EXTENSIVE AIR SHOWER INVESTIGATIONS AT THE TIEN SHAN MOUNTAIN COSMIC RAY STATION: THE CURRENT STATE OF EXPERIMENT

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2017

CONTENTS

- Tien Shan detector complex for registration of the extensive air showers (EAS) after its modernization period of 2000–2015 years

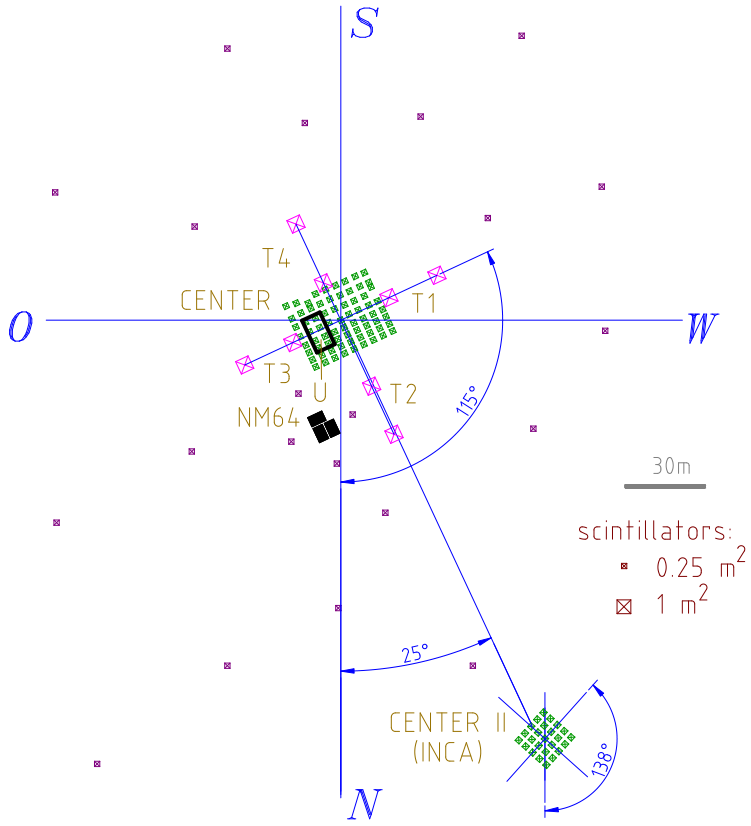
- Current results of the EAS investigation
  * EAS energy spectrum, shower ages, lateral distributions, *etc*;
  * EAS neutron component;
  * high multiplicity events at the underground neutron detector;
  * monitoring data of the intensity of background radiations;
  * EAS & seismology;
  * EAS radio signal;
  * EAS cores within ionization calorimeter.

Technical requirements to present day shower installation aimed specifically for investigation of the EAS core region

- complex detector for simultaneous registration of various EAS components (e/γ, μ, charged and neutral hadrons, Cherenkov photons, *etc*);
- dense disposition of detector points in the central part of installation with spatial step of the same order as the typical shower core sizes of $10^{14} - 10^{17}$ eV EAS ($\lesssim 3 - 5$ м);
- dynamic range of amplitude signal measurements of $\sim 10^5 - 10^6$ order;
- determination of EAS arrival direction.

A. P. Chubenko *et al* New complex EAS installation of the Tien Shan mountain cosmic ray station. Nucl. Instrum. Methods A, 832:158–178, 2016.

Tien Shan EAS detector complex



- CENTER-I:
  - scintillators;
  - neutron detectors;
  - undeground set;
  - radio.
- CENTER-II:
  - scintillators;
  - ionization-neutron calorimeter (*INCA*).

Scintillation shower particles detector system *CENTER*

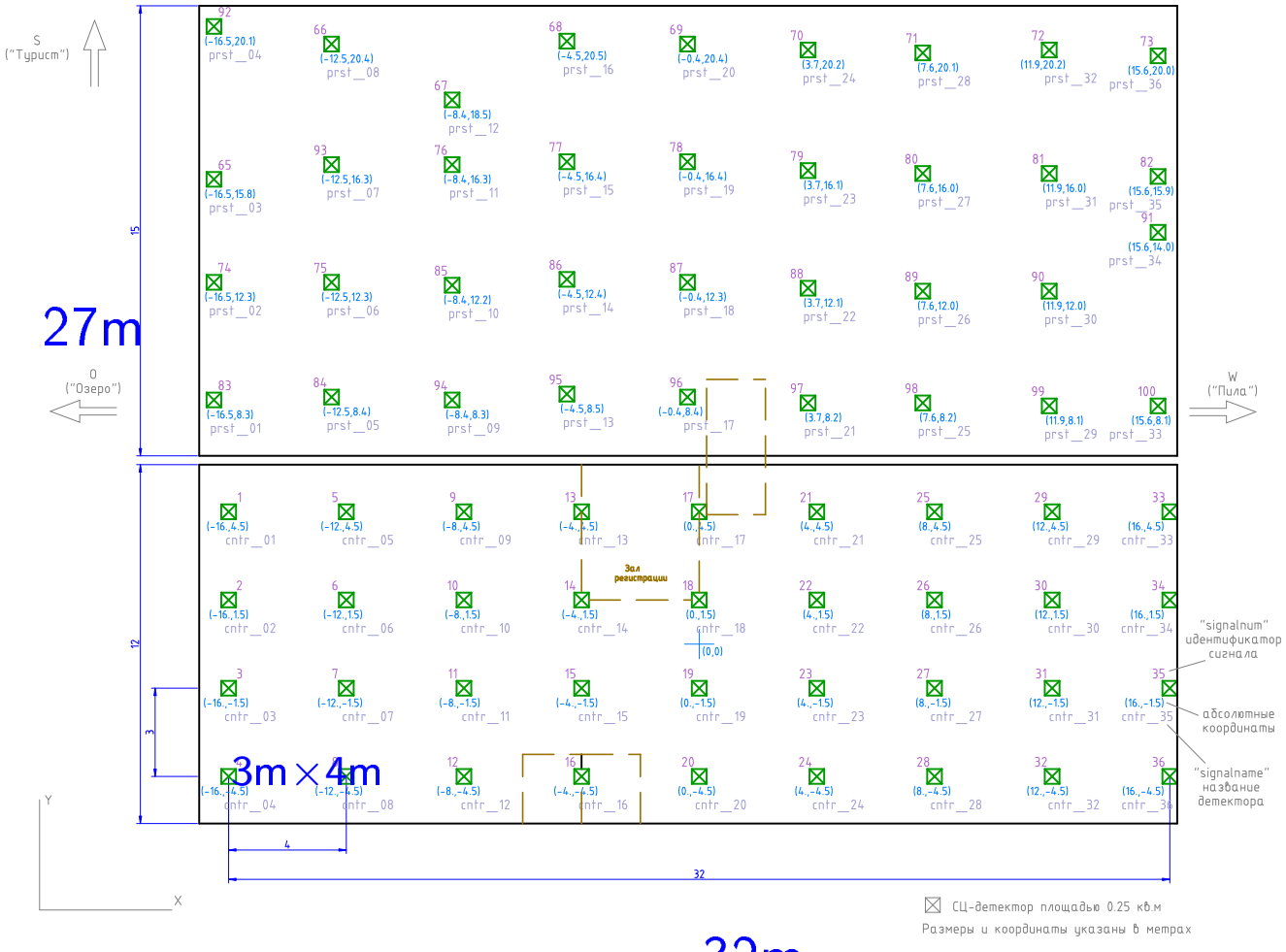
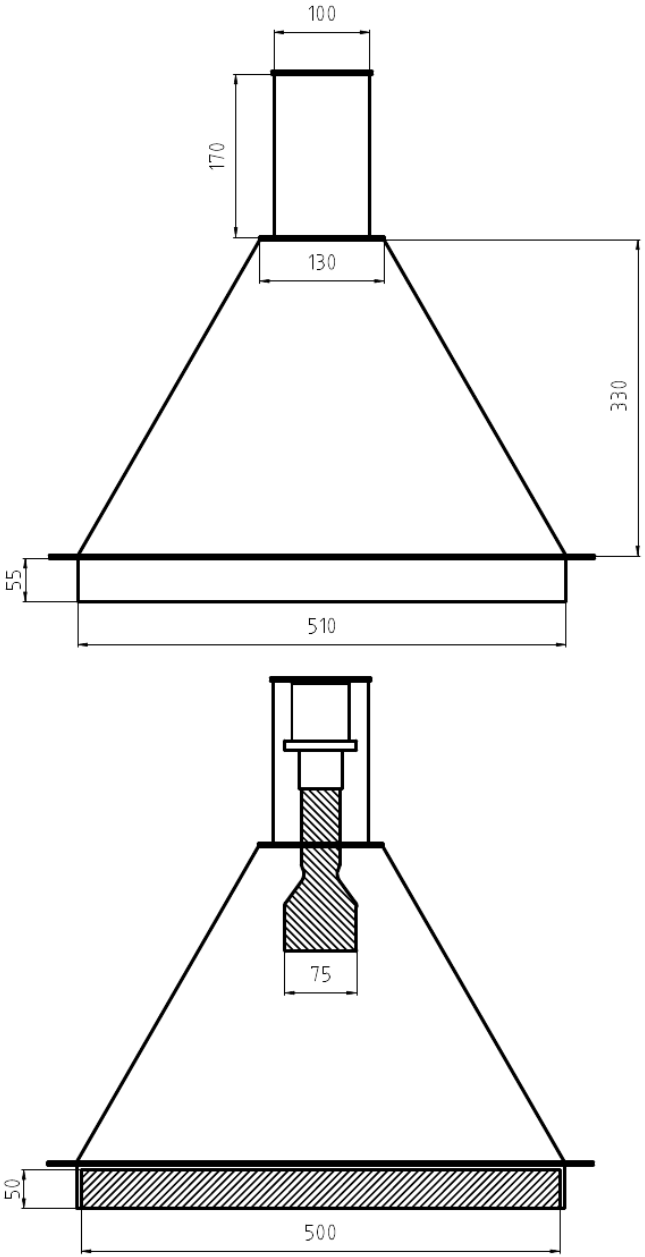
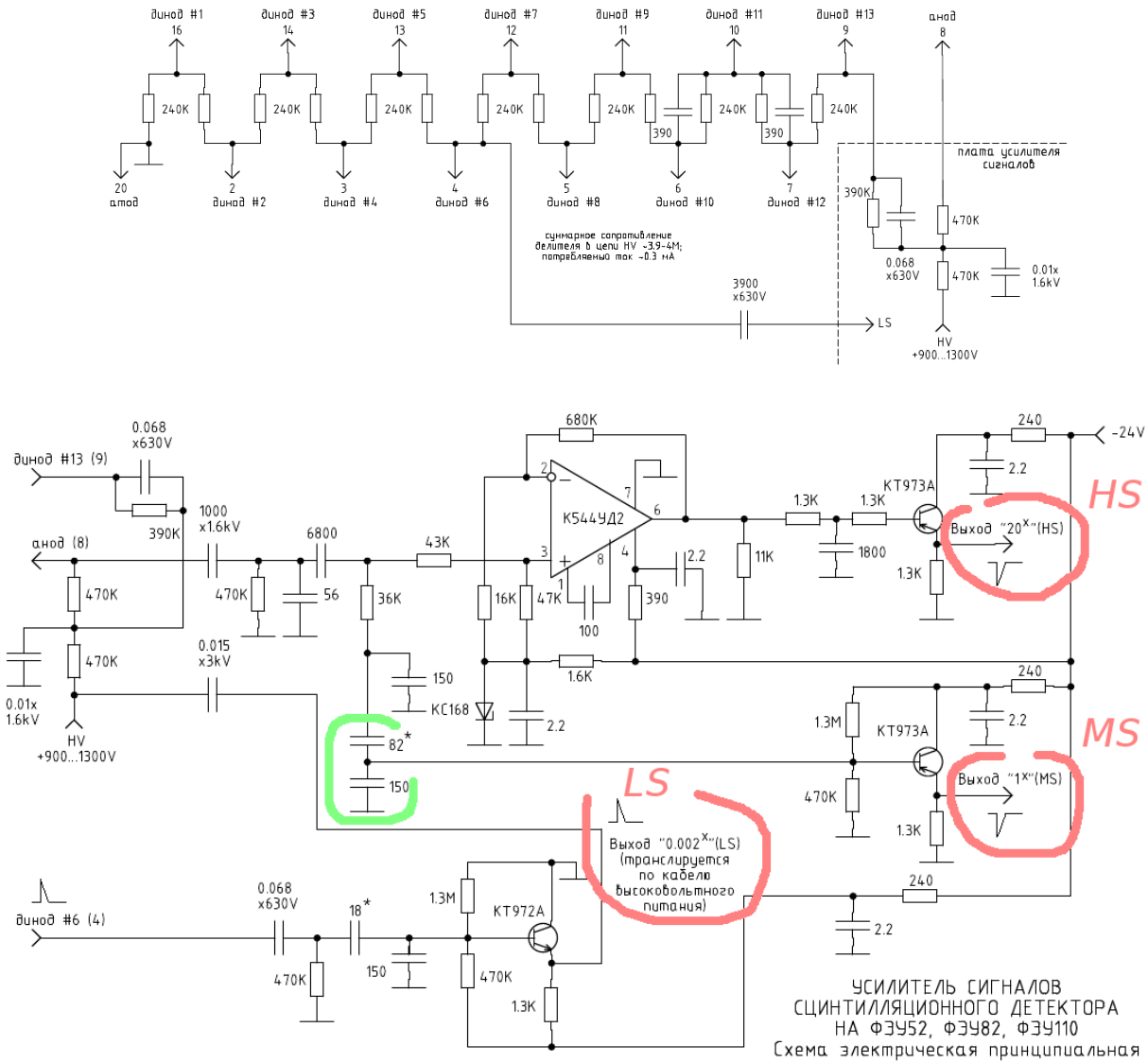


