THE SIGNAL OF LOW ENERGY NEUTRONS AND GAMMA RAYS FROM EXTENSIVE AIR SHOWERS IN THE KNEE REGION OF PRIMARY COSMIC RAY SPECTRUM

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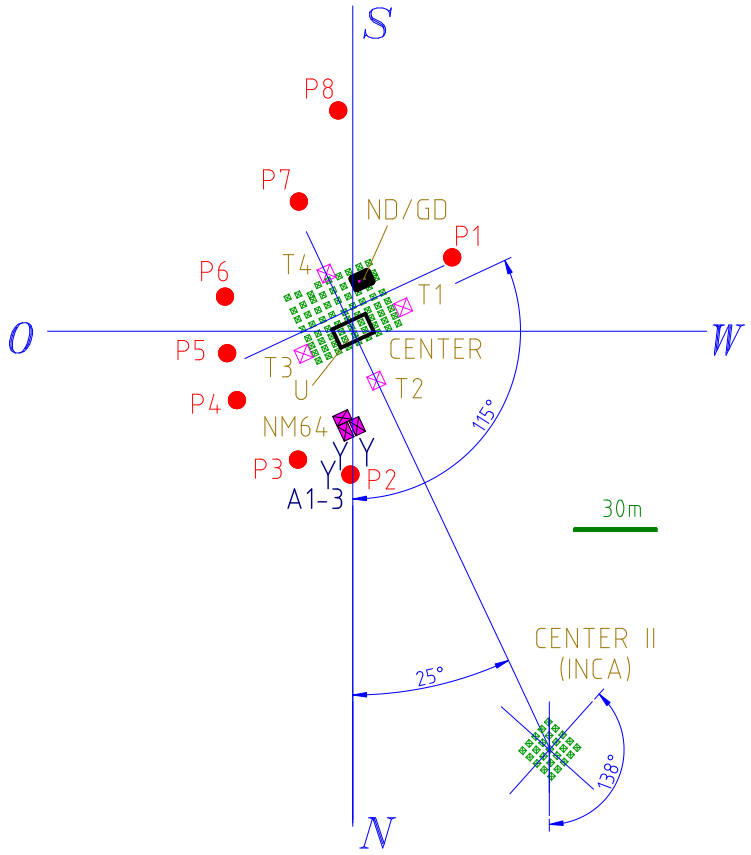
2018

Tien Shan EAS detector complex

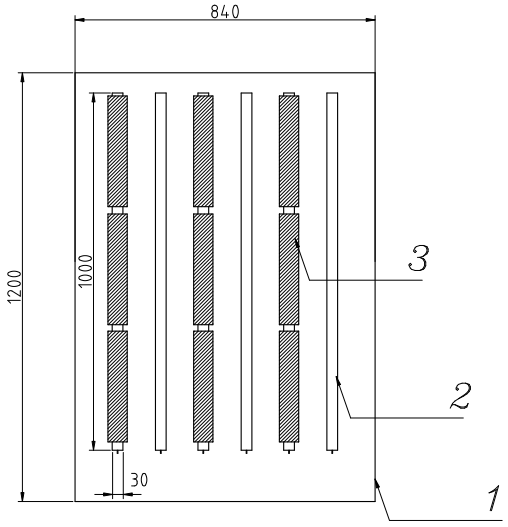
Location: Nothern Tien Shan,
43° North, 75° East, 3340m a.s.l.



- CENTER-I:
  - EAS detector system;
  - neutron and gamma ray detectors;
  - undeground set;
  - radio antennas.
- CENTER-II:
  - EAS detectors;
  - ionization-neutron calorimeter (*INCA*).

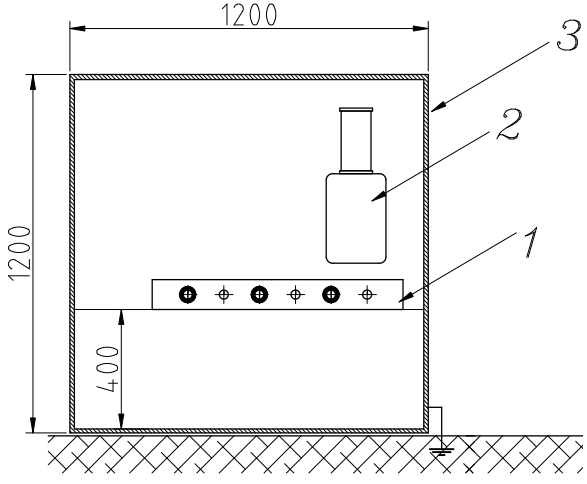
Neutron detector

- Principal construction



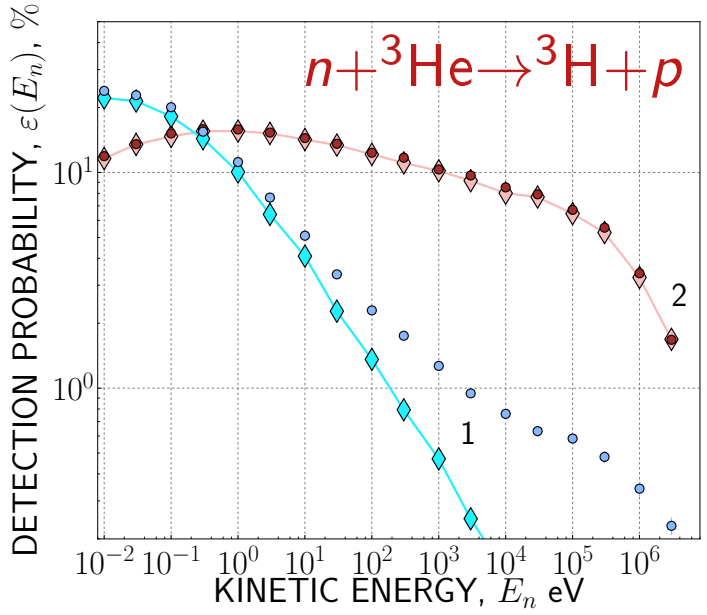
(1) – 1 mm thick wall of an outer aluminum box,
(2) – gas discharge counter with ^{3}He filling,
(3) – the neutron moderator tubes

- General set-up



(1) – neutron detector, *(2)* – gamma detector,
(3) – 2 cm thick solid iron shielding

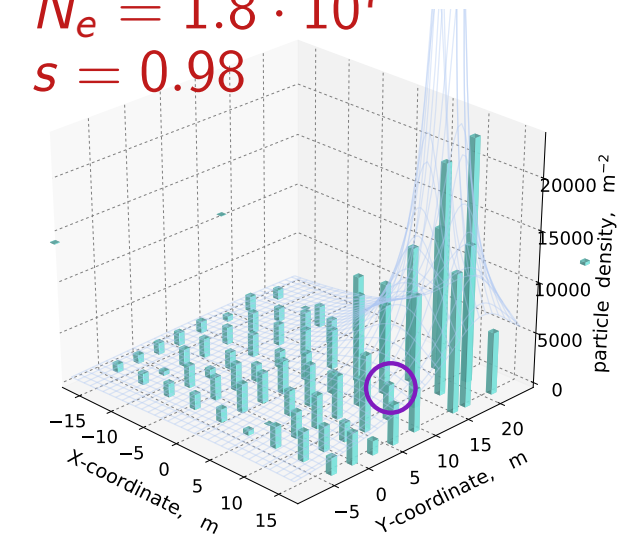
- Efficiency of neutron detection (*Geant4* simulated)



