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Calibration of the EAS Radio Pulse Height

Andreas Horneffer

for the LOPES Collaboration

ASTRON

Max-Planck-Institut für Radioastronomie

Forschungszentrum Karlsruhe in der Helmholtz-Gemeinschaft

Radio Emission from Air Showers

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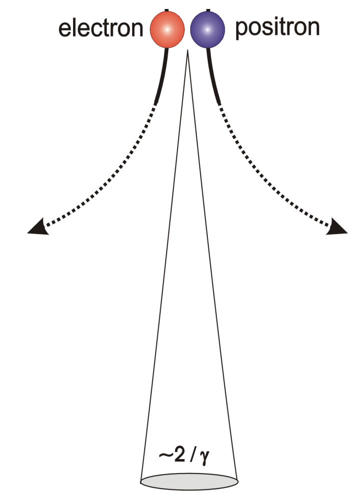
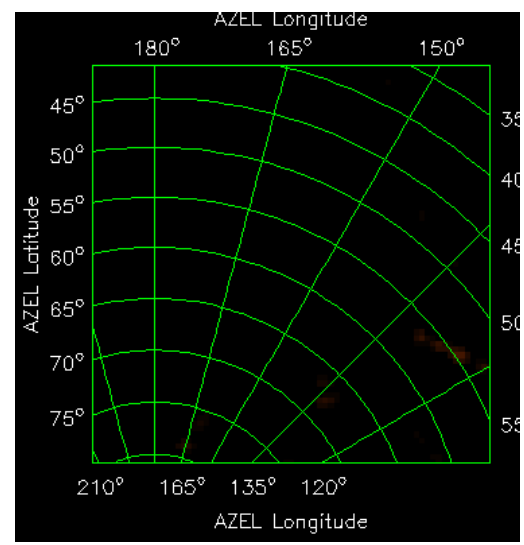


- Air showers emit short, intense radio pulses
- Radiation due to geomagnetic emission process e.g. geosynchrotron
- Coherent emission at low frequencies
- Measuring the radio emission from air showers could give several benefits:
  - Higher duty cycle than fluorescence telescopes
  - Effective RFI suppression allows measuring in polluted (populated) areas
  - Data integrated over the shower evolution, can be complementary to particle detectors
  - High angular resolution possible



LOPES

(**LO**FAR **P**rototyp**e** **S**tation)

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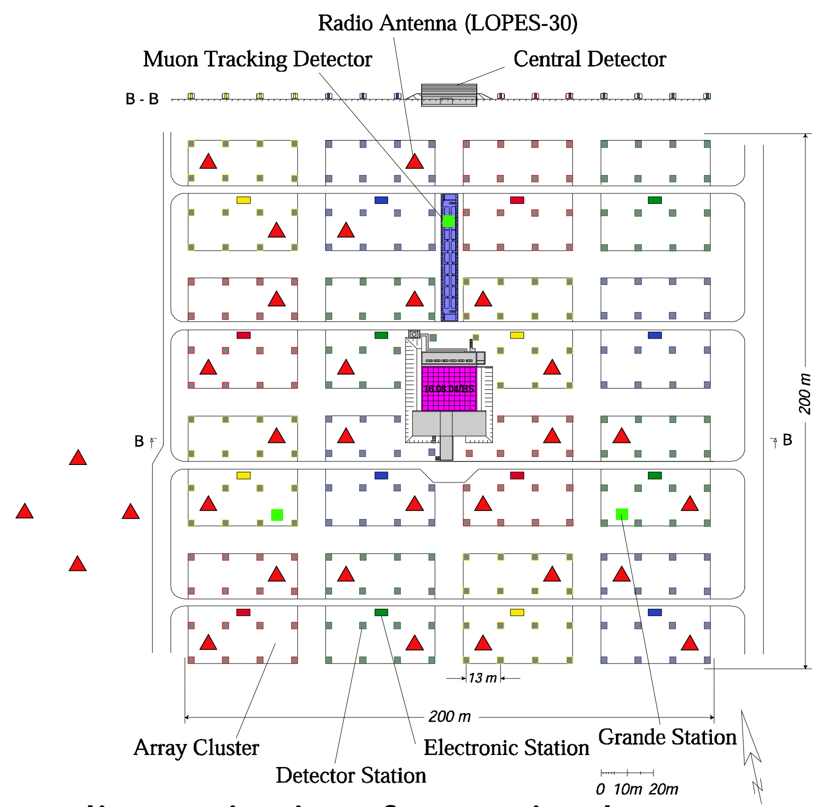
- Set up at the KASCADE-Grande site
- Frequency range of 40 – 80 MHz
- Triggered by large event trigger
- 10 antennas in the first phase, 30 antennas in second phase



