Status of High Granular Neutron Time-of-Flight Detector (HGND) structure and placement at the BM@N Experiment

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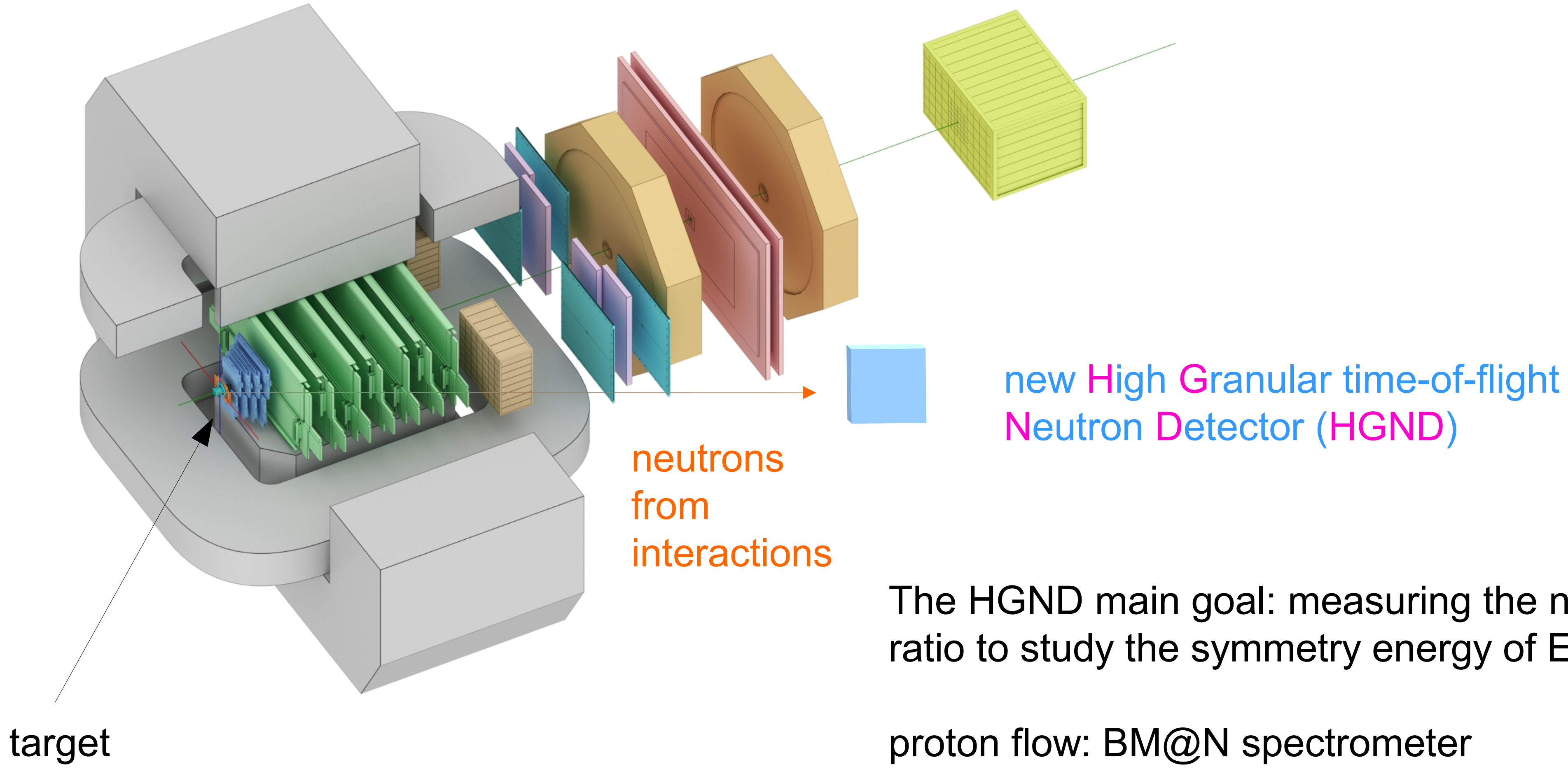
on behalf of INR RAS, Moscow and HGND team

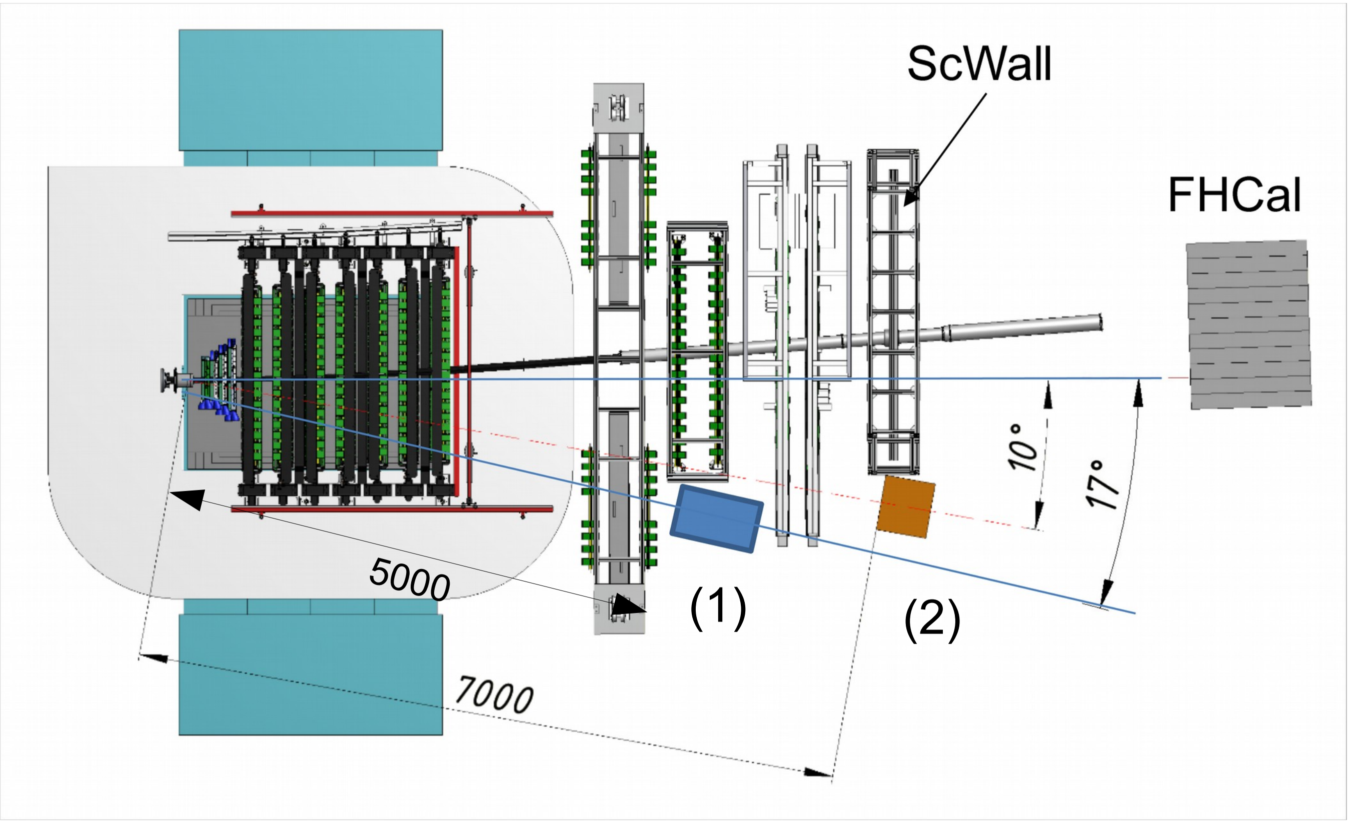
New proposed time-of-flight neutron detector for the BM@N experiment



