Karlsruhe Institute of Technology

Tunka-Rex

First analysis of inclined air-showers detected by Tunka-Rex

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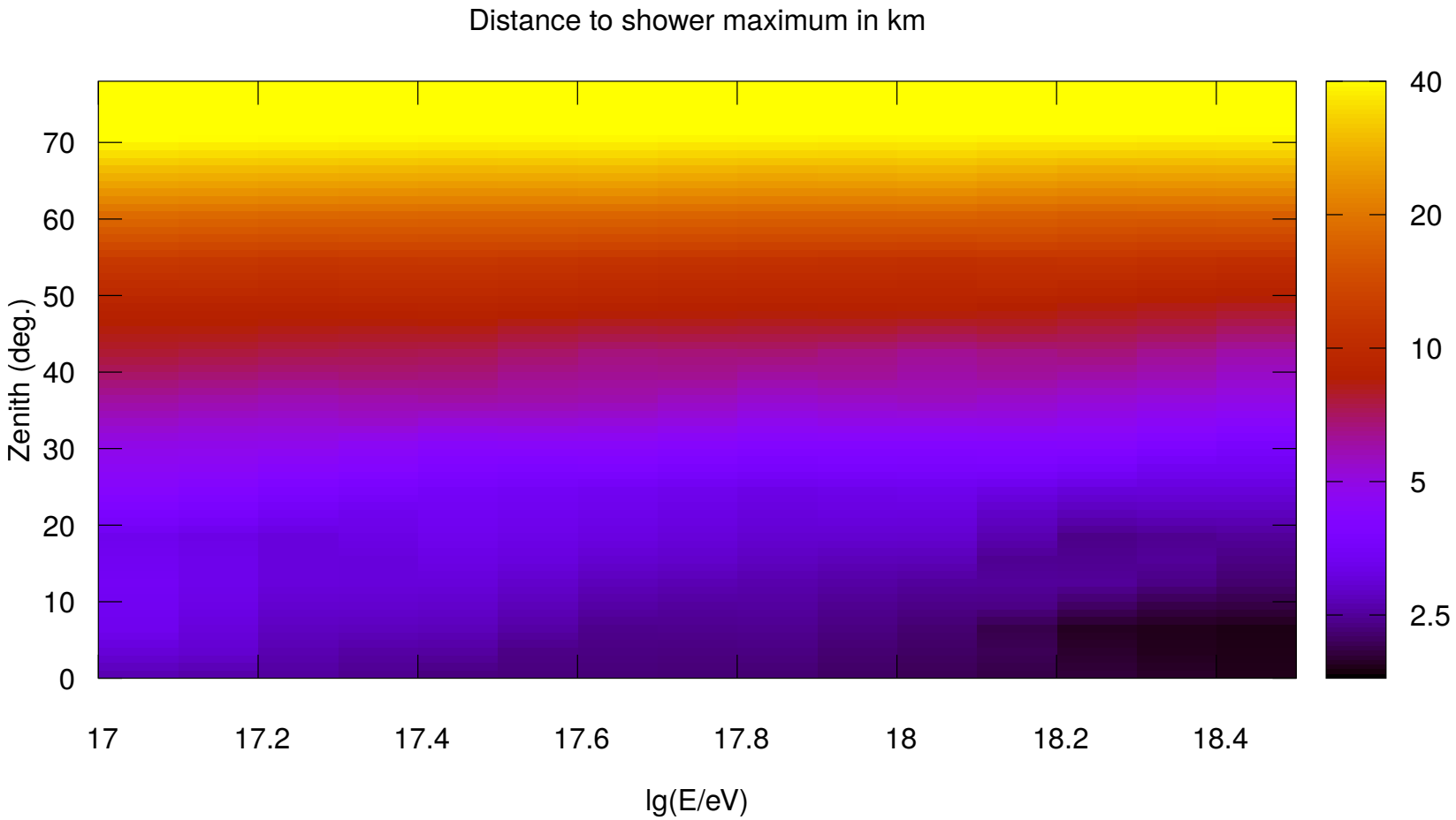
Motivation

We consider inclined events as ones having $\theta > 60^\circ$ (e.g. $\cos\theta < 0.5$)

- Increasing aperture of array in more than two times
  $\Omega \times 2 + S \times n$: solid angle and area (larger footprints)
- CR studies for $E > 10^{18}$ eV
- Neutrino studies

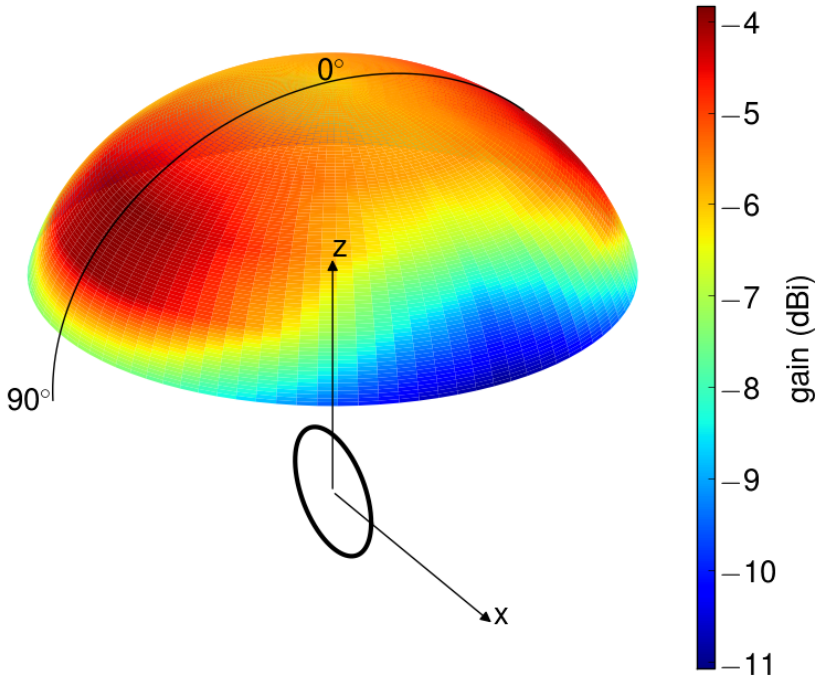
First inclined events have been detected by Tunka-Rex in November, 2012

