Radiodetection of Cosmic Rays

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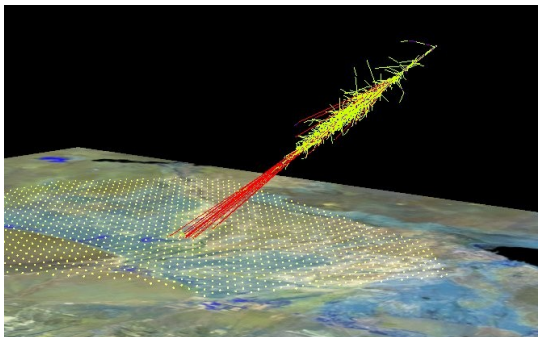
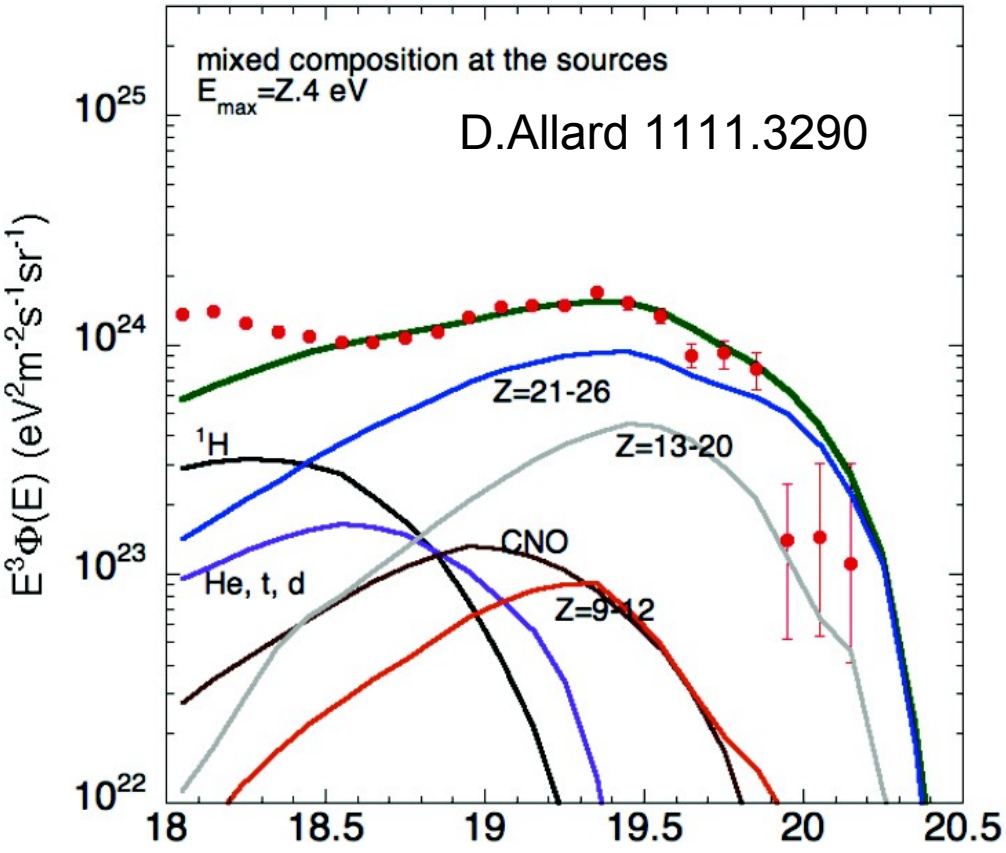
Astroteilchenphysik Deutschland
20.09.2012, Zeuthen



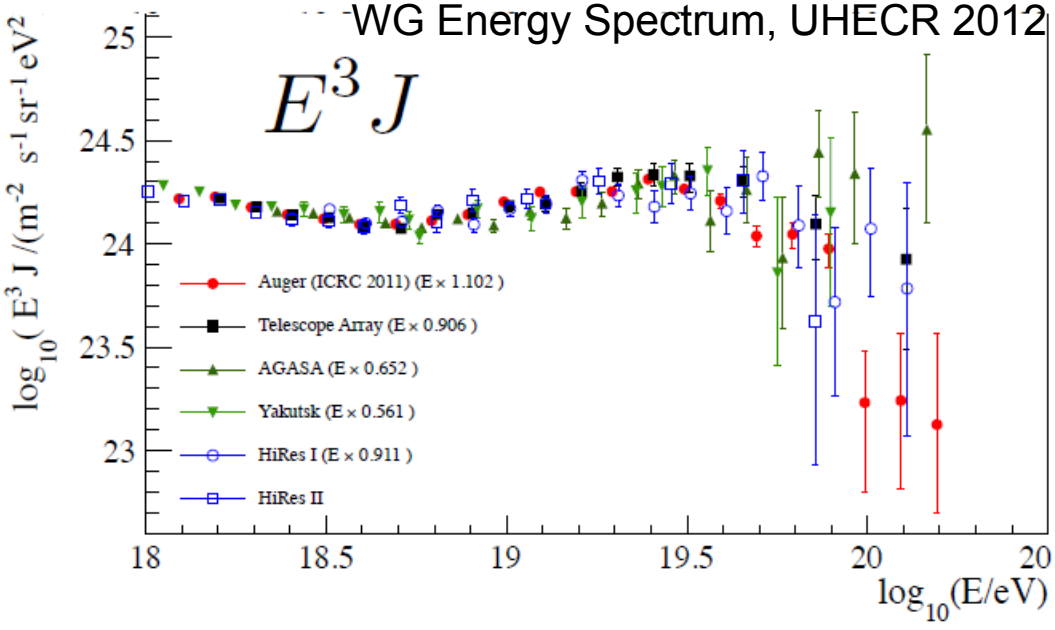
Motivation: “new” detection method

Questions of UHECR:

- GZK cut-off or sources with maximum energy
- Composition at highest energies ($E>10^{19}$eV)



Y.Tsunesada,
WG Energy Spectrum, UHECR 2012

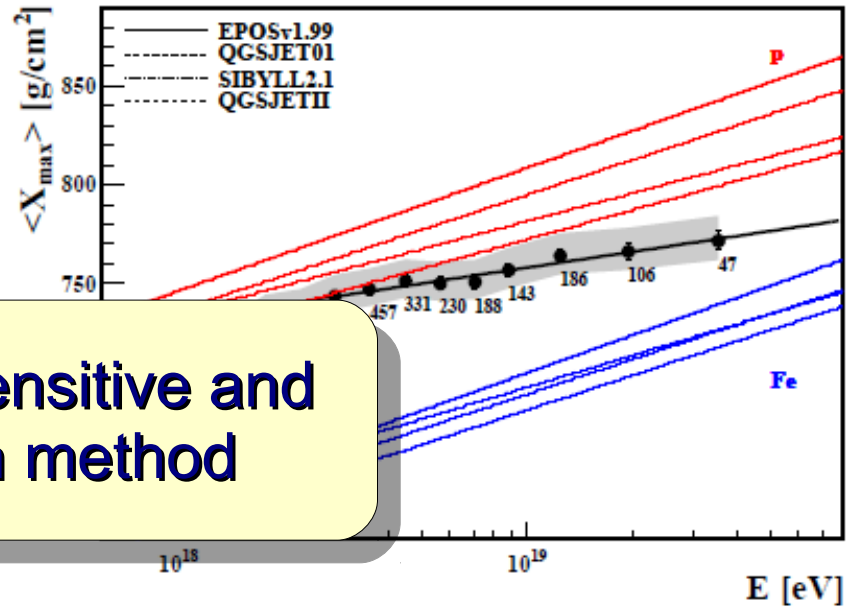


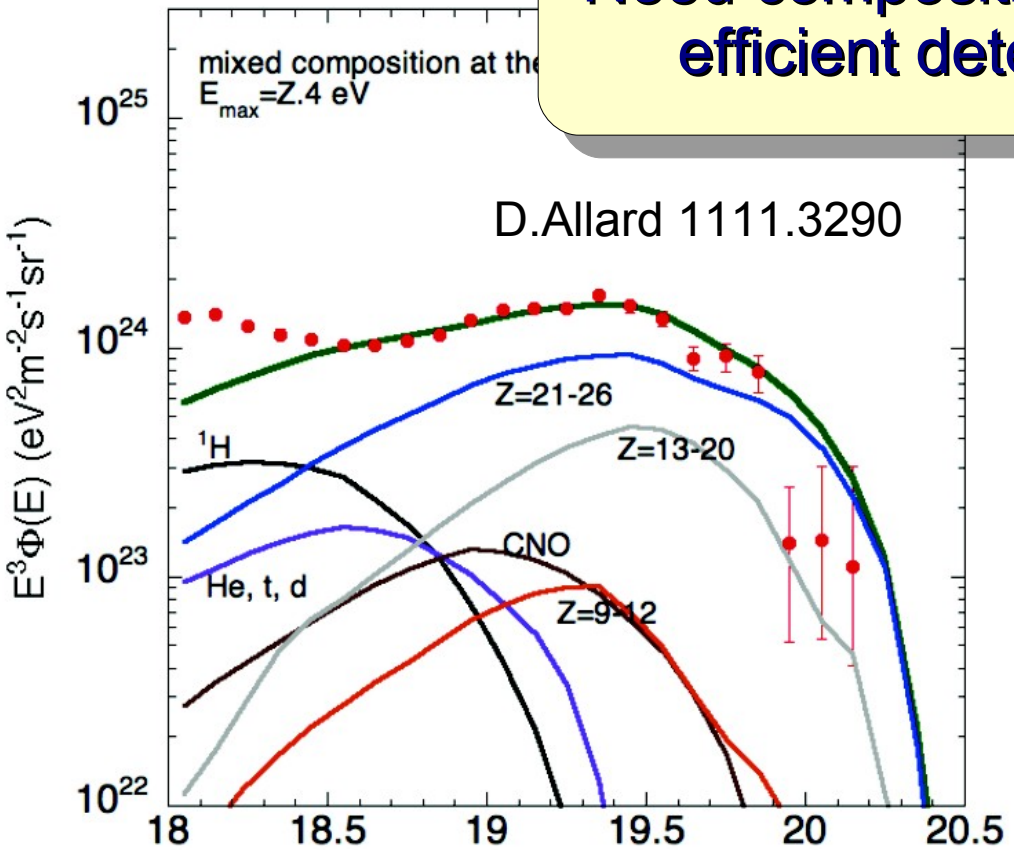
Motivation: “new” detection method

Questions of UHECR:

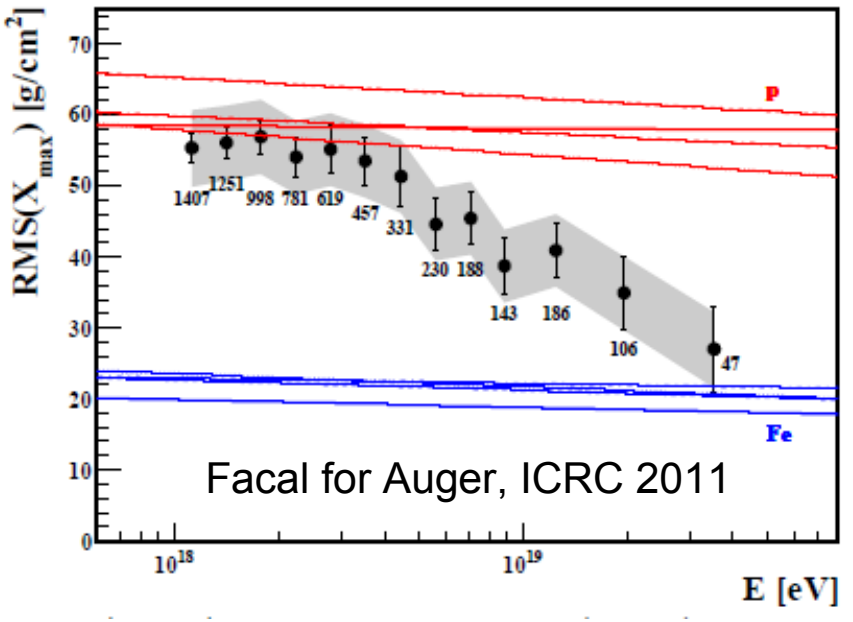
- GZK cut-off or sources with maximum energy
- Composition at highest energies ($E>10^{19}$eV)

Need composition sensitive and efficient detection method





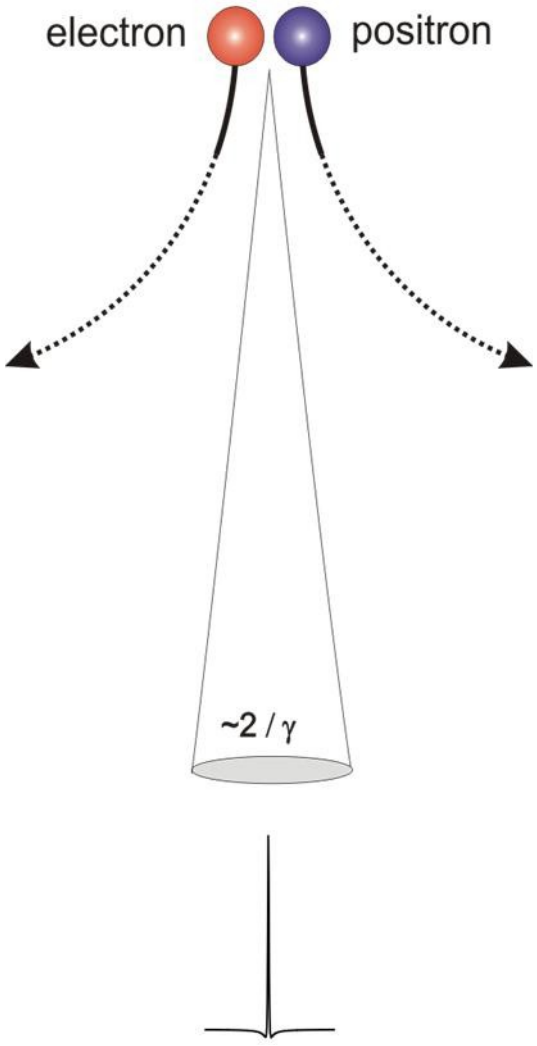
D.Allard 1111.3290



Facal for Auger, ICRC 2011

Renaissance of Radio Detection: Theory

- Early measurements in the 70ties
- Renaissance: Huege & Falke, A&A (2003)
- Geomagnetic effect: v x B
- Coherent emissions from billions of Elektrons
- Emission is focused in beam direction
- Full MC predicting: few ns pulses
  smoothly falling frequency
  scaling energy



