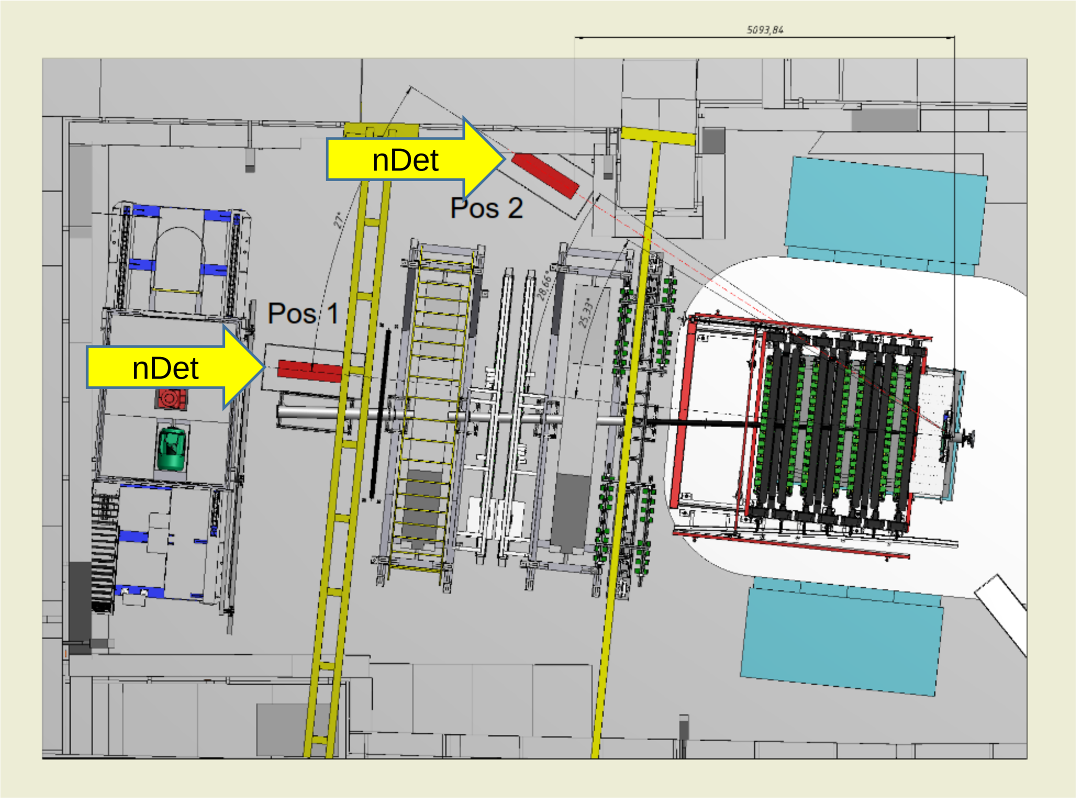
High **G**ranularity **N**eutron detector prototype test in Xe run

Sakulin Dmitriy

On behalf of JINR/KCTEP/INR team

10th Collaboration Meeting of the BM@N Experiment at the NICA Facility 2023

Objectives



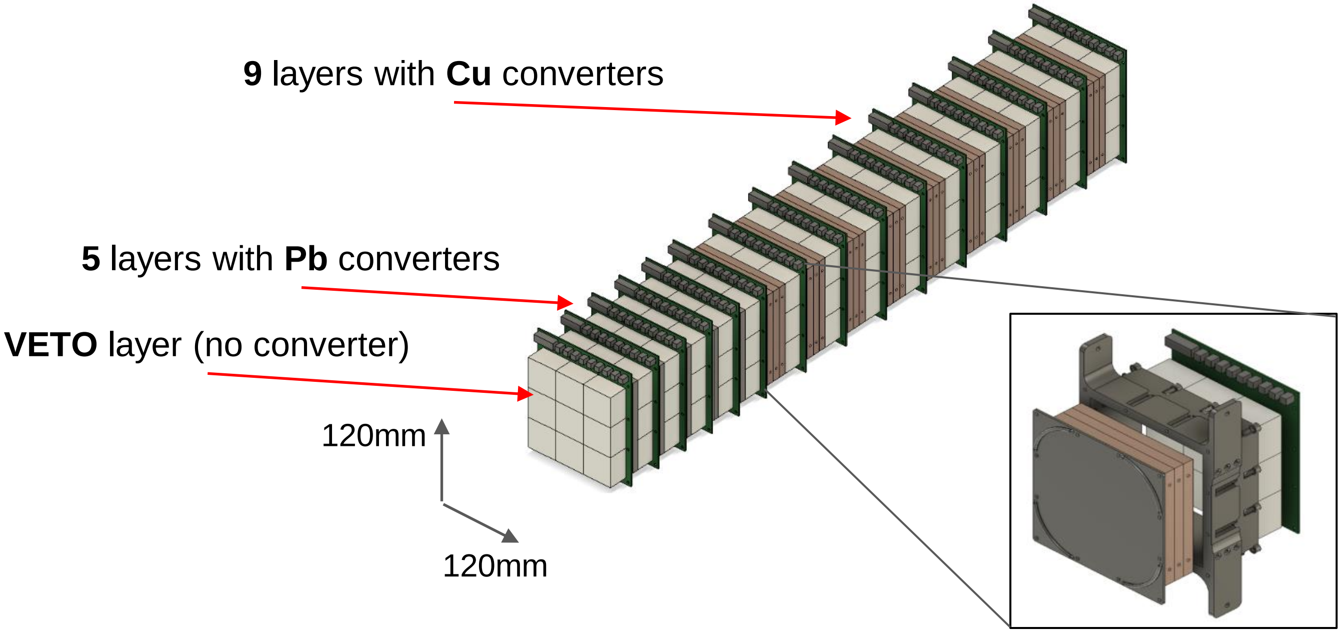
Beam test of HGN prototype for the BM@N experiment;

Identification and energy measurements of fast neutrons up to 4 GeV energies;

Investigation of background conditions on the setup;

Investigation of the time resolution during neutron registration.

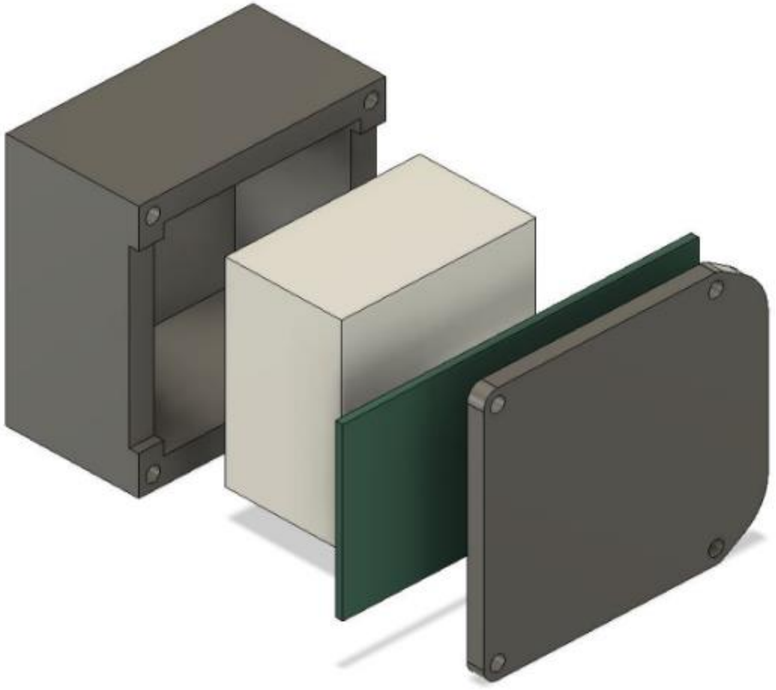
HGN prototype layout



- 3D-printed detector casings
- Light-tight assembly
- Options for Pb, Cu and no converter

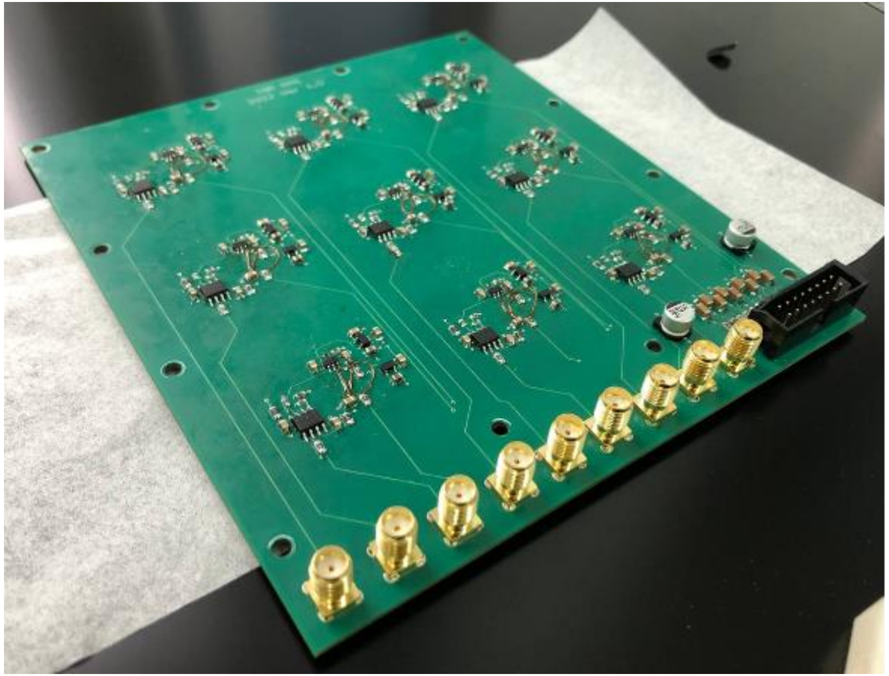
One layer consists of 3x3 cells
Scintillator cell – 40 x 40 x 25 mm^3
Total readout channels 9+45+81 = 135
Total size – 120 x 120 x 825 mm^3
Total nuclear interaction length ~ 2

HGN prototype cell



- JINR-produced fast scintillator
  - Polystyrol + 1.5% p-terphenil and 0.01% POPOP
  - Scintillator cell – 40 x 40 x 25 mm^3
- Timing resolution evaluated with a single-channel detector and a MCP-based trigger
- Photodetector: Hamamatsu S13360-6050PE
  - $6x6mm^2$ photosensitive area
  - 14400 px per ch
  - 50 μm px size
  - $1.7x10^6$ gain
  - 40% PDE

