Karlsruhe Institute of Technology

Institute for Space Sciences

Modern detection techniques in measuring high energetic particles

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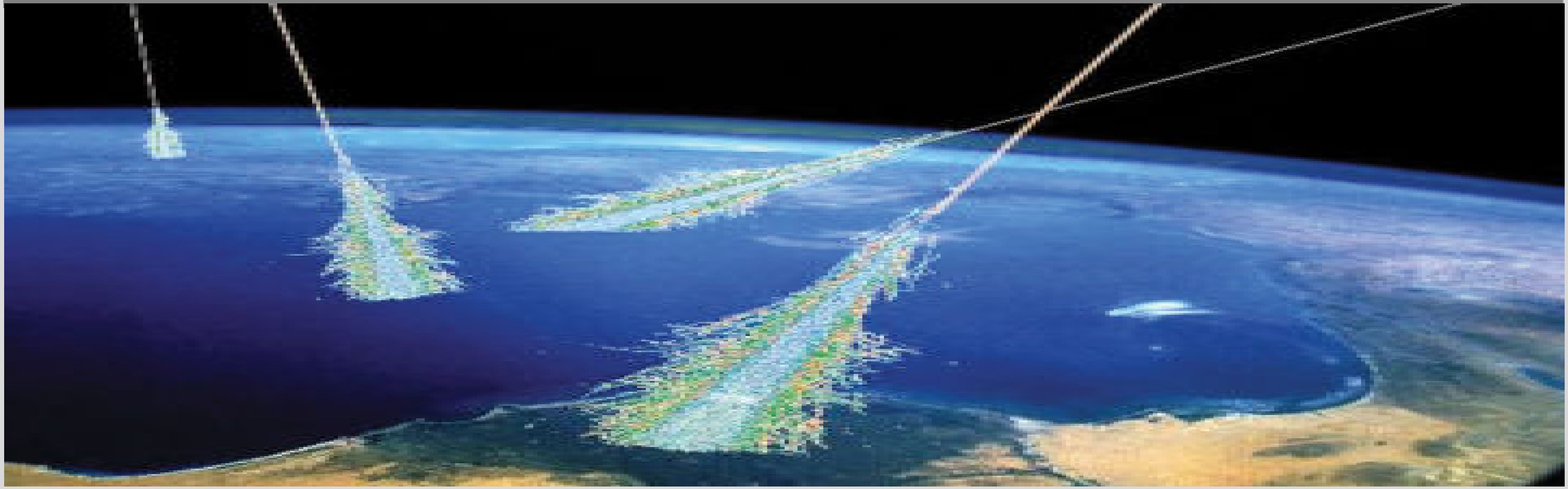
Third High Energy Physics School in Magurele

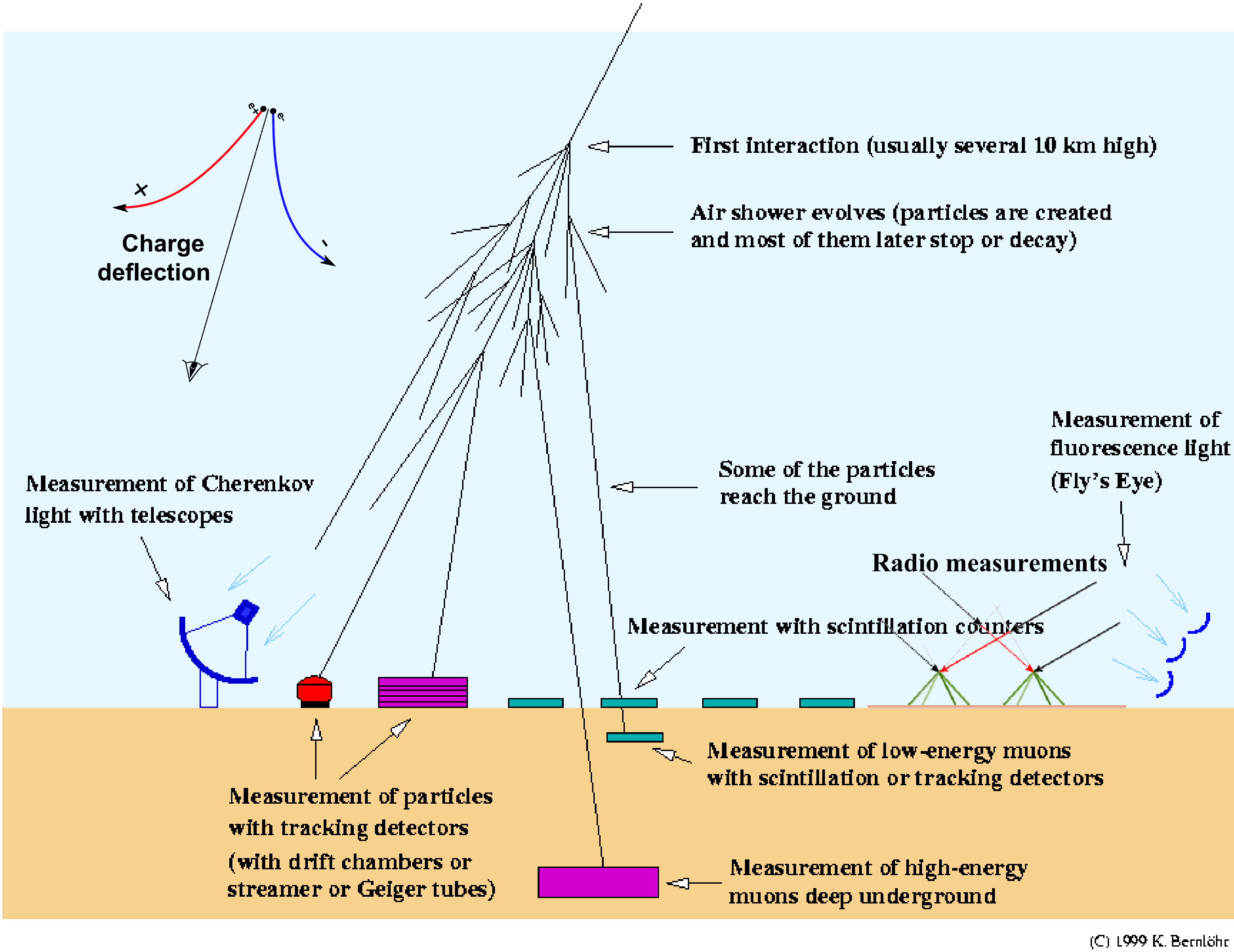
Intitute für Kernphysik, Karlsruhe Institute of Technology, Germany & Institute of Space Sciences, Bucharest, Romania



