Study of ultra high energy cosmic ray with AERA

Auger Engineering Radio Array

Jennifer Maller
on behalf the Pierre Auger Collaboration

PIERRE AUGER OBSERVATORY

Jennifer Maller – JRJC 2013
On behalf the Pierre Auger Collaboration

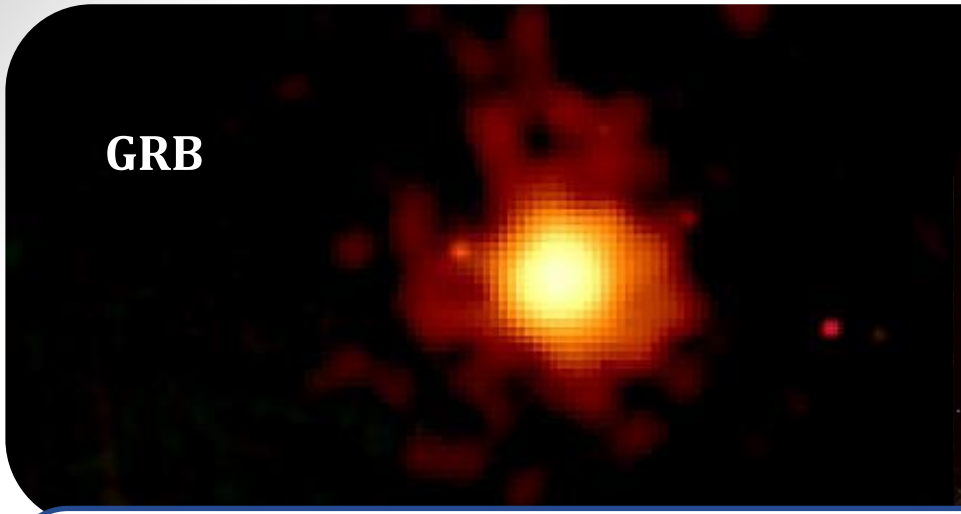
MINES Nantes

Région PAYS DE LA LOIRE

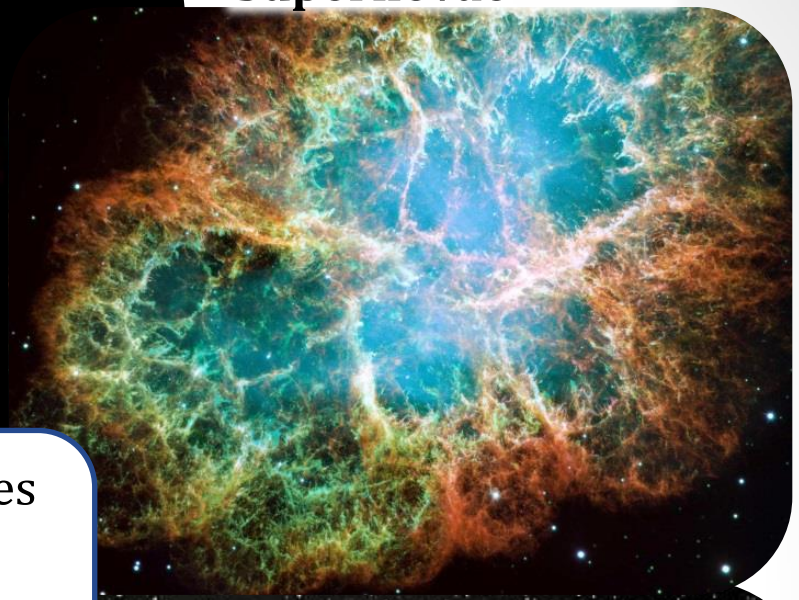
Subatech

UNIVERSITÉ DE NANTES

cnrs IN2P3 Les deux infinis



Supernovae



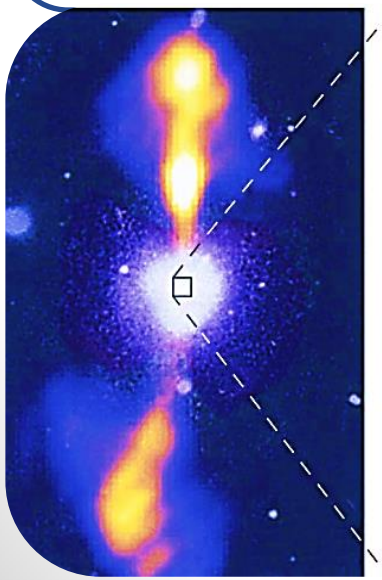
Cosmic rays: high energy charged particles

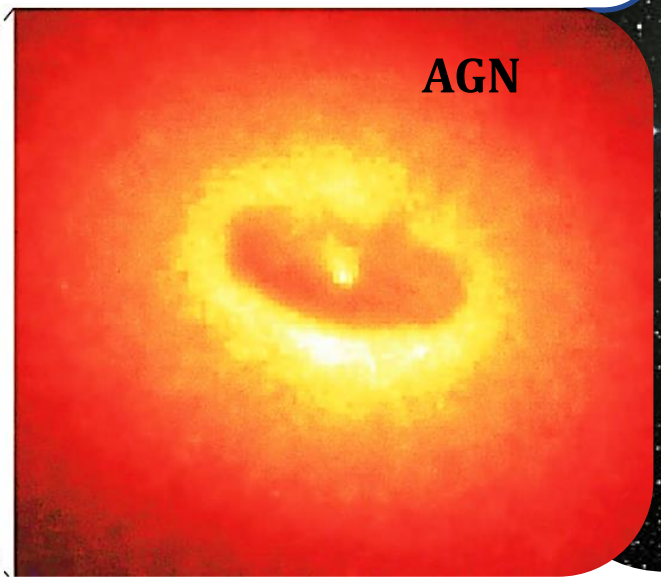
→ From which astrophysical source(s) ?

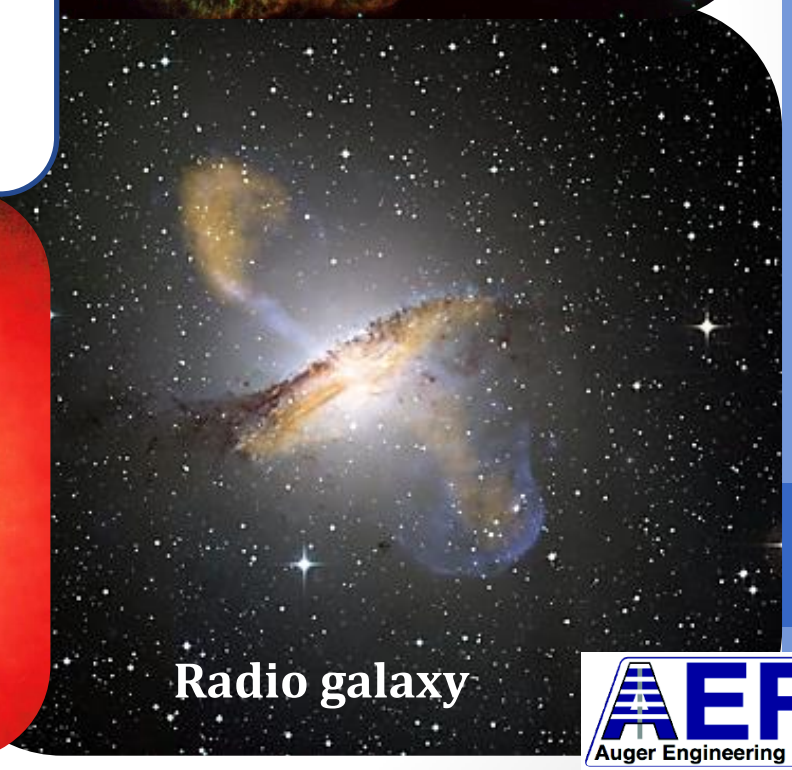
→ Accelerated by which mechanism(s) ?

- Fermi acceleration

→ How they propagate in the Universe ?





