The Results and Perspectives of Cosmic Rays Mass Composition Study with EAS Arrays in the Tunka Valley

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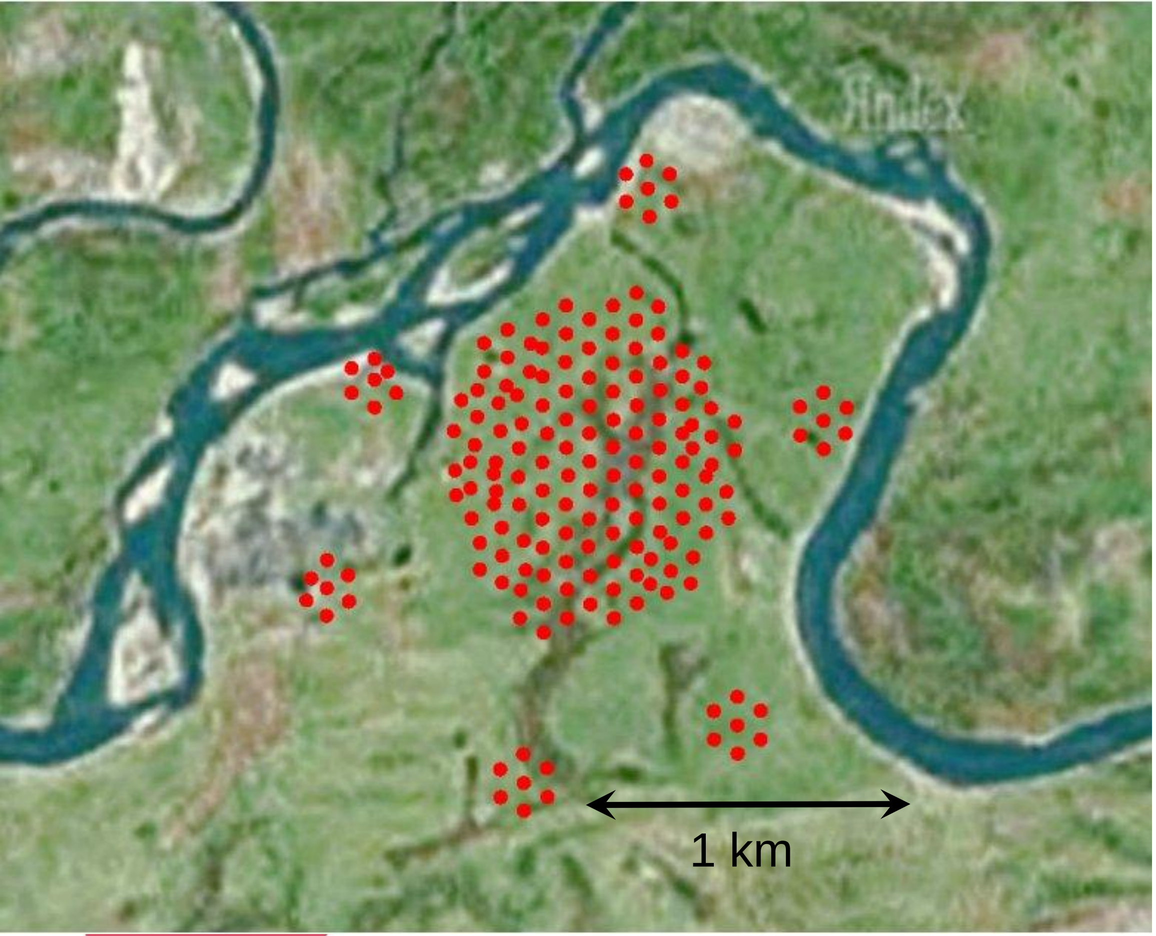
From TAIGA Collaboration

TAUP-2015, Torino, September 2015

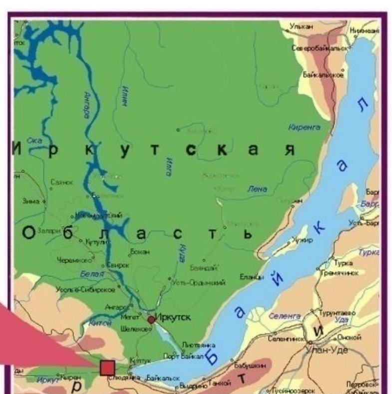


Tunka Valley

Republic Buryatia

150 km from Irkutsk

50 km from the shore of lake Baikal

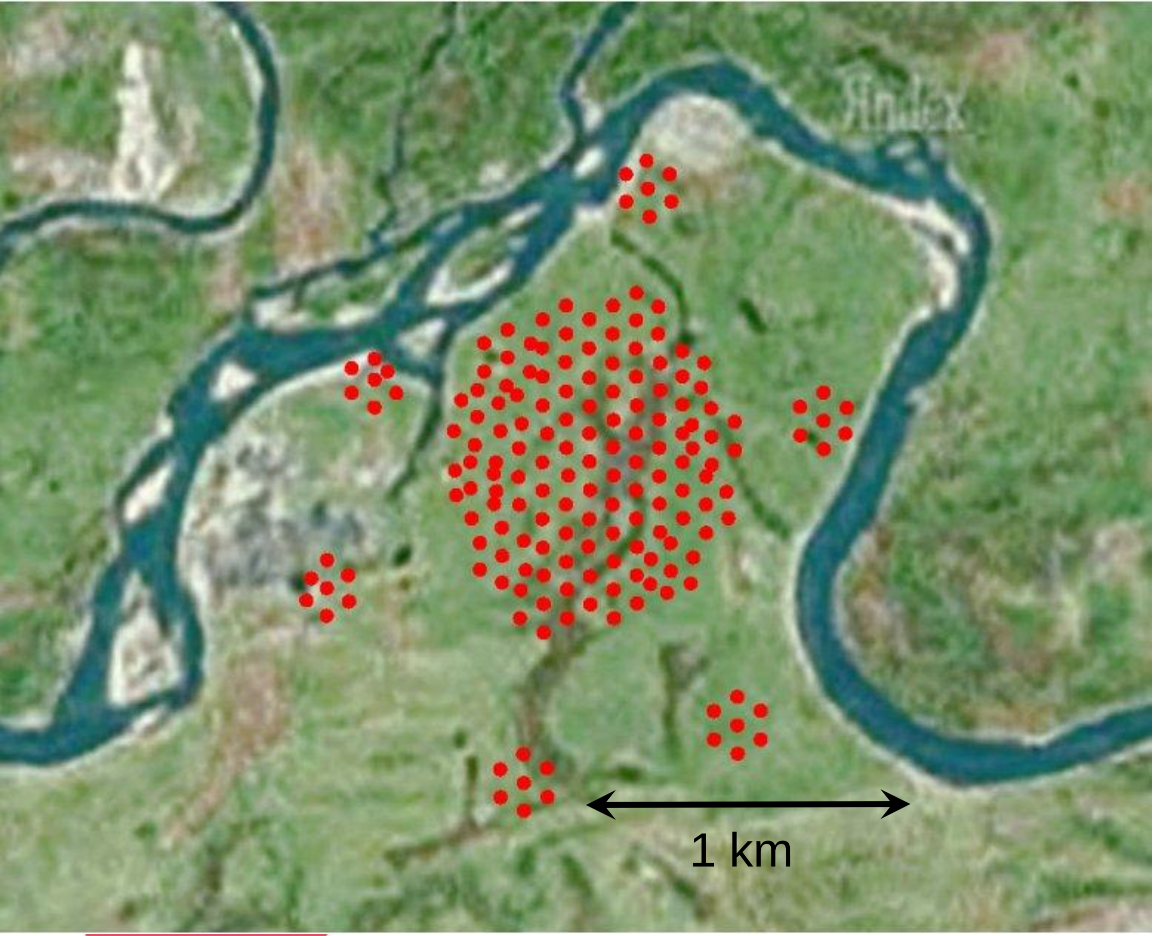


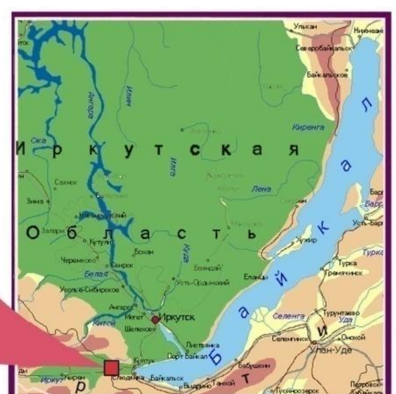
51° 48' 35" N
103° 04' 02" E
675 m a.s.l.


ТУНКИНСКИЙ РАЙОН
НАЦИОНАЛЬНЫЙ ПАРК

EXPERIMENTS
in Tunka Valley

Tunka-133

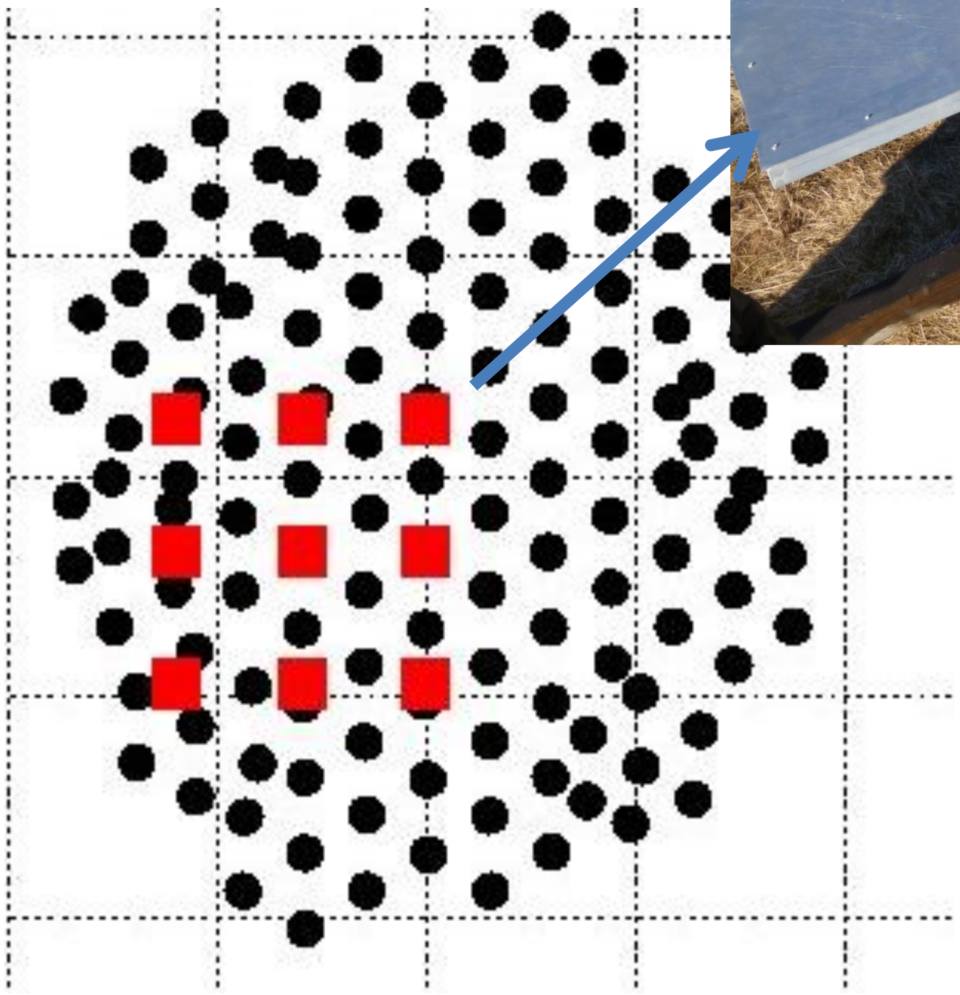




51° 48' 35" N
103° 04' 02" E
675 m a.s.l.