A&A 412, 19–34 (2003)
DOI: 10.1051/0004-6361:20031422

Astronomy & Astrophysics

Radio emission from cosmic ray air showers

Coherent geosynchrotron radiation

T. Huege[1] and H. Falcke[1,2,3]

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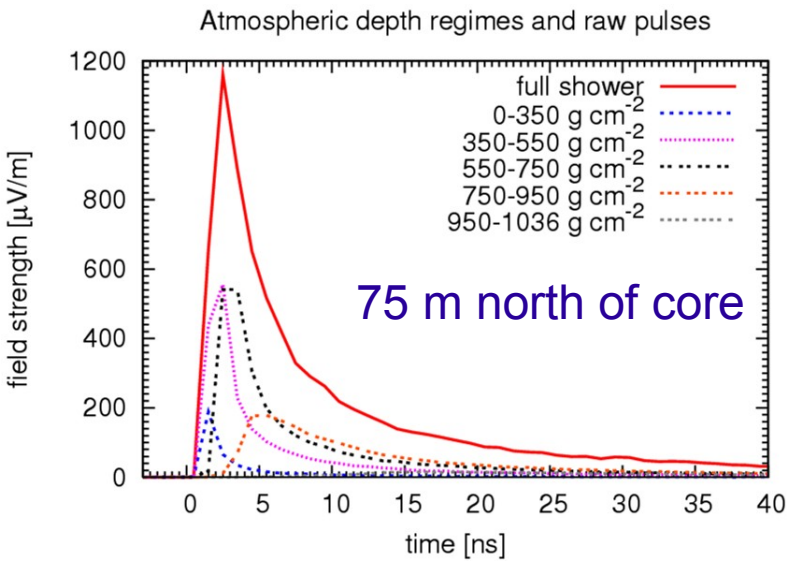
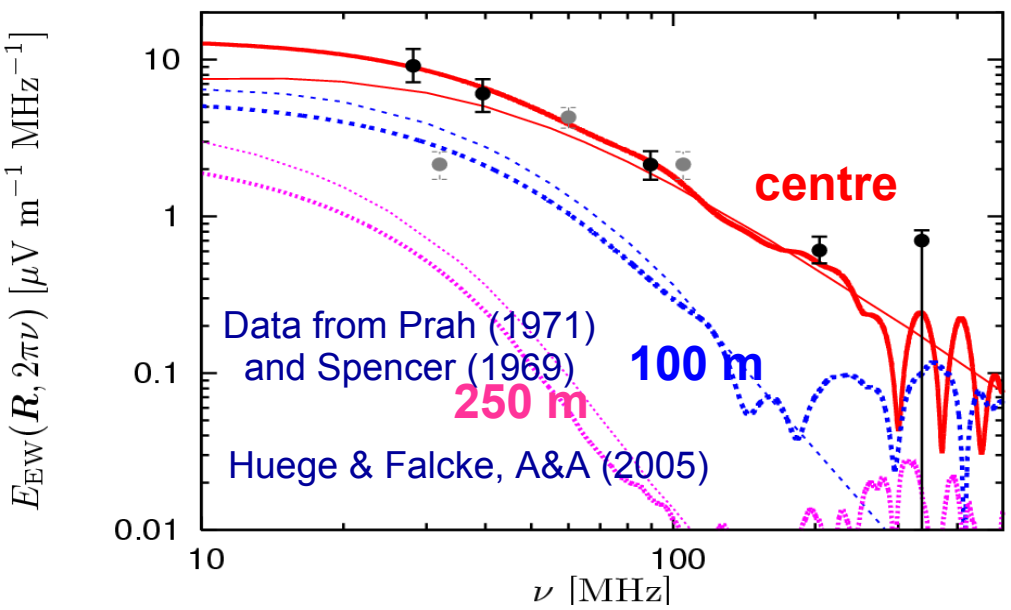
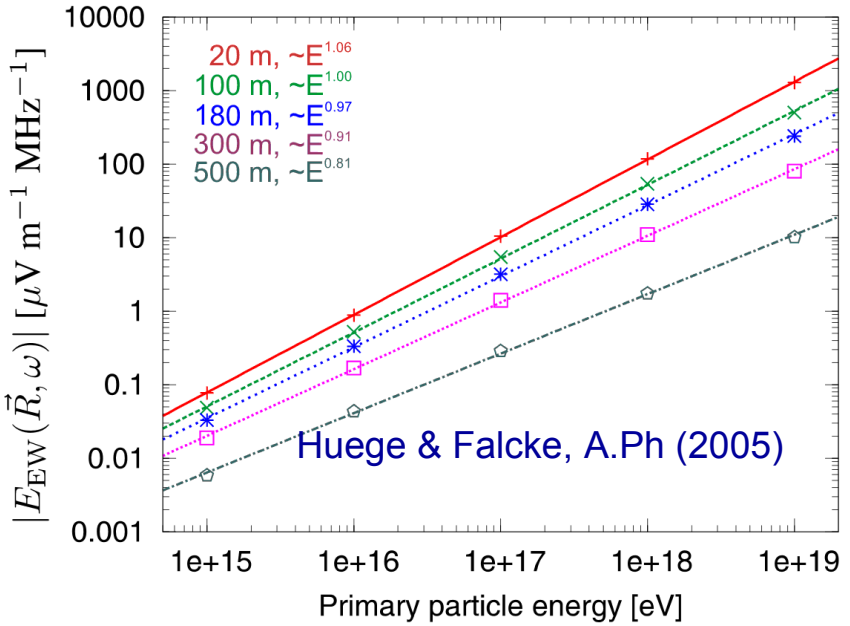




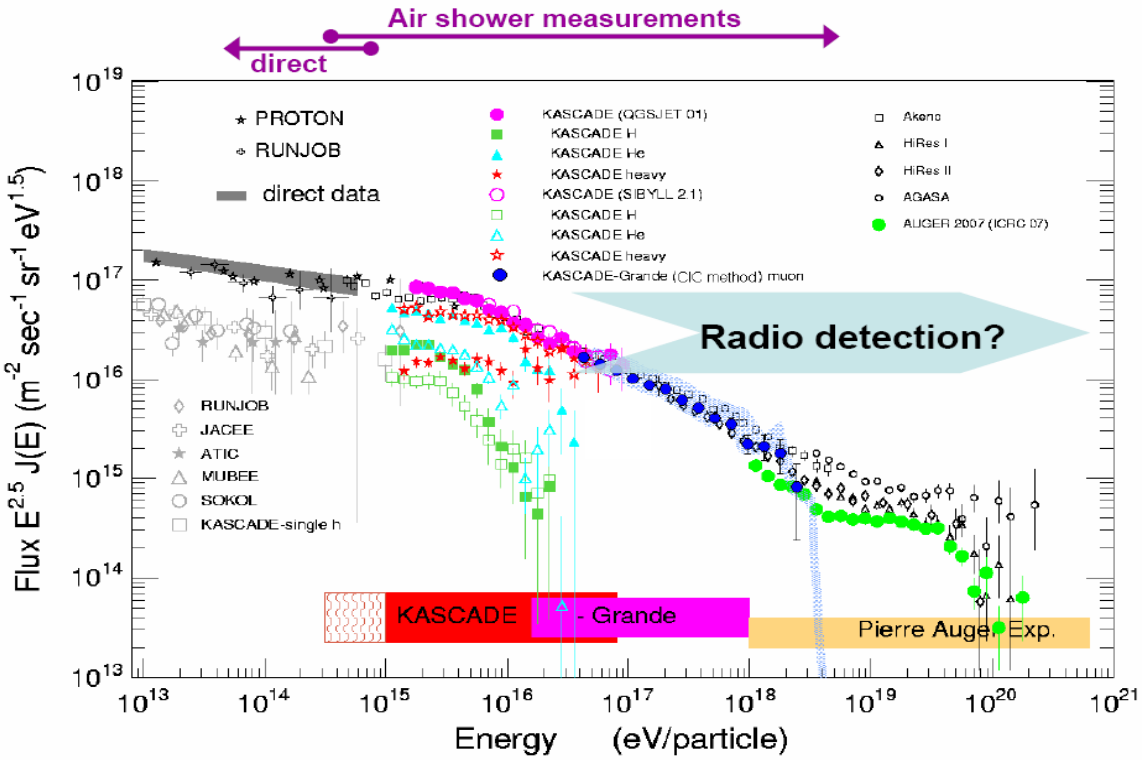


Renaissance of Radio Detection: Experiment

For R&D ideal environment:

- take a running experiment (KASCADE-Grande)
- add new hardware (from new experiment, LOFAR)
- have a look, how EAS look like (Nature 435, 2005)

energy-range from KASCADE-Grande balance shower-rate and signal-height



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Inverted V-shape short dipole
40 — 80 MHz
10, later 30 channels
mainly EW-polarisation
triggered by KASCADE

Renaissance of Radio Detection: Experiment

For R&D ideal environment:

- take a running experiment (KASCADE-Grande)
- add new hardware (from new experiment, LOFAR)
- have a look, how EAS look like (Nature 435, 2005)

externally triggered

understand radio-emission of extended air shower

Publisher: NPG; Journal: Nature:Nature; Article Type: Physics letter
DOI: 10.1038/nature03614
to appear in Nature, May 19, 2005 issue

Detection and imaging of atmospheric radio flashes from cosmic ray air showers

LOPES: pulse-height correlation

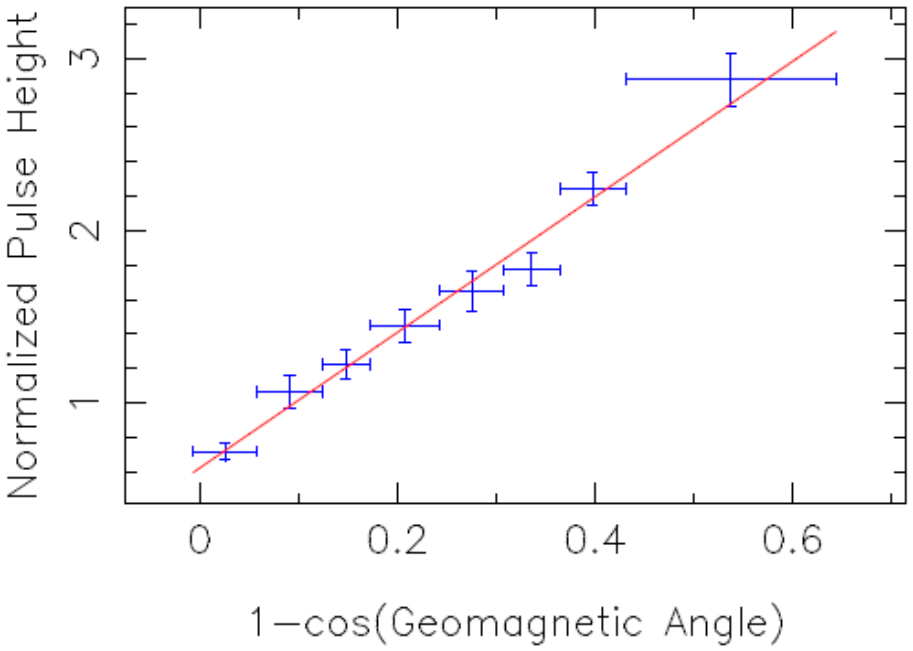
$$\varepsilon_{\text{est-EW}} = A(B-\cos\alpha)\cos\theta\exp(-R/R_0)(E/10^{17}\text{eV})^{\gamma}$$

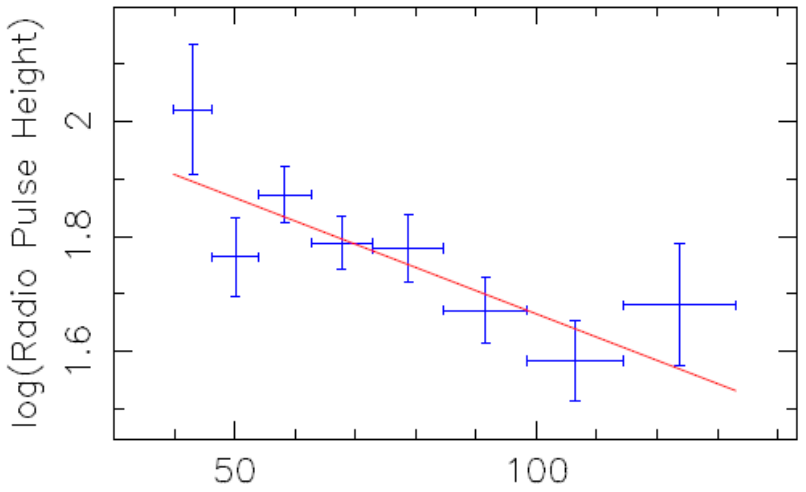
$A = 11. \pm 1.$ $\quad B = 1.16 \pm 0.03$

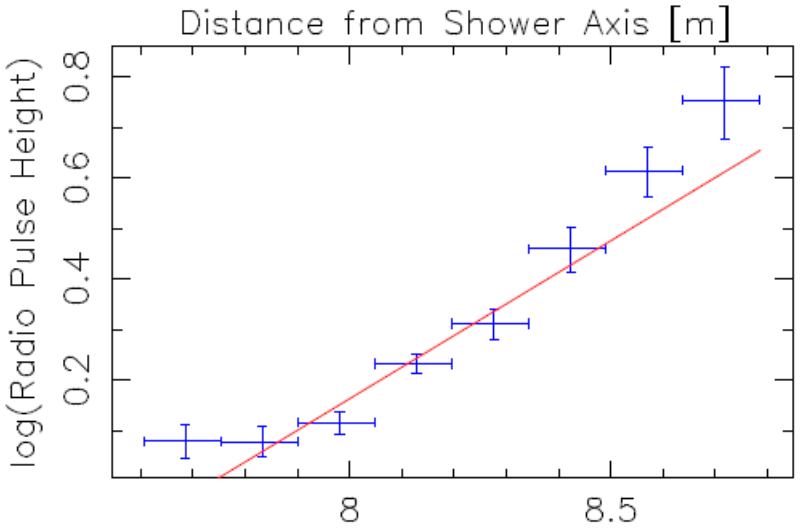
$R_0 = 236 \pm 81$ m $\quad \gamma = 0.95 \pm 0.04$

Correlation of radio pulse-height with shower-variables (KASCADE-Grande reconstruction)

