TAIGA-Observatory: First 5 years of operation of the HiSCORE Air-Cerenkov Array.

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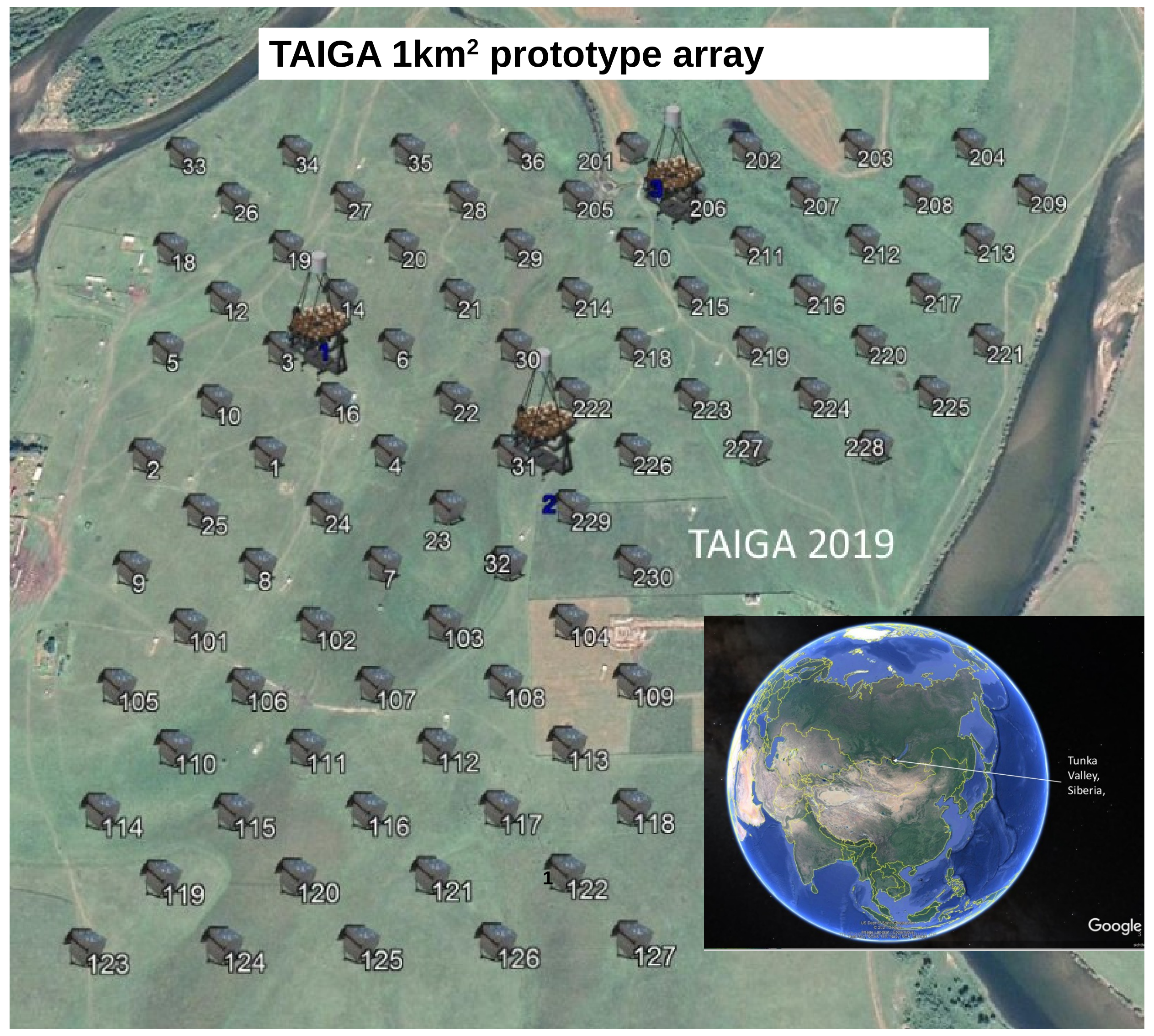
TAIGA observatory: Hybrid detection concempt for Gamma Astronomy above 30TeV and Cosmi Rays physics above 100TeV

TAIGA-HiSCORE is a wide-aperture Air-Cherenkov array, and is a major component of the TAIGA-Observatory (Tunka Instrument for high-energy gamma-ray astronomy and cosmic ray physics),located in the Tunka valley, 50km from Lake Baikal, Russia. A main science target of TAIGA isgamma ray astronomy above ten's of TeV, in particular the search for sources of few 100TeV gammarays (candidate "PeVatrons"), the possible sites of Galactic cosmic ray acceleration. The HiSCORE prototype array will consist of 120 optical Cerenkov stations, deployed on an area of 1km2. Its constructionwill be finished in 2021.We present the performance of HiSCORE during the first 5 years of operation (2015-2020), in various configurations, from 28 to 88 stations. A key for high sensitivity to gamma point sources is precisiontiming of the whole array down to sub-nsec level, required to be stable for the observation period. We apply different methods to reach this goal. The pointing resolution of the array for extended air-showers is obtained as 0.1° for highest energies, and is experimentally verified, based on independentapproaches.



