Helmholtz Russian Joint Research Group

Measurements of Gamma Rays and Charged Cosmic Rays in the Tunka-Valley in Siberia by Innovative New Technologies

Radio Detection of Cosmic Ray Air Showers

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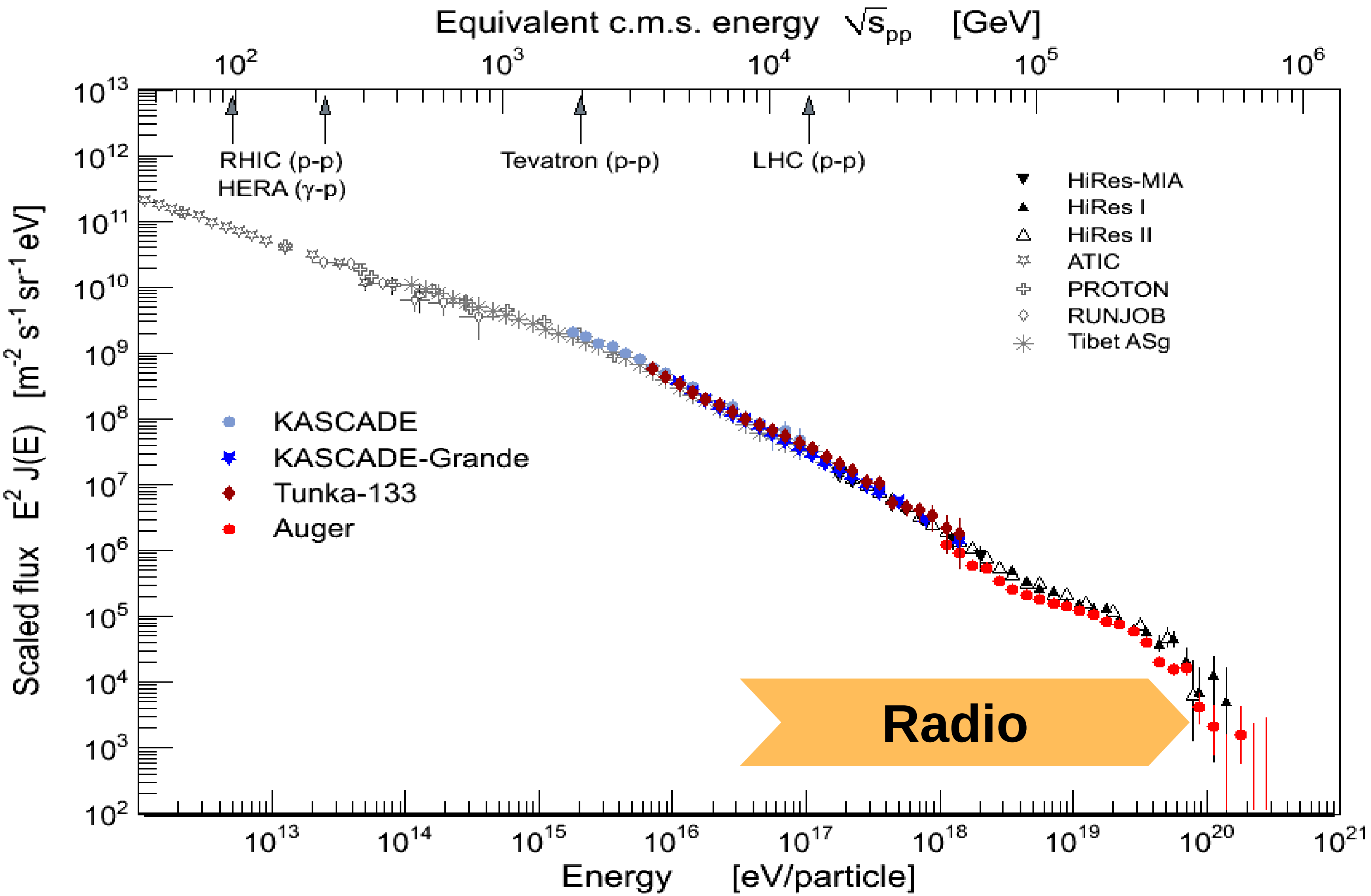
Cosmic ray energy spectrum



