Overview of the Tunka-Rex experiment

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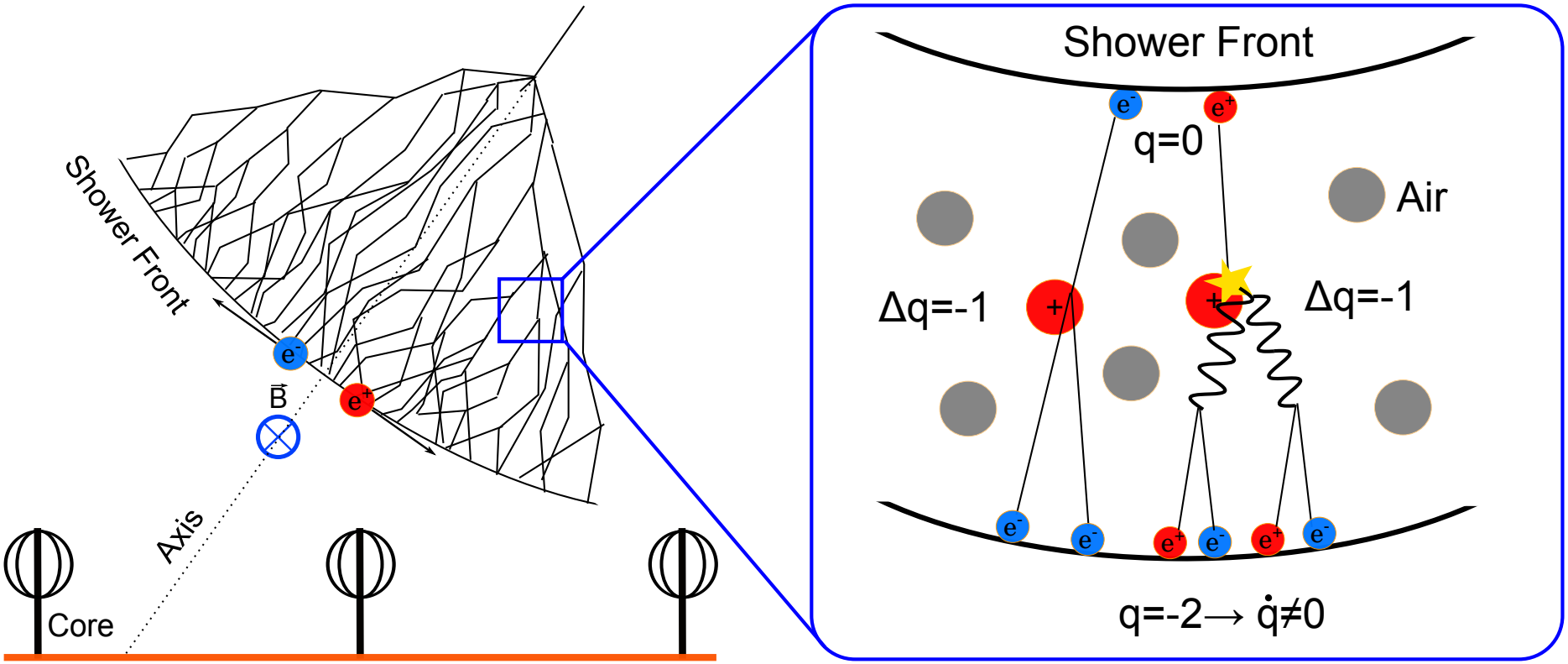
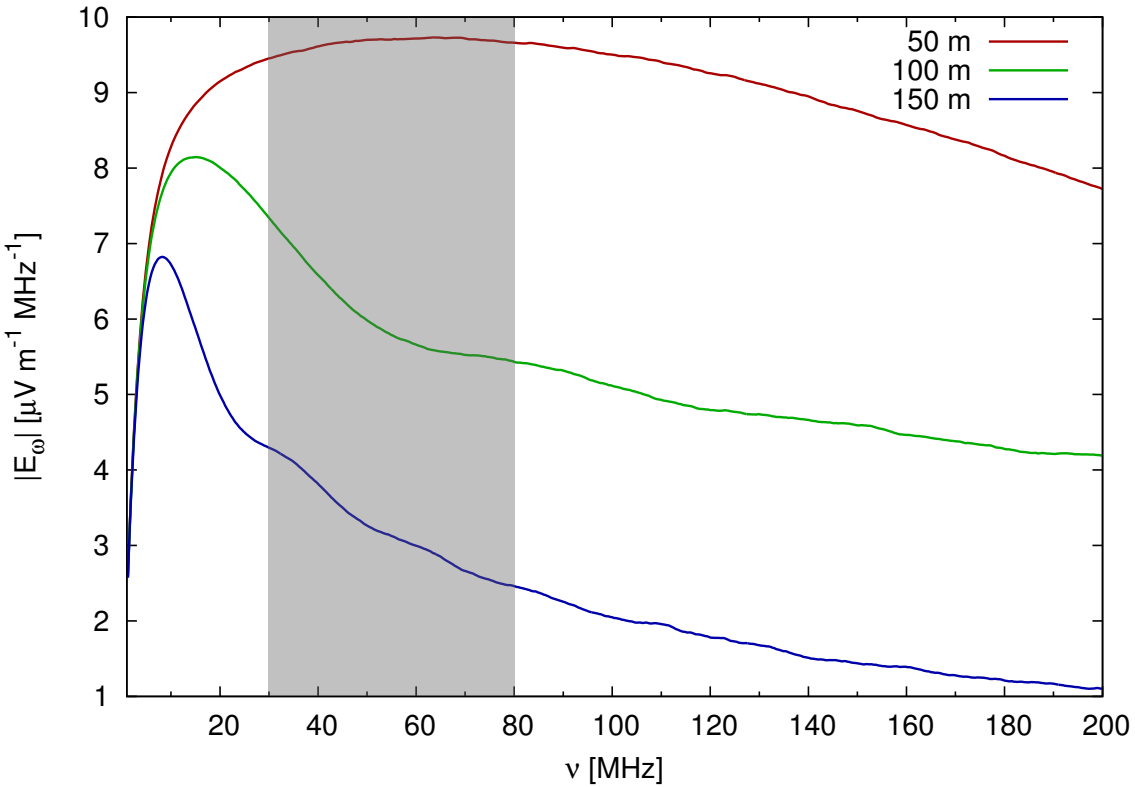
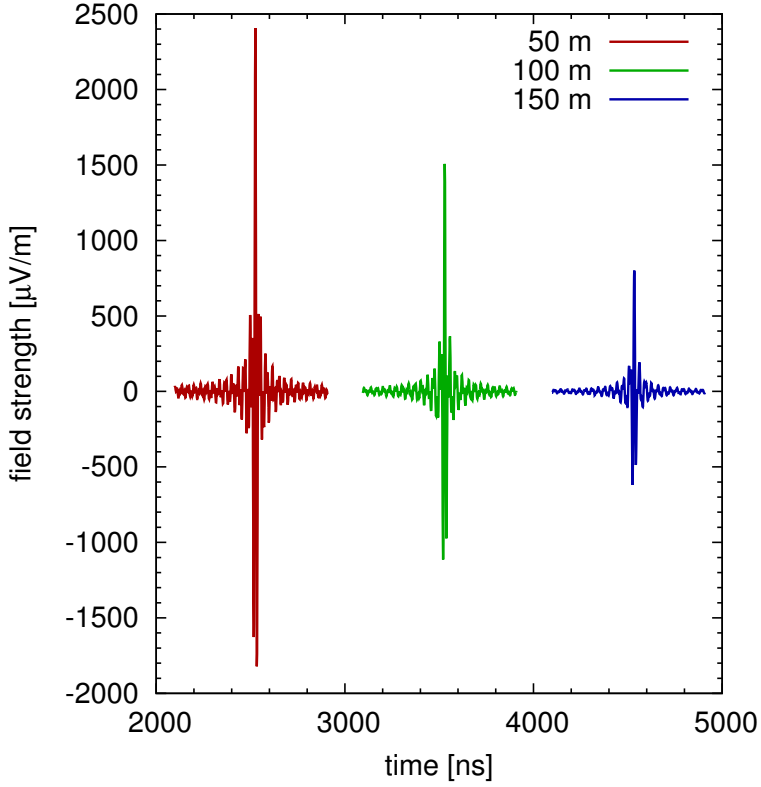
October 24, 2018

