Online monitoring of the High Granular Neutron Time-of-Flight Detector prototype for the BM@N experiment

A. Zubankov[1,2]

[1]*Institute for Nuclear Research, Moscow, Russia; pr. 60-letiya Oktyabrya 7a, Moscow, Russia*
[2]*Moscow Engineering Physics Institute , Moscow, Russia; Kashirskoe highway 31, Moscow, Russia*

The XXVII International Scientific Conference of Young Scientists and Specialists (AYSS-2023)

The High Granular Neutron Time-of-Flight Detector (HGND) at the BM@N experiment will be used for measurement of neutrons produced in nucleus-nucleus collisions. For the first time, the prototype of the HGND was used in Xe+CsI at 3.0 and 3.8 AGeV run at the BM@N. The multilayer structure (absorber/scintillator) of the detector makes it possible to identify and measure the energies of neutrons produced in nucleus-nucleus collisions. The online real-time monitoring system recently developed and used for the HGND prototype is discussed. Additionally, the preliminary results of the HGND prototype data analysis are presented.

BM@N experiment

The BM@N (Baryonic Matter at Nuclotron) experiment is aimed at studying nuclear matter during the interaction of relativistic heavy ion beams with fixed targets in the energy range up to 4.5 AGeV, which is intermediate between experiments at the SIS-18 and NICA/FAIR facilities.

Main objectives of the BM@N experiment:

- Study of the QCD diagram at high baryon densities
- Study of the formation of multi-strange hyperons
- Search for hypernuclei in nucleus-nucleus collisions
- Study of the azimuthal asymmetry of charged particle yields in collisions of heavy nuclei.

The EoS establishes the relationship between pressure, density, energy, temperature and the **symmetry energy**:

$$E_A(\rho,\delta) = E_A(\rho,0) + \mathbf{E_{sym}(\rho)} \cdot \delta^2 + O(\delta^4)$$

The symmetry energy term characterizes the **isospin asymmetry** of nuclear matter:

$$\delta = (\rho_n - \rho_p)/\rho$$

The ratio of the directed and elliptic neutron flow to corresponding flow of protons is a sensitive observable of the symmetry energy contribution to the EoS of high density nuclear matter.

To measure yields and flow of neutrons at the BM@N a new **High Granular Neutron Time-of-Flight Detector** (HGND) is now developed and constructed.

