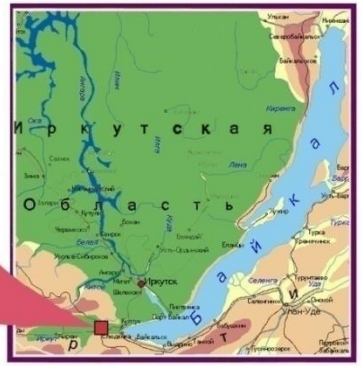
TAIGA: status, results and perspectives

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



L.Kuzmichev (SINP MSU)
On behalf of TAIGA Collaboration

V International Workshop
"Data life cycle in physics", DLC-2021
28/06 2021

Content of report

1. Introduction: Astrophysical complex in Tunka Valley

2. Cosmic ray study at the Astrophysical Complex TAIGA: results and plans

3. High energy gamma-ray astronomy and TAIGA project

4. Interdisciplinary topics

5. The experiment in future

TAIGA - collaboration

Germany

Hamburg University(Hamburg)
DESY (Zeuthen)
MPI (Munich)

Italy

Torino University (Torino)

Romania

ISS (Bucharest)

Russia

MSU (SINP) (Moscow)
ISU (API) (Irkutsk)
INR RAS (Moscow)
JINR (Dubna)
MEPhI (Moscow)
IZMIRAN (Moscow)
BINR SB RAS (Novosibirsk)
NSU (Novosibirsk)
ASU (Barnaul)

1. Introduction: Astrophysical complex in Tunka Valley

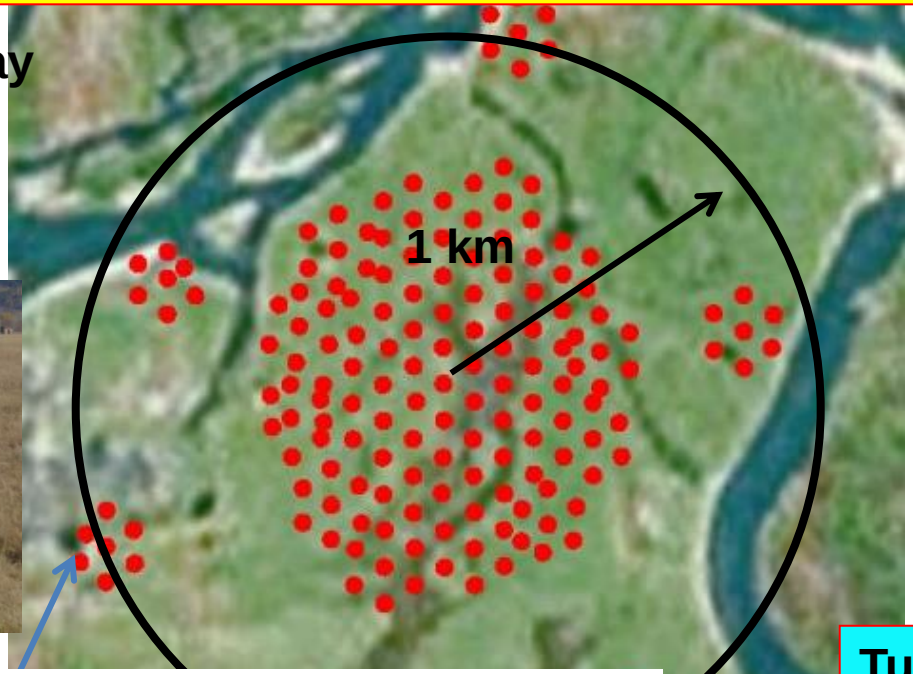
1. Tunka-4 (1993- 1996)
2. Tunka-13 (1997-2000)
3. Tunka-25 (2005 -2005)
4 Tunka -133 (2009 -)
5. Tunka REX (2012-2019)
6. Tunka –Grande (2015 --
7. TAIGA - HiSCORE (2014 –
8. TAIGA-IACTs (2017 -

A.M.Hillas and

G. Navarra

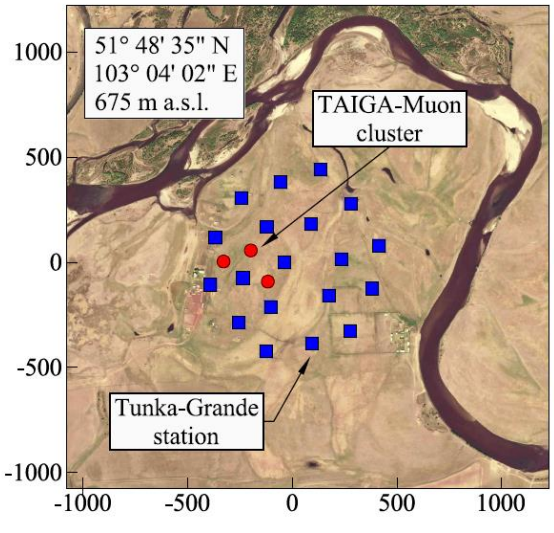
Tunka arrays for study Cosmic rays with energy > 10^{15} eV

Tunka- 25 – 0.1 km² array
(2000-2005)
QUASAR -370 - 37 cm diameter hybrid pmt

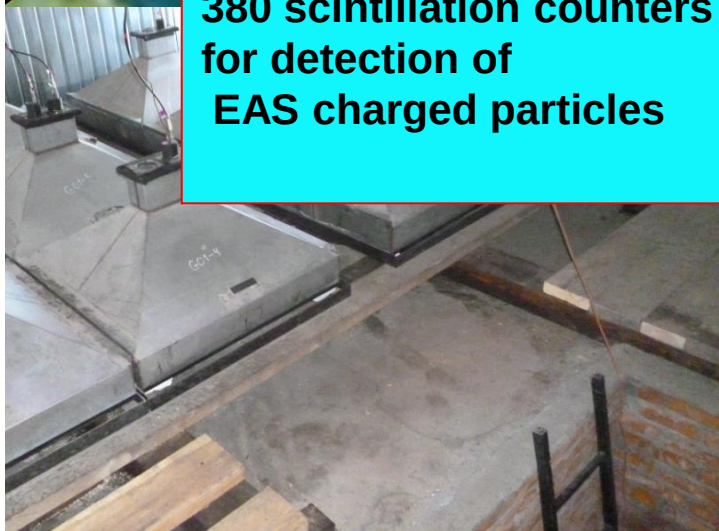


Tunka-133 –
175 optical detectors on the area of 3 km²

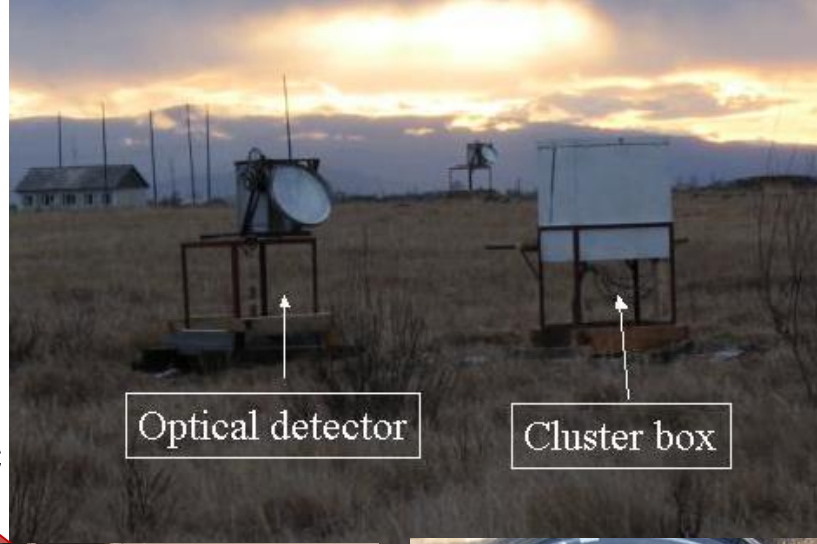
TAIGA_Muon

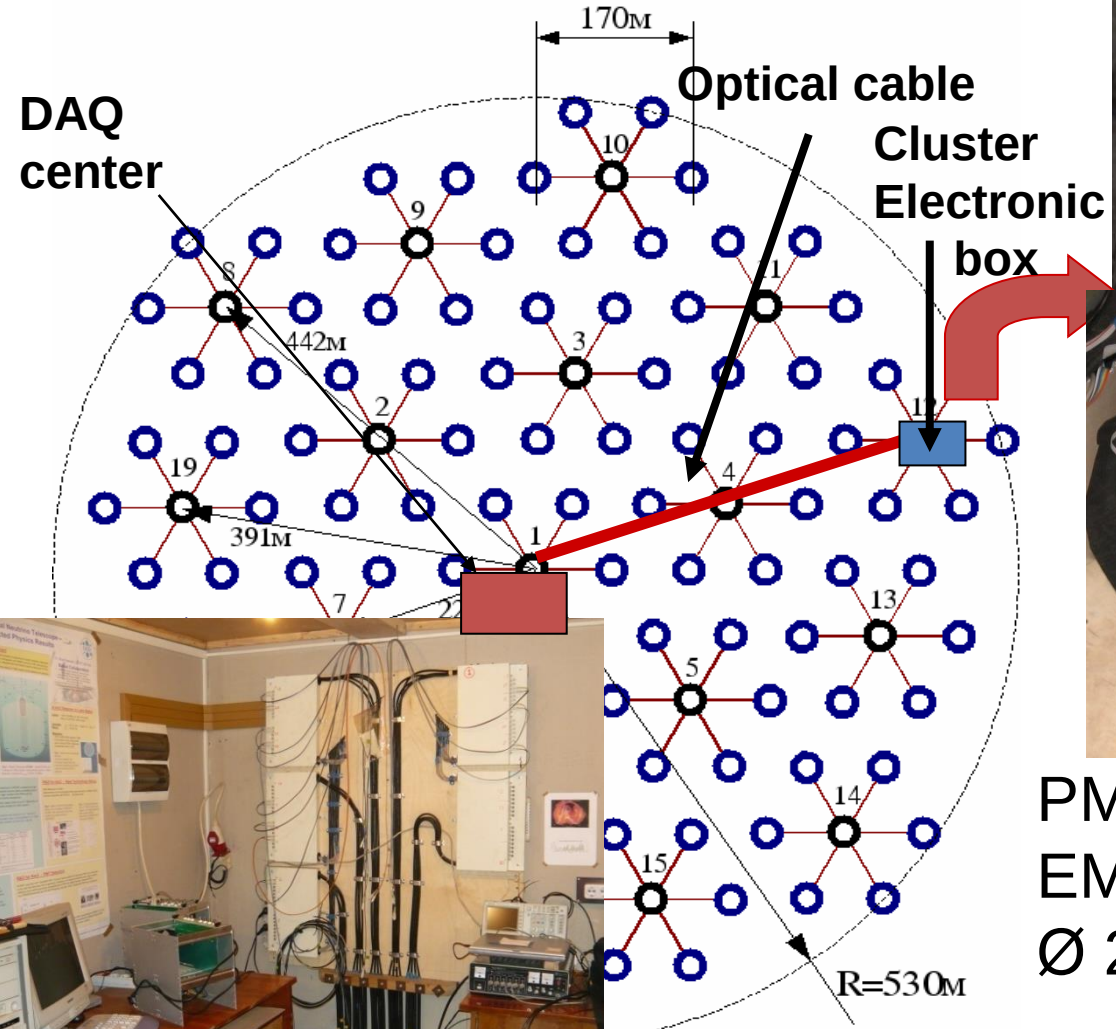


Tunka- Grande –
380 scintillation counters for detection of EAS charged particles