Radio emission from air-showers



Radio signal



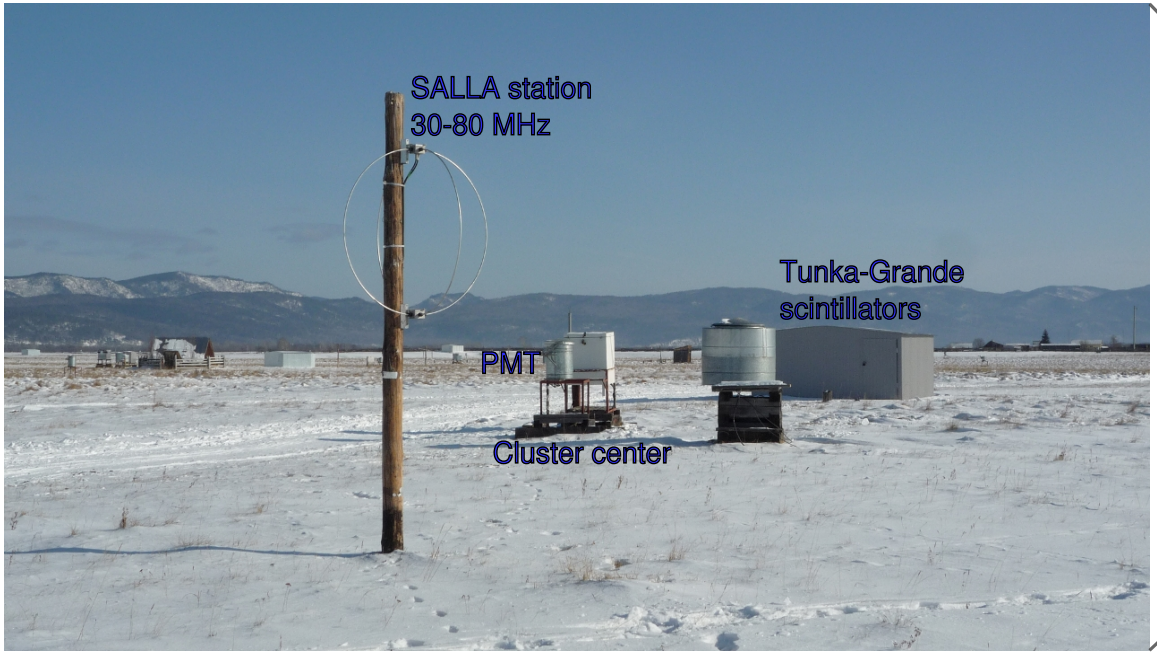


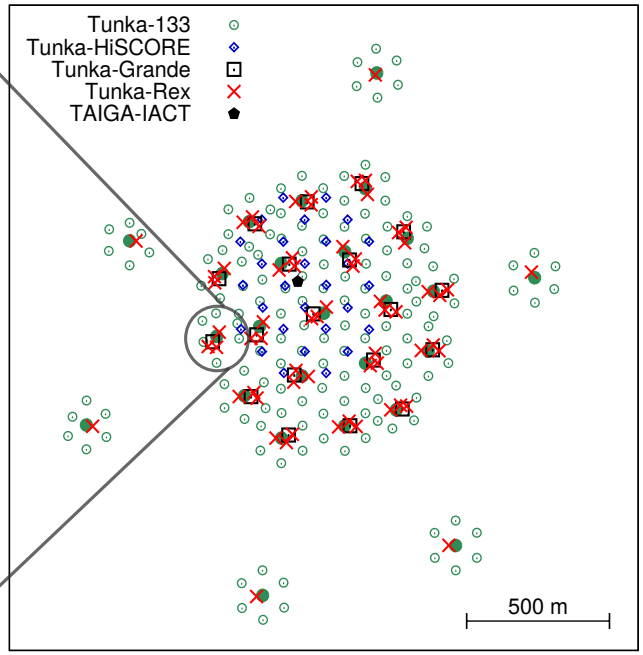
TAIGA

Tunka Advanced Instrument for cosmic ray physics and Gamma Astronomy

- **Cosmic ray detectors <EeV**
  - Tunka-133, air-Cherenkov array
  - **Tunka Radio Extension (Tunka-Rex)**
  - Tunka-Grande scintillators
- **Gamma ray detectors >TeV**
  - TAIGA-HiSCORE
  - TAIGA-IACT

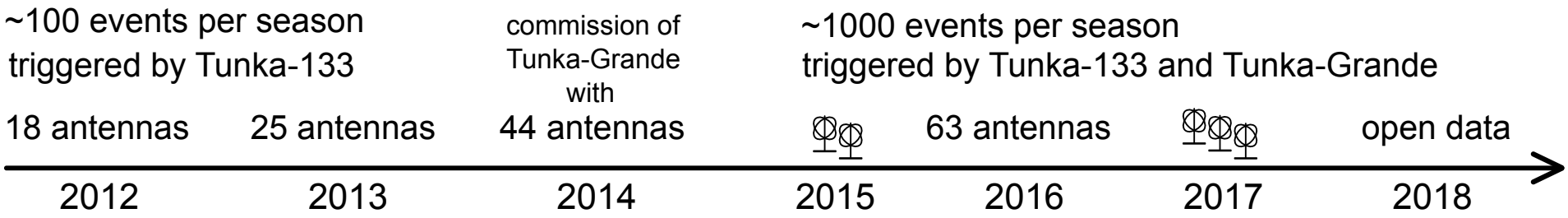
Tunka-Rex





- Tunka-Rex is a sparse antenna array, detecting radio emission from cosmic-ray air showers
- It consists of 63 antenna stations on 1 km^2
- Radio frequency band is 30-80 MHz
