Tunka Experiment: Towards 1км^2 EAS Cherenkov Array at the Tunka Valley

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(5) Universita' Torino , Italy
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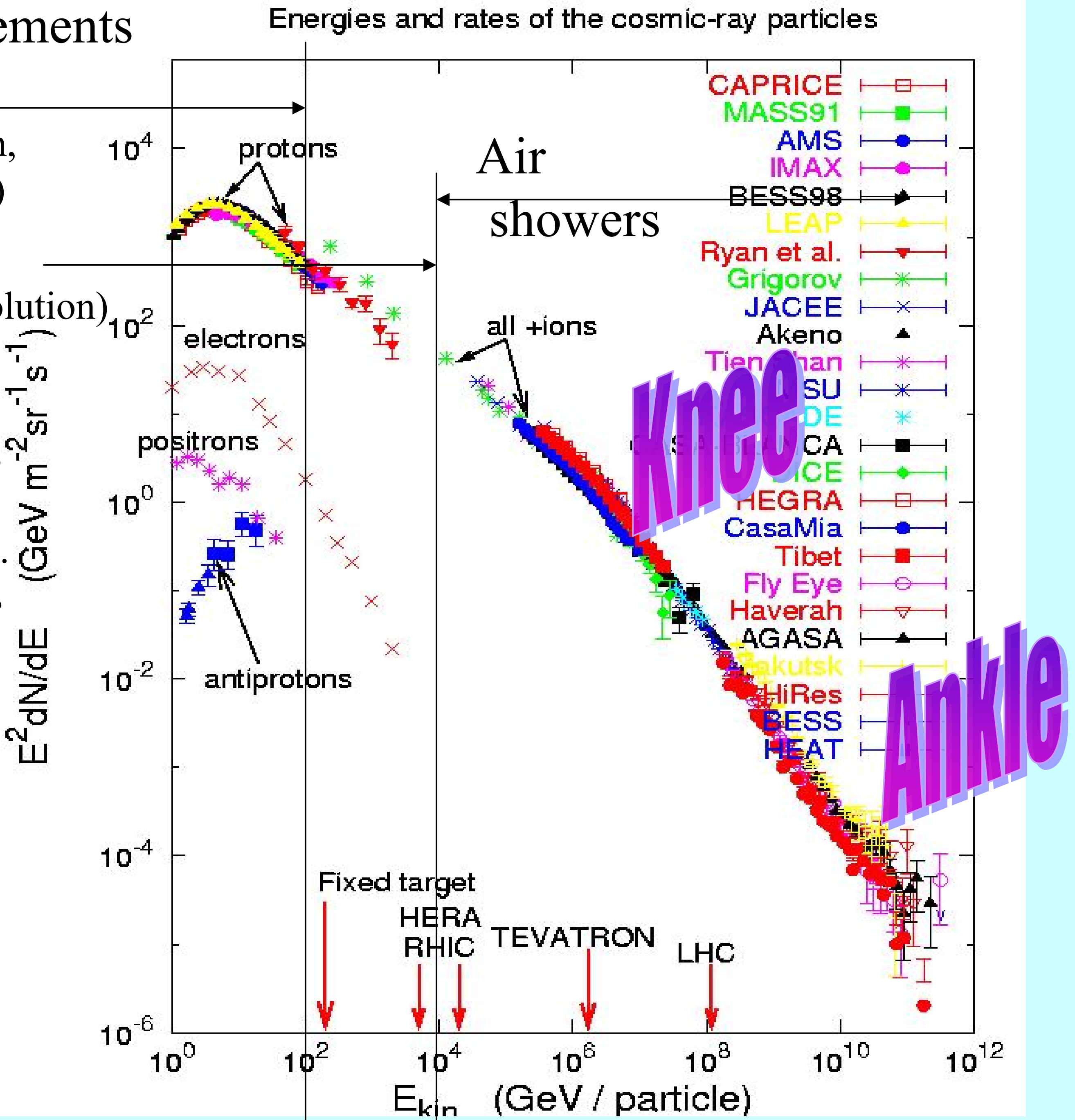
Direct measurements

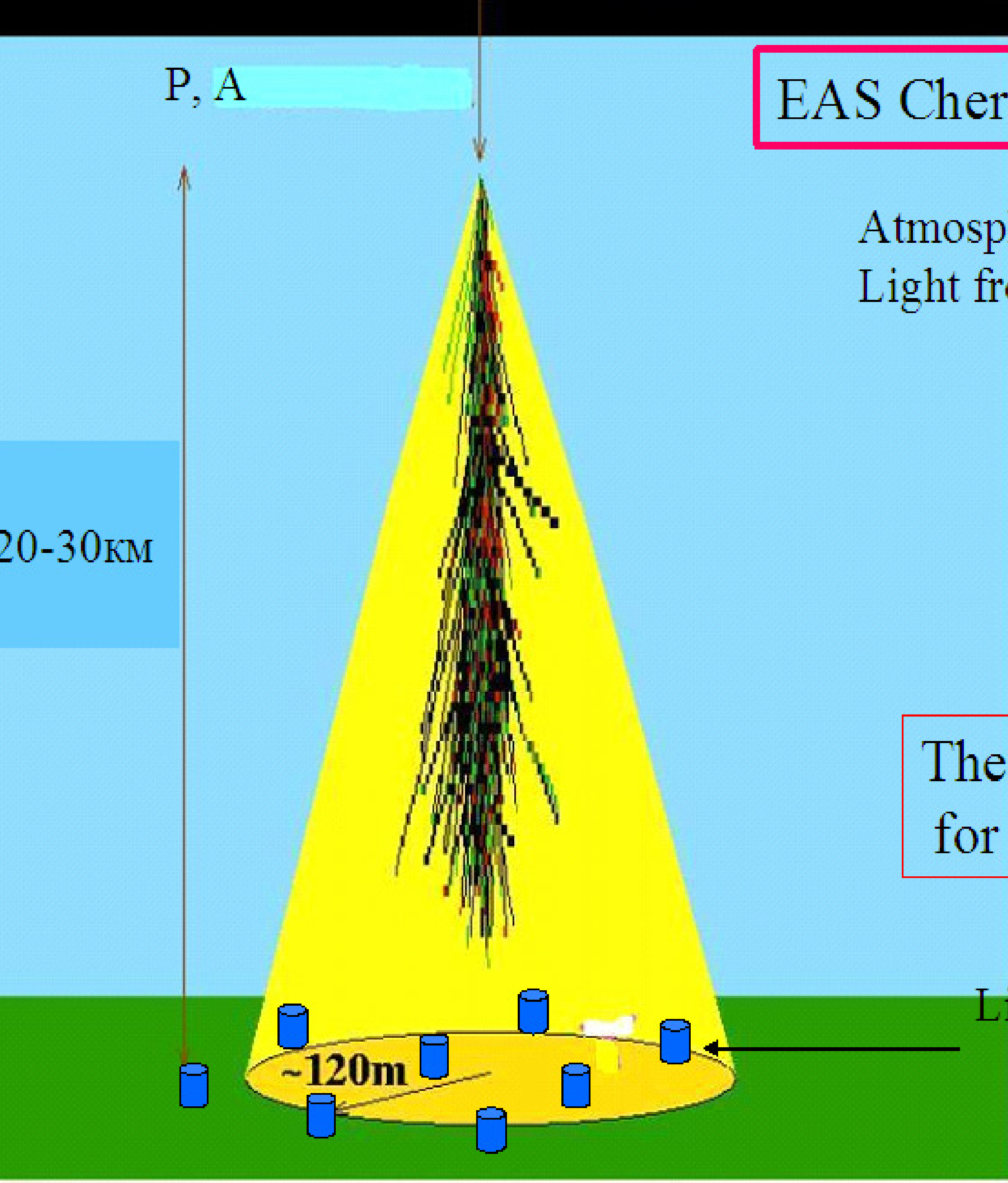
Spectrometers
(ΔA = 1 resolution, good E resolution)

Calorimeters
(less good resolution)

Air-shower arrays on the ground to overcome low flux. Don't see primaries directly.



EAS Cherenkov light



Atmosphere is a huge calorimeter.
Light from all the levels.

$Q_{tot} \sim E$

The most accurate method for EAS energy measurement.

Time of operation:
Clear moonless nights.

View of TUNKA array

TUNKA array is situated in the Tunka Valley on the right bank of Irkut River. Tunka Valley is limited by the east branch of Sayan Mountains (so called Tunka Goltsy, seen in photo) and Hamar-Daban Ridge.

Aim of Experiment

Increase in 10 times the area of "dense" Cherenkov array Tunka-25 to study cosmic rays in the energy range 10^{15} — 10^{18} eV with high energy resolution.

Content of report

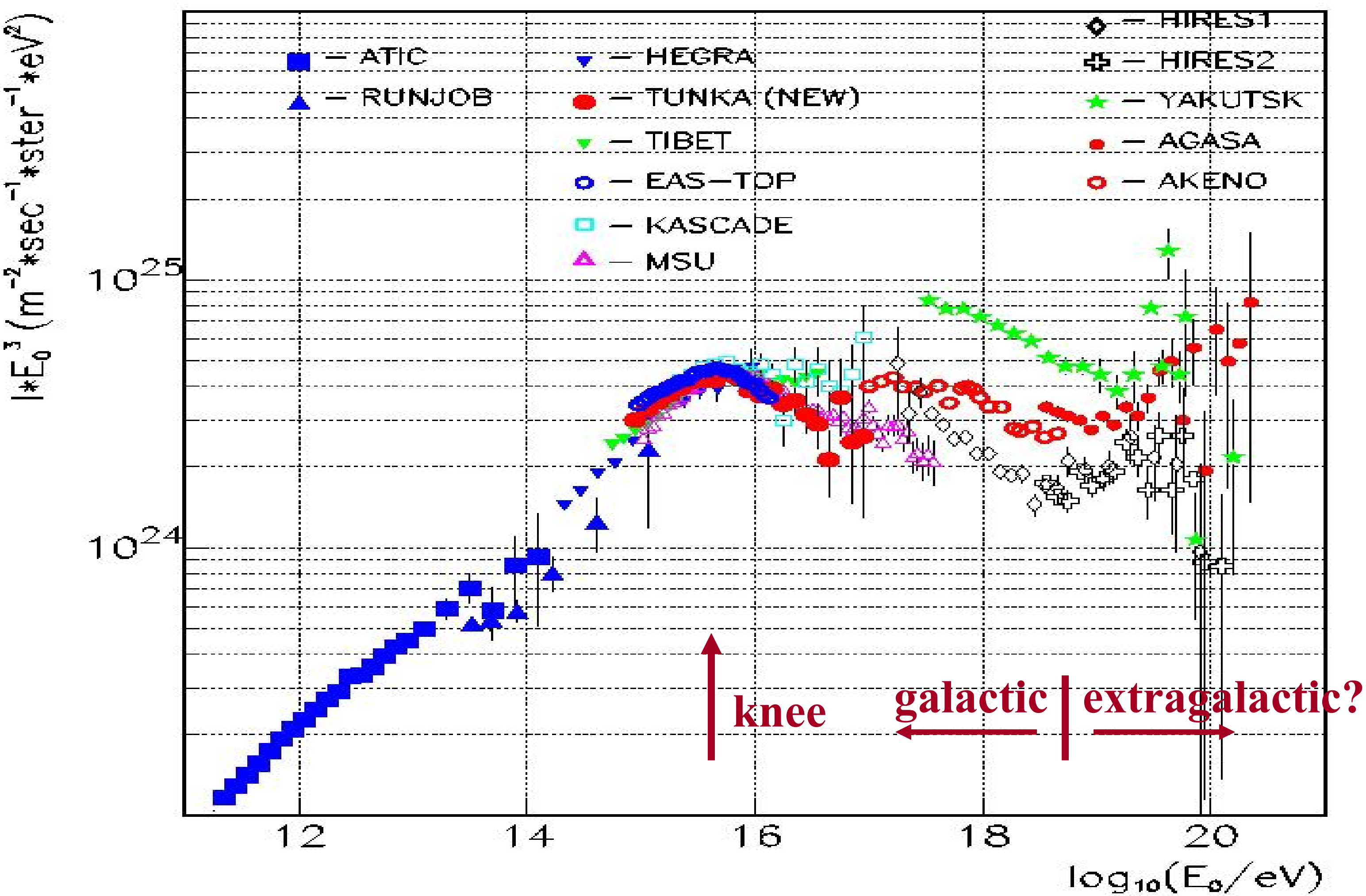
1. Current status of field – motivation for the new array.

2. Tunka-25: history and results.

3. Tunka-133.

Current status of the field

Energy range $10^{16} – 10^{18}$ eV has been covered by very few experiments. Energy spectra determined by different experiments differ significantly, mostly due to the difficulties in proper energy calibration



Why the energy range 10^{16} - 10^{18} is of crucial importance ?

In this energy range may occur transition from galactic to extragalactic cosmic rays.

Accurate measurements in this range provide a good energy calibration for huge arrays (Auger).

Experimental Arguments

1. From KASCADE experiment: at 10^{17} eV Fe component should dominate in cosmic rays.
2. From HiRes experiment : in the energy range $10^{17} – 10^{18}$ eV mass composition of cosmic rays changes from heavy (Fe) to light (p)

The new experiments needed to check this important statement.

Theoretical Arguments.

1. Bell&Lucek (2000, 2001) – Amplification of magnetic field on the front of shock wave $\delta B \sim 100\ \mu G$

   Ptuskin&Zirakashvili(2003)

   $E_{max} \sim Z \cdot 10^{17}$ эВ (in SNR)

2. Berezinsky, Gazizov, Grigoreva (2003, 2004)
   Transition from galactic to extragalactic cosmic rays may occur between 10^{17} and 10^{18} eV.