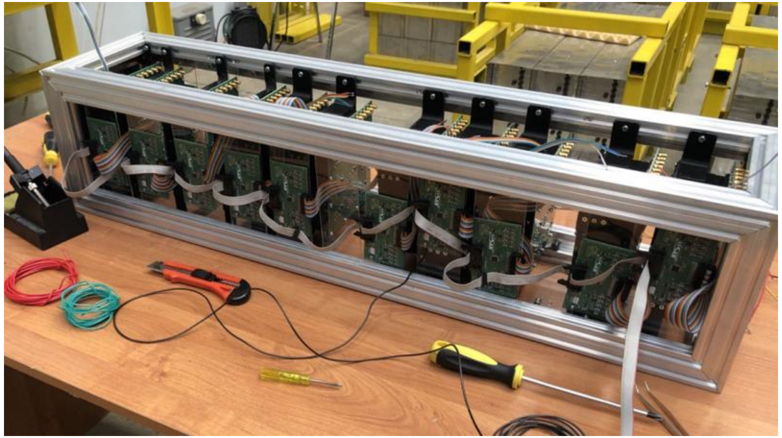
HGN prototype electronics



- **Two types of PCBs** with photodetectors were designed in INR and ITEP
  - Used 9 SiPM per board
  - INR boards are compatible with COMPASS V3 bias supplies
  - KCTEP boards are supplied by single HV source

HGN prototype mechanics

- Detector modules are independent
    - May be inserted and removed with minimal disassembly
- Bias supply system is modular with variable module count



- Support structure for HGN positioning
    - ~2m tall
    - On rollers with retractable feet
    - ~1m high shelf for readout equipment
    - Shelf for additional weight on the bottom
    - Adjustable on all 3 axes of movement and rotation
    - Built with 40x40 Bosch Rexroth profile

HGN neutrons energy resolution and efficiency vs kinetic energy

HGN

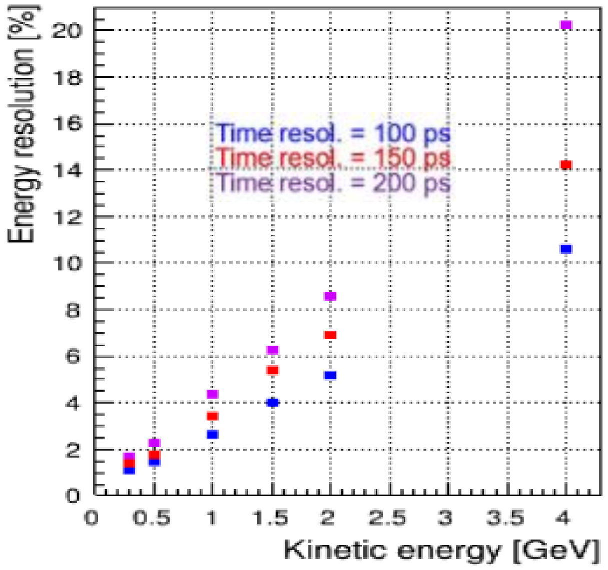
780 cm, 12x12 cm, 9 mods, 4x4 cm, 10000 ev., **w/o magnetic field, 82.5 cm**

Veto 2.5 cm + 5 slices (Pb 0.8 cm + Sc 2.5 cm + G10 0.5cm + Air 0.5 cm) **+**
9 slices (Cu 3 cm + Sc 2.5 cm + G10 0.5cm + Air 0.5 cm)

Time cut in HGN**:** time < **55** nsec (in simulations)

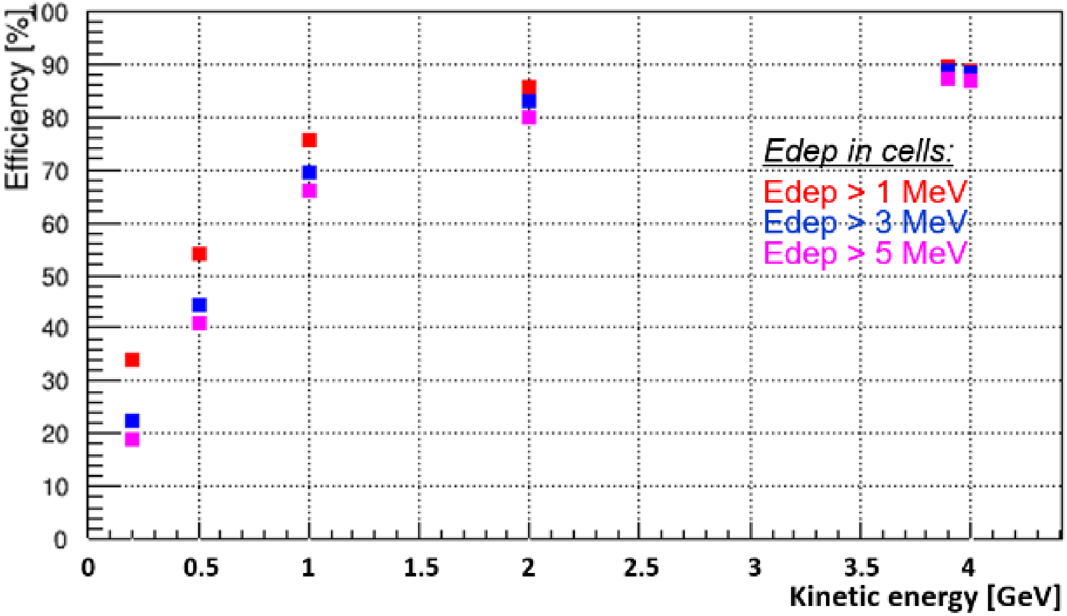
Vac. in cave, neutrons multiplicity = 1, BOX generator, "Huge" spot

Neutrons energy resolution



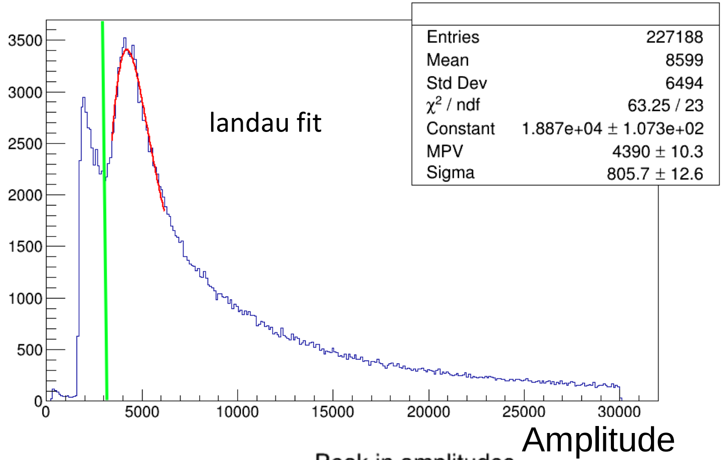
Kinetic energy is reconstructed with hit with min. time,
Edep in cells > 3 MeV and w/o hits in Veto

Efficiency



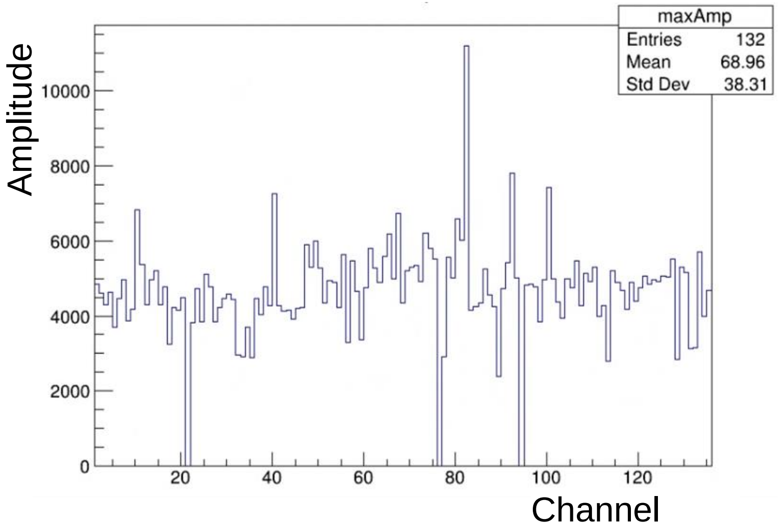
Inefficiency = nb of events w/o hits in nDet / nb of analyzed events
*Efficiency [%] = (1 – Inefficiency) * 100*
Nb of slices in nZDC = 1, 2, ... 14)

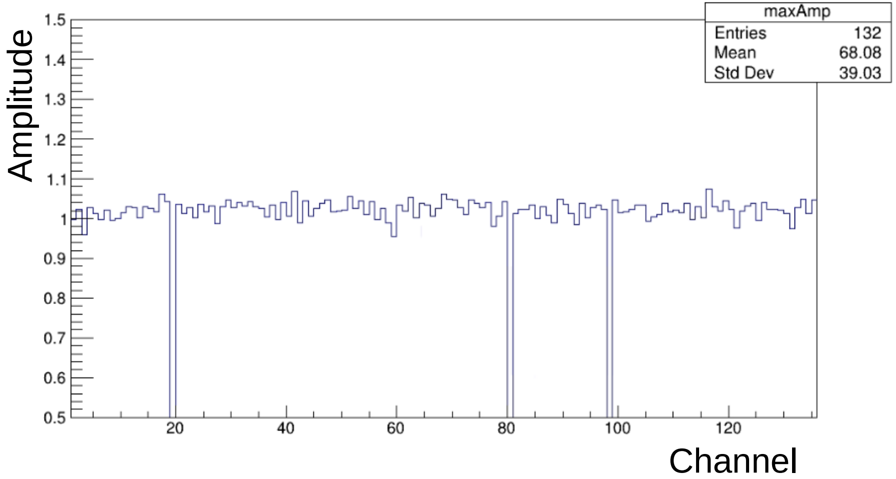
Normalization of amplitudes



Peak in amplitudes

C = 1/ MPV
Ampl = Ampl * C



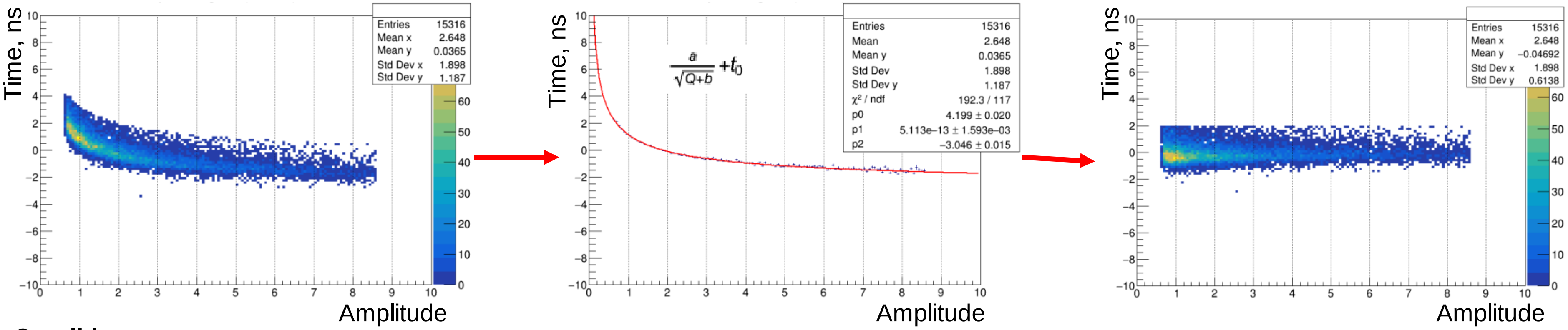


Measurement conditions

Xe+CsI interactions
Selection of events with one Xe core
Trigger CCT2
0 degree position
Energy 3.86 AGeV
No hits in the veto layer for cut off charged particles
Cell times of the first triggered layer in the event