- Energy threshold is 100 PeV
- Triggered by Tunka-Grande and Tunka-133

Timeline



Progress:

* Cross-calibration of radio and air-Cherenkov signal
* Precise reconstruction of energy and shower maximum
* Calibration of absolute energy scales of cosmic-ray experiments via radio extensions
* Estimation of aperture and exposure of radio array
* Mean shower maxima as function of primary energy

Plan:

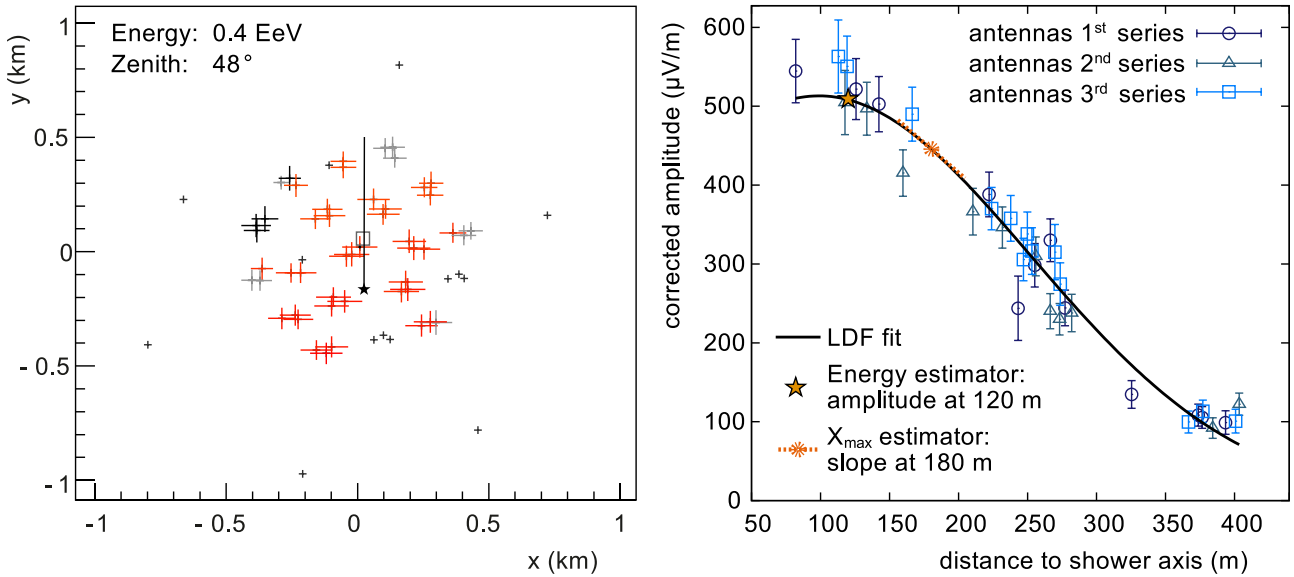
* Independent reconstruction with radio
* Joint reconstruction of electromagnetic and muon components of air showers
* Mass composition study
* Technologies for lowering the threshold
* Open-access to data and software

