The Tunka experiment: past, present and future

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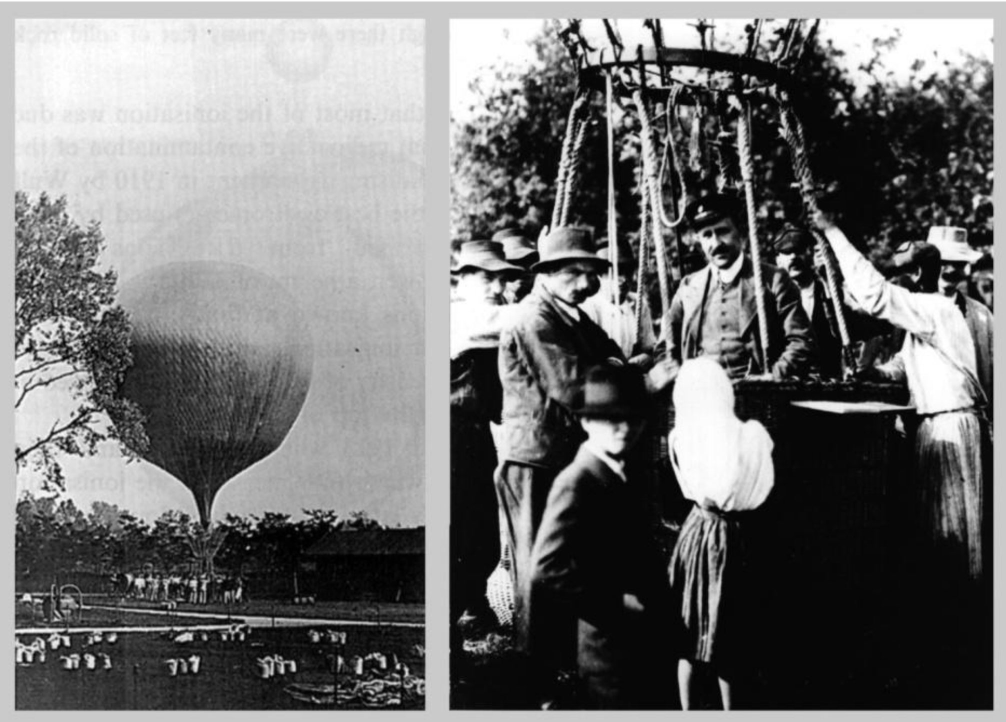
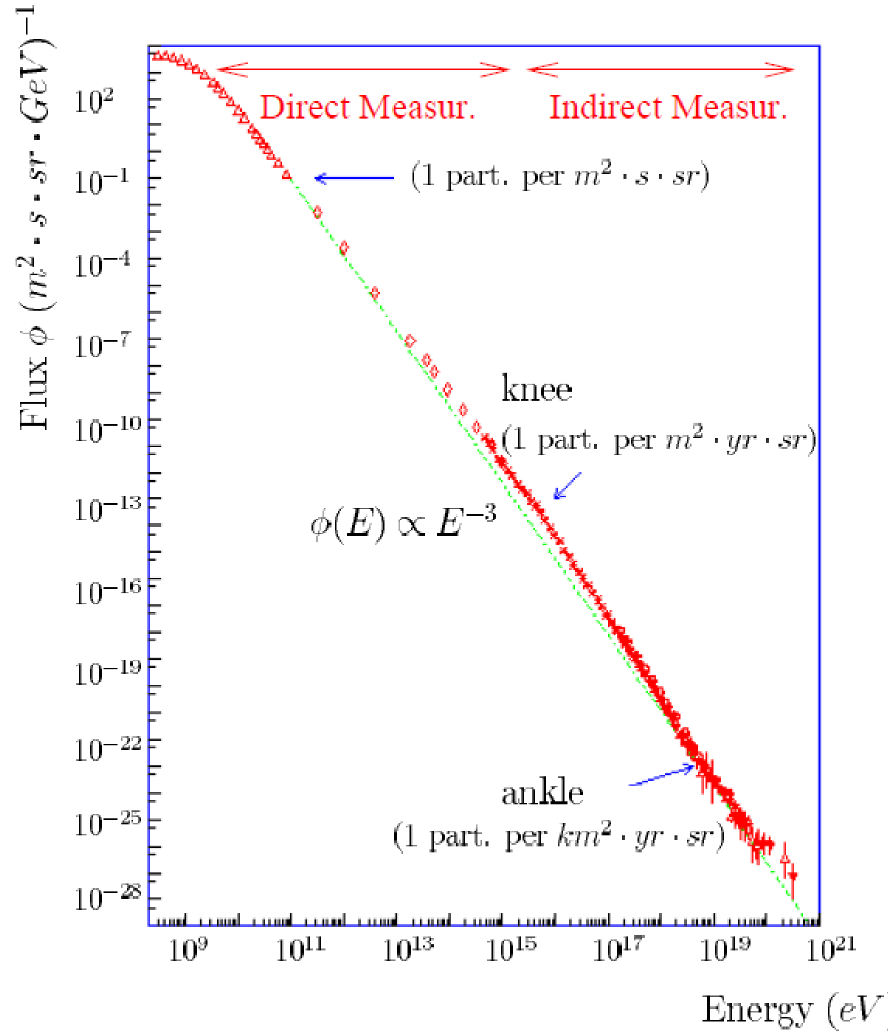
Institute for Nuclear Research of RAS, Moscow Russia
for
TUNKA and TAIGA Collaborations





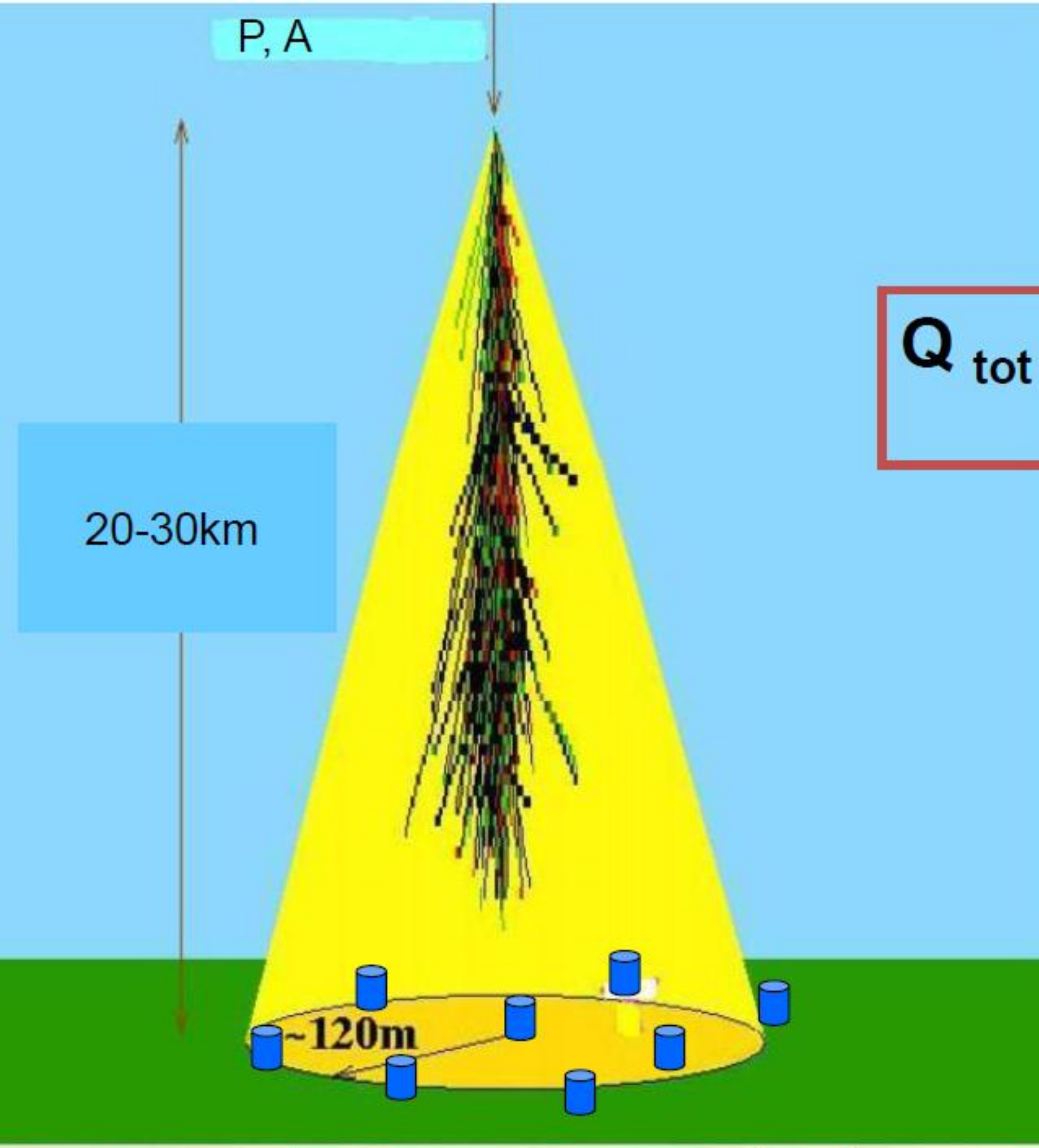
Victor Hess 1912 - Discovery of cosmic rays

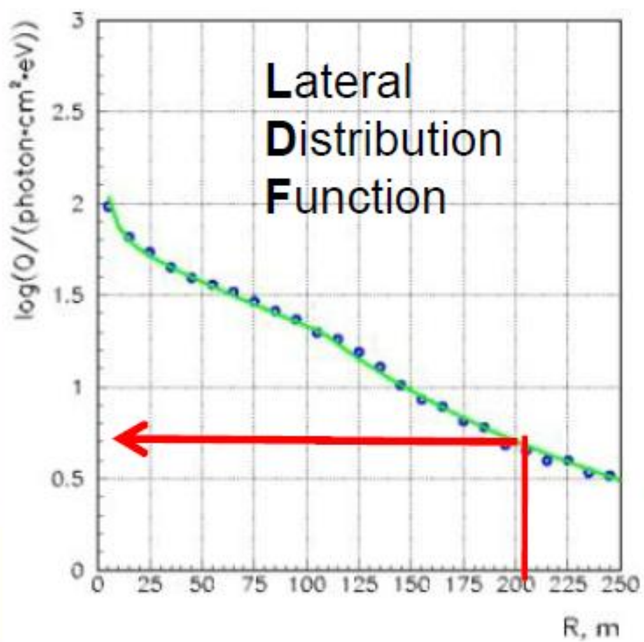
So far the origin of Cosmic Rays is a mystery still!

Atmosphere is used as a huge calorimeter

Cherenkov light

$$Q_{tot} \sim \int N(x)\,dx \sim E$$





Photons detectors

E (PeV) = 0.3 Q(200) ph· ev^{-1} cm^{-2}

Registration of Cherenkov light from EAS by wide-angle optical detectors

Accuracy: core location ~ 10 m

Energy resolution ~ 15% ($E = c\,Q(200)^{0.94}$)

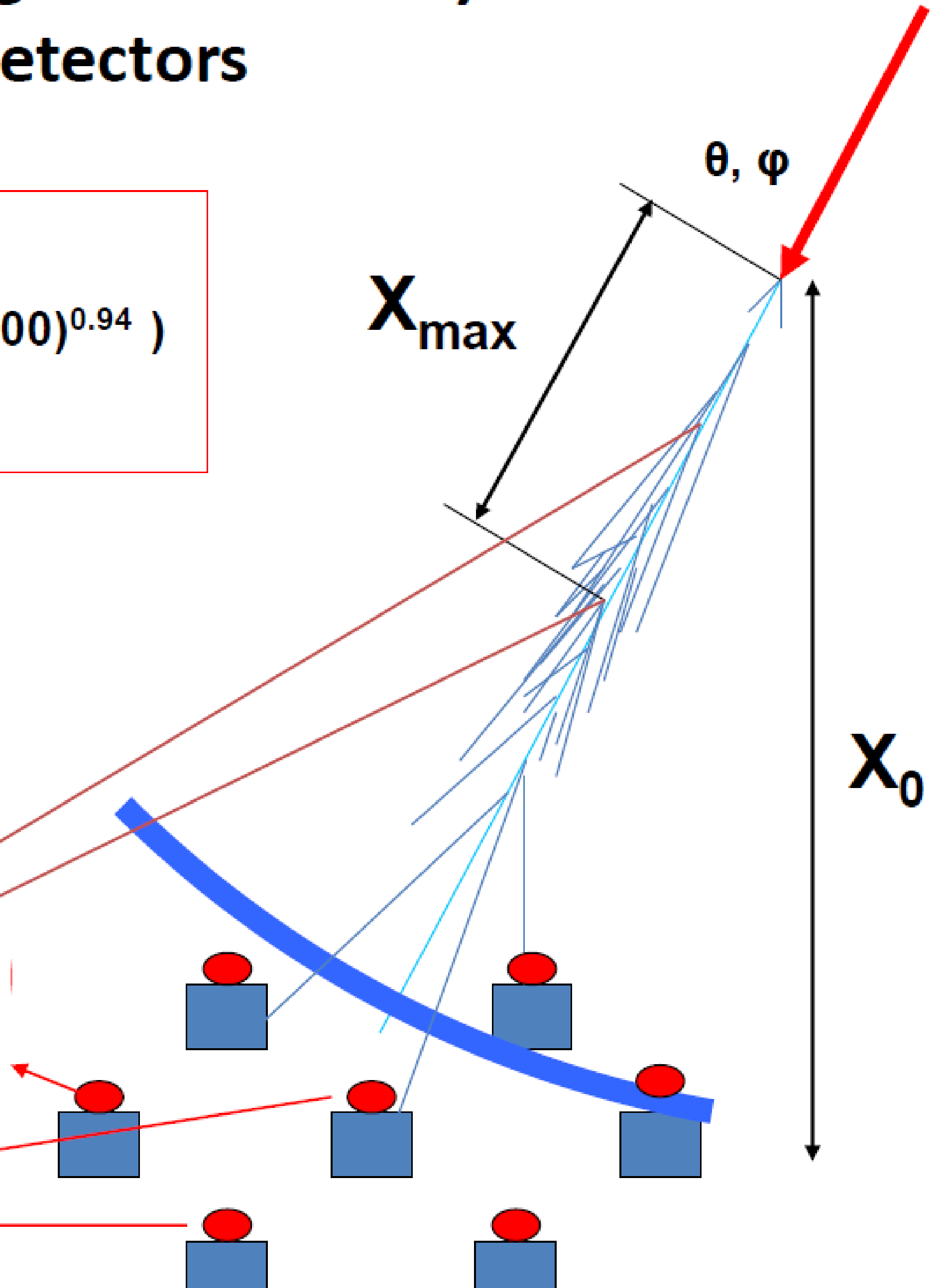
δX_{max} ~ 25 $g \cdot cm^{-2}$

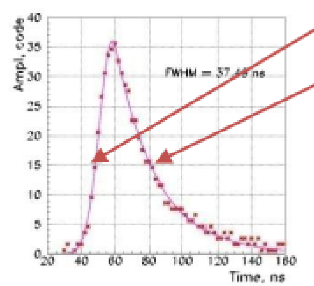
Methods of X_{max} measurement:

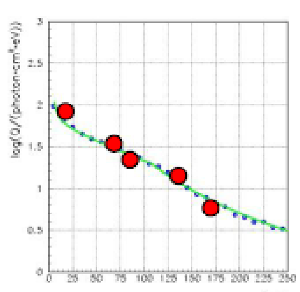
1. Steepness of LDF

2. Signal width ~ ΔX g/cm^2

$\Delta X = X_0/\cos\theta - X_{max}$







Advantage of Cherenkov Technique:

1. Good energy resolution - up to 15%
2. Good accuracy of X_{max} - 20 -25 g/cm^2
3. Good angular resolution - 0.1 – 0.3 deg
4. Low cost – Tunka-133 – 1 km^2 array:
   0.5 10^6 Eur (construction and deployment)