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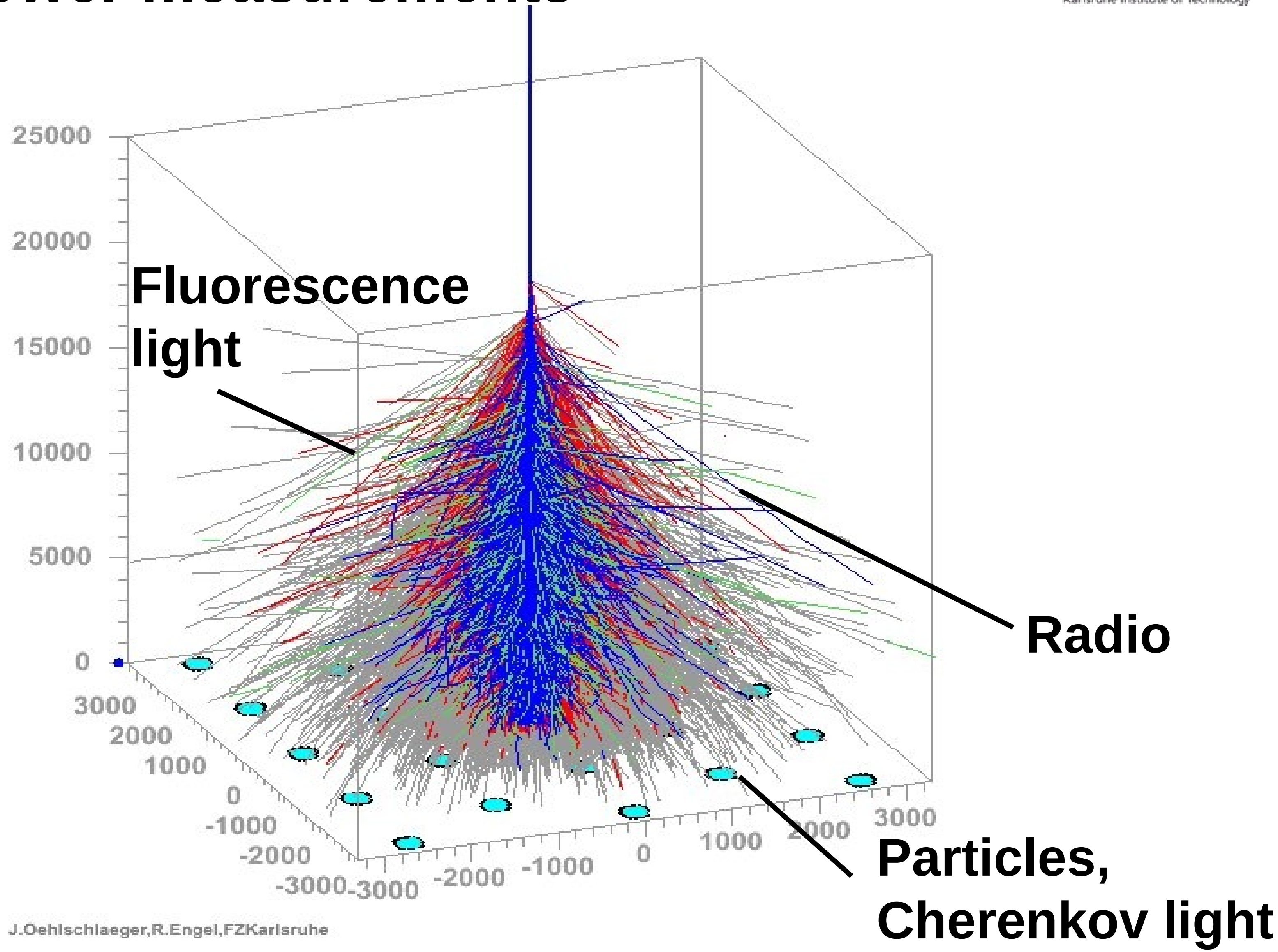
Air shower measurements



Comparison of methods

Current Status	Particles at Ground	Fluorescense / Cherenkov	Radio
Angular resolution	+	o / +	+
Energy	o	+	+ ?
Primary mass	- / o	+	+ ?
Exposure	+	o	-
Duty cycle	~ 100 %	**~ 10 %**	**~ 95 %**
Energy threshold	10^{13} eV	10^{17} eV	10^{17} eV

- Already shown: principle feasibility with radio (e.g. LOPES)
- Still to show: precision + large scale application

