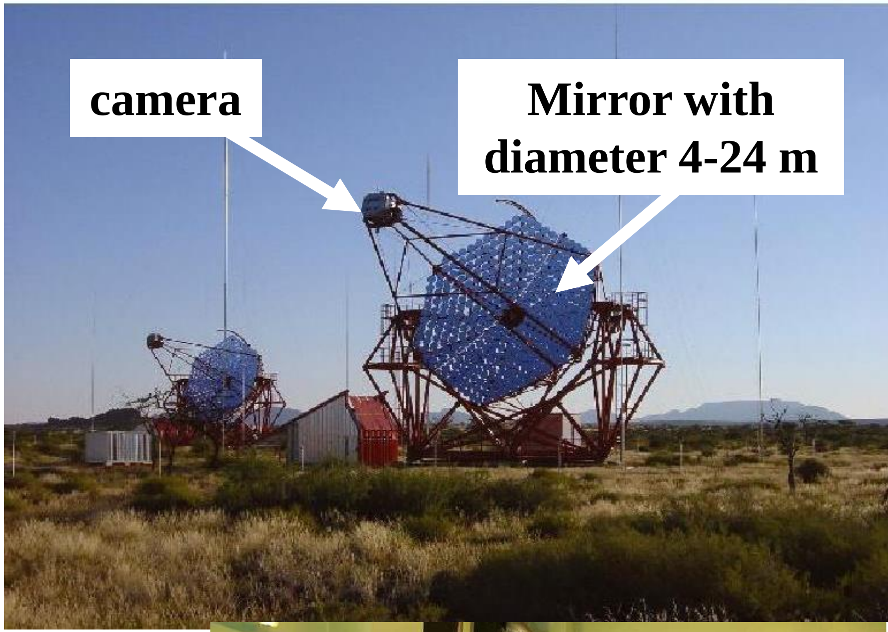
Статус эксперимента TAIGA

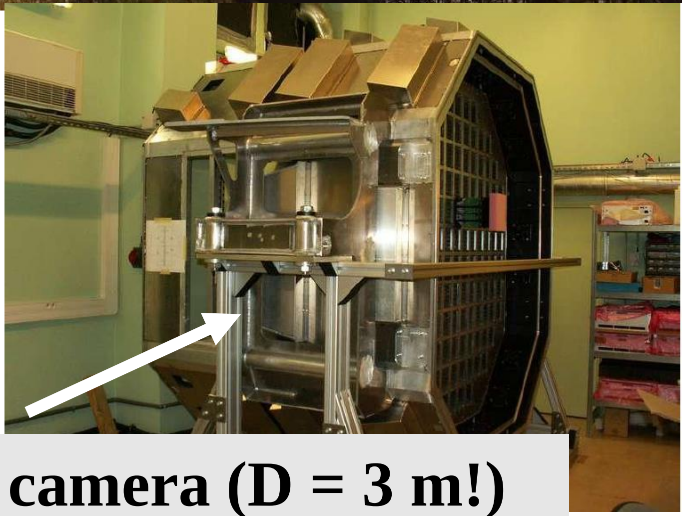
N.Budnev, Irkutsk State University

For TAIGA collaboration

At present an Imaging Atmospheric Cherenkov Telescopes (IACT) are the main instruments for the ground based high energy gamma astronomy

An Imaging Atmospheric Cherenkov Telescope (IACT) - narrow-angle telescope (3-5 FOV) with a mirror of 4 -28 m diameter which reflects EAS Cherenkov light into a camera with up to 1000 PMT where Cherenkov EAS image is formed.

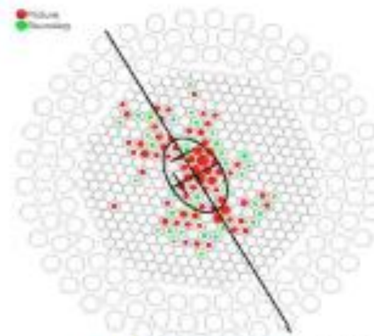




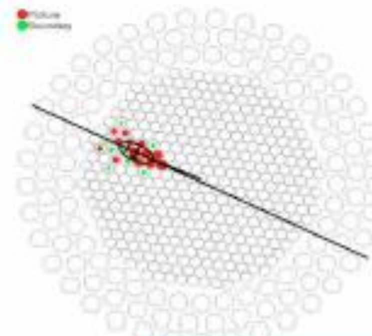
H.E.S.S. camera (D = 3 m!)

Types of images seen by atmospheric Cherenkov camera

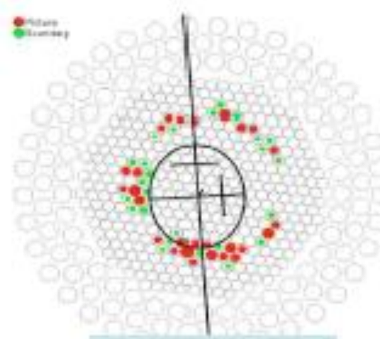
Whipple 10 m Reflector and Camera, 1984
Prototype Imaging System



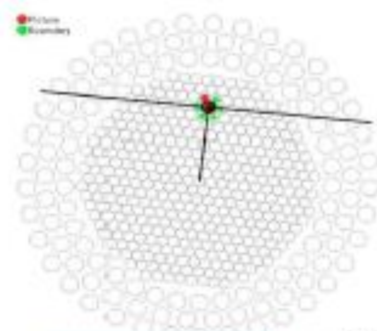
Hadron



Gamma ray



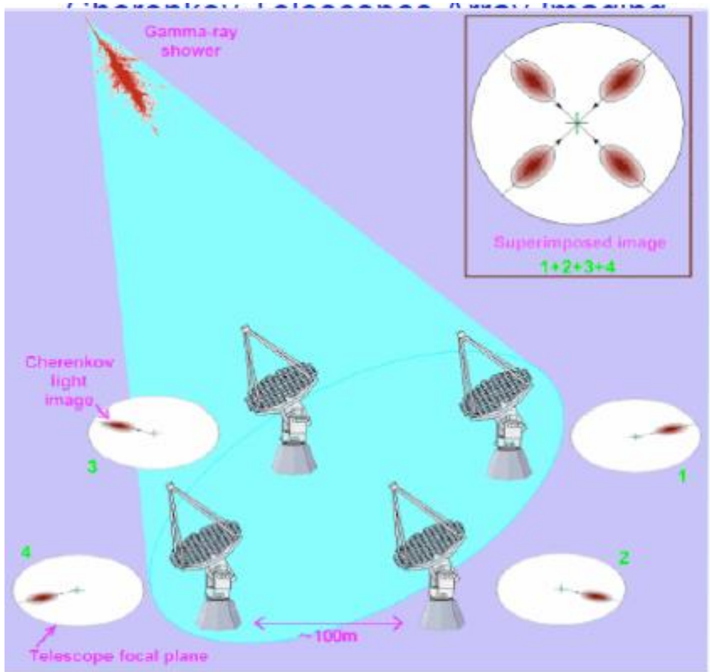
Muon Ring

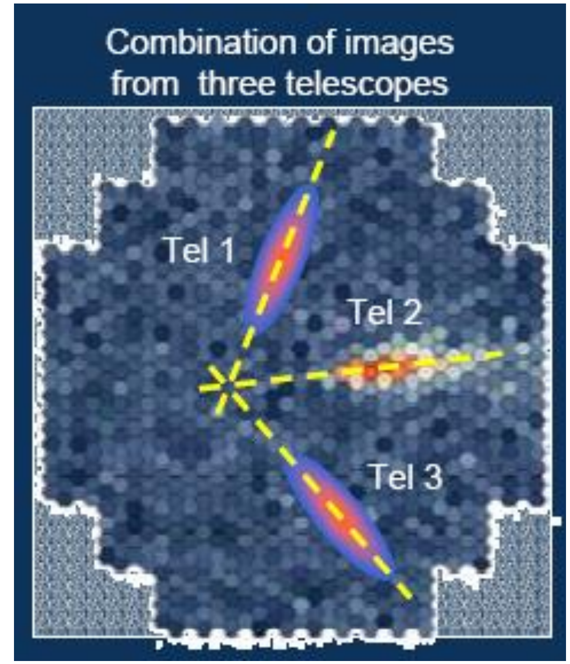


Sky Noise

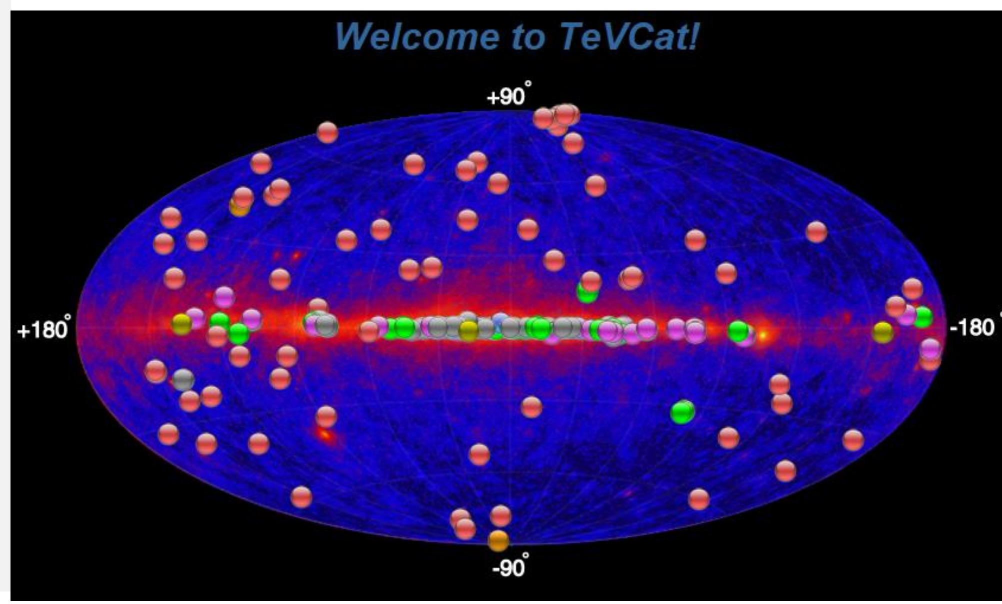
Imaging Atmospheric Cherenkov Arrays (2-5 IACT)

Whipple
HEGRA
H.E.S.S.
MAGIC
VERITAS
S ~ 0.1 km^2

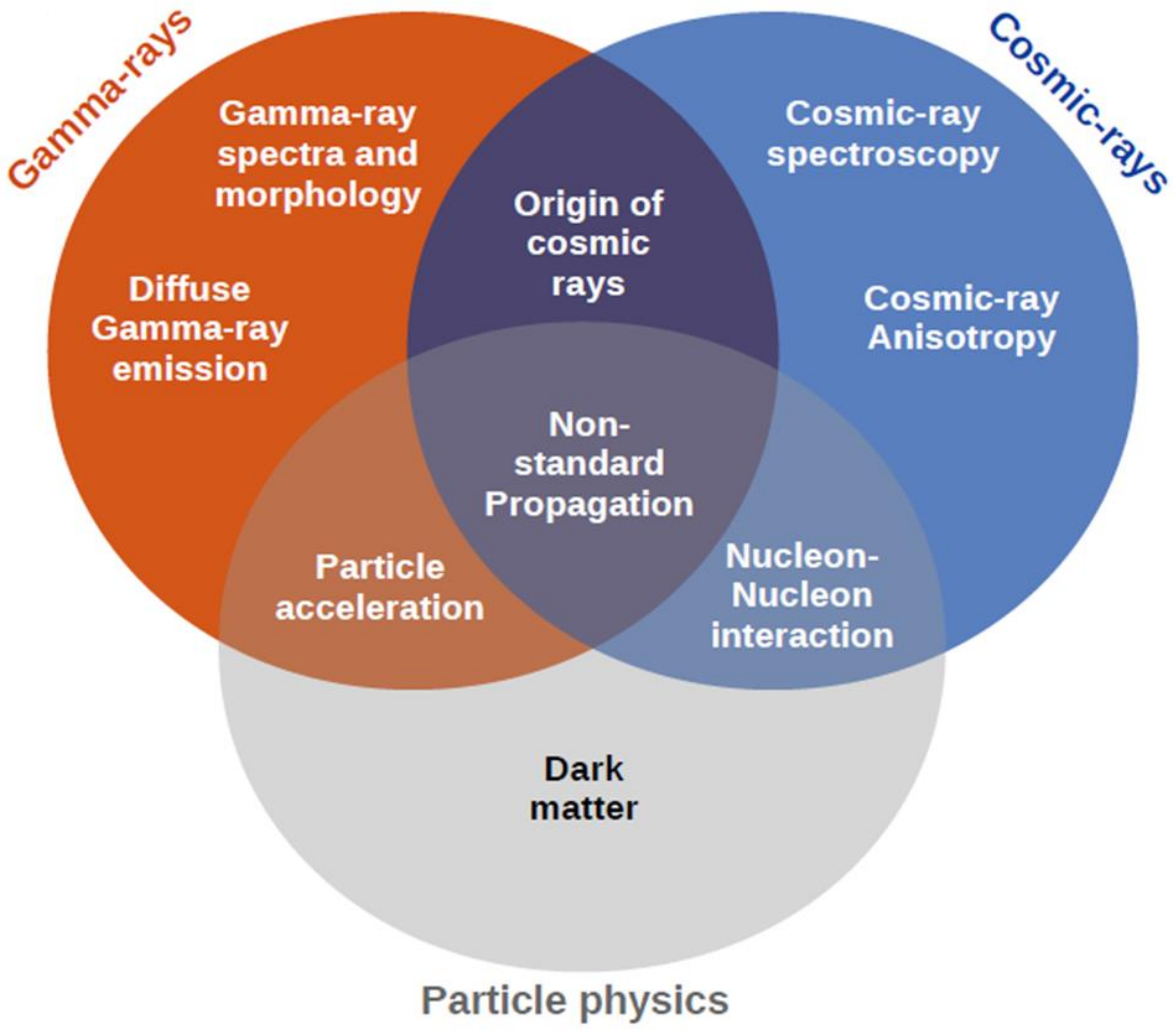




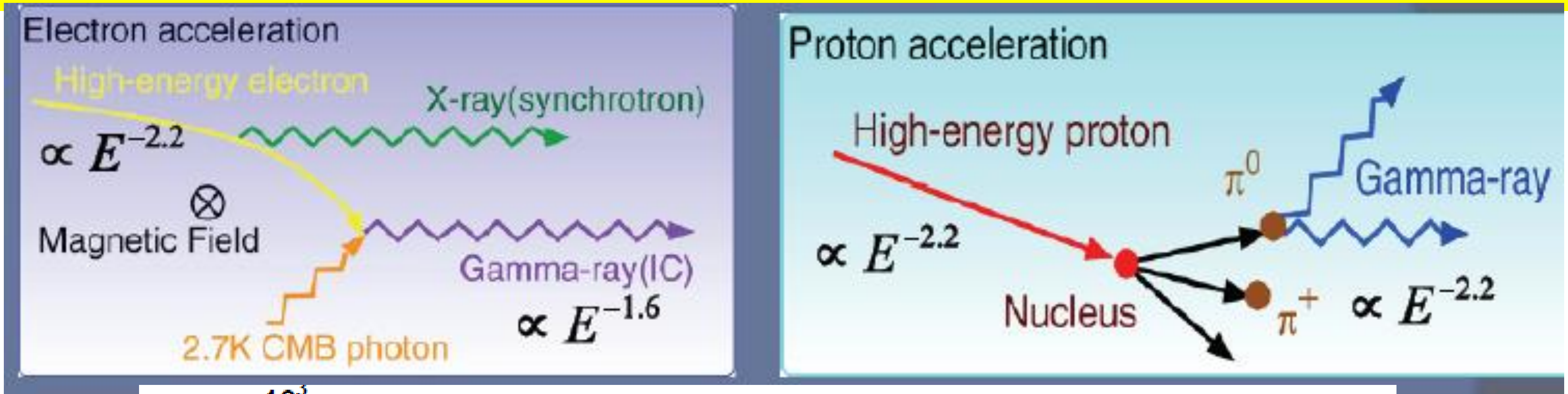
About 200 sources of gamma rays with energy more than 1 TeV were discovered with IACT arrays.
But a few gamma quantum with energy more then 50 TeV were detected up to now.
An area of an array should be a few square kilometers as minimum to detect high energy gamma rays.