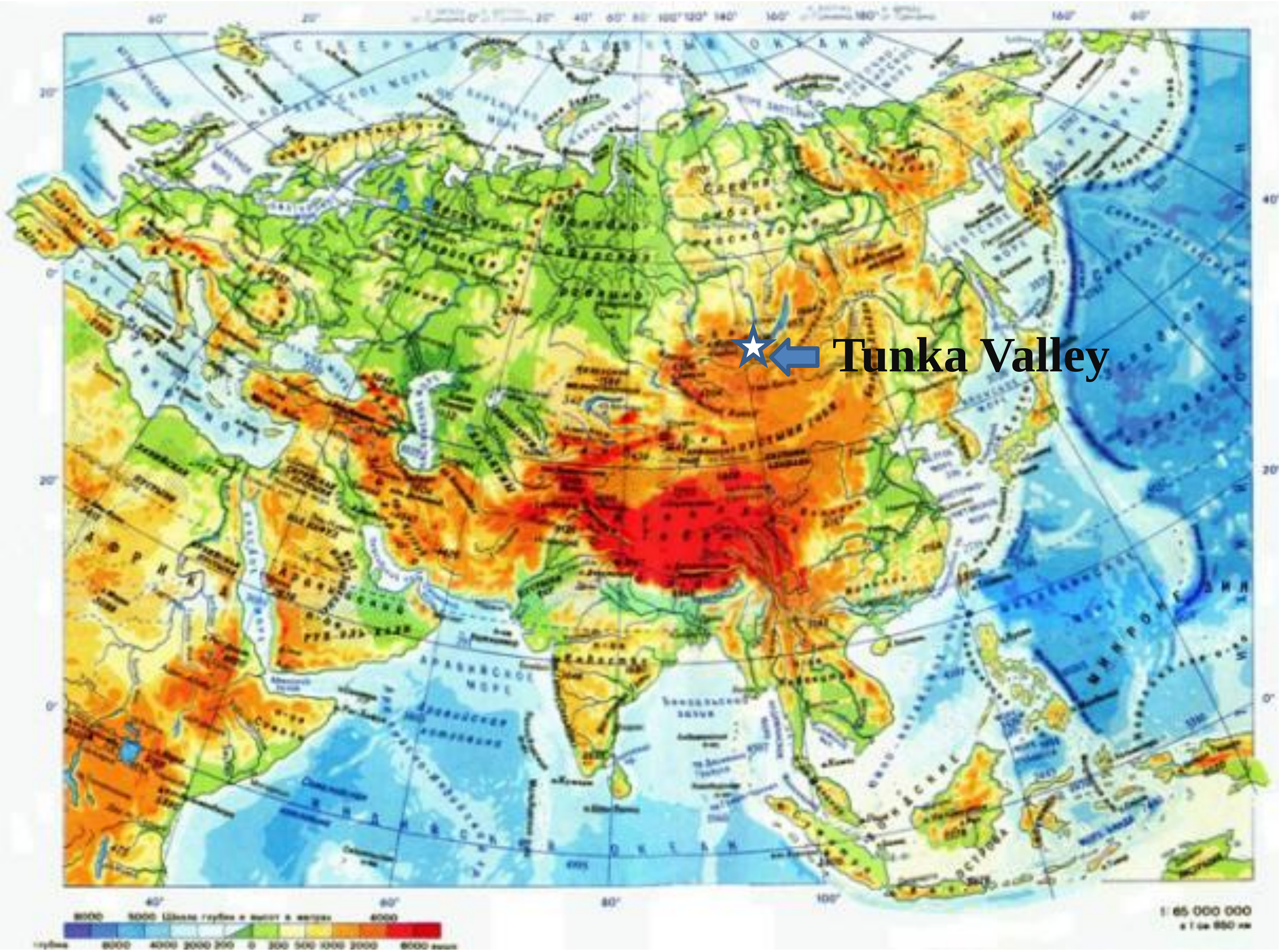
+

0.2 10^6 Eur(PMTs)

100 km^2 array - 10^7 Eur

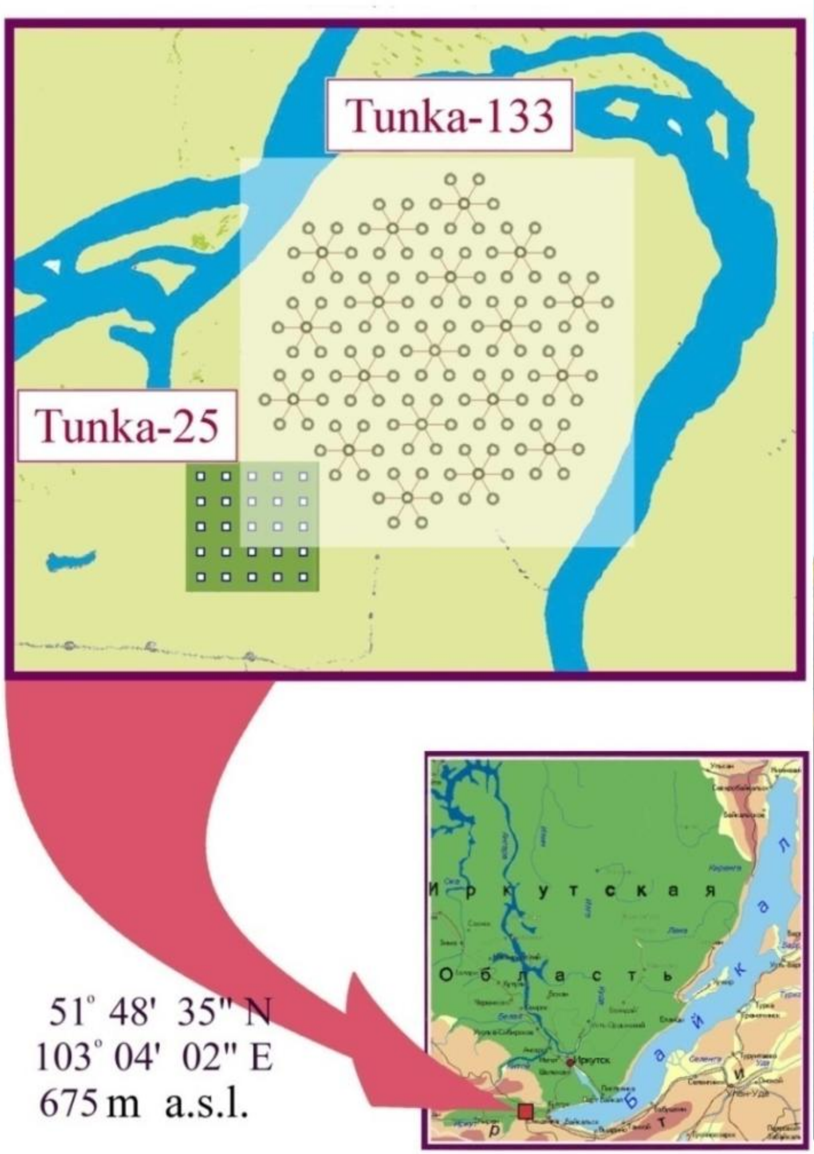
Disadvantage:

1. Small time of operation (moonless, cloudless nights) – 5-10%


Tunka Valley

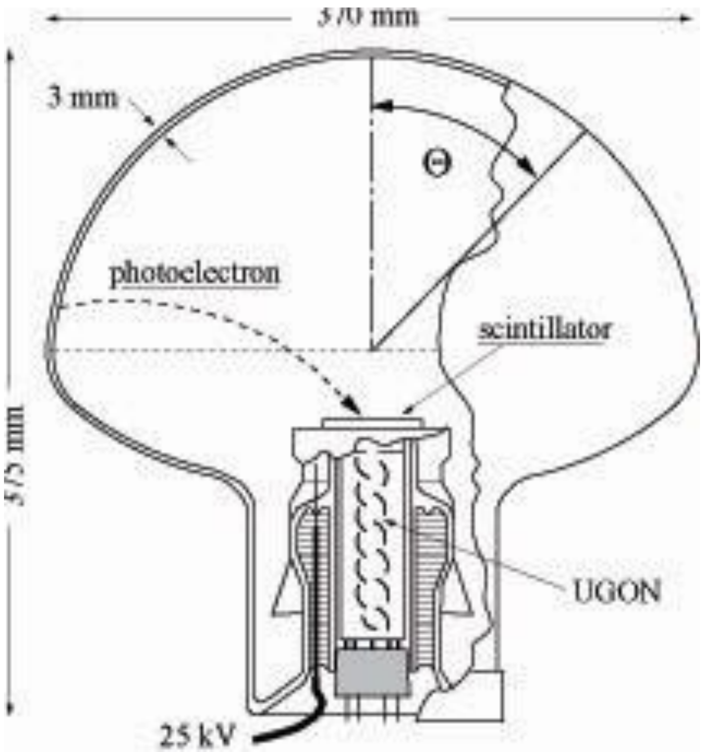
Cherenkov experiments in the Tunka Valley

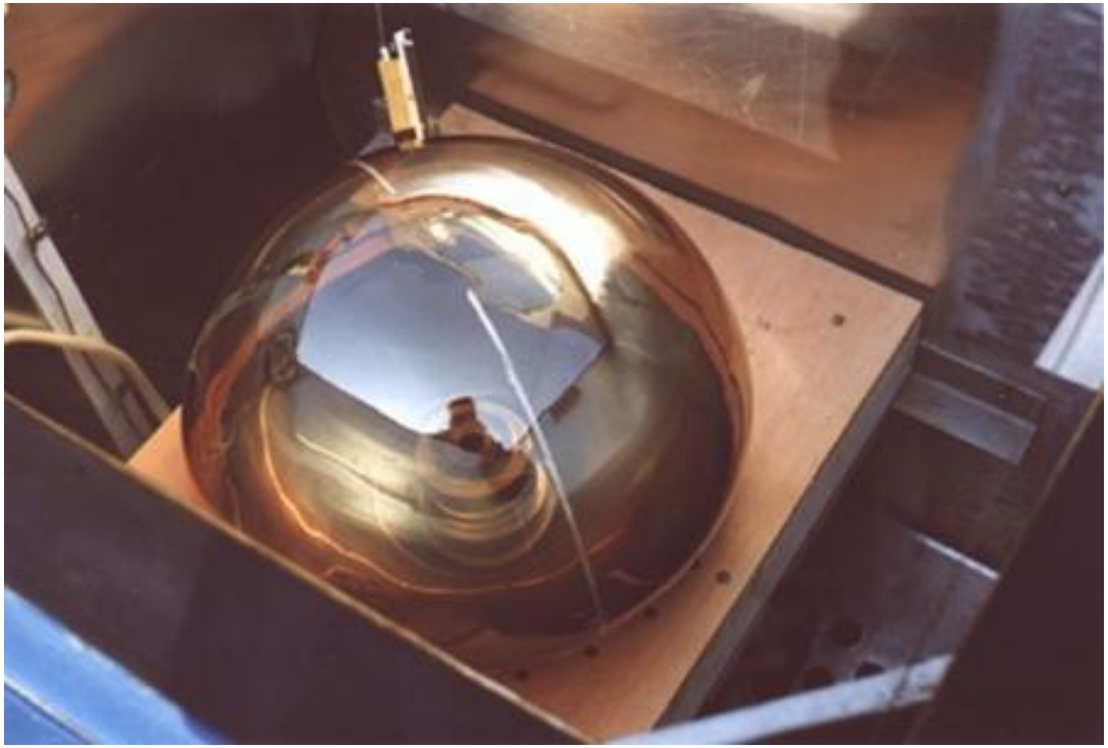
1994 - ……….



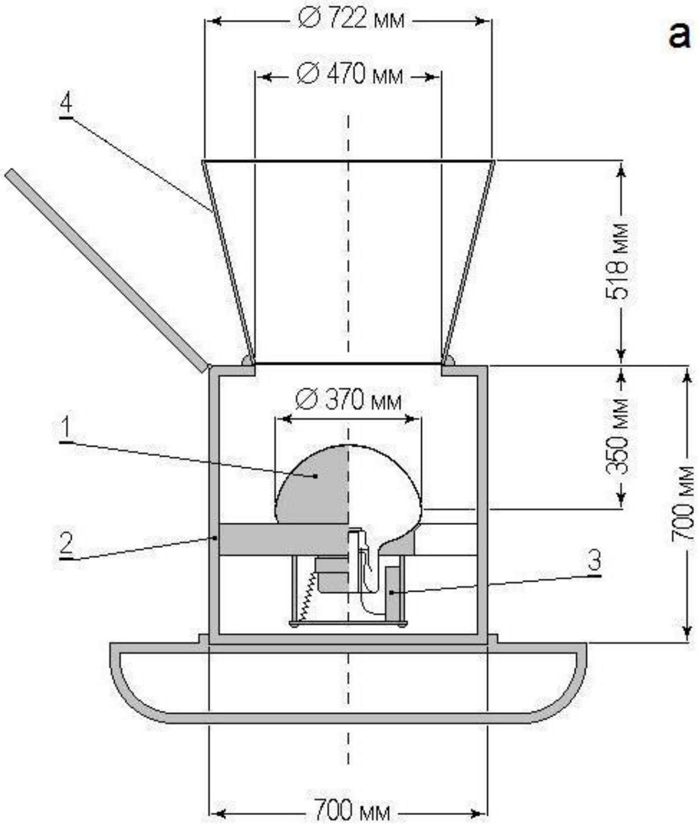
1991-1992: first experiments at the Lake Baikal ice with QUASAR-370 photodetectors (*Bezrukov, Kuzmichev, Lubsandorzhiev et al.)*

1993г. - Move to the Tunka Valley.
(*Bezrukov, Budnev, Kuzmichev, Lubsandorzhiev, Pokhil et al.*)





