Results and future plans of Tunka

L.Kuzmichev (SINP MSU)
On behalf of Tunka and TAIGA Collaboration

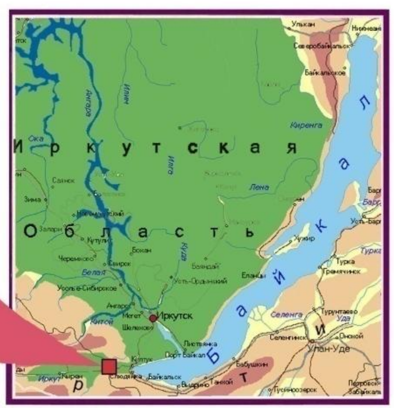
Paris, 28 of May 2014

Outline

1. Tunka array : history, status and main results
2. Tunka Radio Extension (Tunka-REX)
3. Deployment of scintillation station
4. TAIGA array - Towards gamma-astronomy

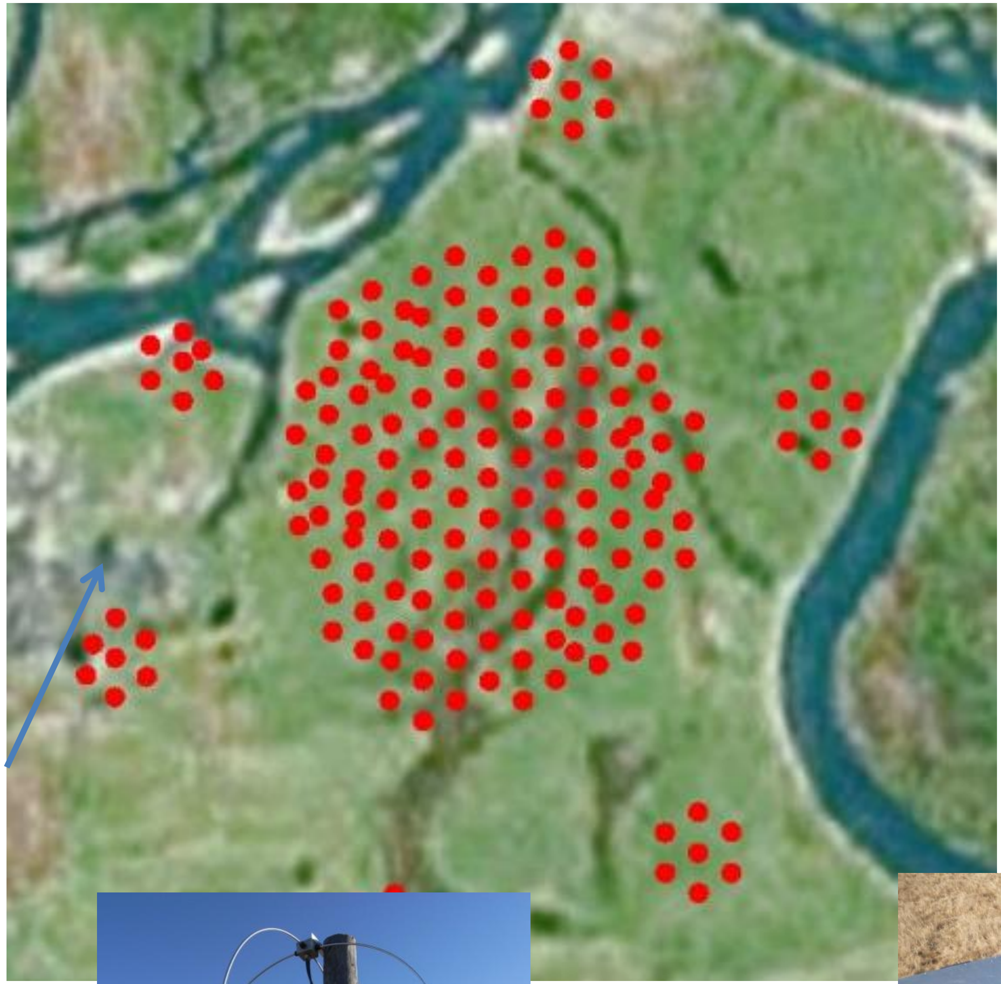
Tunka-133 array:
175 optical detectors on 3 km^2 area

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



Status of 2014

Deploymnet of the new scintillation Stations (from Kascade-Grande)



First 9 stations of HiSCORE array

25 antennas for registration radio signals from EAS Tunka-REX array

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

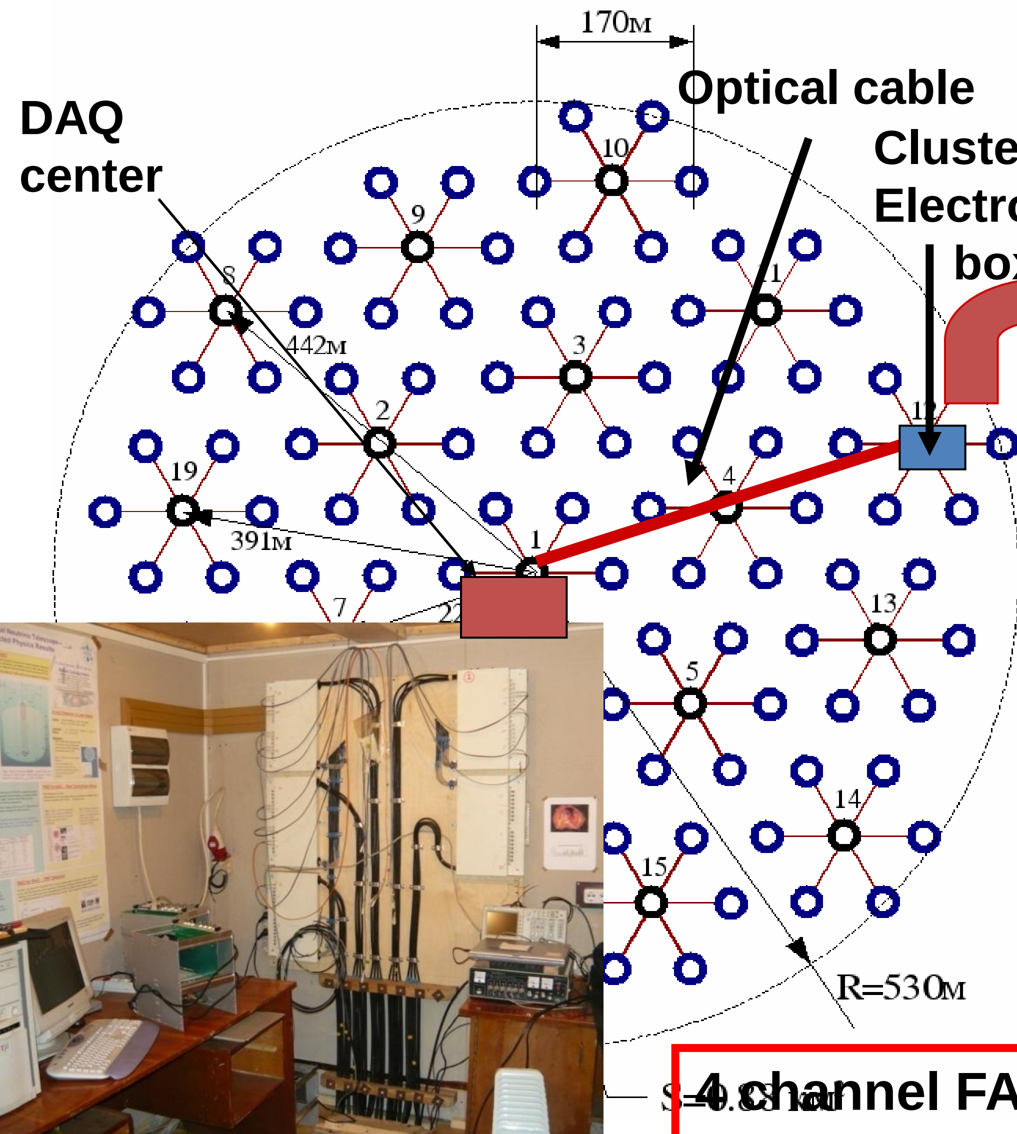
Tunka Inauguration (Septermber 2009)

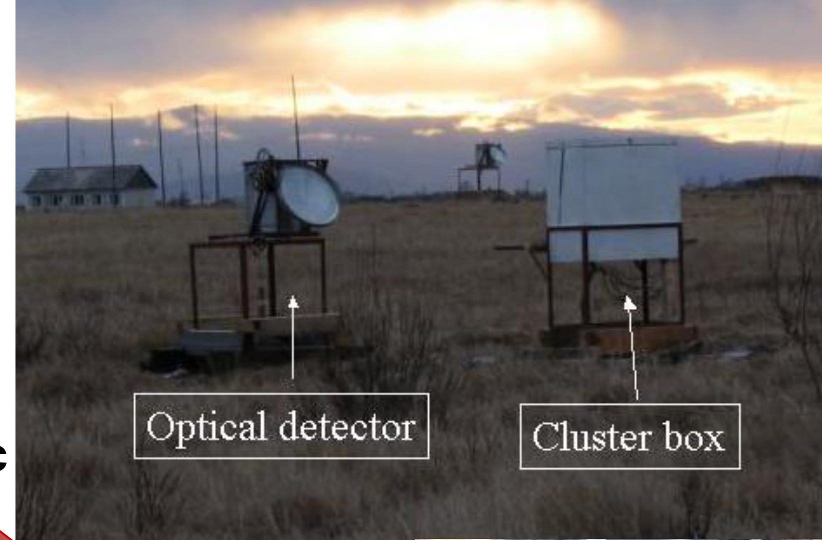
Tunka-133: 25 clusters,
7 detectors in each cluster

DAQ center

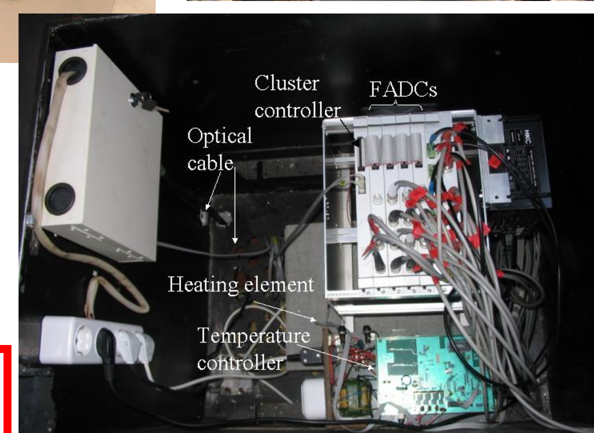
Optical cable

Cluster Electronic box





PMT
EMI 9350
Ø 20 cm



4 channel FADC boards
200 MHz, 12 bit

Physics goals

1. Cosmic Rays study 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

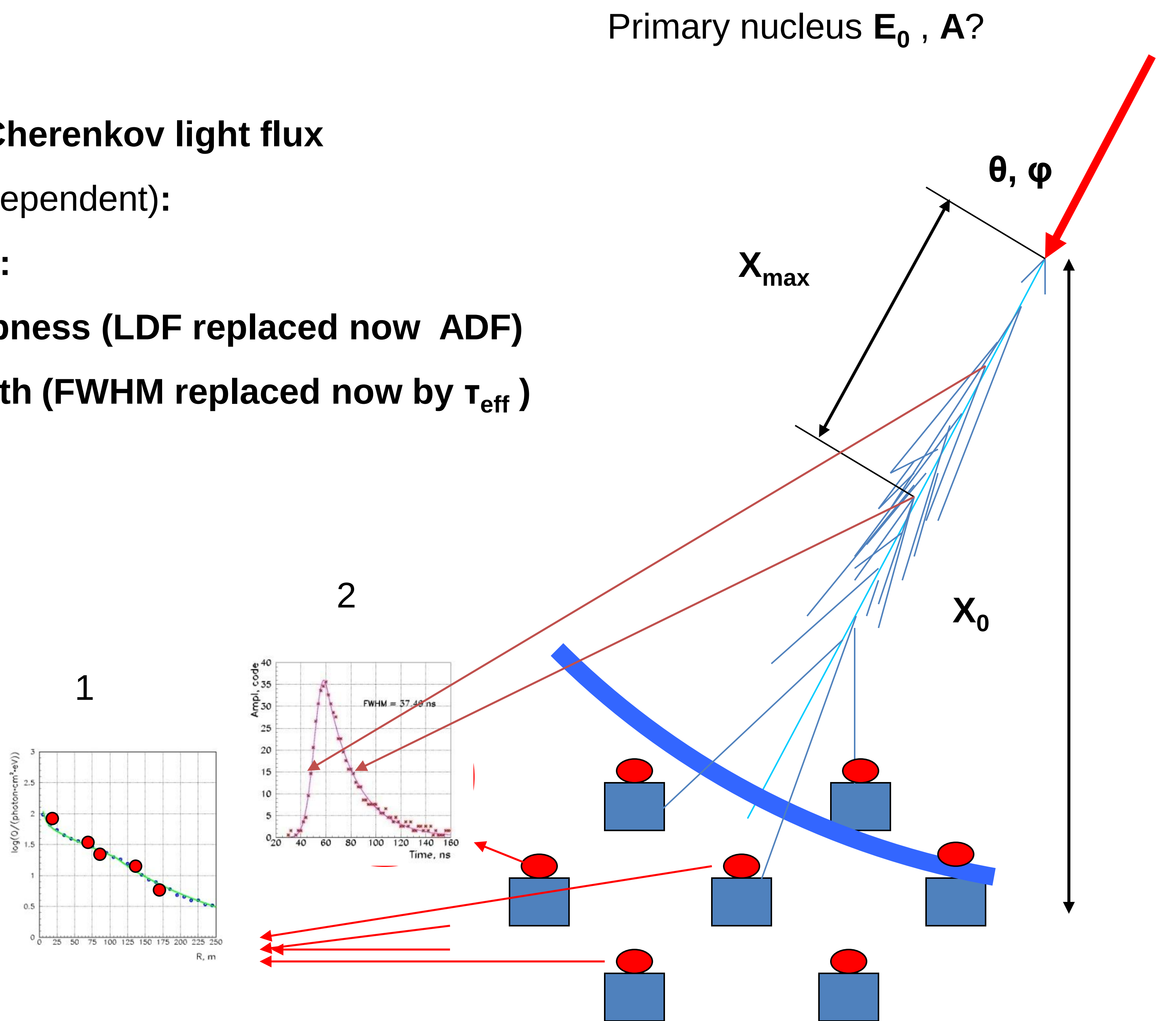
2. Search for gamma-rays with energies of $5 \cdot 10^{16}$ - $5 \cdot 10^{17}$ eV

