V INTERNATIONAL SCIENTIFIC FORUM

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The Highly Granular Neutron Detector prototype at the BM@N experiment

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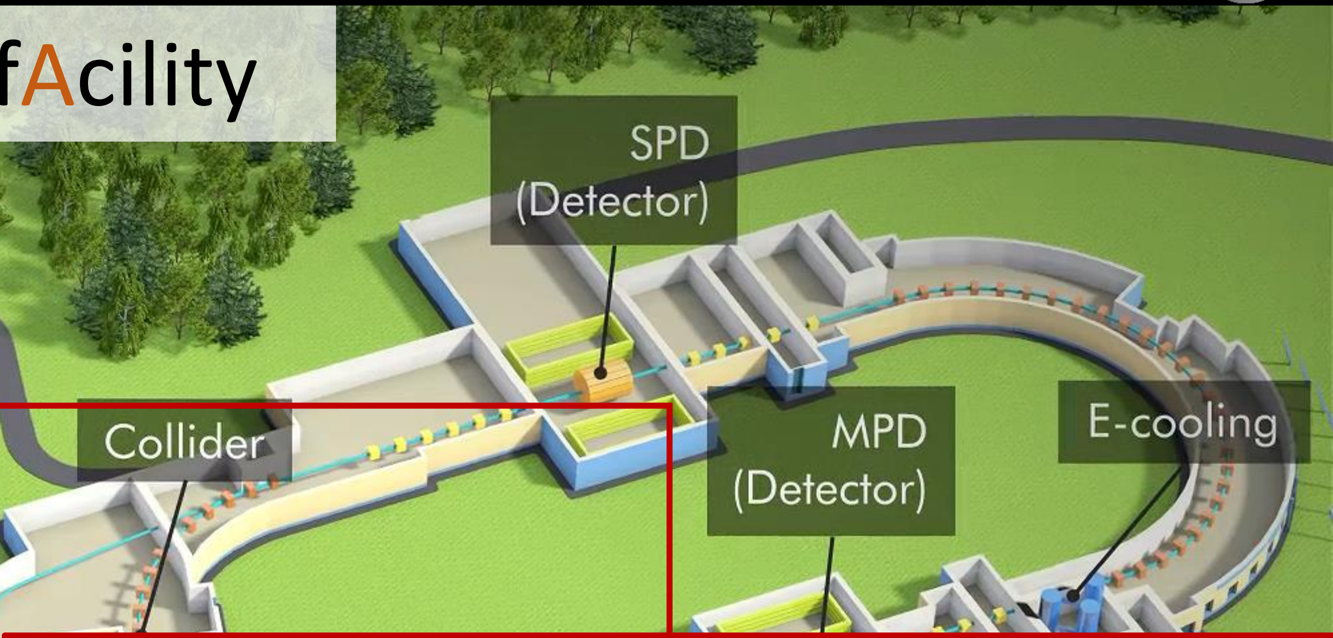
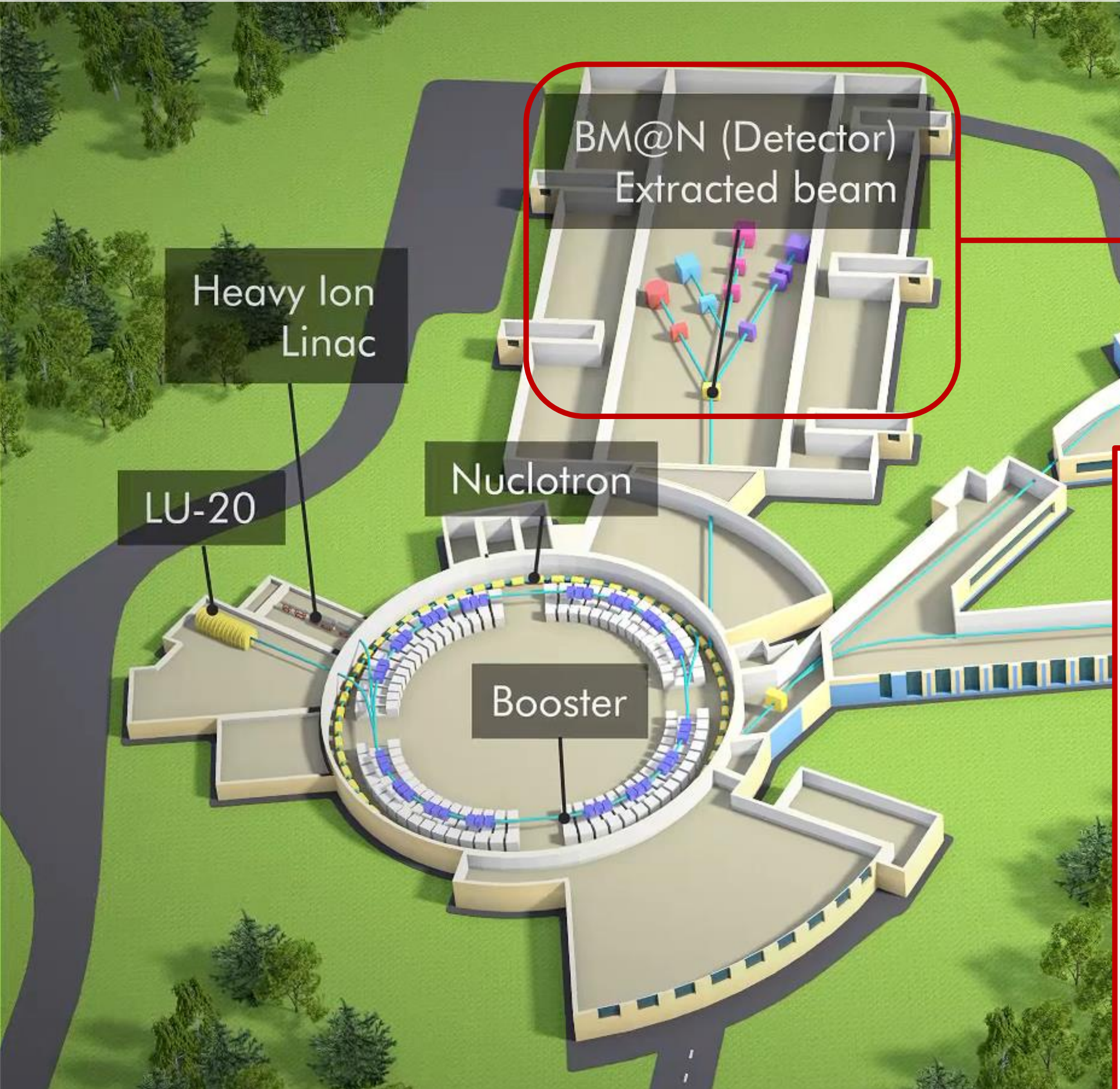
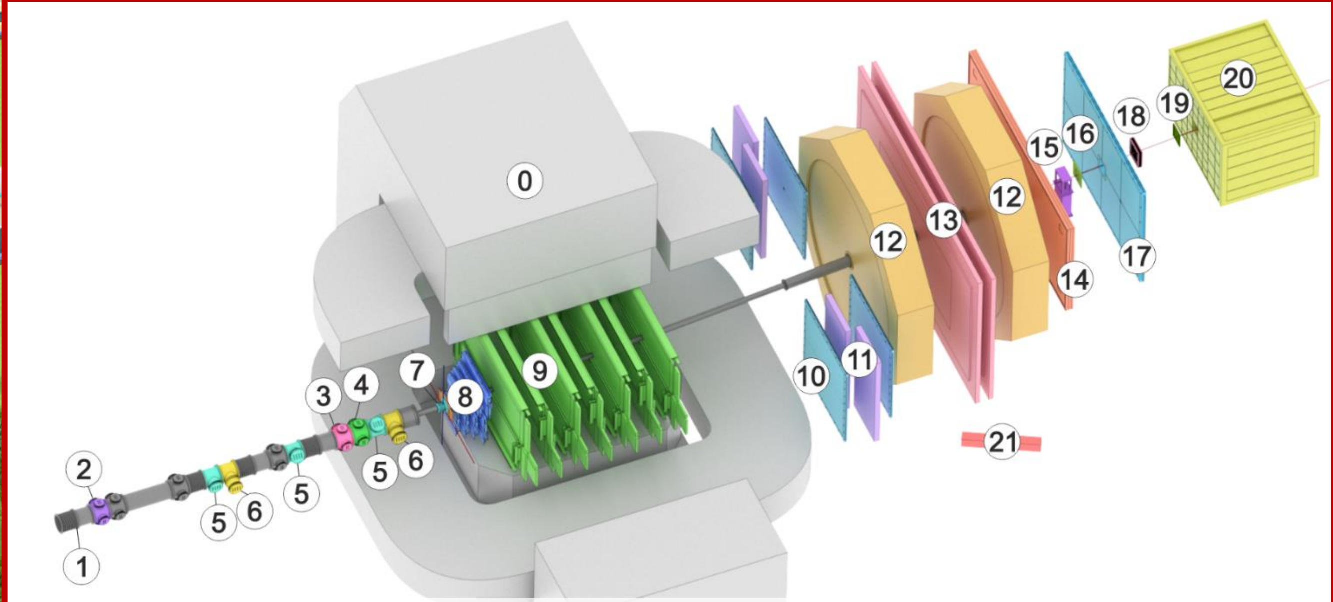
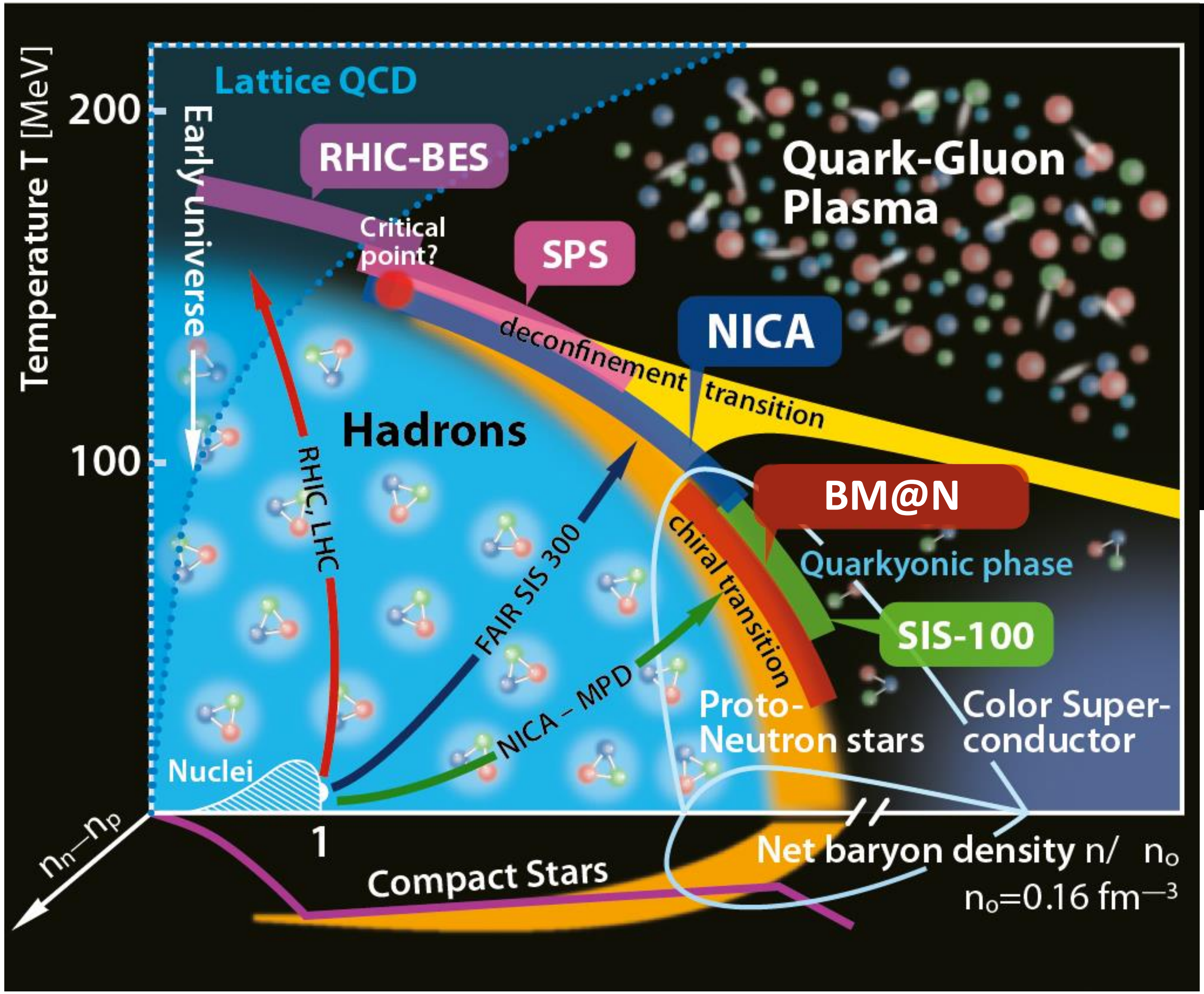
BM@N is the first operational experiment at the NICA complex