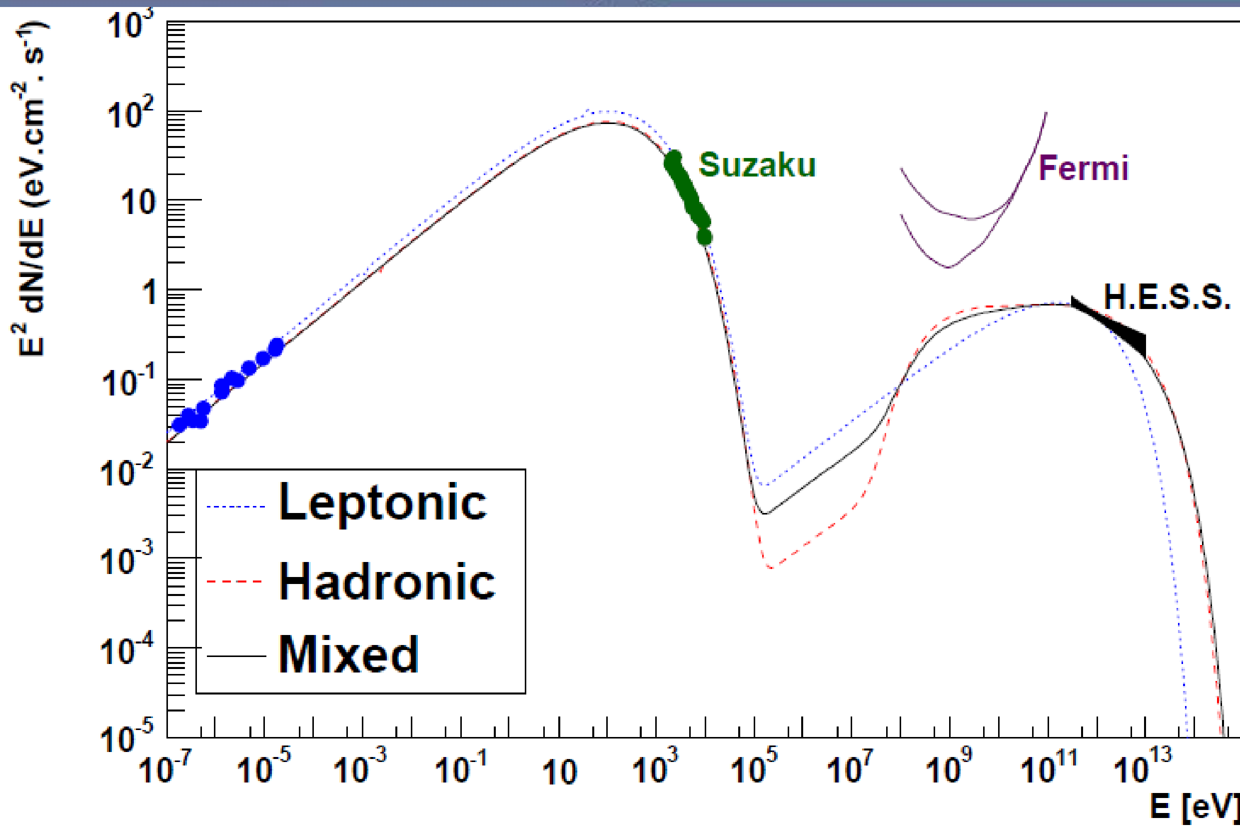


Astroparticle physics topics

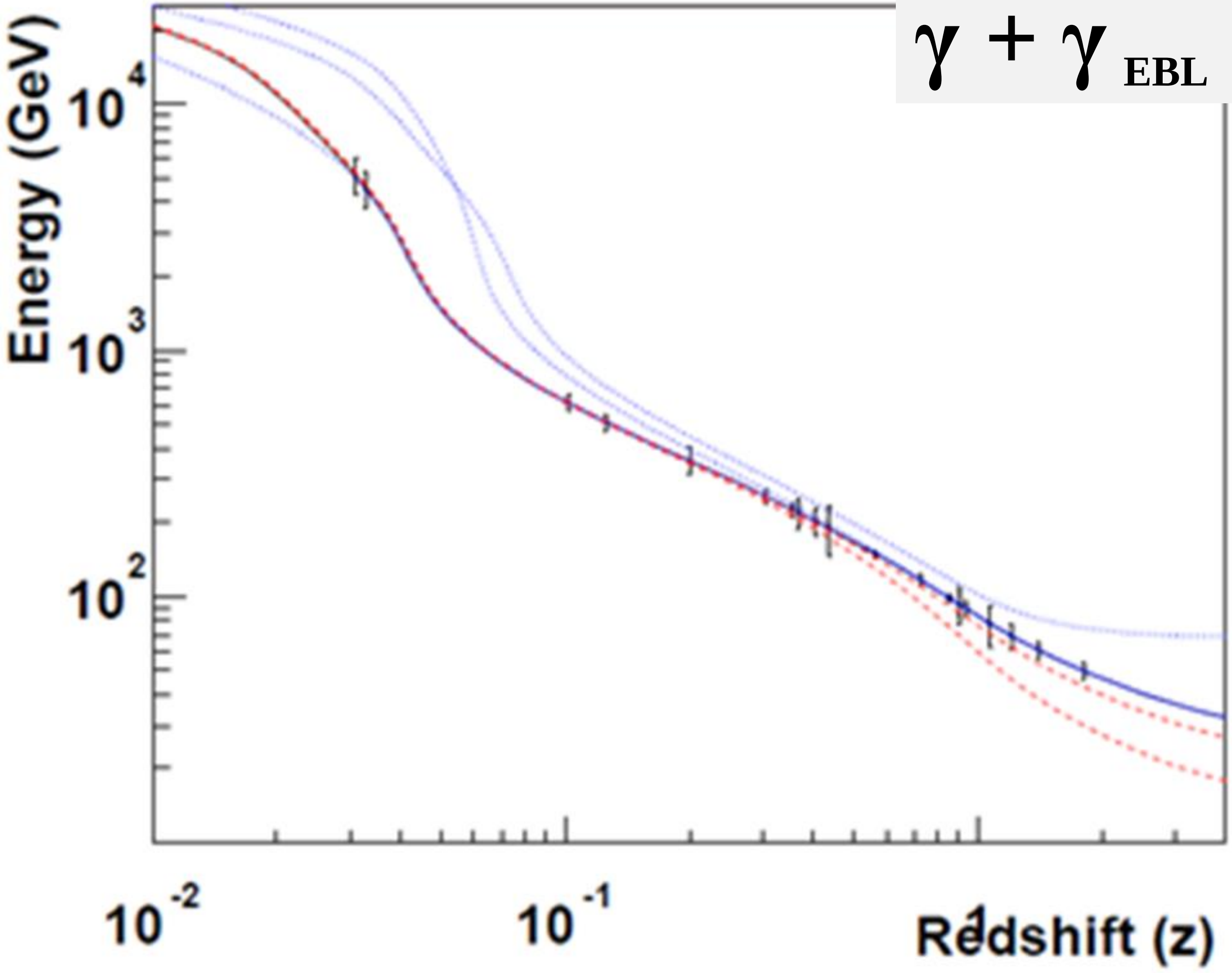


Каков основной механизм генерации гамма-квантов высоких энергий?





Какова прозрачность Вселенной?

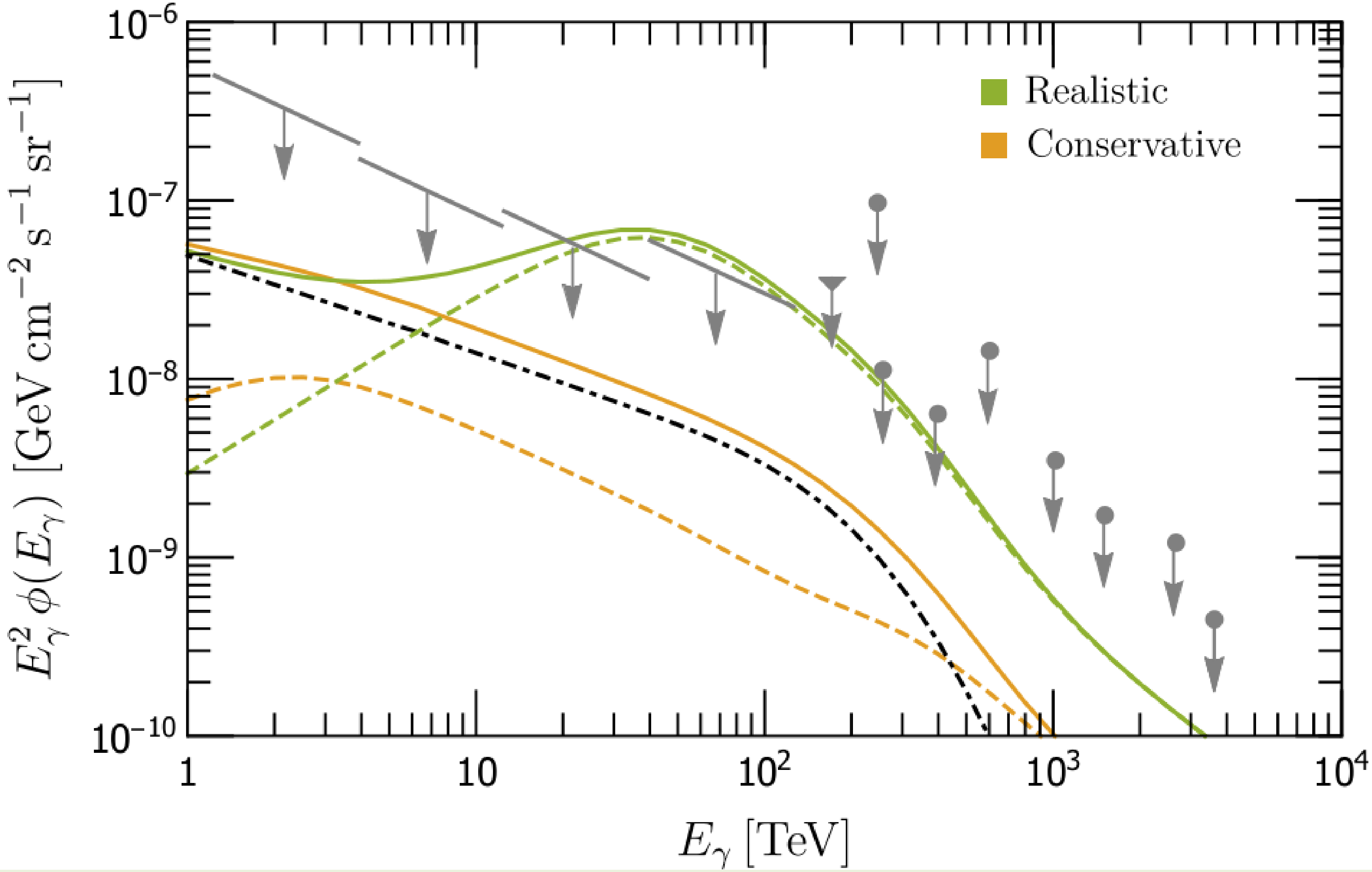


$\gamma + \gamma_{EBL} \rightarrow e^+ + e^-$

Исследование формы спектра гамма-квантов позволит определить спектр Extragalactic Bacground Light (EBL).

Гамма–горизонт (O.Blanch and M.Martinez arXiv:astro-ph/0406061v1) в зависимости от красного смещения для нескольких моделей EBL.

Поток диффузных фотонов с учетом возможного вклада переходов γ → ALPs → γ



Сплошные зеленая и рыжая линии – поток диффузных фотонов с учетом возможного вклада перехода в аксионоподобные частицы ALPs (штрихованные линии) в разных моделях. Вклад фона фотонов от P –P взаимодействий в нашей Галактике – штрих-пунктирная черная линия.

Physics impact: Lorentz violation test

- High energy photons are produced as a secondaries by highest energy cosmic rays on CMB background
- Photons with energies 10^{18} – 10^{19} eV are subject of intensive searches

$$p + \gamma_{2.7K} \rightarrow \Delta(1232) \rightarrow n + \pi^+$$

$$\pi^+ \nearrow \mu^+ + \nu_\mu$$

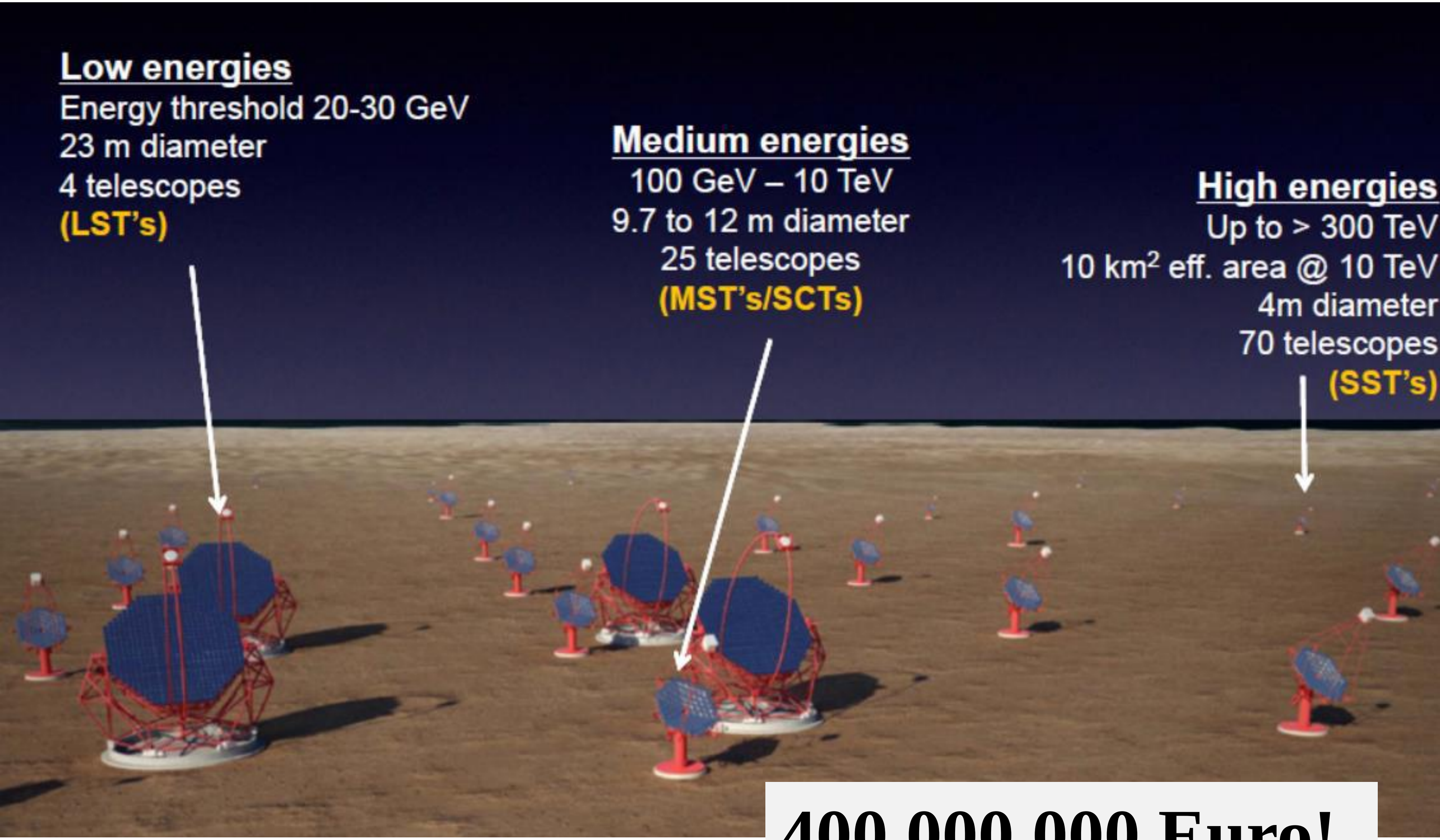
$$\mu^+ \searrow e^+ + \bar{\nu}_\mu + \nu_e$$

$$\Delta(1232) \searrow p + \pi^0$$

$$\pi^0 \searrow \gamma + \gamma$$

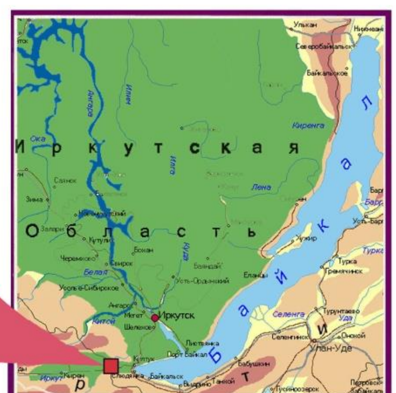
- If Lorentz violation exists, photon is splitting $\gamma \rightarrow 3\gamma$
  - no photons at 10^{18} – 10^{19} eV
  - excess at window 10^{16} – 10^{18} eV

CTA project: 100 IACT about on aria 10 км^2



400 000 000 Euro!

Earth atmospheric shower detection with Cherenkov wide angle arrays in the Tunka - Experiment



51° 48' 35" N
103° 04' 02" E
675 m a.s.l.

EAS Cherenkov light detection technique by wide angle arrays in the Tunka - Experiment

EAS Energy

$$E = A \cdot [N_{ph}(200m)]^{g}$$

$$g = 0.94 \pm 0.01$$

Average CR mass A

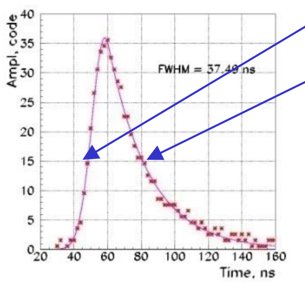
$$LnA \sim X_{max}$$

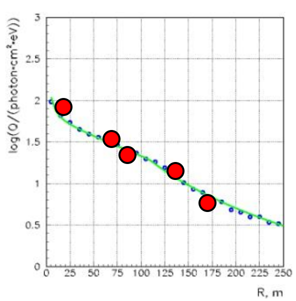
$$X_{max} = C - D \cdot \lg \tau(400)$$

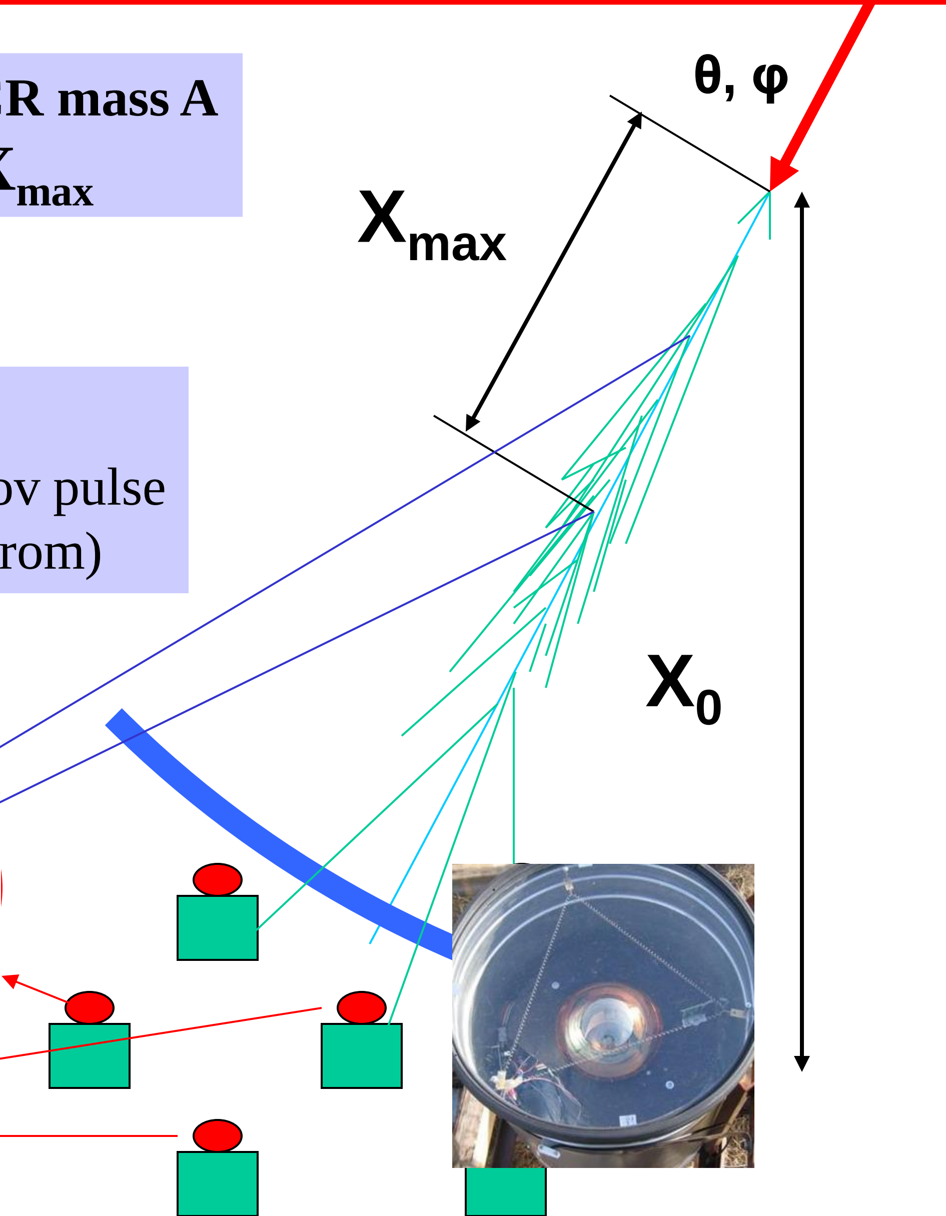
($\tau(400)$ - width of a Cherenkov pulse at distance 400 m EAS core from)

$$X_{max} = F(P)$$

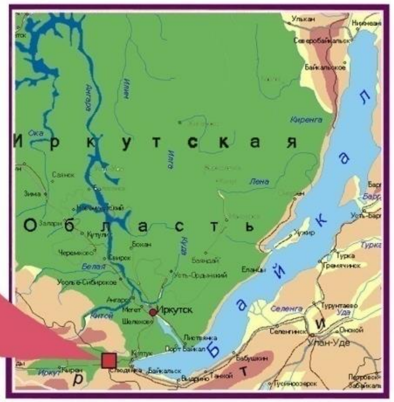
P -Steepness of a Lateral Distribution Function (LDF)





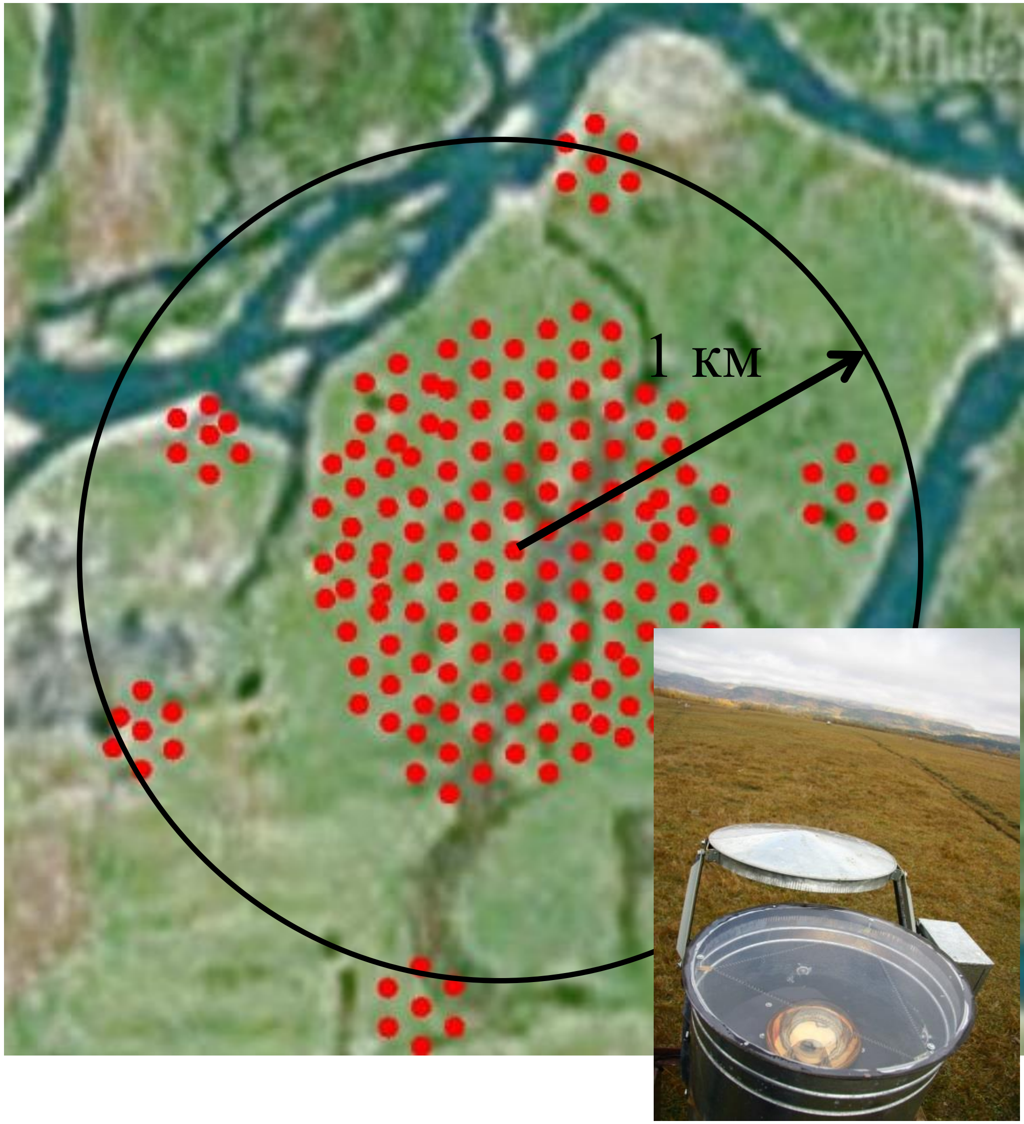


Tunka-133 array: 175 Cherenkov detectors distributed on 3 km^2 area, in operation since 2009y



51° 48' 35" N
103° 04' 02" E
675 m a.s.l.

