Development of new high granular neutron time-of-flight detector for BM@N experiment

Sergey Morozov
on behalf of INR RAS, Moscow

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Outline:

1) Neutron detectors in heavy-ion collision experiments

- main goal of neutron measurements in heavy-ion experiments
- neutron detectors at GSI and why they can not been used at the BM@N

2) HGN time-of-flight detector for BM@N:

- HGN proposed scheme and its place at BM@N experiment area
- some results of MC simulations of HGN and counting rate estimation
- time resolution measurements for scintillation detectors
- status of front-end and readout electronics development for HGN at INR RAS

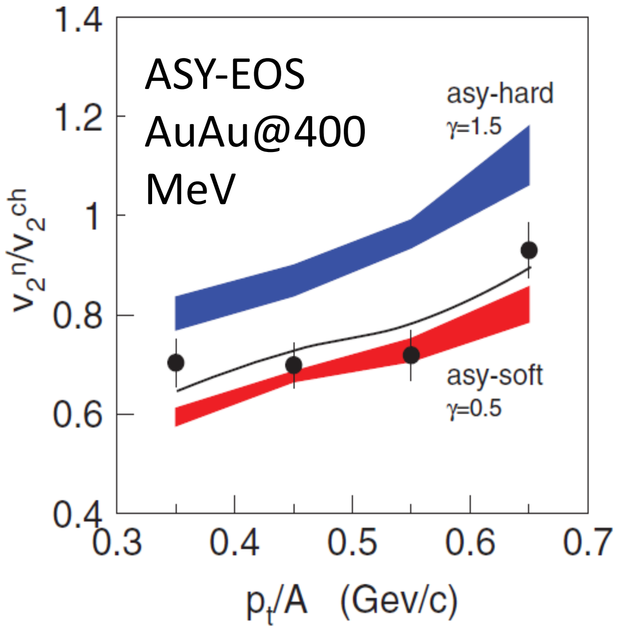
Flow as probe of the high-density EOS

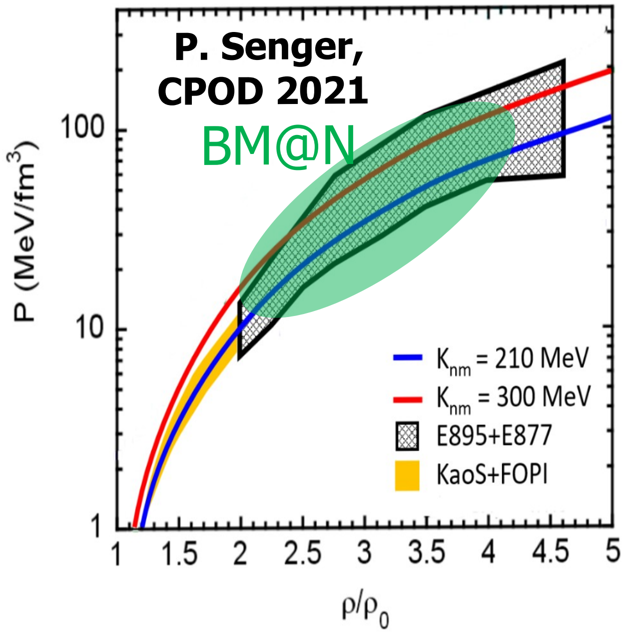
EoS – describes the relation between density, pressure, energy, temperature and the isospin asymmetry

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

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

The neutron-proton elliptic flow ratio - sensitive probe of the high density behavior of the nuclear symmetry energy





No neutron flow data at the energy range of the BM@N so far..

These data will be important to astrophysics: the relation of mass of neutron stars and its radius depends of EoS

For the moment, only few experiments on neutron flow measurements have been done at GSI (only at energies below 1 AGeV) more than 10 years ago.

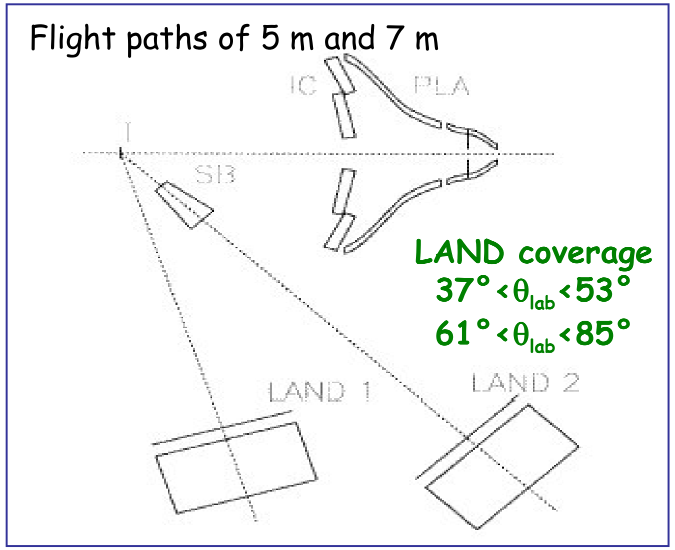
FOPI/LAND

Au+Au, 400 AMeV

Y. Leifels *et al.* Phys. Rev. Lett. 71, 963 (1993)

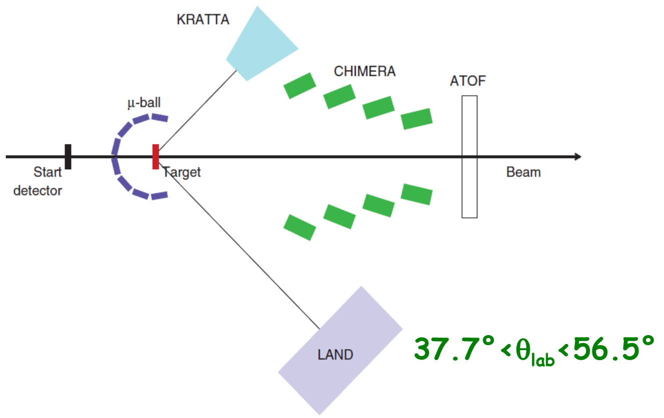
Au+Au, 400-800 AMeV

D. Lambrecht et al., Z. Phys. A 350, 115-120 (1994)



Au+Au, 400 AMeV

P .Russotto et al., Physics Letters B 697 (2011) 471–476



- **direct and elliptic flow both of neutrons and** charged particles with Z=1 (no p, d, t isotopes **identification)** have been done **only with neutron detector**

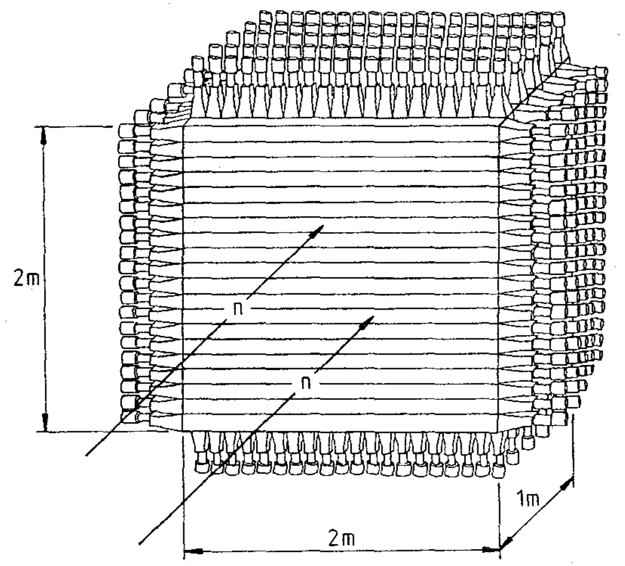
BM@N:

- proton flow can be measured with particle identification at magnet spectrometer
- to measure neutron flow new neutron detector is needed to be developed and constructed

Only two detectors to measure neutrons are available now

LAND - a TOF neutron spectrometer (constructed in 1990).