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})**



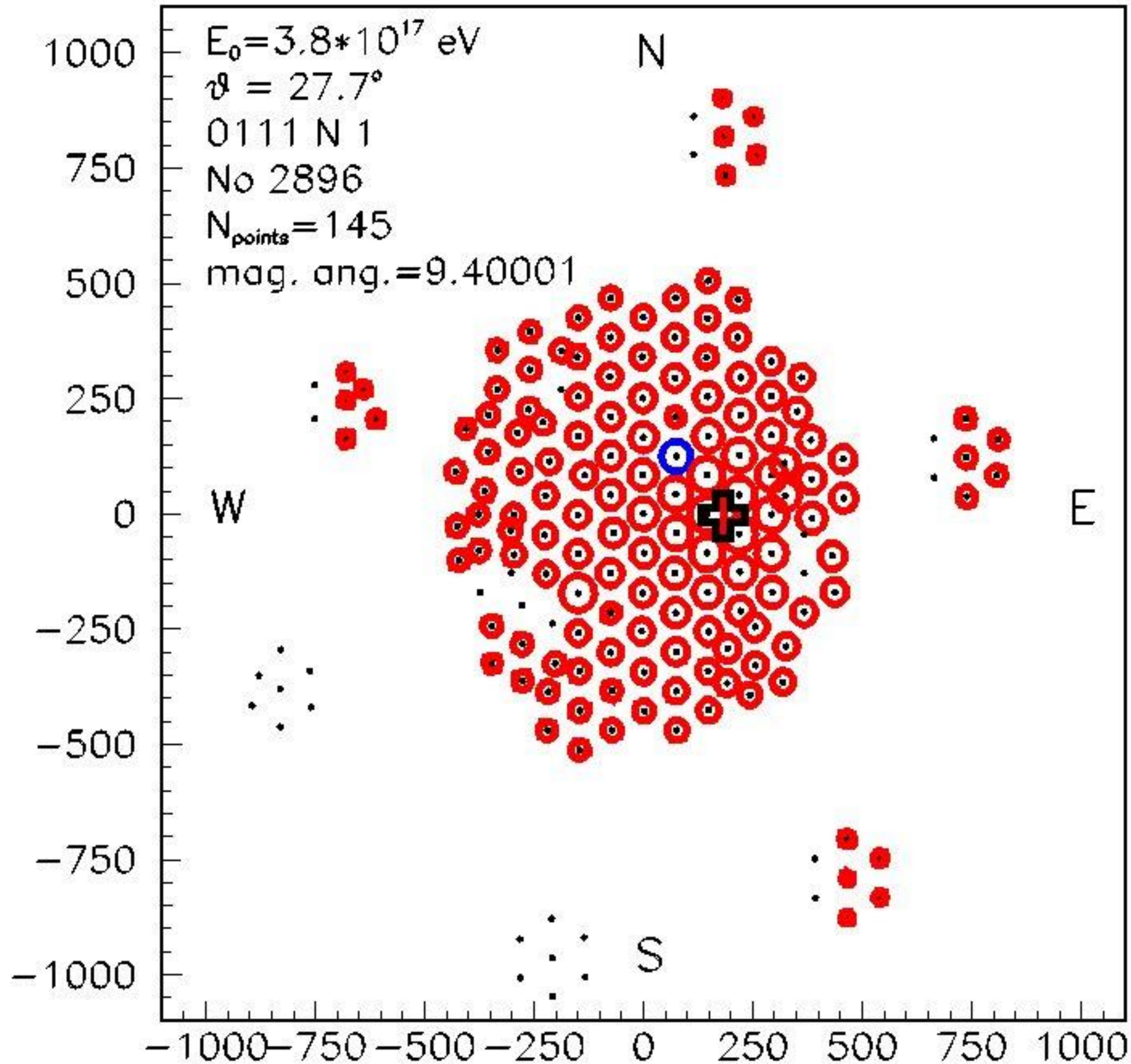
Energy reconstruction

$$E = A\ (Q200)^{g}$$

Density of Cherenkov light at core distance of 200 m

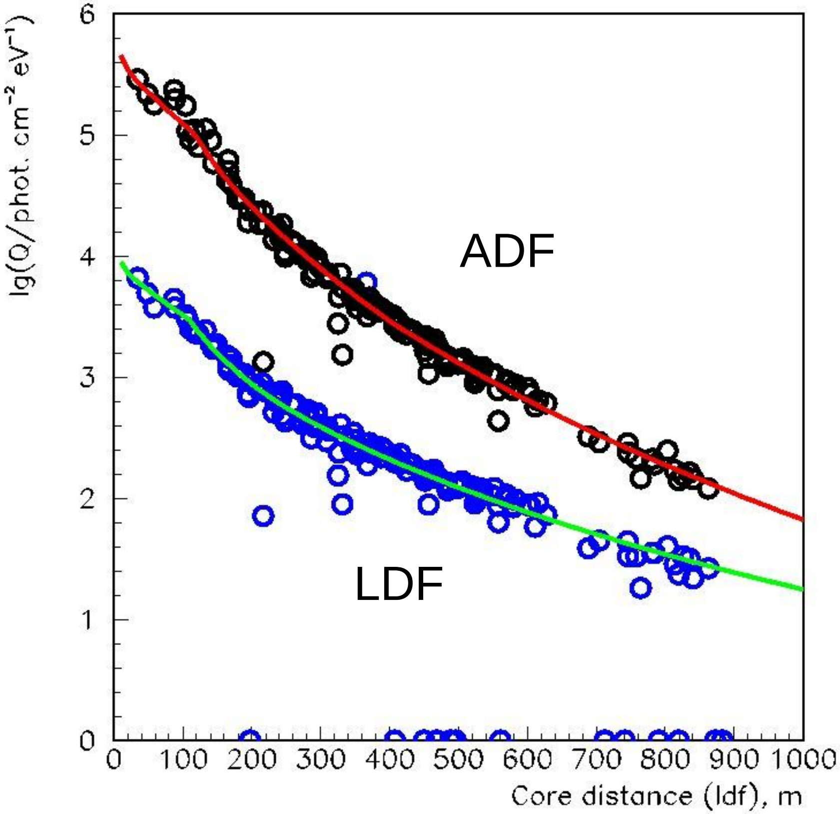
For $10^{16} – 10^{18}$ eV (CORSIKA):

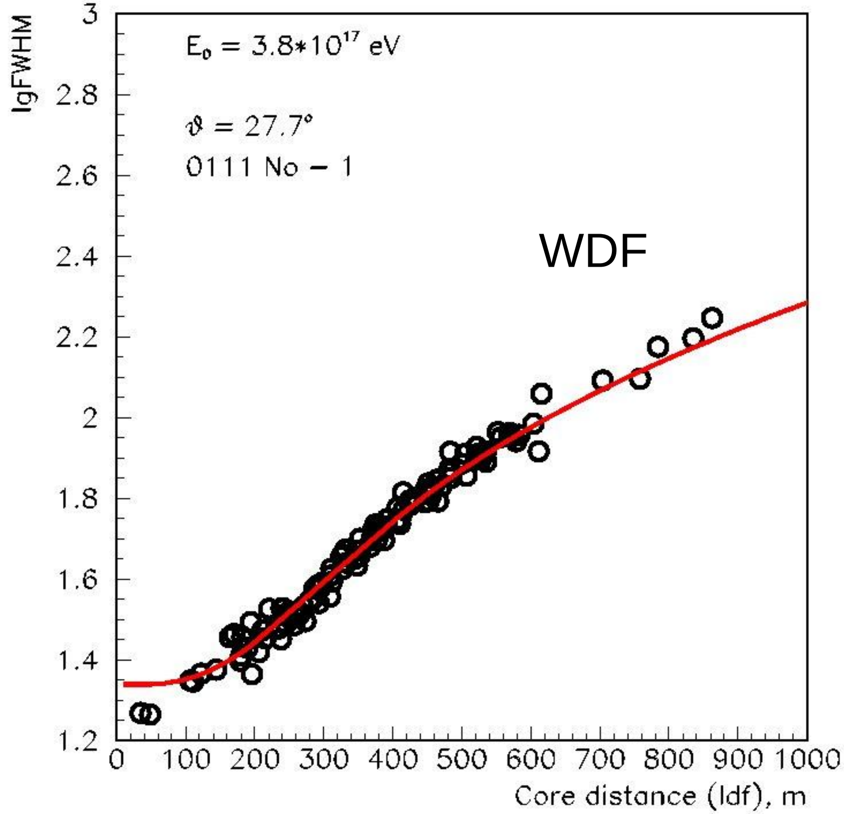
$$g = 0.94 \pm 0.01$$



$E_0=3.8*10^{17}$ eV
$\vartheta = 27.7°$
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

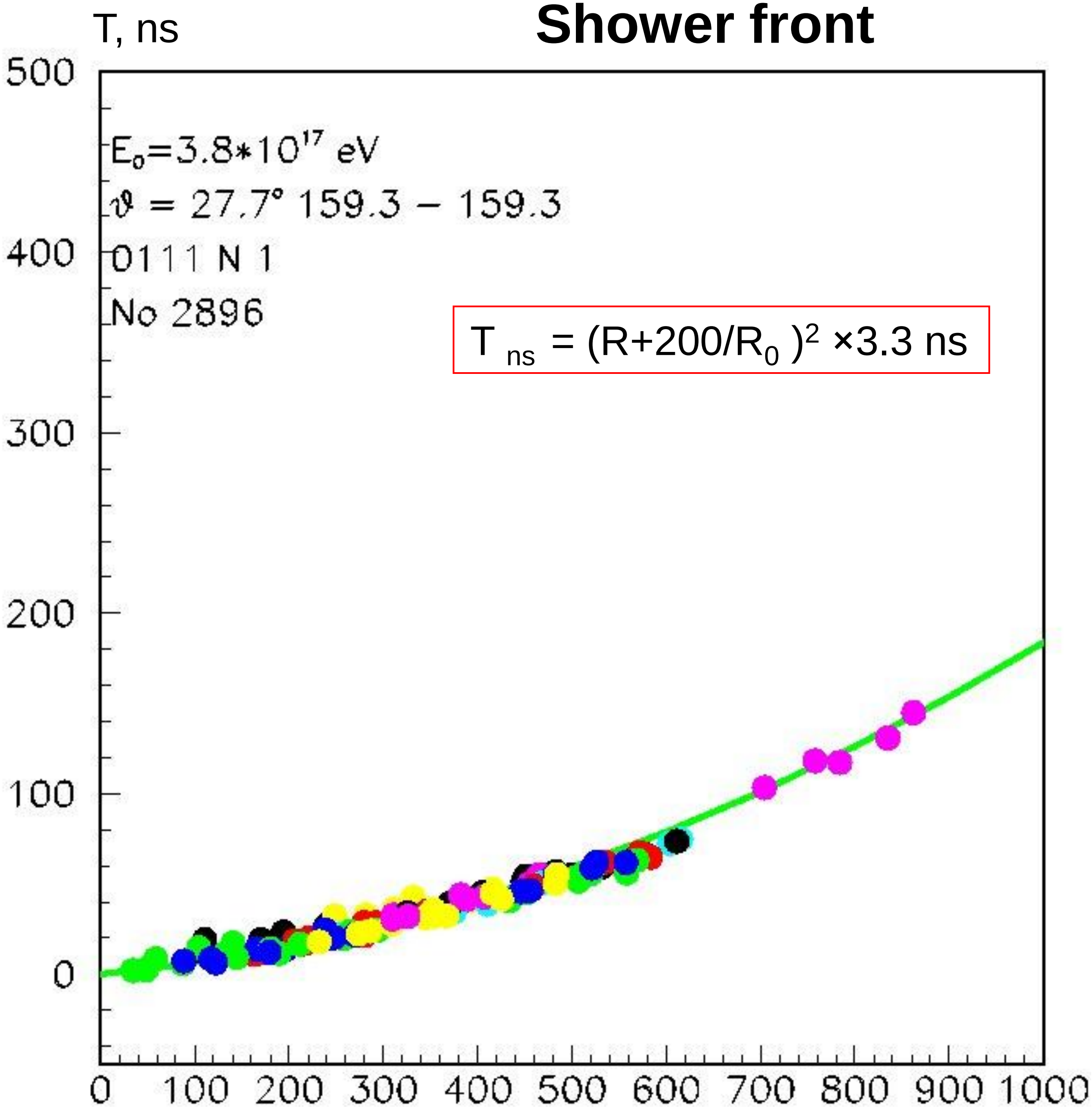
WDF – width distant function



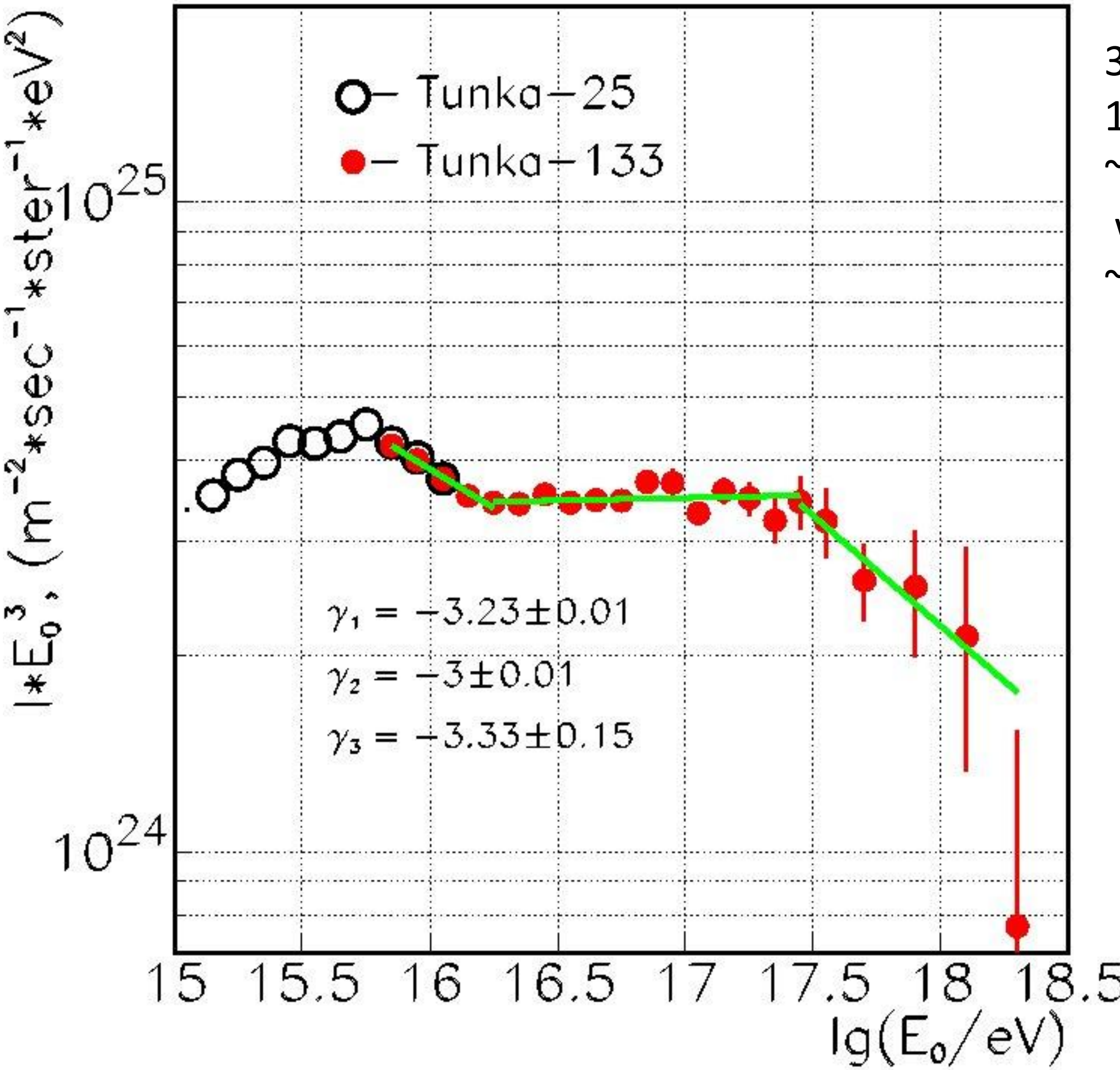


ADF – amplitude distant function is used for core location

Shower front



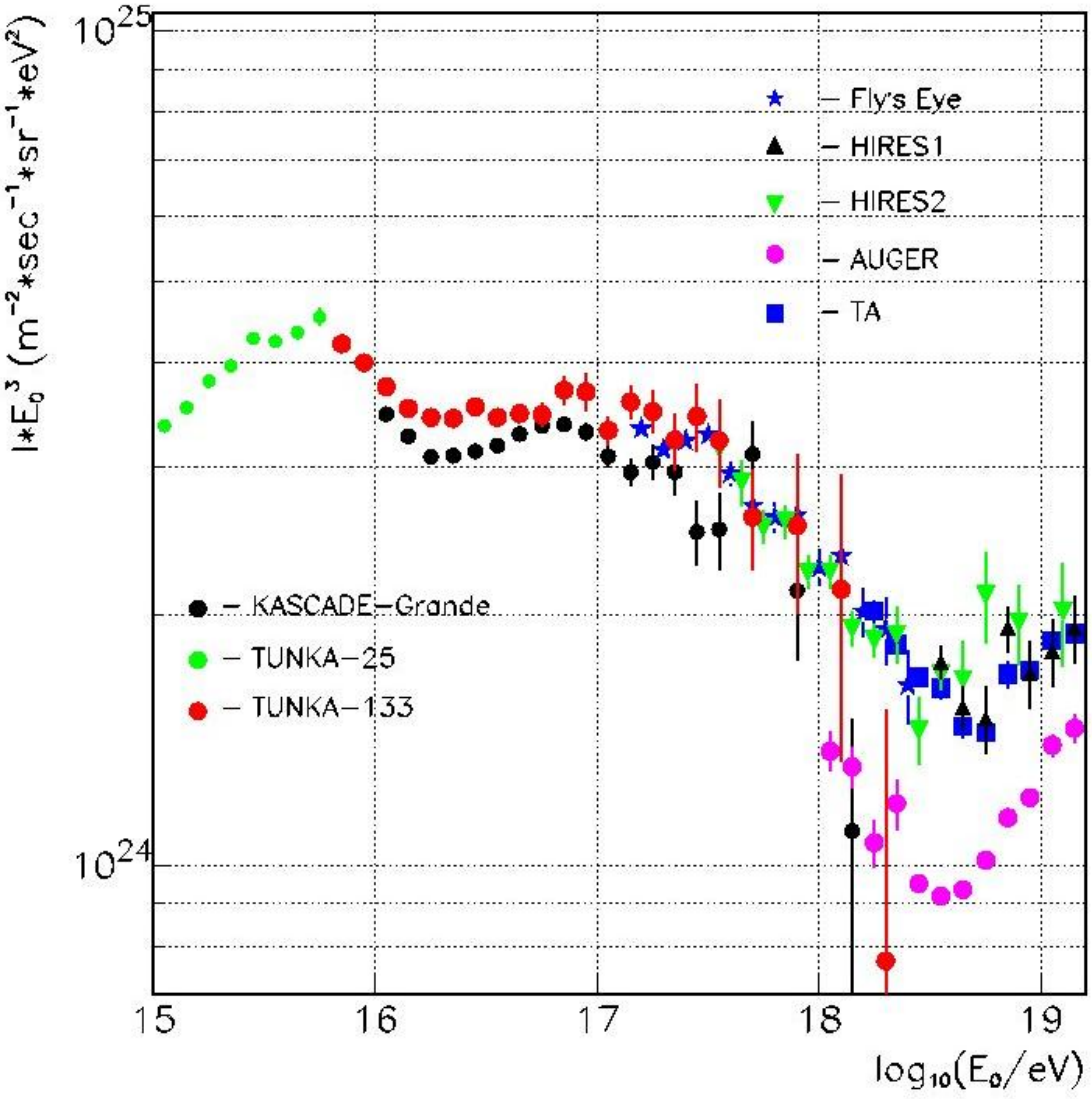
All particle spectrum



3 winter seasons:
165 serene moonless nights
~ 980 h of observation
with a trigger frequency ~ 2 Hz
~ 6 000 000 triggers