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

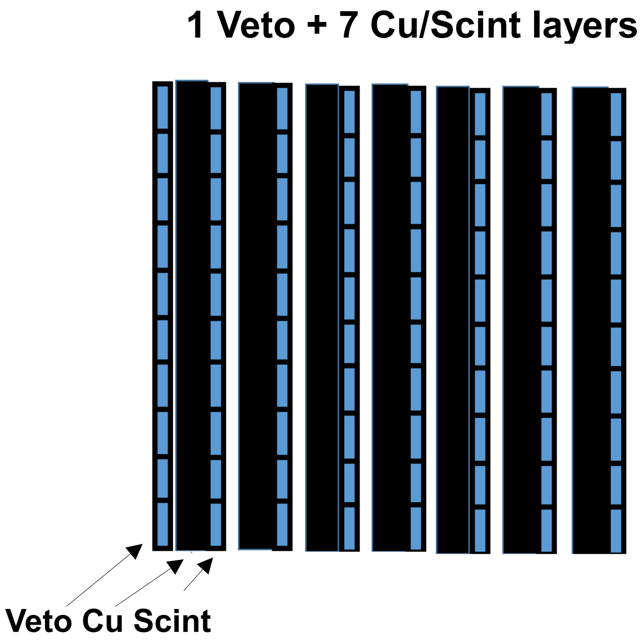


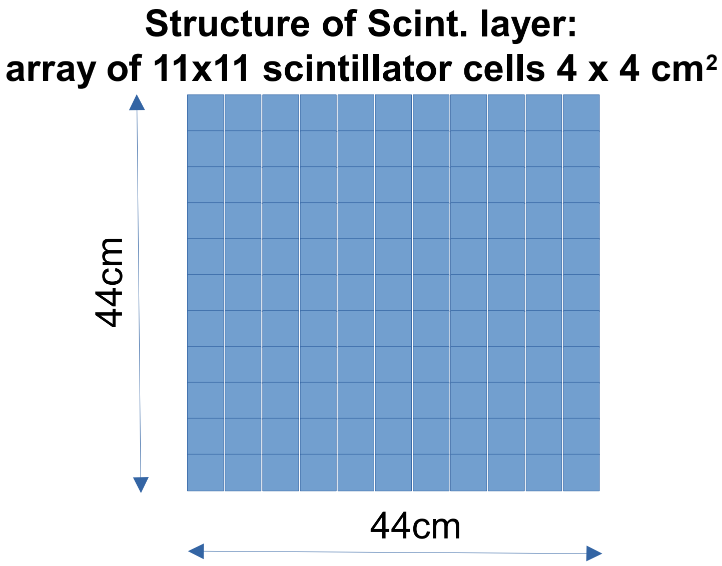
1) previous proposed 16 layer (1 veto + 15 active Scint./absorber) HGND detector configuration in position (1) at 17 deg shows limited rapidity range for neutrons

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 insteed of one 16 layers

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





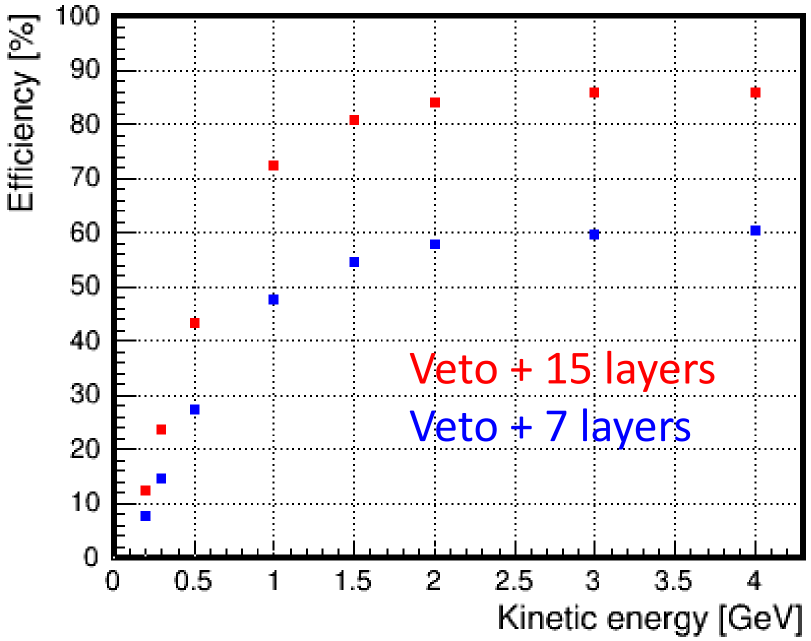
- transverse size of one layer: 44 x 44 cm^2,
- number of layers: 7 with absorber + 1 Veto,
- structure of layer: 3 cm Cu (absorber) + 2.5cm Scint. + 0.5cm (SiPM+FEE)
- size of scintillation detectors (cells): 4x4x2.5 cm^3, 121 cells in each layer
- light readout: one SiPM with sensitive are 6 x 6 mm^2 per cell (EQR-15), measured time res. ~ 120ps
- total length of one HGND half-detector: ~ 48 cm (~1.5 λ_{in})