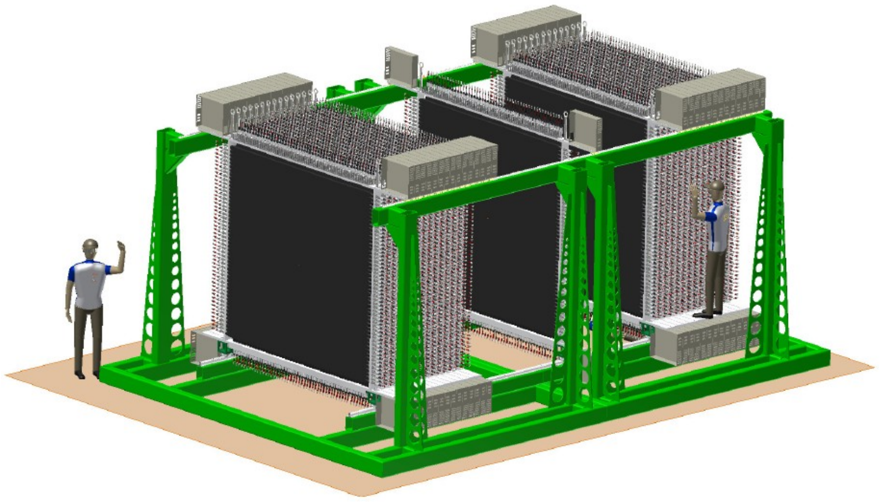
T. Blaich, et al., NIM. A 314 (1992) 136.



- total volume 2.0x2.0x1 m^3
  200 modules (plastic scint/Fe bars 200x10x10 cm^3
- 10 mutually perpendicular planes with 20 bars in each,
- two PMT for each bar readout (400 readout channels)
- $\sigma_t \approx 250$ ps,
- $\sigma_{x,y,z} \leq 3$ cm
- one-neutron efficiency > 80% for energies > 400 MeV
- without 1,2,3H isotopic discriminations

NeuLAND

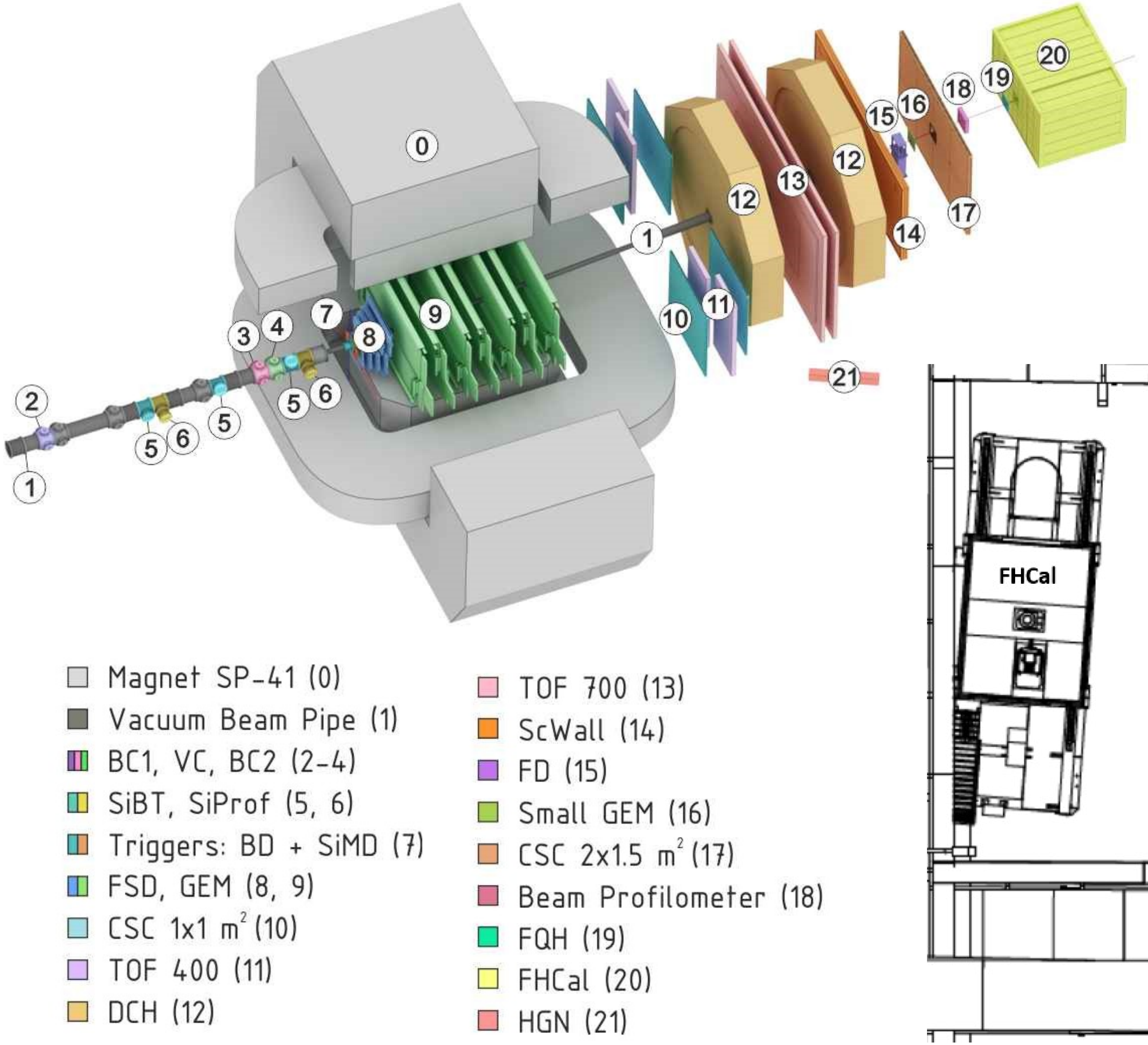
K.Boretzky et al., NIM, A 1014 (2021) 1



- total volume 2.5x2.5x3 m^3
  3000 modules (plastic scintillator bars (w/o Fe)
  250x5x5 cm^3
- 30 double planes mutually perpendicular with 100 bars each
- two PMT for each bar readout (6000 readout channels)
- $\sigma_t \leq 150$ ps
- $\sigma_{x,y,z} \leq 1.5$ cm
- one-neutron efficiency ~95% for energies 200-1000 MeV,

