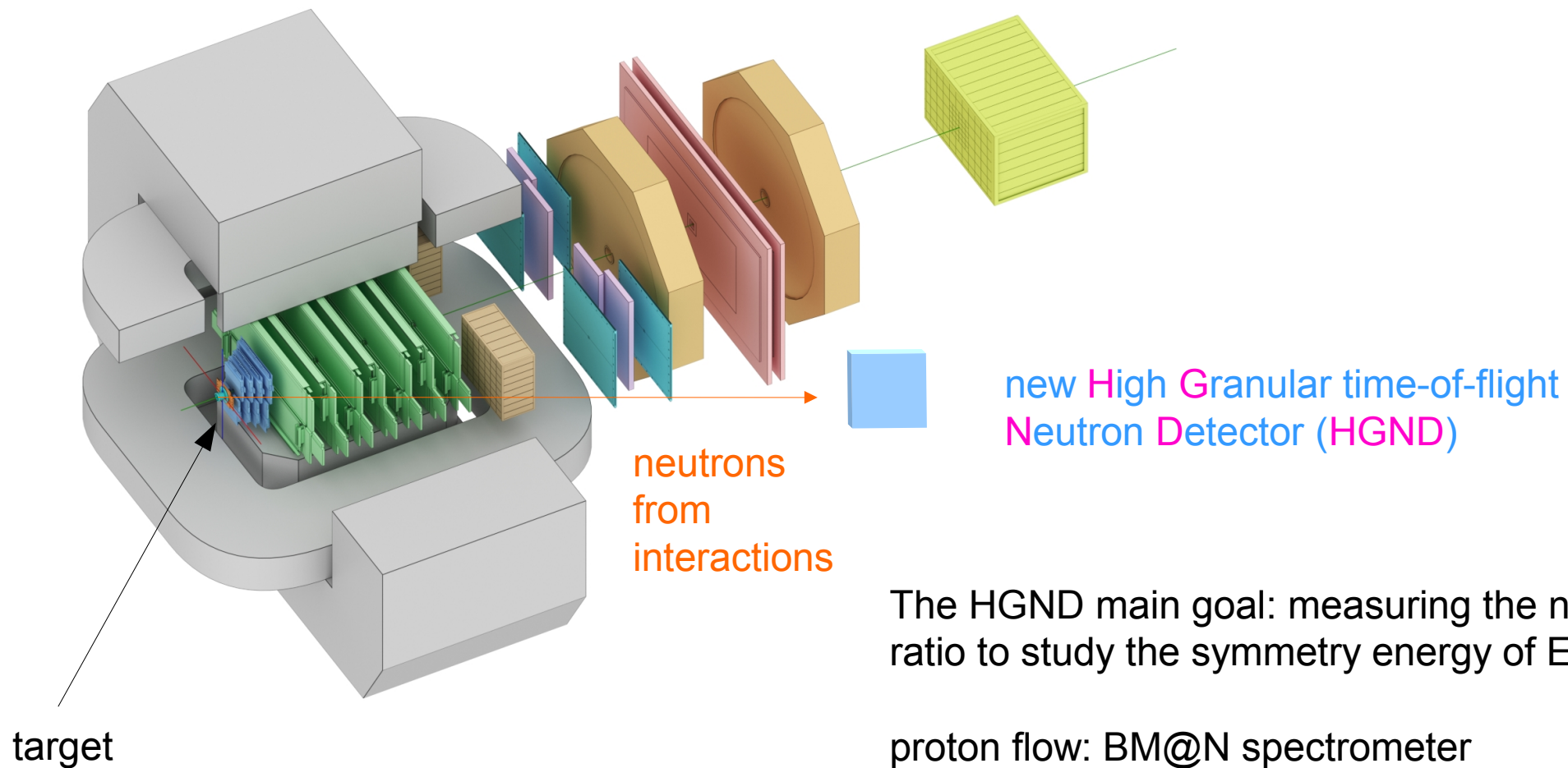


The High Granular Neutron Time-of-Flight Detector (HGND) for the BM@N Experiment

Sergey Morozov, INR RAS, Moscow
on behalf of HGND team



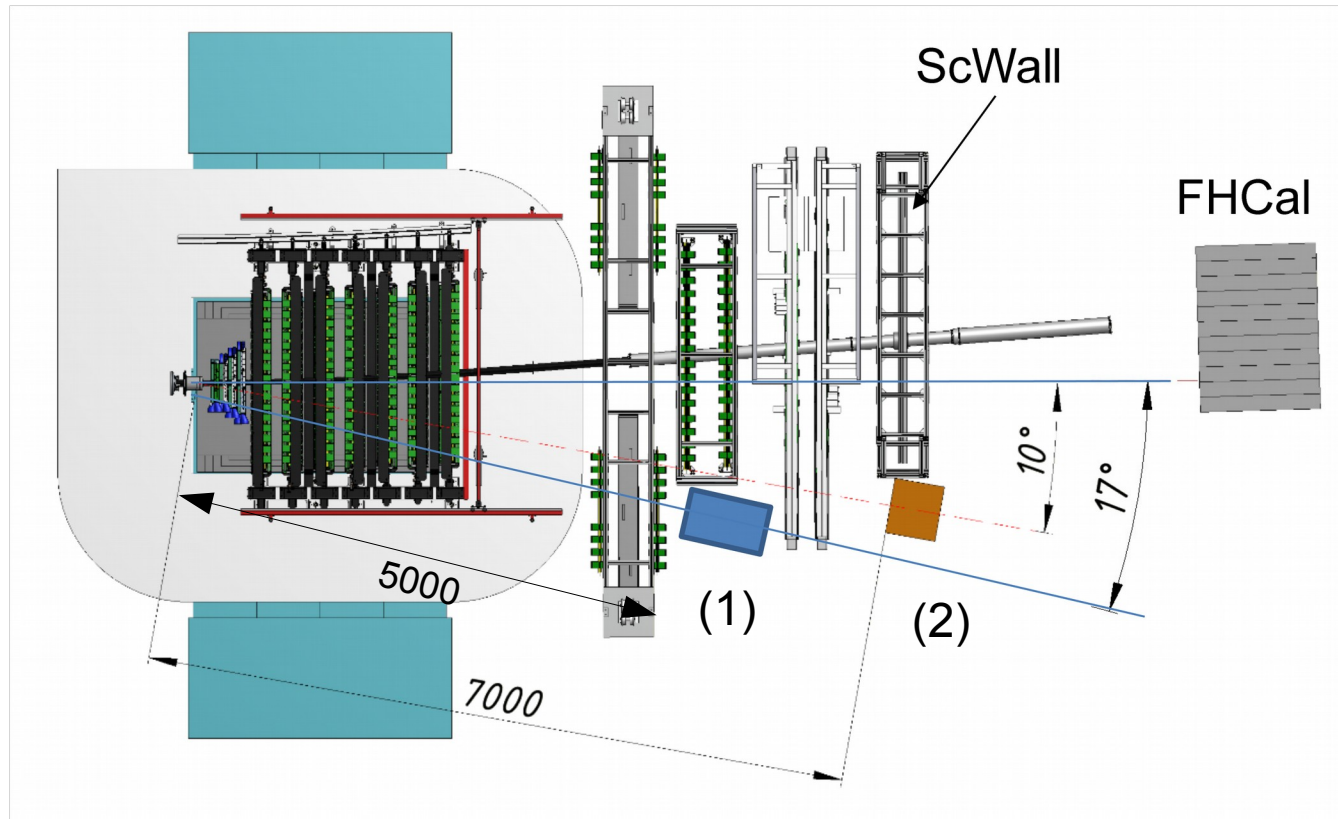
New proposed time-of-flight neutron detector for the BM@N experiment