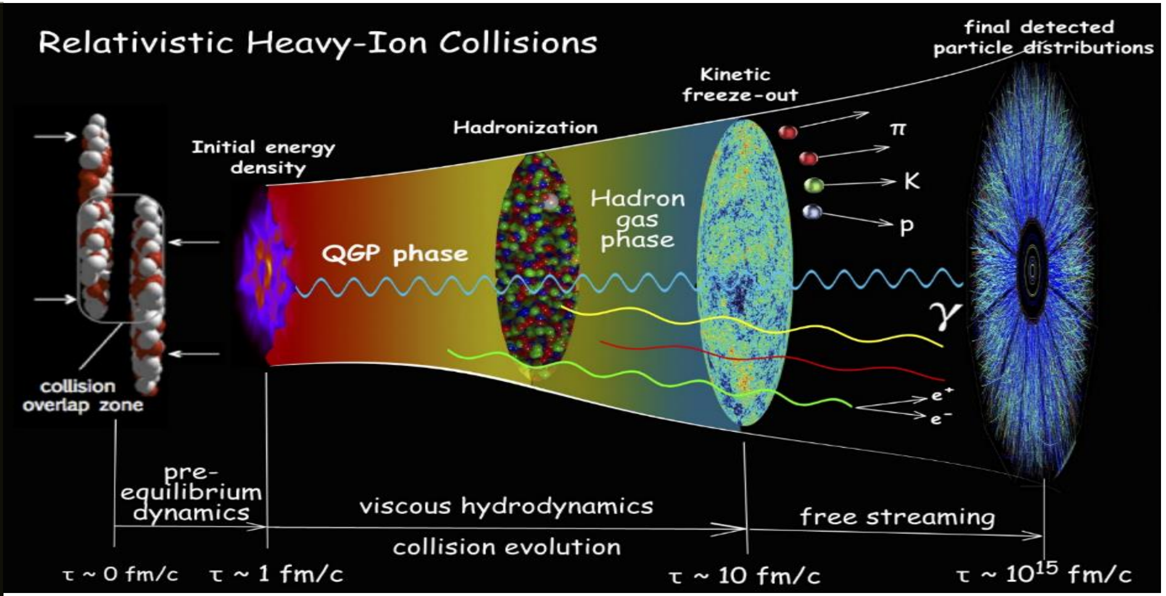
Nuclotron-based Ion Collider fAcility



Baryonic **M**atter at **N**uclotron





- 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.

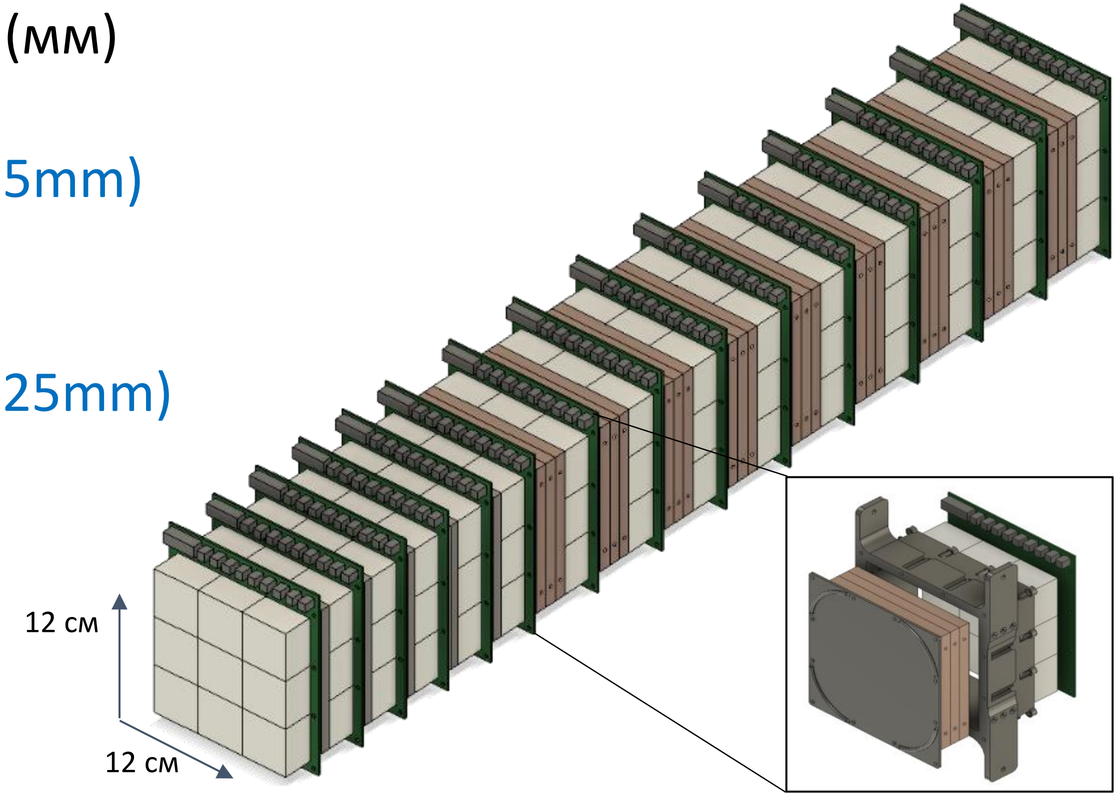
- The Highly Granular Neutron Detector (HGND) at the BM@N experiment is under development for measuring the energy of neutrons up to 4 GeV produced in nucleus-nucleus collisions.
- For the first time, small prototype of the HGND was used in Xe+CsI at 3.8A GeV run at the BM@N.
- The multilayer (absorber/scintillator) and high granular structure of the ToF HGND makes it possible to identify and measure the energies of neutrons.

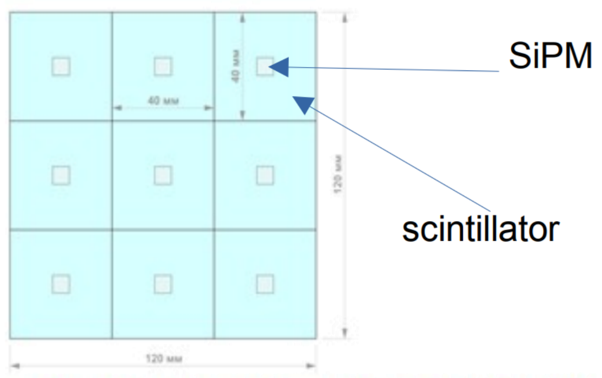
- Design of **H**ighly **G**ranular **N**eutron **D**etector prototype
- HGND prototype in Xe+CsI@3.8A GeV run
- HGND prototype efficiencies
- Estimation of neutron yields

HGND prototype design

- 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

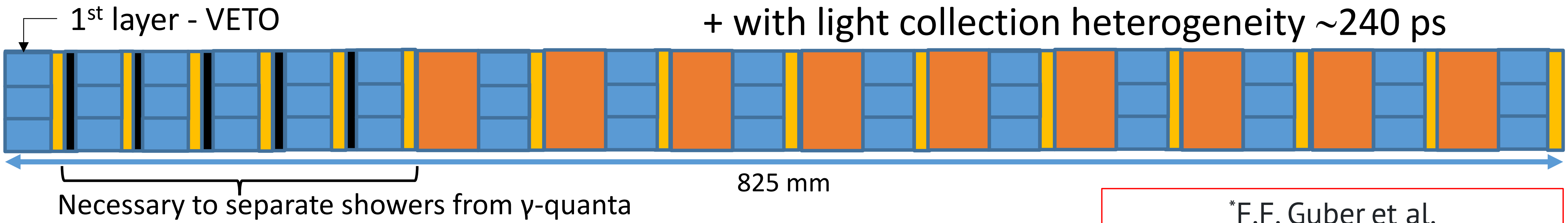
Scint. cell – 40 x 40 x 25 mm^3
Total number of cells – 135
Total size – 12 x 12 x 82.5 cm^3
Total length ~ 2.5 λ_{int}





