Karlsruhe Institute of Technology

EAS Radio Detection with LOPES

results and recent progress

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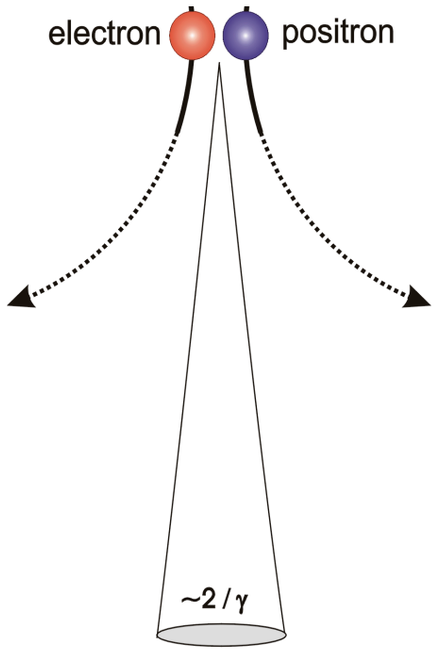
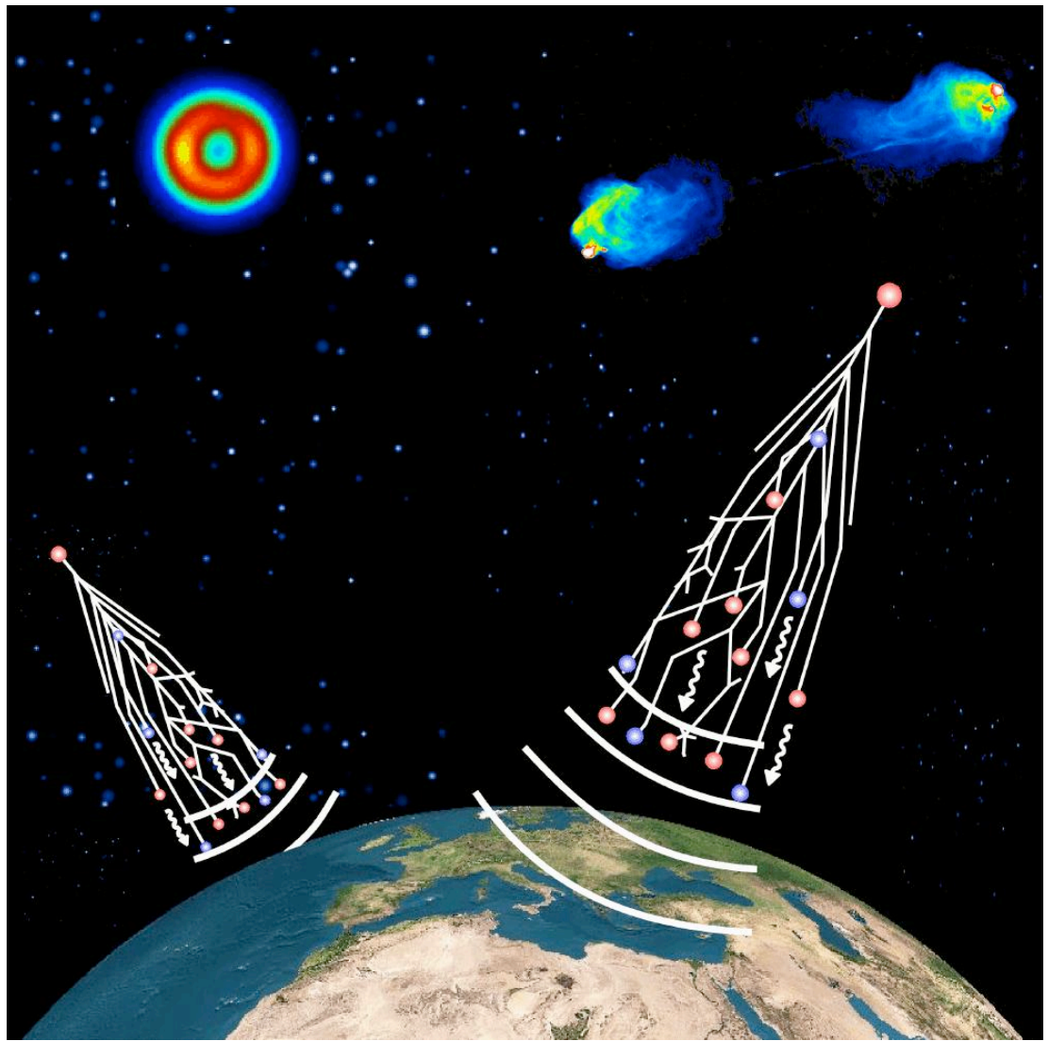
How it works -- in principle

- showers emit short, intense radio pulses
  - Radiation due to geomagnetic emission process e.g. geosynchrotron
  - Coherent emission at low frequencies, e.g. 20-100 MHz
- Historically: fine analog artwork
  - impressive but bound to fail





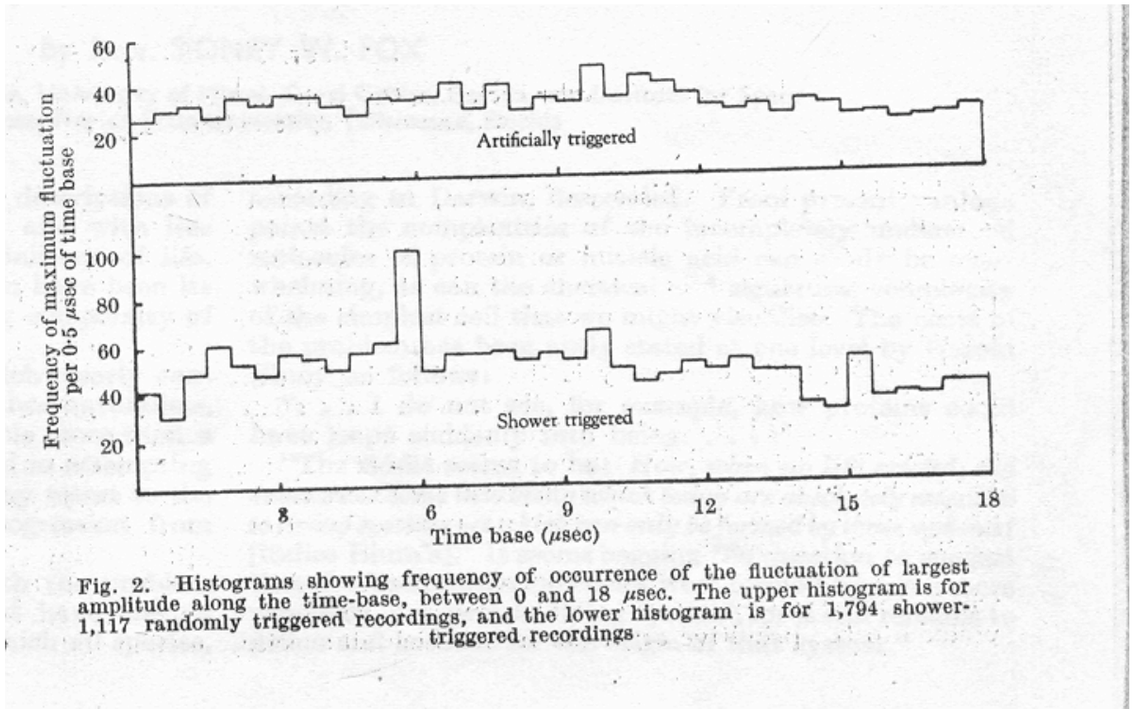


Fig. 2. Histograms showing frequency of occurrence of the fluctuation of largest amplitude along the time-base, between 0 and 18 μsec. The upper histogram is for 1,117 randomly triggered recordings, and the lower histogram is for 1,794 shower-triggered recordings.

▶ use digital radio astronomy instead
LOFAR, LOPES, CODALEMA

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The LOPES Collaboration

- Relations to LOFAR
- Novel technology
  - 100% duty cycle
  - Effective RFI suppression
  - Signal integrated over shower evolution, complementary to particle and optical detection
  - High angular resolution possible
  - extremely large arrays?

Institute for Nuclear Physics, Forschungszentrum Karlsruhe
W.D. Apel [http://www-ik.fzk.de/~apel], A.F. Badea, K. Bekk, H. Blümer [http://www-ik.fzk.de/~bluemer], H. Bozdog, J. van Buren, K. Daumiller, P. Doll, R. Engel [http://www-ik.fzk.de/~engel], A. Haungs [http://www-ik.fzk.de/~haungs], D. Heck [http://www-ik.fzk.de/~heck], J. Hörandel [http://www-ik.fzk.de/~joerg], T. Huege [http://www-ik.fzk.de/~huege], G. Maier, H.J. Mathes [http://www-ik.fzk.de/~mathes], H.J. Mayer, J. Milke, S. Nehls [http://www-ik.fzk.de/~nehls], R. Obenland, J. Oehlschläger, S. Ostapchenko, S. Plewnia [http://www-ik.fzk.de/~plewnia], H. Rebel [http://www-ik.fzk.de/~rebel], H. Schieler, H. Ulrich, A. Weindl [http://www-ik.fzk.de/~weindl], J. Wochele [http://www-ik.fzk.de/~juergen]

Netherlands Foundation for Research in Astronomy, Dwingeloo
L. Bähren [http://www.astron.nl/~bahren], A.G. de Bruyn, H. Butcher, W. van Cappellen, H. Falcke, G.W. Kant, Y. Koopman, H.J. Pepping, G. Schoonderbeek, C.M. de Vos, S. Wijnholds

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Department of Physics, University of Siegen
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Max Planck Institute for Radio Astronomy, Bonn
P.L. Biermann, R. Sowade, J.A. Zensus

Institute for Experimental Nuclear Physics, University of Karlsruhe
J.R. Hörandel, M. Roth, M. Stümpert

Institute for Interplanetary Space Physics, Torino
P.L. Ghia, C. Morello, G.C. Trinchero

Institute of Data Processing and Electronics, Forschungszentrum Karlsruhe
T. Asch, H. Gemmeke, O. Krömer

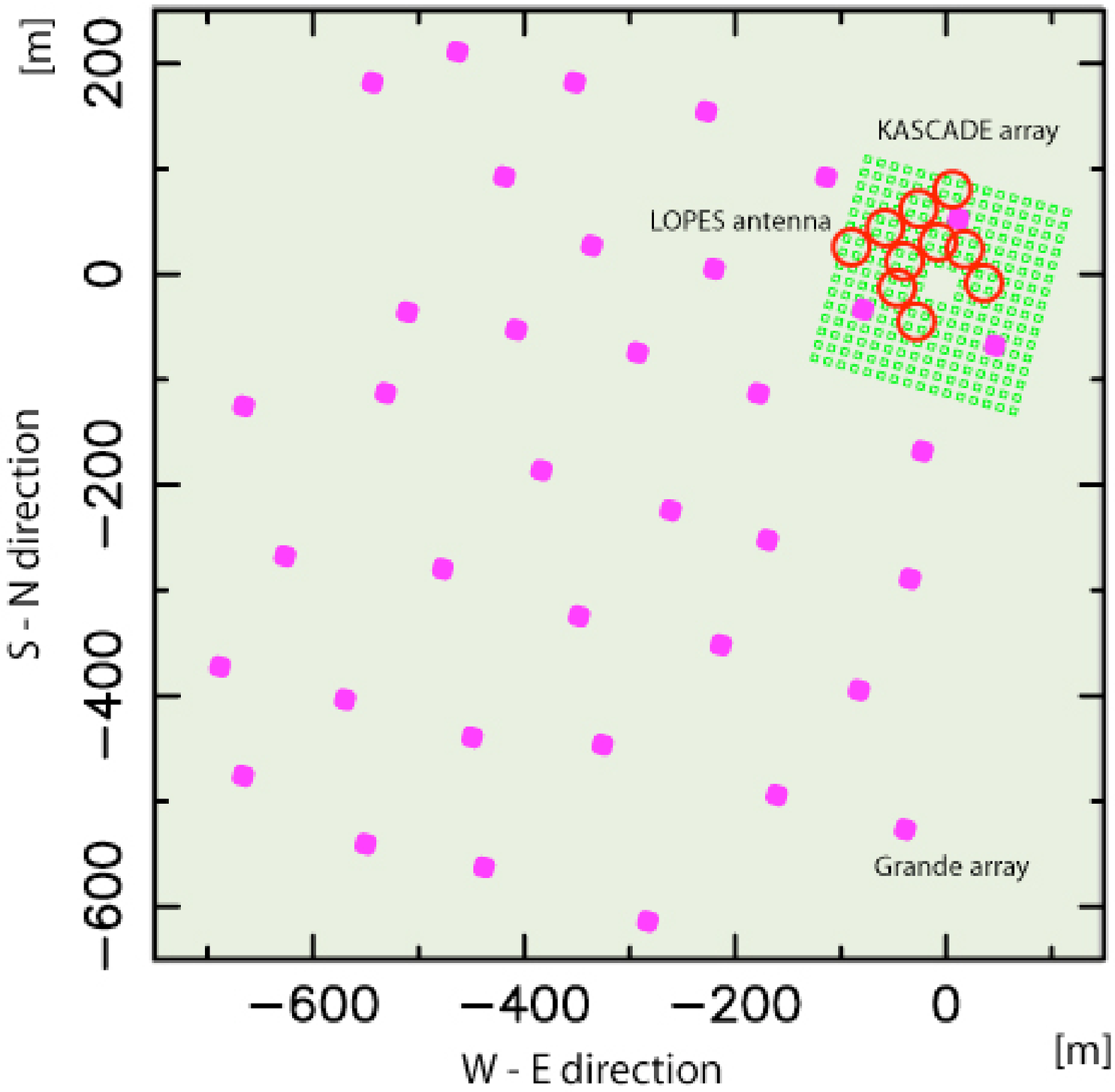
Soltan Institute for Nuclear Studies, Lodz
A. Risse, J. Zabierowski

Department of Pysics, University of Wuppertal
R. Glasstetter, K.-H. Kampert

Radio Astronomical Institute, University of Bonn
U. Klein

LOPES @ KASCADE-Grande

(1)