(1) – free neutron counter,
(2) – the counter inside a paraffin tube with a 2 cm wall thickness

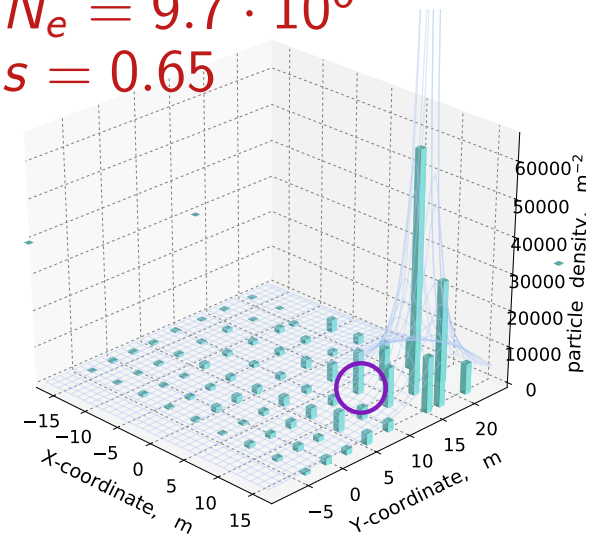
Neutron events around the EAS core region

$N_e = 1.8 \cdot 10^7$
$s = 0.98$



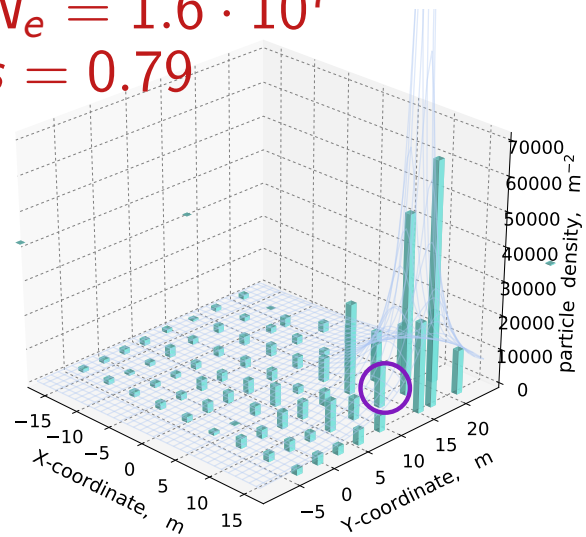
x: 23742; sum: 288222; shower: 10.5 18.1 1.8e+07 0.98 95.0

$N_e = 9.7 \cdot 10^6$
$s = 0.65$



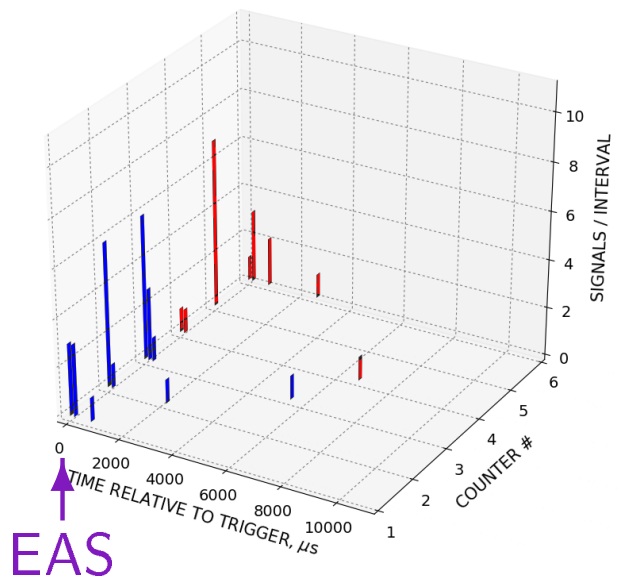
max: 66009; sum: 273356; shower: 12.4 17.0 9.7e+06 0.65 48.4

$N_e = 1.6 \cdot 10^7$
$s = 0.79$



max: 70590; sum: 424332; shower: 13.4 16.4 1.6e+07 0.79 175.5

13 // 133: 22.02.2018 09:18:45



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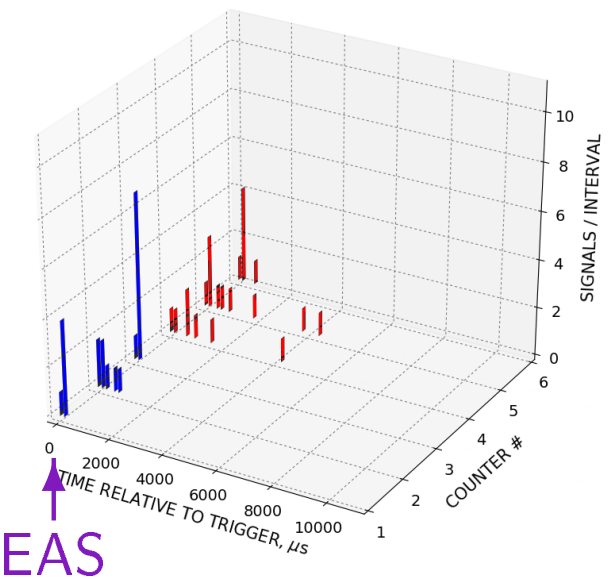

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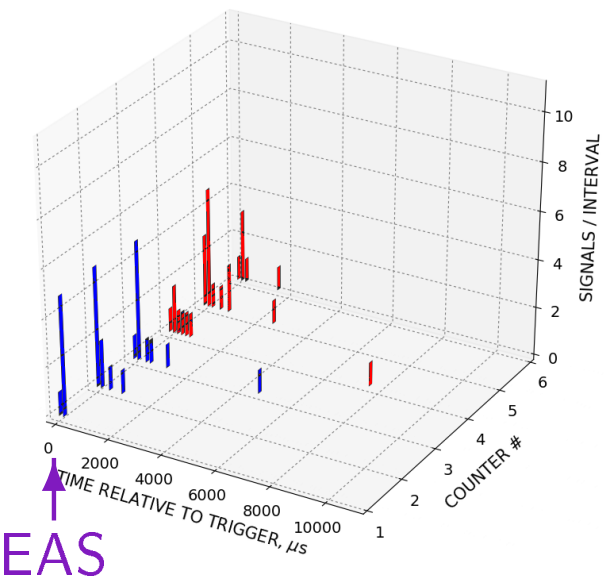
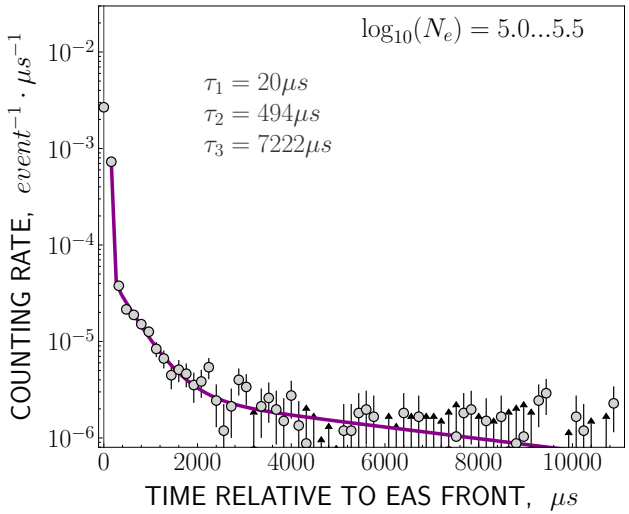
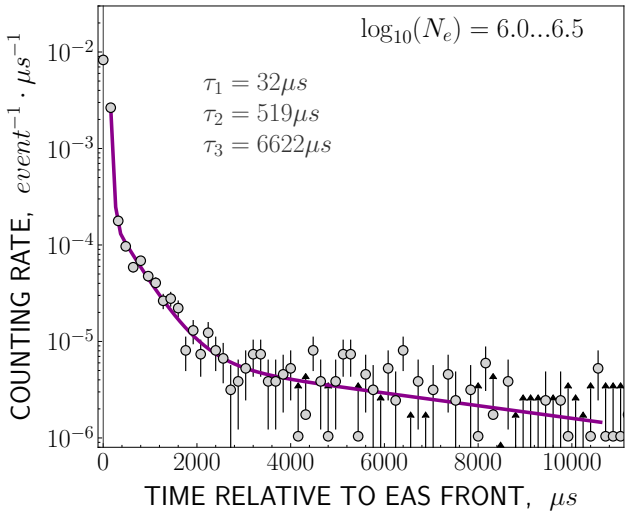