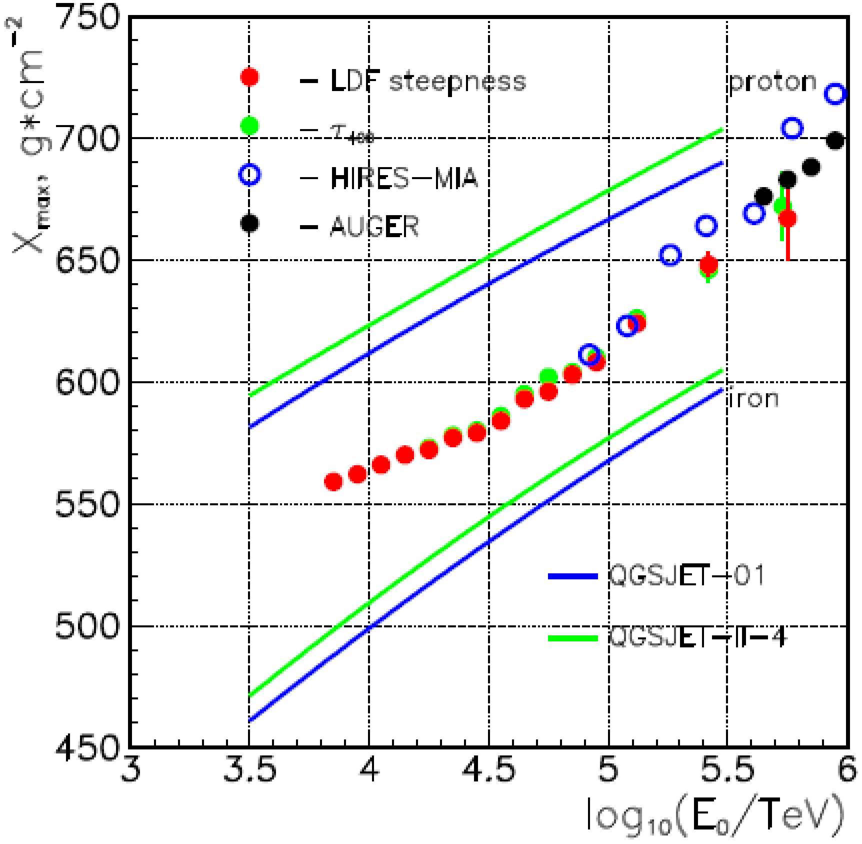
~ 1900 events E_0 >10^{17} eV

Comparison with other experiments

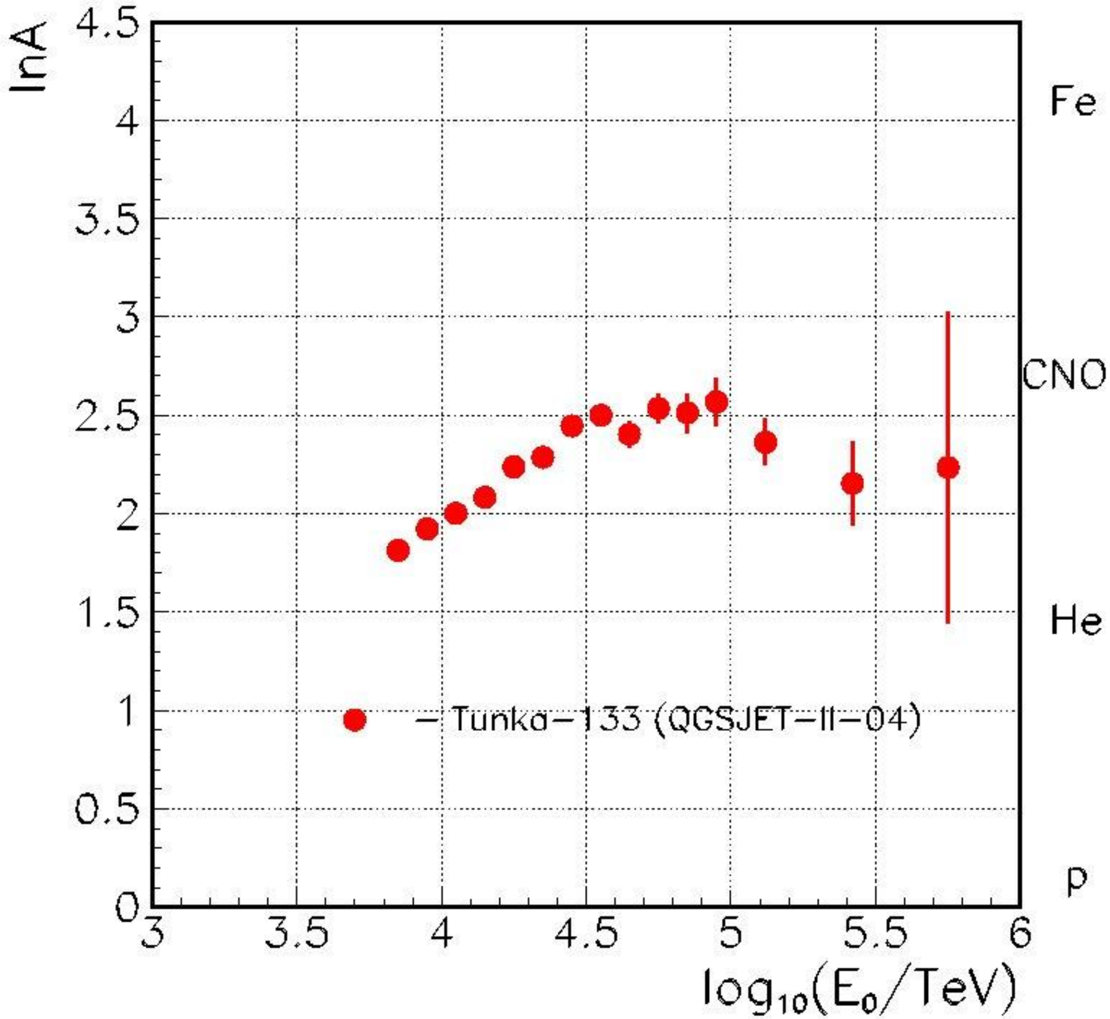


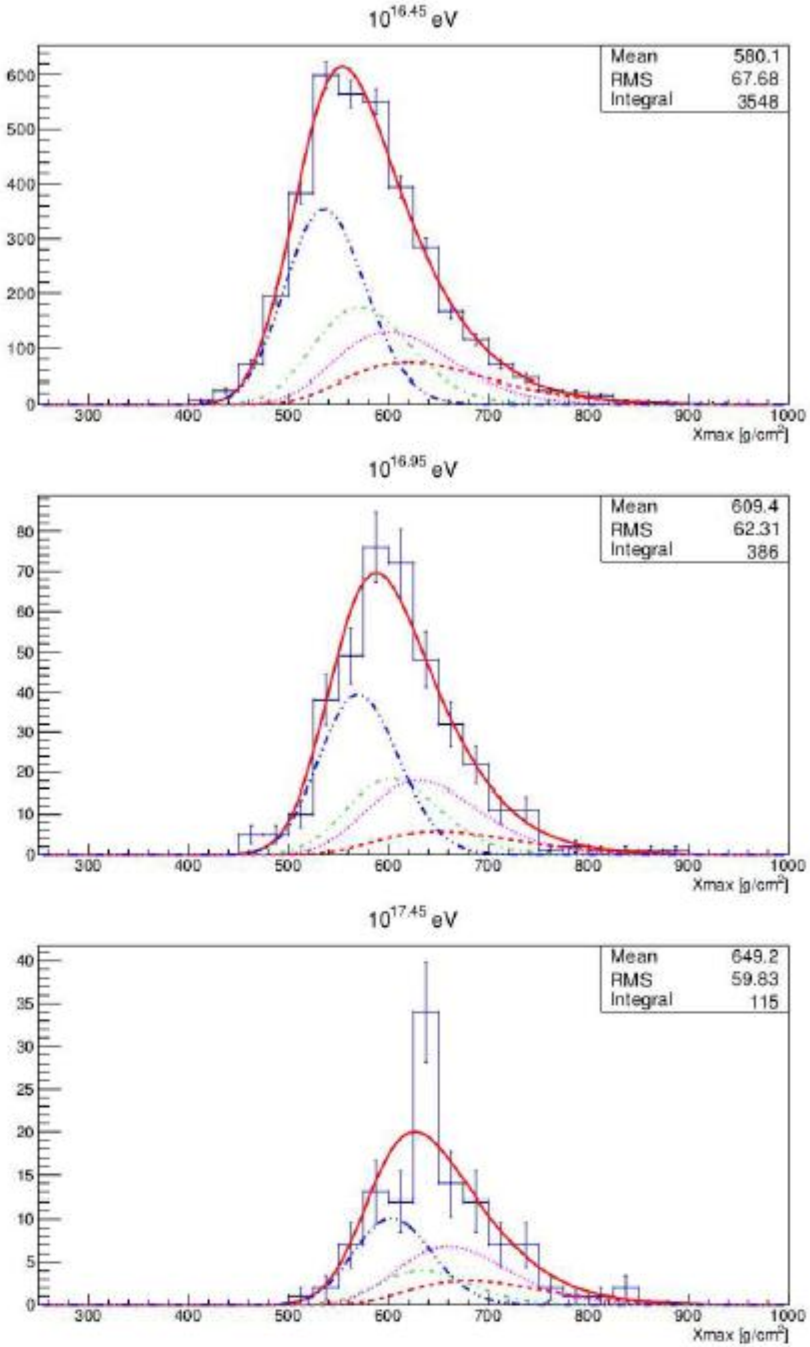
1. Agreement with KASCADE-Grande
2. Agreement with old Fly's Eye, HiRes and TA spectra.

Xmax dependence from energy



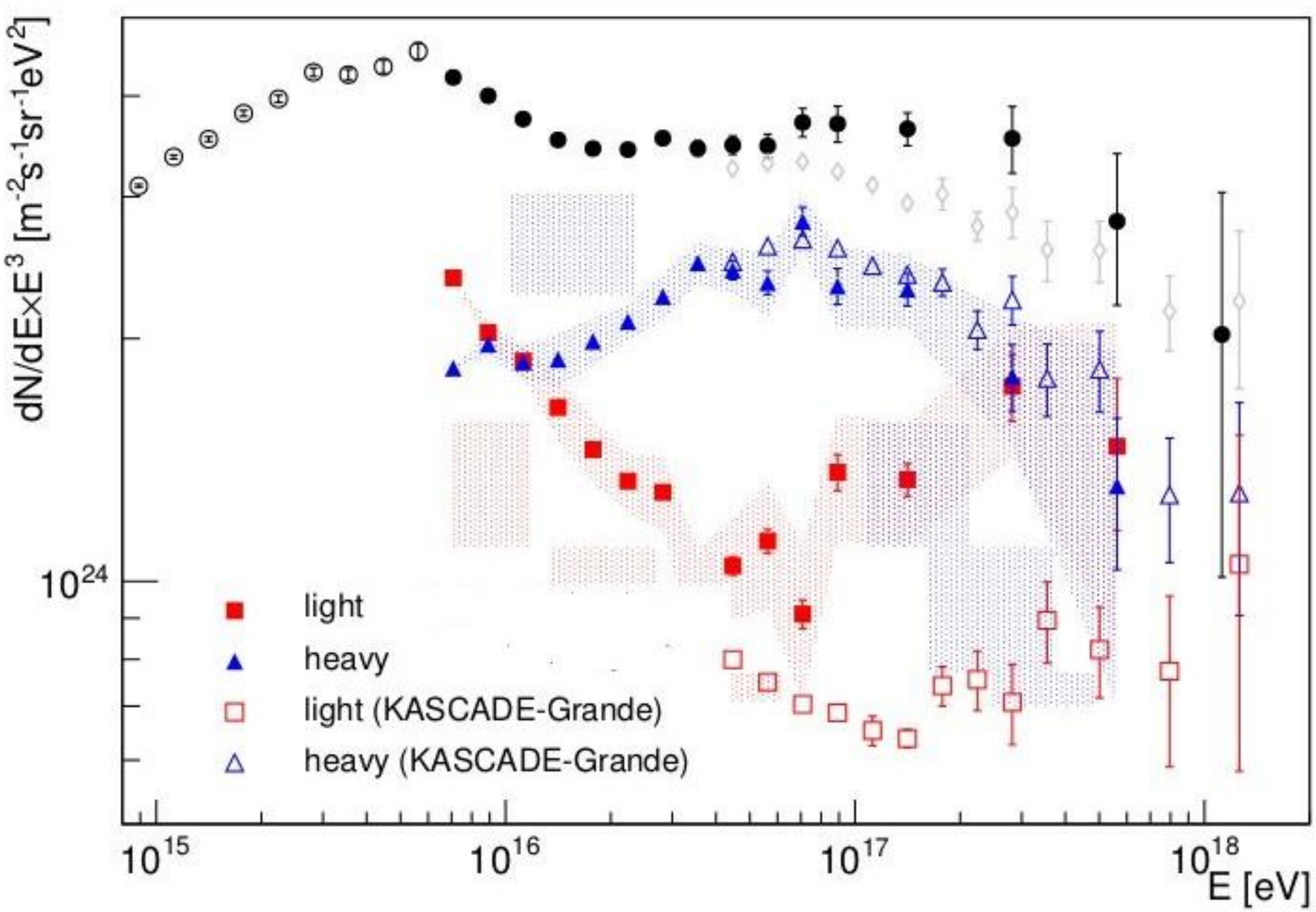
EXPERIMENT: MEAN <lnA> vs. E_0



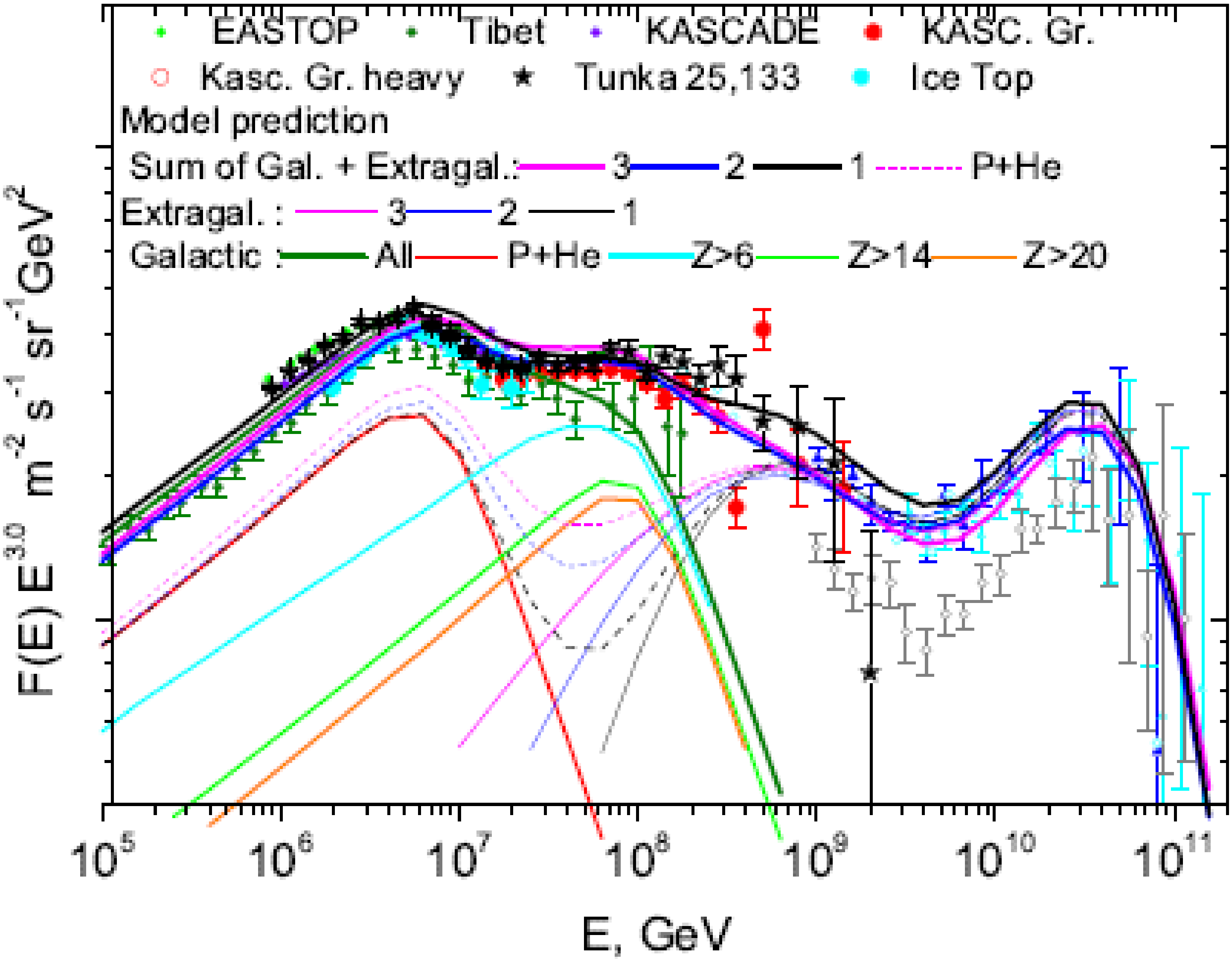


Xmax distribution analysis:

Experimental Xmax distribution
Fitted with sum of distribution
For P, He, CNO, Fe



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]



EASTOP
Tibet
KASCADE
KASC. Gr.
Kasc. Gr. heavy
Tunka 25,133
Ice Top
Model prediction
Sum of Gal. + Extragal.: 3 2 1 P+He
Extragal. : 3 2 1
Galactic : All P+He Z>6 Z>14 Z>20
$F(E)\,E^{3.0}\ m^{-2}\,s^{-1}\,sr^{-1}\,GeV^{2}$
10^{5} 10^{6} 10^{7} 10^{8} 10^{9} 10^{10} 10^{11}
E, GeV

