Radiodetection of extensive air showers with AERA

Auger Engineering Radio Array

Jennifer Maller
on behalf the Pierre Auger Collaboration

PIERRE AUGER OBSERVATORY

Jennifer Maller – RICAP 2013
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MINES TELECOM INSTITUT Mines-Télécom

cnrs IN2P3 Les deux infinis

Région PAYS DE LA LOIRE

Subatech

UNIVERSITÉ DE NANTES

The Pierre Auger Observatory

Hybrid air-shower detector covering 3000 km² **:**

- 24 fluorescence's telescopes (FD) on 4 sites
- 1660 water tanks (SD) – grid size: 1.5 km
- 100% of efficiency at 3 EeV

Low energy enhancement, sensitive to $0.1 < E < 10$ EeV, located near Coihueco:

- **HEAT**: 3 high elevation fluorescence telescopes
- **Infill array:** water tanks with a reduced grid size: 750 m
- **AMIGA**: muon detector
- **AERA → E > 0.1 EeV**

Radiodetection in the MHz range

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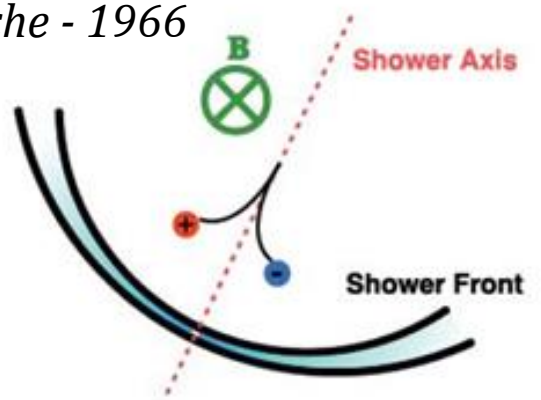
AERA
Auger Engineering Radio Array

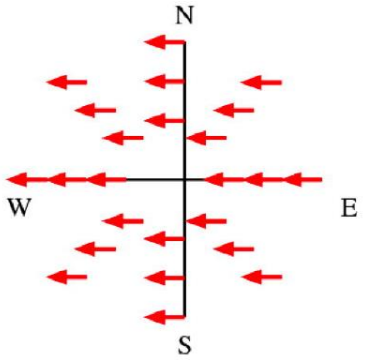
Radiodetection mechanisms in the MHz range

Geomagnetic effect

Kahn & Lerche - 1966

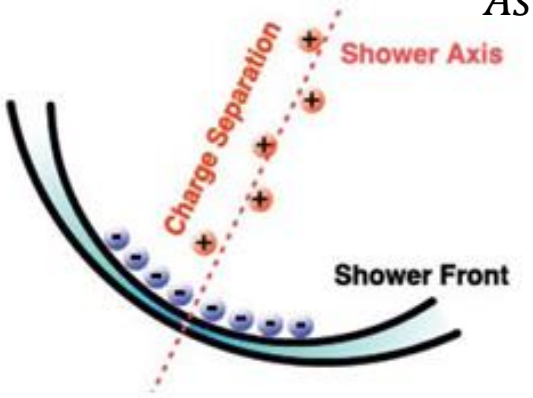


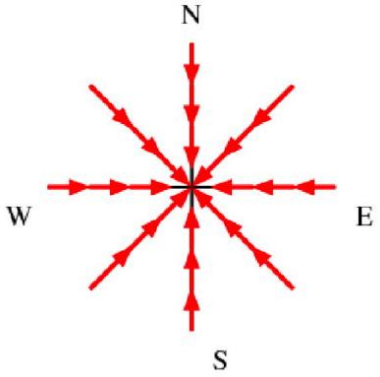
Unidirectional polarization → Aligned with the direction of $\vec{v} \times \vec{B}$



Charge excess effect

Askaryan - 1962





Radial polarization with respect to the shower axis

UHECR2012 – Ad van den Berg

Coherent radio pulse detectable at the ground level

See talk of L. Martin

CODALEMA (Subatech, *France*), **LOPES** (KIT, *Germany*) gave the 1st modern results at low energy $\sim 10^{17}$ eV

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MHz – experiments @ Auger

AERA: Auger Engineering Radio Array

Located in the **low energy extension** of Auger
→ comparison regular SD - infill array - FD - HEAT

Objectives:

- Radiodetection of cosmic rays with $E > 0.1$ EeV
- Disentangle emission mechanisms
- Primary cosmic ray characteristics (arrival direction, energy, nature…)
- Test the performances of a large radio array

Setup 1st stage – 0.5 km²

Dense core installed in 2010, taking data since spring 2011:
24 stations spaced by **144 m** composed of :

- An **antenna** (**LPDA**) measuring both **EW – NS polarizations** in the **30 – 80 MHz** band
- An **EMC box** containing the **electronics** to prevent triggering of the station by RFI from the embedded electronics
- **Solar panels and batteries** for power supply
- **GPS** for precise time measurement