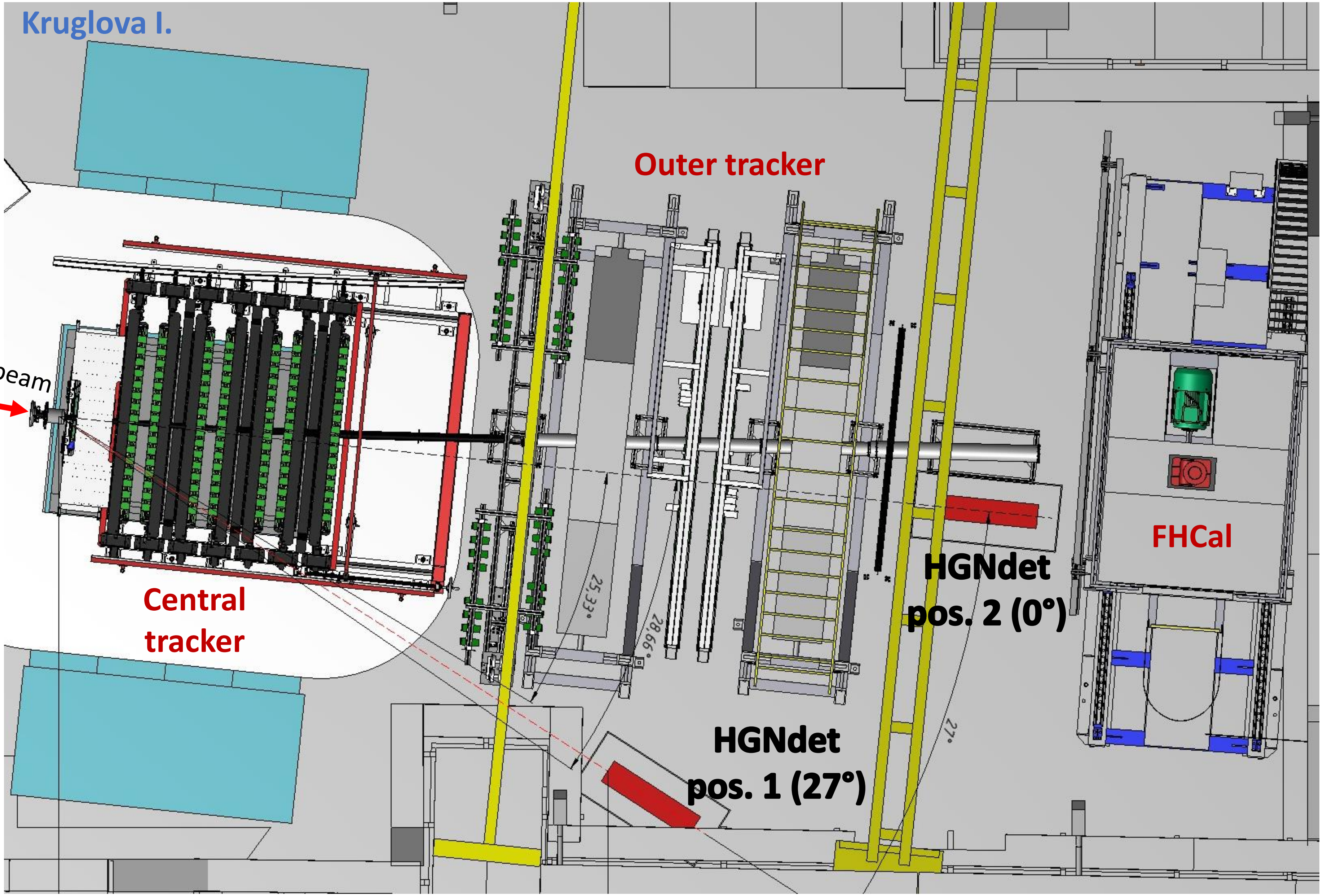
Hamamatsu S13360- 6050PE
Photosensitive area – 6x6 mm^2
Number of pixels – 14400
Pixel size – 50 µm
Gain – 1.7x10^6
PDE – 40%

Time resolution of cell ~200 ps*,
+ with light collection heterogeneity ~240 ps



*F.F. Guber et al.
10.31857/S0032816223030060

HGND prototype in the Xe+CsI@3.8A GeV run of BM@N



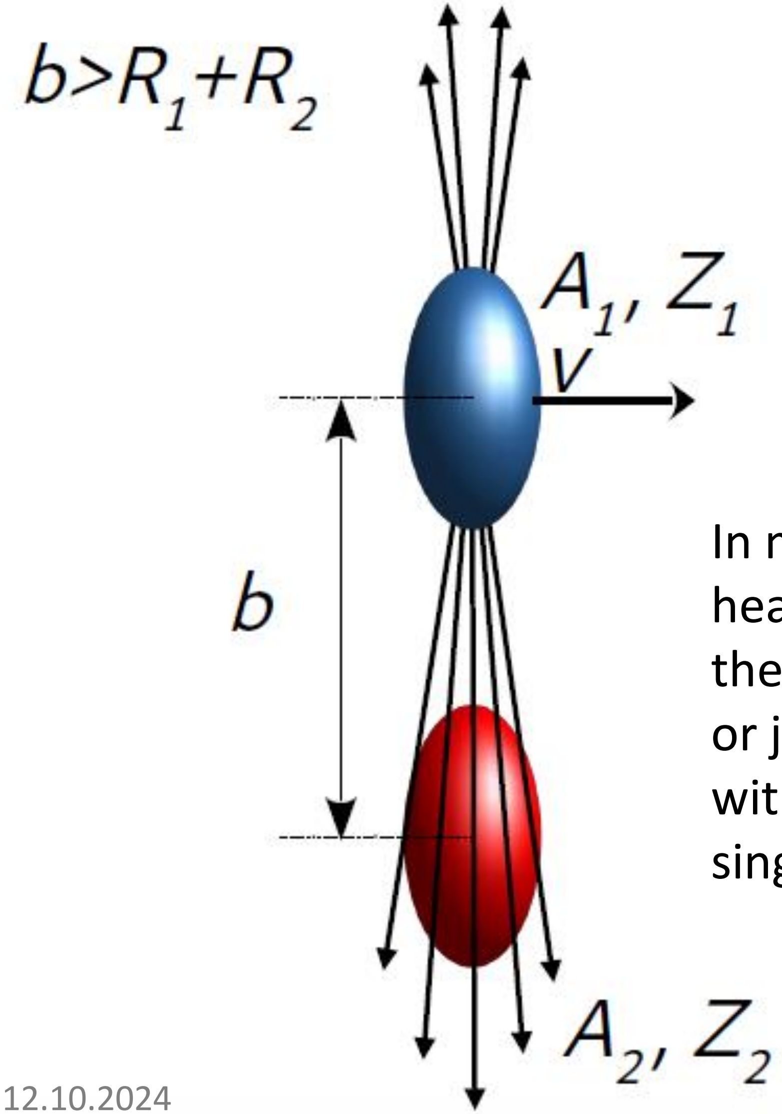
27° position:

Measurements of the neutron spectrum at ~ midrapidity.

0° position:

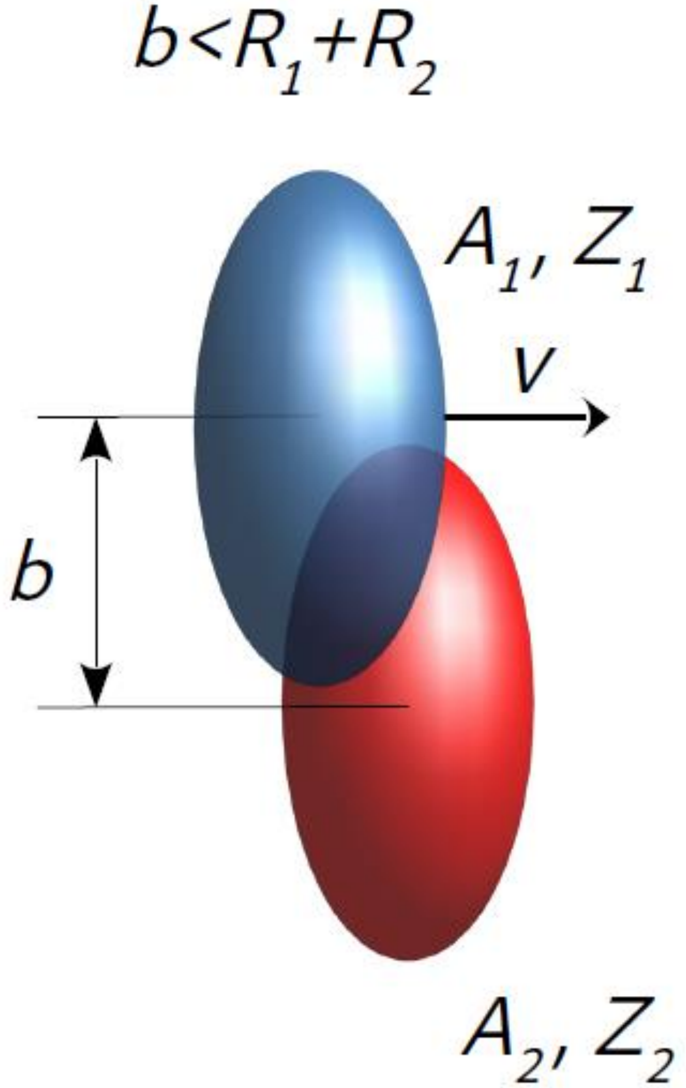
Test and calibration with known neutron energy (energy of a beam of spectator neutrons)

EMD:
without overlap of nuclear densities



In most cases, EMD of a heavy nucleus results in the emission of a single or just few neutrons with the production of a single residual nucleus

