

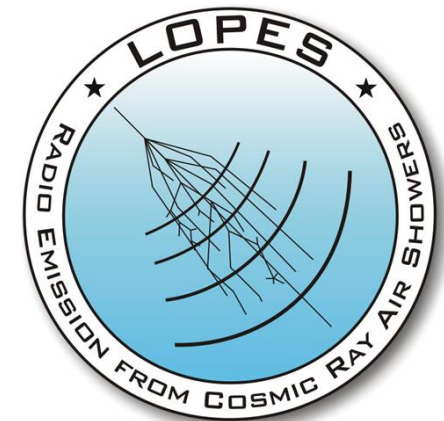
Messung der kosmischen Strahlung mit dem Radio-Antennenfeld LOPES



**Astroteilchenschule Obertrubach,
10. Oktober 2009**

Frank Schröder

LOPES collaboration
Pierre Auger collaboration



LOPES collaboration

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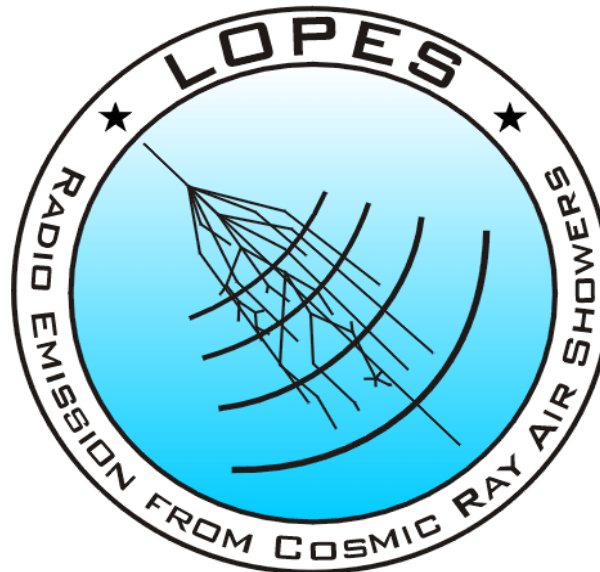
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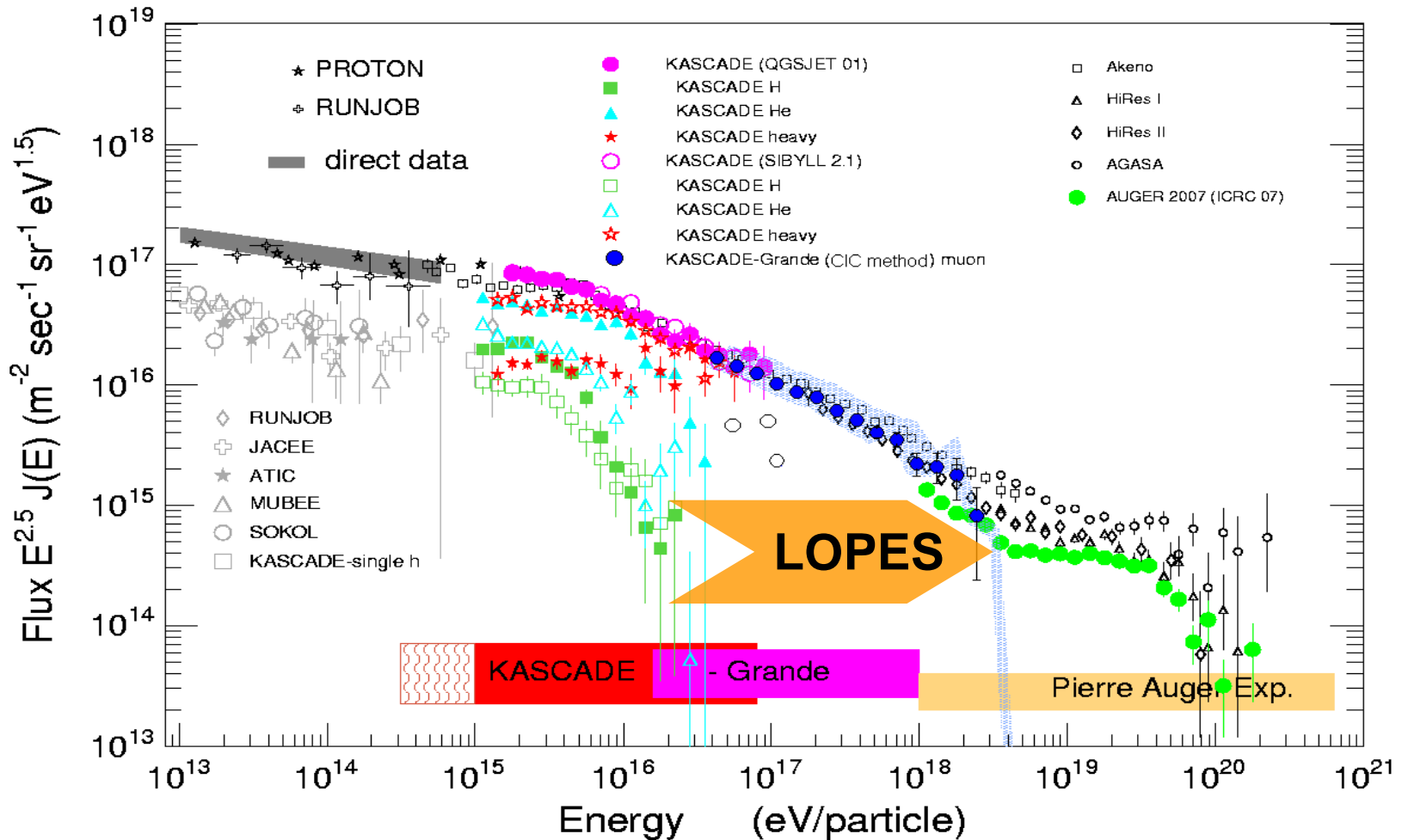
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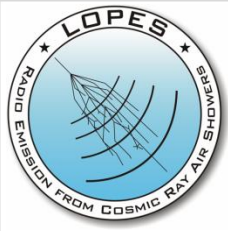