A. Horneffer et al.
ICRC 2007





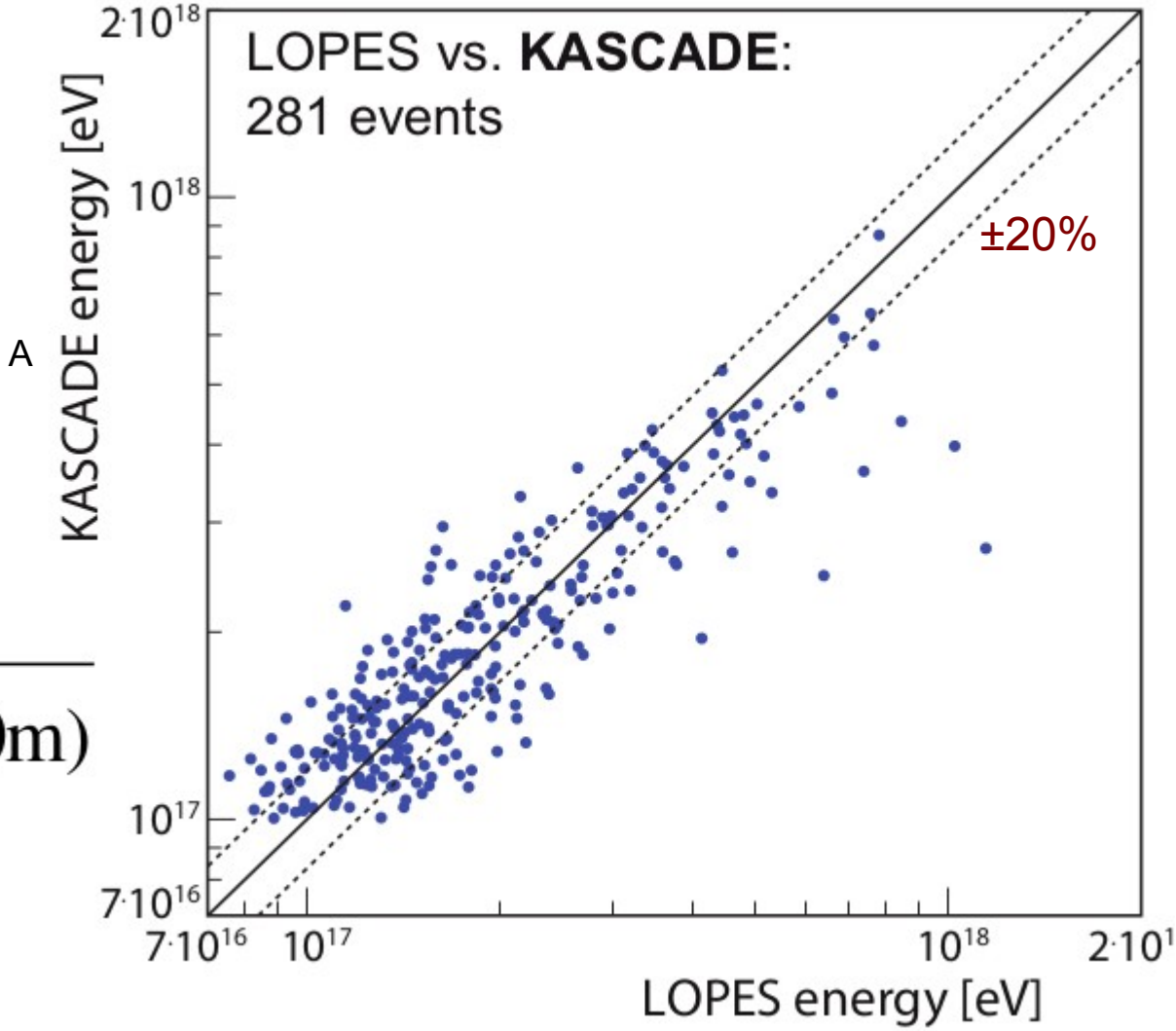


LOPES energy-estimation today

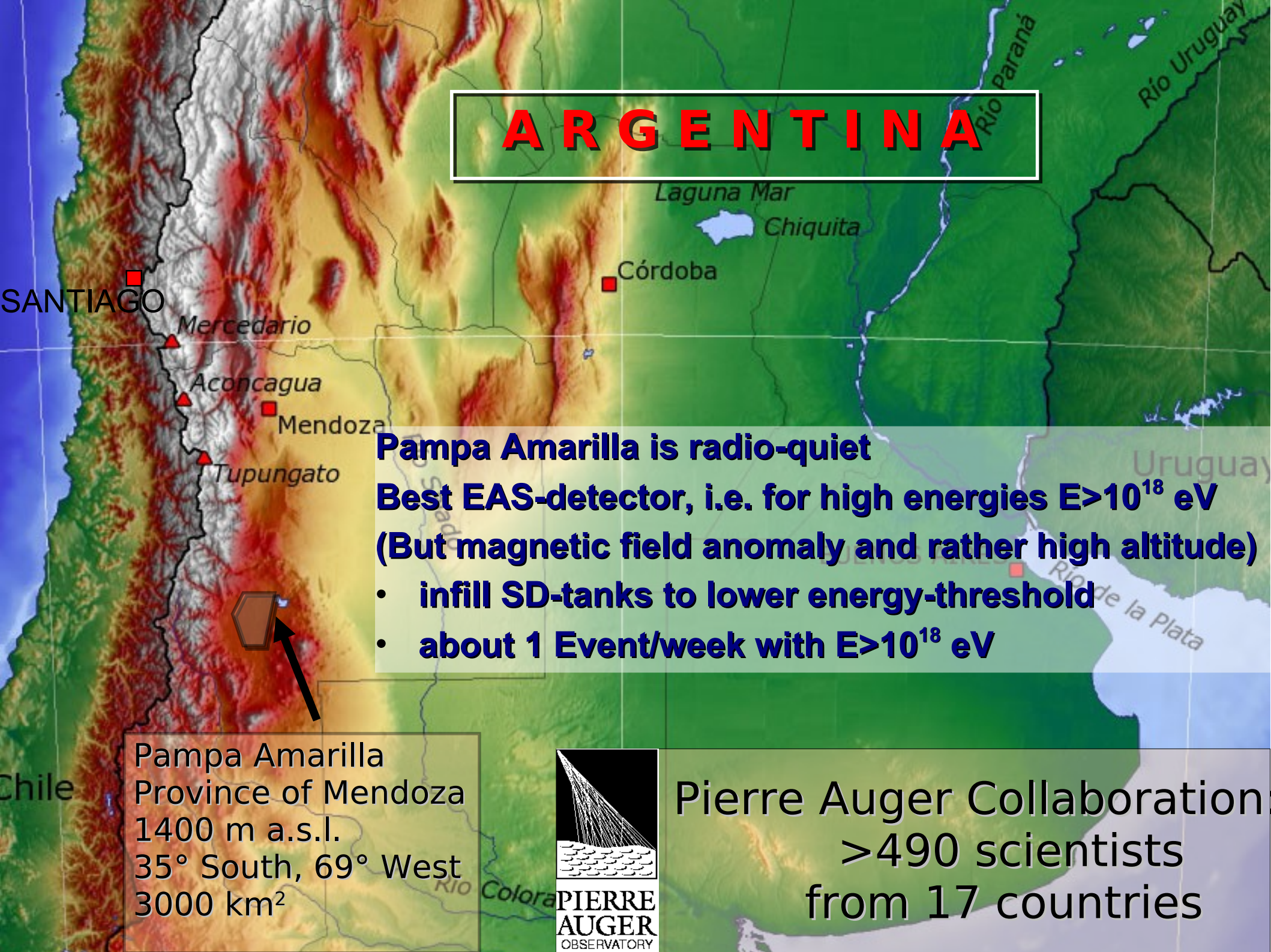
- data from 2005-2009
- many analysis-details improved
- geomagnetic correction
- axis distance correction
- no zenith correction!
  (would increase spread)

$$E = b \cdot \frac{\mathcal{E}_{CC-beam(east-west)}}{\left|\vec{v} \times \vec{B}\right|_{EW}} \cdot \exp(-d/180\mathrm{m})$$

F. Schroeder et al. ARENA 2012




Towards a Radio-Detector
for high energies E>10^18 eV:
Self-triggering!



Pampa Amarilla is radio-quiet

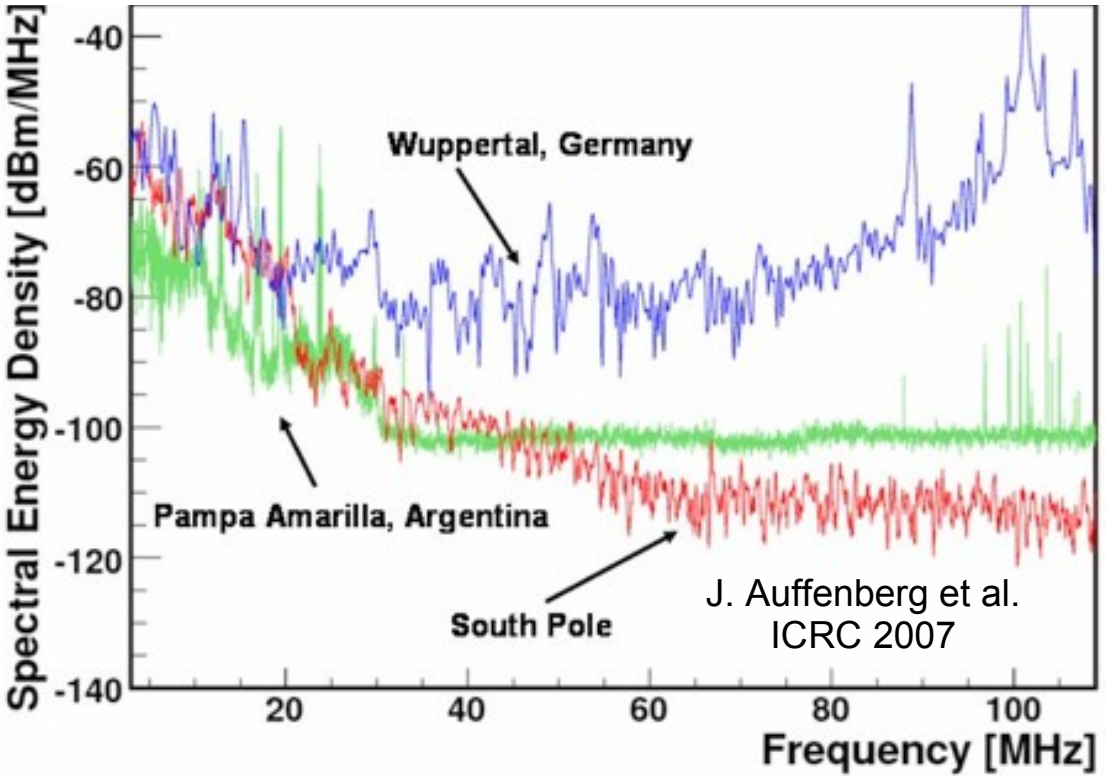
Best EAS-detector, i.e. for high energies $E>10^{18}$ eV

(But magnetic field anomaly and rather high altitude)

- **infill SD-tanks to lower energy-threshold**
- **about 1 Event/week with $E>10^{18}$ eV**

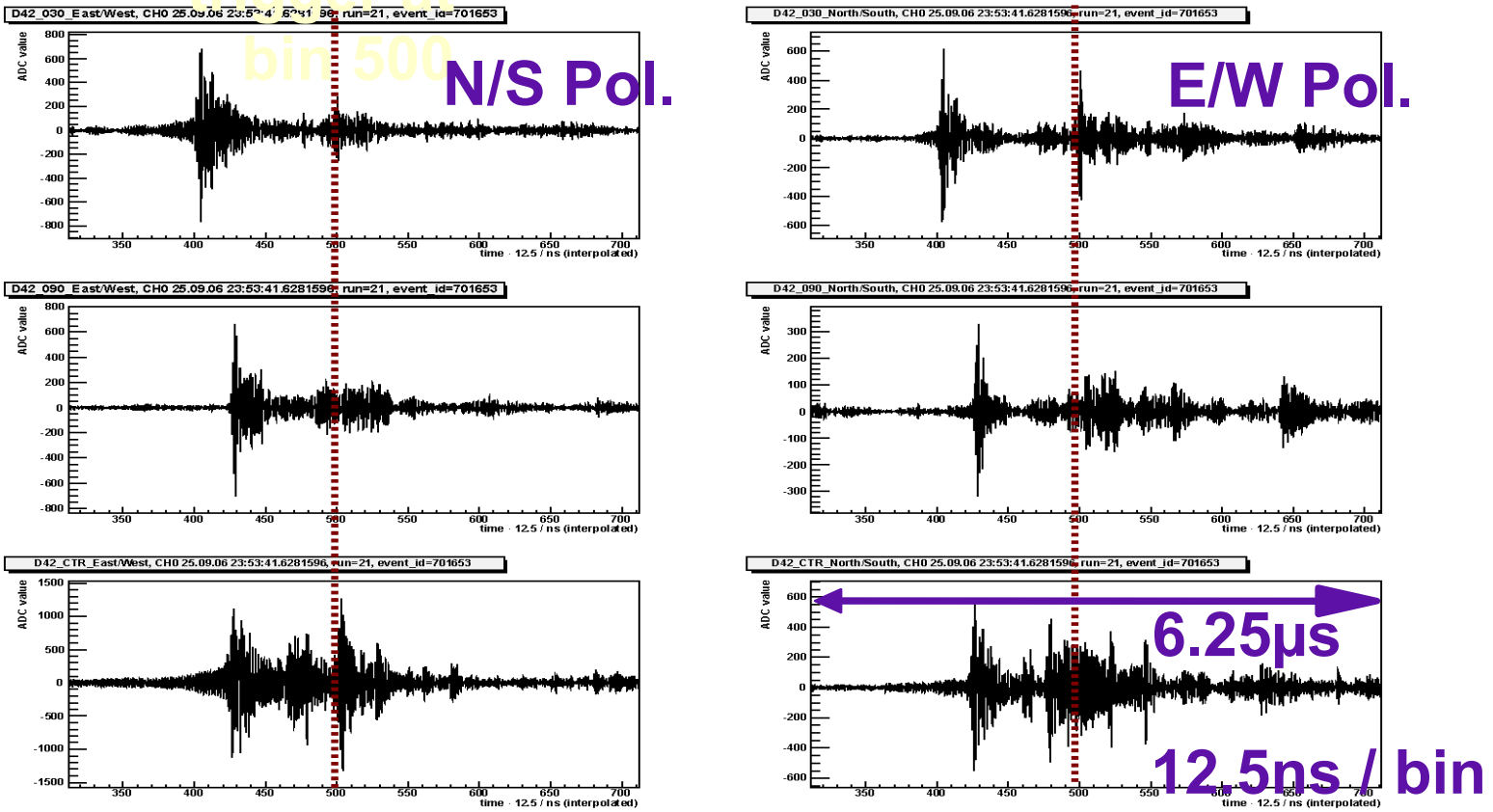
Self-triggering Radio Detector

- Mono-frequent background
- Quiet in 30-80 MHz down to galactic noise level
- But for a threshold-trigger need to look at the time-domain



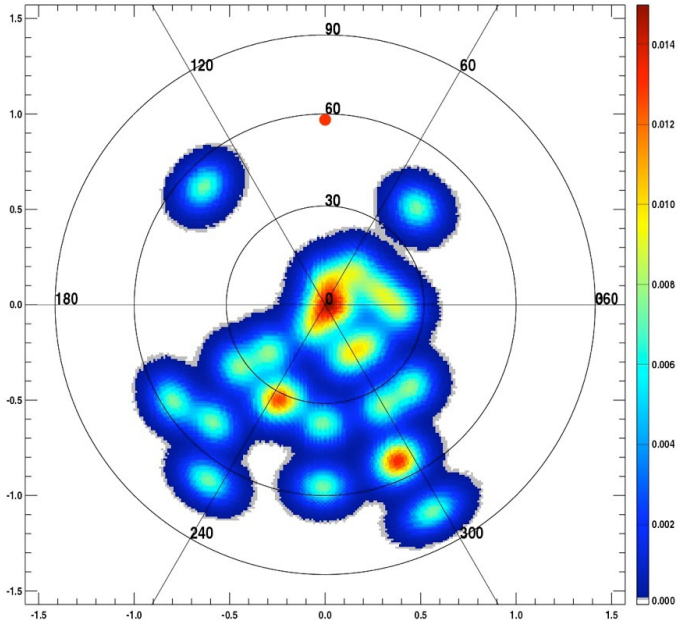
Self-triggering Radio Detector

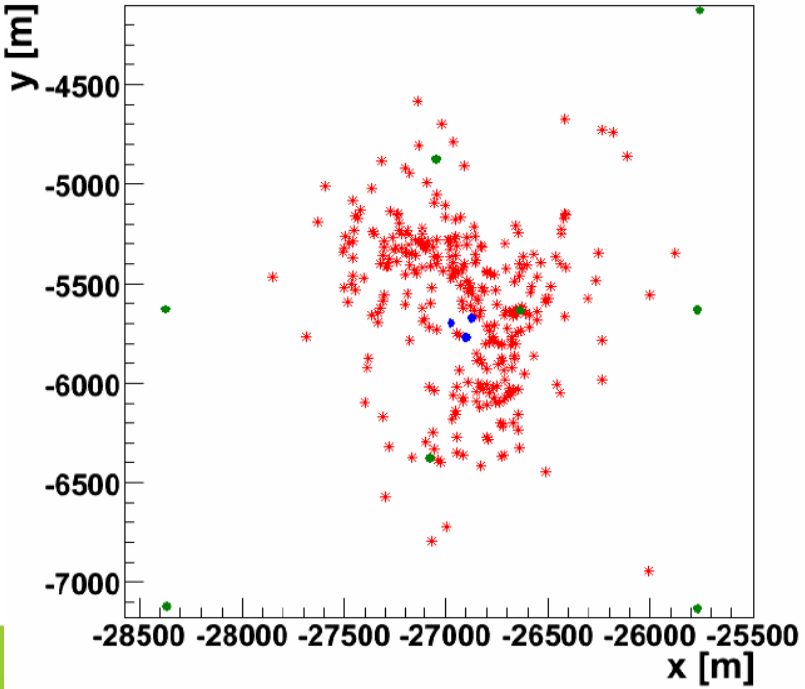
- Mono-frequent background
- Quiet in 30-80 MHz down to galactic noise level
- But for a threshold-trigger need to look at the time-domain
- Transient noise! --- not visible in dynamic spectra
- Not suppressible by up-ward coincidence window

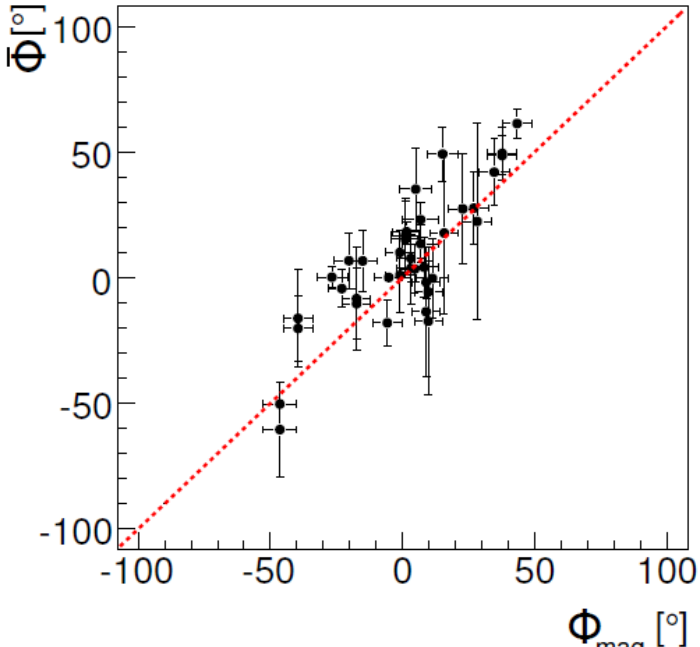


Test set-up data: Self-triggering

- Sky-plot of arrival direction of **self-triggered** events in coincidence with Auger surface detector
- Typical v x B distribution
- Core position around test set-up of 496 coincident events triggered by attached scintillators
- Up to 1.5 km with E-threshold of 0.4 EeV
- Polarisation in agreement with v x B