- Goals:
  - Develop techniques to measure the radio emission from air showers
  - Determine the radiation mechanism of air showers
  - Calibrate the radio data with theoretical and experimental values from an existing air shower array

Radio Data

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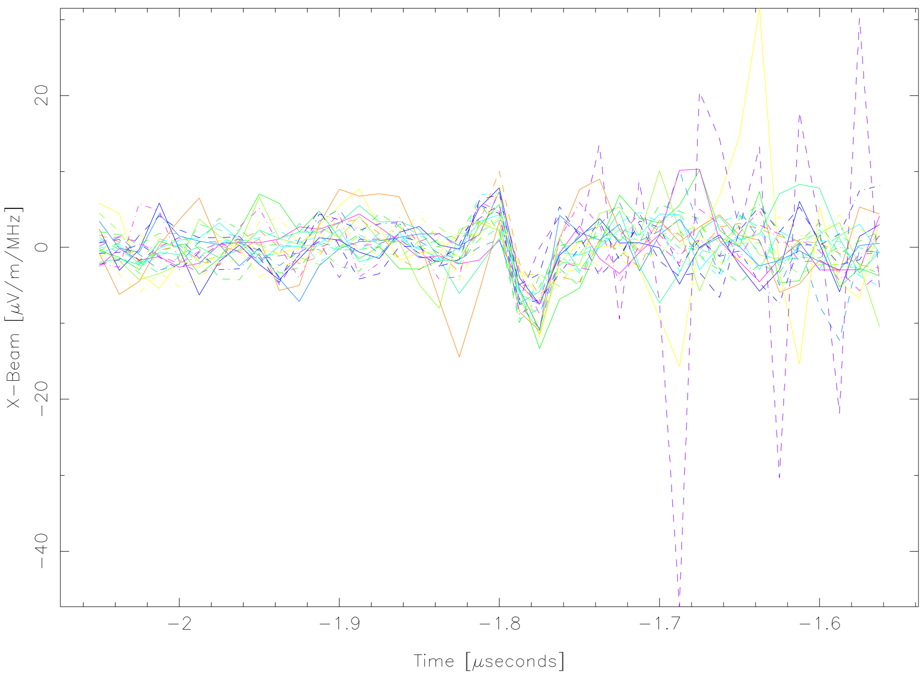
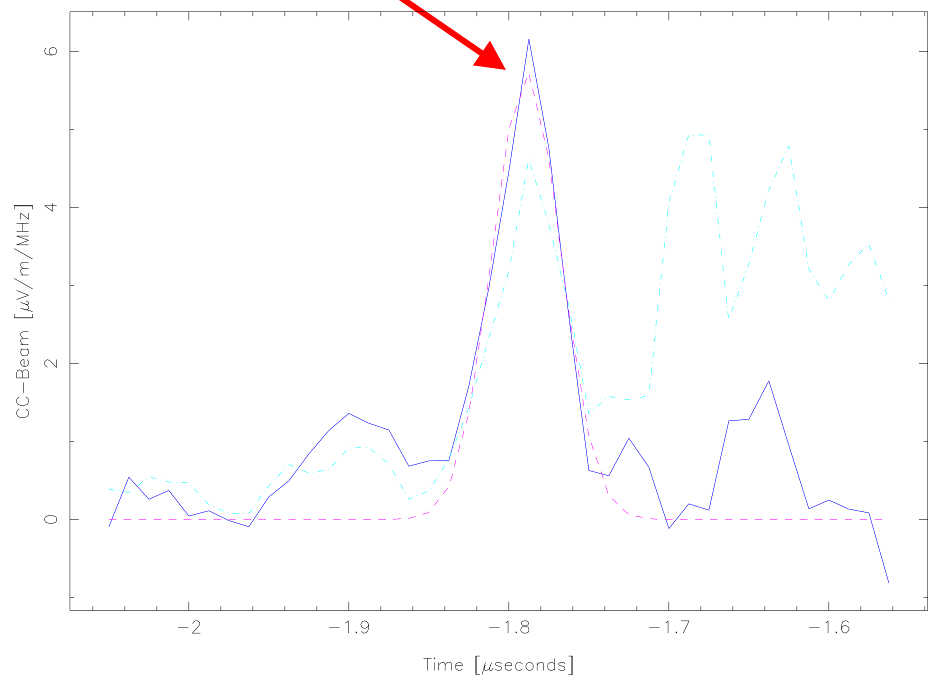
This height is what we want



