Tunka Advanced Instrument for cosmic rays and Gamma-ray Astronomy(TAIGA): status, results and perspectives.

L.Kuzmichev (SINP MSU)
on behalf of TAIGA collaboration

Moscow, 05.03 2018

TAIGA - collaboration

Germany

Hamburg University(Hamburg)

DESY (Zeuthen)

MPI (Munich)

Italy

Torino University (Torino)

Rumania

ISS (Bucharest)

Russia

MSU(SINP)(Moscow)

ISU (API) (Irkutsk)

INR RAS(Moscow)

JINR (Dubna)

MEPHI(Moscow)

IZMIRAN (Moscow)

BINR SB RAS Novosibirsk)

NSU (Novosibirsk)

Complex of arrays in Tunka Valley (50 km from the lake Baikal)

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

Tunka-133

Tunka-Grande

Tunka- REX

TAIGA – HiSCORE

TAIGA -IACT

Cosmic rays

Gamma-ray astronomy

10^{18} eV

10^{15} eV

10^{13} eV

OUTLINE

I. Review of the main CR results in Tunka experiments

II. From High Energy CR to Multi-TeV Gamma-ray astronomy

I. Review of the main CR results at Tunka experiments

Tunka-133 - 175 optical detectors on the area 3 km²

Tunka-Grande – 380 scintillation counters for registration of charged particles

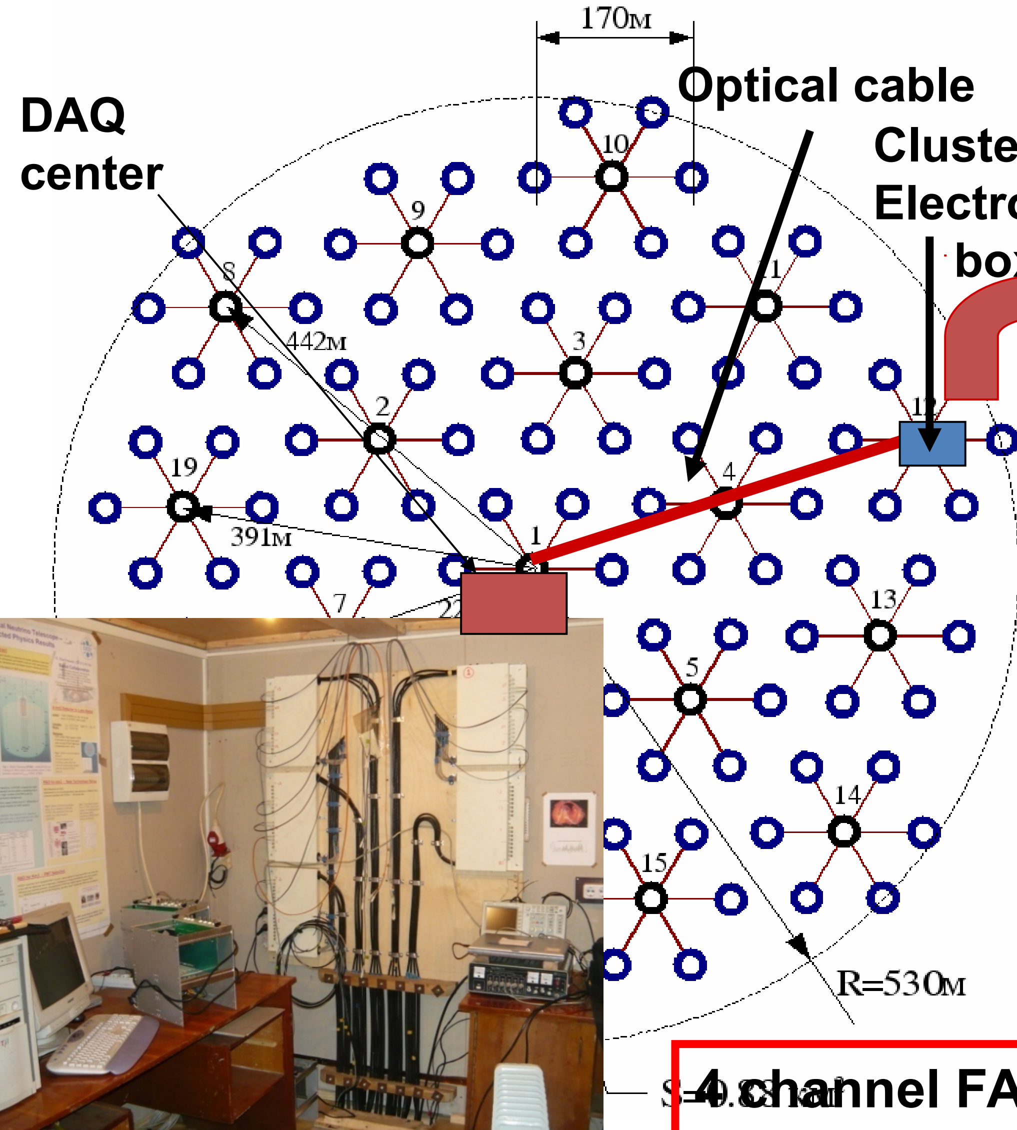
Тунка-REX – 63 antennas for registrations of radio signals From EAS

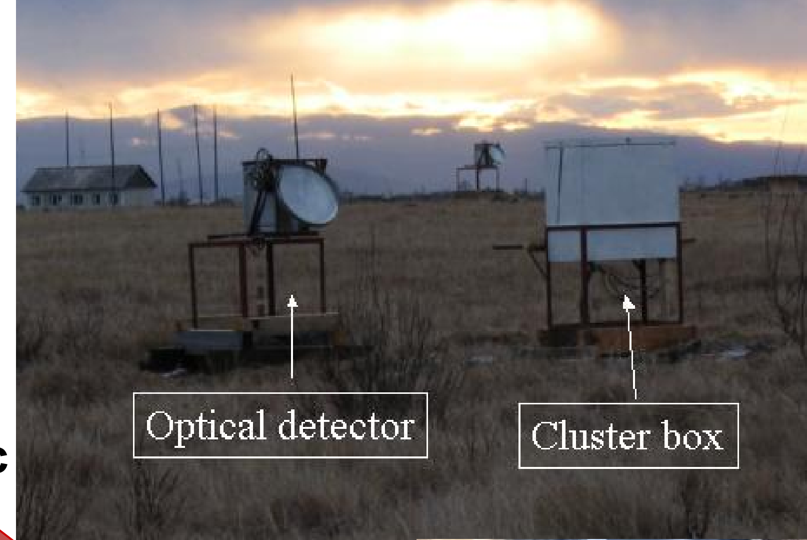
Tunka-133: 19 internal clusters + 6 outside clusters,
7 detectors in each cluster

DAQ center

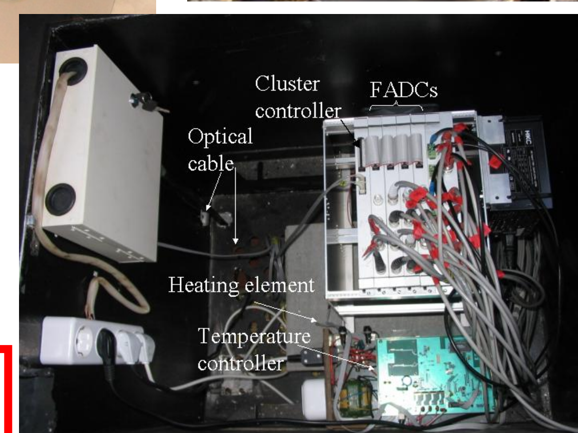
Optical cable

Cluster Electronic box



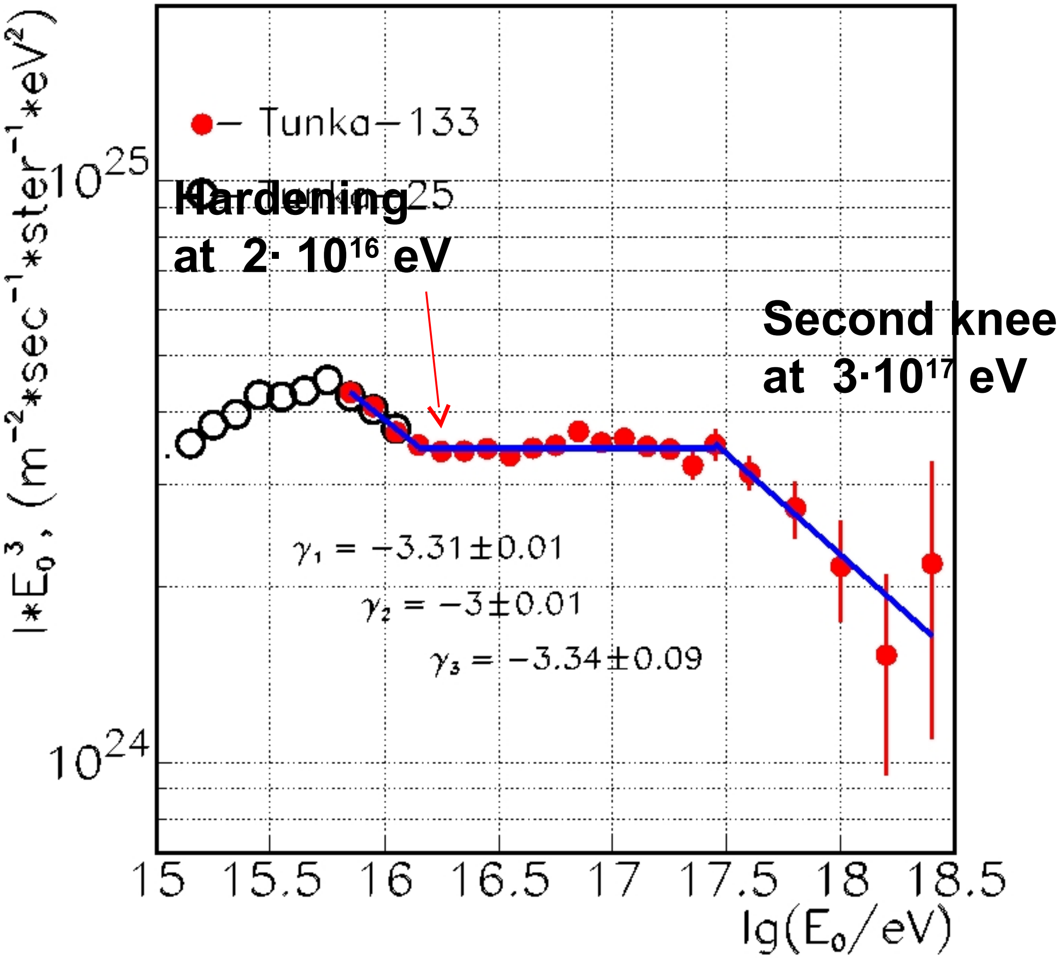


PMT
EMI 9350
Ø 20 cm



4-channel FADC boards
200 MHz, 12 bit

All particle energy spectrum (7 season of operation)



~ 3000 events with E_0 >10^{17} eV

Hardening at 2· 10^{16} eV

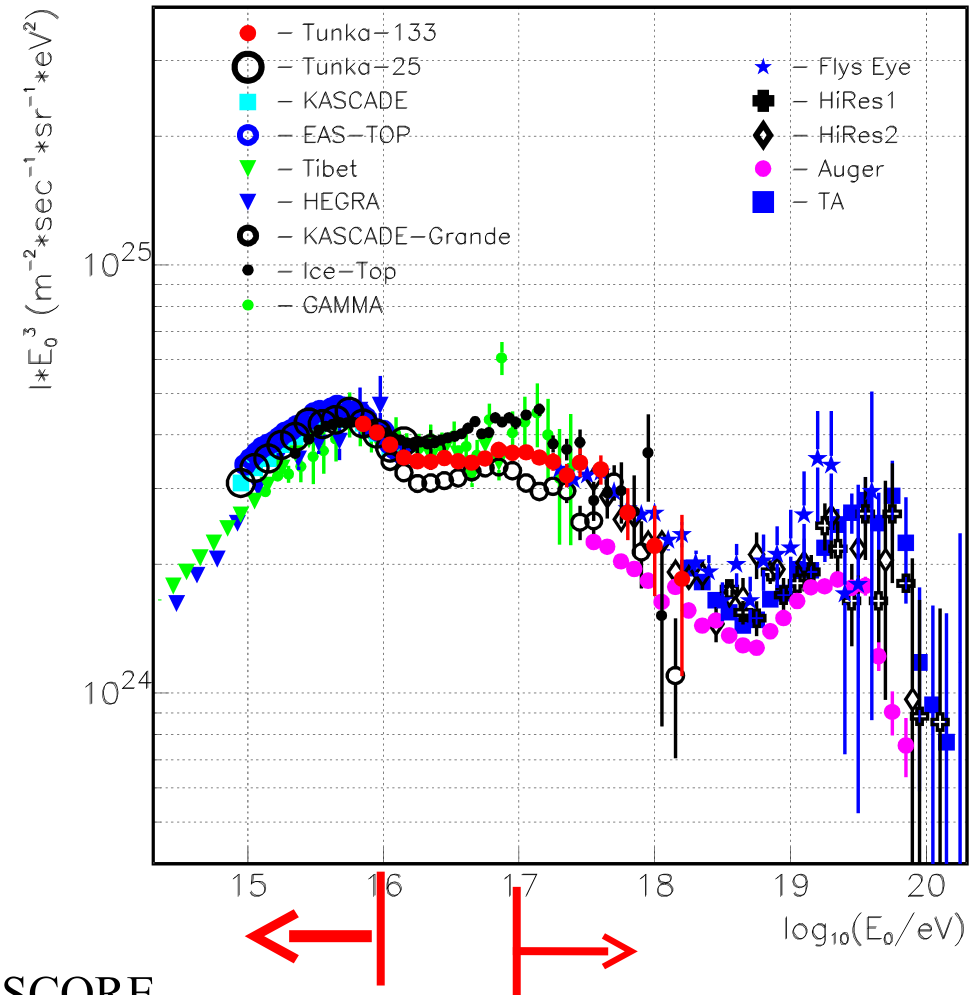
1.KASCADE –Grande (2010)

