High Granular Neutron Time-of-Flight Detector for BM@N Experiment

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on behalf of INR RAS, Moscow

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St Petersburg University

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

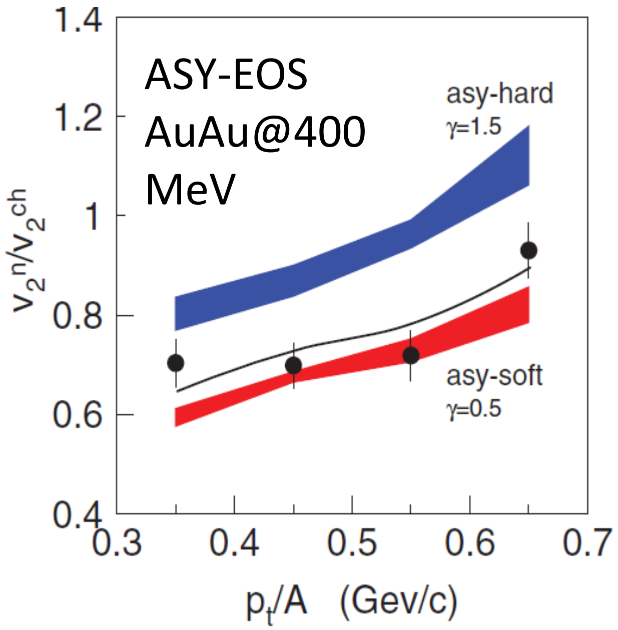
Flow as probe of the high-density EOS

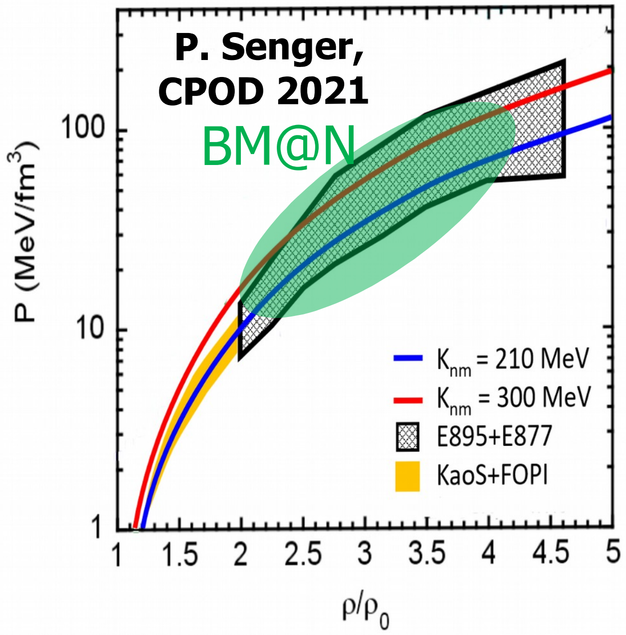
EoS – describes the relation between density, pressure, energy, temperature and the isospin asymmetry

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

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





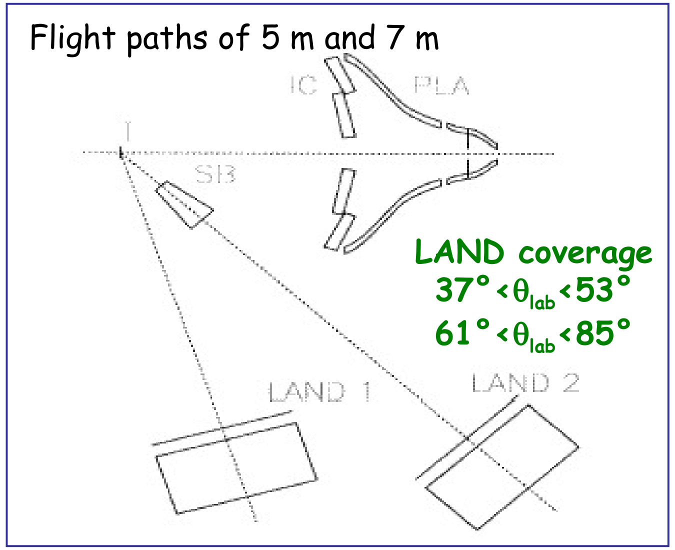
No neutron flow data at the energy range of the BM@N so far..

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.

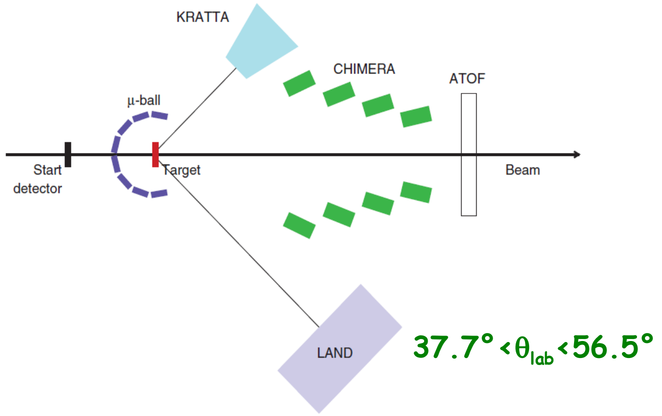
FOPI/LAND

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)


Flight paths of 5 m and 7 m

LAND coverage
$37^\circ < \theta_{lab} < 53^\circ$
$61^\circ < \theta_{lab} < 85^\circ$

Au+Au, 400 AMeV
P .Russotto et al., Physics Letters B 697 (2011) 471–476


$37.7^\circ < \theta_{lab} < 56.5^\circ$

- **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**

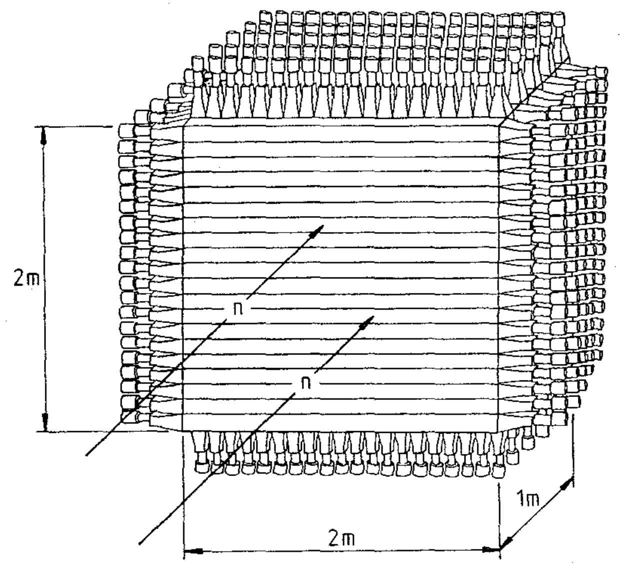
BM@N:

- 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).