SMECA: Surface Mobile EAS Cherenkov Array



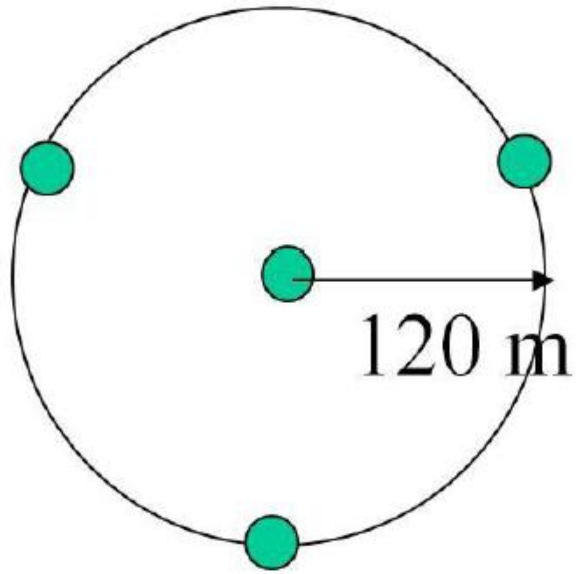
Kuzmichev, Lubsandorzhiev, Pokhil et al

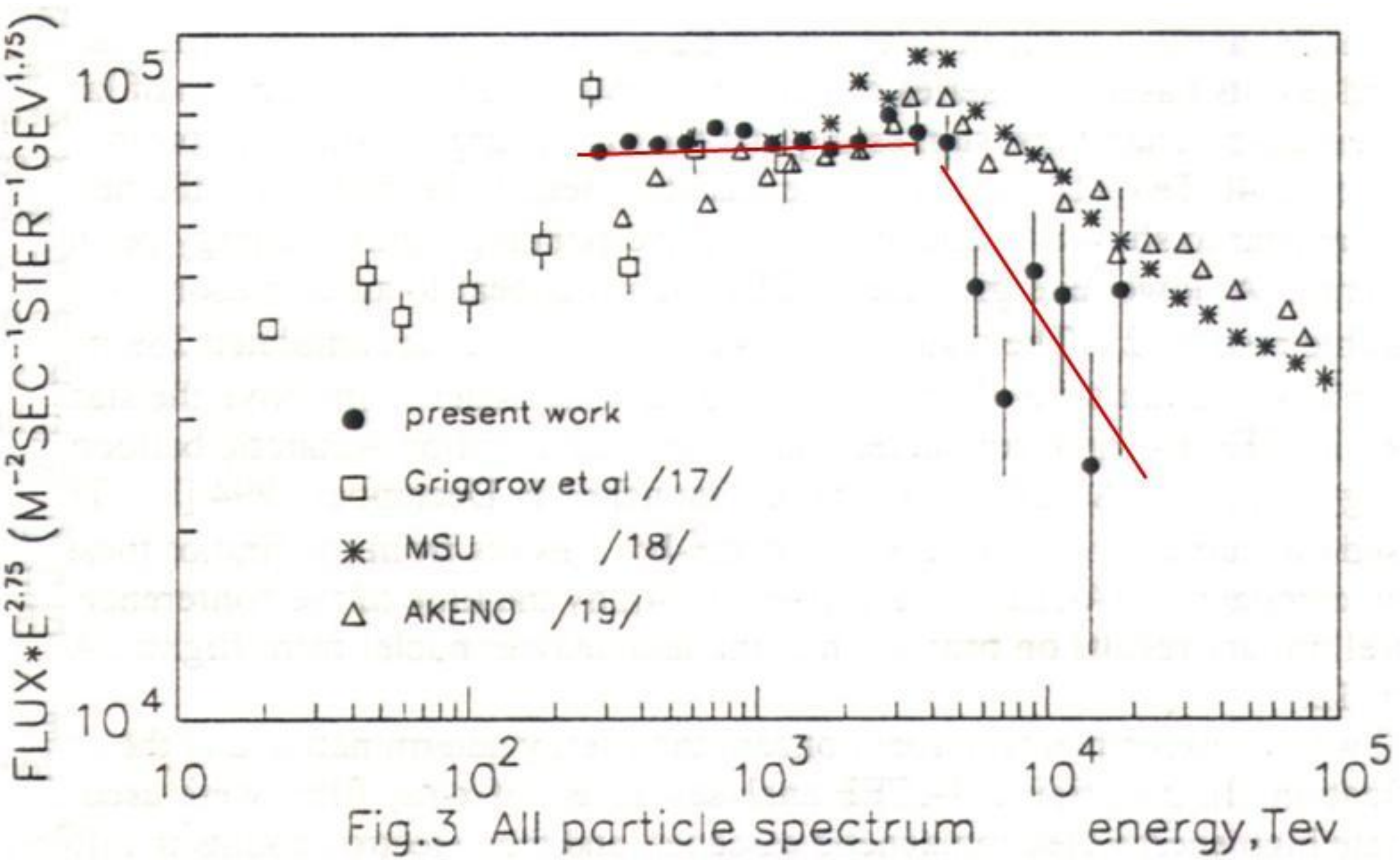
Eth~400 TeV, <θ>~0.5°

Tunka Valley, Buryatia Republic

Tunka-4

4 QUASAR-370 phototubes

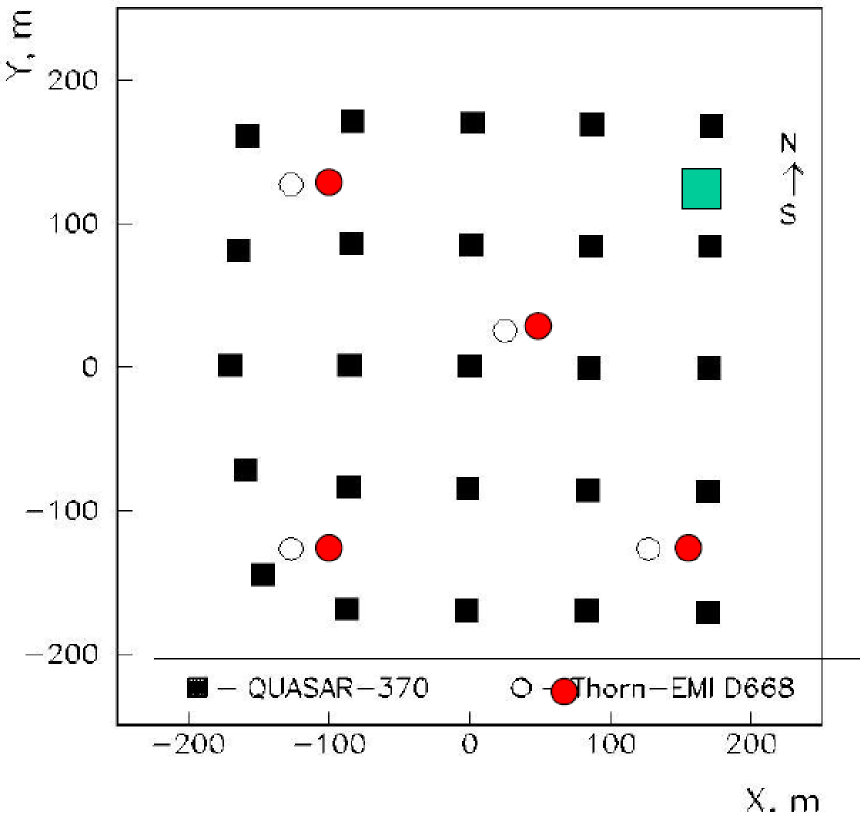




Bezrukov, Kuzmichev, Lubsandorzhiev, Pokhil et al. 24th ICRC 1995 Rome.

“Knee” in the energy spectrum at 3×10^{15} эВ.

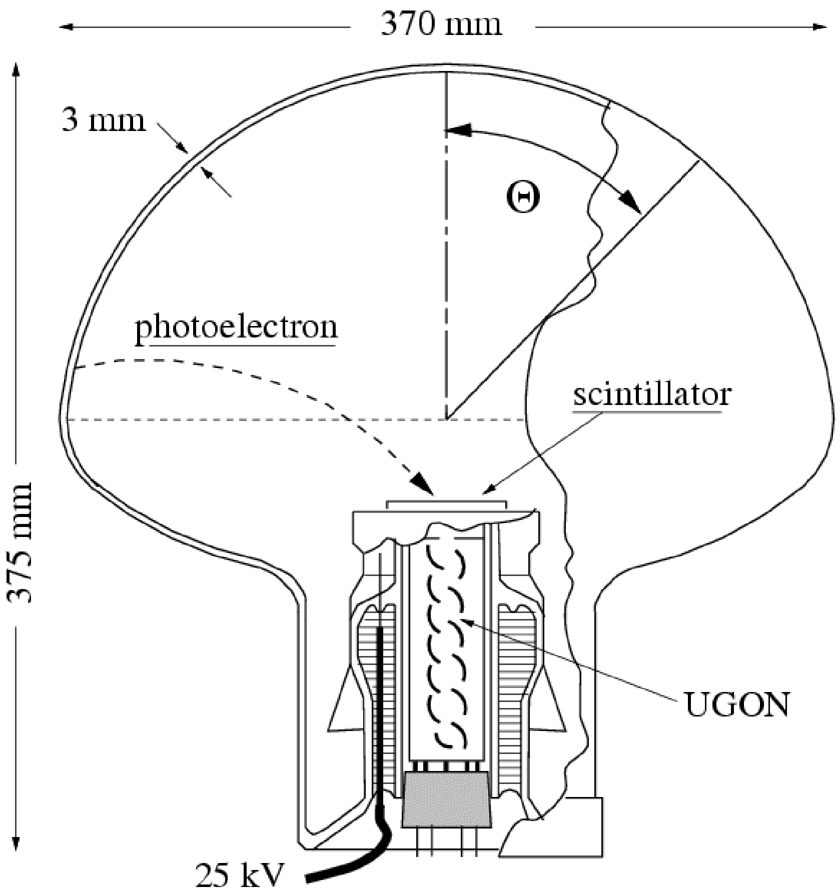
TUNKA-25

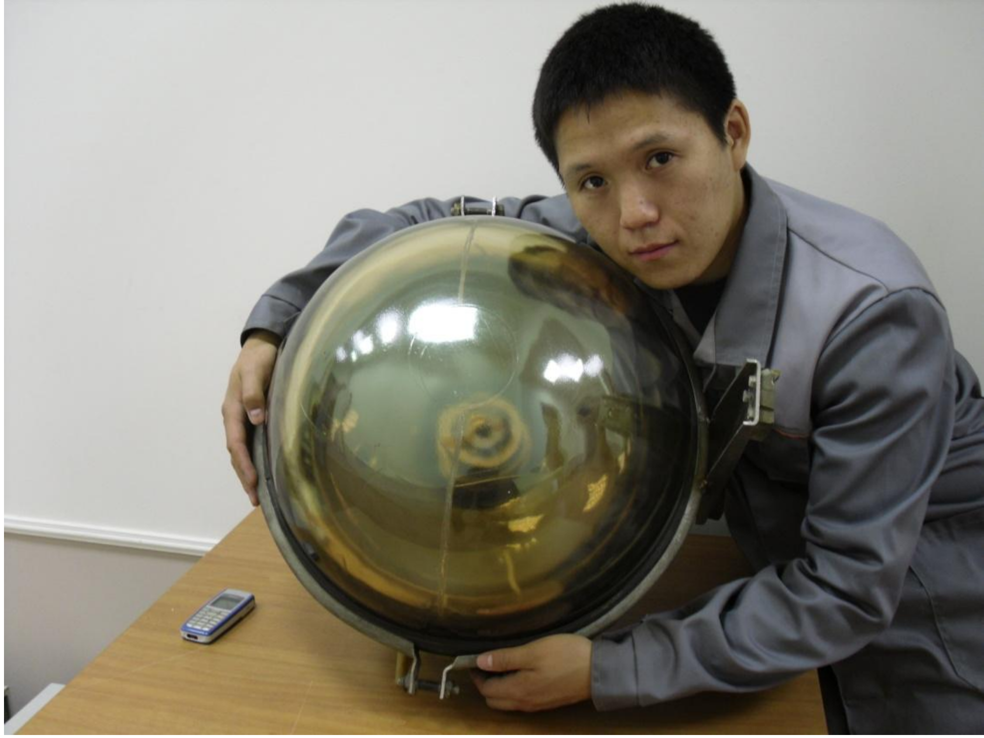


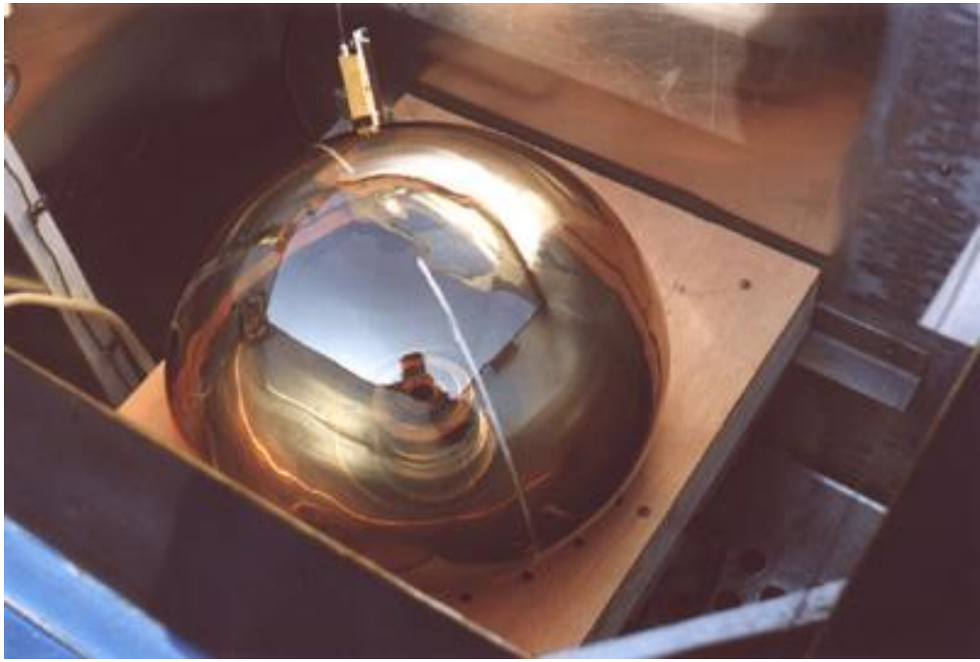
25 large sensitive area hybrid phototubes QUASAR-370G (37cm in diameter)
Area ~ 0.1km^2, E_{th} ~ 4x10^{14} eV, angular resolution ~0.5°

Studies of cosmic rays energy spectrum and mass composition in the energy range of 10^{15}-10^{17}eV

QUASAR-370G







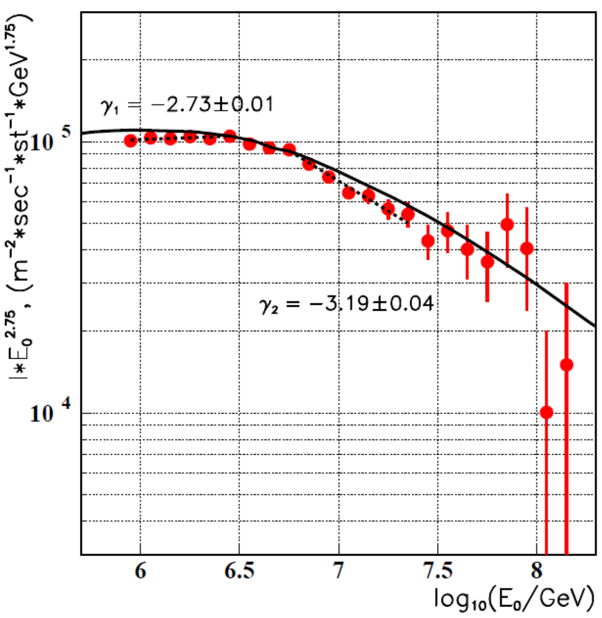
TTS ~ 2 ns (FWHM)
SER ~ 70-80% (FWHM)
Δt < 1 ns
CE ~ 100%

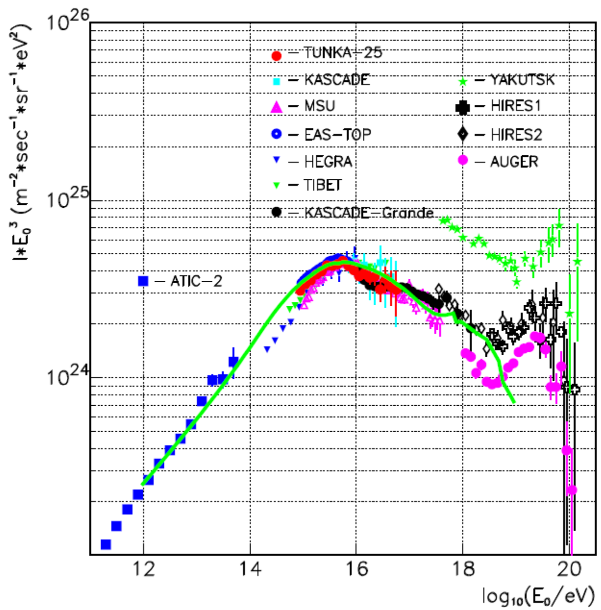
TUNKA-25: final results

Cosmic ray energy spectrum and mass composition in the energy range of 10^{15}-10^{17}eV

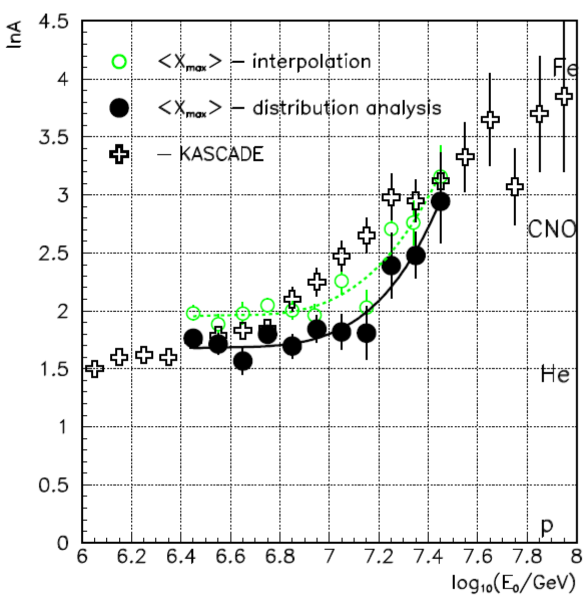
Astroparticle Physics 2013, V.50-52, P.18