Схема расположения детекторов ливневой системы в центральной части ТШВНС

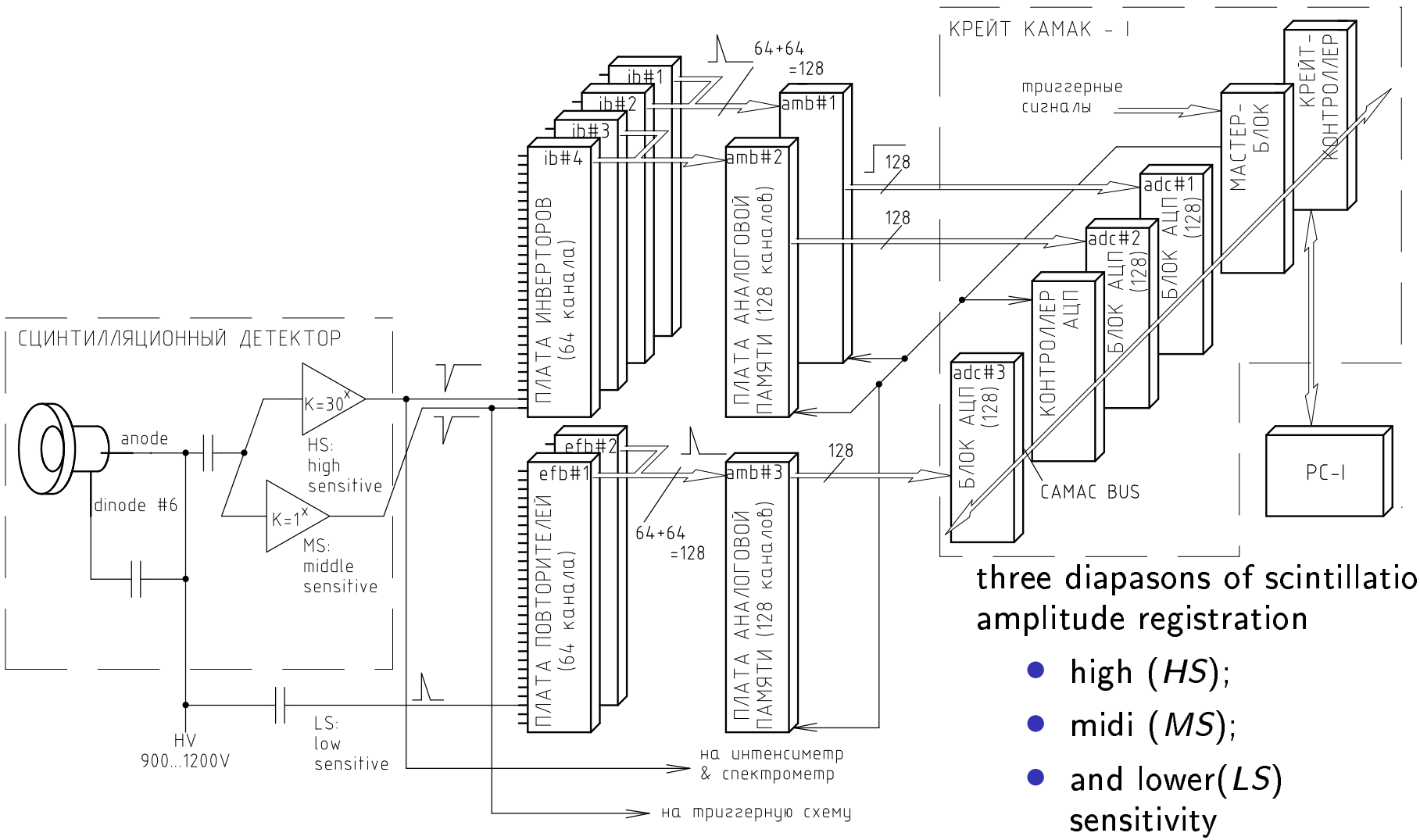
- central ∼900 m^2 scintillation *carpet* with dense detector disposition;
- 72 scintillation detectors with 0.25 m^2 sensitive area.

Scintillation EAS particles detector





Block diagram of multichannel ADC system



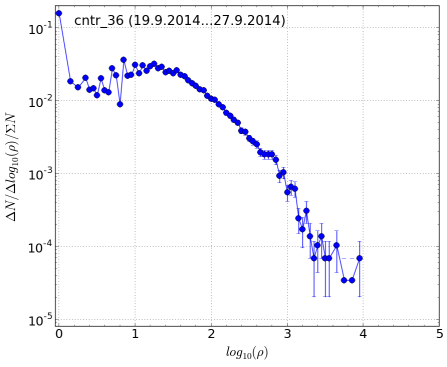
three diapasons of scintillation amplitude registration

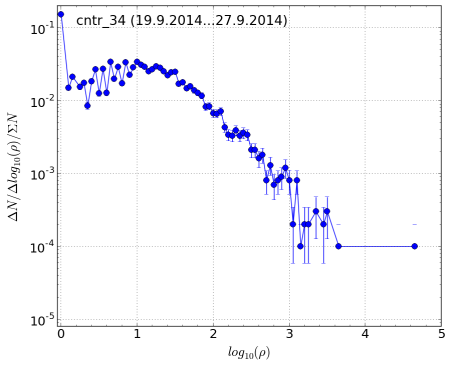
- high (*HS*);
- midi (*MS*);
- and lower(*LS*) sensitivity

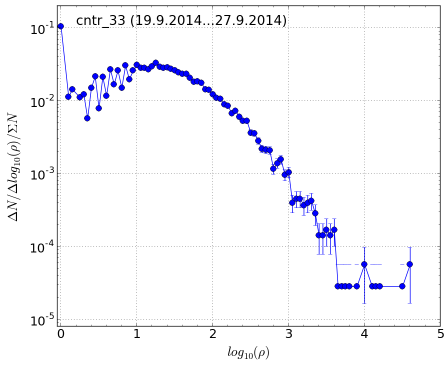
СЦИНТИЛЛЯЦИОННАЯ ЛИВНЕВАЯ УСТАНОВКА "CENTER"
Блок-схема системы АЦП

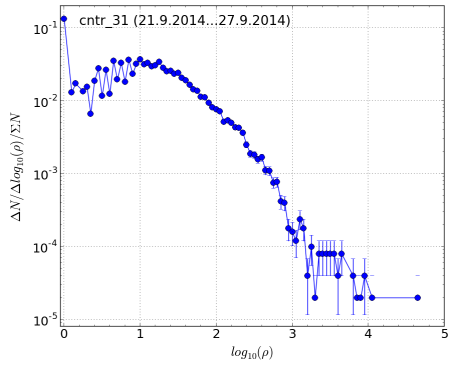
Dynamic range of particle density measurement

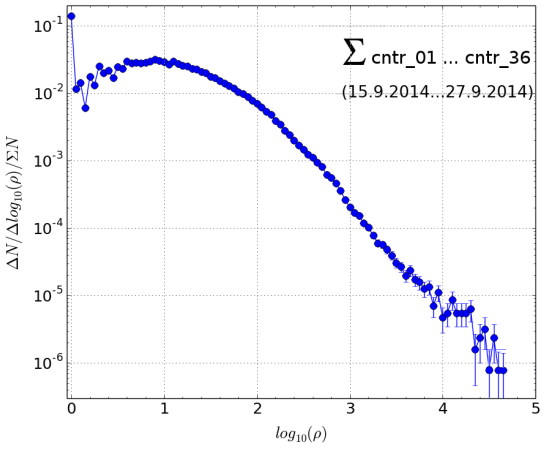
$D^{max} \sim 50000 - 70000$
(using two *HS* and *MS* amplitide diapasons only)

