Tunka-133: status, all particle spectrum and future plans

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On behalf of the Tunka Collaboration

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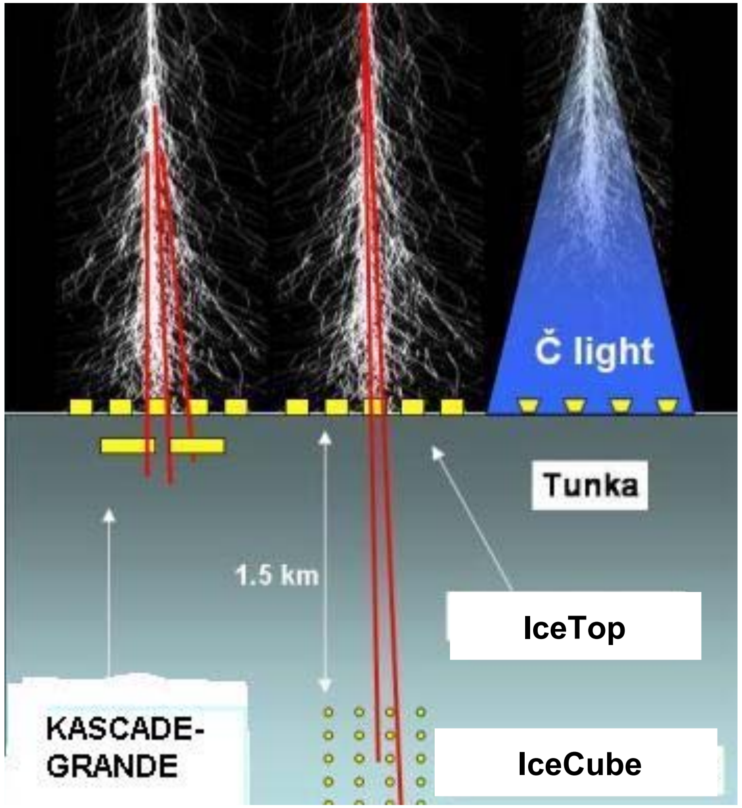
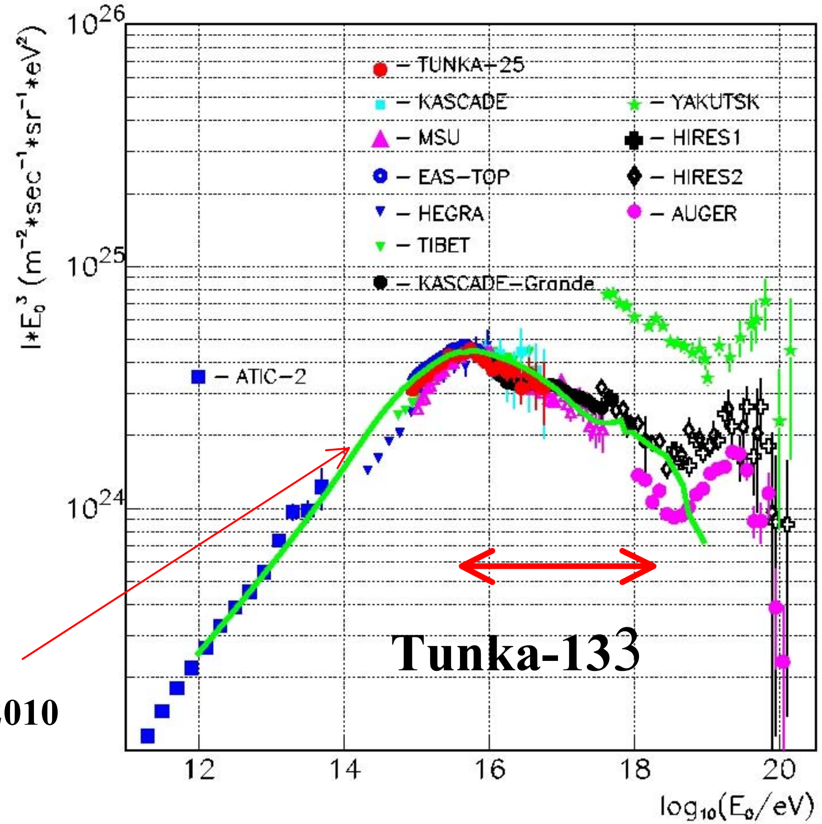
Search for the Acceleration Limit of Galactic Sources

- Energy range 10^{16}-10^{18} eV demands:
- 1 km² with spacing smaller than that at Auger
- complementary techniques

- KASCADE-Grande *terminated*
- IceTop/IceCube ***in operation***
- **Tunka-133 (calorimetric)** ***in operation***
- NEVOD-DÉCOR ***in operation***
-***GAMMA*** ***in operation***
- Auger low energy extension *80% ready*
- *HiSCORE* *planned*
- ***LHAASO*** *planned*

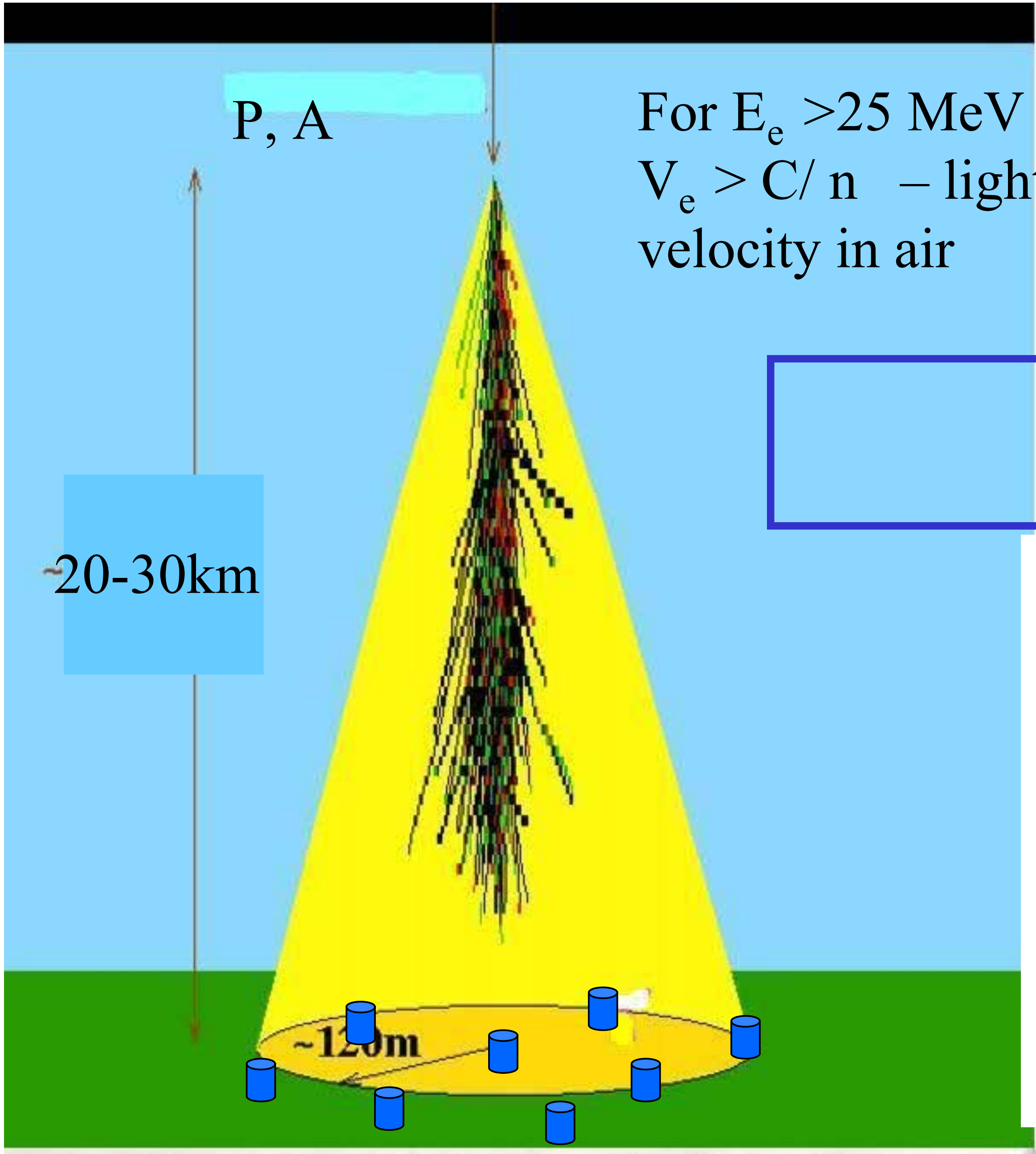




V.Ptuskin and
V.Zirakashvili,2010

OUTLINE

1. Non-imaging Air Cherenkov Technique
2. Tunka-133.
3. Energy spectrum.
4. Mass composition.
5. Plan for the Tunka-133 upgrading.

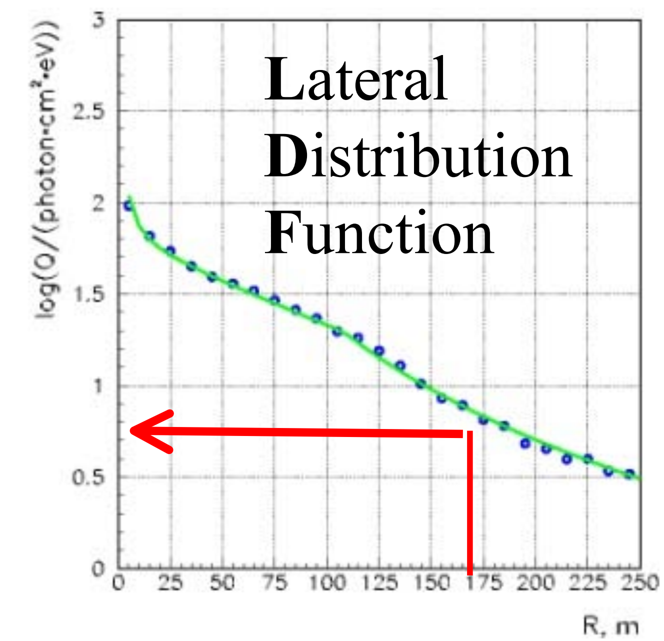


For E_e >25 MeV
V_e > C/ n – light velocity in air

Atmosphere as a huge calorimeter

Cherenkov light

Q **tot** **~** **E**



Photons detectors

E (PeV) = 0.4 Q(175) ph· ev^{-1} cm^{-2}

Advantage of Cherenkov Technique:

1. Good energy resolution - up to 15%
2. Good accuracy of X_{max} - 20 -25 g/cm^2
3. Good angular resolution - 0.1 – 0.3 deg
4. Low cost – Tunka-133 – 1 km^2 array:
   $0.5\ 10^6$ Eur (construction and deployment)

\+

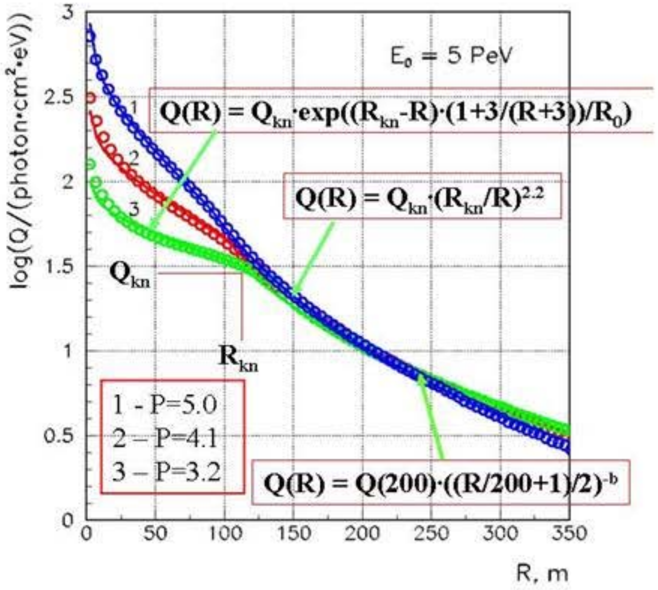
   $0.2\ 10^6$ Eur(PMTs)

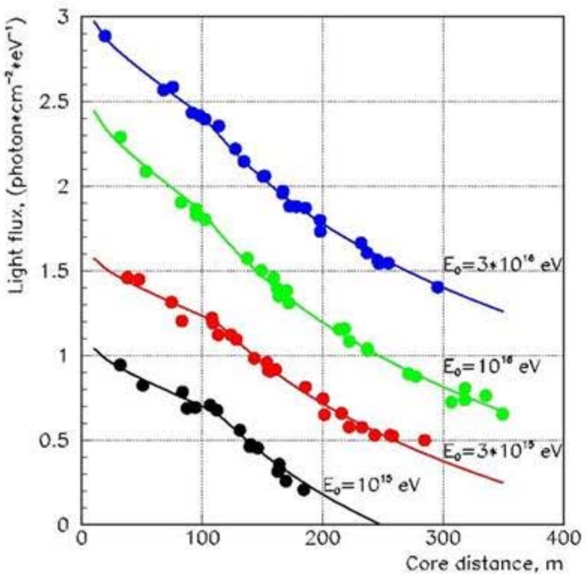
100 km^2 array - 10^7 Eur

Disadvantage:

1.Small time of operation (moonless, cloudless nights) – 5-10%

Usage of Cherenkov Light Lateral Distribution Function (LDF) for the Reconstruction of EAS Parameters





