The Tunka-Rex experiment for detection of air shower radio emission

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2006-2012: Tunka-133 array: 175 optical Cherenkov detectors on 3 km^2 area

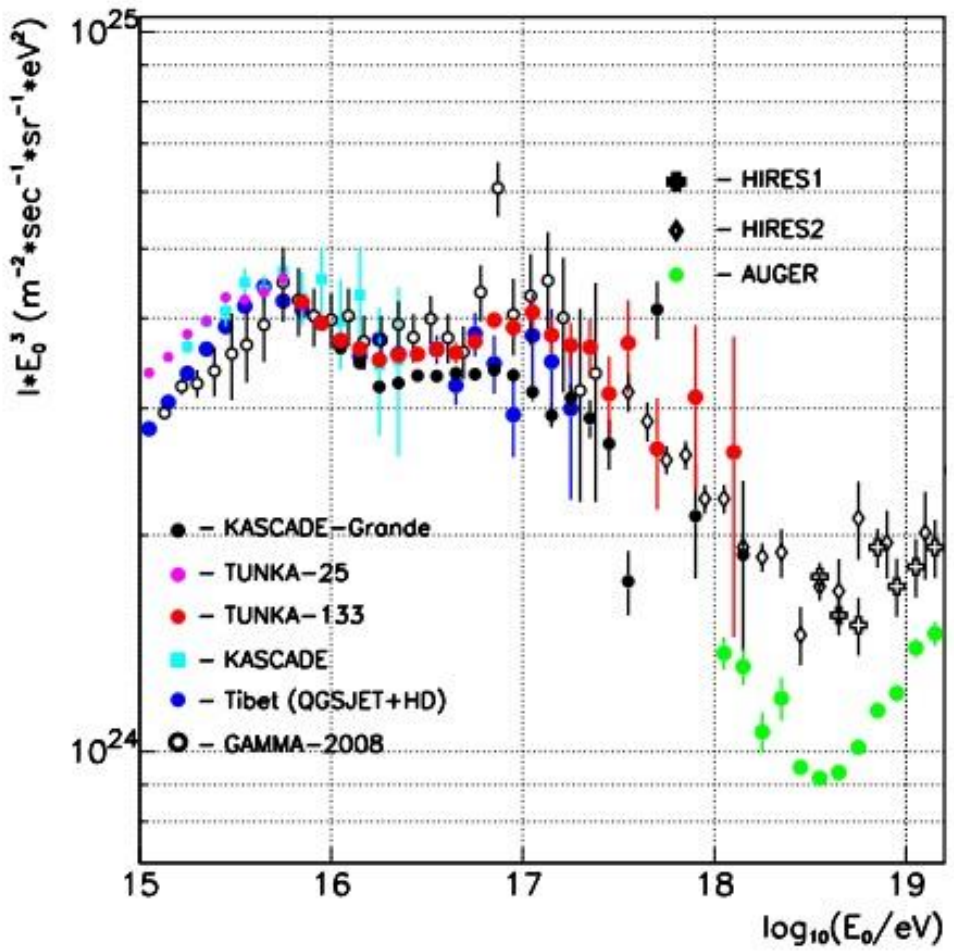
51°48’35” N
103° 04’02” E
675 m a.s.l.

Advantages of the Tunka-133[1] array:

- core reconstruction 5-10 m
- energy resolution ~10 - 15%
- X_{max} precision 20-25g/cm²
- angular resolution 0.3 deg

Disadvantage:

Short time of operation (moonless, cloudless nights) –
5-10% duty cycle



Cosmic ray energy spectrum

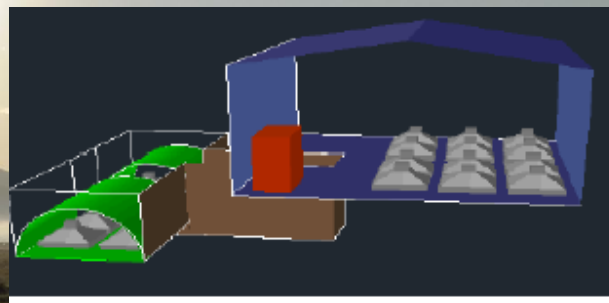
[1] Tunka-133: Main Experimental Results of 3 Year Operation / Prosin V. // the proceeding of ICRC 2013

TAIGA – Tunka Advanced Instrument for cosmic rays and Gamma Astronomy

Array design concept

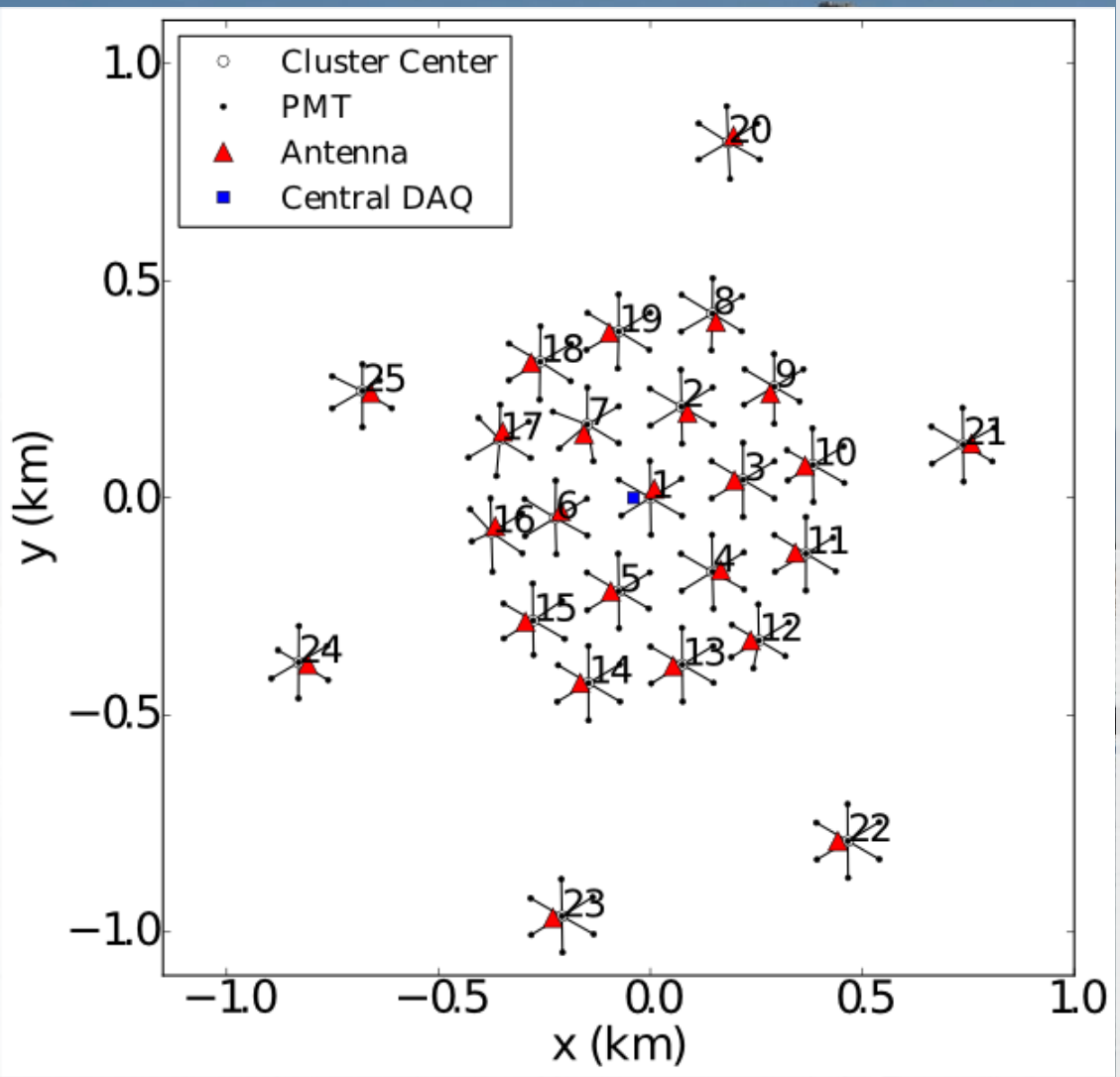
•Net of non imaging wide-angle optical stations (HiSCORE type, M.Tlutzikont et al)

Net of 3-4 m class imaging telescopes



Net of scintillation detectors (including underground muon detectors)
10^2 ➔ $2 \cdot 10^3$ m^2 area.

