Karlsruher Institut für Technologie

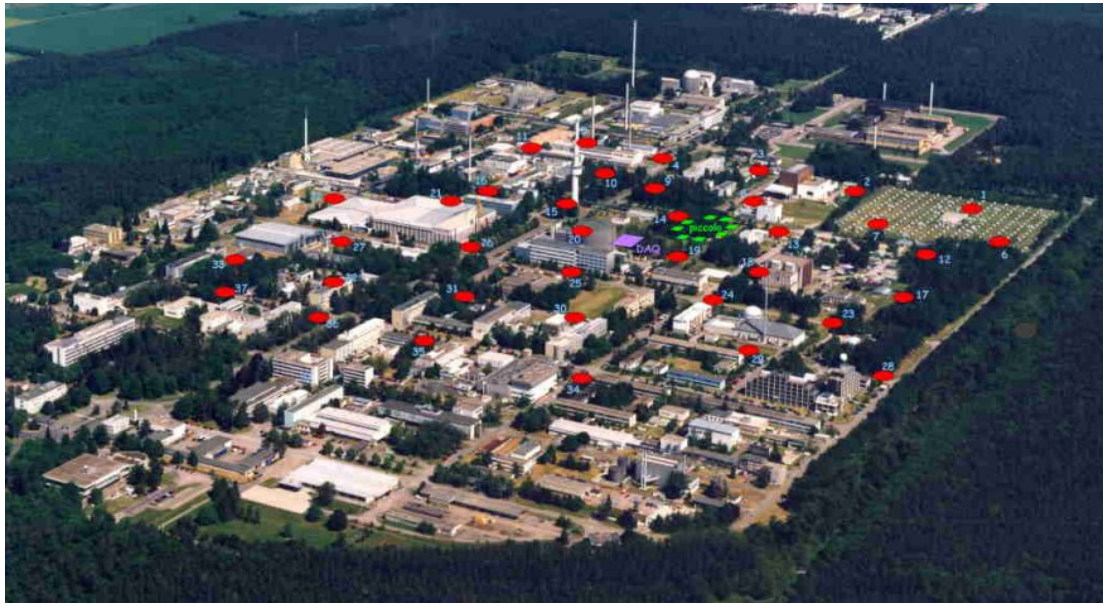
Results, Status, and Perspectives of the LOPES project

Daniel Huber – for the LOPES Collaboration

Karlsruhe Institute of Technology (KIT) - IEKP

10.09.2010

Outline



LOPES

- **LO**FAR **P**rototype **S**tation
- Located within KASCADE at KIT
- External KASCADE-Grande trigger
- Consisted of inverted v-shape radio antennas (now tripole antennas)
- Digital radio interferometer
- Measuring from 40 - 80 MHz

LOPES Collaboration

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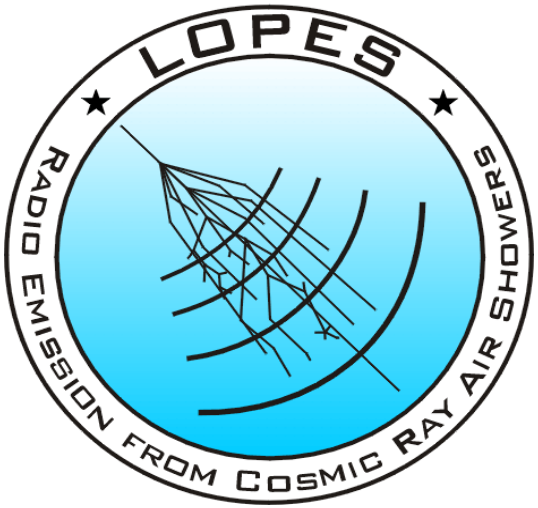

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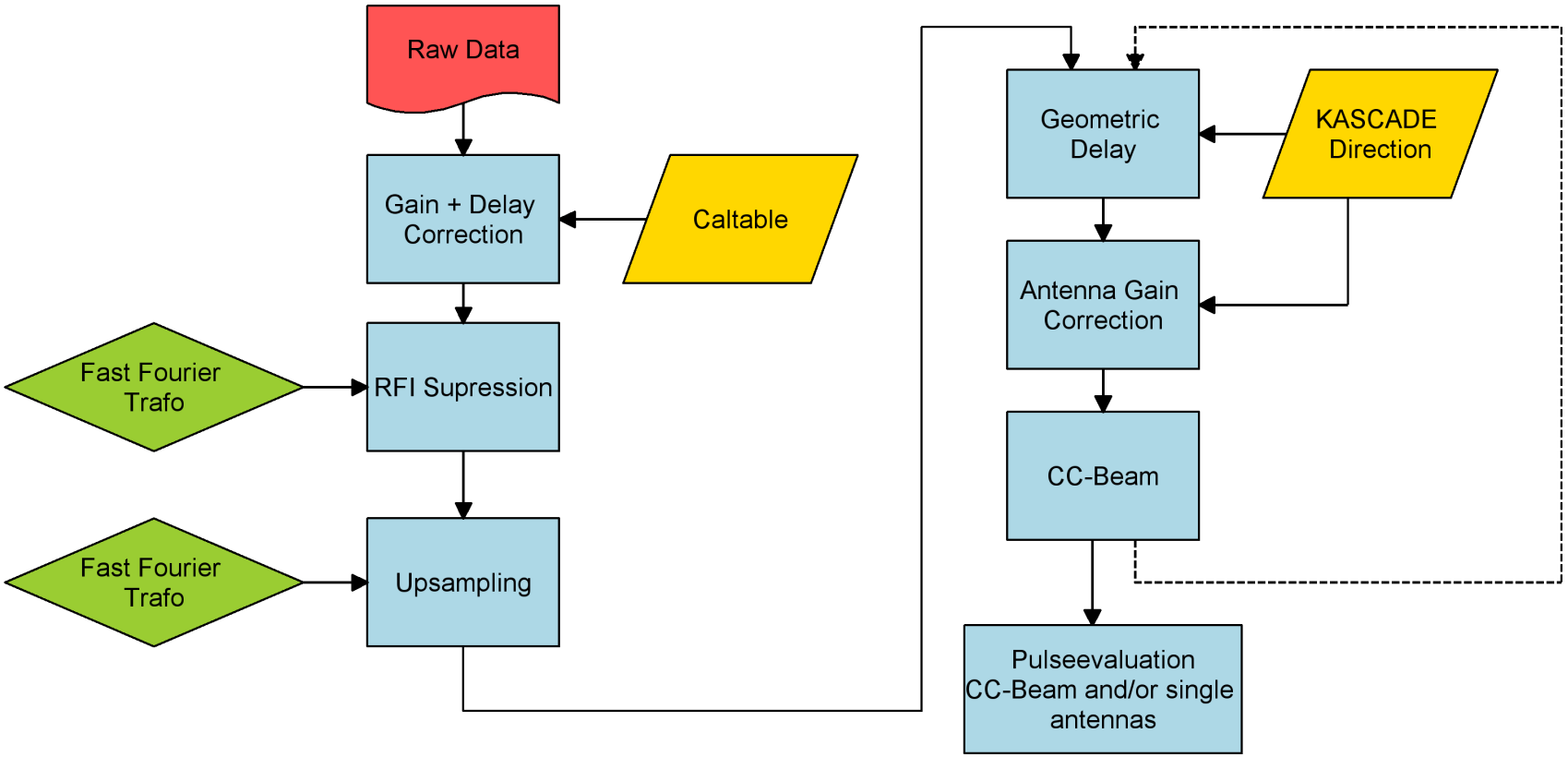
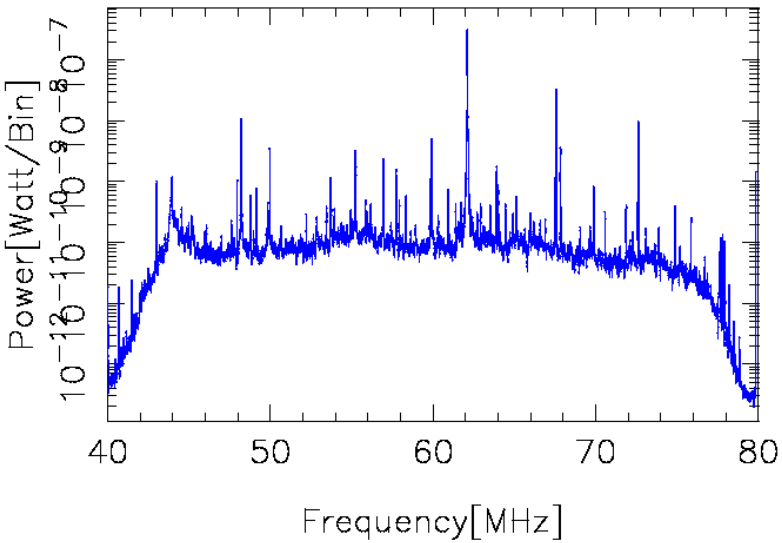
Analysis – rfi

