Technological developments for AERA

Auger Engineering Radio Array

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on behalf the Pierre Auger Collaboration

PIERRE AUGER OBSERVATORY

MINES Nantes

cnrs IN2P3 Les deux infinis

Région PAYS DE LA LOIRE

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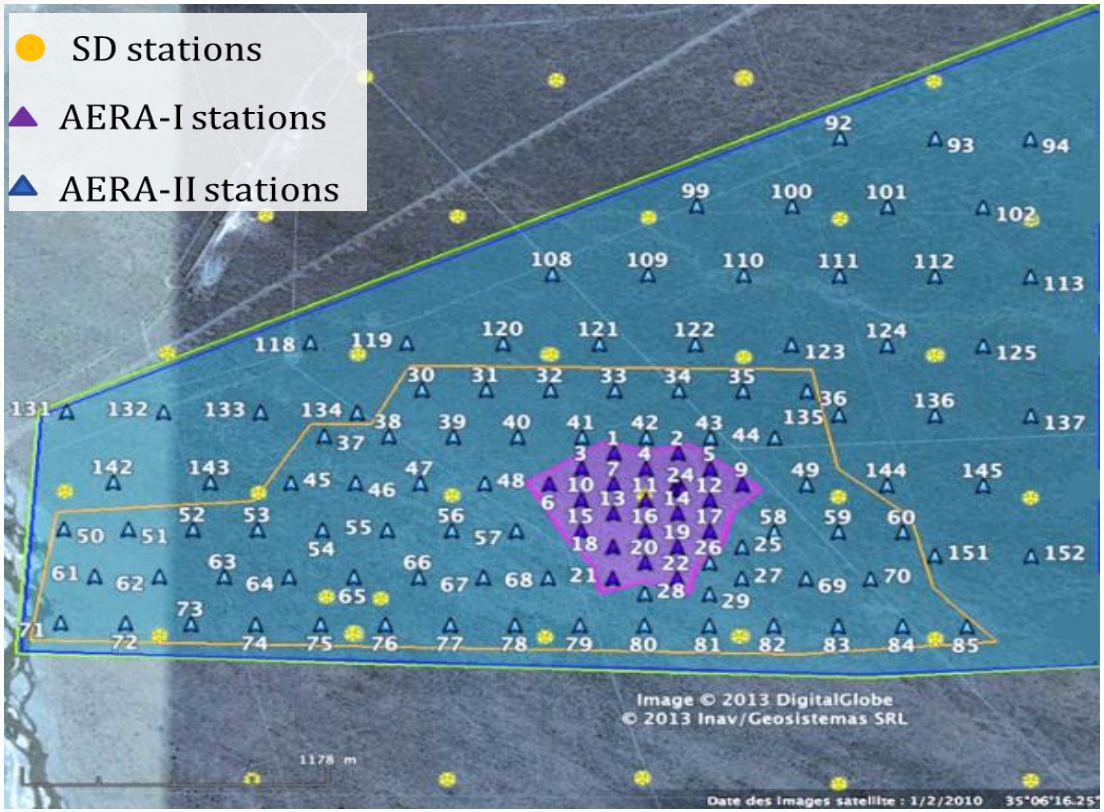
Current status of the Auger Engineering Radio Array



- 77 stations externally *(mainly SD and FD)* **and** self-triggered
- 6 stations **purely** self-triggered
- 40 stations externally (AERA scintillators) **and** self-triggered