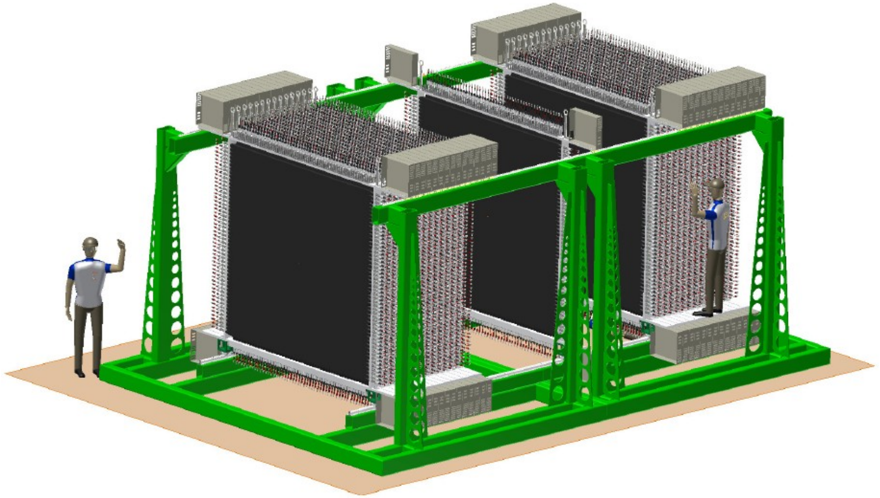
T. Blaich, et al., NIM. A 314 (1992) 136.