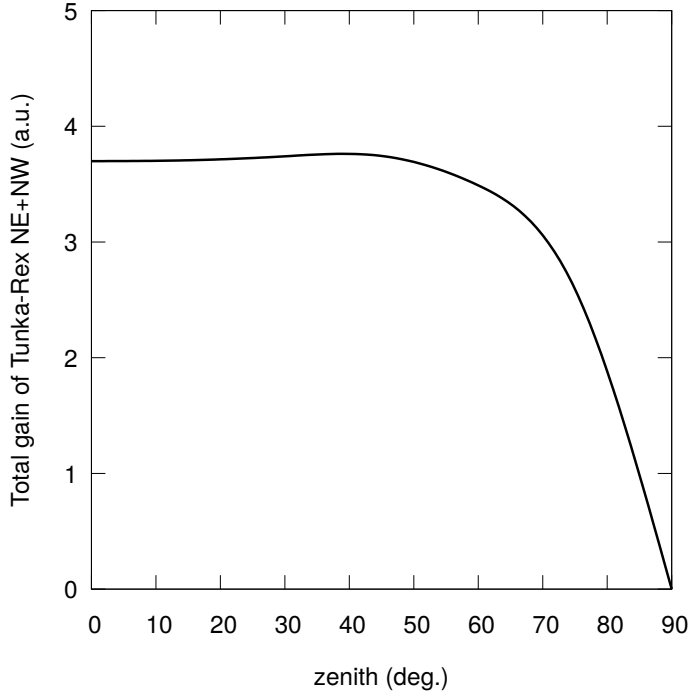
Air-shower geometry



- Dimensions of inclined event much larger than for vertical one
- Amplitude suppression $\sim 1/D_{\max}$

Tunka-Rex antenna station sensitivity

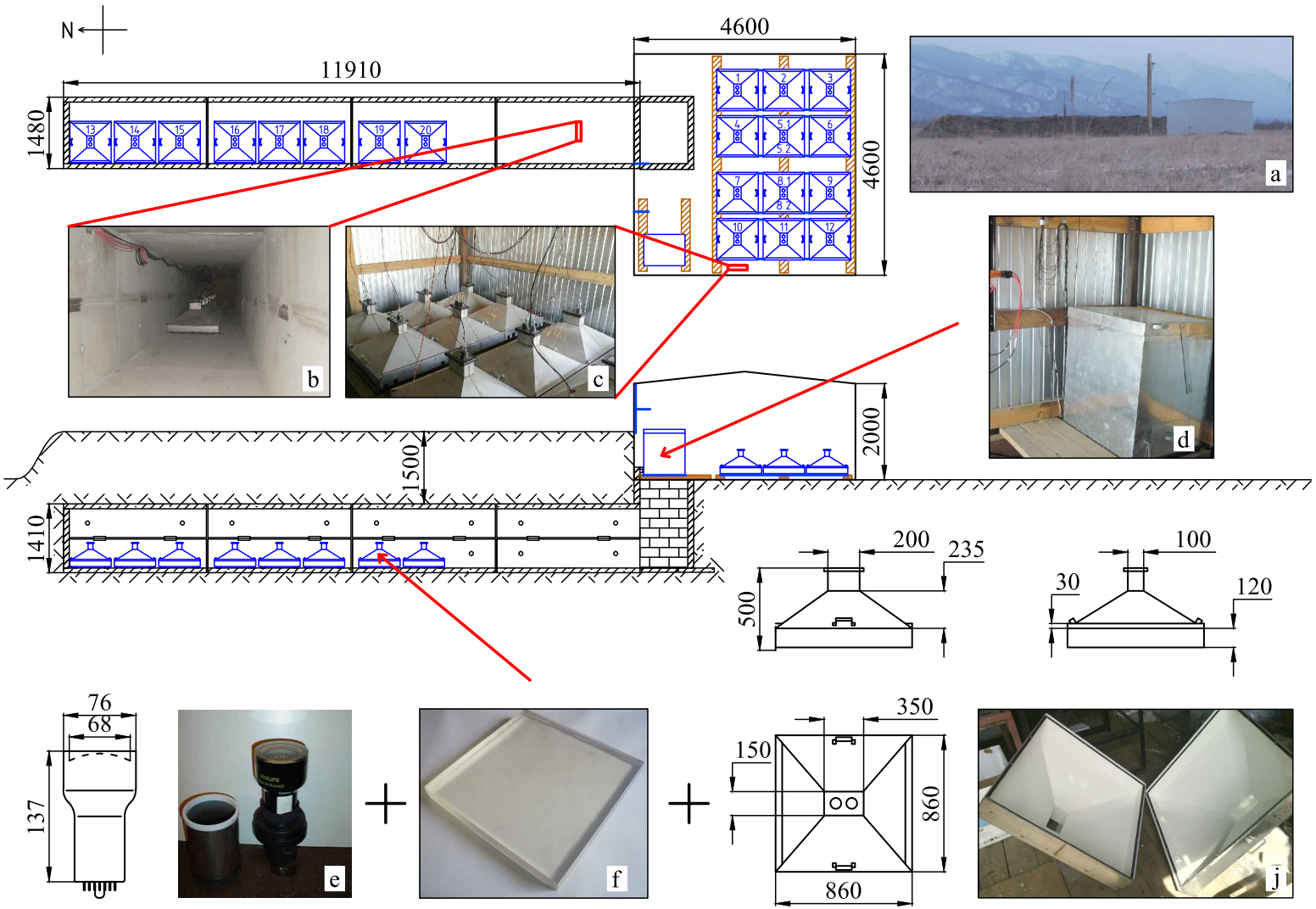




- Short Aperiodic Loaded Loop Antenna[1] is designed to suppress signals from below $\Rightarrow$ reduced ground-related systematics
- $\alpha \approx 90°$, $10^{18} \leq E_{\mathrm{pr}} \leq 10^{19}$ eV for Tunka location/layout

[1] P. Abreu et al. (Pierre Auger), JINST 7, P10011 (2012)

Configuration of the trigger



Reconstruction and quality cuts

Tunka-Grande triggered events from 2015-2017 (424 runs)

