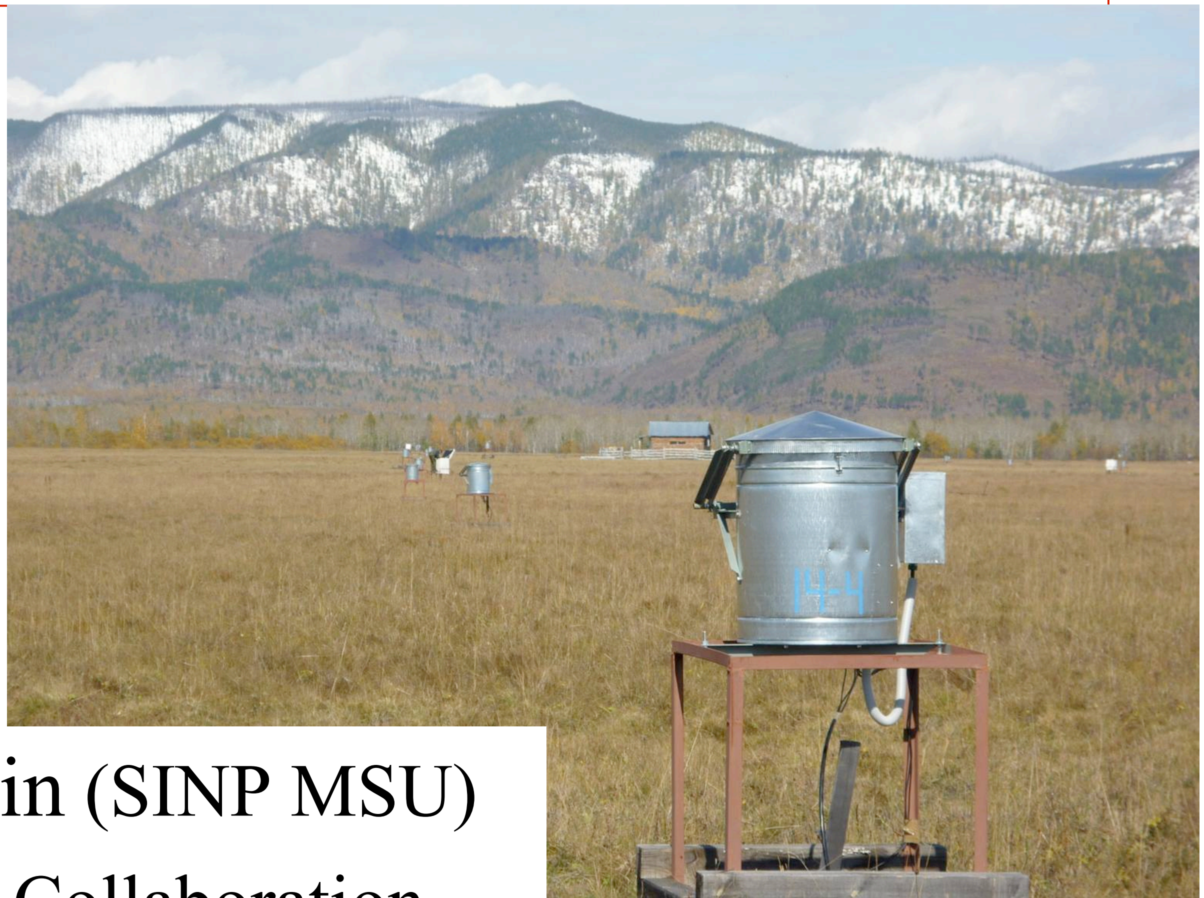
Tunka-133: Methods of Extensive Air Shower Parameters Reconstruction



Vasily Prosin (SINP MSU)

For the Tunka Collaboration

22th ECRS, Turku 2010

Gianni Navarra include to the Tunka experiments from 1995 to 2009

1. The first INTAS grant and contacts with A.M. Hillas (1995 – 2006)
2. Experiment QUEST at EAS-TOP (1998 – 2000)
3. PMT for Tunka-133 from MACRO and some other electronics parts (2002 – 2009)
4. The first CORSIKA simulation made by his PhD student (2000 – 2003)
5. Discussion of methods of analysis and common publications from 2003 to 2009

Gianni Navarra include to the Tunka experiments from 1995 to 2009

Tunka Collaboration

**B.V. Antokhanov, S.F. Beregnev, N.N. Kalmykov, E.E. Korosteleva, N.I. Karpov,
V.A. Kozhin, L.A. Kuzmichev, M.I. Panasyuk, V.V. Prosin, A.A. Silaev,
A.A. Silaev(ju), A.V. Skurikhin, I.V. Yashin, A.V. Zablotsky**
– Skobeltsyn Inst. of Nucl. Phys. of Lomonosov Moscow State Univ., Moscow, Russia;

**N.M. Budnev, A.V. Dyachok , O.A. Chvalaev, O.A. Gress, A.V. Korobchenko, R.R. Mirgazov,
L.V. Pan'kov, Yu.A. Semeney, A.V. Zagorodnikov**
– Inst. of Applied Phys. of Irkutsk State Univ., Irkutsk, Russia;

B.K. Lubsandorzhiev, B.A. Shaibonov(ju)
– Inst. for Nucl. Res. of Russian Academy of Sciences, Moscow, Russia;

V.S. Ptuskin
– IZMIRAN, Troitsk, Moscow Region, Russia;

Ch. Spiering, R. Wischnewski
– DESY-Zeuthen, Zeuthen, Germany;

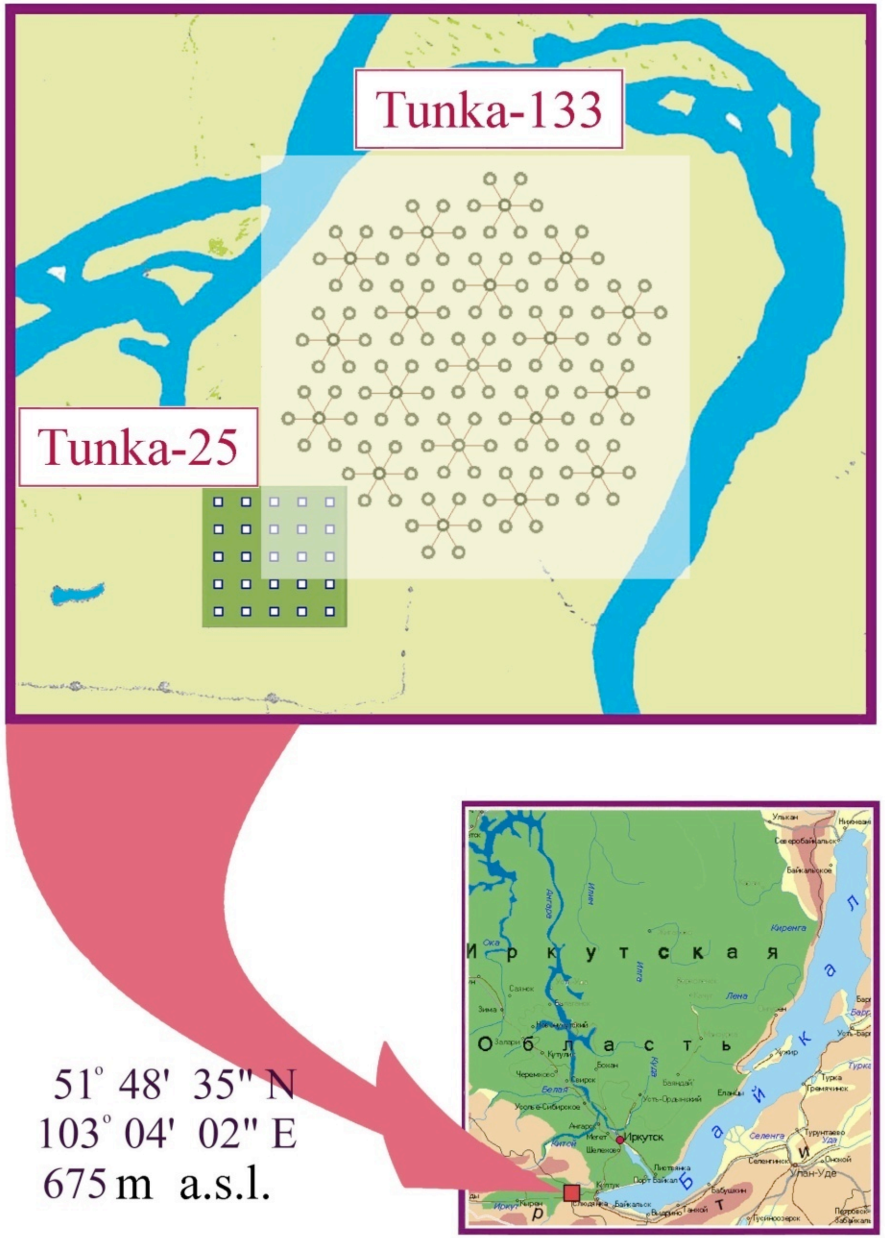
A. Chiavassa
– Dip. di Fisica Generale Universita' di Torino and INFN, Torino, Italy.

D. Besson, J. Snyder, M. Stockham
– Department of Physics and Astronomy, University of Kansas, USA

TUNKA array geography:

RUSSIA, Siberia, 50 km form Lake Baikal

http://dbserv.sinp.msu.ru/tunka



The array deployment

The detector installation

Optical cables

PMT prerparing

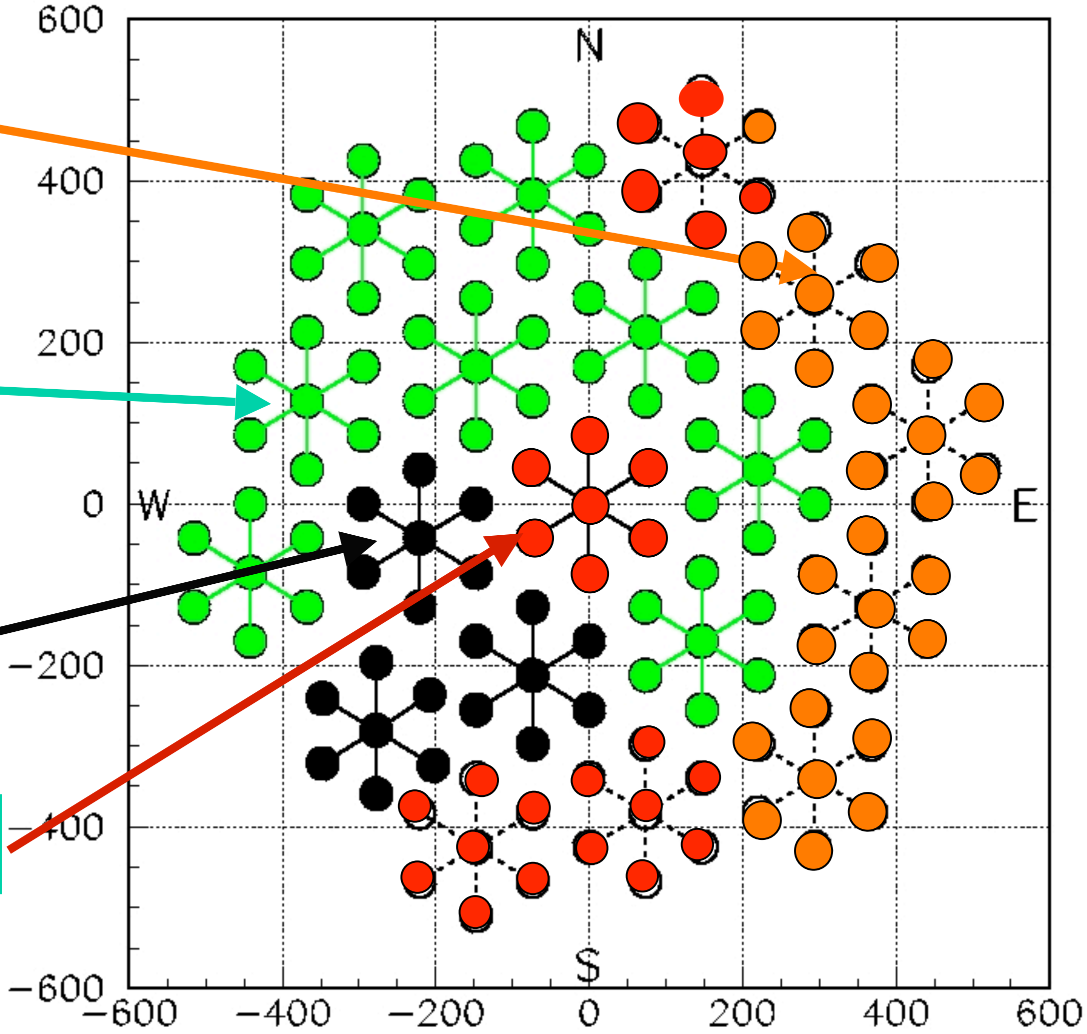
Tunka-133 deployment

2009 – 19 clusters

2008 – 12 clusters

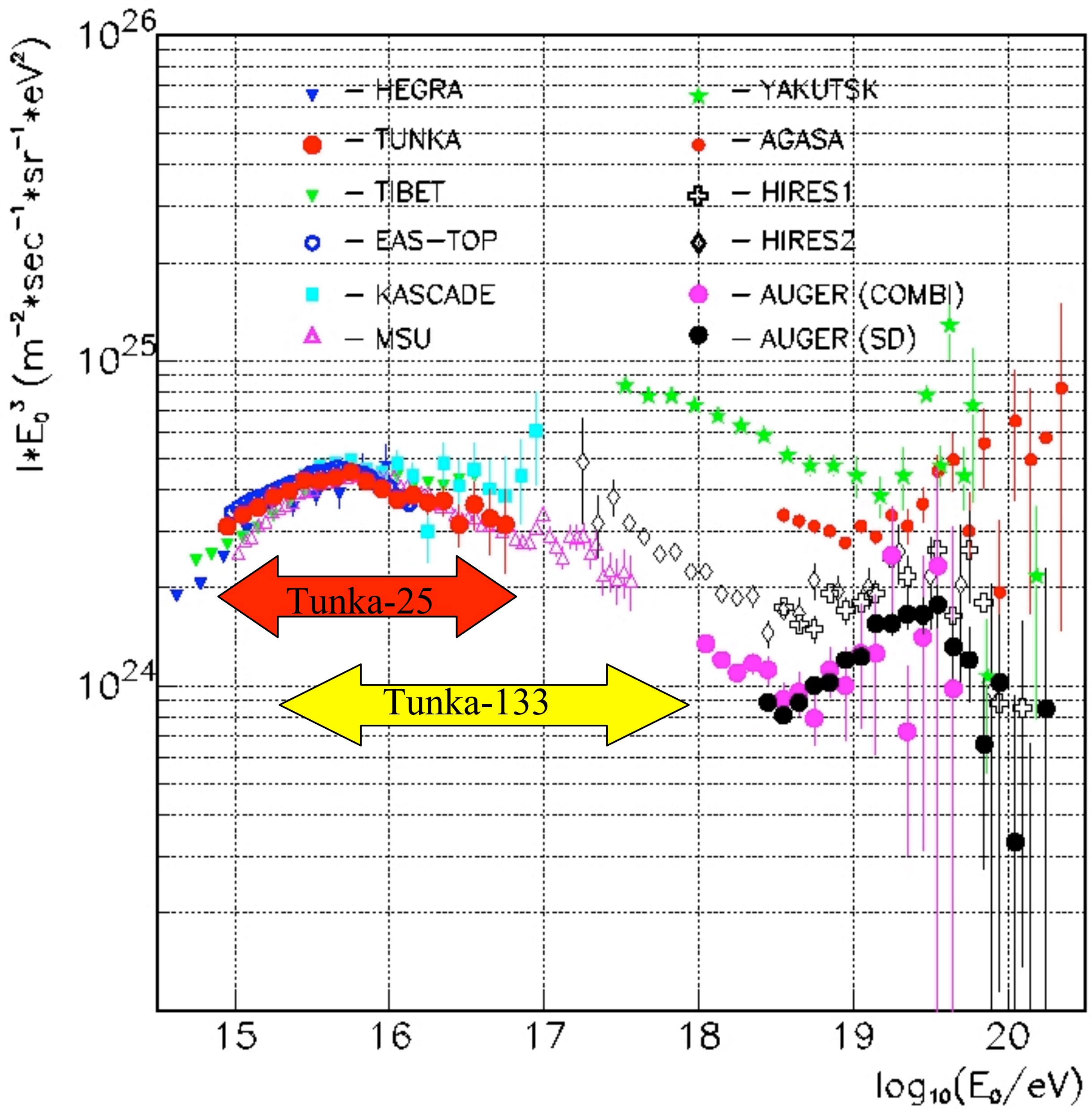
2007 – 4 clusters

2006 – the first cluster

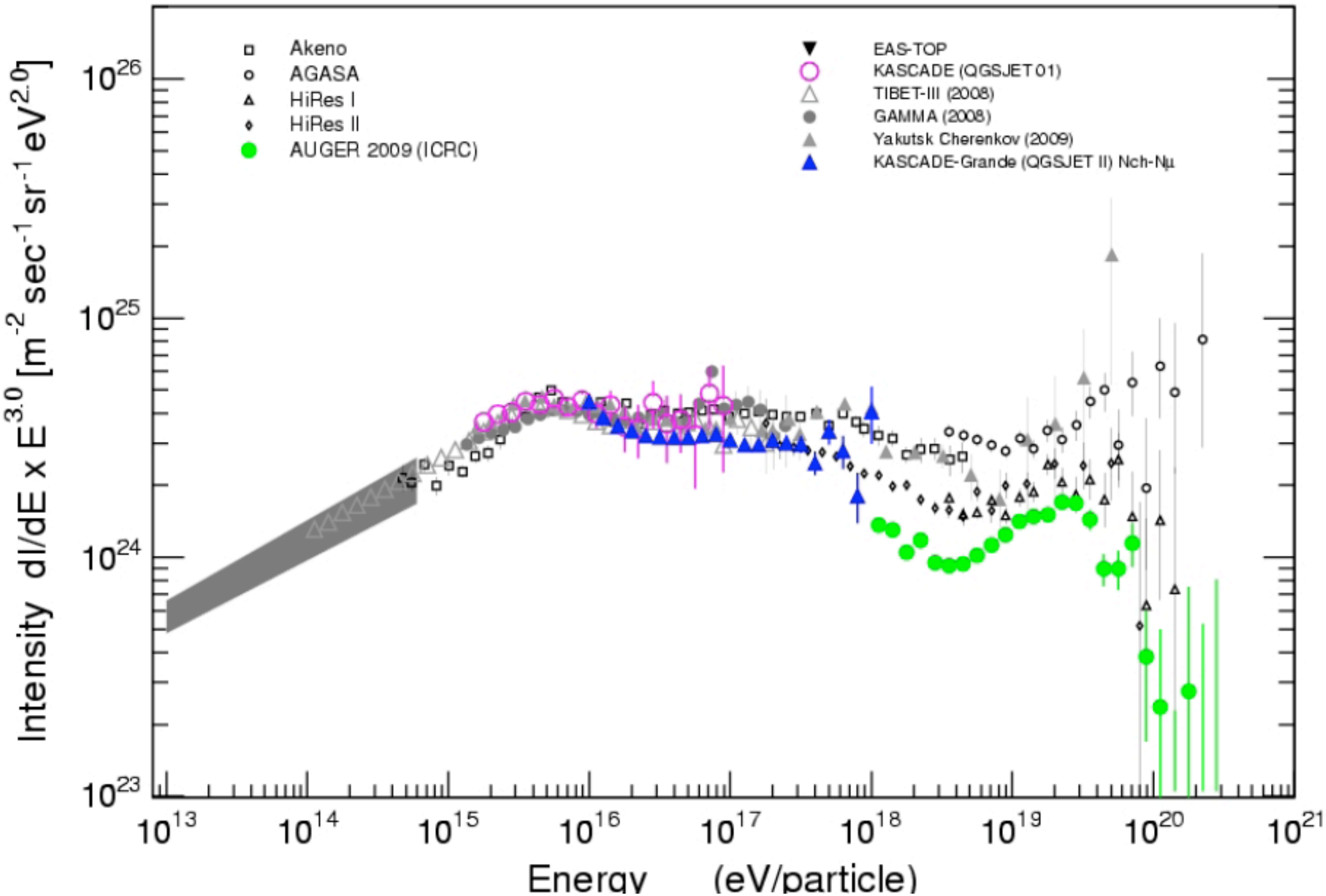


Tunka-133 inauguration: September 2009

Measuring of the detectors coordinates (x,y,z) – accuracy ~ 10 cm.



10^{26}
10^{25}
10^{24}
$I*E_0^3$ ($m^{-2}*sec^{-1}*sr^{-1}*eV^2$)
– HEGRA
– TUNKA
– TIBET
– EAS–TOP
– KASCADE
– MSU
– YAKUTSK
– AGASA
– HIRES1
– HIRES2
– AUGER (COMBI)
– AUGER (SD)
Tunka-25
Tunka-133
15
16
17
18
19
20
$\log_{10}(E_0/eV)$


Akeno
AGASA
HiRes I
HiRes II
AUGER 2009 (ICRC)
EAS-TOP
KASCADE (QGSJET 01)
TIBET-III (2008)
GAMMA (2008)
Yakutsk Cherenkov (2009)
KASCADE-Grande (QGSJET II) Nch-Nμ
Intensity dI/dE x E^3.0 [m^-2 sec^-1 sr^-1 eV^2.0]
Energy (eV/particle)
10^13
10^14
10^15
10^16
10^17
10^18
10^19
10^20
10^21
10^23
10^24
10^25
10^26

Primary nucleus $\mathbf{E_0}$, **A**?

1. $\mathbf{E_0} \sim \mathbf{Q_{175}}$ – Cherenkov light flux

2. $\mathbf{X_{max}}$(model independent):

$\underline{\mathbf{X_{max}}} = \mathbf{Xp} - \delta \mathbf{X_{max}} / \delta \mathbf{lnE} \cdot \underline{\mathbf{lnA}}$

Two methods:

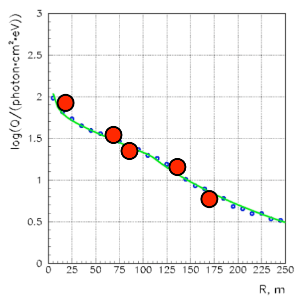
Pulse width:

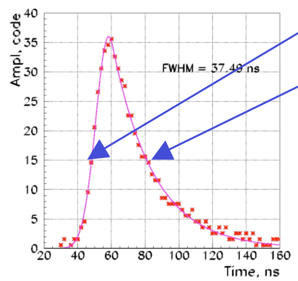
$\Delta \mathbf{X} = \mathbf{a} - \mathbf{b} \cdot \mathbf{FWHM}\ [\mathbf{g/cm^2}]$

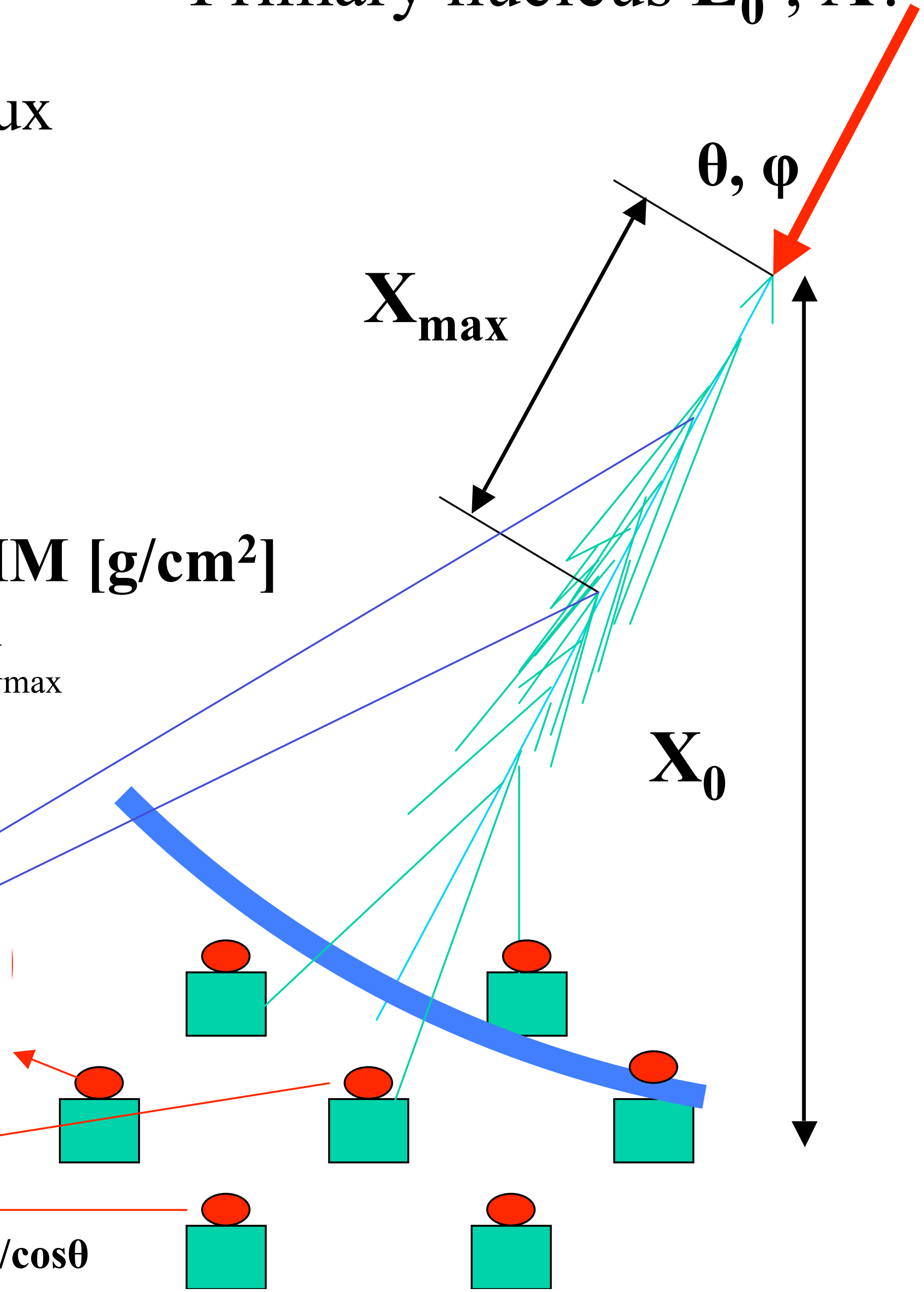
$\Delta X = X_0/\cos\theta - X_{max}$

LDF steepness P:

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





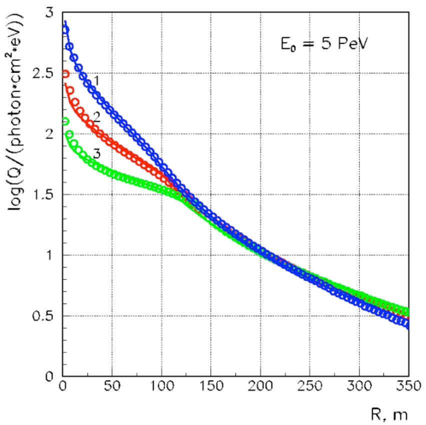


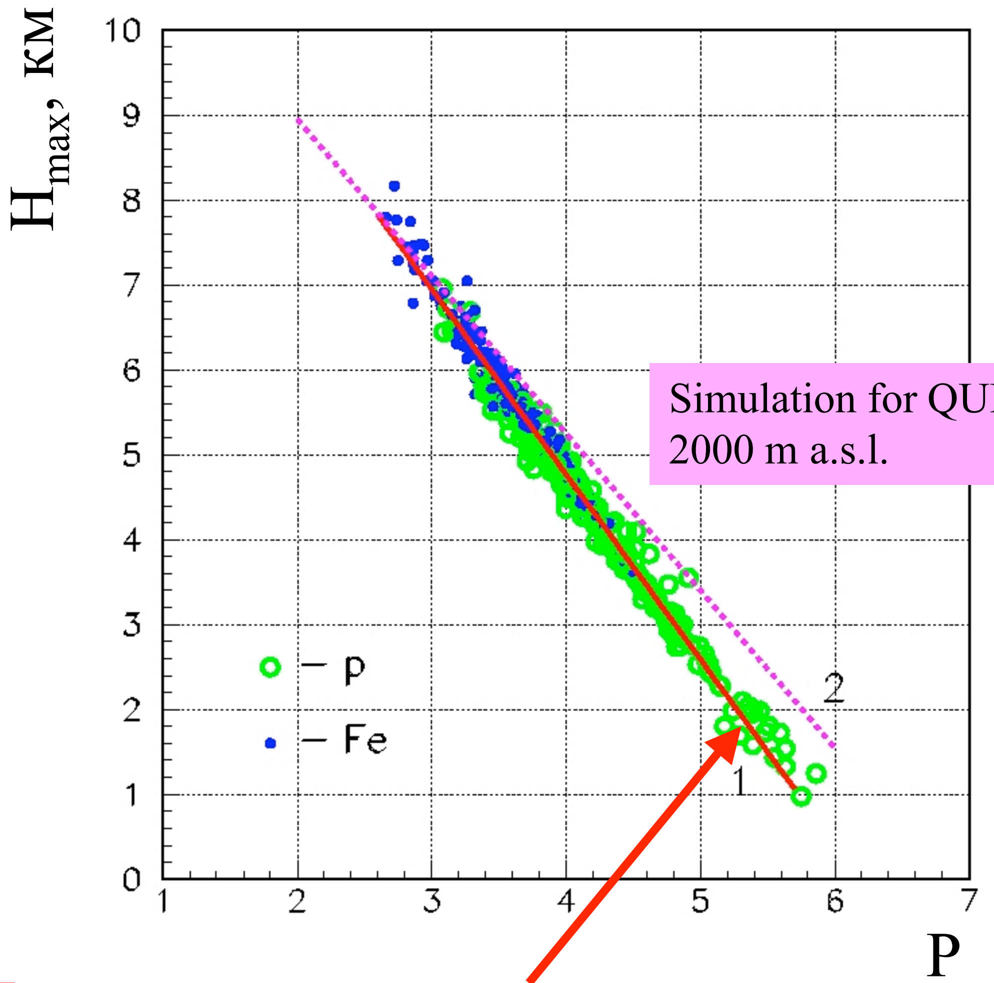
$\mathbf{H_{max}} = (\mathbf{T_0}/\mathbf{grad(T)}((\mathbf{X_{max}}\ \mathbf{cos\theta}\ /\mathbf{X_0})^{\mathbf{C/grad(T)}} - \mathbf{1}) - \mathbf{H_{arr}})/\mathbf{cos\theta}$

Simulation for Tunka.