- 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

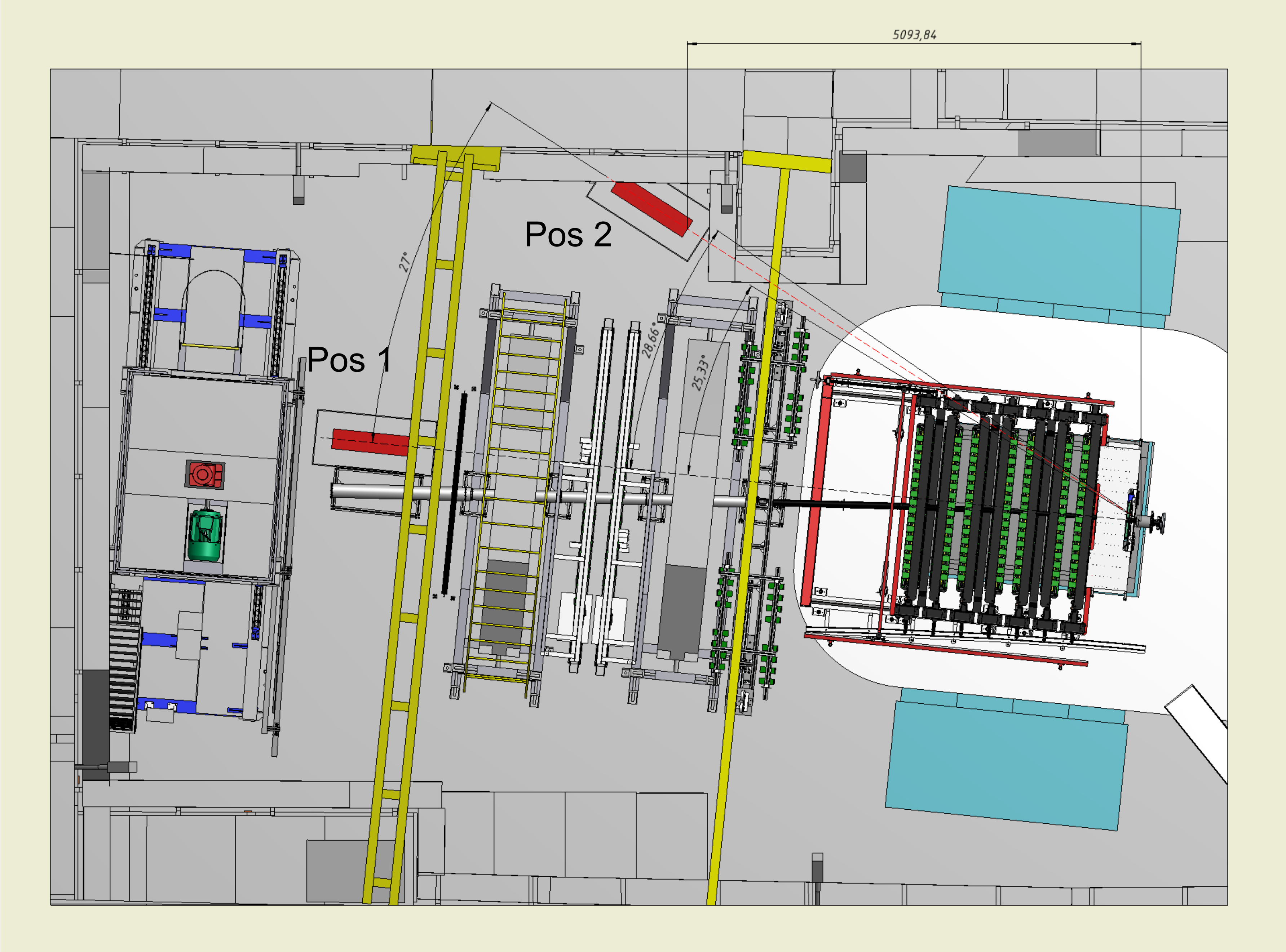
K.Boretzky et al., NIM, A 1014 (2021) 1



- 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,

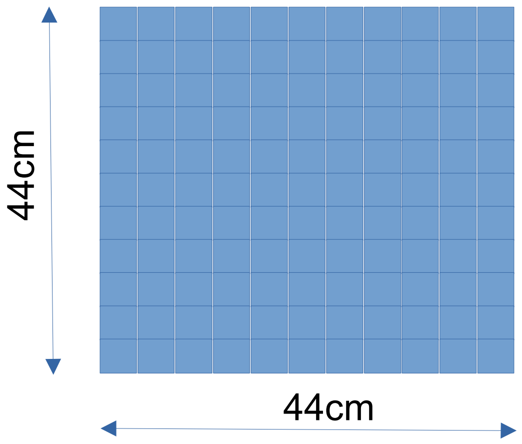
Both of these types of detectors can be not used at the BM@N (size!)

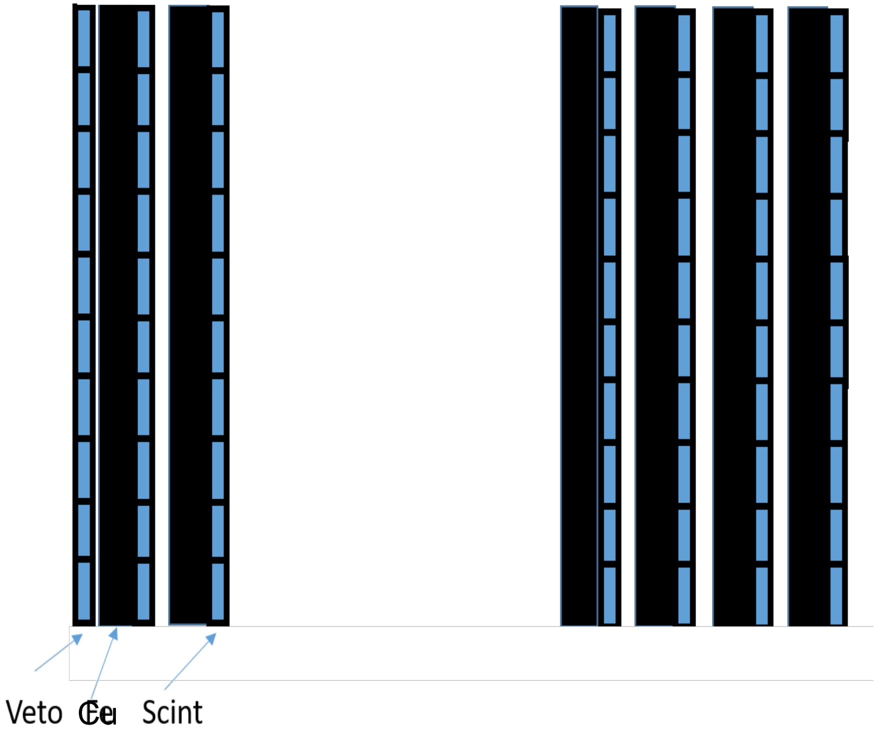
Preliminary positions of neutron detector at the BM@N



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})

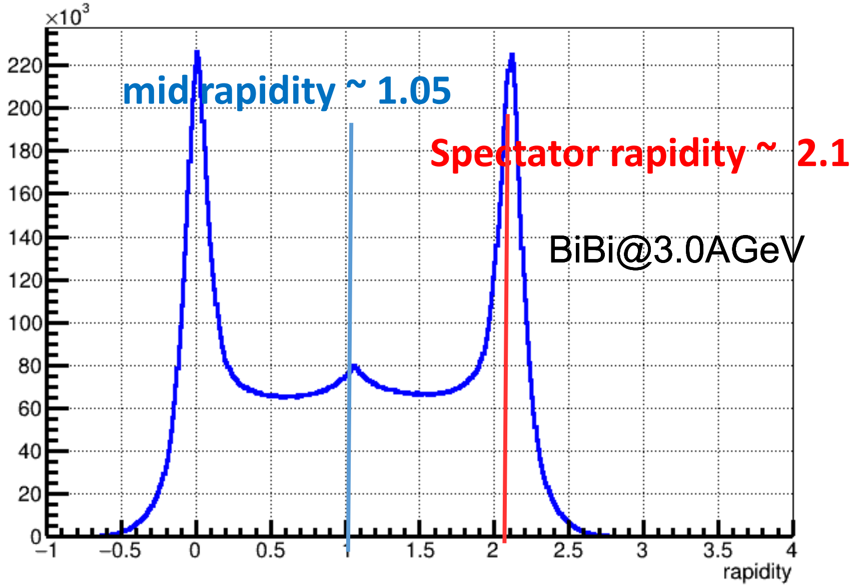
- scintillation detectors (cells):
  size: 4x4x2.5 cm, total number of cells: 1936
  light readout: SiPM, proposed time resolution: ~ 100 ps (~1GeV energy and short distance)