BiBi@3A GeV

DCM-QGSM-SMM

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):

0.6 at 200 MeV
0.66 at 1GeV
0.7 at 4GeV

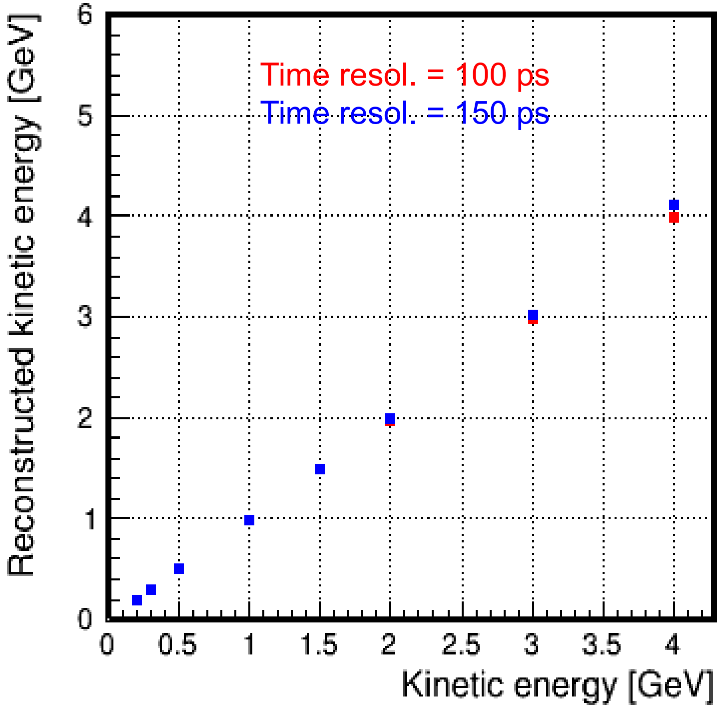
The drop is not ½!

