

Radio detection in the multi-messenger context.

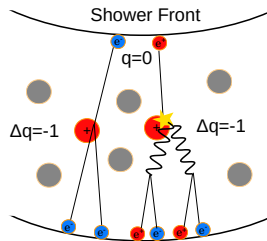
Dmitriy Kostunin
VLVnT 2018
Dubna, 4.10.2018



Radio emission from particle cascades

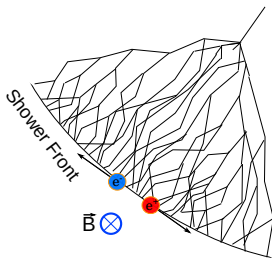
Askaryan (charge-excess) effect

- $\partial q/\partial t$ due to ionization and e^+ annihilation
- Radial polarization
- Dominant effect in dense media, second-order in air-showers

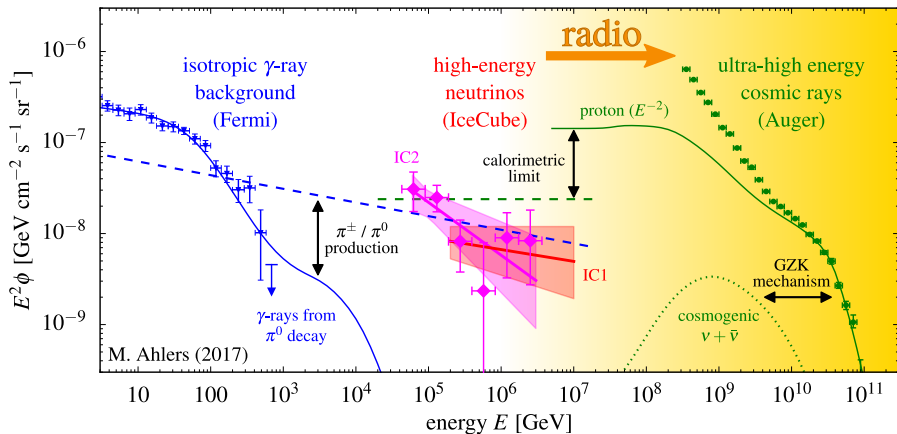


Geomagnetic effect

- $\partial j/\partial t$ due to charge separation in Earth's magnetic field
- Polarization along Lorentz force
- Exists only in air-showers due to cascade dimensions



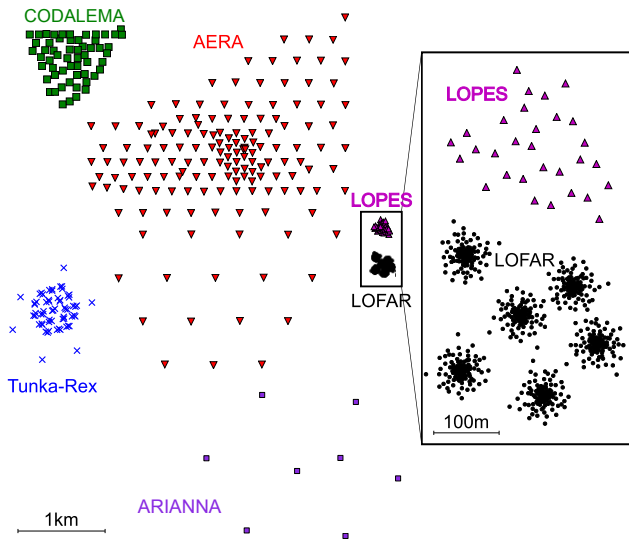
Motivation for radio detection



- Cost-effective technique
- Almost full duty-cycle
- High precision for energy and shower maximum
- **Sensitivity for inclined events**



Digital radio detection of air-showers



First generation:

LOPES
CODALEMA

Second generation:

AERA
Tunka-Rex

Third generation:

ARIANNA
GRAND, Radio@SP

Radiotelescopes:

LOFAR
SKA



Progress of radio detection

- Proof-of-principle (LOPES, CODALEMA)
- Simulation software (CoREAS)
- Precise study of phenomena (LOFAR)
- Precise reconstruction with sparse arrays (Tunka-Rex)
- Large-scale arrays (AERA)

--- we are here ---

- Self-trigger
- Lowering the threshold
- Ultra-large-scale arrays

Resolution: $\sigma E_{\text{pr}} \approx 10\%$, $\sigma X_{\text{max}} \approx 30 \text{ g/cm}^2$, $\sigma \Omega \approx 1^\circ$