Single antenna traces



After beam-forming

Field Strength Calculation

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- The field strength is calculated by:

$$\varepsilon = \sqrt{\frac{4\pi\,\nu\,\mu_0}{G_{(\theta,\phi,\nu)}c}\,\frac{1}{A_{ele(\nu)}R_{ADC}}}\,V_{ADC}$$

(With: ε: field strength, ν: observation frequency, G: antenna gain, A_{ele}: amplification (gain) of the electronics, R_{ADC}: ADC impedance, and V_{ADC}: voltage at the ADC.)

- V_{ADC} is the measured value
- $\boldsymbol{A_{ele}}$ and ***G*** are calibration values that need to be measured
- All other values are either constants or determined by the experiment

Calibration Measurements

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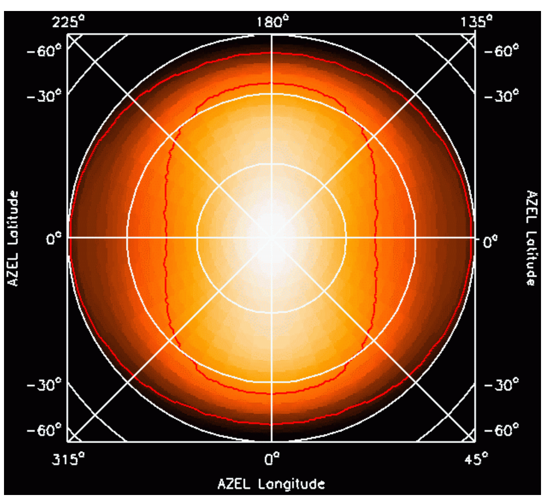
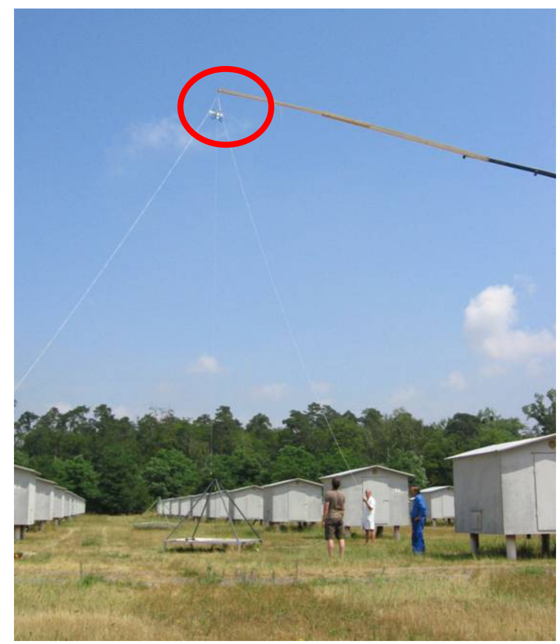
- Antenna gain from simulations
- Electronic Gain from measurements with reference source
  - Also mitigates errors of the antenna simulations

$$\varepsilon = \sqrt{\frac{4\pi \nu \mu_0}{G_{(\theta,\phi,\nu)} c} \frac{1}{A_{ele(\nu)} R_{ADC}}} V_{ADC}$$





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LOPES30 Data

This slide was not in my presentation, but it should have been…

- Used data from November 2005 to September 2006
- used selection for further study:
  - *good* KASCADE data
    - KASCADE array processor didn't fail
    - distance of the core to the array center < 91m
    - good "age parameter"
  - truncated muon number > $10^{5.2}$
  - not during thunderstorm
  - zenith angle < 50º