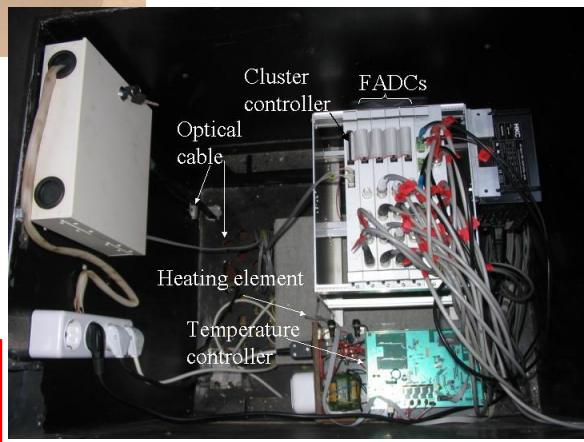


Tunka-133: 25 cluster, 7 detectors in each clusters



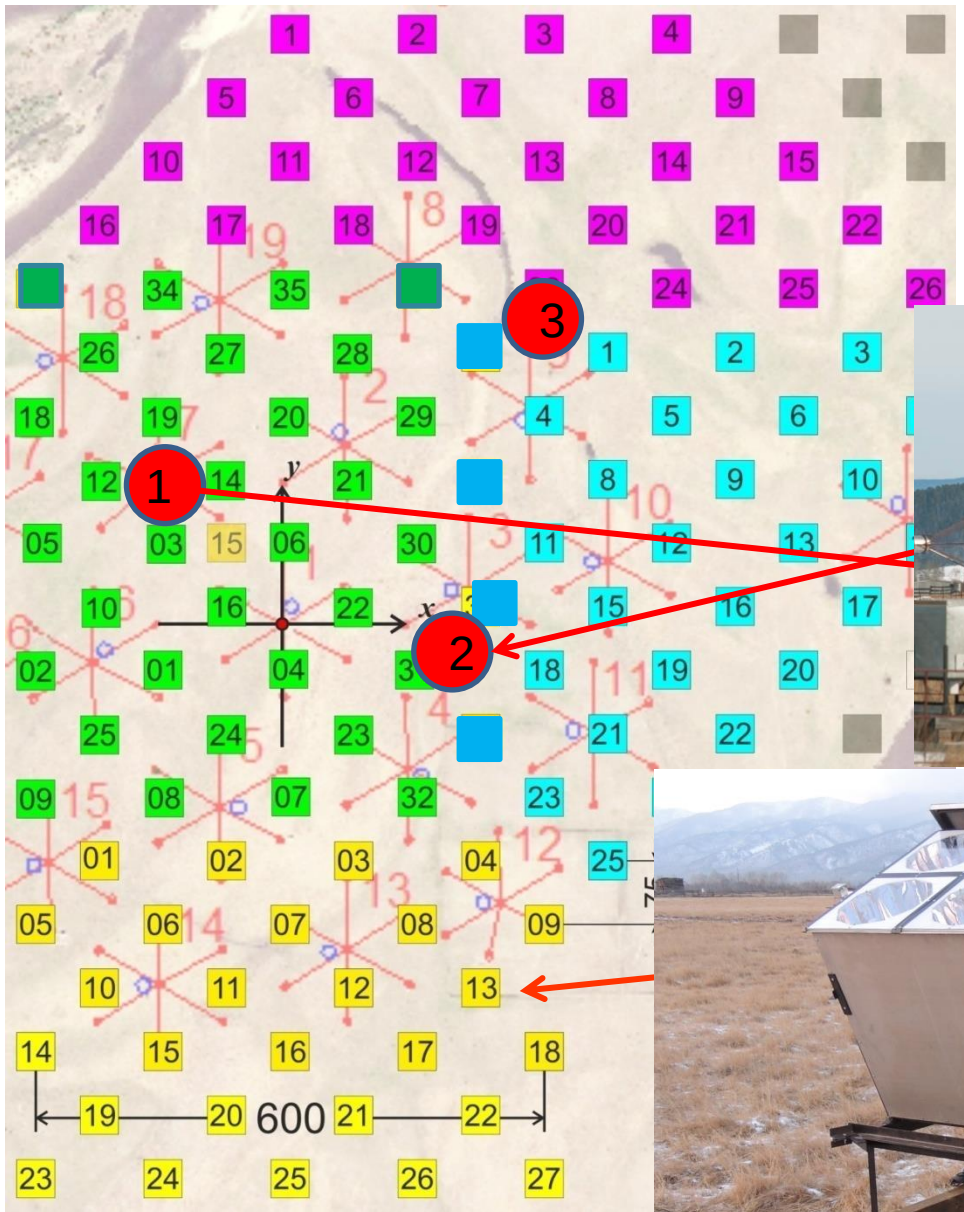


PMT
EMI 9350
Ø 20 cm



4 channels FADC
200 MHz, 12 bit

TAIGA : 120 HiSCORE stations and 3 ICATs



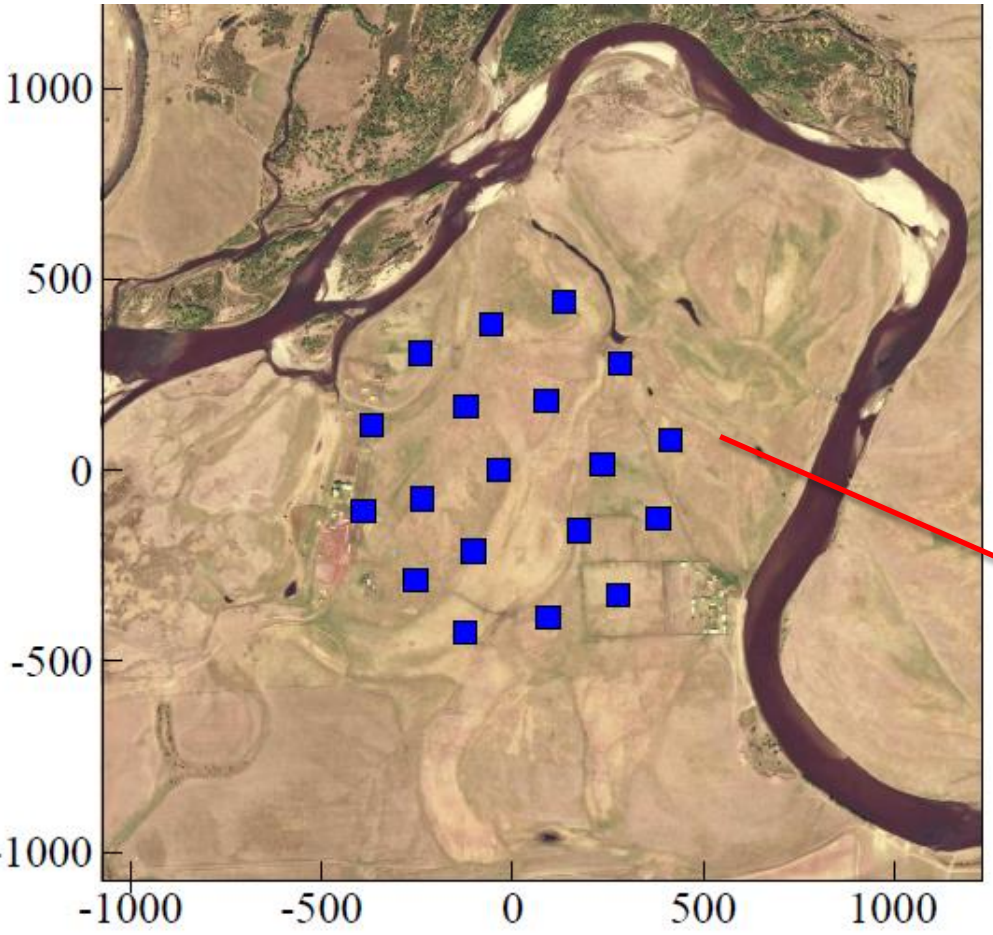
S=1.1 km2

Dish ~9 m² FoV – 9.6°

S tot = 0.5 m²

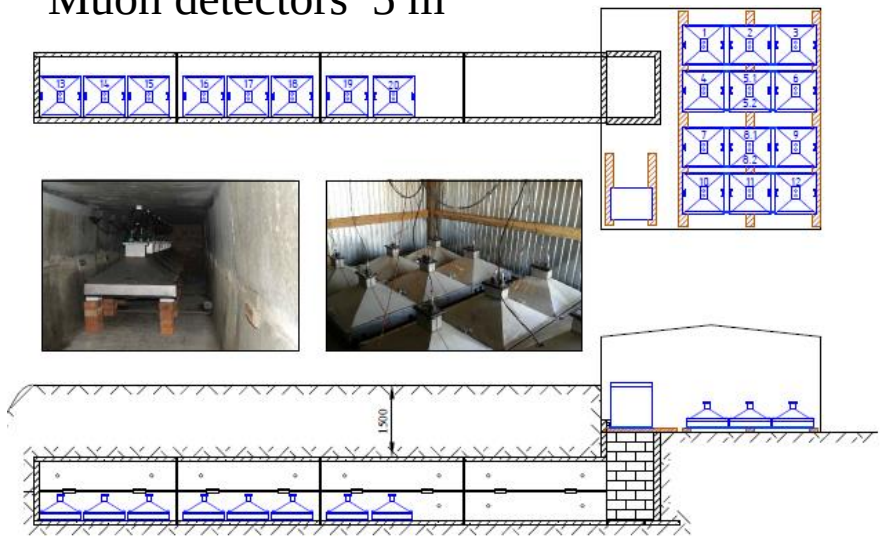
Tunka-Grande

19 stations, 95 m^2 of muon detectors



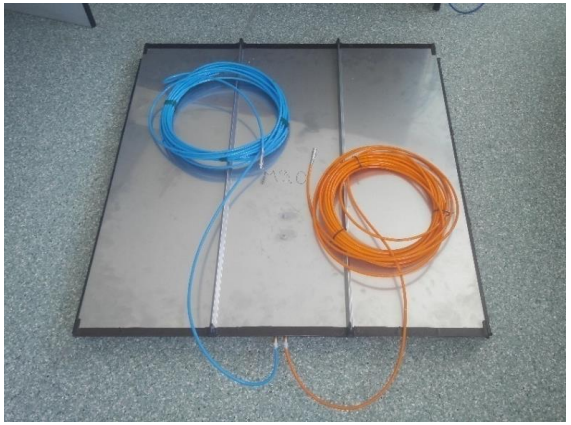
Muon detectors 5 m^2

8 m^2

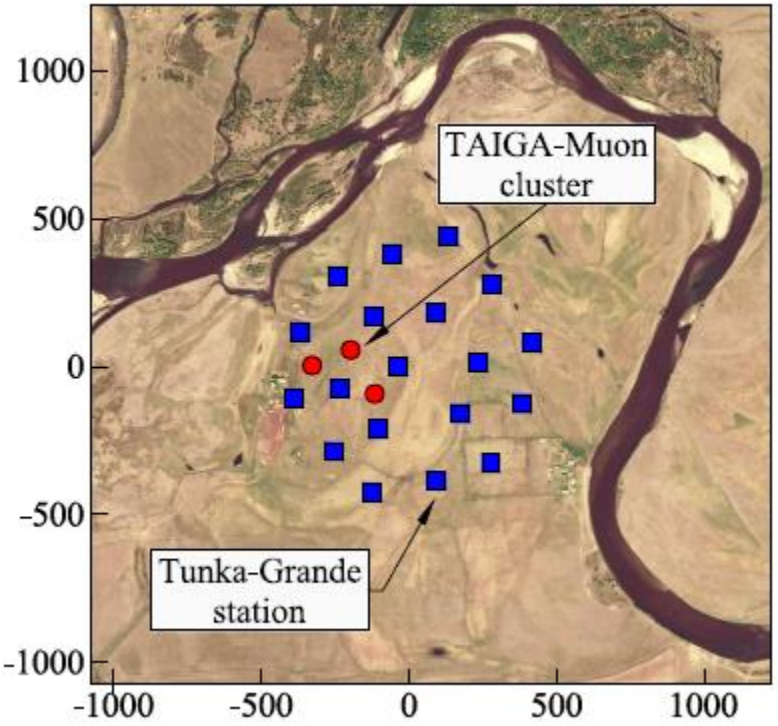


TAIGA-MUON

1 m^2 scintillation detector



8 surface detectors and 8 underground



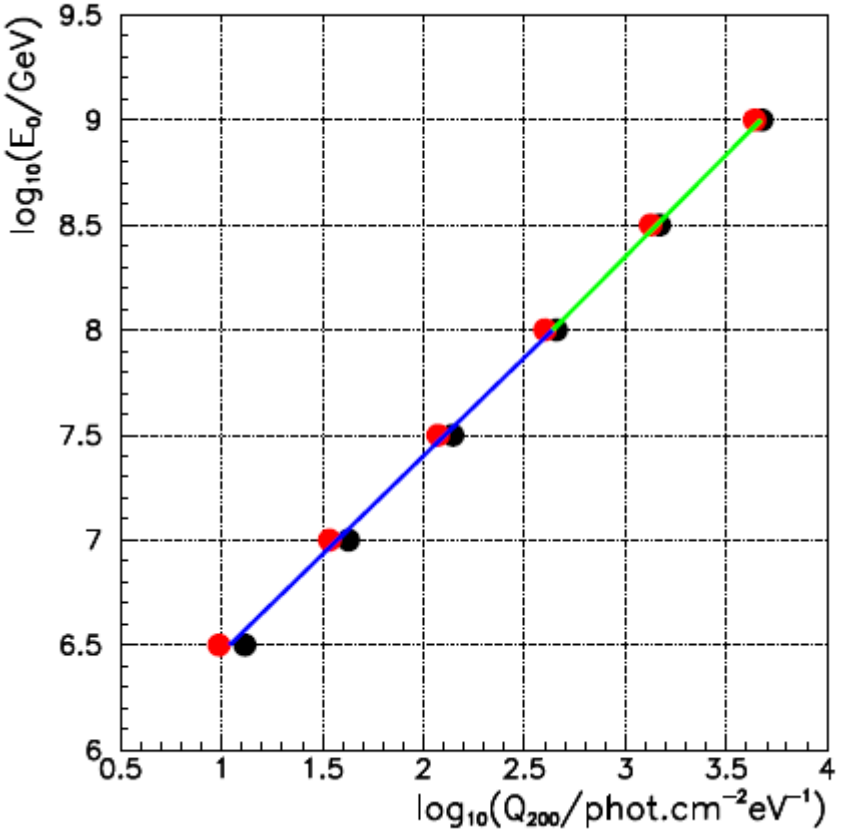
2. Cosmic ray study at the Astrophysical Complex TAIGA: results and plans

1. Methods of the EAS parameters reconstruction

2 .Energy spectrum 10^{14} – 10^{18} eV

3.Mass composition 10^{15} – 10^{18} eV

Energy determination for Cherenkov arrays



$$\log_{10}(E_0) = C_A + (0.94 \pm 0.01) \cdot \log_{10}(Q(200)),$$

Absolute energy calibration - QUEST experiment (Nucl. Phys. B (Proc. Supp.) 165 (2007) 74–80) .