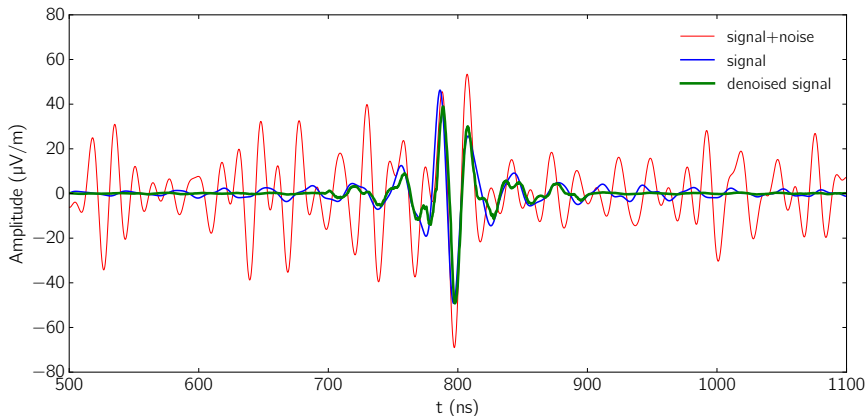
Threshold for single antenna: $E_{\text{th}} \approx 10^{16.5} \text{ eV}$

Background is dominated by Galaxy in radio-quiet locations



Towards self-trigger and lower threshold

Denoising with deep learning technology (Tunka-Rex)

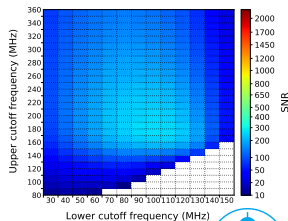
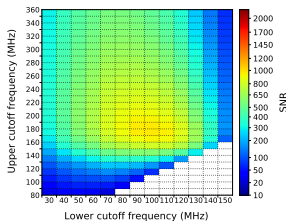
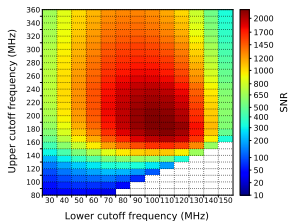
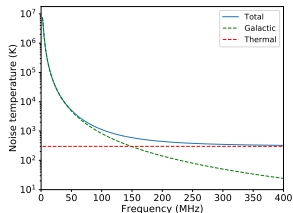
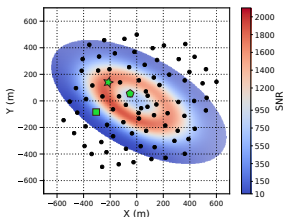


D. Shipilov for the Tunka-Rex collaboration, ARENA2018 conf.



Towards self-trigger and lower threshold

Optimal frequency band (theory for South Pole)

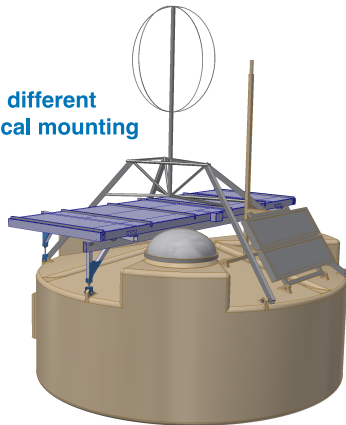
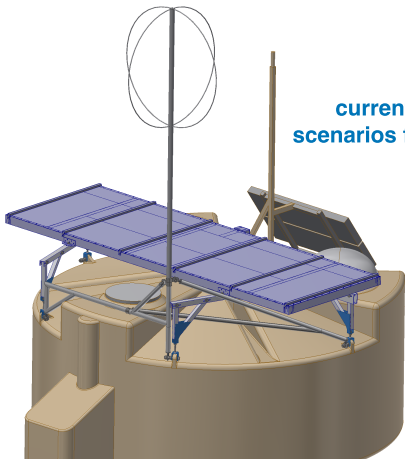


doi:10.1140/epjc/s10052-018-5537-2



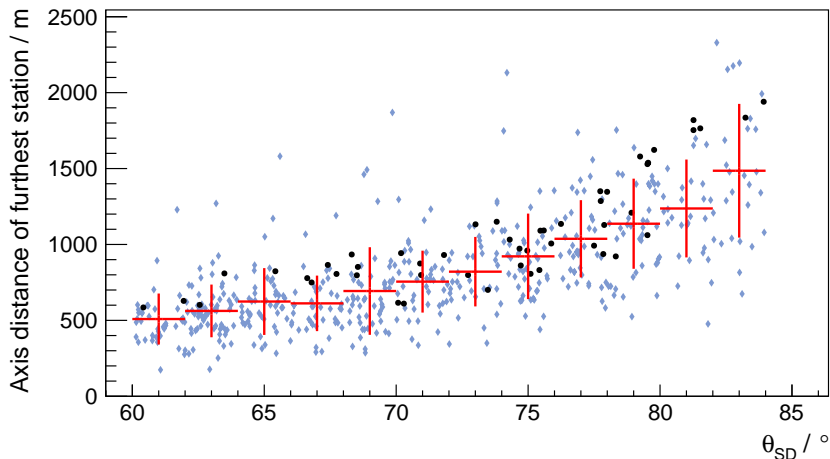
Towards large-scale radio arrays (AERA)

