Karlsruhe Institute of Technology

Tunka-Rex: Radio Measurements of Cosmic Ray Air Showers in Siberia

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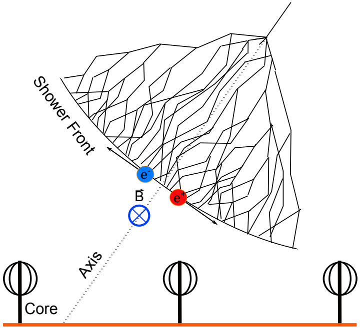
Helmholtz Russian Joint Research Group 303

INSTITUT FÜR KERNPHYSIK

Radio emission processes

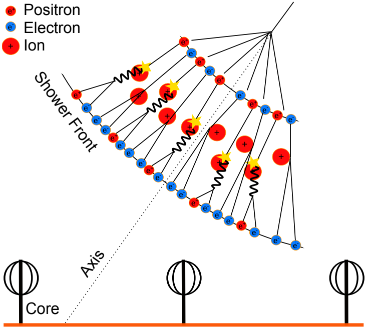
Geomagnetic effect

- Time-varying transverse currents
- East-West polarisation
- Dominant effect ($\sim \sin \alpha$)



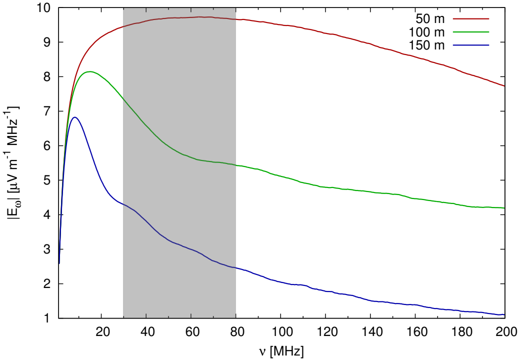
Askaryan effect

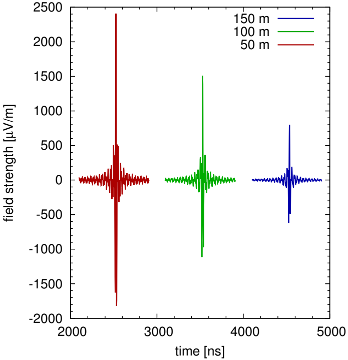
- Time-varying net charge
- Radial polarisation
- Second order effect ($\approx 10\%$)



Radio emission from cosmic rays

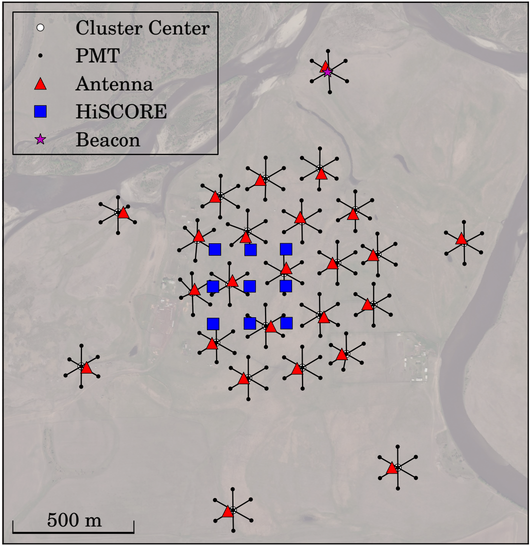
- Radio emission in MHz–GHz range
- Tunka-Rex: 30-80 MHz band, not used commercially





Vertical EeV air-shower simulated with CoREAS v1.0

Tunka facility



- Tunka-133 air-Cherenkov detector
- **Tunka Radio Extension** (Tunka-Rex)
- HiSCORE gamma ray detector
- Particle detectors

