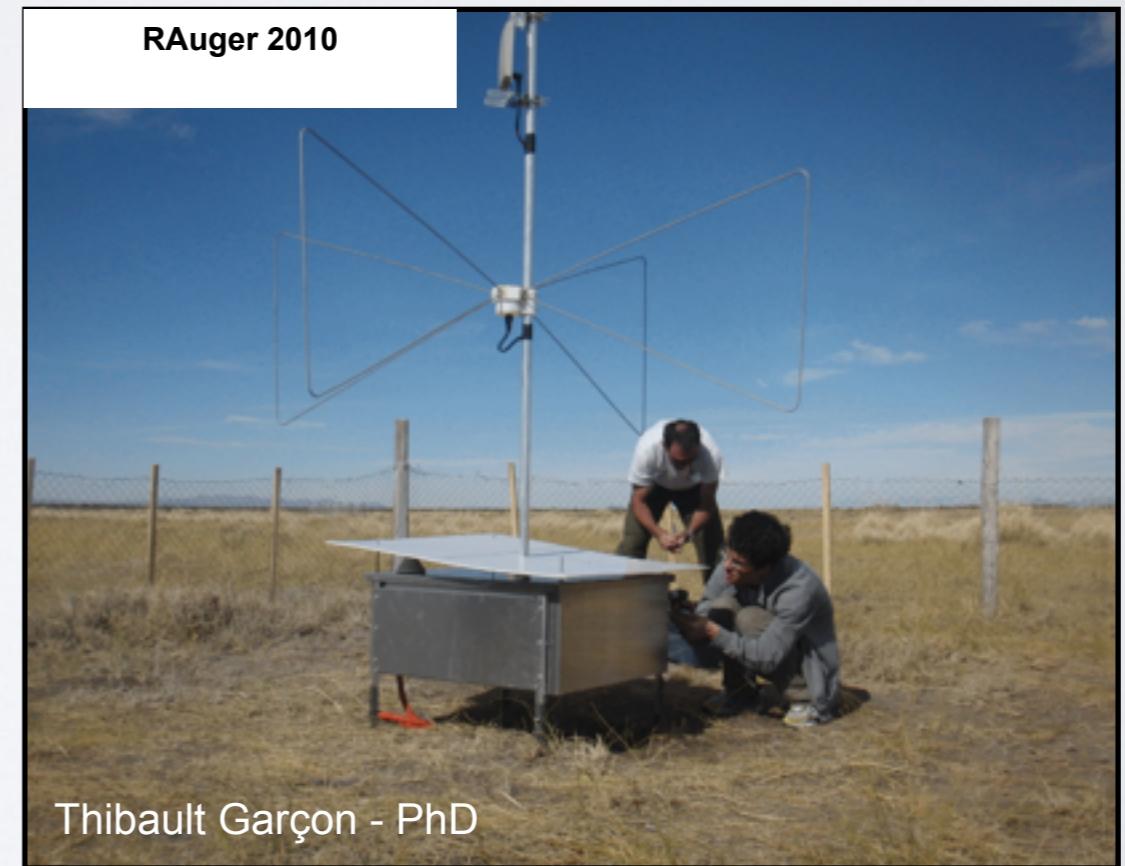
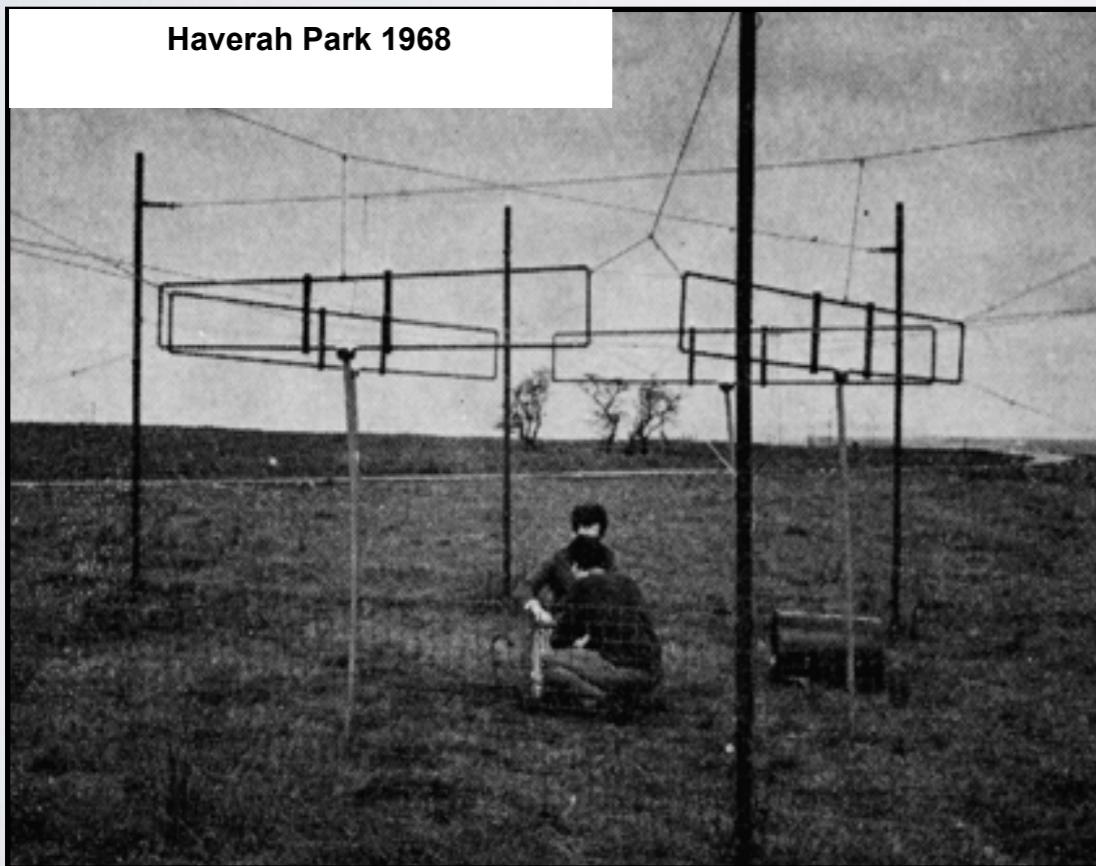


IDENTIFICATION OF FAST TRANSIENT SIGNALS

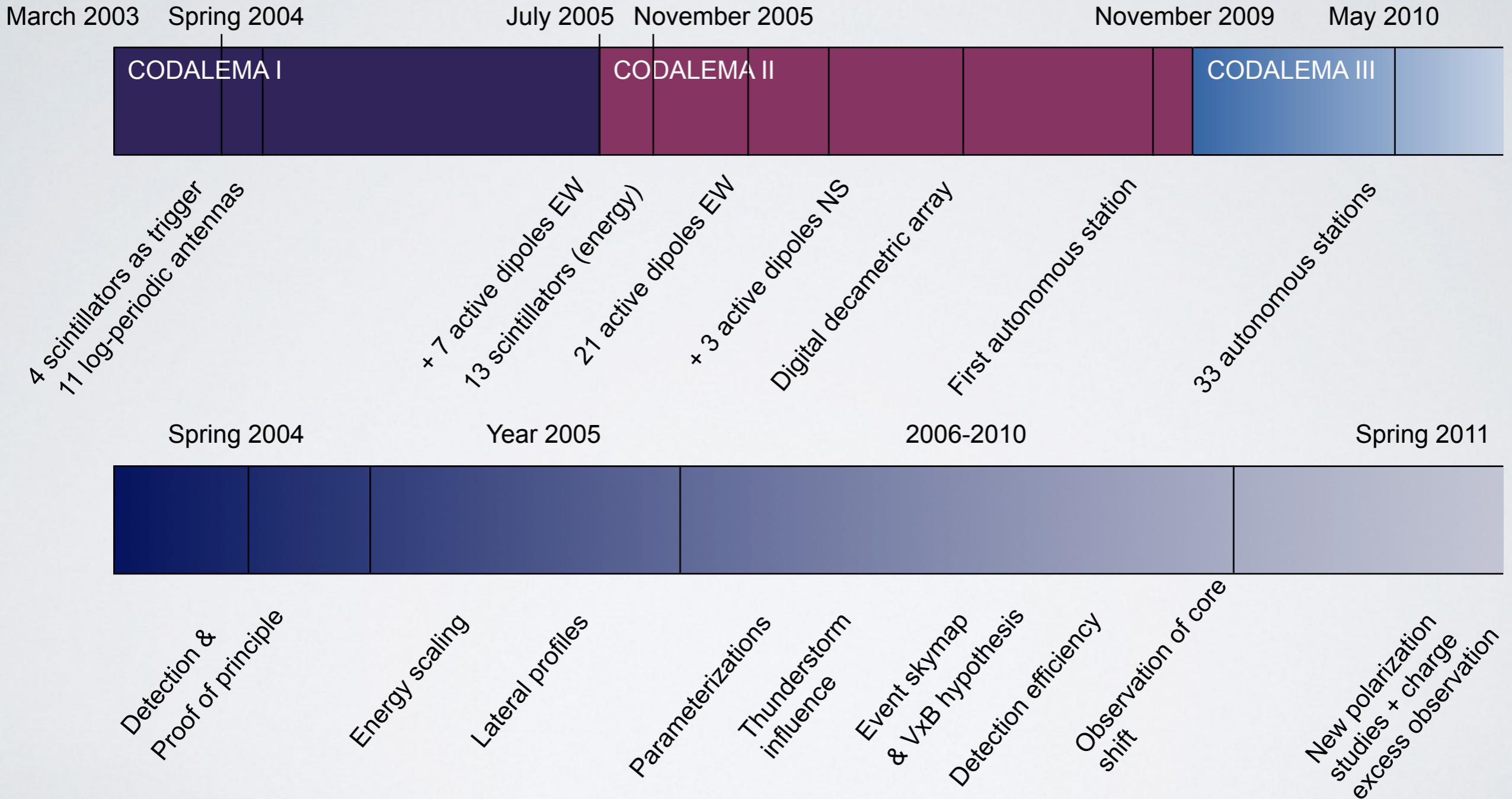
IN COSMIC RAY RADIO DETECTION EXPERIMENTS

Richard Dallier

Subatech, CNRS/IN2P3 - Ecole des Mines de Nantes - Université de Nantes



SUBATECH COSMIC RAY RADIO DETECTION TIMELINE: CODALEMA @ NANÇAY



OTHER EXPERIMENTS

- Gauhati group (1990), India
- EAS-Top (~1990-1992), Gran Sasso, Italy
- LOPES (2003-2012), nearby KASCADE, Karlsruhe, Germany
- ANITA (≥ 2003), balloon borne detection for neutrinos, Antarctica
- TREND (since 2009), nearby 2ICMA, Ulastai, Tianshan, China
- RASTA (since 2009), top of IceCube, Antarctica
- RAuger-2 (2010 - 2013), in Auger, Argentina
- AERA (since 2010), in Auger, Argentina
- LOFAR (since 2011), digital radio telescope core, Netherlands
- EASIER-MHz (2010-2013), in Auger, Argentina
- T-Rex (since 2012), nearby Tunka CR detector, Russia

OTHER EXPERIMENTS

- Gauhati group (1990), India
- EAS-Top (~1990-1992), Gran Sasso, Italy
- LOPES (2003-2012), nearby KASCADE, Karlsruhe, Germany
- ANITA (≥ 2003), balloon borne detection for neutrinos, Antarctica
- **TREND** (since 2009), nearby 2ICMA, Ulastai, Tianshan, China
- RASTA (since 2009), top of IceCube, Antarctica
- RAuger-2 (2010 - 2013), in Auger, Argentina
- AERA (since 2010), in Auger, Argentina
- LOFAR (since 2011), digital radio telescope core, Netherlands
- EASIER-MHz (2010-2013), in Auger, Argentina
- T-Rex (since 2012), nearby Tunka CR detector, Russia

Olivier Martineau-Huynh, from TREND, is attending the workshop: for any question on TREND please meet him!

March 2003 Spring 2004

July 2005 November 2005

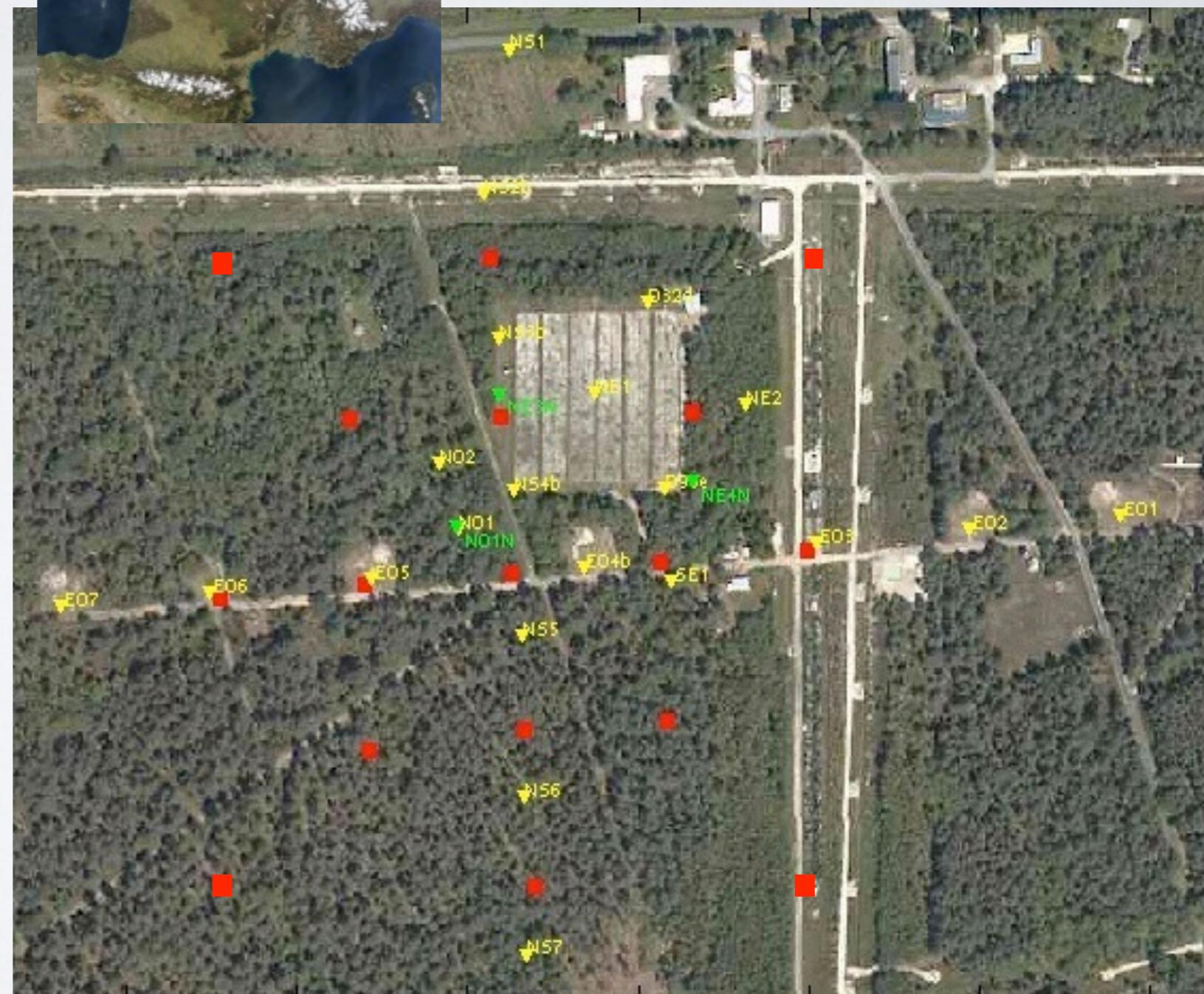
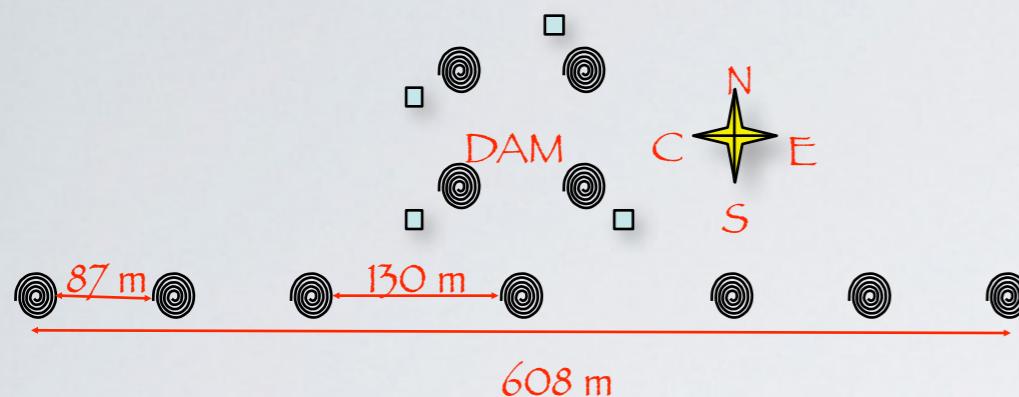
November 2009

May 2010

CODALEMA I

CODALEMA II

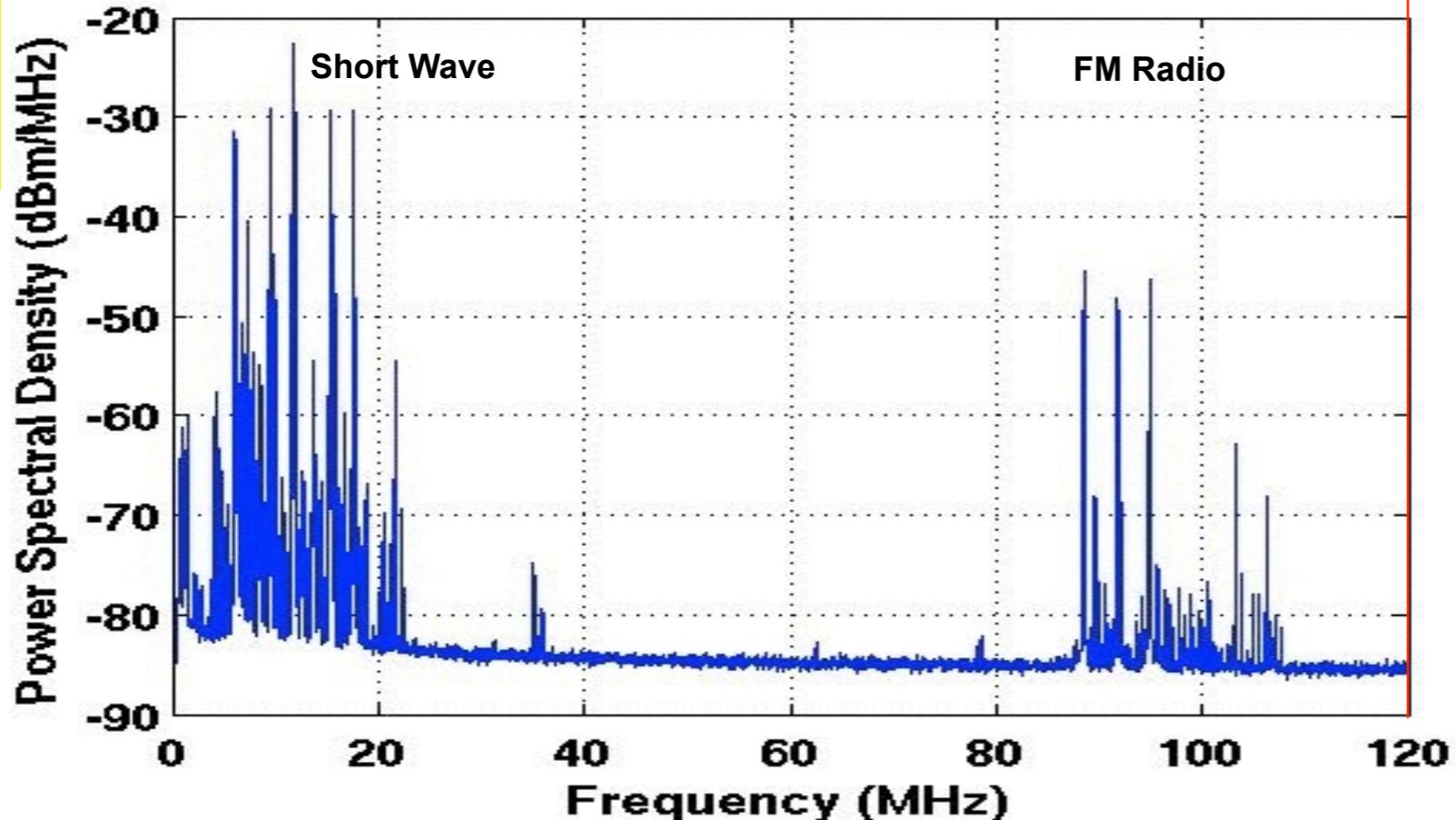
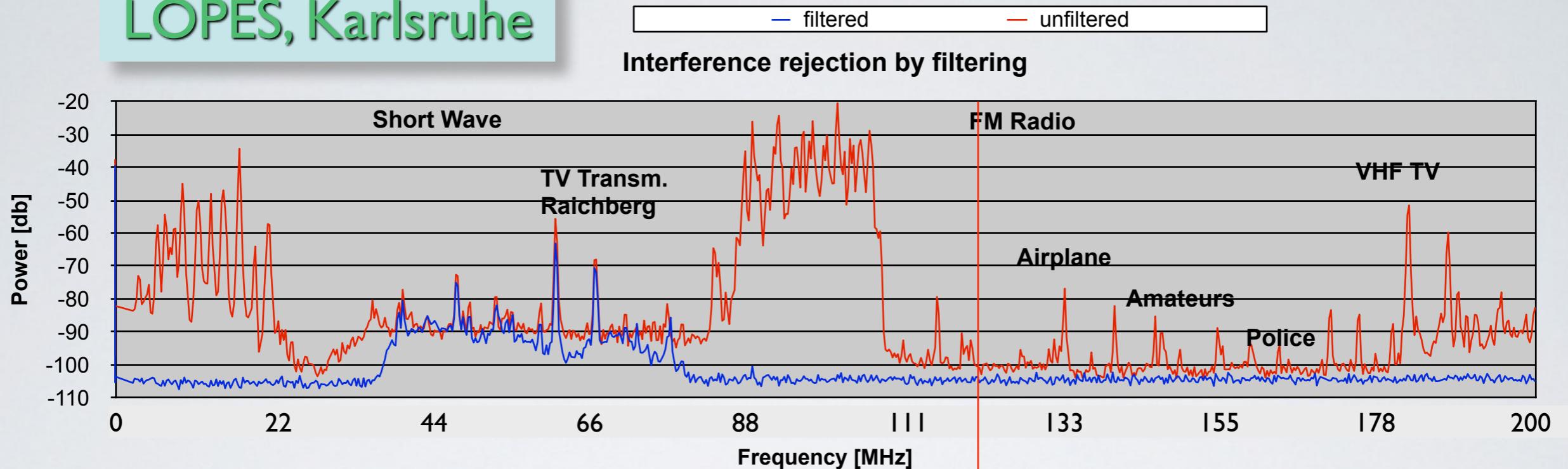
CODALEMA III



PROBLEM: RFI NOISE

LOPES, Karlsruhe

(Not the same unit)

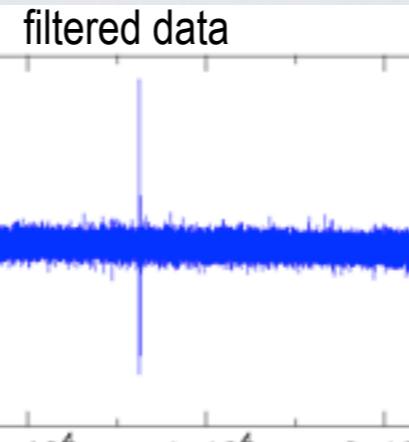
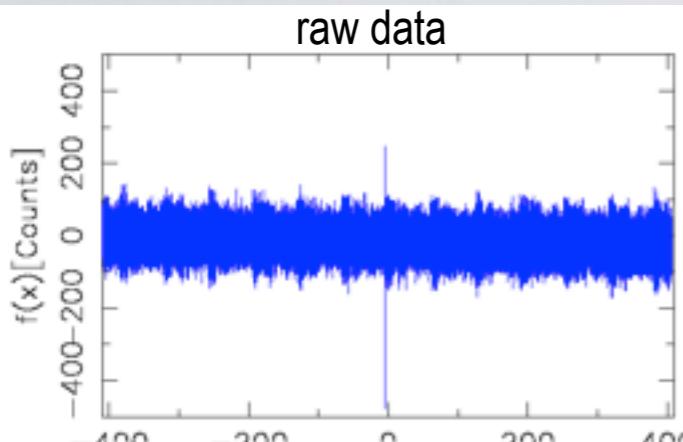


CODALEMA,
Nançay

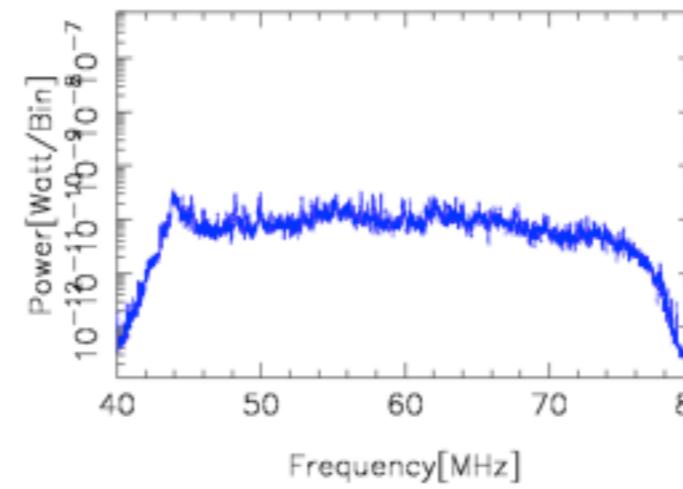
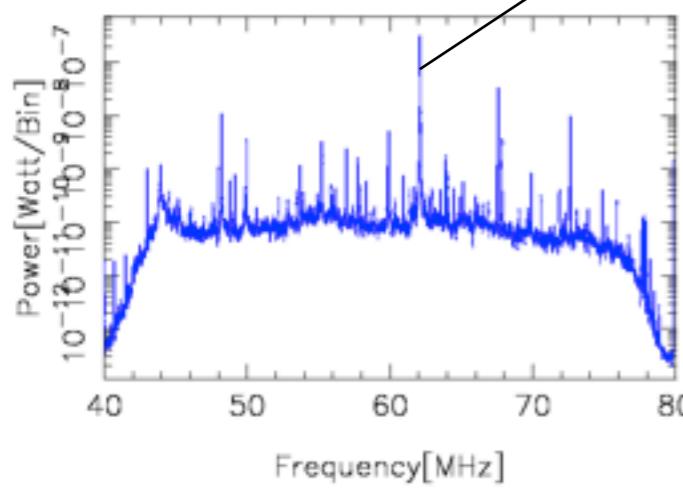
Wide band
recording is
possible

LOPES WAVEFORM PROCESSING PRINCIPLE

time domain



frequency domain



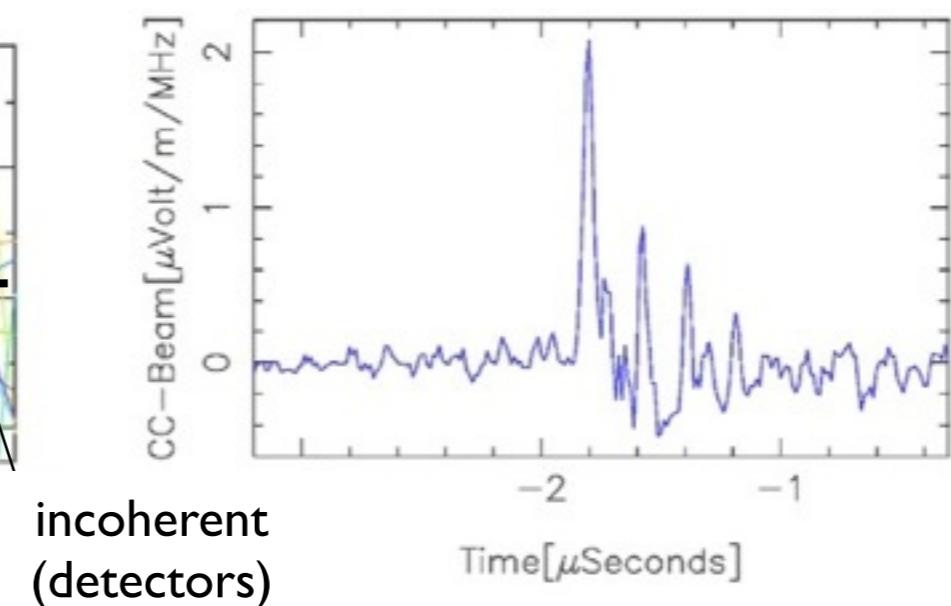
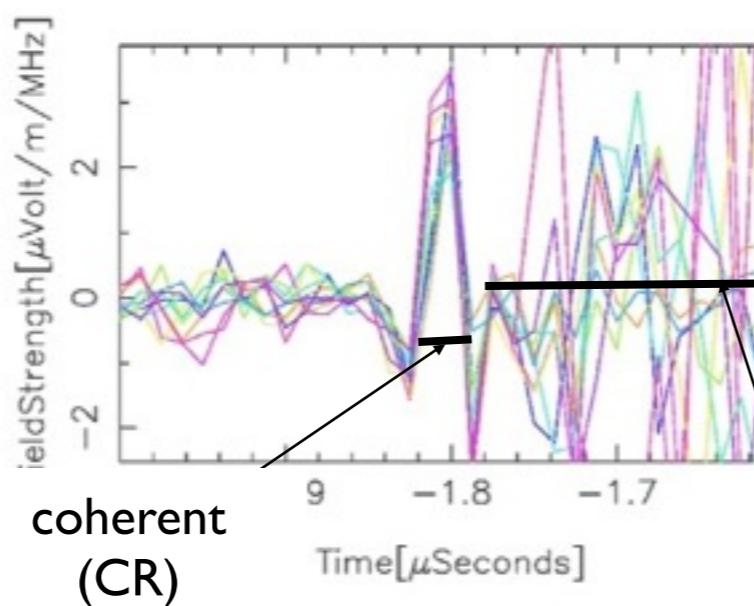
Very noisy environment + low sampling (80 MS/s)
⇒ Narrow band

← RFI suppression

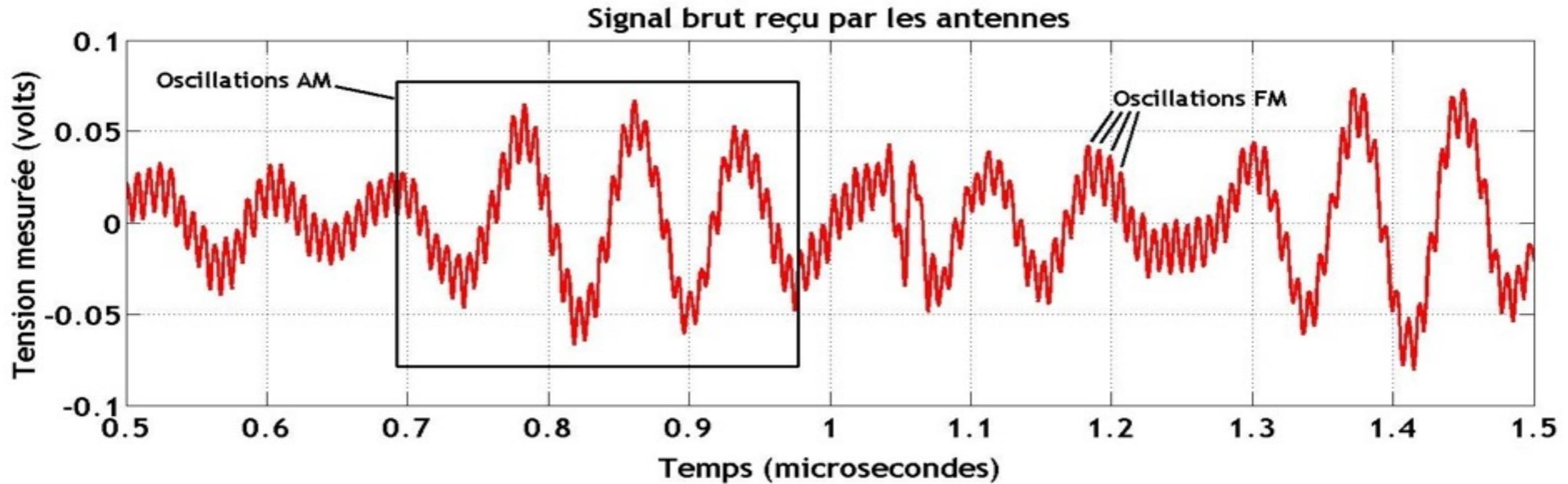
Sum of delay-corrected E-field from all antennas, squared

Electric field at each antenna corrected for arrival direction of CR with the help of KASCADE data

⇒ Time scaling (beam forming)

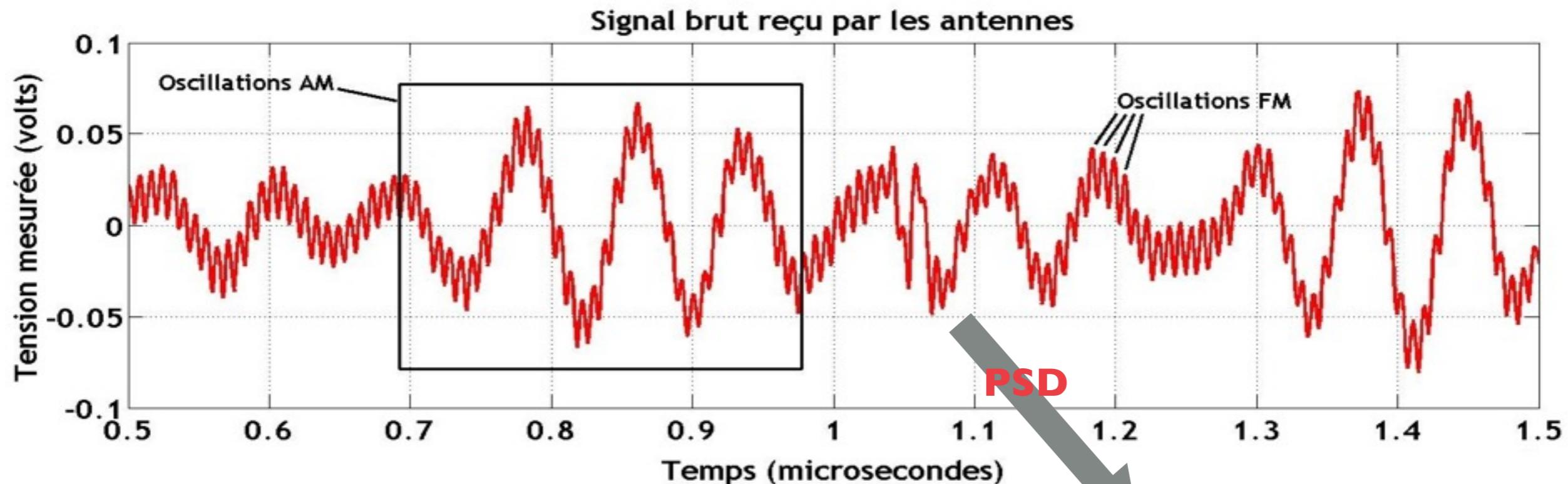


CODALEMA-2 WAVEFORM PROCESSING PRINCIPLE

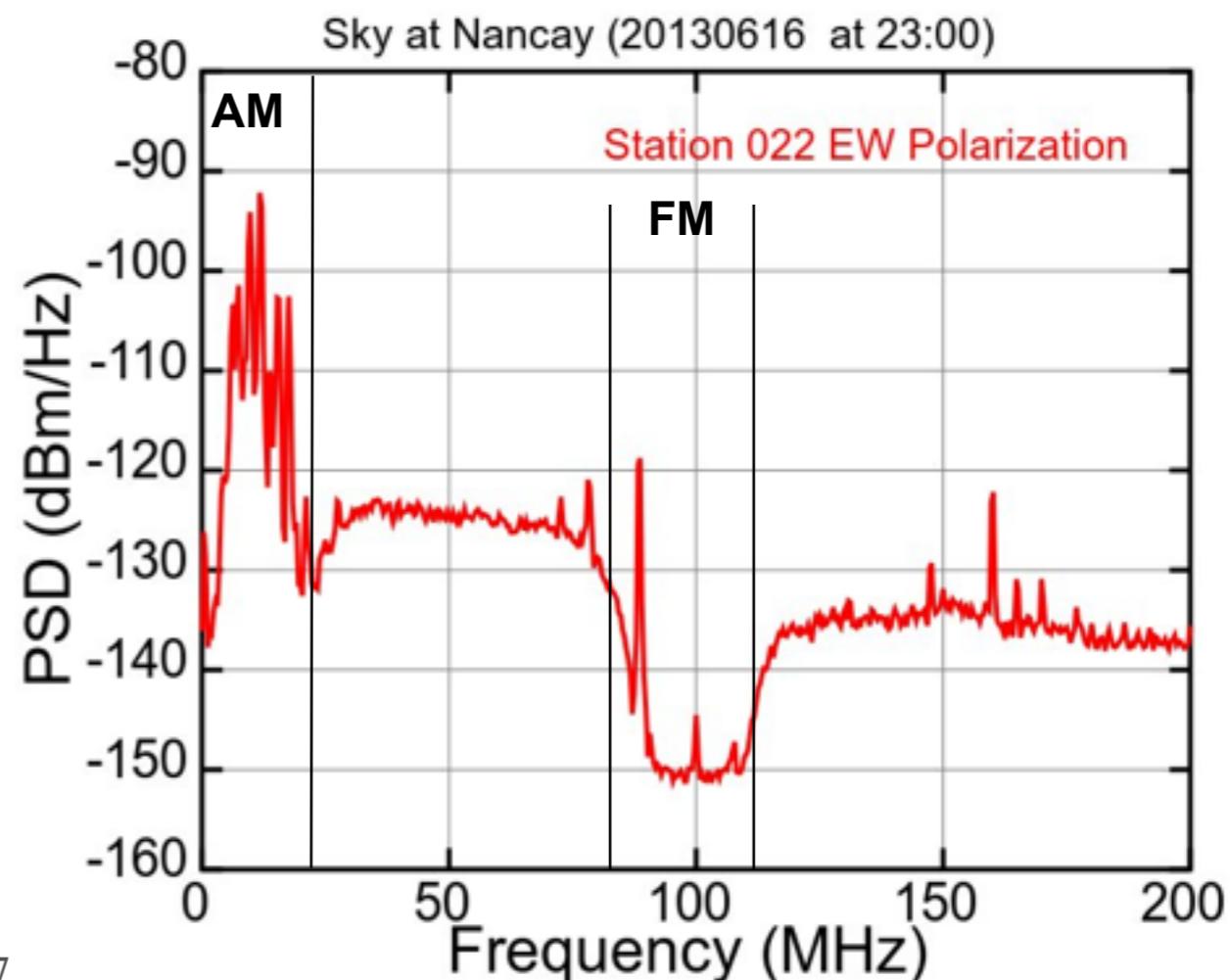


- I) Radio transmitters mask the transient

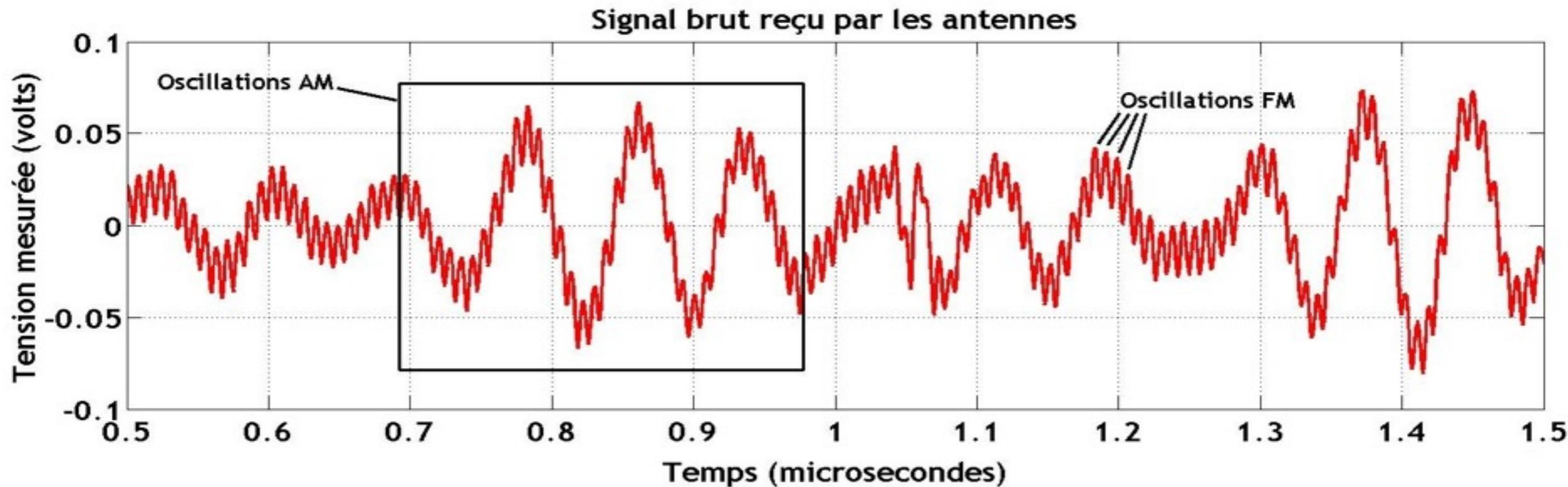
CODALEMA-2 WAVEFORM PROCESSING PRINCIPLE



I) Radio transmitters mask the transient

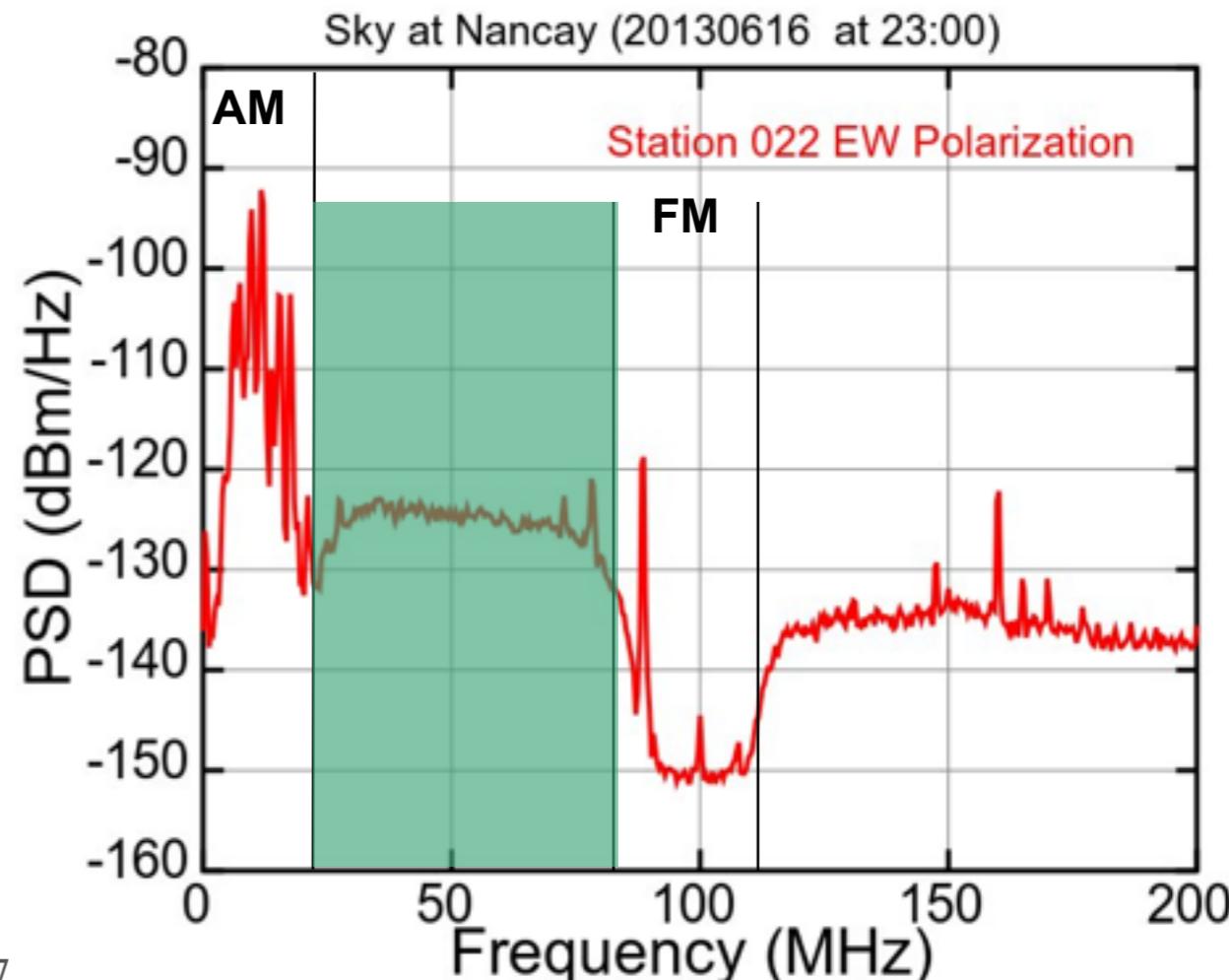


CODALEMA-2 WAVEFORM PROCESSING PRINCIPLE

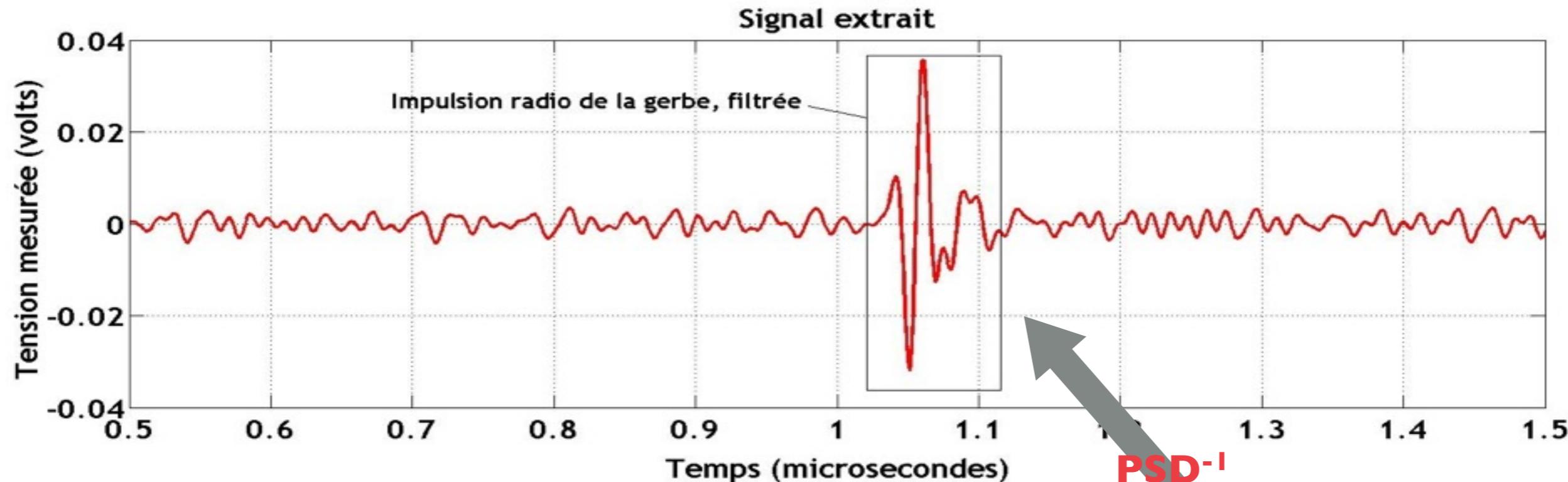


- 1) Radio transmitters mask the transient
- 2) Filtering waveform unveils the pulse and keeps its transient nature.

