The Tunka Radio Extension, an antenna array for high-energy cosmic-ray detection

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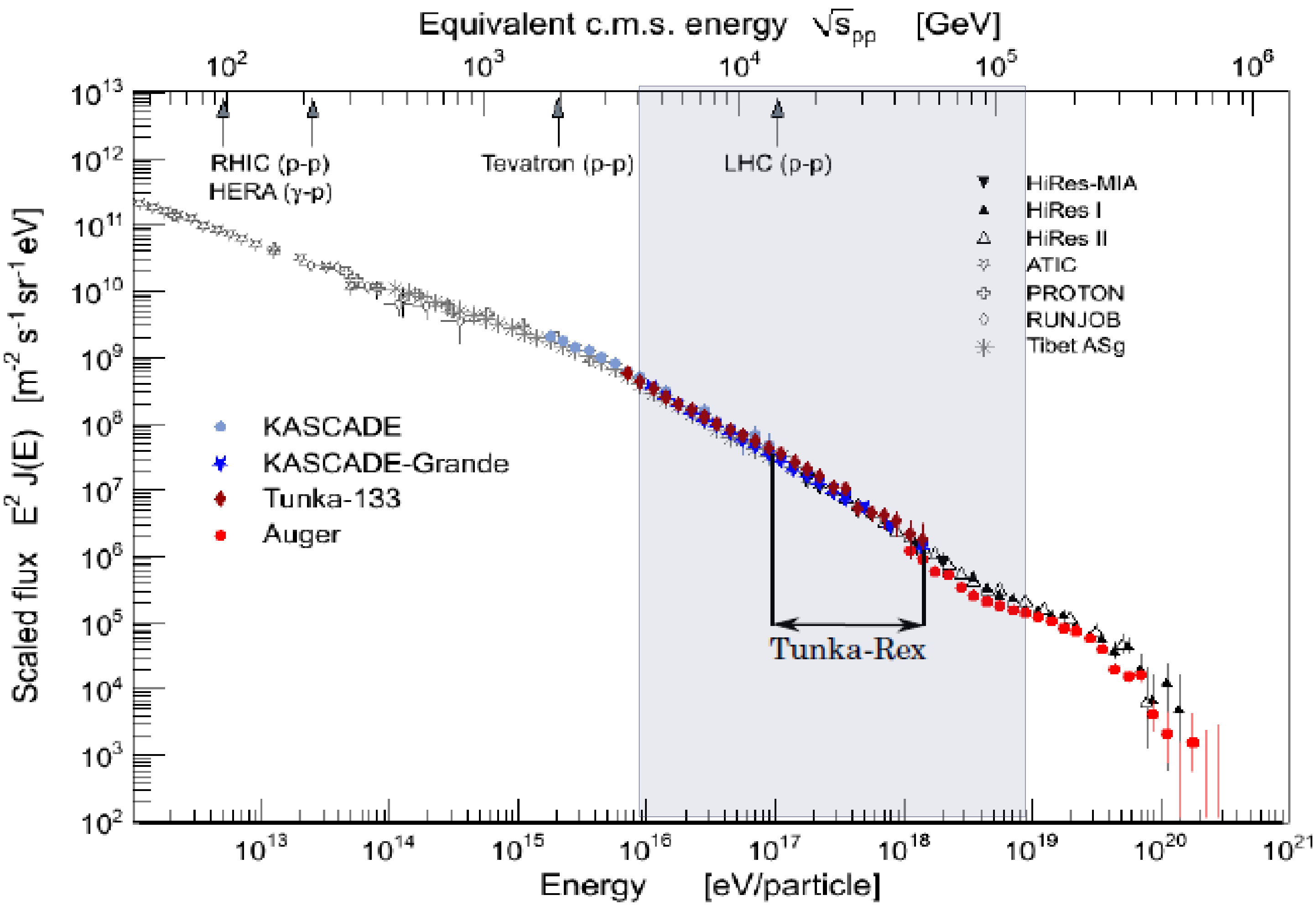
Cosmic rays



Main puzzles of high-energy cosmic rays:
- ✓ Sources of cosmic rays?
- ✓ Acceleration mechanisms?