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

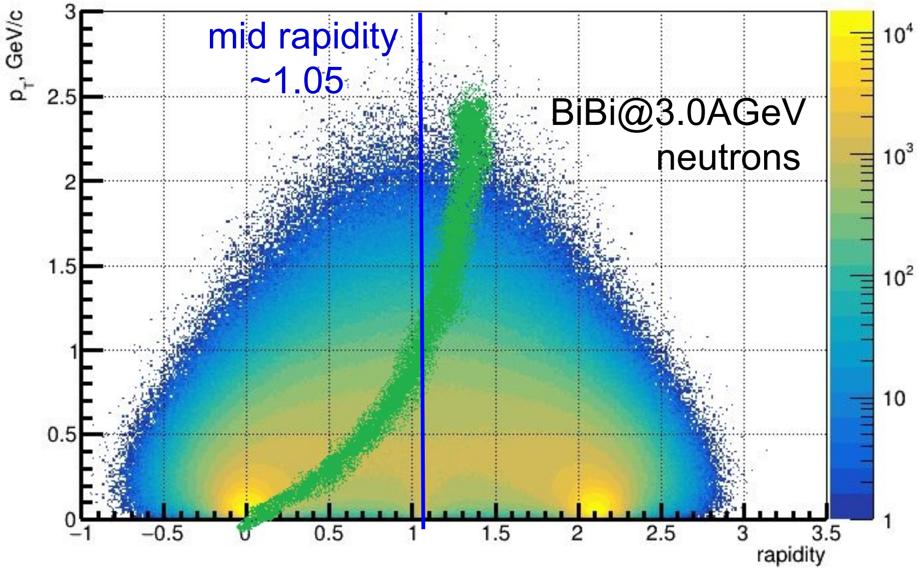
Expected spectra of rapidity and neutron energy spectra for heavy-ion collisions

Simulation: Bi + Bi @ 3AGeV, DCM-SMM, HGN detector at 27º

Rapidity spectrum for neutrons



Acceptance of HGN detector



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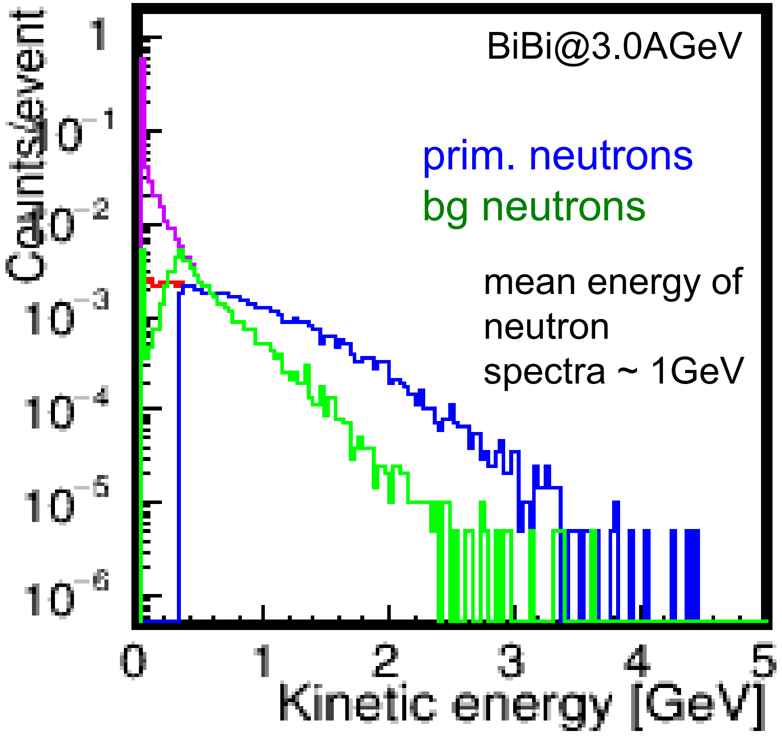
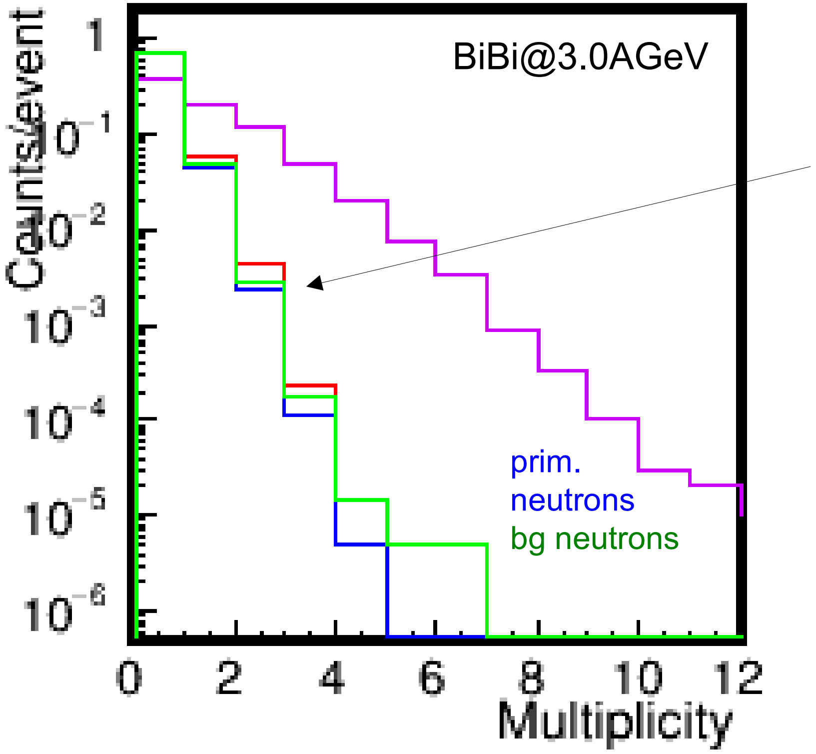
Simulation: Bi + Bi @ 3AGeV, DCM-SMM, HGN detector at 27º