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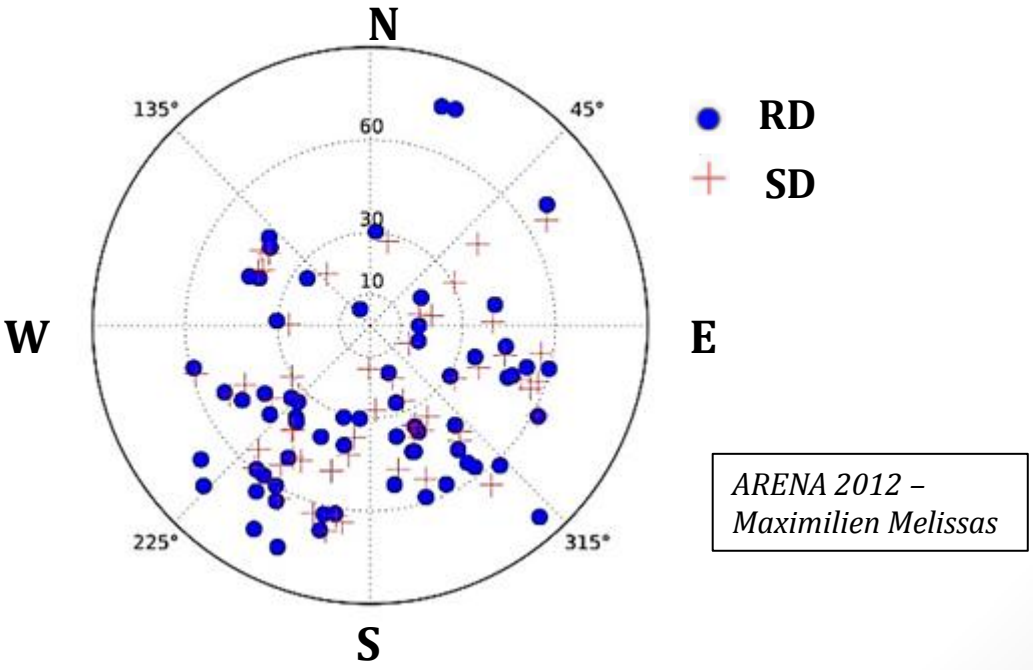
AERA24 – 2 trigger modes

- **Self-trigger:** based on pulse-shape analysis:
  - Individual timestamps (T2) are sent at 500 s^{-1}
  - High level trigger (T3) built from T2s (rejects 99,95% of background signal)
- **External trigger**: AERA is triggered by
  - SD events if distance $\leq 5km$
  - FD (Coihueco and HEAT) events (tbd)
- Search for coincidences with the SD: **AERA vs SD arrival directions**

Self-triggered events

SD/RD angular difference: ~ 4°



ARENA 2012 – Maximilien Melissas

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AERA24 – Proposed rejection algorithm (T2)

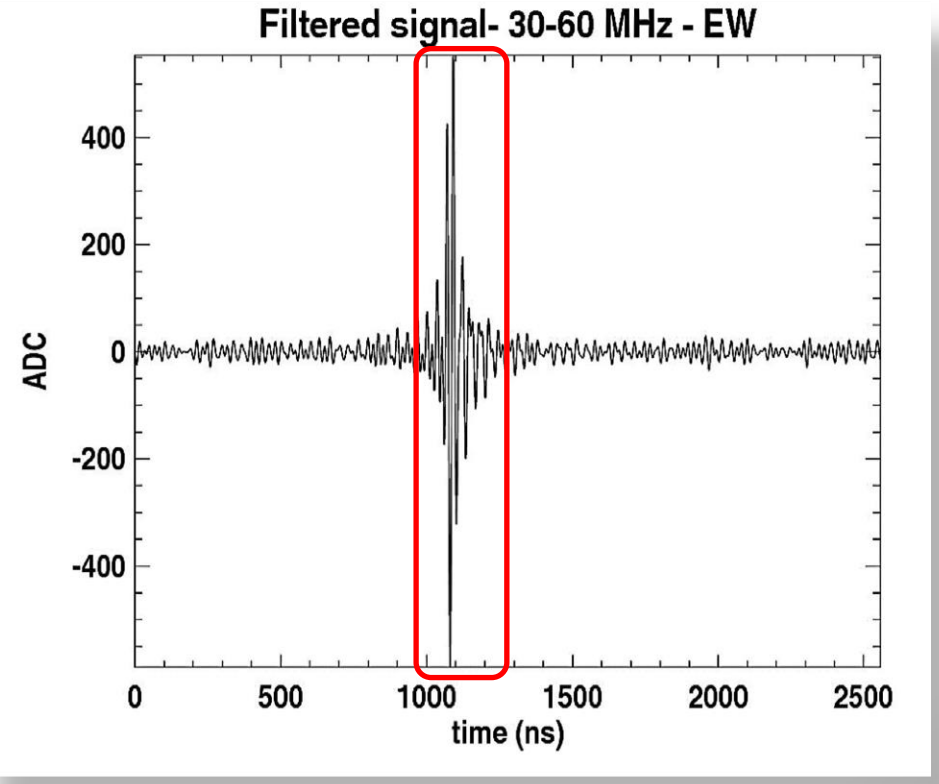
Self-triggered mode: radio stations mostly triggered by anthropic background

→ Need to develop **rejection algorithms** to avoid to send a huge number of T2s to save bandwidth for really interesting triggers

❑ **Example of an algorithm based on pulse-shape analysis**

→ Use the **time evolution of the signal** in a given time window containing the signal pulse