LOPES30 Pulse Height Dependence

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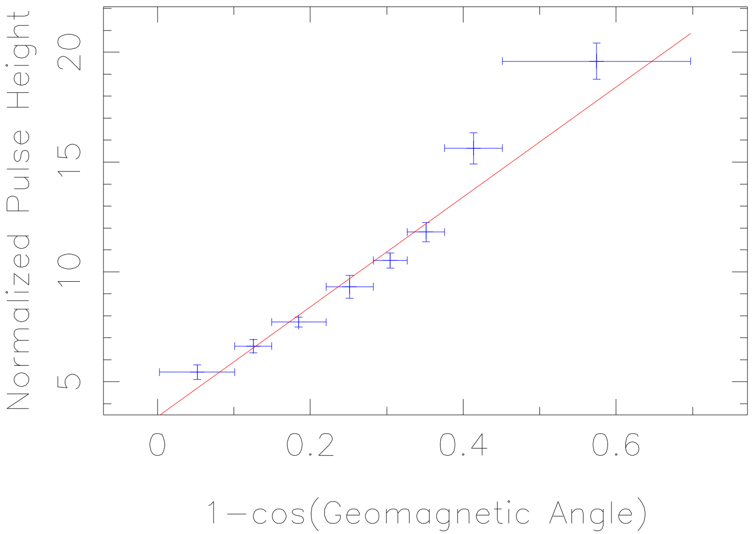

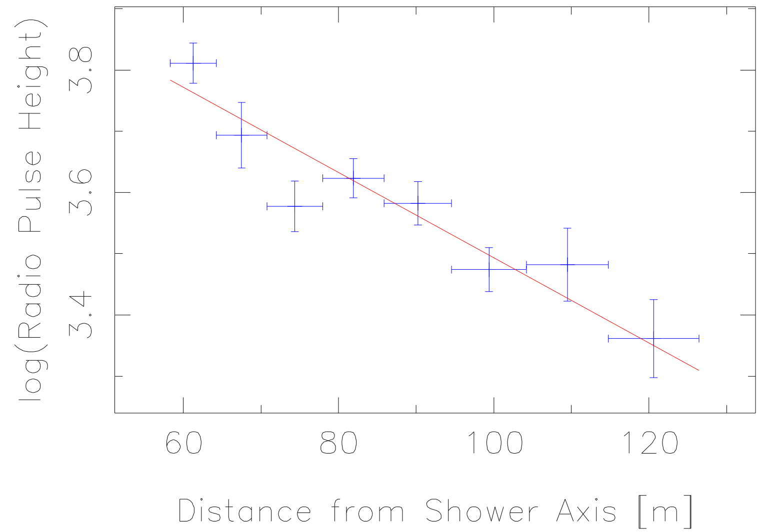

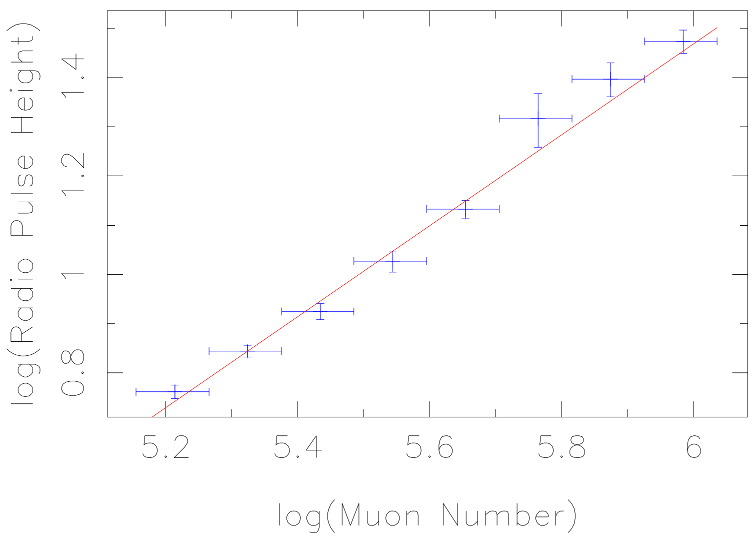

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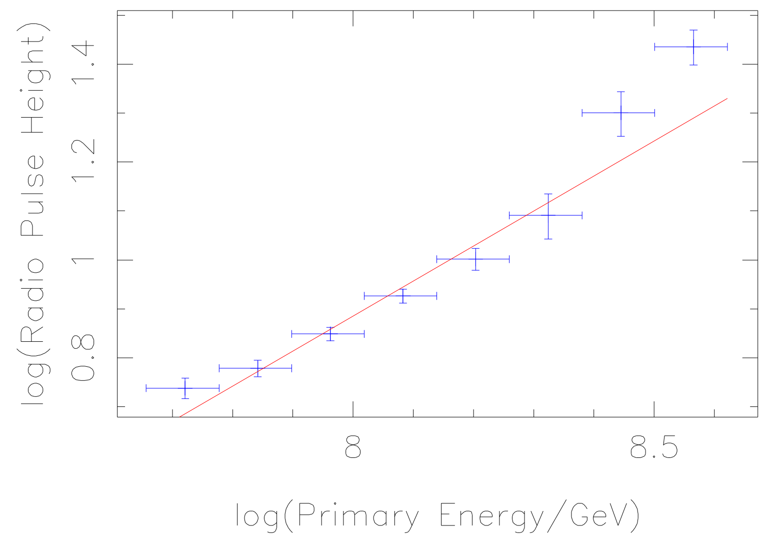