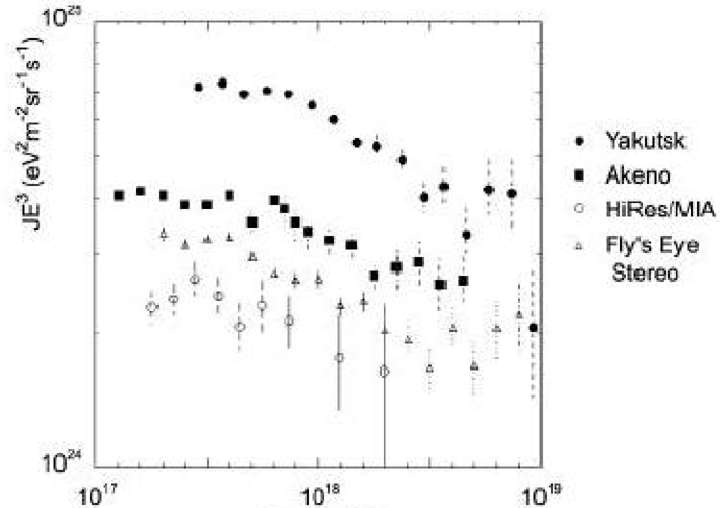
Galactic component at $E \geq 1\times10^{17}$ eV is assumed to be iron nuclei. The spectrum is found as difference of the total (observed) spectrum and extragalactic proton spectrum. E_c is considered as a free parameter in a range $(0.3 - 2)\times10^{18}$ eV

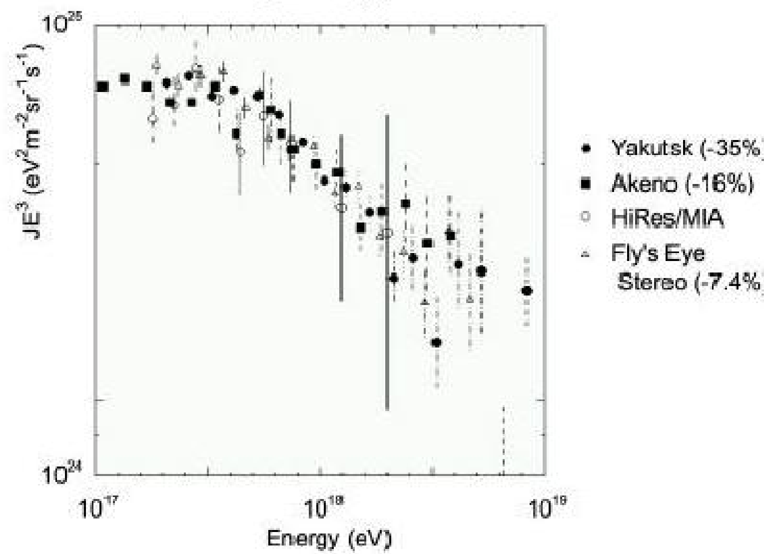
Experiment and theory point out, that in energy range $10^{17} - 10^{18}$ eV the transition from galactic to extragalactic cosmic rays may occur.

Importance of UHE experiments energy calibration.

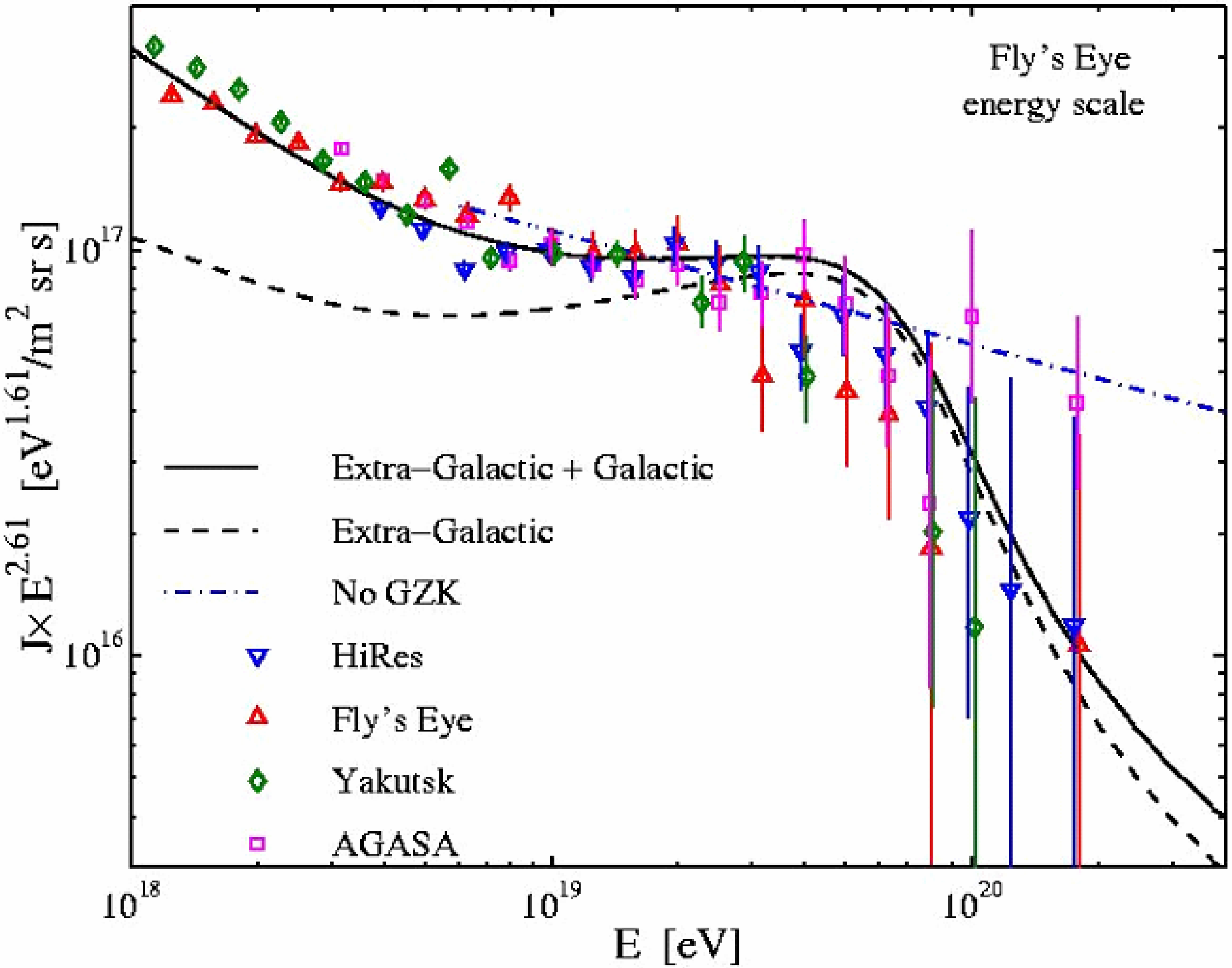
Second Knee at $10^{17.6}$ eV

- Yakutsk, Akeno, Fly's Eye Stereo, HiRes Prototype/MIA all saw flat spectrum followed by a steepening in the power law. The break is called the second knee.
- Correct for varying energy scales: all agree on location of the second knee.
- There are THREE spectral features in the UHE regime





Why good energy calibration is very important?
(from the work of Waxman and Bahcall)

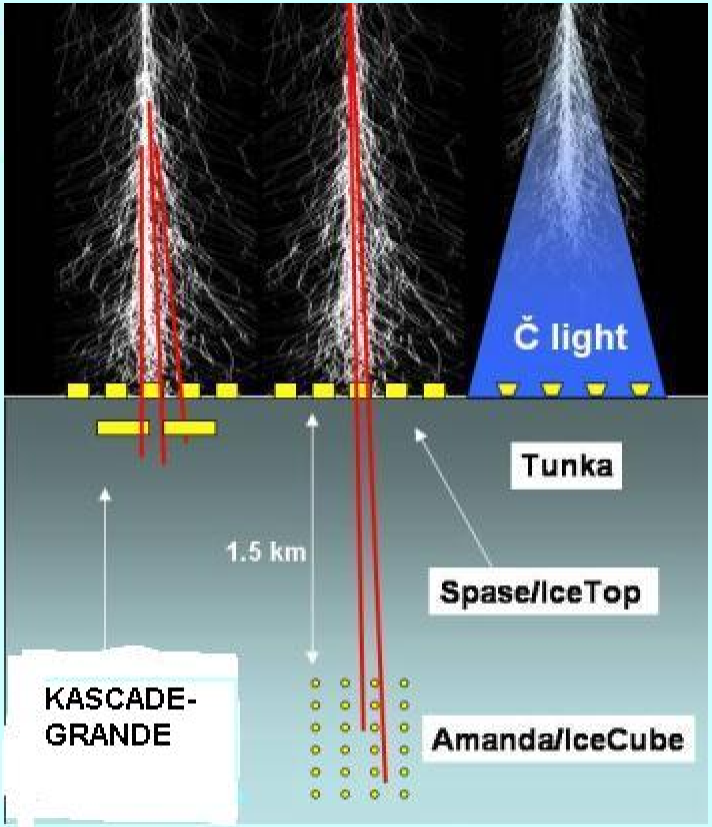


A careful investigation of the region $10^{16} – 10^{18}$ eV requires:

-Detectors with area 1 km^2 or more, but much smaller spacing than that of arrays for ultra-high energies.

-The detectors should exploit as many as possible complementary techniques, which can be cross-checked against each-other.

-Precise energy measurement is crucial to detect fine structure in the spectrum. Therefore the set of techniques should include a calorimetric methods, which – for this energy range – is Cherenkov technique.



A trinity of detectors complementing each other:
KASCADE-Grande, Space/IceTop, Tunka

Tunka-25 array

Tunka experiment : history and results

1. 1992 – 4 PMT QUASAR-370 on the ice of lake Baikal.
2. 1993 – moving to Tunka valey (50 from the lake Baikal)

   1993 – 1995 TUNKA-4 – The first measurement of energy spectrum in the knee region with Cherenkov light.
3. 1996 – 1999 TUNKA-25 – Spectrum and mass composition.
4. 1998 – 2000 - QUEST (QUASAR-370 at EAS-TOP)
5. 2000 TUNKA-25

0.1 km^2

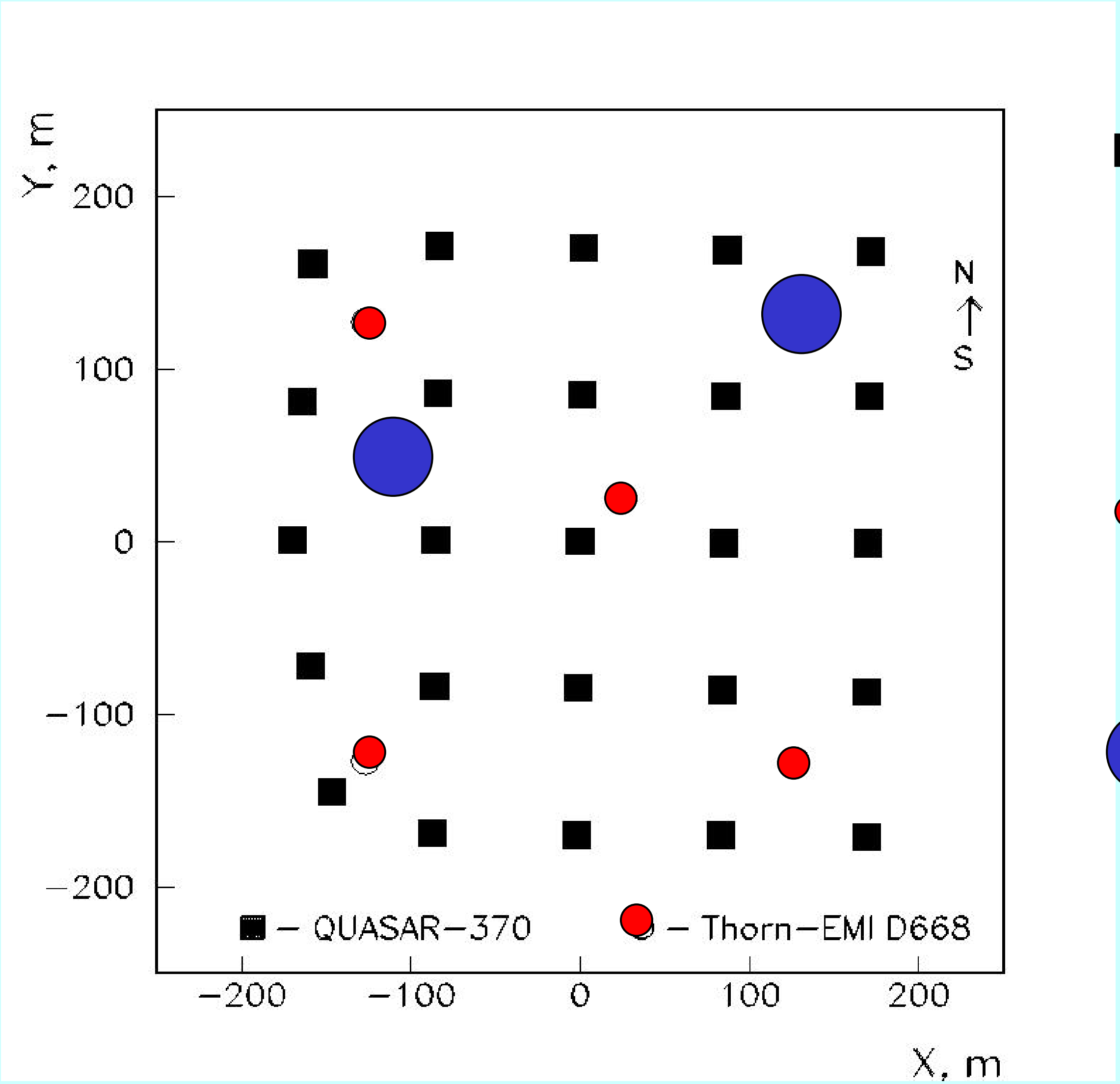
Method development:
accuracy of axis reconstruction,
LDF, energy callibration

