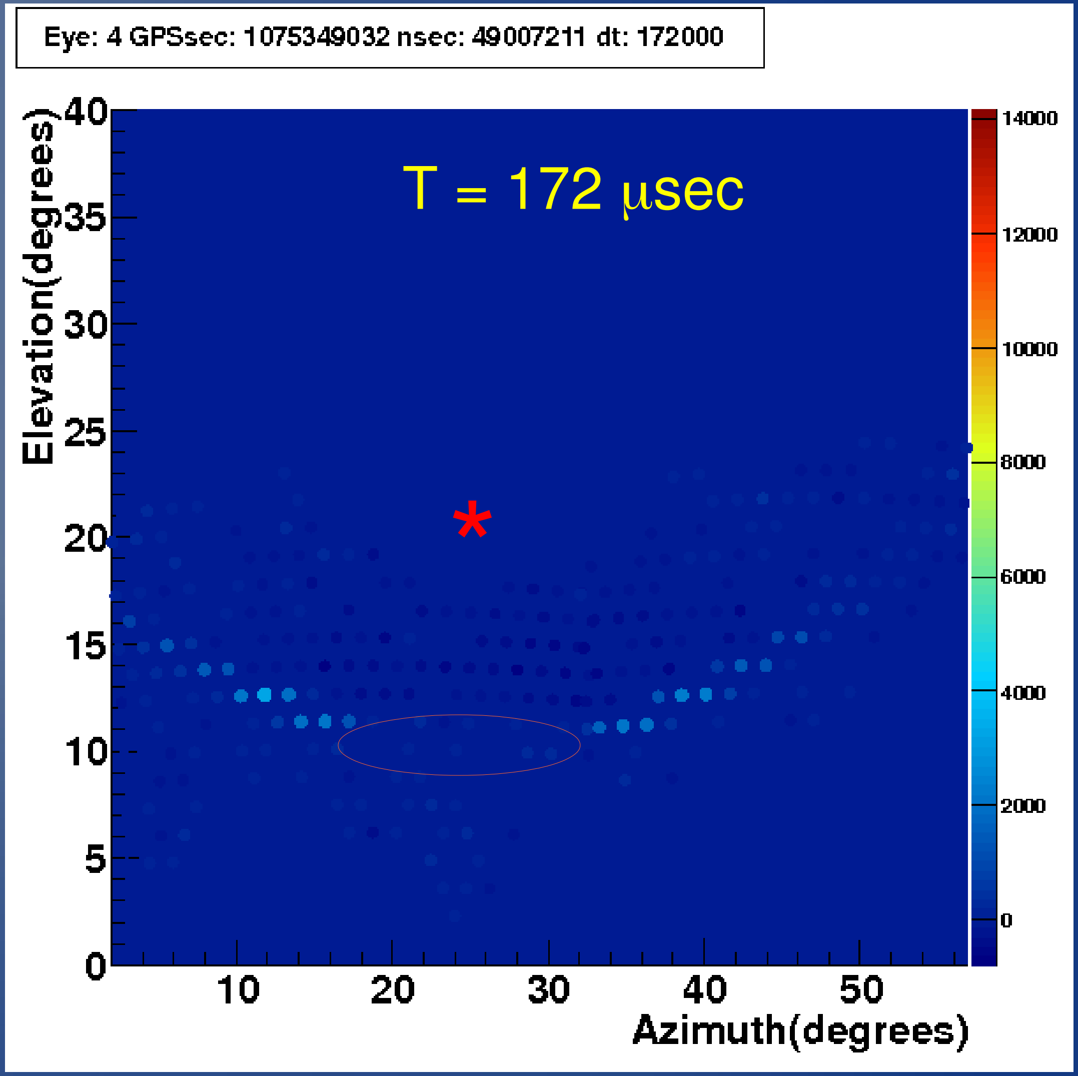




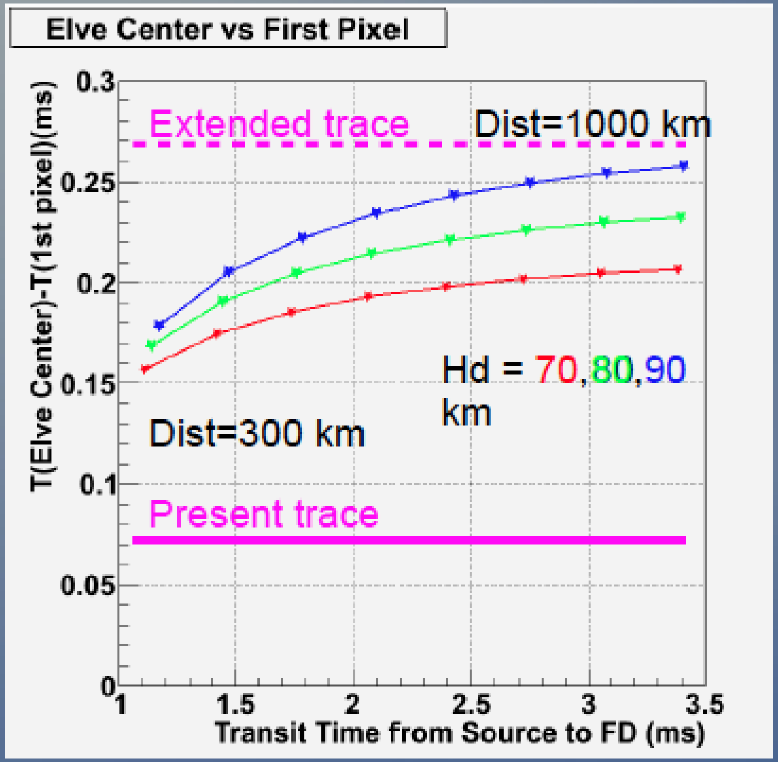
Here we start seeing the vertical above the lightning

