Установка Тунка: от космических лучей к гамма-астрономии

Л.А.Кузьмичев (НИИЯФ МГУ)
От коллаборции Тунка и TAIGA

Дубна, 13 августа 2014

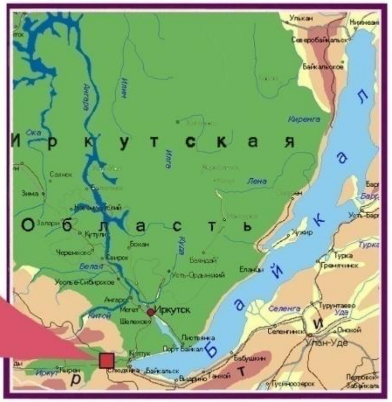
План доклада

- 1. Статус установки Тунка-133 и главные результаты
- 2. Планы по модернизации установки

  3. Гамма-астрономия высоких энергий в Тункинской долине

Tunka-133 array:
175 optical detectors on 3 km^2 area

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



Some important steps towards Tunka-133

1. 2002: G.Navarra suggested to ask for PMTs from MACRO for the new array.

2. 30.12 2003: 200 PMT in Moscow.

3 2004 : Starting R&D - financial support from DFG- RFBR.

4. 2005: Optical cable (~ 10km) from the closed project EAS1000.

5. 2006 : Starting of financial support of the project from Ministry of Education and Science. Project budget ~ 100 -150 KEU per year

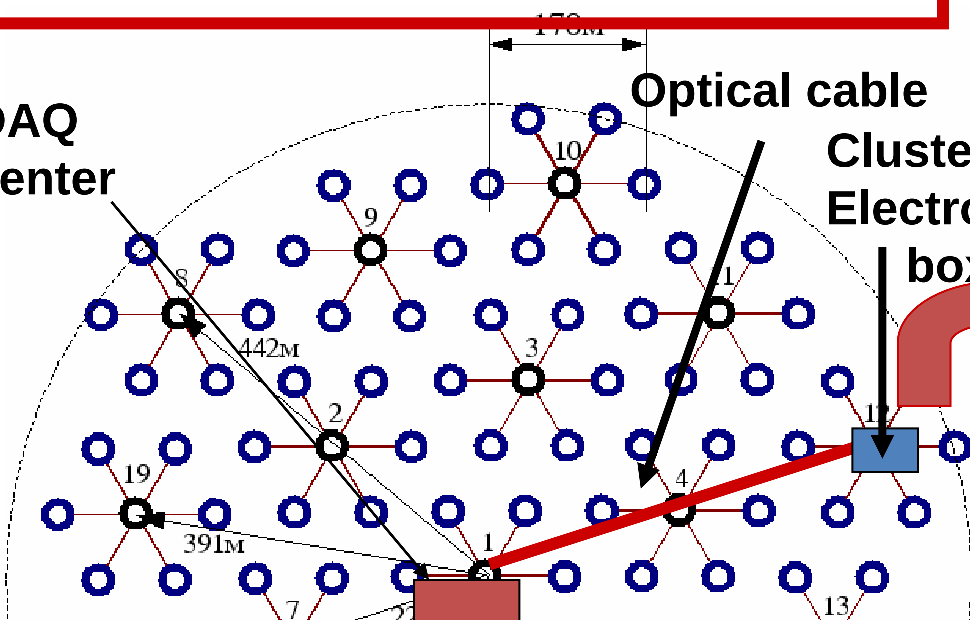
Gianni("Ramon") Navarra
12/9/1945 - 24/8/2009

Karlsruhe, March 2009

Moscow, October 2005

Tunka Inauguration (Septermber 2009)

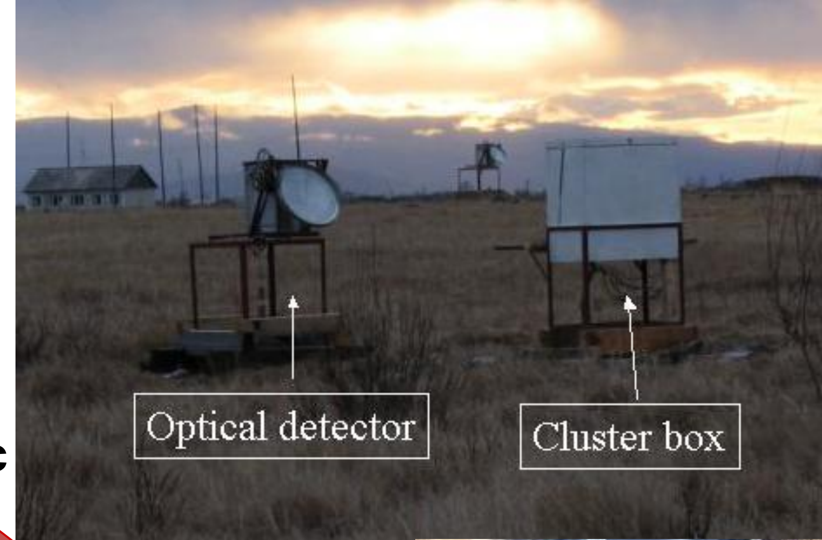
Tunka-133: 19 clusters,
7 detectors in each cluster

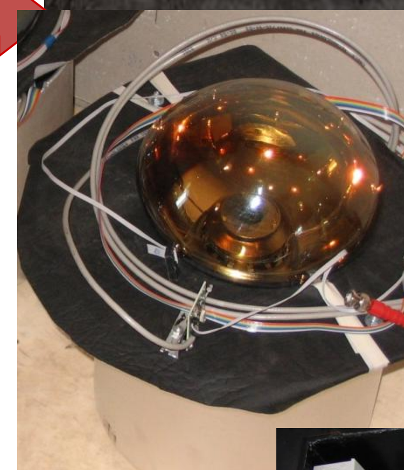


DAQ center

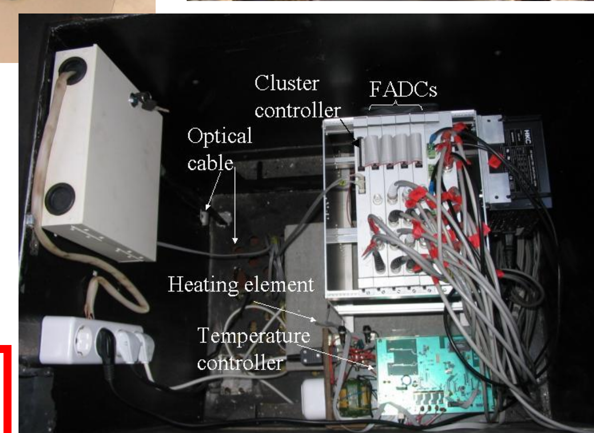
Optical cable

Cluster Electronic box





PMT
EMI 9350
Ø 20 cm



4 channel FADC boards
200 MHz, 12 bit

Physics goals

1. Cosmic Rays in the energy range of 10^{16} - 10^{18} eV: Transition form Galactic CR to extragalactic.
Main results: all particle energy spectrum and mass composition

2. Search for gamma-rays with energies of $5 \cdot 10^{16}$ - $5 \cdot 10^{17}$ eV

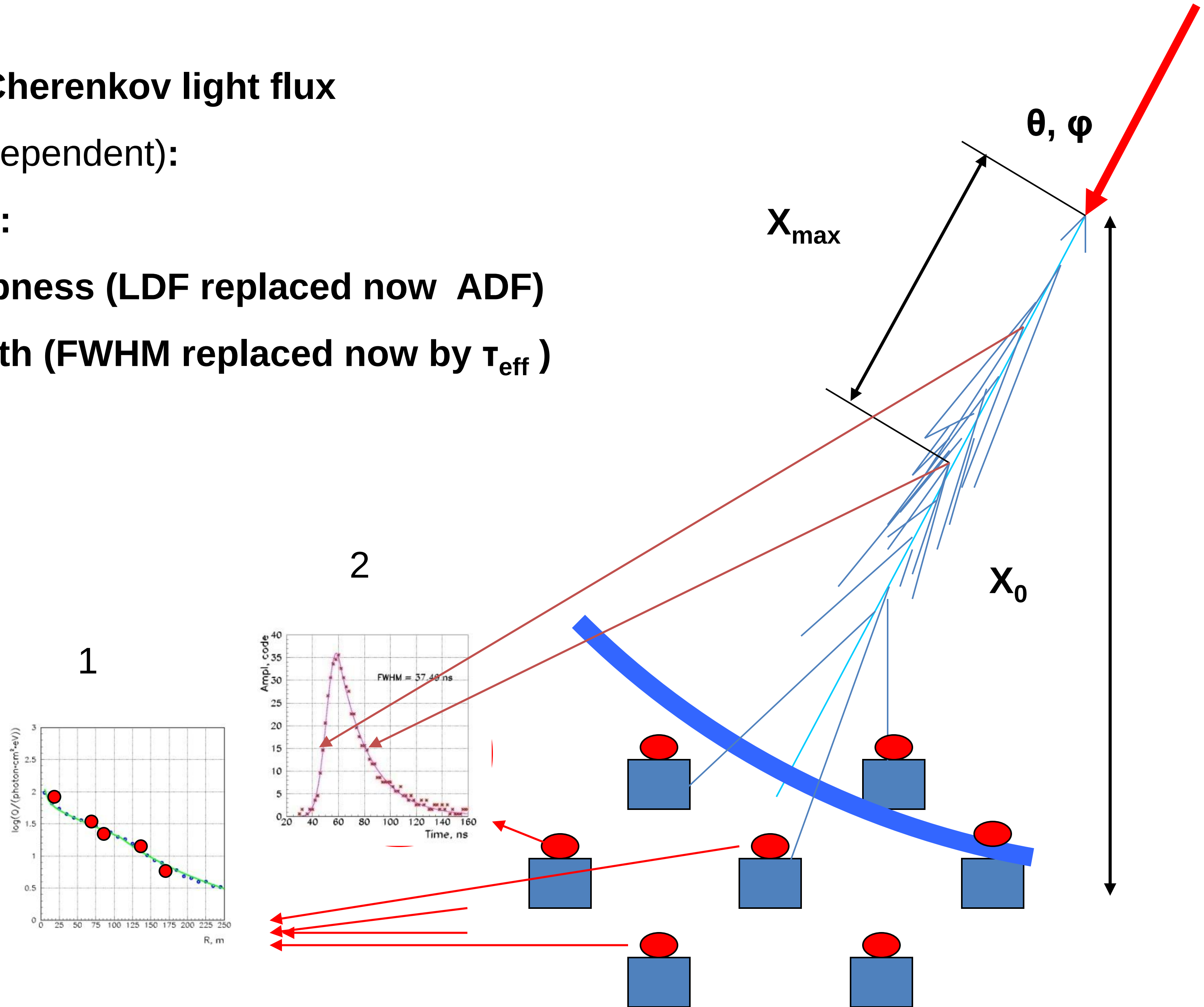
Primary nucleus E_0 , **A**?

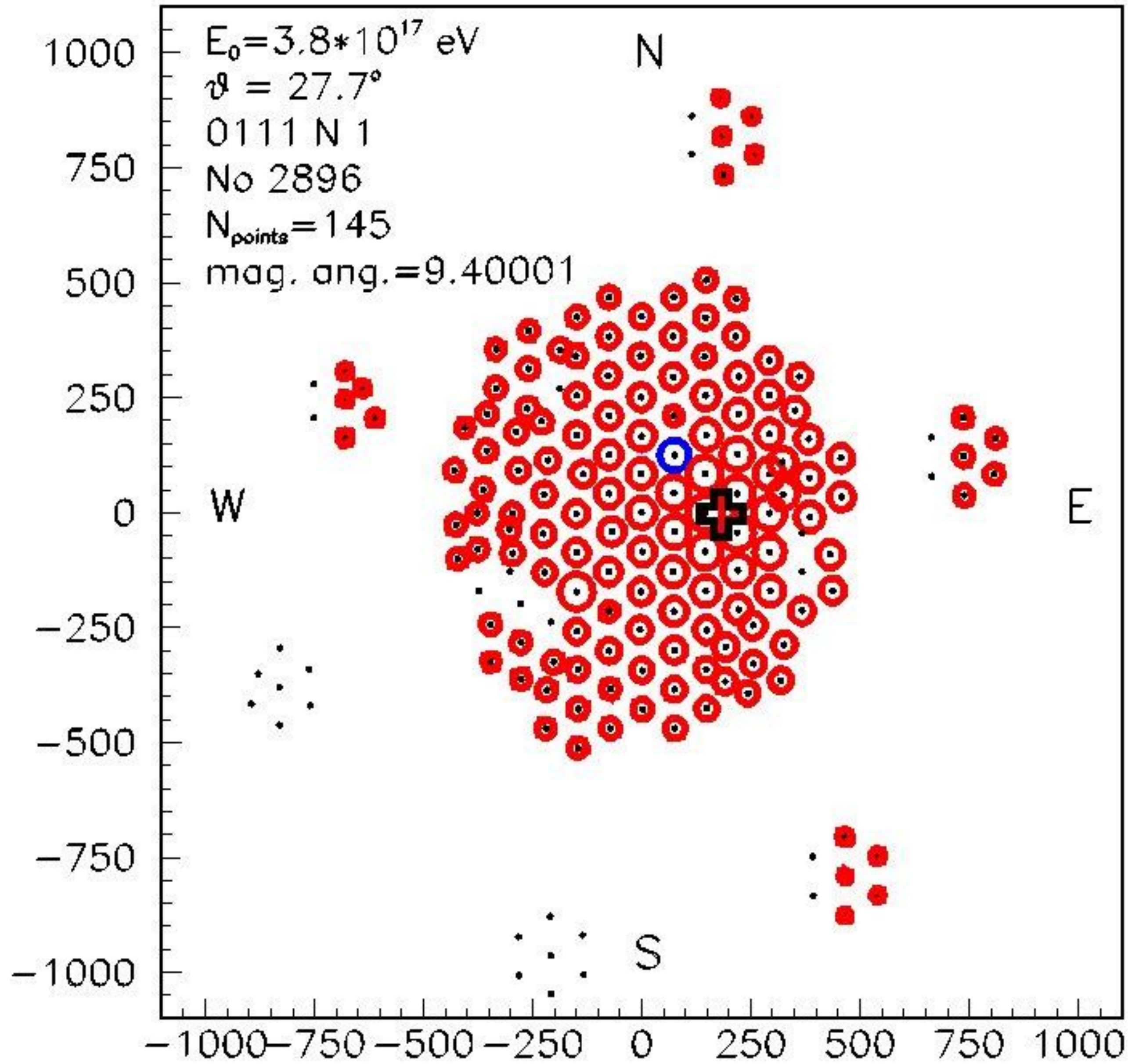
E_0 ~ Q(200) Cherenkov light flux

X_{max}(model independent)**:**

Two methods:

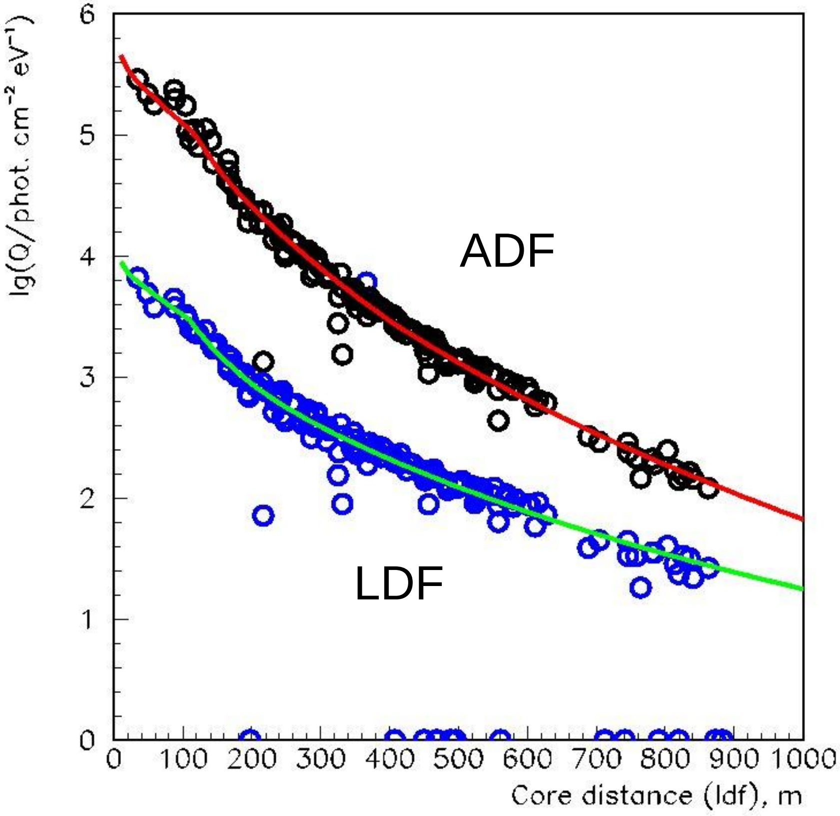
1. **ADF steepness (LDF replaced now ADF)**
2. **Pulse width (FWHM replaced now by τ_{eff})**

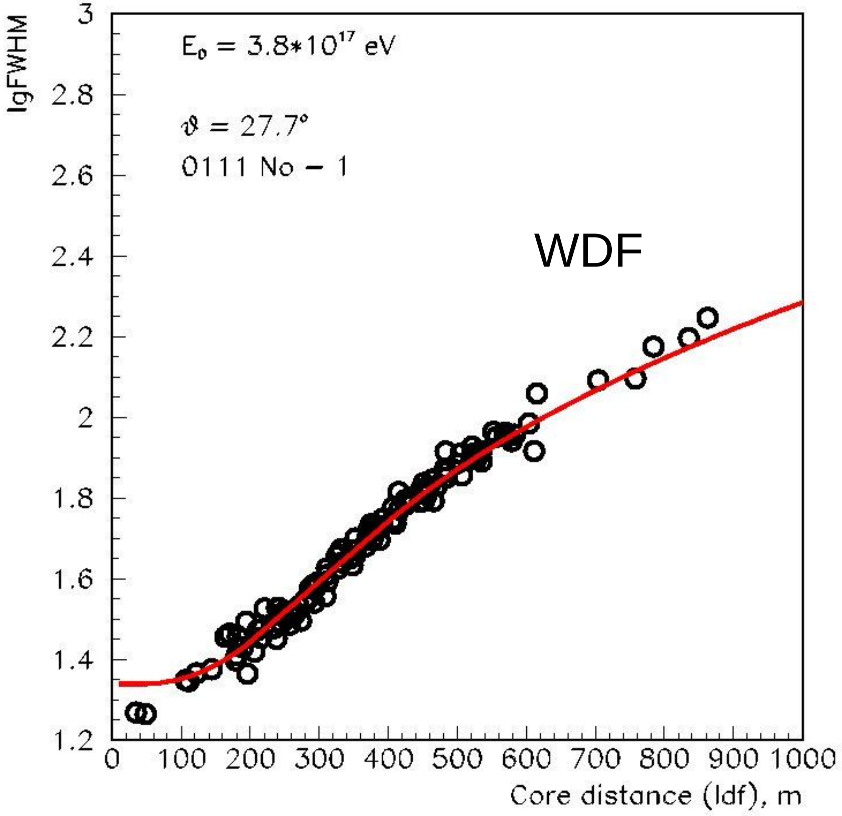




E_0=3.8*10^17 eV
ϑ = 27.7°
0111 N 1
No 2896
N_{points}=145
mag. ang.=9.40001
N
W
E
S
1000
750
500
250
0
−250
−500
−750
−1000
−1000 −750 −500 −250 0 250 500 750 1000