200 PMT from INFN,
GRAN SASSO LAB.

Project of
TUNKA-133

133 PMT
on 1 km^2

The Tunka-25 array in 2005

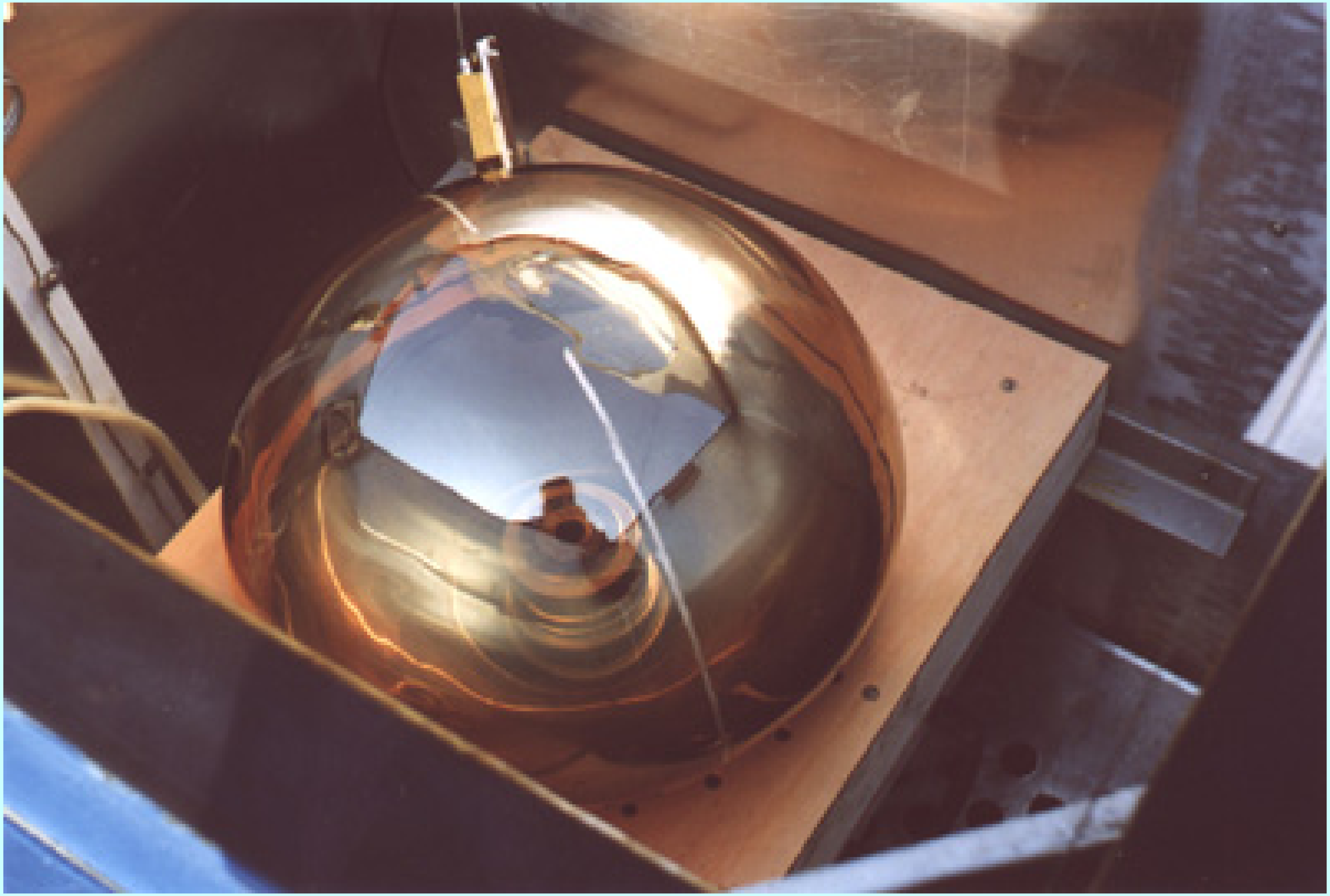


■ 25 QUASAR-370 tubes
- -37 cm diameter
- - integrating

4 EMI D668 tubes
- -20 cm diameter
- -fiber read-out
- -FADC

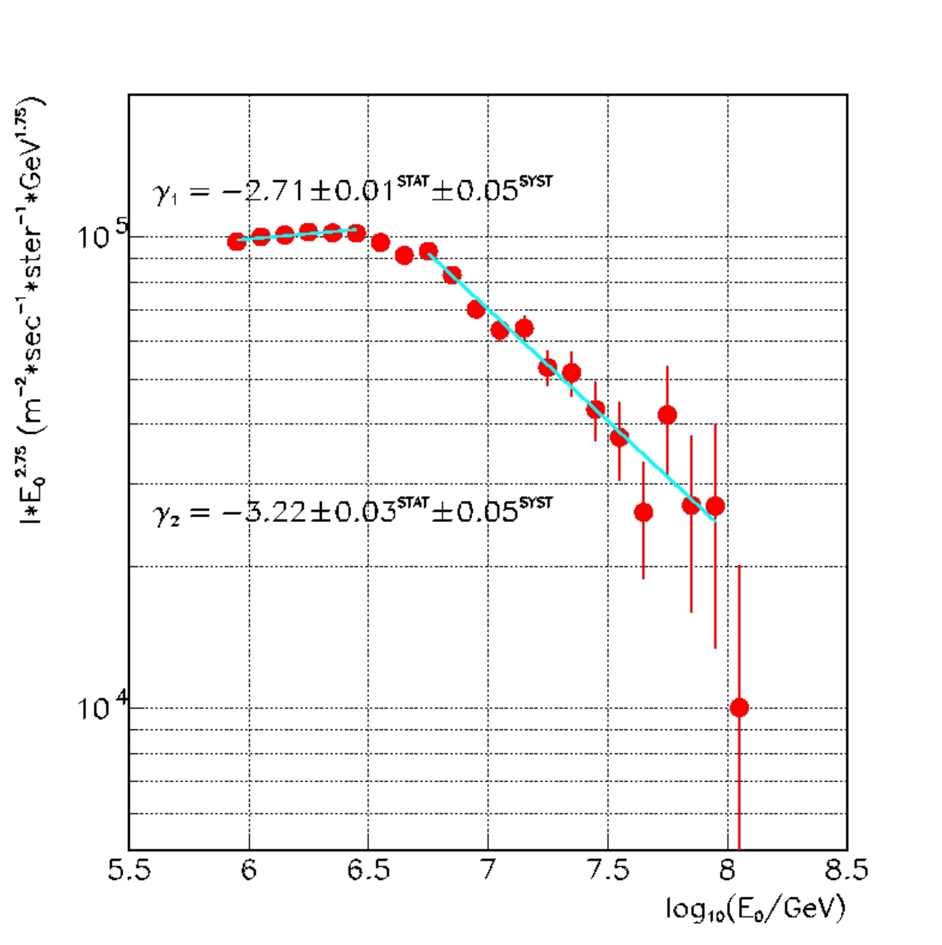
Water tank
($S=10\ m^2$)

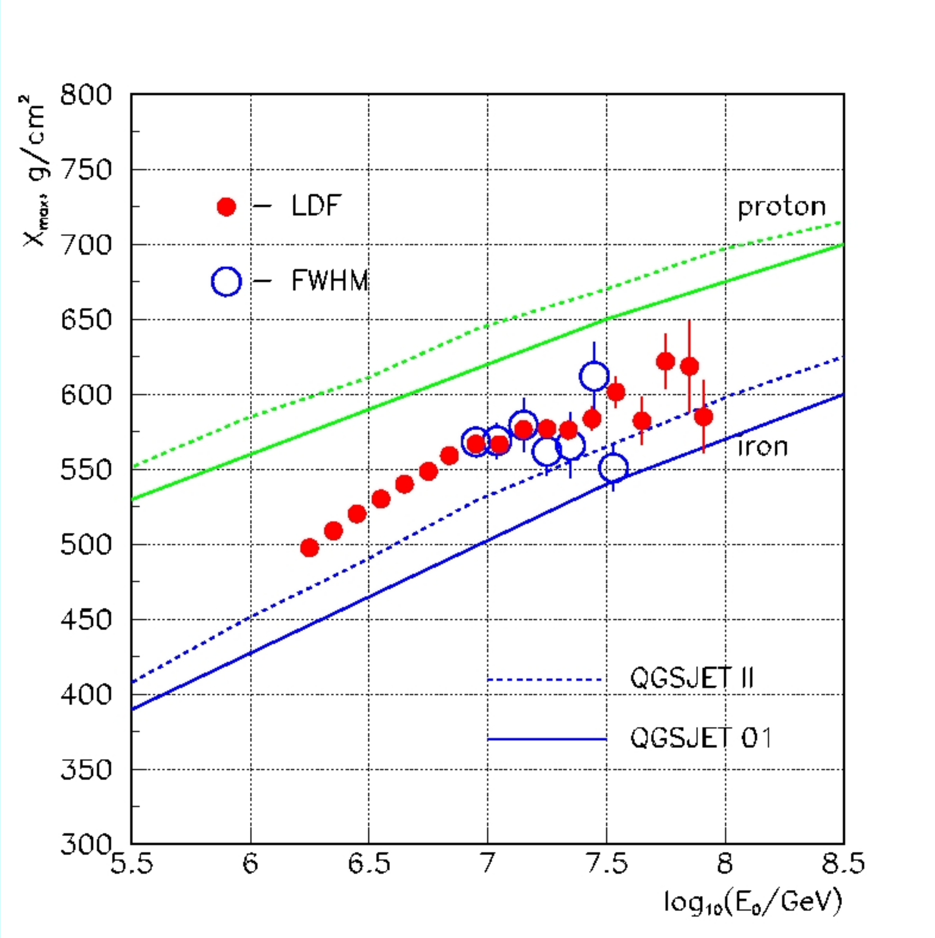
QUASAR PHOTO-TUBE

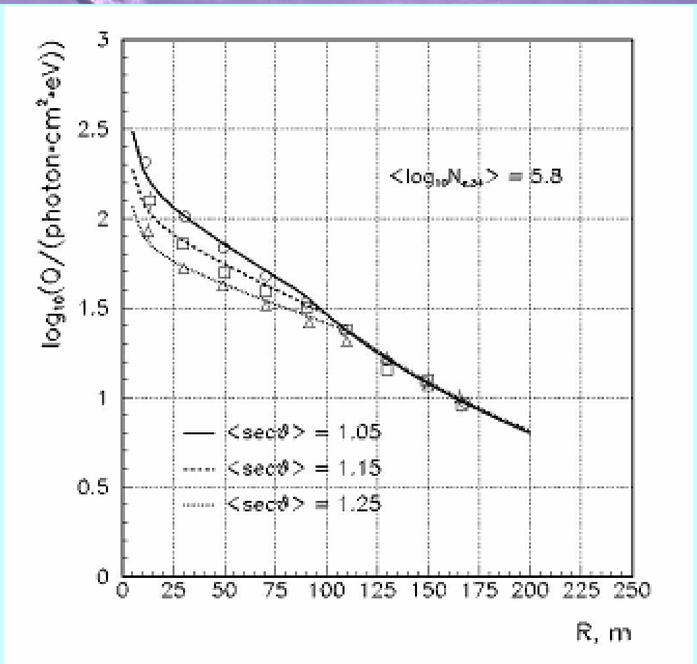


The base time integrated detector of TUNKA array

Main Tunka-25 results: energy spectrum and mass composition.







ACCORDO QUADRO DI COOPERAZIONE ACCADEMICA

TRA

L'UNIVERSITA' DEGLI STUDI DI TORINO

(ITALIA)

E

L'UNIVERSITA' STATALE LOMONOSOV DI MOSCA

(RUSSIA)

salvo diverso accordo, in copropriet̀à a entrambe le Università, che si impegnano a proteggerli e a valorizzarli, secondo le norme di diritto industriale dei rispettivi ordinamenti. Ciascuna Università si impegna inoltre a prevenire ogni pretesa che possa derivare da eventuali diritti rivendicabili dal personale di propria afferenza, o da soggetti in contatto con esso, onde consentire una più agevole negoziabilità dei risultati ottenuti.

Art. 7

Il presente accordo avrà una durata di tre anni dalla data dell'ultima firma da parte dei Rettori delle due Università e previa approvazione dei competenti Organi Accademici.
Ogni modifica del presente accordo richiede l'approvazione scritta delle due Università.
Il presente accordo potrà essere rinnovato solo con approvazione scritta degli organi accademici competenti.
In caso di mancato rinnovo dell'accordo, gli scambi effettuati nell'ultimo anno dovranno essere tali da bilanciare gli scambi complessivamente effettuati durante l'intera durata dell'accordo.

Art. 8

Il presente accordo, redatto in lingua italiana, russa e inglese, è firmato in sei copie originali, tre delle quali verranno conservate presso ogni Universita'.

Firmato a Torino	Firmato a Mosca
Il 06 NOV. 2002	Il 22.01.2003
Per l'Università degli Studi di Torino	Per l'Università Statale Lomonosov di Mosca
Il Rettore	Il Rettore
Prof. Rinaldo Bertolino	Accademico V.A. Sadovnichy

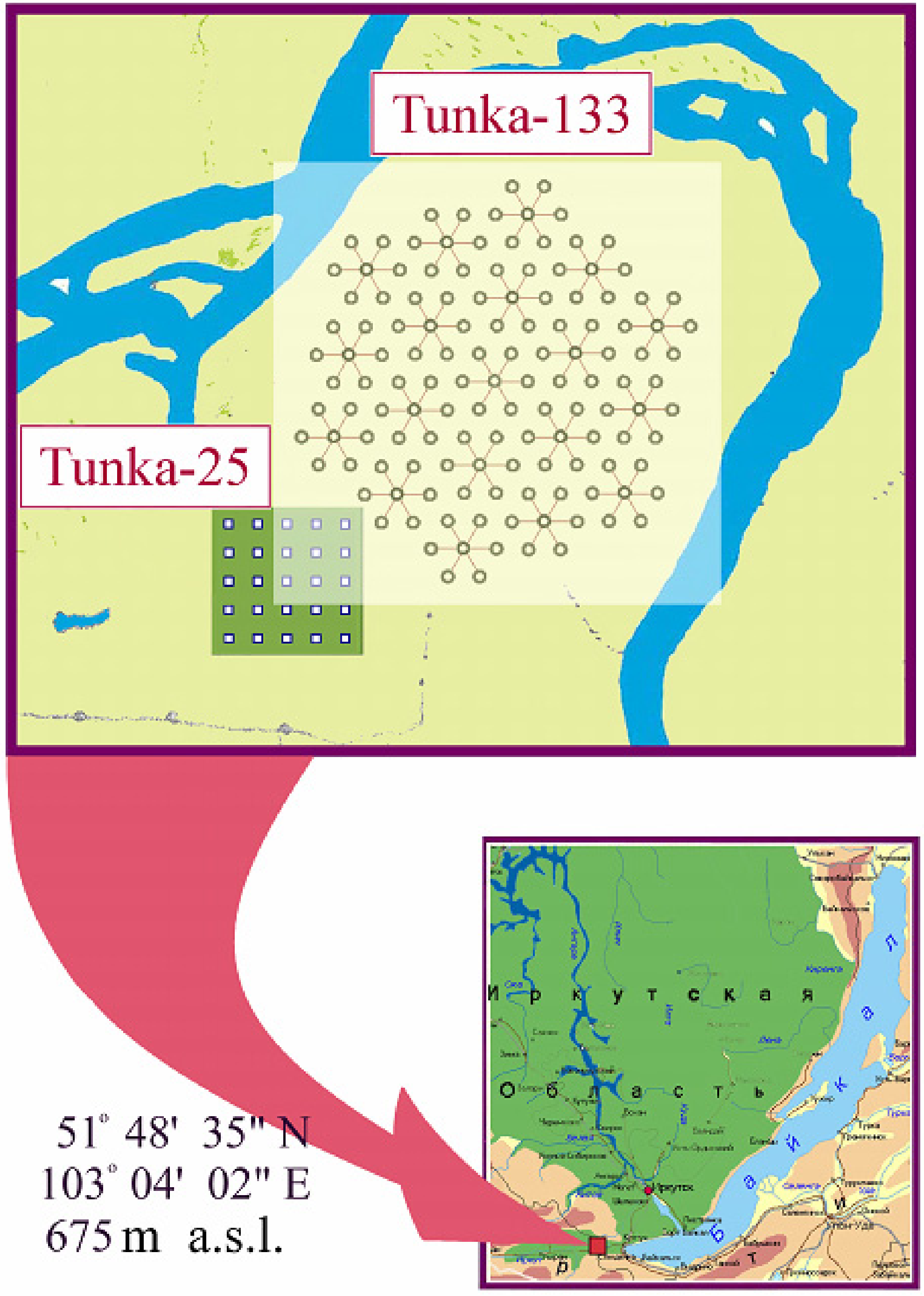
Tunka-133

133 optical detectors in the area of ~ 1 km^2
and 6 water tanks.
Energy Threshold ~ 10^{15} eV

Expected statistic from 1 year operation (400 hours):

> $3 \cdot 10^{15}$ eV	~	$5.0 \cdot 10^5$ events
> 10^{17} eV	~	300 events
> 10^{18} eV	~	2 – 3 events

Tunka array geography:
Russia, Siberia,
50 km from the Lake Baikal.