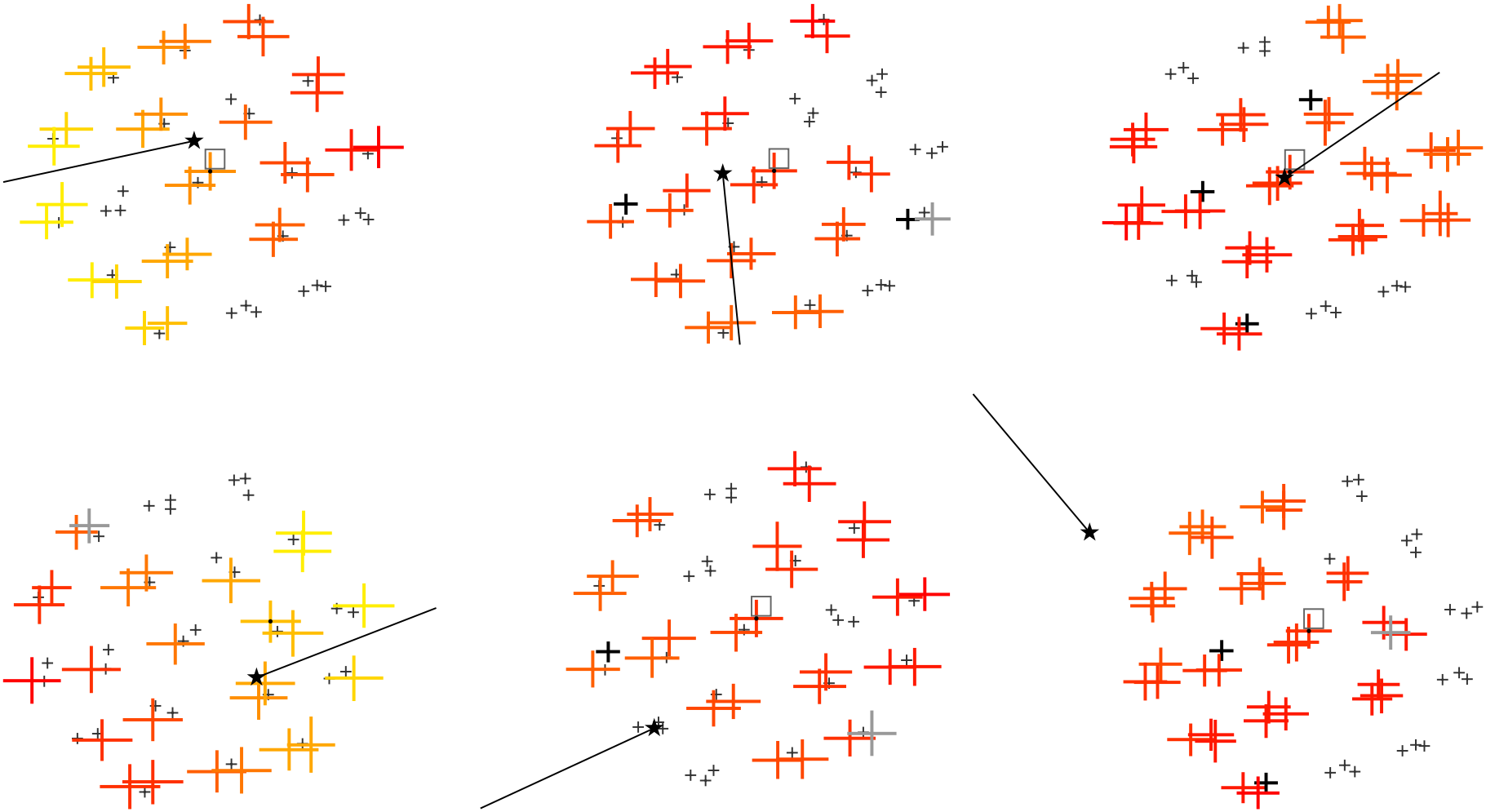
Reconstruction is similar to standard one, except few modifications:

- Signal window is extended from 200 to 500 ns (geometry reasons)
- All air-shower parameters are reconstructed by Tunka-Rex
- No cross-check with Tunka-Grande (radio standalone reconstruction)

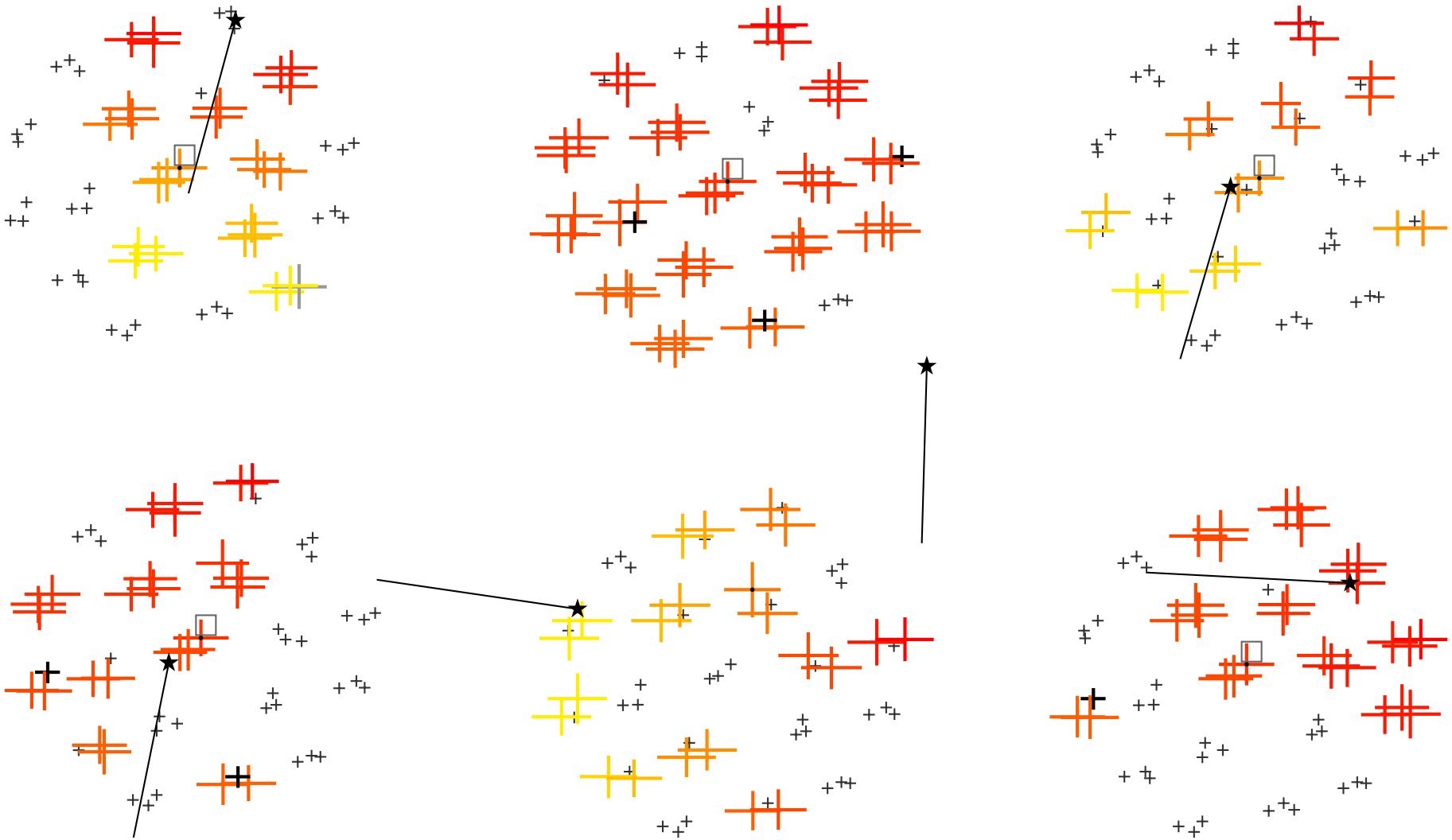
Quality cut on number of antenna stations with signal