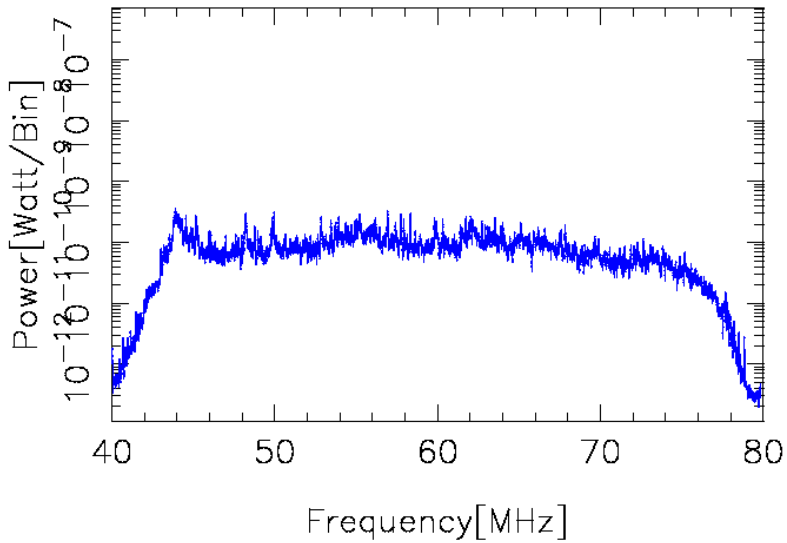


Analysis – rfi

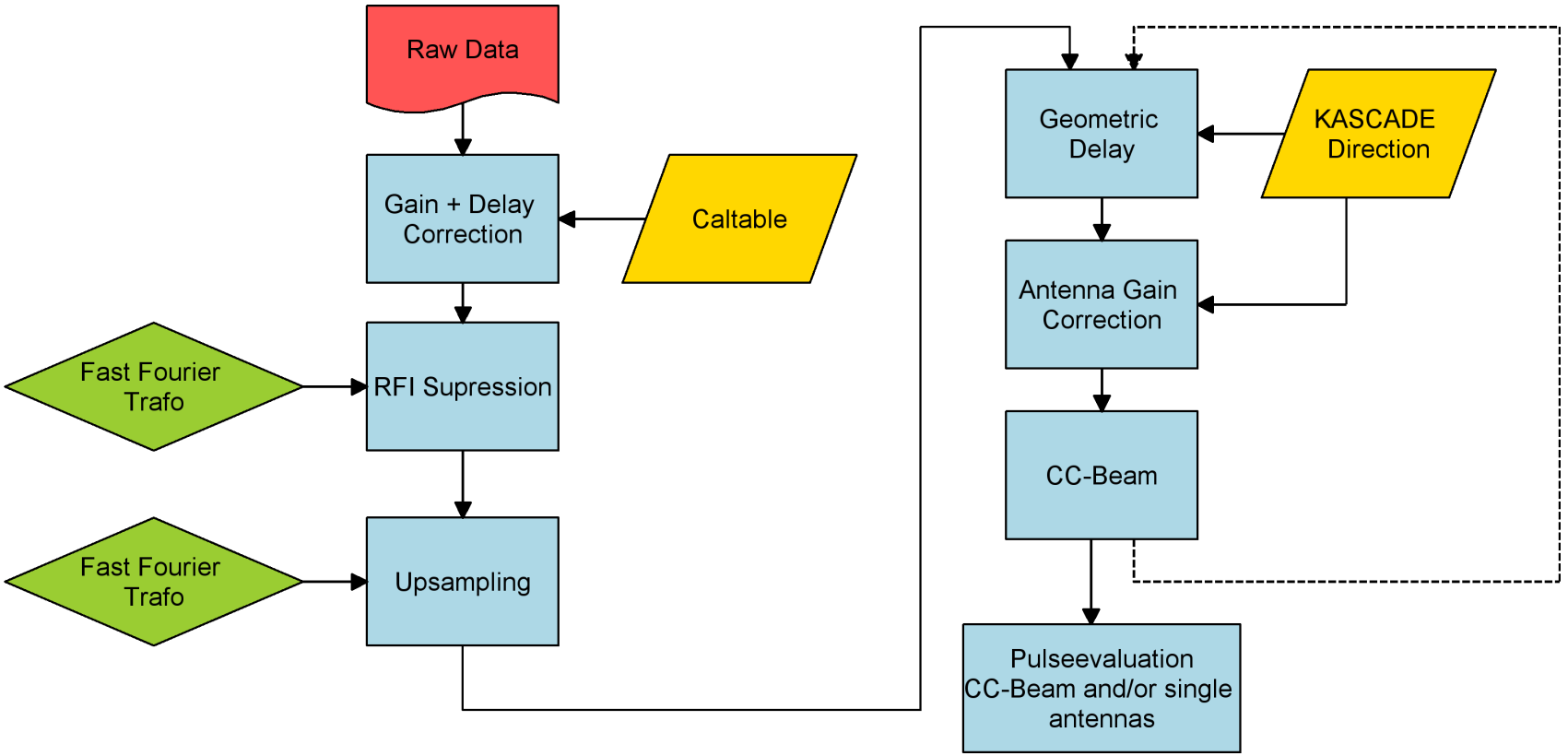
before RFI supression



after RFI supression

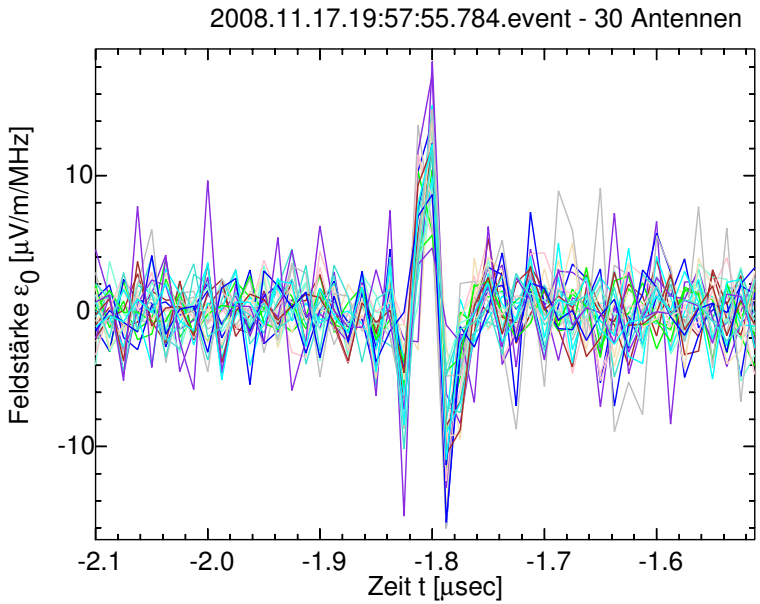


Analysis – upsampling

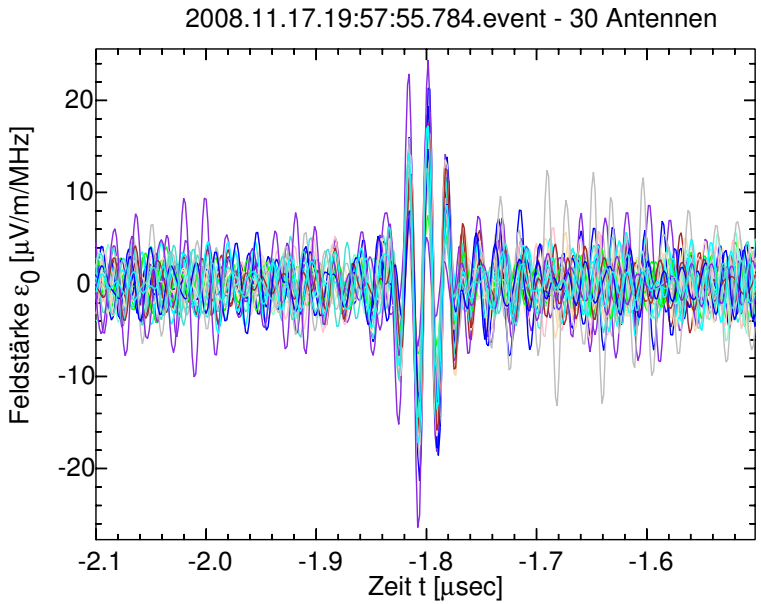


Analysis – upsampling

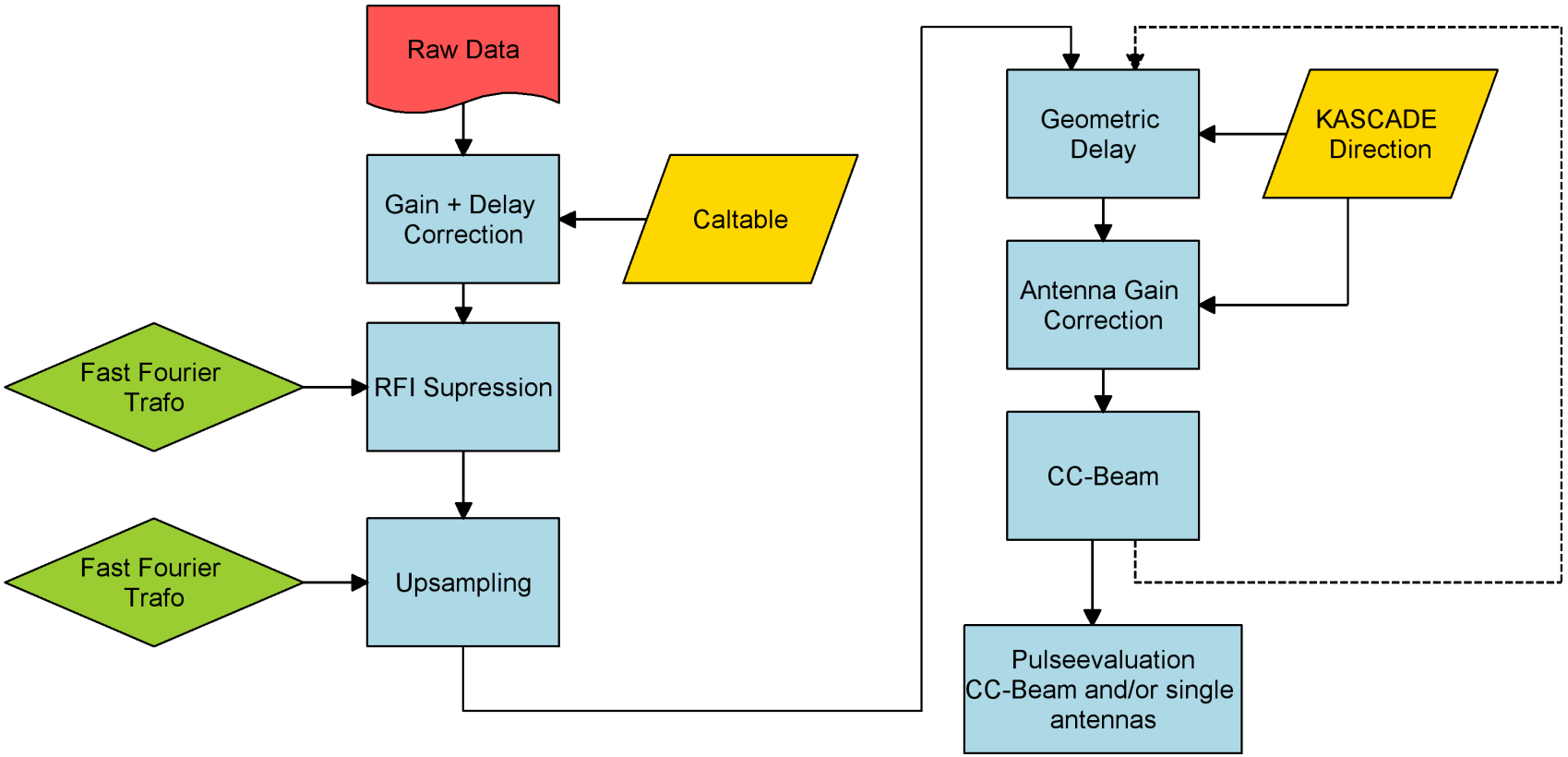
before upsampling



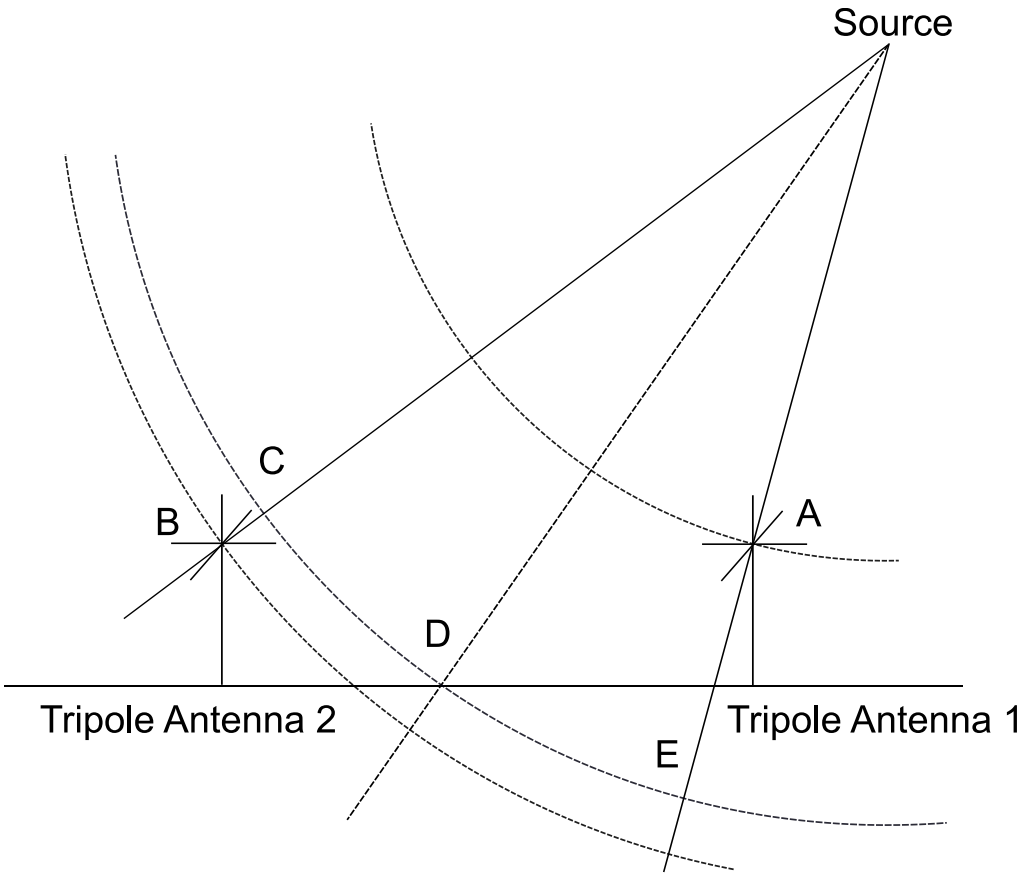
after upsampling