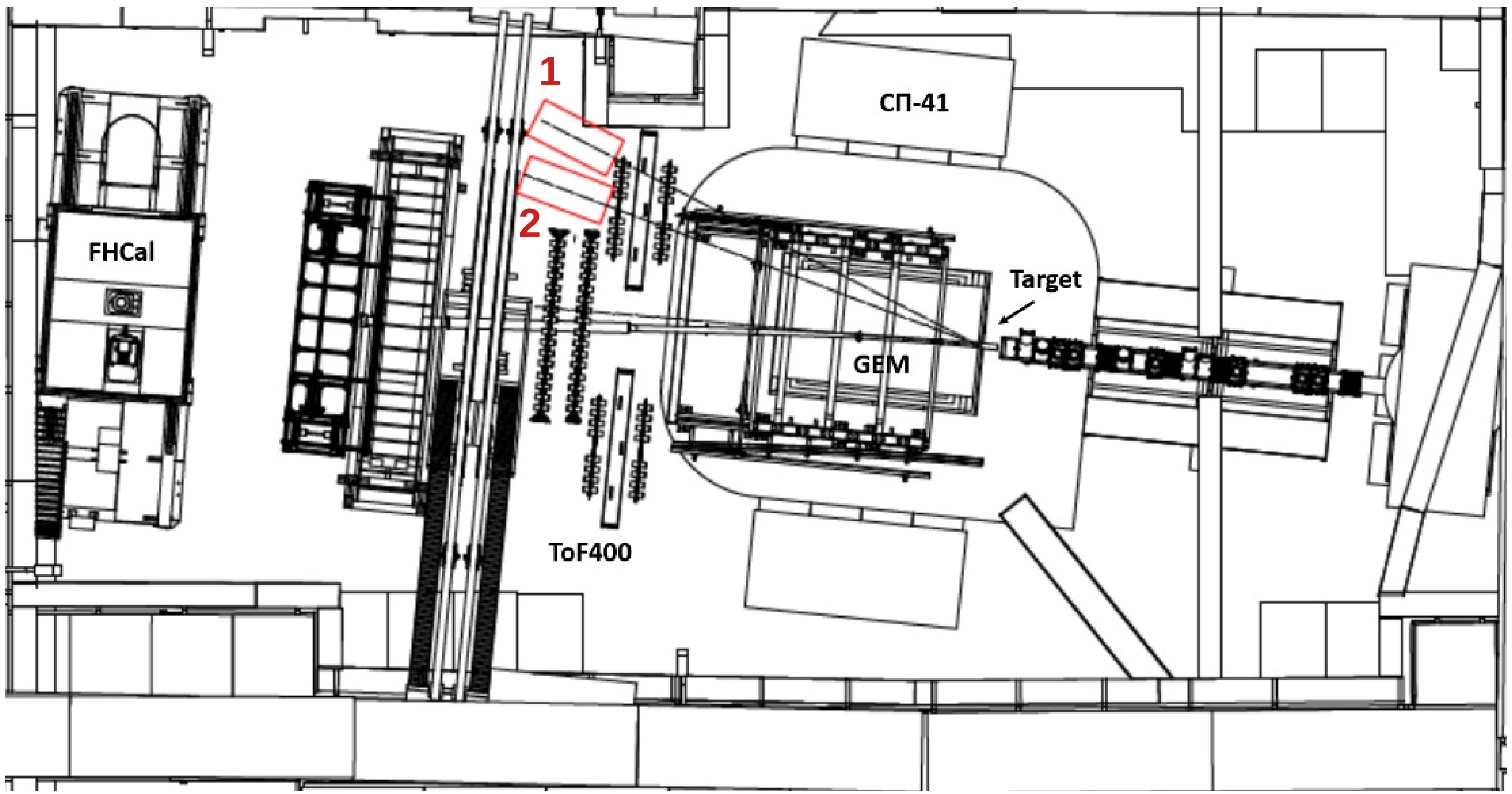
Both of these types of detectors can be not used at the BM@N (size!)

Preliminary positions of neutron detector at the BM@N



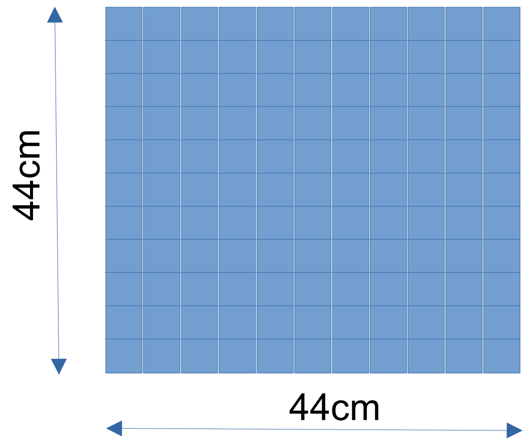
Due to limited space in the BM@N setup area the possible HGN detector positions are:

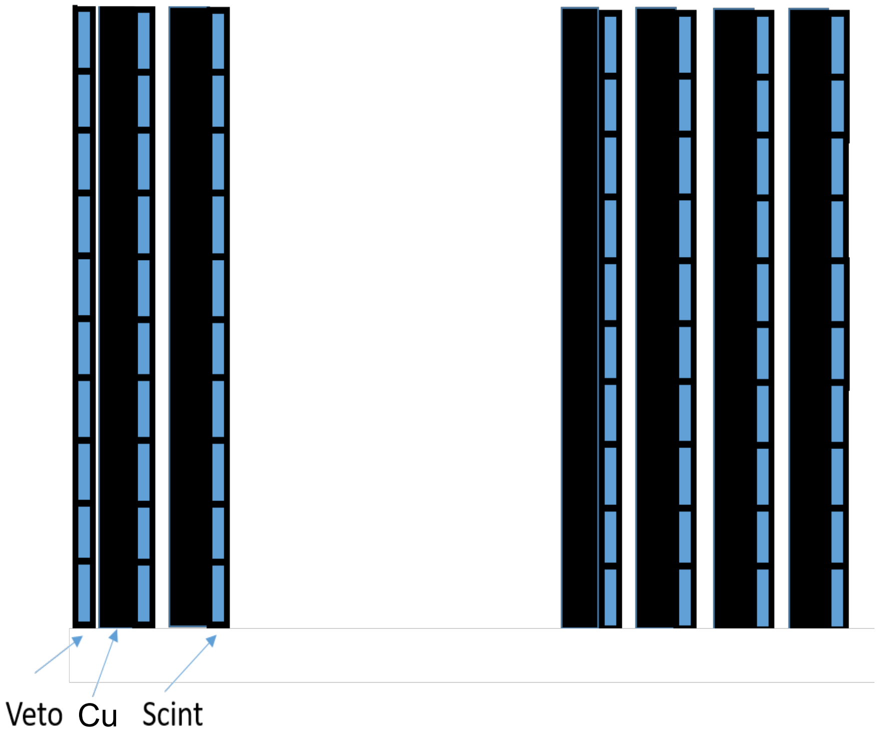
(1) 22.3° (2) 15.6°



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

One layer: map of 11x11 scintillator cells





- transverse size of one layer: 44 x 44 cm

- number of layers: 3 cm Cu (absorber) + 2.5cm Scintillator + 0.5cm Plastic (for electronics) – 16