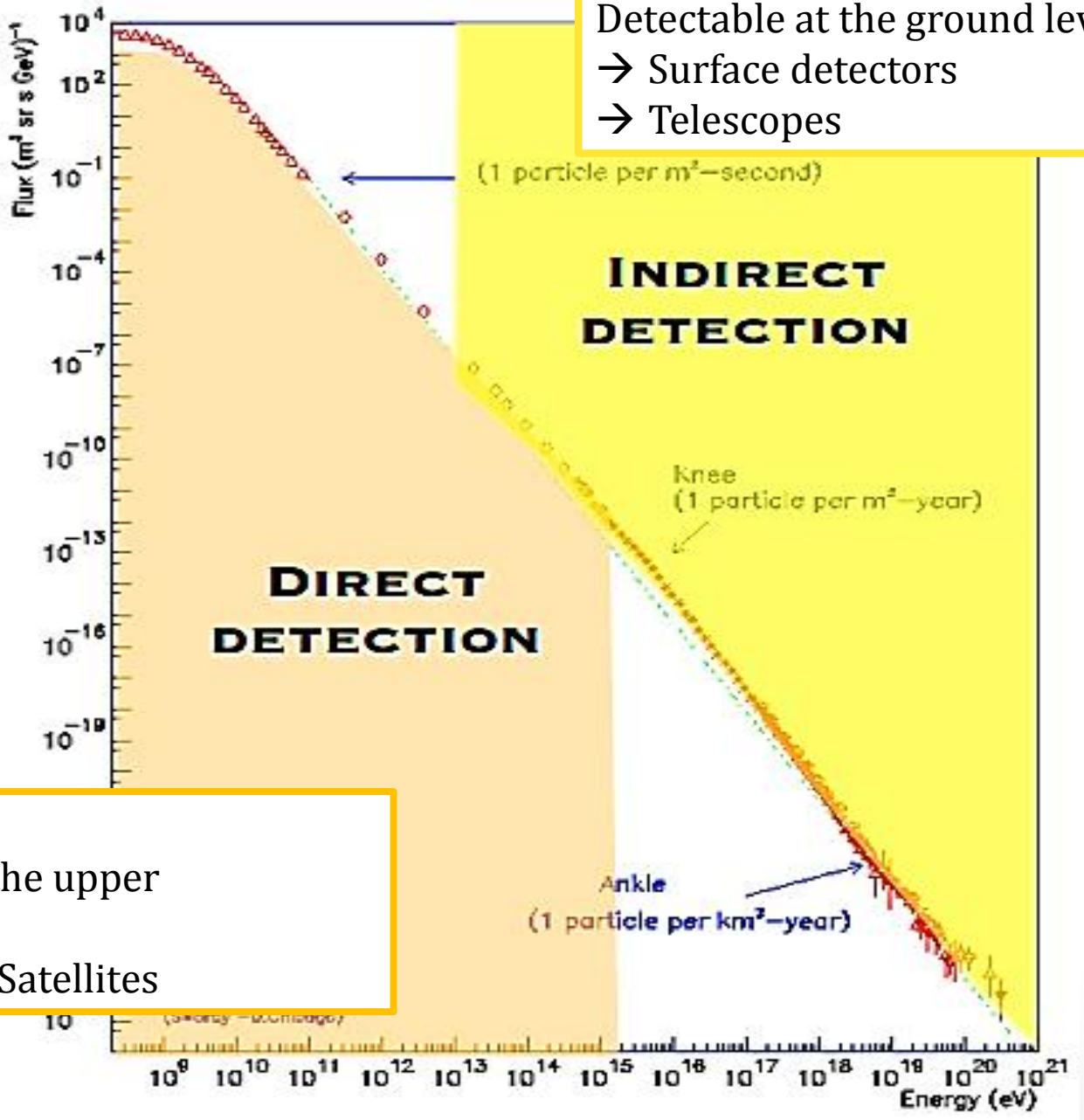


PIERRE AUGER OBSERVATORY

AERA Auger Engineering Radio Array

Cosmic ray energy spectrum

Low flux
Detectable at the ground level
→ Surface detectors
→ Telescopes



High flux
Absorbed in the upper atmosphere
→ Balloons - Satellites

PIERRE AUGER OBSERVATORY

Jennifer Maller – JRJC 2013
On behalf the Pierre Auger Collaboration

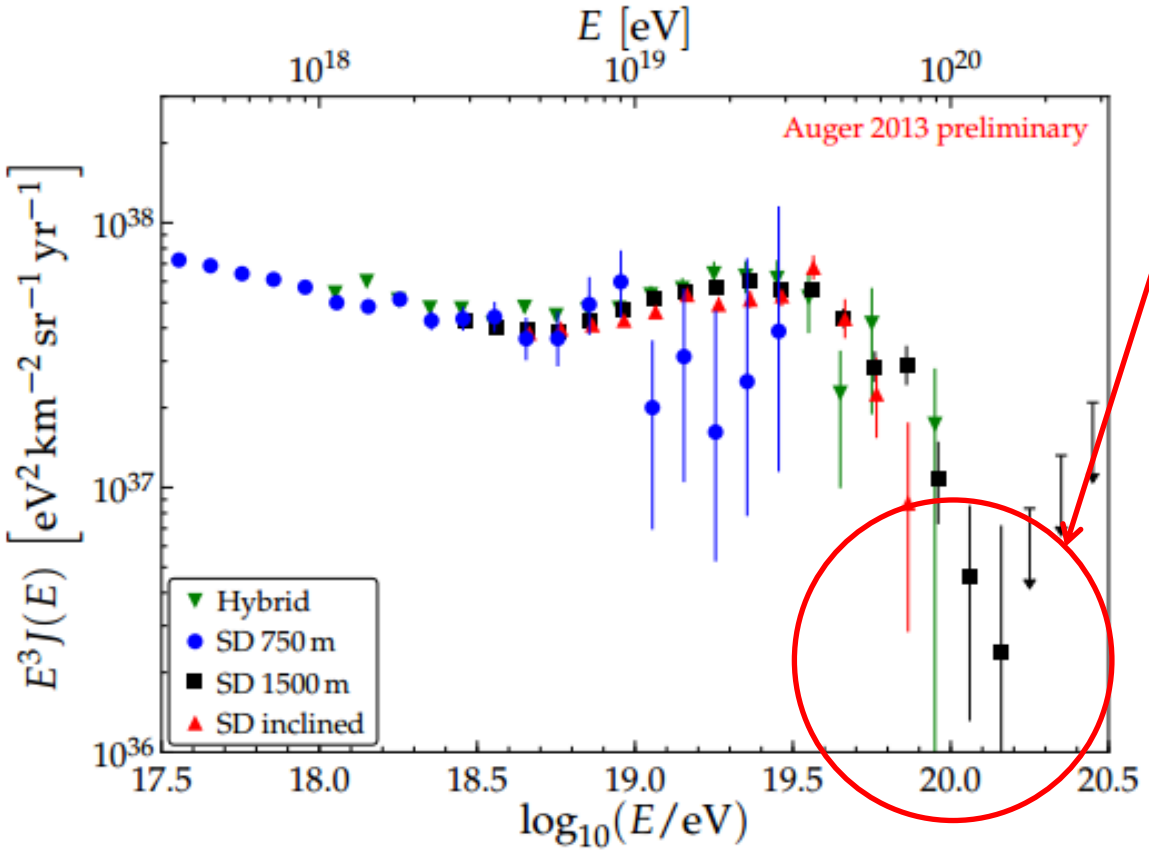
AERA Auger Engineering Radio Array

Recent results

- **Energy spectrum at high energy**

Cut-off:

- Interaction with the CMB ?
- Maximum energy reachable by the source ?