LOPES - A LOFAR▲ Prototype Station

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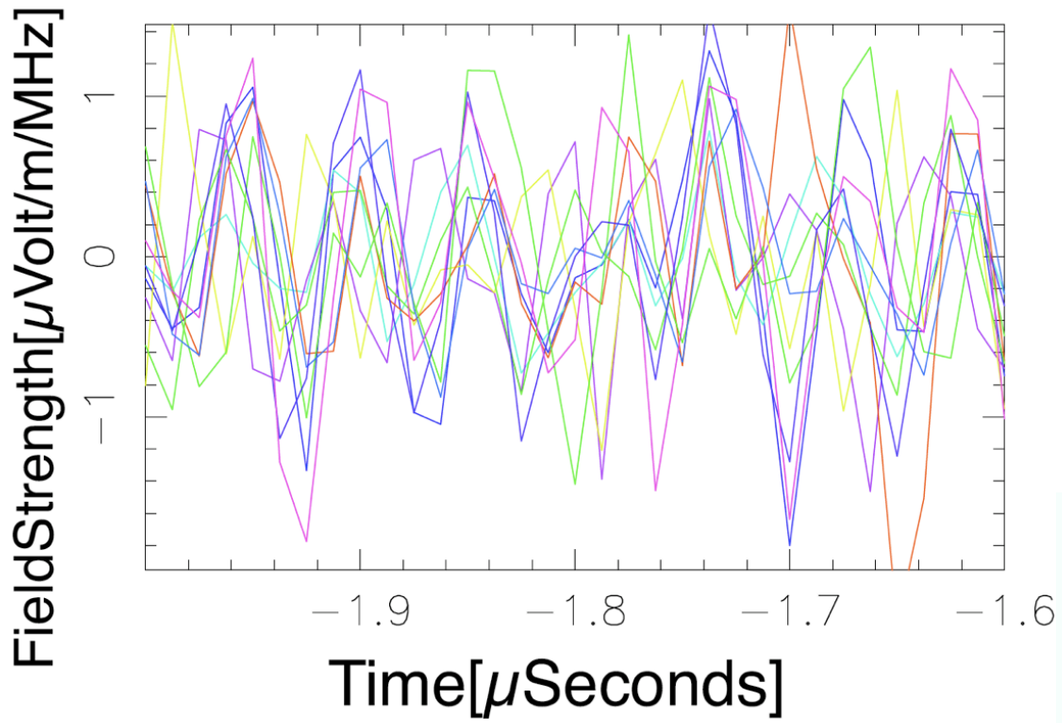
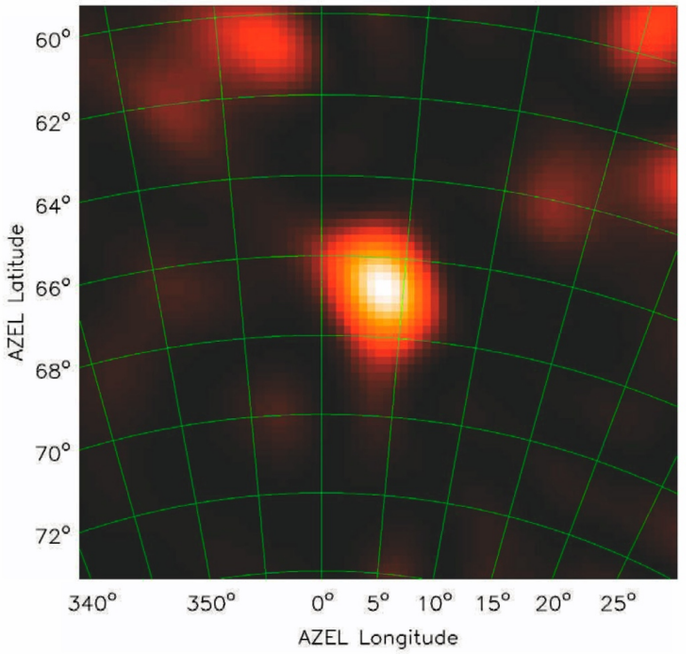
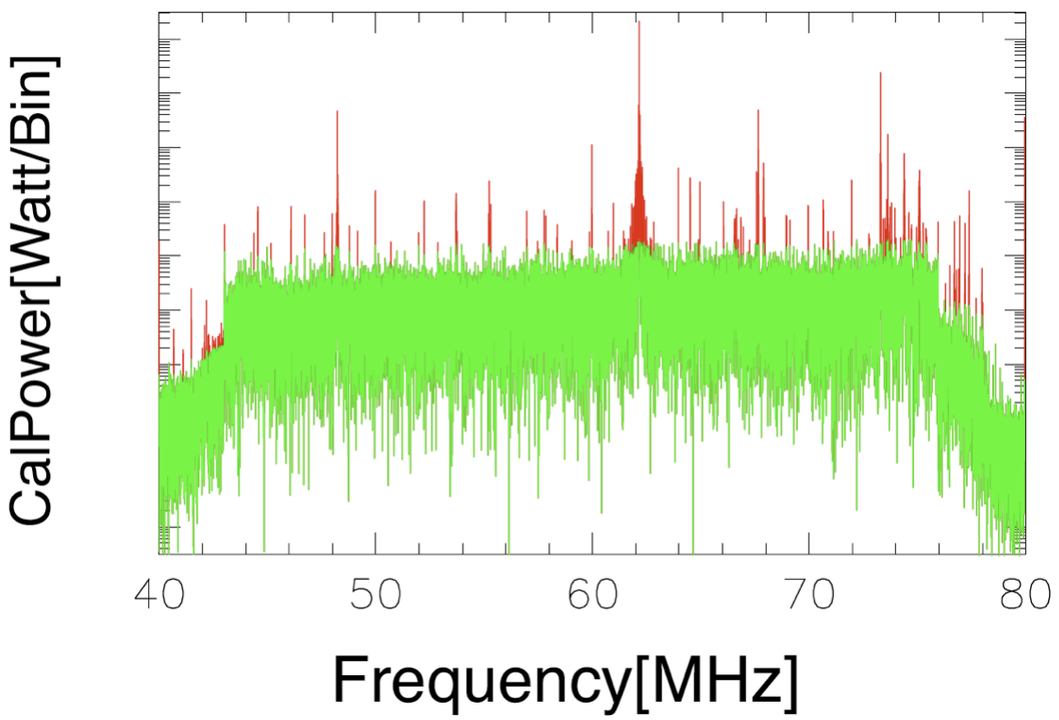
How it works -- digitally

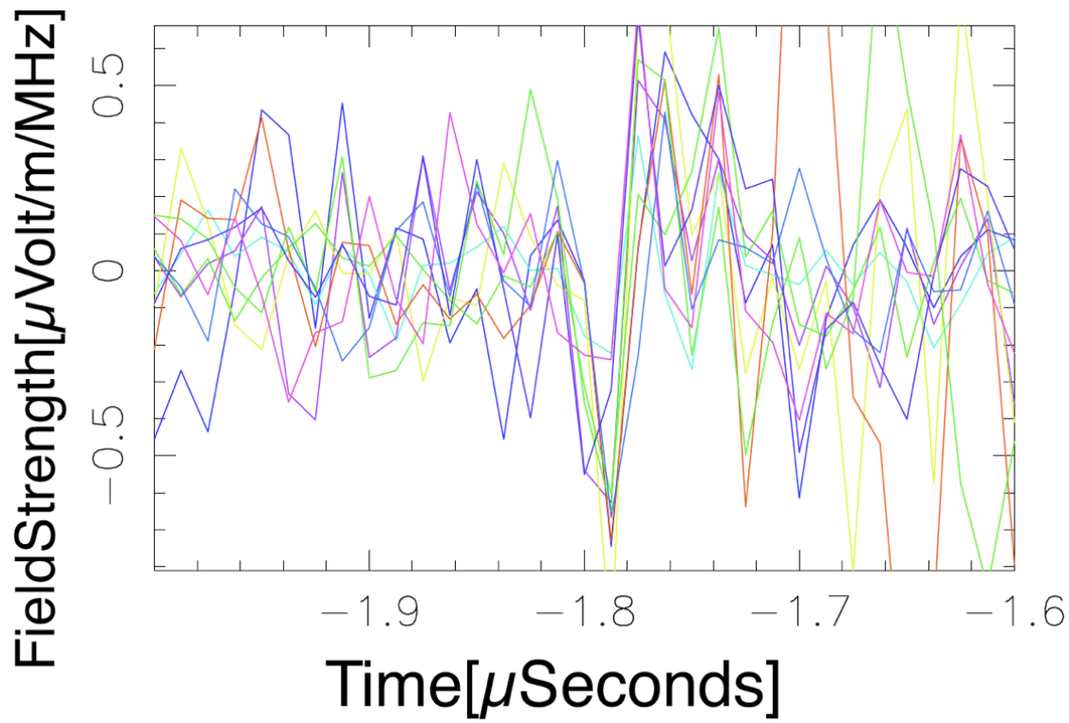


☚ raw

↙ filter align ☝ power ➥







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LOPES -- current work

(1)

- ✓distant events
- ✓thunderstorm events
- ✓inclined showers
- ★calibration
- ★LOPES30
- ★polarisation
- ★self-trigger
- ★modelling

2007 refereed publications

Monte Carlo simulations of geosynchrotron radio emission from CORSIKA-simulated air showers
Huege, T., Ulrich, R. and Engel, R.
2007, Astroparticle Physics 27, 392-405

Amplified radio emission from cosmic ray air showers in thunderstorms
Buitink, S. et al. - LOPES collaboration
2007, Astronomy & Astrophysics 467, 385-394

Radio emission of highly inclined cosmic ray air showers measured with LOPES
Petrovic, J. et al. - LOPES collaboration
2007, Astronomy & Astrophysics 462, 389-395

2006

Progress in air shower radio measurements: Detection of distant events
Apel, W.D. et al. - LOPES collaboration
2006, Astroparticle Physics 26, 332-340

2007 ICRC contributions

Energy and composition sensitivity of geosynchrotron radio emission from EAS
Huege, T., Ulrich, R., Engel, R.
2007, Proceedings of the 30th ICRC, Merida, Mexico

REAS2: CORSIKA-based Monte Carlo simulations of geosynchrotron radio emission
Huege, T., Ulrich, R., Engel, R.
2007, Proceedings of the 30th ICRC, Merida, Mexico

The LOFAR Air Shower Front Evolution Library
Lafebre, S., Huege, T., Falcke, H., Kuijpers, J.
2007, Proceedings of the 30th ICRC, Merida, Mexico

Primary Particle Energy Calibration of the EAS Radio Pulse Height Slides
Horneffer, A. and the LOPES Collaboration
2007, Proceedings of the 30th ICRC, Merida, Mexico

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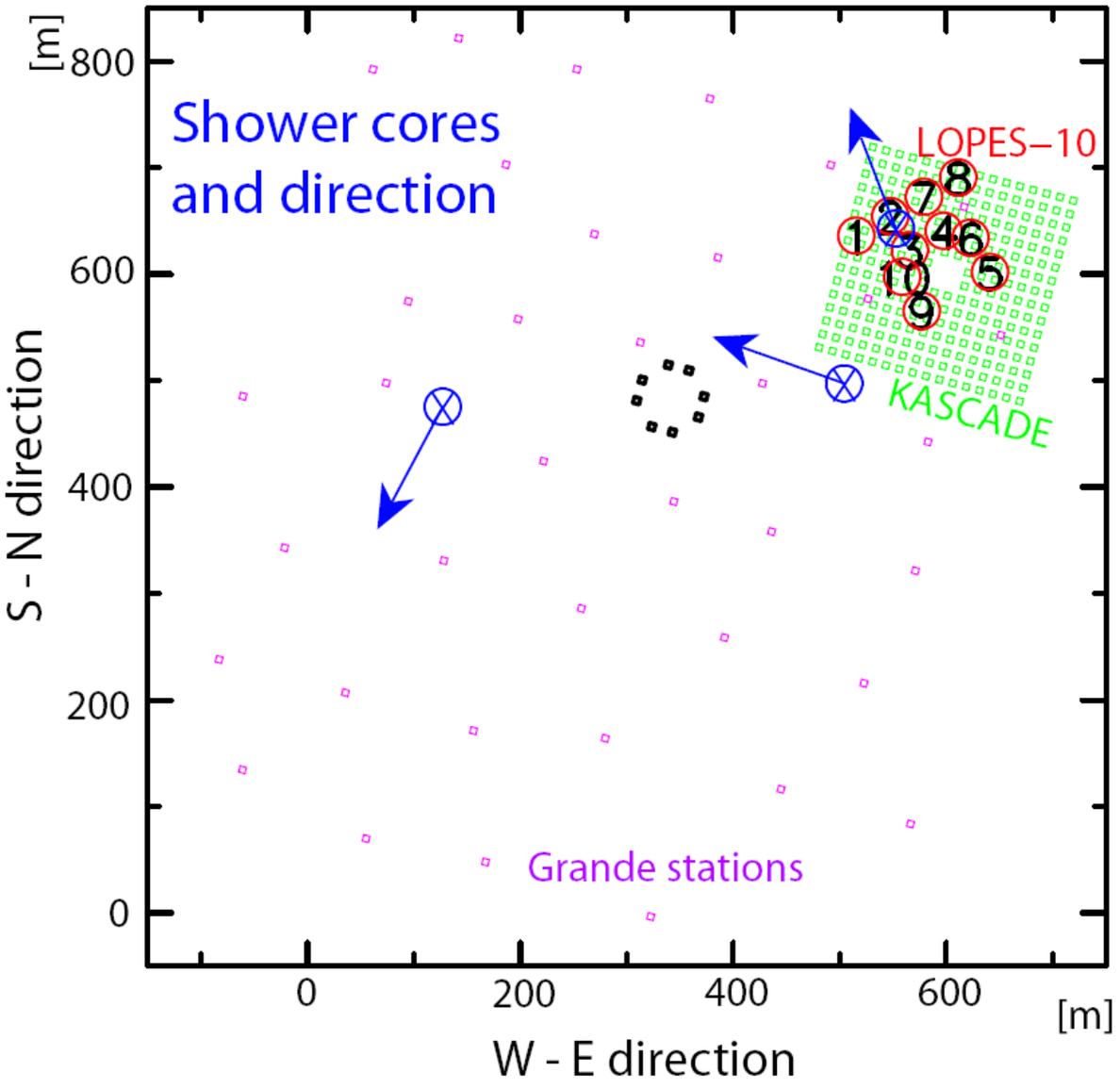
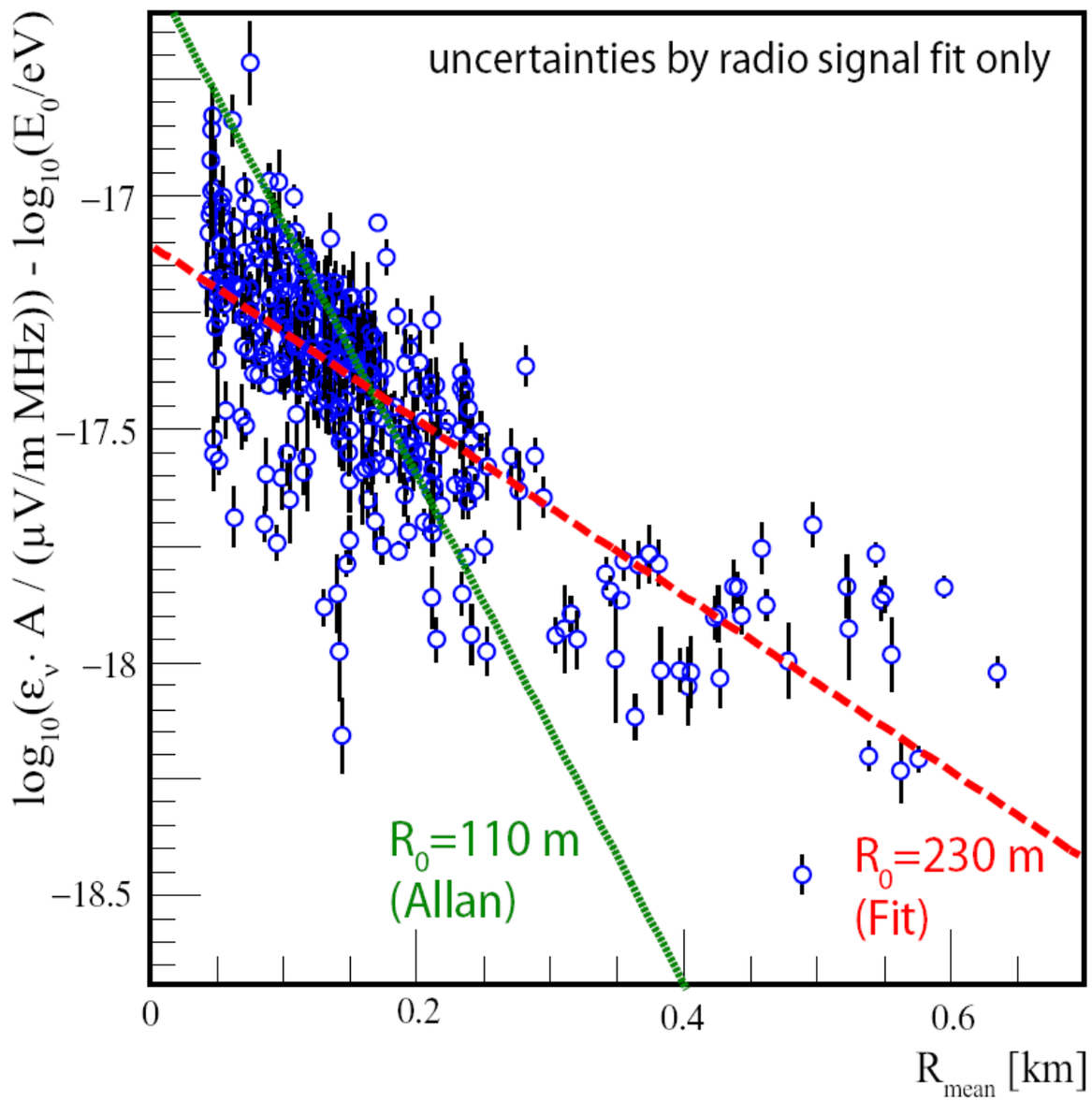
Distant events -- reconstructed with K-Grande