- length of HGN: ~ 100 cm (~3 λ_{in})

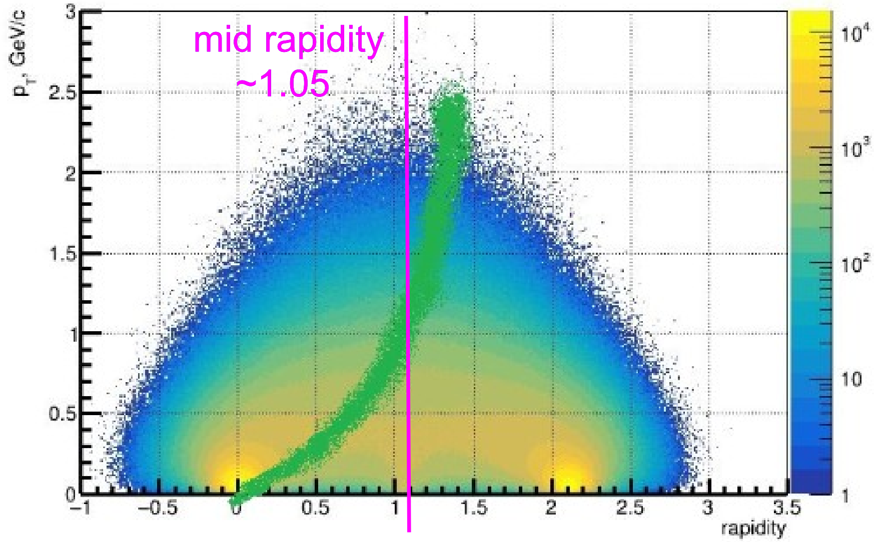
- scintillation detectors (cells):
  size: 4x4x2.5 cm, total number of cells: 1936
  light readout: SiPM, proposed time resolution: ~ 100 ps (~1GeV energy and short distance)

Final parameters are still discussed (based on MC simulations and results from HGN prototype beam tests)

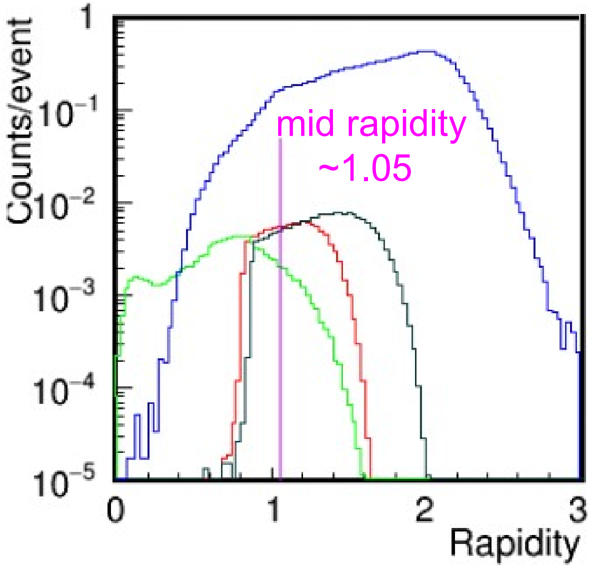
Expected spectra of rapidity and neutron energy spectra for heavy-ion collisions

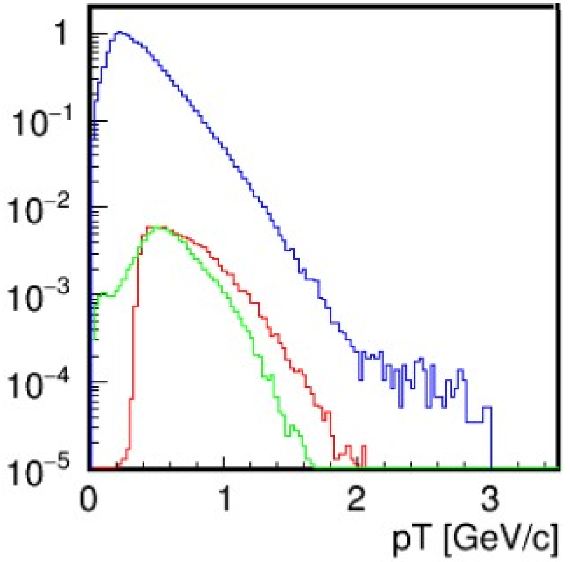
Simulation: Bi + Bi @ 3AGeV, DCM-SMM

Acceptance of HGN detector at 22.3°



time of flight < 22ns
protons, neutrons at 22.3°, neutrons at 15.6°, bg neurtrons