The HGND main goal: measuring the n/p flow ratio to study the symmetry energy of EoS

proton flow: BM@N spectrometer
neutron flow: HGND

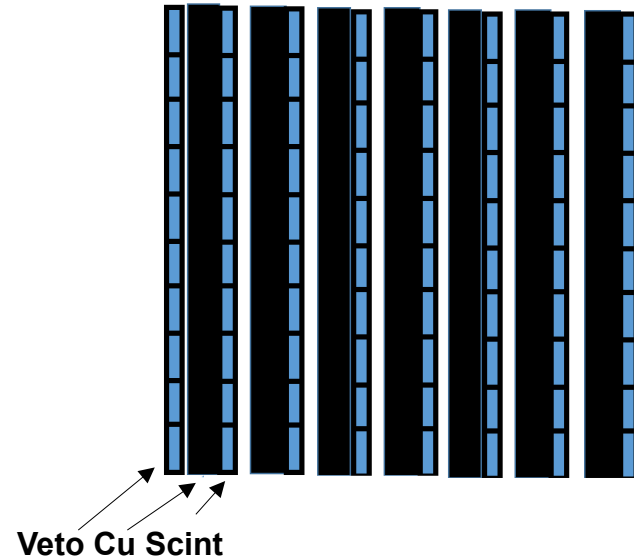
New proposed time-of-flight neutron detector for the BM@N experiment



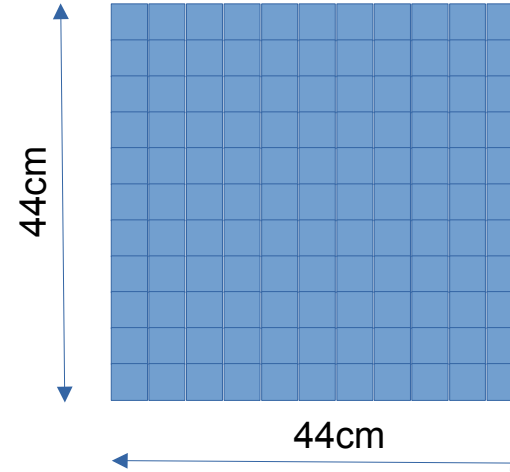
- 1) previous proposed 16 layer (1 veto + 15 active Scint./absorber) HGND detector configuration in position (1) at 17 deg shows limited rapidity range for neutrons
- 2) in order to extend neutron rapidity range the new position (2) has been found at 10 deg but the distance is 7m from target now, resulting in lost of acceptance
- 3) in order to keep the acceptance for neutrons the new system has been checked: two 8 layers (1 veto + 7 active Scint./absorber) detectors instead of one 16 layers

Conception of neutron detector for the BM@N: High Granular Neutron time-of-flight Detector (HGND) with SiPM readout

1 Veto + 7 Cu/Scint layers



Structure of Scint. layer:
array of 11x11 scintillator cells 4 x 4 cm²



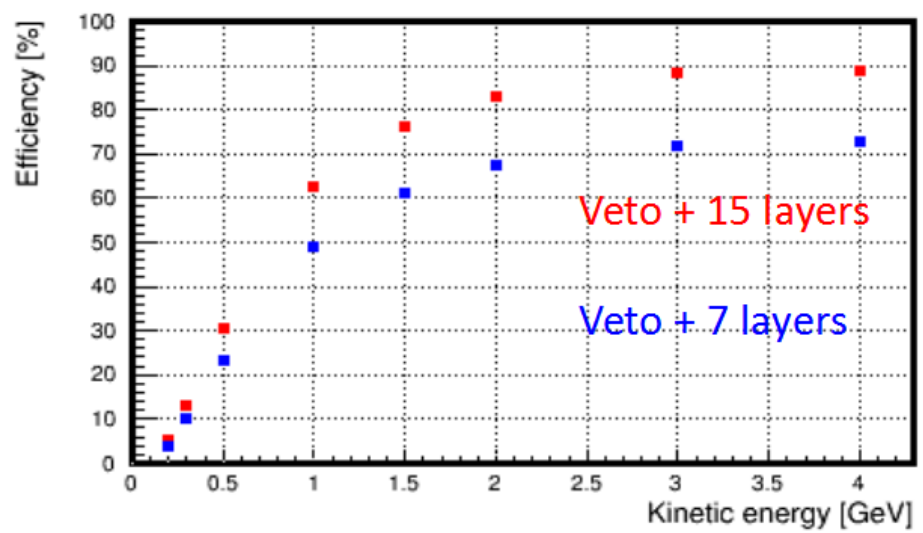
- transverse size of one layer: 44 x 44 cm²,
- number of layers: 7 with absorber + 1 Veto,
- structure of layer: 3 cm Cu (absorber) + 2.5cm Scint. + 0.5cm (SiPM+FEE)
- size of scintillation detectors (cells): 4x4x2.5 cm³, 121 cells in each layer
- light readout: one SiPM with sensitive area 6 x 6 mm² per cell (EQR-15), measured time res. ~ 120ps
- total length of one HGND half-detector: ~ 48 cm (~1.5 λ_{in})

Comparison of neutron detection efficiency for the HGND with 7 and 15 active layers

Single neutrons with different kinetic energies on the HGND surface

$$\text{Efficiency} = 1 - \frac{\text{Nevents without selected hits in HGND}}{\text{Nevents}}$$

Hit selection: minimum 2 hits with > 3 MeV (~1/2 MIP) signal



Reconstruction of neutron energy performs with the ToF of the fastest hit in HGND cell.

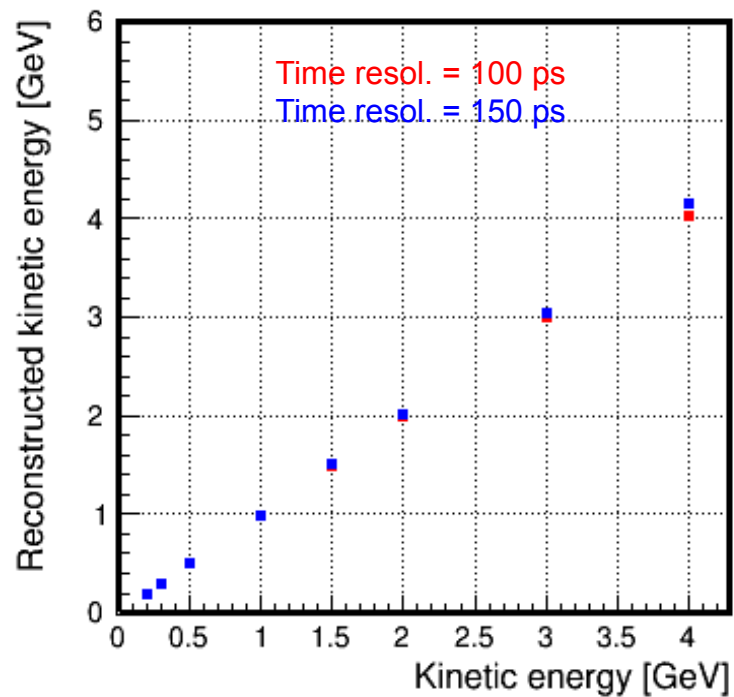
Neutron detection efficiency ratio (HGND with 7 layers / HGND with 15 layers):

