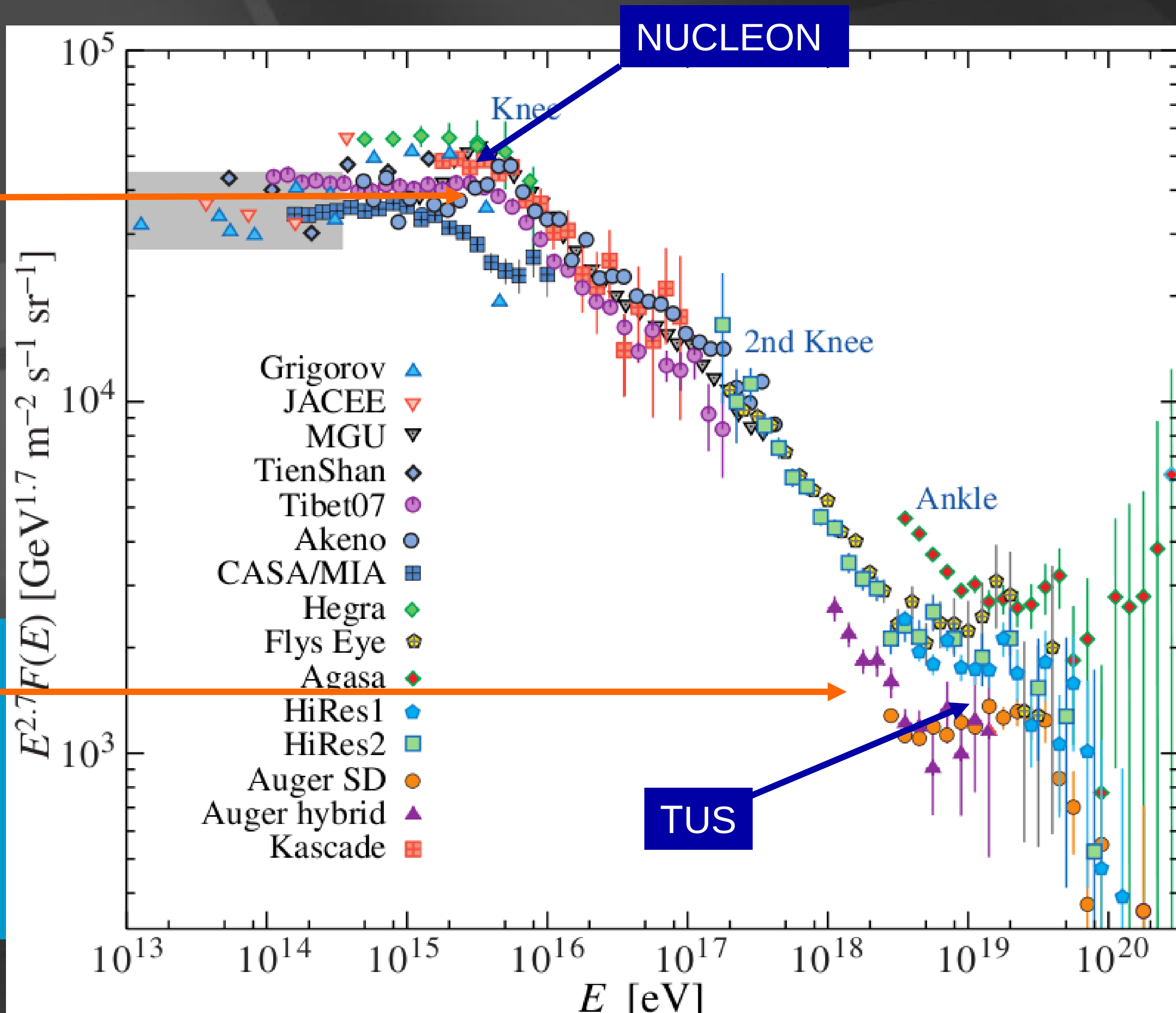
JINR activity in the NUCLEON and TUS/KLYPVE space experiments

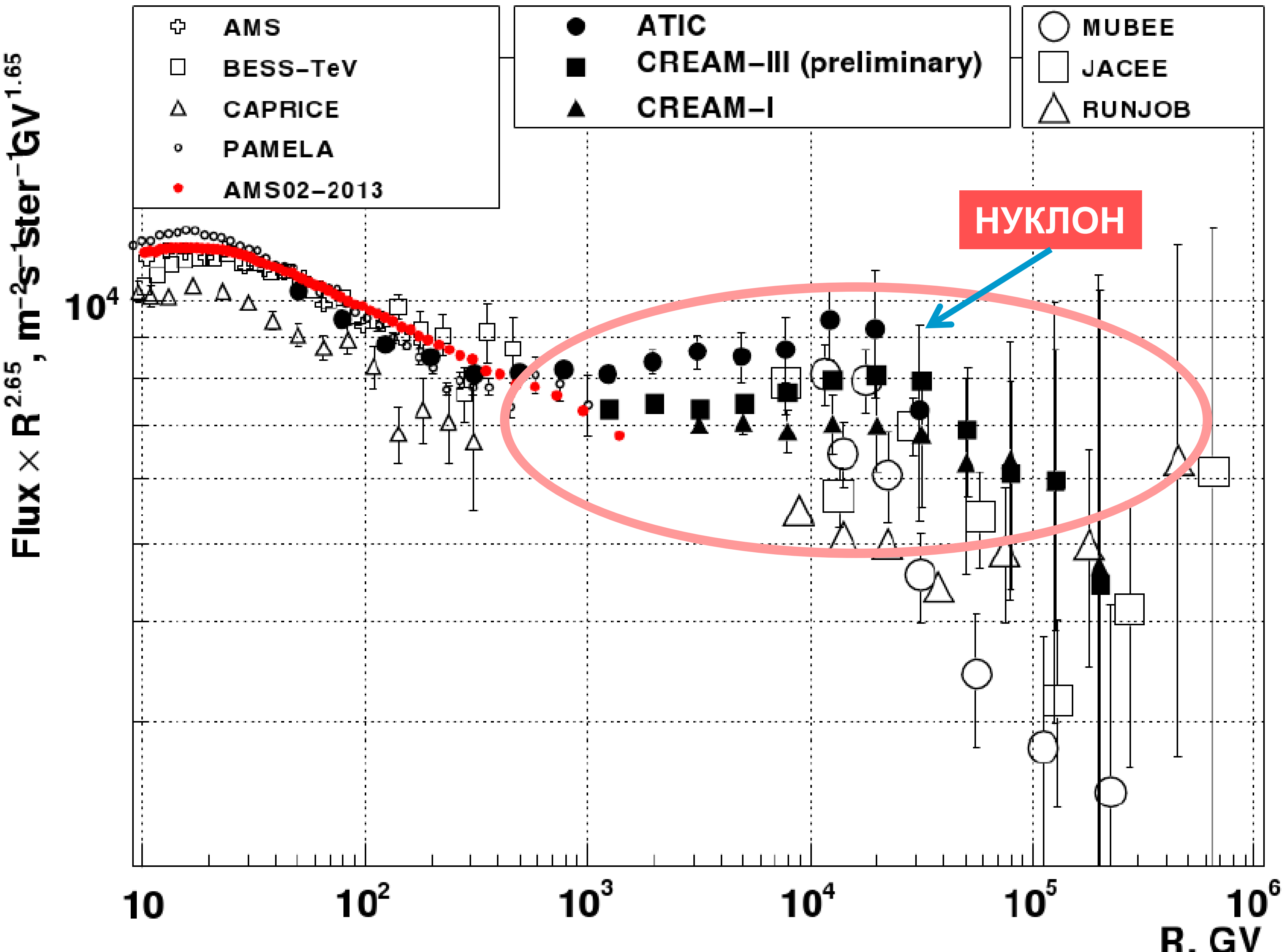
Galactic: supernova remnants?

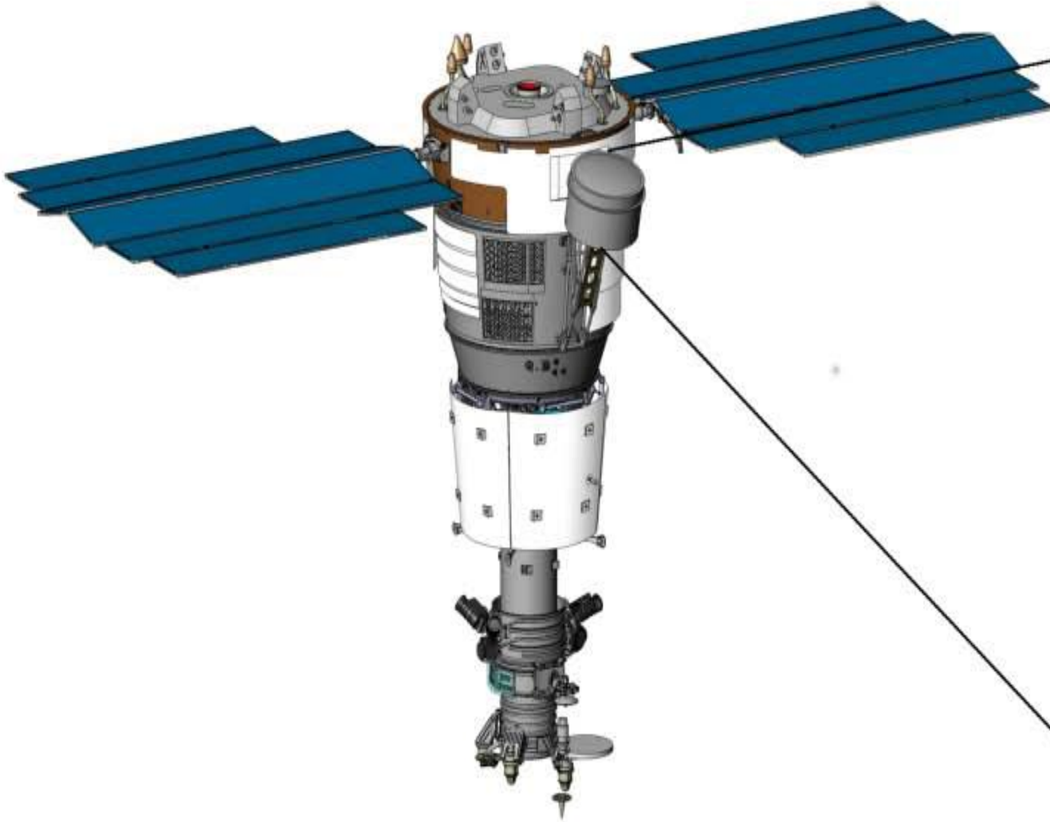


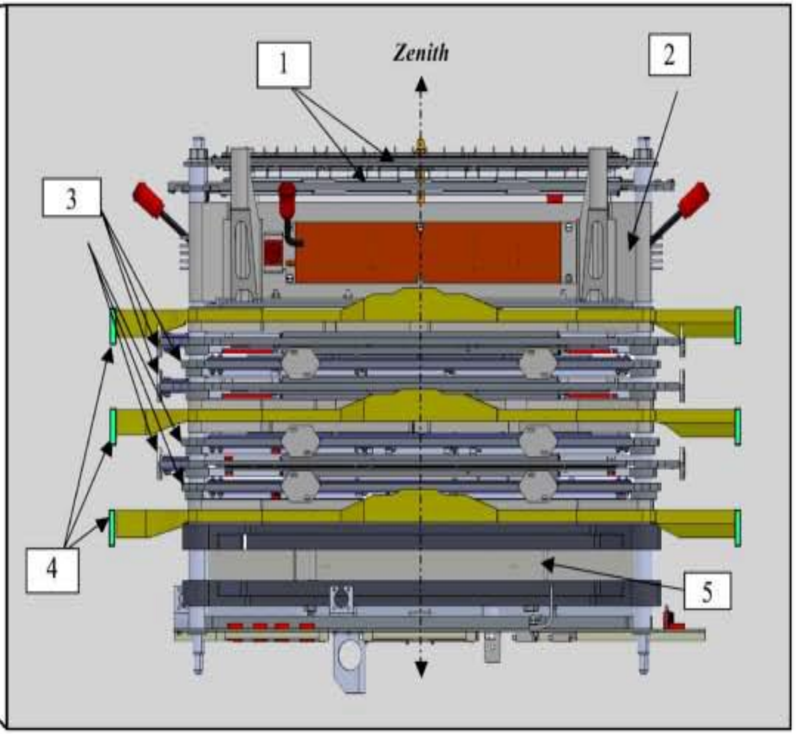
extragalactic: gamma ray bursts?

NUCLEON experiment
$10^{11} < E < 4*10^{14}$ эВ

SINP MSU, Moscow
“Gorizont”, Ekaterinburg
НИИ Материаловедения, Zelenograd
JINR, Dubna
Frunze Arsenal Design Bureau, St.-Petersburg


AMS
BESS−TeV
CAPRICE
PAMELA
AMS02−2013
ATIC
CREAM−III (preliminary)
CREAM−I
MUBEE
JACEE
RUNJOB
НУКЛОН
Flux × R^{2.65}, m^{-2}s^{-1}ster^{-1}GV^{1.65}
10^4
10
10^2
10^3
10^4
10^5
10^6
R, GV





Main NUCLEON parameters:

-Total weight ~ 350 kg
(for detector ~250 kg);
- Power cunsumtion~150 W
(for detectors ~ 120 W);
- Telemetry ~270 MB/day;
- Data taking period ≥5
years.

1 – Charge measurement system

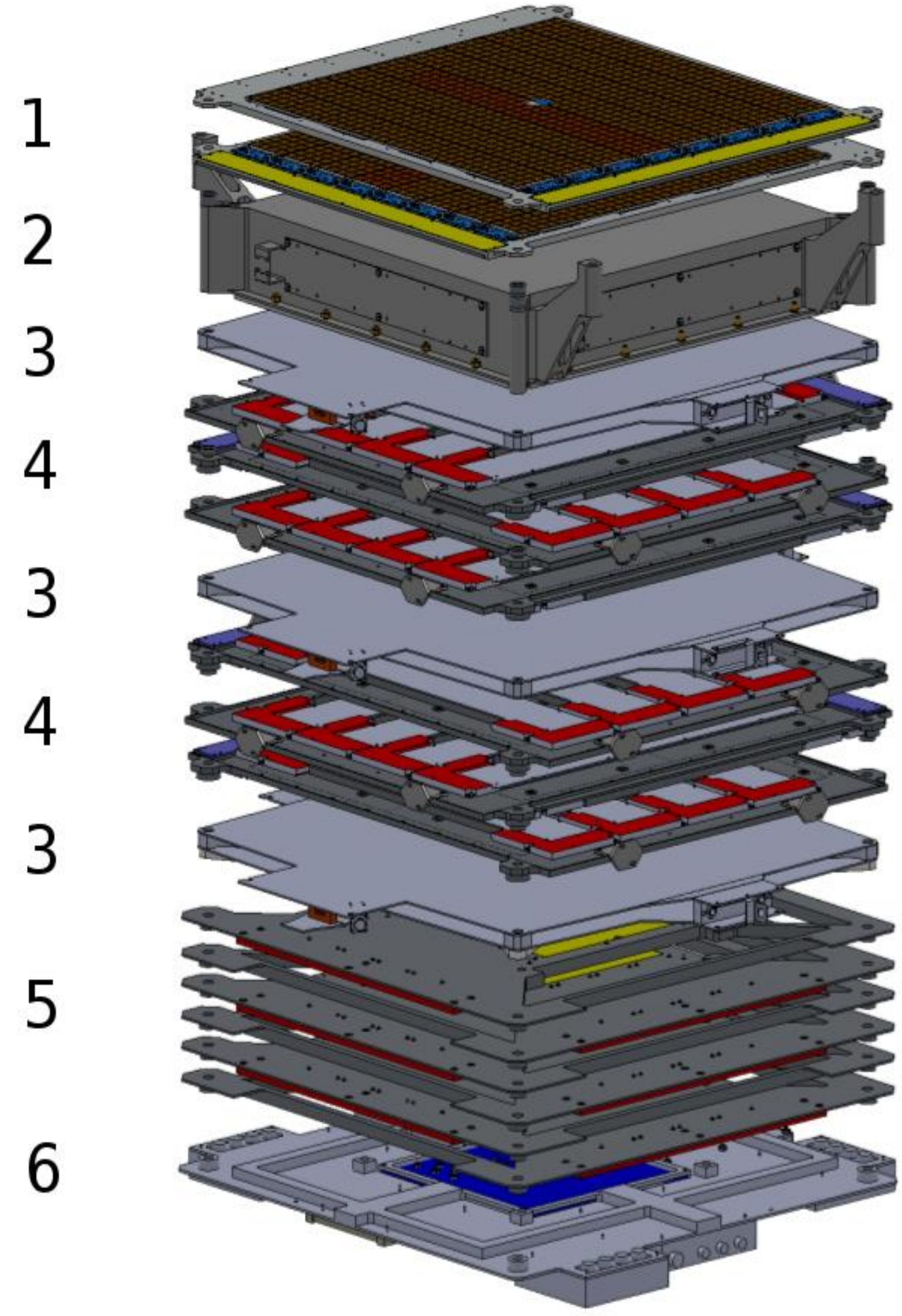
2 – Carbon target

3 – Scintillator fast trigger system

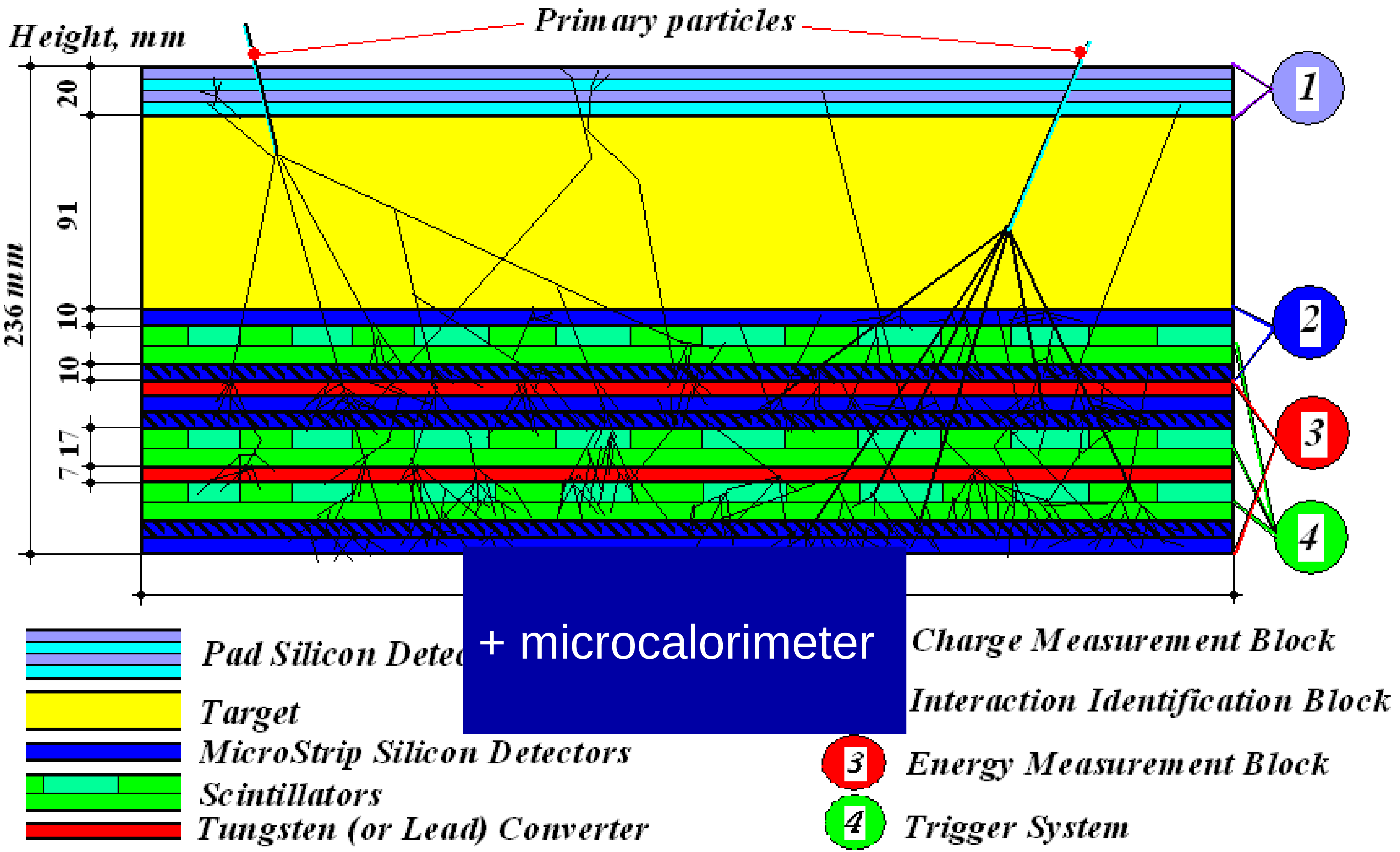
4 – Energy measurement system

5 – calorimeter

6 – Auxiliary electronics

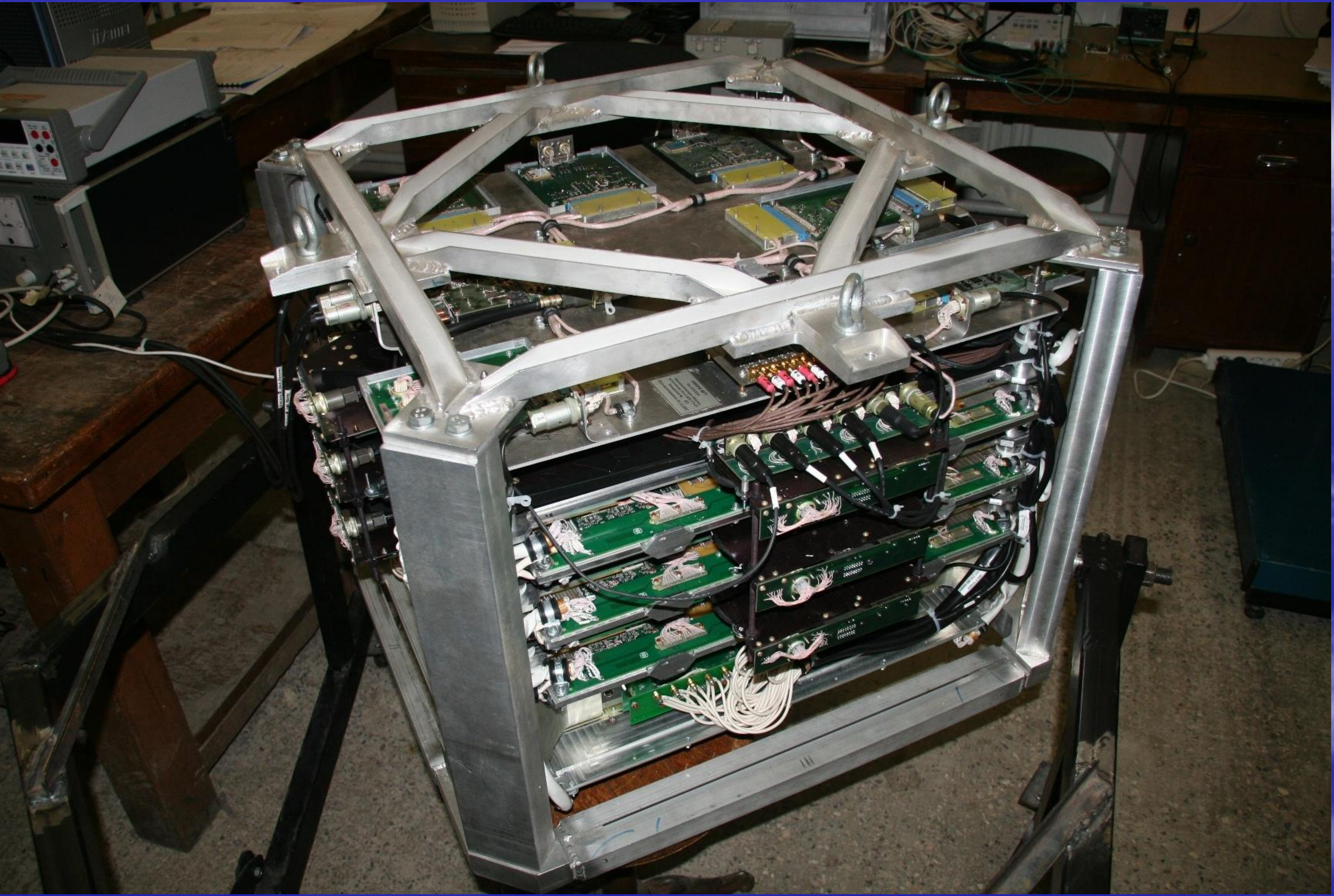


NUCLEON detector




Комплект изготовленных в
ОИЯИ триггерных плоскостей
детектора НУКЛОН


Модуль ССБТ №3
3076-01-01-14.05 (2)



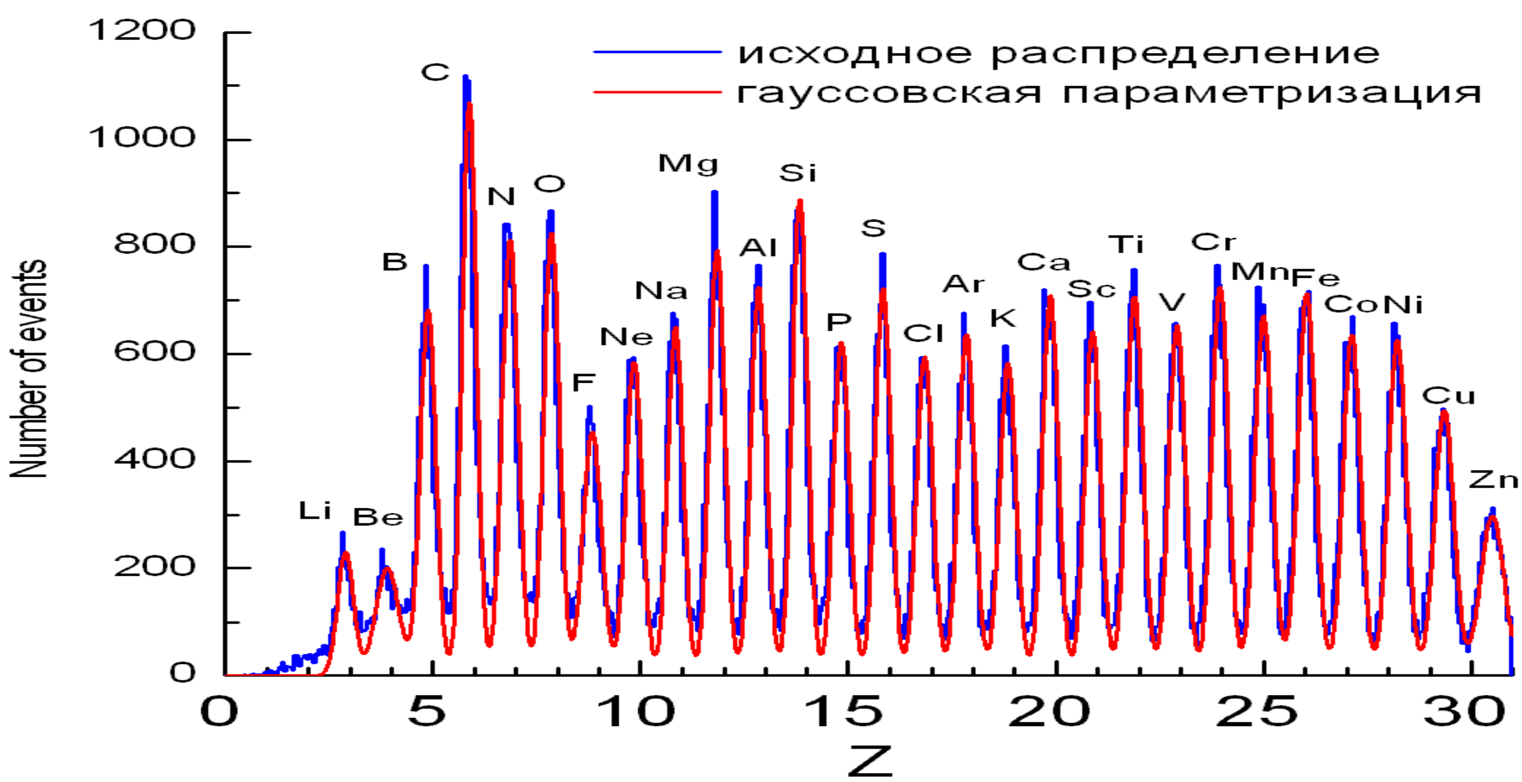
Детектор НУКЛОН перед тестом на SPS в ЦЕРН

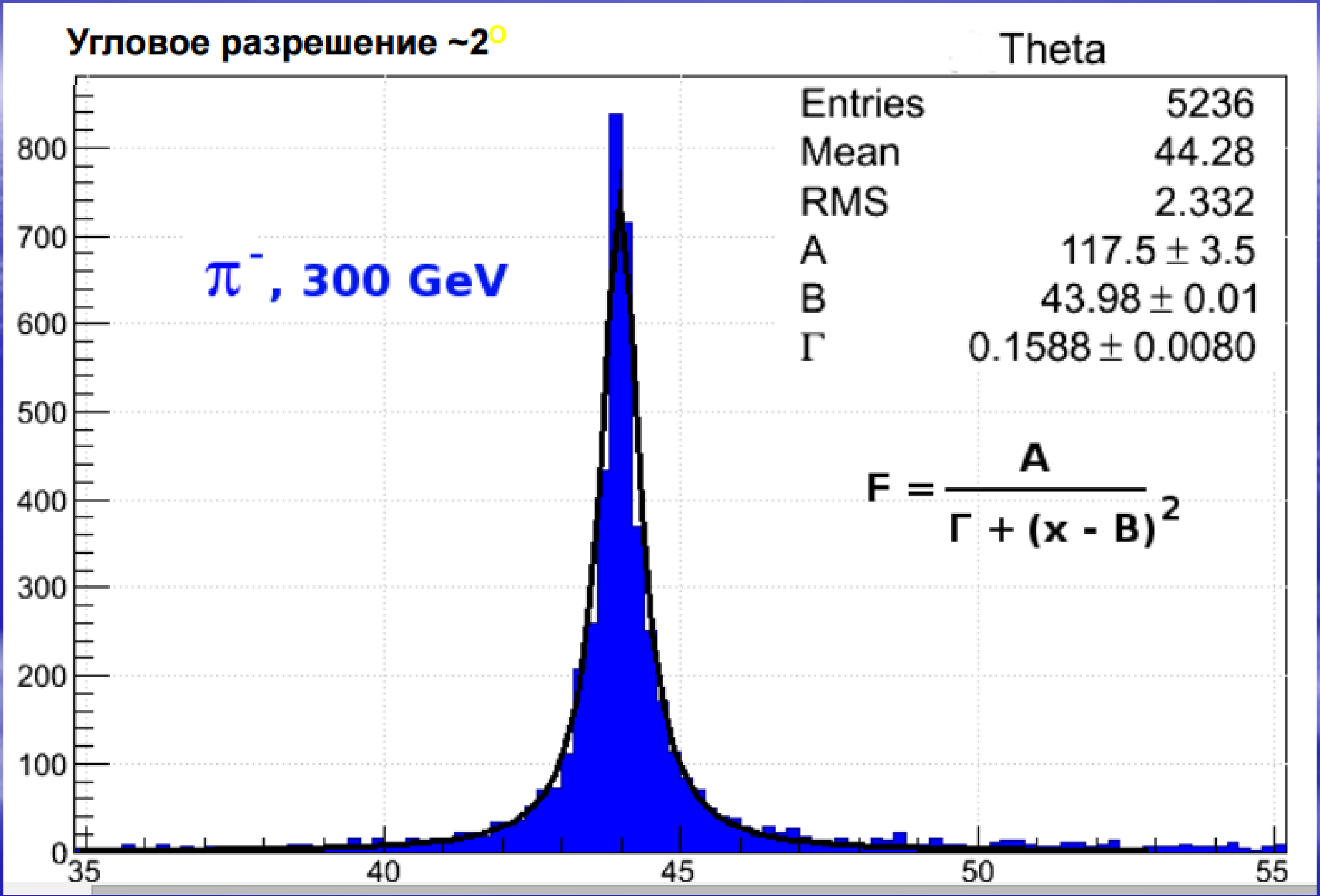
Измерения заряда КЛ

Система измерения заряда представлена 4096 кремниевыми падами размером 1.5x1.5 см (по 1024 в одном слое). Динамический диапазон ~1000 mip. Перекрытие в каждом слое ~98%, для 4 слоев ~100%.

