Performance of the Highly Granular Neutron Detector prototype in Xe+CsI@3.8A GeV collisions at the BM@N experiment

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Preparing for submission to JINST

09.10.2024

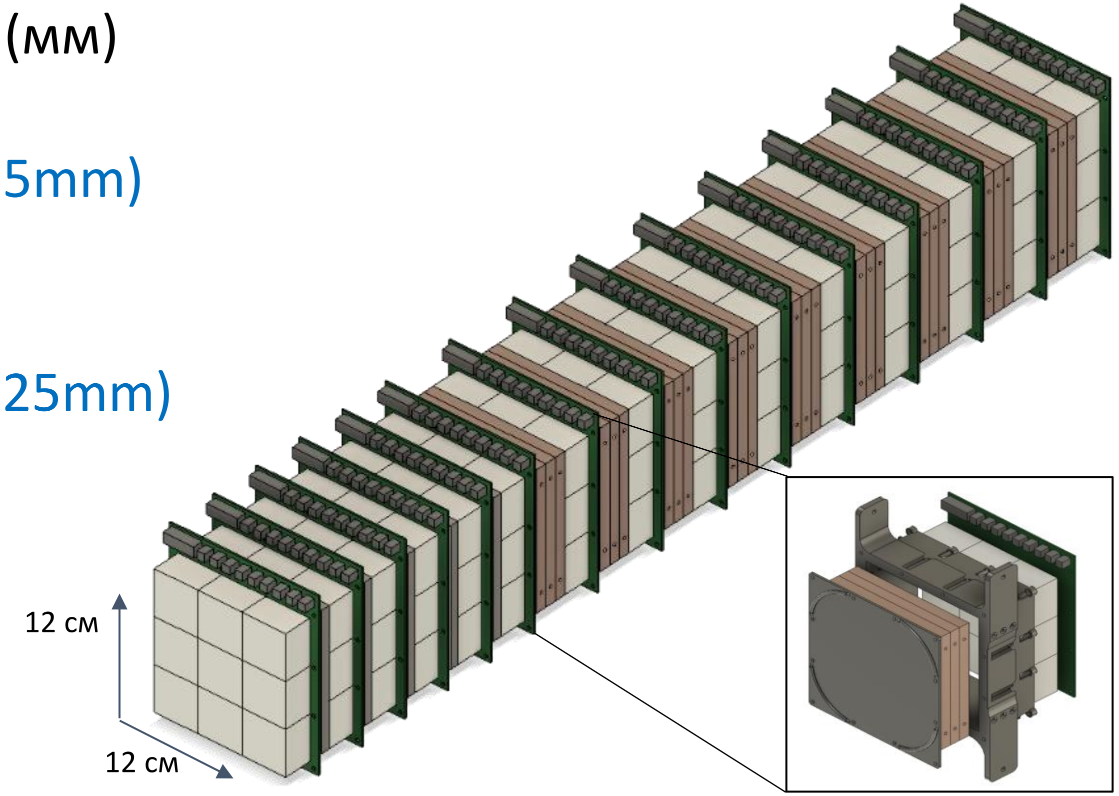
Outline

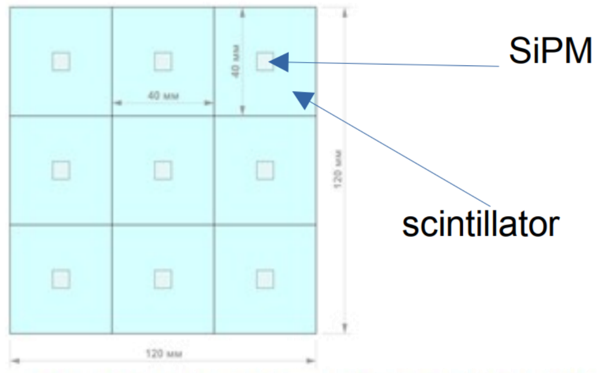
- Design of **H**ighly **G**ranular **N**eutron **D**etector prototype
- Selection criteria for EMD and hadronic interaction events with neutron emission
- HGND prototype efficiencies
- Neutron yields from hadronic interactions and EMD

HGND prototype design

- Scint. layer **Veto** 120x120x25 (мм)
- 1^{st} (electromagnetic) part:
  5 layers: **Pb (8mm)** + Scint. (25mm)
  + PCB + air
- 2^{nd} (hadronic) part:
  9 layers: **Cu (30mm)** + Scint. (25mm)
  + PCB + air