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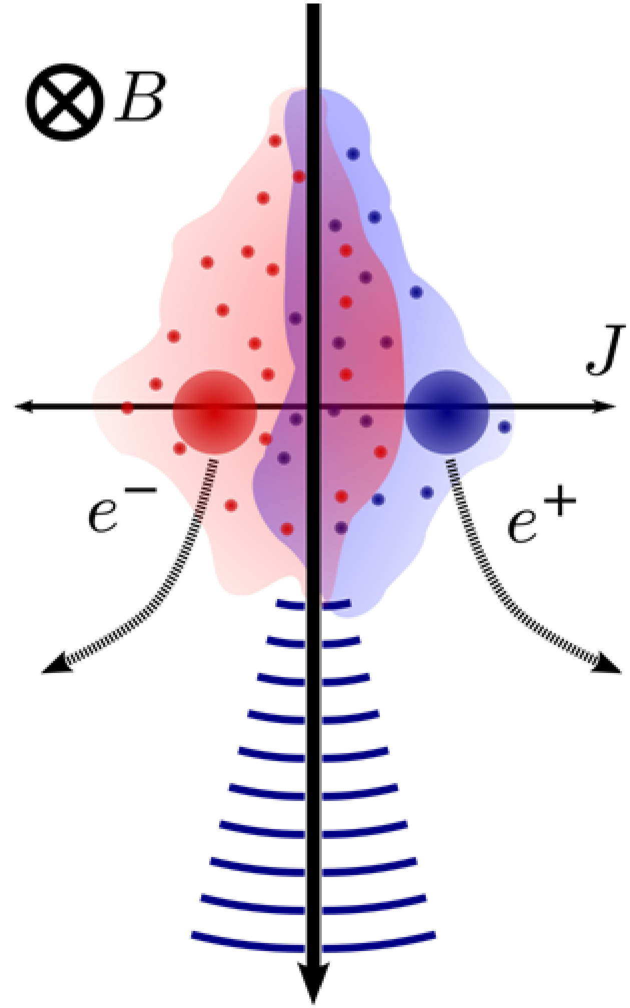
Radio emission processes

- Geomagnetic deflection of e^- and e^+
  - dominant effect
  - theoretical prediction: Kahn + Lerche 1966
  - many experimental proofs
- Variation of net charge excess
  - ~ 10% effect depending on geometry
  - theoretical prediction: Askaryan 1962
  - experimental proof by CODALEMA 2011
- Emission up to ~100 MHz, due to coherence condition:
  - λ > thickness of shower pancake (~ m)



T. Huege, M. Ludwig

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Experiments world wide

- Historic, analog experiments (since 1960`s)
  - e.g., UK, US, Russia (e.g. at MSU, Yakutsk), …
- Revival in 2003 with digital radio arrays
  - **LOPES**
  - CODALEMA
- New generation of digital radio experiments
  - **Auger Engineering Radio Array (AERA)**
  - **Tunka radio extension**
  - ANITA, RASTA at Antarctica
  - LOFAR (Netherlands), TREND (Tianshan, China)
  - Continuation, new analyses of experiments at MSU, Yakutsk, …

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LOPES at KIT

- Location and trigger: KASCADE-Grande
- 30 dipole antennas
- 40 - 80 MHz
- Absolute amplitude calibration
- Relative timing ~ 1ns
- Radio interferometer
  - digital combination of antennas to one beam