LDF from CORSIKA

Experimental data fitted with LDF

Q(R) = F(R, p) (only one parameter)

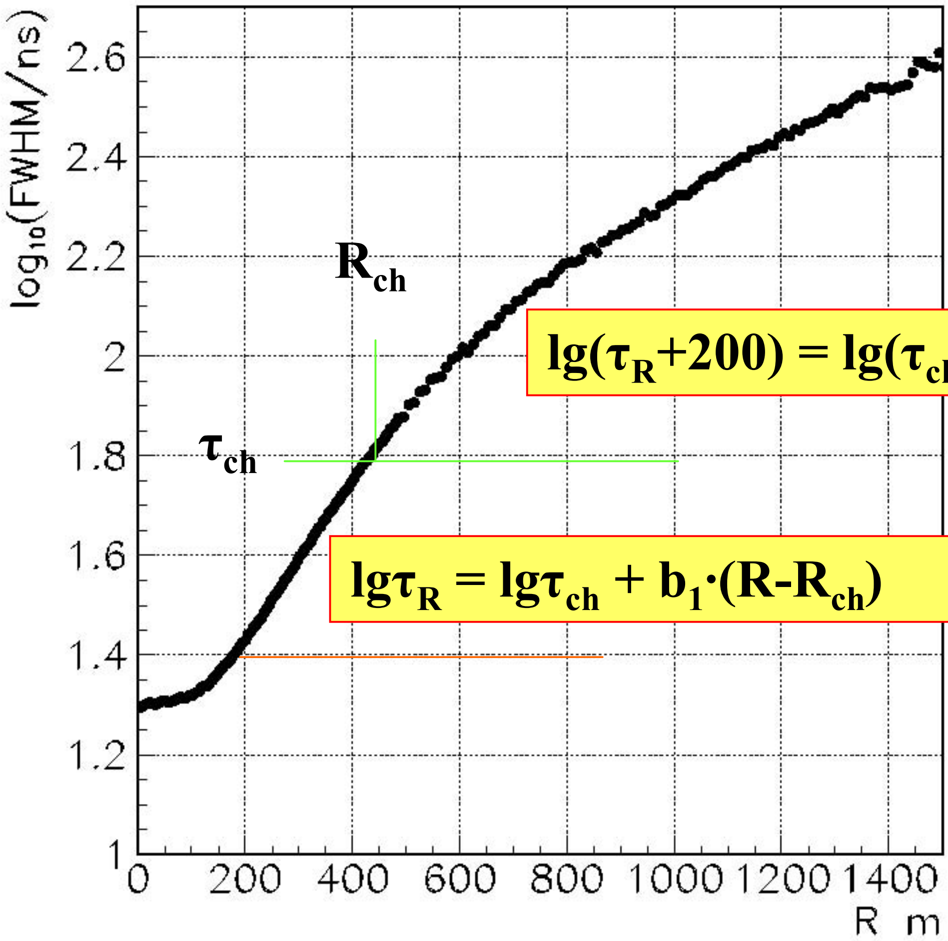
↑

steepness of LDF →

light flux at core distance 175 m - **Q_{175} ~ Energy**

P = Q(100)/Q(200) → X_{max}

CORSIKA:
WDF(Width Distant Function) fitting



τ_R=FWHM(R)

WDF has a single variable - FWHM(400)

$b_1=0.00196\cdot lg\tau_{400}-0.00183$

$b_2=0.000381\cdot lg\tau_{400}-0.000335$

$R_{ch}=3976-3429\cdot lg\tau_{400}+786\cdot(lg\tau_{400})^2$

$lg\tau_{ch}=lg\tau_{400}+b_1(R_{ch}-400)$, $R_{ch}<400$ m

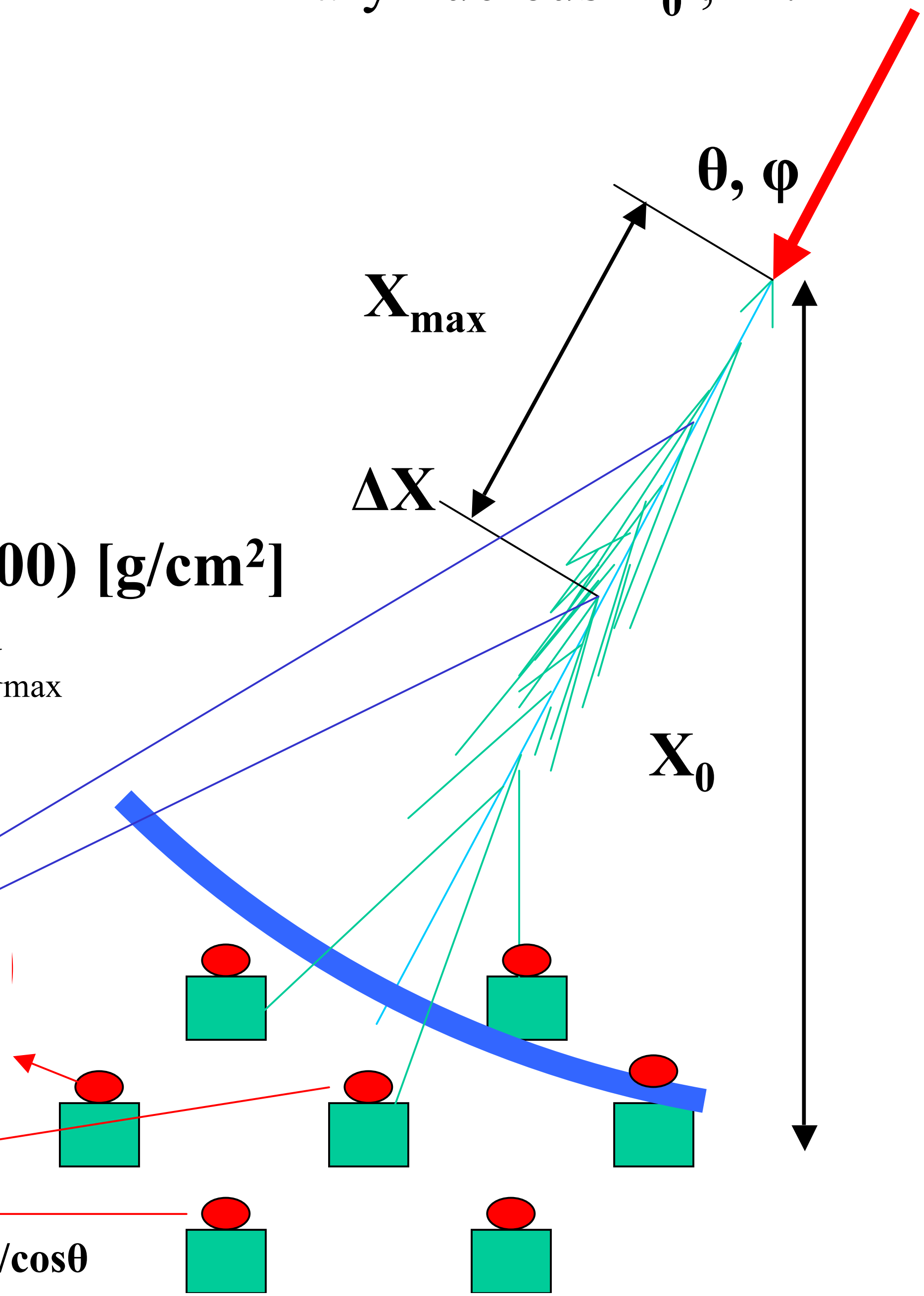
$lg(\tau_R+200)=$

$lg(\tau_{ch}+200) + b_2(R_{ch}-400)$, $R_{ch}>400$ m

X_{max}(model independent):

Two methods: LDF steepness

Pulse width



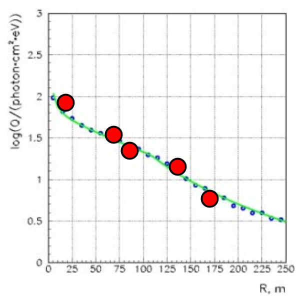
2. Pulse width:

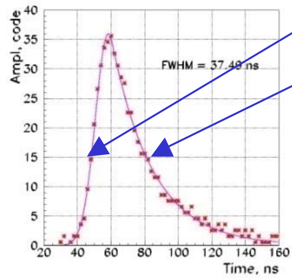
$= a - b \cdot \log(tau400)$ [g/cm²]

$\Delta X = X_0/\cos\theta - X_{max}$

1. LDF steepness P:

$H_{max} = c - d \cdot P$

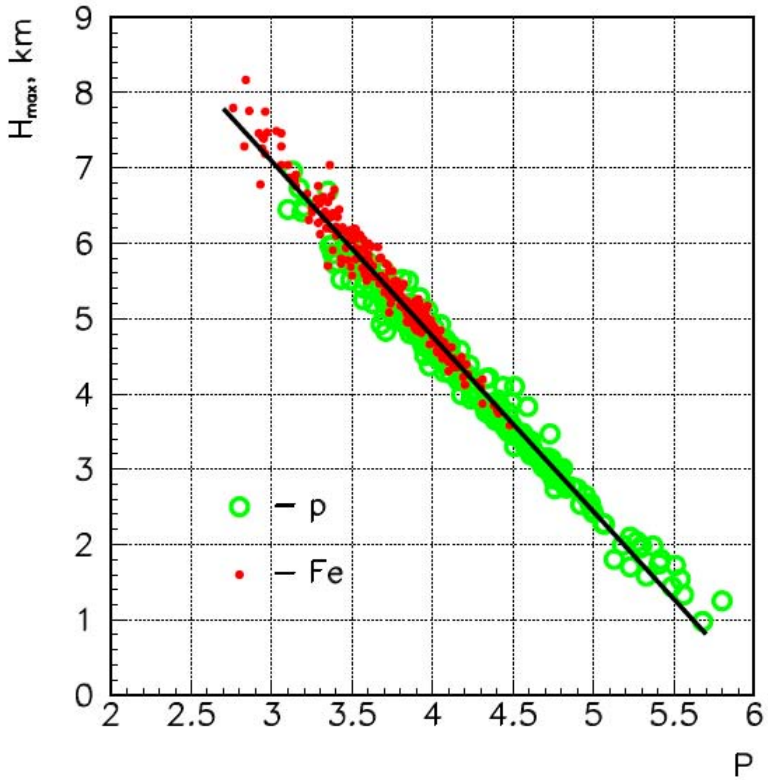




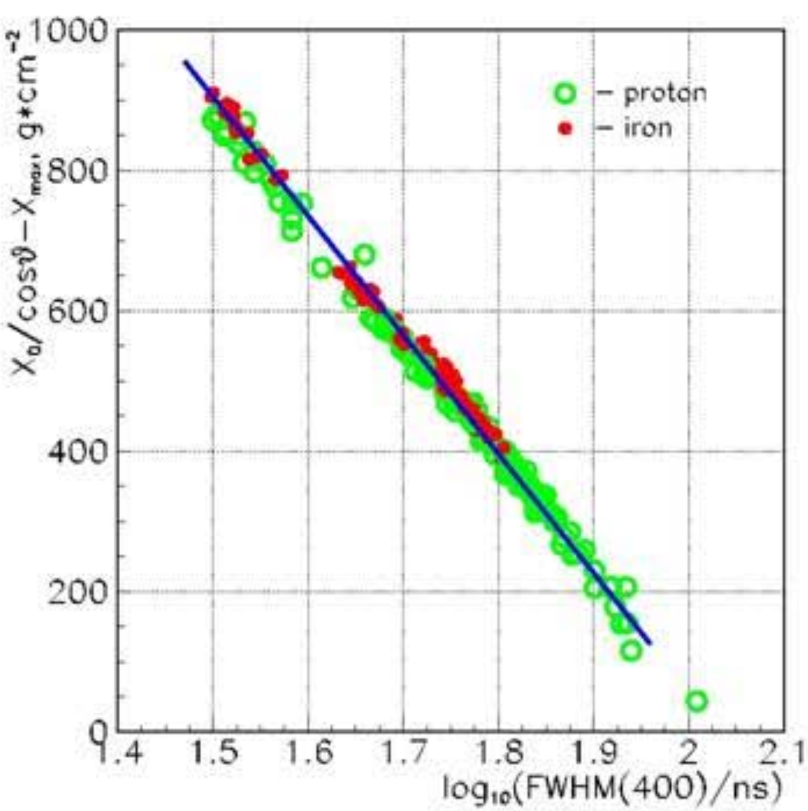
$H_{max} = (T_0/grad(T)((X_{max}\cos\theta/X_0)^{C/grad(T)} - 1) - H_{arr})/\cos\theta$