Zenith angle (deg.)	$\min(N_{\text{ant.}})$	Detected events
60 – 70	21	28
70 – 80	16	19
80 – 90	10	5
		52

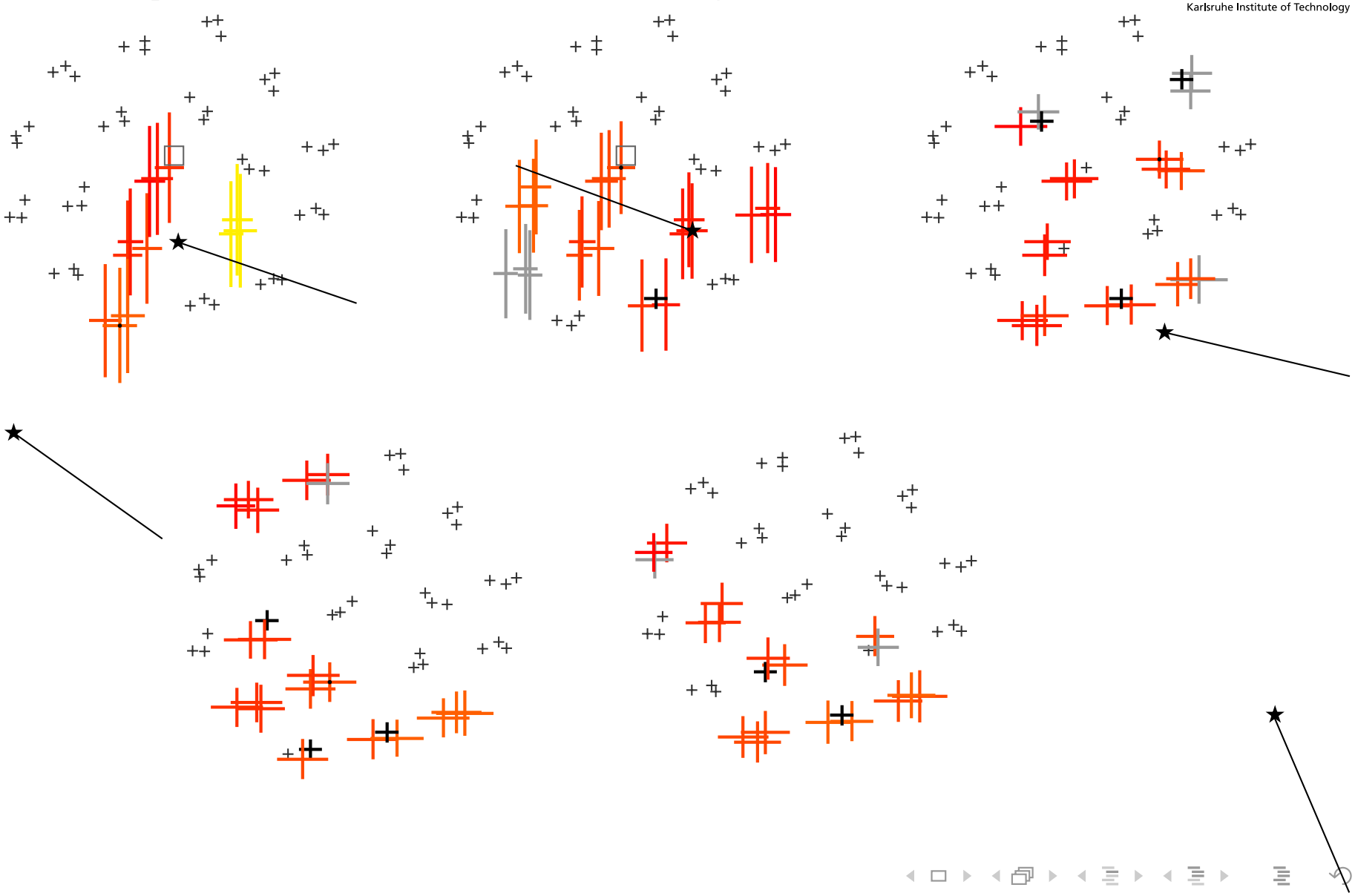
Example events (60 – 70 deg.)



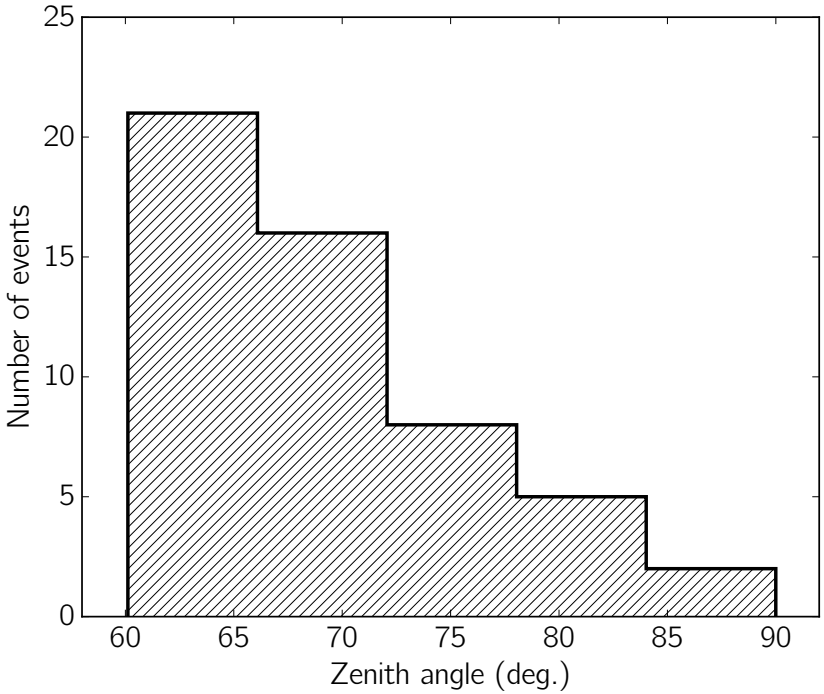
Example events (70 – 80 deg.)

