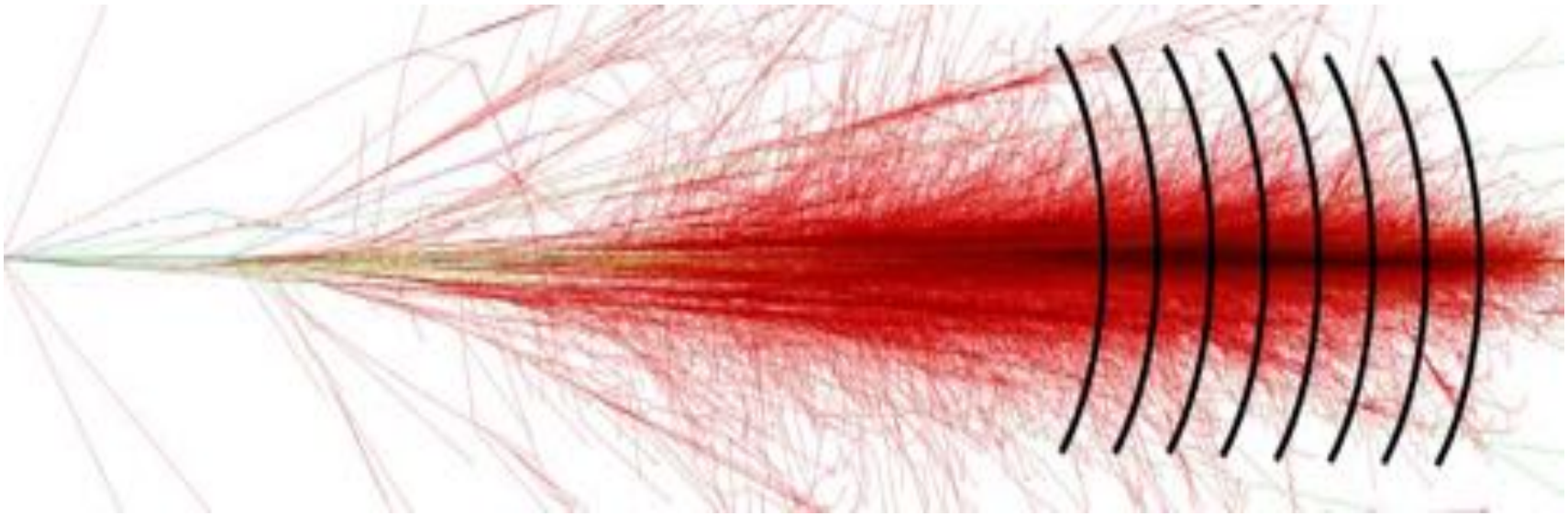
Latest results of the CODALEMA experiment: cosmic rays radio-detection in a self-trigger mode



By Diego Torres Machado
Astroparticles group at SUBATECH

Subatech

cnrs IN2P3 Les deux infinis

UNIVERSITÉ DE NANTES

ECOLE DES MINES DE NANTES

Contents

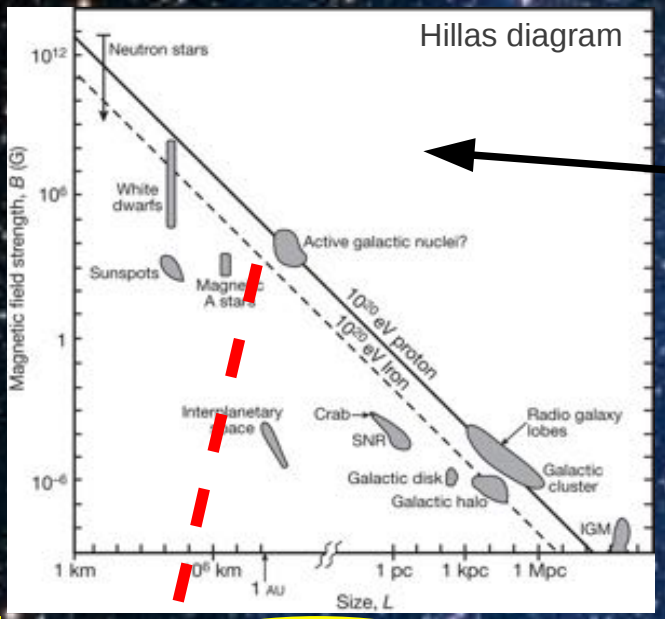
- Scientific issues
- Extensive Air Showers (EAS)
- CODALEMA experiment: radio-detection of EAS
- EAS detection & polarization
- Outlook