Why Tunka?

1. Good weather conditions (~ 400 hours of observation per year) and existence of accessible territory.

2. Existence of needed infrastructure: laboratory building, dormitory on 20 beds, garage, workshop.

3. 10-years experience of working with Cherenkov EAS arrays : from Tunka-4 to Tunka-25.

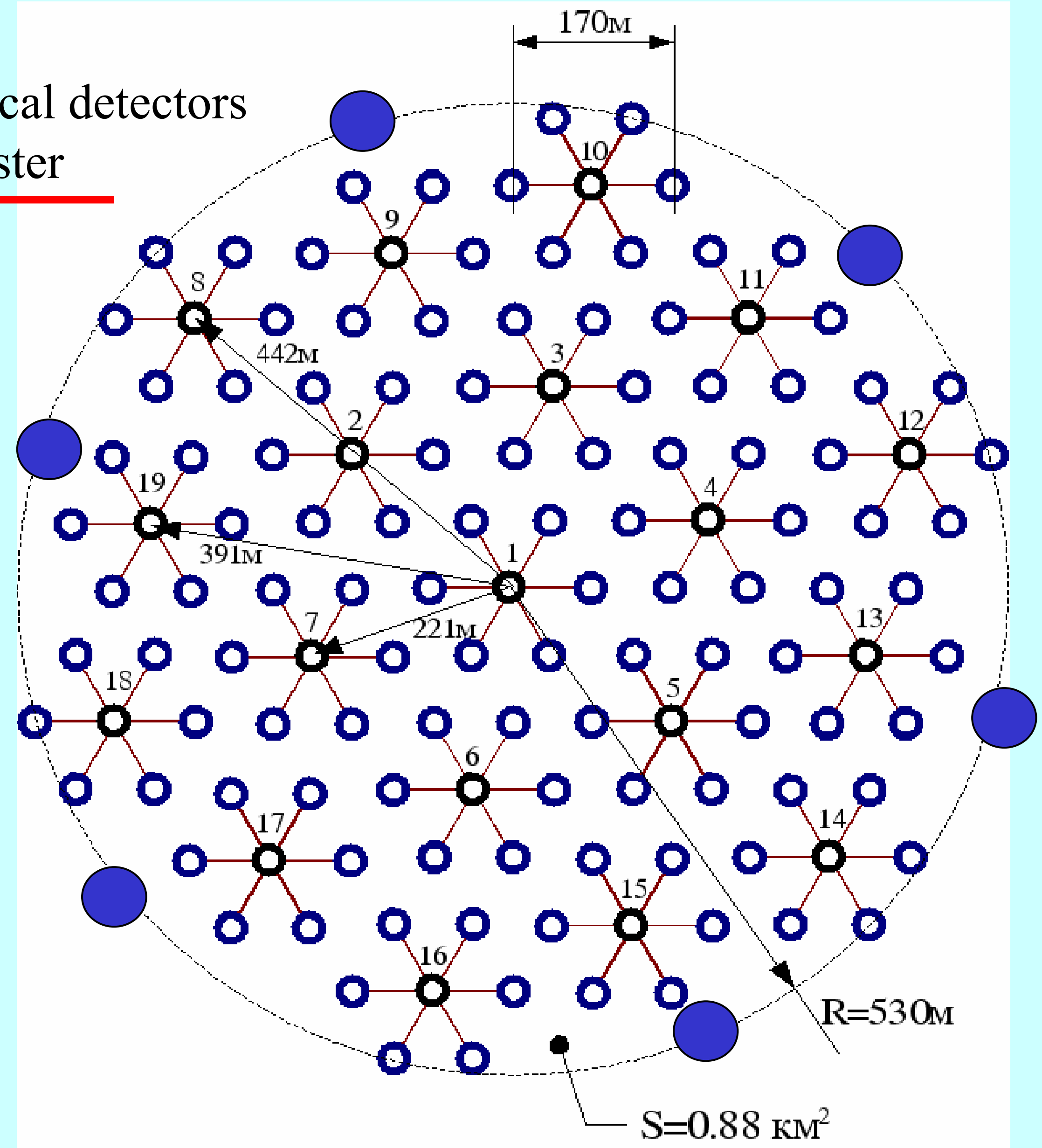
4. Considerable progress in method of EAS parameters reconstruction.

5. Existence of 200 PMTs (from INFN, MACRO) with 20 cm diameter photocathodes.

Plan of Tunka-133

Seven optical detectors form Cluster

Water tank



Accuracy of EAS parameters reconstruction

accuracy of core location ~ 6 m

accuracy of E_0 determination ~ 15%

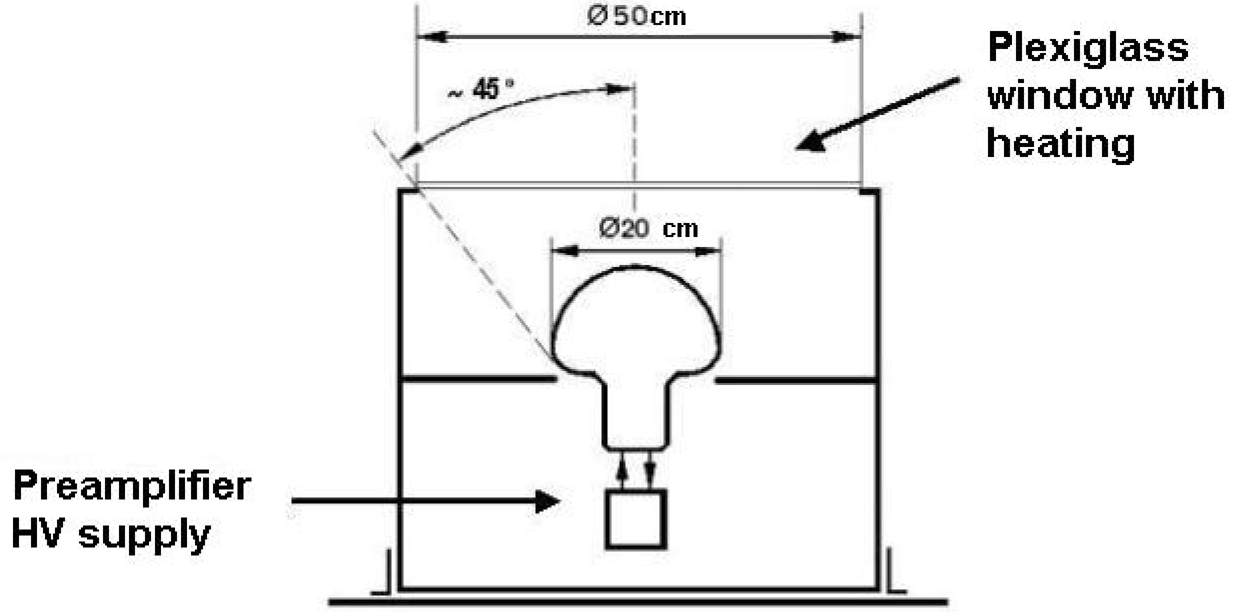
From the lateral distribution steepness

accuracy of X_{max} determination ~ 35 g/cm^2

From the pulse duration (at 250 – 350 m from the core)