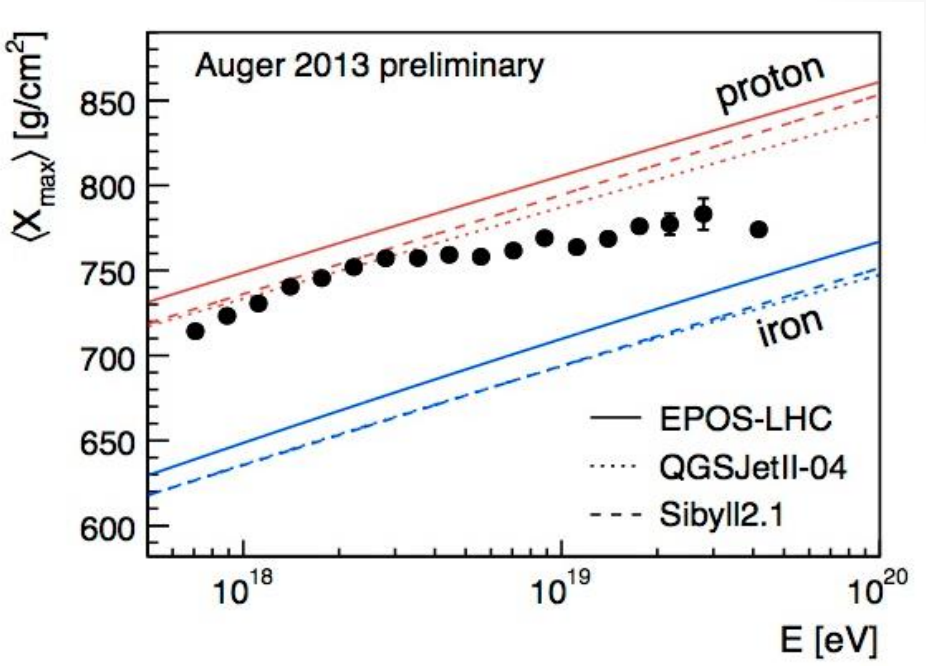


AERA Auger Engineering Radio Array

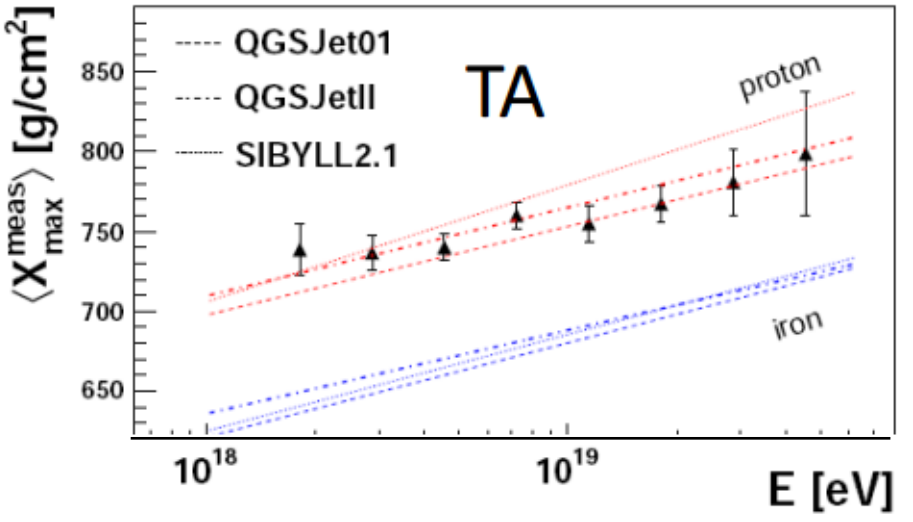
Recent results

- **Composition**

Auger: heaviest nuclei at high energy



TA: end of the spectrum compatible with protons



AERA Auger Engineering Radio Array

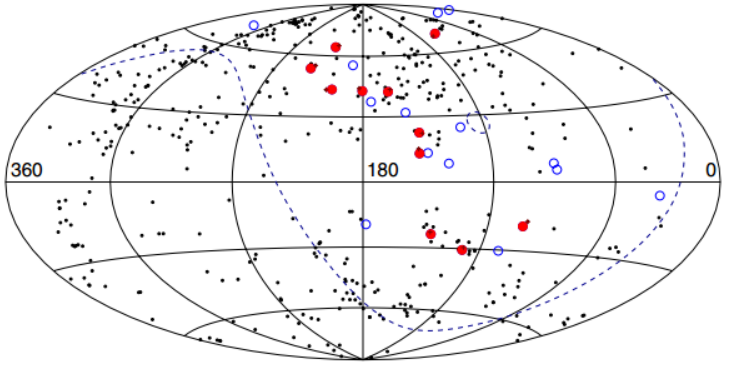
Recent results

- **Arrival directions**

Northern hemisphere

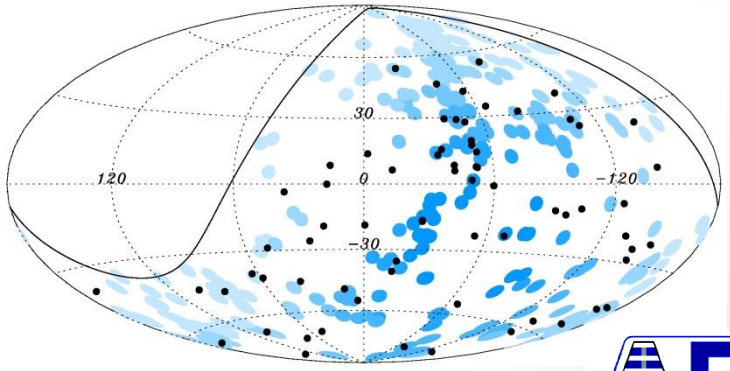
→ HiRes: compatibility with an isotropic flux (with a 95% confidence level)

→ TA: no significant deviation observed from an isotropic behavior



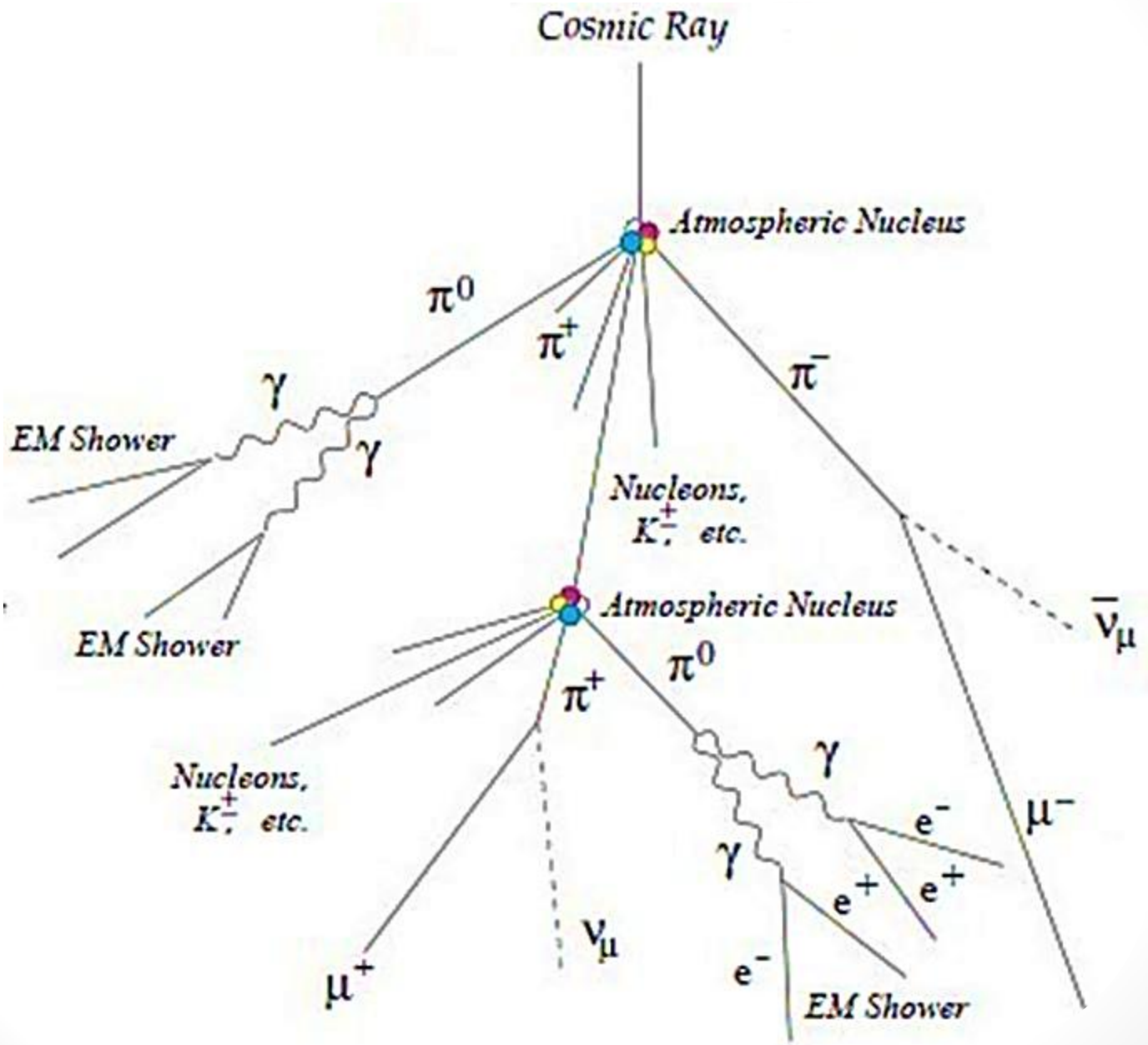
Southern hemisphere

→ Pierre Auger observatory:
A correlation with AGN is observed with a degree of about 30%



AERA Auger Engineering Radio Array

Air shower development



AERA Auger Engineering Radio Array

Air shower measurement **challenge**: **composition** of primary cosmic rays

→ Origin and production mechanisms

Radio technics sensitive to the shower development

→ FD-like measurement but with a much higher duty cycle

Aim: measure observable sensitive to the nature of the primary cosmic ray

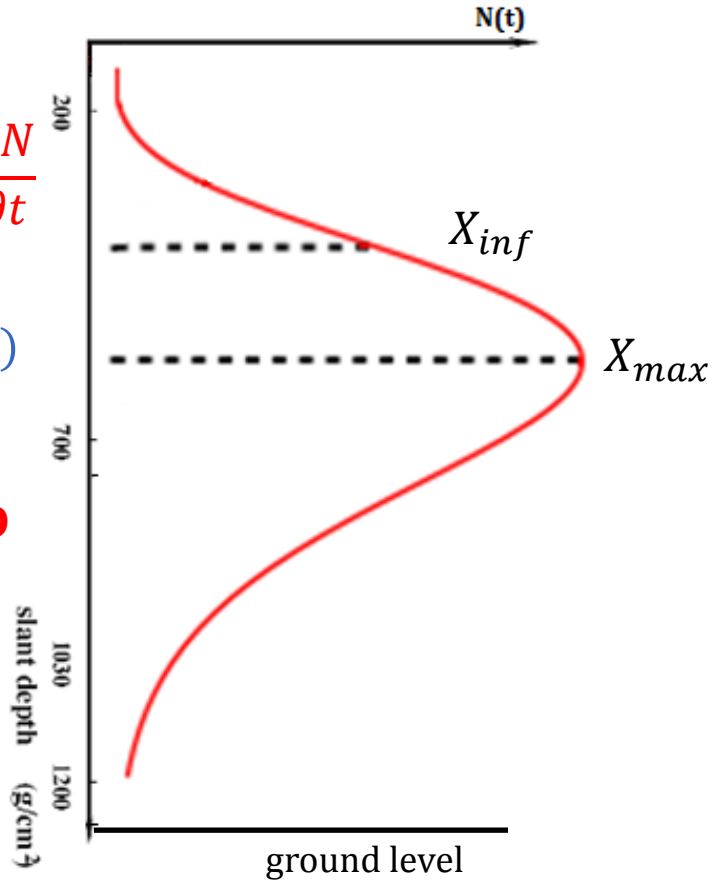
→ X_{max}, X_{inf}

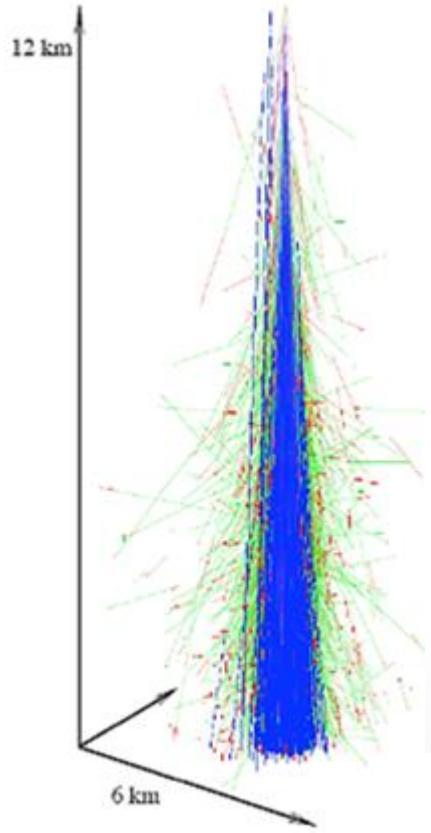
RD $\propto N(t) + \frac{\partial N}{\partial t}$