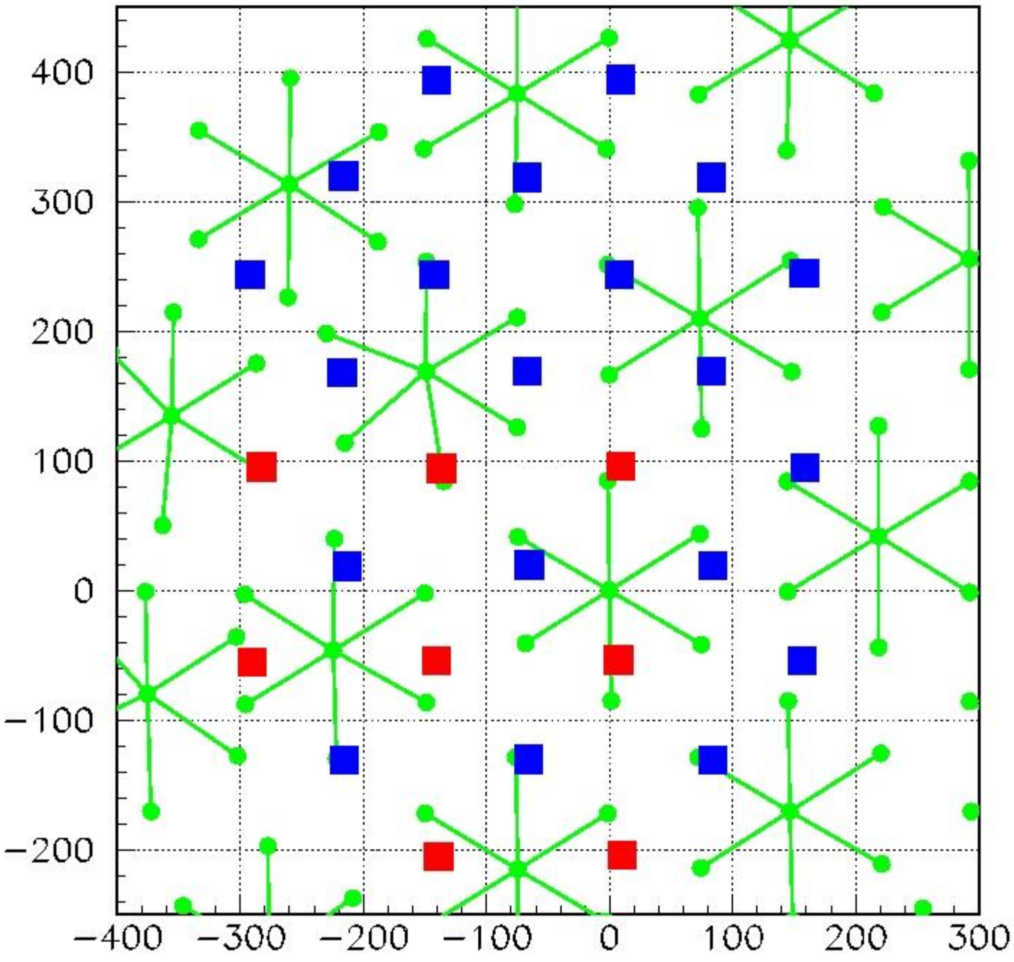
175 optical detectors
EMI 9350 and HAMAMATSU Ø 20 cm

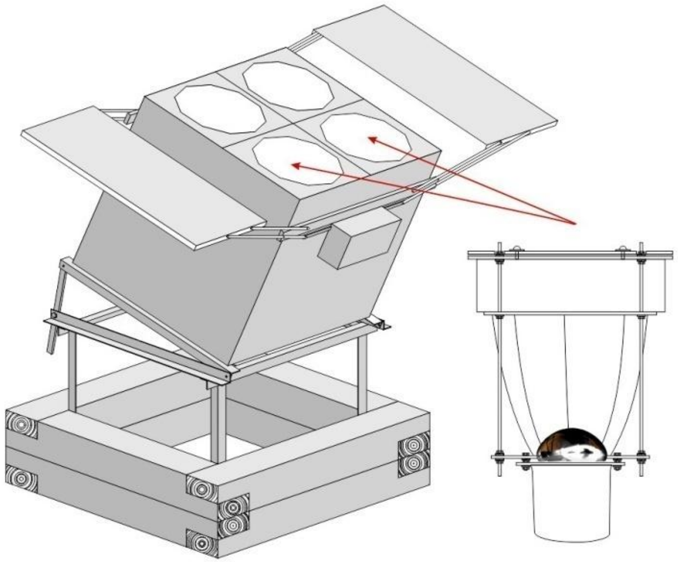
Tunka-HiSCORE
2013 – 2014



Prototype with 9 optical stations

Tunka-HiSCORE (2015-2016) – 28 stations





All the stations will be tilted for 25° to the South for observation of Crab Nebulae

About 20-60 γ-events from Crab are expected during 100 h of observation.

Tunka-REX

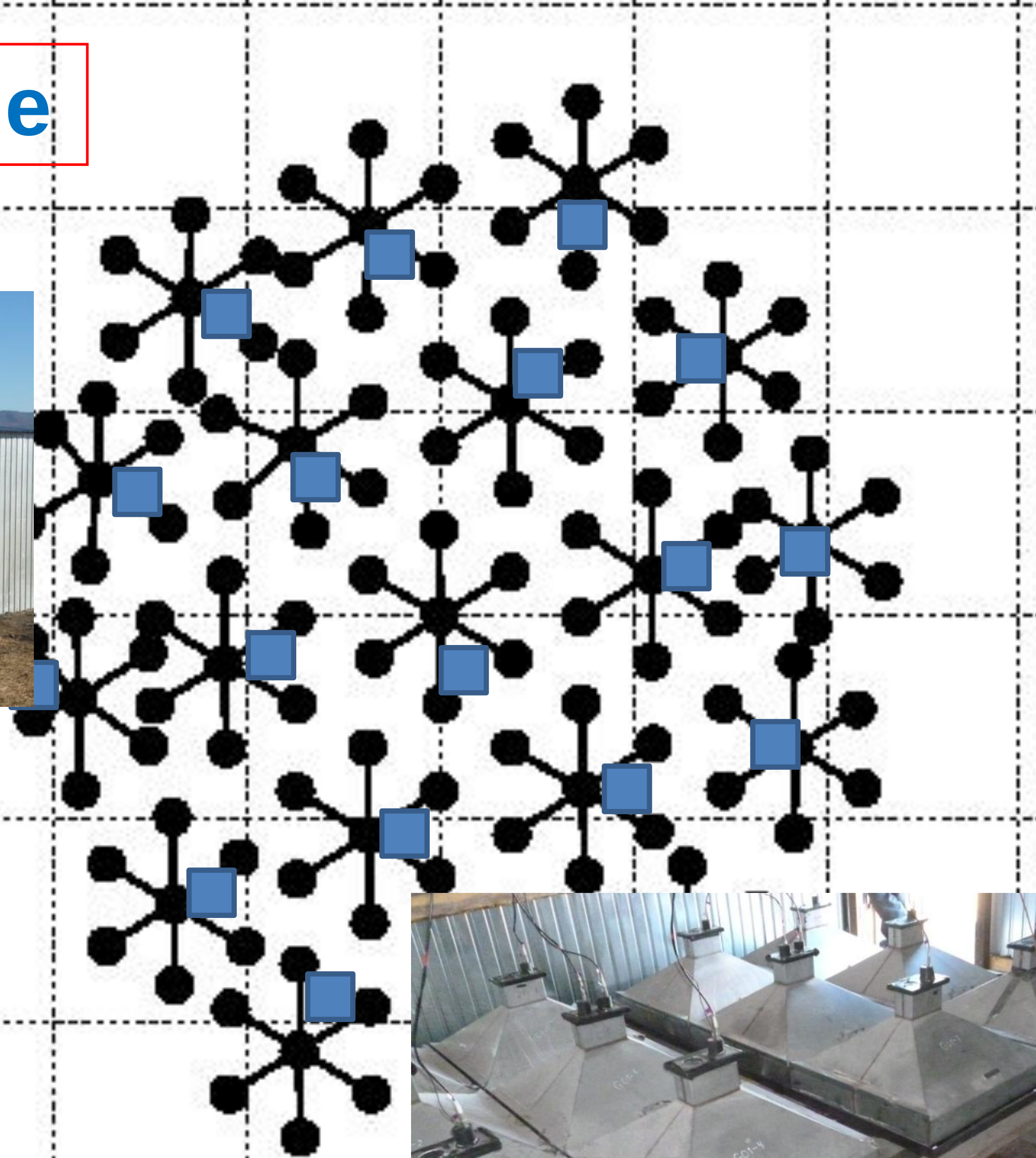
Connection of 2 antennas to
2 free channel of FADC

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

38 antennas are situated at the area of 1 km^2 now.

Tunka-Grande

19 stations



228 detectors (0.64 m^2)
 on the surface

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

Entrence to
Muon detector

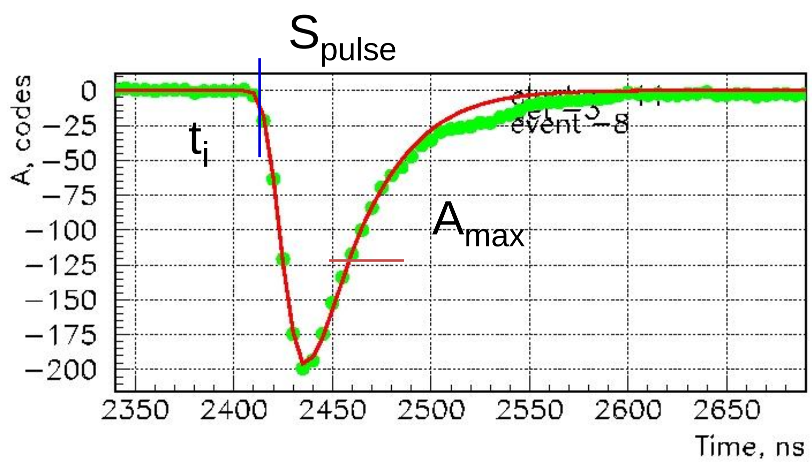
Tunka-133 data processing

Tunka-133 Single detector readout:

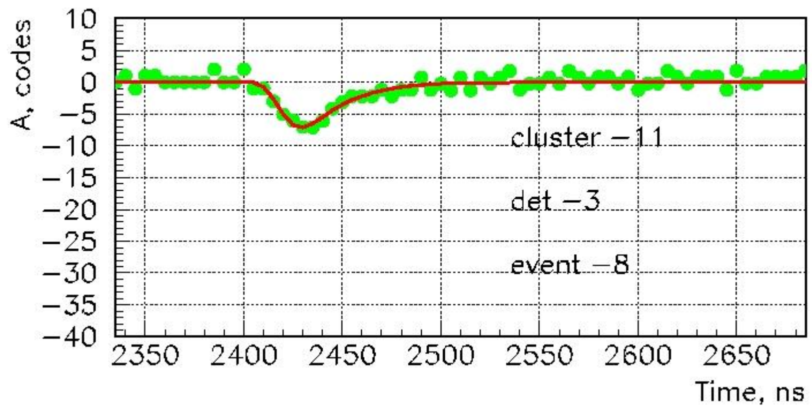
Fitting of a pulse and measuring of the parameters: $Q=c\cdot S_{pulse}$, A_{max}, t_i , $\tau_{eff}=S/A/1.24$

Time step = 5 ns

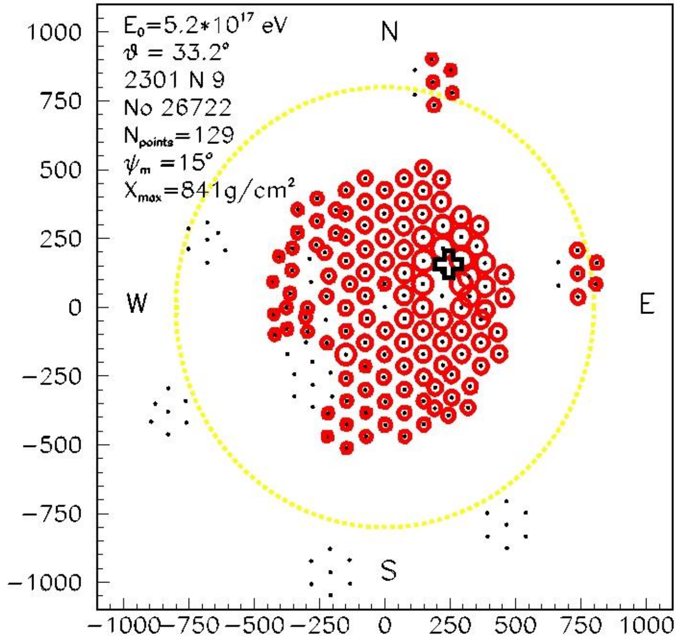
anode:



dinode:

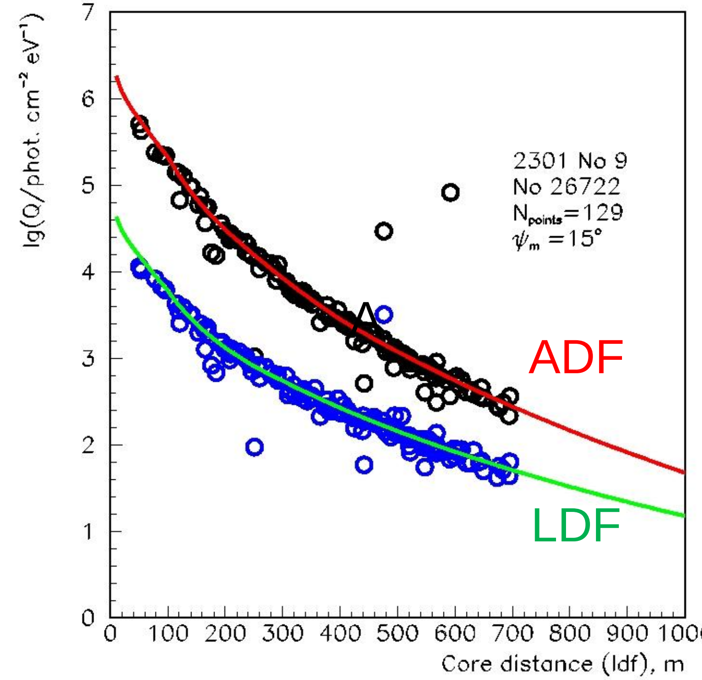


Single event example

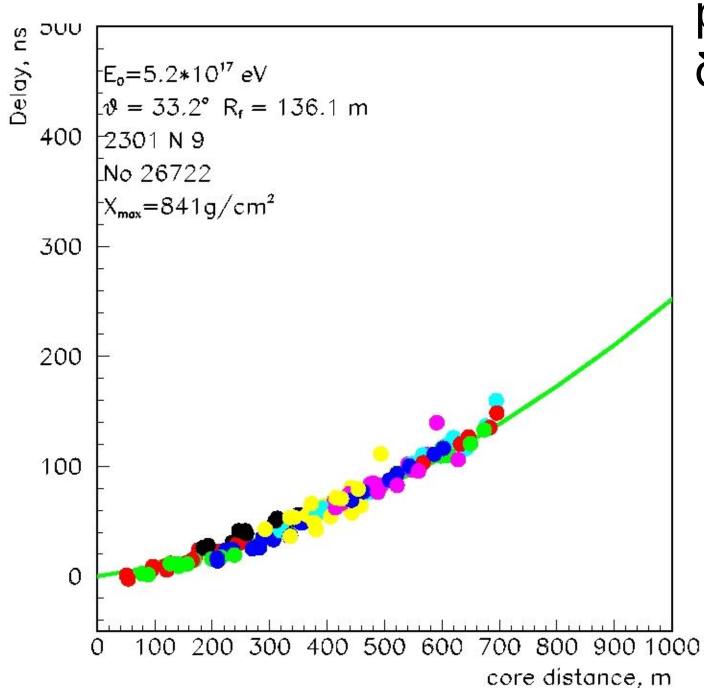


Plan

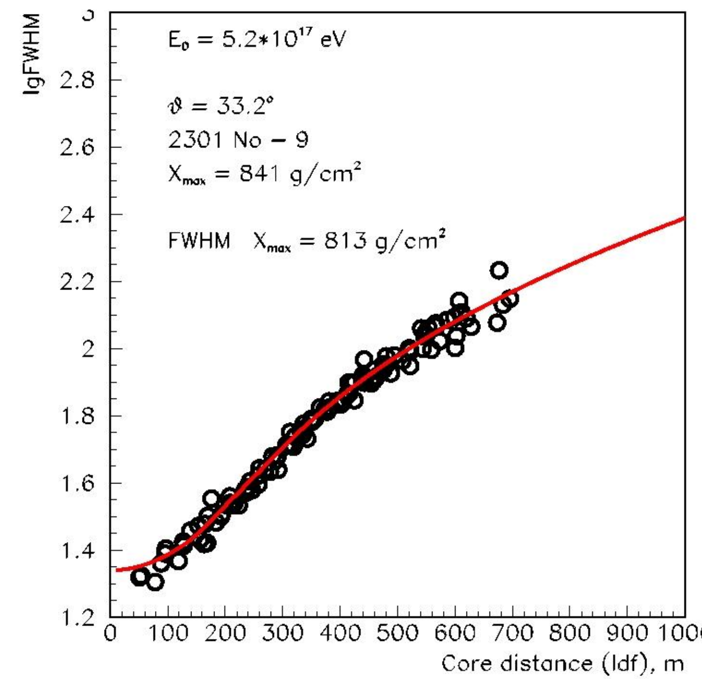
ADF and LDF



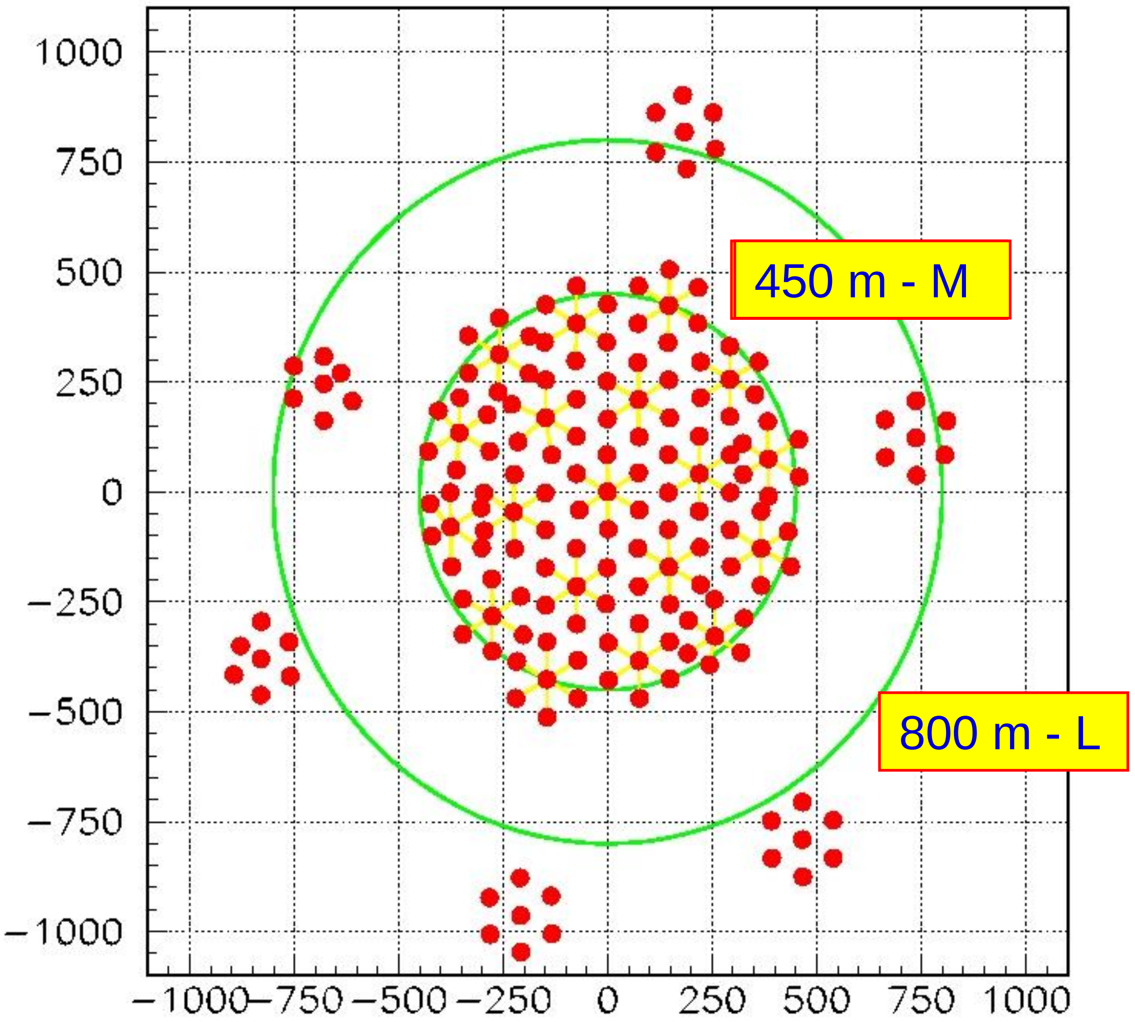
Curve EAS time front provides $\delta\theta<0.5°$



τ_{eff} vs. core distance



Effective areas



Tunka-133 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
The cuts for the energy spectrum used:
$\theta \leq 45°$

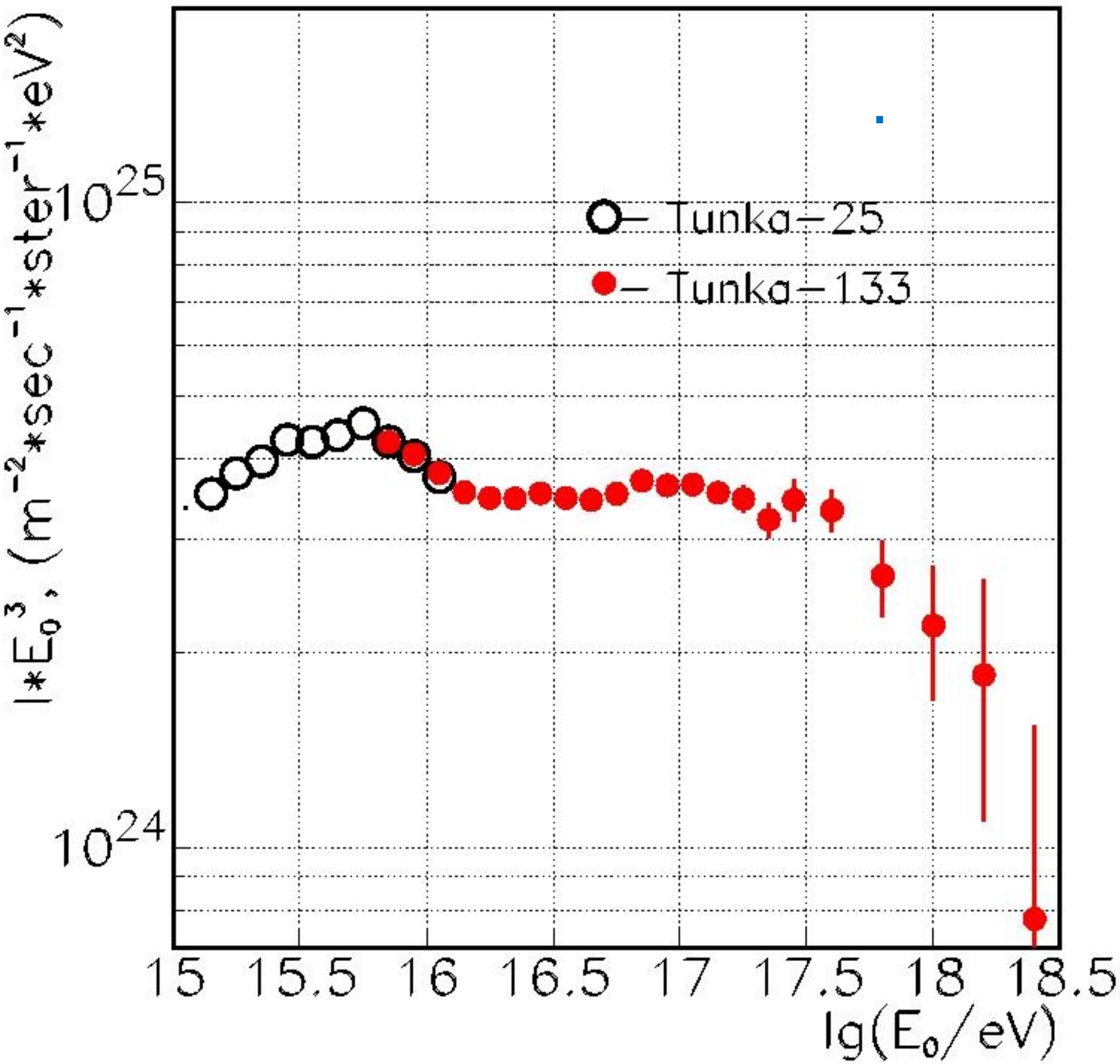
M: $R_{center} < 450$ m:

~ 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

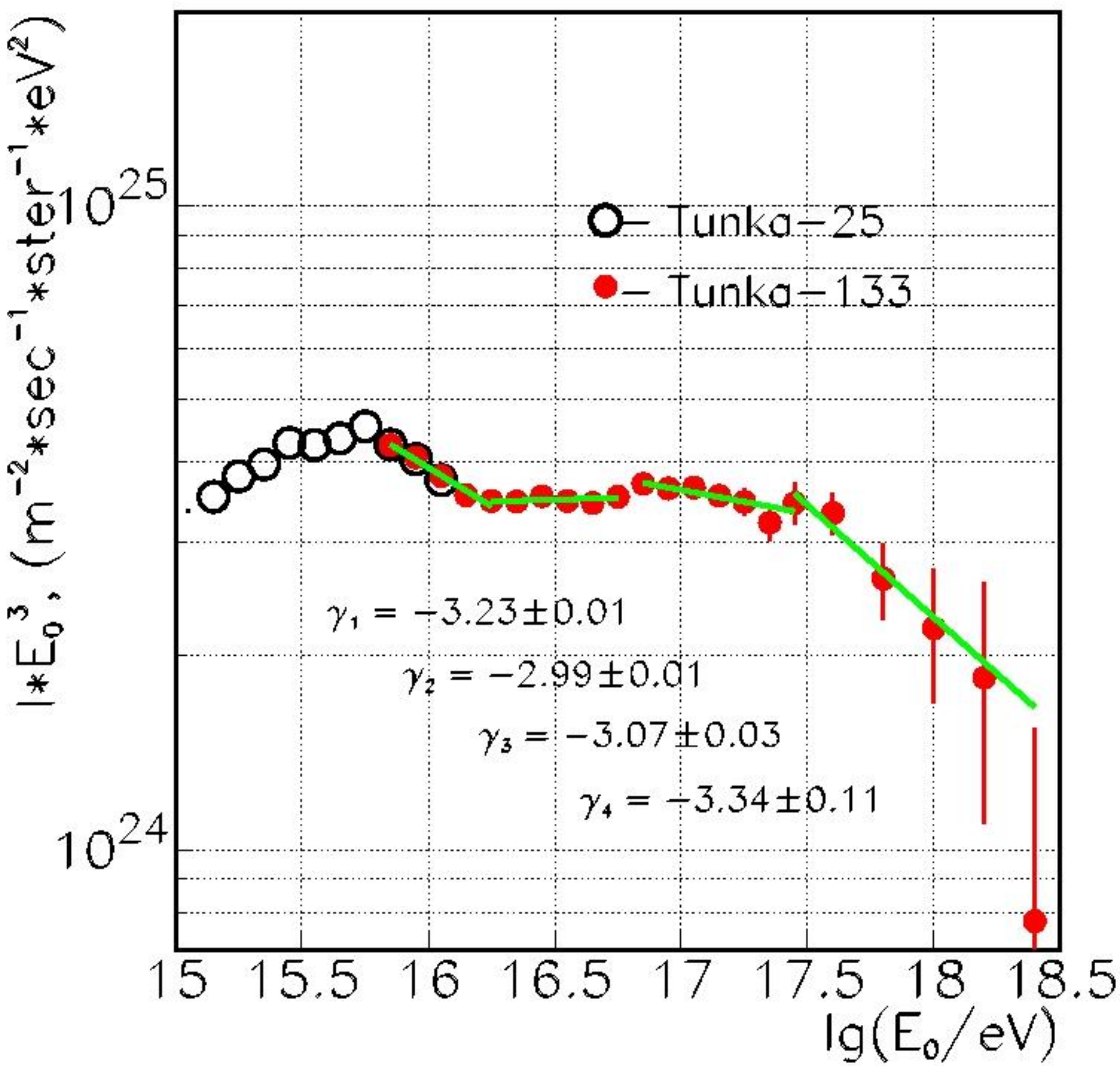
L: $R_{center} < 800$ m:

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

Energy spectrum:



Energy spectrum: power law fitting

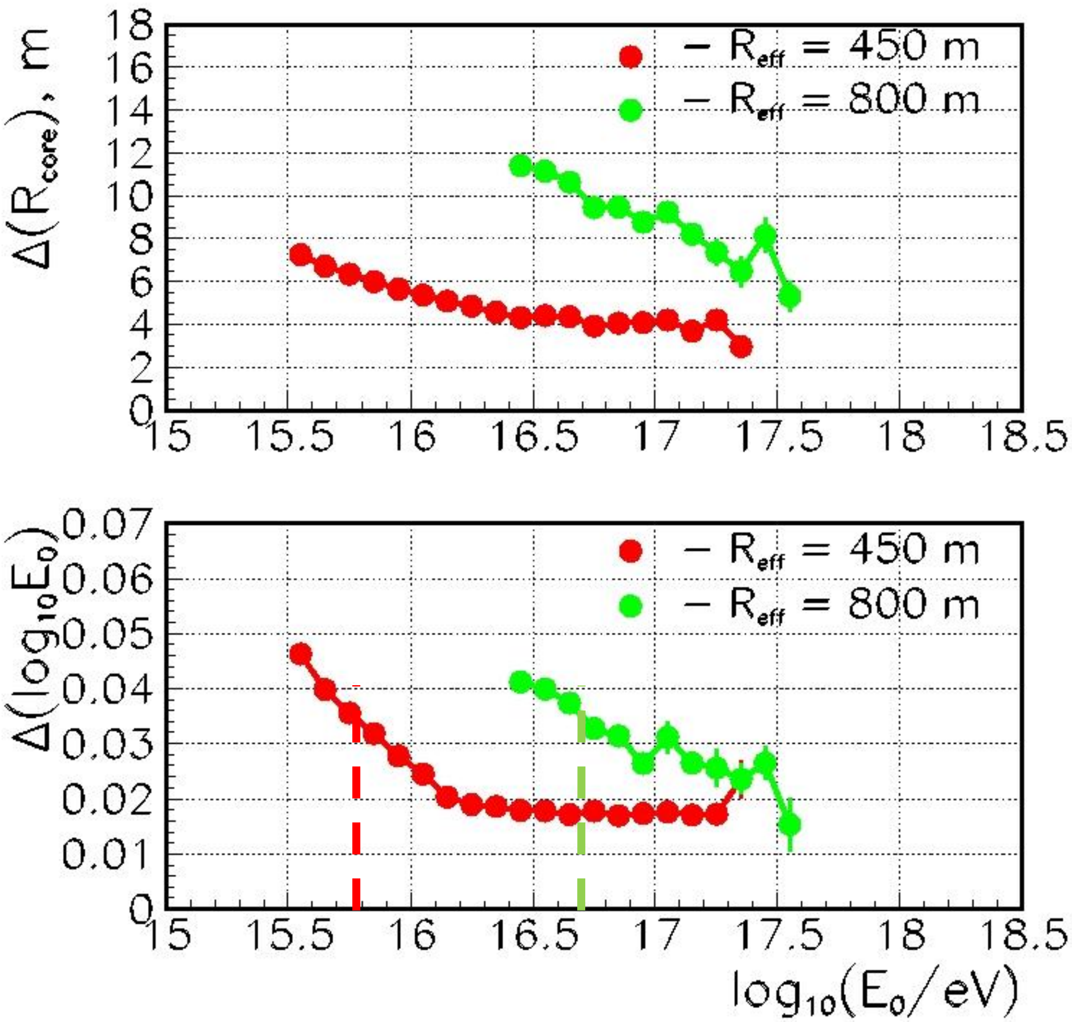


EAS parameters accuracy: experimental estimations by chessboard method

Separation to two sub-arrays:
a) odd detectors
b) even detectors - comparison of EAS parameters:

Error=Difference/√2

Lines – threshold for spectrum



Tunka-HiSCORE data processing

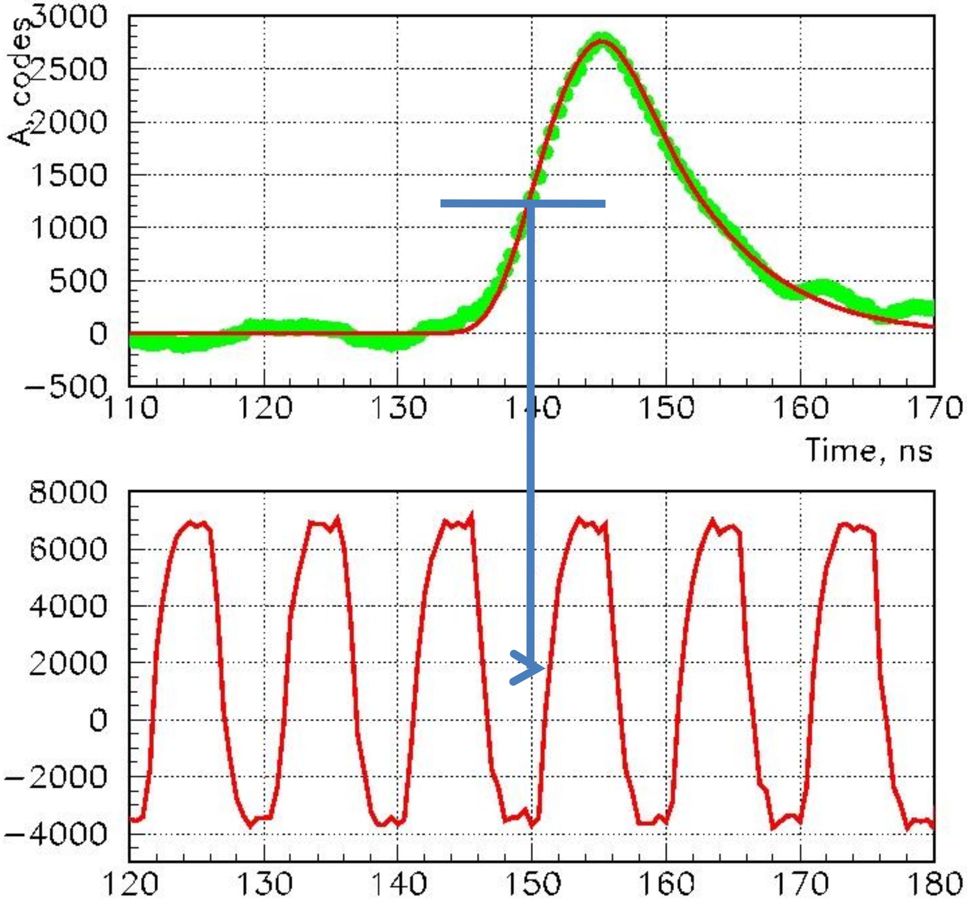
Tunka-HiSCORE record (DRS-4): parameters: $Q=c\cdot S_{pulse}$, A_{max}, t_i , $\tau_{eff}=S/A/1.24$