Typical useful band: 30-80 MHz, possibly > 150 MHz.
Inherent presence of strong AM and FM narrow band emitters → An FM stop band filter is inserted after the LNA.

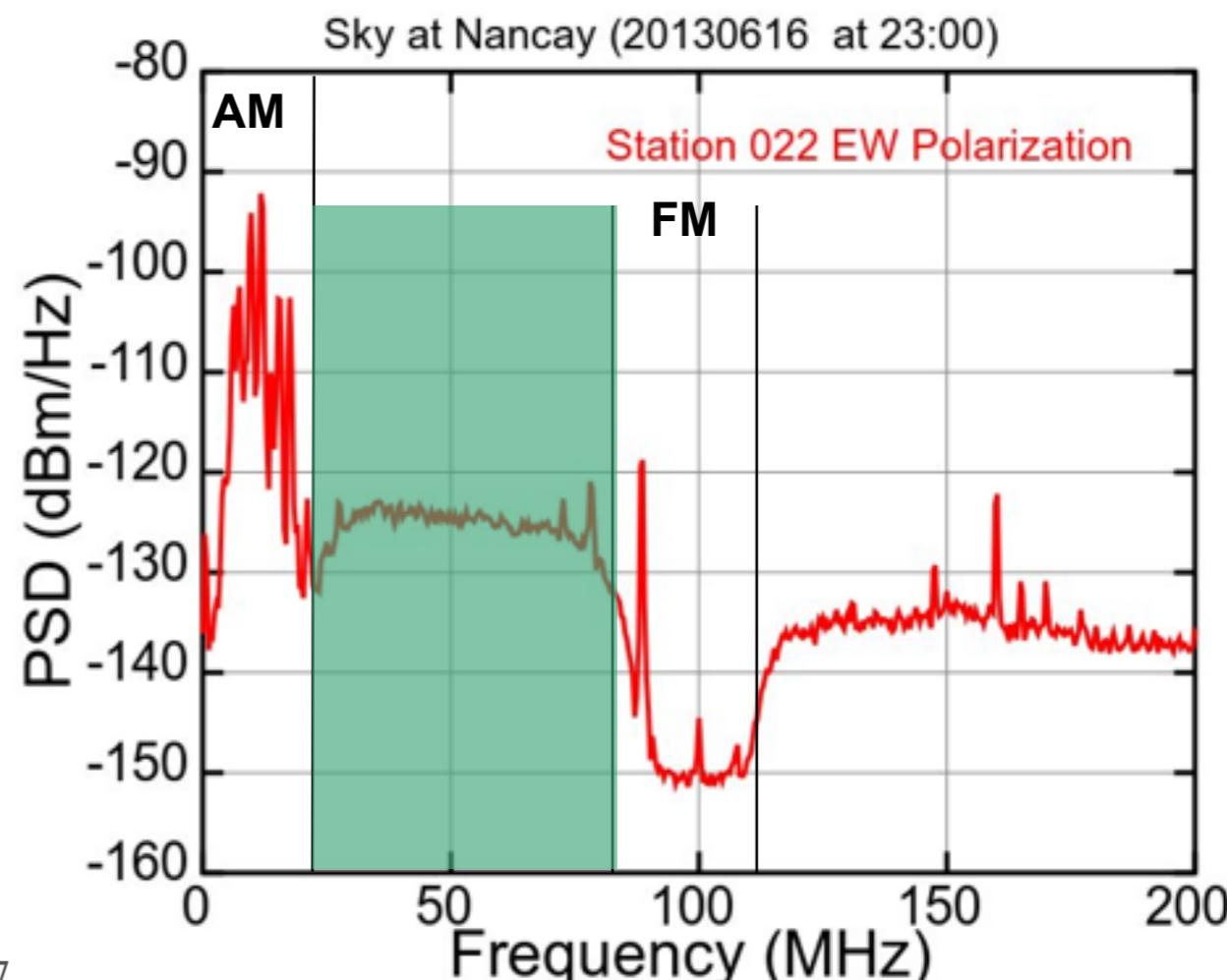


CODALEMA-2 WAVEFORM PROCESSING PRINCIPLE

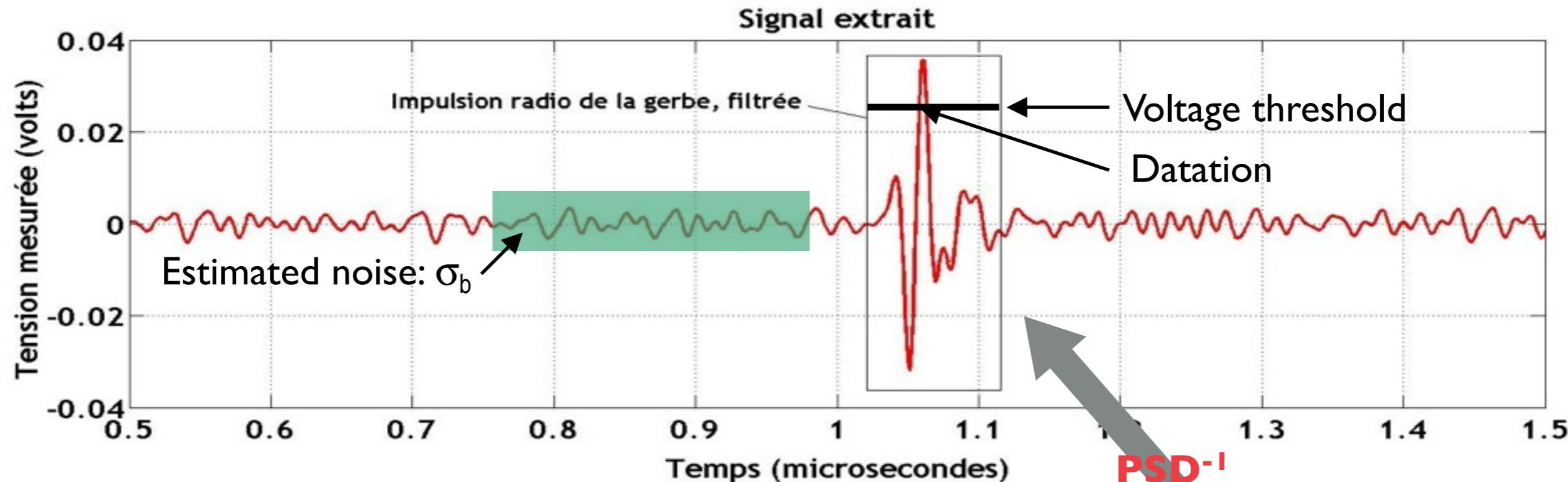


- 1) Radio transmitters mask the transient
- 2) Filtering waveform unveils the pulse and keeps its transient nature.

Typical useful band: 30-80 MHz, possibly > 150 MHz.
Inherent presence of strong AM and FM narrow band emitters → An FM stop band filter is inserted after the LNA.

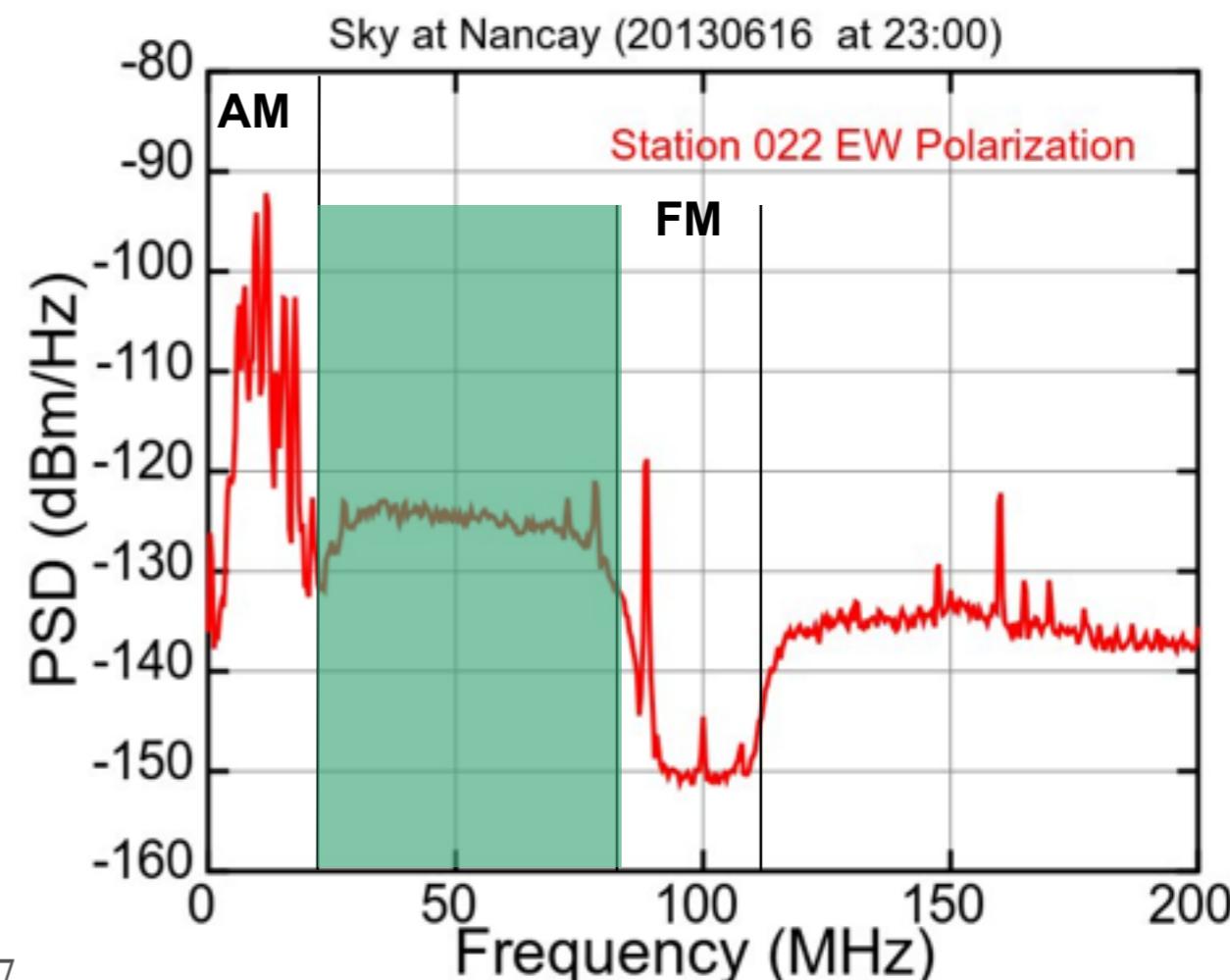


CODALEMA-2 WAVEFORM PROCESSING PRINCIPLE

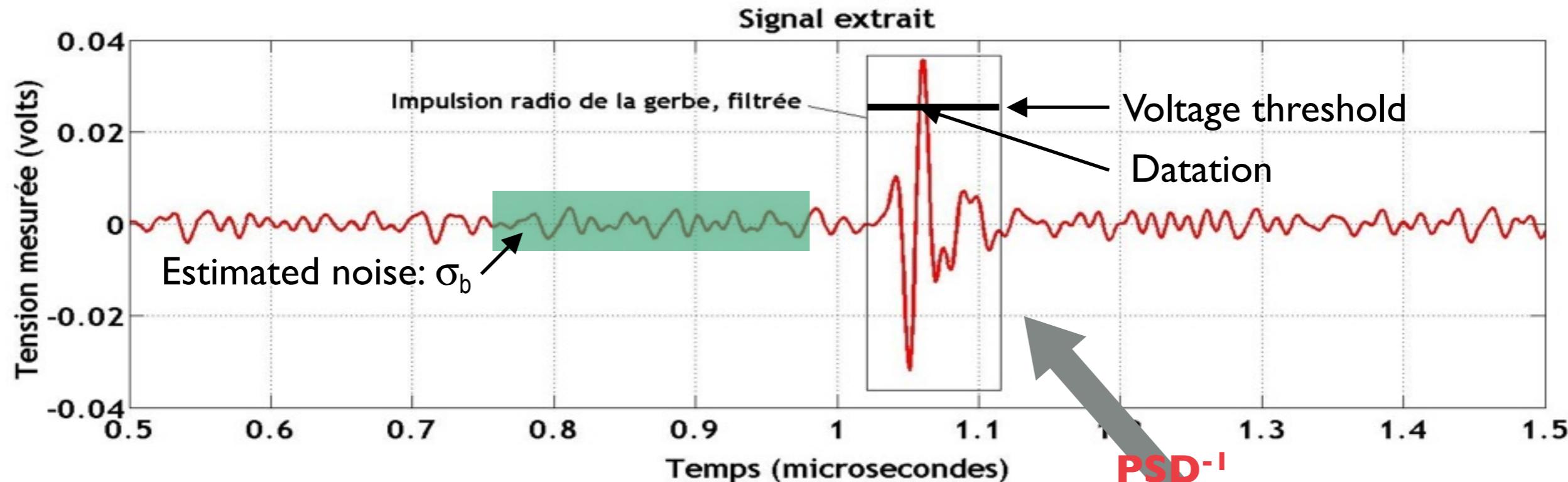


- 1) Radio transmitters mask the transient
- 2) Filtering waveform unveils the pulse and keeps its transient nature.
- 3) Applying a threshold depending on noise = triggering and datation

Typical useful band: 30-80 MHz, possibly > 150 MHz.
Inherent presence of strong AM and FM narrow band emitters → An FM stop band filter is inserted after the LNA.



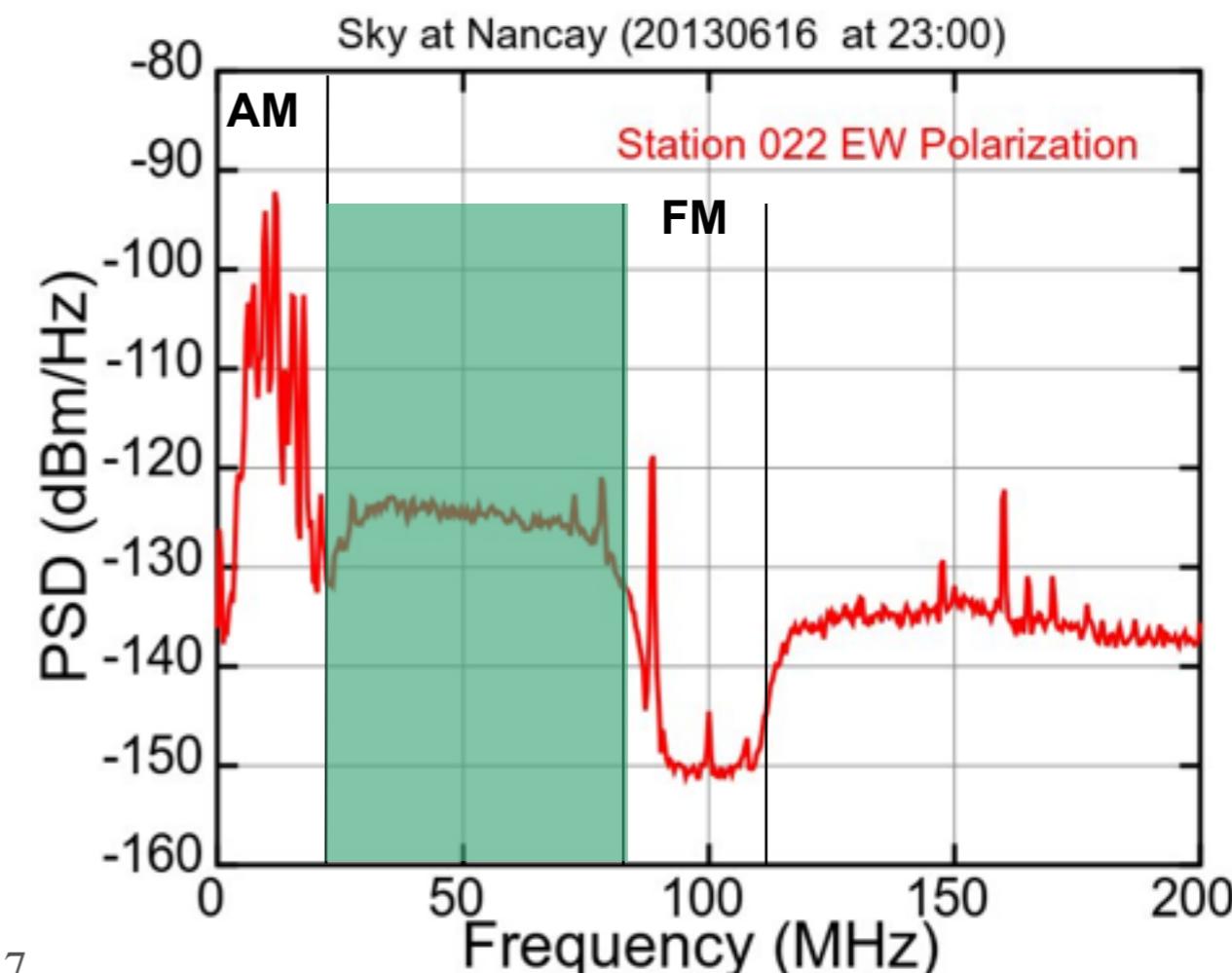
CODALEMA-2 WAVEFORM PROCESSING PRINCIPLE



- 1) Radio transmitters mask the transient
- 2) Filtering waveform unveils the pulse and keeps its transient nature.
- 3) Applying a threshold depending on noise = triggering and datation

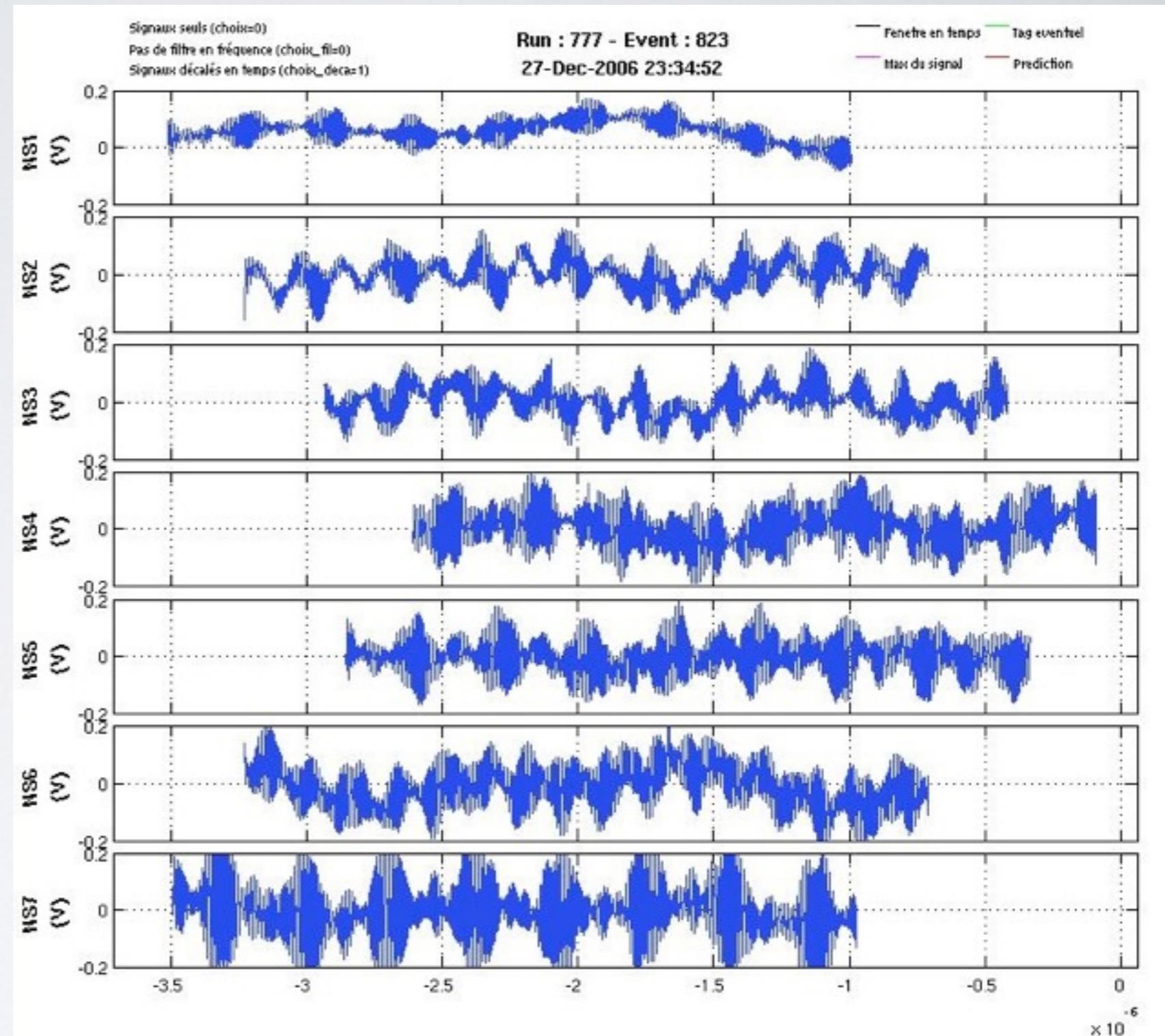
Method applied online and/or offline

Typical useful band: 30-80 MHz, possibly > 150 MHz.
Inherent presence of strong AM and FM narrow band emitters → An FM stop band filter is inserted after the LNA.



CODALEMA-2 ILLUSTRATIVE EXAMPLE

Wide bandwidth recording
(1-250 MHz): transients
are hidden by transmitters

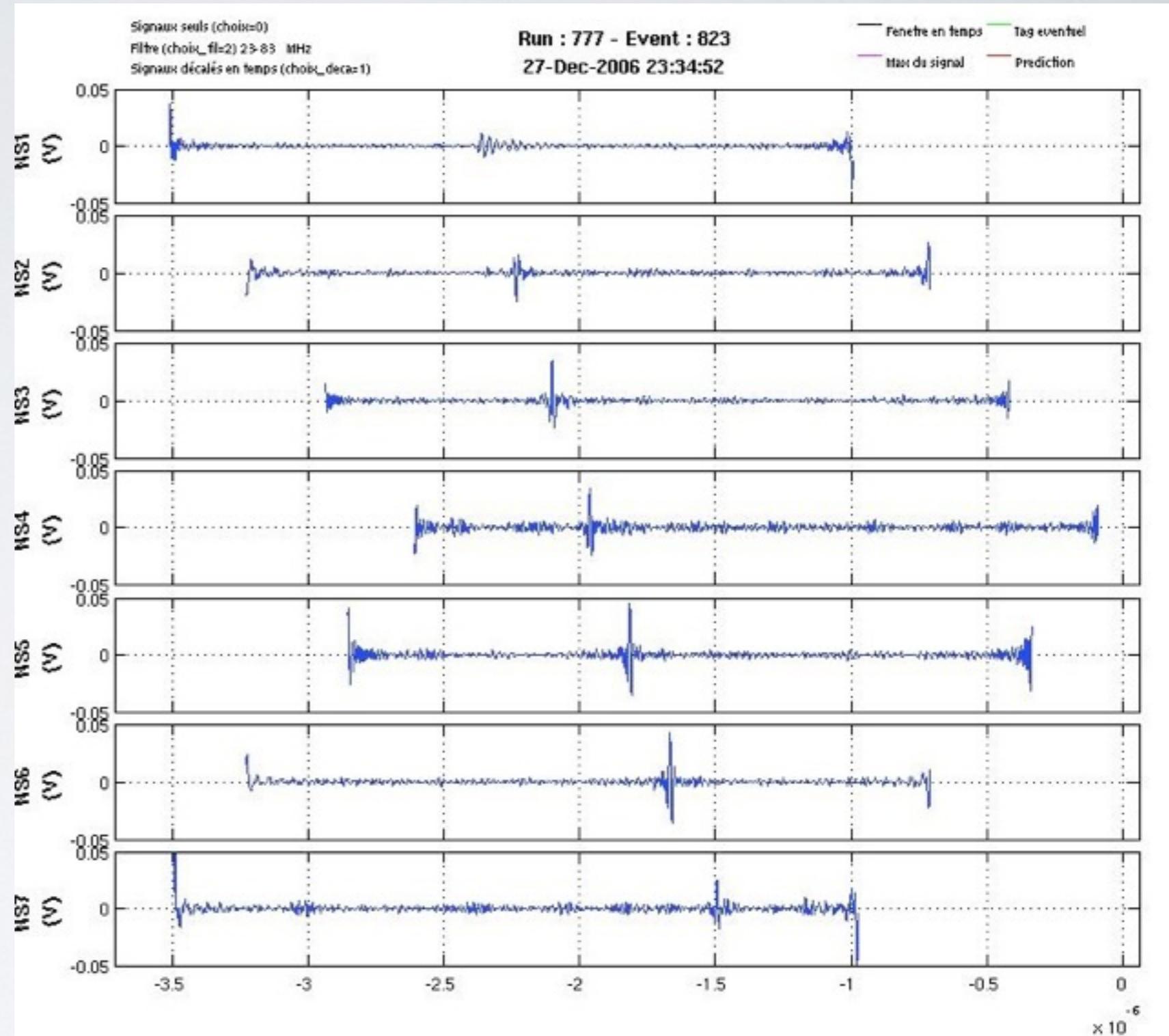


CODALEMA-2 ILLUSTRATIVE EXAMPLE

Wide bandwidth recording
(1-250 MHz): transients
are hidden by transmitters



Narrow band filtering
(here 23-83 MHz)

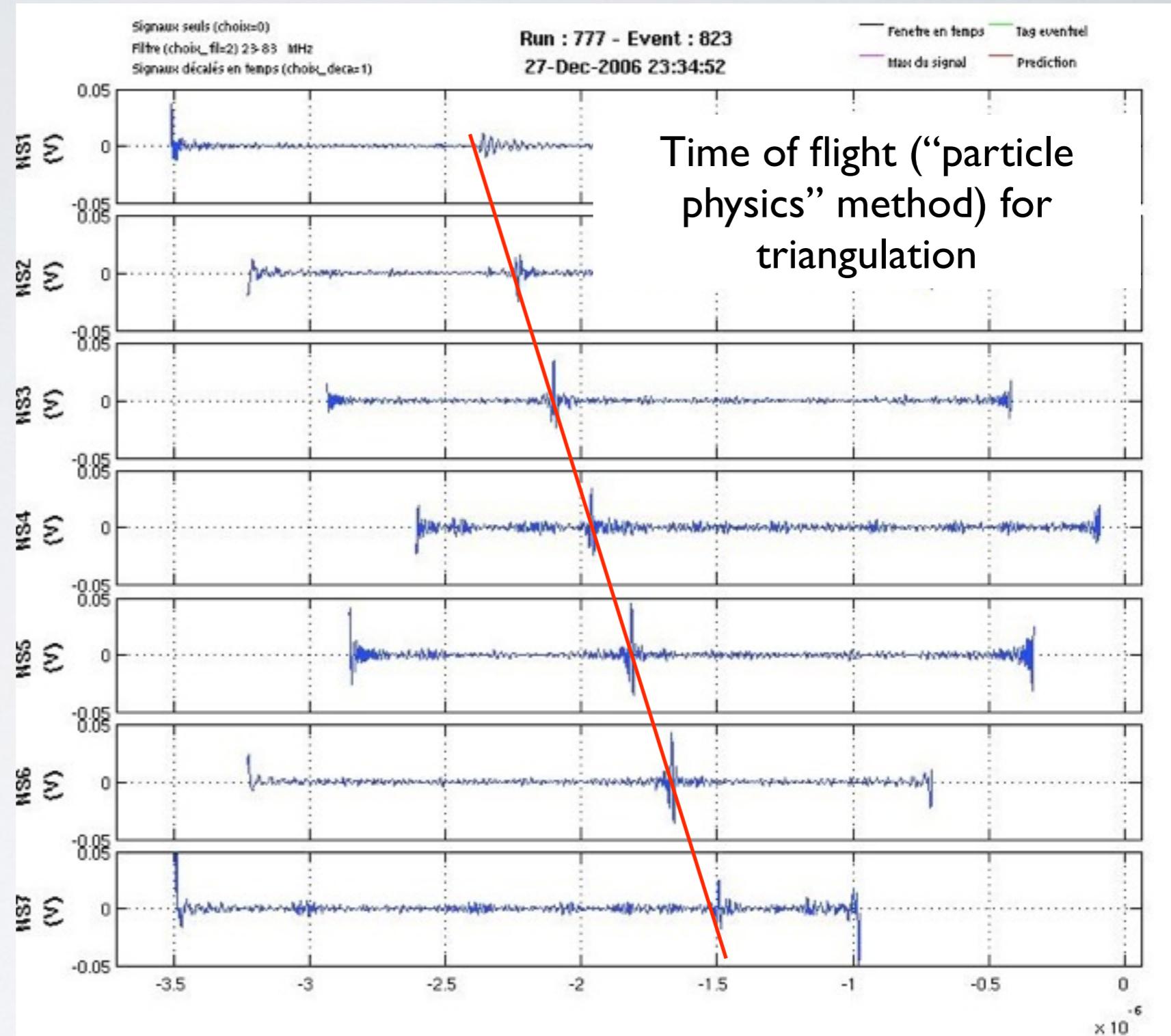


CODALEMA-2 ILLUSTRATIVE EXAMPLE

Wide bandwidth recording
(1-250 MHz): transients
are hidden by transmitters



Narrow band filtering
(here 23-83 MHz)



CODALEMA-2 ILLUSTRATIVE EXAMPLE

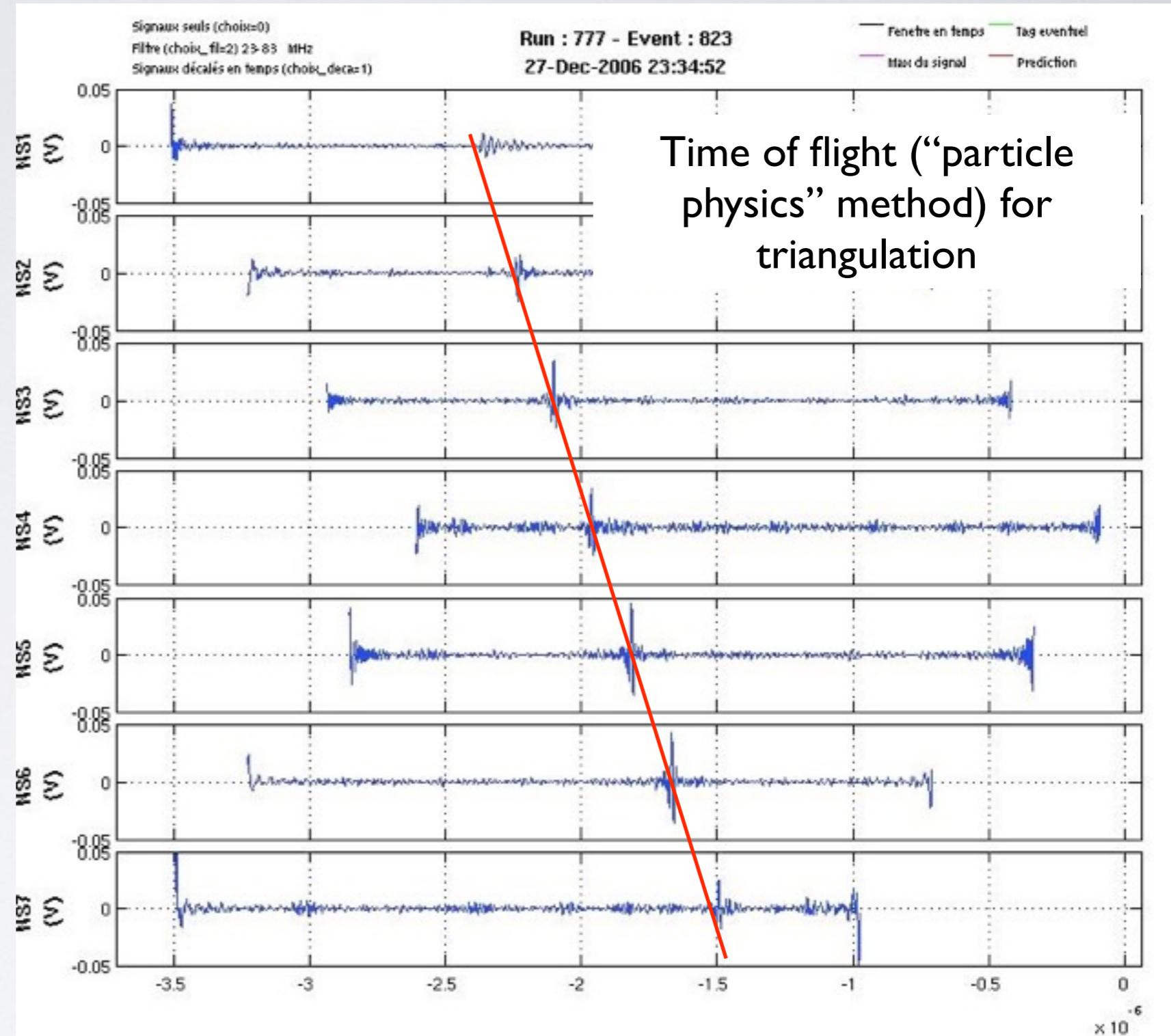
Wide bandwidth recording
(1-250 MHz): transients
are hidden by transmitters



Narrow band filtering
(here 23-83 MHz)

Radio signal gives
independent parameters:

Direction by triangulation, core
position, shower field profile
(sampled antenna by antenna)...



CODALEMA-2 ILLUSTRATIVE EXAMPLE

Wide bandwidth recording
(1-250 MHz): transients
are hidden by transmitters



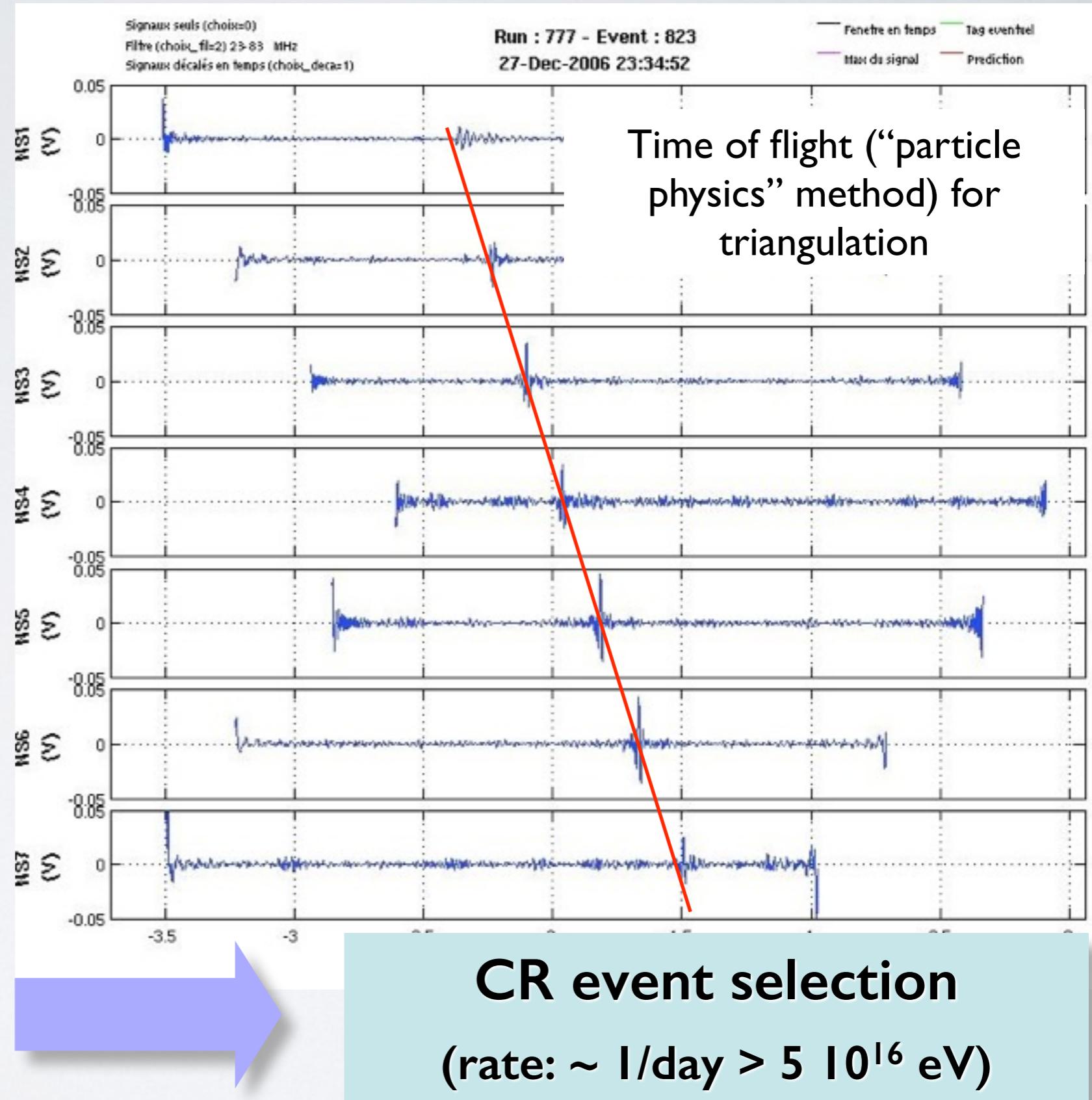
Narrow band filtering
(here 23-83 MHz)

Radio signal gives
independent parameters:

Direction by triangulation, core
position, shower field profile
(sampled antenna by antenna)...