Energy spectrum



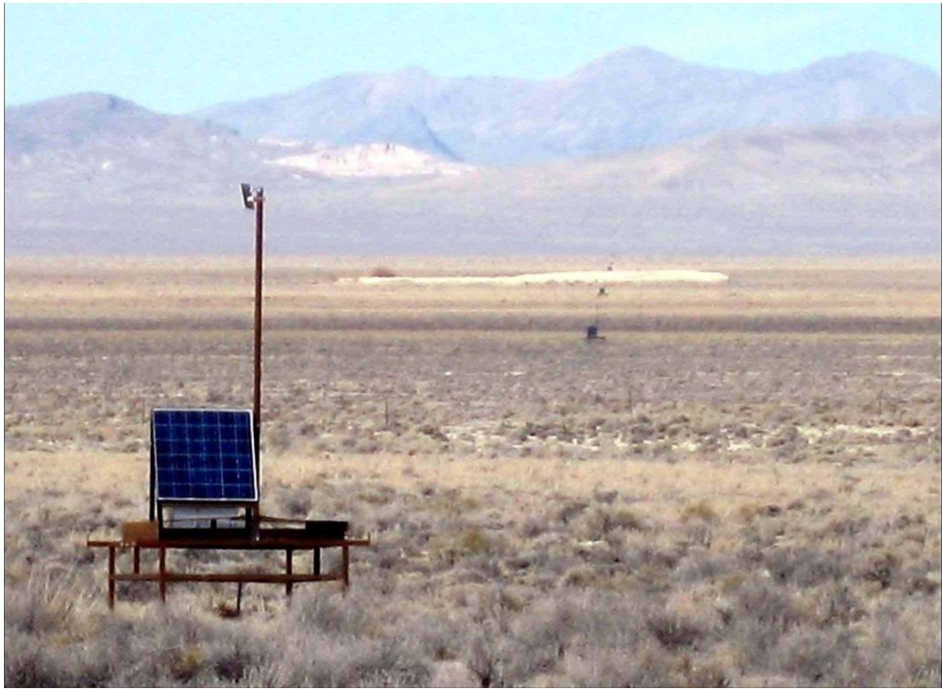


Mass composition



Tunka Valley (Quasar-370G phototubes)

Utah desert (Low energy extension of TA)



Towards covering “Knee”&GZK cut-off
by one experiment!

3 km^2 Cherenkov array Tunka-133

TUNKA-133 collaboration

Skobeltsyn Institute of Nucl. Phys. of Moscow State University, Moscow,

Institute of Applied Phys. of Irkutsk State University, Irkutsk, Russia;

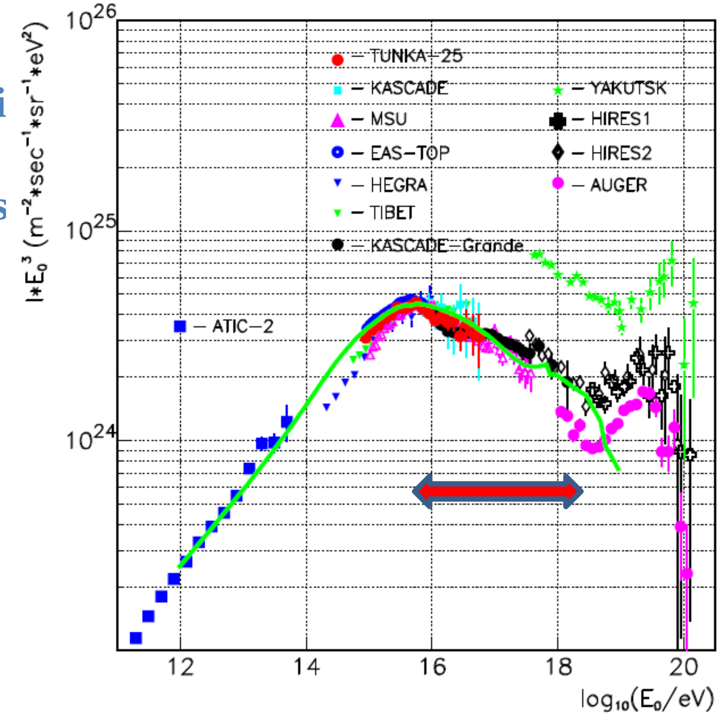
Institute for Nucl. Res. of the Russian Academy of Sciences, Moscow, Russia;

IZMIRAN, Troitsk, Moscow Region, Russia;

DESY-Zeuthen, Zeuthen, Germany;

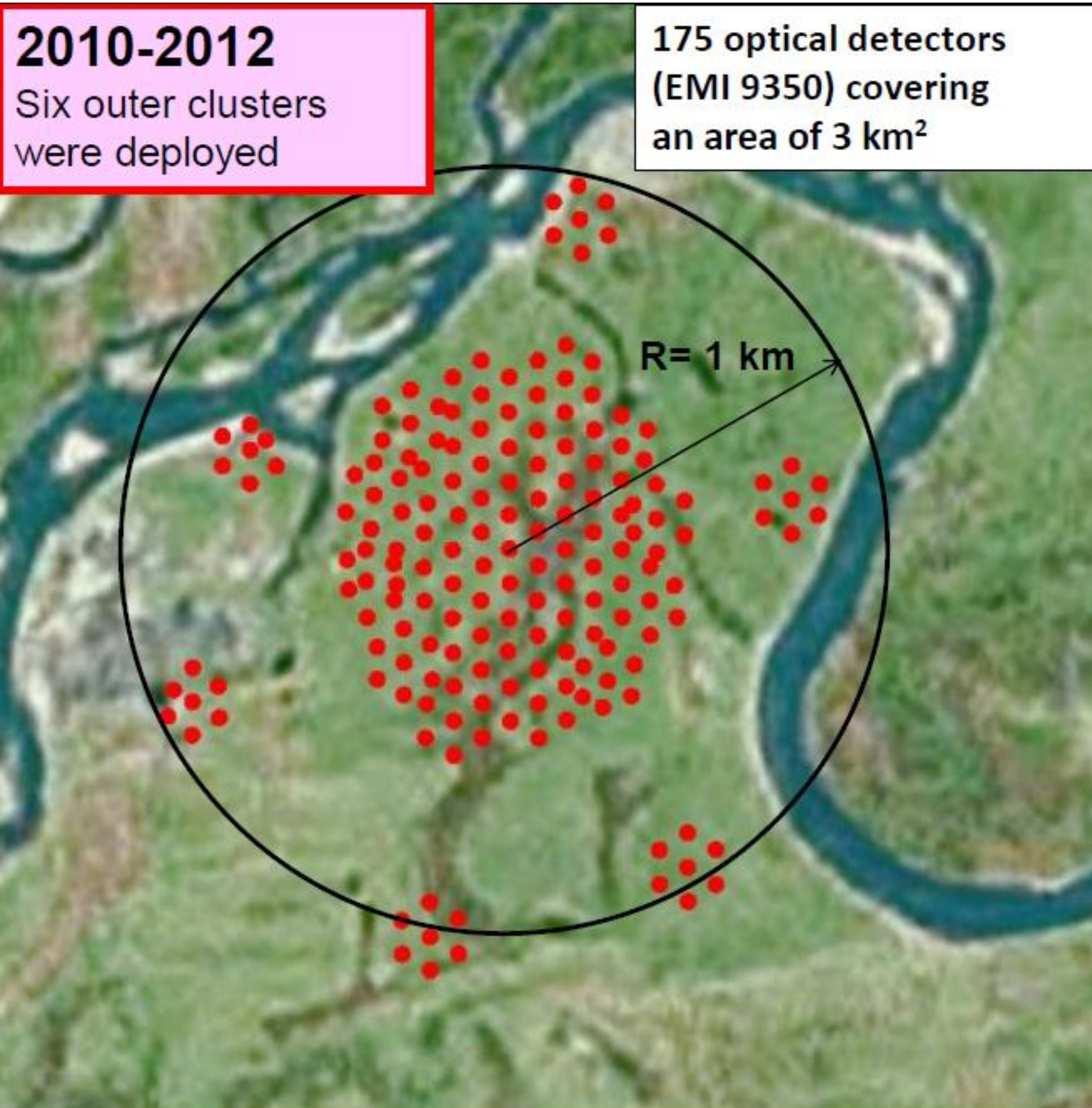
Dip. di Fisica Generale Universita' di Torino and INFN, Tori

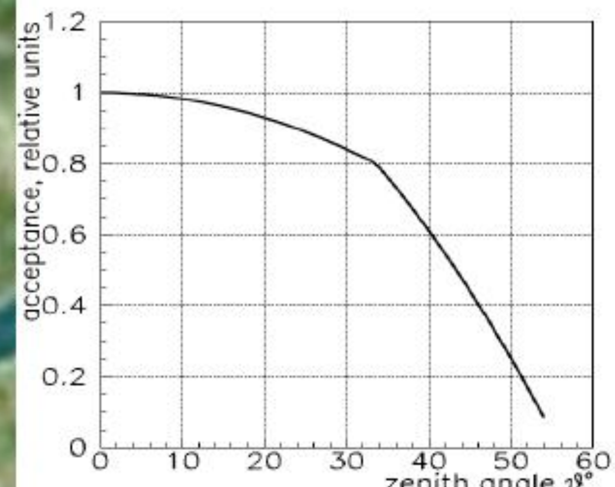
Department of Physics and Astronomy, University of Kansas



2010-2012
Six outer clusters were deployed

175 optical detectors (EMI 9350) covering an area of 3 km^2

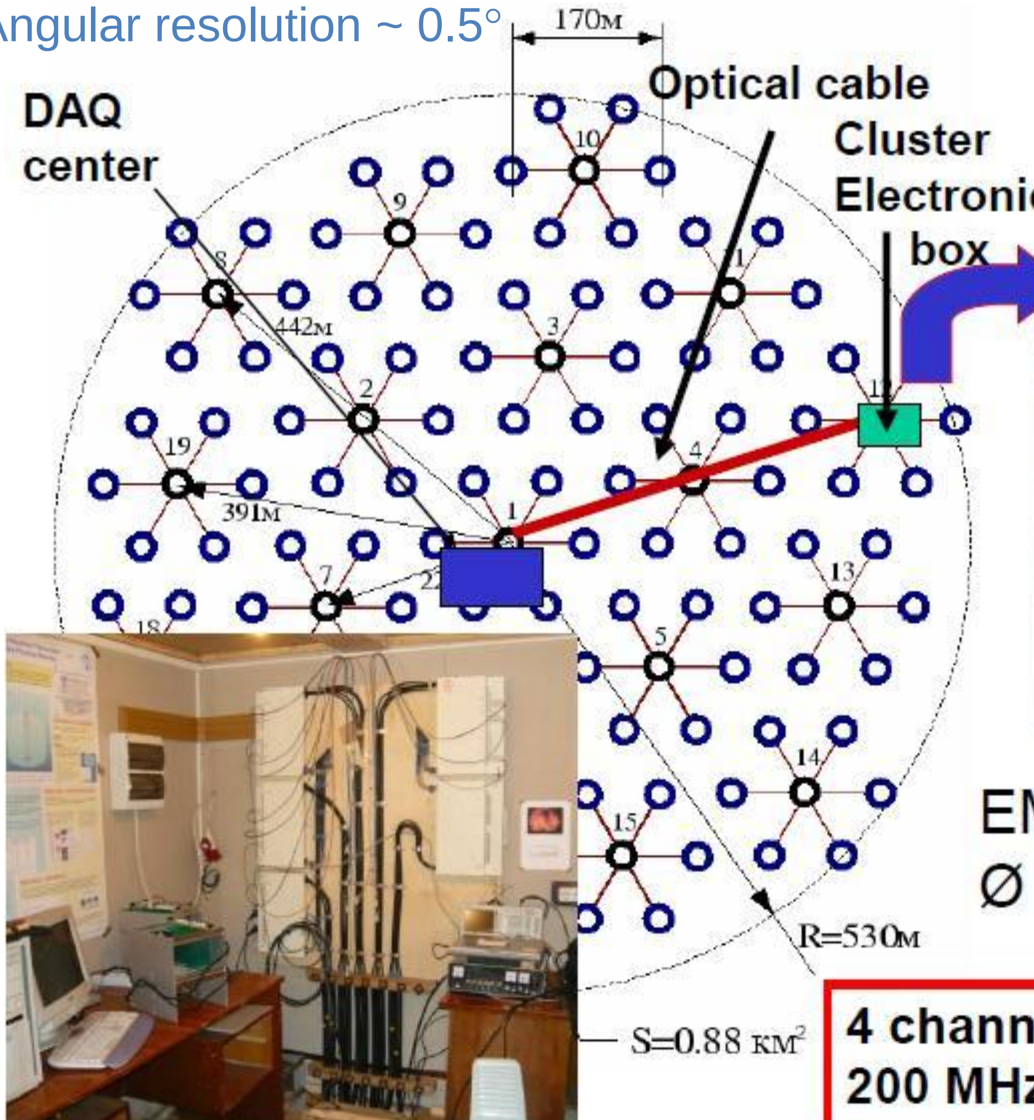


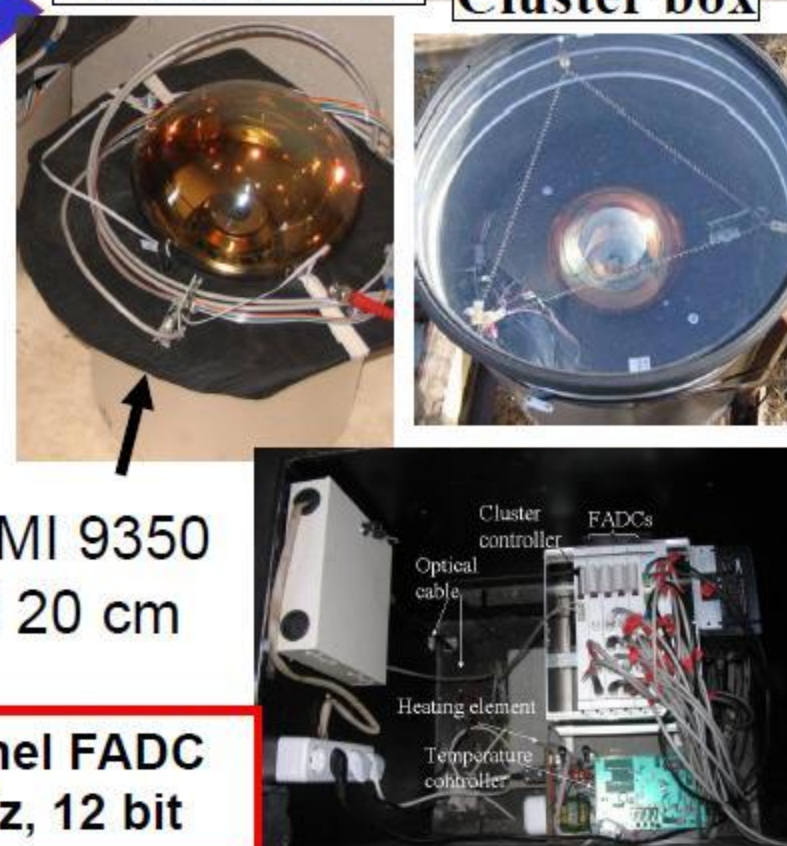


Angular sensitivity

~3 km^2 dense Cherenkov array

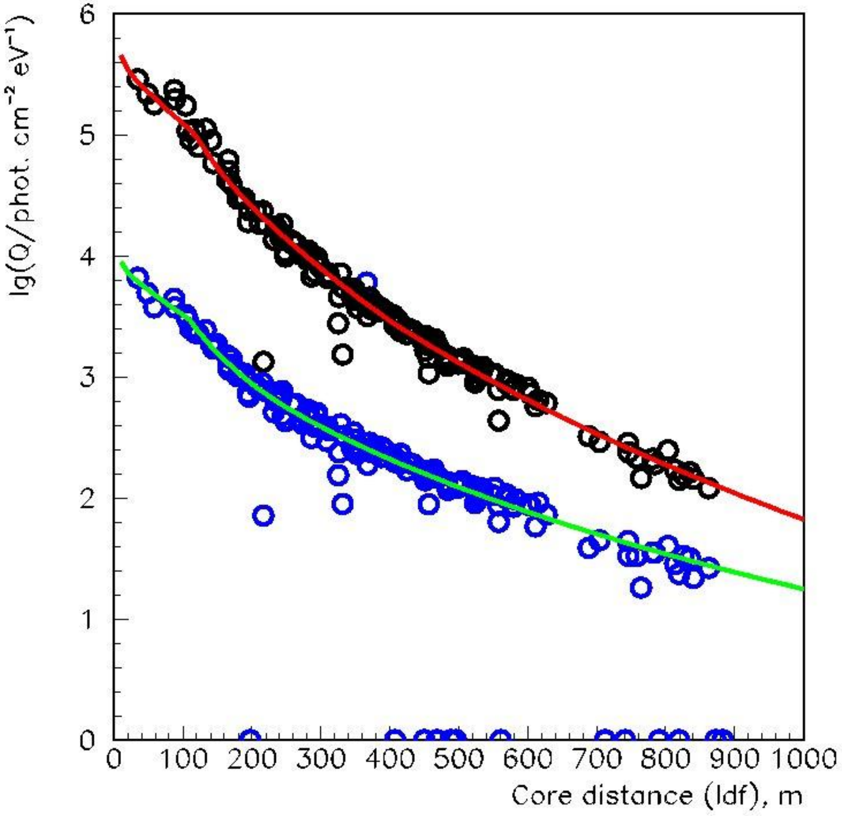
175 optical detectors (8" PMTs – EMI9350KB)
~3 km^2 area
E_{th} ~ 10^{15} eV
Angular resolution ~ 0.5°