Need to know:
- ✓ Direction
- ✓ Primary energy
- ✓ **Mass composition**

10^{16}-10^{19} eV:

a transition from galactic to extragalactic sources

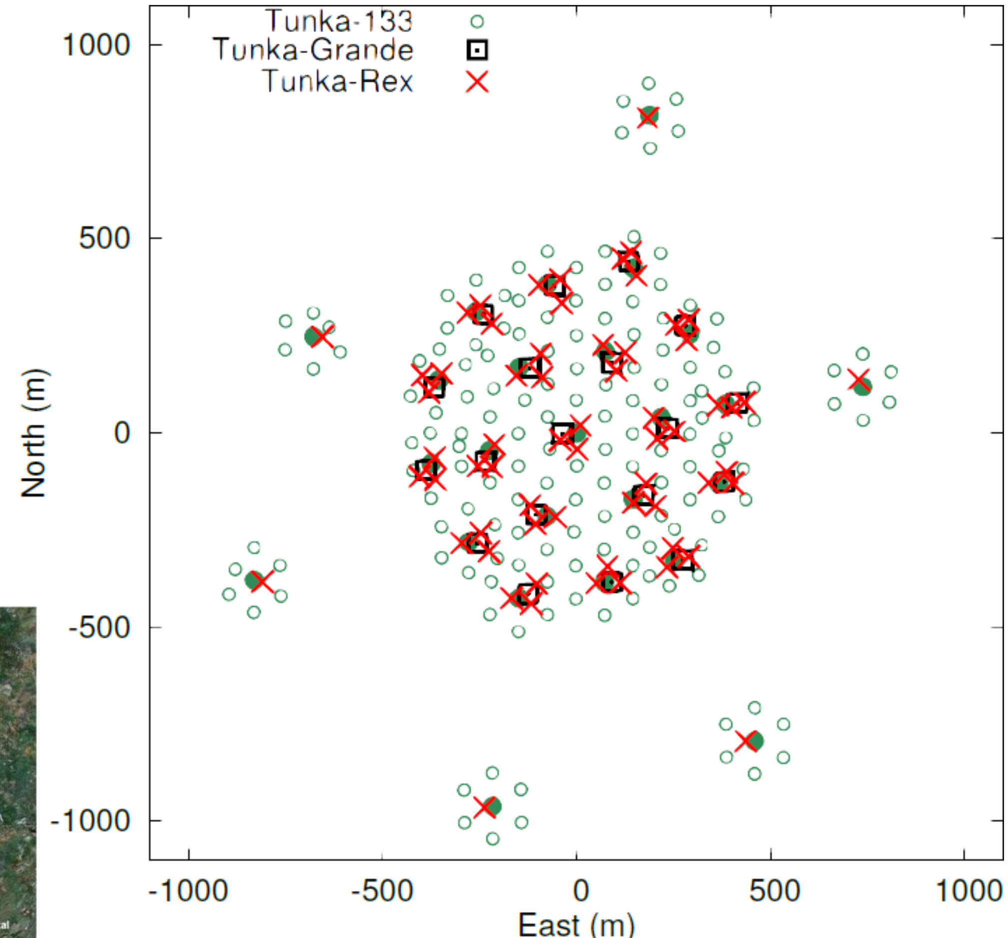
TAIGA - Tunka Advanced Instrument for cosmic rays and Gamma Astronomy:

Cosmic ray detectors

- ✓ Tunka-133 air-Cherenkov
- ✓ Tunka Radio Extension (Tunka-Rex)
- ✓ Tunka-Grande scintillators

Gamma ray detectors

- ✓ HiSCORE
- ✓ IACT



Tunka-133

✓ 175 optical modules (7 per cluster, 25 clusters) on 3 km²

✓ E resolution: ~ 15 %,
X_{max} resolution: ~ 28 g/cm²

✓ Measurement during moonless winter nights (only ~10% of duty cycle)

Tunka-Grande

✓ 19 scintillator stations with spacing of 200 m over 1 km²

✓ Each station consists of electron (8 m²) and muon (5 m²) detectors

(Electron/muon ratio → information about mass composition)