- 0.7 at 500 MeV
- 0.79 at 1GeV
- 0.81 at 4GeV

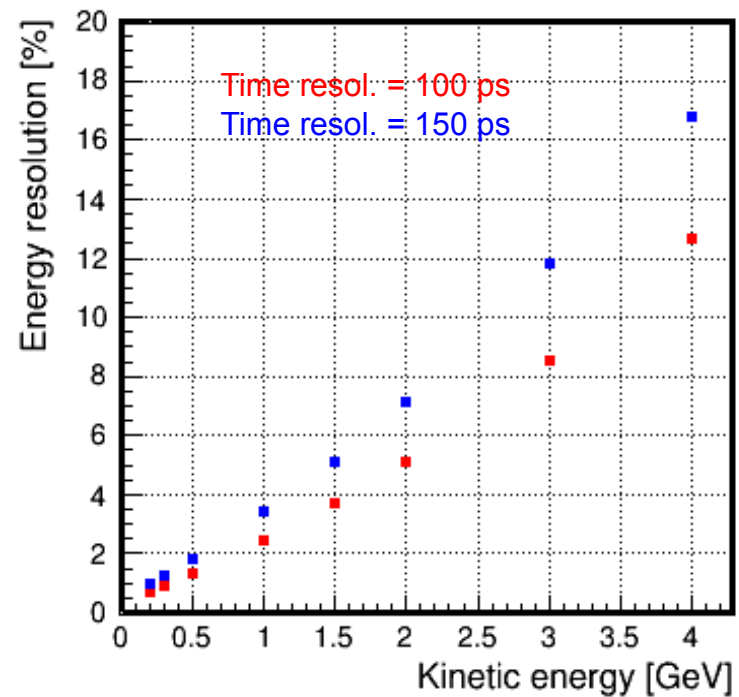
The drop is not 1/2!

Reconstruction of neutron kinetic energy and energy resolution

Reconstructed kinetic energy

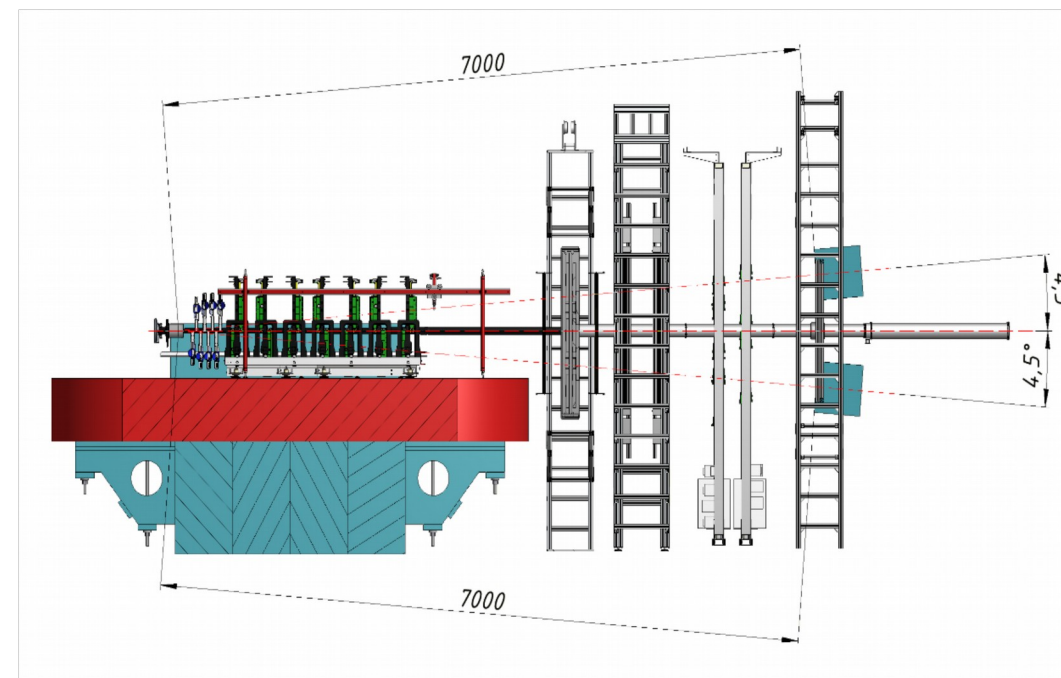
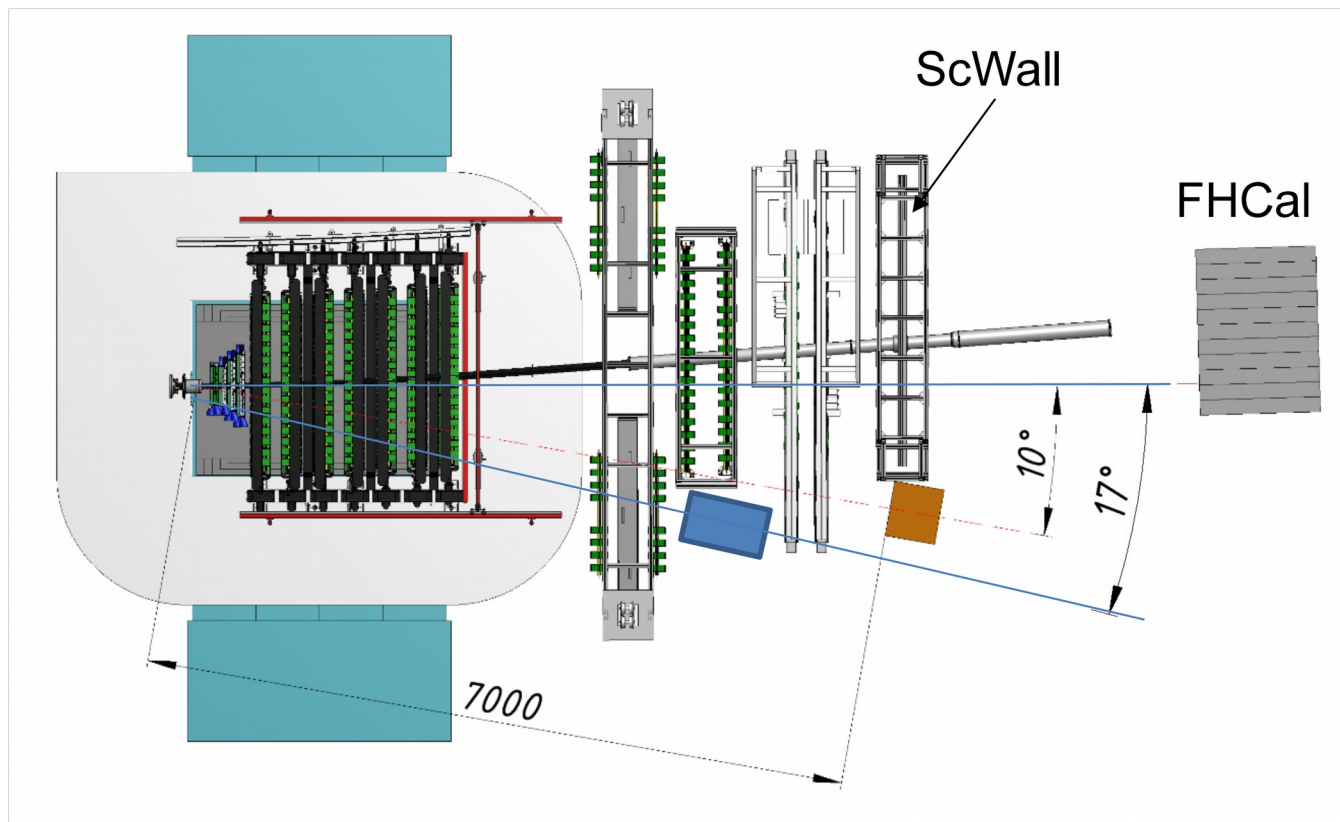