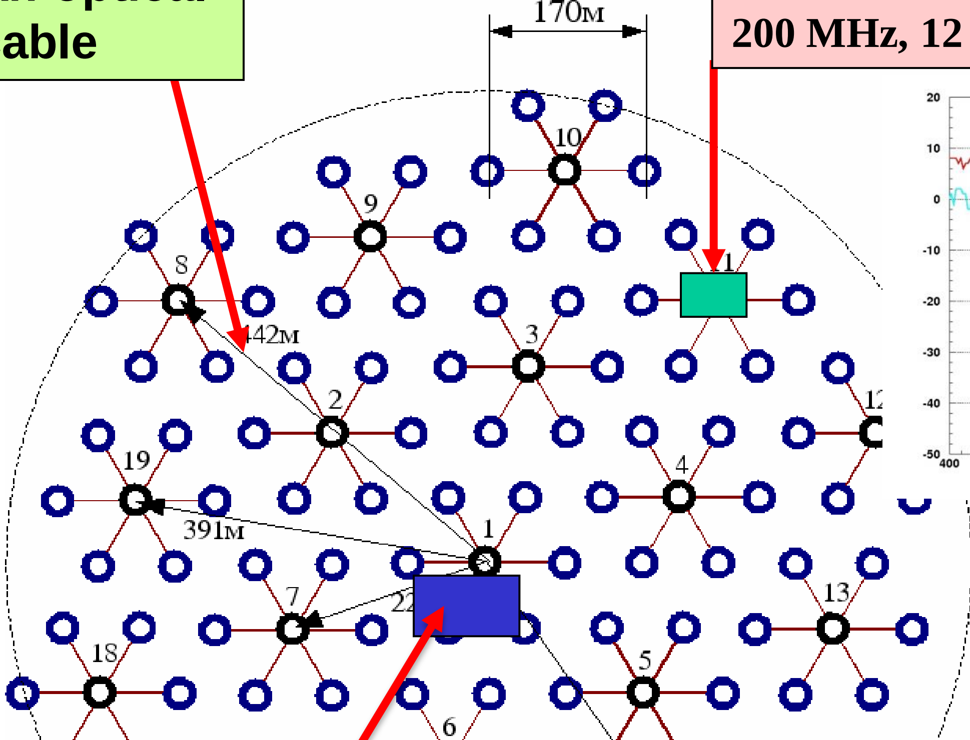
50 km from Lake Baikal

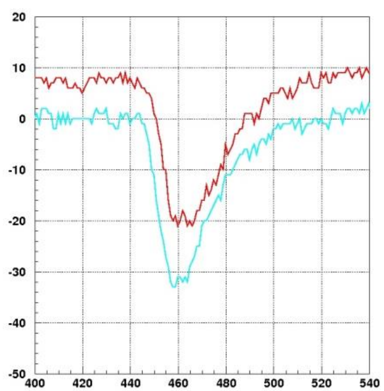


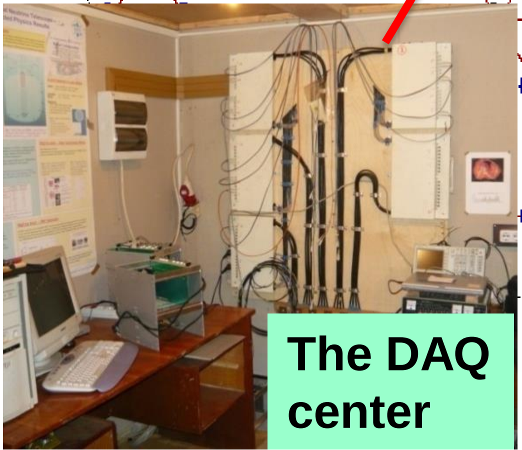
The Tunka-133 array

An optical cable

Cluster Electronic box
4 channel FADC boards
200 MHz, 12 bit





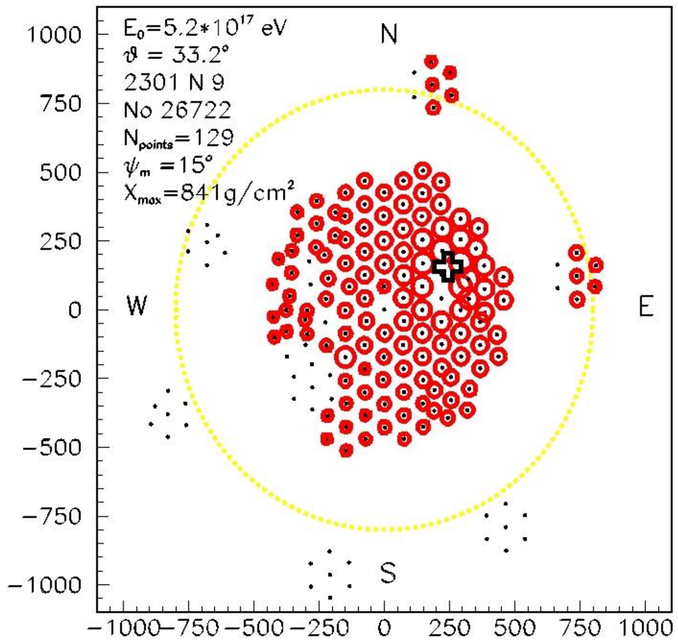


The DAQ center

PMT
EMI 9350
Ø 20 cm

Pietro Fre

An event example



Hitted detectors

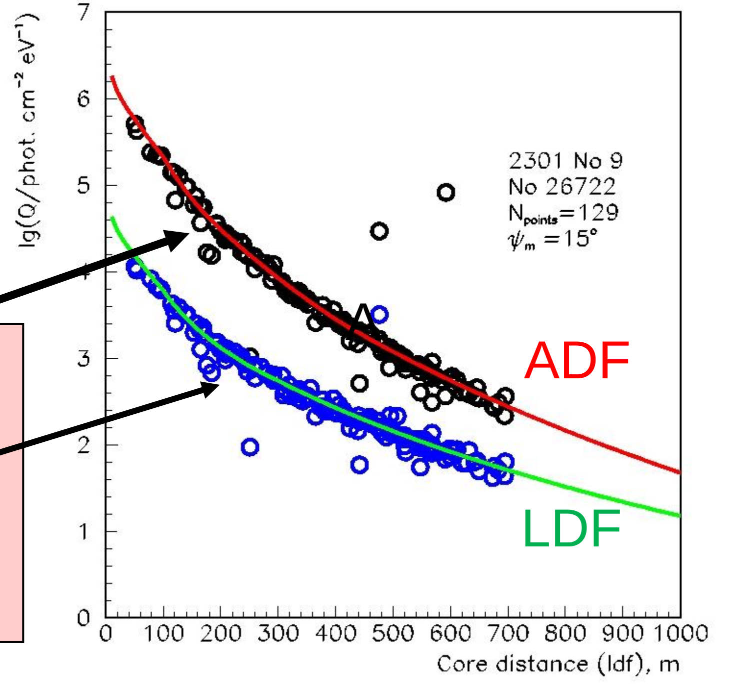
ADF

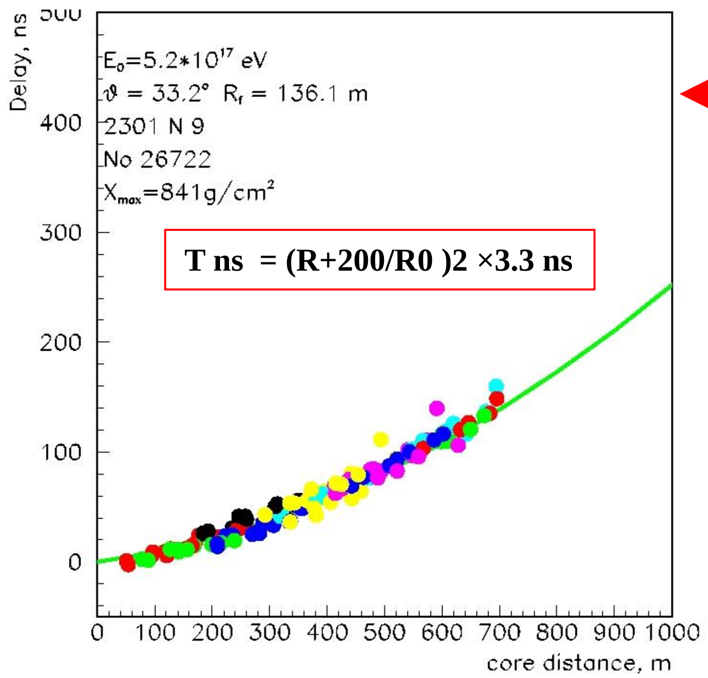
Amplitude distant function

&

LDF

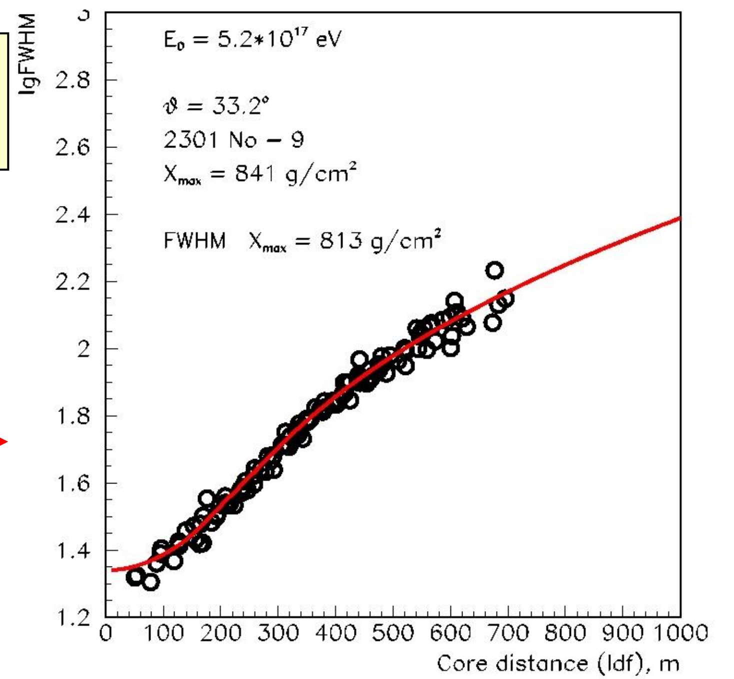
Lateral Distribution function





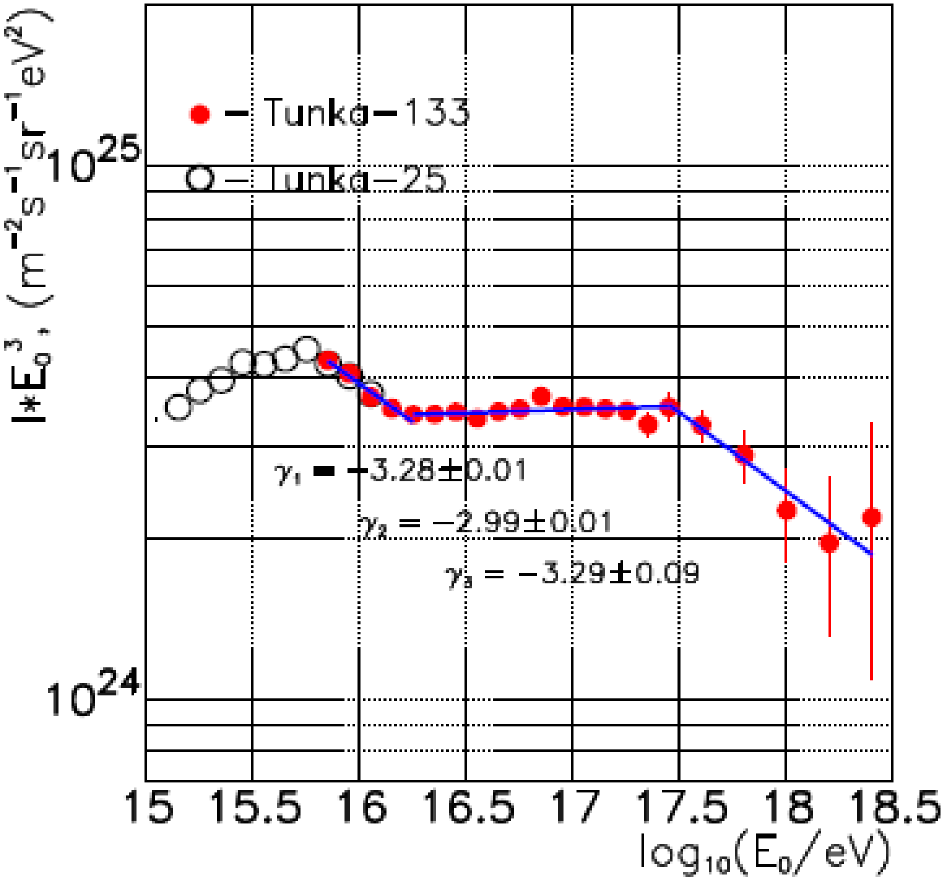
Delay time vs. Distance from core

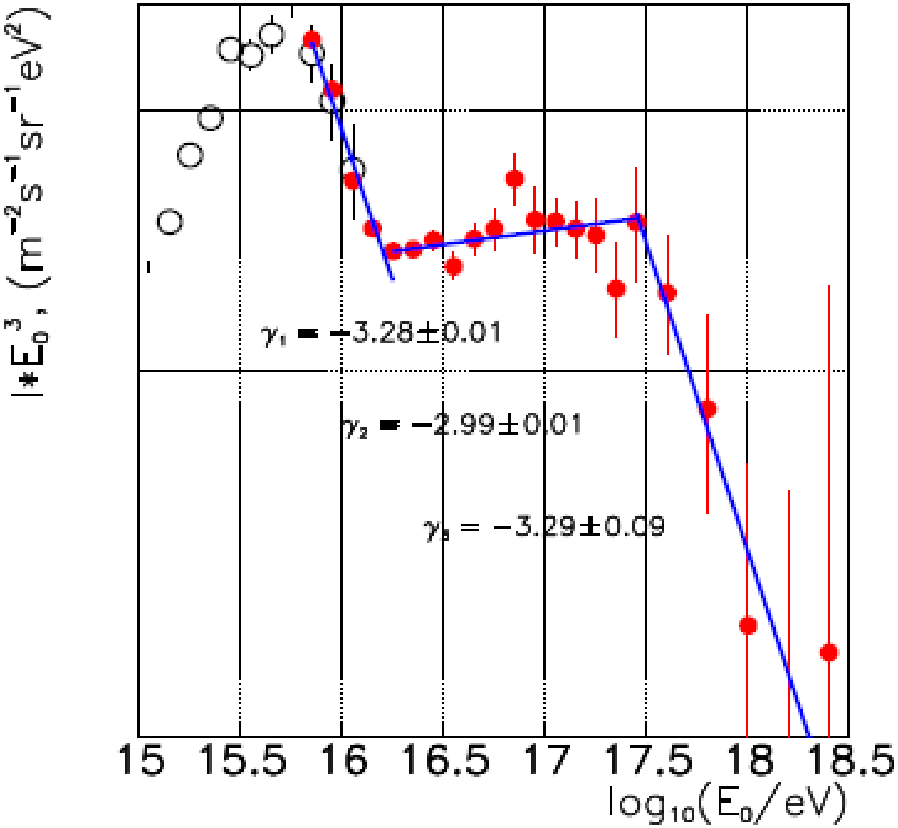
WDF – width distant function



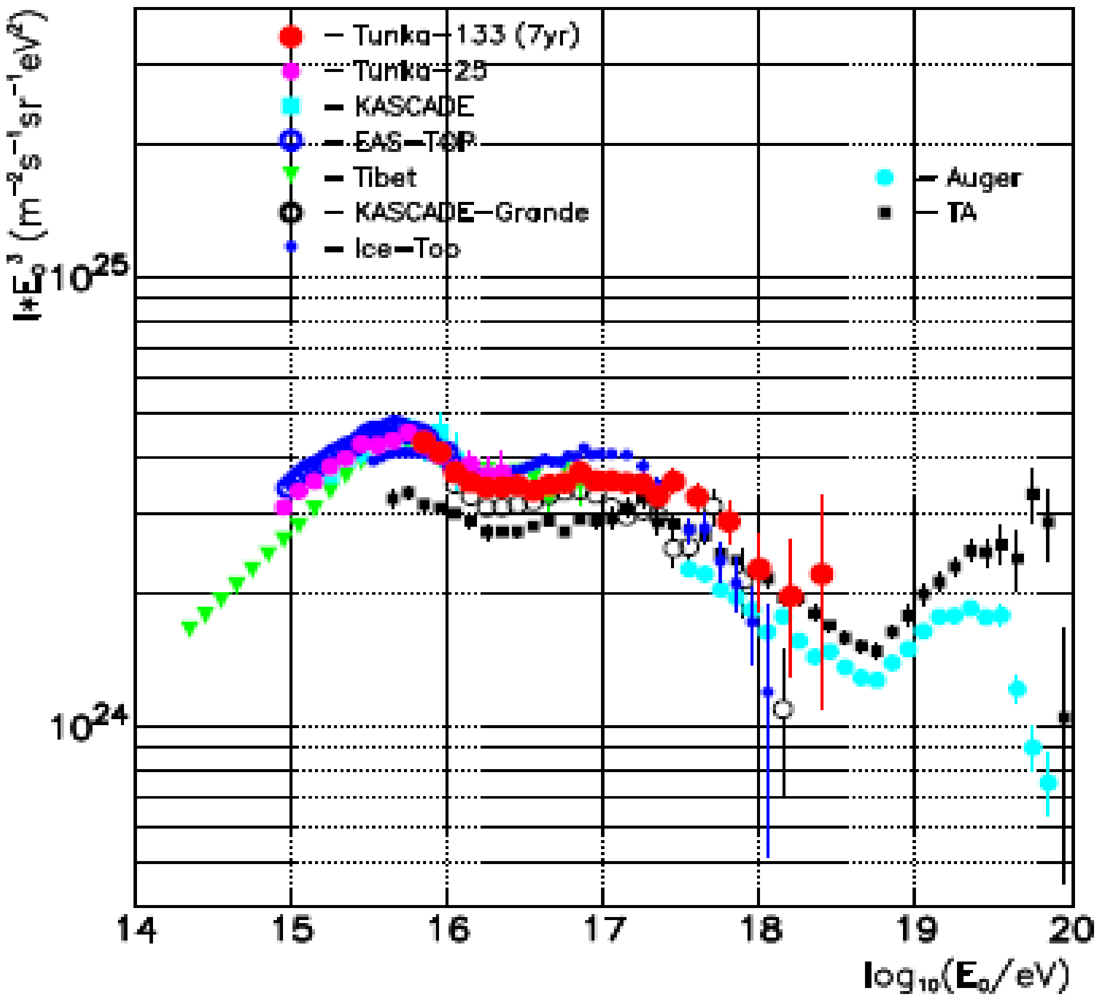
The all particles energy spectrum I(E)·E^3