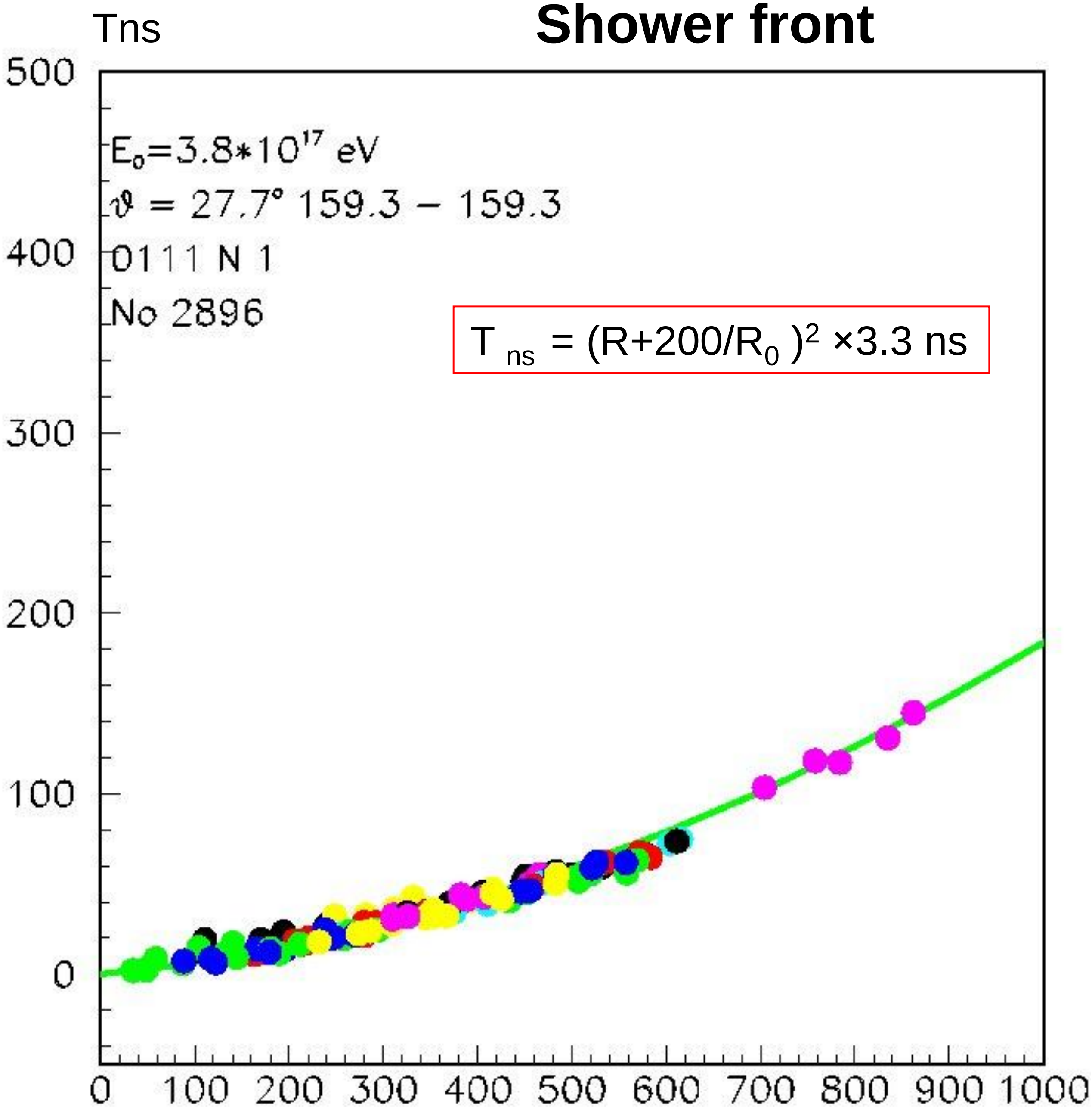
WDF – width distant function





ADF – amplitude distant function is used for core location

Shower front

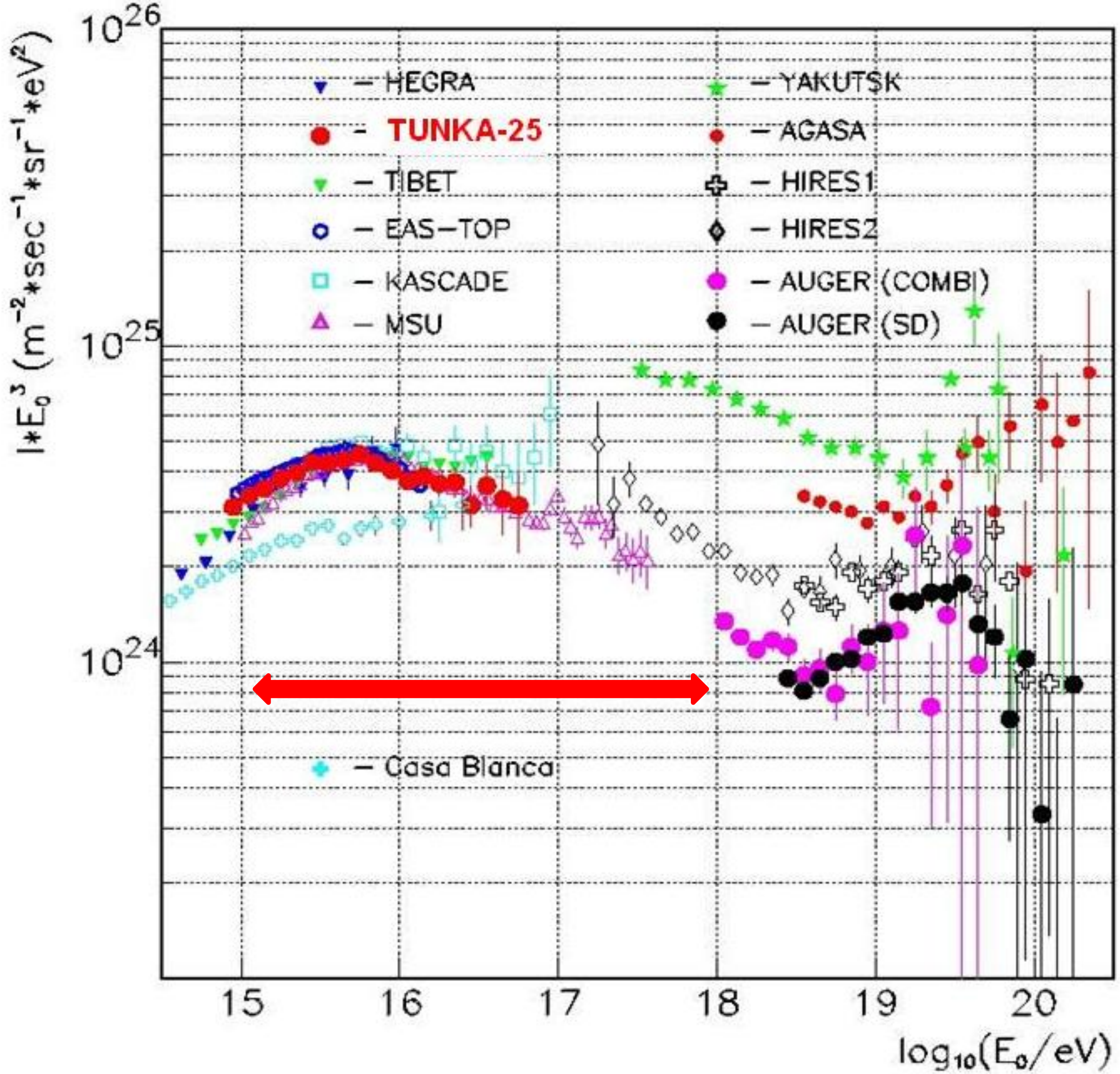


Энергетический спектр

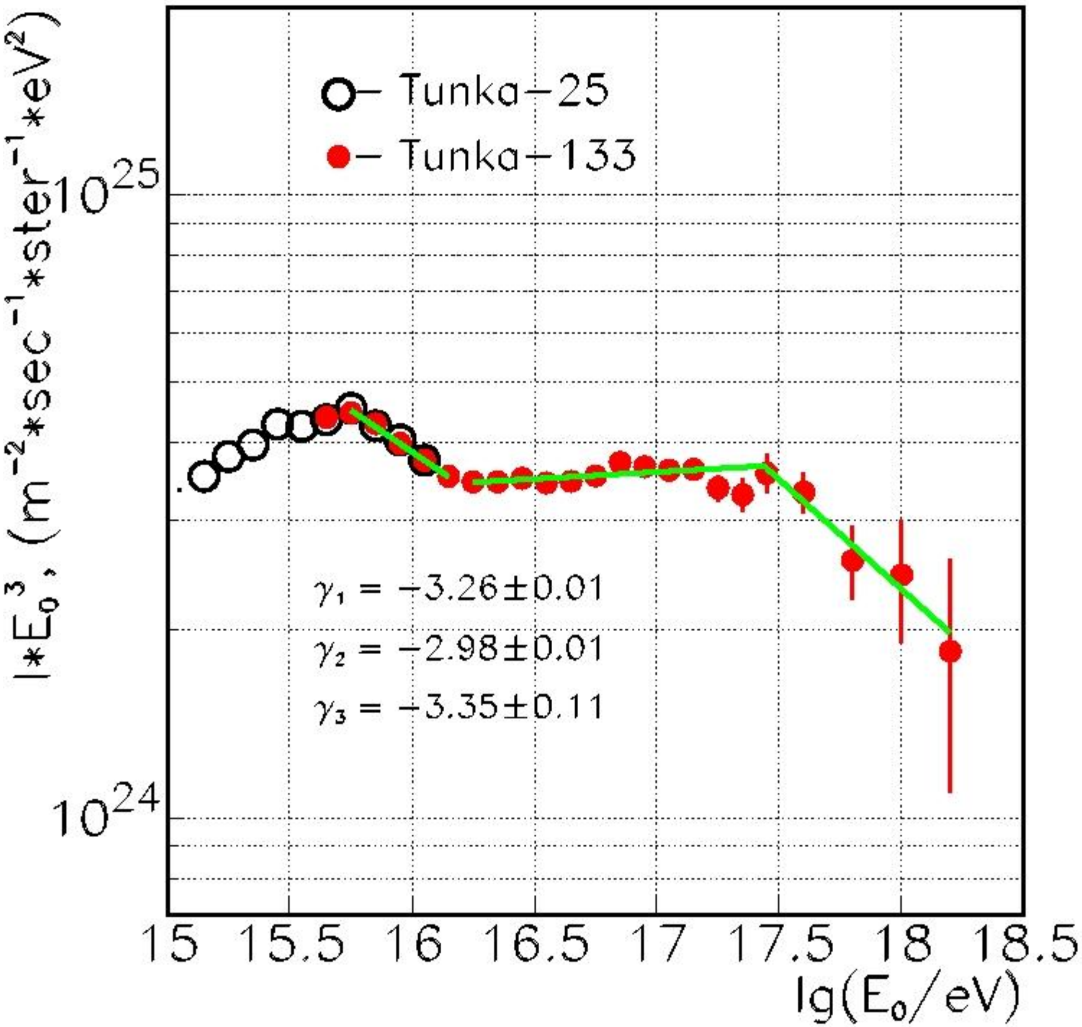
262 ясных безлунных ночи
~ 1540 часов наблюдений с частотой триггера ~ 2 Гц
~ 10 000 000 триггерных событий

~ 12400 событий с E_0 >$5 \cdot 10^{16}$ eV
~ 3000 событий с E_0 >10^{17} eV

Спектр всех частиц (10 лет назад)



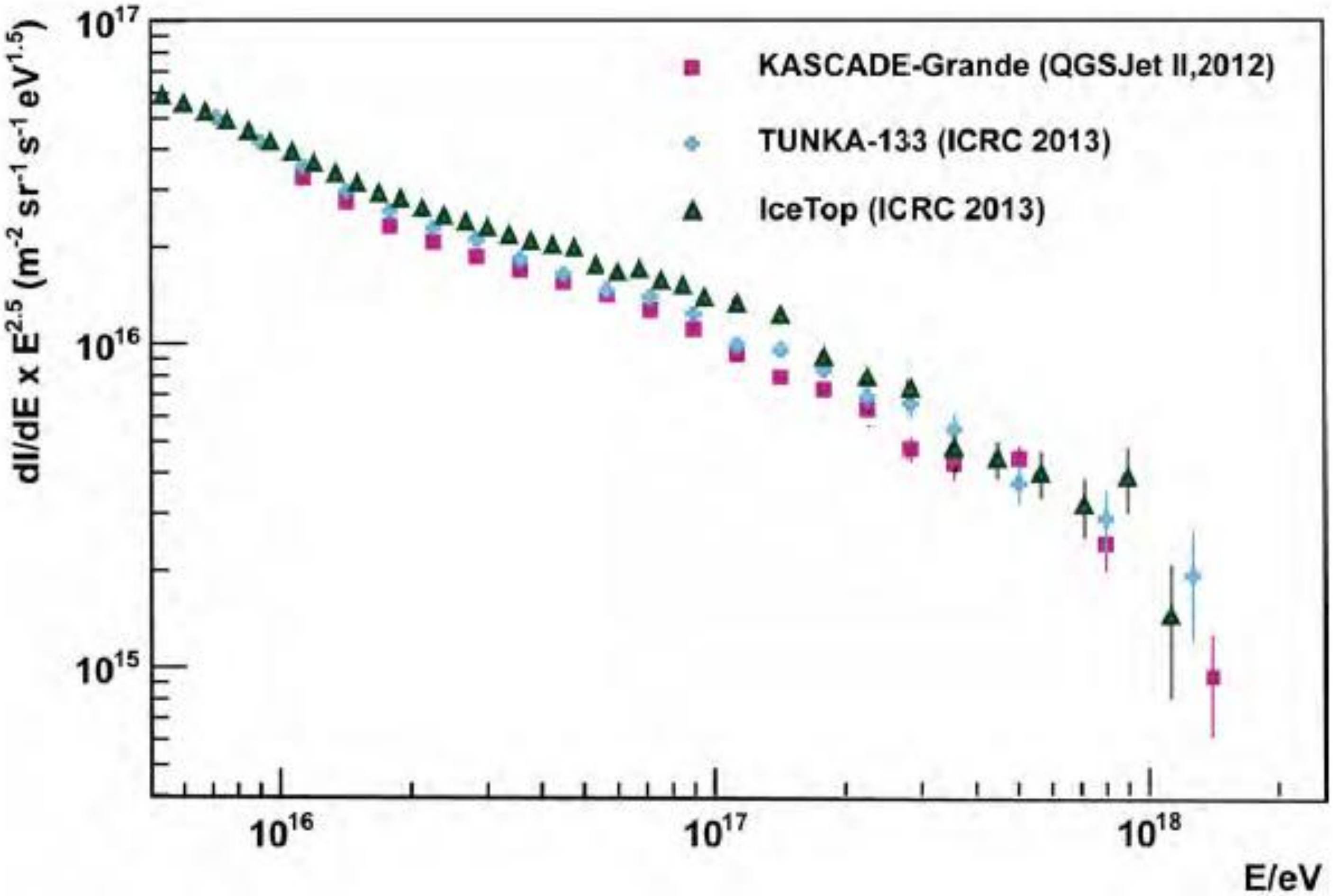
Спектр всех частиц (за 5 сезонов)



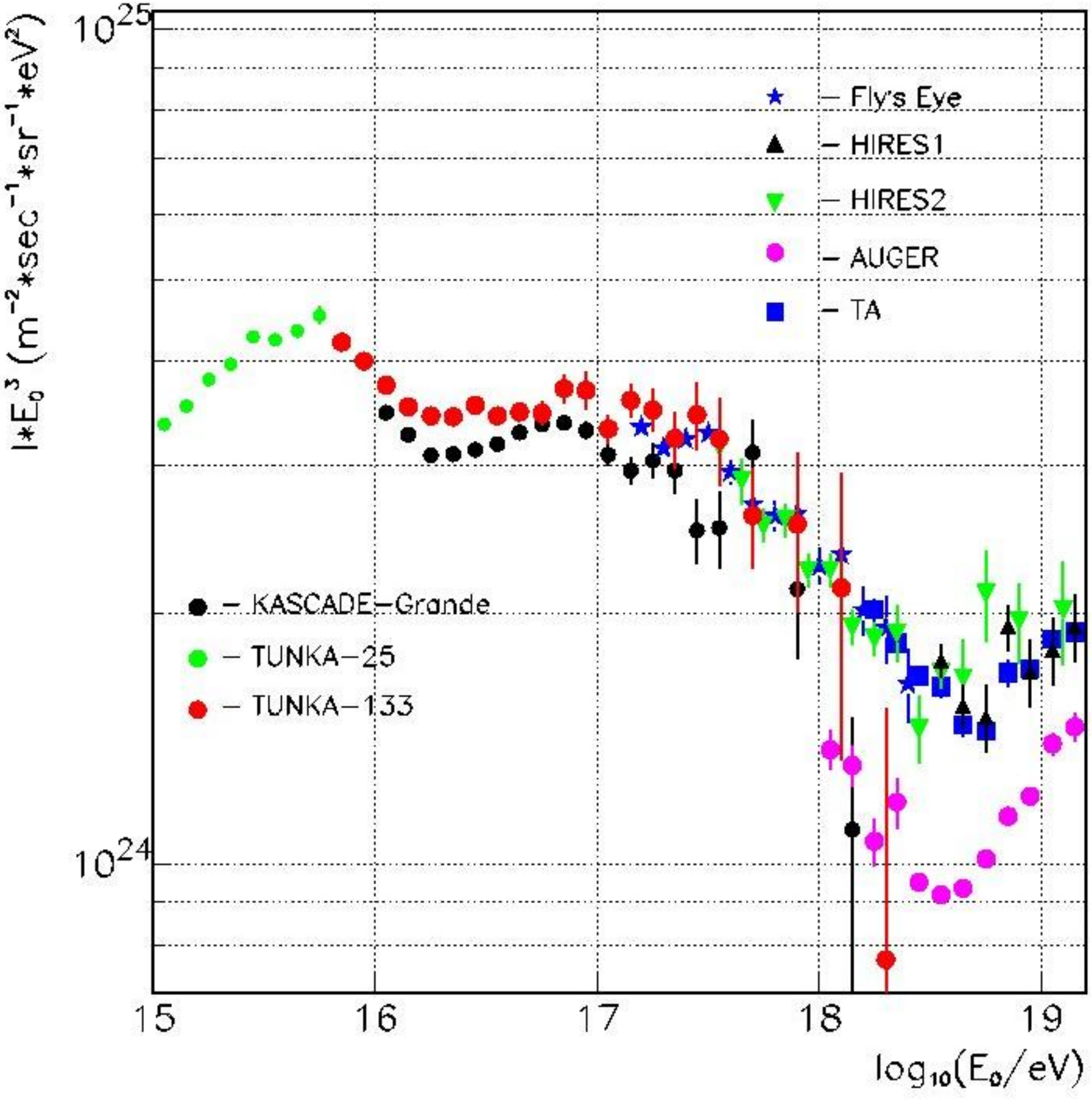
~ 3000 событий $E_0 > 10^{17}$ eV

Доклад В.В.Просина

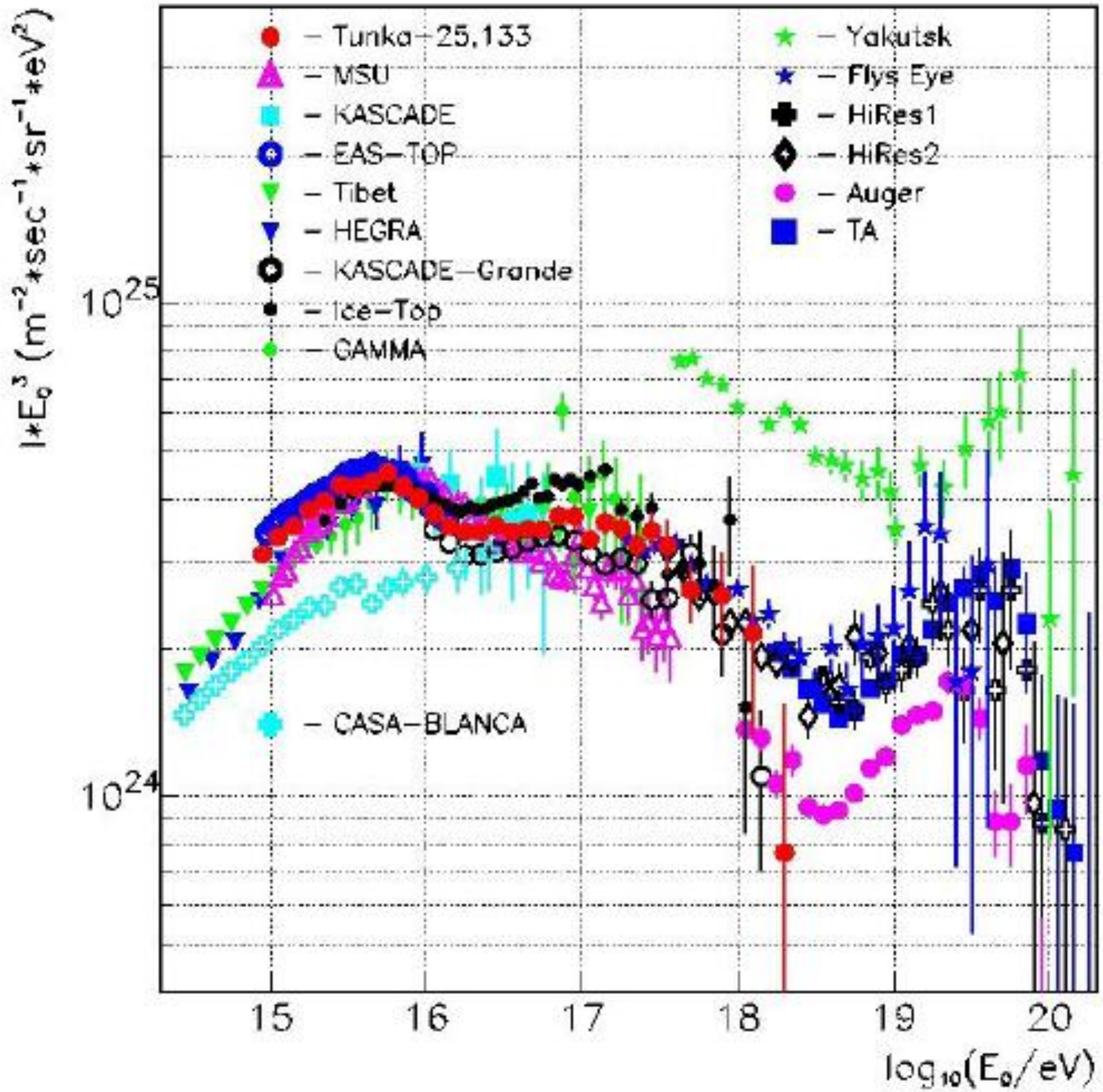
Сравнение данных 3-х установок (А.Хонгс)