- iron
- proton

$\sigma \log E = \pm 0.04$ (sist) ± 0.02 (stat) < 0.1(bin width)

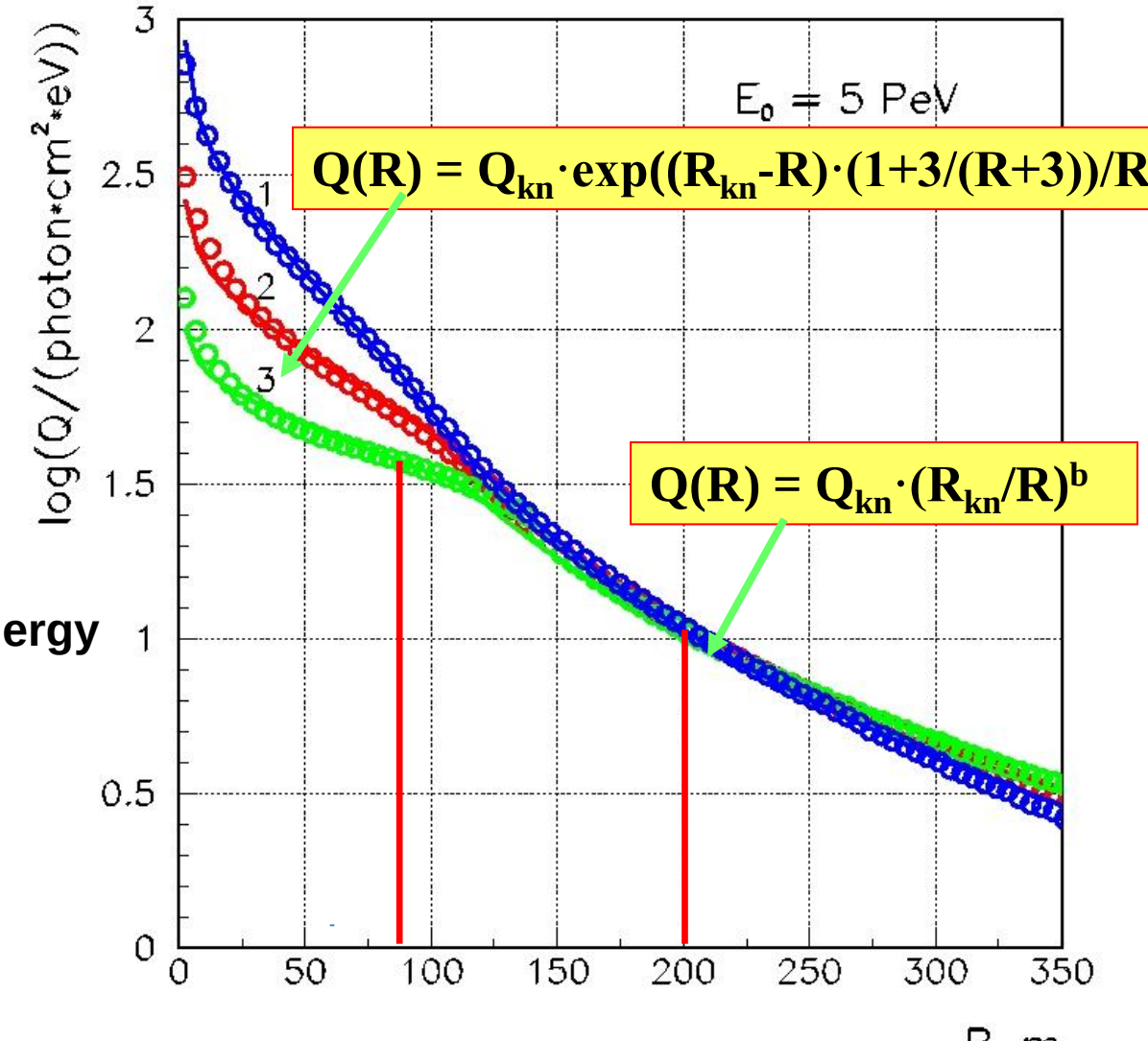
Lateral Distribution Function (LDF)

Steepness of LDF :
P=Q(80)/Q(200)

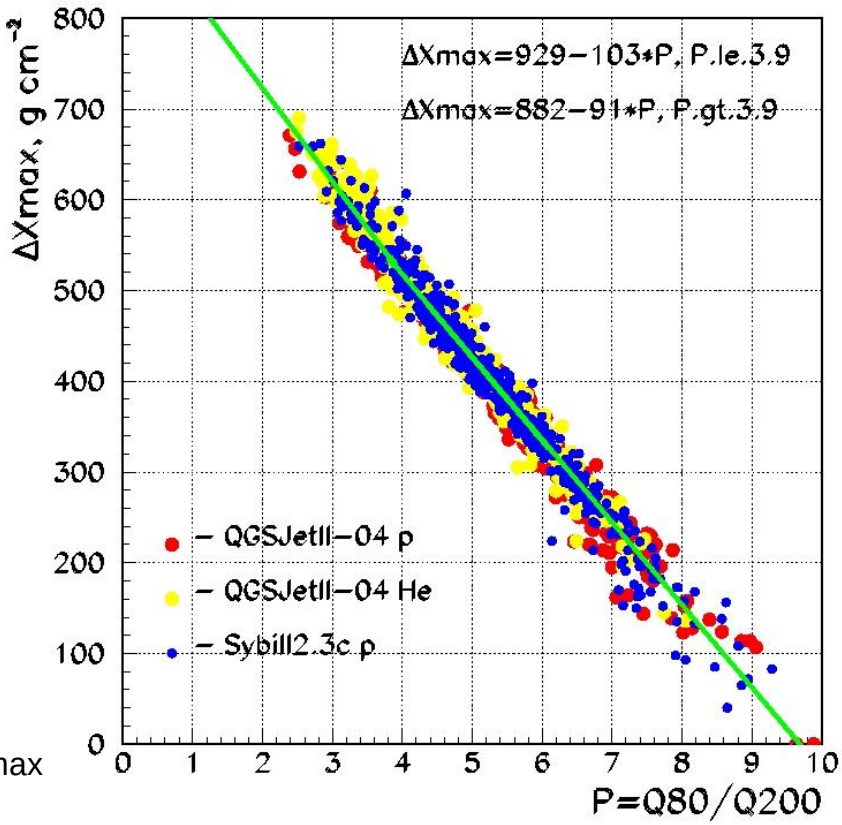
light flux at core

distance 200 m – **Q_{200}** - **Energy**

P = **Q(80)/Q(200)** - **X_{max}**

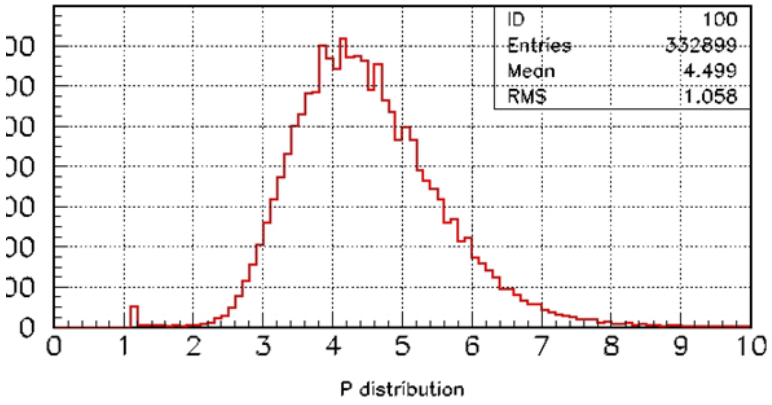


Correlation of the X max maximum and the steepness of the LDF



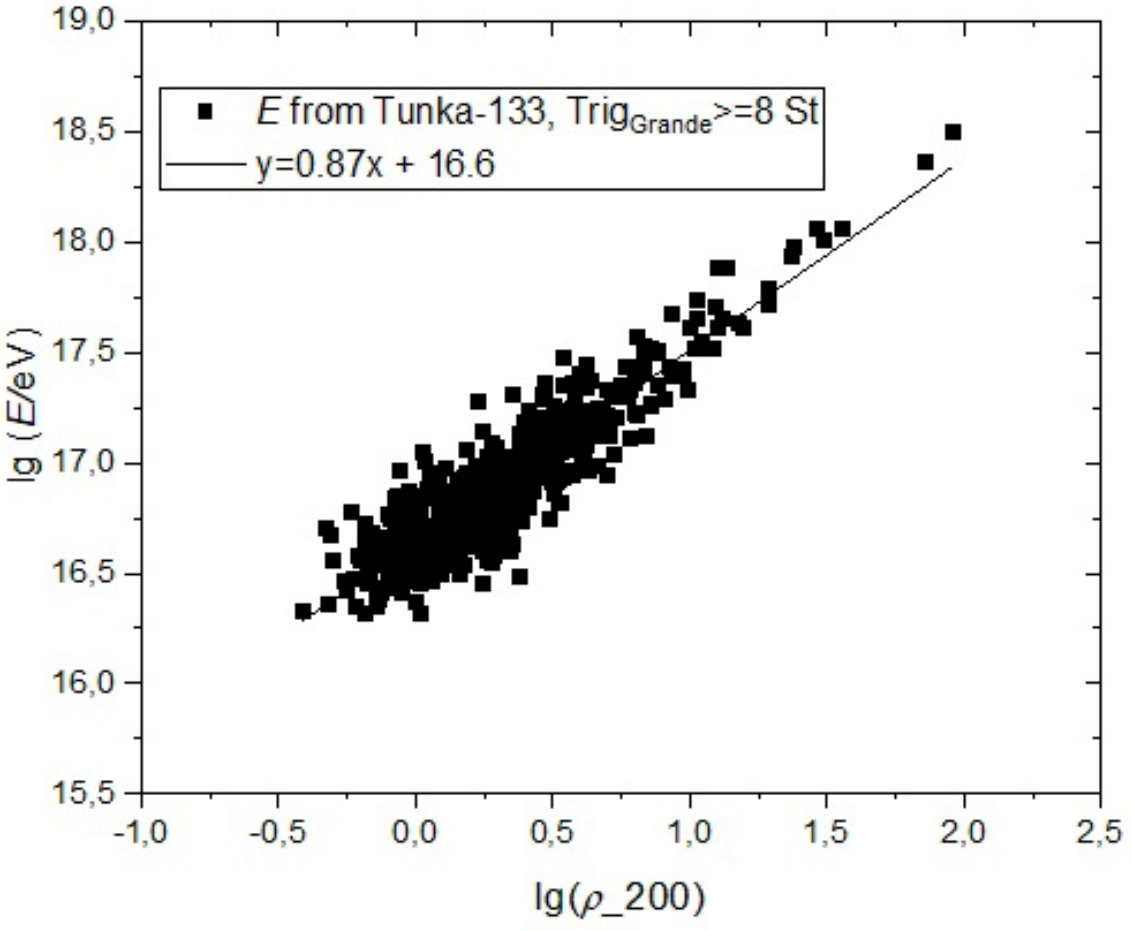
Steepness: P = Q(80)/Q(200)
$\Delta X_{max} = X0/\cos\theta - X_{max}$

Recalculation from the parameter P to ΔX_{max} does not depend on
the energy (10^{15}-10^{18} eV),
nor on the zenith angle of the shower (0° - 30°),
nor on the model of interaction
of the primary particle

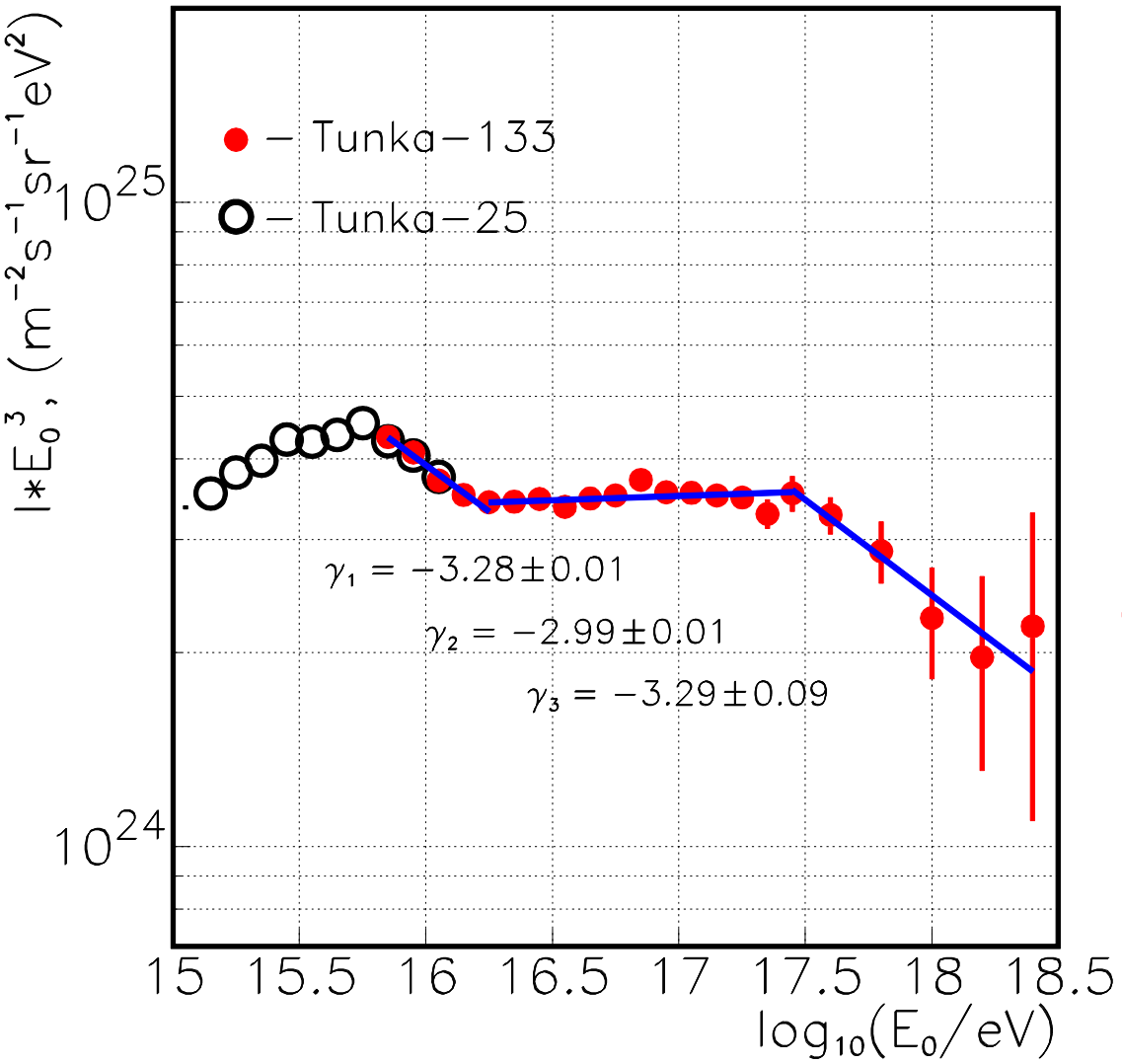


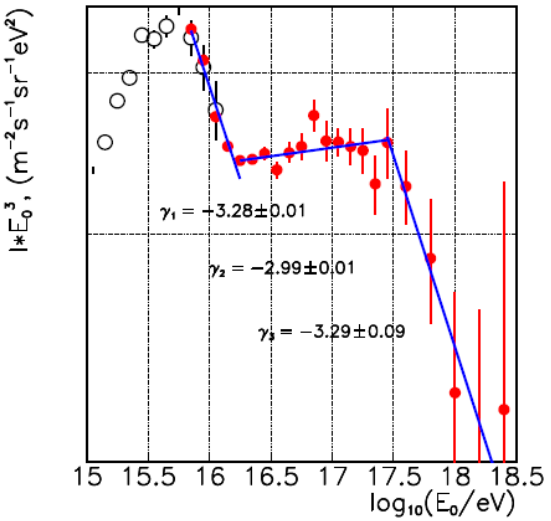
Energy determination by Tunka-Grande

Lg E = C + 0.87 Lg (ϱ _200), ϱ _200 – density of particles at 200 m from EAS core