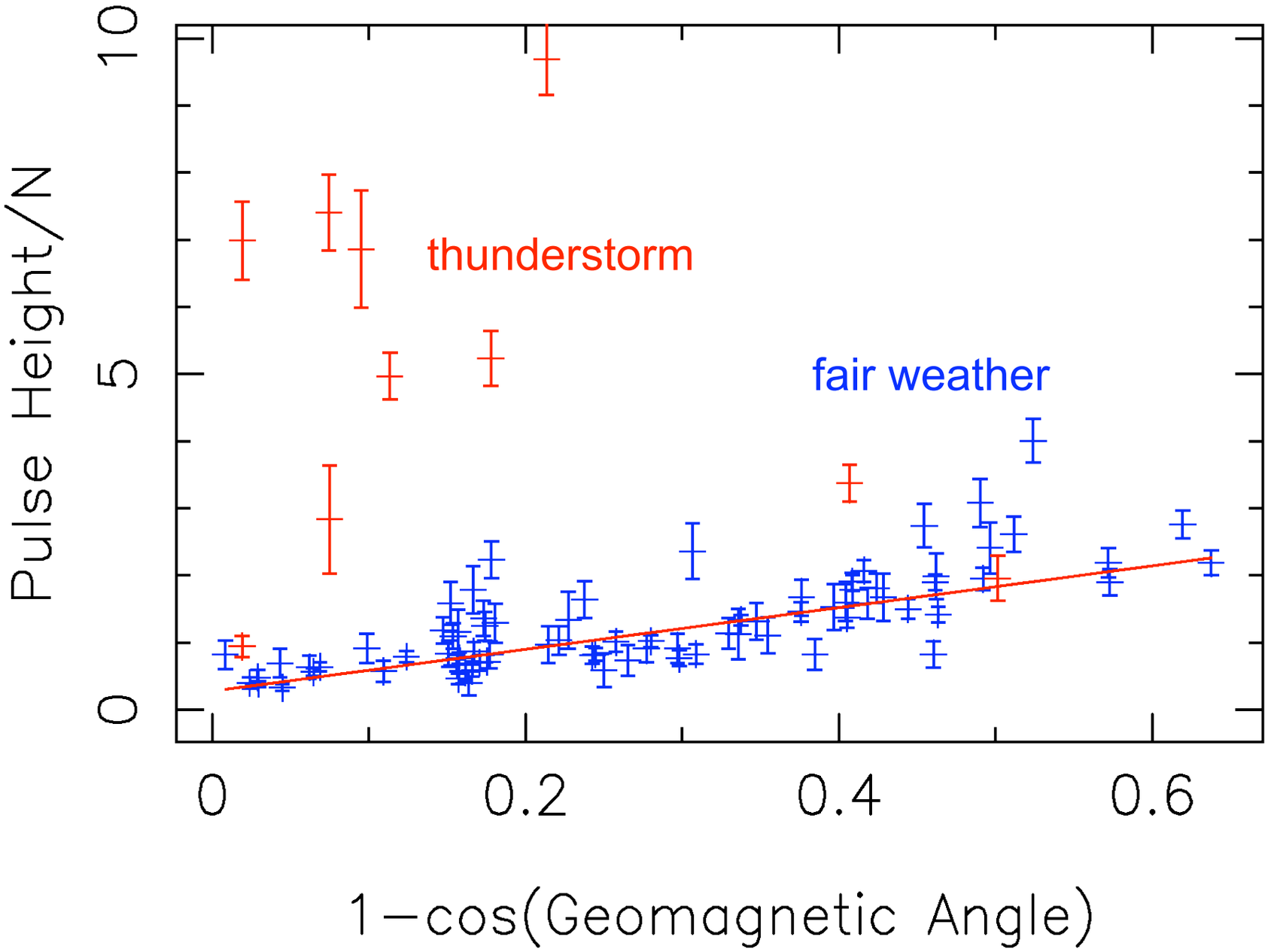
even a small radio array improves the Grande reconstruction accuracy (good angular resolution)



radio signal from showers are visible to distances >600m at 40-80 MHz

Thunderstorm events

- atmospheric E-fields >100 kV/m close to thunderstorms
- strongly enhanced radio emission
- normal fields with 10-100 V/m have no effect



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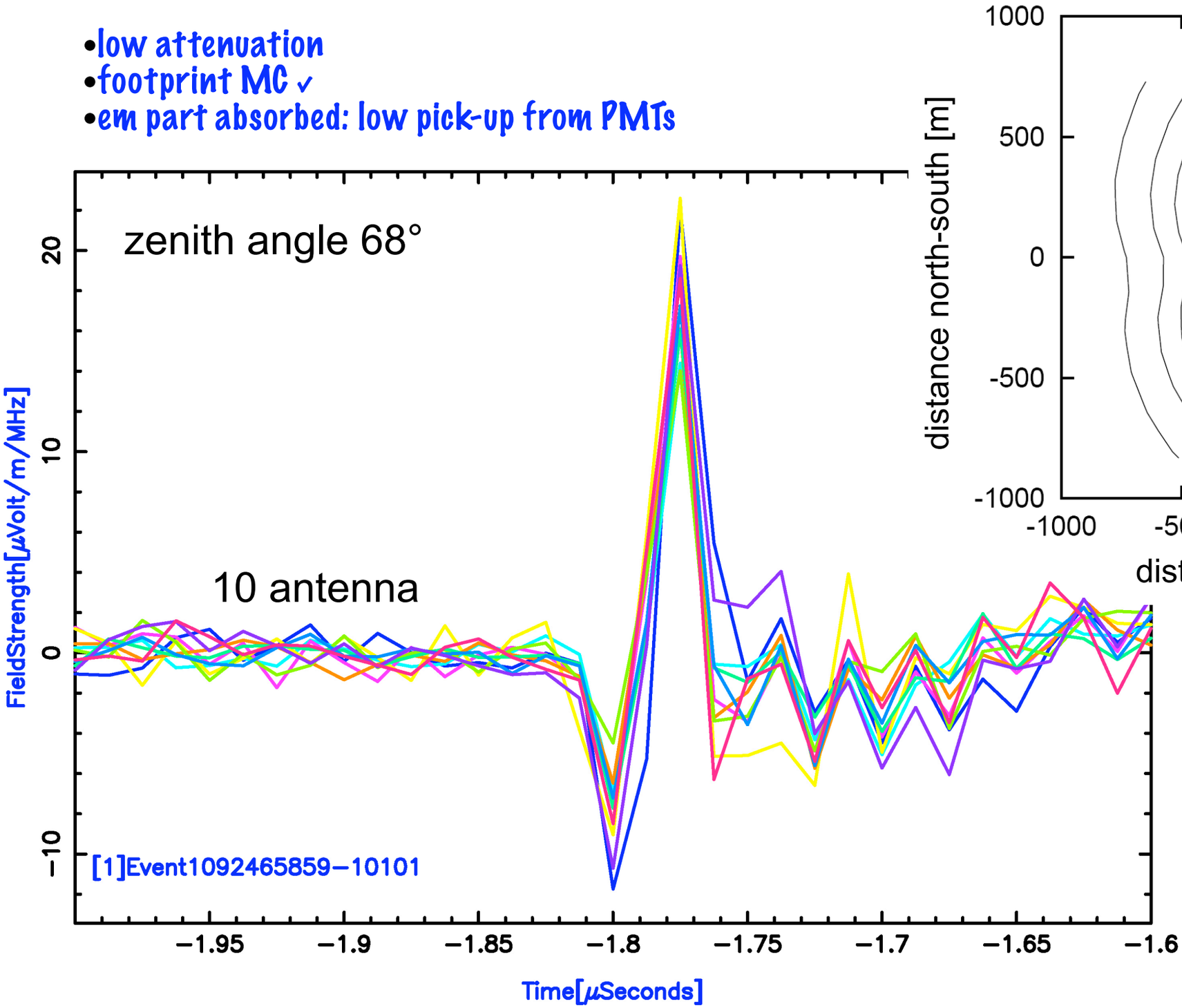
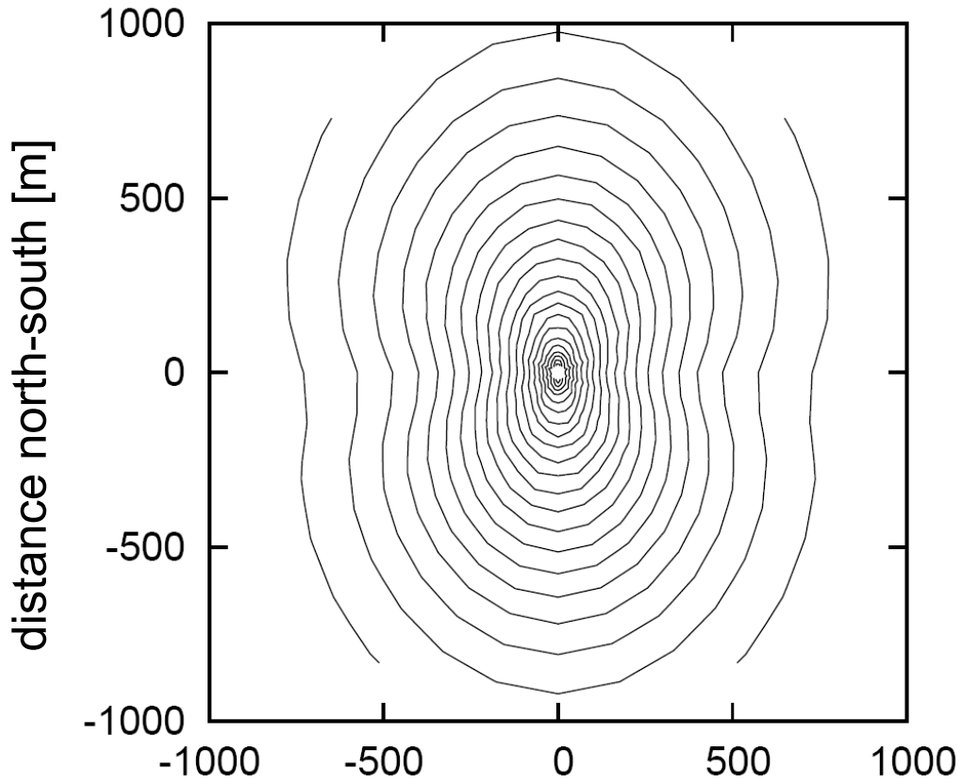
Inclined showers

- low attenuation
- footprint MC ✓
- em part absorbed: low pick-up from PMTs





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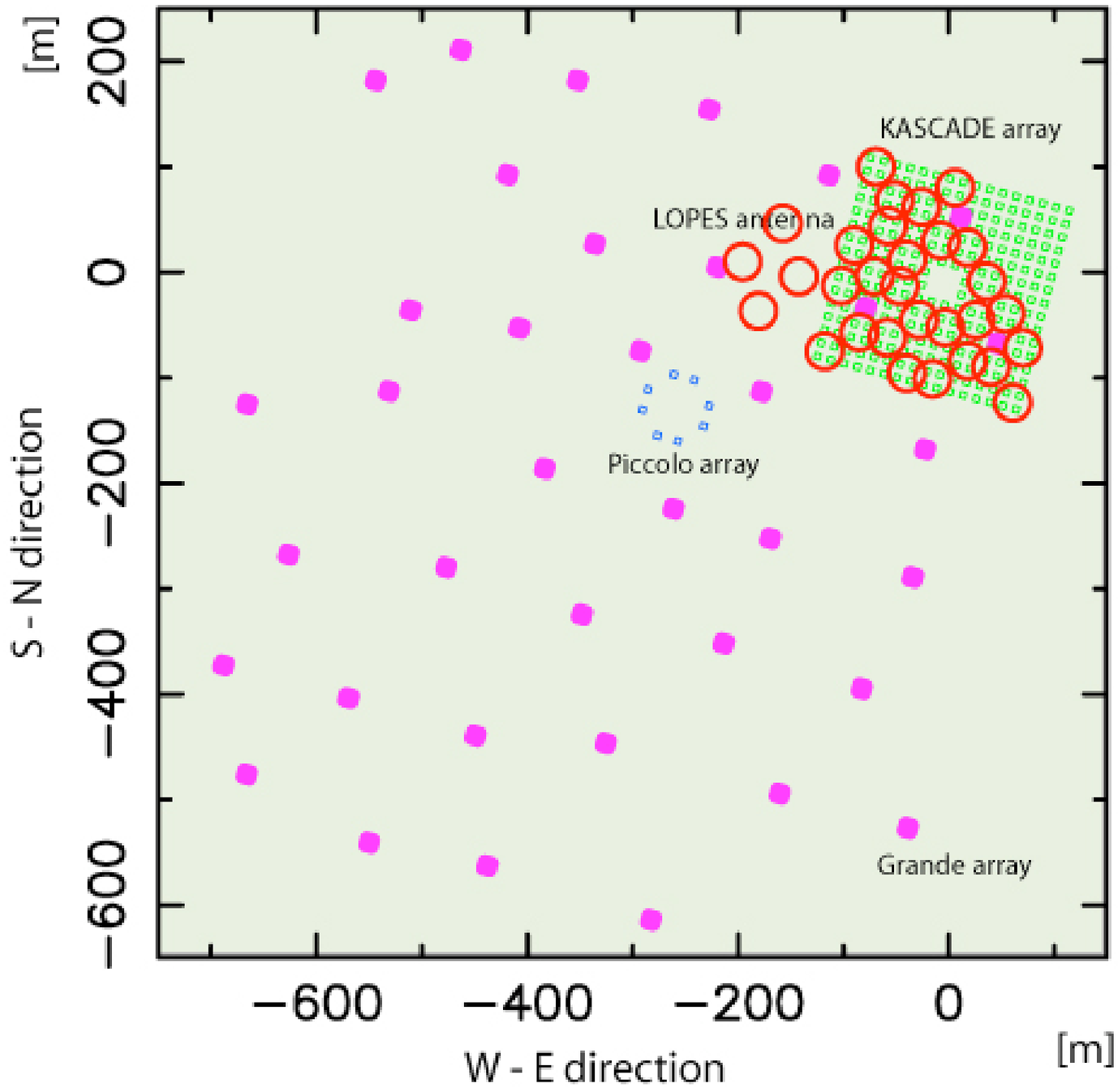
LOPES30