accuracy of X_{max} determination ~ 25 g/cm^2

Optical detecor

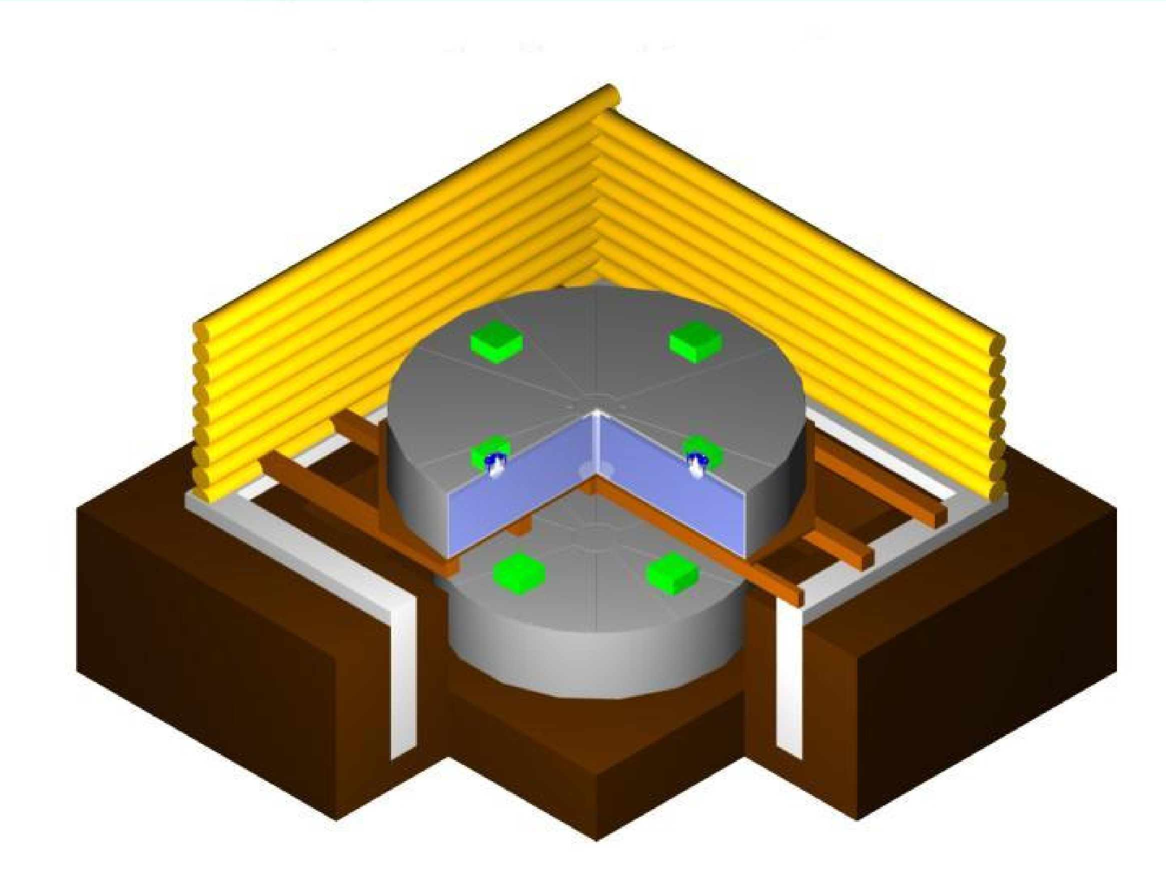


Water Cherenkov detector

S= 10 m^2, h=90 cm

2 level detector:
upper tank – e, γ
bottom tank - μ

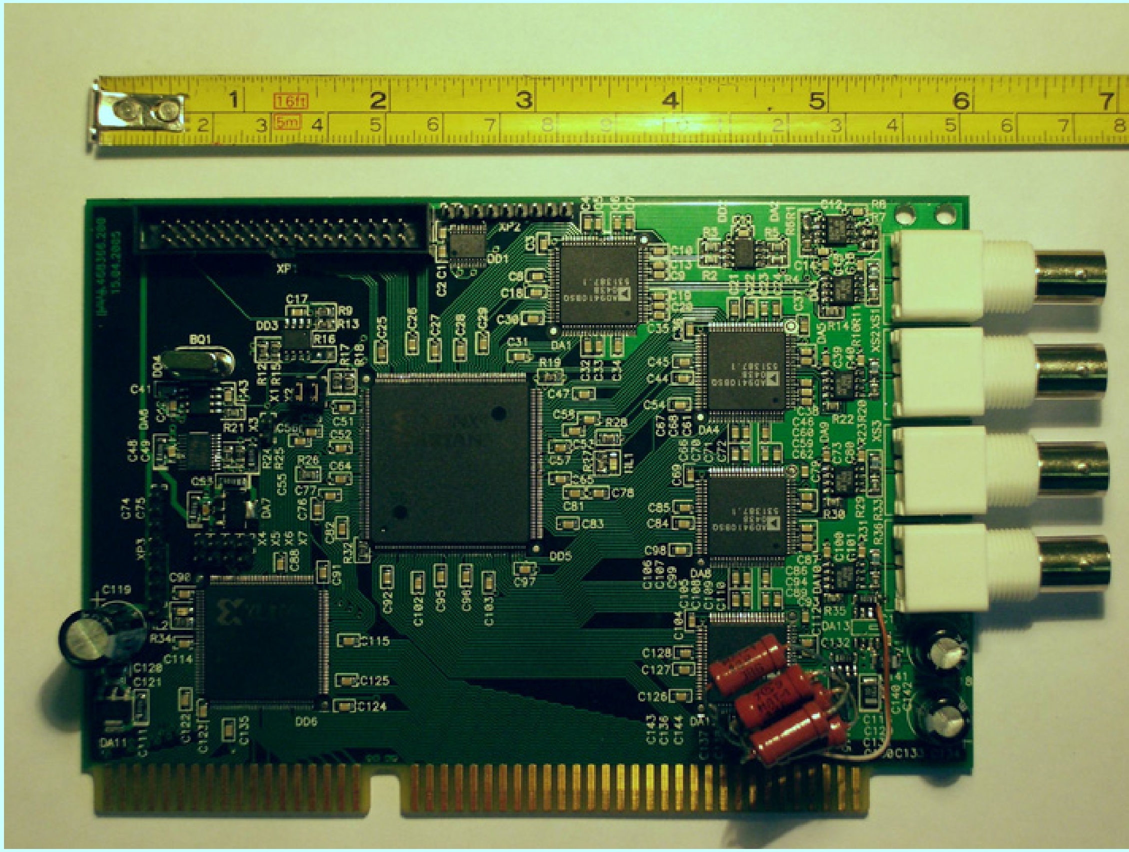
Now only bottom tanks were installed



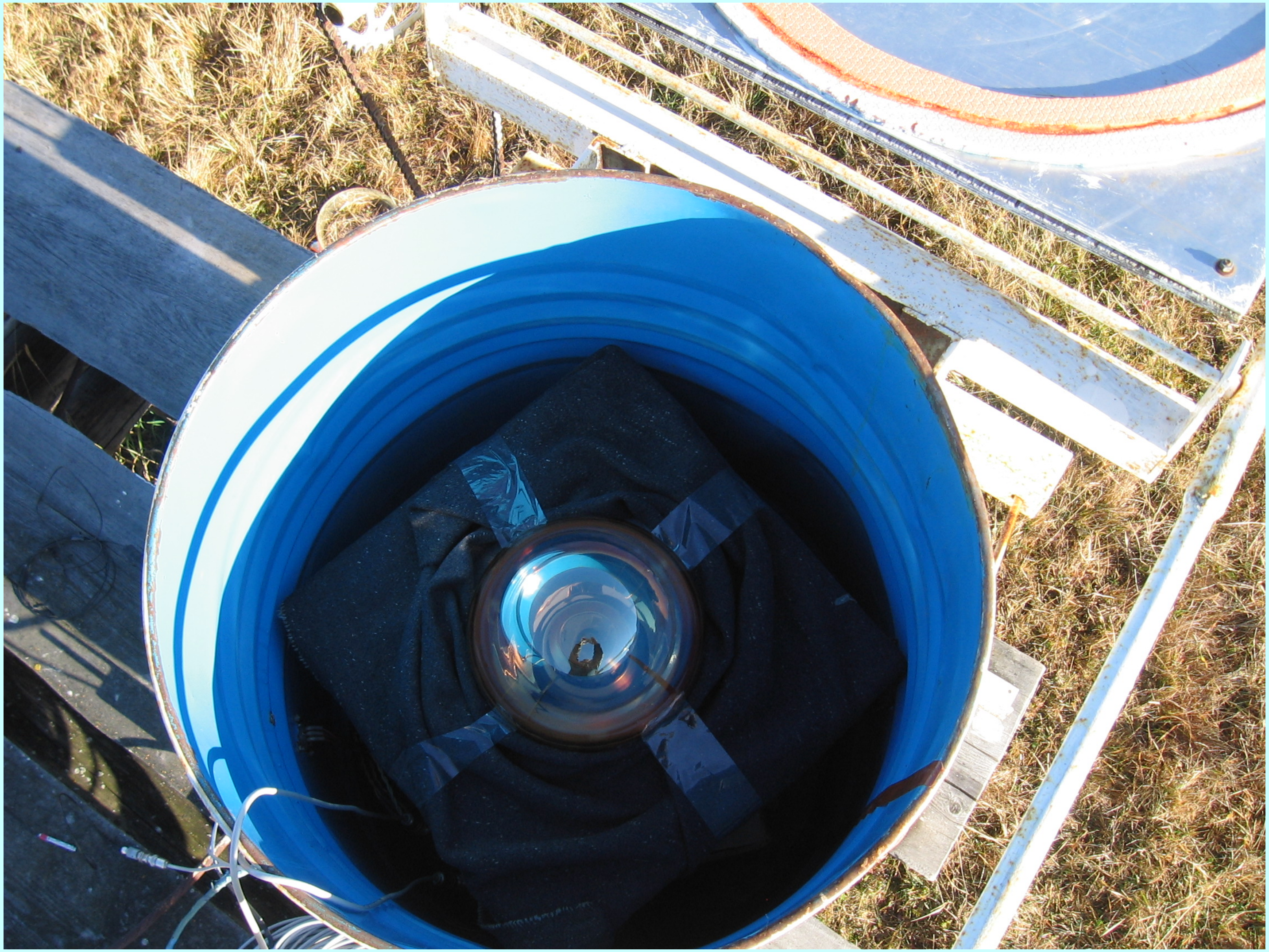
FADC FOR TUNKA-133

Tested example:
ISA-card, 4 10bit, 200 MHz ADC (AD9410)

Will be : 3U –VME,
4 12 bit, 200 MHz ADC (AD9430)



Prototype of optical detector.



Tunka Collaboration

SINP MSU (Moscow): Front-end electronics, data acquisition system, data analysis.

API (Irkutsk): Mechanical devices, array deployment.

IZMIRAN (Troitsk): The acceleration in SNR, Galactic propagation.

Torino Univ.: PMT, array calibration development, M-C simulation.

DESY-Zeuthen: Digital electronics, software.

Tunka-133

Time schedule of the array deployment

The cluster electronics partly prepared and tested. A test of the first optical detector and analog electronics in the Tunka valley has been carried out in October 2005.

The first 4 clusters (Tunka-28) will be deployed in the fall of 2006. The test operation of the array will extend over the winter season 2006-2007.

The further installation of array depends on the financial support. In case of sufficient support, the rest of array could be constructed in 2006 and 2007 and installed in Summer/Autumn 2007.


ТУНКА-133

October 2005. The center of the future array.

Conclusion

A 1-km^2 array in the Tunka valley (Buratia, Siberia) is planned to record EAS from cosmic rays of super-high energies by their Cherenkov light. It will allow to study cosmic rays by a single method covering uniformly the energy range $10^{15} – 10^{18}$ eV.

This includes the classical knee at $\sim 3 \cdot 10^{15}$ eV as well as the second knee at a few 10^{17} eV, allowing to study features of the spectrum probably connected with the transition from galactic to extra-galactic cosmic rays.

With this installation we are going to study up to which maximal energy particles in supernova remnants are accelerated and will also provide a low – energy calibration to much larger installations like Auger.

Array may be constructed and give first results in 2-3 years.

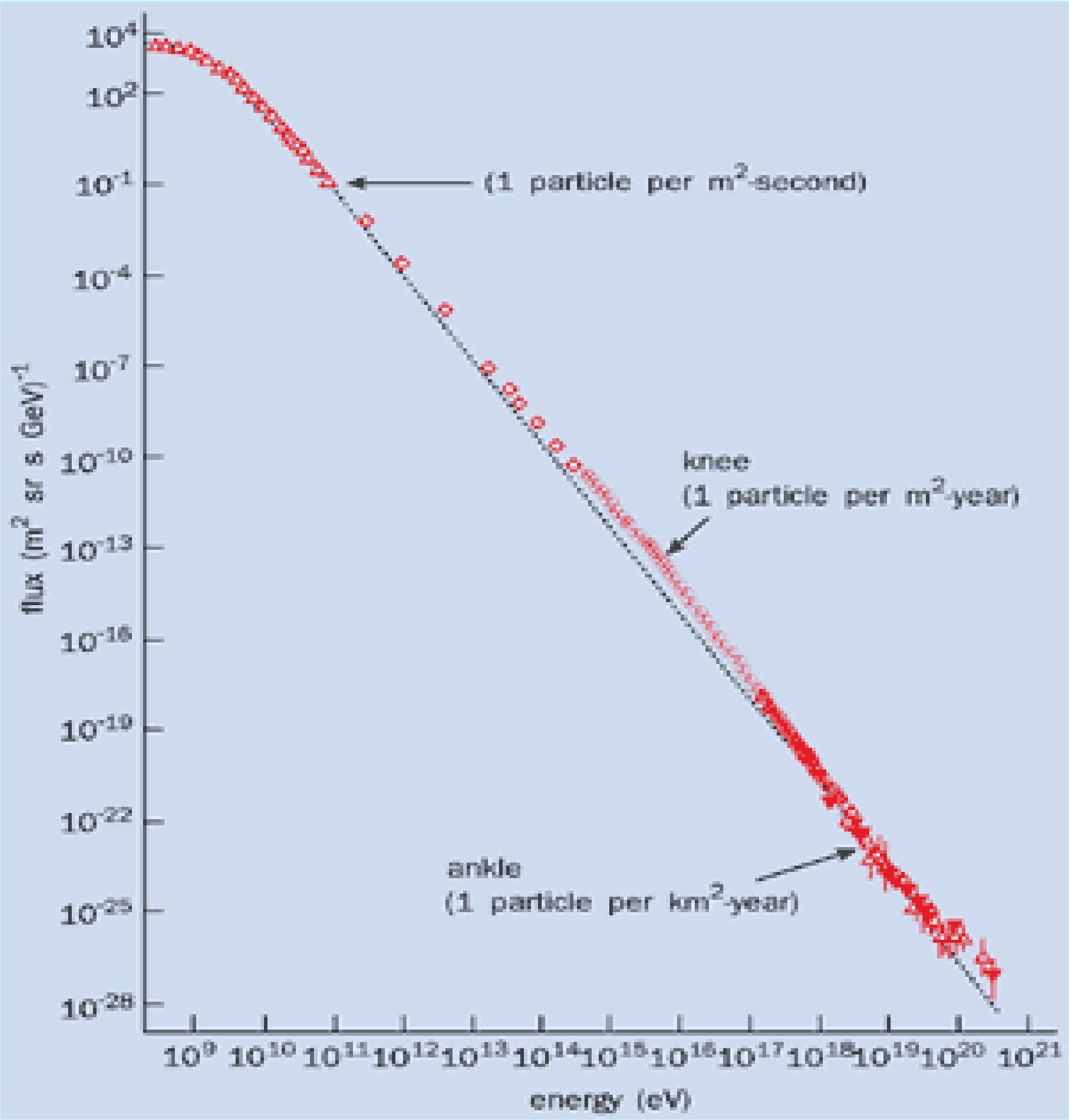
Is there second knee in cosmic rays spectrum?

Akeno - $6 \cdot 10^{17}$ эВ

Fly's Eye - $4 \cdot 10^{17}$ эВ

HiRes - $7 \cdot 10^{17}$ эВ

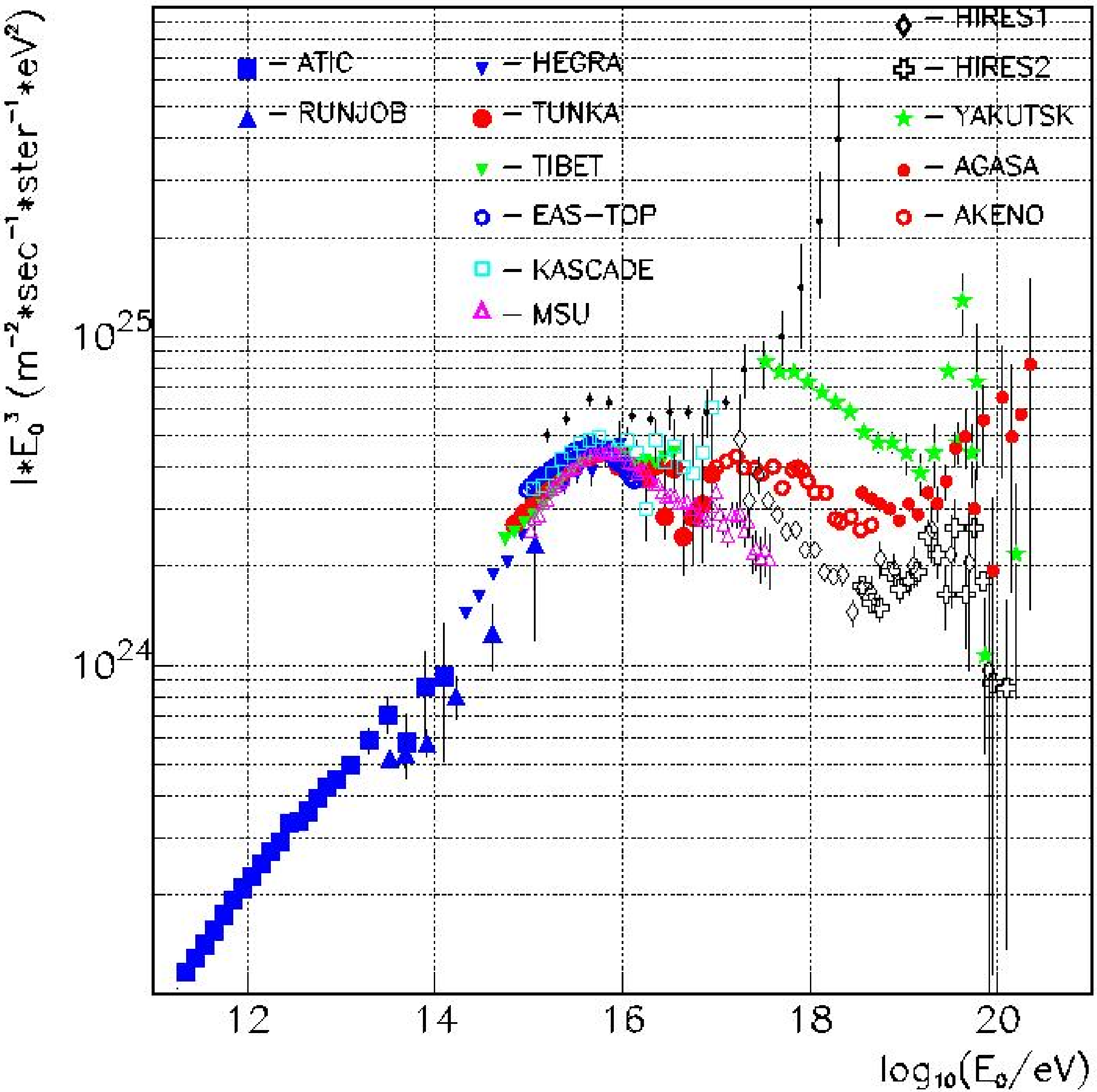
Якутск - $8 \cdot 10^{17}$ эВ



10^4
10^2
10^-1
10^-4
10^-7
10^-10
10^-13
10^-16
10^-19
10^-22
10^-25
10^-28
flux (m^2 sr s GeV)^-1
(1 particle per m^2-second)
knee
(1 particle per m^2-year)
ankle
(1 particle per km^2-year)
10^9 10^10 10^11 10^12 10^13 10^14 10^15 10^16 10^17 10^18 10^19 10^20 10^21
energy (eV)