Reconstructed energy resolution



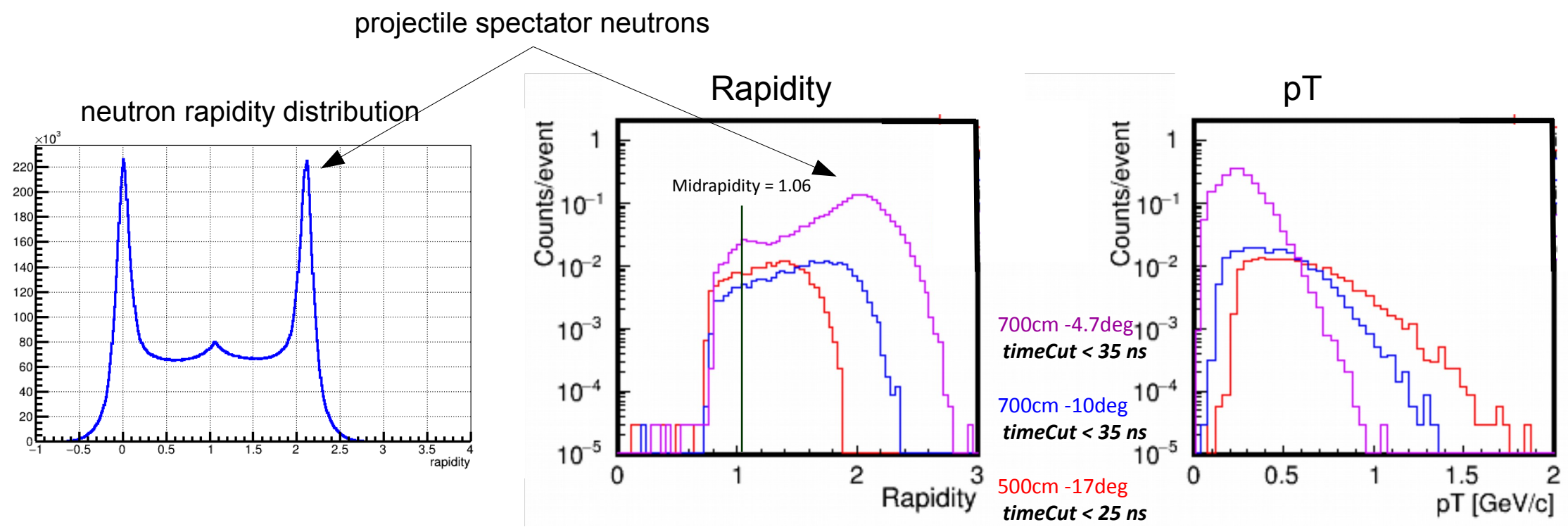
Experimentally measured time resolution of the HGND scintillation cell ~ 120ps

The HGND position on the BM@N experiment



- To place the HGND on 10 degrees (instead of 17 degrees considered earlier) to increase accepted rapidity range
- Use two shorter HGND detectors instead of one to increase acceptance x2

Comparison of primary neutrons rapidity and pT distributions on the HGND entrance surface for different positions of the HGND



ToF vs kinetic energy of different type of particles at the HGND 700cm, 10 deg -4.5 deg

At nDet entrance

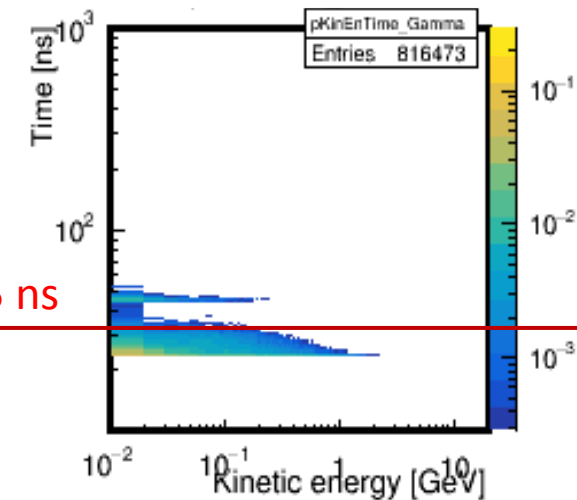
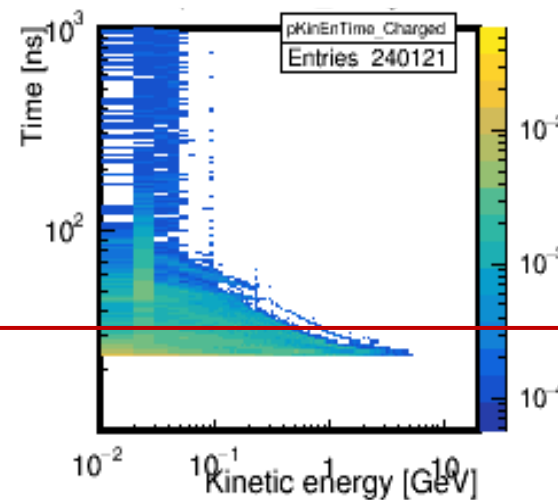
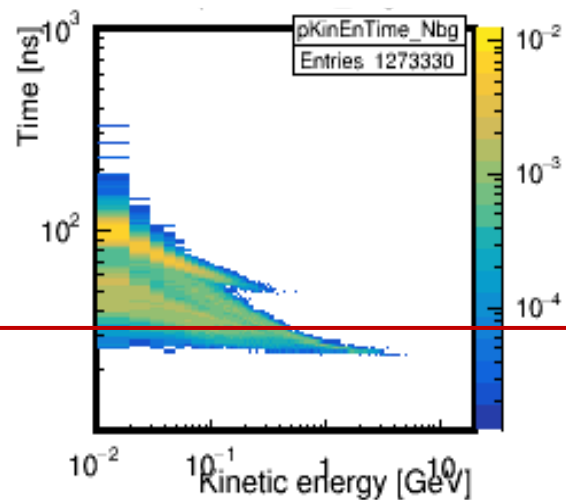
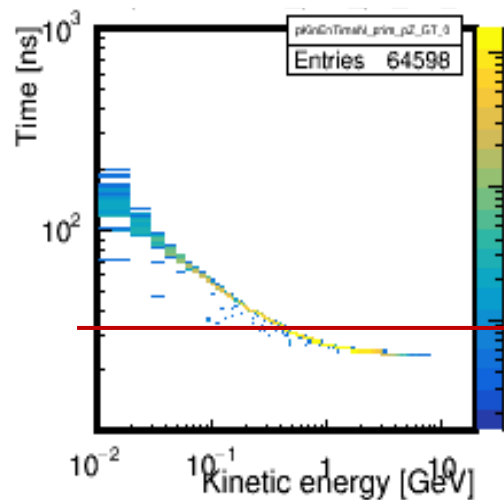
Around all nDet surfaces