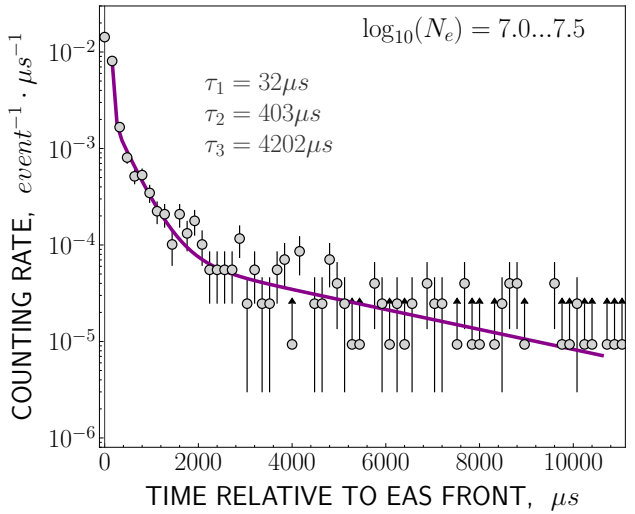
The counters within 2 cm thick moderator tubes are *#1*, *#2*, *#3*;
plain neutron counters are *#4*, *#5*, *#6*.

Average time distributions of neutron intensity (background subtracted)