Correlation with particles
(time, arrival direction)



CODALEMA-2 ILLUSTRATIVE EXAMPLE

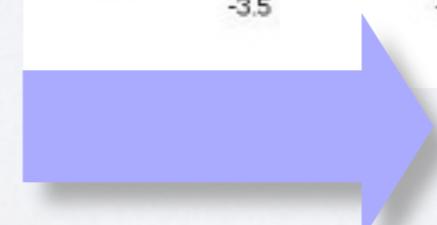
Wide bandwidth recording
(1-250 MHz): transients
are hidden by transmitters



This is not a continuous,
but a triggered
observation (“snapshots”
of few μ s)

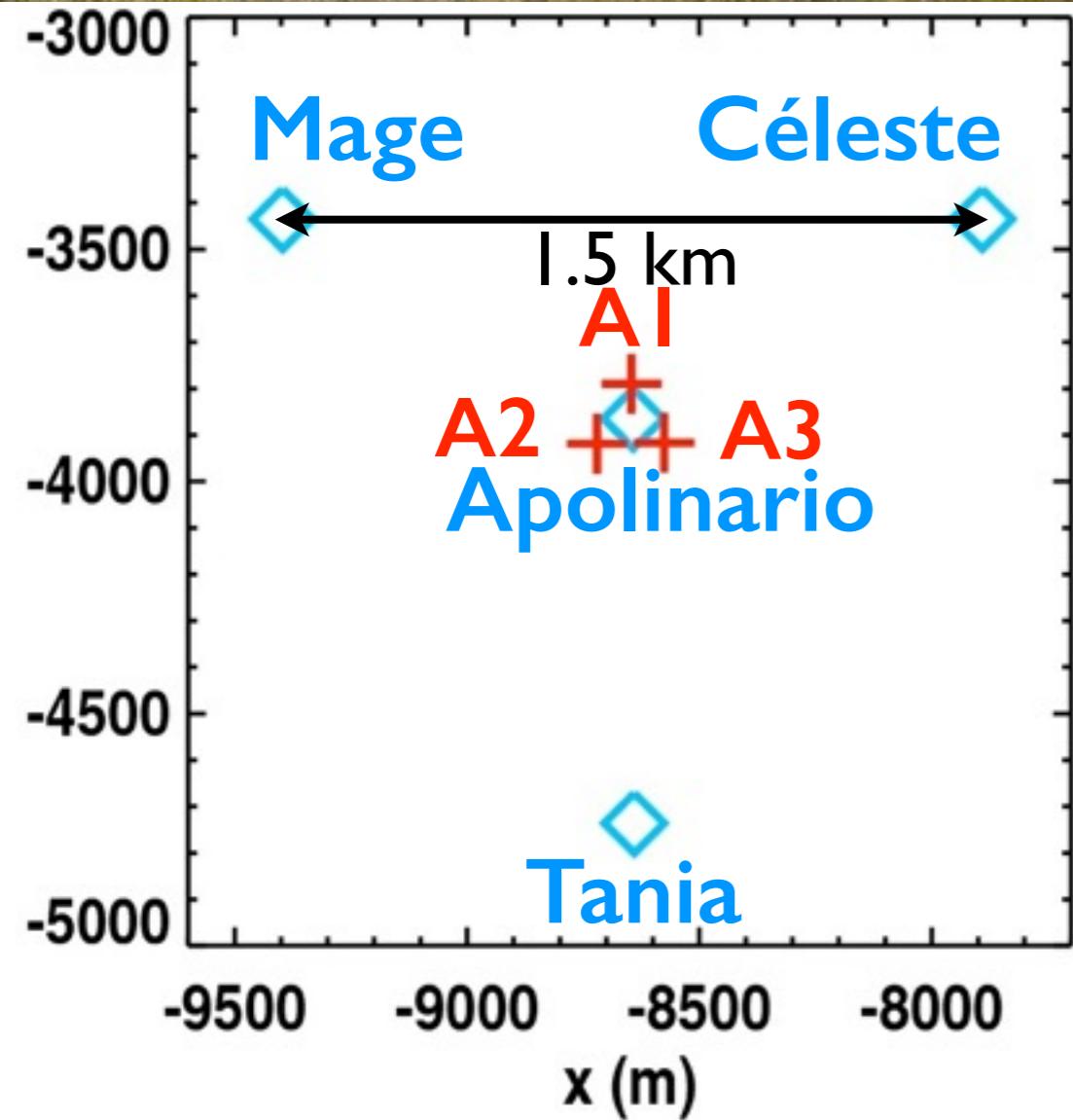
Narrow band
(here 23-83 MHz)
Radio signals
independently
Direction by
position, shown
(sampled antenna)

Correlation with particles
(time, arrival direction)

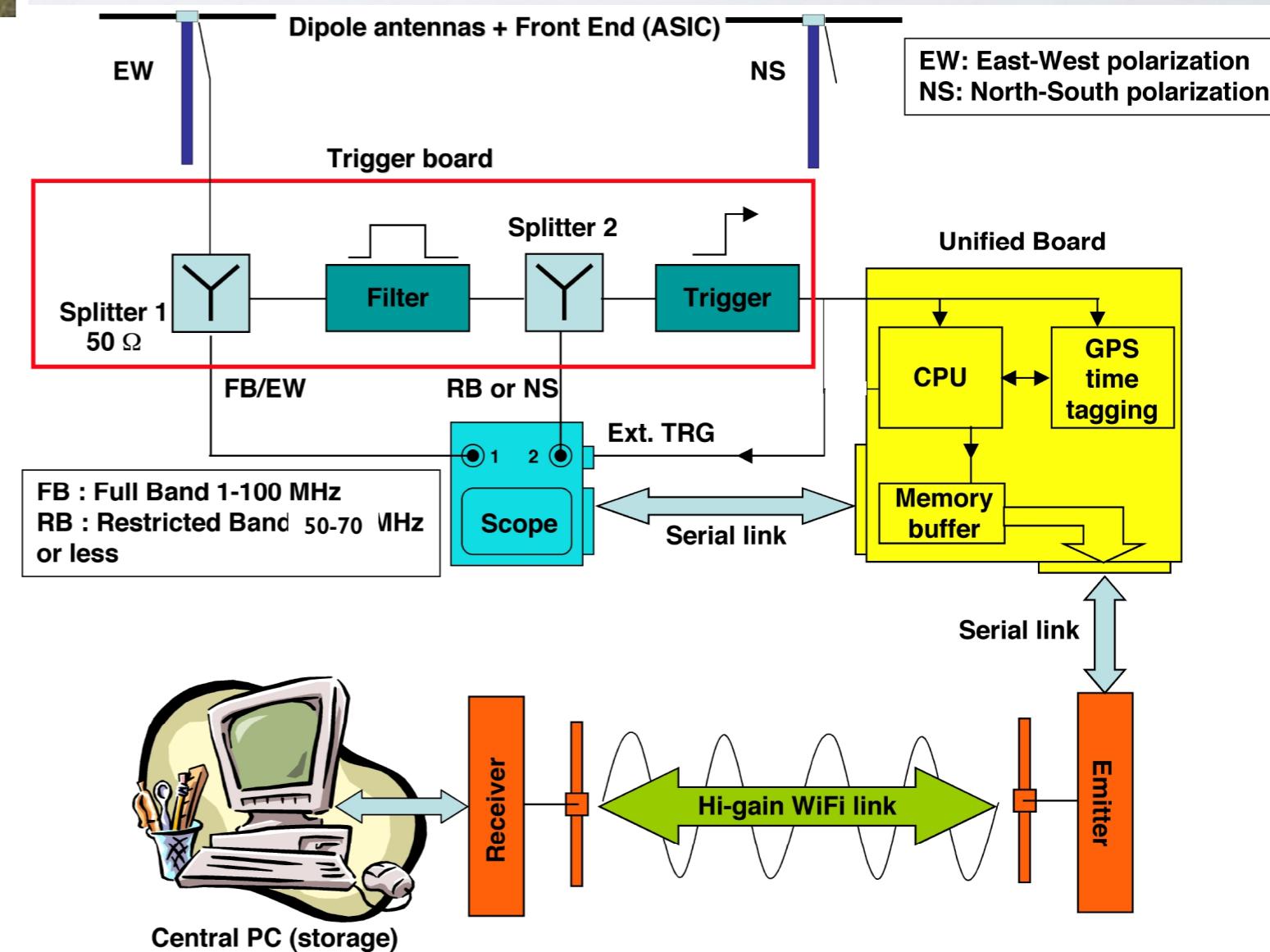


CR event selection
(rate: $\sim 1/\text{day} > 5 \cdot 10^{16} \text{ eV}$)

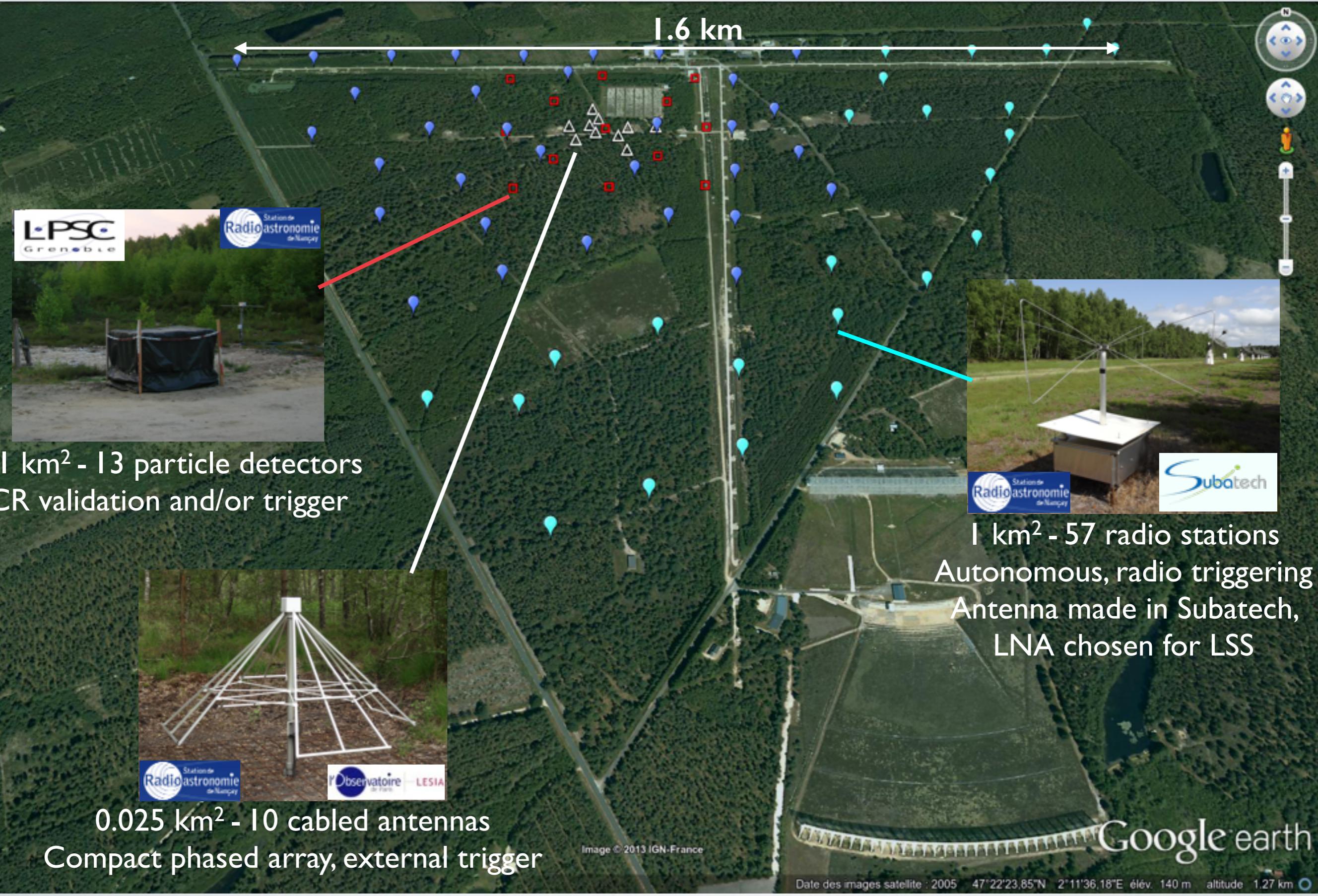
RAUGER-I : 2006-2010 (AUGER)



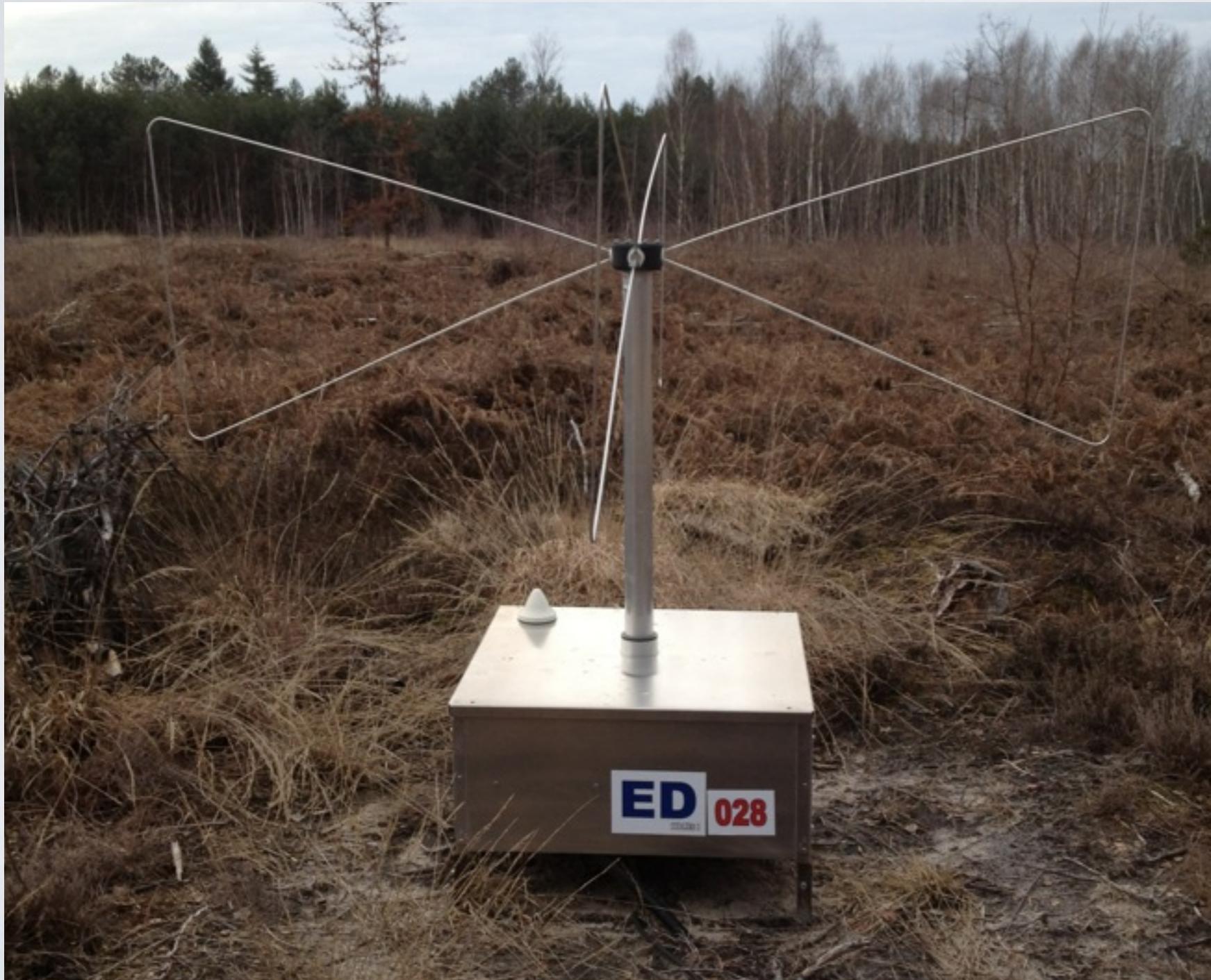
- 3 autonomous stations of 2 CODALEMA dipolar antennas (EW and NS polarizations)
- Trigger with a simple threshold in the 50-70 MHz band, EW polarization (analogic filter)
- Send the data by wifi to a distant PC



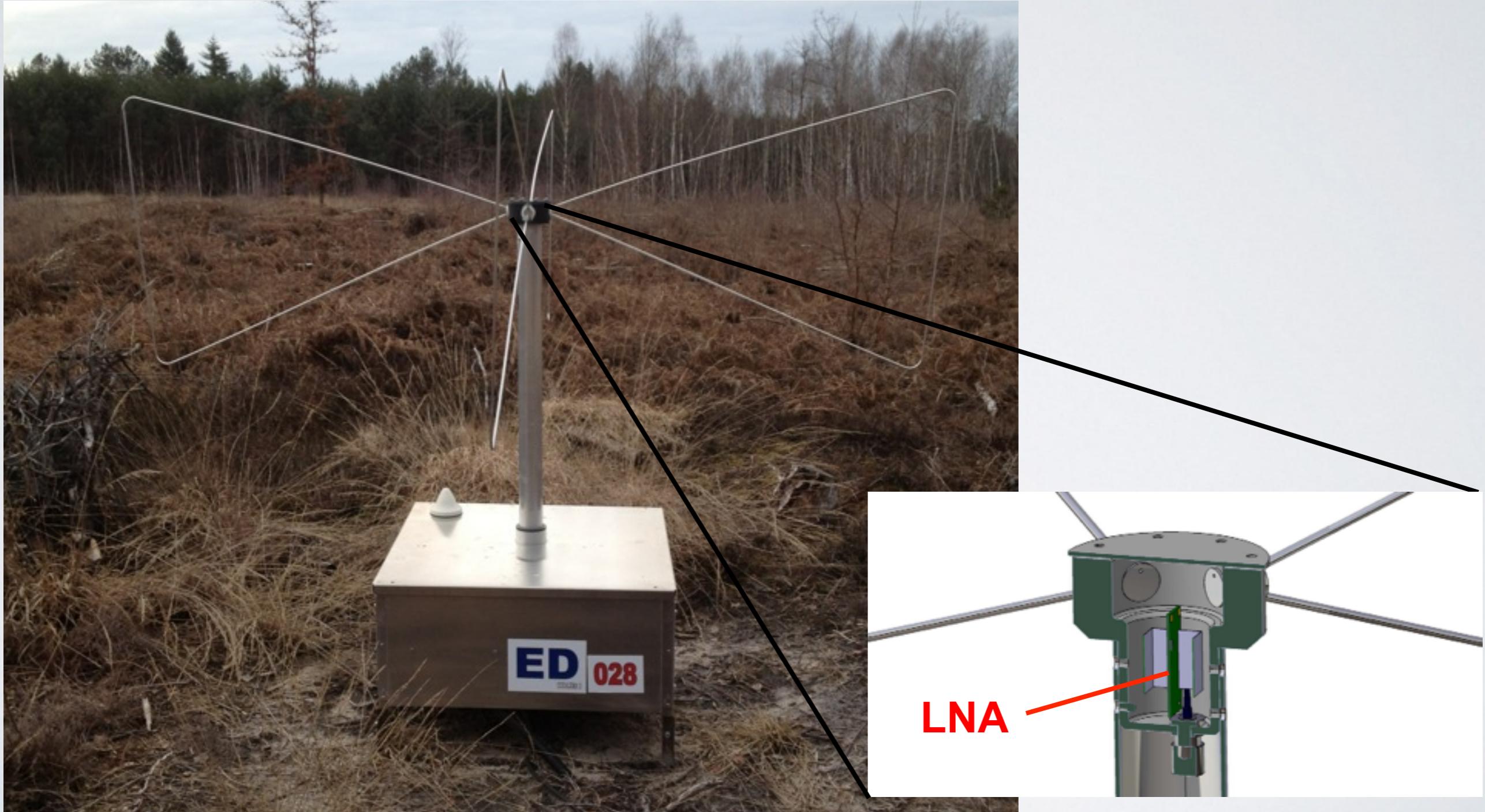
CODALEMA-3 (2010 - 2013 - ...)



LAST GENERATION OF SENSORS: THE BUTTERFLY ANTENNA

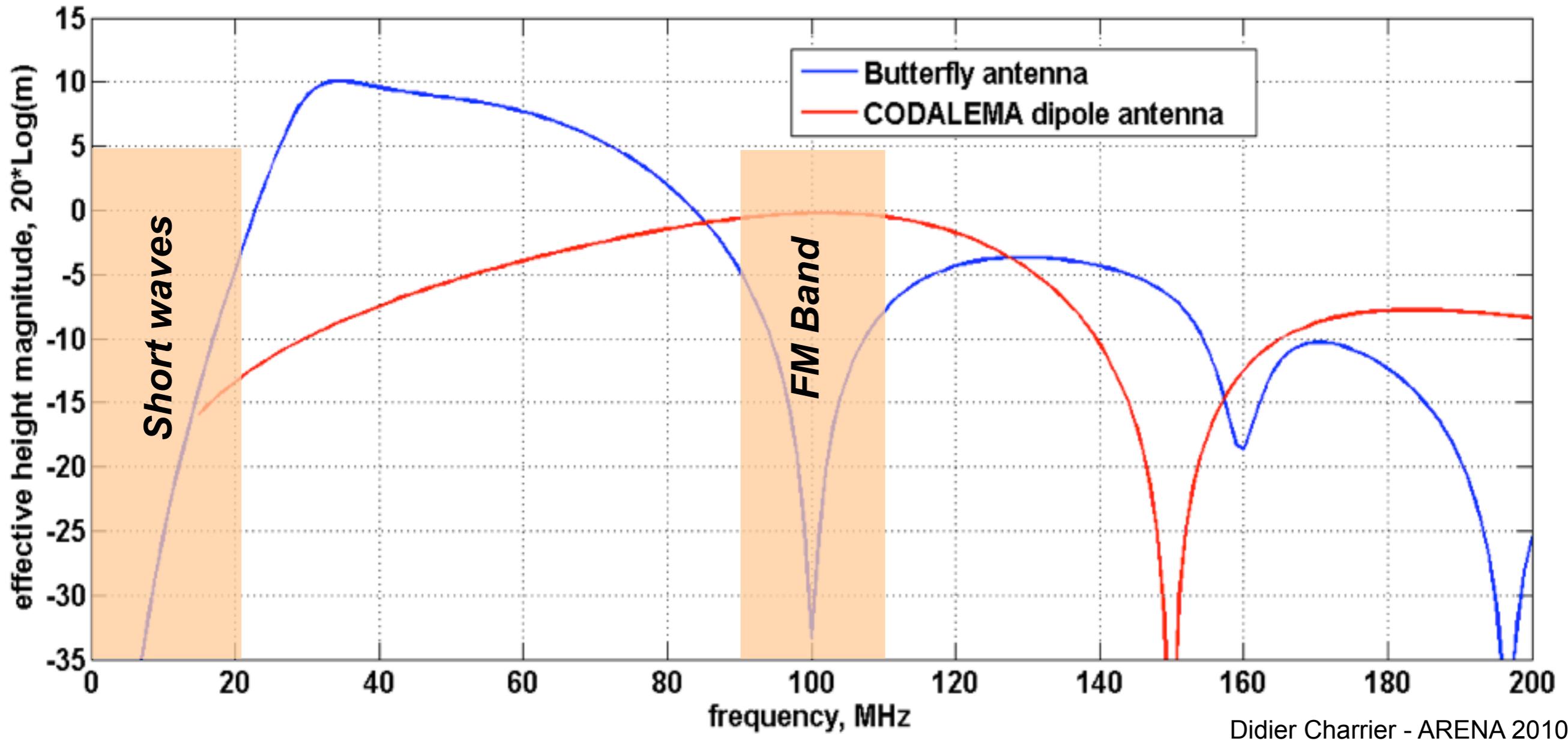


LAST GENERATION OF SENSORS: THE BUTTERFLY ANTENNA



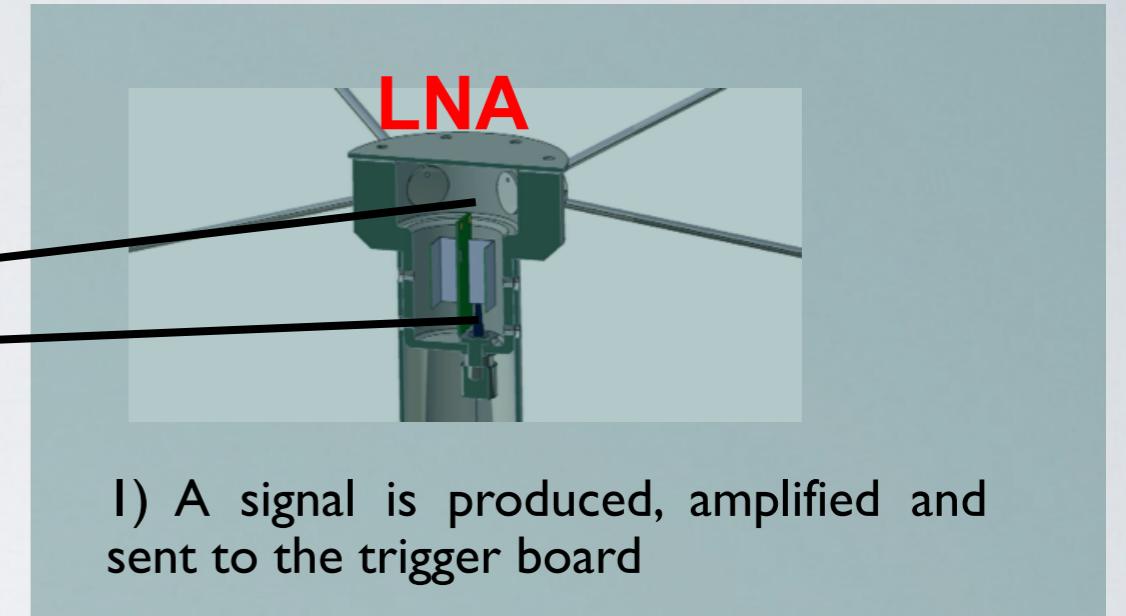
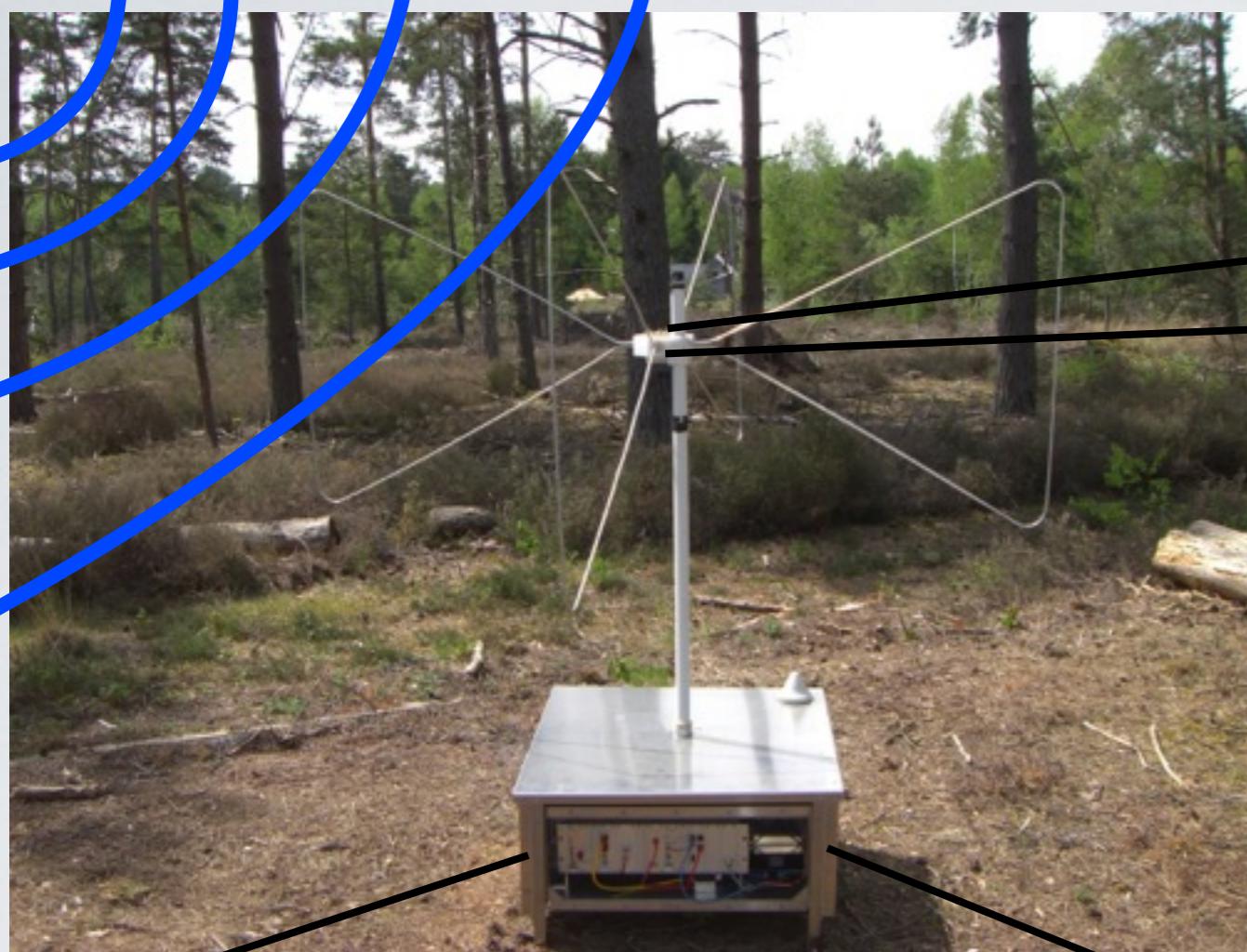
THE BUTTERFLY ANTENNA

$20 \cdot \log_{10}(\text{Abs}(V_{lna}/E))$, for $\theta=0^\circ$ (zenith)

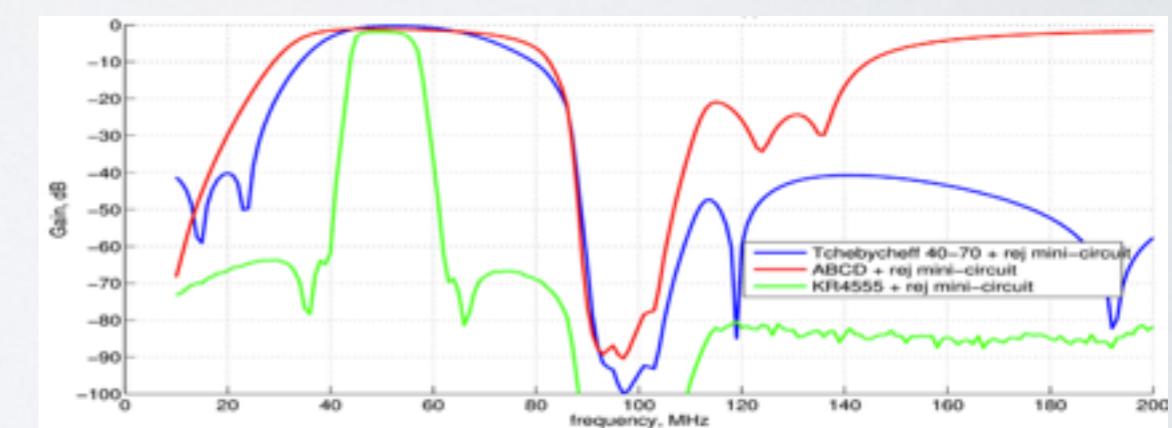


- The radio background can't be used at DC-20MHz and 88-108MHz band
- Cosmic rays detection is supposed to be better with low frequencies
⇒ Frequency range of the butterfly is maximized for the 25-90MHz band
- Butterfly sensitivity is much better for this frequency range

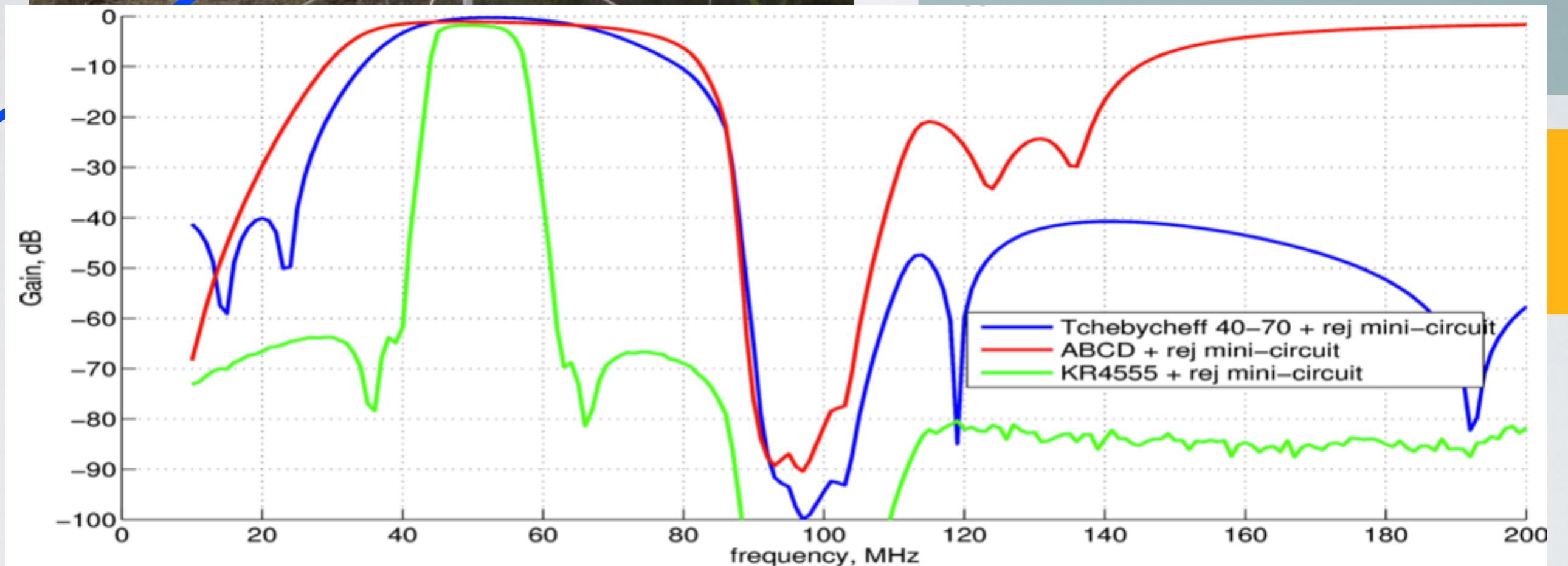
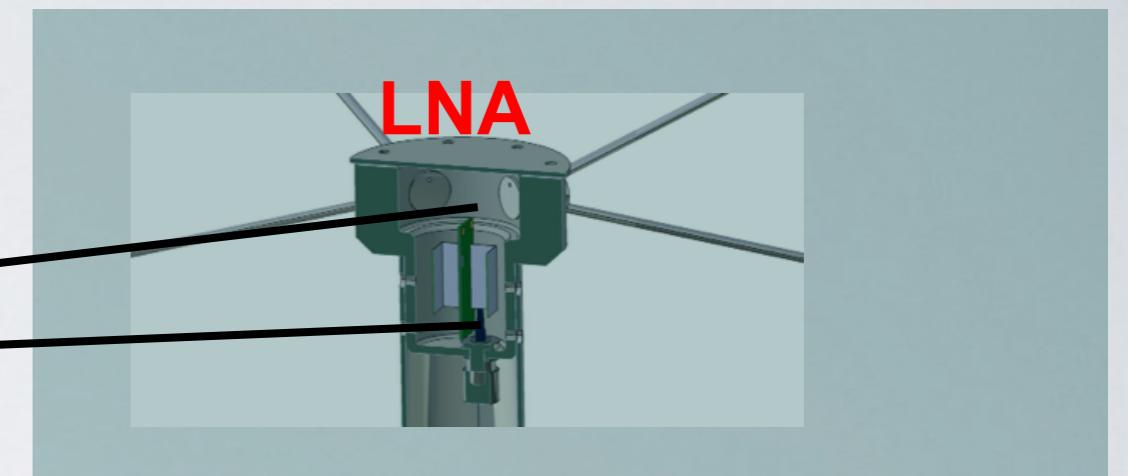
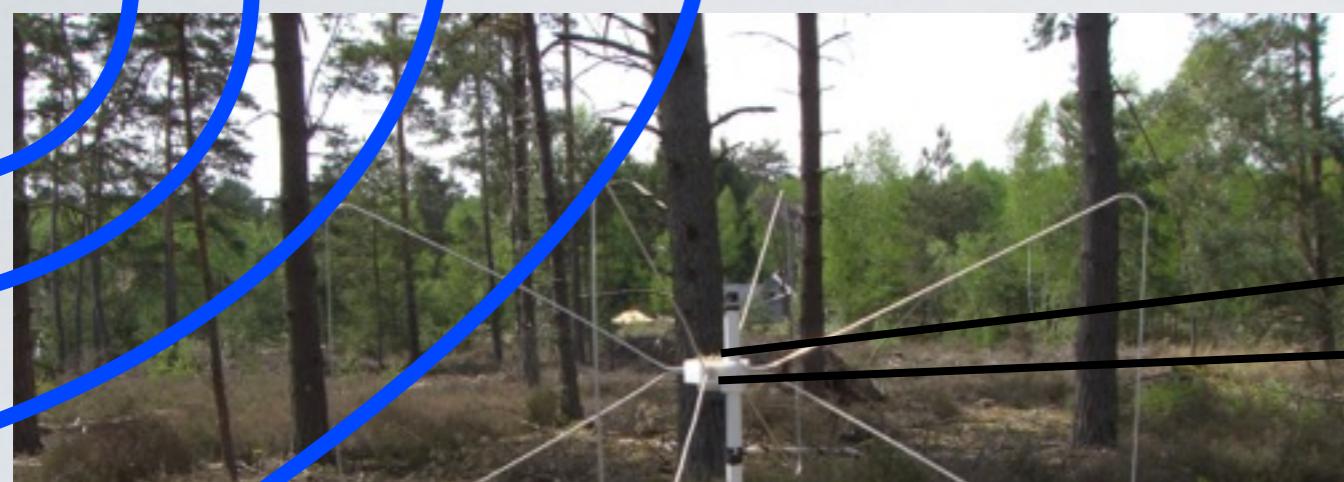
HOW DOES AN AUTONOMOUS STATION WORK ?



I) A signal is produced, amplified and sent to the trigger board



HOW DOES AN AUTONOMOUS STATION WORK ?



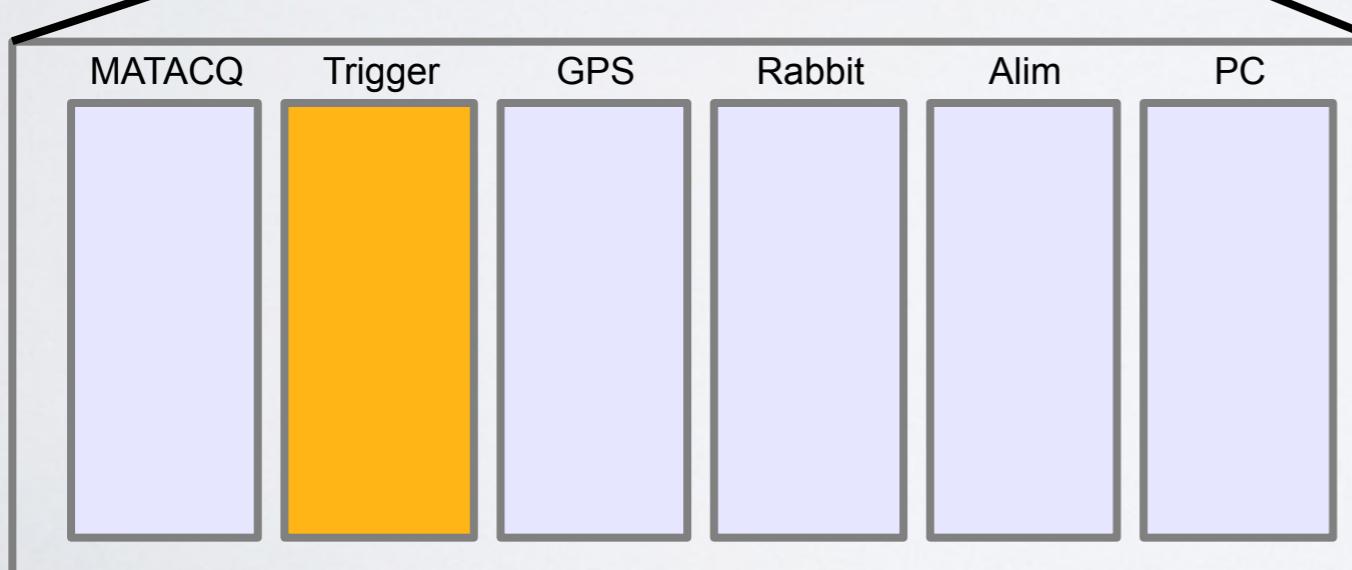
HOW DOES AN AUTONOMOUS STATION WORK ?



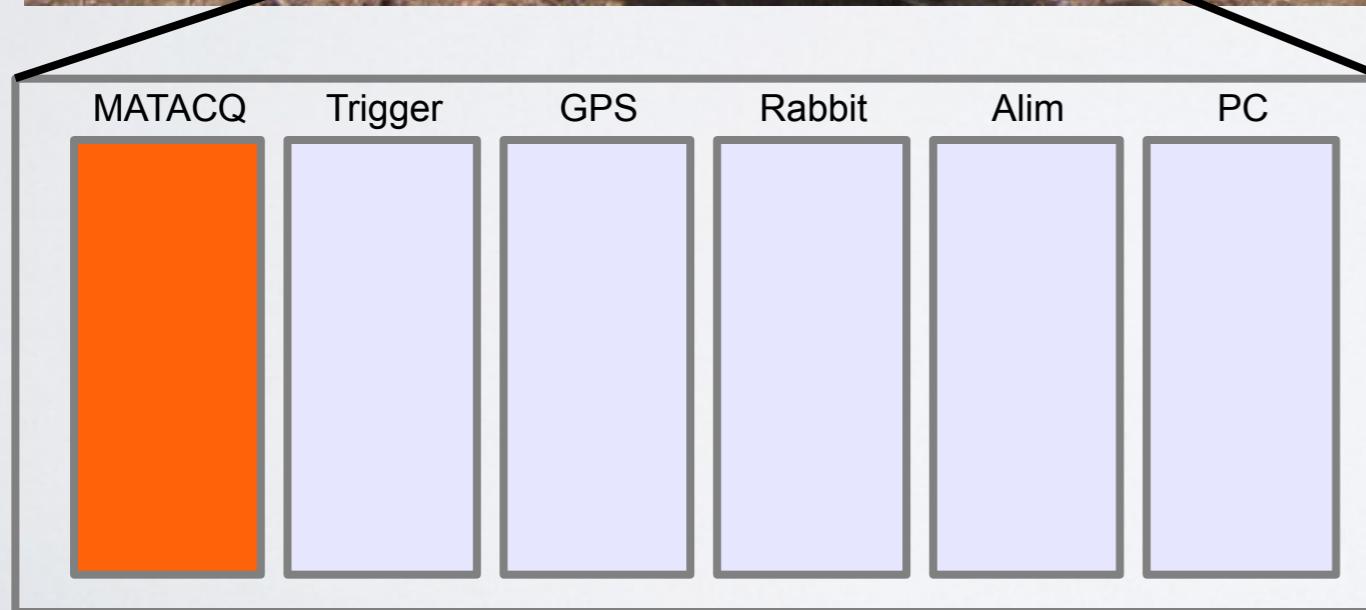
LNA

1) A signal is produced, amplified and sent to the trigger board

2) This analog signal is filtered in the trigger frequency band and is compared to a threshold value. If the signal $>$ threshold \rightarrow data acquisition starts



HOW DOES AN AUTONOMOUS STATION WORK ?