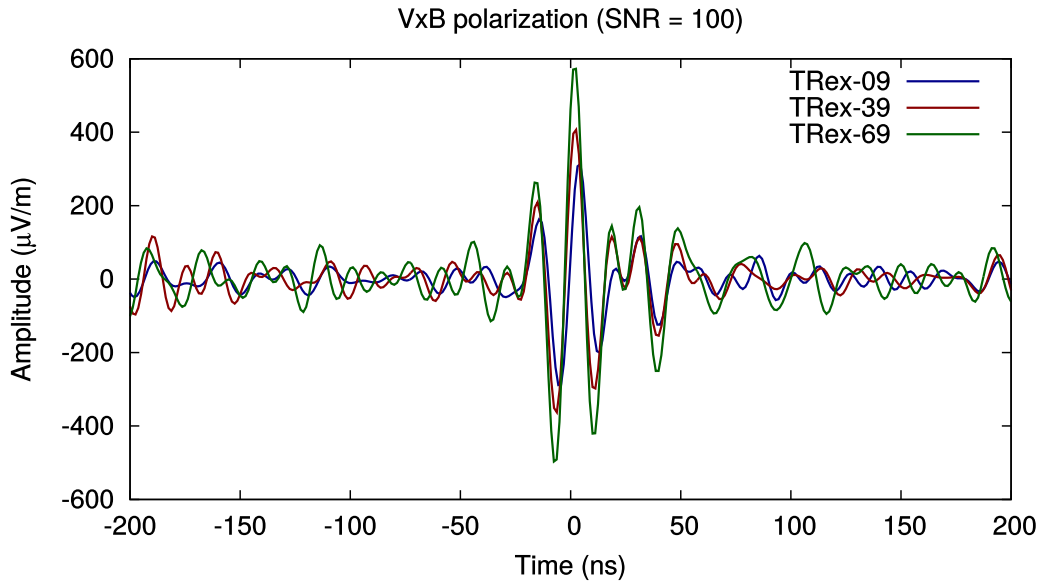
- Measurement season from October to April
- Starting from 2015 Tunka-Rex reached 85% uptime
- Duplex and triplex measurements ($e/\mu, \gamma_c$, radio)

Reconstuction pipeline

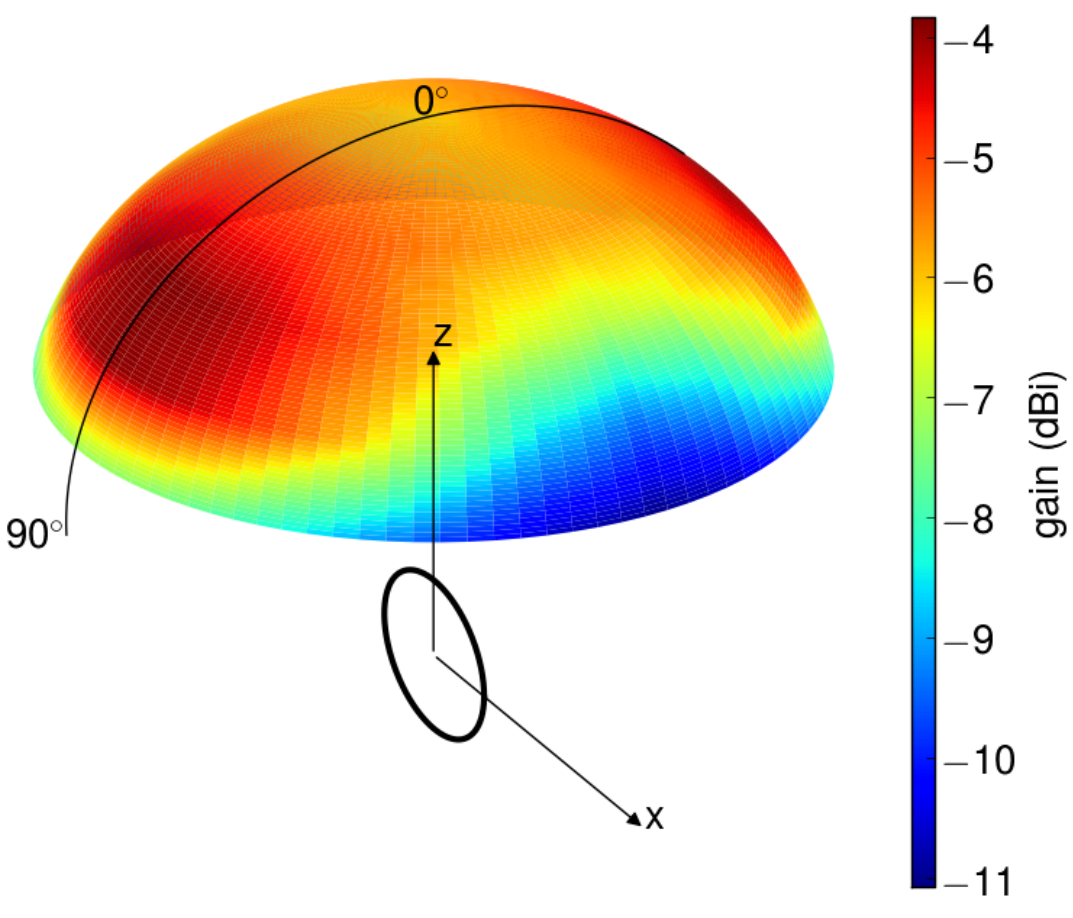
- Station-level analysis
  - Digital filtering
  - RFI rejection
  - SNR cuts
- Event-level analysis
  - $N_{ant} \geqslant 3$
  - Reconstruction of arrival direction and core position
  - Comparison with Tunka-133/Tunka-Grande reconstruction ($\triangle\Omega < 5^{\circ}$)
  - Signal correction (adjustment $f_c(t', SNR)$, $V \times V \times B$ correction)
  - Amplitude fits
  - Energy and shower maximum reconstruction
- Statistical analysis
  - Quality and efficiency cuts
  - Aperture and exposure estimation