Primary neutrons

Bg neutrons

Charged particles

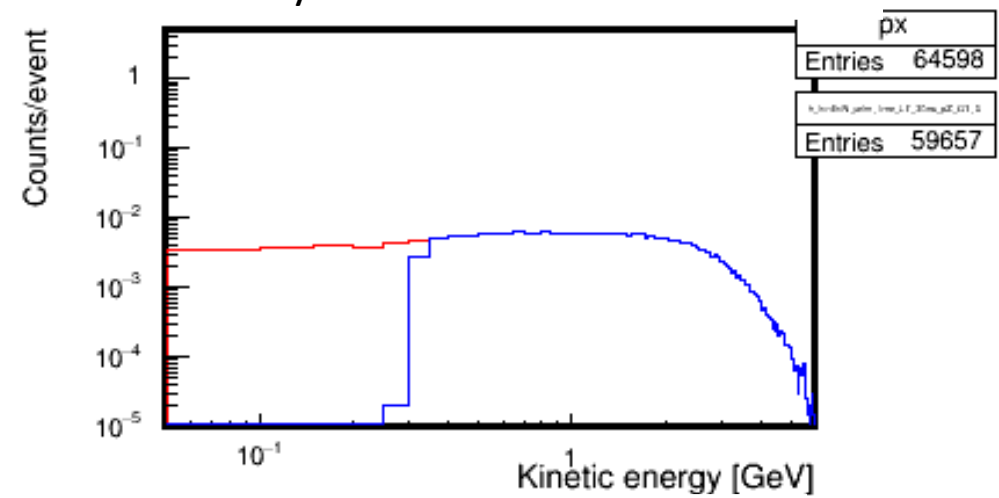
Gamma



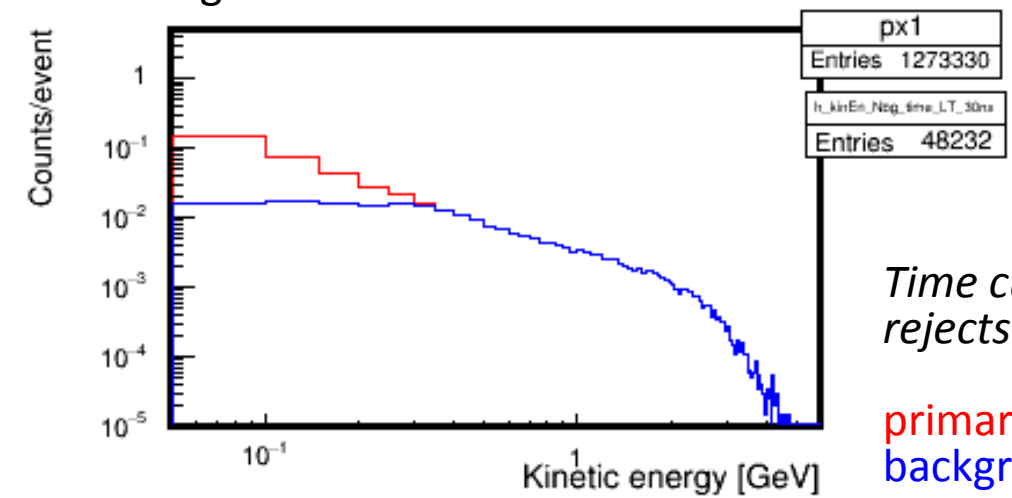
35 ns

Spectra of kinetic energy of different type of particles at the HGND 700cm, 10 deg -4.5 deg

Primary neutrons at HGND entrance



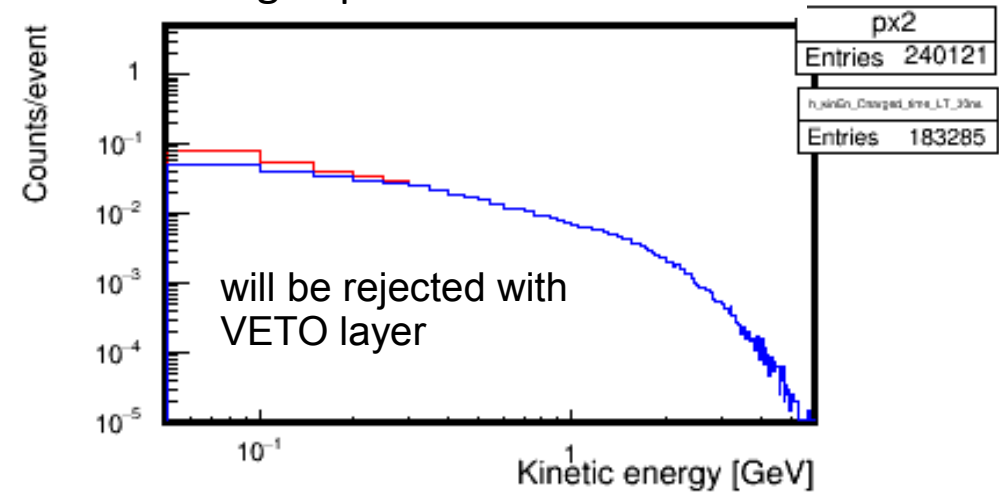
Bg neutrons around HGND



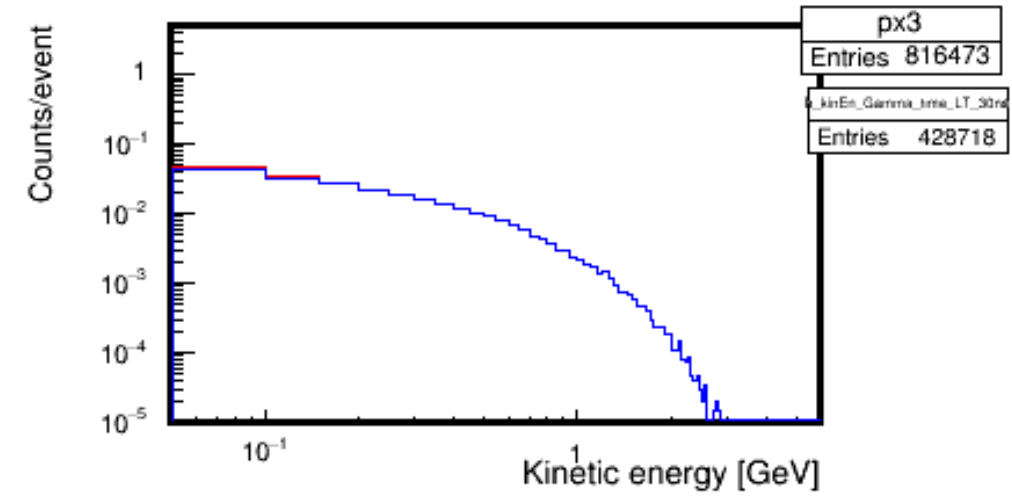
*Time cut (time < 35 ns)
rejects at nDet entrance:*