Зарядовое разрешение составляет ~0.2 зарядовые единицы

Распределения получены в ходе ускорительного эксперимента.

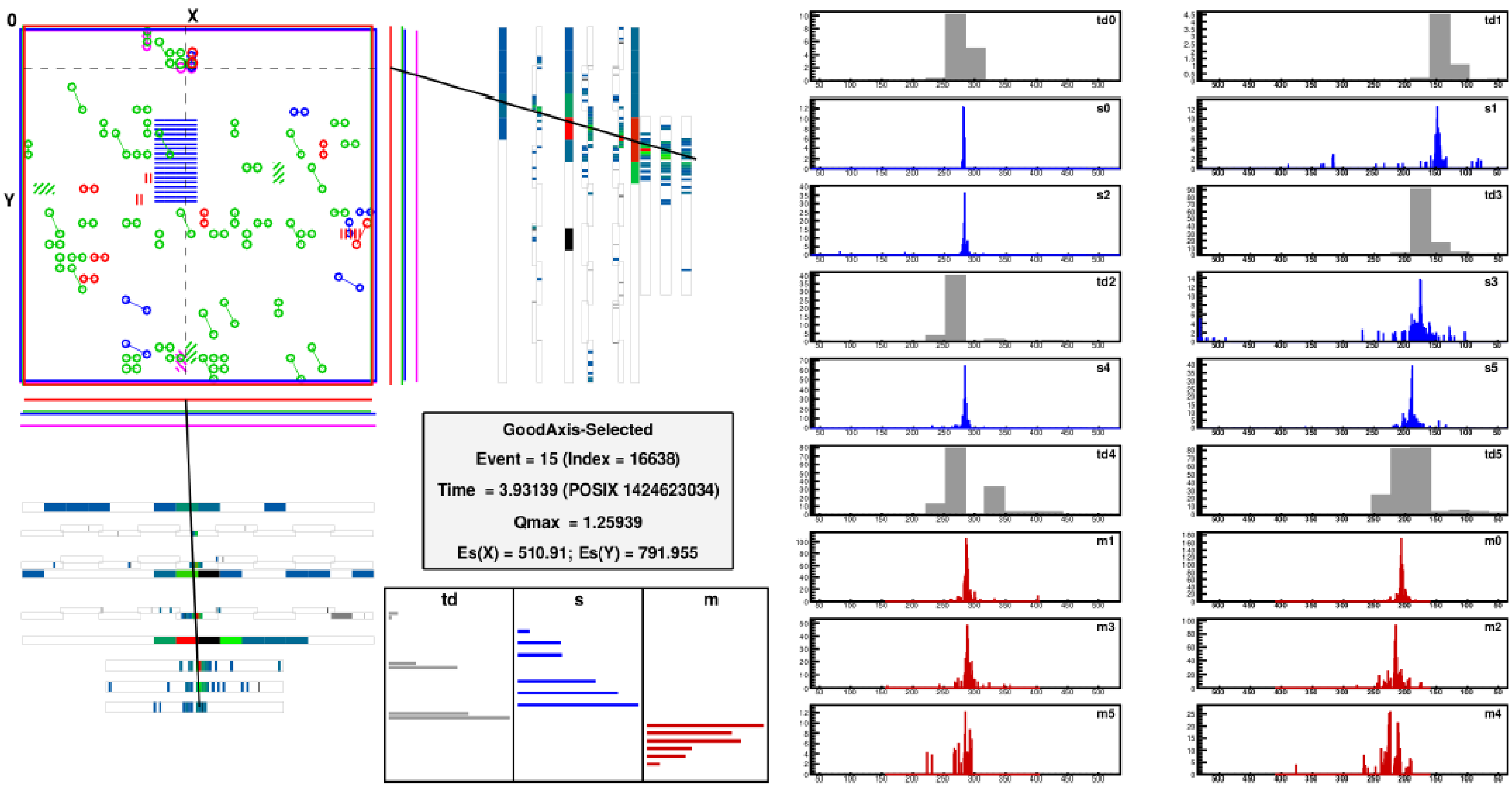




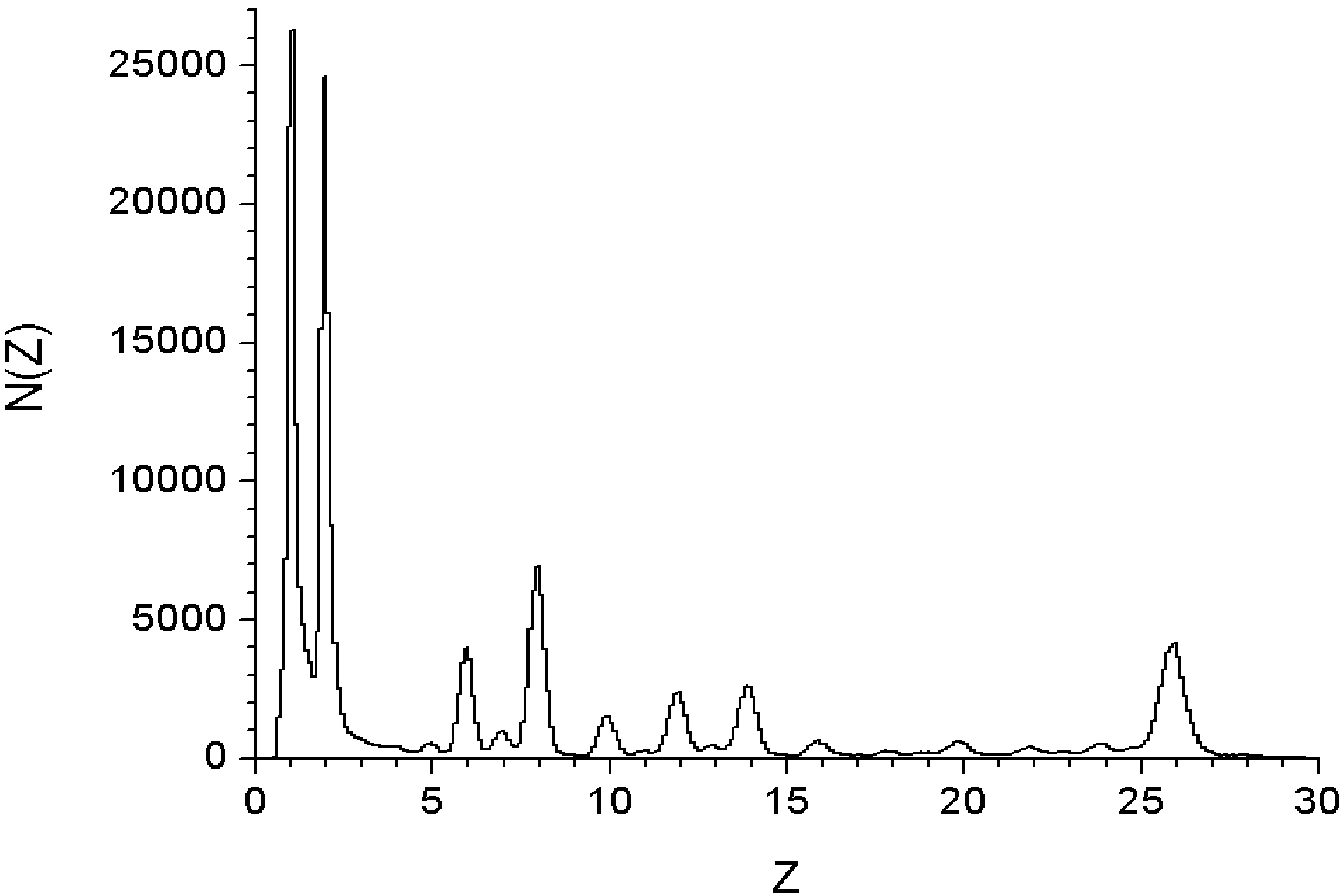
NUCLEON detector angular resolution at the SPS tests measurement

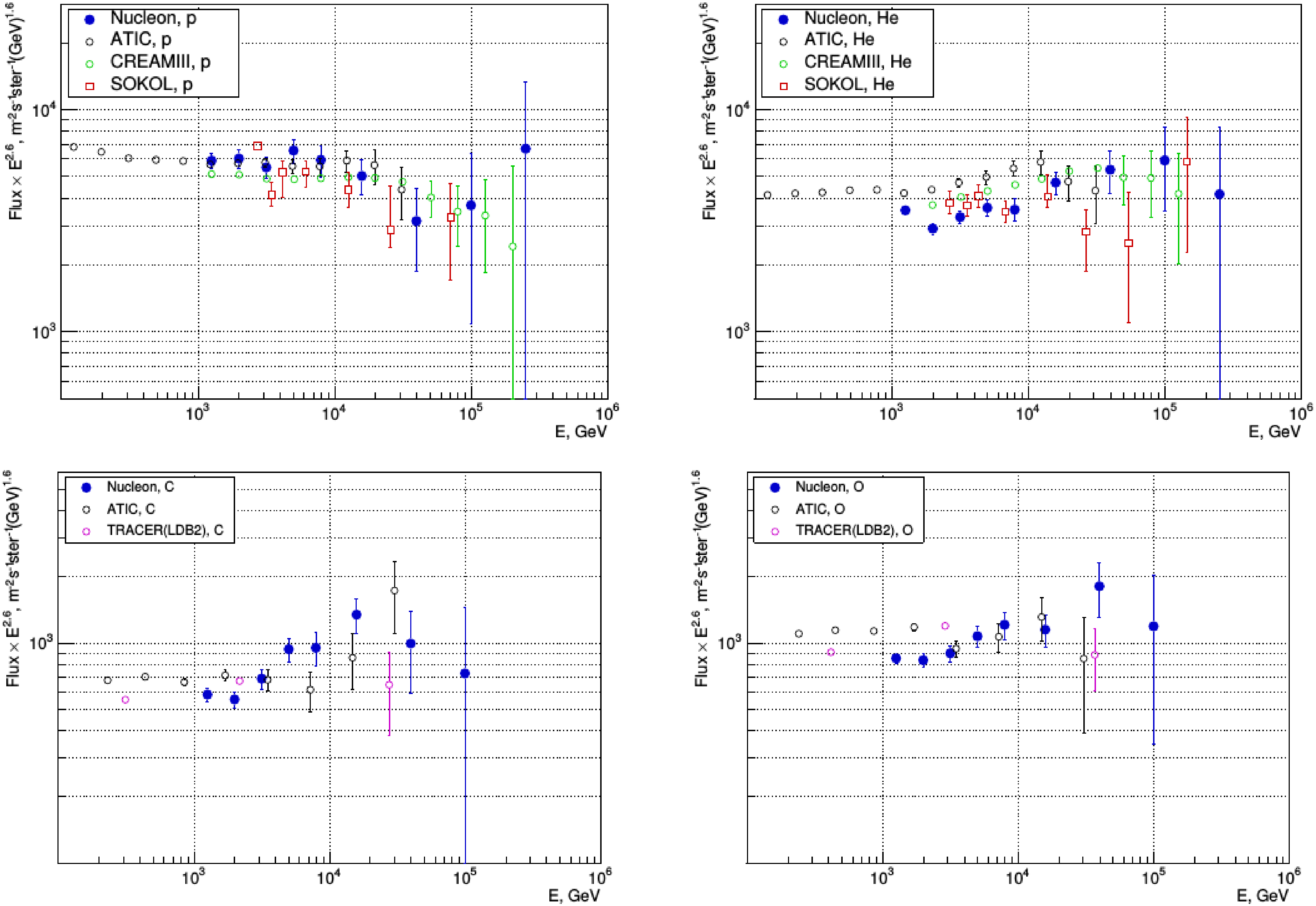

Запуск спутника РЕСУРС П №2.
Байконур, 26 декабря 2014 г., 23:55

Каскад вторичных частиц, вызван протоном провзаимодействовавшим в мишени

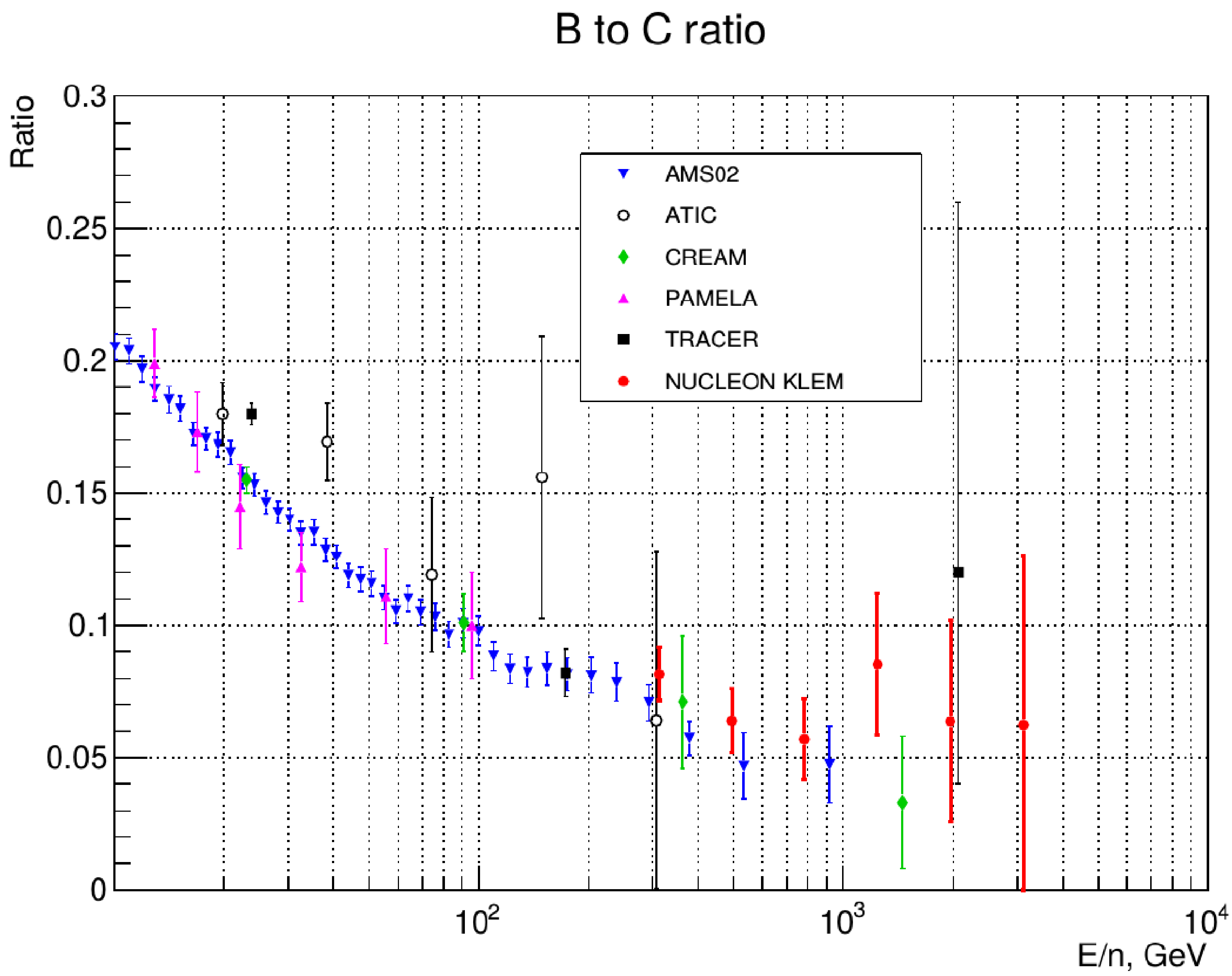


Все ядра (май 2015 – февраль 2016). Погрешность определения заряда 0.15-0.30





Nucleon, p
ATIC, p
CREAMIII, p
SOKOL, p
Flux × E^2.6, m^-2s^-1ster^-1(GeV)^1.6
E, GeV
Nucleon, He
ATIC, He
CREAMIII, He
SOKOL, He
Flux × E^2.6, m^-2s^-1ster^-1(GeV)^1.6
E, GeV
Nucleon, C
ATIC, C
TRACER(LDB2), C
Flux × E^2.6, m^-2s^-1ster^-1(GeV)^1.6
E, GeV
Nucleon, O
ATIC, O
TRACER(LDB2), O
Flux × E^2.6, m^-2s^-1ster^-1(GeV)^1.6
E, GeV

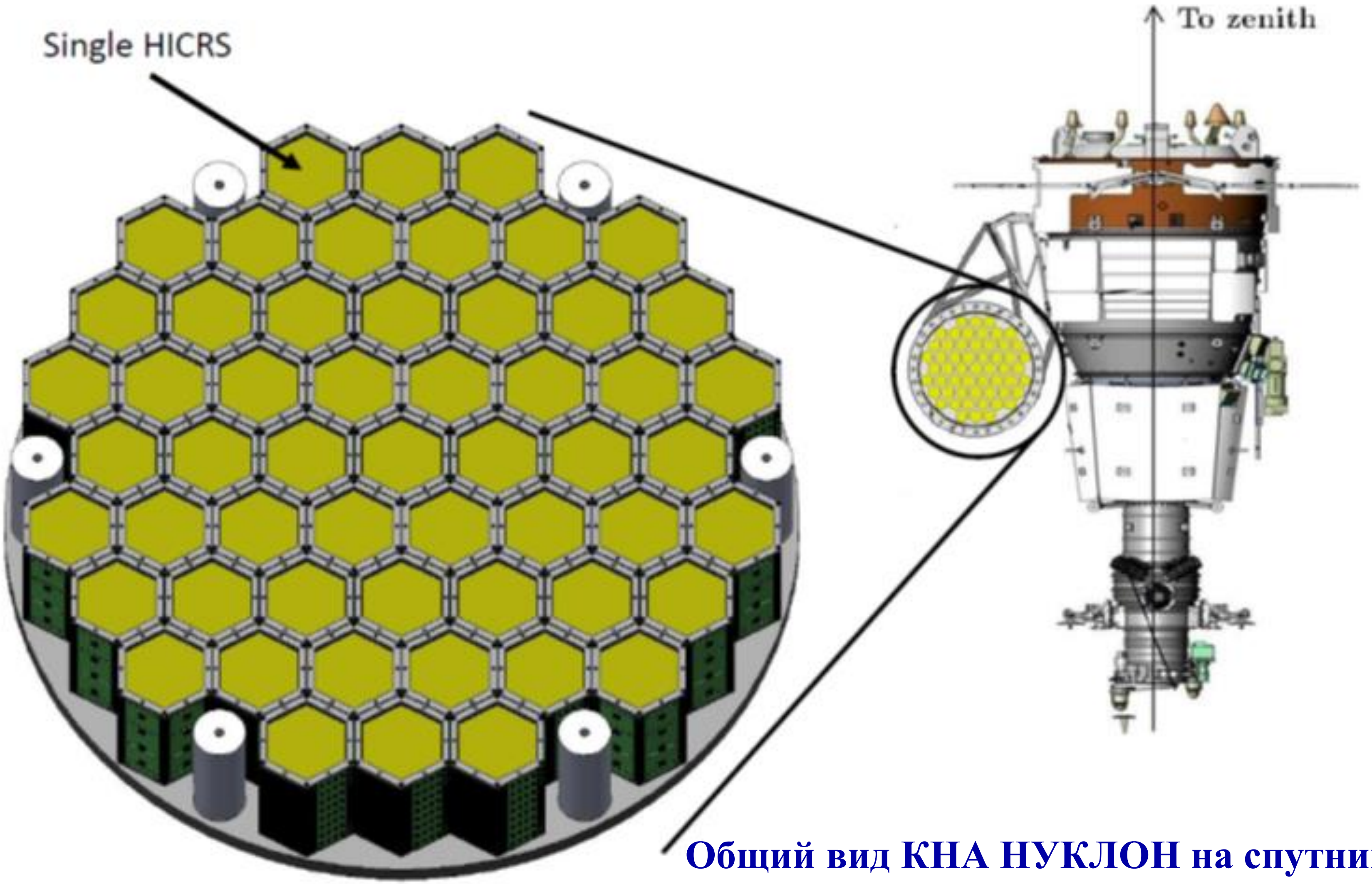


B to C ratio
Ratio
0.3
0.25
0.2
0.15
0.1
0.05
0
AMS02
ATIC
CREAM
PAMELA
TRACER
NUCLEON KLEM
10^2
10^3
10^4
E/n, GeV

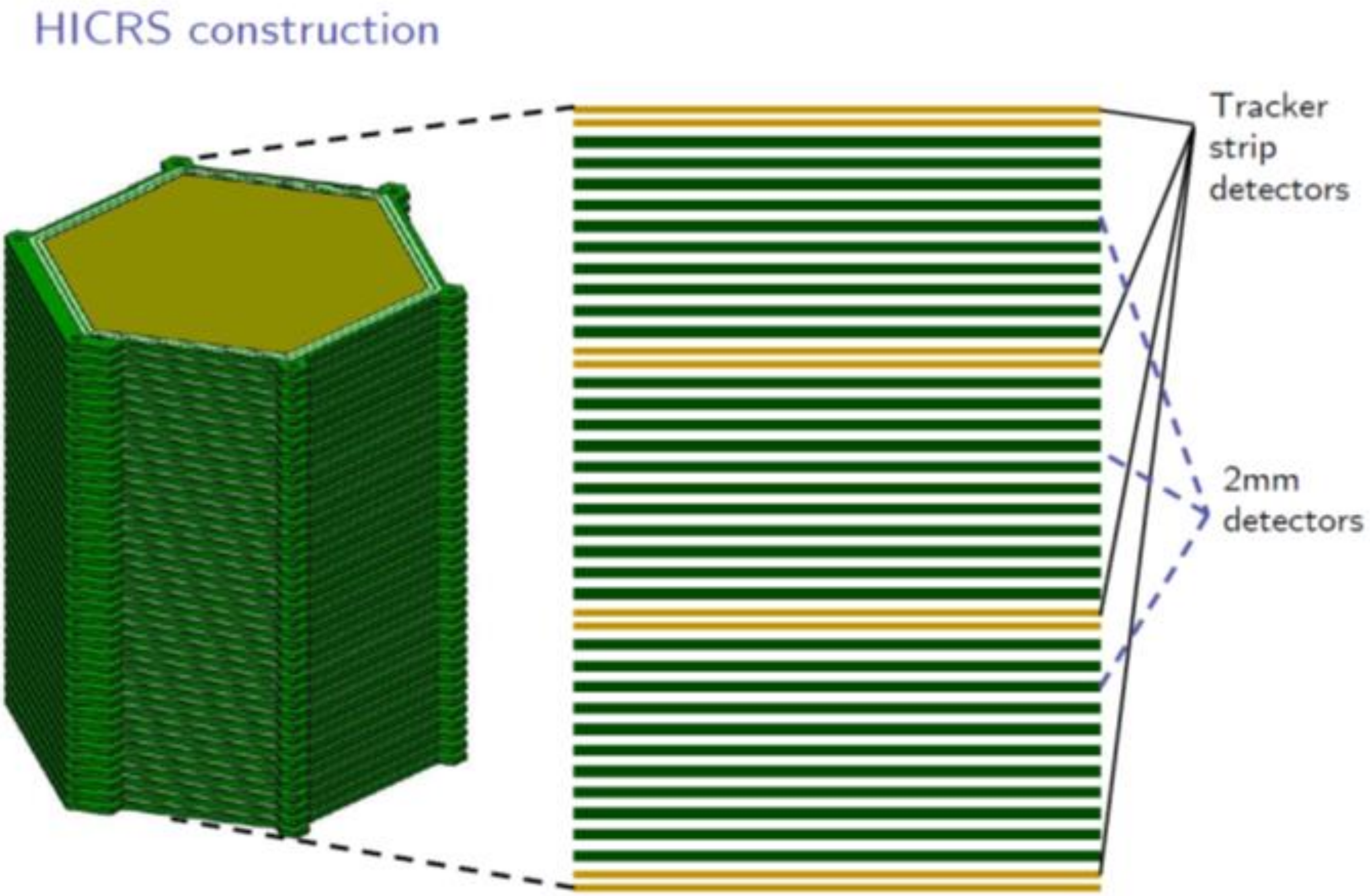
Next steps

- NUCLEON-2 mission for CR **isotopes** measurements in law energy region (200-300 MeV/n)   ~ 2021
- ОЛВЭ-HERO – CR spectra measurement in the energy region 10^{14}-10^{16} eV for all Z
- ~2025

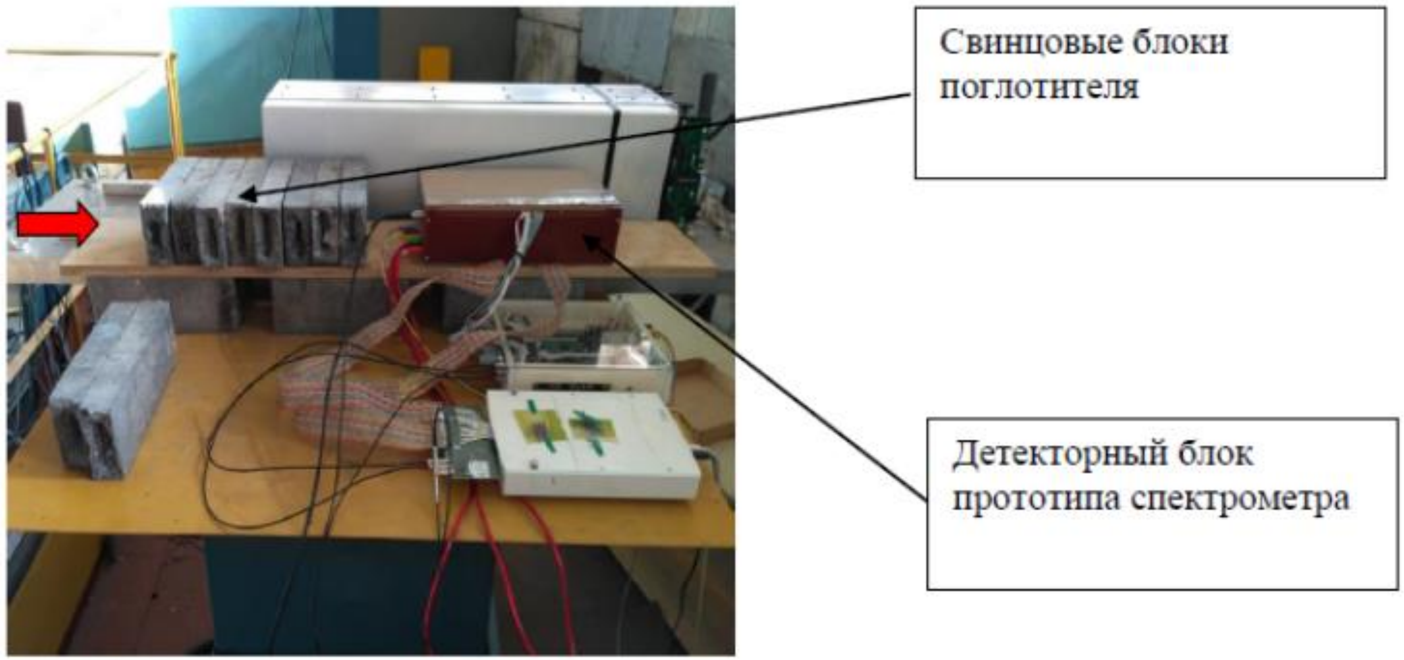
Supposed NUCLEON-2 construction and arrangement



Общий вид КНА НУКЛОН на спутнике РЕСУРС

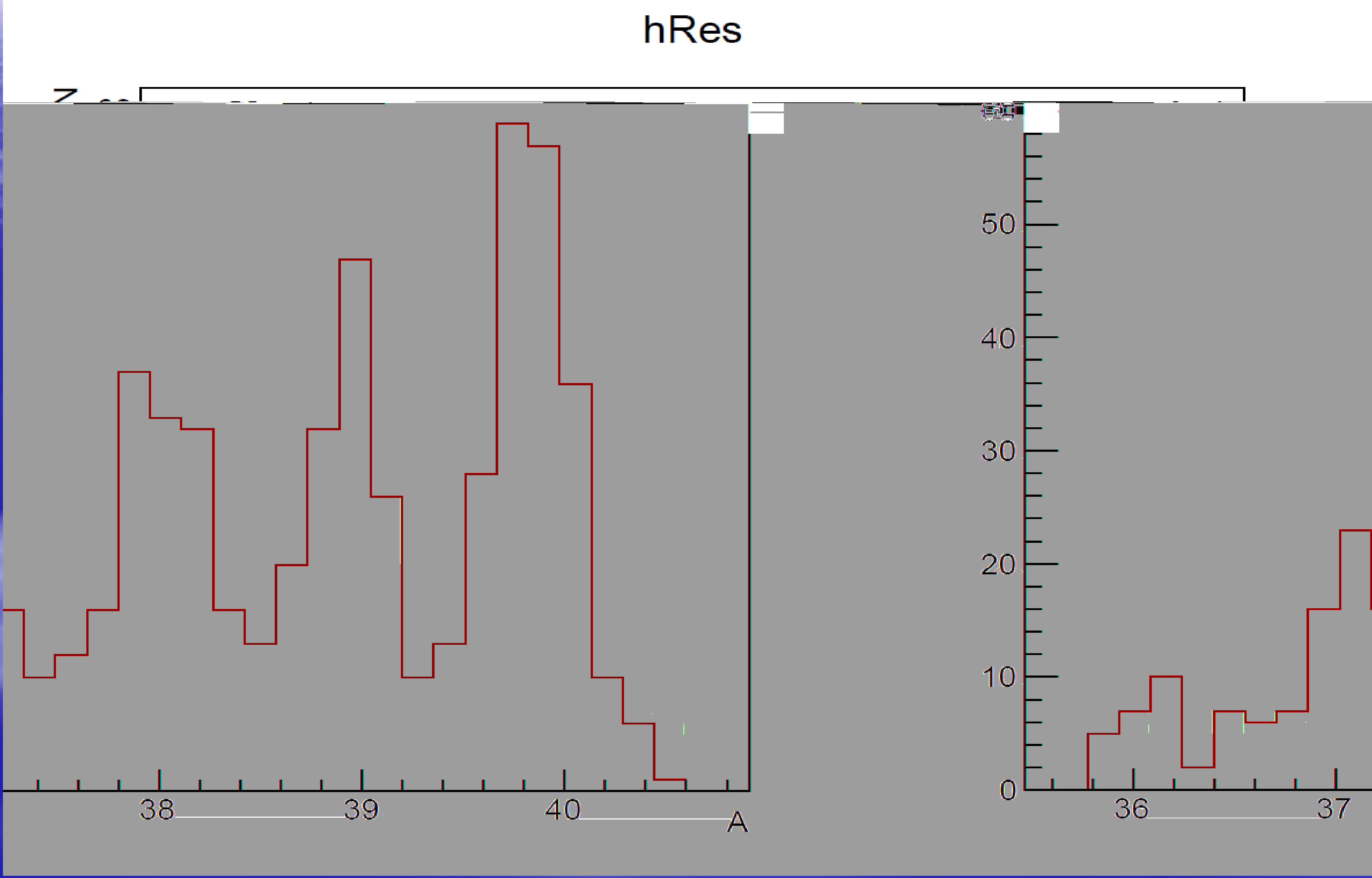


Общий вид модуля КНА НУКЛОН-2



NUCLEON-2 prototype beam test at NUCLOTRON
It was C beam in 2016 at НИС-ГИБС
and Ar beam in 2017 at BM@N

Argon isotopes distribution measurement in the NUCLOTRON beam test



A "breakthrough" experiment is needed, which will turn high-energy astroparticle physics into an exact science!