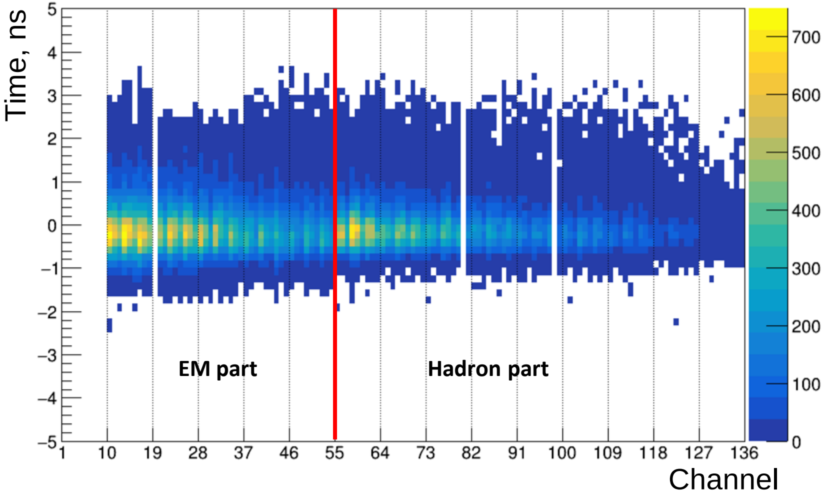
Slewing correction

Dependence between time and amplitude for one detector channel



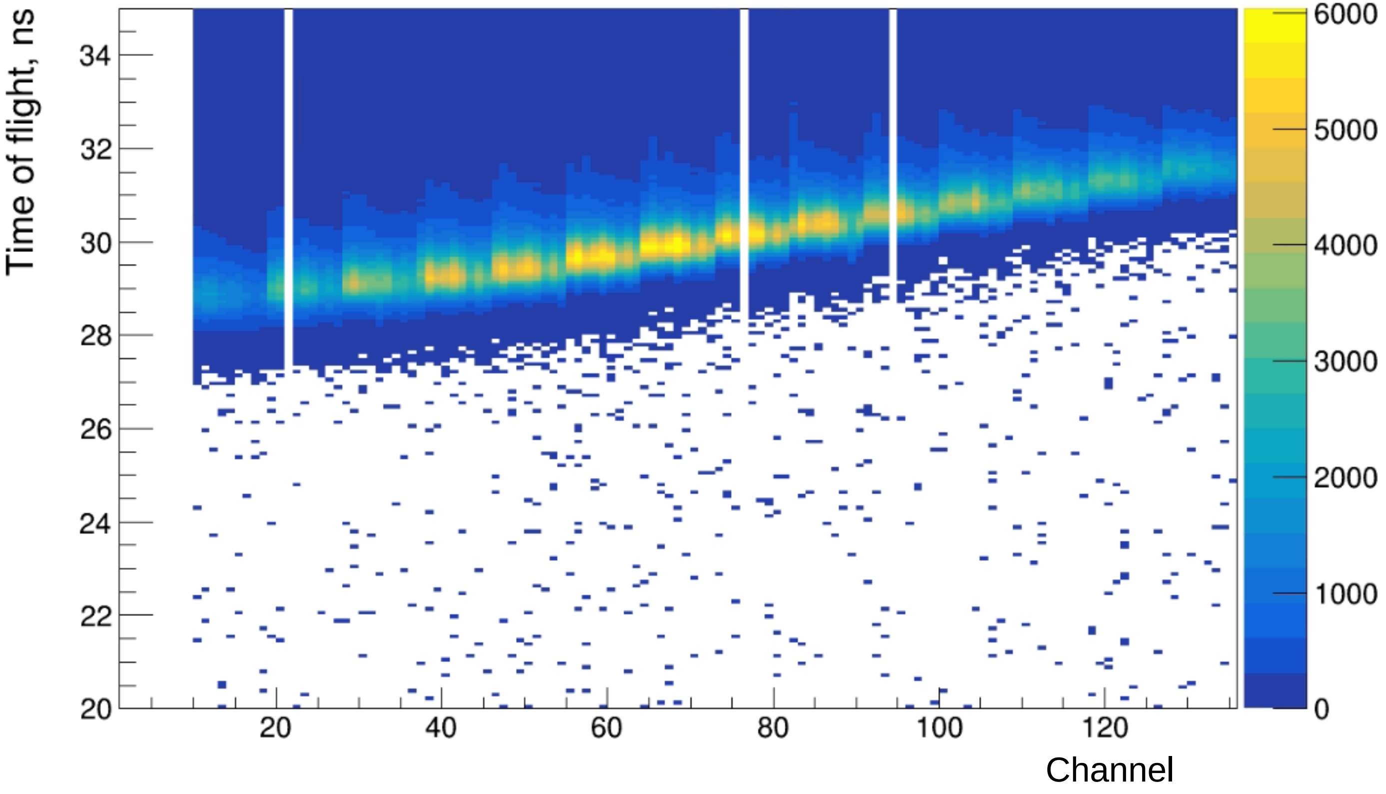
Conditions:

- Individual amplitude thresholds have been selected to cut off background events
- Amplitudes was normalized to MIP peak
- Slewing correction for start counter

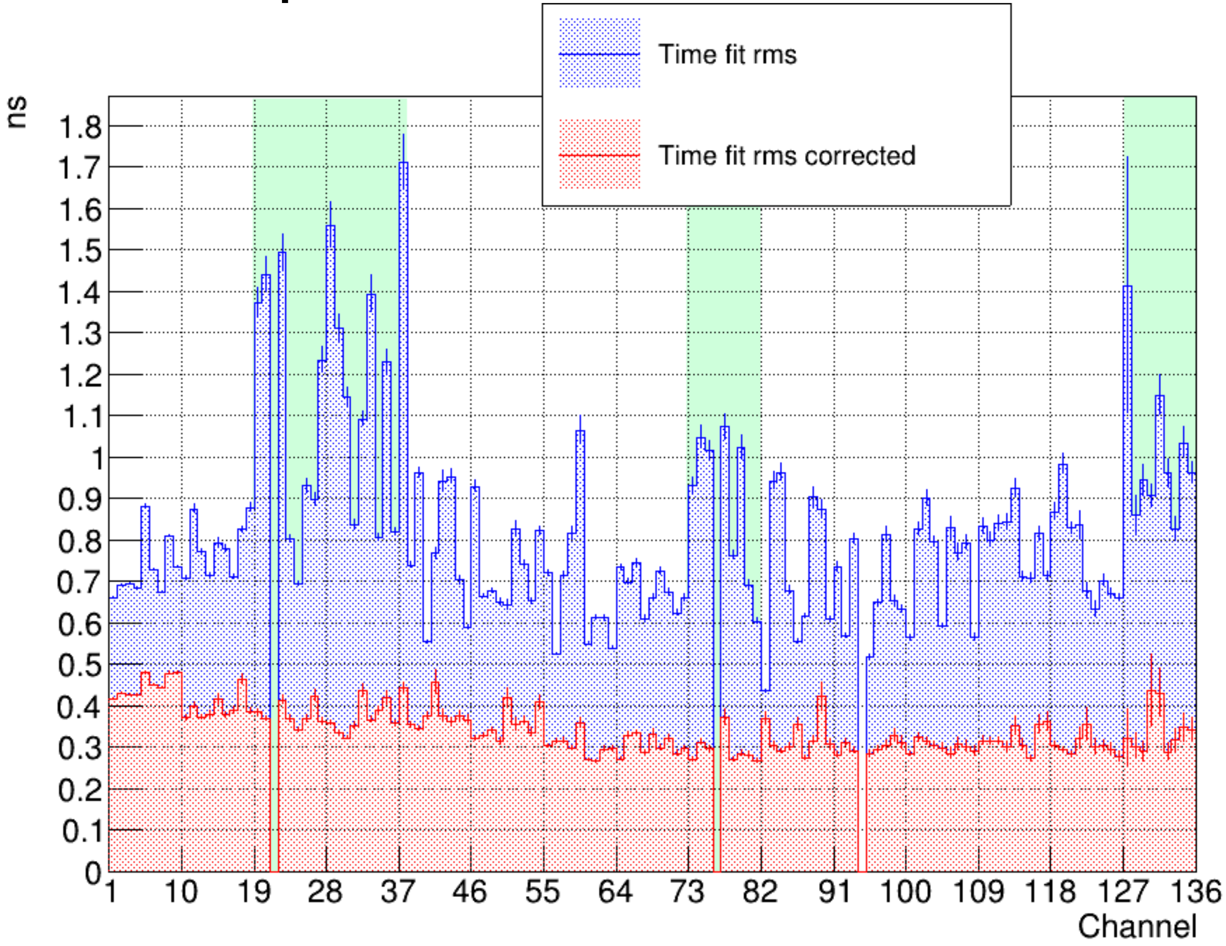


Time of flight for all detector channels

The time was calculated depending on the distance from the target to the detector layer and the neutron velocity.
The time peak corresponds to the neutron energy of 3.86 GeV



Uniformity of the time parameters



Estimation of time resolution of single cells

Cut – hits in 4 layers: (i) & (i+1) & (i+2) & (i+3)

Layers 6 – 11

Run ID	Trigger	N_ events	Ndet pos	CCT2 & BC1S ev.	Ndet ev.	Veto=0 ev.
7513-7521	Mixed	3M	0°	986k	634k	465k