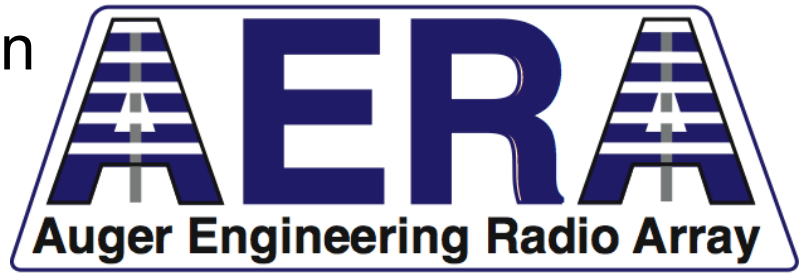






Auger Engineering Radio Array

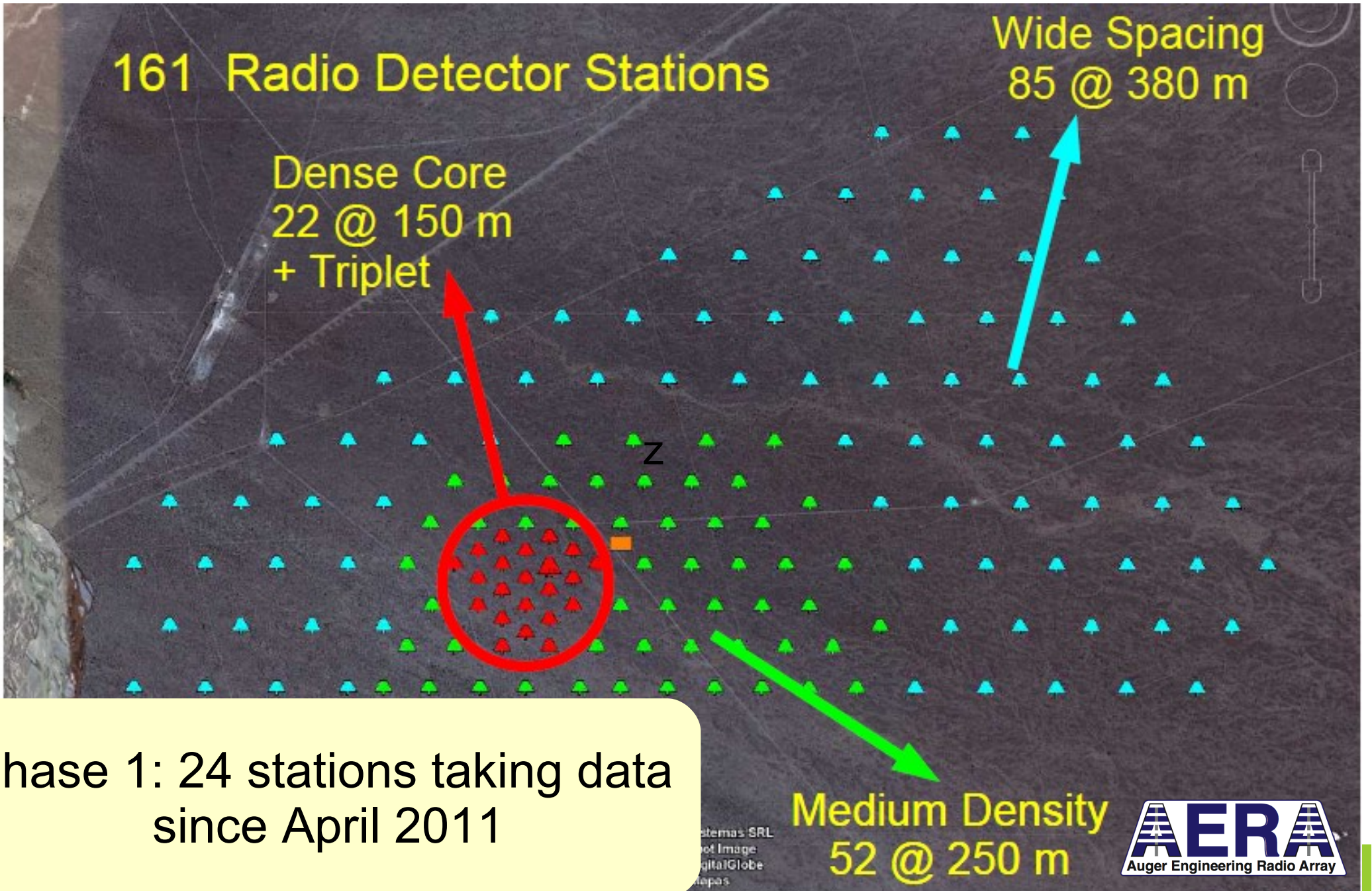
~20 km² mit ~160 dual-polarised radio-station
- dense core 100% efficient for E>10^{18}eV
- More than 500 events per year at E>10^{18}eV



Super-hybrid detection with HEAT and AMIGA (SD-Infill and muon-counter)

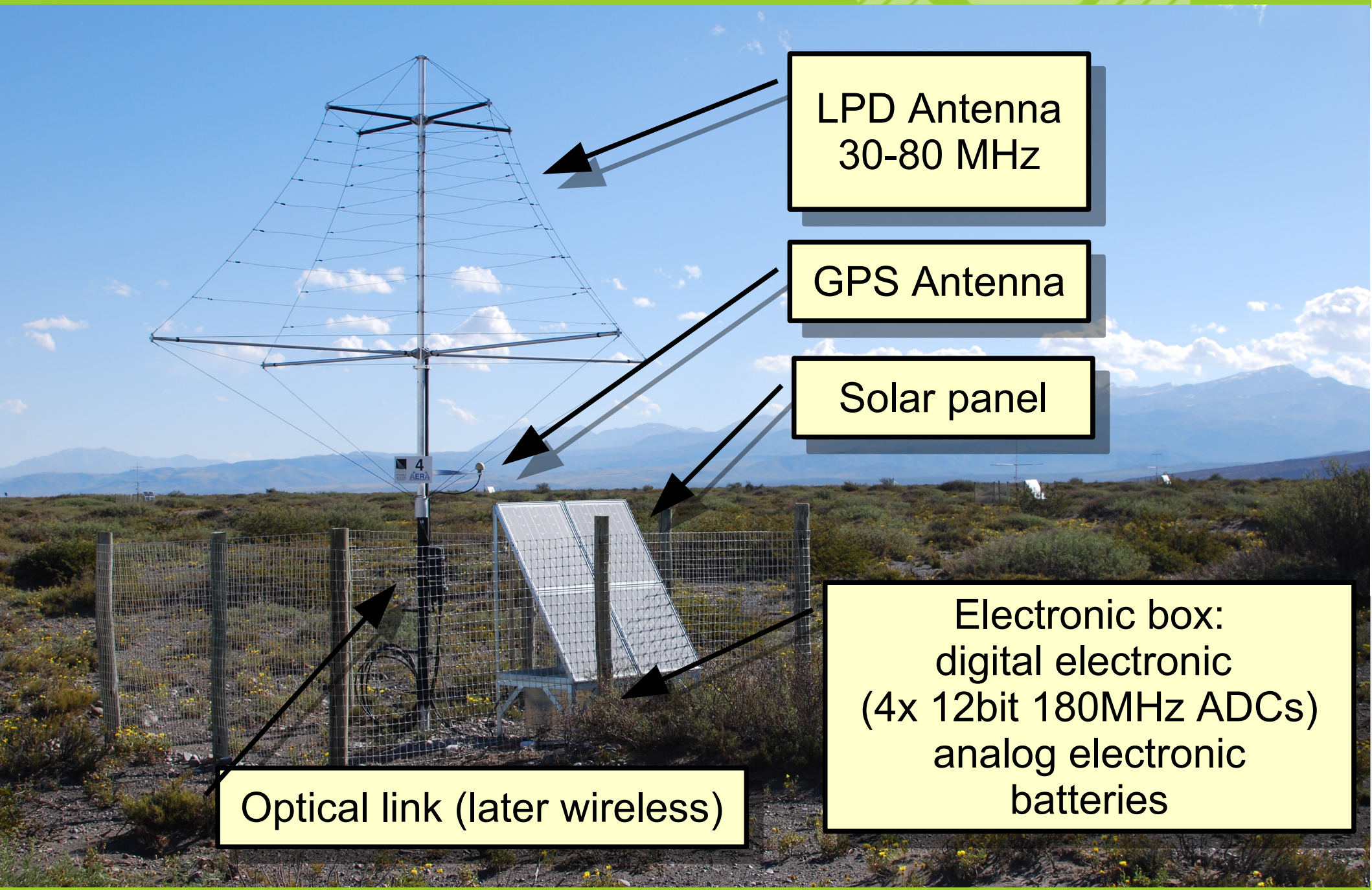
Scientific goals of AERA:
- Exploration of radio-emission above ~$10^{17.5}$ eV
- Feasability of radio-detection
  - Primary energy
  - Primary mass
  - Geometry of the air-shower
- Measure in the transition region of galacic to intergalactic cosmic rays

Layout



Phase 1: 24 stations taking data since April 2011

AERA Station



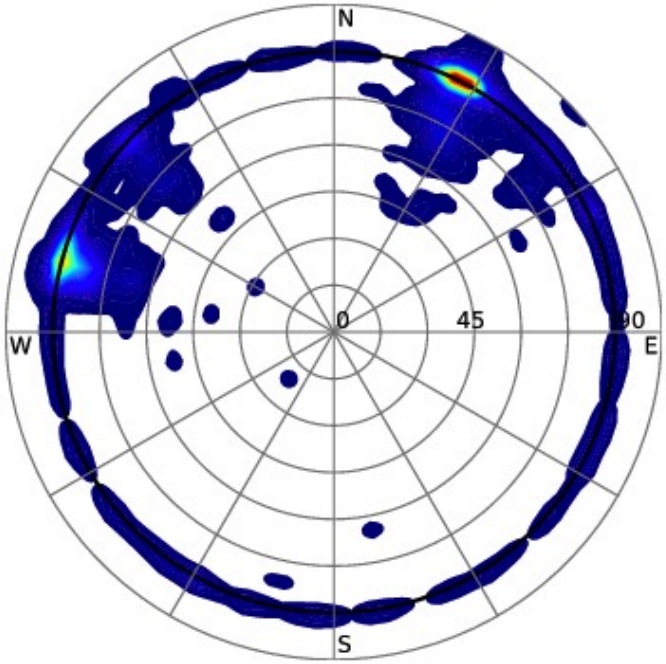
AERA antenna studies

- Lot of work optimising antenna for radio-detection
- In addition to LPDA: SALLA and Butterfly (next 100 stations)

- 50 page Auger paper accepted by JINST
- Full scale antenna calibration of LPDA
- Benchmarking with galactic noise

first data

- Again self-triggering problems with transients
- Spikes are very similar to EAS
- High trigger-rate and very low purity

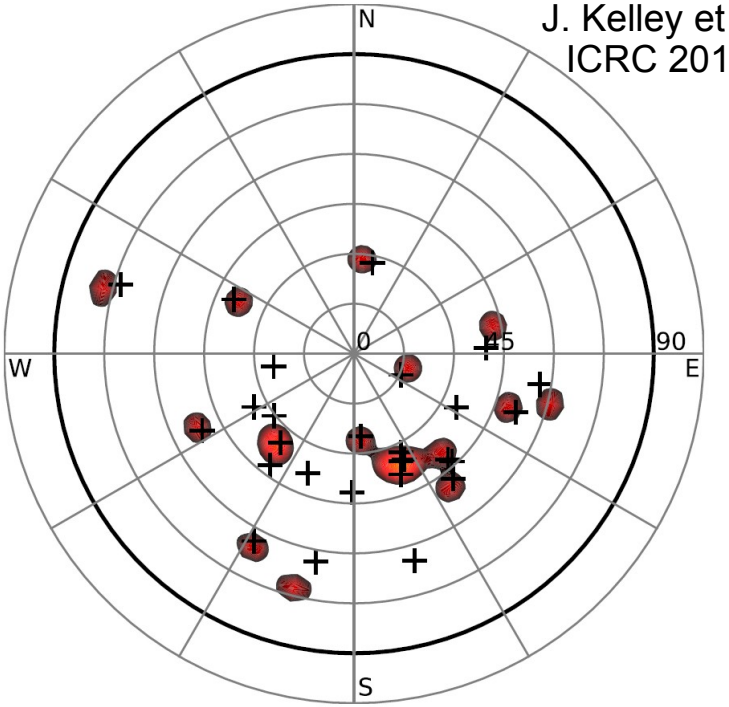


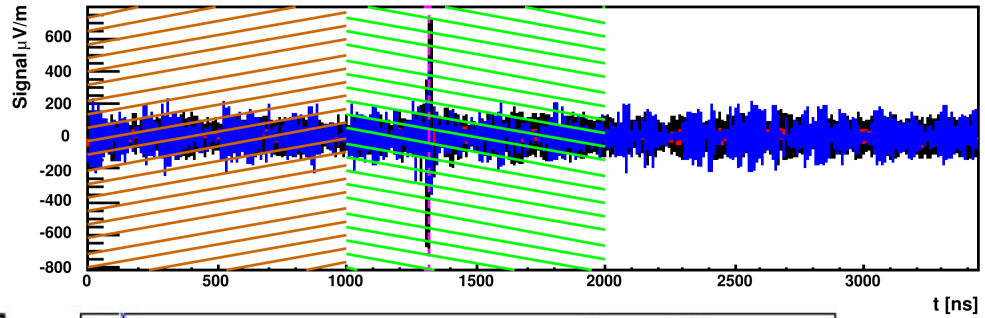
- Need external trigger to understand signal/BG discrimination
- Since beginning 2012 most stations are equipped with KIT/BUW FE-cards that record events triggered by SD due to long memory buffer

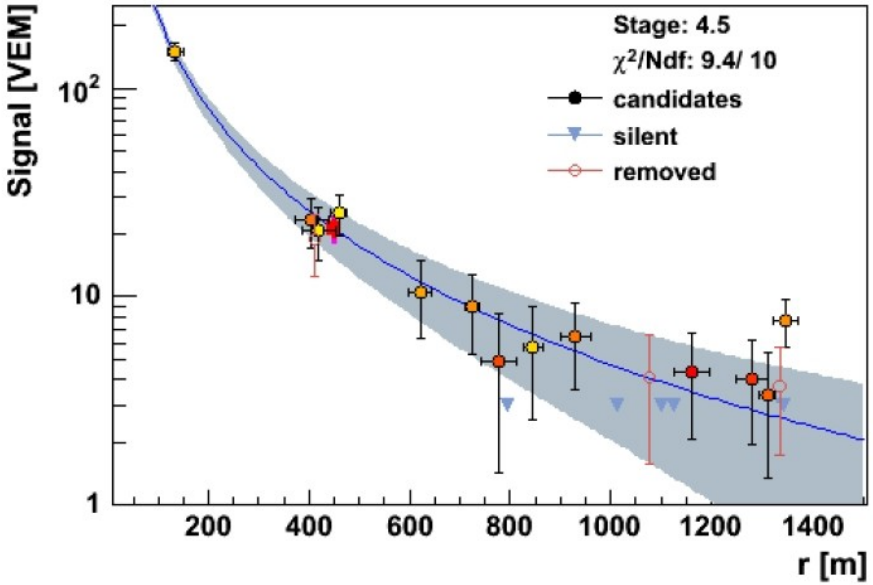
first data

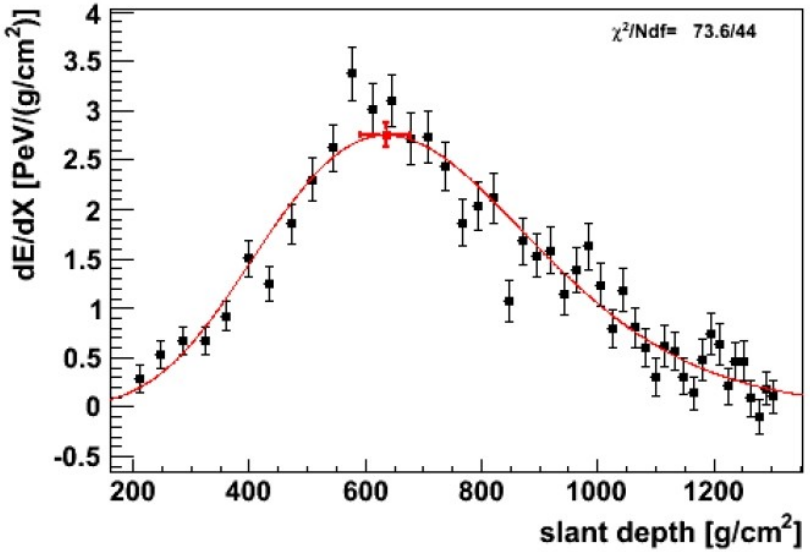
- > 30 self-triggered coincident events in April-August 2011
- Surface/Fluorescence/Radio super hybrid
- 1.8 EeV (FD)