Спектр всех частиц



Новый спектр ТА до 10^{16} эВ. (доклад Г.Рубцова после обеда)



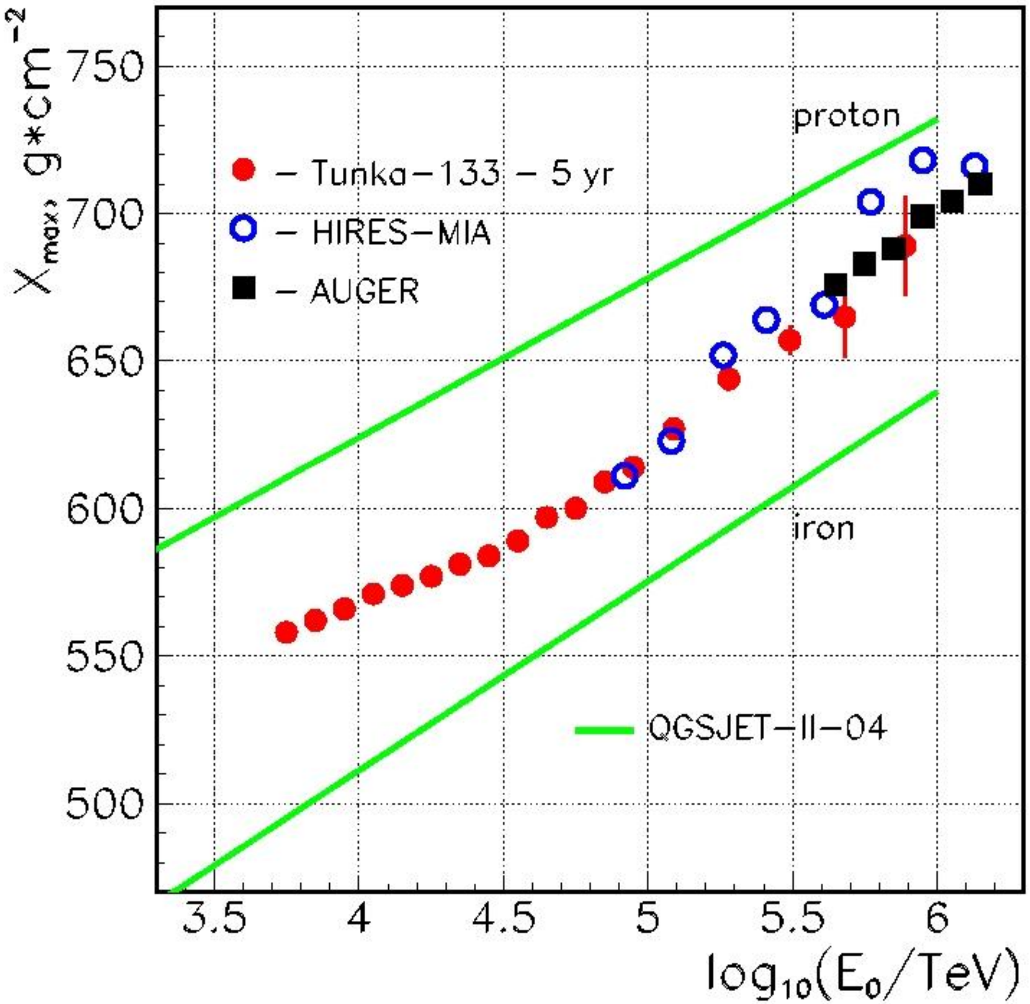
I*E_0^3 (m^-2*sec^-1*sr^-1*eV^2)
- Tunka-25,133
- MSU
- KASCADE
- EAS-TOP
- Tibet
- HEGRA
- KASCADE-Grande
- Ice-Top
- GAMMA
- CASA-BLANCA
- Yakutsk
- Flys Eye
- HiRes1
- HiRes2
- Auger
- TA
10^25
10^24
15
16
17
18
19
20
log10(E_0/eV)

Массовый состав

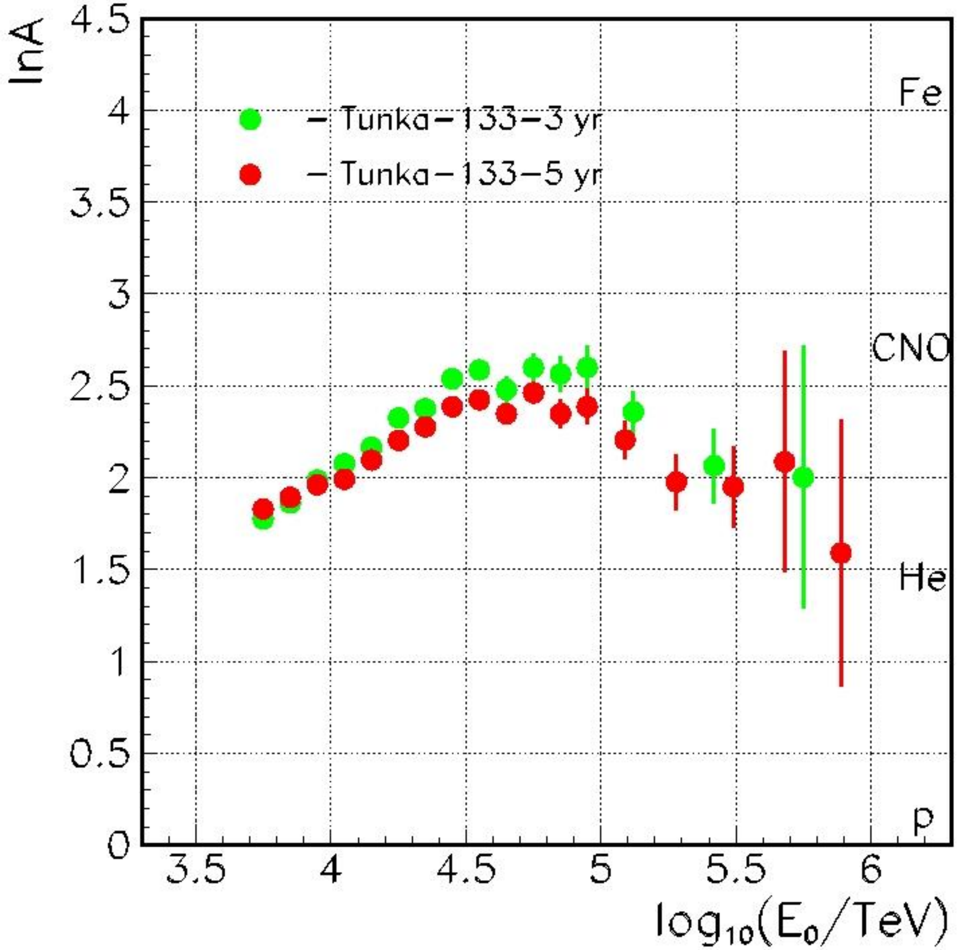
1. Зависимость среднего Xmax среднего от энергии - зависимость ln A

2. Распределение по Xmax - спектр отельных компонент.

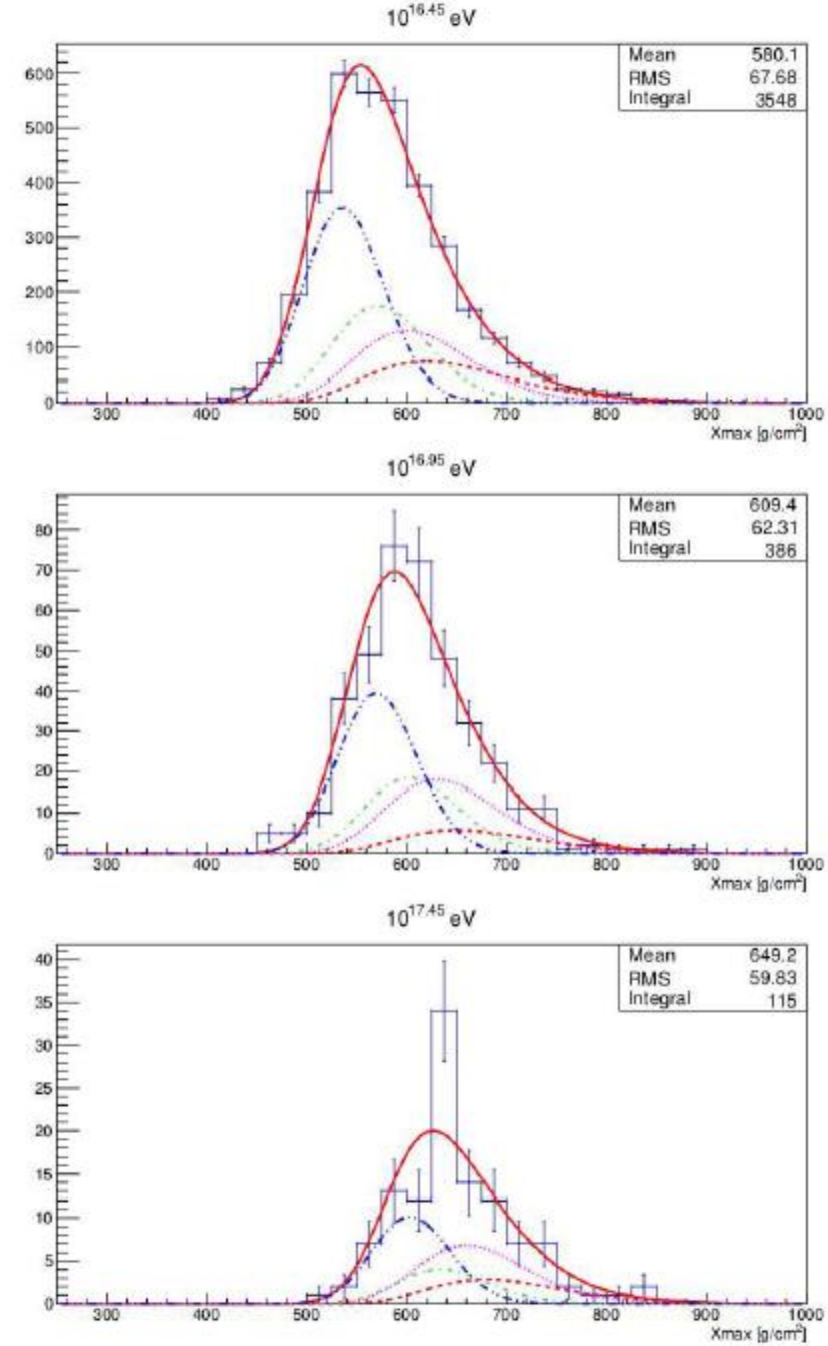
Зависимость Xmax от энергии



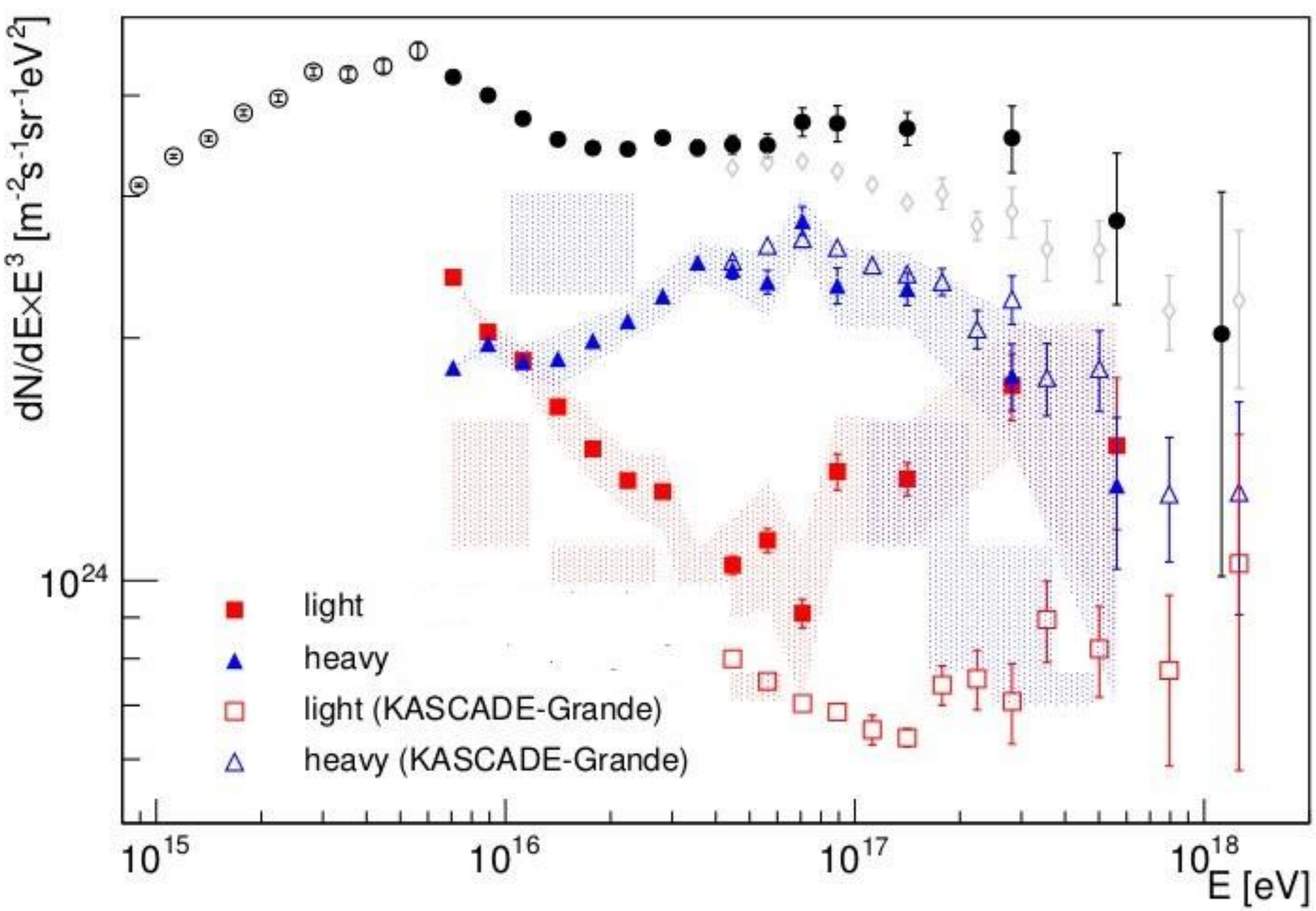
<lnA> vs. E_0



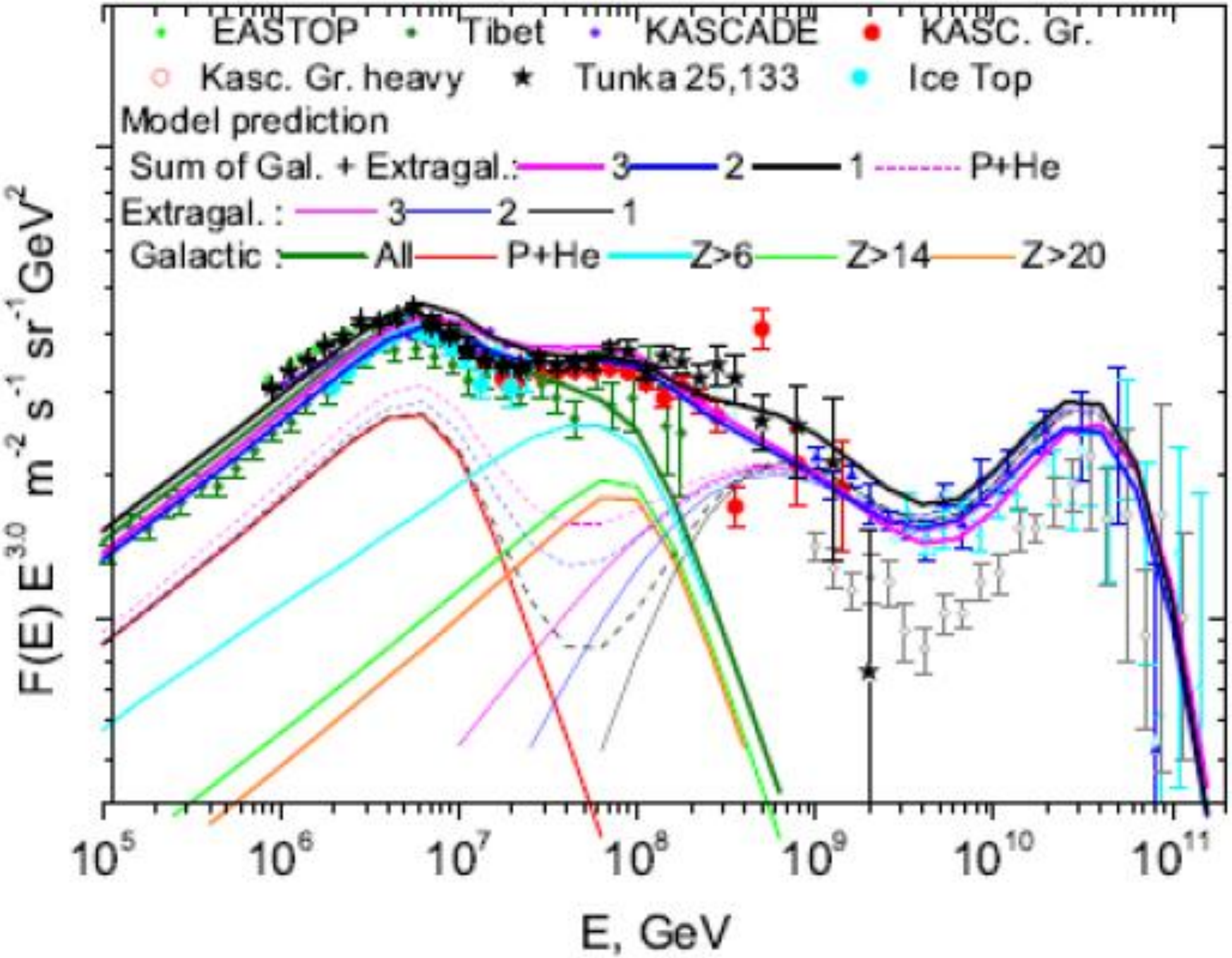
lnA
Fe
CNO
He
p
– Tunka-133-3 yr
– Tunka-133-5 yr
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
3.5
4
4.5
5
5.5
6
log10(E0/TeV)



$10^{16.45}$ eV
Mean 580.1
RMS 67.68
Integral 3548
Xmax [g/cm^2]
$10^{16.95}$ eV
Mean 609.4
RMS 62.31
Integral 386
Xmax [g/cm^2]
$10^{17.45}$ eV
Mean 649.2
RMS 59.83
Integral 115
Xmax [g/cm^2]



dN/dE×E^3 [m^{-2}s^{-1}sr^{-1}eV^2]
10^{24}
light
heavy
light (KASCADE-Grande)
heavy (KASCADE-Grande)
10^{15}
10^{16}
10^{17}
10^{18}
E [eV]



При 1 ПэВ : 17% P, 46 % He, 8% CNO, 16% Fe

Развитие установки:

Регистрация радио излучения от ШАЛ.