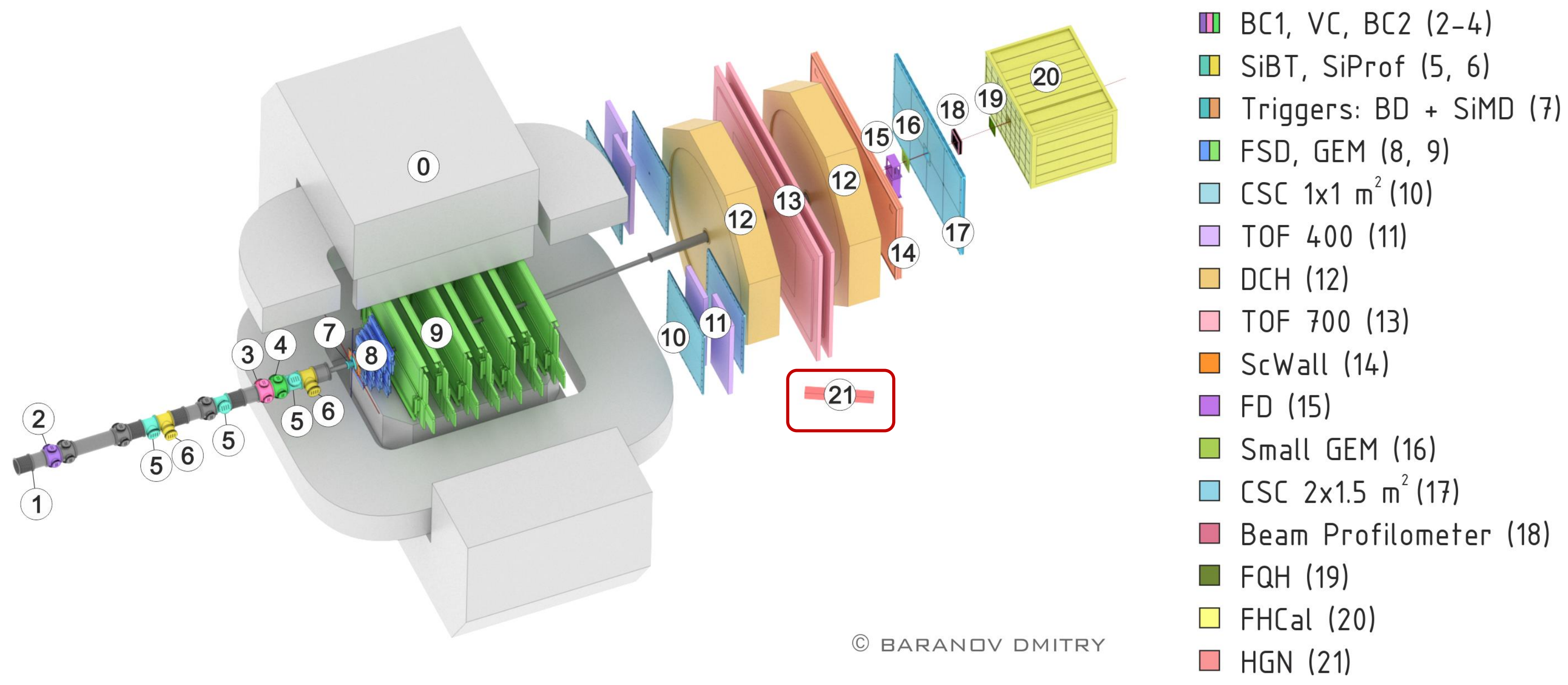
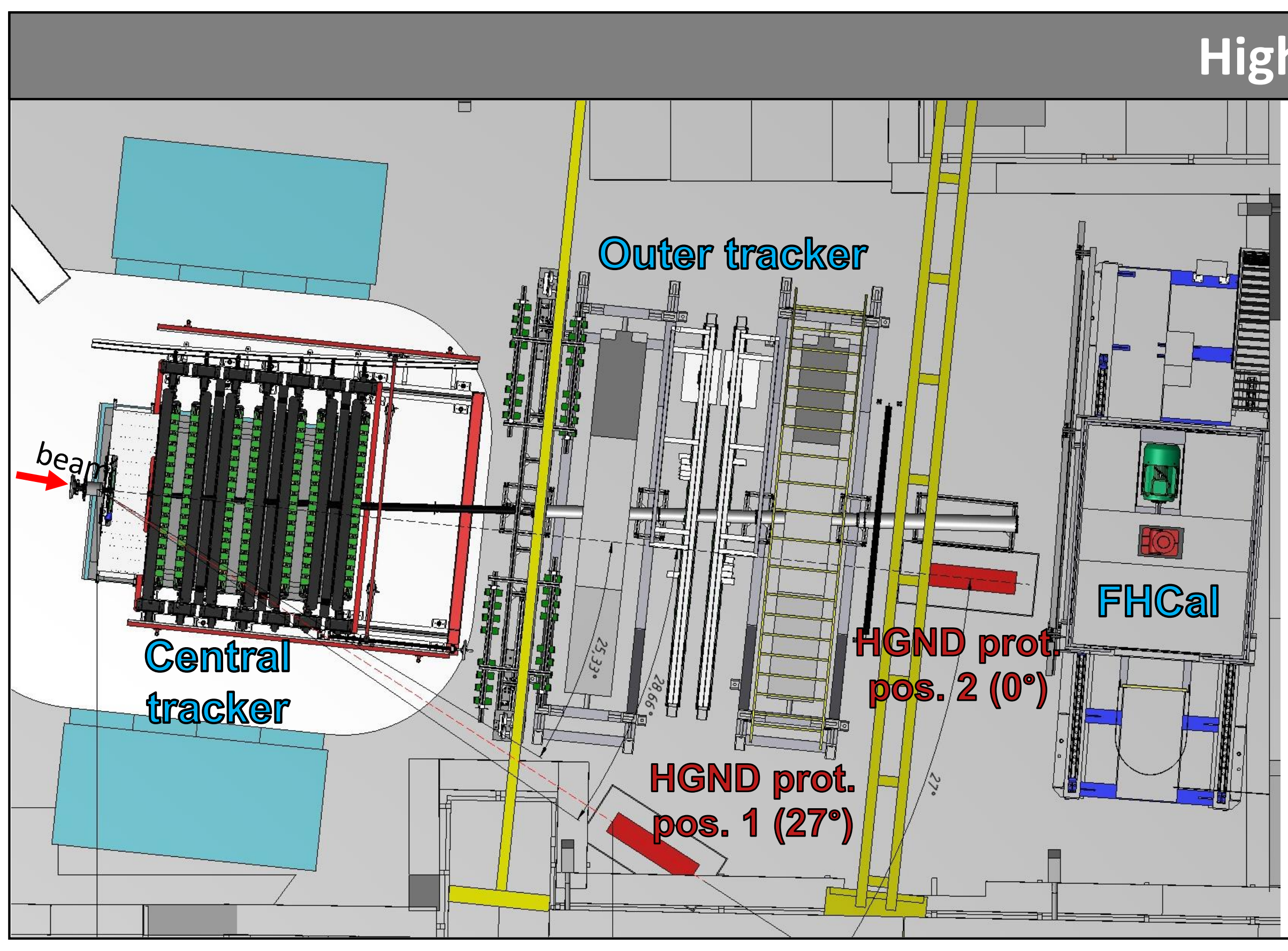