That is

HERO

"High Energy Rays Observatory"

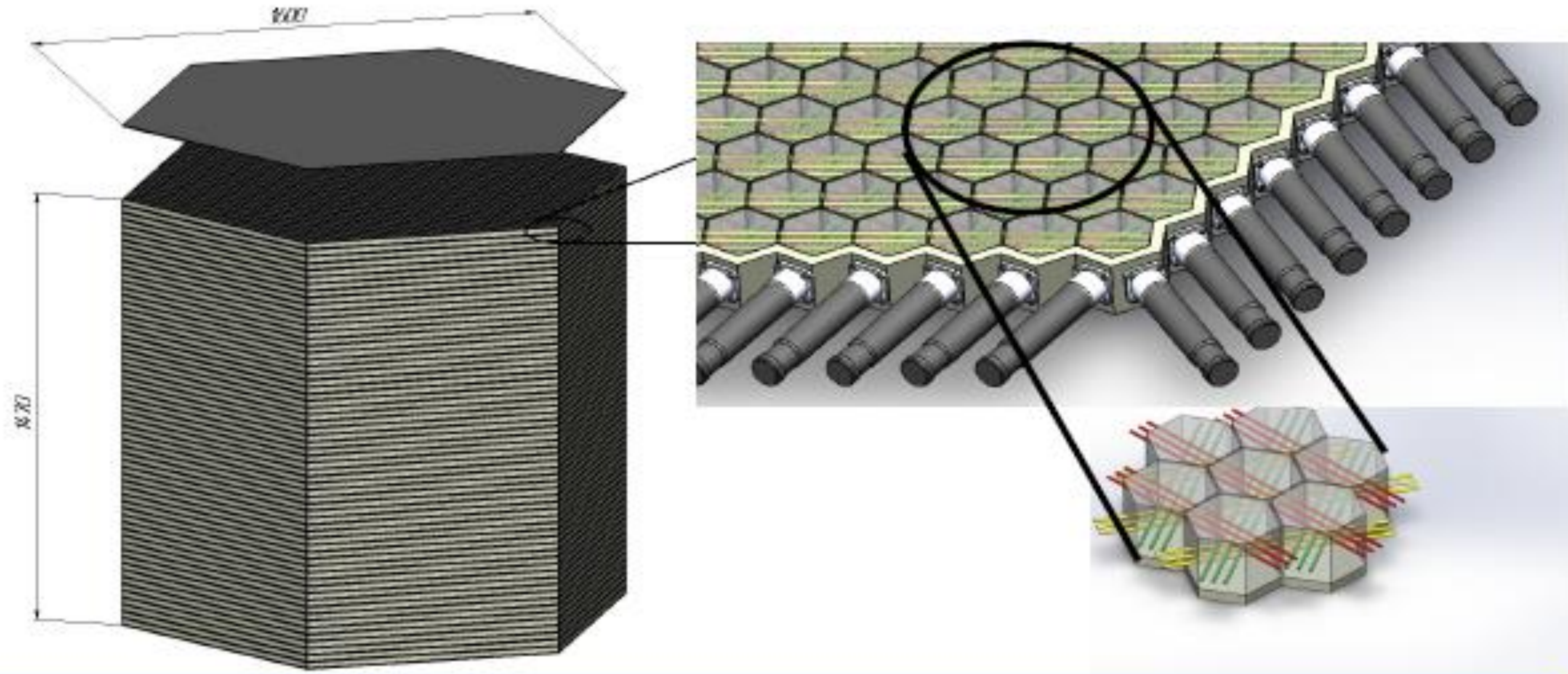
supported by the Russian Academy of Sciences and included in the Russian Federal Space Program

Main Requirements:

- Effective exposure factor >120 m^2 sr year
- Energy resolution
  - for Protons at 10^{15}-10^{16} eV < 30%
  - at 10^{12}-10^{15} eV < 20%
  - for Nuclei at 10^{12}-10^{16} eV < 15-20%
  - for Leptons at $3*10^{11}$-10^{13} eV < 1%
- Charge resolution < 0.2 ch. u. for all Nuclei in full energy range

Preliminary Design of HERO

Ionization Calorimeter



- Geometrical dimensions of IC: Diameter of outer circle 1600 mm, height 1470 mm, Weight ~ 10 tons
- IR consists of 62 identical layers. Each layer is a hexagonal plane, 23,5 mm thick, with a polystyrene scintillator (ρ~1.0 g/cm3, h=20 mm) and a tungsten-copper-nickel alloy absorber (ρ~16/5 g/cm3, h=3,5 mm)
- Number of registration channels 6696.

ОЛВЭ-HERO prototype tests

- SPS at CERN
- 2016 – Pb beam (150 Gev/n, A/Z = 2.2- 2.5)
- 2017 - Xe beam 13 Gev/nucl, rijidity A/Z =2.1,
- ~5000 part/sec
- moderation of evaporated neutrons

  14 Mev → 0.1 eV for 2.7 usec and reaction

  $$n + {}^{10}B \rightarrow {}^{7}Li + \alpha + 2.78\ MeV$$
- Delayed neutron yield measurements in borotized scintillator

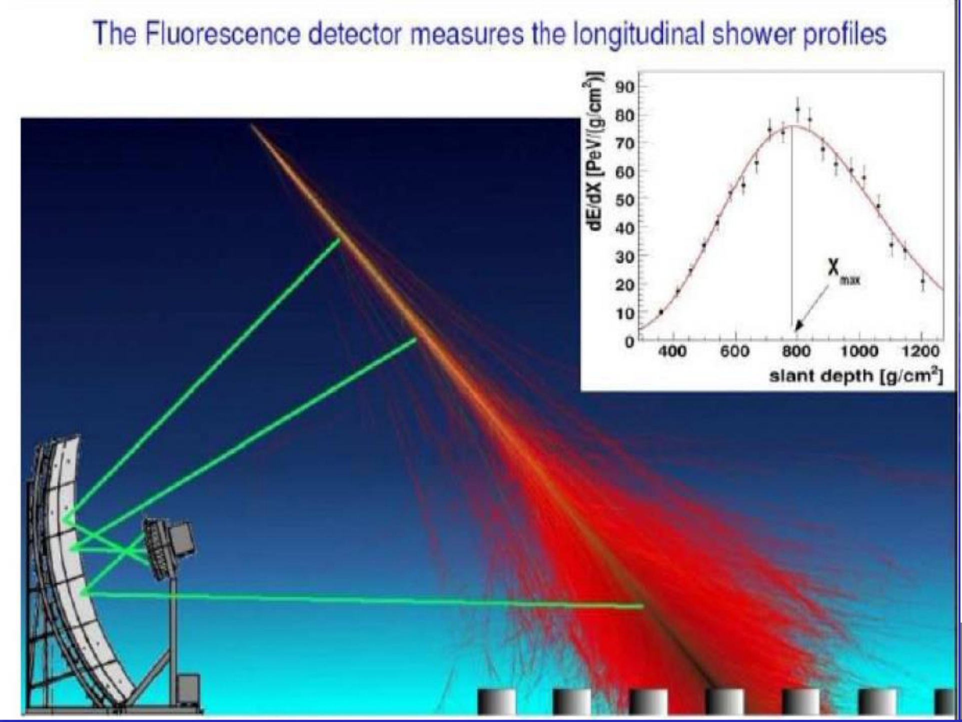
Conclusion - NUCLEON

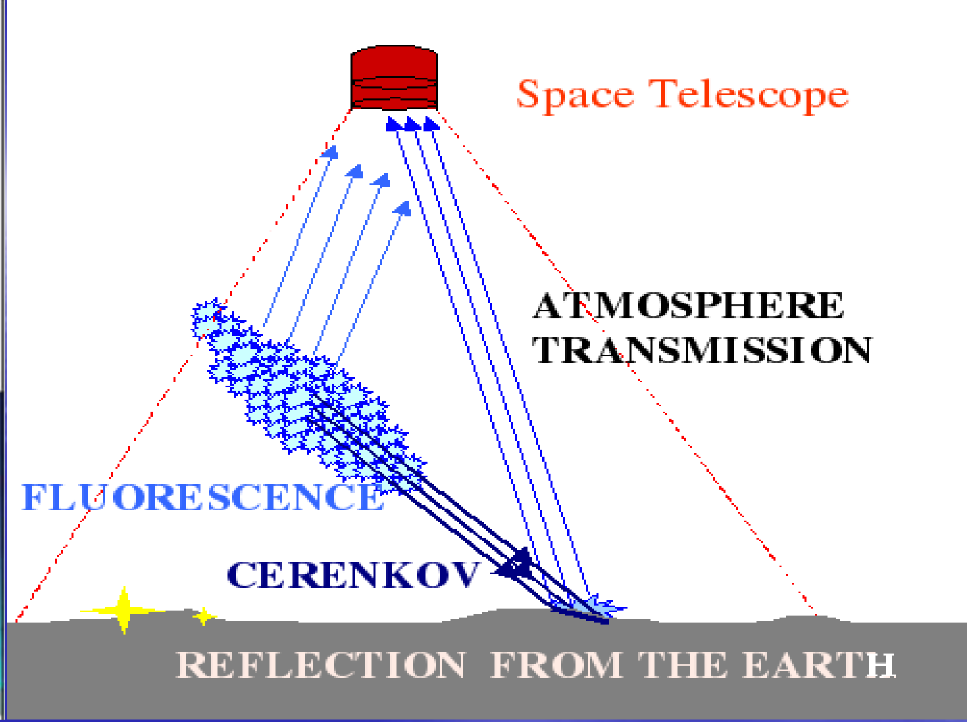
- The **NUCLEON mission** is in orbit for operation since December of **2014** for **5 years of data taking**
- **A few millions of CR events were taken and analysed**
- Next step is the **NUCLEON-2 experiment on the RESURS sattelite** at 2021-2022
- **NUCLEON-2** prototypes were tested at SPS CERN and NUCLOTRON JINR
- **ОЛВЭ-HERO space experiment ~2025 г.**

Design and beam tests of prototypes at SPS CERN

Ultra High Energy Cosmic Rays
TUS experiment status
(E > $4*10^{19}$ эВ)

- Skobeltsyn Institute of Nuclear Physics, MSU, Moscow, Russia
- Joint Institute for Nuclear Research
- Space Regatta Consortium, Korolev, Moscow region, Russia
- Physics Department, EWHA Woman University, Seoul, Korea
- University of Puebla, Puebla, Puebla, Mexico
- University of Michiocan, Morelia, Michiocan, Mexico
- INFN Torino, Italy

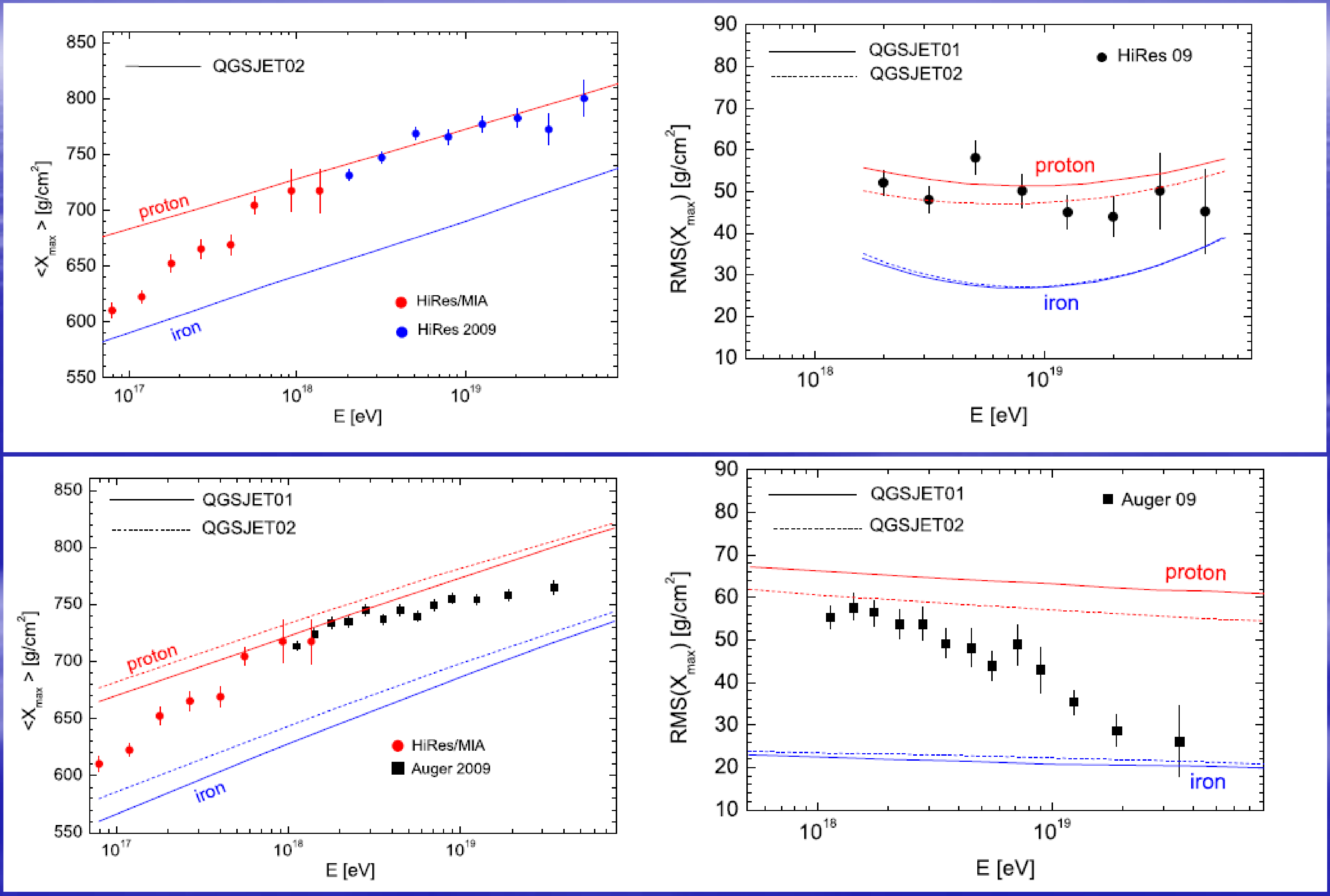




The fluorescence EAS radiation may be measured by the ground or space detectors to get the longitudinal shower profile and obtain the UHECR parameters: energy, arrival direction and nature (proton or nuclear). A Cerenkov radiation reflected from the Earth surface or clouds may be measured from space also.

Atmospheric conditions are much more stable in upper layers of the atmosphere that is important to reduce systematic uncertainty of the UHECR energy measurement.

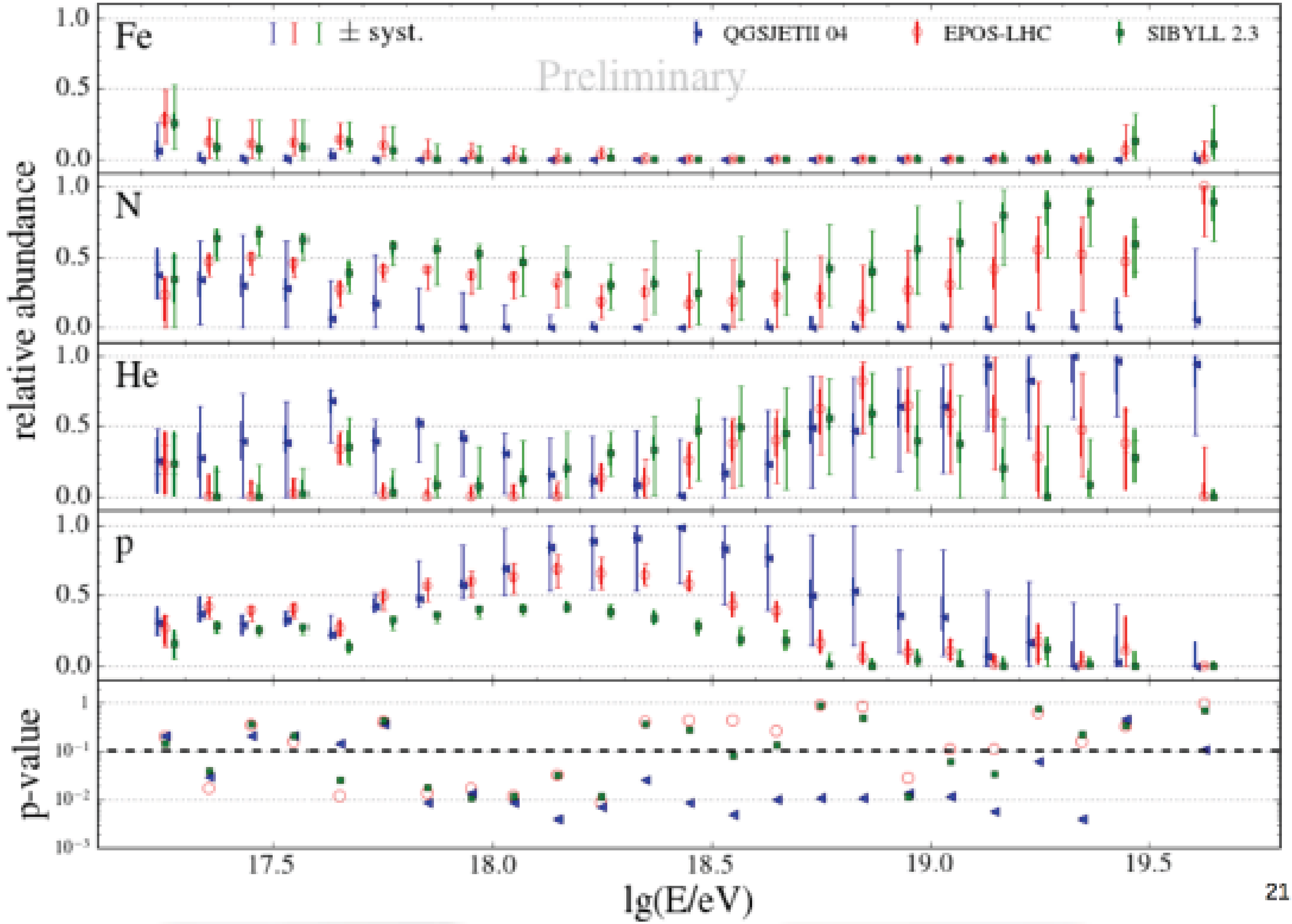
CRISIS 2009: MASS COMPOSITION



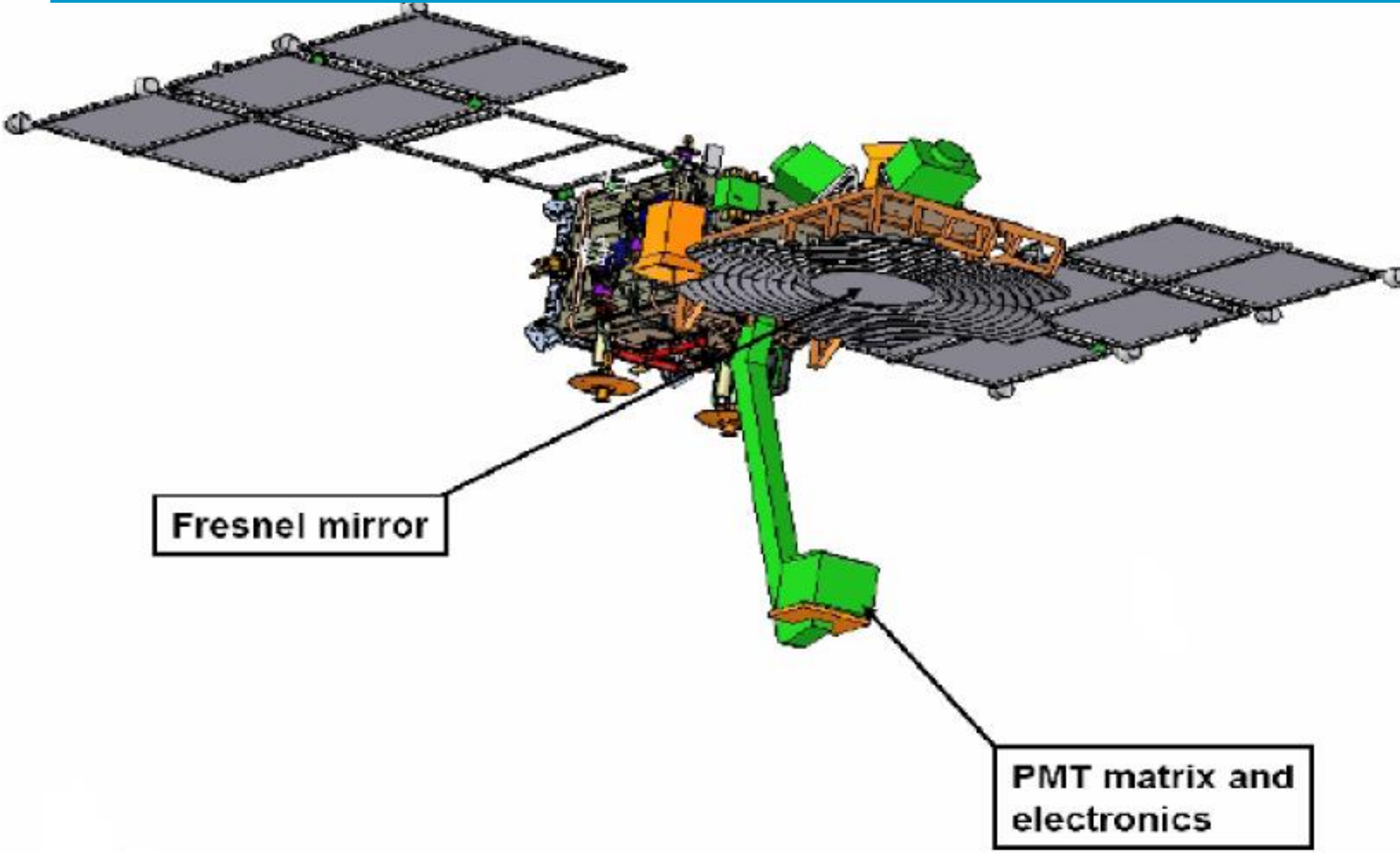
2017

Composition fractions

(obtained from fits to the X_{max} distributions)

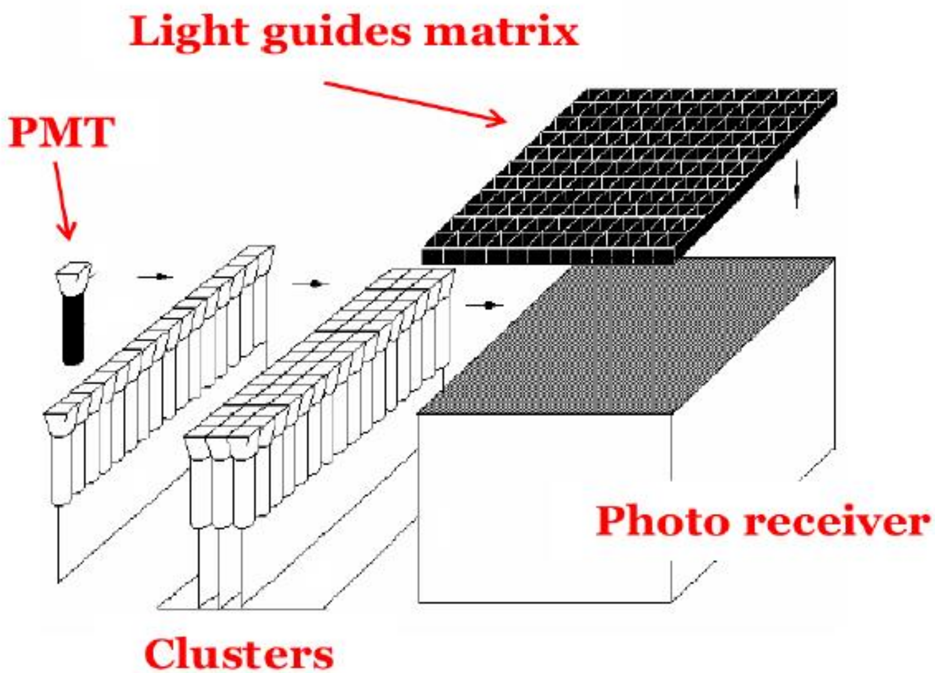


The TUS detector at the “Mikhail Lomonosov” КА МВЛ-300 satellite



TUS photo-detector

Photo detector consists of 256 photo multipliers (of size 1.5 x 1.5 cm^2) with the time resolution 0.8 μs and the spatial resolution 5x5 km (for the orbit height of 500 km).



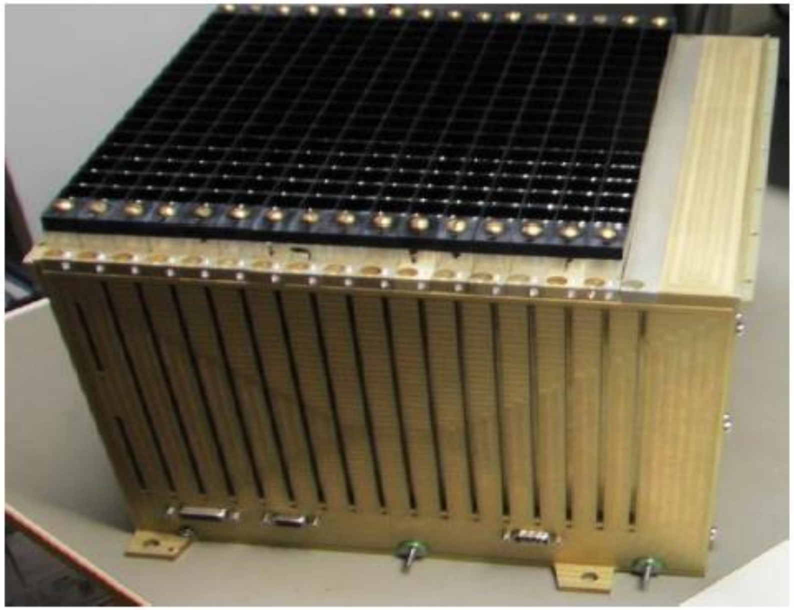
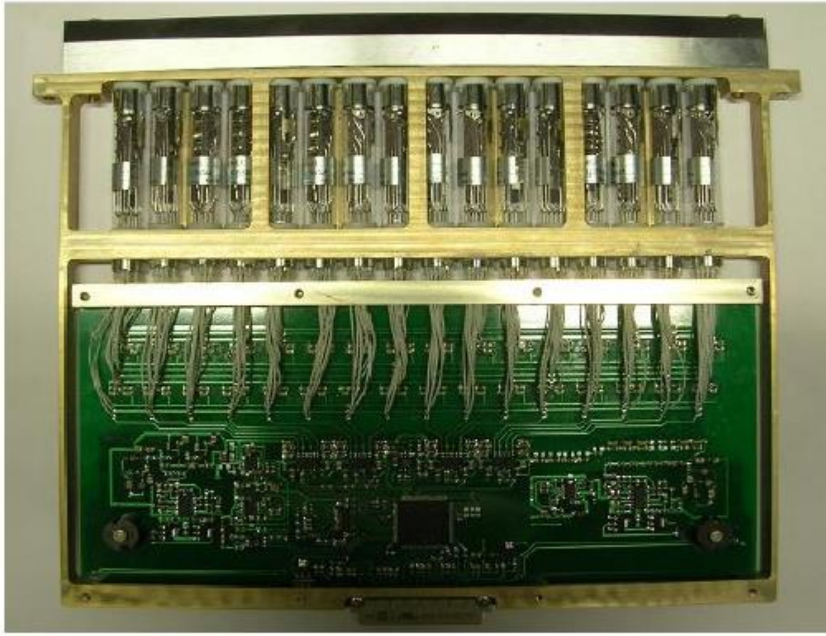
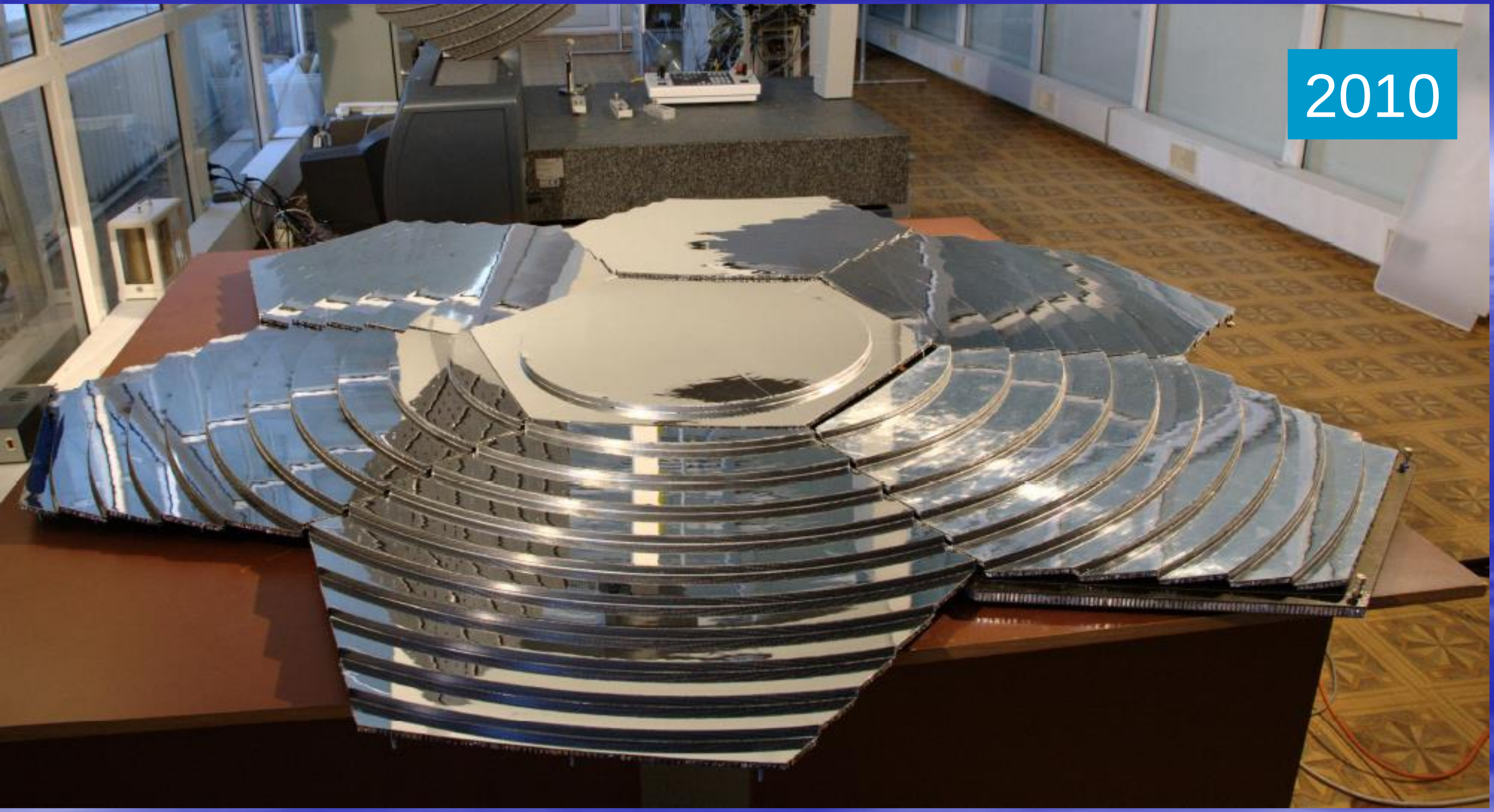


Photo receiver

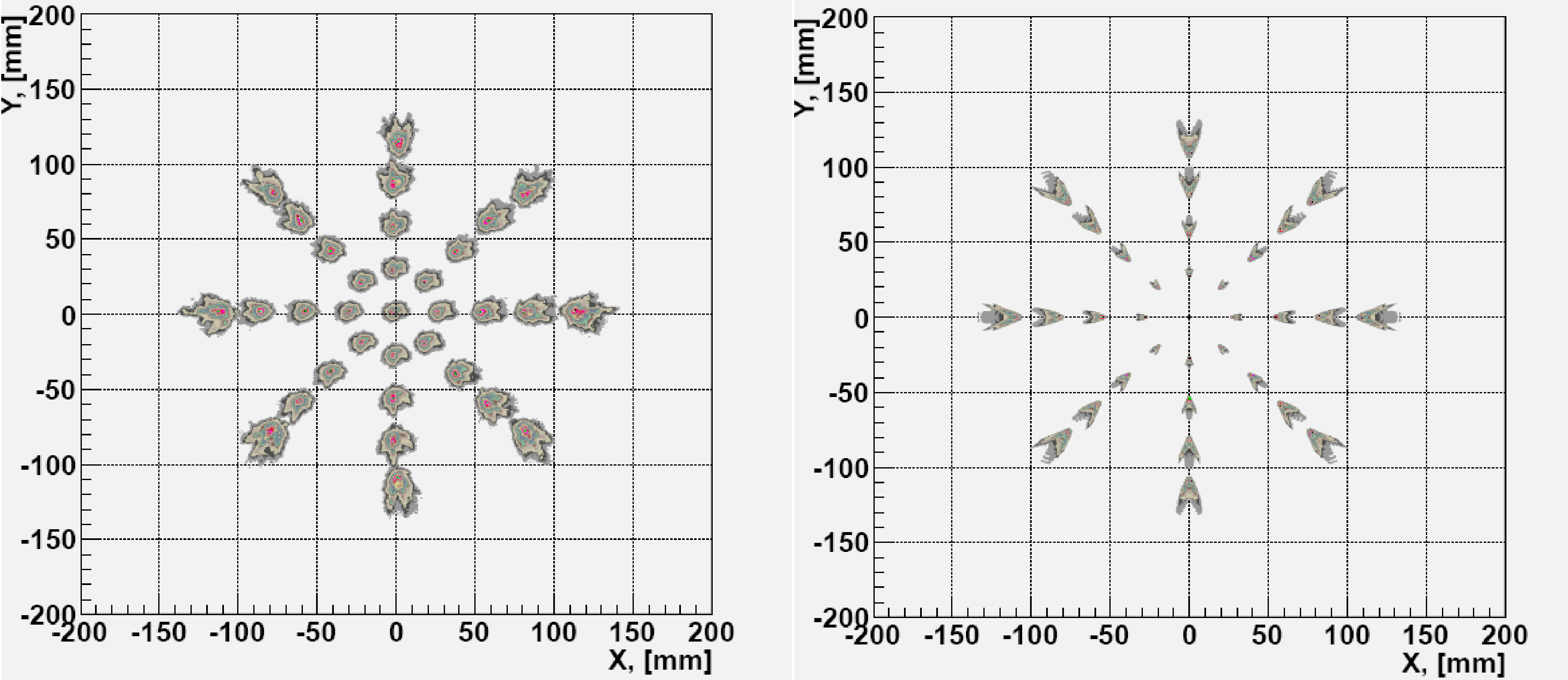


PMT's cluster

JINR responsibility: Fresnel mirror production, tests and optical parameter measurements



The technological Fresnel mirror.