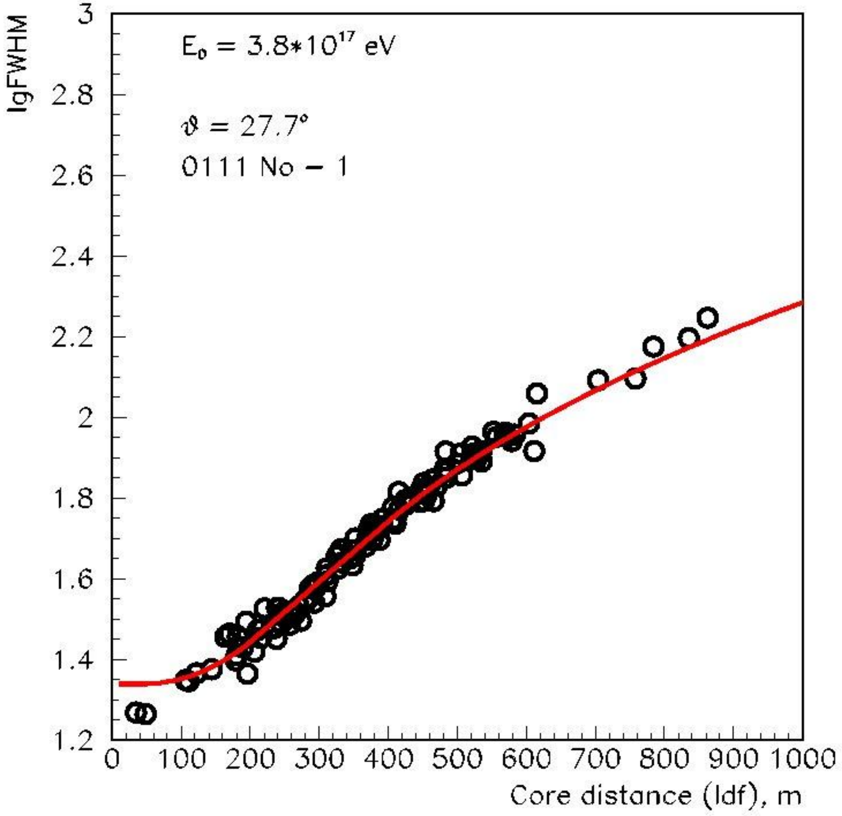




ADF – amplitude distant function

WDF – width distant function

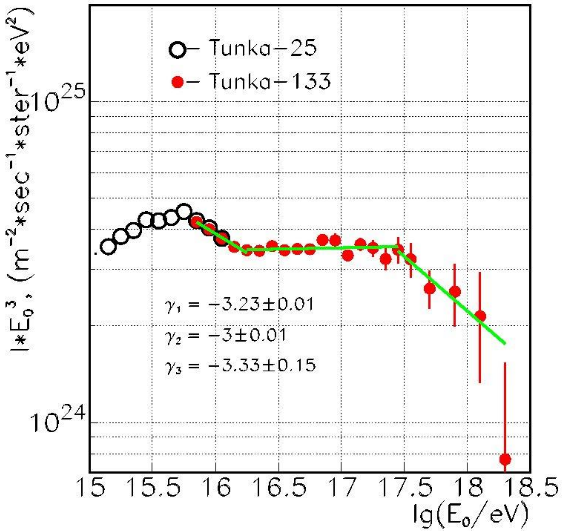


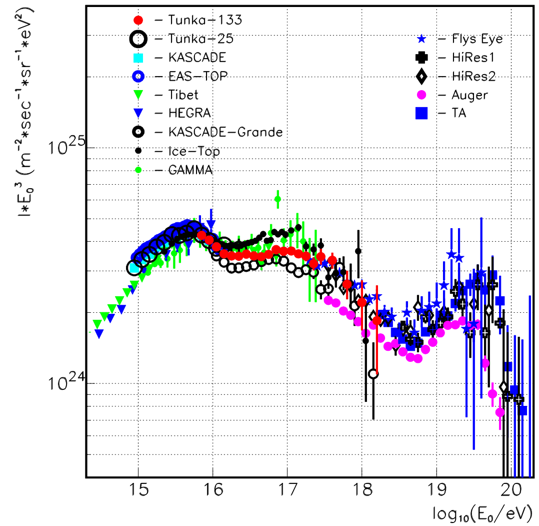


LDF – lateral distribution function

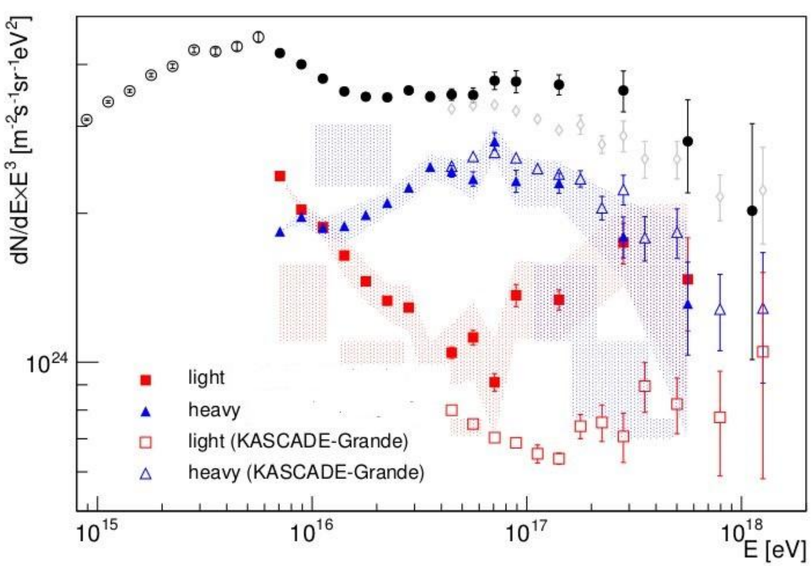
TUNKA-133: recent results

Energy spectrum

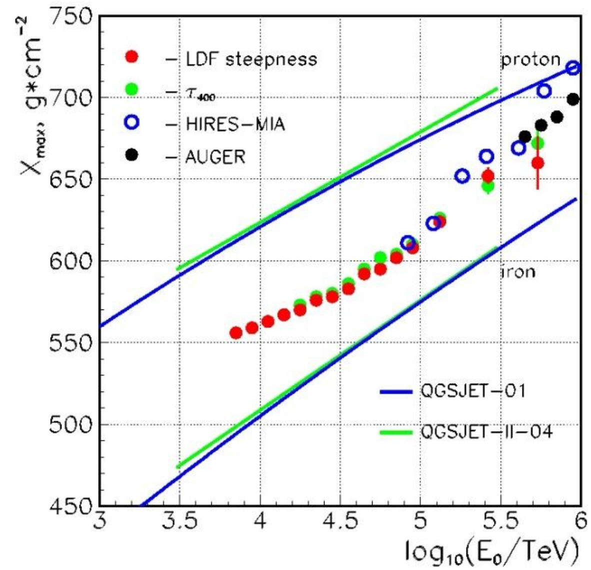




Energy spectrum of “light” and “heavy” components



Mass composition



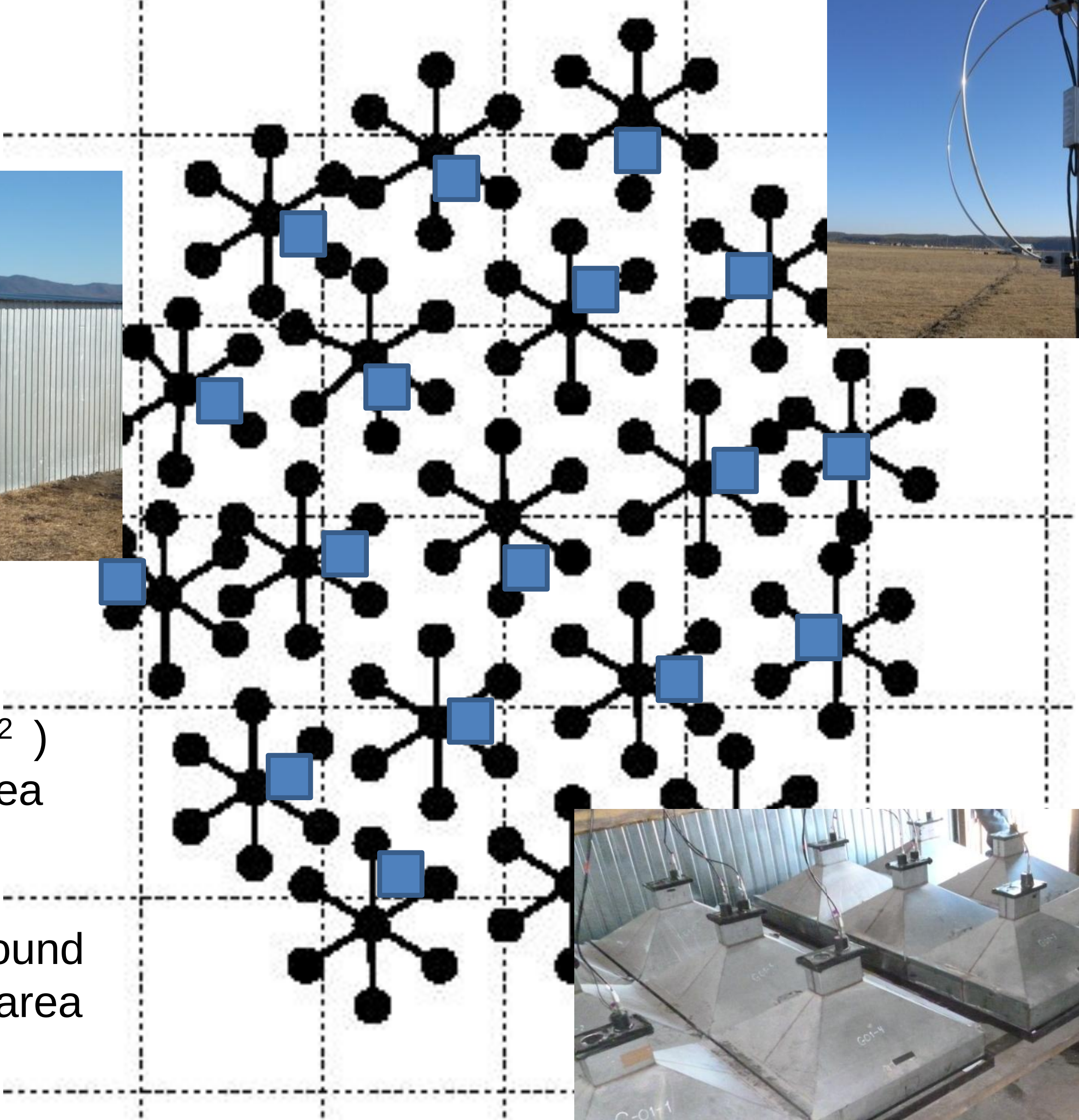
Scintillation detectors from Kascade-Grande

19 stations

228 detectors (0.64 m^2) on the surface, total area 146 m^2)

152 detectors underground (muon detectors, total area 100 m^2)

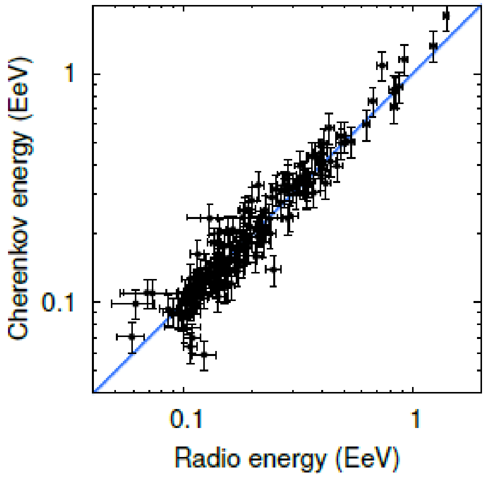
Tunka-Rex: Net of 63 radioantenna



Further extension of Tunka-133 scint. surface and muon detectors, radio.

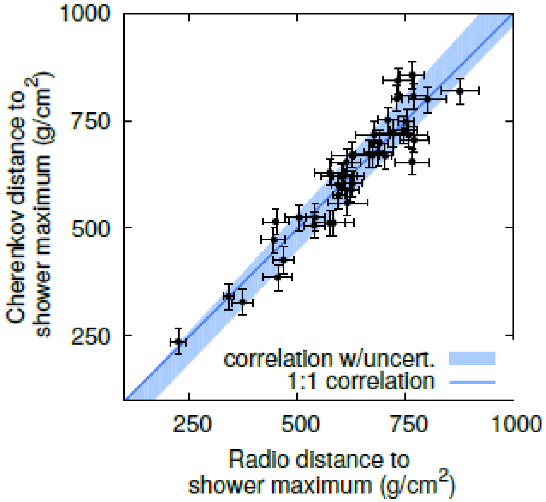
Tunka Radio extension (Tunka-Rex)

Energy



resolution: 15%

Shower maximum



resolution: 38 g/cm²

Total 63 antennas (2016)

TAIGA

(Tunka Advanced Instrument for Gamma & cosmic ray Astrophysics)

- **Array of non imaging wide-angle optical stations (HiSCORE type, *M.Tluzikont et al*)**

TAIGA-HiSCORE

5 km^2 array (500 stations)

- **Net of imaging telescopes 9-10 m^2 area**

TAIGA-IACT

10-16 IACTs

- **Net of muon detectors 10^2 - 10^3 m^2 area.**

TAIGA-GRANDE

~2000 m^2

TAIGA Collaboration

Russia

Moscow:

- MSU (SINP)
- INR RAS
- MEPhI
- IZMIRAN

Dubna: JINR
Irkutsk: ISU
Novosibirsk: Budker INP & University
Ulan Ude: IPSM

Germany

Hamburg University
DESY (Zeuthen)
MPI Munich

Italy

Torino University

Romania

ISS Bucharest

TAIGA combines the following detector components:

- **TUNKA-133 air Cherenkov integrating** (175 stations, operational)
- **HiSCORE air Cherenkov integrating** (until now operating with 28 stations, ~30 more stations are added during this summer, planning to commission in the next year)
- **Imaging Atmospheric Cherenkov Telescope** (1^{st} telescope under assembly on site, parts of 2 more telescopes under preparation)
- **Surface and underground μ, $e^{\pm}$ detectors** (19 stations operating, each of ~8m² (surface) and 5m² (2m underground); a future big challenge will be to complete it till ~2000 m² area)
- **Radio emission from EAS,** TAIGA hosts an array of 63 detectors (*KIT, Karlsruhe*)

Gamma-ray Astronomy

Search for PeVatrons.