Tunka-REX

Connection of 2 antennas to 2 free channels of FADC

Tunka-Rex detector

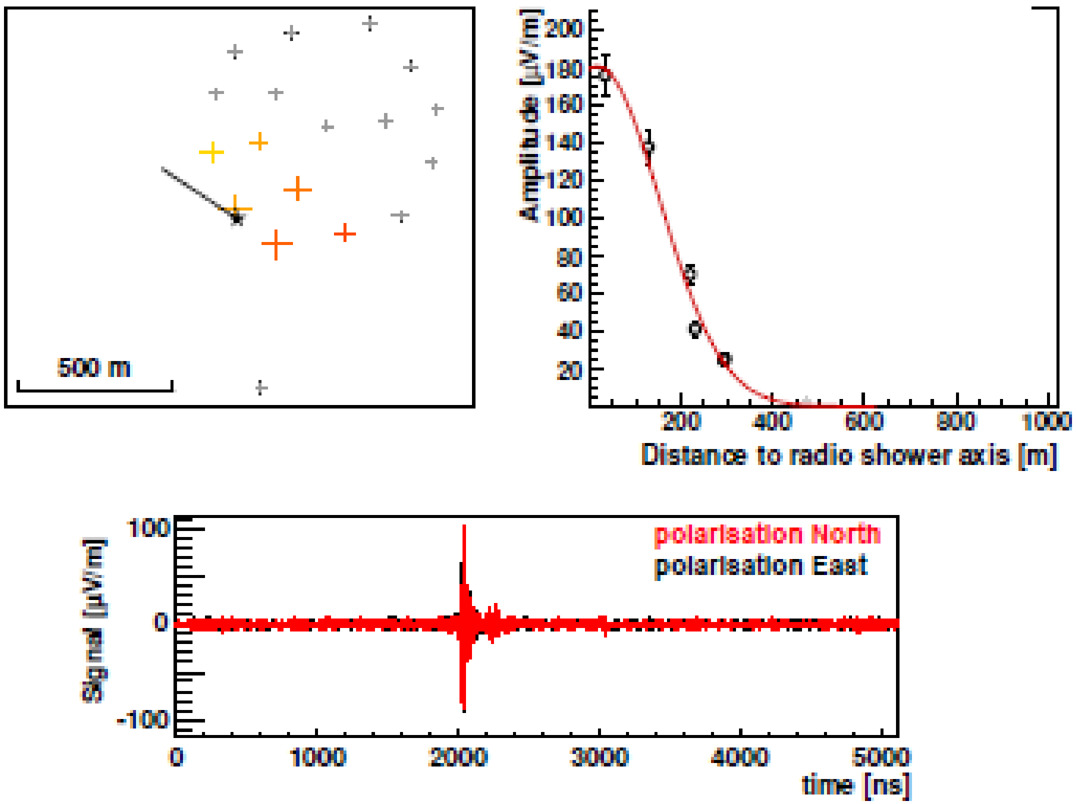
- 25 antennas on 1 km^2 area
- Existing DAQ of Tunka-133
- Trigger and information from air-Cherenkov detector

- 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)

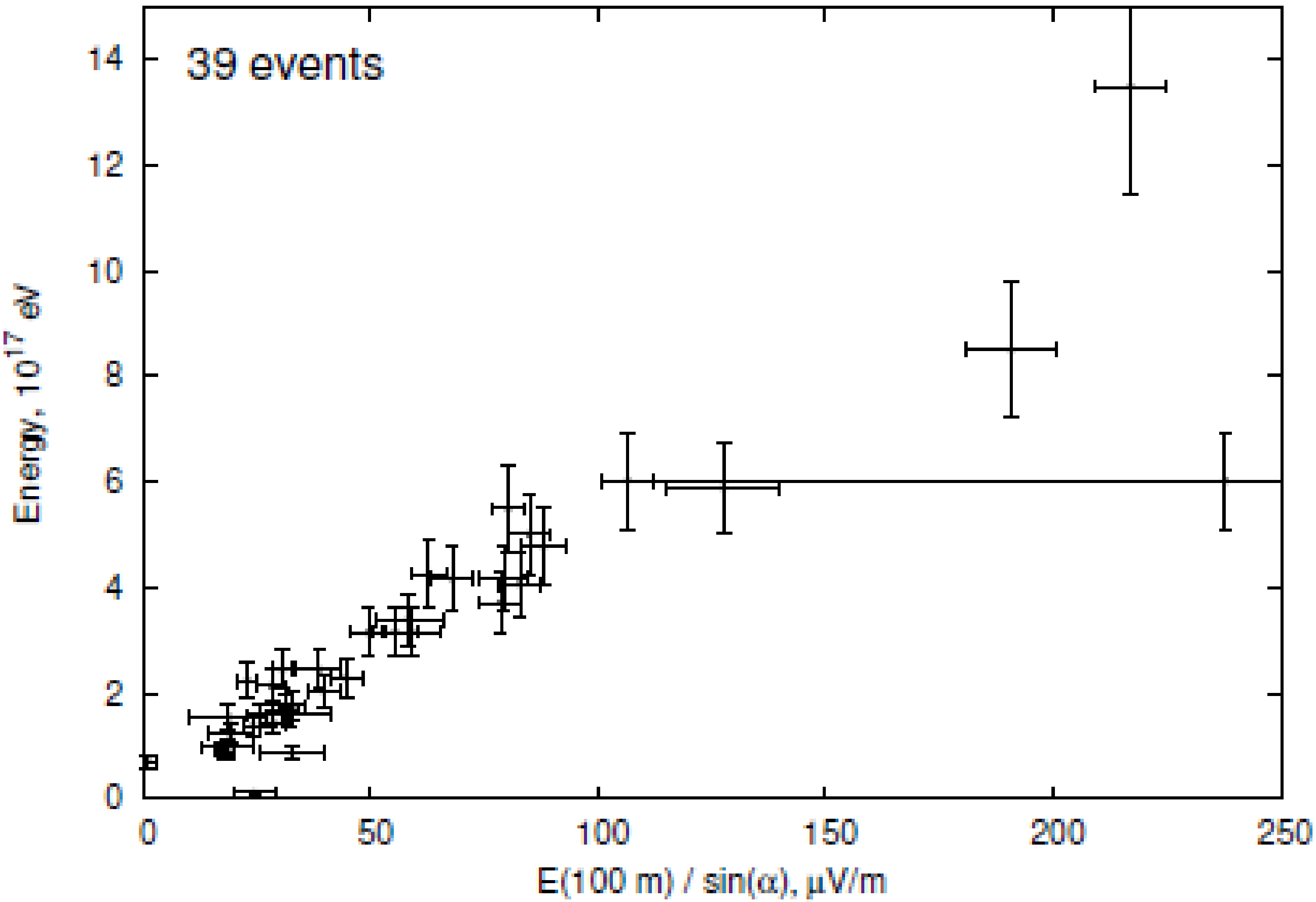
Tunka-Rex example event

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 ($n = 2$)



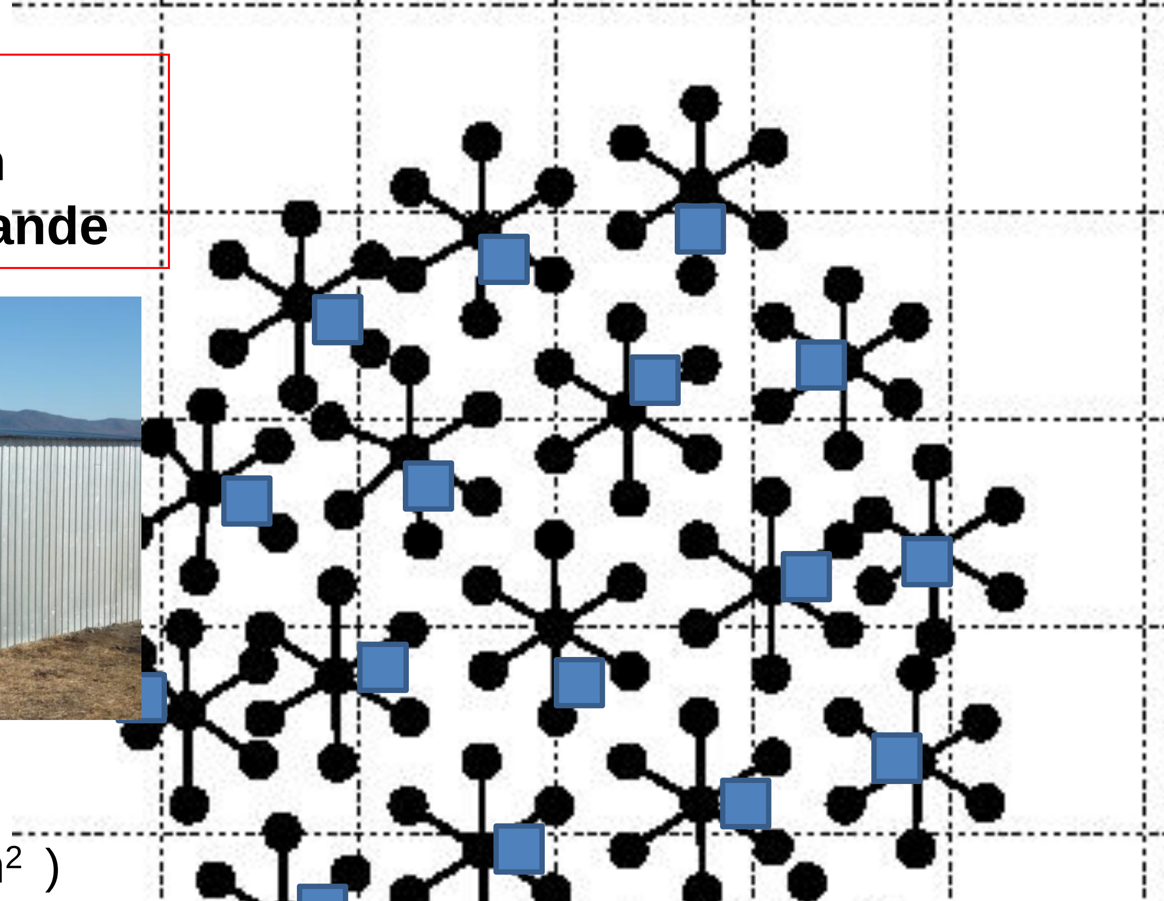
Grande detectors reached Tunka (July 2013)

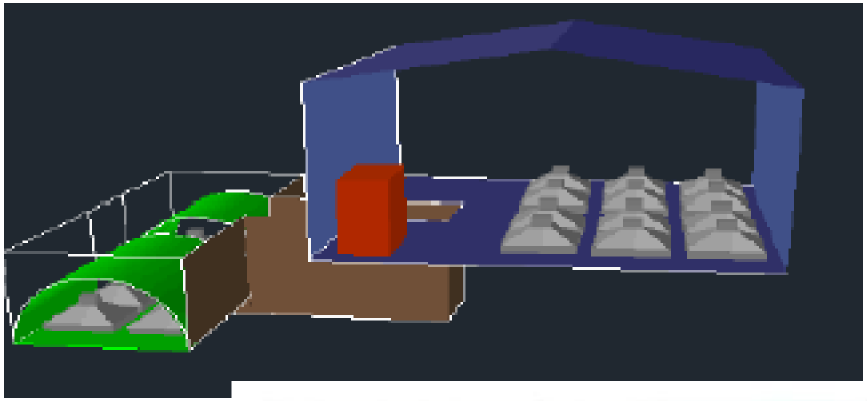
Scintillation station from Kascade-Grande