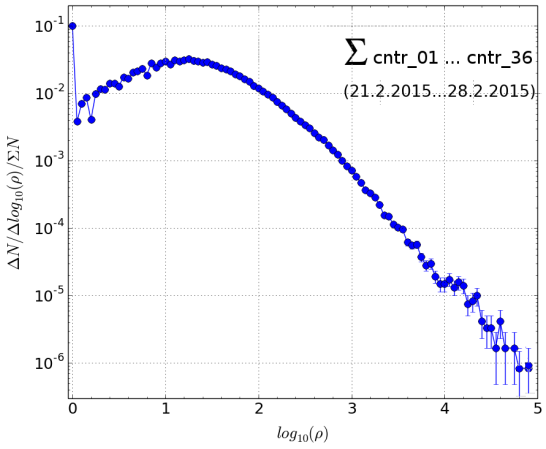


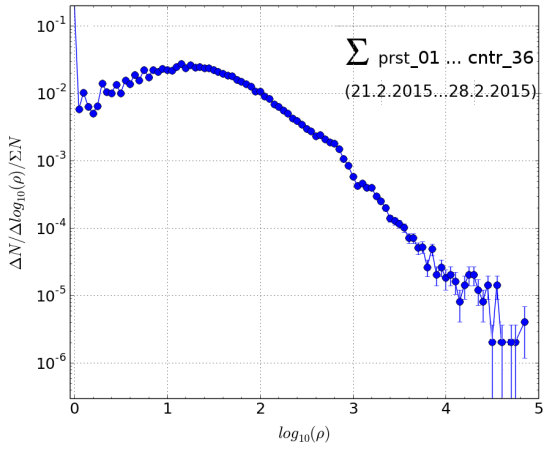






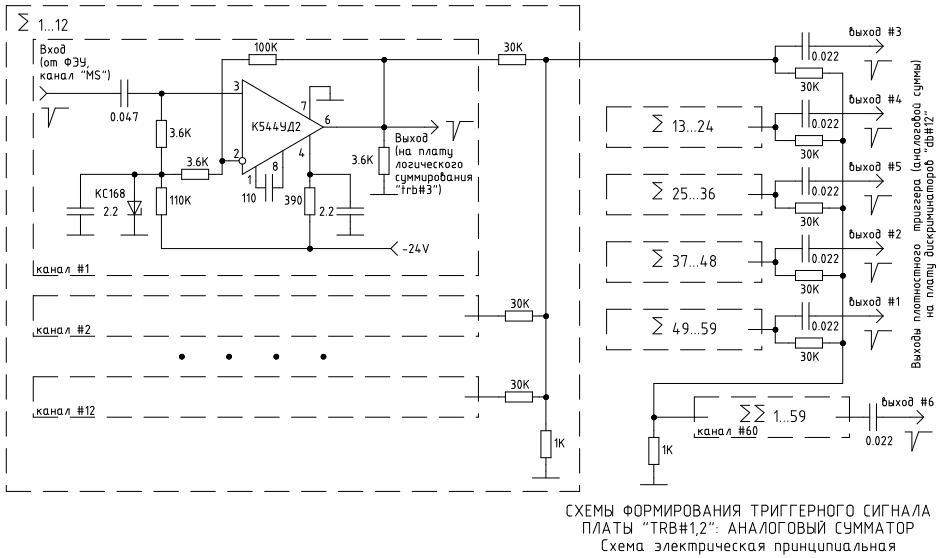






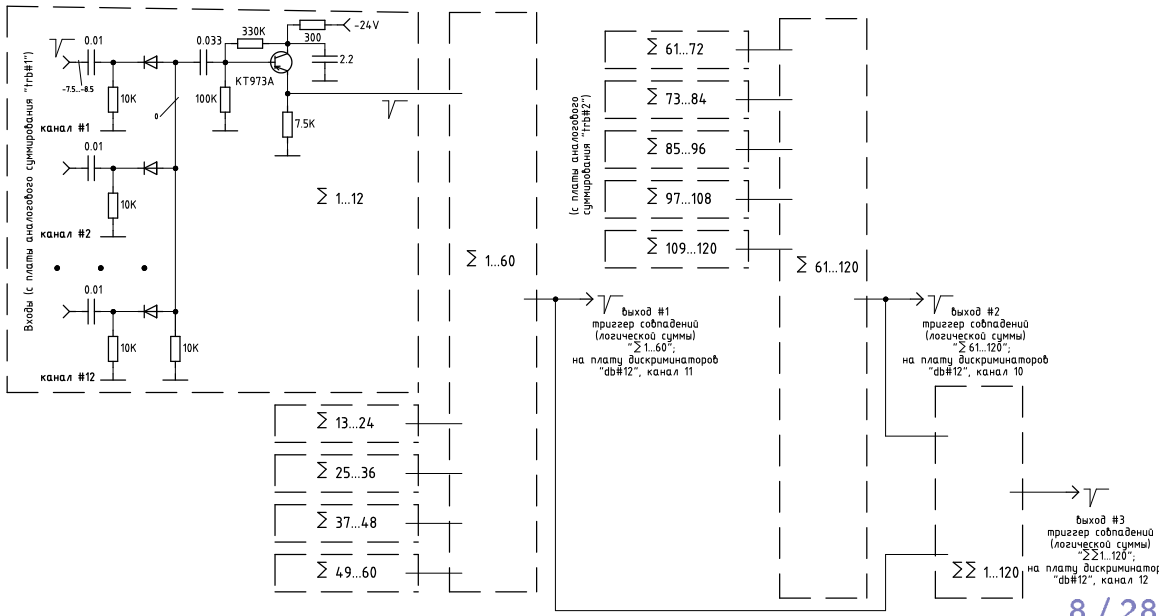
Shower trigger generation logic

Density trigger: $\sum_{\forall D}(A_D) > T$



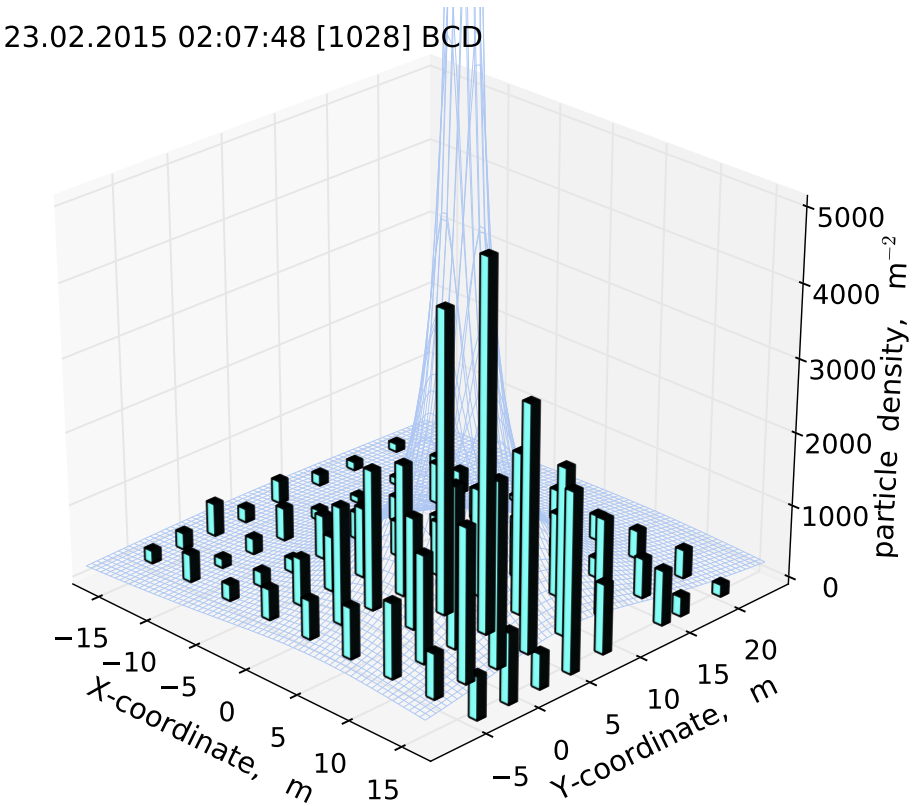
СХЕМЫ ФОРМИРОВАНИЯ ТРИГГЕРНОГО СИГНАЛА
ПЛАТЫ "TRB#1,2": АНАЛОГОВЫЙ СУММАТОР
Схема электрическая принципиальная

Impact trigger: $\exists D : A_D > T$

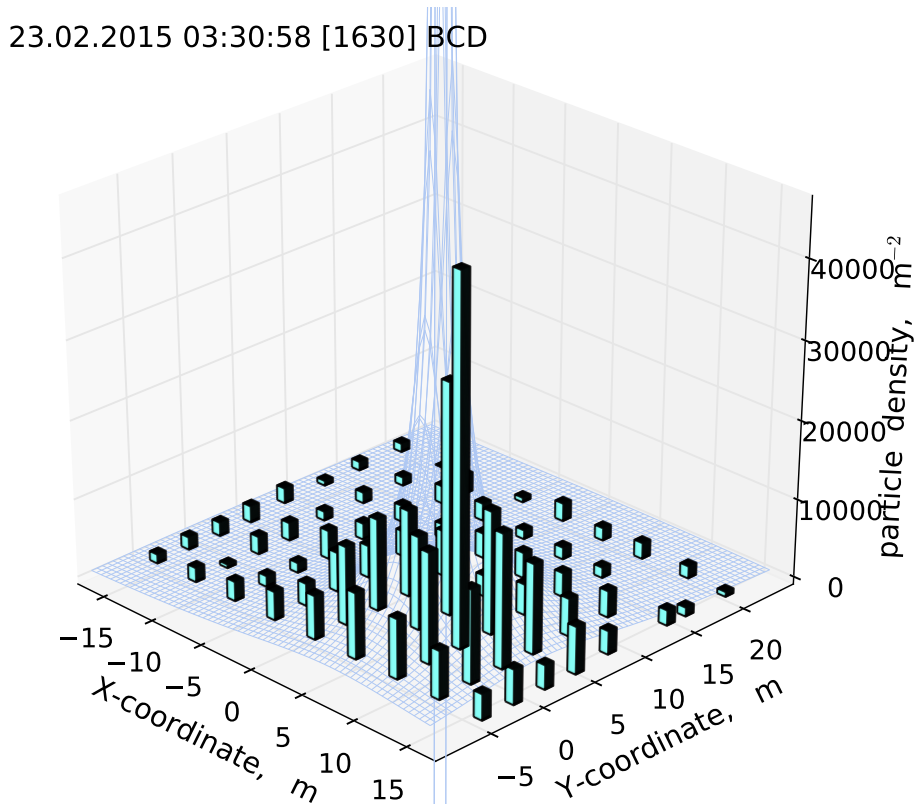


Approximation of particle distribution in an EAS event

$$\chi^2 = \sum_D \left(\frac{n_D/S_D - \rho_{NKG}(r_D(x_0,y_0),s,N_e)}{\sigma(n_D/S_D)} \right)^2 \rightarrow \min_{[x_0,y_0,s,N_e]}$$



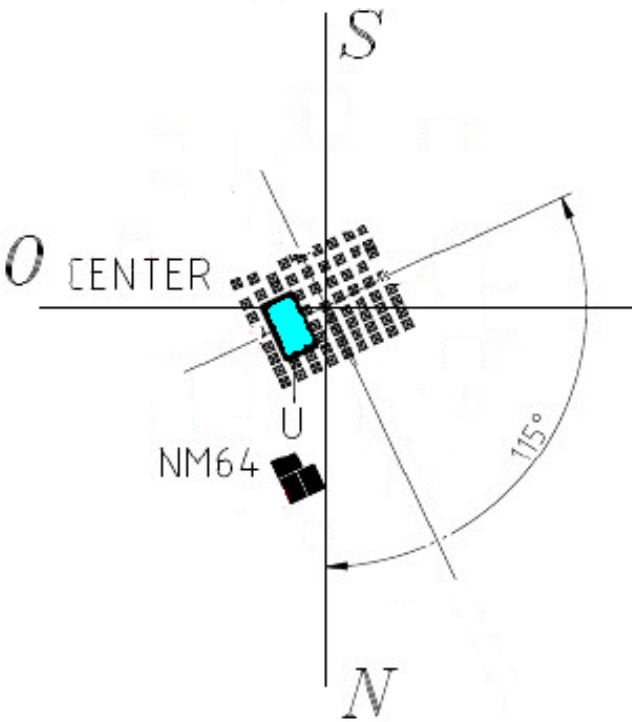
max: 5035; sum: 61163; shower: 6.3 4.2 2.5e+06 0.94 35.6



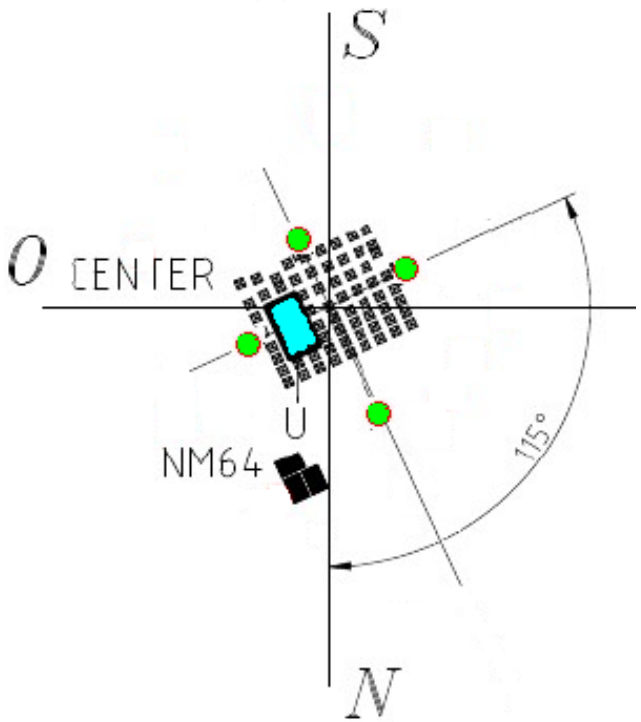
max: 46530; sum: 348186; shower: 7.1 1.0 1.2e+07 0.87 219.5