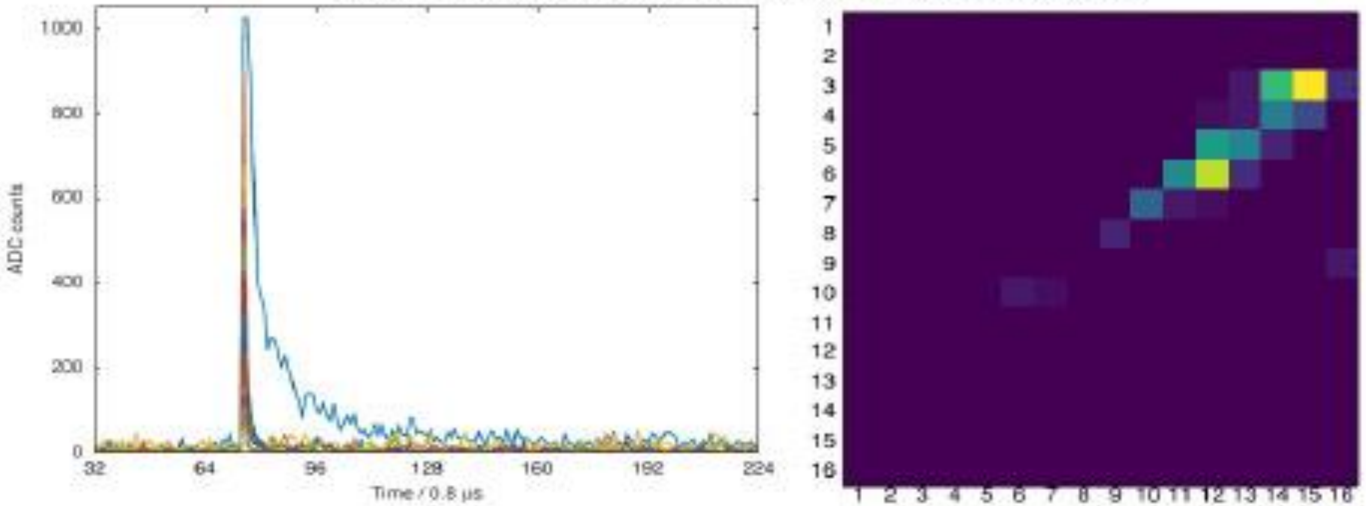


Left: The PSF angular dependence of the **TUS** Fresnel mirror
Right: The PSF angular dependence of the **ideal** Fresnel mirror.

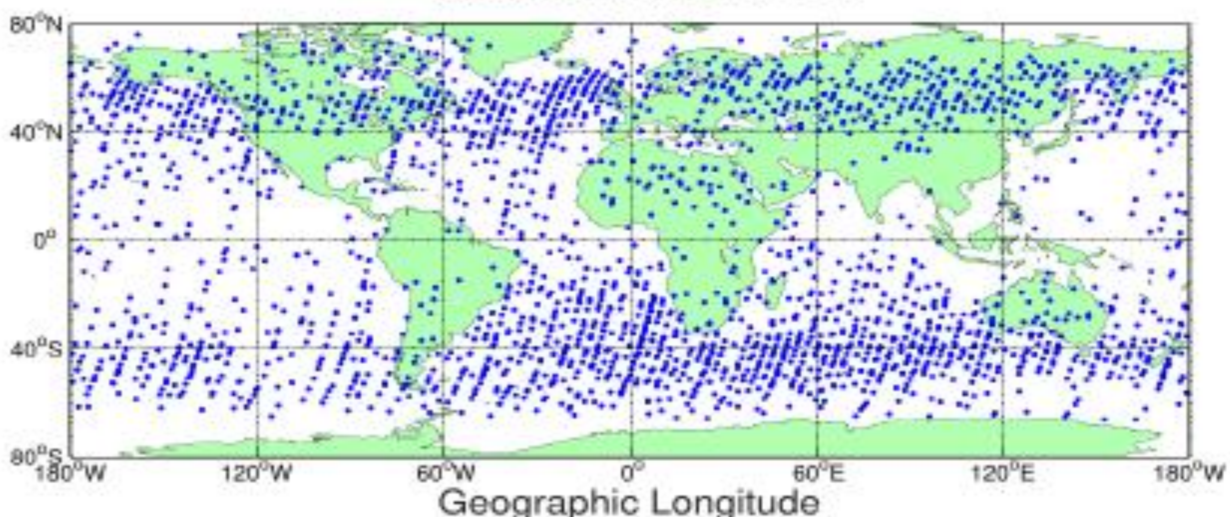
Detector TUS at “Mikhail Lomonosov” satellite during tests at 2013

Launch of the “Lomonosov” satellite on April 28, 2016

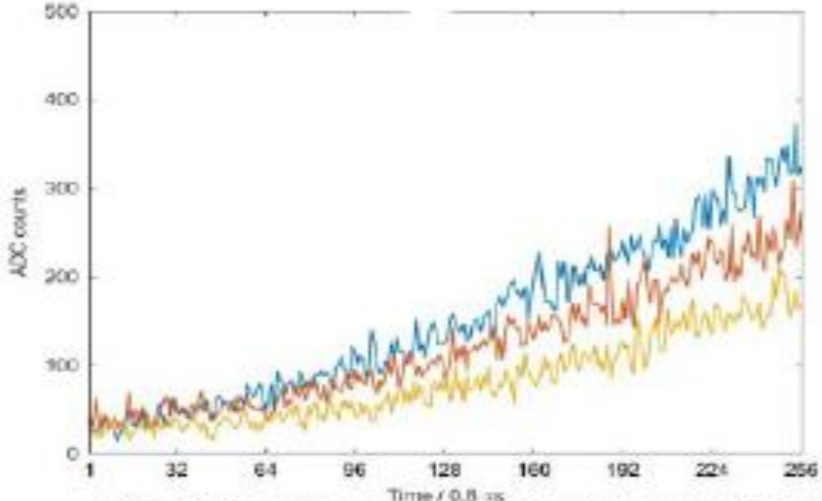
Instant track-like flashes



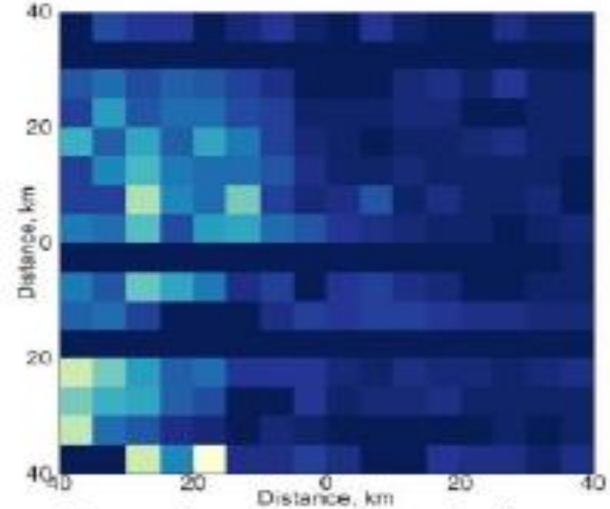
Left: waveforms of ten PMTs that demonstrated the highest amplitudes. Colors denote different pixels. Right: snapshot of the focal plane at the moment of maximum amplitudes.



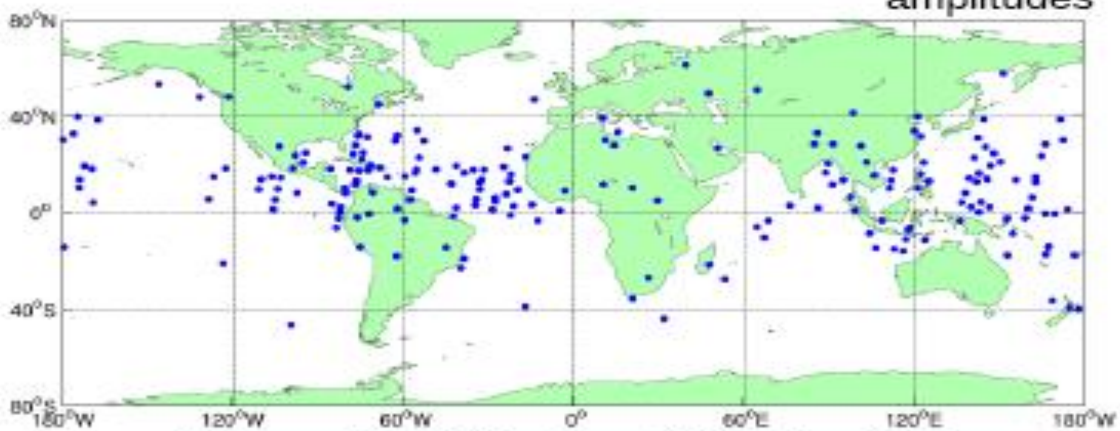
Slow-Flashes



Example of a waveform of a slow flash



Snapshot of the focal plane at the moment of maximum amplitudes



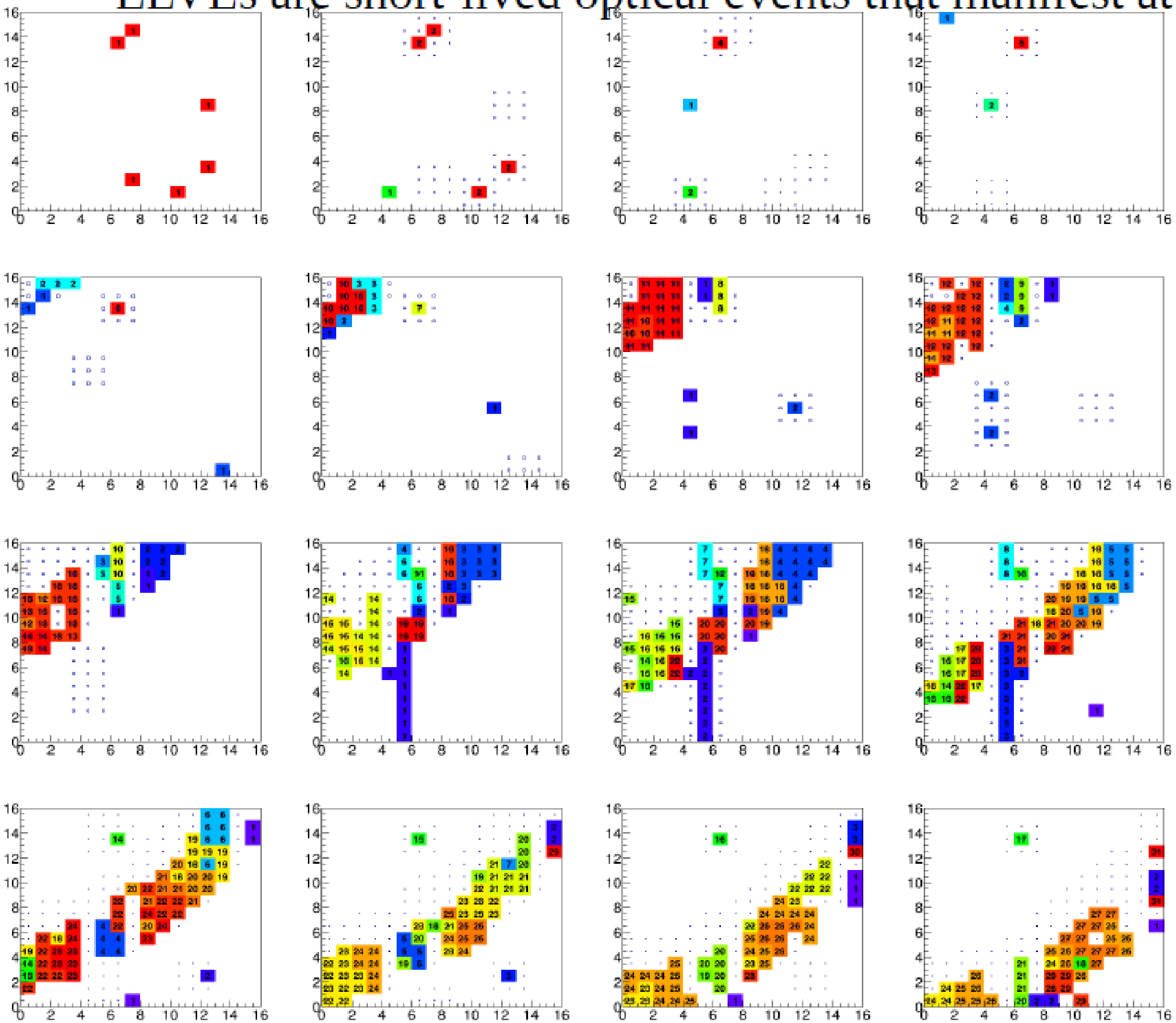
Geographic distribution of 207 slow flashes.

EAS reconstruction program for TUS

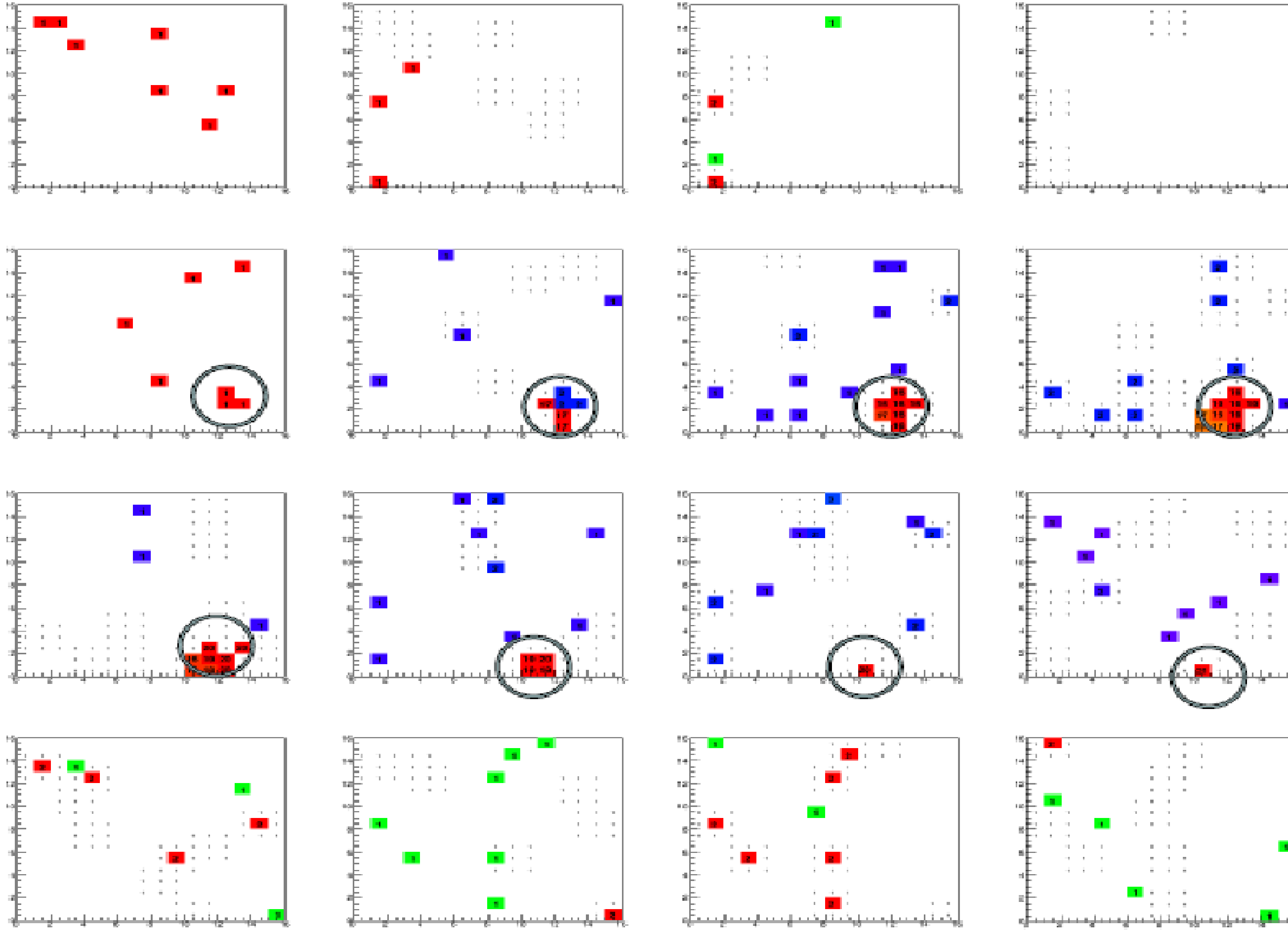
ELVE

(Emission of Light and Very-low frequency perturbation from an Electromagnetic pulse sources)

ELVEs are short-lived optical events that manifest at the lower edge of the the ionosphere (altitudes of 80–90 km) as bright rings expanding at the speed of light up to a maximum radius of ∼ 300 km. The life time of an elve is ∼1 ms.

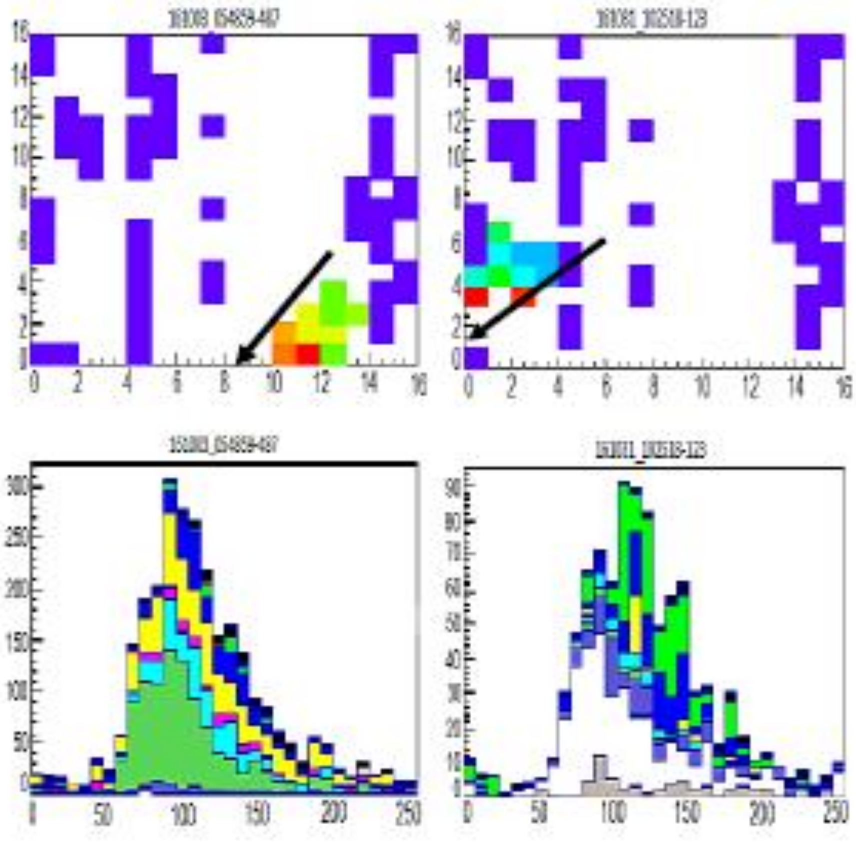


The event-map plots of the sequential frames of 16 × 0.8 μs steps.

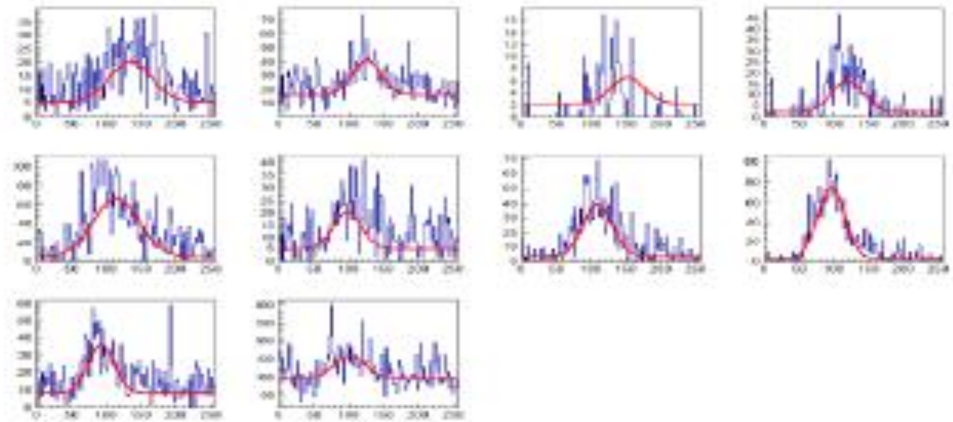


The event-map plots of the sequential frames of 12.8 μs steps.

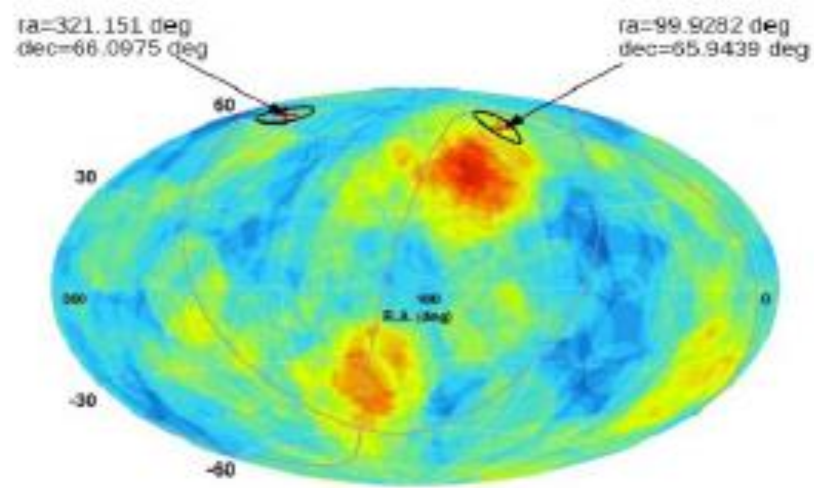
EAS candidates



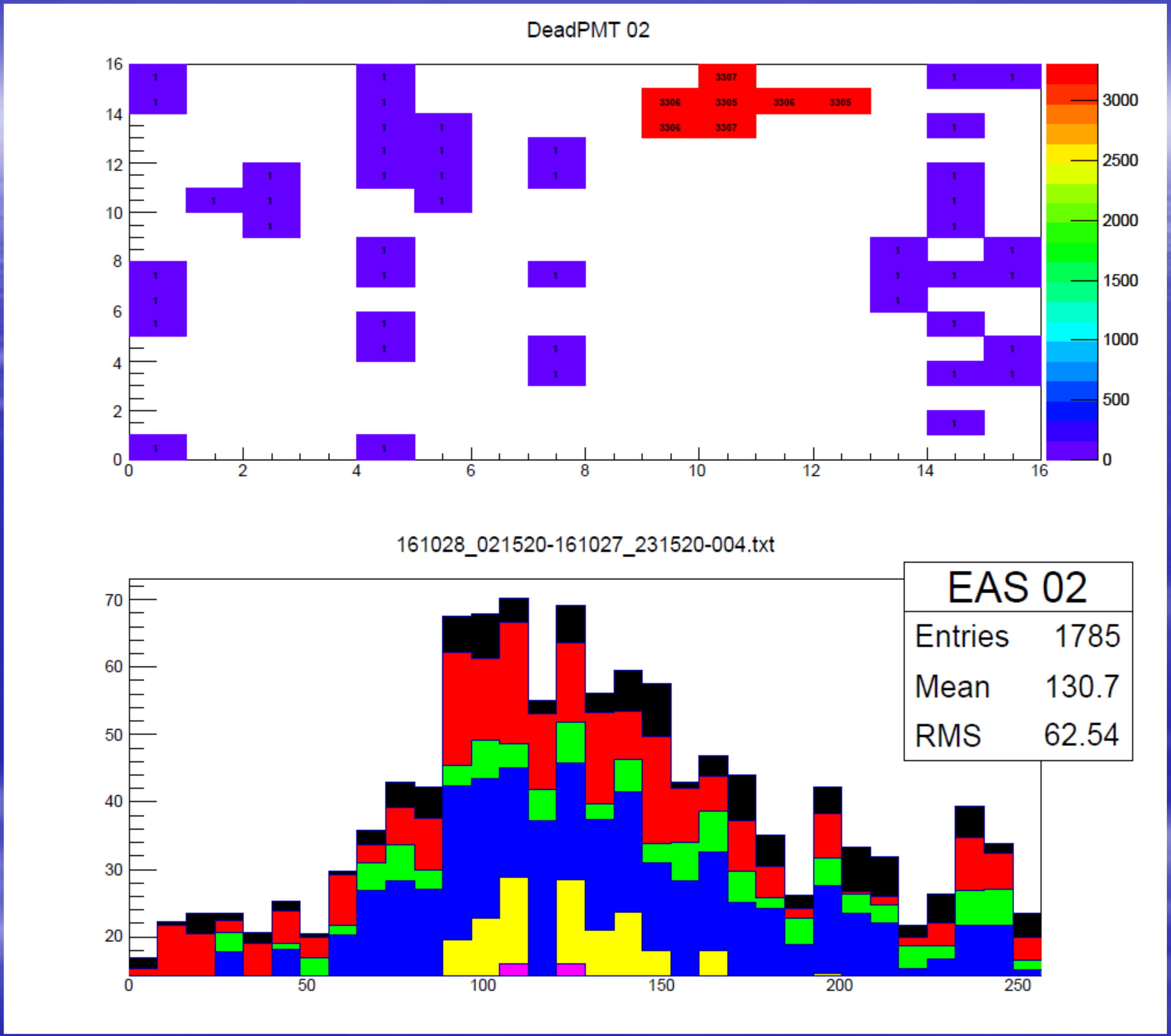
The EAS candidates. Upper plots – image of event with hit pixels and not-working (blue) ones.
Bottom plots – the amplitude variation of time for selected hit pixels.



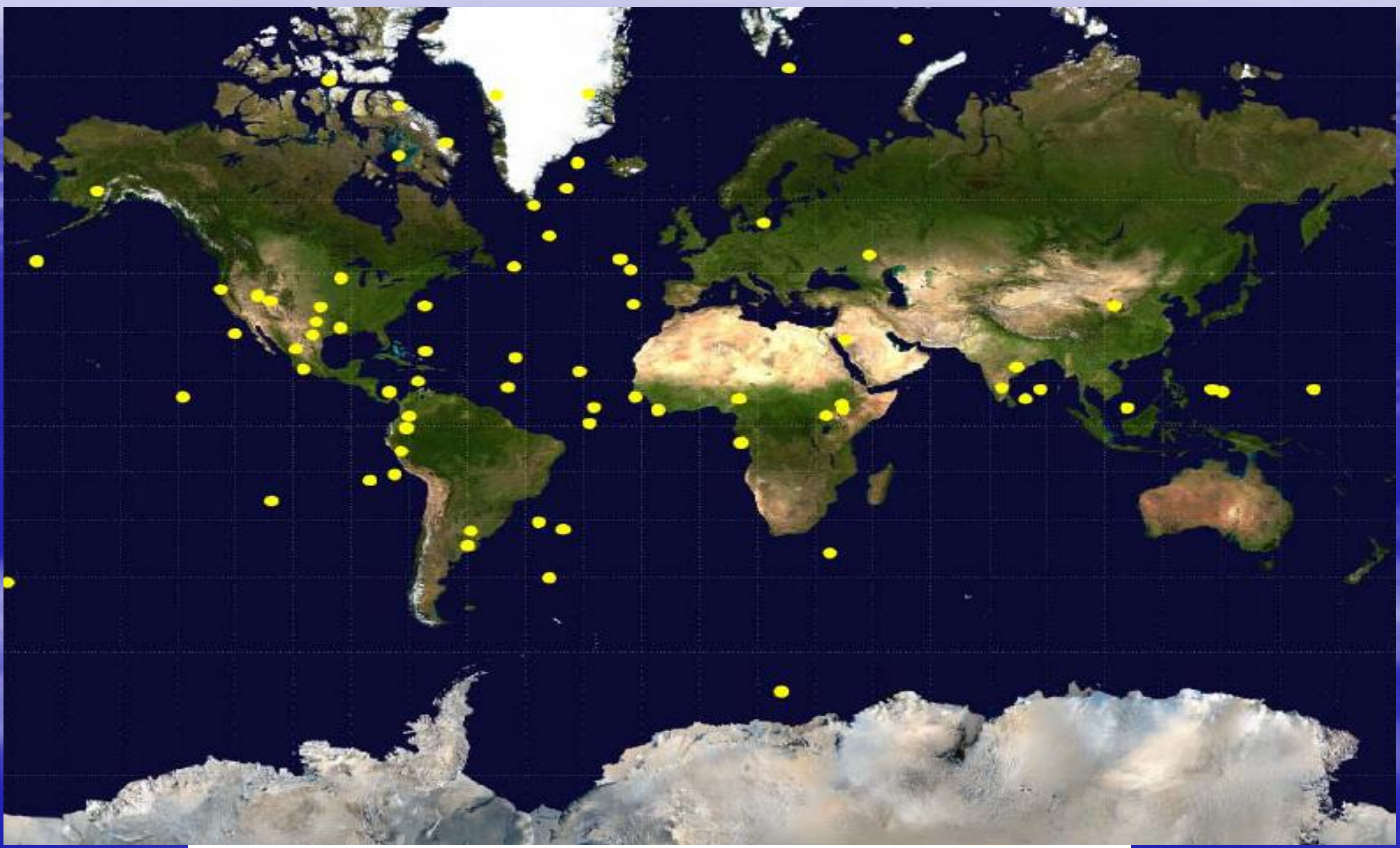
Time distributions of the EAS signals in the hit PMT pixels of the EAS candidate event №487.