AERA: one radio array of 6 km^2, different instruments in comparison

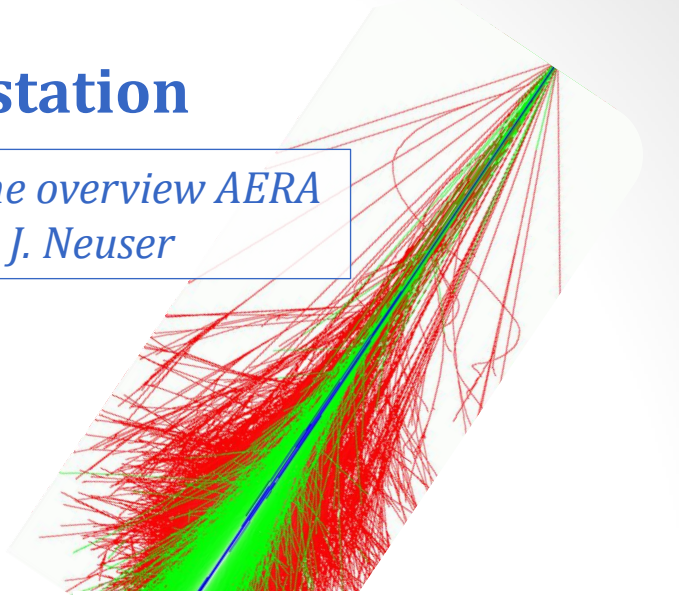
→ Continuous technological developments to keep improving the measurement of the electric field induced by air-showers

AERA Auger Engineering Radio Array

Schematic view of an AERA local station

The electromagnetic part of the shower induced an electromagnetic (EM) field

See the overview AERA talk – J. Neuser



Antenna + LNA

EM field:
- detected by the antenna,
- directly amplified by a LNA

Solar powered

Filter/Amplifier

Analogical processing of the signal

GPS antenna for precise time measurements

Trigger/digitizer

Digital processing
→Trigger algorithms (T1/T2)

Communication with the central DAQ

Communication antenna

AERA Auger Engineering Radio Array

Local station - The Antennas and their LNAs

2 antenna types – Measuring the horizontal polarizations of the electric field in a 30-80 MHz range (radio quiet band)

Log-Periodic Dipole Antenna - AERA-I, since March 2011

24 stations – Spacing: 140 m

- Used for one of the AERA pathfinders (MAXIMA)
- Two independent planes → $4 \times 4 \times 3.4\ m^3$
- **LNA**: Infineon amplified with a BGA420 MMIC

Local station - The Antennas and their LNAs

2 antenna types – Measuring the horizontal polarizations of the electric field in a 30-80 MHz range (radio quiet band)

Butterfly – Active bowtie antenna - AERA-II stations, since May 2013

100 stations – Spacing: 250 m or 375 m

See D. Charrier talk

- Developed for CODALEMA
- Used for one of the AERA pathfinders (RAuger)
- Two bowtie antennas → $2 \times 2 \times 2\ m^3$
- **LNA**: ASIC – AMS BiCMOS 0.8 µm

Local station - The Antennas and their LNAs

Why did we chose the Butterfly for stage 2 ?

The Pierre Auger Collaboration
*2012 JINST **7** P10011*

- The LPDAs provided (and still provide) good data for AERA-I together with a stable acquisition
- A detailed study of different antenna types was necessary to choose the most relevant one for a deployment of a large radio array, meaning the one that:
  - induces the smallest signal distortion
  - is the most sensitive to the radio signal
  - is robust: site exposed to high speed winds (up to 160 km/h)
  - minimizes the costs for production and maintenance
  - is convenient for the deployment