Tunka facility

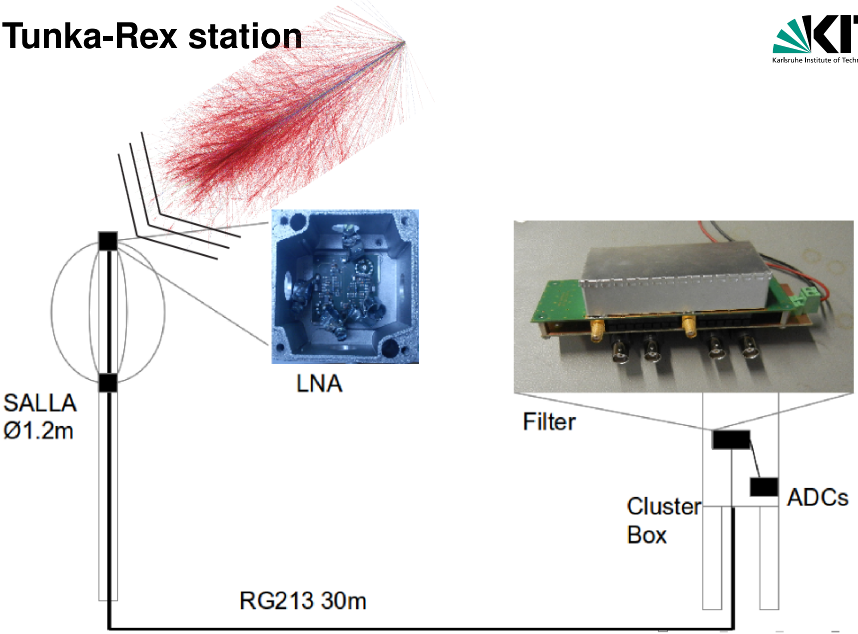
Tunka-Rex detector

- 25 antennas on 1 km^2 area
- Existing DAQ of Tunka-133
- Trigger and information from air-Cherenkov detector

- Radio quiet rural location
- Strong geomagnetic field ($\approx$ 60 μT)

- Joint operation of radio and air-Cherenkov detectors
- Goal: precision of radio reconstruction for shower parameters (energy and shower maximum)

Tunka-Rex station

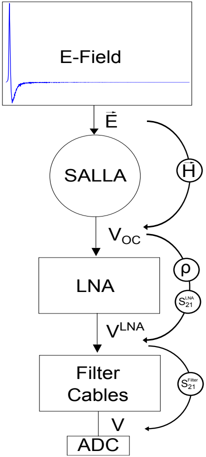


Tunka-Rex signal chain – formal

- Convolution with response funtion
- Linearity $\rightarrow$ invertibility
- Inversion via Convolution Theorem

$$f_{ADC}(t) = f_{in}(t) * g_{Hardware}(t)$$
$$f_{ADC}(t) = F^{-1}(\tilde{f}_{in}(\nu) \cdot \tilde{g}_{Hardware}(\nu))$$
$$f_{in}(t) = F^{-1}(\tilde{f}_{ADC}(\nu) / \tilde{g}_{Hardware}(\nu))$$

- Noise is non-linear



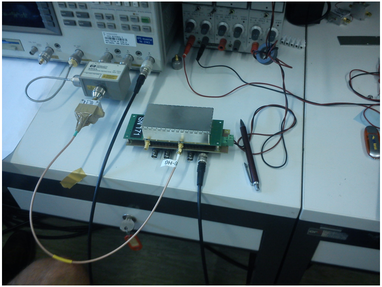
Full signal chain:

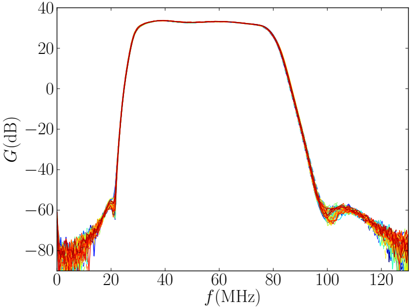
$$\tilde{U}_i(\nu) = \tilde{S}_{21} \cdot \rho \cdot \vec{\tilde{H}} \cdot \vec{\tilde{E}}$$

Electronics

- Analog chain LNA,Cable,Filter
- Transmission S_{21} measured with network analizer
- Antenna matching

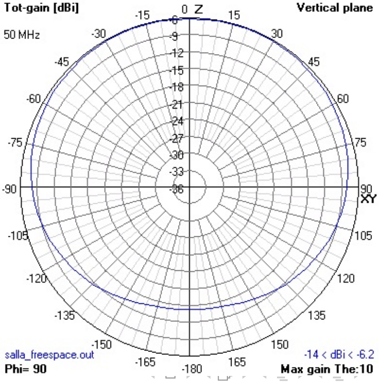
$$\rho = \frac{Z_{LNA}}{Z_{LNA}+Z_{SALLA}}$$