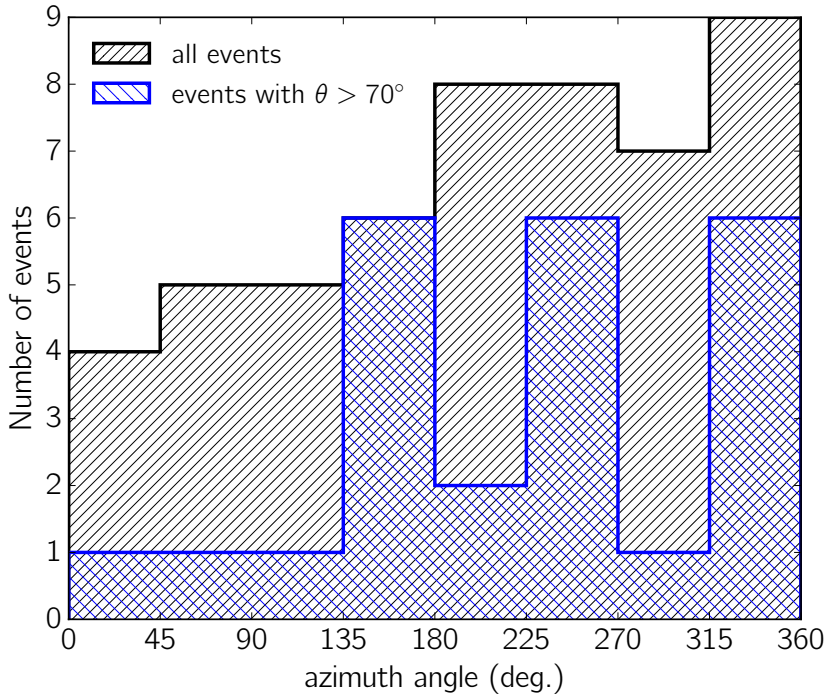


Example events (80 – 90 deg.)



Distribution on the sky

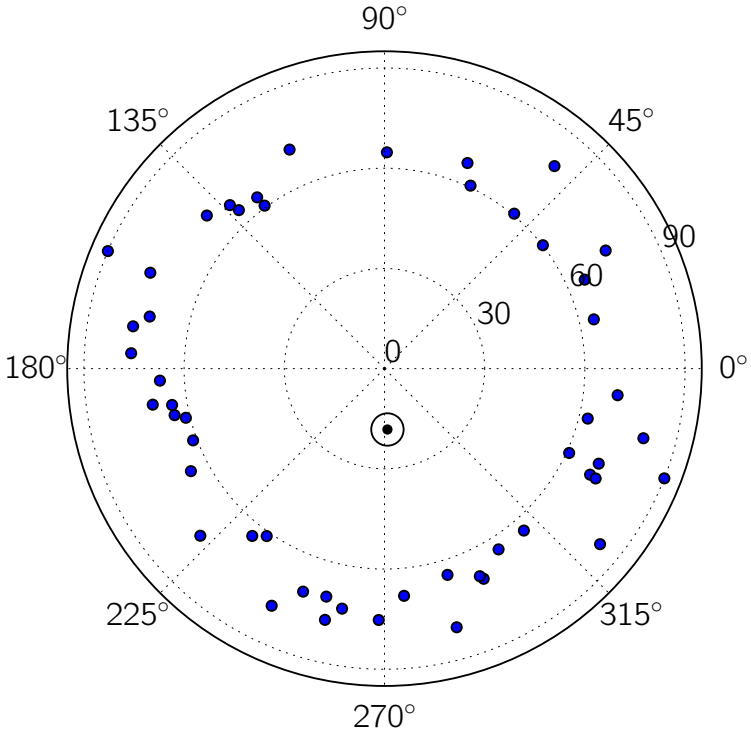


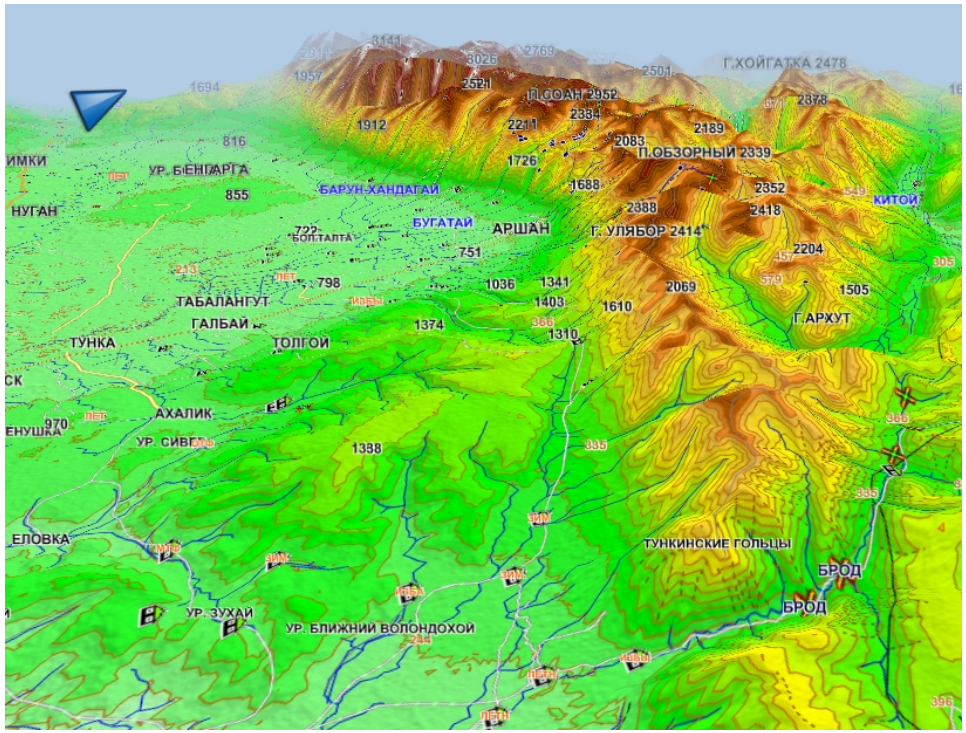


- Zenith distribution as expected
- Supression of flux from North

Shadow from the mountains?