→ 3 antenna types compared: LPDA, Butterfly and SALLA

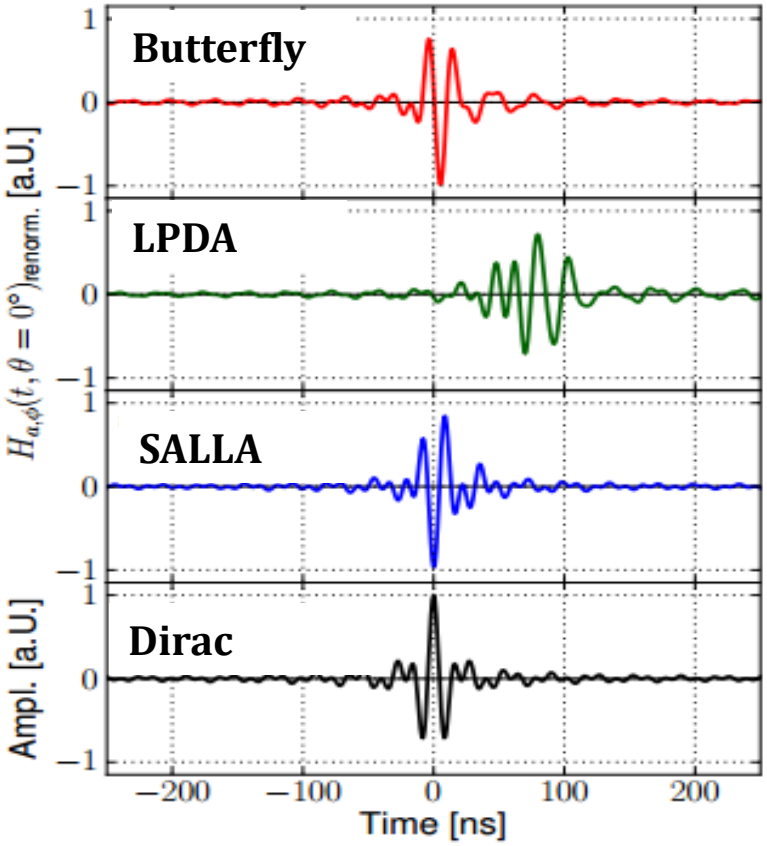
SALLA ≡ Short Aperiodic Loaded Loop Antenna
→ Tunka-Rex Beverage antenna

See Y. KAZARINA talk

Local station - Study of the antenna + LNA responses

Measured data = convolution of the incoming electric field with the antenna and electronics response

→ Must be well known to allow an efficient deconvolution of the incoming signal



Local station - Study of the antenna sensitivities

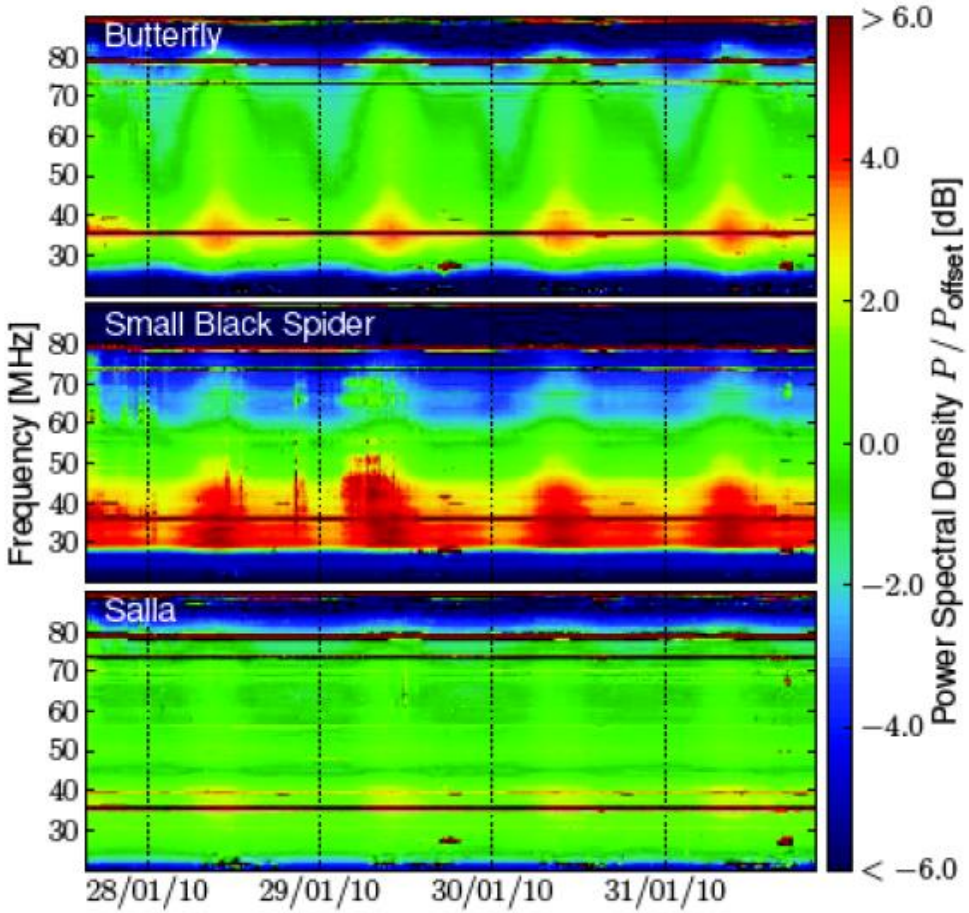
→ The combination antenna/LNA determines the signal-to-noise ratio