Hadronic interactions:
with overlap of nuclear densities



Criteria for selecting events with neutrons

Ultra-peripheral collisions – EMD:

- Single Xe ion in target + **Beam trigger (BT)**
- Forward Quartz Hodoscope (FQH) Z^2>2500

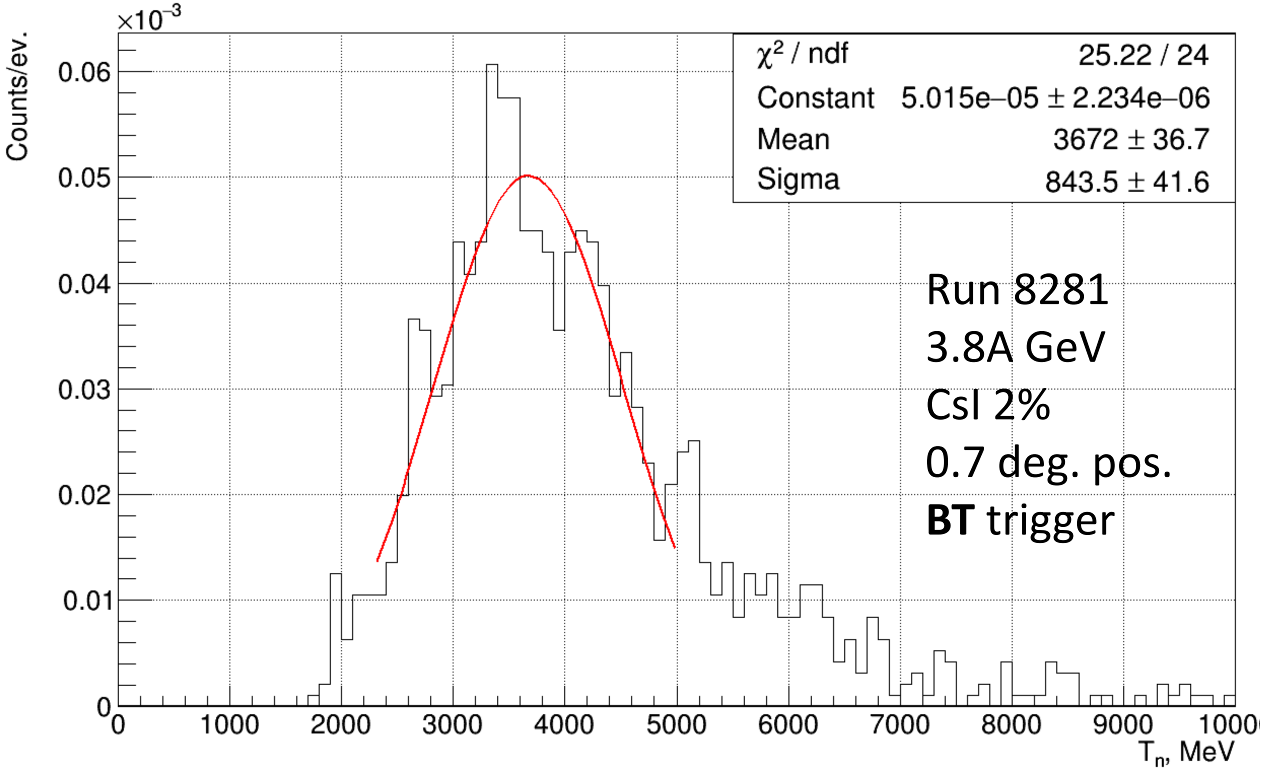
Central & semi-central collisions – hadronic interactions:

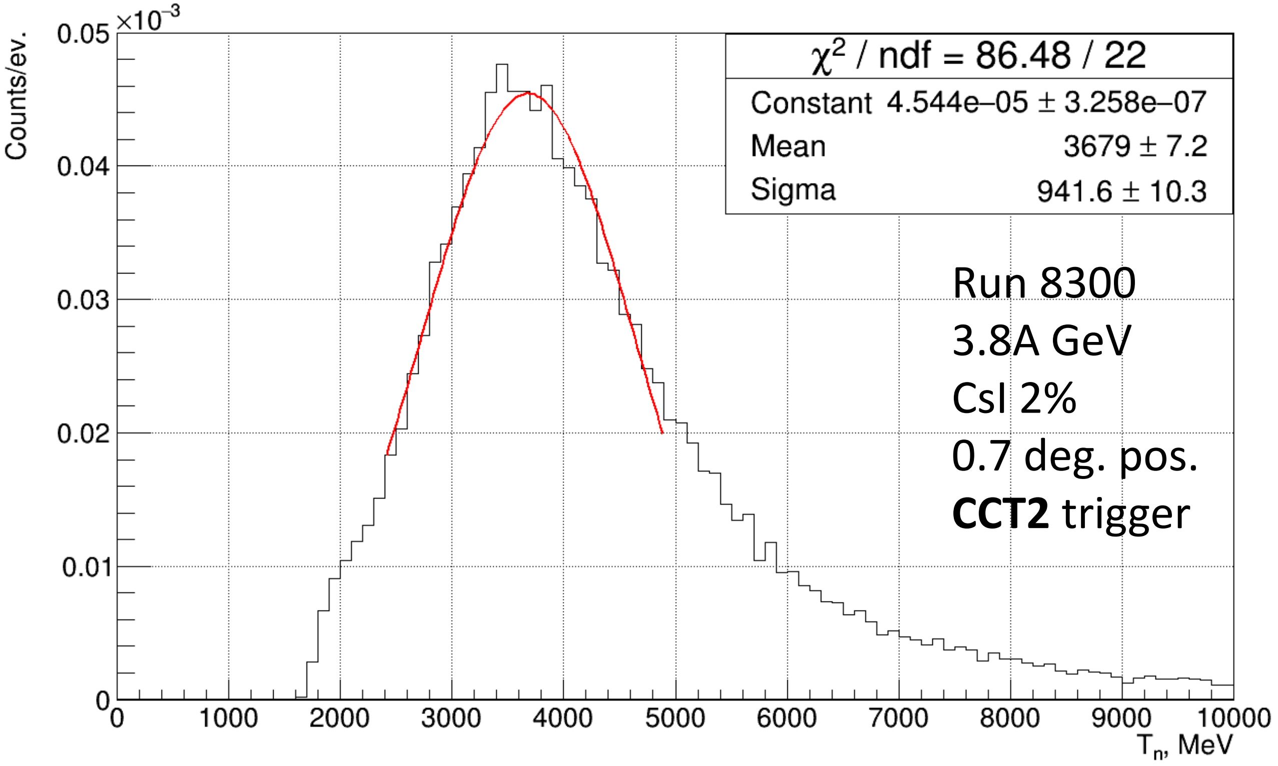
- Single Xe ion in target + **Central trigger (CCT2)**
- Forward Detector amplitude < 4500

- Selection of events without charged particles, ToF cut, γ-cut (1.55 X_0 or 0.11 λ_{int})