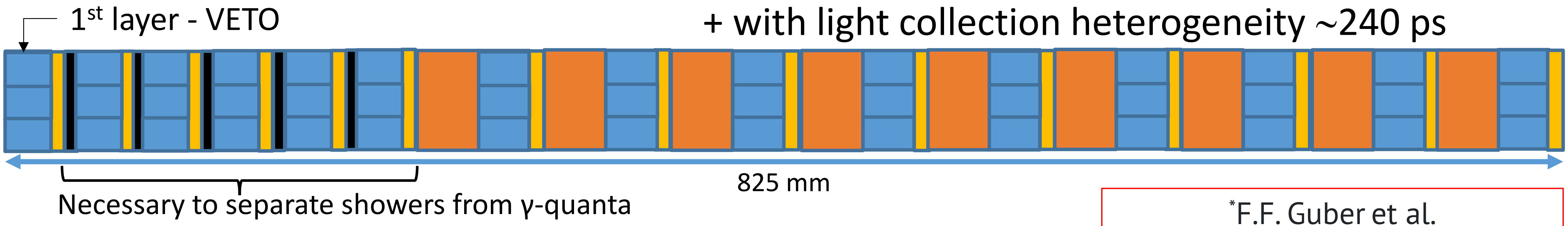
Scint. cell – 40 x 40 x 25 mm^3
Total number of cells – 135
Total size – 12 x 12 x 82.5 cm^3
Total length ~ 2.5 λ_{int}





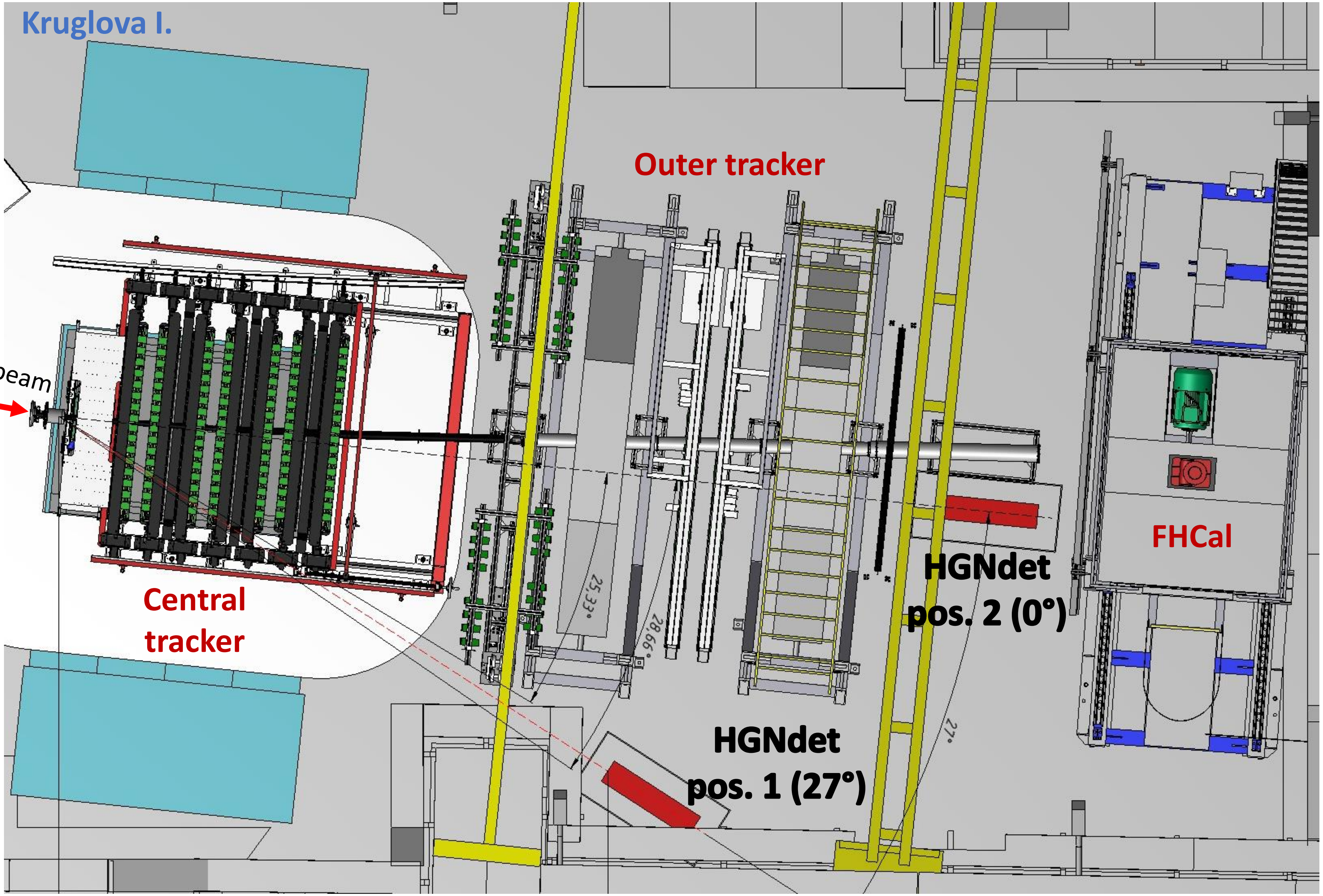
Hamamatsu S13360- 6050PE
Photosensitive area – 6x6 mm^2
Number of pixels – 14400
Pixel size – 50 μm
Gain – $1.7x10^6$
PDE – 40%