Analysis – geometric delay



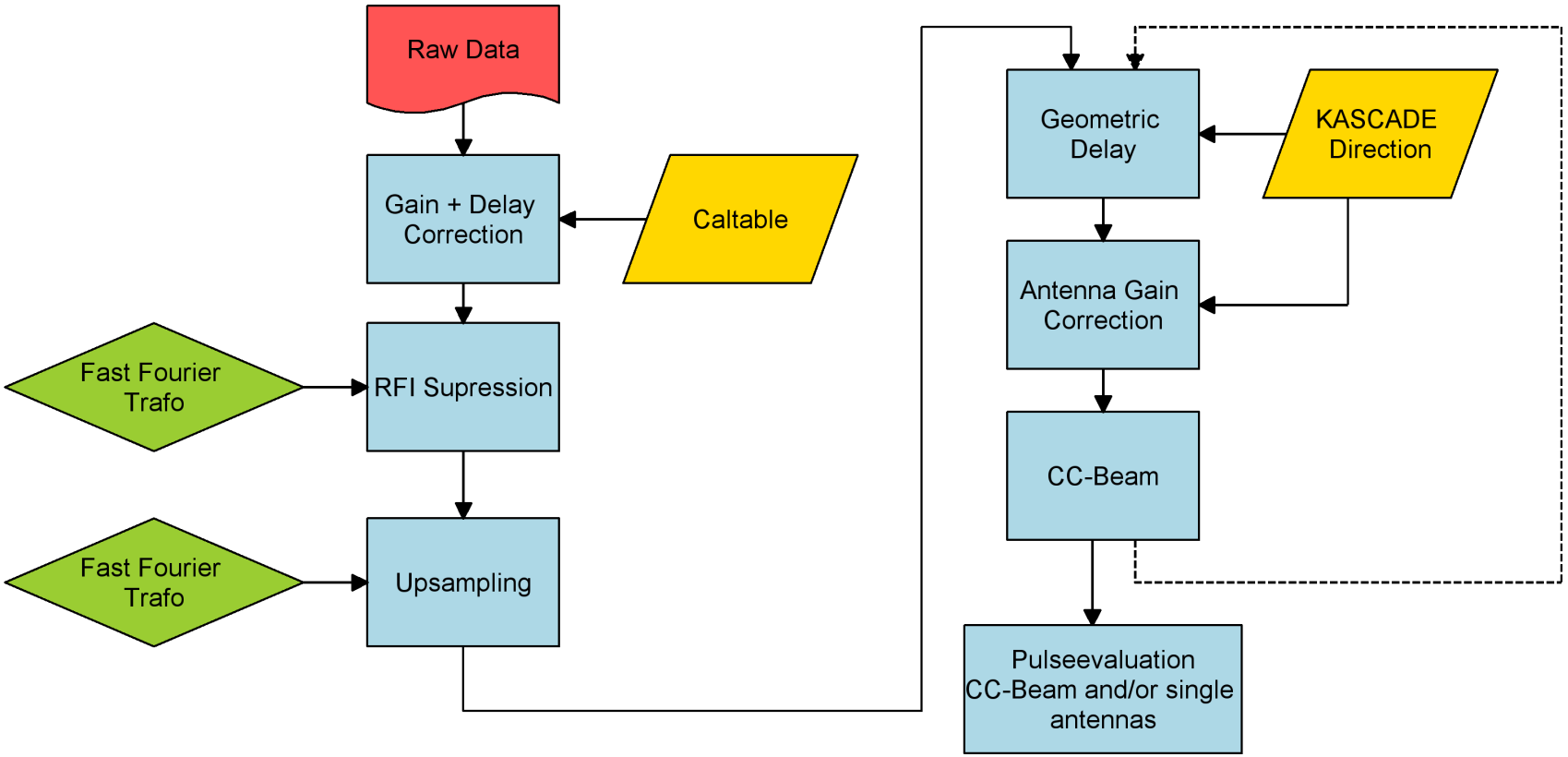
Analysis – geometric delay



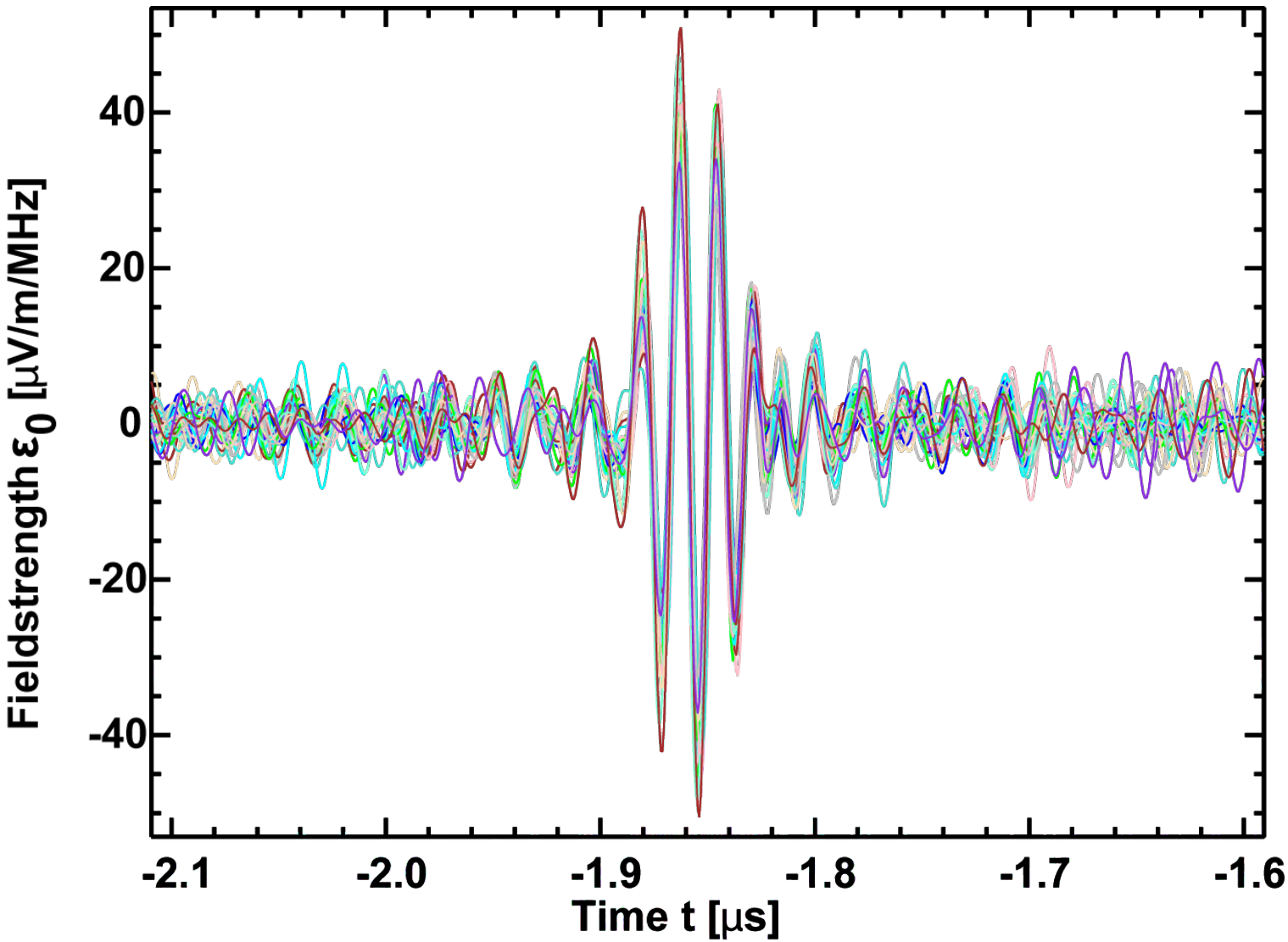
- $1\,\text{ns} \sim 30\,\text{cm}$
- Spherical shape

$$\Delta t_1 = \frac{|E-A|}{c}$$
$$\Delta t_2 = \frac{|C-B|}{c}$$
$$\text{trace-1}_{corr} = \text{trace-1}_{raw} + \Delta t_1$$
$$\text{trace-2}_{corr} = \text{trace-2}_{raw} - \Delta t_2$$