Developed for RAuger *(one of the pathfinders of AERA)*
J. Maller – B. Revenu



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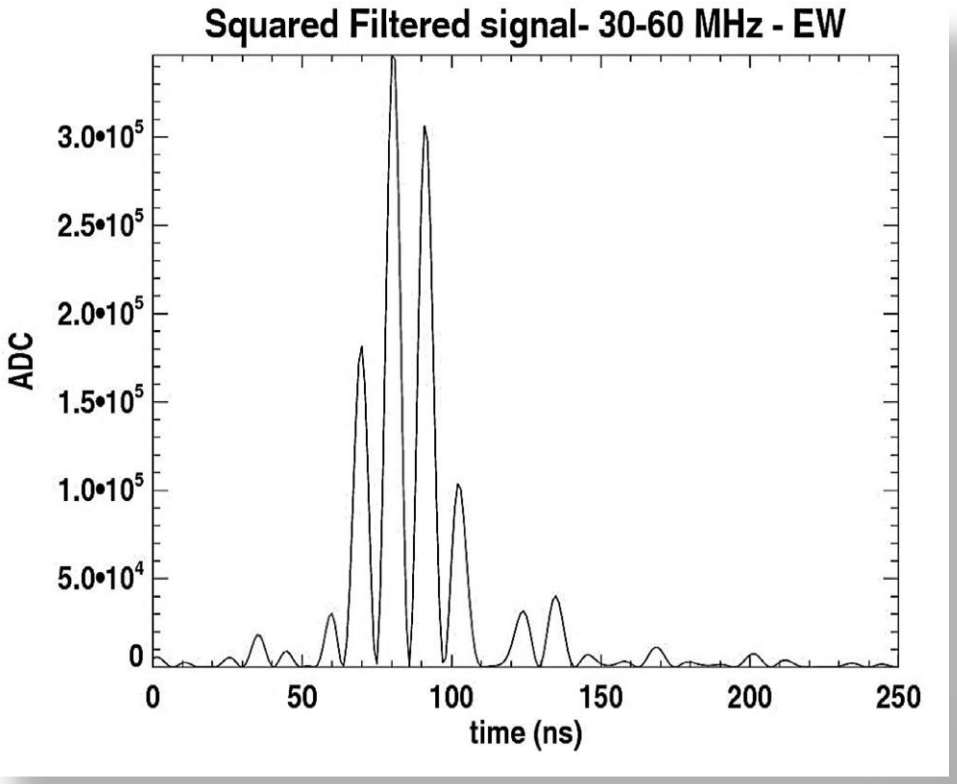

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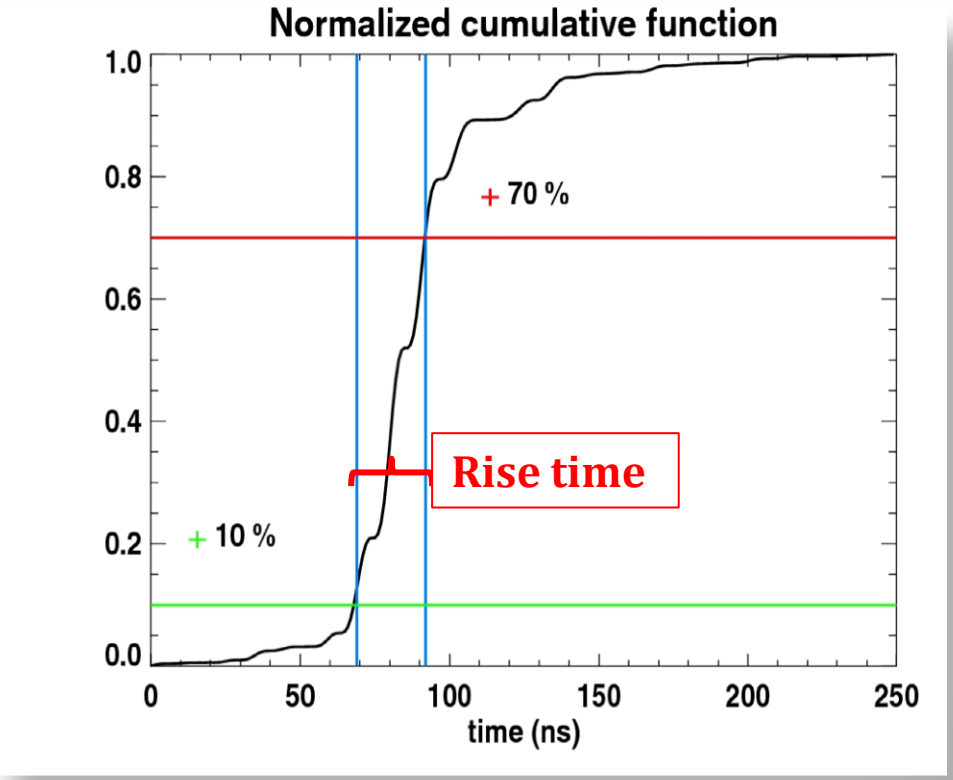
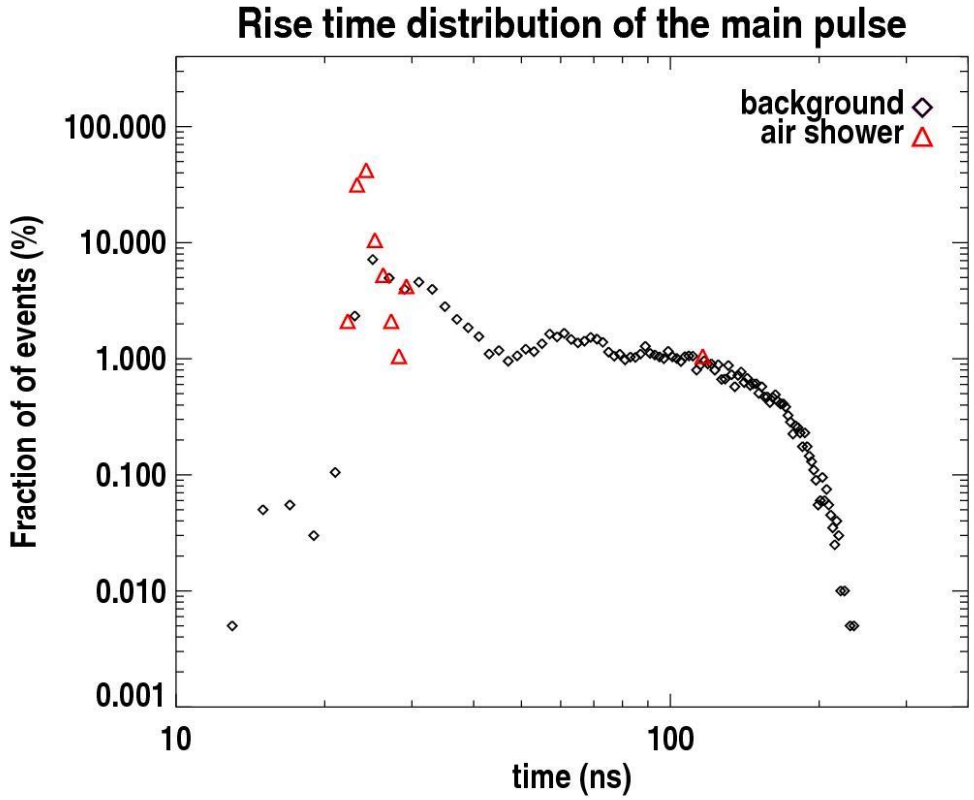