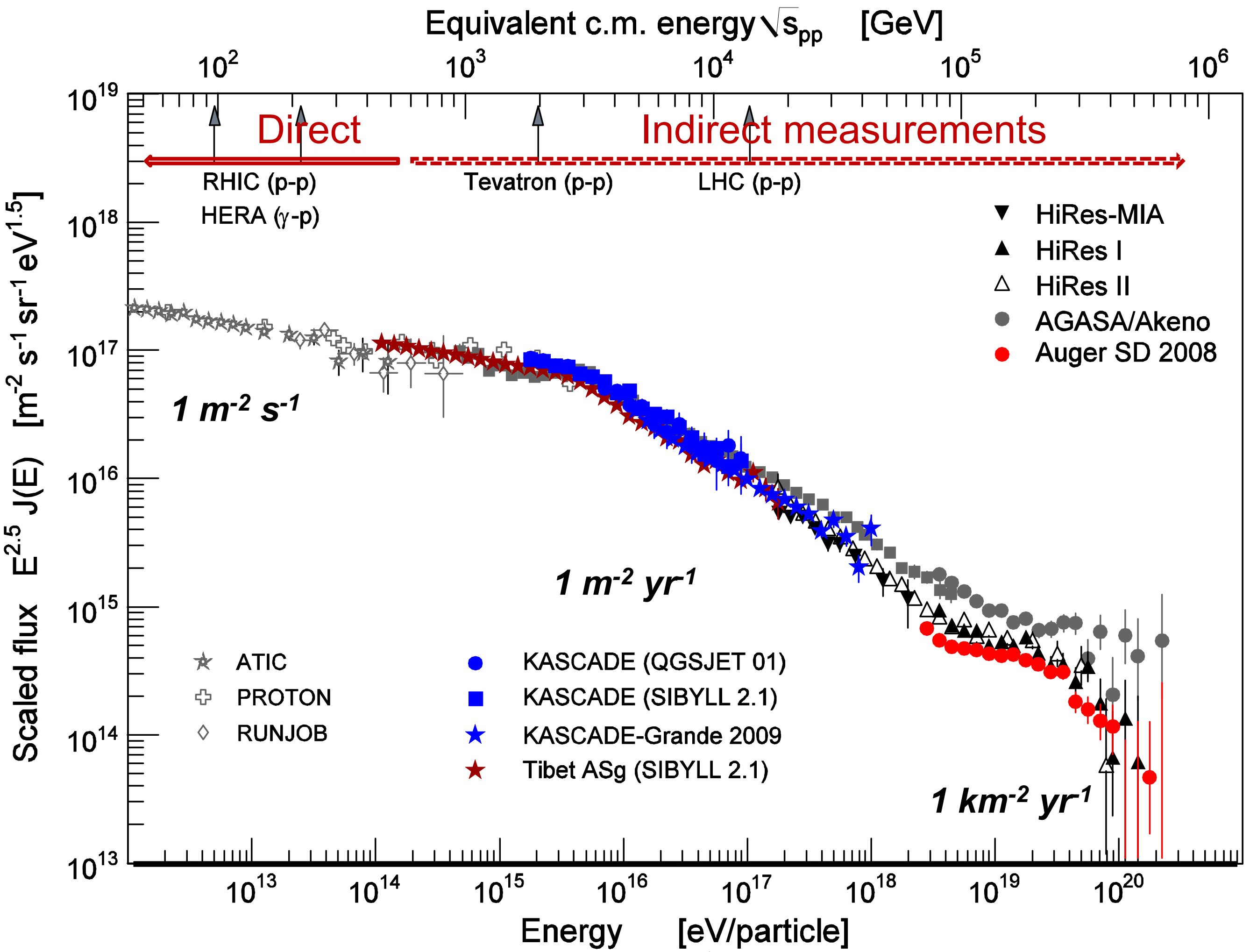
Outline

- Introduction
  - Cosmic ray air showers
    - Energy spectrum
- Modern experiments:
  - KASCADE-Grande (particle-detector)
  - LOFAR PrototypE Station (radio-interferometry)
  - Piere Auger Observatory (hybrid-detector)
- Summary

Cosmic ray air showers



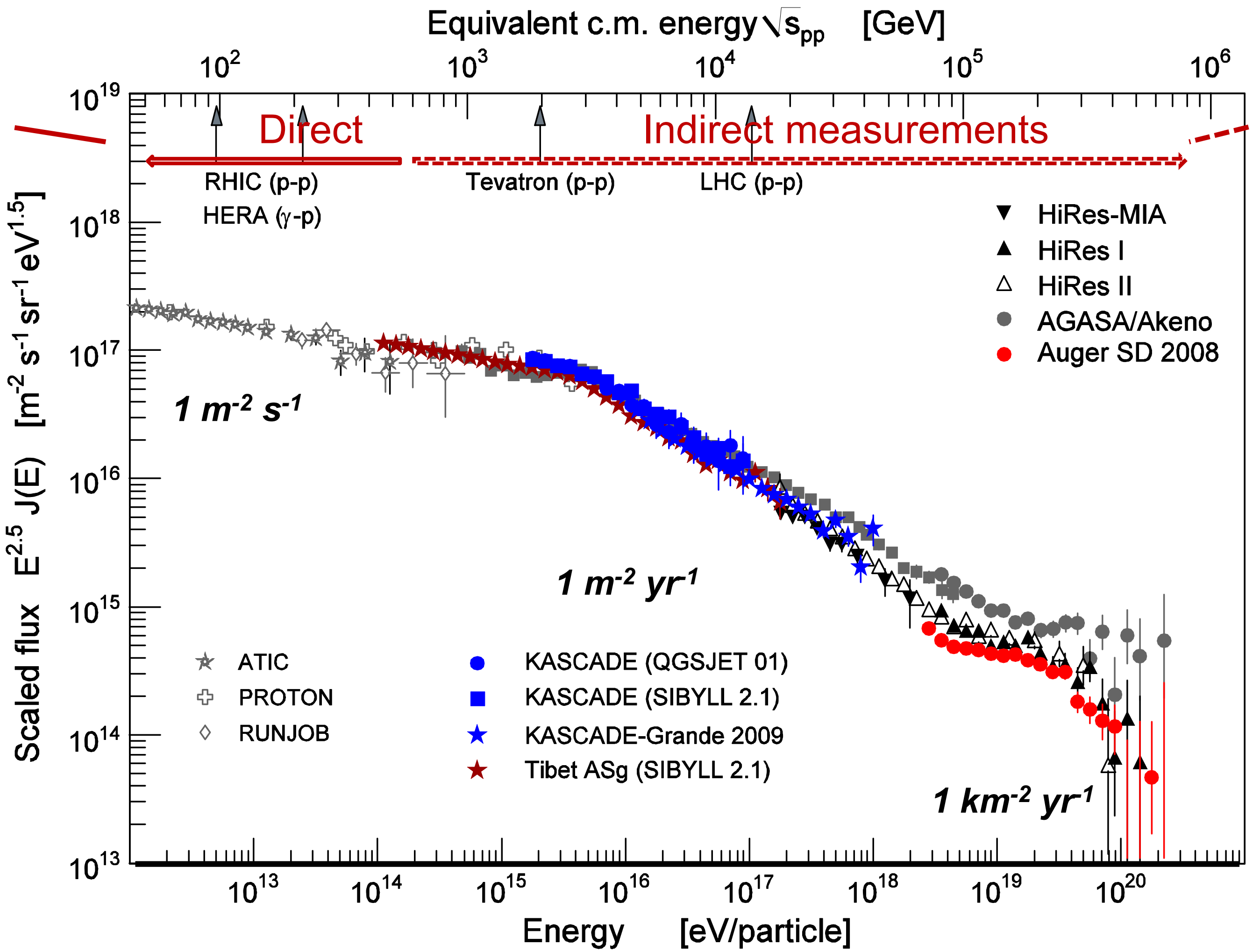
Energy Spectrum



Bertaina et al., The KASCADE-Grande Coll., ICRC'09, Lodz

Energy Spectrum

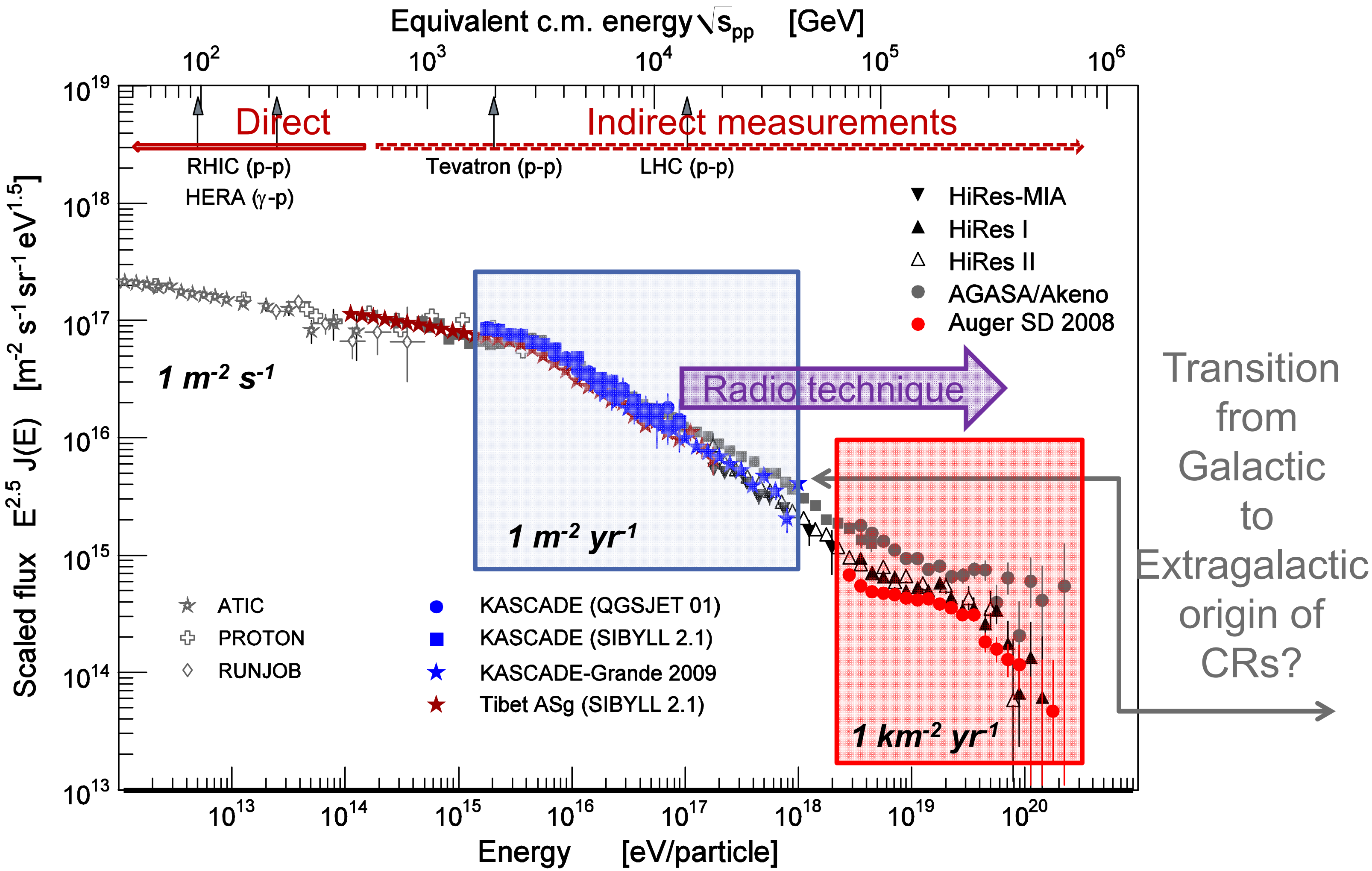
Space Based (ballon, calorimeter satelite, station)