✓ Almost full time duty-cycle

Tunka-133
Tunka-Grande } Trigger for the Tunka-Rex

Tunka-Rex

Upgrade

~100 events per season
triggered by Tunka-133

18 antennas — 25 antennas

expected more than 2000 events per season
triggered by Tunka-133 & Tunka-Grande

44 antennas — 63 antennas

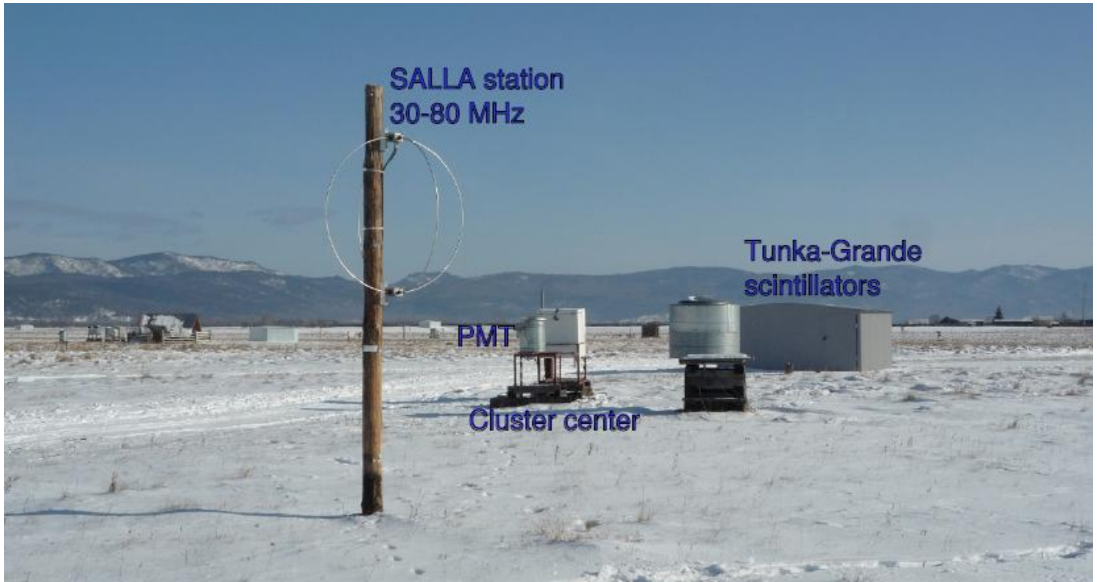
2012 — 2013 — 2014 — 2015 — 2016 — 2017

Achieved:

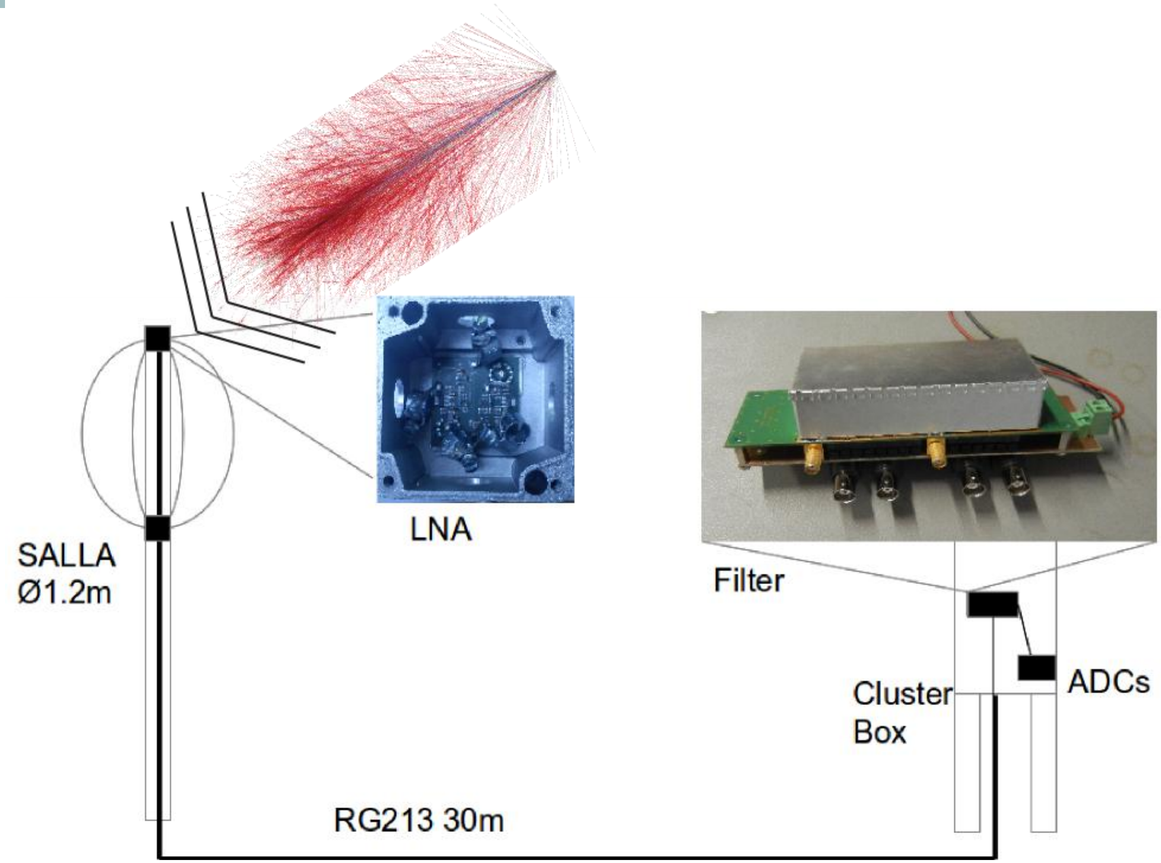
* Cross-calibration of radio and air-Cerenkov signal
* Determine achievable precision of the radio technique