BiBi@3A GeV

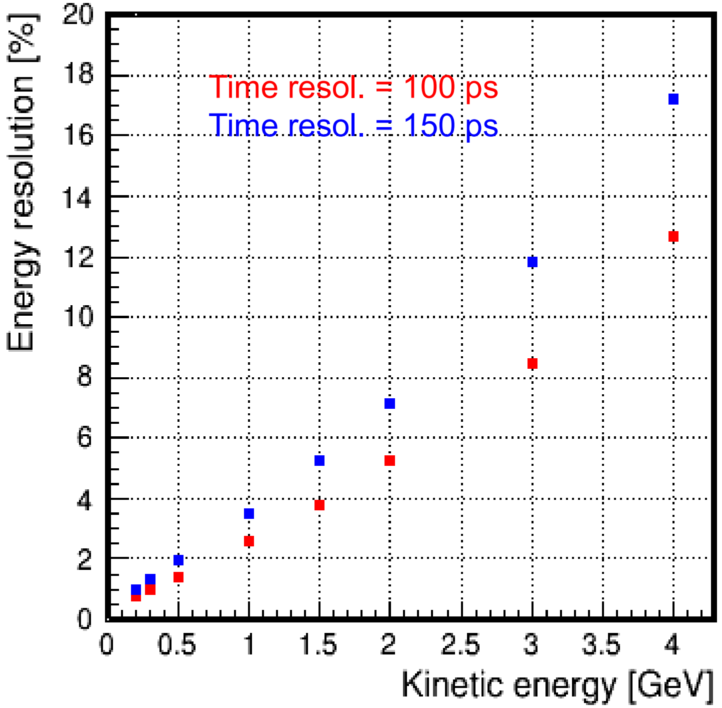
DCM-QGSM-SMM

Reconstruction of neutron kinetic energy and energy resolution

Reconstructed kinetic energy

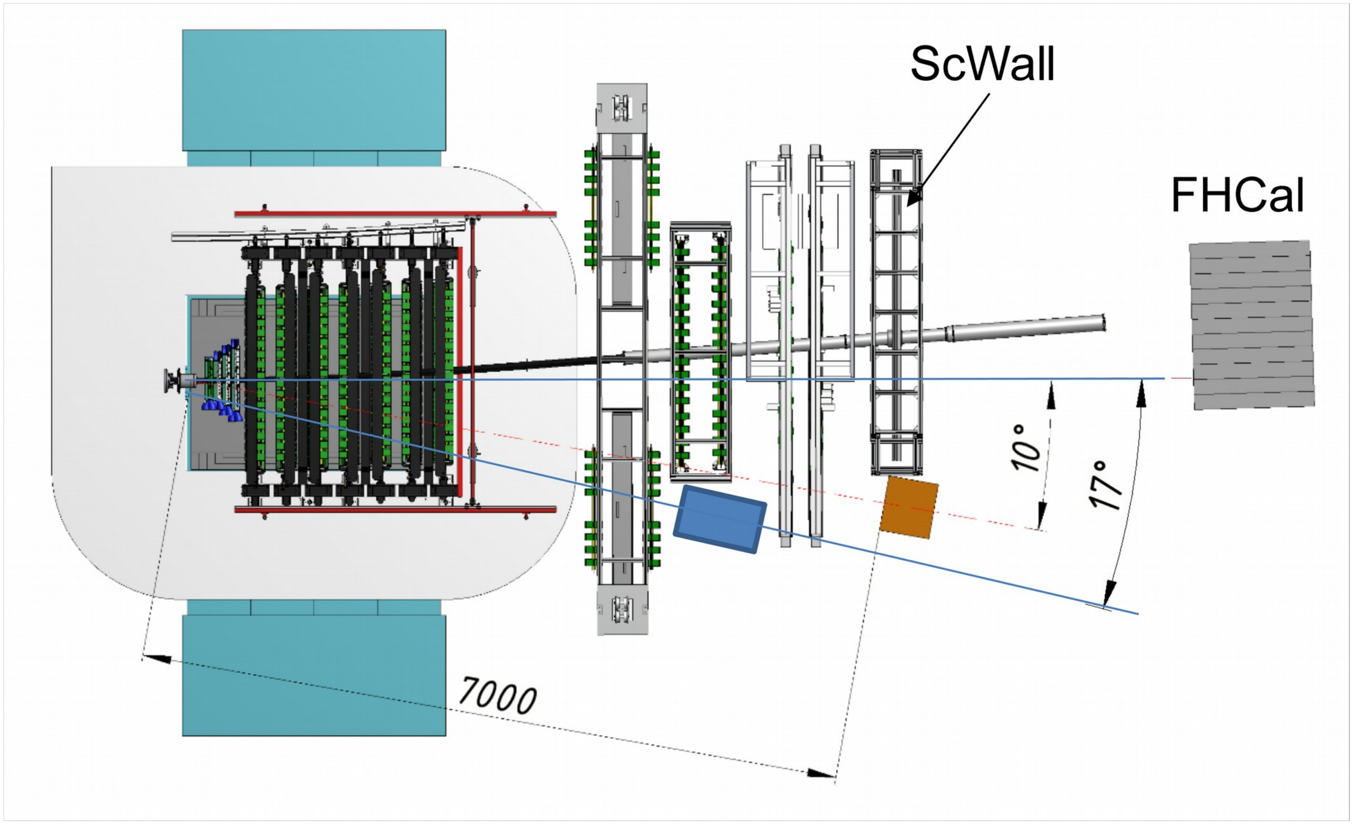


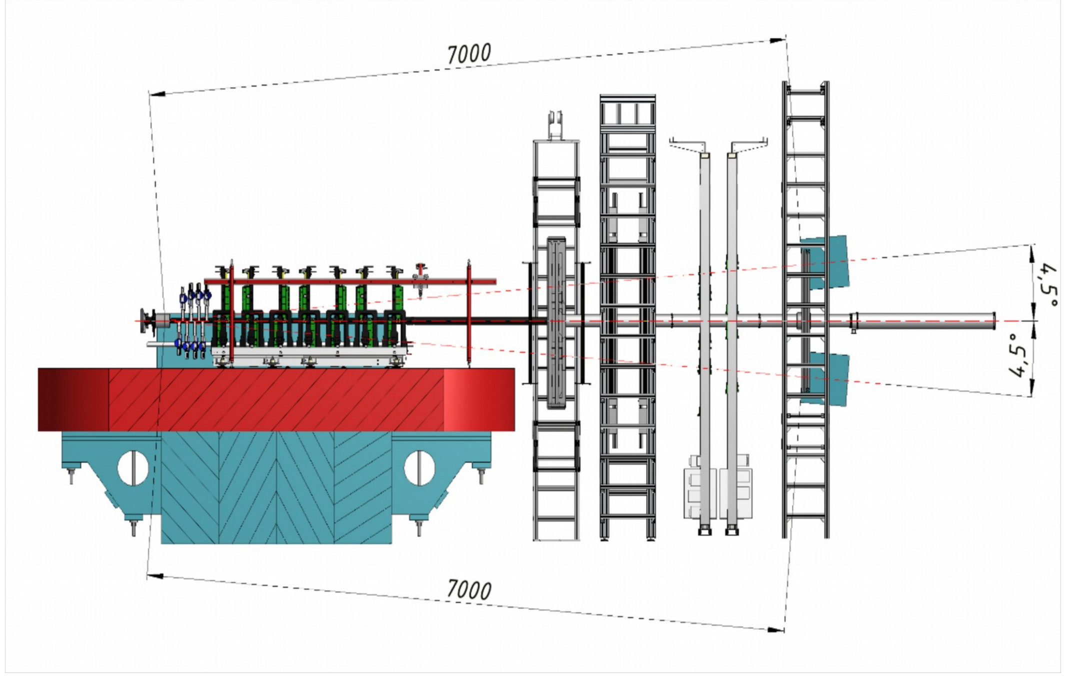
Reconstructed energy resolution



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

Optimization of 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

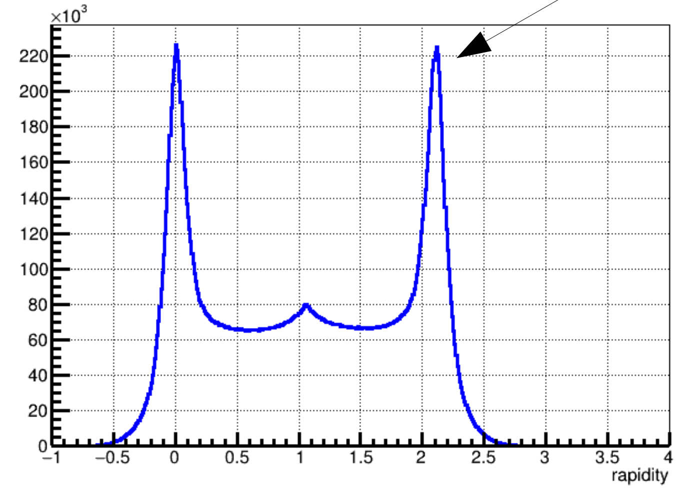
BiBi@3A GeV

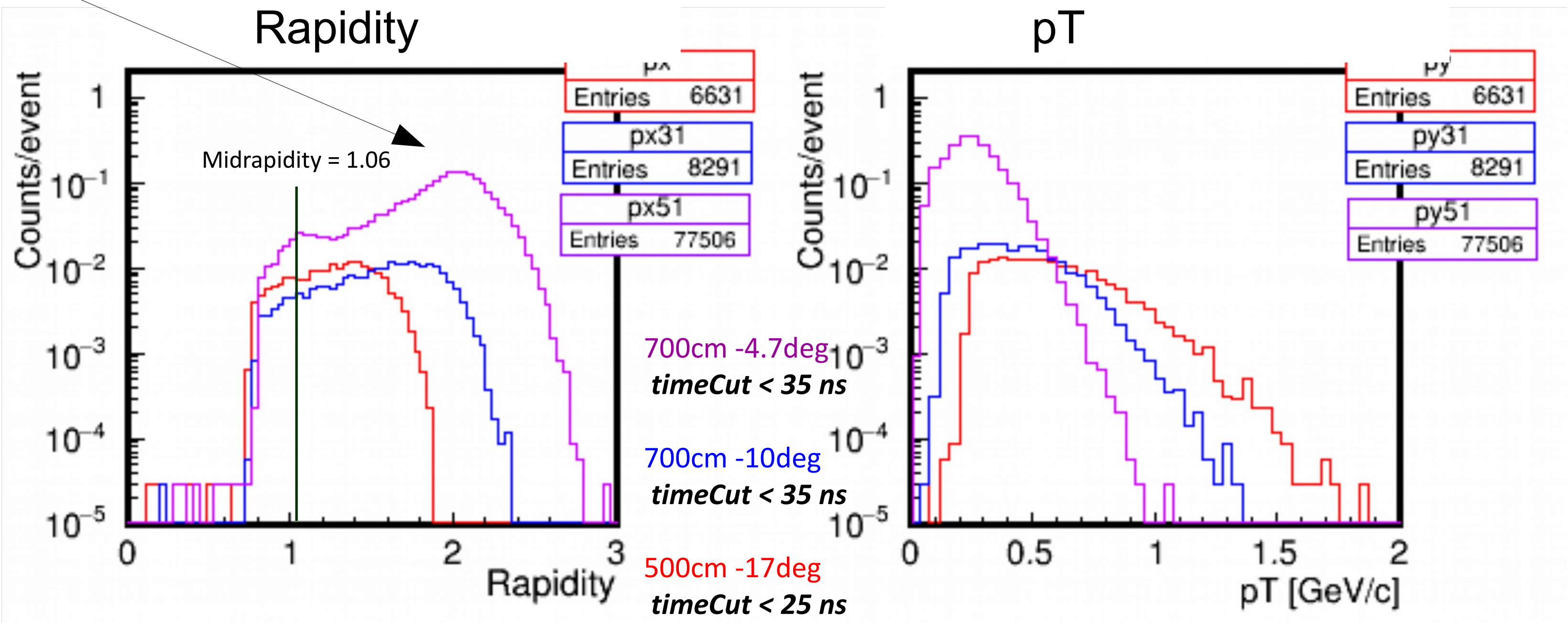
DCM-QGSM-SMM

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