- primary neutrons - 8%
- background neutrons - 77%
- gamma - 15%

Charged particles around HGND



Gamma around HGND

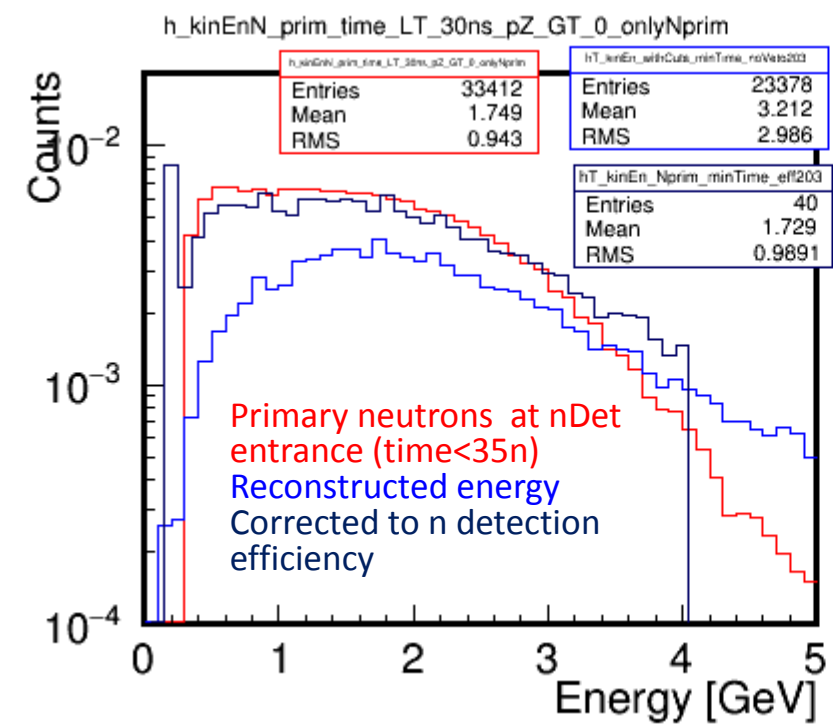
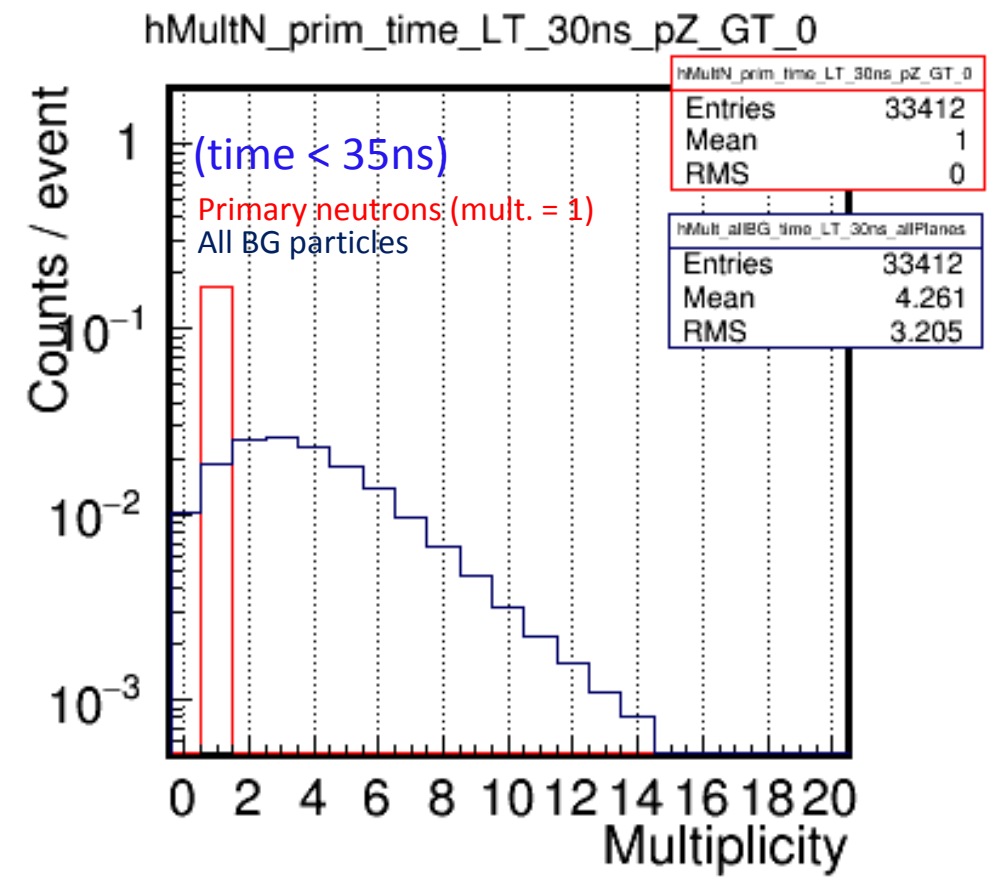


Multiplicity of neutrons

Events with only 1 primary neutron at nDet entrance (time < 35ns)

Background at all nDet planes (time < 35ns)