TAIGA-HiSCORE
Integrating Air Cherenkov timing array – 120 stations

TAIGA-IACT
2 telescopes operating.
Telescope 3 in construction

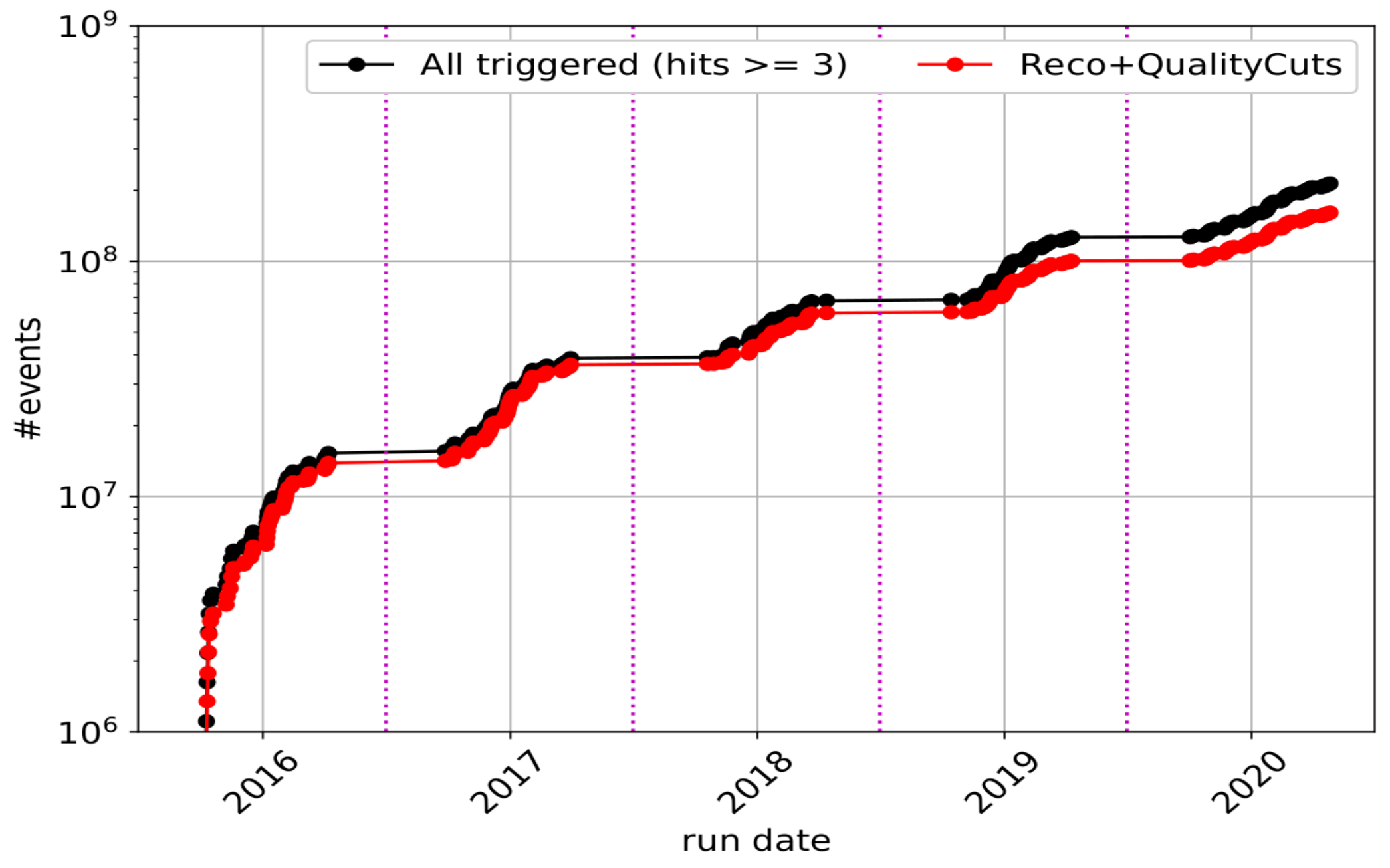
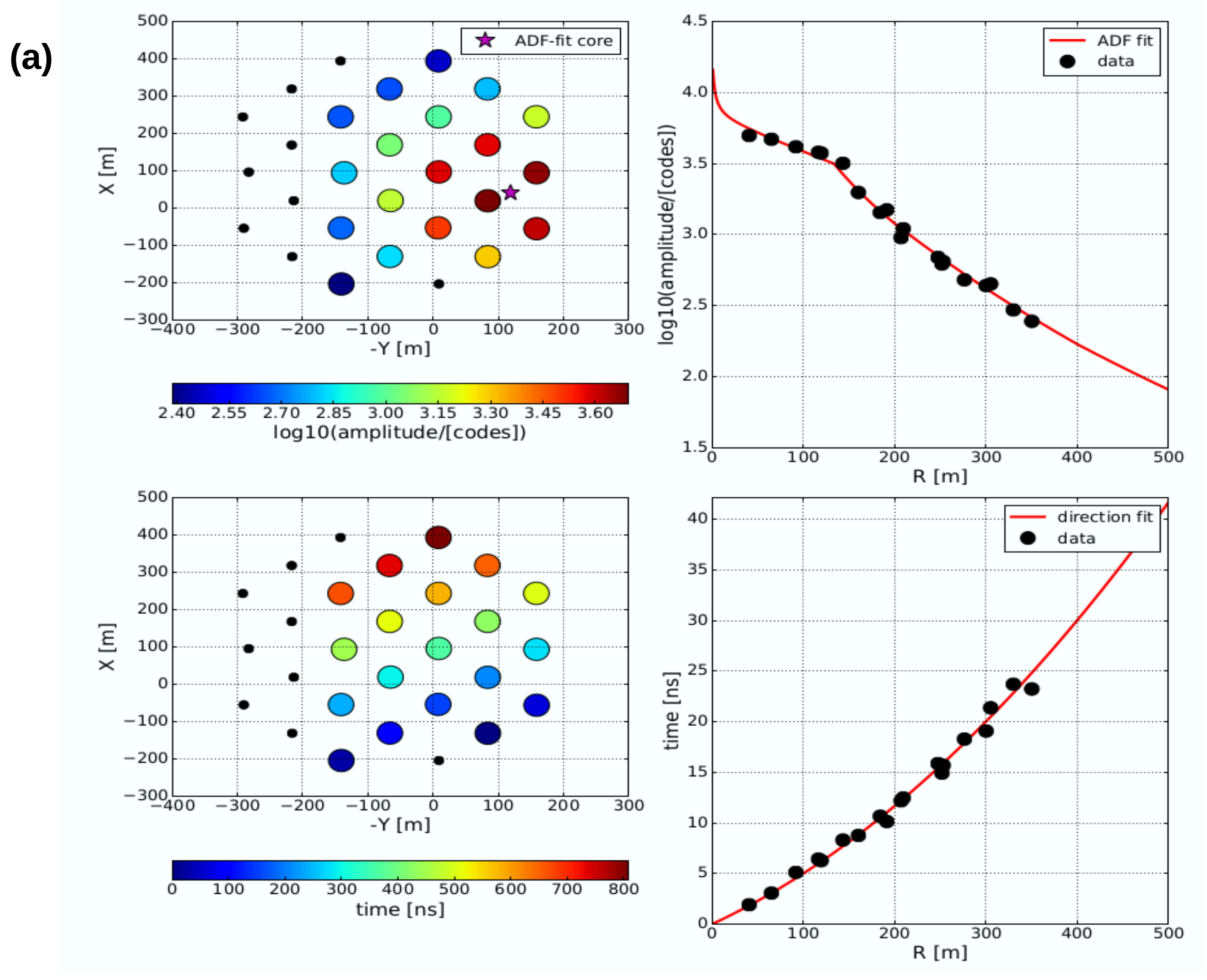