AERA24 – Proposed rejection algorithm (T2)

90 % level of the maximum of the cumulative function reached within a rise time of ≈ 50 ns for the cosmic rays.

Much higher for a large fraction of background events.



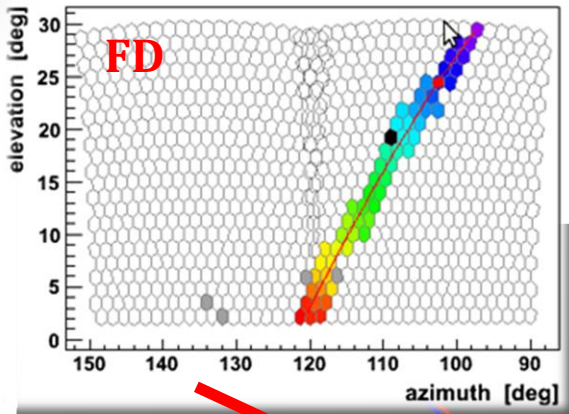
- Reached ~ 90% of efficiency for RAuger (off-line)
- Installed online on CODALEMA – 94 % efficiency
- Currently tested off-line on AERA

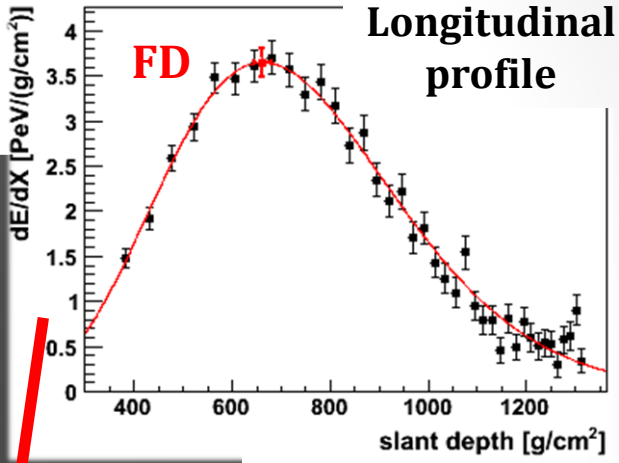
AERA24 – Main results