projectile spectator neutrons

neutron rapidity distribution





BiBi@3A GeV

DCM-QGSM-SMM

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

At nDet entrance

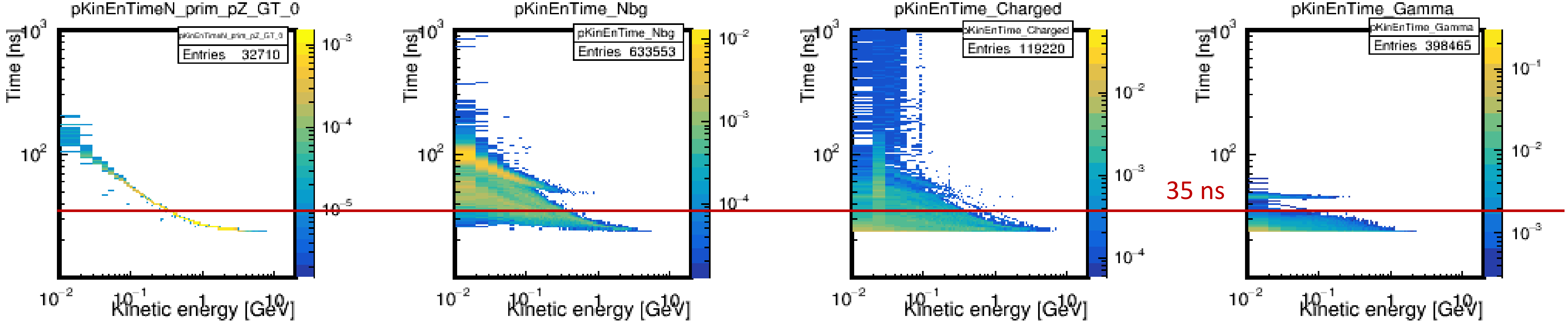
Around all nDet surfaces

Primary neutrons

Bg neutrons

Charged particles

Gamma

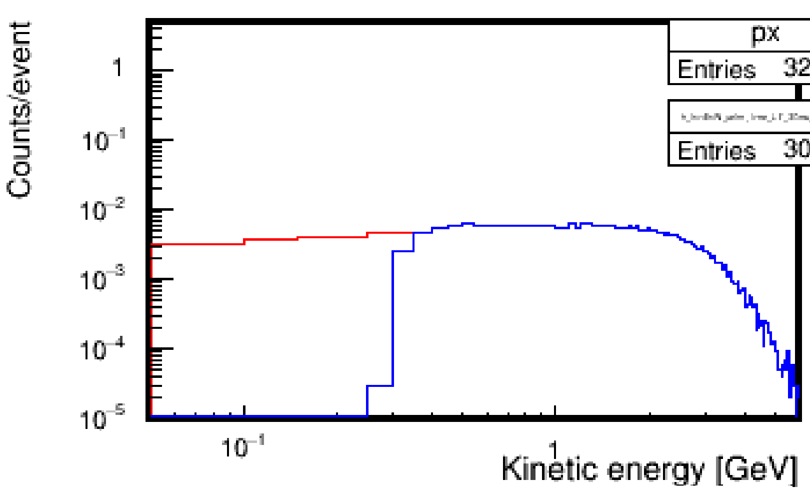


BiBi@3A GeV

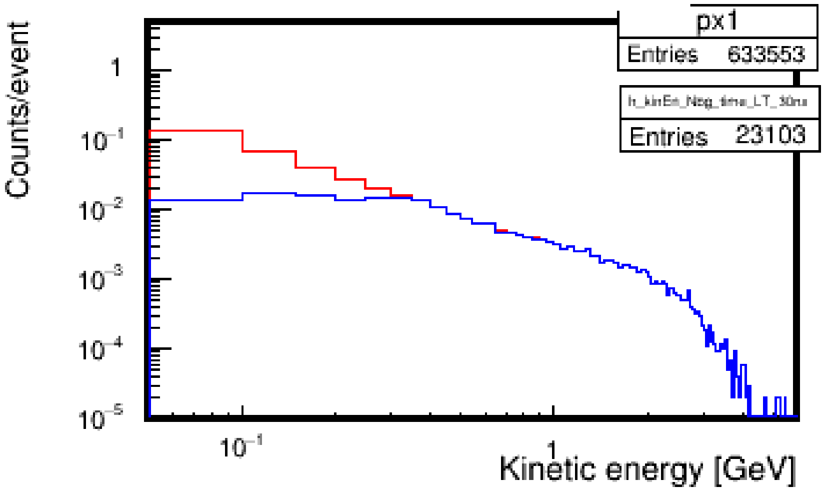
DCM-QGSM-SMM

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

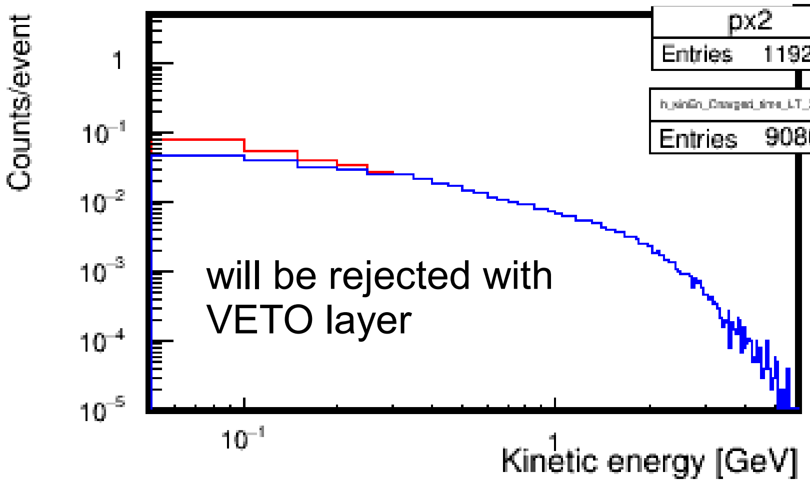
Primary neutrons at HGND entrance