Figure 2:TAIGA-HiSCORE integrated number of triggered events(#hits≥5, black), and after quality cuts (red), over the first 5 years of operation.

Figure 1 (Left): TAIGA Observatory. (a) TAIGA prototype array layout planned for fall 2021: 120 HiSCOREarray stations, 2(+1 in construction) operating IACT telescopes. A sparse surface/underground TAIGA-Muondetectors (240m2) will start operation soon.

TAIGA-HiSCORE EAS reconstruction

The main role of HiSCORE in TAIGA is to provide accurate shower core and direction recon-struction, as well as shower energy. The standard EAS reconstruction procedure [3,4] is done in twosteps. A first approximation of the shower core is obtained from a weighted average of the detectedamplitude, while a plane wave fit of the pulse arrival time provides a first estimation of the showerdirection. If more than 5 stations are triggered, a more precise reconstruction of the core is possible by fitting the amplitude distribution as function of the core distance (ADF), while for the direction, afit of the shower front with a parabolic (PAR) model is performed. Figure 3(a) gives an example of areconstructed HiSCORE events (1 cluster array), while figure 3(b) shows the core and arival directionacceptance for HiSCORE operating with 3 cluster.



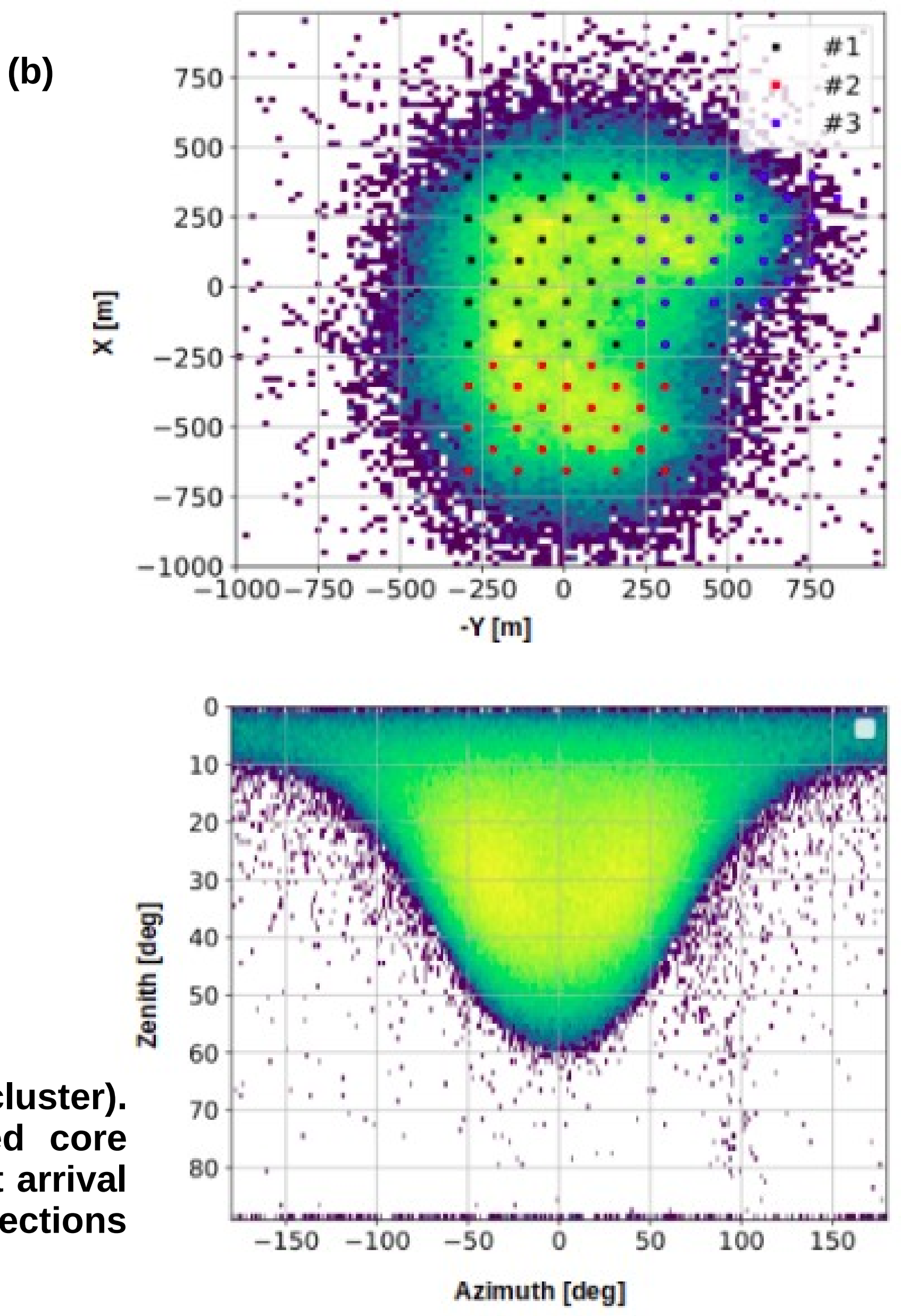
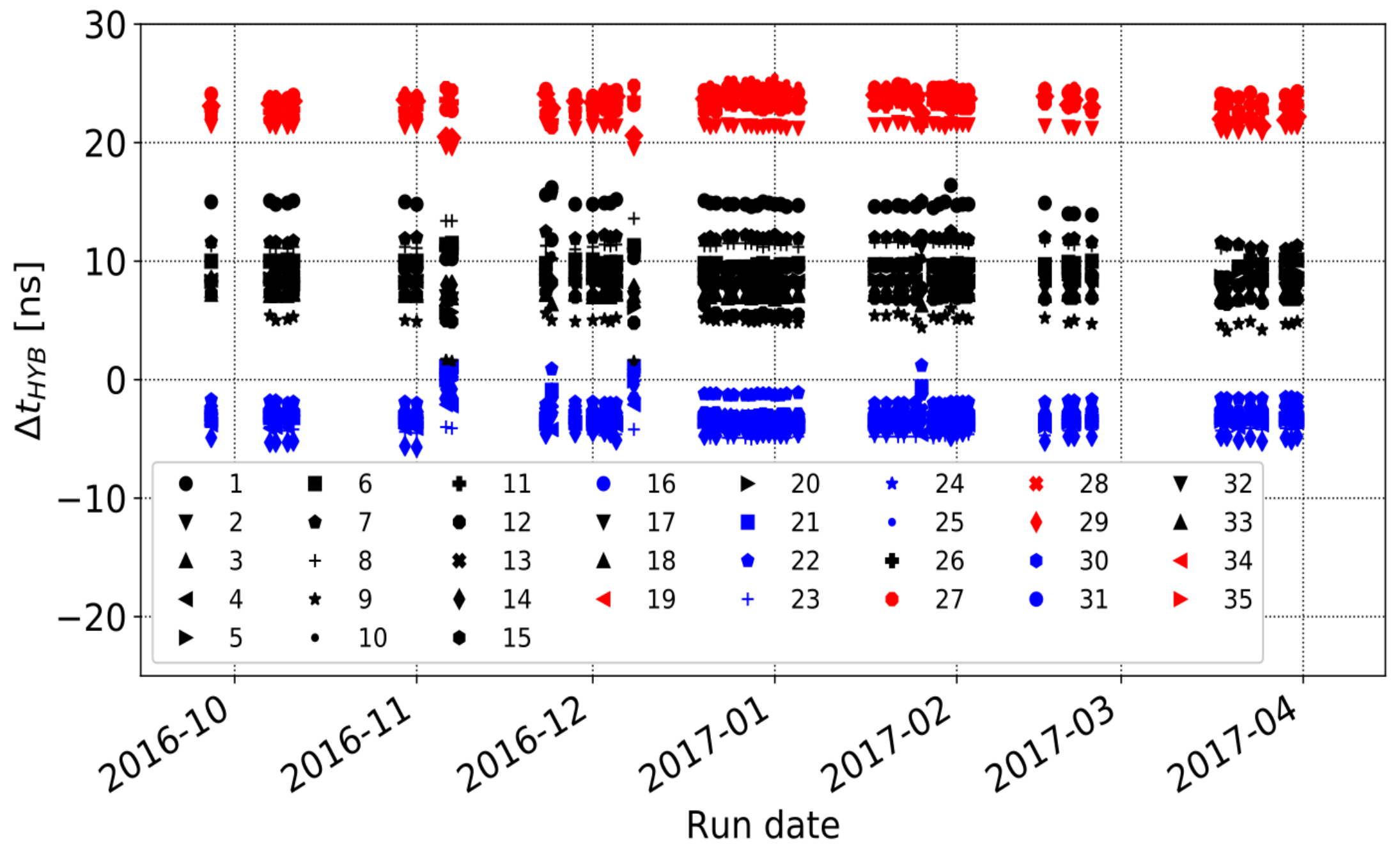