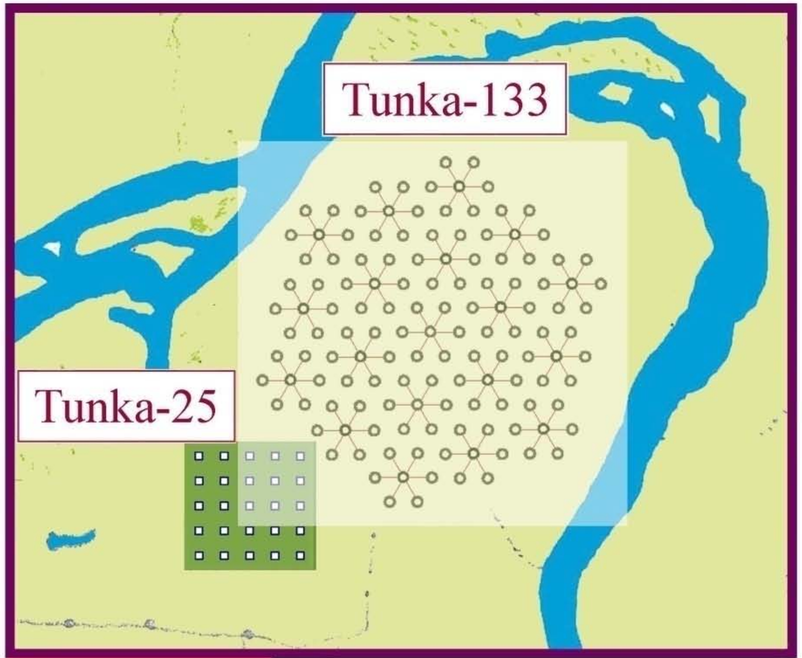
X_{max} by p (steepness) LDF

–

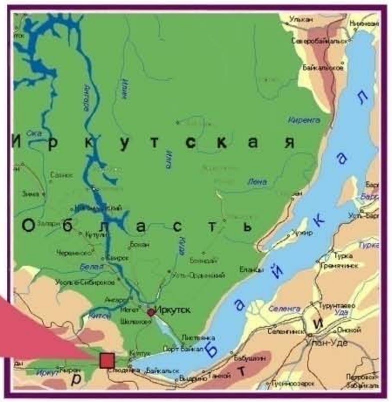


X_{max} by tau(400) WDF





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

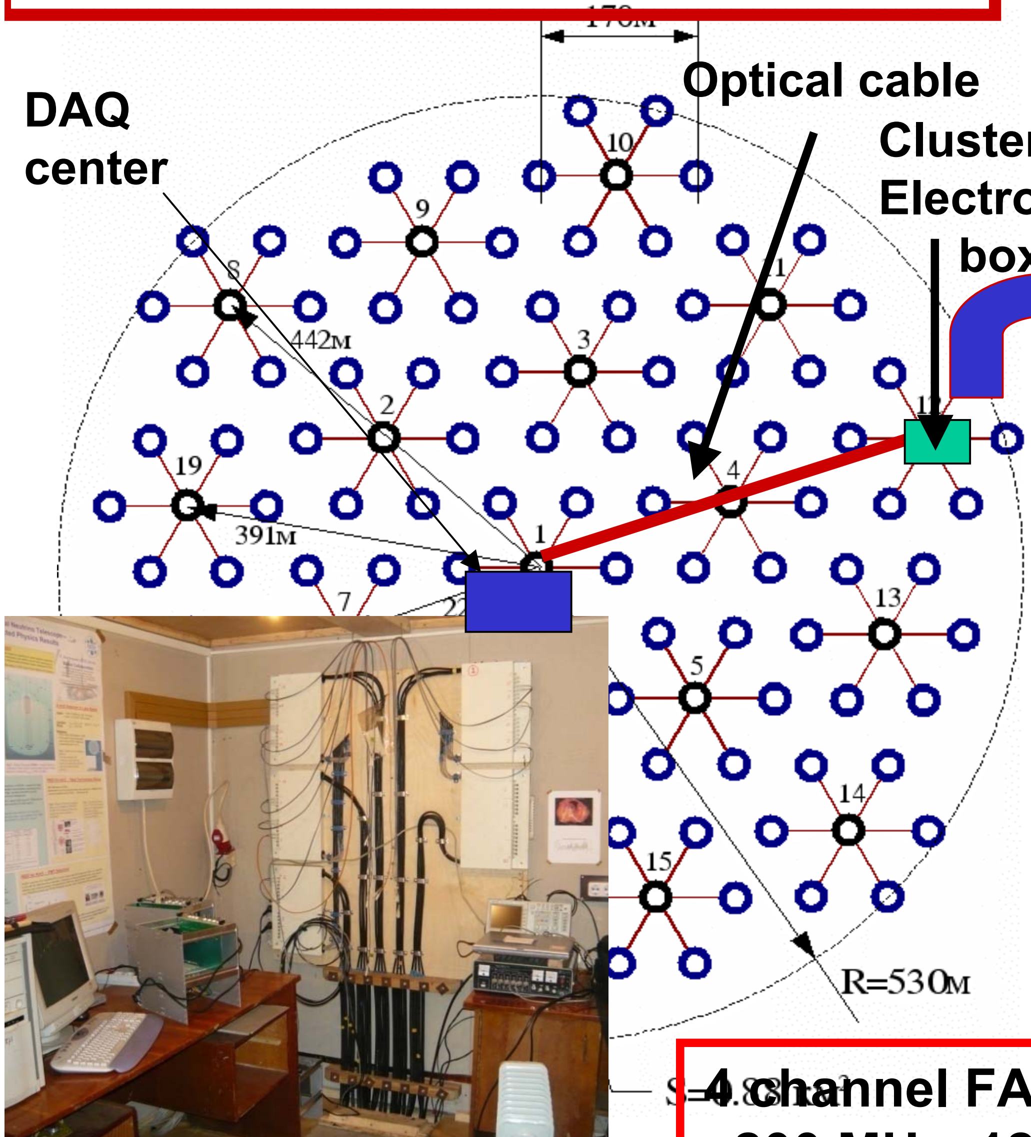


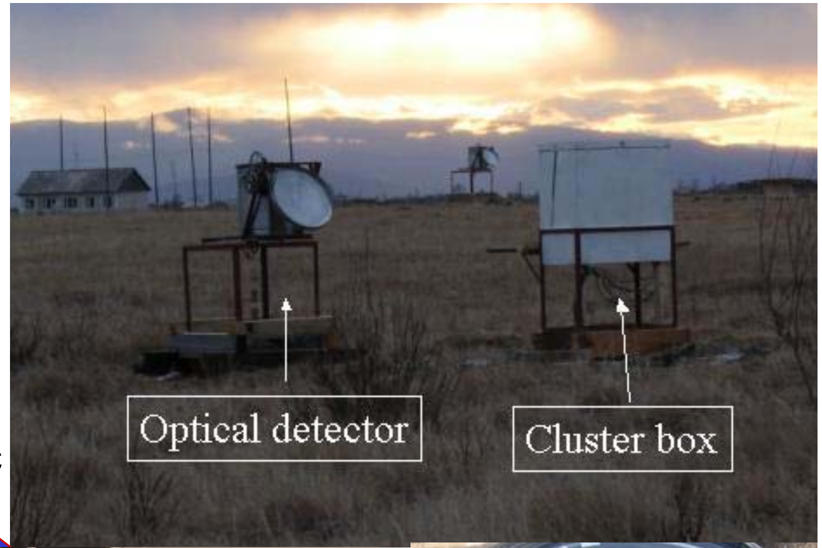
Tunka-133 – 1 km² "dense" EAS Cherenkov light array

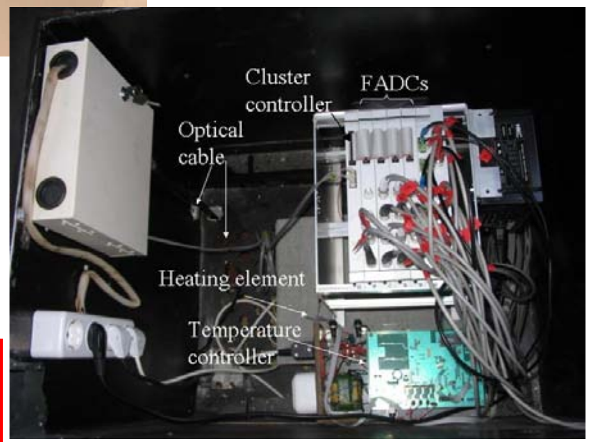
Energy threshold 10^{15} eV

Accuracy: core location ~ 10 m
energy resolution ~ 15%
$\delta X_{max} < 25$ g·cm^{-2}

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





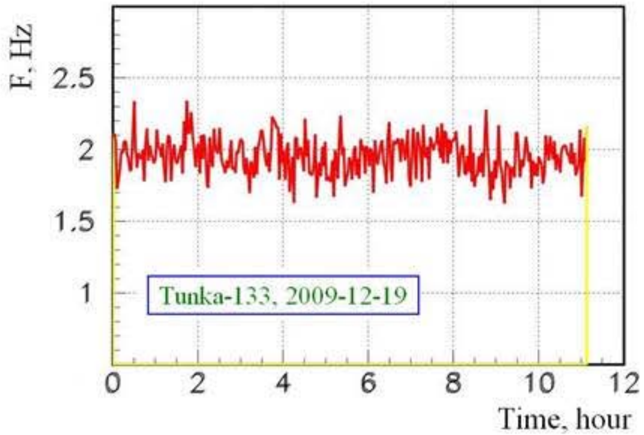


PMT
EMI 9350
Ø 20 cm

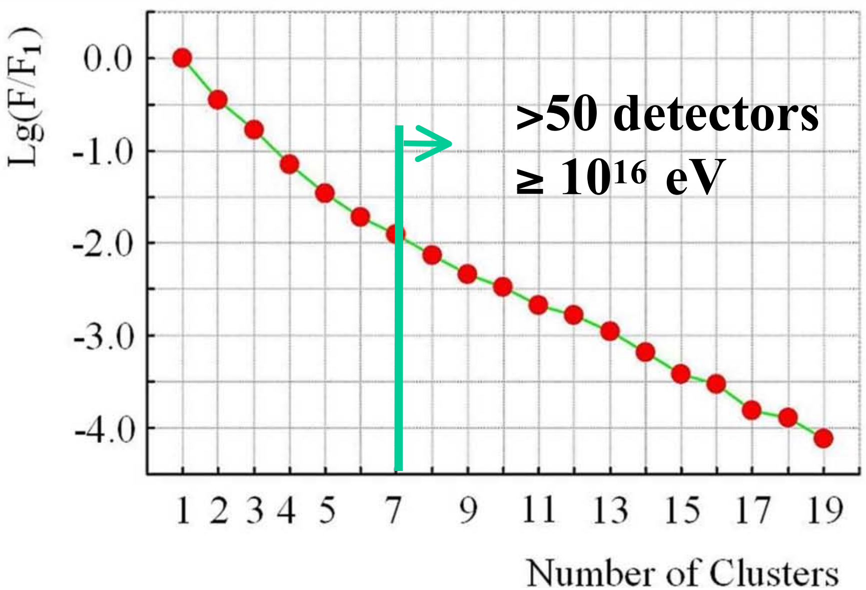
4 channel FADC boards
200 MHz, 12 bit

Two seasons of array operation

2009 - 2010 :286 hours of good weather .
2010 – 2011: 270 hours of good weather.
> $4 \cdot 10^6$ events with energy ≥10^{15} эВ.



Trigger counting rate during one night .



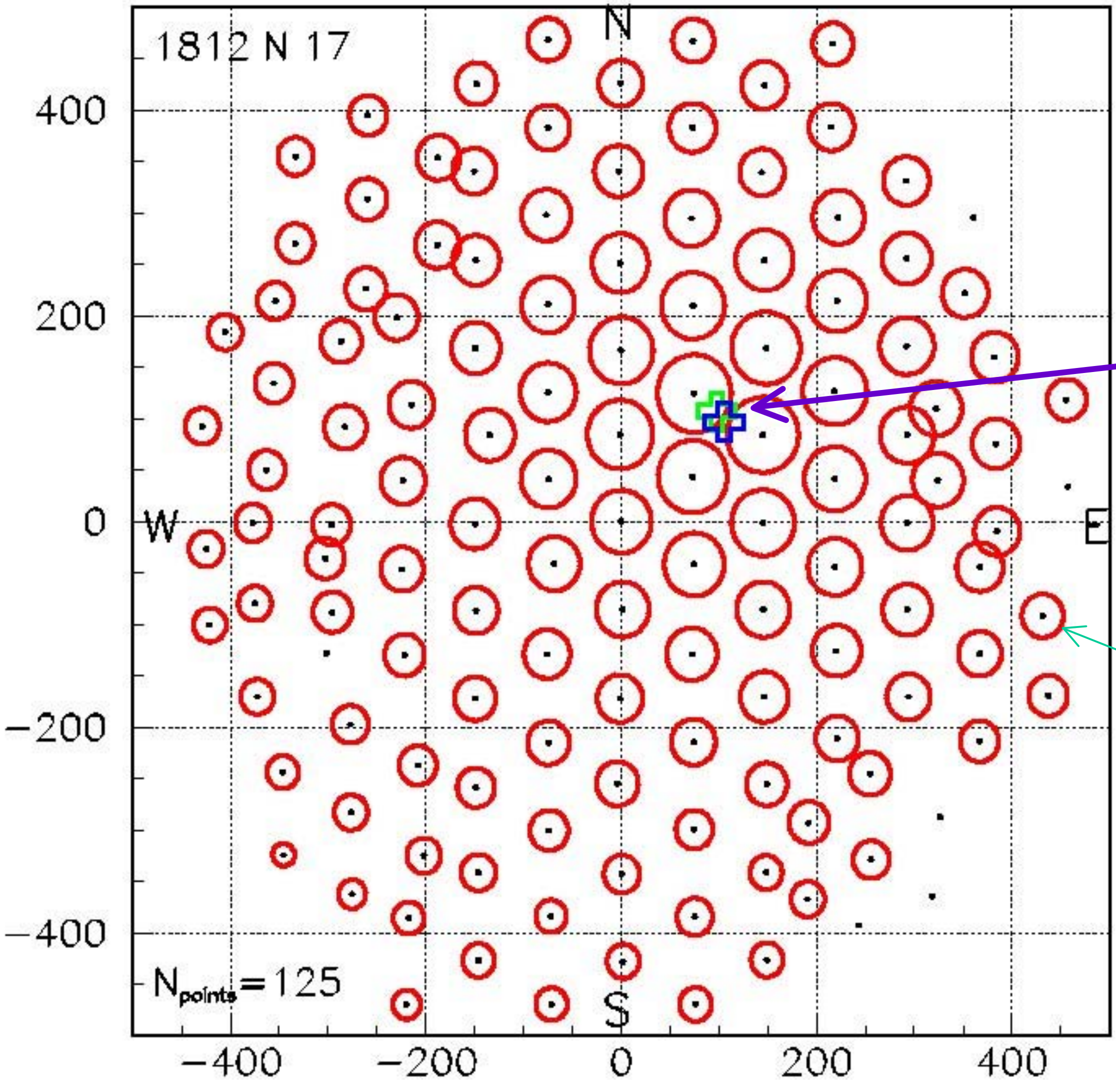
Distribution of the number of hitted clusters in one event.