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 run



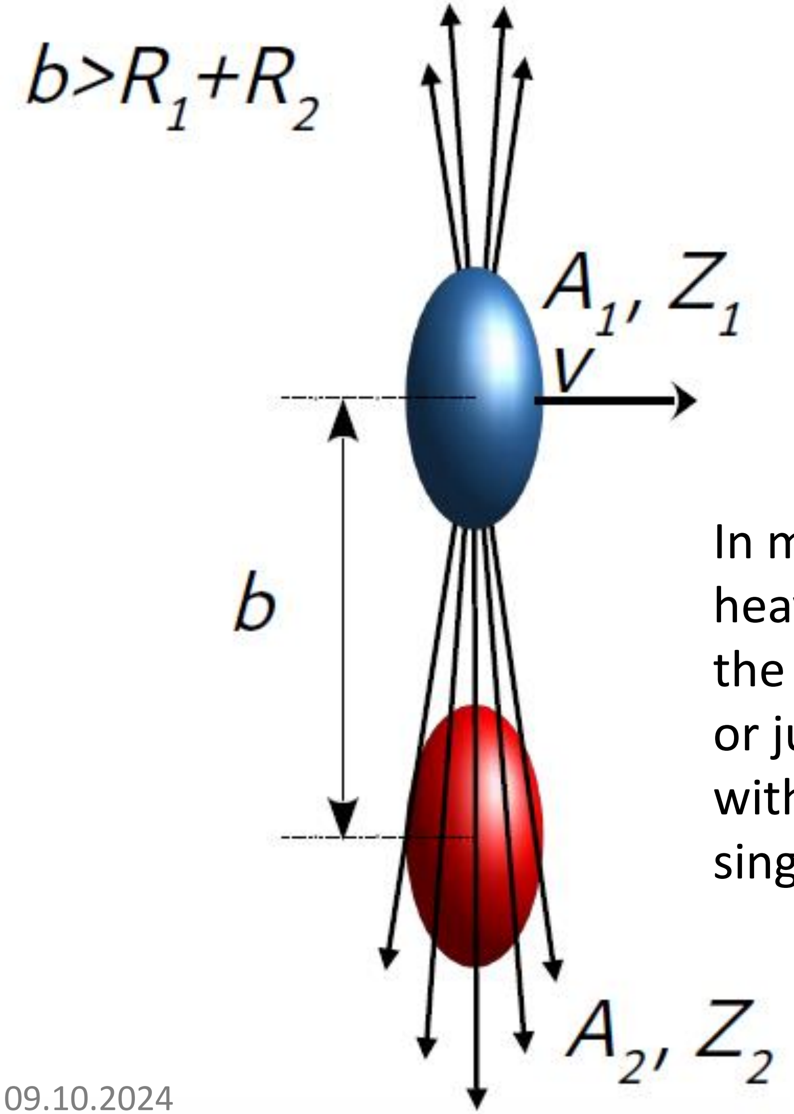
27° position:

Measurements of the neutron spectrum at ~ midrapidity.