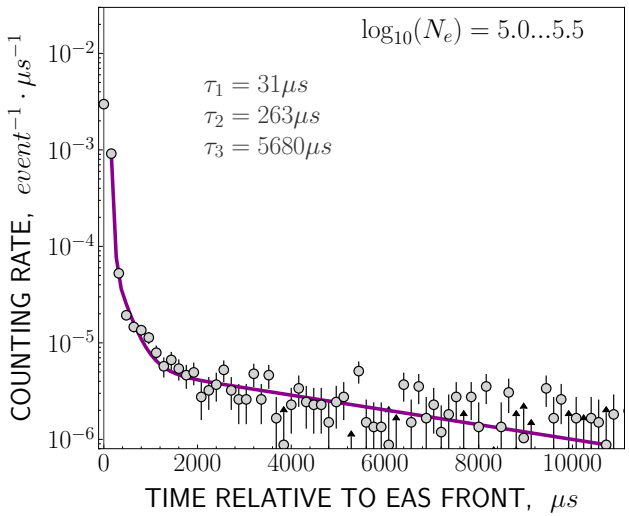
- Thermal

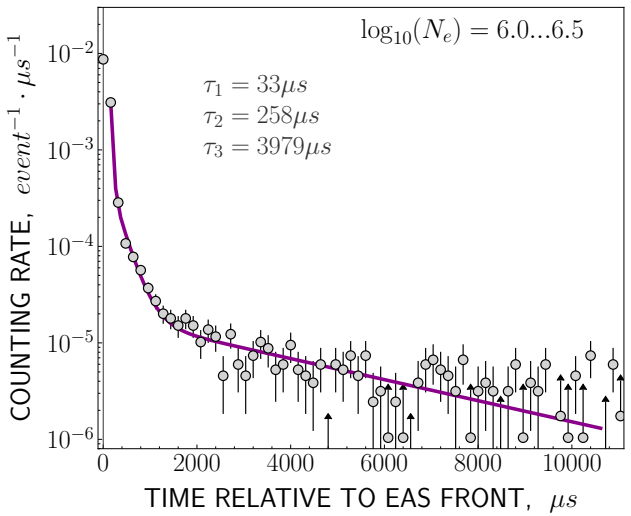


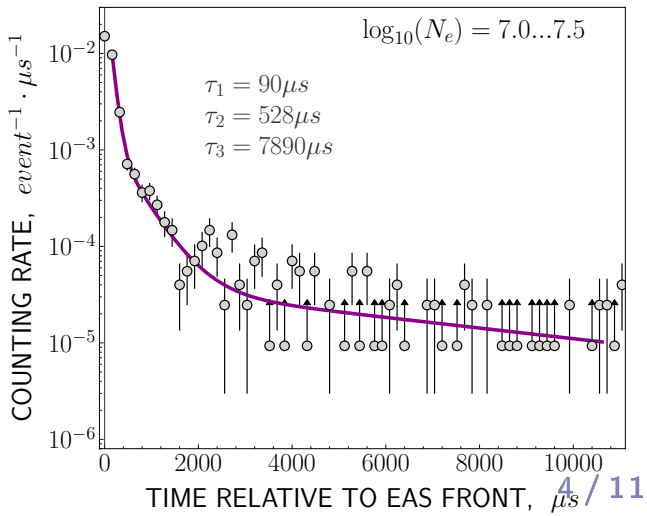




- Epithermal

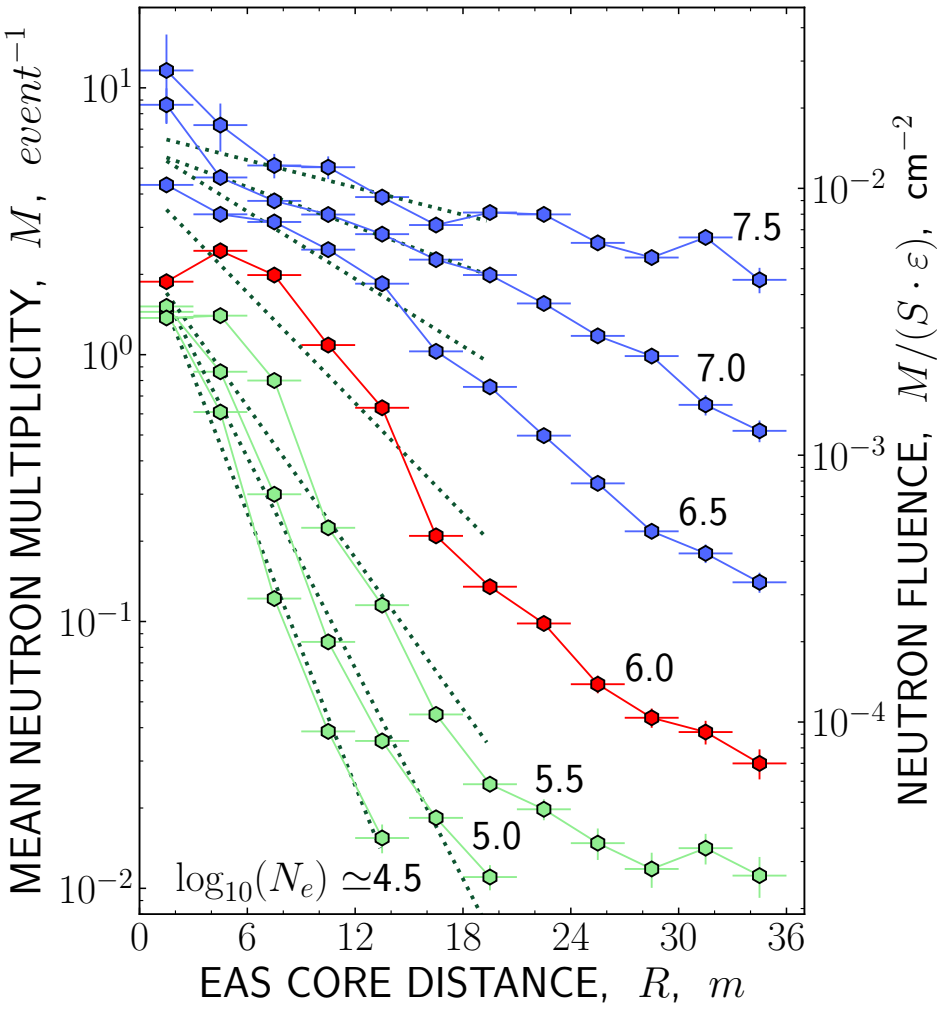




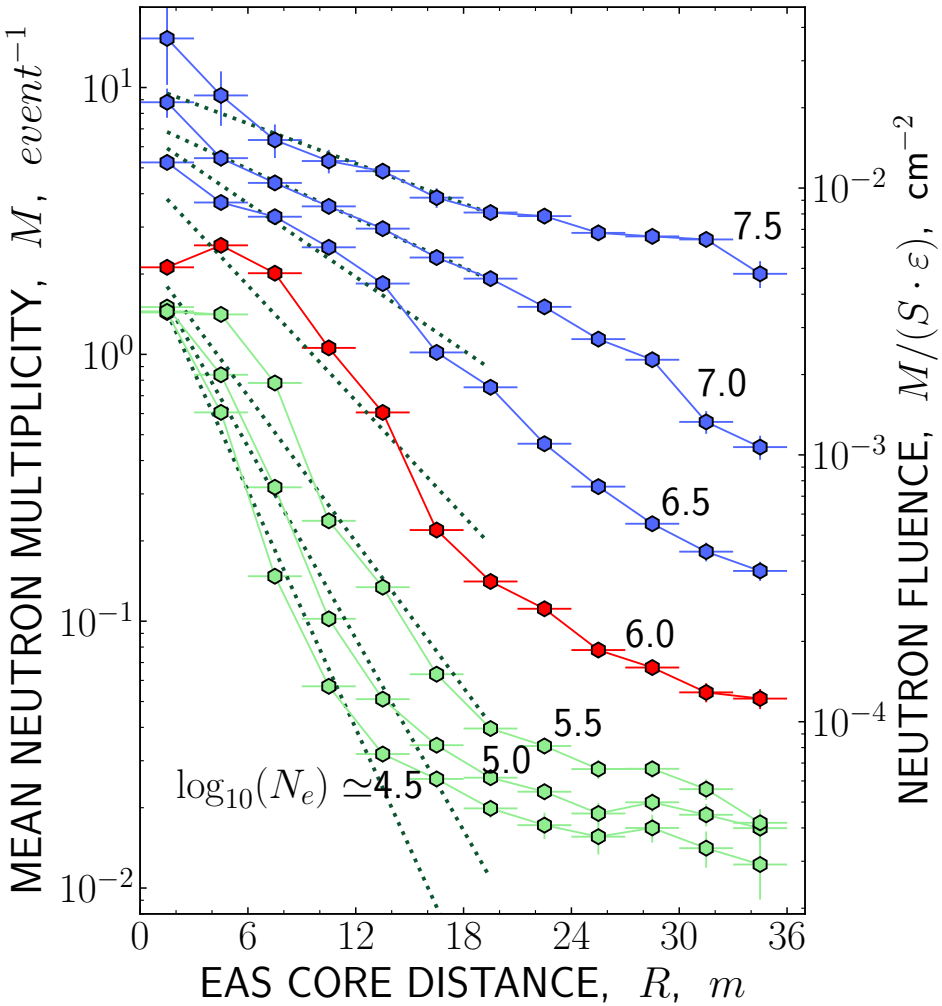


Lateral distribution of the intensity of neutron flux (background subtracted)