Tunka-Rex: detector



Tunka-Rex started data taking on 8 of Oct. 2012

Existing DAQ
Trigger and information from air-Cherenkov detector

Radio quiet rural location

The main goal is cross-calibration of radio + air Cherenkov:

- joint operation and analysis
- determine radio energy precision
- determine radio X_{max} precision

Tunka-Rex collaboration

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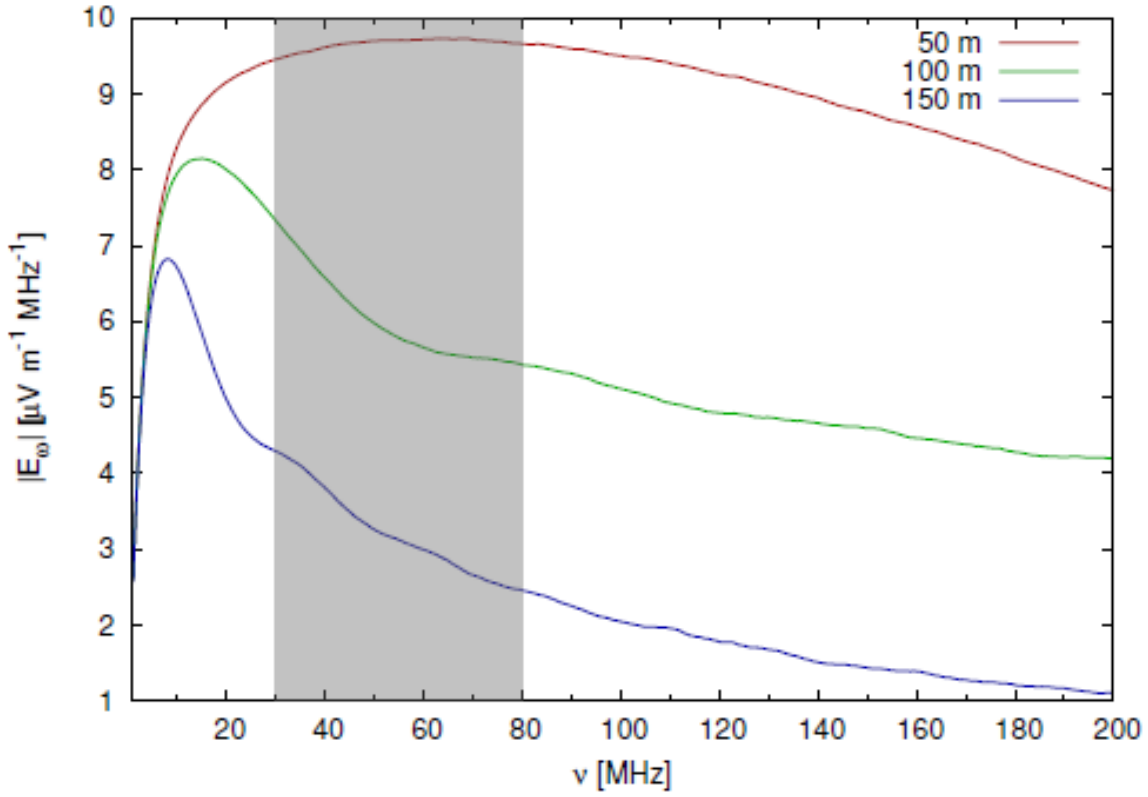
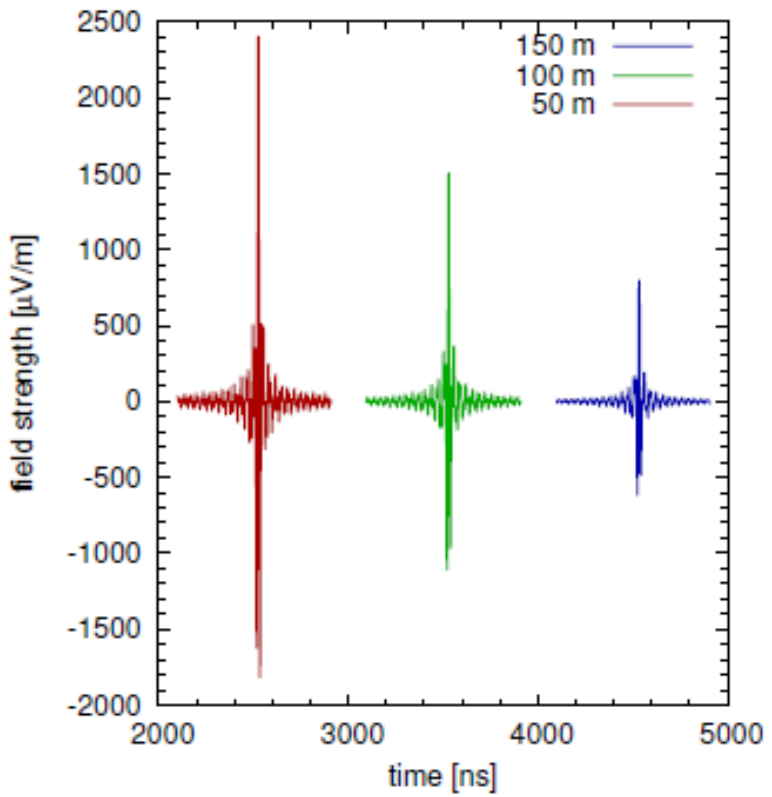
5 **Institute for Nuclear Research of the Russian Academy of Sciences**, Moscow
6 **DESY**, Zeuthen, Germany

Radio emission from cosmic rays

- ✓ Radio emission in MHz-GHz range
- ✓ Tunka-Rex: 30-80 MHz band (as other experiments)