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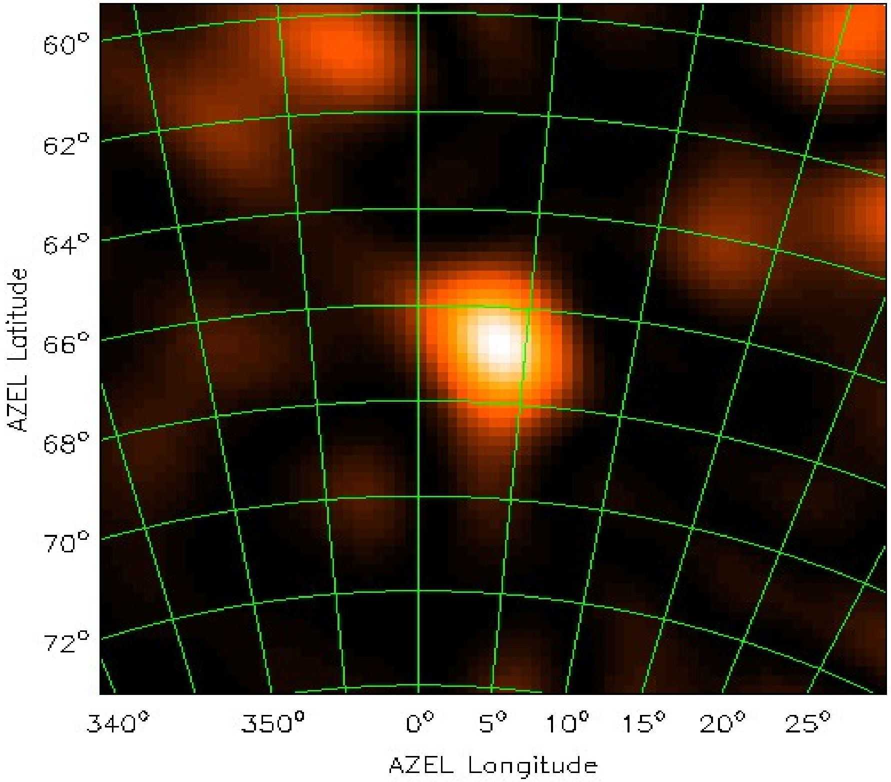
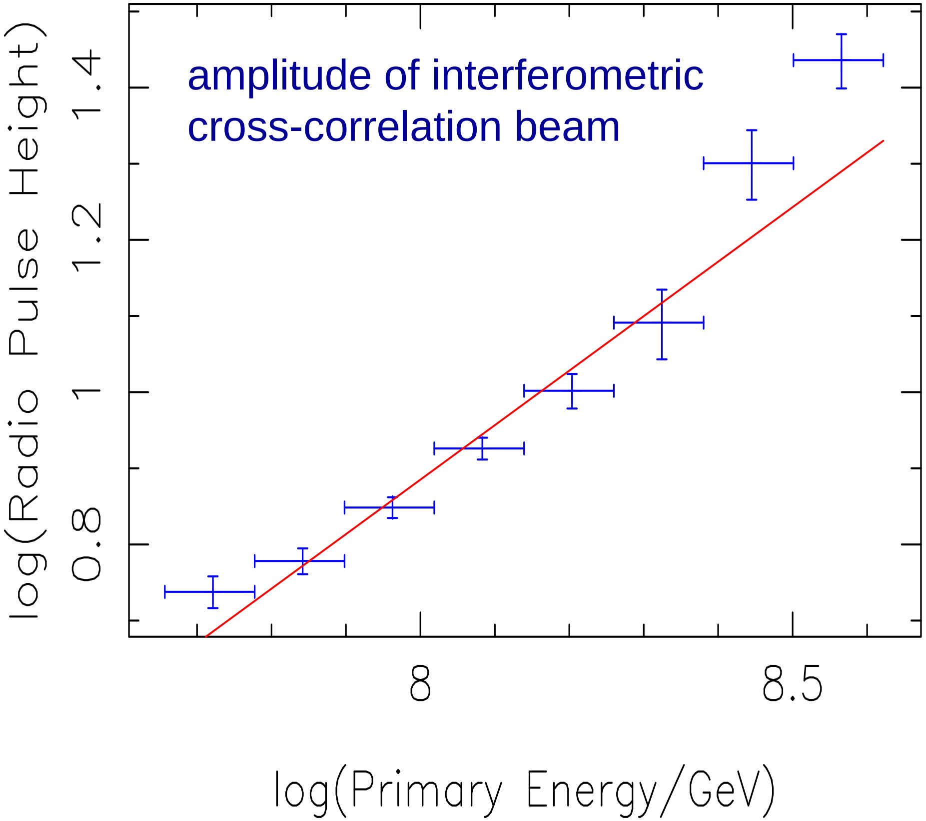
Direction and energy reconstruction

Visualization of radio pulse



Falcke et al. (LOPES coll.) 2005, Nature

Energy ~ amplitude



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Reconstructing cosmic rays with radio

- Arrival direction
  - very good, better than 1°
- Energy
  - precision is at least sufficient < 25%
  - theoretical expected: even better precision
- Type and **mass of primary particle**
  - via distance between detector and **shower maximum**:

    protons interact deeper in the atmosphere than heavy particles
  - two possible ways (LOPES + REAS3 simulations):