FD $\propto N(t)$

RD

SD $\propto N(t_{ground})$





AERA Auger Engineering Radio Array

Air shower measurement **challenge**: **composition** of primary cosmic rays

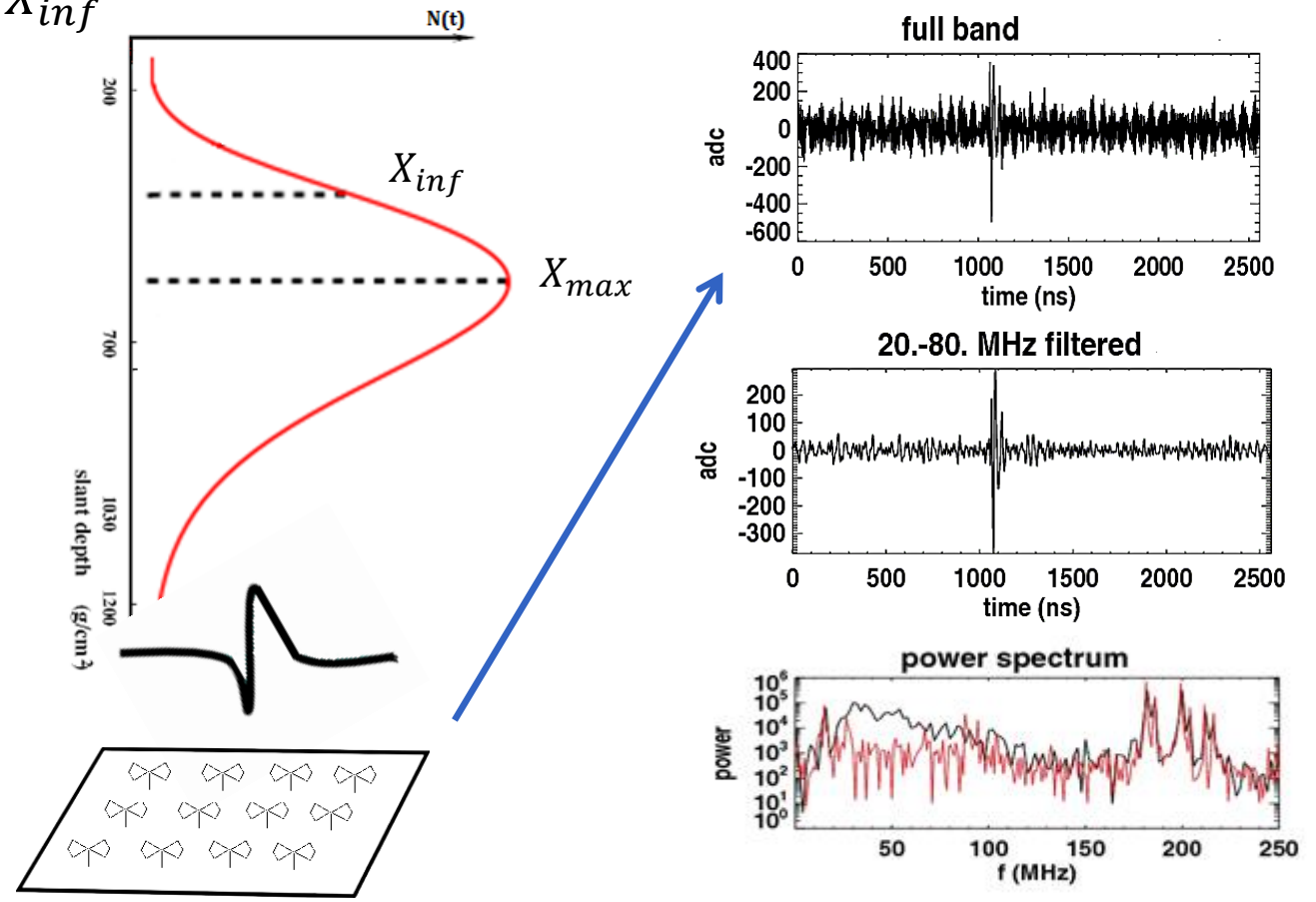
→ Origin and production mechanisms

Radio technics sensitive to the shower development

→ FD-like measurement but with a much higher duty cycle

Aim: measure observable sensitive to the nature of the primary cosmic ray

→ X_{max}, X_{inf}



Jennifer Maller – JRJC 2013
On behalf the Pierre Auger Collaboration

AERA Auger Engineering Radio Array

The Pierre Auger Observatory

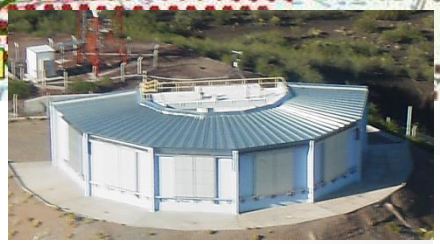
Hybrid air-shower detector covering 3000 km² **:**

- 24 fluorescence's telescopes (FD) on 4 sites
- 1660 water tanks (SD: surface detector) – 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



PIERRE AUGER OBSERVATORY

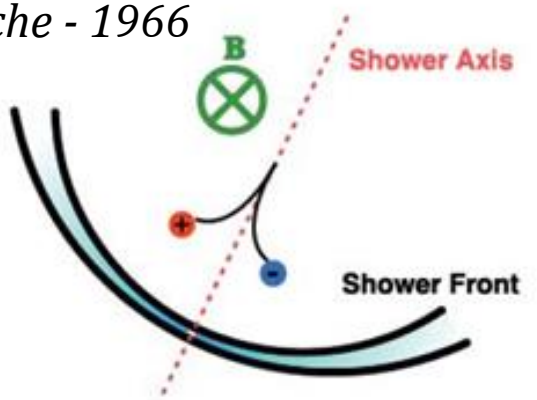
Jennifer Maller – JRJC 2013
On behalf the Pierre Auger Collaboration

AERA Auger Engineering Radio Array

Radiodetection mechanisms in the MHz range

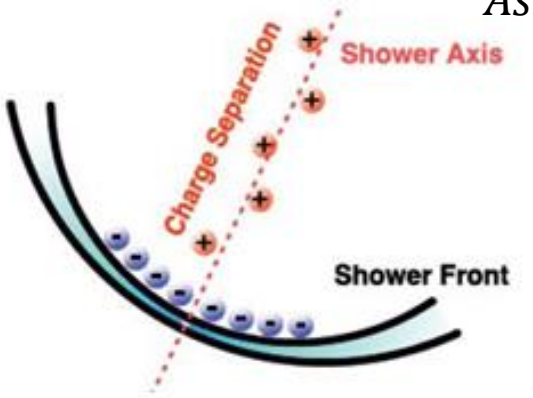
Geomagnetic effect

Kahn et Lerche - 1966

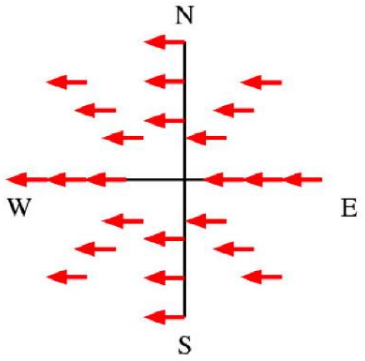


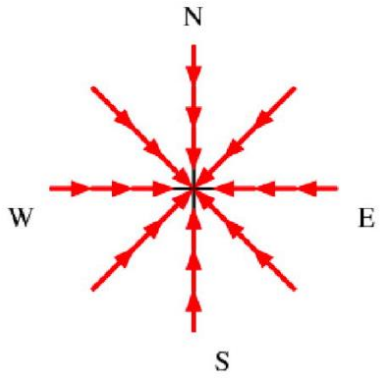
Charge excess effect

Askaryan - 1962



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





Radial polarization with respect to the shower axis

UHECR2012 – Ad van den Berg

Coherent radio pulse detectable at the ground level

AERA Auger Engineering Radio Array

MHz – experiments @ Auger

AERA: **A**uger **E**ngineering **R**adio **A**rray

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

MHz – experiments @ Auger

AERA: **A**uger **E**ngineering **R**adio **A**rray

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 2nd stage – 6 km²

Deployed since May 2013.

100 new stations installed around AERA24

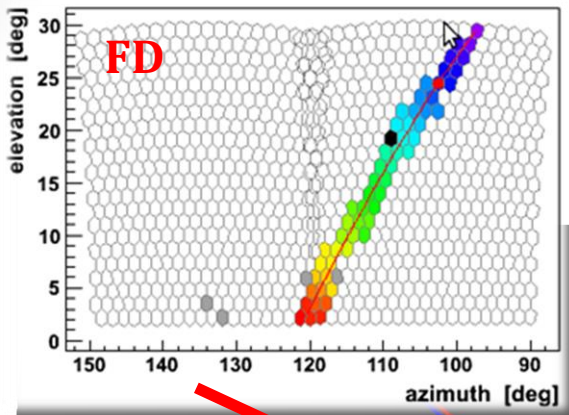
→ Equipped with the CODALEMA–like Butterfly antenna

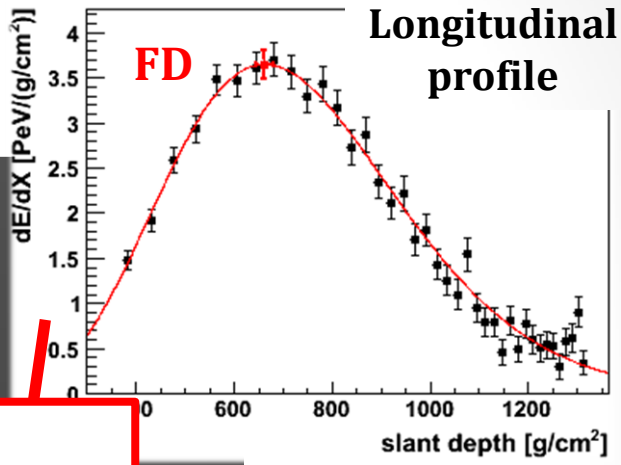
Scintillator pair in 40 of the new stations

Hybrid coincidences

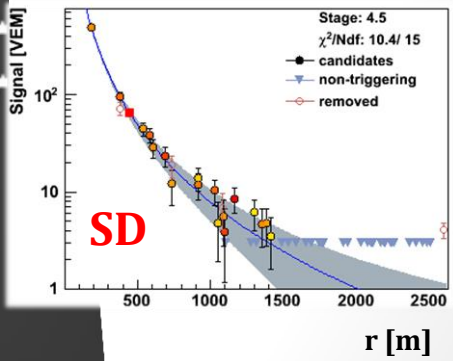
→ comparison of radio observables with SD and FD data