19 stations

228 detectors (0.64 m^2) on the surface

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

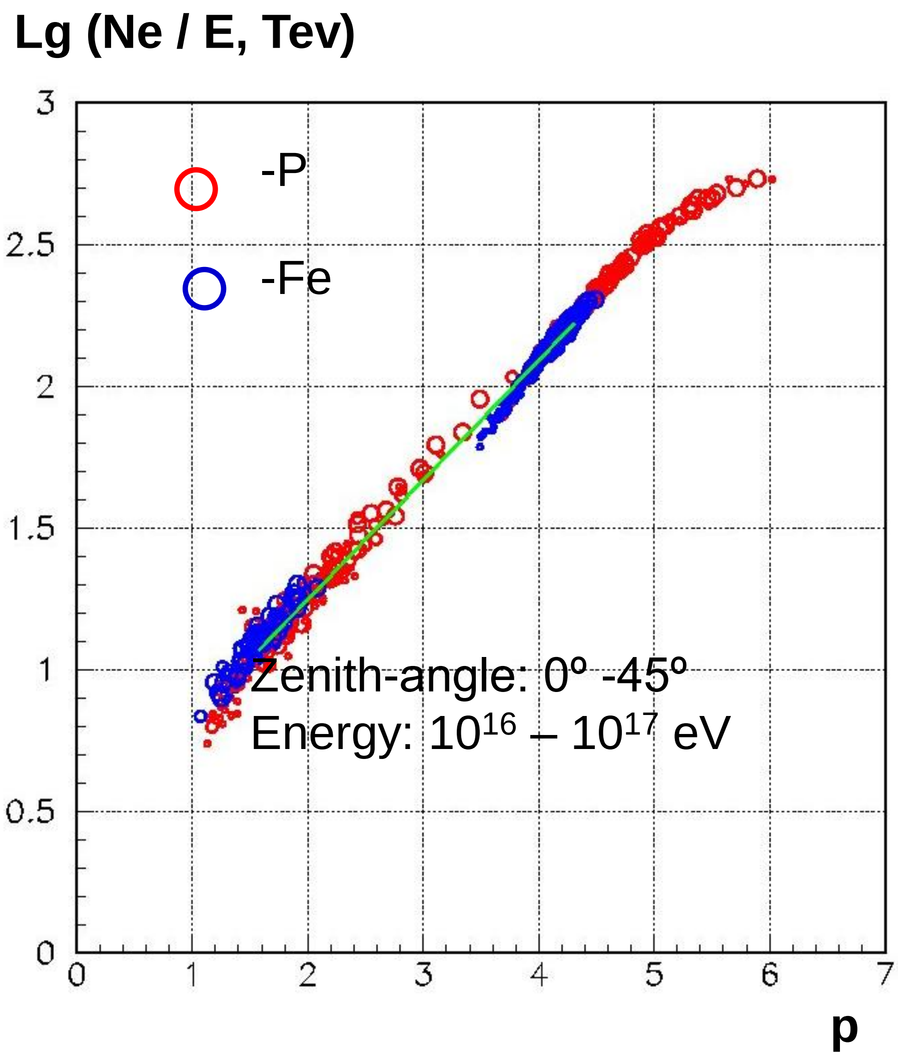




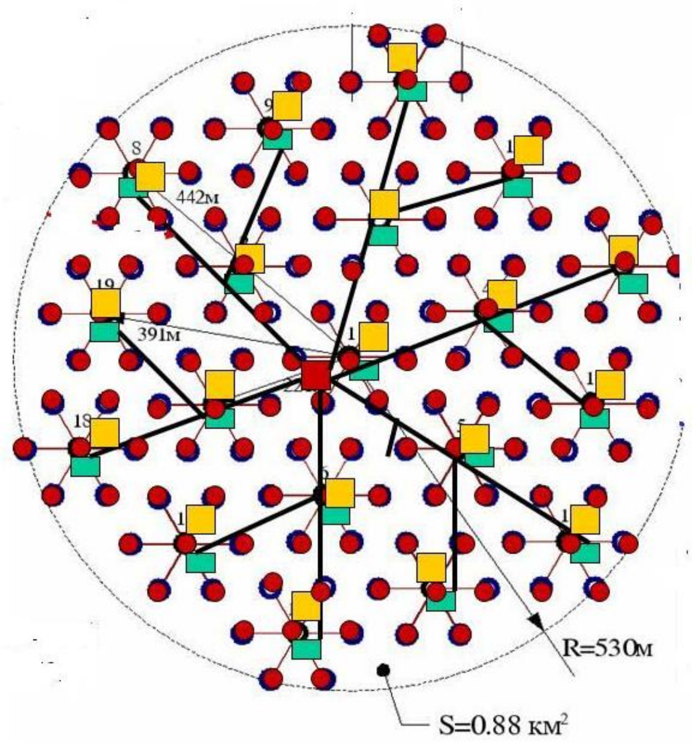
Muon detector




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



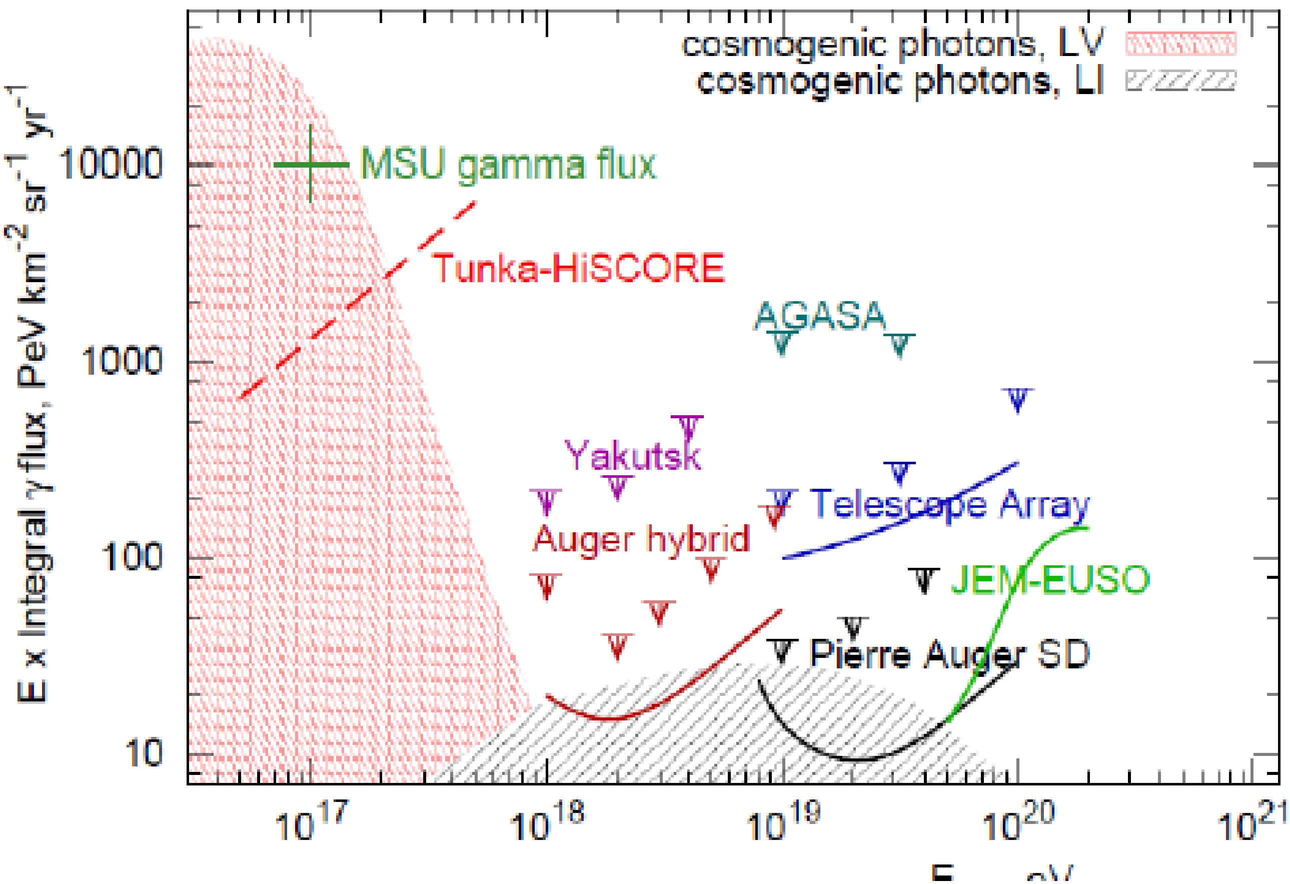
P – steepness of LDF



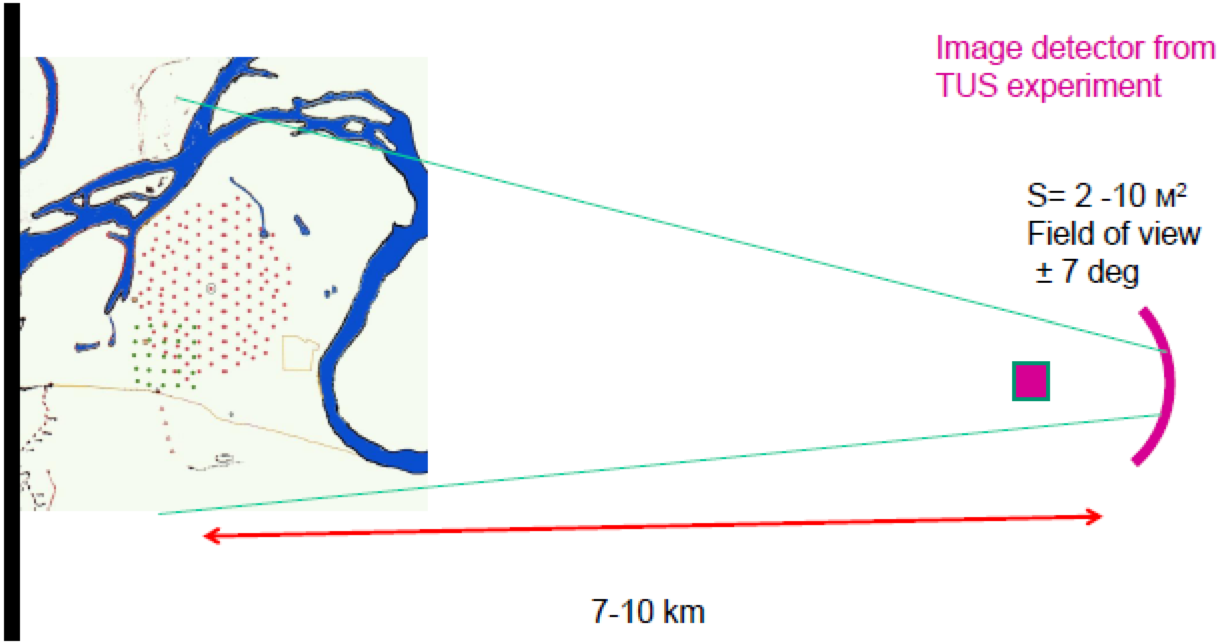
-20 scintillation counters, 10 m^2

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

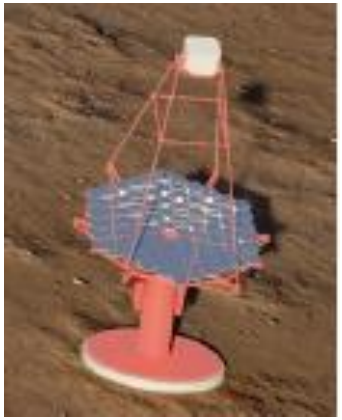


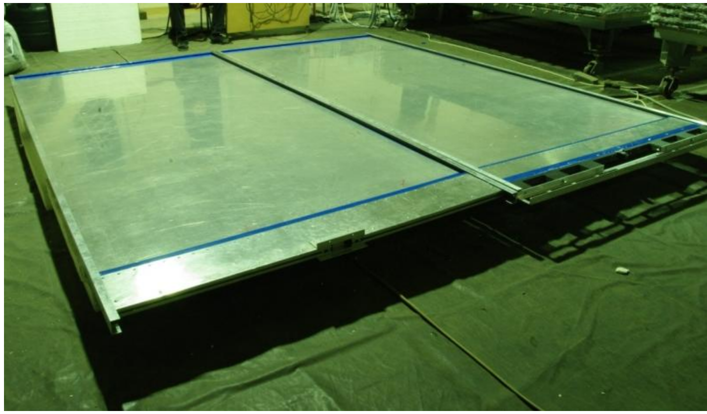
The movable support produced in JINR

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)

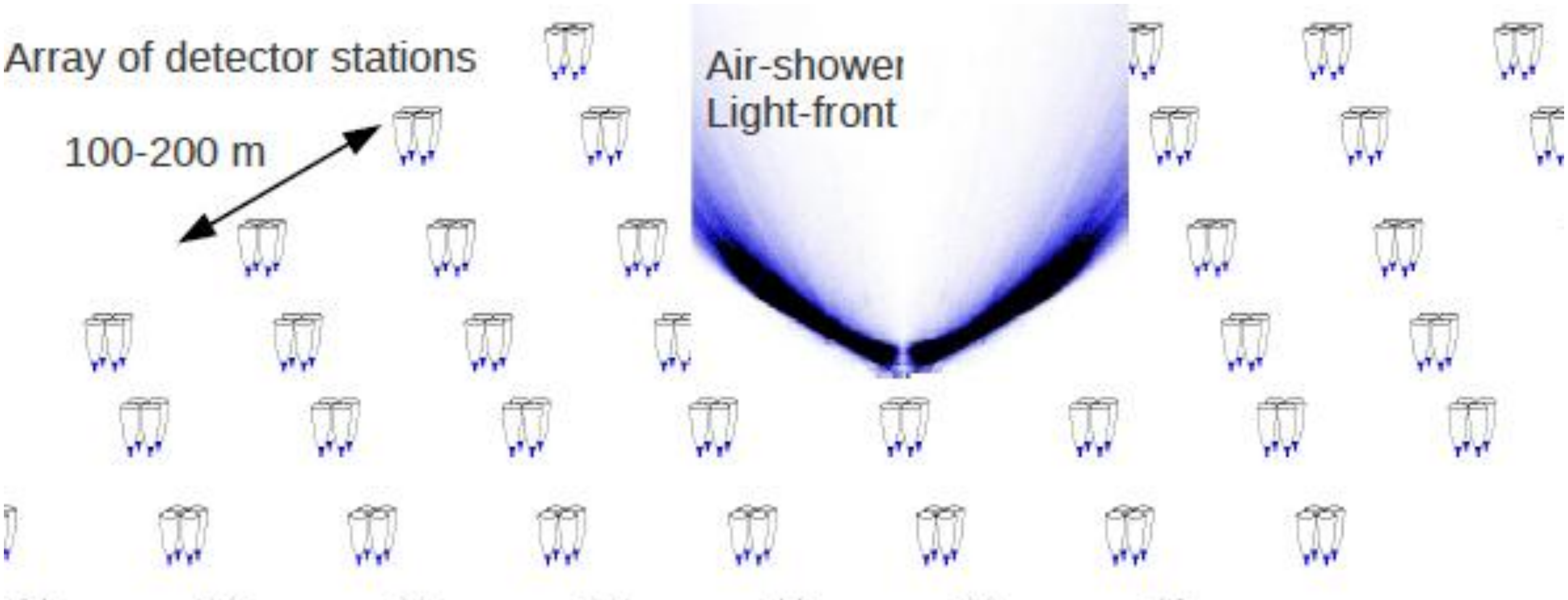
Methodical approaches

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

Ways of threshold decreasing

$$E_{th} \sim (S_{det.}\,\eta)^{-1/2}\,(T_{signal})^{1/2}$$

1. Winston cones - PMT area increase in 4 times
   ($K = 1/\sin^2(tet)$ tet=30° - K =4)

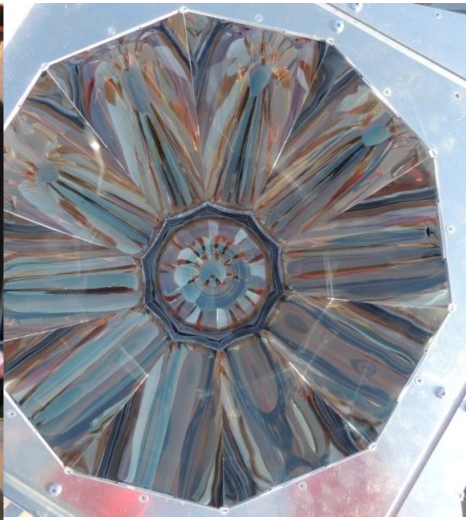
2. Analog summation of signals in one station

3. Decreasing of T_{signal} to 7-10 ns

4. QE max = 35-40%

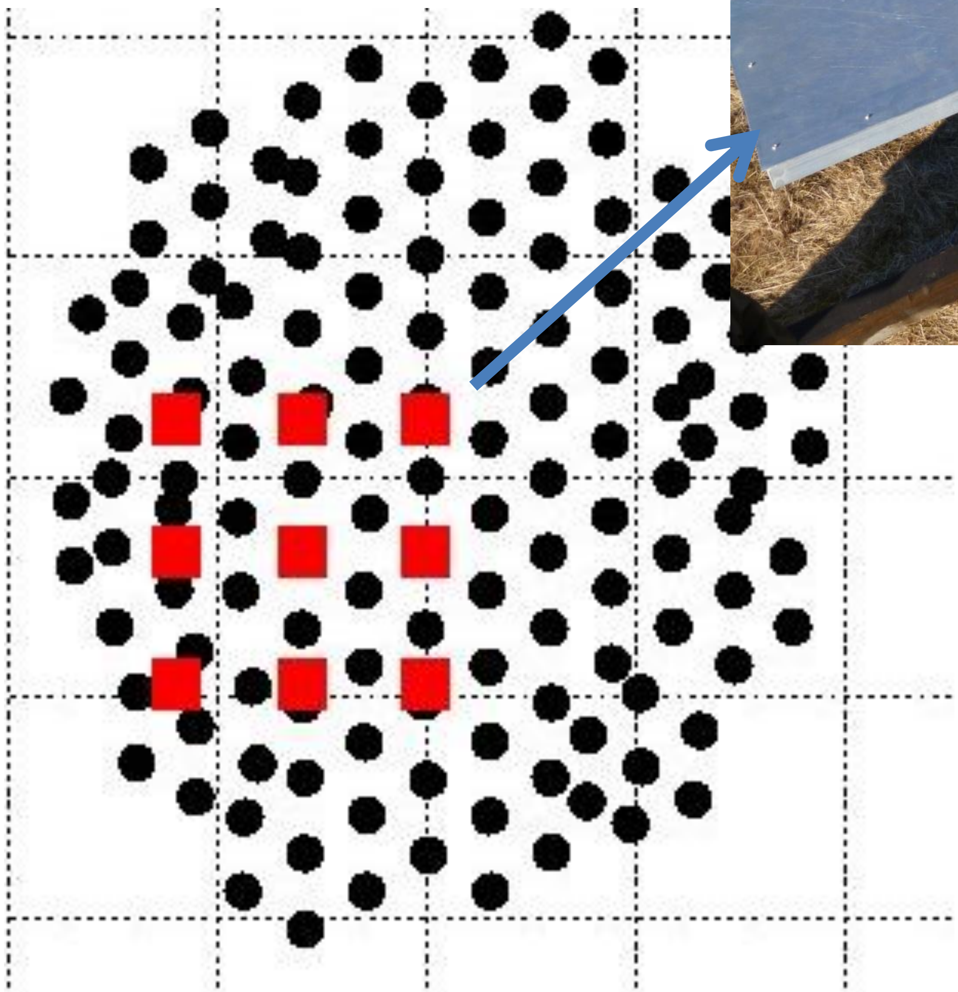
5. Using of wavelength shifter

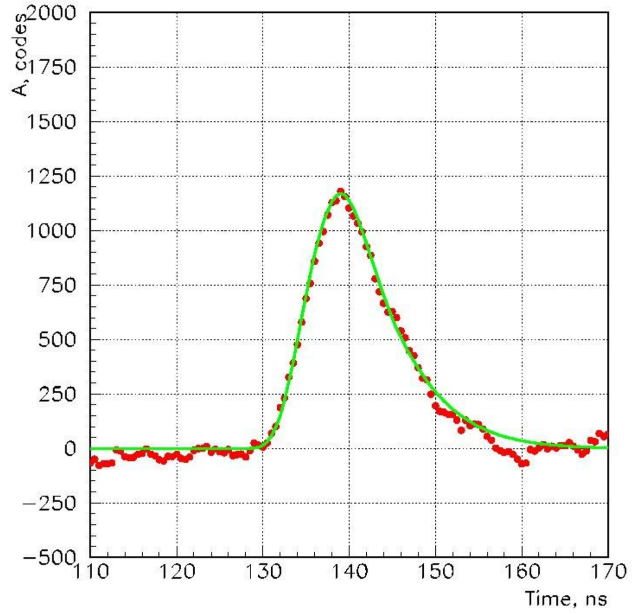
Winston cone



9 optical stations

36 PMT R5912 (8")

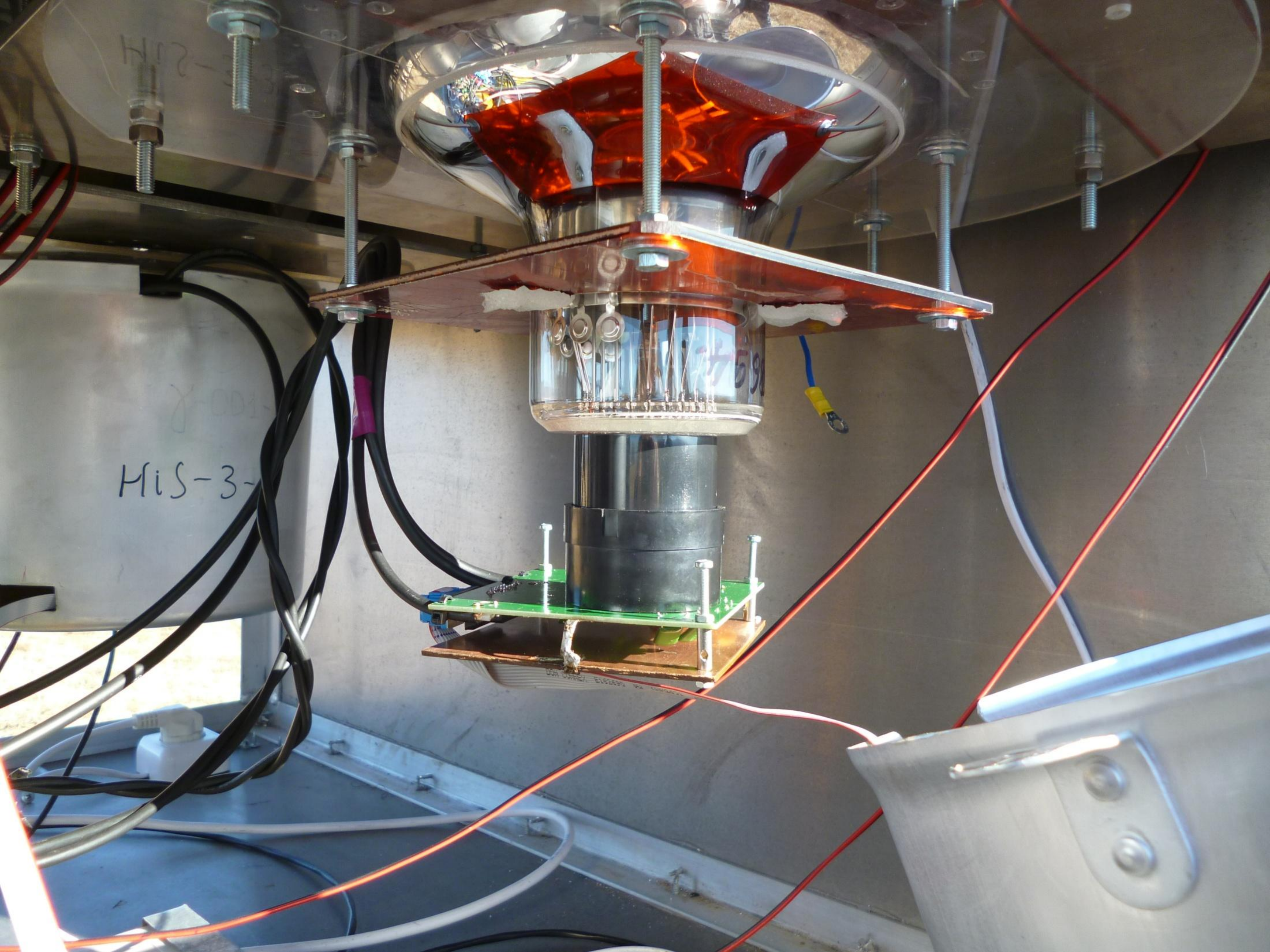




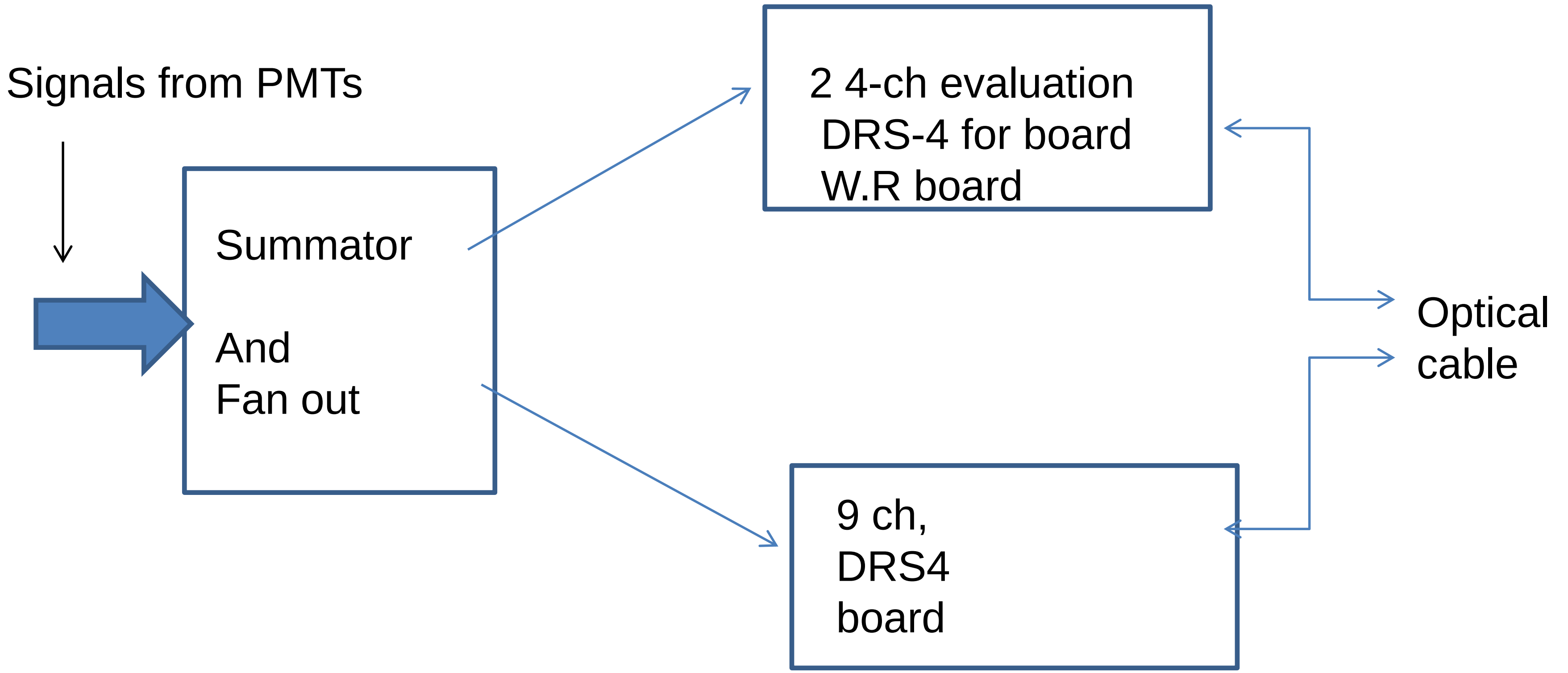
DRS-4 board (0.5 ns step)