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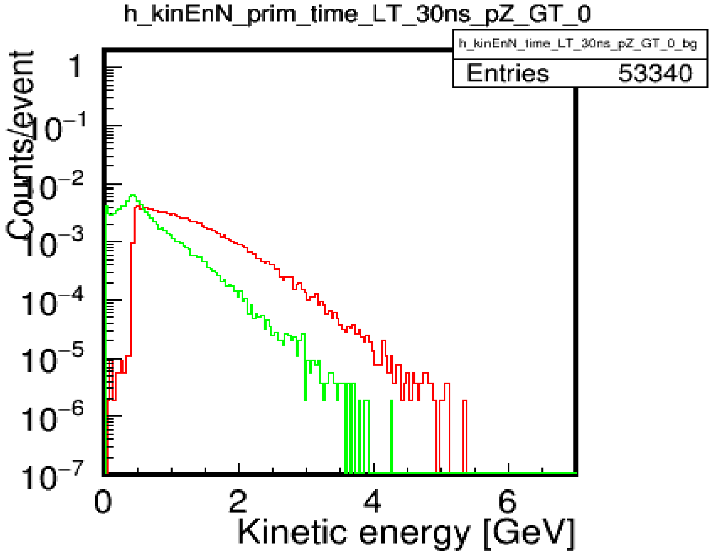
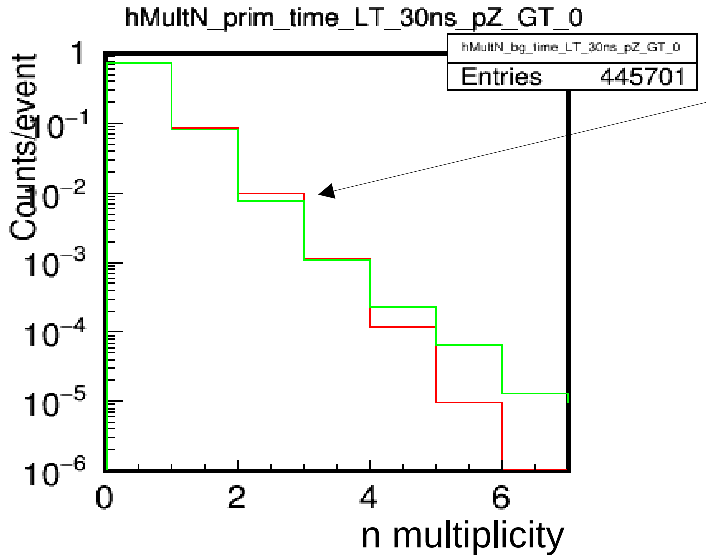
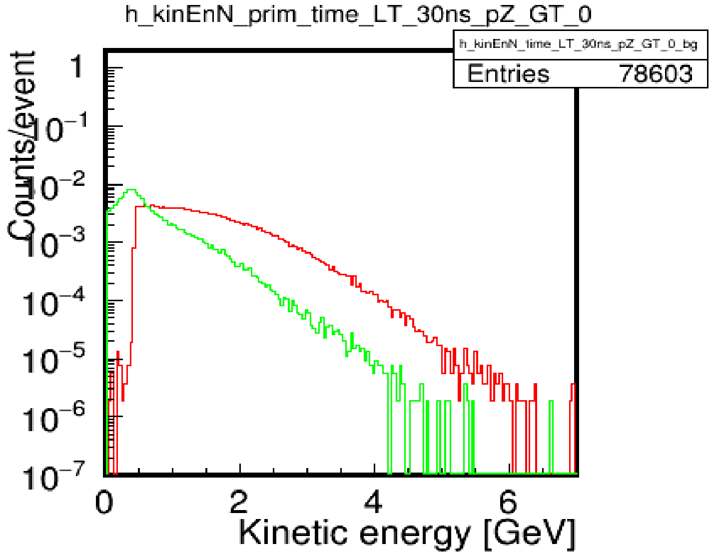


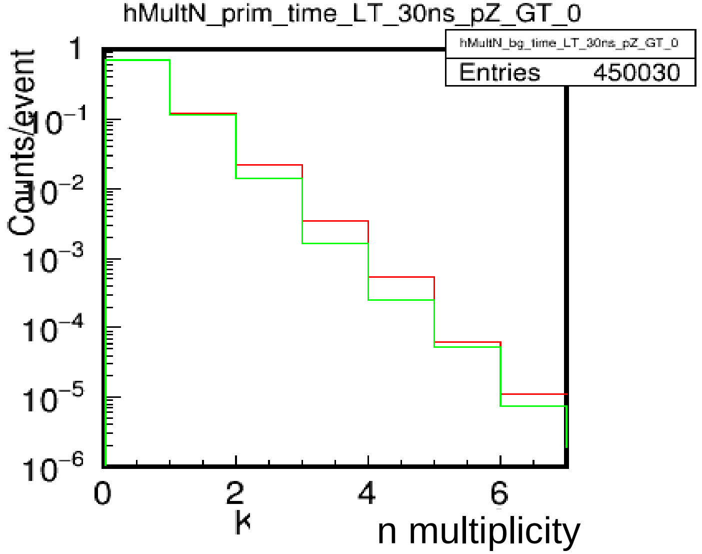


one order of magnitude
for > 1 neutron in HGN

HGN detector at 22.3º

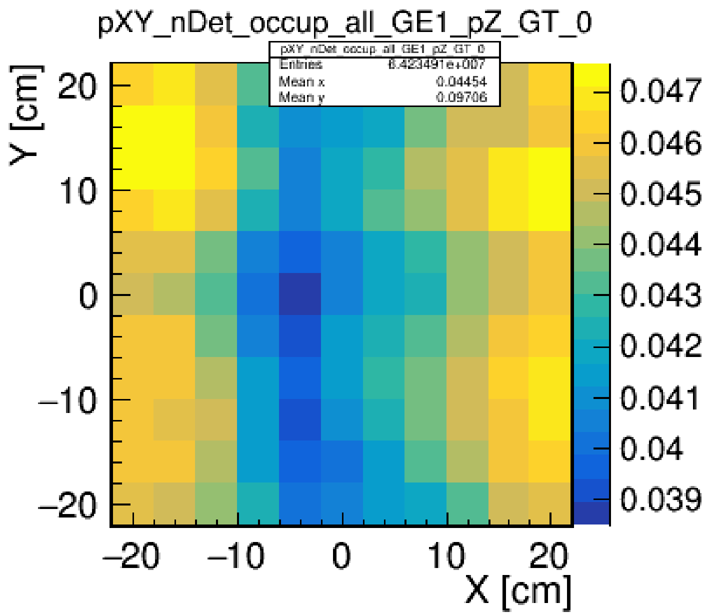
prim. neutrons
bg neutrons

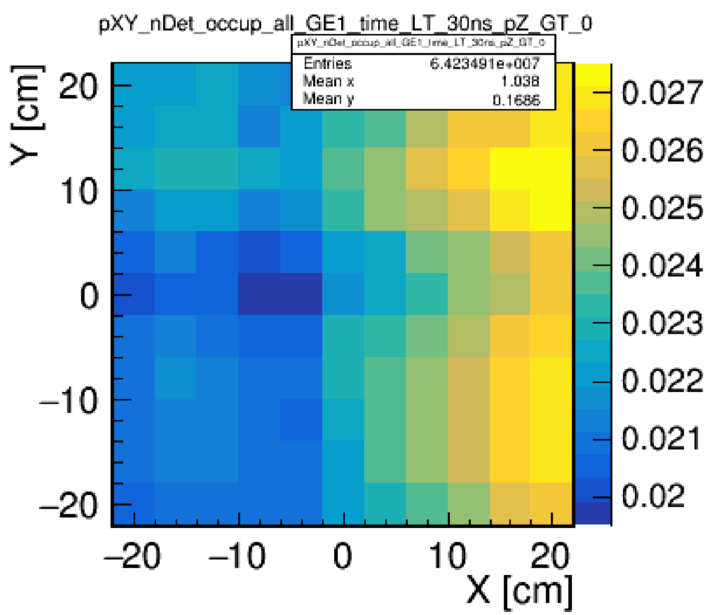




HGN detector at 15.6º

Hit occupancy of HGN based on simulations (BiBi@3.0A GeV, 22ns time cut), HGN at 22.3 deg