slope of lateral distribution	**angle of conical wavefront**

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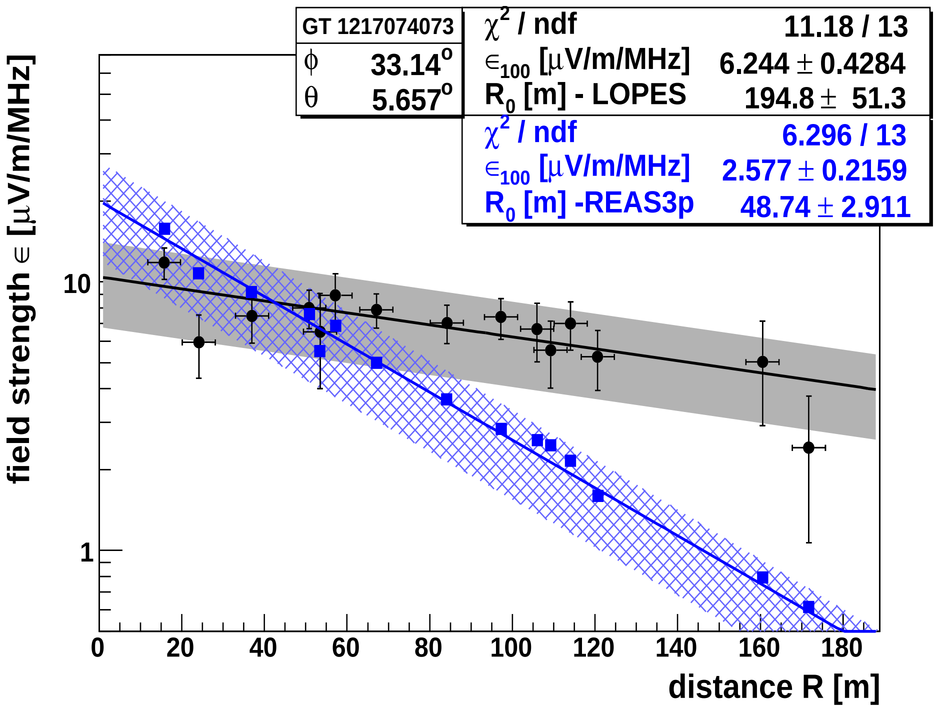
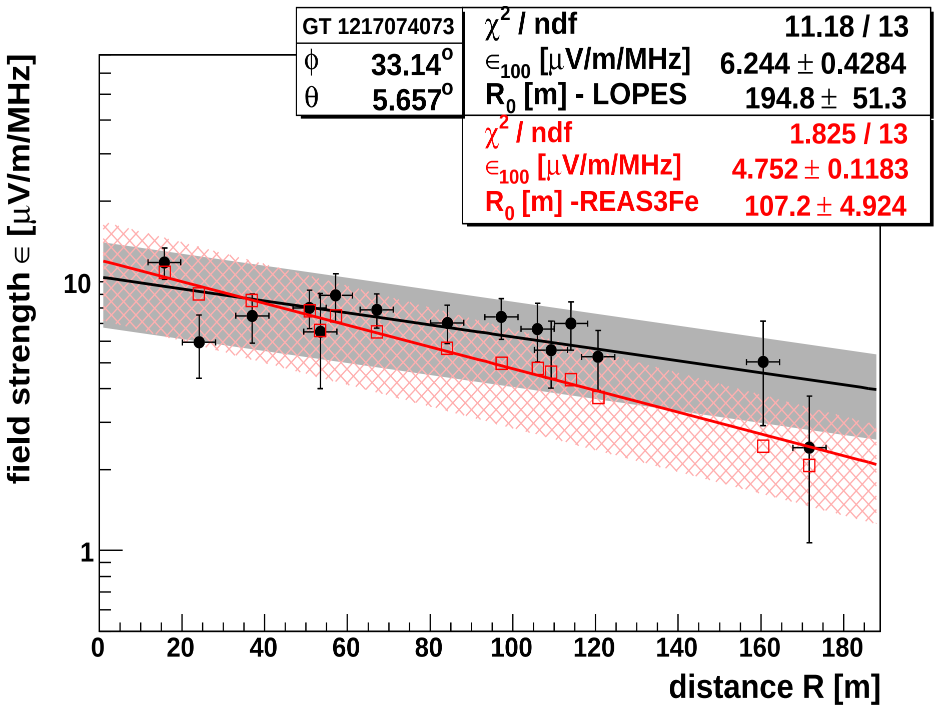
Lateral distribution example event

- REAS3 radio simulations for each LOPES event
- Proton lateral distribution steeper than iron

LOPES vs. REAS3 p



LOPES vs. REAS3 Fe



Thanks to M. Ludwig and T. Huege for the REAS3 simulations

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Status mass sensitivity

- Theoretical X_{max} resolution of 30 g/cm² possible
  - typical difference between proton and iron ~ 100 g/cm²
- However, LOPES performance is limited
  - high noise level at KIT makes precision much worse
  - absolute scale from simulations, mismatch with data
- Cross-calibration with independent method required
  - fluorescense light measurements of X_{max} at Auger
  - Cherenkov light measurements of X_{max} at Tunka

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Comparison AERA vs. Tunka radio ext.