Vertical EeV air-shower simulated with CoREAS v1.0

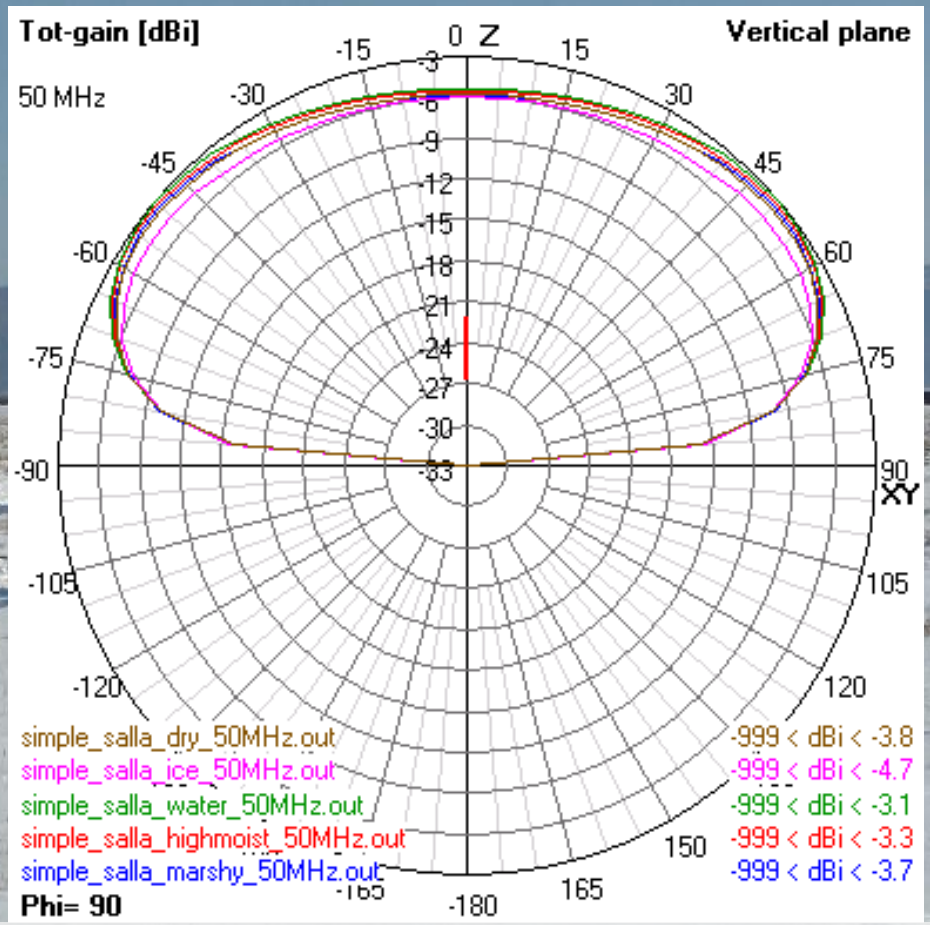
Technical characteristics of Tunka-Rex

- Number of antennas — 25(2 channels each)
- Antenna type — SALLA
- Distance between antennas — ~200 m
- Frequency band — 30-80 MHz
- Channel alignment — NW - SE, NE-SW
- Area — 1 km^2
- Sampling: rate — 200 MHz
- Trace length — 1024 samples (≈ 5 μs)
- Approximate energy range — $10^{16.5}$ –10^{18} eV
- For the analysis we use the radio part of the Auger Offline software[1]

[1]Pierre Auger Collaboration, NIM A 635 (2011) 92

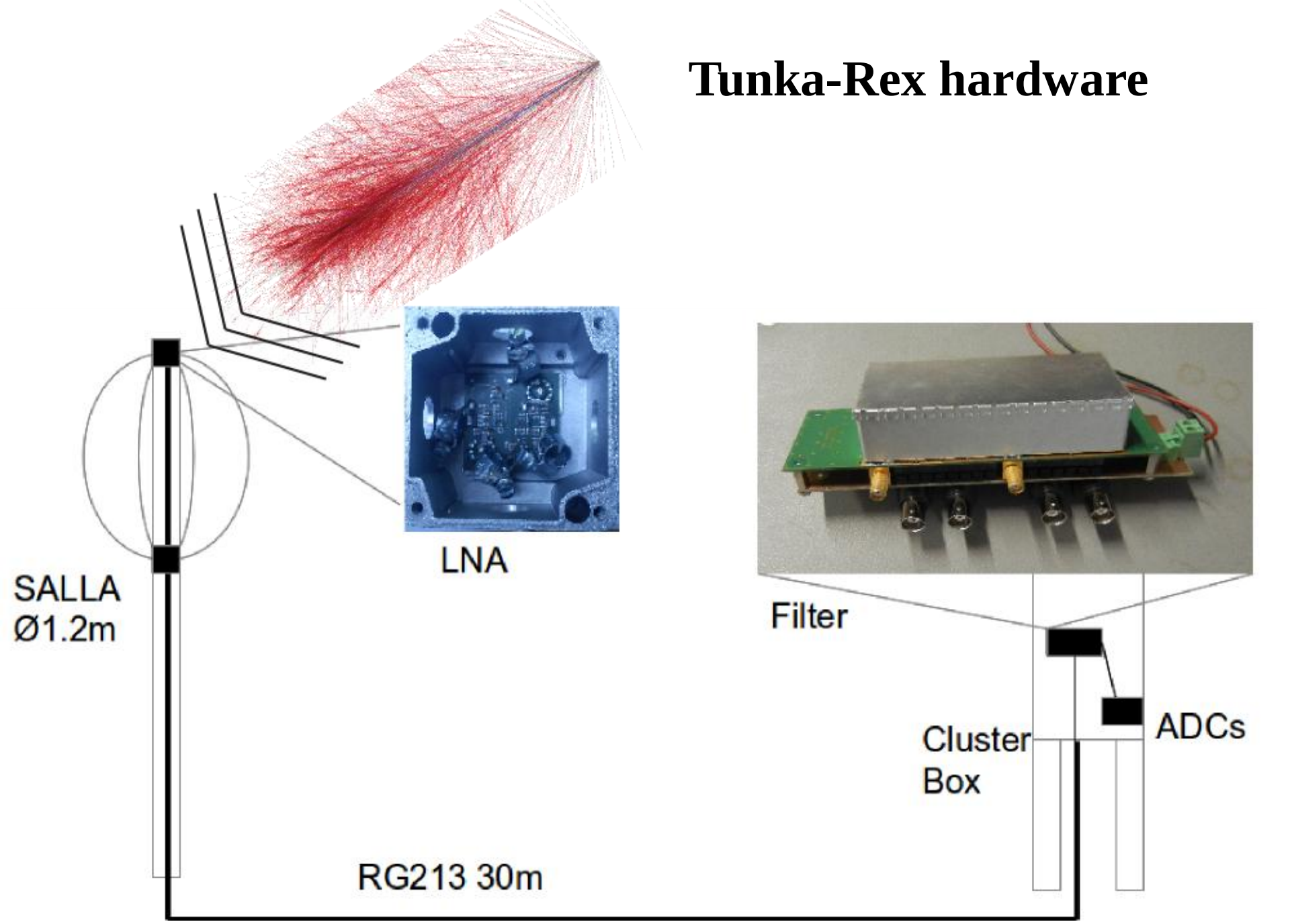
Short Aperiodic Loaded Loop Antenna (SALLA)

- Cheap, simple and stable antenna
- Low gain, but also low dependency on ground conditions, good zenith coverage



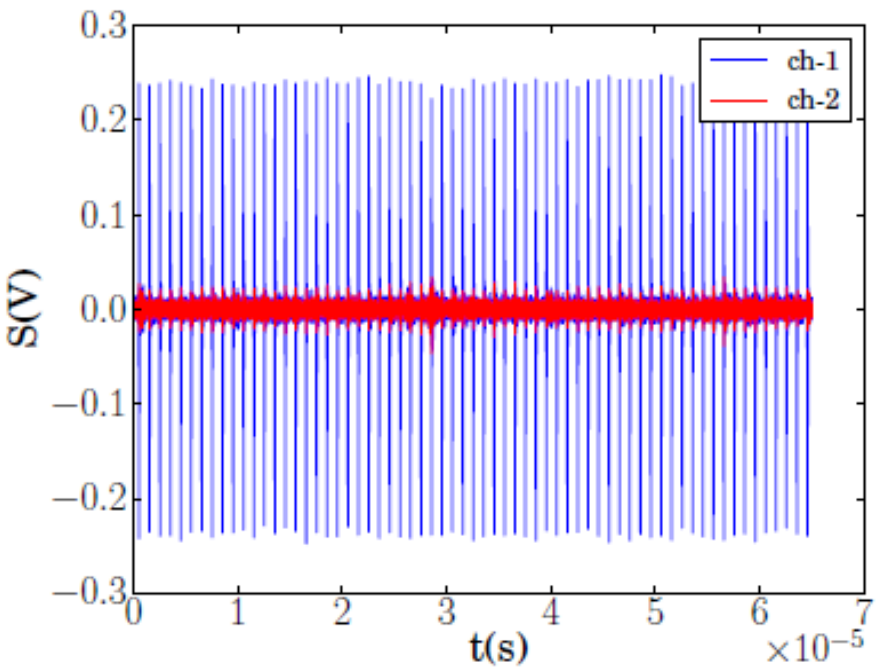
Gain of the SALLA in the vertical plane for a frequency of 50 MHz. The different lines correspond to different ground types