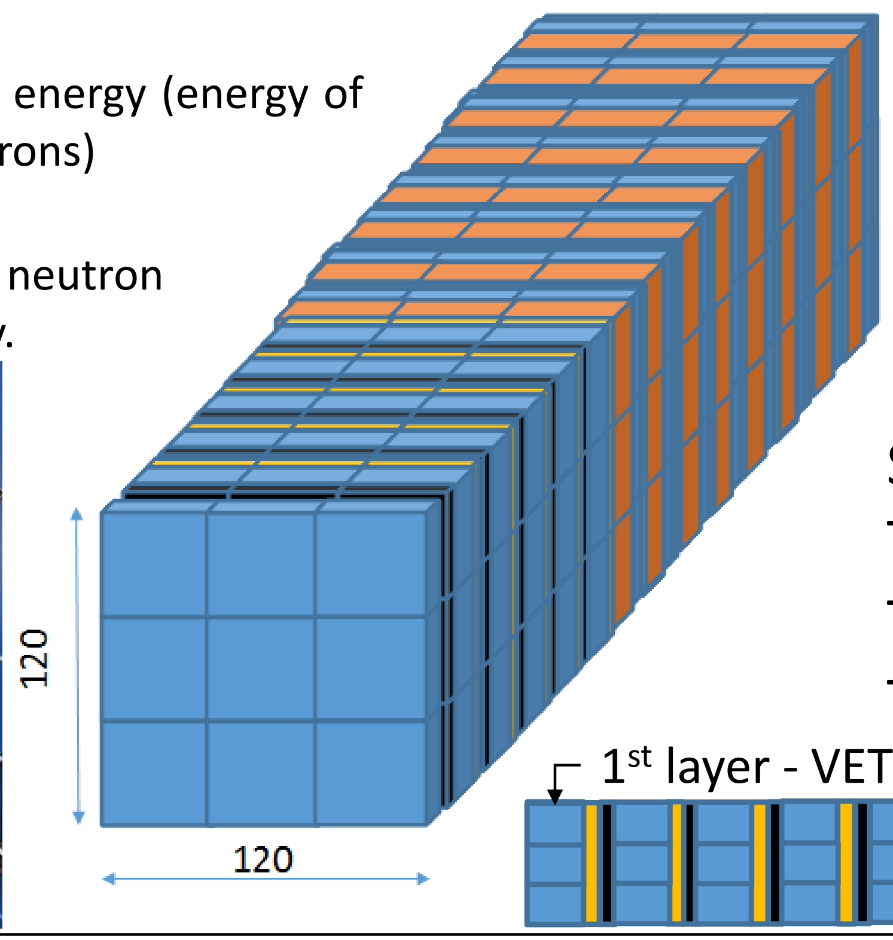
Fig.1. Scheme of the BM@N setup in the Xe beam run.

For the first time, the HGND prototype was used in Xe+CsI at 3.8 and 3.0 AGeV run. The BM@N setup is shown in Fig.1, where the HGND prototype is labeled 21.

High Granular Neutron Time-of-Flight Detector (HGND) prototype

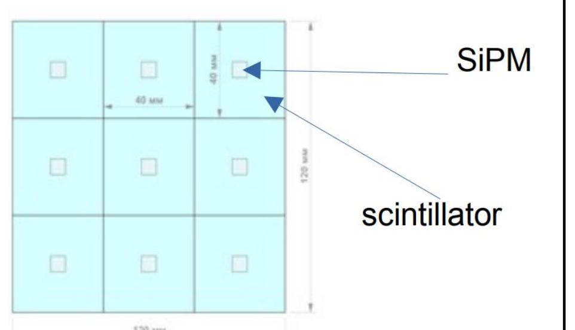


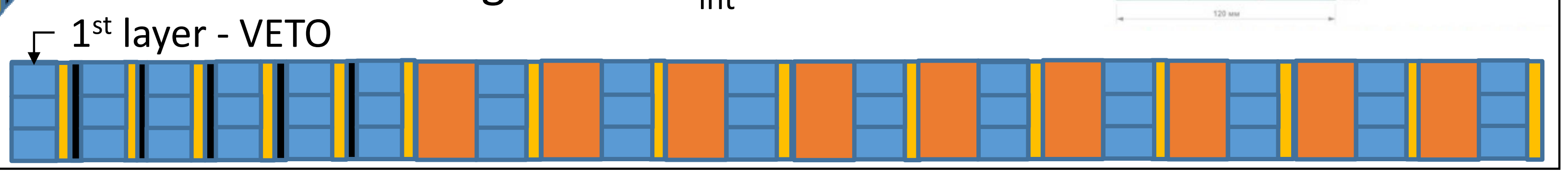
0° position:
Test with known neutron energy (energy of a beam of spectator neutrons)
27° position:
Measurements of the neutron spectrum at ~ midrapidity.



