

Cosmic ray measurements with Tunka Radio Extension

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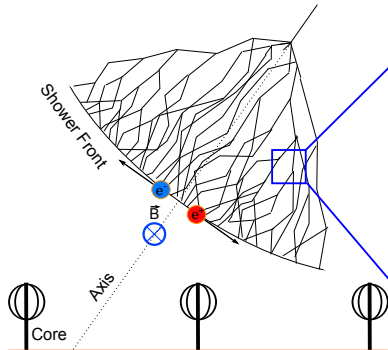
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Radio emission from air-showers

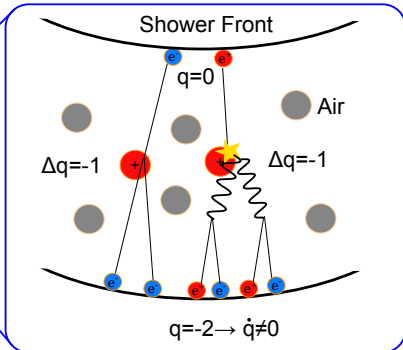
Geomagnetic effect

- Time-varying transverse currents
- Polarization along Lorentz force
- Dominant effect ($\sim \sin \alpha$)

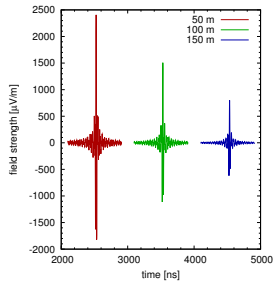
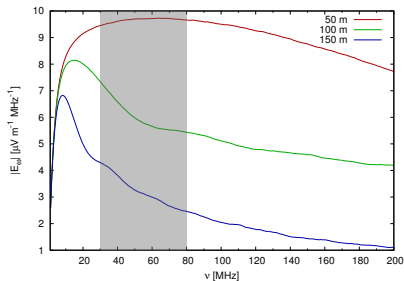


Askaryan effect

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



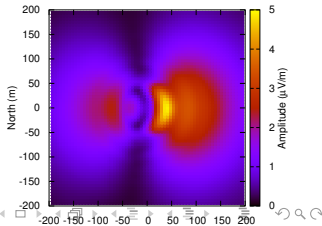
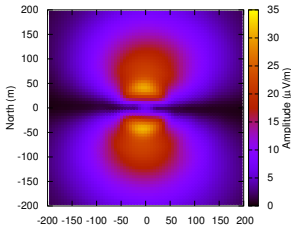
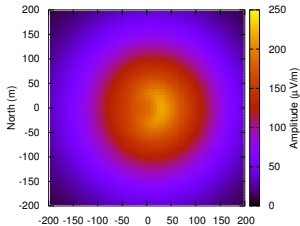
Properties of radio signal



East-West component

North-South component

Vertical component





Tunka Radio Extension

- Frequency band 30-80 MHz
- Cost-effective
- Duplex and triplex measurements:
 $\gamma_{\text{ch}}/\mu/e + \text{radio}$
- World-unique radio and
air-Cherenkov cross-calibration
- First direct measurement
of shower maximum with radio
- **Proof-of-feasible**

Air-shower reconstruction

Lateral distribution function (LDF)

$$\mathcal{E}(r) = \mathcal{E}_{r_0} \exp(a_1(r-r_0) + a_2(r-r_0)^2),$$

Fixing quadratic term

$$a_2(\theta, E_{\text{pr}}^{\text{est}}) = a_{20}(E_{\text{pr}}^{\text{est}}) + a_{21}(E_{\text{pr}}^{\text{est}}) \cos \theta,$$

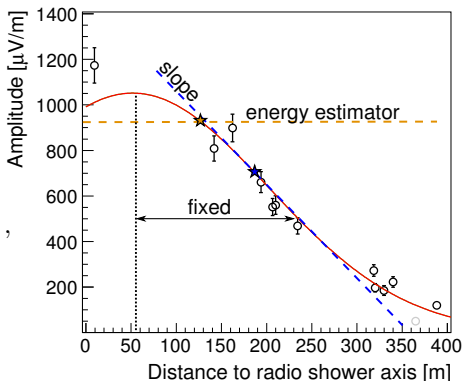
LDF slope

$$\eta = \frac{\mathcal{E}'}{\mathcal{E}}$$

Air-shower parameters

$$E_{\text{pr}} = \kappa_L \mathcal{E}(r_e)$$

$$X_{\text{max}} = X_0 / \cos \theta - (A + B \log(\eta(r_x) + \bar{b}))$$

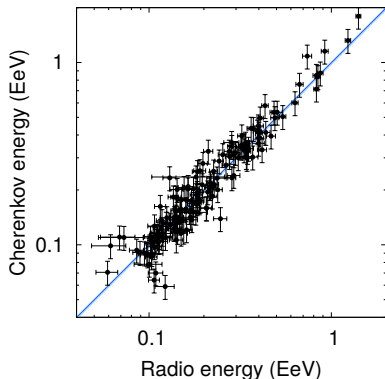


Model parameters from CoREAS simulations

[doi:10.1016/j.astropartphys.2015.10.004](https://doi.org/10.1016/j.astropartphys.2015.10.004)

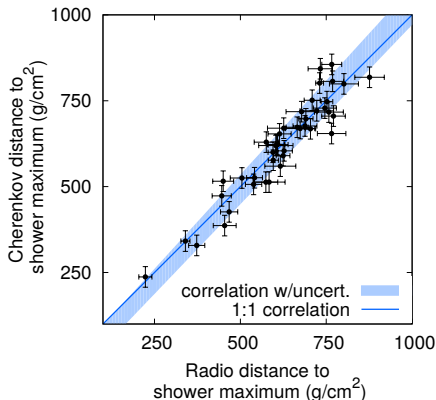
Cross-check with Tunka-133

Energy



resolution: 15%

Shower maximum



resolution: $38 \text{ g}/\text{cm}^2$

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