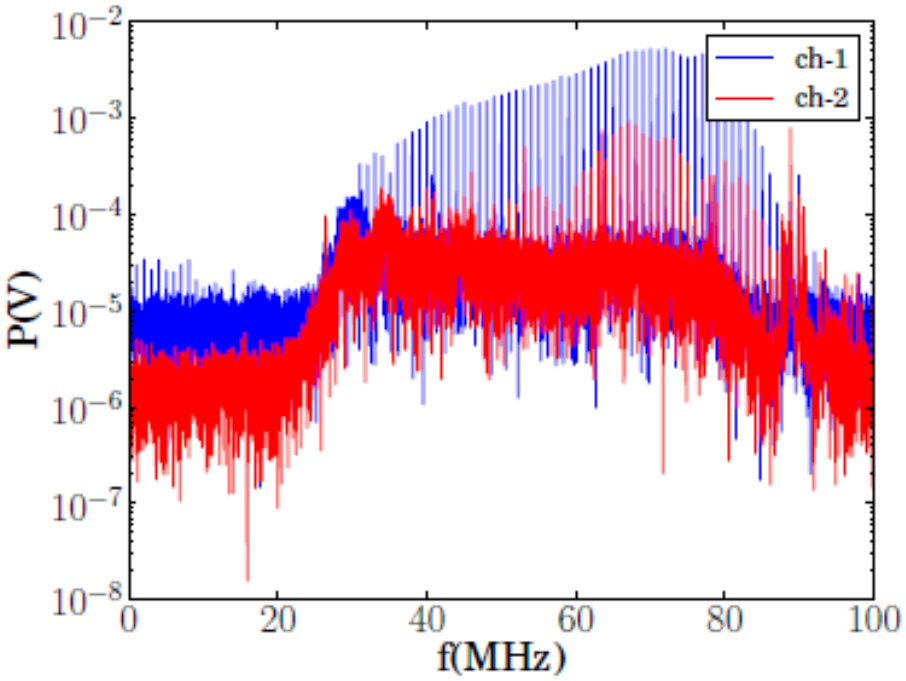
Tunka-Rex hardware



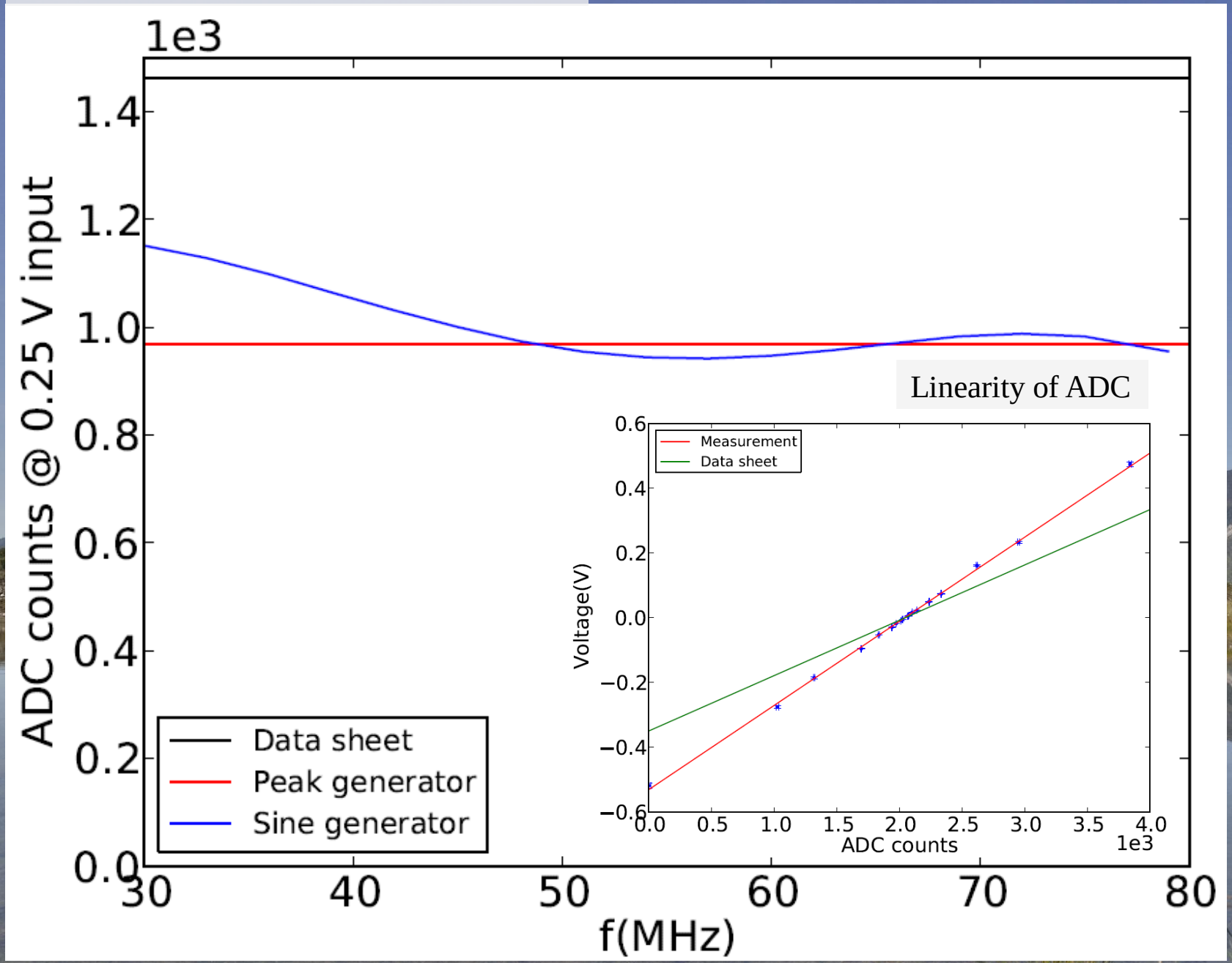
Antenna calibration

- ✓ SALLA at KIT, oscilloscope as DAQ
- ✓ LOPES method and equipment
- ✓ ≈ 10 m above antenna, DGPS
- ✓ Align from ground