National Inst of Physics and Nuclear Engineering Bucharest, Romania

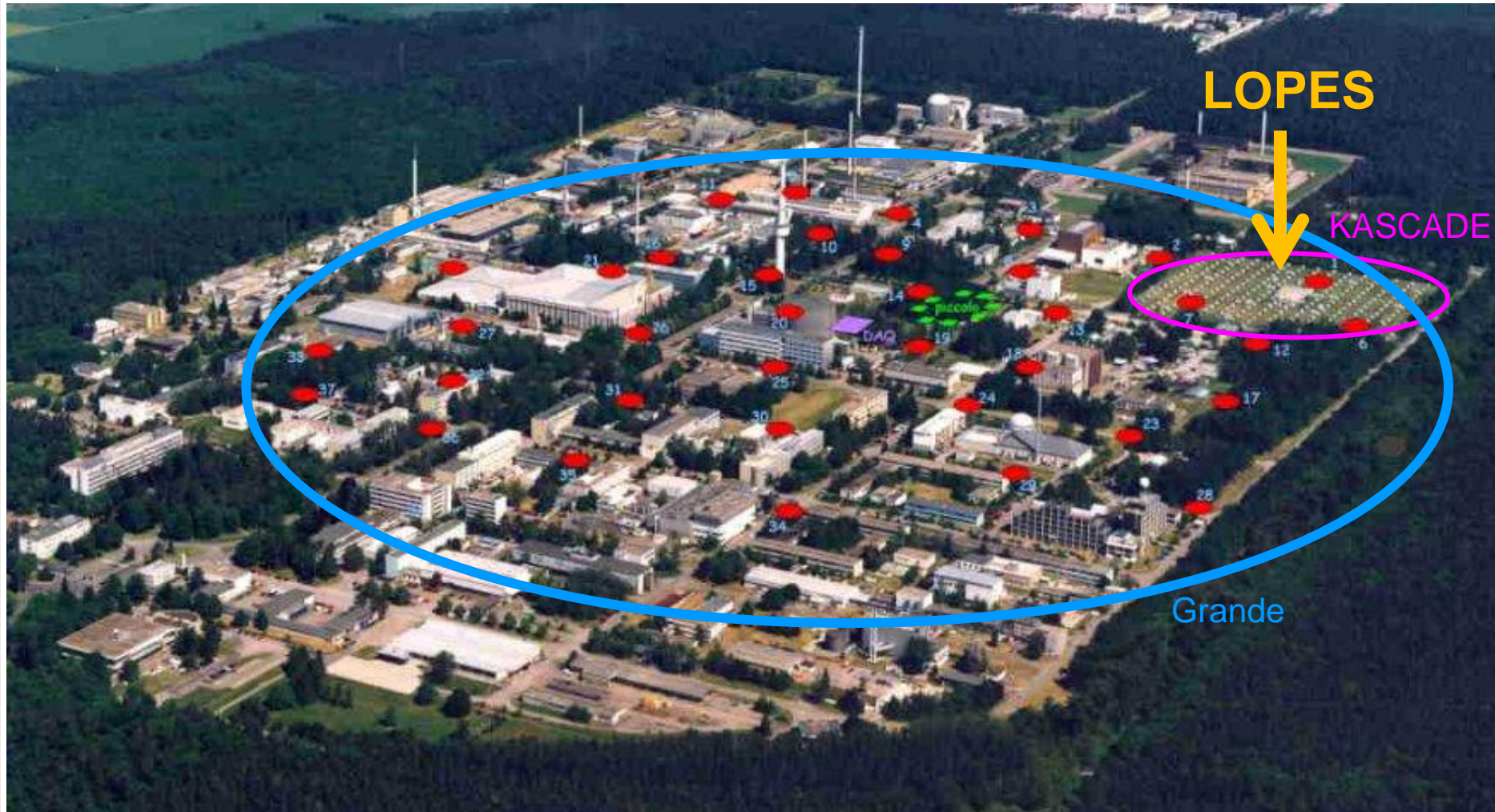
I.M. Brancus	B. Mitrica
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O. Sima	G. Toma

Energiespektrum



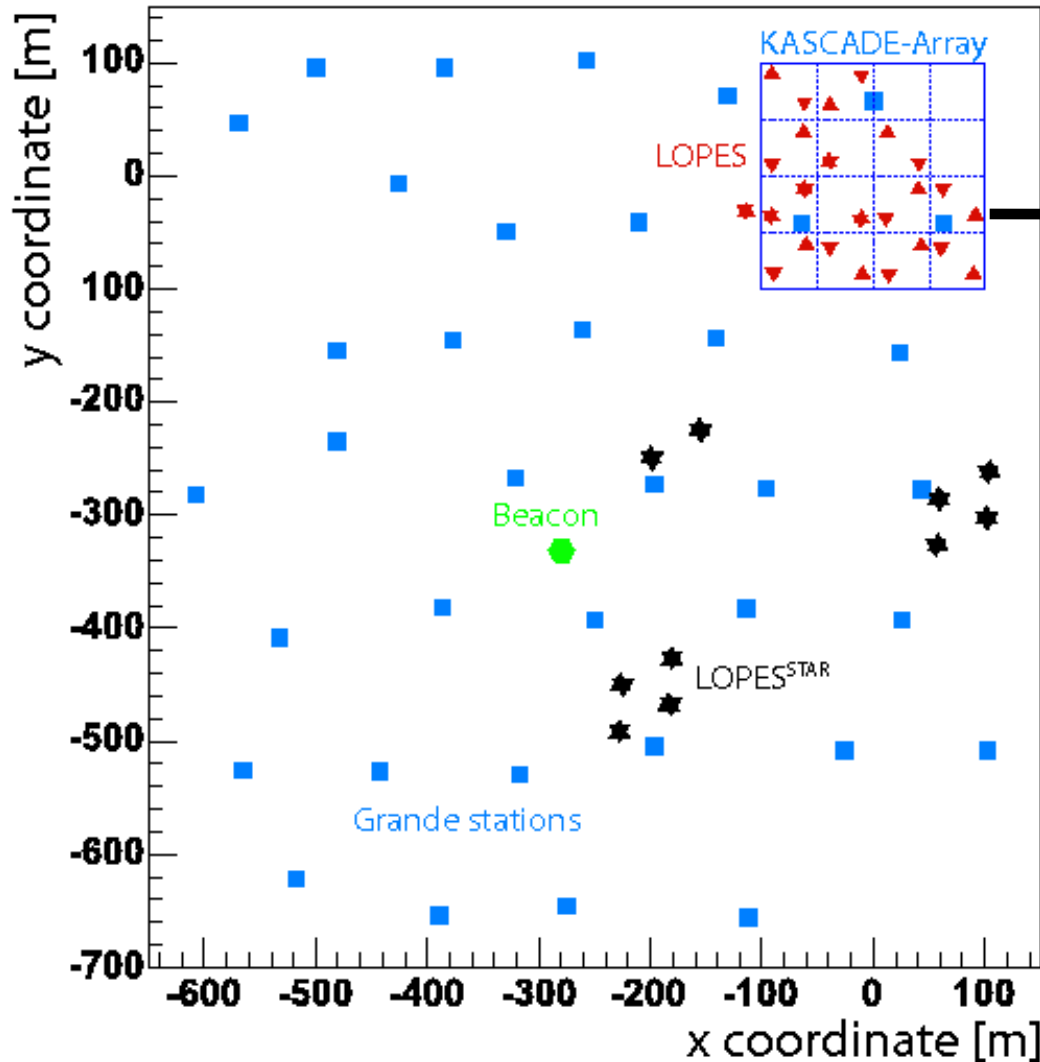


LOPES im KIT Campus Nord

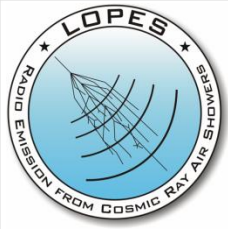




LOPES: Layout



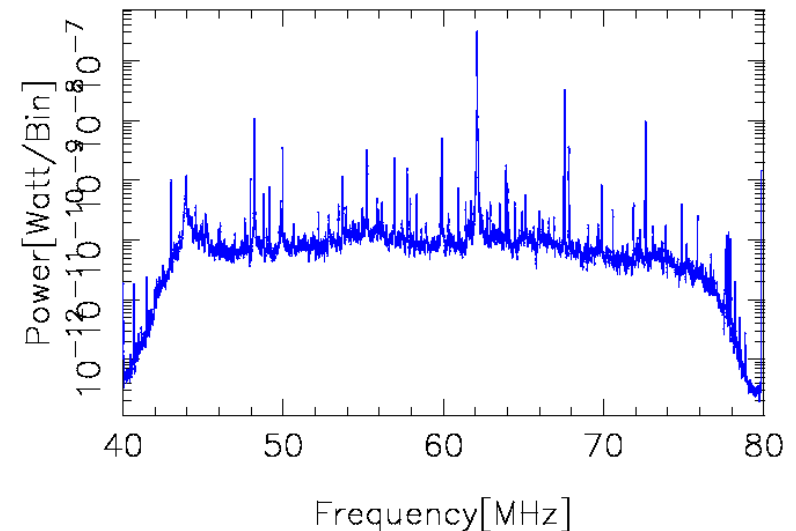
- 30 Dipolantennen
 - 15 ost-west
 - 15 nord-süd
- 10 Auger-Prototyp-Antennen