Ground Based (scintilator, water tank, optical, radio telescope)

Bertaina et al., The KASCADE-Grande Coll., ICRC‘09, Lodz

Energy Spectrum



Bertaina et al., The KASCADE-Grande Coll., ICRC‘09, Lodz

(Indirect) detection techniques

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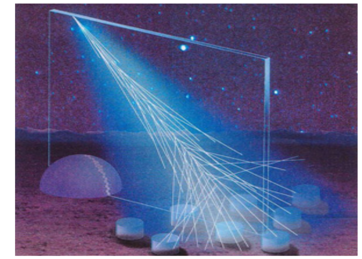
KASCADE - Grande

- Particle detector (scintillator + muon tracking detector)
- Measure the galactic CRs
- E_p:10^{15-18} eV
- Grande - extended KASCADE
- Located At KIT

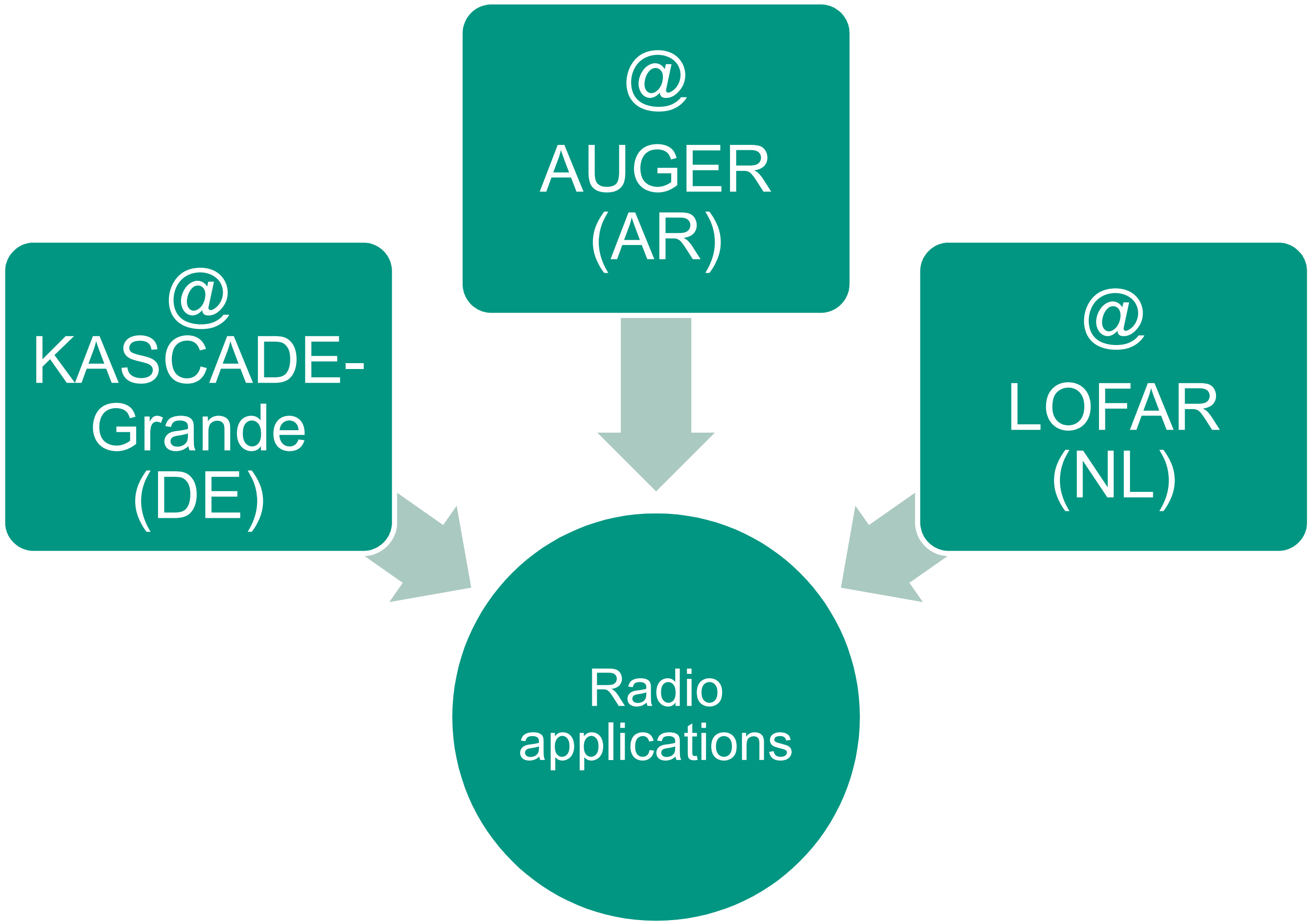
LOPES

- LOFAR Prototype Station
- Radio detector
- $E_p > 10^{16.5}$ eV
- 40 - 80 MHz
- Uses KASCADE & Grande trigger
- Self-trigger: LOPES^{STAR}



Pierre Auger Observatory

- Hybrid detector (fluorescence + water tank)
- Measure the extragalactic CRs
- $E_p > 10^{17.5}$ eV
- Located in Argentina
- Auger-radio: AERA

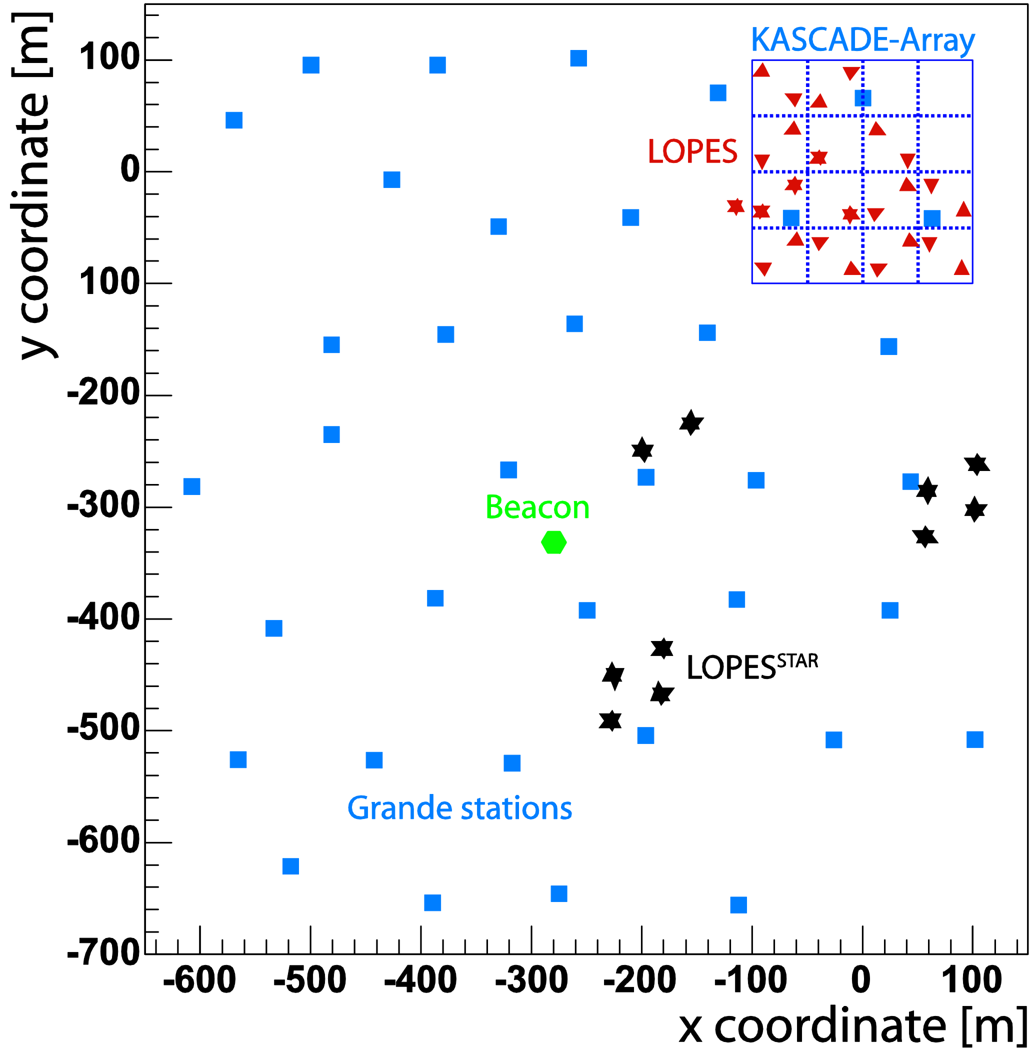

@
AUGER
(AR)
@
KASCADE-
Grande
(DE)
@
LOFAR
(NL)
Radio
applications

Radio @ KASCADE-Grande

LOPES (LOFAR Prototype Station): 40 - 80 MHz

<u>Step-by-Step evolution:</u>

1. LOPES-10 (2004)
   - Proof-of-principle
   - Single polarization
2. LOPES-30 (2005)
   - Large baseline
   - Abs. Amp. Calib.
3. LOPES-Pol (2006)
   - Dual-polarization
4. LOPES* (2005)
   - Self trigger
5. LOPES-3D (2010)
   - Full-polarization