All particles energy spectrum (7 year)

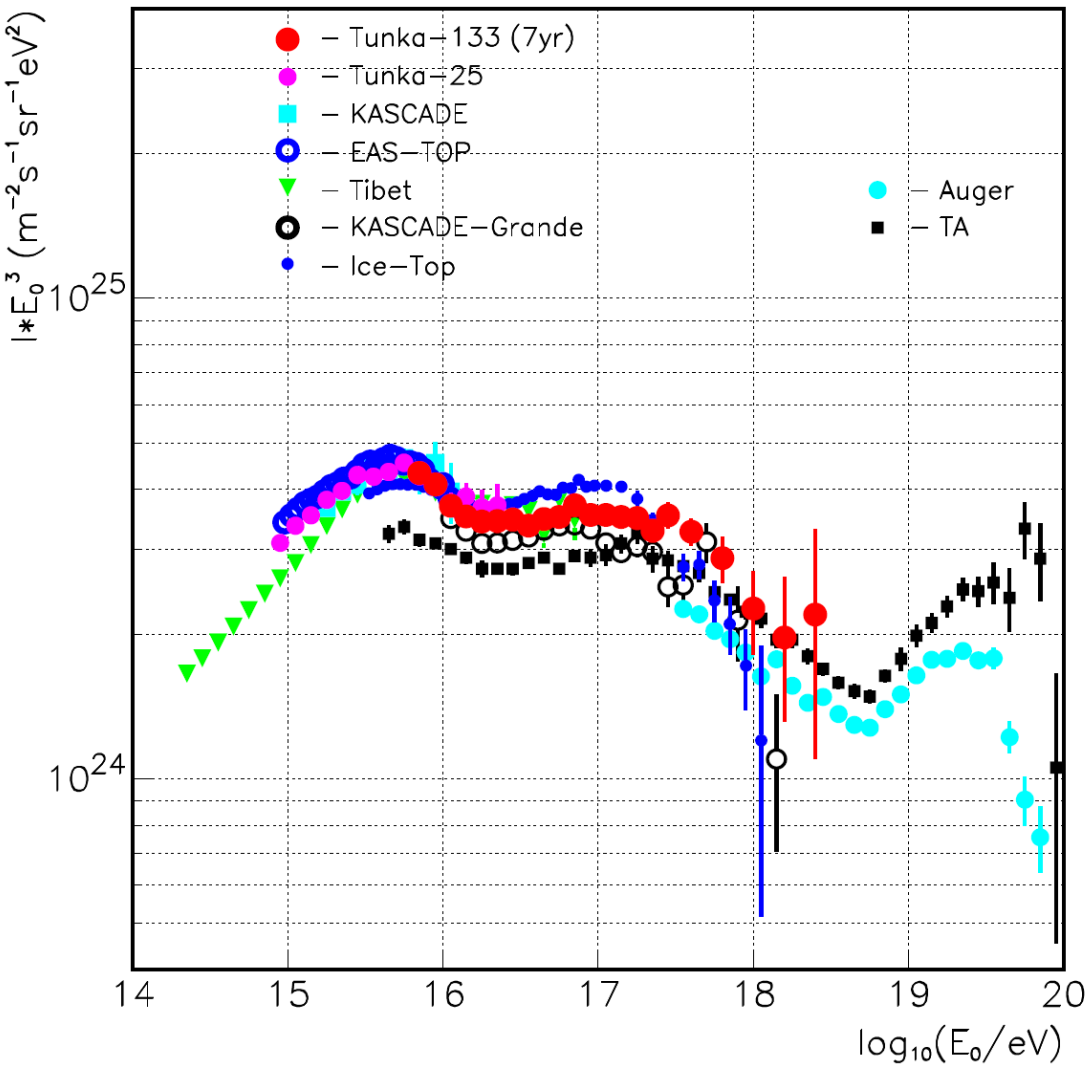




~4200 events with $E_0 > 10^{17}$ eV

APP, 117 (2020) 102406

Comparison of energy spectra obtained at the Tunka site to other experimental results



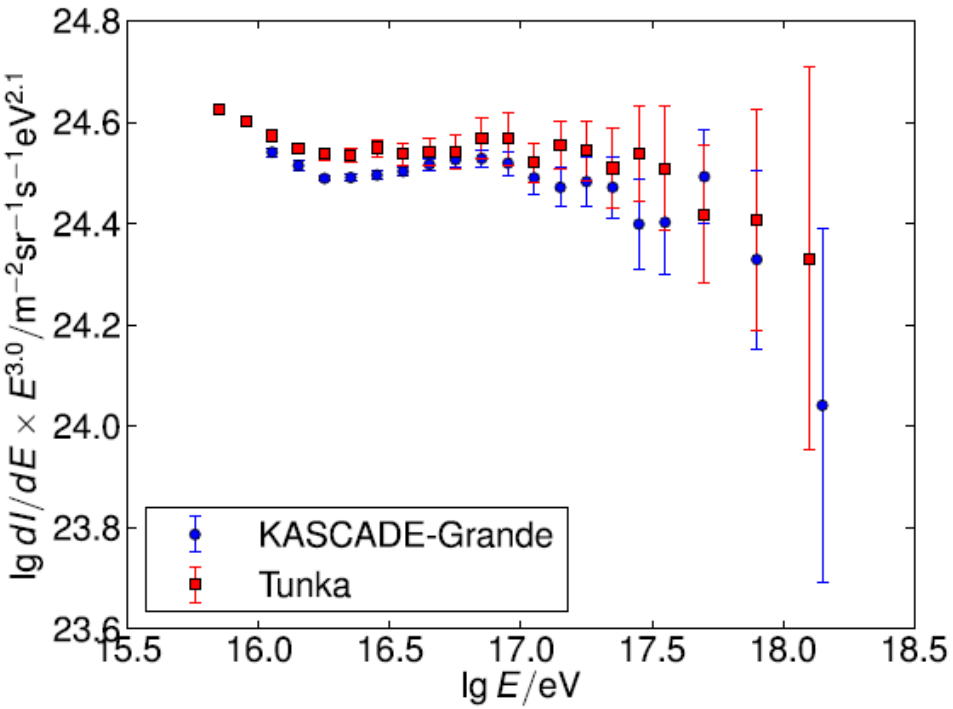
Harding of spectrums at
E = (1.5 – 2) 10^{16} eV

Δɣ ~ 0.2-0.3

Difference in intensity
~30% , due to difference in
energy calibration ~10% ?

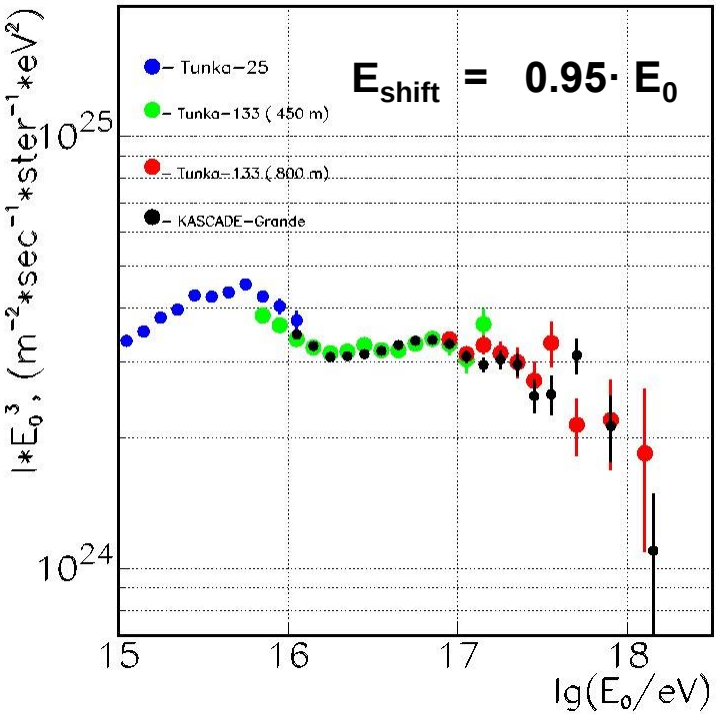
The second knee
(1-3) 10^{17} eV
Δɣ ~ 0.3

A comparison of the energy scales of Tunka-133 and KASCADE – Grande via their radio extension Tunka-Rex and LOPES