1 Primary neutron

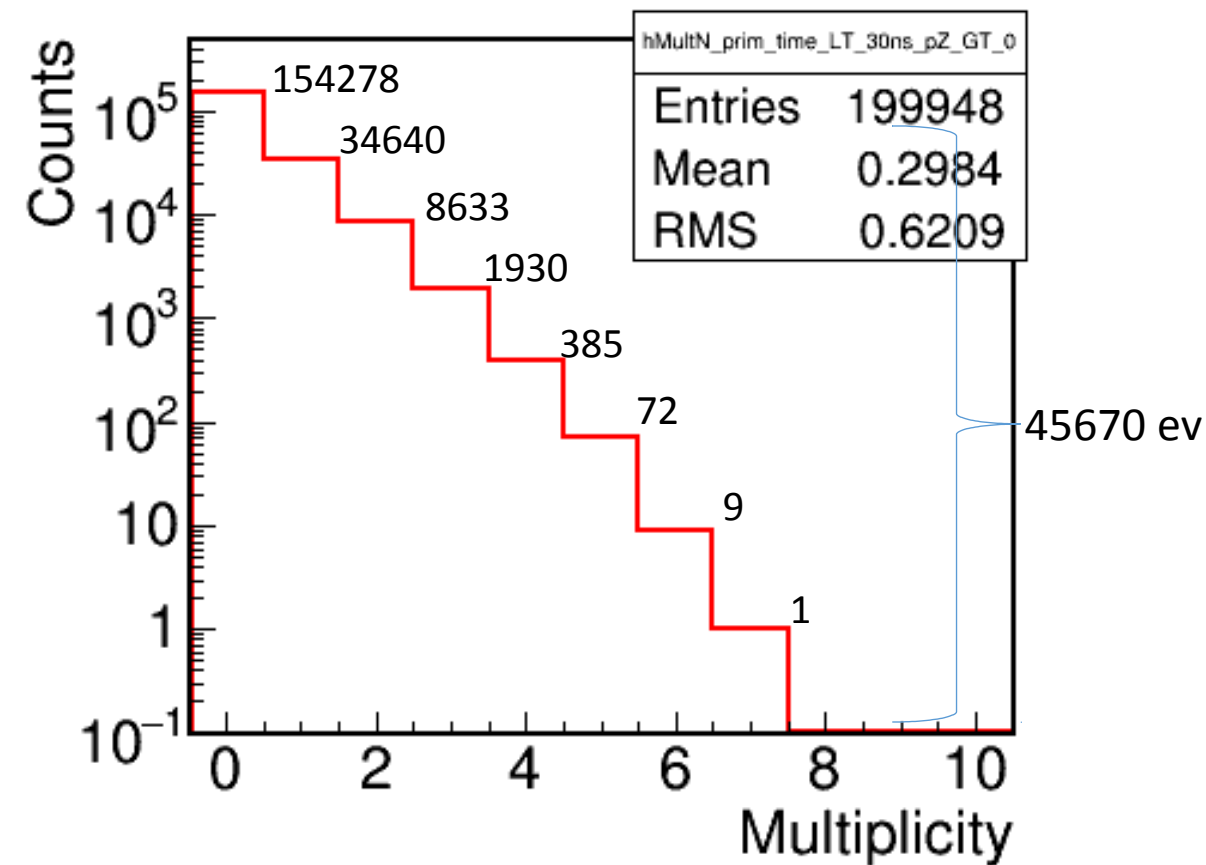


Neutron energy in events with only one primary neutron can be correctly reconstructed by determining fastest time in the HGND cells.

Neutron energy reconstruction for events with more than 1 neutron in events requires development of more sophisticated methods of energy reconstruction.

Estimation of primary neutrons count rate at BiBi@3 AGeV run

number of registered primary neutrons at the HGND



Beam rate - 10^6 per spill,
 Duty factor of the beam - 50%
 Efficiency of accelerator operation - 70%

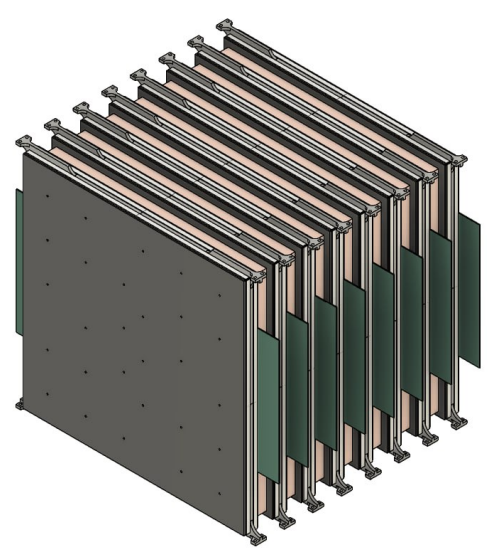
Target interaction length - 2%,
 Mean primary neutron yield:
 0.17 (single) - 0.23 (all) neutron / interaction
 Mean efficiency of the HGND detector - 50%

During **1 month** of the BM@N run $\sim 1.2 \cdot 10^9$ *single* primary neutrons with kinetic energy > 300 MeV can be collected with 2 x HGNDs

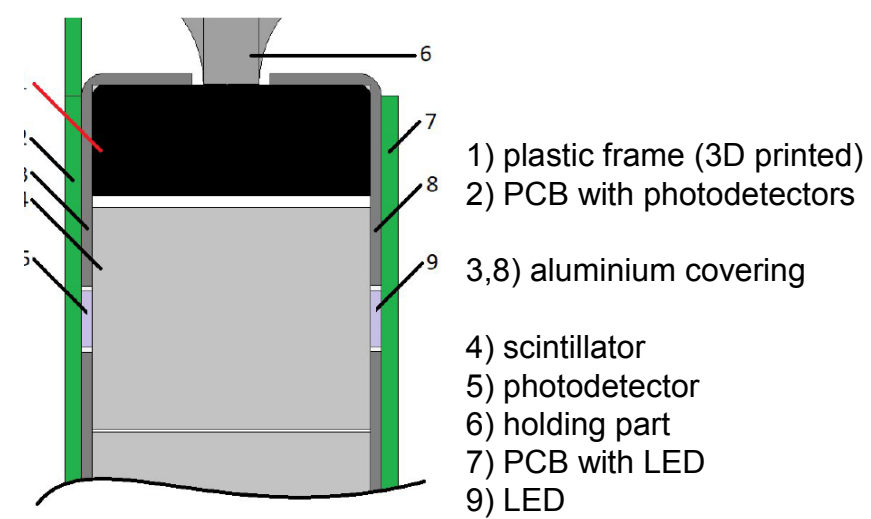
Upper limit is $1.5 \cdot 10^9$ neutrons (additional multi-neutron event recognition is required).

Schematic of the HGND mechanics

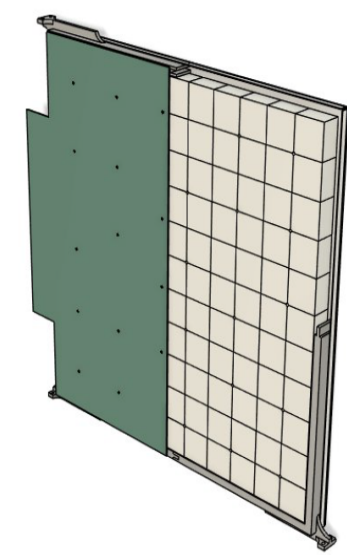
3D view of the HGND



Structure of active layer



Active layer cassette



Status of mechanics and electronics development see in D.Finogeev et al. presentation.

Status of the HGND construction

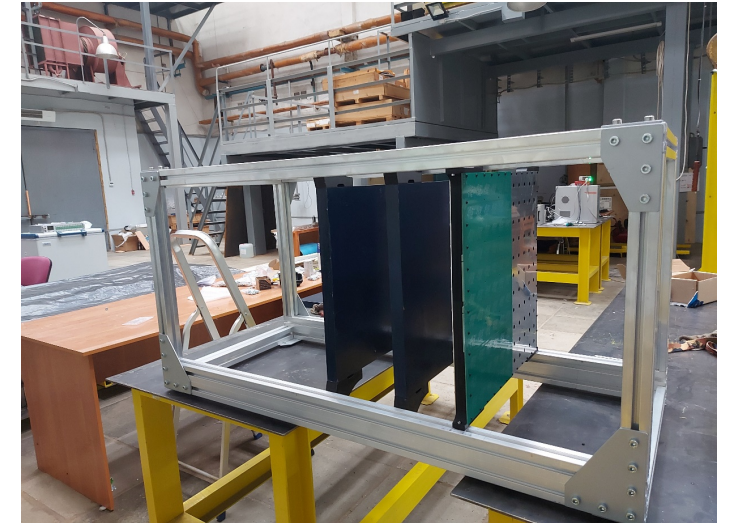
scintillator layer assembled



active layer PCB positioning



The HGND mock-up assembled at INR



- all scintillator cells 40x40x25 mm³ (~ 2000 pcs) have been constructed
- first scintillator layer has been assembled

Status of mechanics and electronics development see in D.Finogeev et al. presentation.