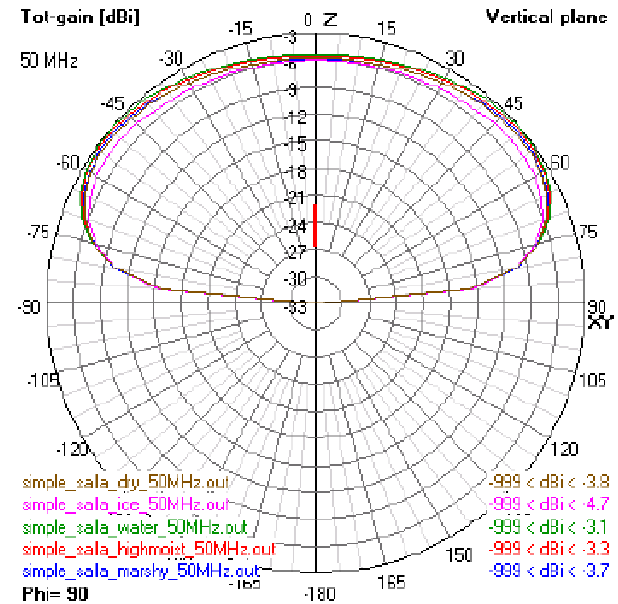
Plan:

* Core reconstruction with radio
* Joint reconstruction of electromagnetic (Tunka-Rex) and muon (Tunka-Grande) components of air showers
* Mass composition study



Tunka-Rex station

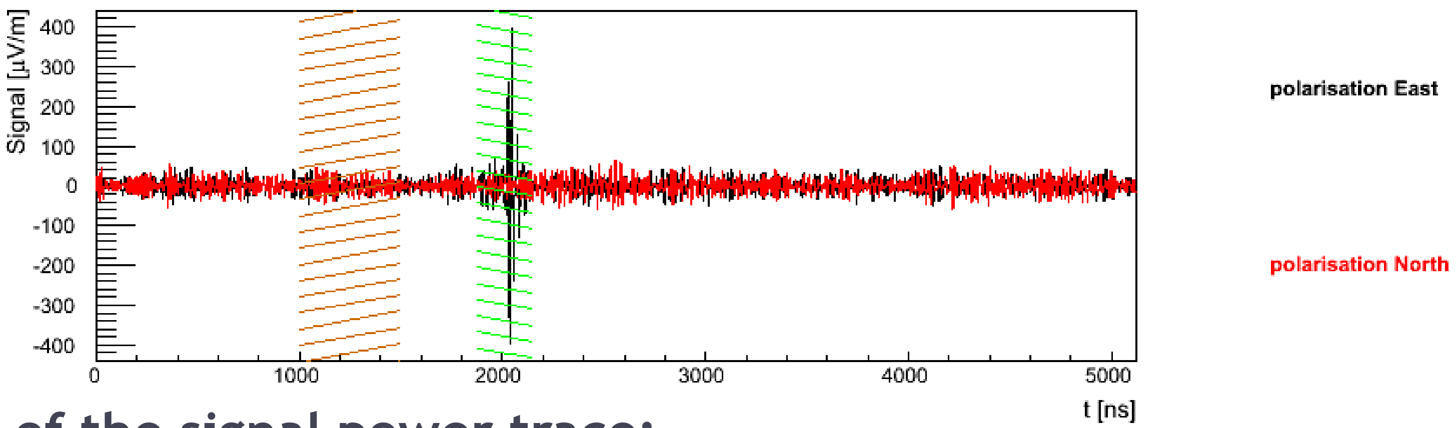




- ✓ Effective frequency band: 35-76 MHz
- ✓ Antenna type SALLA (Loop antenna with isotropic pattern)
- ✓ Absolute scale