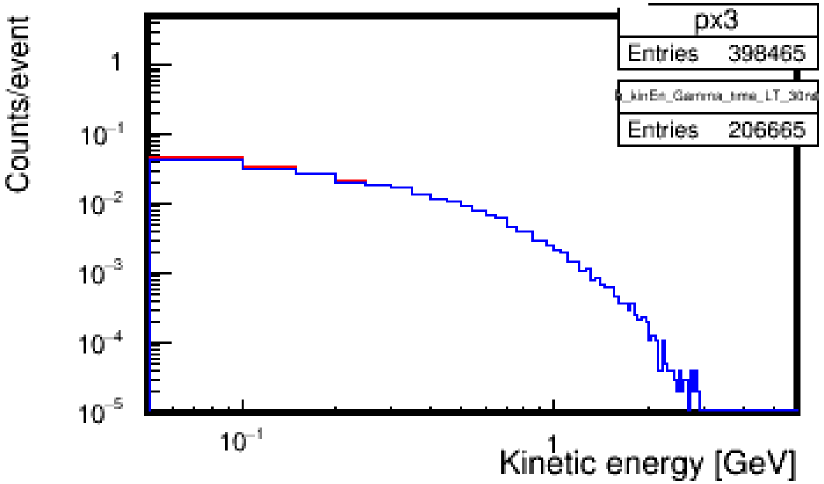
Bg neutrons around HGND



Charged particles around HGND



Gamma around HGND



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

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

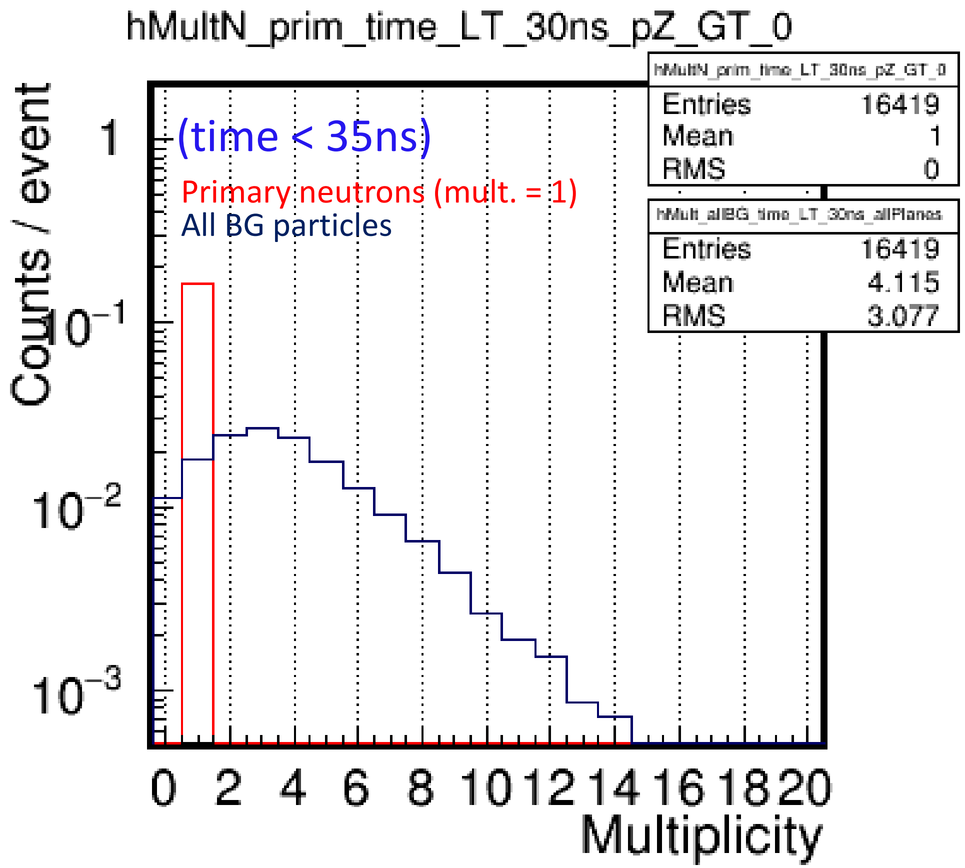
BiBi@3A GeV

DCM-QGSM-SMM

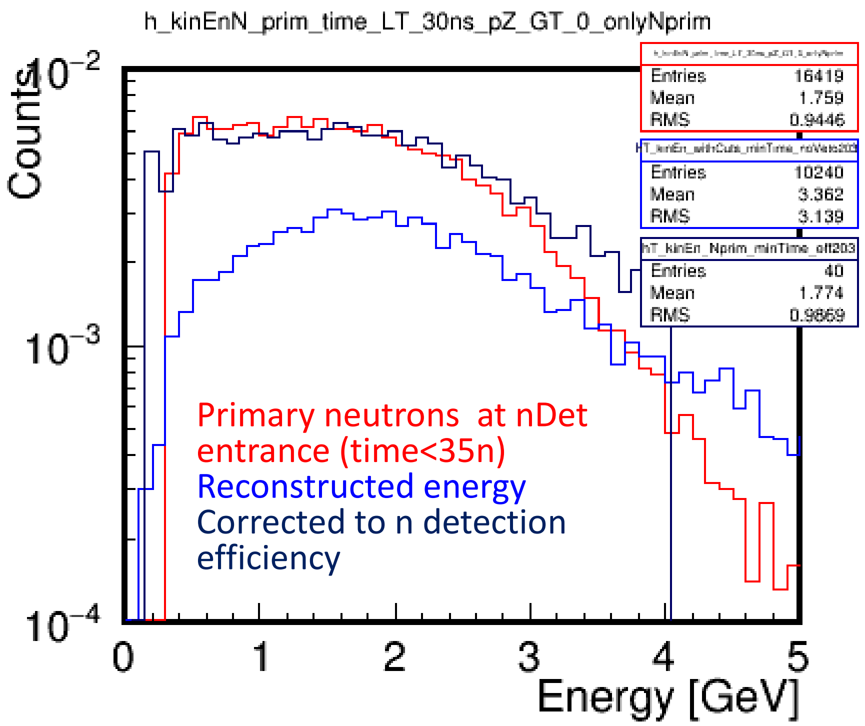
Multiplicity of neutrons

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.

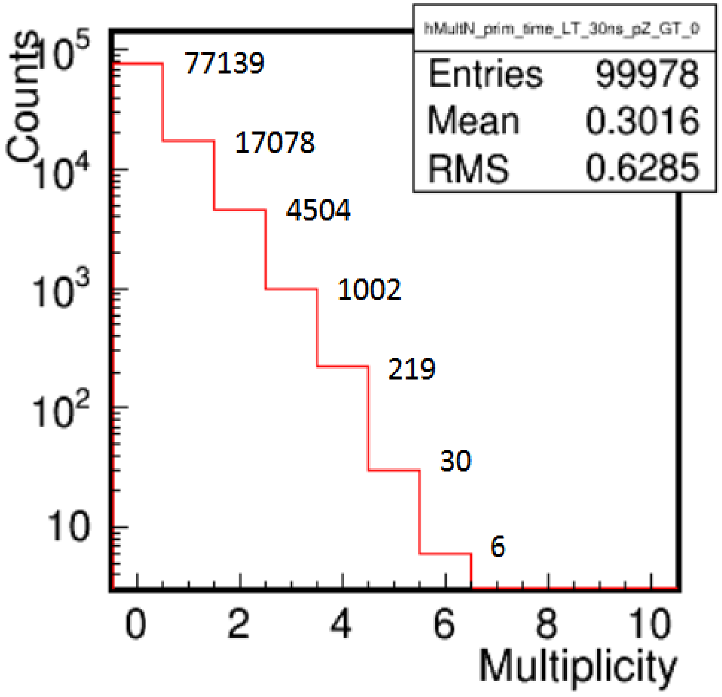