2. Tunka-133 (2011)

3. Ice-Top (2012)

4. TA LE(2014)

All particle energy spectrum



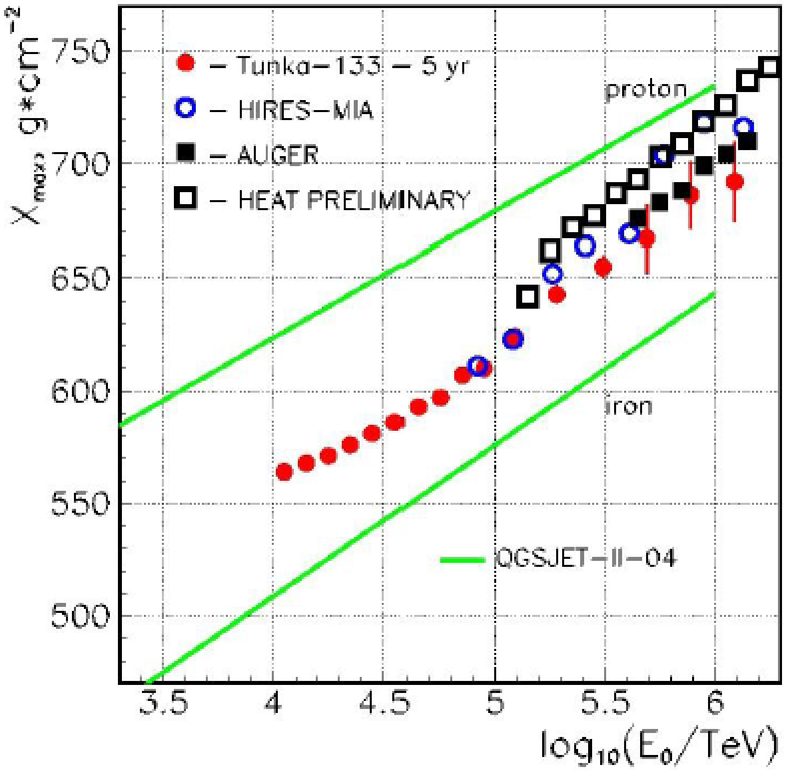
TAIGA -HiSCORE

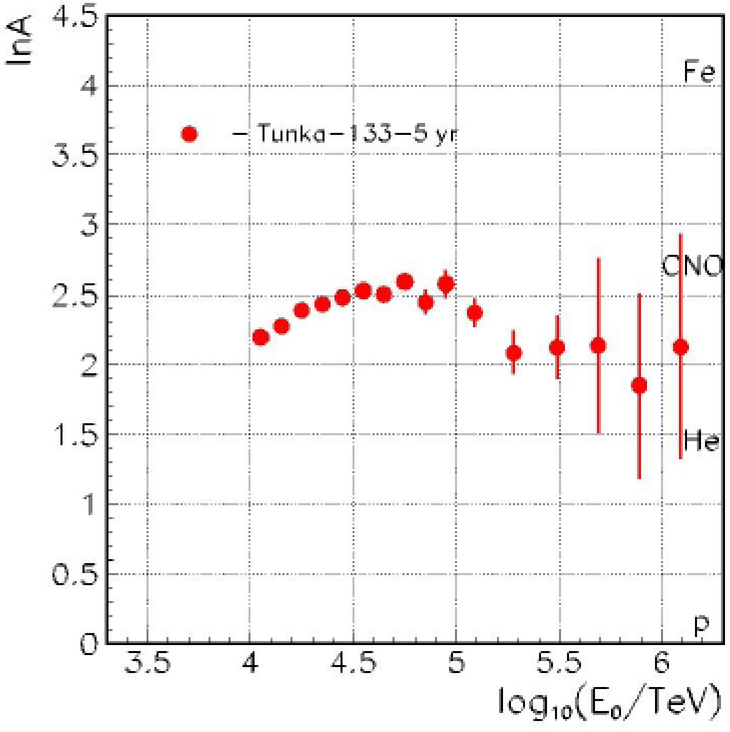
Tunka –Grande + Tunka-REX

Mass composition

$<X_{max}>$ vs. E_0

Mean <lnA> vs. E





Tunka-REX
(Tunka Radio EXtension)

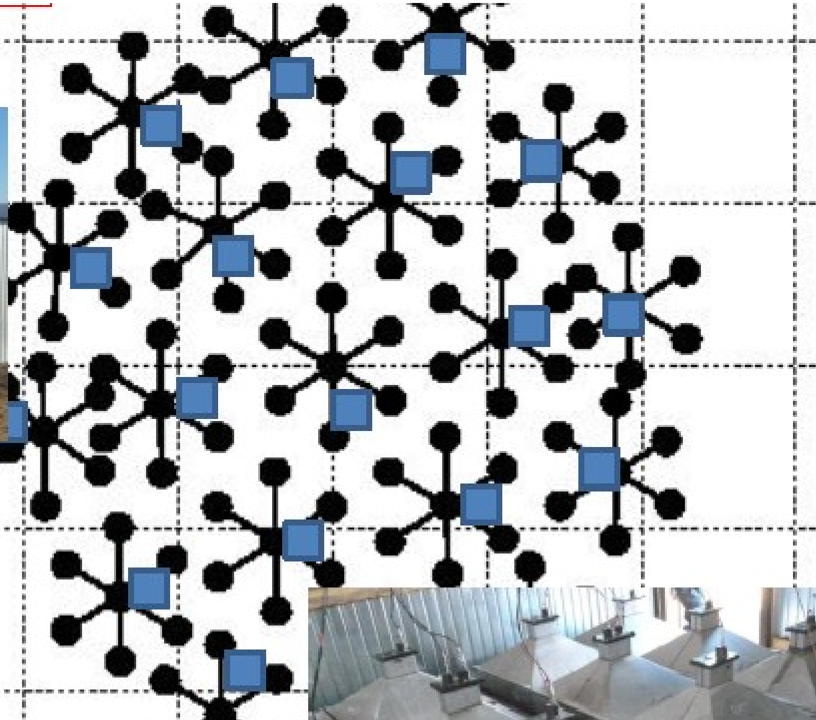
Connection of 2 antennas to
2 free channel of FADC

Main result: energy resolution radio-method
is near to 17%

- 63 antennas

Stintillation array Tunka-Grande

19 stations

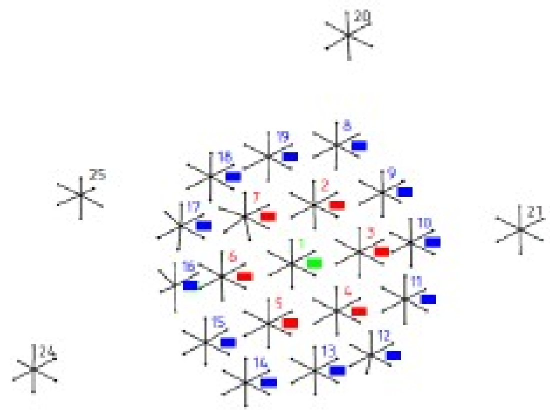


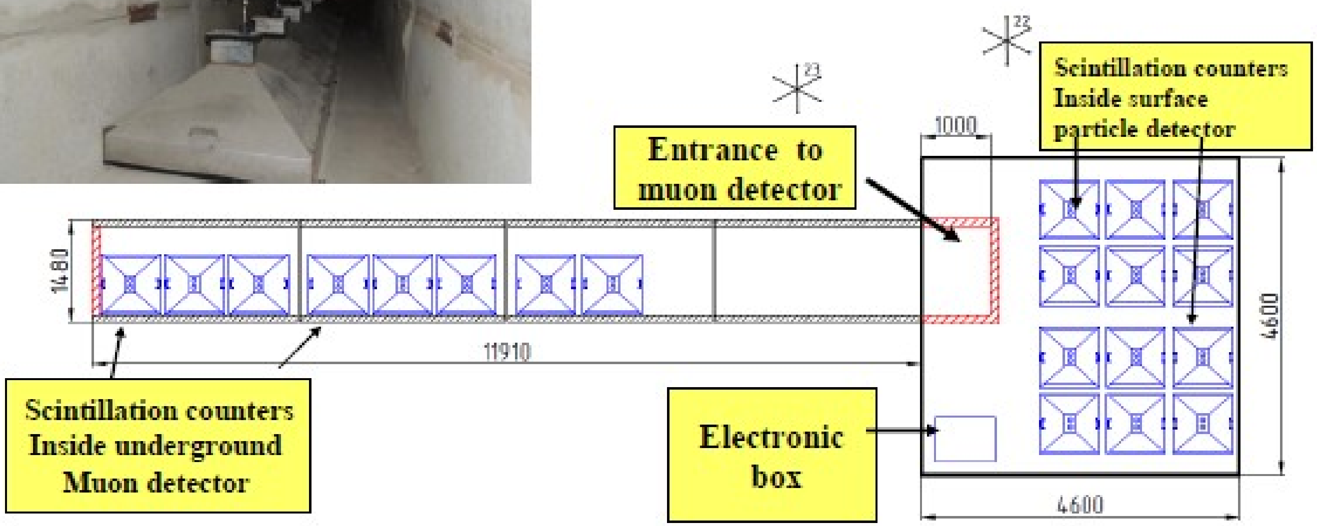
228 detectors (0.64 m^2) on the surface

152 detectors undeground (muons detectors), total area = 100 m^2

Start of data taking December 2015

Scintillation station





Each station operate independently under local trigger

Counting rate ~ 15 Hz

4 channel FADC boards
200 MHz, 12 bit

New results will be presented at ECRS-2018

II. From High Energy CR to Multi-TeV Gamma-ray astronomy

More than 150 sources of gamma rays with energies above 0.1 TeV

No single source with the energy of gamma rays above 80 TeV

Where are the sources of Galactic cosmic rays with energies of the order of 1 PeV (Pevatrons) ?

To search for Pevatrons and studying gamma-ray sources at the edge of the energy spectrum the area of arrays need to be over 1 km^2

TAIGA gamma-observatory

+

+

• 500 wide angle optical stations on the 5 km² area, energy threshold 30 TeV

• up to 16 IACT (10 m² mirrors).

• Muon detectors with total area 2.0 10³ m².

TAIGA - HiSCORE

(High Sensitivity Cosmic Origin Explorer).

Non-imaging air Cherenkov array

Angular resolution : ~ 0.4 - 0.1 degree

Energy threshold for gamma-rays : ~ 30 TeV

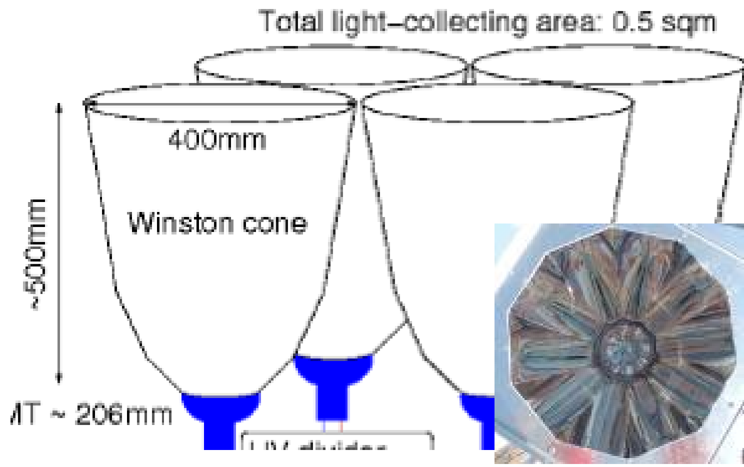
Large Field of view (FOV): ~ 0.6 sr

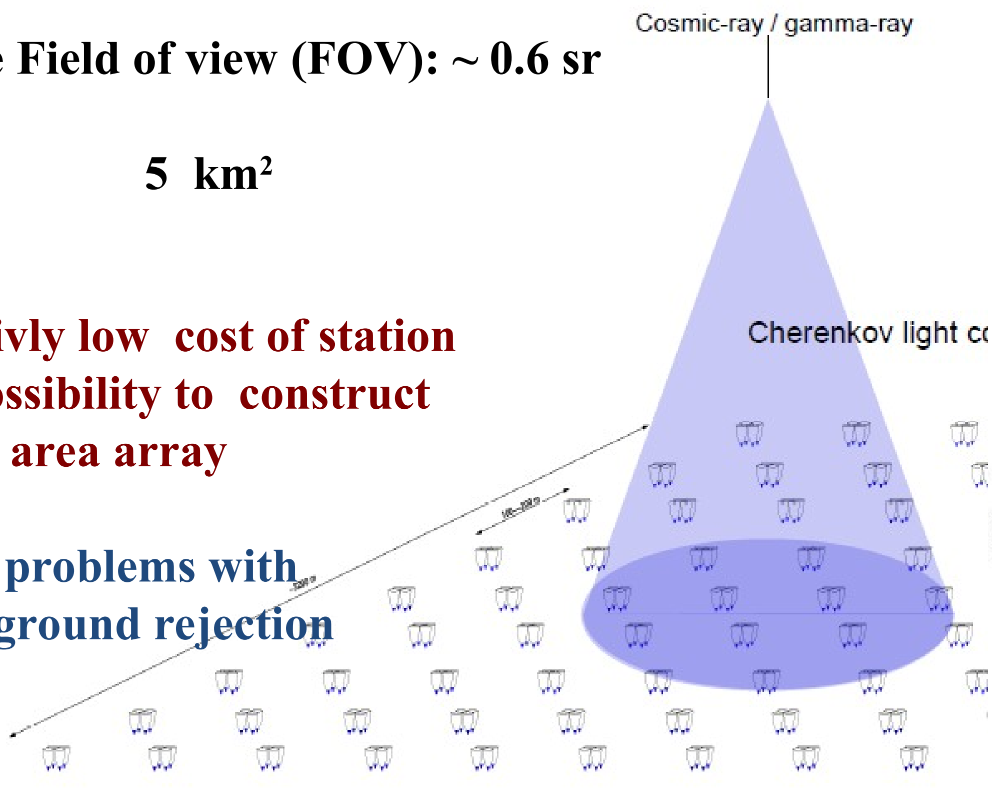
Area: 5 km^2

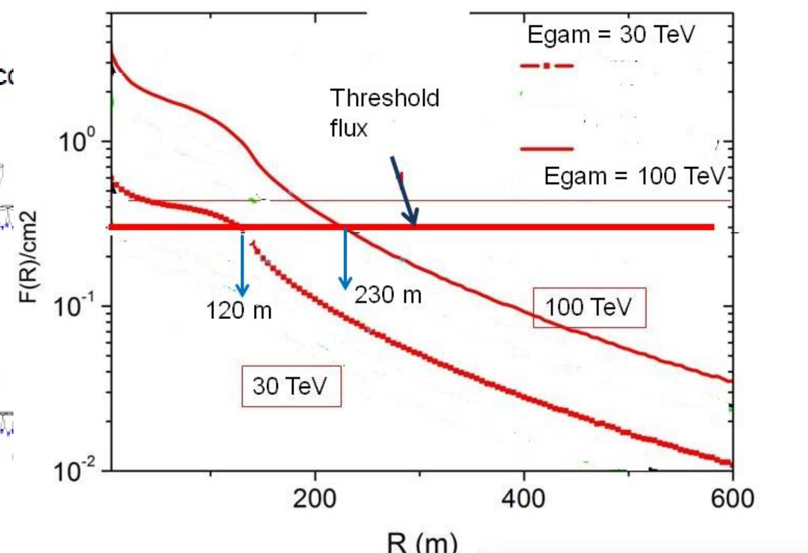
.