prim. neutrons

bg neutrons

mean energy of neutron spectra ~ 1GeV



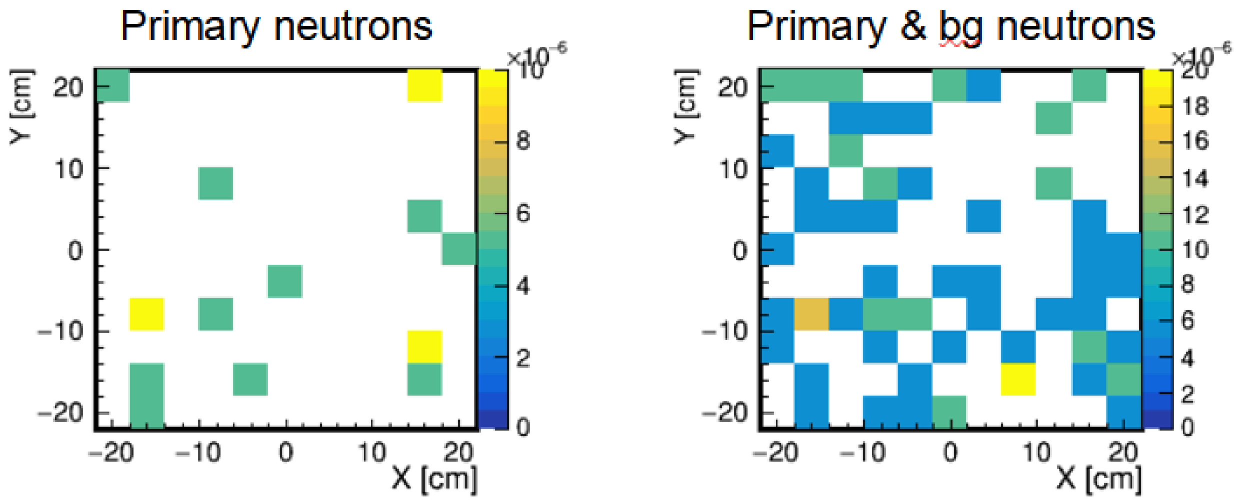
prim. neutrons

bg neutrons

one order of magnitude for > 1 neutron in HGN

Hit occupancy of HGN based on simulations (BiBi@3.0A GeV, 30ns time cut), HGN at 27 deg

Probability to have 2 hits or more in one cell



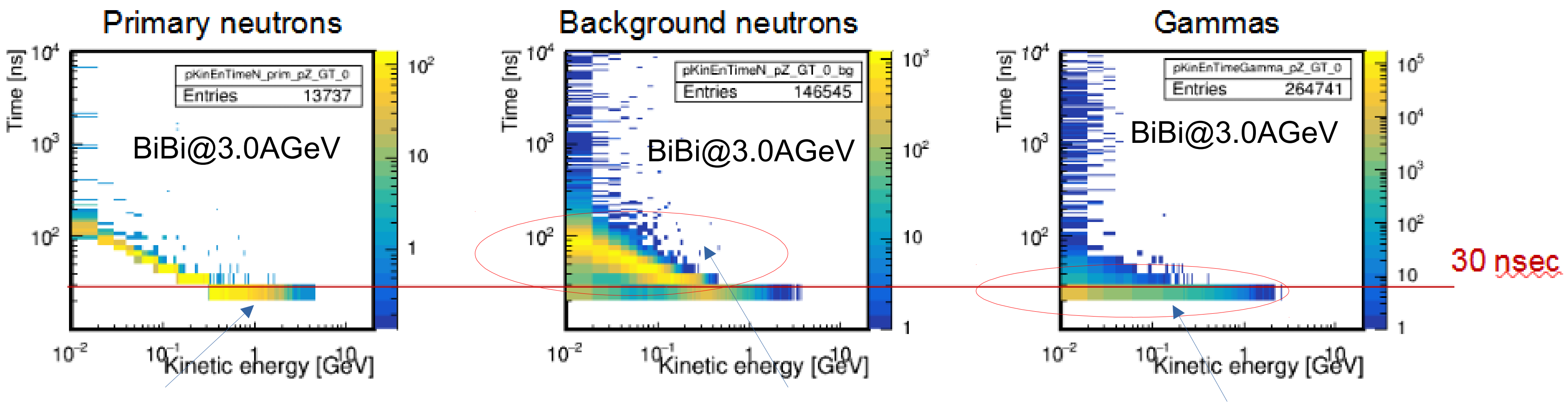
Data taking rate estimation:

Probability of: 1 n ~ 0.05, 2 n ~ 0.003 in one MB interaction (slide 10)

Beam (Bi) (M. Kapishin slides) 1.5 * 10^6 ions/spill (4s in 12s cycle) with 2% target: 1.5 * 10^6 / 12s * 0.02 (2%) * 0.053 (n/interaction) ≈ 130 n / sec

With 60% eff. of Nuclotron operation ~ 2 * 10^8 n events / month expected (without neutron detection efficiency taken into account.. see next slide..)

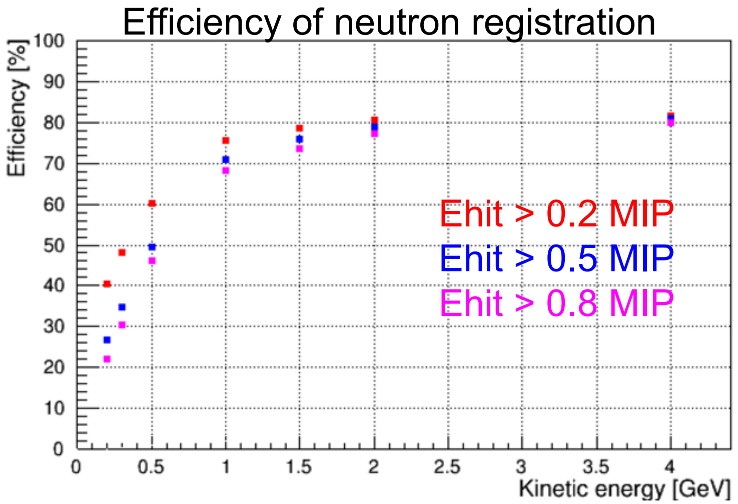
Primary neutron reconstruction and background neutrons and gamma rejection