Сцинтилляцилнные станции

Tunka-REX

Connection of 2 antennas to 2 free channel of FADC

Tunka-Rex detector

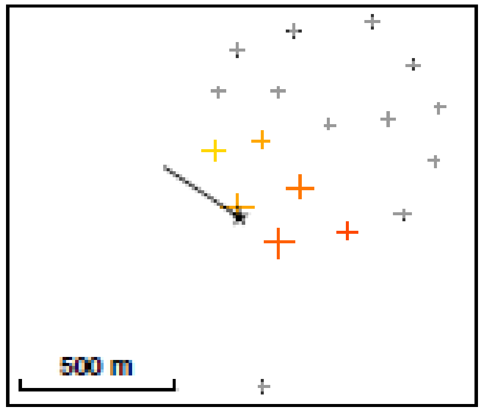
- 25 antennas on 1 km^2 area
- Existing DAQ of Tunka-133
- Trigger and information from air-Cherenkov detector

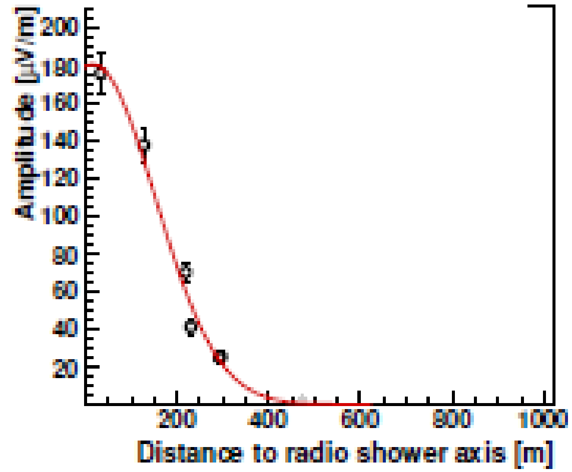
- Radio quiet rural location
- Strong geomagnetic field ($\approx 60\ \mu$T)

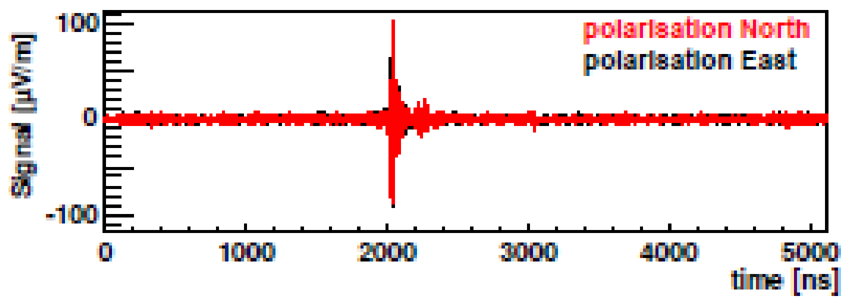
- Joint operation of radio and air-Cherenkov detectors
- Goal: precision of radio reconstruction for shower parameters (energy and shower maximum)

Tunka-Rex example event

For analysis we use the radio part of the Auger Offline software[1]

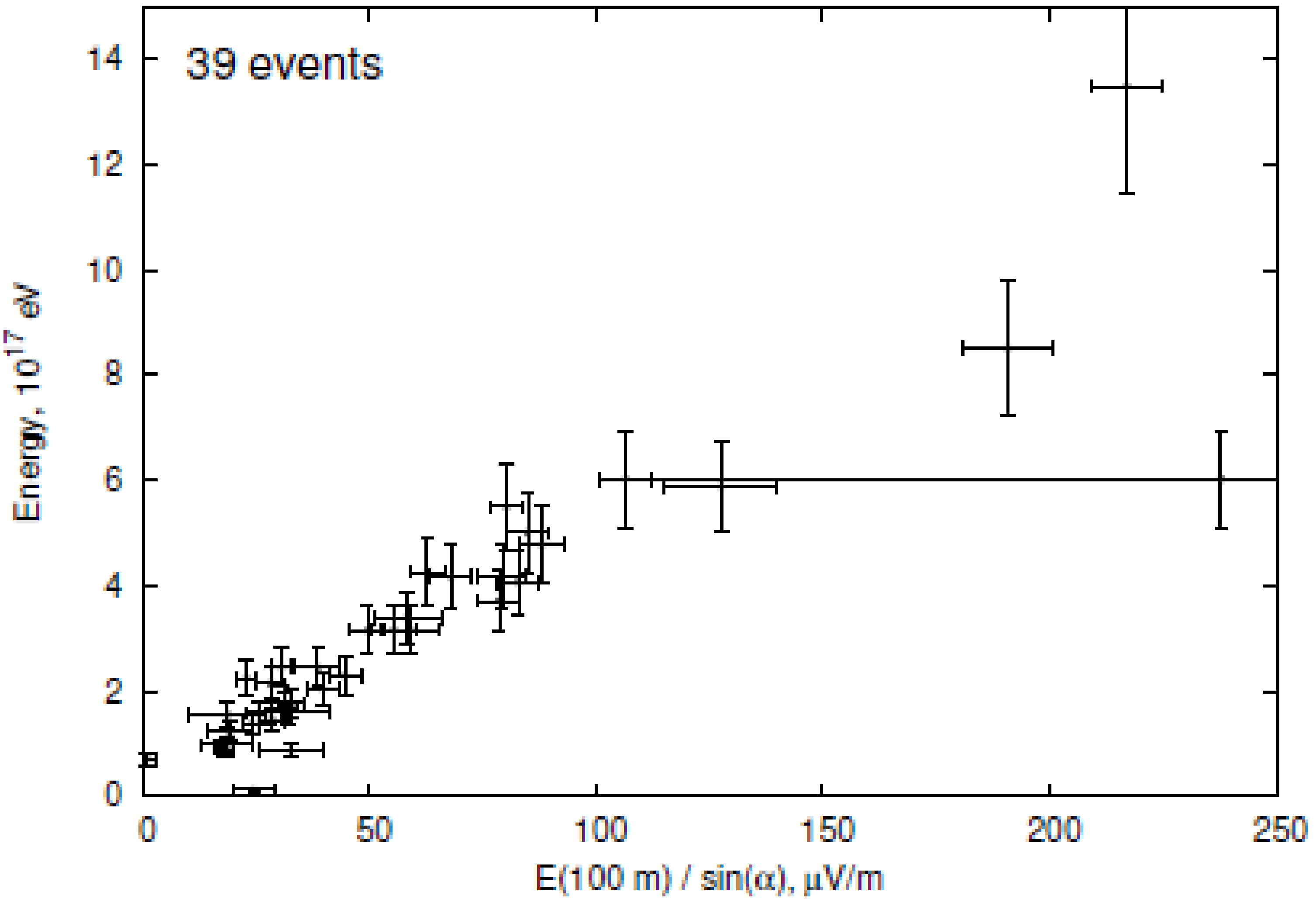






[1] Pierre Auger Collaboration, NIM A 635 (2011) 92

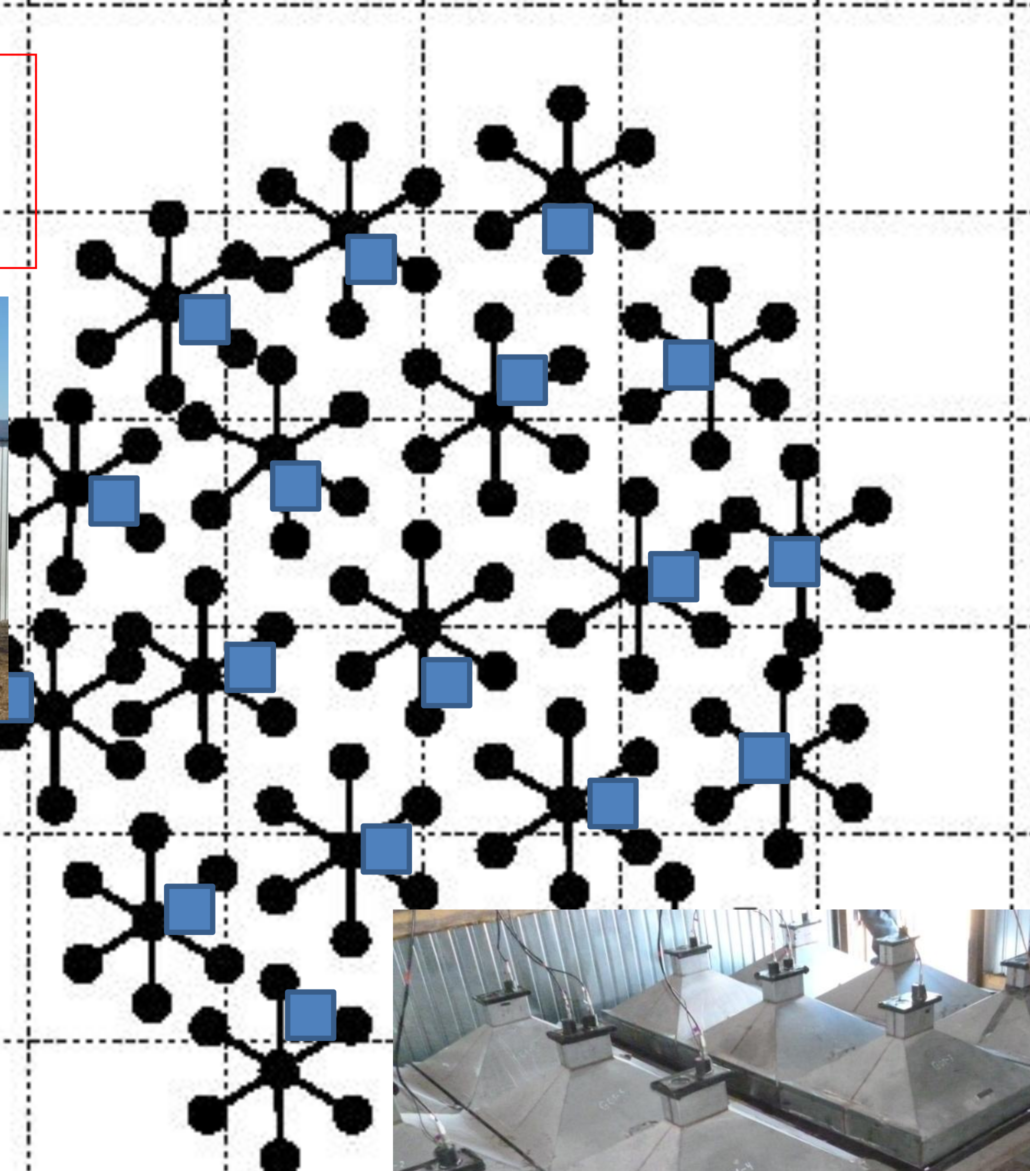
Correlation with amplitude ($n = 2$)



Grande detectors reached Tunka (July 2013)

Scintillation station from Kascade-Grande

19 stations

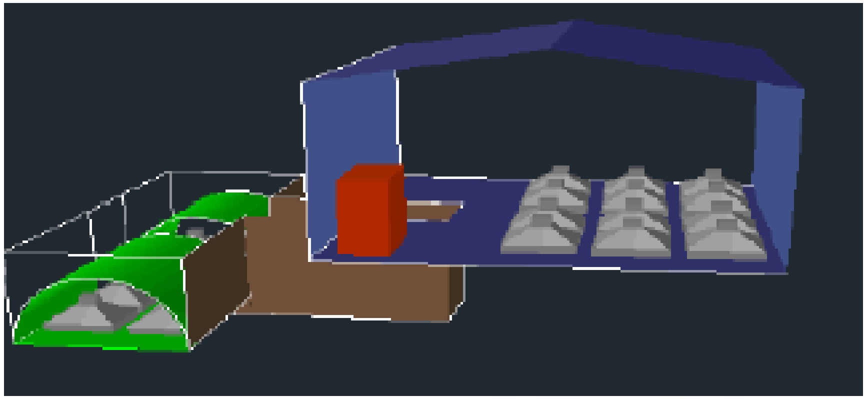


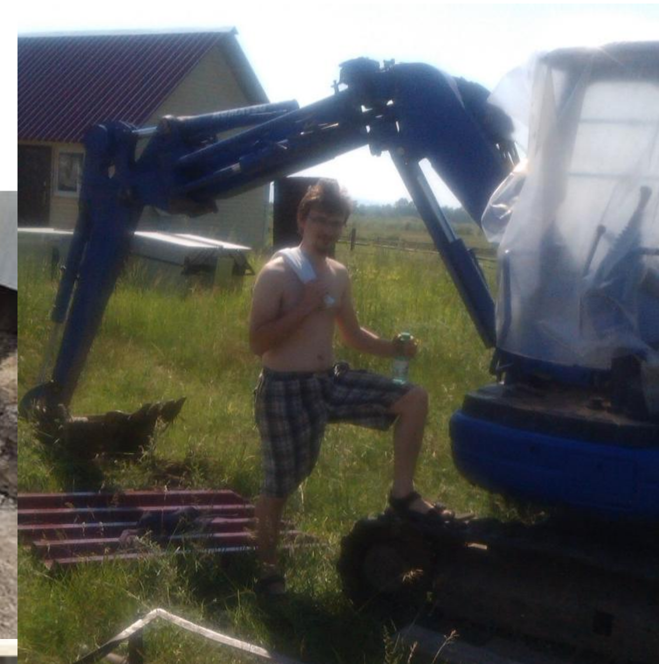
228 detectors (0.64 m^2) on the surface

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

ID : 3 , ID :107

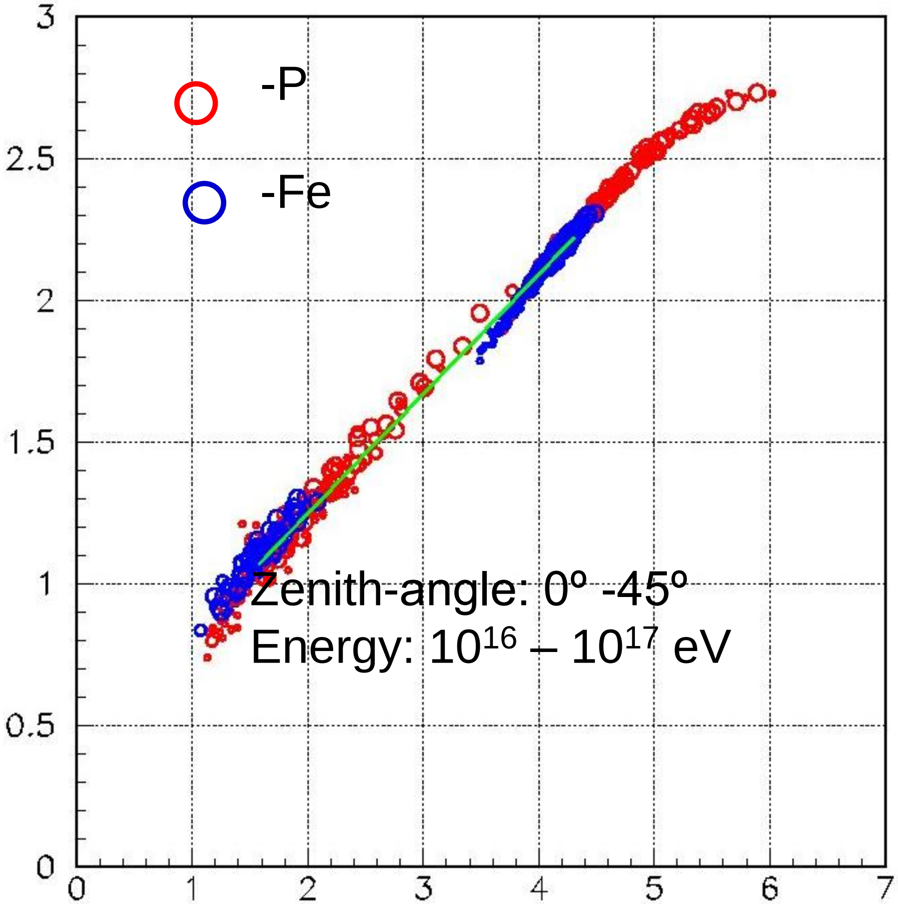
Muon detector





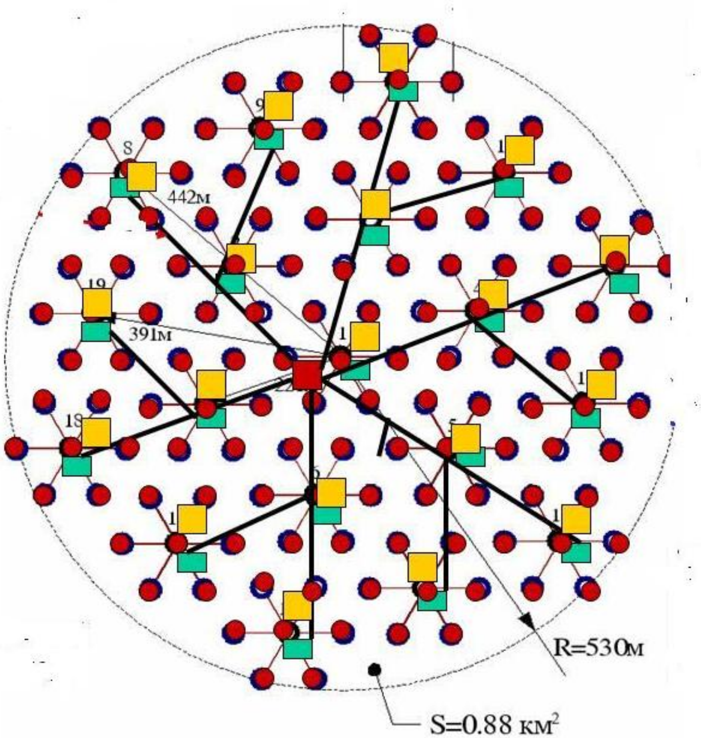
Absolute energy calibration experiment. Repeating the "QUEST" at 10^{16} -10^{17} eV