LOPES30: Field Strength Parameterization

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$$\varepsilon_{est,N_\mu} = (55.5 \pm 5.8)\left[\frac{\mu V}{m\ MHz}\right]\left(1 + (0.08 \pm 0.013) - \cos(\alpha)\right)$$

$$\times \exp\left(\frac{-R_{SA}}{(145 \pm 31)\,m}\right)\left(\frac{N_\mu}{10^6}\right)^{(0.98 \pm 0.03)}$$

$$\varepsilon_{est,E_p} = (10.9 \pm 1.1)\left[\frac{\mu V}{m\ MHz}\right]\left(1 + (0.16 \pm 0.02) - \cos(\alpha)\right)\cos(\theta)$$

$$\times \exp\left(\frac{-R_{SA}}{(202 \pm 64)\,m}\right)\left(\frac{E_p}{10^{17}\,eV}\right)^{(0.94 \pm 0.03)}$$

preliminary!

(ε_{est}: EW-pol field strength per unit bandwidth, α: geomagnetic angle, θ: zenith angle, R_{SA}: mean distance antennas ↔ shower axis, N_μ: truncated muon number, E_p: primary particle energy)

Statistical Spread

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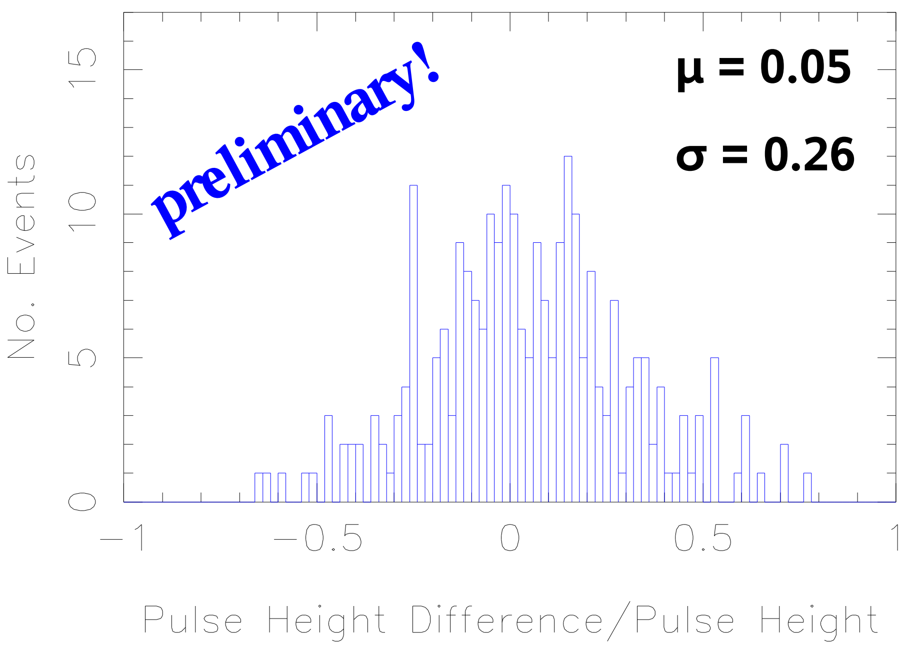