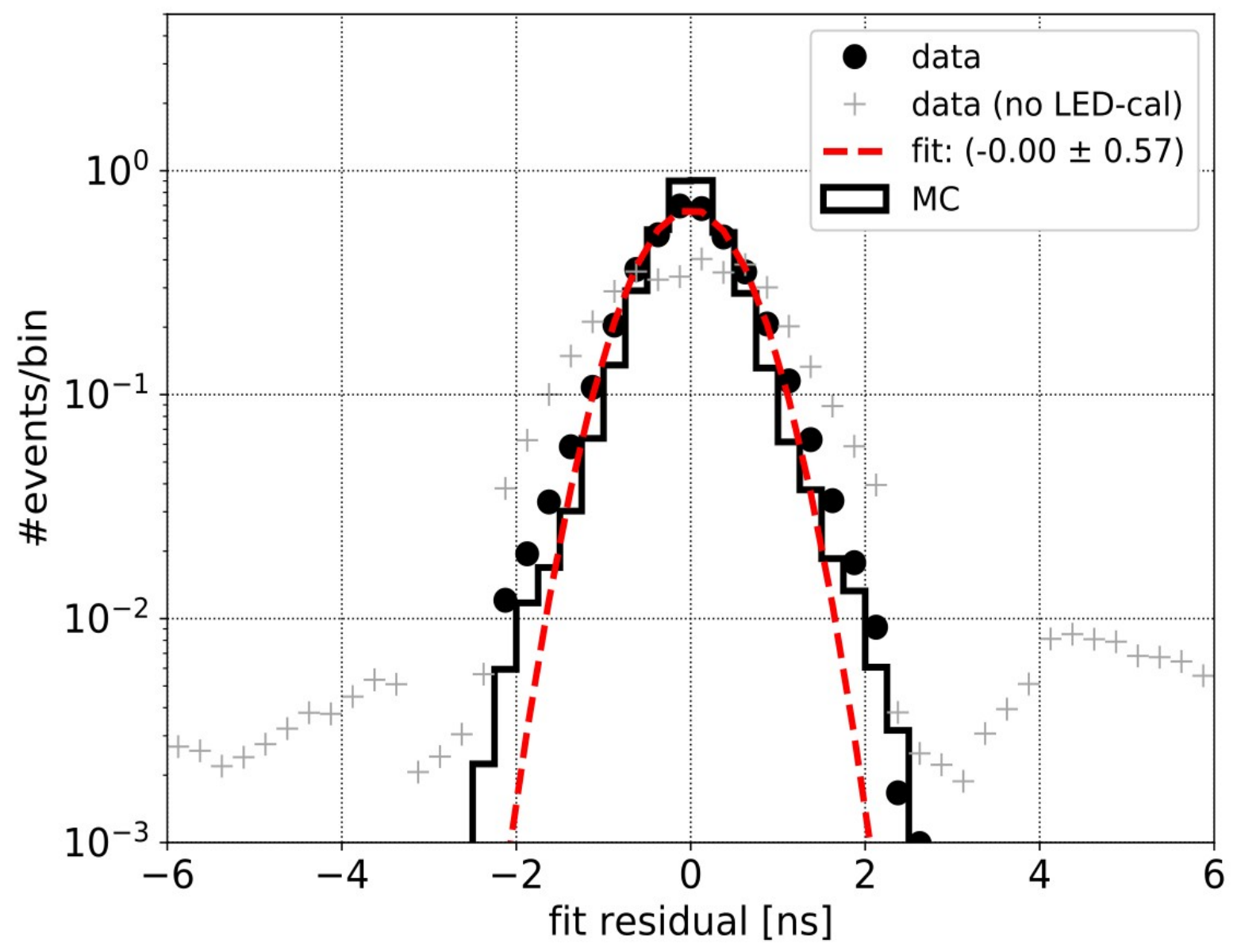
Figure 3: TAIGA-HiSCORE reconstruction: (a) Reconstructed EAS event (1 cluster). Top-left: station pulse amplitudes distribution (purple star: reconstructed core position). Bottom-left: station pulse arrival times. Bottom-right: shower front arrival time. Red lines: ADF and PAR fit. (b) Reconstructed cores (top) and arrival directions (bottom) distribution for a 3 cluster HiSCORE array.