CORSIKA:
Measurement of a distance to EAS maximum with the Cherenkov light LDF steepness P

480 simulated events with E_0 from 1 PeV to 20 PeV and zenith angles θ from 0° to 25°

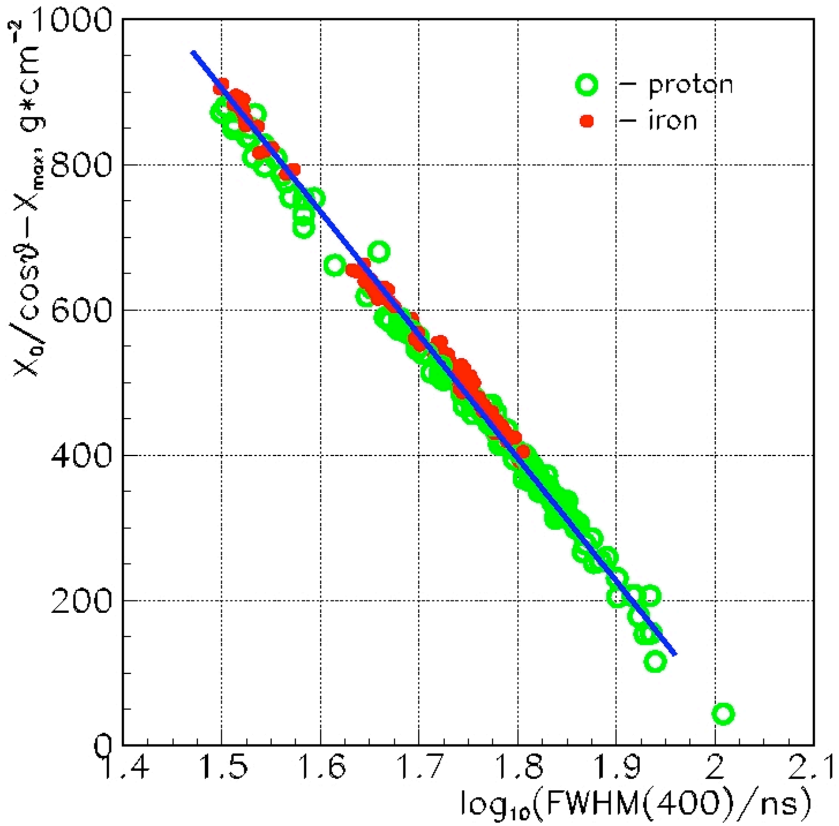




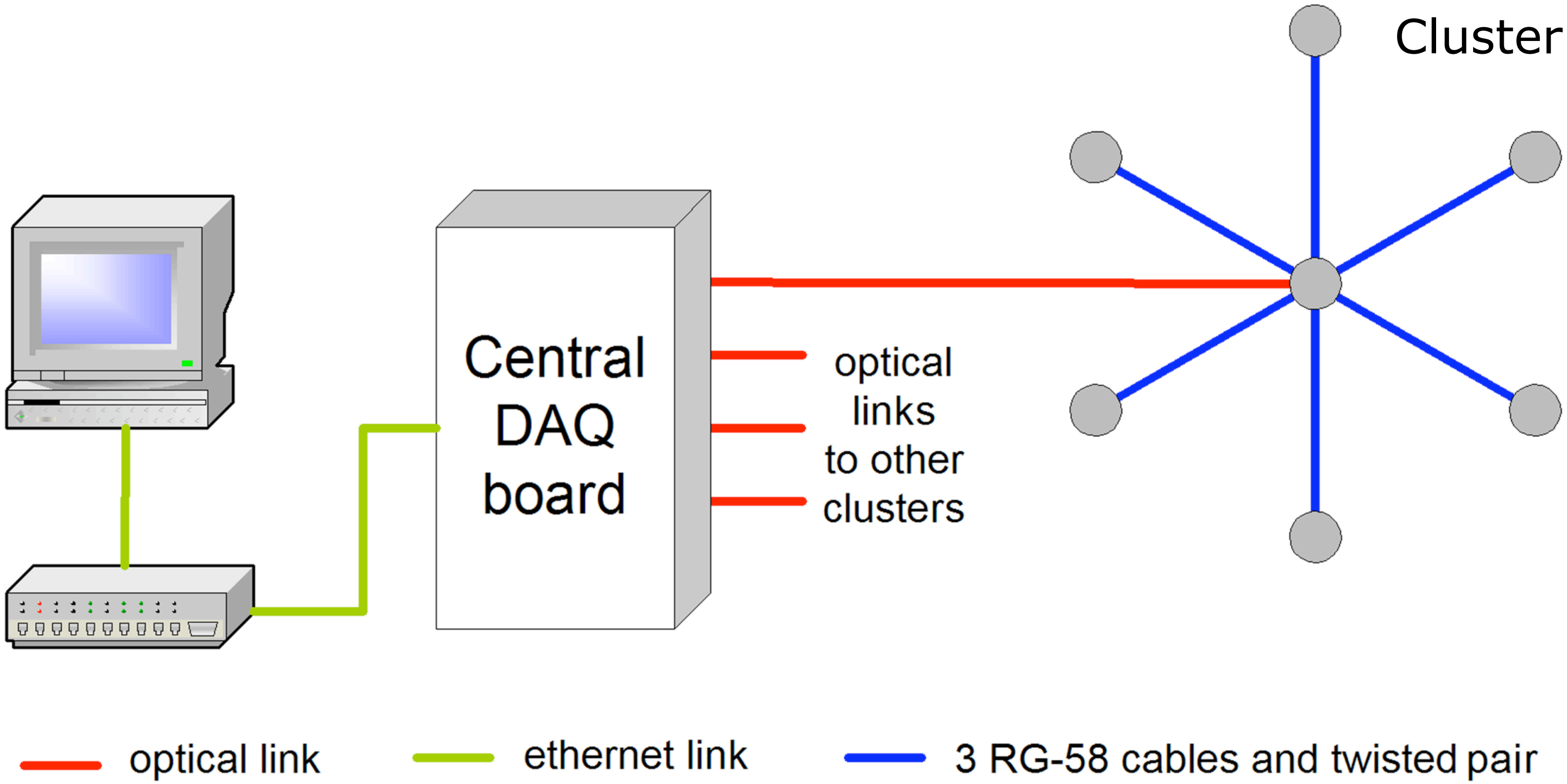
Simulation for QUEST
2000 m a.s.l.

$$H_{max} = 13.61 - 2.18 \cdot P\ ,\ [\text{km}]$$

CORSIKA: X_{max} vs. FWHM(400)



DAQ system



Cluster
Central DAQ board
optical links to other clusters
optical link
ethernet link
3 RG-58 cables and twisted pair

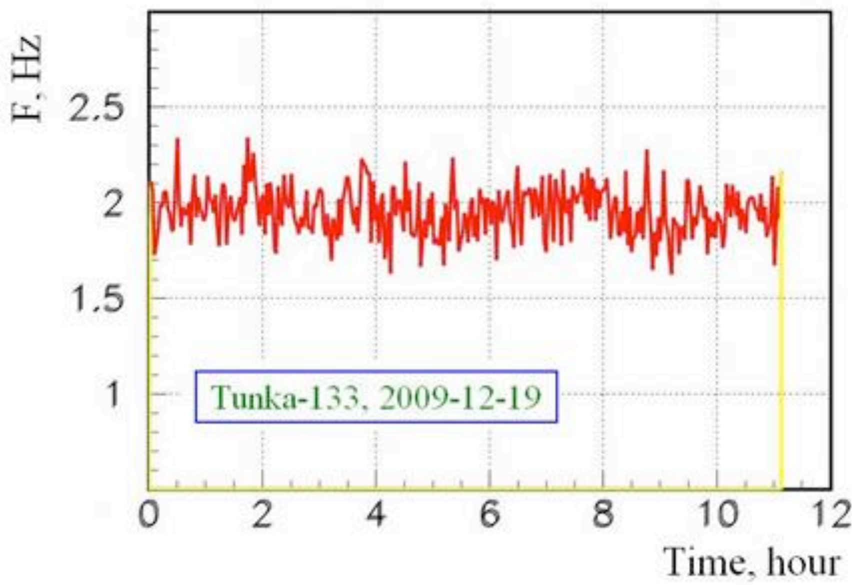
«Event» = 7 – 133 recorded pulse pairs

The single «record» – 1024 x 2 bites

Data flux – continuous binary record of mixed parts of events from all the 19 clusters .

1. Decoding – collecting of cluster data to the joint multi-cluster physical event inside the clock gate of 2 μs.
2. Event count rate measuring, selection of clean weather periods. (The last winter – 49 clean weather nights, total registration time 286 h.)

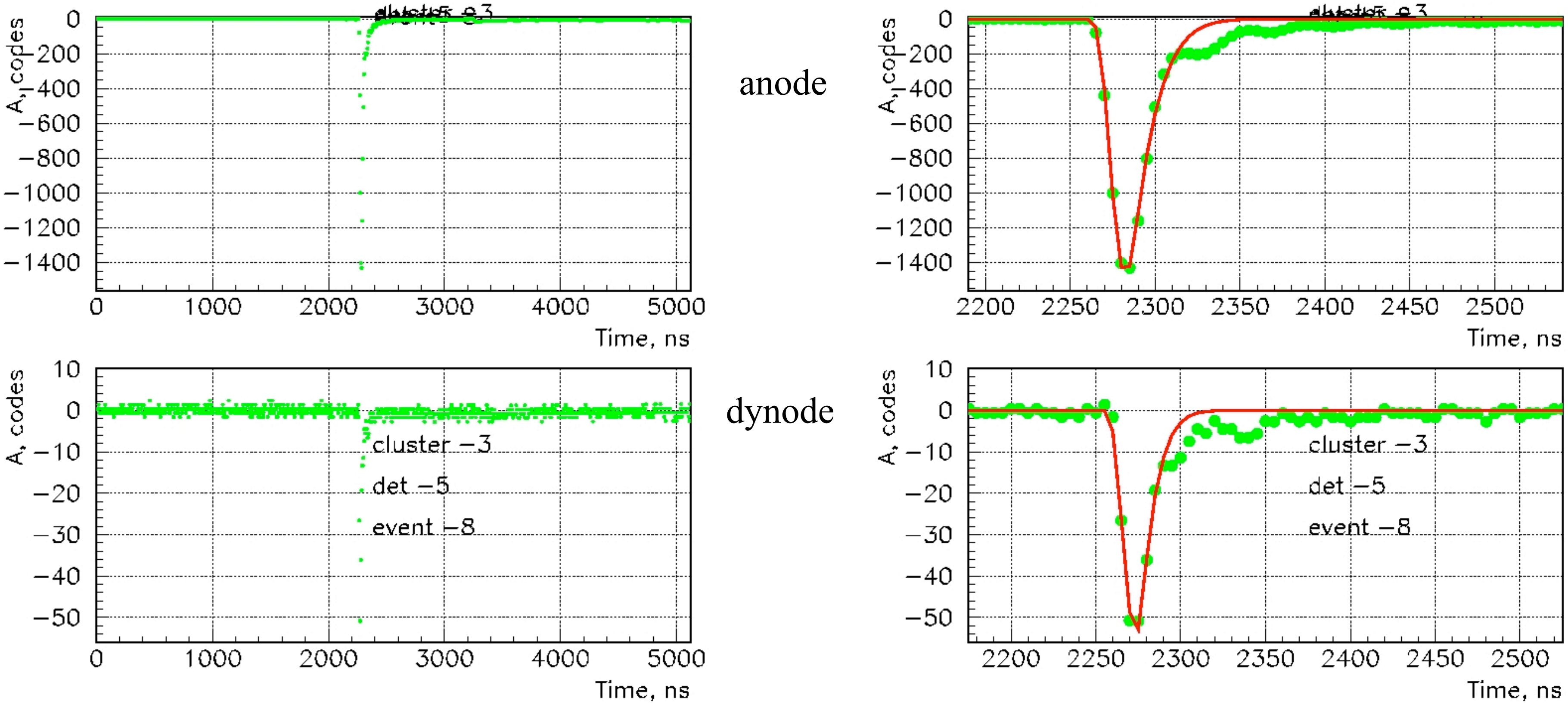
Trigger count rate during one of the nights



EXPERIMENT:
Every event = 7 – 133 pairs of records:

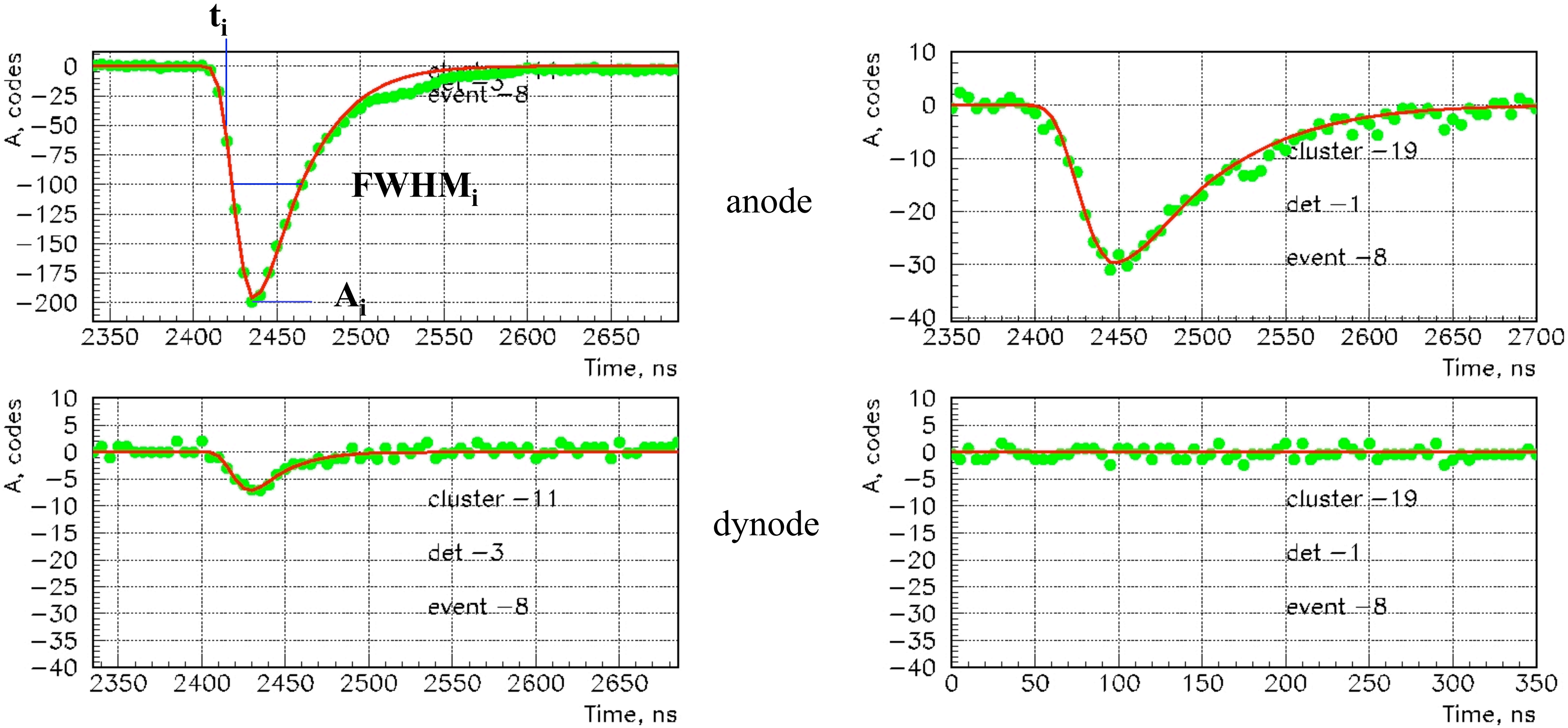
The primary data record for each Cherenkov light detector containes 1024 points of amplitude vs. time with the 5 ns time step:

1. Pulse selection
2. Apparatus distortions correction
3. Pulse waveform fitting



EXPERIMENT:

The main parameters determination – area (light flux) Q_i, amplitude A_i, width $FWHM_i$ and front delay t_i at $0.25A_i$.
(The more accurate $FWHM = \tau_{eff}/1.24$, $\tau_{eff} = Q_i/A_i$)



Calibration using the recorded events

1. Calibration of the ratio of anode and dynode channel gains as the ratio of Q_a/Q_d for the recorded pulses.
2. Calibration of the relative detector gains by the comparison of the integral light flux spectra recorded by each detector.