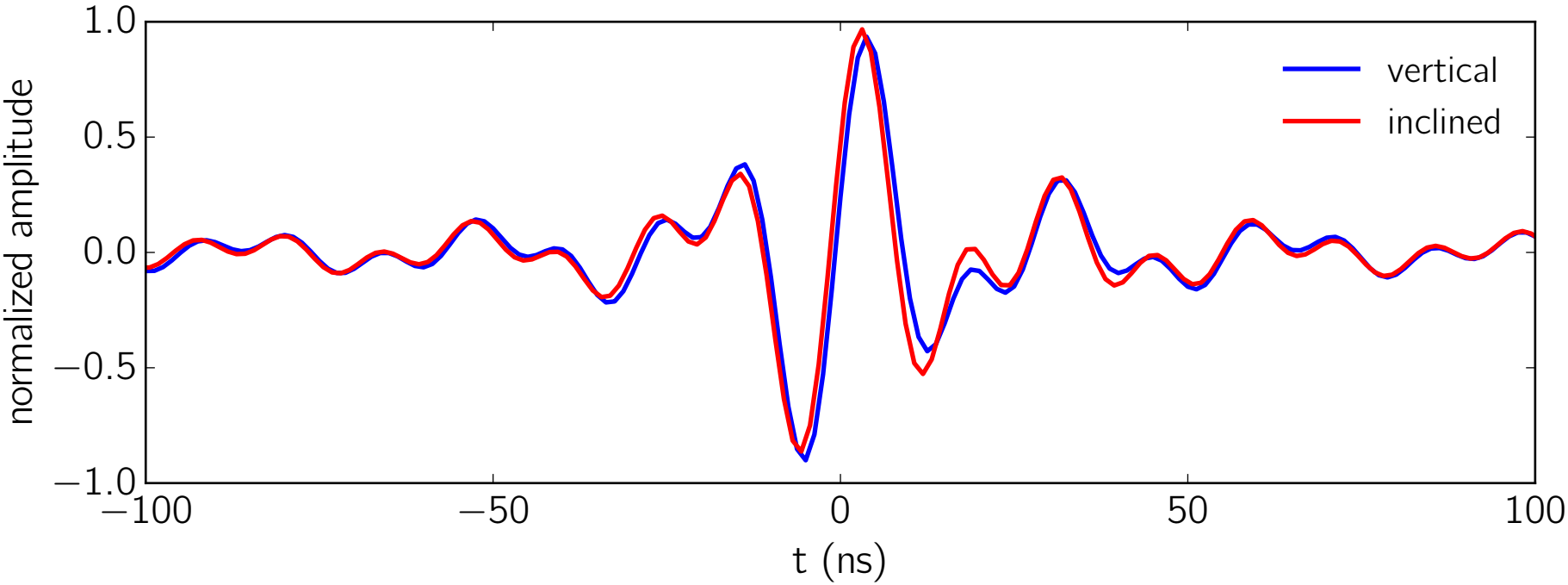
Mountain chain of height 1.5–2.5 km in 5-10 towards North