J. Kelley et al. ICRC 2011









Simulation

- Large variety of Codes based on different Ansätze
- Big contribution from Helmholtz-group T. Huege

T. Huege, ARENA 2012

more „microscopic“

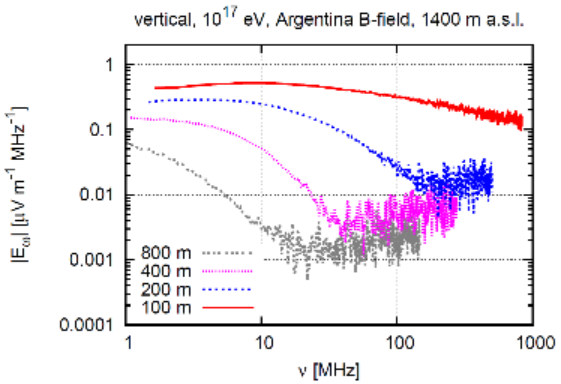
MGMR	time-domain, analytic, parametrized shower, fast, free parameters, summing up „mechanisms“
Dave‘s model	frequency-domain, analytic, parametrized shower, fast, free parameters, summing up „mechanisms“
EVA	frequency-domain, analytic, fitted CONEX shower,summing up „mechanisms“
SELFAS2	time-domain, shower from universality, summing up vector potentials for tracks
REAS3.1	time-domain, histogrammed CORSIKA showers, endpoint formalism, open source
Kalmykov et al.	frequency-domain, CORSIKA showers, ZHS-like formalism
ZHAireS	time- and frequency-domain, Aires showers, ZHS formalism
CoREAS	time- (later frequency-) domain, CORSIKA showers, endpoint formalism

Simulation

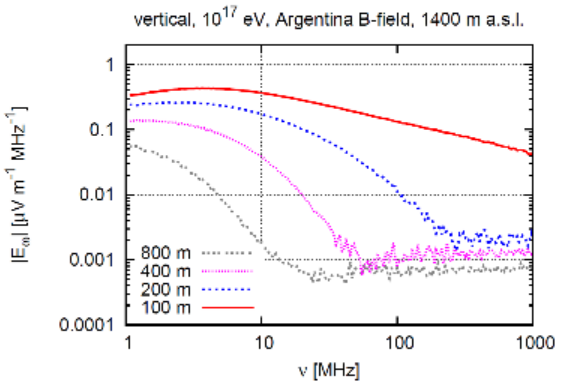
- Large variety of Codes based on different Ansätze
- Big contribution from Helmholtz-group T. Huege
- Realistic refractive index

T. Huege, ARENA 2012

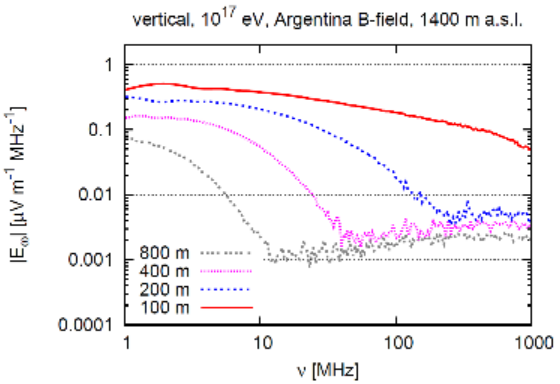
REAS3.1



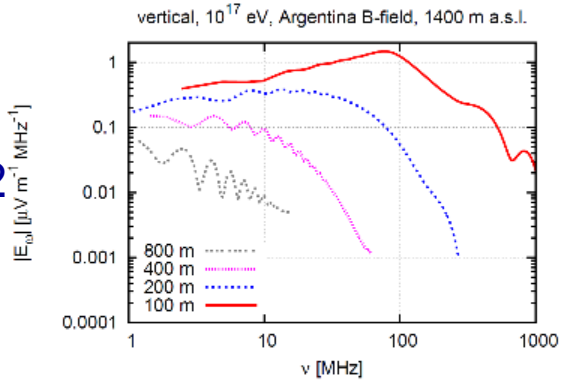
CoREAS



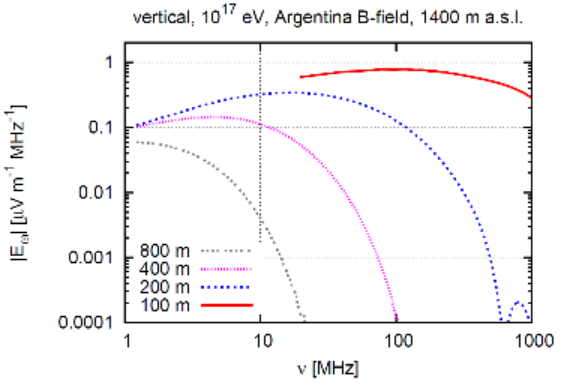
ZHAireS



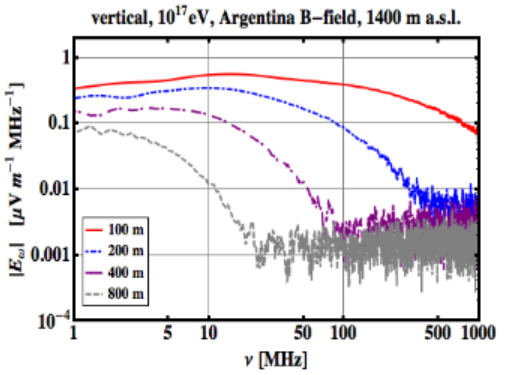
MGMR



EVA



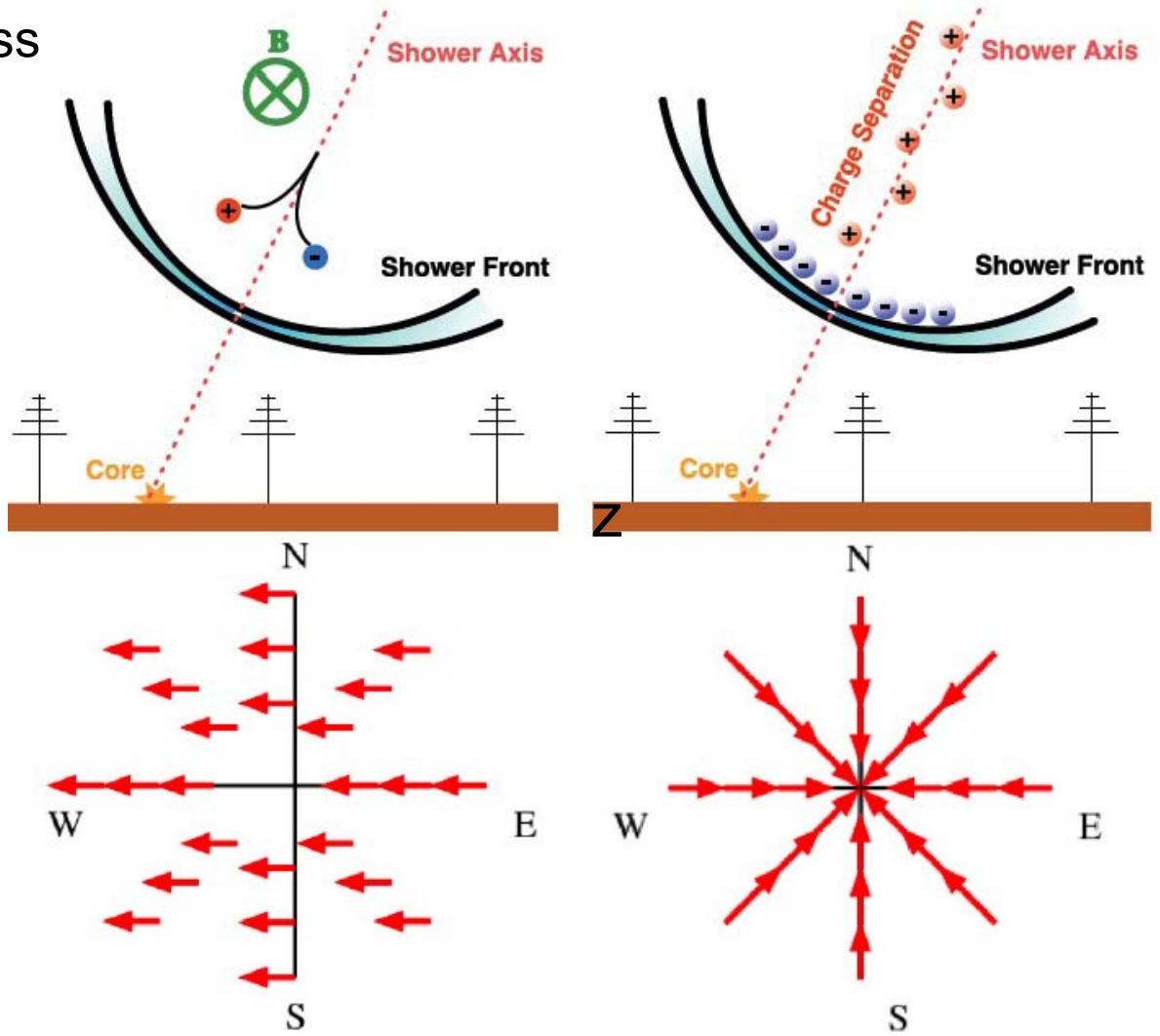
SELFAS2



Simulation: emission mechanism

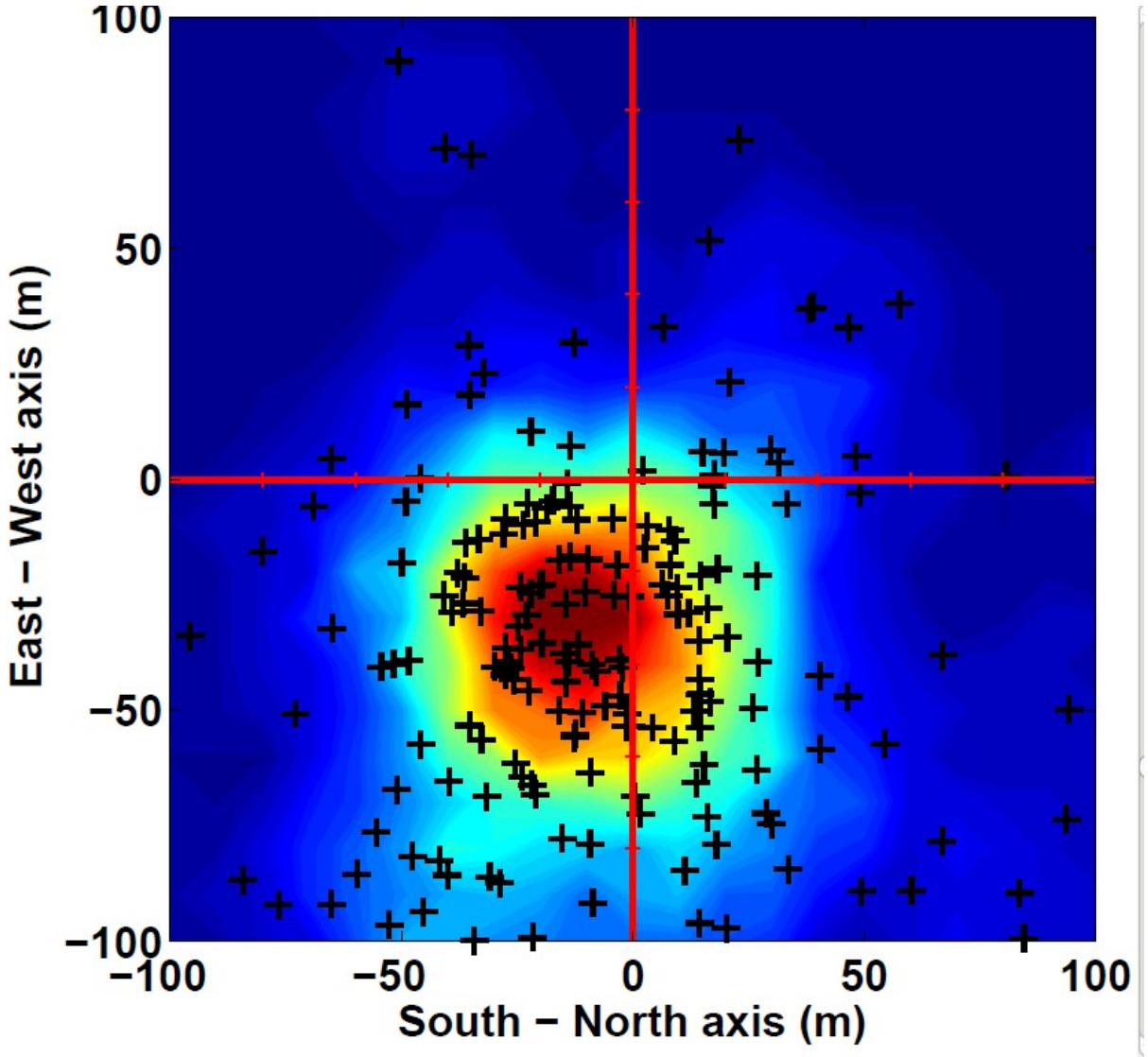
- Macroscopic model:
  - Time variation of transverse current
  - Time variation of charge access
  - …
- Compatible with microscopic model:
  - end-point formalism

    James et al. Phys.Rev.E (2011)
- Separable with Polarisation!
- Depending on antenna-position w.r.t. shower core constructive or destructive interference



Indication for charge-excess contribution

- Because of interference, position of radio-maximum is shifted towards east
- Seen by CODALEMA
- ca. 20m offset between core position of radio and surface detector reconstruction



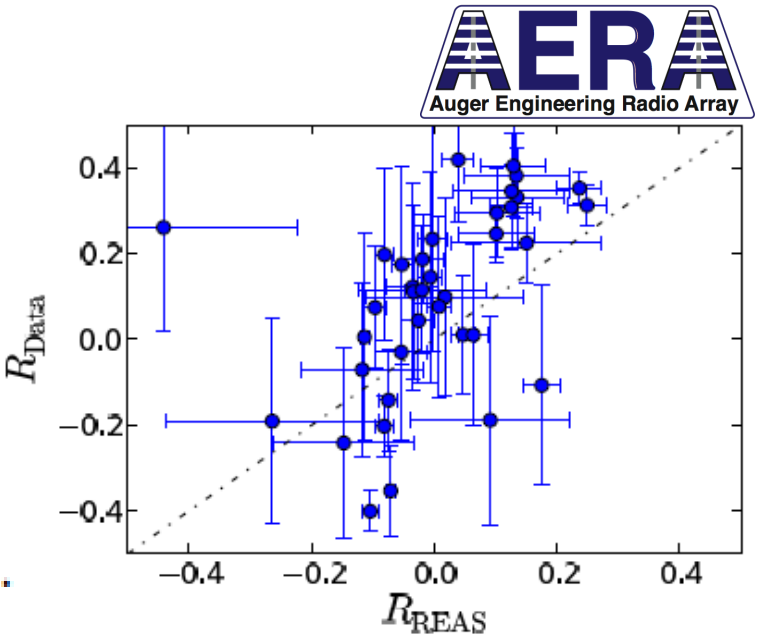
A. Belletoile et al.
ICRC 2011

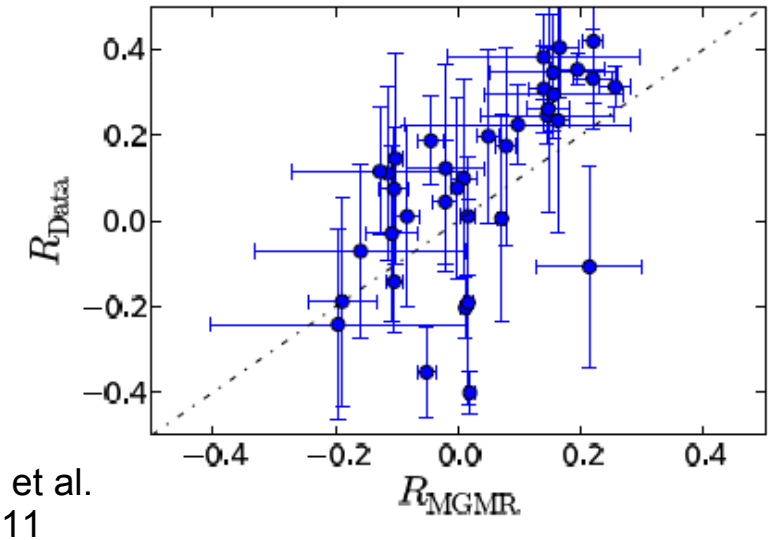
Indication for charge-excess contribution