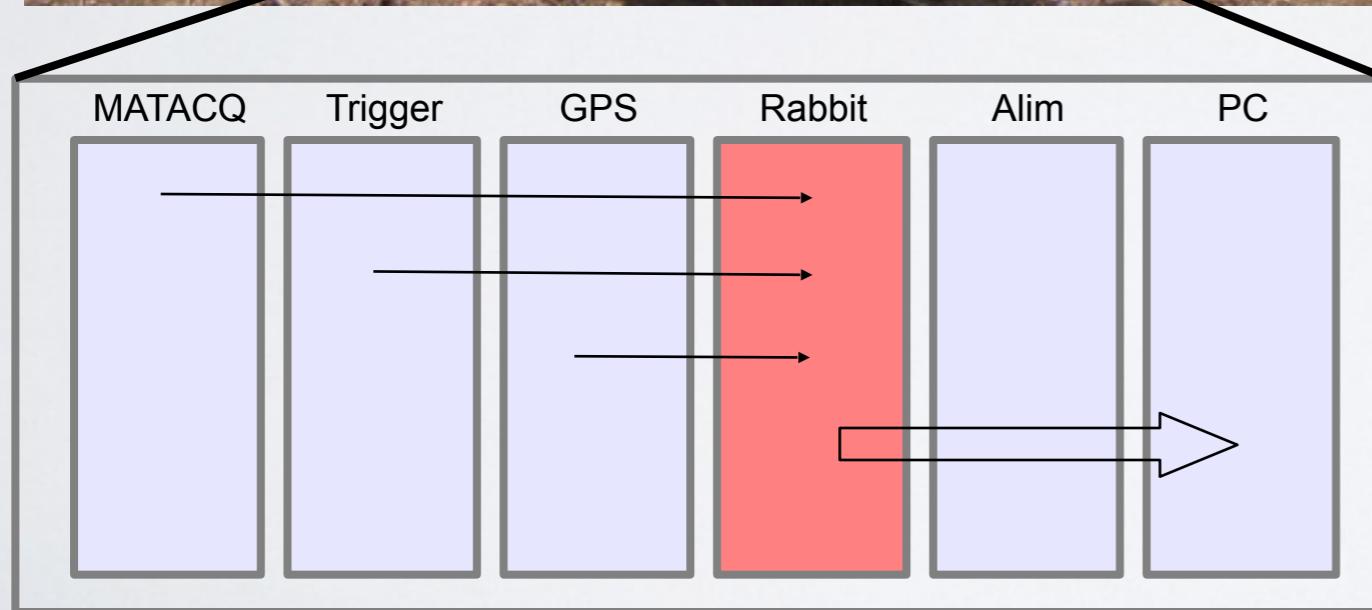


1) A signal is produced, amplified and sent to the trigger board

2) This analog signal is filtered in the trigger frequency band and is compared to a threshold value. If the signal > threshold → data acquisition starts

3) The signal is digitized (1 GS/s)

HOW DOES AN AUTONOMOUS STATION WORK ?



LNA

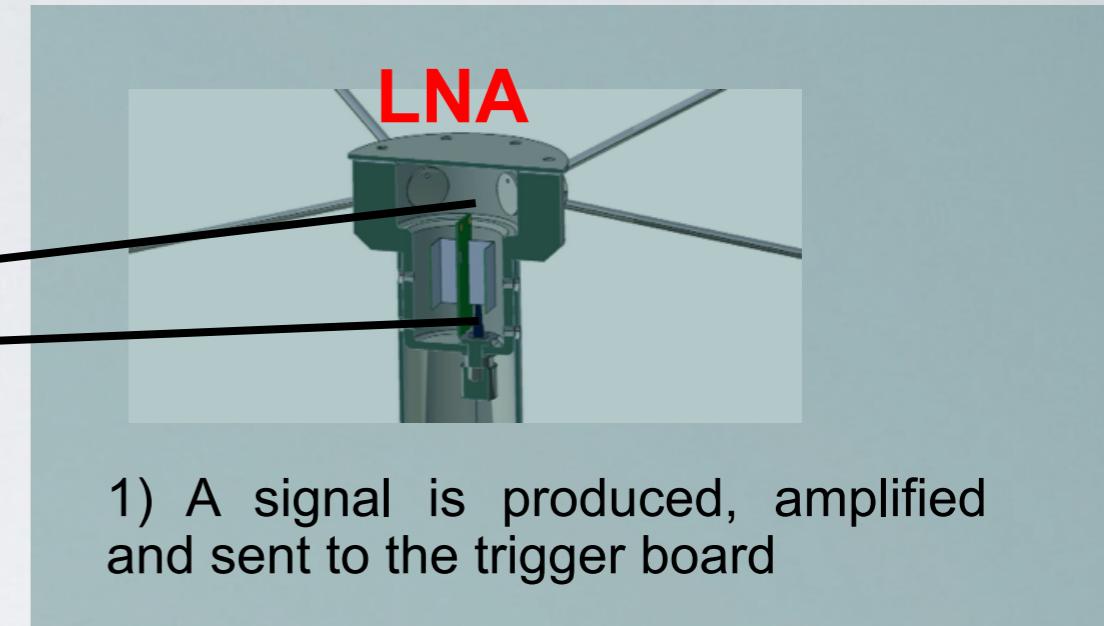
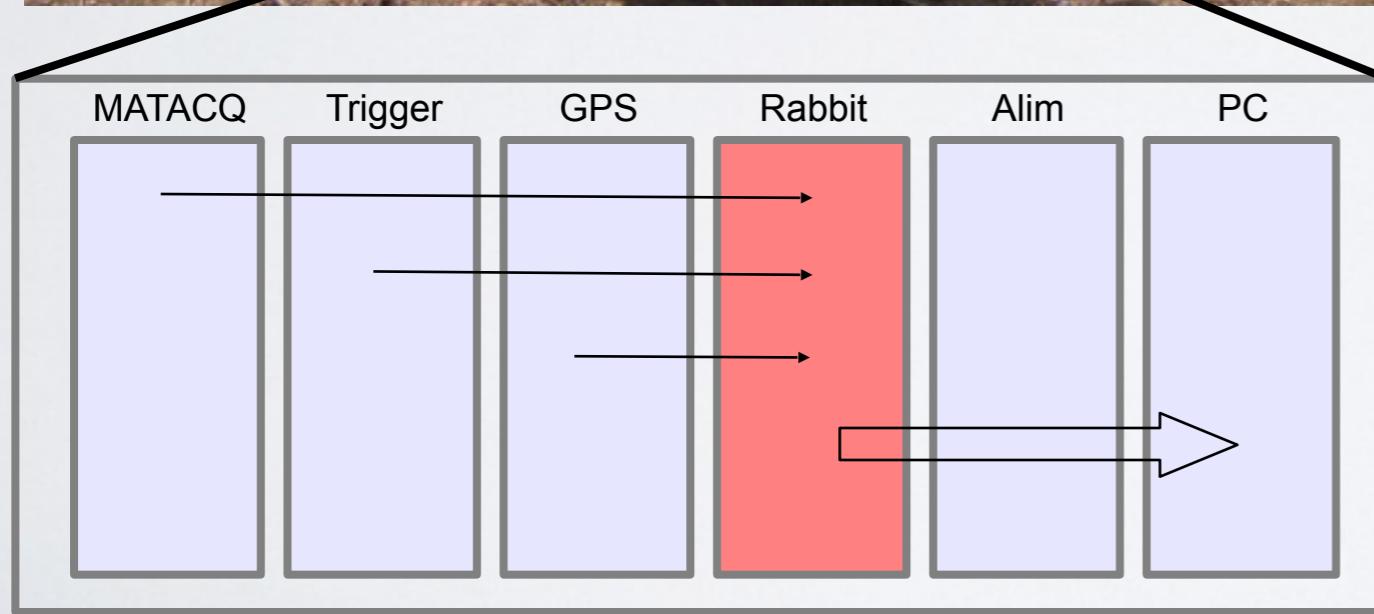
1) A signal is produced, amplified and sent to the trigger board

2) This analog signal is filtered in the trigger frequency band and is compared to a threshold value. If the signal > threshold → data acquisition starts

3) The signal is digitized (1 GS/s)

4) Data from MATAcq, Trigger and GPS boards are sent to the PC from the Rabbit board.

HOW DOES AN AUTONOMOUS STATION WORK ?



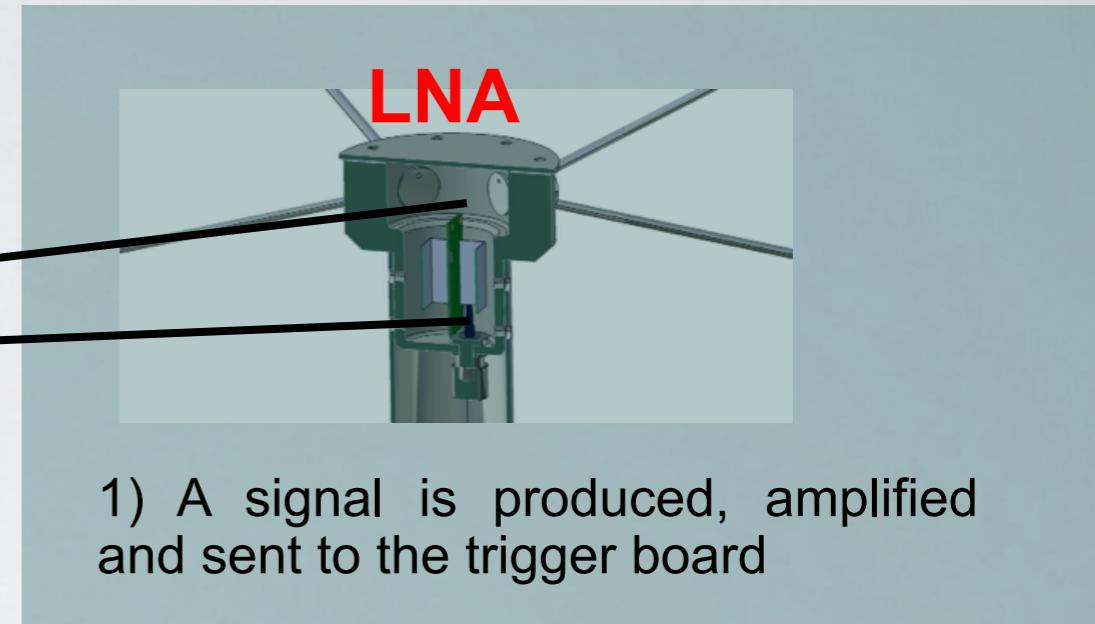
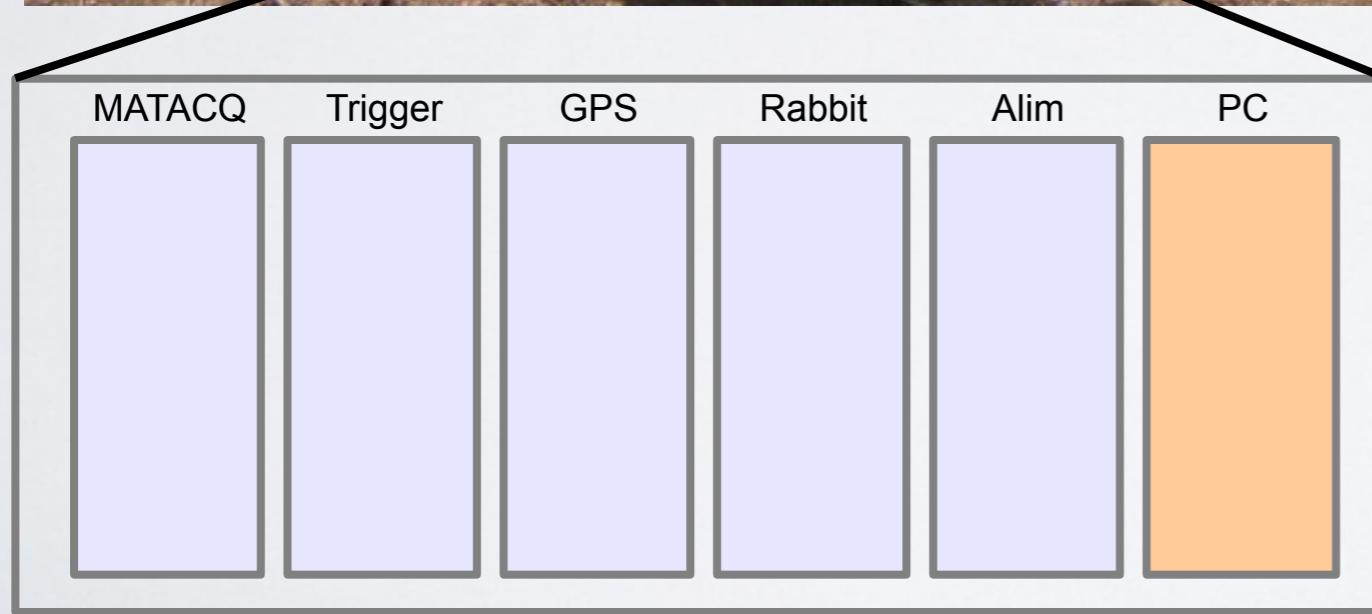
2) This analog signal is filtered in the trigger frequency band and is compared to a threshold value. If the signal > threshold → data acquisition starts

3) The signal is digitized (1 GS/s)

4) Data from MATAcq, Trigger and GPS boards are sent to the PC from the Rabbit board.

Dead time

HOW DOES AN AUTONOMOUS STATION WORK ?



1) A signal is produced, amplified and sent to the trigger board

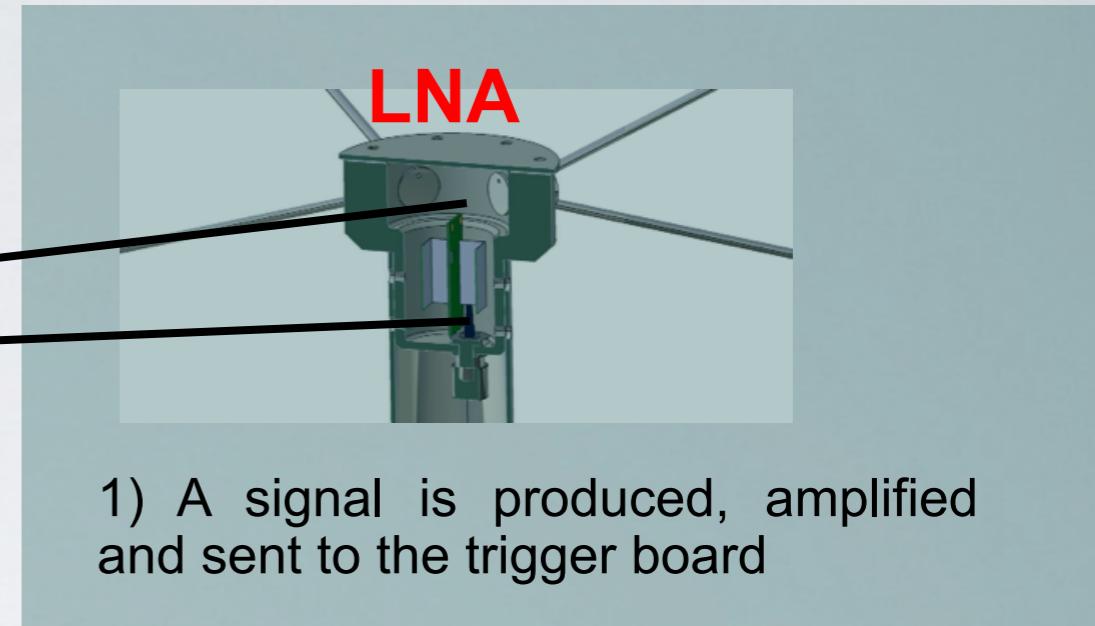
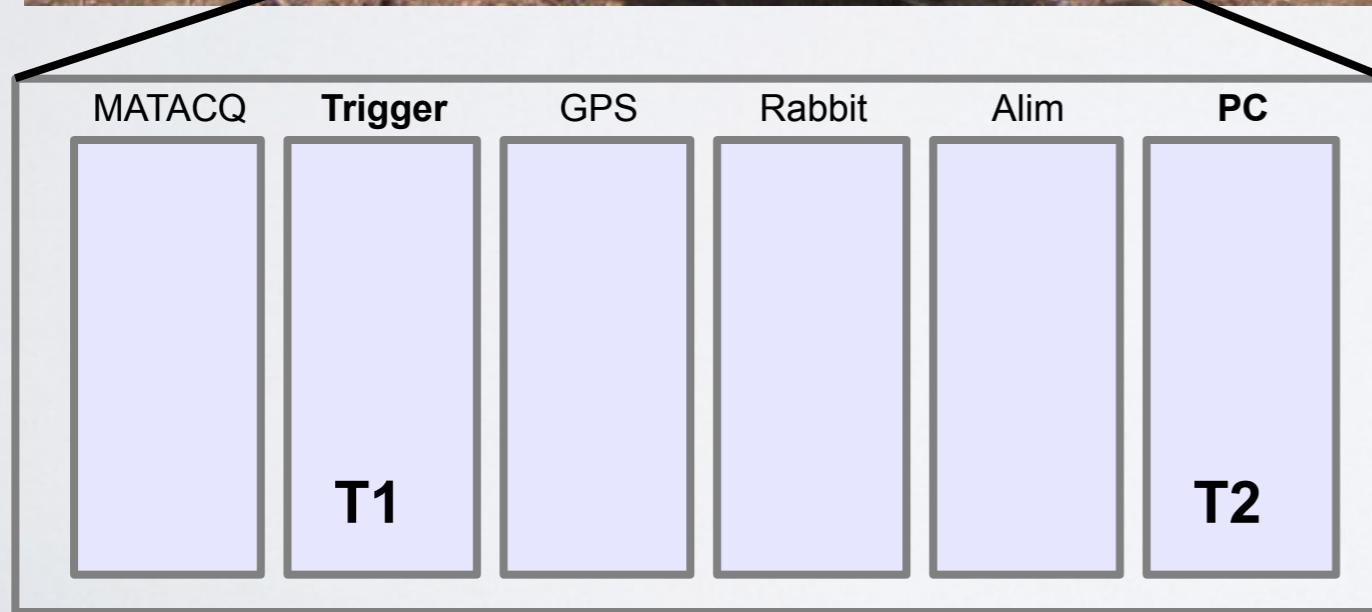
2) This analog signal is filtered in the trigger frequency band and is compared to a threshold value. If the signal > threshold → data acquisition starts

3) The signal is digitized (1 GS/s)

4) Data from MATAcq, Trigger and GPS boards are sent to the PC from the Rabbit board.

5) Event building and communication with the outside world

HOW DOES AN AUTONOMOUS STATION WORK ?



1) A signal is produced, amplified and sent to the trigger board

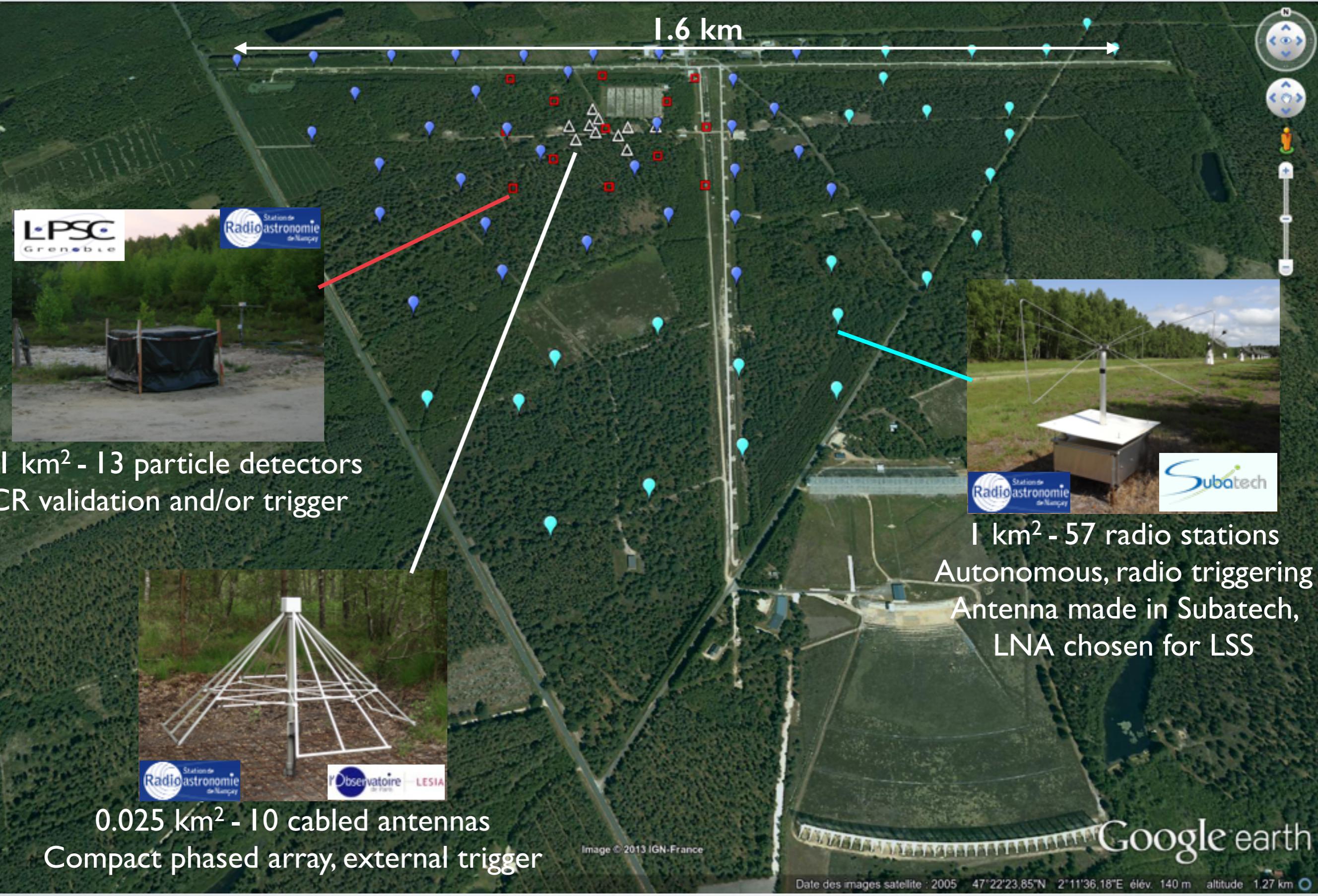
2) This analog signal is filtered in the trigger frequency band and is compared to a threshold value. If the signal > threshold → data acquisition starts

3) The signal is digitized (1 GS/s)

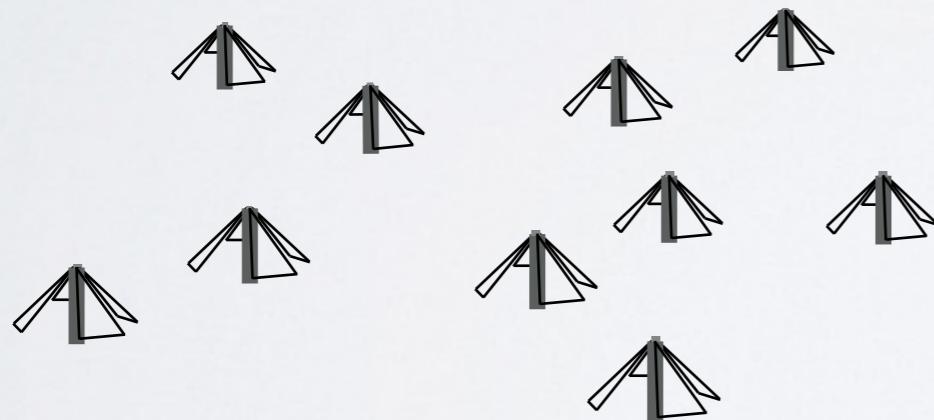
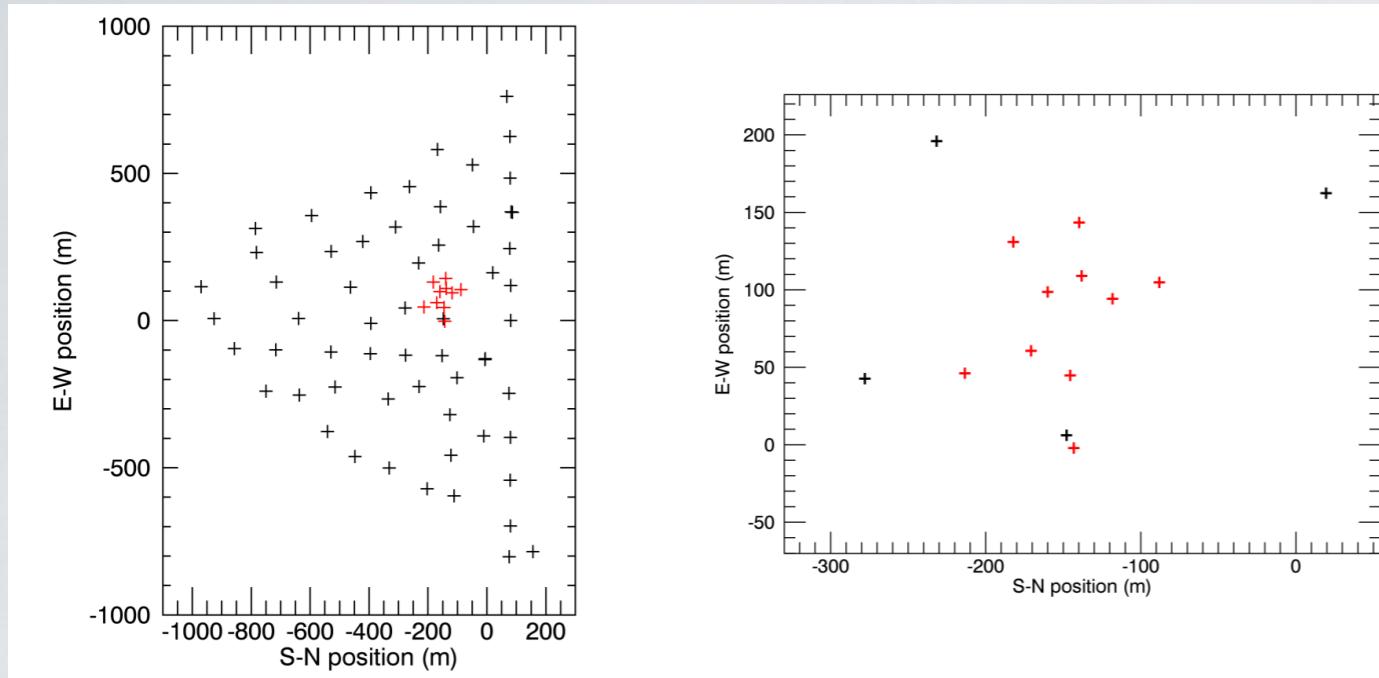
4) Data from MATAcq, Trigger and GPS boards are sent to the PC from the Rabbit board.

5) Event building and communication with the outside world

CODALEMA-3 (2010 - 2013 - ...)



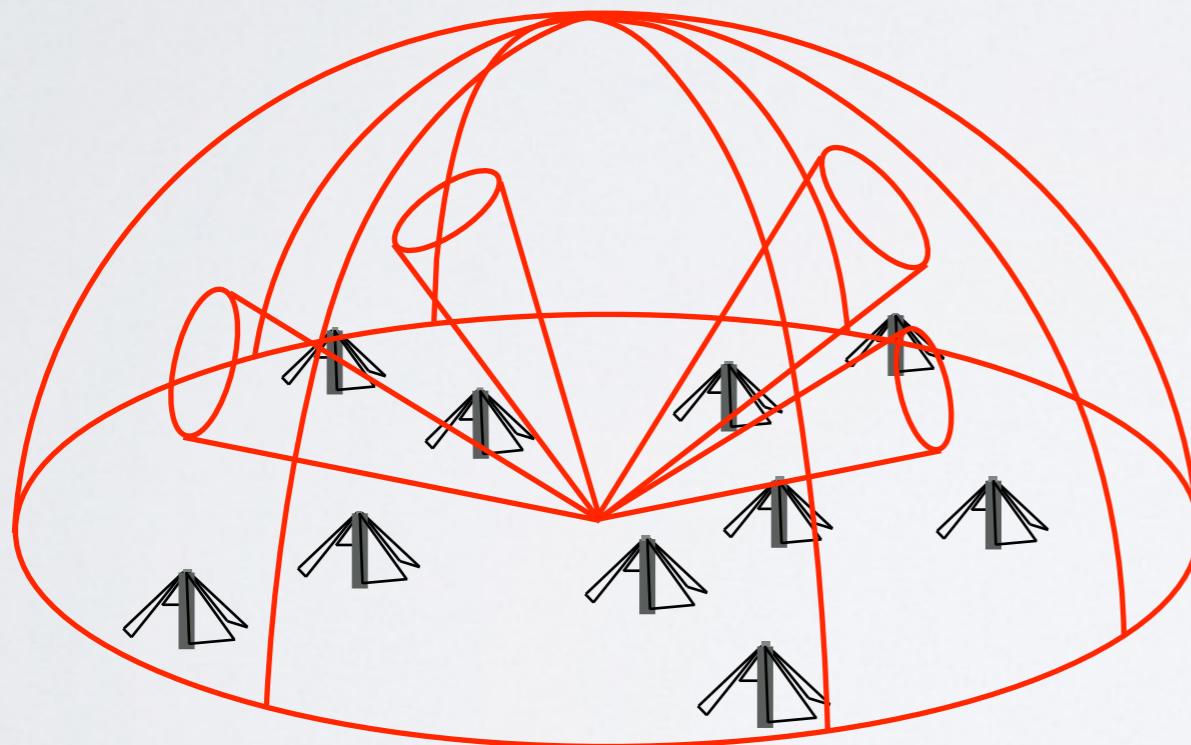
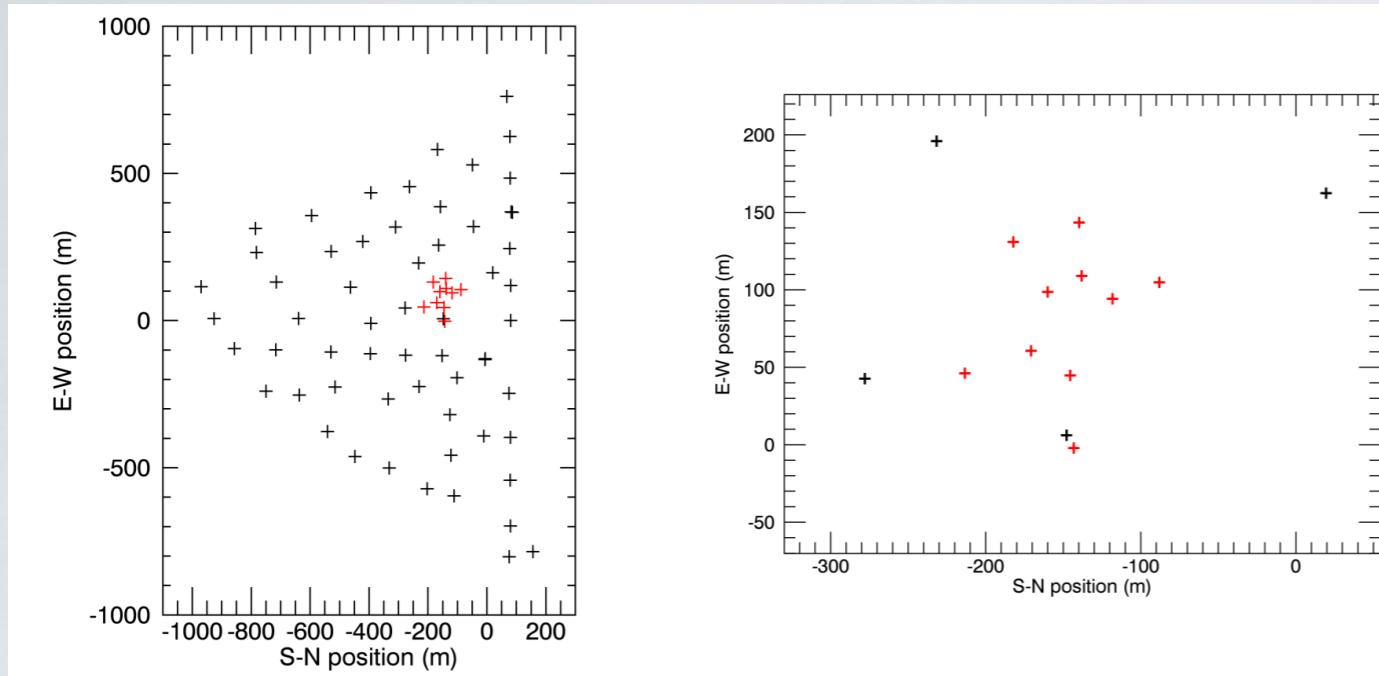
THE COMPACT ARRAY:A COMPOSITE DETECTOR



ADC rate: 250 MS/s

GPU for online reconstruction of array lobes (1°) over 2π sr

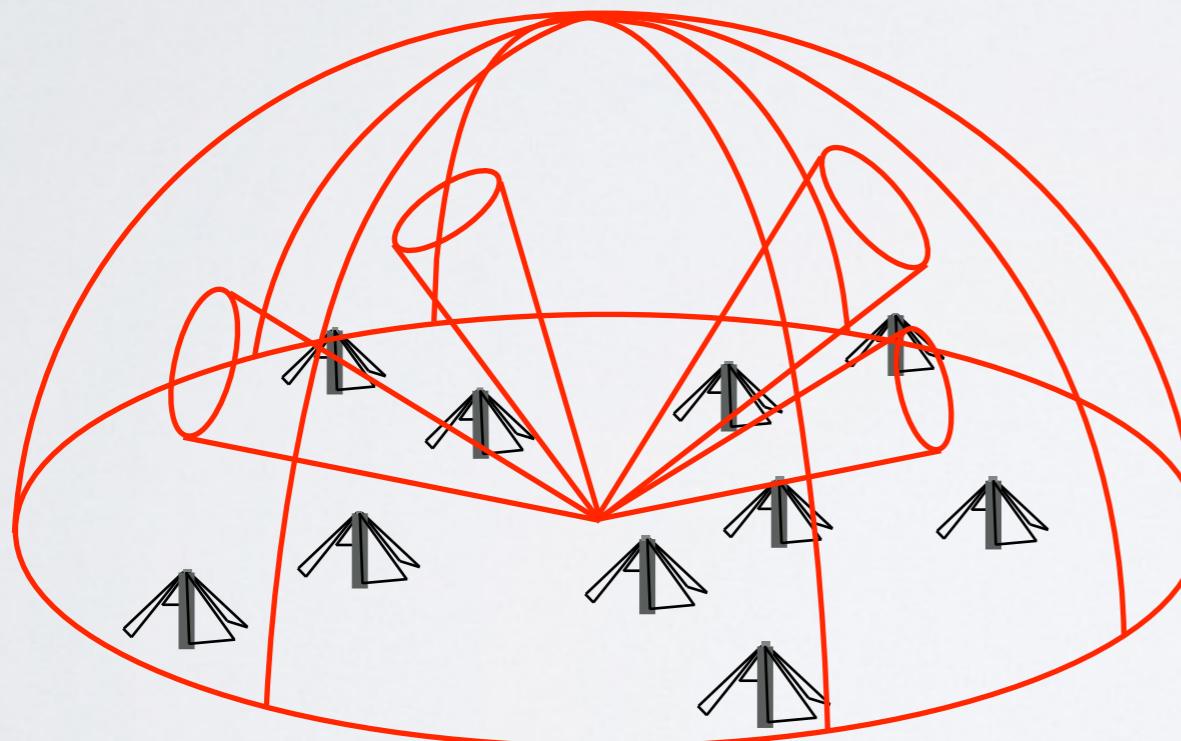
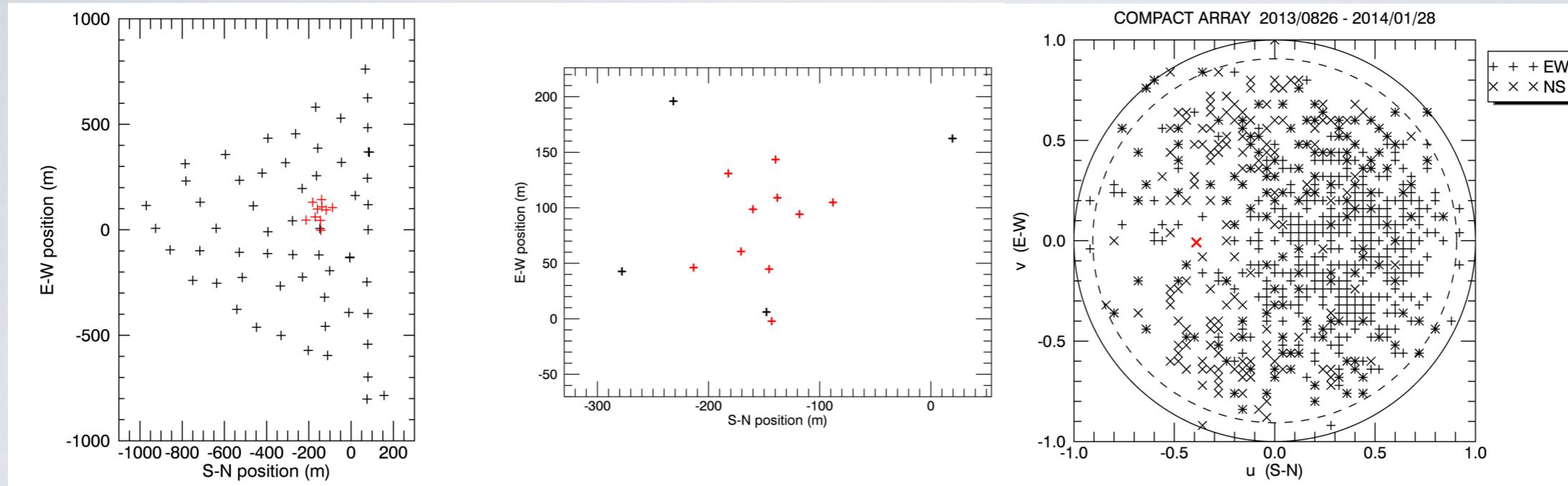
THE COMPACT ARRAY:A COMPOSITE DETECTOR