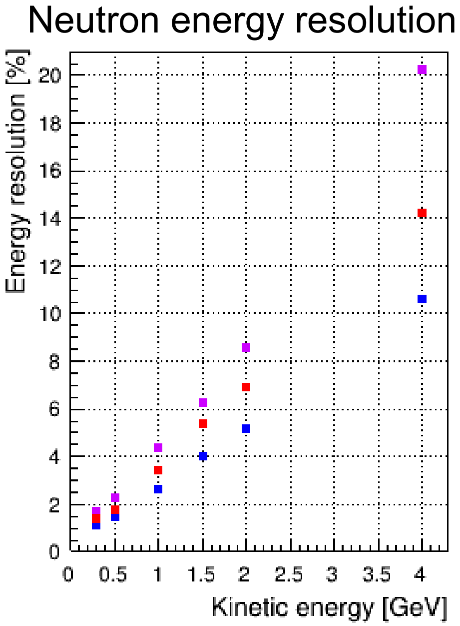


primary neutrons with energies 0.3 – 3 GeV

background neutrons can be significantly reduced with time cut

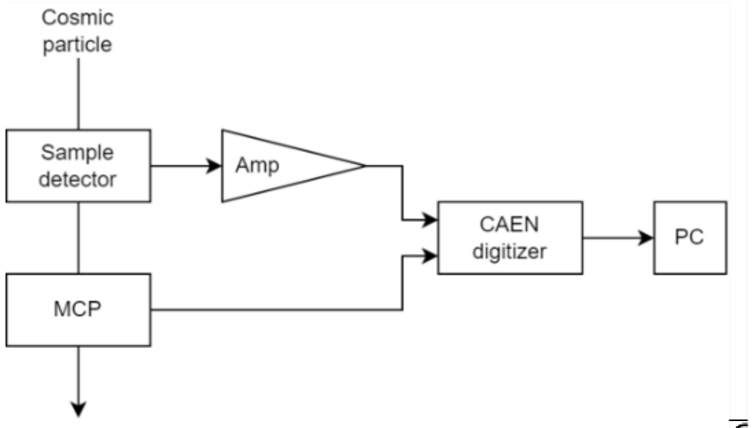
rejection of gamma will use HGN high granularity

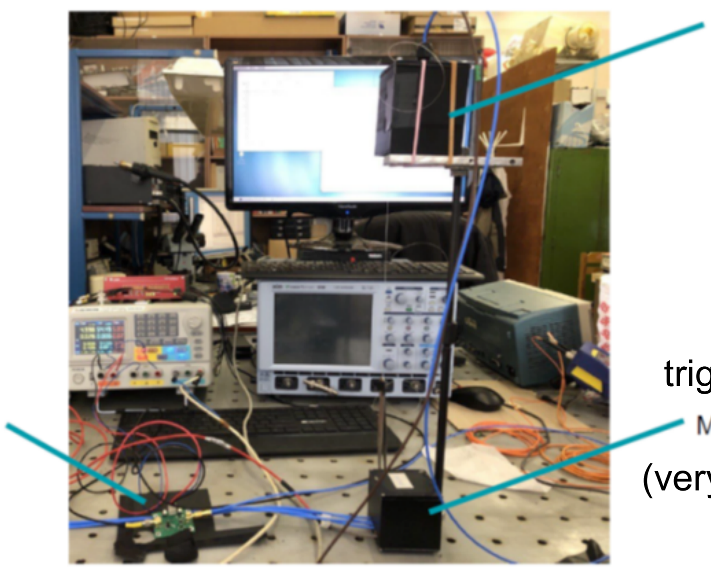




Scint. detector energy resolution:
100ps
150ps
200ps

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



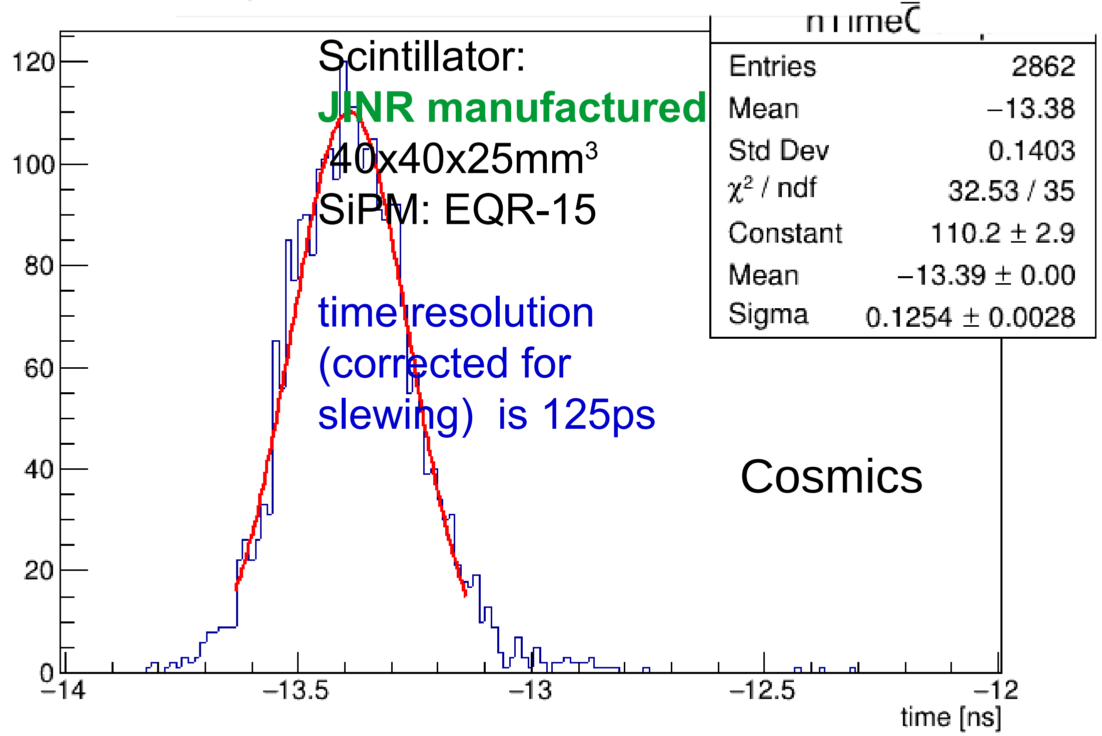

Sample detector

Sample detector amplifier

trigger detector

MCP FIT T0

(very fast, ~18ps)