- array extended to 30 antennas with longer baselines
- better sensitivity
- better angular resolution
- per-event measurement of lateral profile
- monitoring of environmental conditions



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LOPES30

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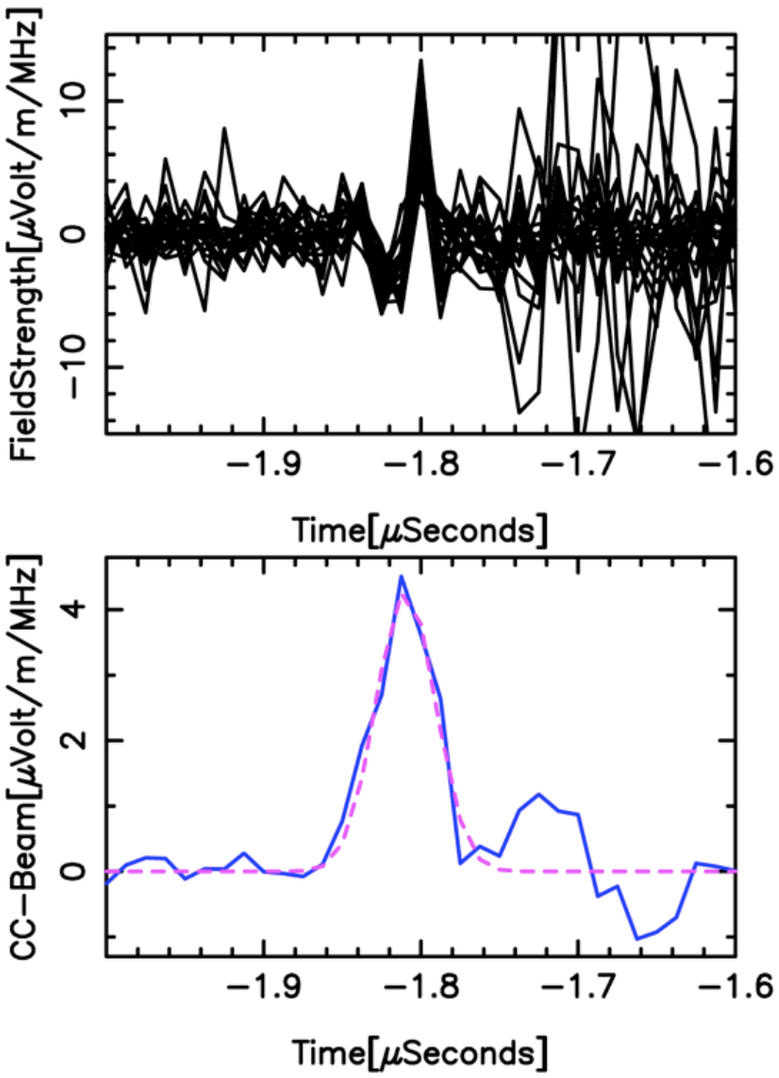

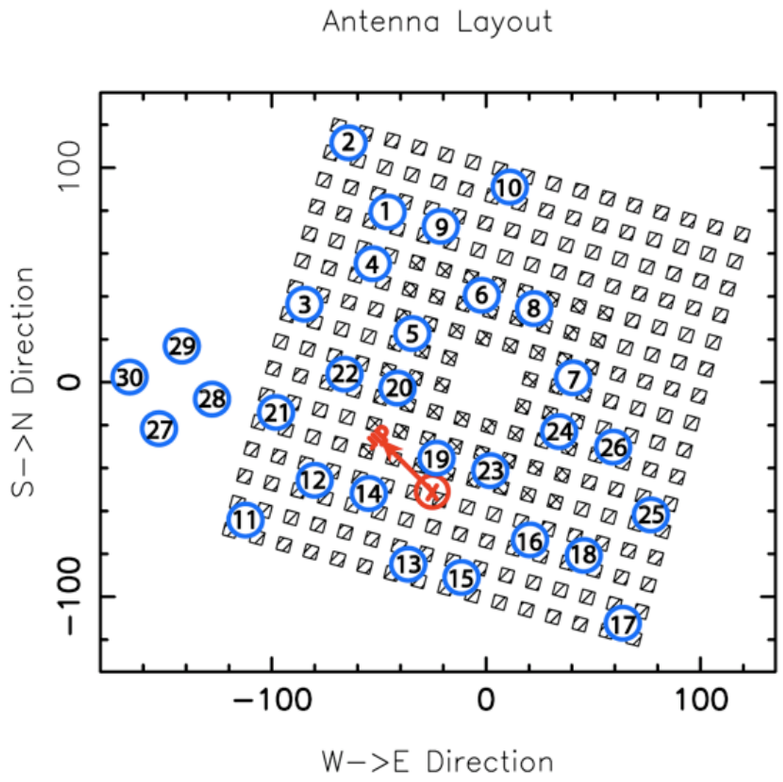

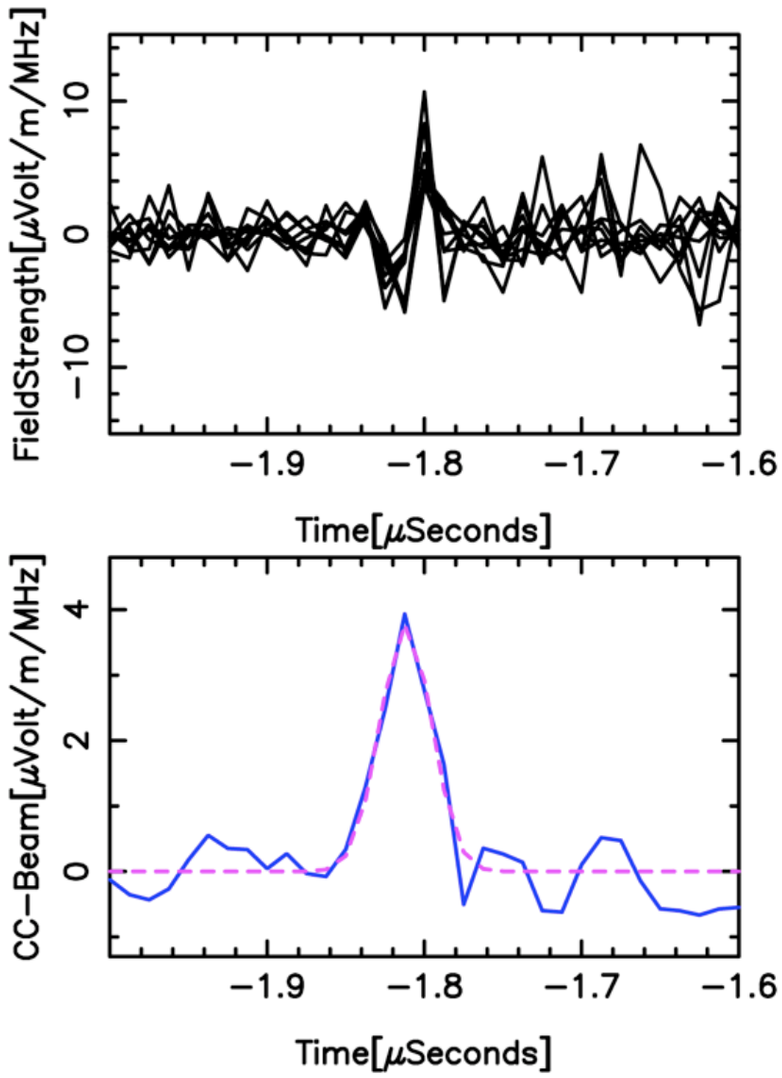

reduced noise far away from the core...

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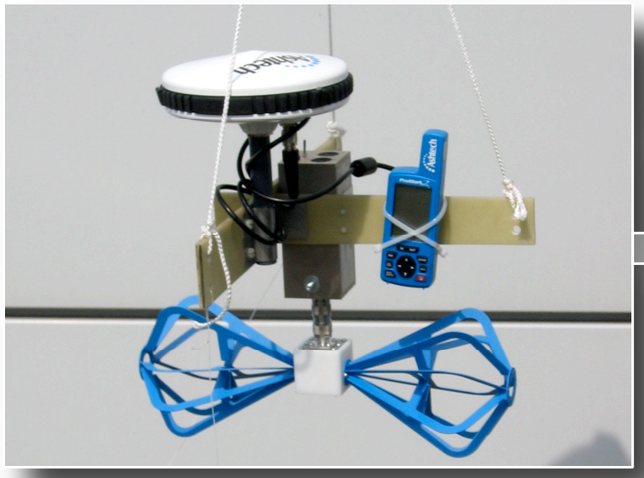
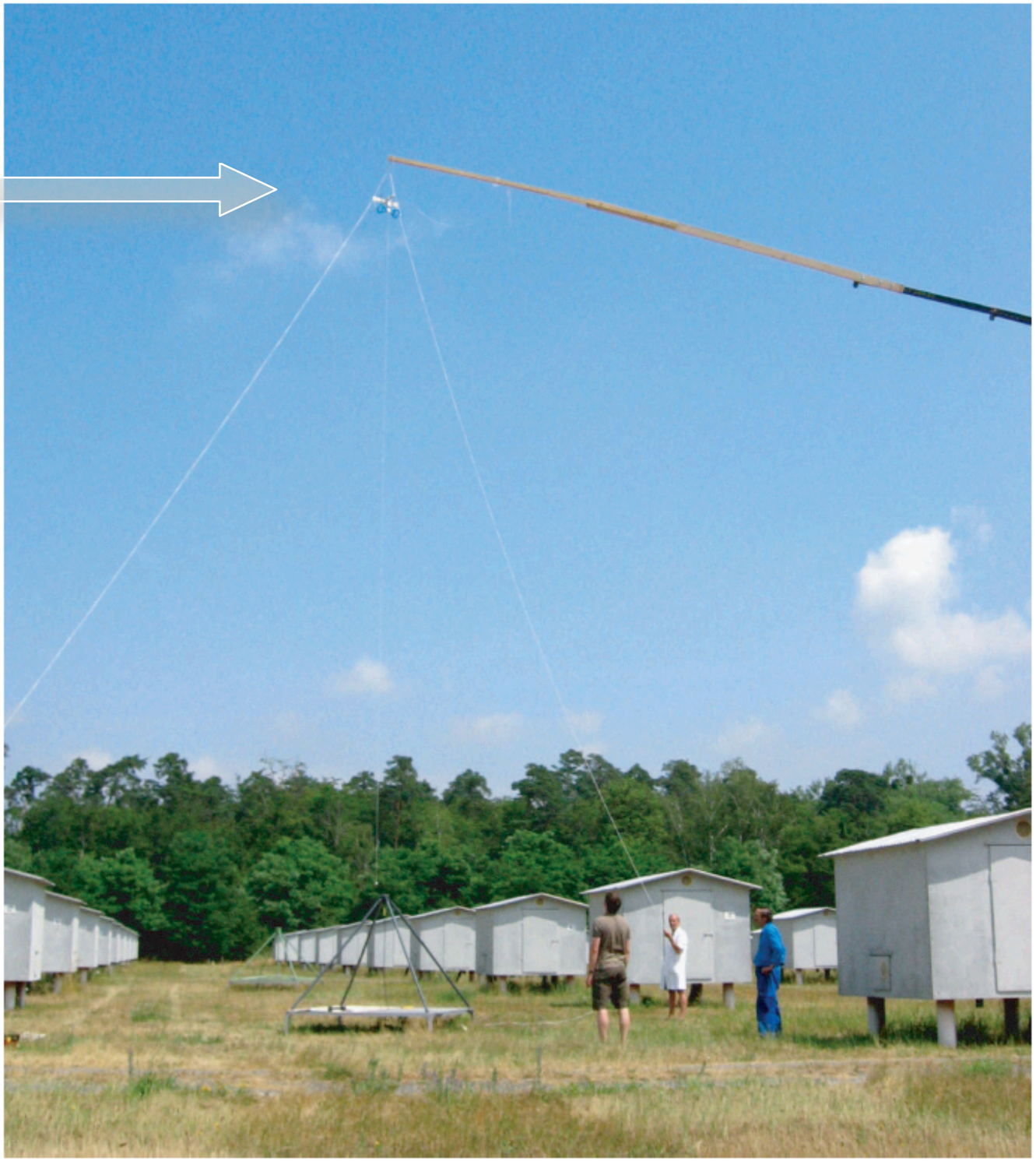
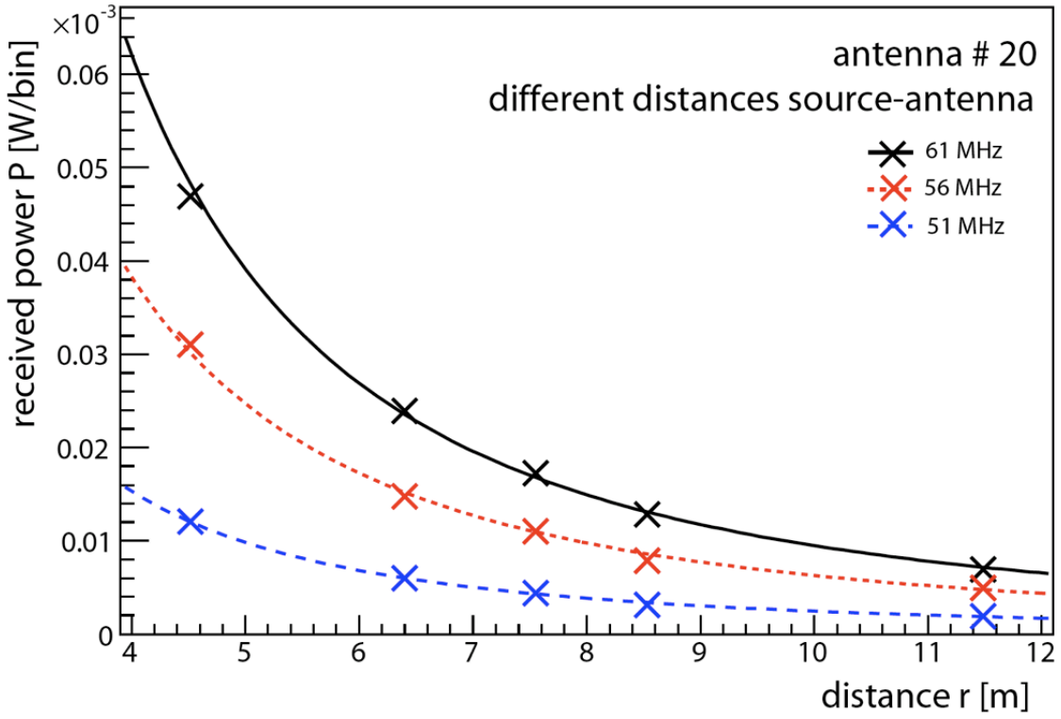
Calibrations: instruments





free field ~ok:



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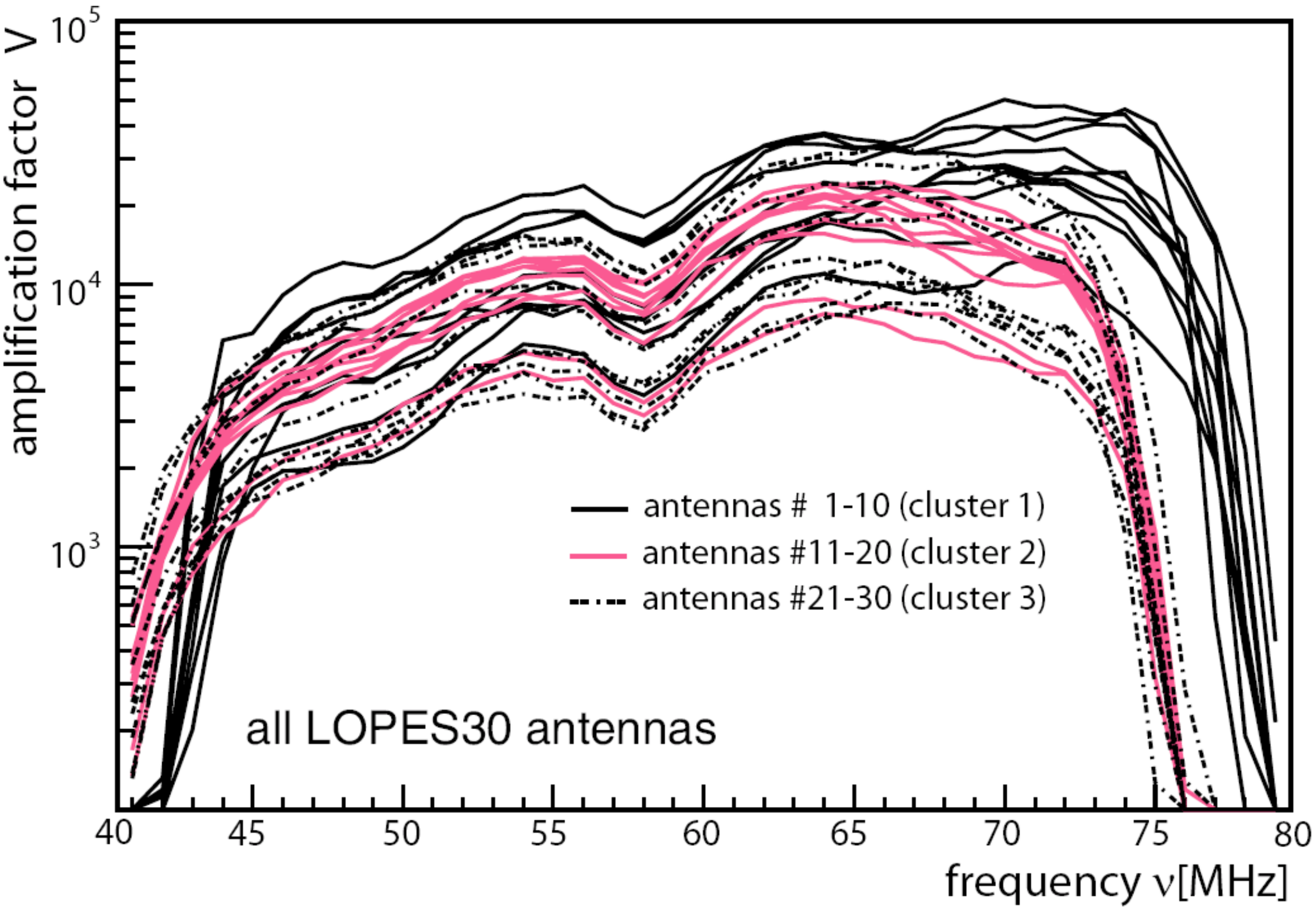
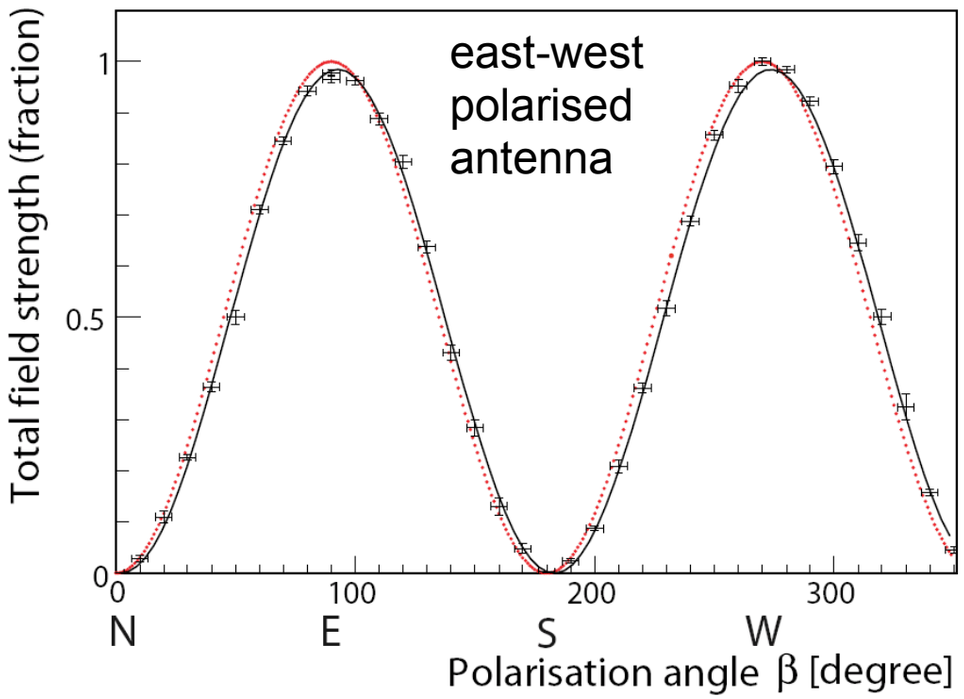
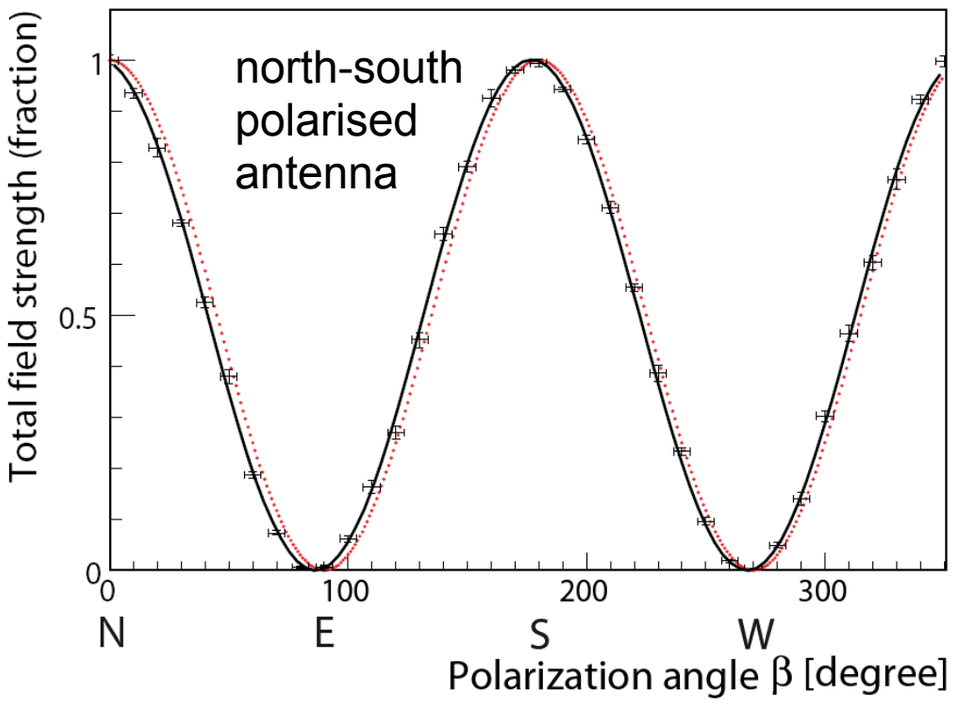
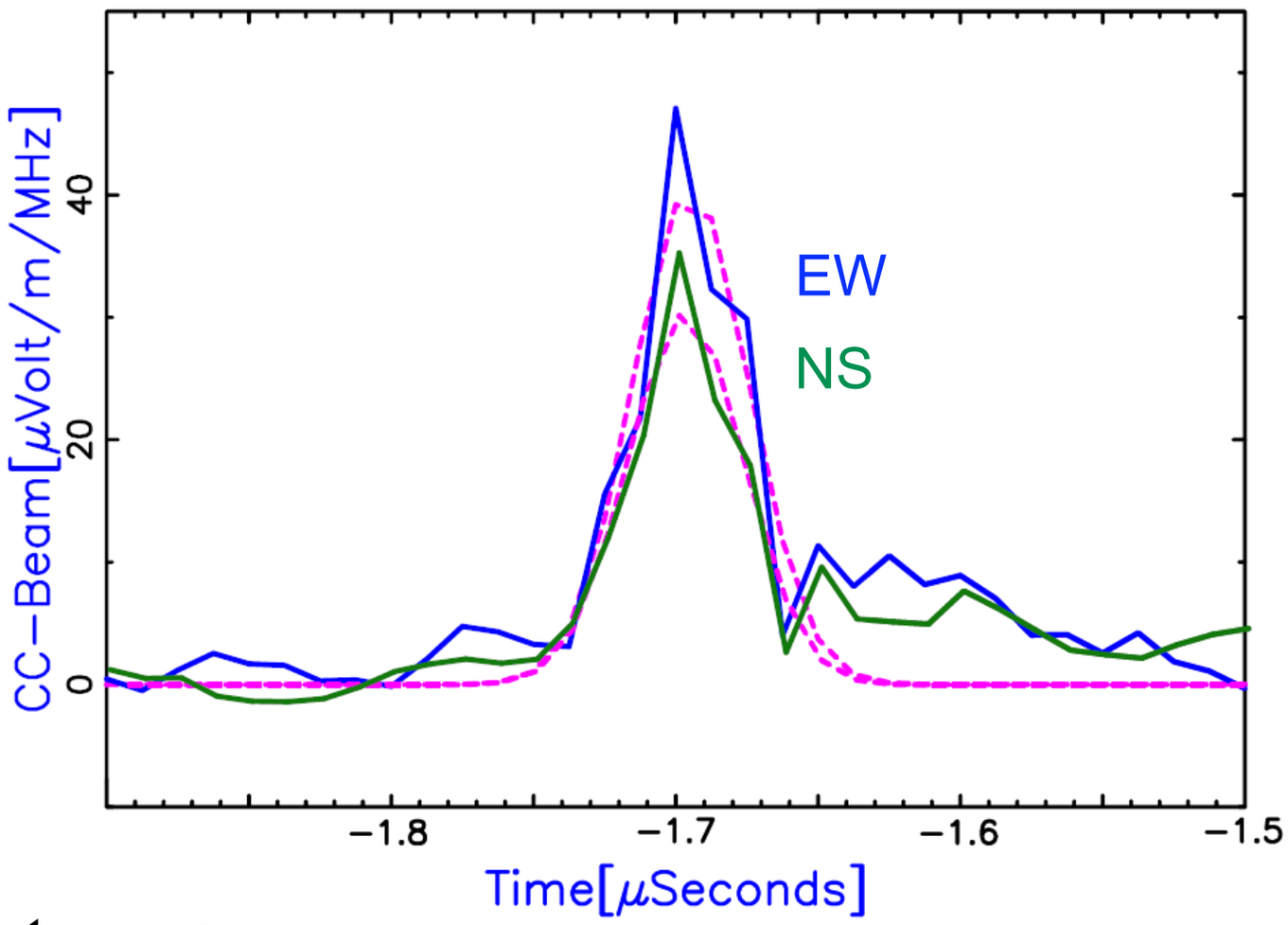
Calibrations: antenna gains



Calibrations: both polarisations







◀ data, fit

....theory

efficiency needs to be checked with both polarisations (60% previously)

