Primary CR Energy Spectrum and Mass Composition by the Data of Tunka-133 Array

by the Tunka-133 Collaboration

Tunka-HiSCORE: First results on all-particle spectrum

by the Tunka-HiSCORE Collaboration

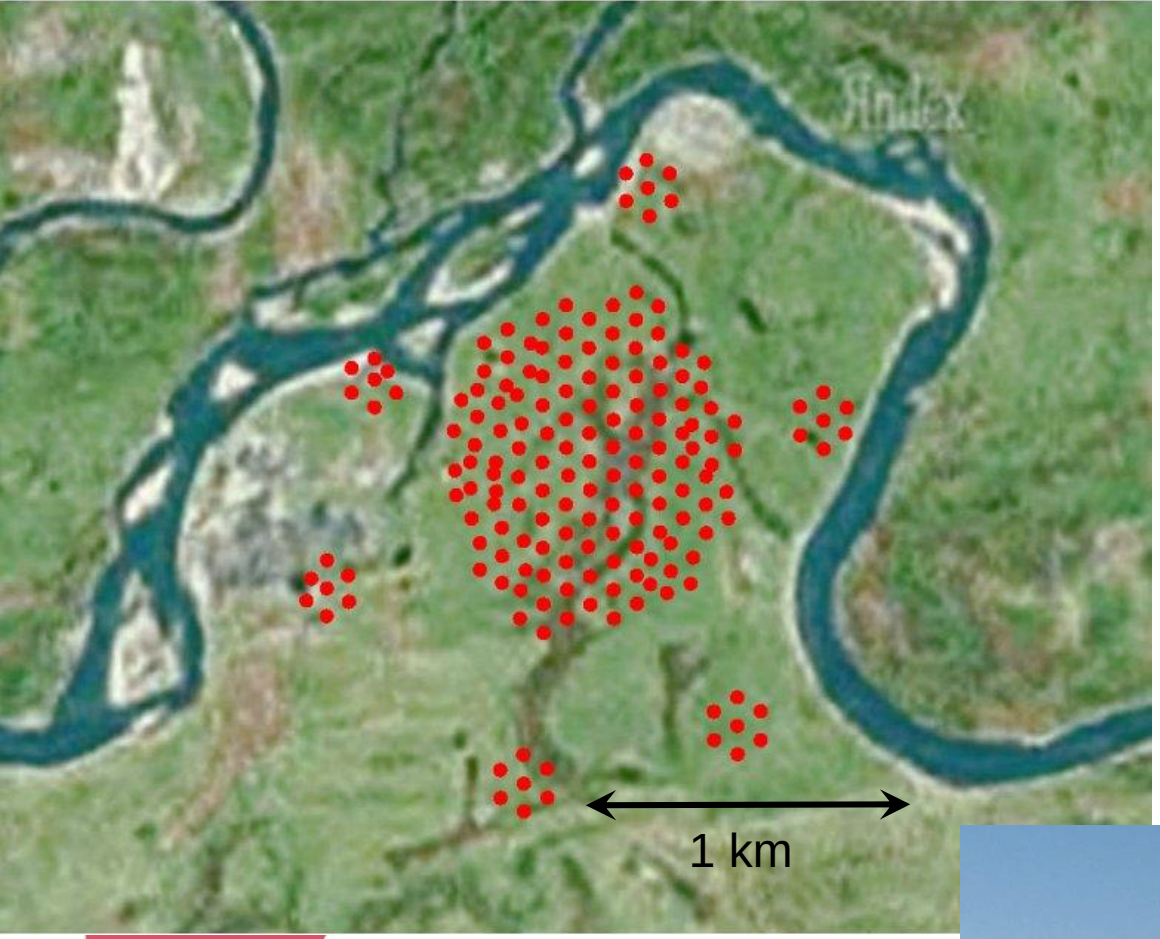
combined talk - presenter: Frank G. Schröder (KIT)

Tunka Valley

Republic of Buryatia

150 km from Irkutsk

50 km from the shore of lake Baikal



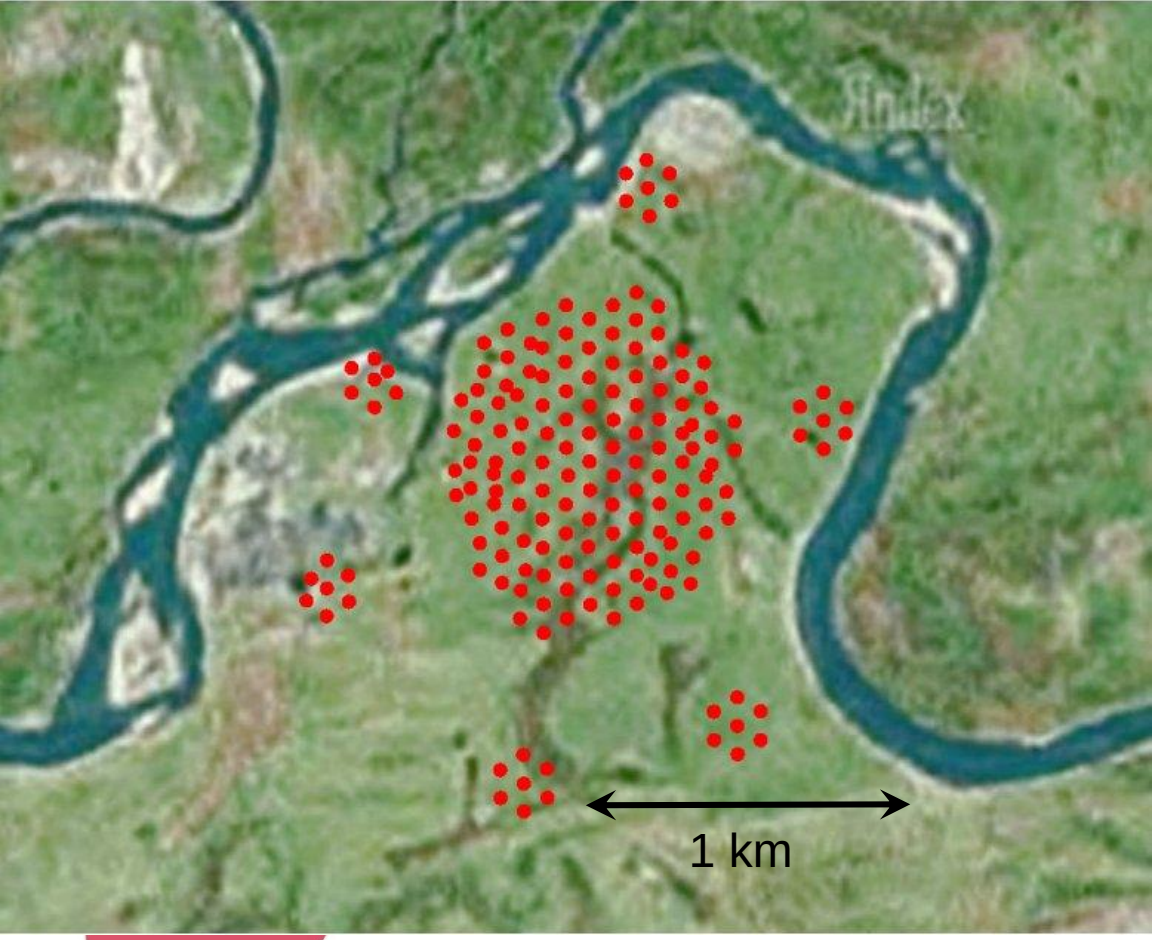
Experiments in the Tunka Valley

Current Status (2013-2014):