Main continuous radio contribution
→Galactic radio background: rise and fall of the galactic plane

Butterfly

LPDA

SALLA



AERA Auger Engineering Radio Array

Local station - The Antennas and their LNAs

Why did we chose the Butterfly for stage 2 ?

→ 3 antenna types compared: LPDA, Butterfly and SALLA

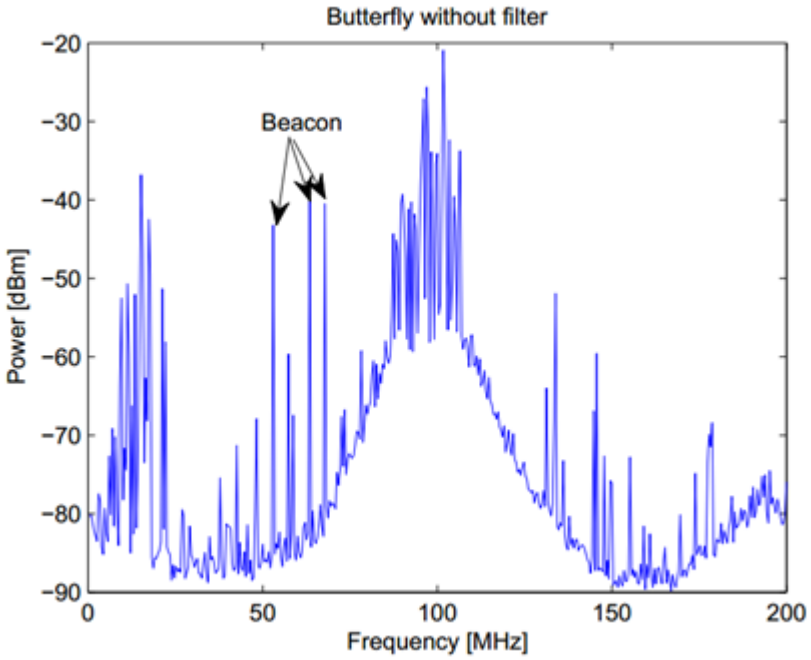
The Butterfly antenna:

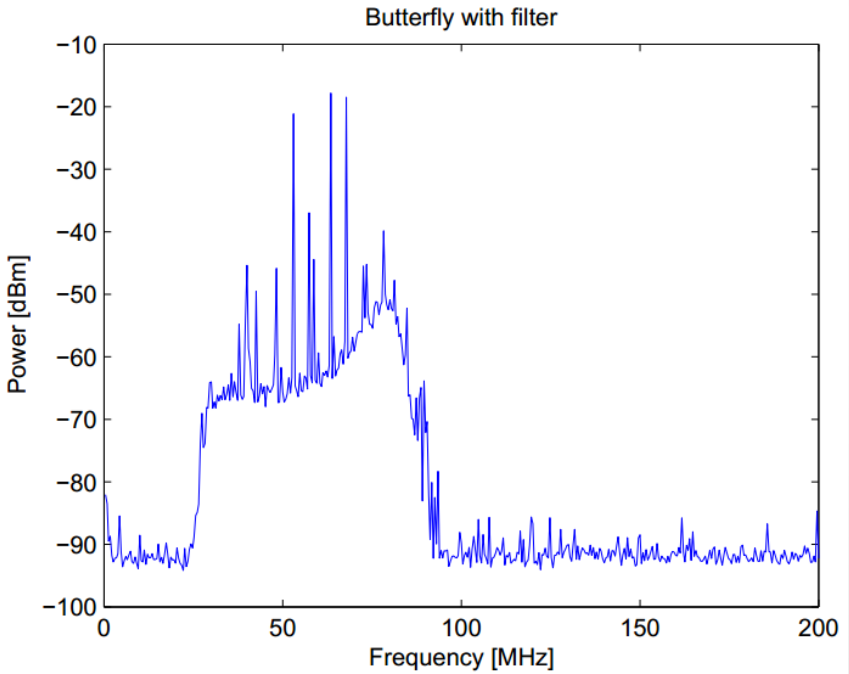
- induces the smallest signal distortion
- is the most sensitive to the radio signal (galactic radio background, transients such as cosmic-rays or planes …)
- is robust
- minimizes the costs for production and maintenance
- is compact and convenient for the installation