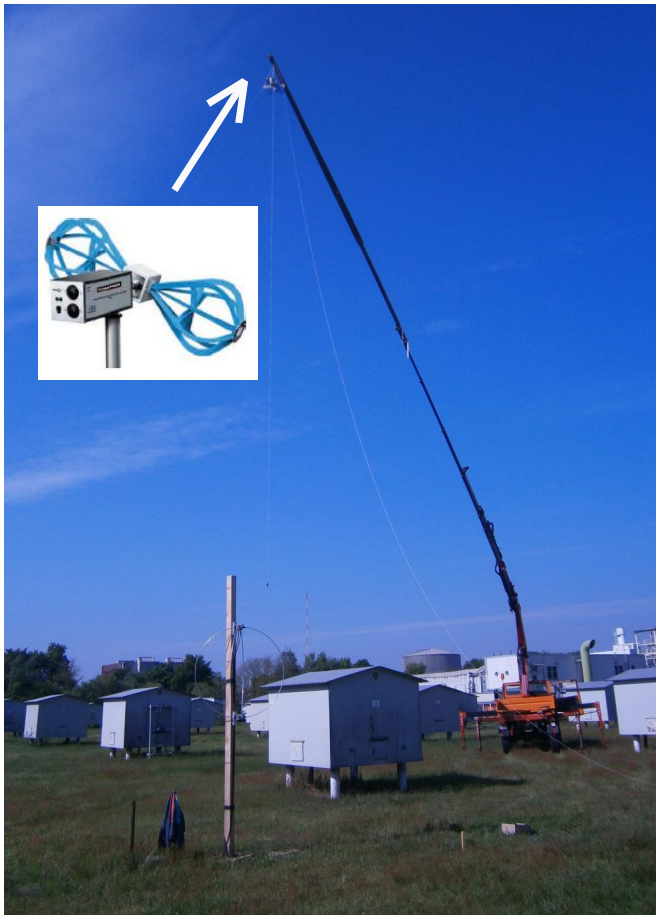
Example of event





Amplitude calibration of Tunka-Rex

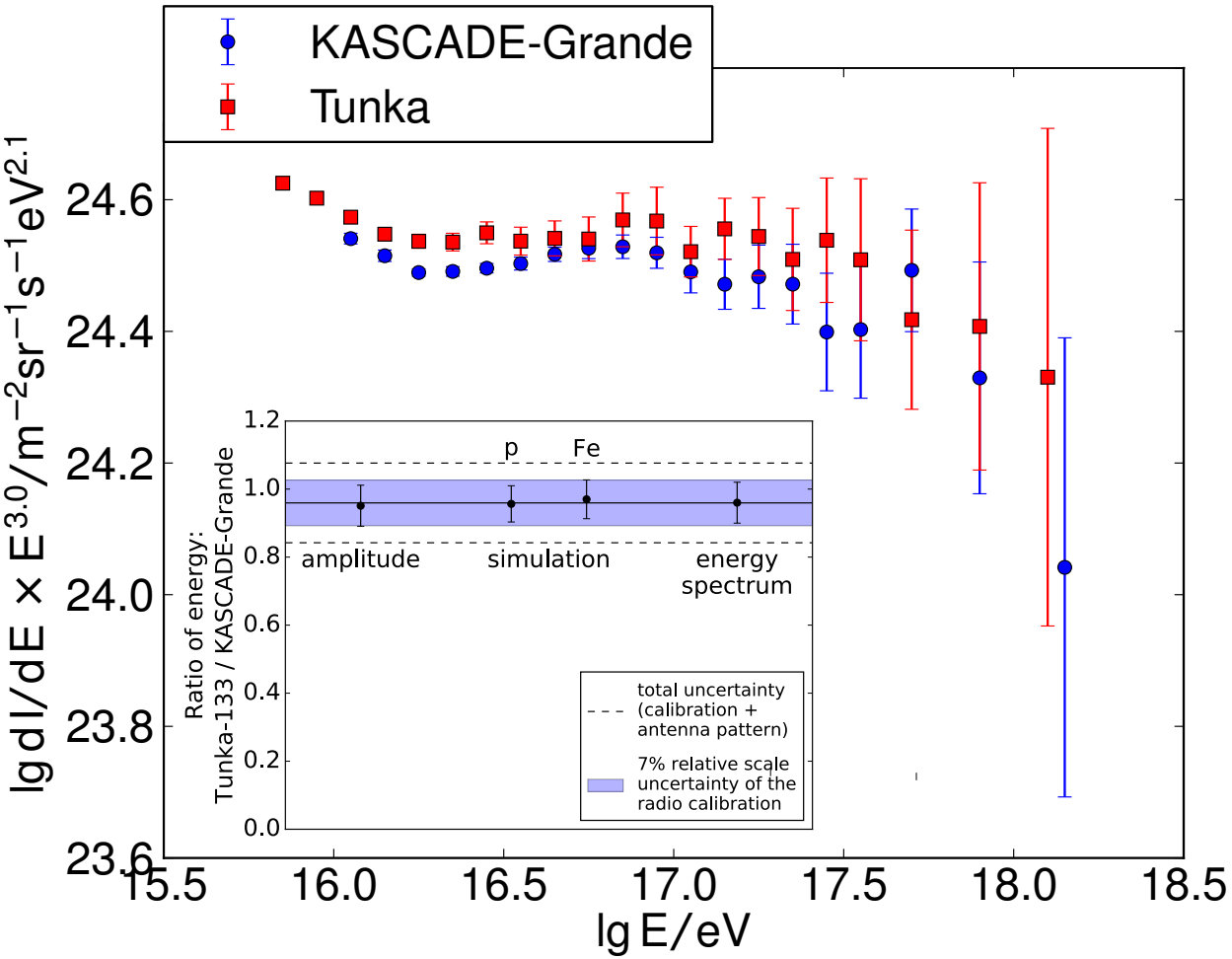




- Tunka-Rex, LOPES and LOFAR calibrated consistently with same source
- Calibration is used as normalization for simulated antenna pattern