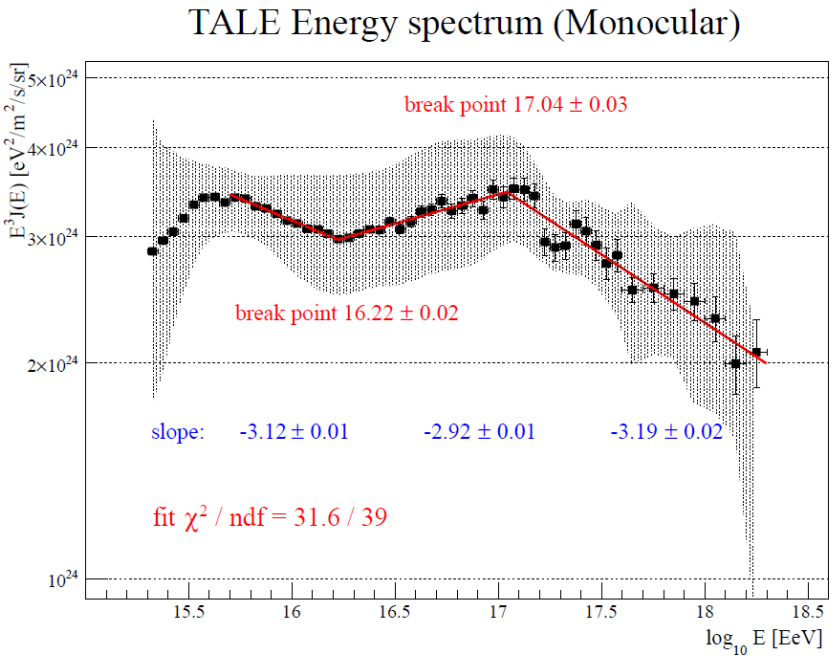


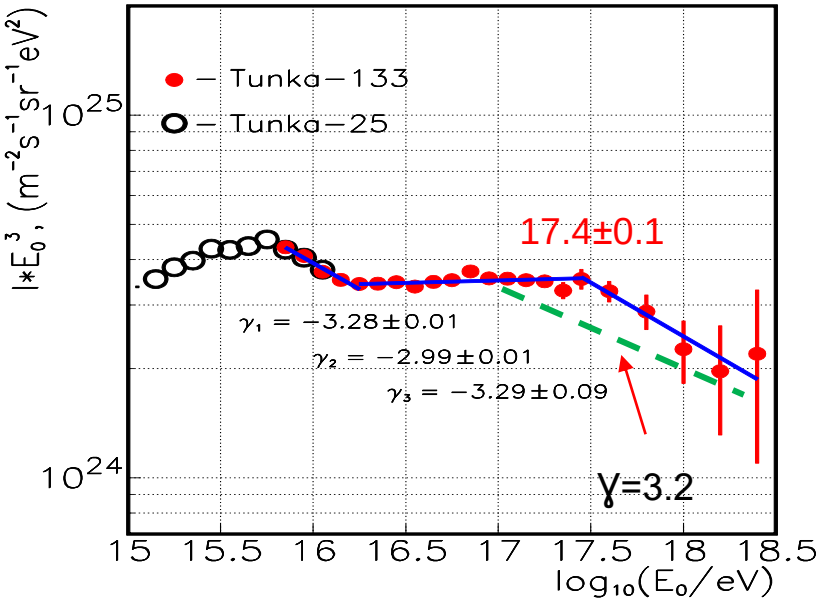
Physics Letters B,
V 763(2017) 179

$E_{K\text{-}G} / E_{Tunka} = 0.96 \pm 0.05$

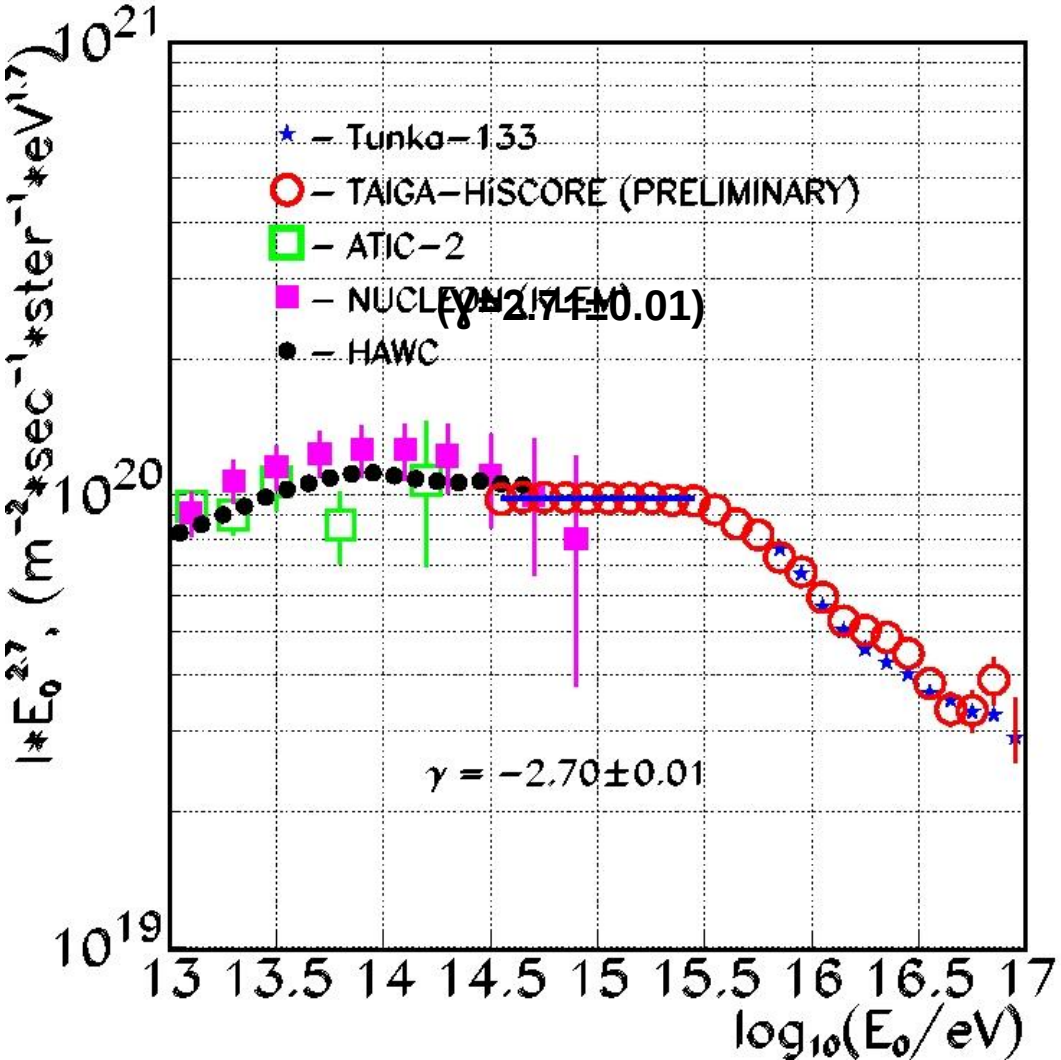


The second knee

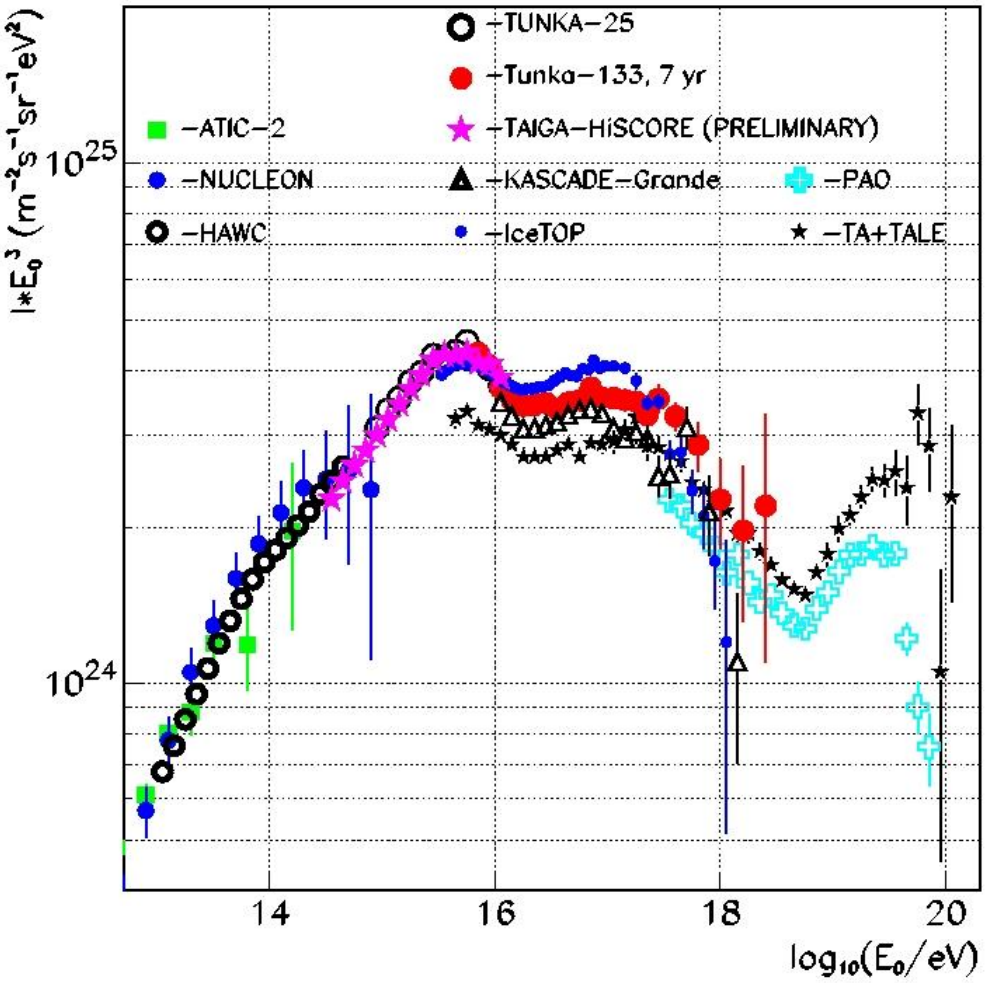




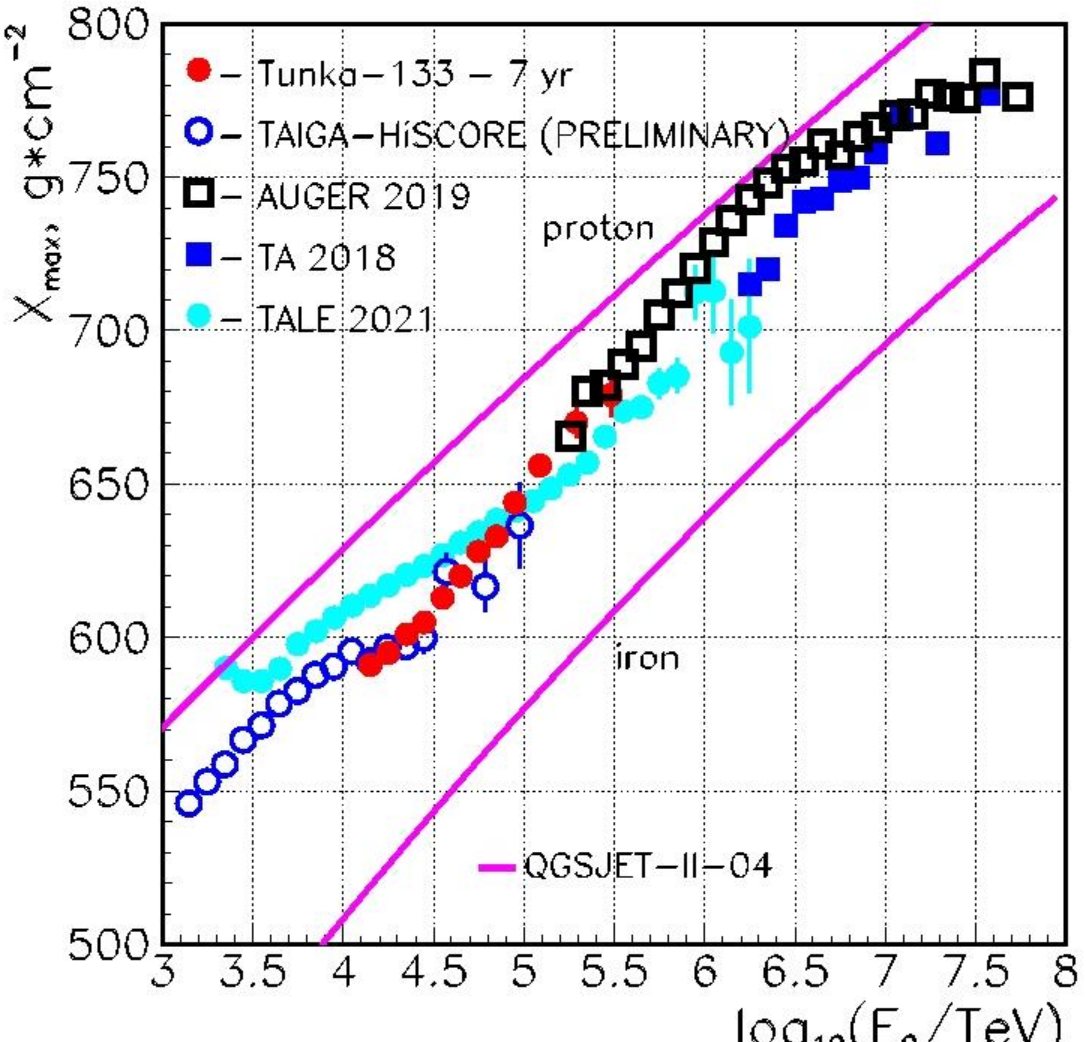
HiSCORE energy spectrum



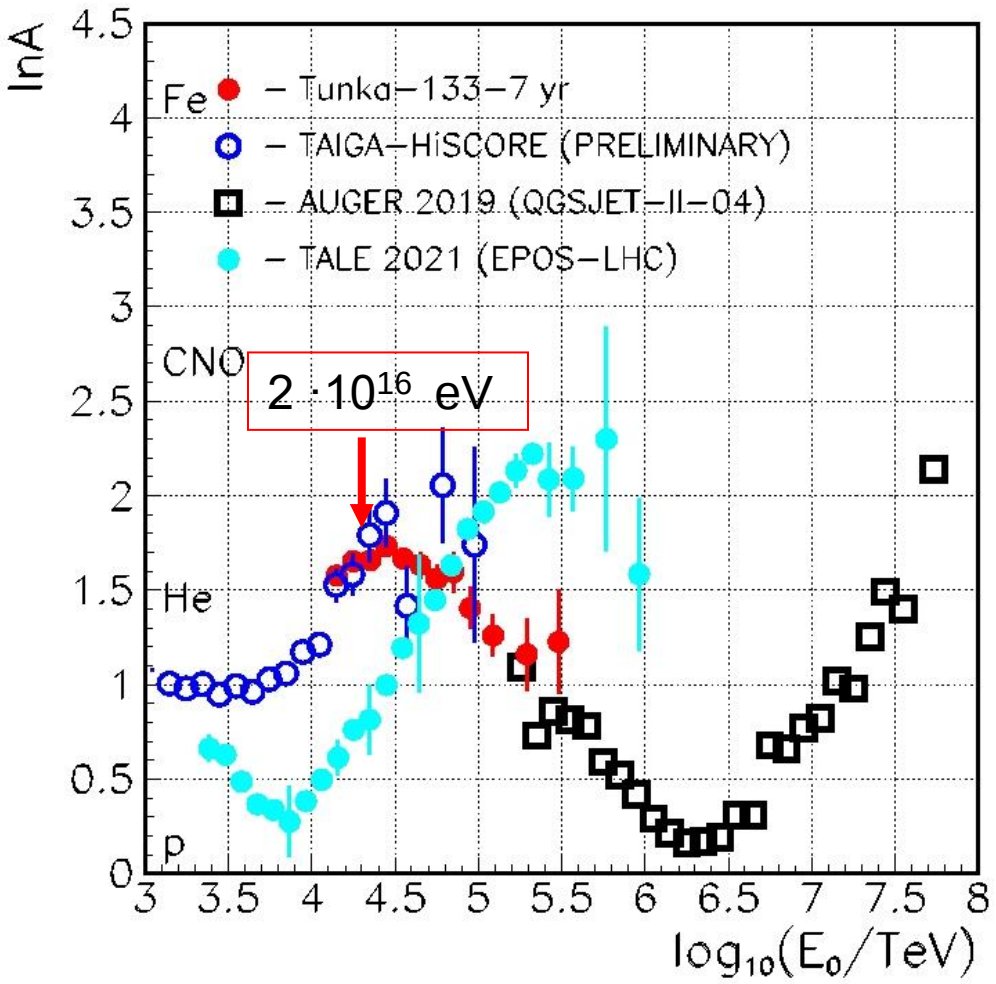
Comparison of energy spectra obtained at the Tunka site to other experimental results



Xmax & Energy


Tunka–133 – 7 yr
TAIGA–HiSCORE (PRELIMINARY)
AUGER 2019
TA 2018
TALE 2021
proton
iron
QGSJET–II–04
X_{max}, g*cm^{-2}
$\log_{10}(E_0/\mathrm{TeV})$
800
750
700
650
600
550
500
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8

LnA & Energy


lnA
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Fe
CNO
He
p
– Tunka–133–7 yr
– TAIGA–HiSCORE (PRELIMINARY)
– AUGER 2019 (QGSJET–II–04)
– TALE 2021 (EPOS–LHC)
2 ·10^16 eV
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5
8
log10(E0/TeV)