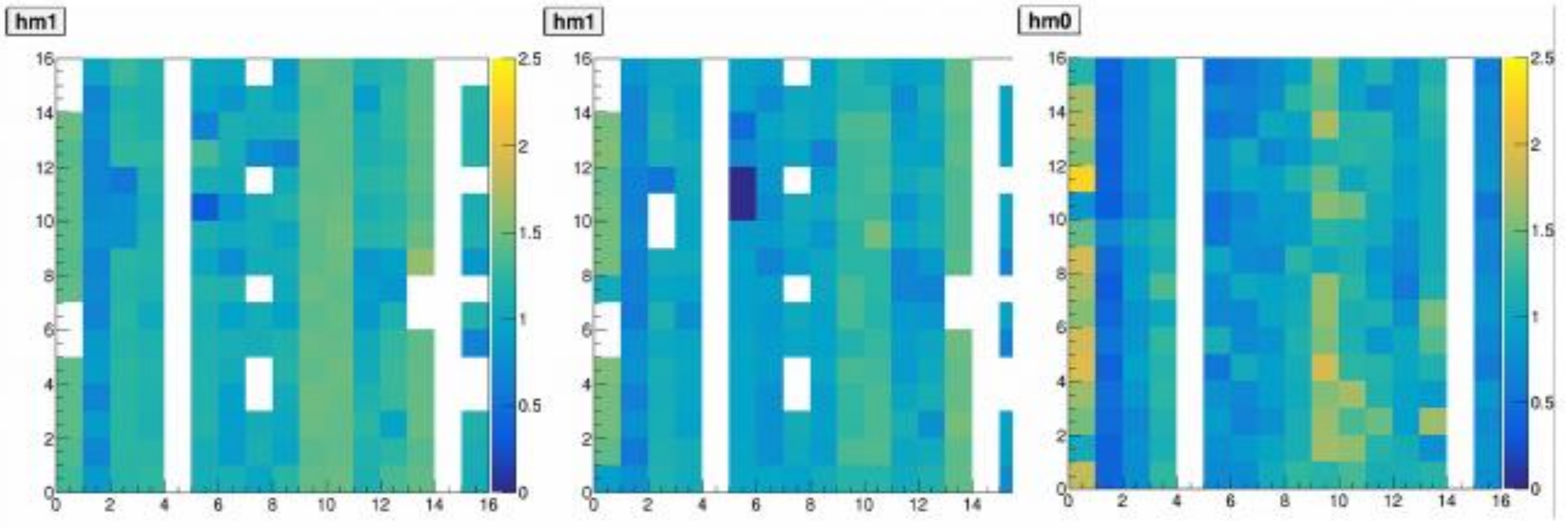
Location of the EAS candidates in the equatorial coordinate system on top of the Auger+ TA data



An example of the time profile for the pseudo EAS event



Distribution of the pseudo EAS events.

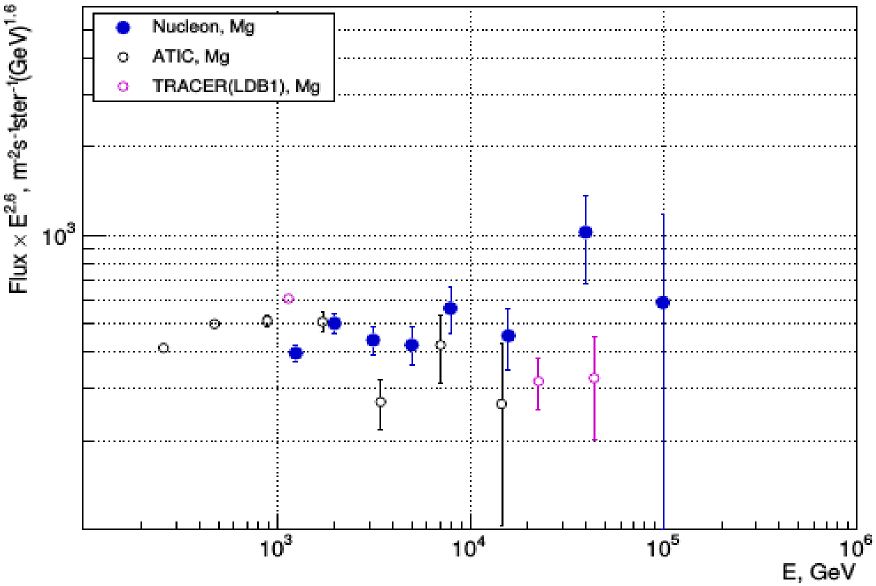


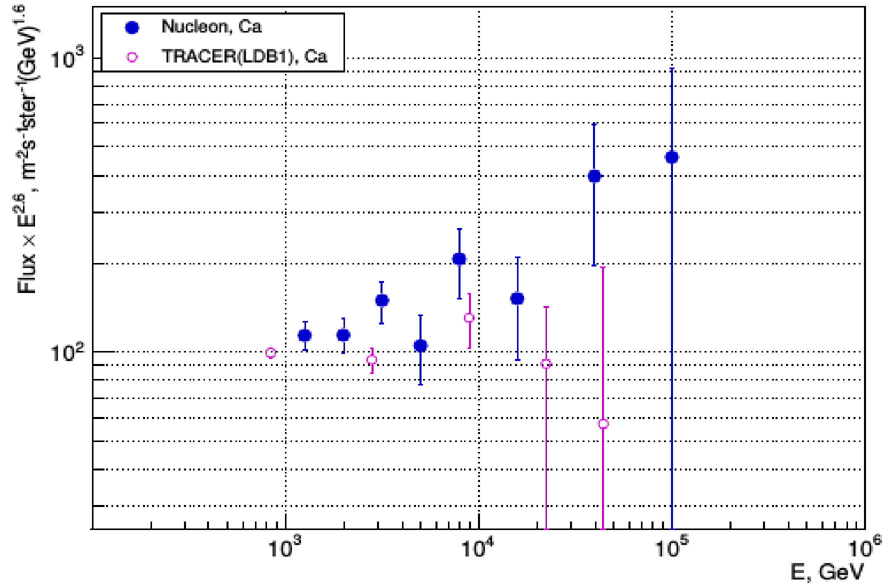
Calibration of PMTs and comparison to pre-flight measurements. Relative PMT gain calibration was done by analyzing background events and is presented here for 2 statistically independent subsets of data (left and center). Pre-flight measurements (right) are shown with 2 PMT modules that later stopped working turned off for comparison.

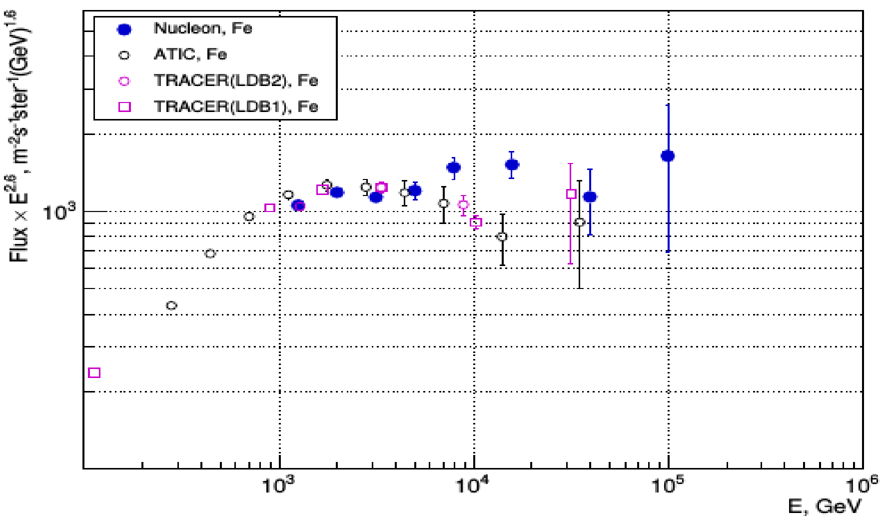
Conclusion - TUS

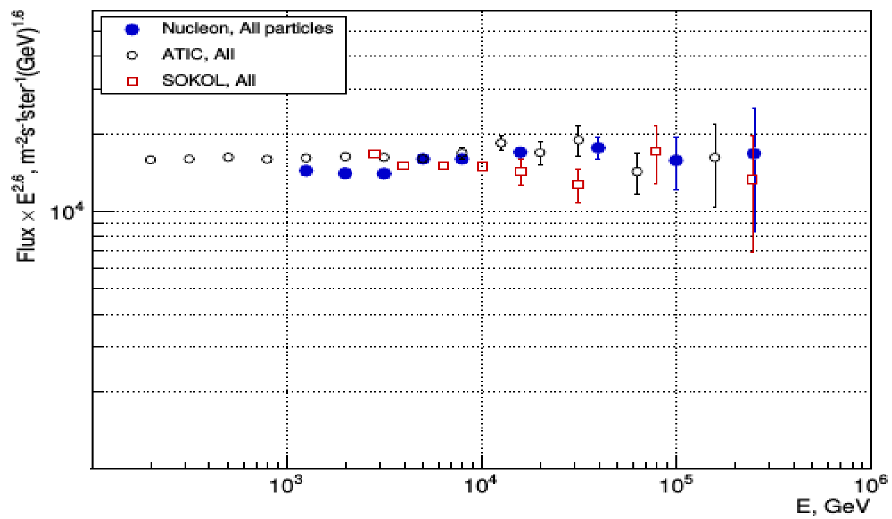
- The **TUS mission** is in orbit for operation since April of **2016** at the dedicated "Mikhail Lomonosov" satellite for **3 years of data taking**
- **A few EAS of UHECR candidates were found and analysed**
- **TUS is the pilot experiment** to confirm a possibility UHECR study from space.
- Next step is **KLYPVE/K-EUSO experiment on ISS** at ~2022

- Thank you


Nucleon, Mg
ATIC, Mg
TRACER(LDB1), Mg
Flux × E^2.6, m^-2s^-1ster^-1(GeV)^1.6
E, GeV


Nucleon, Ca
TRACER(LDB1), Ca
Flux × E^2.6, m^-2s^-1ster^-1(GeV)^1.6
E, GeV


Nucleon, Fe
ATIC, Fe
TRACER(LDB2), Fe
TRACER(LDB1), Fe
Flux × E^2.6, m^-2s^-1ster^-1(GeV)^1.6
E, GeV


Nucleon, All particles
ATIC, All
SOKOL, All
Flux × E^2.6, m^-2s^-1ster^-1(GeV)^1.6
E, GeV

$p + \gamma_{CMB} \rightarrow N$ + pions,   E > 4*10^{19} eV – GZK cutoff

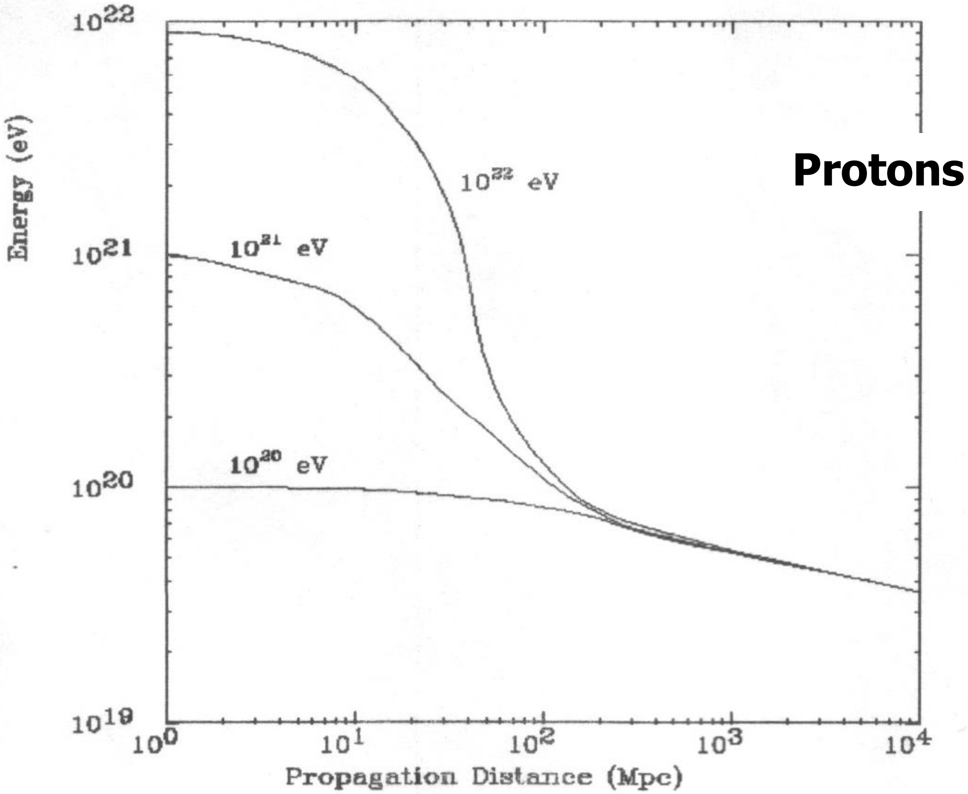
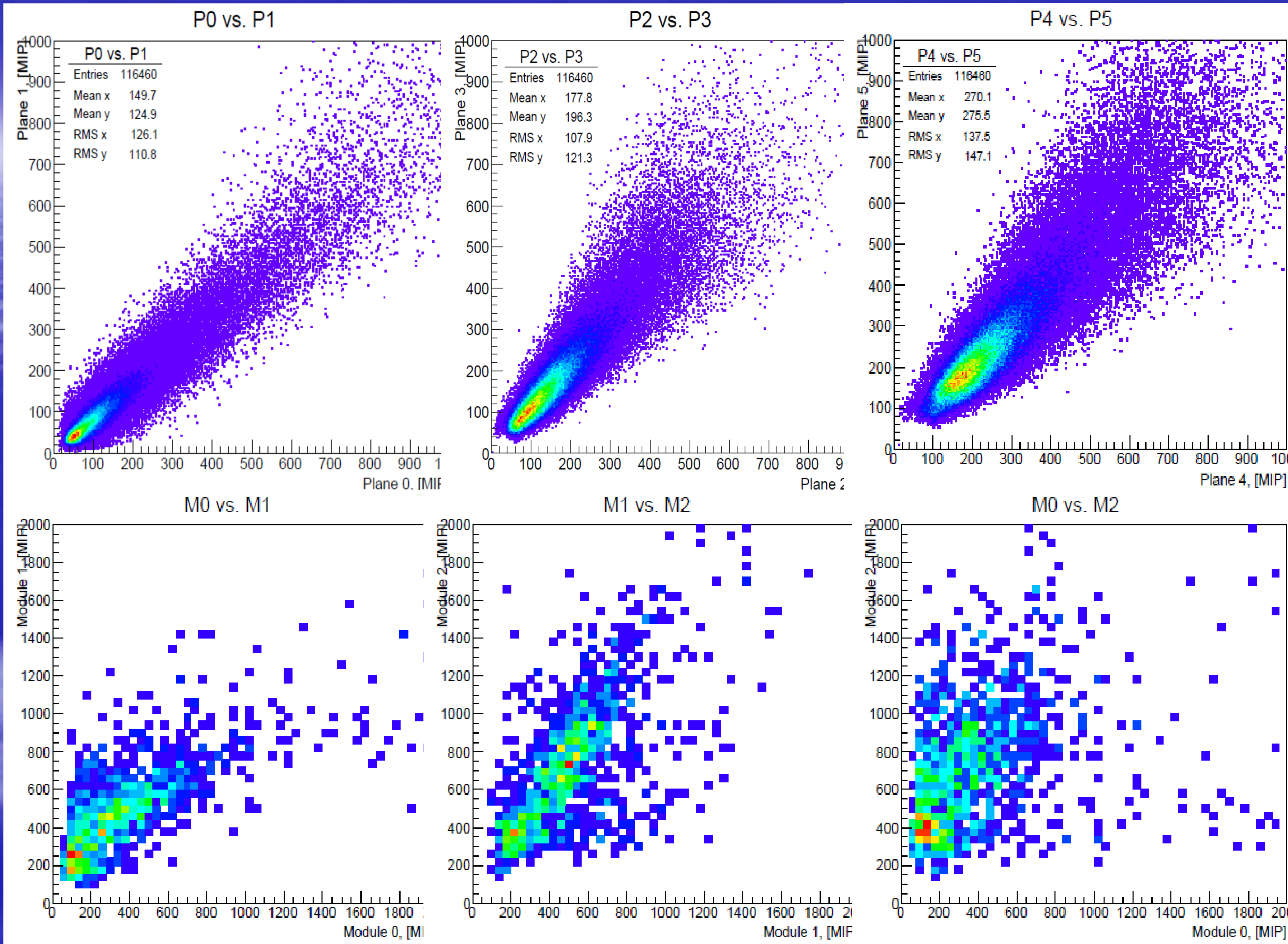


Рис. 9. Эффект Грейзена-Зацепина-Кузьмина (GZK-cutoff)

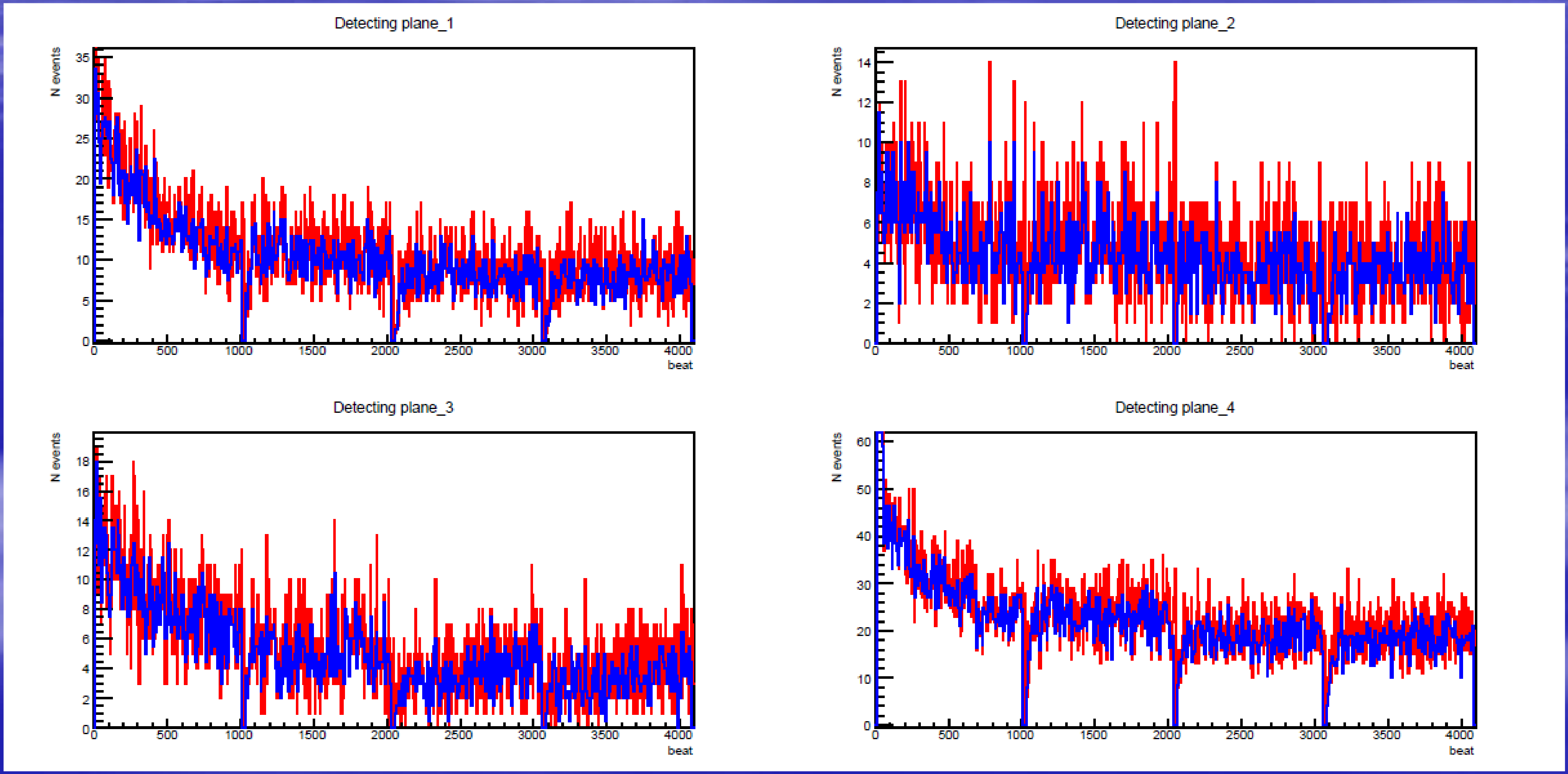
Backup slides


P0 vs. P1
P0 vs. P1
Entries 116460
Mean x 149.7
Mean y 124.9
RMS x 126.1
RMS y 110.8
Plane 1, [MIP]
Plane 0, [MIP
P2 vs. P3
P2 vs. P3
Entries 116460
Mean x 177.8
Mean y 196.3
RMS x 107.9
RMS y 121.3
Plane 3, [MIP]
Plane 2
P4 vs. P5
P4 vs. P5
Entries 116460
Mean x 270.1
Mean y 275.5
RMS x 137.5
RMS y 147.1
Plane 5, [MIP]
Plane 4, [MIP]
M0 vs. M1
Module 1, [MIP]
Module 0, [MI
M1 vs. M2
Module 2, [MIP]
Module 1, [MIP
M0 vs. M2
Module 2, [MIP]
Module 0, [MIP]

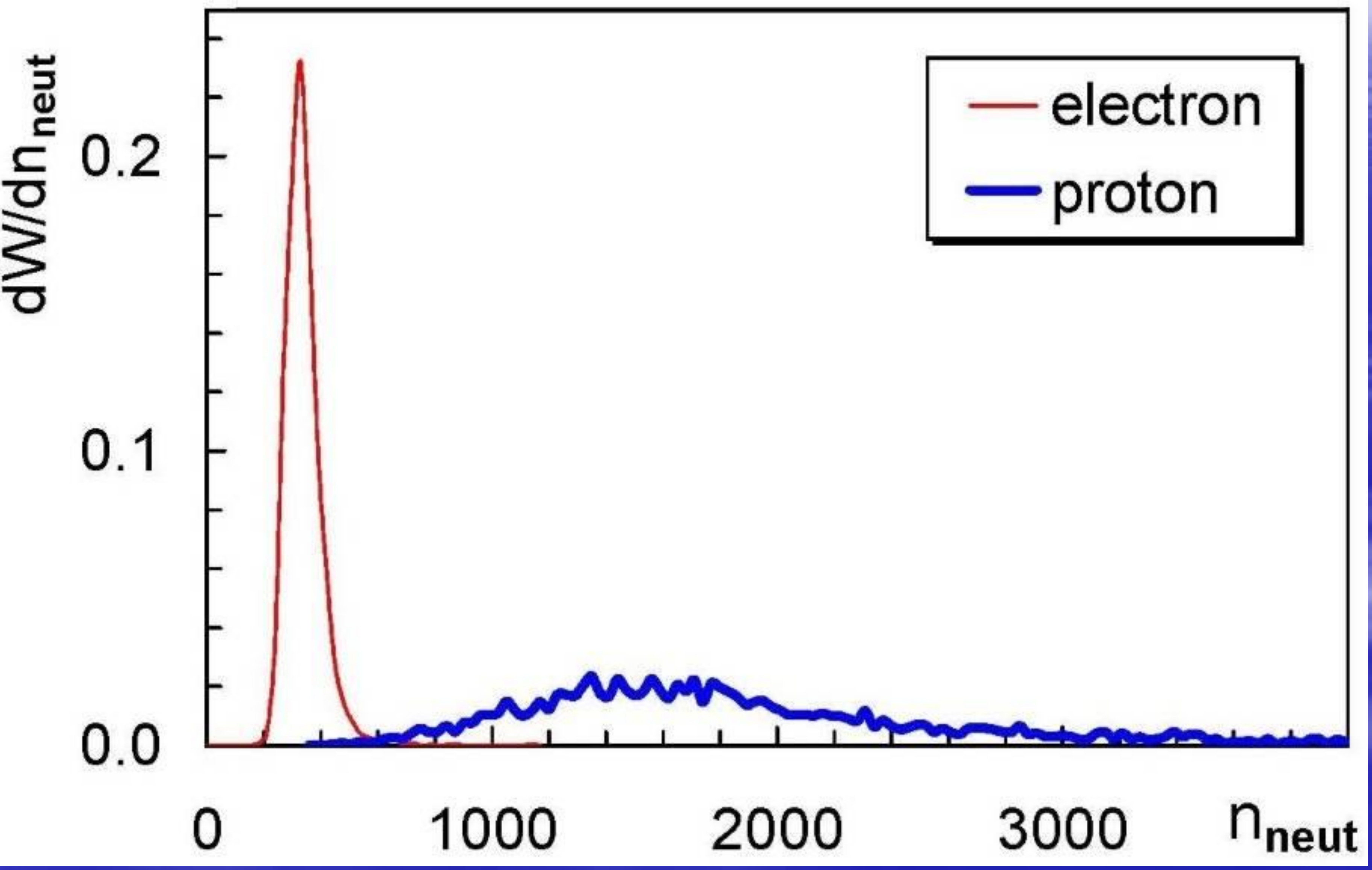
Delayed neutron yield:

Xe beam 13 Gev/nucl, rijidity A/Z =2.1

$\Delta T = 0 - 12$ usec



2018-2019 tests: measurement of the neutron yield with initial electron and proton beams



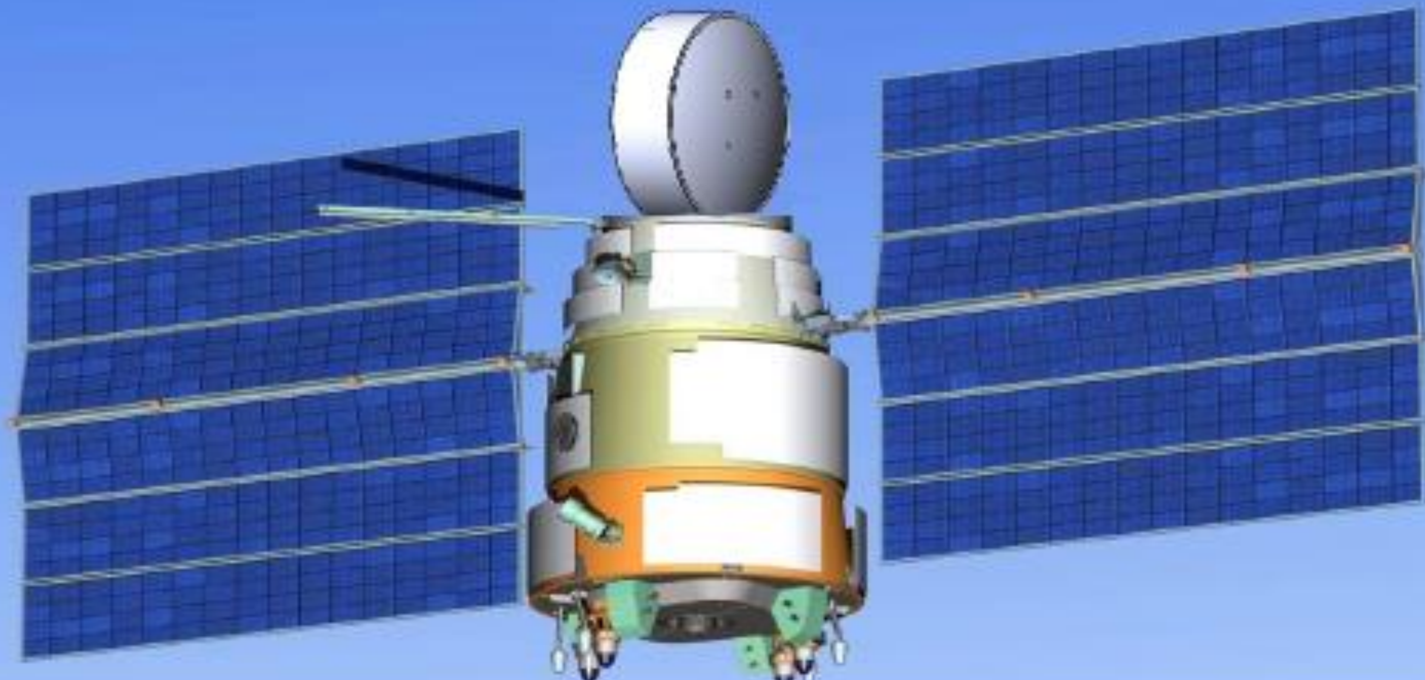
HERO

"High Energy Rays Observatory"

current status

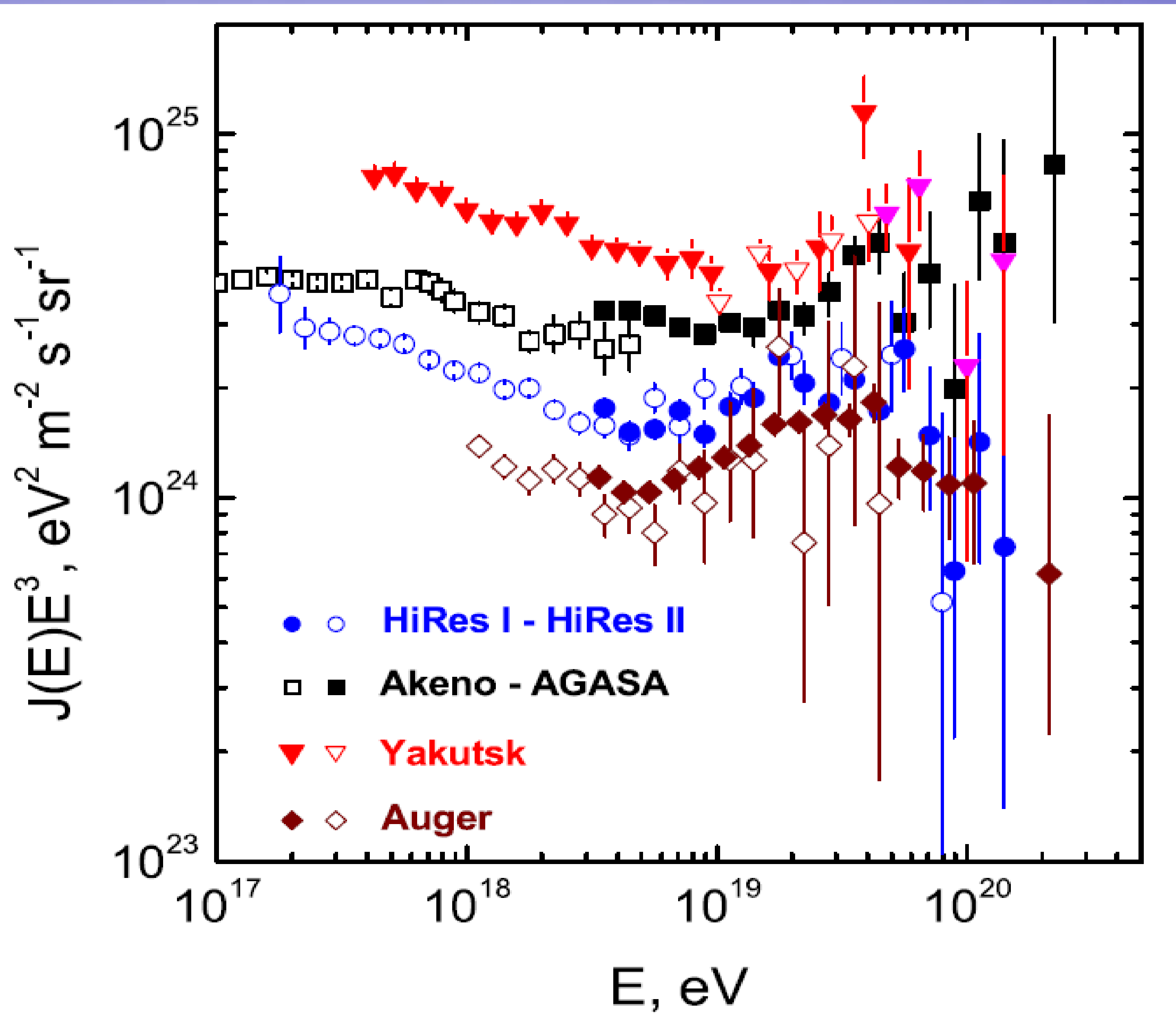
D. Karmanov, A. Panov, D. Podorozhny,
L. Tkachev, A. Turundaevskiy