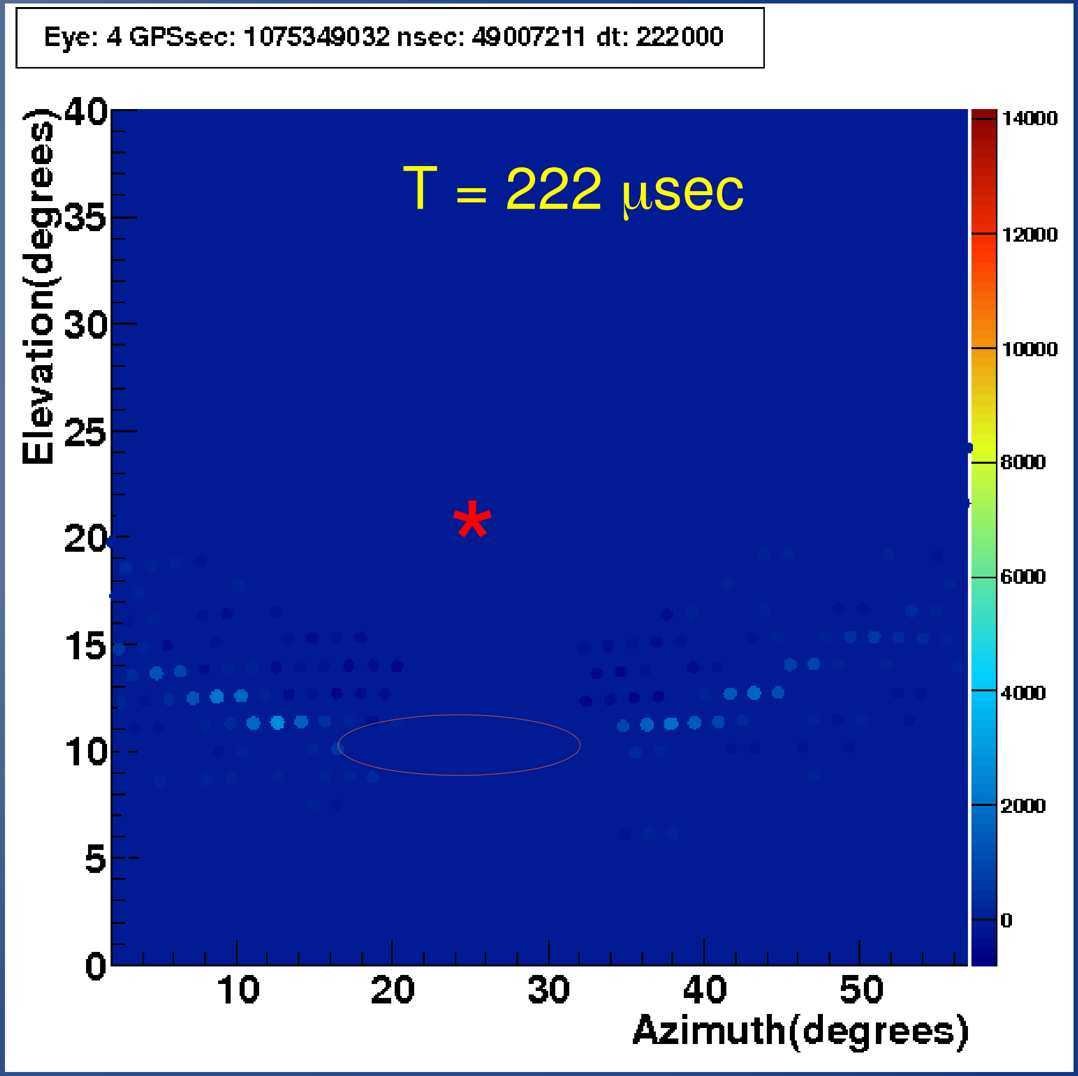
Extended readout



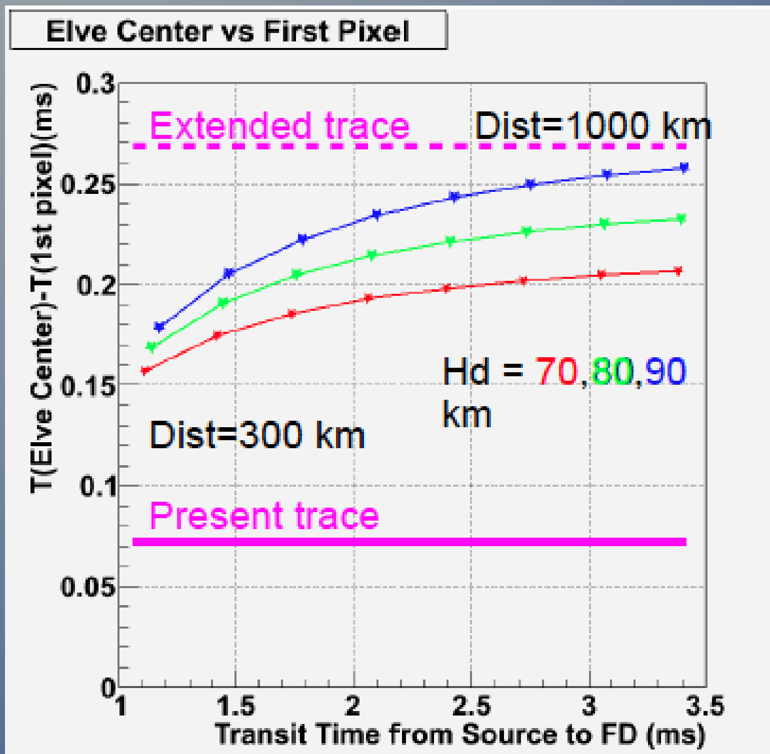


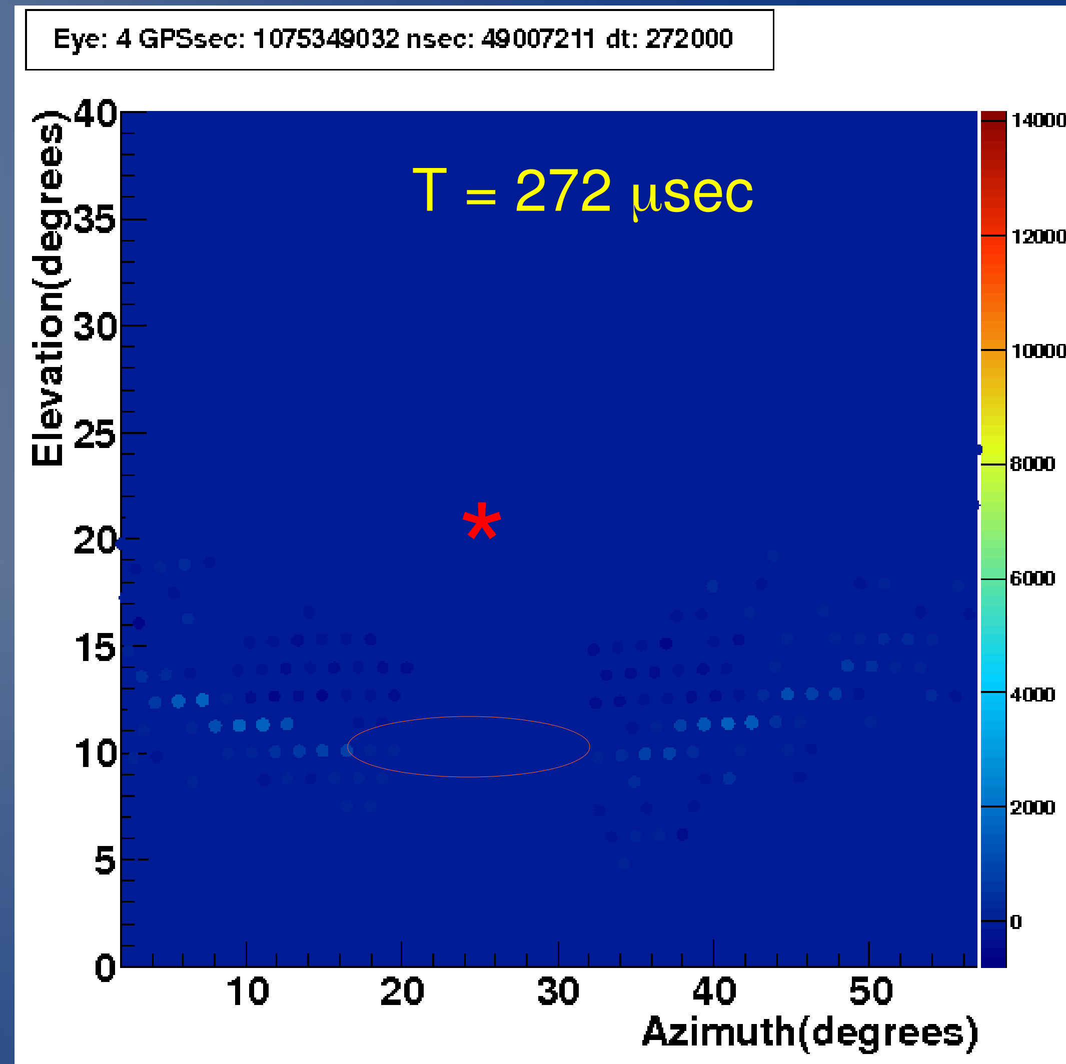
Extended readout



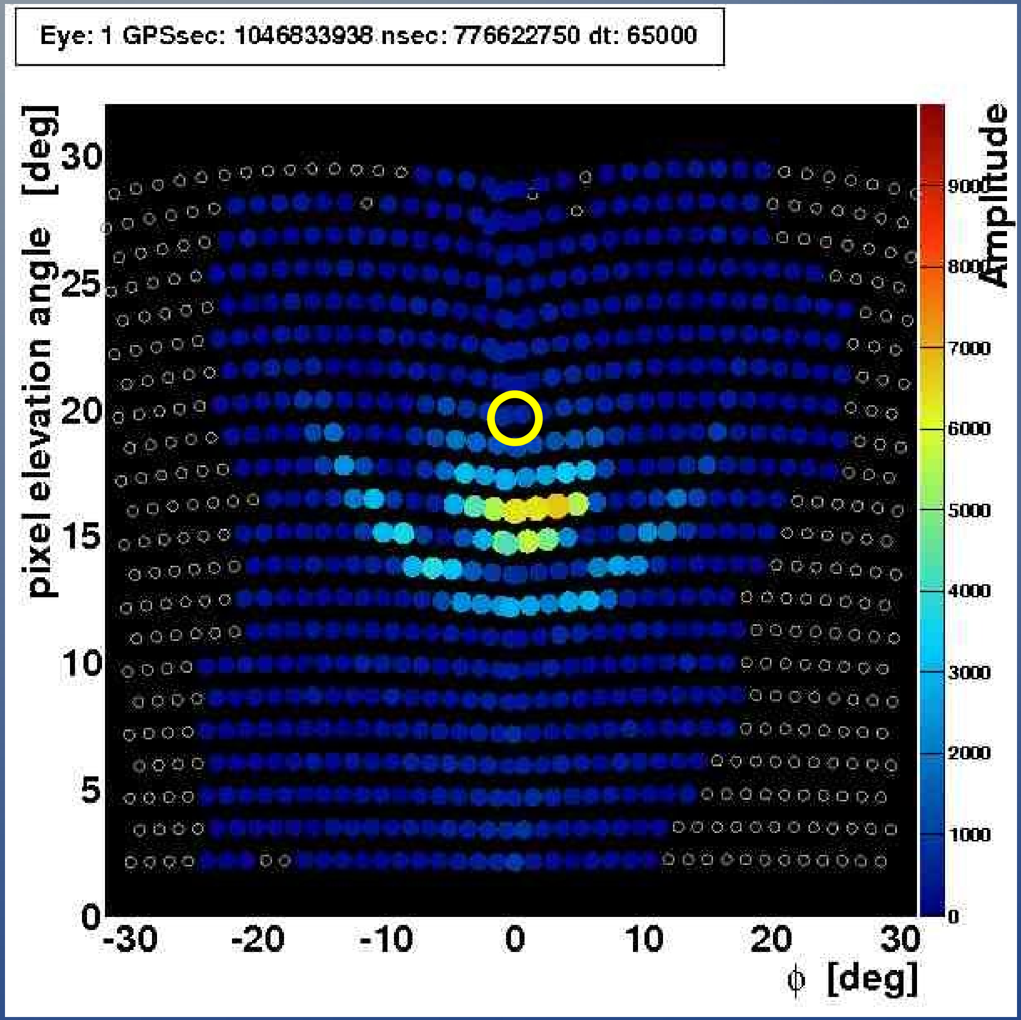


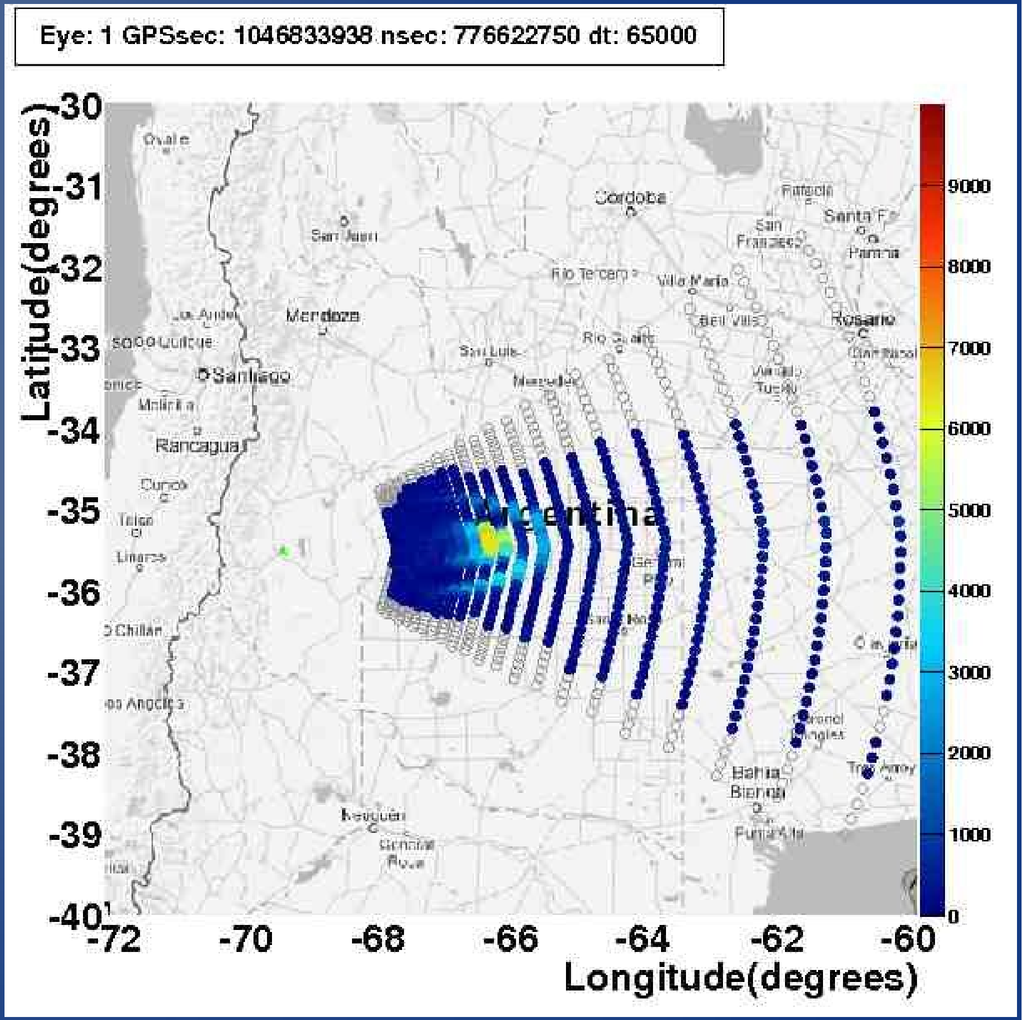
Extended readout





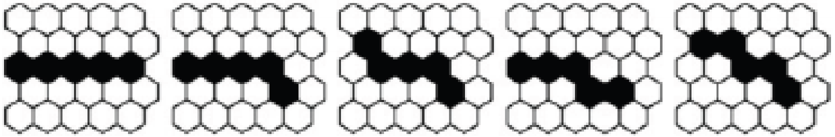
Double elves: example of GOLDEN type