Reconstruction of energy by maximum velocity

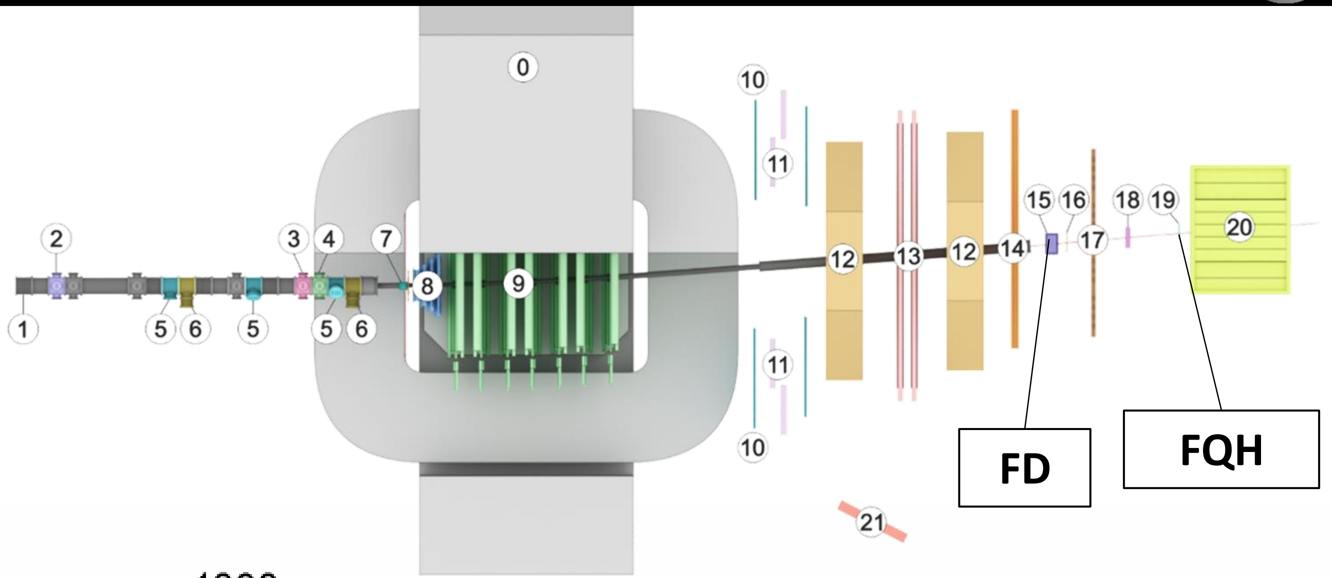
Scaled by incident ion beam rate



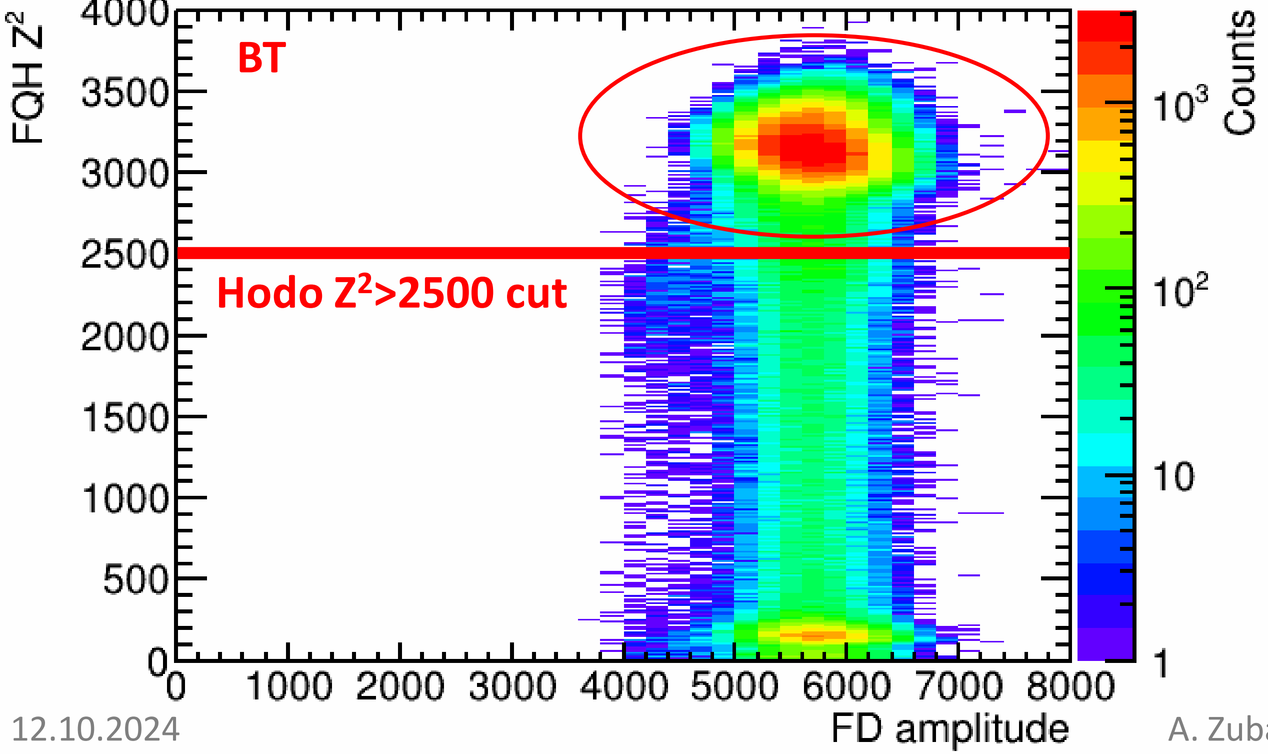


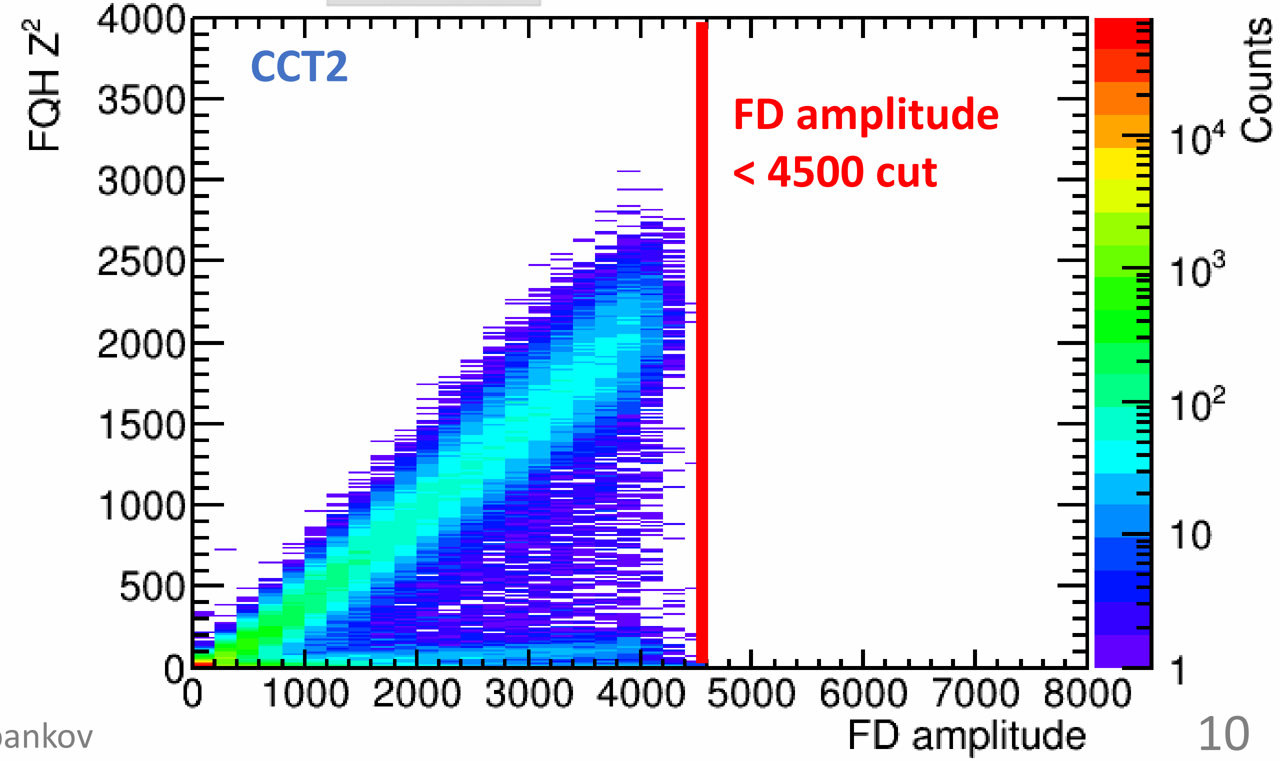
Event selection

Comparison of hadronic interactions (CCT2) with electromagnetic dissociation (BT)
on **Hodoscope** vs **FD**
Run **8281 (BT)** vs **8300 (CCT2)** 3.8A GeV