1.	**Tunka-133**	**175 detectors**	**single PMT of Ø 20 cm**
2.	**Tunka-HiSCORE**	**9 stations**	**4 PMT with Winston cones**
3.	**Tunka-Rex**	**25 radio antennas**	

Under Construction and Deployment:

1. **Scintillation detectors of electrons and muons (from EAS-TOP and KASCADE-Grande) 19 stations, total area for muons: 100 m^2**
2. **Tunka-HiSCORE + 24 stations (2014)**
3. **Net of IACT 5 telescopes with 10 m^2 mirror area, 8° FoV**
4. **New muon scintillation detectors total area: 2000 m^2**
5. **Tunka-Rex + 20 radio antennas**



175 optical detectors
EMI 9350 and HAMAMATSU Ø 20 cm

Scintillator station from KASCADE-Grande

19 stations

228 detectors (0.64 m^2) on the surface

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

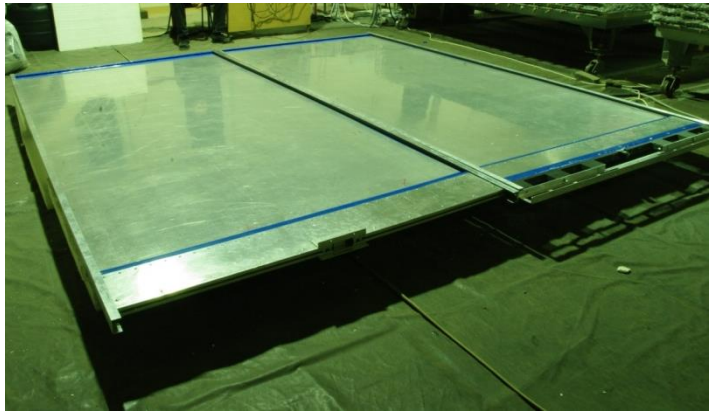
Towards High Energy Gamma-Rays Astronomy in Tunka Valley

TAIGA – Tunka Advanced Instrument for cosmic rays and Gamma Astronomy

Array design concept

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

•Net of imaging telescopes with mirrors of 10 m^2 area.



•Array of muon detectors 10^2 → 2 10^3 m^2 area.

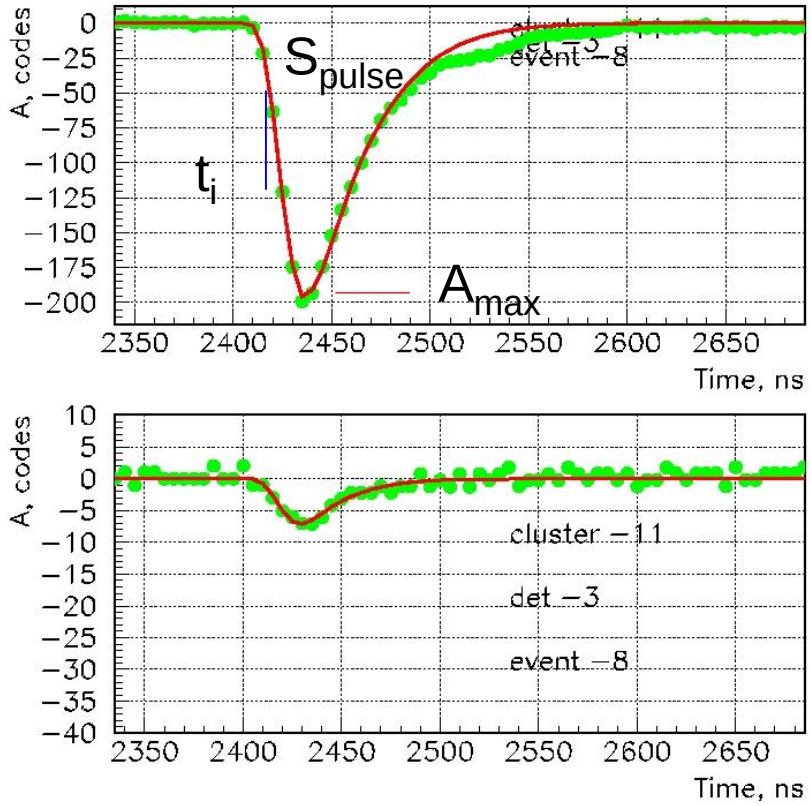
Single detector readout:

Fitting a pulse and measuring parameters:

$Q=c\cdot S_{pulse}$, A_{max}, t_i , $\tau_{eff}=S/A/1.24$

anode:

dynode:



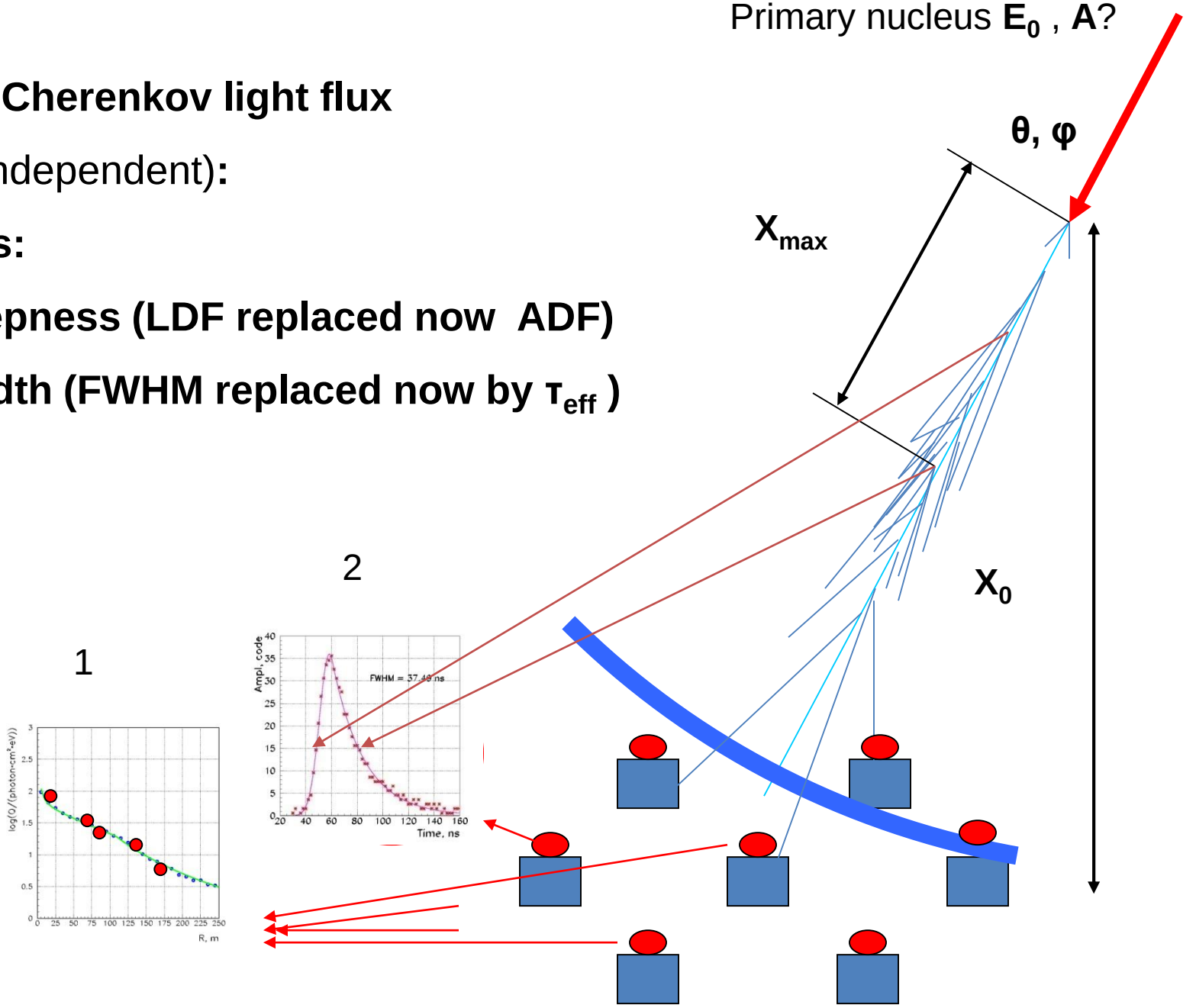
Primary nucleus E_0 , A?