energy resolution ~ 15%, in principal up to - 10%





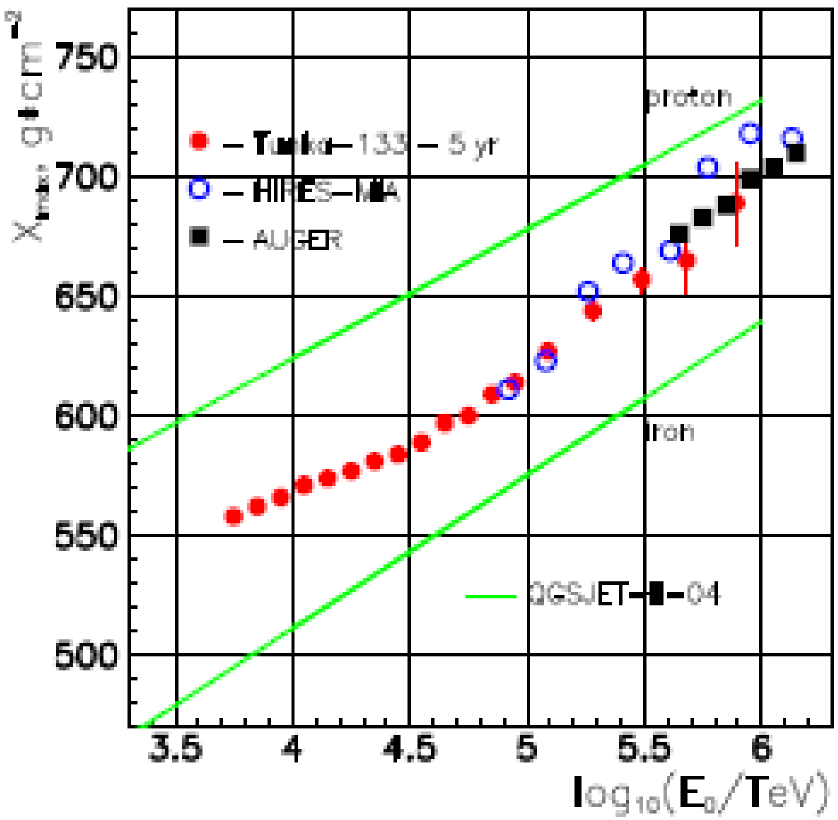
The all particles energy spectrum $I(E) \cdot E^3$

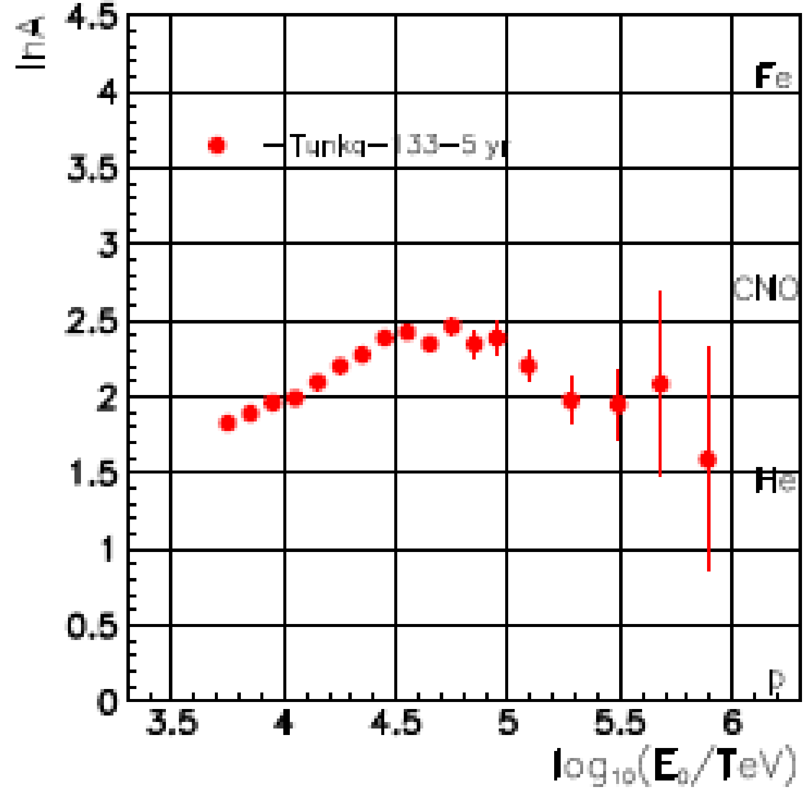


1. Agreement with KASCADE-Grande, Ice-TOP and TALE (TA Cherenkov).
2. The high energy tail do not contradict to the Fly's Eye, HiRes and TA spectra..

Mean Depth of EAS maximum X_{max} g·cm^{-2}

Mean logarithm of primary mass.





The primary CR mass composition changes from light (He) to heavy up to energy ~ 30 PeV

A lightening of the mass composition take place for starting from an energy 100 PeV

Advantage of the Tunka-133 array:

1. Good accuracy positioning of EAS core (5 -10 m)
2. Good energy resolution (~15%)
2. Good accuracy of primary particle mass identification (accuracy of X_{max} measurement ~ 20 -25 g/cm^2).
3. Good angular resolution (~0.5 degree)
4. Low cost: **the Tunka-133 – 3 km^2 array ~ 10^6 Euro**

TAIGA - Collaboration

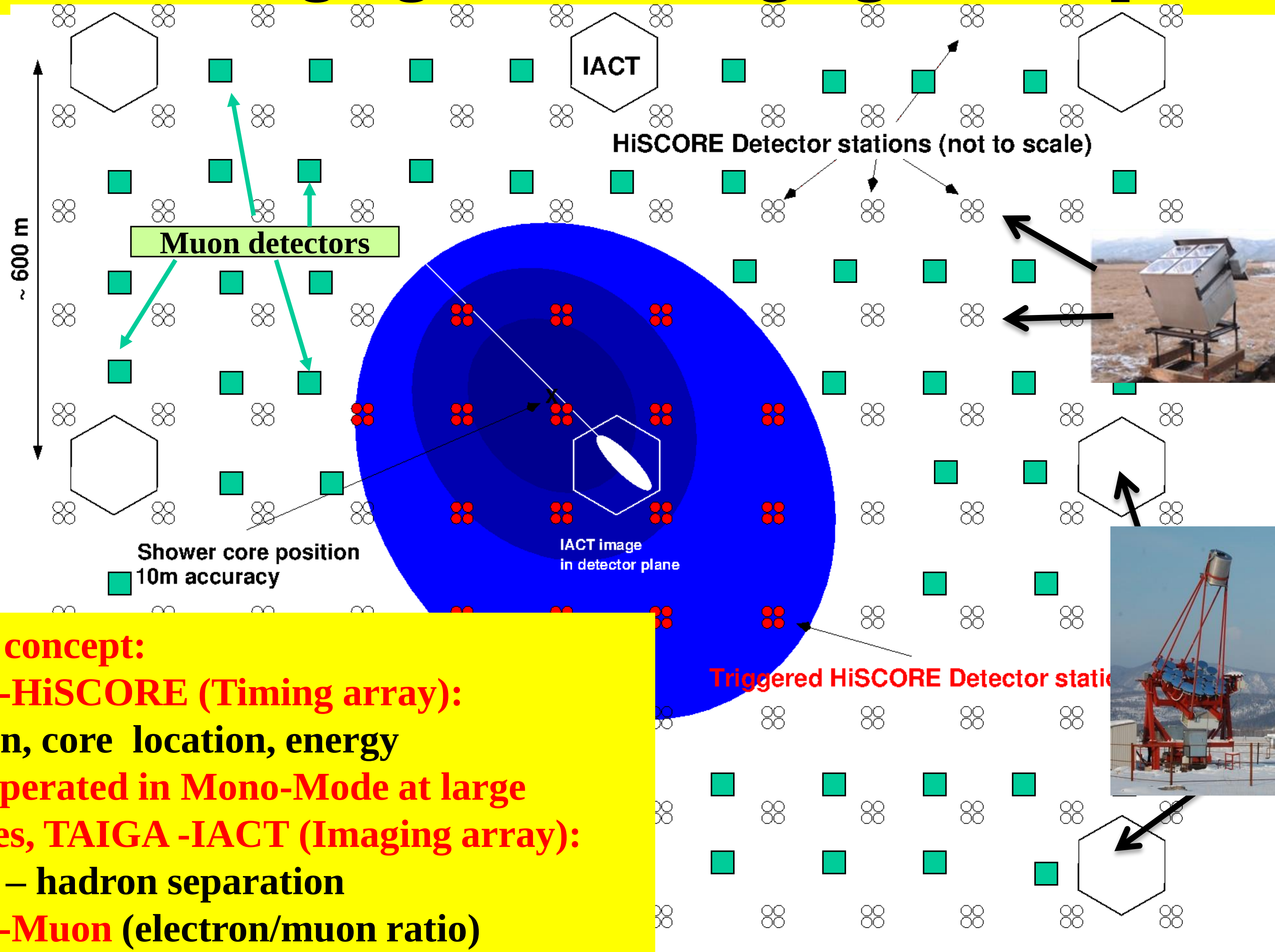
- **Irkutsk State University (ISU), Irkutsk, Russia**
- **Scobeltsyn Institute of Nuclear Physics of Moscow State University (SINP MSU), Moscow, Russia**
- **Institute for Nuclear Research of RAS (INR), Moscow, Russia**
- **Institute of Terrestrial Magnetism, Ionosphere and Radiowave Propagation of RAS (IZMIRAN), Troitsk, Russia**
- **Joint Institute for Nuclear Research (JINR), Dubna, Russia**
- **National Research Nuclear University (MEPhI), Moscow, Russia**
- **Budker Institute of Nuclear Physics SB RAS (BINP), Novosibirsk, Russia**
- **Novosibirsk State University (NSU), Novosibirsk, Russia**
- **Altay State University (ASU), Barnaul, Russia**

- **Deutsches Elektronen Synchrotron (DESY), Zeuthen, Germany**
- **Institut fur Experimentalphysik, University of Hamburg (UH), Germany**
- **Max-Planck-Institut für Physik (MPI), Munich, Germany**
- **Fisica Generale Universita di Torino and INFN, Torino, Italy**
- **ISS , Bucharest, Rumania**

TAIGA - Collaboration

$\approx$ 80 scientists from 15 institutes (EU + Russia)

TAIGA: Imaging + non-imaging techniques



Hybrid concept:

TAIGA-HiSCORE (Timing array):

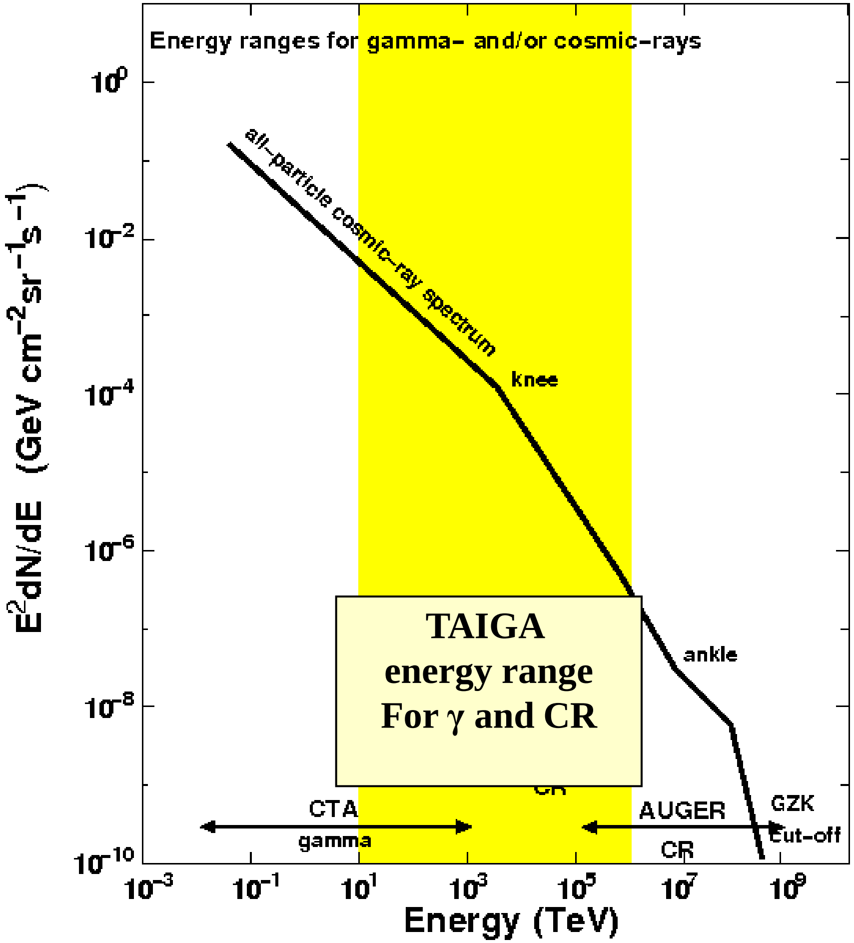
direction, core location, energy

IACT operated in Mono-Mode at large distances, TAIGA -IACT (Imaging array):

gamma – hadron separation

TAIGA-Muon (electron/muon ratio)

Main Topics for the TAIGA observatory



Gamma-ray Astronomy

Search for the PeVatrons.
VHE spectra of known sources: where do they stop?
Absorption in IRF and CMB.
Diffuse emission: Galactic plane, Local supercluster.

Charged cosmic ray physics

Energy spectrum and mass composition anisotropies from 10^{14} to 10^{18} eV.
10^{8} events (in 1 km^2 array) with energy > 10^{14} eV

Particle physics

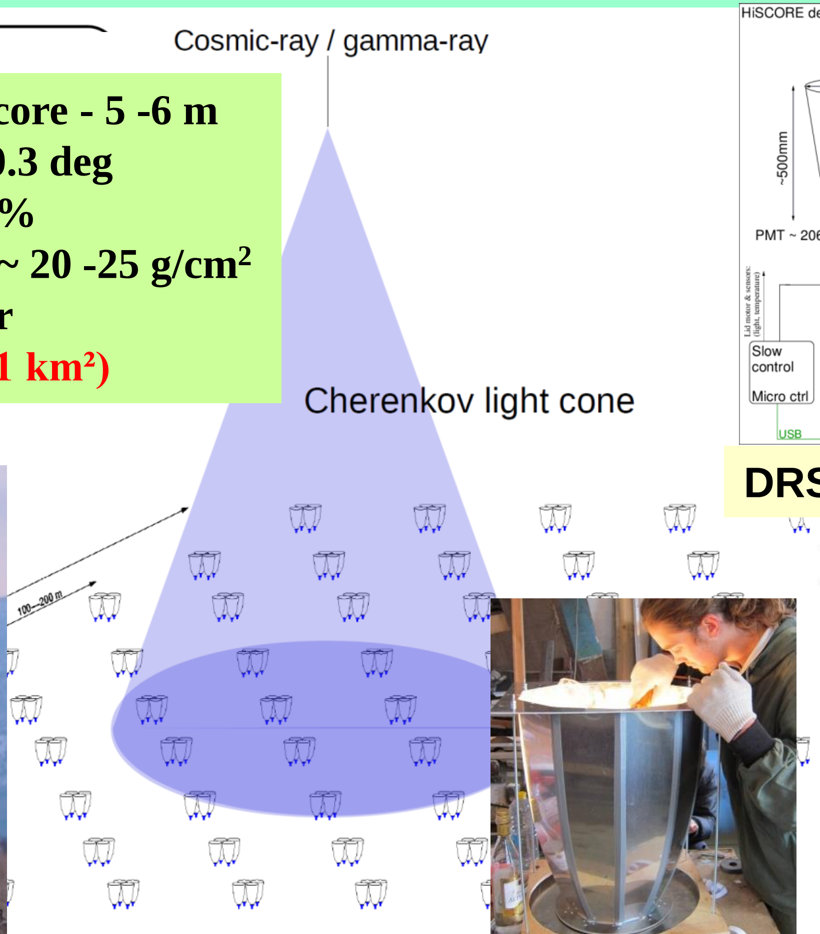
Axion/photon conversion.
Hidden photon/photon oscillations.
Lorentz invariance violation.
pp cross-section measurement.
Quark-gluon plasma.