>10 events during every night with number of hitted detectors more than 100.

Example of event

Energy: 2.0·10^{17} eV
zenith angle : 12.6 °

125 detectors

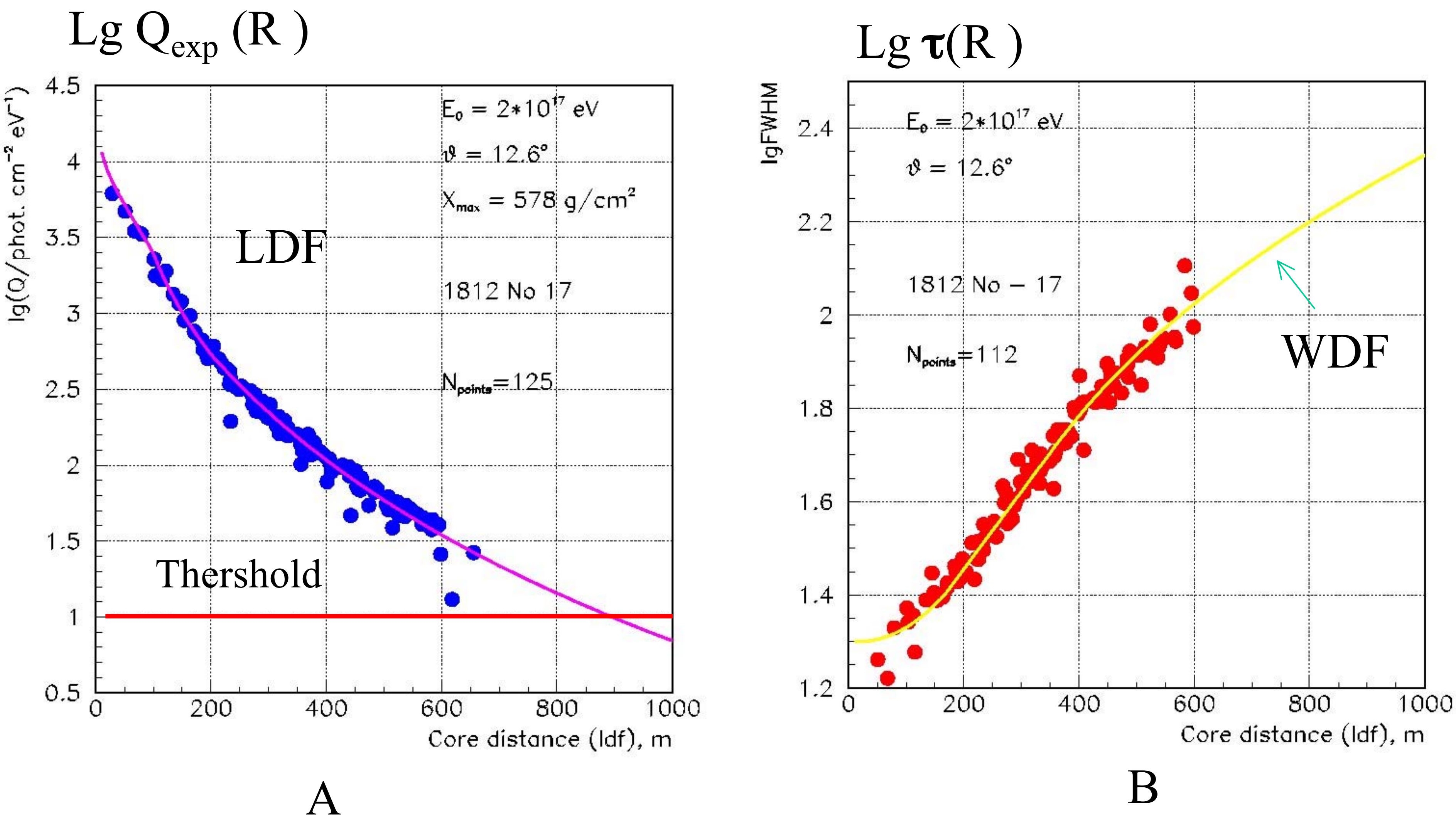


Core position:

LDF -method

WDF -method

R ~ lg (I_{light})

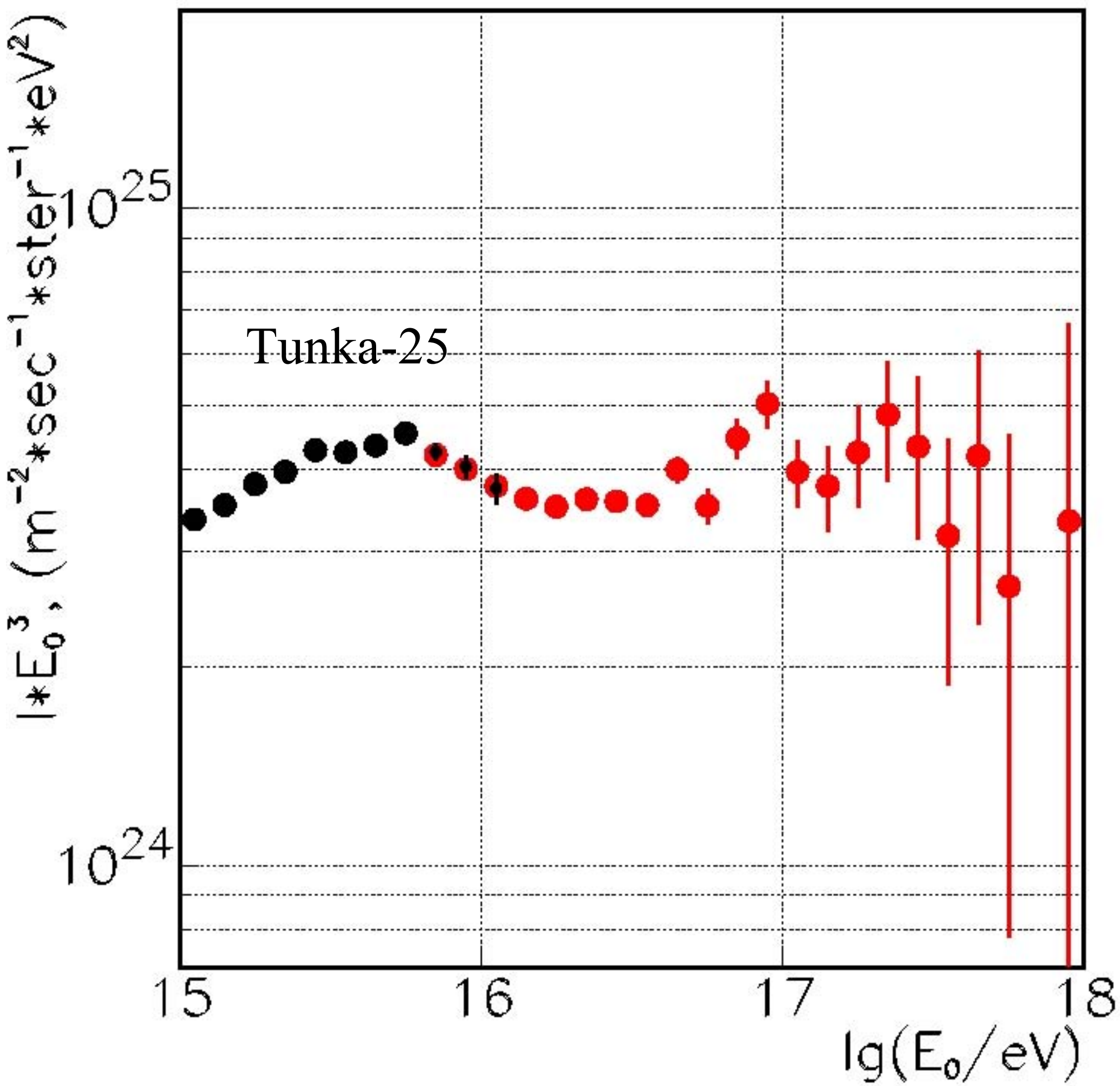


.A– Fitting experimental points with LDF

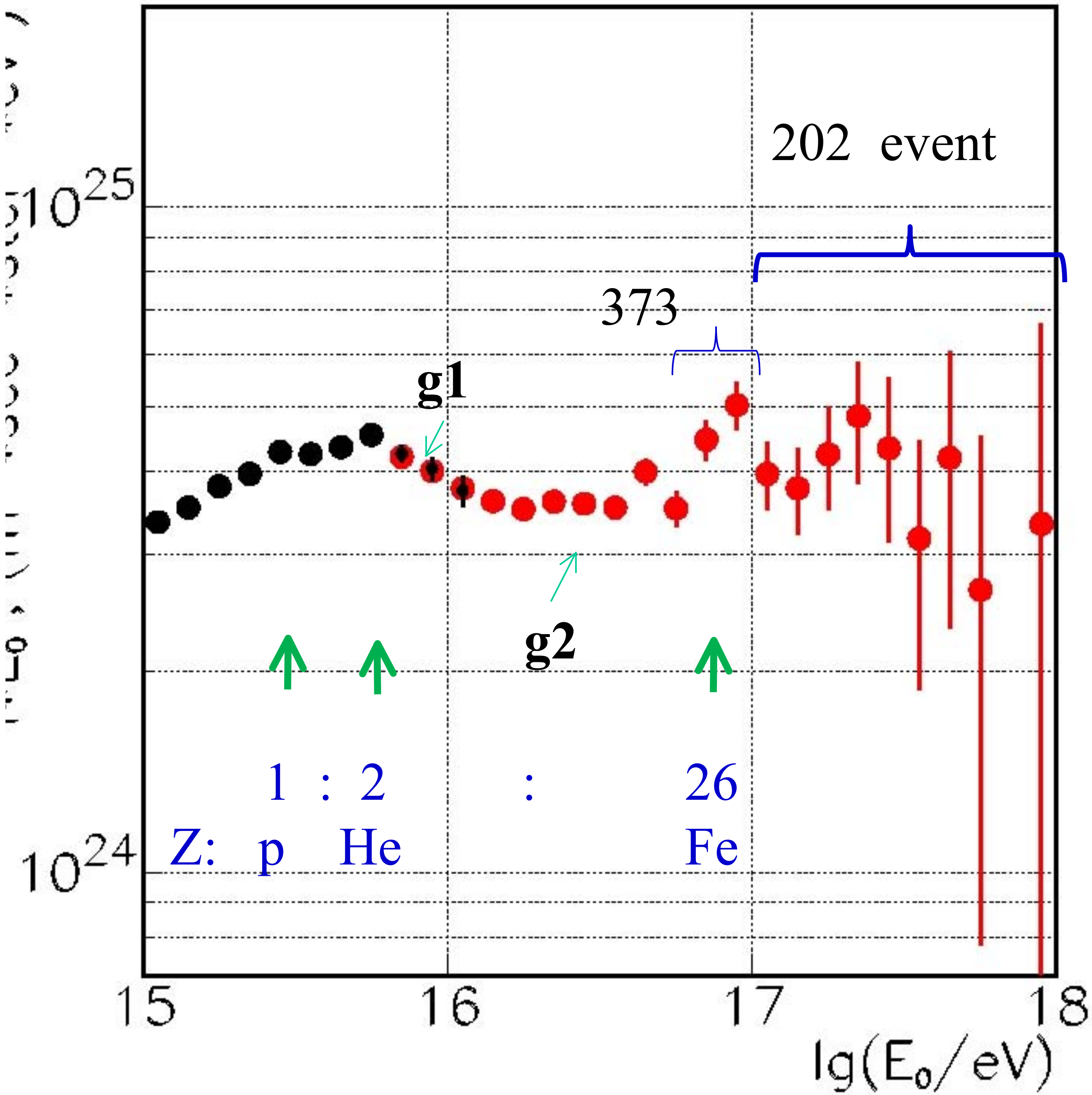
B – Fitting of $\boldsymbol{\tau}$(R) with Width – Distance Function.