CENTER subsystem: three measurement runs

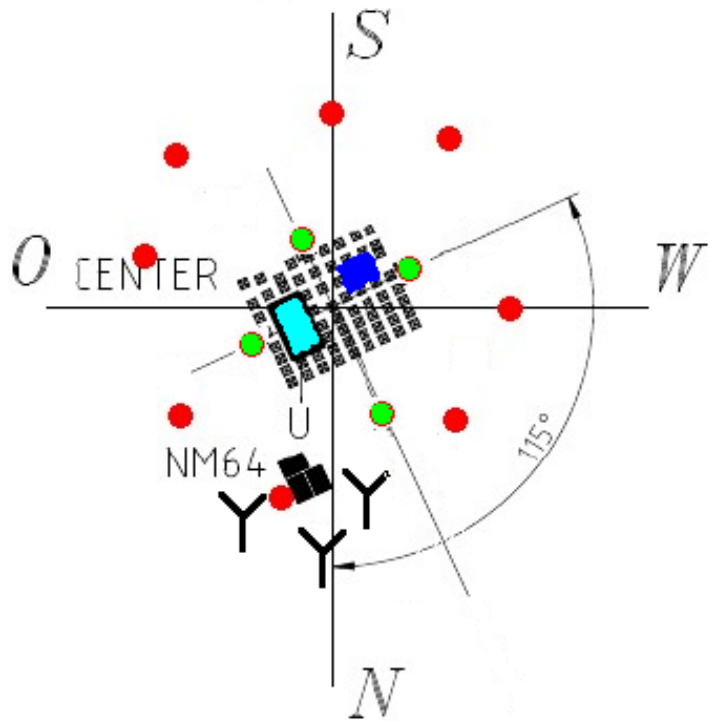
- 2014-2015



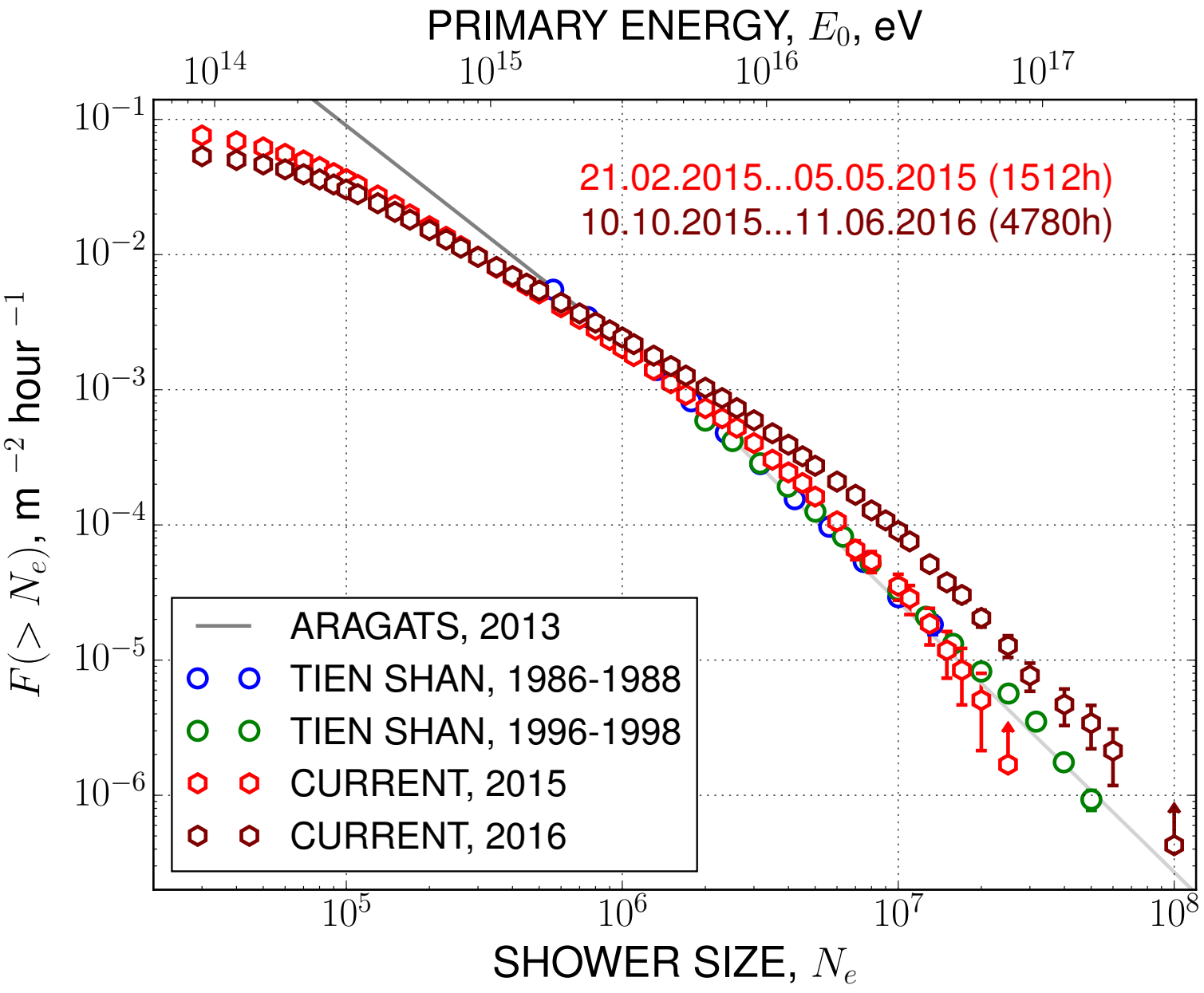
- 2015-2016



- 2016-2017



EAS size spectrum

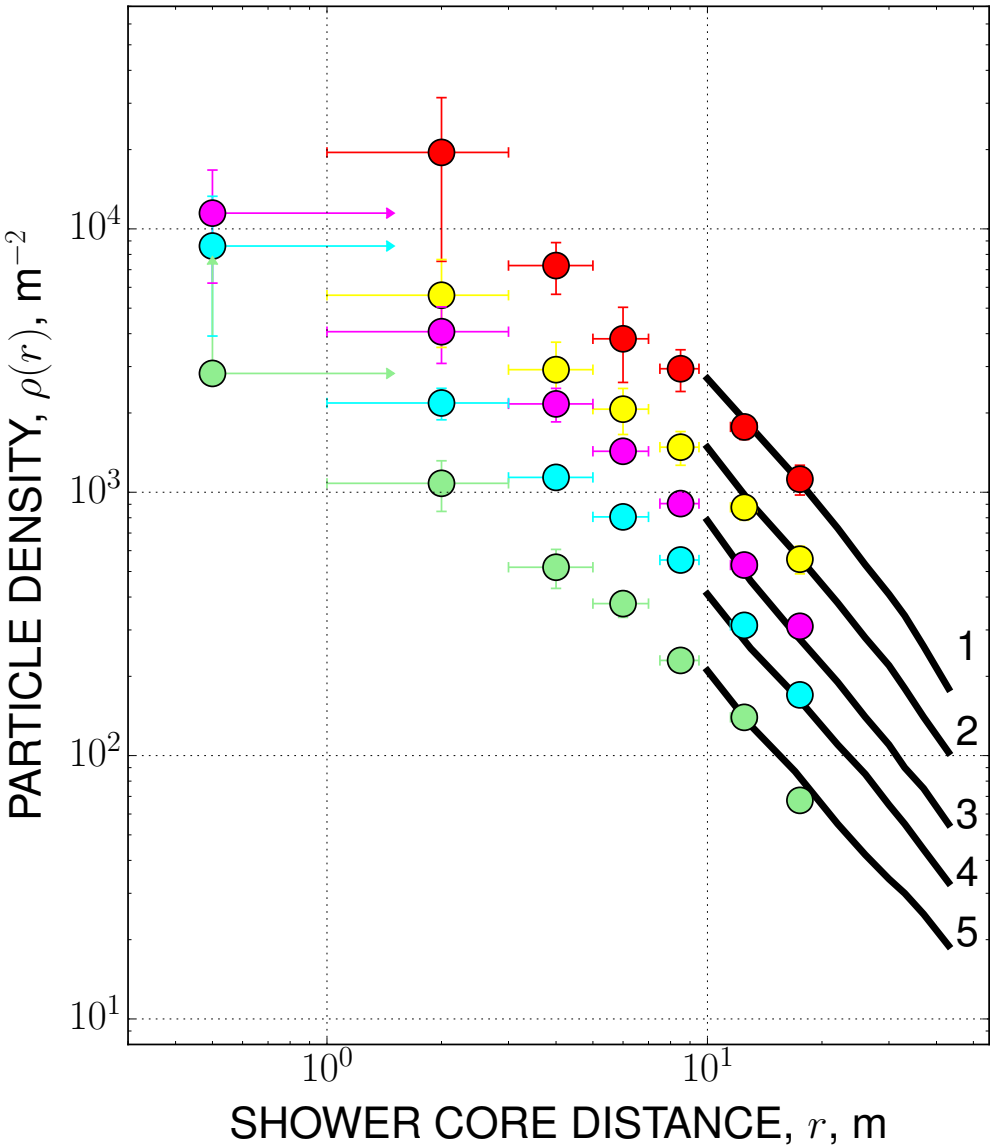


EAS spectrum & events statistics

Expected EAS number for 1000h long operation time

Threshold	*CENTER*	*CENTER* + periphery $R \lesssim 100$м
$N_e > 10^5$ ($E_0 \gtrsim 3 \cdot 10^{14}$eV)	$2 \cdot 10^5$	$8 \cdot 10^5$
$N_e > 10^6$ ($E_0 \gtrsim 3 \cdot 10^{15}$eV)	$6 \cdot 10^3$	$2 \cdot 10^4$
$N_e > 10^7$ ($E_0 \gtrsim 3 \cdot 10^{16}$eV)	60	200
$N_e > 10^8$ ($E_0 \gtrsim 3 \cdot 10^{17}$eV)	–	2

Lateral distribution of shower particles



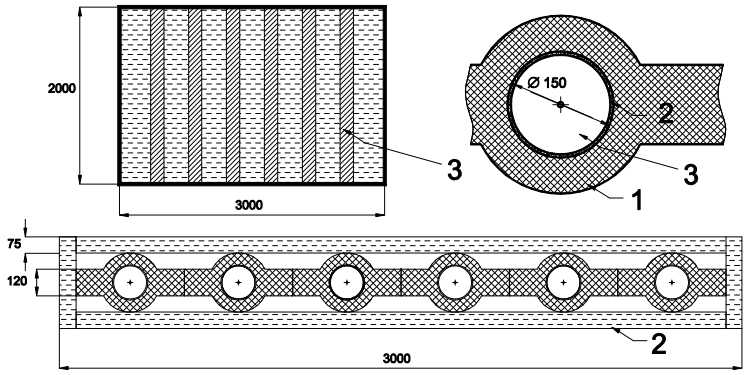
TIEN SHAN, 2014-2016:

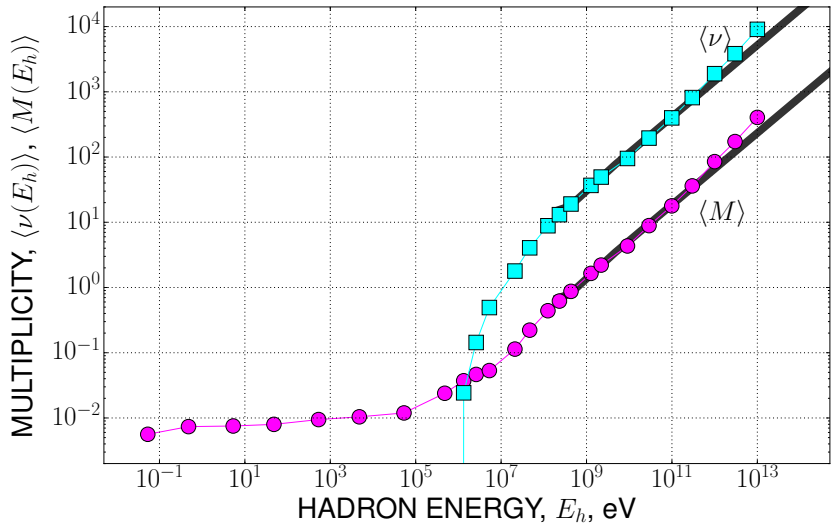
- $N_e = 7.3 \cdot 10^6$ (1)
- $N_e = 4.1 \cdot 10^6$ (2)
- $N_e = 2.3 \cdot 10^6$ (3)
- $N_e = 1.3 \cdot 10^6$ (4)
- $N_e = 7.3 \cdot 10^5$ (5)

- ARAGATS (lines)