	AERA	Tunka radio ext.
number of antennas	150	20
area	10 km²	1 km²
radio cross-calibration with	fluorescence	Cherenkov
estimated energy range	$10^{17.5}$ – 10^{19} eV	$10^{16.5}$ – 10^{18} eV
type of antenna station	autonomous	attached to Tunka
approx. cost per antenna	5 k€	0.5 k€

- Competition of most sophisticated vs. simple technology
- Complementary approach for same physics goal:
  What is the mass resolution of radio measurements?

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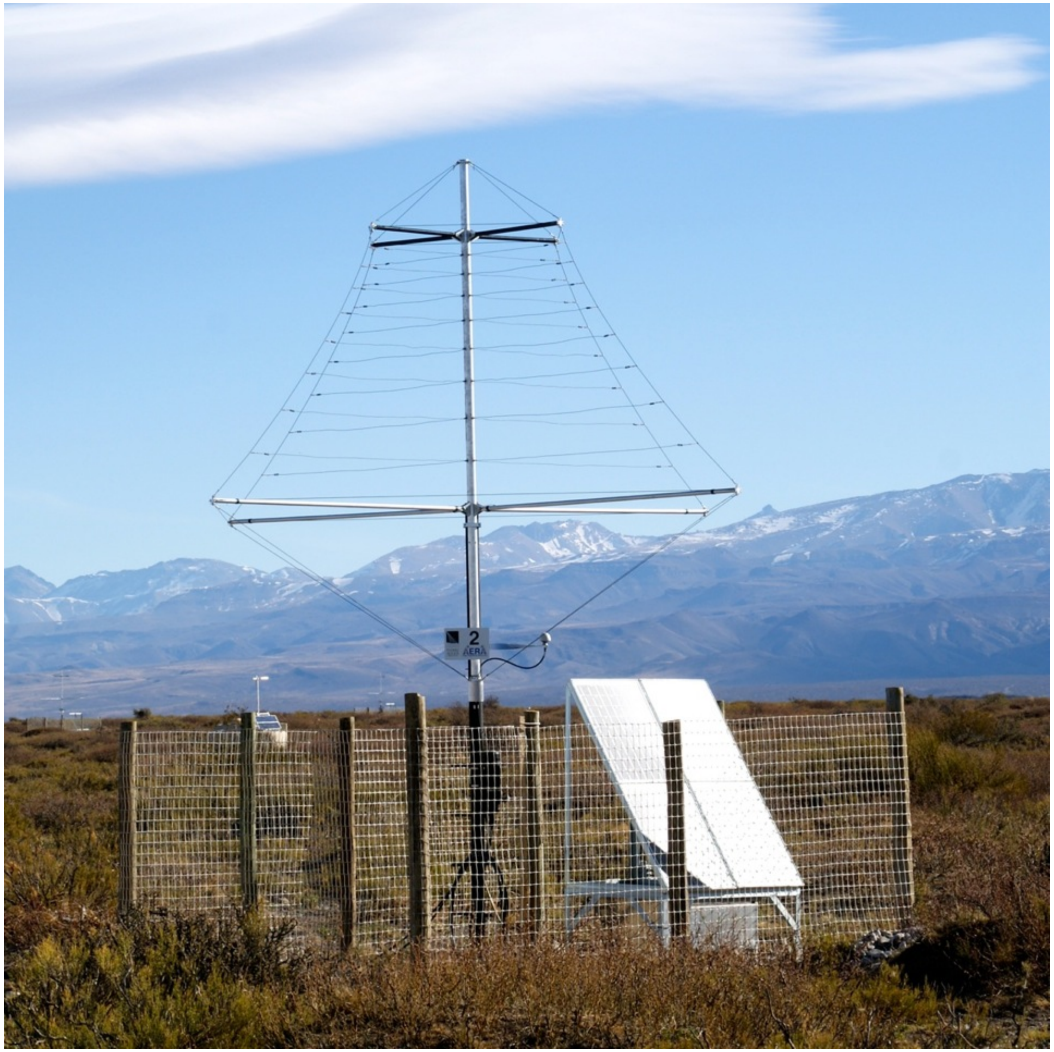
AERA
Auger Engineering Radio Array

PIERRE AUGER OBSERVATORY

KIT Karlsruhe Institute of Technology

- 150 antennas on 10 km²
- 24 stations in operation
- 30-80 MHz
- Self-triggered, autonomous stations
- First cosmic ray events in spring 2011

  (earlier events with prototype radio stations at Auger)