- Neutron energy reconstruction for events with more than 1 neutron in events requires development of more sophisticated methods of energy reconstruction.

BiBi@3A GeV

DCM-QGSM-SMM

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%

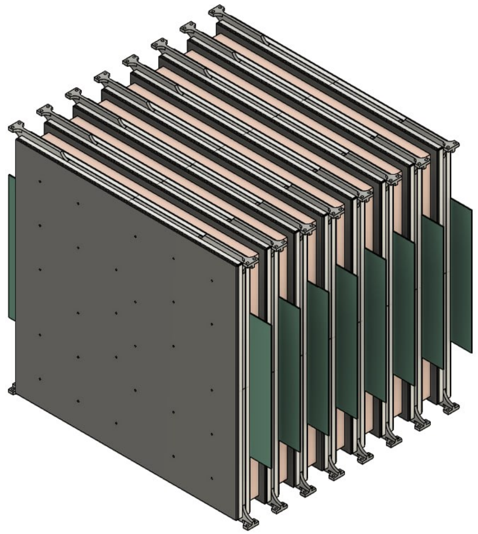
Target interaction length - 2%,
Mean primary neutron yield:
0.17 (single) - 0.23 (all) neutron / interaction
Mean efficiency of the HGND detector - 40%

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

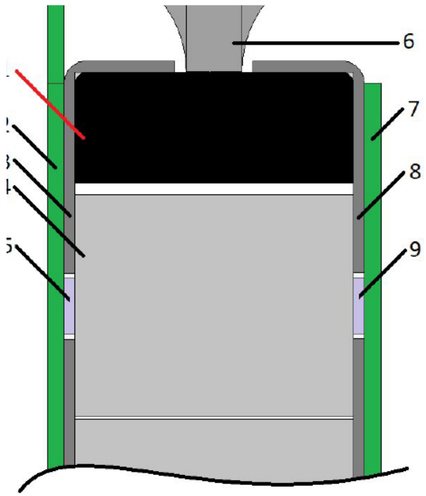
Upper limit is **1.3 * 10^9** neutrons (additional multi-neutron event recognition is required).