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})**



Energy reconstruction

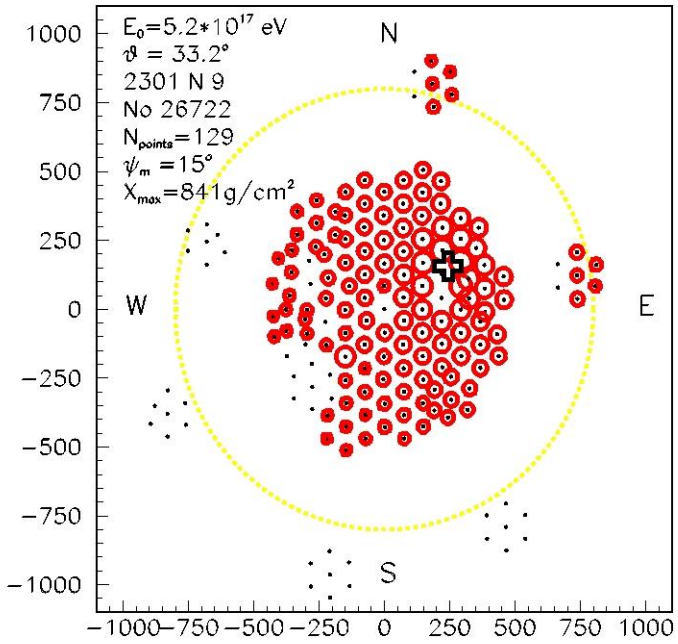
$$E = A\ (Q200)^{g}$$

Density of Cherenkov light at core distance of 200 m

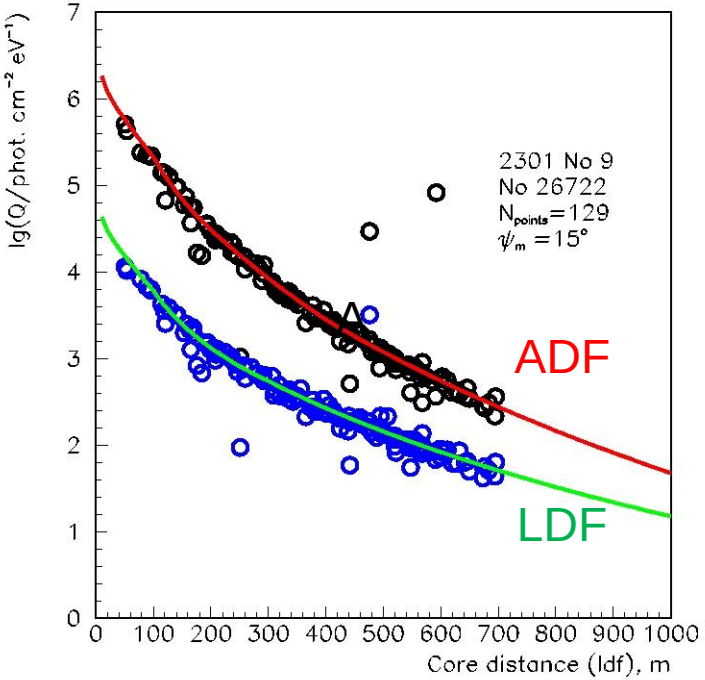
For $10^{16} – 10^{18}$ eV (CORSIKA):

$$g = 0.94 \pm 0.01$$

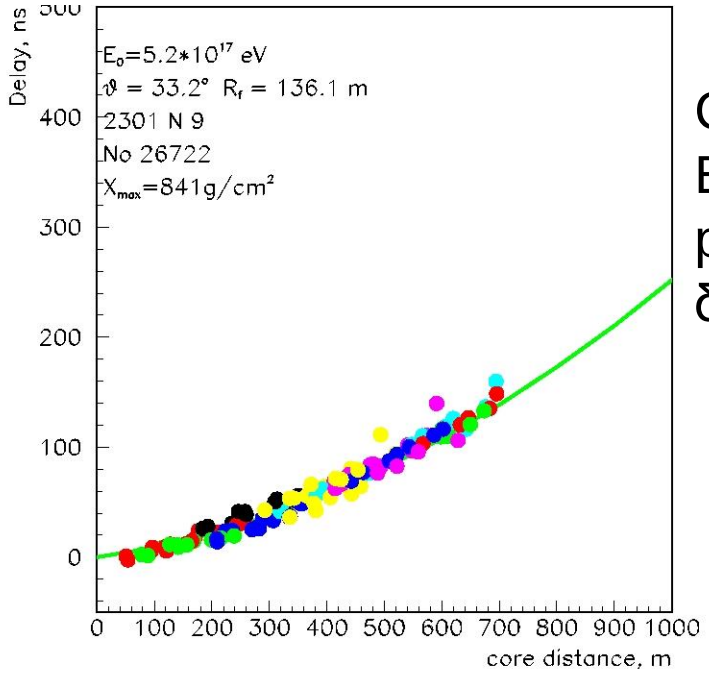
Single event example



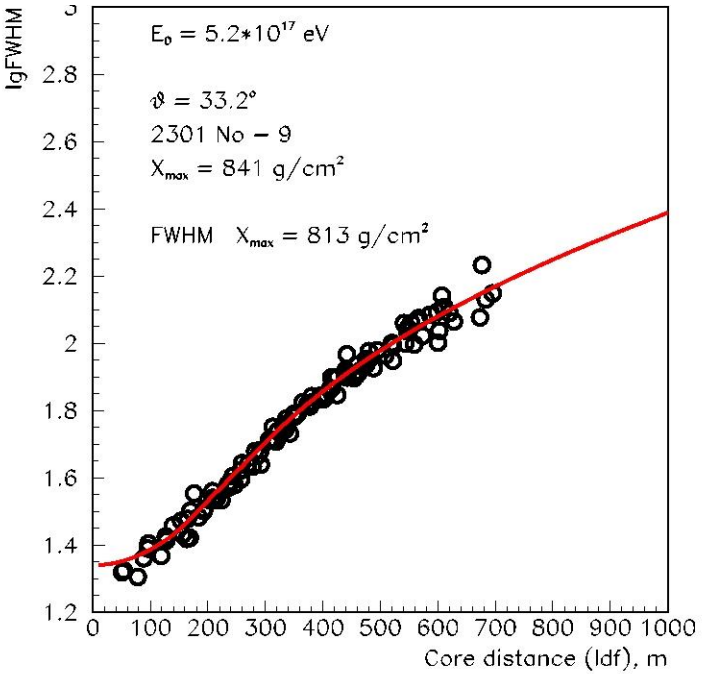
Footprint



ADF and LDF



Curved EAS time front provides $\delta\theta<0.5°$



τ_{eff} vs. core distance

Experimental data

5 winter seasons: 2009-2010 , 2010-2011, 2011-2012, 2012-2013, 2013-2014
262 clear moonless nights
~ 1540 h of observation with a trigger frequency ~ 2 Hz
~ 10 000 000 triggers
Cuts used for the energy spectrum:
$\theta \leq 45°$