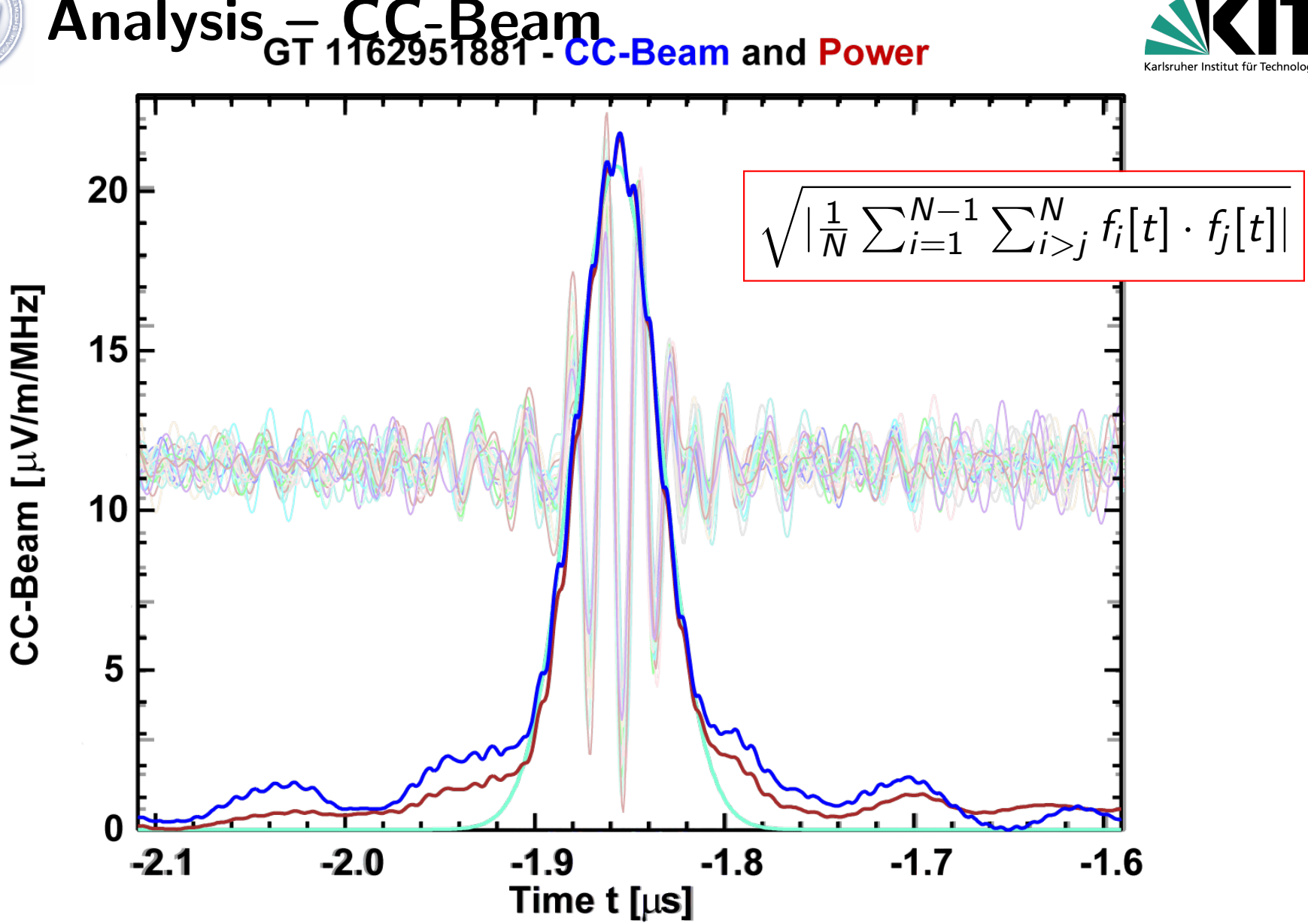
Analysis – CC-Beam



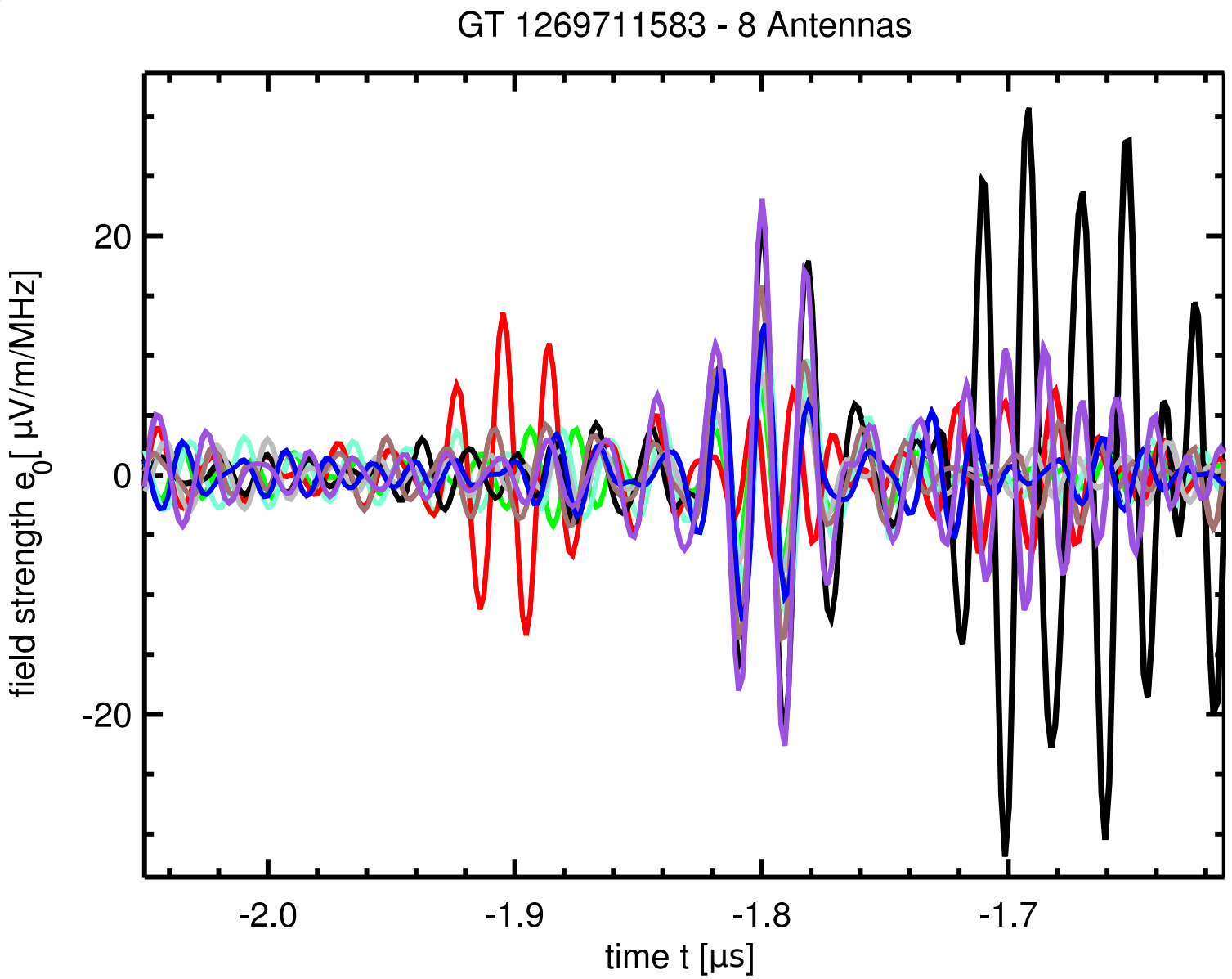
Analysis – CC-Beam



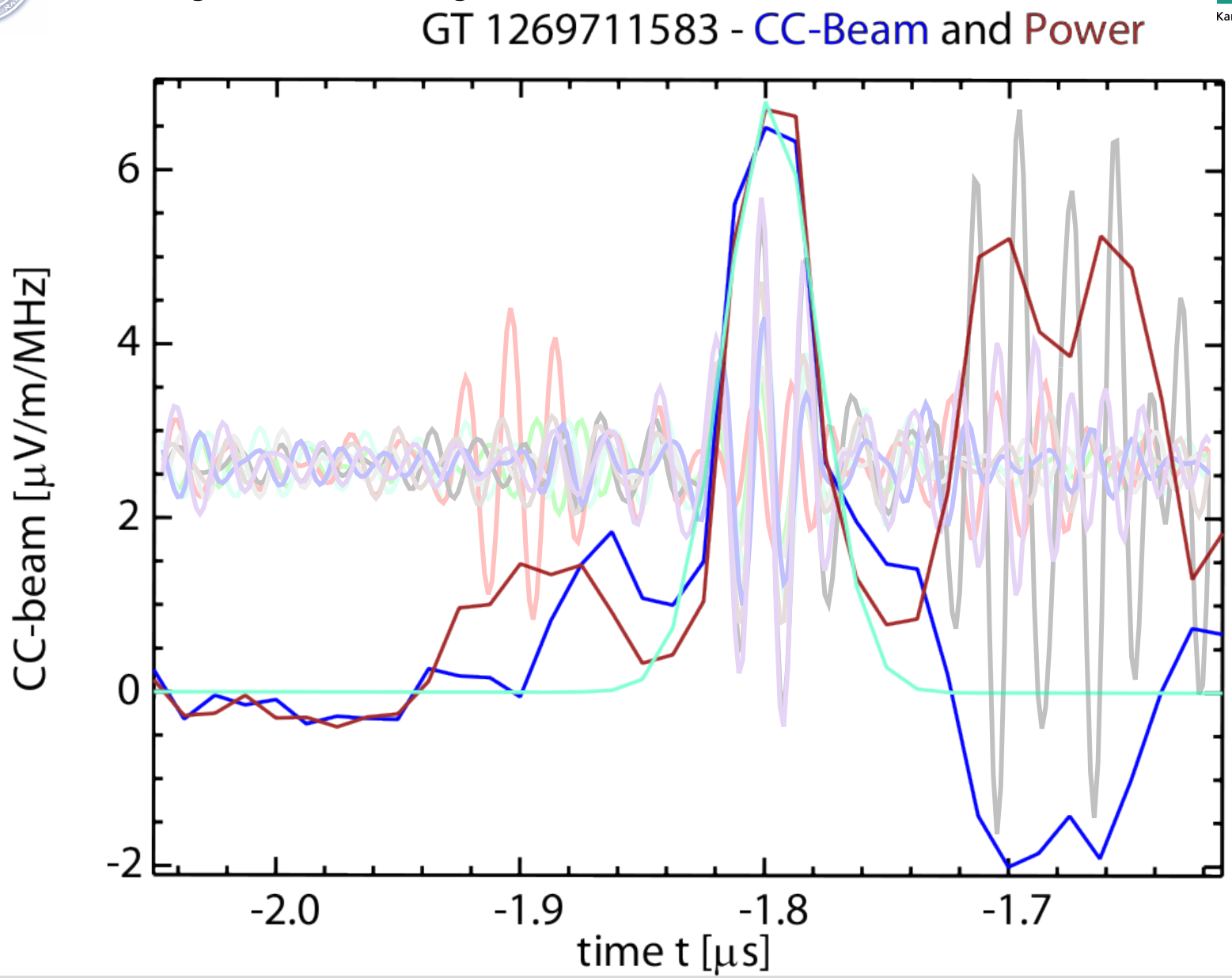
Analysis – CC-Beam



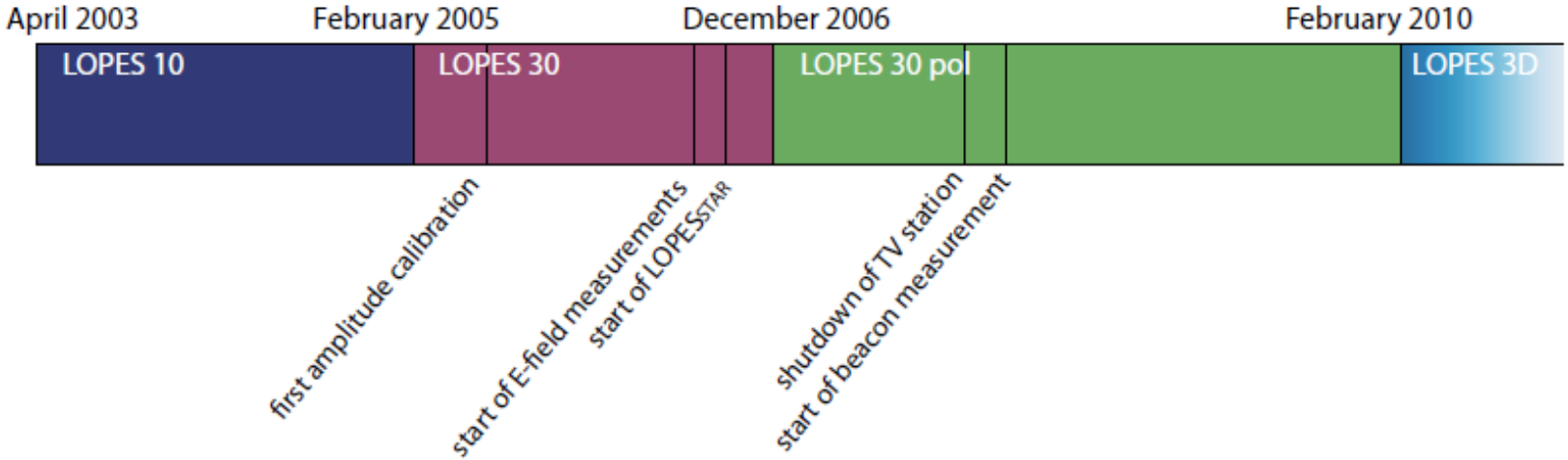
Analysis – why CC-Beam

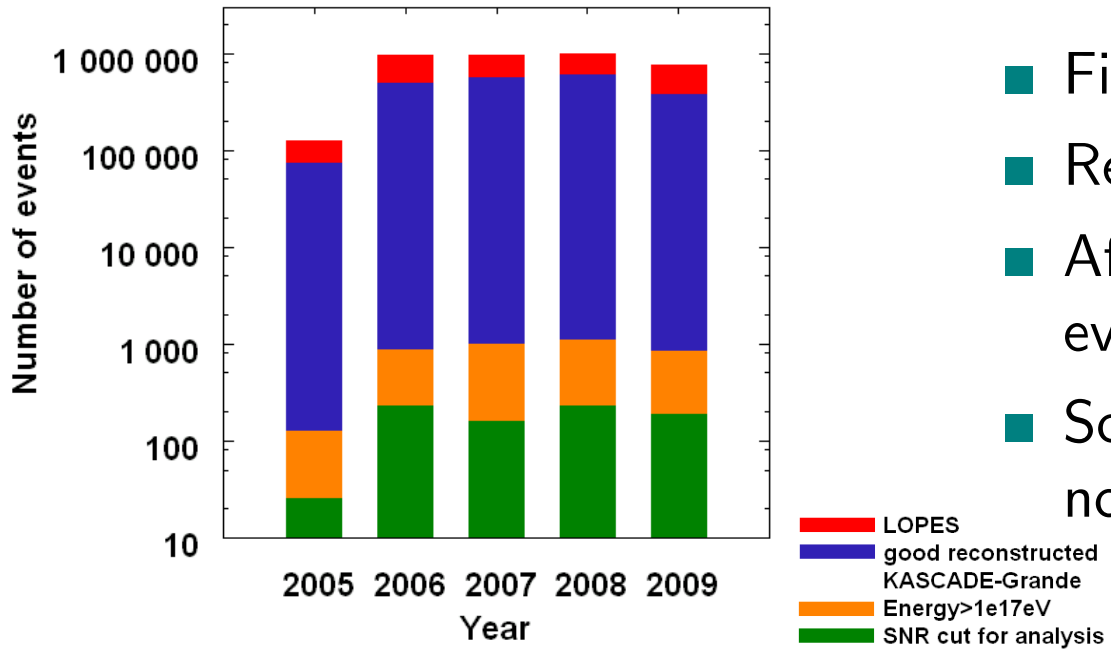


Analysis – why CC-Beam



LOPES – an ever evolving experiment

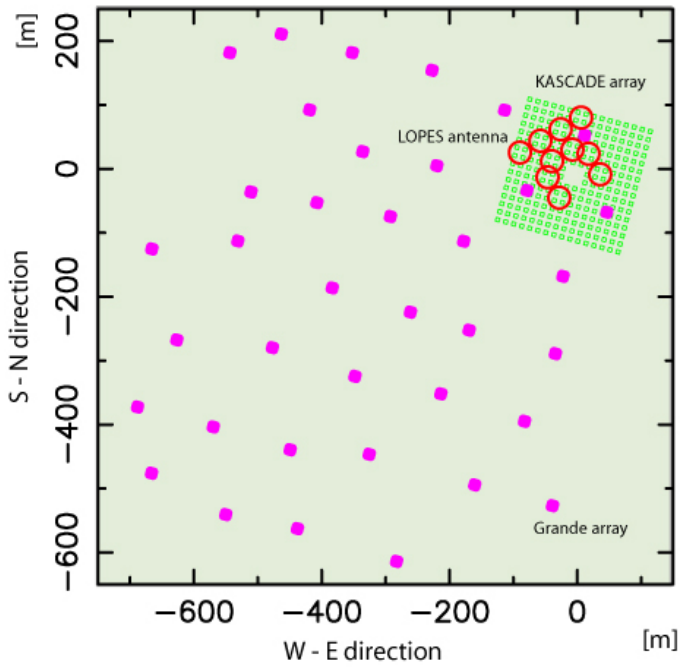




- First prototype station
- Reconfigured several times
- After quality cuts $\sim$ 1000 events
- Sophisticated analyses and noise reduction

LOPES 10

- 10 inverted v-shape antennas
- Purely east-west polarization
- Proof-of-principle

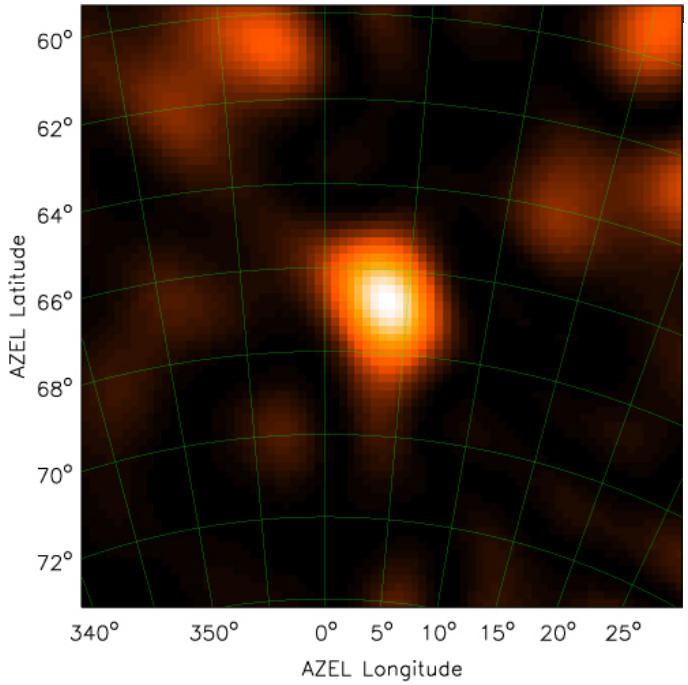


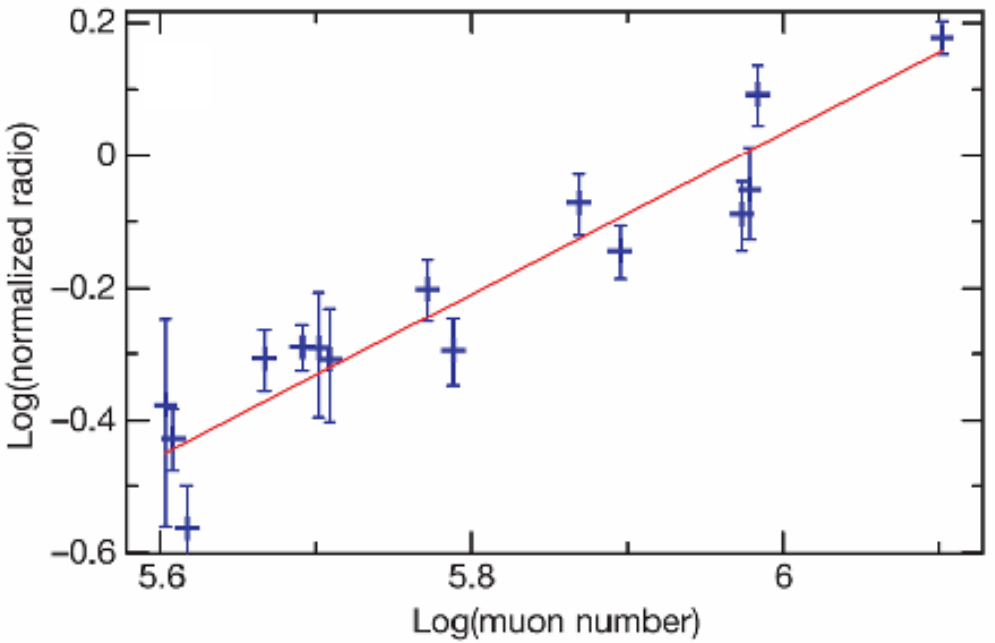
LOPES 10 – results I