0° position:

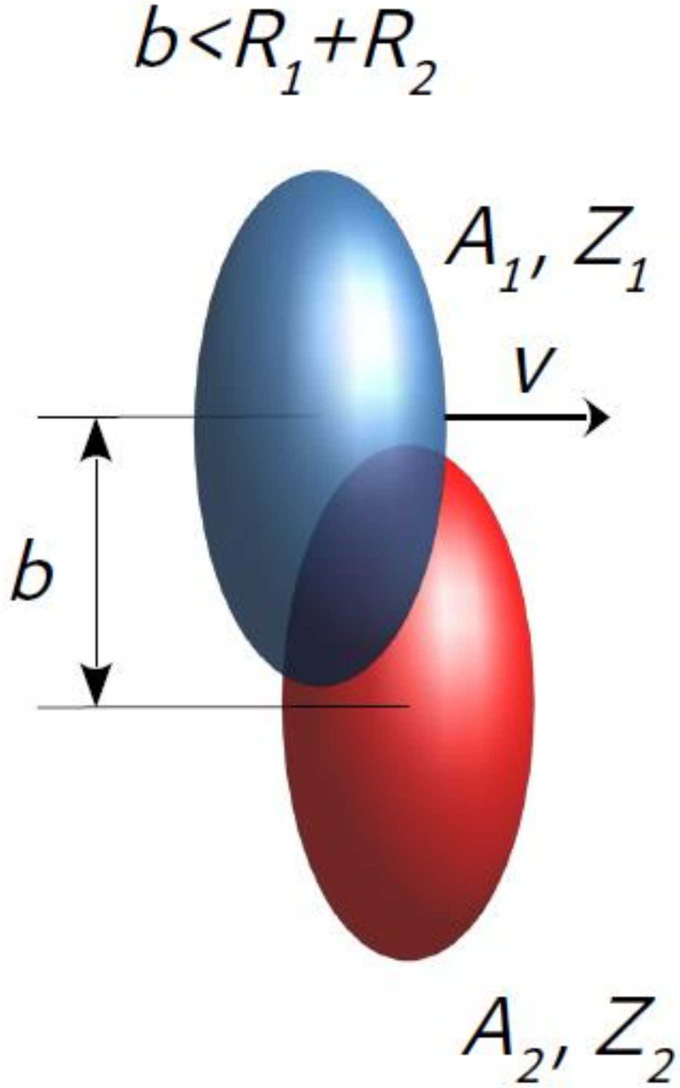
Test and calibration with known neutron energy (energy of a beam of spectator neutrons)

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) $Z^2 > 2500$

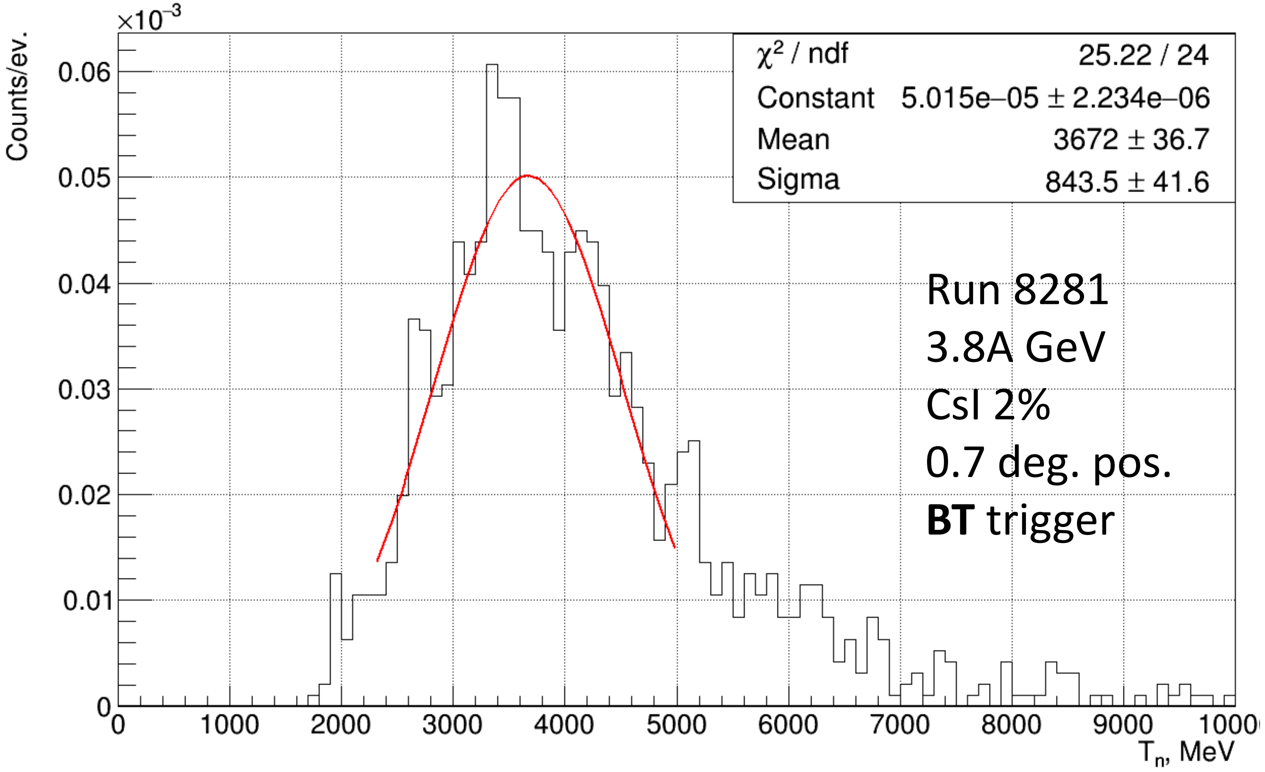
Central & semi-central collisions – hadronic interactions:

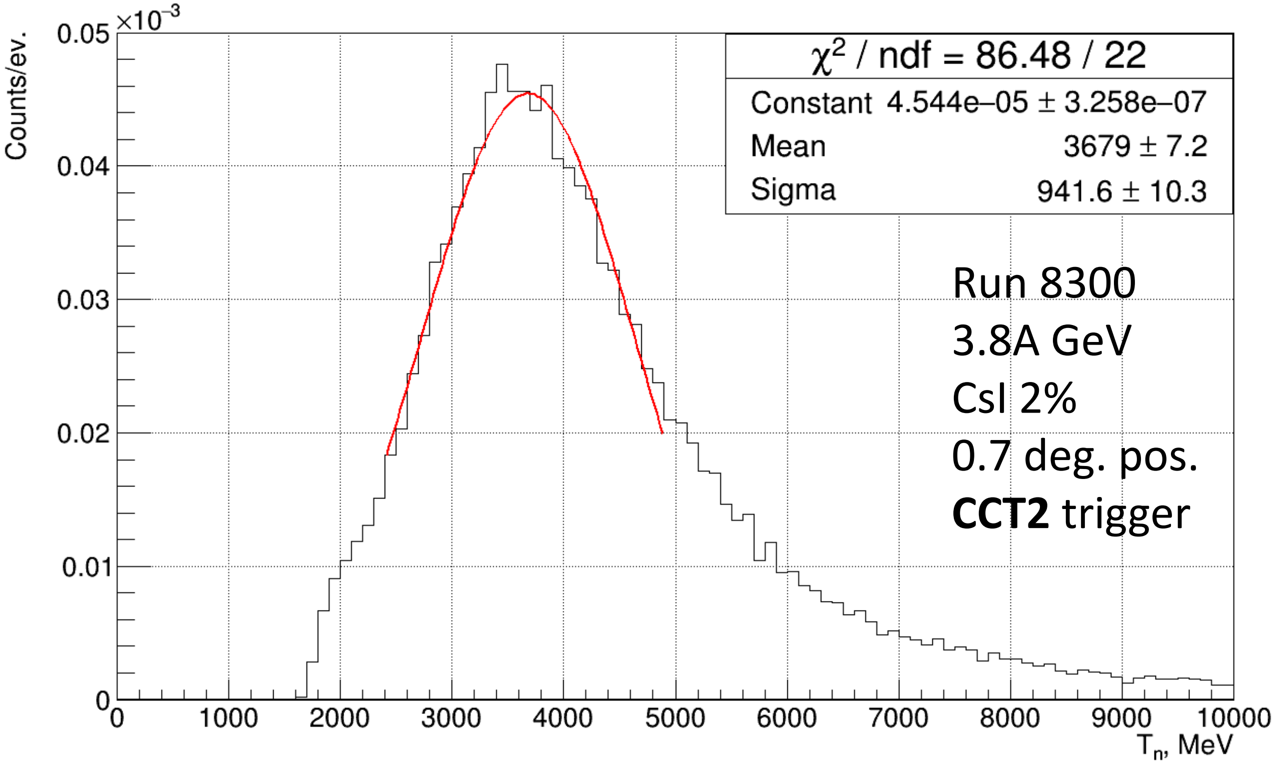
- Single Xe ion in target + **Central trigger (CCT2)**
- Forward Detector amplitude < 4500