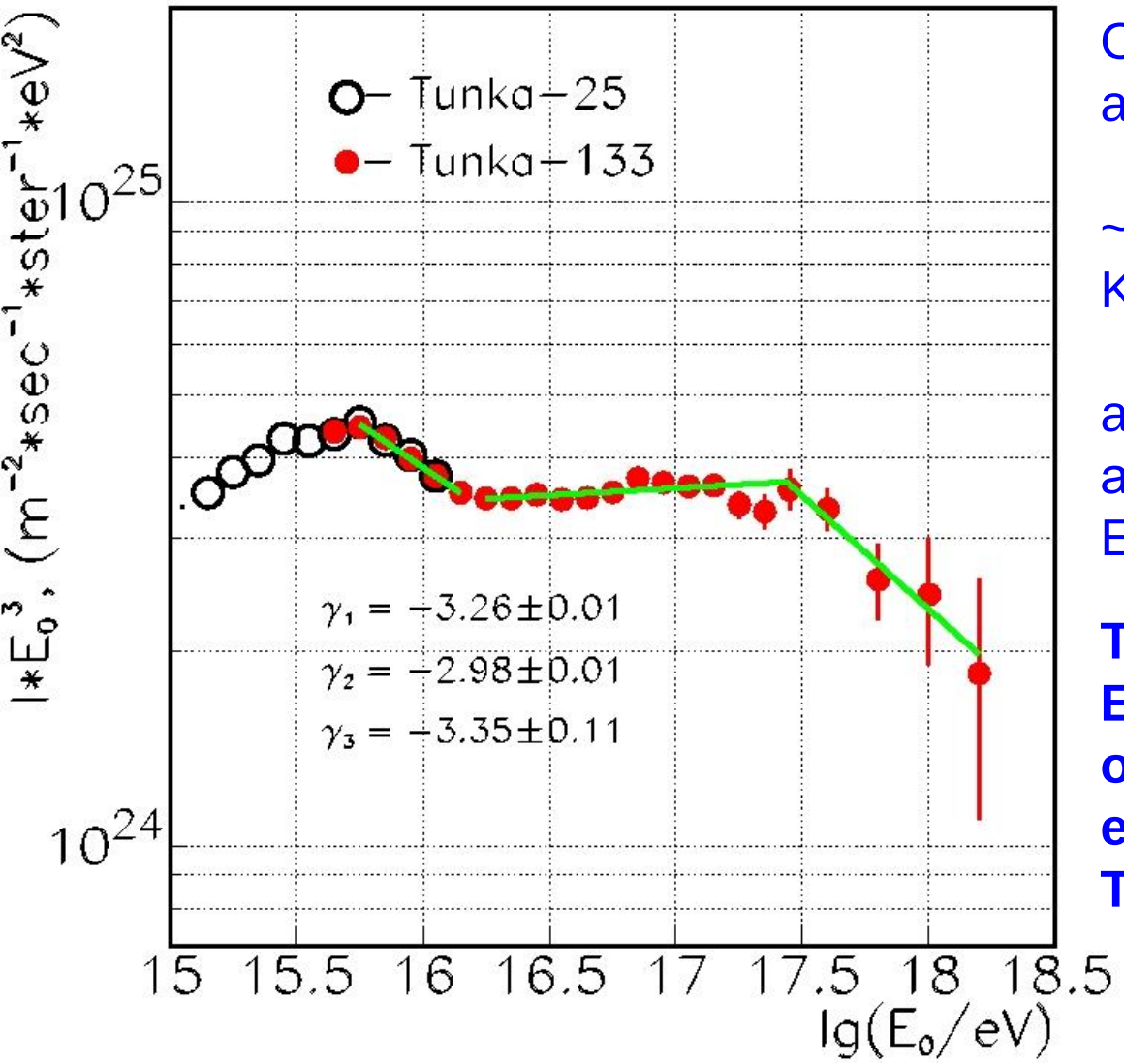
M: $R_{center} < 450$ m:

~ 270 000 events with $E_0 > 6 \cdot 10^{15}$ eV – 100% efficiency
~ 99 000 events $E_0 > 10^{16}$ eV
~ 4000 events $E_0 > 5 \cdot 10^{16}$ eV
~ 983 events $E_0 > 10^{17}$ eV

L: $R_{center} < 800$ m:

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

Energy spectrum: power law fitting



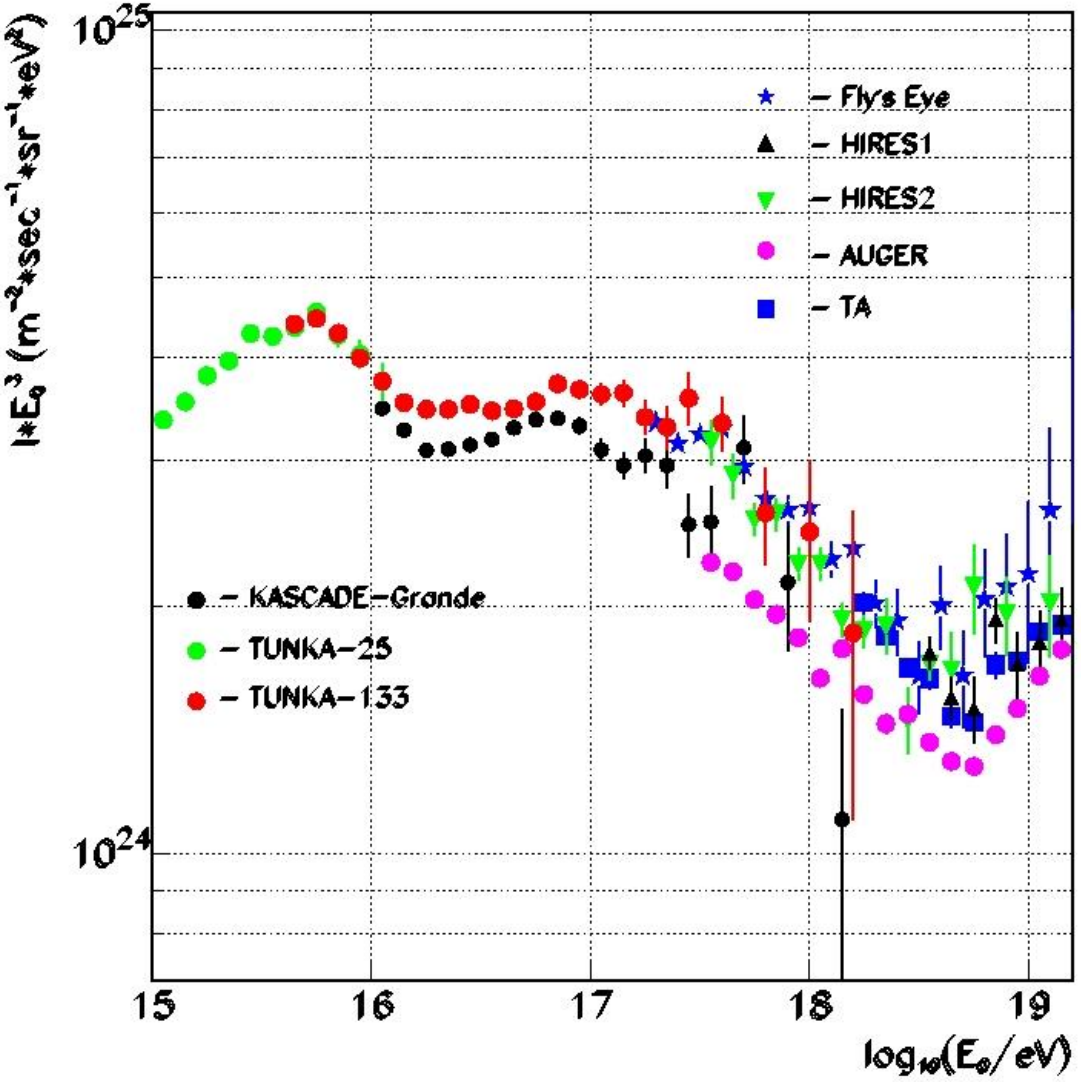
One can see two sharp features at the energies:

~$2 \cdot 10^{16}$ eV (first announced by KASCADE-Grande in 2010)

and ~$3 \cdot 10^{17}$ eV (similar to that, announced by Yakutsk and Fly's Eye in 90th)

The power law index at $E_0 > 10^{17}$ is similar to that obtained by the giant experiments: TA, HiRes, Auger.

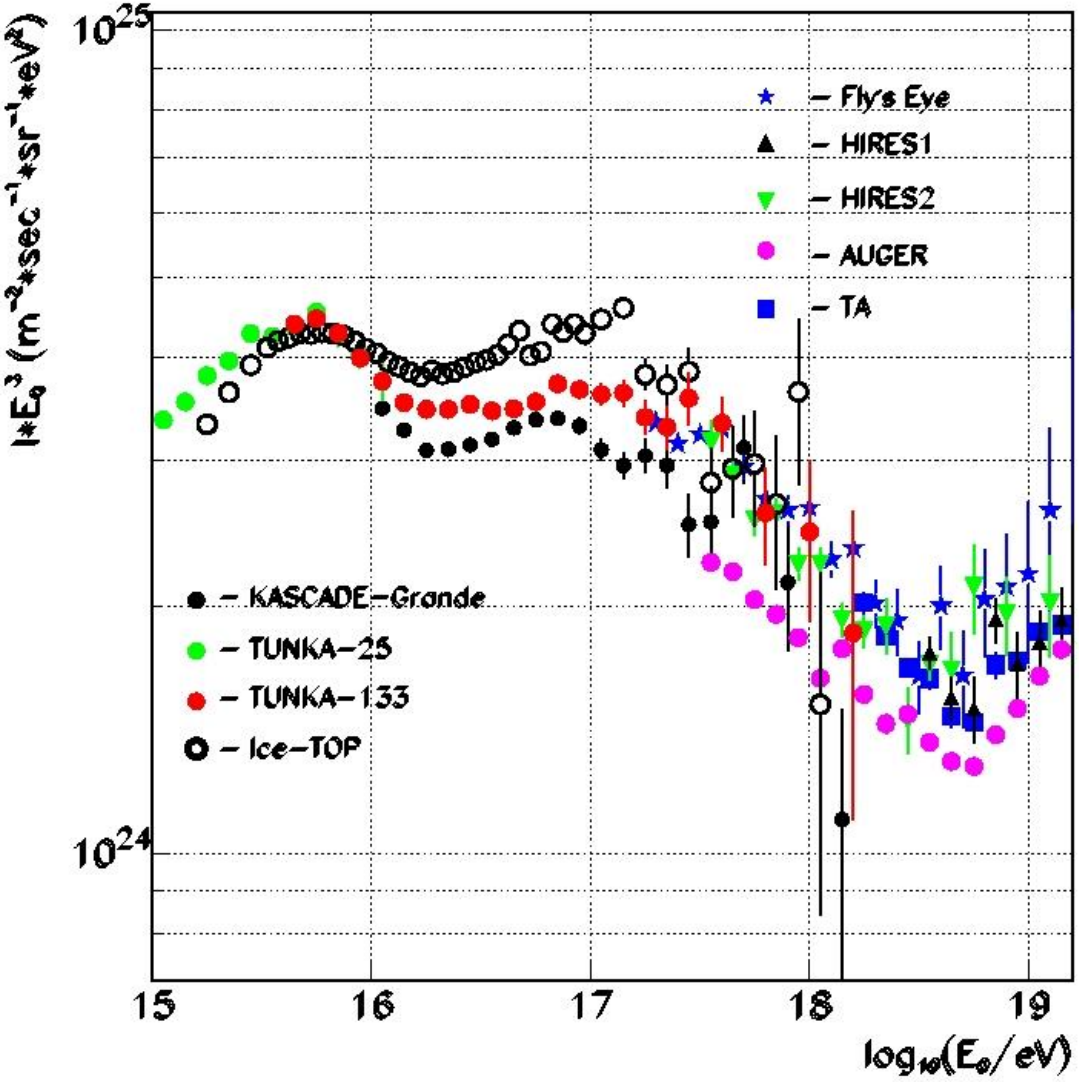
Combined spectrum: comparison with some other works



Agreement with KASCADE-Grande

Agreement with old Fly's Eye, HiRes and TA spectra.