Conclusions:

- 2-arms HGND detector system is proposed (7m from the target position and 10 deg angle)
- the response of the 2-arms HGND was studied (BiBi 3 AGeV)
- mechanics of HGND mock up was assembled at INR and will be used for tests

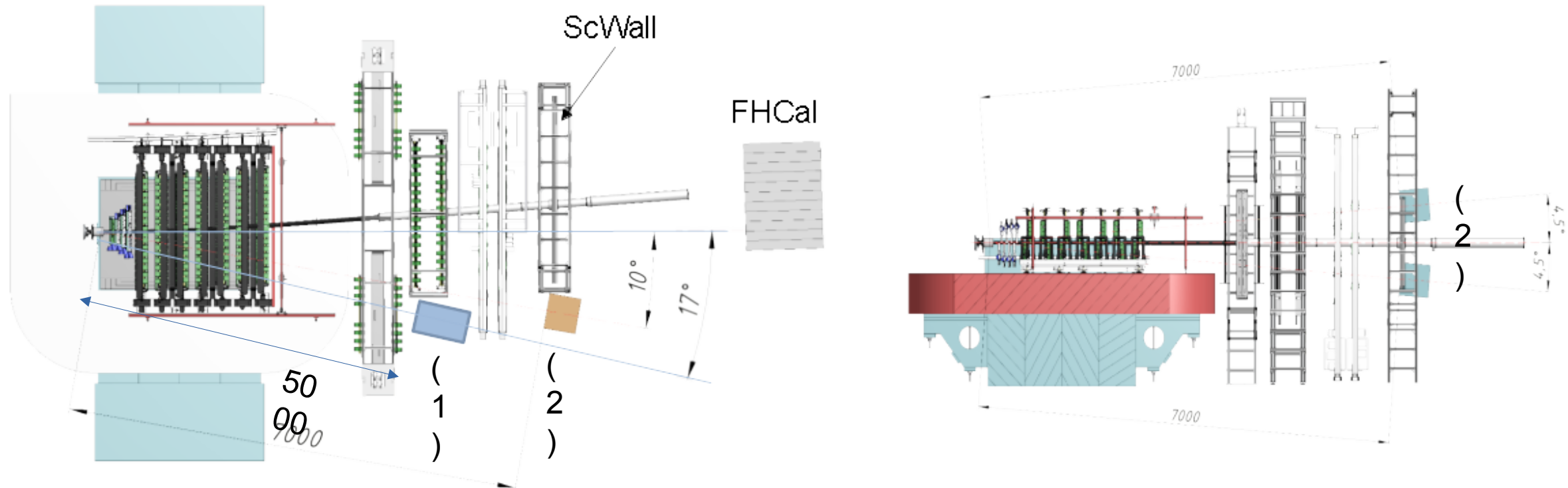
Outlook:

- the HGND mock-up will be ready to test at the BM@N in Fall 2024
- neutron detection algorithms are still under discussions (cluster method, ML etc.)

Thank you for your attention!

Backup

Возможные положения нейтронного детектора HGND на установке BM@N



- 1) расстояние от мишени 5м, длина 15 активных слоев, ограниченный диапазон по скорости регистрируемых нейтронов
- 2) расстояние от мишени 7м, детектор из 2-х частей (для сохранения акцептанса) по 7 активных слоев, меньше эффективность регистрации нейтронов, но шире диапазон по скорости

Measurements of time resolution of scintillation detectors (scint + SiPM)

F.Guber et.al., *Instruments and Experimental Techniques*, 2023, Vol. 66, No. 4, pp. 553–557

(JINR + Hamamatsu, SensL photodetectors)

F.Guber et.al., arXiv:2309.03614v1 [hep-ex] 7 Sep 2023 (JINR, EJ230 scint. + EQR photodetector)

Photodetector:

EQR15 11-6060D-S

(sensitive area - 6x6 mm², 15μm pixel pitch, 160 000 pixels, PDE - 45%, gain - 4x10⁵)

Scintillator:

1) JINR produced (40x40x25mm³), 1.5% paraterphenyl and 0.01% POPOP) with light time decay of 3.9 ± 0.7 ns

2) EJ230 with light time decay of 2.8 ± 0.5 ns

FEE: LMH6629MF preamp (20 dB gain, bandwidth of 600 MHz at a 3 dB level, and noise of <2.2 nV/√Hz) + rapid discriminator (ADCMP553) with a fixed threshold.

Readout: CAEN DT5742

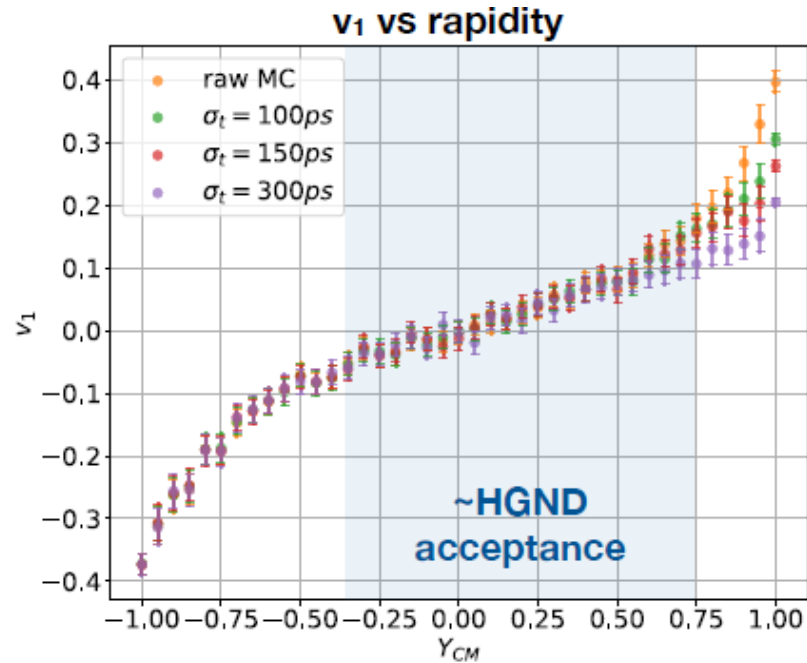
Test results on e-beam at LPI

→ $\sigma \sim 117$ ps, N ph.el. = 158 ± 9

→ $\sigma \sim 74$ ps, N ph.el. = 292 ± 2

JINR scintillators will be used for the HGN detector because they are available and significantly cheaper than EJ230.

Time resolution and neutron flow measurements (based on V. Bocharnikov slides on 11th BM@N CM)



Influence of HGND time resolution on flow coefficients

- Data source: all primary neutrons from initial DCM-QGSM-SMM Bi+Bi @ 3 AGeV reaction
 - MC truth information
 - Y_{CM} and P_T are converted to time at distance of 5.72m along \mathbf{p} and recalculated after time smearing
 - v_1 vs Y_{CM} selection criteria:
 - $E_{kin} > 0.5$ GeV
 - Impact parameter $\in (6, 9)$ fm
 - $p_T \in (1., 1.5)$ GeV
 - v_2 vs P_t selection criteria:
 - $E_{kin} > 0.5$ GeV
 - Impact parameter $\in (6, 9)$ fm
 - Rapidity in c.m. $\in (-0.2, 0.2)$
- p_T and rapidity cuts are on distorted values)*

Time resolution effect gets noticeable only at forward rapidities