Xe ions on Hodoscope
around Z^2=3000 in EMD

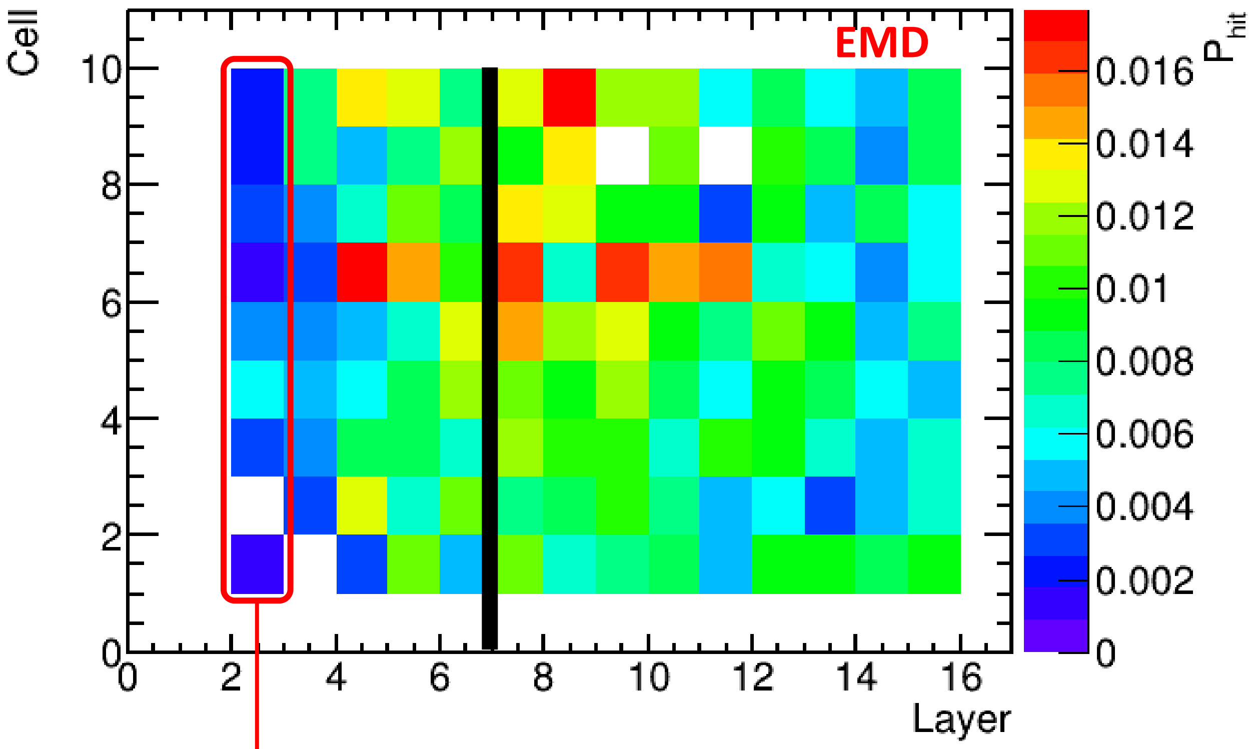


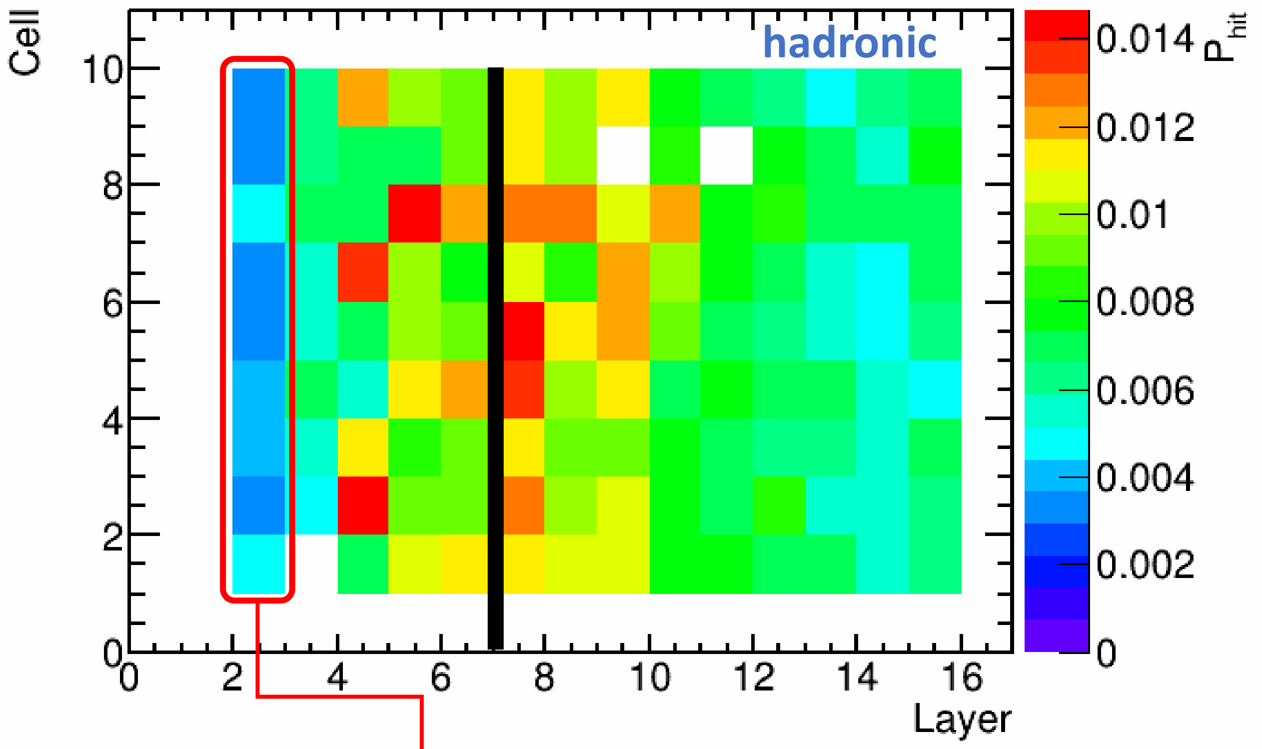


Fastest cells for EMD vs hadronic interactions

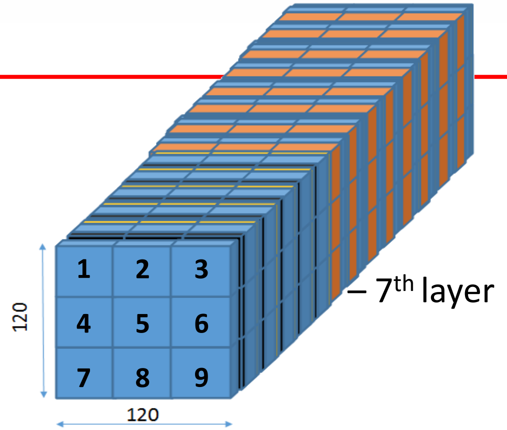
Comparison of hadronic interactions (CCT2) with electromagnetic dissociation (BT)

Run 8281 (BT) vs 8300 (CCT2) 3.8 AGeV





γ-quanta cut – no hits in 1-2 layers in module => 1.55 X_0 or 0.11 λ_{int}

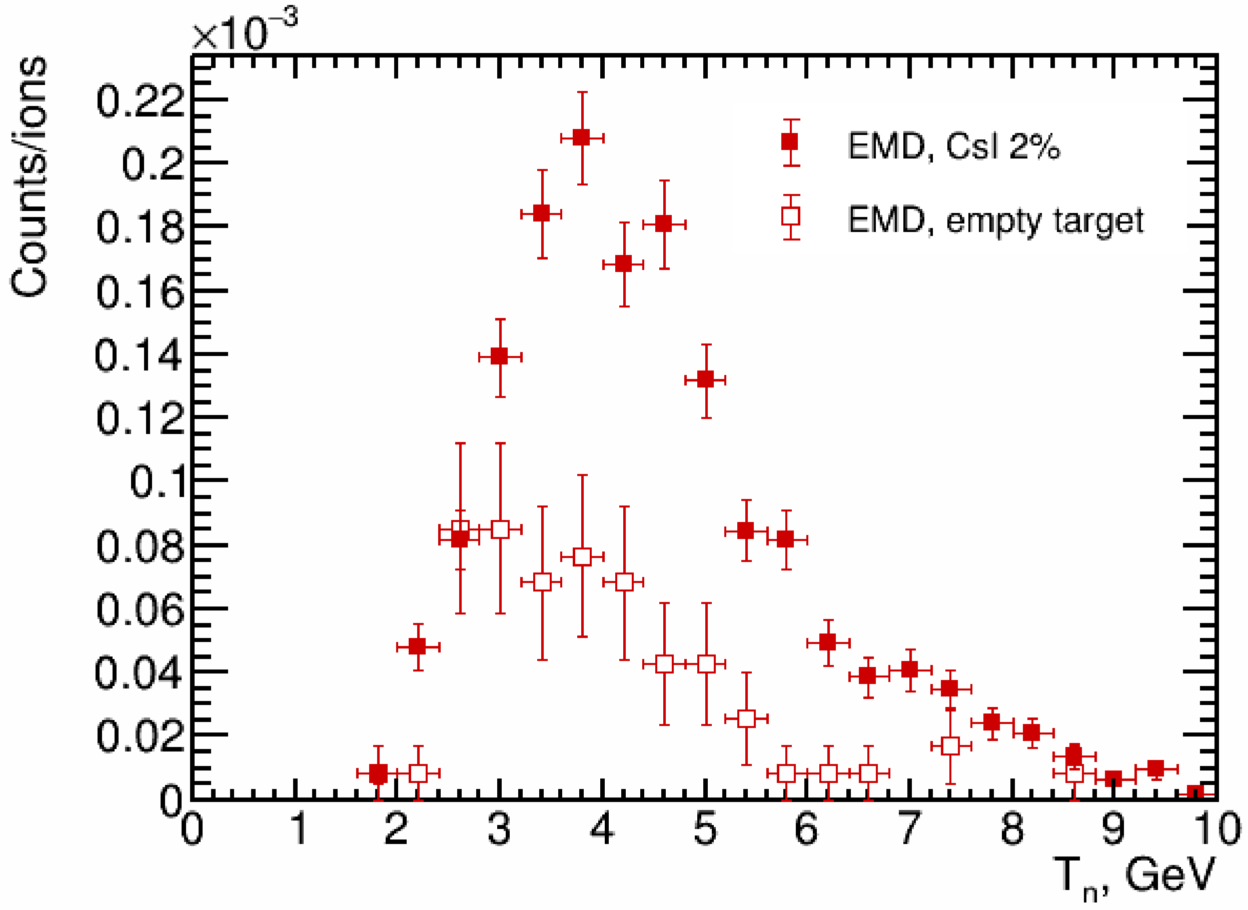


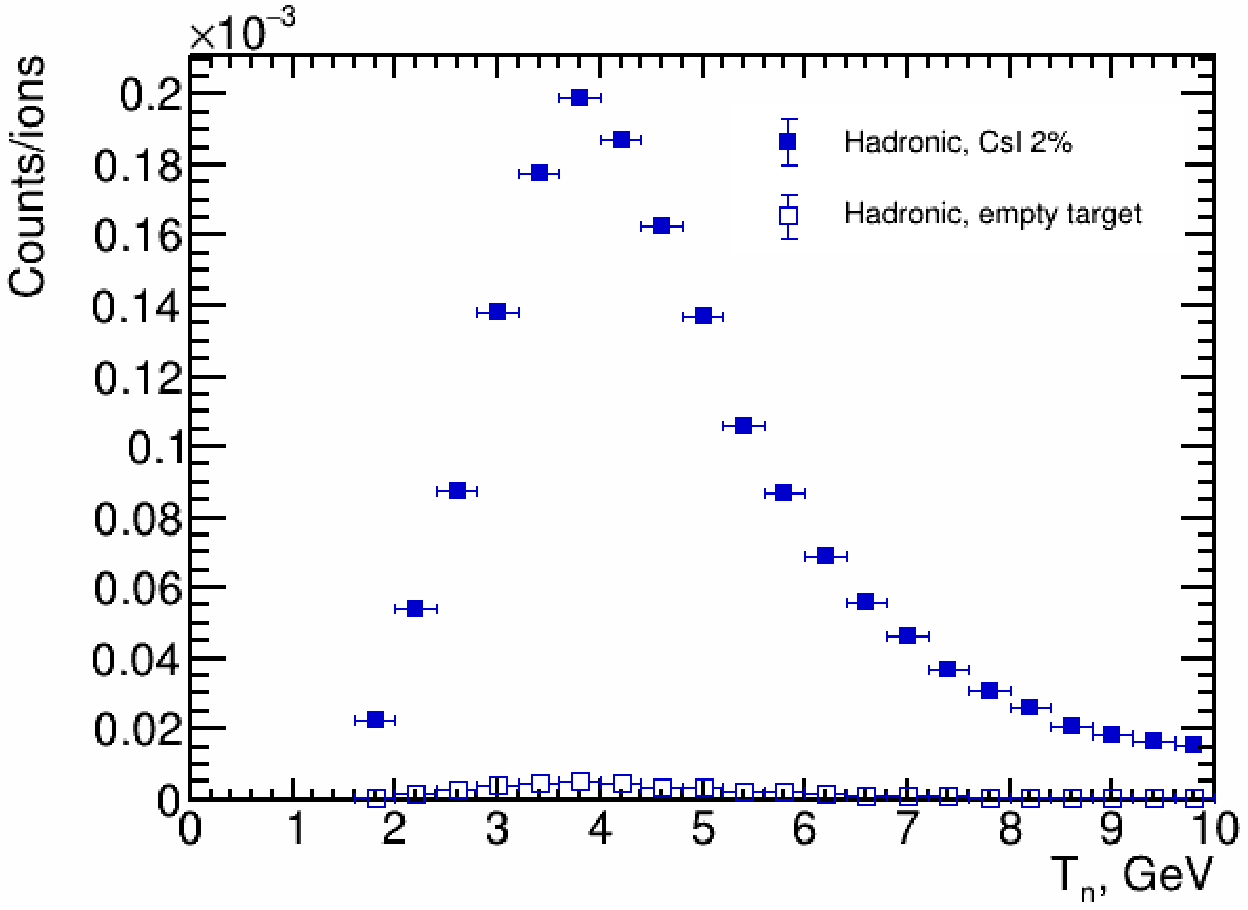
Most of the neutrons are deposited after the 7th layer for both EMD and nuclear interaction