ADC rate: 250 MS/s

GPU for online reconstruction of array lobes (1°) over 2π sr

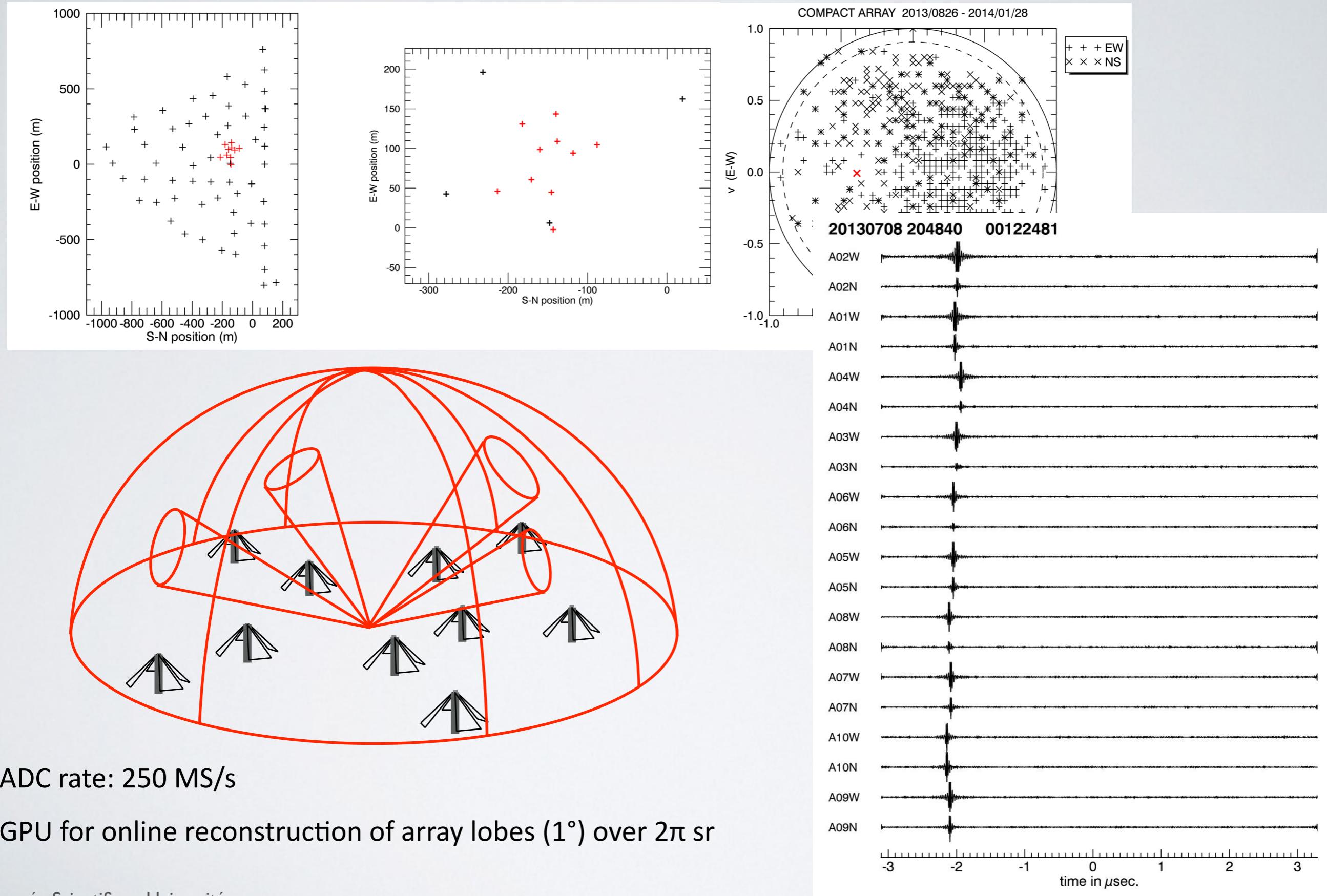
THE COMPACT ARRAY:A COMPOSITE DETECTOR



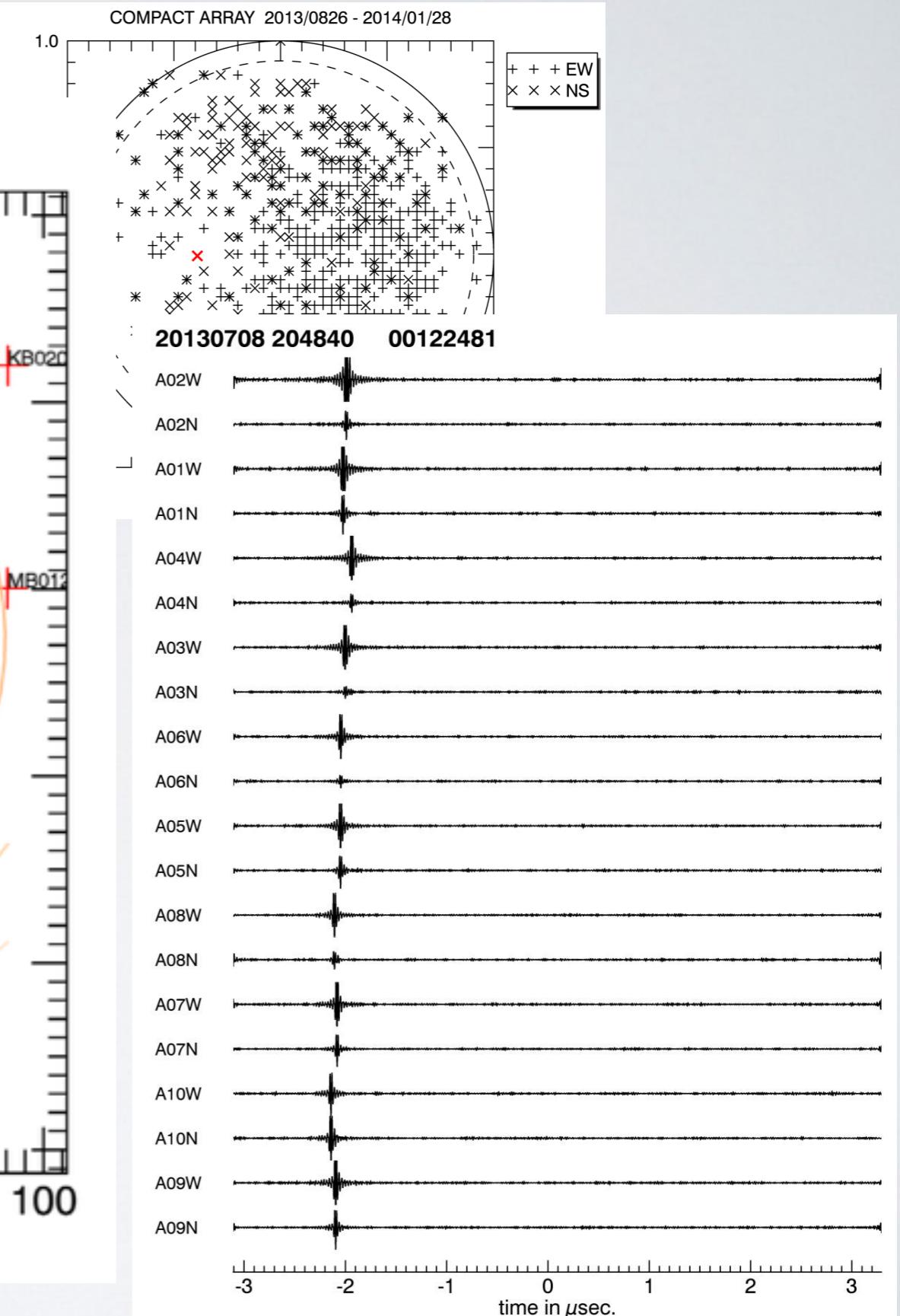
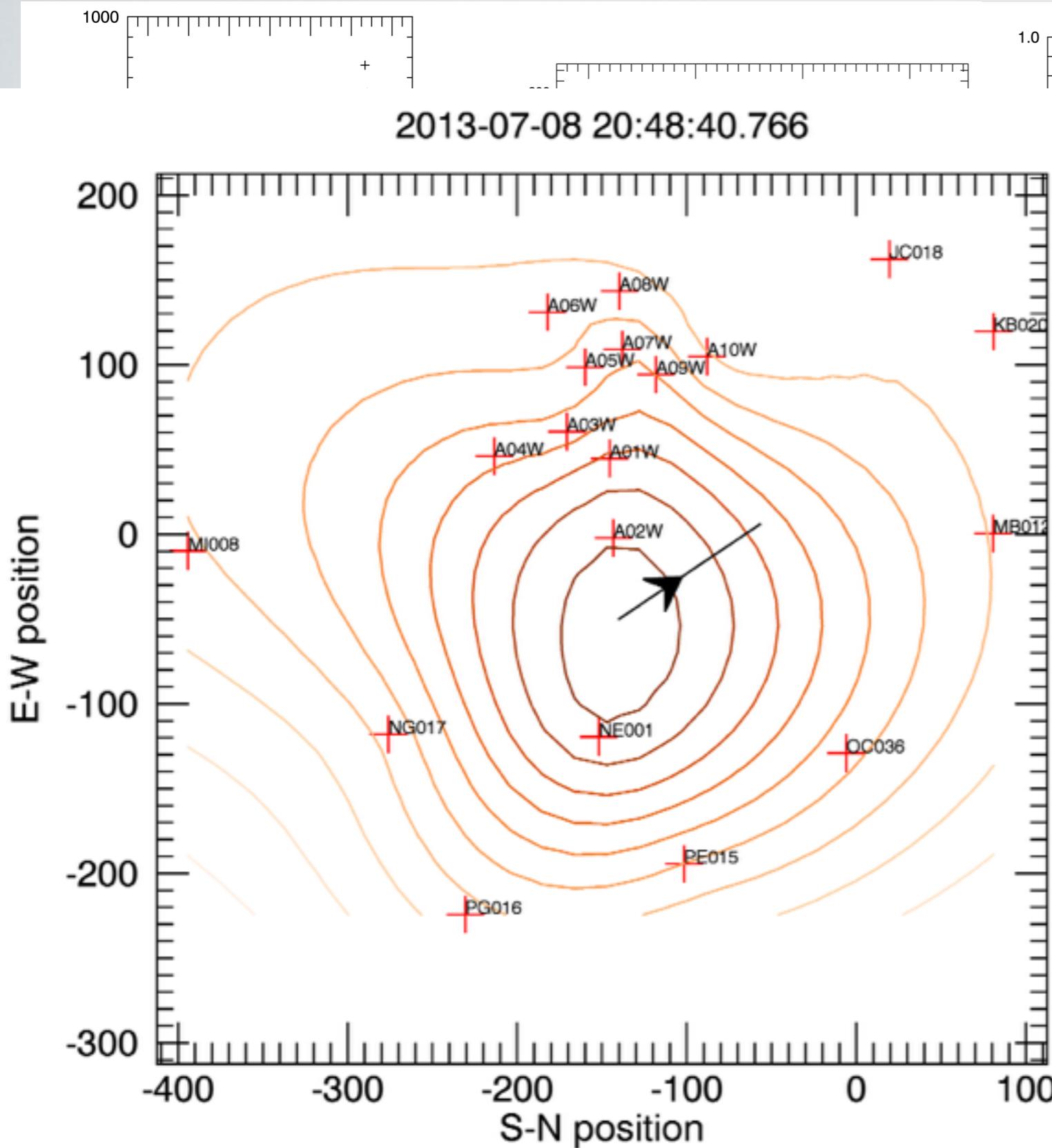
ADC rate: 250 MS/s

GPU for online reconstruction of array lobes (1°) over 2π sr

THE COMPACT ARRAY:A COMPOSITE DETECTOR



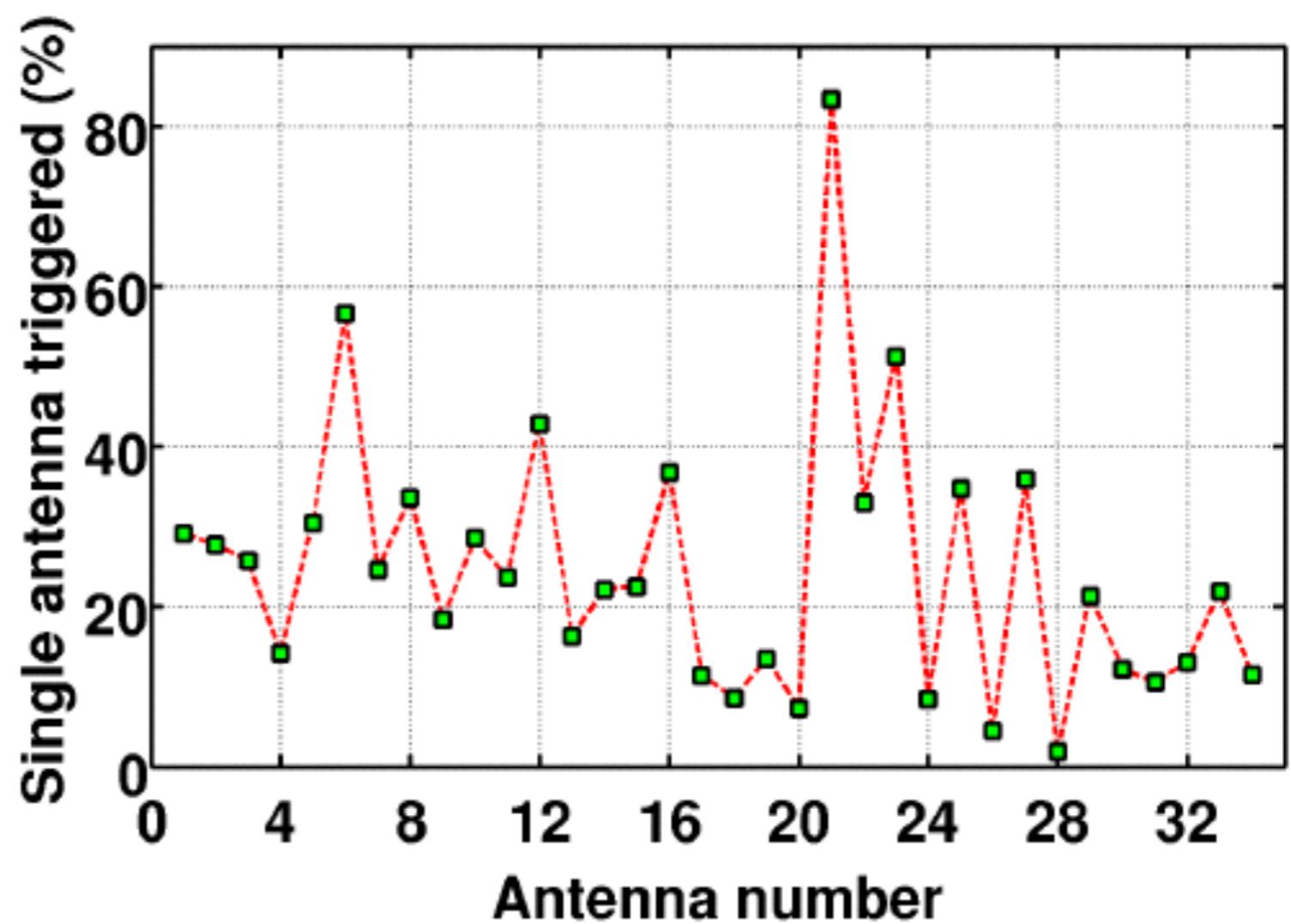
THE COMPACT ARRAY:A COMPOSITE DETECTOR



THE FEATURES OF THE RADIO TRANSIENT BACKGROUND

A first data analysis (03/2011 – 07/2011)

- $\sim 10^6$ signals recorded per day
- Around 1 cosmic ray event expected per day for 1 km² and 10¹⁶ – 10¹⁸ eV
- A significant fraction of singles events
→ local transient sources

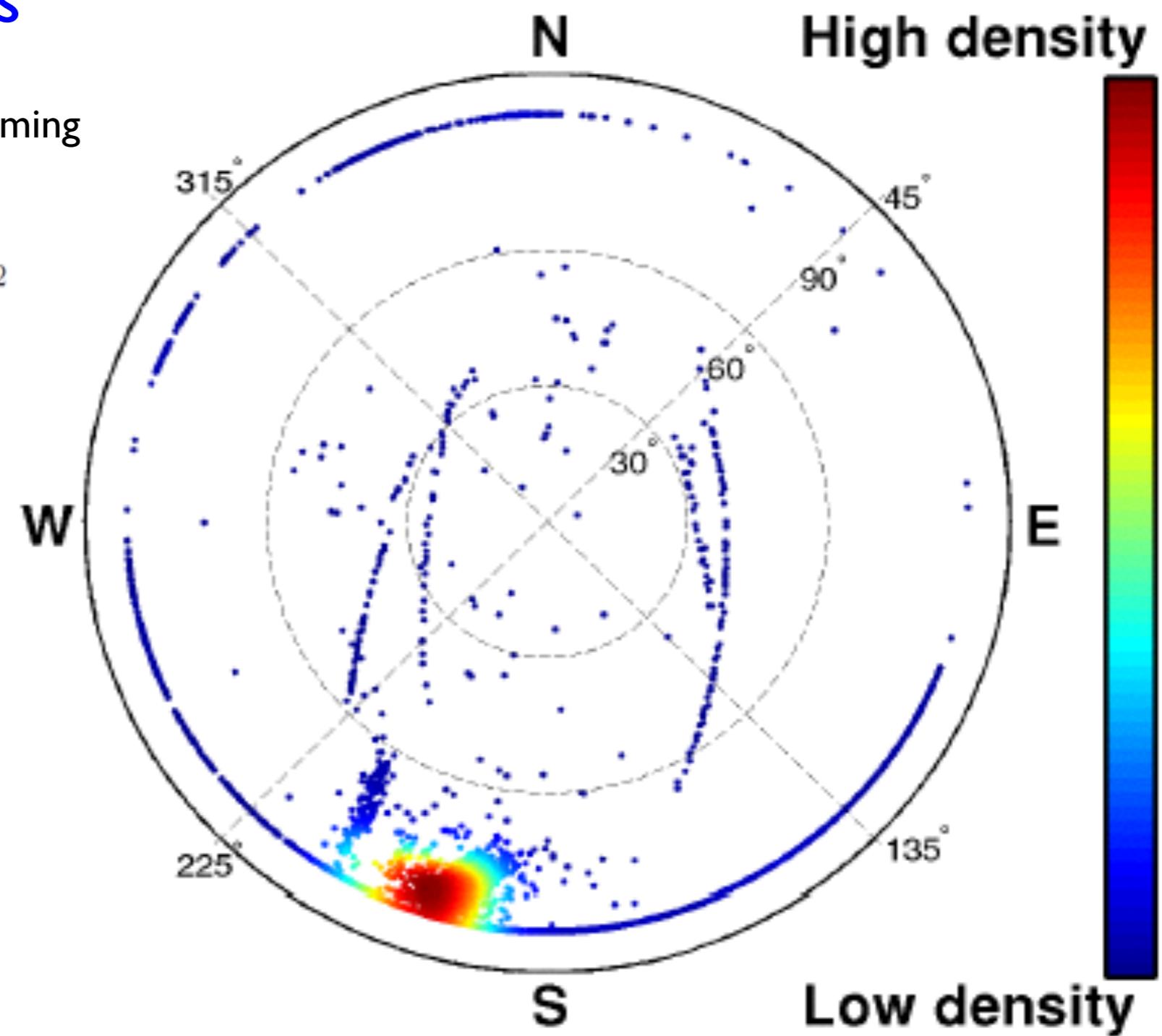


THE FEATURES OF THE RADIO TRANSIENT BACKGROUND

Noise source features

- Arrival direction obtained from timing in individual stations

$$\chi^2 = \frac{1}{N} \sum_{i=1}^N (c(t_{0i} - t_{det}) - (u.x_i + v.y_i))^2$$



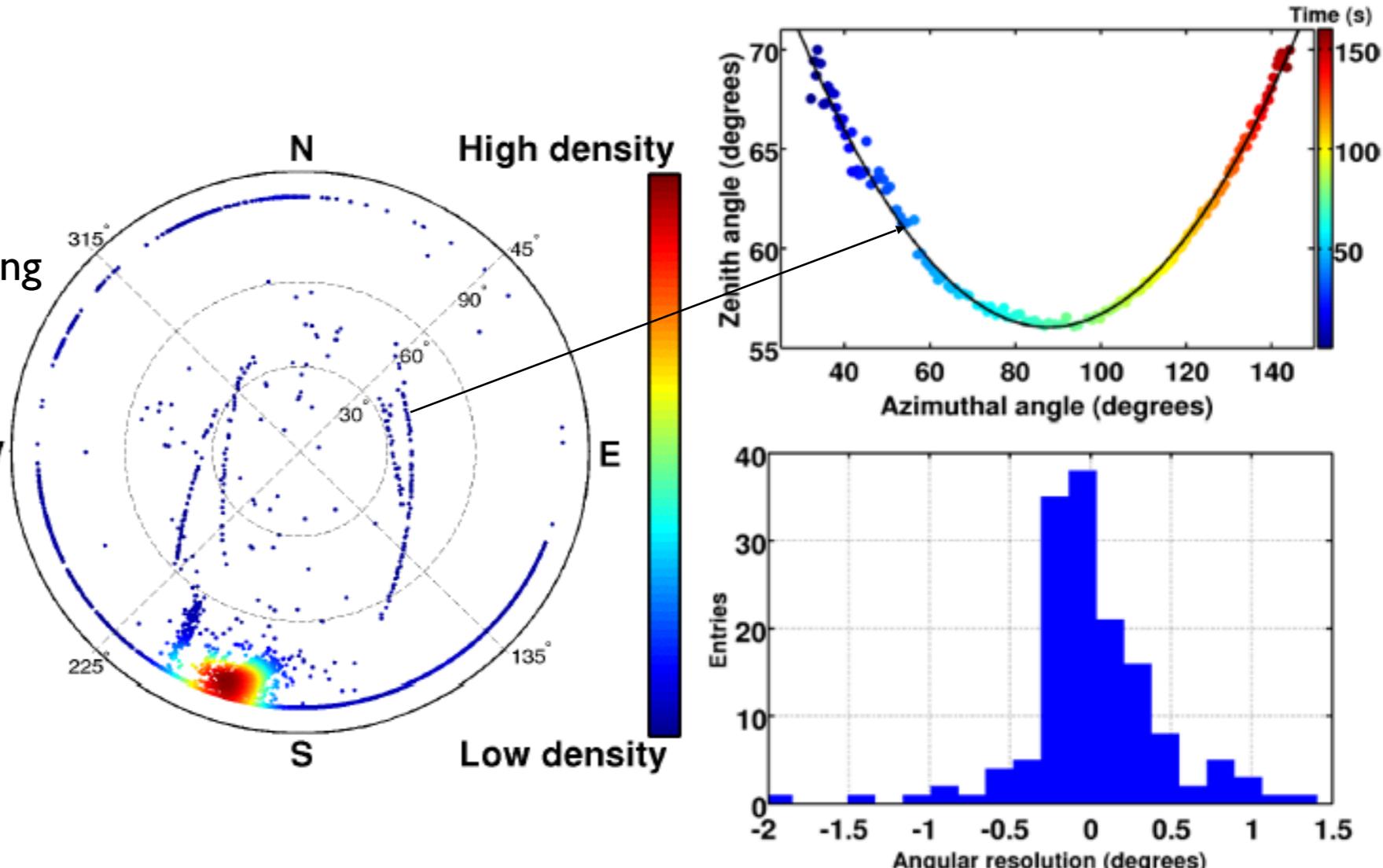
THE FEATURES OF THE RADIO TRANSIENT BACKGROUND

Noise source features

- Arrival direction obtained from timing in individual stations

$$\chi^2 = \frac{1}{N} \sum_{i=1}^N (c(t_{0i} - t_{det}) - (u.x_i + v.y_i))^2$$

- Mobile sources (air planes)



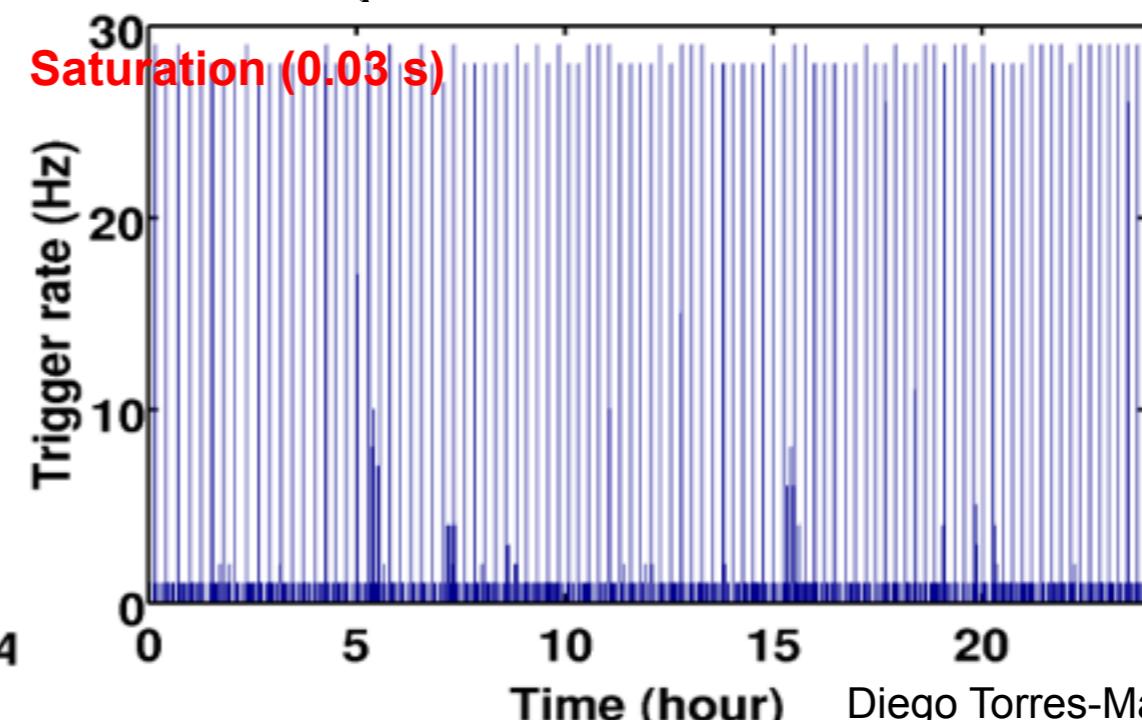
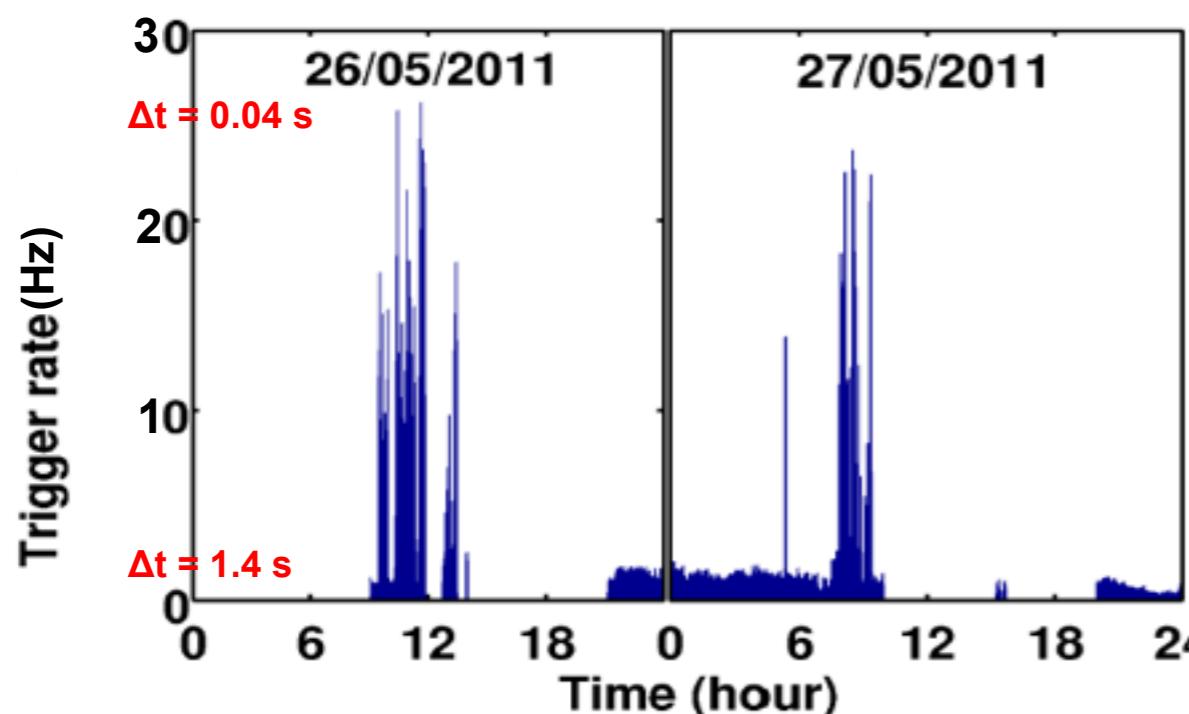
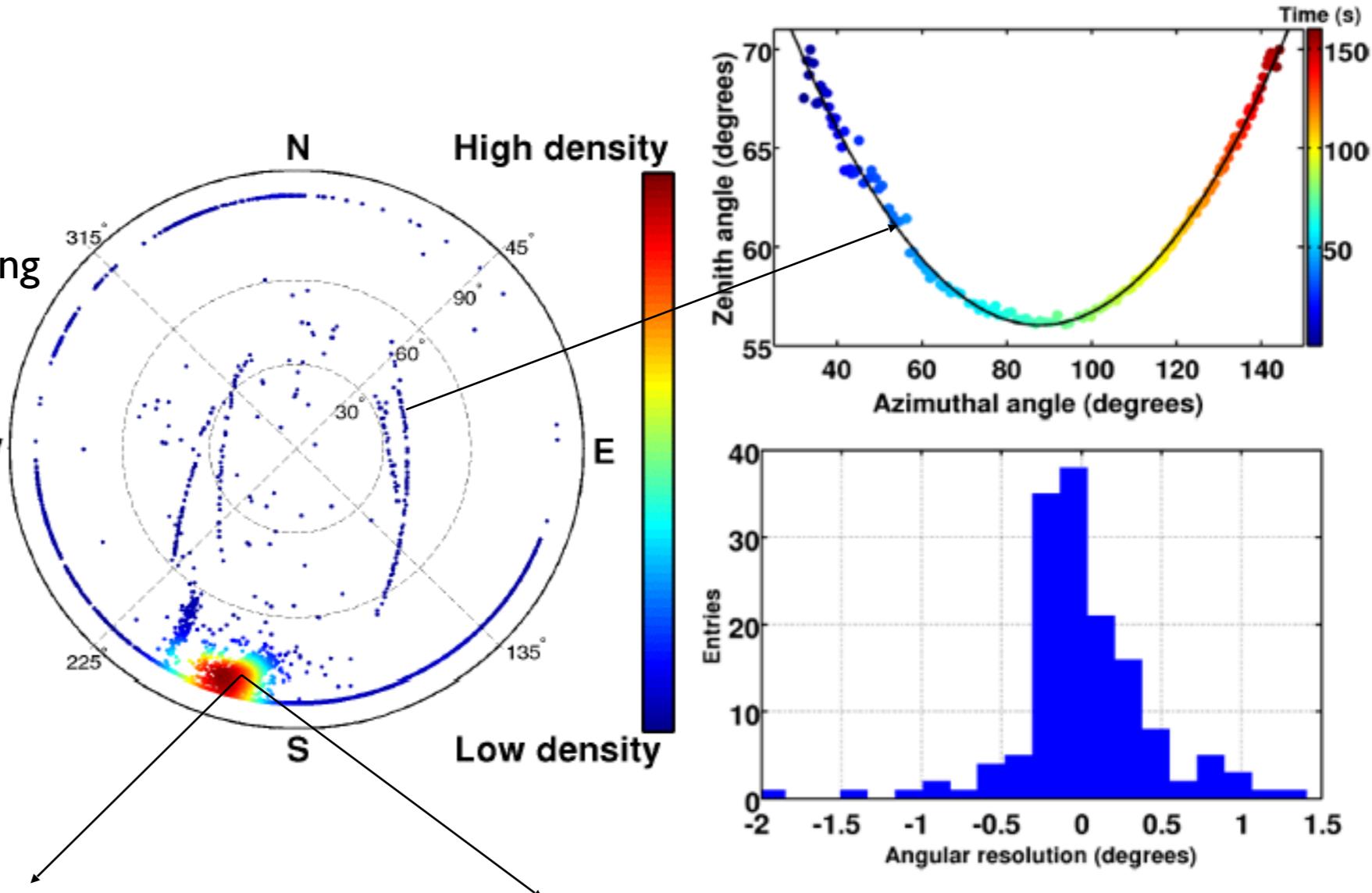
THE FEATURES OF THE RADIO TRANSIENT BACKGROUND

Noise source features

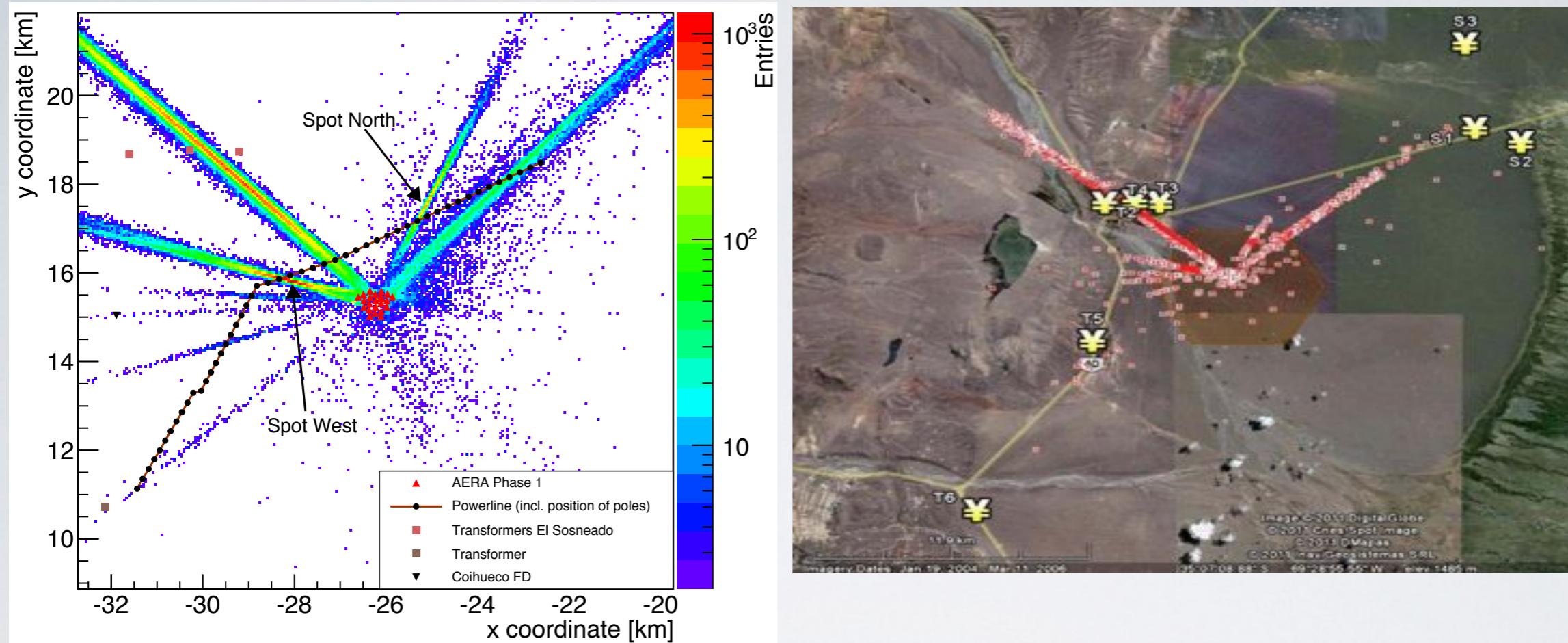
- Arrival direction obtained from timing in individual stations

$$\chi^2 = \frac{1}{N} \sum_{i=1}^N (c(t_{0i} - t_{det}) - (u.x_i + v.y_i))^2$$

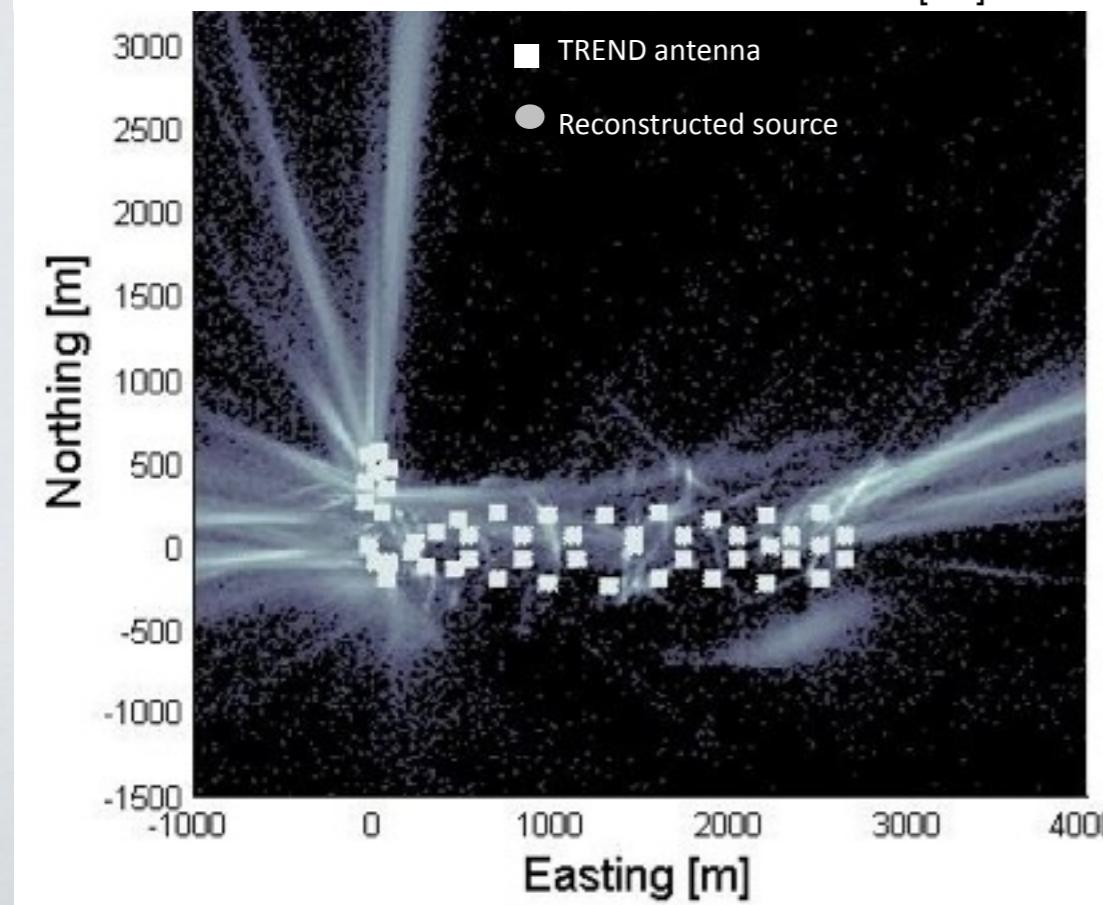
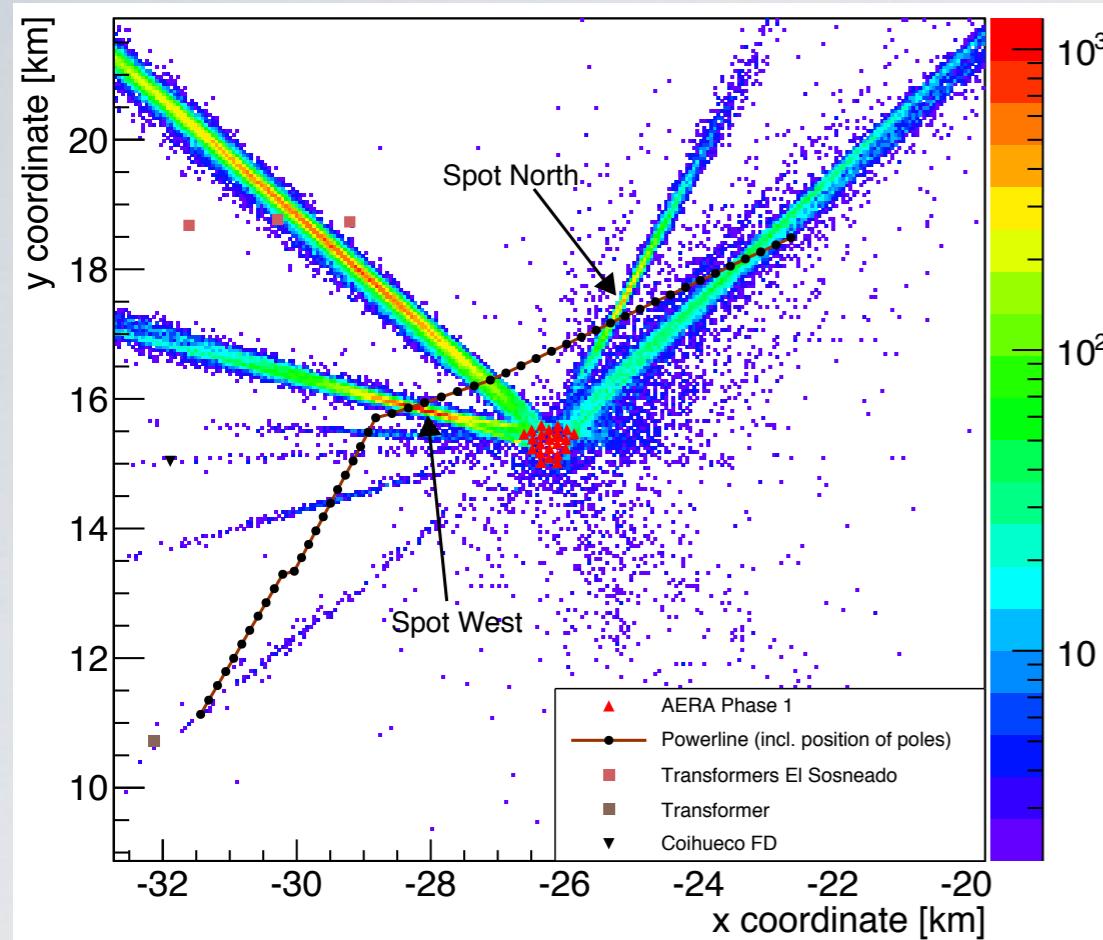
- Mobile sources (air planes)
- Static sources
 - Periodic sources
 - Intermittent sources



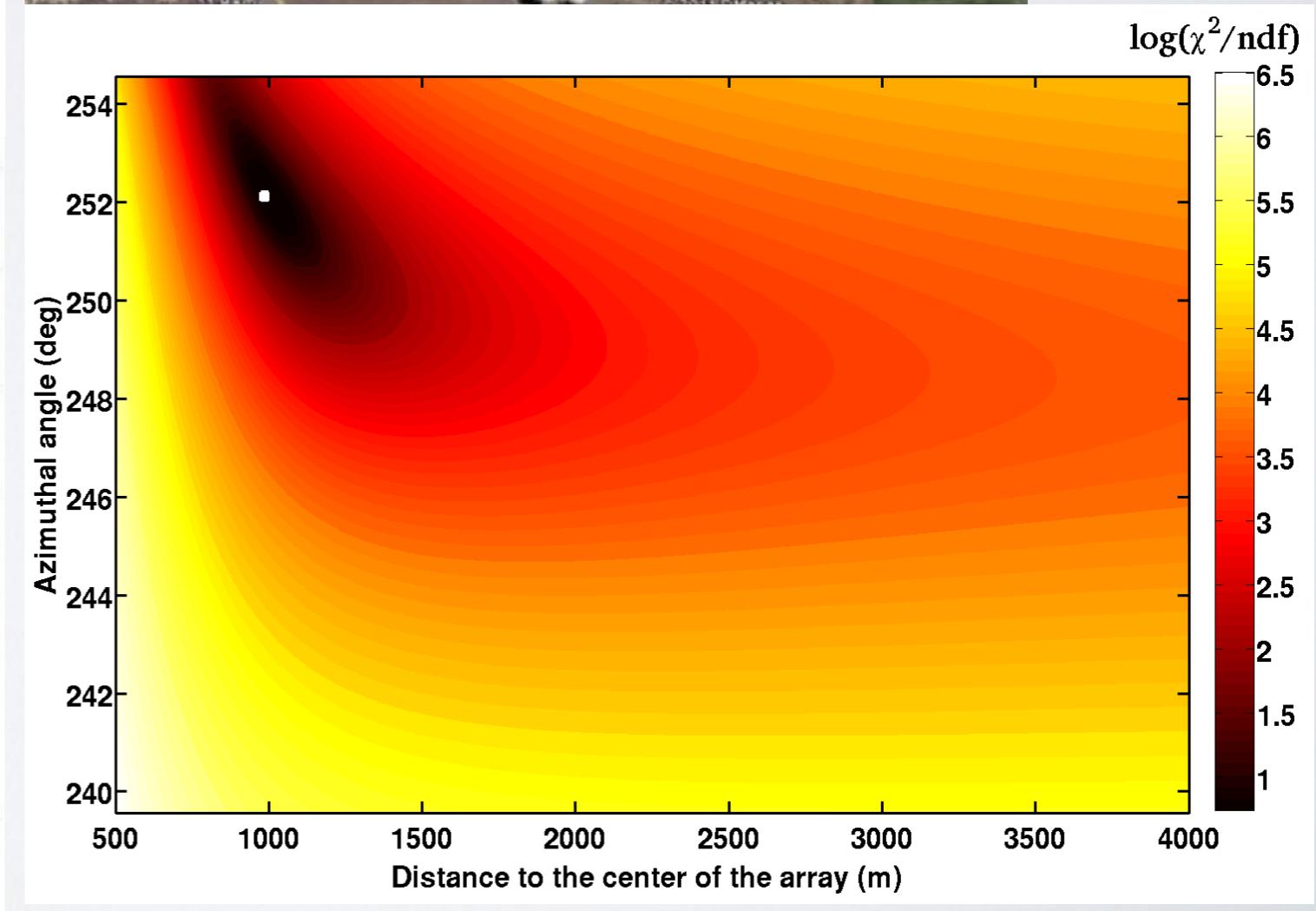
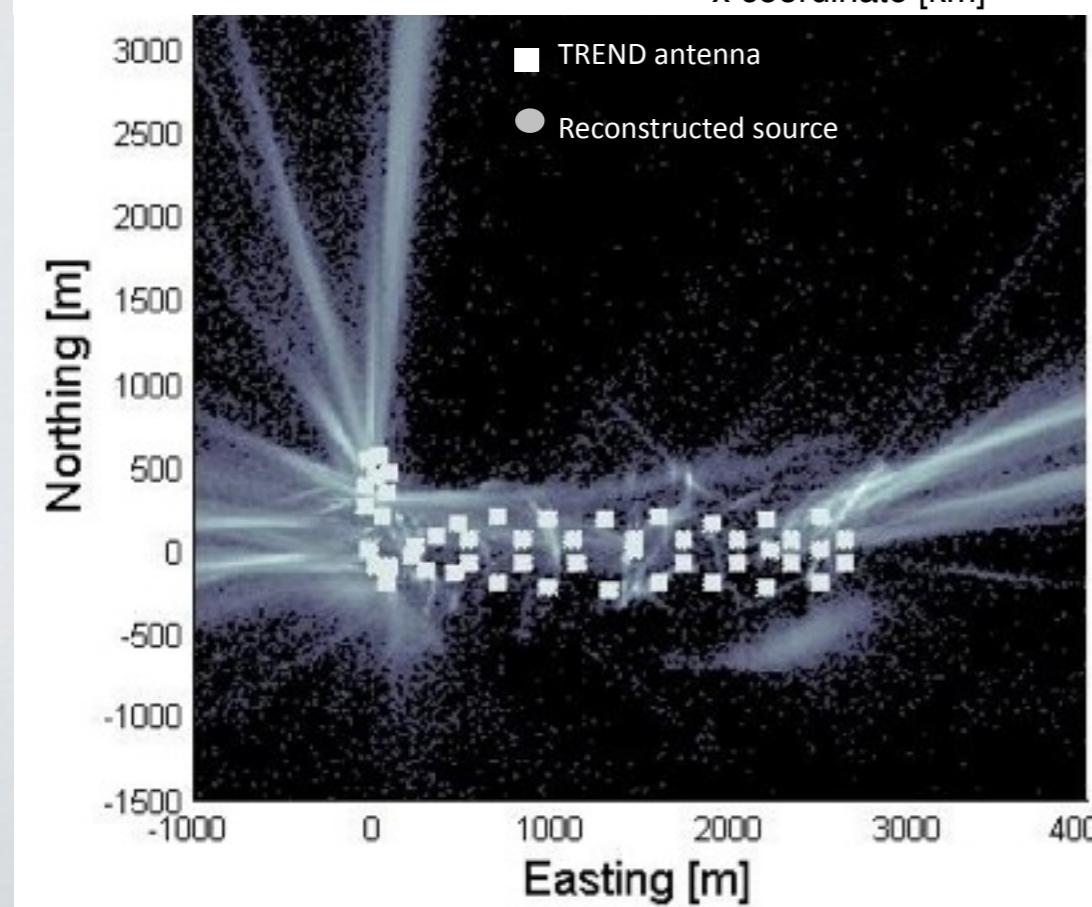
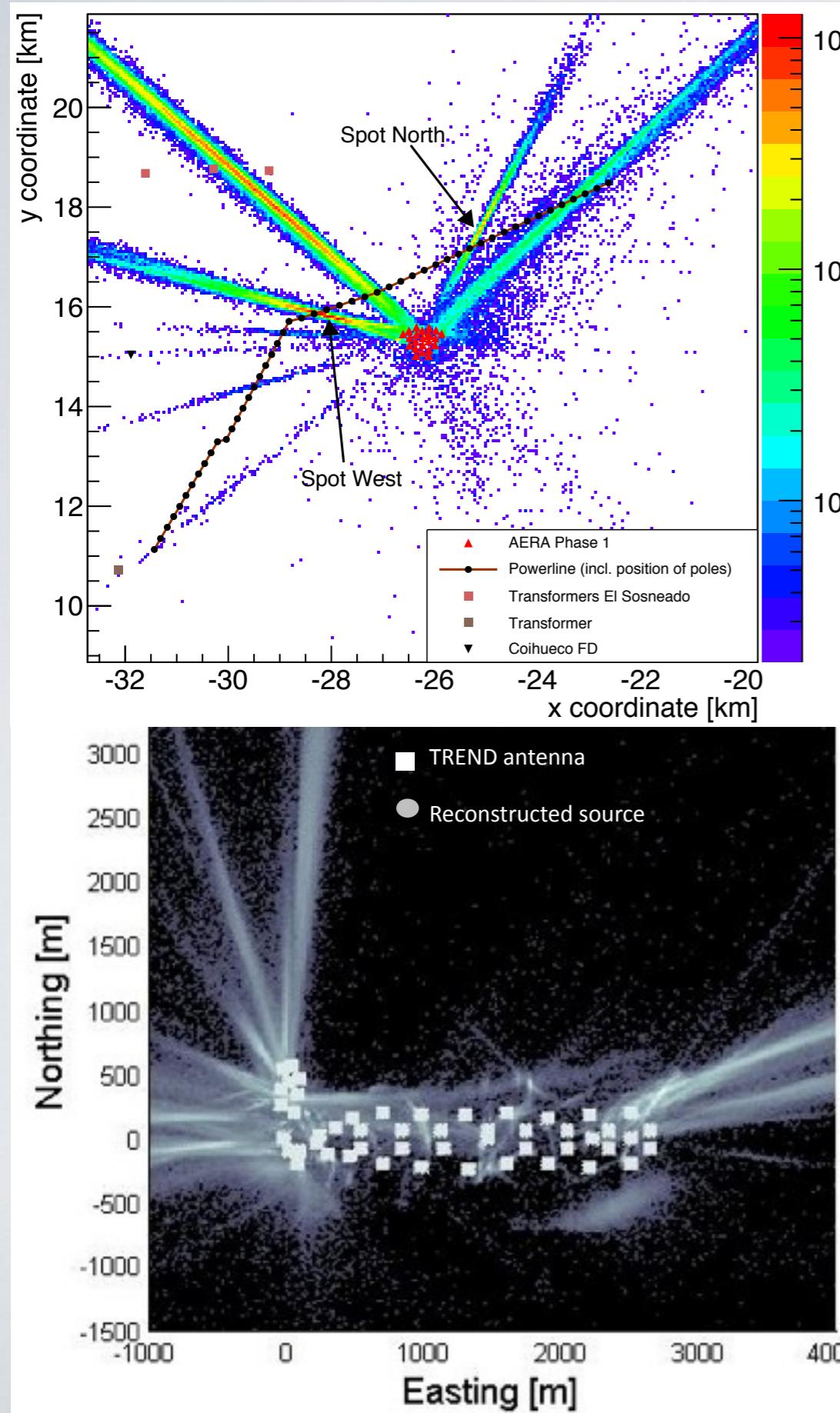
...BUT NOT EASY TO LOCALIZE SOURCES