Relativly low cost of station – possibility to construct large area array

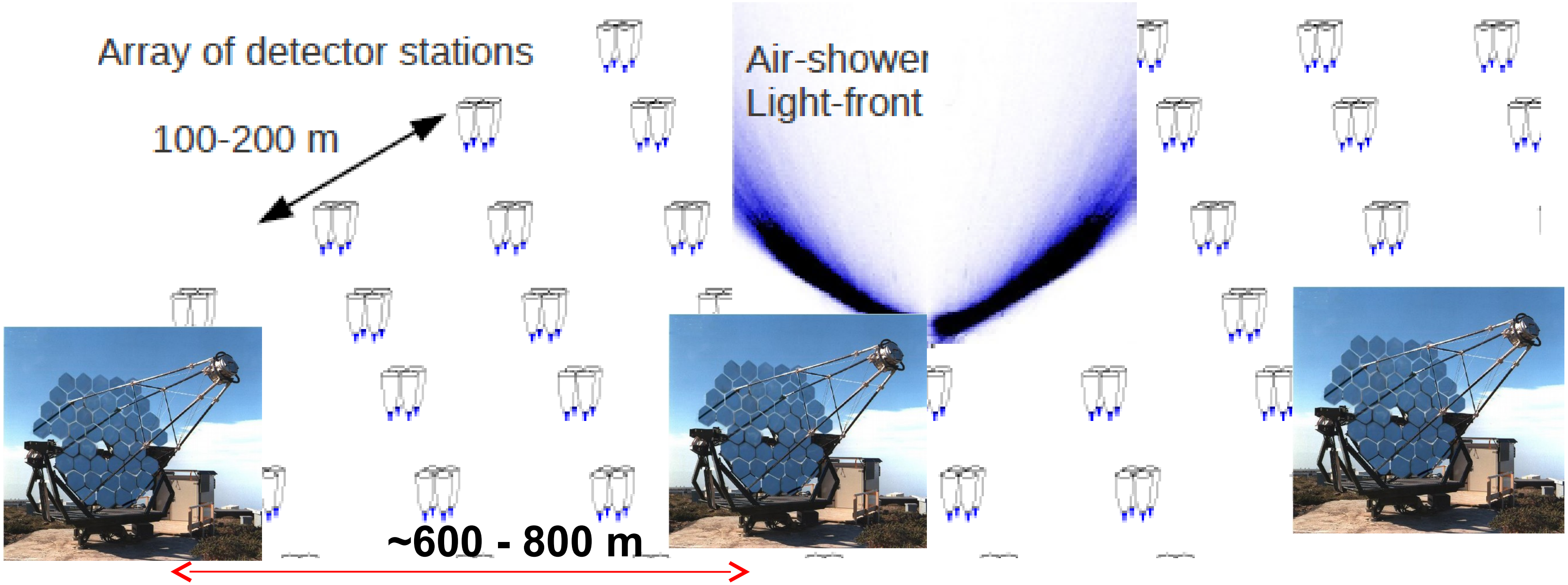
But – problems with background rejection





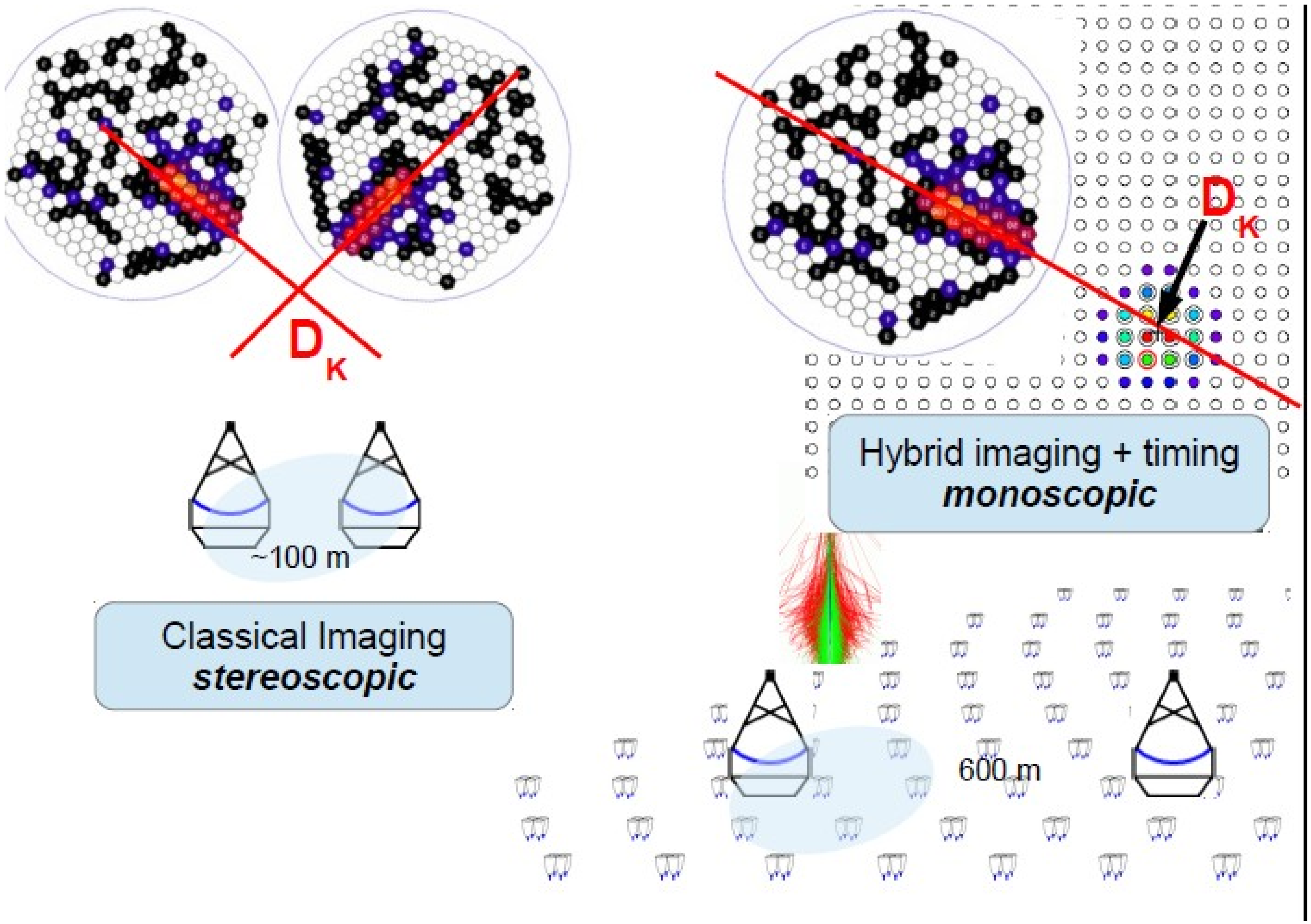


TAIGA : Imaging + non-imaging techniques



TAIGA - HiSCORE: core position, direction and energy Gamma/ hadron separation - TAIGA-IACT (image form, monoscopic operation)

Hybrid approach to hadron rejection



The differences between an isolated operation of the IACT and a joint operation together with HiSCORE

Shower source direction and shower core position may come from HiSCORE, not from the IACT image analysis

Shower core may be located on a greater distances from the IACT, so images can partly spread outside of the camera and be truncated

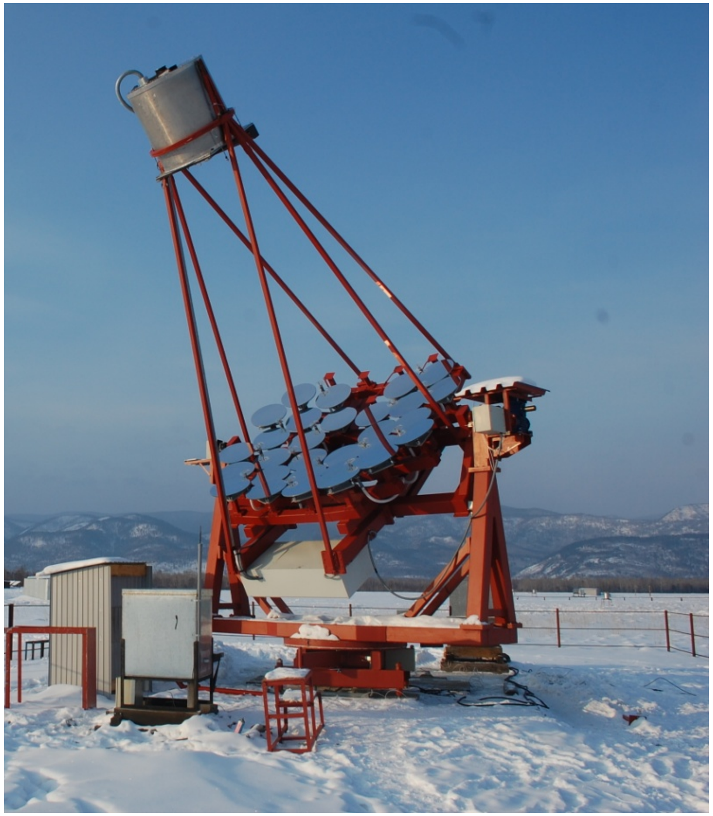
(poster of E.Postnikov et al for more information)

What we can see with 5 km^2 array (short list)

Name	RA degrees	Decl	Flux at 1 TeV, $10^{-12} cm^{-2} s^{-1} TeV^{-1}$ slope Γ	Flux at 35 TeV, $10^{-17} cm^{-2} s^{-1} TeV^{-1}$ (from Milagro)	Time of observation per one year (x 0.5- weater factor)	Number of events per one season E> 40 TeV
Tycho SNR (J0025+641)	6.359	64.13	0.17 ±0.05 Γ=1.95 ±0.5		**236h**	**~80-140 2.5 σ – for HiSCORE, for 12 σ - TAIGA**
Crab	83.6329	22.0145	32.6 ±.9.0 Γ=2.6 ±0.3	162.6 ±9.4	**110h**	~ **300**
SNR IC443 (**MAGIC J0616+225**)	94.1792	22.5300	0.58 ±0.12 Γ=3.1 ±0.30	28.8 ±9.5	**112h**	**10**–(from MAGIC) **200** (from Milagro)
Geminga MGRO C3 PSR	98.50	17.76		37.7 ±10.7	**102h**	**400**
M82 (Starburst Galaxy)	148.7	69.7	0.25 ±0.12 Γ=2.5 ±0.6±0.2		**325h**	**50**
Mkn 421 (BL, z=0.031 Variable)	166.114	38.2088	50-200 Γ=2.0-2.6		**140h**	**20 – 1000 ??**
SNR 106.6+2.7 (J2229.0+6114)	337.26	61.34	1.42 ±0.33 ±0.41 Γ=2.29 ±0.33 ±0.30	70.9 ±10.8	**167h**	**400** (from VERITAS **700** (from Milagro)
Cas A (SNR)	350.853	58.8154	1.26 ±0.18 Γ=2.61 ±0.24±0.2		**177h**	**100**
CTA_1(SNR,PWN)	1.5	72.8	1.3 Γ=2.3		**266 h**	**500**