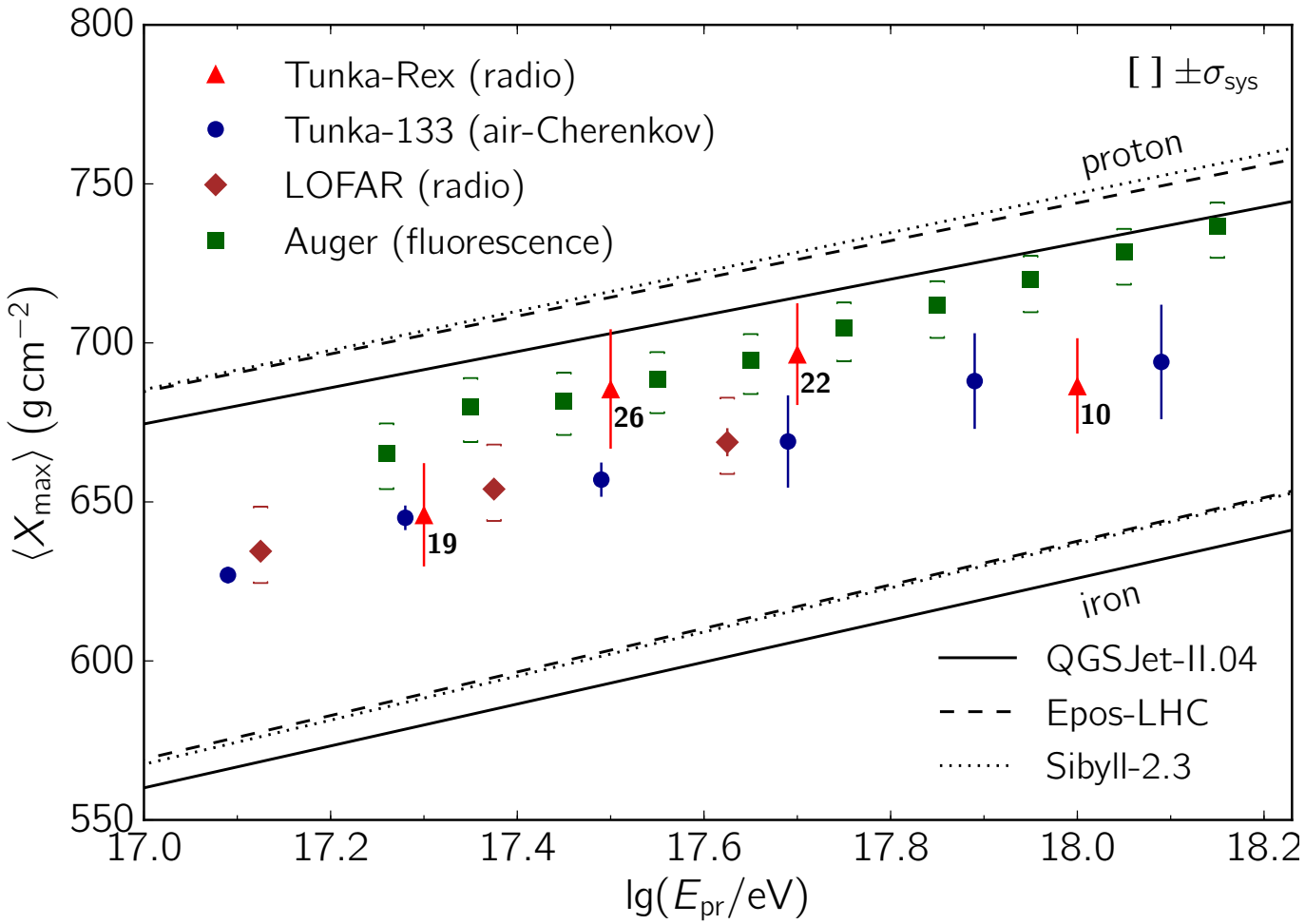
doi:10.1016/j.nima.2015.08.061

Energy scale comparison of Tunka-133 and KASKADE-Grande



Tunka-Rex + LOPES Colls., PLB 763 (2016) 179

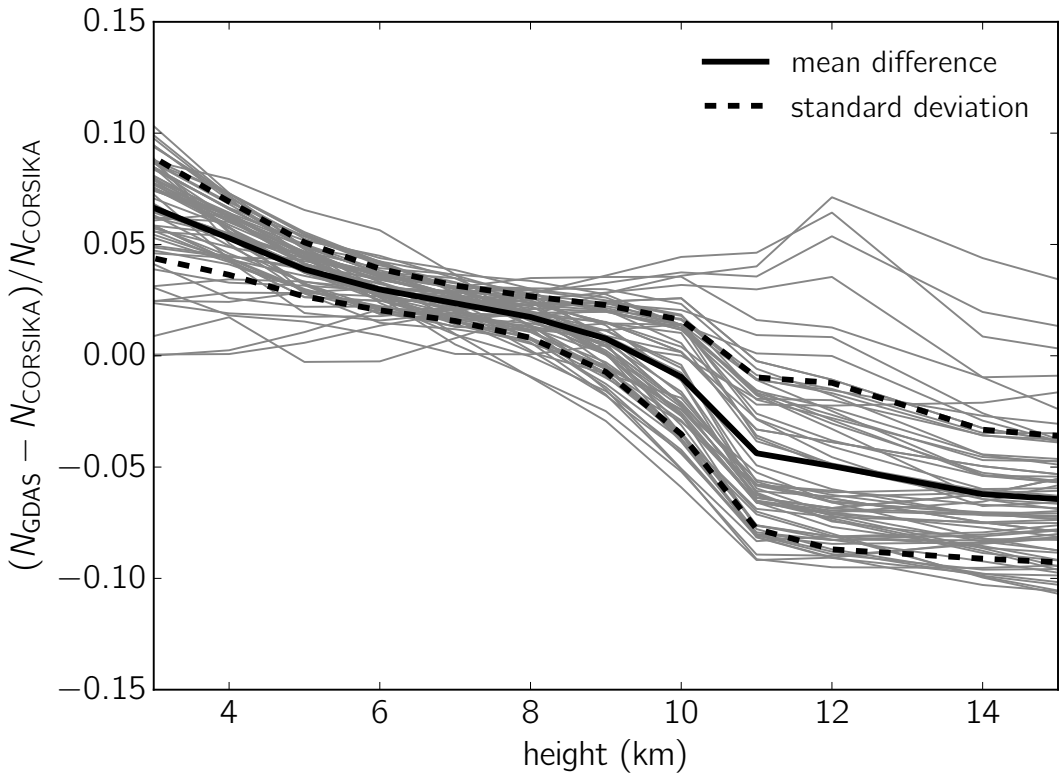
$\langle X_{max} \rangle$ as function of primary energy [Phys.Rev. D 97, 122004]