Cost of the array (in thousand EUR)

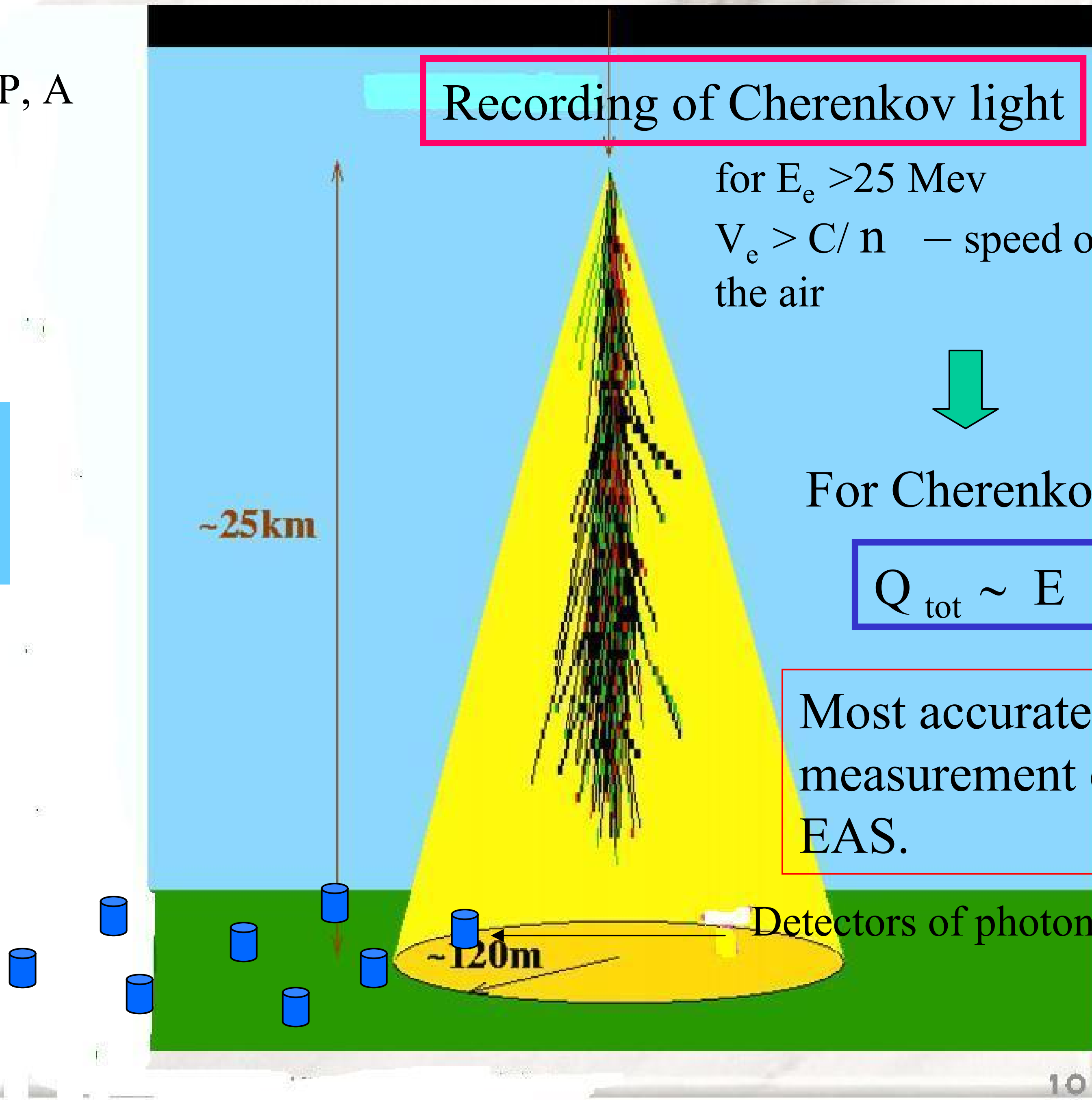
1.Electronic -	80
2. Mechanical devices –	70
3. Cables	-30
Total	180



ATIC
RUNJOB
HEGRA
TUNKA
TIBET
EAS-TOP
KASCADE
MSU
HIRES1
HIRES2
YAKUTSK
AGASA
AKENO
$I*E_0^3$ (m^{-2}*sec^{-1}*$ster^{-1}$*eV^2)
10^{25}
10^{24}
12
14
16
18
20
$log_{10}(E_0/eV)$

P, A

20-30км



Recording of Cherenkov light

for E_e >25 Mev

$V_e > C/n$ – speed of ligh in the air

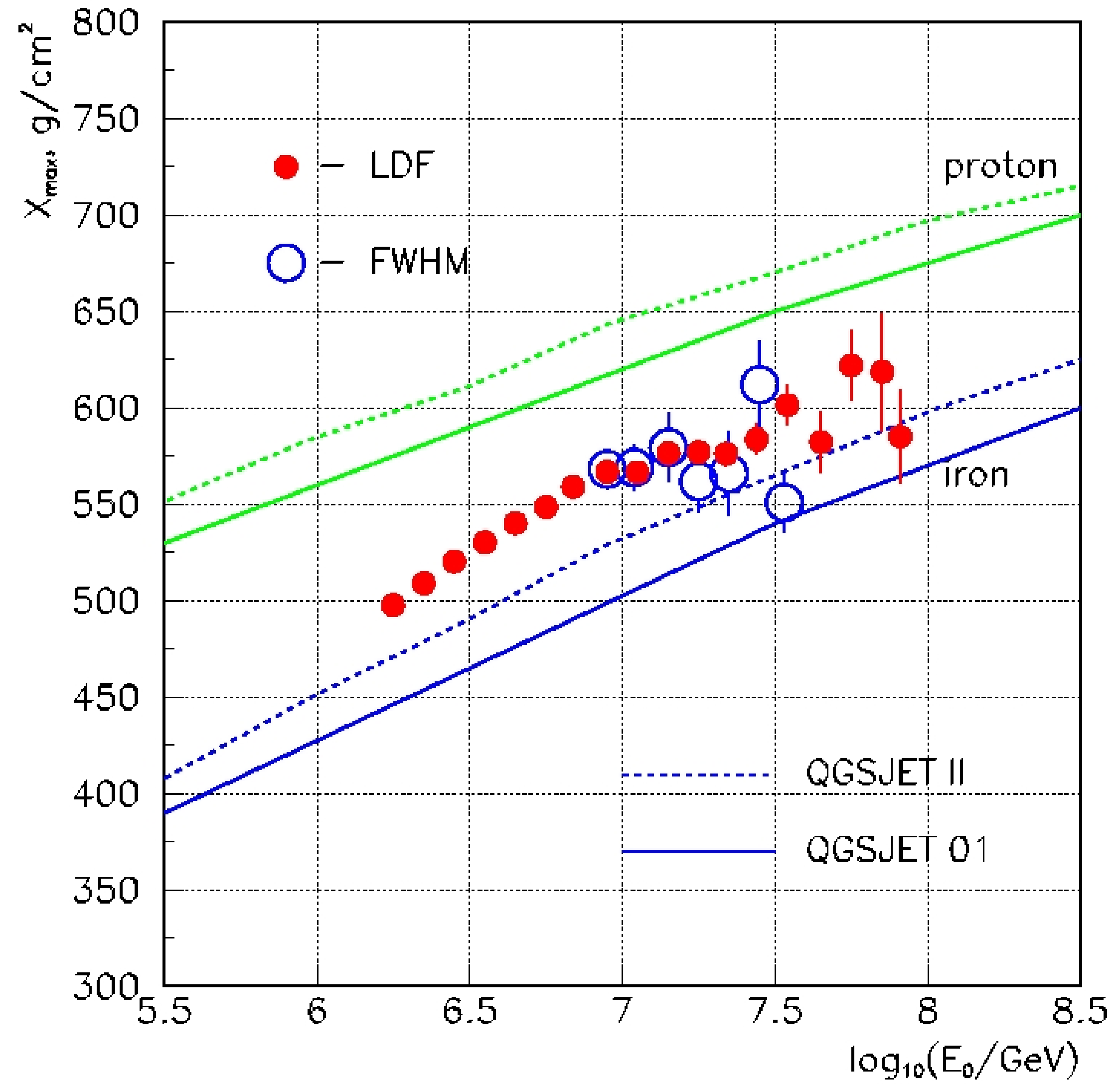
For Cherenkov light

$Q_{tot} \sim E$

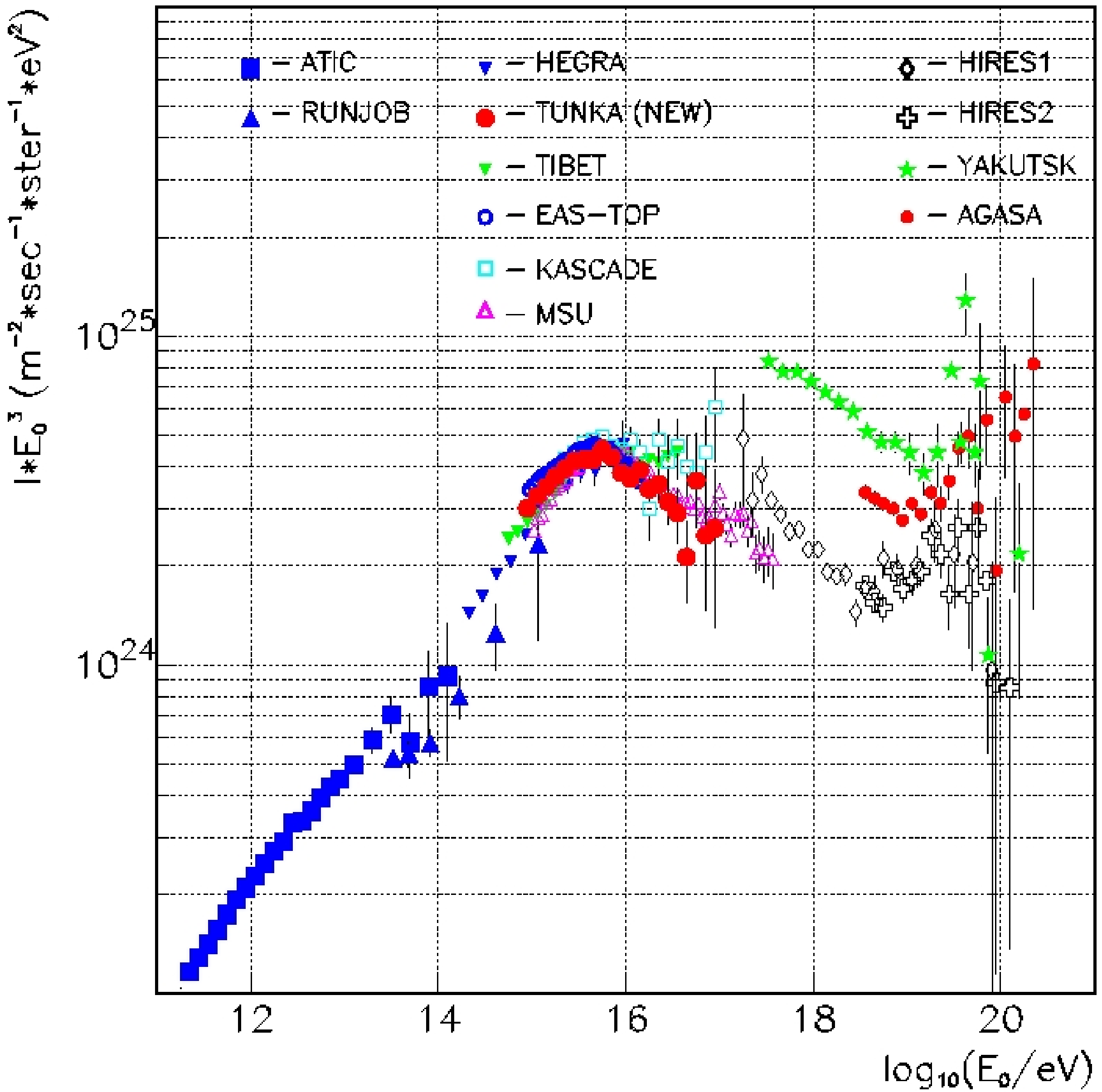
Most accurate method for measurement energy of EAS.

Detectors of photons

Mean depth of EAS maximum



Some recent primary energy spectrum, data



The region above 10^{16} is of crucial importance for understanding of the origin and propagation of cosmic rays in the Galaxy.