VHE spectra of known sources: where do they stop?

Absorption on IR and CMB.

Diffuse emission: Galactic plane, Local supercluster.

Charged cosmic ray physics

Energy spectrum and mass composition from 10^{14} to10^{18} eV.

Particle physics

Axion/photon conversion.

Hidden photon/photon oscillations.

Lorentz invariance violation.

pp cross-section measurement.

A novel concept: TAIGA hybrid detector, combining the imaging and non-imaging techniques

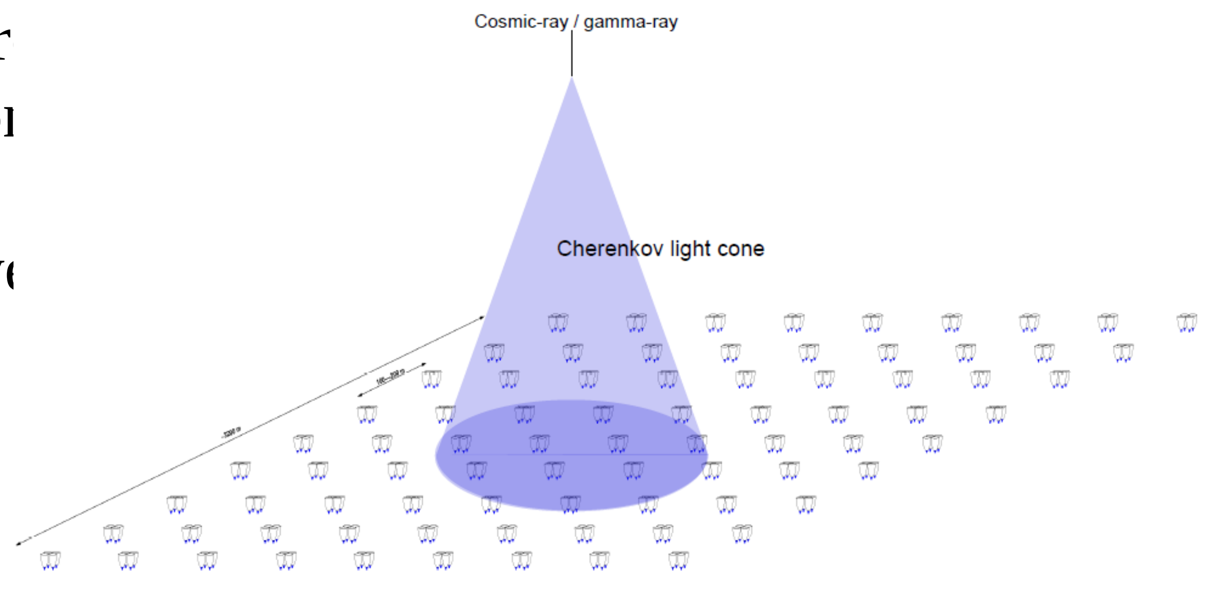
- The IACT and the HiSCORE will “observe” the same source
- The IACT can measure the source spectrum starting @ a few TeV
- The HiSCORE will “join” the observation starting at ~ 30 TeV
- At impact distances ≥ (200-300) m E_{th} of an IACT will increase, the images will become truncated; the precision of measured shape and angular parameters of an image will degrade
- HiSCORE can counteract this degradation, by providing the impact distance and with good precision (~0.1° @ ≥ 60 TeV) the inclination angle of the shower, hence helping to tag the background events
- By using the selected events from the IACT, simultaneously measured by HiSCORE, the latter “can learn” background rejection and apply this for any other source observations

- The benefit of this will be to construct an array of a large size, using much lower number of IACTs (compared to CTA), set on distances of 800 -1200 m from each other
- The operational range of a single IACT will be extended to impact distances of 400 – 600 m
- In this way a single IACT shall be able to provide a collection area of ~ (0.5 – 1) x 10^6 m^2 at small zenith angle observations
- Another benefits are the low-cost, the simplicity, the ease of transportation and the robustness of static HiSCORE stations
- With the TAIGA prototype array, including 2 IACTS, we shall be able to prove this concept
- For this purpose we plan to install the 2^{nd} IACT on 300m from the 1^{st} one and scan the distance range till 600 m, at least in one direction

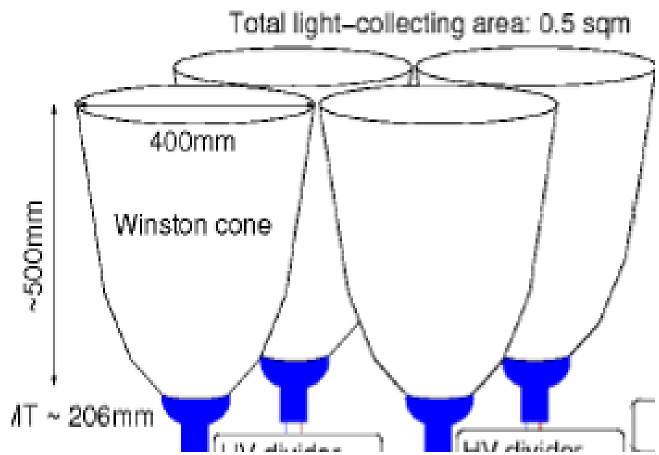
TAIGA - HiSCORE
(High Sensitivity Cosmic Origin Explorer).

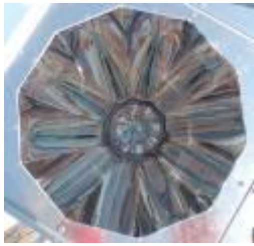
- Distributed array of non-imaging Cherenkov light-integrating detectors, sampling EAS front
- Angular resolution, f(E): ~ 0.1° - 0.4°

- Aimed $E_{threshold}$ for γ-rays : ~ 30 TeV
- Aimed full-scale final ar
- Low-cost detector statio
  → can be built many
- Need to learn to effectiv
  reject the background



TAIGA – HiSCORE optical station

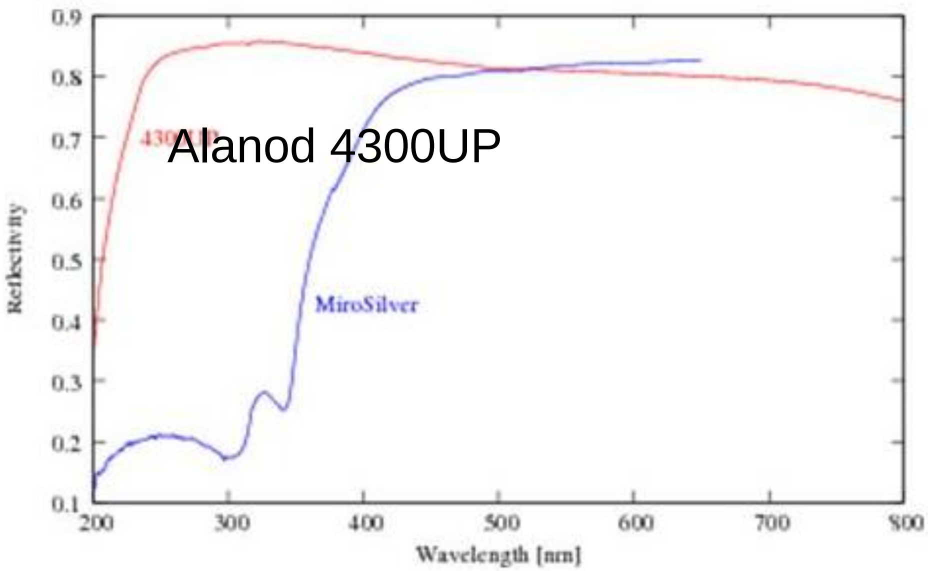




- Signals from 4 PMTs of 8’ or 10’ size are locally added, providing fast coincidence
- Detector active area: 0.5 m²
- Field of view (FOV): ~ 0.6 sr

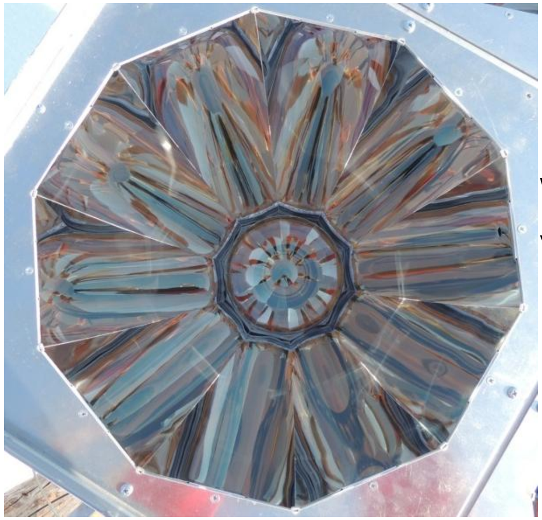
- 4 PMTs attached to 4 Winston-cone type light concentrators
- Plexiglas protective window

Refelectivity of Winston cone (Alanod4300UP)



Optical station

Winston cone
Side view

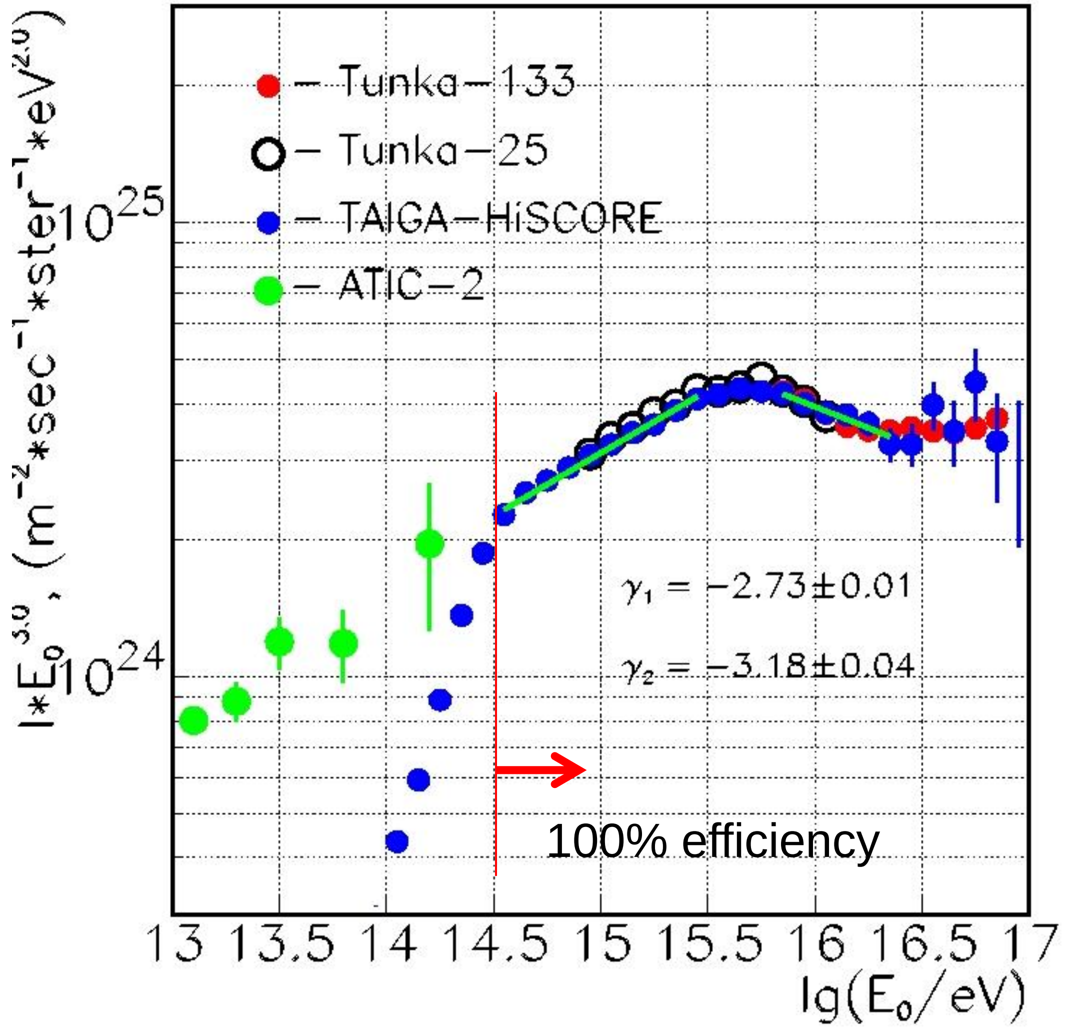


Winston cone
View from above

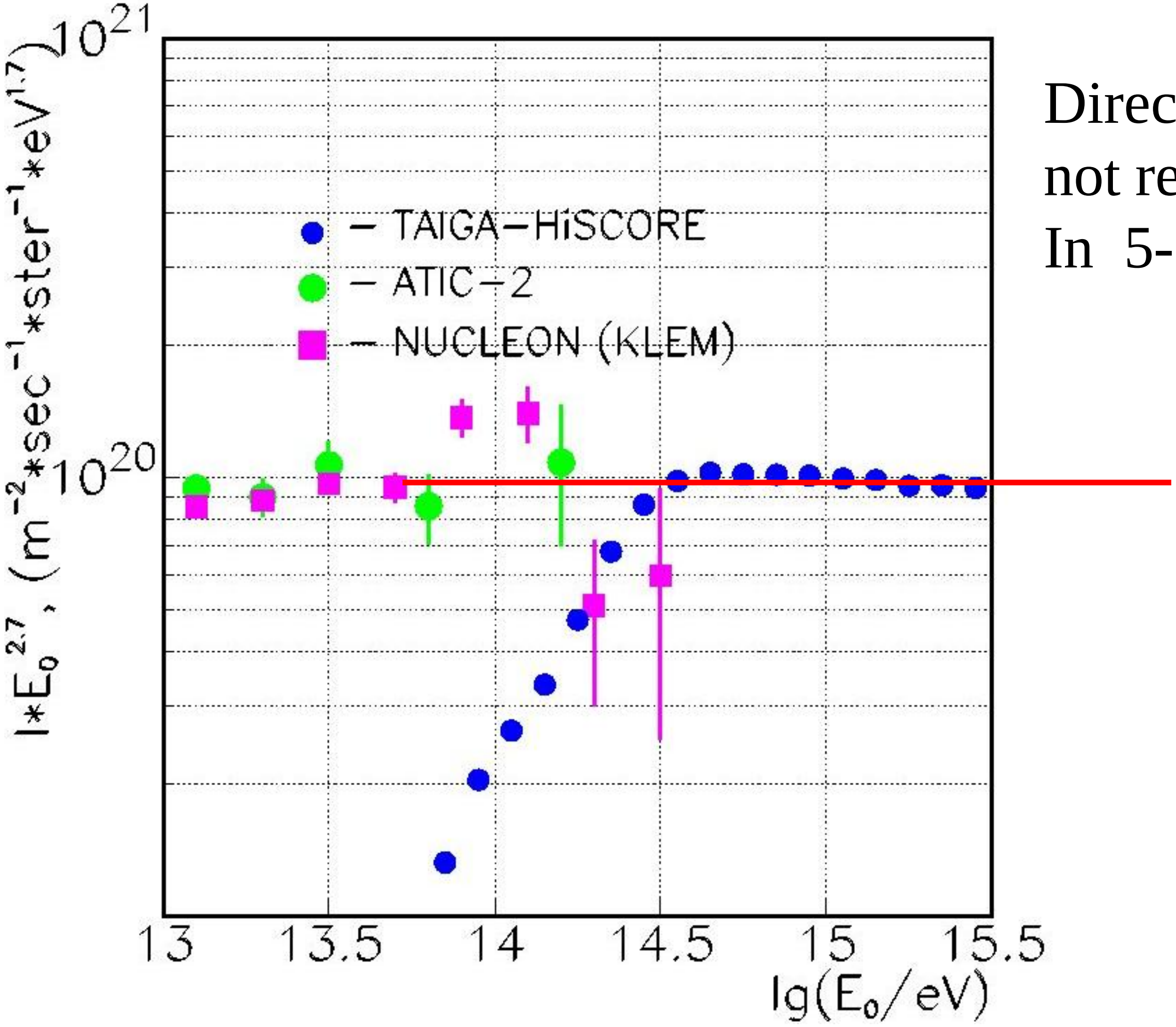
TAIGA HiSCORE – IACT prototype array

- 28 HiSCORE stations have been deployed and operated since fall 2014
- This summer the number of HiSCORE stations has been increased by another 30; these will be commissioned in the next
- We plan to operate these 58 HiSCORE stations in coincidence with the 1st IACT, which is currently under assembly in the Tunka valley
- The 2nd IACT is planned to be installed in 300m from the 1st one