X_{max} resolution is 25-35 g/cm^2, E_{pr} resolution is 10%

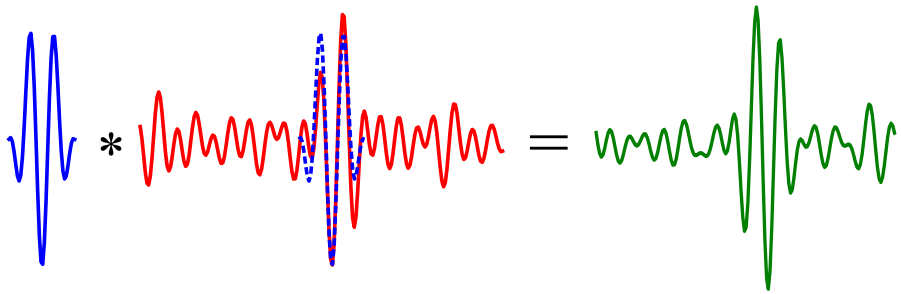
Influence of air refractivity

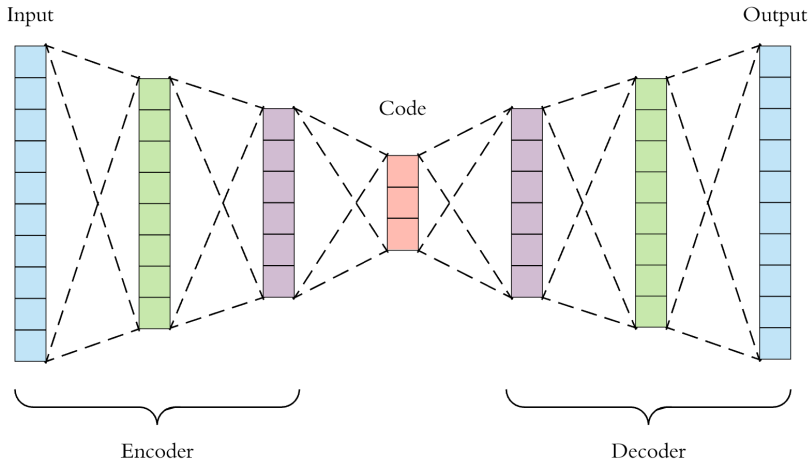
Refractivity $n = 1 + N \times 10^{-6}$



- Event-to-event uncertainty 3 g/cm^2 (refractivity variation of 2%)
- Systematic shift up to 5 g/cm^2 (refractivity difference of 5%)