Tunka-Rex is the most cost-effective of all radio arrays

Example of Tunka-133 triggered event



Searching of the signal power trace:

- ✓ Digiting filtering
- ✓ N antennas ≥ 3
- ✓ SNR ≥ 10

Rejecting false positive events:

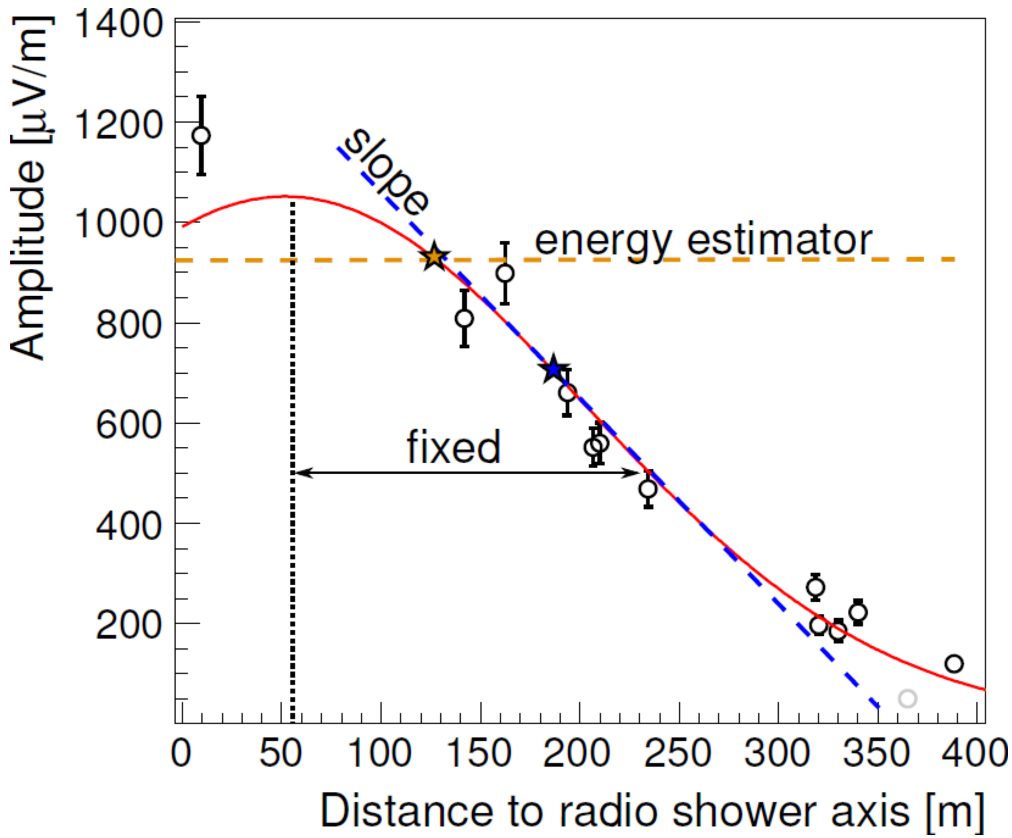
- ✓ Comparison with Cherenkov reconstruction ($\Omega < 5^\circ$)
- ✓ Rejecting outliers from the LDF (using Tunka-133 core coordinates)
- ✓ Reconstruction of arrival direction with plane fit

Quality cuts for X_{max}: reconstruction at least one antenna at d_{axis} > 200 m

For analysis we use the radio part of the Auger Offline software
Pierre Auger Collaboration, NIM A 635 (2011) 92