Lg (Ne / E, Tev)



p

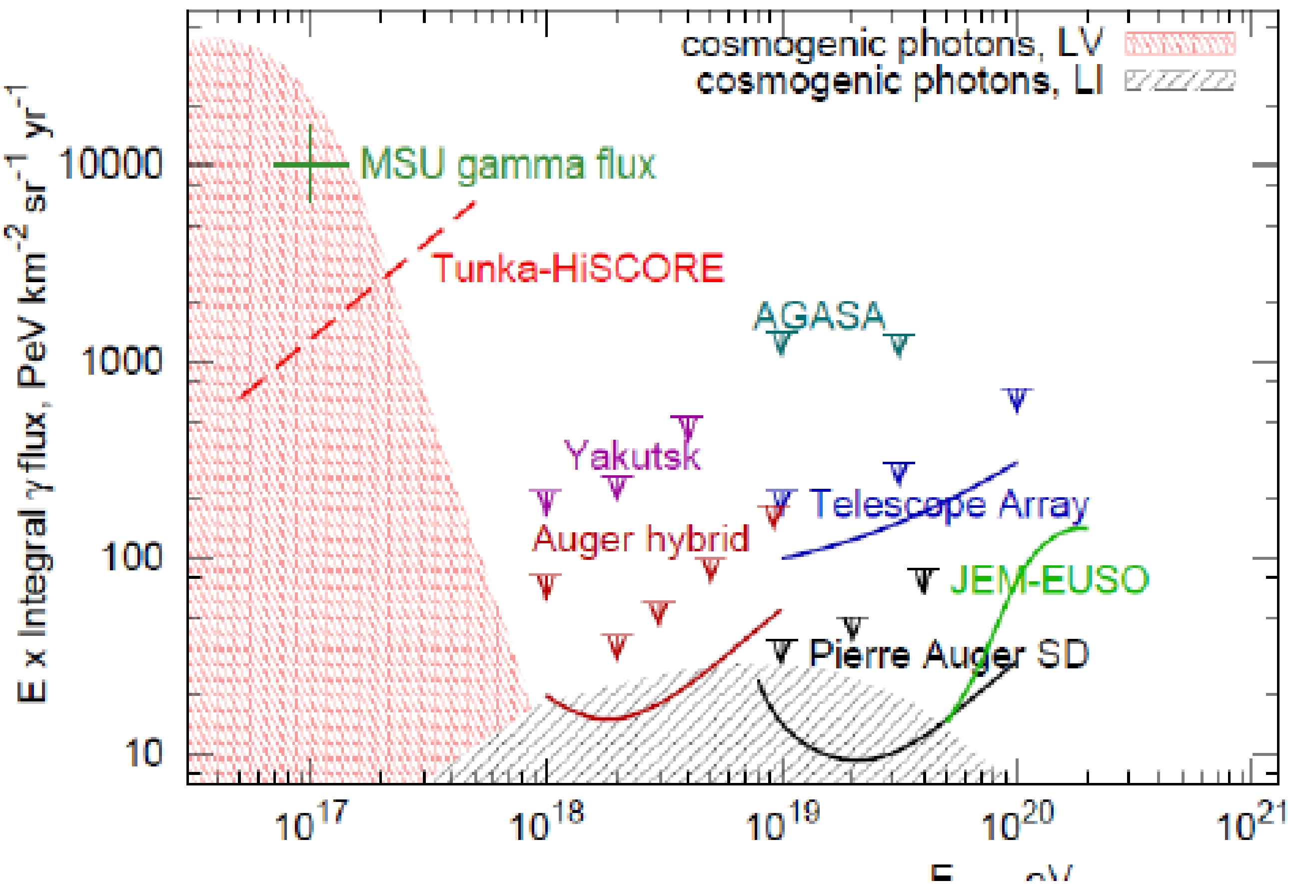
P – steepness of LDF



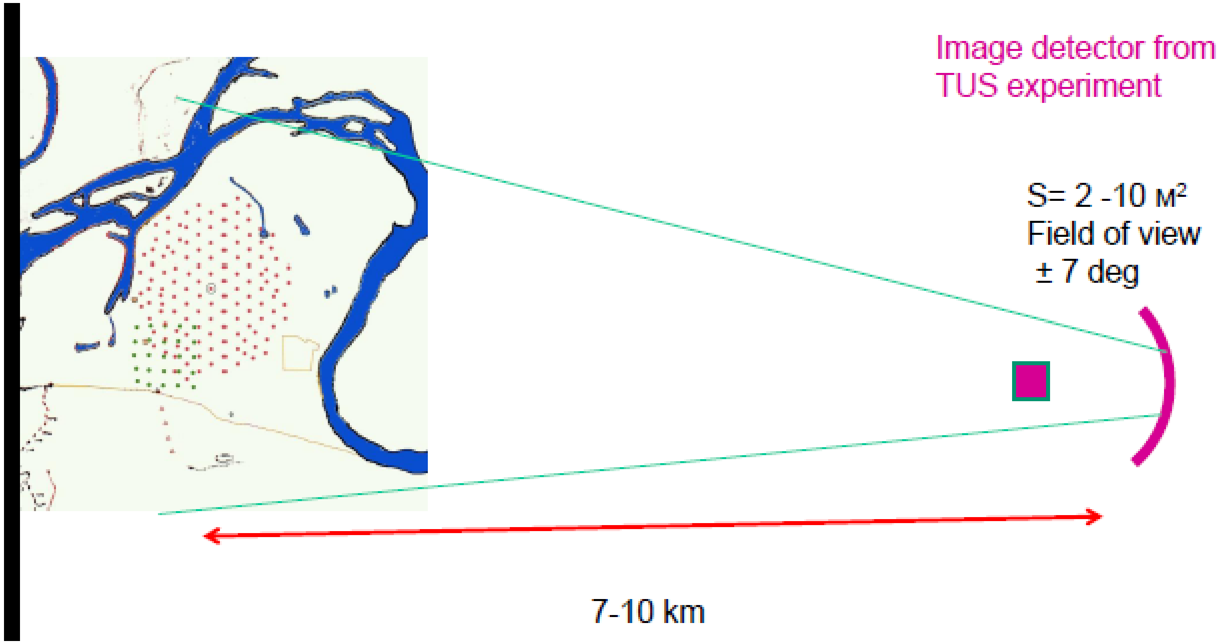
-20 scintillation counters, 10 m^2

2000 events with E >$3 \cdot 10^{16}$ eV per season

Search for gamma-rays with energy $5 \cdot 10^{16}$ - $5 \cdot 10^{17}$ eV



Fluorescent detector

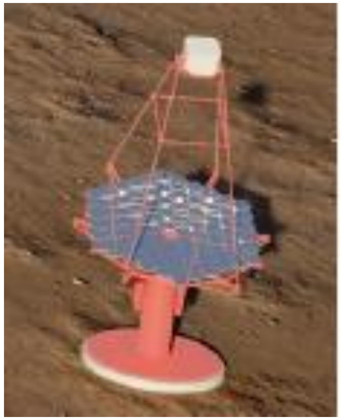


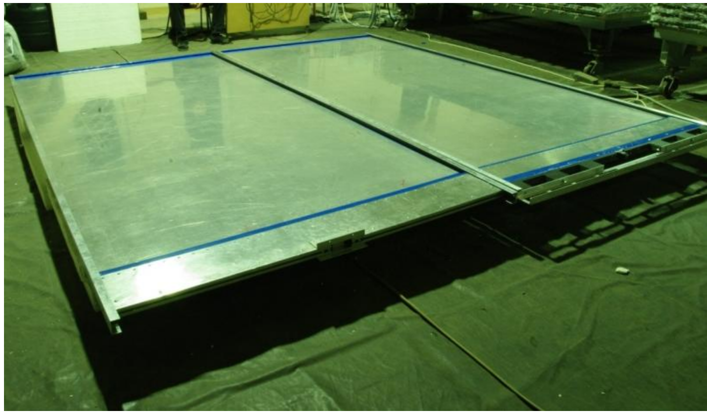
The movable support produced in JINR

Towards High Energy Gamma-Rays Astronomy array at Tunka Valley

TAIGA – Tunka Advanced Instrument for cosmic rays and Gamma and Astronomy

Array design concept





- **Non imaging wide-angle optical stations (HiSCORE type)**

- **Net of imaging detectors with mirrors 10 m^2 square.**

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

TAIGA Collaboratipn

Germany

Hamburg University(Hamburg)
DESY (Zeuthen)
MPI (Munich)
Humbolt University

ITALY

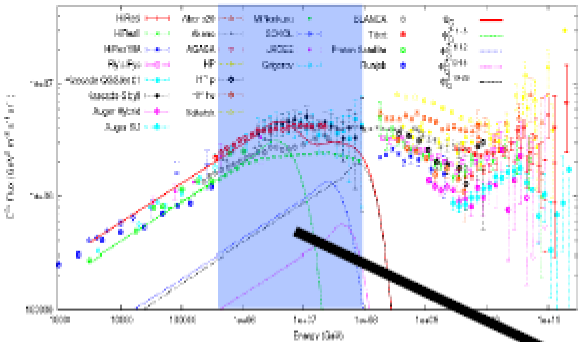
Torino University

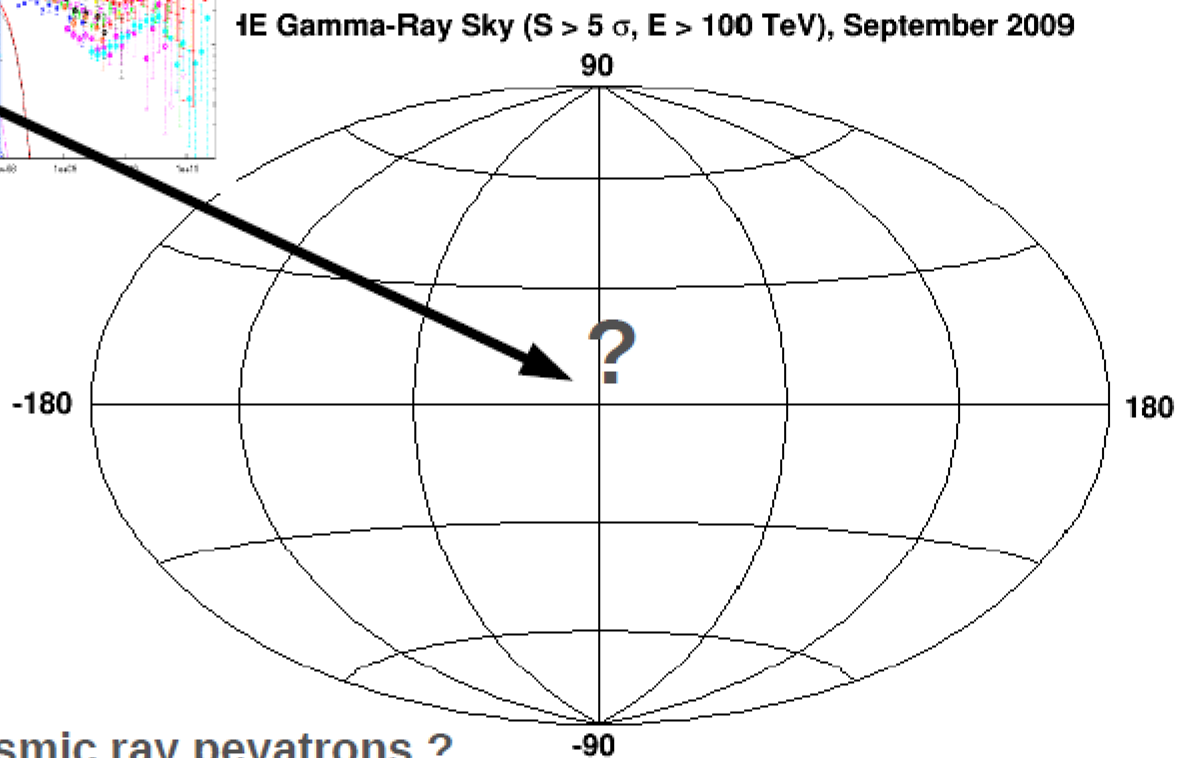
Russia

MSU(SINP)(Moscow)
ISU (API) (Irkutsk)
INR RAS(Moscow
JINR (Dubna)
MEPHI(Moscow)
IZMIRAN
Kurchatov Institute
IPSM(Ulan-Ude)

Pevatron sky

Universität Hamburg
DER FORSCHUNG | DER LEHRE | DER BILDUNG

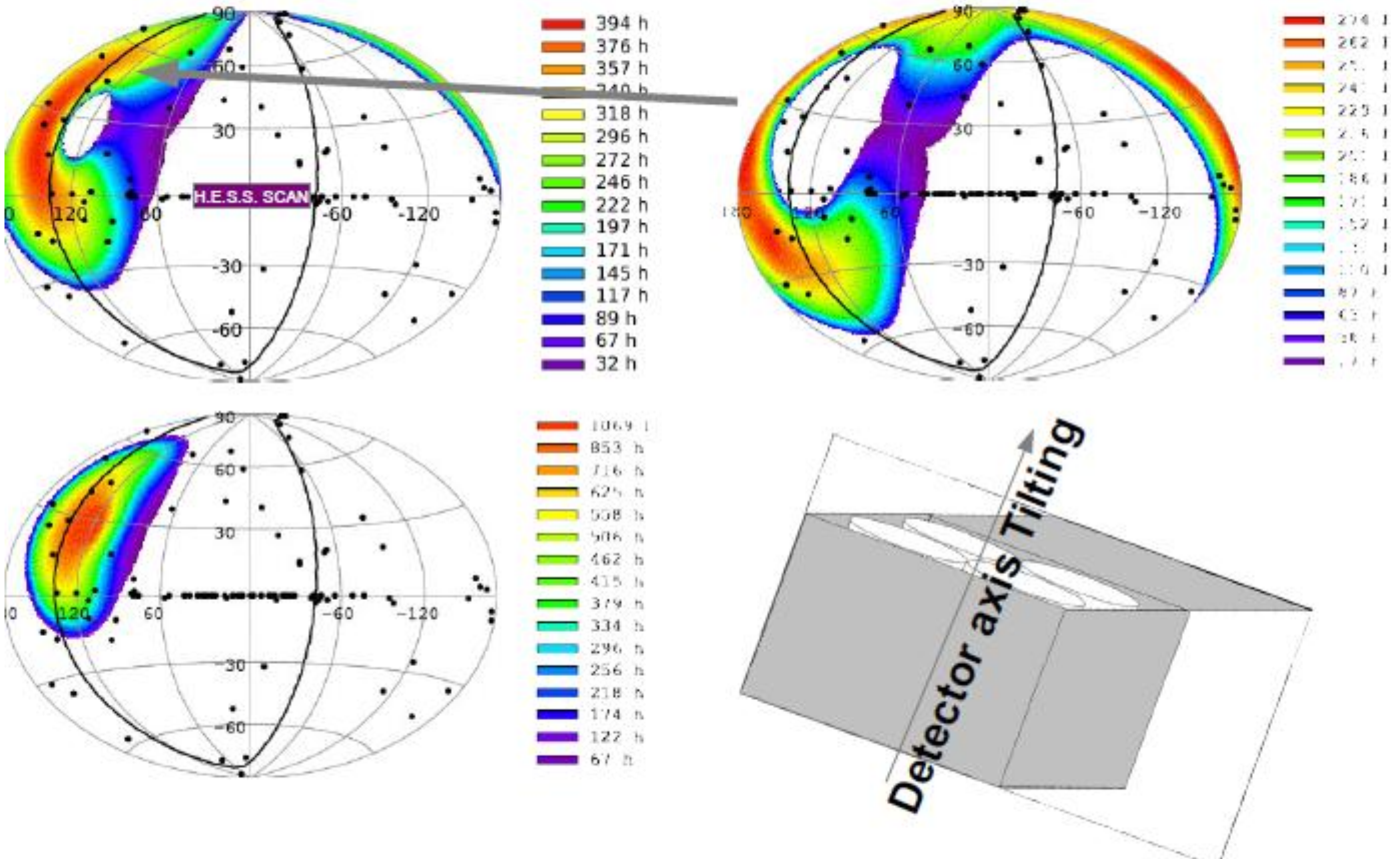




Where are the cosmic ray pevatrons ?

HELMHOLTZ
GEMEINSCHAFT

Какую часть неба мы можем наблюдать



What we can see with 1 km^2 array (short list)

Name	**RA degrees**	**Decl**	**Flux F at 1 TeV, $10^{-12}cm^{-2}\ s^{1}TeV^{-1}$ Γ**	**Flux F at 35 TeV, $10^{-17}cm^{-2}\ s^{-1}TeV^{-1}$ (from Milagro)**	**Time of observation per one year (x 0.5- weater factor)**
Tycho SNR (J0025+641)	6.359	64.13	0.17 ±0.05 Γ=1.95 ±0.5		**236h**
Crab	83.6329	22.0145	32.6 ±.9.0 Γ=2.6 ±0.3	162.6 ±9.4	**110h**,
SNR IC443 (**MAGIC J0616+225**)	94.1792	22.5300	0.58 ±0.12 Γ=3.1 ±0.30	28.8 ±9.5	**112h**,
Geminga MGRO C3 PSR	98.50	17.76		37.7 ±10.7	**102h**,
M82 (Starburst Galaxy)	148.7	69.7	0.25 ±0.12 Γ=2.5 ±0.6±0.2		**325h,**
Mkn 421 (BL, z=0.031 Variable)	166.114	38.2088	50-200 Γ=2.0-2.6		**140h**
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**
Cas A (SNR, G111.7-2.1)[6]	350.853	58.8154	1.26 ±0.18 Γ=2.61 ±0.24±0.2		**177h**
CTA_1(SNR,PWN)	1.5	72.8	1.3 Γ=2.3		**266 h**

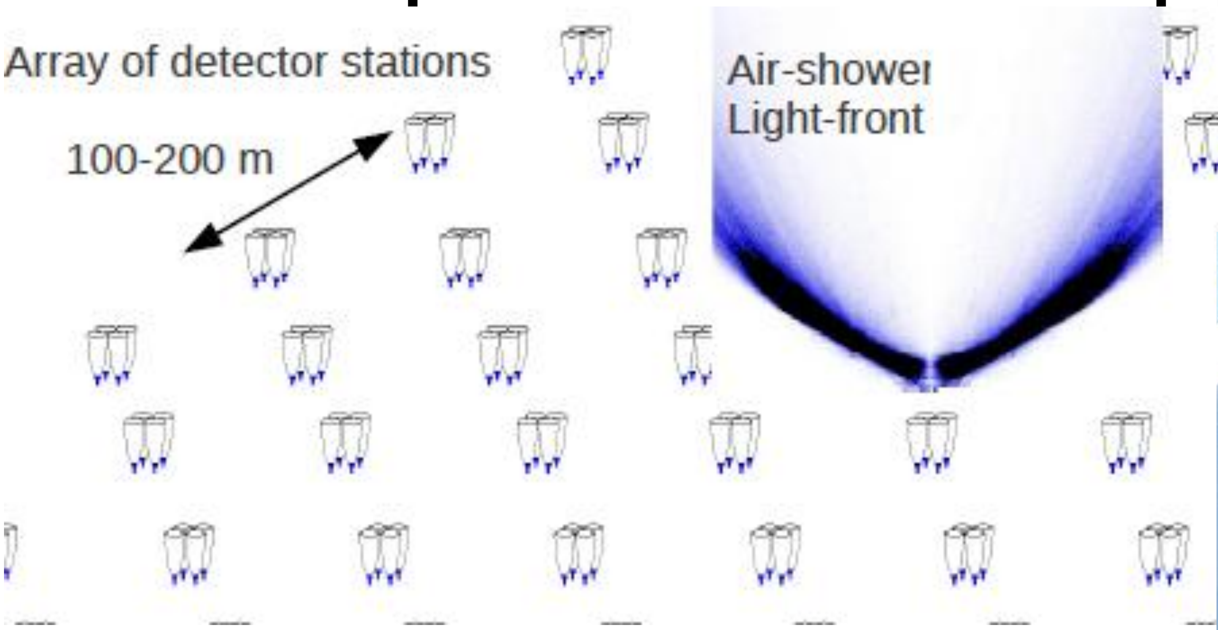
Methodical approaches for 3 stages

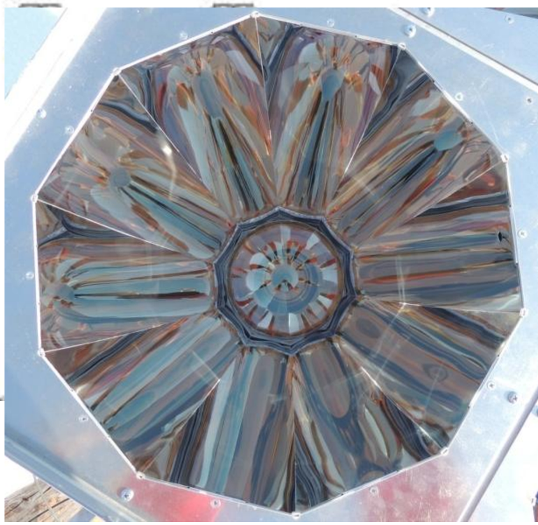
1. Shower front and LDF sampling technique .
   Angular resolution – 0.1 deg,
   X_{max} measurement for hadron rejection.