Time step = 0.5 ns

Cerenkov light pulse record

Delay measurement accuracy = 0.2 ns

Clock signal 100 MHz



Tunka-HiSCORE Experimental Data

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

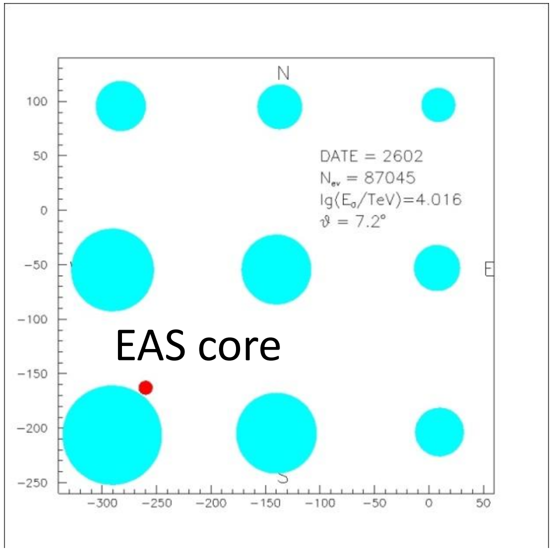
~ 21 000 events $E_0 > 10^{15}$ eV

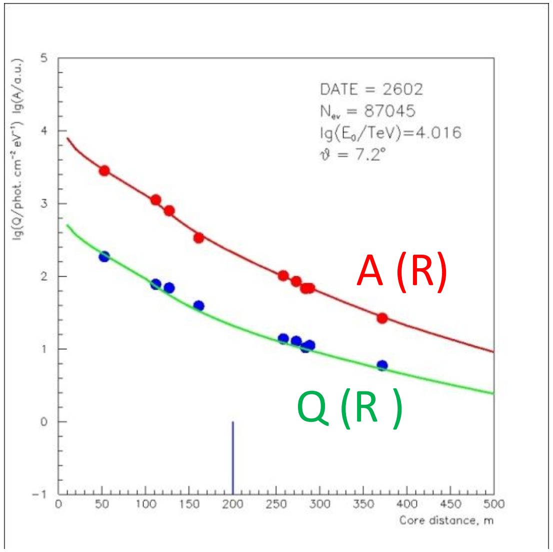
~ 200 events $E_0 > 10^{16}$ eV

Tunka-HiSCORE event example

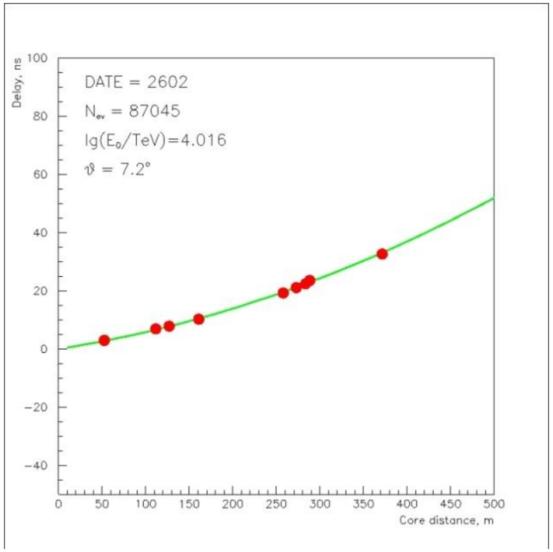
Zenith angle = 7.2°

Energy = 10^{16} eV

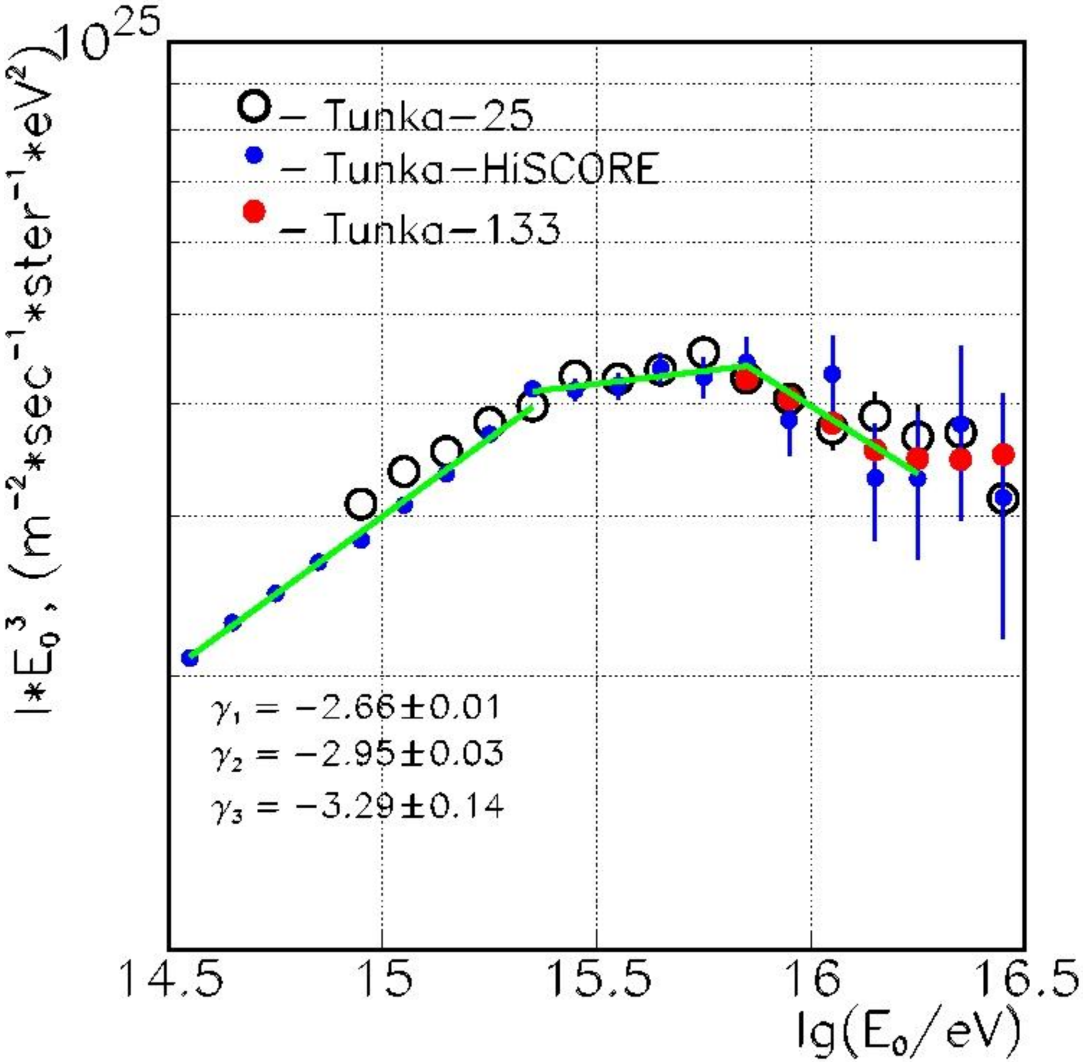




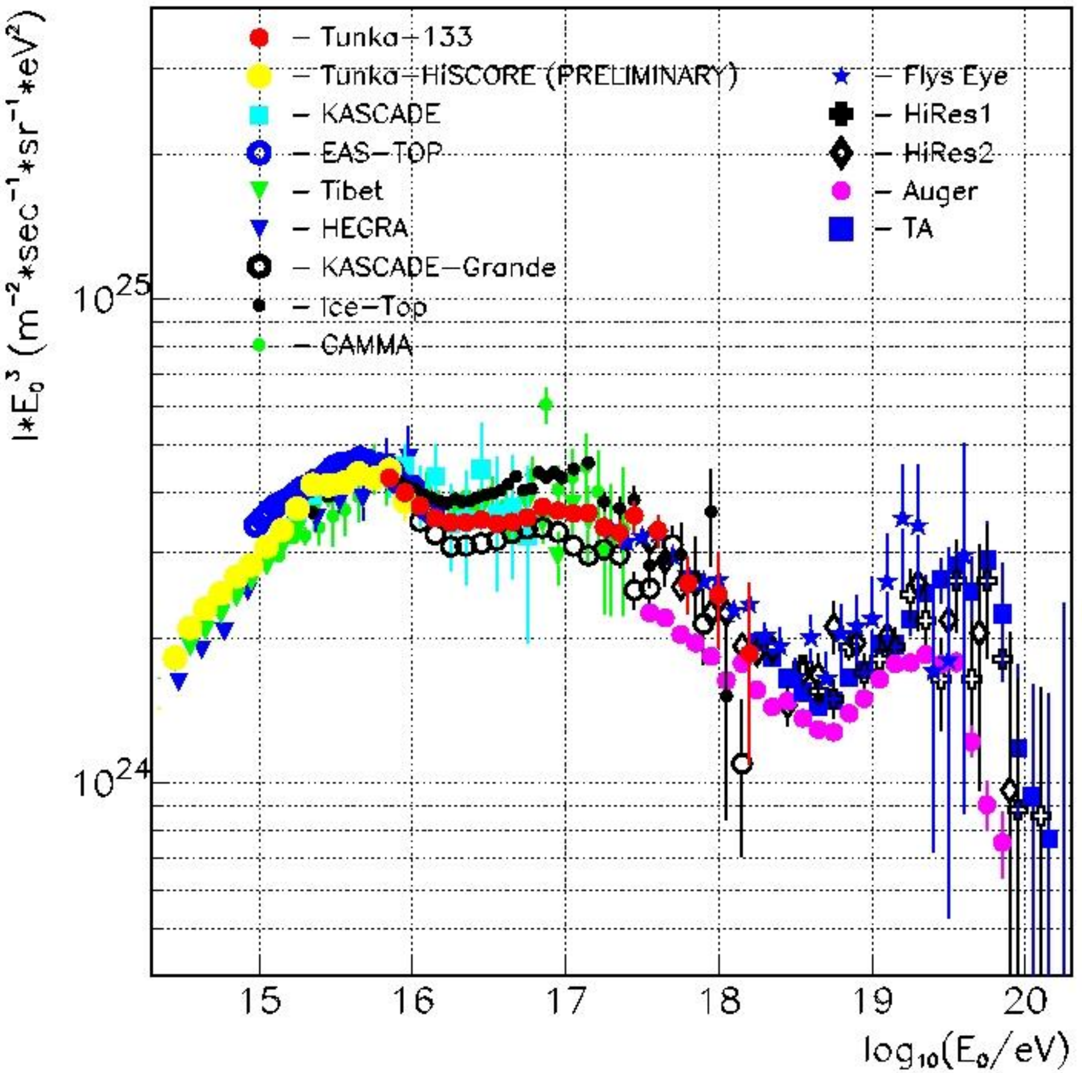
Shower front



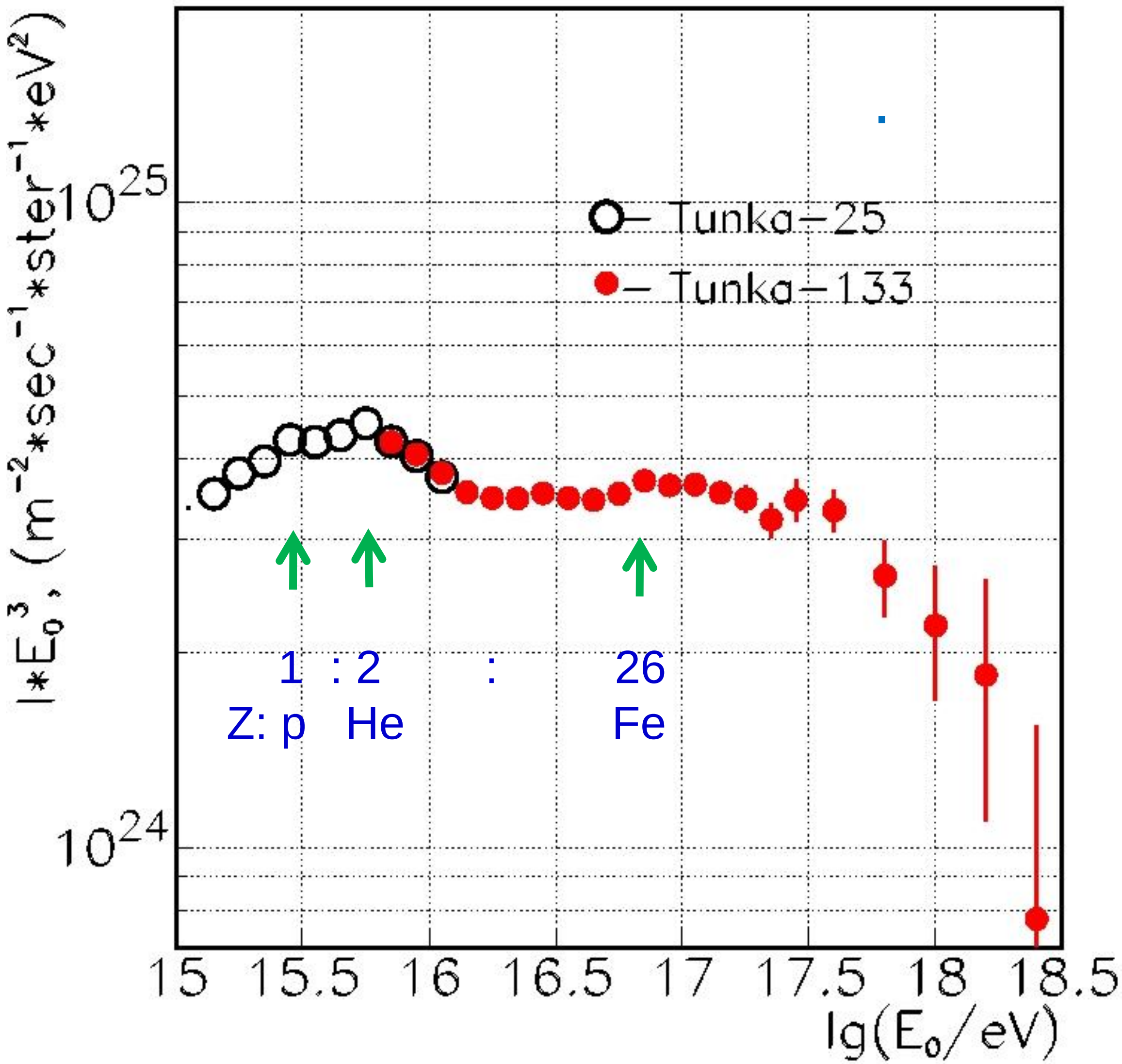
Spectrum Structure in the Knee



Energy Spectrum: Comparison of Experiments



Energy spectrum: Sharp features reflecting the termination energy for different elemental groups at one of the sources

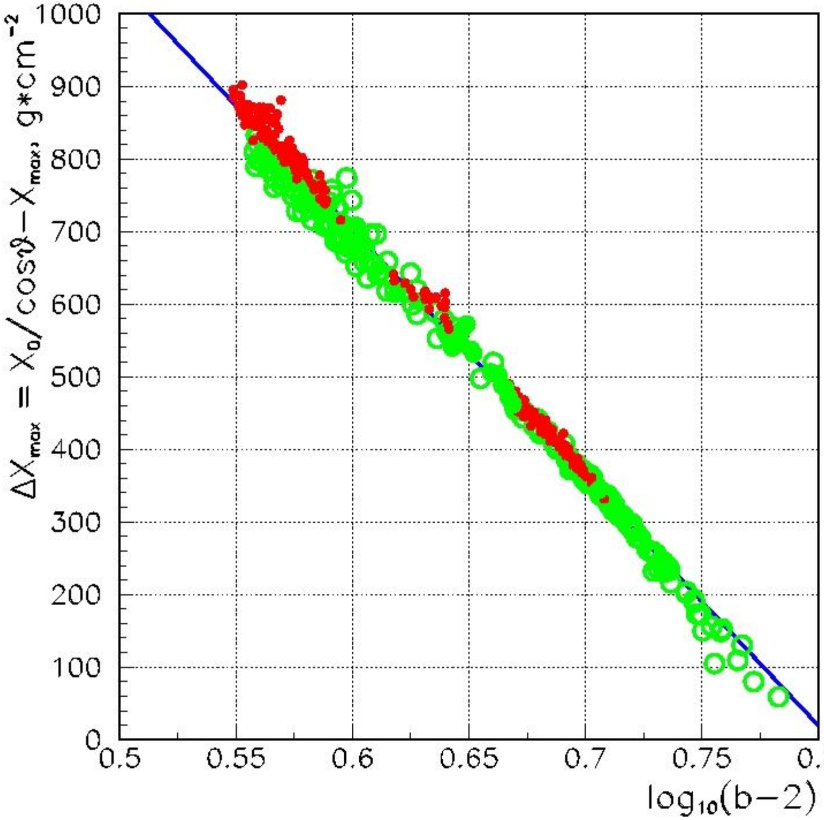


X_{max} method of mass analysis

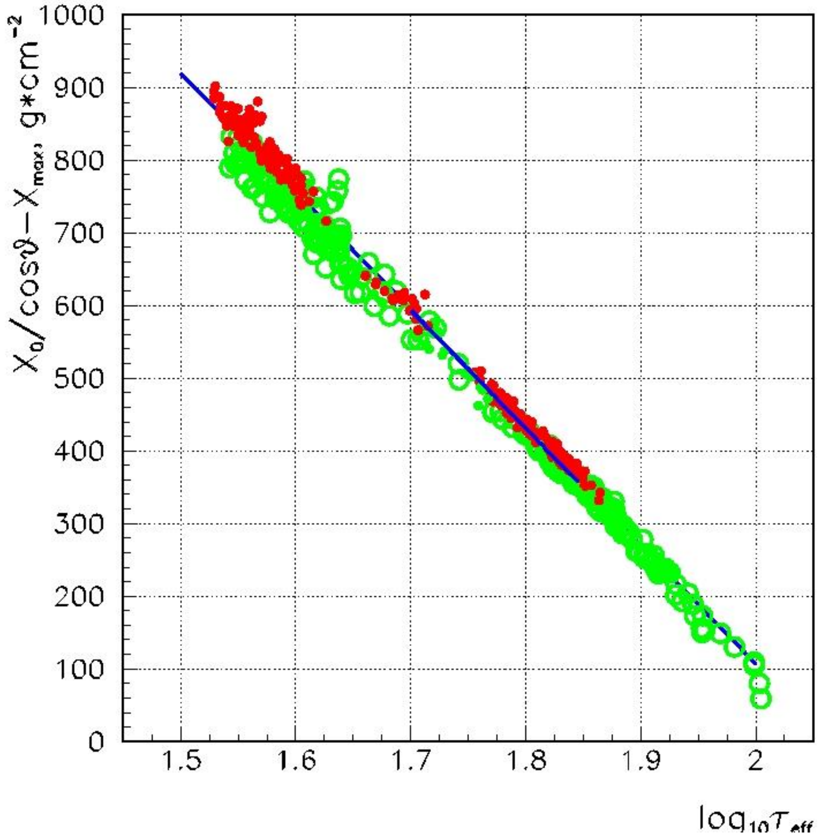
CORSIKA

(**Correlations are model, energy, zenith angle and composition independent**)

ΔX_{max} vs. b_A (ADF steepness)