Reconstruction method

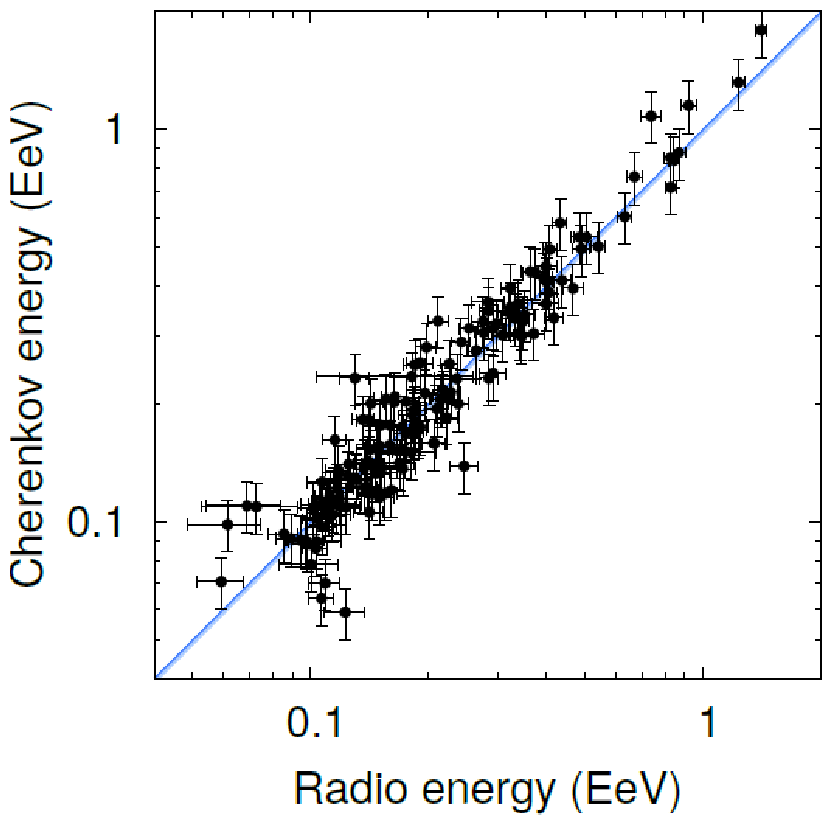
✓ LDF correction for the azimuthal asymmetry and for the geomagnetic angle
✓ Gaussian LDF, three parameters: A_{120m}, slope and width (fixed)
✓ E_{pr} ~ A at 120 m, X_{max} depends on slope at 180 m



(doi:10.1016/j.astropartphys.2015.10.004)

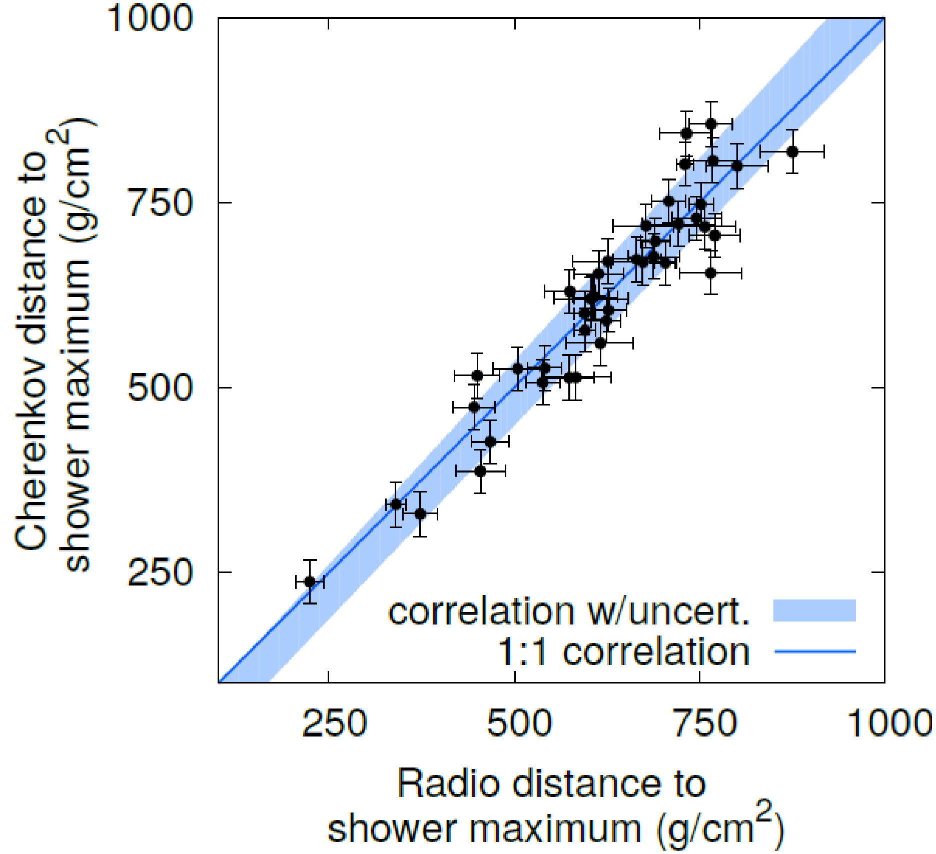
Cross-check with Tunka-133 (2012-2014 seasons)