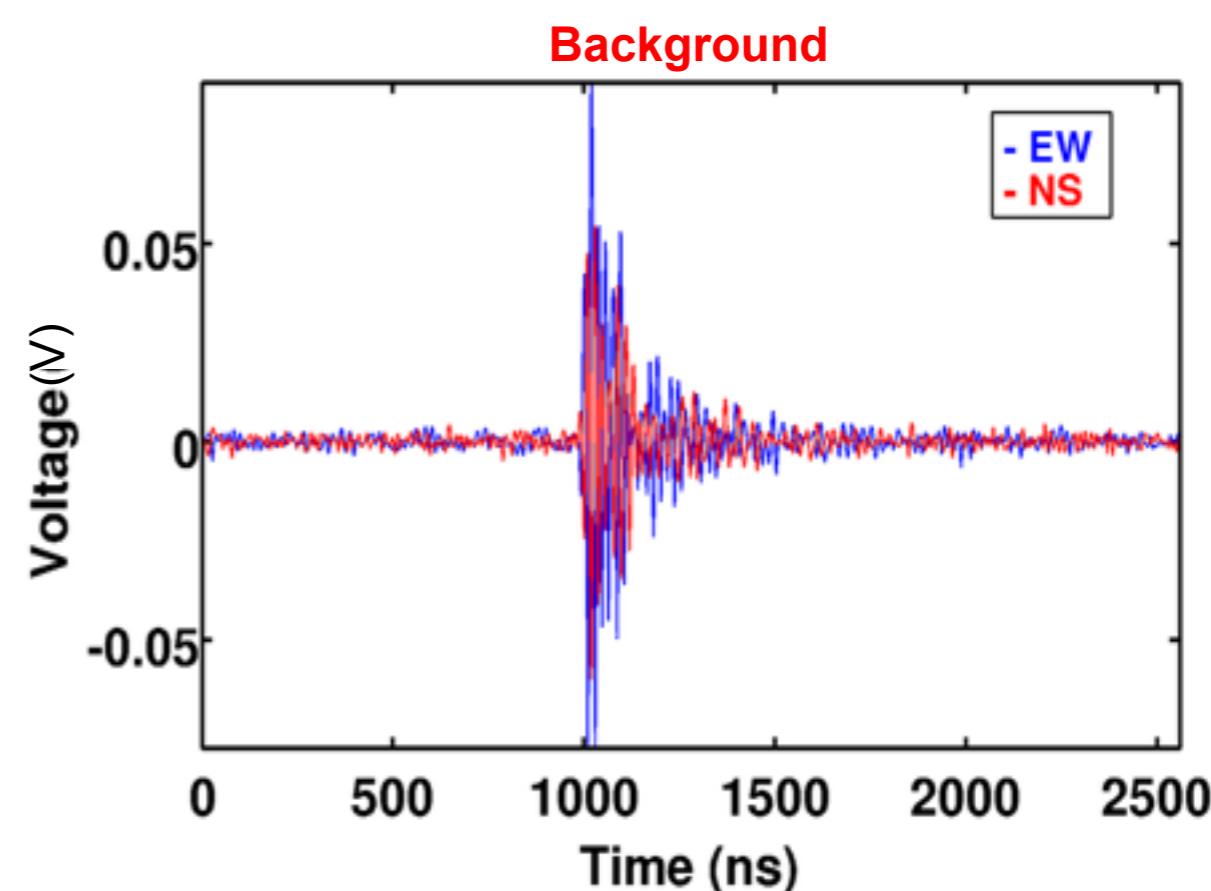
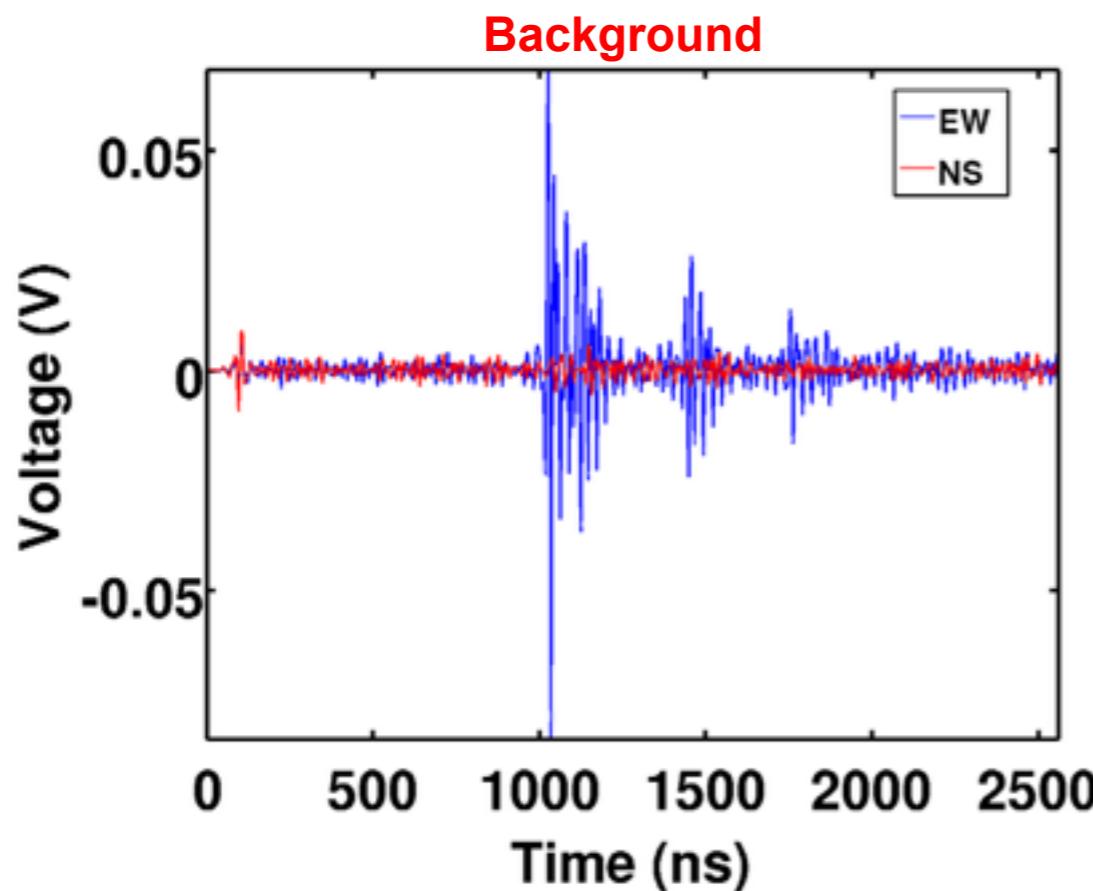
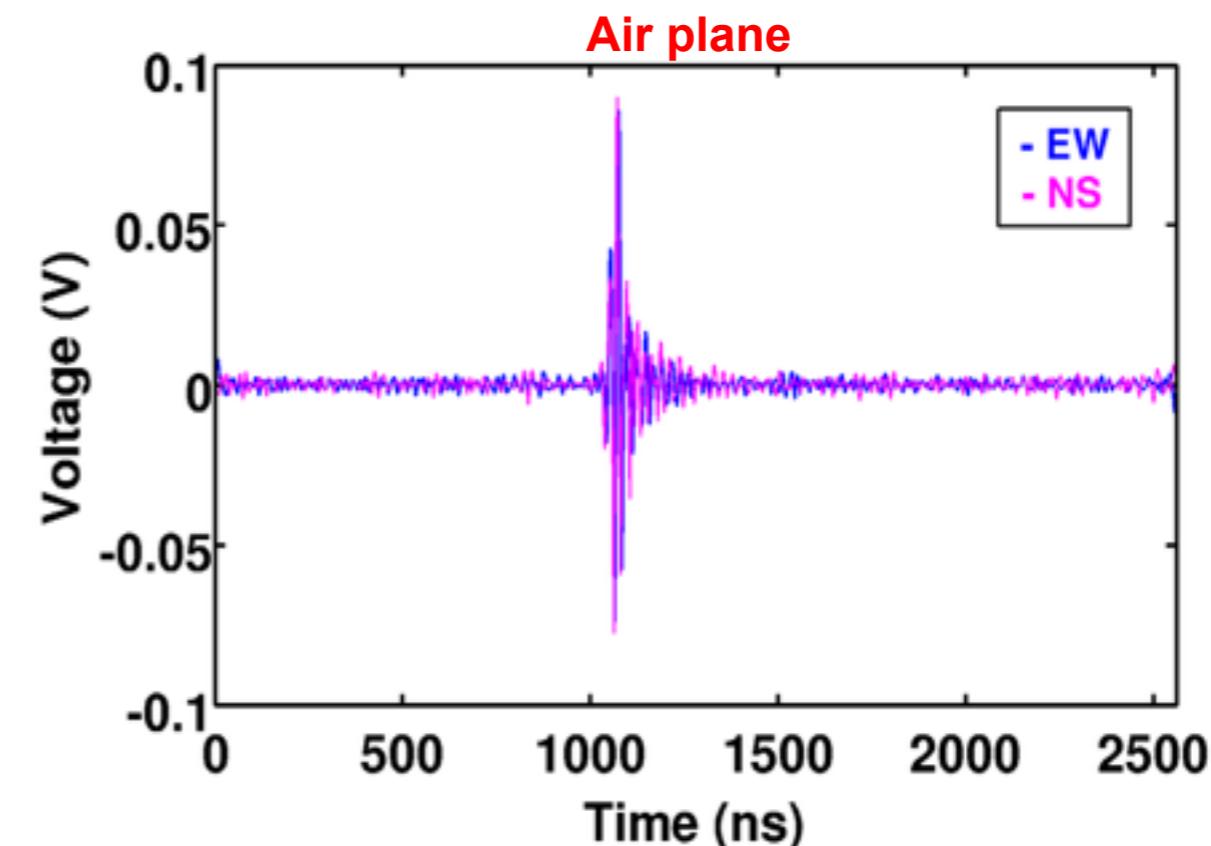
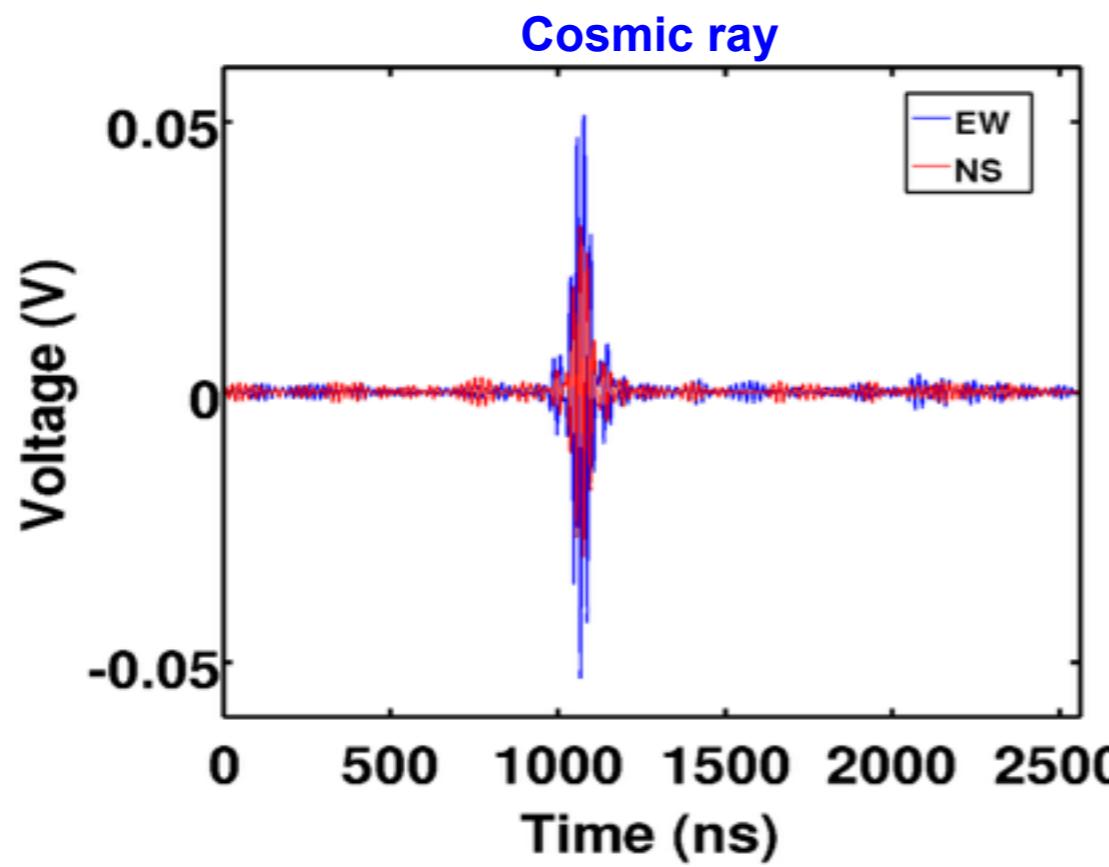
...BUT NOT EASY TO LOCALIZE SOURCES



...BUT NOT EASY TO LOCALIZE SOURCES



ZOOLOGY OF TRANSIENTS



FLIGHT 7I4 TO BUENOS AIRES...

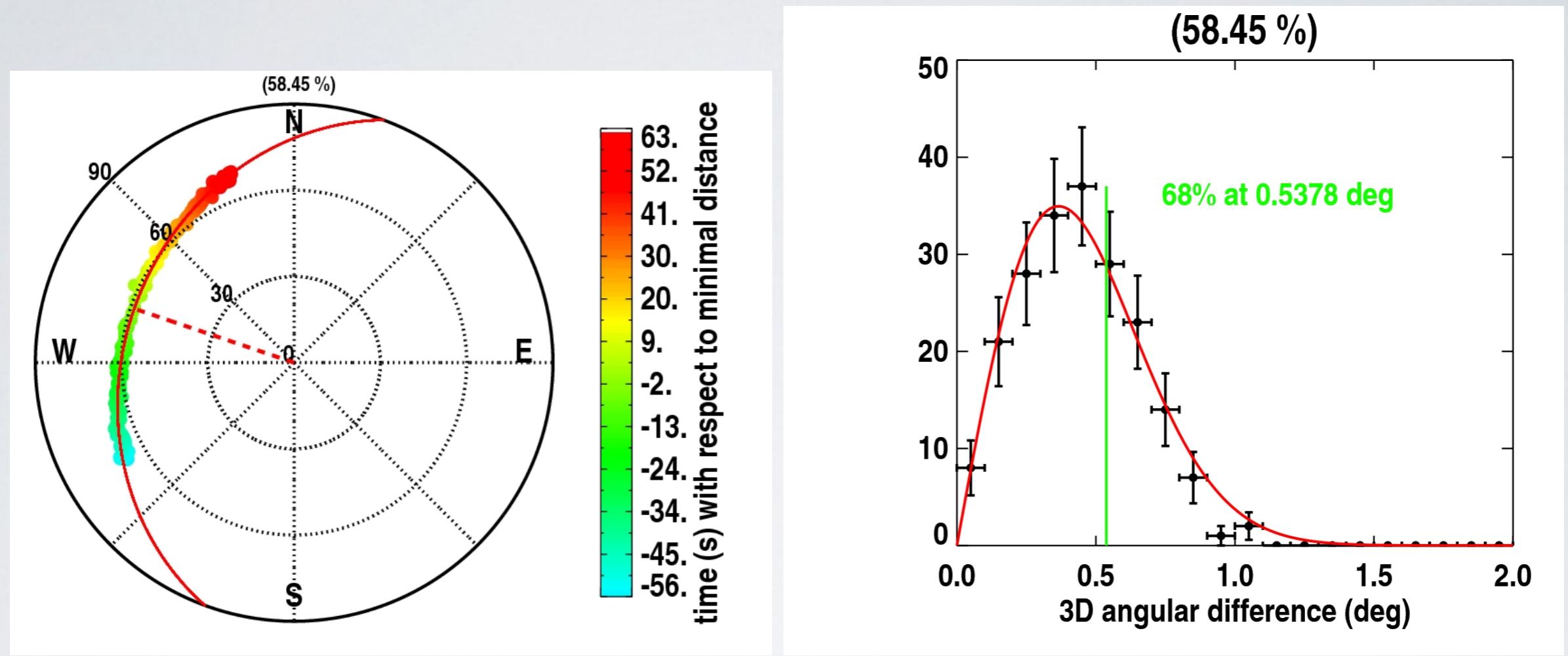


Figure 1: Left: skymap of the detected (color dots) and fitted (plain red line) airplane trajectory. The closest point of the trajectory is indicated by the red dashed line. The color scale indicates the timing relatively to the closest point of the trajectory from RAuger. Right: on this trajectory, the angular resolution is estimated at 0.53° .

FLIGHT 7I4 TO BUENOS AIRES...

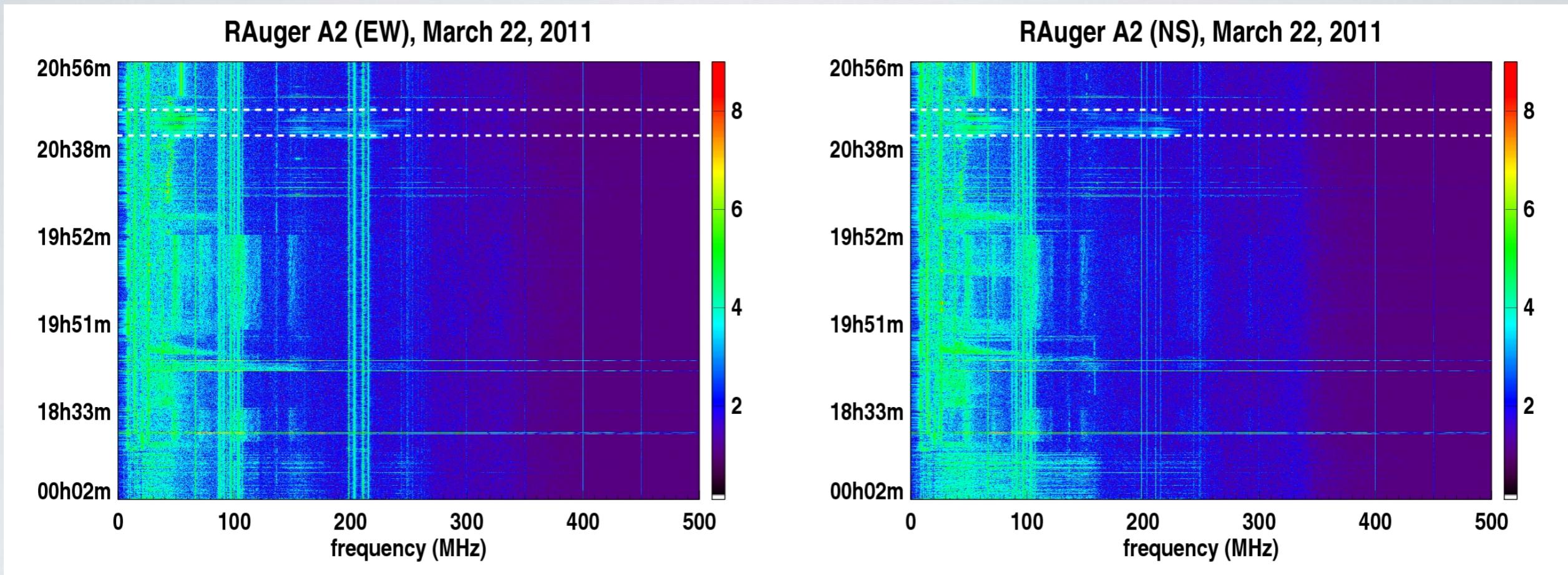


Figure 2: Time-frequency diagram for the first 10 000 events recorded by A2 on March 22, 2011, in both EW (left) and NS (right) polarizations. The highly variable trigger rate is visible in the event occurrence time scale. The airplane transit occurred between the two horizontal dashed lines between 20h45 UTC and 20h47 UTC.

FLIGHT 714 TO BUENOS AIRES...

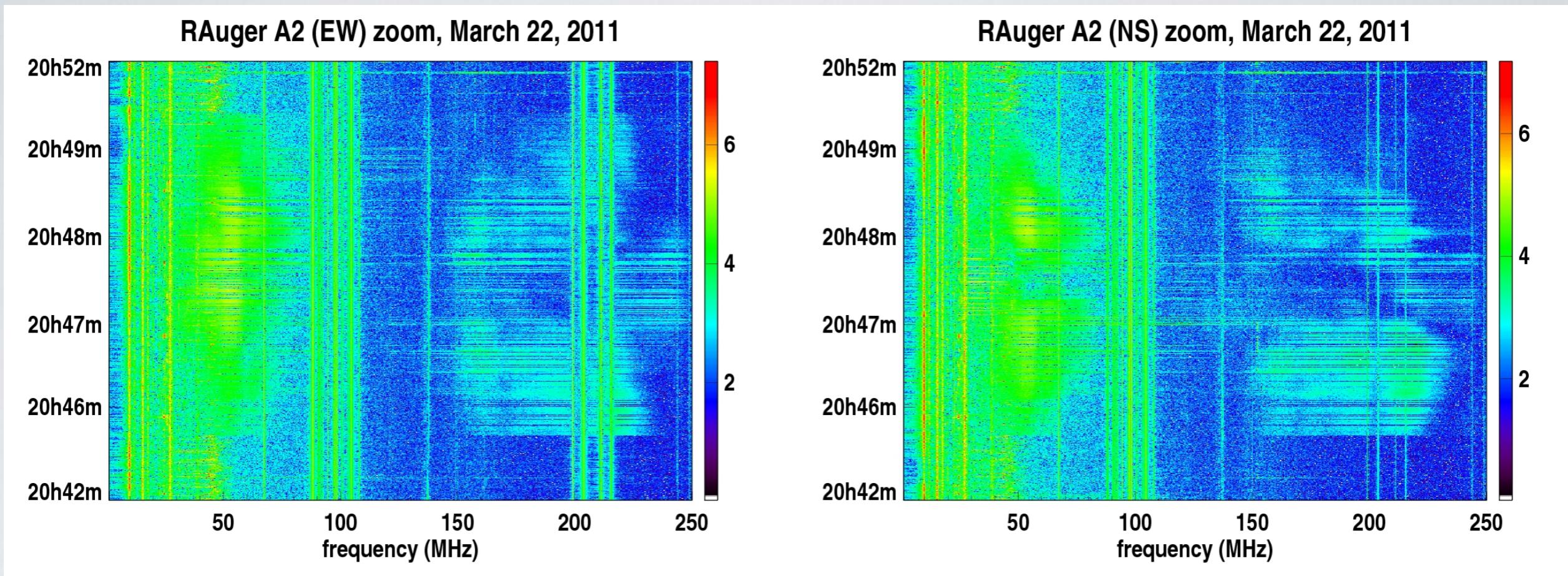


Figure 2: Time-frequency diagram for the first 10 000 events recorded by A2 on March 22, 2011, in both EW (left) and NS (right) polarizations. The highly variable trigger rate is visible in the event occurrence time scale. The airplane transit occurred between the two horizontal dashed lines between 20h45 UTC and 20h47 UTC.

FLIGHT 7I4 TO BUENOS AIRES...

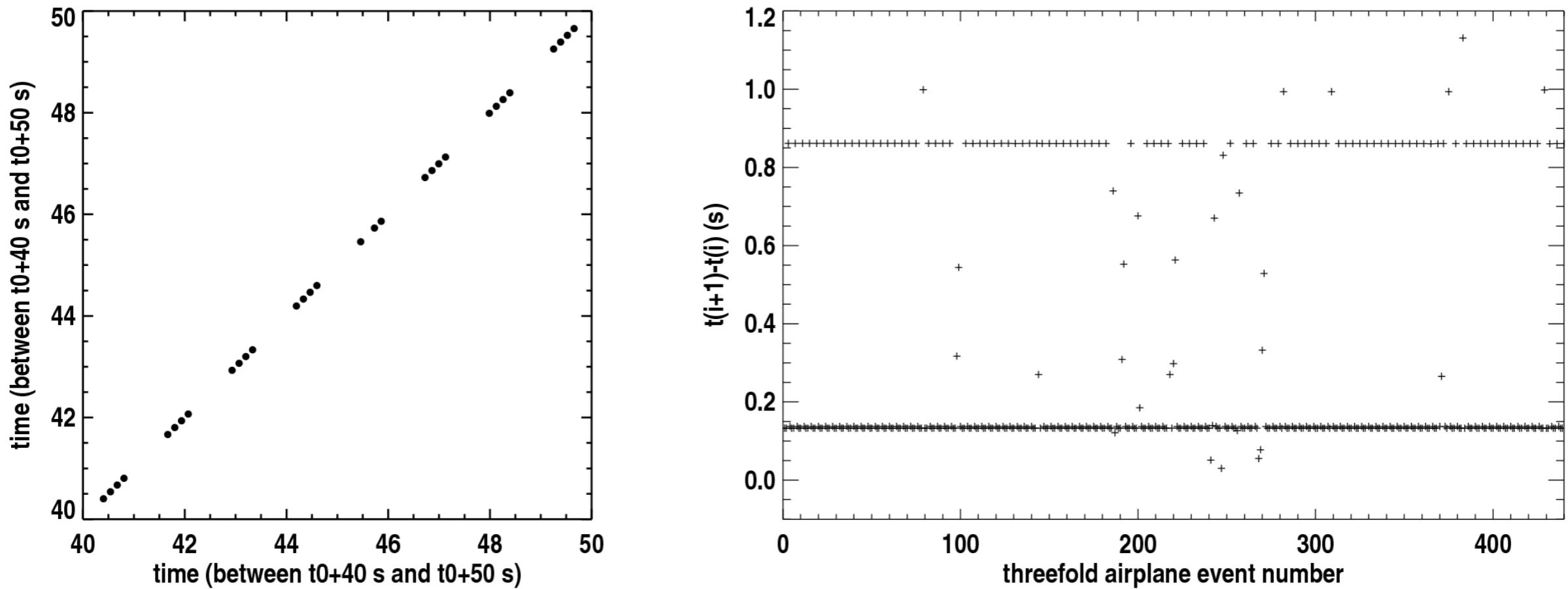


Figure 7: Left: reception times of the airplane signals as a function of time. The airplane sends data in bunches of 4 pulses (we missed the second pulse in the 5th bunch). These bunches are separated by 0.86112 ± 0.00028 s. Inside a bunch of 4 pulses, the time interval is 0.13287 ± 0.00009 s. t_0 denote the first time we can triangulate the airplane. Right: time intervals between two consecutive airplane pulses as a function of the event number (threefold events corresponding to the airplane).

FLIGHT 7I4 TO BUENOS AIRES...

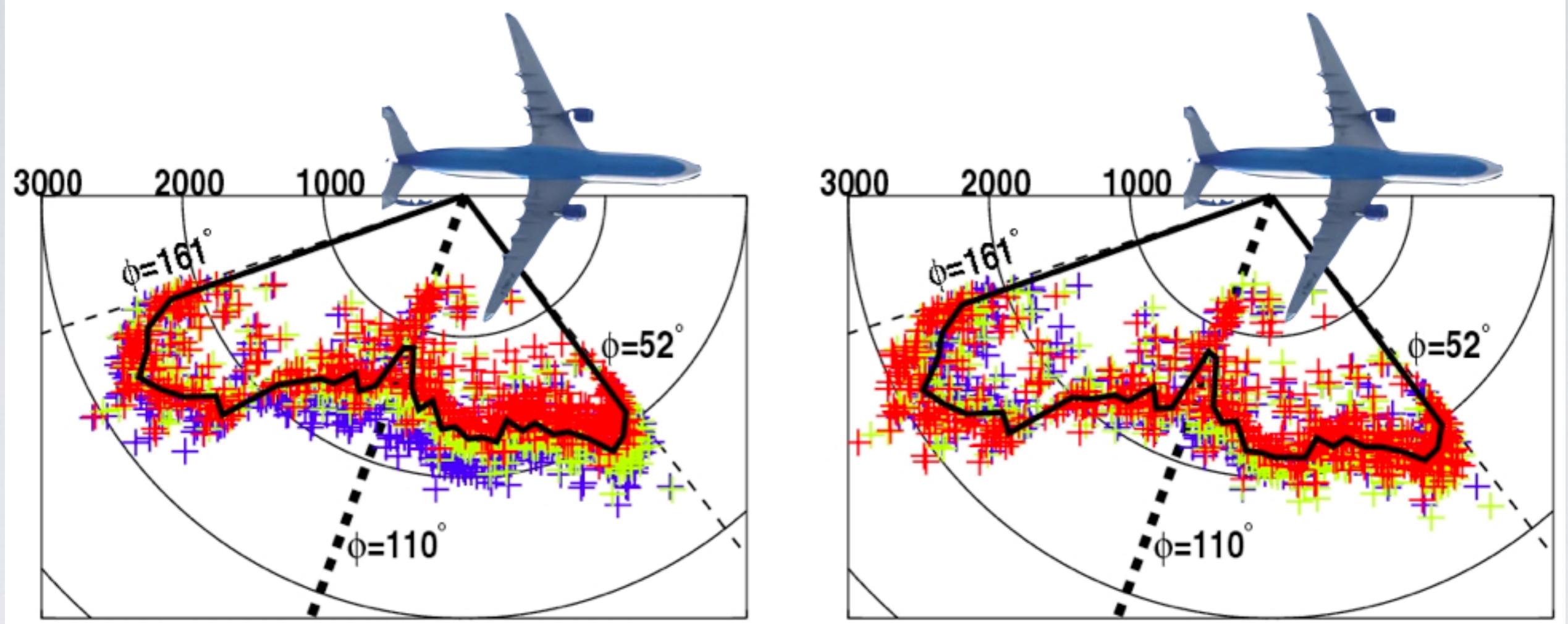
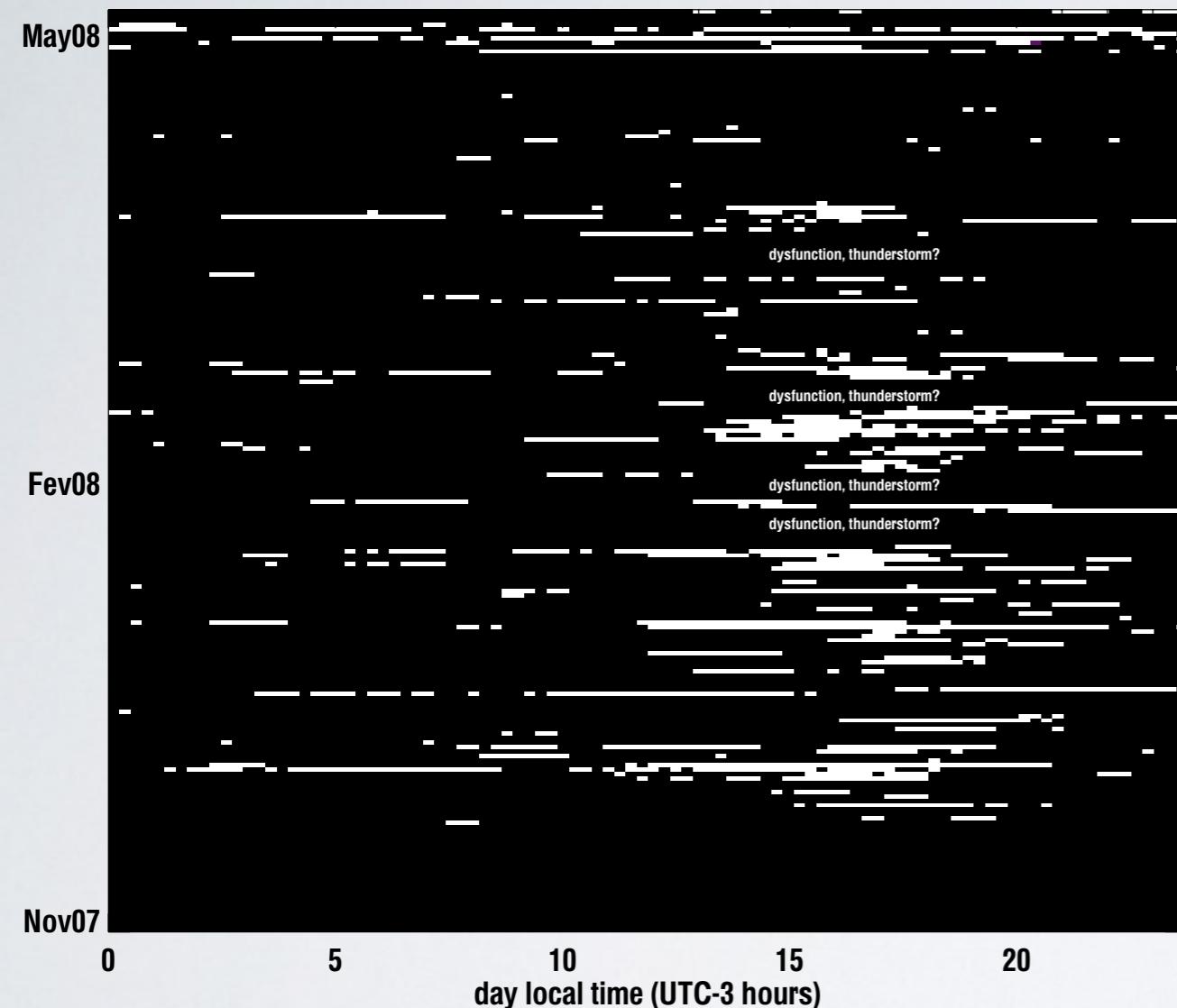


Figure 12: Emission patterns of the airplane, deduced from the measurements at ground. The total electric field value for stations A2, A3 and A4 is represented by the blue, yellow, red crosses respectively. The left plot correspond to the raw data recorded by the 3 stations. The right plot takes into account the intercalibration correction, using A2 data as reference. The circles labelled by 1000, 2000 and 3000 represents the amplitude of the total electric field.

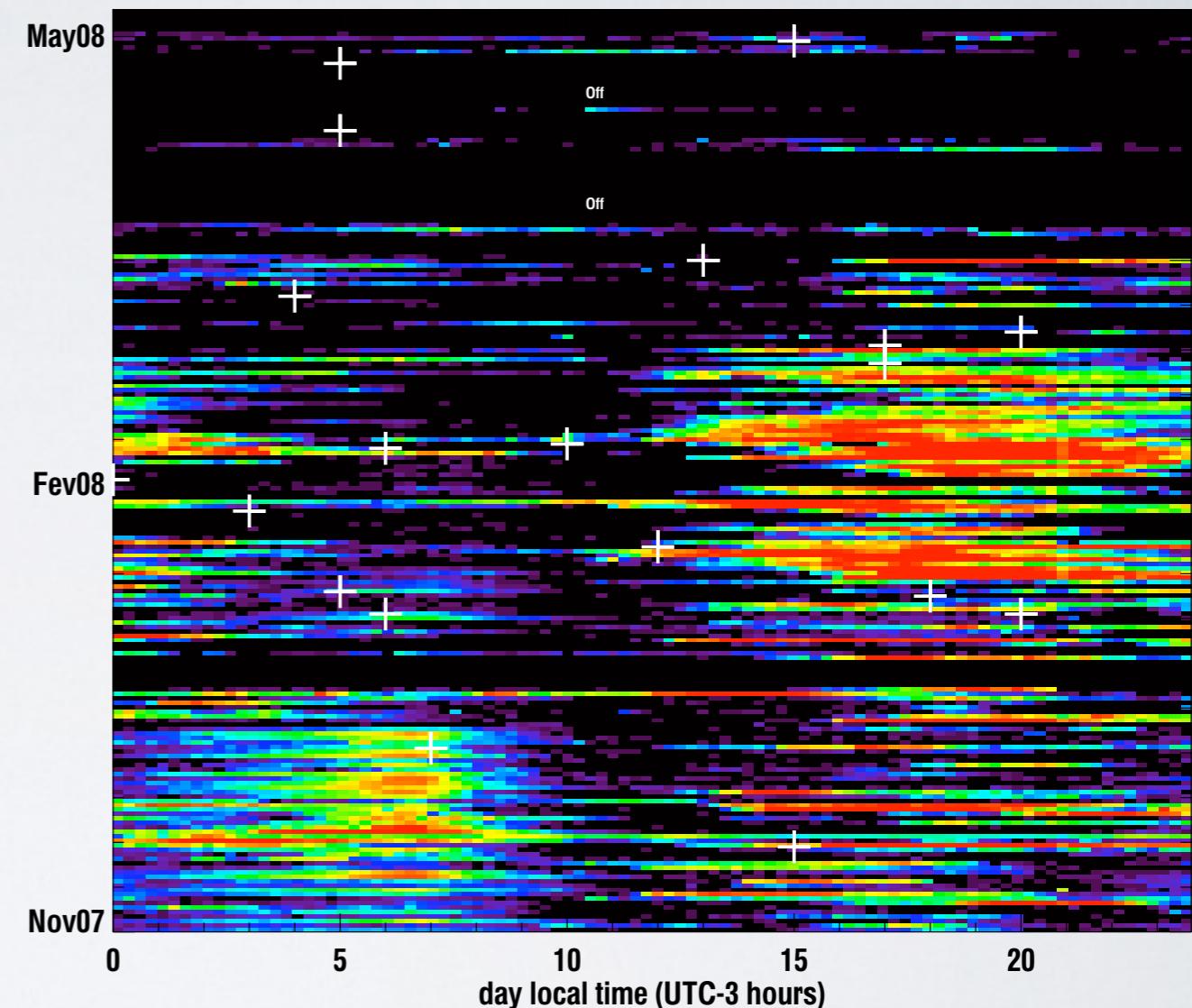
THERE IS ELECTRICITY IN THE AIR...