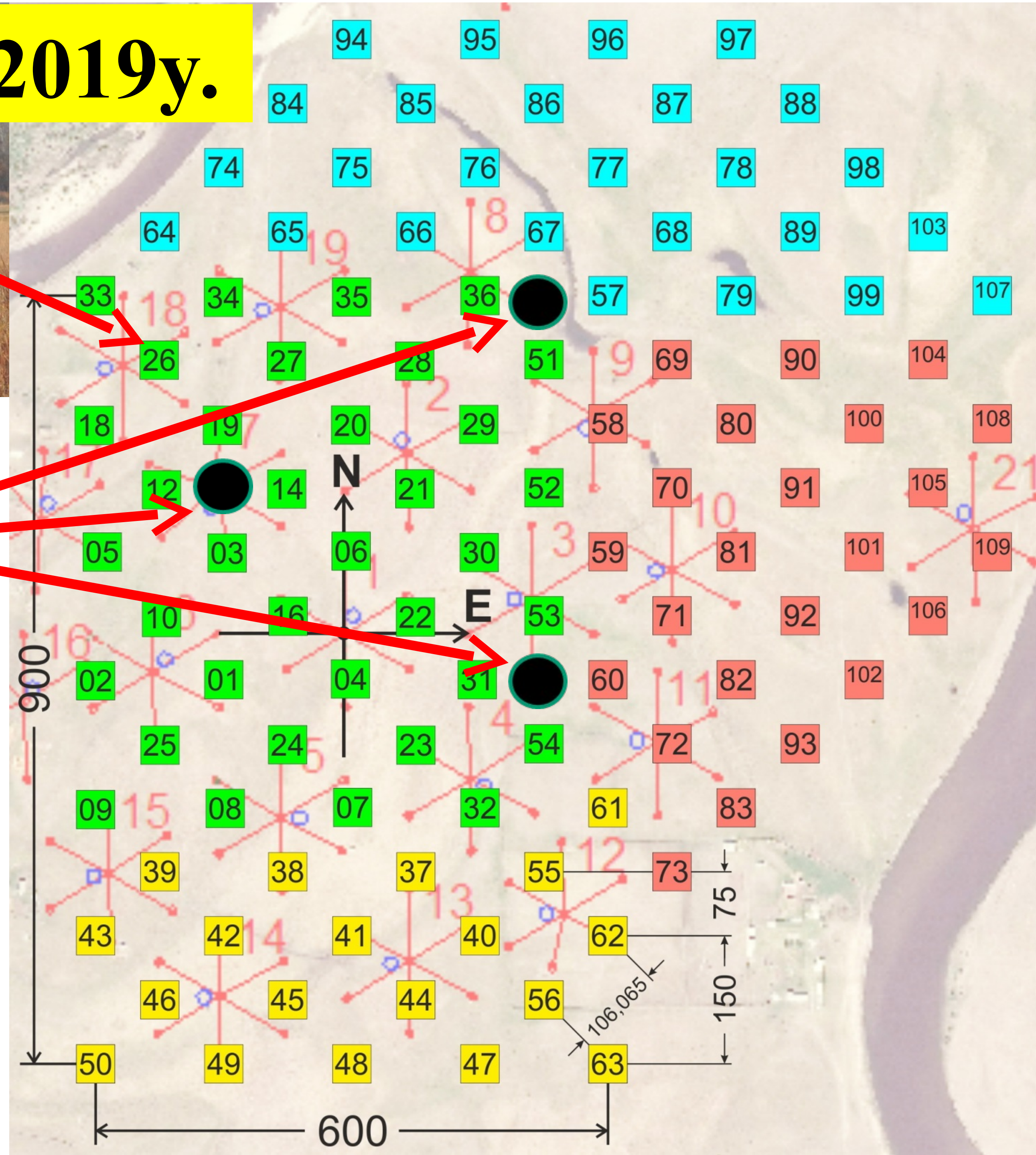
TAIGA- prototype

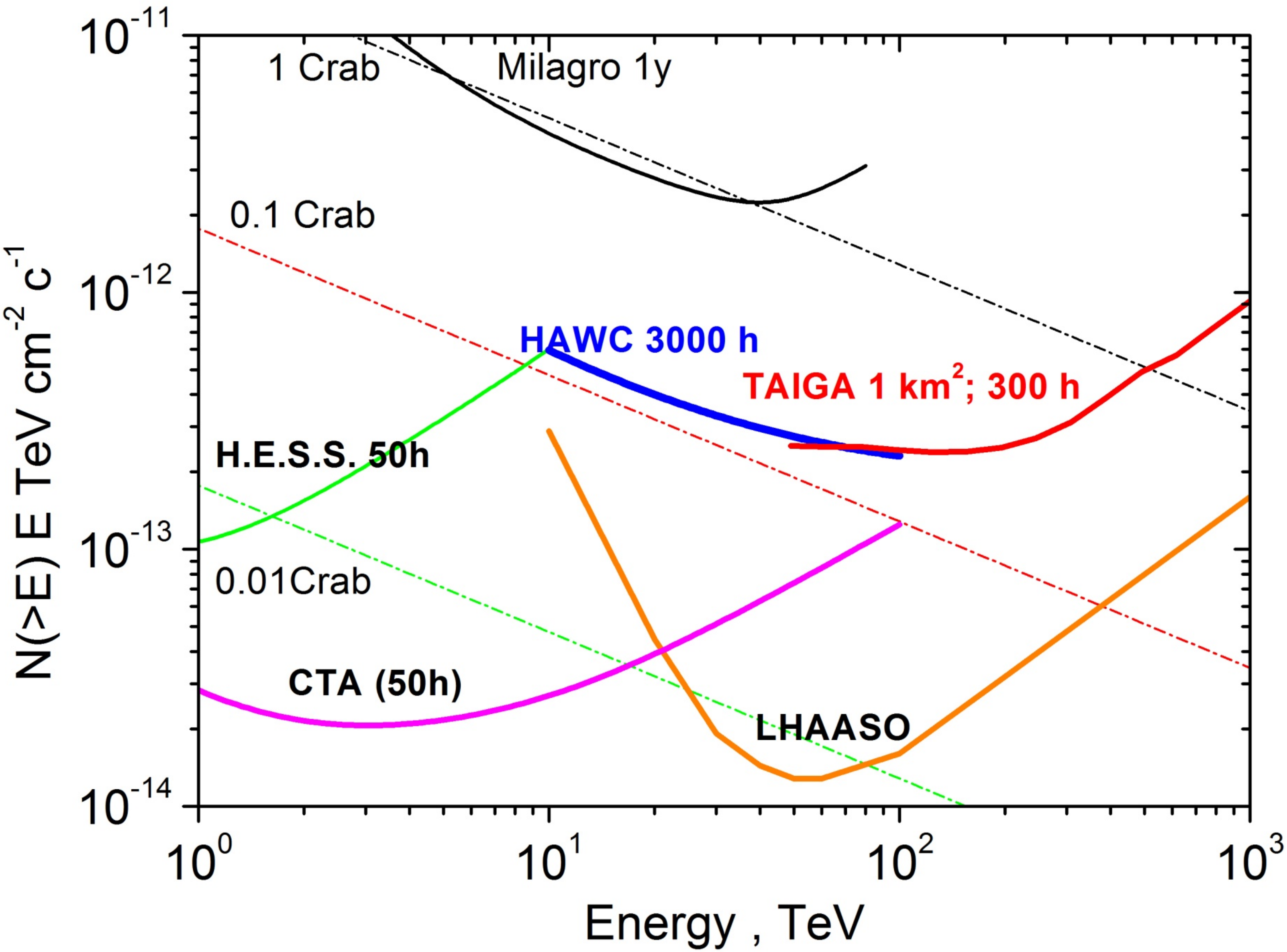
100 wide angle station on the area 1 km² and 3 IACTs



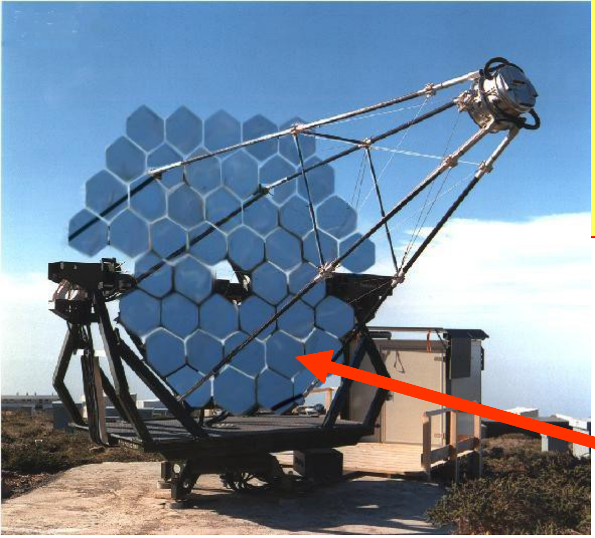
All station are tilting to the South on 25 deg

The TAIGA 2019y.





1 Crab
Milagro 1y
0.1 Crab
HAWC 3000 h
TAIGA 1 km^2; 300 h
H.E.S.S. 50h
0.01Crab
CTA (50h)
LHAASO
10^{-11}
10^{-12}
10^{-13}
10^{-14}
10^0
10^1
10^2
10^3
N(>E) E TeV cm^{-2} c^{-1}
Energy , TeV



TAIGA-IACT

D = 4.32m F = 4.75m

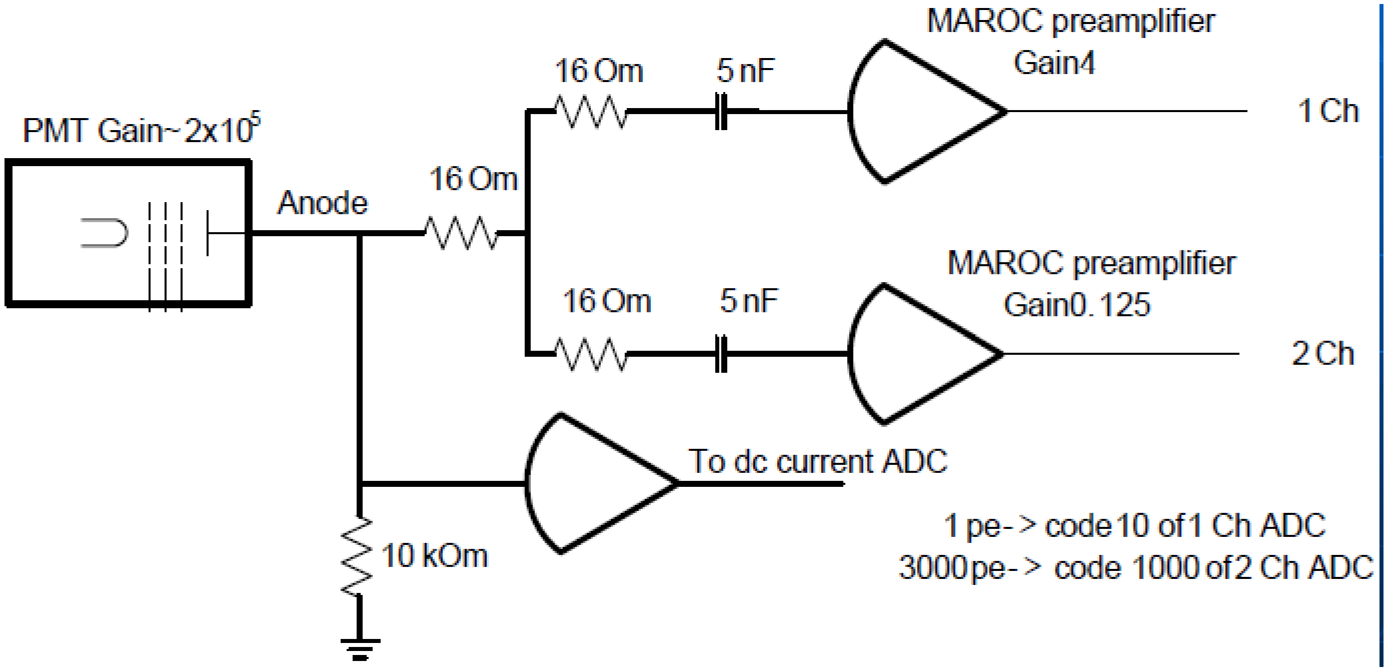
34 mirrors of 60 cm diameters

Camera : 547 PMTs (XP 1911) with 15 mm useful diameter of photocathode
Winston cone: 30 mm input size, 15 output size
1 single pixel = 0.36 deg
full angular size 9.6x9.6 deg