1st step 1-3 layers

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

1st step 2-4 layers

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

2nd step 1-3 layers

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

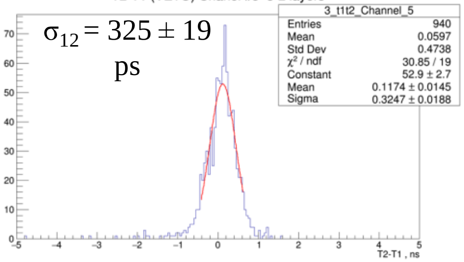
2nd step 2-4 layers

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

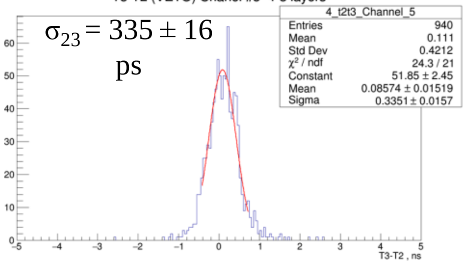
$$\sigma_1^2 + \sigma_2^2 = \sigma_{12}^2$$
$$\sigma_2^2 + \sigma_3^2 = \sigma_{23}^2$$
$$\sigma_1^2 + \sigma_3^2 = \sigma_{13}^2$$

$$\sigma_1 = \sqrt{((\sigma_{12}^2 + \sigma_{13}^2 - \sigma_{23}^2)/2)}$$
$$\sigma_2 = \sqrt{((\sigma_{12}^2 + \sigma_{23}^2 - \sigma_{13}^2)/2)}$$
$$\sigma_3 = \sqrt{((\sigma_{13}^2 + \sigma_{23}^2 - \sigma_{12}^2)/2)}$$

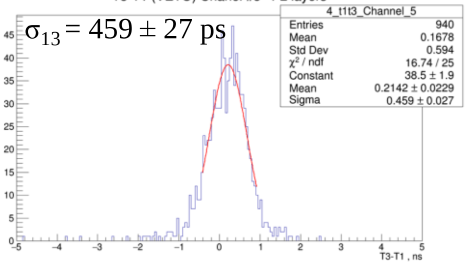
T2-T1 (VETO) Chanel #5 3-2 layers



T3-T2 (VETO) Chanel #5 4-3 layers



T3-T1 (VETO) Chanel #5 4-2 layers



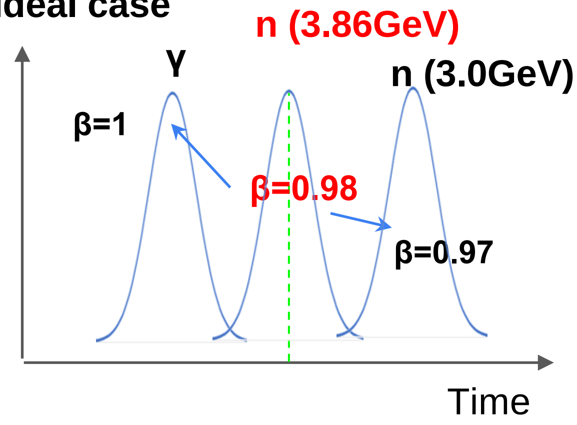
Cell 1	***Cell 2***	***Cell 3***
202±10	213±21	206±21
127±8	124±23	141±34
197±8	207±10	197±15
Cell 4	***Cell 5***	***Cell 6***
221±19	249±28	234±65
131±27	154±23	150±69
206±25	247±11	220±55
Cell 7	***Cell 8***	***Cell 9***
186±12	-	206±12
118±19	-	126±11
187±22	-	200±11

For center cell

134±27 ps

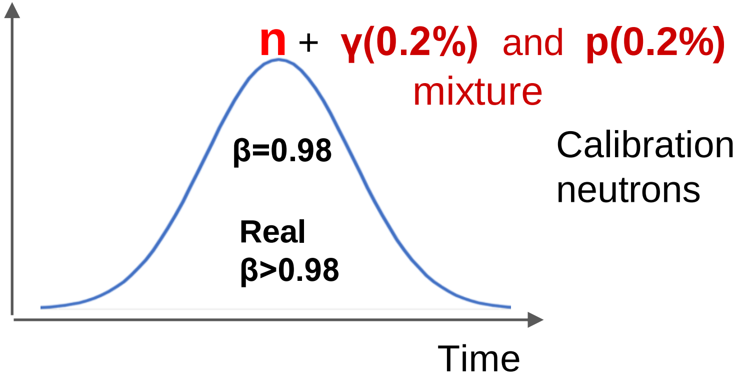
Reconstruction of neutron energy from time of flight

Ideal case

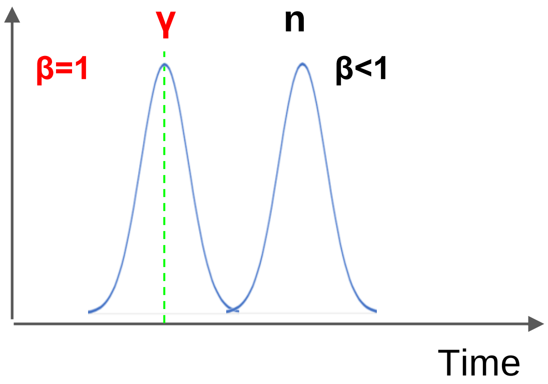


Calibration on neutrons

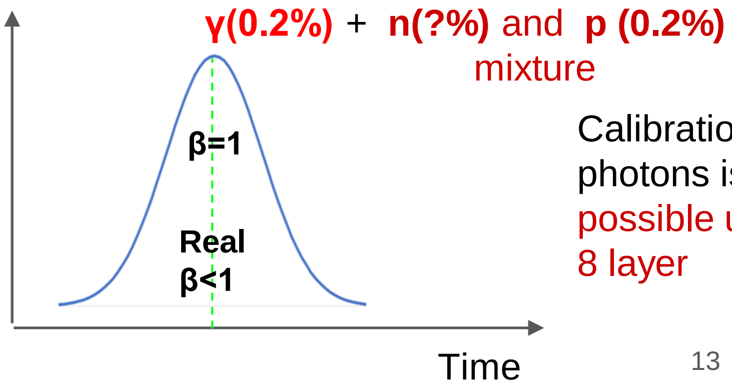
Real data



Calibration on neutrons



Calibration on photons



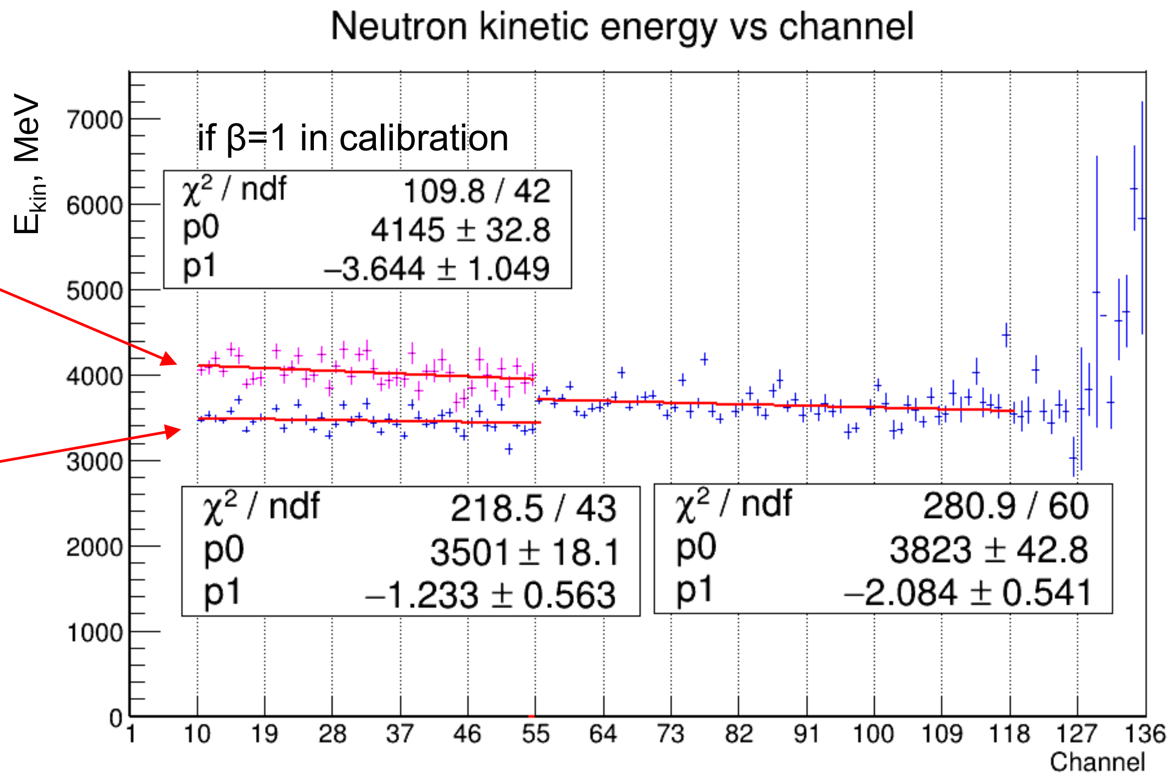
Calibration on photons is possible up to 8 layer

Reconstruction of neutron energy from time of flight

Dependence of the energy reconstruction on the calibration method based on the time spectra of photons and neutrons

Based on photon calibration

Based on neutrons calibration

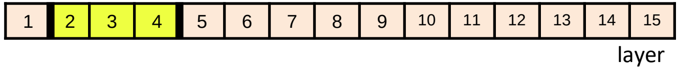


Gamma events selection

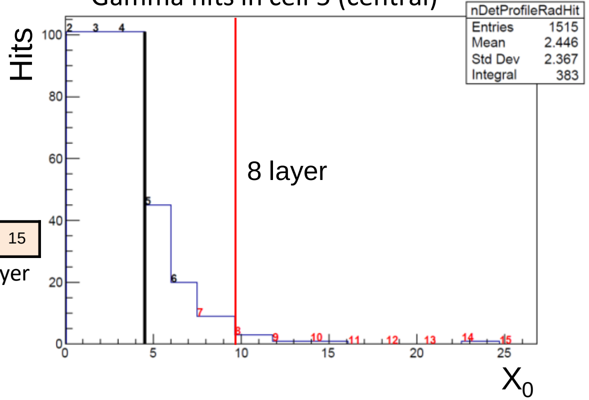
"Gamma":