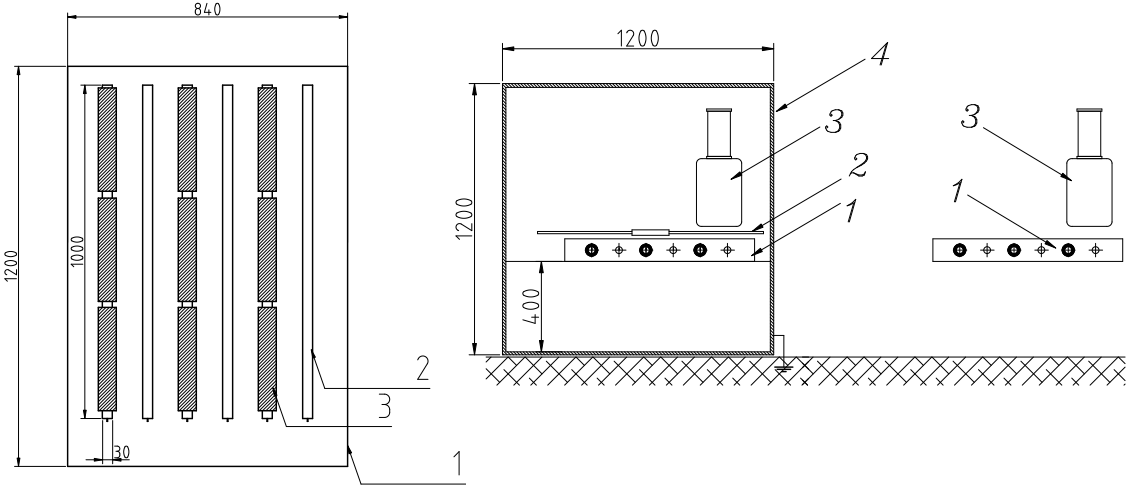
Neutron detectors

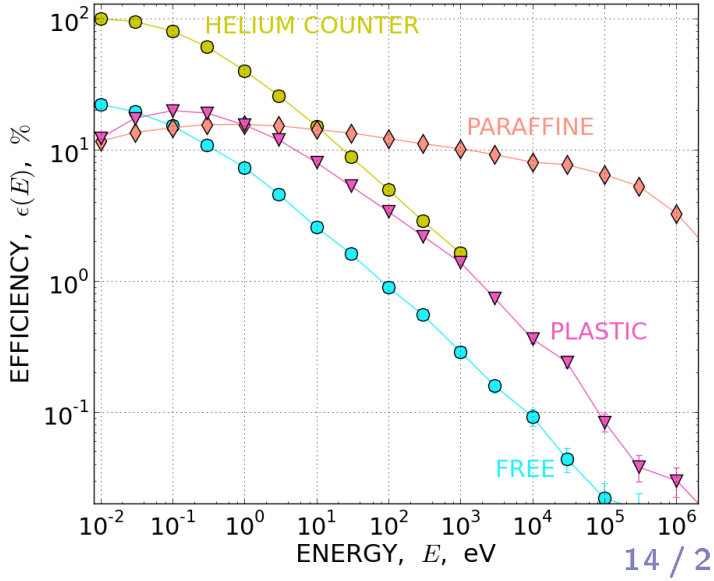
- NM64 neutron supermonitor



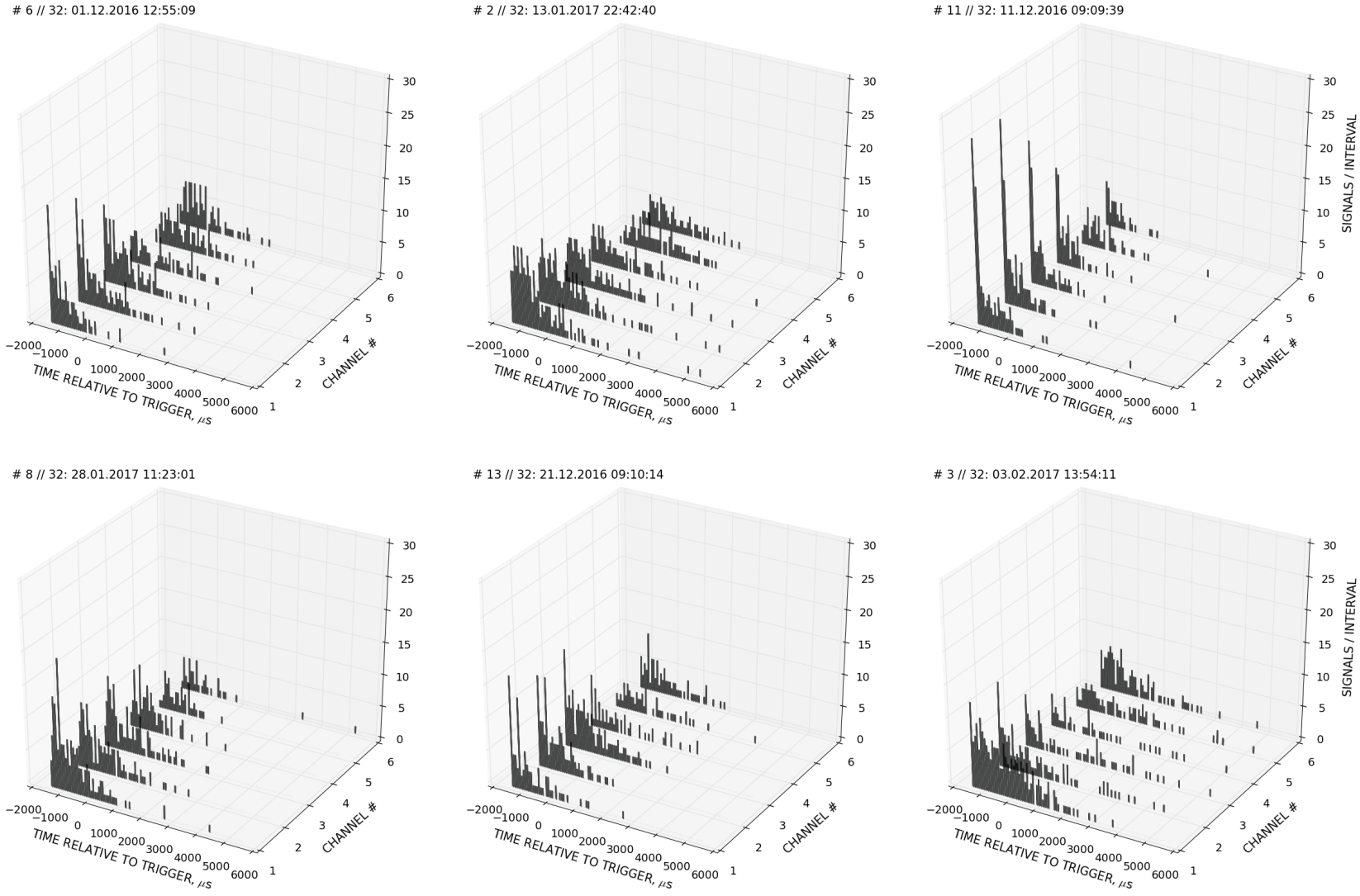


- Low-energy neutron detector in 2016–2017





EAS cores within the neutron supermonitor: 2016–1017 data

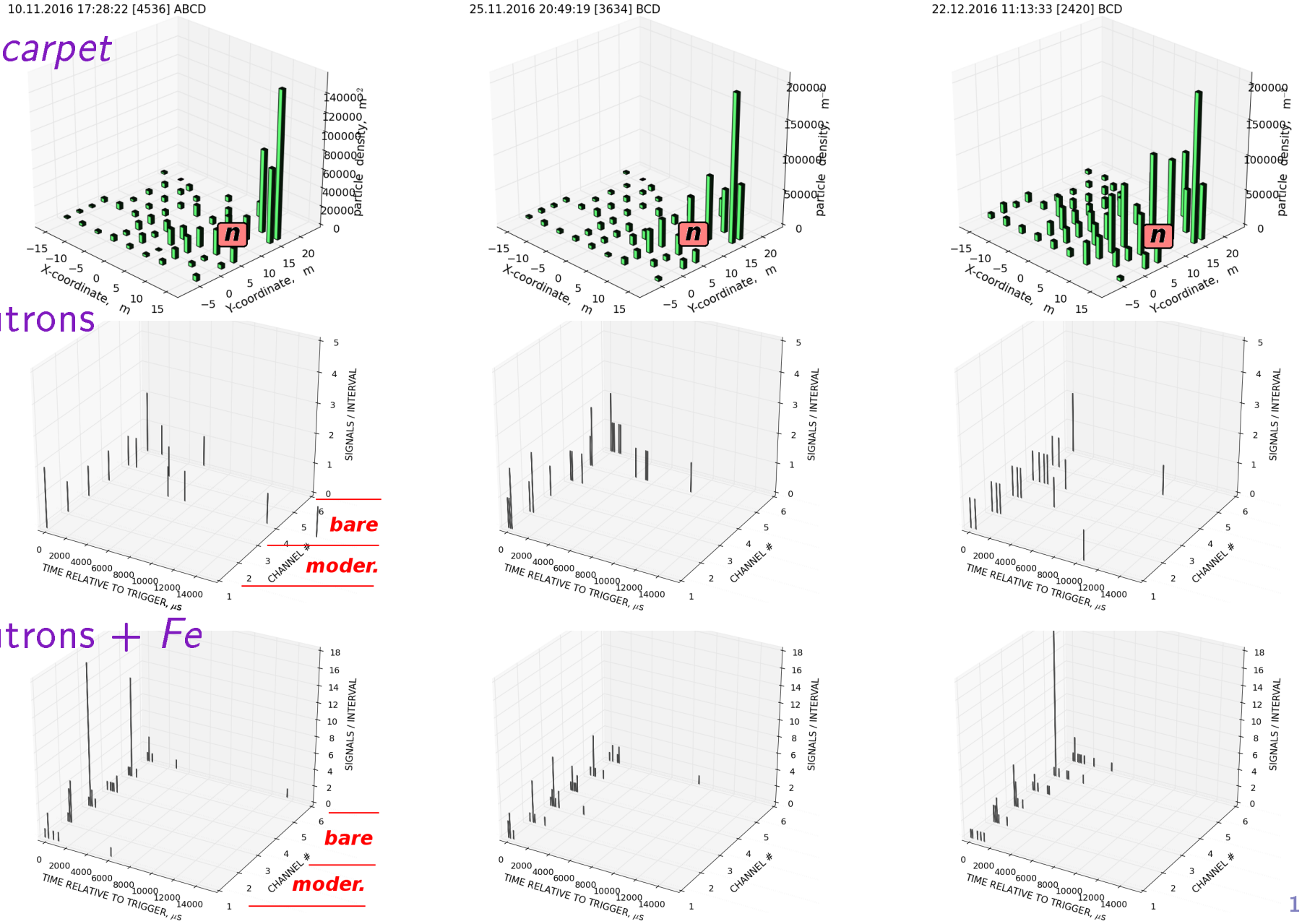


EAS & neutrons

SC *carpet*

Neutrons

Neutrons + *Fe*

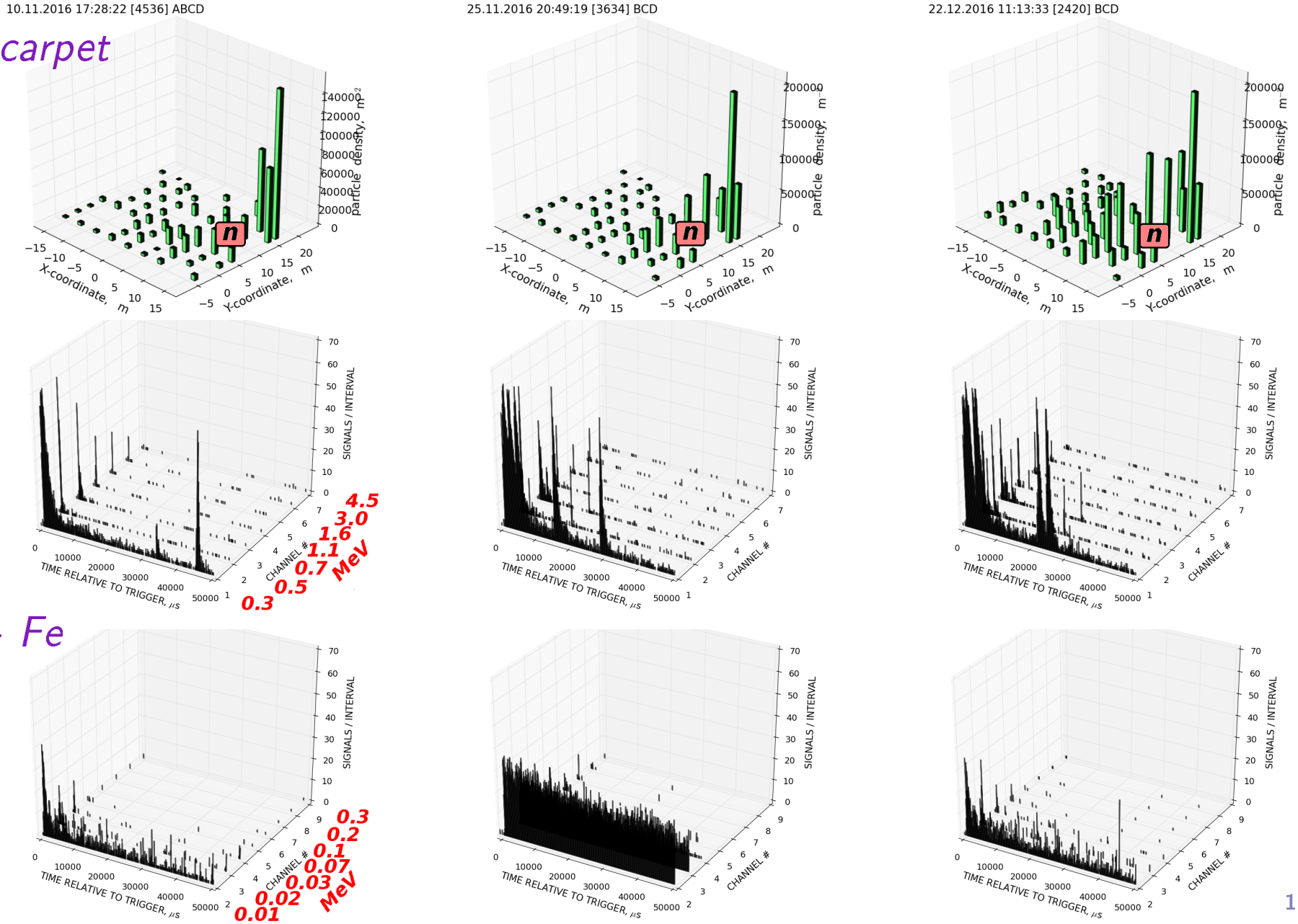


EAS & low-energy γ-ray signal

SC *carpet*

γ

γ + *Fe*

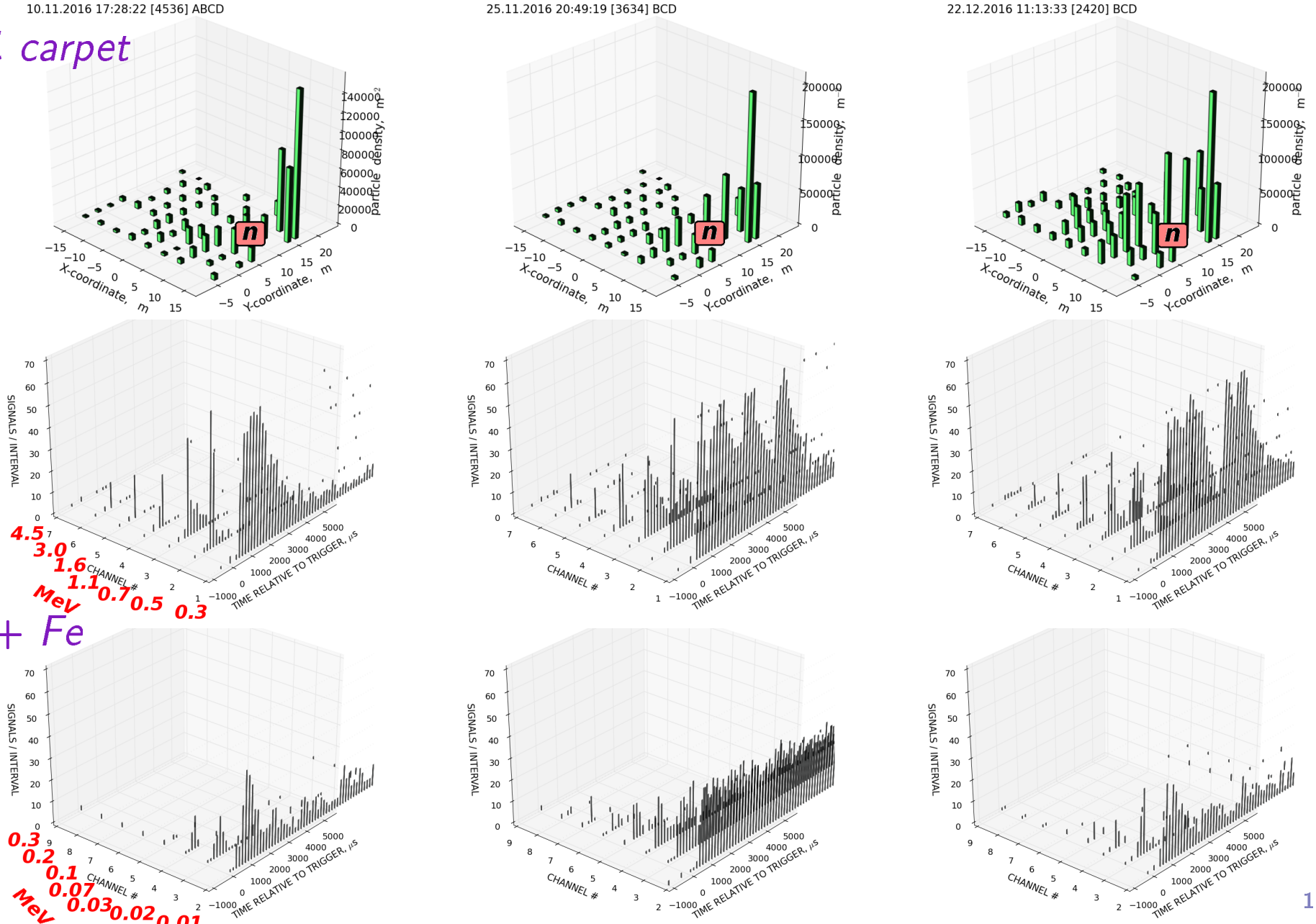


EAS & low-energy γ-ray signal's beginning

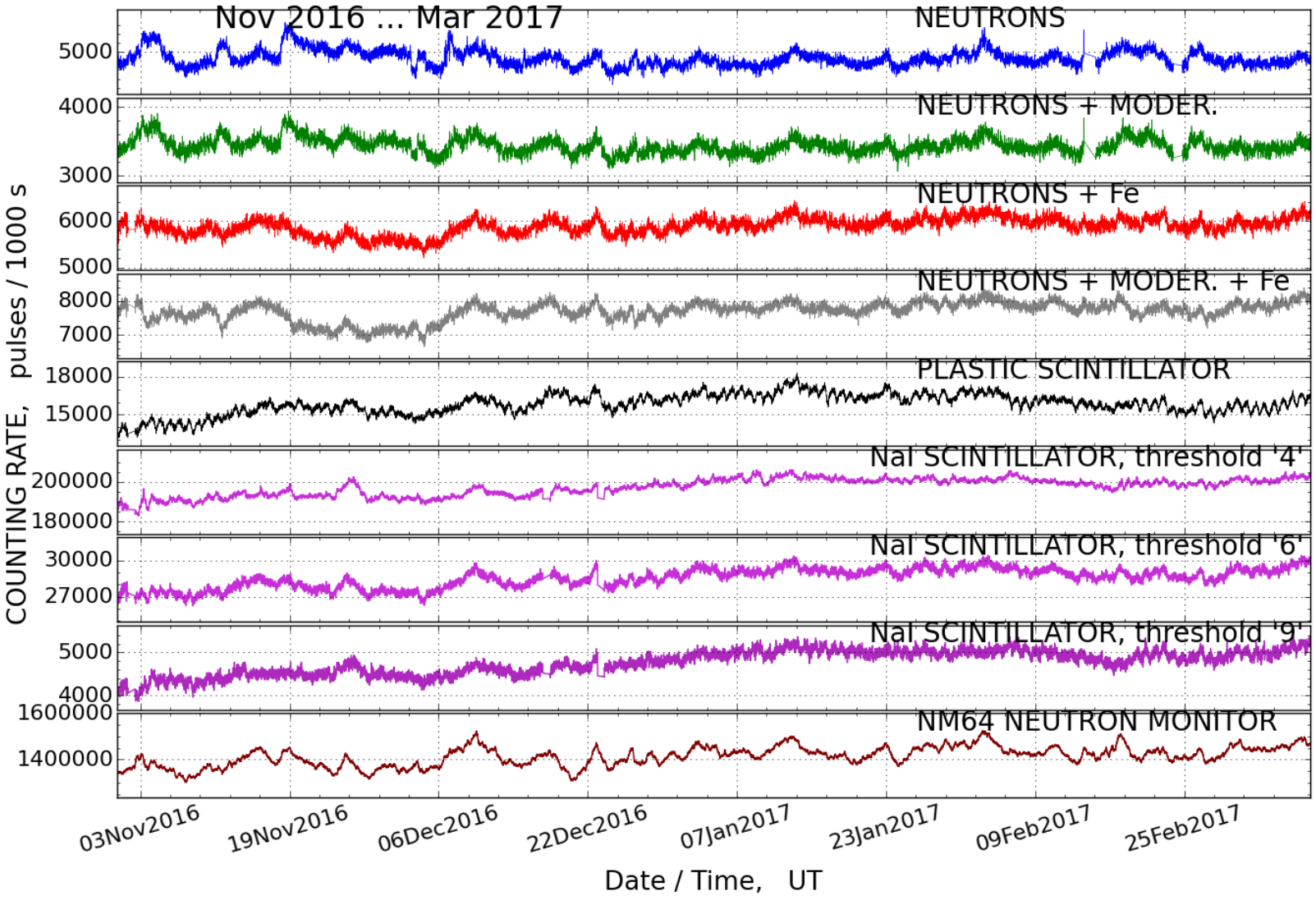
SC *carpet*

γ

$\gamma + Fe$

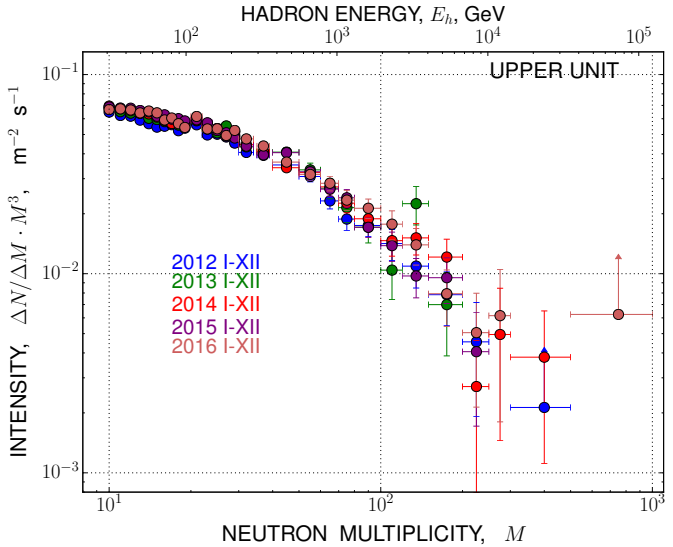