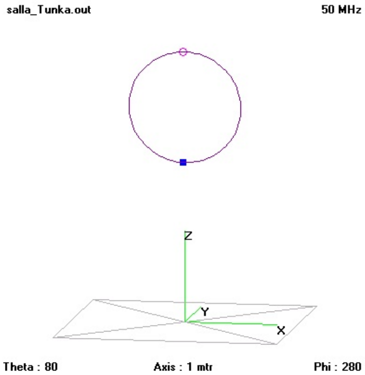
Short Aperiodic Loaded Loop Antenna

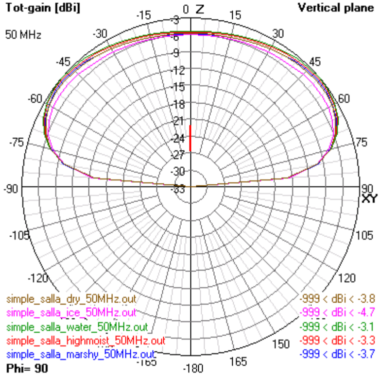
- Cheap, simple and stable antenna
- Low dependency on ground conditions, good zenit coverage
- E-Field→Voltage $\vec{U} = H(\nu, \theta, \varphi) \cdot \vec{E}$



Antenna Simulations

- Antenna characteristic from simulation
- 4NEC2 simulation programm for wire antennas
- Normalize with calibration





Antenna Calibration

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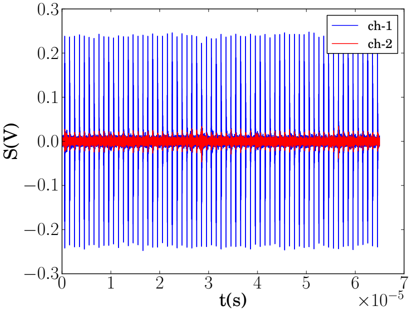
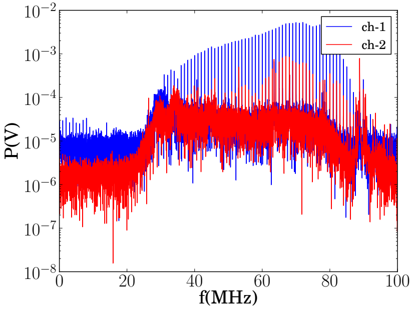
- SALLA at KIT, oscilloscope as DAQ
- LOPES method and equipment
- ≈ 10 m above antenna, DGPS
- Align from ground