- Thermal



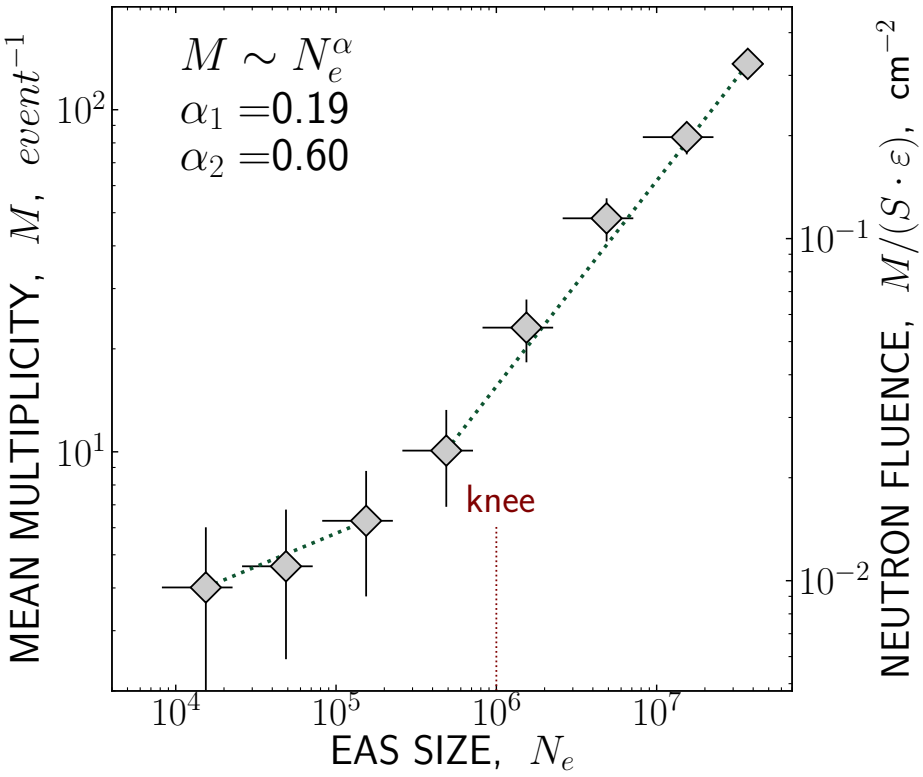
- Epithermal



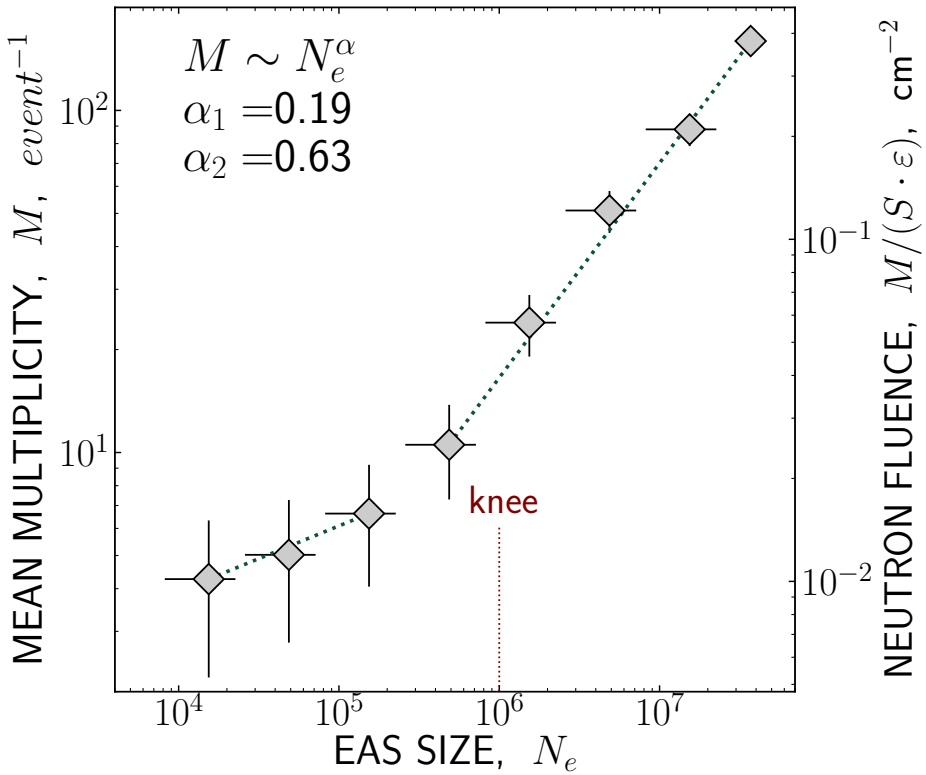
Gate time $T_g = 160...8480\mu s$.

Mean multiplicity of neutron signals

- Thermal



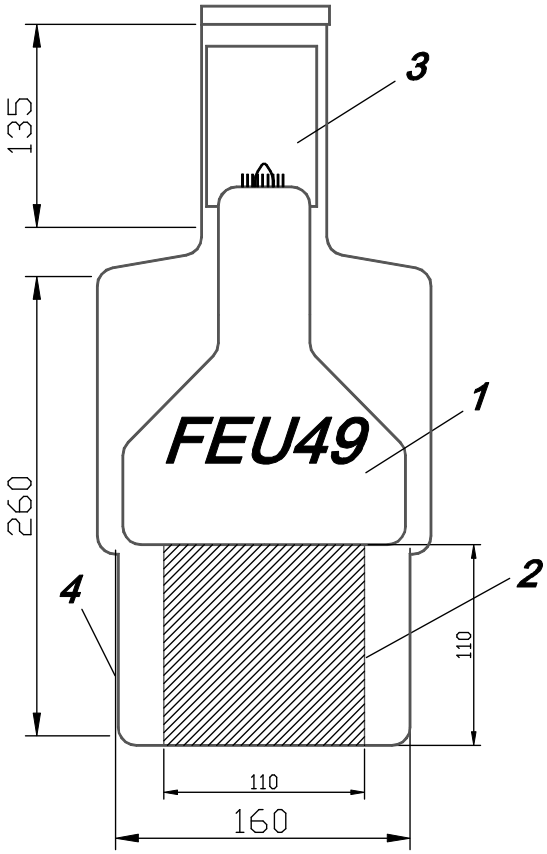
- Epithermal



Gate time $T_g = 160...8480\mu s$.
EAS core distance range $R = 0...36$m.