ΔX_{max} vs. $\tau_{eff}(400)$

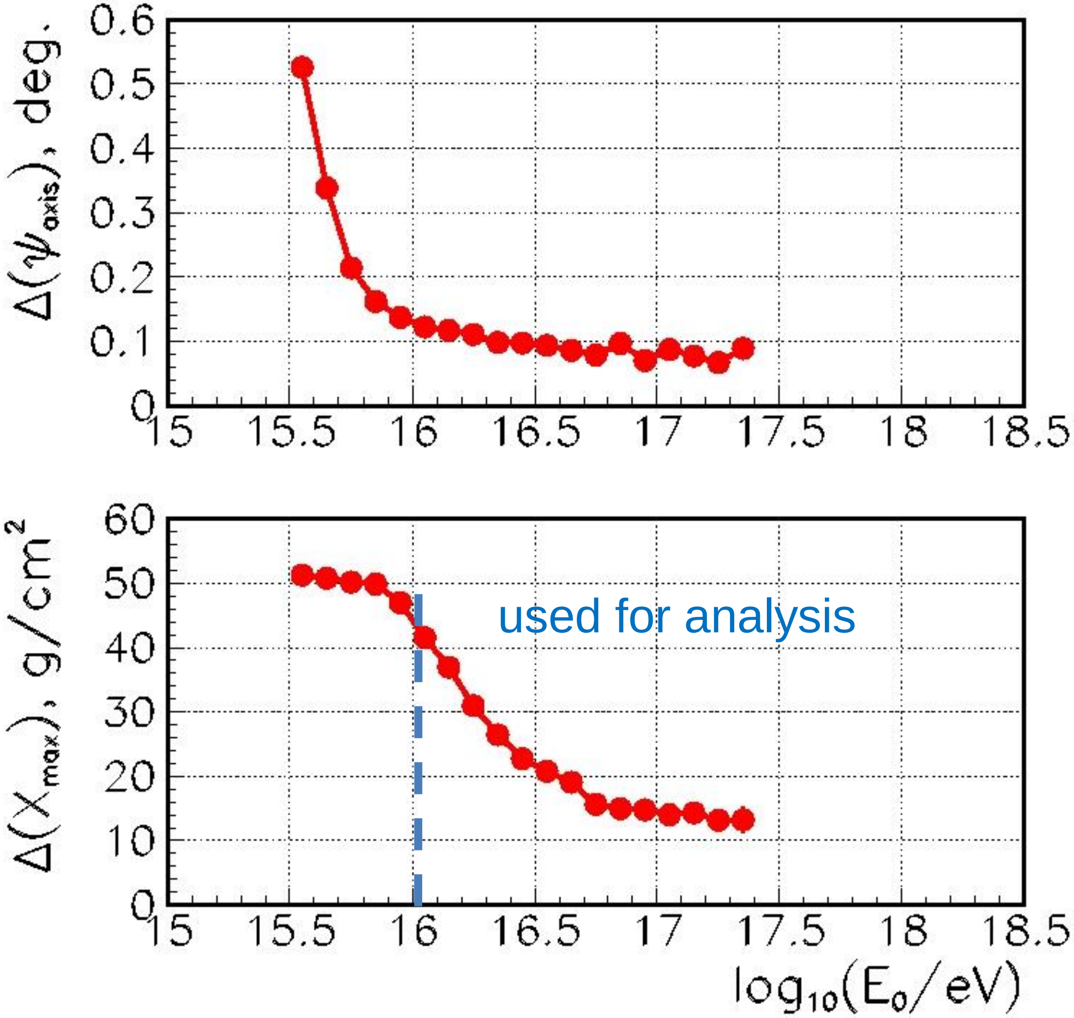


~ 500 events – 10^7 GeV < E_0 <10^8 GeV, θ = 0°, 30°, 45°
green – p, red – Fe

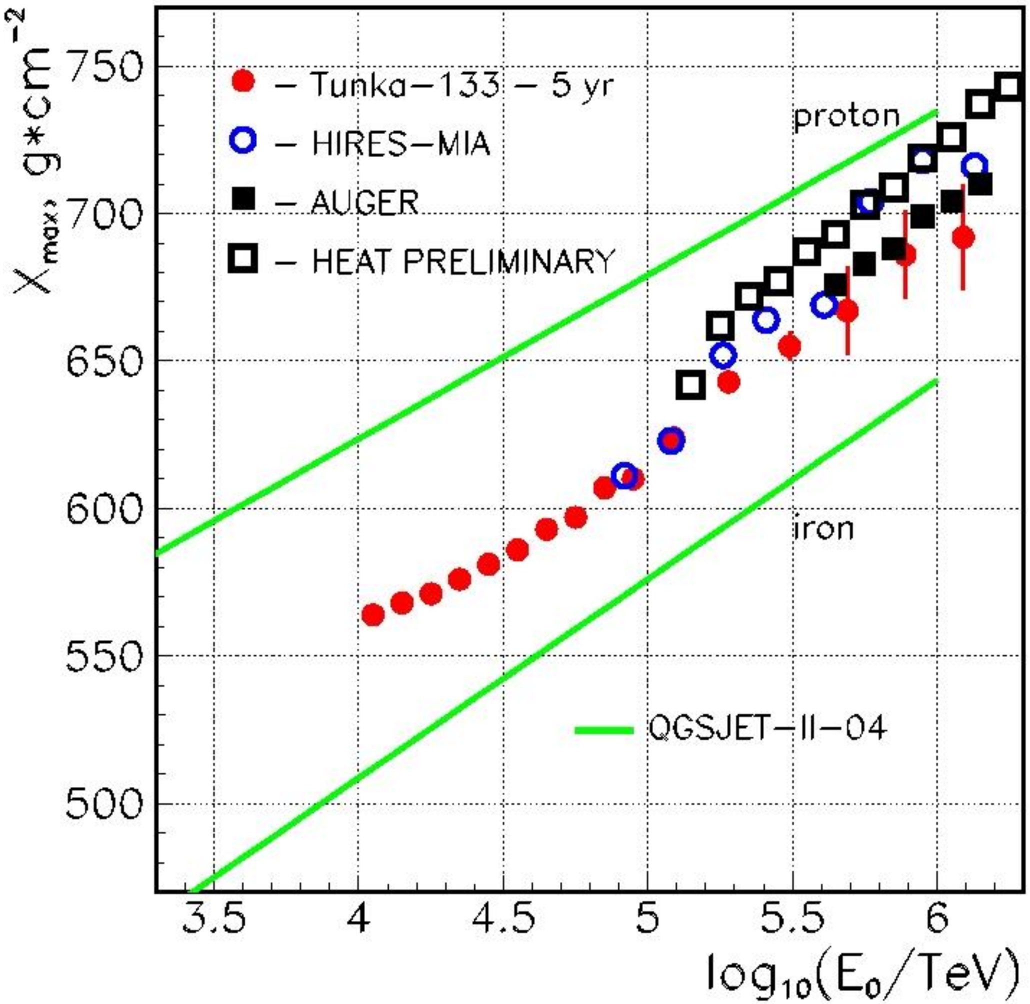
EAS arrival direction and X_{max} accuracy:

Chessboard method:

Error=Difference/√2

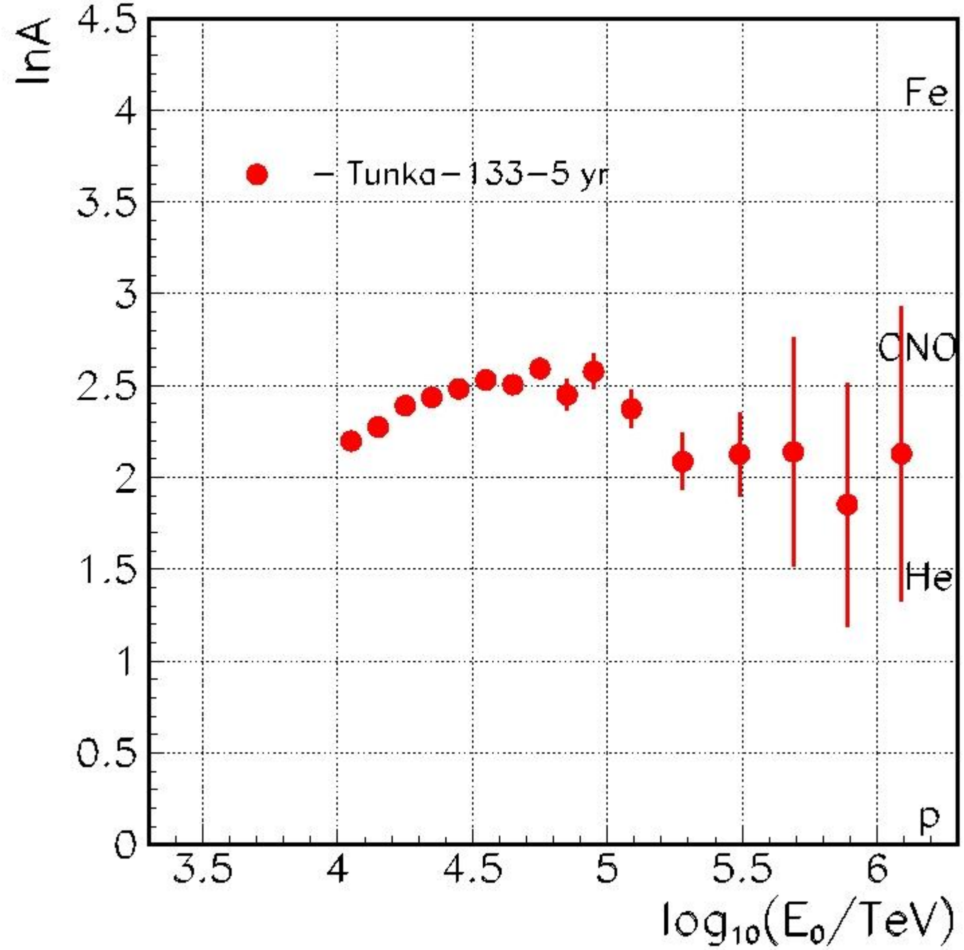


<X_{max}> vs. E_0

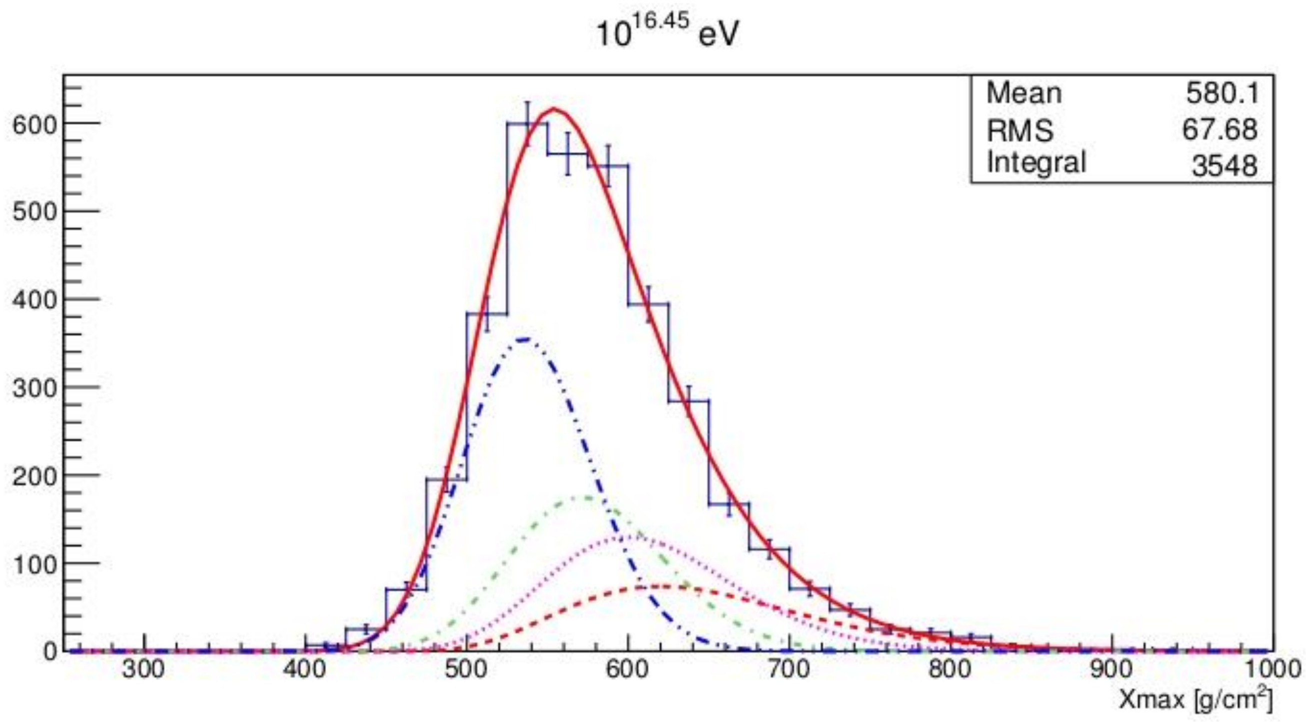


X_{max}, $g*cm^{-2}$
750
700
650
600
550
500
– Tunka-133 – 5 yr
– HIRES-MIA
– AUGER
– HEAT PRELIMINARY
proton
iron
QGSJET-II-04
3.5
4
4.5
5
5.5
6
$\log_{10}(E_0/TeV)$

EXPERIMENT: MEAN <lnA> vs. E_0

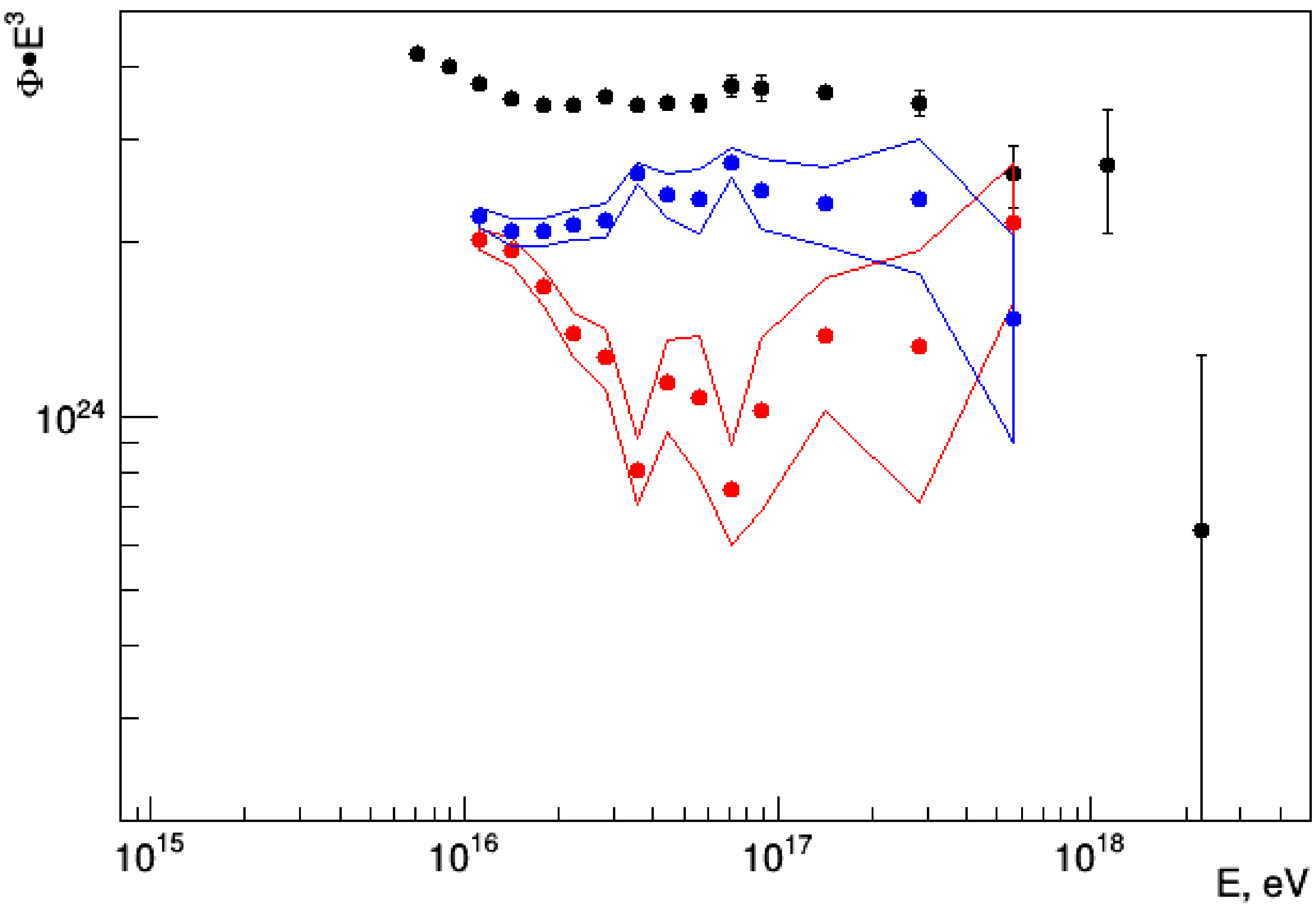


ANALYSIS of X_{max} DISTRIBUTIONS
PRELIMINARY



Fit with weighted sum of 4 group MC simulated distributions: Fe, CNO, He, p

Spectra of light (p+He) and heavy (all other) CR components (2015) PRELIMINARY



Further perspectives

To expand the energy range of mass analysis:

1. $10^{15} – 10^{16}$ – Tunka-HiSCORE-28 – adapting of Tunka-133 methods to the new array. Results will appear next (2016) year.