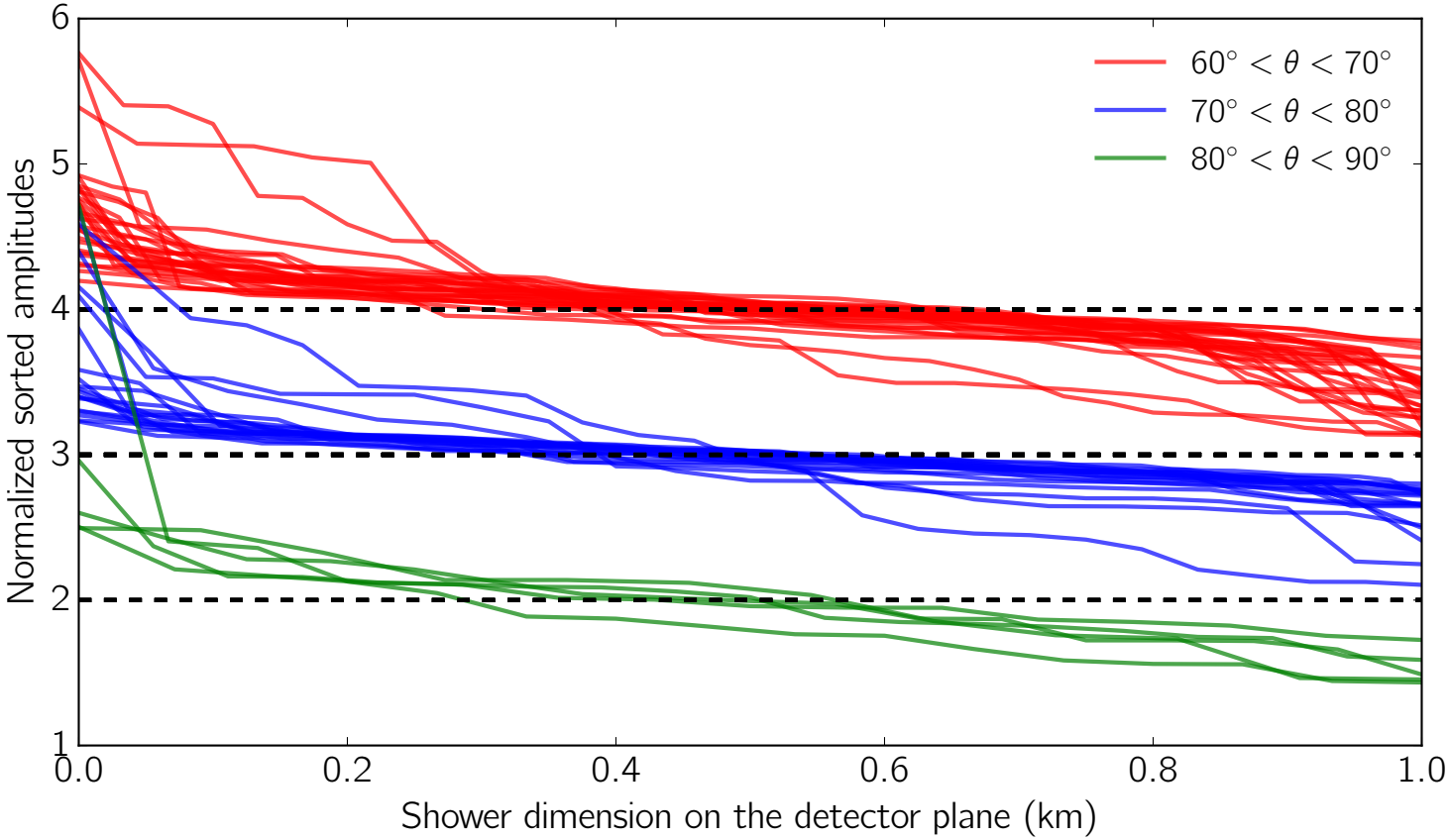


Comparison of signal properties

In average, pulse shapes of vertical and inclined events agree



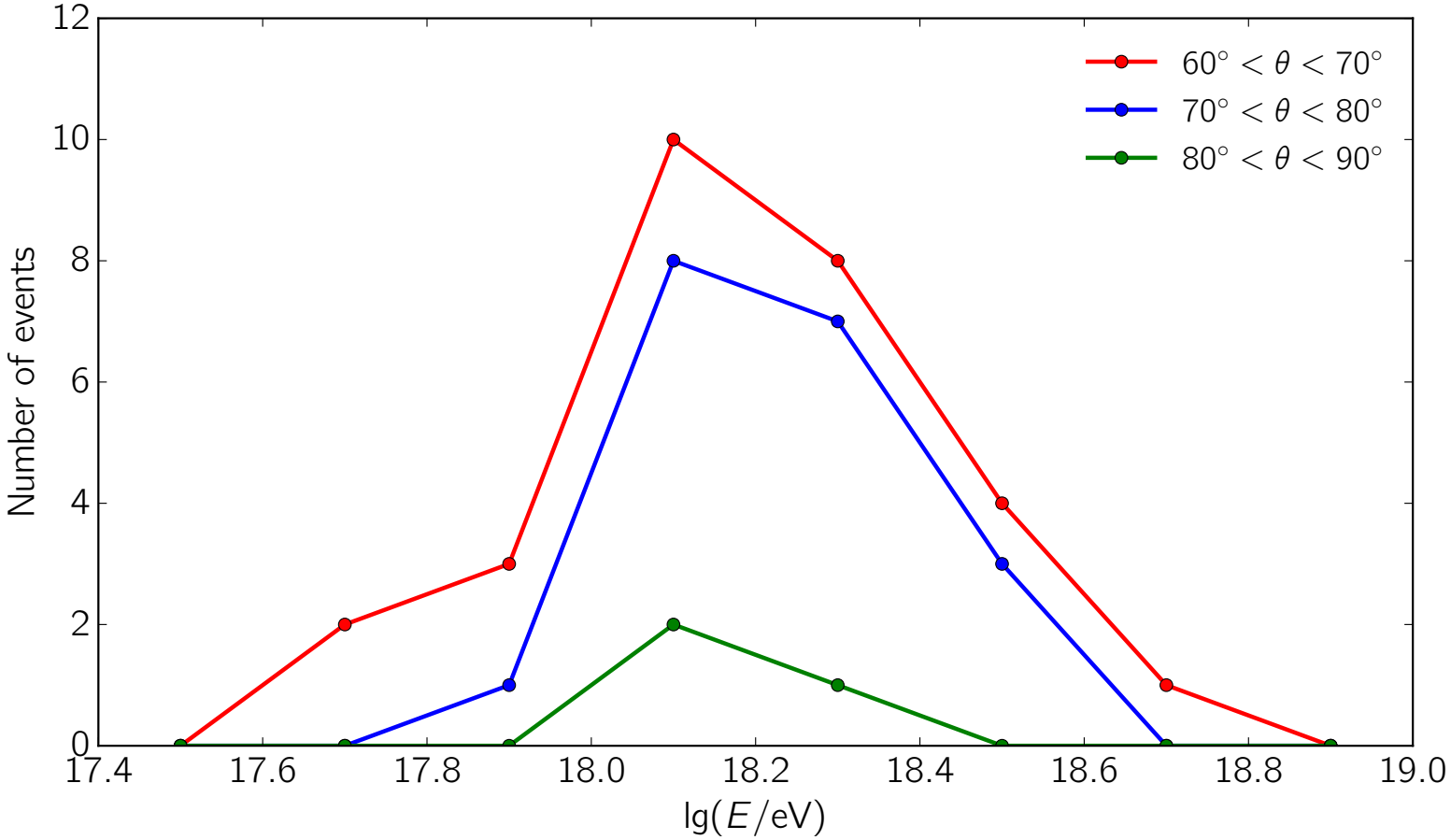
Lateral distribution of amplitudes



- Dimensions of the detector does not allow to resolve air-shower structure (Cherenkov bump, slope, axis core)
- NoLDF methods of reconstruction? (template fit, polarization, spectrum slope)

Rough energy estimation

Energy estimated as $E = \kappa \times (D_{70^\circ}/D_{50^\circ})\langle\mathcal{E}\rangle$



+ 2 more very inclined (90°) events with estimated $E > 10^{20}$ eV

Search for double burst events

Exotic or rare (arXiv:1111.0504) air-showers profiles
with two bumps in $N(X), X \gg 1000$ g/cm^2

Structure can bee seen in radio (inclination + $c_{\mathrm{radio}} < c_{\mathrm{particles}}$)

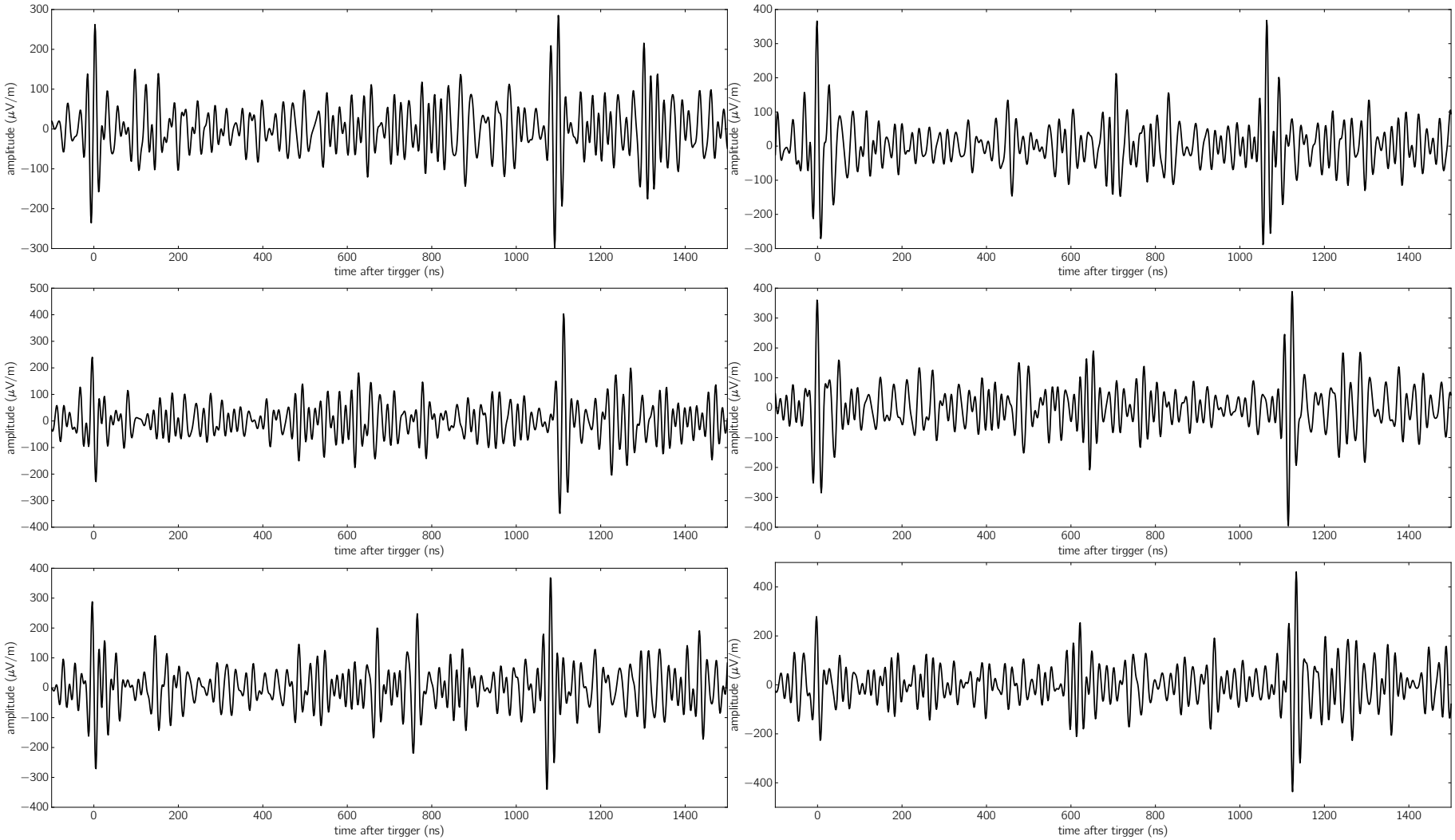
Lag in pulses is described by relation $L(n-1) = \tau c$,
where lag τ corresponds to distance between bumps L