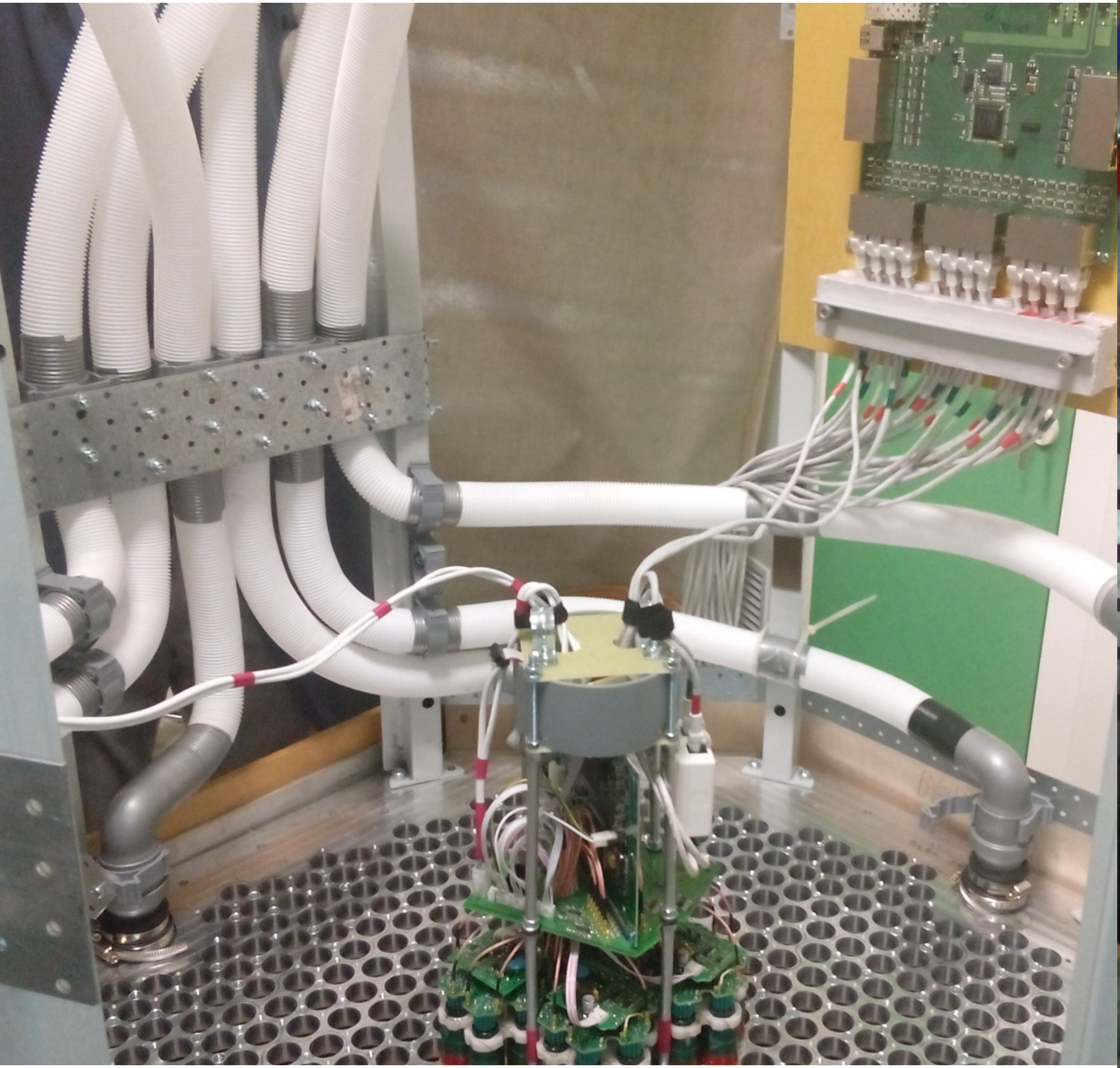
Energy threshold ~1.5 TeV

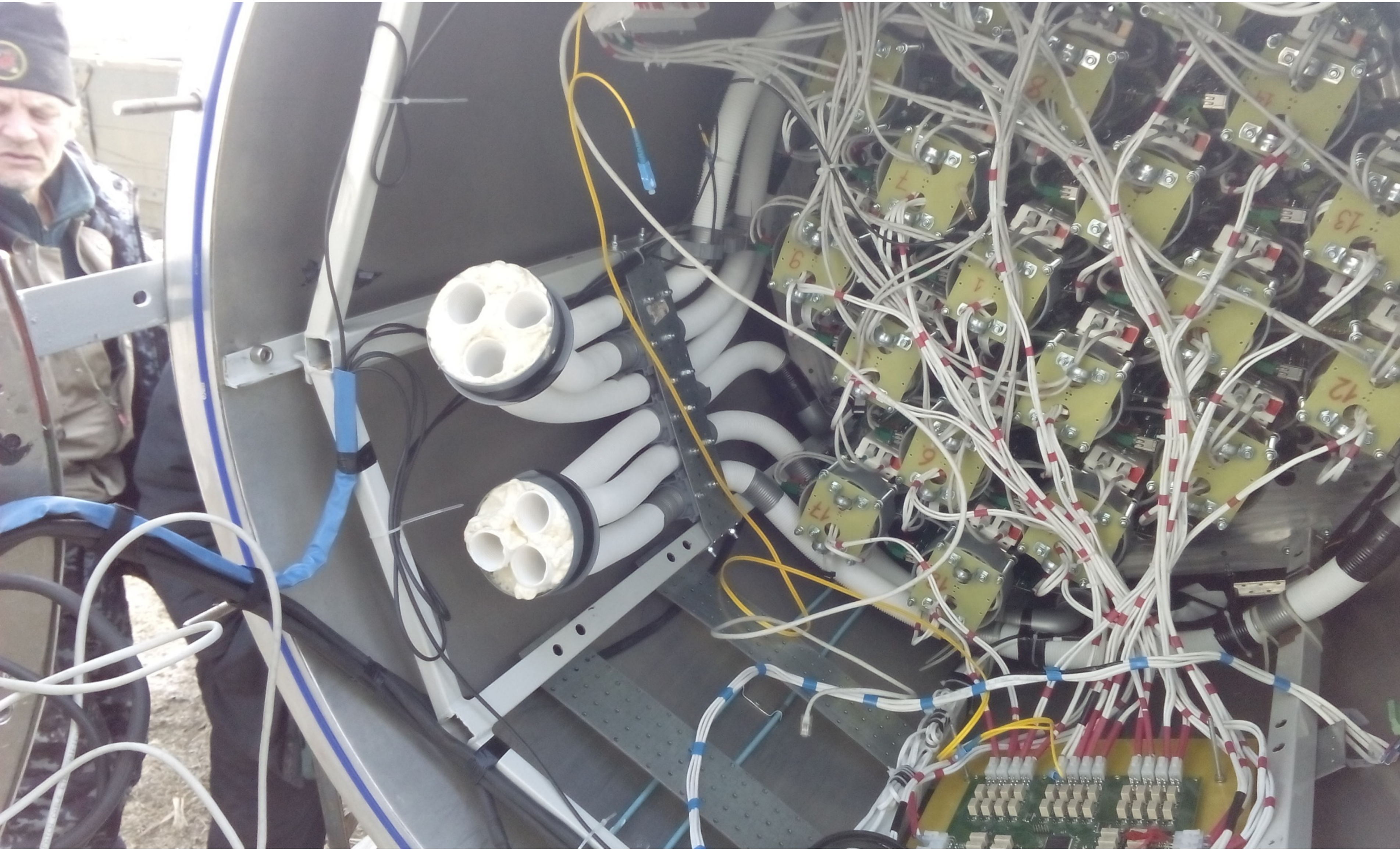
Cost : 300 Keur

Marching of the PMT anode signal output with MAROC-3

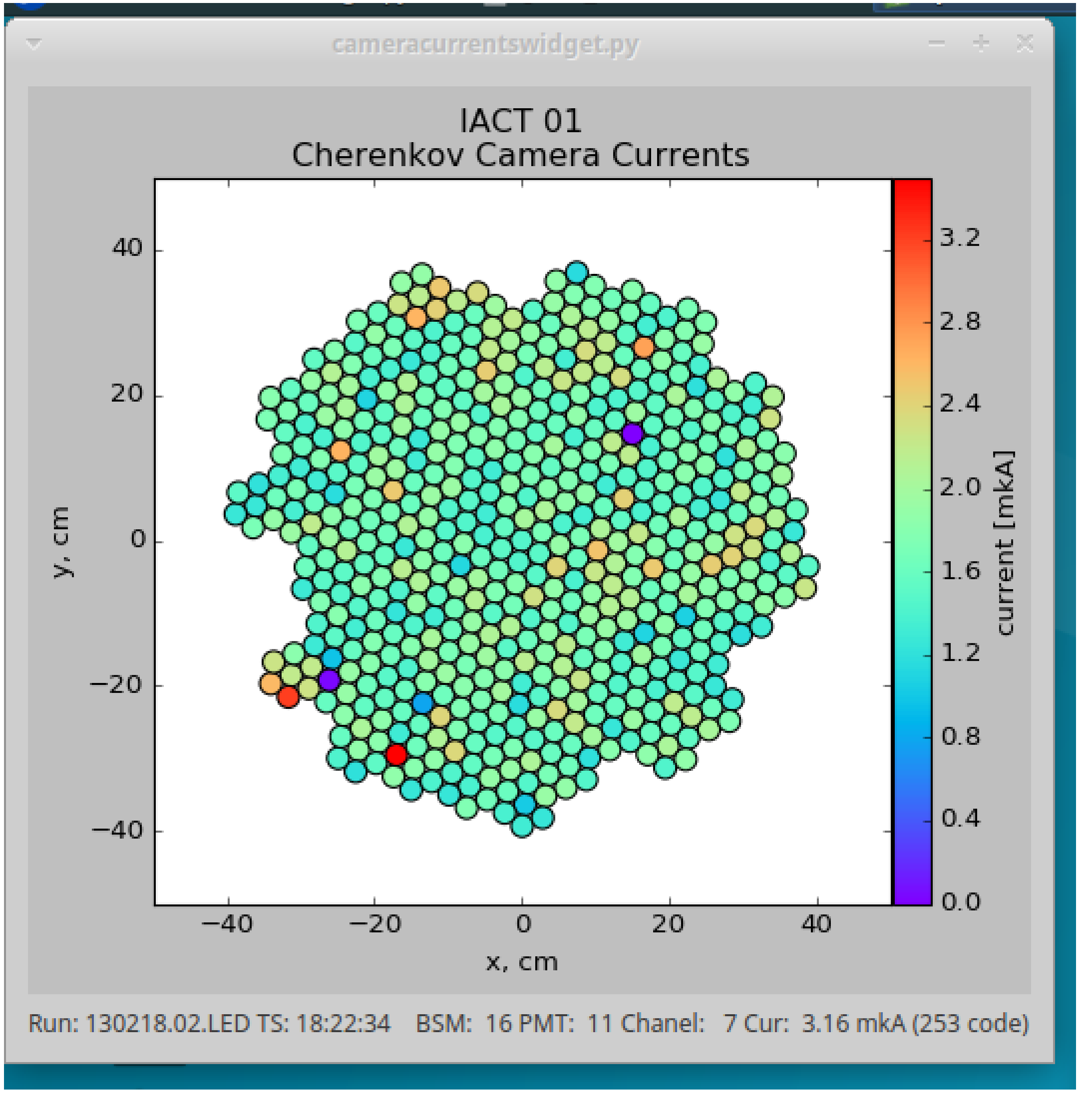


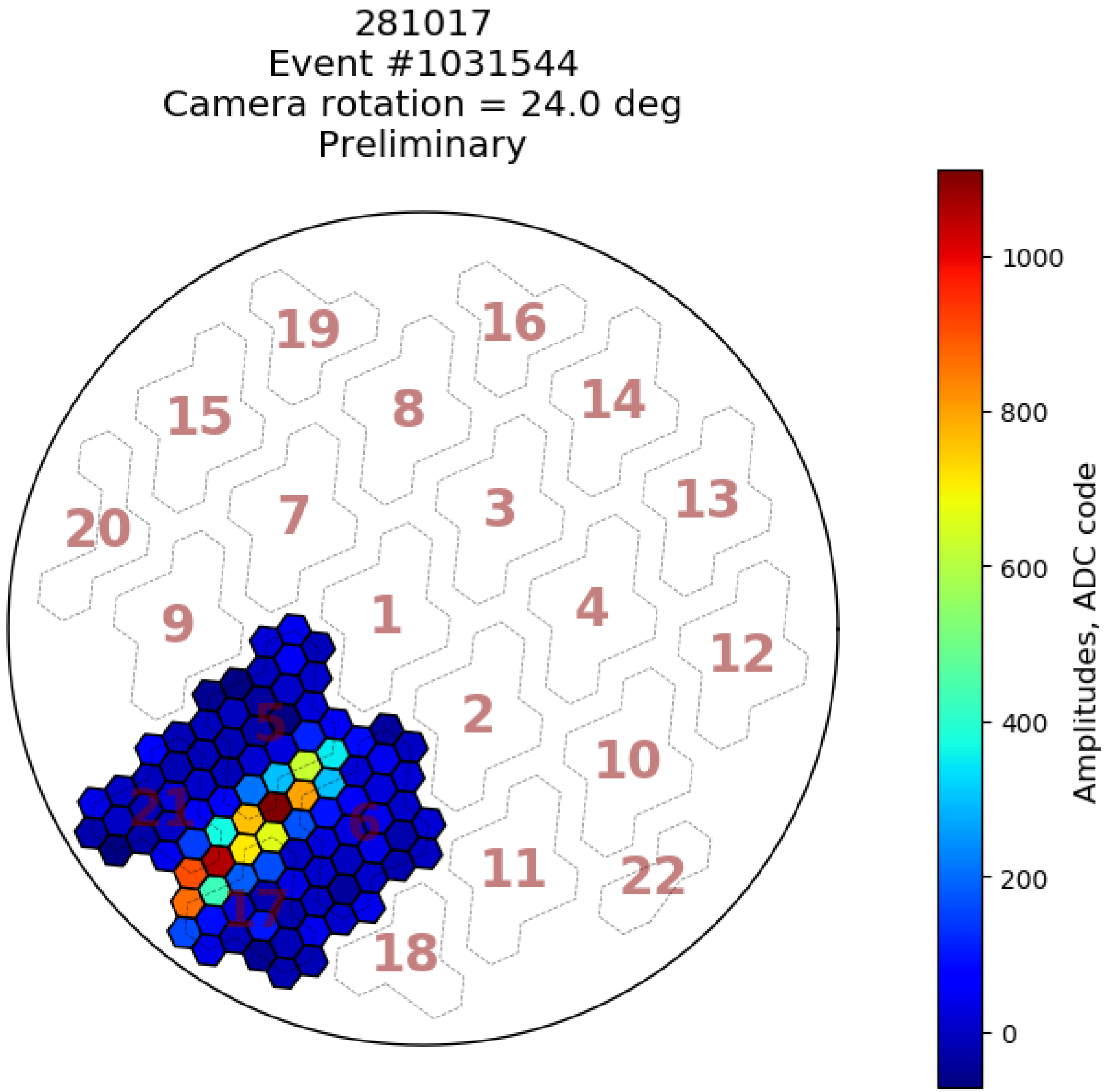
Dynamic range ~ $4 \cdot 10^4$ p.e.