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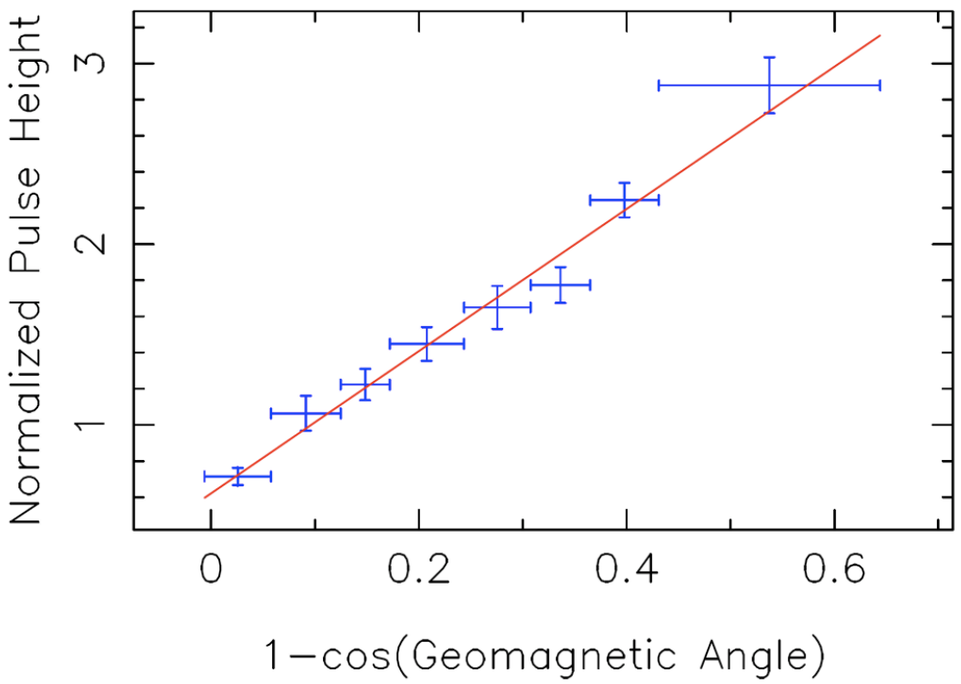
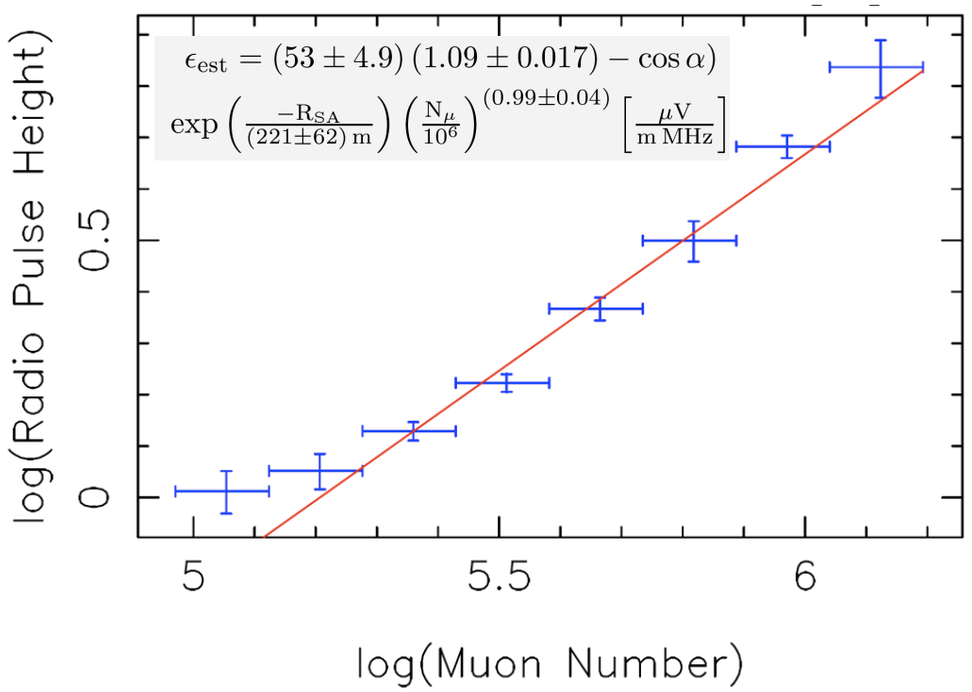
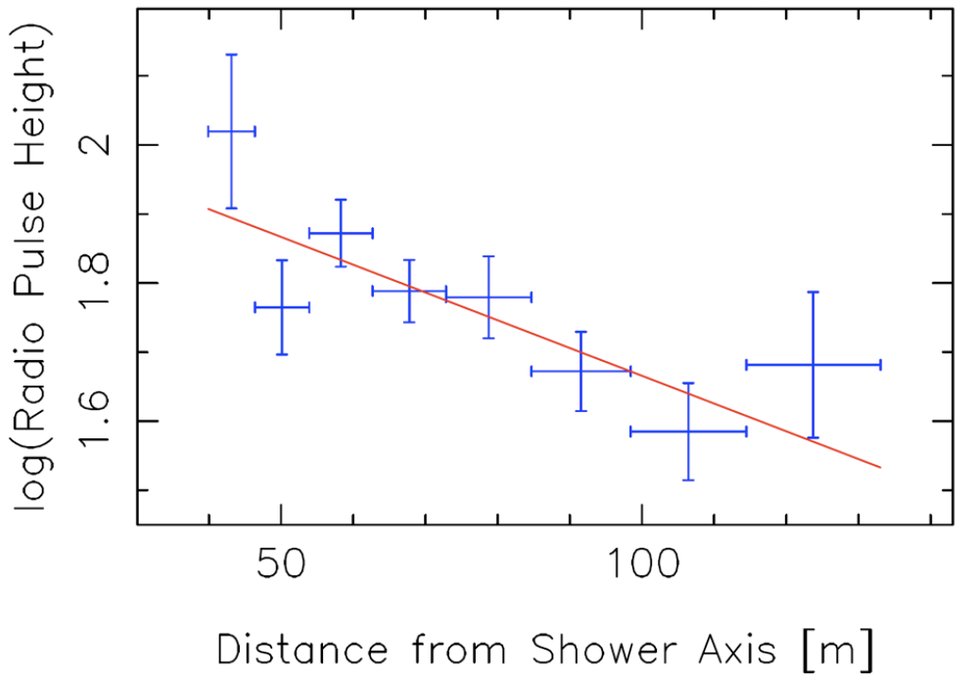
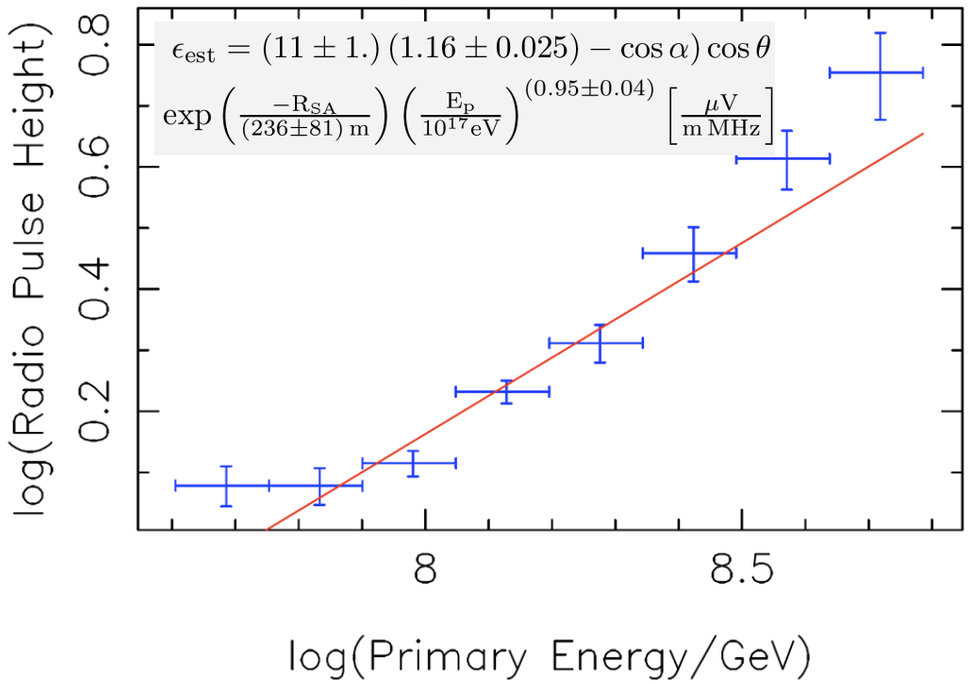
Calibrations: radio signal -- energy



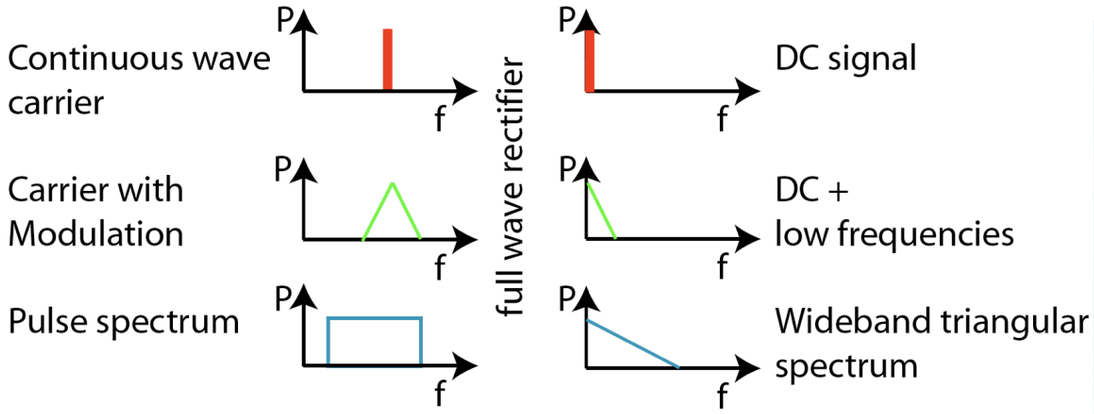


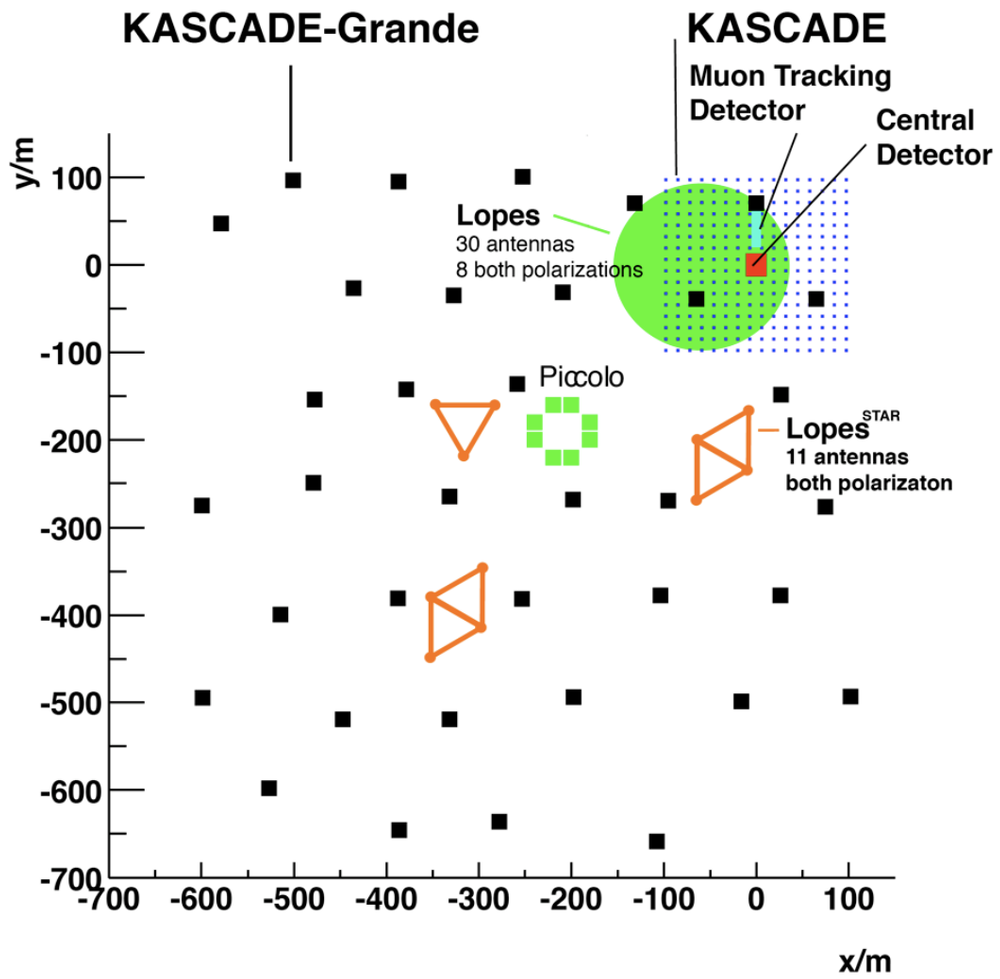


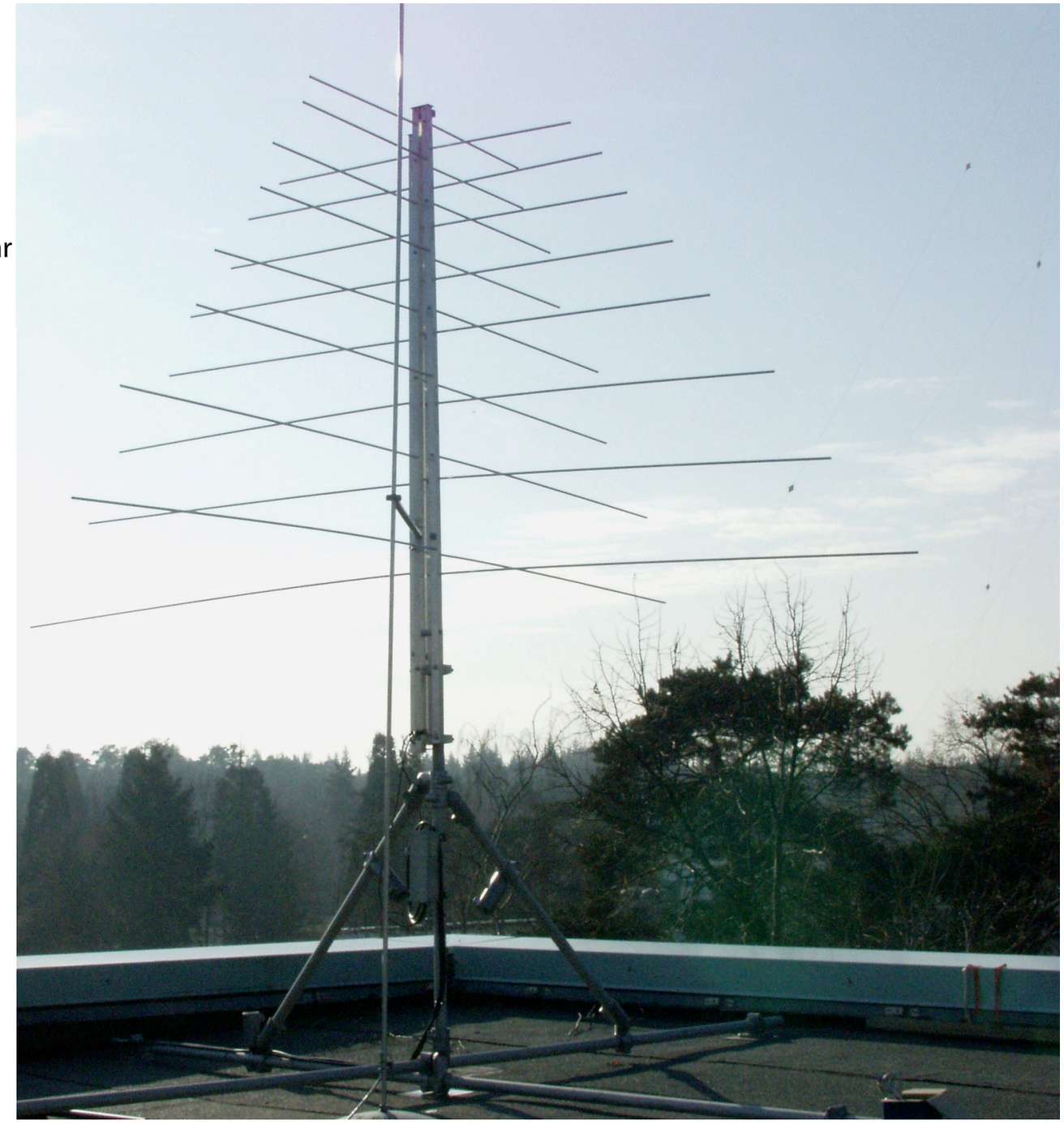


this is using one polarisation only...; spread between radio calibration and KG-energy is 20%