Combined spectrum: comparison with some other works

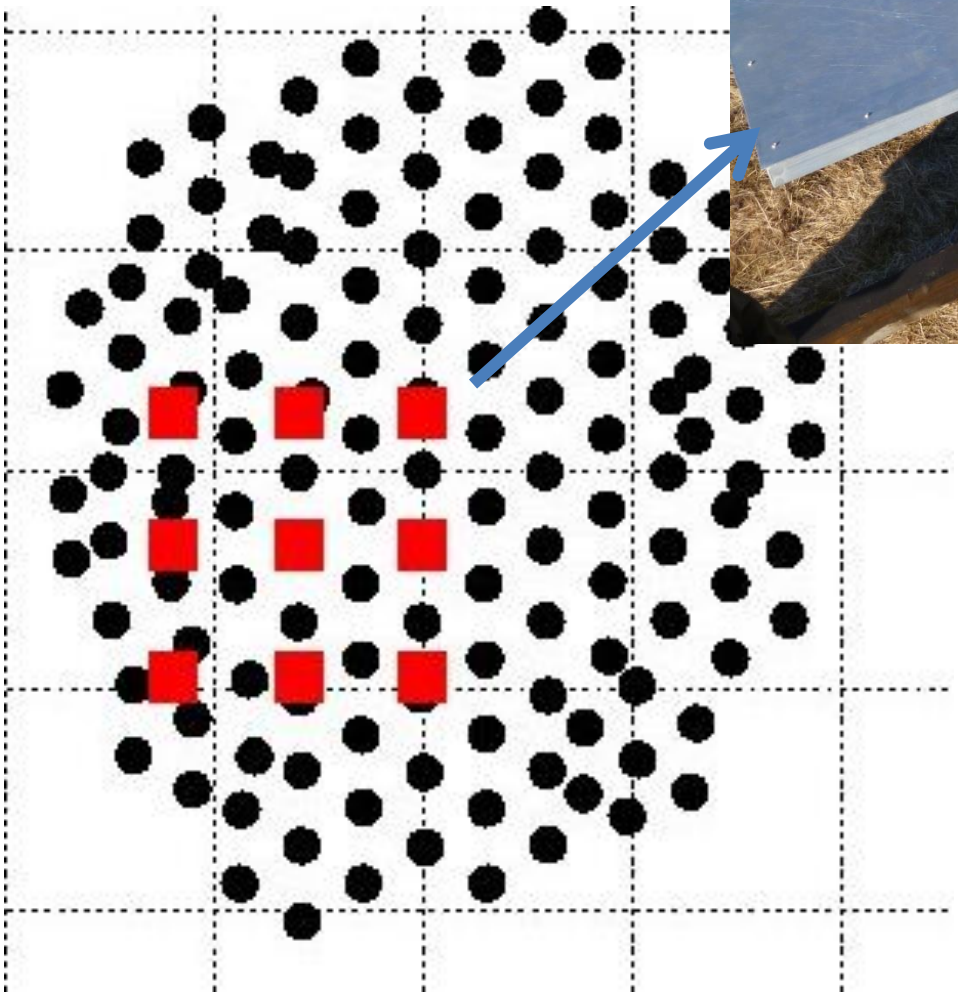


Agreement with KASCADE-Grande and Ice-TOP (2013)

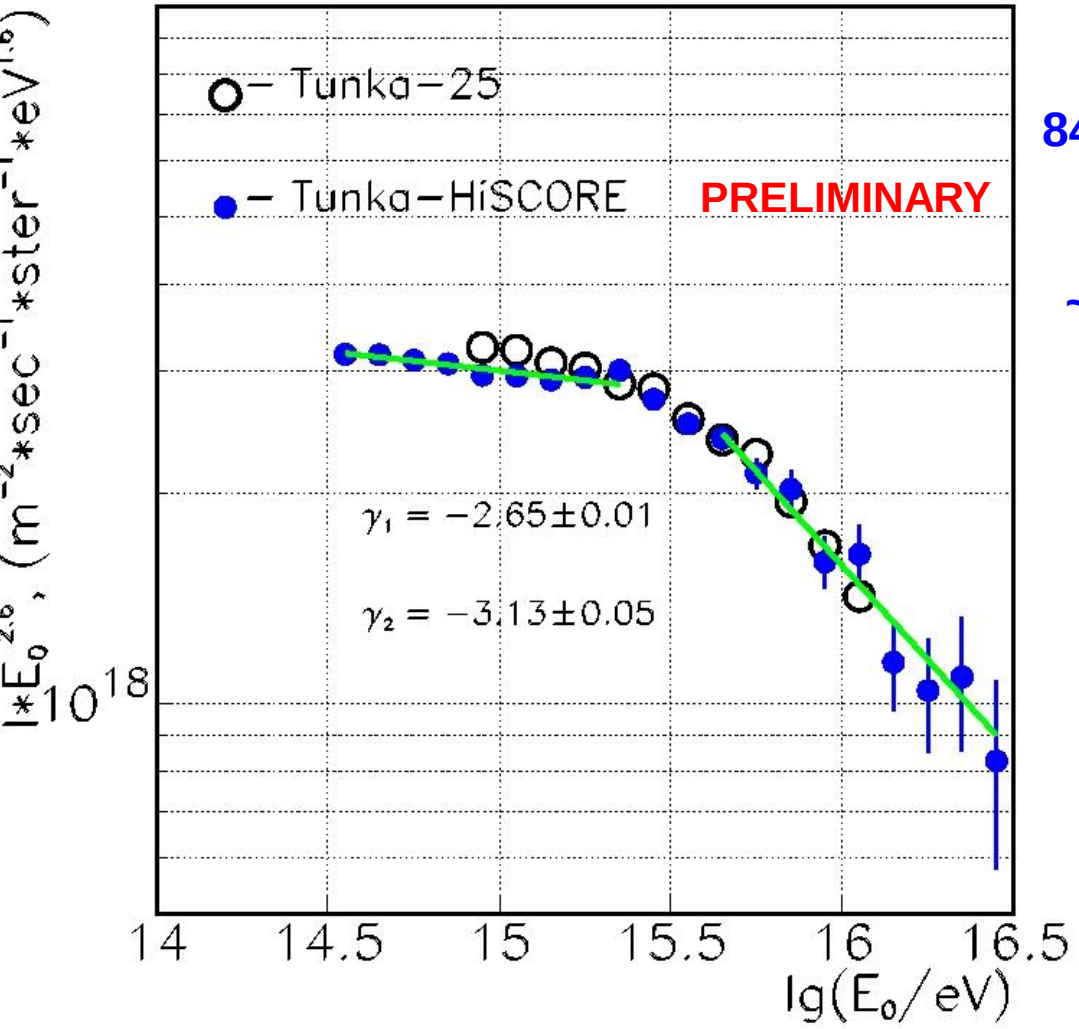
All the spectra coincide with Tunka-133, if energy of KASCADE-Grande is increased by 3% and energy of Ice-TOP is decreased by 3%.

This shift is less than announced experimental accuracy.