2008-2011: search for ELVES in FD-SLT data

	type	purpose	event rate
First Level Trigger (FLT)	**HW**	Pixel threshold trigger	100 Hz / pixel
↓ **T1**			
Second Level Trigger (SLT)	**HW**	Track shape identification	0.1-10 Hz / tel
↓ **T2**			



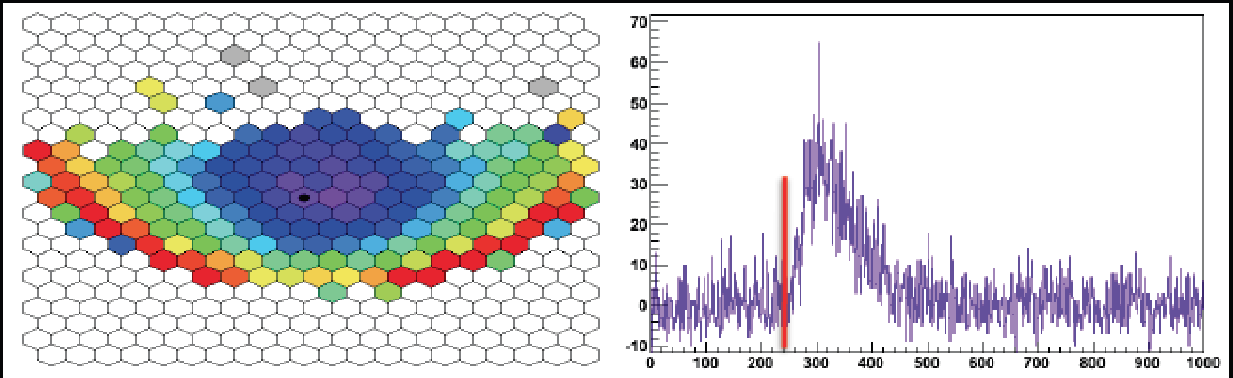
We decided to analize the fraction of events which pass the 2nd level of trigger, which is saved with prescaling factor 1/100 in a separate data stream (*minimum bias*) and is used for measuring efficiencies and testing new trigger algorithms.
All minimum bias data from 2008 to 2011 were analyzed.

58 new events were found. (poster at AGU FALL 2012)

Online trigger algorithm for ELVES

Tonachini et al Proc.ICRC 2013

1. Find the FIRST PIXEL and define the PULSE START TIME



Pulse length must be > 25 bins

2. Quality cuts on start time

3. Check PIXELS on the same ROW
   - at least 3 pixels before ***OR*** 3 after the central one
   - **80%** of the pixels must show an increasing pulse time

4. Check PIXELS on the same COLUMN
   - at least 3 pixels before ***AND*** 3 after the central one
   - **80%** of the pixels must show an increasing pulse time

5. **Check signal amplitude**
   - **for each pixel measure average ADC counts before trigger**
   - **find signal peak**
   - ***at least ONE pixel with > 50 ADC counts***