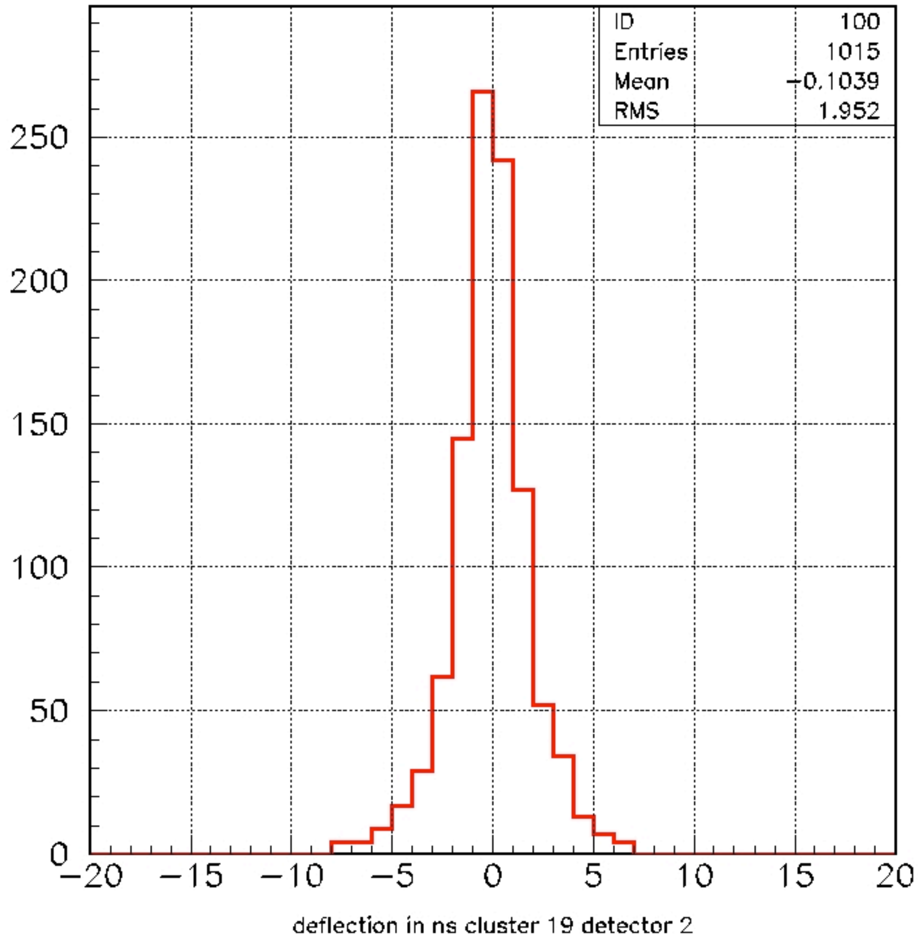
The residual deflection of a single detector time delay from the shower front.

Calibration of relative apparatus time delays by the multiple EAS time front reconstruction with the measured detector delays with correction of the apparatus delays at each step.

The mean residual delay = 0 ns.

The assumed mean arrival direction is zenith.

RMS = the delay measurement accuracy ~ 2 ns.



Single night statistics for a detector is ~ 1000 events.

EAS parameters reconstruction

1. EAS arrival direction measurement by the single cluster with the maximum light flux.
2. Traditional: Reconstruction of EAS core position by the method of Q_i fitting with LDF.
   Measuring of the LDF steepness P. Getting of WDF for the event and measuring of FWHM(400).
3. The new: Reconstruction of EAS core position by the method of FWHM fiiting with WDF.
   Getting of FWHM(400) and the LDF steepness P for this core position.

CORSIKA: Simulated lateral distributions and fitting function (LDF)

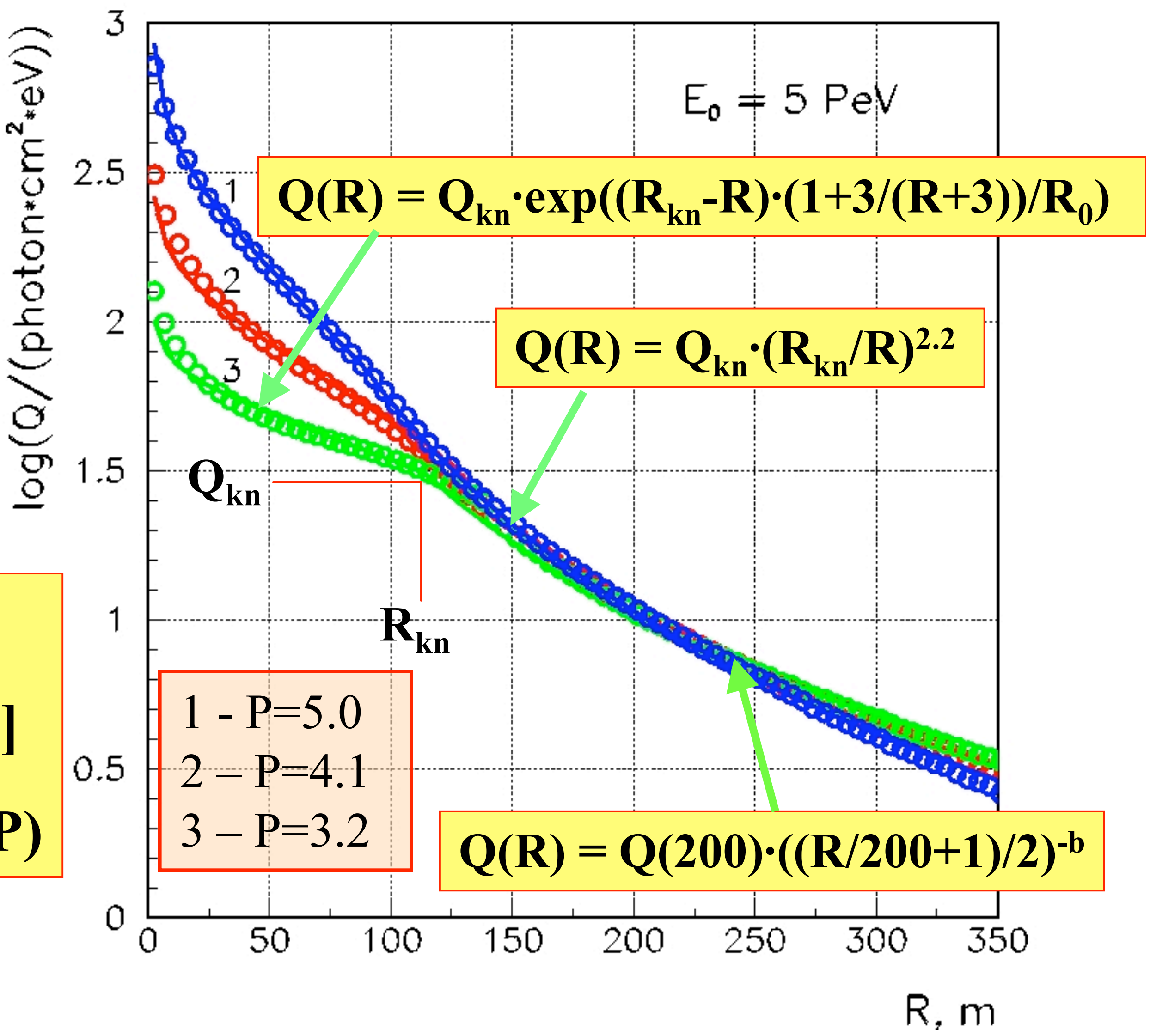
LDF has a single variable parameter of shape - **steepness:**
P=Q(100)/Q(200)

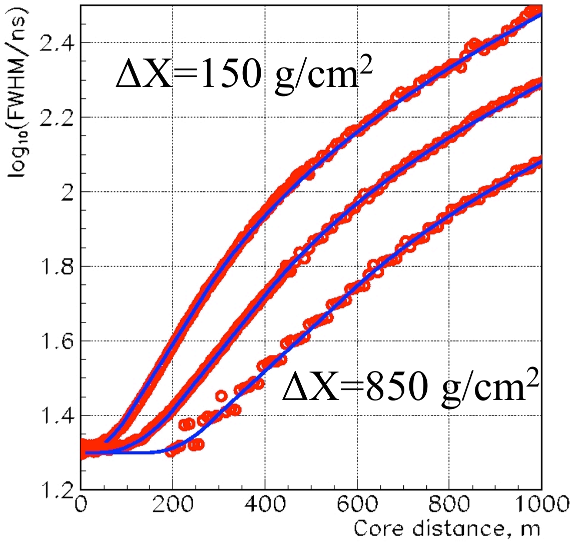
0 < R < 700 m

$R_0 = 10^{2.95-0.245 \cdot P}$ [m]

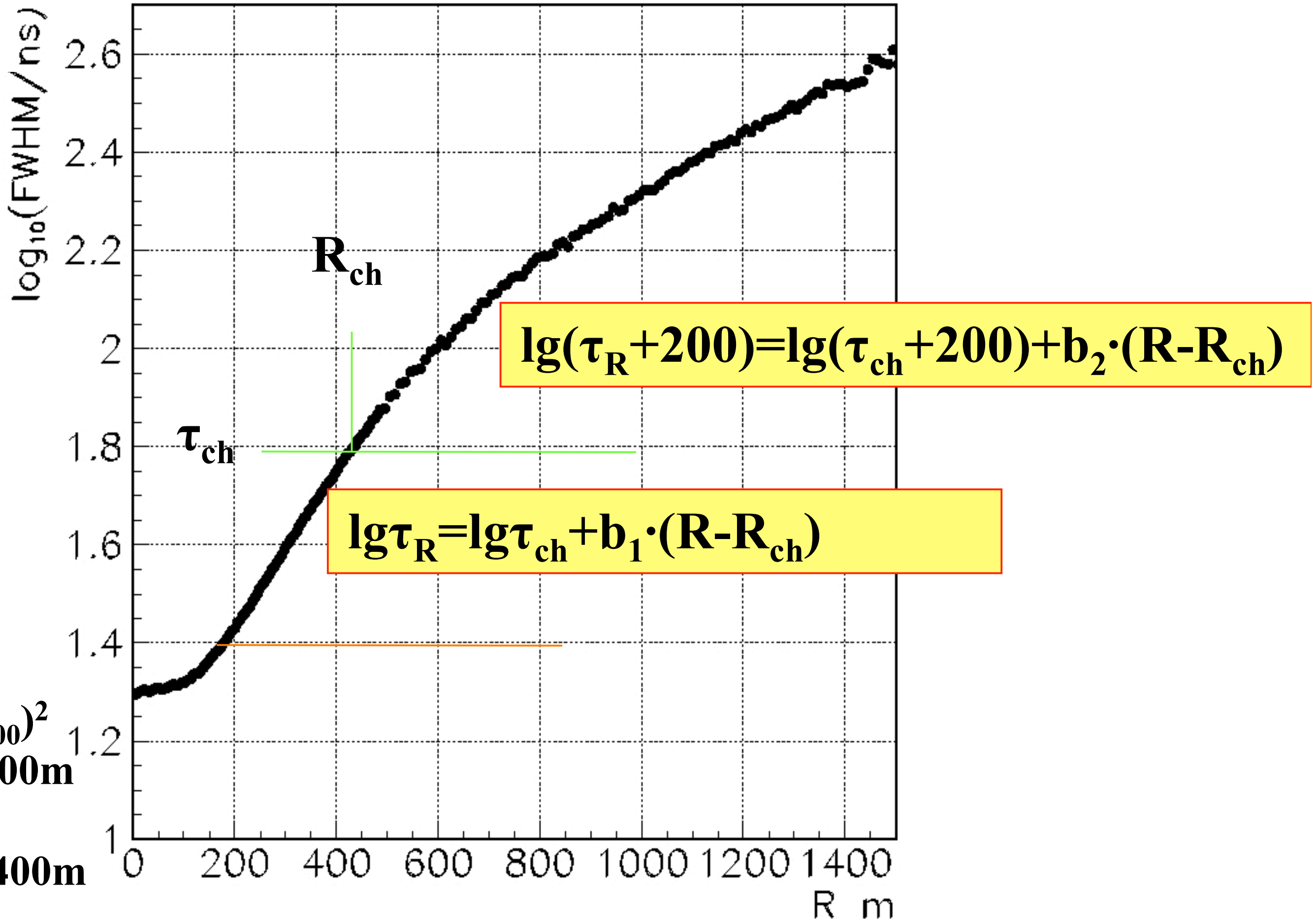
$R_{kn} = 109 - 24.5 \cdot (P-4)$ [m]

$b = 4.84 - 2.83 \cdot \log_{10}(6.5-P)$





CORSIKA: Width vs. Distance Function (WDF)



τ_R=FWHM(R)

WDF has a single variable - FWHM(400)