- Veto == 0
- Ampl > 0.5 MIP
- Hits in layers 2 & 3 & 4 in cell

=> 4.52 X_0 or 0.266 λ_{int}

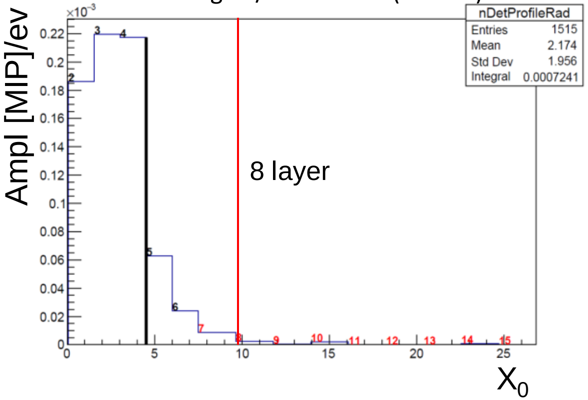


Gamma hits in cell 5 (central)



Single individual cells

Gamma signal/ev. in cell 5 (central)



Full HGN prototype (all cells)

Runs 8100-8104 (CsI 2%)
HGN 27 deg. pos.
Hit selection: Ampl > 0.5 MIP
Total number of events:
(CCT2+BC1S) – 1202k (100%)
+ Veto – 68.2k (5.67%)

Cell 1 (layer 3 didn't work)	***Cell 2*** **0.0092 %** ±0.0009 %	***Cell 3*** **0.0097 %** ±0.0009 %
Cell 4 **0.0202 %** ±0.0013 %	***Cell 5*** **0.0084 %** ±0.0008 %	***Cell 6*** **0.0099 %** ±0.0009 %
Cell 7 **0.0221 %** ±0.0014 %	***Cell 8*** **0.0118 %** ±0.0010 %	***Cell 9*** **0.0102 %** ±0.0009 %

0.17317 %
±0.00004 **%**

~15 times more then in one cell

Comparable with simulation (0.1 – 0.2%)

Neutron energy determination algorithms

1. Minimum time in first triggered layer

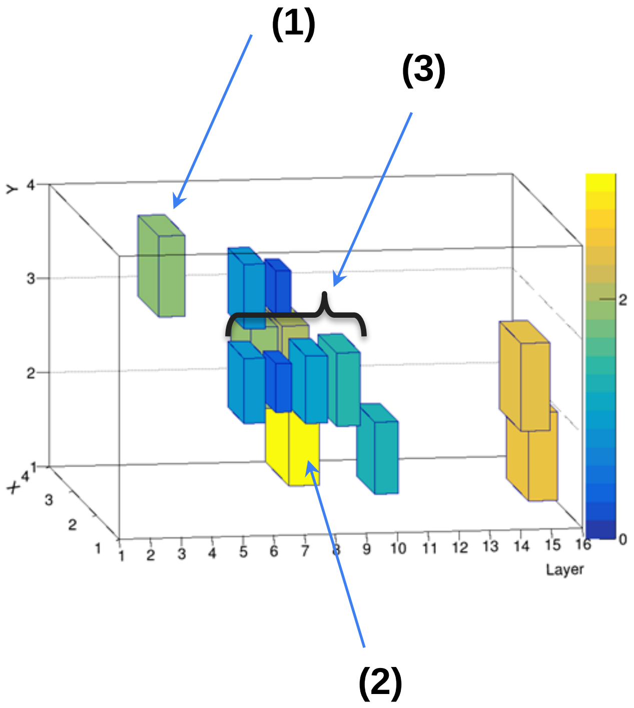
- First triggered layer on the Z axis;
- Cell with the minimum time in this layer $\textbf{time}_{\textbf{layer}}$
- Cut on EM shower

2. Maximum particle speed in event

- Cell with the maximum particle speed in event $\textbf{time}_{\textbf{event}}$

3. Search for neutron clusters

- In the first approximation, the simplest clusters containing 4 consecutive cells was considered

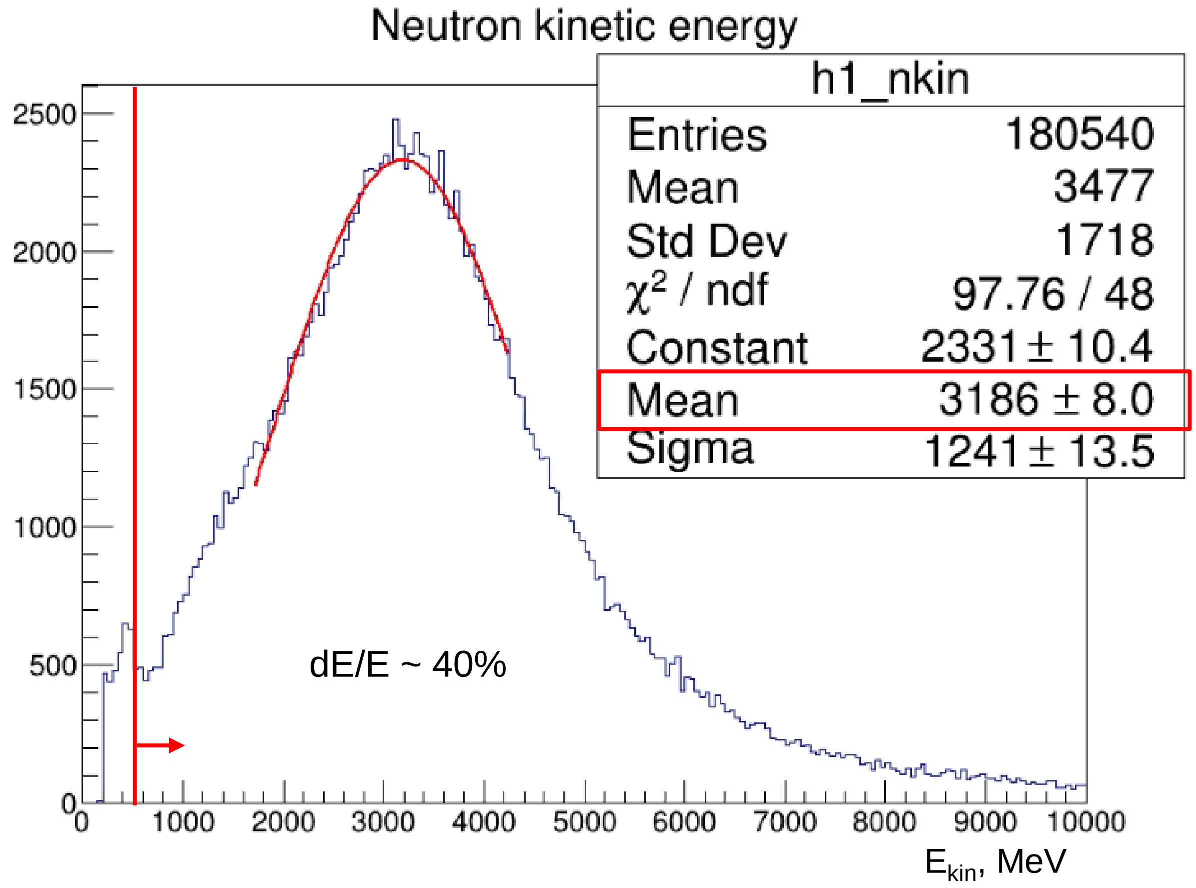


1. Minimum time in first triggered layer

Beam energy 3.86 AGeV

Search:
- First triggered layer on the Z axis;
- Cell with the minimum time in this layer $\mathbf{time_{layer}}$

No signals in VETO layer;
E_{kin} > 500 MeV

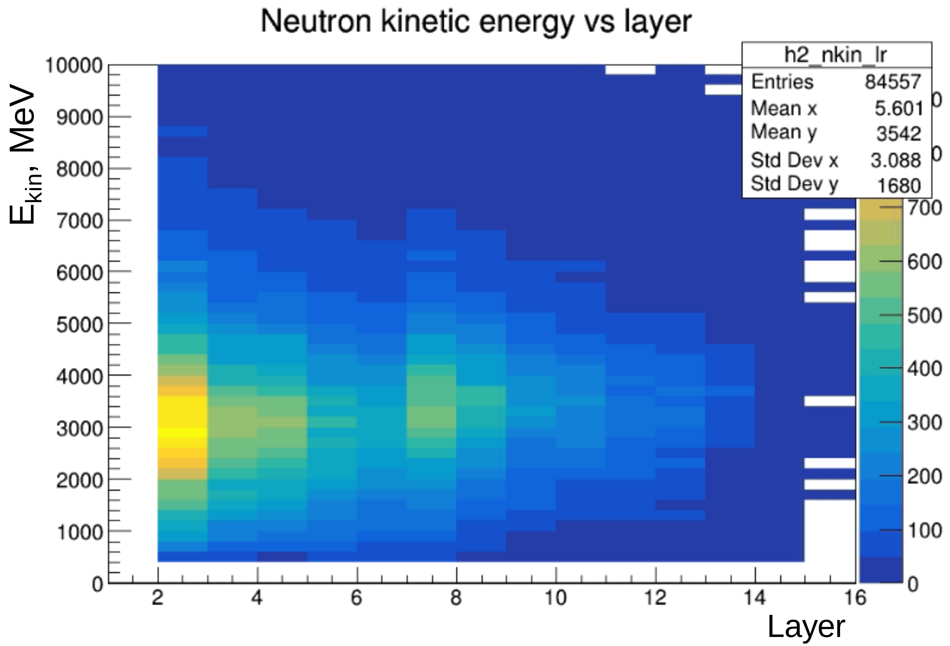


Gamma suppression

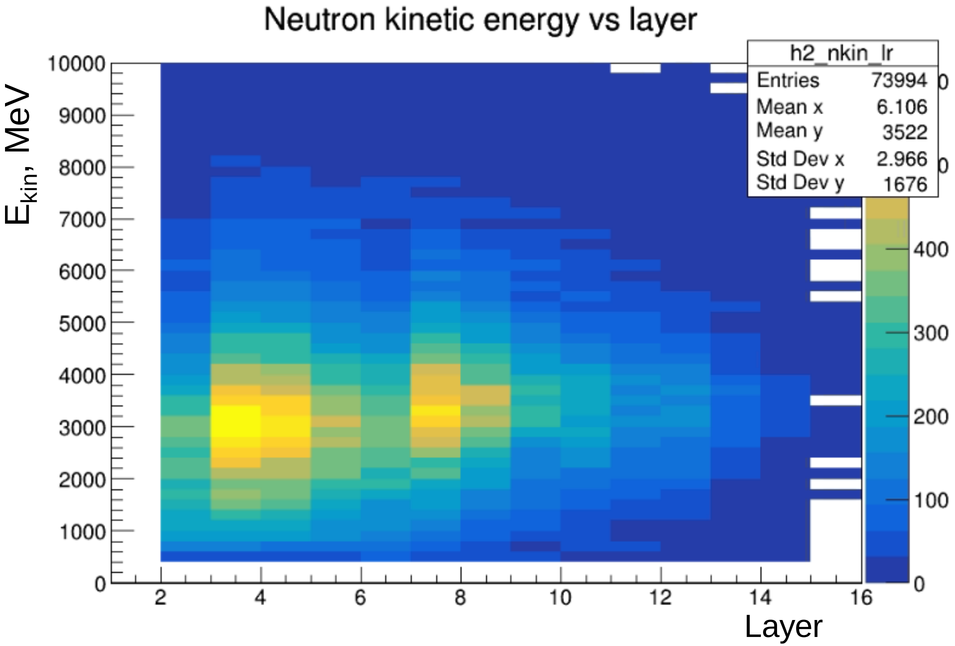
Mix of neutrons and electrons in EM part