Scintillator: **JINR manufactured**

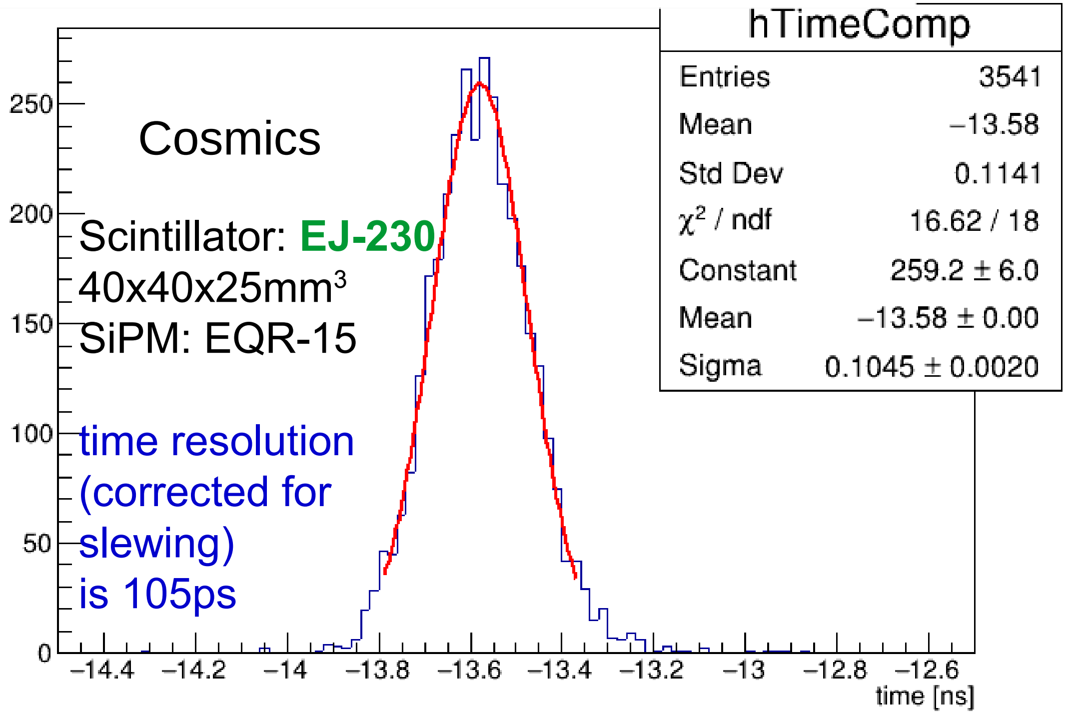
40x40x25mm^3

SiPM: EQR-15

time resolution (corrected for slewing) is 125ps

Cosmics

time(SiPM2) - time(MCP), [ns]



Cosmics

Scintillator: **EJ-230**

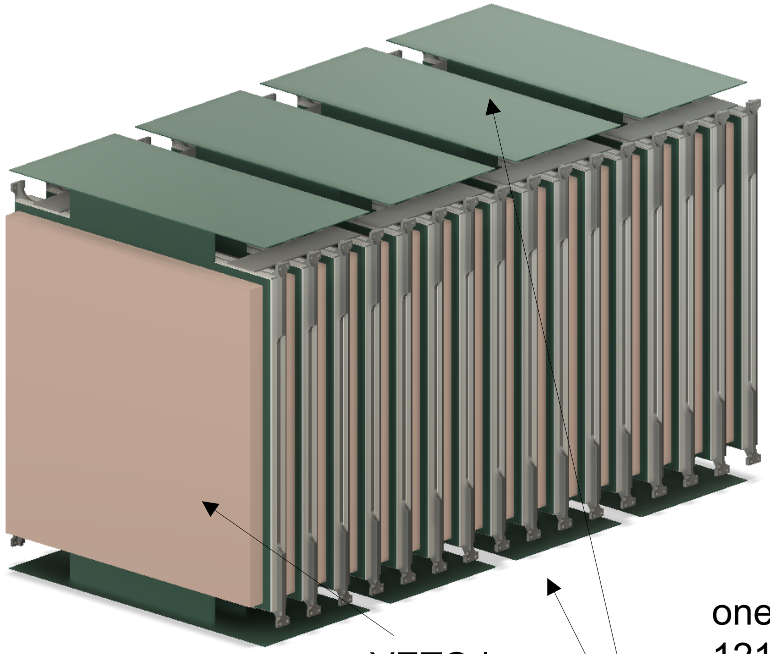
40x40x25mm^3

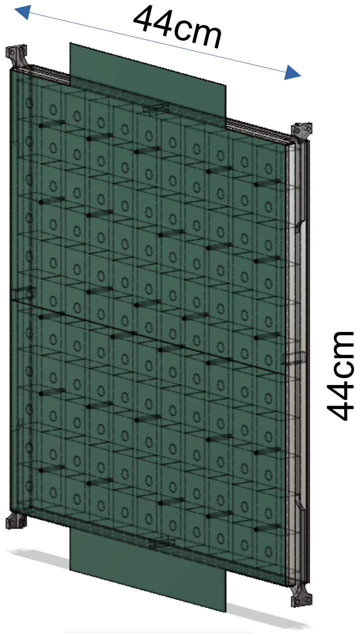
SiPM: EQR-15

time resolution (corrected for slewing) is 105ps

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

Development of HGN in progress..