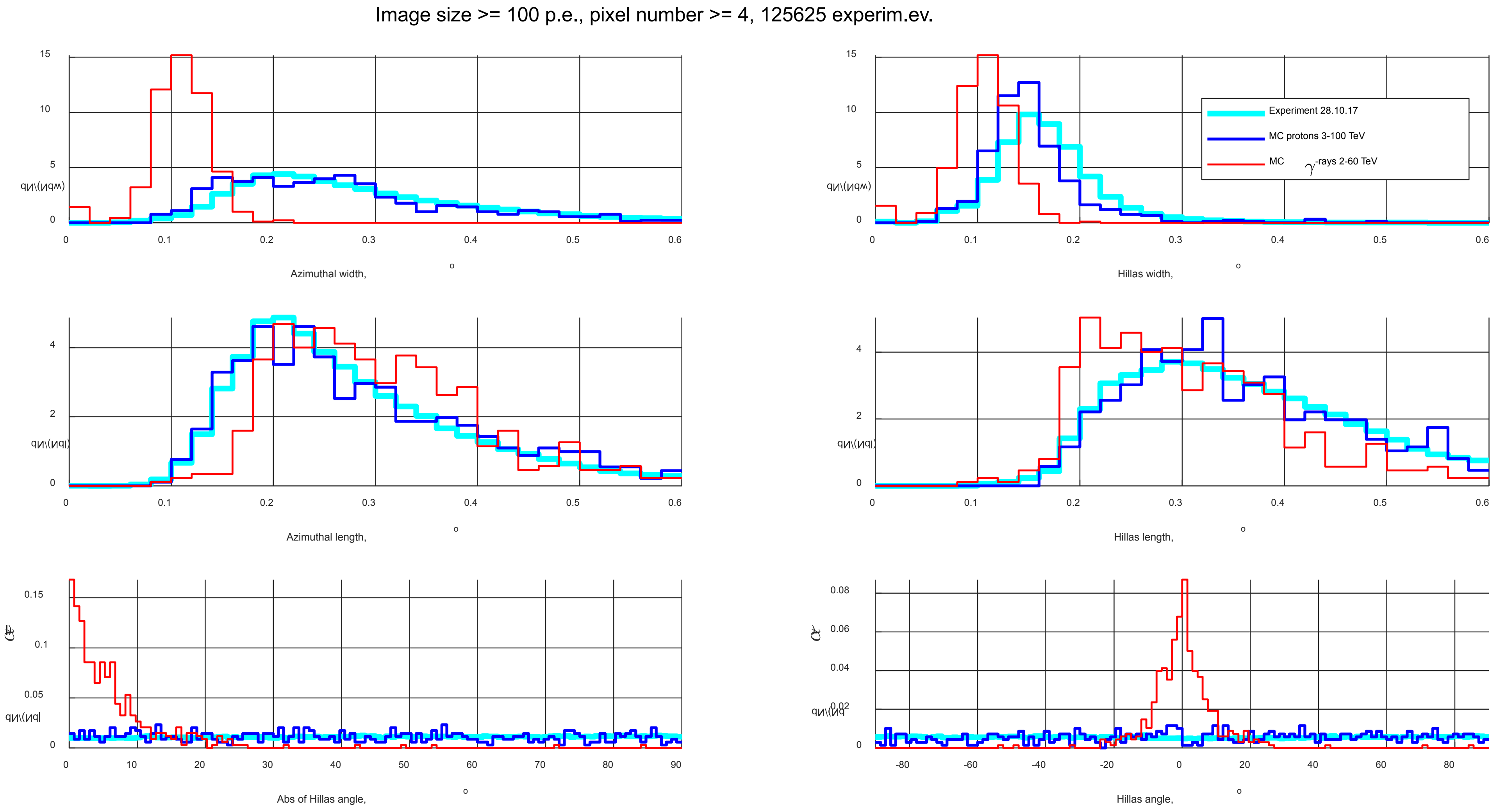
Current monitor

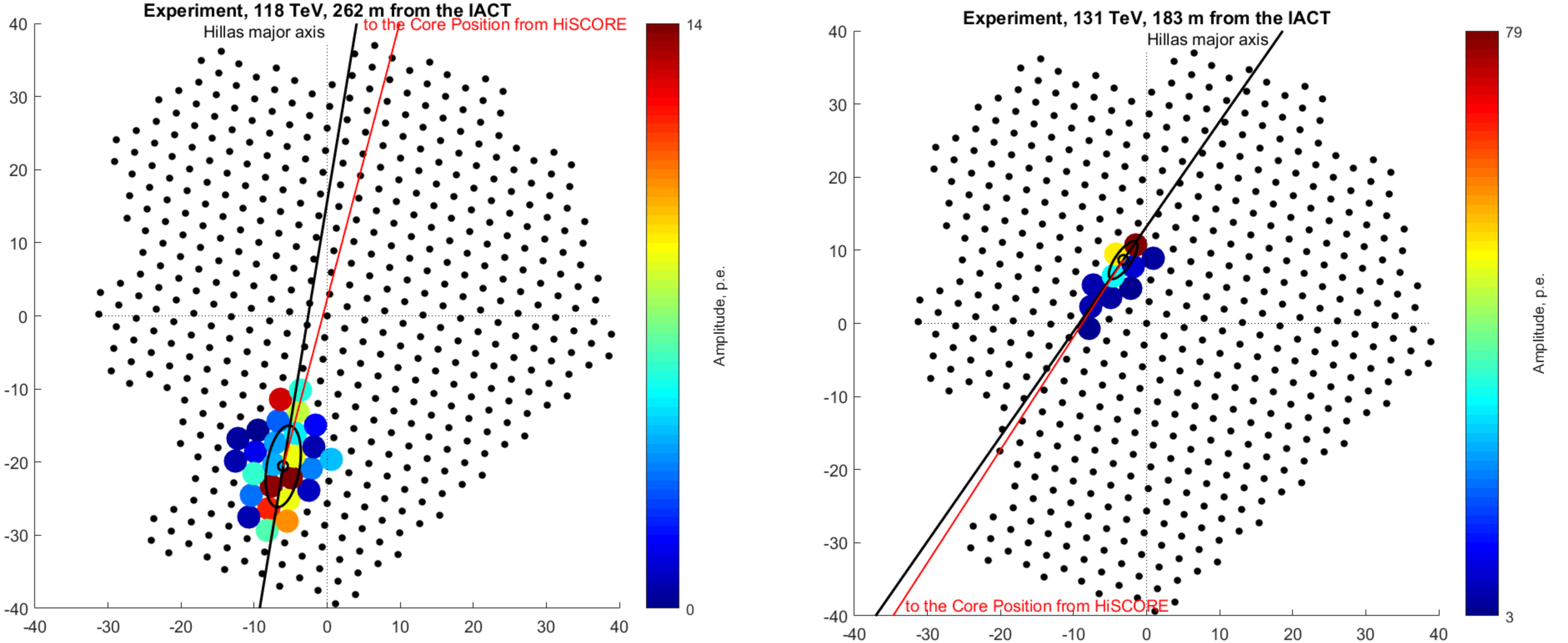




281017
Event #1031544
Camera rotation = 24.0 deg
Preliminary
19
16
15
8
14
20
7
3
13
9
1
4
12
5
2
10
21
6
11
22
17
18
1000
800
600
400
200
0
Amplitudes, ADC code

- **Good agreement between experiment and Monte Carlo (protons) in image form and orientation** parameters: width, length etc.

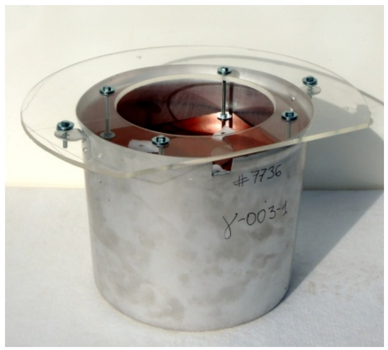




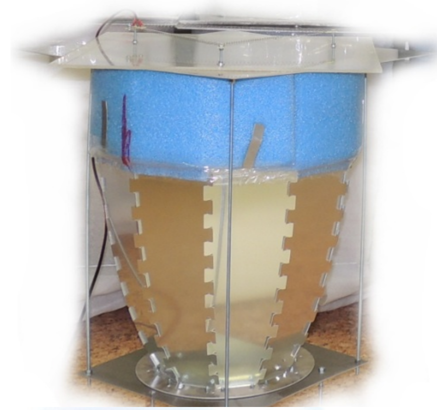
Examples of images of EAS with different energies and different distances from axis of the EAS to the telescope. Black line - the direction of the major axis of the ellipse Hillas. Red line - direction to the position of the EAS axis according to data HISCORE. With perfect recovery, both lines must coincide

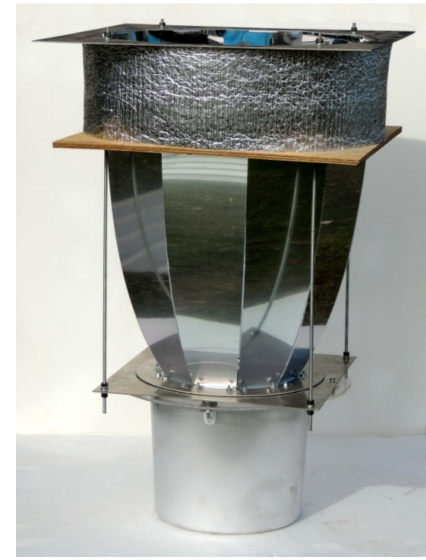
HiSCORE optical station

20 см



40 см

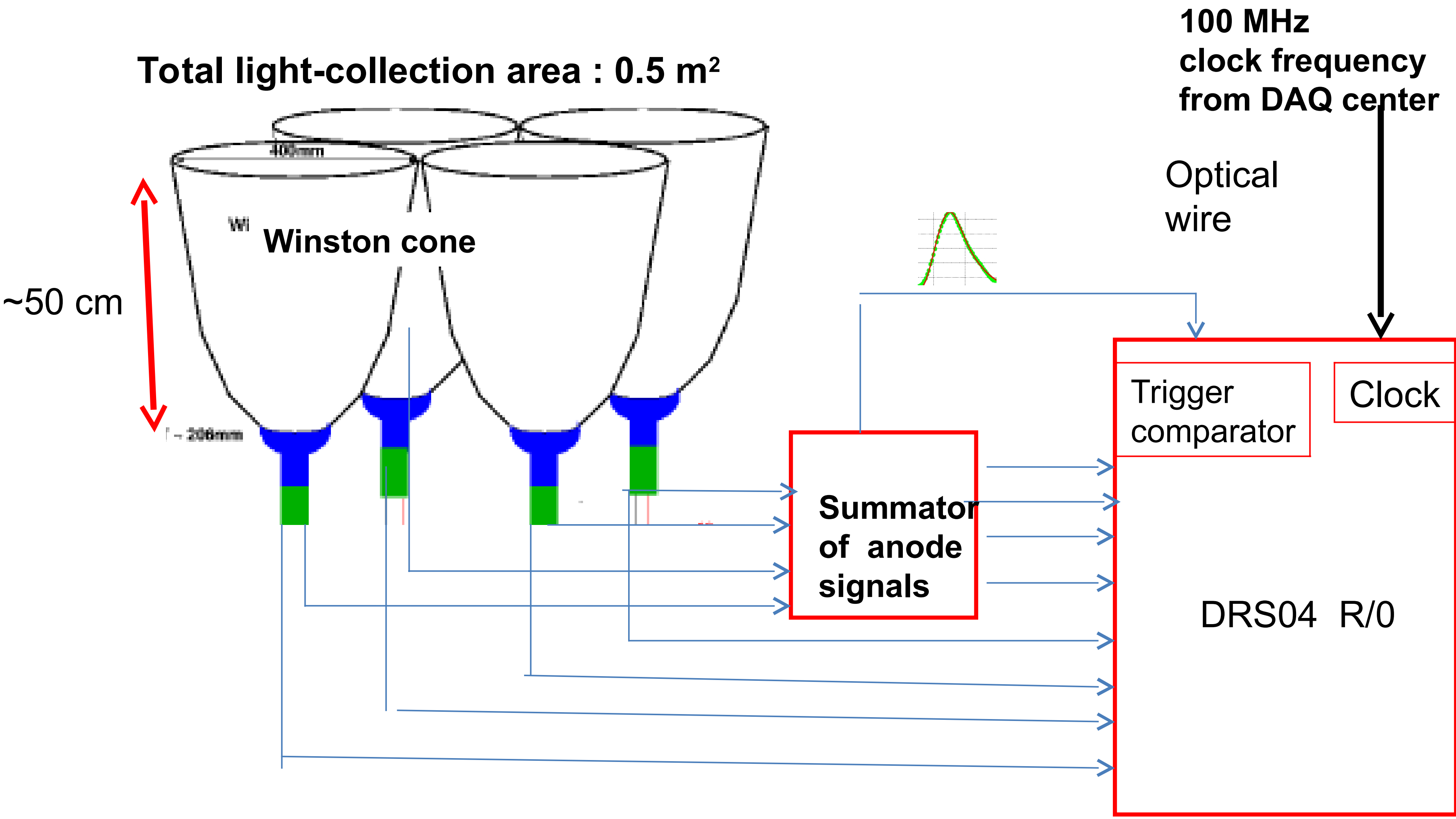




S = 0.5 m²

FOV = 0.6 ster
(±30°)

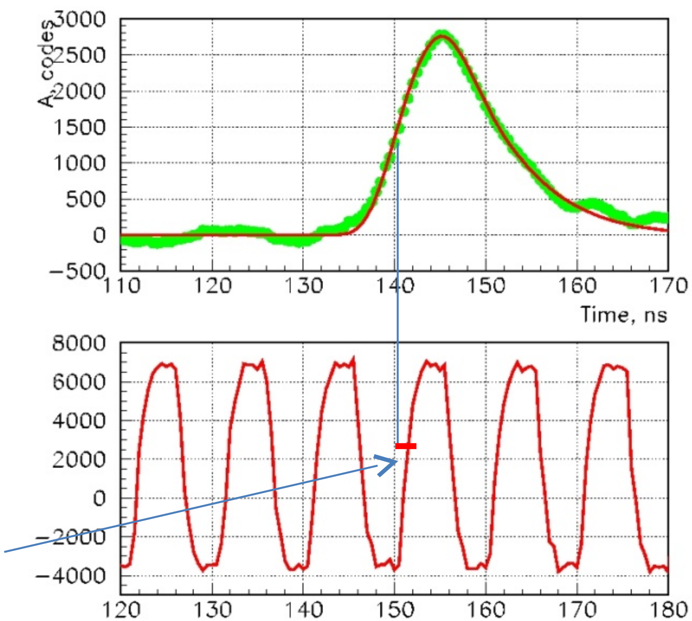
Triggering and Readout



Accuracy of time measurement

Readout of DRS-4 board

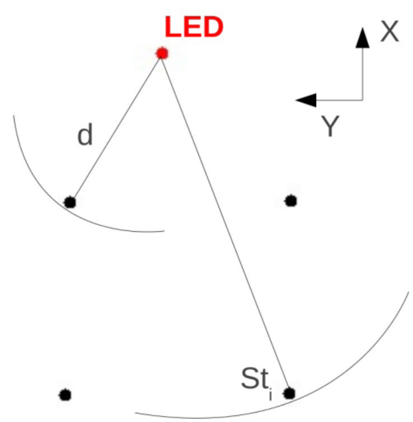
t_ns = T_opt.cable (0.1 ns step)
+T_clock (10 ns step)
+ t_add (0.5 ns step)
+ t_corr - after calibration by experimental data