Array time calibration

The correction of unknown station time offsets (array time calibration) is needed to ensure a requred accuracy and precision in the EAS direction reconstruction. This is obtained using the Hybrid method [5], which combinaes information from detected EASs, and external LED calibration for few array stations. Figure 4 gives and example of estimated station time offset corrections for cluster 1, during season 2015-16.

The calibration proved to be stable and efficient. We obtain a final sub-nsec relative time synchronization betweein the stations (fig.5), and the required reconstruction angular resolution.





Detector Angular Resolution: Chessboard Method

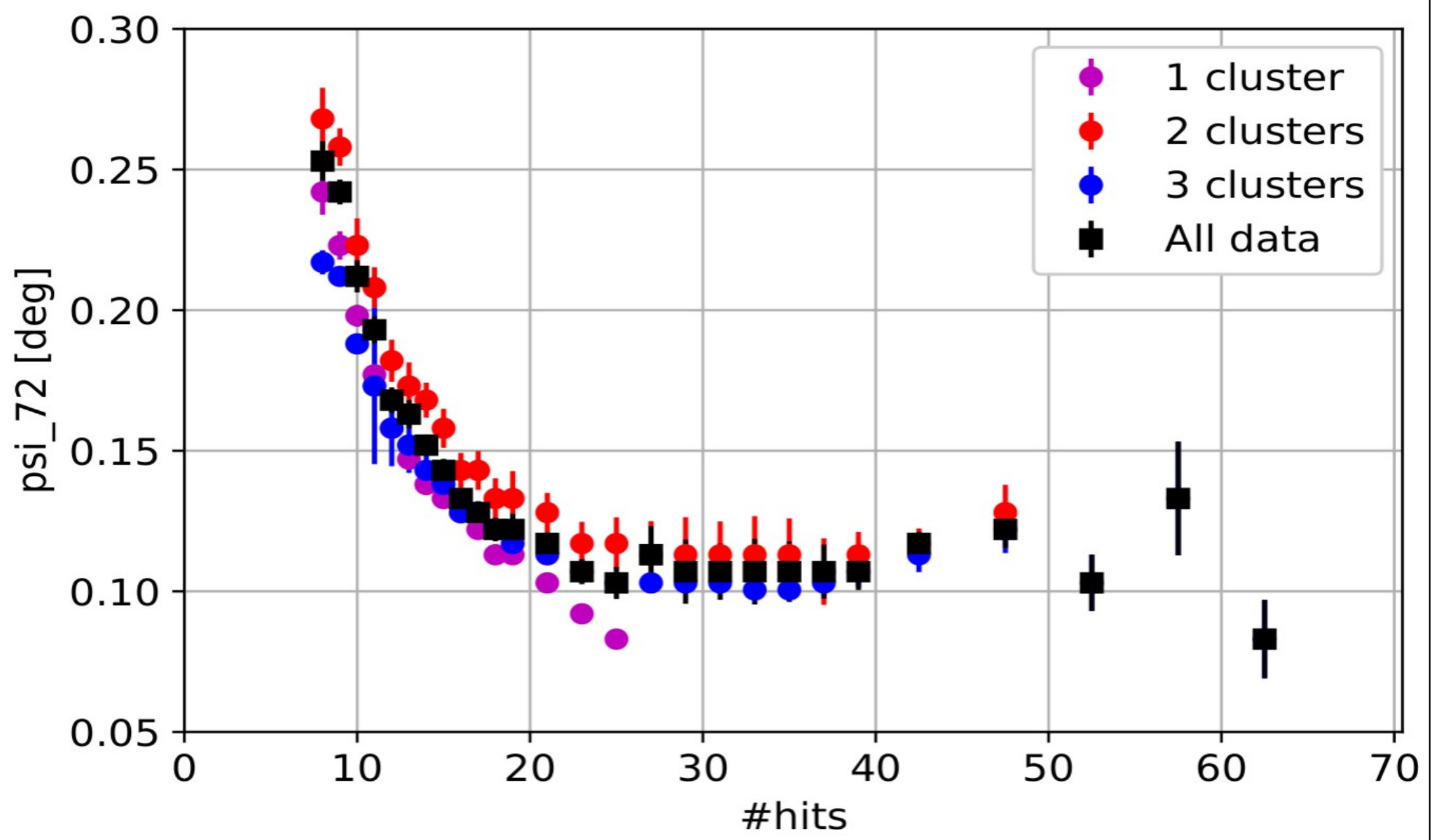
Beside using MC simulation, the detector angular resolution is experimentally determined using the chessboard method [7]. The array is split into two interspersed sub-arrays (like a chessboard), and each triggered shower is reconstructed using the two indpendent sub-arrays. The space angle between the two reconstructed directions, with good approximation, is twice the full-array angular error, *psi*.