Tunka-HiSCORE prototype
9 optical stations



Tunka-HiSCORE:
All particle energy spectrum.
PRELIMINARY

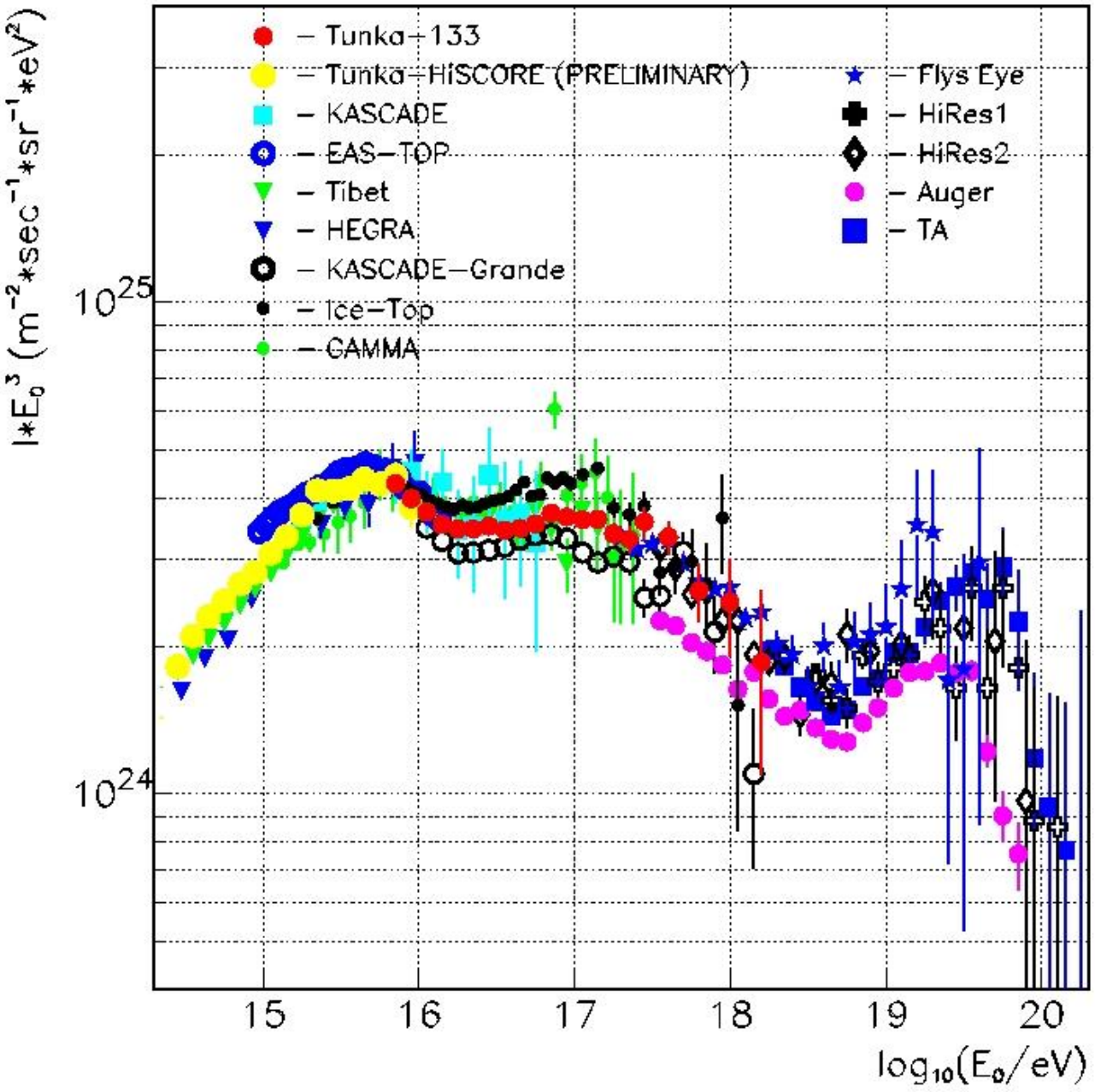


84 h during 13 clean moonless nights in February and March of 2014

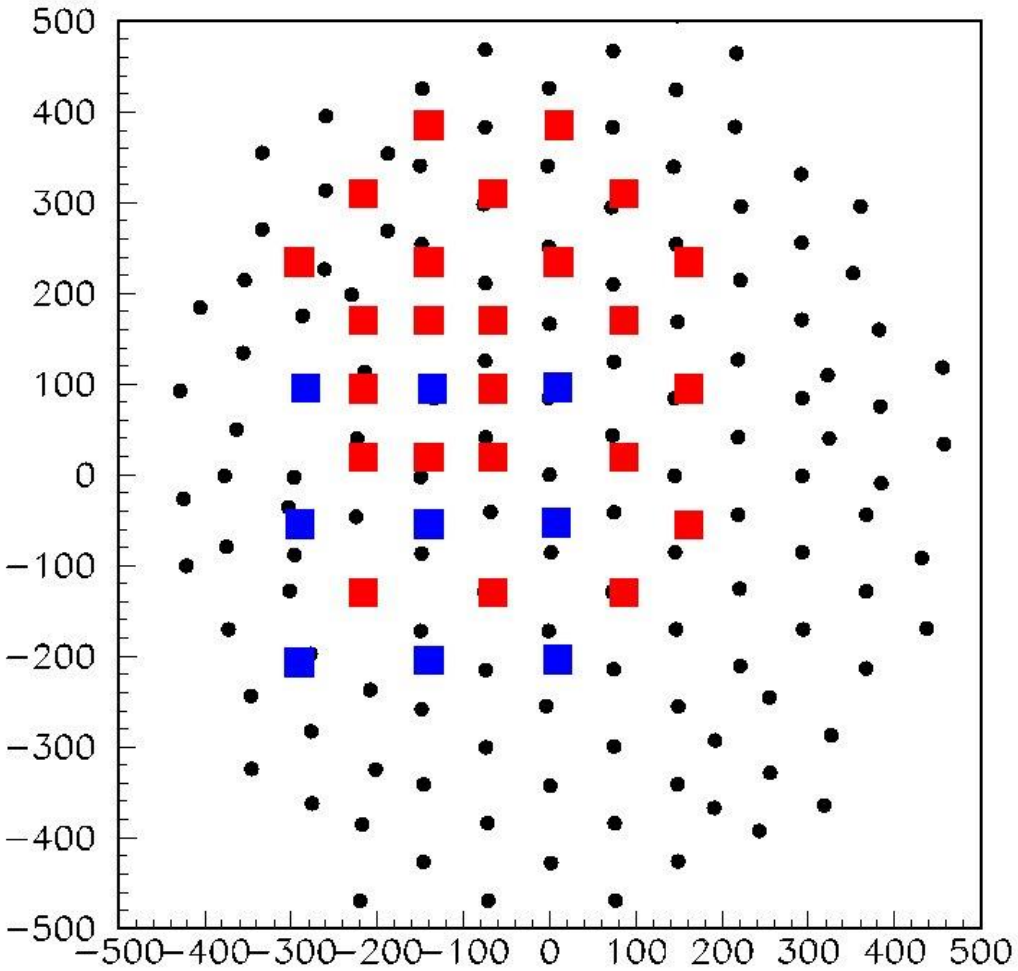
~ 145 000 events with $E_0 > 3 \cdot 10^{14}$ eV (100% efficiency)

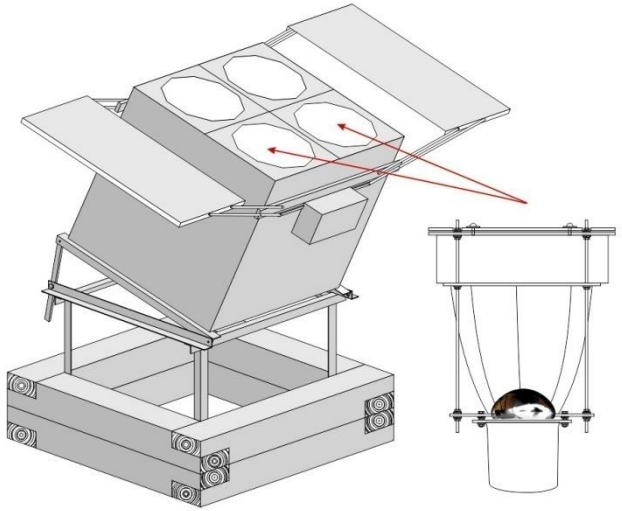
~ 21 000 events $E_0 > 10^{15}$ eV

~ 200 events $E_0 > 10^{16}$ eV


– Tunka–133
– Tunka–HiSCORE (PRELIMINARY)
– KASCADE
– EAS–TOP
– Tibet
– HEGRA
– KASCADE–Grande
– Ice–Top
– CAMMA
– Flys Eye
– HiRes1
– HiRes2
– Auger
– TA
$I*E_0^3$ ($m^{-2}*sec^{-1}*sr^{-1}*eV^2$)
10^{25}
10^{24}
15
16
17
18
19
20
$\log_{10}(E_0/eV)$

Tunka-HiSCORE next winter (2014-2015) –
33 stations
Decreasing of a threshold for γ to ~40 TeV