Local station - Analogical signal processing

→ filter/ amplifier block:

- 30-80 MHz band-pass filter ≡ remove FM and short wave emitters
- amplification of the signal in this frequency range





Local station - Digital signal processing

→ 2 types of digitizer

Sampling frequency (MS/s)	180	200
Resolution (bits)	12	14
Number of channels	4	4
Field Programmable Gate Array	Altera Cyclone 3	Altera Cyclone 3 for AERA-I, 4 for AERA-II
Total power consumption of the digital board (W)	10.8	6-7
Filter		Infinite-impulse-response-filters (IIR) → Before the trigger decision to reduce background

Local station - Communication system

→ Communication between the stations and the central DAQ

AERA-I: optical fiber communication system

Not relevant for the 100 stations of stage 2

AERA-II: comparison of two Wi-Fi communication systems

❑ Custom TDMA (Time Division Multiple access) → mobile phones
- 2.4 GHz band
- Bandwidth: 5.5 Mb/s
- Up to 180 stations/channel

❑ Commercial 802.11n+TDMA
- 5 GHz band
- Bandwidth: 80 Mb/s
- From 80 to 100 stations/channel

Local station - Self-trigger

- radio stations mostly triggered by anthropic background
- a lot of studies have been done in low level trigger development

- **first level trigger**:
  - signal processing in the frequency domain to remove RFI
  - comparison of the voltage in the time domain with fixed or variable thresholds

- **second level trigger:**
  - mainly based on pulse shape analysis

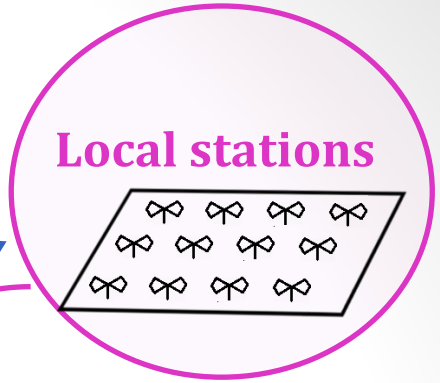
→ Not efficient enough.

→ We decided to:

- select self-triggered events at the central DAQ level
- externally- trigger the local stations

Central DAQ – Trigger board

→ Located at Coihueco FD building



Ask for traces of events of the T3s list

Send T2s ~ 500 Hz

Send a T3s list of selected events ~ 2-5 Hz

Postmaster

Sends T2s

Send the traces

T3Maker

Externally-triggered events

- Processing of the T3 requests

Self-triggered events

- Sort T2s
- Computes the event arrival direction
- Rejects events reconstructed with a same incoming direction in a short time slot

→ **Cone algorithm**

Send of externally triggering requests:

FD: HEAT + Coihueco

SD: regular, infill, AERALET

Airplane, GUI, 10 s snapshots, random

Event builder

→ Creation of raw data files

Data rate written to disk: 1 Mb/s

Central DAQ – The cone algorithm

❖ Self-trigger decision process :

→ applied for self-triggered events reconstructed ie. with $\theta \in [0°, 90°]$
→ uses a pixellisation of the sphere