Conditions for the selection of events without electromagnetic shower

Only VETO



NO hits in veto and in three first layers simultaneously

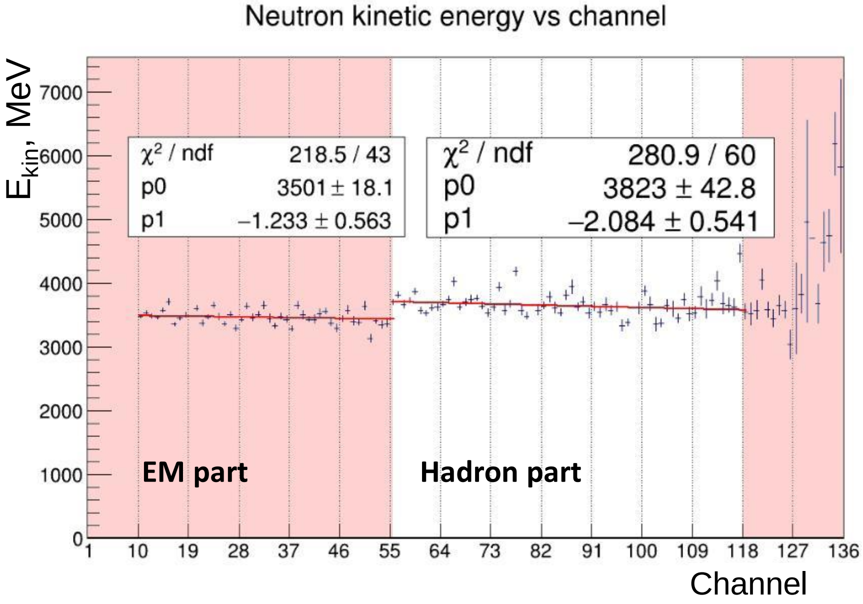


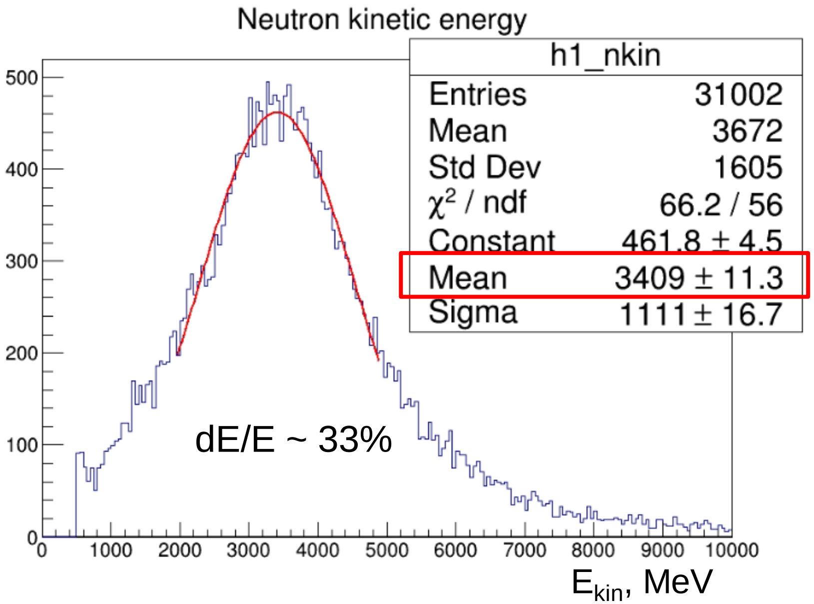
Statistics decreased by 12%

- # Cut on EM part

6 < Layer **time$_{layer}$** < 14

Applied conditions make the energy lower due to the presence of EM processes in the calibration data





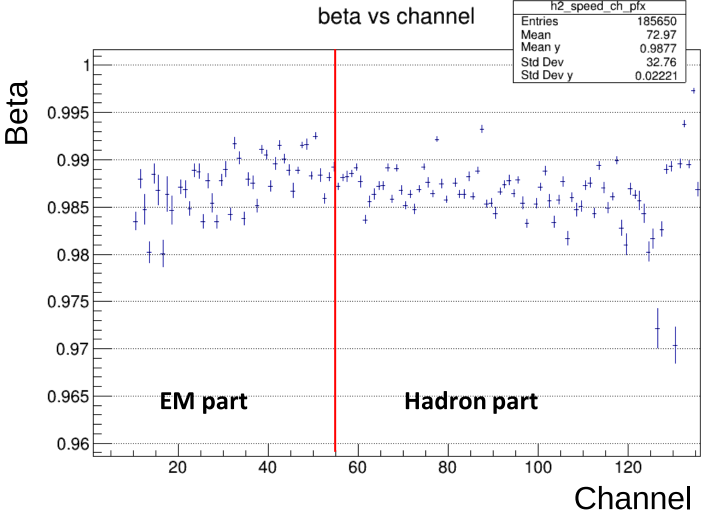
2. Maximum particle speed in event

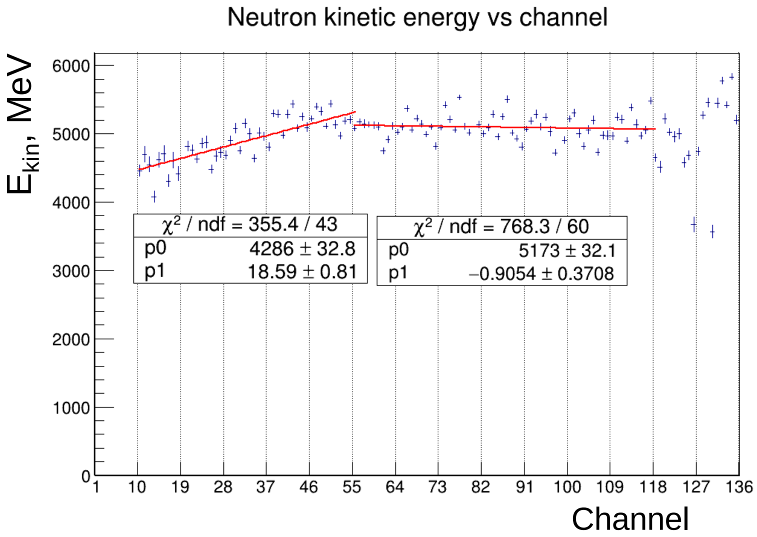
Beam energy 3.86 AGeV

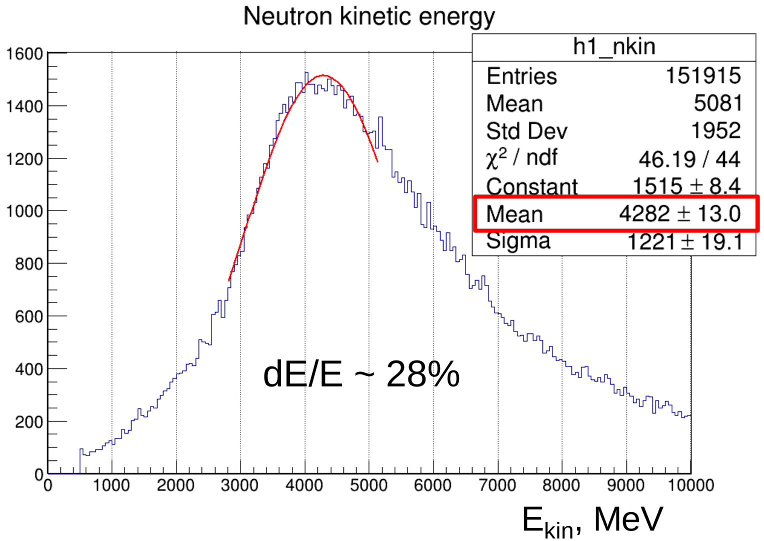
Search:

- Cell with the maximum particle speed in event **$time_{event}$**

No signals in VETO layer;
E_k > 500 MeV







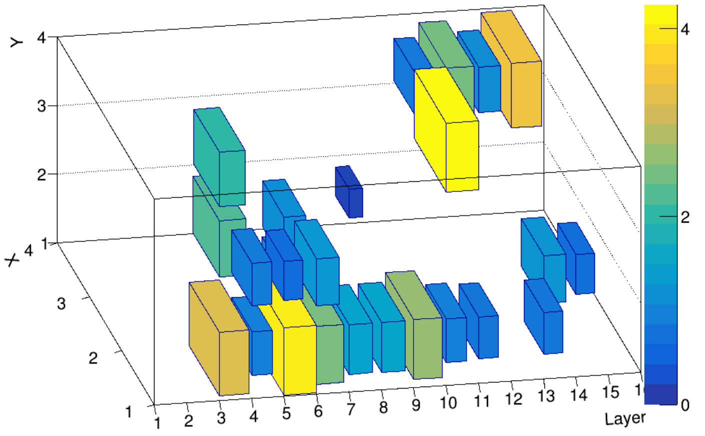
3. Clusterization

Beam energy 3.86 AGeV

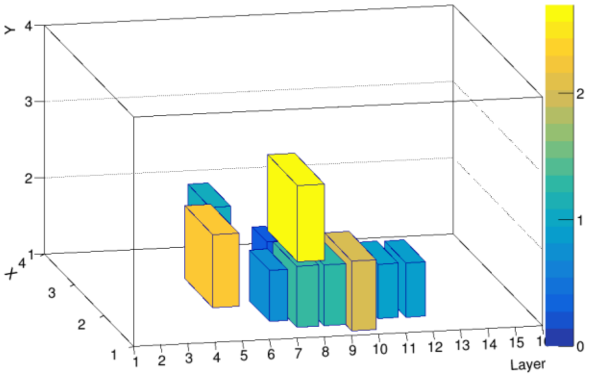
The neutron detector was designed to select clusters and analyze it for reconstruction of neutrons energy.
In the first approximation, the simplest clusters containing 4 consecutive cells was considered