Datenerfassung

- Trigger: KASCADE-Grande
- Frequenzbereich: 40 – 80 MHz
- Digitaler 80 MHz ADC
- Spurlänge $\sim 800 \mu\text{s}$
 - Gute Frequenzauflösung
- Digitale Signalverarbeitung
 - Rauschunterdrückung
 - Amplitudenkalibration
 - Zeitkalibration

Spektrum eines Ereignisses

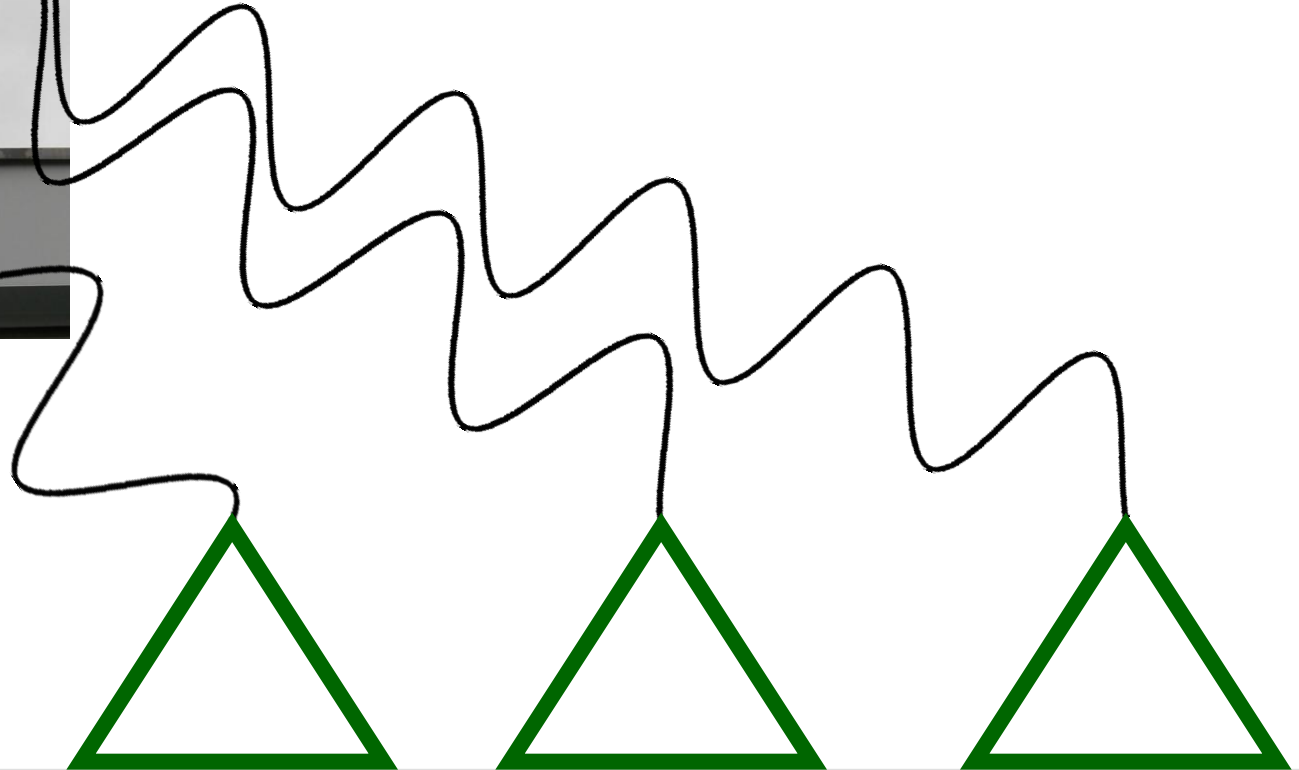


Zeitkalibration



Referenz-Beacon

- Messung der (frequenz-abhängigen) Delays
- Kontinuierliche Überwachung

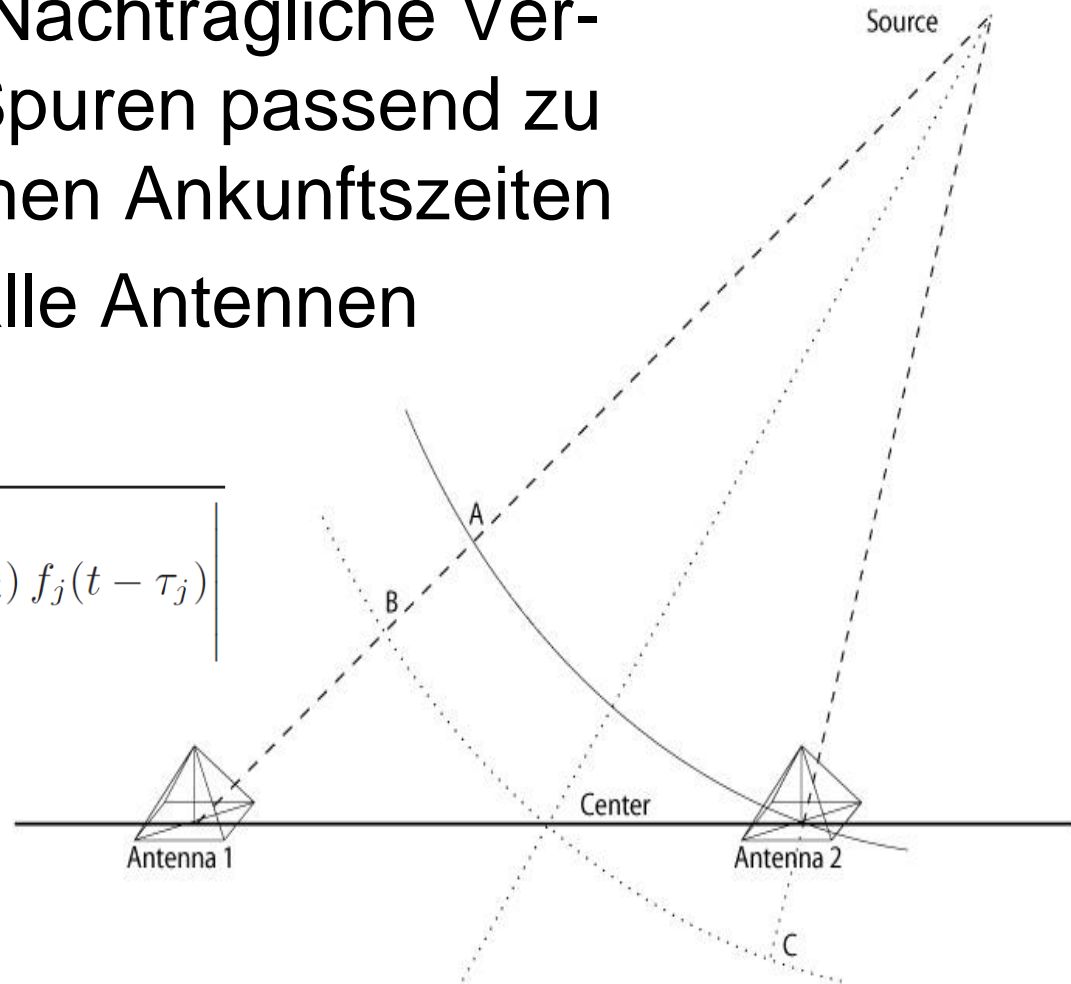


Digitale Interferometrie

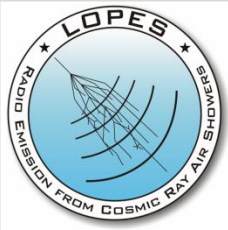


- Beamforming = Nachträgliche Verschiebung der Spuren passend zu den geometrischen Ankunftszeiten
- Summierung über alle Antennen
- Cross correlation:

$$S_{cc}(t) = \pm \sqrt{\left| \frac{1}{N_{pairs}} \sum_{i=1}^{N-1} \sum_{j>i}^N f_i(t - \tau_i) f_j(t - \tau_j) \right|}$$