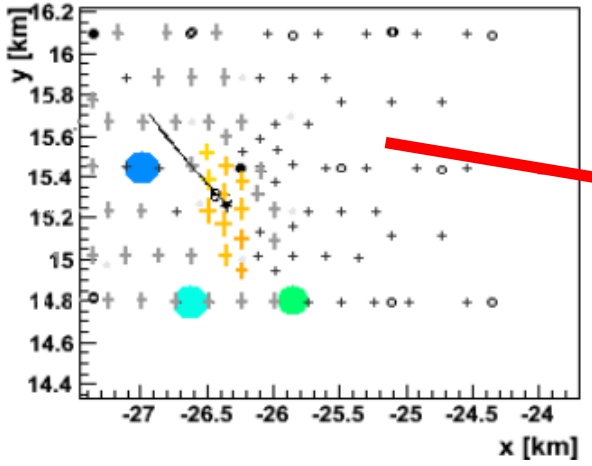
→ Study of the whole shower development

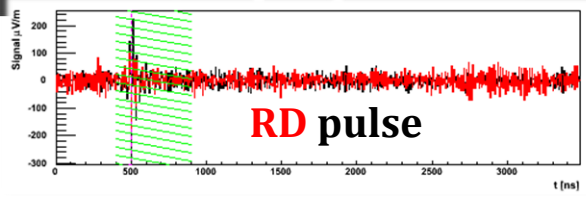




AERA triggered by: FD – SD – Scintillators
Self-trigger







RD + SD reconstruction

AERA Auger Engineering Radio Array

Data selection

Data dominated by man-made background
→ Saturation of bandwidth and disk
→ Increasing of the dead time

500 Hz of level 2 triggers
→ Data rate written to disk: 1 Mb/s

} **AERA 2**

Development of a selection method of coincident events between SD and AERA (SD triggered events).

Idea: having coincidences lists - few days after the data acquisition
- with few computations

Development of a selection method of coincidences
→ Using a minimal number of variables

→ **Check for the compatibility of the arrival of a shower on both the SD and the AERA arrays.**

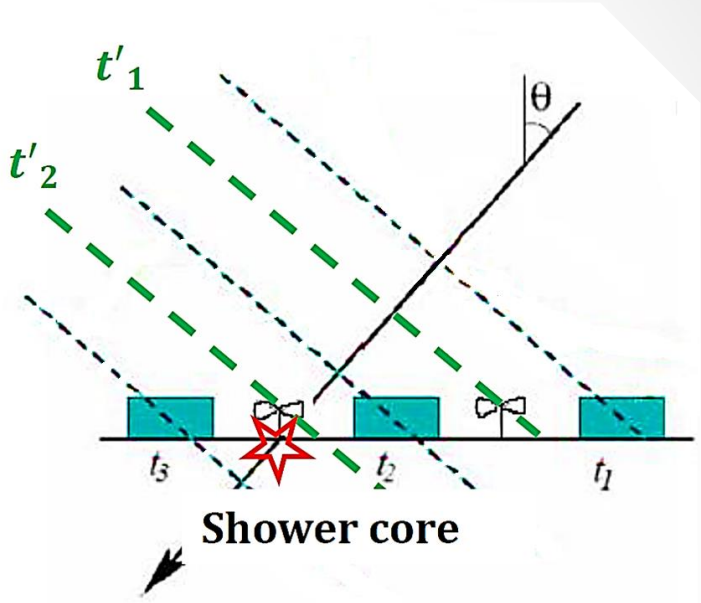
Method

For each candidate compare:

- $dt_m = t_{SD,m} - t_{RD,m}$

- With the expected time difference

→ $dt_{exp} = t_{SD-RD,exp}$



Assuming a plane front moving at c :

$$dt_{exp} = -\frac{u(x_{SD,core} - x_{RD}) + v(y_{SD,core} - y_{RD})}{c}$$ with : $u = \sin\theta \cdot \cos\varphi$, $v = \sin\theta \cdot \sin\varphi$

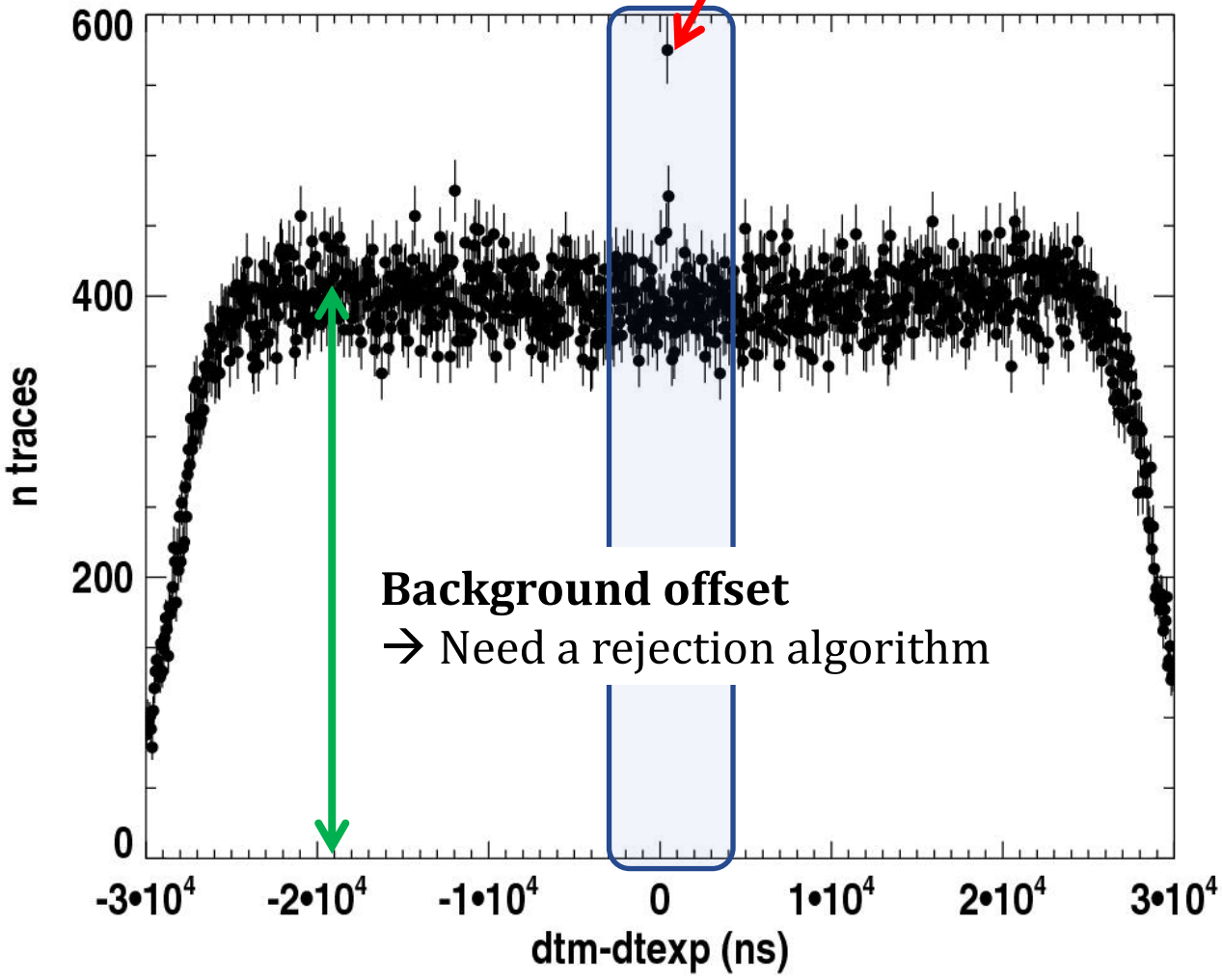
$x_{SD,core}$, $y_{SD,core}$, Θ and ϕ of SD reconstruction

Expected behavior: - dt_m and dt_{exp} strongly correlated for air shower events

- random difference for background events

Study on AERA stage 1 data

Example on 11 days of data taking:



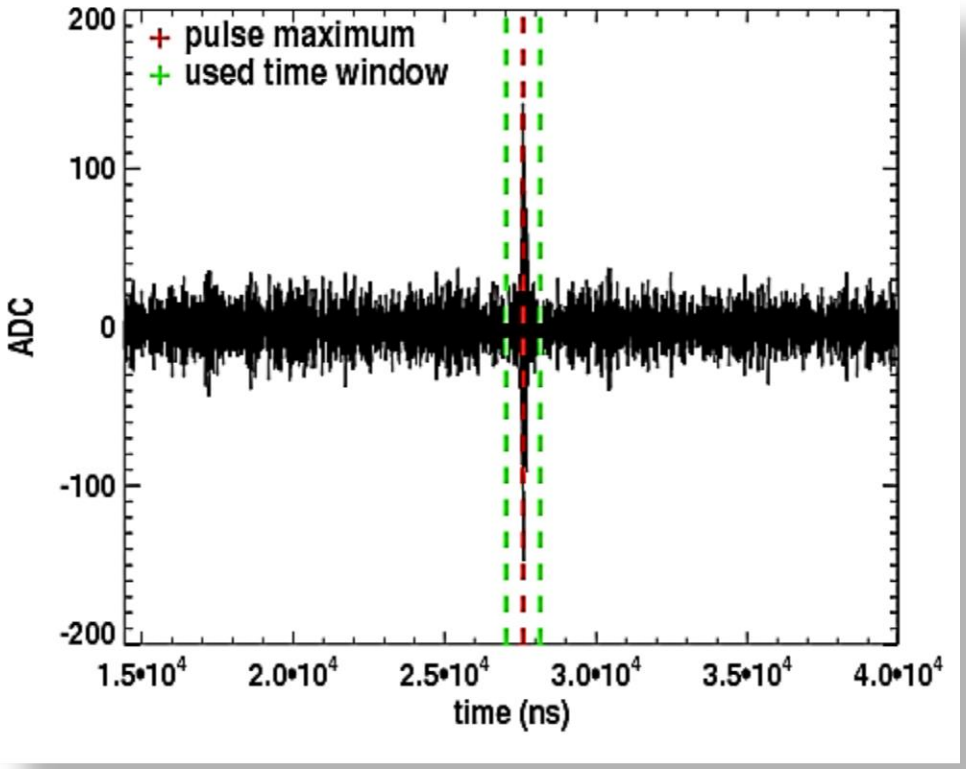
AERA Auger Engineering Radio Array

Rise time study

To reject the random coincidences remaining in the peak

→ Use of a rejection algorithm **developed for RAuger**

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

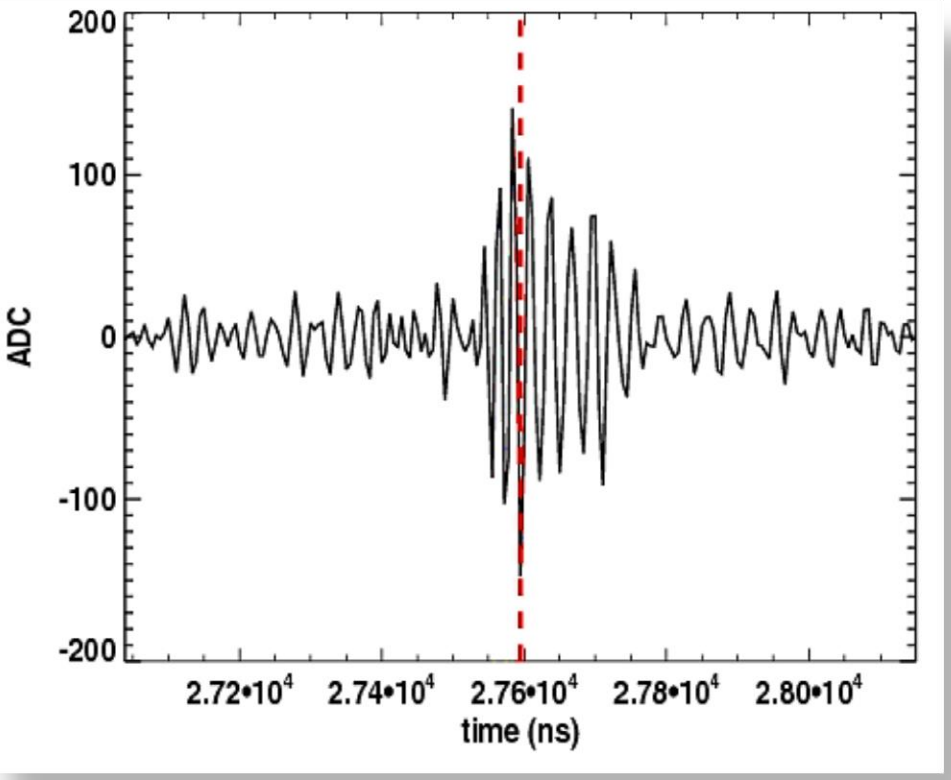


Rise time study

To reject the random coincidences remaining in the peak

→ Use of a rejection algorithm **developed for RAuger**

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

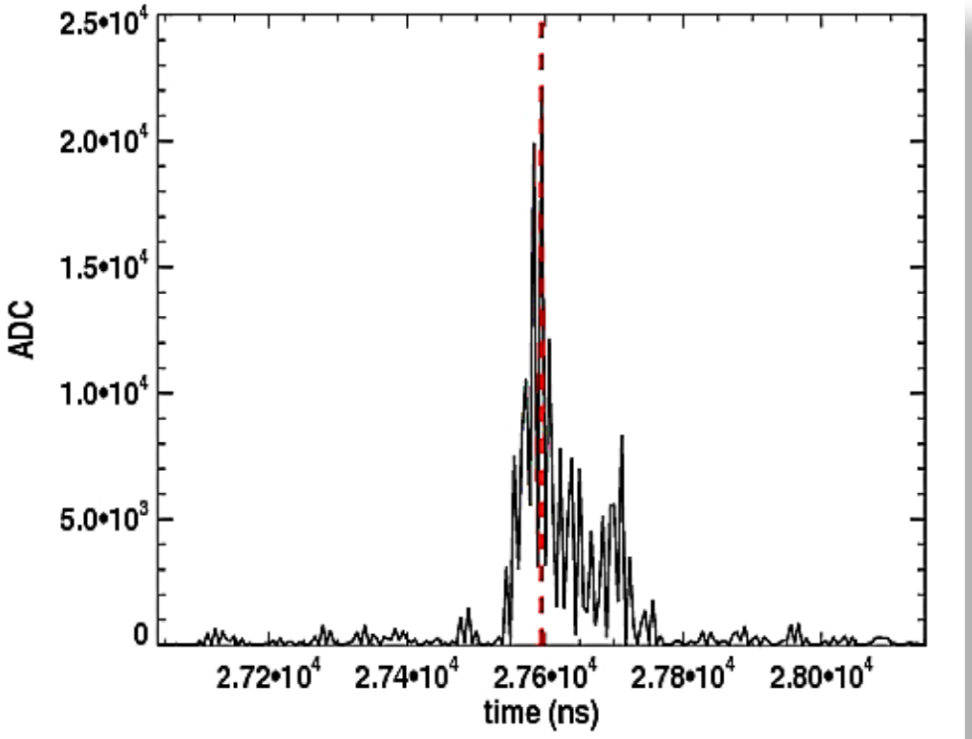


Rise time study

To reject the random coincidences remaining in the peak

→ Use of a rejection algorithm **developed for RAuger**

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

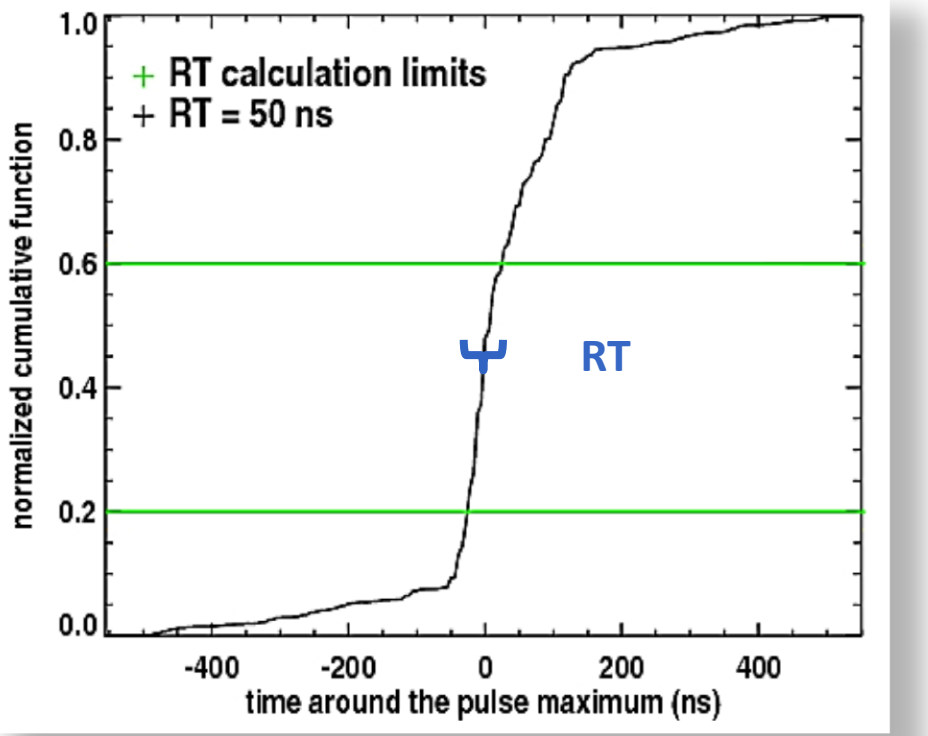


Rise time study

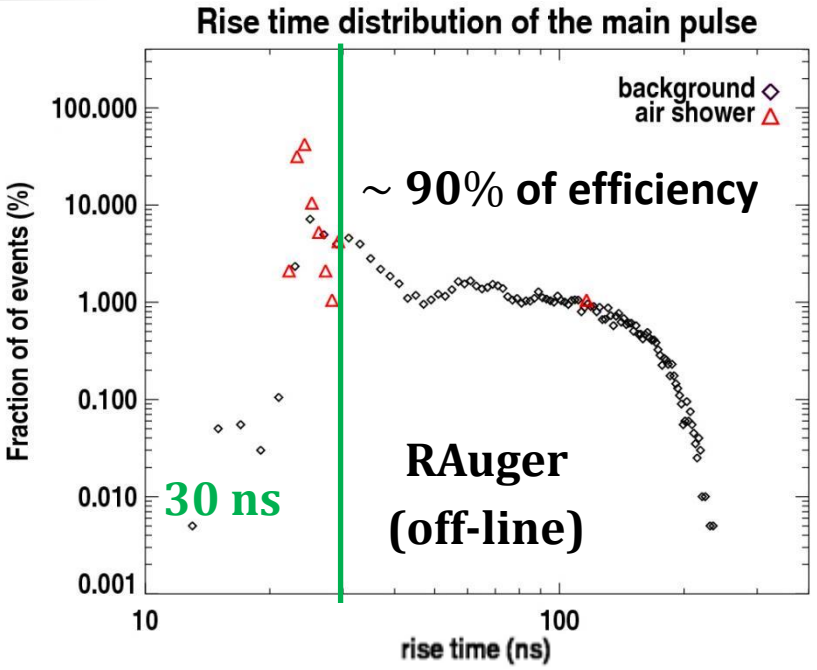
To reject the random coincidences remaining in the peak