2. $10^{17} – 10^{18}$ – Total time duty measurements by Tunka-Rex and Tunka-Grande. Rate of data acquisition will be 20 times higher than for Cherenkov light experiment (4000 events/year). The first results are expected at the next (2016) year.

Tunka-REX

EAS energy measurement by the radio emission

Tunka-REX

Cerenkov light trigger (from Tunka-133). Independent EAS parameters reconstruction:

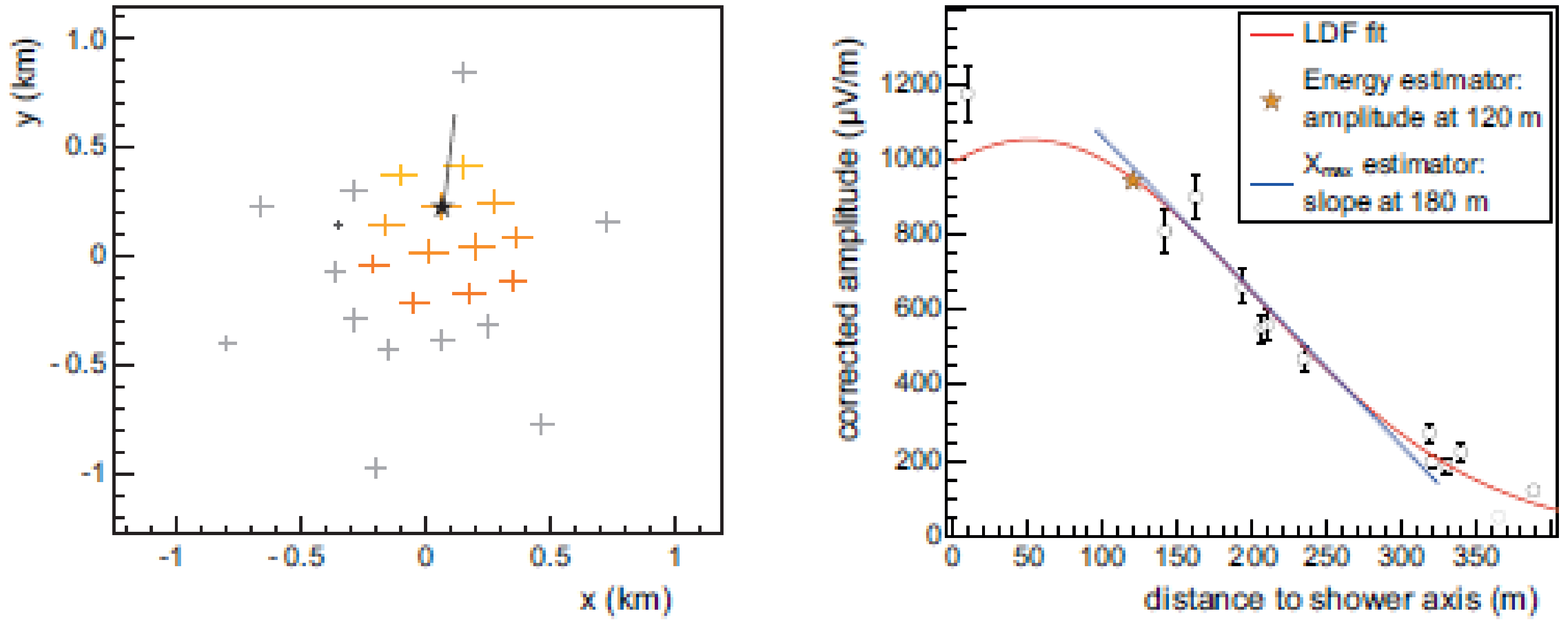
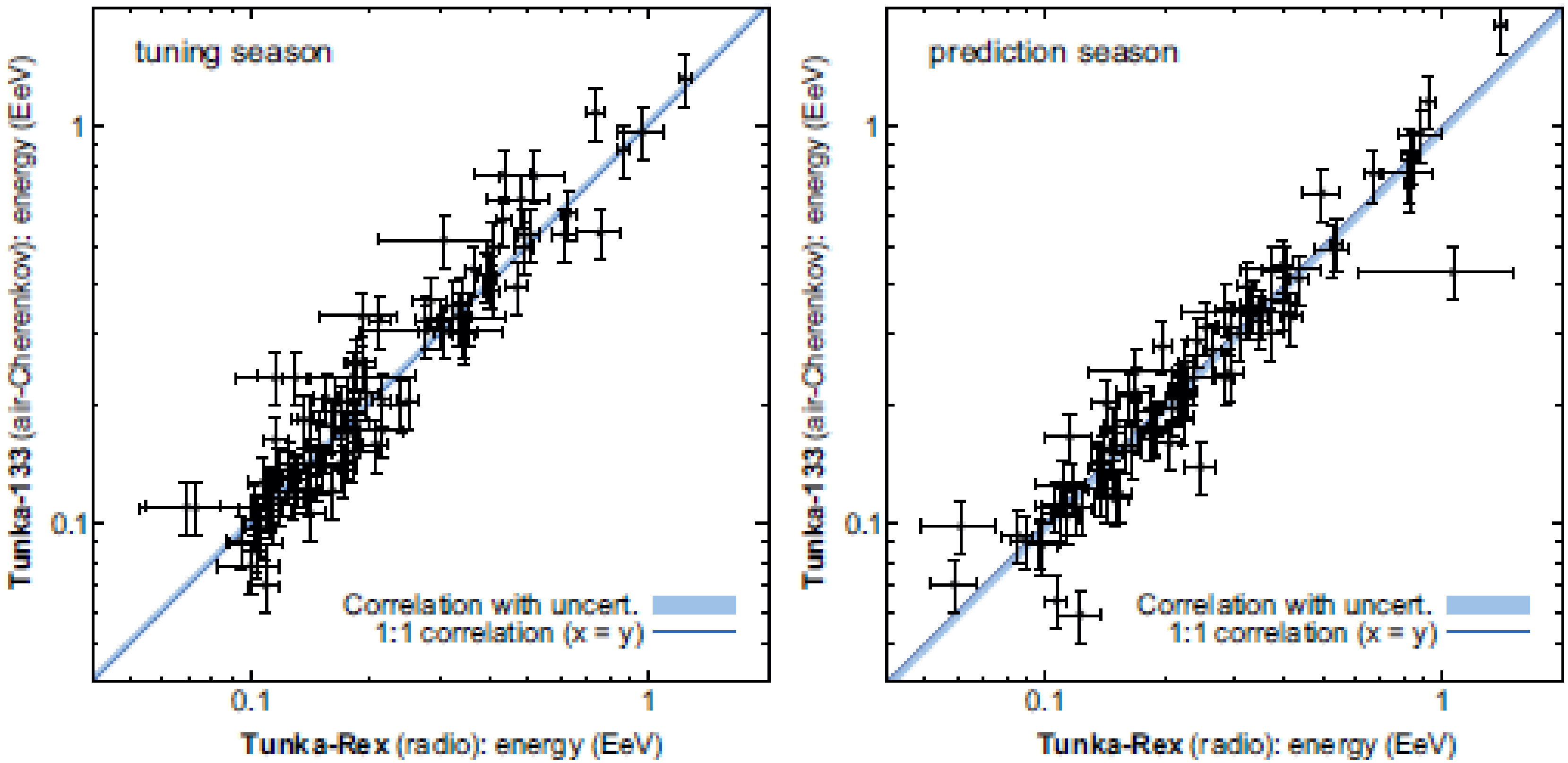


Figure 5. Example event. Left: footprint with arrival time in color code. Light gray crosses are stations below the signal-to-noise threshold. The small dark-gray cross is a station without measurement for this event. The star and the line indicate the reconstructed shower core and direction. Right: Lateral distribution after asymmetry correction and fitted LDF. The light gray point is a station below threshold.

Tunka-REX

Correlation of the shower energy reconstructed with Tunka-Rex radio and Tunka-133 air Cherenkov measurements:



$$\frac{E_{CL} - E_{Radio}}{E_{CL}} = (17 \pm 2)\ \%$$

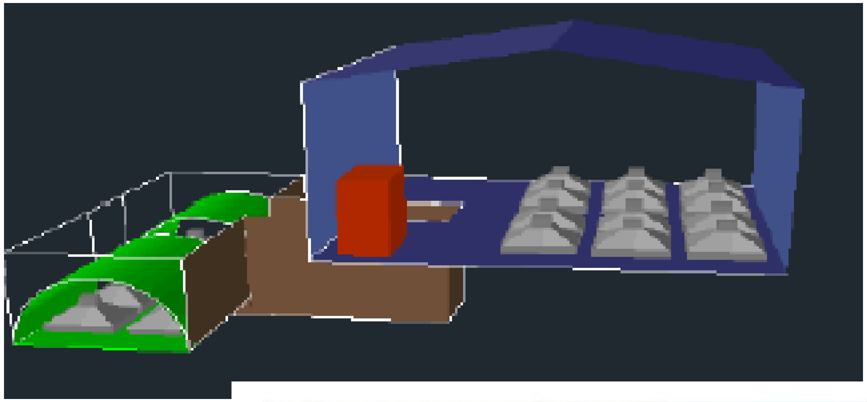
Tunka-Grande

Scintillation detectors for EAS electron and muon measurements.

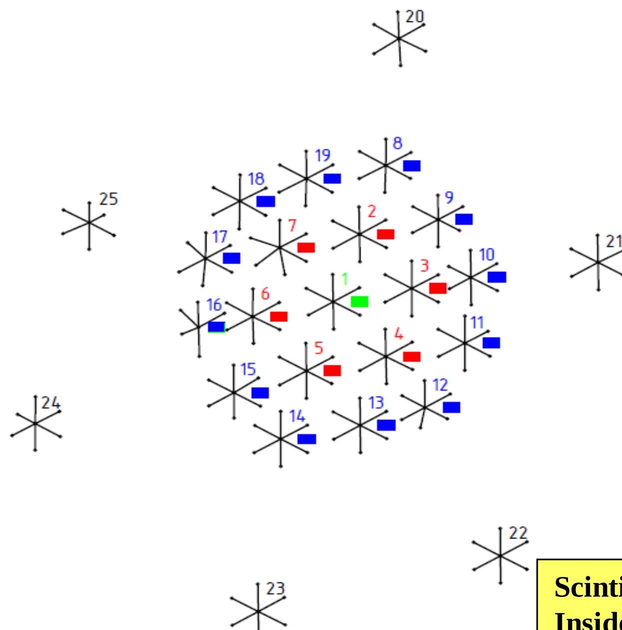
(Former EAS-TOP and KASCADE-Grande detectors)

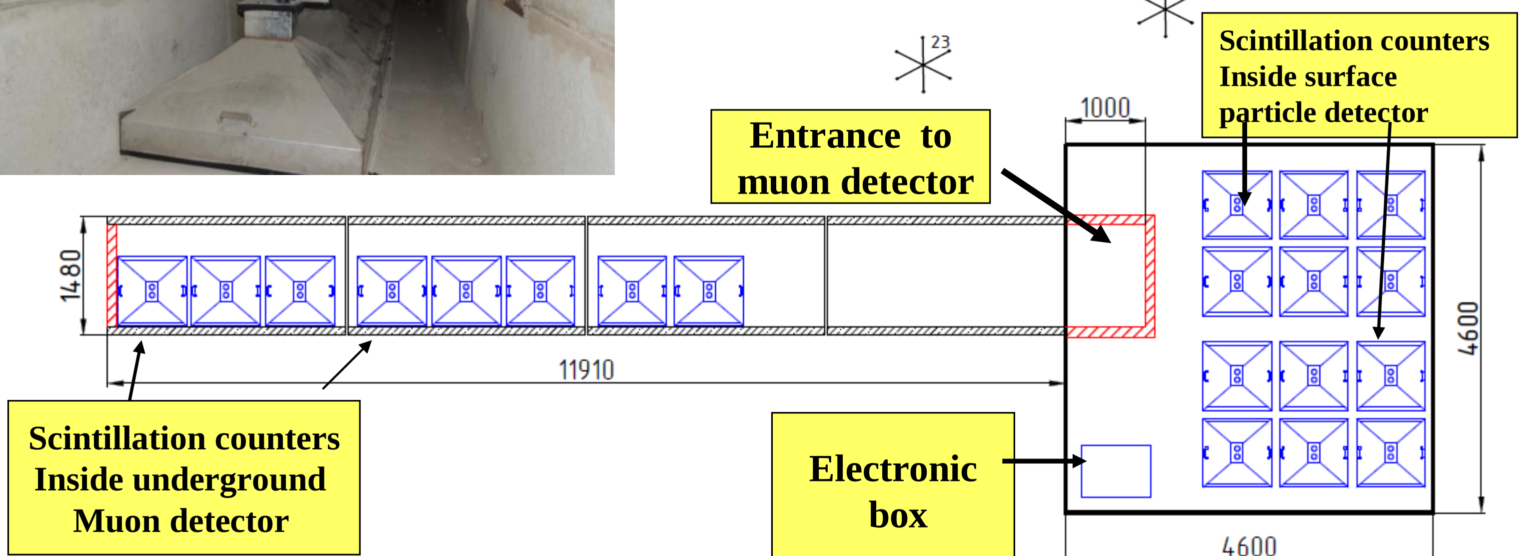
Tunka-Grande:
Transportation of SD to Tunka Valley