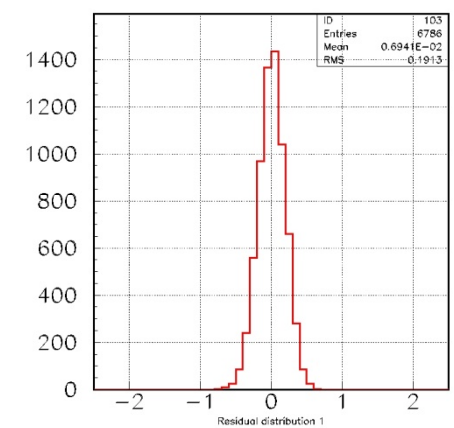
t_add

100 MHz clock frequency

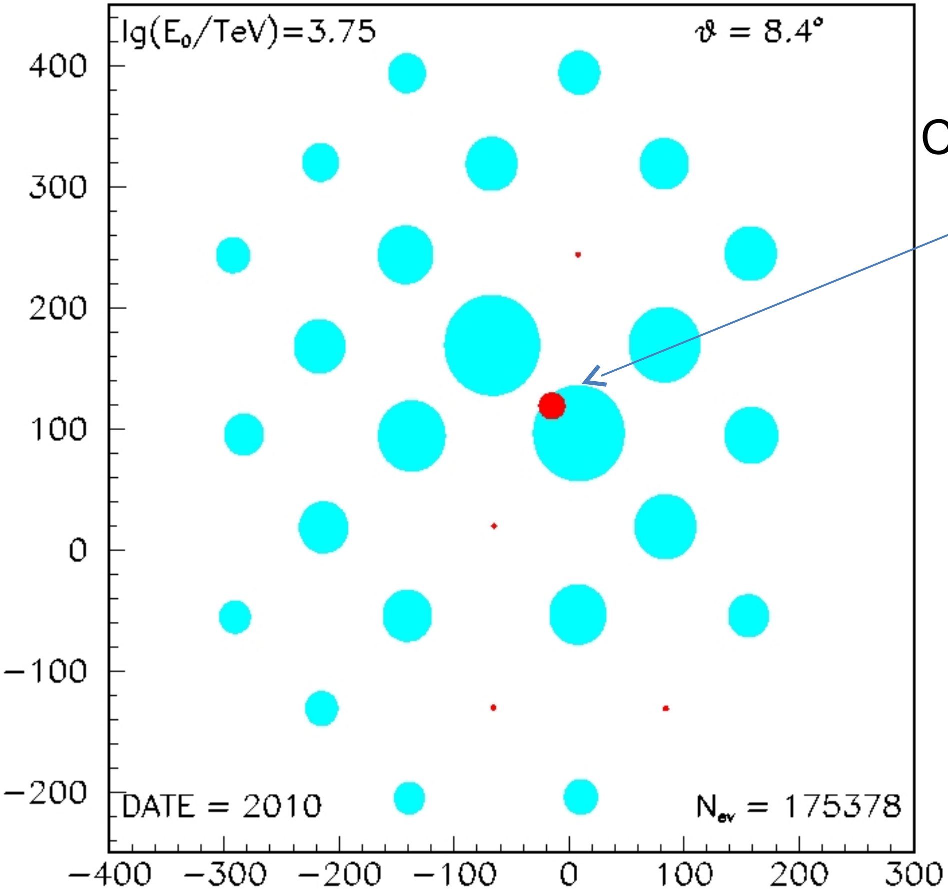
Time calibration with single LED



Delay distribution at one of the stations for LED pulses relative to geometrical calculation in ns – RMS=0.2 ns

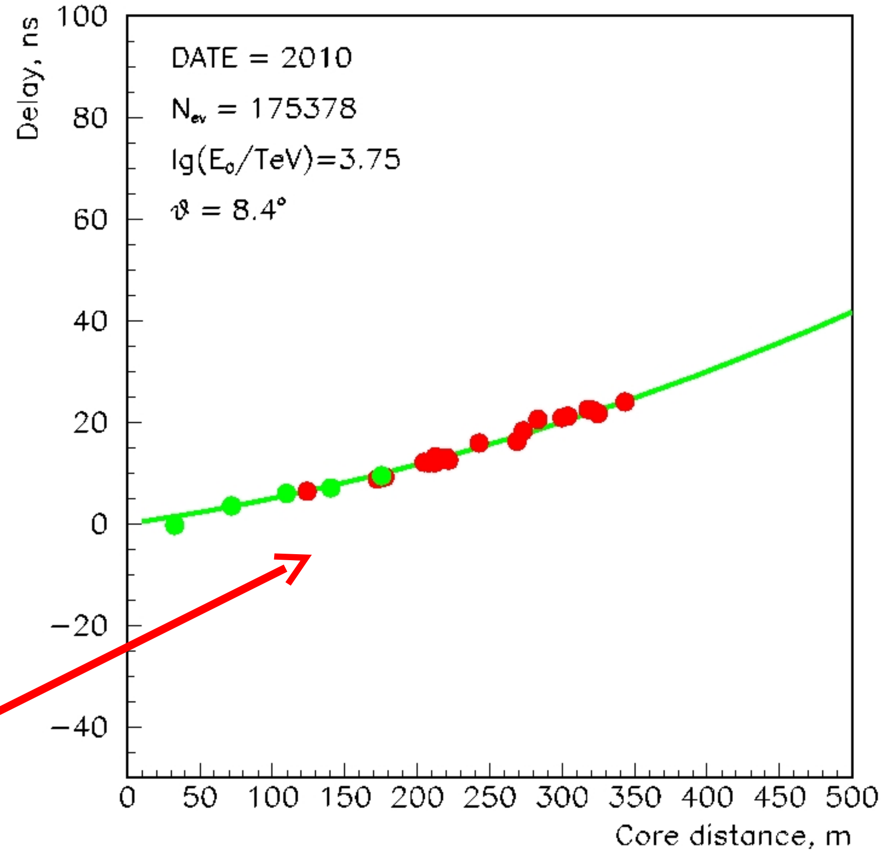


Event example

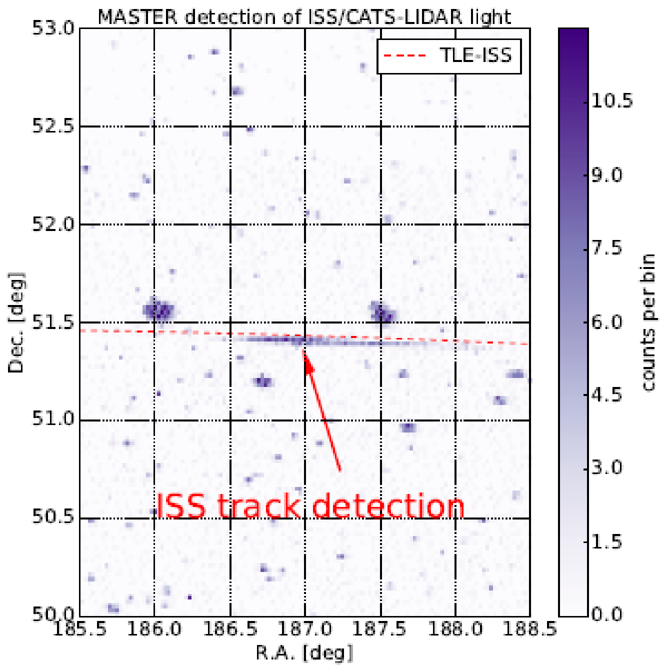


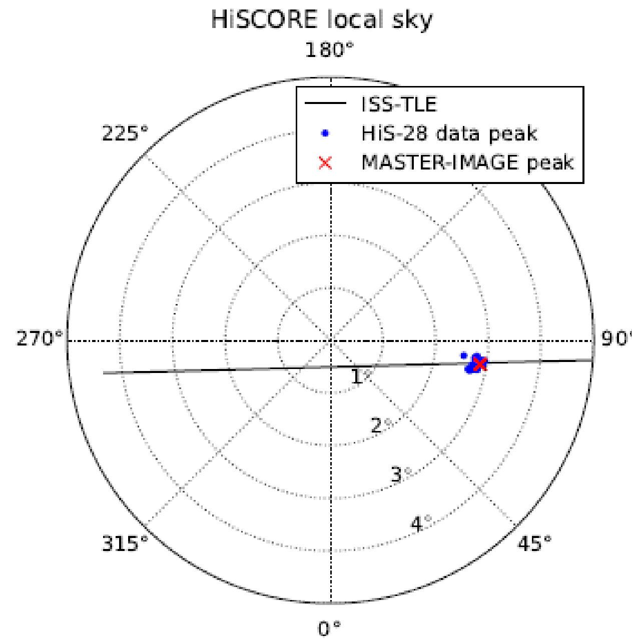
R ~ Lg (Photon flux)

Core Position



EAS time front

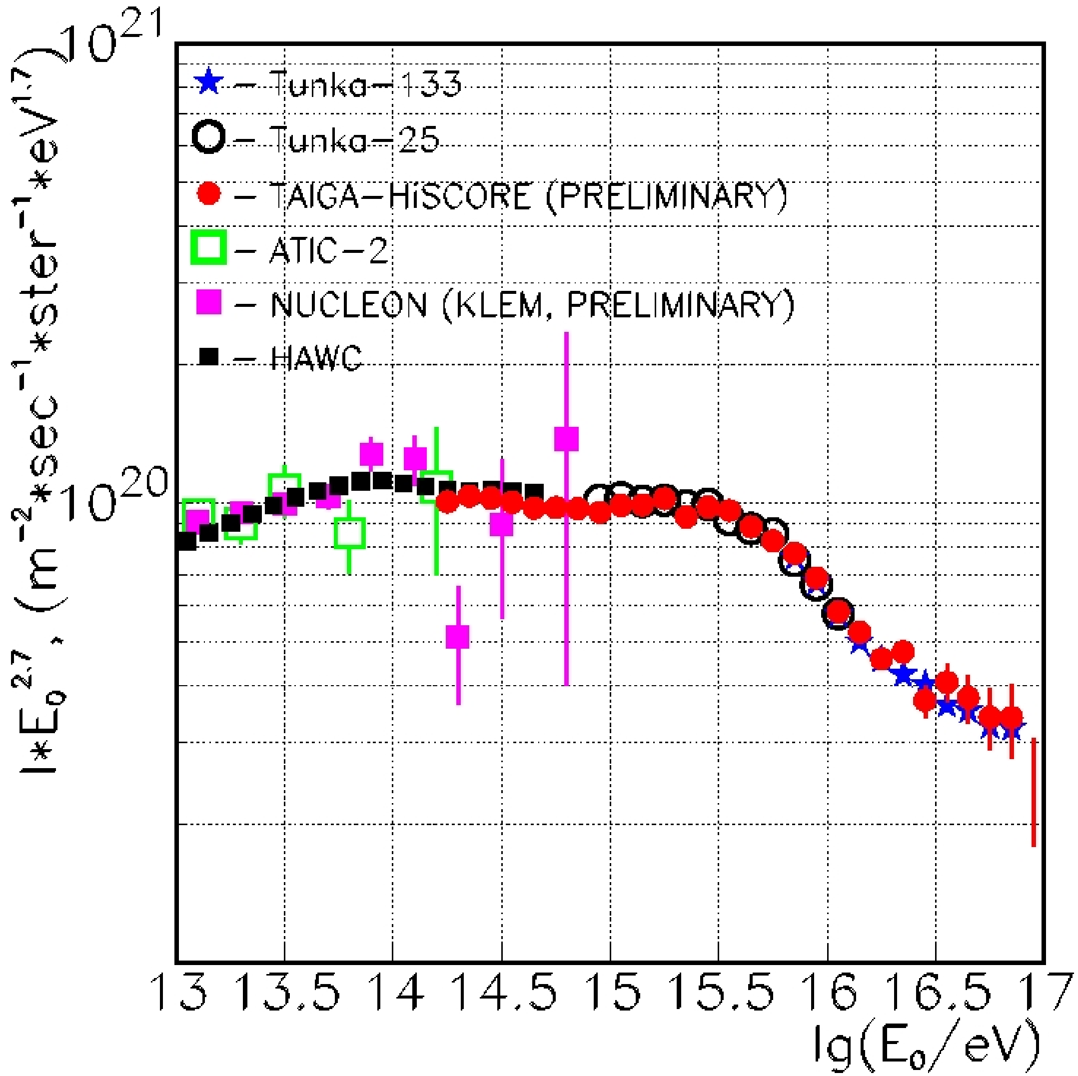




Joint monitoring of the signal from the CATS (Cloud Aerosol Transport System) - Lidar onboard the ISS (23.03 2017) with the MASTER telescope and the TAIGA-HiSCORE installation