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

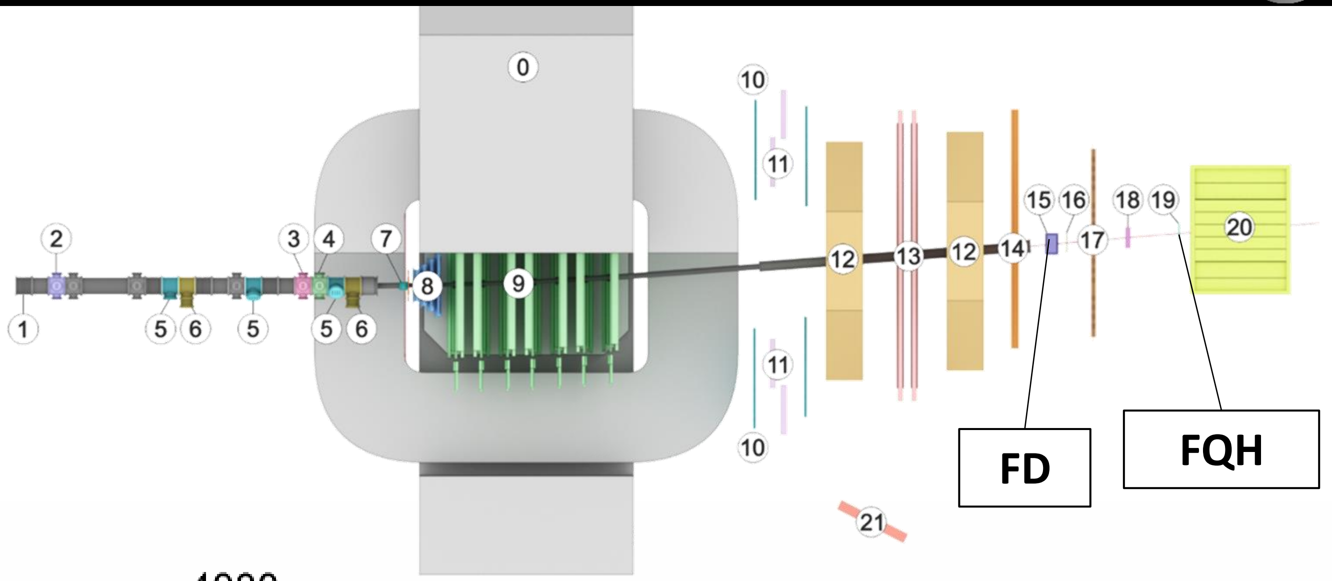
Reconstruction of energy by maximum velocity