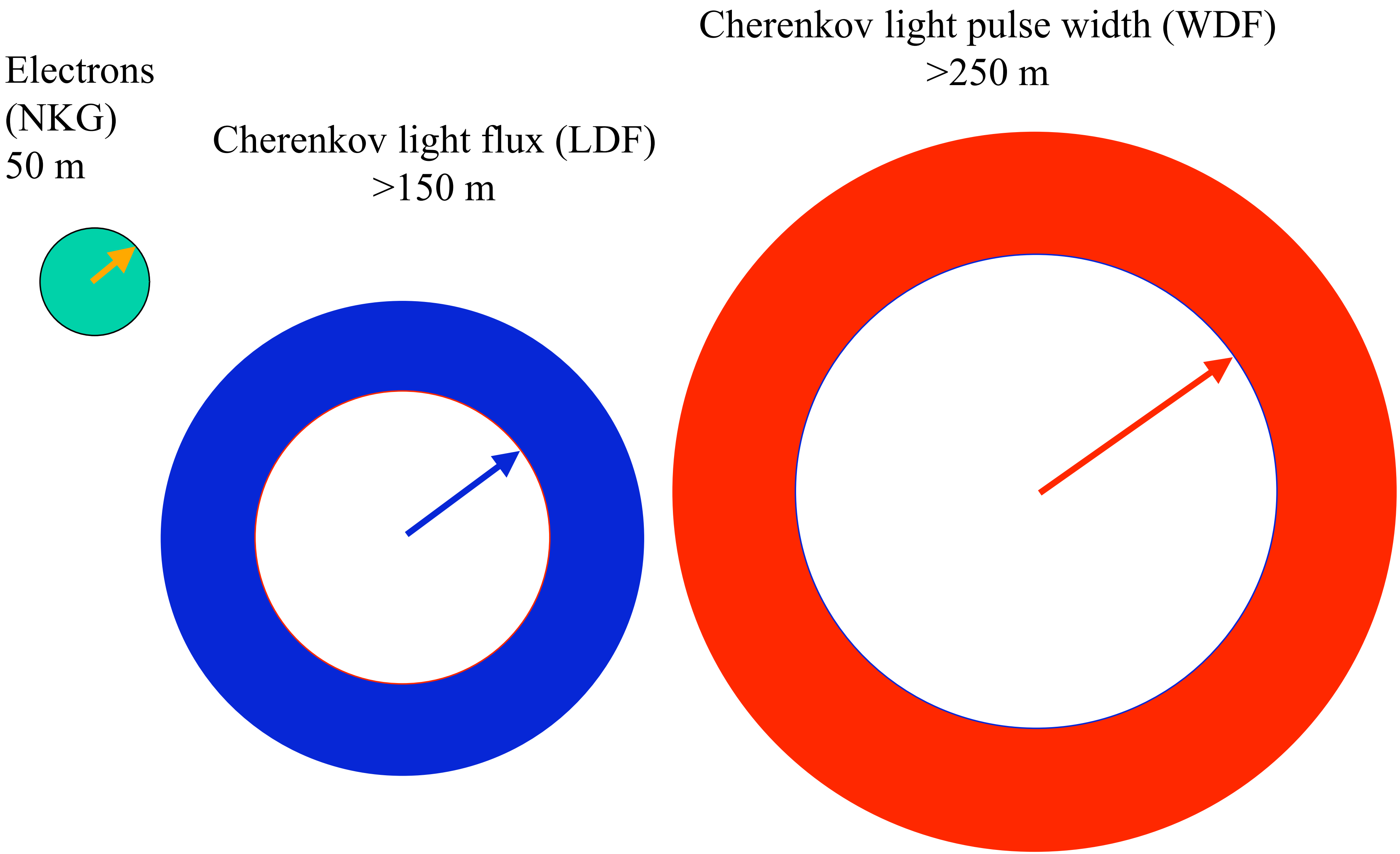
$b_1=0.00196\cdot\lg\tau_{400}-0.00183$
$b_2=0.000381\cdot\lg\tau_{400}-0.000335$
$R_{ch}=3976-3429\cdot\lg\tau_{400}+786\cdot(\lg\tau_{400})^2$
$\lg\tau_{ch}=\lg\tau_{400}+b_1(R_{ch}-400)$, $R_{ch}<400$m
$\lg(\tau_R+200)=$
$\lg(\tau_{ch}+200) + b_2(R_{ch}-400)$, $R_{ch}>400$m

EAS parameters reconstruction with different methods:

The “steep” fitting function is needed for the reconstruction of the core position.

- The “electrons” – NKG function – steep enough in the core distance range: 0 – 100 m – the suitable array size can be < 50 m.
- EAS Cherenkov light – flux LDF – steep enough for R > 150 m – the suitable array size has to be > 150 m
- EAS Cherenkov light pulse width – Width vs. Distance Function (WDF) – steep enough for R > 250 m – the suitable array size can be > 250 m

The possible sizes of arrays for different EAS components



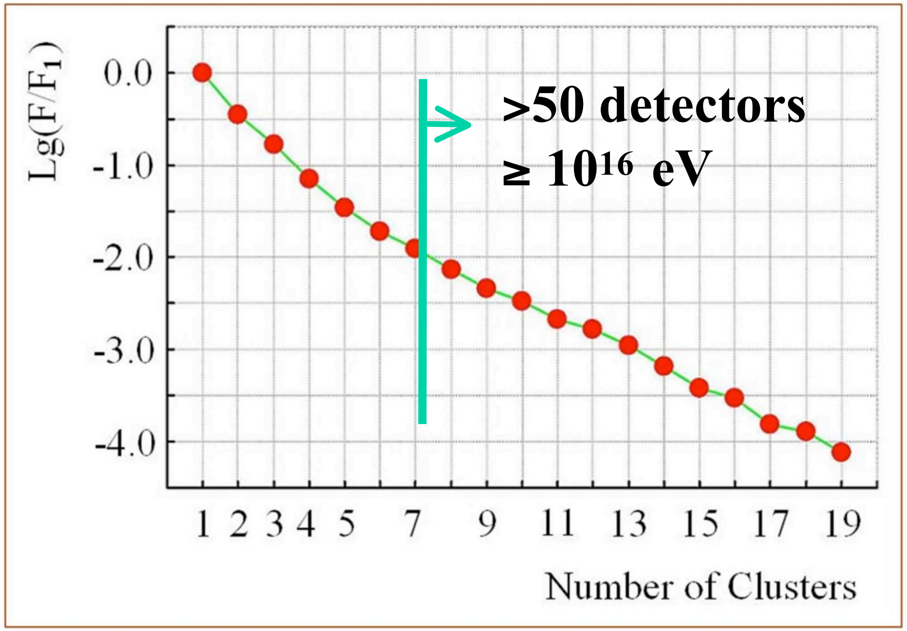
The first season of observation: November 2009 – March 2010

286 h. of clean weather

> $2 \cdot 10^6$ events with energy $\geq 10^{15}$ eV.

> 100 EAS with energy $>10^{17}$ eV inside the circle R<400 m and θ<40°

>10 events with 19 clusters hit every night



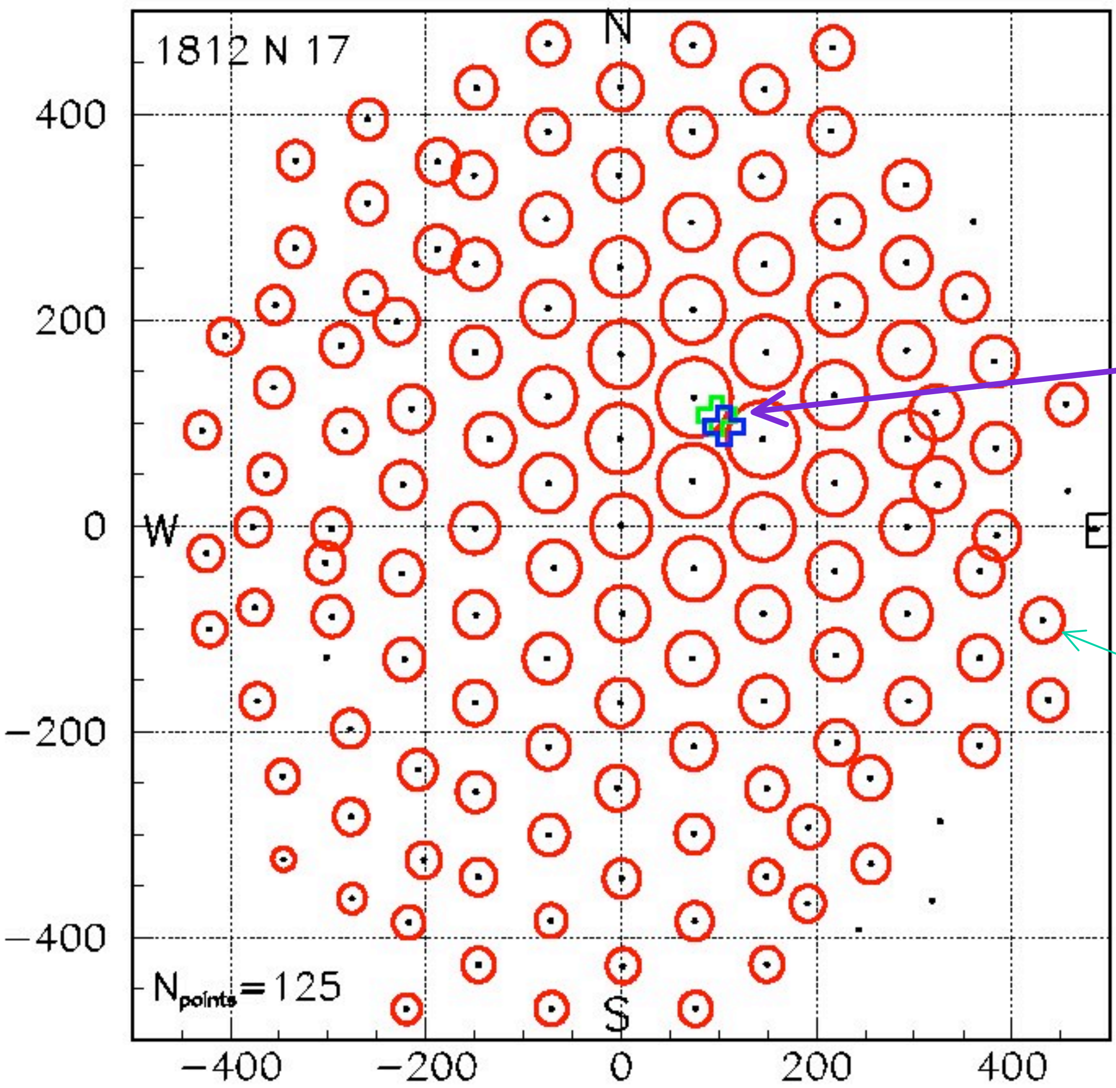
Cluster multiplicity distribution

Tunka-133 <u>single night</u> statistics is comparable with that of Tunka-25 <u>single winter</u>

Example of an event

Energy: $2.0 \cdot 10^{17}$ eV
zenith angle: 12.6 °

125 detectors



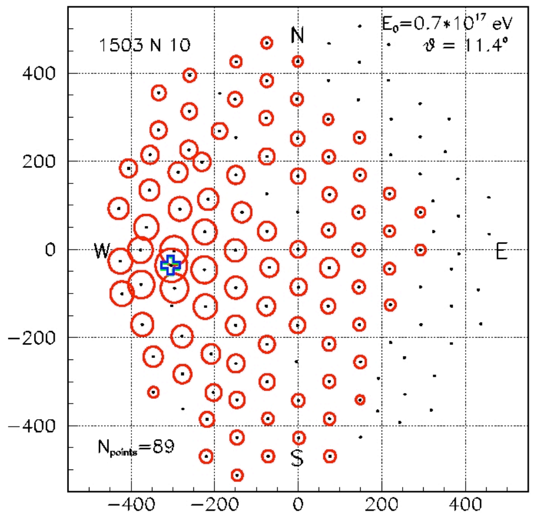
Core position:

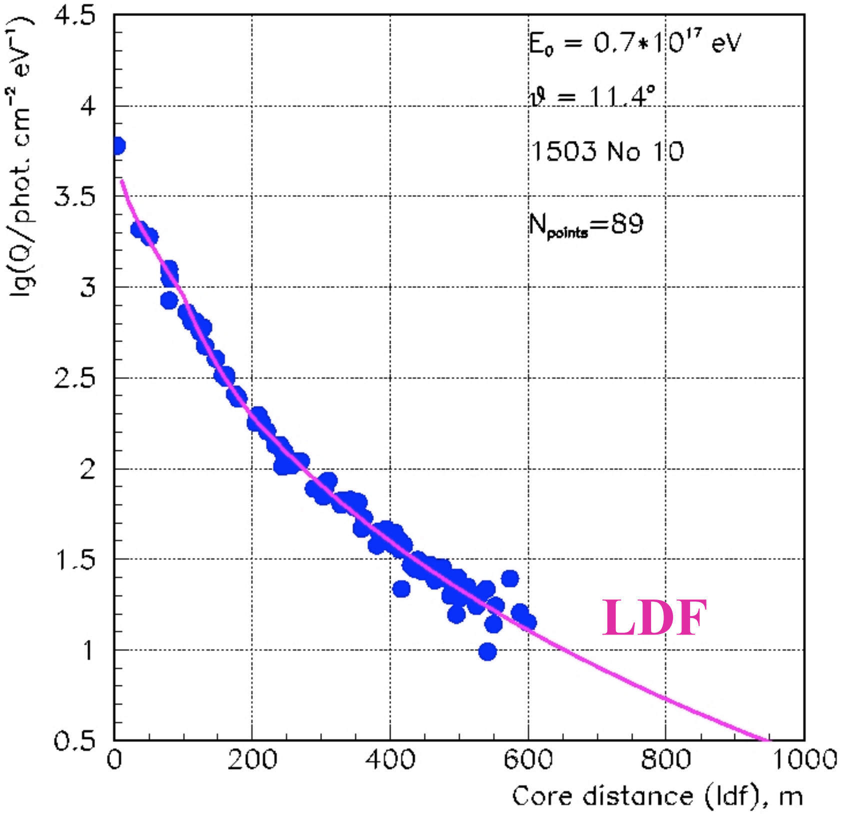
LDF -method

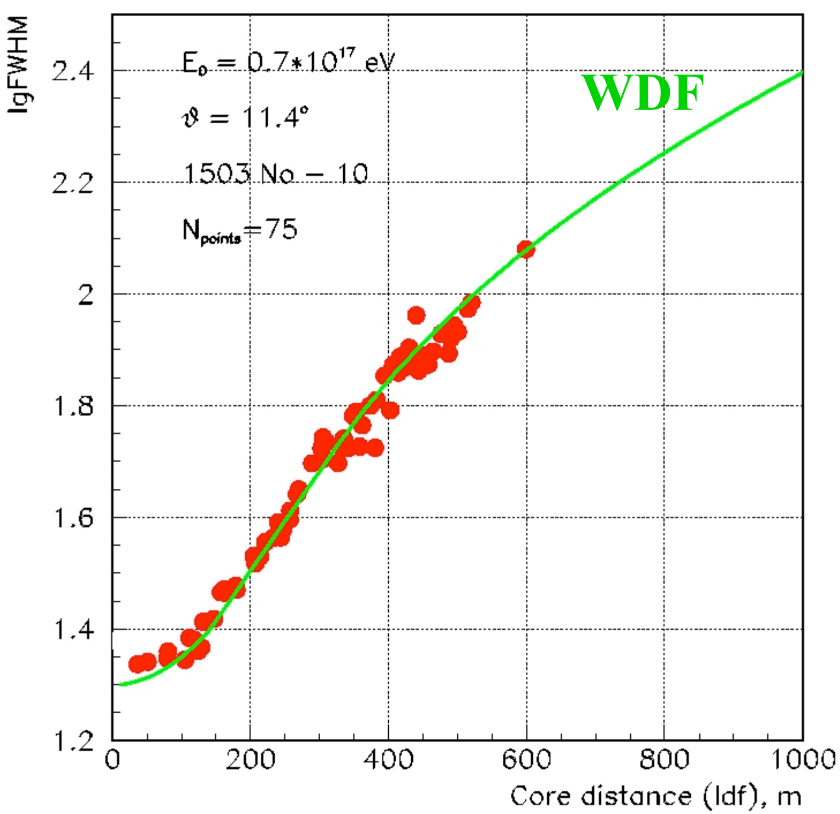
WDF -method

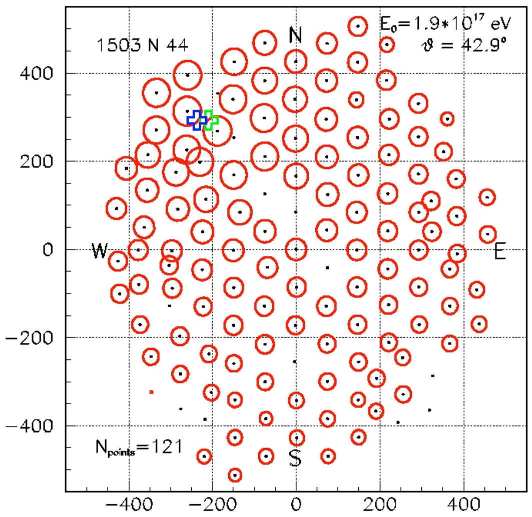
R ~ lg Q

The event example.
15.03.2010

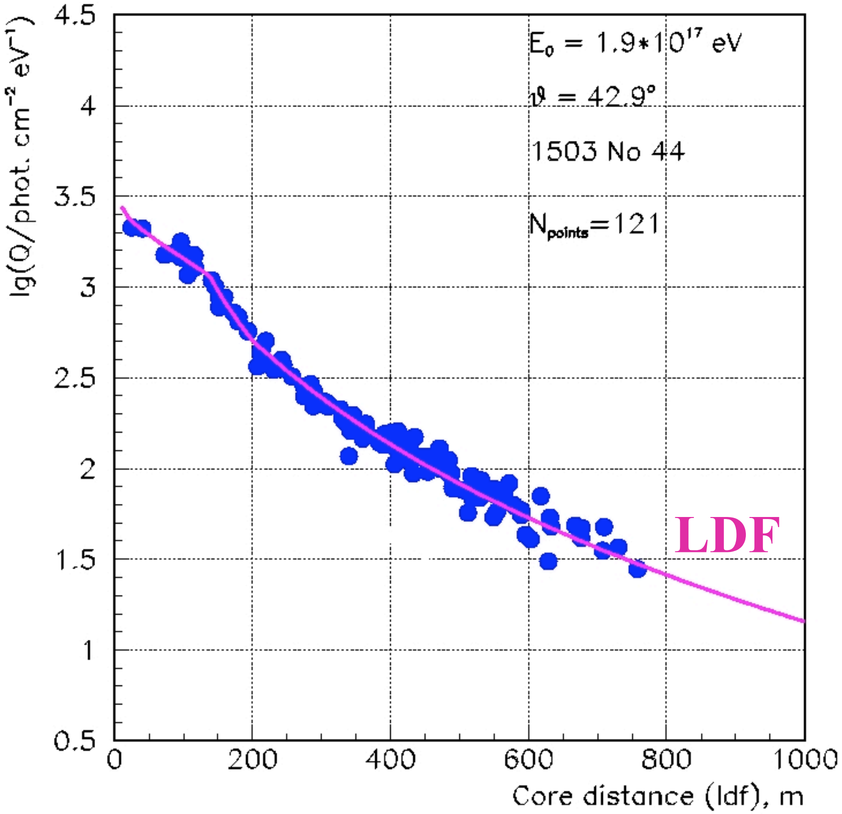


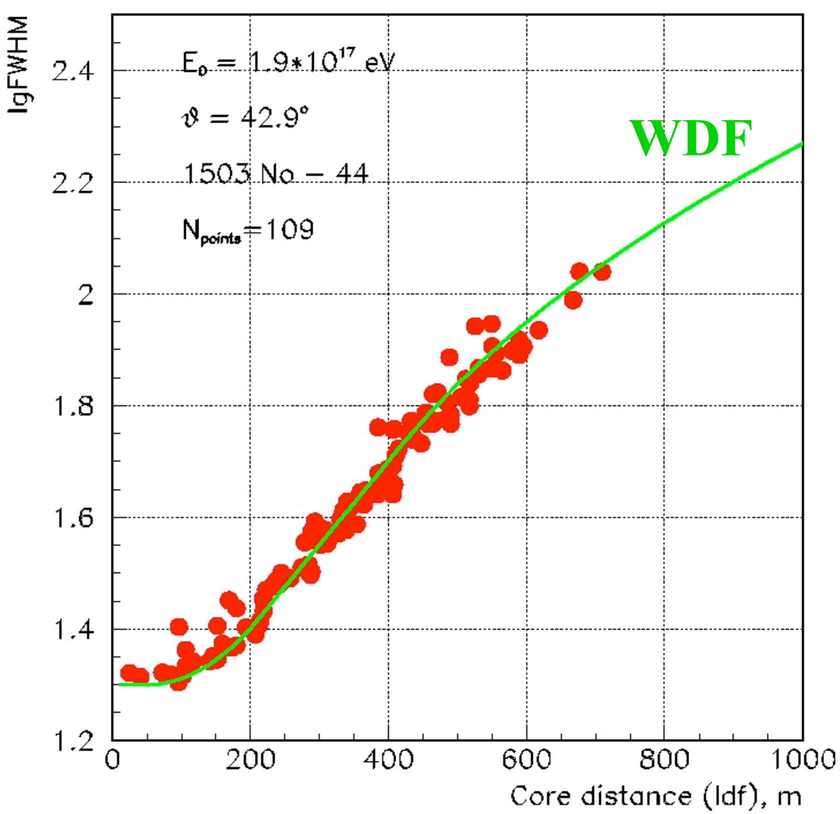




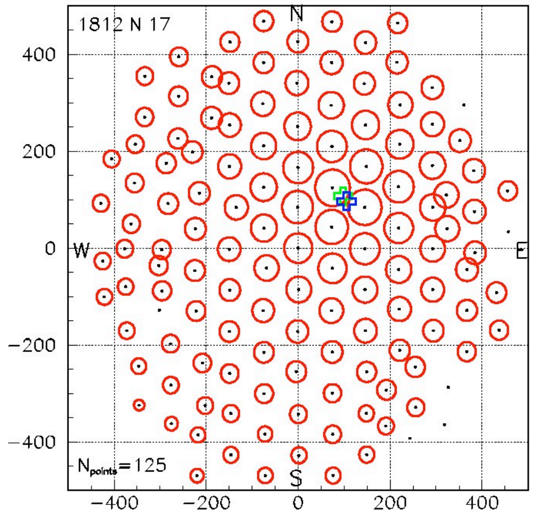


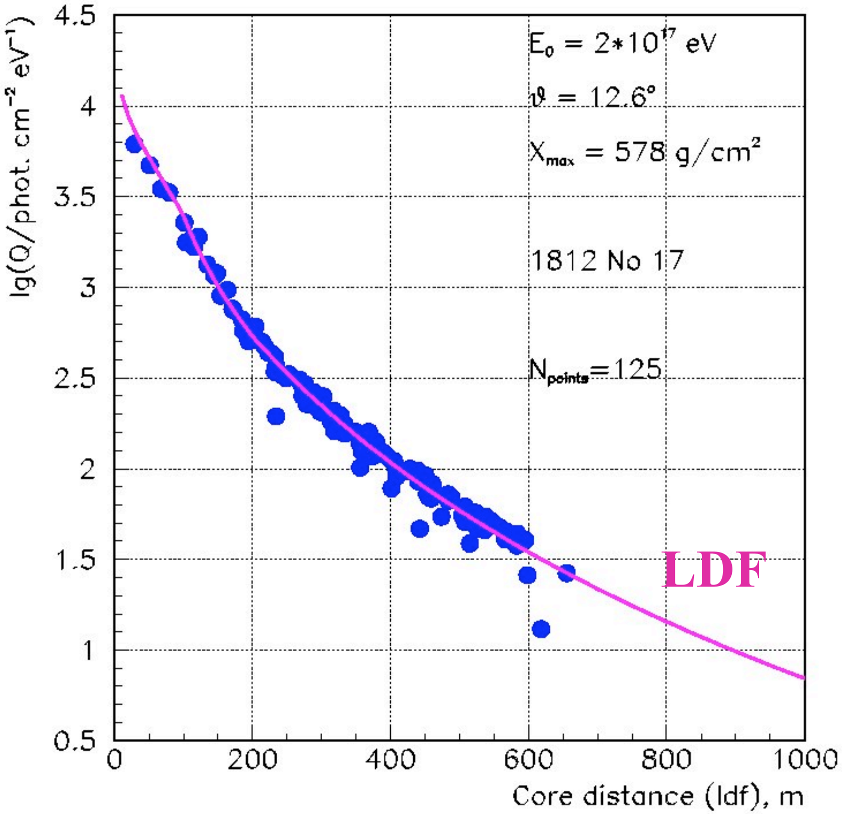
The event example.
15.03.2010

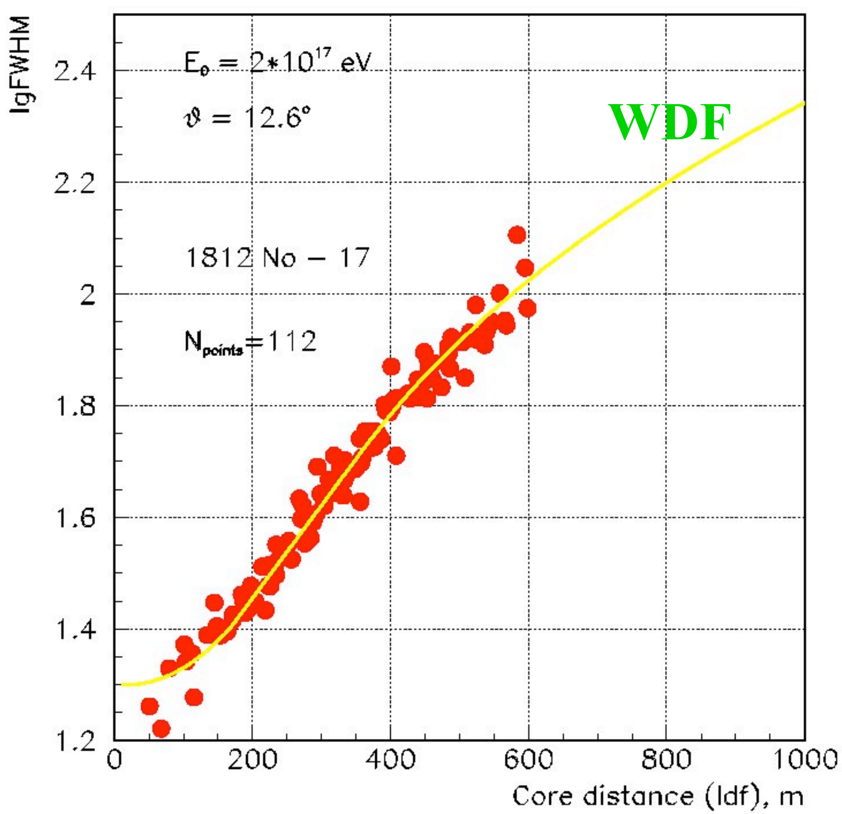




The event example.
18.12.2010







The event example.
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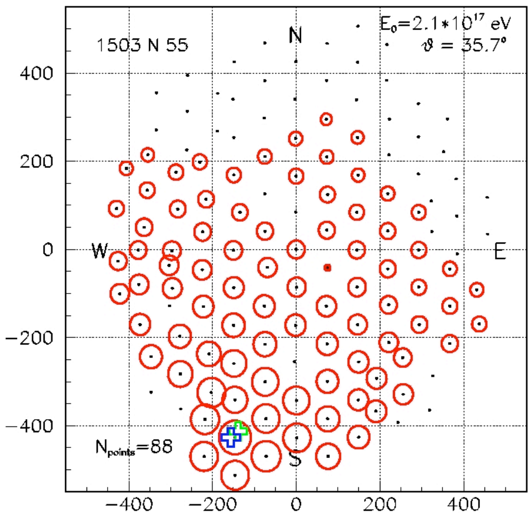
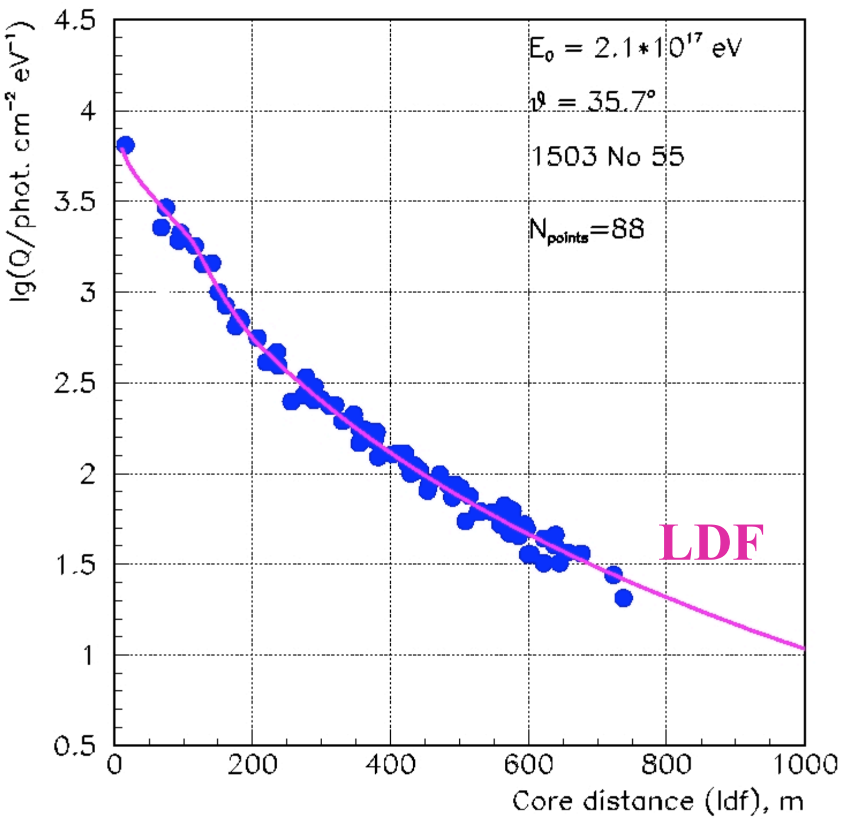
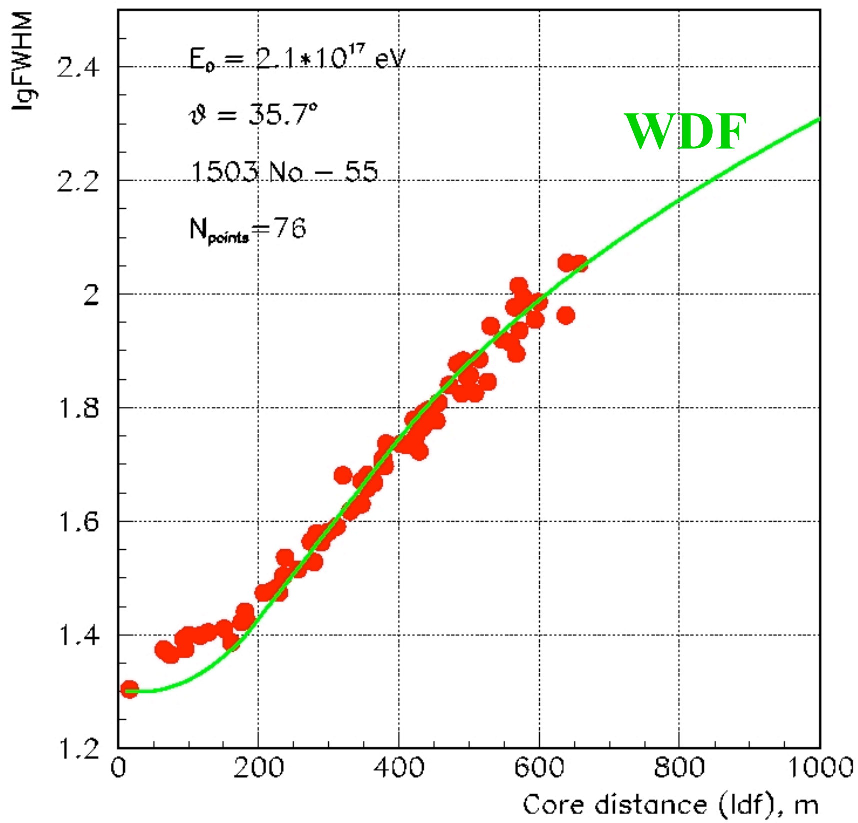
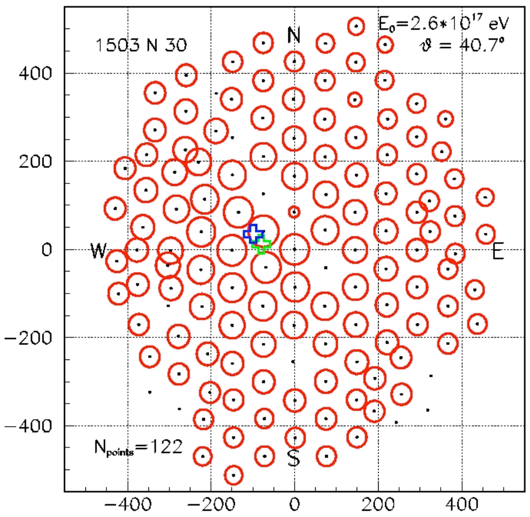
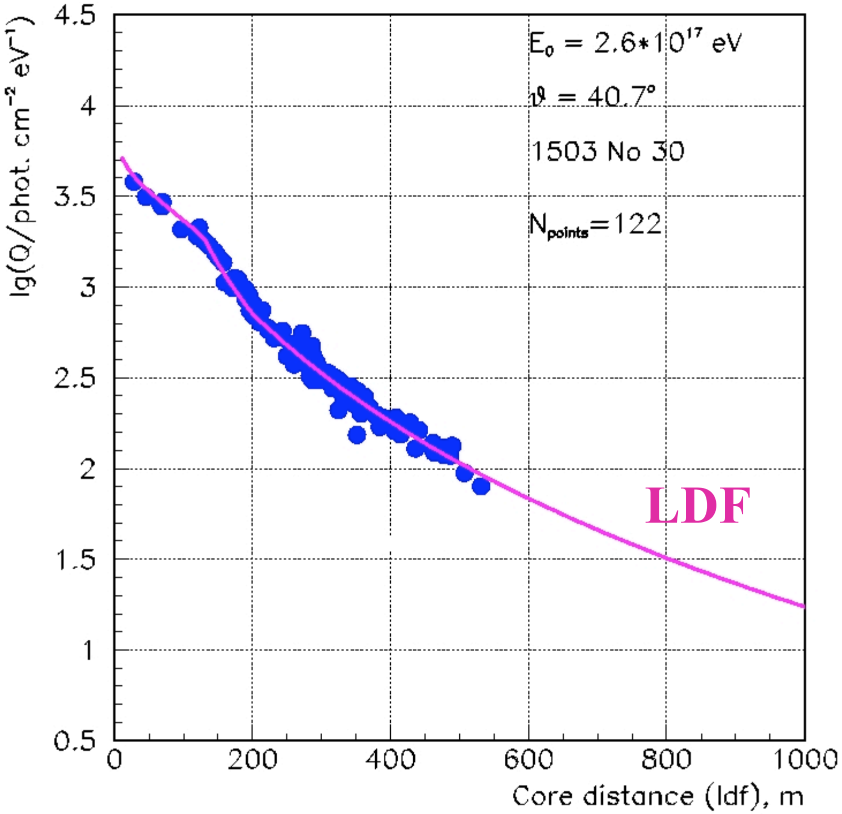