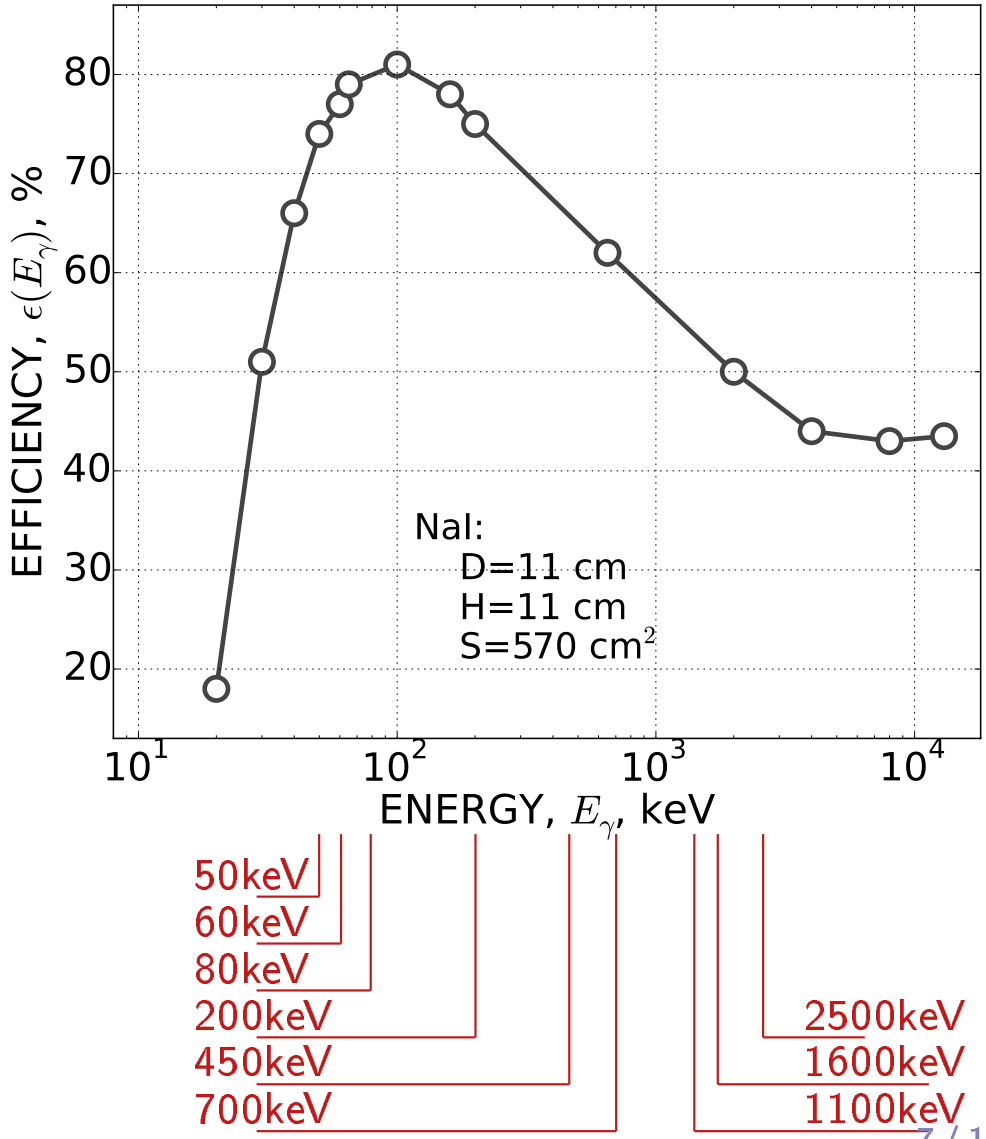
Low energy gamma ray detector

- Internal set-up



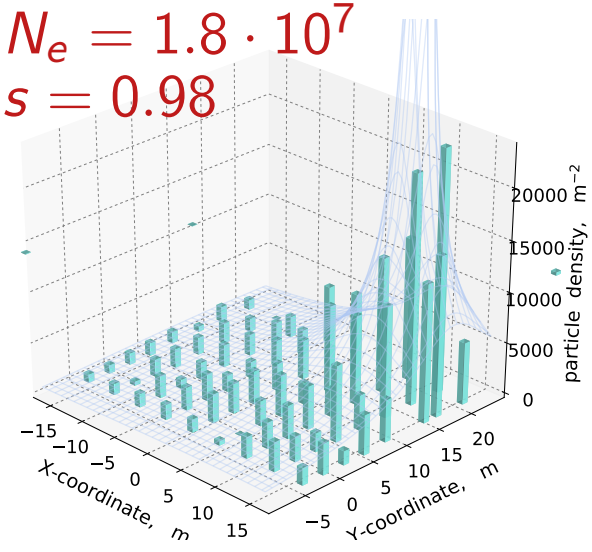
(1) – PMT, *(2)* – NaI crystal,
(3) – electronics board,
(4) – 1mm thick outer aluminum housing.

- Efficiency of gamma ray detection (*Geant4* simul.)



EAS events with excessive gamma production

$N_e = 1.8 \cdot 10^7$
$s = 0.98$



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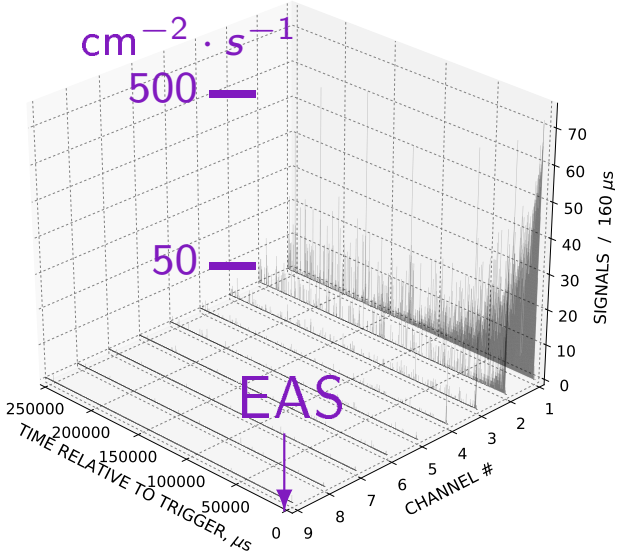
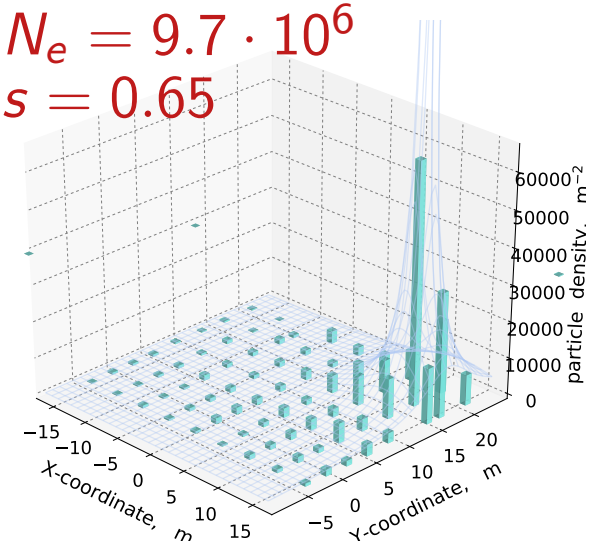


$N_e = 9.7 \cdot 10^6$
$s = 0.65$



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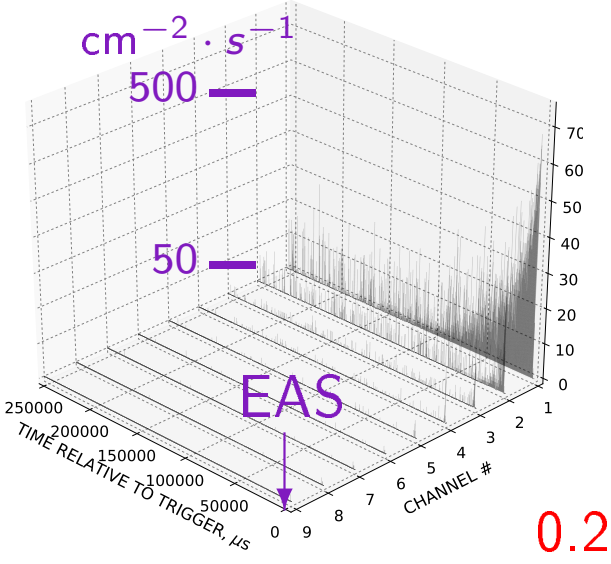
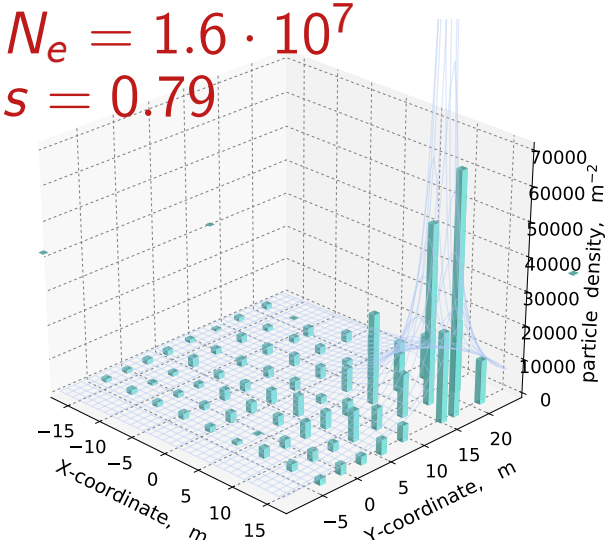


$N_e = 1.6 \cdot 10^7$
$s = 0.79$



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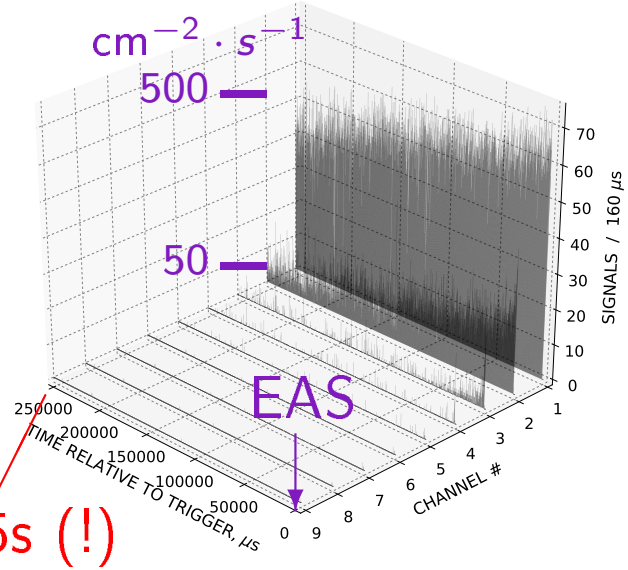