Energy spectrum and mass composition after first season (2009-2010) of array operation

Tunka-133: Primary energy spectrum(preliminary)



TEXAS 2010 procceding



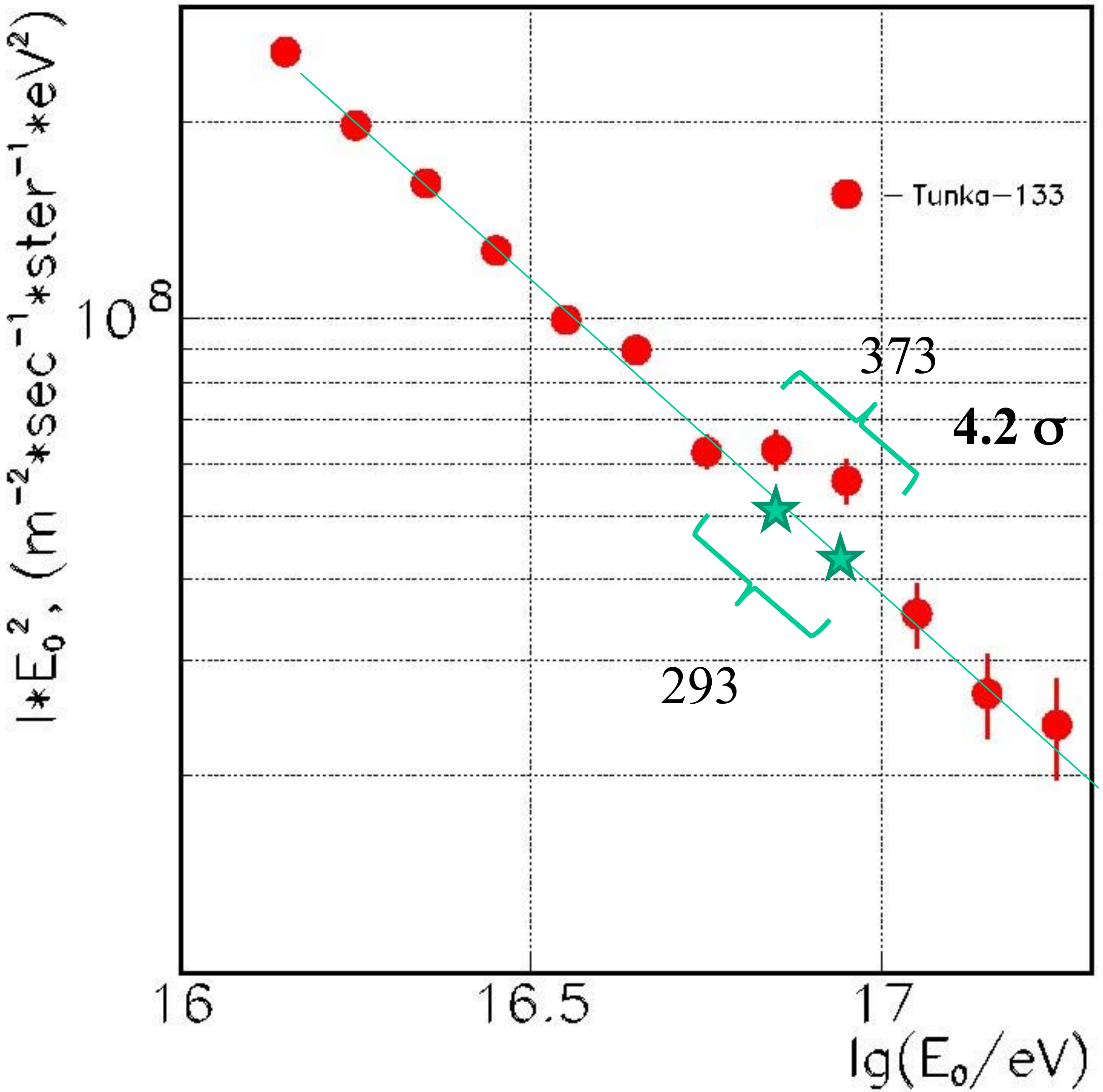
Combined spectrum

Tunka 25(•) plus

Tunka 133 (●)

g1 = 3.2

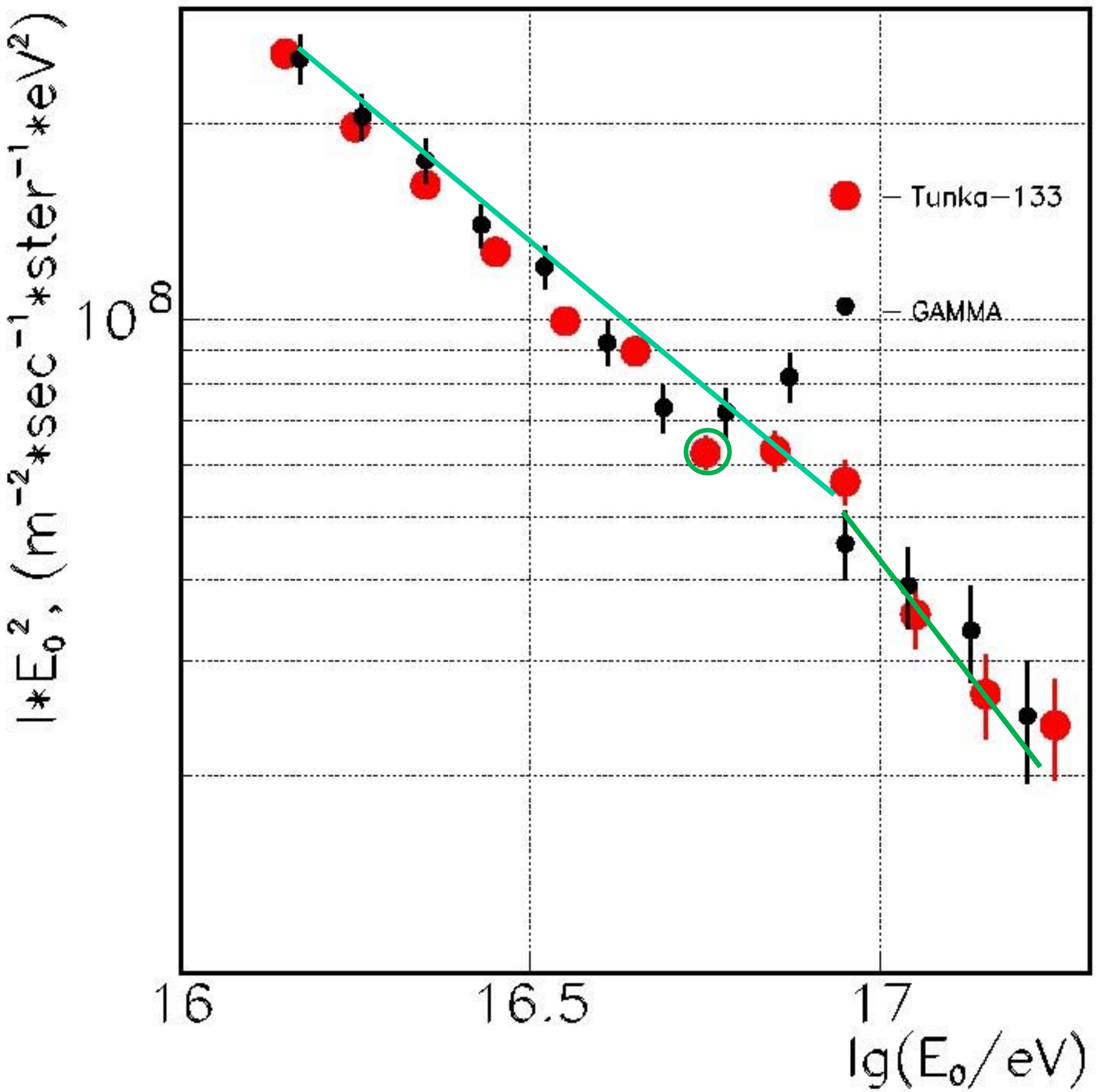
g2 = 3.0



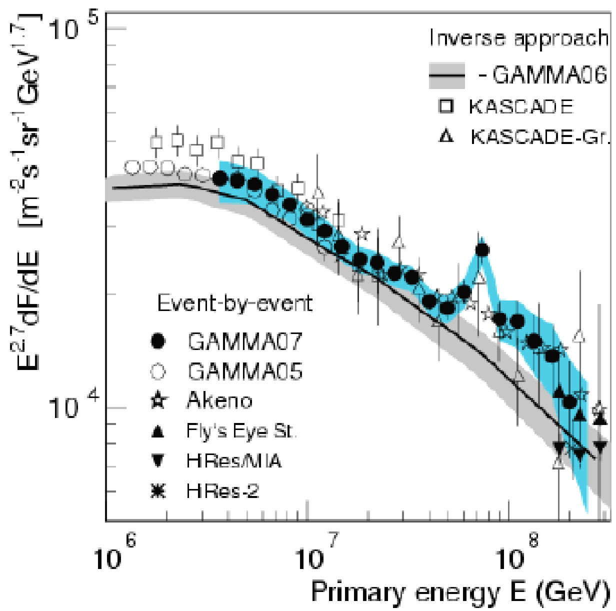
$I*E_0^2$, $(m^{-2}*sec^{-1}*ster^{-1}*eV^2)$
10^8
Tunka−133
373
4.2 σ
293
16
16.5
17
$lg(E_0/eV)$