Localisation of pathological variation of electric field



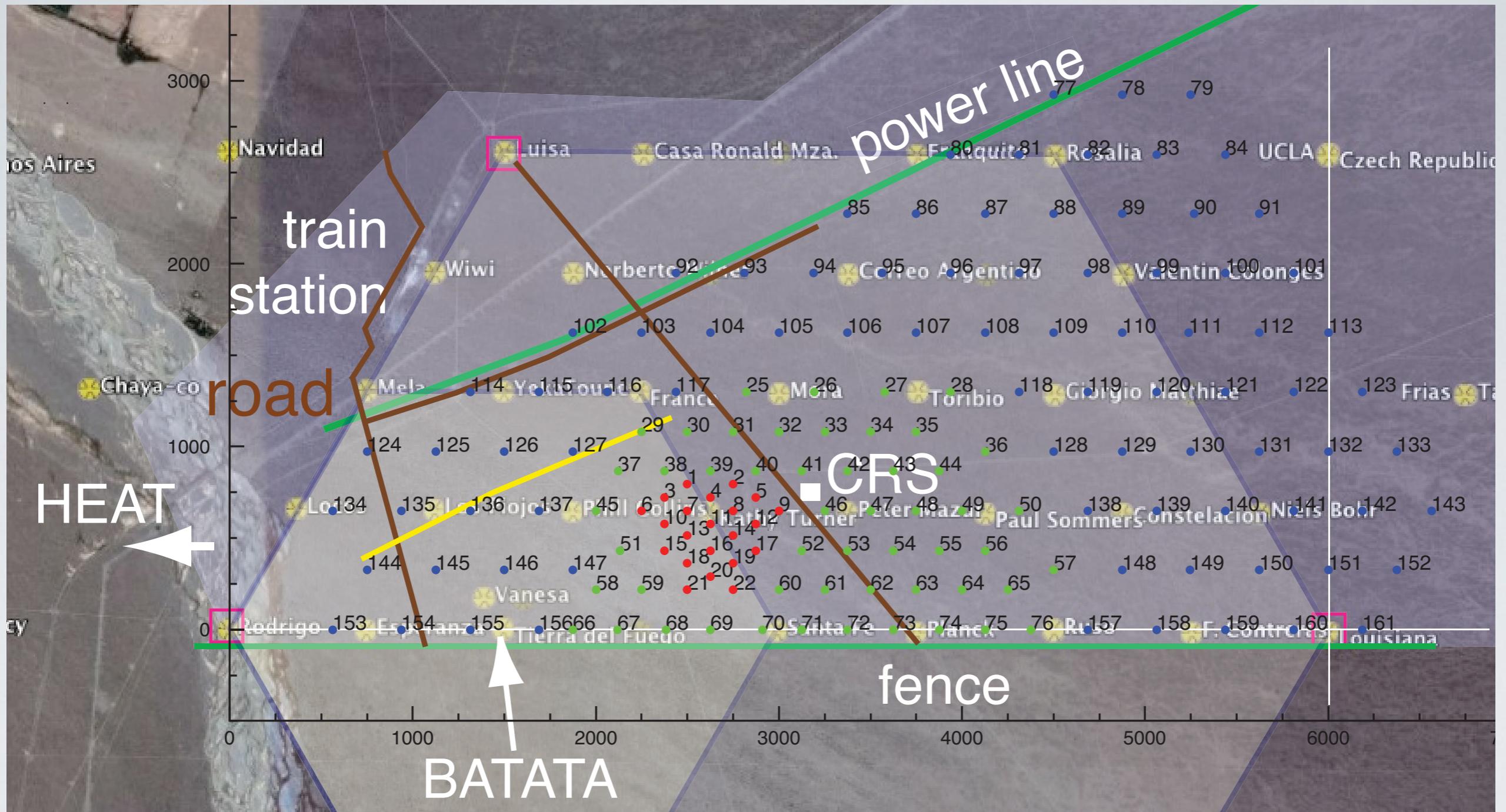
E-field > 50 V/m above average

Trigger rate for A1 from 2 Nov 2007 to 26 May 2008

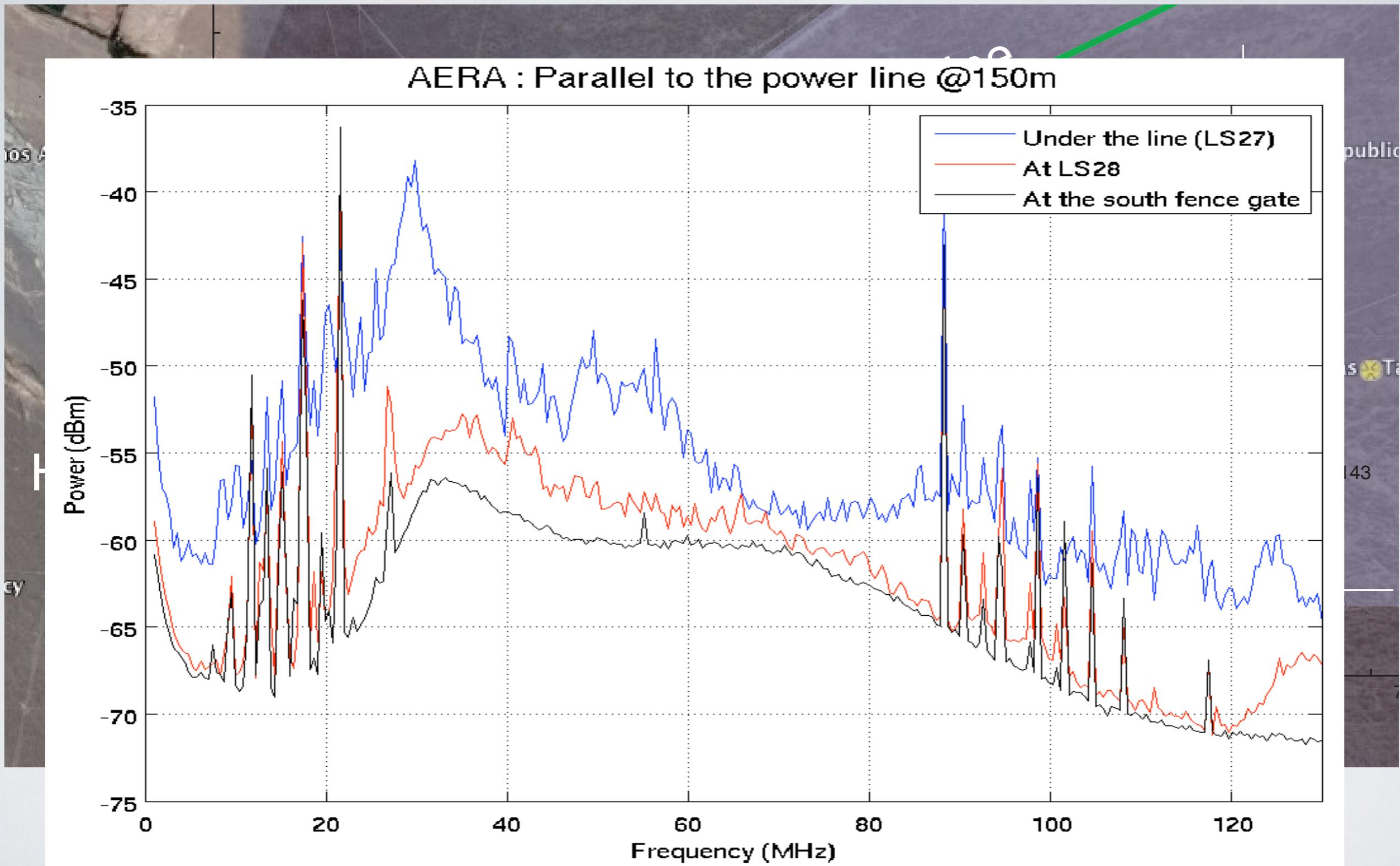


Trigger rate on 1 station

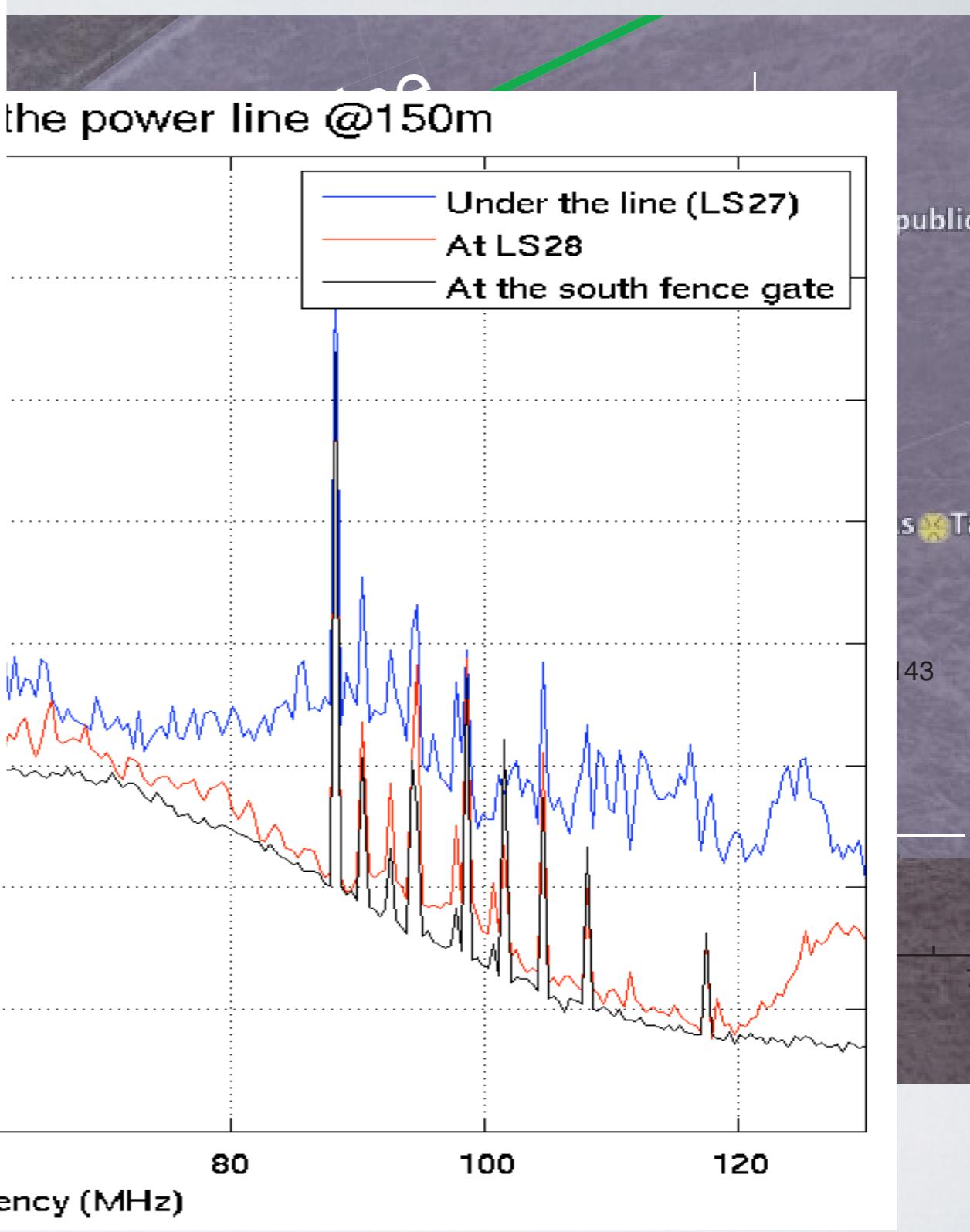
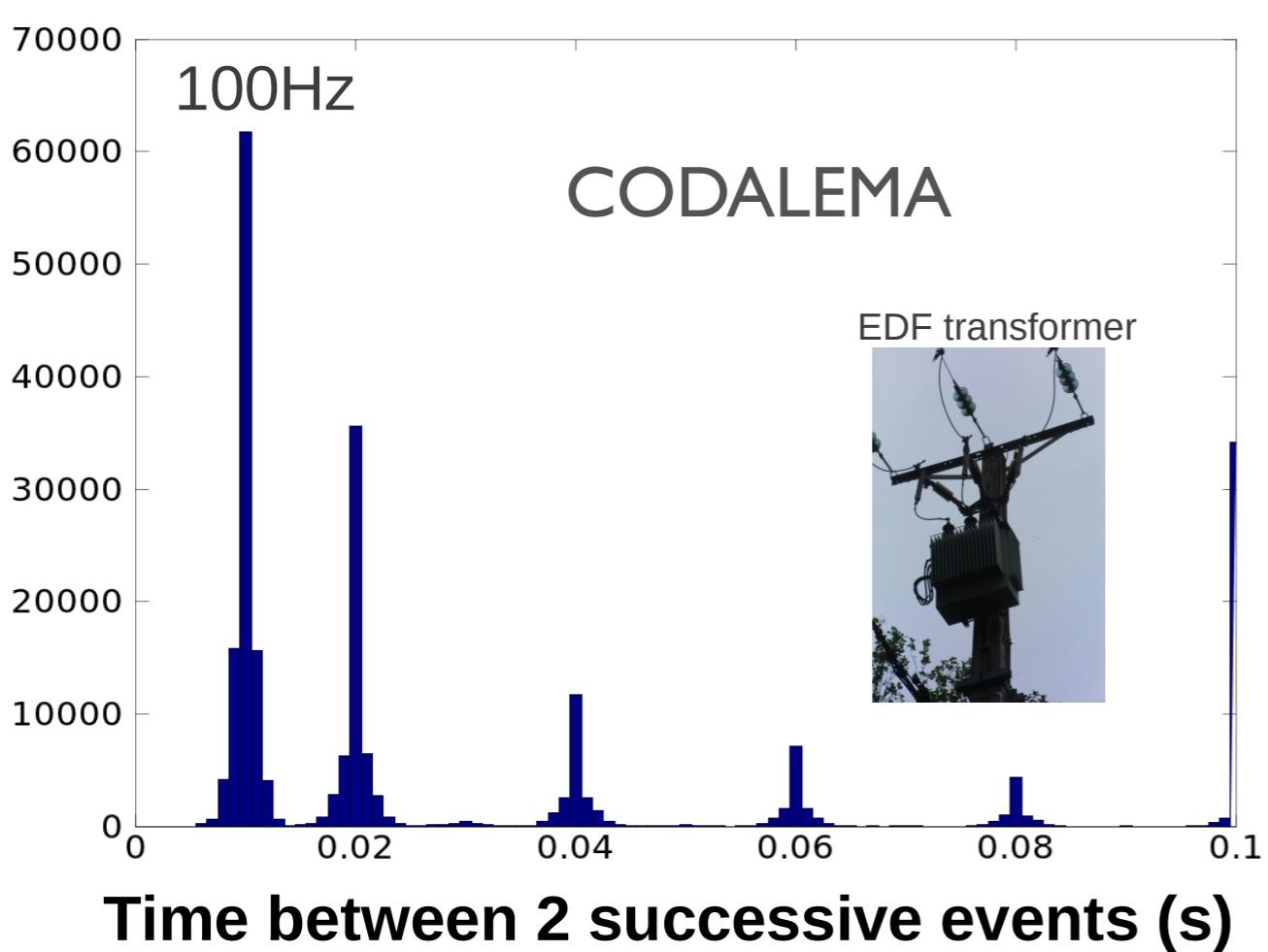
...BUT ALSO IN THE WIRES



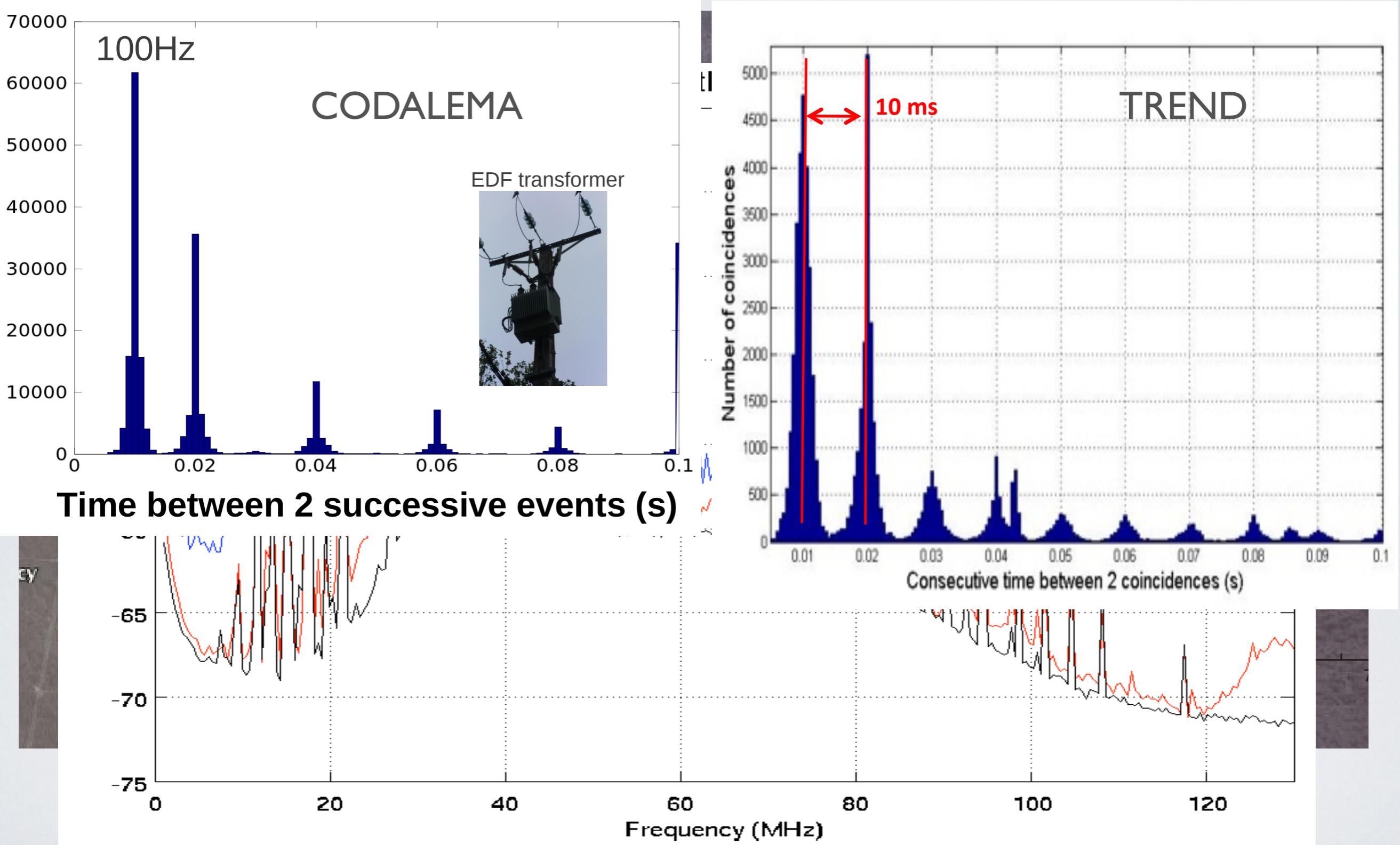
...BUT ALSO IN THE WIRES



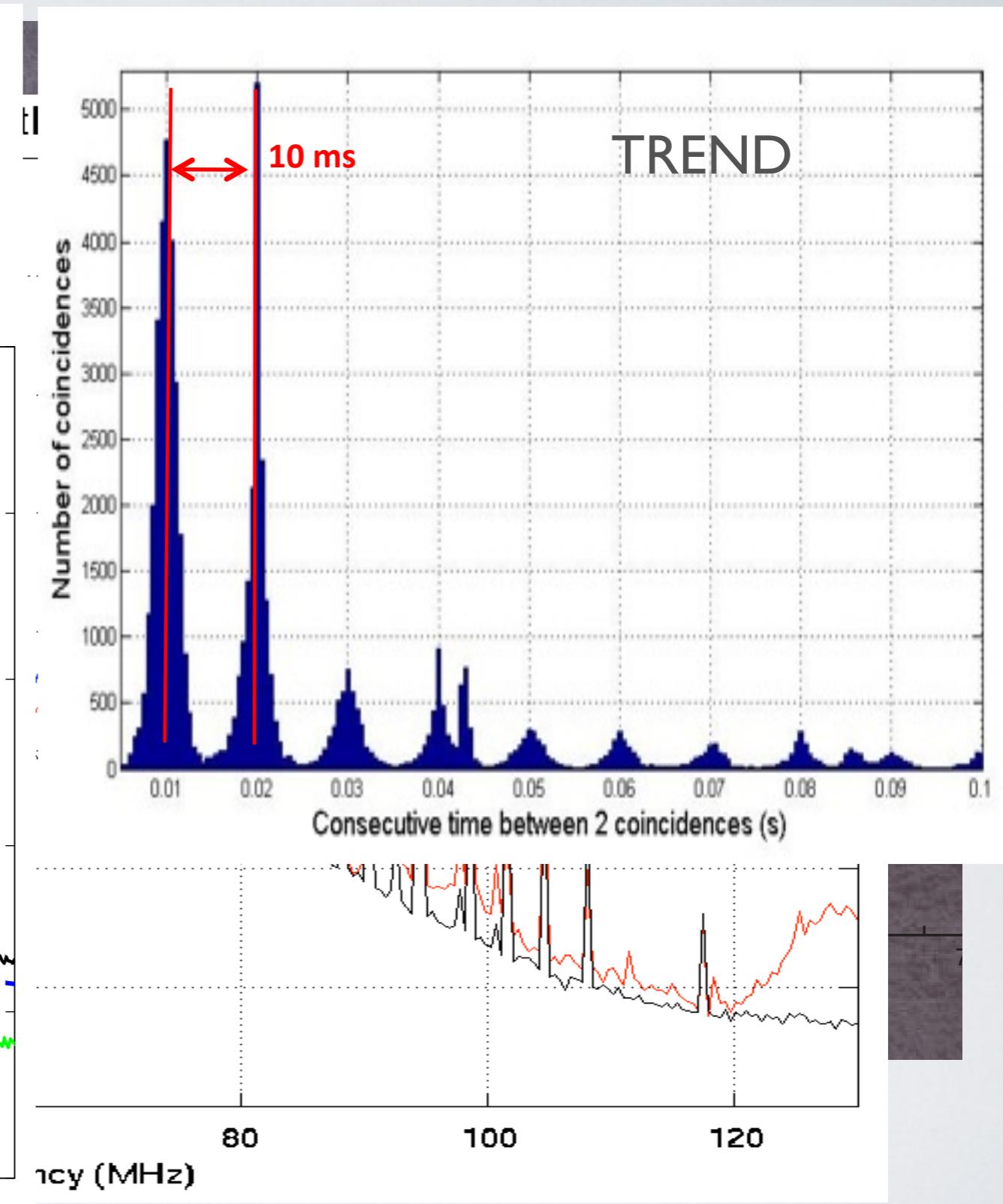
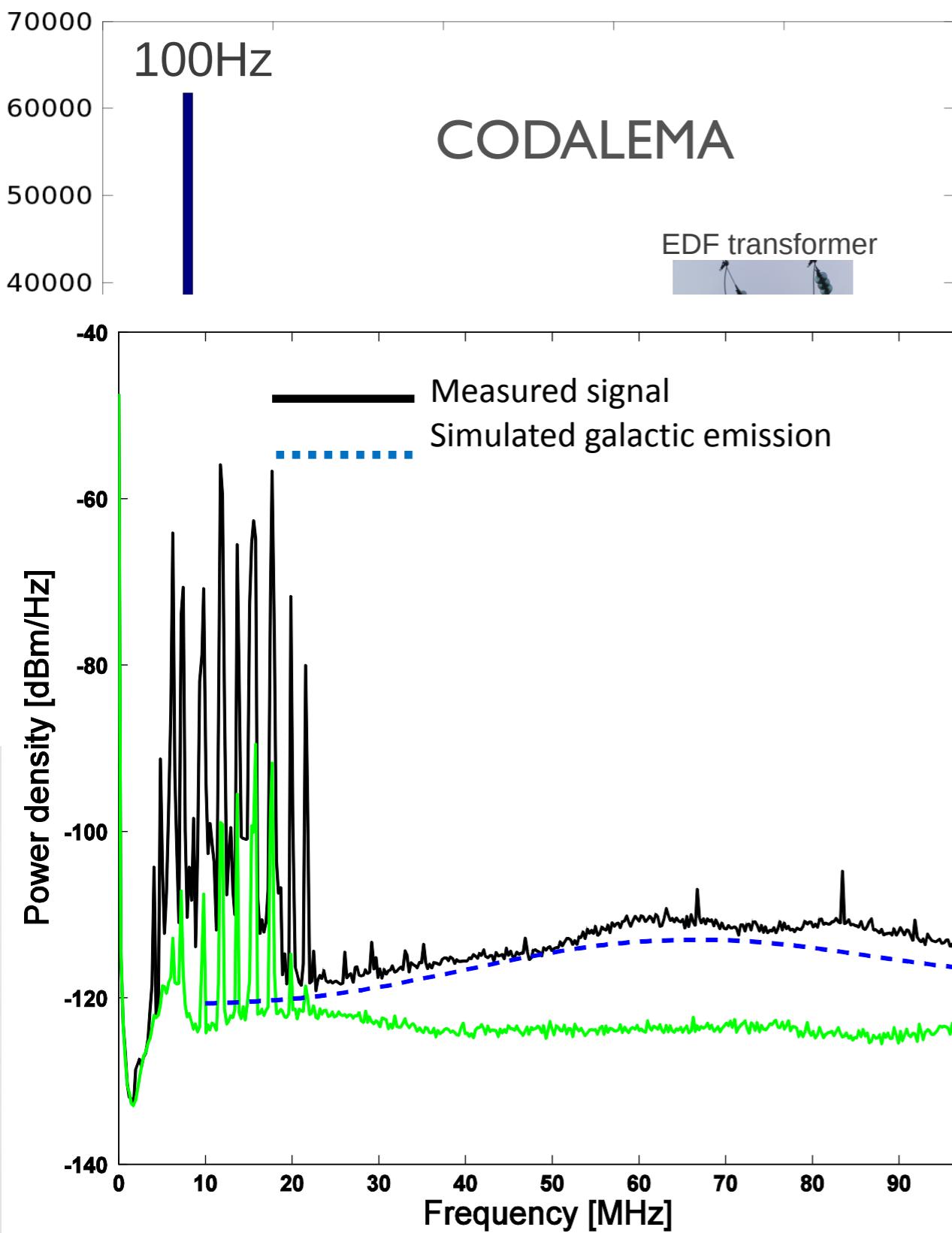
...BUT ALSO IN THE WIRES



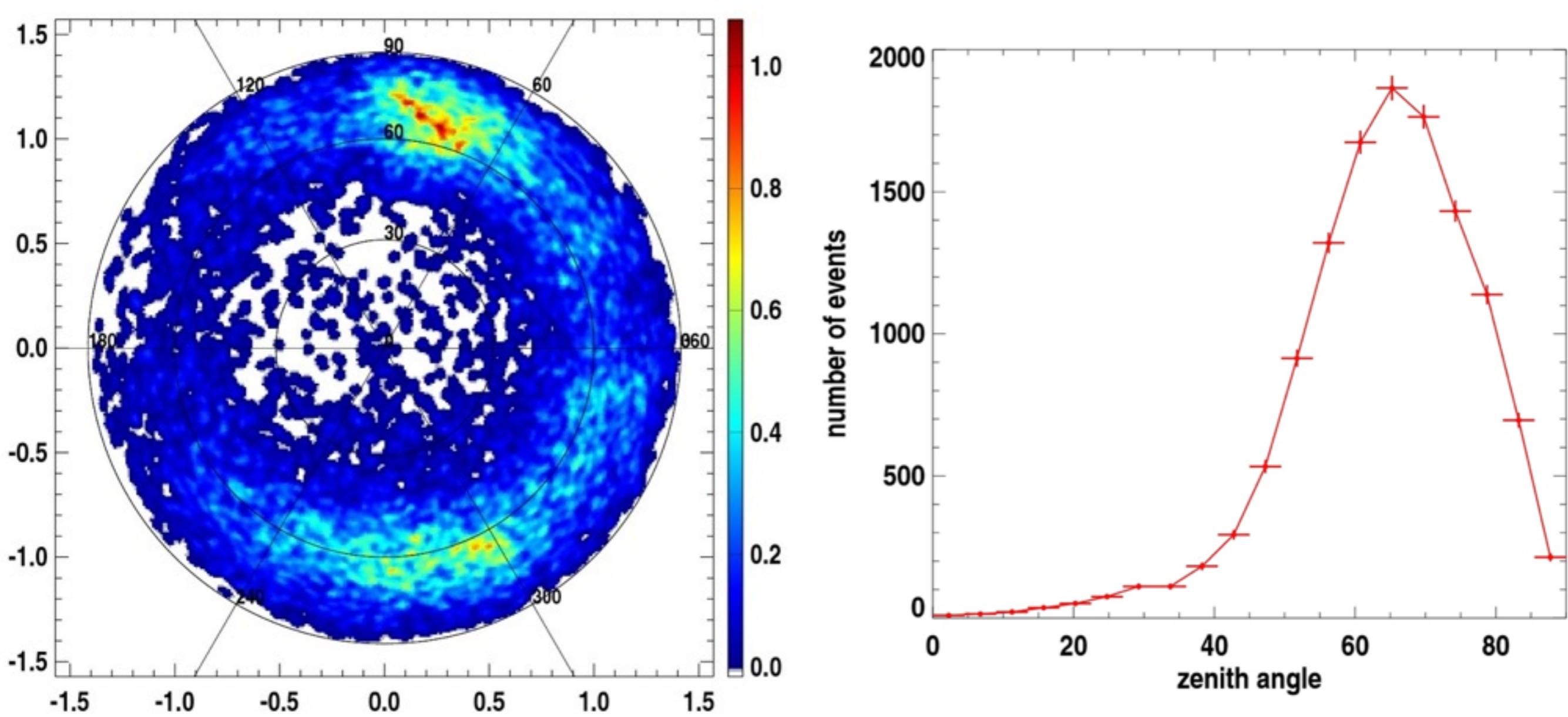
...BUT ALSO IN THE WIRES



...BUT ALSO IN THE WIRES

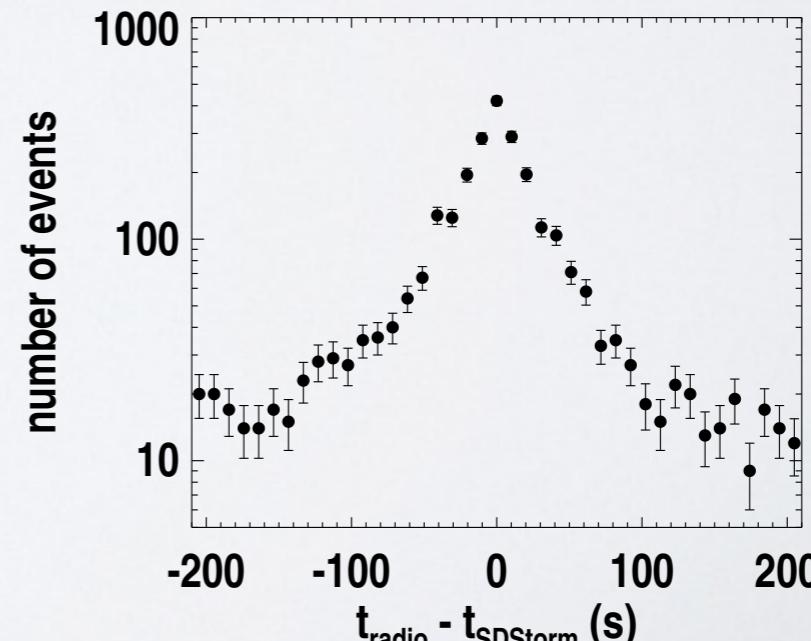
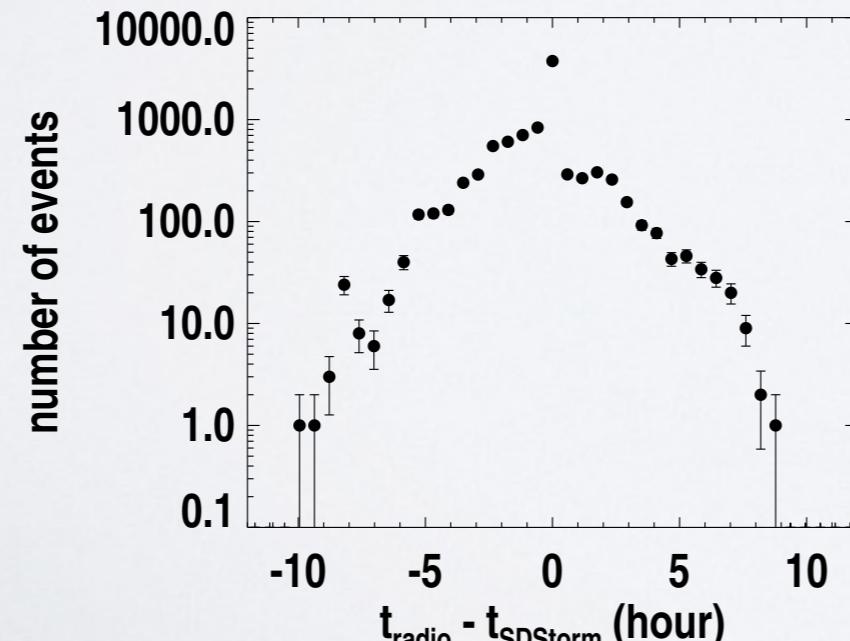
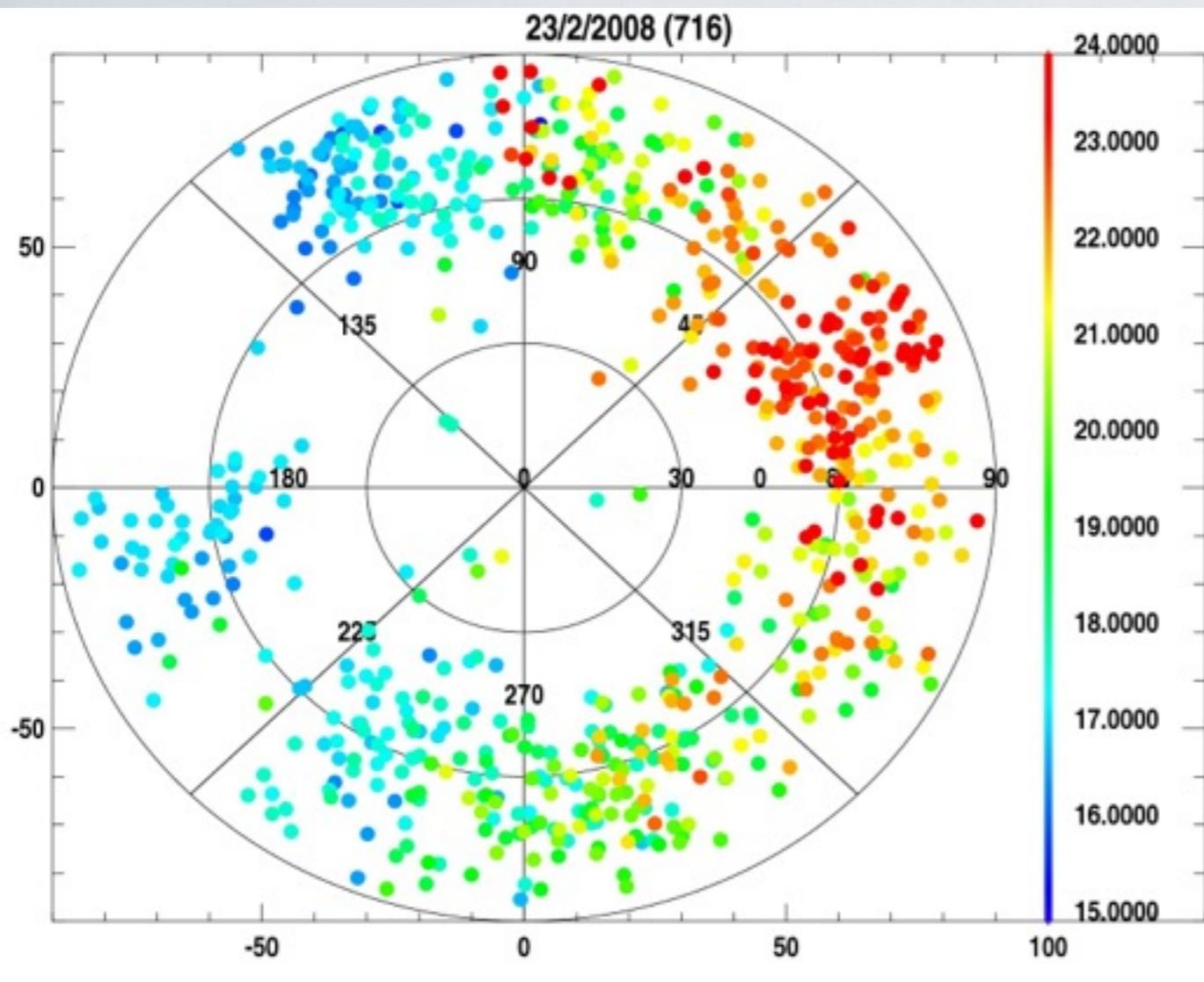


RAUGERs ON THE STORM

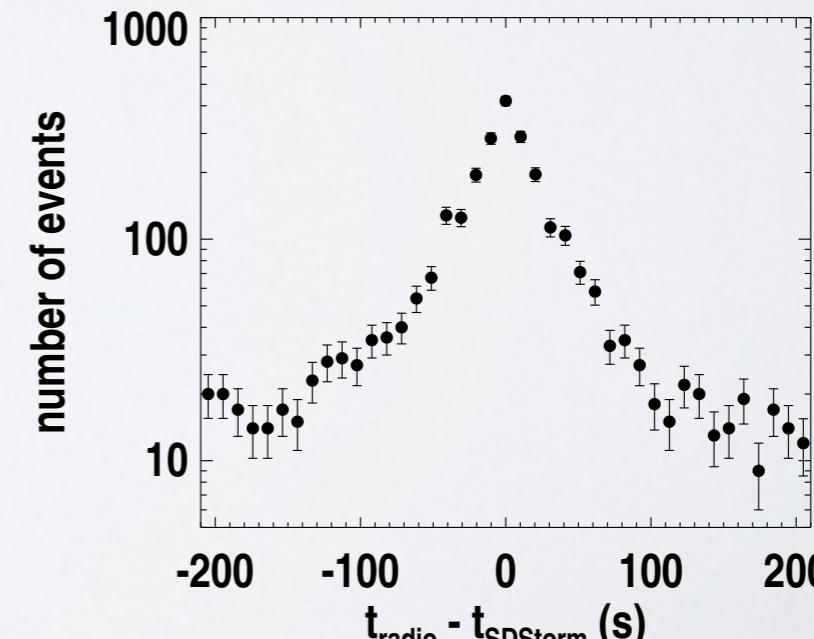
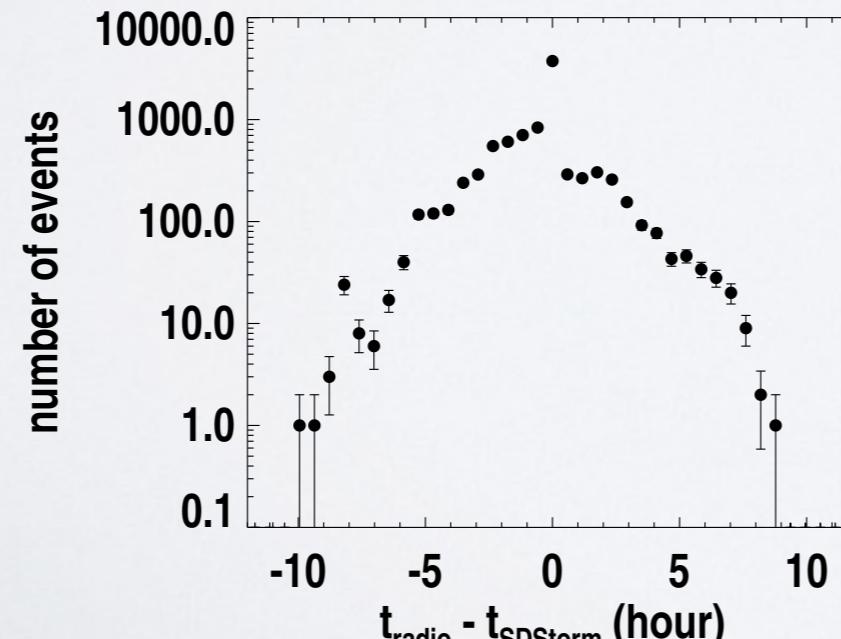
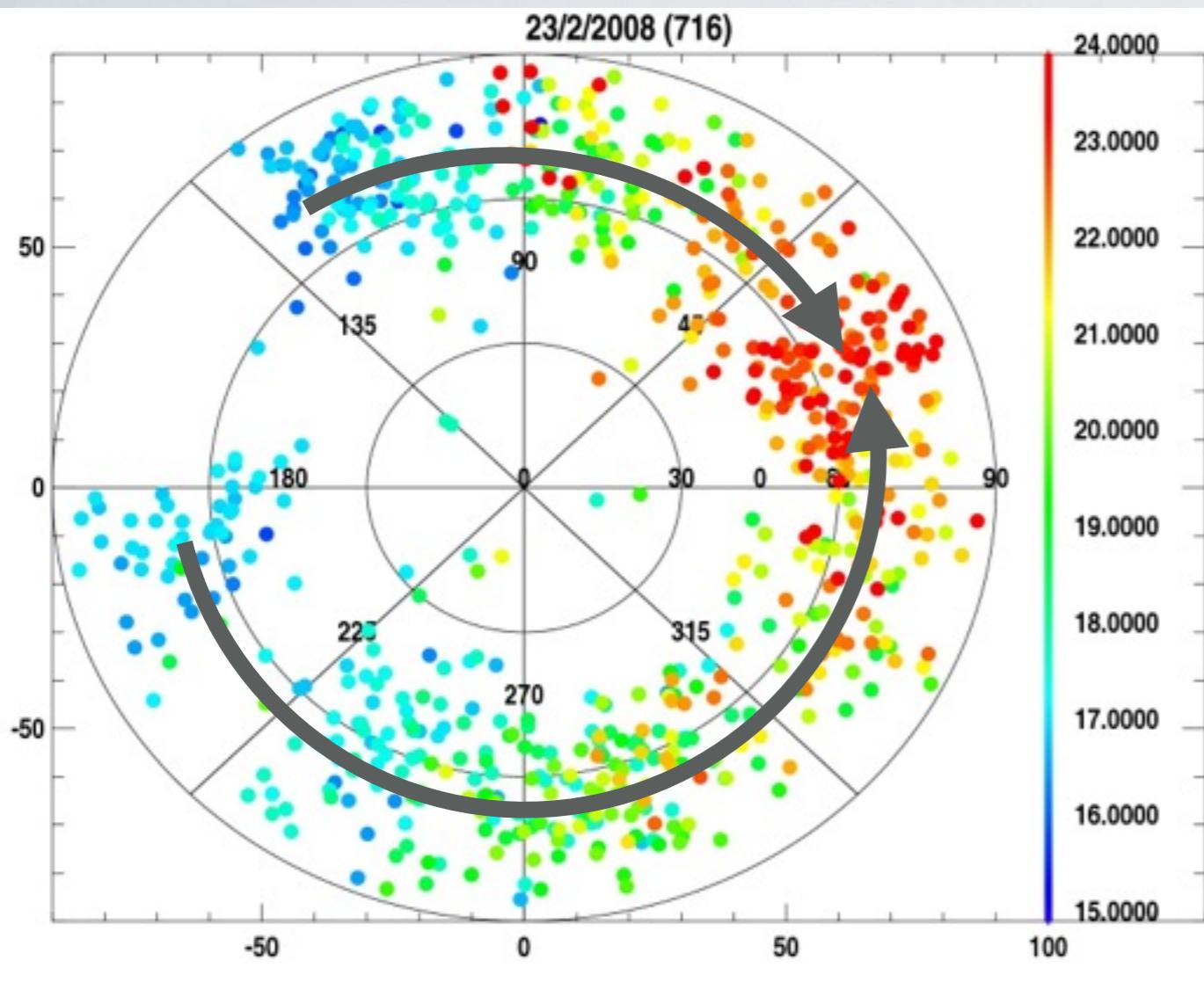