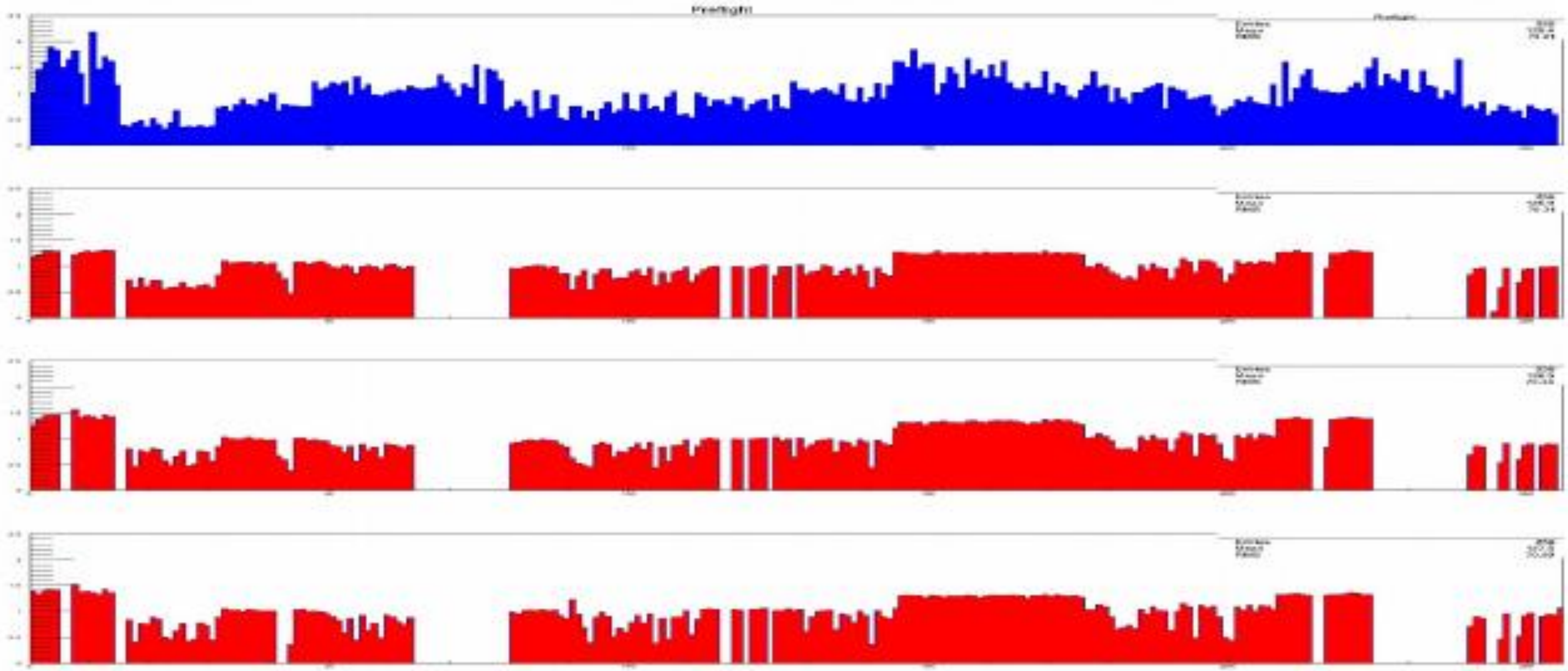
Dmitry Podorozhny 08.06.2018



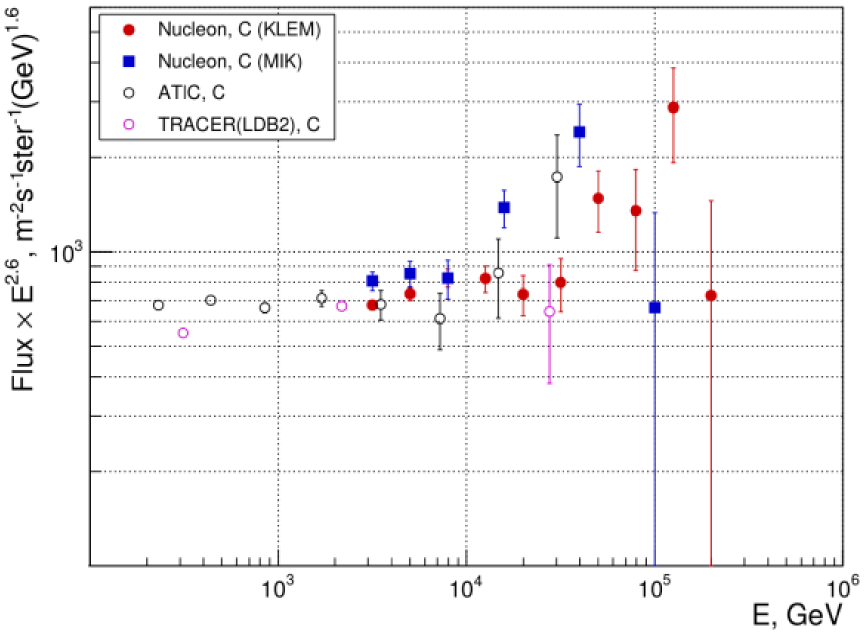
Total mass of OLHE device: 12.5 tons
Power consumption: no more than 5000 W
Daily telemetry: ~ 100 GB;
Exposure time ≥7 years

КЛПВЭ – UHECR
2005

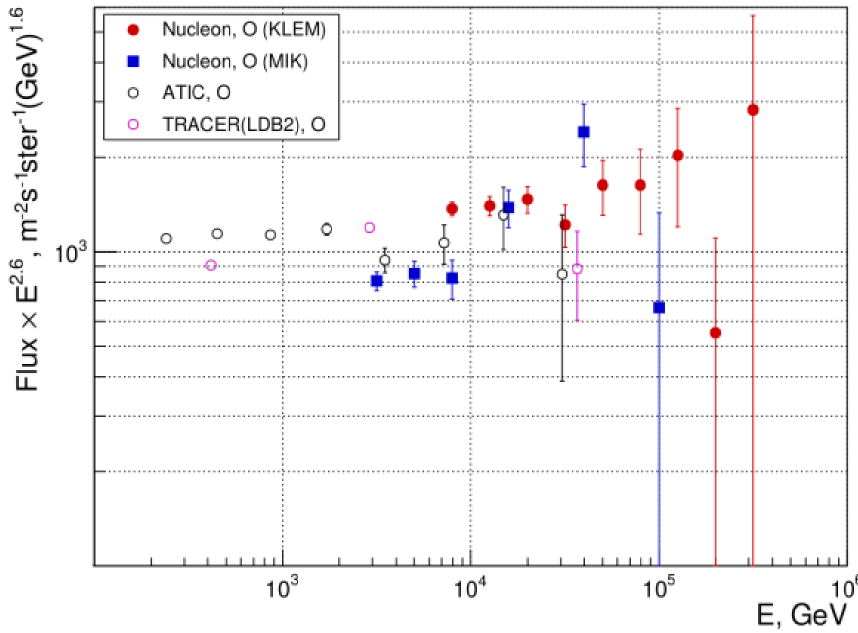




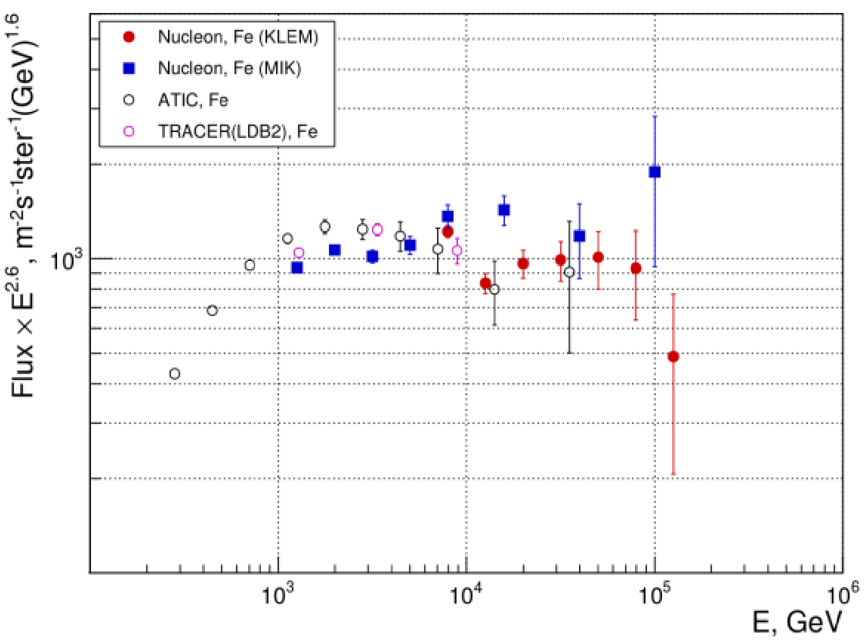
Relative PMT gain coefficients for all 256 channels according to pre-flight measurements (top) and reconstructed from background data for first 3 half-years of operation



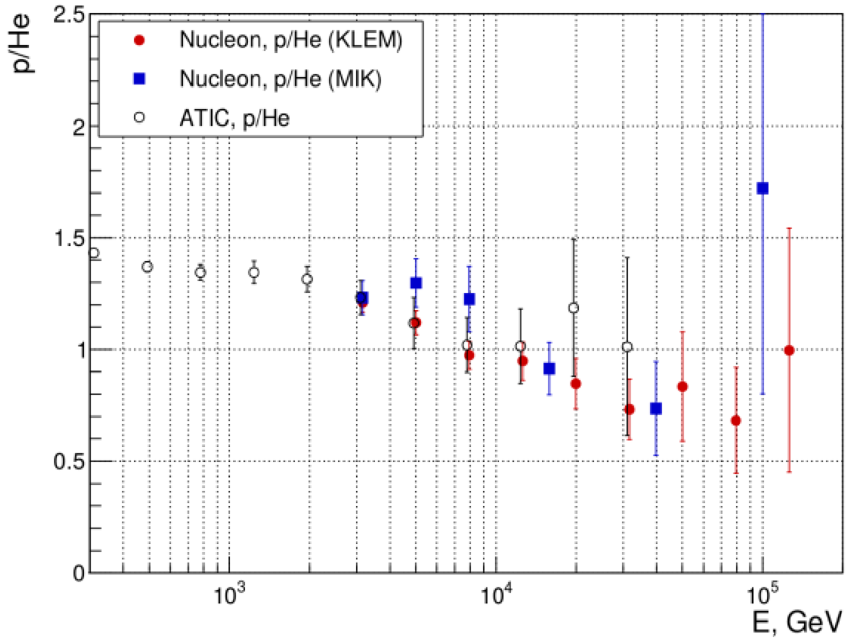
Nucleon, C (KLEM)
Nucleon, C (MIK)
ATIC, C
TRACER(LDB2), C
Flux × E^2.6, m^-2s^-1ster^-1(GeV)^1.6
10^3
10^4
10^5
10^6
E, GeV



Nucleon, O (KLEM)
Nucleon, O (MIK)
ATIC, O
TRACER(LDB2), O
Flux × E^2.6, m^-2s^-1ster^-1(GeV)^1.6
10^3
10^4
10^5
10^6
E, GeV

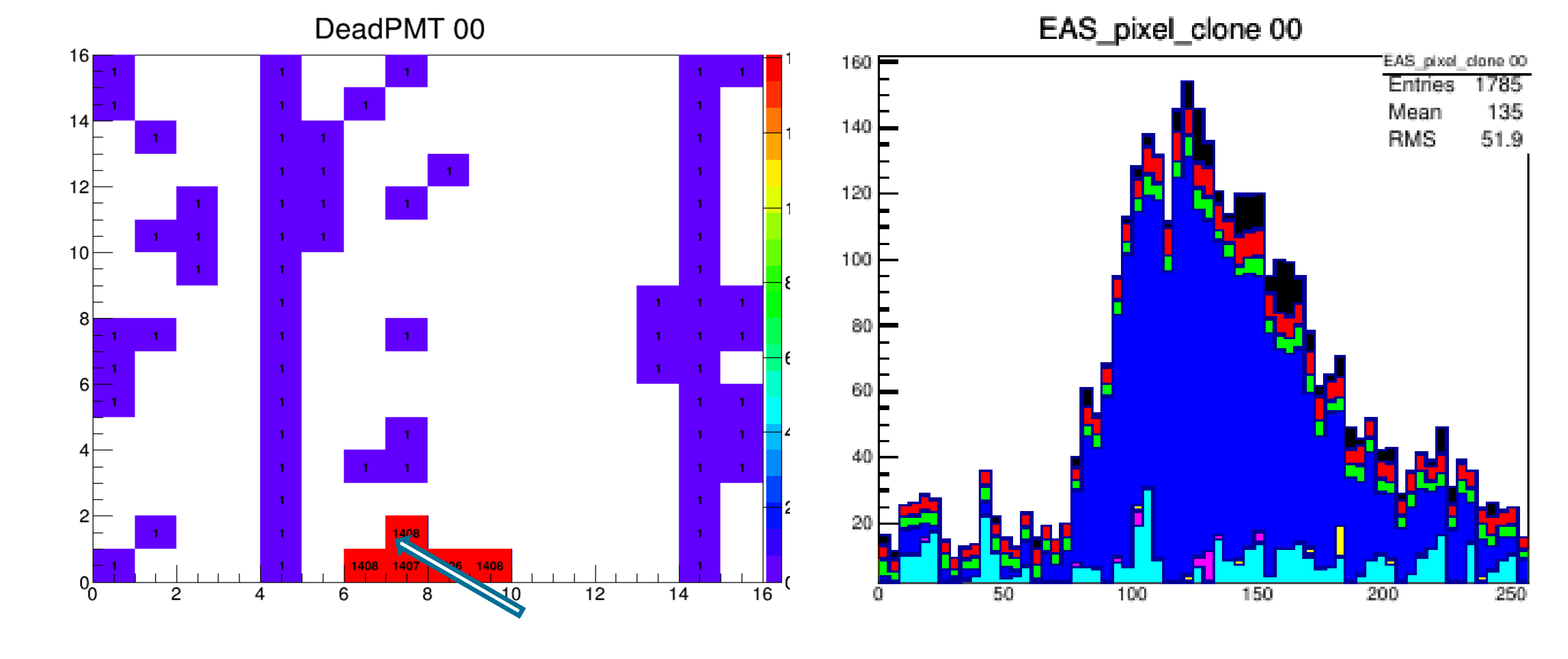


Nucleon, Fe (KLEM)
Nucleon, Fe (MIK)
ATIC, Fe
TRACER(LDB2), Fe
Flux × E^2.6, m^-2s^-1ster^-1(GeV)^1.6
10^3
10^4
10^5
10^6
E, GeV



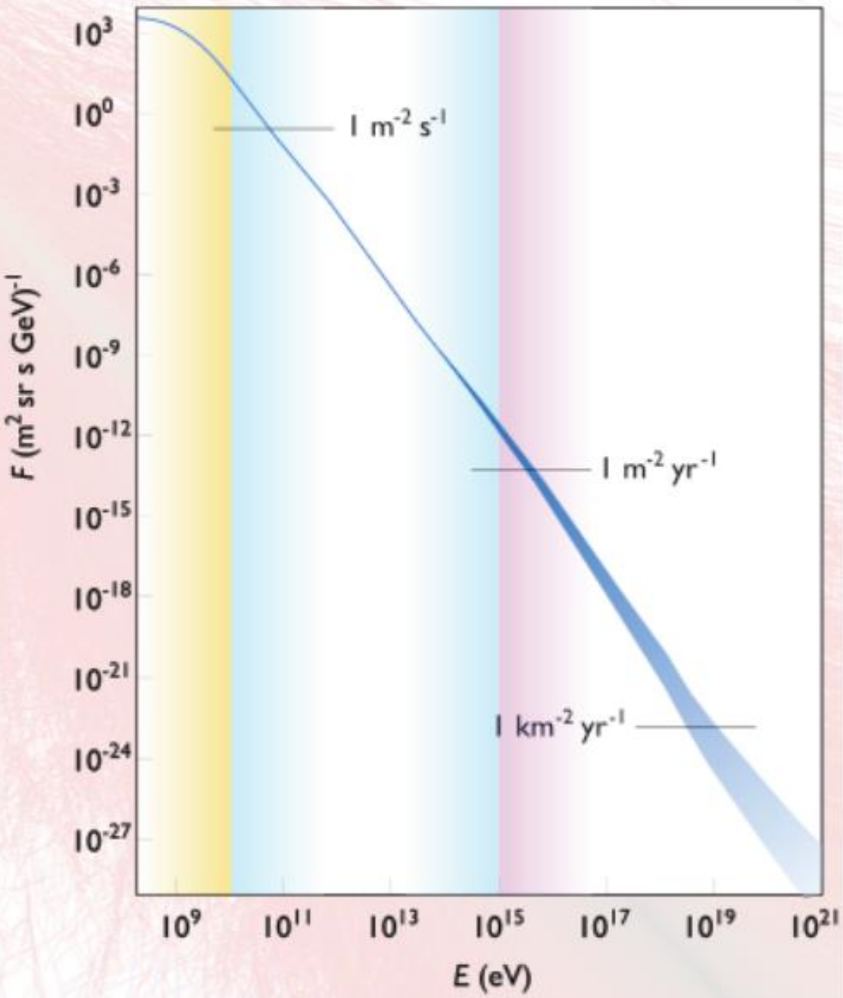
Nucleon, p/He (KLEM)
Nucleon, p/He (MIK)
ATIC, p/He
p/He
2.5
2
1.5
1
0.5
0
10^3
10^4
10^5
E, GeV

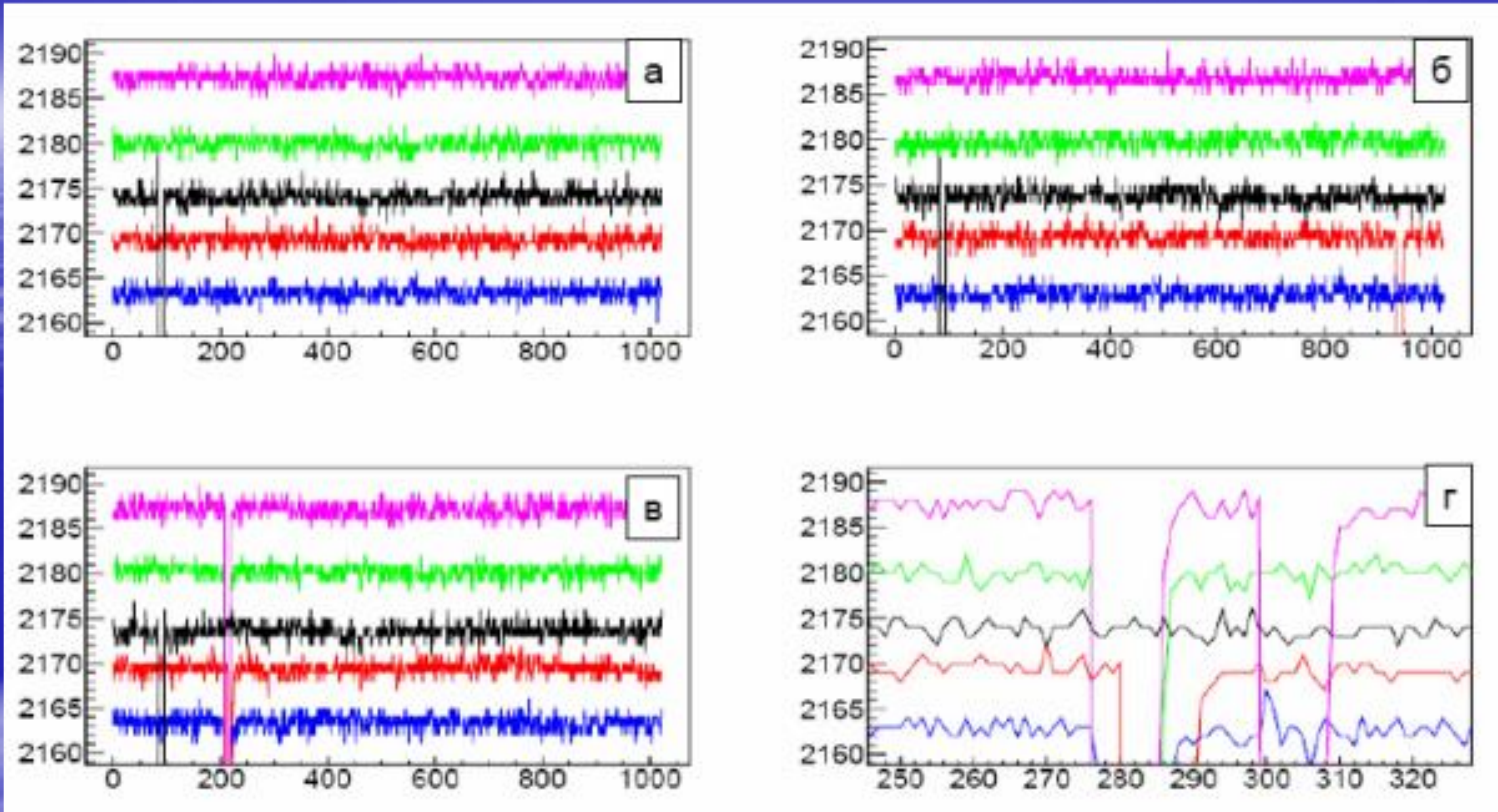
New EAS candidate



Galactic CR

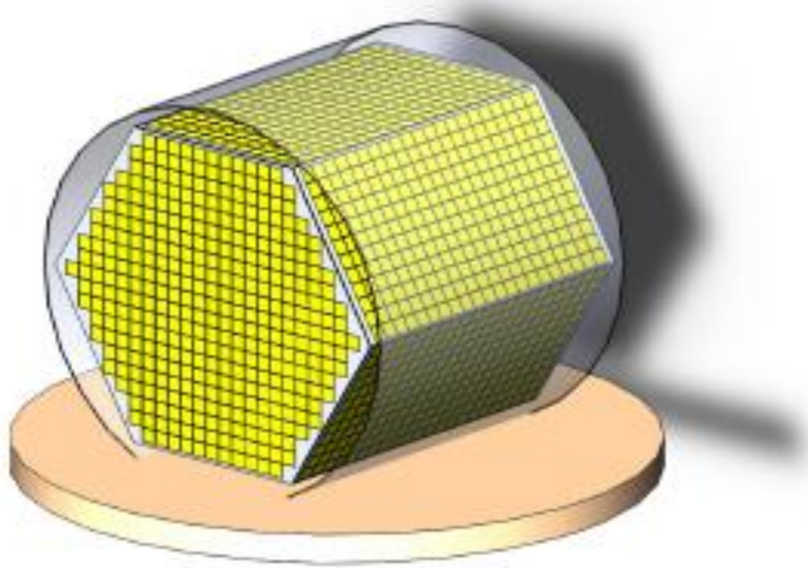
- The total energy density of CR particles is about 1 eV/ cm^{-3}.
- About 1% of energy from SN required to sustain CR abundance.
- At 1 TeV, B~1uG, Gyro-Radius ~ 200AU, 0.001pc → Highly isotropic





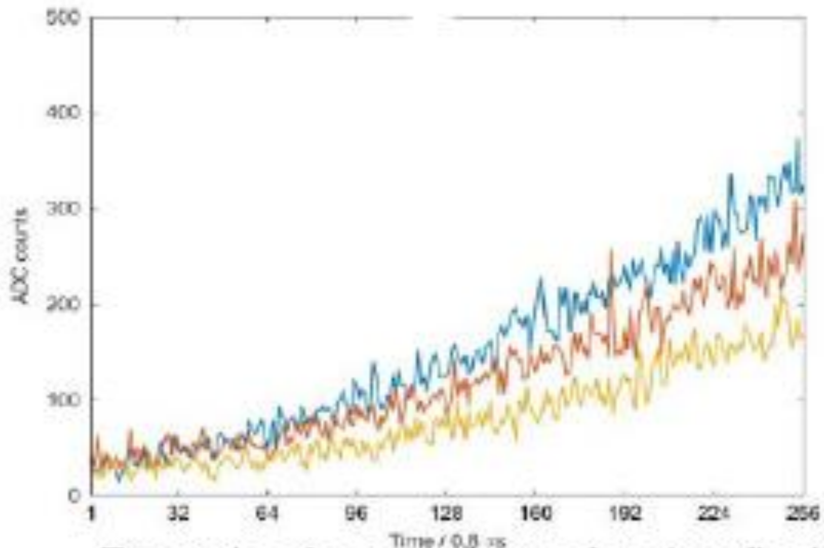
Временные зависимости амплитуд с шагом 4 наносекунды во временном окне длительностью 1024 шагов = 4 мкс

Charge Measuring System

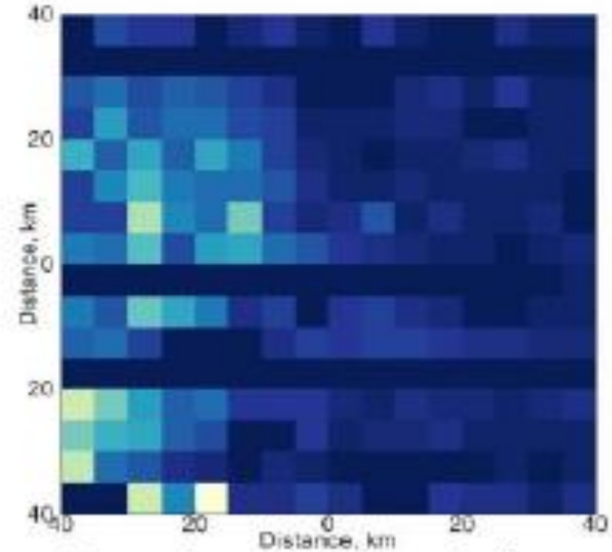


- IC is surrounded on all sides by four-layer Silicon Matrixes. Each matrix consists of several independent leaders comprising from 3 to 16 detectors with dimensions of 100x100x0.5 mm3. Each detector is divided into 100 independent pads. In total, HERO includes ~ 8000 detectors (~8000×100 independent channels)

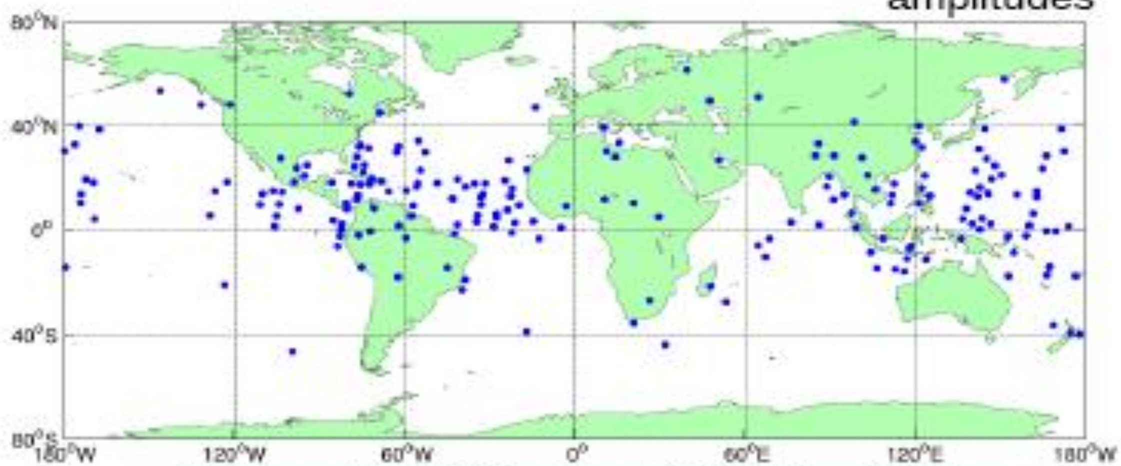
Slow-Flashes



Example of a waveform of a slow flash



Snapshot of the focal plane at the moment of maximum amplitudes



Geographic distribution of 207 slow flashes.

EAS - like events

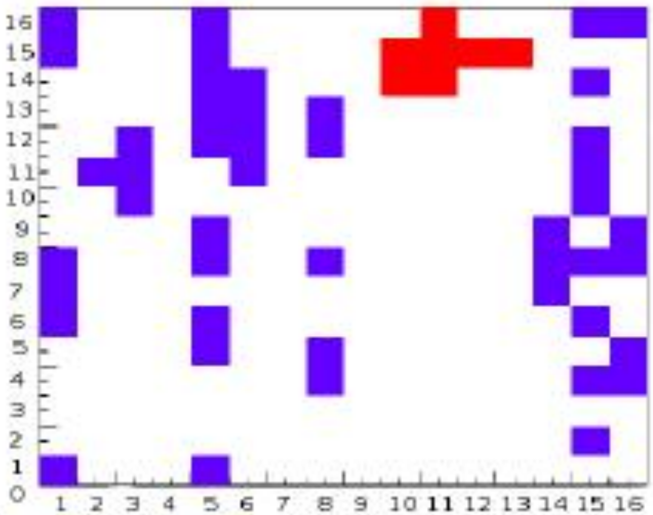
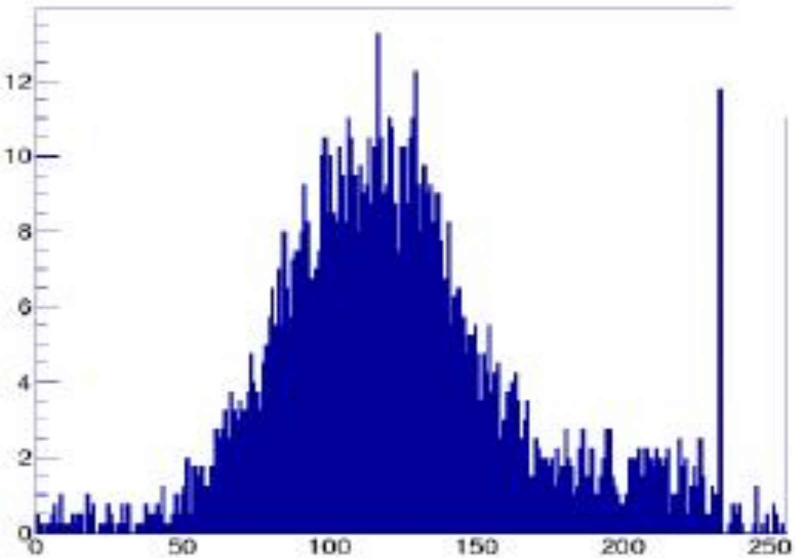
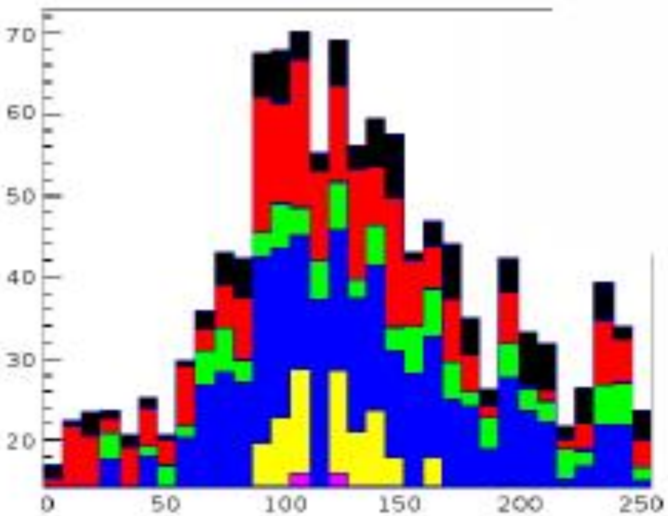


Image of event with hit pixels(red) and not-working (blue) ones on photodecector matrix



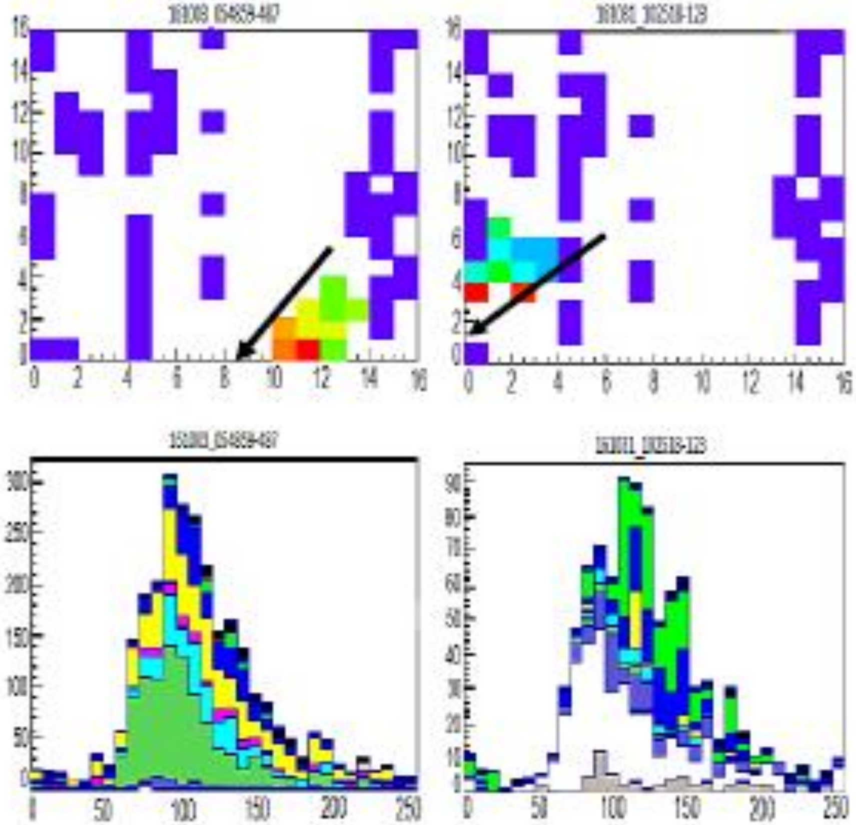
ESAF MC event. E = 10^{20} эВ, θ = 60°



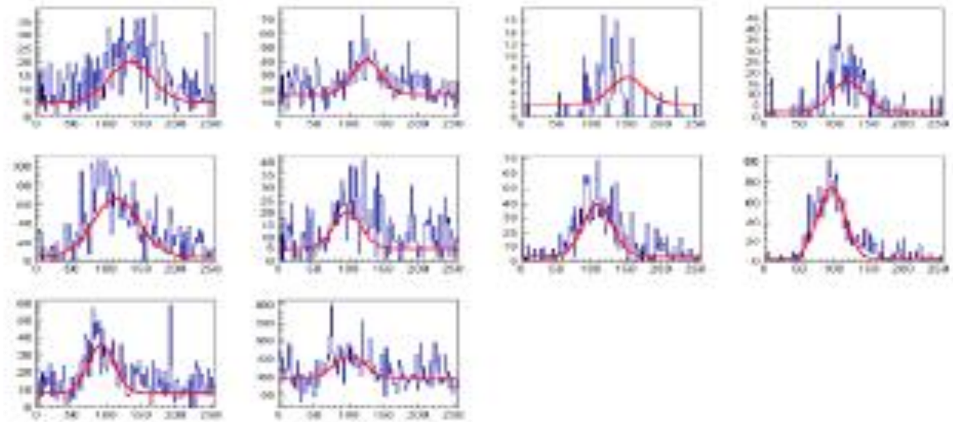
Example of EAS-like event

Geographic distribution of EAS-like events.