К КОНТР-РУ


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


HiS-3-

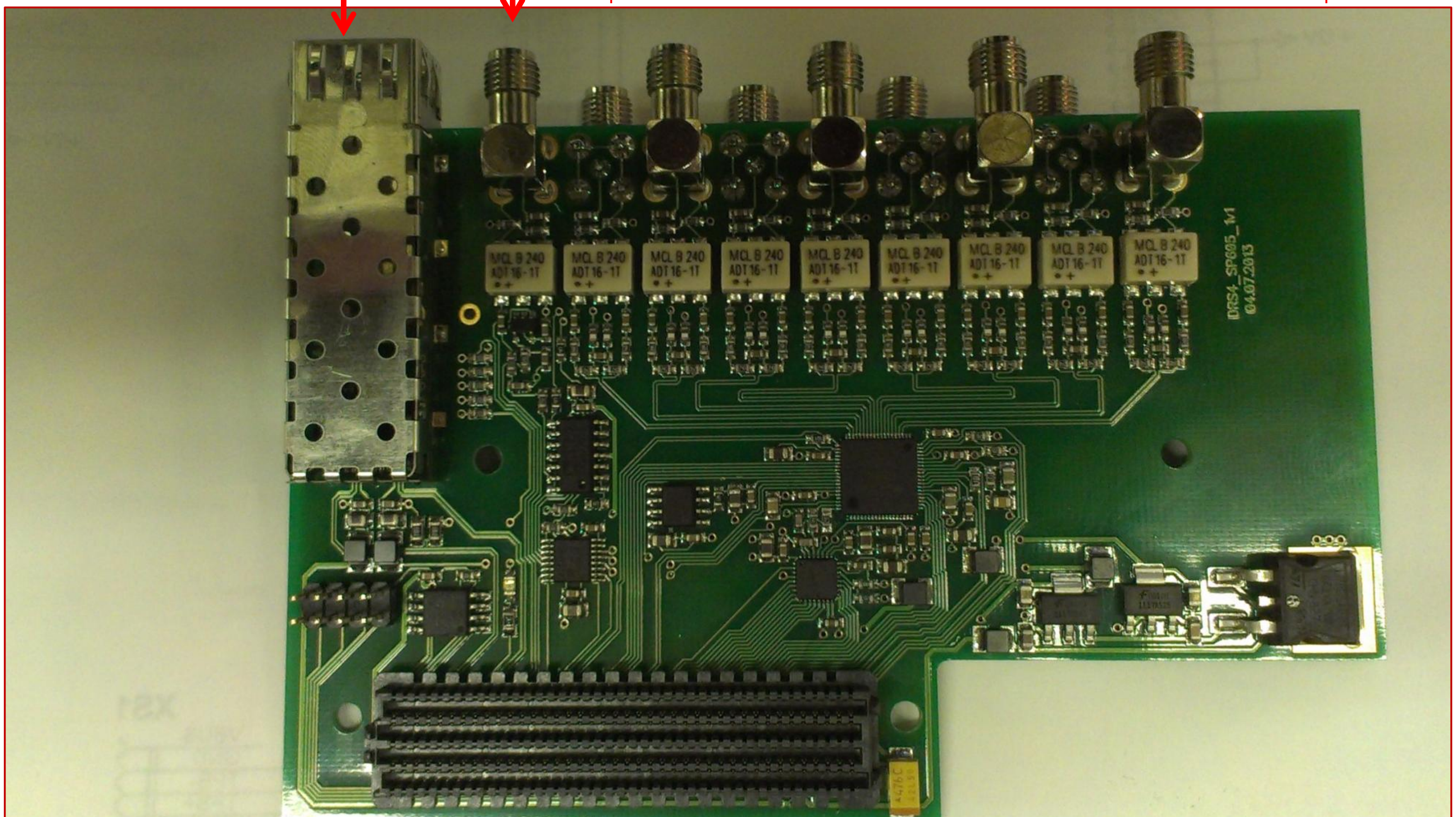
DAQ for one station

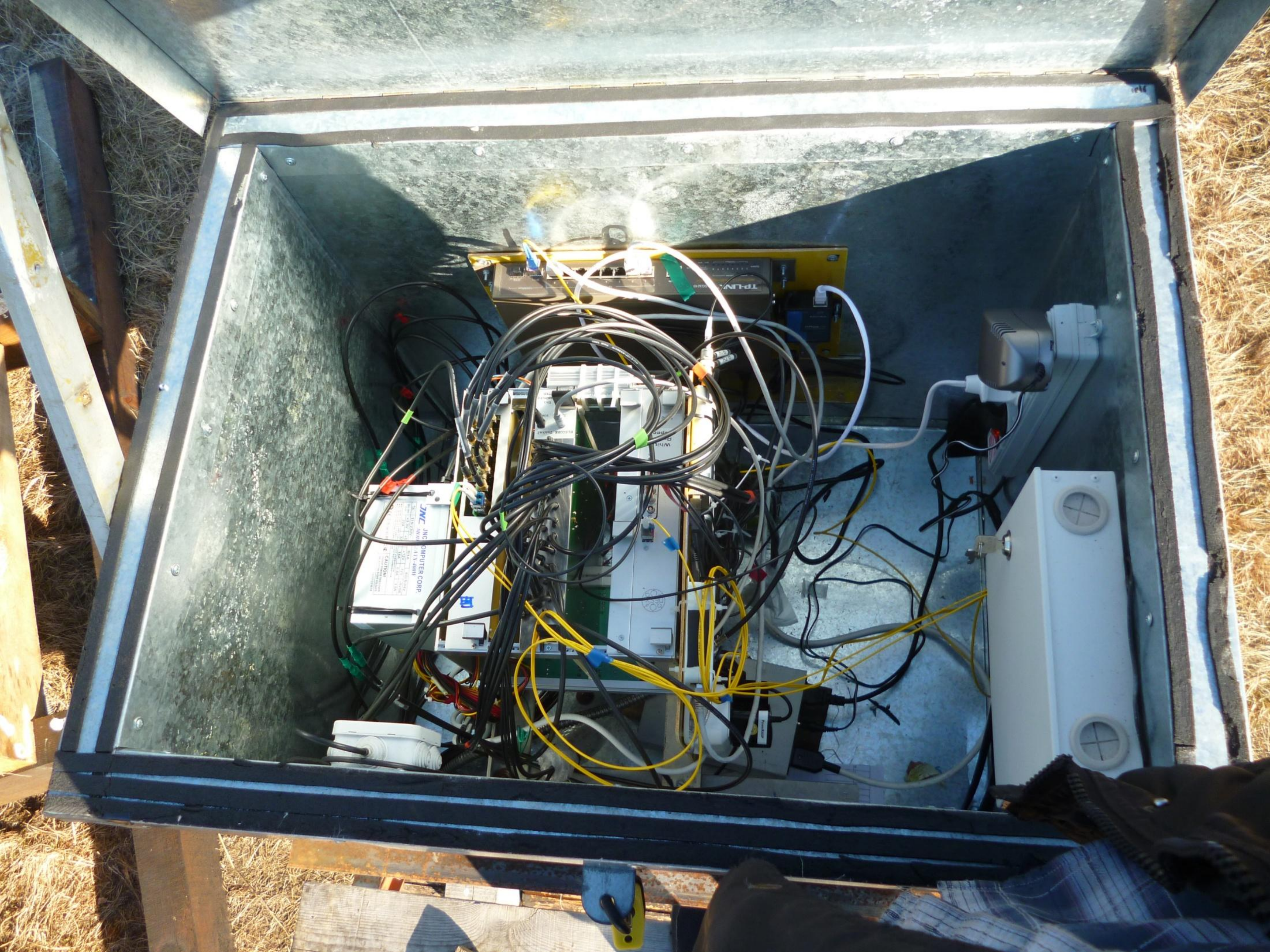


100 MHz clock for synchronization

Sum of 4 anod signals

4 anod and 4 dinod signals





Pulse delay = timer + opt. line length + add. delay

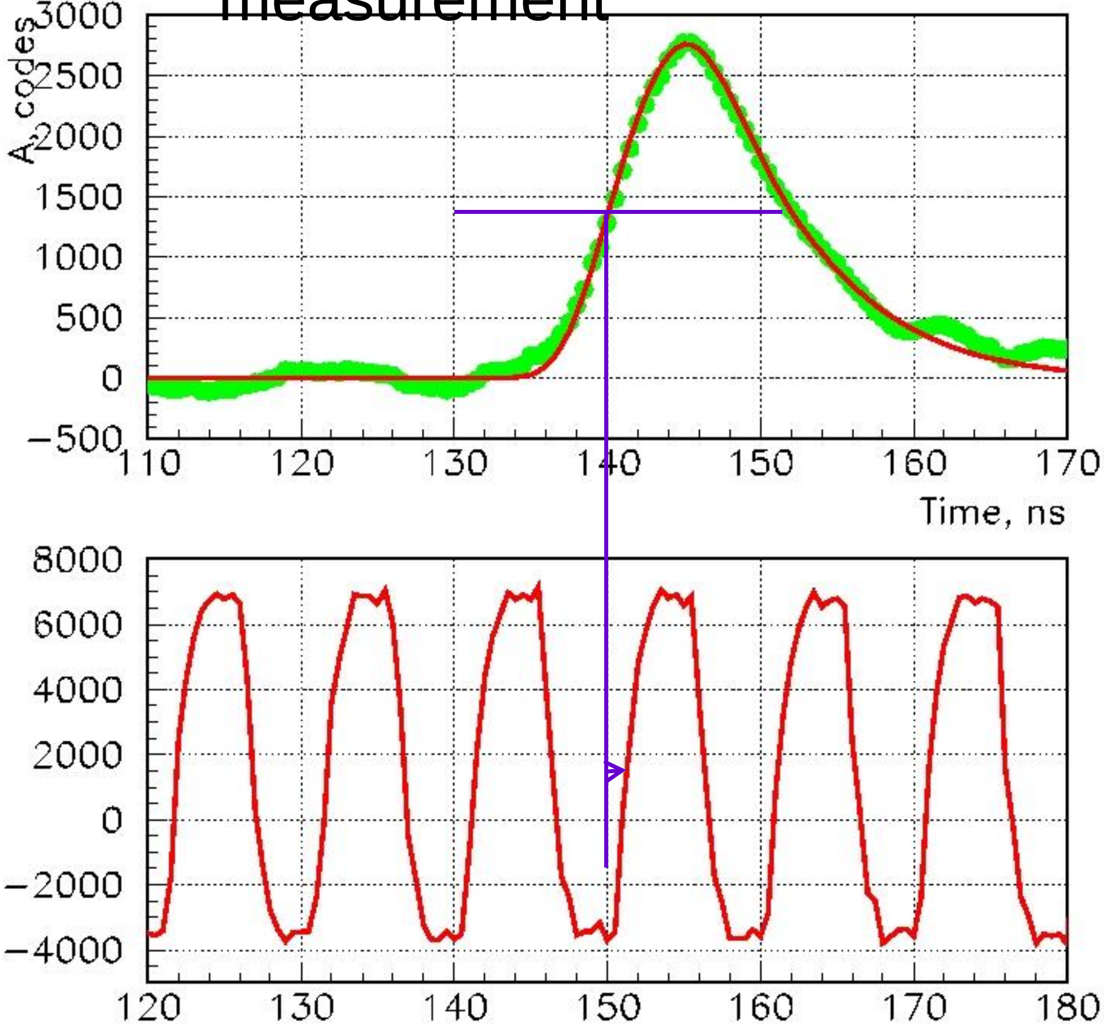
opt. lengths, ns

1. 327.2
2. 841.7
3. 245.4
4. 0.0
5. 765.2
6. 18.7
7. 876.2
8. 804.3
9. 1311.7

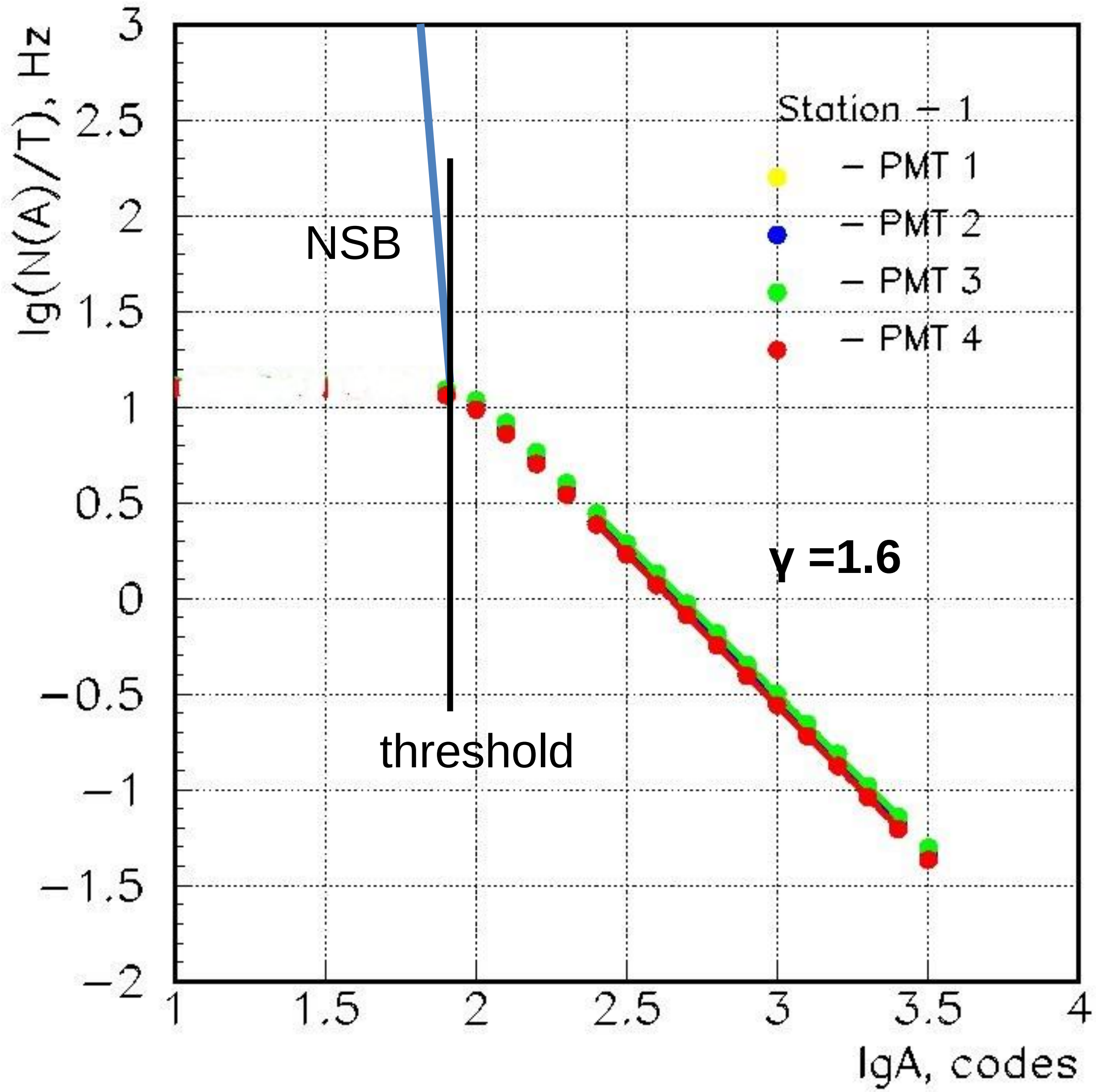
Recorded anode pulse – 1st – 4th channels of DRS 0.5 ns step