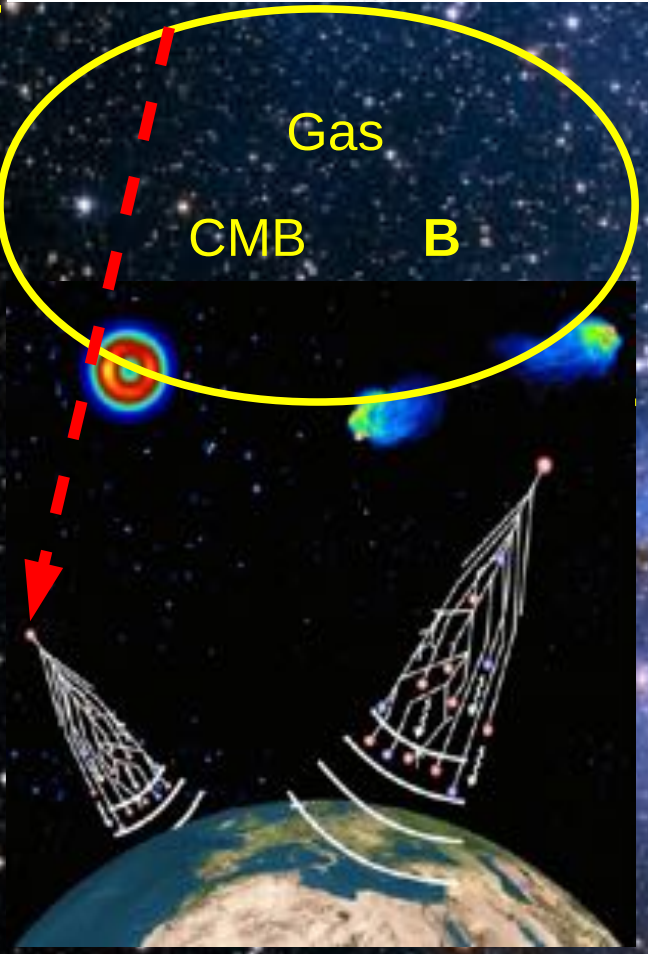
1912

2012

Scientific issues

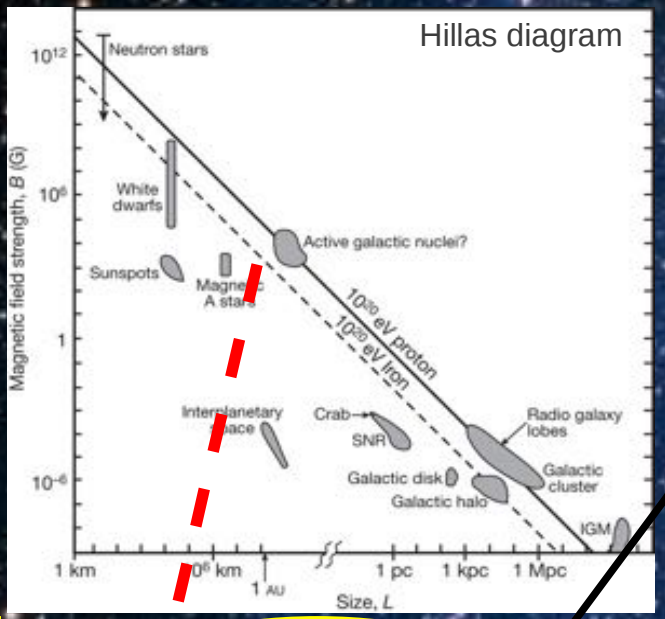
- **Sources / acceleration mechanisms**

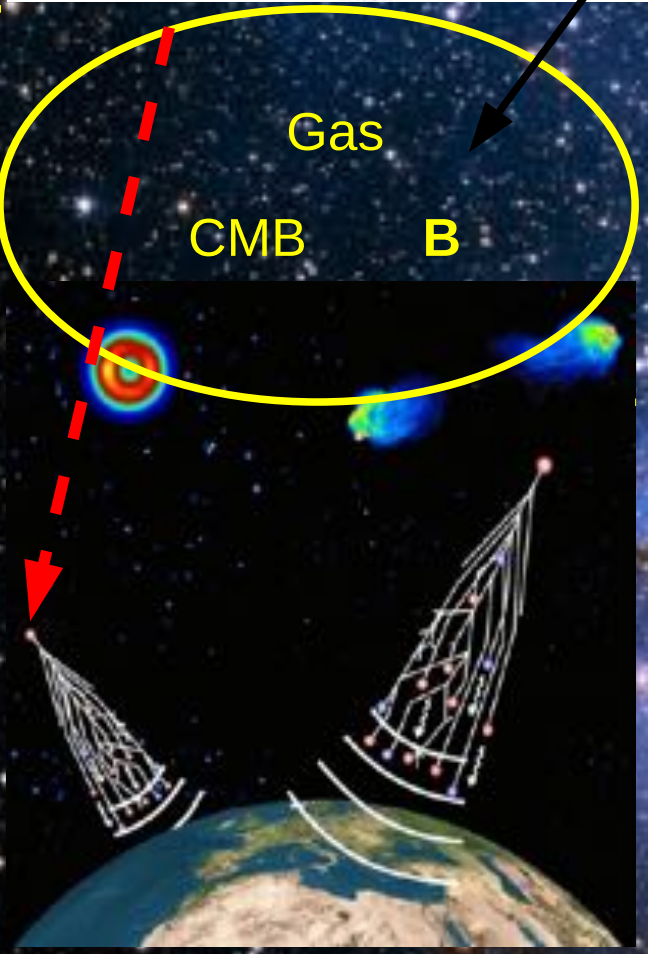




Scientific issues

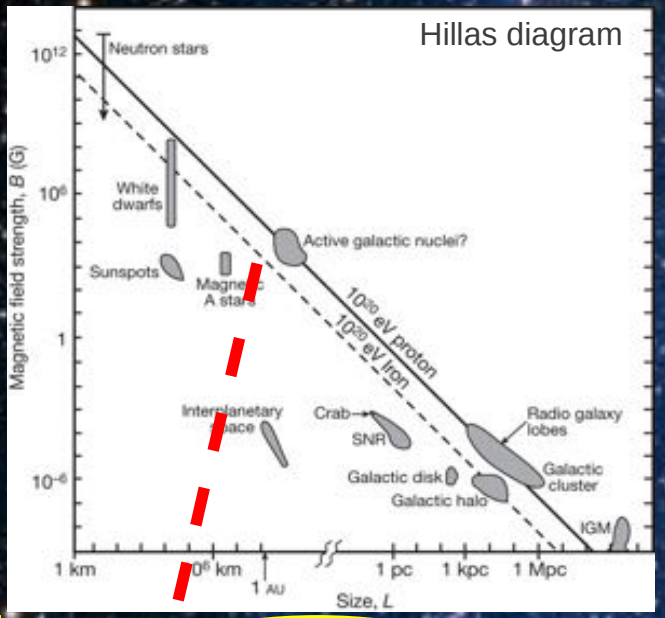
- Sources / acceleration mechanisms
- **Medium crossed by cosmic rays**

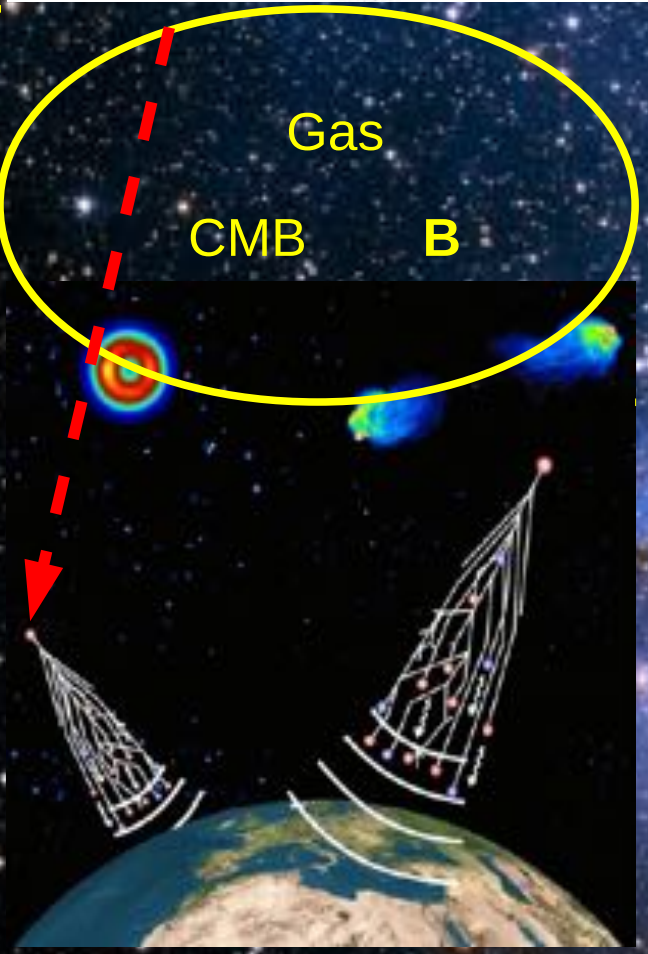


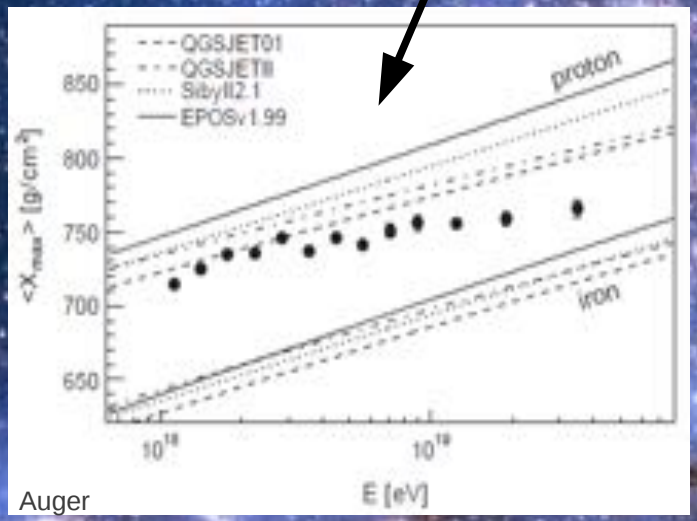


Scientific issues

- Sources / acceleration mechanisms
- Medium crossed by cosmic rays
- **Composition at ultra high energy**

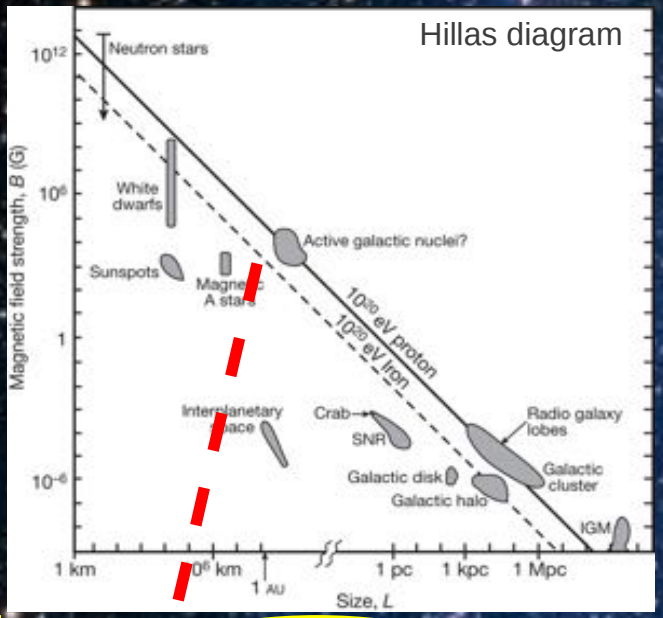


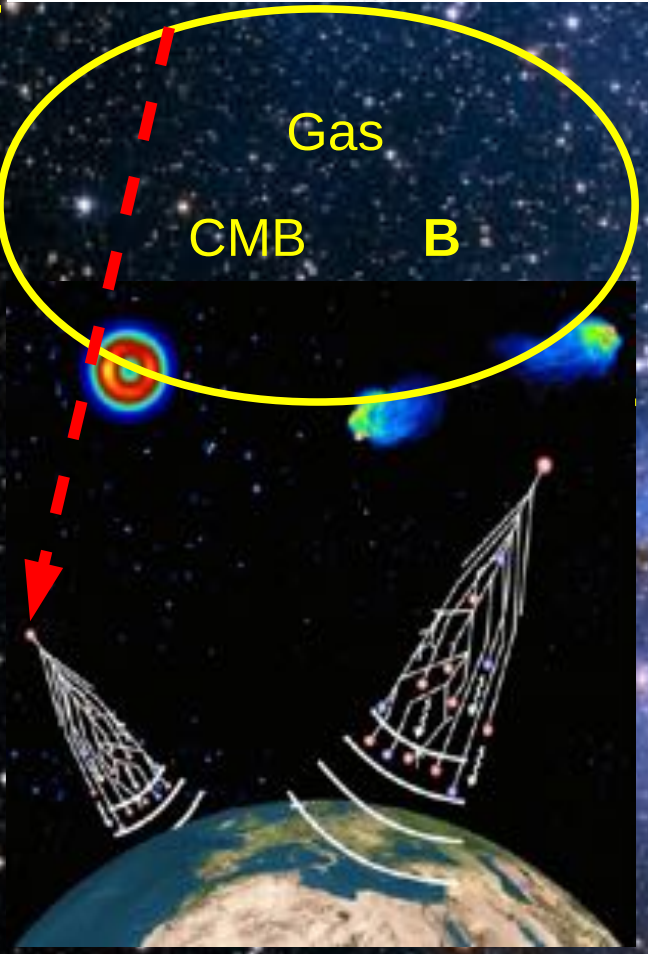


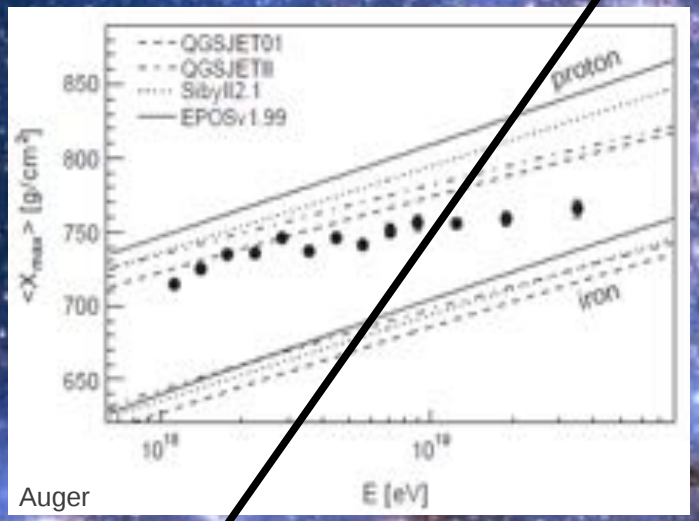


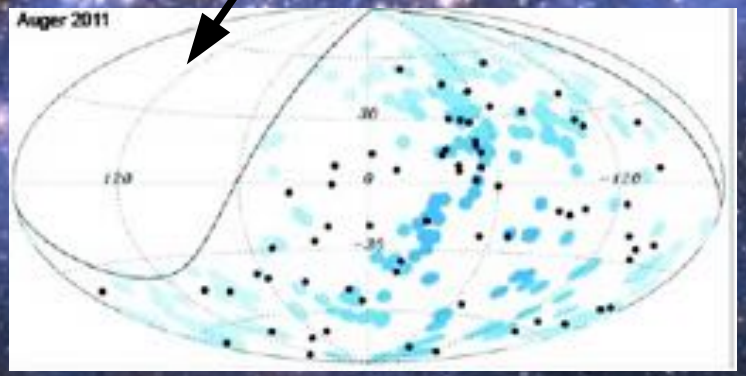
Scientific issues

- Sources / acceleration mechanisms
- Medium crossed by cosmic rays
- Composition at ultra high energy
- **Anisotropy: proton astronomy is possible ?**