for $L \sim$ km : $\tau \sim$ ns

Challenging, but can be resolved for events with $\theta > 70°$

Tunka-Rex is searching for such kind of events

Event with delayed signal (RFI?)



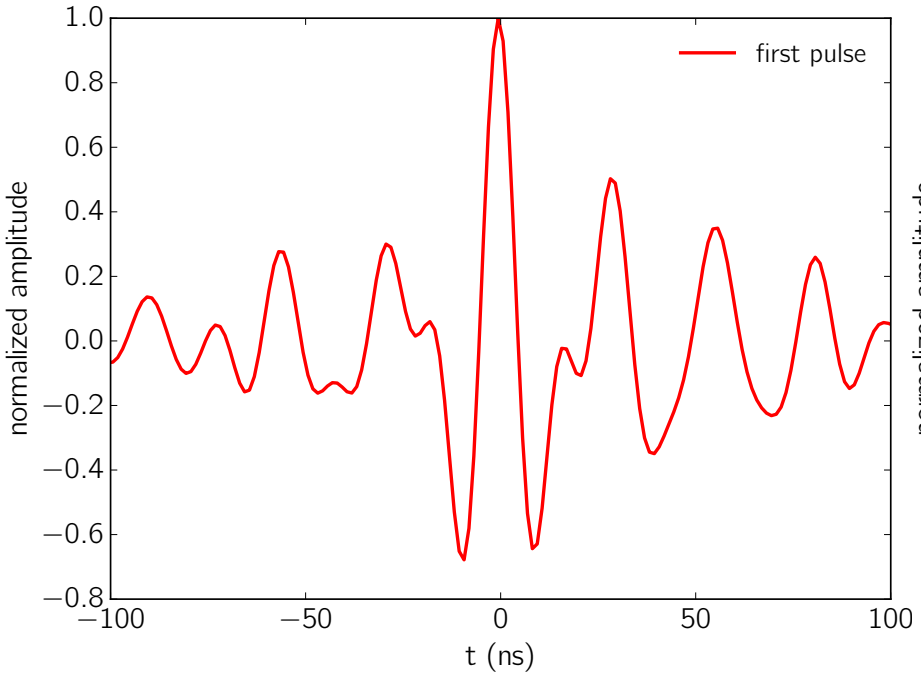
Event with delayed signal (RFI?)

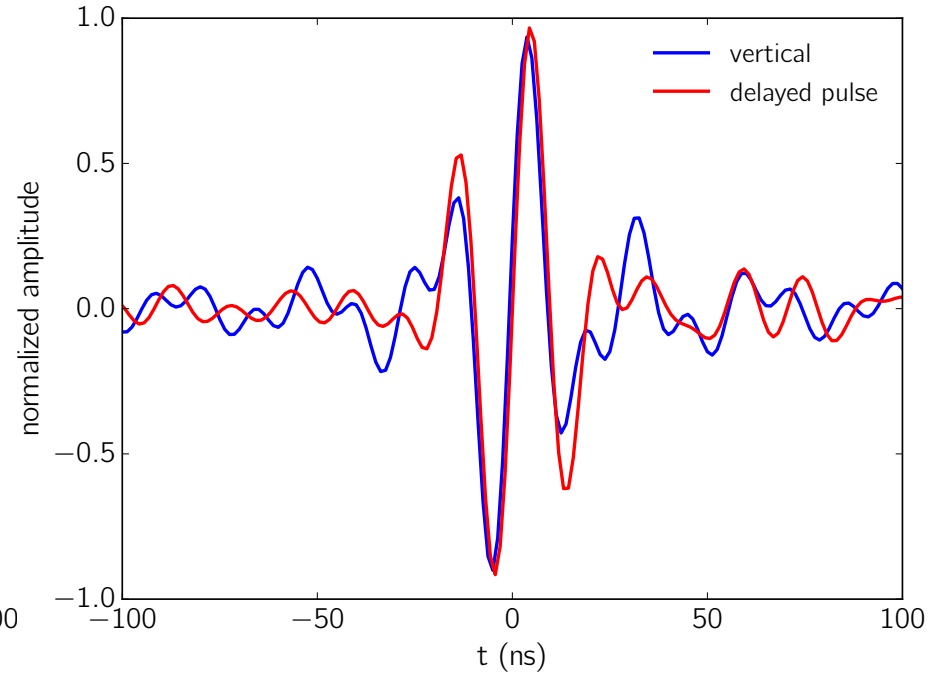
Inclination $\theta = 80°$

Lag between signals $\approx$ µs

Signals are prominent in $V \times V \times B$ polarization

Delayed signals are very similar to Tunka-Rex typical ones





More questions than answers

Summary

- Tunka-Rex with SALLA is sensitive to very inclined air-showers
- We probably see shadow from mountains
  $\Rightarrow$ testbed for GRAND-like setups
- Singal properties show no exotics, influence of ground
  is under investigation
- It is hard to resolve shower geometry with Tunka-Rex dimensions
- Test of rare or exotic scenarios visible only in inclined cascades