currently studying different scenarios for mechanical mounting



Funding for covering PAO with radio antennas is obtained

Detection of inclined events at AERA

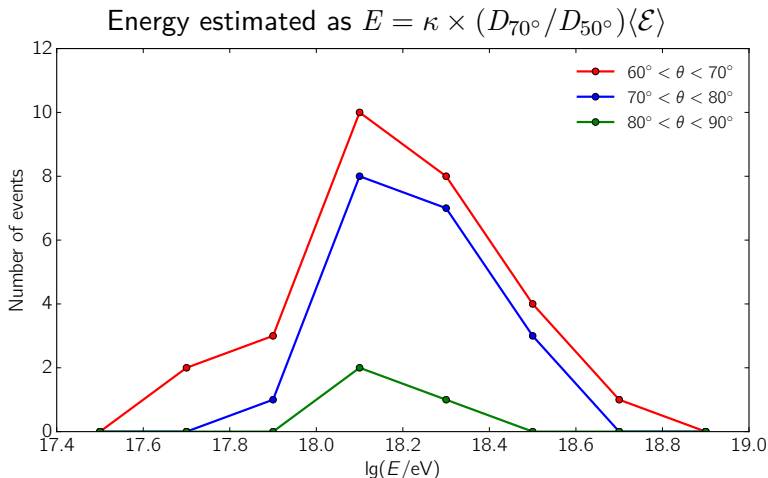


arXiv:1806.05386

Measured footprints are consistent with expectation



Tunka-Rex energy estimation of inclined events

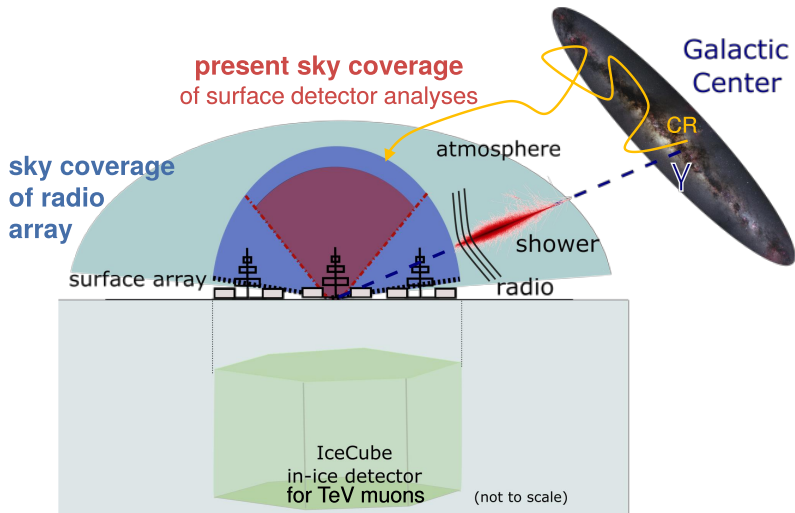


T. Marshalkina for the Tunka-Rex collaboration, ARENA2018 conf.

Obtained sensitivity is consistent with expectations



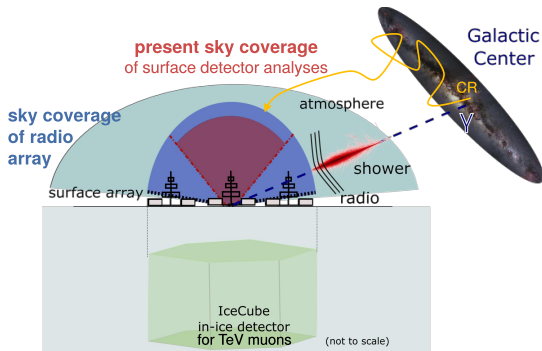
Surface array at South pole



F.G. Schröder for the IceCube-Gen2 collaboration, ARENA2018 conf.

Surface array at South pole

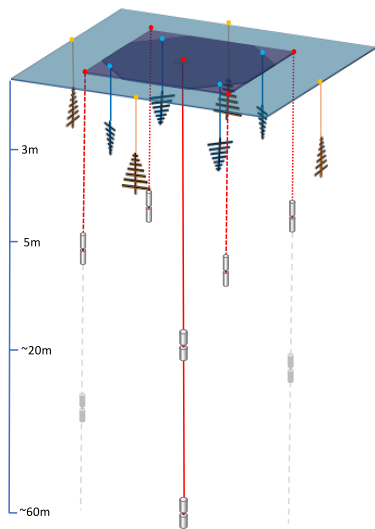
- γ : Galactic center is full-time visible under $\theta = 60^\circ$ – increased exposure for PeV particles
- CR: increased sensitivity to mass composition (X_{\max} , radio+ μ), mass-dependent anisotropy study