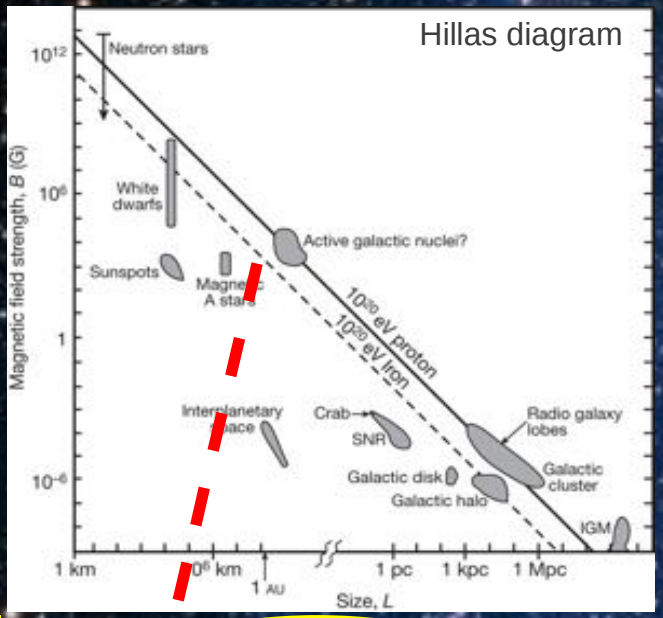


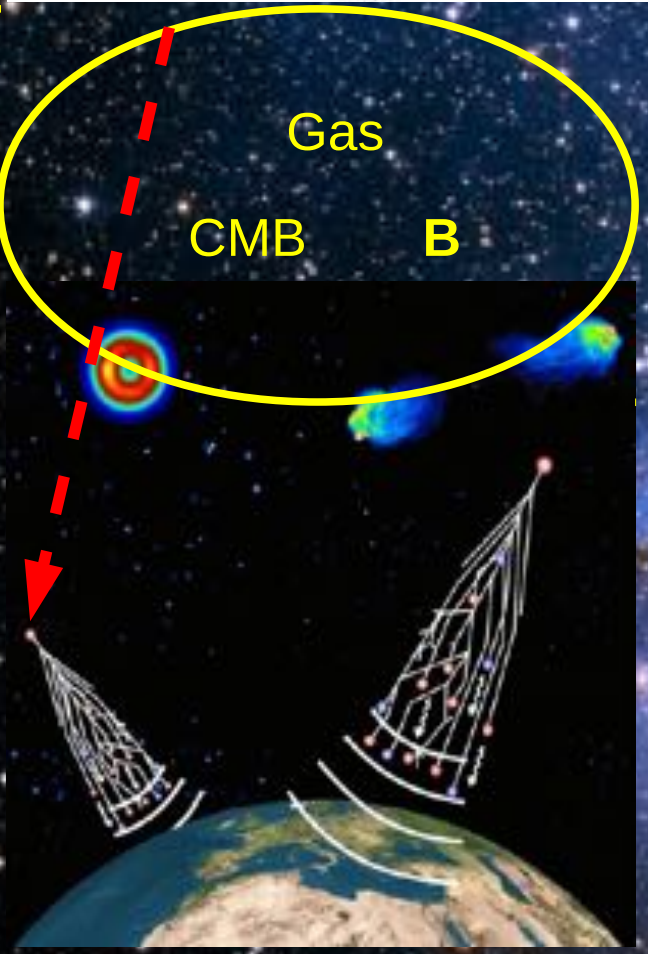


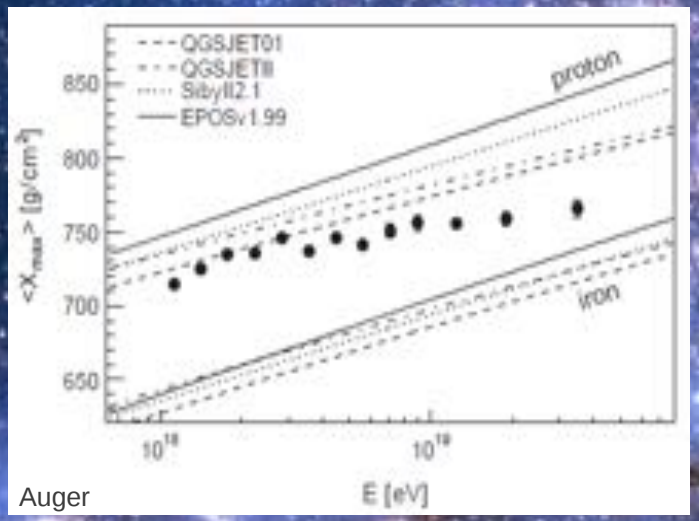


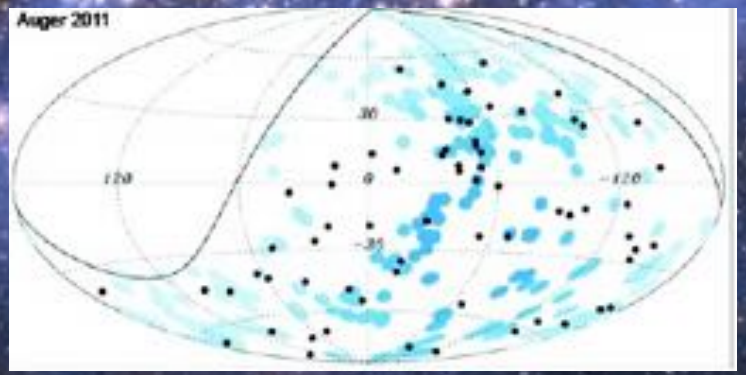
Scientific issues

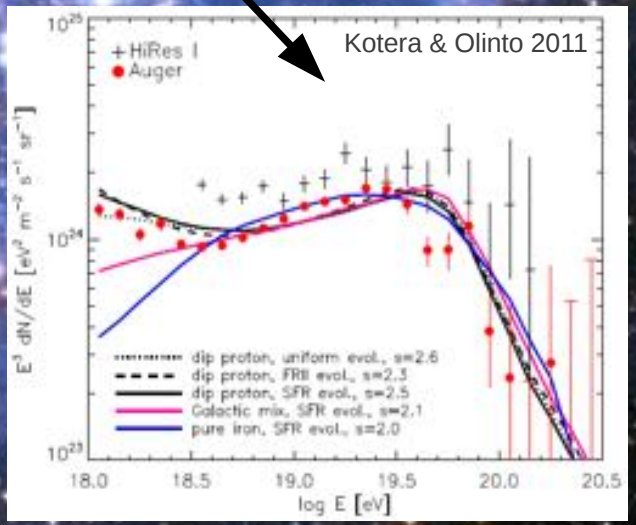
- Sources / acceleration mechanisms
- Medium crossed by cosmic rays
- Composition at ultra high energy
- Anisotropy: proton astronomy is possible ?
- **High energy cut-off: GZK or acceleration limit ?**