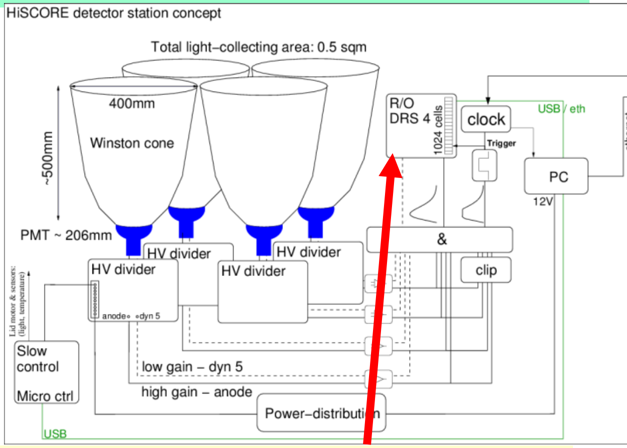
TAIGA-HiSCORE (High Sensitivity Cosmic Origin Explorer)

- **Wide-angle time- amplitude sampling non-imaging air Cherenkov array.**
- **Spacing between Cherenkov stations 80-120 m ~ 80 -150 channels / km^2.**

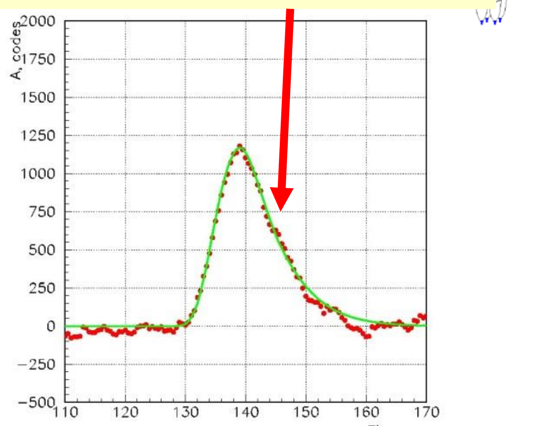
1. Accuracy positioning EAS core - 5 -6 m
2. Angular resolution ~ 0.1 – 0.3 deg
3. Energy resolution ~ 10 - 15%
4. Accuracy of X_{max} measure ~ 20 -25 g/cm^2
5. Large Field of view: ~ 0.6 sr

Total cost ~ 2 ·millions $ (for 1 km²)

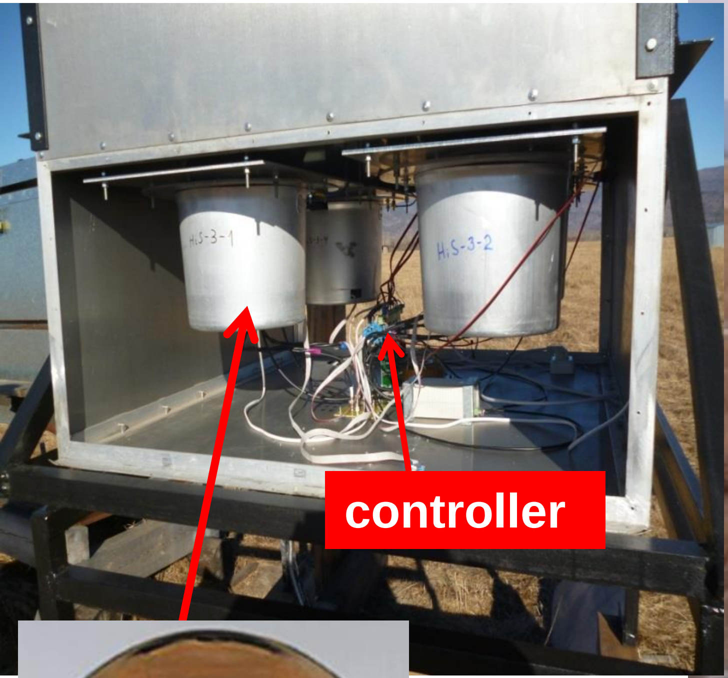




DRS-4 board (0.5 ns step)

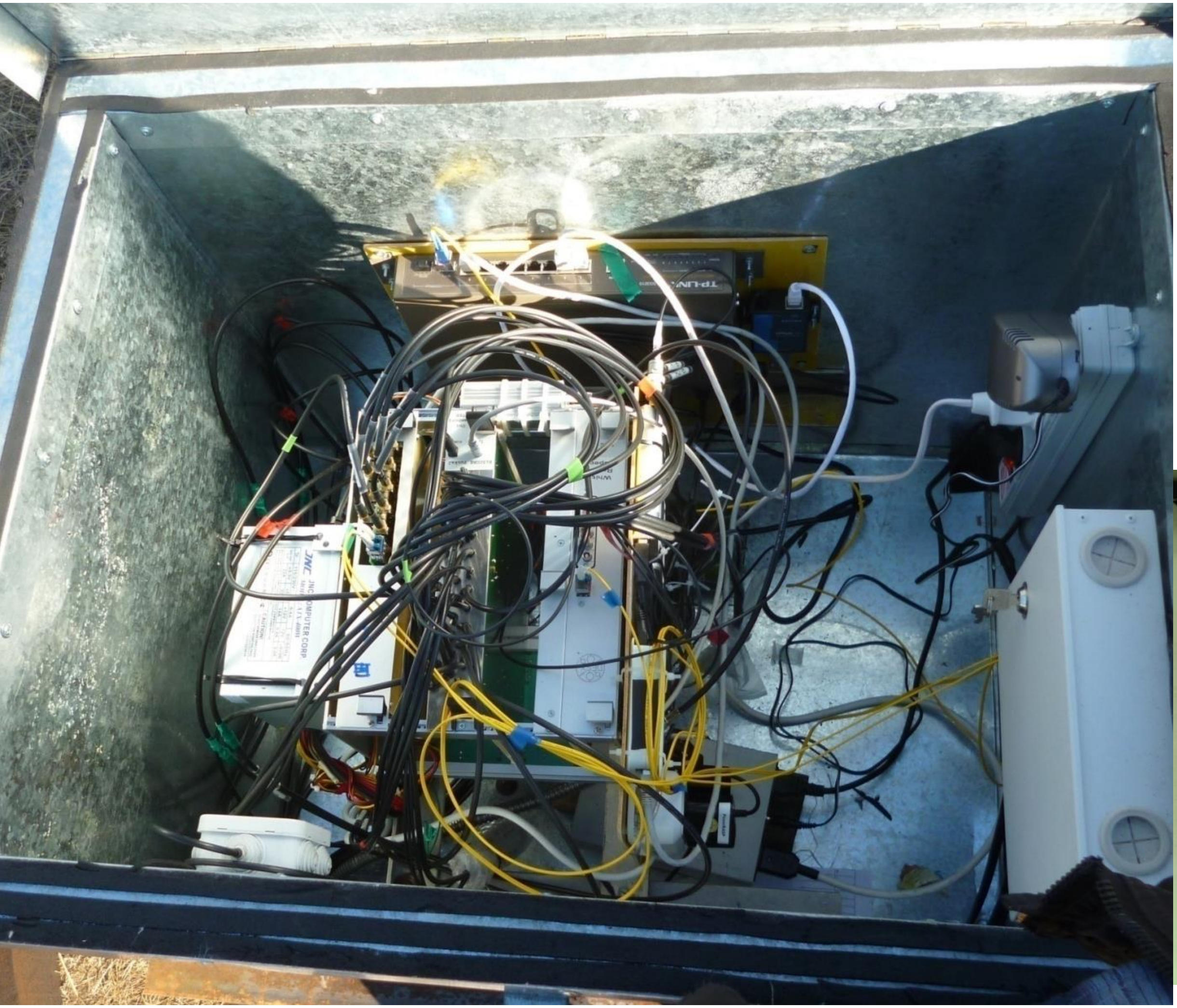


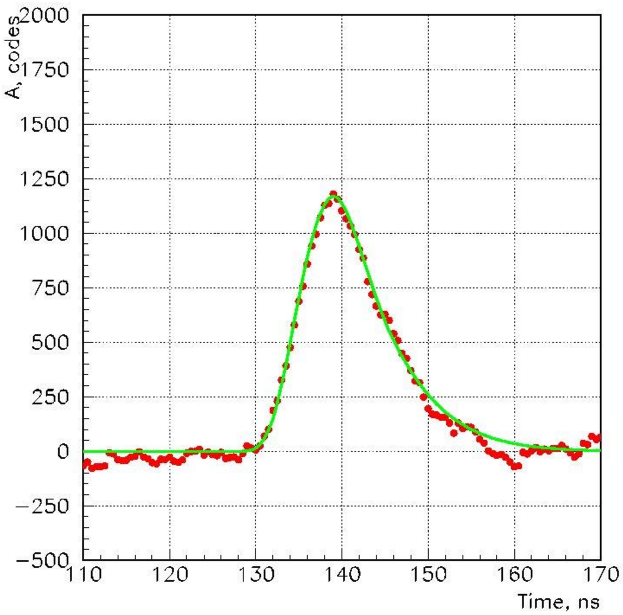
Оптическая станция установки TAIGA – HiSCORE



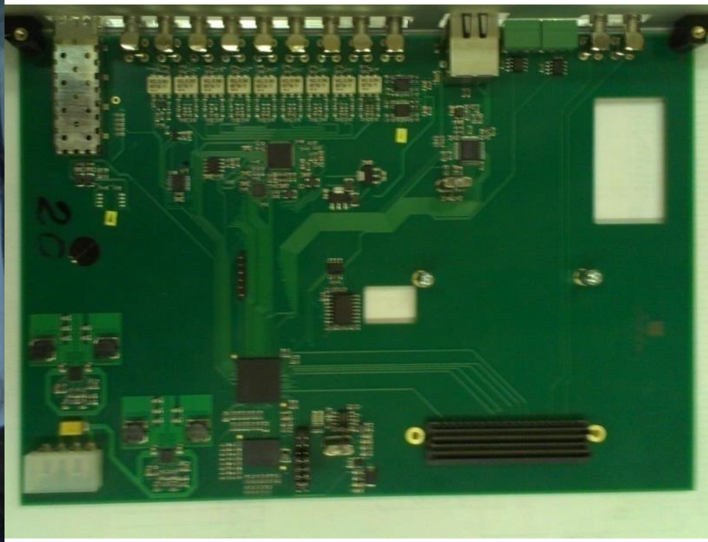
PMT HAMANTSU R5912

The TAIGA_HiSCORE Station electronic box

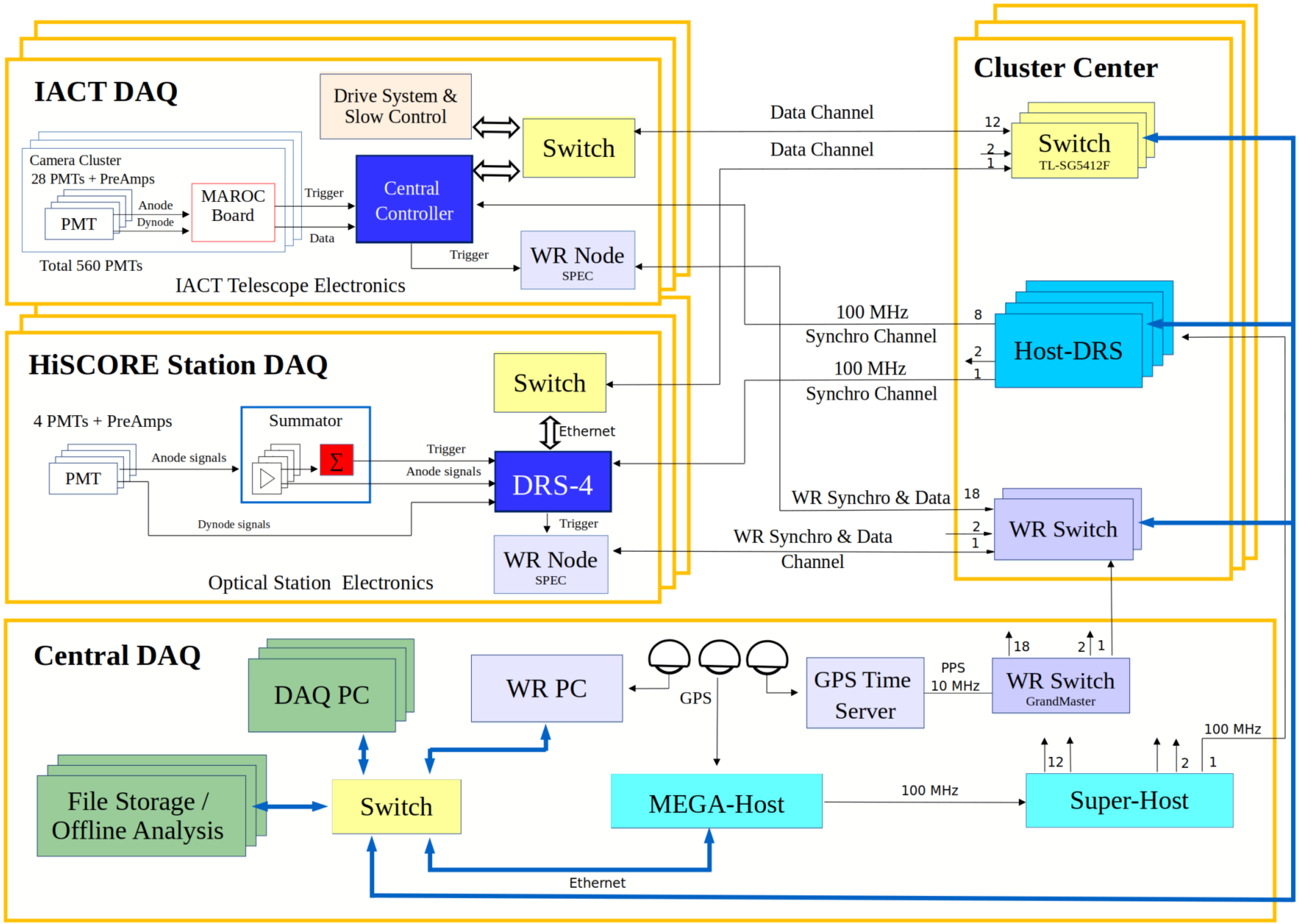




9 channel
DRS-4 board (0.5 ns step)

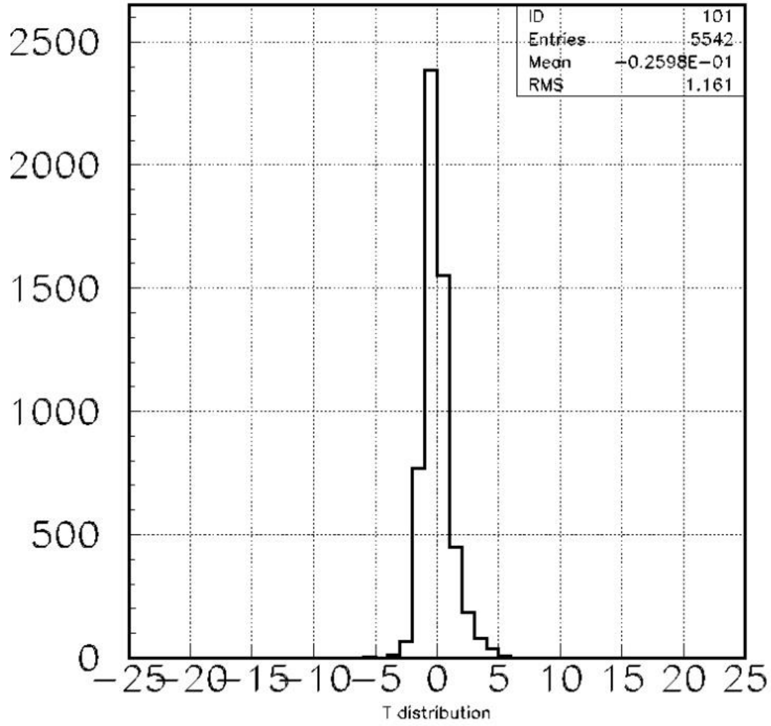


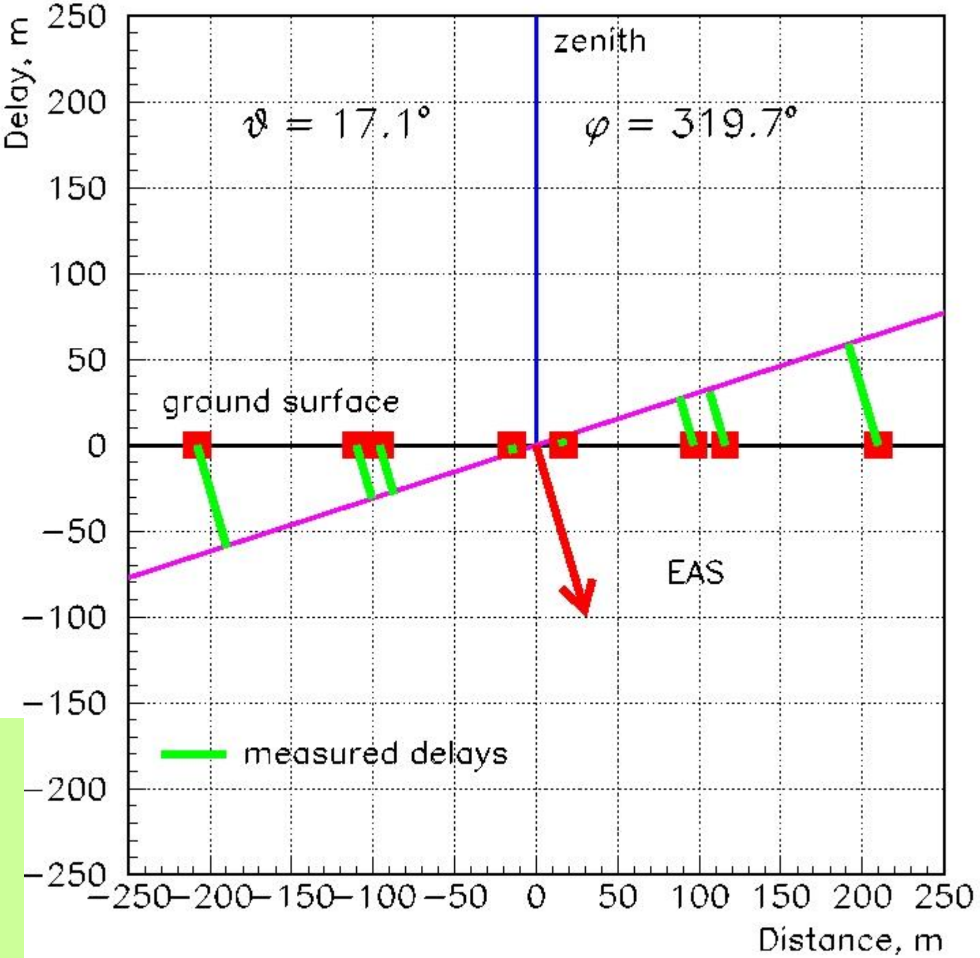
TAIGA DAQ



IACT DAQ
Drive System & Slow Control
Switch
Camera Cluster
28 PMTs + PreAmps
PMT
Anode
Dynode
MAROC Board
Trigger
Data
Central Controller
Trigger
WR Node
SPEC
Total 560 PMTs
IACT Telescope Electronics
HiSCORE Station DAQ
Switch
4 PMTs + PreAmps
Summator
Σ
PMT
Anode signals
Trigger
Anode signals
Ethernet
DRS-4
Dynode signals
Trigger
WR Node
SPEC
Optical Station Electronics
Cluster Center
Data Channel
Data Channel
12
2
1
Switch
TL-SG5412F
100 MHz
Synchro Channel
8
Host-DRS
2
1
100 MHz
Synchro Channel
WR Synchro & Data
18
WR Switch
2
1
WR Synchro & Data
Channel
Central DAQ
DAQ PC
WR PC
GPS
GPS Time Server
PPS
10 MHz
WR Switch
GrandMaster
18
2
1
File Storage / Offline Analysis
Switch
MEGA-Host
100 MHz
12
2
1
100 MHz
Super-Host
Ethernet

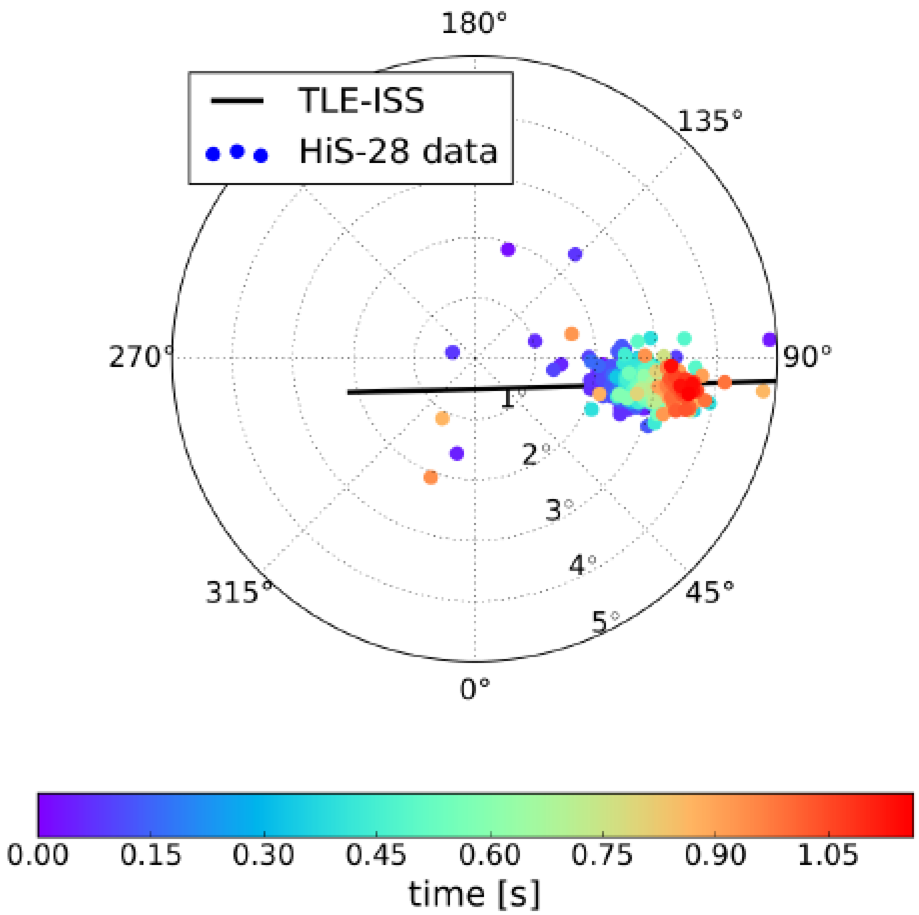
An accuracy of EAS axis direction reconstruction with TAIGA-HiSCORE