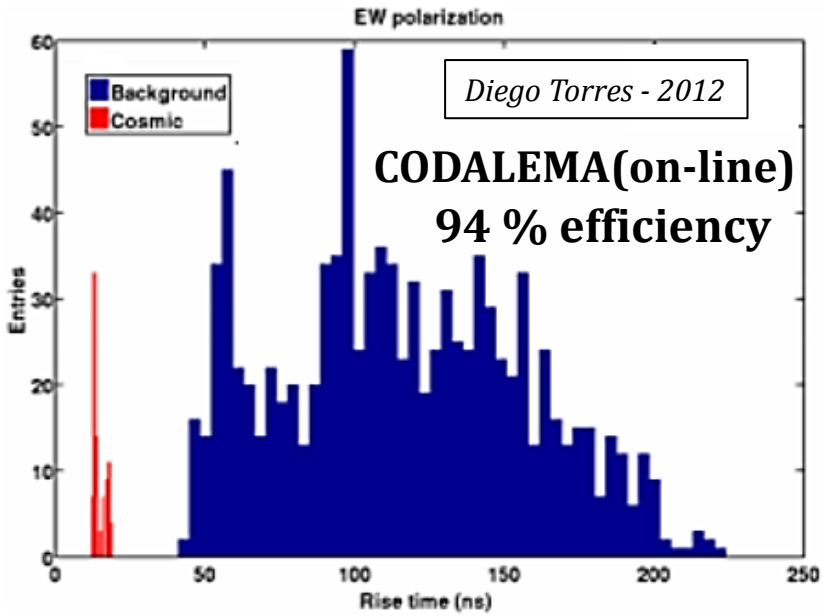
→ Use of a rejection algorithm **developed for RAuger**