Fig. 6 shows the detector angular error (at 72% containment) as function of the total number, for three different HiSCORE layouts: 1, 2, and 3 clusters. In black, the result obtained usng all the 5 years data sample. An error of ~0.2° is achieved at event multiplicity 10, and ~0.1° at event multiplicity 20.

Figure 4 (top): Hybrid method station time offsets as function of run date (x-axis) and station ID (marker). The color code indicates the different PMT types operating in the optical modules.

Figure 5 (corner): EAS direction reconstruction fit residual before (grey crosses) and after applying the HYB calibration (black). A 0.54 ns rms is obtained, proving the calibration efficiency and the sub-ns time synchronization between thestations.

Figure 6 (right): Estimated angular resolution as function of total number of triggered stations: ~0.2° at multiplicity ≥ 10; ~0.1° at multiplicity ≥ 20.



Point source analysis

We developed a full-sky point source analysis [6] based on the *Direct Integration* method [11].

For this analysis, we select events which survive reconstruction quality cuts, and with number of hists ≥ 10 (angular resolution ≤ 0.2°). Additionally, events from known space LIDARs signal (ISS/CATS, CALIPSO) are excluded.

For each reconstructed and selected event filling the signal map, we fill the background map by generating 100 fake events with random time. Each bin in the maps is scaled by a factor 1/cos(δ), and both maps are then smoothed using a uniform kernel of radius 0.3° (serach radius, ~1.58×0.2°).

The significance is calculate using Li&MA formula 14 [13], with an α factor of 0.01.The full-sky 5 years significance distribution (fig.7, black), well described by a gaussian with μ=0 and σ=1, is a good indication of correct background estimation. The analysis detection potential is proved by the detection of few unknown satellite LIDAR signals, as shown in fig.7 (grey). Figure 8 shows a detail of the significance map, zoomed around the Crab direction.

As expected, no source above 5s is observed, due to the large background (no g/h separation available yet). An energy binned analysis, where smaller search radius can be used at higher energy could improve the results.