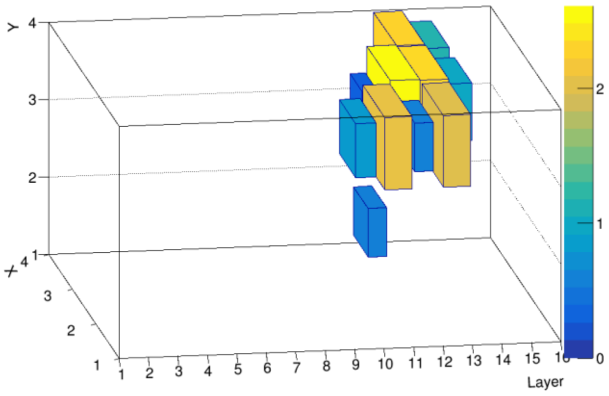
Search:

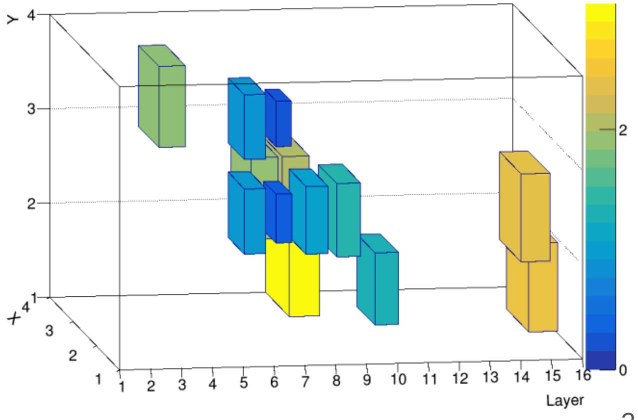
- 4 layers triggered in a row along the Z axis within the boundaries of one cell
- Average cluster speed



No signals in VETO layer;
E_{kin} > 500 MeV





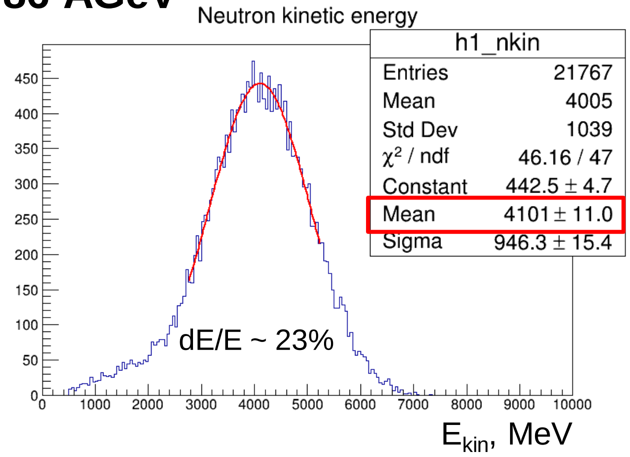


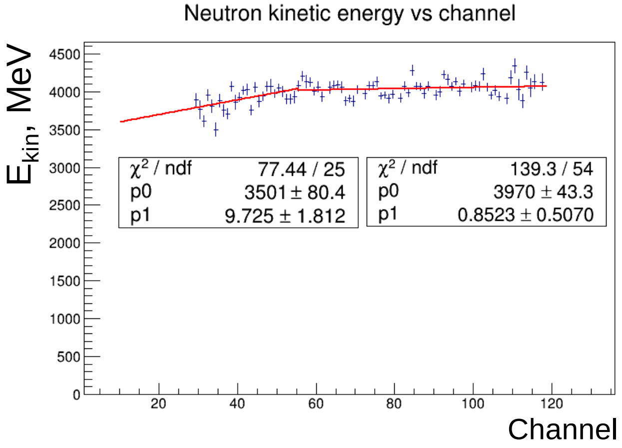
Clusterization

The neutron energy was determined by the average value of the energy measured in each cell of the cluster. Cells with energy $E > E_{mean} + 3\sigma$ was skipped

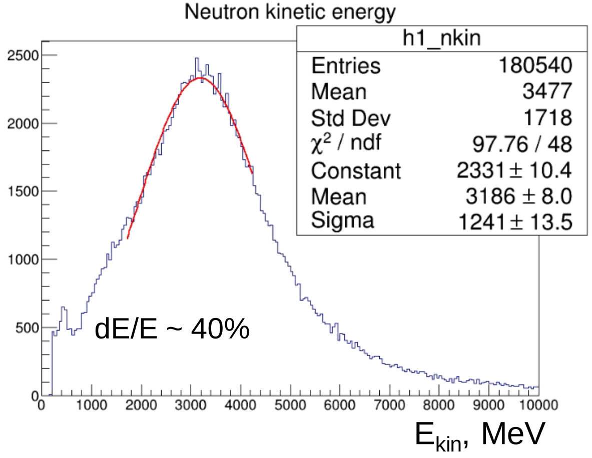
Beam energy 3.86 AGeV

With clustering (No EM shower in calibration)





W/O clustering

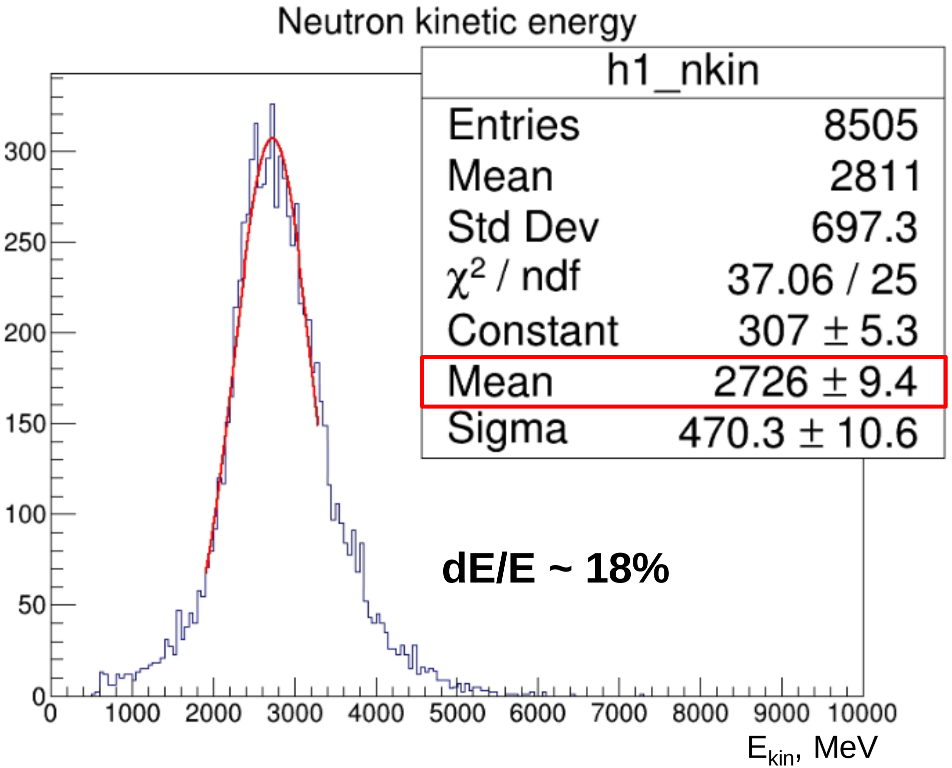


Clusterization

Beam energy 3 AGeV

$E < E_{mean} + 3\sigma$

With clustering
(No EM shower
in calibration)



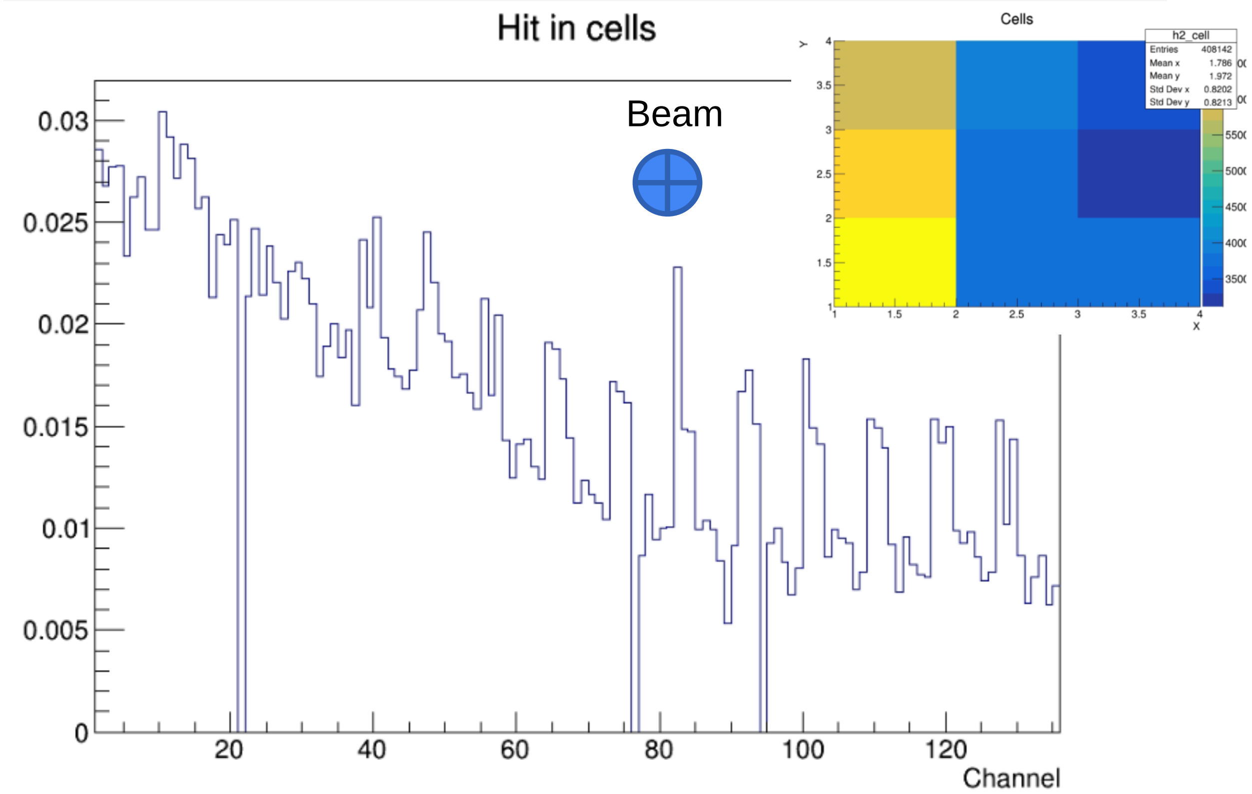
dE/E ~ 18%

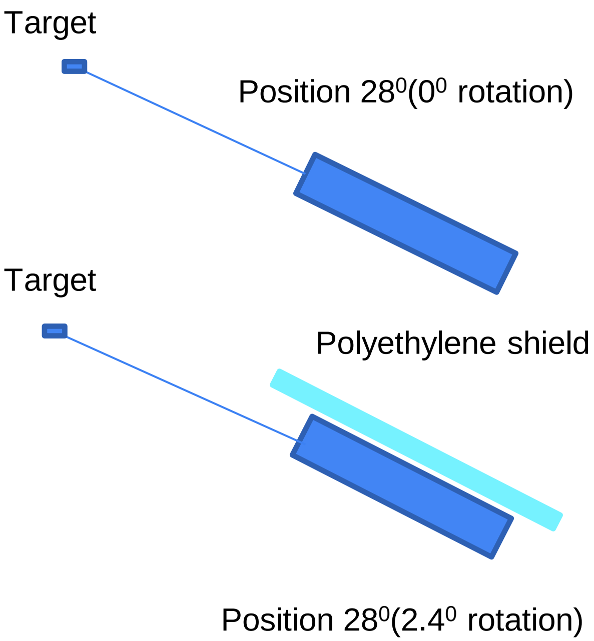
Status, conclusions and further work

- Prototype of neutron detector based on 3.86 and 3 AGeV beams in various configurations was assembled and successfully tested;
- The time resolution of 134 ps was achieved for cells;
- 3 methods of neutron energy reconstruction was tested;
- Obtained energy resolution is comparable to simulation;
- The results will be used for development of HGN detector;
- Need to next effort for data analysis.