- Rotating x,y to x' in direction of the v x B polarisation, y' orthogonal to it
- Define R:

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

- For geomagnetic R = 0

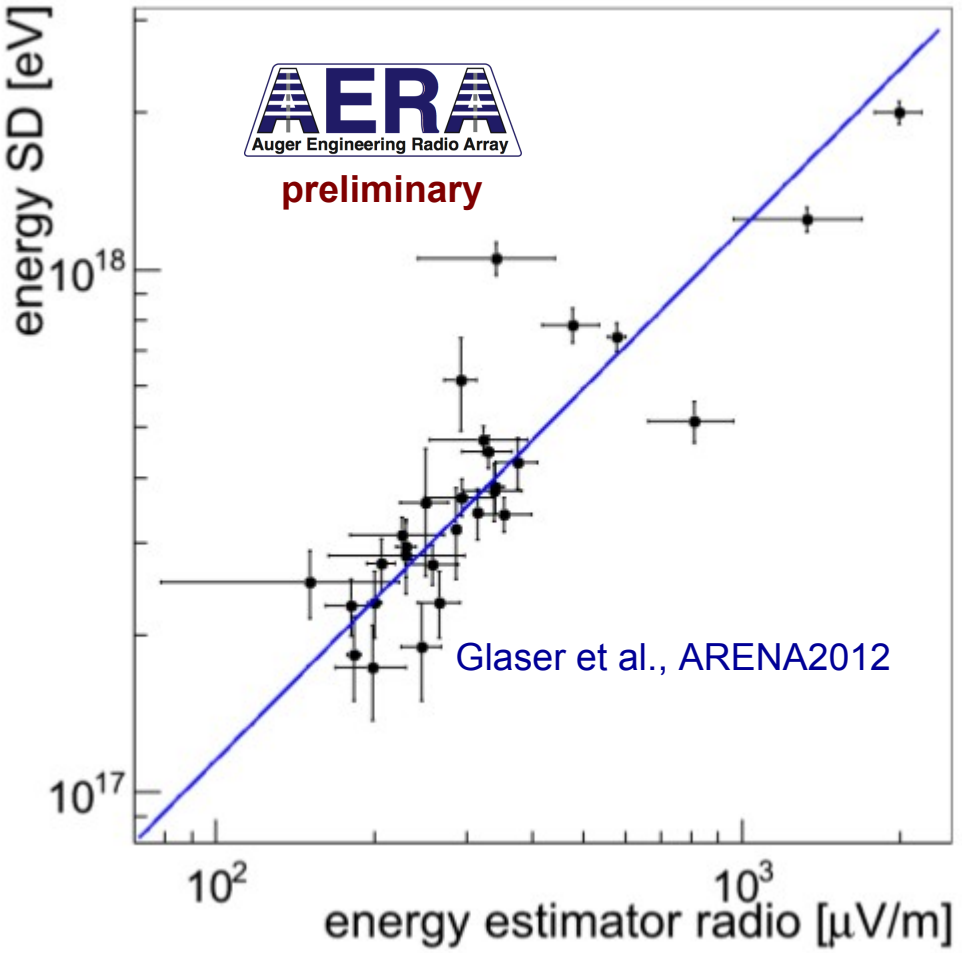




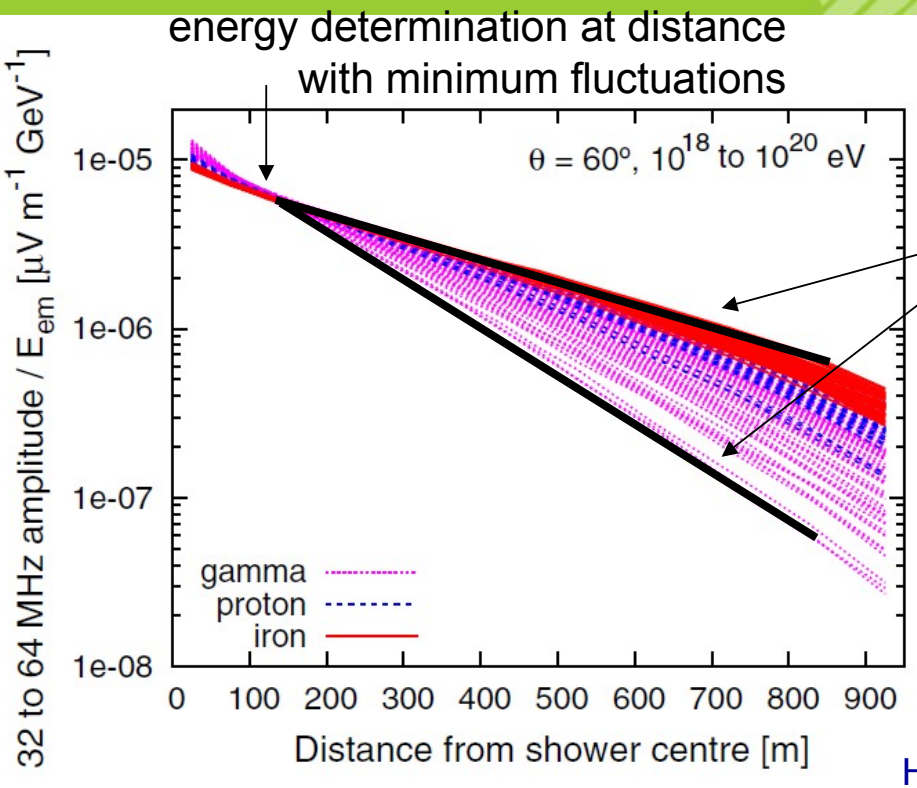
B. Revenue et al.
ICRC 2011

Energy-calibration

- Energy from Surface Detectors correlated with field-strength
- Good correlation up to more than 10^{18}eV
- σ ~25% including SD!



REAS simulation for composition



Xmax determination from lateral slope

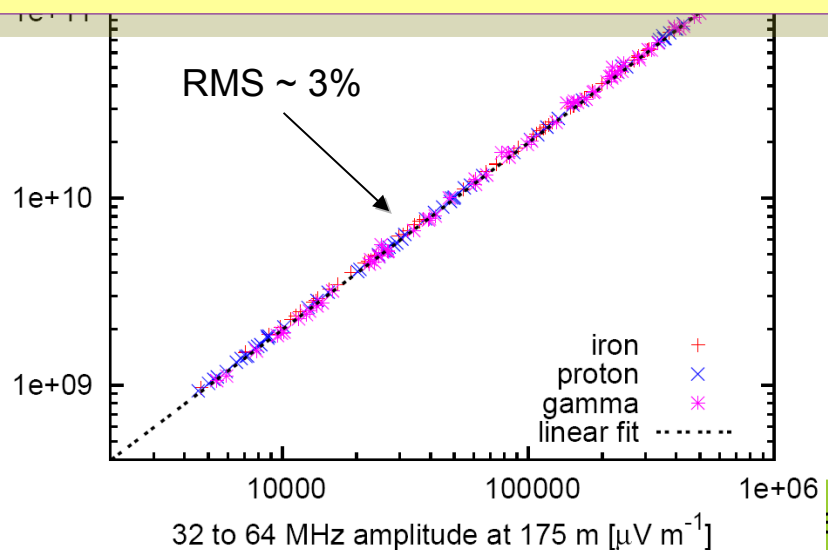
Fe – flat

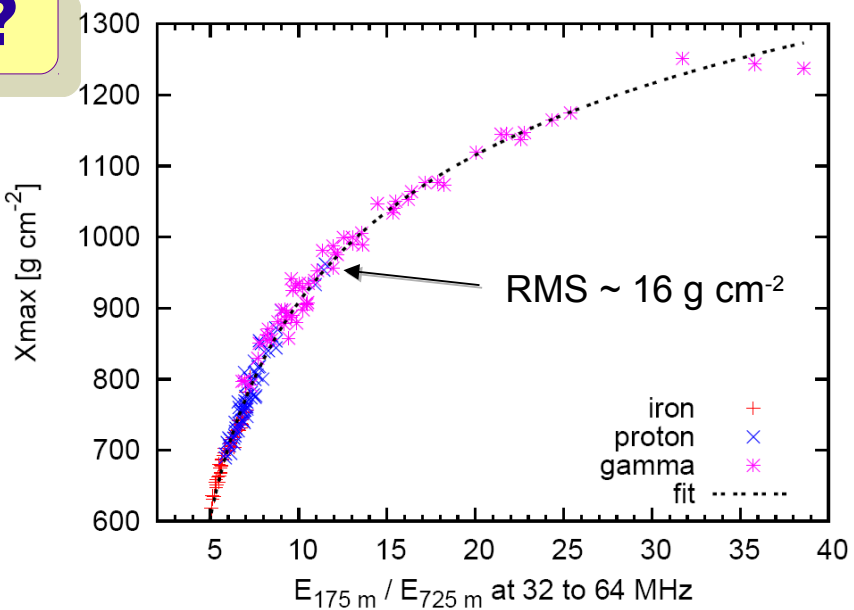
p – steeper, fluctuating

γ – steepest, fluctuating

Huege, Ulrich, Engel (Astrop. Phys. 2008)

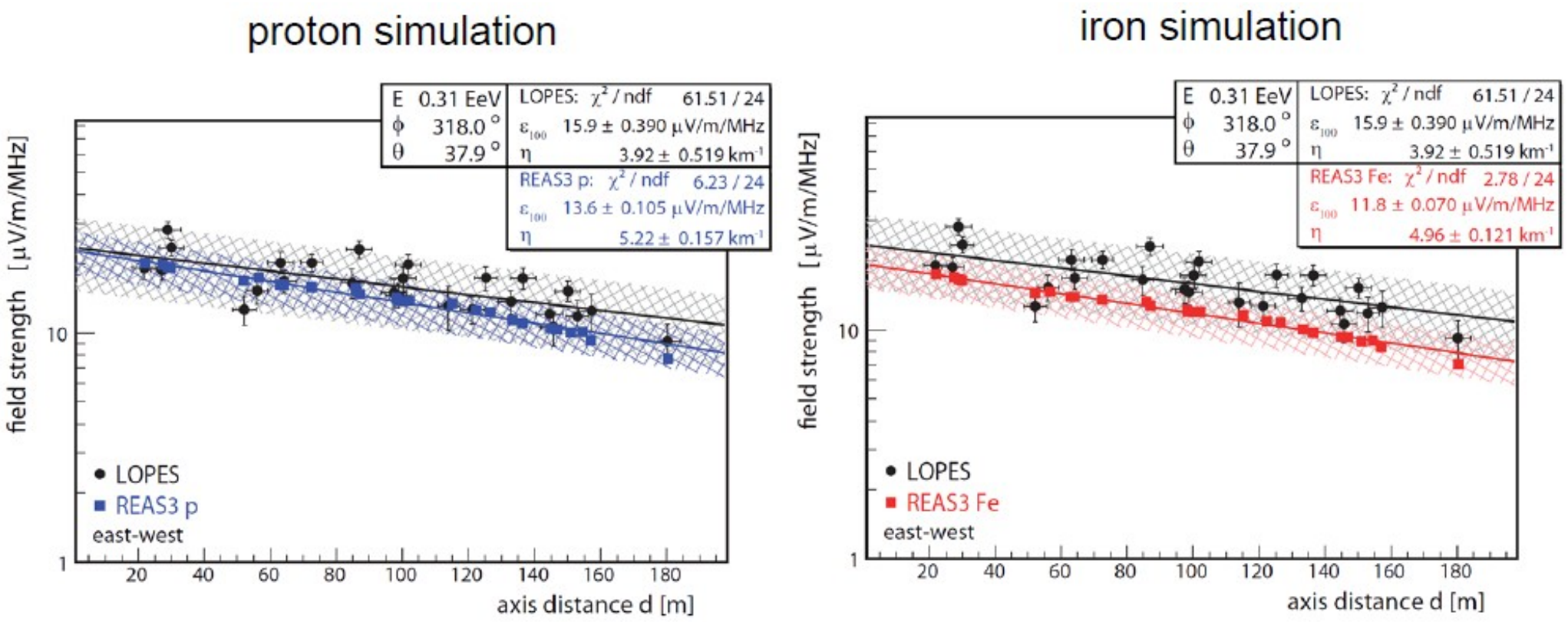
Ultimate handle on UHECR?





LDF Comparison REAS - LOPES

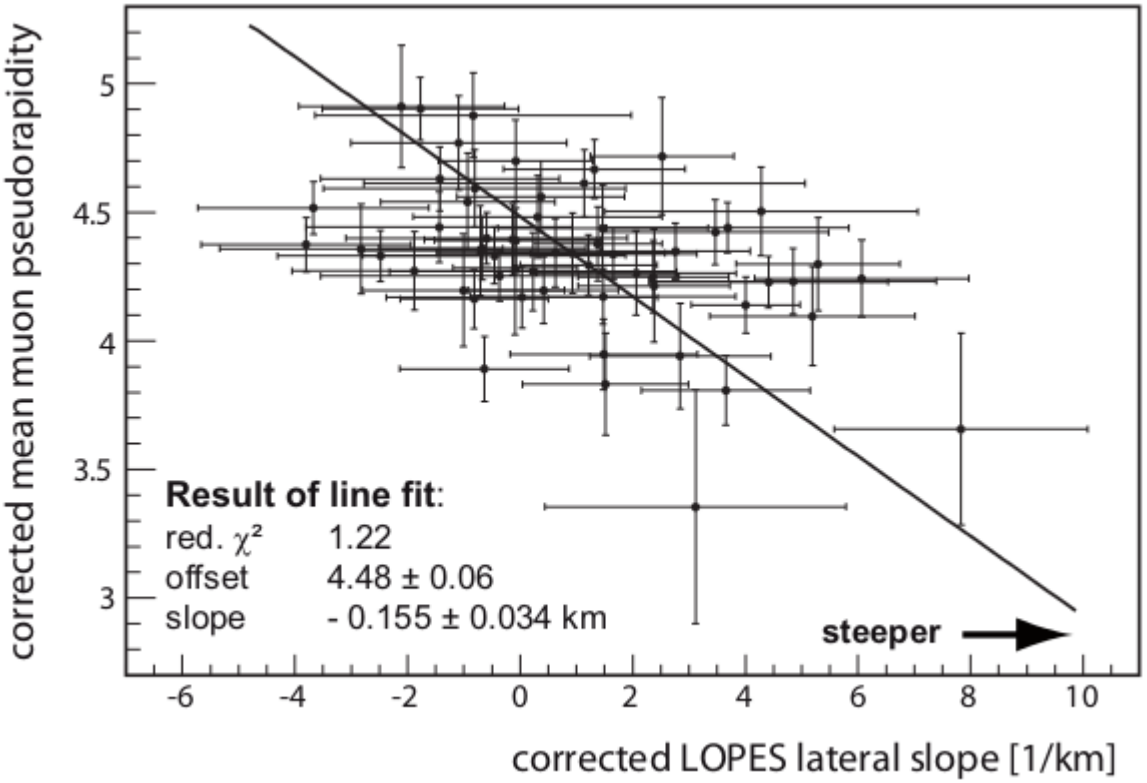
W.D. Apel et al. (LOPES Coll.), Astroparticle Physics submitted