2. Using of mirrors net with cheap matrix of PMTs for imaging technique.

3. Using of large area muon detectors for hadron rejection.

Concept of HiSCORE approach



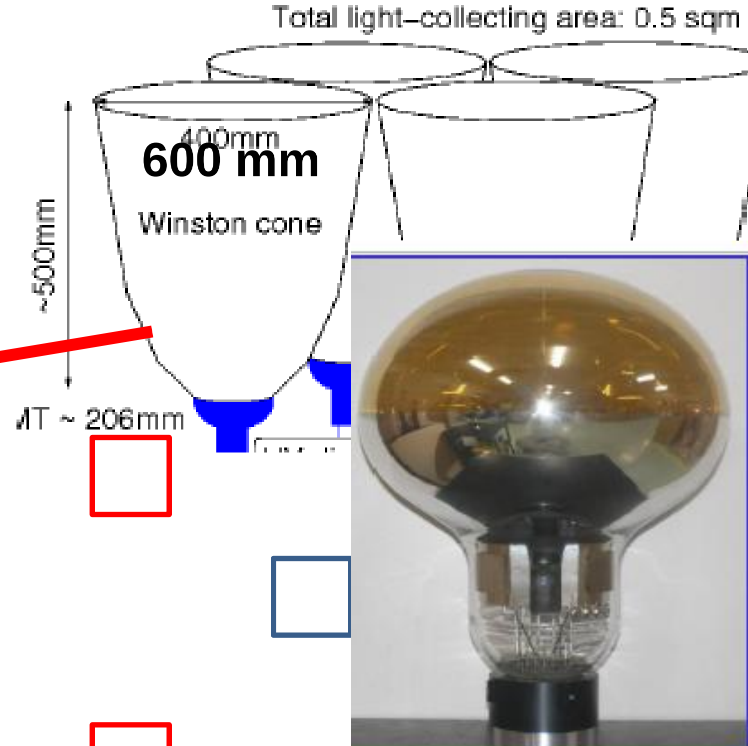


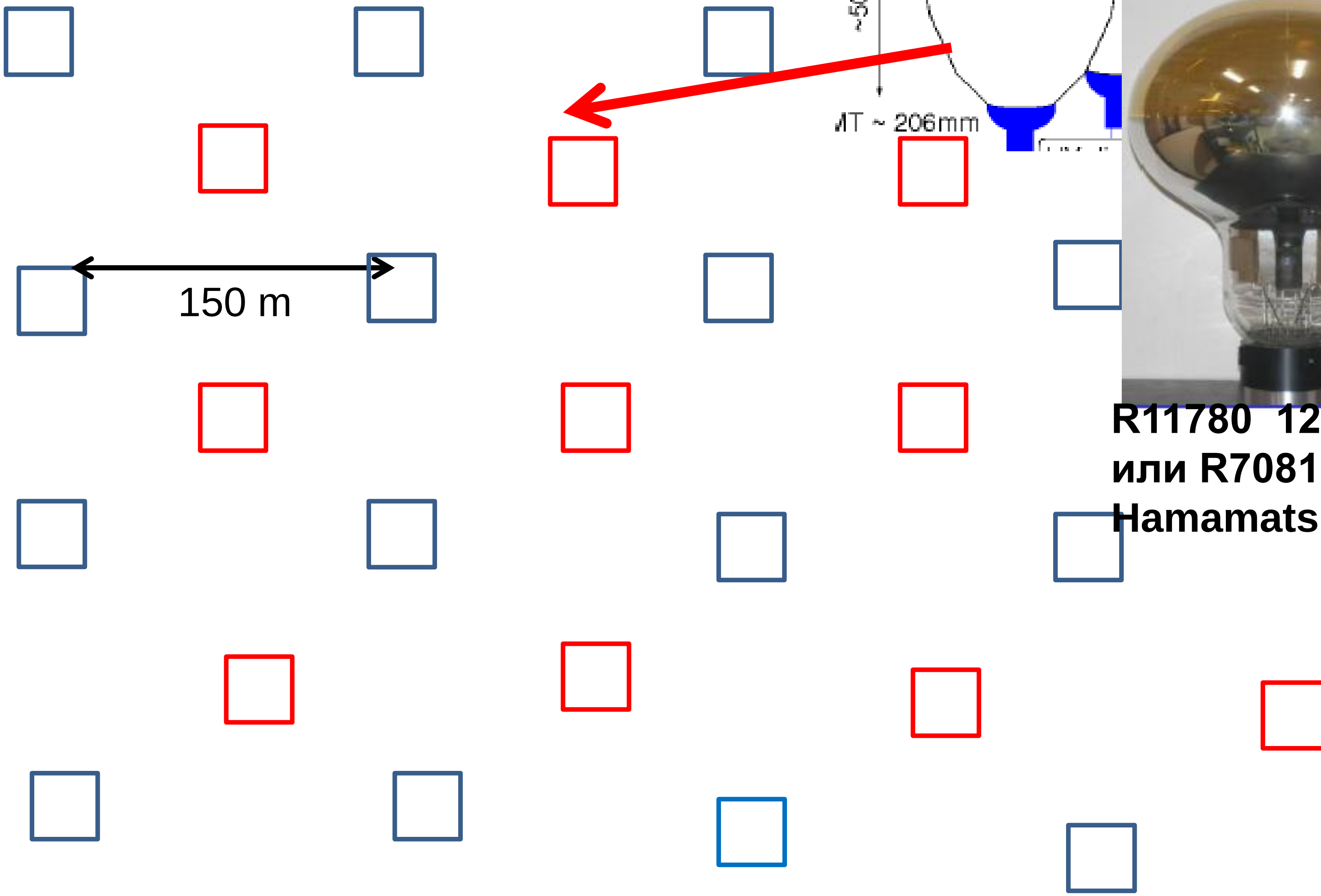
-Better than for Tunka angular resolution,- up to 0.1 degree
-much lower energy threshold – up to 30 TeV .
-Field of View (FOV) – 0.6 sr (±30 deq)
- Low cost of each station – possibility to cover large area

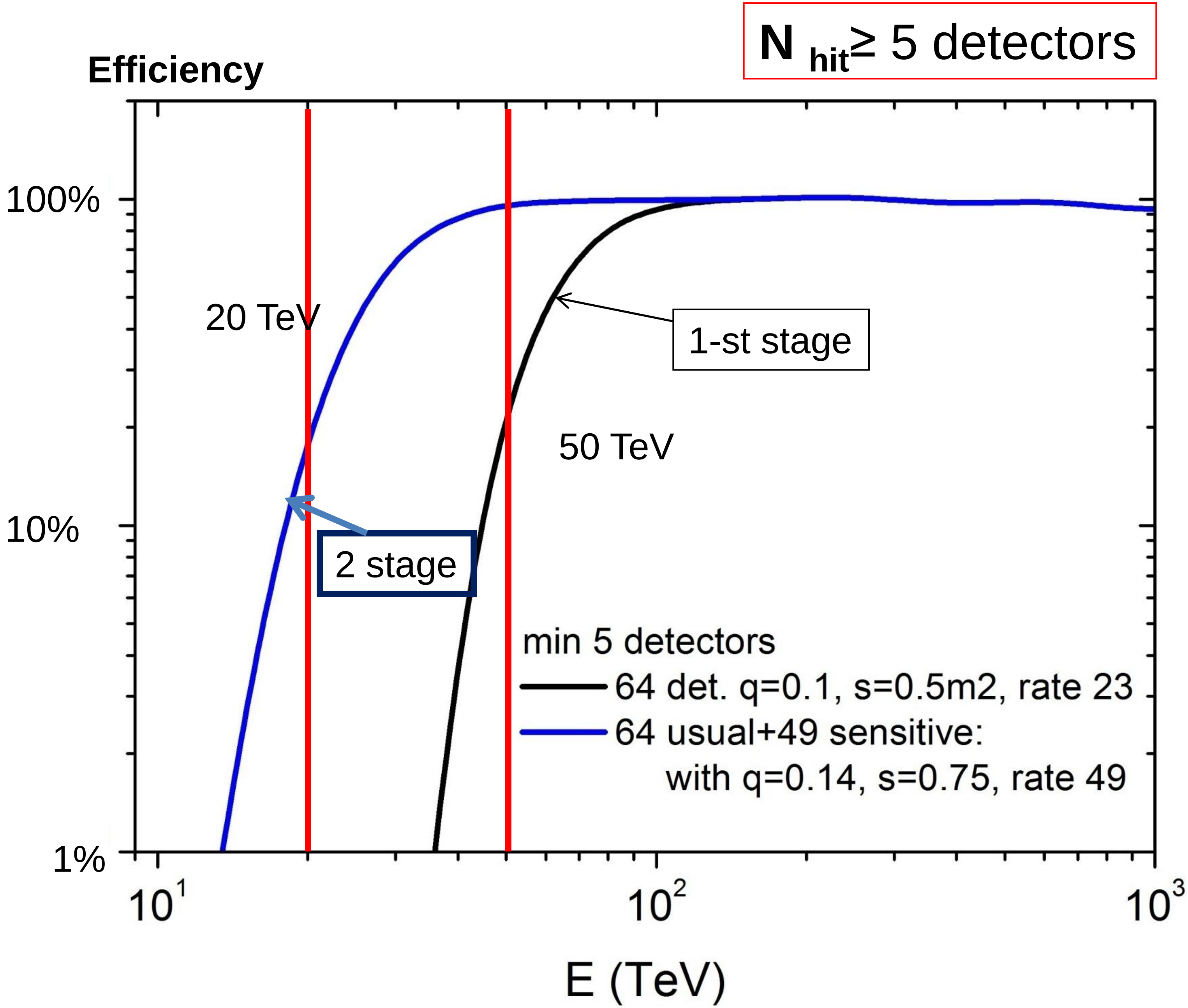
HiSCORE – Hundred* i Square-km Cosmic Origin Explorer

Tunka-HiSCORE – 1km^2

2 stage

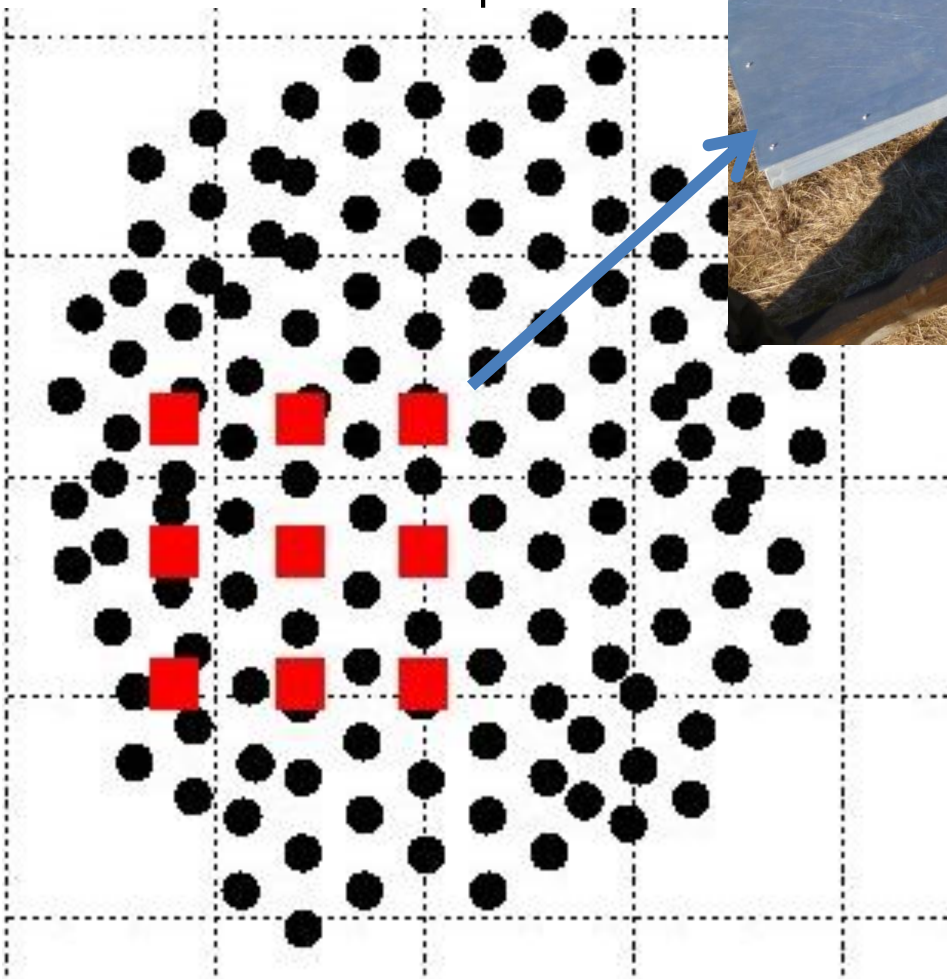


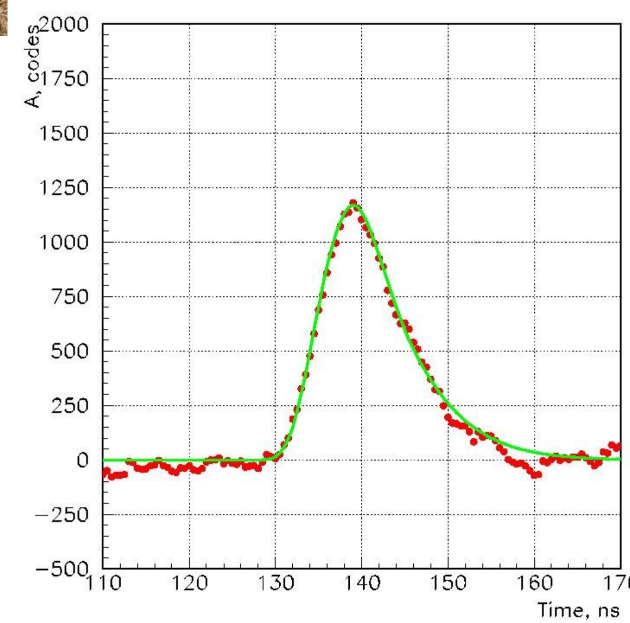



N hit≥ 5 detectors
Efficiency
100%
10%
1%
20 TeV
50 TeV
1-st stage
2 stage
min 5 detectors
64 det. q=0.1, s=0.5m2, rate 23
64 usual+49 sensitive:
with q=0.14, s=0.75, rate 49
10^1
10^2
10^3
E (TeV)

9 оптических станций

36 ФЭУ R5912 (8’’)
Новые предусилители.
Новая система сбора

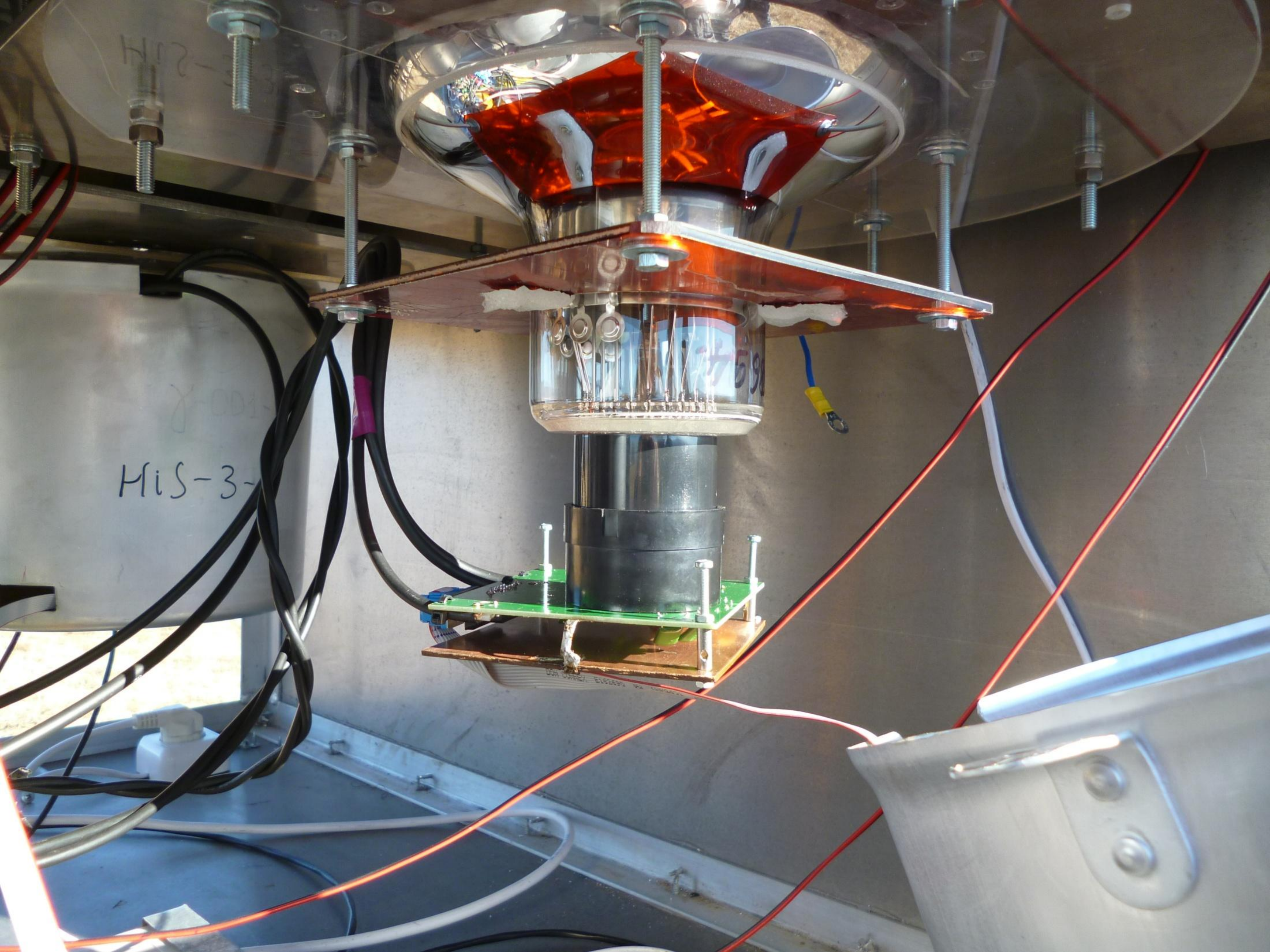




DRS-4 board (0.5 ns step)