- Proof-of-principle

→ successful coincident radio detection with KASCADE

- Geomagnetic origin of emission mechanism
- Coherent scaling of radiosignal





H. Falcke et al. (The LOPES Collaboration), Nature 2005

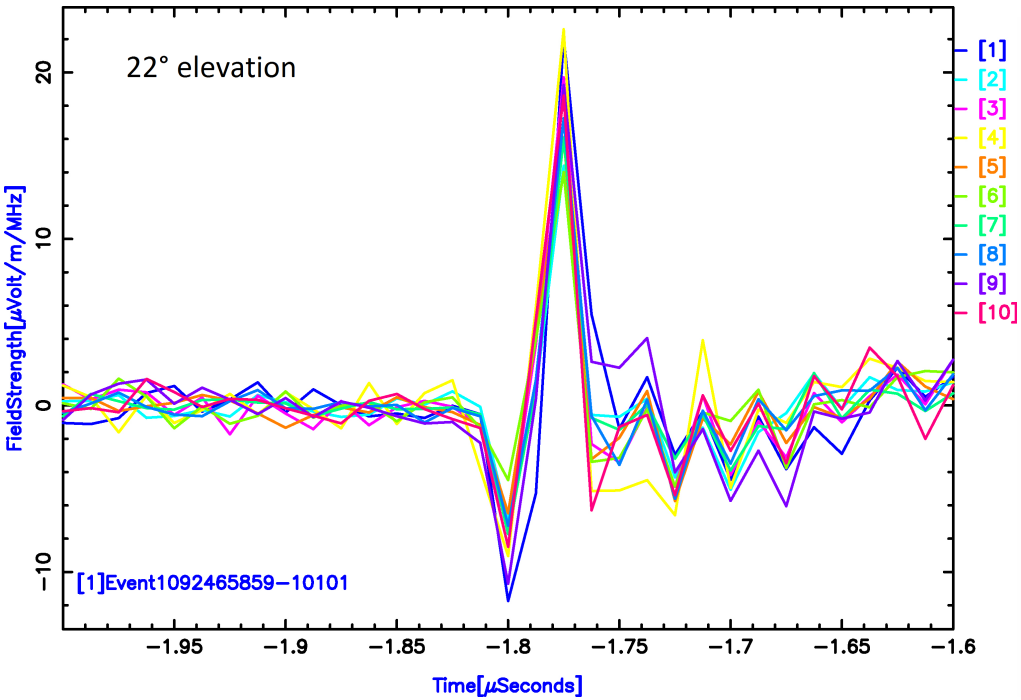
LOPES 10 – results II

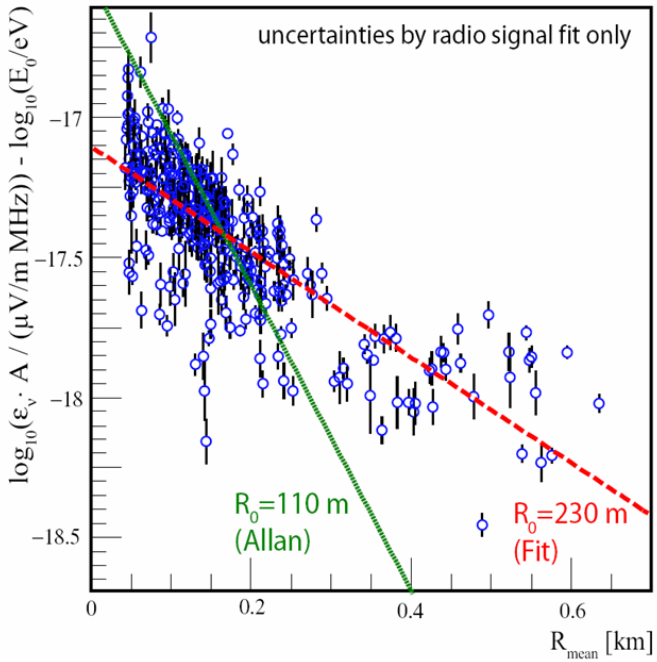
- LOPES sees very inclined showers

  J. Petrovic et al. (The LOPES Collaboration), Astronomy & Astrophysics 2007

- Exponential lateral distribution
- $R_0 \sim 230\,\mathrm{m}$

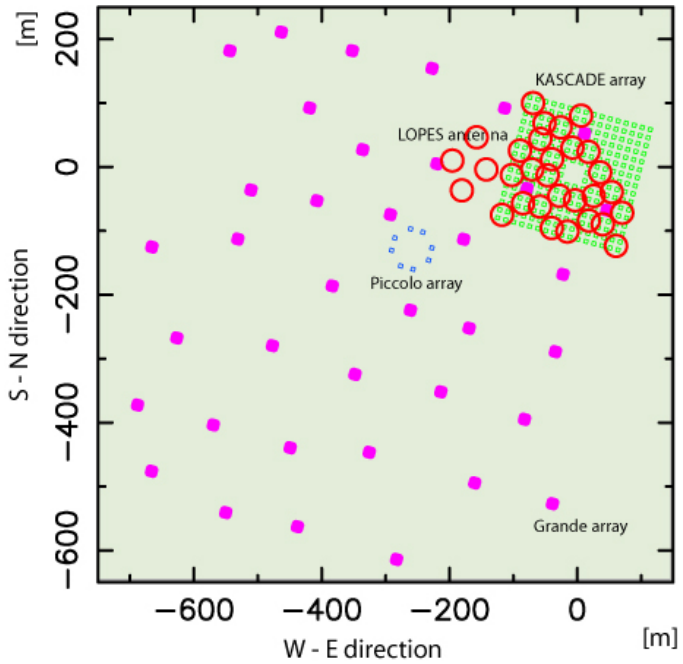
  W.D. Apel et al. (The LOPES Collaboration), Astroparticle Physics 2006





LOPES 30

- 30 inverted v-shape antennas
- Purely east-west polarization
- Absolut calibration
- Monitoring of atmospheric E-field