Clock signal – the 9th channel of DRS

Additional delay measurement



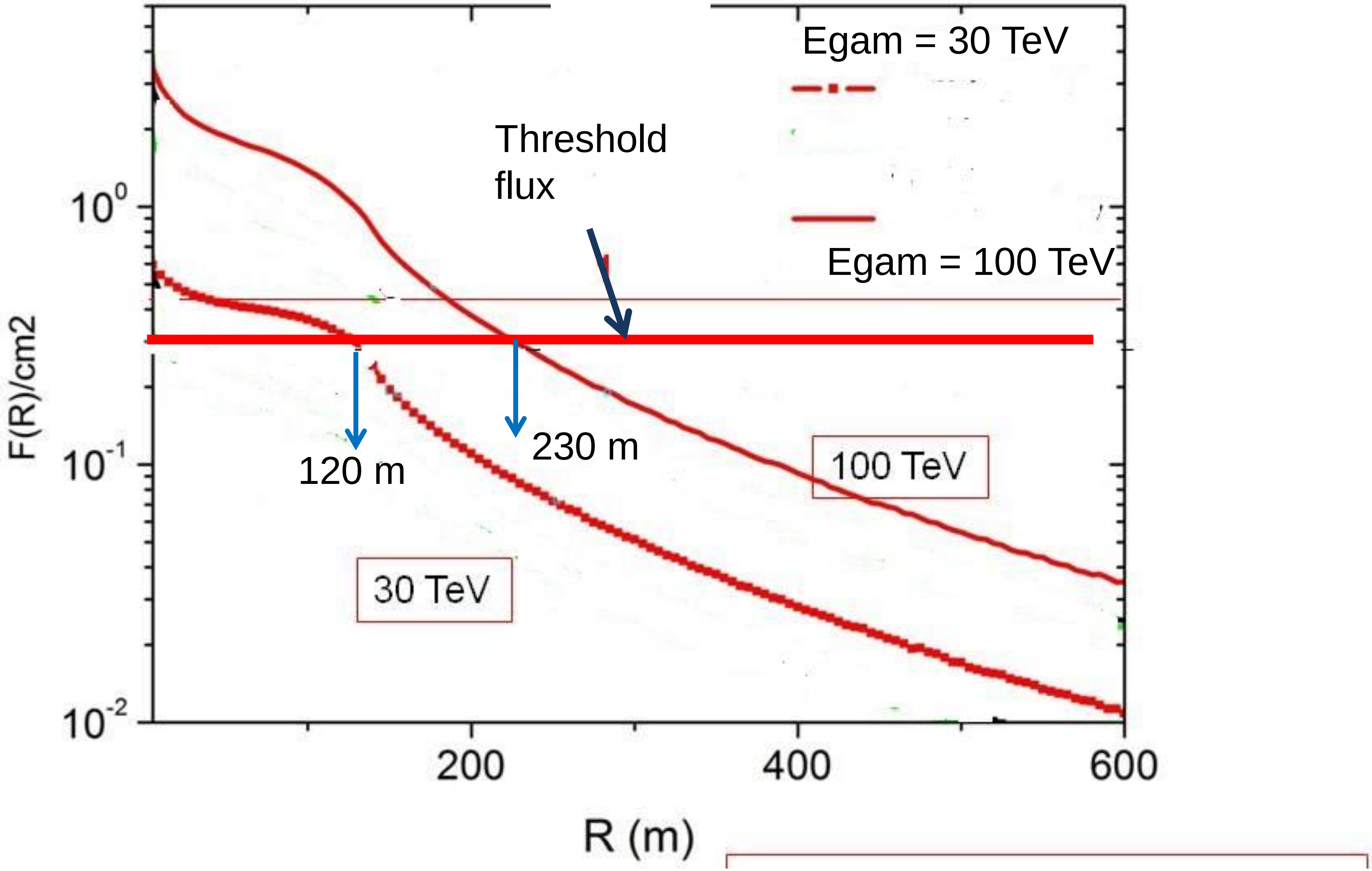
Amplitude spectrum of PMTs in station

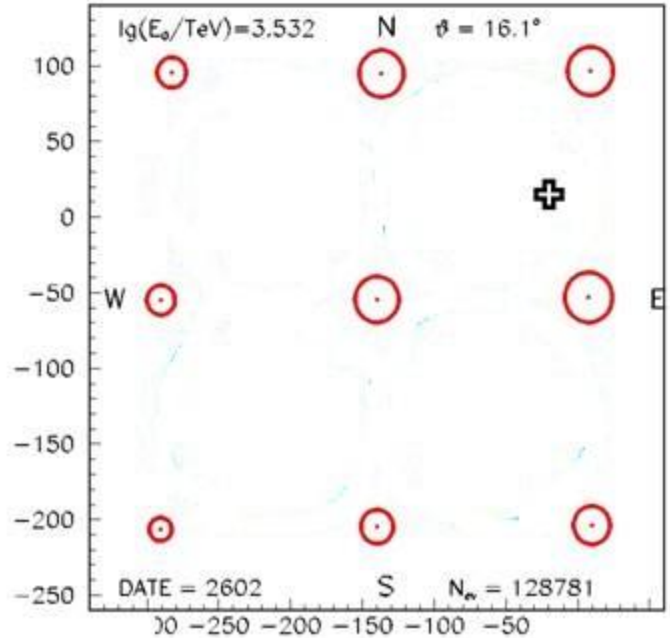


Counting rate = 12 -16 Hz

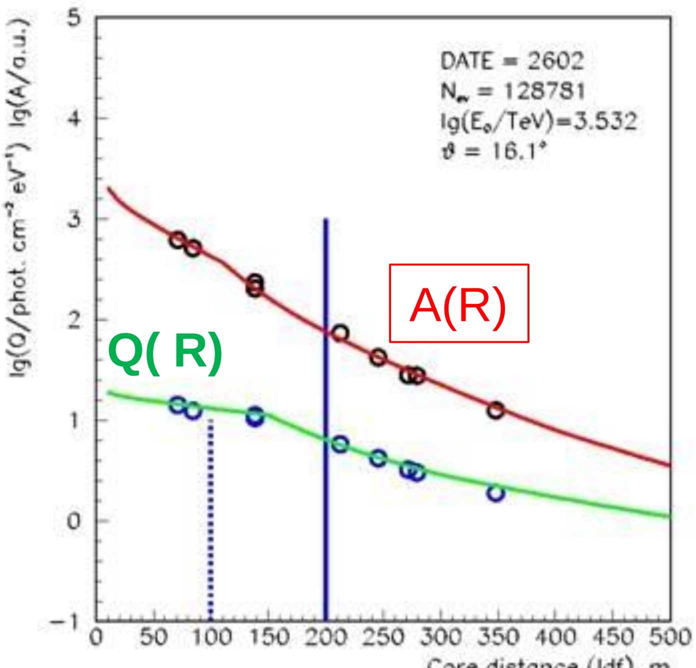
Threshold flux:
0.25 – 0.3 ph / cm^2

LDF of Cherenkov light from EAS from gamma-rays

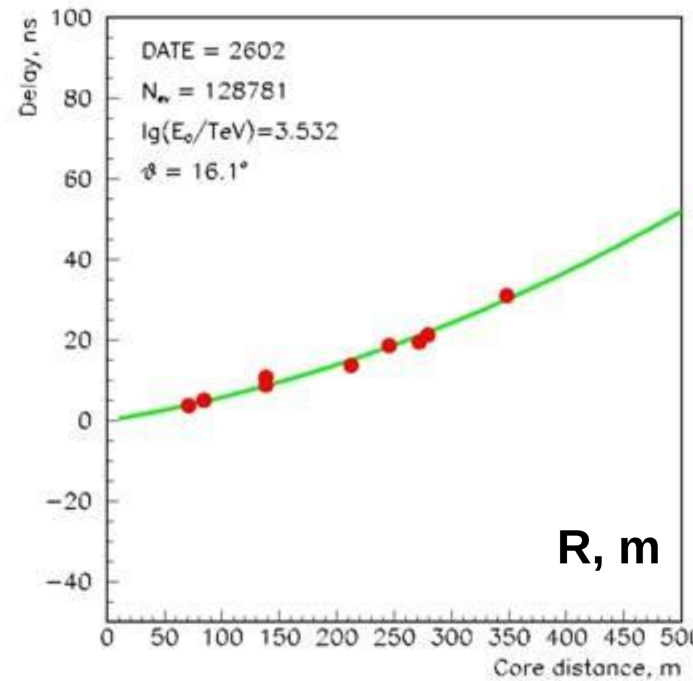




Delay, ns



R, m

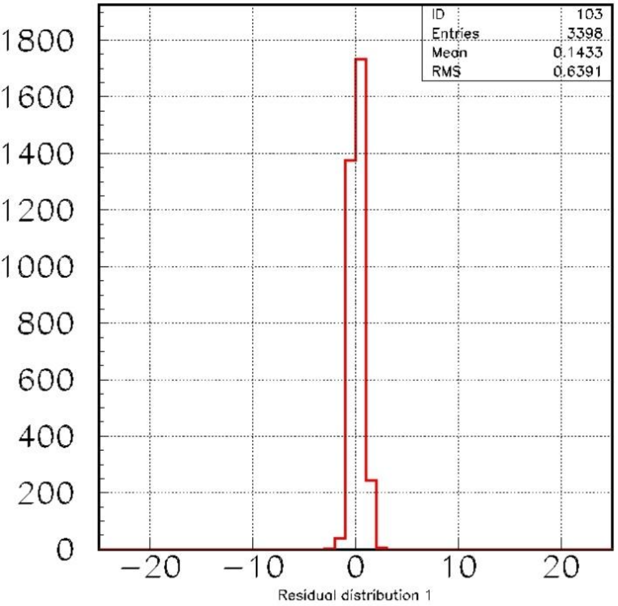


R, m

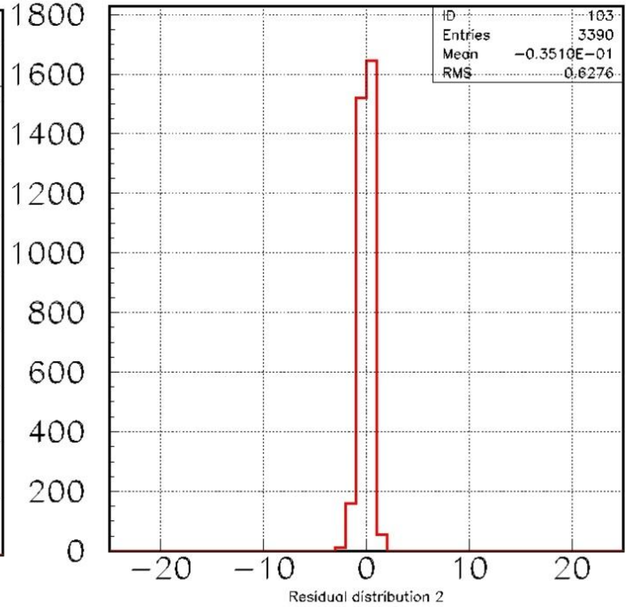
Residual time (T exp – Tfit) distributions