- **Hybrid coincidences**

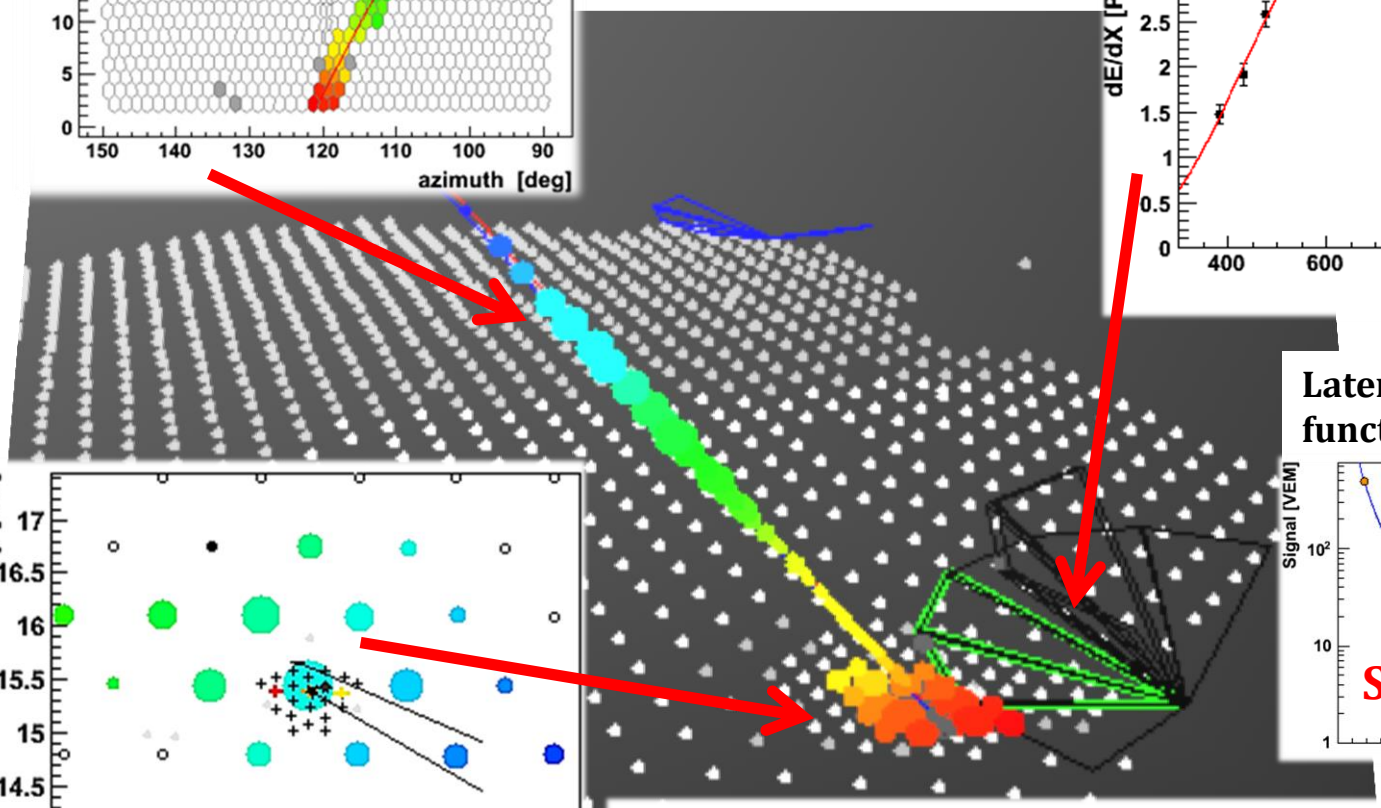
→ comparison of radio observables with SD and FD data

→ Study of the whole shower development

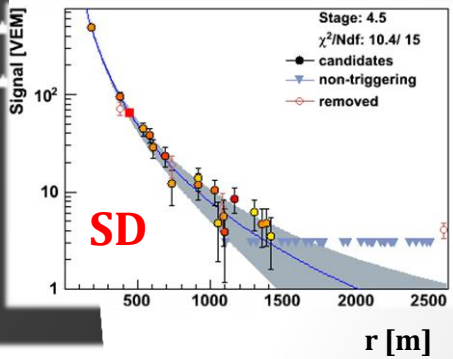




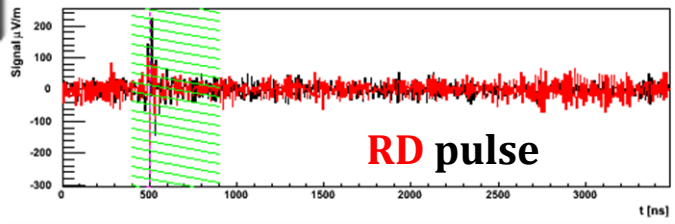
Longitudinal profile



Lateral distribution function (LDF)



RD + SD reconstruction



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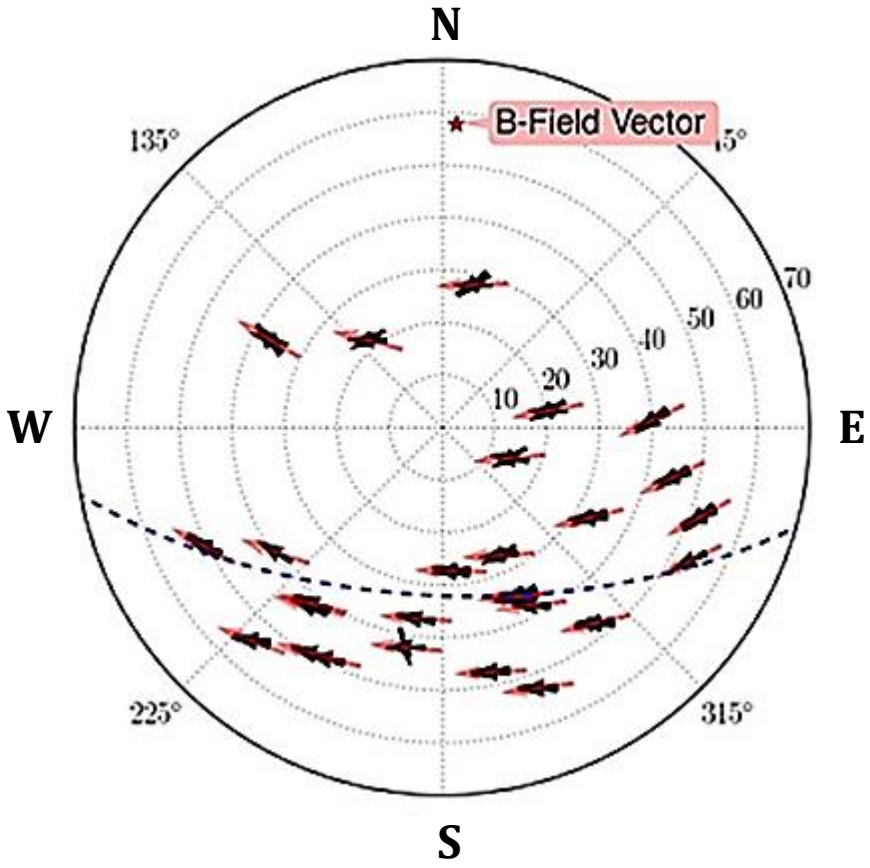
AERA24 – Main results