Proof-of-principle

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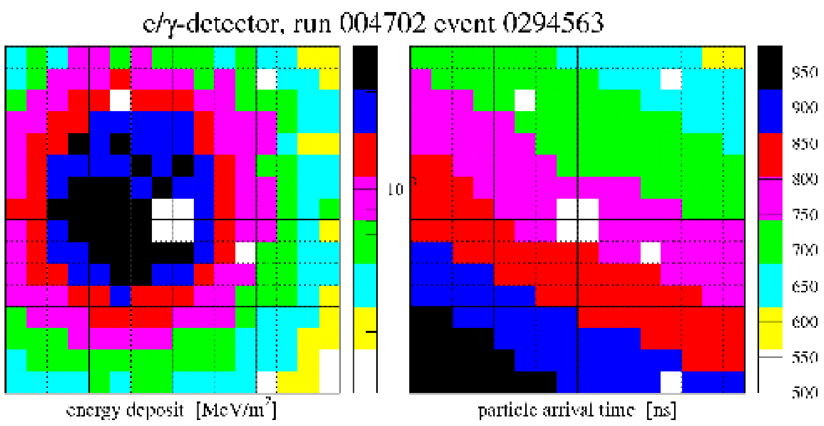
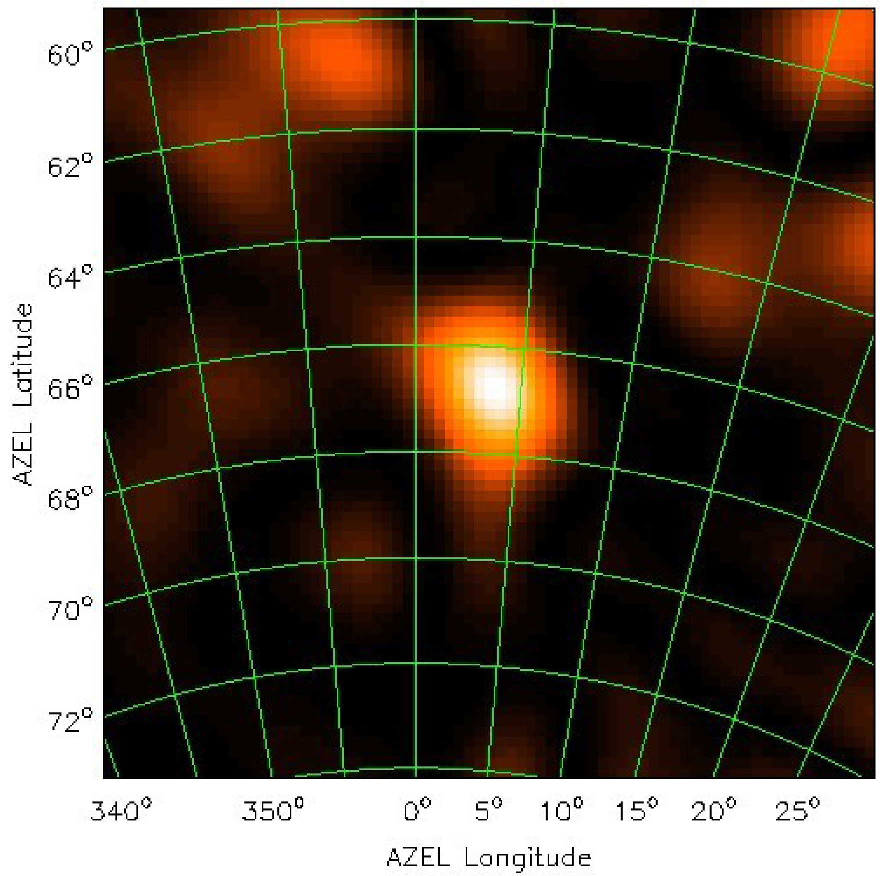
- 1st unambiguously detected EAS generated radio flash!
- Dominant geomagnetic effect!





LOPES collaboration, Nature 435, 313 (2005)

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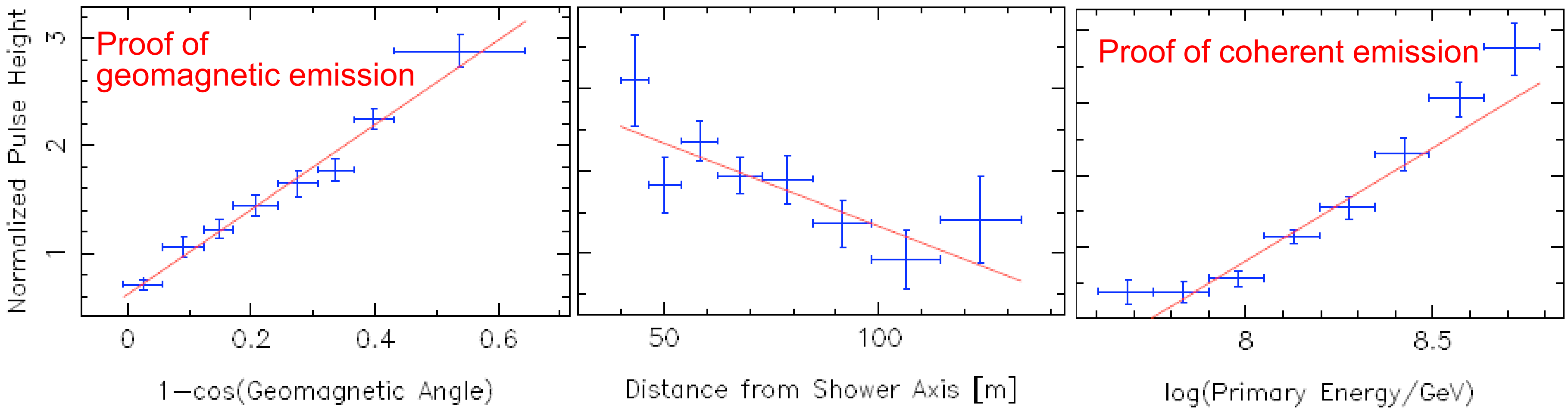
LOPES-30 results

Dependencies & Parametrization

- $f(1-\cos(\alpha), R, E)$, i.e. geomagnetic angle, direction, energy
- Signal parametrization (east-west polarization, abs. amplitude calibration) using KASCADE shower geometry



$$\varepsilon_{est}^{EW} = (11 \pm 1)[(1.16 \pm 0.025) - \cos(\alpha)]\cos(\theta)\exp\left(\frac{-R}{(236 \pm 81)\,m}\right)\left(\frac{E}{10^{17}\,eV}\right)^{0.95 \pm 0.04} \mu V / m / MHz$$