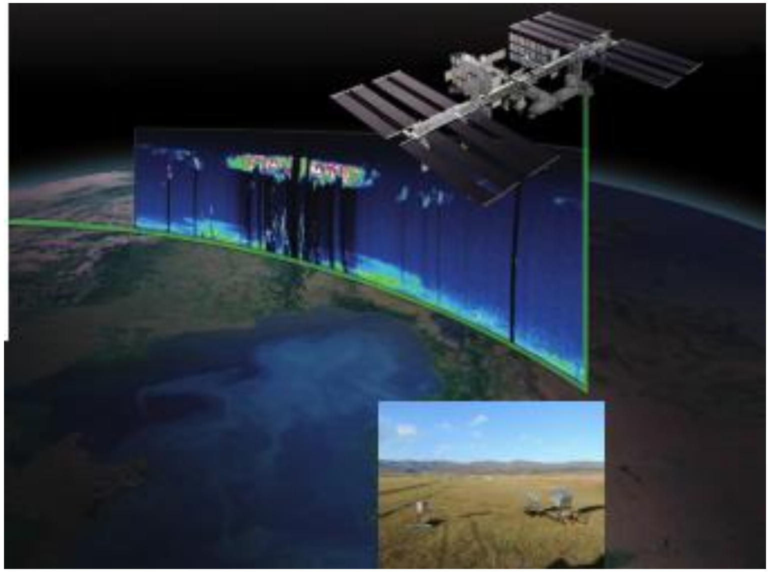




The RMS=1.1 ns for TAIGA-HiSCORE provides an accuracy of an γ and CR arrival direction about 0.1 degree

First TAIGA-HiSCORE results (0.25 км^2)



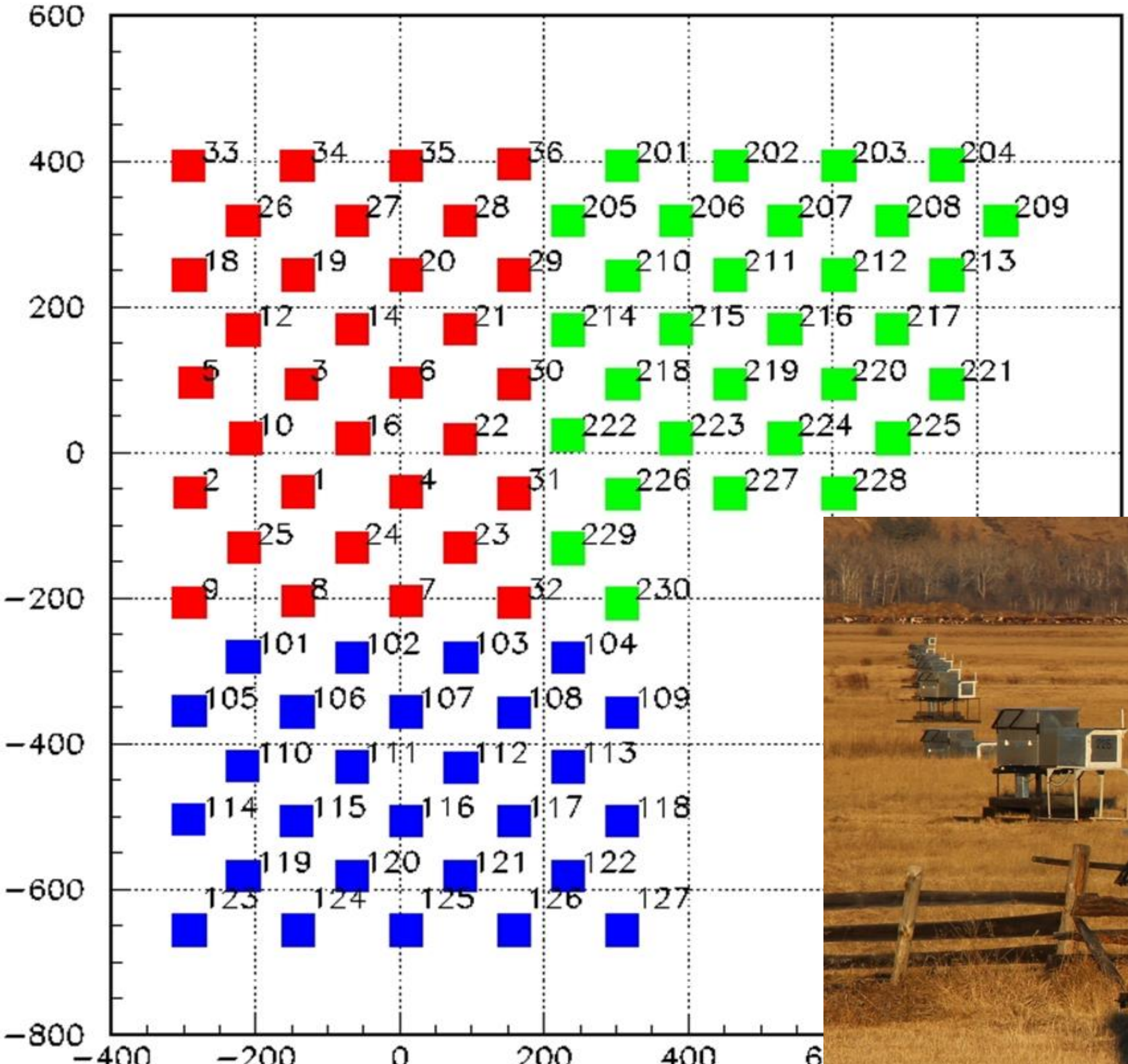


CATS Lidar,
532 nm, 4 khz, 10^13y/m2

- **Excellent HiSCORE calibration source**
- **– flat timing profile**
- **- precision pointing**

Precision verification with Laser on-board International Space Station (ISS) <0.1deg

TAIGA-HiSCORE 2019 year setup



86 wide- angle Cherenkov detectors on area 0.75 km^2 about

The TAIGA – IACT

The TAIGA – IACT: First - 2017y, second - 2019y, third - 2020y situated at the vertices of a triangle with sides: 300 m, 400 m and 500 m about

- 34-segment reflectors (Davis-Cotton)

- Diameter 4.3 m, area ~10 m^2

- Focal length 4.75 m –

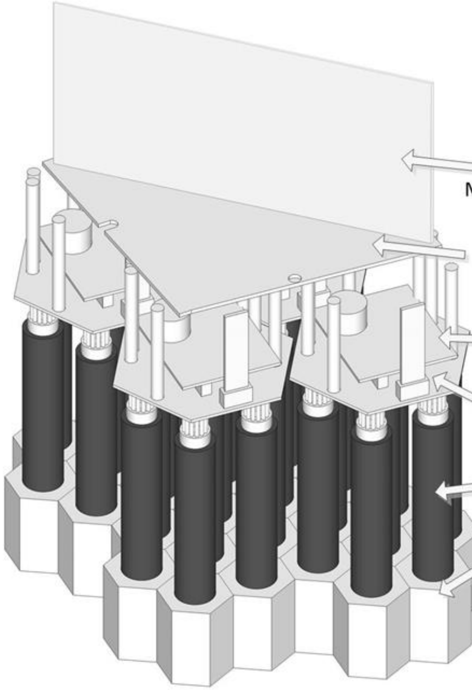
Threshold energy ~ 1.5 TeV

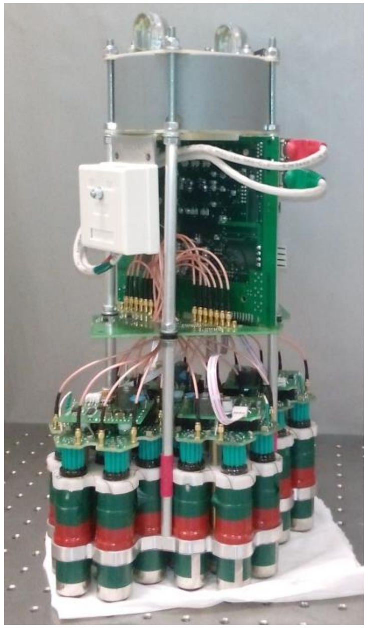
▪

Assembling of the 1st mount.

The Camera of the TAIGA-IACT

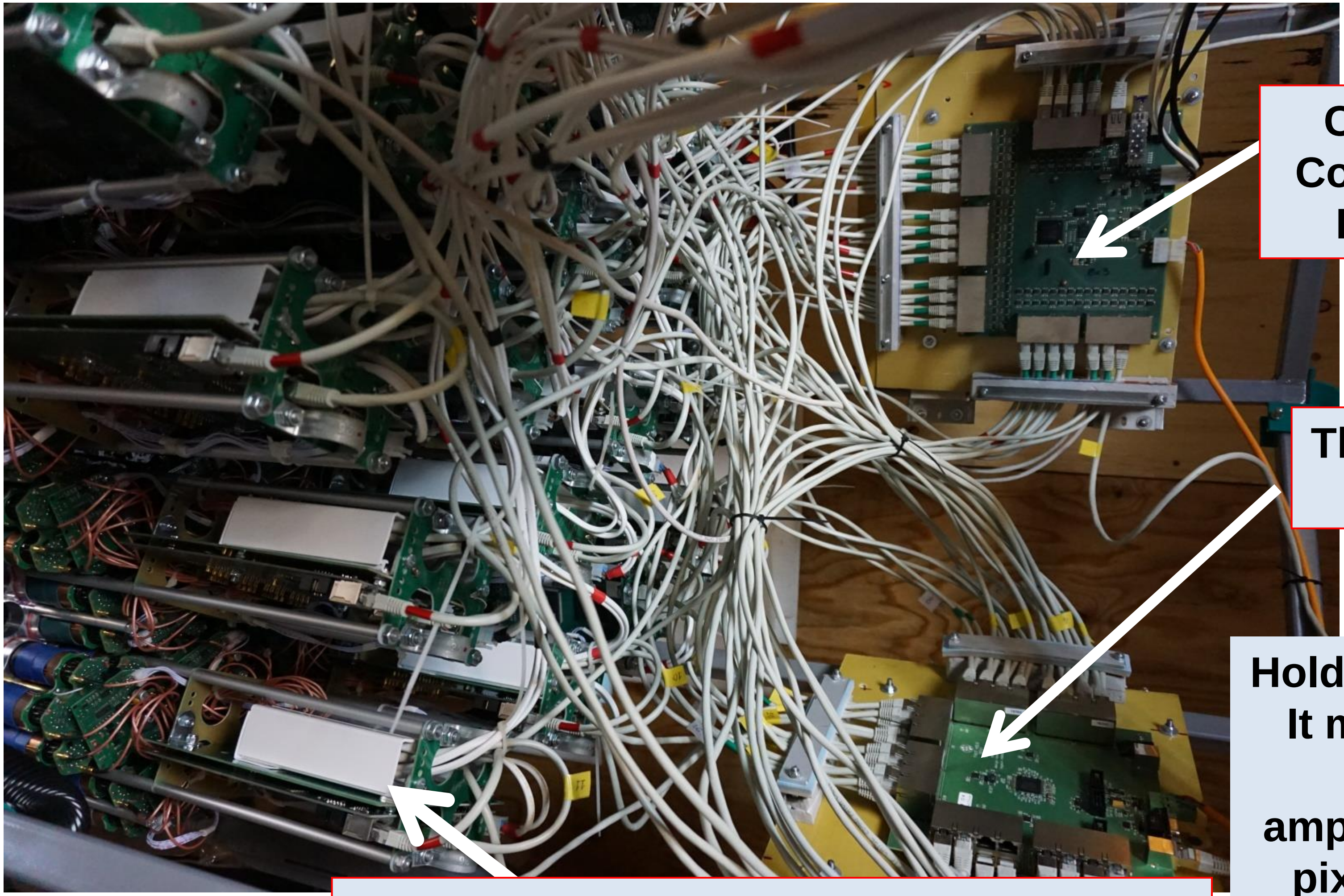
- 560 PMTs (XP 1911) with
- 15 mm useful diameter of photocathode
- Winston cone: 30mm input size
- each pixel = 0.36 deg
- FOV 10 x 10 deg





Basic cluster: 28 PMT-pixels. Signal processing: PMT DAQ board based on MAROC3 ASIC

Camera of IACT-2



Central Controller Board

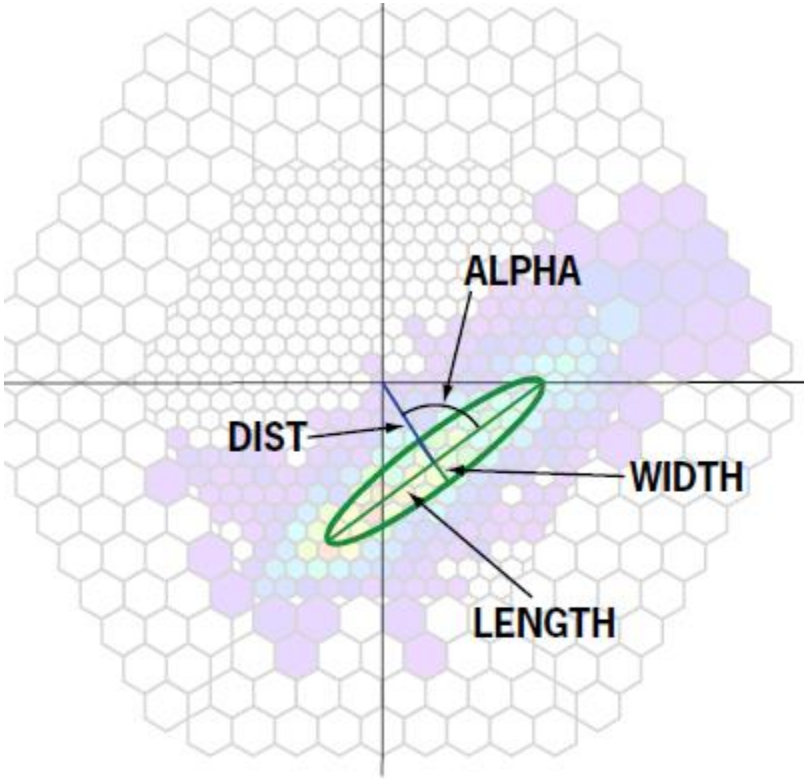
The Fast_Hold Boards

Hold on all clusters. It make possible to read out amplitudes from all pixels of camera

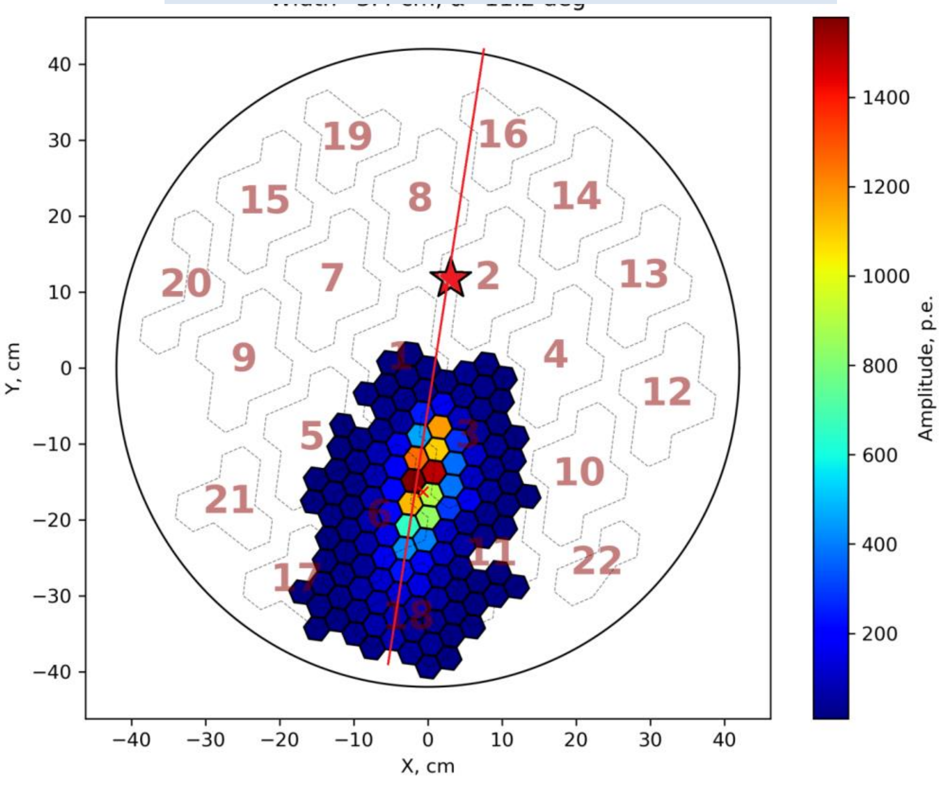
28 PMTs cluster on the base of MAROC-3

TAIGA-IACT and TAIGA-HiSCORE joint events.

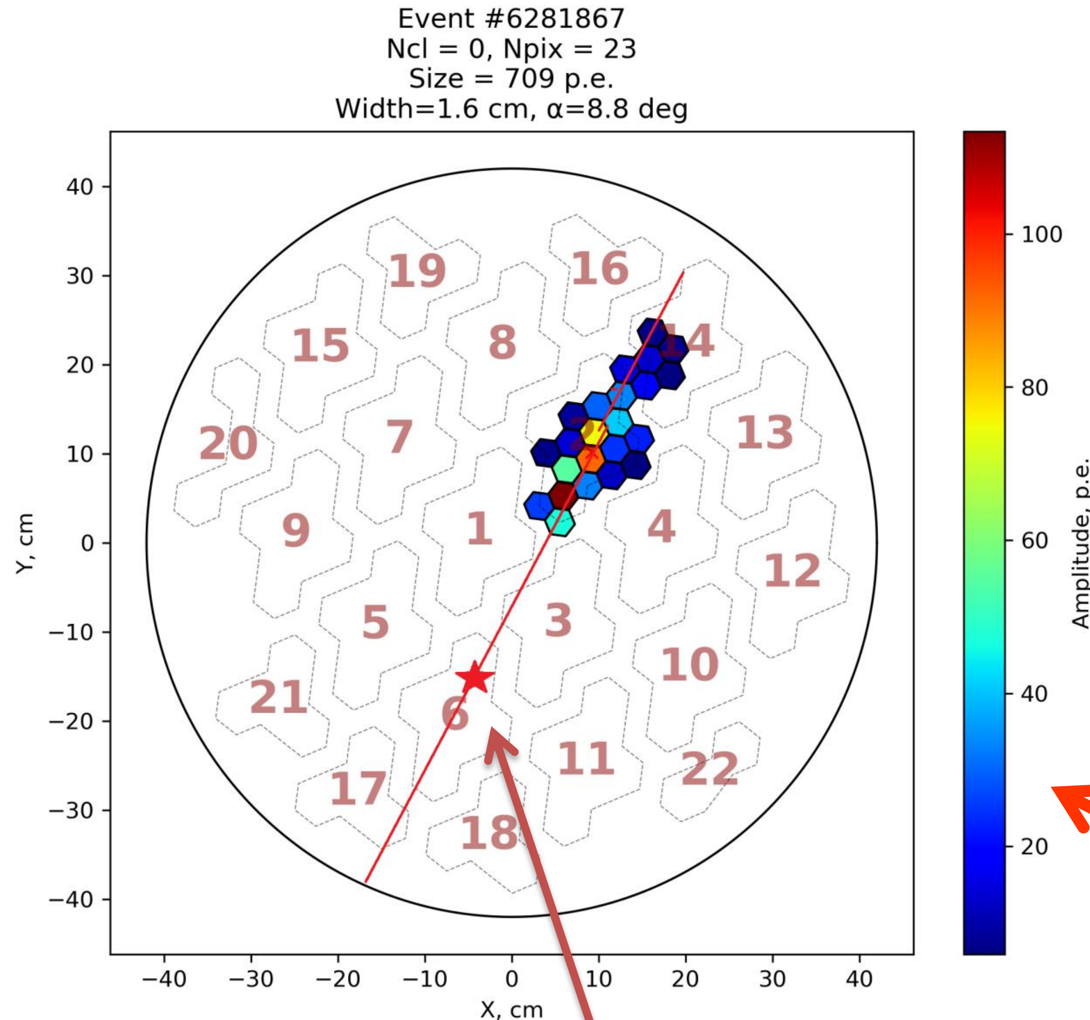
Hillas parameters



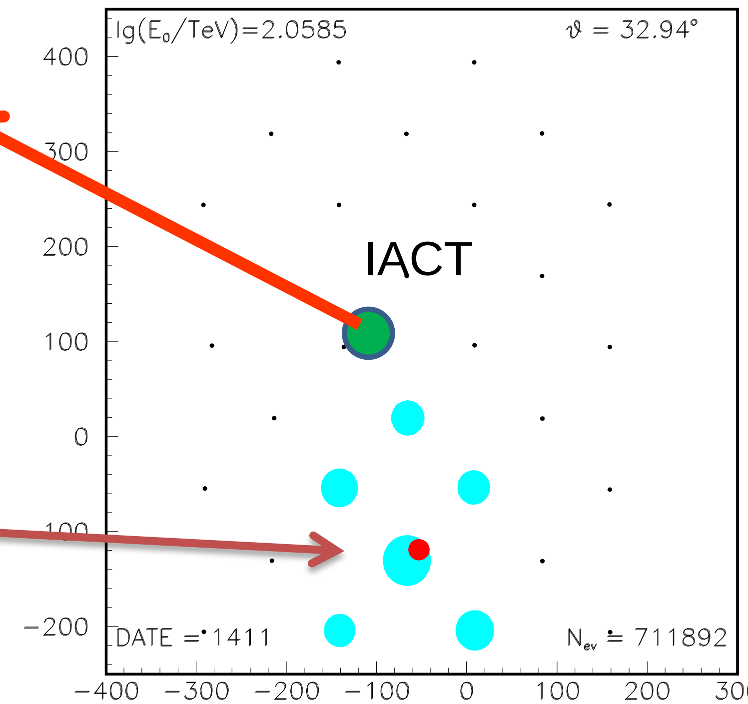
Most of events are “Hadron-like”
E = 880 TeV
width = 0.4°