Extensive Air Showers: properties

Very low flux at ultra high energy

↓

Indirect detection + Large surface

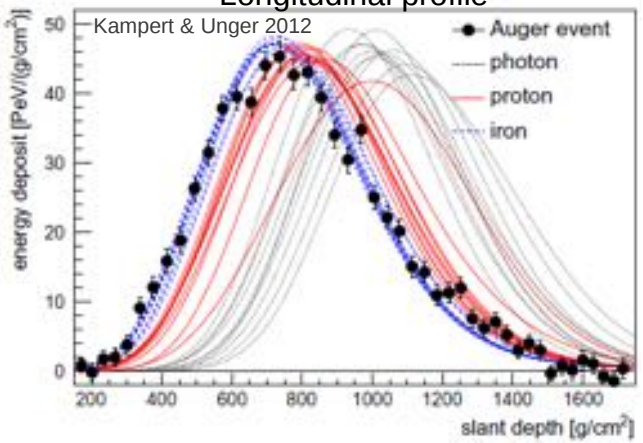
↓

Shower parameters

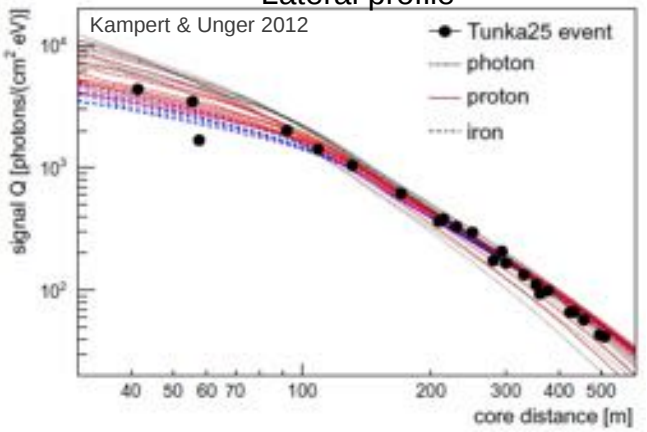
↓

Direction, Nature and Energy of the primary cosmic ray

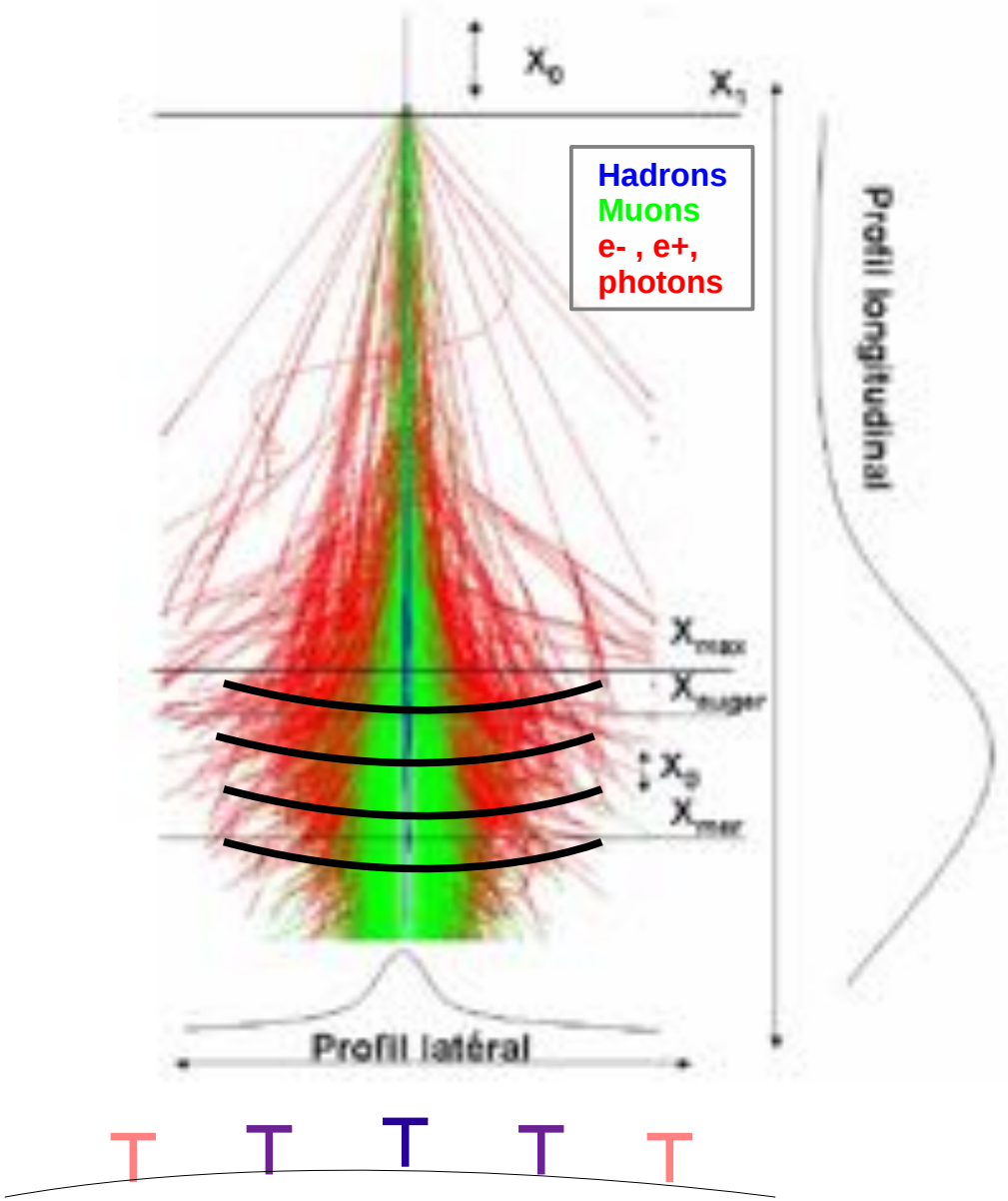
Longitudinal profile



Lateral profile



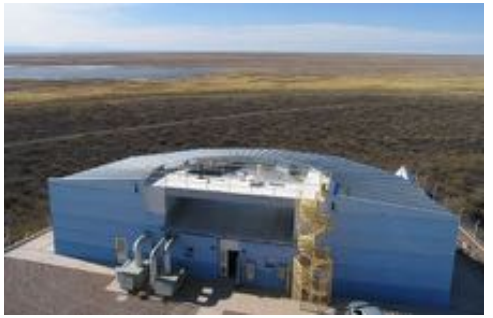
EAS simulation for a 10^{15}eV cosmic ray

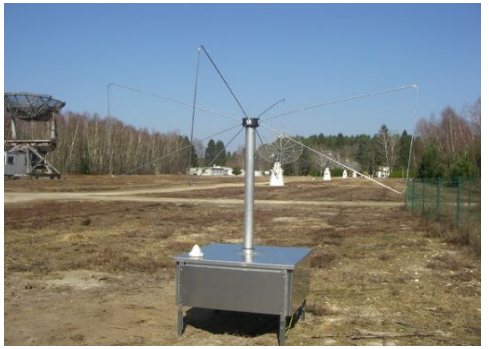


Extensive Air Showers: detection instruments

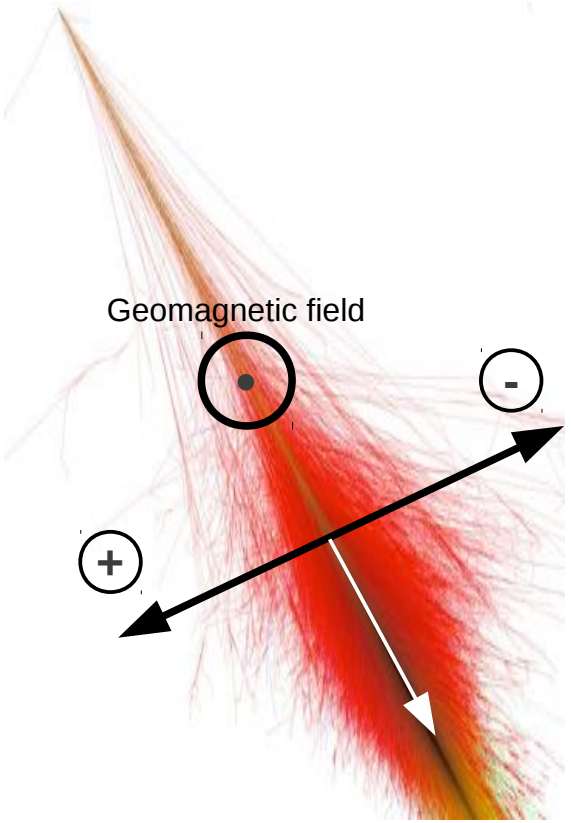
How to detect it ?

	Observable	Advantages	Drawbacks
Water Cherenkov Detectors Scintillators	Particle density at the ground level ↓ Lateral spread	Duty cycle~100% Direct measure of the particle density	Model-dependent for energy computation
Air Fluorescence Detectors	Nitrogen fluorescence in the atmosphere ↓ Longitudinal spread	3D shower development Detection at several km	Low duty cycle
Radio-Detection	Electric field ↓ Lateral spread of the electric field + Longitudinal spread?	High duty cycle Low cost Angular acceptance	Sensitivity to the Radio Frequency Interferences





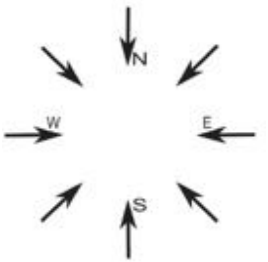
Extensive Air Showers: emission mechanisms



CORSIKA simulation

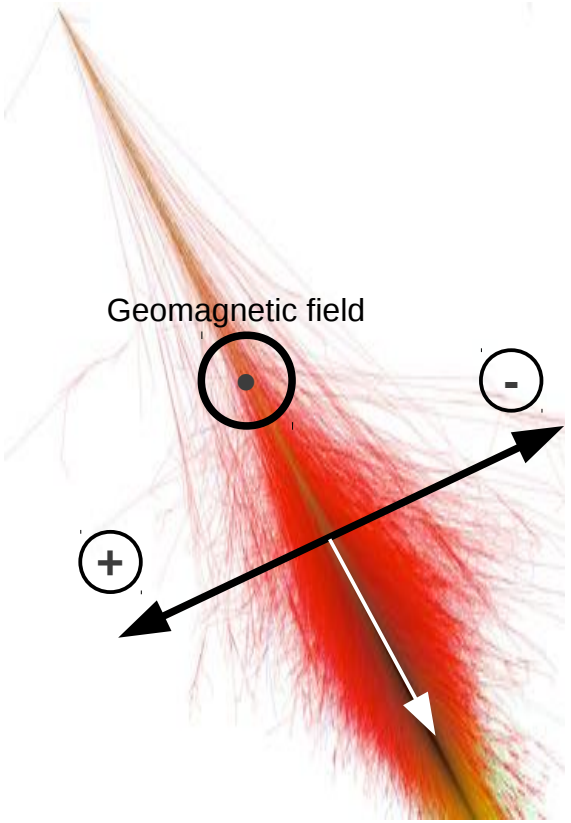
Origins of the electric field:

- Cerenkov radiation due to time varying charge excess (10-20%) - monopolar emission



$$\boldsymbol{E}(\boldsymbol{x},t) = \frac{1}{4\pi\epsilon_0}\left\{ \left[\frac{\boldsymbol{n}q(t_{ret})}{R^2(1-\boldsymbol{\beta}.\boldsymbol{n})}\right]_{\text{ret}} + \frac{1}{c}\frac{\partial}{\partial t}\left[\frac{\boldsymbol{n}q(t_{ret})}{R(1-\boldsymbol{\beta}.\boldsymbol{n})}\right]_{\text{ret}} - \frac{1}{c^2}\frac{\partial}{\partial t}\left[\frac{\boldsymbol{v}q(t_{ret})}{R(1-\boldsymbol{\beta}.\boldsymbol{n})}\right]_{\text{ret}} \right\}$$

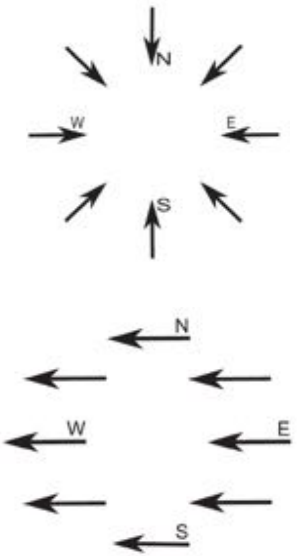
Extensive Air Showers: emission mechanisms