- Lateral distribution for the station-signals for one event
- simulation according to KASCADE-Grande reconstruction

Composition sensitivity: LOPES

W.D. Apel et al. (LOPES Coll.), Phys. Rev. D 85, 071101(R) (2012)

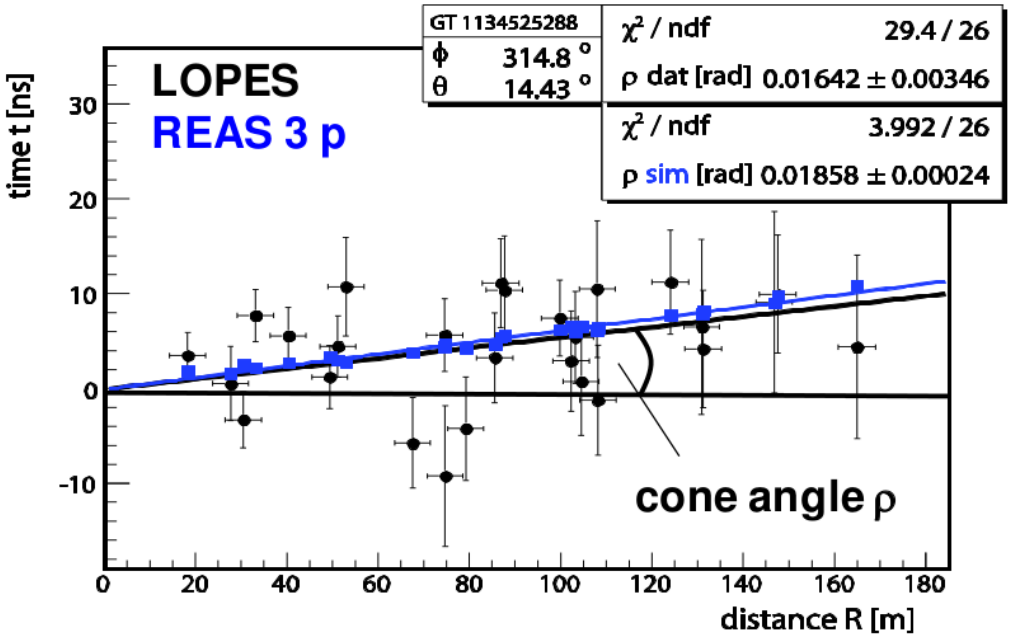


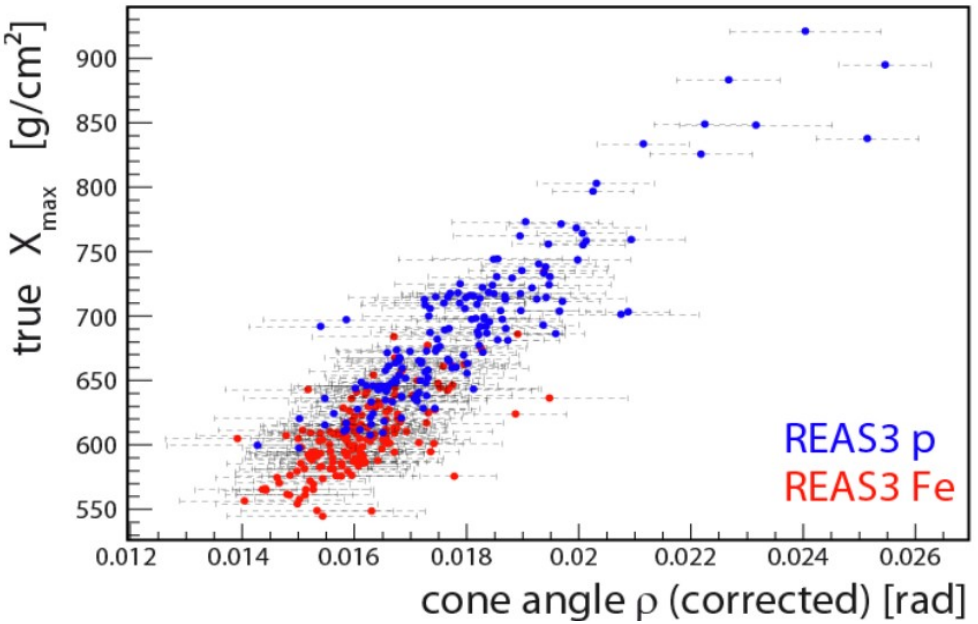
59 Events
3.7σ

- Slope of lateral distribution for the station-signals
- Psudo-rapidity (~production-height) of single muons as measured with KASCADE-Grande muon traking detector (MTD)
- Radio is sensitive to the longitudinal development of EAS

Composition sensitivity: LOPES

LOPES ICRC 2011

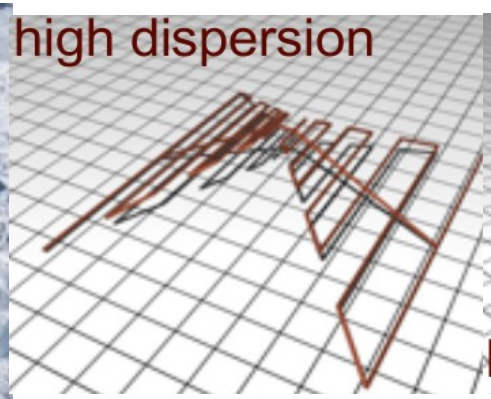


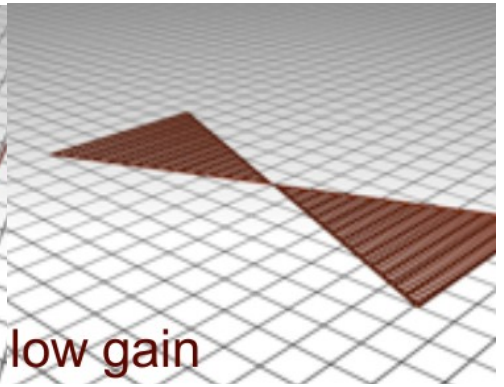


- Fit arrival-time relative to shower-plane with conical wave-front improves reconstruction
- Simulation shows correlation with X_{max}

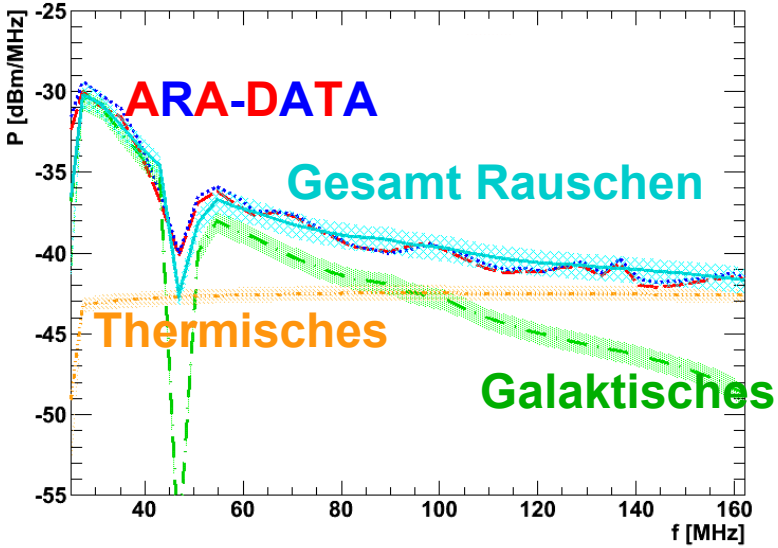
Rasta at South Pole

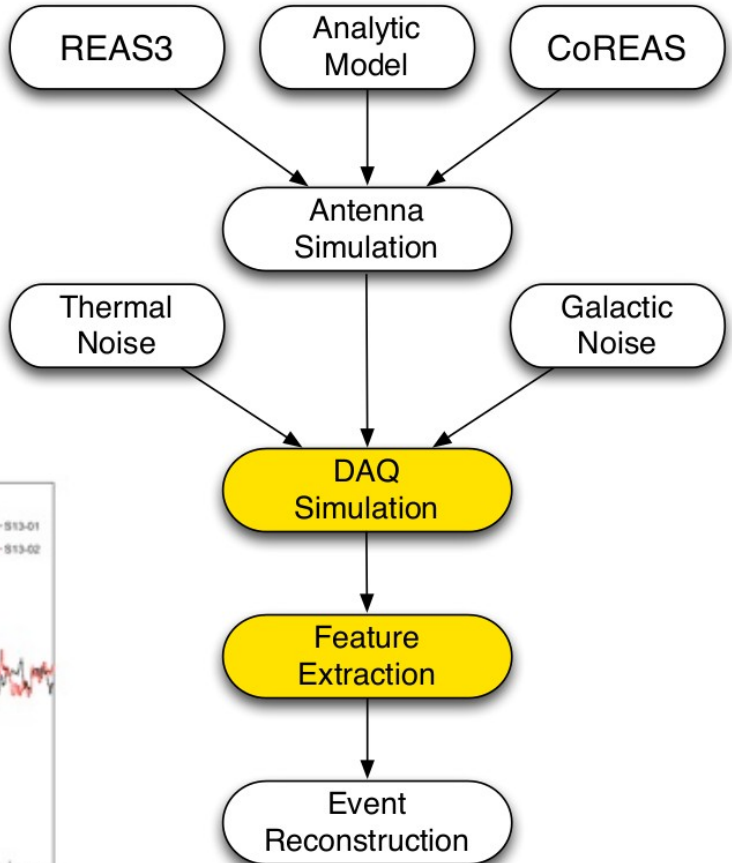
- Antenna studies for deployment in ice: Fat Wire-Dipole





- Full simulation and reconstruction analyis chain implemented in IceCube Framework
- Good environment knowledge





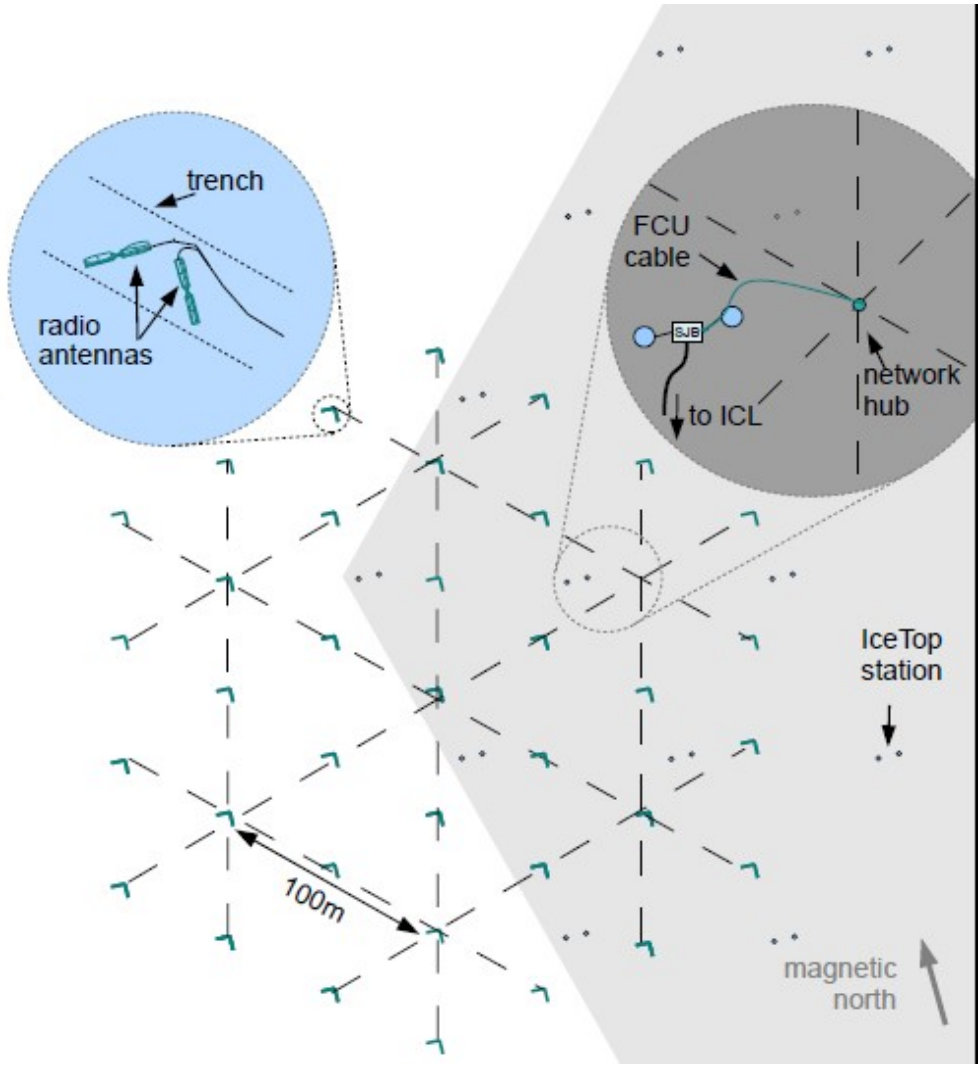
Rasta at South Pole

Proposed Setup

- 37 stations
- 2 antennas per station
- AERA-like DAQ

Goals

- develop technologies
  - trigger (IceCube/IceTop)
  - timing
  - readout
- detect air-showers
  - proof-of-principle
- start analysis
- expected dataset (REAS3.0)
  - 50k radio triggers/year
  - 15k IceTop coincident trigger/year

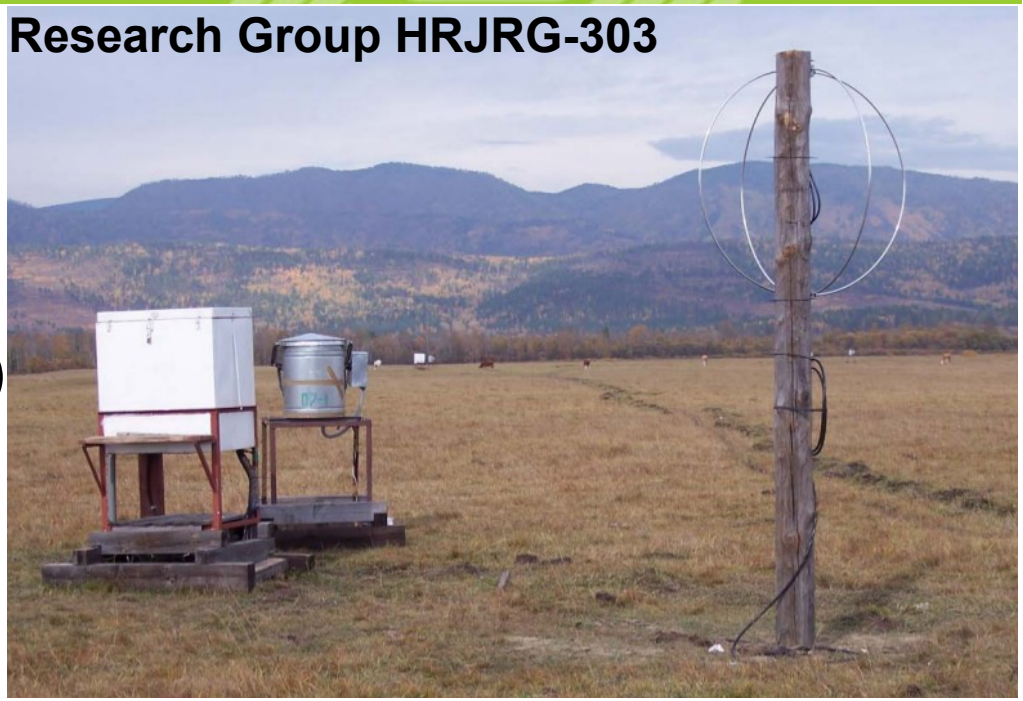


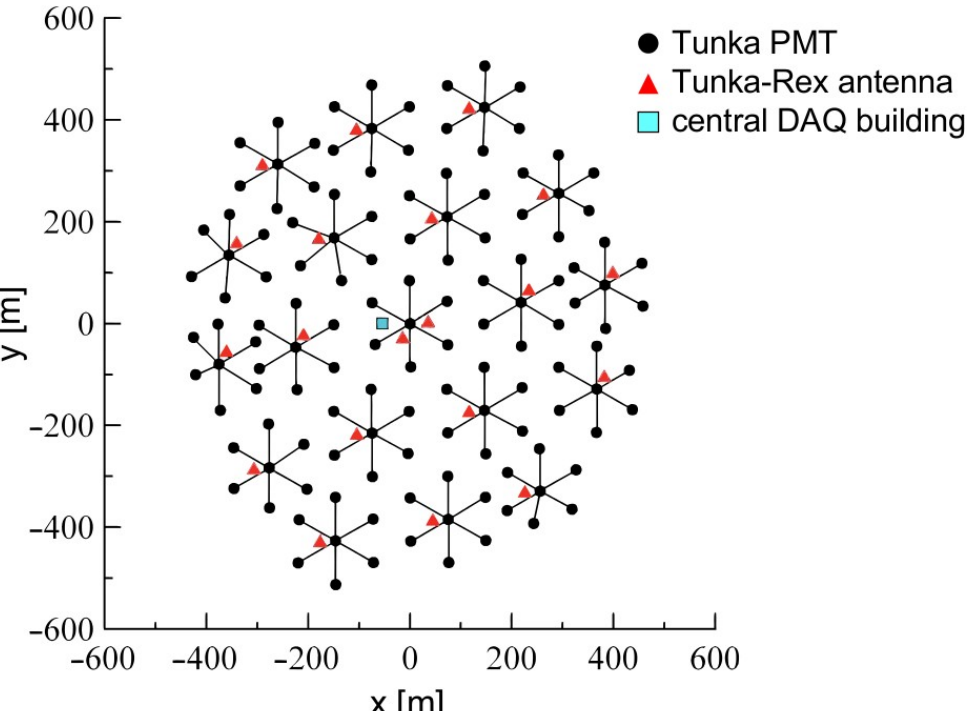
- NSF rejected the proposal
- Future within ARA?