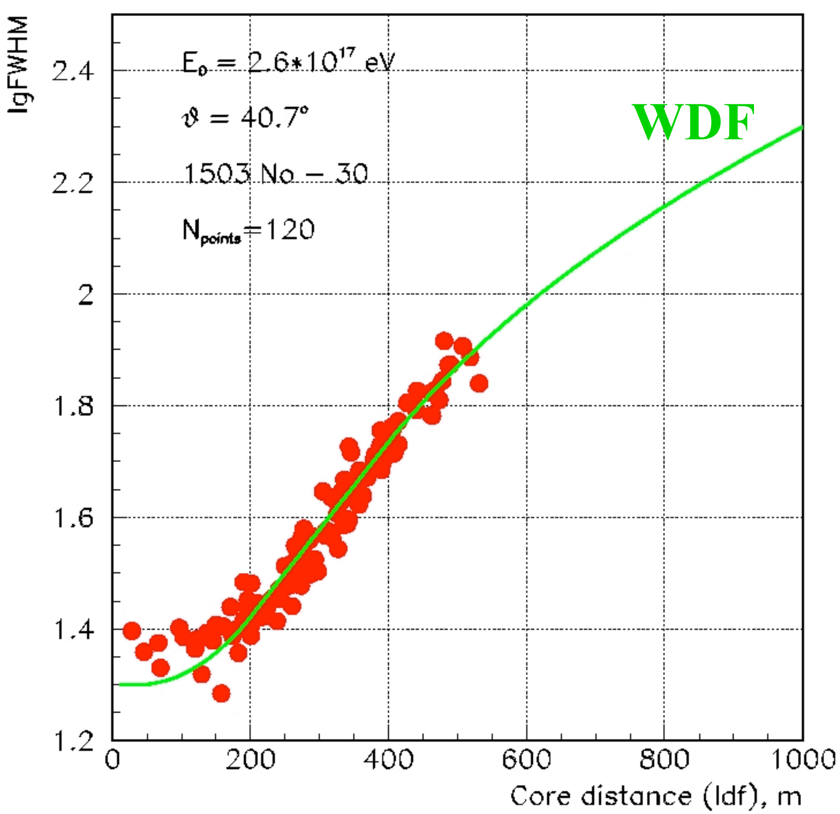




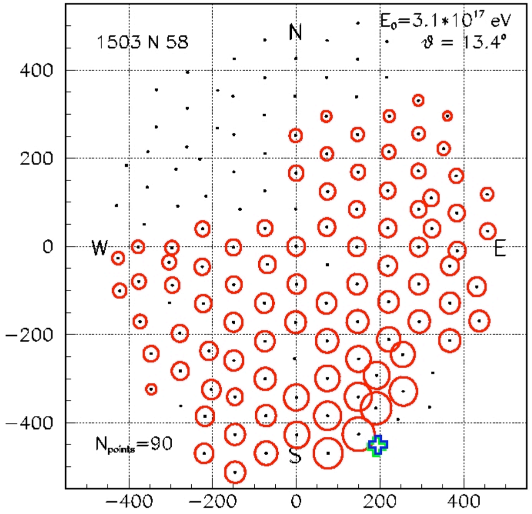


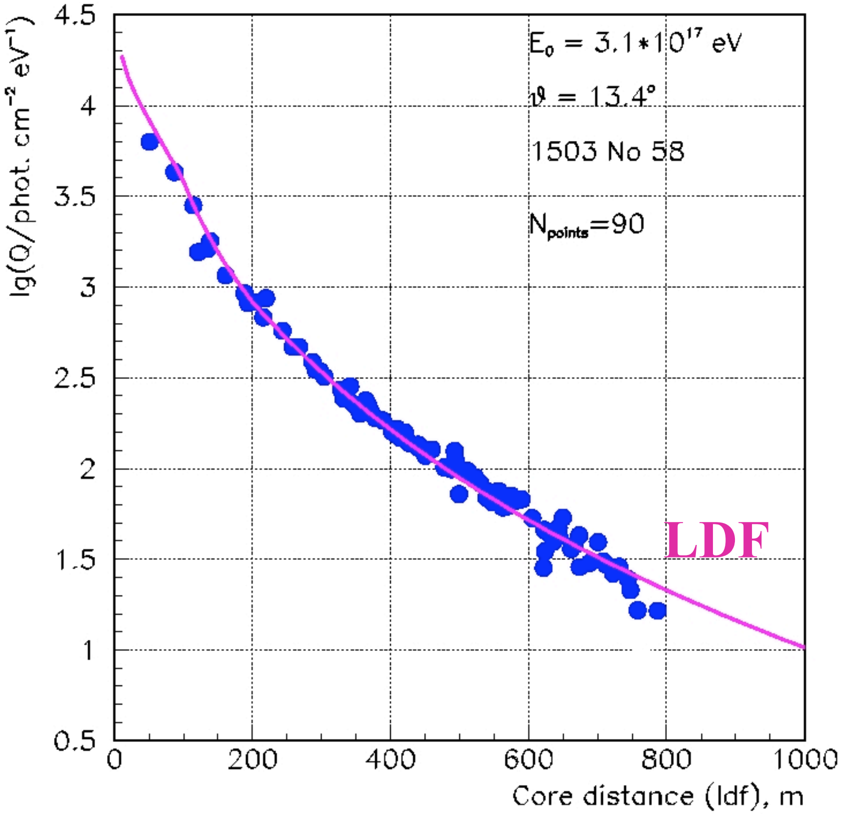
The event example.
15.03.2010

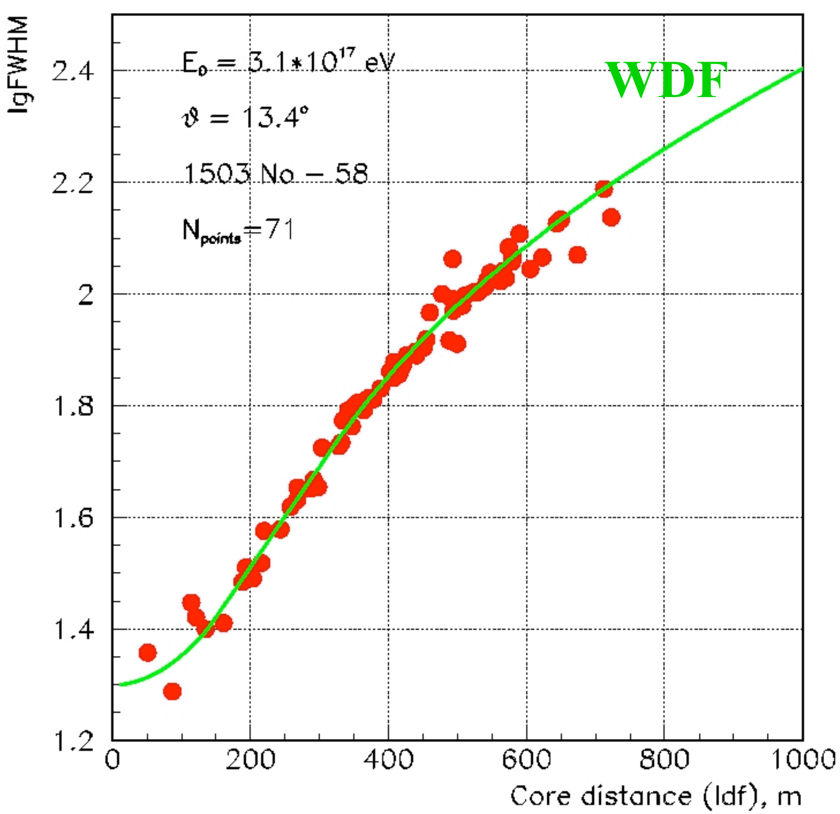




The event example.
15.03.2010







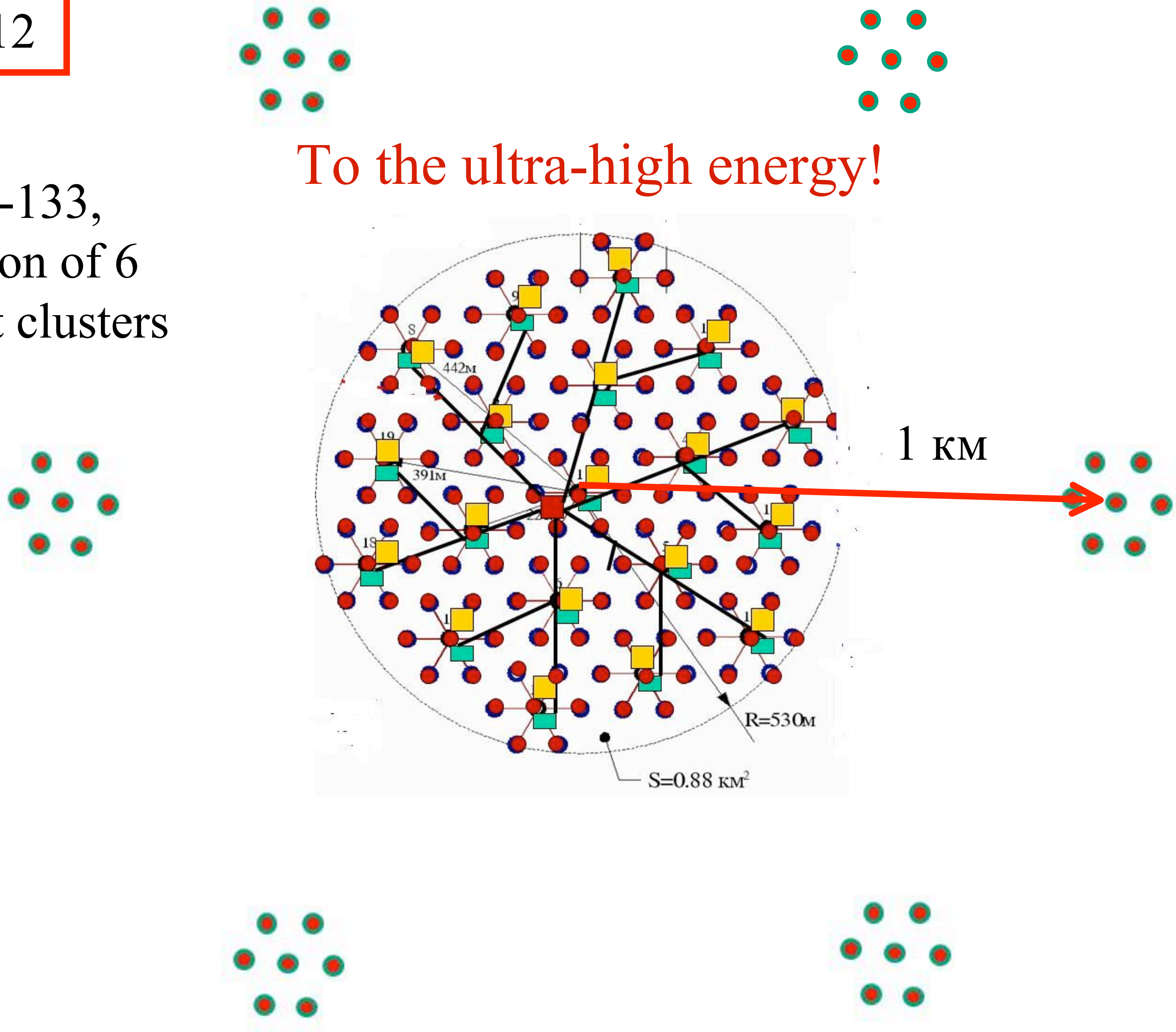
Further information analysis: the results to be published next year (2011)

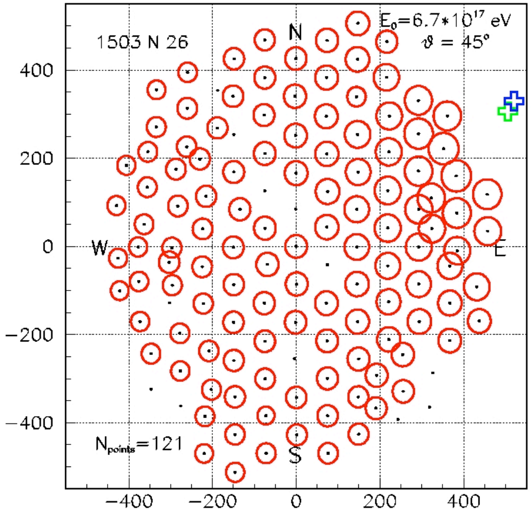
1. The differential energy spectrum in the energy range $3 \cdot 10^{15} - 10^{18}$ eV.
2. X_{max} distributions in the narrow lgE_0 bins.
3. Simulation of X_{max} distributions for the different primary mass groups.
4. Comparison of the experimental and combined simulated distributions and thus estimation of the most probable primary composition for the every energy bin.
5. Estimation of $\langle \ln A \rangle$ vs. E_0 in the energy range $3 \cdot 10^{15} - 3 \cdot 10^{17}$ eV.