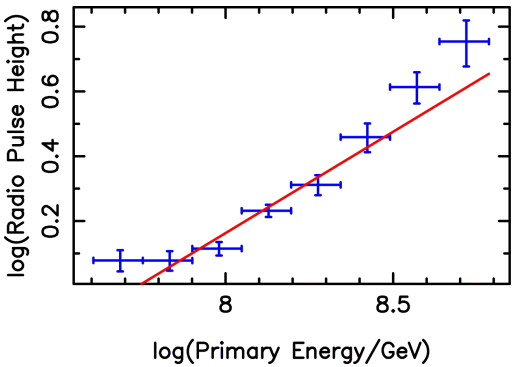
LOPES 30 – results I

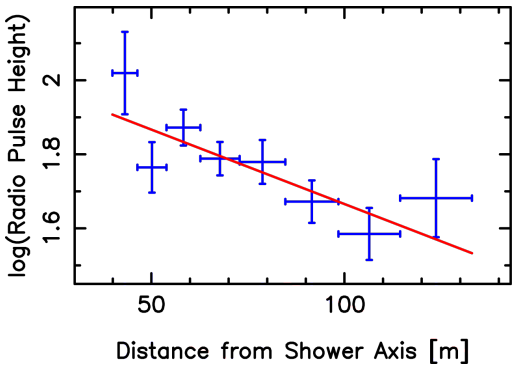
- Parametrization of east-west polarized part of the radio signal

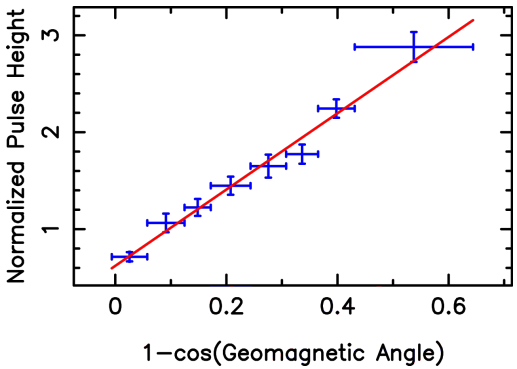
$$\epsilon_{EW} = A(1+B-cos(\alpha))\cdot cos(\Theta)\cdot exp(\frac{-R}{R_0})\cdot(\frac{E}{10^{17}\,eV})^{\gamma}\ [\mu V/m/MHz]$$

$A = 10.9 \pm 1.1$ $\quad R_0 = 202 \pm 64\,m$

$B = 1.16 \pm 0.02$ $\quad \gamma = 0.94 \pm 0.03$



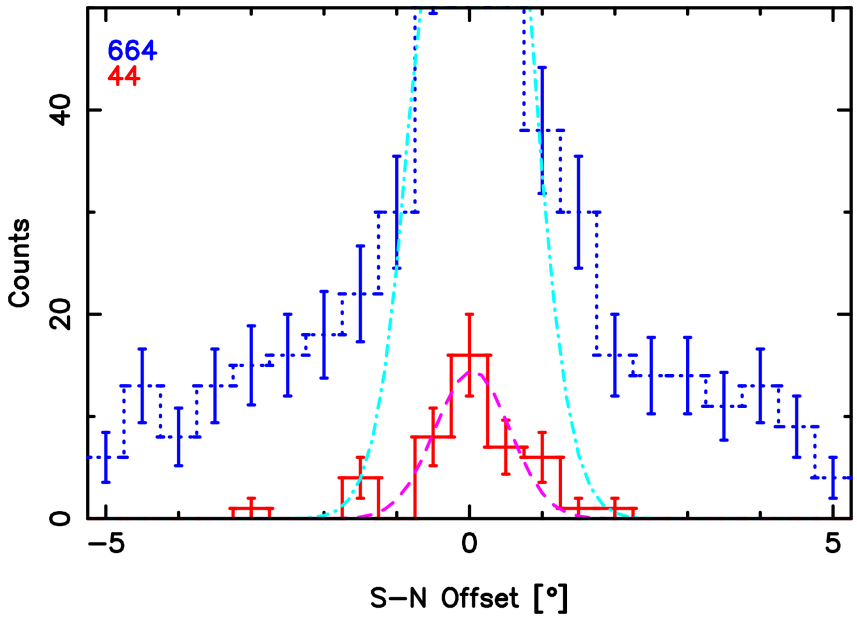




A. Horneffer et al. (The LOPES Collaboration), ICRC 2007

LOPES 30 – results II

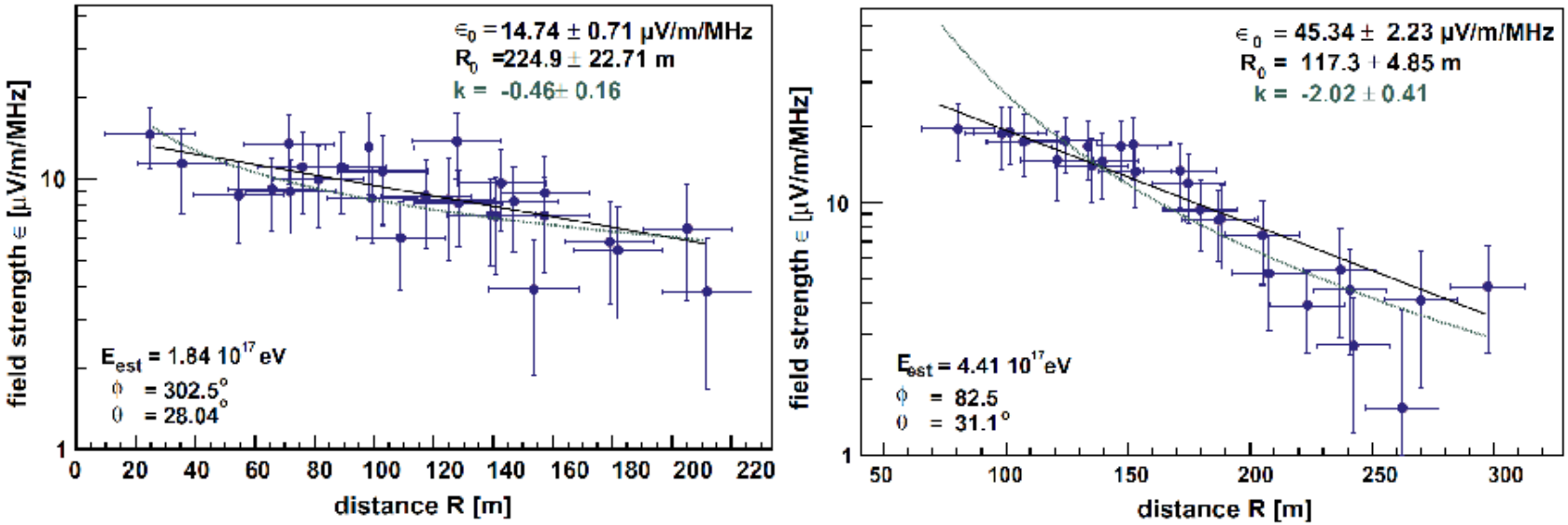
- Amplified radio signals during thunderstorms
  S. Buitink et al. (The LOPES Collaboration), Astronomy & Astrophysics 2007
- Angular resolution of LOPES 30 better than 1.5°
  A. Nigl et al. (The LOPES Collaboration), Astronomy & Astrophysics 2008



thunderstorm fair weather

LOPES 30 – results III

- Good per-event lateral distributions
- ∼80% exponential fit, ∼20% flat lateral distribution or flattening to core

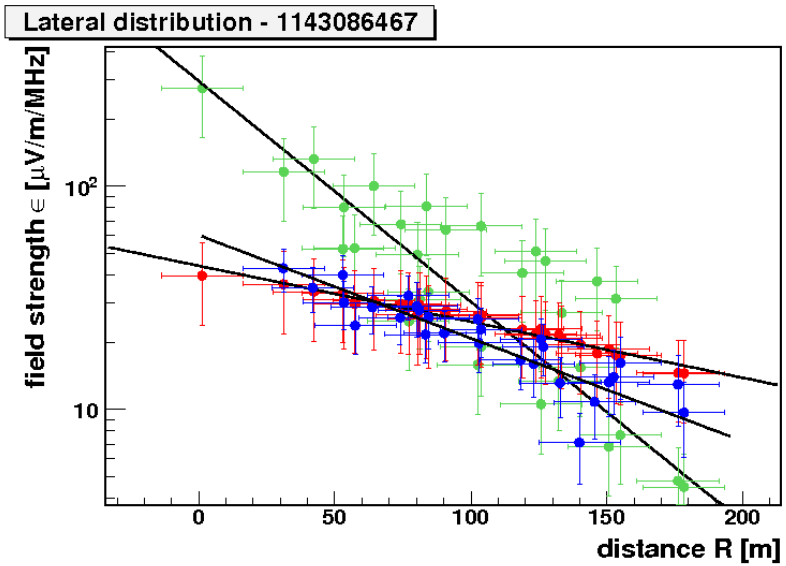


W.D. Apel et al. (The LOPES Collaboration), Astroparticle Physics 2010

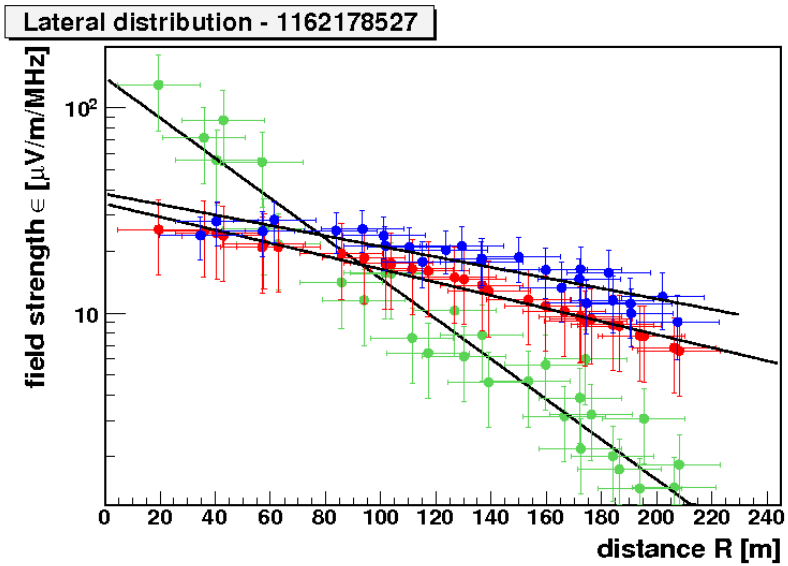
LOPES 30 – comparison with simulations I