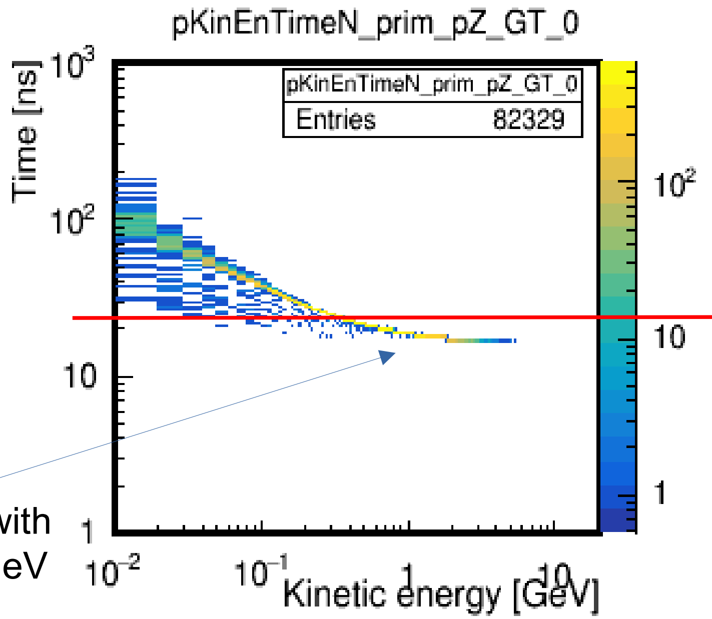




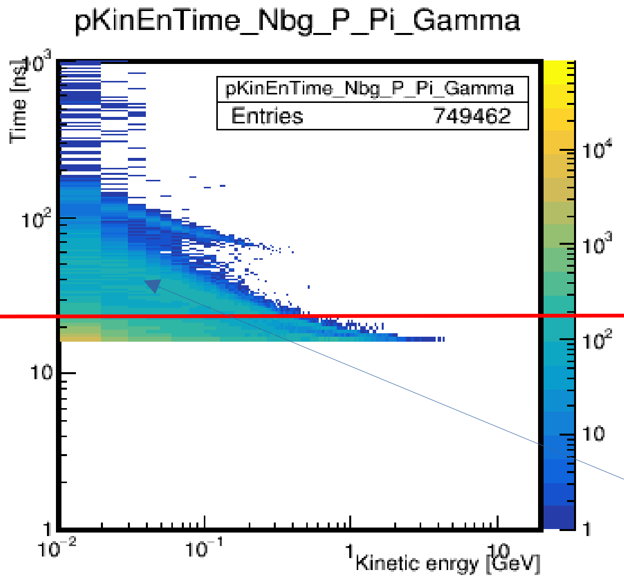
- at interaction rate of about 10 kHz the maximum count rate in the VETO single scintillator detector is expected on the level of 30 particles per second.

- probability to have 2 hits or more in one cell < 1%

Primary neutron reconstruction and background neutrons rejection

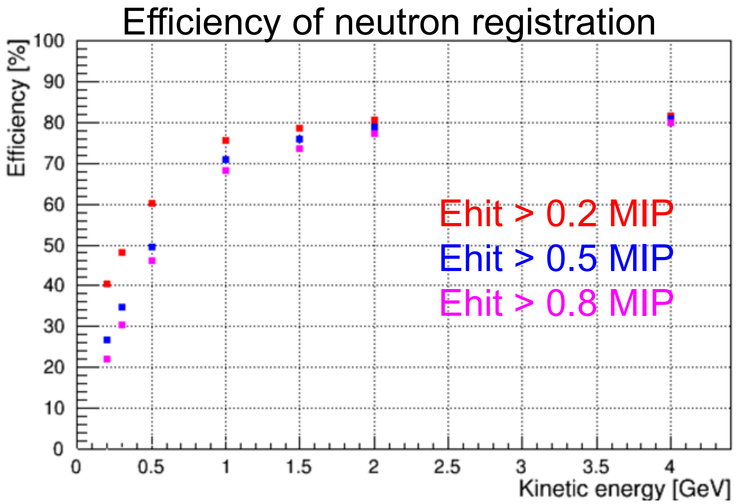


primary neutrons with energies 0.3 – 4 GeV

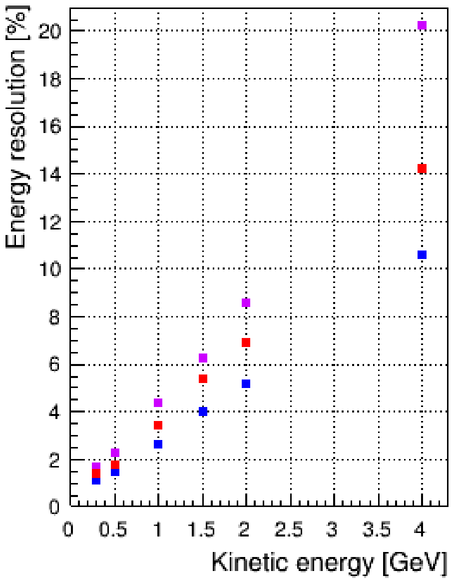


22ns time cut

background neutrons can be significantly reduced with time cut



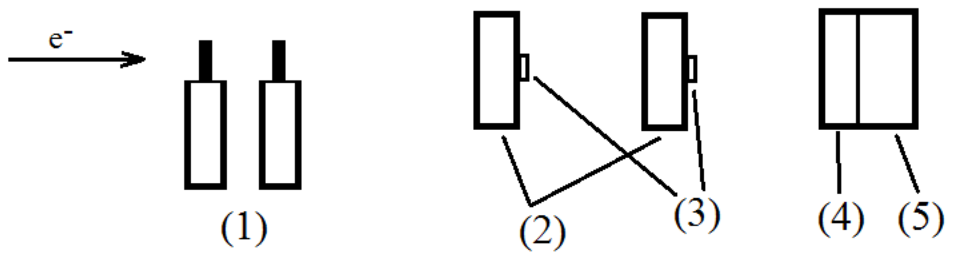
Neutron energy resolution



Scint. detector energy resolution:
100ps
150ps
200ps

Measurements of time resolution of scintillating detector assemblies (scint + SiPM)