CORSIKA simulation

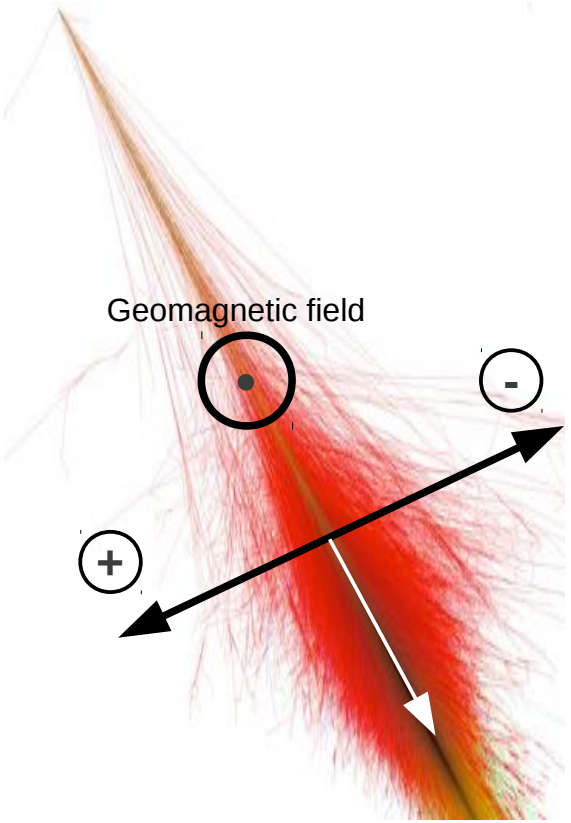
Origins of the electric field:

- Cerenkov radiation due to time varying charge excess (10-20%) - monopolar emission
- Synchrotron radiation due to time varying transverse current – dipolar emission along **v** x **B**



$$\boldsymbol{E}(\boldsymbol{x},t) = \frac{1}{4\pi\epsilon_0}\left\{ \left[\frac{\boldsymbol{n}q(t_{ret})}{R^2(1-\boldsymbol{\beta}.\boldsymbol{n})}\right]_{\rm ret} + \frac{1}{c}\frac{\partial}{\partial t}\left[\frac{\boldsymbol{n}q(t_{ret})}{R(1-\boldsymbol{\beta}.\boldsymbol{n})}\right]_{\rm ret} - \frac{1}{c^2}\frac{\partial}{\partial t}\left[\frac{\boldsymbol{v}q(t_{ret})}{R(1-\boldsymbol{\beta}.\boldsymbol{n})}\right]_{\rm ret}\right\}$$

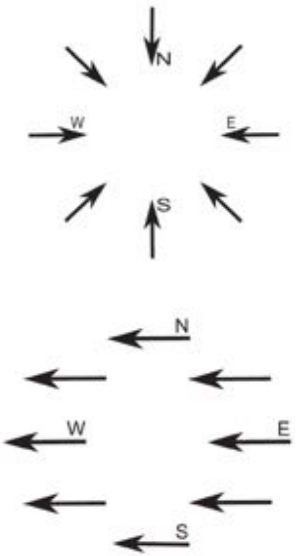
Extensive Air Showers: emission mechanisms



CORSIKA simulation

Origins of the electric field:

- Cerenkov radiation due to time varying charge excess (10-20%) - monopolar emission
- Synchrotron radiation due to time varying transverse current – dipolar emission along **v** x **B**



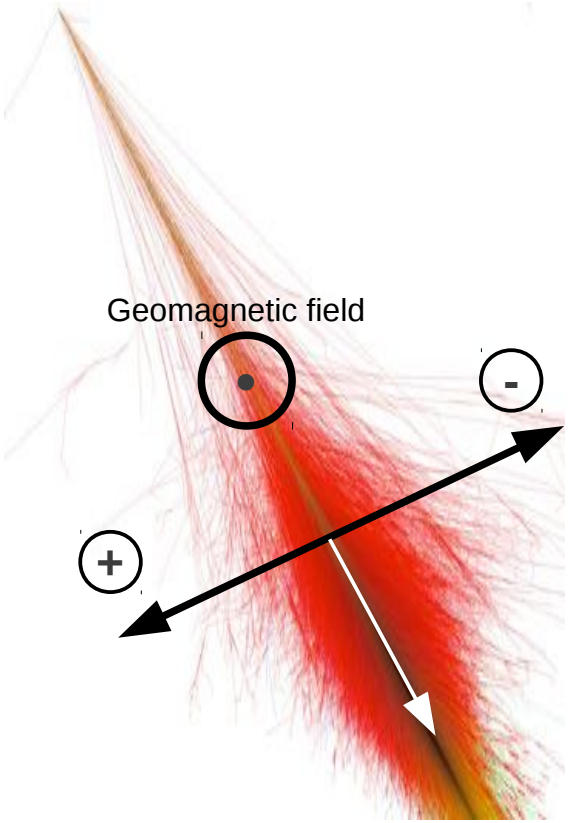
⇩

✔ **Confirmed by CODALEMA data**

Ardouin D et al 2009 Astropart. Phys **31** 192-200
Marin V & Revenu B 2012: http://arxiv.org/abs/1203.5248v1

$$\boldsymbol{E}(\boldsymbol{x},t) = \frac{1}{4\pi\epsilon_0}\left\{ \left[\frac{\boldsymbol{n}q(t_{ret})}{R^2(1-\boldsymbol{\beta}.\boldsymbol{n})}\right]_{\text{ret}} + \frac{1}{c}\frac{\partial}{\partial t}\left[\frac{\boldsymbol{n}q(t_{ret})}{R(1-\boldsymbol{\beta}.\boldsymbol{n})}\right]_{\text{ret}} - \frac{1}{c^2}\frac{\partial}{\partial t}\left[\frac{\boldsymbol{v}q(t_{ret})}{R(1-\boldsymbol{\beta}.\boldsymbol{n})}\right]_{\text{ret}} \right\}$$

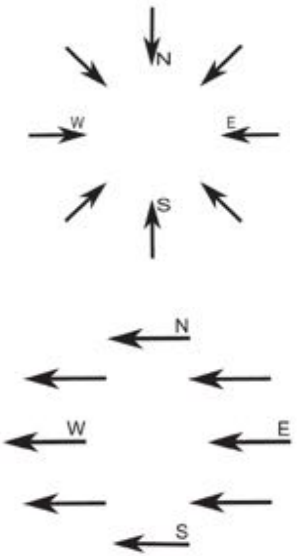
Extensive Air Showers: emission mechanisms



CORSIKA simulation

Origins of the electric field:

- Cerenkov radiation due to time varying charge excess (10-20%) - monopolar emission
- Synchrotron radiation due to time varying transverse current – dipolar emission along **v** x **B**



⇩

✔ **Confirmed by CODALEMA data**

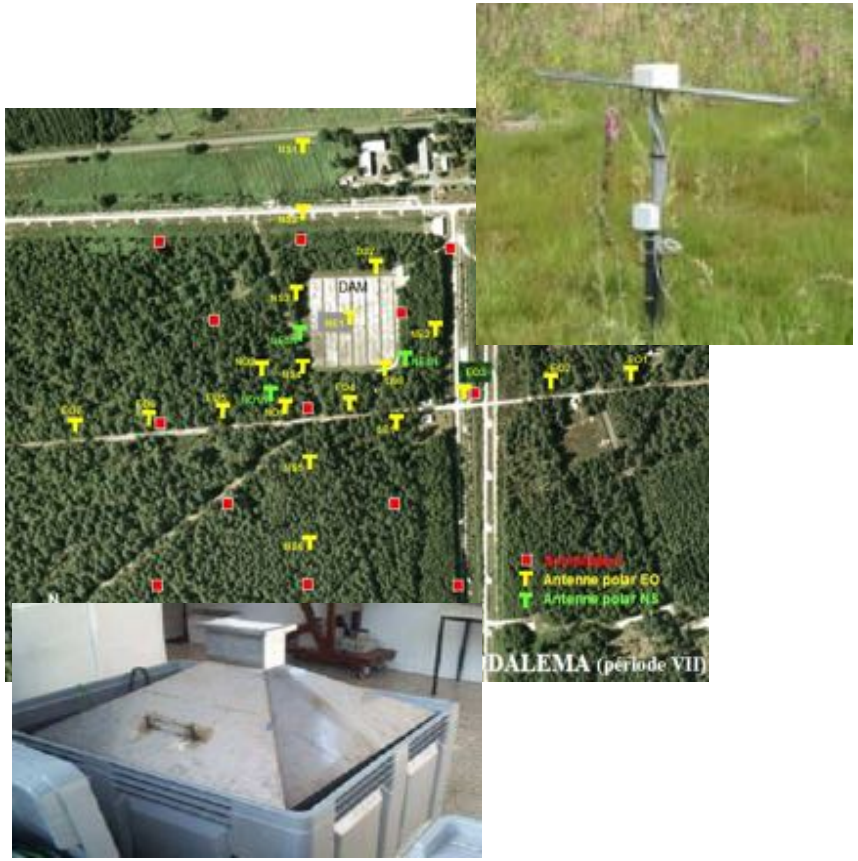
Ardouin D et al 2009 Astropart. Phys **31** 192-200
Marin V & Revenu B 2012: http://arxiv.org/abs/1203.5248v1

$$\boldsymbol{E}(\boldsymbol{x},t) = \frac{1}{4\pi\epsilon_0}\left\{ \left[\frac{\boldsymbol{n}q(t_{ret})}{R^2(1-\boldsymbol{\beta}.\boldsymbol{n})}\right]_{\text{ret}} + \frac{1}{c}\frac{\partial}{\partial t}\left[\frac{\boldsymbol{n}q(t_{ret})}{R(1-\boldsymbol{\beta}.\boldsymbol{n})}\right]_{\text{ret}} - \frac{1}{c^2}\frac{\partial}{\partial t}\left[\frac{\boldsymbol{v}q(t_{ret})}{R(1-\boldsymbol{\beta}.\boldsymbol{n})}\right]_{\text{ret}} \right\}$$