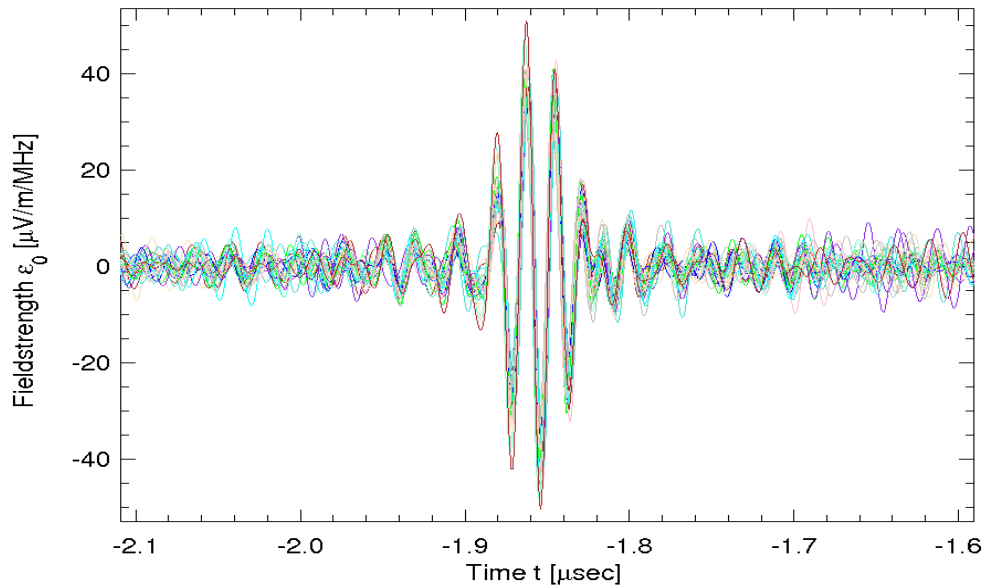


Cross-Correlation-Beam

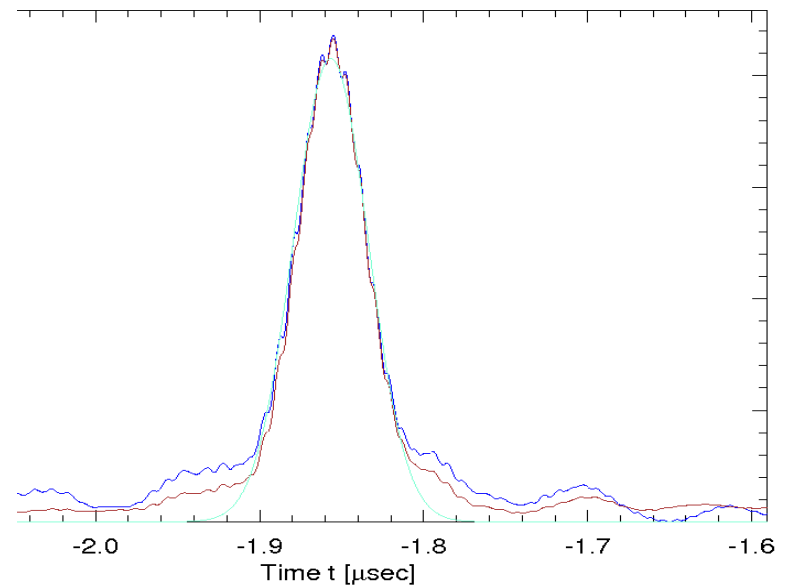


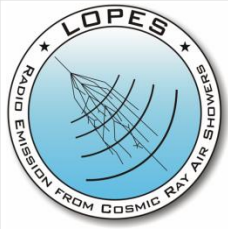
- Erwartete Kohärenz des Radiosignals von Luftschauern ist in Daten sichtbar
- Sensitivität erfordert Zeitgenauigkeit von ~ 1 ns!