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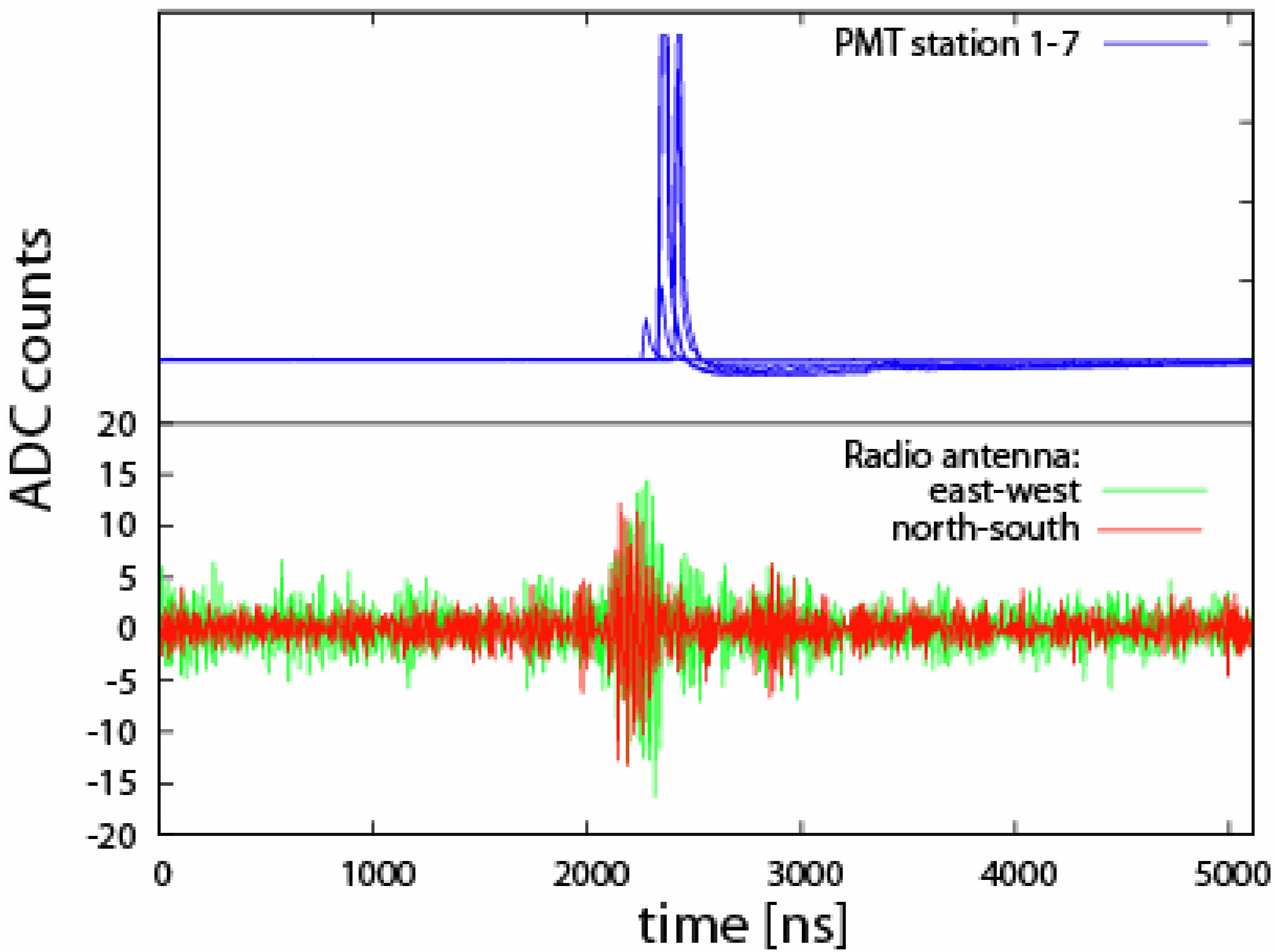
Tunka radio extension (antennas 2 + 3)

Tunka radio event (with first antenna)



Tunka radio extension

- Current status
  - 3 antennas in the field, operation of antenna 2+3 starts soon
- 2012 start of larger radio array within HRJRG

  “Measurements of Gamma Rays and Charged Cosmic Rays in the Tunka-Valley in Siberia by Innovative New Technologies ”

  - hybrid measurements with Cherenkov light detectors
  - determine energy and mass precision of radio measurements

  → **Seeking PhD students (at least one from Russia)**
- Mid-term outlook
  - enhance duty cycle of Tunka by a factor of 10, when combining radio array with scintillator extension