- **Polarization studies → Emissions processes**



Vulcano Workshop 2012-
K. Weidenhaupt

→ Measured $\vec{E}$-field of AERA events in coincidence with SD

→ $\boldsymbol{v \times B}$

→ **geomagnetic mechanism confirmed and dominant**

Some deviations: presence of others mechanisms

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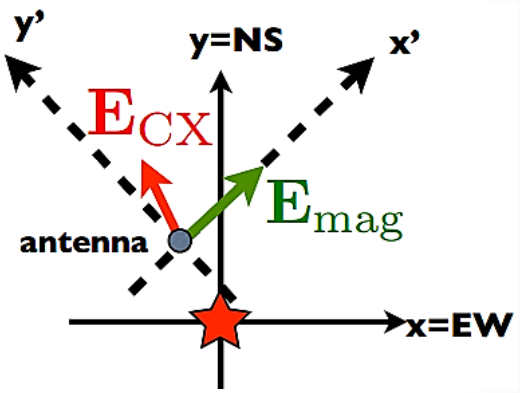
AERA24 – Main results

- **Polarization studies → Emissions processes**

$$R = \frac{\sum_{i=1}^{N} E_{x'}(t_i)\, E_{y'}(t_i)}{\sum_{i=1}^{N} E_{x'}^2(t_i) + E_{y'}^2(t_i)}$$

Detected shower:
$\theta, \varphi, \mathrm{E}, x_{core}, y_{core}$



- Measured **Electric field** in the x (EW) and y (NS) directions

→ Deduction of the **Electric field** in the x', y' directions where x' is aligned with the direction of $\boldsymbol{v} \times \boldsymbol{B}$ in the horizontal plan

- Calculation of the R-factor = formula

→ By construction: $R = 0$ for a purely geomagnetic emission

R_{data}

R_{sim}

Simulated event with same parameters $\theta, \varphi, E, x_{core}, y_{core}$

1- Geomagnetic only
2- Geomagnetic + Charge excess

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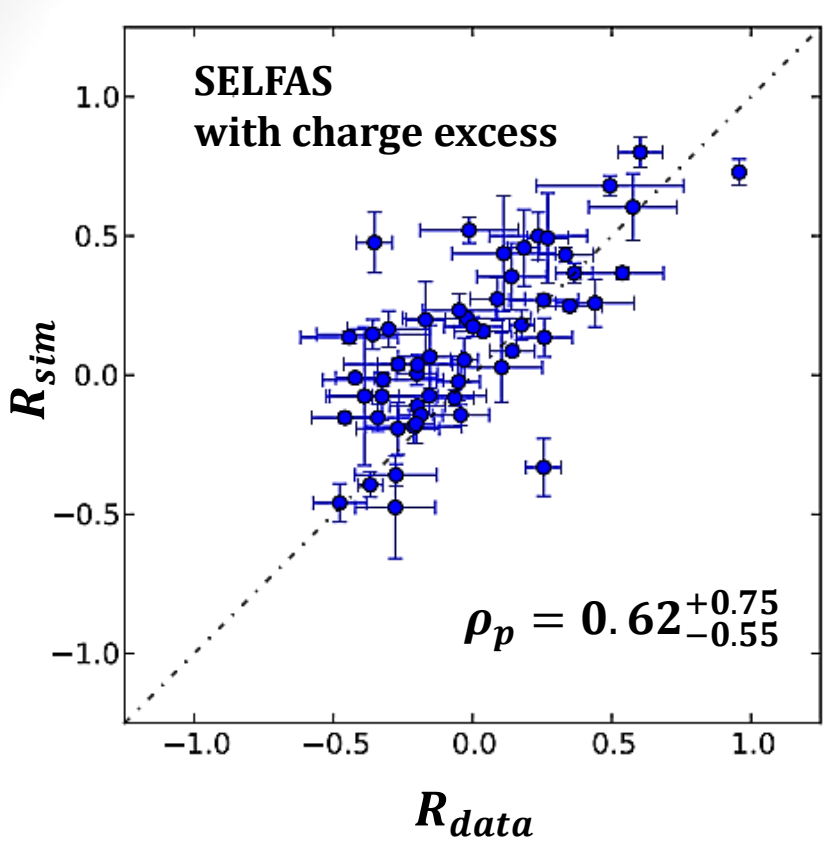
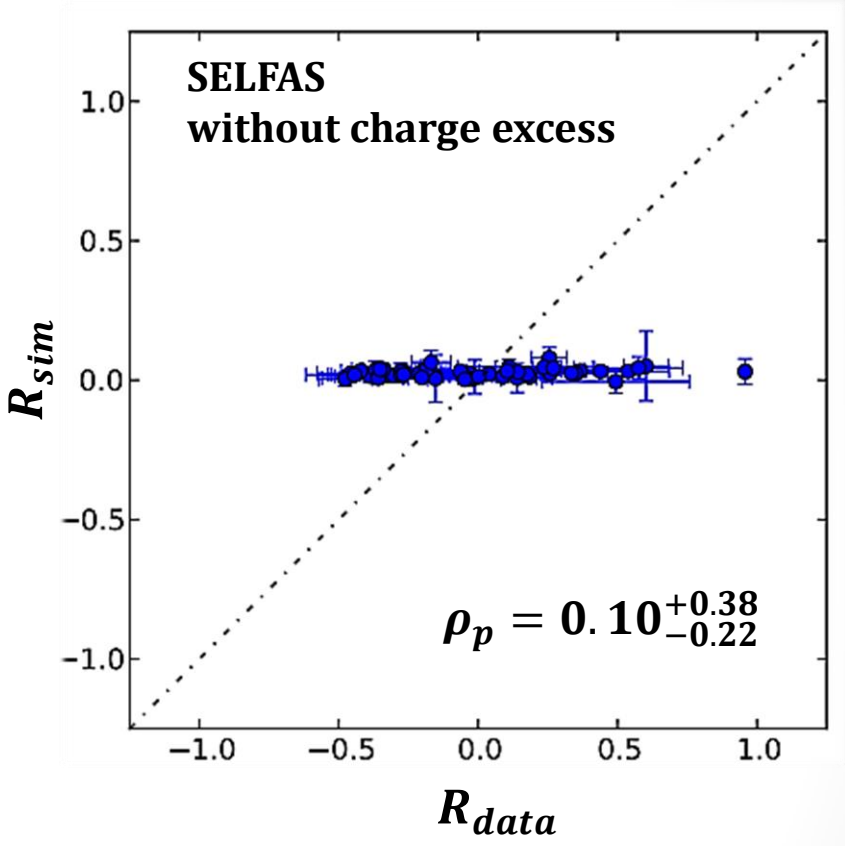
AERA24 – Main results