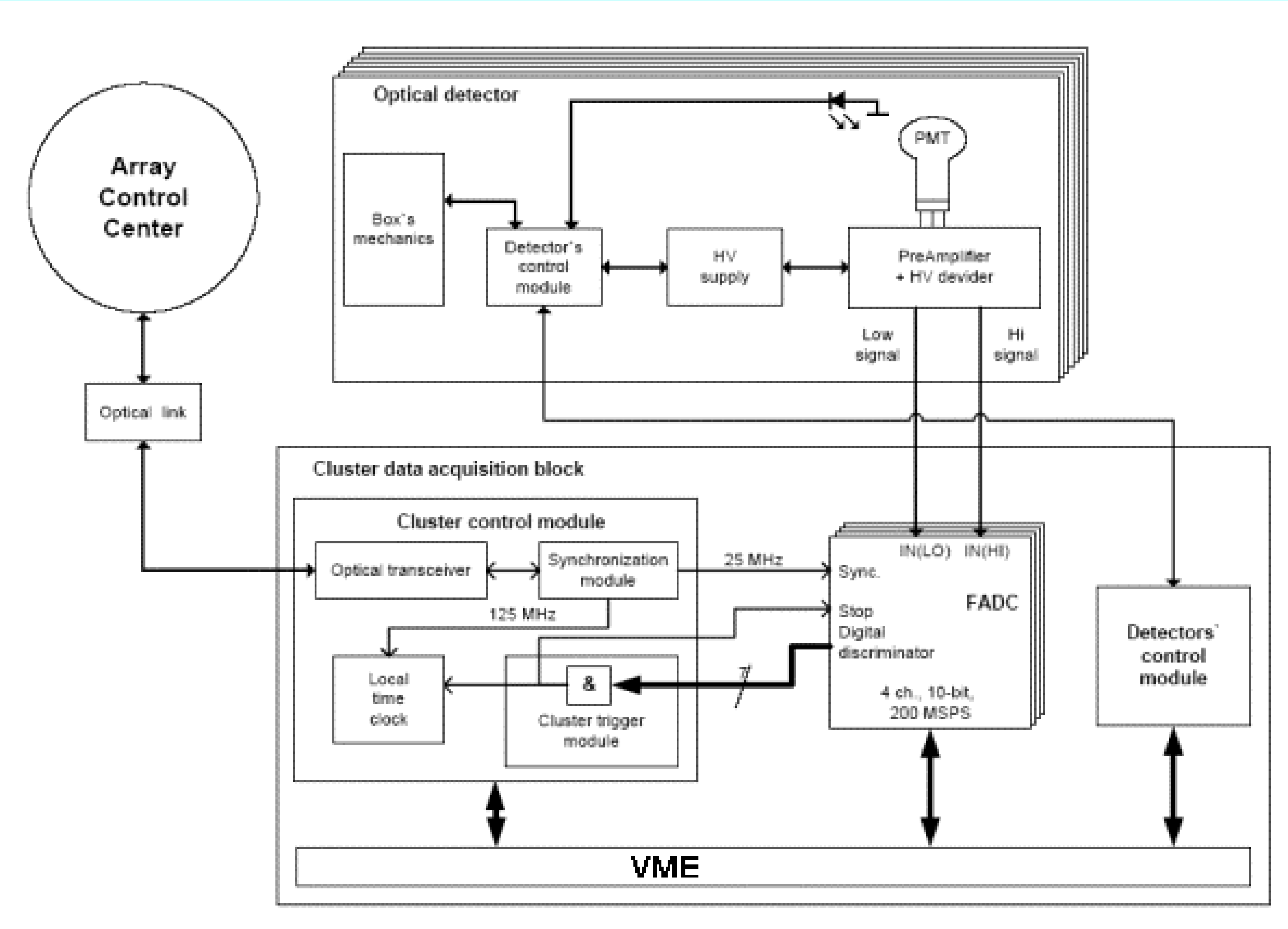
- Is there an "iron knee" above the classical knee at $3 \cdot 10^{15}$ eV? The identification of an iron knee could provide a final understanding of this region.

- What is the mass composition above a possible iron knee? Is this region dominated by sources different to supernova remnants?

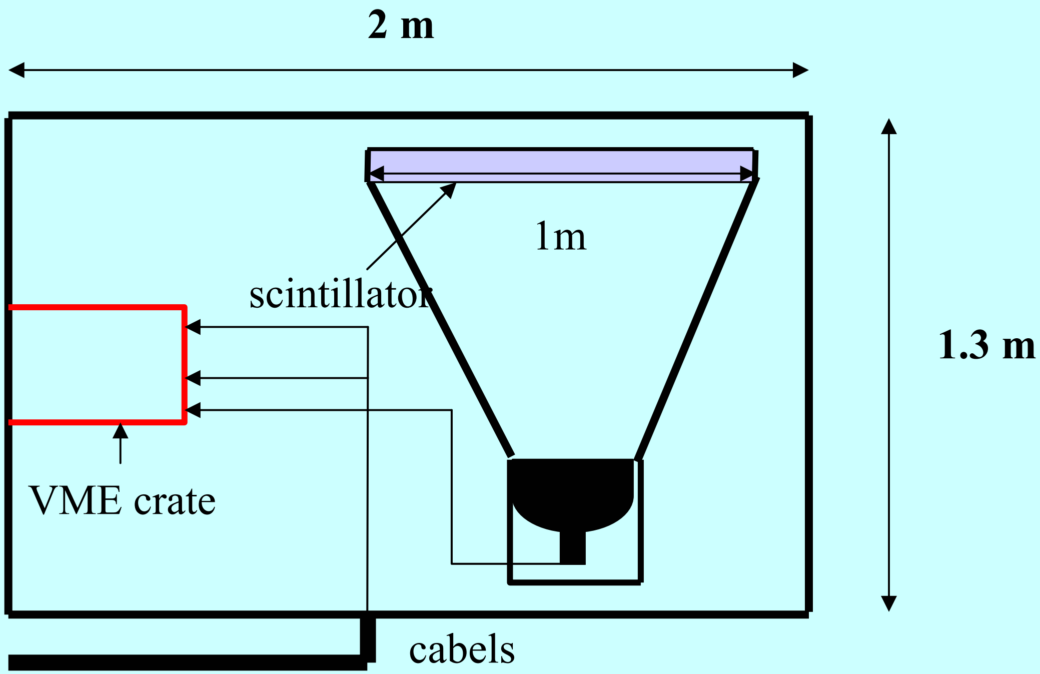
- What is the nature of the observed "second knee" at $3\text{-}5 \cdot 10^{17}$ eV? Is it caused by end of the galactic component?

- What is the relation between cut-off effects due to leakage out of Galaxy and cut-off effects due to maximum energies in sources?

Cluster Electronic



Cluster Electronic Box



Tunka-Italian cooperation : past and future

Past

1. Common INTAS grant in 1998-2000 for construction Tunka-25
2. Installing 5 QUASAR-370 for common operation with EAS-TOP (Experiment QUEST) – 1998-2000
3. M-C simulation and data analysis. Methods of absolute energy calibration for Cherenkov EAS arrays – 2000-2003
4. Tunka-133 project. 200 PMT from GRAN SASSO LAB. for new array. New INTAS application (successfully passing 1 stage) 2003-2005.

Tunka-Italian cooperation : past and future

Future

1. Preparing software for Tunka-133 date acquisition system.
2. Exchange students for passing practice in running and evaluating of KASKADE-Grande and Tunka-133.
3. Performing M-C simulation for Tunka-133 completing experience of sites in detecting Cherenkov light and charge particles (especially in water tank methodic).
4. Discussion of experimental results and preparing publication.
5. Support from Theory.

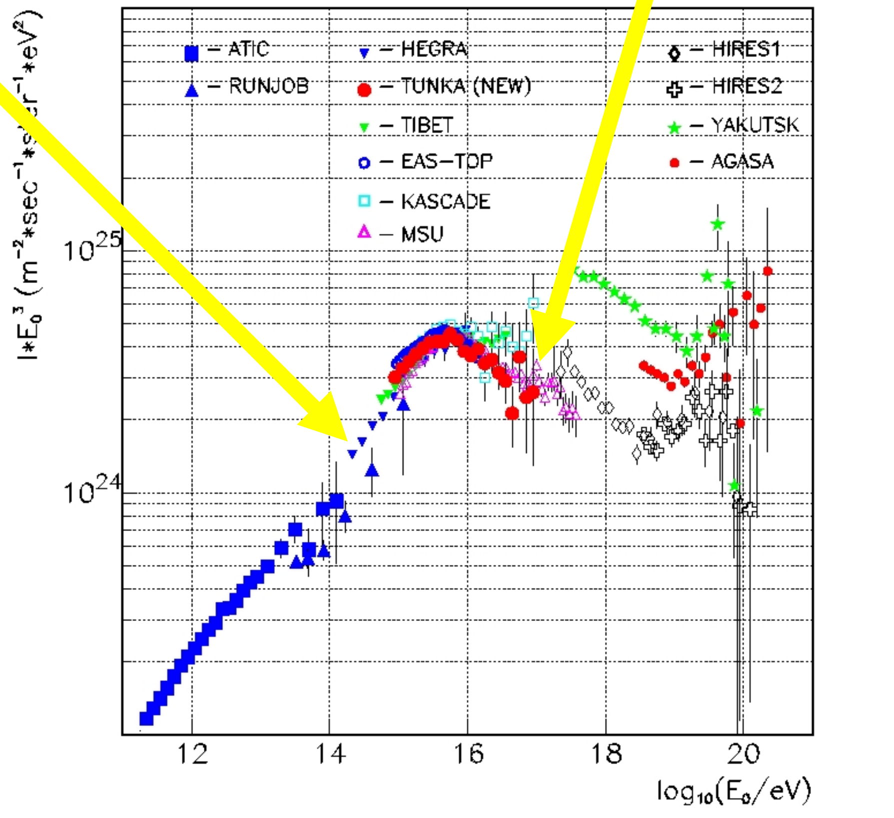
FURTHER STEPS

10^{14} - 10^{15} eV

25 sphere mirrors of 1 m in diameter - 2005-2007.

10^{16} - 10^{18} eV

TUNKA-133 project 2005 - 2007 - …



Approach to the mass composition

Primary nucleus E_0 , A?

$\langle X_{max} \rangle \sim \langle \ln A \rangle$

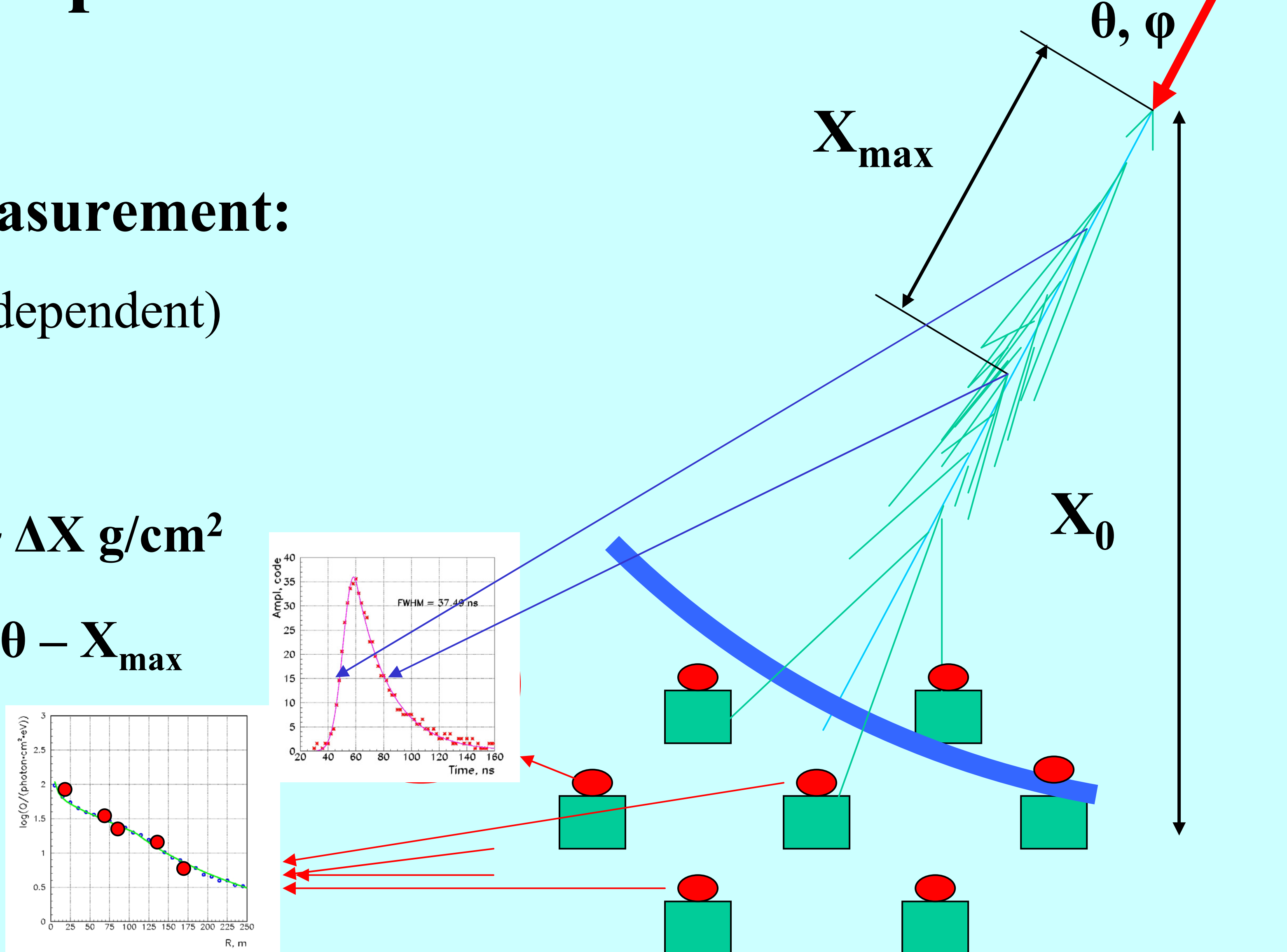
X_{max} **measurement:**

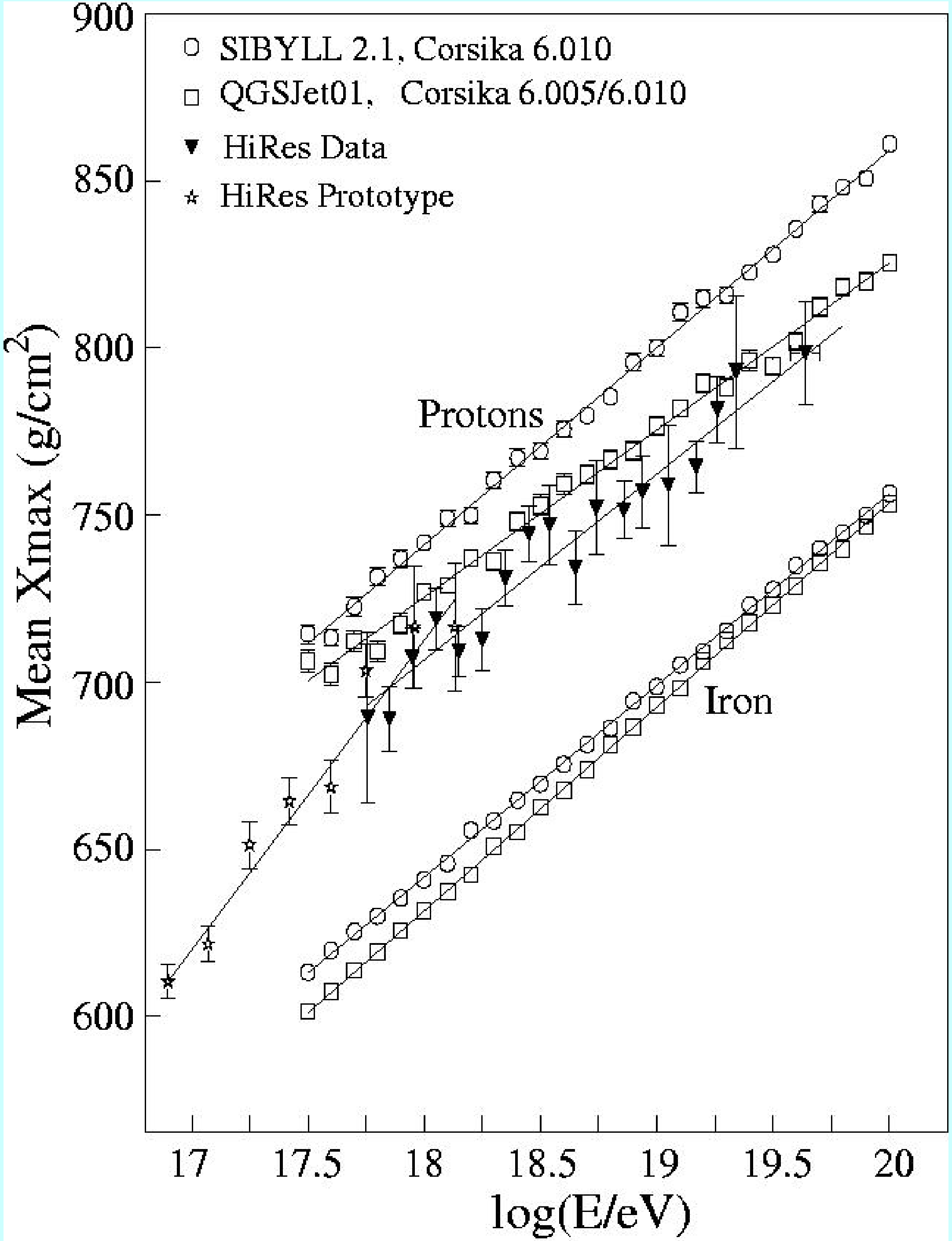
(model independent)