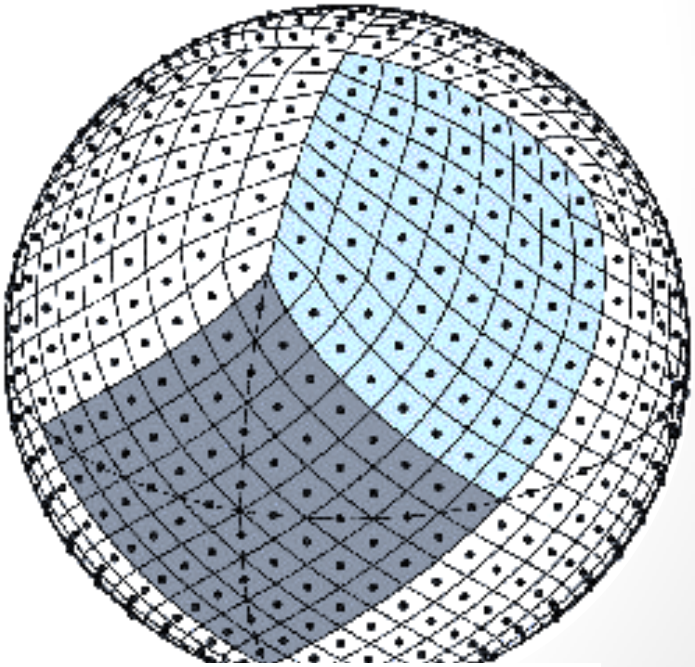
The T3Maker computes the event arrival direction:

- each incoming arrival direction of the sky corresponds to a pixel of the sphere
- at one pixel is associated a counter

→ When an event is reconstructed, the corresponding pixel counter is incremented by one point

→ Within 5 minutes:

- if a counter exceeds 2 points, the event is rejected and the neighboring pixels are incremented by one point
- if not the counter is reinitialized to zero



HEALPix pixellisation

Central DAQ – The cone algorithm

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The T3Maker computes the event arrival direction:

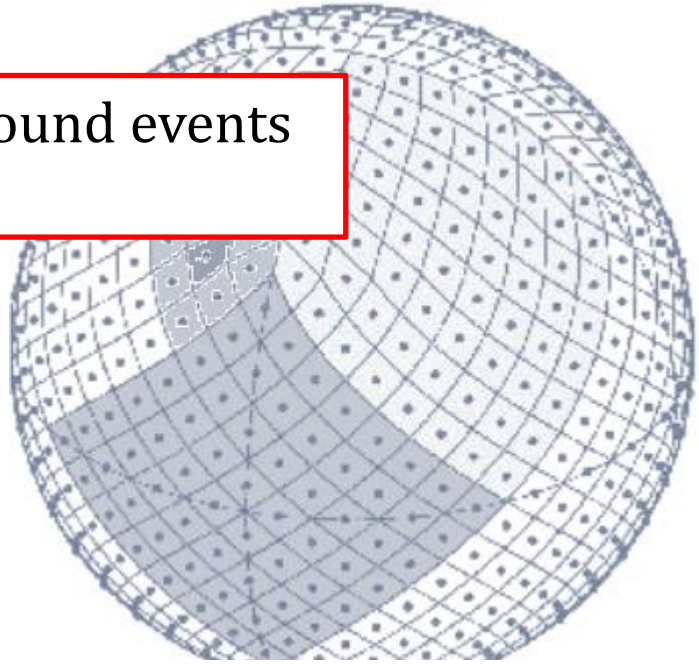
- each incoming arrival direction of the sky cor
- at o

→Significant reduction of background events
→Save disk space

→ When an event is reconstructed, the corresponding pixel counter is incremented by one point

→ Within 5 minutes:

- if a counter exceeds 2 points, the event is rejected and the neighboring pixels are incremented by one point
- if not the counter is reinitialized to zero



HEALPix pixellisation

Summary

AERA: one radio array, different instruments in comparison

- ❑ Continuous technological developments to keep improving the measurement of the electric field induced by air-showers

The stage 2 of AERA is taking data since May 2013
→ AERA covers now 6 km^2 with 124 radio stations

- ❑ The 100 new ones are equipped with Butterfly antennas:
  - more sensitive to the radio signal
  - small signal distortion

- ❑ Powerful electronics, communication system and central DAQ have been developed :
  - fast data processing
  - self-triggered events selected at the central DAQ level
  - local stations are externally- triggered