- Scint. layer **Veto** 120x120x25 (мм)
- 1st (electromagnetic) part:
  5 layers: Pb (8mm) + Scint. (25mm) + PCB + air
- 2nd (hadronic) part:
  9 layers: Cu (30mm) + Scint. (25mm) + PCB + air

Scint. cell – 40 x 40 x 25 mm^3
Total number of cells – 9+45+81=135
Total size – 12 x 12 x 82.5 см^3
Total length ~ 2.5 λ_{int}

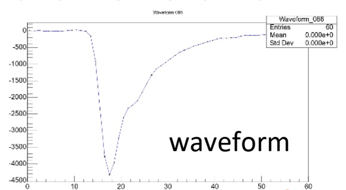


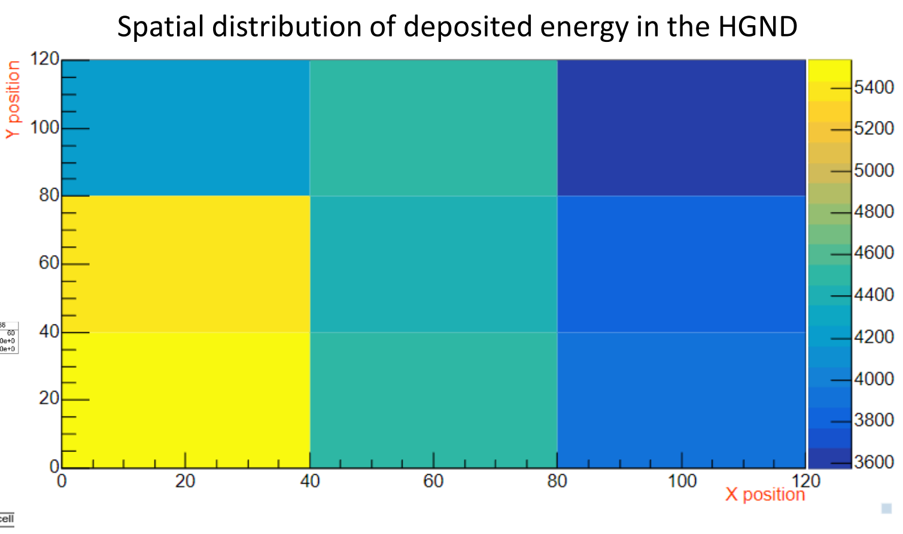


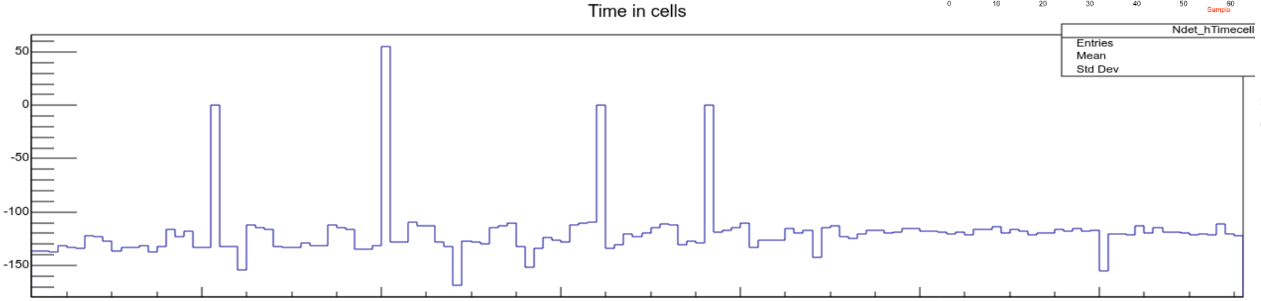
Online monitoring of HGND prototype