- REAS3 fits nicely
- REAS2 often too steep
- Good shower information provided by KASCADE-Grande

proton induced



iron induced



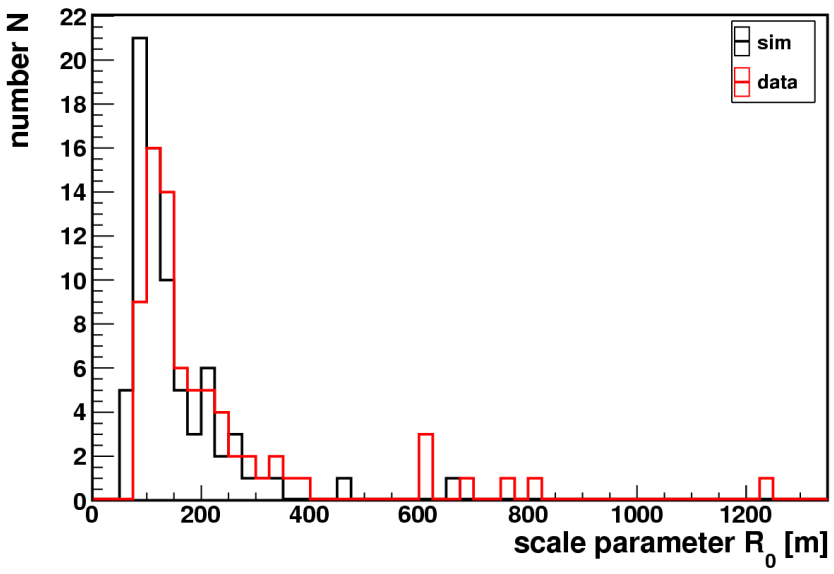
LOPES REAS3 REAS2

T. Huege et al. (The LOPES Collaboration), ARENA 2010

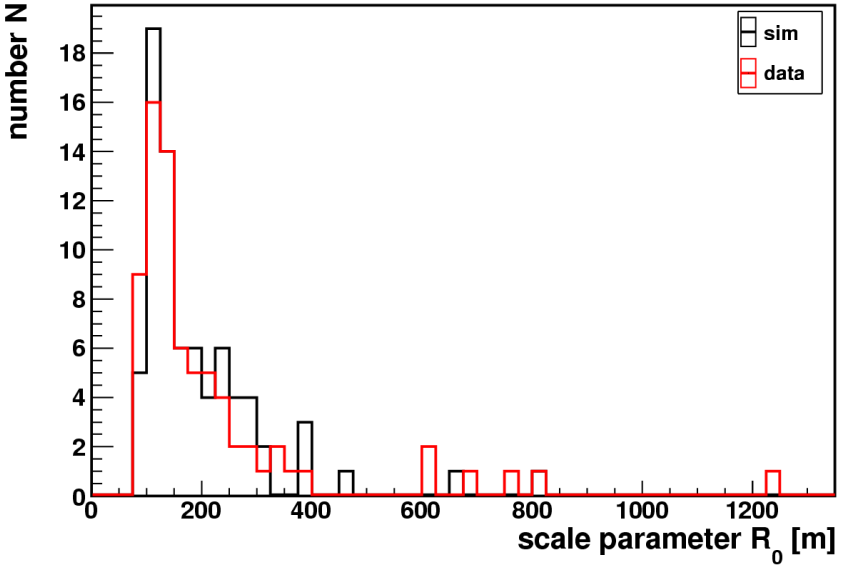
LOPES 30 – comparison with simulations II

- Iron simulations fit data better than proton simulations
- No extremly flat LDFs reproduced with REAS3

proton induced



iron induced

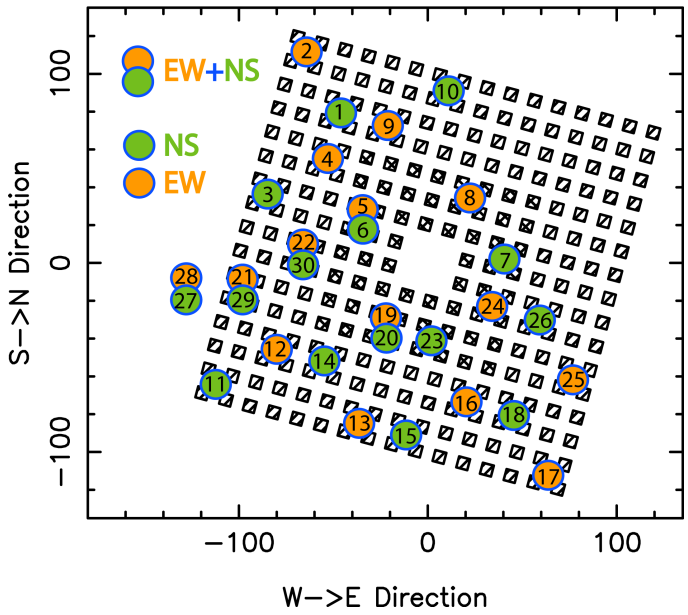


Energy of events $\sim 10^{17}$ eV LOPES REAS3

LOPES 30 pol

- Additional north-south polarization
- 10 purely north-south polarized antennas
- 10 purely east-west polarized antennas
- 5 double polarized antennas

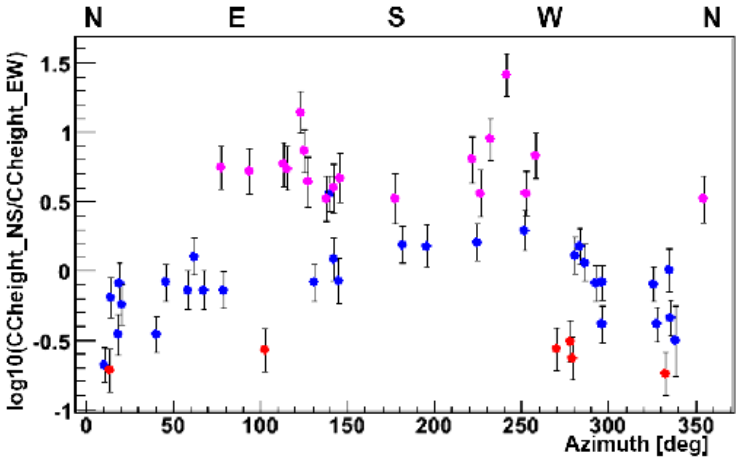
Antenna Layout

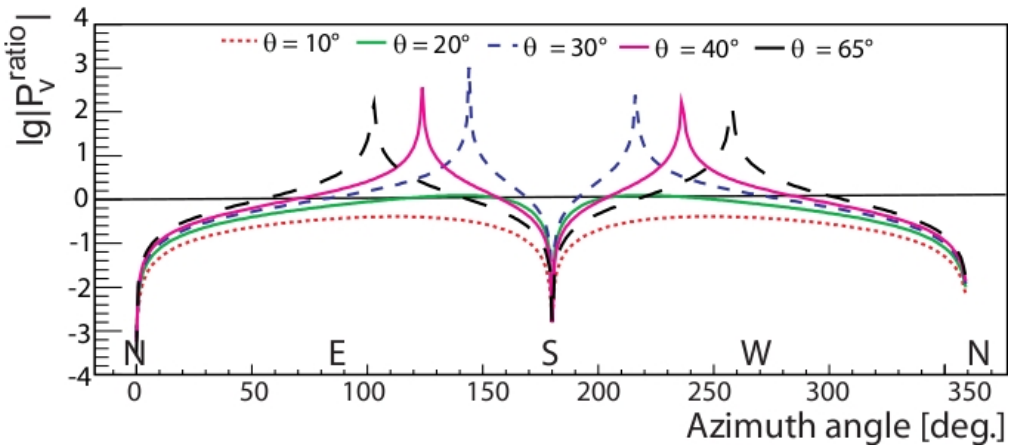


LOPES 30 pol – preliminary results

- Analyses still in progress
- First order data seems to follow $\vec{v} \times \vec{B}$ model

  Hints for deviation from pure $\vec{v} \times \vec{B}$



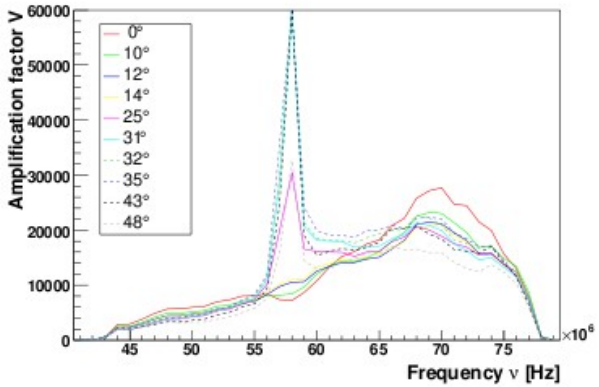


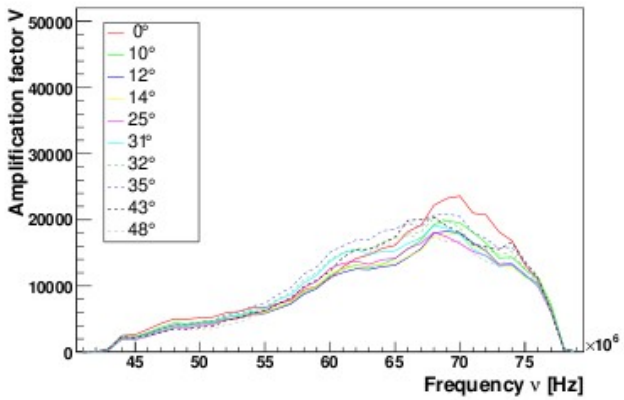
only ns detected both detected only ew detected

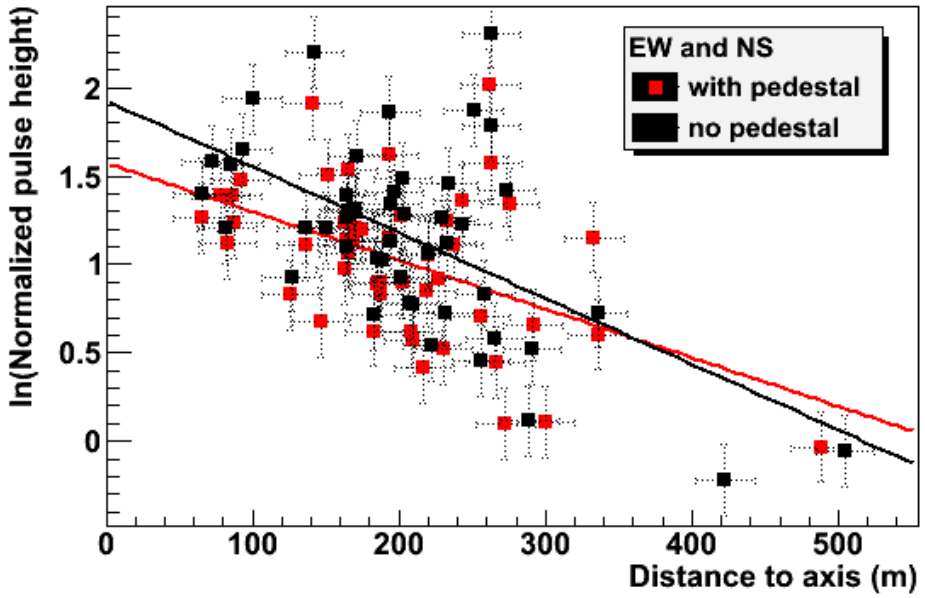
Isar et al. (The LOPES Collaboration), ICRC 2009

LOPES 30 pol additional analyses

- Very inclined showers from high distance can be observed
- Important – good knowledge of the antenna characteristics
- Analyses going on wiht LOPES 30 pol data