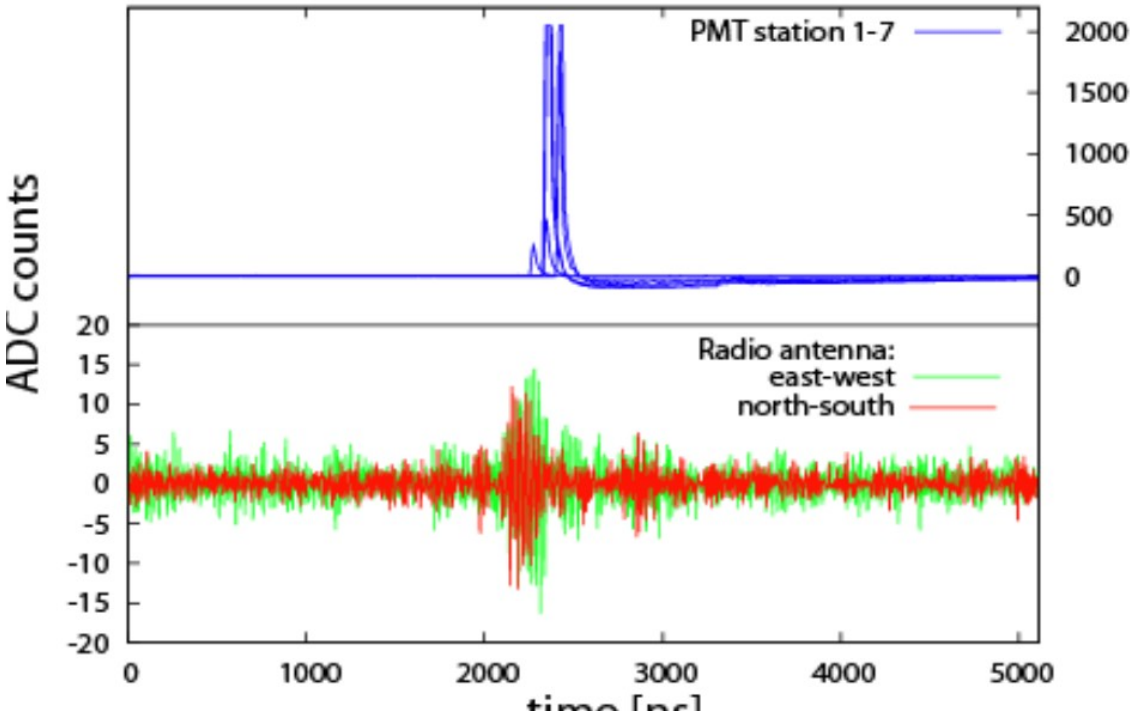
Tunka Rex

Helmholtz Russia Joint Research Group HRJRG-303

- Tunka Radio Extension
- 20-30 SALLAs (200m)
- Tunka trigger
- Tunka-DAQ (200 MHz,1k samples)
- start in autumn 2012
- first radio-Cherenkov hybrid measurements







- Radio-emission of extended air shower described by geomagnetic effect
- LOPES-measurements to understand general amplitude-dependence, LDF and composition sensitivity
- Auger started measure with 24 Stations at $E>10^{18}$ eV, super-hybrid, first signs for charge-access contribution, next 100 Stations shipped for deployment
- South Pole has quiet environment for radio-detection, but RASTA on ice
- Tunka-Rex hybrid with Cherenkov
- Radio-detection has potential to solve UHECR puzzle

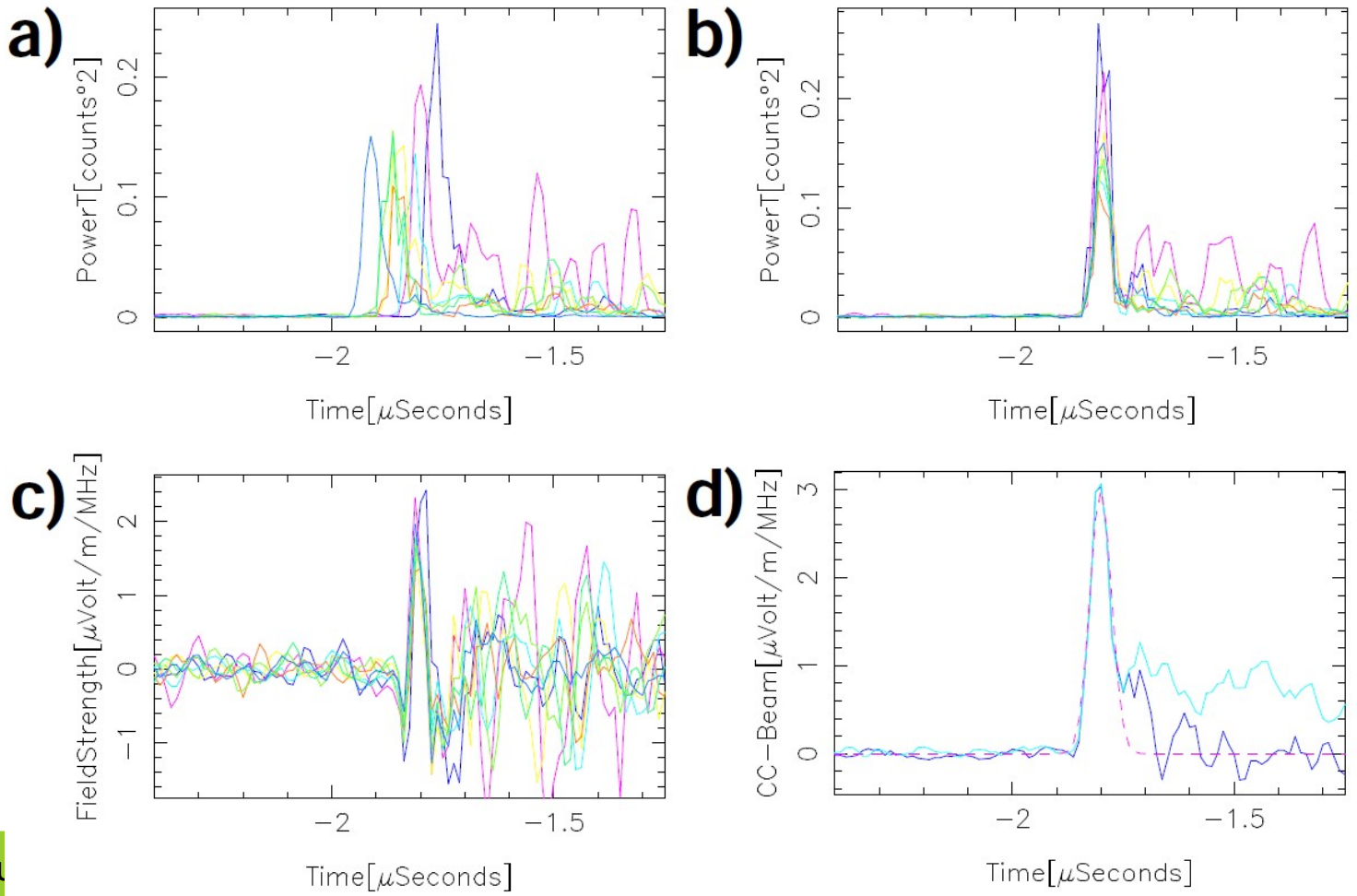
Renaissance of Radio Detection: Experiment

Interferometric reconstruction

$$cc[t] = \pm\sqrt{\left|\frac{1}{N_{Pairs}}\sum_{i=1}^{N-1}\sum_{j>i}^{N} s_i[t]s_j[t]\right|}$$

$s_i[t]$: signal of station i at time t

Signal to noise scales with #antenna



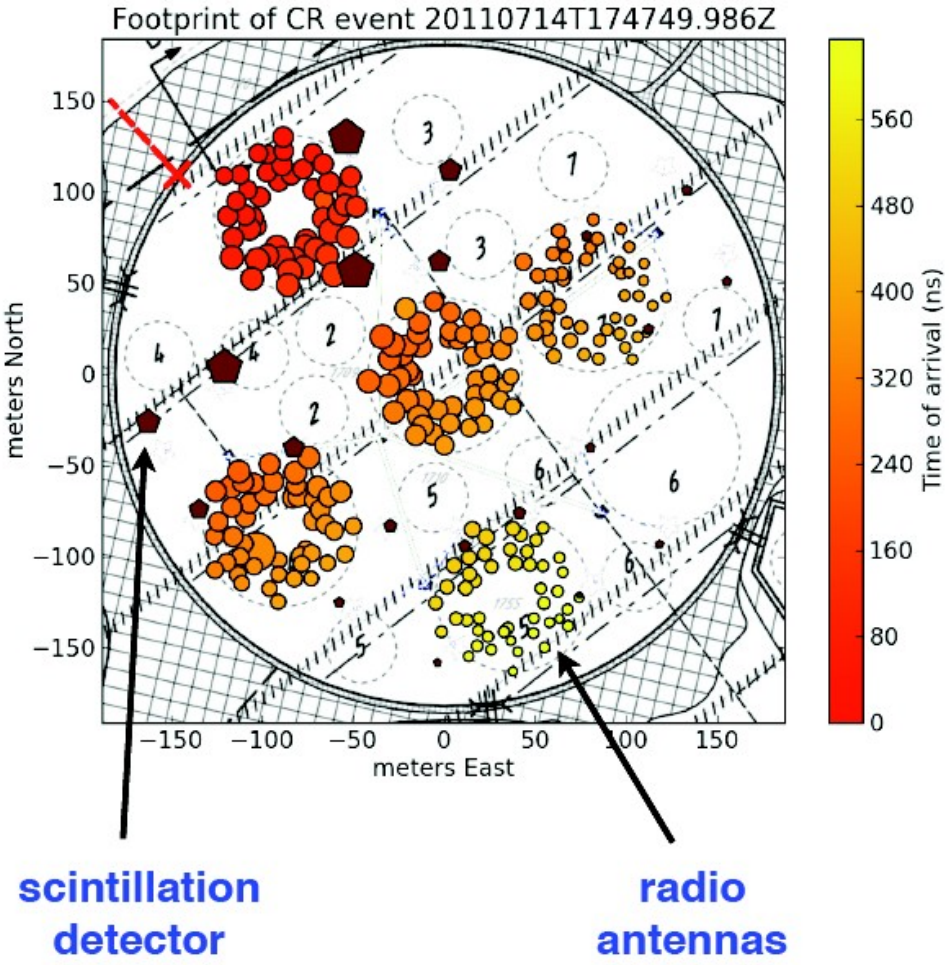
LOFAR and LORA

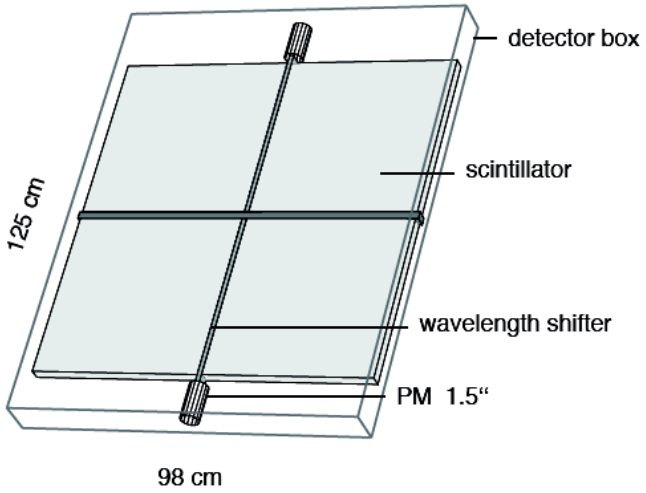
LOFAR Radboud Air Shower Array

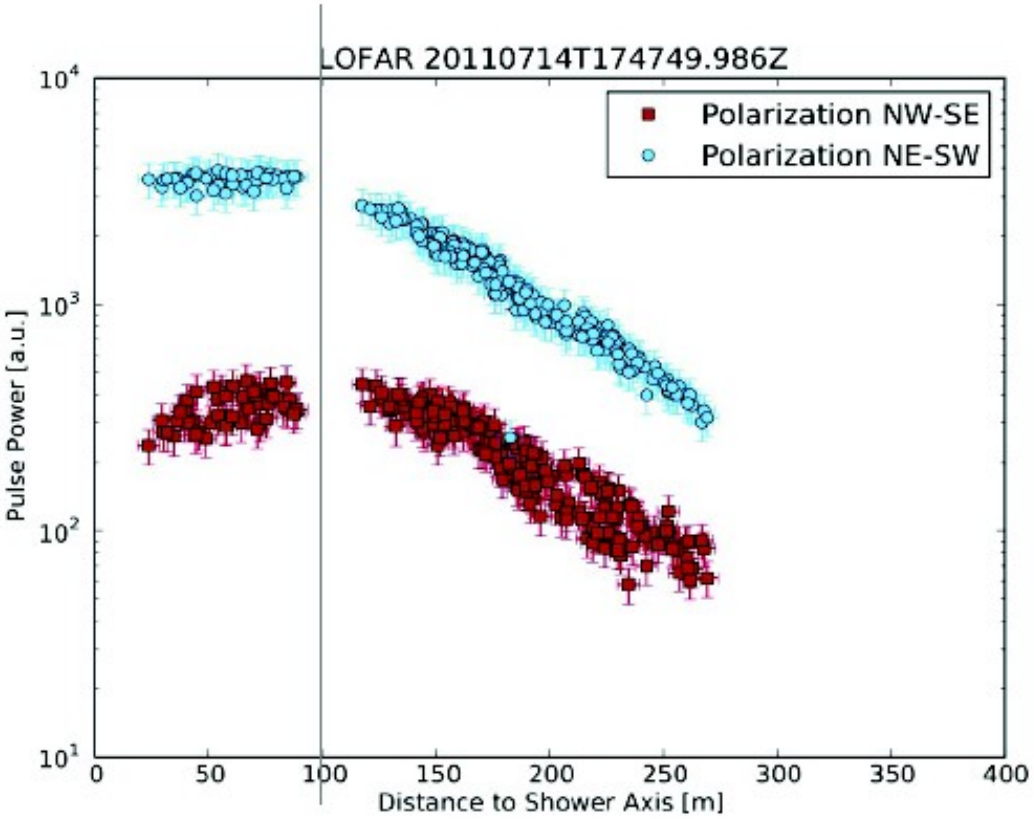
20 scintillation detectors of ~1 m^2

At low energies hundreds of channels

Very good measurment of LDF







Self-triggering Radio Detector

- Mono-frequent background
- Quiet in 30-80 MHz
- But for a threshold-trigger need to look at the time-domain
- Transient noise!
- Not suppressible by up-ward coincidence window
- Δt between following events dominated by power-line 50Hz