Horneffer et al. The LOPES Coll., ICRC, Mexico 4 (2008) 83

LOPES-POL

Polarization measurements

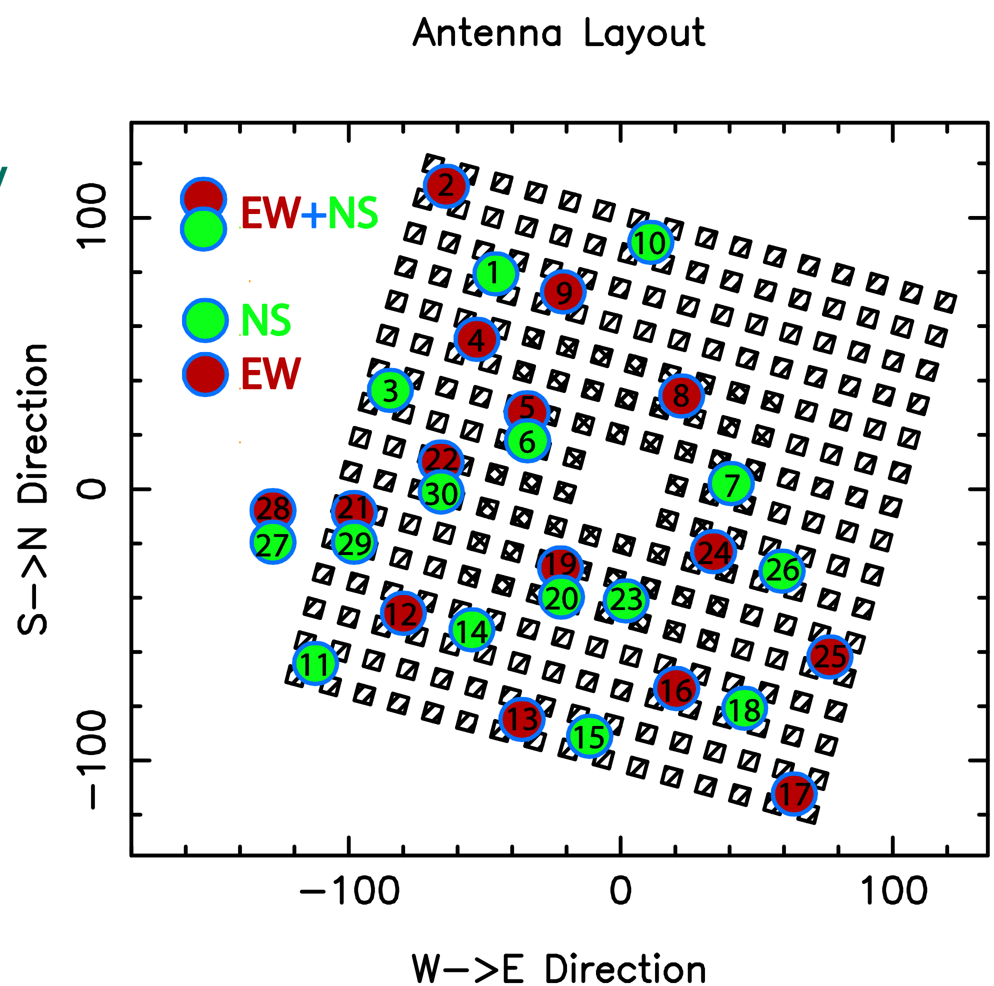
(issue of my PhD, see bottom link)

- Motivation:
  - Emission highly linearly polarized in the direction ⊥ to shower axis and B-field
- Antenna configuration:

  10 EW, 10 NS, 5 EW+NS

  (Dec'06 – Dec'09)
- Trigger source:

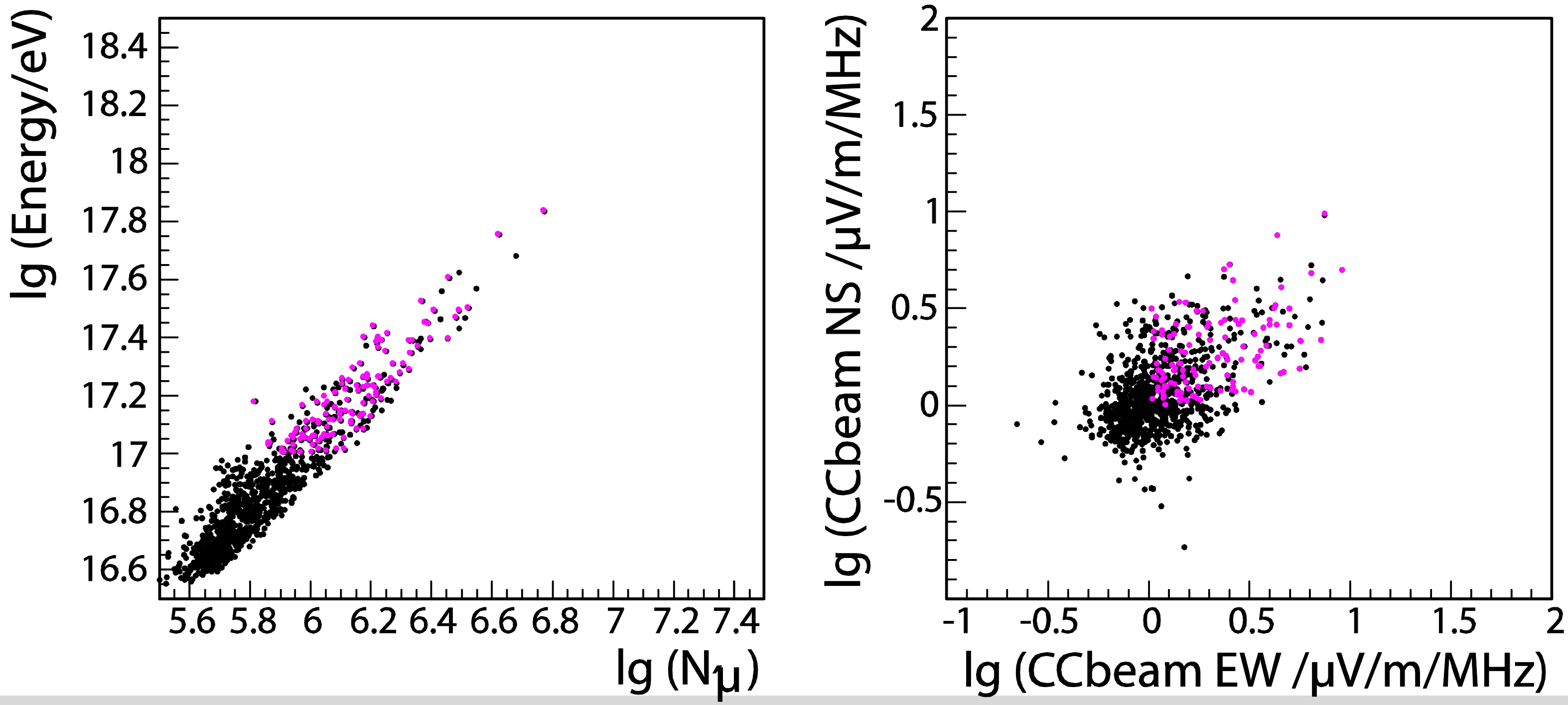
  KASCADE-Grande



http://digbib.ubka.uni-karlsruhe.de/volltexte/1000017925

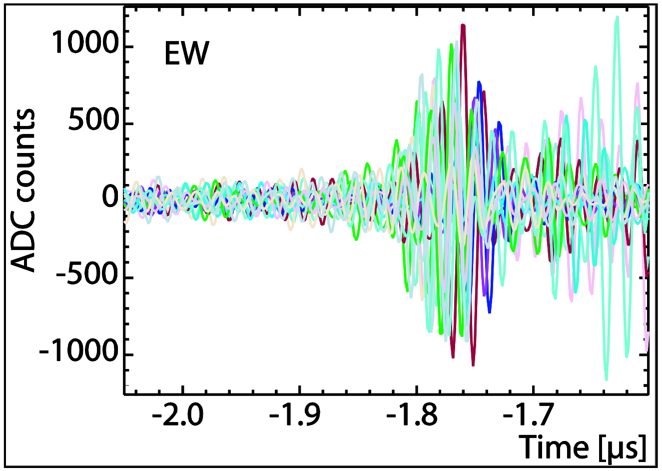
Event selection: quality cuts

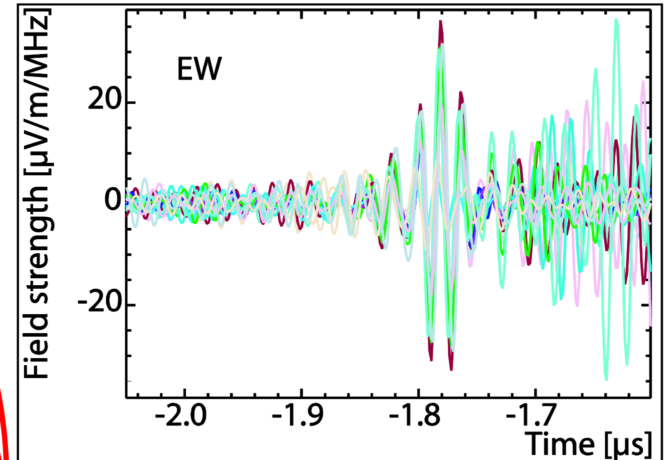
- EAS observables:
  - Core position (KASCADE or Grande)
  - Direction (φ ,θ < 40°)
  - Primary energy ($E_p > 10^{17}$ eV)
- Radio observables: SNR > 4, CCbeam > 1 µV/m/MHz