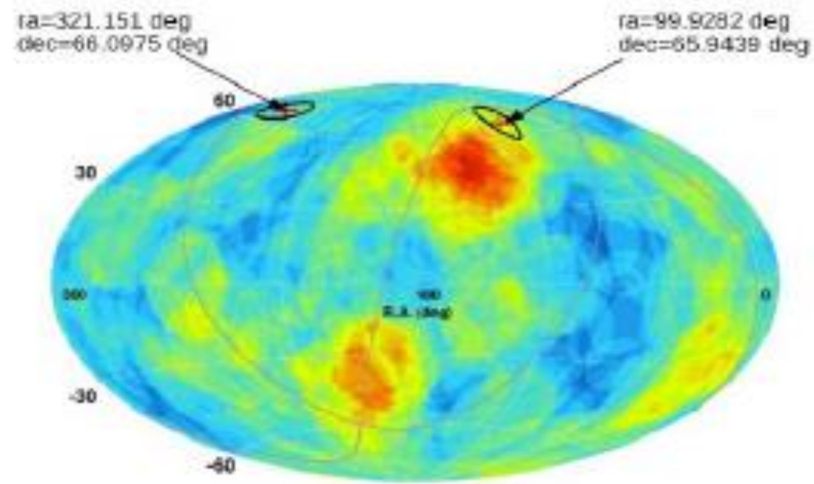
EAS candidates



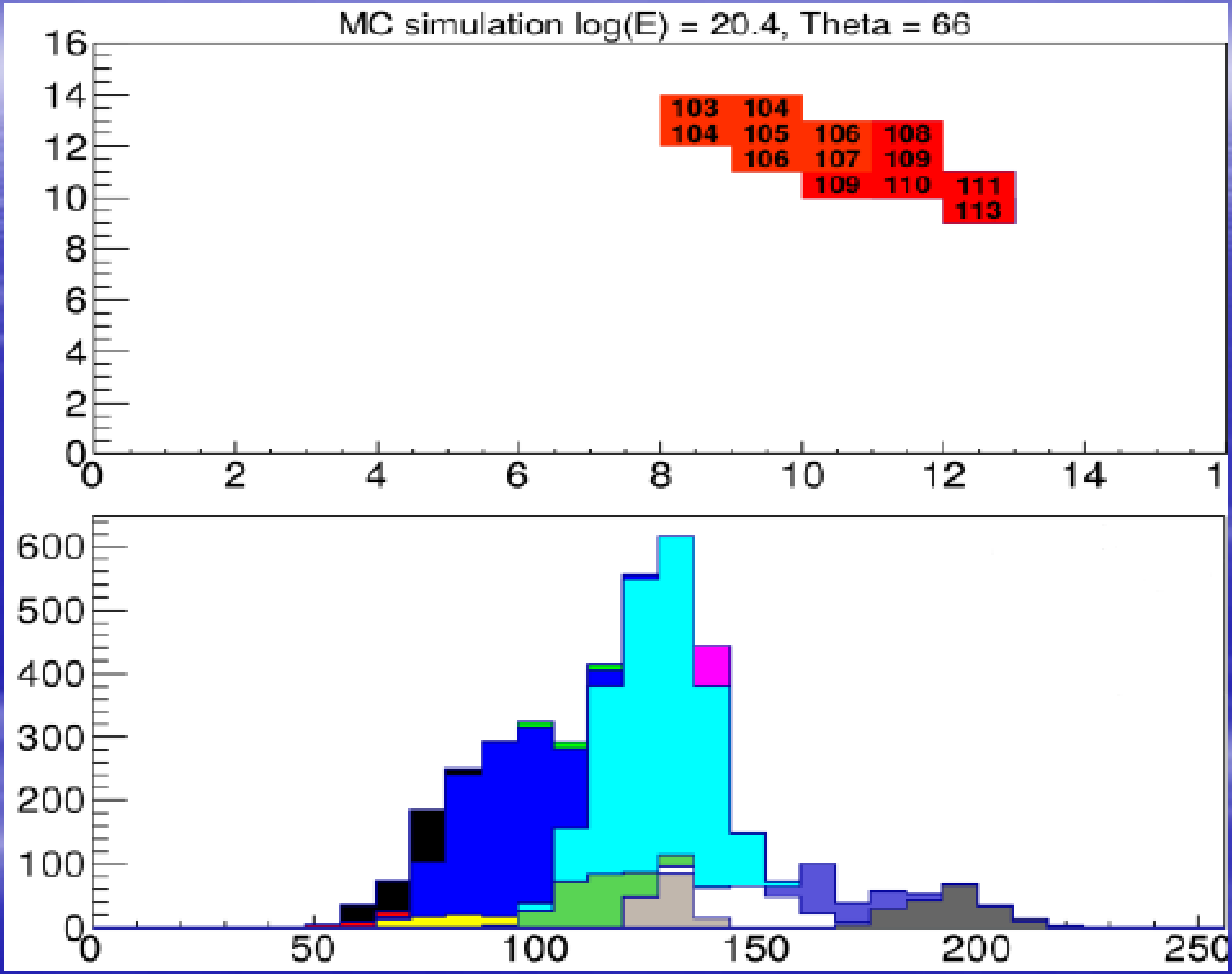
The EAS candidates. Upper plots – image of event with hit pixels and not-working (blue) ones.
Bottom plots – the amplitude variation of time for selected hit pixels.



Time distributions of the EAS signals in the hit PMT pixels of the EAS candidate event №487.

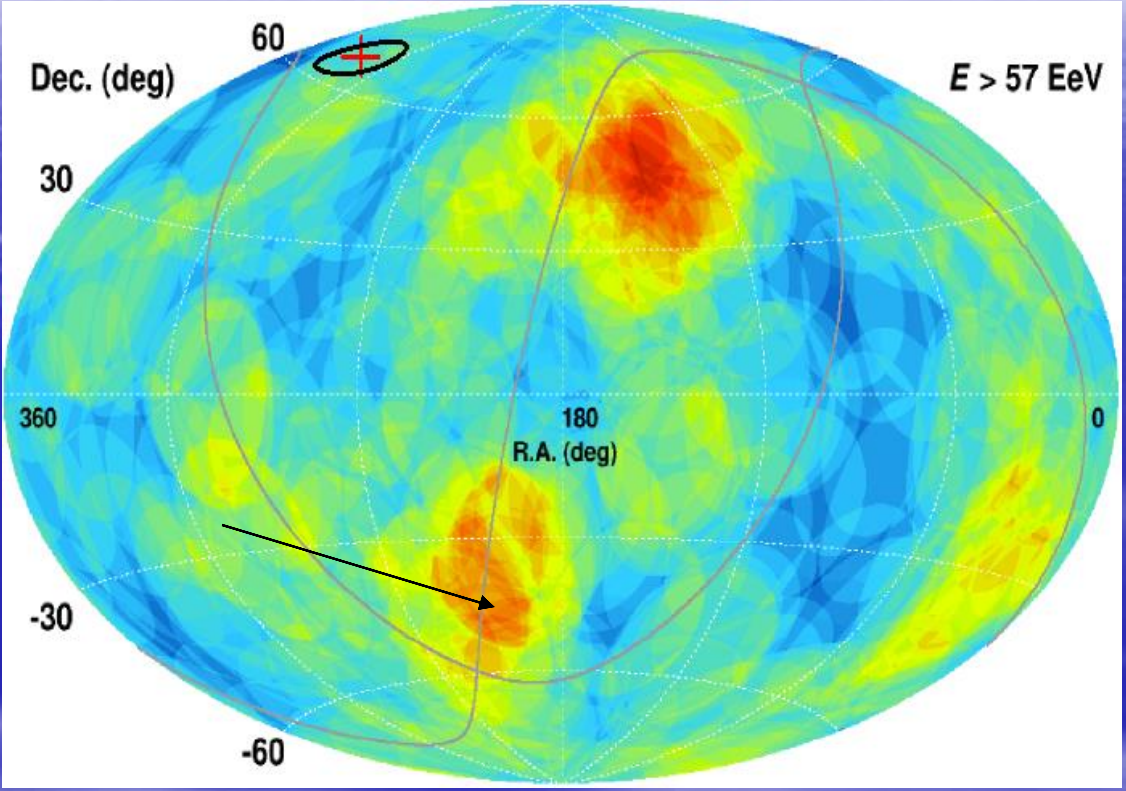


Location of the EAS candidates in the equatorial coordinate system on top of the Auger+ TA data

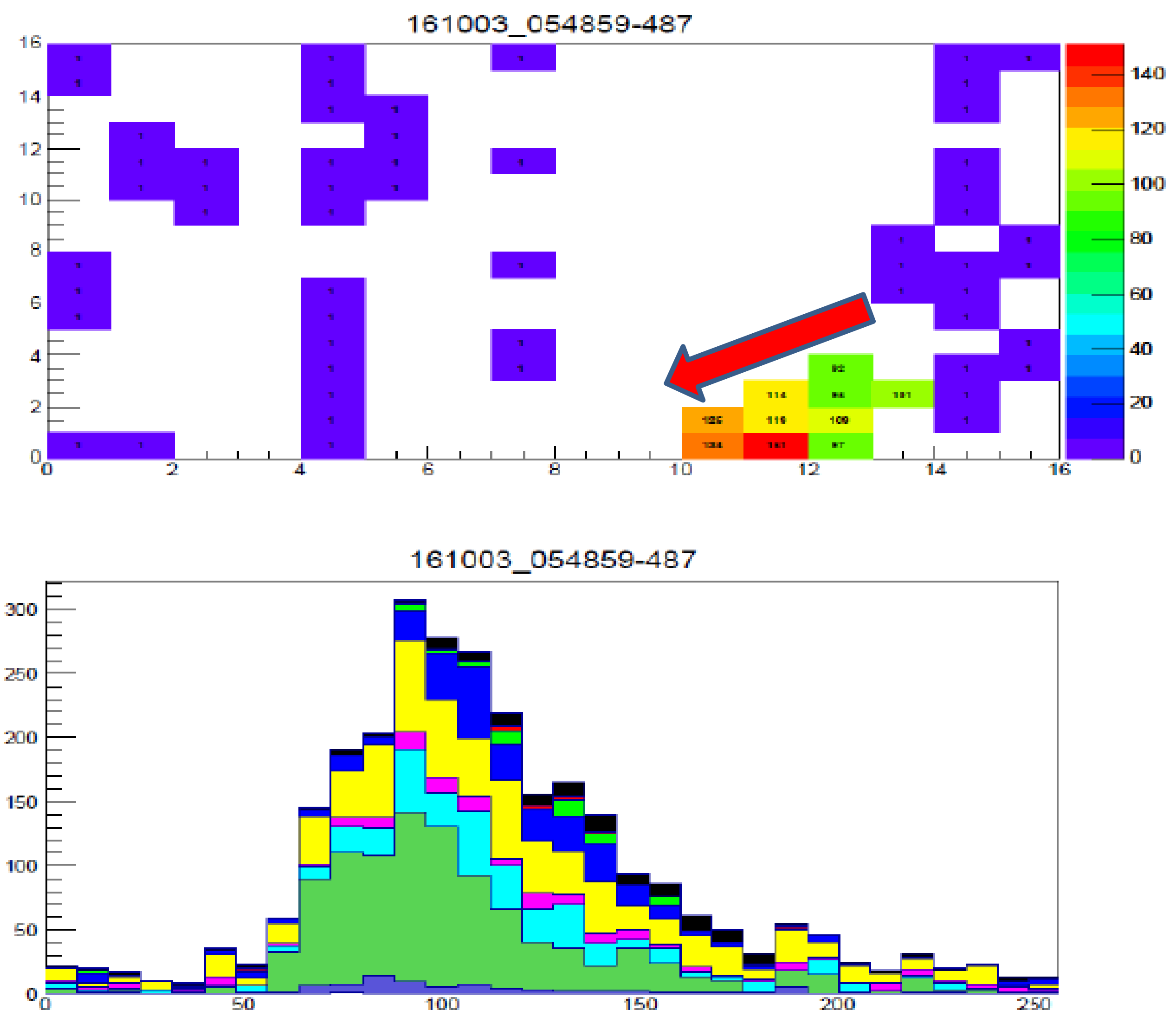


Simulated EAS event image .The hit pixel amplitudes time dependence distribution

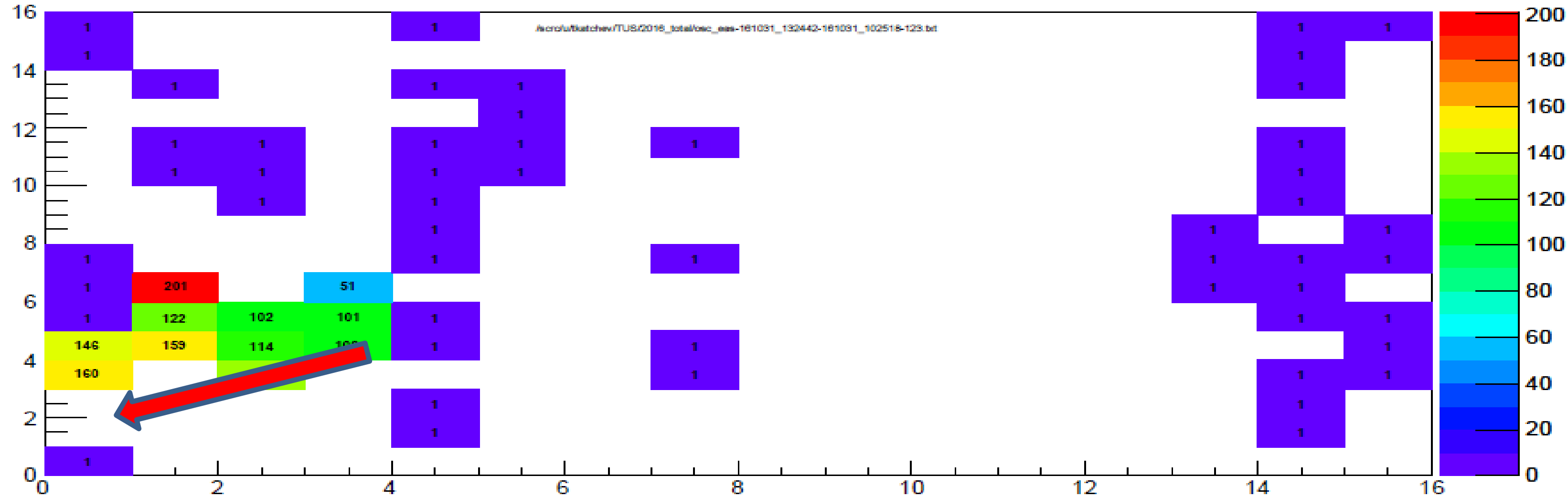
EAS event candidate detected on 03.10.2016 with reconstructed arrival direction: Right Ascension 321°, Declination 66°.



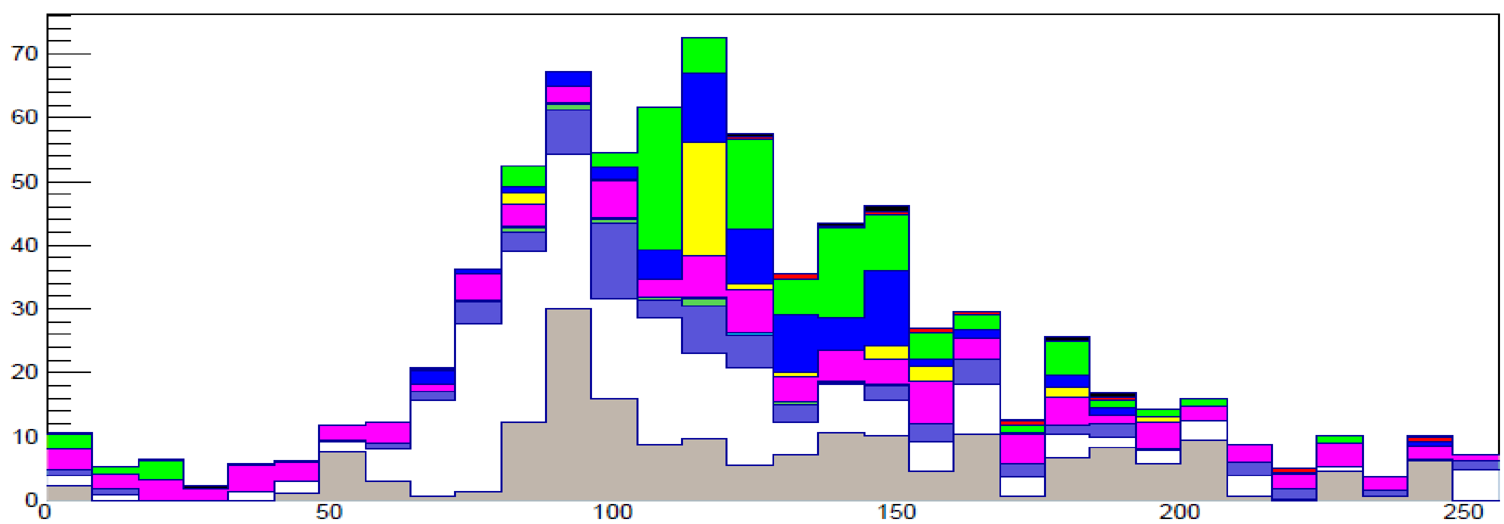
Location of the EAS candidate in the equatorial coordinate system on top of the Auger+ TA data



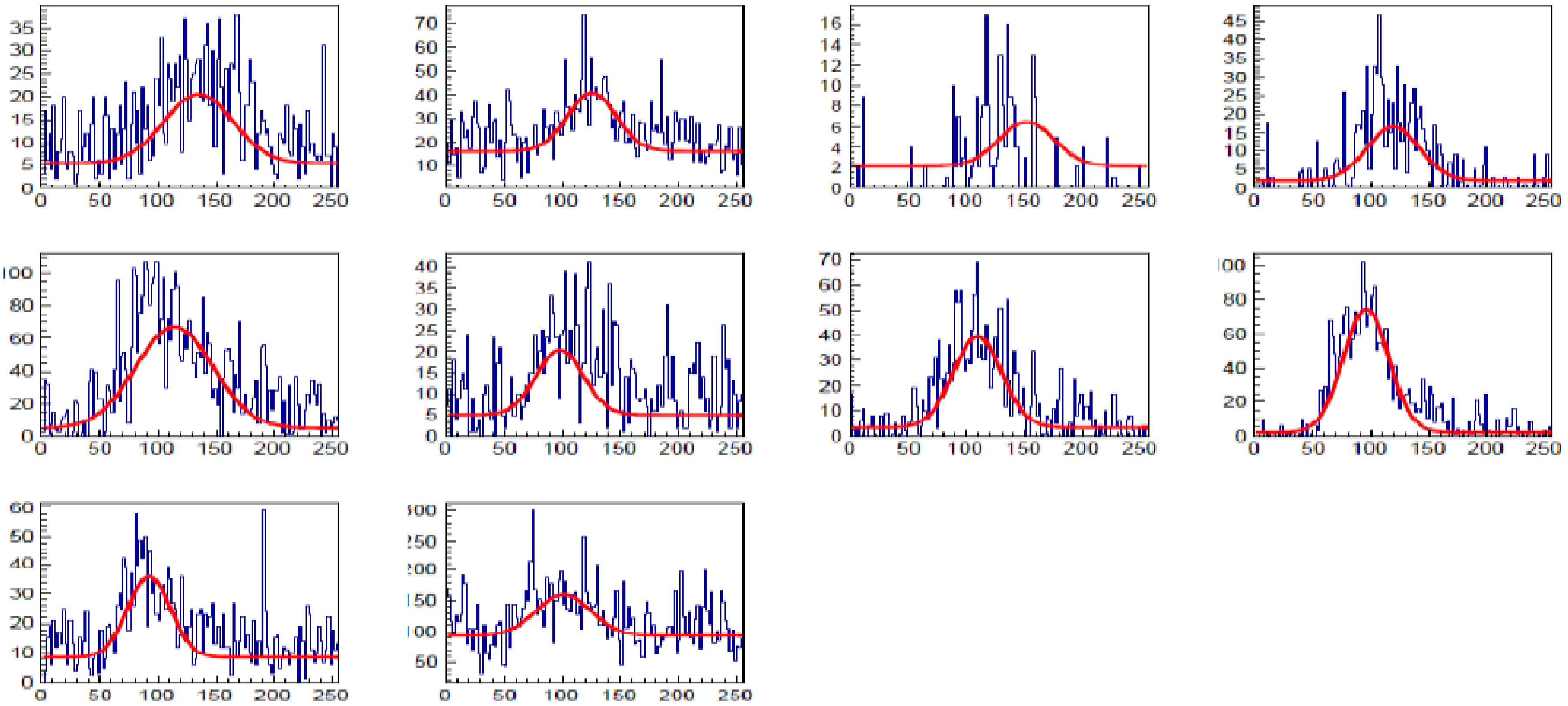
The EAS candidate with hit pixels. Upper plot – image of event with hit pixels and dead (blue) ones. Bottom plot – the amplitude variation of time for selected hit pixels (stack histogram).



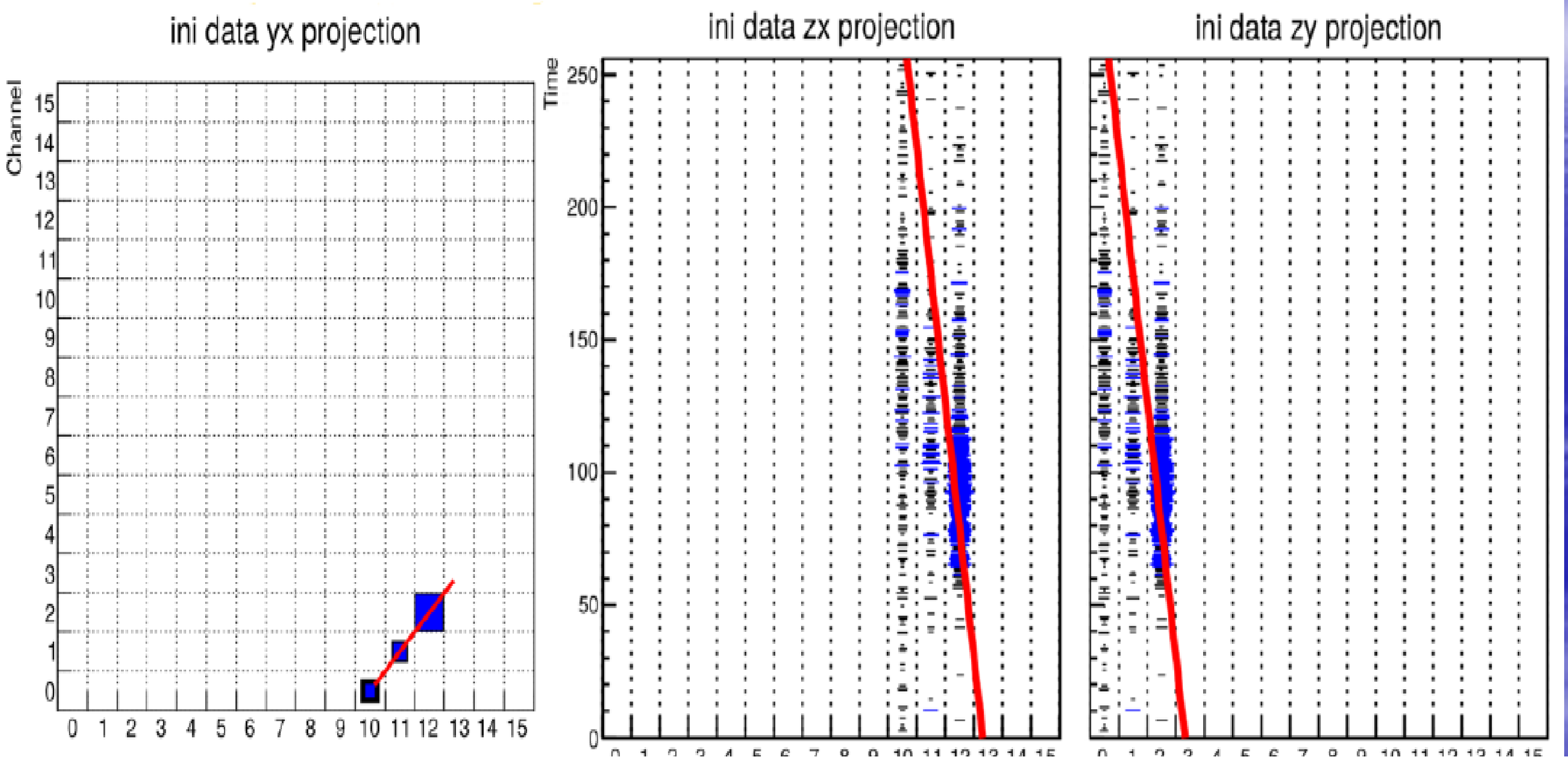
0 2 4 6 8 10 12 14 16
200 180 160 140 120 100 80 60 40 20 0
201
51
122
102
101
146
159
114
160



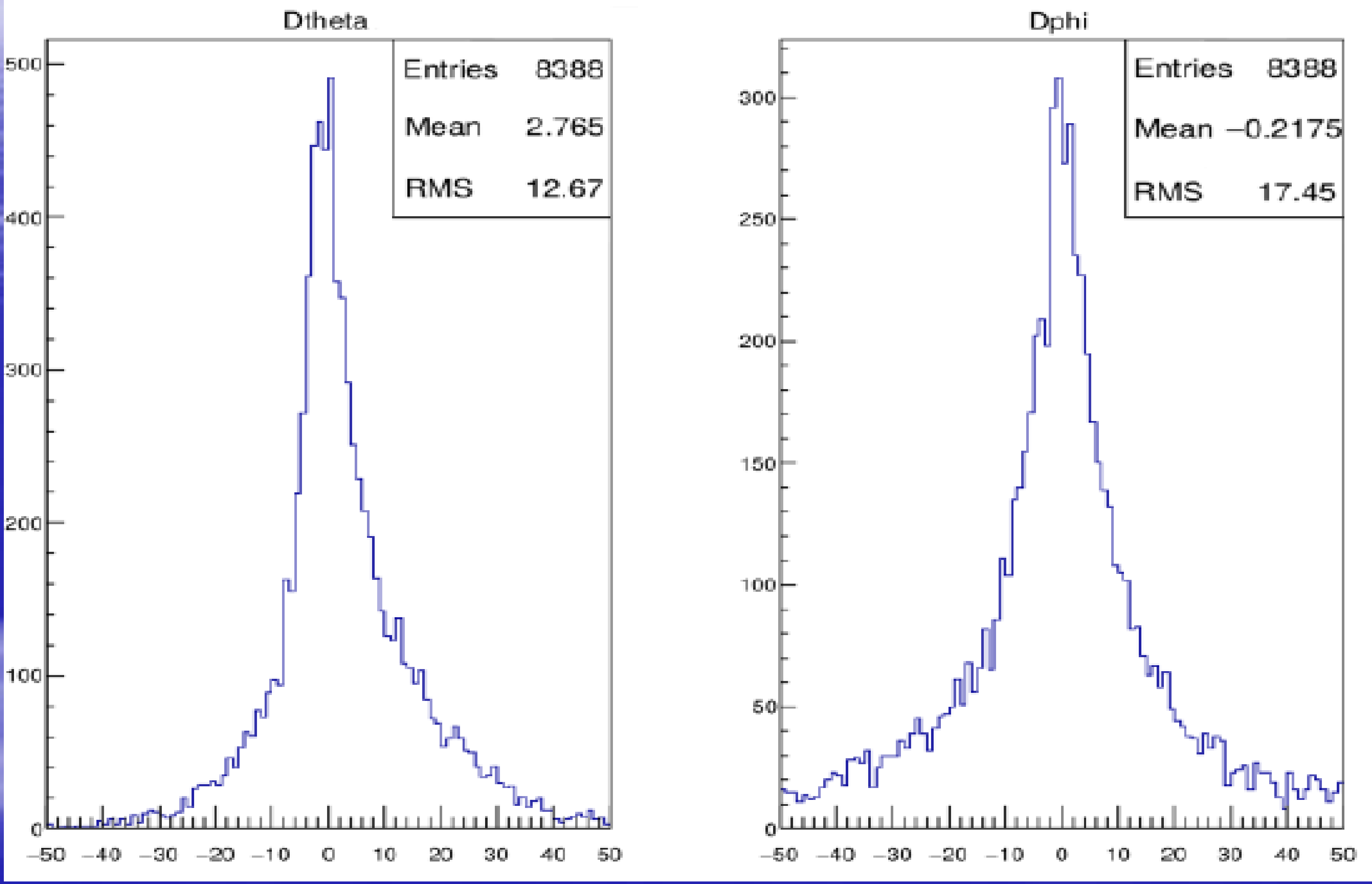
0 10 20 30 40 50 60 70
0 50 100 150 200 250



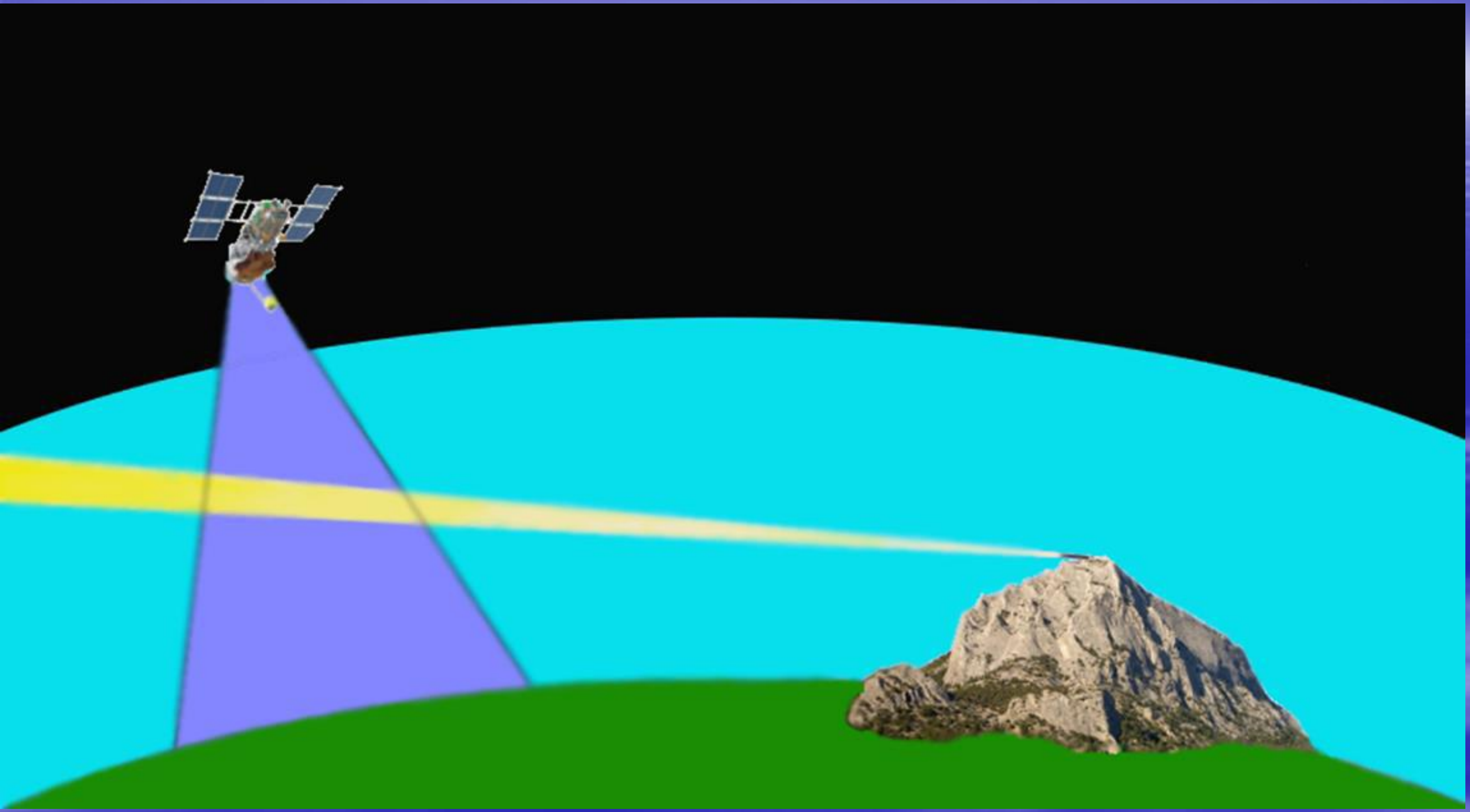
Time distributions of the EAS signals in the hit PMTpixels of the EAS candidate event.