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Conclusion

- Digital radio antenna arrays =

  alternative instrument for air shower detection
- LOPES at KIT is still one of the leading experiments
  - proof-of-principle for digital radio interferometry (for cosmic rays)
  - reconstruction of air shower direction, primary energy and primary mass (via distance to shower maximum)
  - precision limited due to high background at KIT
- Next generation radio experiments: AERA + Tunka
  - lower background
  - cross-calibration with established techniques
  - last development step to use radio for cosmic ray physics

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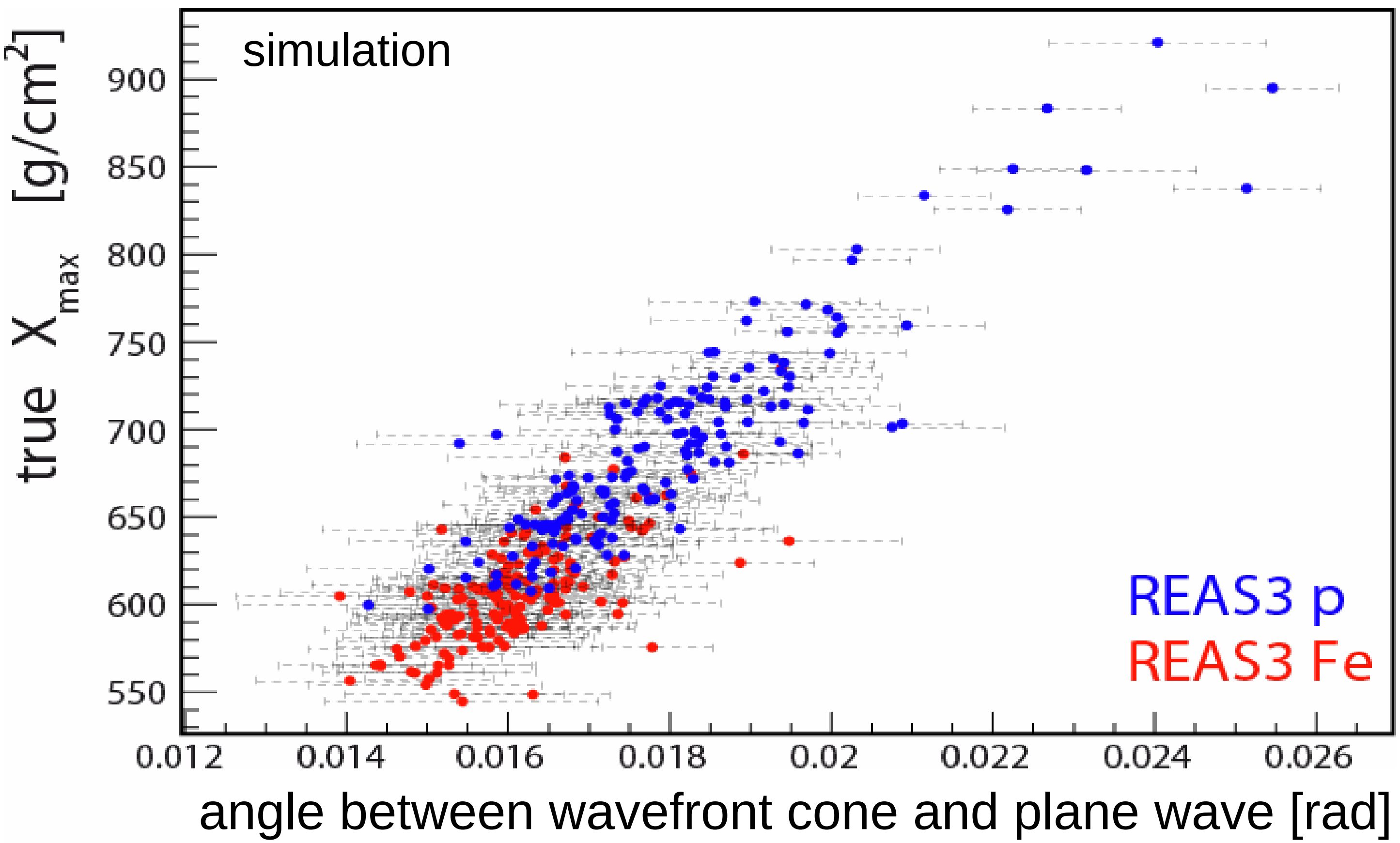
Conical wavefront

- Wavefront reconstructed with pulse times
- Protons have steeper wavefront cone than irons



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