3.High-energy gamma-astronomy and the TAIGA project

Scientific Program

Search for the acceleration limit of particle in known supernova remnants and PWN: Crab Nebulae и Boomerang (PWN), Tycho и Cas A (SNR), Dragonfly Nebula (2HWC J2019+367) ARGO J2031+4157 (Cygnus Cocoon)

Long-term monitoring and study of the edge of the energy spectrum bright blazars as a method for searching for distribution anomalies gamma rays in the universe and the search for axion-like particles. (1ES 0229+200, 1ES 1959+650, Mrk501, Mrk421, Arp 220, M82)

Search for excess diffuse gamma – rays with energies above 100 TeV Gamma-ray in accompany with neutrino (10^{-4} from CR) if part of IceCube neutrino from Galactic source

Study of CR mass composition in energy range 100-3000 TeV by hybrid approach

Four approaches to detecting gamma rays in the TAIGA experiment

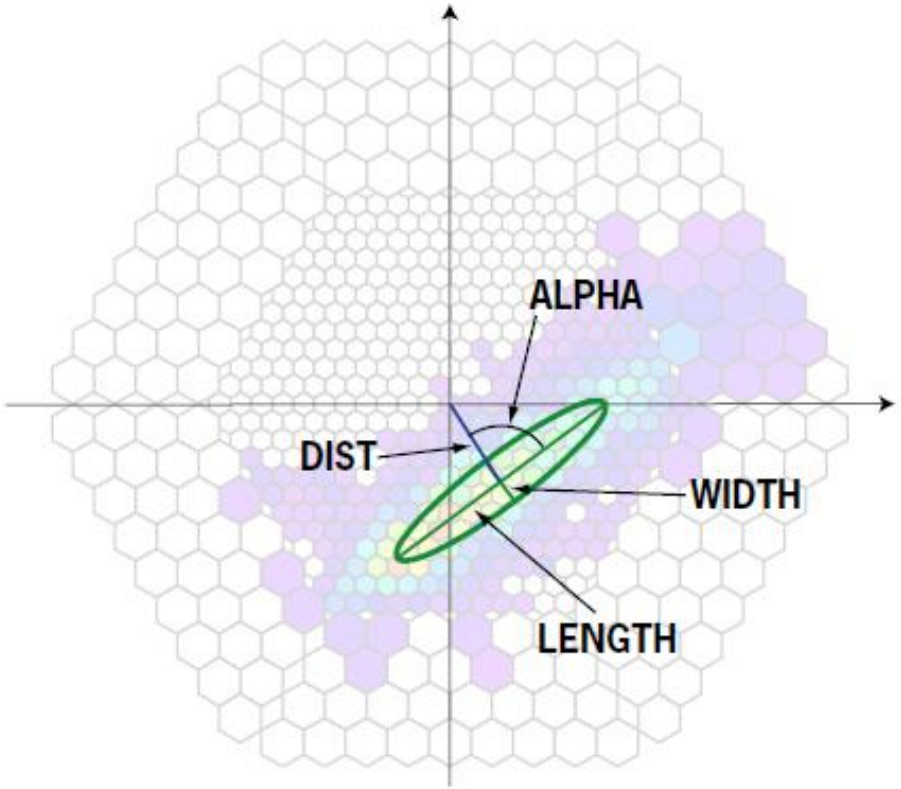
1. Autonomous work of one telescope E < 10-15 TeV

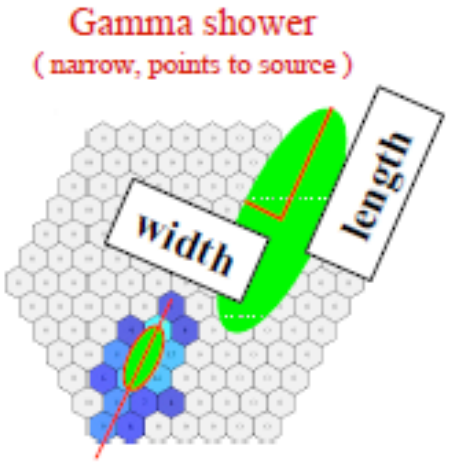
2 Stereoscopic approach for large distances between telescopes E ≥ 10 TeV

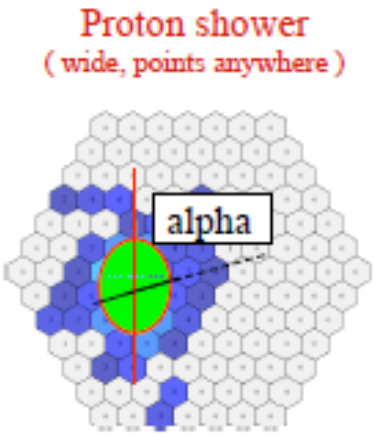
3. Hybrid approach – joint operation HiSCORE and IACTs E ≥ 40 TeV