Linear 3D fit of the central hit pixels for EAS event



The difference measurement between simulated and reconstructed zenith θ and azimuthal φ angles.



Частота следования импульсов (Гц.)……….1-5
Длина волны излучения (нм)…………… …..532
Энергия излучения (мДж.) ……………… … ..100
Стабильность энергии излучения (%)………85
Длительность импульса излучения (пс.)….150
Расходимость излучения (рад.) …………...2 10^{-5}
Стабильность оси диаграммы напр (рад.).$3 \cdot 10^{-5}$

LOMONOSOV MOSCOW STATE UNIVERSITY

МОСКОВСКИЙ ГОСУДАРСТВЕННЫЙ УНИВЕРСИТЕТ ИМЕНИ М.В.ЛОМОНОСОВА

1755

MSU

НИИЯФ МГУ

РОСКОСМОС

Российская академия наук

ОИЯИ

НАЦИОНАЛЬНЫЙ ИССЛЕДОВАТЕЛЬСКИЙ ЯДЕРНЫЙ УНИВЕРСИТЕТ

МИФИ

НПОЛ

РКЦ ПРОГРЕСС

ЦНИИМАШ

TSNIIMASH

НЦ ОМЗ

НИИМВ

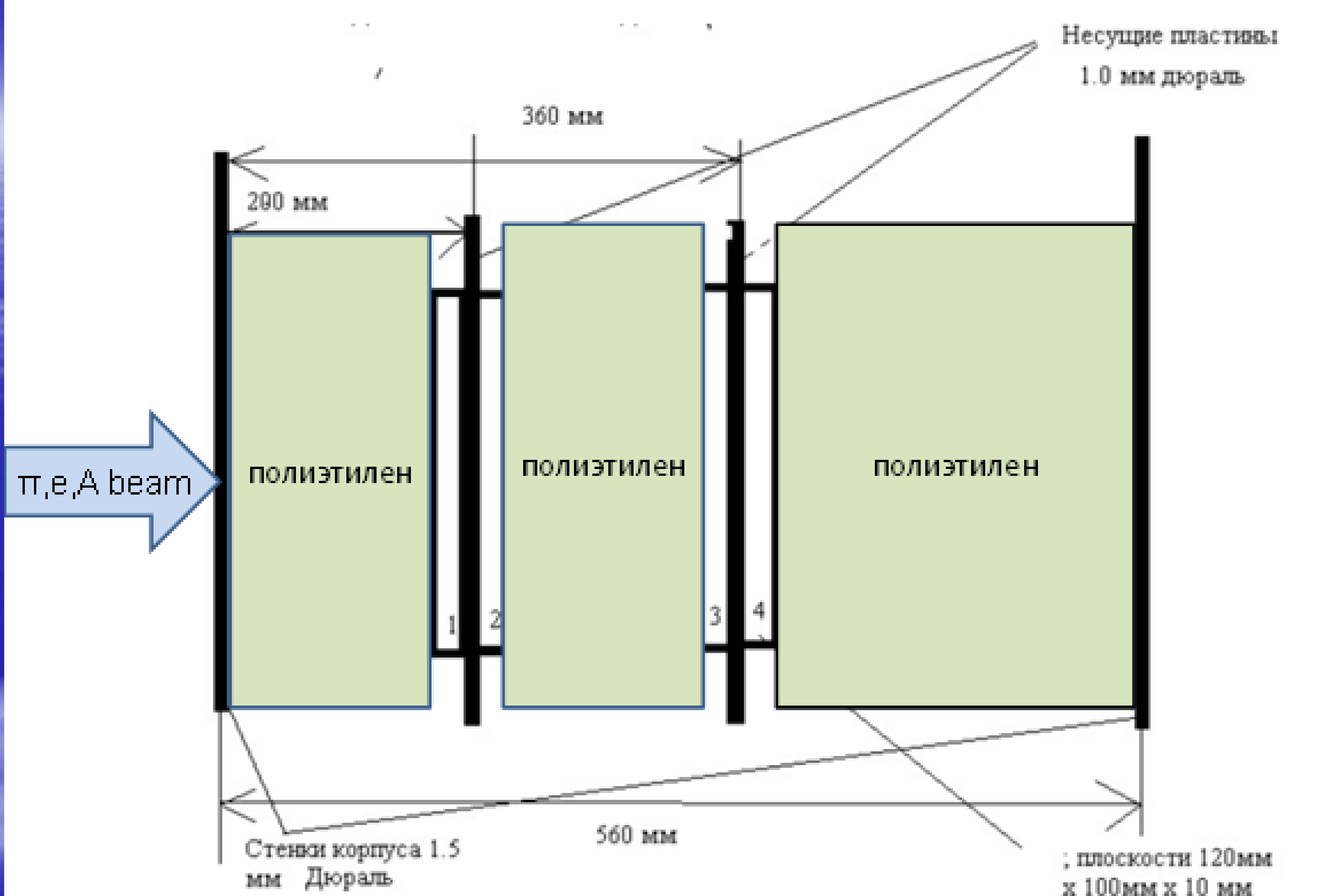
«САИТ»

Тесты прототипа

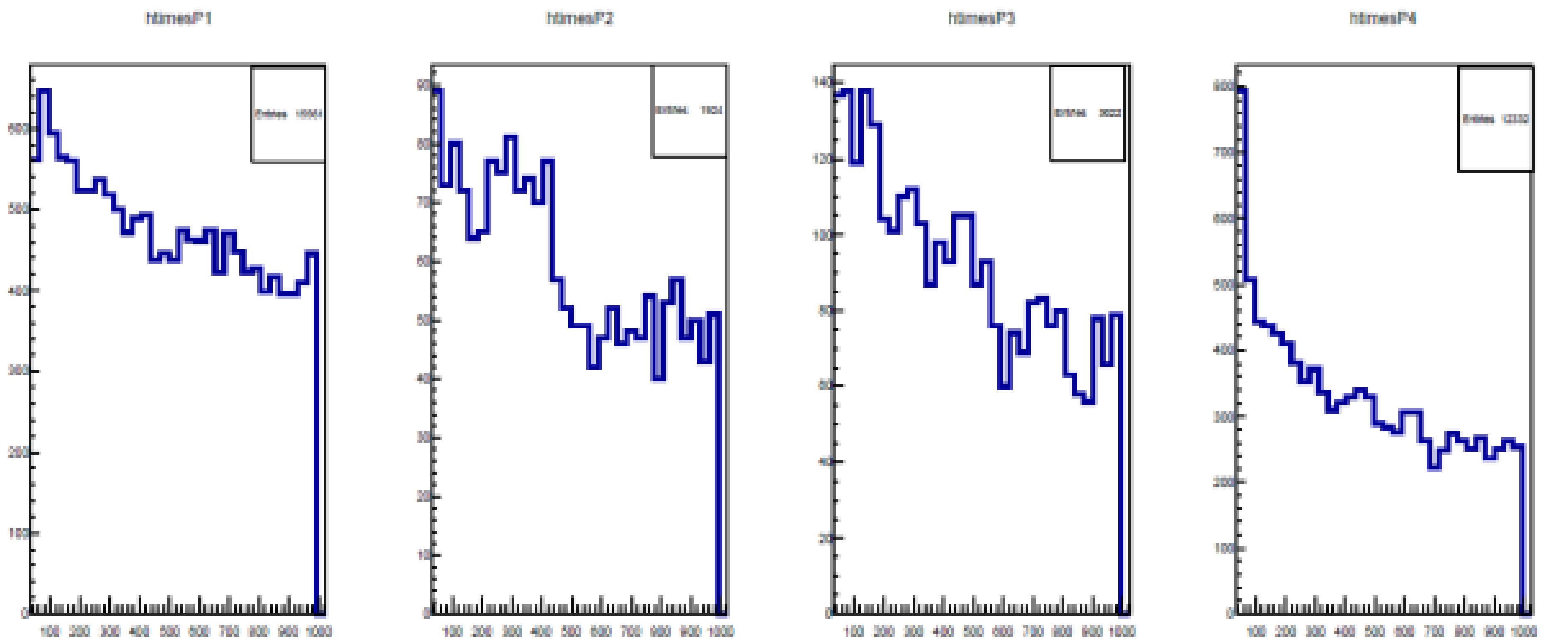
- Тесты проводились на SPS в ЦЕРН на пучках ядер свинца Pb (150 Gev/n, A/Z = 2.2-2.5) в 2016 г. и ядер ксенона Xe с энергий 13 Gev/nucl и жесткостью, соответствующей A/Z =2.1 в 2017 г. с интенсивностью ~5000 part/sec
- Использовалась реакция замедленных нейтронов

$$n + {}^{10}B \rightarrow {}^{7}Li + \alpha + 2.78\ MeV.$$

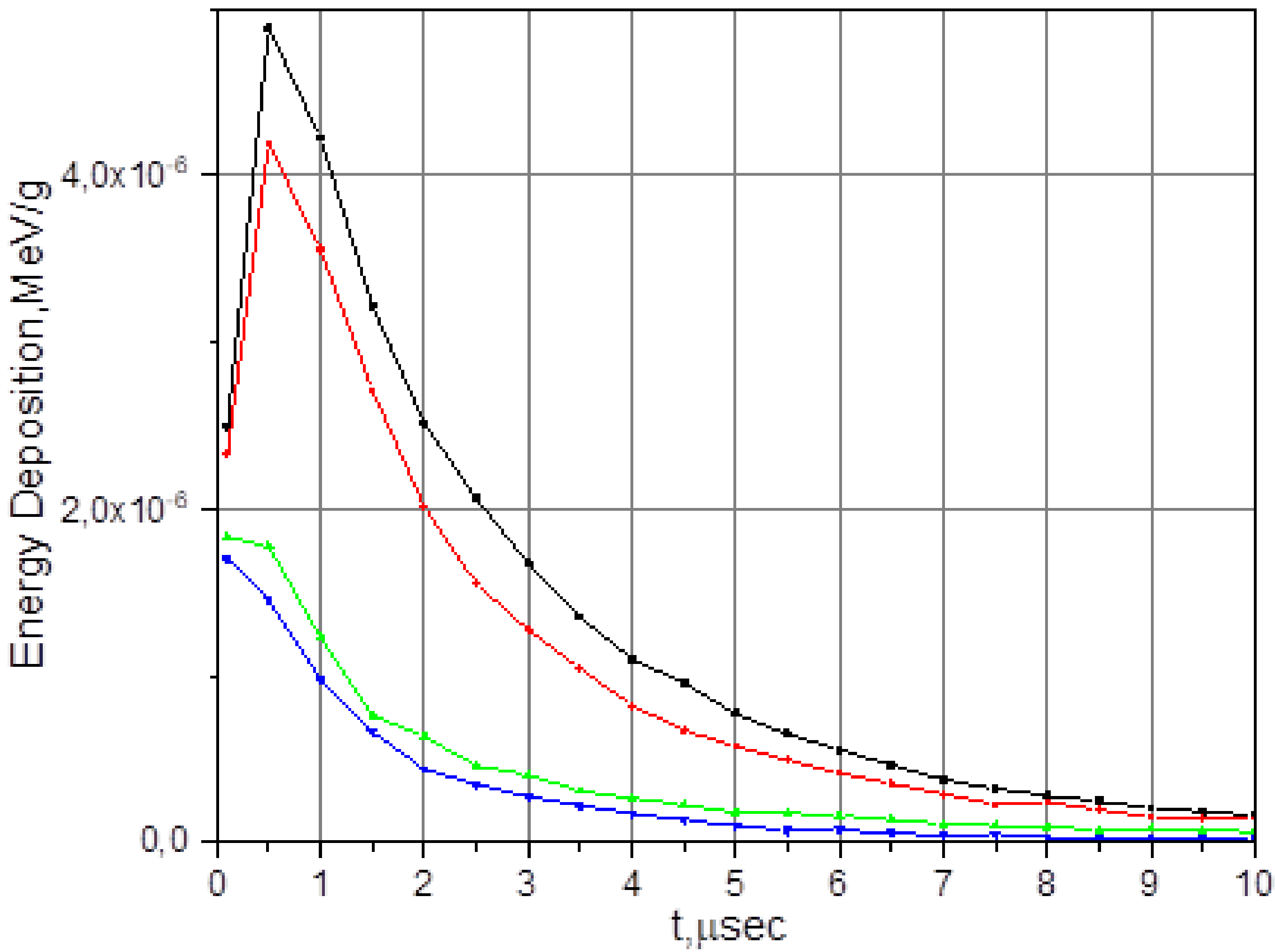
в борированном сцинтилляторе



Свинцовая мишень перед детектором



Trigger 1@2@3@4 Xe, ΔT =0, dec14-14_12_46.dat Signals passed though discriminators Threshold 30 mV. Add 24 mm Pb on front of box. Add Polyetilene



Зависимость величины нейтронного сигнала от времени задержки

UHECR propagation through the space – free path is ~ 50 Mpc due to interaction with CMB photons:

Protons

$p + \gamma_{\mathrm{CMB}} \rightarrow p + e^+ + e^-$

$p + \gamma_{\mathrm{CMB}} \rightarrow N$ + pions, **$E > 4 \cdot 10^{19}$ eV – GZK cutoff**

Nuclei

$Z + \gamma_{\mathrm{CMB}} \rightarrow Z + e^+ + e^-$

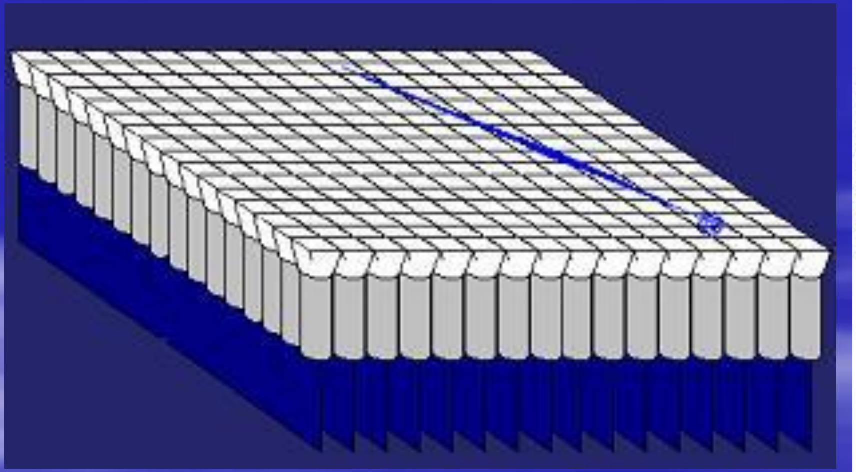
$A + \gamma_{\mathrm{CMB}} \rightarrow (A - 1) + N$

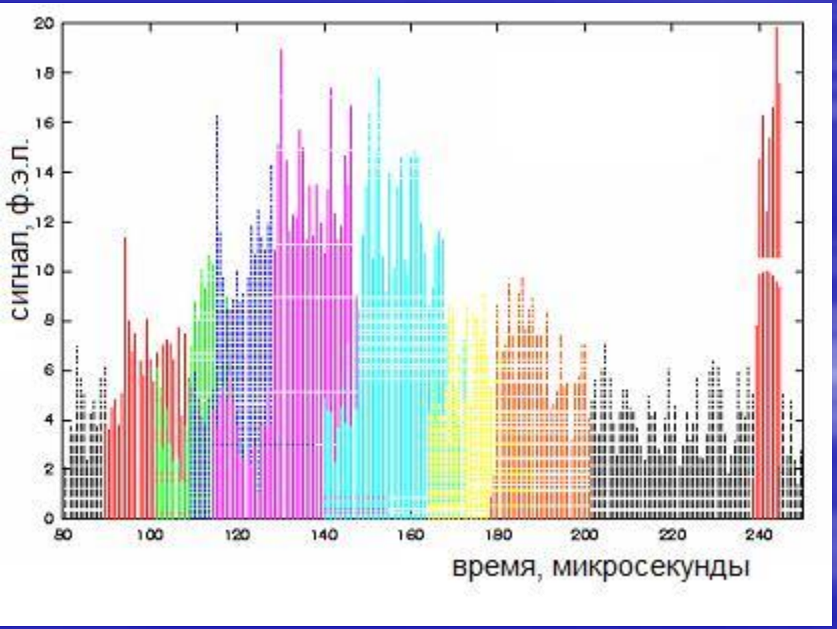
$A + \gamma_{\mathrm{CMB}} \rightarrow A' + N$ + pions, $E > 2 \cdot 10^{21}$ eV for iron nuclei

No GZK neutrinos at $E \sim 10^{20}$ eV primary nuclei

Движение диска частиц ШАЛ в атмосфере измеряется как временной профиль сигнала в ячейках детектора.

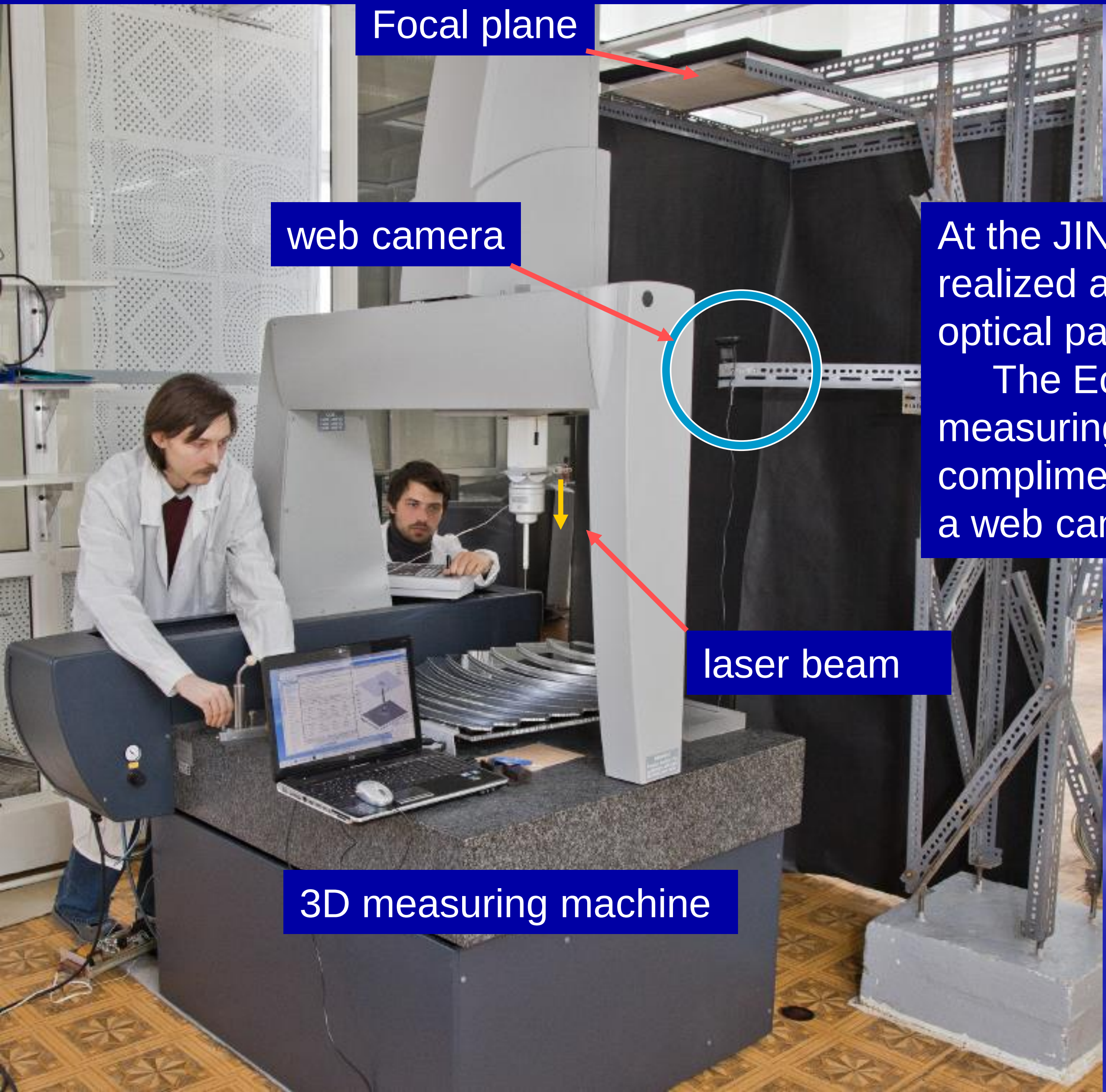
Точность определения энергии и направления первичной частицы определяется качеством фокусирования зеркала, размером ячейки фотоприемника и точностью определения амплитуды и времени сигнала в ячейках. Для энергий E>2 10^{19} эВ и зенитных углов более 60° погрешность определения энергии составит не более 20%, а направления- не более 2°





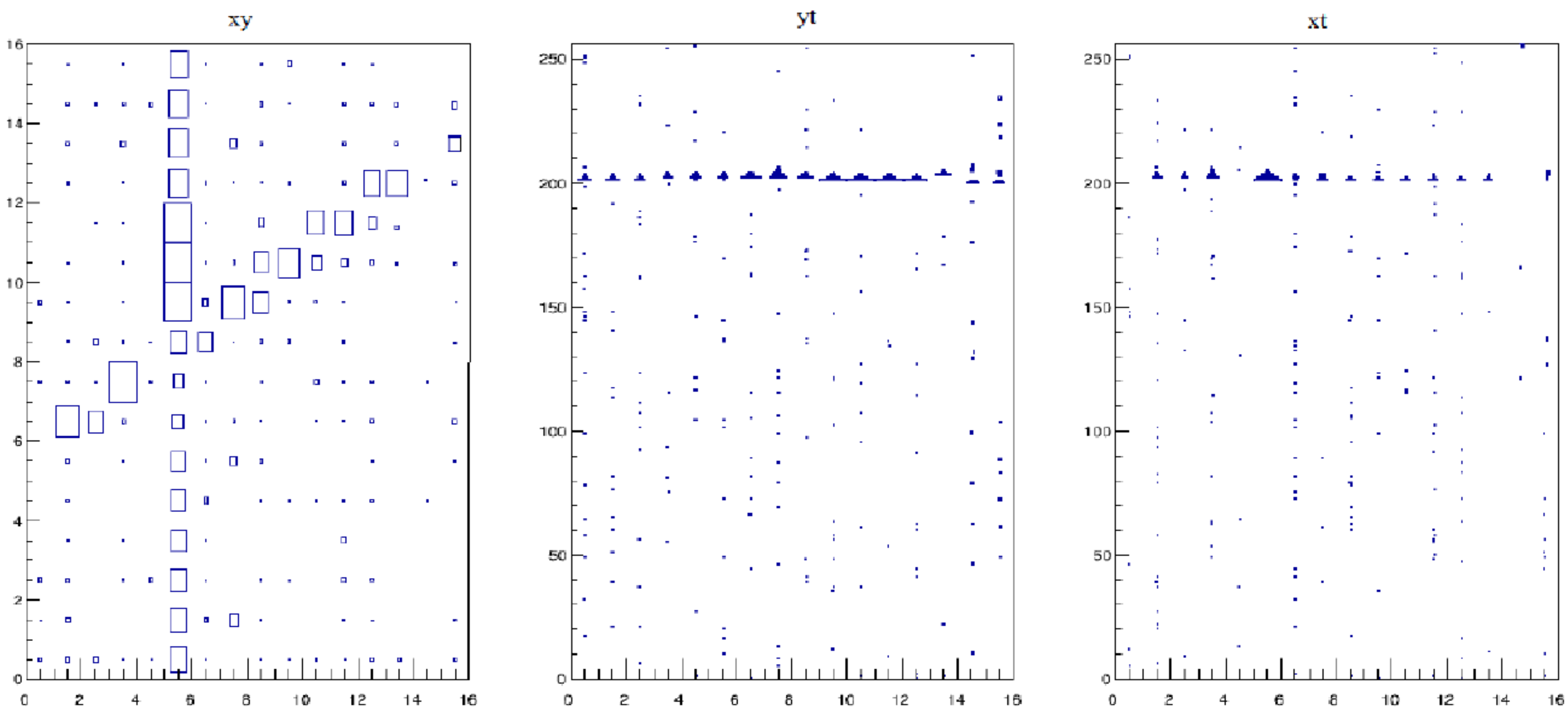
Optical parameter measurements of the flight Fresnel mirror modules.

2011

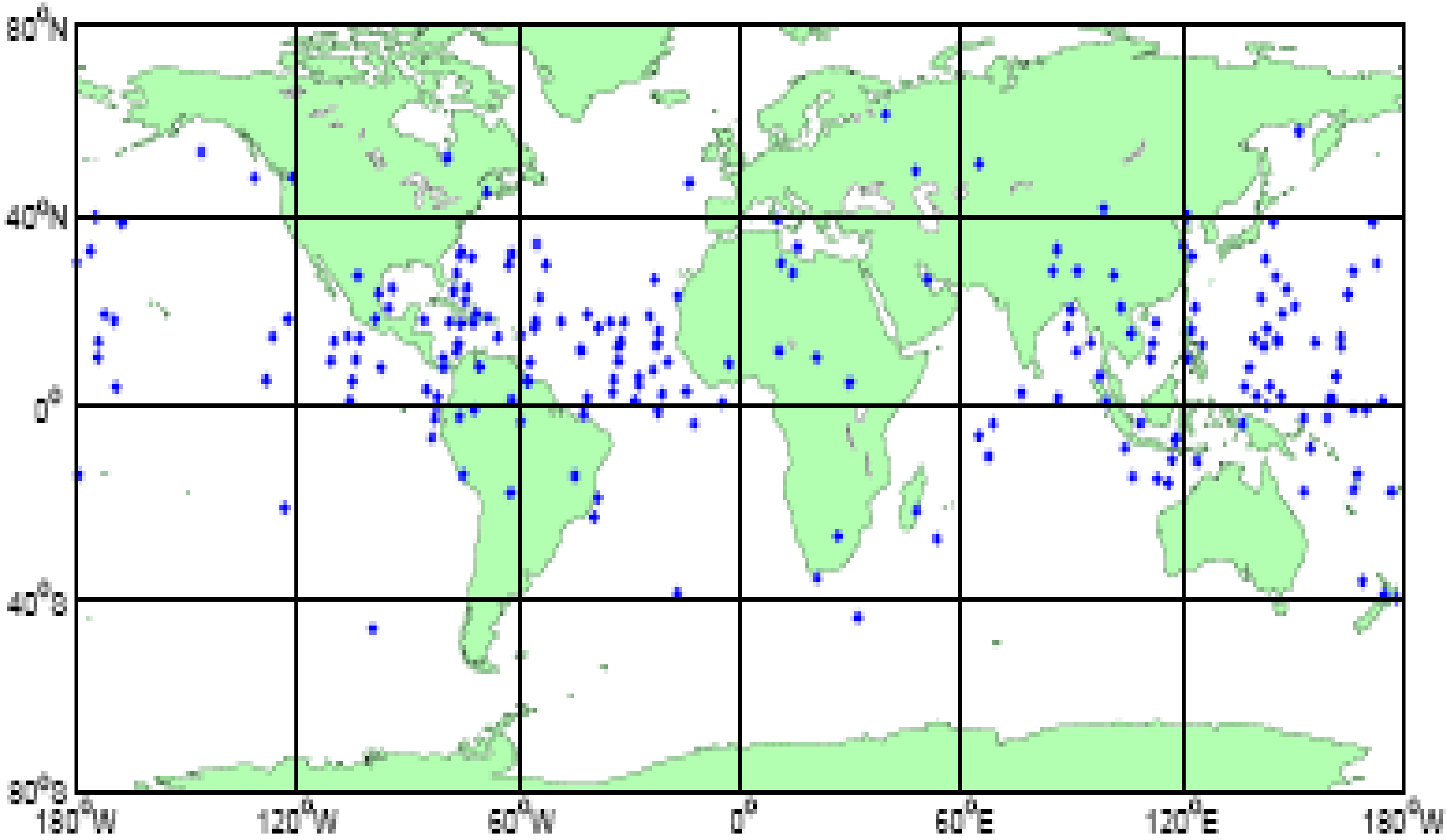


At the JINR was proposed and realized a procedure to measure optical parameters.

The Eclipse 700/1000 coordinate measuring machine from Carl Zeiss, complimented by a laser head and a web camera, were used.



An example of the CR track event in the UV filter.
The xy-, yt-, xt-projections of the 3-dimentional raw data PMT amplitudes are given.



80°N
40°N
0°
40°S
80°S
180°W
120°W
60°W
0°
60°E
120°E
180°W