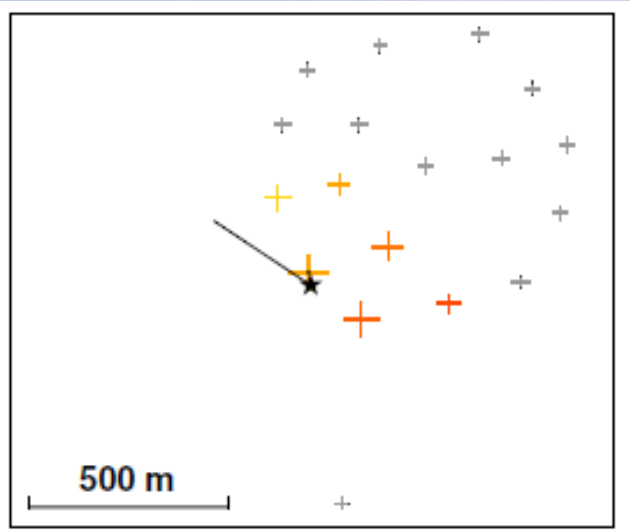


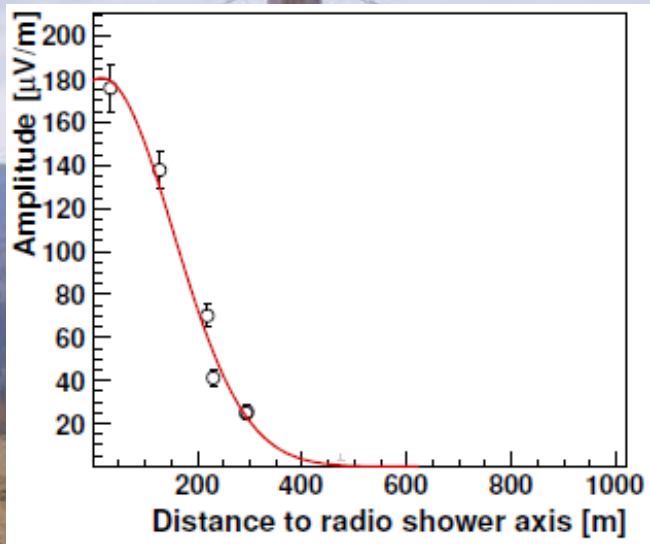


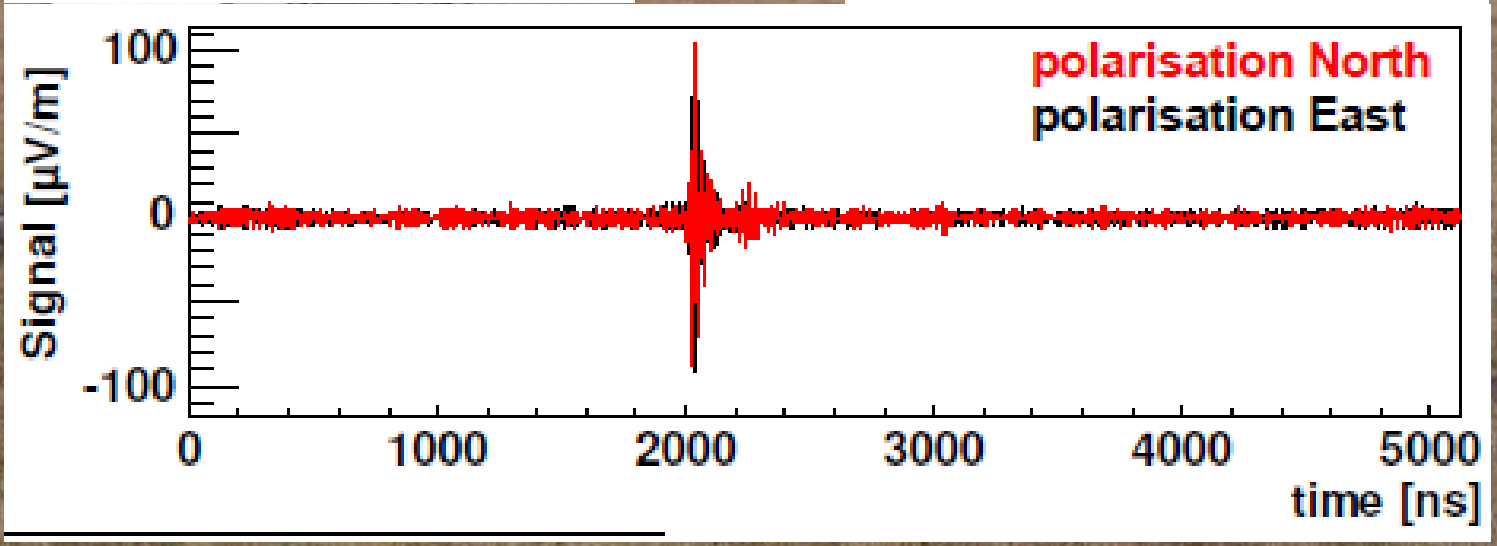
ADC calibration



Example for the Tunka-Rex event







Analysis strategy: semi-blind analysis

- First season: Oct 2012 – Apr 2013
  - Air-Cherenkov reconstruction available: Geometry, Energy, Xmax
  - Used to develop and tune methods for energy and Xmax reconstruction
- Second season: Oct 2013 – Apr 2014
  - Only geometry from air-Cherenkov reconstruction
  - Energy and Xmax kept secret by the Tunka-133 collaboration
  - Will be revealed later for cross-check

Reconstructed events (data of 2012-2013 season)

Total time of measurements - 392 hours

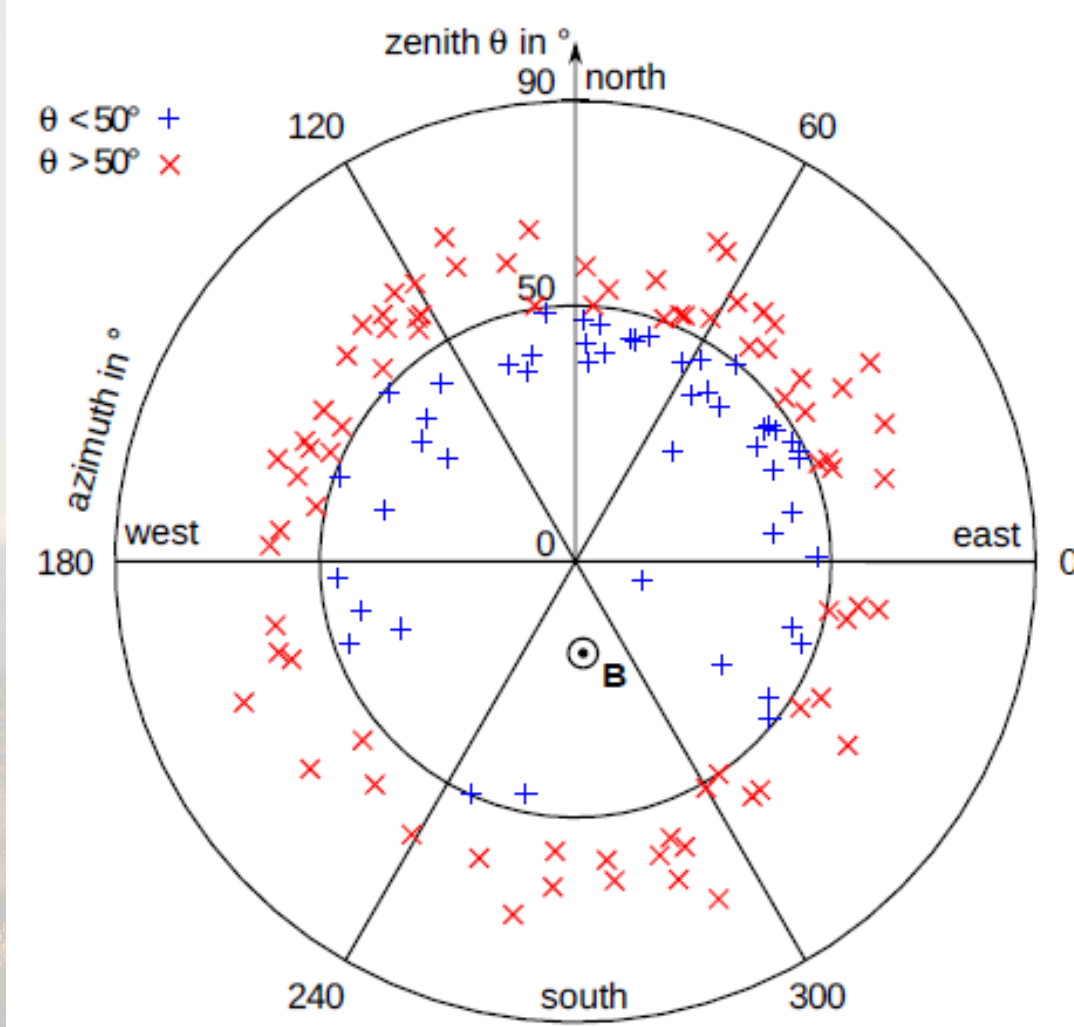
Total reconstructed events: 146

- Reconstructed 62 events with $\Theta \leq 50°$ (Energy, geometry, X_{max} from cherenkov)
- Reconstructed 84 events with $\Theta > 50°$ (only direction from cherenkov)