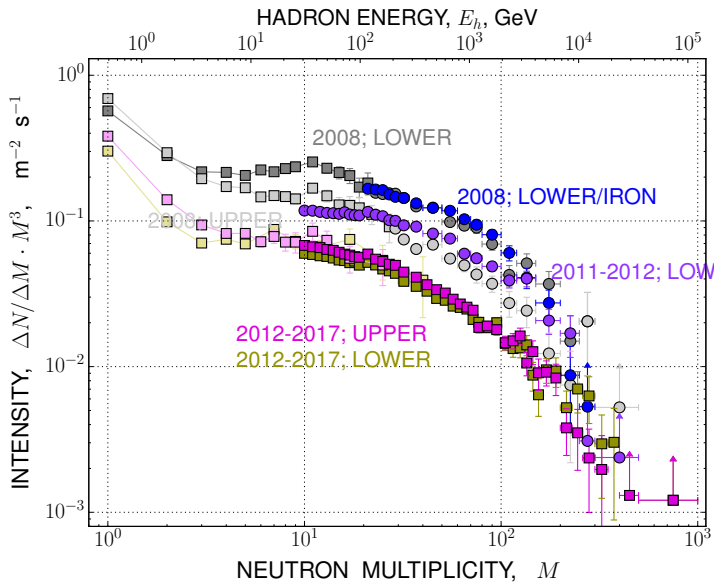
Monitoring data of the neutron background intensity

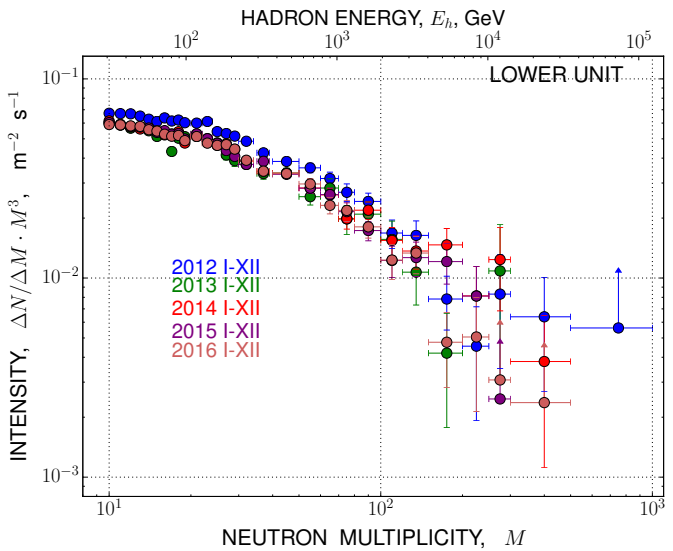


- effective registration of the various neutron energy components
- uninterruptable duty cycle during many years
- original 10 s periodicity of intensity data record

On the underground neutron monitor





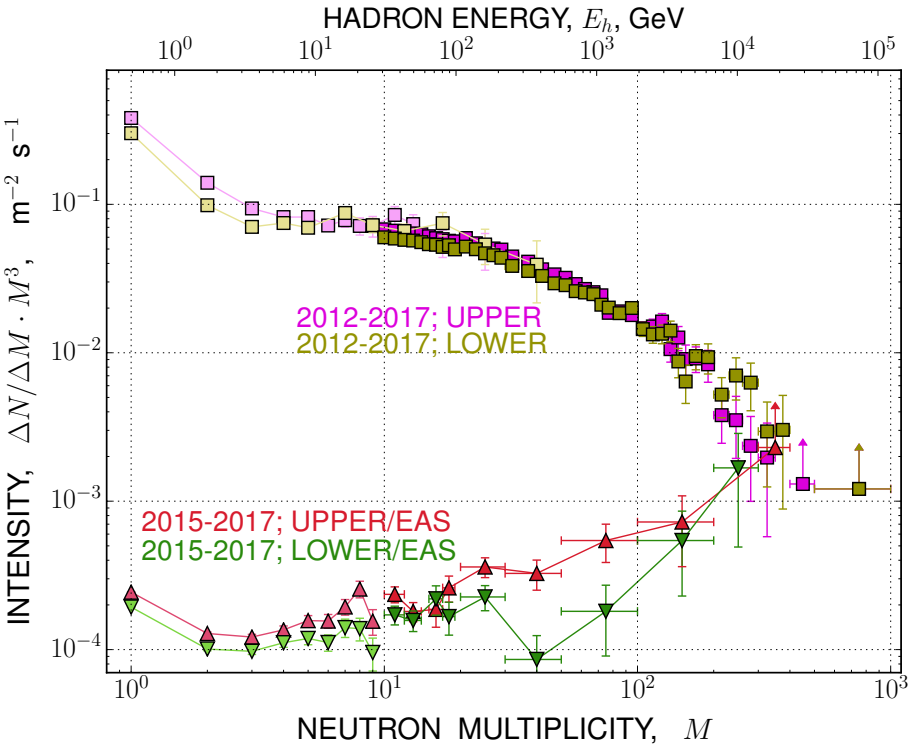


A.P.Chubenko *et al* Neutron Events in the Underground Monitor of the Tien Shan High-Altitude Station // BLPH vol. 38, 2007, 34, 4, 107–113.

A.P.Chubenko *et al* The underground neutron events at Tien-Shan // Proc. of 30th ICRC, 2008, 4, 3–6.

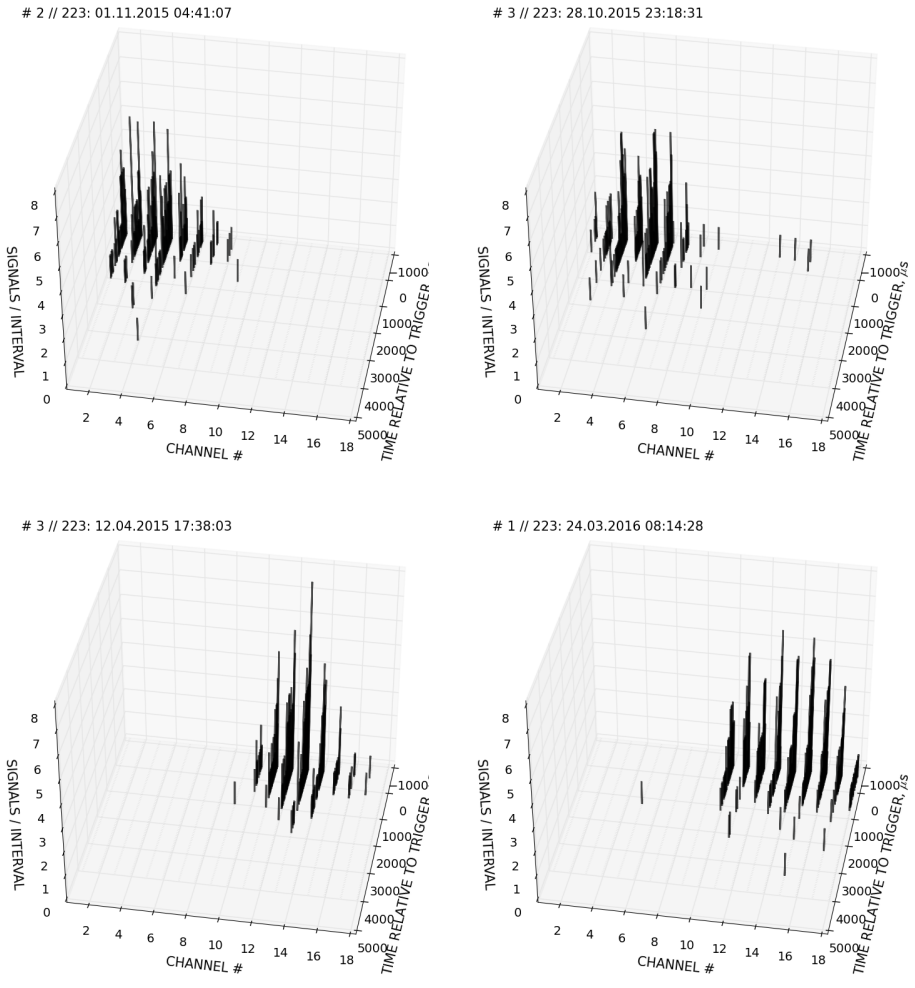
Neutron events at the ungerground monitor