Self-trigger

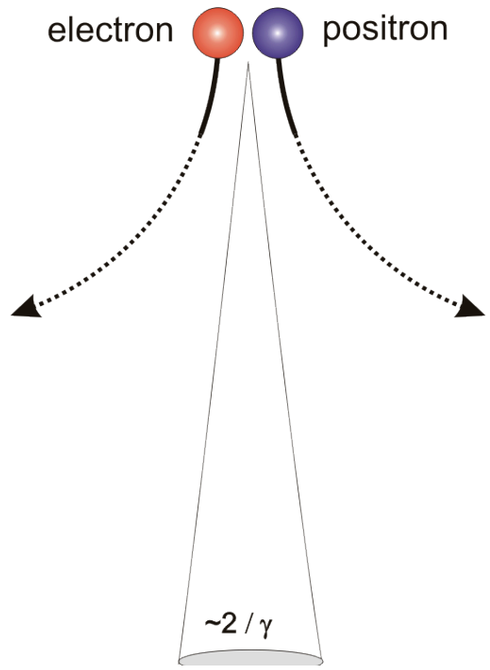


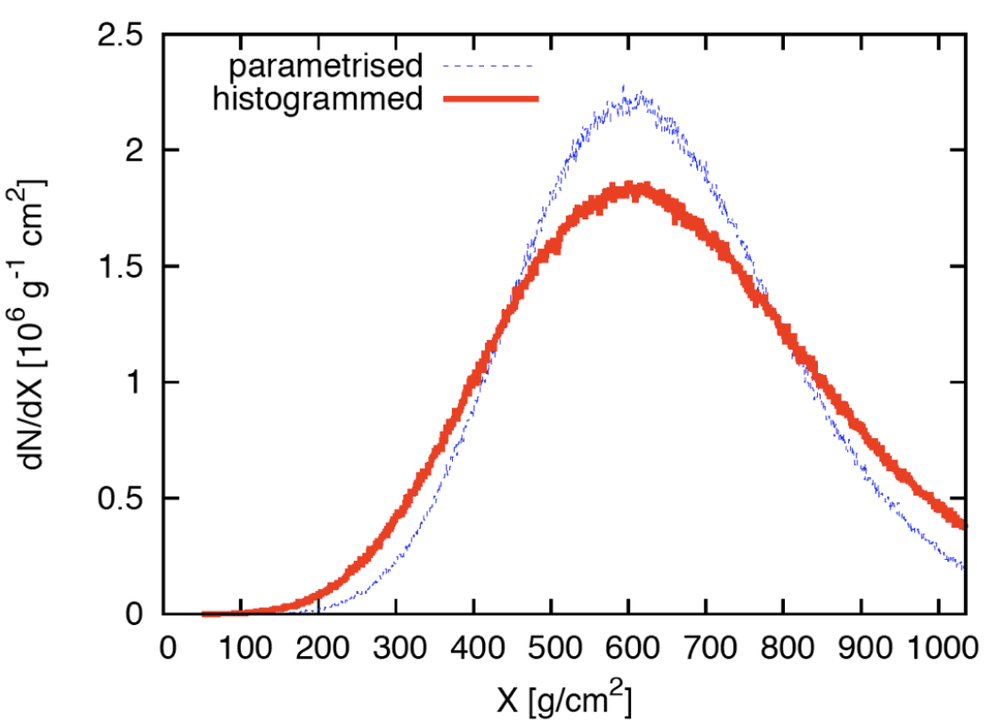


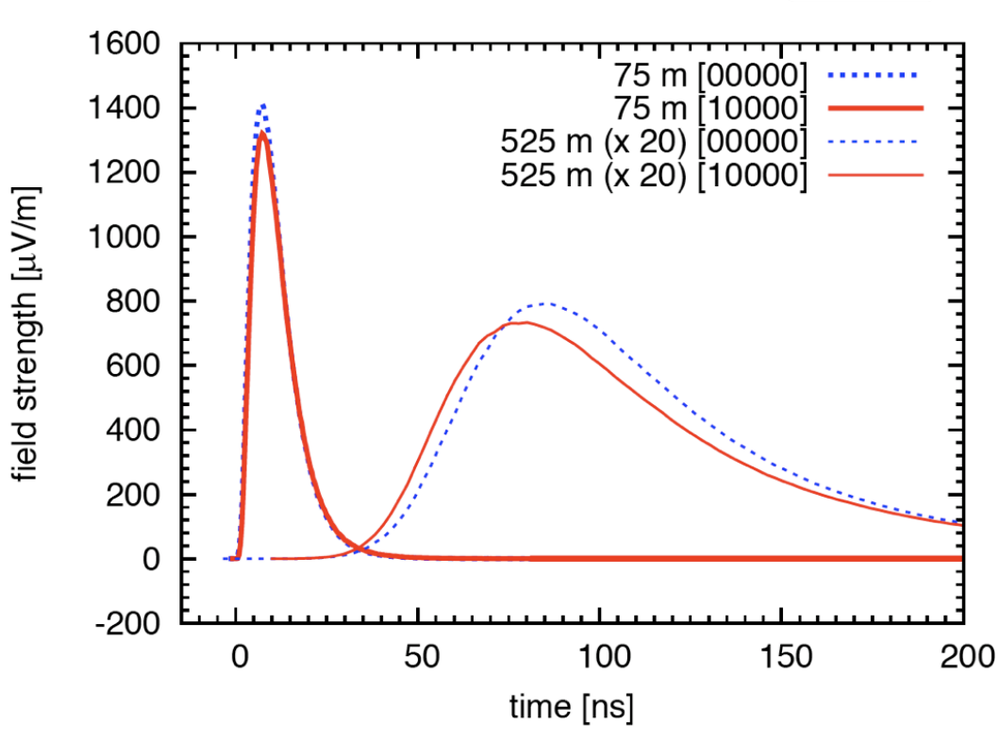


Modelling -- overview

- historical studies, Jelly 1965, Allan 1971++
- electron-positron pairs gyrate in Earth's B-field: radio pulses
- coherent emission at tens of MHz
- 1 - analytical calculations
- 2 - REAS1 MC with parametrised air shower model
- 3 - REAS2 MC with CORSIKA air showers
  - example: shower profile & radio pulse
  - more...







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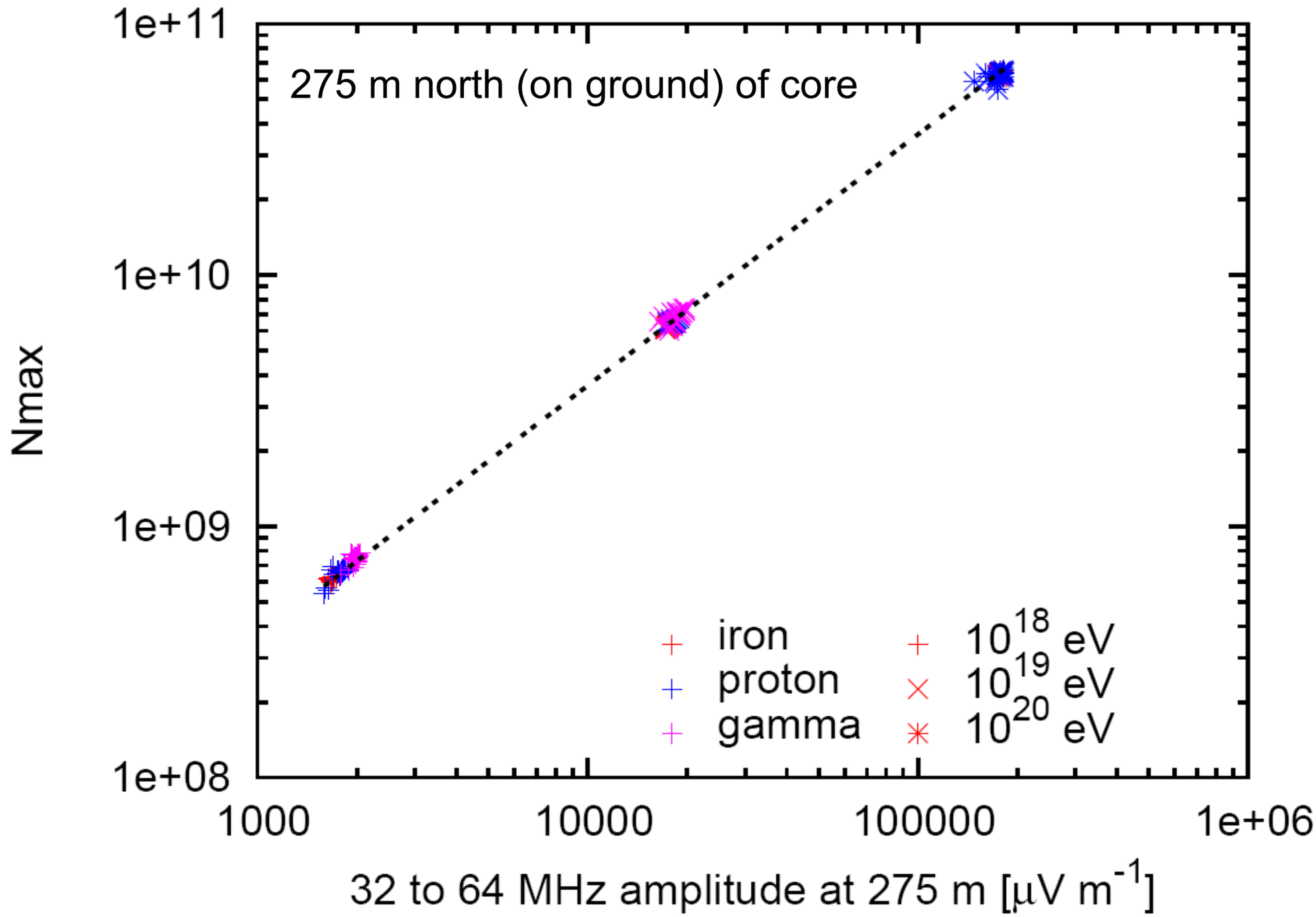
Modelling -- energy estimation with radio