Sensitivity to the entire shower development

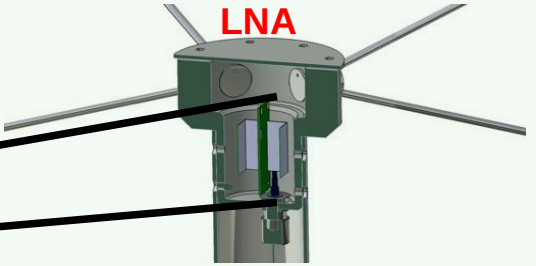
CODALEMA experiment: the antenna array

Nançay Observatory



- Area: 0.5km² → more statistics in 10^{16} – 10^{18}eV energy range
- Better understanding of lateral/longitudinal profiles
- Cosmic rays composition at the 2nd knee
- R&D for future giant & hybrid detectors (AERA, Auger next)

CODALEMA experiment: a new method of detection

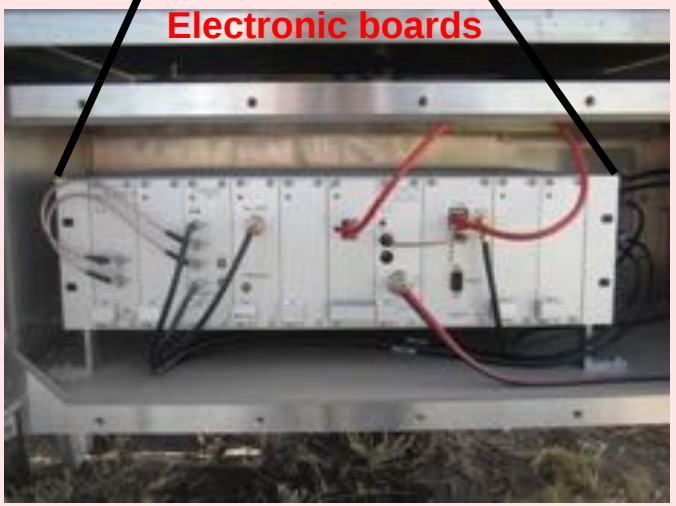


Signal is produced and amplified

Trigger in 45-55MHz

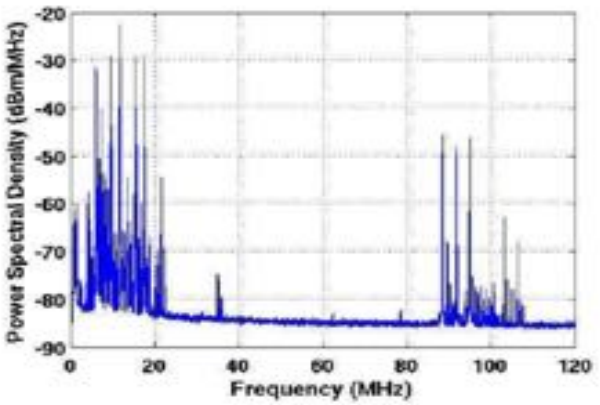
Signal digitization over 2.56µs
GPS dating
Data acquisition

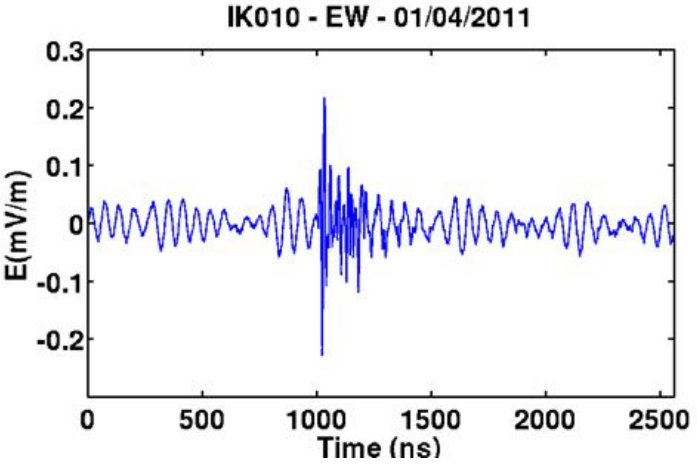
Offline data analysis

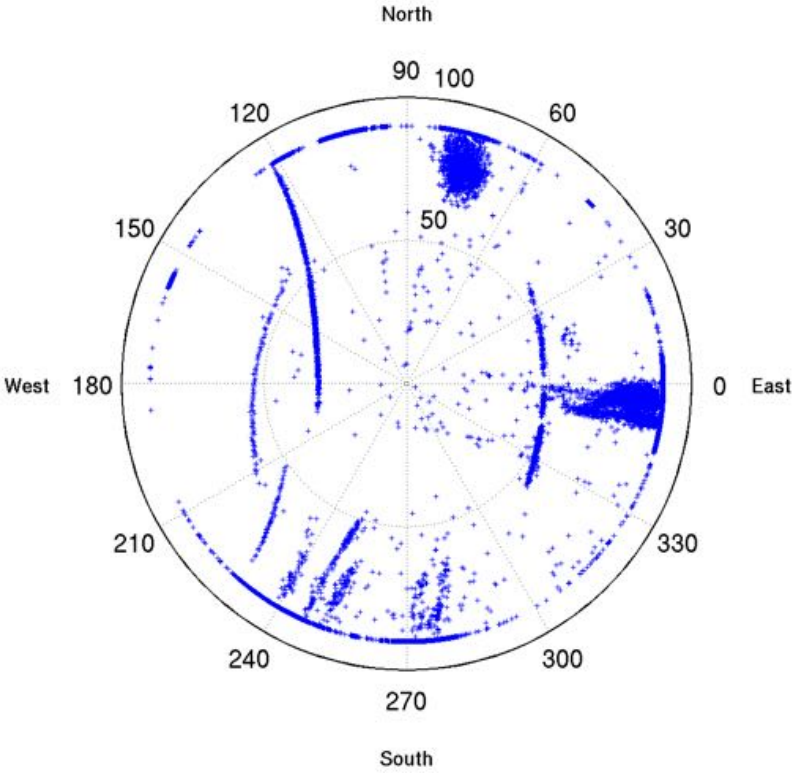


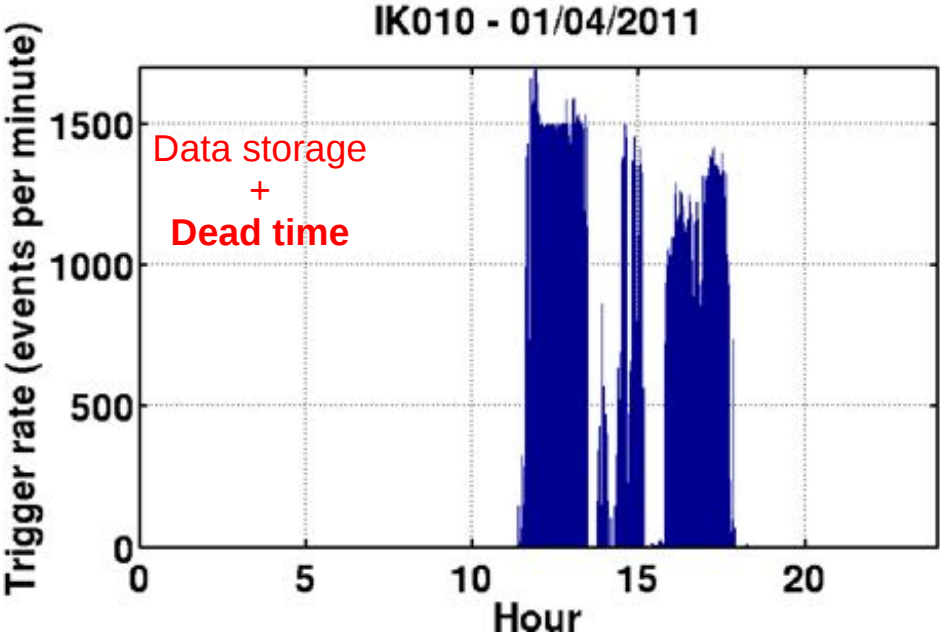
Standalone detection: Noise sources

Sensitivity to the radio background sources





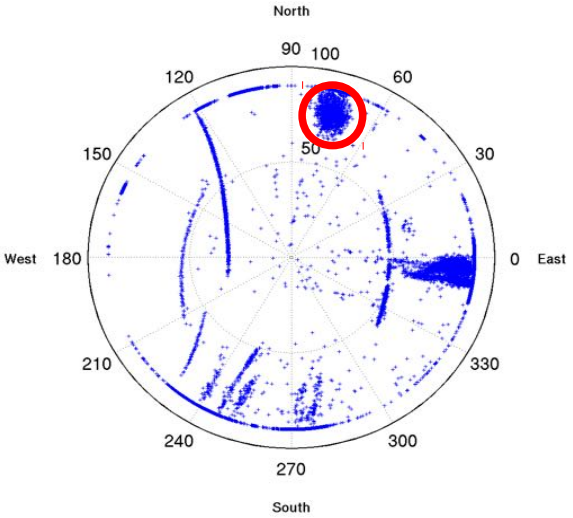


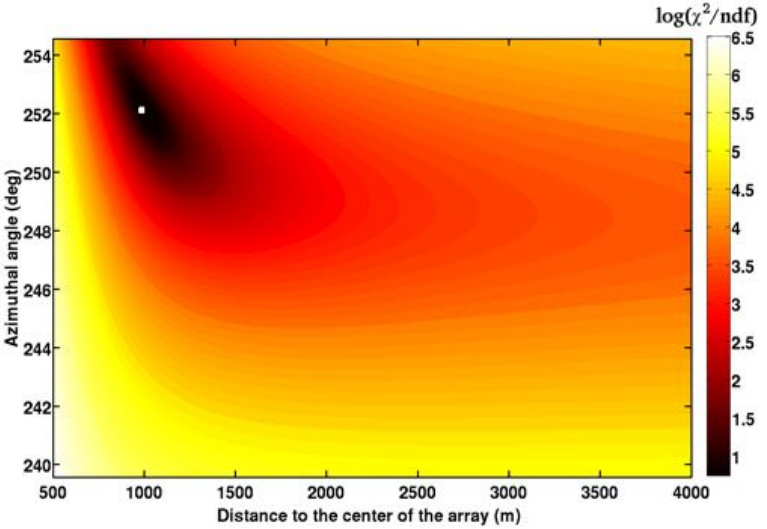


Standalone detection: rejection modes & reconstruction

Spherical reconstruction of the wave front (offline)