2. FWHM ~ ΔX g/cm^2

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

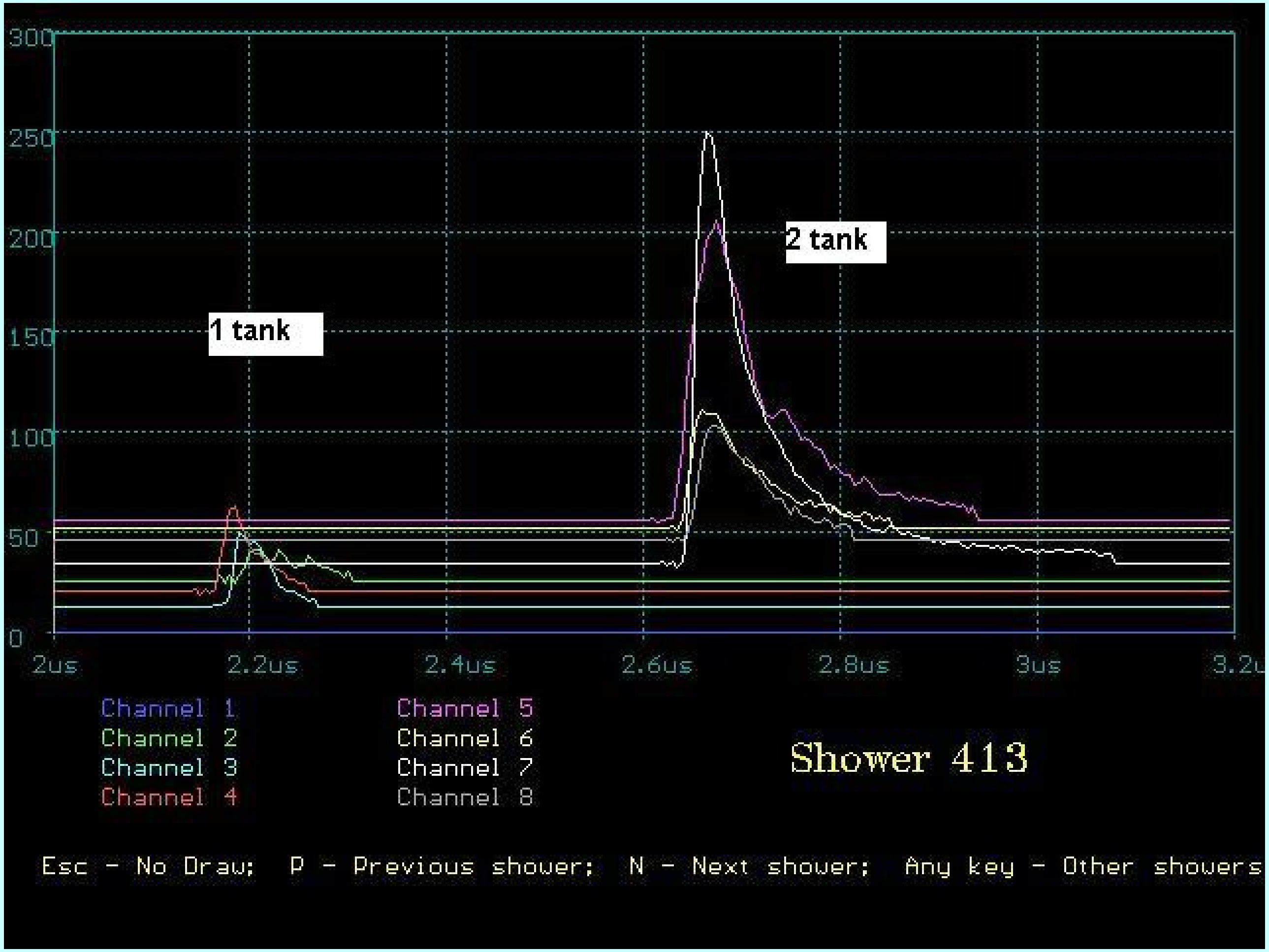
1. LDF steepness



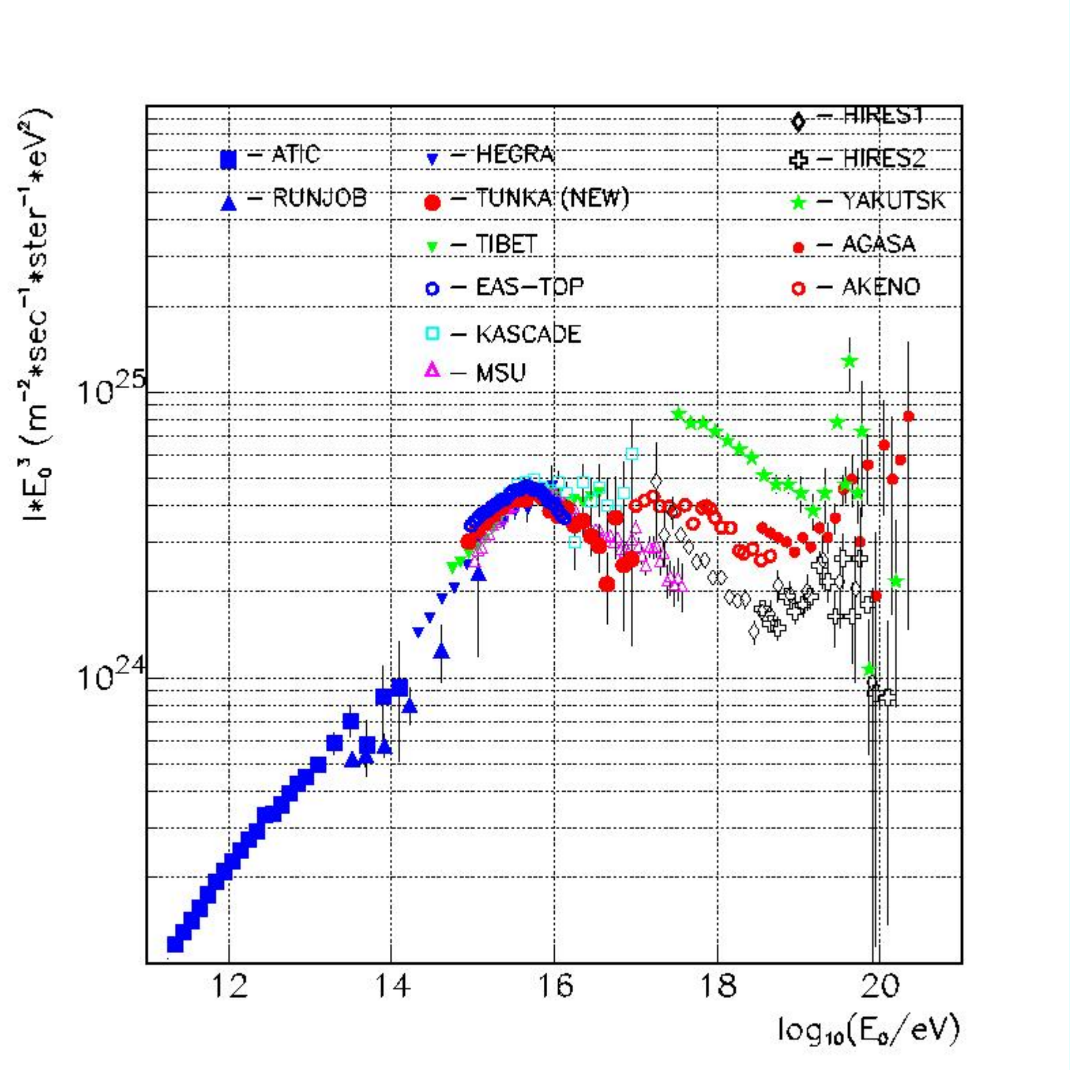


SIBYLL 2.1, Corsika 6.010
QGSJet01, Corsika 6.005/6.010
HiRes Data
HiRes Prototype
Protons
Iron
Mean Xmax (g/cm^2)
log(E/eV)
900
850
800
750
700
650
600
17
17.5
18
18.5
19
19.5
20

Example of event (in water tanks)



Motivation for Tunka-133: energy range $10^{16} – 10^{18}$ eV has been covered by very few experiments. Energy spectra determined by different experiments differ significantly, mostly due to the difficulties in proper energy calibration



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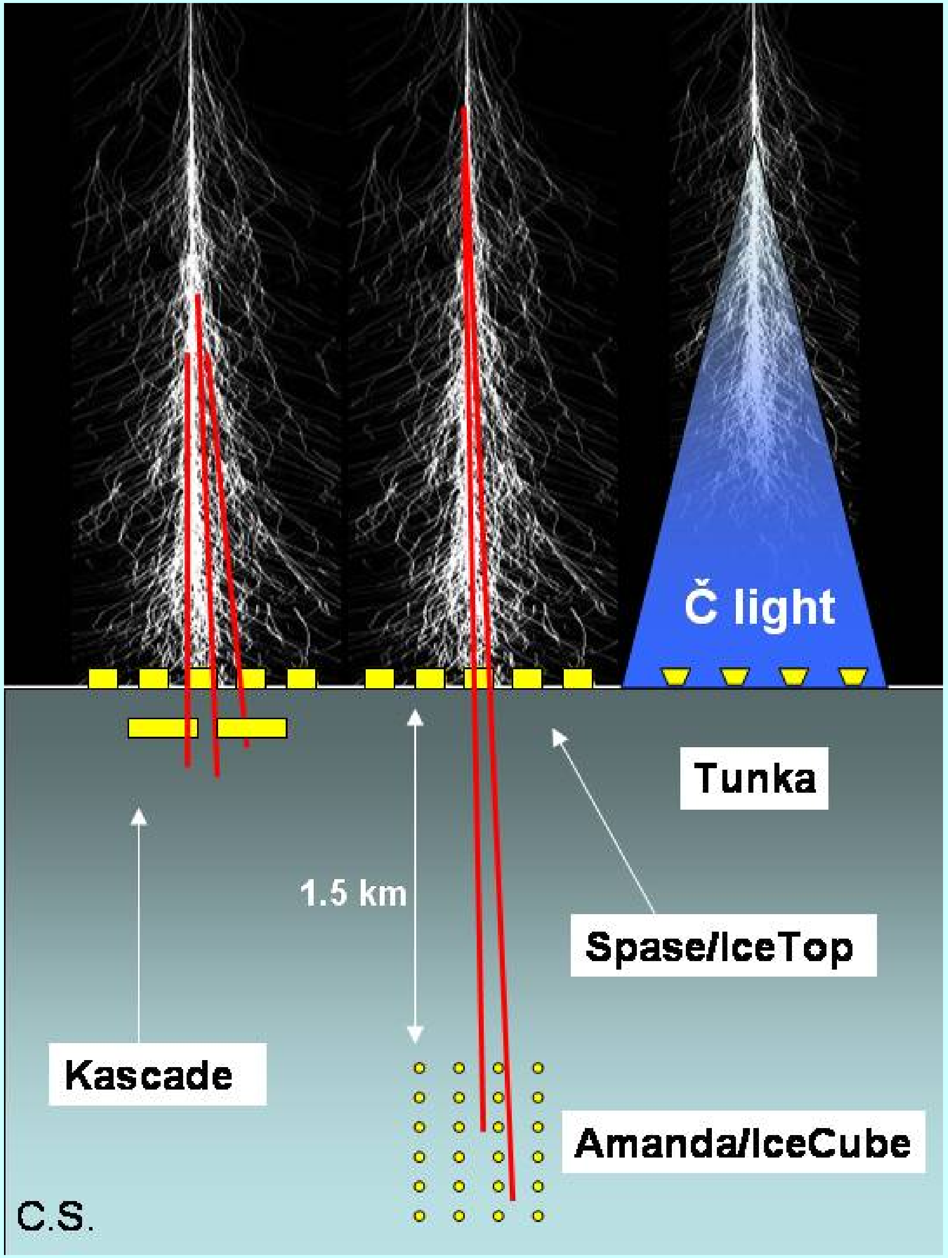

A trinity of detectors complementing each other: KASKADE-Grande, Space/IceTop, Tunka

Коллаборация ТУНКА. Пуск установки ТУНКА-25, октябрь 2000 г.

Differential energy spectrum: power law fitting

300 hours

θ<25°

140000 events

10000 events with $\mathbf{E_0} > 3 \cdot 10^{15}$ eV