Tunka-Grande:
The first muon detector



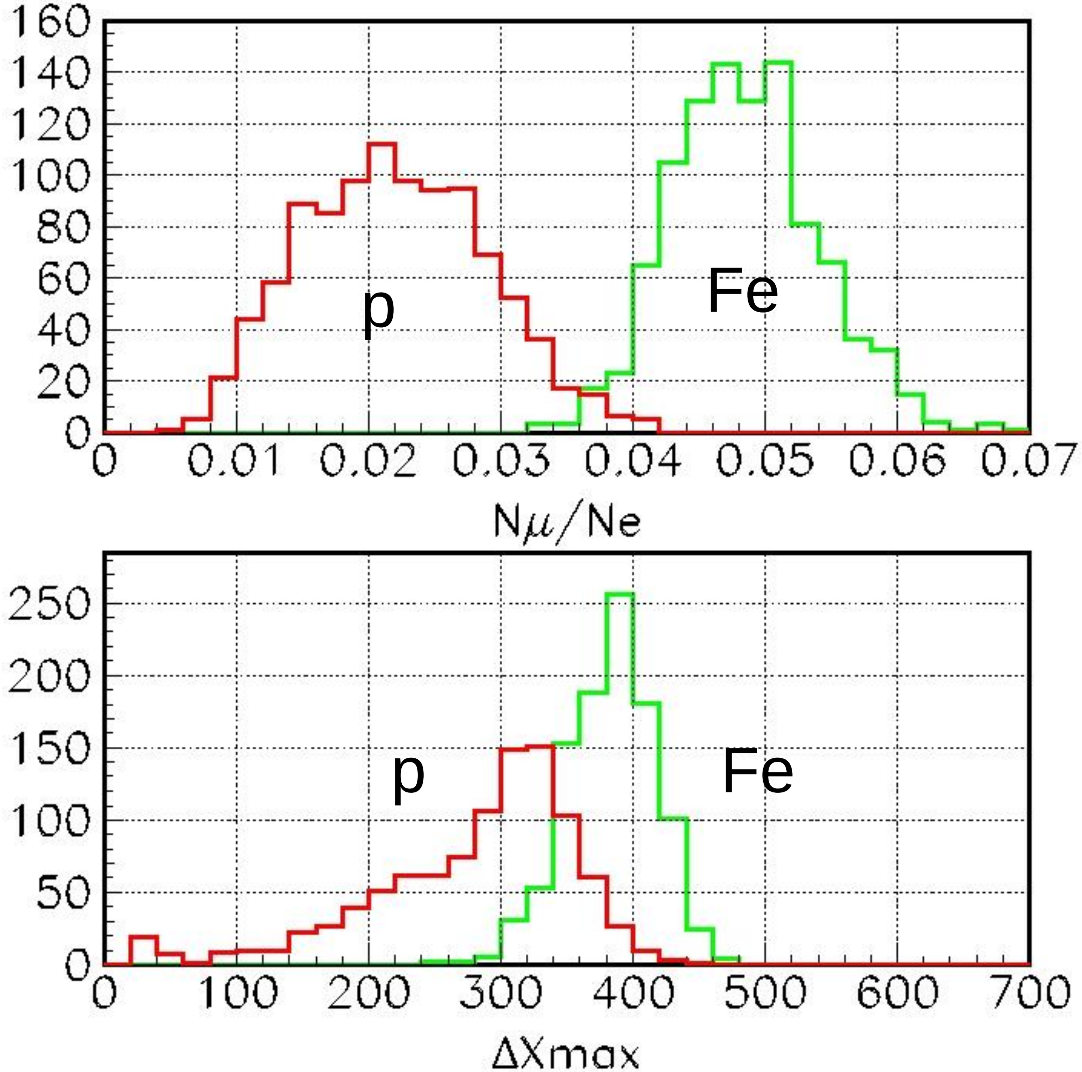
Tunka-Grande: Surface and underground detectors of EAS electrons and muons





AIRES simulation 10^{17} eV

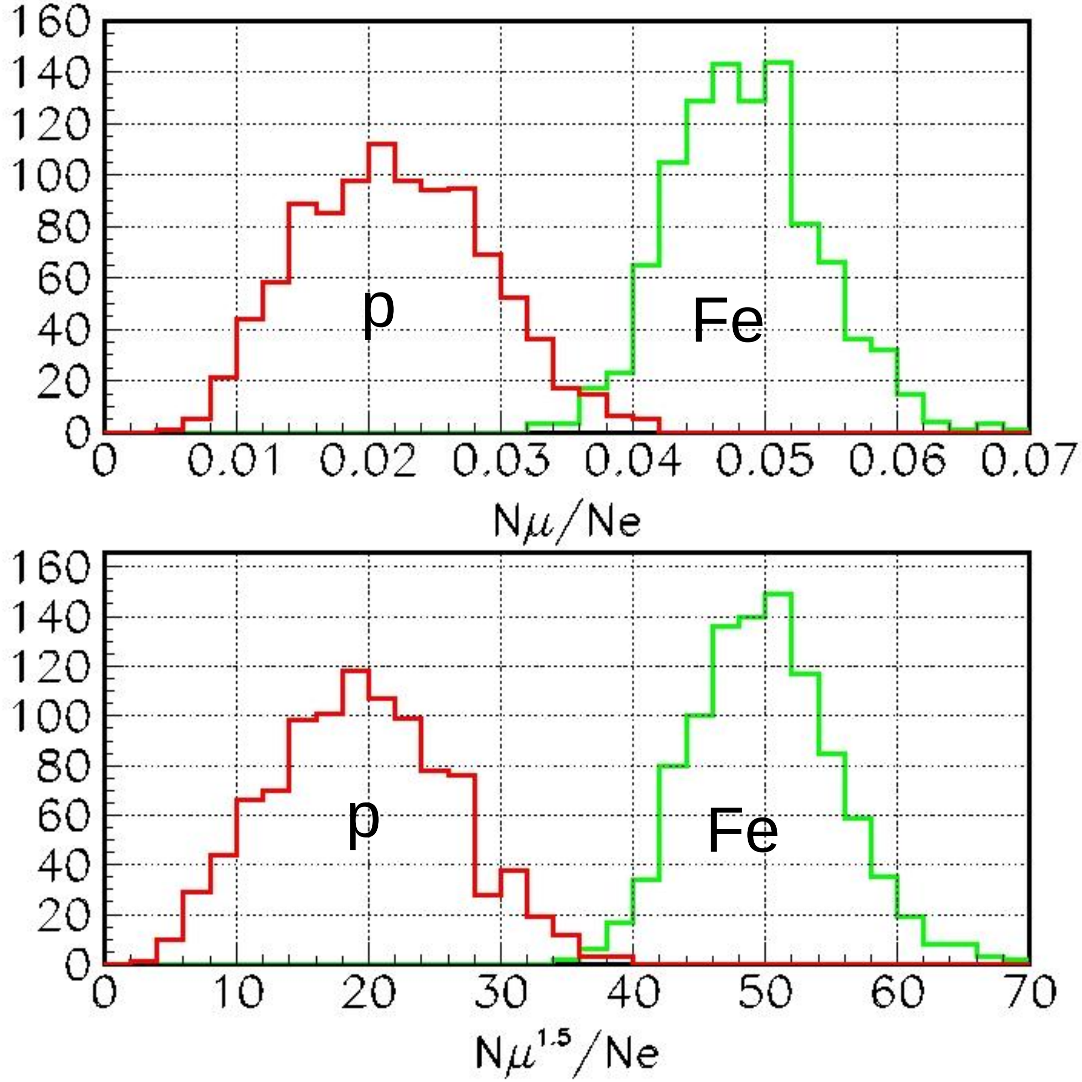
Mass resolution better than for X_{max} method:



AIRES simulation

$E_0 = 10^{17}$ eV, $\theta = 0°$

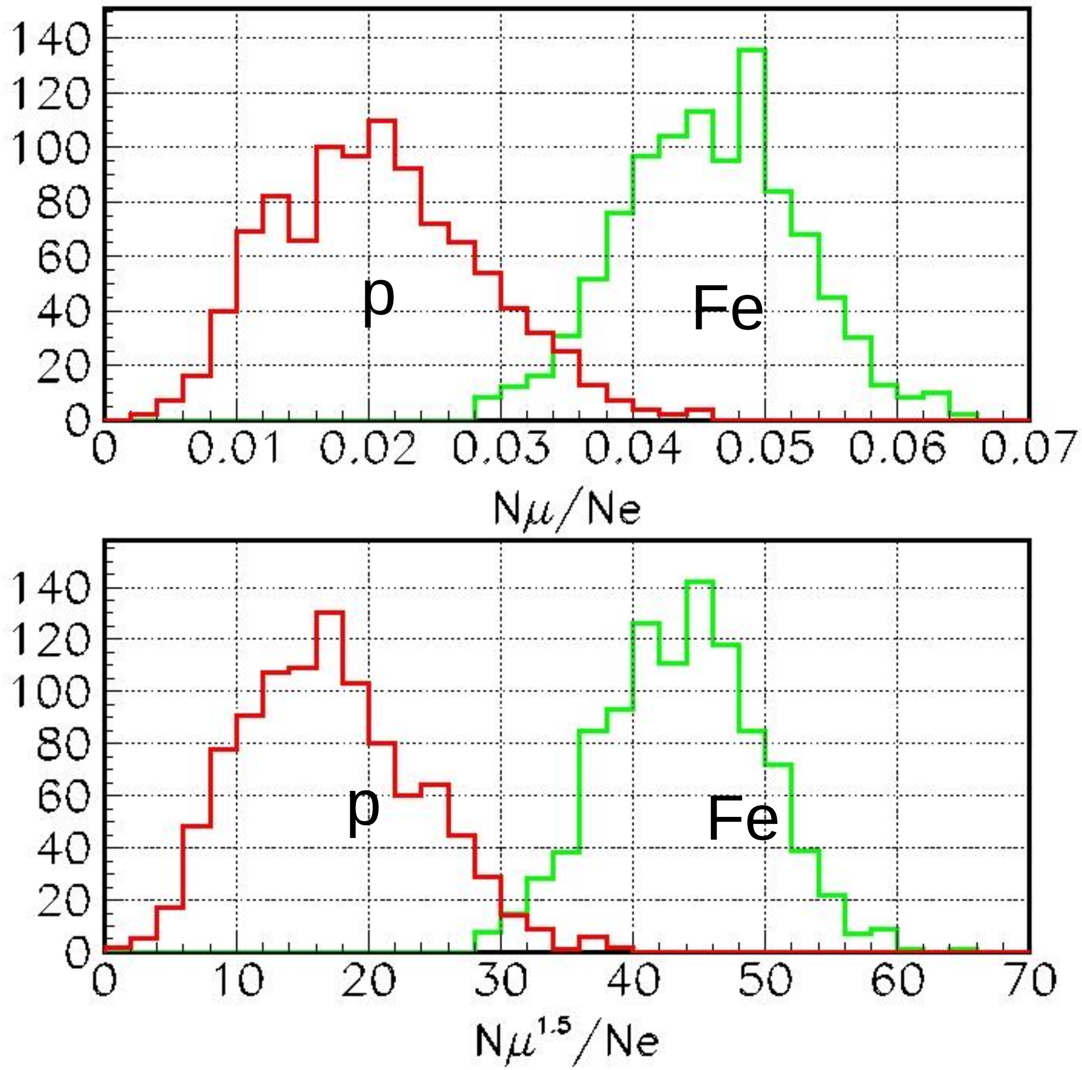
Improvement of mass resolution: Change of $\mathbf{N_\mu}$ to $\mathbf{N_\mu^{1.5}}$



AIRES simulation

$E_0 = 10^{17}$ eV, $\theta = 30°$

Improvement of mass resolution: Change of $\mathbf{N_\mu}$ to $\mathbf{N_\mu^{1.5}}$



CONCLUSIONS

1. **Composition changes to heavy from 10^{16} to $3 \cdot 10^{16}$ and changes back to light in the range 10^{17} – 10^{18} eV, but the variations are less than it seemed about 5 years ago.**

2. **The X_{max} obtained at Tunka-133 do not contradict to that of HiRes-MIA and Auger data. But the new data from HEAT-AUGER shows more light composition (pure protons) before 10^{18} eV**

3. **Possible double structures in the first and the second knees as well as the possible variations of composition has to be investigated with new statistics from Tunka-HiSCORE-28 and Tunka-Grande arrays.**

4. **We hope to get the separate spectra of light and heavy nuclei at the energy range 10^{17} – 10^{18} eV. The results are expected next year (2016).**

Thank you!