setup for test on electron beam

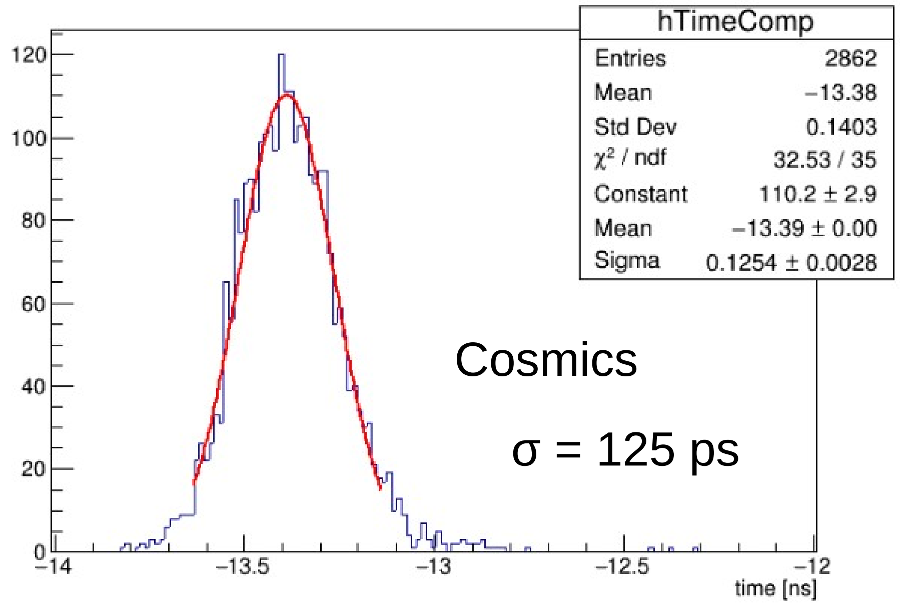


(1) beam counters
(2) scintillarots with 3) SiPMs
(4) quartz radiator + (5) MCP

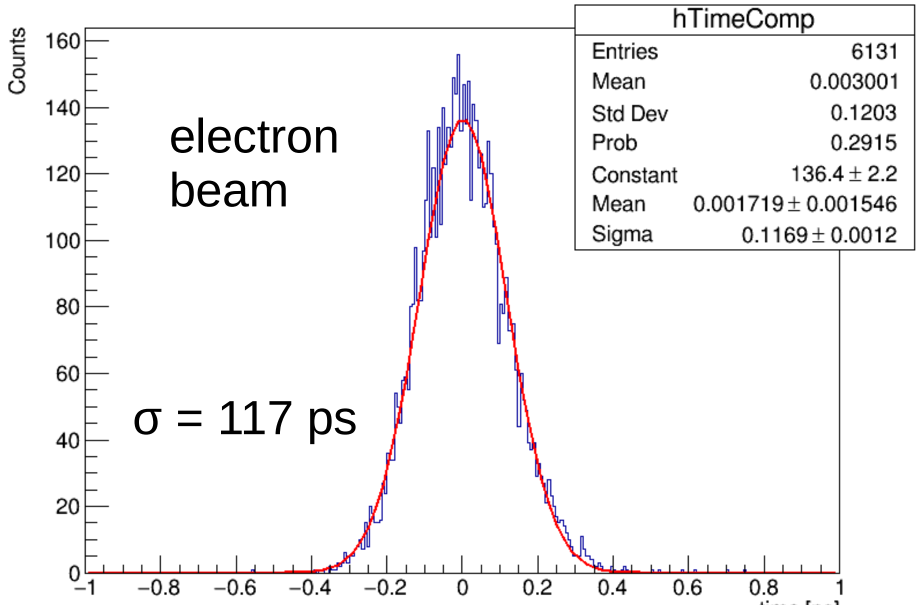
Phododetector: EQR15 11-6060D-S (45% PDE, gain of $4x10^5$)

Scintillator: JINR produced ($40x40x25mm^3$, 1.5% paraterphenyl and 0.01% POPOP)

Read-out: 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

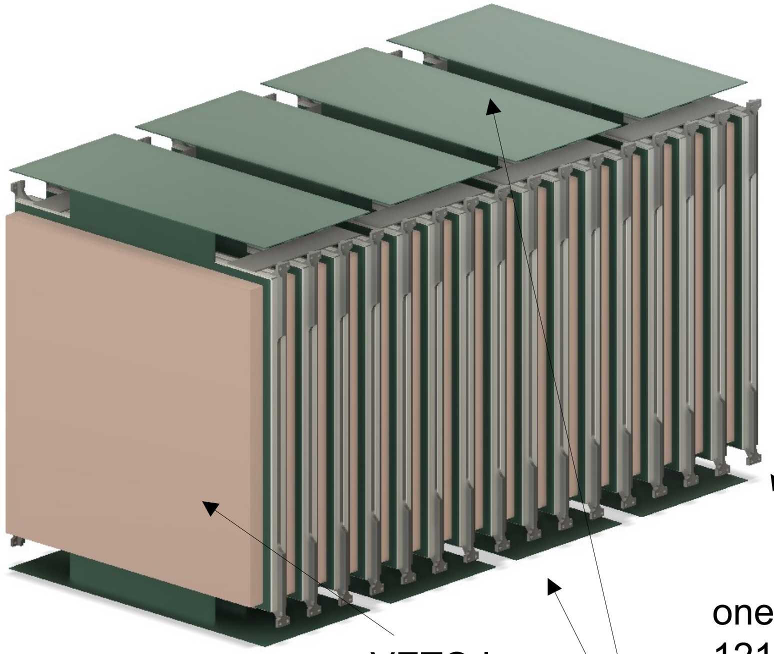


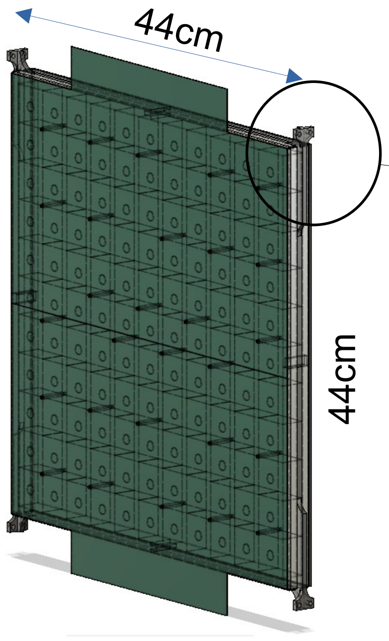
time(SiPM) - time(MCP), [ns]

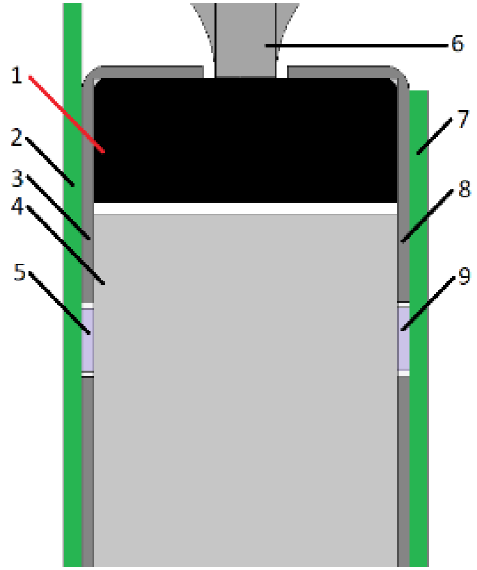


time(SiPM) - time(MCP), [ns]

Development of HGN in progress..