MAY 2011

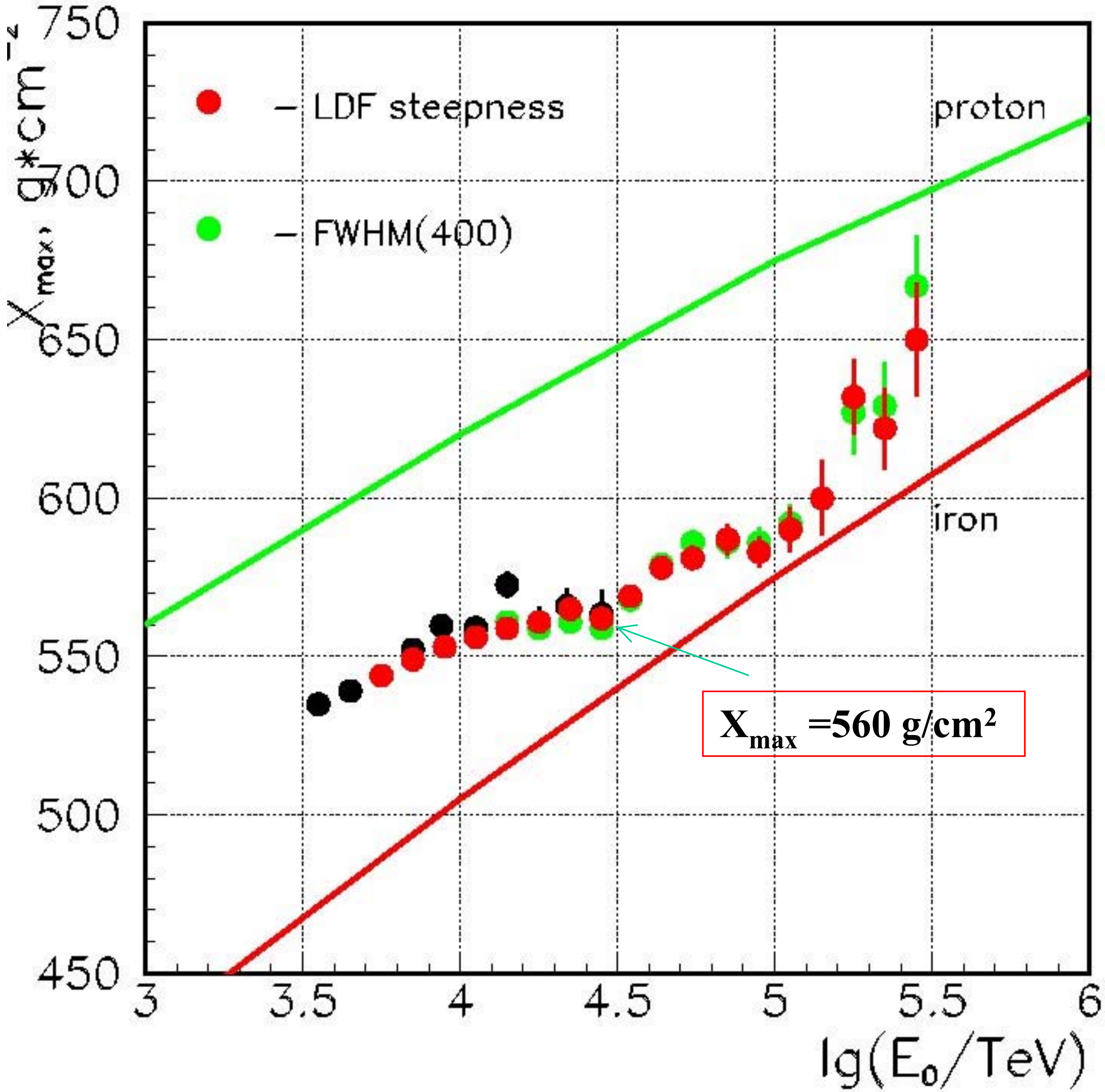
Comparison with GAMMA results



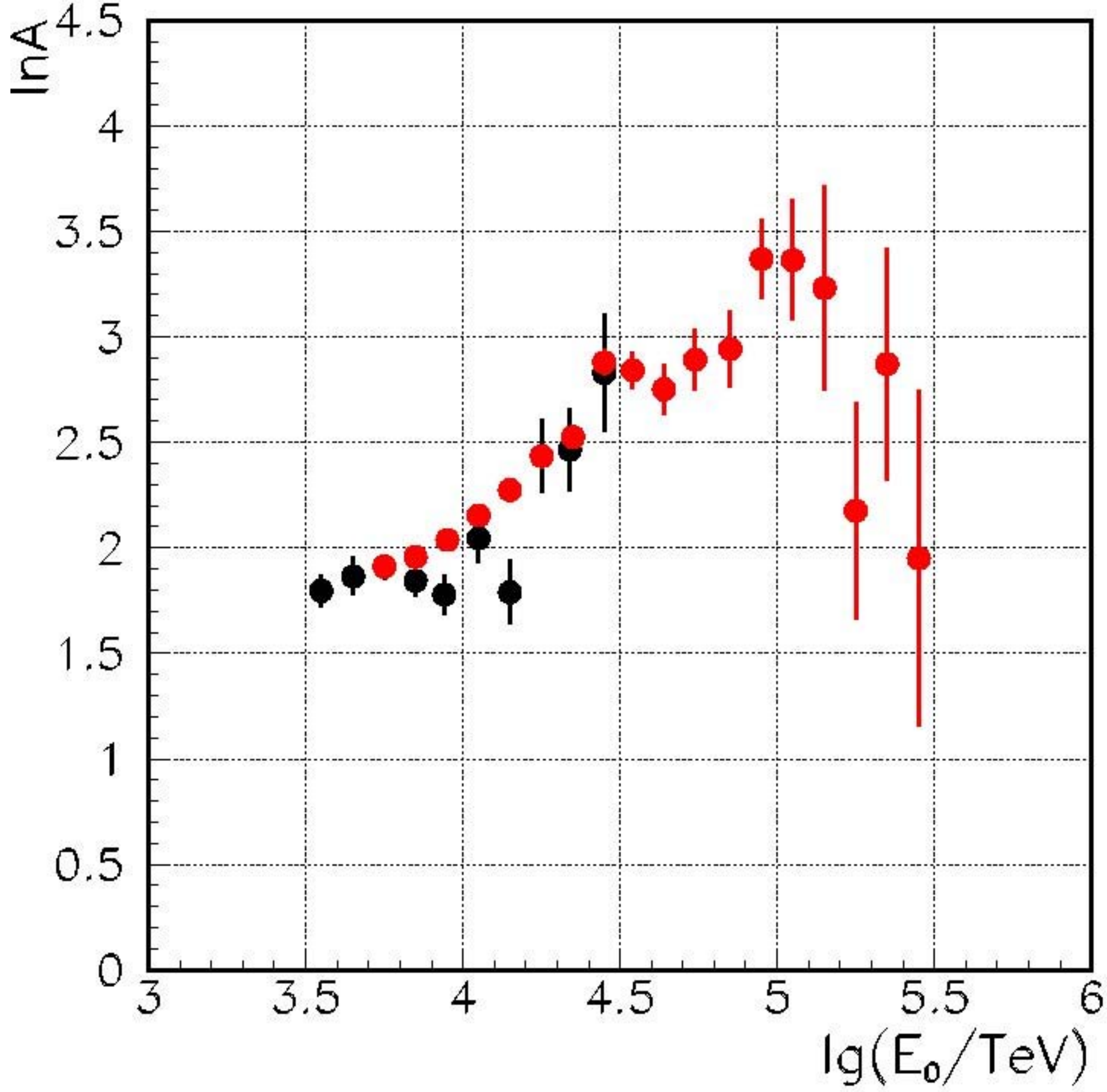
Peak or second knee?



Very Preliminary

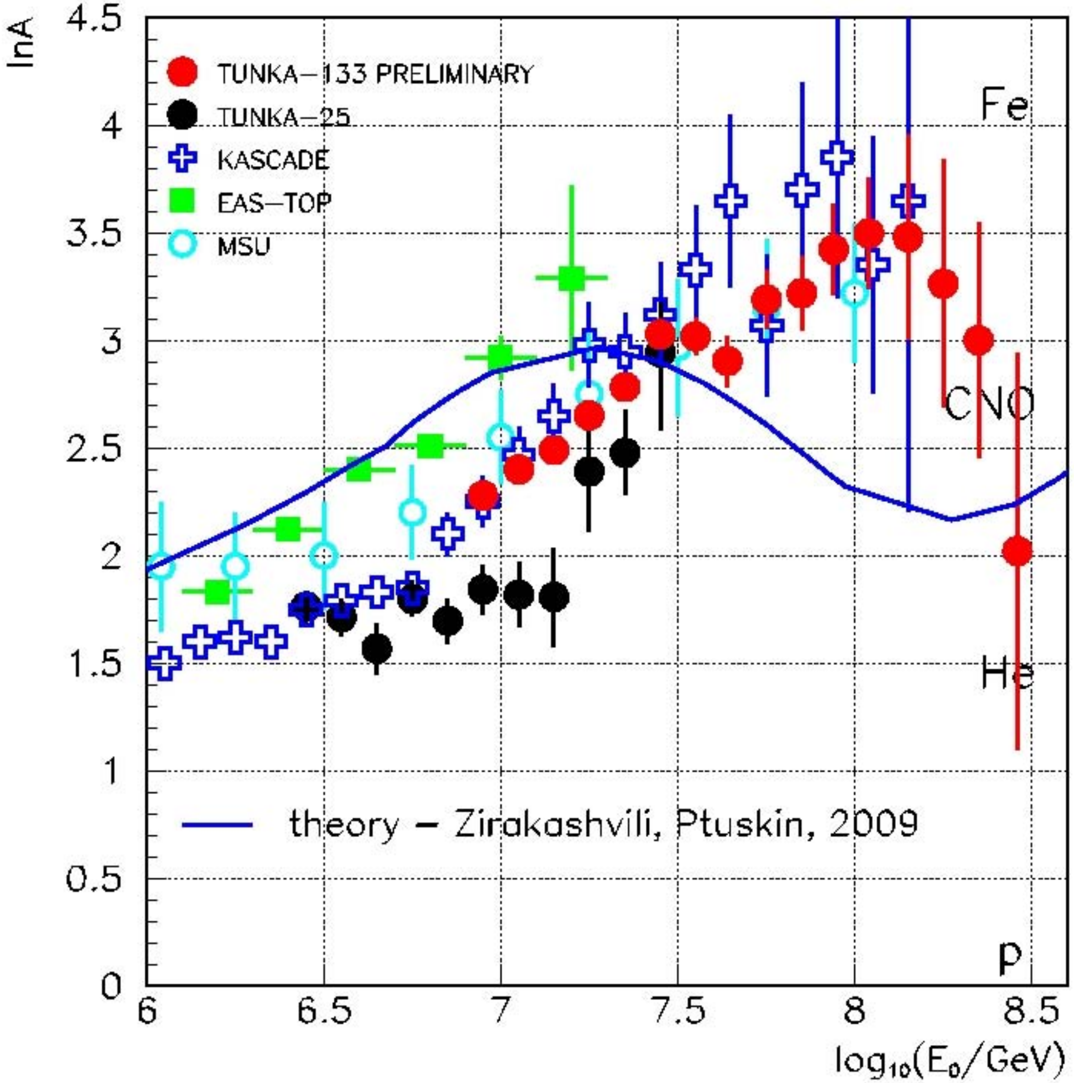


● Tunka-25

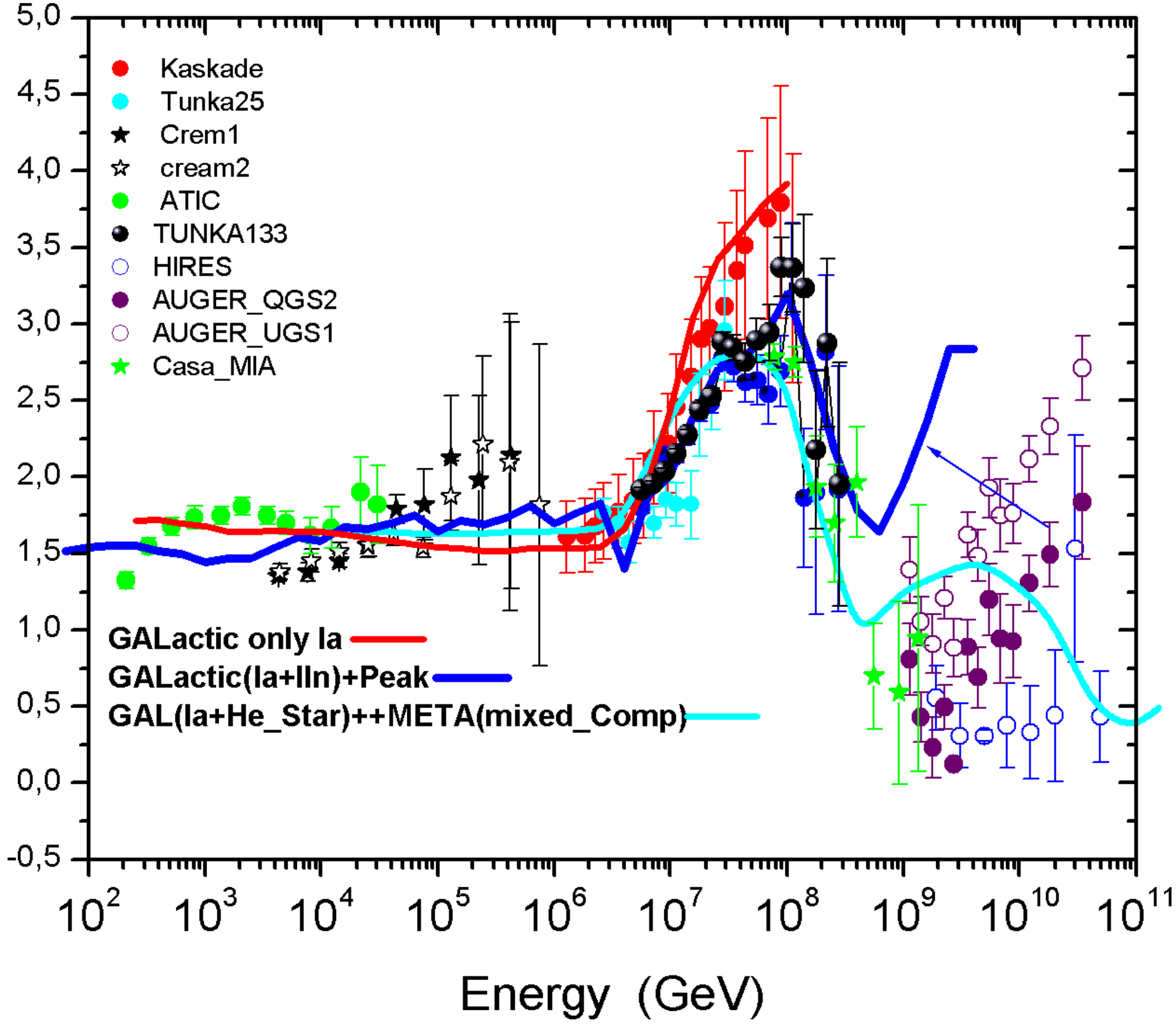


lnA
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
3
3.5
4
4.5
5
5.5
6
lg(E0/TeV)

Mean mass composition Tunka-133



Mass composition: 3 dif. variants



- 1) Emax (P)
- In Galaxy ; 4 PeV

- 2) Emax (P)=4 and
- 600 PeV
- This variant predicts a heavy composition at 10^{18} eV