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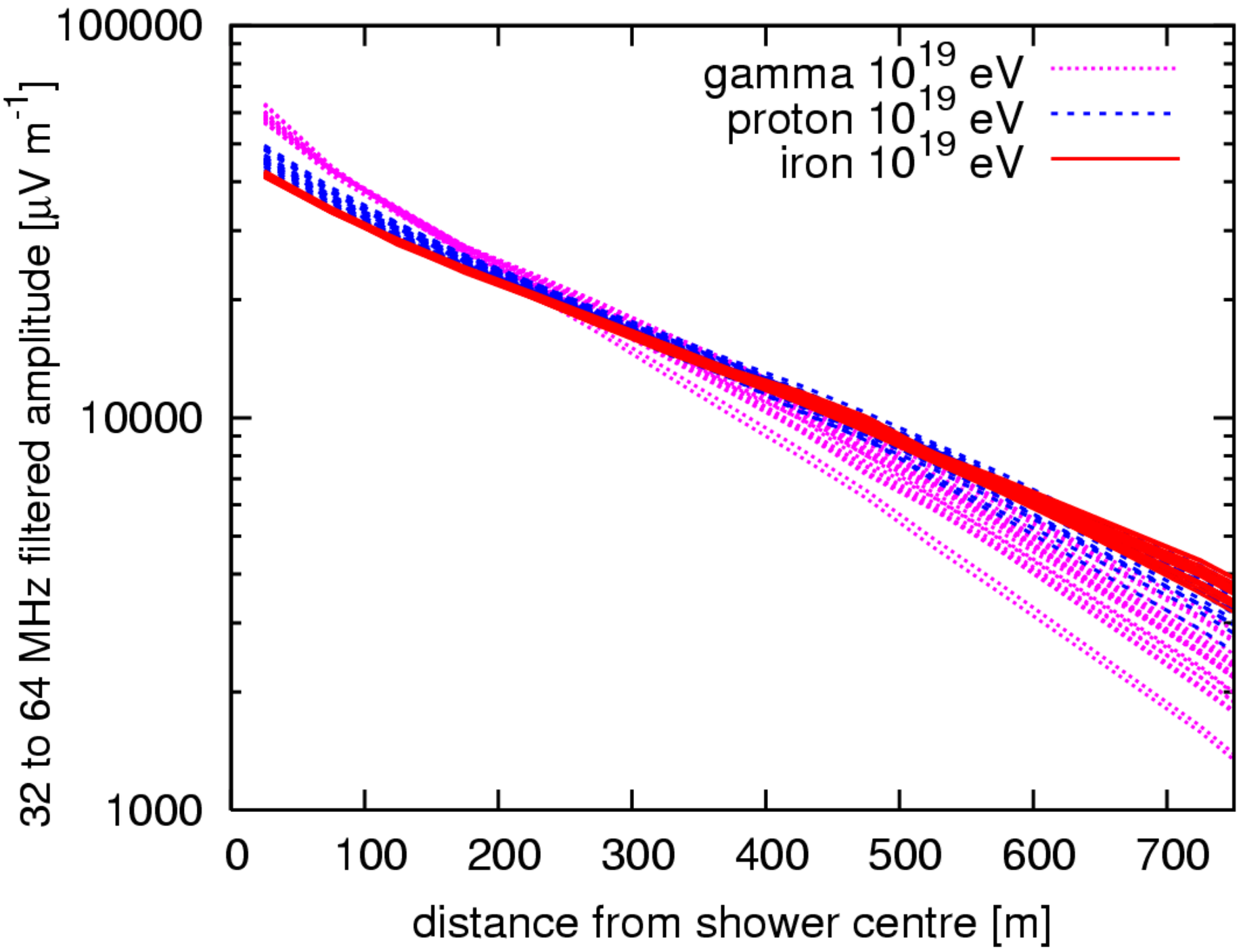
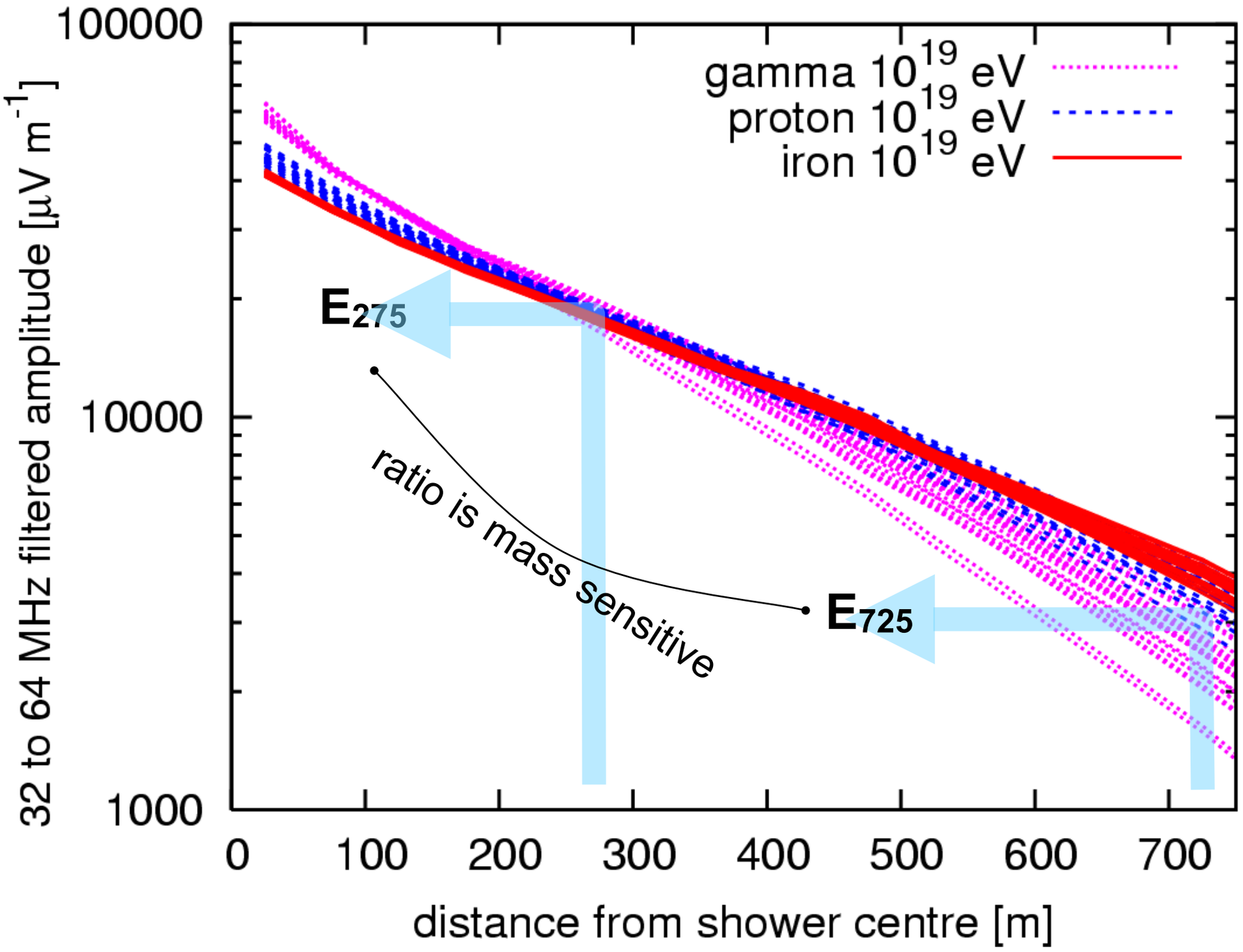
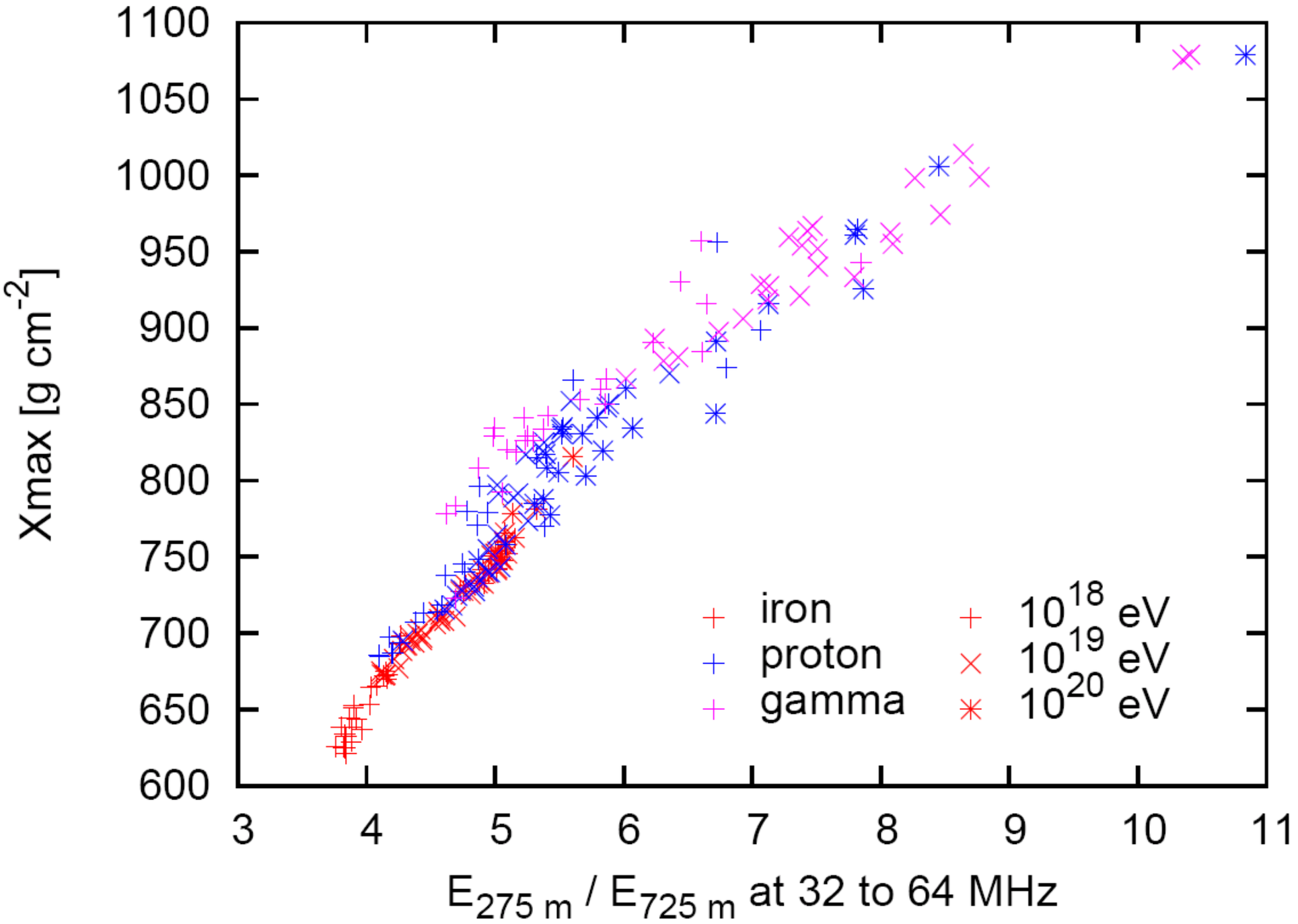
Modelling -- lateral profiles, θ=60°



Modelling -- lateral profiles, θ=60°



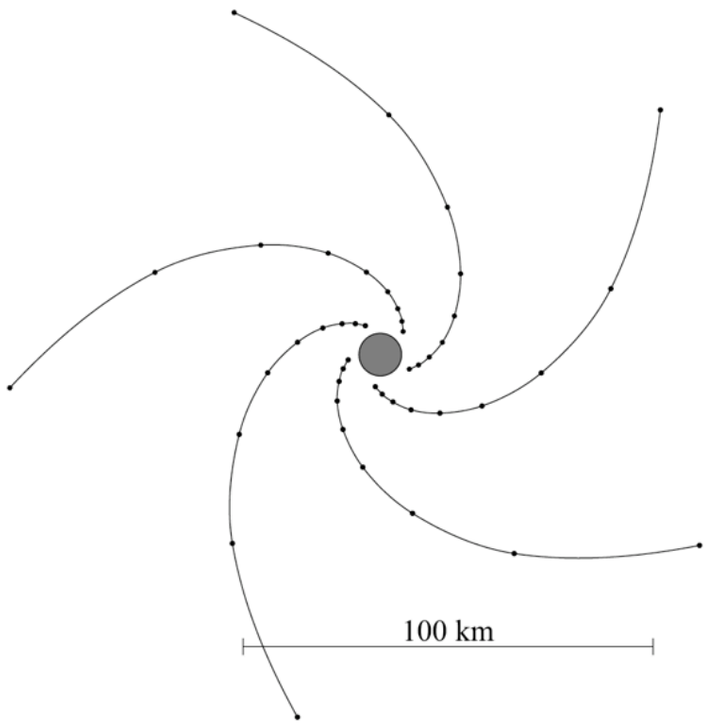
Modelling -- X_{max} estimation with radio

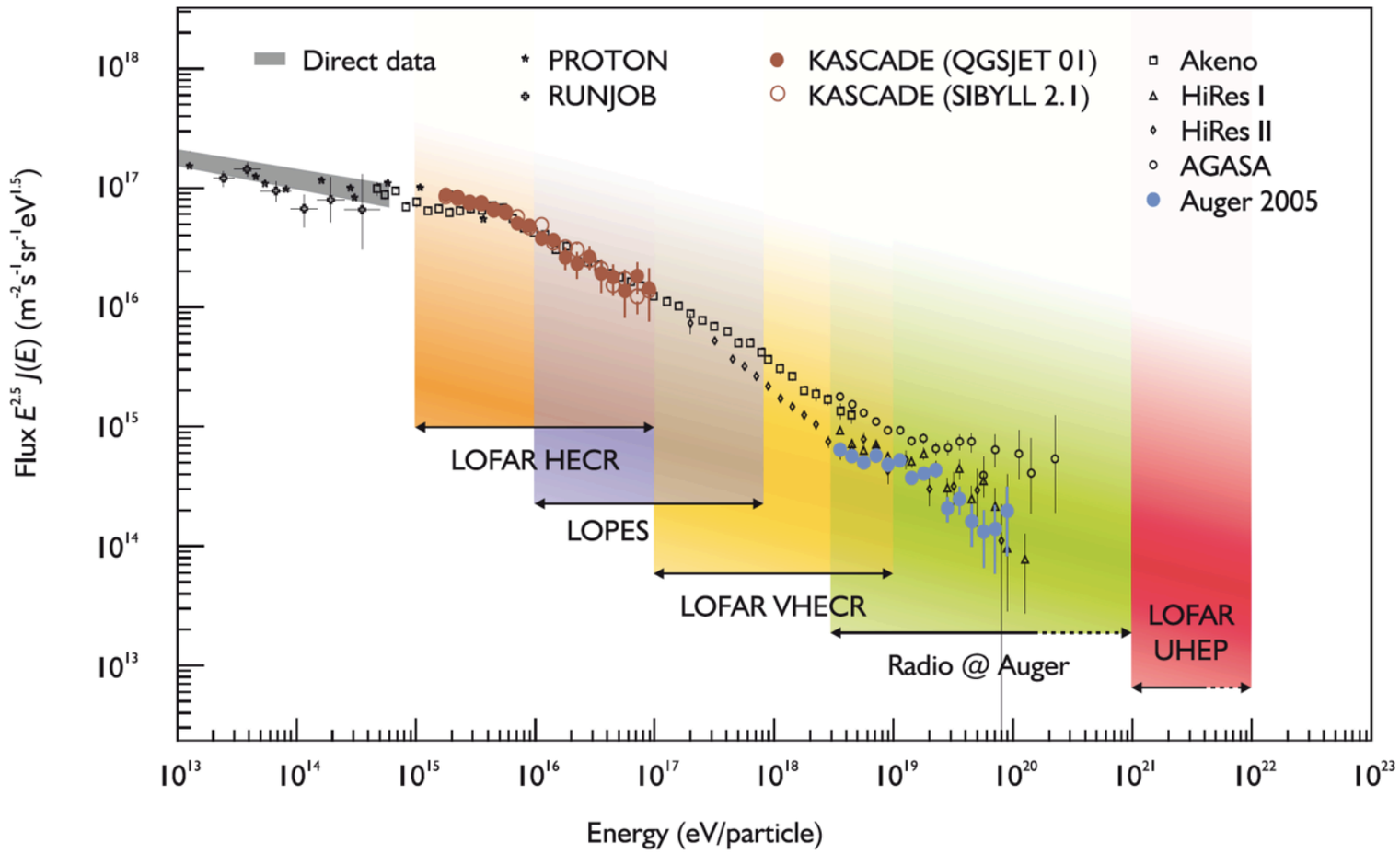


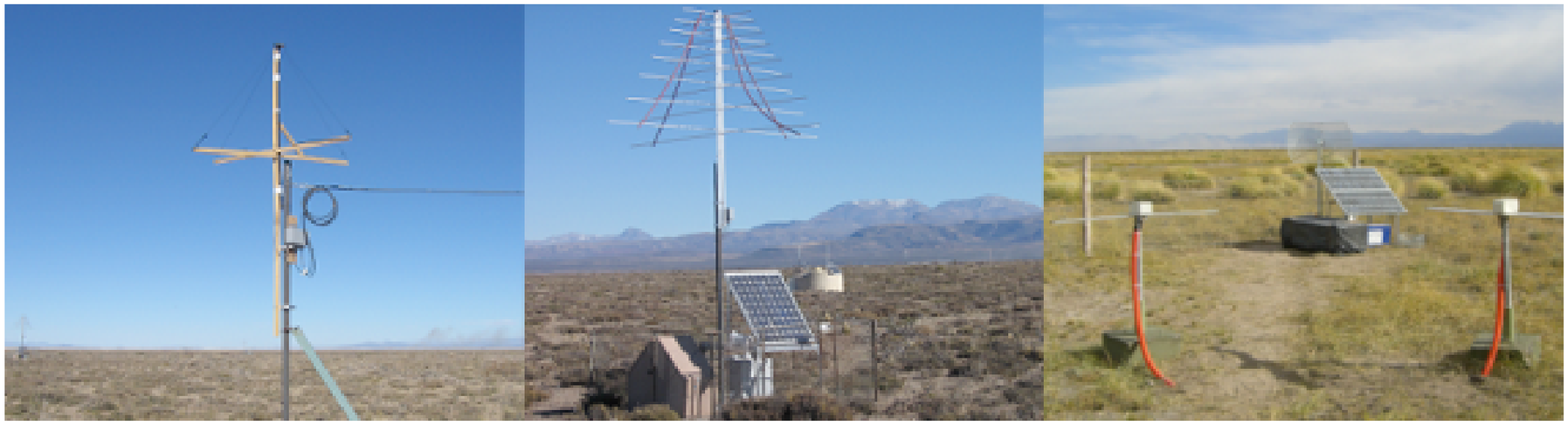
Perspectives: promising AND a lot of work ahead

(1)

the (optimistic) LOFAR view...







actual transfer from LOPES and CODALEMA to Auger

▶ K.-H. Kampert, Friday

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EAS Radio Detection with LOPES

results and recent progress

THANK YOU!

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