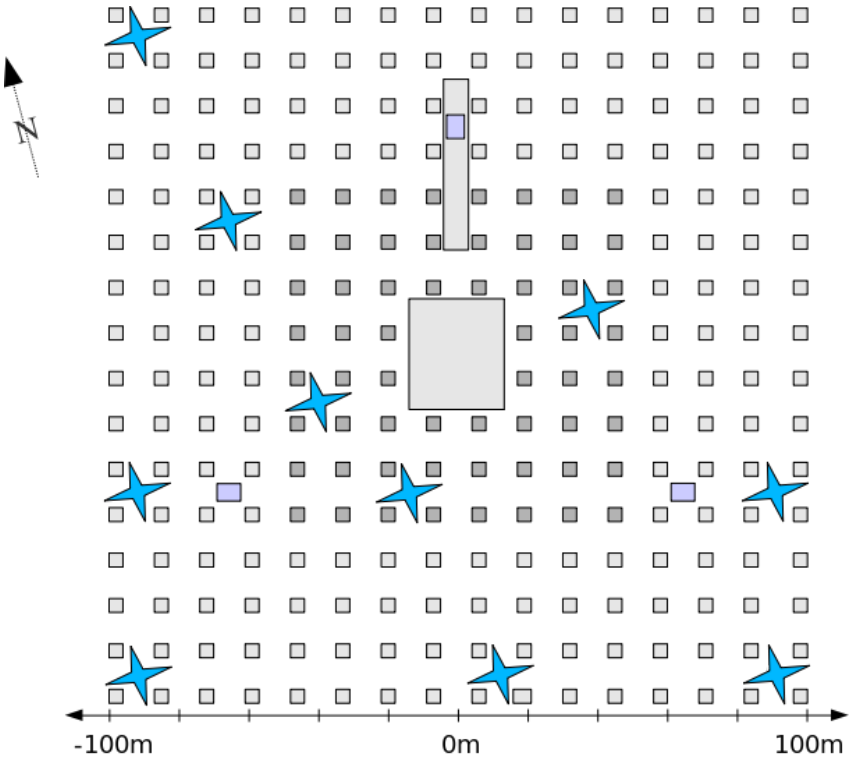


LOPES 3D

- Additional vertical polarization
- 10 tripole antennas

new LNAs + antenna type

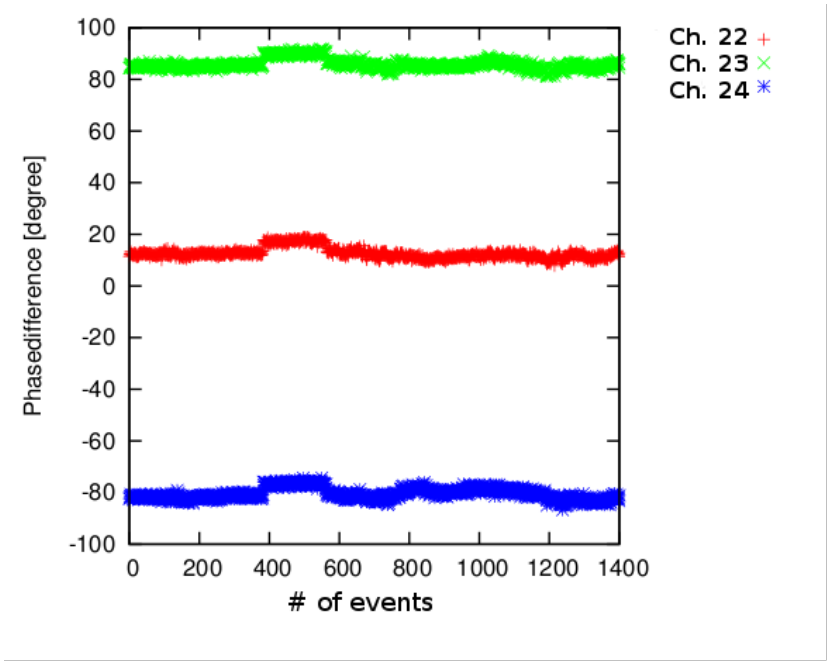
kept Readout

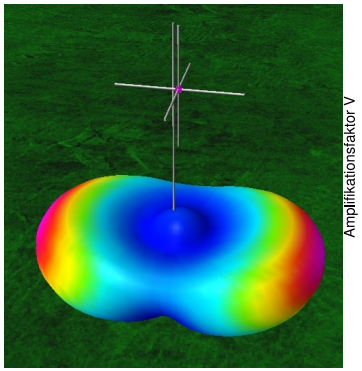


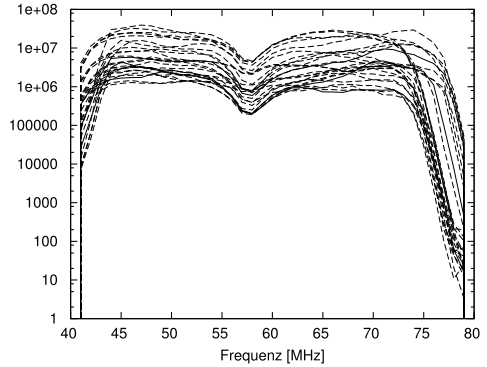
LOPES 3D calibration

- ✓ Simulating the gain pattern
- ✓ Delay measurements
- ✓ Calculating reference phases
- ✓ Measuring the antenna positions via GPS
- ✓ Amplitude calibration

⇒ **Calibration completed**



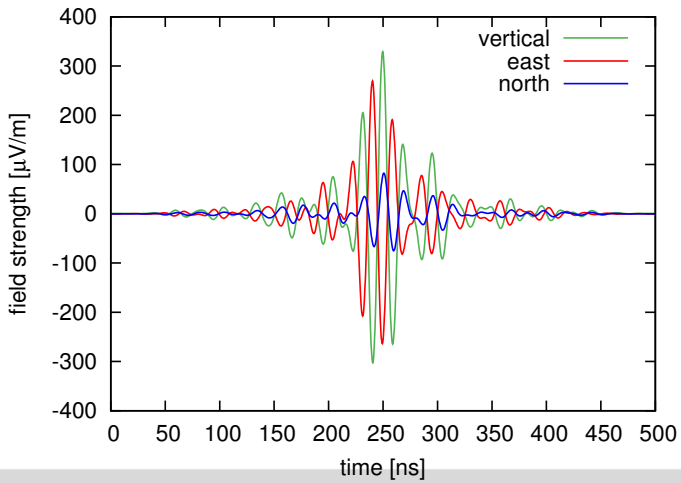


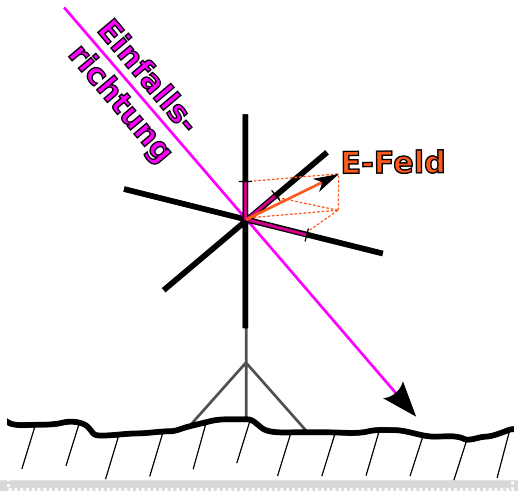


Motivation

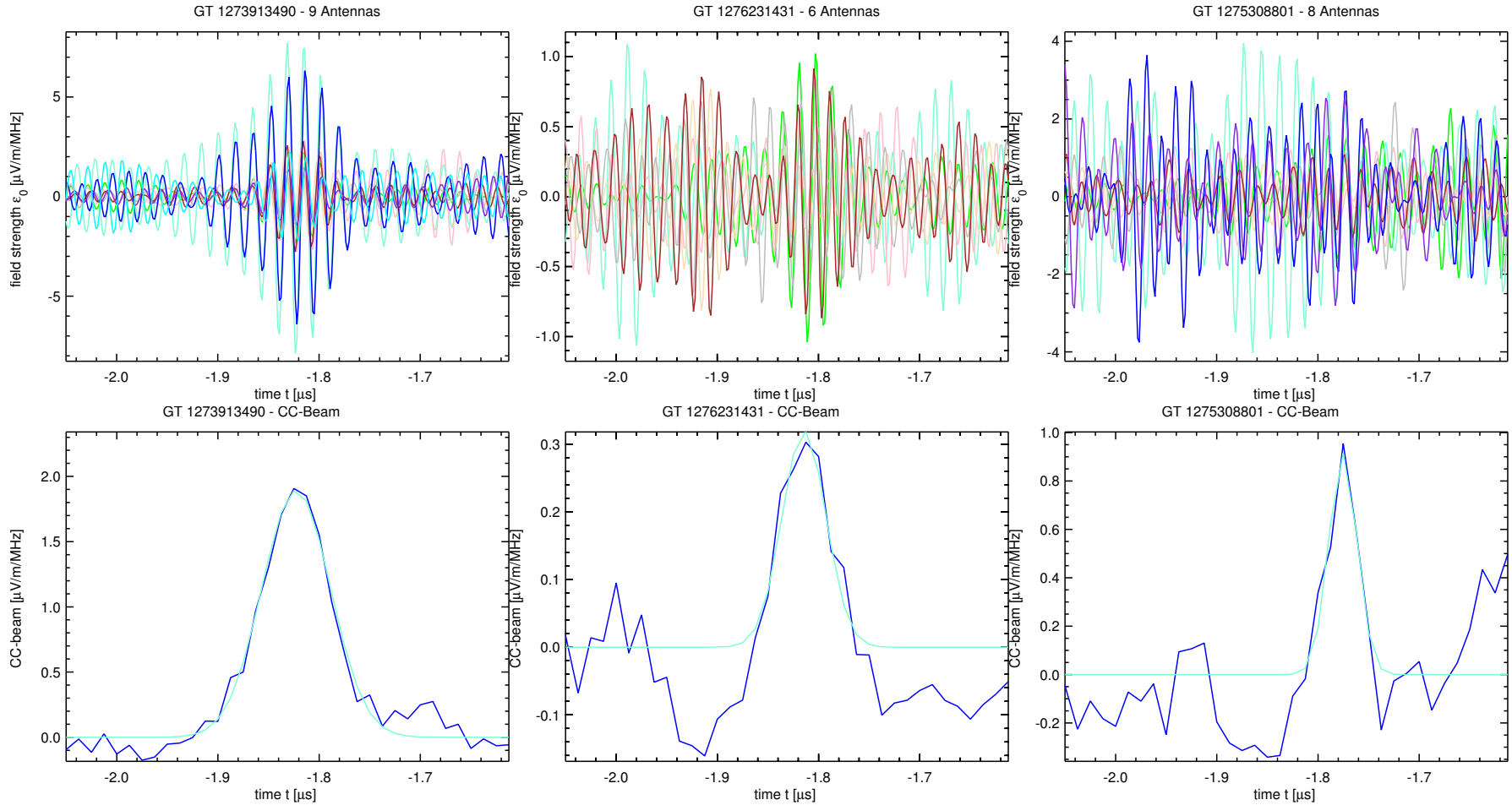
- To measure full information of the electric field vector not only a projection
- Vertical polarization allows higher sensitivity to horizontal showers (low elevation)
- Get direction information of the air shower axis based on one antenna
- A better comparison with emission models like the geosynchroton model is possible

→ better understanding of the emission mechanism





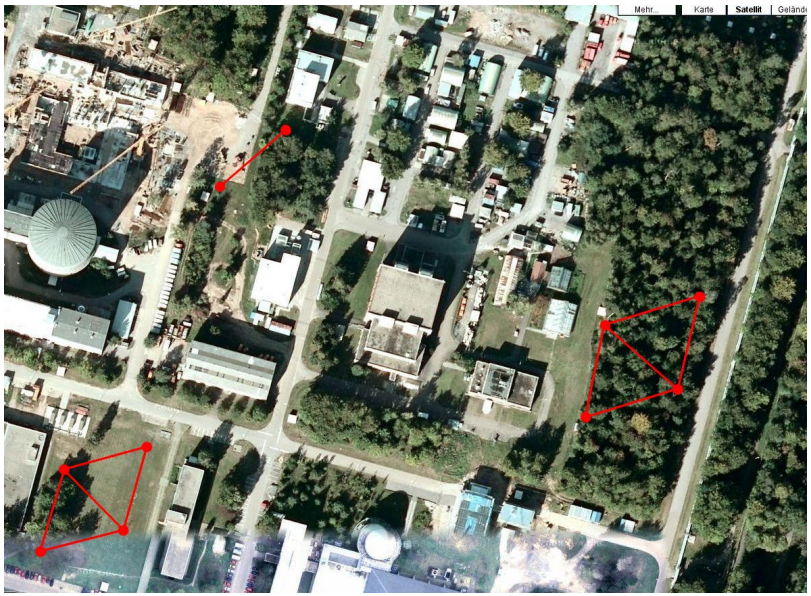
LOPES 3D – first data – preliminary



EW NS VE

LOPES^{STAR}

- **S**elf **t**riggerede **a**rray of **r**adio detectors
- Developments for large scale radio experiments
  - → Antennas (LPDA, SALLA)
  - → LNAs, filters (low power consumption)
  - → Self trigger with a real time digital RFI supression, upsampling an envelopping using an FPGA (**f**ield **p**rogrammable **g**ate **a**rray)
- Data taking in coincidence with LOPES



Summary and outlook

- LOPES is an ever evolving experiment
- KASCADE-Grande provides LOPES with high quality shower information (hybrid detection of air showers)
- Latest configuration LOPES 3D (fully calibrated and taking data since May 2010)
- Analyses with LOPES are going on (LDF, comparison with simulations, polarization, mass sensitivity,noise treatment ...)
- LOPES ideal test station (R&D) for large scale experiments

Thanks for your attention !!!