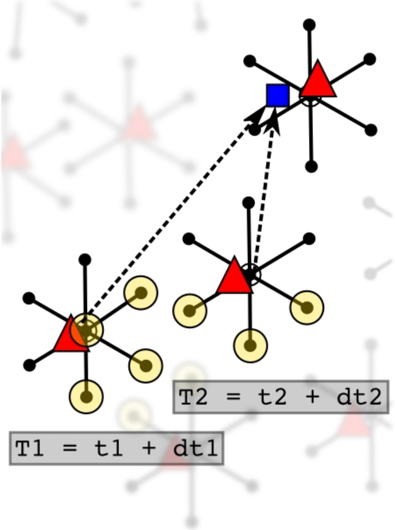
Antenna Calibration

- VSQ 1000 and DPA 4000
- Frequency comb, calibrated at 10 m distance



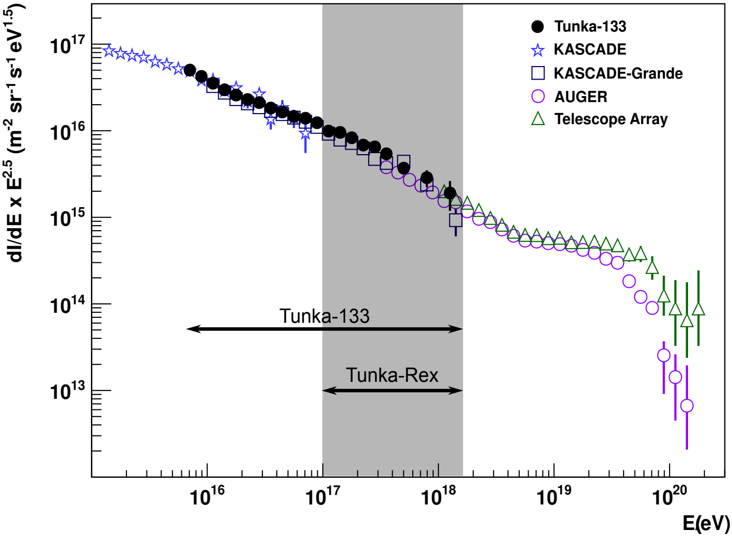


Data acquisition and event merging



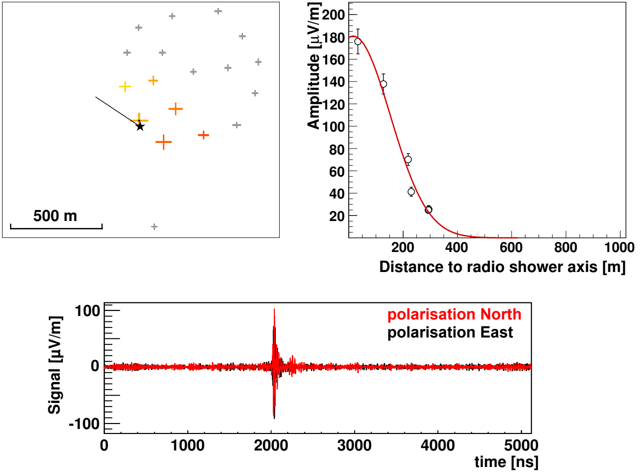
- Every run local clocks set to zero
- Cluster centers have independent triggers (more than 2 simultaneous signals from PMT consider as event)
- Delays in optical fibers are taken into account. Event time is $T = \text{local time} + \text{fiber delay}$
- We merge separate events with $\Delta T \leqslant 7000$ ns into one
- UTC time sets for each event in DAQ center and then data reader choses one for merged event.

Cosmic ray energy spectrum



Tunka-Rex example event

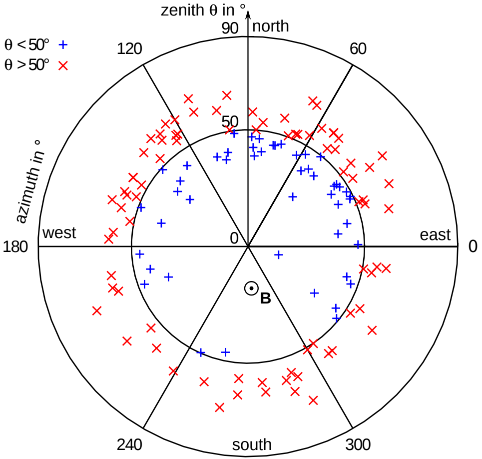
For analysis we use the radio part of the Auger Offline software[1]



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

Check of reconstruction purity

- Minimum 3 antennas with SNR > 6
- Direction reconstruction with plane fit
- Comparison with Cherenkov reconstruction ($\Delta\Omega < 5^\circ$)



- 62 events with $\theta \leqslant 50^\circ$
- 84 events with $\theta > 50^\circ$
- North-South assymetry observed

Quality cuts

Non-blind analysis for season 2012/2013
Total time of measurements $\approx$ 450 hours

- Core position from Cherenkov reconstruction for events with $\theta \leqslant 50^\circ$
- Rejecting antennas with false signal
- Direction from radio
- LDF fitting

LDF ansatz

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

$$f(x) = \sum_{k=1}^{n} a_k x^k,$$

$$n = 1, 2; \;\; r_0 = 100 \text{ m}$$

Shower parameters

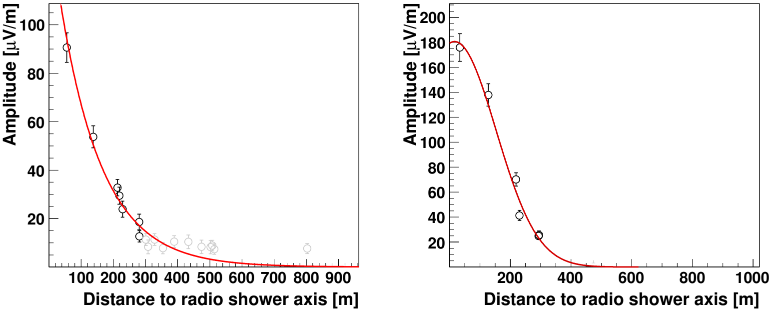
$$E_{pr}(\varepsilon_{r_0}) = \kappa \varepsilon_{r_0}$$