GT 1162951881 - 26 Antennas

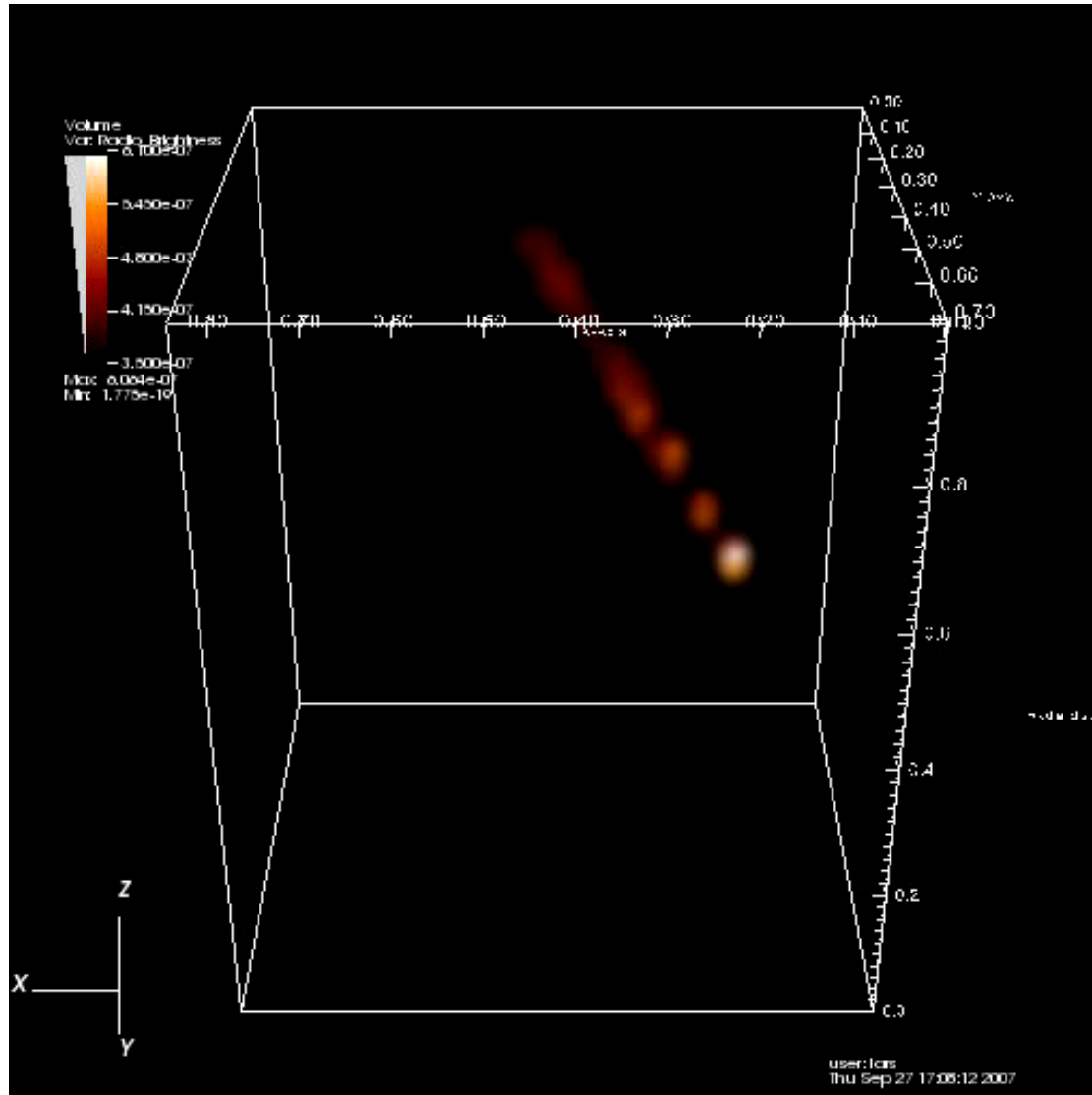


GT 1162951881 - CC-Beam and Power

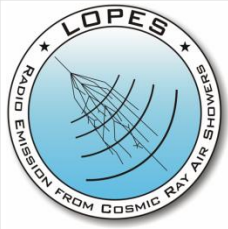




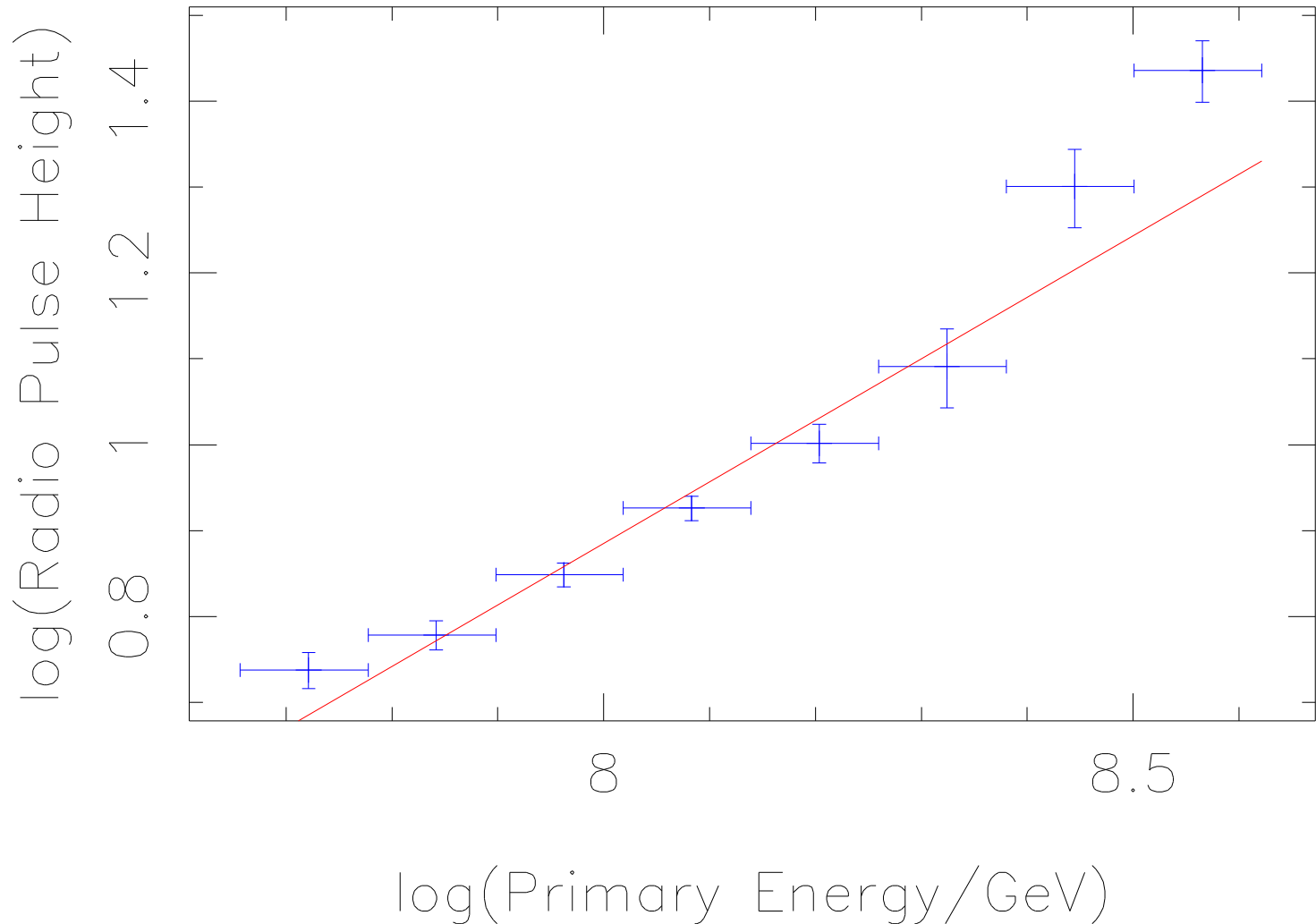
Skymaps: Ankunftsrichtung



L. Bühren



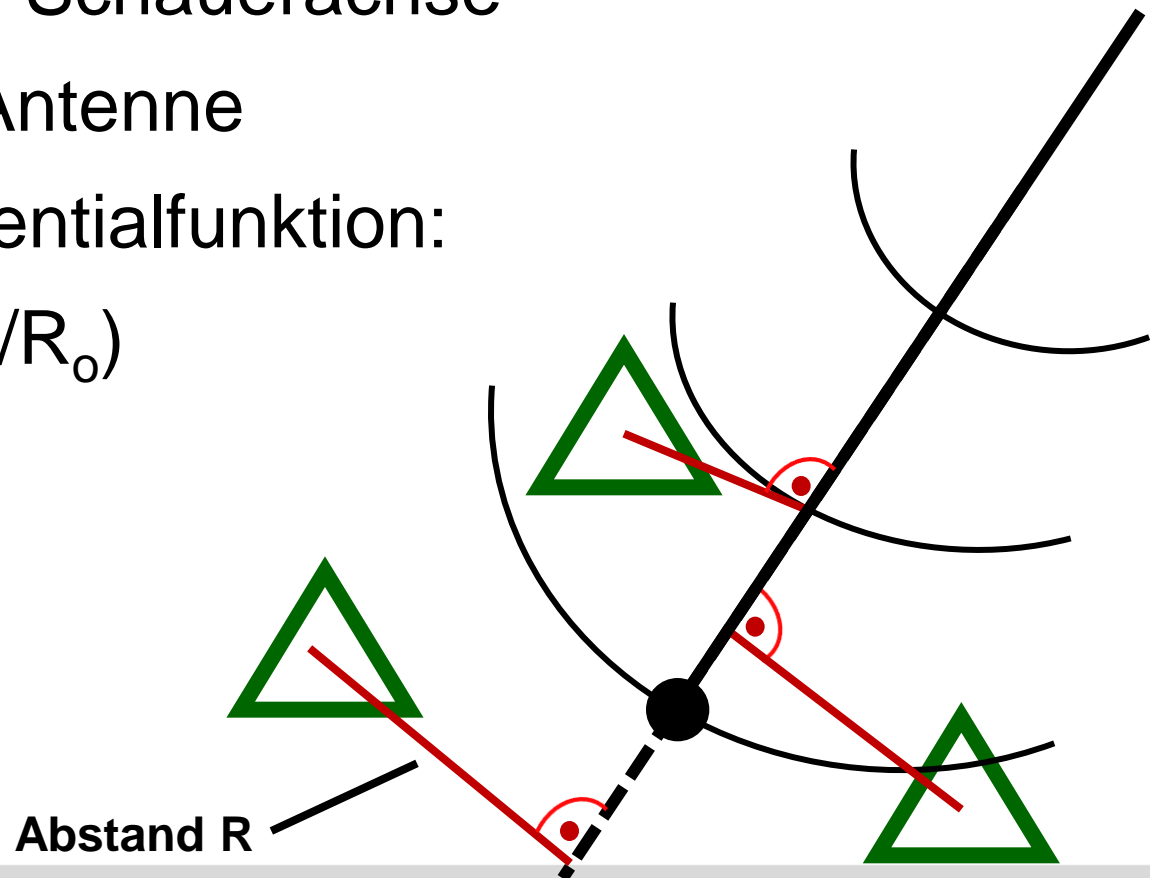
Energieabschätzung



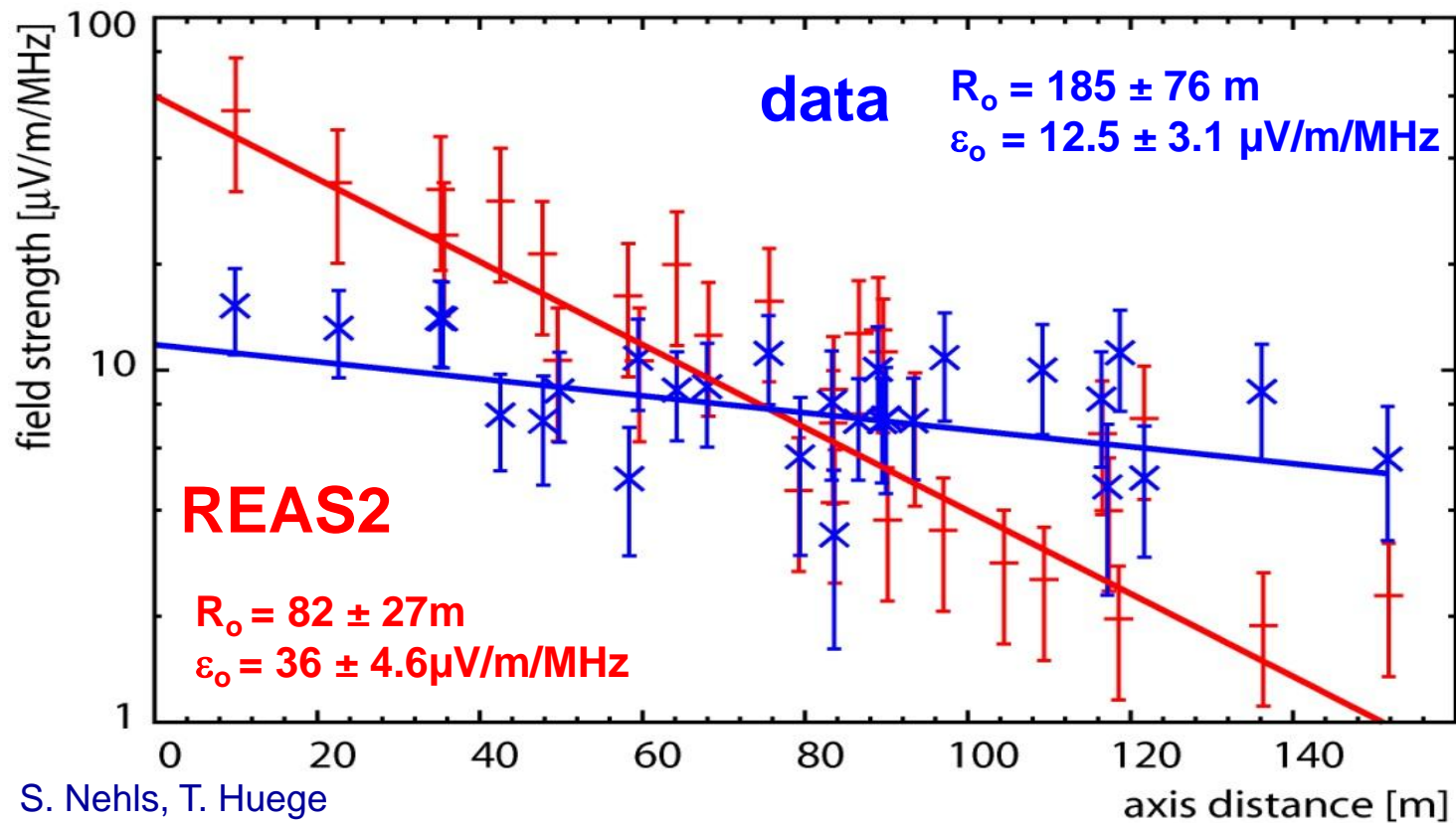
A. Horneffer

- Gemessene Signalthöhe ε in Abhängigkeit vom Abstand R zur Schauerrachse
- Ein Wert pro Antenne
- Fit von Exponentialfunktion:

$$\varepsilon = \varepsilon_0 \cdot \exp(-R/R_0)$$



- Simulationen steiler, aber in gleicher Größenordnung



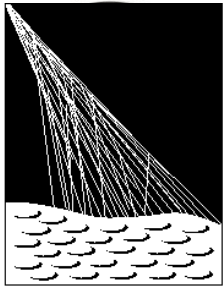
ev# 1143070602 $x_c = -44.3\text{m}$ $y_c = -22\text{m}$ $E_0 = 2.3 \cdot 10^{17}\text{ eV}$ $\phi = 19.3^\circ$ $\theta = 5.9^\circ$

- STAR = Self Triggered Array of Radio Detectors
- Entwicklung für das Auger Engineering Radio Array
 - Selbsttriggerung
 - Elektronik
 - Antennentypen