ERC funding of 1.6 M€ is obtained

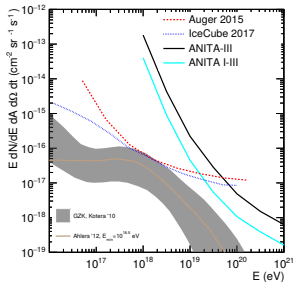
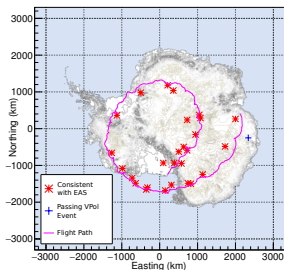


In-ice arrays (ARA & ARIANNA)



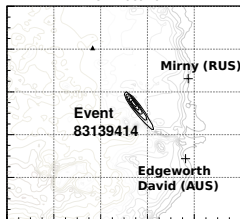
- Ice is more complicated medium than expected (doi:10.1088/1475-7516/2018/07/055)
- Lowering the threshold with interferometry (arXiv:1809.04573)
- Merging ARA and ARIANNA approaches in common array
- Greenland Neutrino Observatory is proposed (doi:10.22323/1.236.1150)

Latest ANITA results

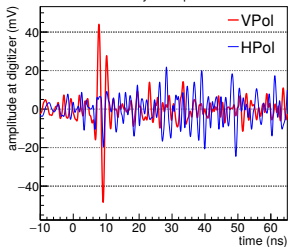


- Best neutrino sensitivity for $E > 10^{19.5}$ eV
- Four flights in 2006-2007, 2008-2009, 2014-2015, 2016

Event Location



Coherently-Dispersed

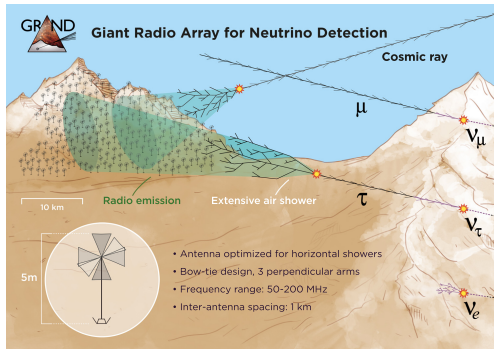


- ANITA-V will be $\times 4$ more sensitive
- Few mystery events are detected (noise, tau, SUSY?)

doi:10.1103/Phys-RevD.98.022001

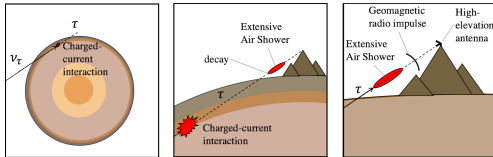


Ultra-large scale ground arrays



- Focus on inclined air-showers
- CR, ν_{all} , γ from above, ν_τ from below
- Testing different detection technologies and layouts
- Sparse arrays in mountain area
- Multiple locations: China, Kazakhstan, Russia

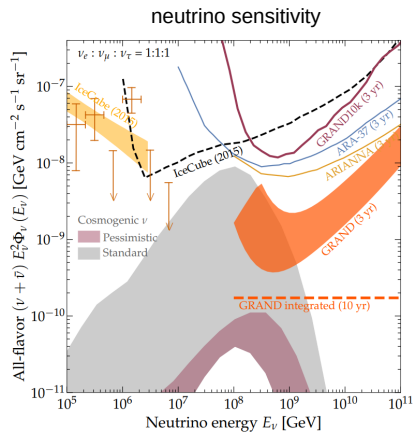
BEACON: Beamforming Elevated Array for COsmic Neutrinos



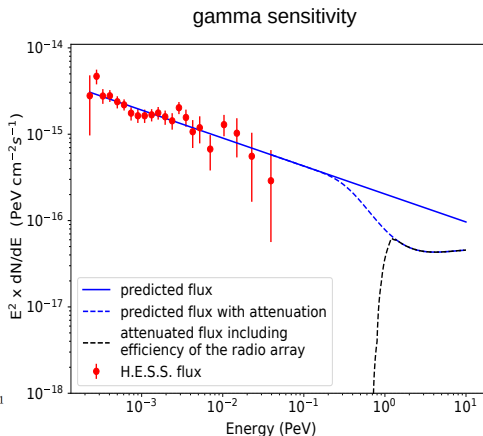
see ARENA2018
contributions for details



Sensitivity curves & conclusion



doi: 10.22323/1.301.0996



doi: 10.1140/epjc/s10052-018-5537-2

- Realistic sensitivity for EeV neutrinos
- (very) Optimistic sensitivity for PeV gammas at South Pole