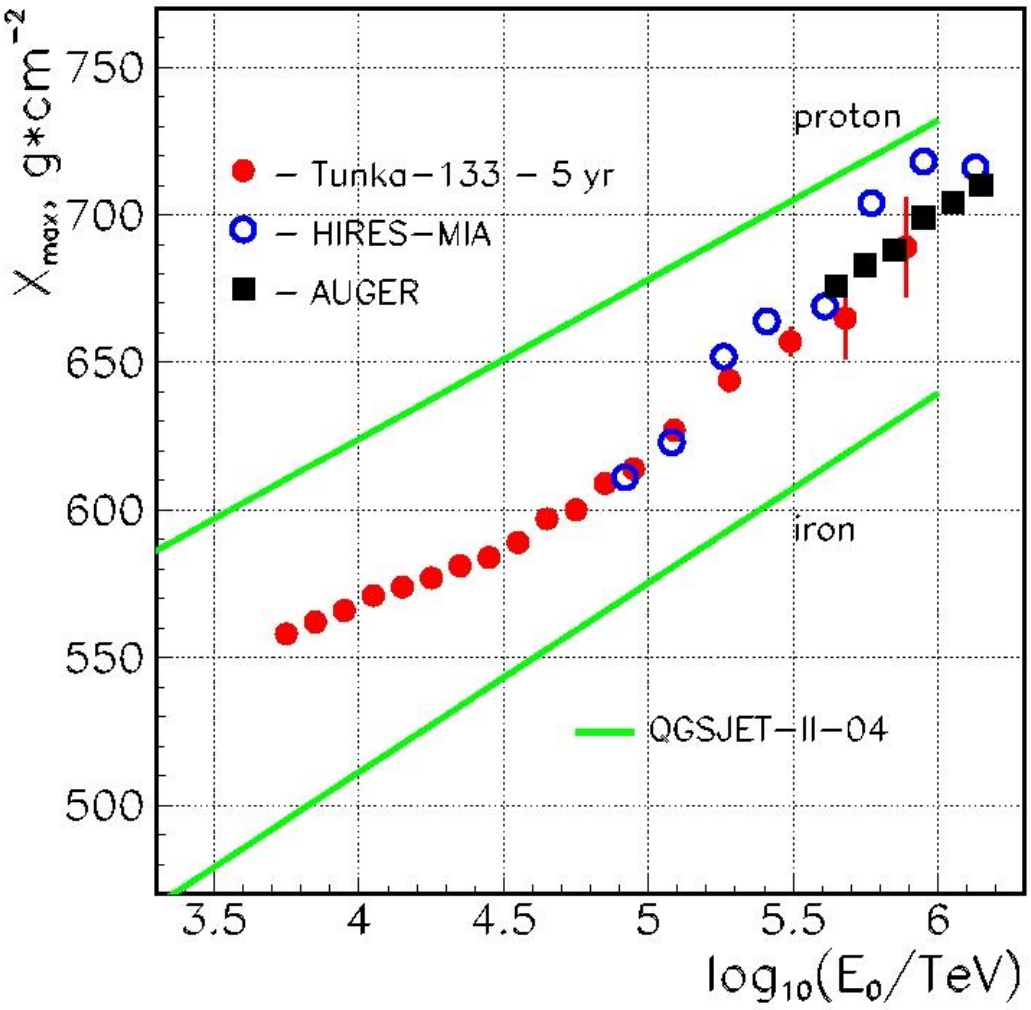


All the stations will be tilted for 30° to the South for observation of Crab Nebulae

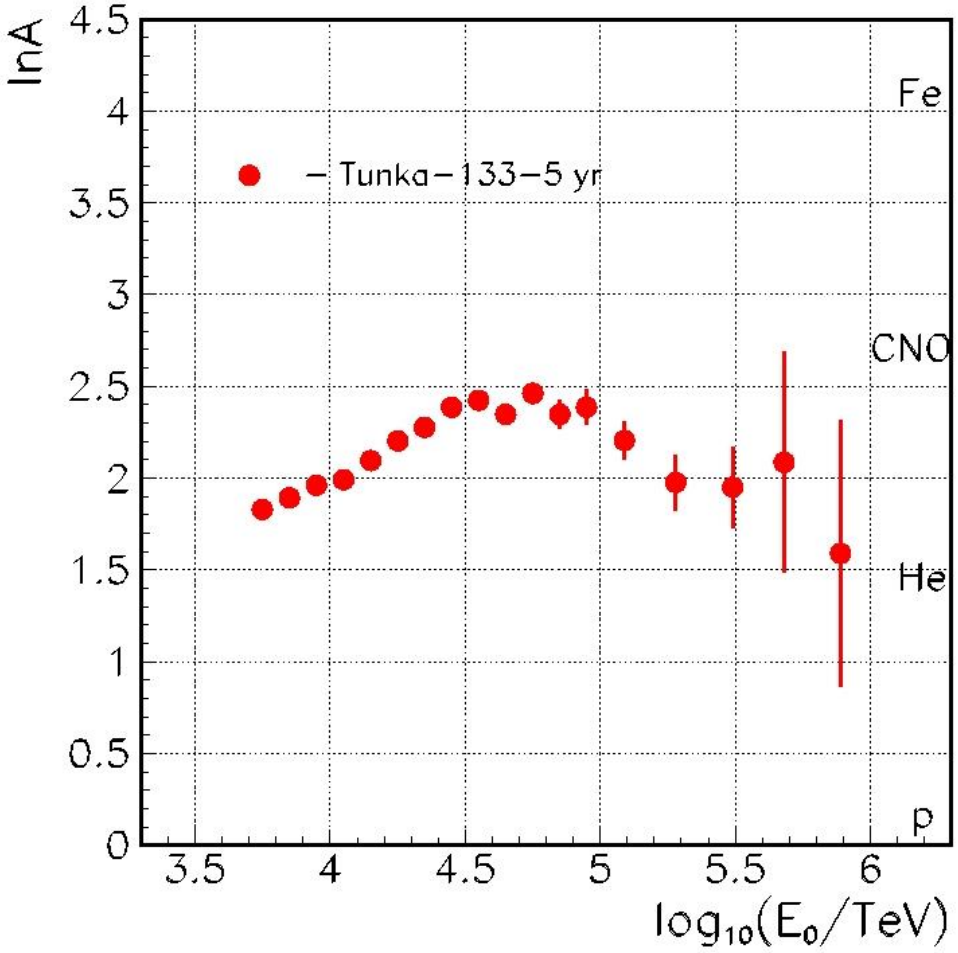
About 10-30 γ-events from Crab are expected during 100 h of observation.

$\langle X_{max} \rangle$ vs. E_0

Agreement with HiRes-MIA and Auger results at 10^{17} – 10^{18} eV



Tunka-133 experiment: mean <lnA> vs. E_0



Conclusions

1. The energy spectrum from $6 \cdot 10^{15}$ eV to 10^{18} eV cannot be fitted with a single power law index:

$\gamma = 3.25 \pm 0.01$	$5 \cdot 10^{15}$ eV < E_0 < $2 \cdot 10^{16}$ eV.
$\gamma = 2.98 \pm 0.01$	$2 \cdot 10^{16}$ eV < E_0 < $3 \cdot 10^{17}$ eV.
$\gamma = 3.35 \pm 0.11$	$E_0 > 3 \cdot 10^{17}$ eV.

2. Agreement with KASCADE-Grande and Ice-TOP within a shift of the energy scale of only 3-4%, agreement with TALE (TA Cherenkov).

3. The high energy tail does not contradict to the Fly's Eye, HiRes and TA spectra.

4. Tunka-HiSCORE prototype data can be used for the primary energy spectrum reconstruction in the knee energy range and before the knee. The spectrum is in agreement with Tibet and Hegra-AIROBICC results. Further steps to decrease the energy threshold are in progress.

5. Composition changes from light to heavy in the energy region 10^{16} – 10^{17} eV and then back to light in the region 10^{17} – 10^{18} eV.

Back up slides

EAS parameters accuracy: experimental estimations

Comparison of one the same shower parameters, measured by different arrays.