- neutron multiplicity spectrum of EAS trigger events

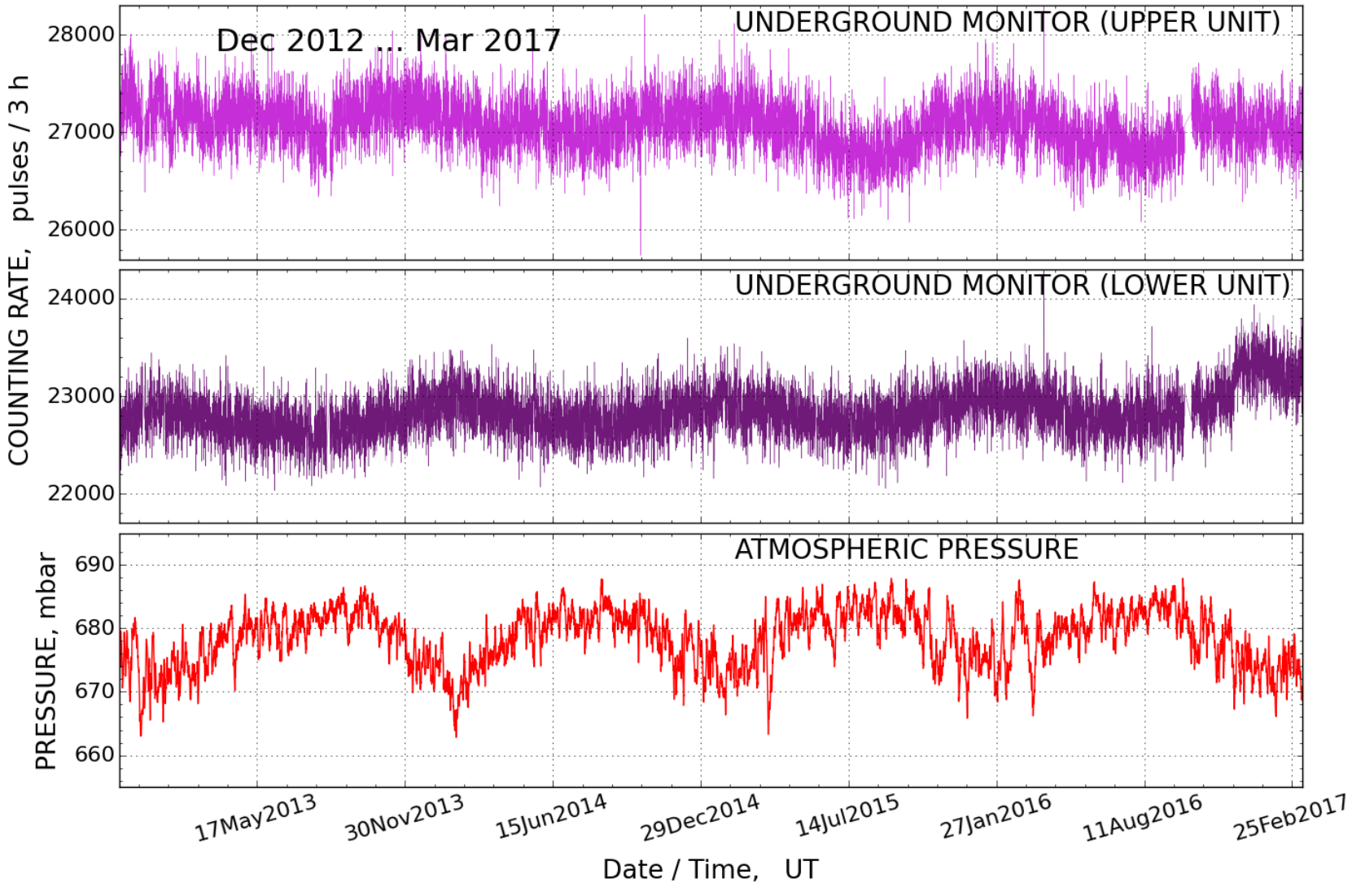


- statictics for 1000h
  - $M \gtrsim 100$: 31 events, of them 1.2 with shower trigger;
  - $M \gtrsim 200$: 6 ev., 0.4 shw.;
  - $M \gtrsim 300$: 0.2 ev., 0.1 shw.;

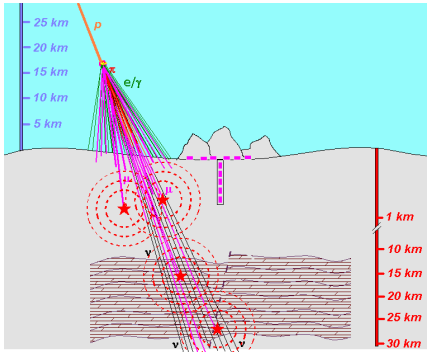
- a sample of high multiplicity underground events

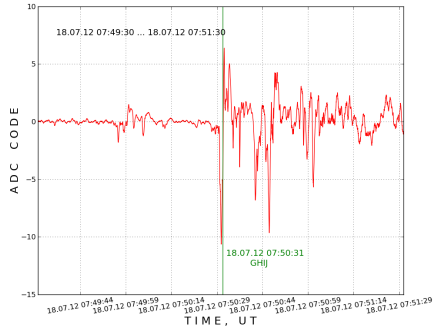


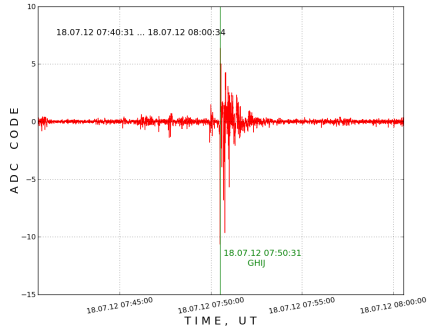
Neutron intensity monitoring at the underground detector

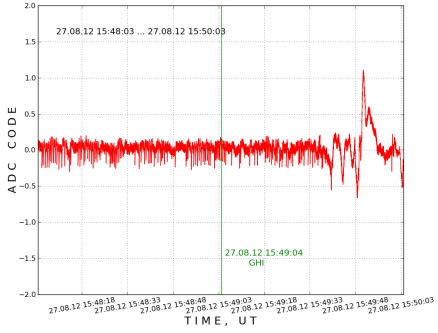


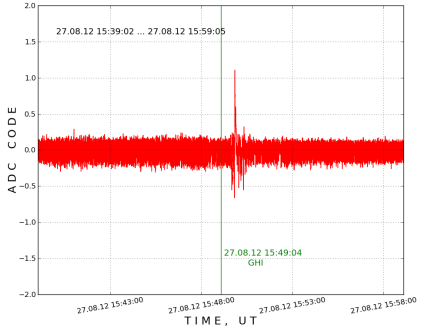
EAS & seismology (acoustics)

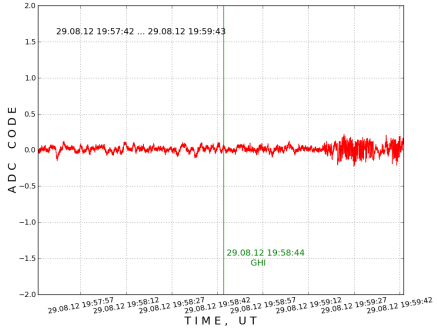


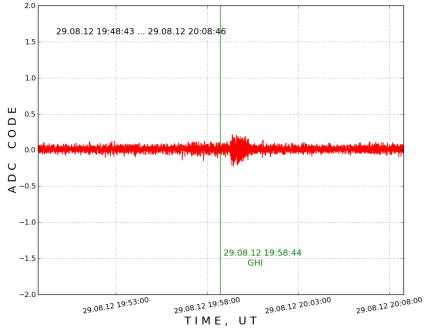


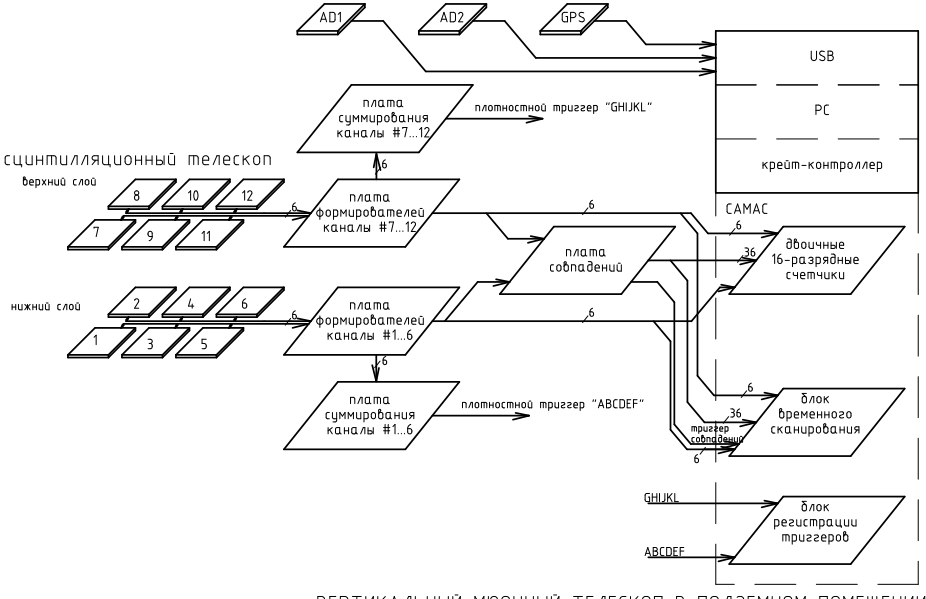










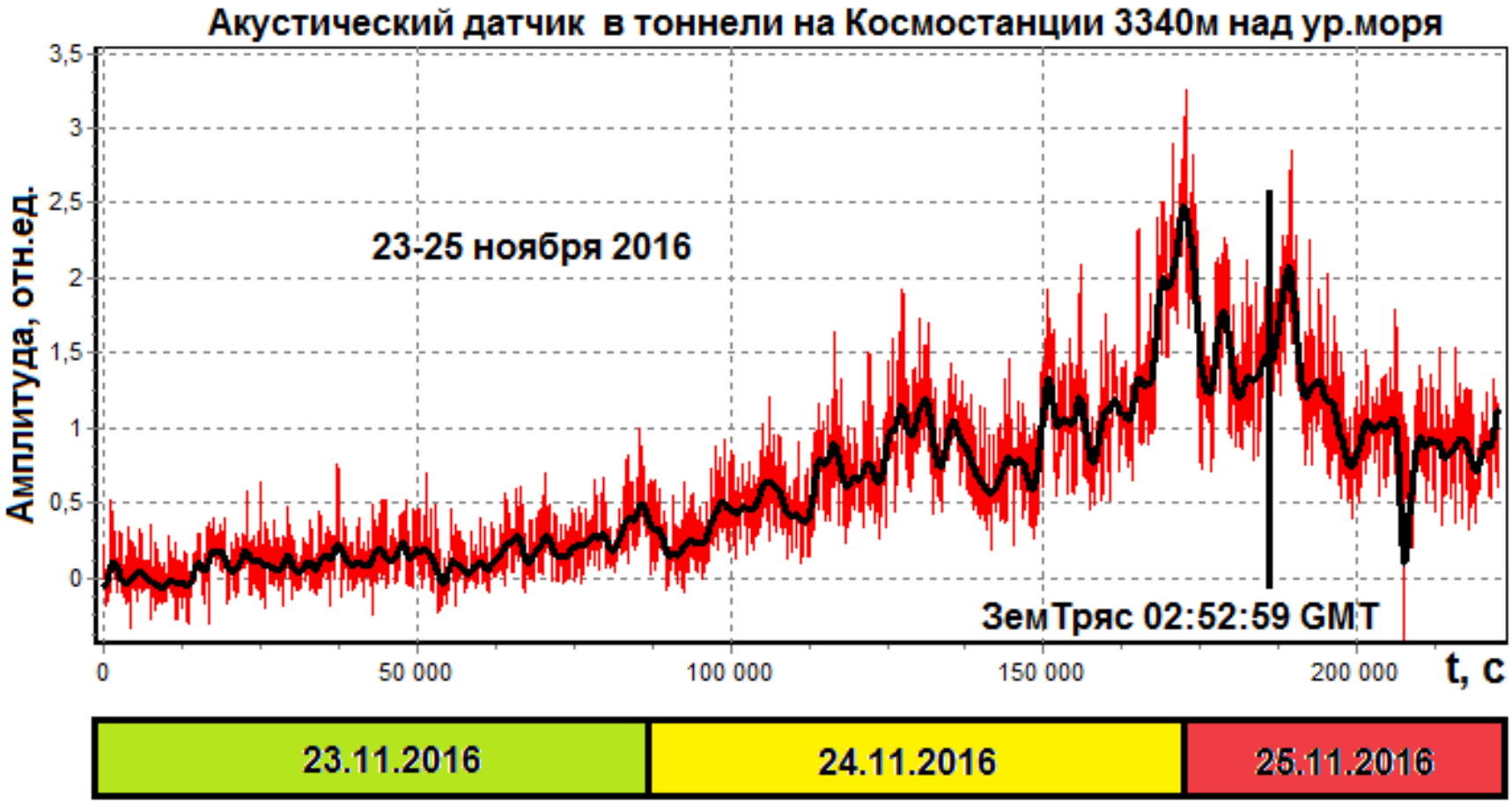


ВЕРТИКАЛЬНЫЙ МЮОННЫЙ ТЕЛЕСКОП В ПОДЗЕМНОМ ПОМЕЩЕНИИ
Функциональная схема

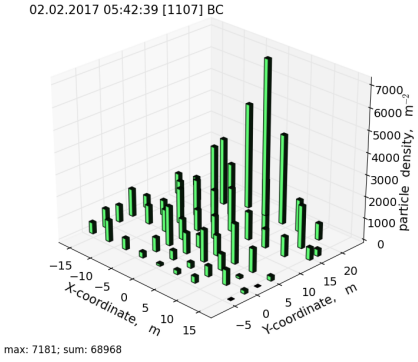
G.A. Gusev *et al* Cosmic Rays as a New Instrument of Seismological Studies // BLPH vol. 38, 2011, 12, 374.