- Sensitivity to the initial conditions
- High accuracy required about antenna's position and timing of events

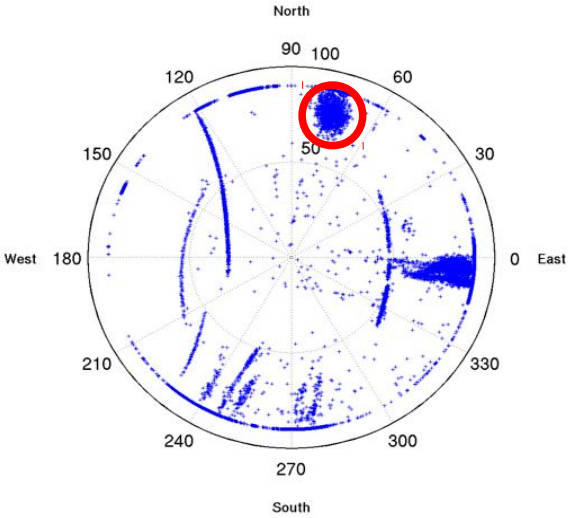


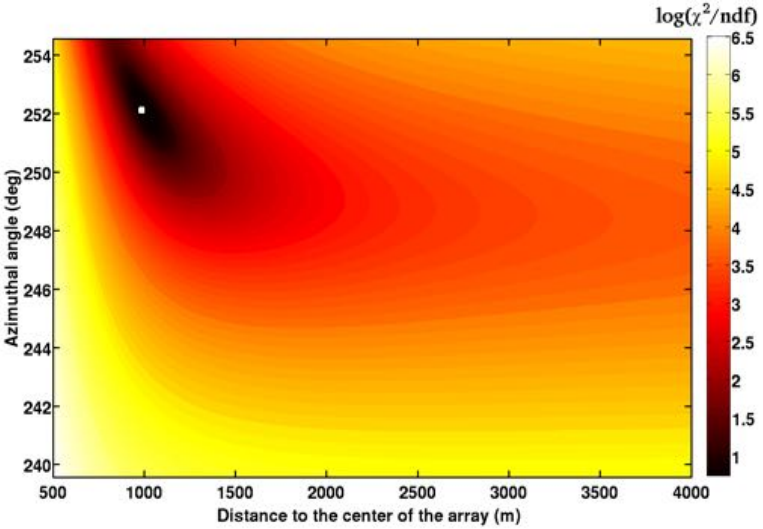


Standalone detection: rejection modes & reconstruction

Spherical reconstruction of the wave front (offline)

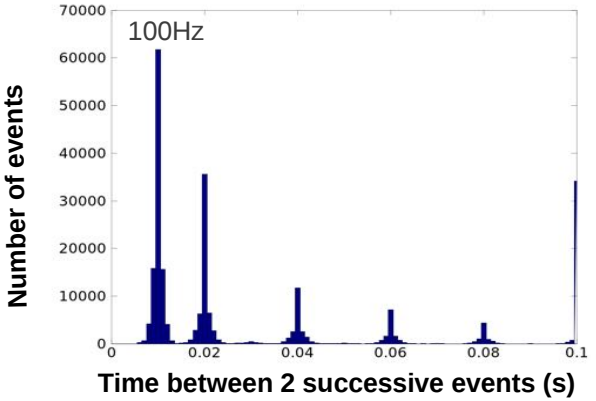
- Sensitivity to the initial conditions
- High accuracy required about antenna's position and timing of events





Rejection of periodic events (online)

- Radio environment of each antenna

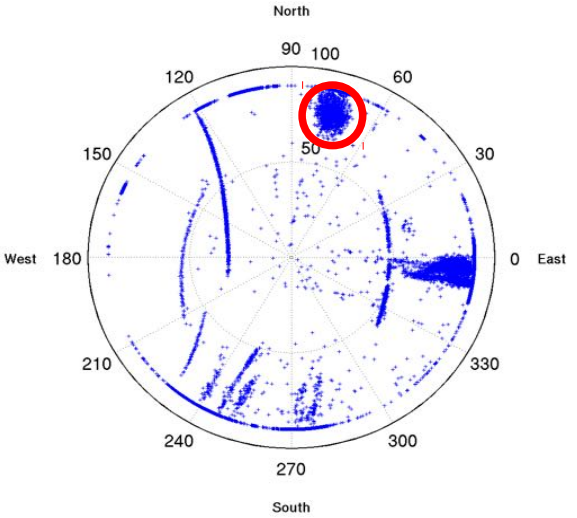


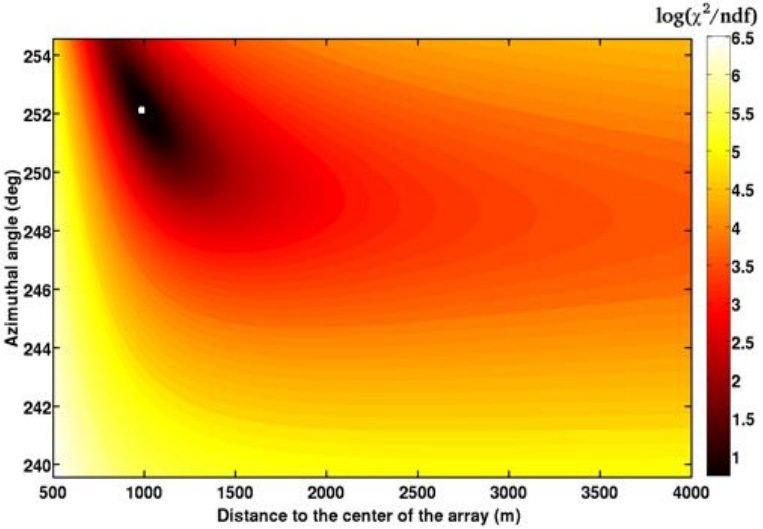
EDF transformer

Standalone detection: rejection modes & reconstruction

Spherical reconstruction of the wave front (offline)

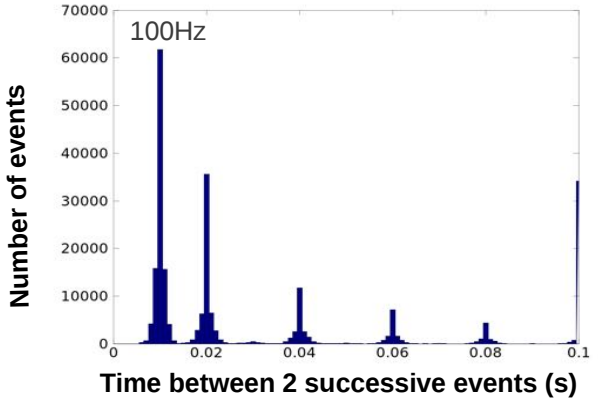
- Sensitivity to the initial conditions
- High accuracy required about antenna's position and timing of events





Rejection of periodic events (online)

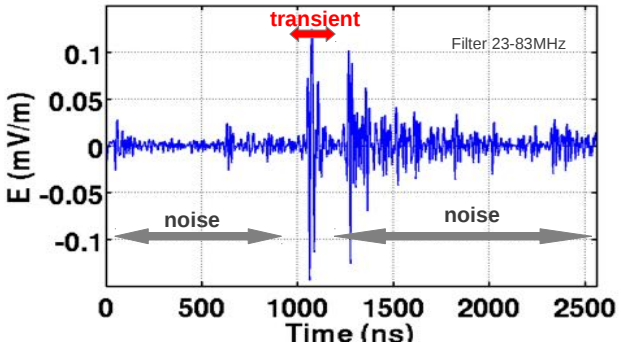
- Radio environment of each antenna



EDF transformer

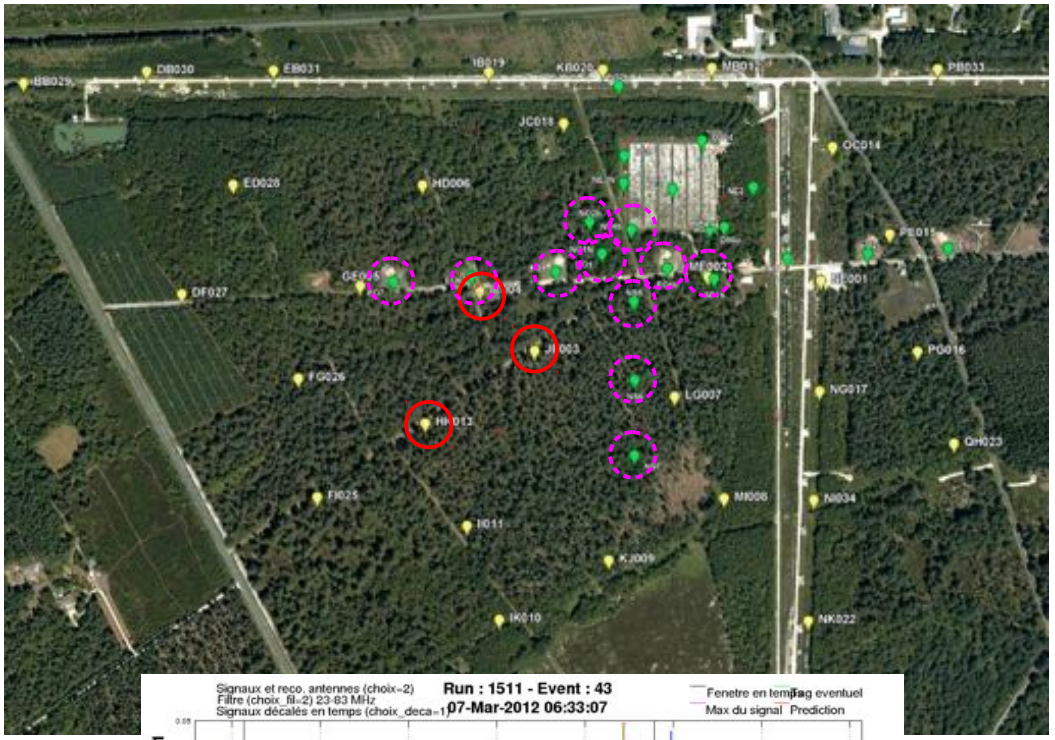
Wave shape analysis (online)