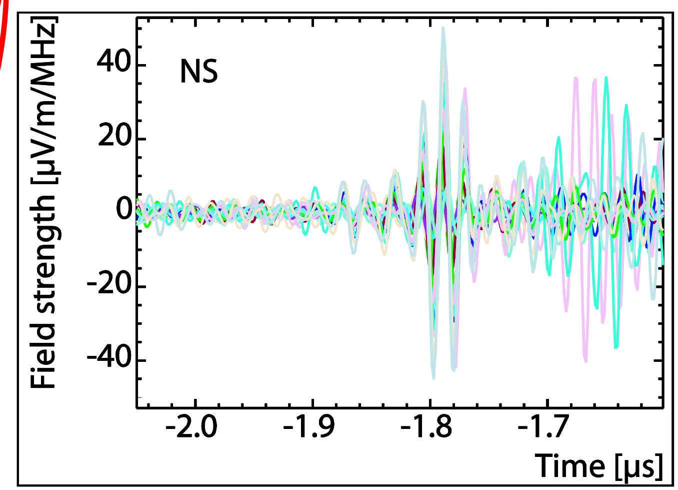
Event example

1. Raw data

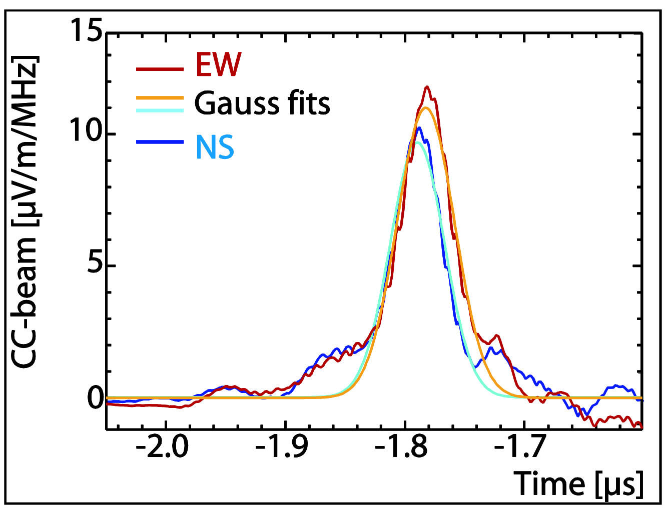




2. Radio signal reconstruction

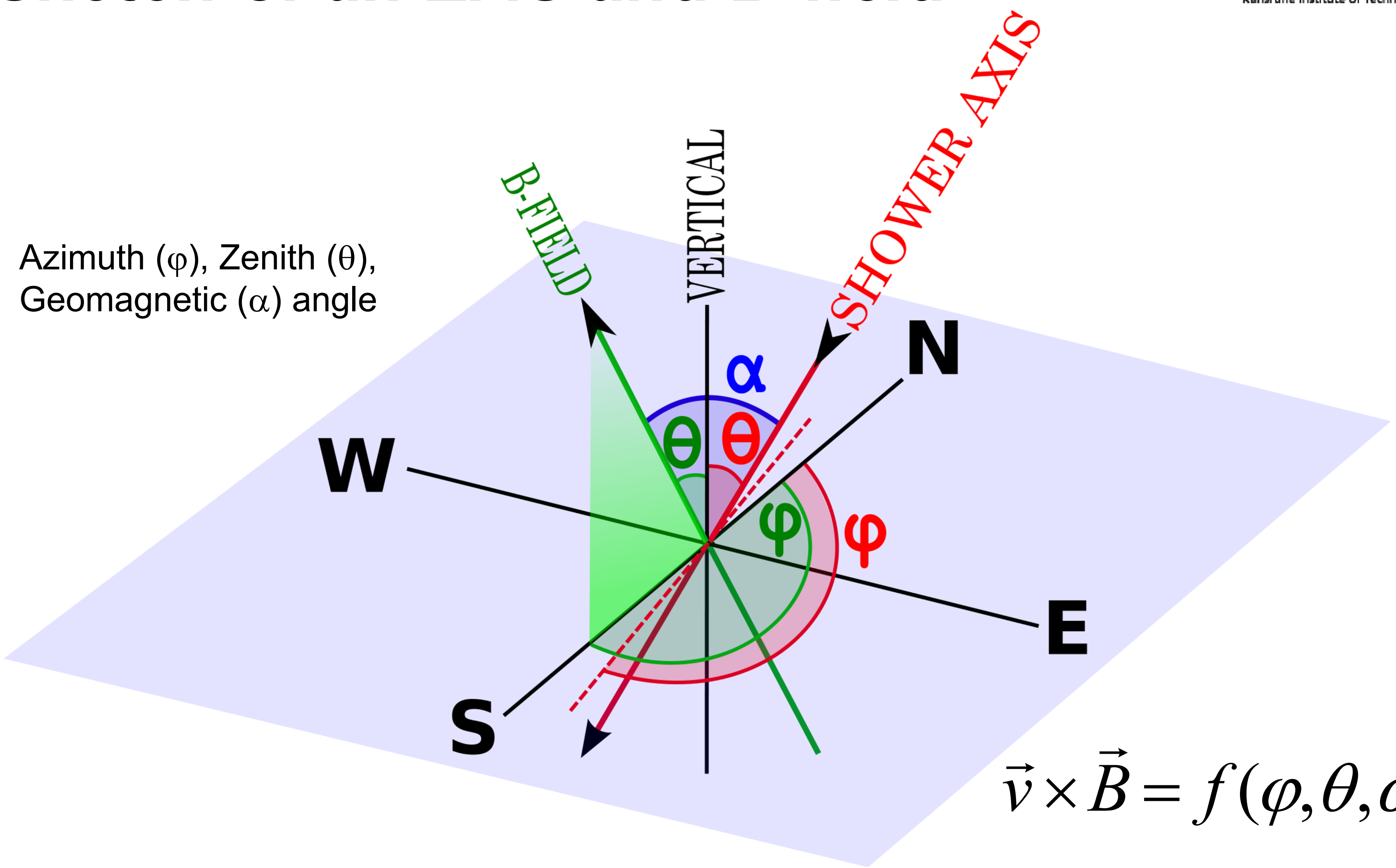


3. Pulse quantification



Sketch of an EAS and B-field

Azimuth (φ), Zenith (θ), Geomagnetic (α) angle



$$\vec{v} \times \vec{B} = f(\varphi, \theta, \alpha)$$

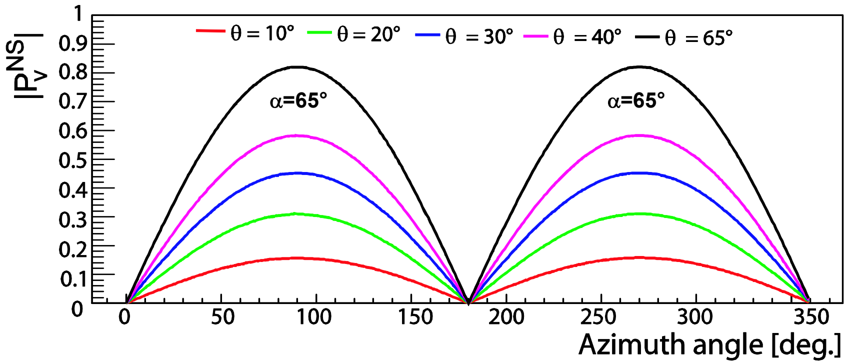
Q: Is the geomagnetic effect the main radio emission mechanism?

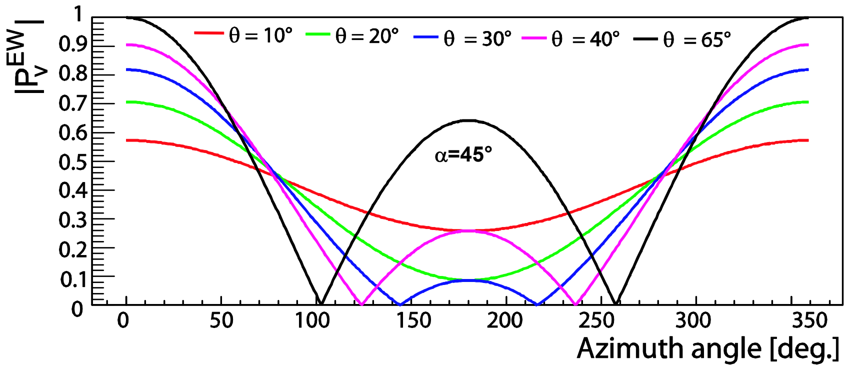
Simplified geomagnetic model

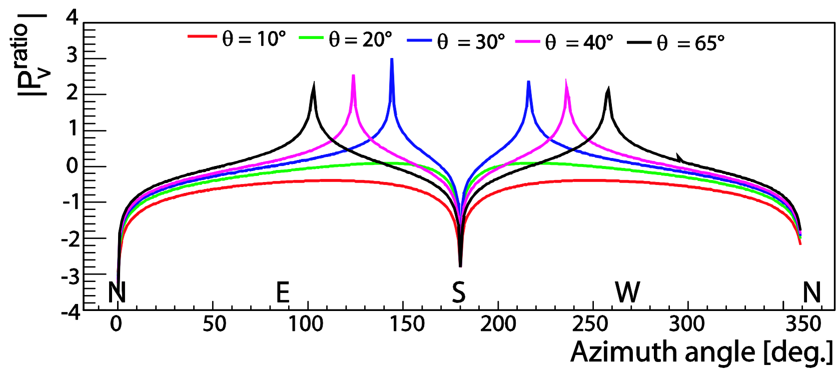
- Azimuth dependence

  $\vec{P}_v = \vec{v} \times \vec{B} = f(\varphi, \theta, \alpha)$

- Large $\vec{P}_v$ for θ=65°!
- $\vec{P}_{NS}$:expect showers coming from E & W dir.
- $\vec{P}_{EW}$:expect showers coming from N & S dir.
- $\vec{P}_{ratio} = \vec{P}_{NS} / \vec{P}_{EW}$
  - > 0: NS dominat
  - < 0: EW dominat