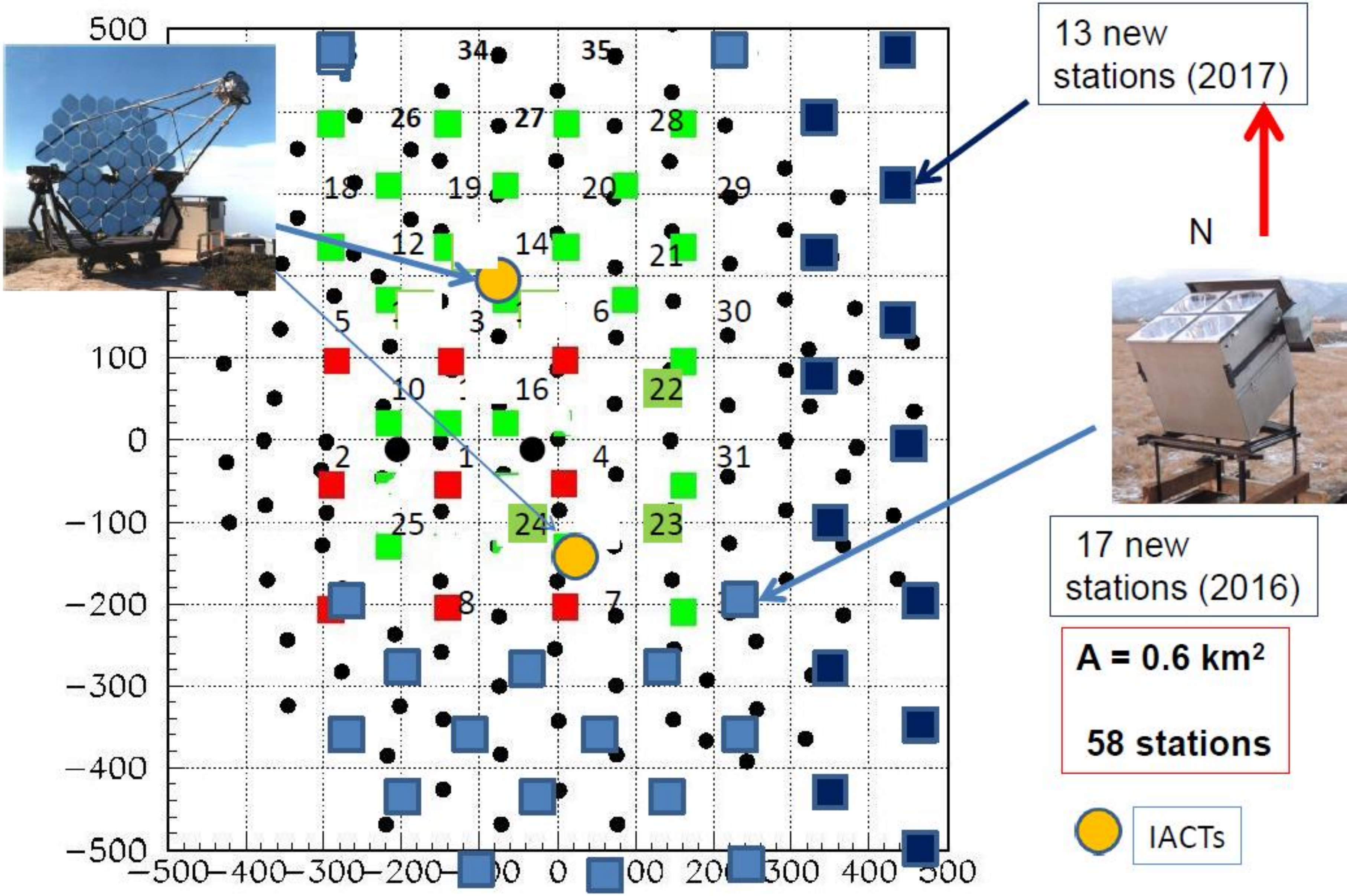
All particle energy spectrum (28 optical stations of HiSCORE)



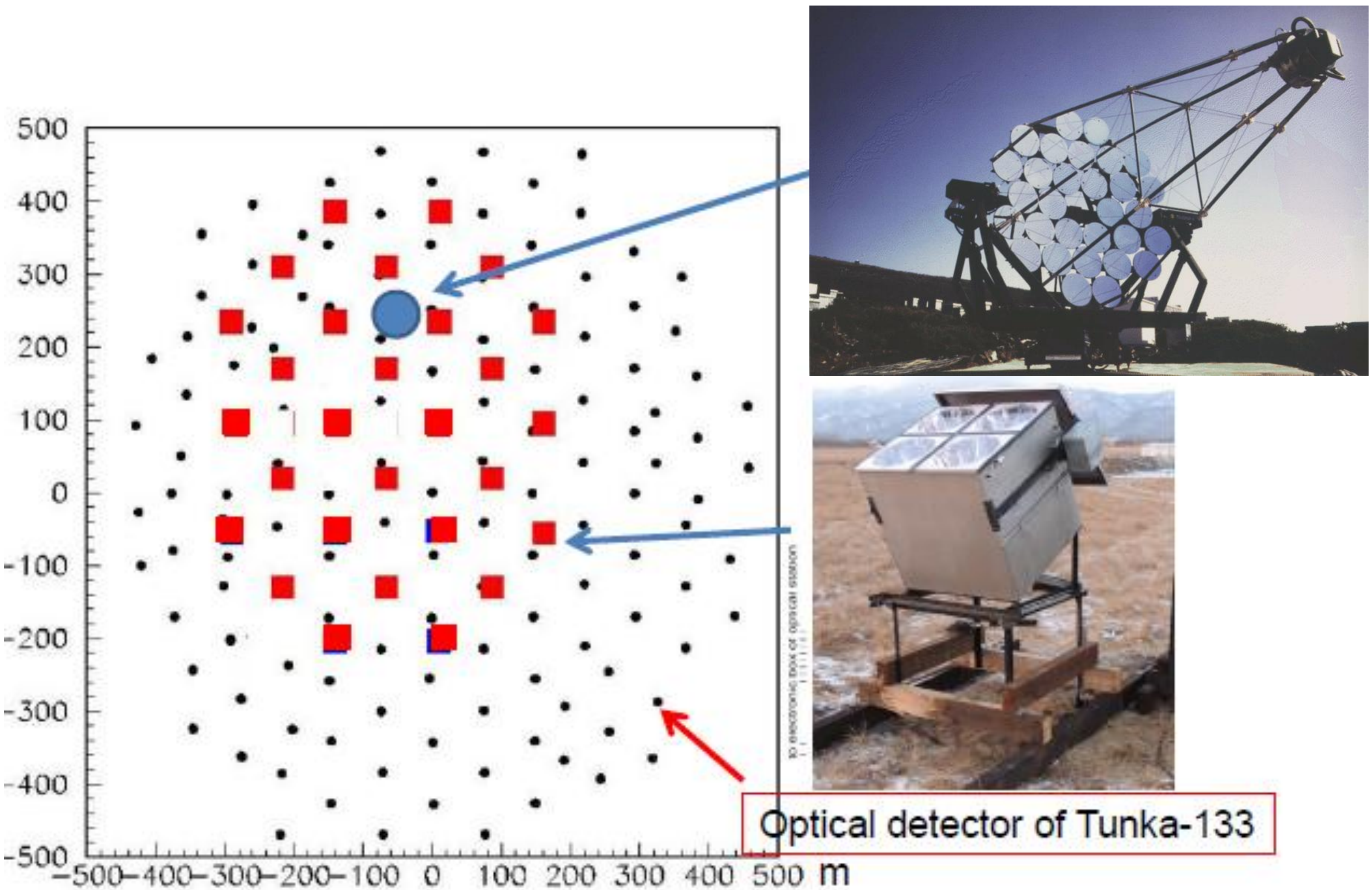
All particle spectrum (HiSCORE & Nucleon)



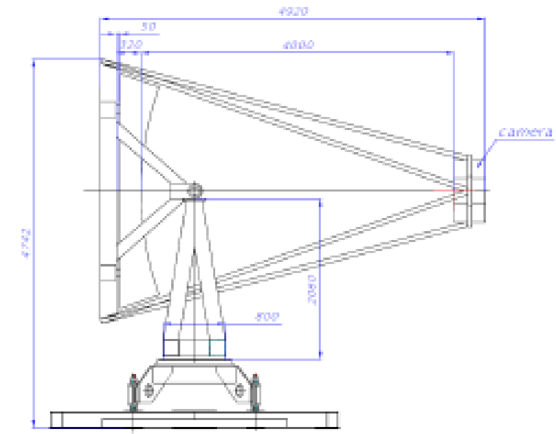
Direct measurement will not reach knee region In 5-10 years


13 new stations (2017)
N
17 new stations (2016)
A = 0.6 km²
58 stations
IACTs

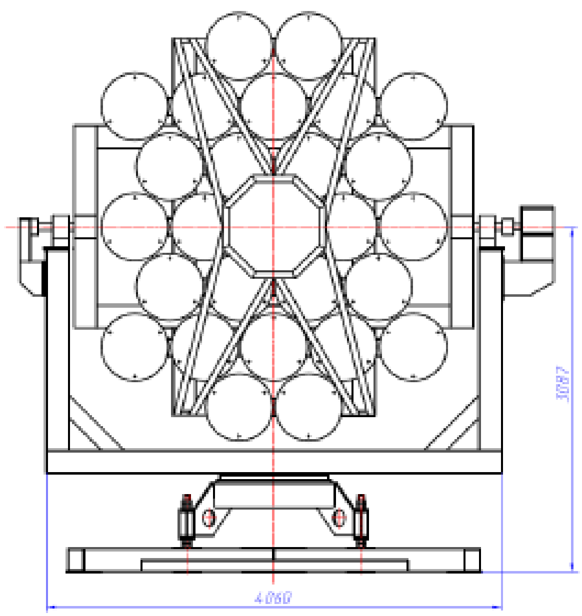
One of the TAIGA high-priority goals: operate 58 HiSCORE stations with the 1st IACT