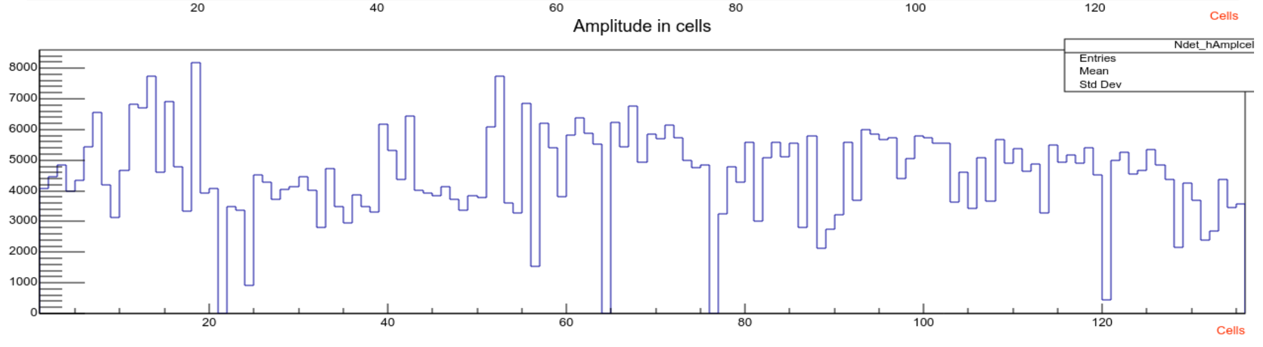
Allows real-time monitoring of detector response using updated histograms. Based on BmnRoot.

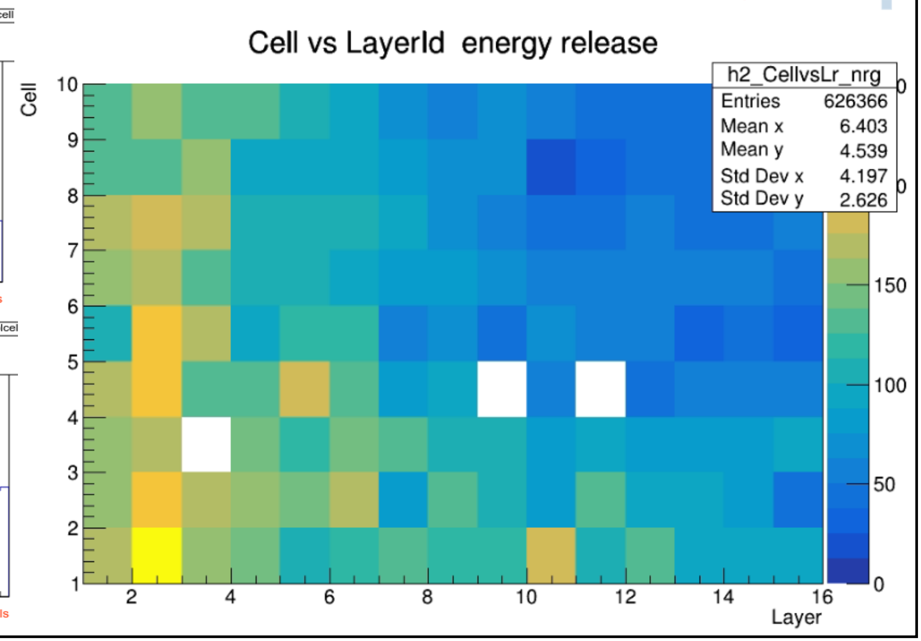
- Implemented channel selection for drawing waveforms and spectra
- Implemented the ability to overlay simulations and previous data sets on histograms





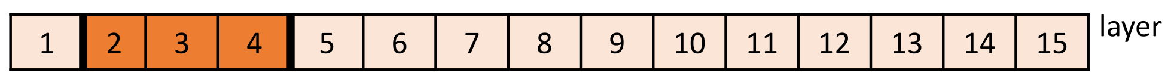






Online monitoring of HGND prototype

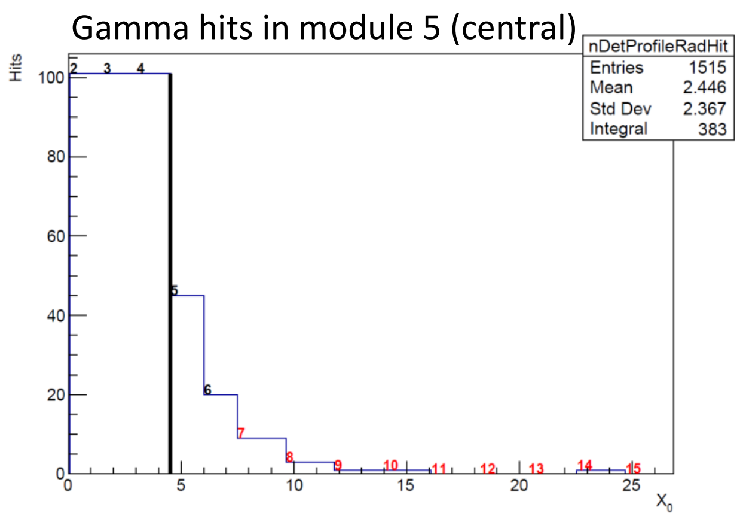
Criterion for selecting events with “γ-quanta”:

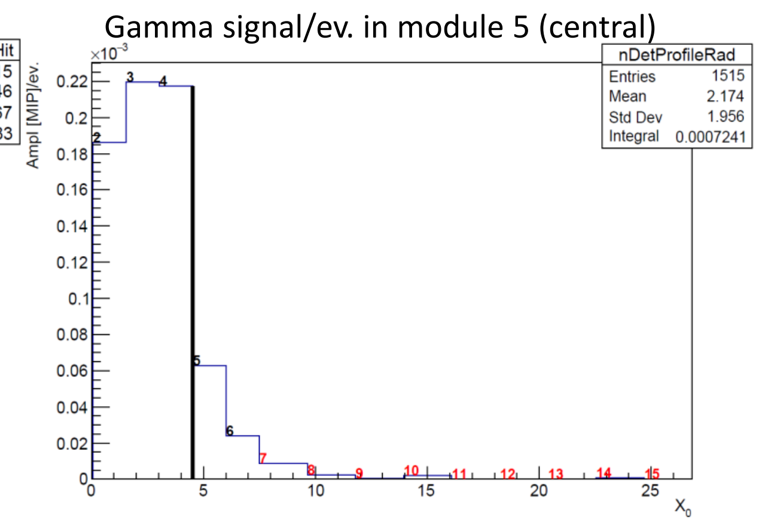


- Veto == 0
- Ampl > 0.5 MIP
- Hits in 2 & 3 & 4 layers in module

=> 4.52 X_0 or 0.266 λ_{int}

Xe + CsI (2%) @ 3.8 AGeV
HGN 27 deg. pos.
Total number of events:
1 Xe ion, central & semi-central collisions – 1.2M (100%)
+ Veto cut – 68.2k (5.67%)





Fraction of γ-ev. in single individual cells

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 %

Fraction of γ-ev. in full HGND prototype (all cells)

0.173 %

~ 15 times more than in one cell

Comparable to simulation (0.1–0.2%)