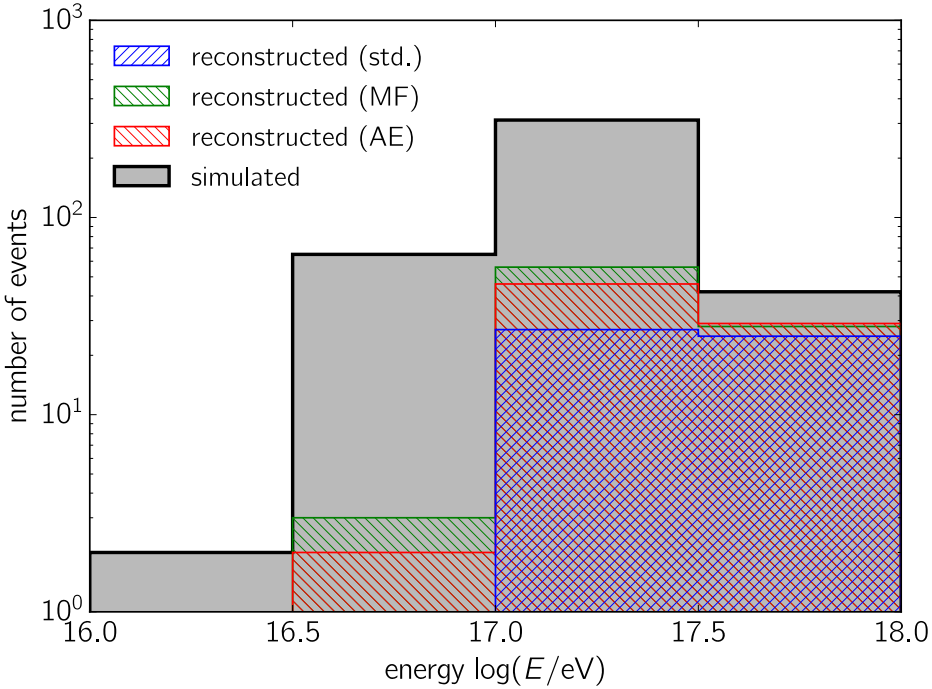
Methods of signal reconstruction: matched filtering and neural networks

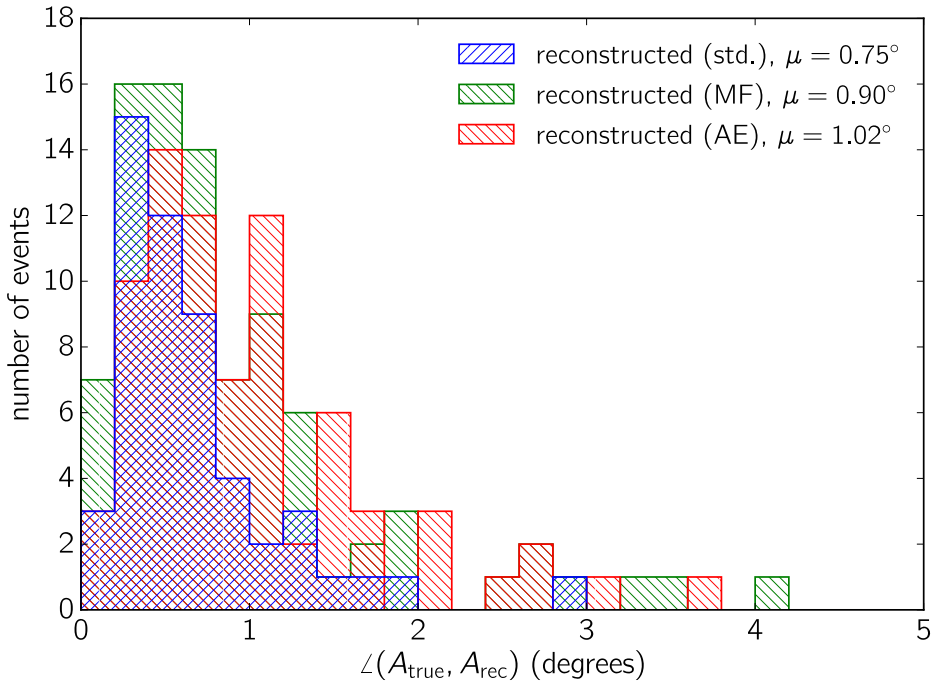




- Matched filtering is based on the convolution of input trace with template. Its the best performance can be achieved only in the case of white noise
- To improve the recognition of non-gaussian features in the traces convolutional neural networks with autoencoder architecture were applied

Impovements of signal reconstruction methods: matched filtering and autoencoder





Applying of matched filtering and autoencoder on simulated dataset have shown their ability to detect low energy events

Summary

- Tunka-Rex is a modern, cost-effective radio detector with precision competitive to established techniques
- $\langle X_{max} \rangle$ as function of primary energy, reconstructed by Tunka-Rex, is in agreement with other experiments. Developed methods will allow to increase statistics of TAIGA facility in ultra-high energy range.
- We are continuously improving signal reconstruction of Tunka-Rex: matched filtering and autoencoder will be implemented in data analysis soon