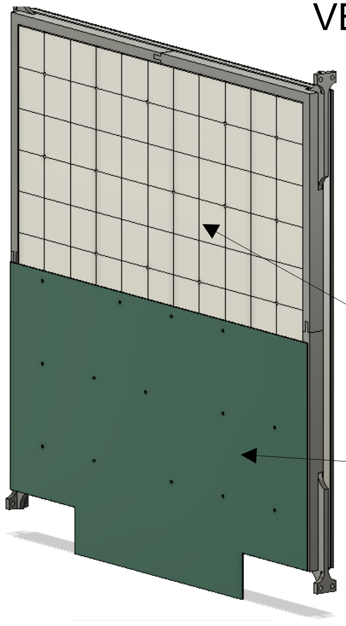




VETO layer

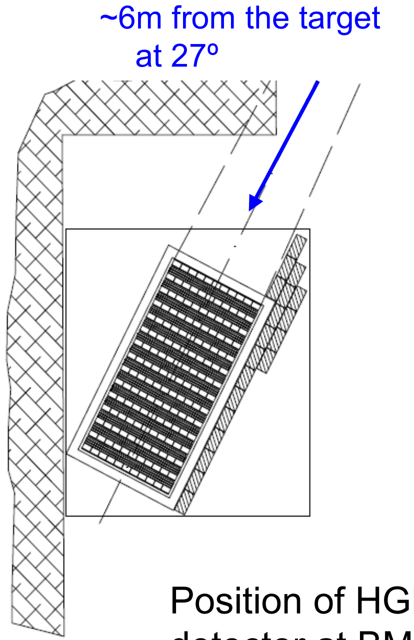
one layer containing
121 scintillating
detectors with individual
SiPM read-out

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



scintillation cells

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



Position of HGN
detector at BM@N

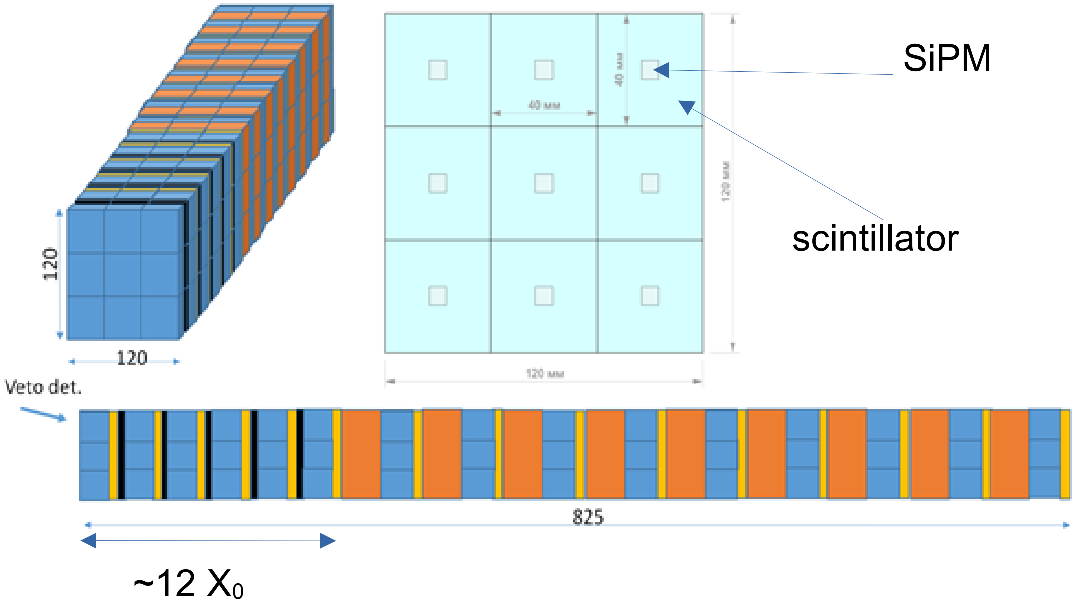
Front-End-Electronics:

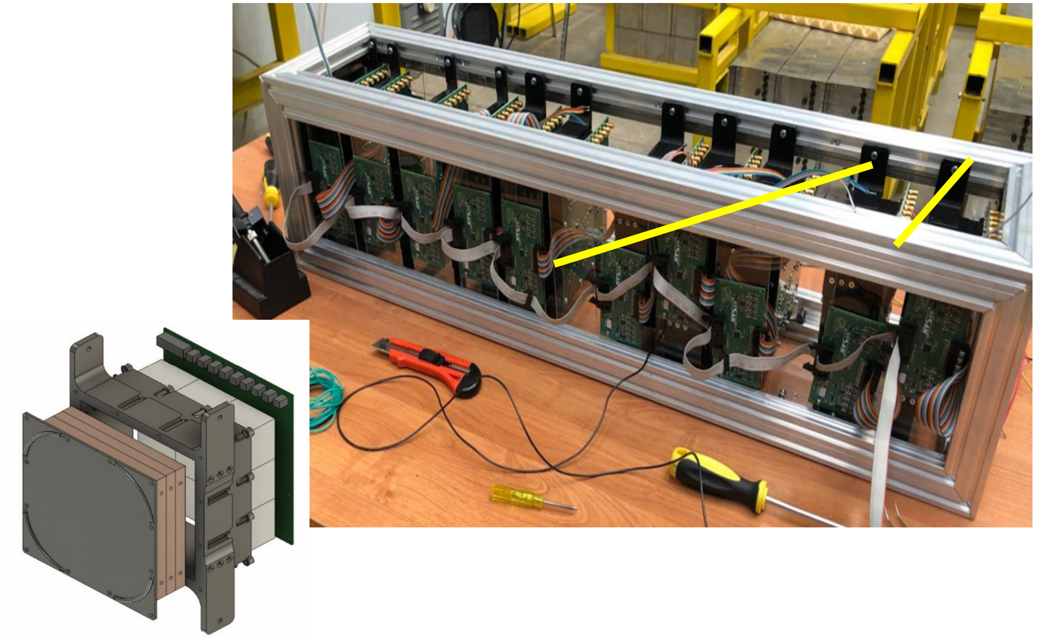
- SiPM HV power supply with temperature gain compensation
- amplification of SiPM signal with discriminators for TDC

Read-out electronics:

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

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

Measured time resolution of cell ~ 150 ps

..see presentation of Dmitry Sakhulin for details..

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!