4. Only by HiSCIRE > 100 TeV (or we need some additional hadron suppression

Hillas parameters

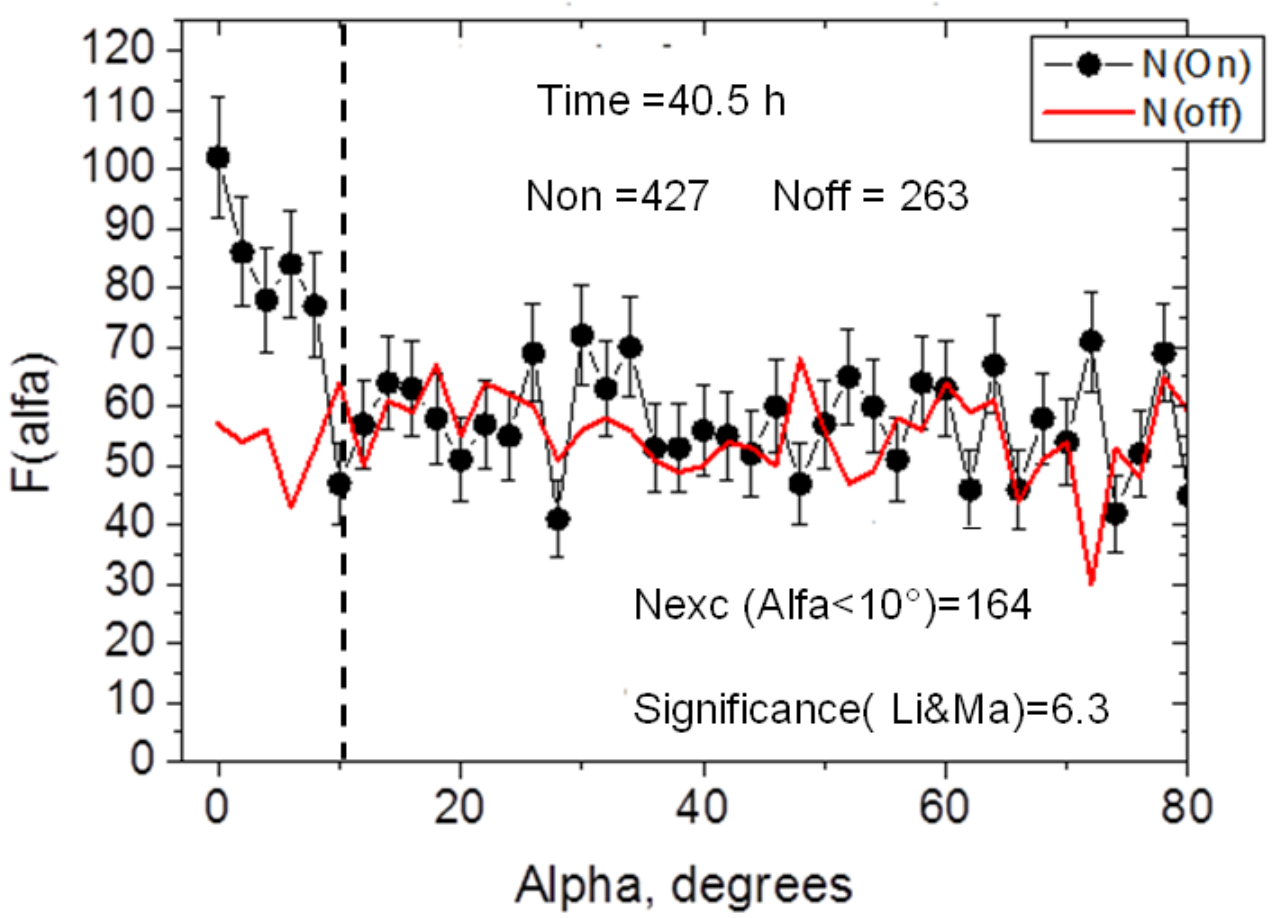




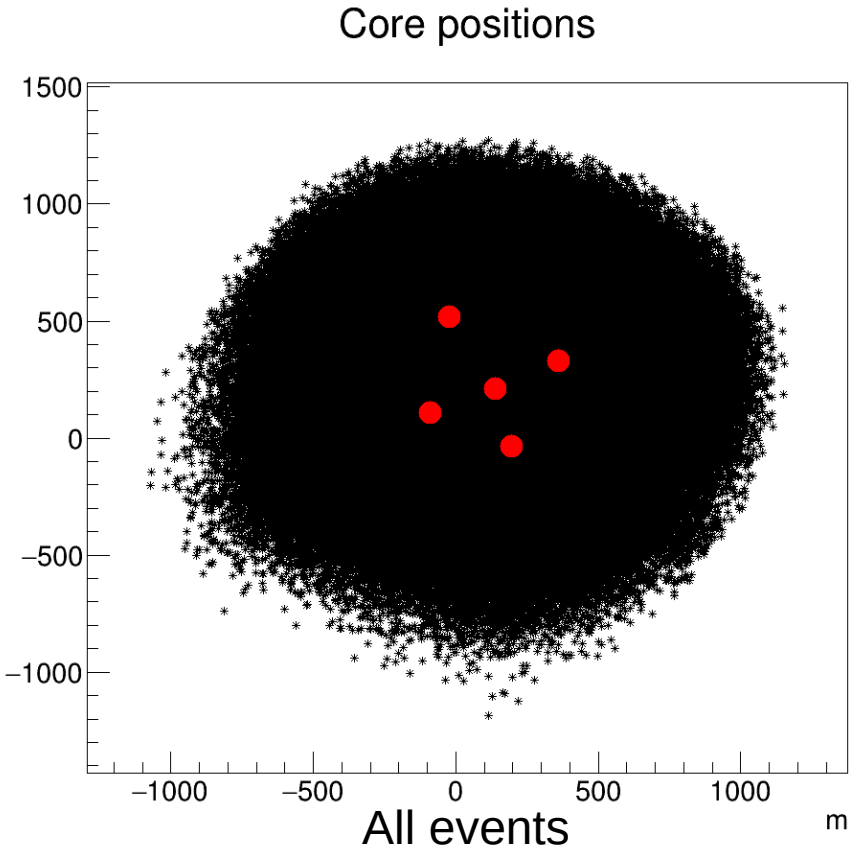


Size -
total number of P.E in image

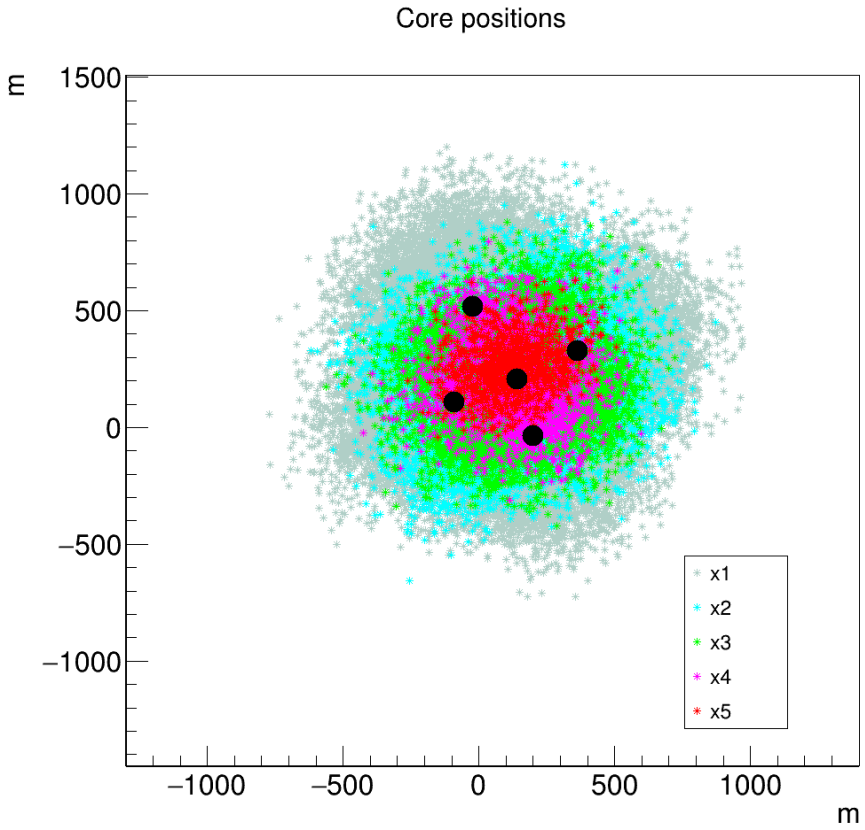
Signal from Crab



Stereo-method – MC for 5 IACTS



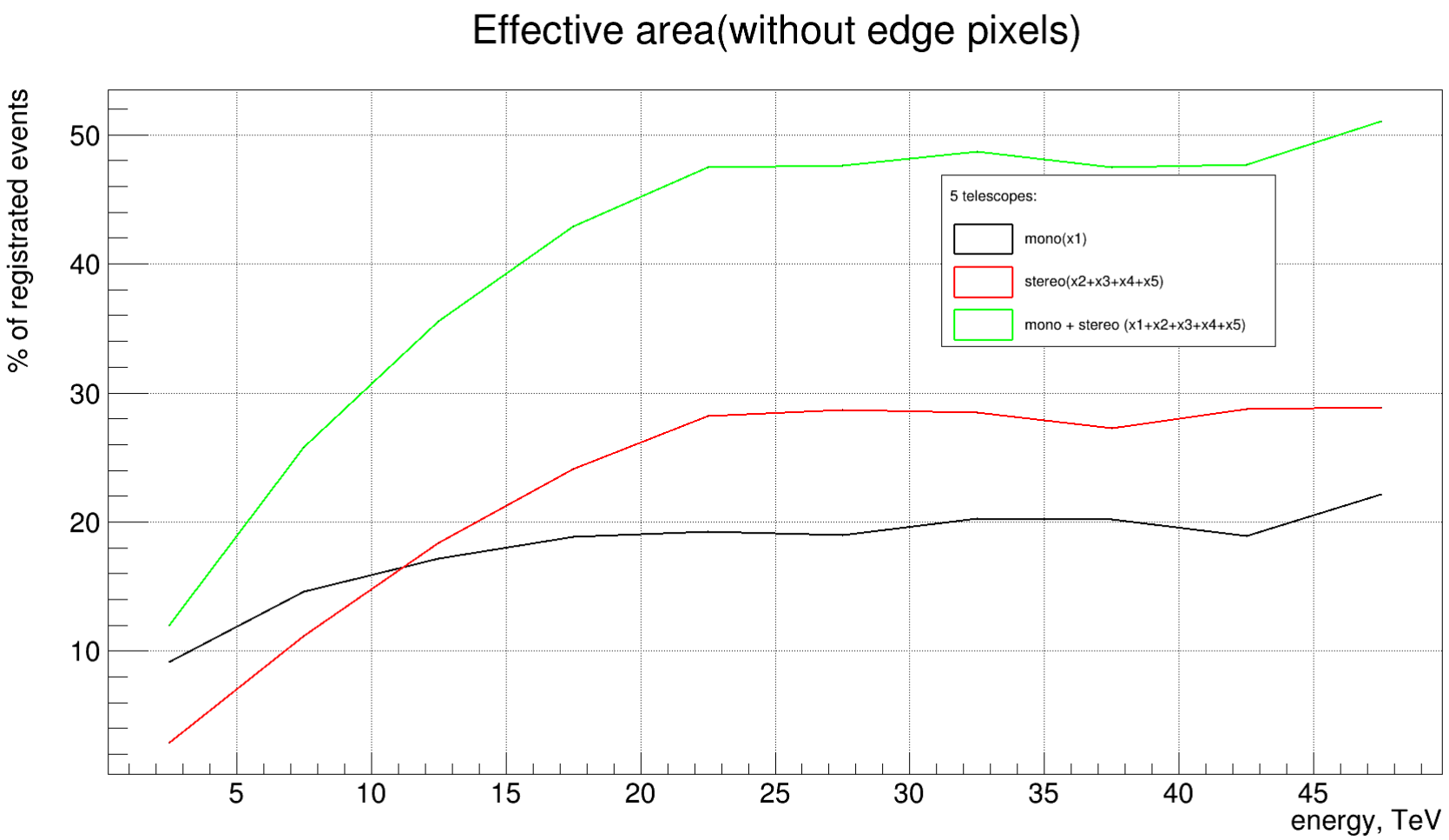
All events



After IACT trigger

Energy range 2-50 TeV

Effective area



Sensitivity

For E gamma >10 TeV

Ψ_{68} = 0.24°

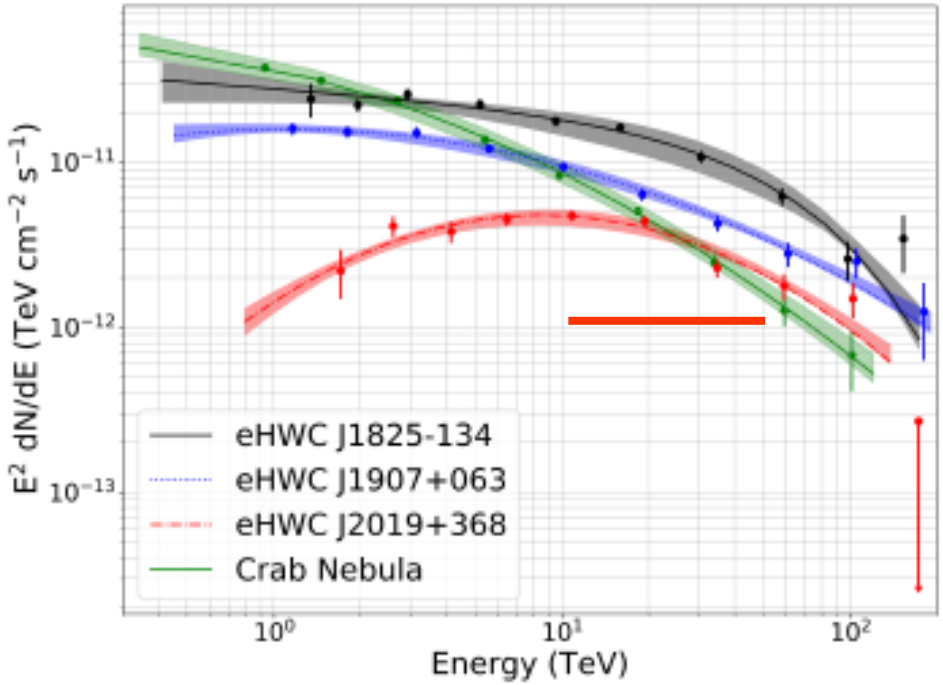
Hadron rejection – cut on angle+ width cut

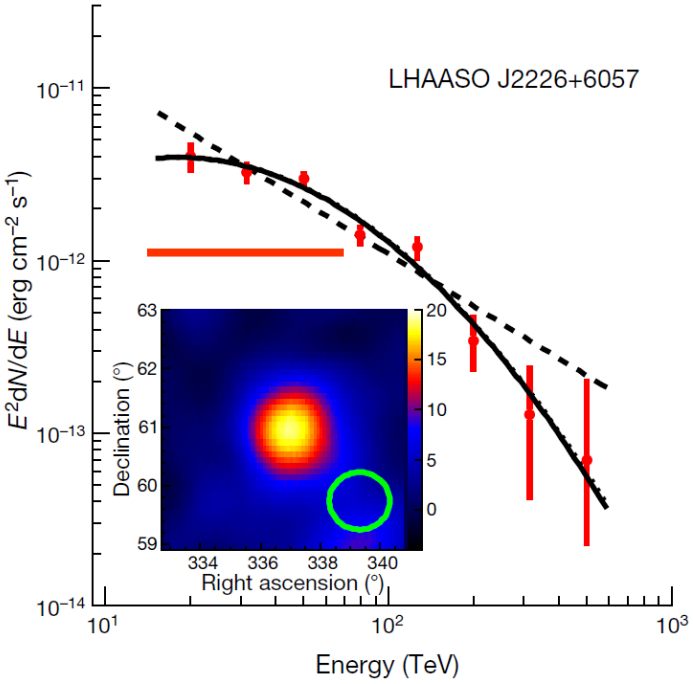
$2\ 10^{-4}$

$E^2\ dN/dE = 10^{-12}$ TEV cm-2 sec-1

5 sigma for 100 hours

HAW&LHASSO events





Hybrid events – Hiscore +IACT
Crab, 120 hours

6 ON events (50% gamma after cuts)

1 Off events

E > 100 TeV

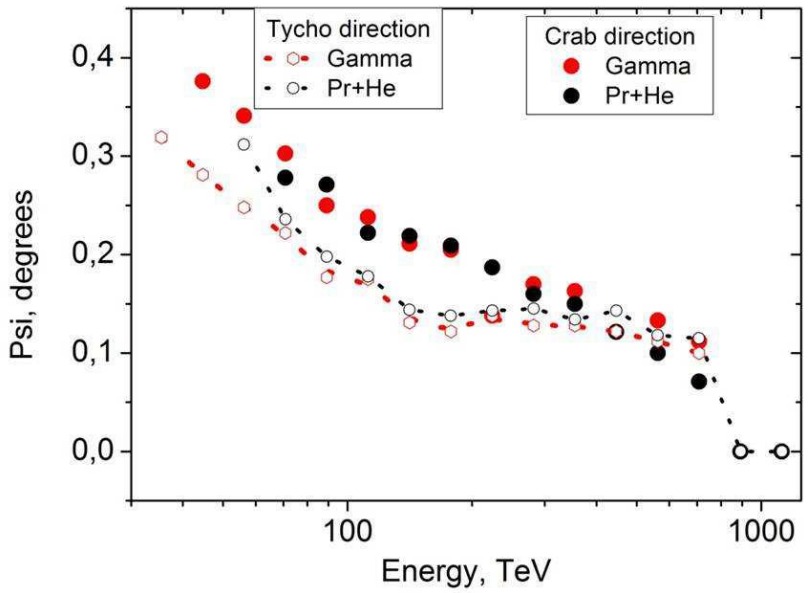
(S = 0.25 km2)

10 gamma events

Should be 9 (!?)

Selection gamma only by HiSCORE

Hadron rejection only by good angular resolution



Ψ68 = 0.25°

for 0.25 km2 and 120 hours

in circle 0.25° ---6 events

From 6 hybrid events in circle 0.25° ---2 events

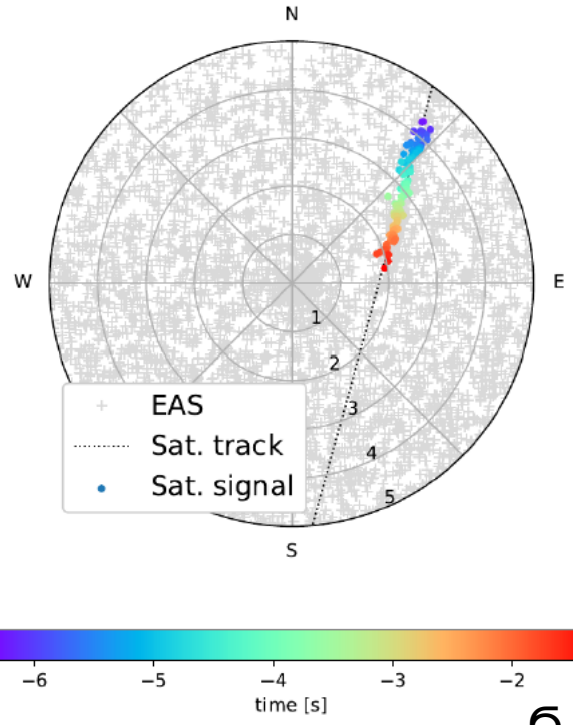
Statistic or error in poiting calibration

Calibration with lidar on Calipso

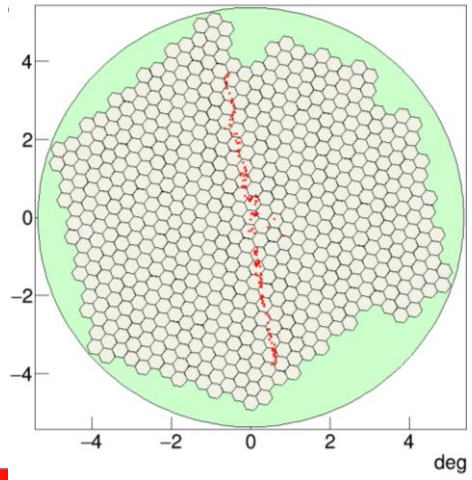
- 2015-2021: 10 Calipso observations
- 2016-2017: 12 observations of Int.SpaceStation Laser [see PoS(ICRC2017)754]

• Calipso: started targeted IACT observation in April, 2021 (stereo mode)

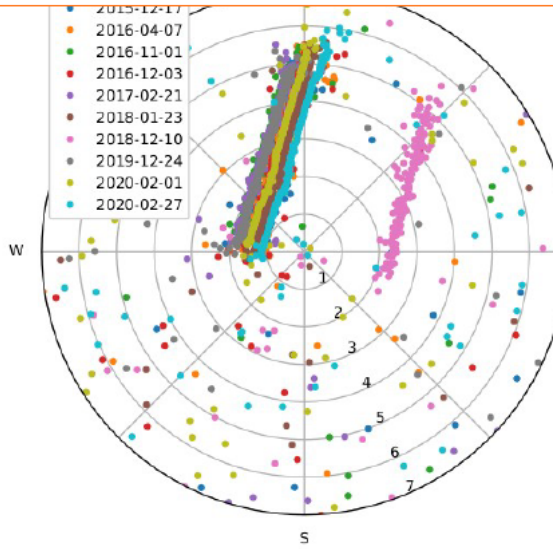
Example: Calipso Satellite passage over TAIGA-IACT on 18.12.2018