No target vs CsI 2%

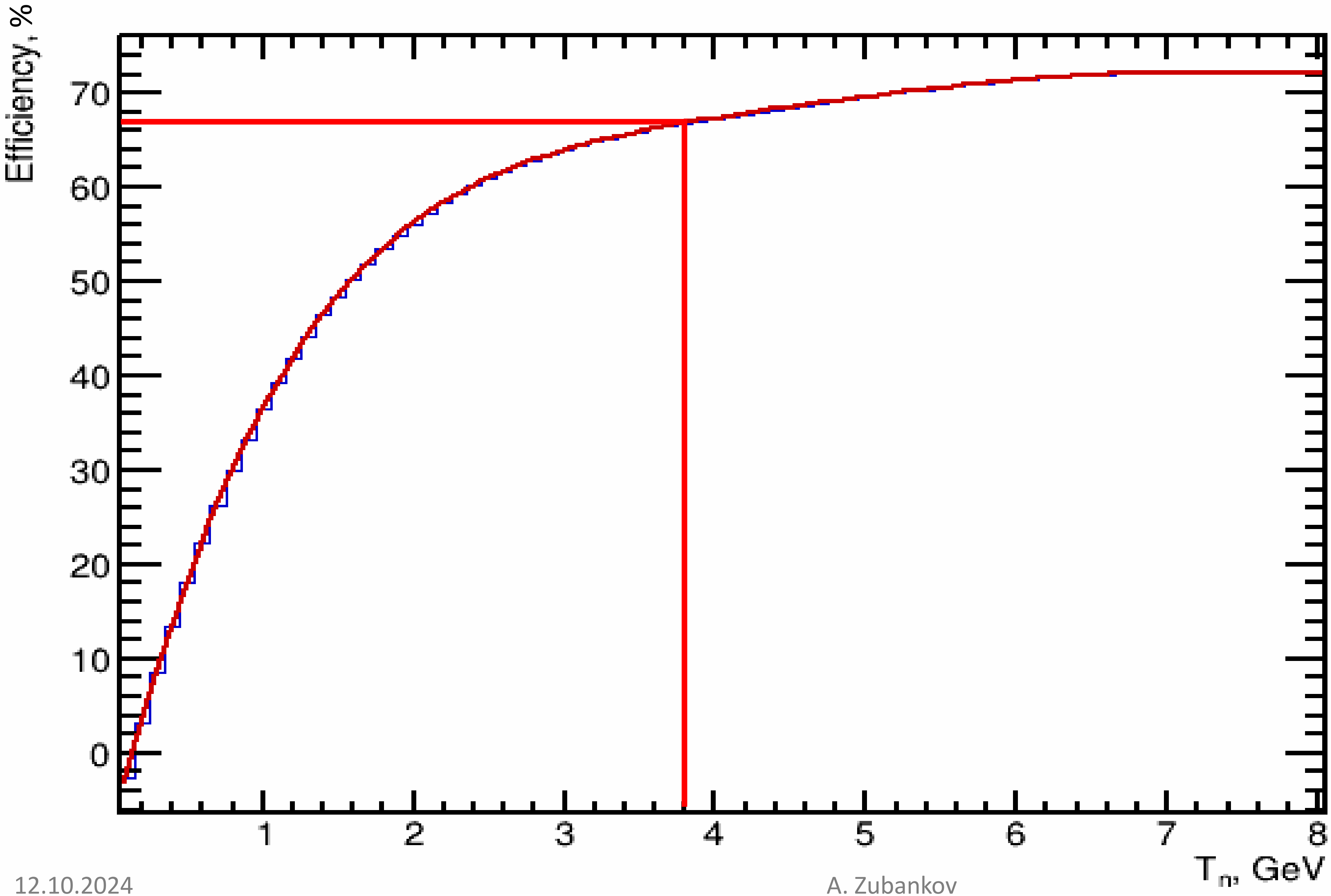
0.7 deg., 3.8 AGeV

Scaled by incident ion beam rate





HGND prototype efficiency for neutrons



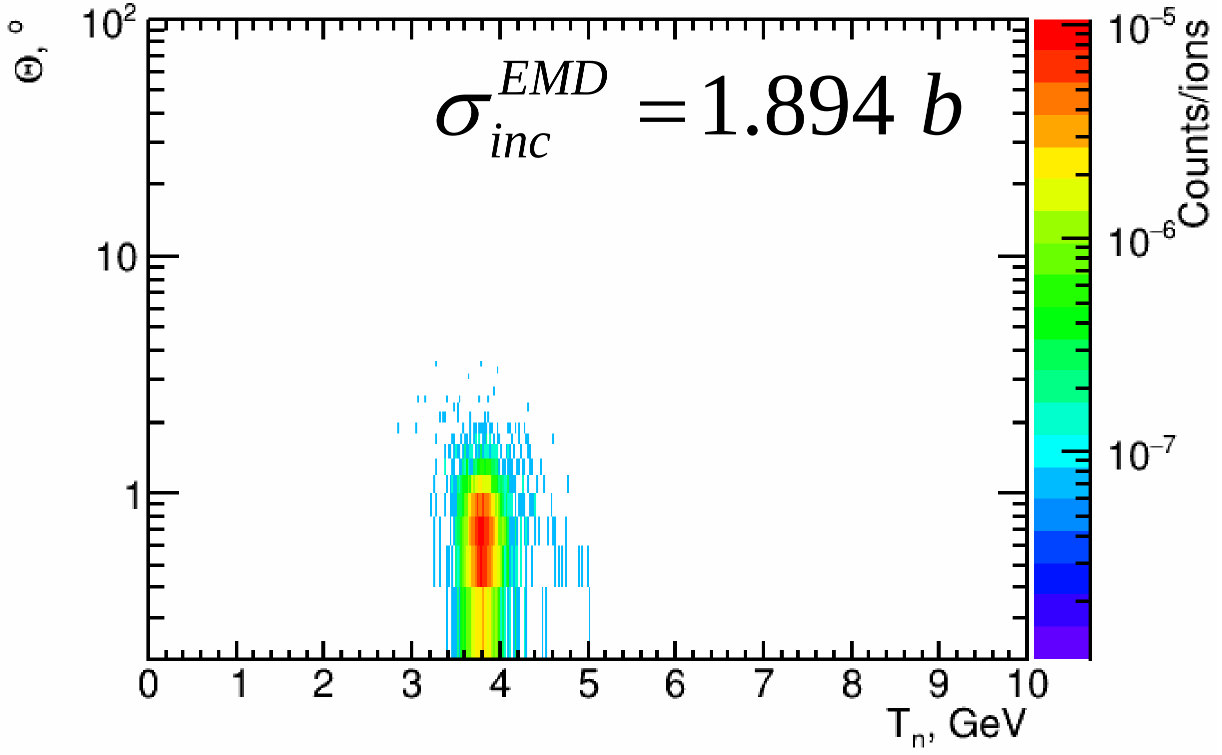
Geant4 simulation:
Box generator
Only neutrons

- VETO-cut
- γ-cut
- ToF cut

EMD vs Nuclear interaction in simulation

RELDIS*

$^{124}Xe + ^{130}Xe$ @ 3.8 AGeV

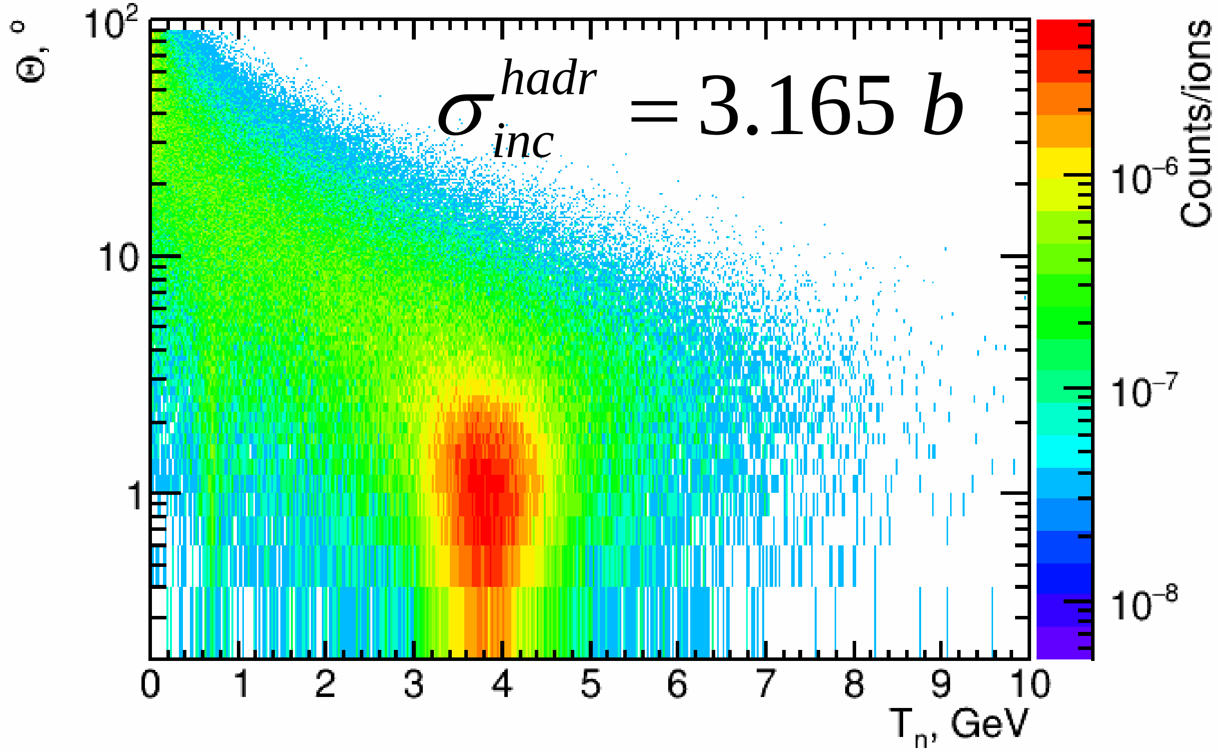


Neutron multiplicity – **1.05**

Neutron hit multiplicity on the surface – **1.02**

DCM-QGSM-SMM** (0-60%)

^{131}Xe + Cs @ 3.8AGeV



Neutron multiplicity – **14.21**

Neutron hit multiplicity on the surface – **1.54**

*I. Pshenichnov, Electromagnetic Excitation and Fragmentation of Ultrarelativistic Nuclei. *Phys. Part. Nucl.* **2011**, 42 (2), 215-250.