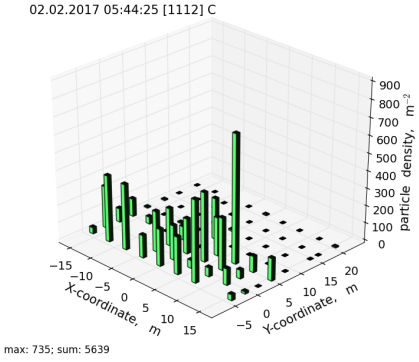
G.A. Gusev *et al* The First Results of Observations of Acoustic Signals Generated by Cosmic Ray Muons in a Seismically Stressed Medium // BLPH vol. 40, 2013, 3, 74.

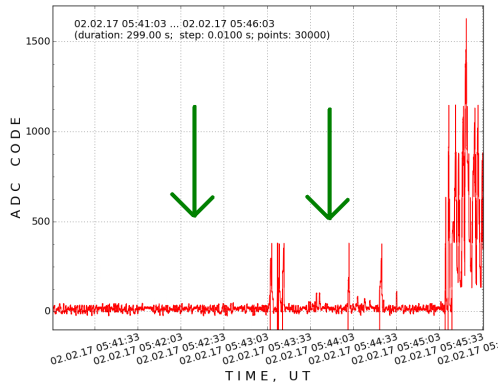
Acoustics in 2016 г

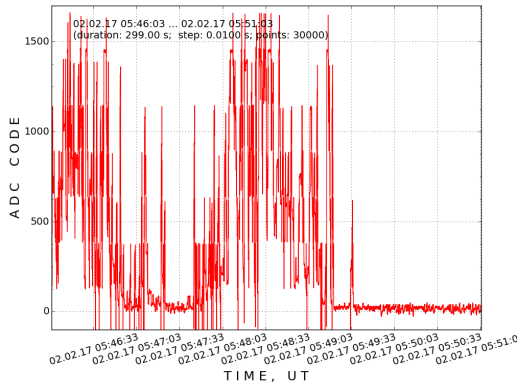


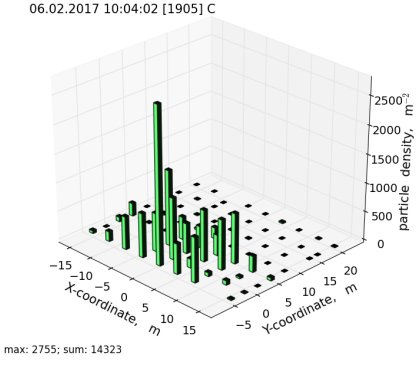
EAS & acoustics : 2016–2017

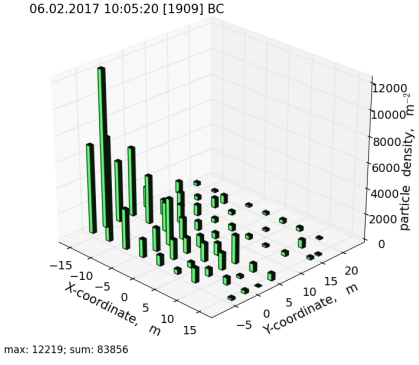


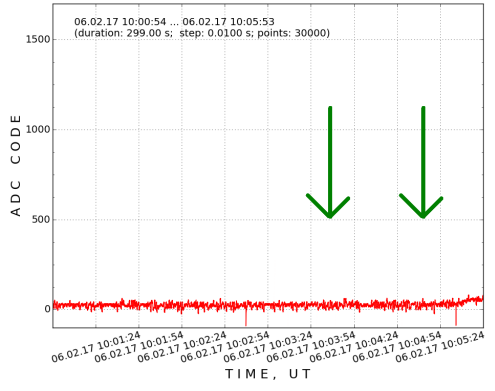


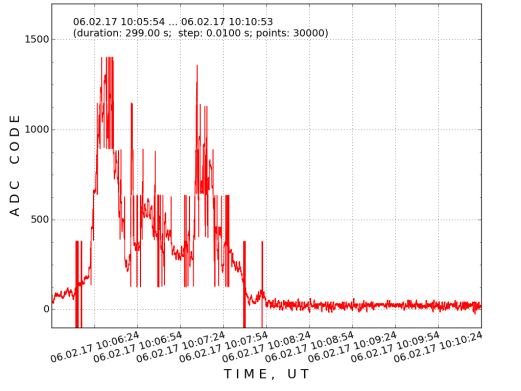


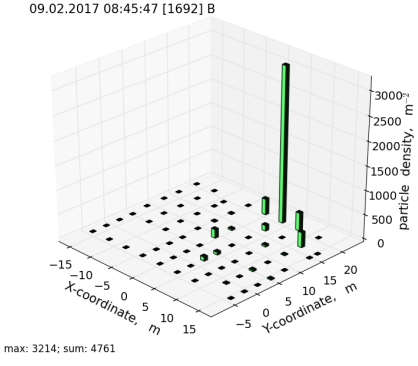


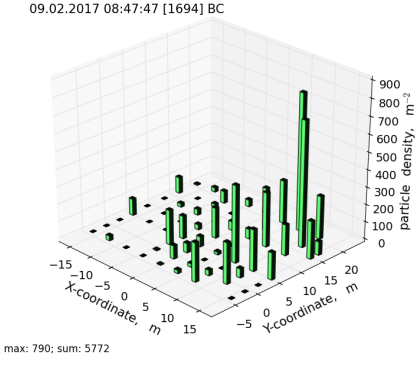


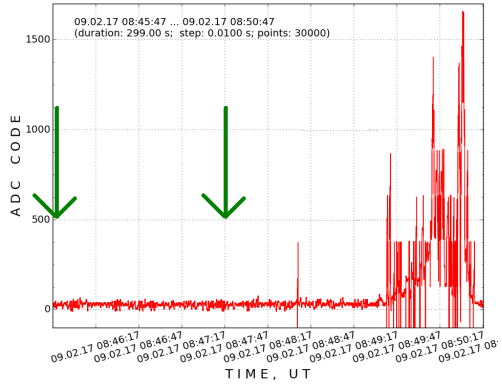


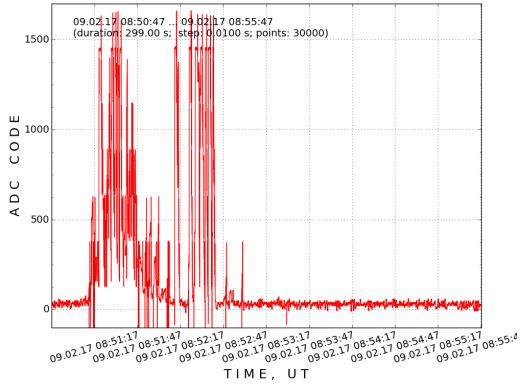




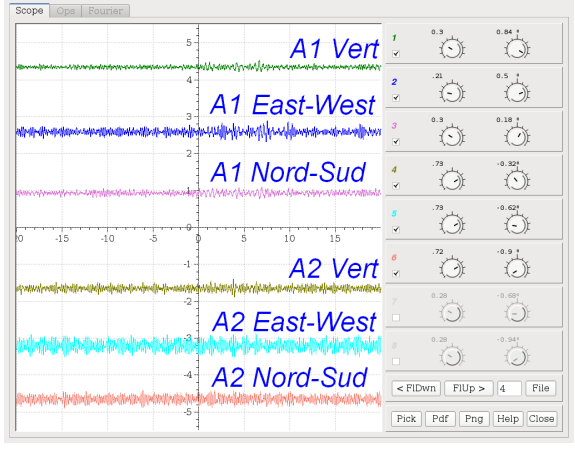






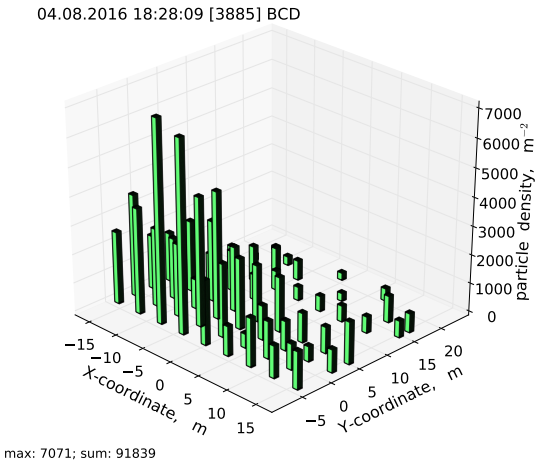


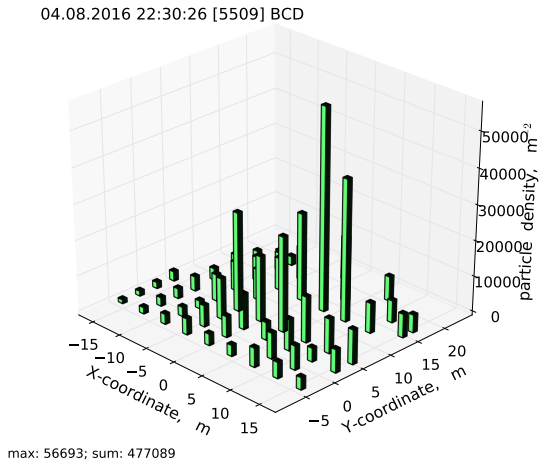
EAS radio-signal — *I*

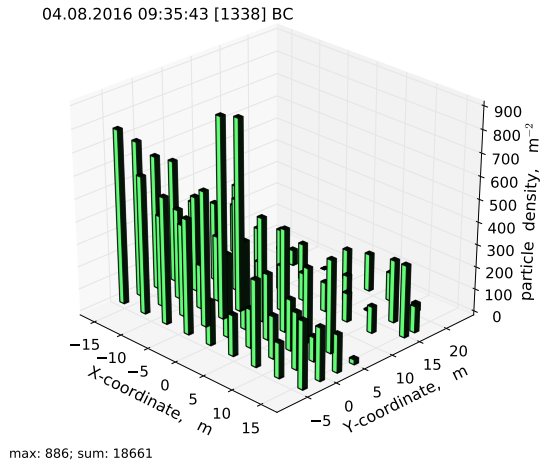


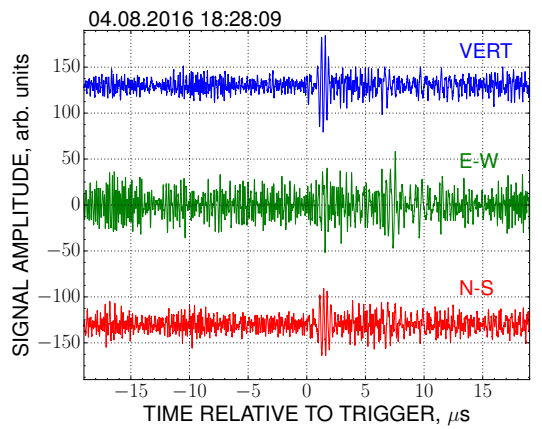
- frequency range 25-75 MHz;
- 3 registration points around *CENTER* scintillation *carpet*;
- 2 antennas with horizontal and one with vertical polarization in every point;
- 12 bit ADC with 4 ns measurement granularity;
  8 informational channels $\times$ 10000 time intervals in each event;
- synchronization by EAS trigger.

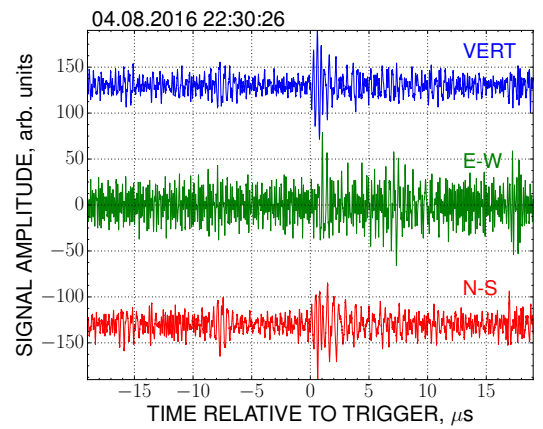
EAS radio-signal — //

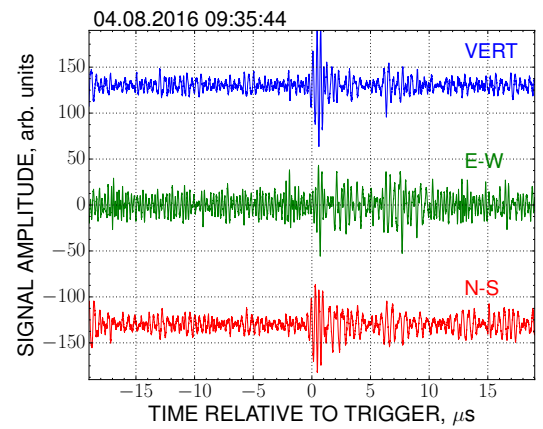












EAS cores within ionization calorimeter