Energy



resolution: 15%

Shower maximum

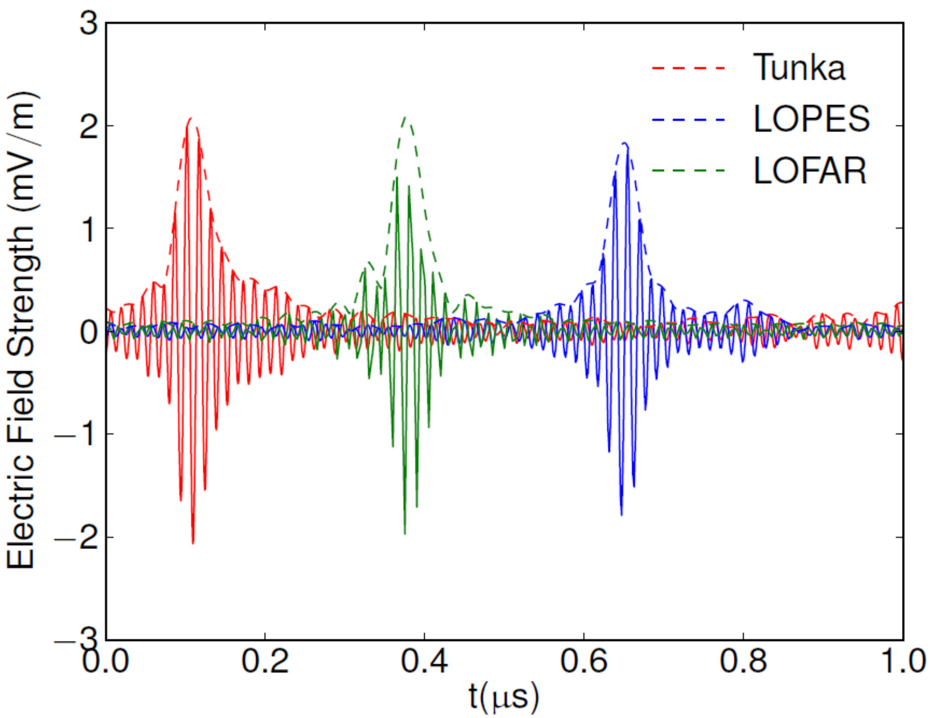


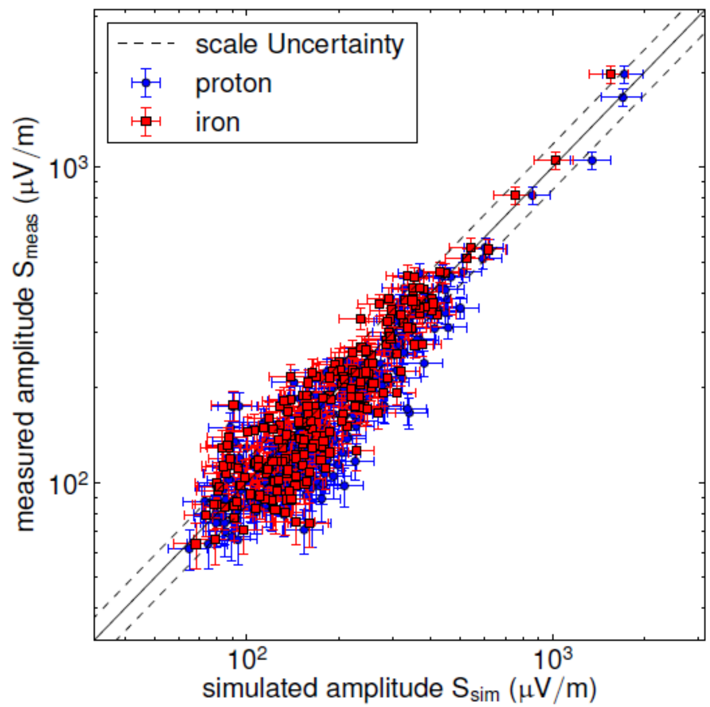
resolution: 38 g/cm^2

Tunka-Rex Collaboration, JCAP 1601 (2016) no.01, 052 [doi:10.1088/1475-7516/2016/01/052]