12576 events between december 2007 and april 2009 during thunderstorm conditions

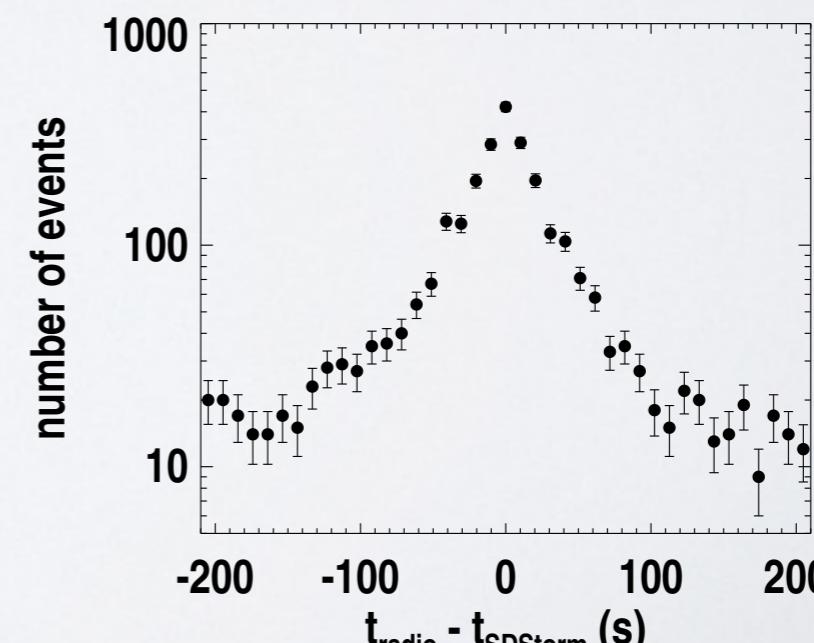
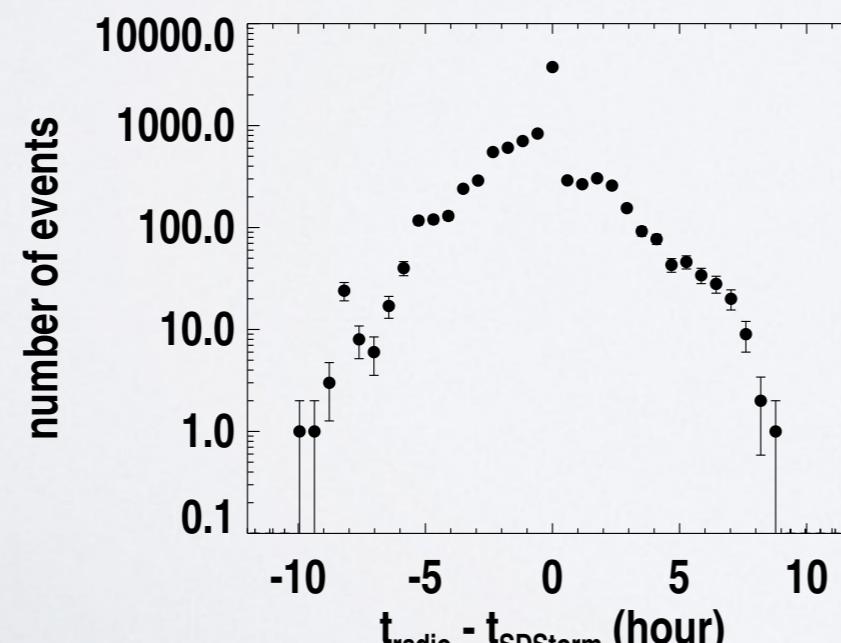
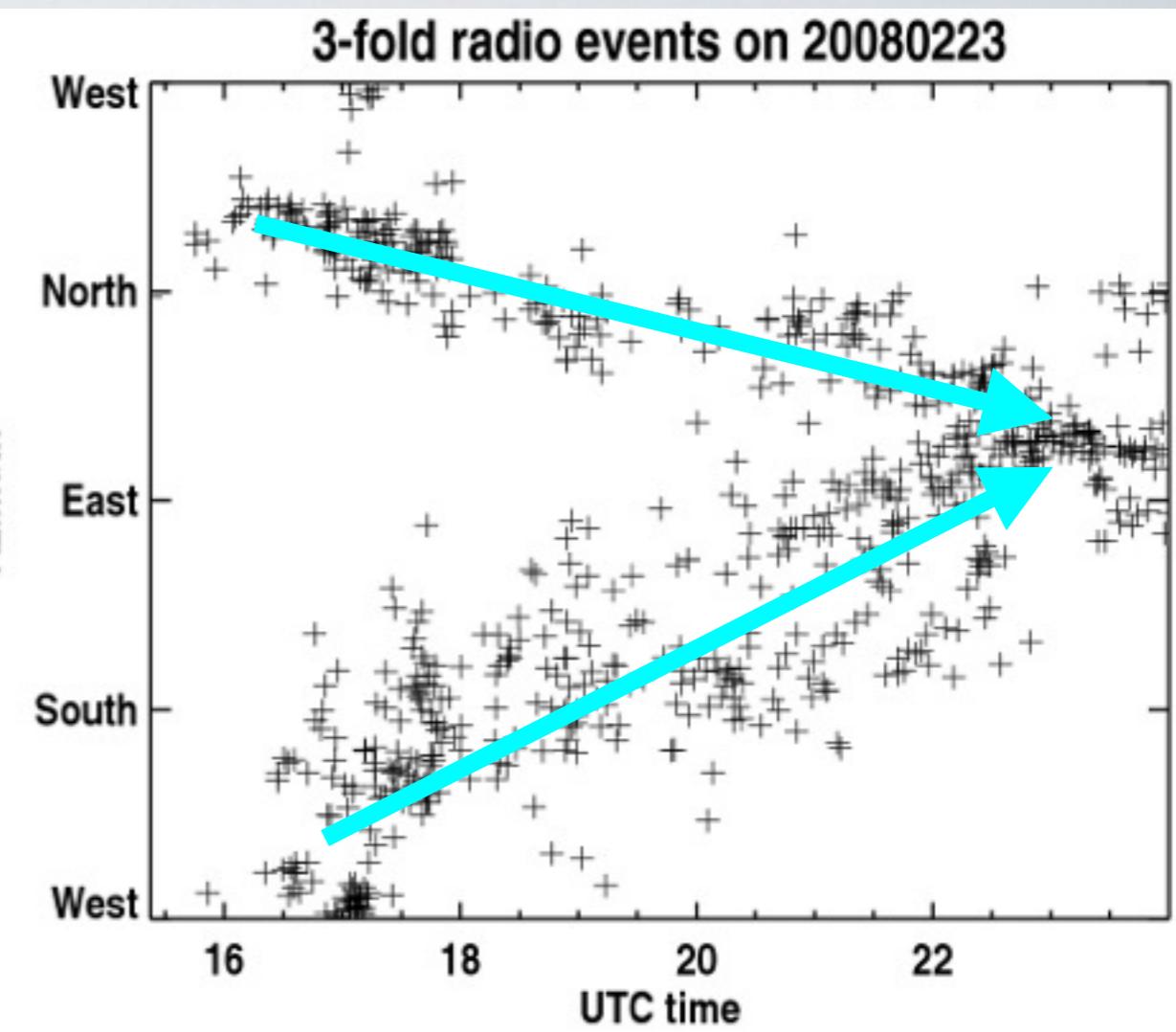
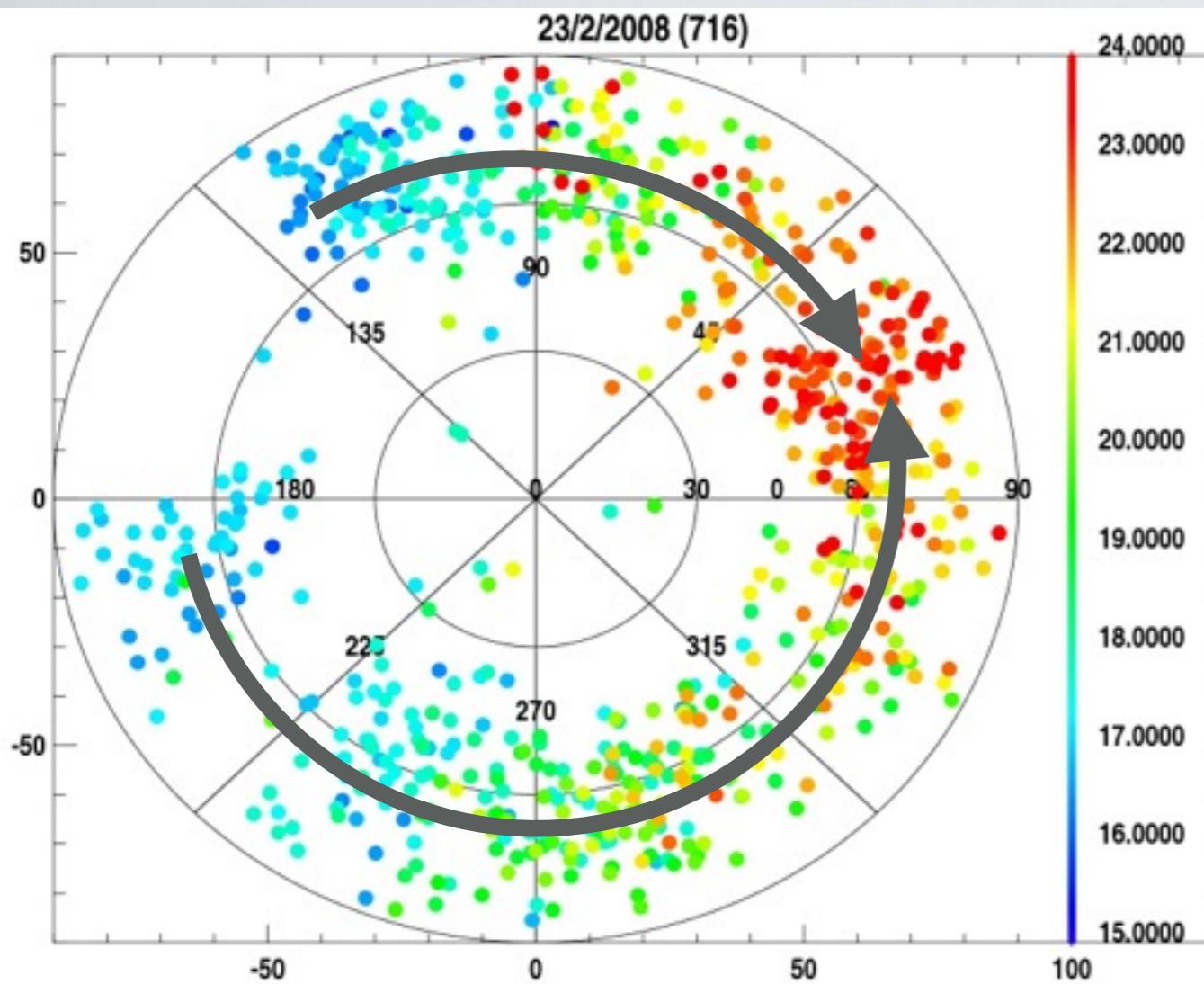
RAUGERs ON THE STORM



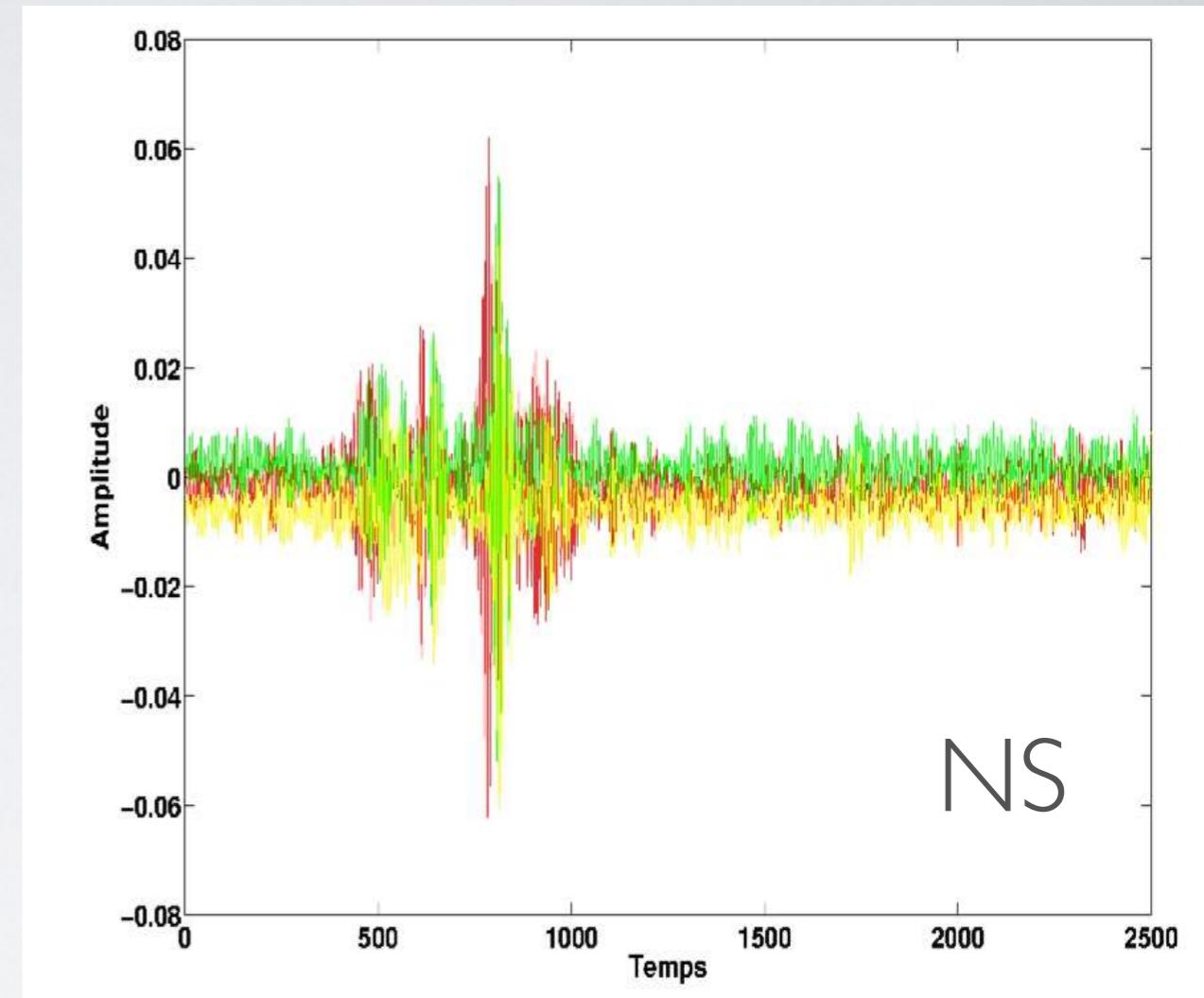
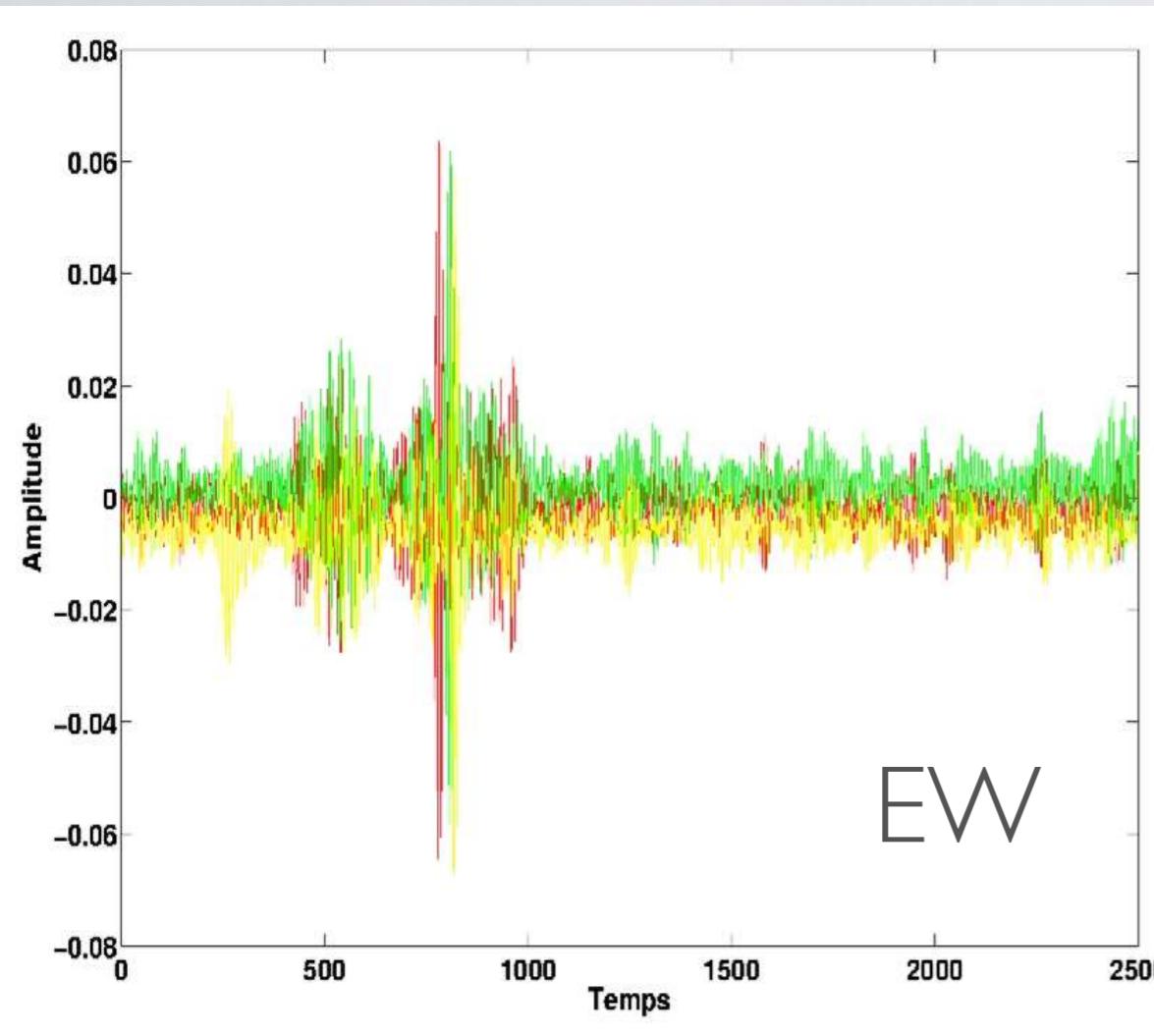
RAUGERs ON THE STORM



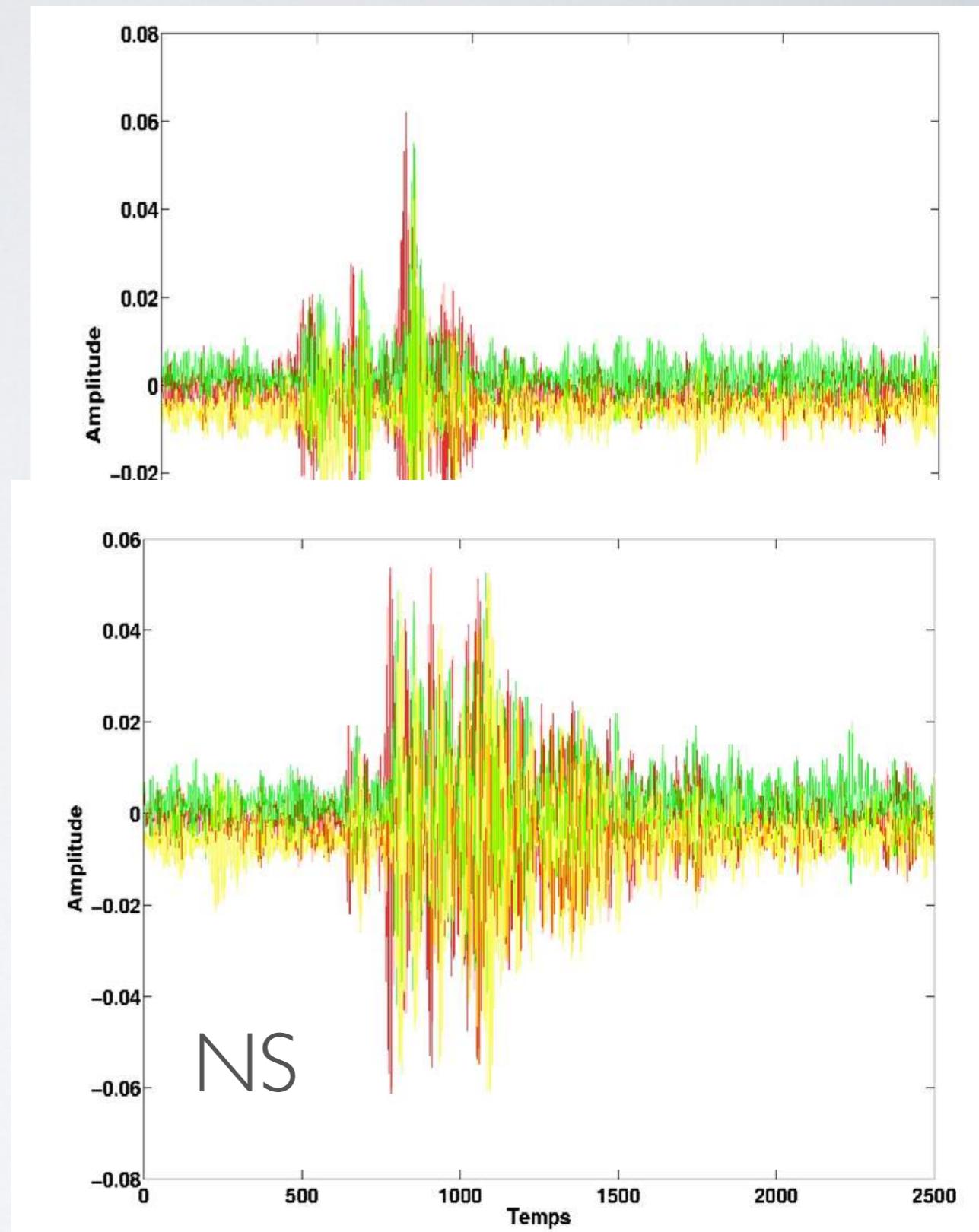
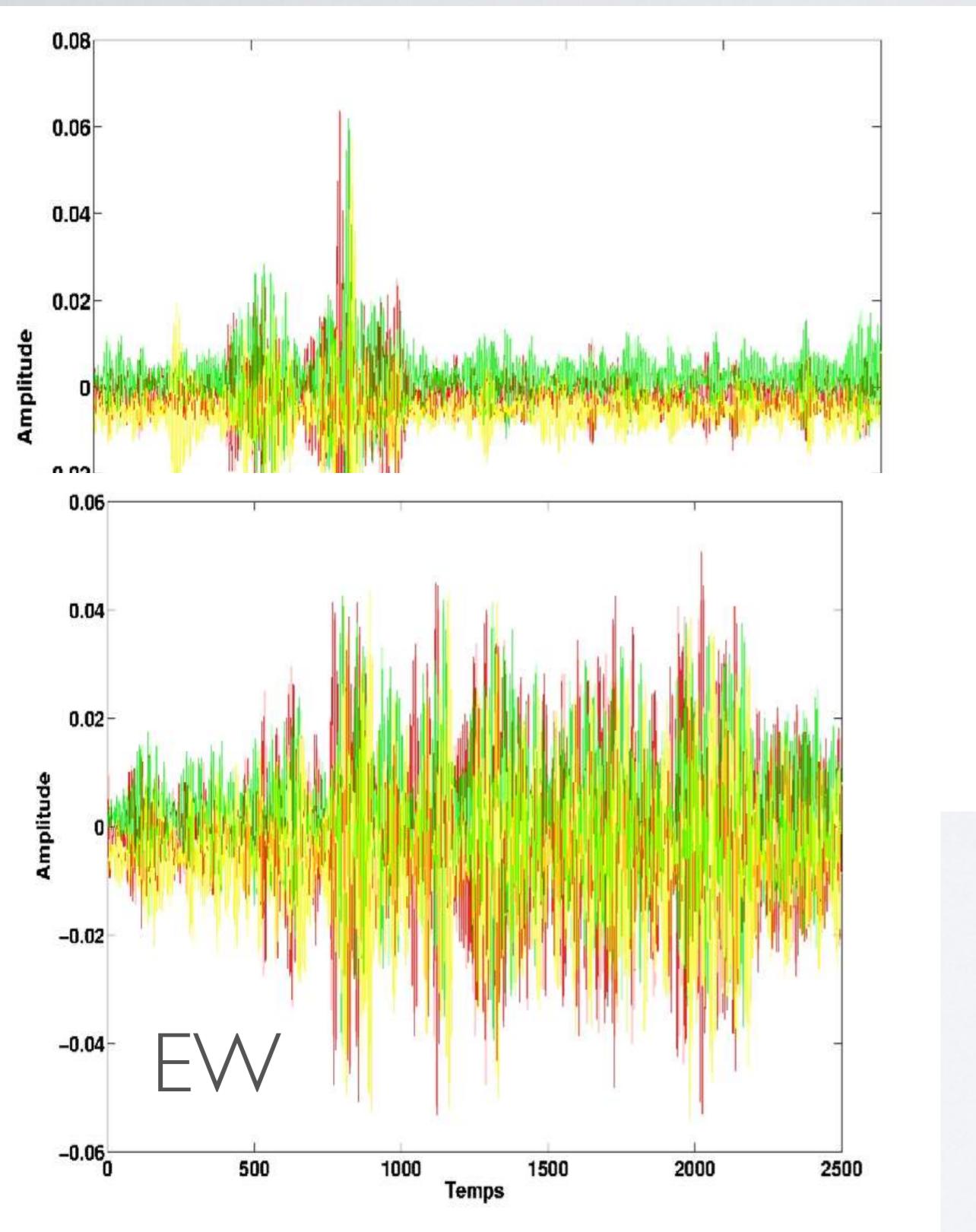
RAUGERs ON THE STORM



RAUGERs ON THE STORM

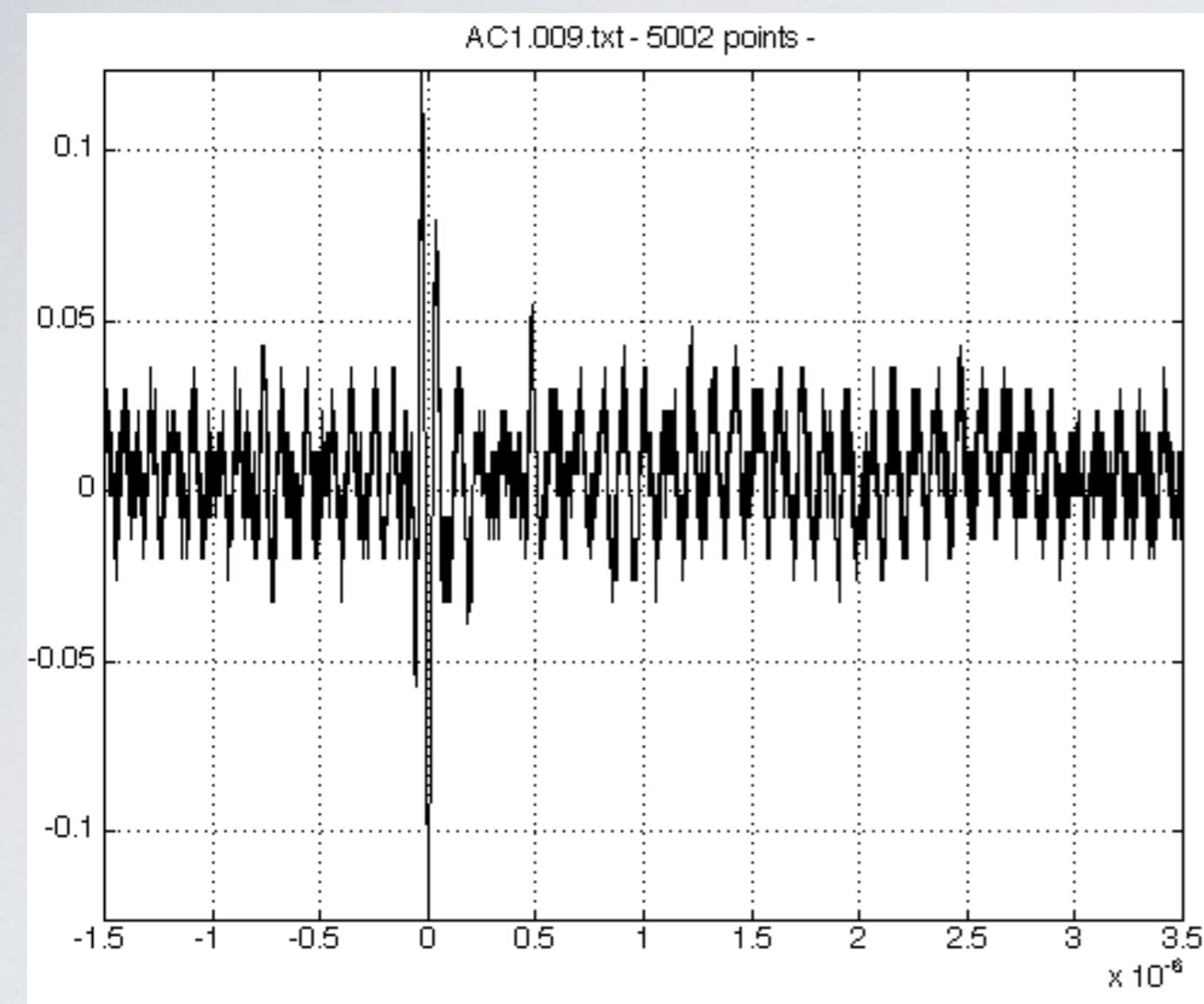


RAUGERs ON THE STORM



RAUGERs ON THE STORM

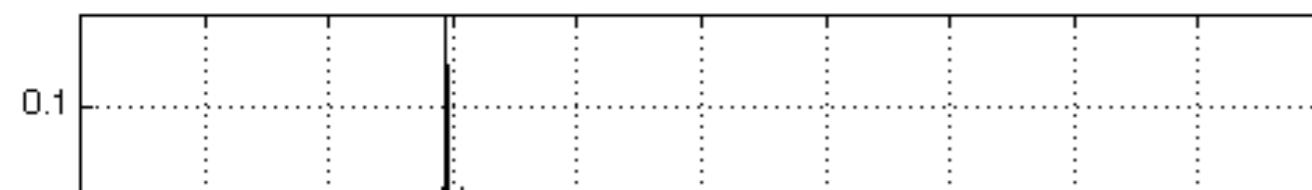
“CODALEMA” 2002!



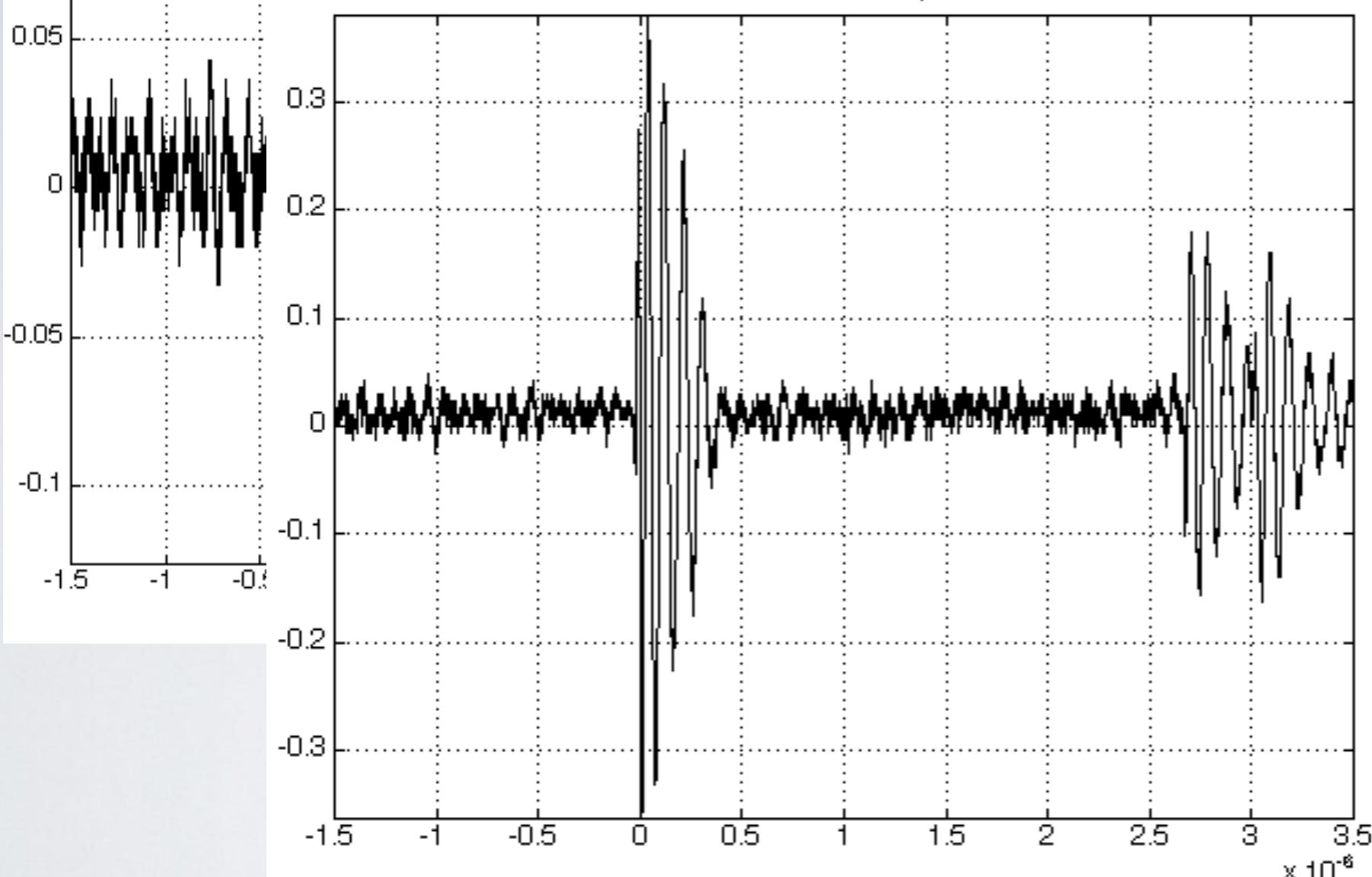
RAUGERs ON THE STORM

“CODALEMA” 2002!

AC1.009.txt - 5002 points -



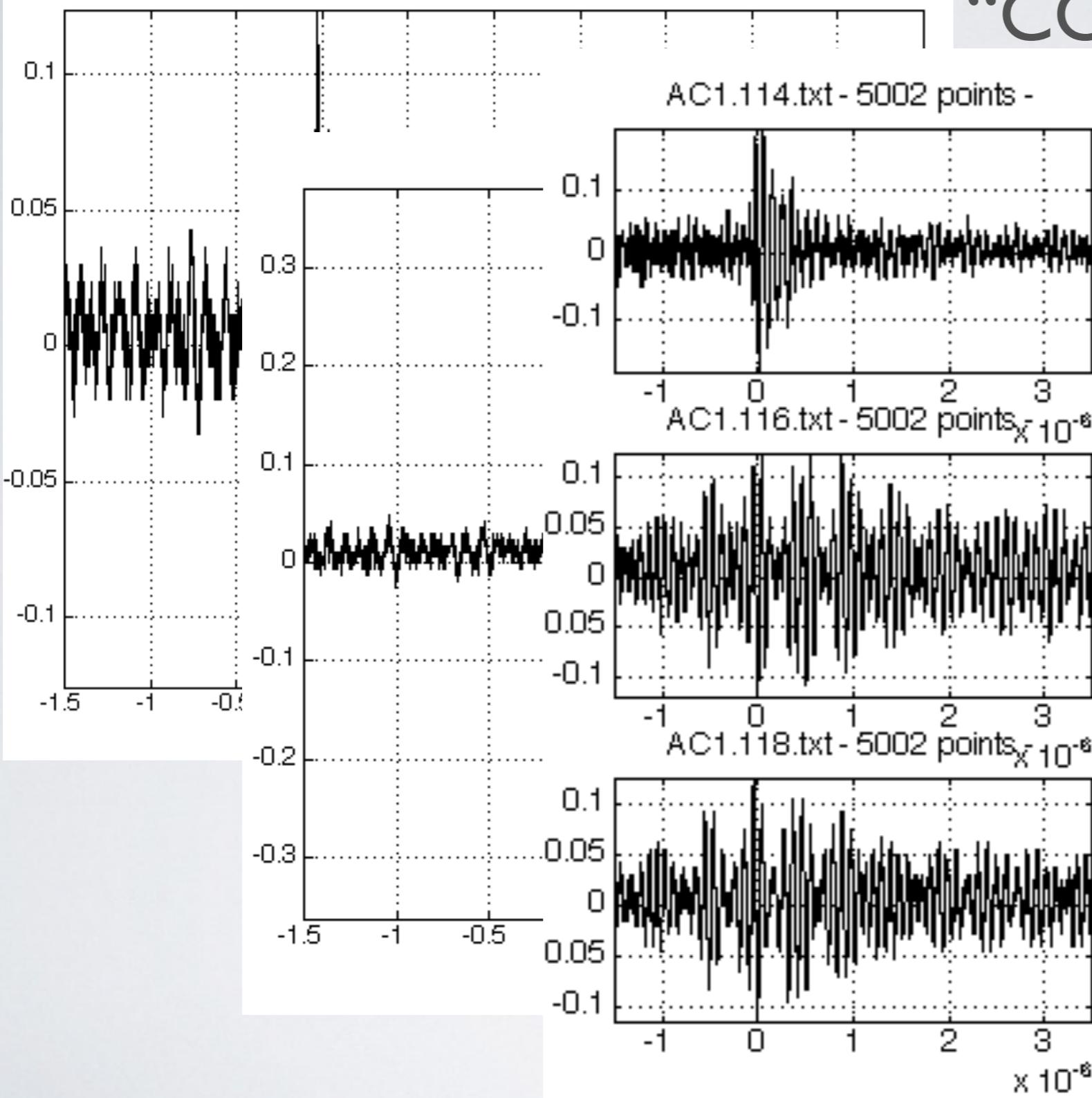
AC1.001.txt - 5002 points -



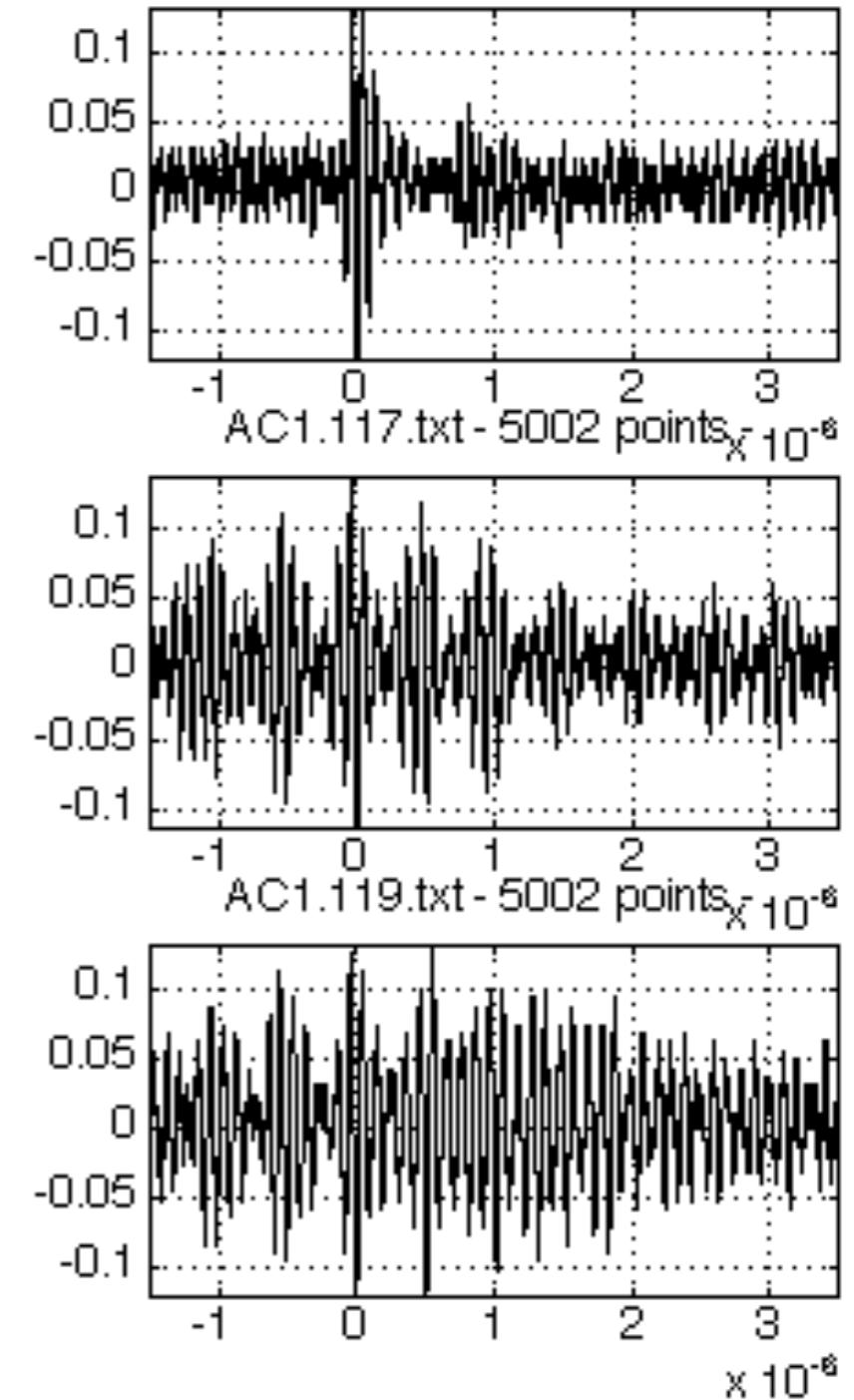
RAUGERs ON THE STORM

“CODALEMA” 2002!

AC1.009.txt - 5002 points -



AC1.115.txt - 5002 points -



CONCLUSION

- Very fast transient signals were not well known at the beginning of CODALEMA...
- ...but still are a problem in CR detection
- We have to know them to help identifying CR
- Detection techniques are now more powerful
- The concept and tools could be used for other observations (thunderstorms, lightnings, fast astrophysical transients...?)
- We expect a fruitful crossover between other domains and ours