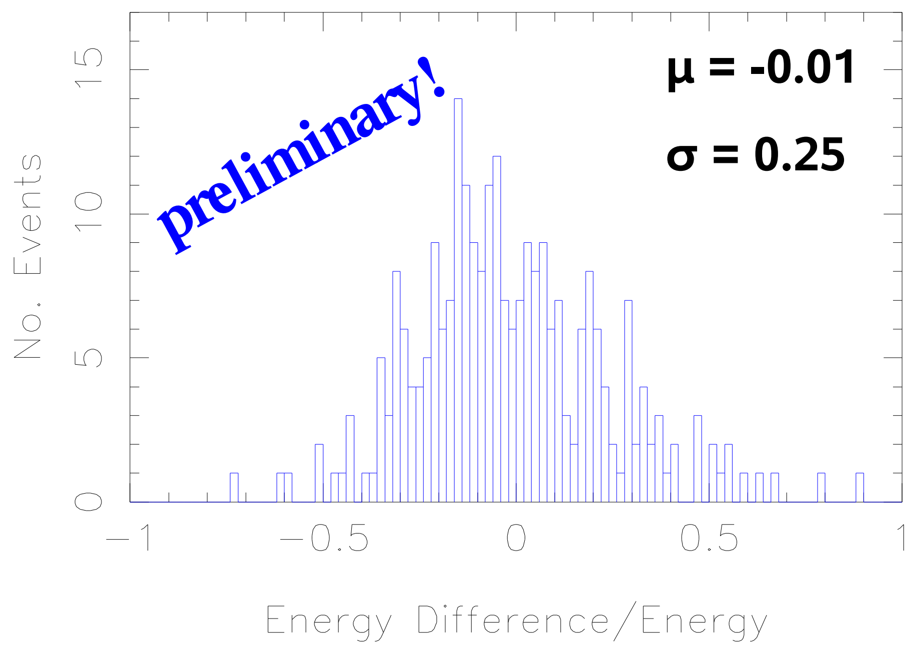

Summary

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- LOPES has demonstrated that radio measurement of air showers is a viable method
- Full end to end calibration of the electronics is the key to good field strength determination
- The radio pulse height can be parameterized as a function of α, θ, R_{SA}, and N_{μ} or E_p
- This parameterization can be used to determine the primary particle energy from radio data alone.

LOPES Collaboration

Radboud University Nijmegen

ASTRON, Dwingeloo, The Netherlands
L. Bähren H. Butcher
G. de Bruyn C.M. de Vos
H. Falcke G.W. Kant
Y. Koopman H.J. Pepping
G. Schoonderbeek W. van Capellen
S. Wijnholds

Department of Astrophysics, Nijmegen
The Netherlands
S. Buitink A. Horneffer
J. Kuijpers S. Lafebre
A. Nigl J. Petrovic
K. Singh

National Institute of Physics and Nuclear Engineering
Bucharest,Romania
A. Bercuci I.M. Brancus
B. Mitrica M. Petcu
A. Saftiou O. Sima
G. Toma

Universität Wuppertal, Germany
J. Auffenberg R. Glasstetter
K.H. Kampert J. Rauthenberg

Universität Siegen, Germany
M. Brüggemann P. Buchholz
C. Grupen Y. Kolotaev
S. Over W. Walkowiak
D. Zimmermann

Max-Planck-Institut für Radio-astronomie, Bonn, Germany
P.L. Biermann J.A. Zensus

Istituto di Fisica dello Spazio Interplanetario, Torino, Italy
P.L. Ghia C. Morello
G.C. Trinchero

Soltan Institute for Nuclear Studies, Lodz, Poland
P. Luczak A. Risse
J. Zabierowski

Institut für Kernphysik, Forschungszentrum Karlsruhe, Germany
W.D. Apel A.F. Badea
K. Bekk J. Blümer
H. Bozdog F. Cossavella
K. Daumiller P. Doll
R. Engel A. Hakenjos
A. Haungs D. Heck
T. Huege P.G. Isar
H.J. Mathes H.J. Mayer
C. Meurer J. Milke
S. Nehls R. Obenland
J. Oehlschläger S. Ostapchenko
T. Pierog S. Plewnia
H. Rebel M. Roth
H. Schieler H. Ulrich
J. van Buren A. Weindl
J. Wochele

Institut für Prozessdatenver-arbeitung und Elektronik, FZK, Germany
T. Asch H. Gemmeke
O. Krömer

Dipartimento di Fisica Generale dell'Universita, Torino, Italy
M. Bertaina A. Chiavassa
F. di Pierro G. Navarra

Institut für Experimentelle Kernphysik Universität Karlsruhe, Germany
E. Bettini M. Deutsch
A. Hakenjos J.R. Hörandel
M. Stümpert

LOFAR

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- Digital radio interferometer for the frequency range of 10 - 270 MHz
- Array of 77+ stations of 96 simple antennas
- Fully digital: received waves are digitized and sent to a central computer cluster
  - Digital radio interference suppression
  - Ability to store the complete radio data for a short amount of time
  - This allows to form beams after a transient event has been detected, combining the advantages of low gain and high gain antennas
- LOFAR will be a good tool to measure the radio emission from air showers