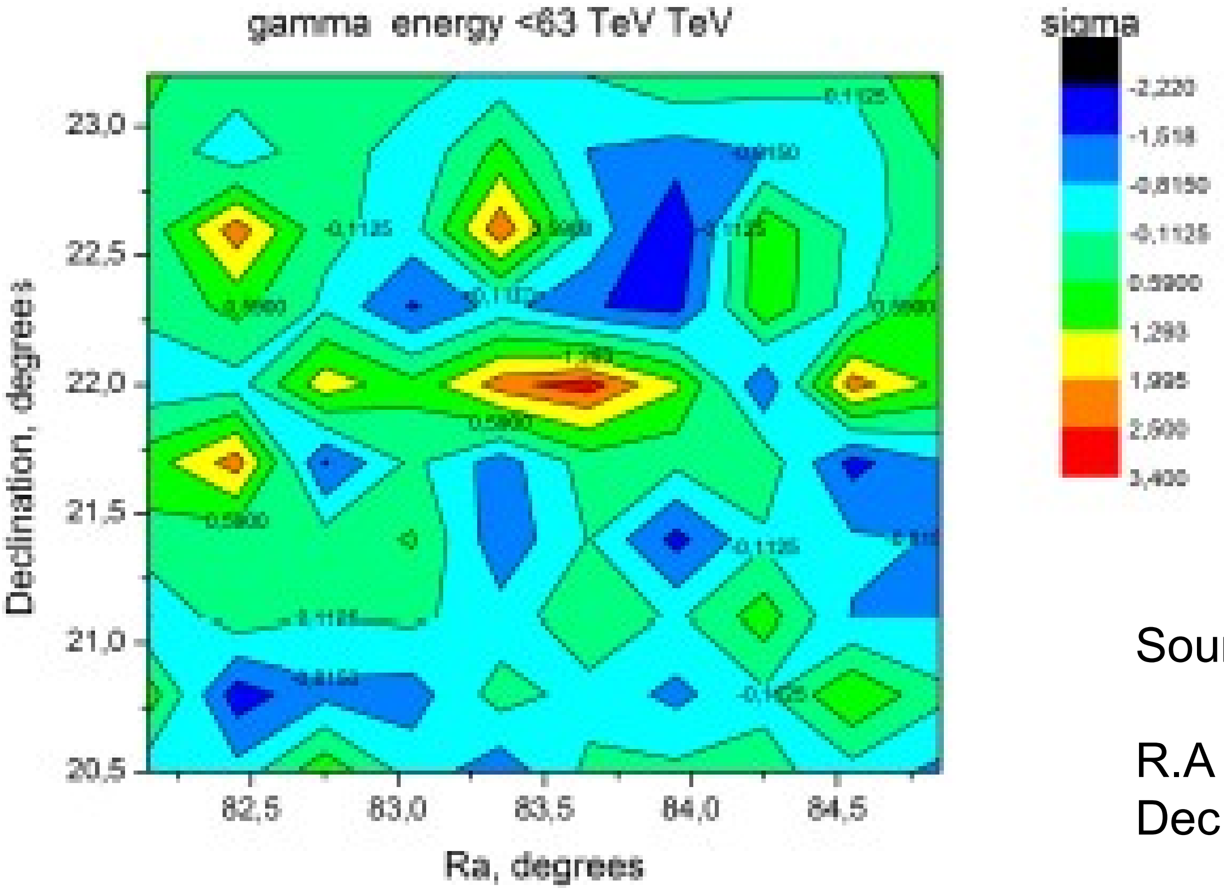
A)Source track on telescope observation MASTER
B) The position in the local coordinate system of events from a source restored According to the installation of TAIGA-HiSCORE. The events with the largest amplitude are selected in the stations.
Cross - the position of the brightest point of the track, recounted in local reference system

Error of angle reconstruction by HiSCORE <0.1 °



- Tunka-133
- Tunka-25
- TAIGA-HiSCORE (PRELIMINARY)
- ATIC-2
- NUCLEON (KLEM, PRELIMINARY)
- HAWC
$I*E_0^{2.7}$, $(m^{-2}*sec^{-1}*ster^{-1}*eV^{1.7})$
10^{21}
10^{20}
13 13.5 14 14.5 15 15.5 16 16.5 17
$lg(E_0/eV)$

Signal from Crab Nebula in High energy range (2.5 σ) – in agreement with expected



Source position

R.A = 83.6 deg
Dec = 22.01 deg

Conclusion

1 TAIGA - 5 km^2 hybrid array (500 wide-angle stations and 10-16 IACTs). The sensitivity for local sources in the energy range 30 -200 TeV is expected be **– 10^{-13} TeV cm^{-2} sec^{-1} (for 500 h observation)**

2. Deployment of the full scale TAIGA prototype -100 wide-angle stations and three IACTs will be finished in 2019.

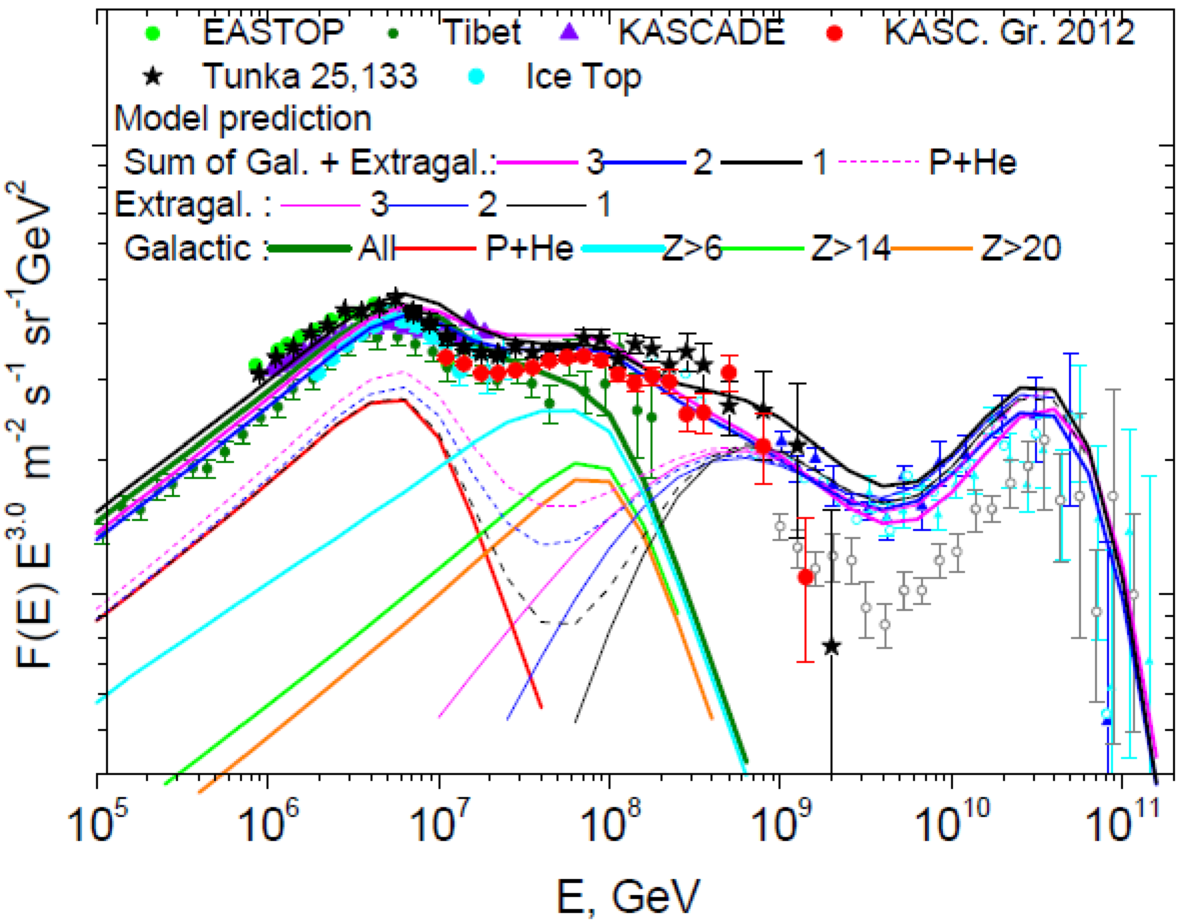
The expected sensitivity for 300 hours source observation with this array in th range 30 – 200 TeV is about **2.5 10^{-13} TeV/(cm^2 sec),** extending the energy range of existing and planned experiments to the ultra-high energy range.

3. The first commission seasons were successful:

- Suppression of bugs in hardware and software
- CR energy spectrum below the knee
- 2.5 σ signal from Crab (in agreement with expected)
- Lidar on board ISS – light calibration source for TAIGA
- First results from joint operation of HiSCORE and IACT

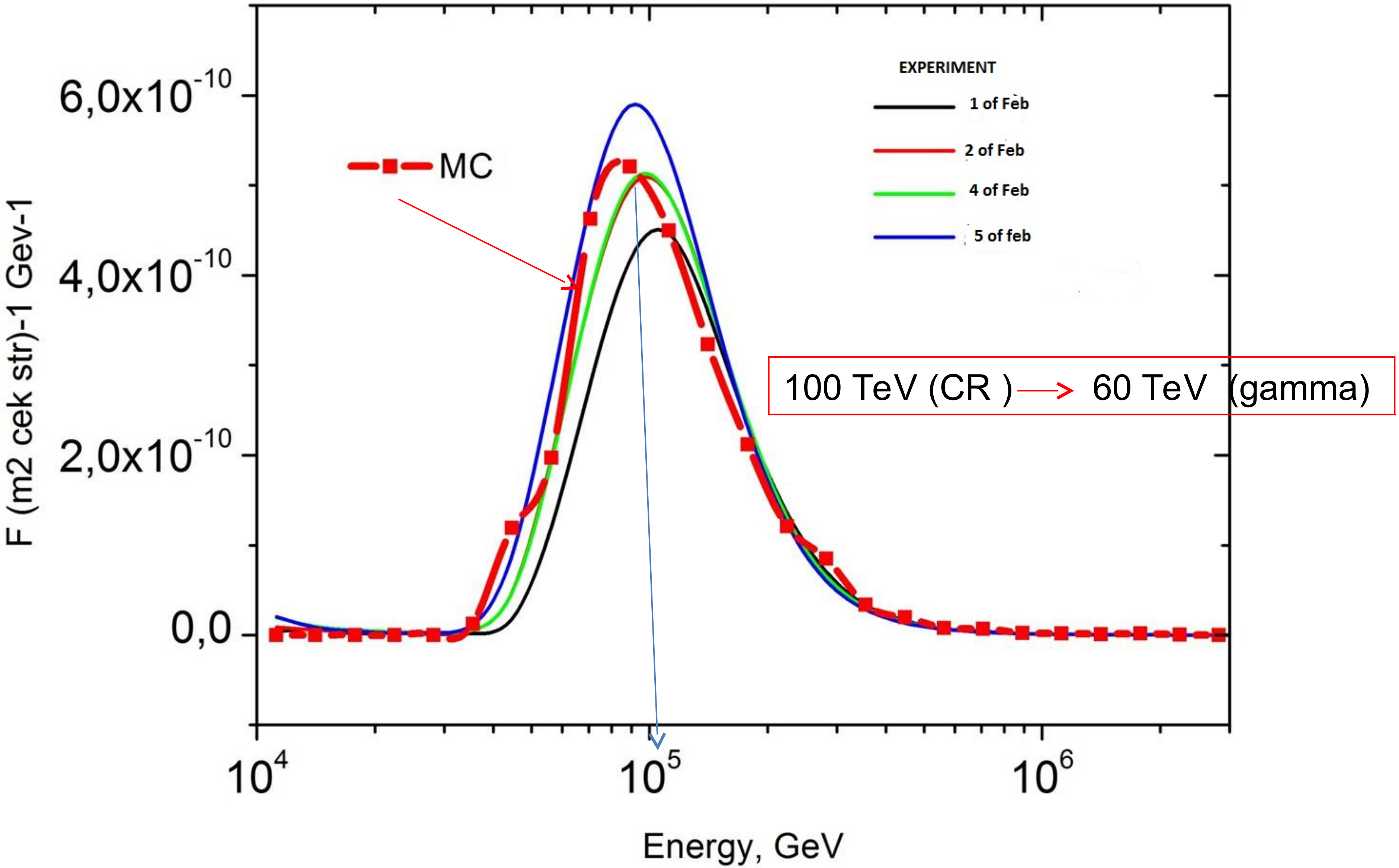
Thank you

The attempt to explain hardening (L.Sveshnikova 2013)

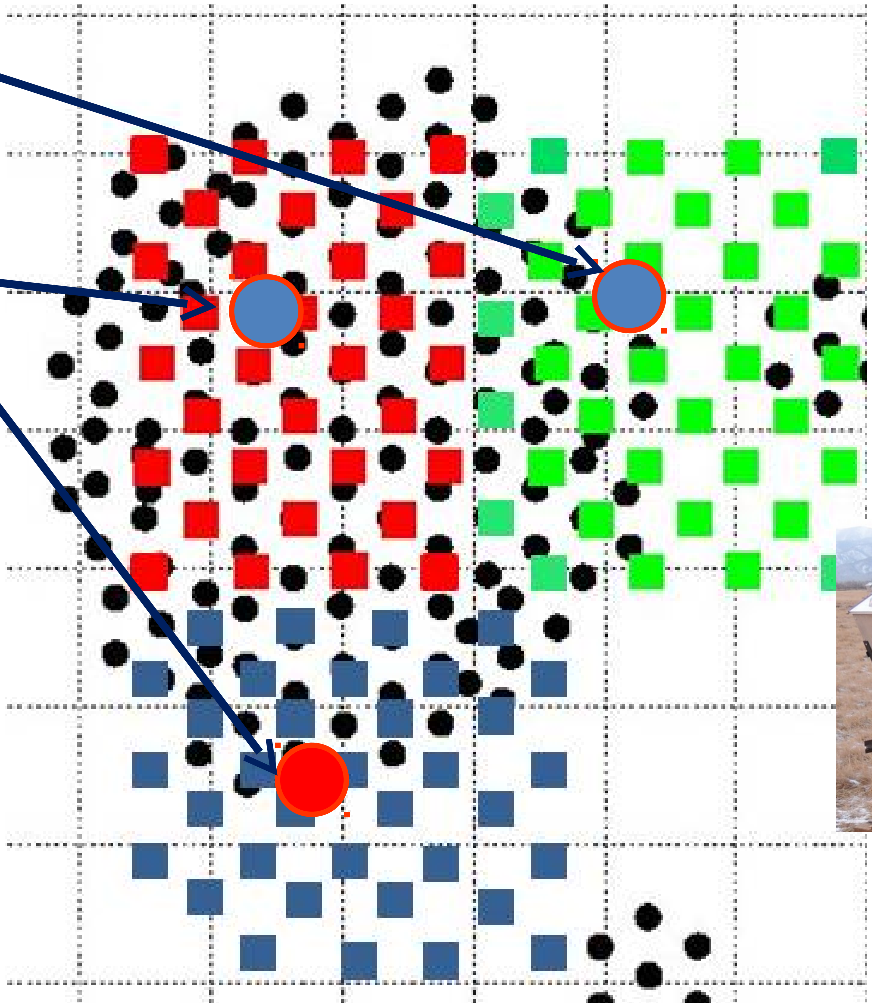


composition at 1PeV: H 17%, He 46%,
CNO 8%, Fe 16%

Energy distribution (MC & Experiment)



План развития гамма-обсерватории TAIGA на 2017-2019 годы.



3 телескопа
TAIGA-IACT
100-120 станций
TAIGA-HiSCORE
500 м^2
TAIGA-Muon
Площадь 1 км^2