$$X_{max}(f) = \; ?$$

Lateral distribution treatment

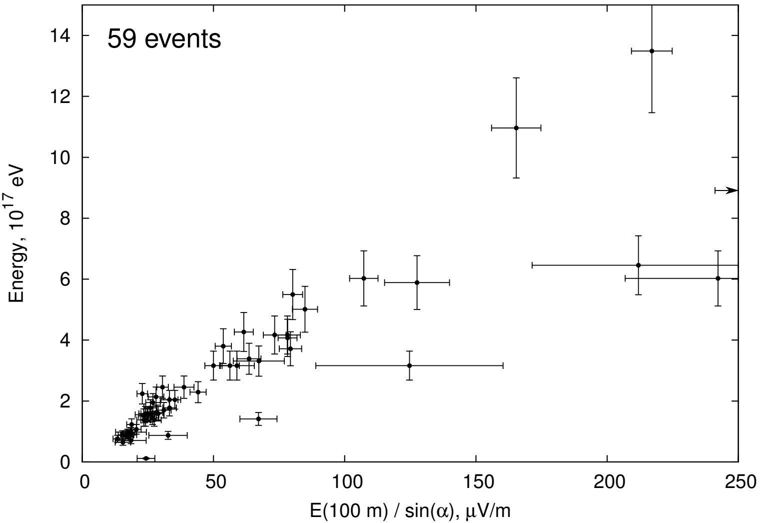
$n = 1$ (exponential)
$\varepsilon(r) = \varepsilon_{r_0} \exp\left[-\eta(r - r_0)\right]$

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

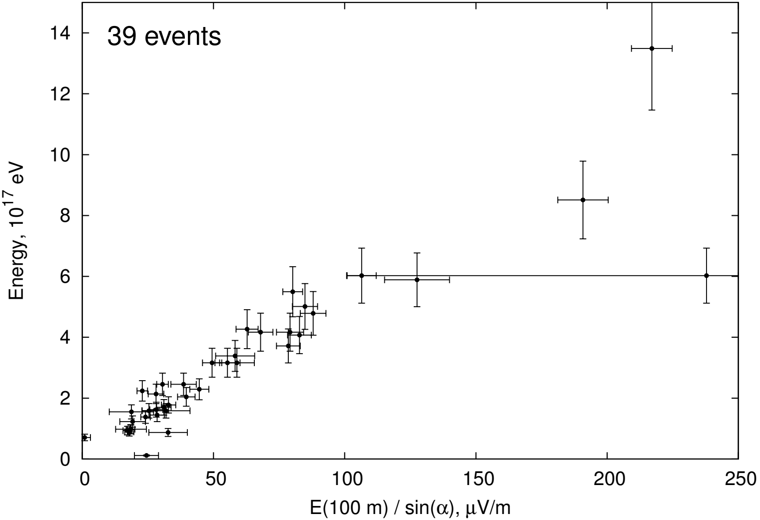


Minimum number of antennas: $n + 2$, required $\chi^2/\mathrm{NDF} < 8$

Correlation with amplitude ($n = 1$)

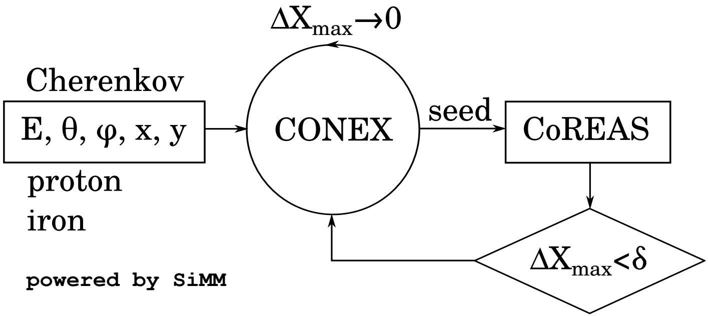


Correlation with amplitude ($n = 2$)