Schematic of the HGND mechanics

3D view of the HGND



Structure of active layer

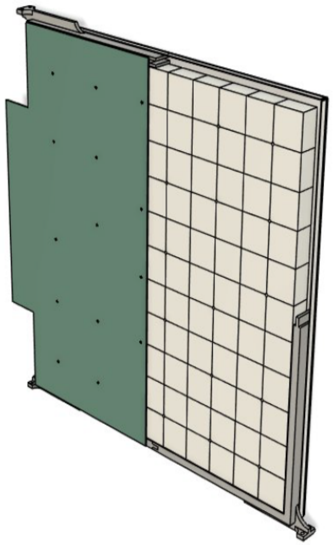


1) plastic frame (3D printed)
2) PCB with photodetectors

3,8) aluminium covering

4) scintillator
5) photodetector
6) holding part
7) PCB with LED
9) LED

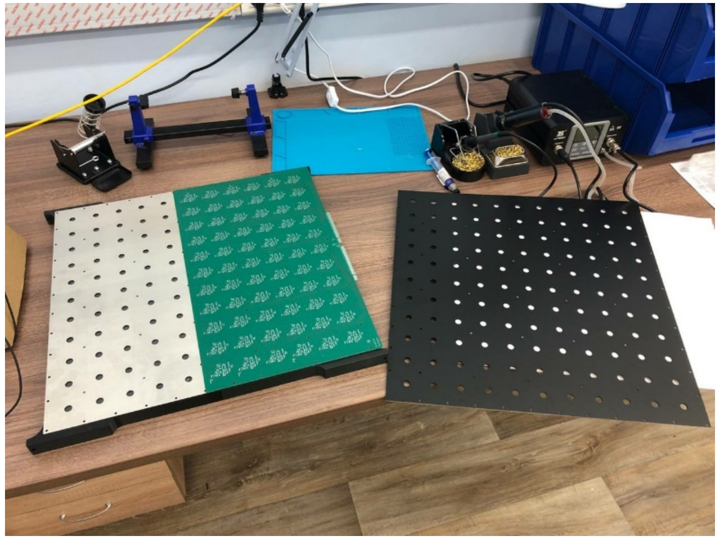
Active layer cassette



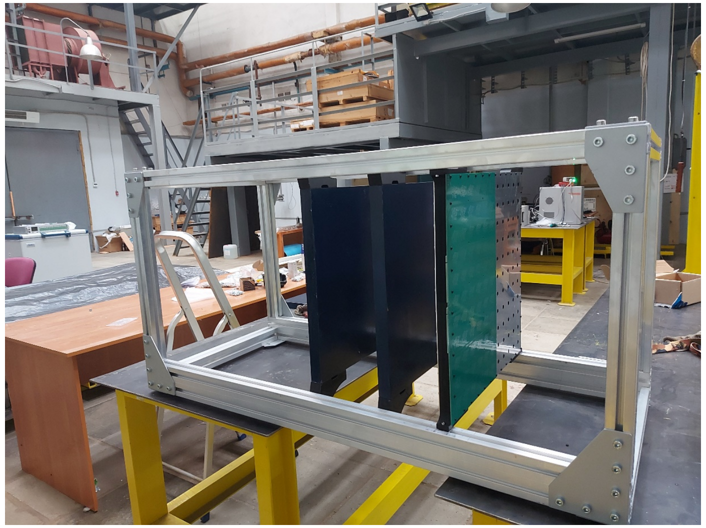
Status of the HGND construction

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 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
- 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 is still under discussions (cluster method, ML etc.)

Thank you for your attention!

Backup

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 mm^2, 15mkm pixel pitch, 160 000 pixels, PDE - 45%, gain - $4x10^5$)

Test results on e-beam at LPI

Scintillator:

1) JINR produced (40x40x25mm^3), 1.5% paraterphenyl and 0.01% POPOP) with light time decay of 3.9 ± 0.7 ns → σ ~117 ps, N ph.el. = 158 ± 9

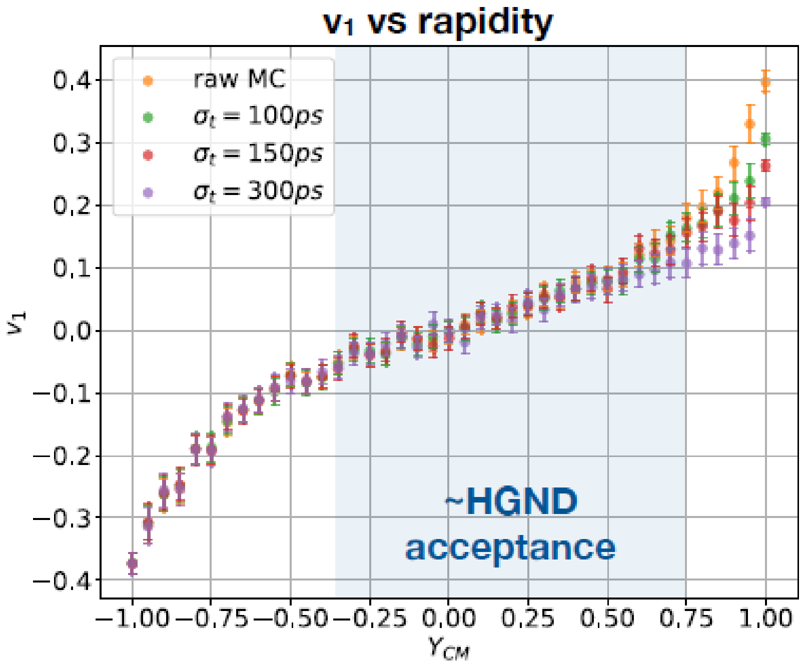
2) EJ230 with light time decay of 2.8 ± 0.5 ns → σ ~ 74 ps, N ph.el. = 292 ± 2

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

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 **p** and recalculated after time smearing
- v_1 vs Y_{CM} selection criteria:
  - E_{kin} > 0.5 GeV
  - Impact parameter ∈ (6, 9) fm
  - p_T ∈ (1., 1.5) GeV
- v_2 vs Pt selection criteria:
  - E_{kin} > 0.5 GeV
  - Impact parameter ∈ (6, 9) fm
  - Rapidity in c.m. ∈ (-0.2, 0.2)

p_T and rapidity cuts are on distorted values)

Time resolution effect gets noticeable only at forward rapidities