Absolute Pointing <0.1°



Analysis of 2015-2020 data archive: 10 precision-reconstructed passages



CALIPSO lidar pulse duration is ~20 ns
Altitude 700 km

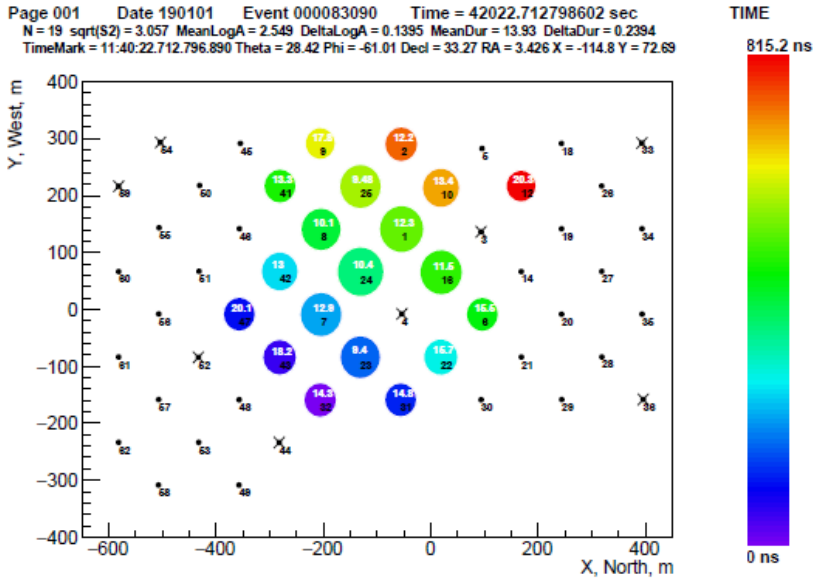
σ (Ψn - Ψ n-1 +0.05°)~0.05°

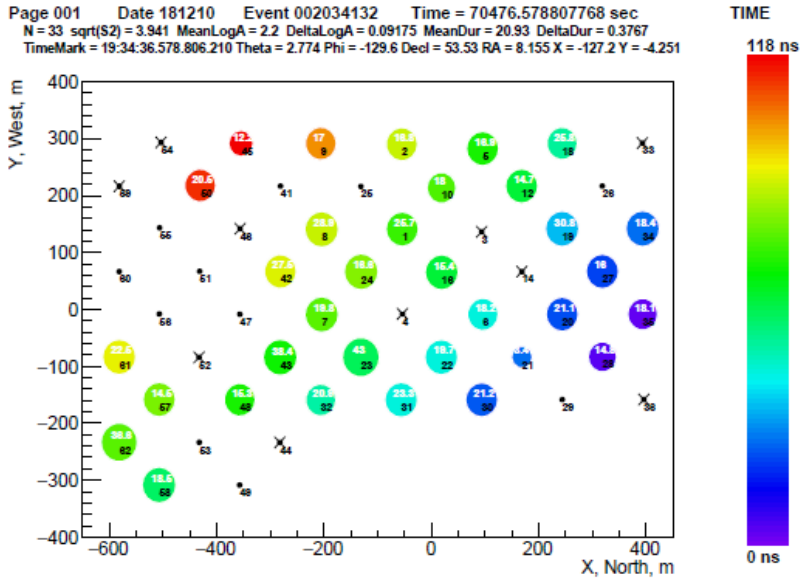
4. Interdisciplinary topics

1. Search for astrophysical nanosecond optical transients for SETI

2. Stellar Intensity Interferometry

EAS &lidar Calipso

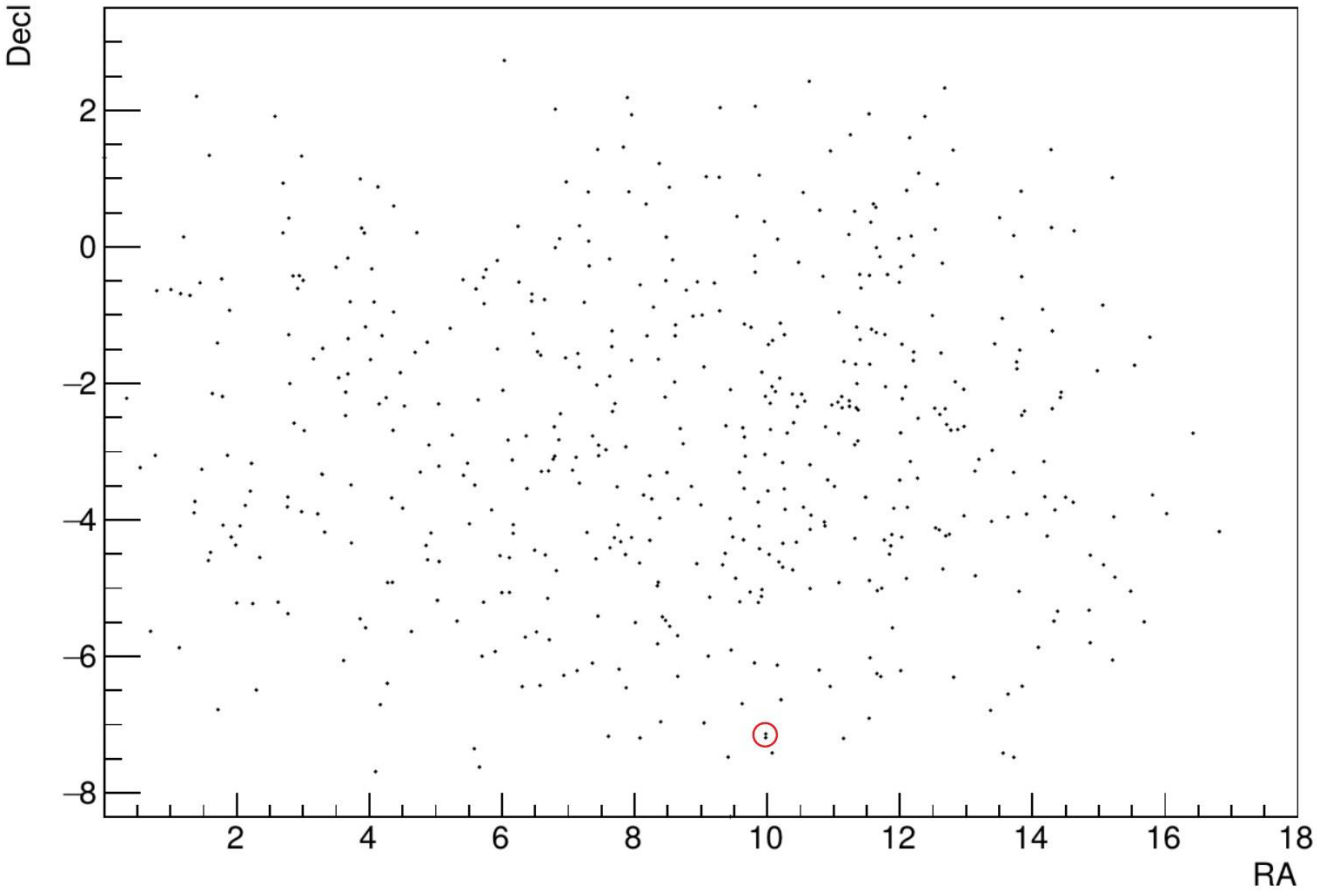




Flatness cut +
additional set of cuts

With these cats satellite Calipso was found. It was an accidental discivert

511 evets after all cuts
(data 2018-2020, 288 ster -hour)



$\Delta\Psi = 0.04°$.

Probability
of one pair
~10%

the flux is less than
~2x10–3 events/sr/hour

Threshold flux: 3000 photons/m^2 per 10 ns = 10^{-4} erg/s/cm2

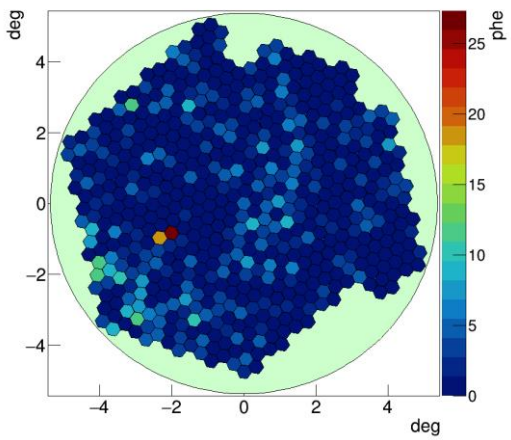
TAIGA-IACT

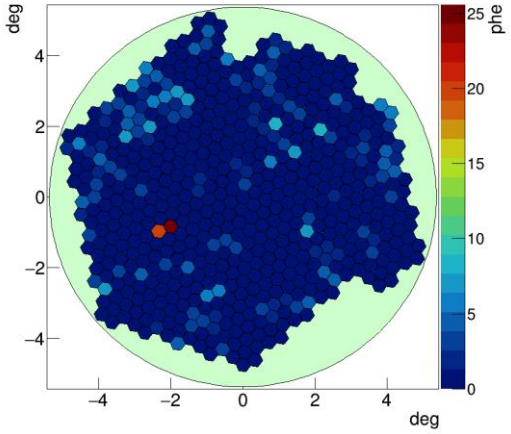
Area of mirrors - 9.6 m^2 (34mirrors)
Focus length 4.75 m

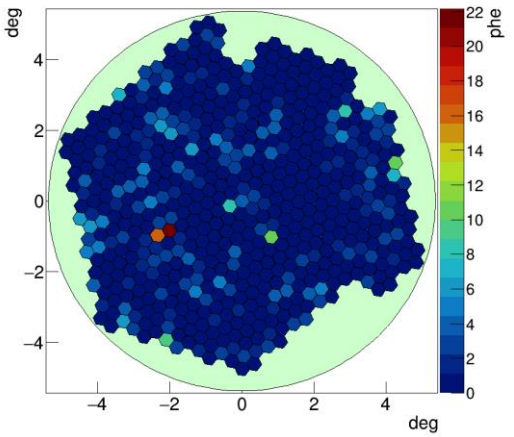
Camera:
FOV **9.6º** (0.015 ster)
560 pixels(pmt XP1911) pixel FoV 0.36°
camera trigger : signals in neighboring pixels with an amplitude > 10 p.e for 15 ns

Light flux from an infinity source for 90% of trigger output: 50 photons/m^2 per 10 ns

PSF ~ 0.07°
CCD for checking telescope pointing direction.



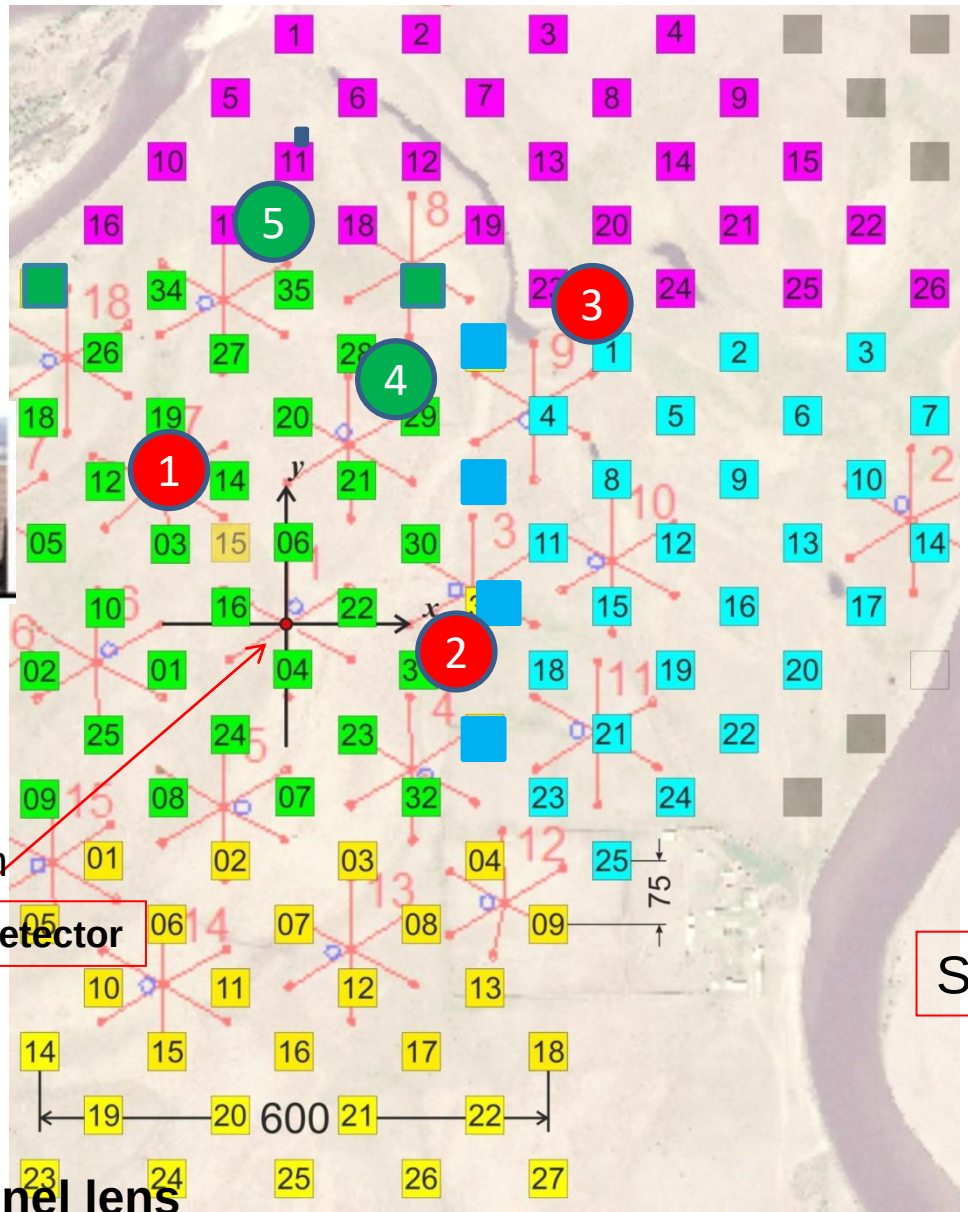




Signal signature: 2 hitted pixels in all 3 cameras in the same place of cameras with a correct delay in time. Probability of imitation < 10^{-4} for 500 h of observation

5. The future of experiment

TAIGA -2022-24



Three first IACT

Two new IACT

Fluorescent Detector

Area of muon detectors:
- from 100 m^2 to 200 m^2

2-3 km

Fluorescent Detector

3 m^2 Fresnel lens

Search for a site for HiS-10

Thank you for the attention