К КОНТР-РУ

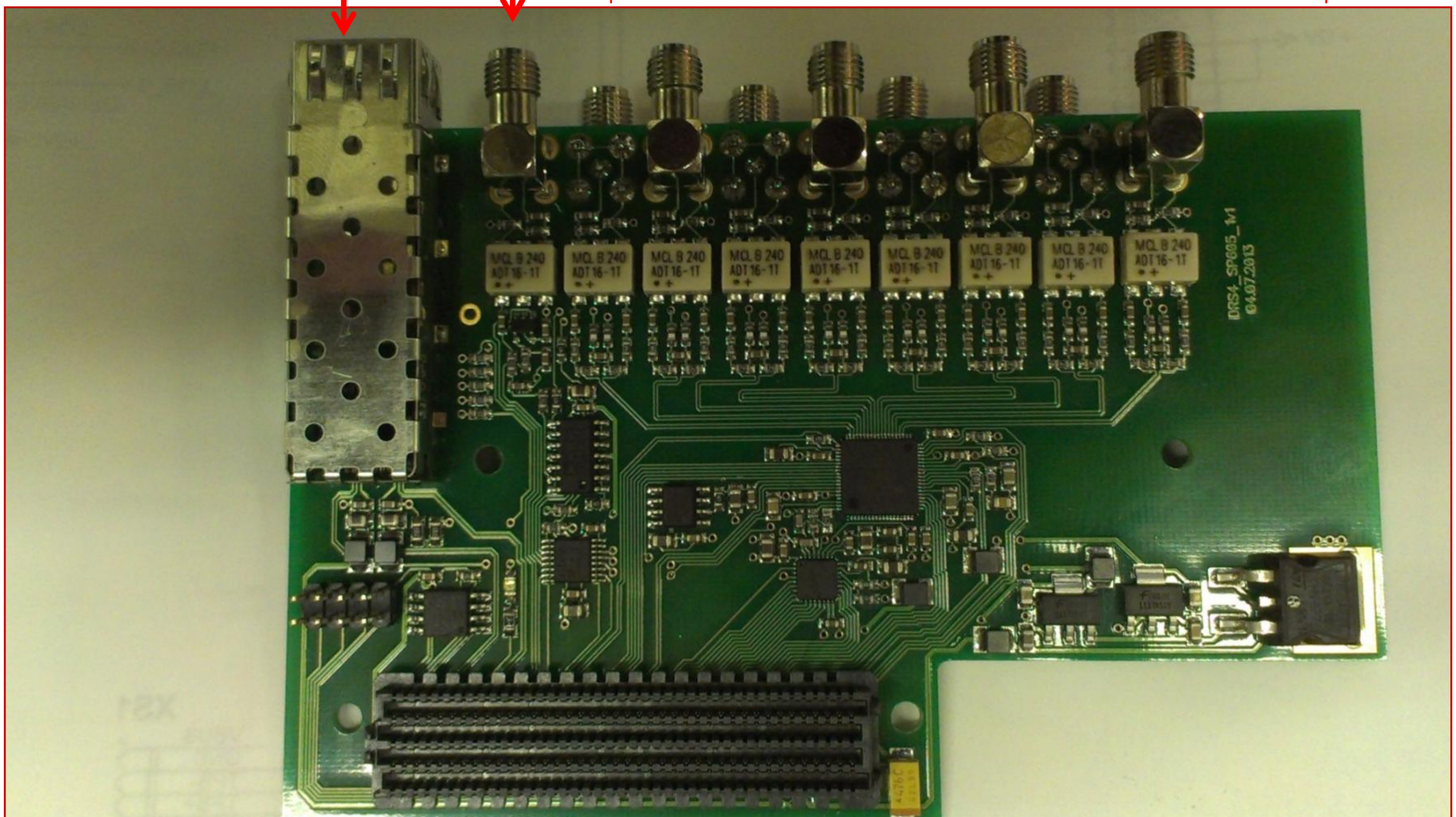

HiS-3-1
HiS-3-4
HiS-3-2
controller
HV -power supply

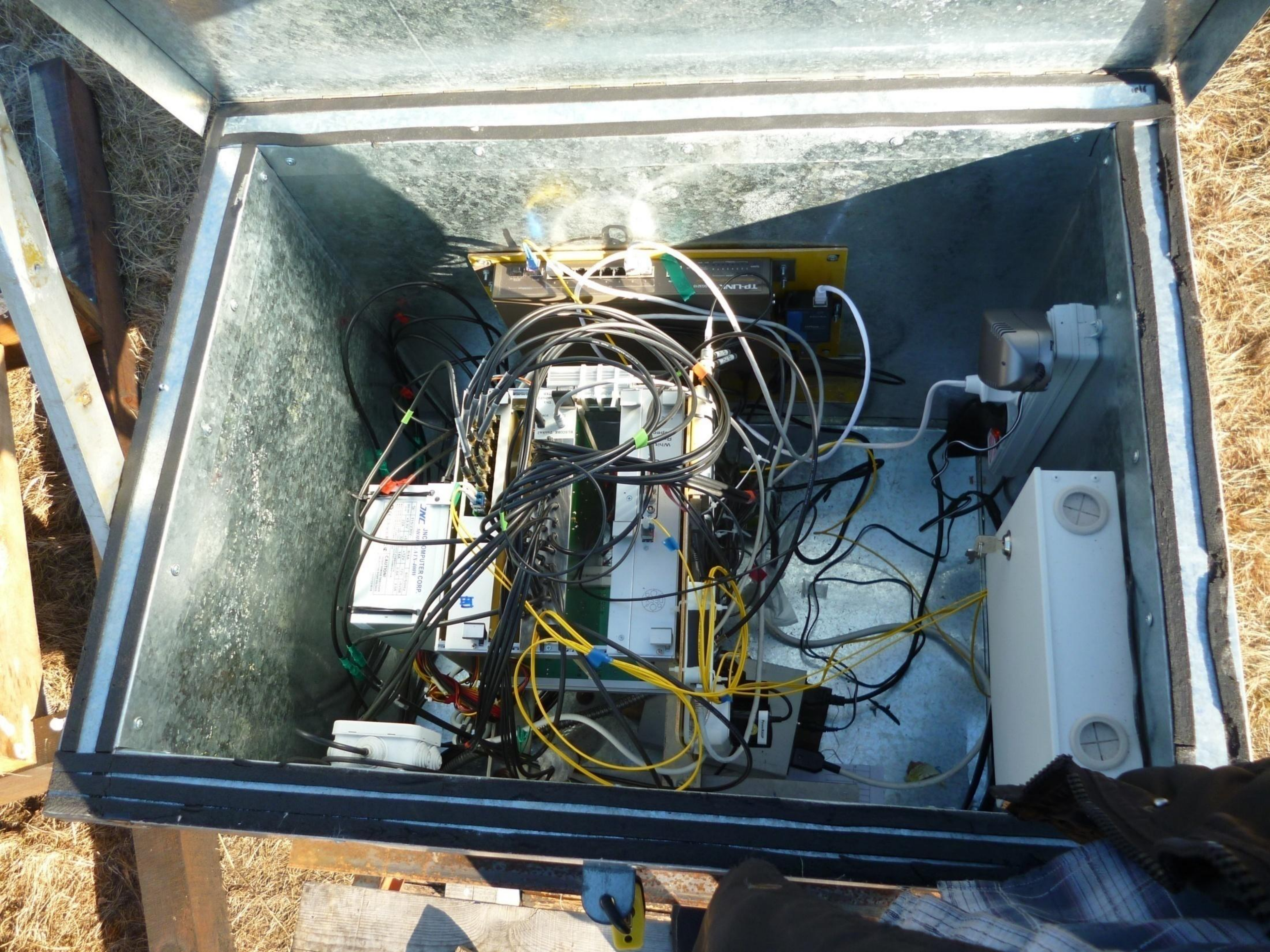

HiS-3-

100 MHz clock for synchronization

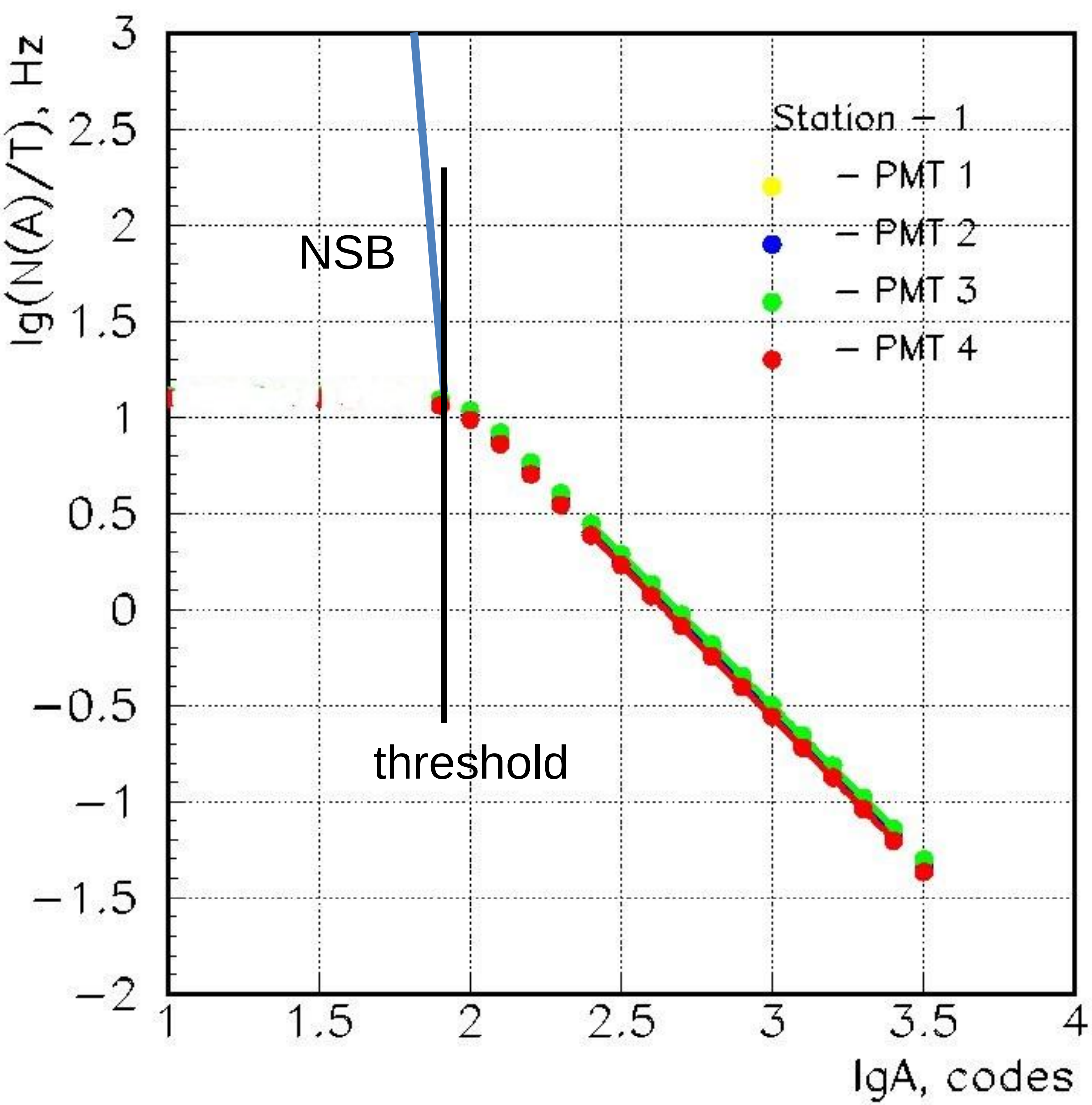
Sum of 4 anods signals

4 anods and 4 dinods signals





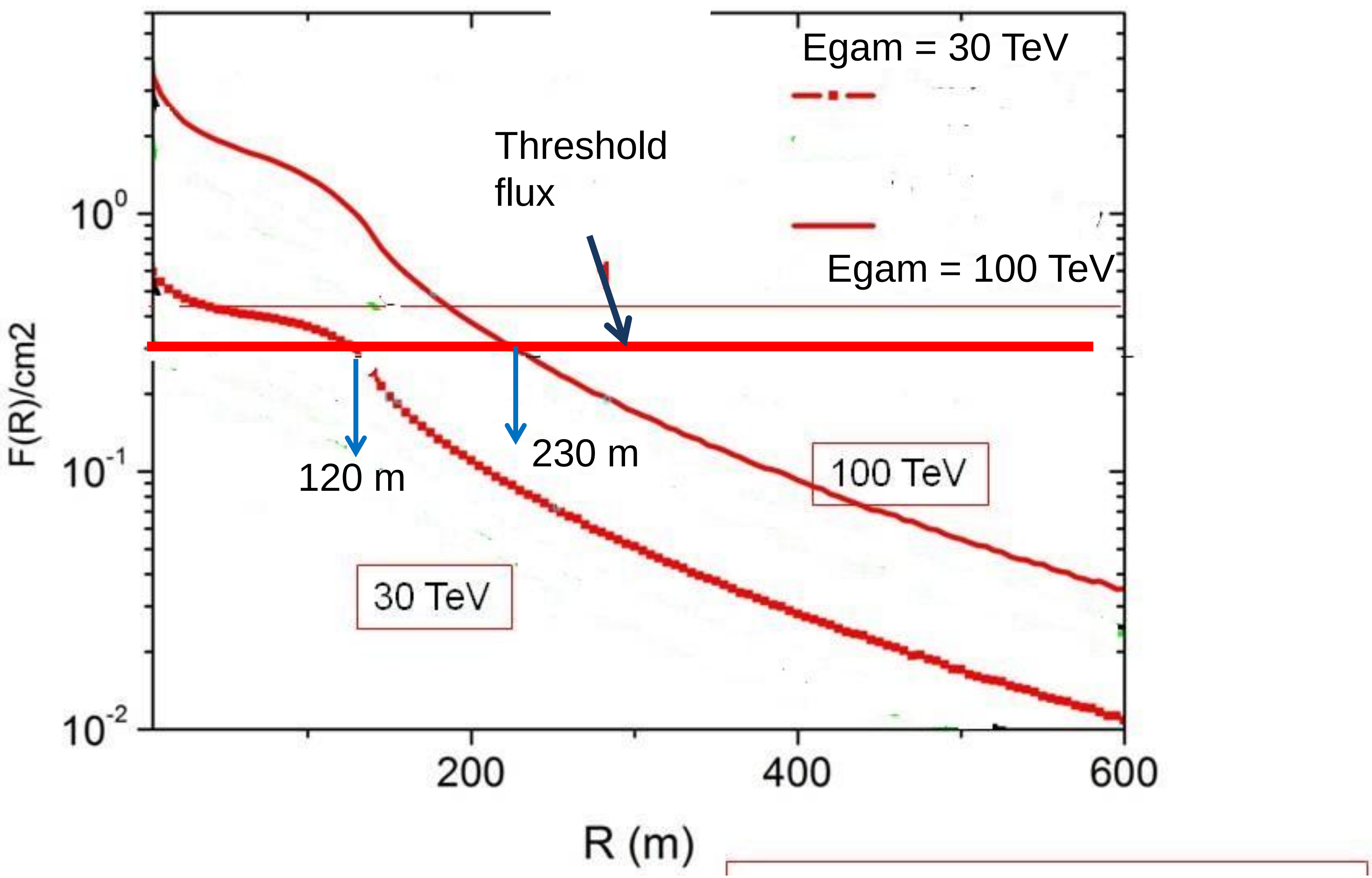
Amplitude spectrum of PMTs in station

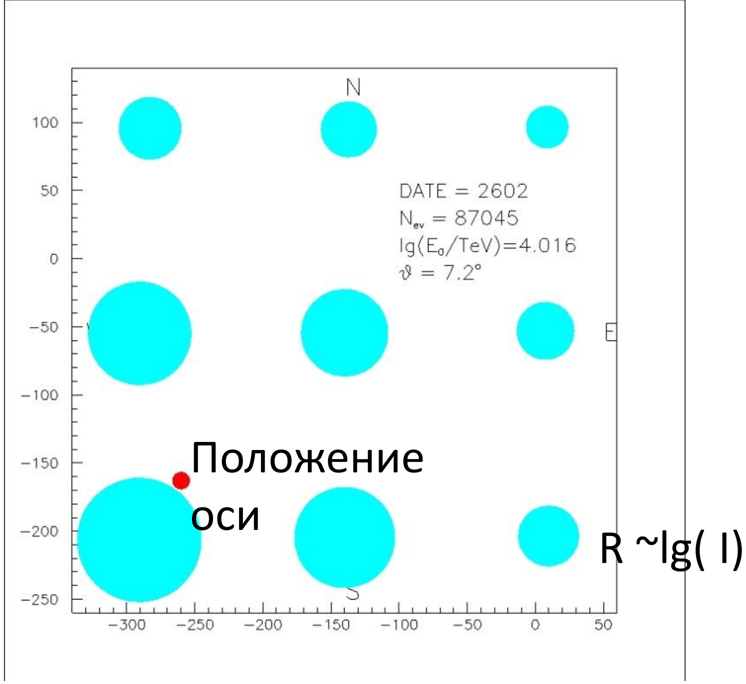


Counting rate = 12 -16 Hz

Threshold flux:
0.25 – 0.3 ph / cm^2

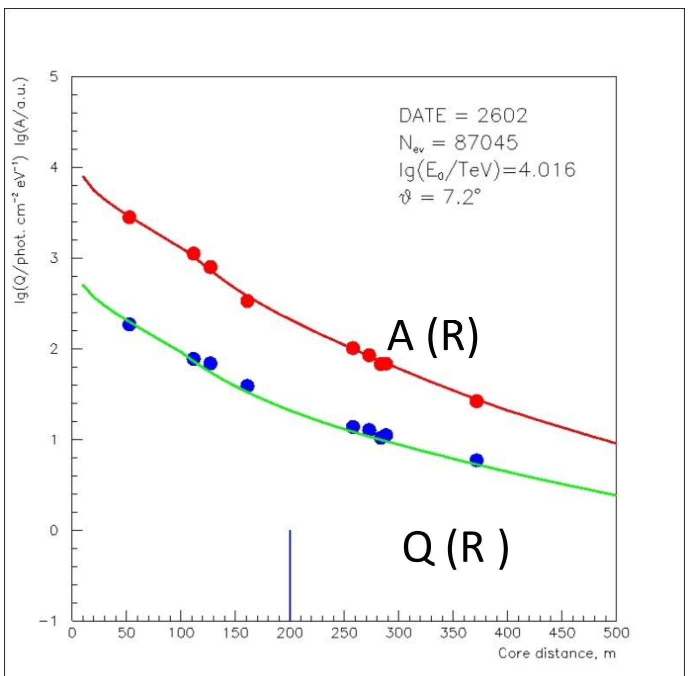
LDF of Cherenkov light from EAS from gamma-rays



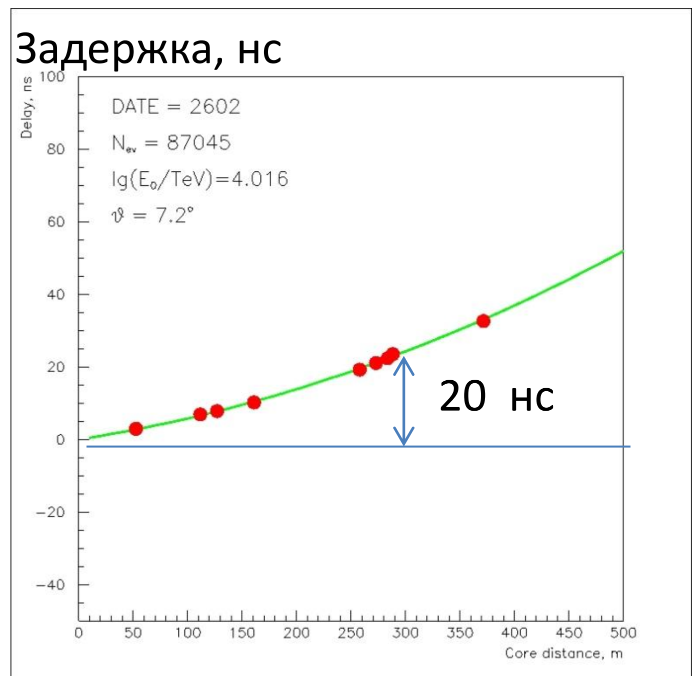


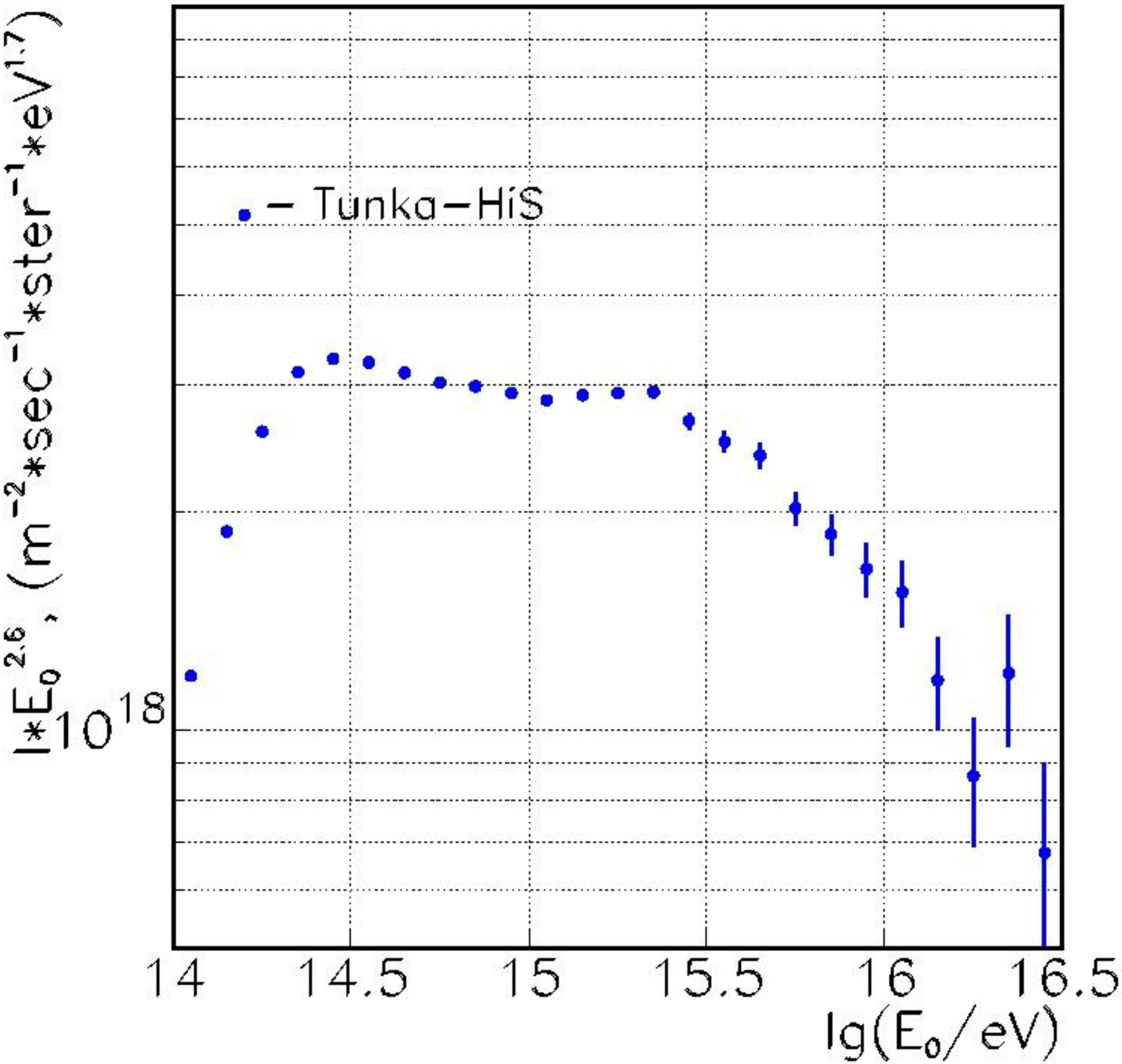
Пример события
зенитный угол – 7.2°
энергия - 1.0 10^{16} эВ