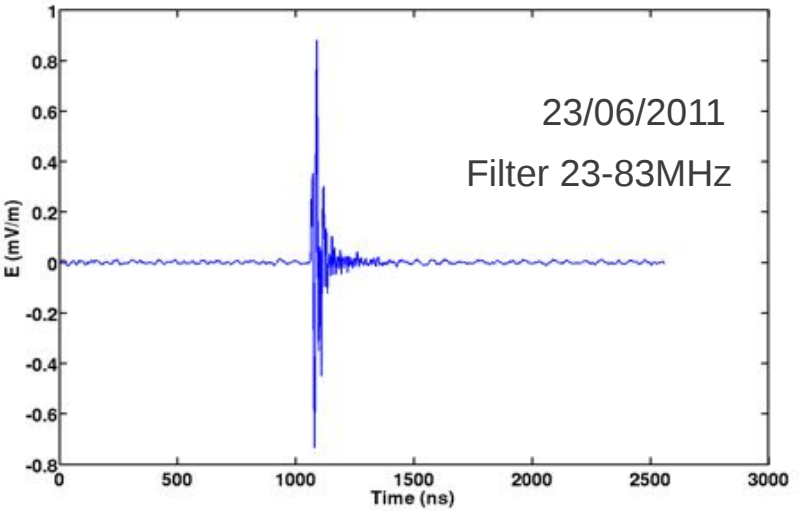
- Expected transient coming from an EAS: < 100ns



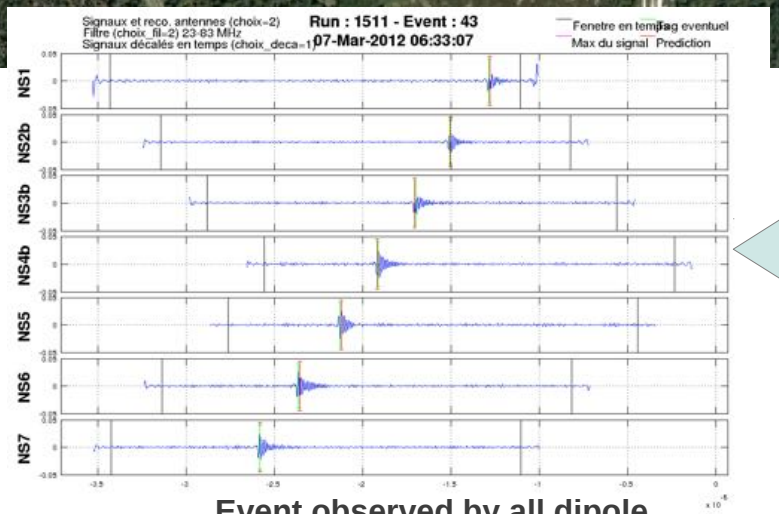
EAS detection & polarization

09/06/2011 20:30:49 TU





07/03/2012 06:33:07 TU – 14 self-triggering antennas in coincidence with scintillators



Event observed by all dipole antennas!

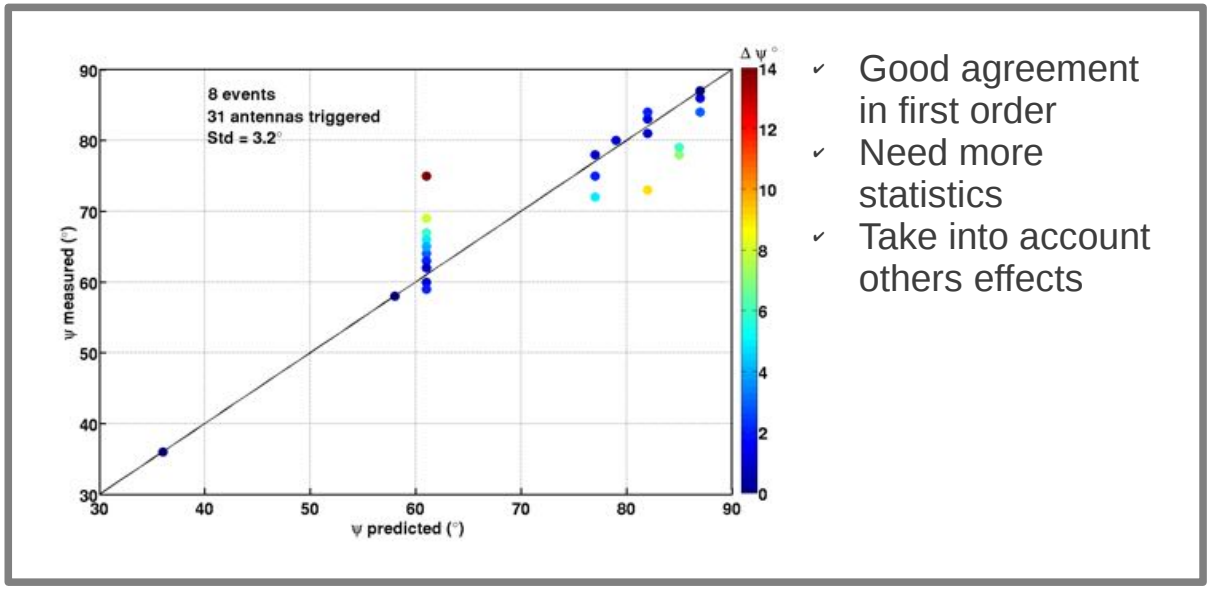
Wave transit time: 4.3µs

EAS detection & polarization

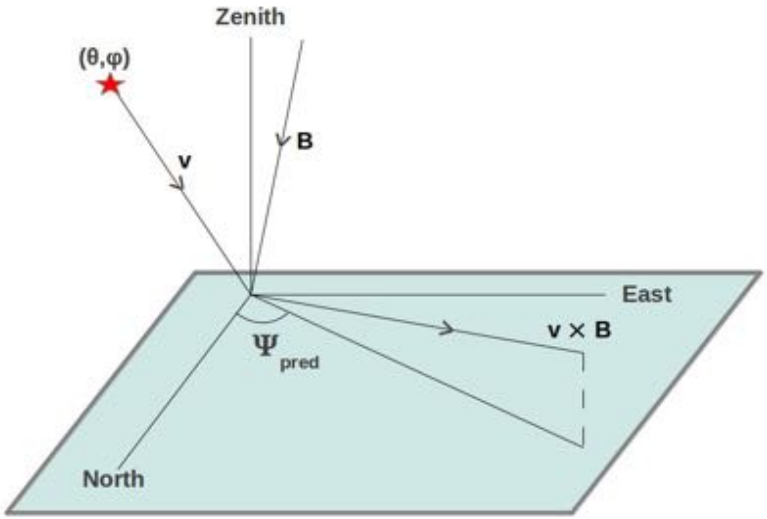
E $\propto$ **v** $\times$ **B** and polarization depending on the arrival direction (first order)

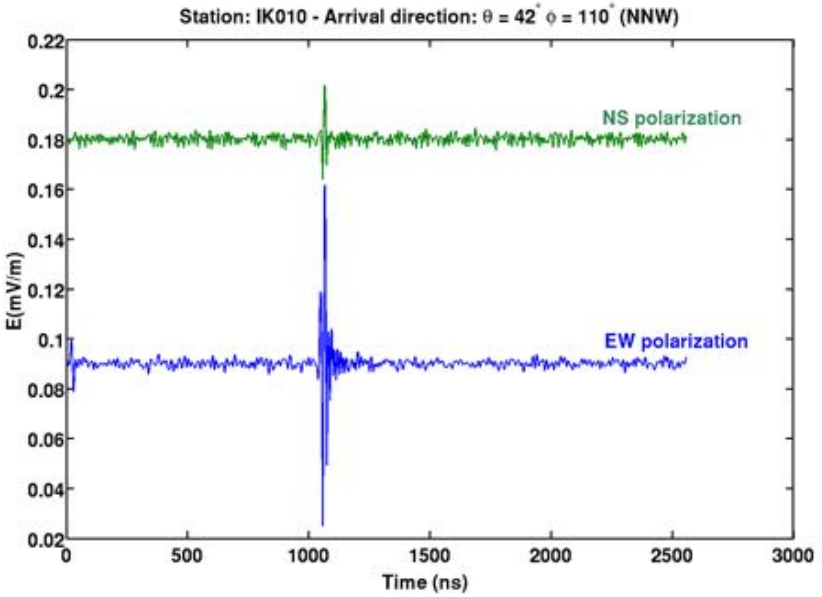
⇩

Possibility to estimate the azimuthal angle and to confirm the EAS detection using one antenna



- Good agreement in first order
- Need more statistics
- Take into account others effects





$$\Psi_{meas} = \arctan(E_{EW}/E_{NS})$$

Outlook

- **Main mechanisms** of radio production by EAS **identified**
- Possibility to estimate the **energy** and **nature** of primary cosmic ray with radio
- **Polarization** can provide informations about EAS detection and noise sources

↙ Open questions:

→ What is the range of radio signal ?

→ What is the efficiency of self-triggering antennas ?

→ Which observables will be derived from the electric field distribution ?