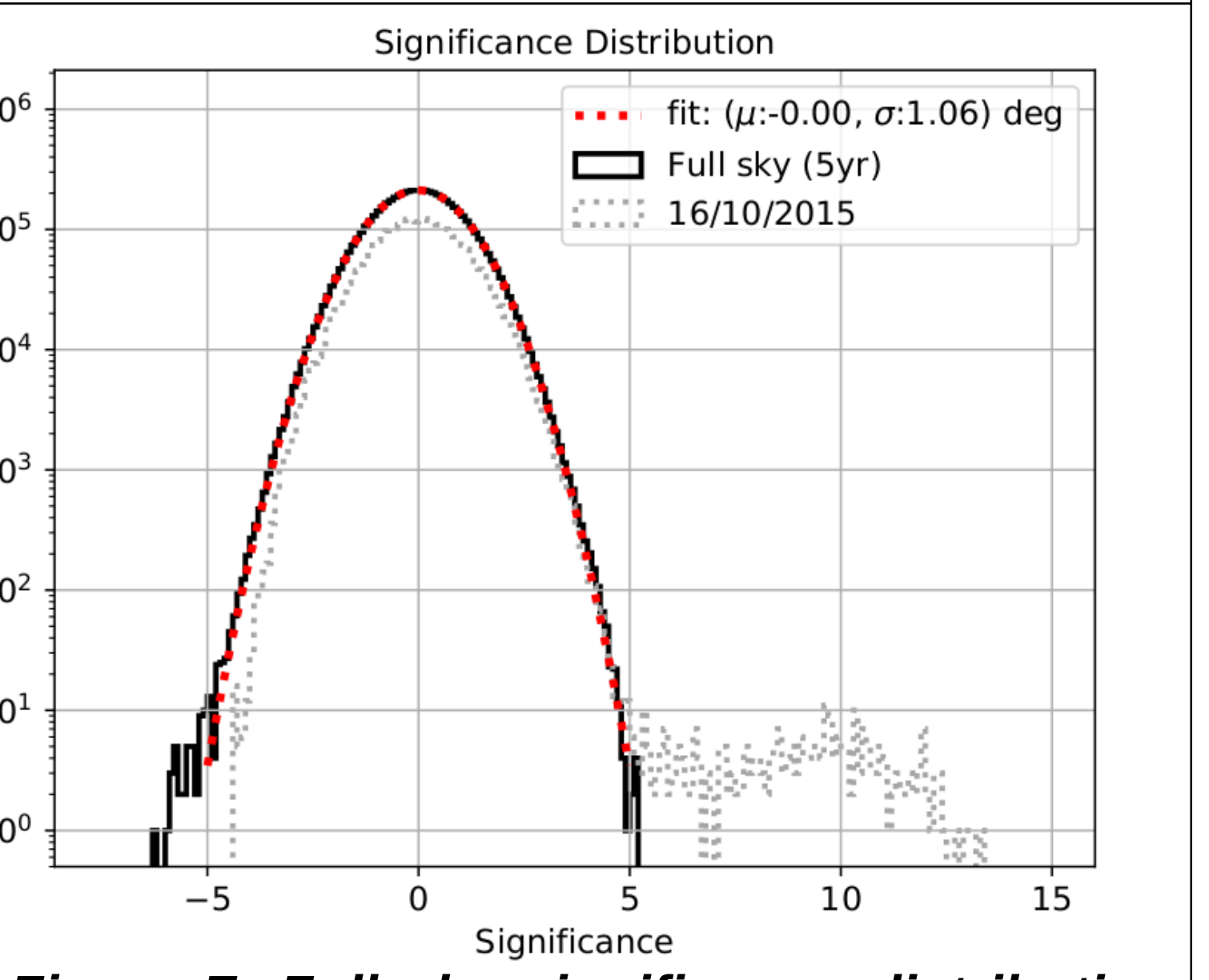


Figure 7: Full sky significance distribution for 5 years data set (black line), and for run 16/10/15 containing sapce LIDAR signal.

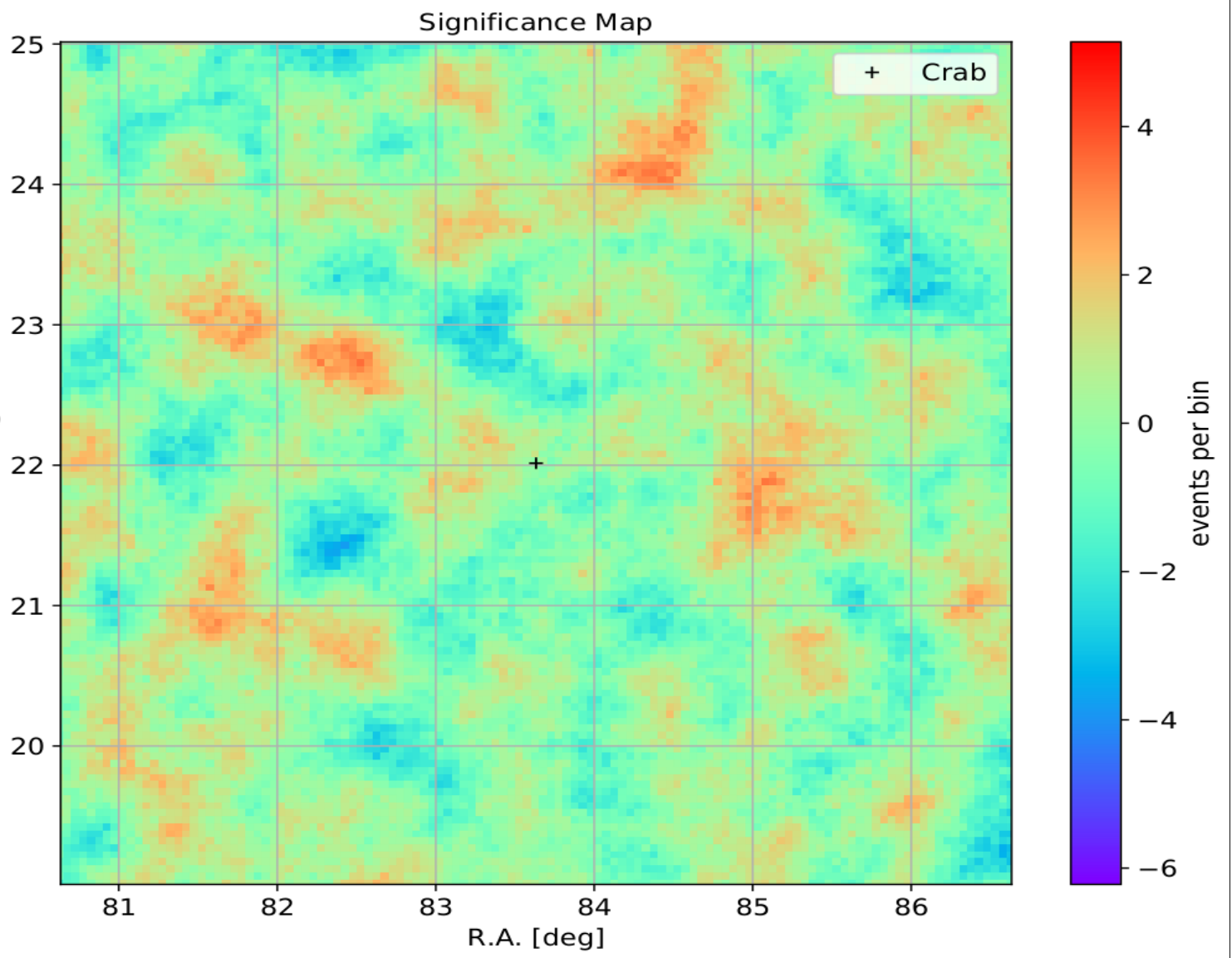


Figure 8: Detail of the full sky significance map, zoomed around the Crab direction.

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TAIGA facility in the Tunka valley
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RSF Russian Science Foundation