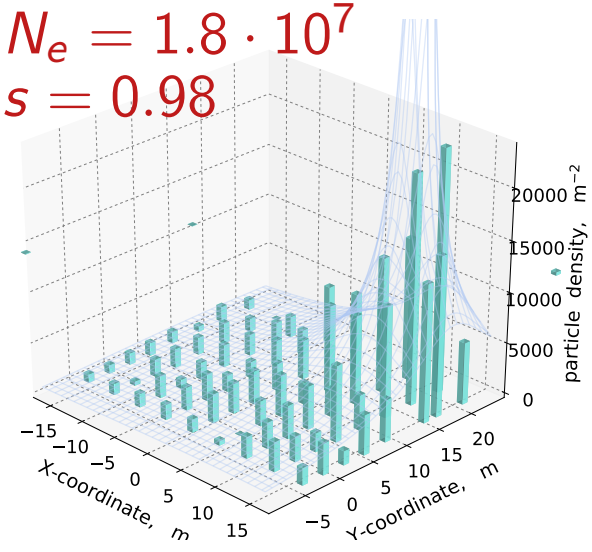
0.25s (!)

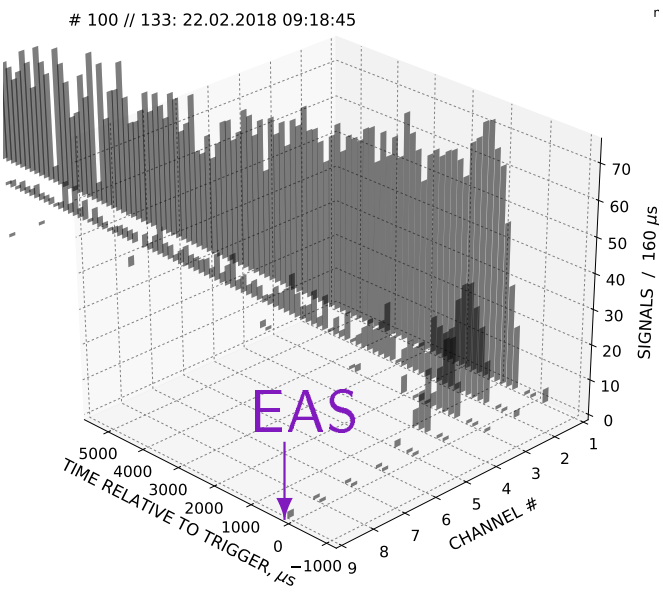
Amplitude thresholds:

1 – 50 keV; *2* – 60 keV; *3* – 80 keV; *4* – 200 keV; *5* – 450 keV;
6 – 700 keV; *7* – 1100 keV; *8* – 1600 keV; *9* – 2500 keV.

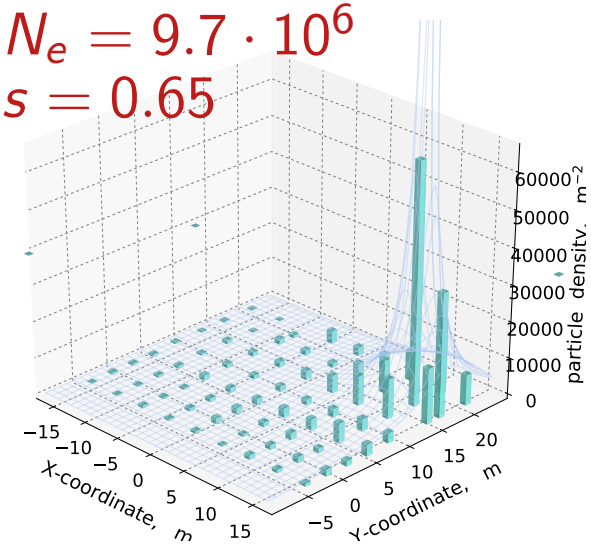
Delayed emission of “excessive” gamma rays