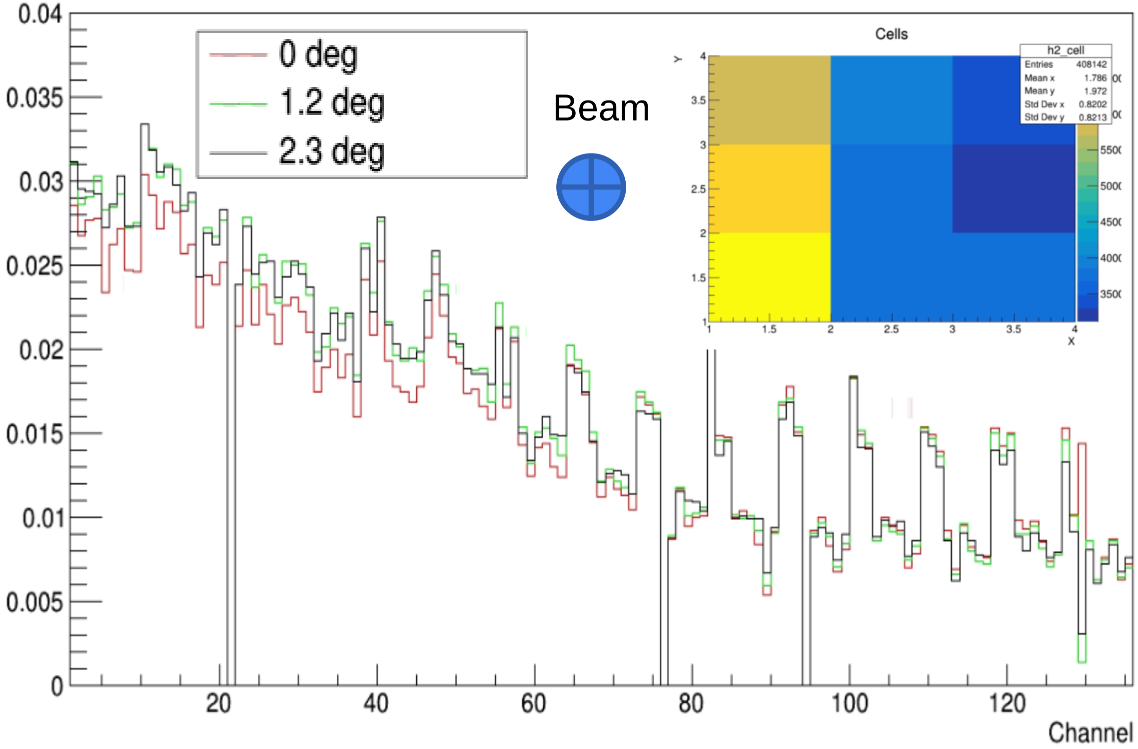
Thanks for attention

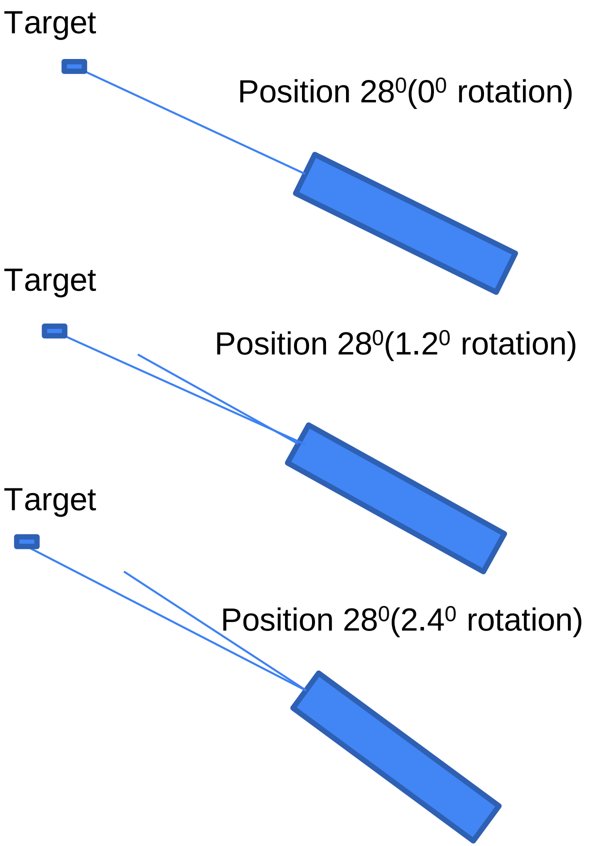
Non uniform occupancy in the cells of HGN. (position 28^0)



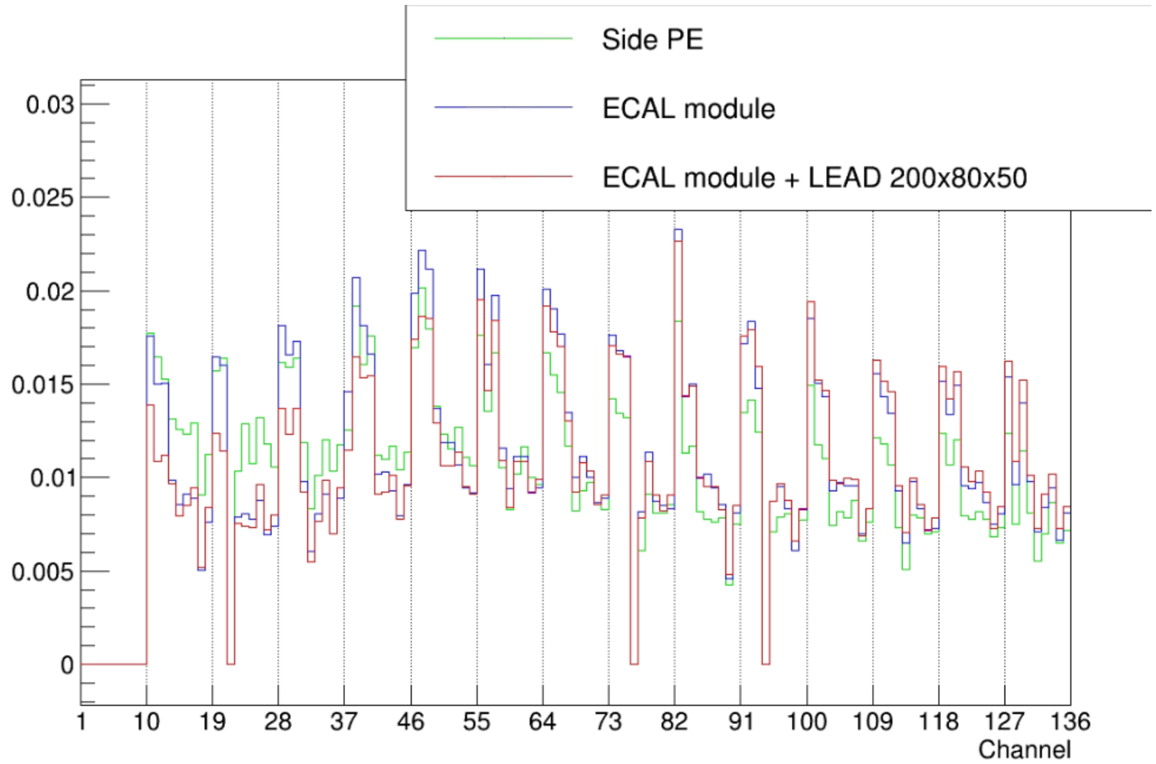


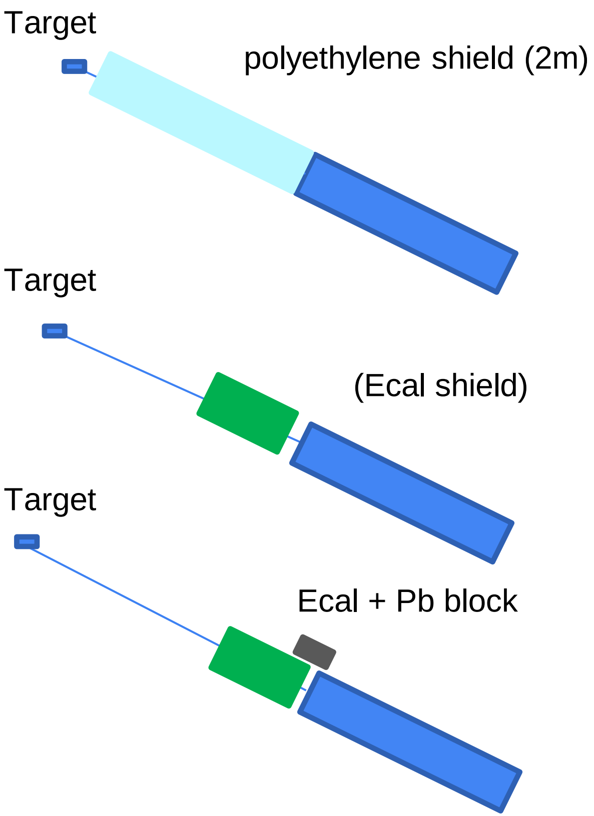
Non uniform occupancy in the cells of HGN. (position 28^0)





Non uniform occupancy in the cells of HGN. (position 28^0)





Backside background from GEM +TOF+…