M. Banzat et al., Monte-Carlo Generator of Heavy Ion Collisions DCM-SMM, *Phys. Part. Nucl. Lett.* **2020, 17, 303.

HGND prototype efficiencies

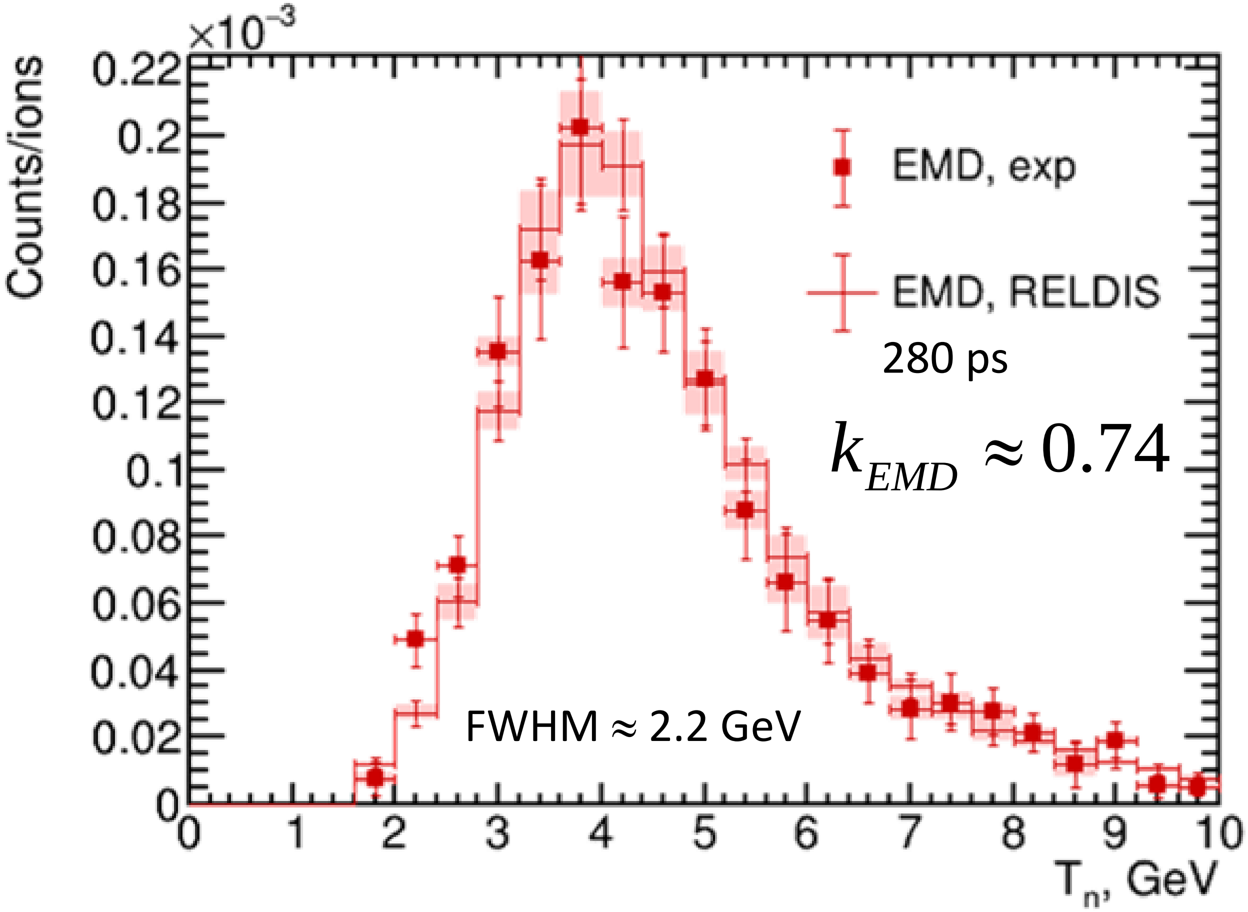
$$acc = \frac{N_{hit}}{N_{gen}} \qquad \varepsilon = \frac{N_{rec}}{N_{hit}}$$

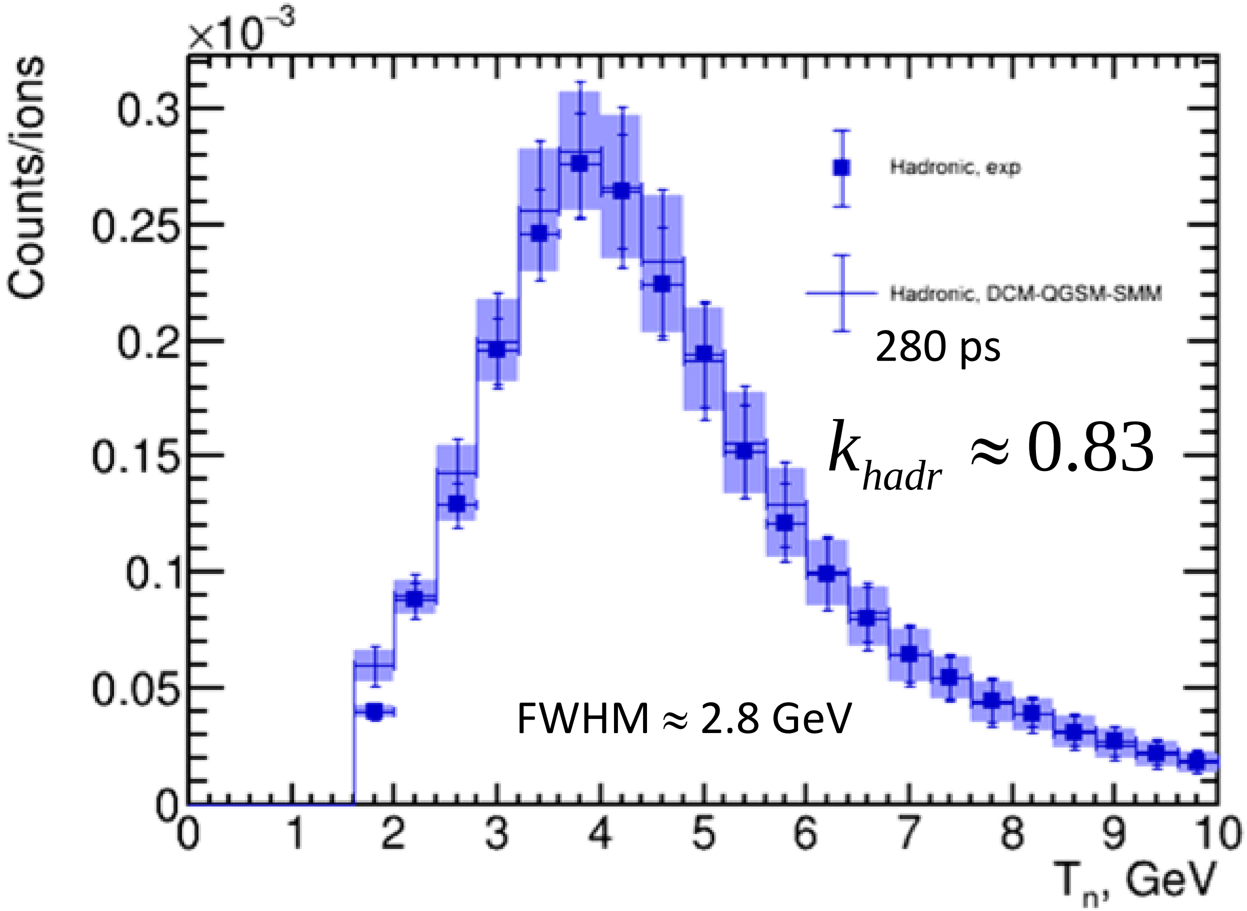
Model	*acc*, %	ε, %	*acc* x ε, %
DCM-QGSM-SMM	3.87 ± 0.02	35.31 ± 0.15	1.37 ± 0.01
RELDIS	34.31 ± 0.25	61.31 ± 0.45	21.04 ± 0.15

The difference in *acc* is explained by the considerably smaller angular distribution of neutron emission in EMD than in hadronic interactions.

The difference in *ε* is due to the ~1.5 times different average multiplicity of neutrons hitting the detector, since in the current detector configuration it is impossible to reconstruct more than 1 neutron in an event.

Time resolution





$$\Upsilon = acc \cdot \varepsilon \cdot \langle N \rangle \cdot \sigma_{inc} \frac{d \cdot N_A \cdot \rho}{A} \cdot k$$

Estimation of neutron yields

Simulation

$$\Upsilon = acc \cdot \varepsilon \cdot \langle N \rangle \cdot \sigma_{inc} \frac{d \cdot N_A \cdot \rho}{A} \cdot k$$

$$k_{hadr} \approx 0.83$$

$$k_{EMD} \approx 0.74$$

$$\frac{\Upsilon_{hadr}}{\Upsilon_{EMD}} = \frac{\sigma_{inc}^{hadr}}{\sigma_{inc}^{EMD}} \cdot \frac{acc_{hadr} \cdot \varepsilon_{hadr} \cdot \langle N_{hadr} \rangle}{acc_{EMD} \cdot \varepsilon_{EMD} \cdot \langle N_{EMD} \rangle} \cdot \frac{k_{hadr}}{k_{EMD}}$$

$$\frac{\Upsilon_{hadr}}{\Upsilon_{EMD}} = 1.73 \pm 0.01(stat) \pm 0.17(sys)$$

Experiment

$$\frac{Y_{hadr}}{Y_{EMD}} = \frac{N_{hadr} / I_{hadr} - N_{hadr}^{empty} / I_{hadr}^{empty}}{N_{EMD} / I_{EMD} - N_{EMD}^{empty} / I_{EMD}^{empty}}$$

$$\frac{Y_{hadr}}{Y_{EMD}} = 1.70 \pm 0.16(stat) \pm 0.25(sys)$$

Conclusions

- The acceptances and efficiencies of the HGND prototype to neutrons from the hadronic interaction and EMD were studied.
- The ratio of neutron yields from a hadronic interactions to EMD is 1.70±0.16±0.25, which is close to the simulation – 1.73±0.01±0.17.
- EMD in the BM@N experiment can be used as a source of high energy neutrons with multiplicity ≈1 per event.
- Spectator neutrons from hadronic interactions and neutrons from EMD can be used to calibrate HGND and study its efficiency.

Thank you for your attention!