- 3) SNR Ia + He stars +MetaGalactic with mixed composition in sources

Plan for Tunka-133 upgrading

- Far distant clusters for increasing effective area

- Net of radio antennas

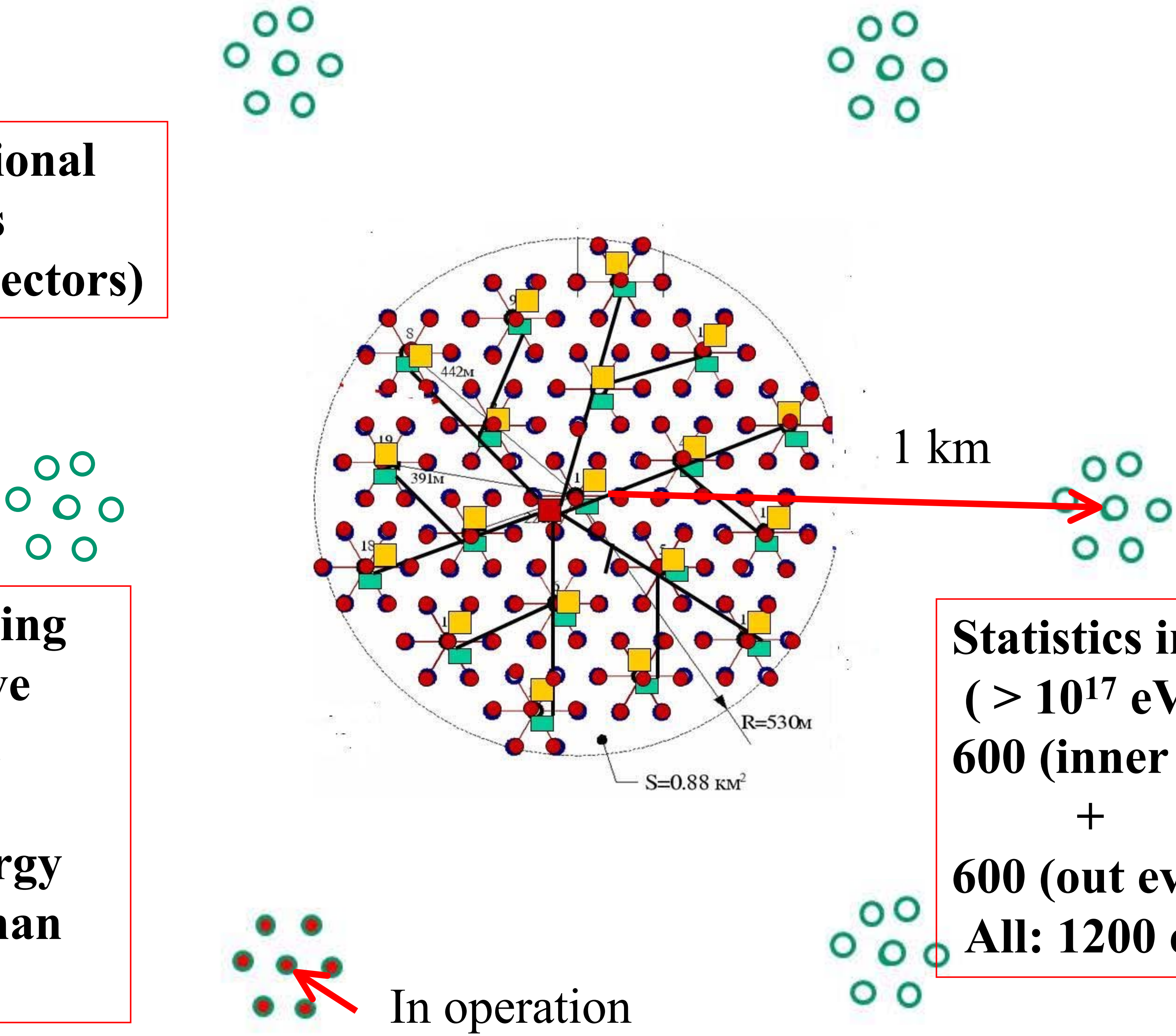
- Low energy threshold array

- Scintillation muon counters

  E_0 , X_{max} (from Tunka-133), N_μ

6 additional clusters
(42 detectors)

Increasing Effective Area in 4 times for energy more than 10^{17} eV



Statistics in 2012
(> 10^{17} eV) :
600 (inner events)
+
600 (out events)
All: 1200 events

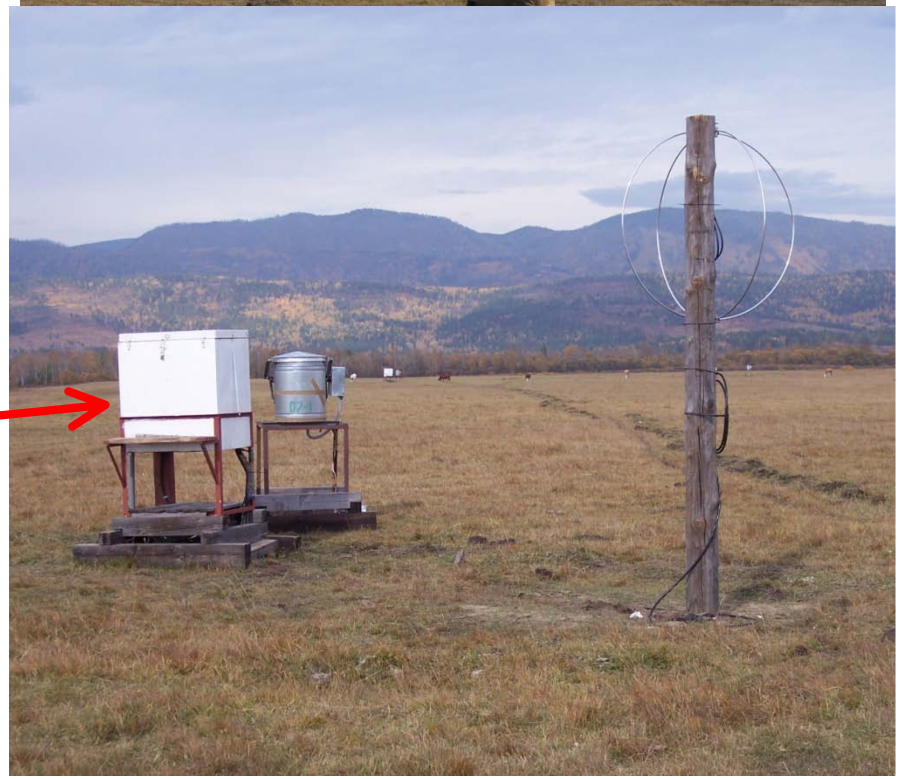
Registration of radio signals from EAS

Short Aperiodic Loaded Loop Antenna (SALLA)
(A.Haungs et al. Institute fur Kernphysick, Forschungszentrum, Karslruhe, Germany

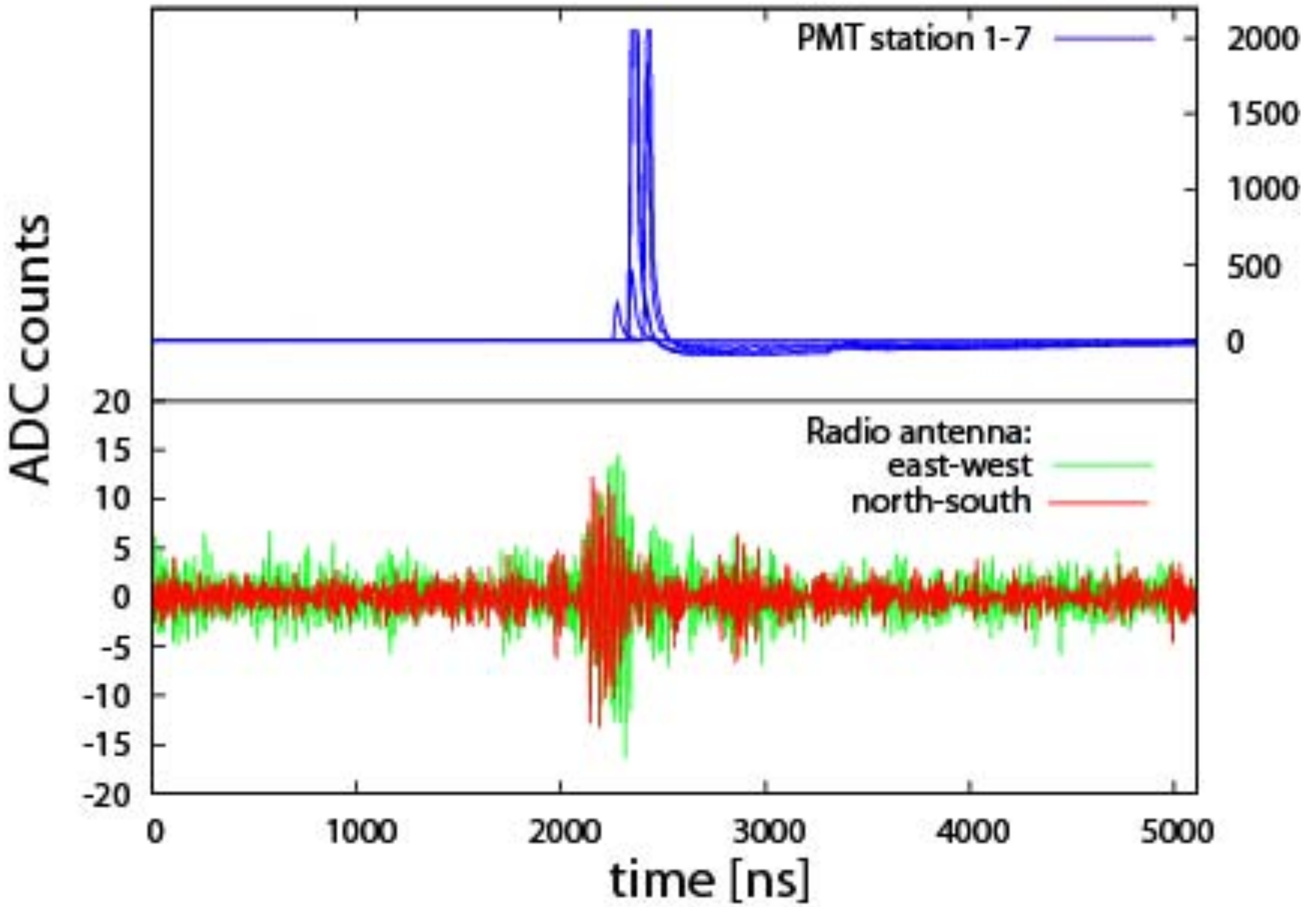
2 antennas + 4 (this summer) + 19 (next summer)

Nearly 70 radio EAS candidates

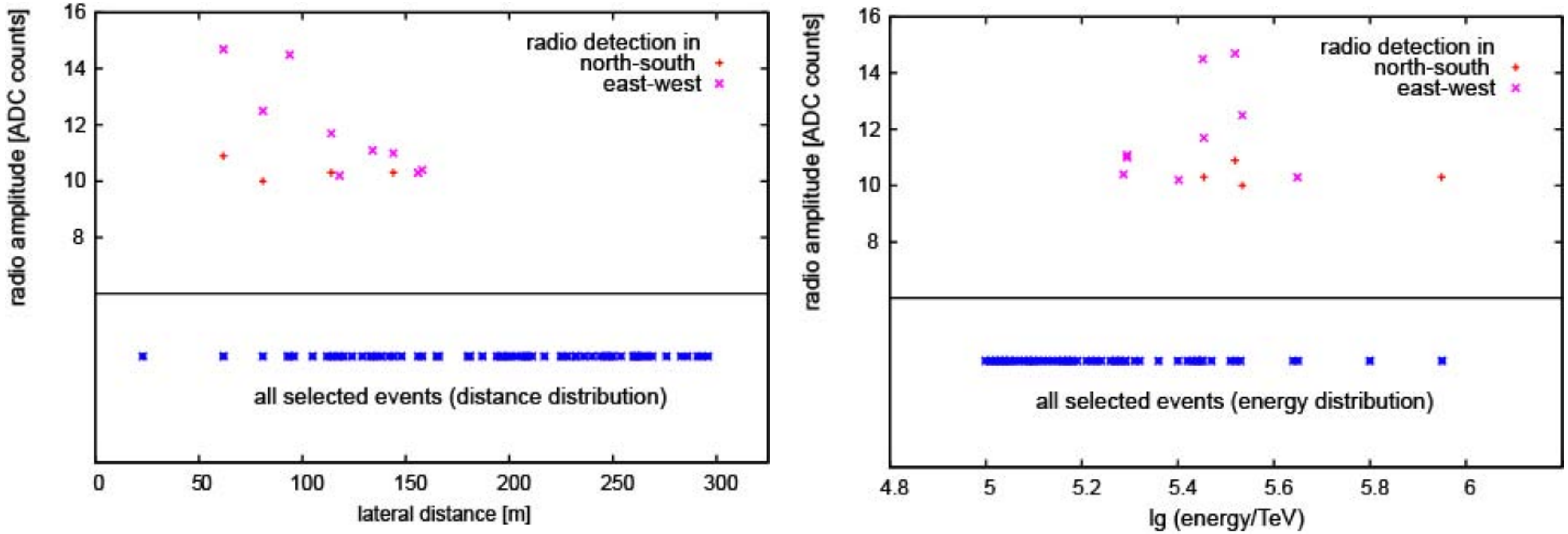
Antennas are connected to the free FADC channels of Tunka-133 cluster electronics