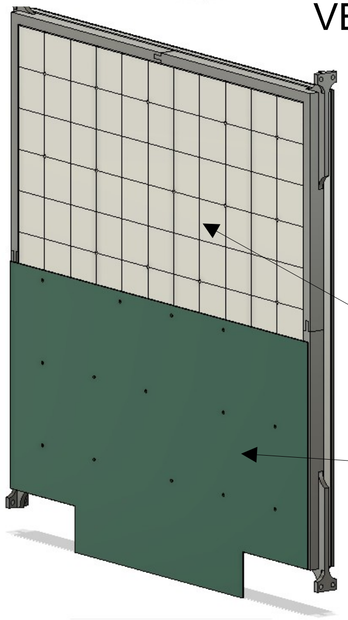




VETO layer

one layer containing 121 scintillating detectors with individual SiPM read-out

FPGA based fast TDC read-out with **amplitude measurement (ToT method)**



scintillation cells

large PCB with Front-End-Electronics (FEE) components

Front-End-Electronics:

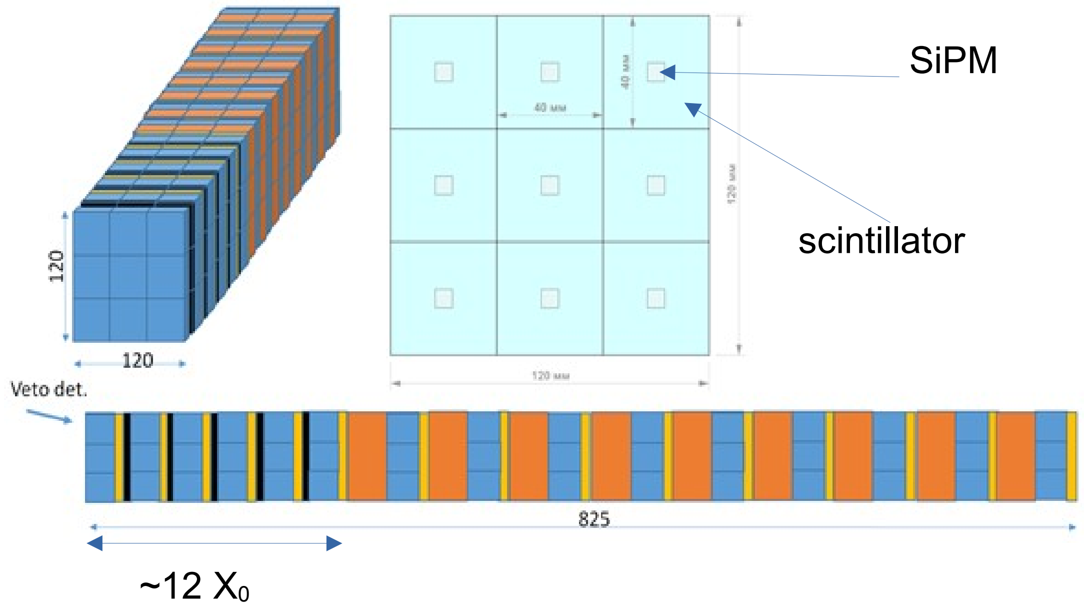
- SiPM HV power supply with temperature gain compensation

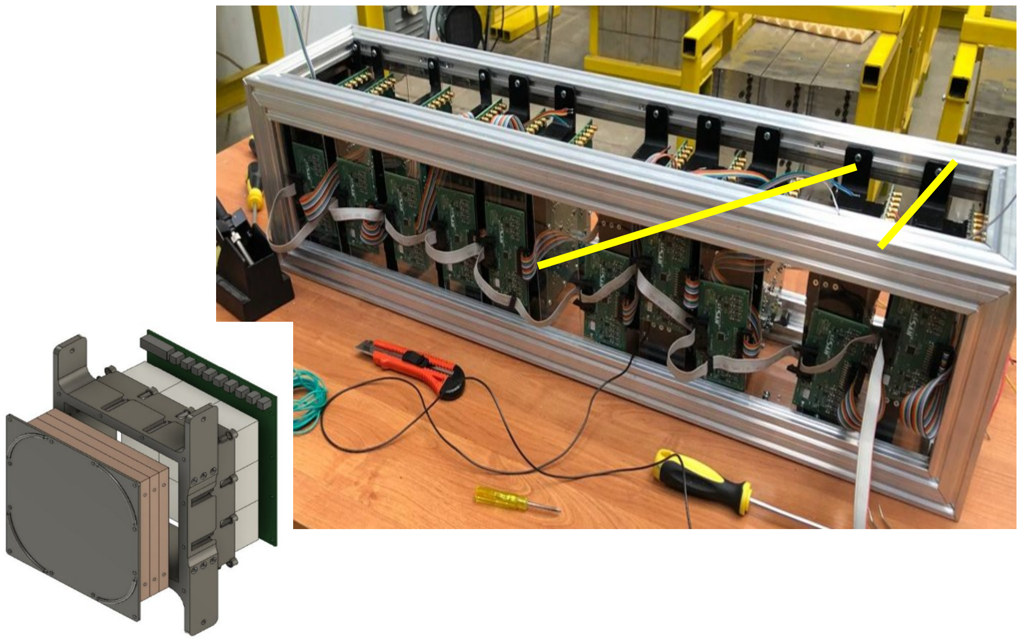
- amplification of SiPM signal with discriminators for TDC

Read-out electronics:

- FPGA based TDC boards with
  1) TDC for time measurements and
  2) ToT for amplitude measurements

1 – the frame of the case;
2 – one of the two PCBs with 55 or 66 SiPMs (5);
3 and 8 - aluminum plates for both sides of the frame case with cutouts for SiPMs and LEDs;
4 – scintillator; 5 – SiPM,
6 – layer support bracket;
7 – LED PCB; 9 – LED;





HGN prototype at XeCsI run in 2023

HGN prototype (15 layers, thickness ~ 2 λ_{int}):

1-st layer – VETO

2-6 layers – γ-detection (E/M) part (Pb/Scint.)

7-15 layer – n-detection part (Cu/Scint.)

Absorbers - 8mm Pb, 30mm Cu,

145 scintillator cells (40x40x25mm)

Hamamatsu MPPCs are used

Main goals:

- study of mechanics and FEE design
- developments of neutrons registration methods
- measured time resolution of cell ~ 150 ps

Conclusions & Outlook:

- new HGN time-of-flight detector is developing and constructing at INR RAS (end 2025)

- scintillation detectors have been studied on cosmics and electron test beam (~ 100ps time resolution)

- front-end and read-out electronics is under developing now (FPGA based TDC + ToT method)

- HGN prototype has been used at XeCsI run in 2023 on the BM@N and will be used in upcoming runs

- full scale HGN operation: end of 2025

The development of HGN is supported by RSF grant No. 22-12-00132

Thank you for your attention!