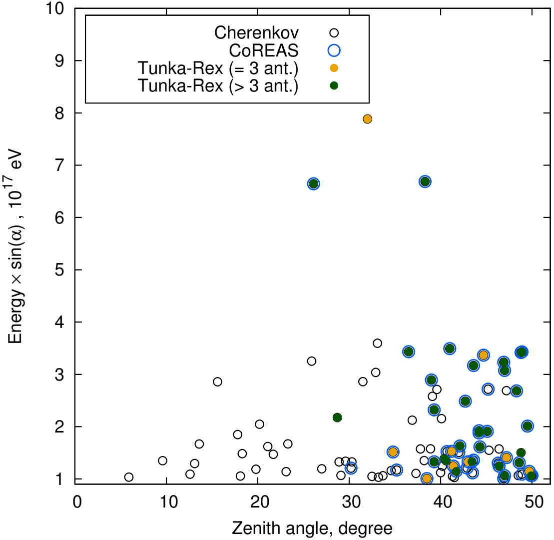
Simulation procedure

Input for **CONEX** and **CoREAS v1.0** from Cherenkov reconstruction



- Energy, direction, core position from Tunka-133 for each event
- Two primary particles (proton,iron) per event
- CONEX pre-simulation (proper random seeds search)
- Select shower with X_{max} close to Cherenkov X_{max}

Detector efficiency



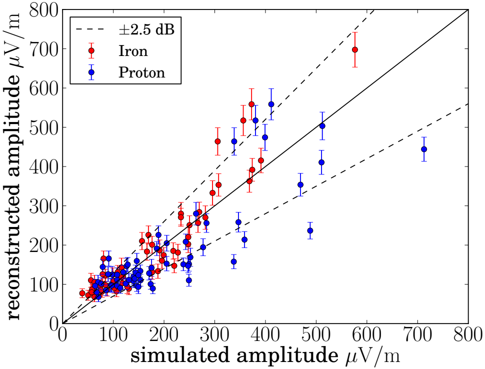
Cuts

- $\theta \leq 50°$
- $E \times \sin(\alpha) \geq 0.1$ EeV
- $|(x, y)| \leq 500$ m
- $\Delta X_{max} \leq 30$ g/cm^2

Threshold also depends on shower maximum

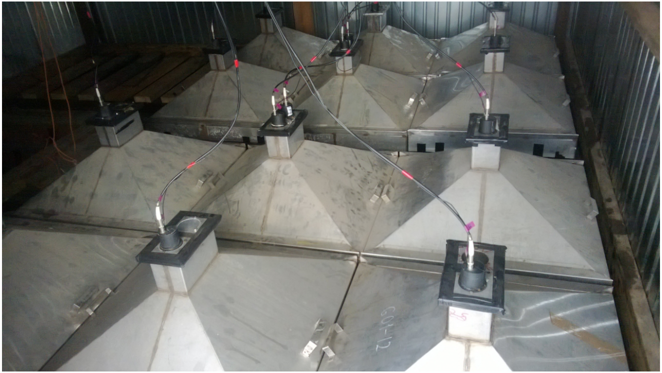
Comparison to CoREAS 1.0

- 2012/13 cherenkov events, min. 4 antennas SNR ≥ 8, $\Delta\Omega \leq 5^\circ \rightarrow$ 42 events
- sim. energy, direction, core from Cherenkov reconstruction
- repeated simulation, only $\Delta X_{\max} < 10$ g/cm^2 selected
- results:
  10 events for iron,
  12 events for proton,
  97/116 independent antennas



Future plans

- KASCADE-Grande scintillators installed at Tunka: electron and muon measurements
- $\sim$ 20 new antennas will be conntected to particle detectors in 2014 (increasing duty cycle up to 100%)



Conclusions

- 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 (caveat: ADC calibration)
- Sensitivity to shower maximum is under investigation.
- Tunka-Rex has high sensitivity to inclined air-showers.
- Exntension with scintillator trigger planned for this year.

BACKUP

Tunka-Rex Collaboration

N.M. Budnev[1], O.A. Gress[1], A. Haungs[2], R. Hiller[2], T. Huege[2], Y. Kazarina[1], M. Kleifges[3], A. Konstantinov[4], E.N. Konstantinov[1], E.E. Korosteleva[4], D. Kostunin[2], O. Krömer[3], L.A. Kuzmichev[4], R.R. Mirgazov[1], L. Pankov[1], V.V. Prosin[4], G.I. Rubtsov[5], C. Rühle[3], F.G. Schröder[2], E. Svetnitsky[1], R. Wischnewski[6], A. Zagorodnikov[1]

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

Digital filtering

We can use two types of digital filters:

- Median filter. Remove inner and outer narrow band interferences
- Bandstop filter. Remove temporary broadband noise