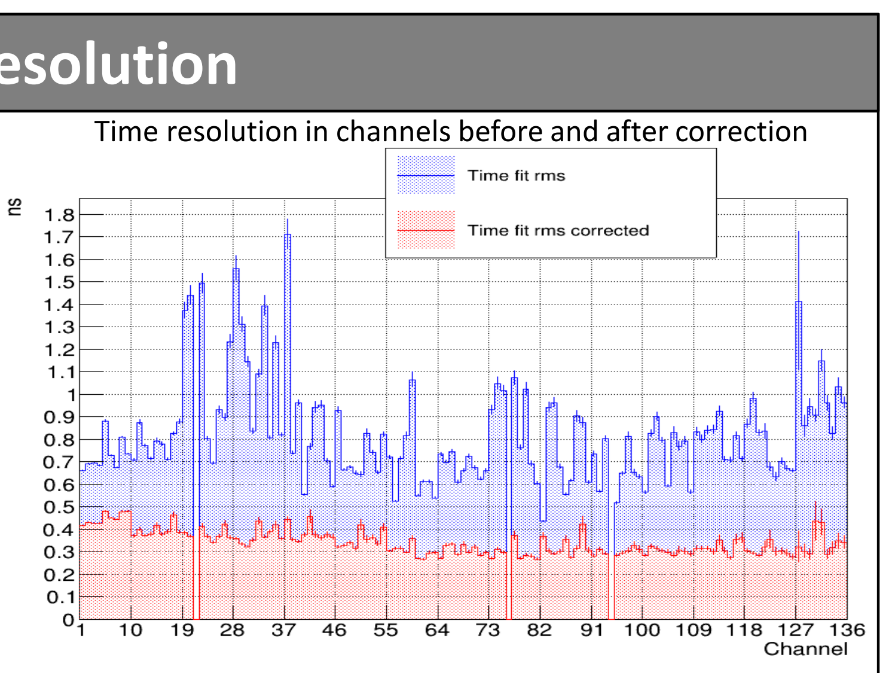
Conclusions

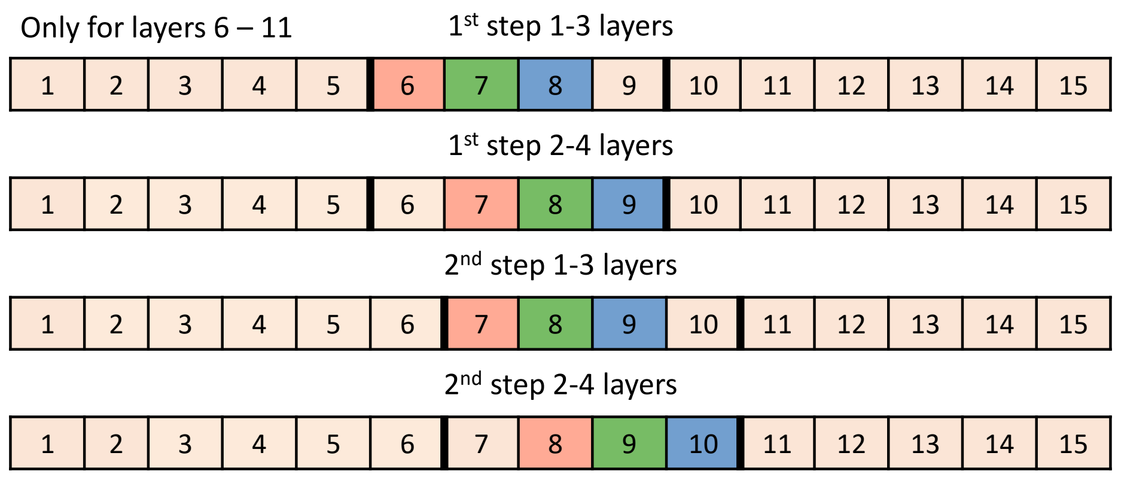
- Online monitoring of the HGND prototype was developed and used to track its response in real time in the Xe run of BM@N
- Time-amplitude correction of signals improved the time resolution by 2.4 times
- The average time resolution of cells was 134±29 ps
- The number of events with γ-quanta was 0.173%, which is comparable to simulation
- The energy spectrum of neutrons was reconstructed for 2 positions of HGND prototype

Estimation of cell time resolution

Time-amplitude correction of signals made it possible to get rid of the dependence of time on signal amplitude, which improved the time resolution by ~2.4 times.

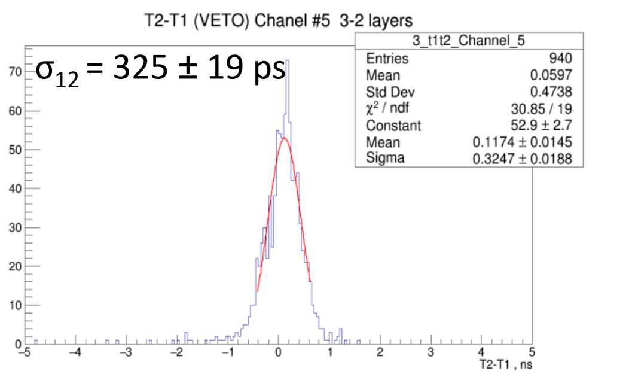
To calculate the time resolution of an individual cell, it is necessary to perform a selection – hits in 4 consecutive layers: (i) & (i+1) & (i+2) & (i+3) – 3 of which are used for calculations.

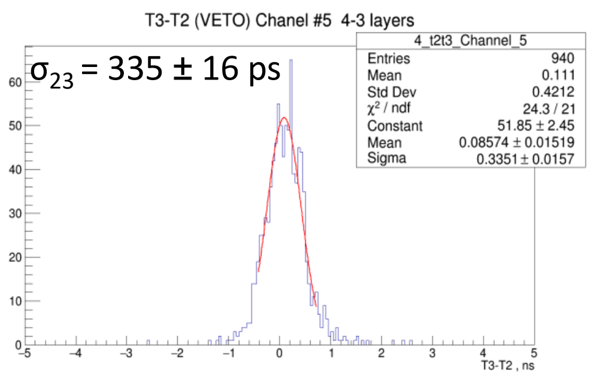


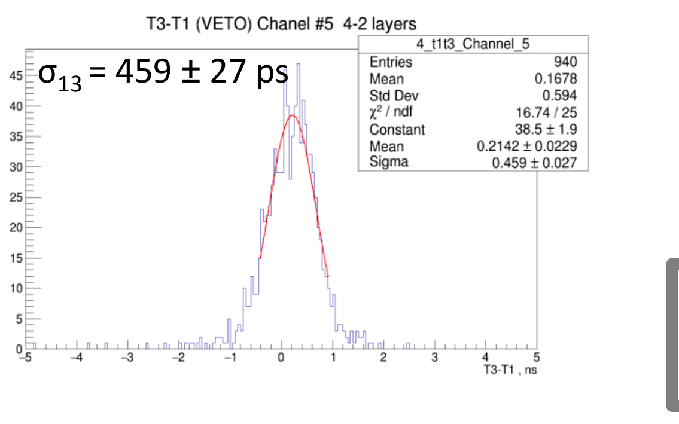


$$\sigma_1^2 + \sigma_2^2 = \sigma_{12}^2$$
$$\sigma_2^2 + \sigma_3^2 = \sigma_{23}^2$$
$$\sigma_1^2 + \sigma_3^2 = \sigma_{13}^2$$