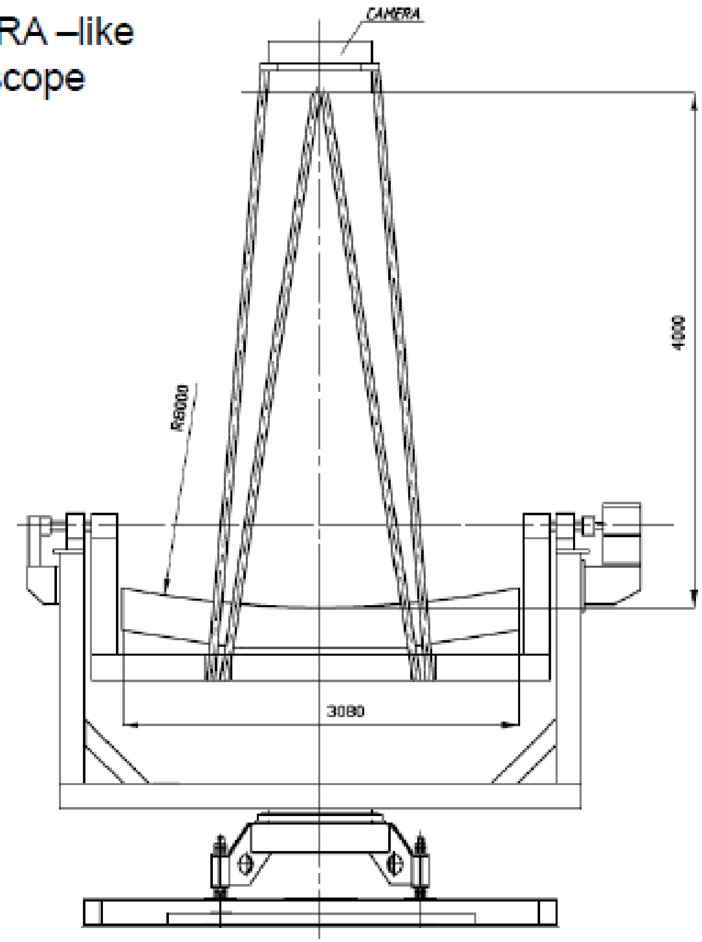


TAIGA IACTs are based on HEGRA-like telescopes



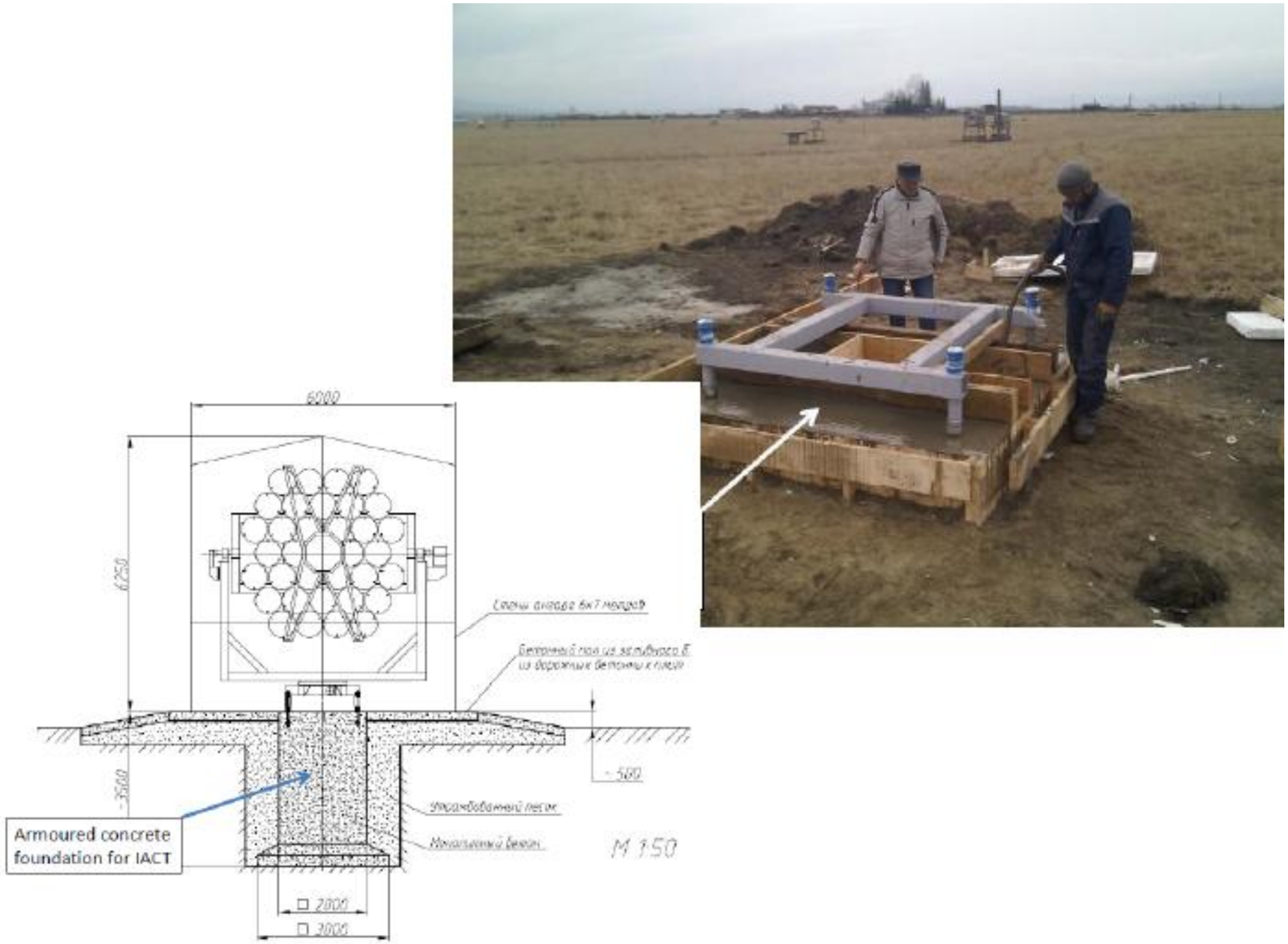
HEGRA –like telescope

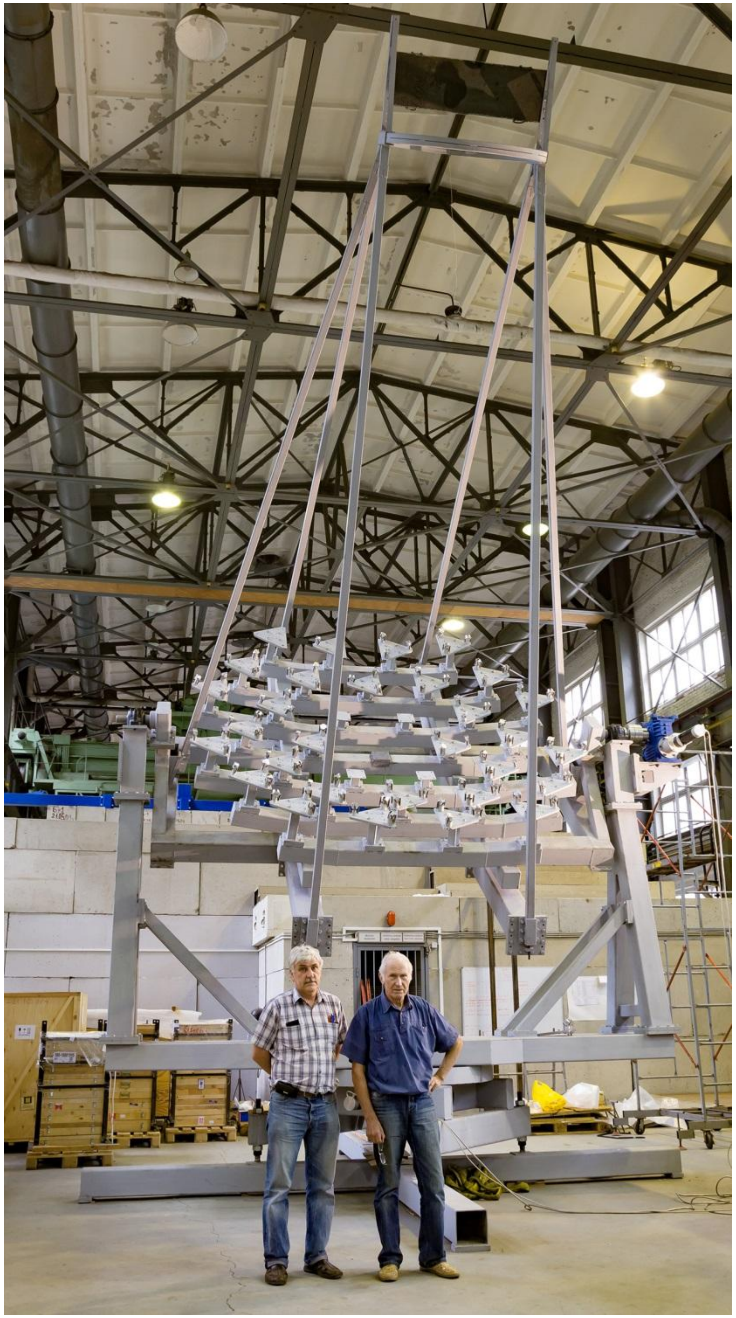




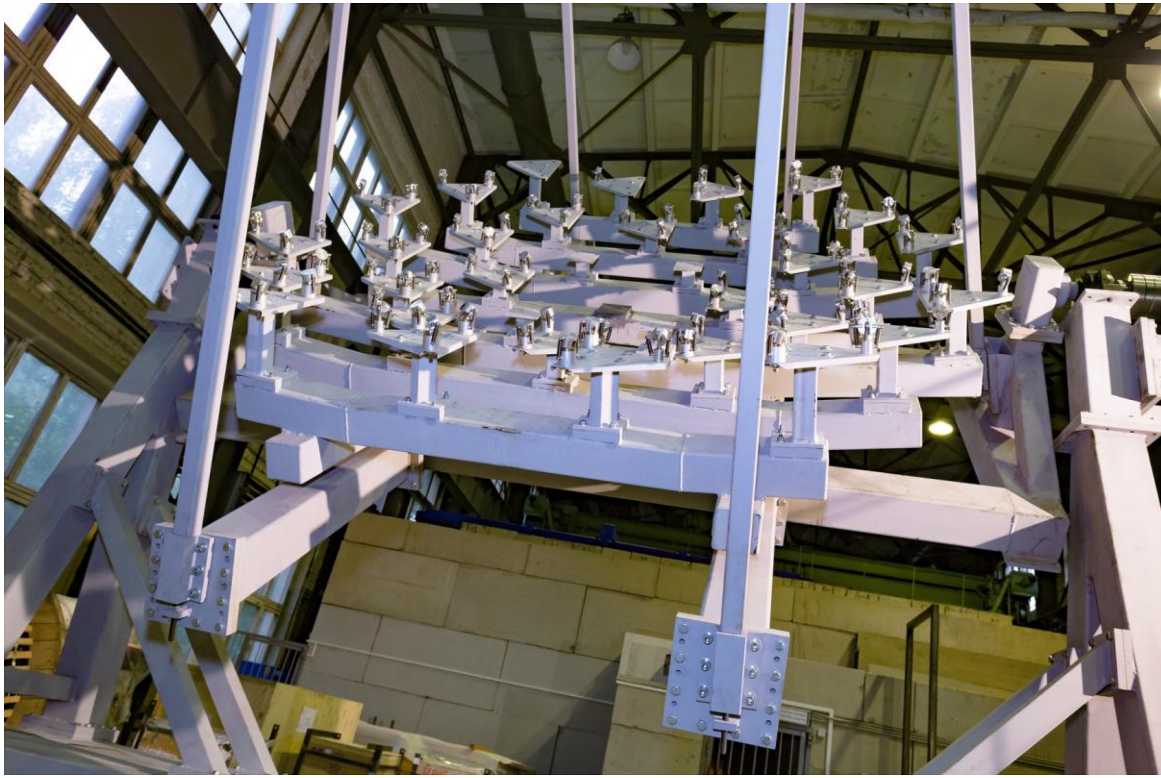
Now in production in JINR

Concrete foundation of the 1st TAIGA-IACT





The mechanical structure of the TAIGA-1 telescope in a workshop hall of the JINR in Dubna in June 2016



The reflector frame of the TAIGA-1 telescope built in a JINR workshop in Dubna

Parameters of the 1st TAIGA imaging telescope:

Optical system

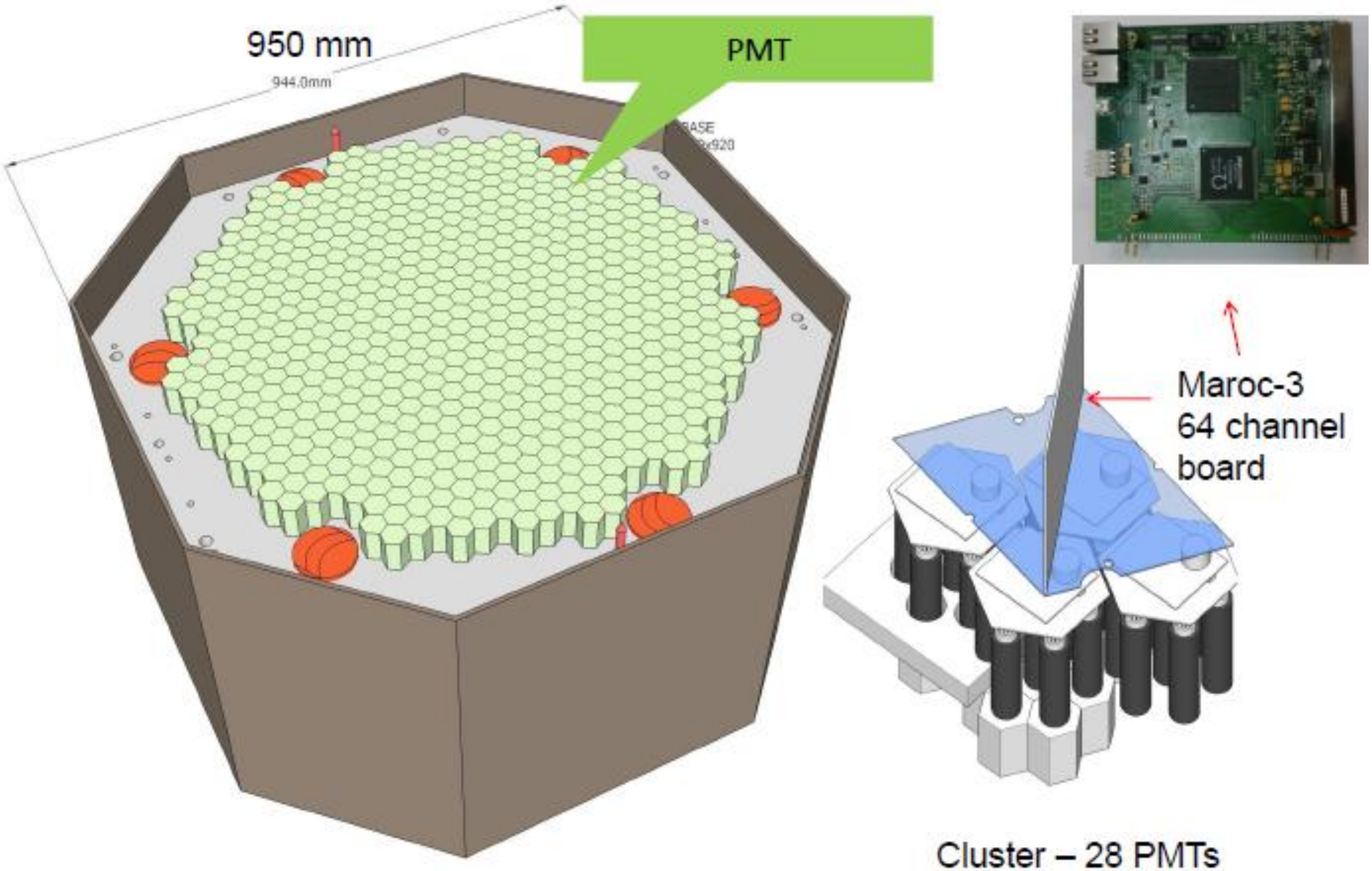
- Davies-Cotton design
- Tessellated reflector, 34 mirrors
- Mirror segment diameter 600 mm, of round shape
- Distance between centers of mirror segments of 620 mm (in projection)
- Focal length: 4752 mm

Imaging camera:

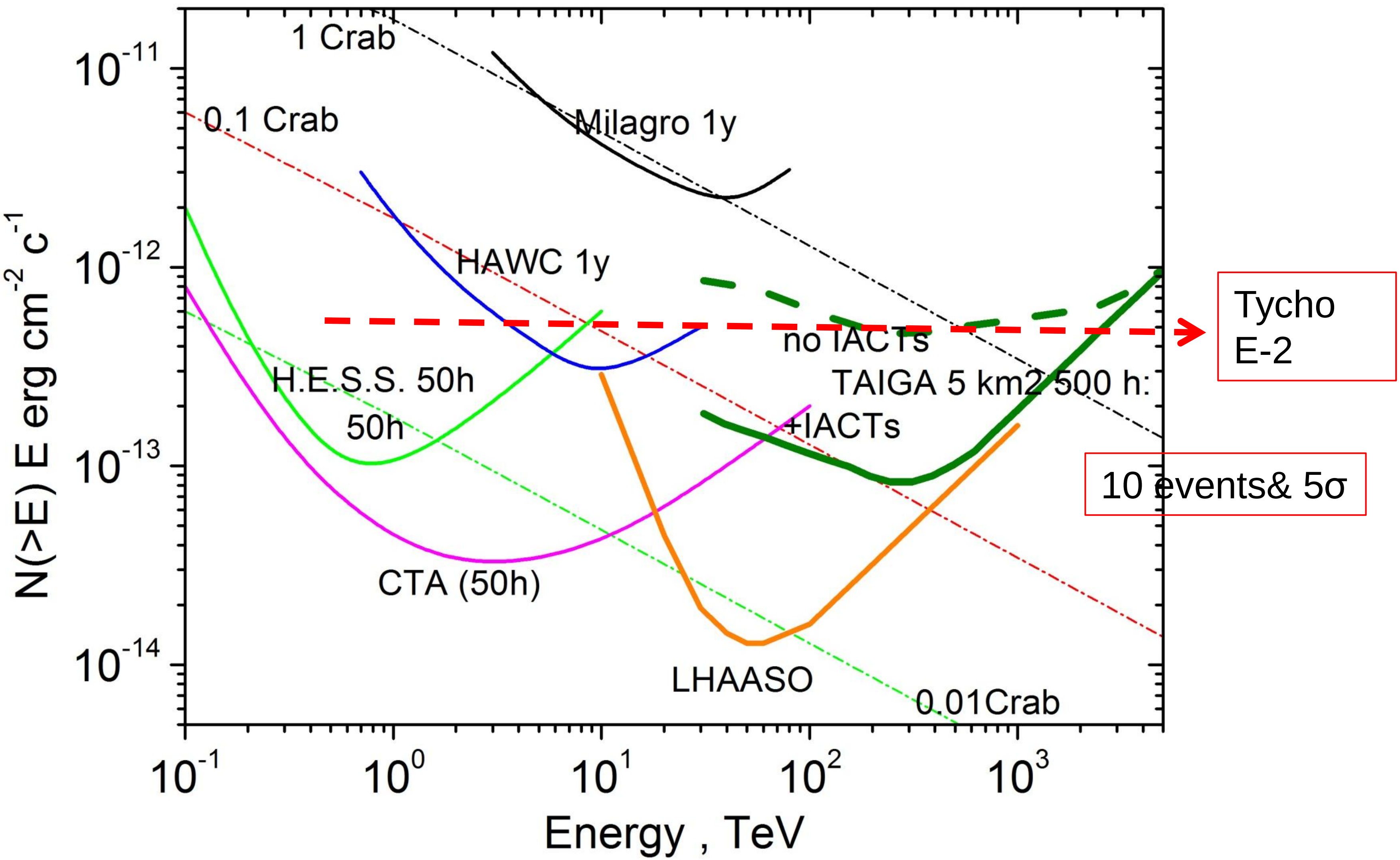
- Winston cone on the each pixel
- hexagonal pixel shape
- pixel center-to-center plate scale of 30 mm/0.36°
- 547 pixel imaging camera, covering an aperture of ~ 9.5°
- PMT type: Philips XP1911, (¾)’

Mechanics of the 1st TAIGA IACT installed on-site on 26.08.16

Imaging camera of the 1st TAIGA IACT



TAIGA sensitivity



Conclusion

Cherenkov experiments have been operating in the Tunka Valley since 1994.

They evolved from small “toy” array into a complex >3 km^2 experiment.

The TAIGA projected started with ambitious goals.

Thank you!