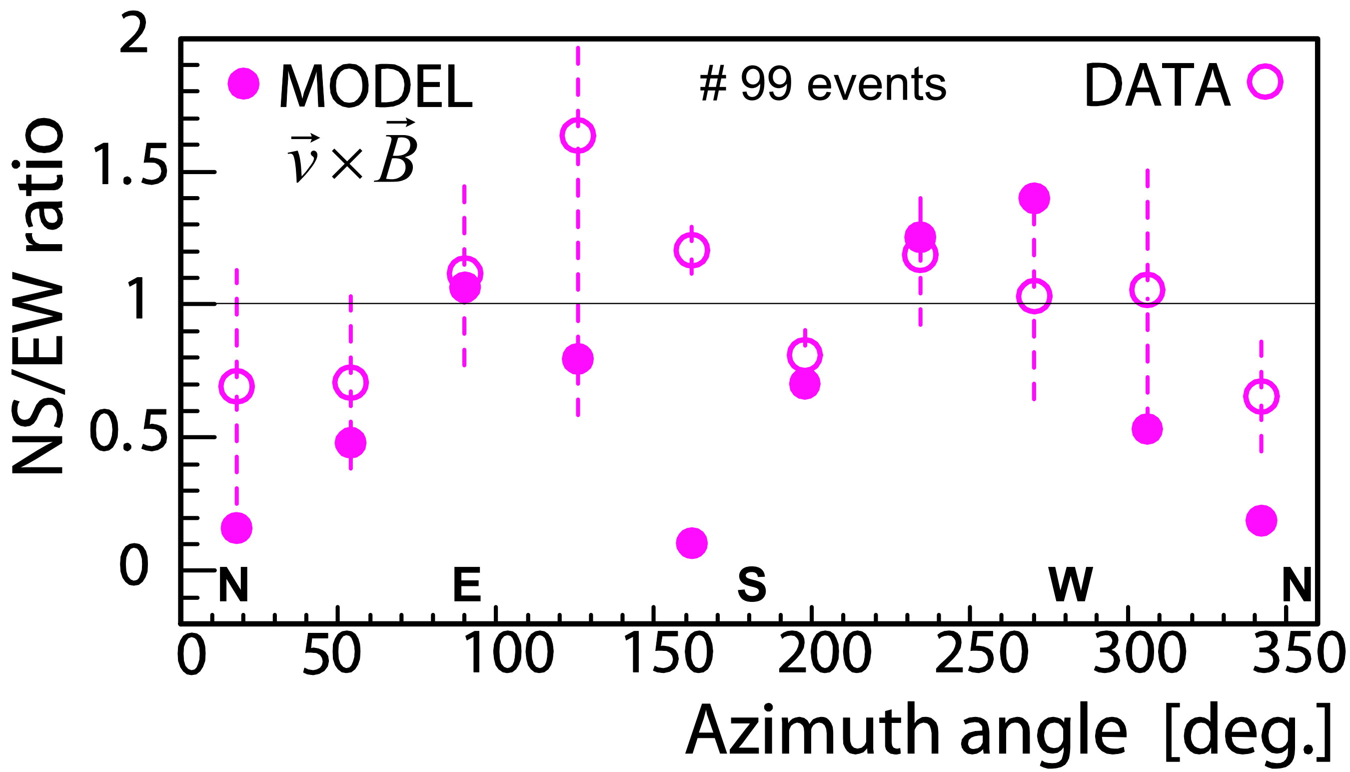






Comparison: Model & Data

Ratio >1 dominant NS detection, otherwise EW detection
Deviations obseved in the North and South directions:
Another emission mechanism?

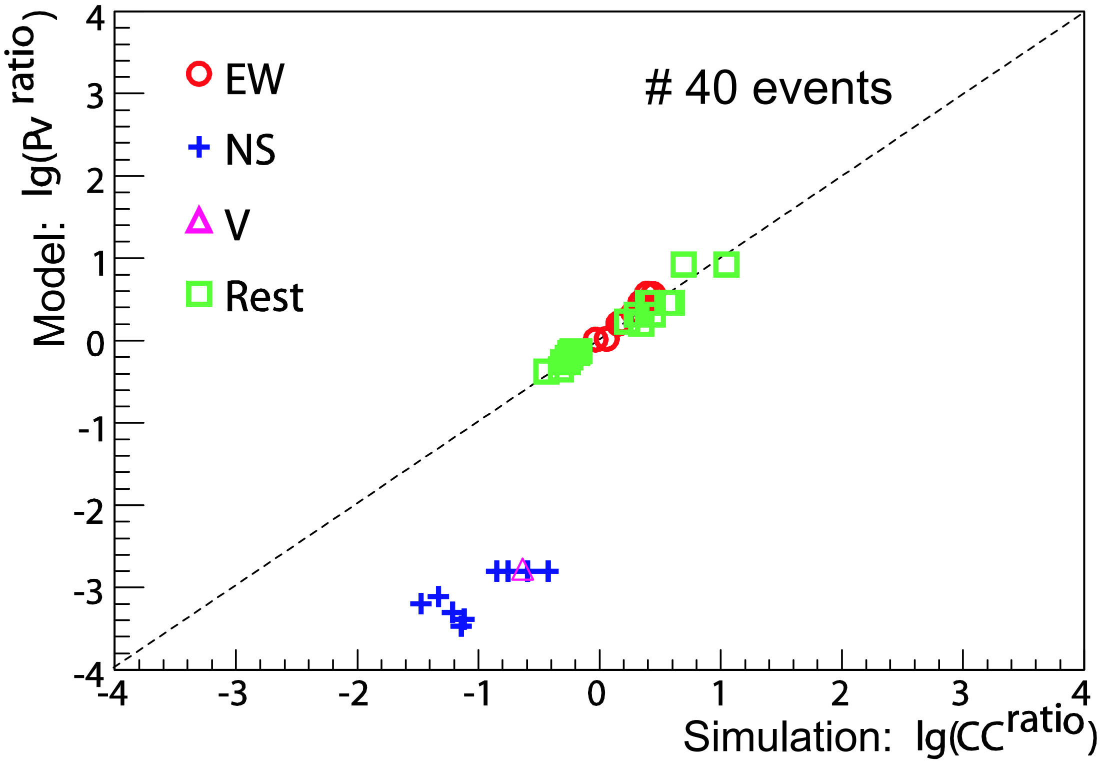


Comparison: Model & Simulation

CORSIKA(showers)-REAS3(radio) simulation

Good agreement observed, except incoming showers from North and South directions. Negative charge excess (~10%) joining the geomagnetic effect?