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







Xe + CsI (2%) @ 3.8 AGeV
1 Xe ion,
Central & semi-central collisions
HGN 0 deg. pos., Veto cut

Average time resolution
$\overline{\sigma_2}$ = 134±29 пс

	Cell 1	*Cell 2*	*Cell 3*
$\overline{\sigma_3}$, ps	202±10	213±21	206±21
$\overline{\sigma_2}$, ps	127±8	124±23	141±34
$\overline{\sigma_1}$, ps	197±8	207±10	197±15
	Cell 4	***Cell 5***	***Cell 6***
$\overline{\sigma_3}$, ps	221±19	249±28	234±65
$\overline{\sigma_2}$, ps	131±27	154±23	150±69
$\overline{\sigma_1}$, ps	206±25	247±11	220±55
	Cell 7	***Cell 8***	***Cell 9***
$\overline{\sigma_3}$, ps	186±12	-	206±12
$\overline{\sigma_2}$, ps	118±19	-	126±11
$\overline{\sigma_1}$, ps	187±22	-	200±11

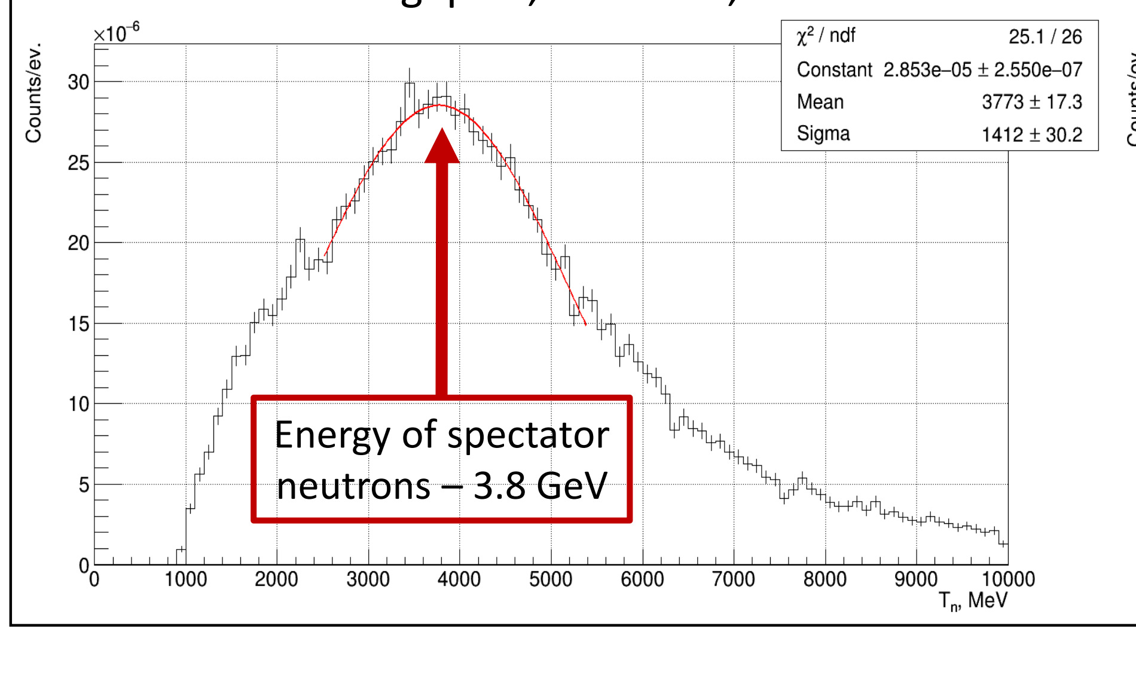
Estimation of the energy spectrum of neutrons

Criteria for selecting events with neutrons:

- 1 Xe ion, central & semi-central collisions
- Veto == 0, Ampl > 0.5 MIP, time cut
- Gamma cut: no hits in 2 & 3 & 4 layers in module => 4.52 X_0 or 0.266 λ_{int}

Without efficiency correction

0 deg. pos., 3.8 AGeV,



27 deg. pos., 3.8 AGeV