Amplitude calibration

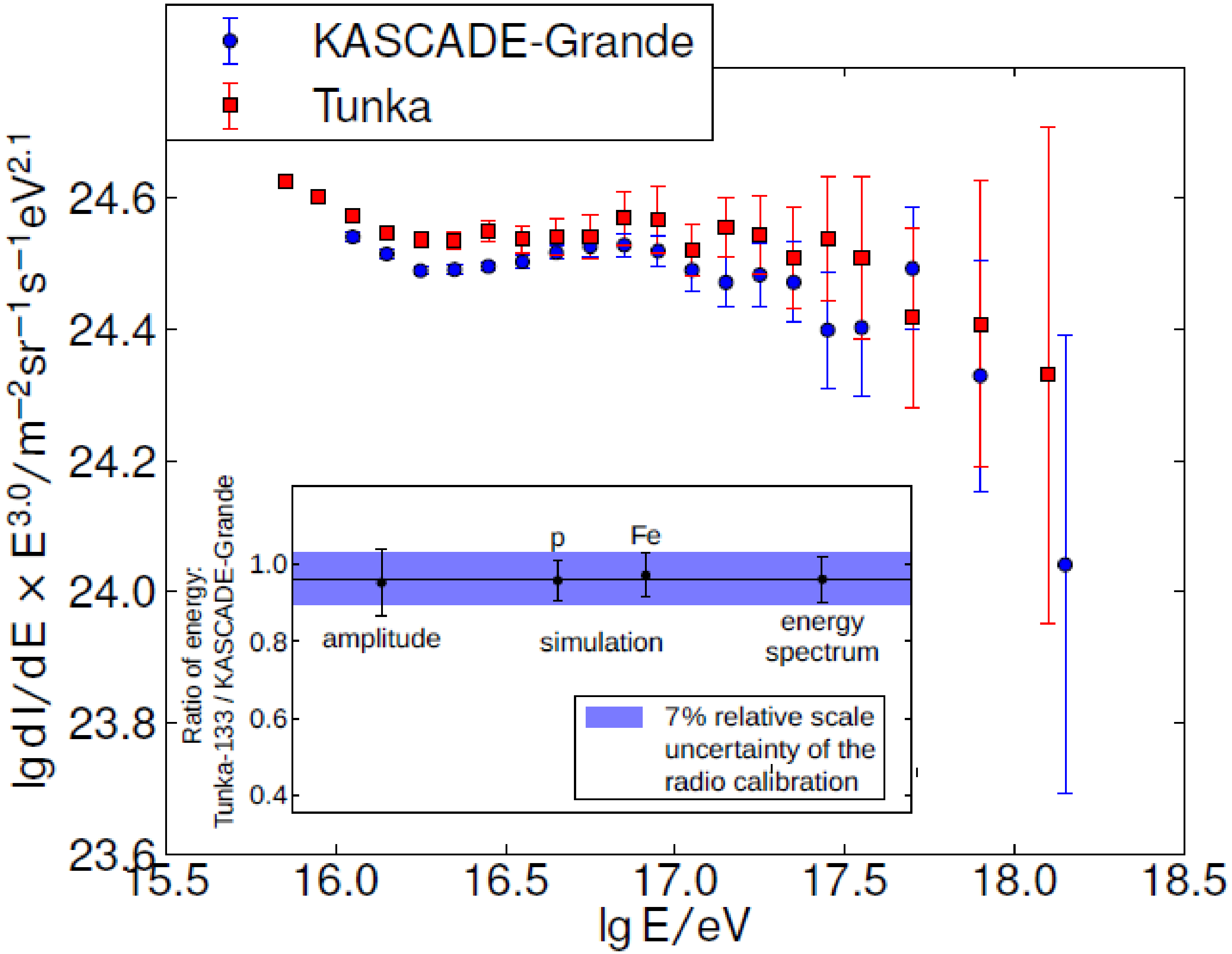
- ✓Absolute reference source for Tunka-Rex, LOFAR and LOPES
- ✓CoREAS amplitude scale confirmed (17%)





(doi:10.1016/j.nima.2015.08.061)

Comparison of energy scales of Tunka-133 and KASCADE-Grande



Conclusion

✓Tunka-Rex provides competitive precision of energy and shower maximum

✓Absolute amplitudes compatible with CoREAS simulations and LOPES measurements

✓After its upgrade, Tunka-Rex focuses on the mass-composition study jointly with Tunka-Grande