$$\vec{P}_v = \vec{v} \times \vec{B}$$



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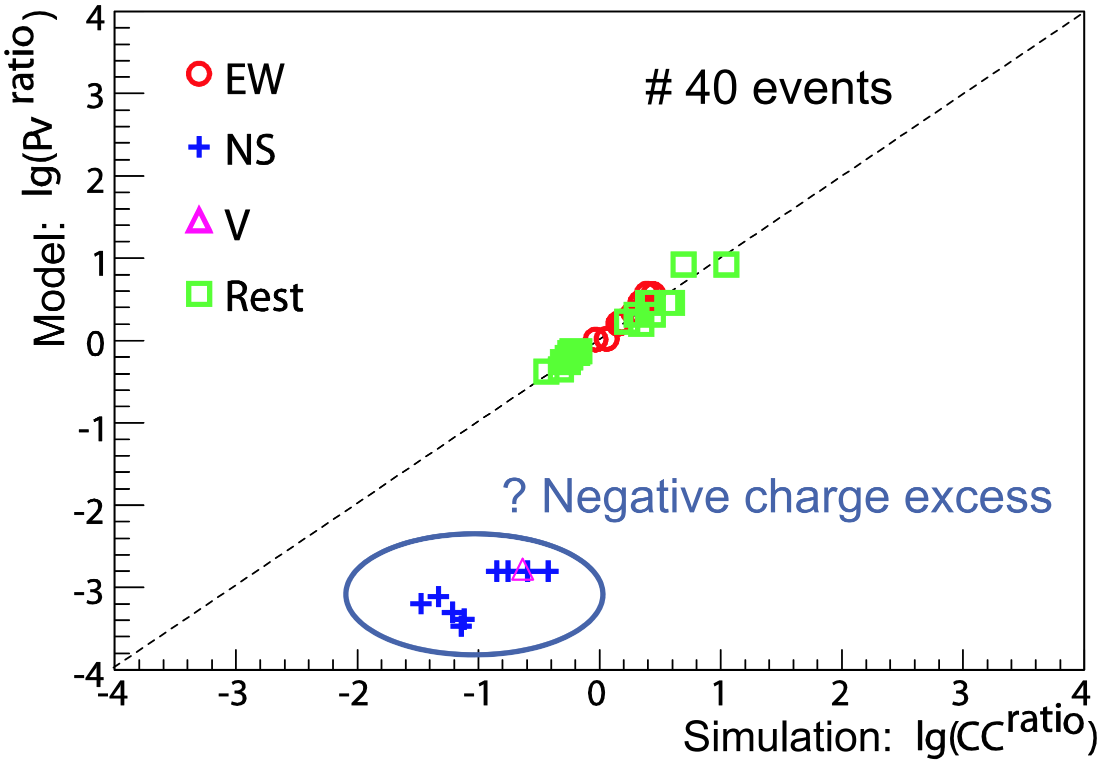
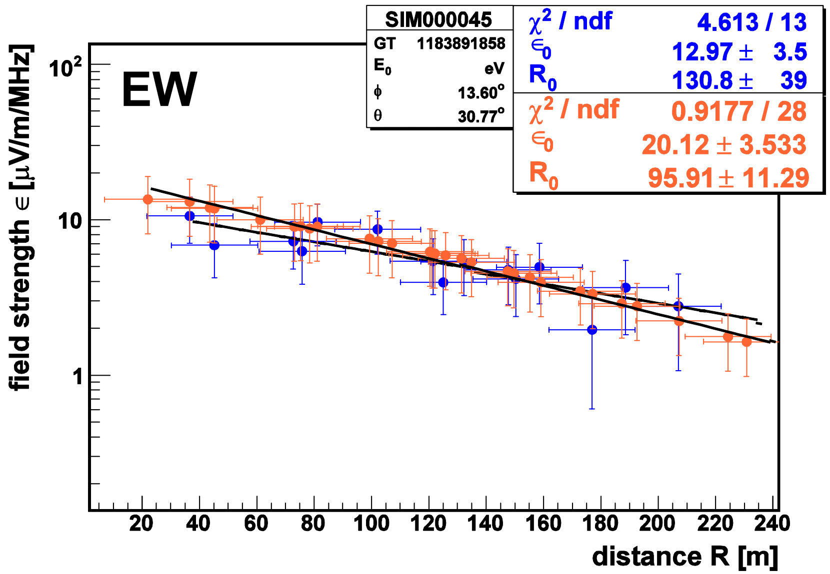
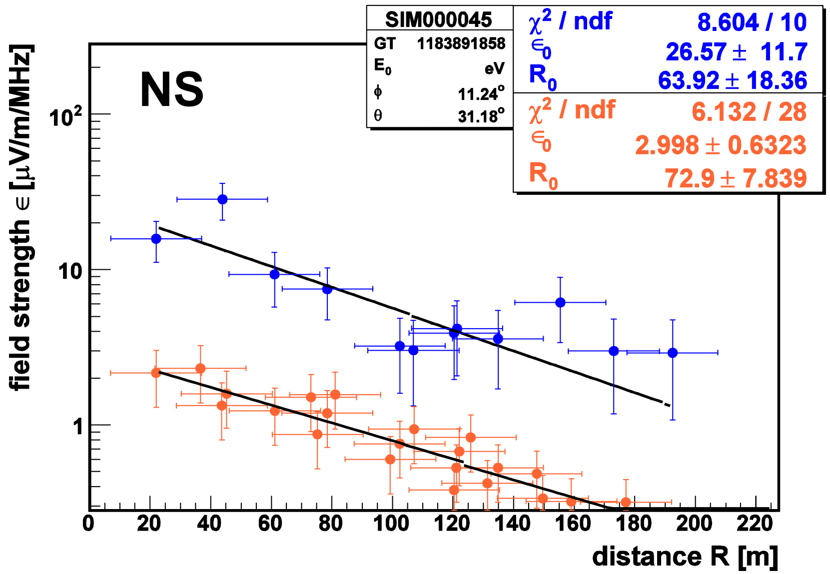


Comparison: Simulation & Data

Lateral distribution

Event example: shower coming from North direction gives signal in both polarizations: another hint to an additional emission mechanism besides the geomagnetic effect.





Radio@LOFAR

Low Frequency Array (10 - 270 MHz) of LOPES stations

36 Duch stations + 8 international (DE, FR, SE, UK, ..)

… up to 1500 km spacing

Coincident trigger by scintilators with shower information for primary energies > 10^{17} eV

Radio@AUGER

Super-hybrid detection of air showers: Radio + FD + SD

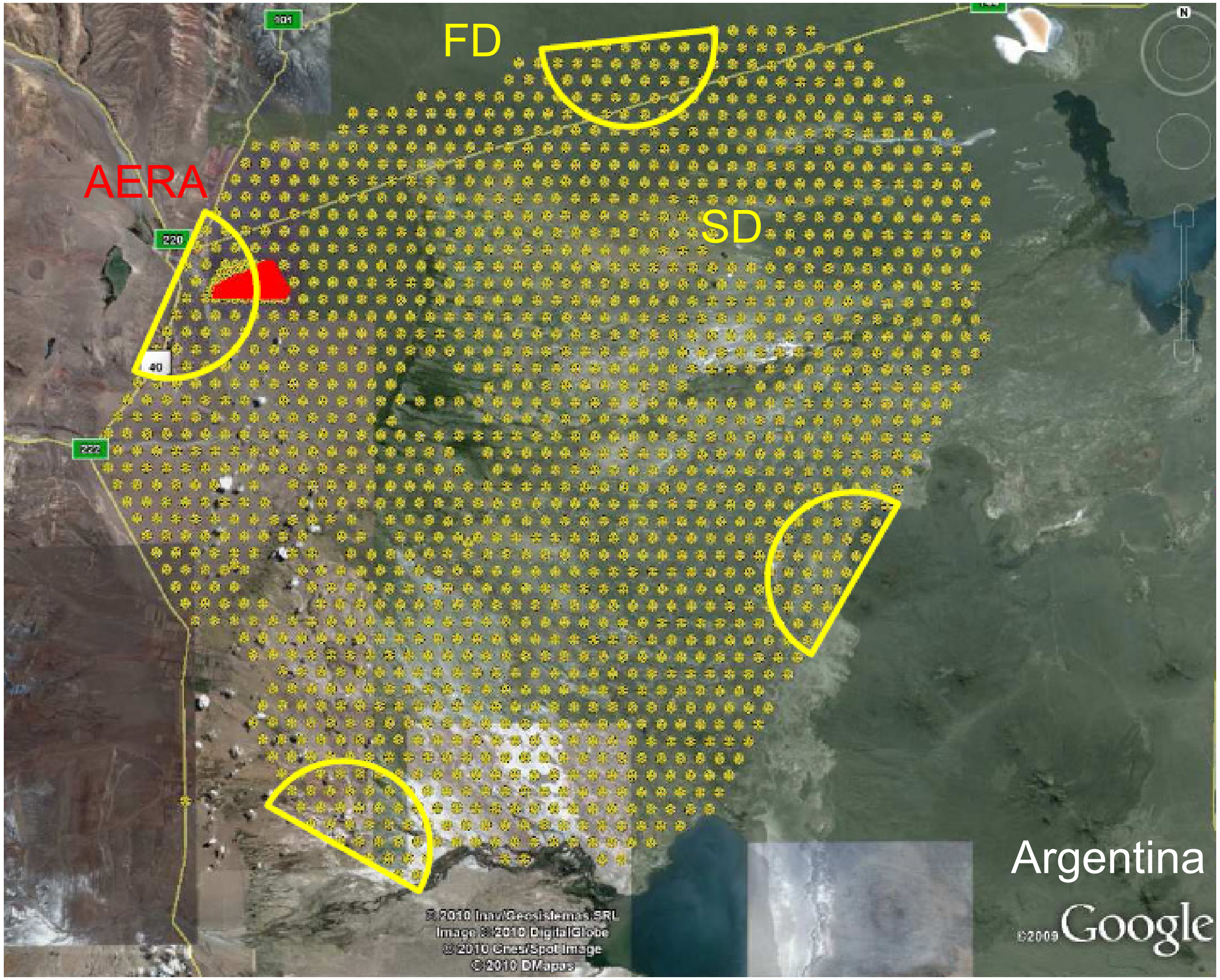
Low background RFI

Energy: > 10^{17} eV

161 radio stations

1600 water tanks
(1.5 km spacing)

4 optical telescopes
-> mass sensitivity



Summary

- KASCADE-Grande: offers well-reconstructed shower information in the galactic region
  - Test facility: the current status
- LOPES: has opened a new window for CRs observations
  - Signal: dependencies on direction, distance, energy
  - Emission mechanism: geomagnetic effect dominant! – negative charge excess a contributing effect?
  - R&D: large scale applications exploring transition to extragalactic region and the highest energies
  - 3D: the current status

Thanks for your attention!

Questions?