Reconstruction cuts:

- angle difference cherenkov-radio < 5°
- 3 antennas SNR > 6

North-South asymmetry is observed

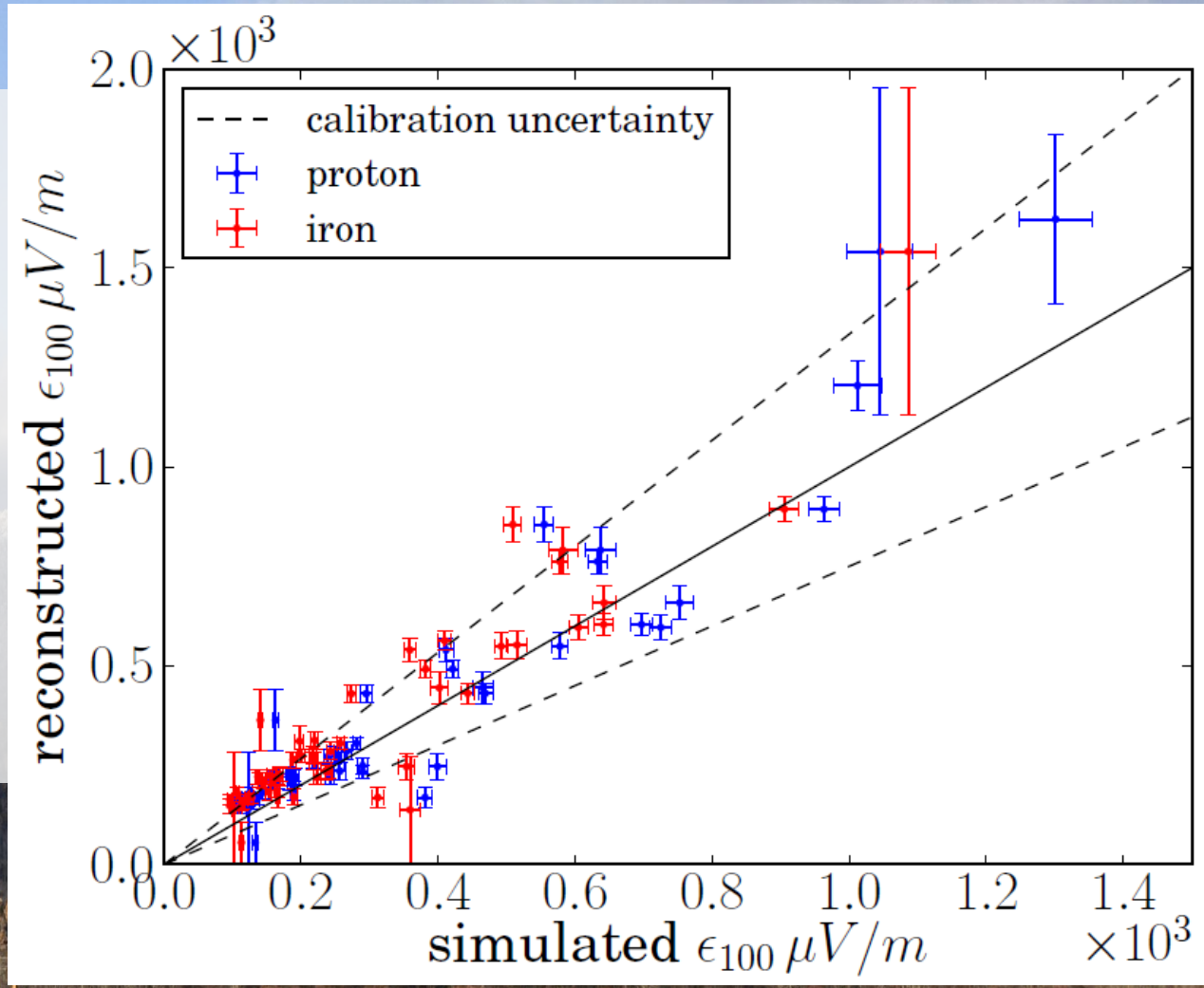


Amplitude comparison with CoREAS

2012/2013 cherenkov events,
min. 3 antennas SNR ≥ 8,
$\Delta\Omega \leq 5^\circ \rightarrow$ 57 events