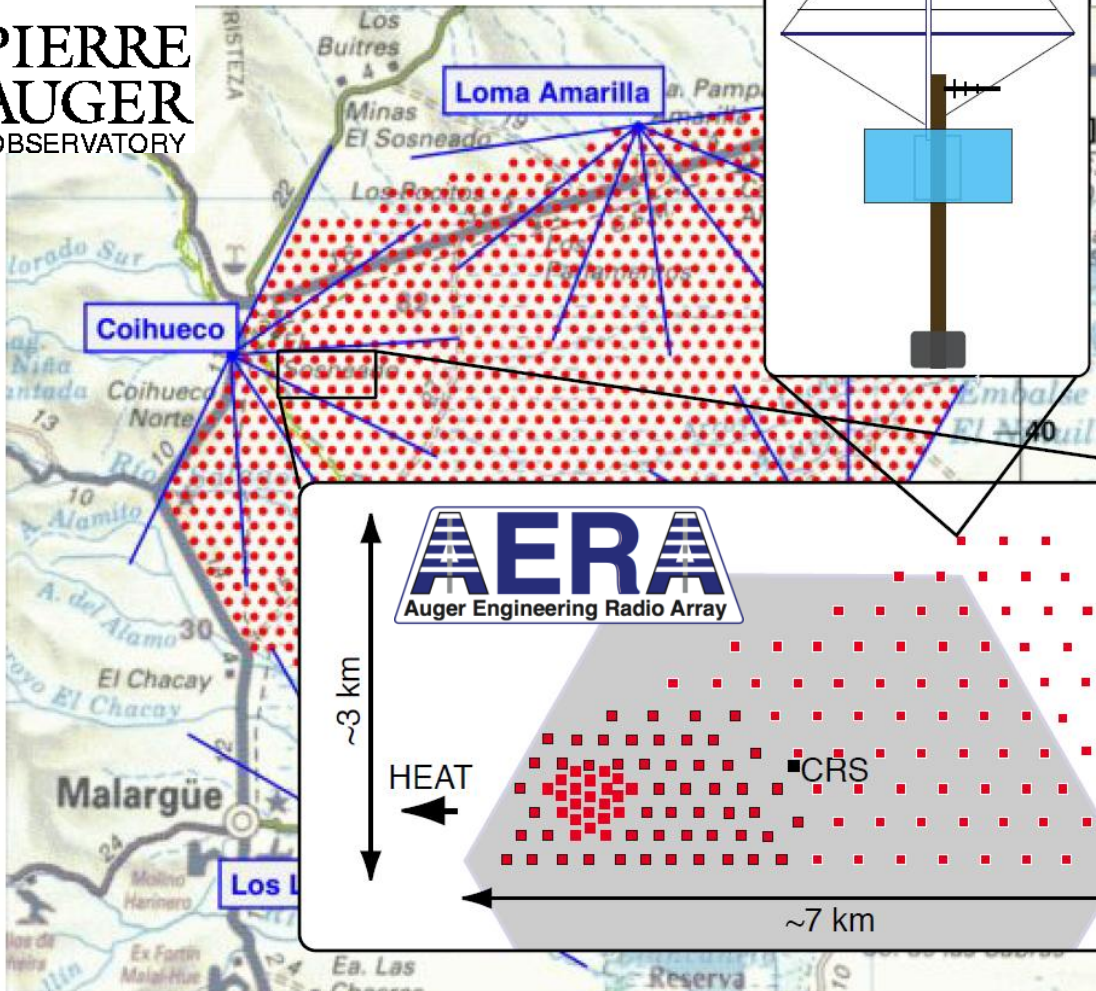


O. Krömer

Radio bei Auger



**PIERRE
AUGER
OBSERVATORY**



- 150 Antennen
- Unabhängigkeit:
 - Sonnenenergie
 - Drahtlos
 - Selbsttrigger
- Start 2010

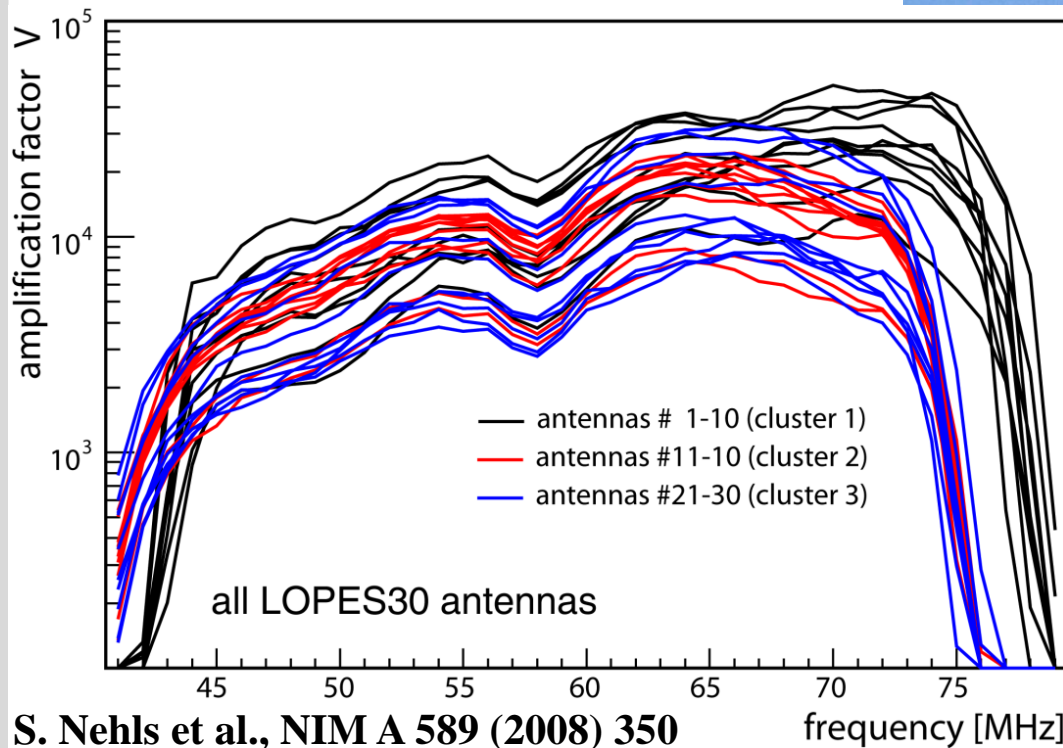
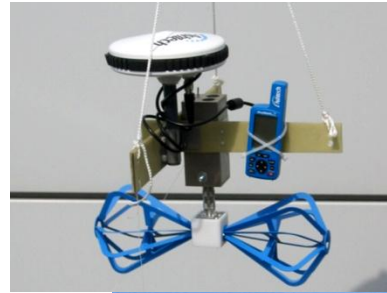


Zusammenfassung

- LOPES ist ein digitales Radiointerferometer zur Messung von kosmischer Strahlung
- Erfordert gute Zeitkalibration und ausgefeilte Techniken zur Signalverarbeitung
- Messung von Richtung, Energie und evtl. Masse
- Testfeld zur Weiterentwicklung von Hardware, Kalibrations- und Analysetechniken
- Nächster Schritt: Antennenfeld AERA im Pierre-Auger-Observatorium in Argentinien

Genauigkeit (power):

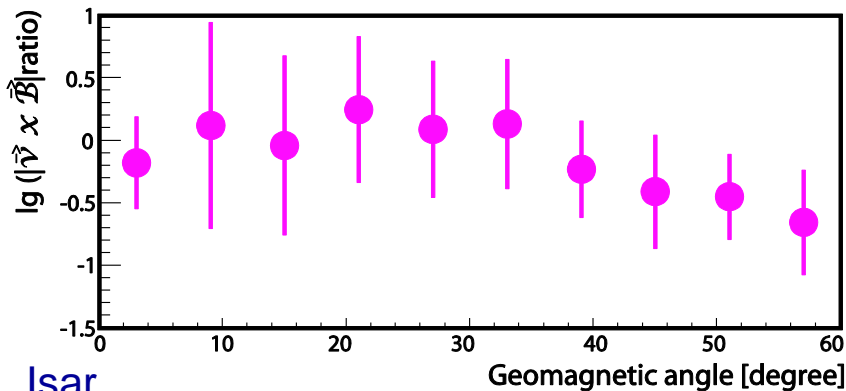
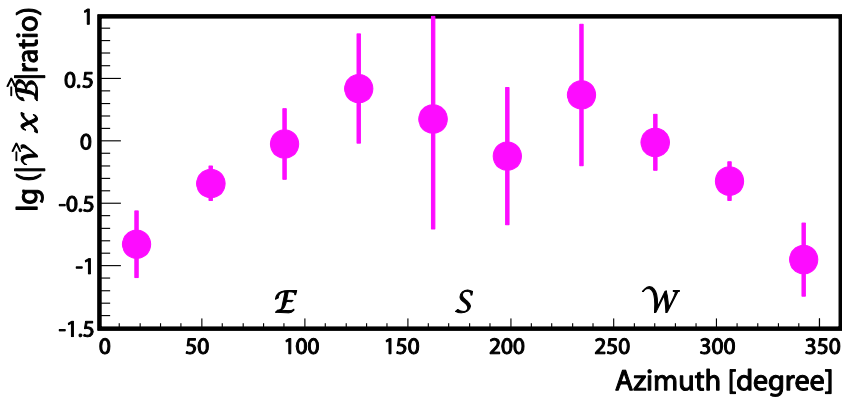
- 20 % syst. Fehler
- 67 % Referenz