2012

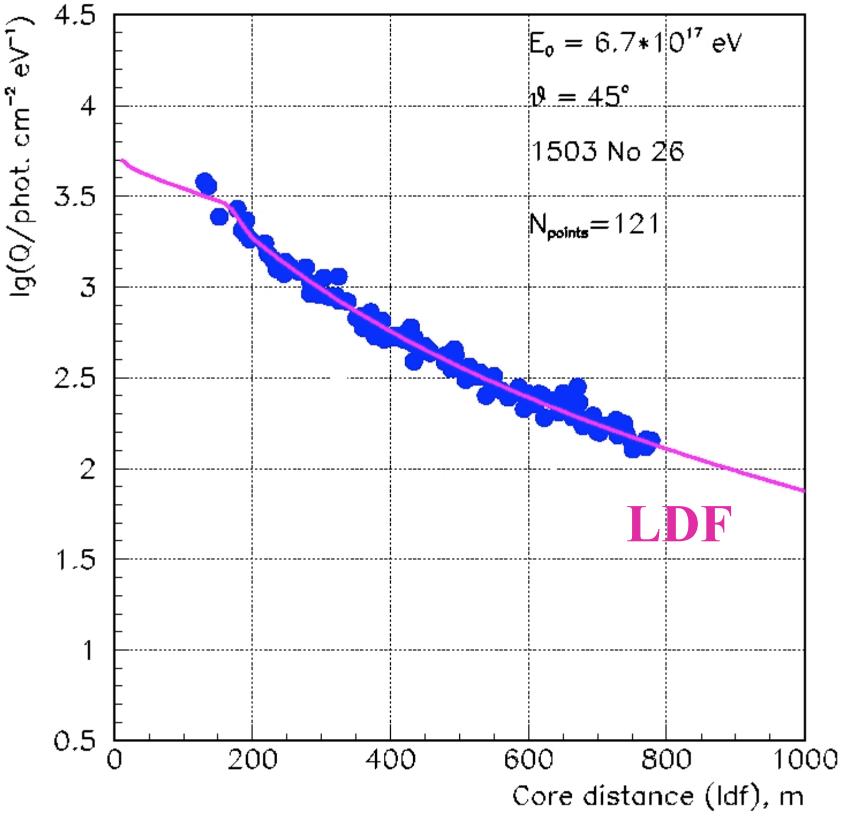
To the ultra-high energy!

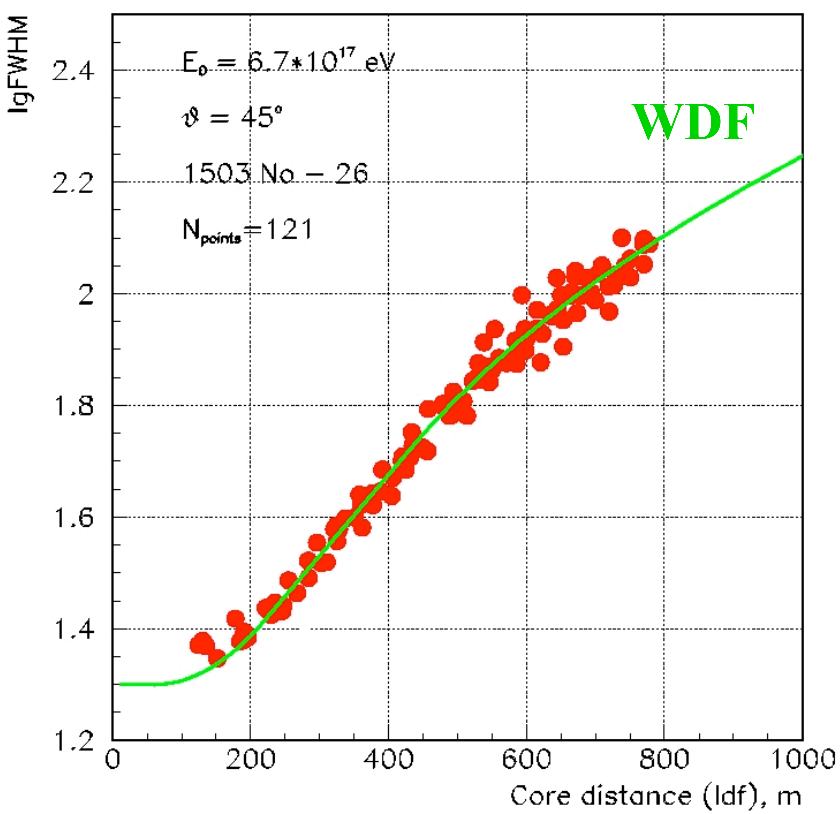
Tunka-133, addition of 6 distant clusters





The event example.
15.03.2010

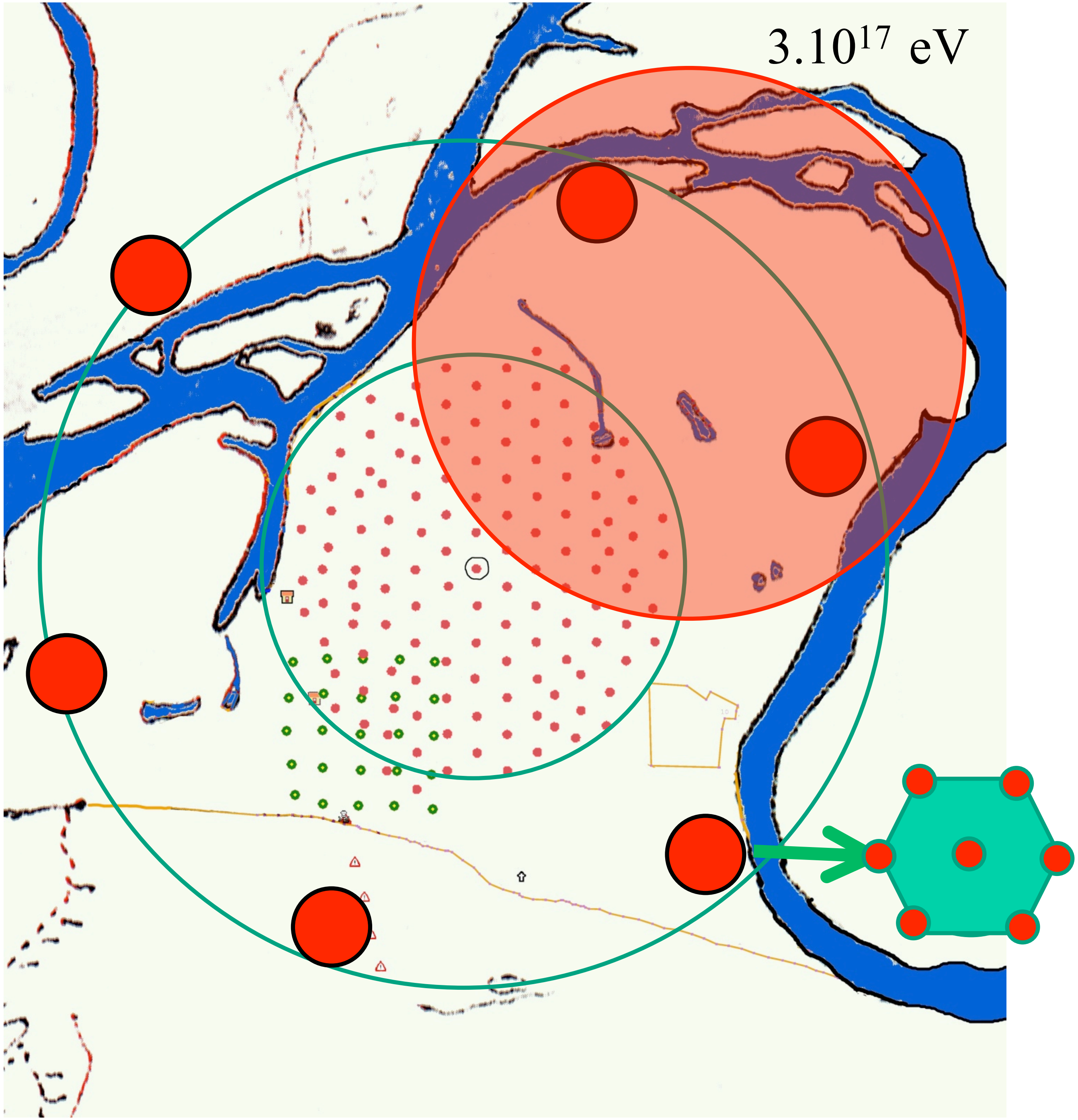




6 distant clusters (42 optical detectors)

The effective area enlarging to about 4 times for the EAS with the energy > 10^{17} eV

Further possibility of the effective area enlarging to about 10 times for the external EAS with the energy > $5 \cdot 10^{17}$ eV

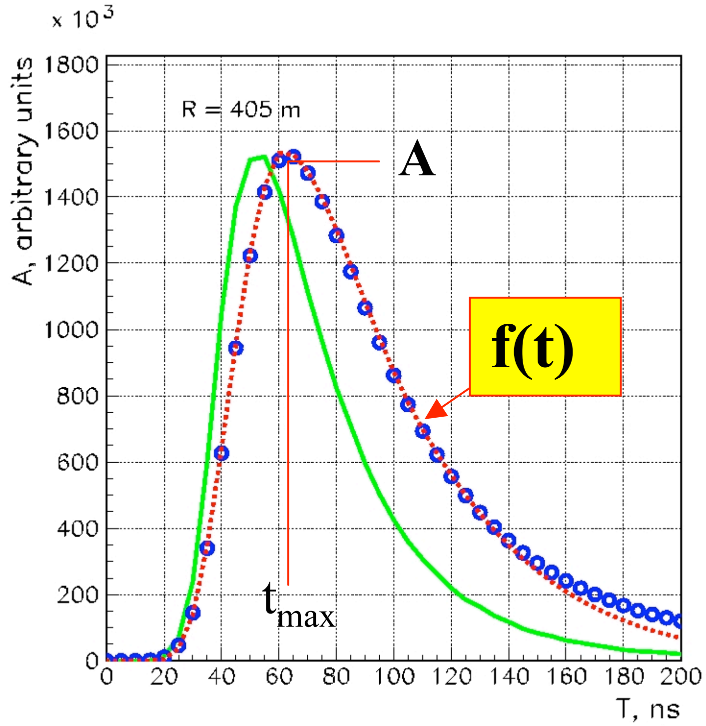


Thank you!

Pulse fitting

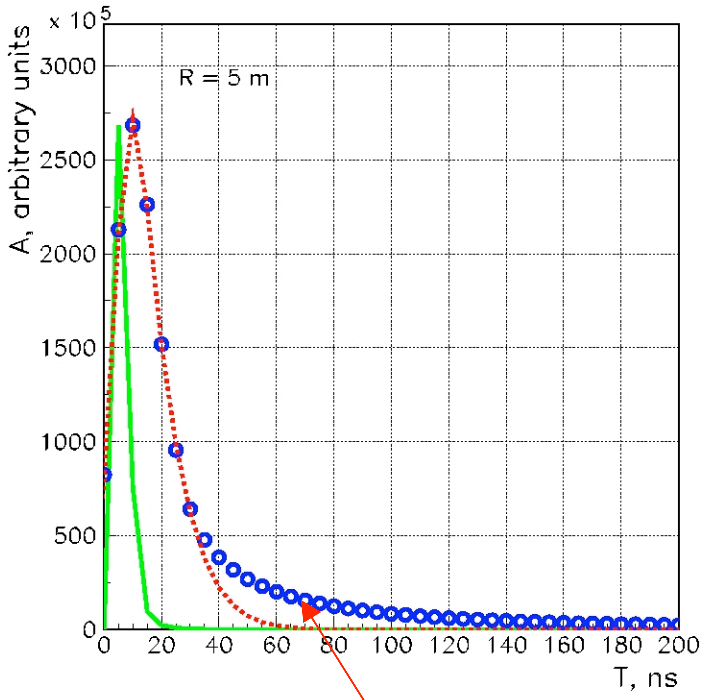
$x = t - t_{max}$
$f = |x/t_{front}|$
$g = x/t_{droop}$
$h = 1.7 - 0.5 \cdot g, \qquad g < 0.8$
$h = 1.3, \qquad g \geq 0.8$

$f(t) = A \cdot \exp(-f^{2+0.5 \cdot f}), \qquad x \leq 0$
$f(t) = A \cdot \exp(-g^{h}), \qquad x > 0$

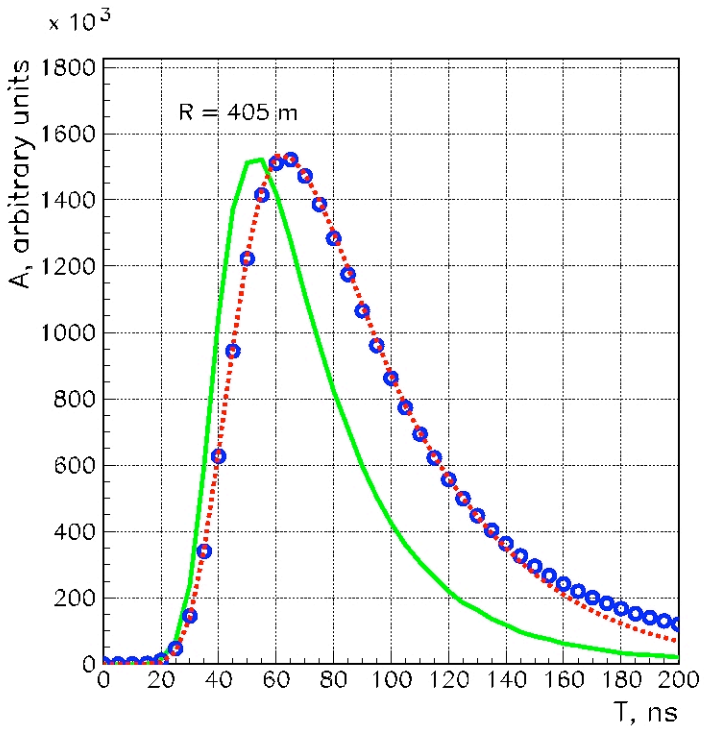


Pulse distortion by the coaxial cable

PMT + preamplifier + 100 m of RG-58 coaxial cable provide the minimum FWHM=20 ns



The “tail” of $\sim(T+T_0)^{-2}$ type.



Green curve – simulated pulse,
blue points – modeled distortion,
red dotted line - fitting

FWHM – output vs. input