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

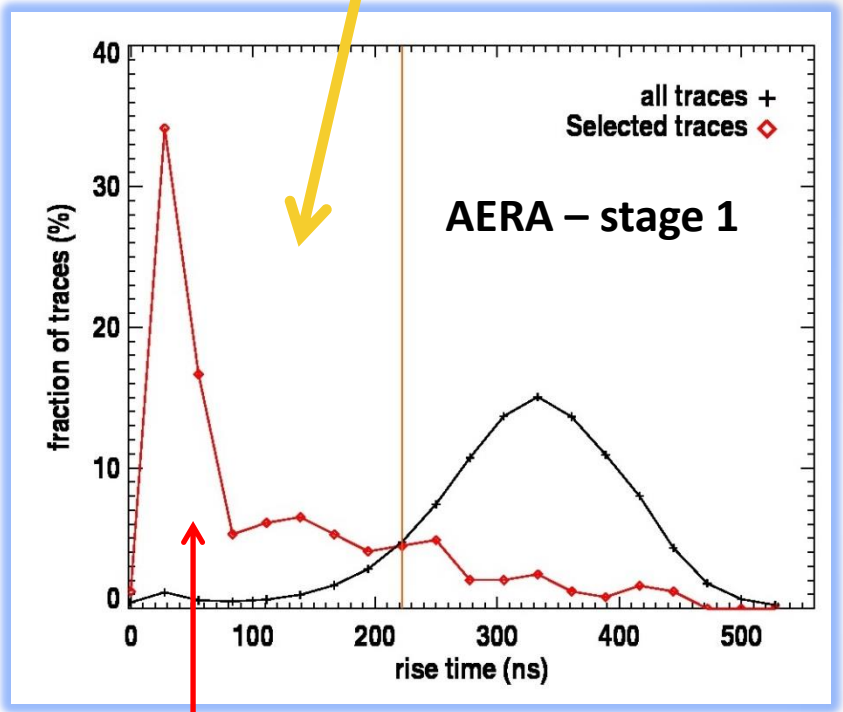


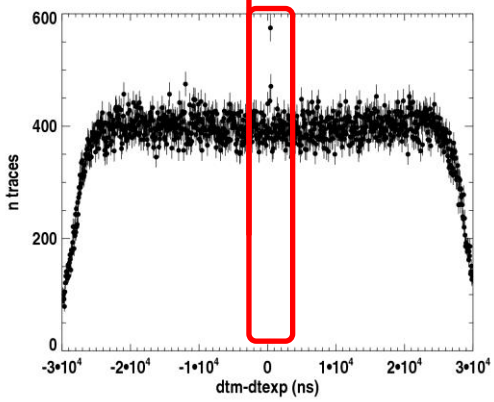
Rise time





Before 220 ns:
80% of the selected events
10% of the whole data set

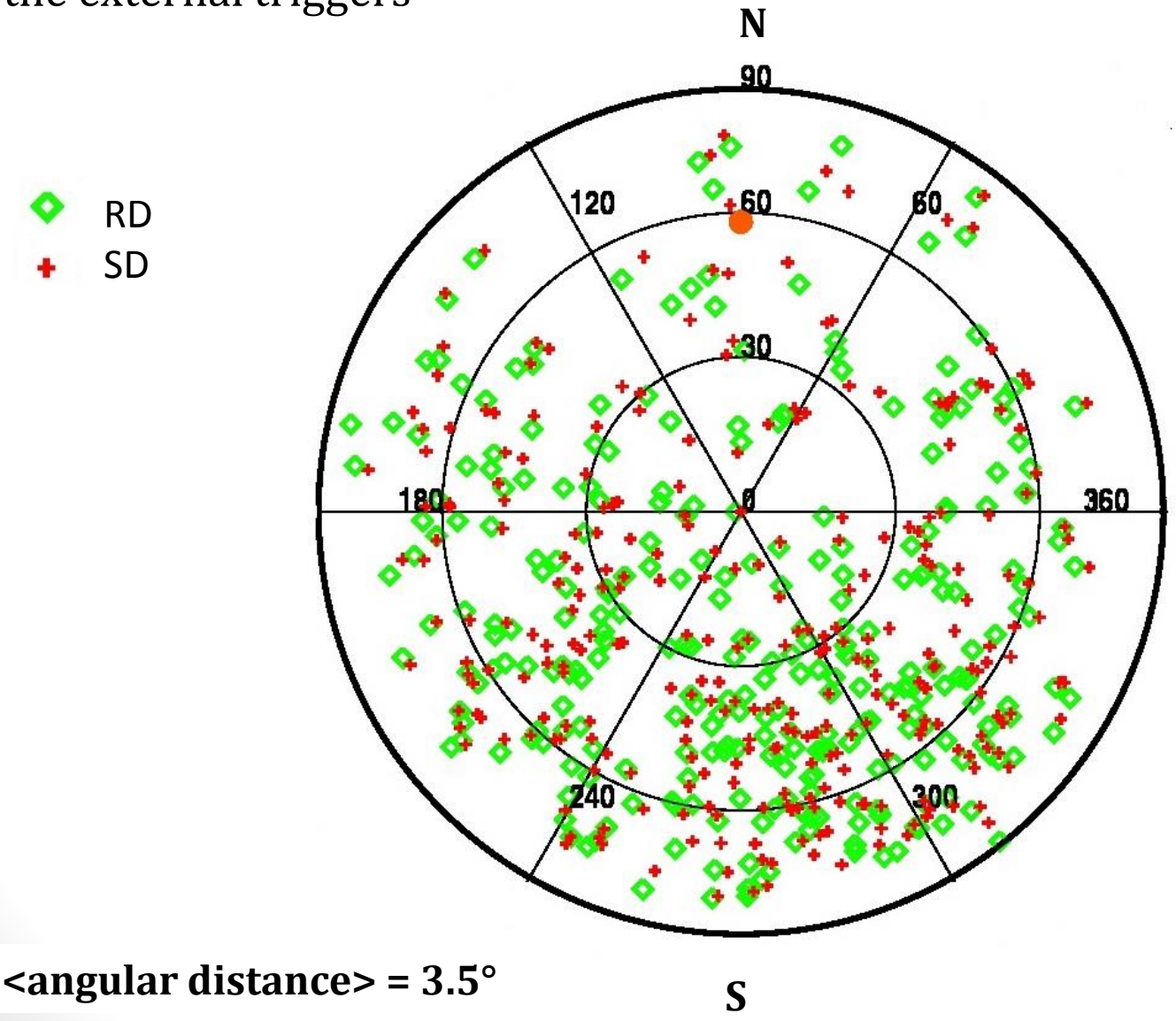




AERA
Auger Engineering Radio Array

Results for AERA stage 1

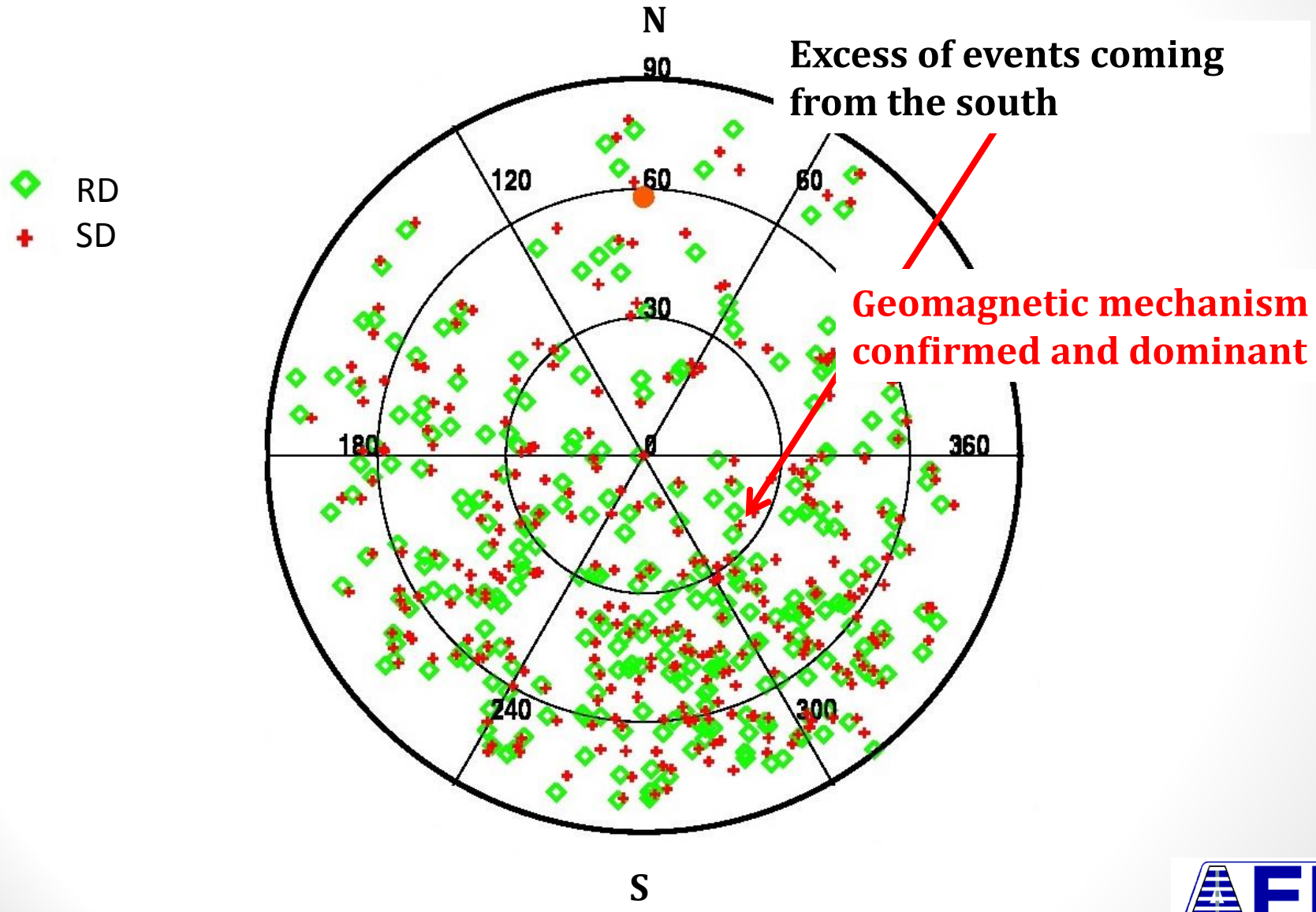
Reconstructed arrival directions with a rise time cut set at 220 ns for the external triggers



<angular distance> = 3.5°

AERA Auger Engineering Radio Array

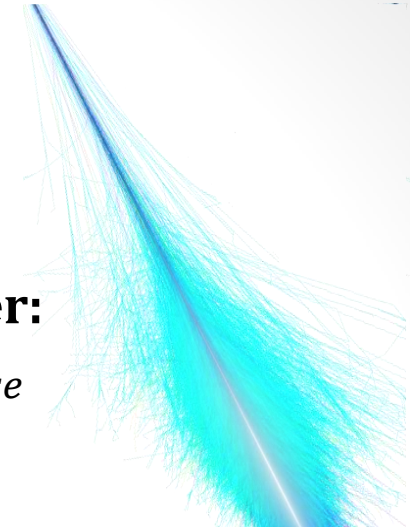
Polarization studies
→ Emissions processes



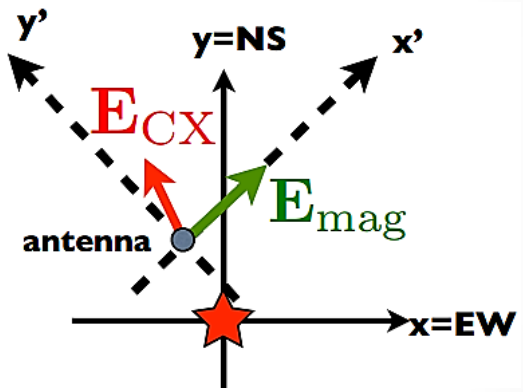
Polarization studies
→ Emissions processes

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

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 plane



- ❑ Calculation of the R-factor = formula
- → By construction: $R = 0$ for a purely geomagnetic emission

R_{data}

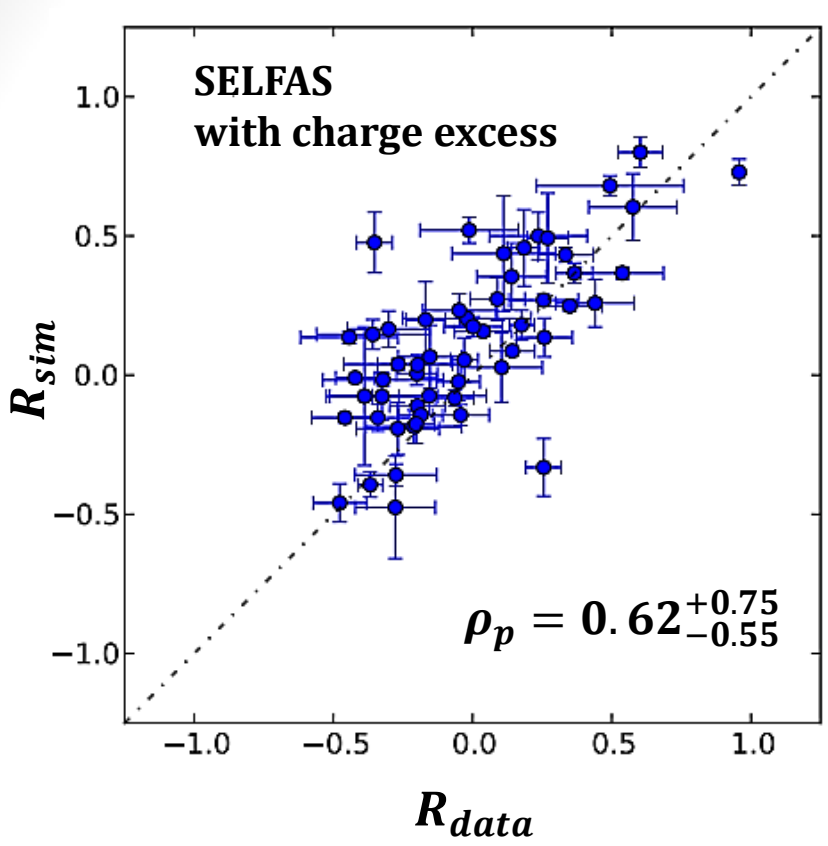
R_{sim}

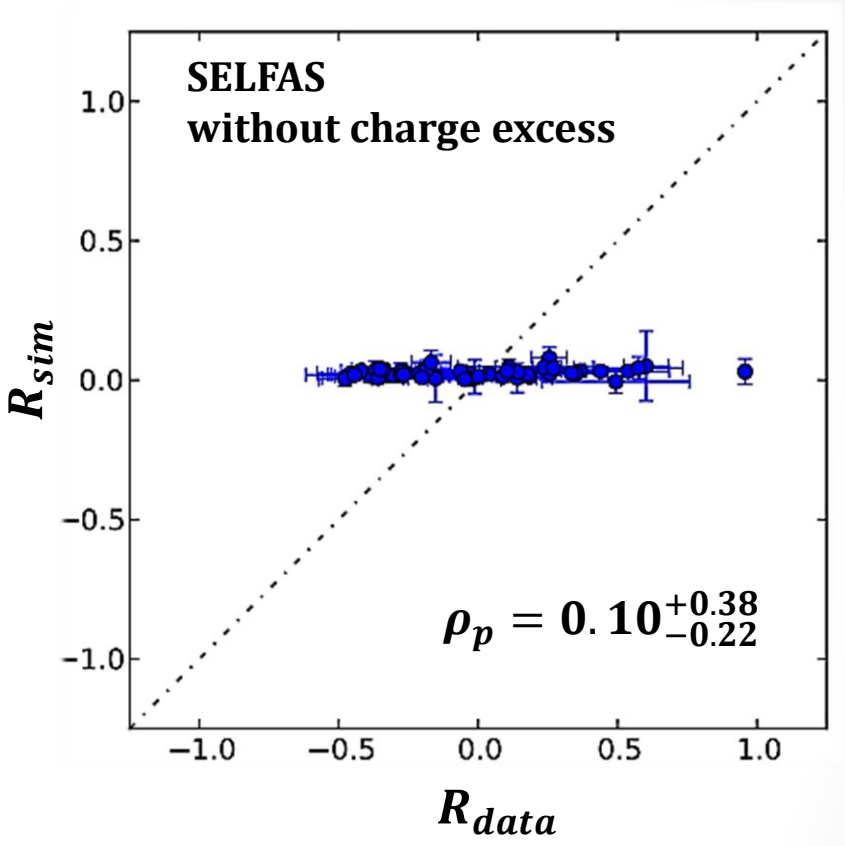
Simulated event with same parameters $\theta, \varphi, E, x_{core}, y_{core}$

1- Geomagnetic only
2- Geomagnetic + Charge excess

AERA Auger Engineering Radio Array

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
ICRC 2013 - Tim Huege

PIERRE AUGER OBSERVATORY

Jennifer Maller – JRJC 2013
On behalf the Pierre Auger Collaboration

AERA Auger Engineering Radio Array

Summary

- Selection of air shower events detected in coincidence with the SD:
  - → efficient in time and computing
  - → consistent with the previous study
  - → whole analysis can now be kept for really interesting events

- Rejection algorithm:
  - → need few computations
  - → efficient on several experiments: RAuger, CODALEMA, AERA

Perspectives

- SD/AERA coincidences analysis
  - → Extend the study to the full data set – stage 2 (in progress)

  - → polarization study of the measured electric field (in progress)

- FD/AERA coincidences study (in progress)
  - → nature of the primary cosmic ray