Event example

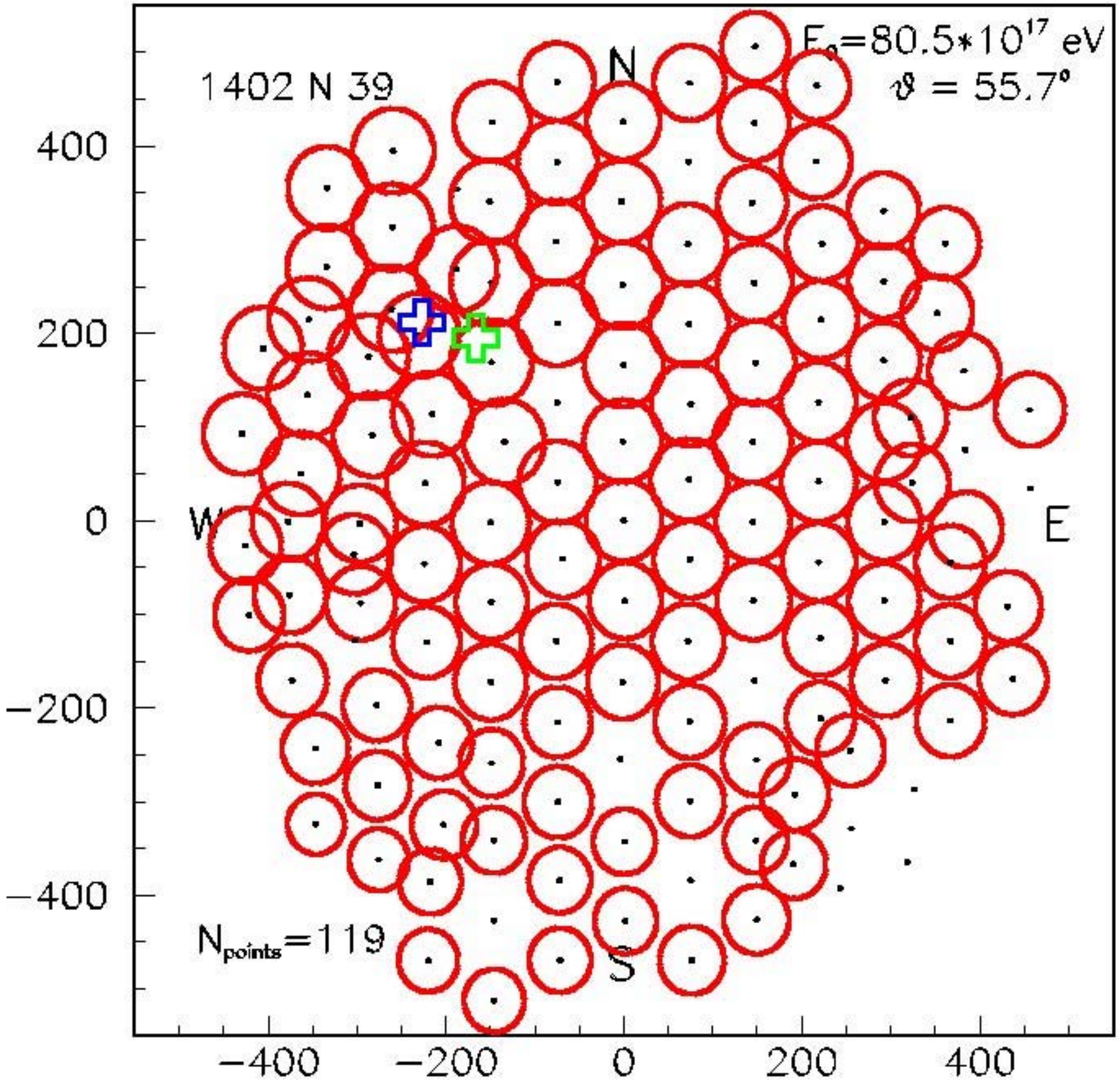


Correlation with Energy + Distance



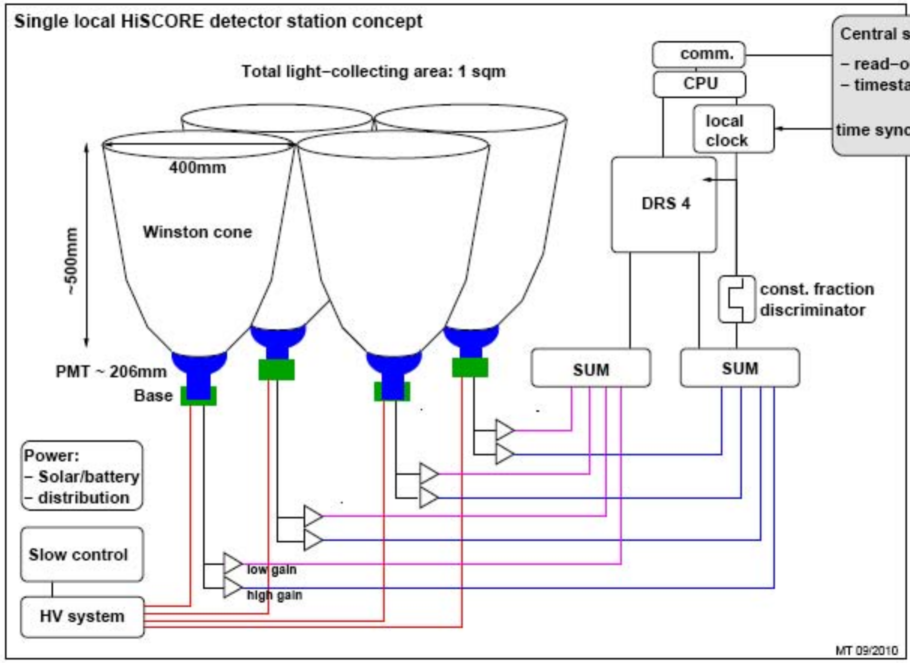
Candidate events at high energies + low distances:
Clearly linked to air showers

Events with largest energy – near to 10^{19} eV – was found out with the help of radio antenna



HiSCORE project – wide-angle gamma-telescope with area 100 km^2 and threshold 30 TeV
(M.Tluczykont et al , ArXiv: 0909.0445 and yesterday report)

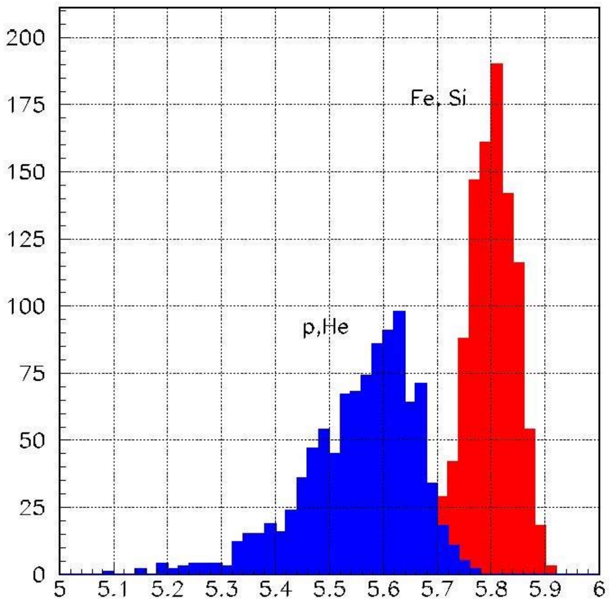
HiSCORE:Hundred i Square-km Cosmic ORigin Explorer



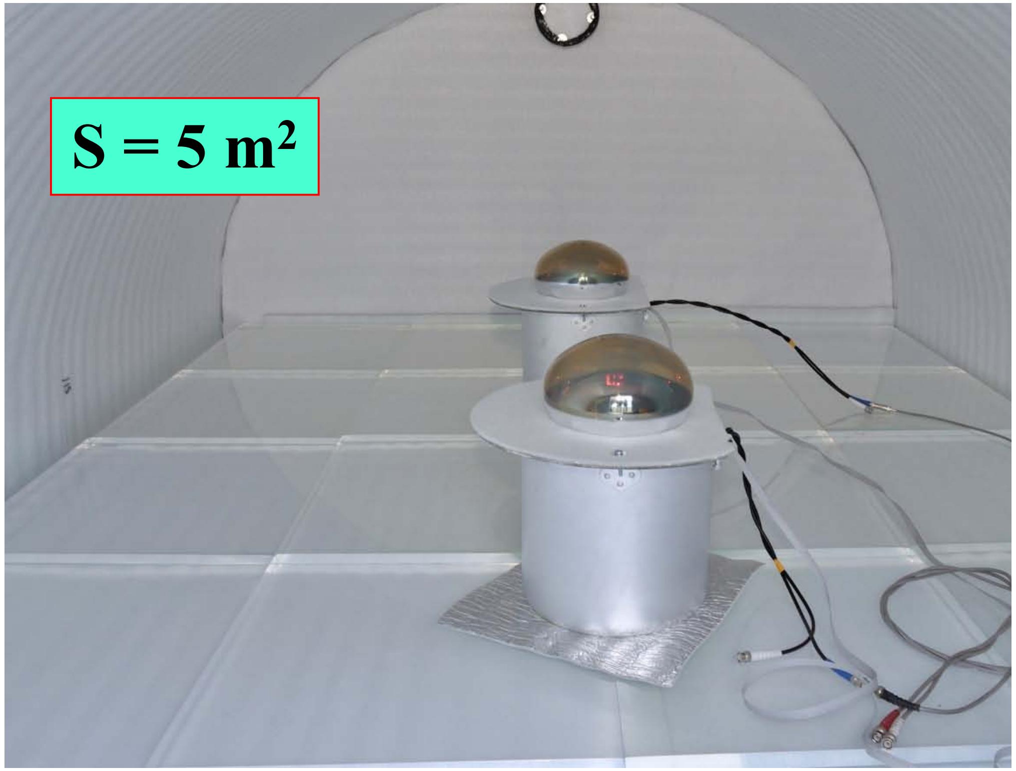
Time schedule
1.First SCORE Station will be installed at Tunka in this summer-autumn
2.25 station at 2012 –
1 sq. km wide-angle gamma telescope

Energy spectrum from 10^{14} - 10^{17} eV -
compare with Tunka-25 and Tunka-133 results

Muon detectores



$$lgN\mu\ (corr) = lgN\mu - \frac{X_{max} - 600}{1500}$$



40 muon detectors on the area of $1 km^2$

Conclusion

1.The spectrum from 10^{16} to 10^{17} eV cannot be fitted with one power law index
g : 3.2 to 3.0 at 2 10^{16} eV.

2. Very good agreement with KASKADE-Grande results (up to $7 \cdot 10^{16}$).

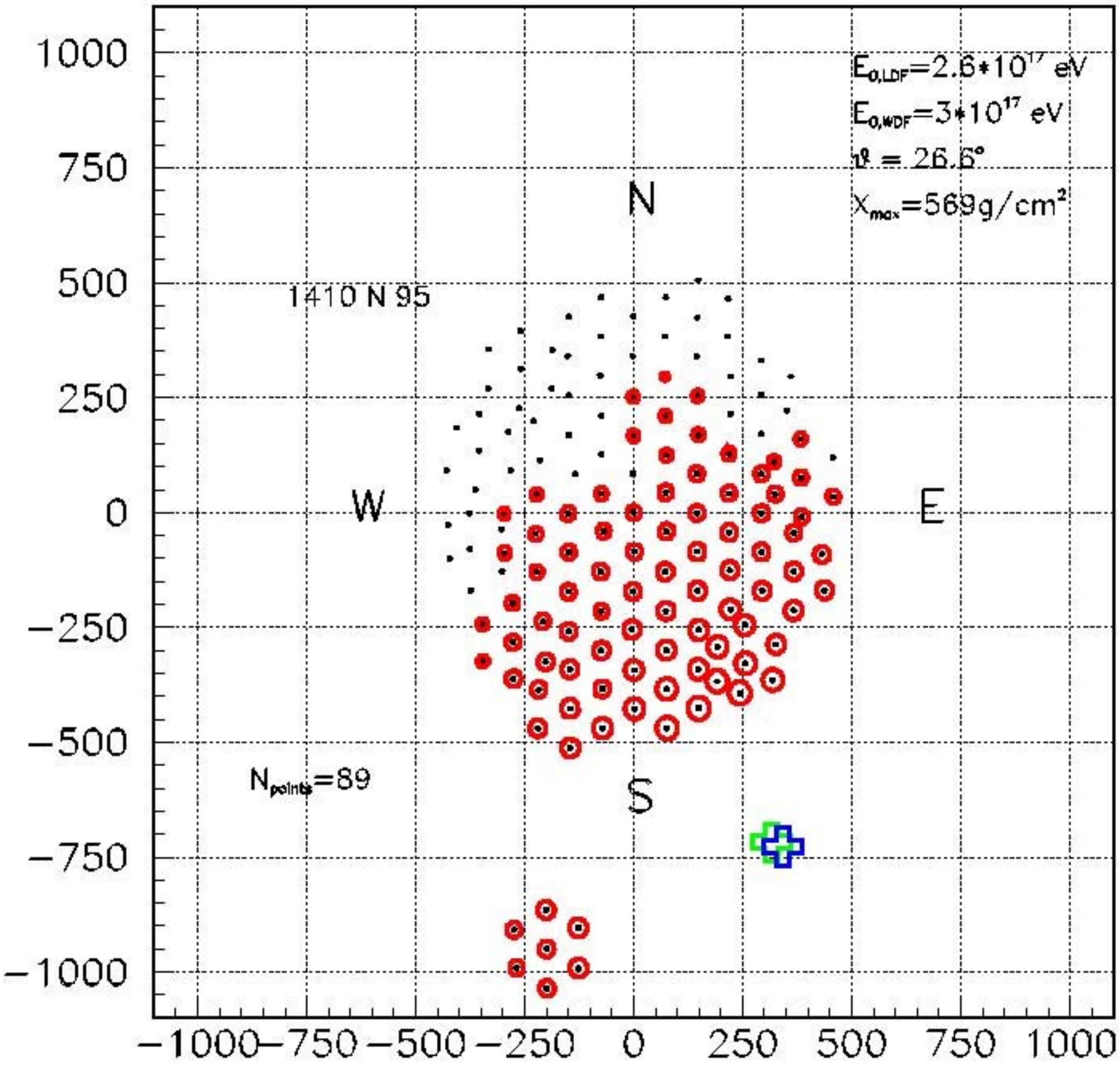
3. For energy > 10^{17} eV we need much more statistics.

4. "Bump" at 8.10^{16} eV - possible indication of a bump + agreement with GAMMA. But not seen by KASKADE-Grande.

5. Indication on light composition at energy > 10^{17} eV

6.Update (2011-2012):
- **Far distant clusters.**
- **Net of radio antennas.**
- **First SCORE detectors.**

Thank You



E0,LDF=2.6*10^17 eV
E0,WDF=3*10^17 eV
ϑ = 26.6°
Xmax=569g/cm²
N
W
E
S
1410 N 95
Npoints=89
1000
750
500
250
0
−250
−500
−750
−1000
−1000 −750 −500 −250 0 250 500 750 1000