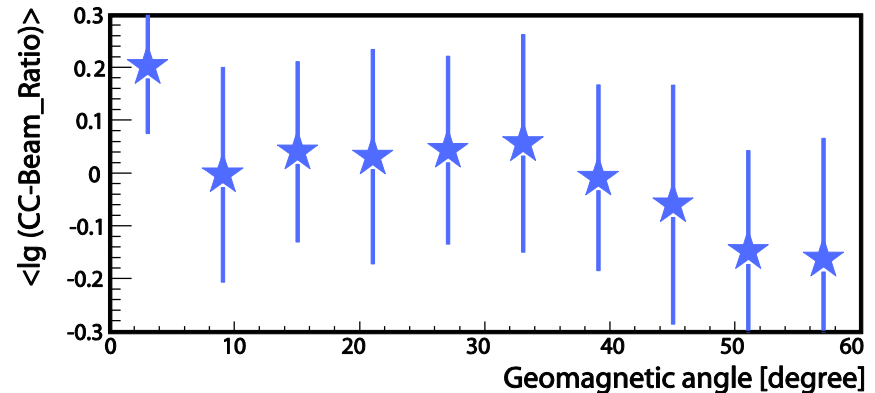
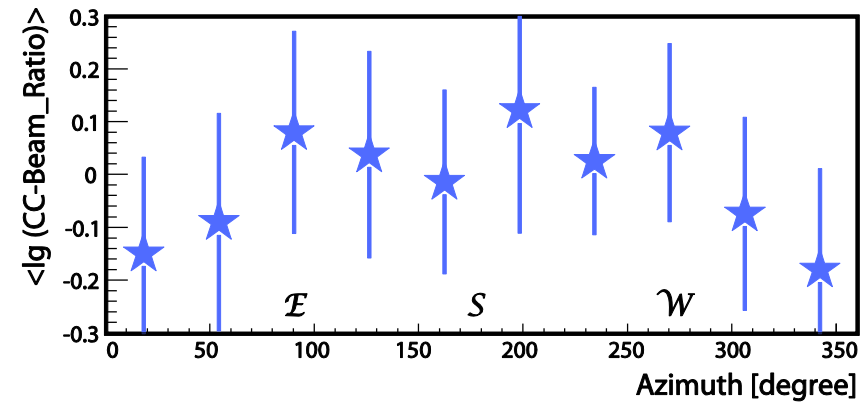
S. Nehls et al., NIM A 589 (2008) 350

- Simple, geo-magnetical, analytical $\mathbf{E} \sim \mathbf{v} \times \mathbf{B}$ model

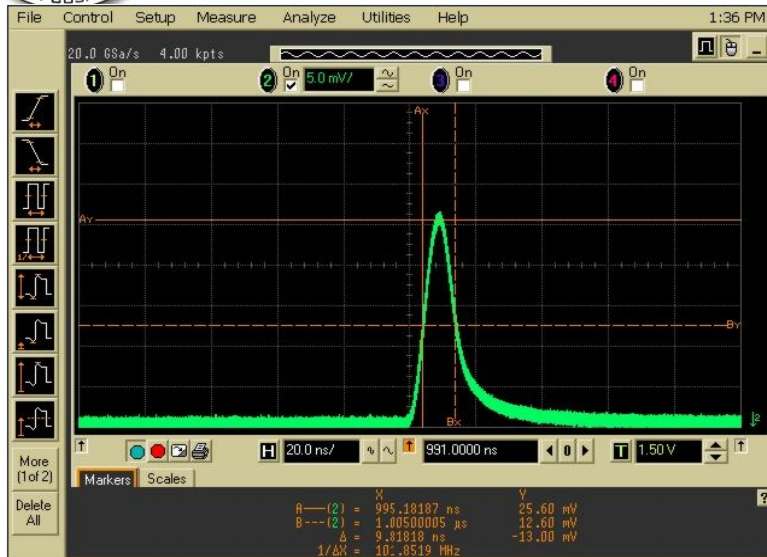
model prediction



LOPES data

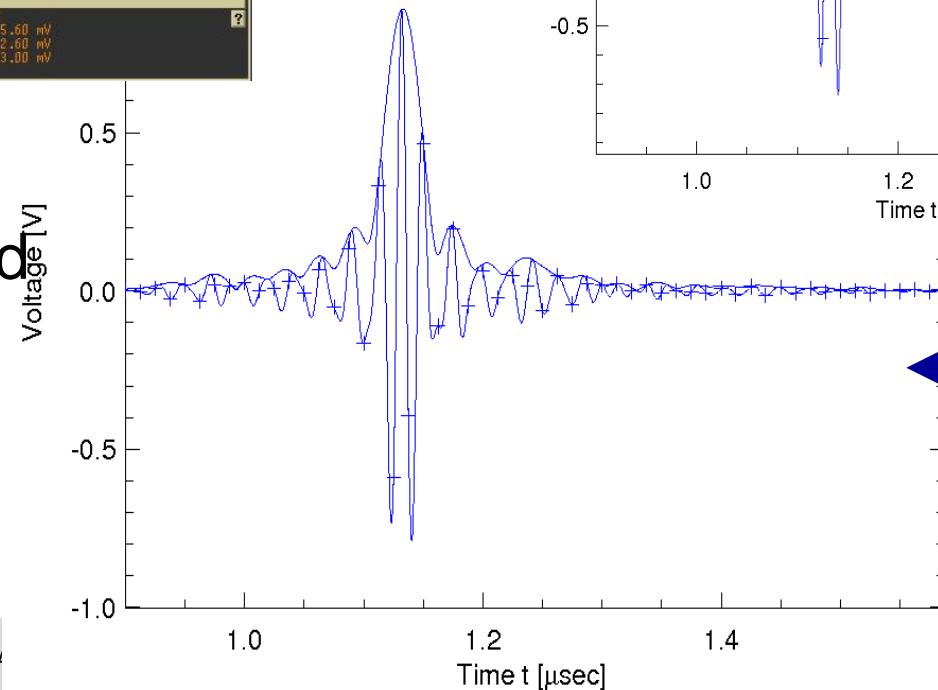
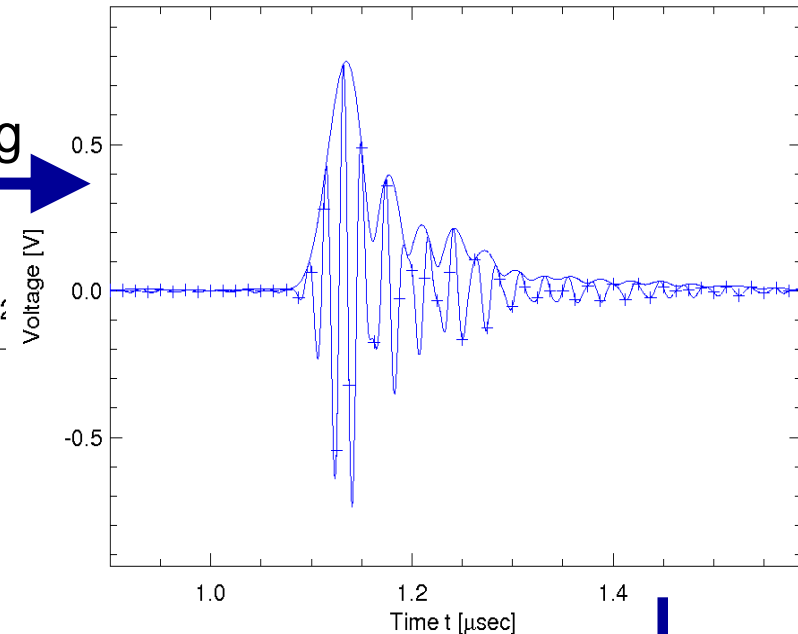


G. Isar



measuring

GT 12179:



correcting dispersion

■ Difference in pulse height and width:
~ 10 %

■ Determination of pulse timing in the data