- **Polarization studies → Emissions processes**





Better correlation between R_{Sim} and R_{data} when **simulation includes charge excess calculations**

→ **Charge excess signature**

ECRS 2012 - Daniël Fraenkel
ICRC 2011 - Benoît Revenu
Coming ICRC 2013 - Tim Huege

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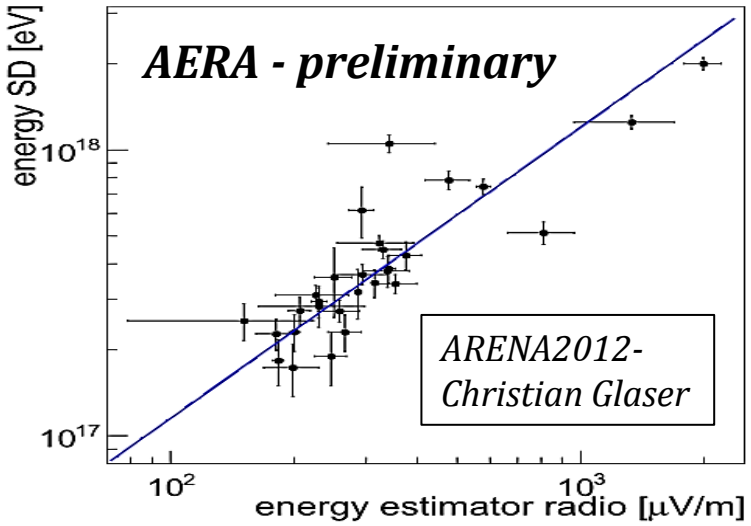
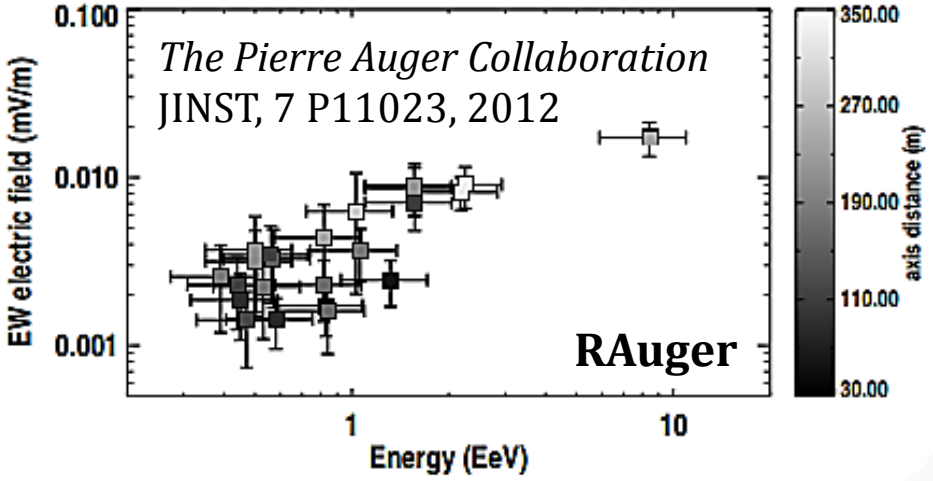
AERA24 – Main results

- **Energy estimation**

Requirement:

- Deconvolution of the antenna response
- Efficient energy estimation from SD and FD
- Study of systematic errors





AERA: preliminary results → good agreement with other experiments

→ **Linear dependence between infill SD energy and the preliminary radio energy estimator**