Scaled by incident ion beam rate

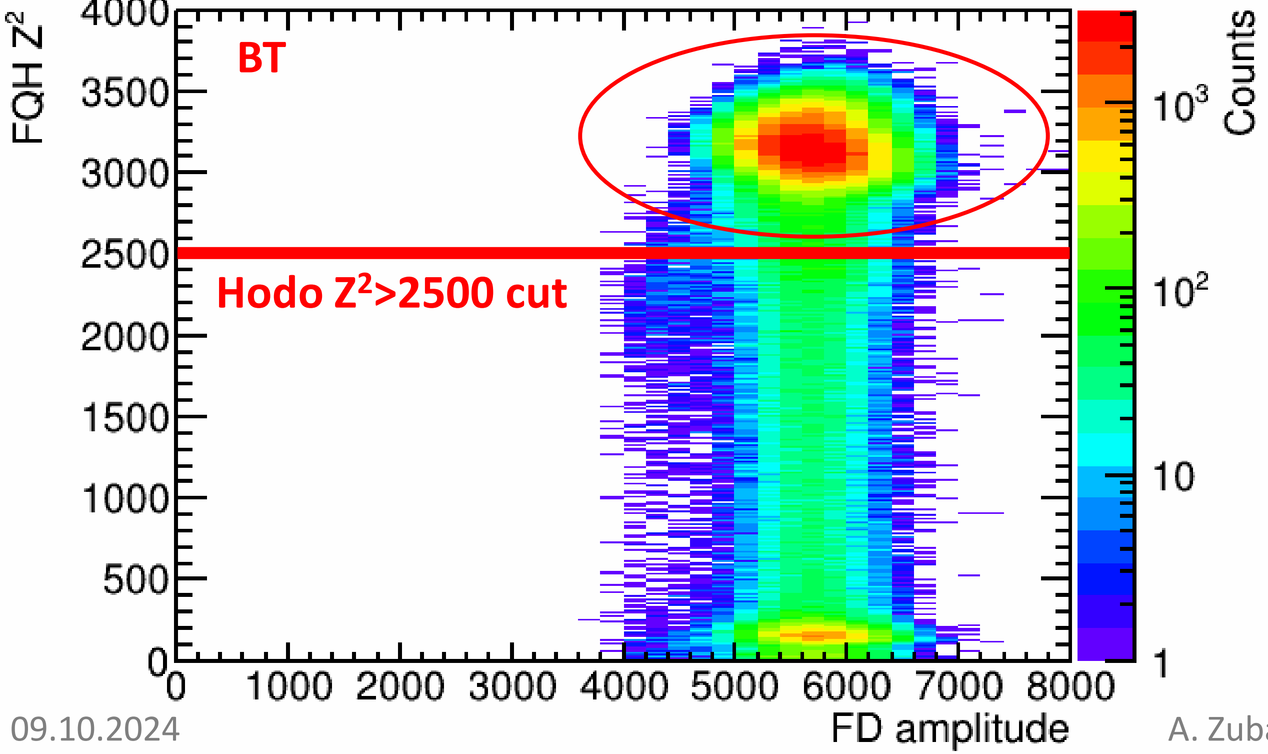


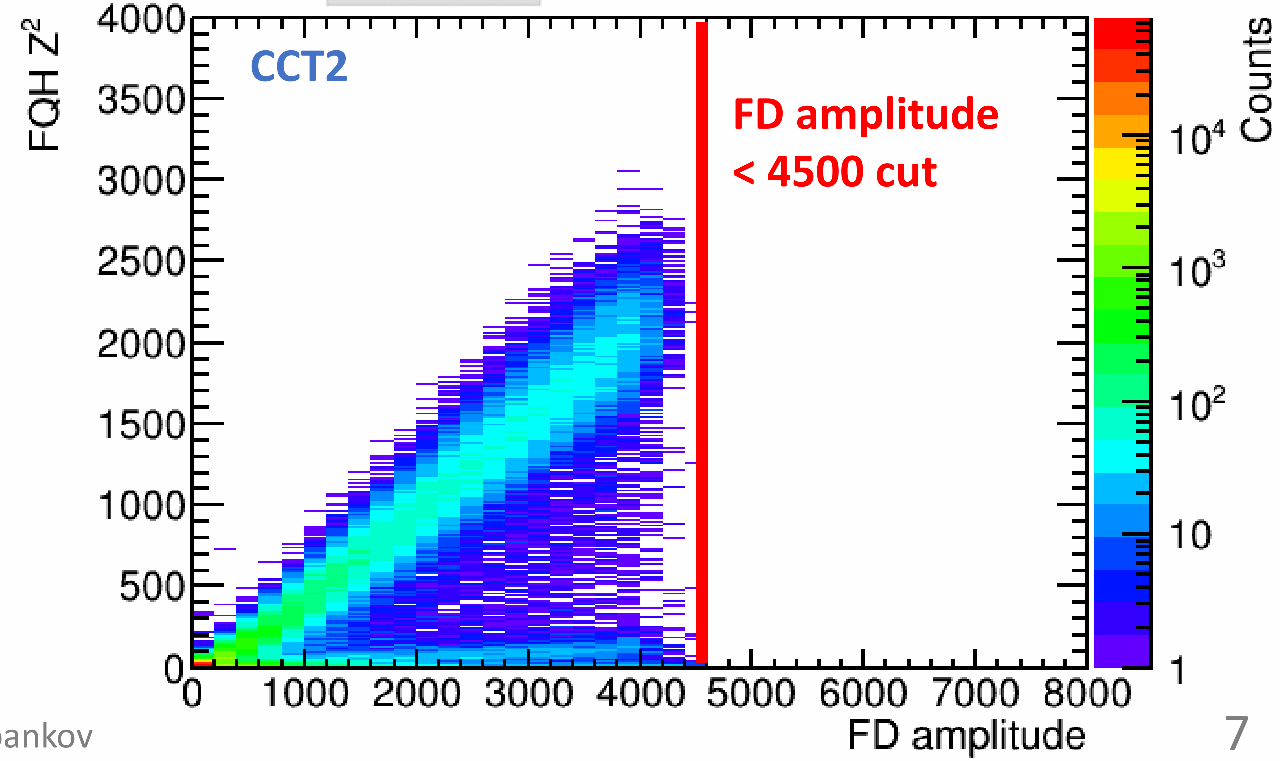


Comparison of hadronic interactions (CCT2) with electromagnetic dissociation (BT)