RMS ~ 0.6 ns

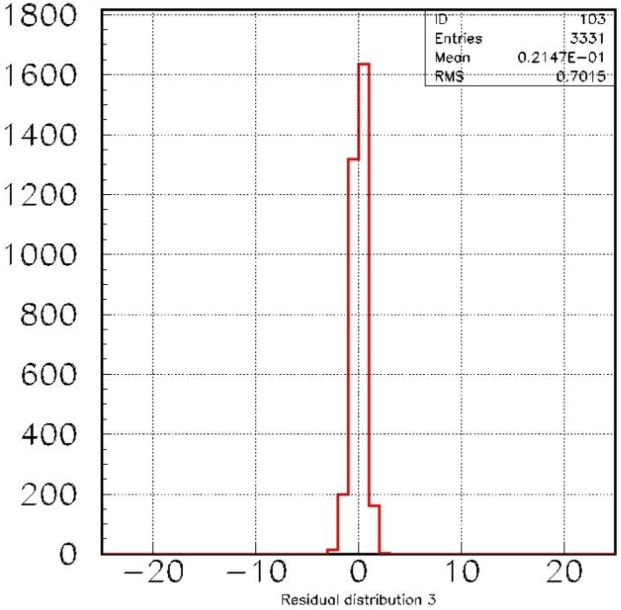
Station 1



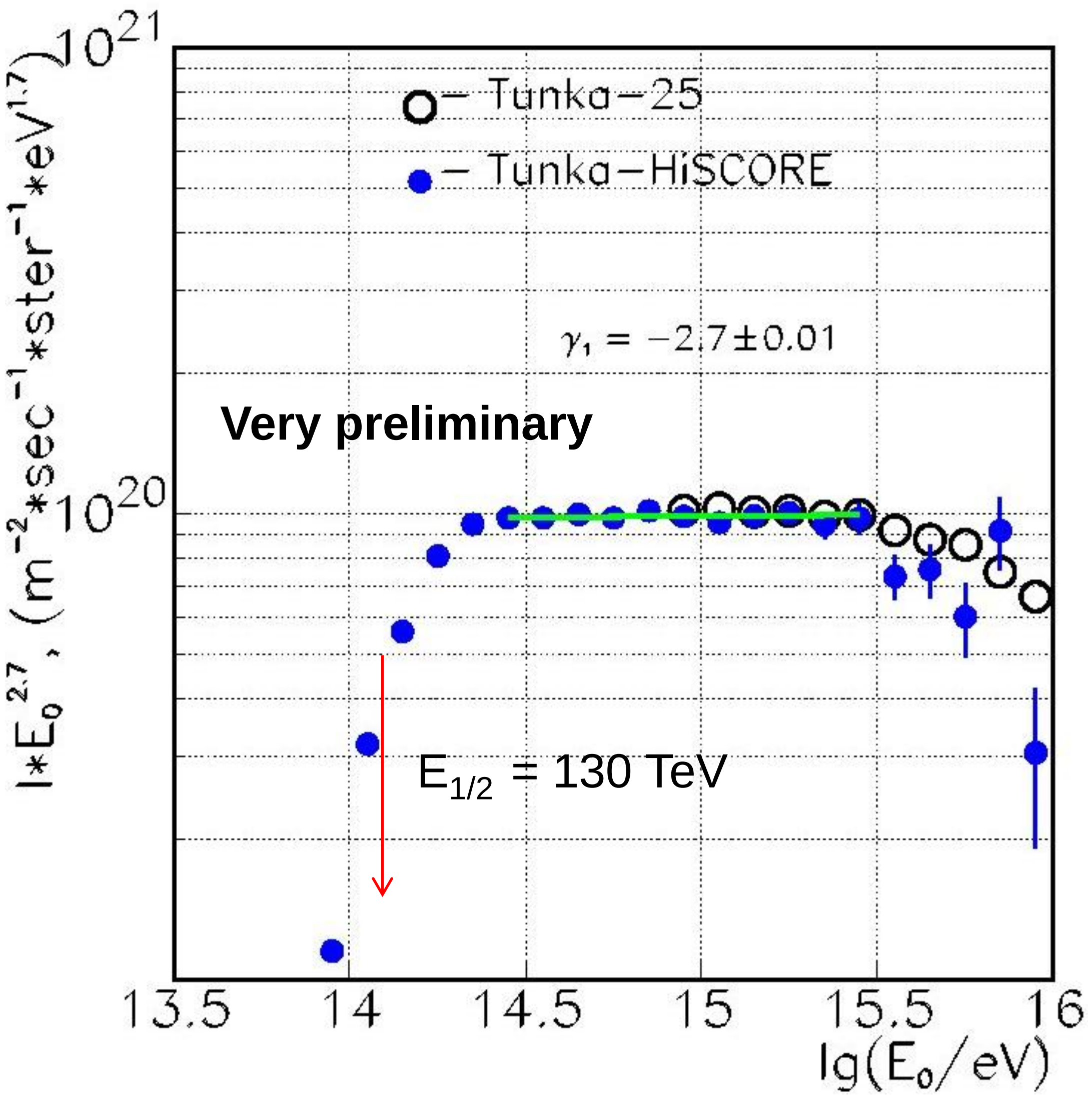
Station 3

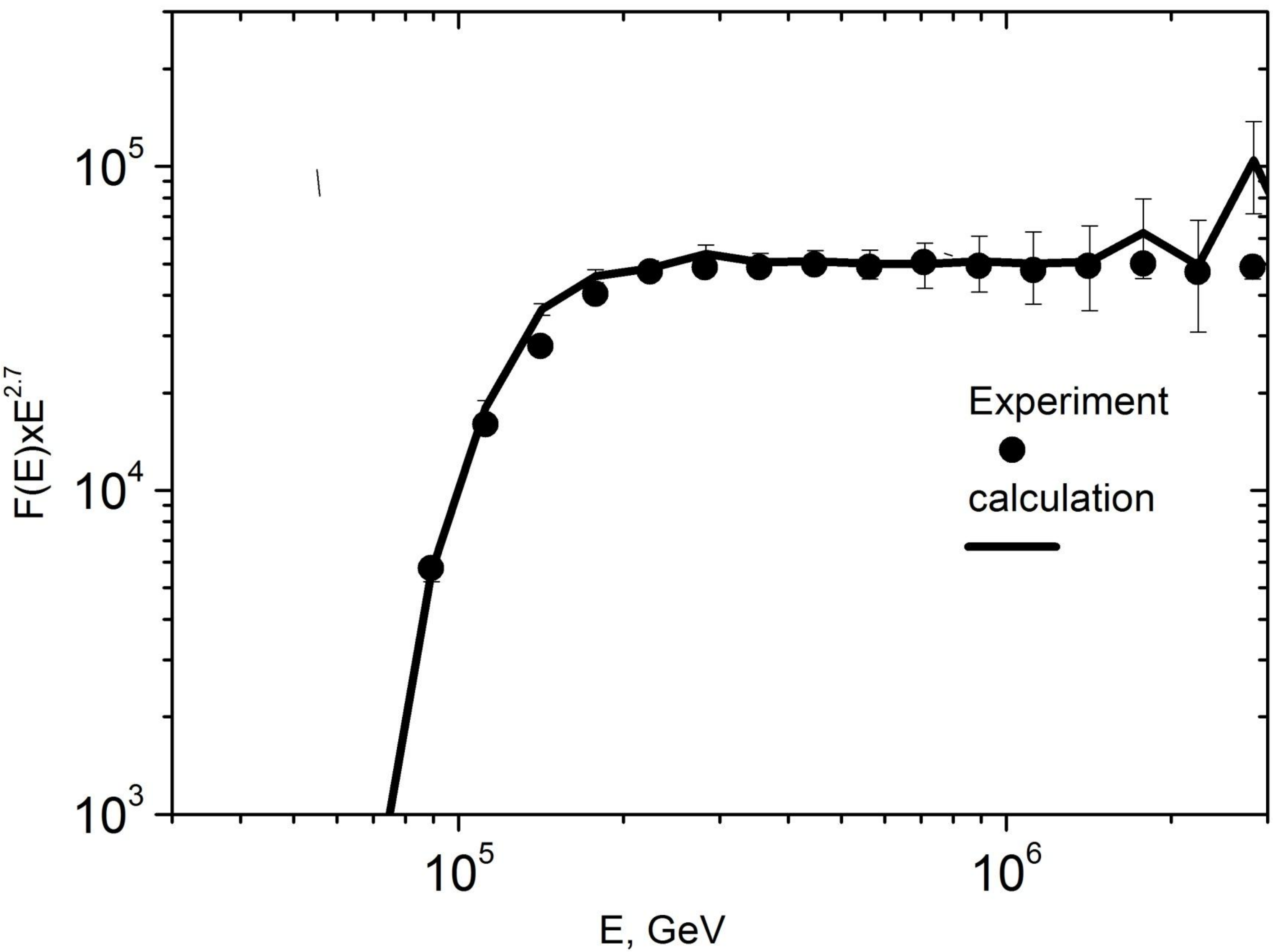


Station 3



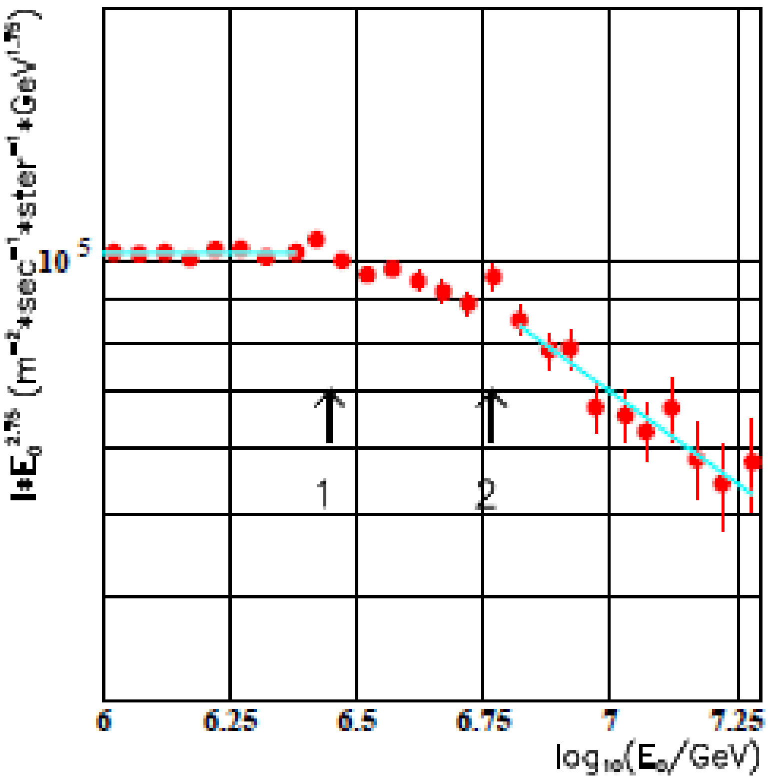
Energy spectrum (from 1 night)





F(E)xE^{2.7}
10^5
10^4
10^3
10^5
10^6
E, GeV
Experiment
calculation

Energy spectrum from Tunka-25 (300 hours)

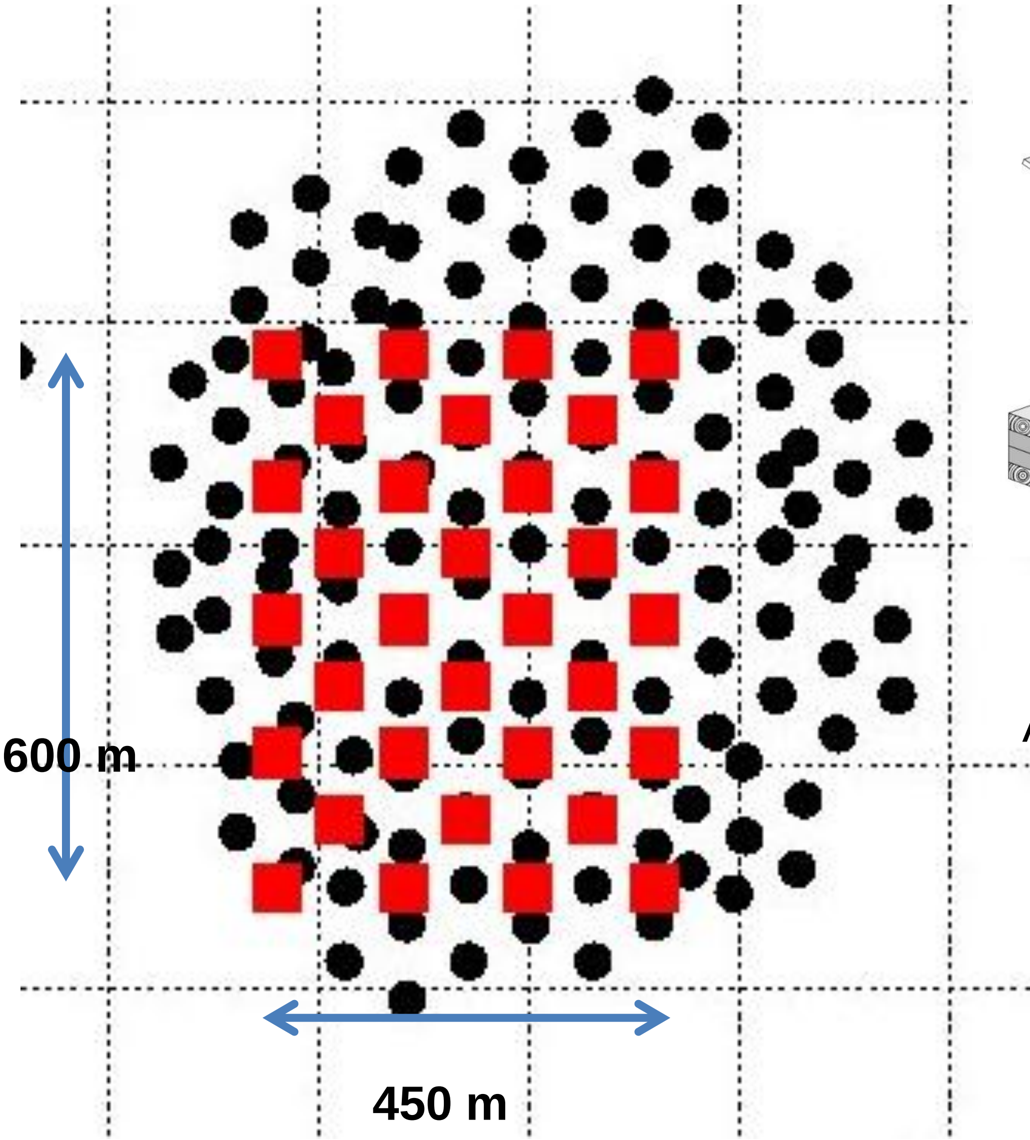


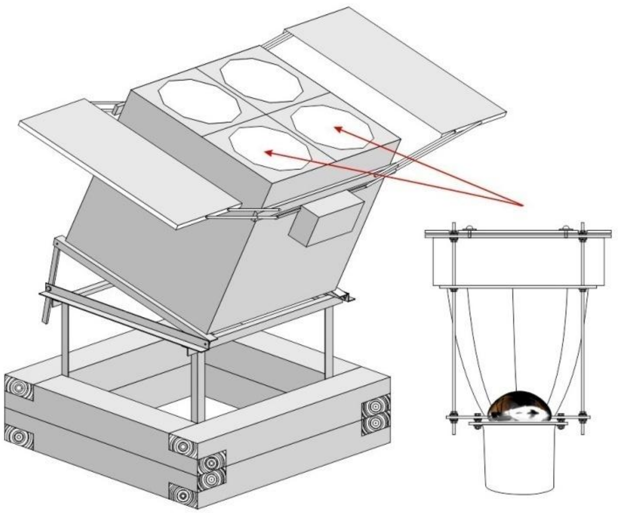
Area of Tunka-25 – 0.1 km^2

With 1 km^2 Tunka- HiSCORE this spectrum can be checked

2014

32 stations – 0.3 sq.km array

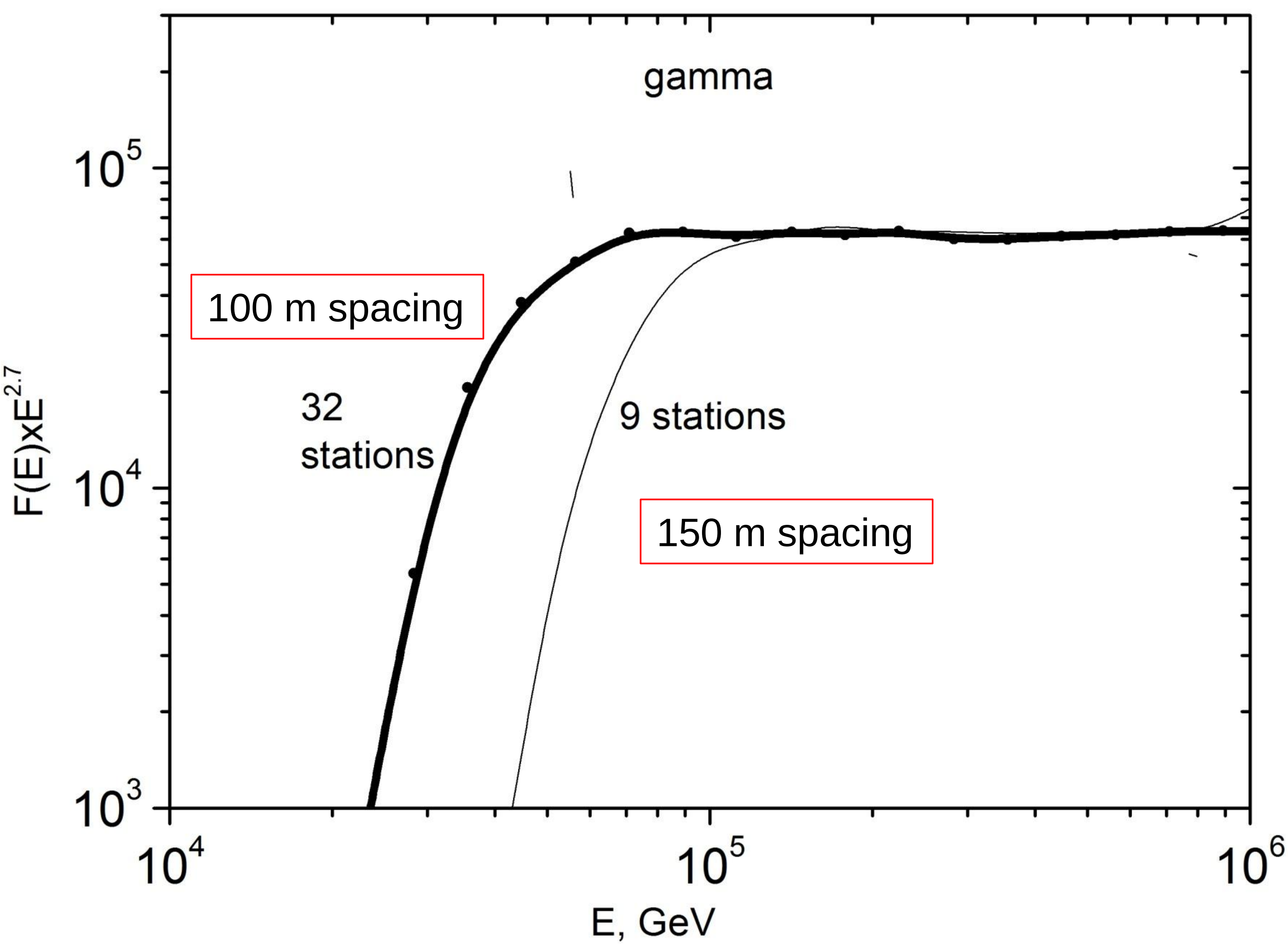


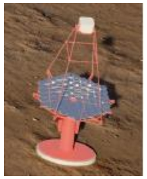


All station are tilted on 25° to the South

100 m spacing

Threshold for gamma –ray flux





Telescope parameters

D = 4.32m F = 4.75 m

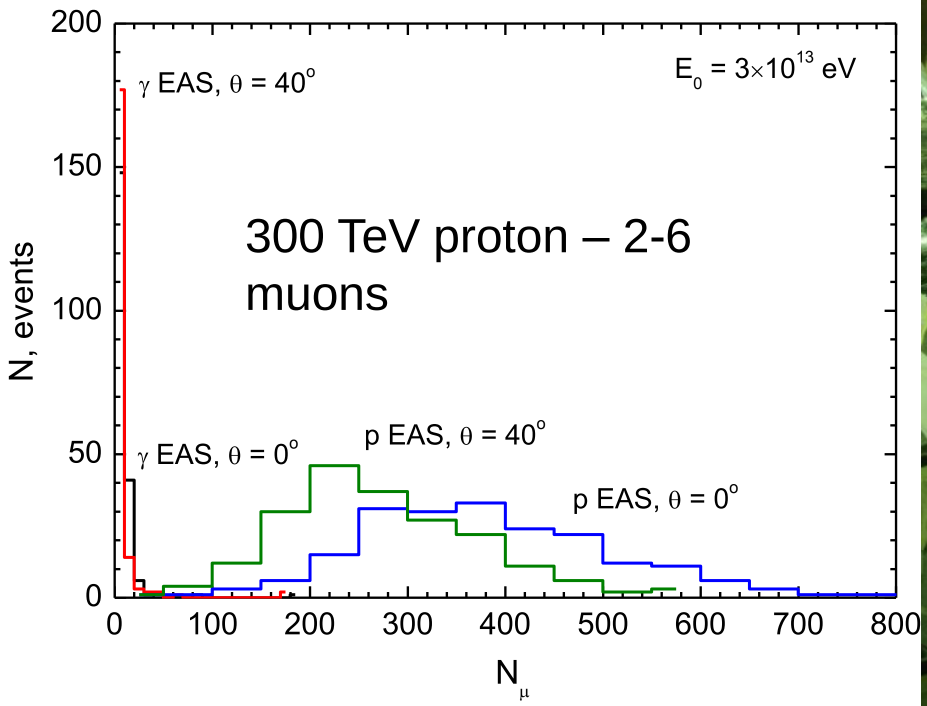
34 mirrors with 60 cm diameters

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

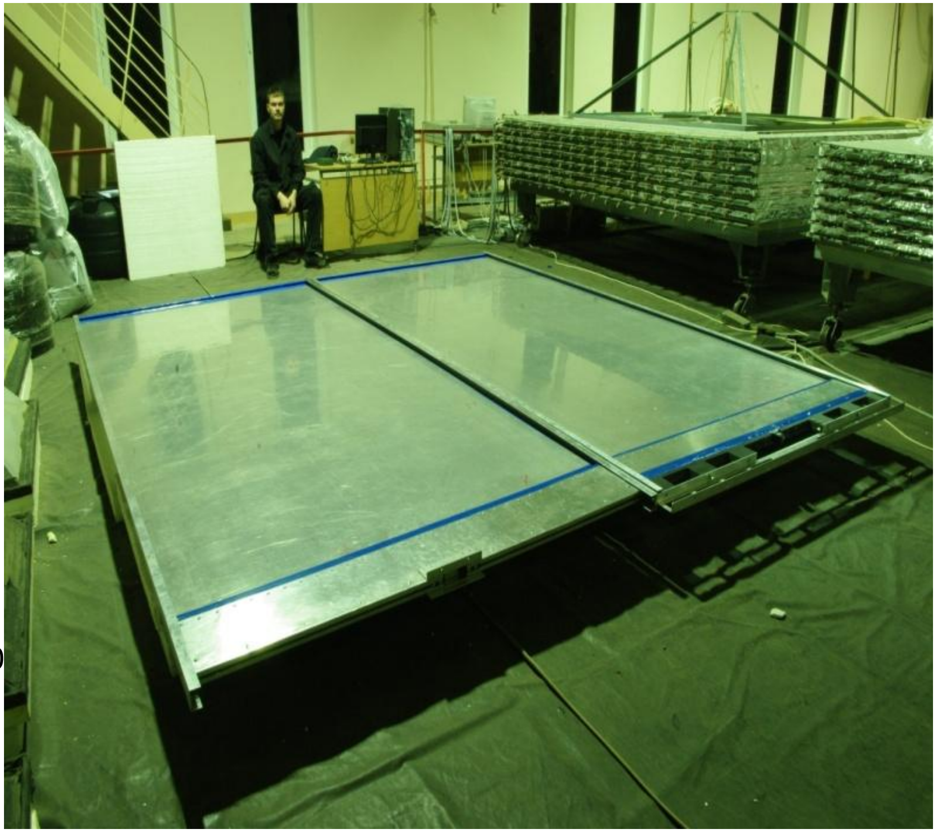
DAQ - MAROC3

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

Conclusion

1. Tunka-133 will continue data taking with scintillation detectors 5 years more.

2. Additional ~20 antennas will be deployed

3. TAIGA array will be deployed (in full scale) in 3-5 year.

Thank you