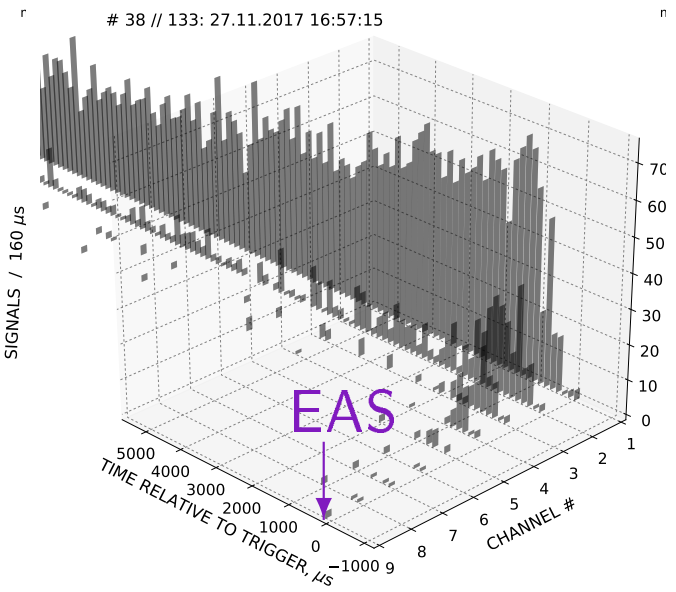
$N_e = 1.8 \cdot 10^7$
$s = 0.98$



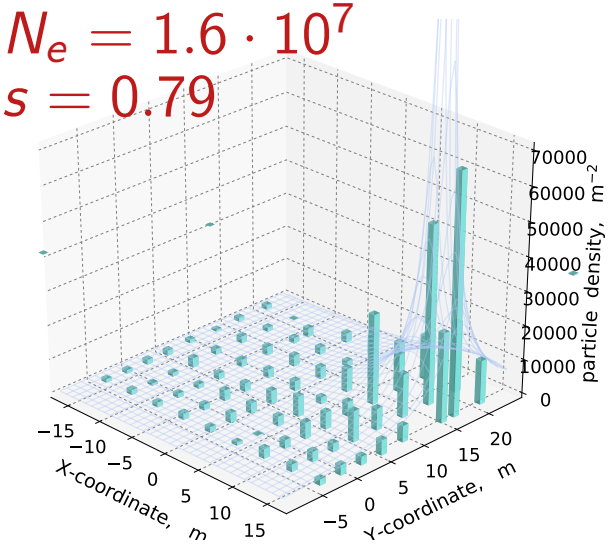


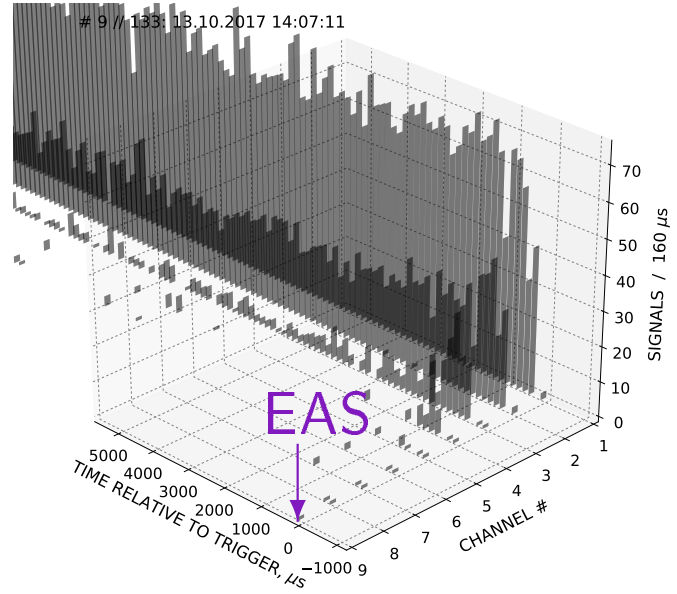
$N_e = 9.7 \cdot 10^6$
$s = 0.65$





$N_e = 1.6 \cdot 10^7$
$s = 0.79$



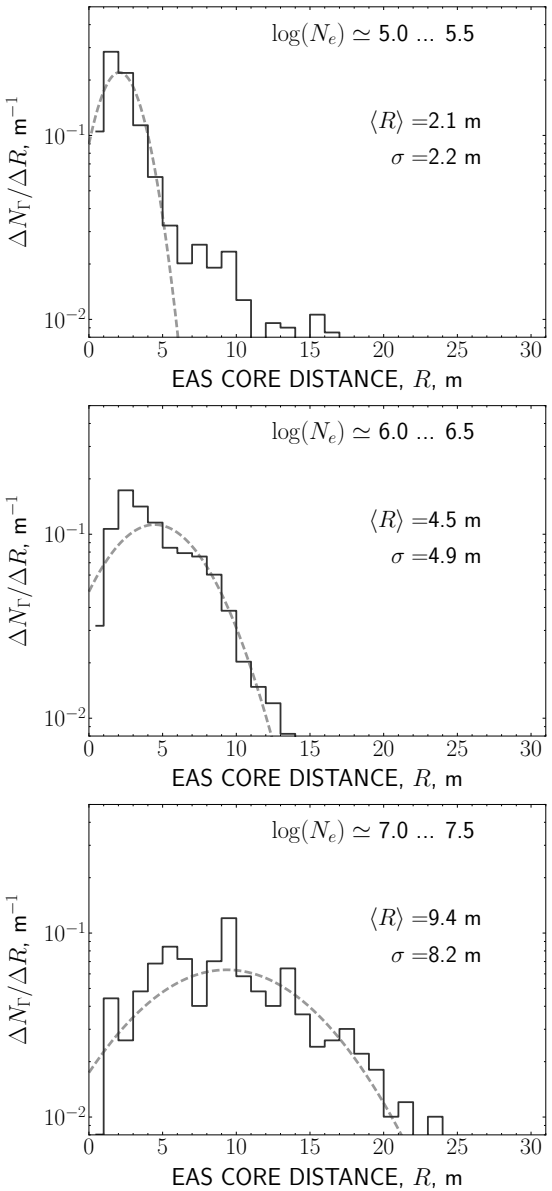


Amplitude thresholds:

1 – 50 keV; *2* – 60 keV; *3* – 80 keV; *4* – 200 keV; *5* – 450 keV;
6 – 700 keV; *7* – 1100 keV; *8* – 1600 keV; *9* – 2500 keV.

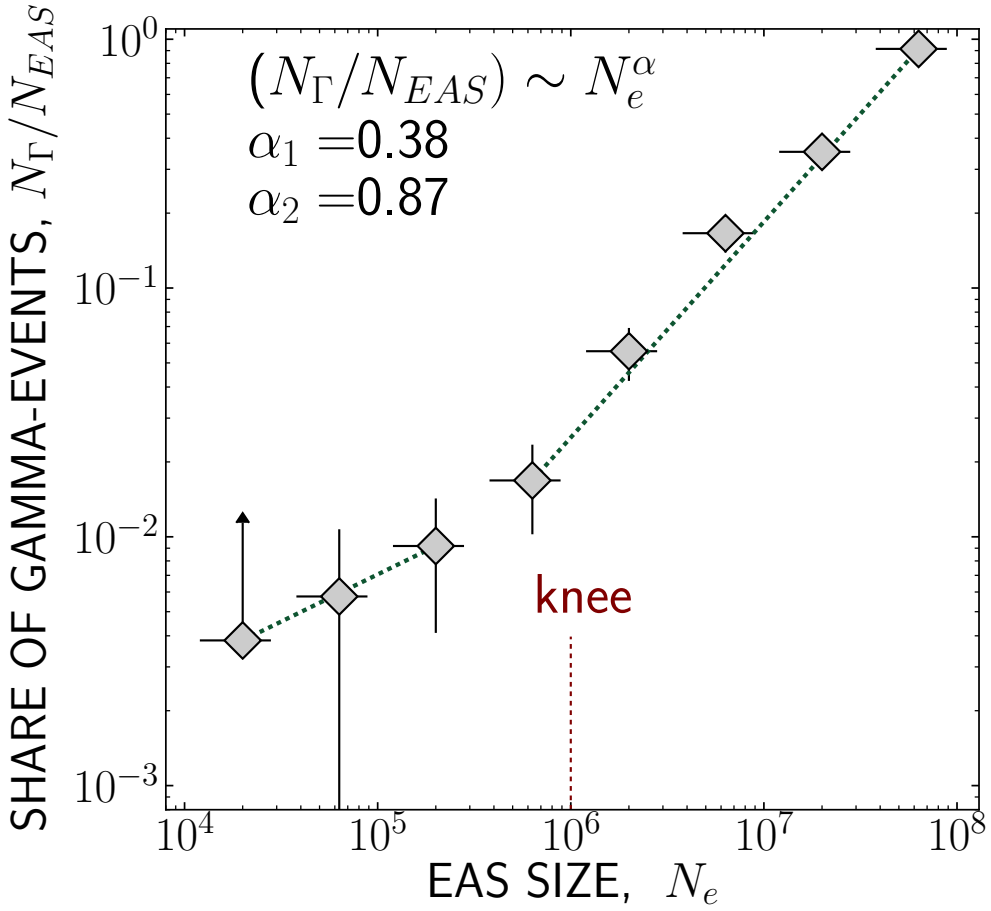
Statistics of the "excessive" gamma emission events

- Lateral distribution



- Relative observation frequency

"events with gamma / total EAS count"



$R \leqslant 20$ m around the gamma detector;
540000 EAS taken for the period of
20 Sep 2016 ... 5 May 2018.

CONCLUSION

- the average temporal, lateral, and multiplicity characteristics of low-energy neutron accompaniment were obtained for the $10^{14} - 10^{16}$eV EAS;
- within the central EAS region (up to 5–10 m from shower axis) the integral neutron fluence detected after a shower passage varies in the limits of 10^{-3}–10^{-2} cm^{-2} for the said range of primary EAS energies;
- seemingly, the behavior of the average neutron flux parameters changes noticeably near the knee of primary cosmic ray spectrum;
- remarkable events with excessively prolonged emission of soft gamma radiation (the flux of 50–100 keV gamma rays remains at the level of 10–500 $cm^{-2}s^{-1}$ up to a few hundreds of milliseconds after the passage of shower front) were found amongst the cases when the cores of above-the-knee EAS were passing in vicinity to detector system.