sim.energy, direction, core from Cherenkov reconstruction
repeated simulation

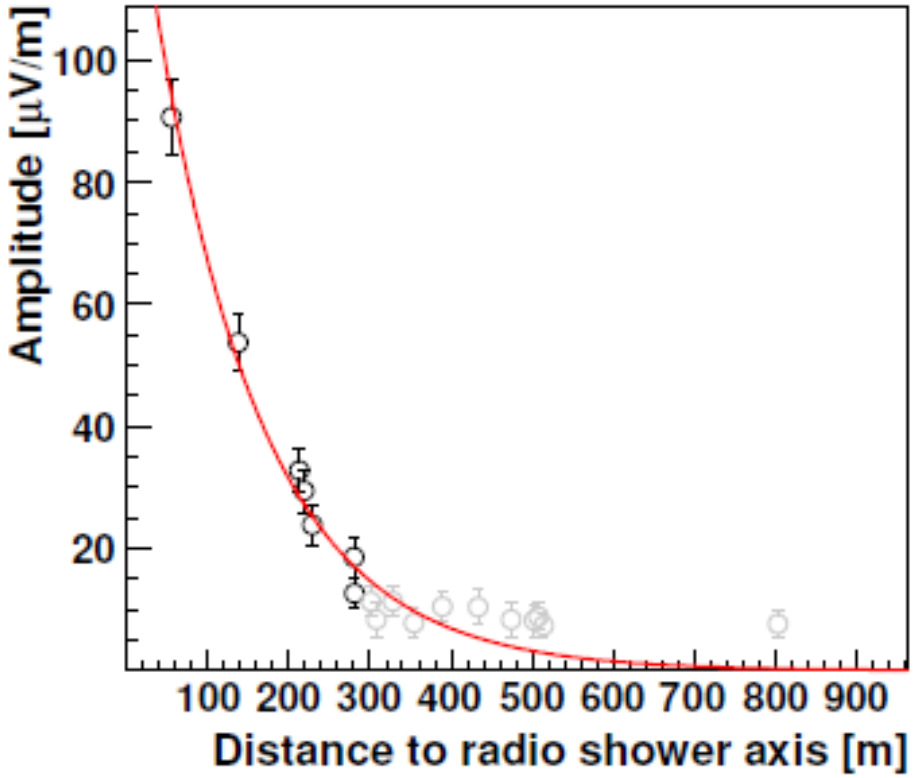
E >10^{17} eV



Lateral distribution treatment

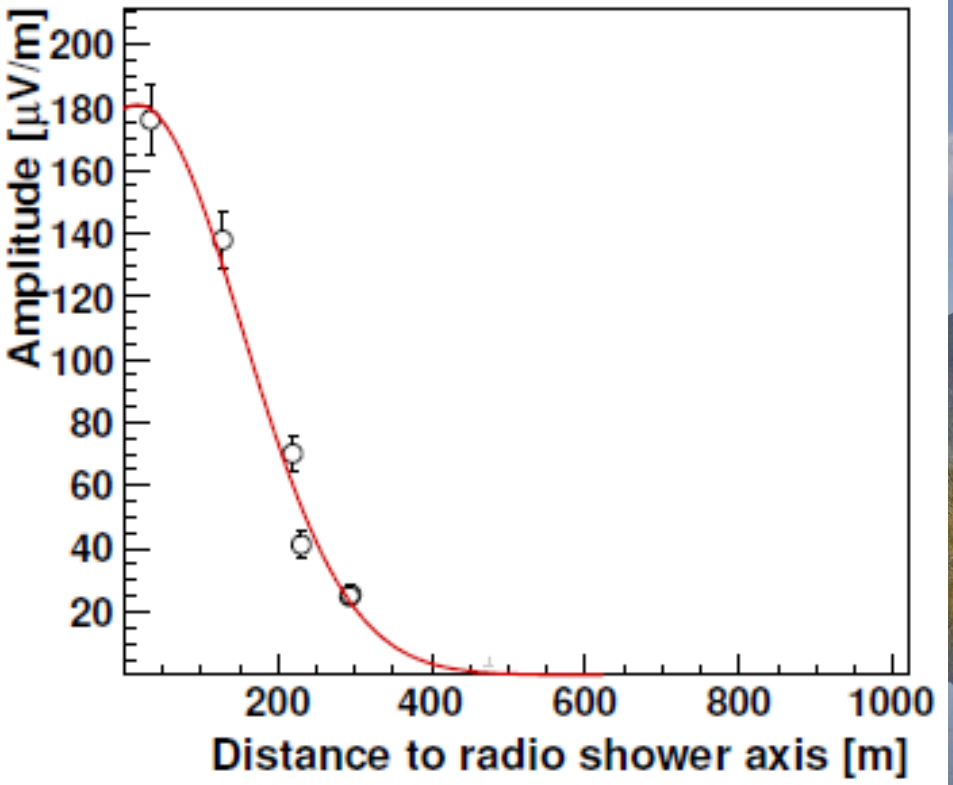
exponential

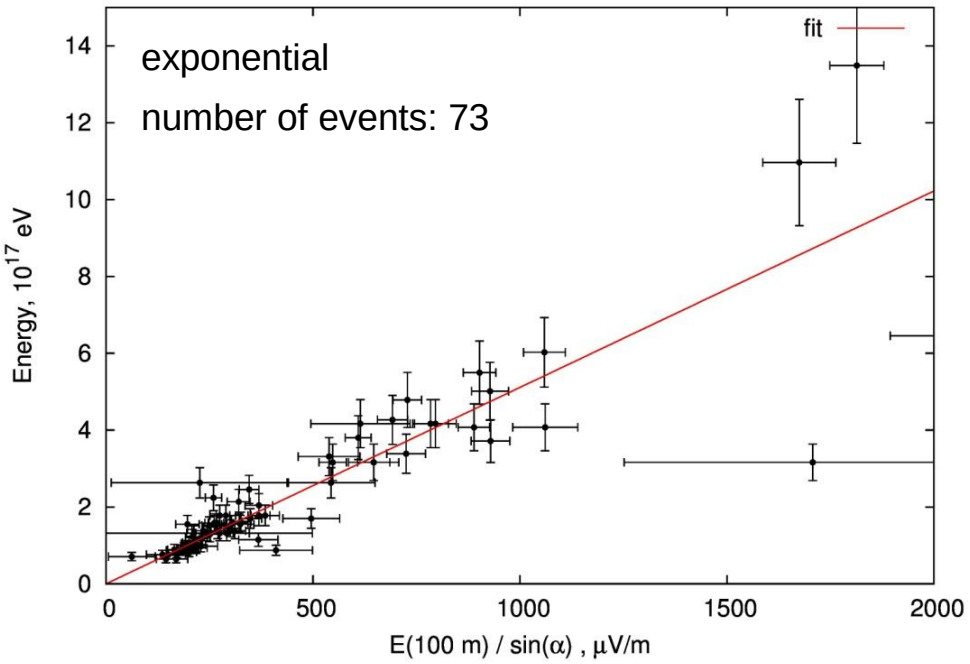
$$\varepsilon(r) = \varepsilon_{r_0} \exp\left[-\eta(r - r_0)\right]$$