$E = c\, Q(200)^{-0.94}$



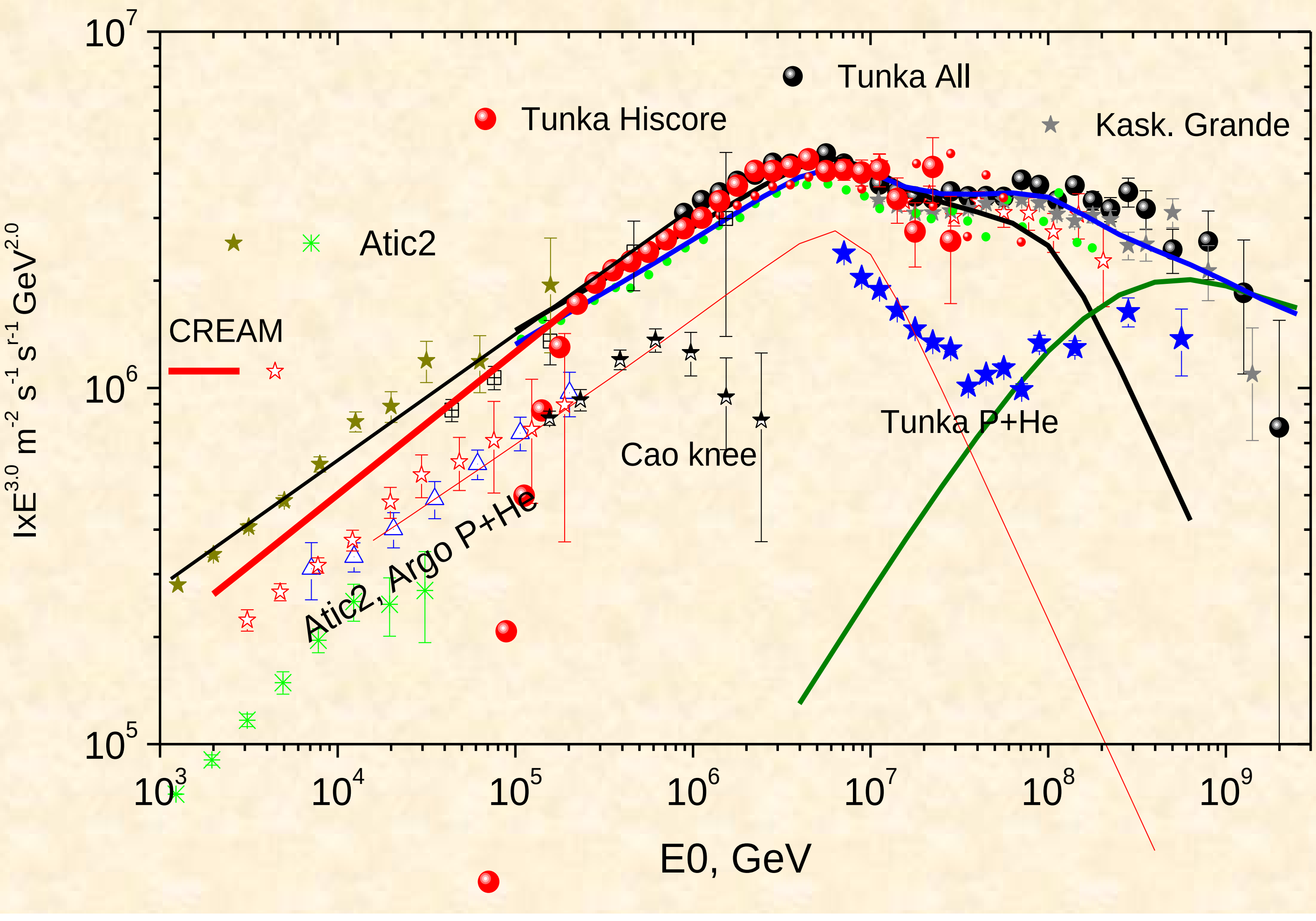
Фронт ШАЛ



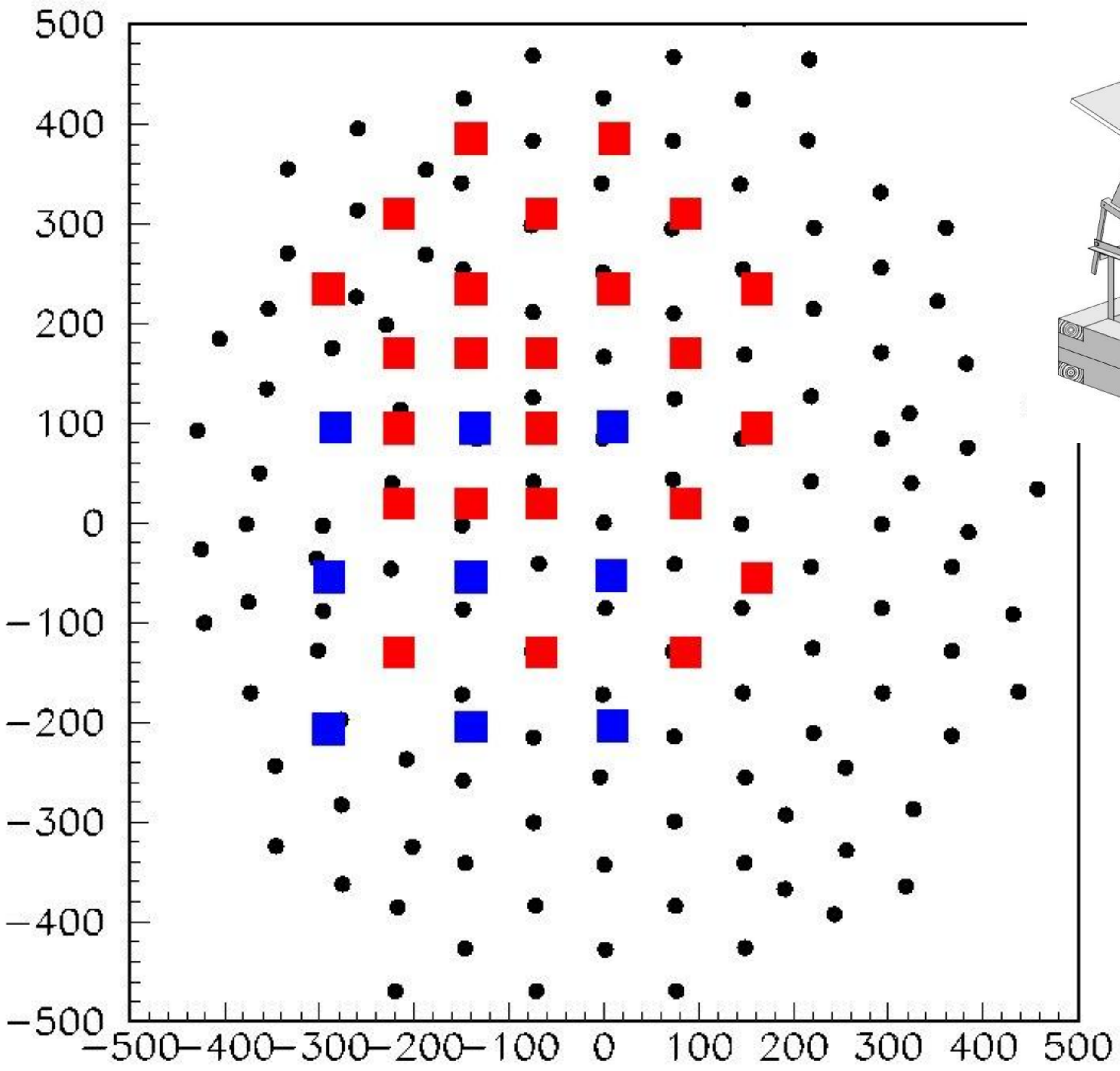


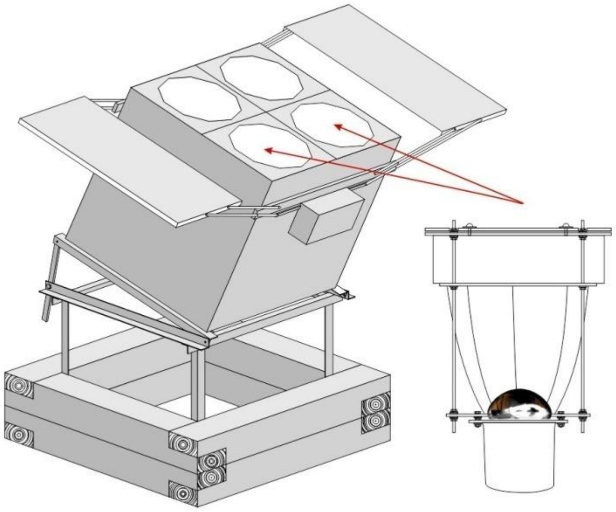
Доклад
Л.Г.Свешниковой

Спектр всех частиц



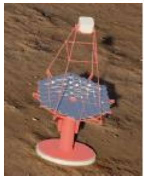
Установка 2014-2015 года – 33 станции





Все станции наклонены
к Югу на 30 град

20-60 событий от
Краба за 100 часов



Telescope parameters

D = 4.32m   F = 4.75

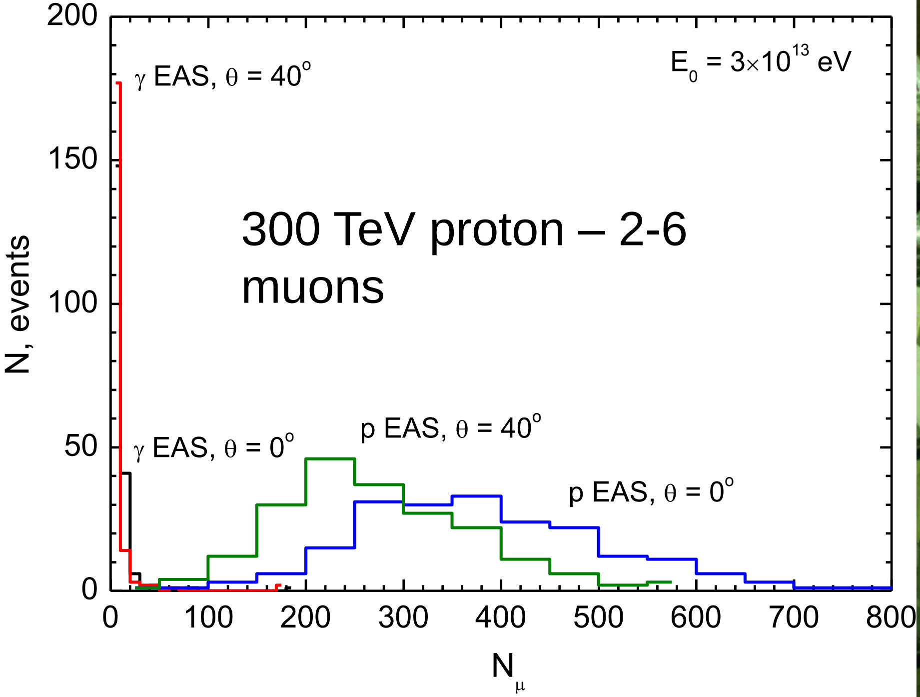
34 mirrors   with 60 cm diameters

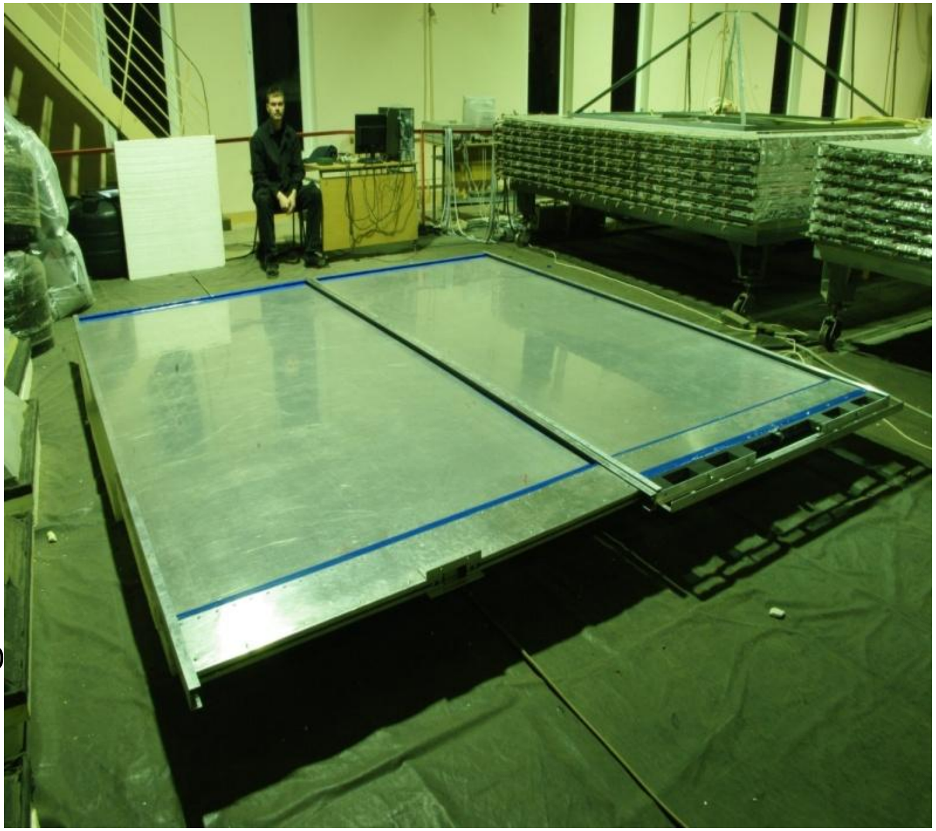
Camera : 400 PMTs (XP 1911) with 15 mm useful diameter of photocathode
Winston cone: 30 mm input size, 15 output size
1 single pixel = 0.36 deg
full angular size   8.3 deg

DAQ - MAROC3

First telescope in autumn 2015

2000 m² muon detectors (0.2% of array area)

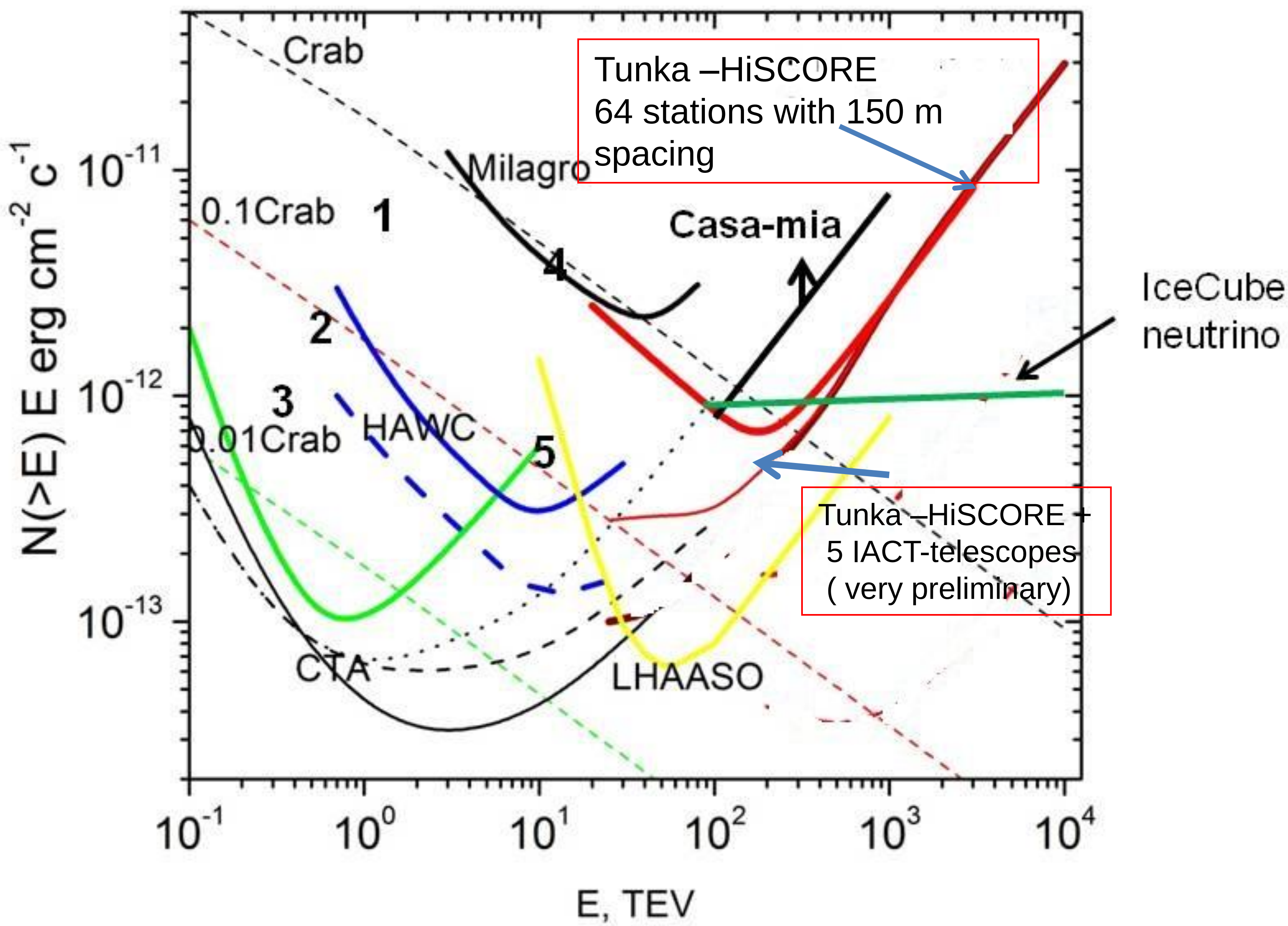




Rejection of hadron background by 10 times at 300 TeV

Scintillation detectors developed in Mephi

ID : 122



Tunka –HiSCORE
64 stations with 150 m
spacing
Crab
Milagro
0.1Crab
1
Casa-mia
4
IceCube
neutrino
2
3
HAWC
0.01Crab
5
Tunka –HiSCORE +
5 IACT-telescopes
(very preliminary)
CTA
LHAASO
N(>E) E erg cm^{-2} c^{-1}
10^{-11}
10^{-12}
10^{-13}
10^{-1}
10^{0}
10^{1}
10^{2}
10^{3}
10^{4}
E, TEV

Заключение

1. Tunka-133 :

Пять ближайших лет будет продолжен набор данных совместно сцинтилляционными станциями и радиоантеннами.
Далее будет проведена серьезная модернизация для перехода в другой интервал энергии.

2. Первые 9 станций HiSCORE успешно проработали первый зимний сезон. Восстановлен энергетический спектр от 200 ТэВ до 10 ПэВ На установке 2014-15 года (33 станции) мы надеемся зарегистрировать сигнал от Краба.

3. Первый телескоп начнет работать 2015 году.

Спасибо за внимание