But some events looks as “Gamma-like”

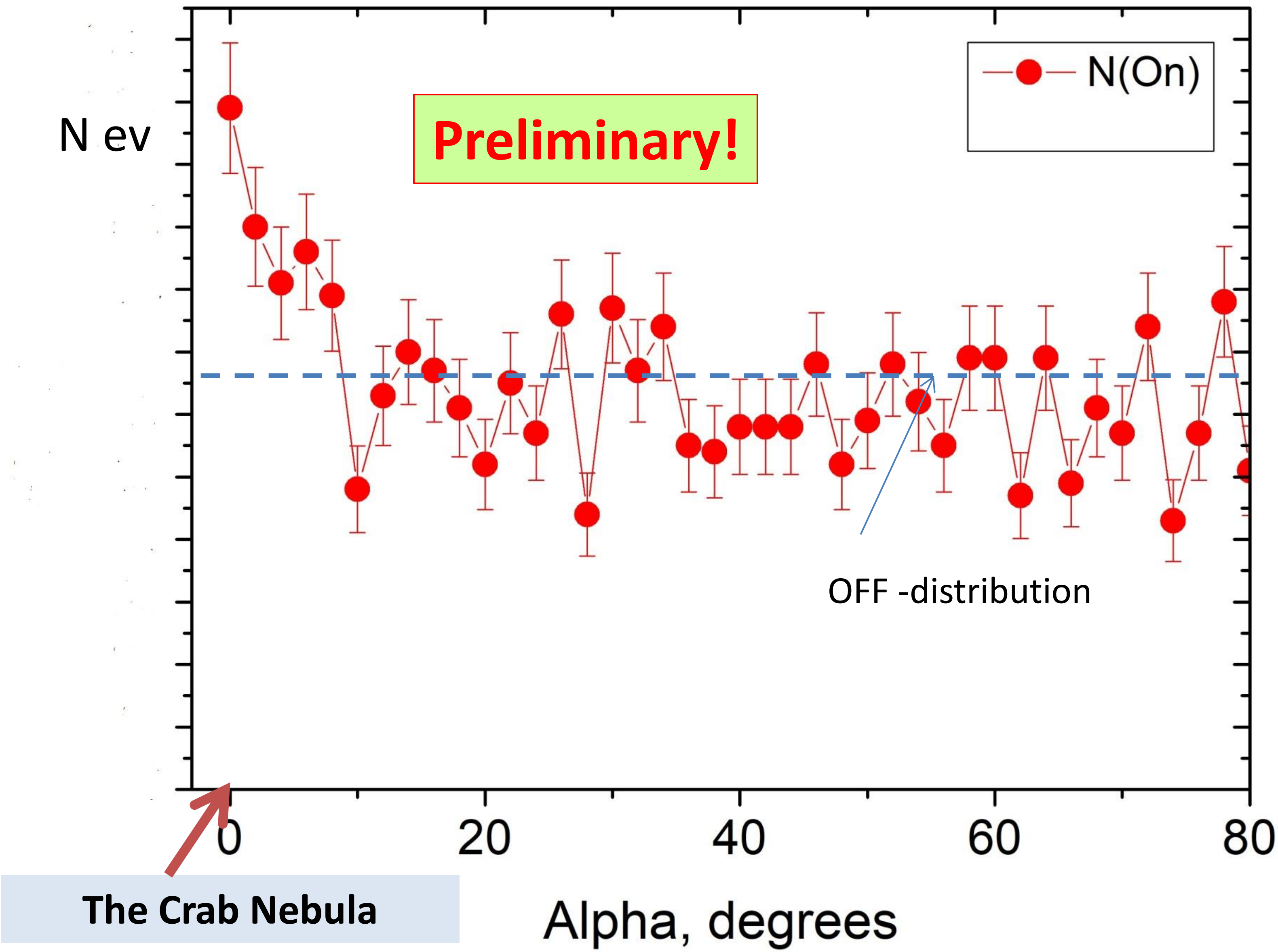


E = 50 TeV
Width = 0.19°



Core position

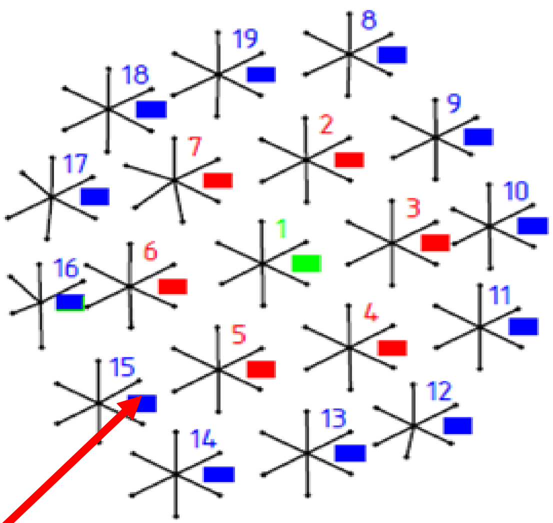
A histogram of the events distribution around direction on the Crab Nebula

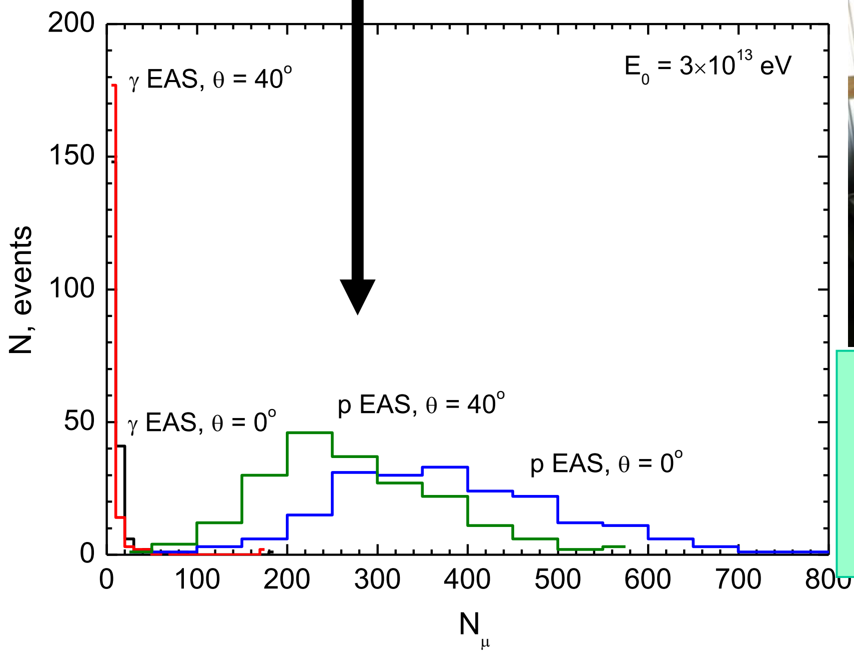


The TAIGA particle detectors.

The Tunka – Grande scintillation array

- **Permanent absolute energy calibration of Cherenkov arrays Tunka-133 and TAIGA-HiSCORE.**
- **Round-the-clock duty cycle;**
- **Trigger for radio array Tunka-Rex**
- **Improvement of mass composition data**
- **Rejection of p-N background**





228 former KASCADE-Grande scintillation counters with S=0.64 m^2

152 the same underground muon counters in 19 stations.

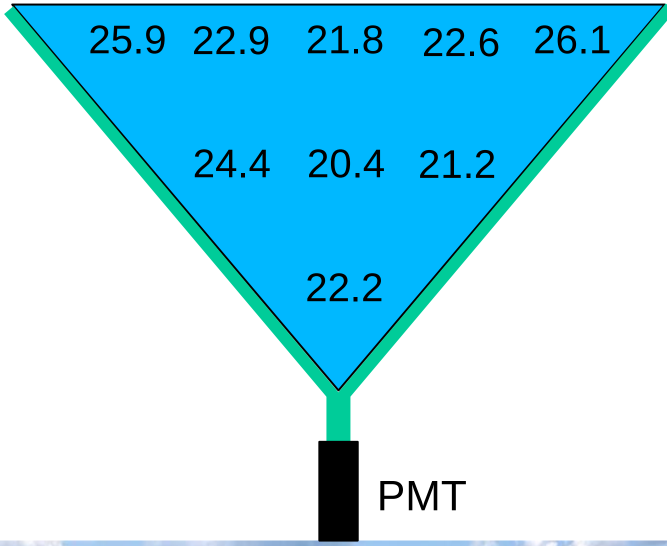
The TAIGA-Muon scintillation array

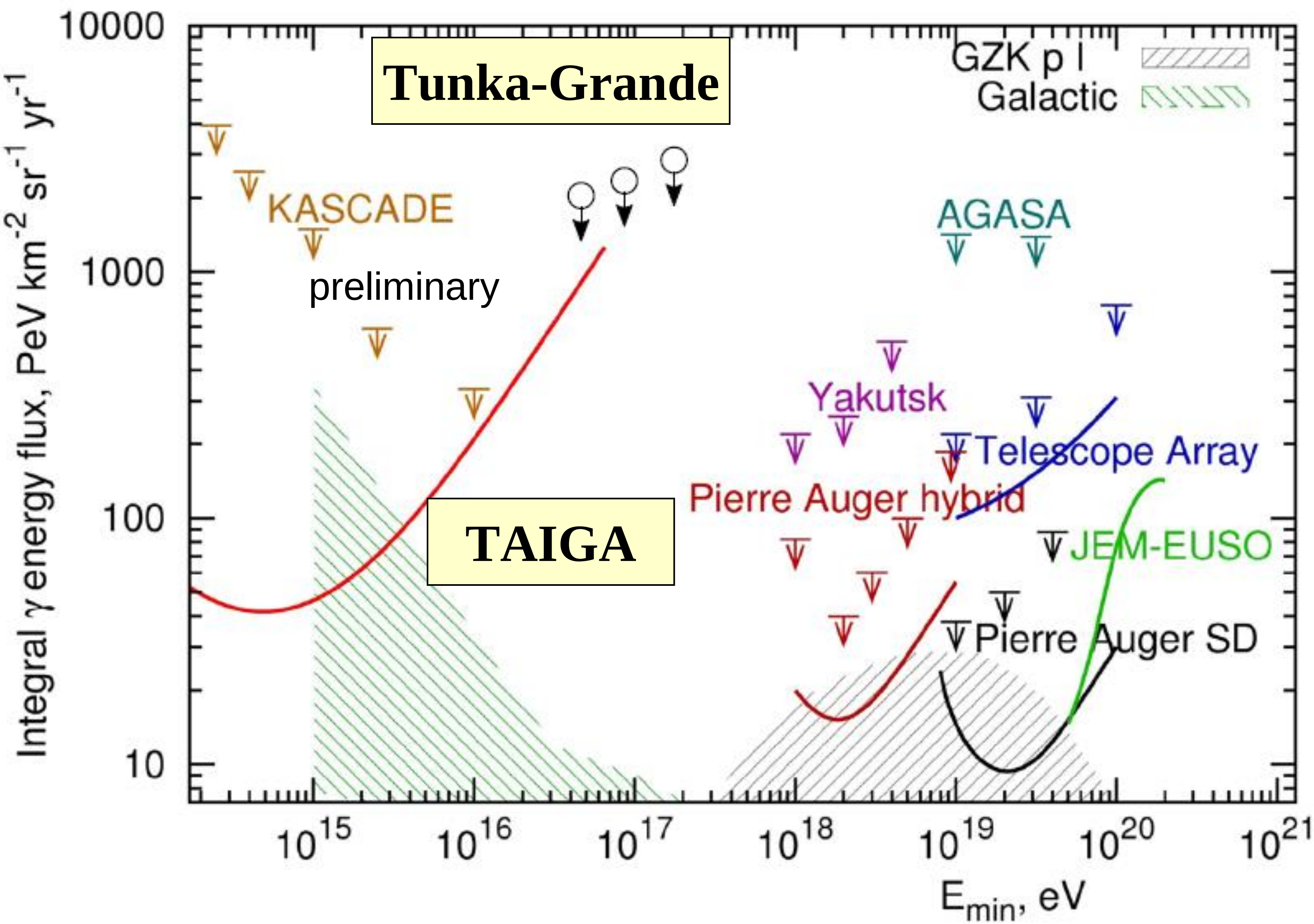
Counter dimension 1x1 m^{2}.

Wavelength shifting bars are used for collection of the scintillation light.

Mean amplitude from cosmic muon is 23.1 p,e, with ±15% variation.

A clear peak in amplitude spectrum is seen from cosmic muons in a self trigger mode





Серая область - возможный поток GZK-фотонов в Стандартной Модели для протонного первичного состава. Зеленая область — поток космогенных фотонов в одной из моделей с Лоренц-нарушением. Показаны существующие ограничения на поток фотонов.

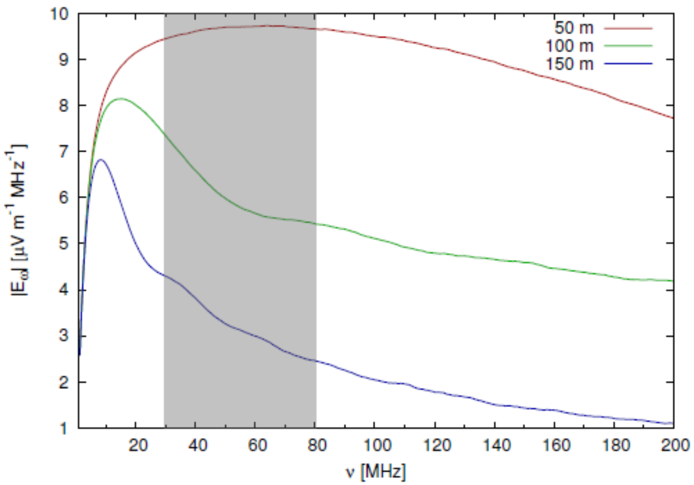
Air-shower radio emission

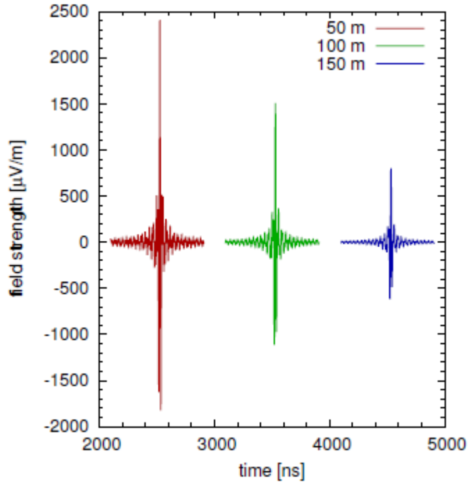
Mechanisms:

* Geomagnetic effect

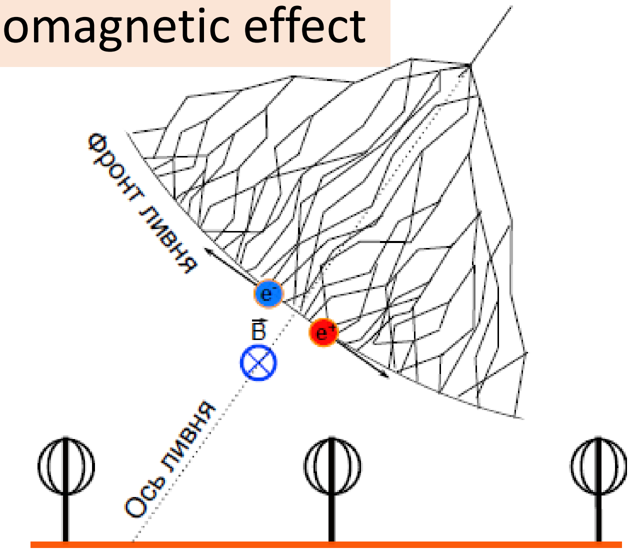
* Asatryan effect

Coherent Broadband Pulses

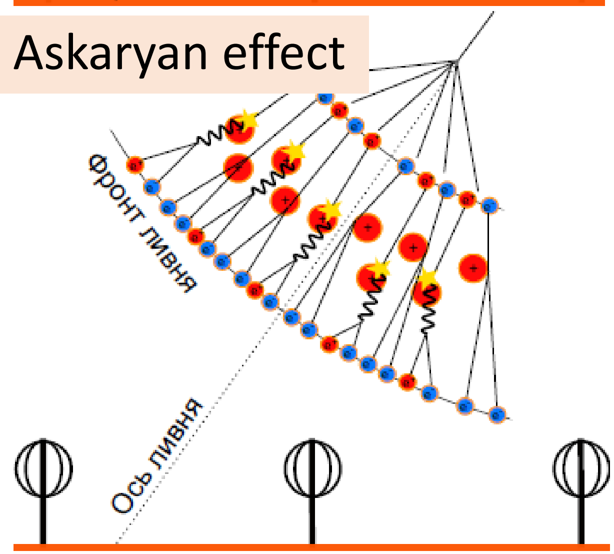




Geomagnetic effect



Askaryan effect



Advantages:

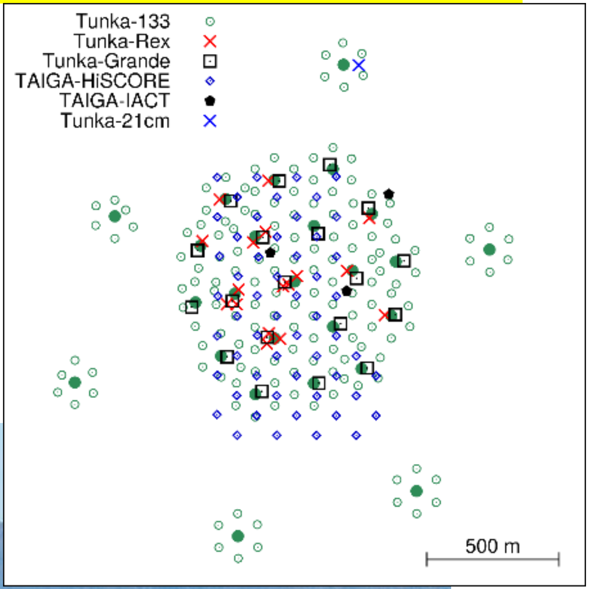
* Sensitive to the energy and shower maximum
* Almost full duty cycle
* Simple and cost-effective