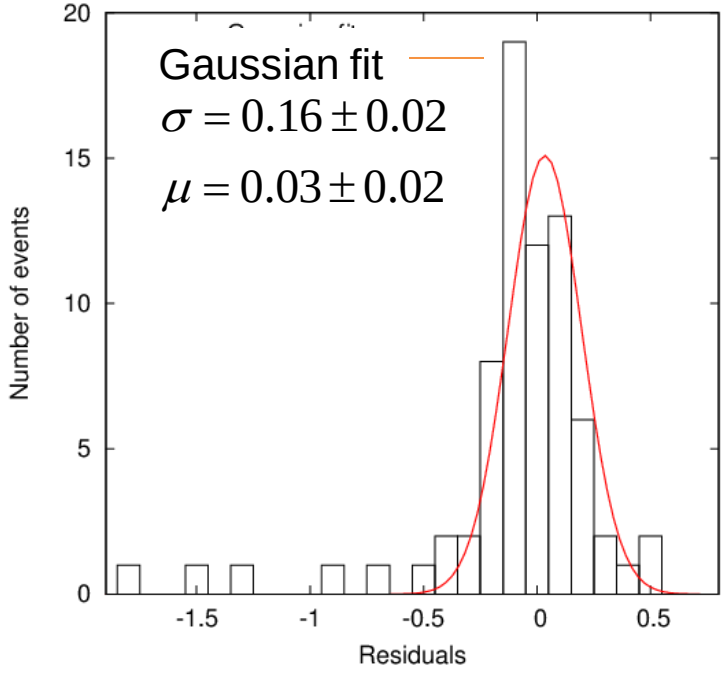


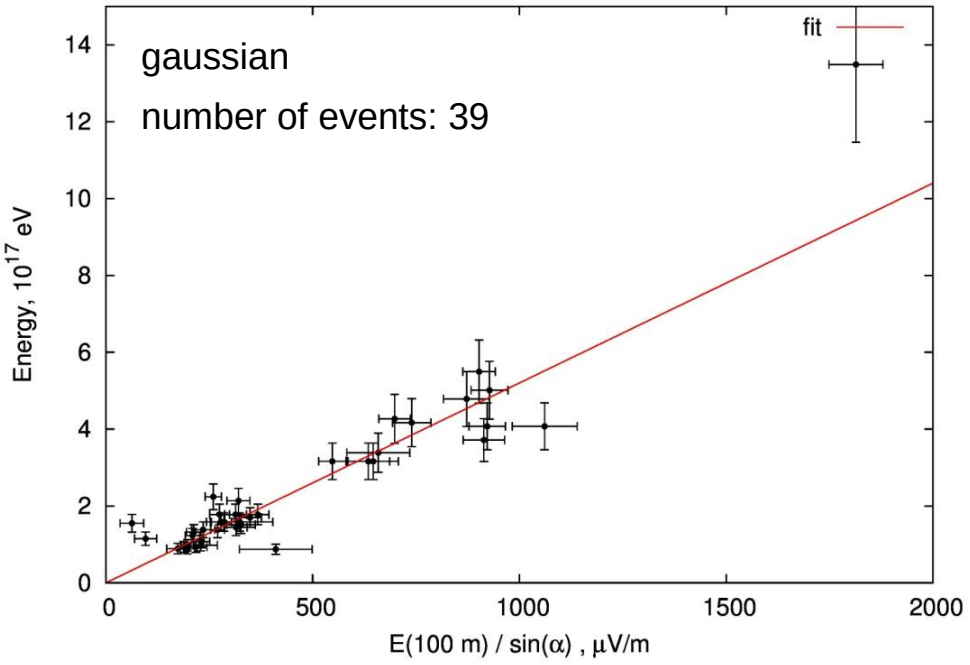
gaussian

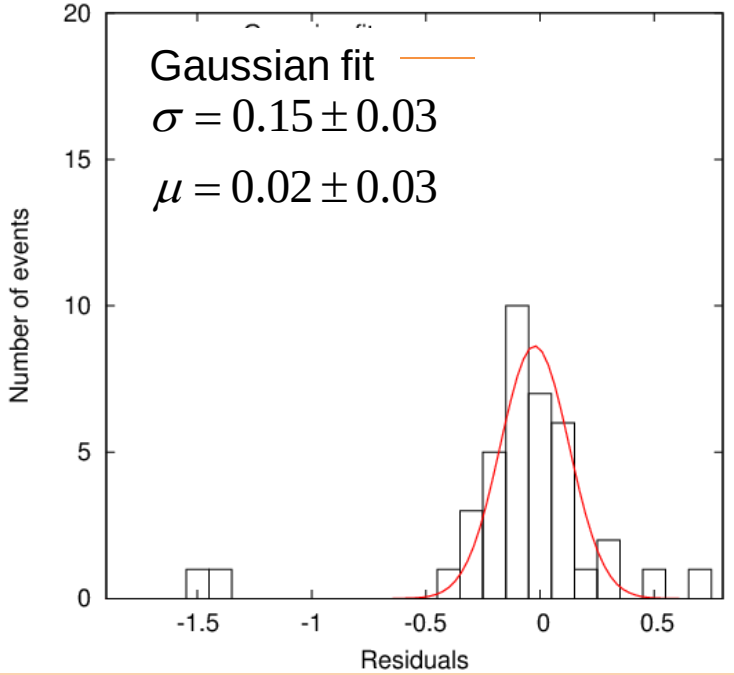
$$\varepsilon(r) = \varepsilon_{r_0} \exp\left[-a(r - r_0)^2 + b(r - r_0)\right]$$




exponential
number of events: 73
fit
Energy, 10^{17} eV
E(100 m) / sin(α) , μV/m
0
2
4
6
8
10
12
14
0
500
1000
1500
2000


Gaussian fit
$\sigma = 0.16 \pm 0.02$
$\mu = 0.03 \pm 0.02$
Number of events
Residuals
0
5
10
15
20
-1.5
-1
-0.5
0
0.5


gaussian
number of events: 39
fit
Energy, 10^{17} eV
E(100 m) / sin(α) , μV/m
0
2
4
6
8
10
12
14
0
500
1000
1500
2000


Gaussian fit
$\sigma = 0.15 \pm 0.03$
$\mu = 0.02 \pm 0.03$
Number of events
Residuals
0
5
10
15
20
-1.5
-1
-0.5
0
0.5

Conclusion

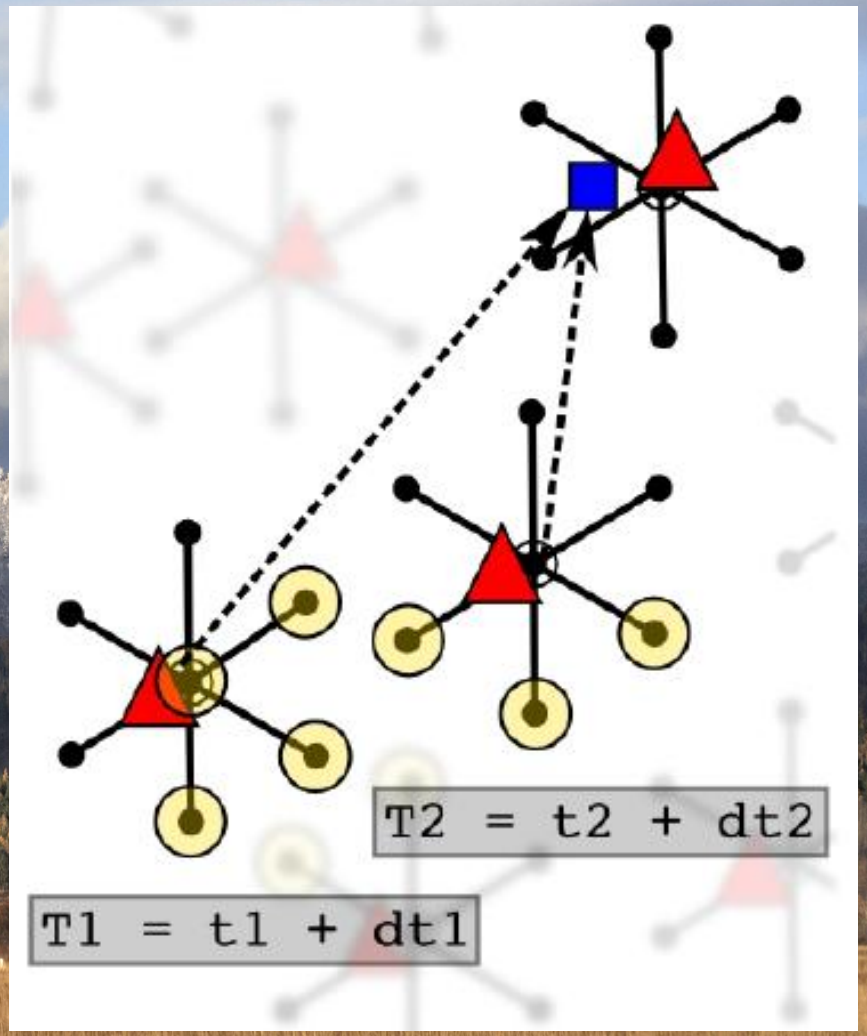
- Results of the 2012/2013 season have shown that Tunka-Rex detects the radio emission from extensive air showers
- After quality cuts strong correlation between amplitude and energy
- Amplitudes agree with CoREAS
- Tunka-Rex has high sensitivity to inclined air-showers

Plans for the future

- Investigate possibilities of X_{max} reconstruction
- Cross check results with 2013/2014 data set (semi-blind analysis)
- Trigger Tunka-Rex also by the scintillator extension for an increased duty cycle

Data acquisition and event merging

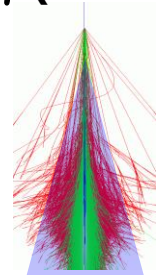
- trigger on cluster level by 3 coincident PMT
- offline combination of coincident cluster trigger for event search
- time synchronization via central clock + measured fibre delay



Helmholtz Russia Joint Research Group HRJRG-303
Measurements of Gamma Rays and Cosmic Rays in the Tunka-Valley in Siberia by innovative new technologies

High energy γ (GeV / TeV / PeV):

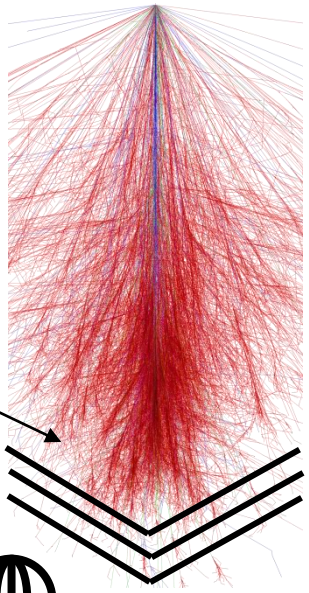
Ultra-high energy CR (PeV - EeV):



HRJRG-303:
Resolve open questions of cosmic rays with innovative methods

Cherenkov

Radio



Cherenkov light cone

HiSCORE

Tunka-Rex