→ **Needs more statistics** ⟷ AERA stage 2

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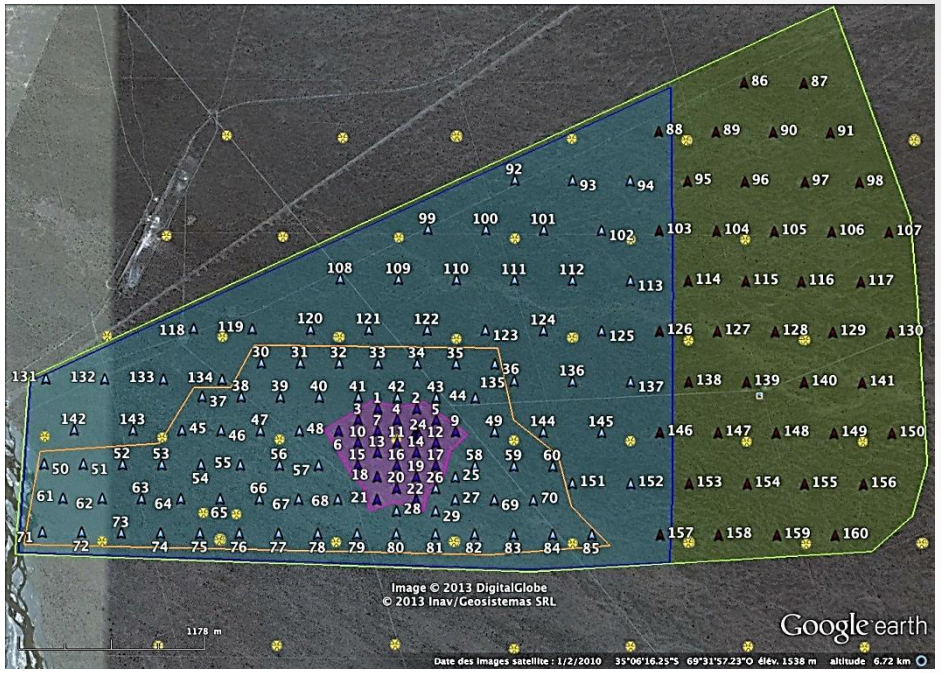
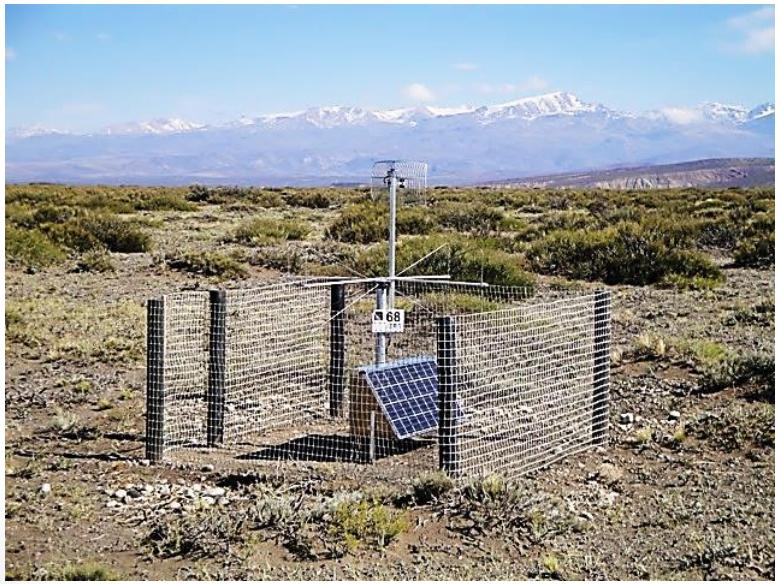
Next stage deployment

May 2013 - AERA 124 ~ 7 km²
100 new stations installed around AERA24 (purple dense core)
With a spacing of 250 m for stations included in the orange line (56), 375 m for the others (39).

→ New stations equipped with the CODALEMA–like Butterfly antenna





Final stage: 160 stations – 12 km²

- 1000 events expected per year
- Approximately an equal number of events below and above 1 EeV

→ **Study of the transition from a galactic to an extra-galactic origin of cosmic ray**

Improved estimate of the **nature** of the primary cosmic ray and the **energy resolution** using additional detectors

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GHz – experiments @ Auger

Expected signal from Molecular Bremsstrahlung Radiation :

→ interaction of low-energy electrons with neutral air molecules

→ 1-10 GHz – Isotropic - Unpolarized

EASIER: **E**xtensive **A**ir **S**hower **I**dentification using **E**lectron **R**adiometer

- 61 antenna horns triggered by SD
- One air shower event detected since 2011

MIDAS: **MI**crowave **D**etection of **A**ir **S**hower

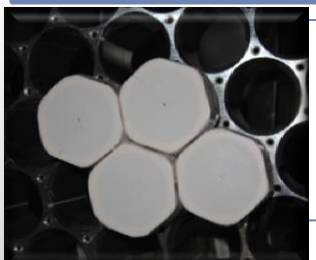
- Self-triggered parabolic dish: 4.5 m- Running 6 months in Chicago

→ candidates measured but not definitively identified as air shower events.

- Moved to Auger near Los Leones in September 2012

AMBER: **A**ir shower **M**icrowave **B**remsstrahlung **E**xperimental **R**adiometer

- Triggered by SD - Parabolic dish: 2.4 m
- Installed since may 2011 – Data analysis underway



FDWave

Proposal: GHz receivers in empty PMT positions at Los Leones (where PMT's were moved to HEAT) - Triggered by FD

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Summary

- **AERA24 is taking data since spring 2011 with 24 radio stations running in self-triggered mode and externally-triggered mode**
- **AERA is located in the low energy enhancement of Auger and allows comparison of interesting observables with SD and FD**
- **Rejection algorithms are being developed to discriminate air shower events from background events**
- **Both data analysis (polarization studies) and simulations are improving our knowledge about emission mechanisms**
- **100 new stations installed since the beginning of May 2013**
  → better signal and larger statistics to improve
  - **the estimate of the nature of the primary cosmic ray**
  - **the energy resolution**


Thank you for your
attention !