Disadvantages:

* Low signal-to-noise ratios (SNR) and many transient background (RFI)

Tunka-Rex (Tunka – Radio extension

* Detected energies - $10^{16.5}$ - $10^{18.5}$ eV
* Detector area - 3 km^2
* 63 antenna stations
* Frequency band 30 - 80 MHz
* Two trigger modes (Tunka-133 and Tunka-Grande)



~100 events per season triggered by Tunka-133

commission of Tunka-Grande w i th

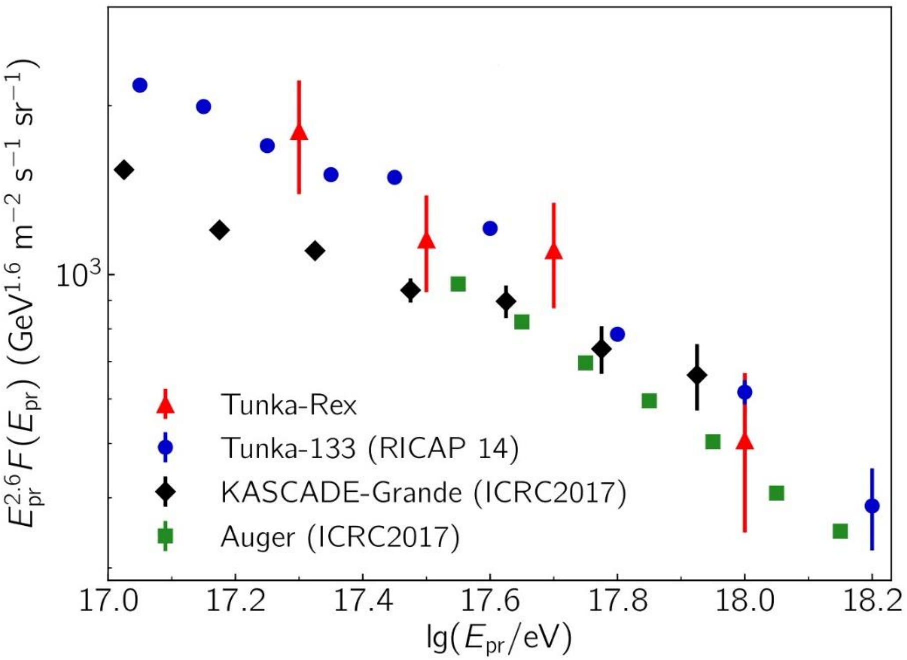
~1000 events per season triggered by Tunka-133 and Tunka-Grande

2012	2013	2014	2015	2016	2017	2018	2019
18 antennas	25 antennas	44 antennas		63 antennas			TRVO and decommission

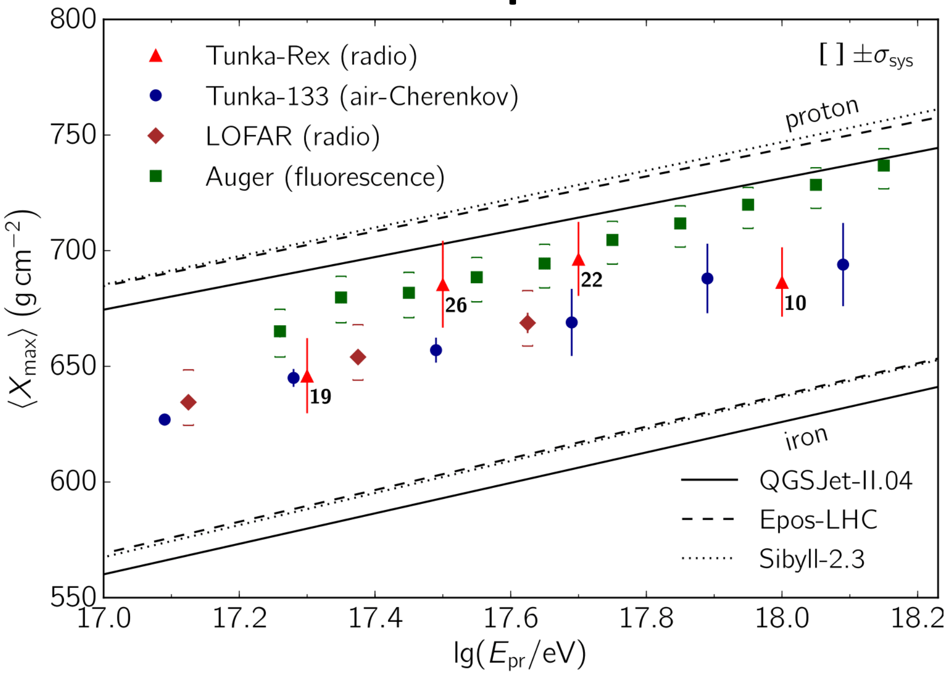
Tunka-Rex results

* Tunka-Rex successfully operated since 2012
* Energy resolution of 10-15%, shower maximum resolution of 25–35 g/cm²
* Ideal tool for energy scale calibration between CR experiments (KG + Tunka-133)
* SALLA will be used in the radio upgrade of the Pierre Auger Observatory
* Study of inclined air-showers
* Small engineering arrays
* Development of self-trigger for radio

Energy spectrum



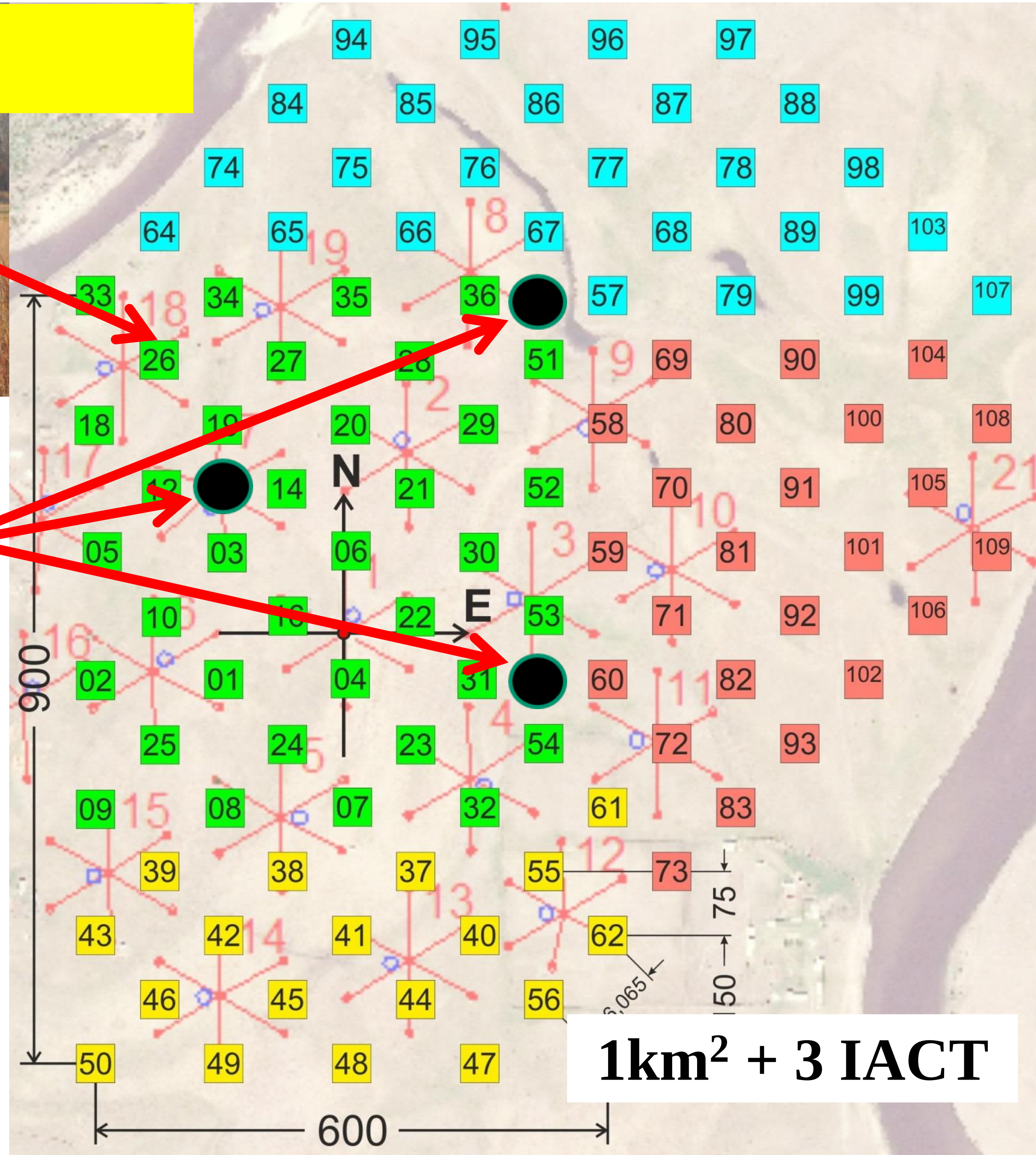
Mass composition



TAIGA, 2020

TAIGA-HiSCORE
120 detectors

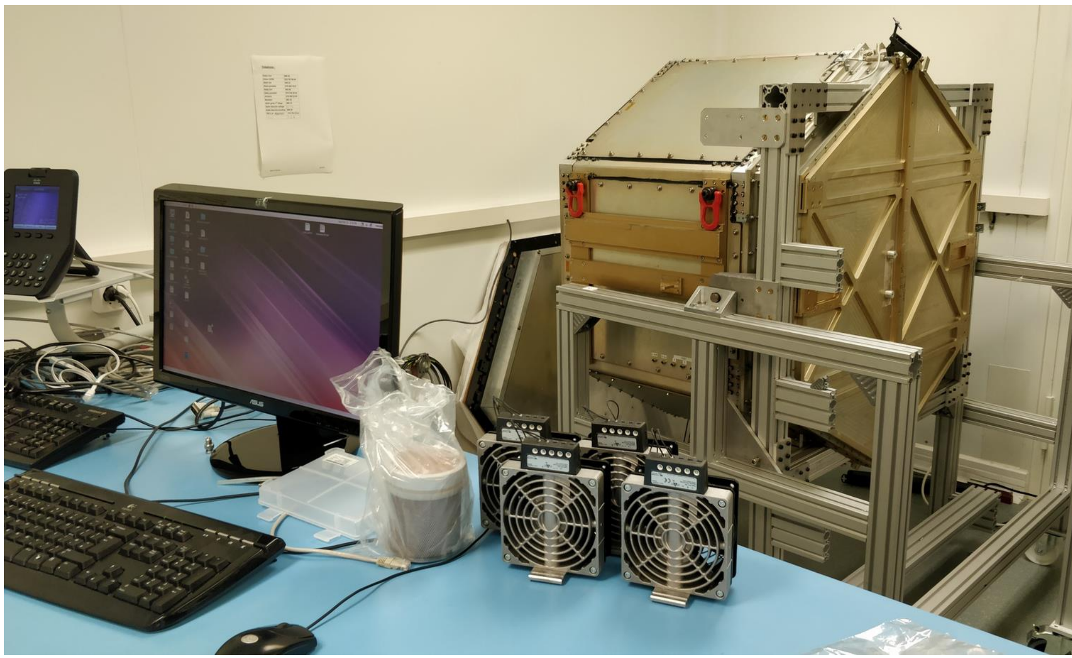
3 TAIGA-IACT

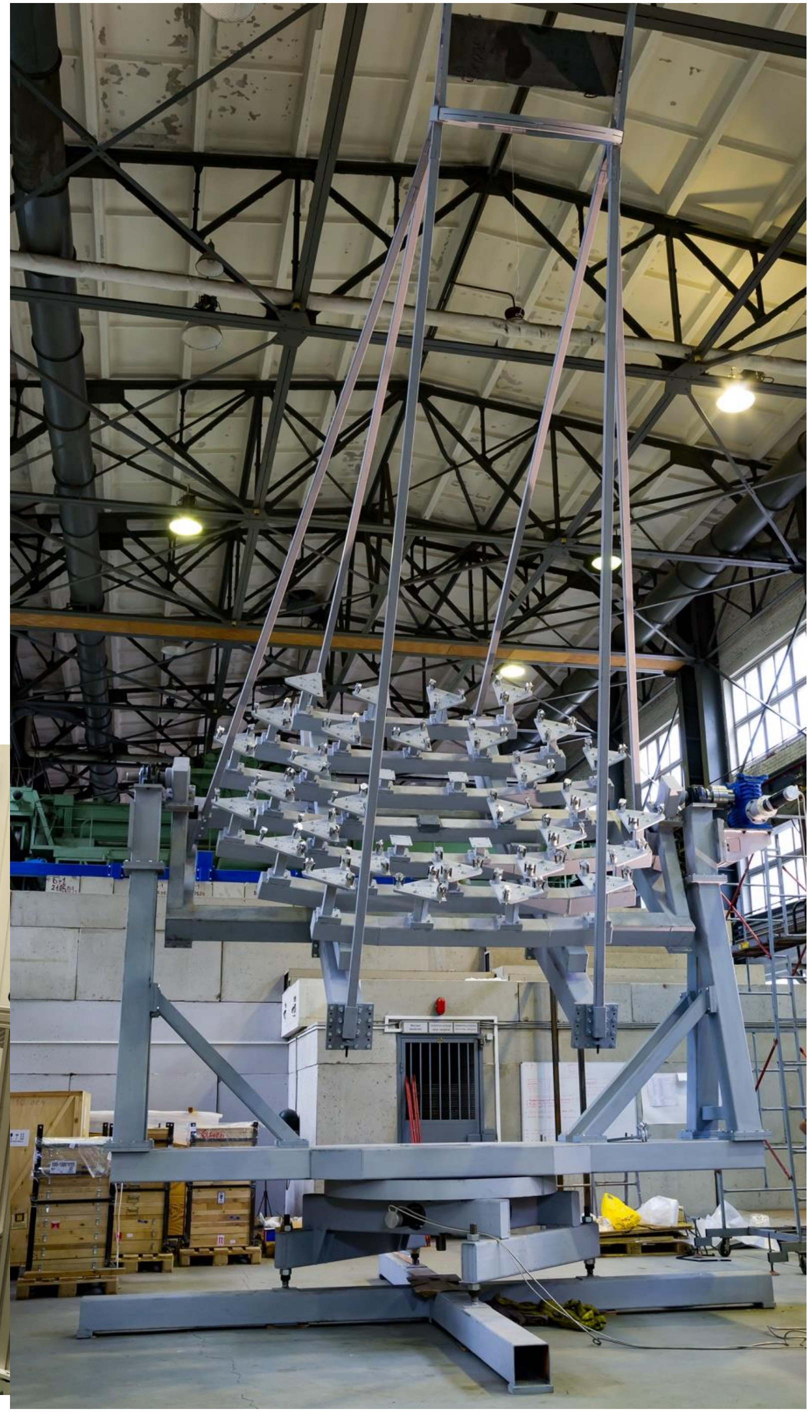


1km^2 + 3 IACT

CTA & TAIGA

Летом 2020 года планируется установить на изготовленной в ЛЯП ОИЯИ монтировке третьего телескопа камеру на базе полупроводниковых фотоумножителей (SiPM), разработанную Женевским университетом для телескопов SST-1M проекта CTA.



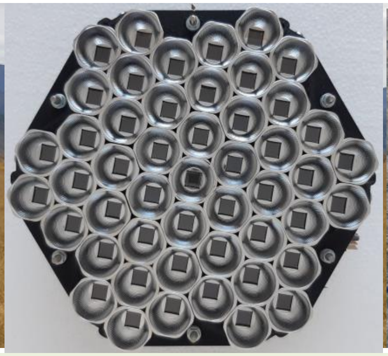


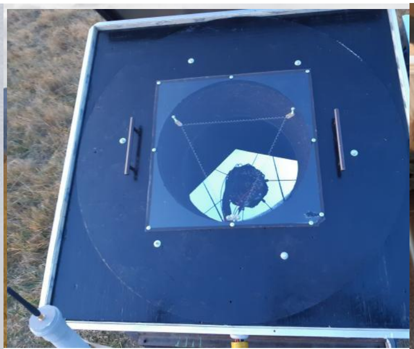
A compact-size wide Field of View IACT with a SiPM-based camera for energies above 10 TeV.

FoV of TAIGA-HiSCORE detectors is 60° but TAIGA-IACT – 10° as a result we have only 1% of joint events.

To study the gamma-ray with energy above 30 TeV we started off a development of a Small Image Telescopes (SAT) with a SiPM-based camera with a FoV up to 60° and an effective recording area of 1m². We intend to test 3 variants of the SAT optical system: spherical mirror, a system of Fresnel lenses, combination of the two mentioned technologies.

Prototype SIT (FOV ~ 20°, S ~ 0.1 m^2, 49 SIPM SensL MicroFC-60035-SMT, 6 ×6 mm^2) was installed in the Tunka Valley for operation together with the TAIGA-HiSCORE array in September 2019.





Examples of detected events by the SIT prototype

A future 10 square kilometer scale hybrid array for astroparticle physics, gamma-astronomy and cosmic ray physics

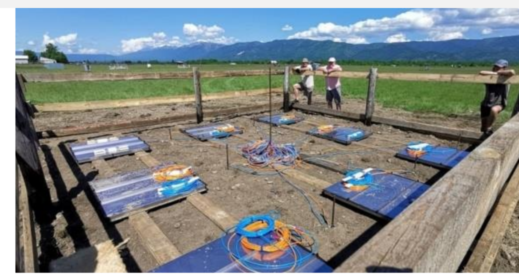
A site requirement:

- altitude – 2000 m about,
- no artificial light background,
- good astroclimat,
- enough vacant rather flat space,
- acceptable logistic condition,
- availability of electrical power

Tunka, Altay…..??????????

TAIGA-HiSCORE - array.
A net of 1000 non imaging wide-angle detectors distributed on area 10 km^2 with spacing 100 m about
An EAS core position, direction and energy reconstruction.

TAIGA-IACT - array
of 12 - 16 IACT with mirrors – 4.3 m diameter.
Charged particles rejection using imaging technique.



TAIGA-Muon array
of scintillation detectors, including underground muon detectors with area - 2000 – 3000 m^2
Charged particles rejection

Summary and outlook

TAIGA aims at establishing a new, hybrid gamma-ray detection technology for >30 TeV

2020 year 1 km^2 TAIGA setup:

- 120 wide – angle Cherenkov detectors of TAIGA - HiSCORE "non-imaging" timing array
- 3 Imaging Atmospheric Cherenkov Telescopes of TAIGA-IACT "imaging" array
- 200 m^2 muon detectors of TAIGA-Muon and Tunka-Grande arrays.

A point source sensitivity: 2.5 10^{-13} TeV/cm^2 s (300 hours, 30–200 TeV)

Commissioning seasons were successful

- Stable operation, precision calibration in progress, E_{th}~30TeV
- CR energy spectrum 100 TeV – 1 EeV
- A signal from Crab in agreement with expectation.
- Joint operation of TAIGA-HiSCORE and IACT: data analyses is in progress

Future plan : 10 square kilometers scale TAIGA + new technologies

- array with about 1000 Cherenkov detectors of TAIGA - HiSCORE "non-imaging" timing array
- 12 – 16 Imaging Atmospheric Cherenkov Telescopes of TAIGA-IACT "imaging" array
- 3000 m^2 muon detectors of TAIGA-Muon array.
- A point source sensitivity: 2.5 10^{-14} TeV/cm^2 s (300 hours, 30–200 TeV)

- Cooperating with CTA
- development of detecting systems, based on SiPM sensitive optical and ultraviolet (UV) bands.
- development of compact-size wide Field of View IACT with a SiPM-based camera.

Thank you for attention!