on **Hodoscope** vs **FD**
Run **8281 (BT)** vs **8300 (CCT2)** 3.8A GeV



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

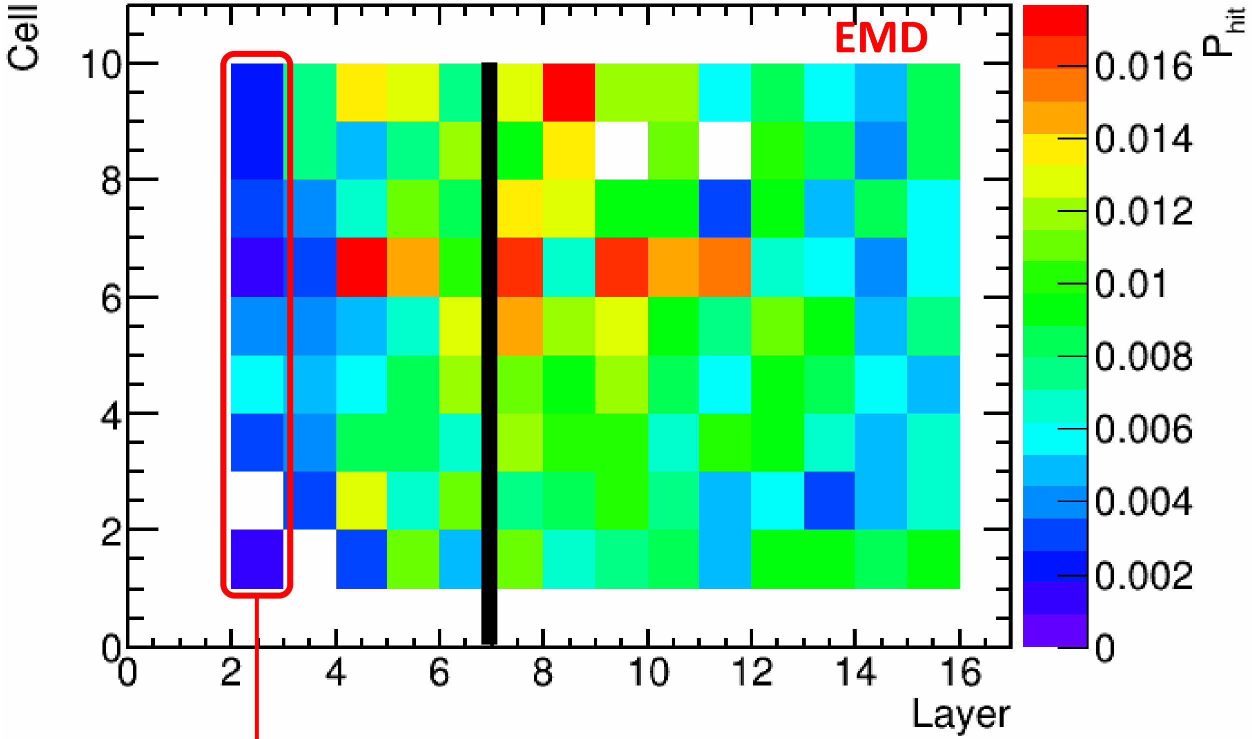


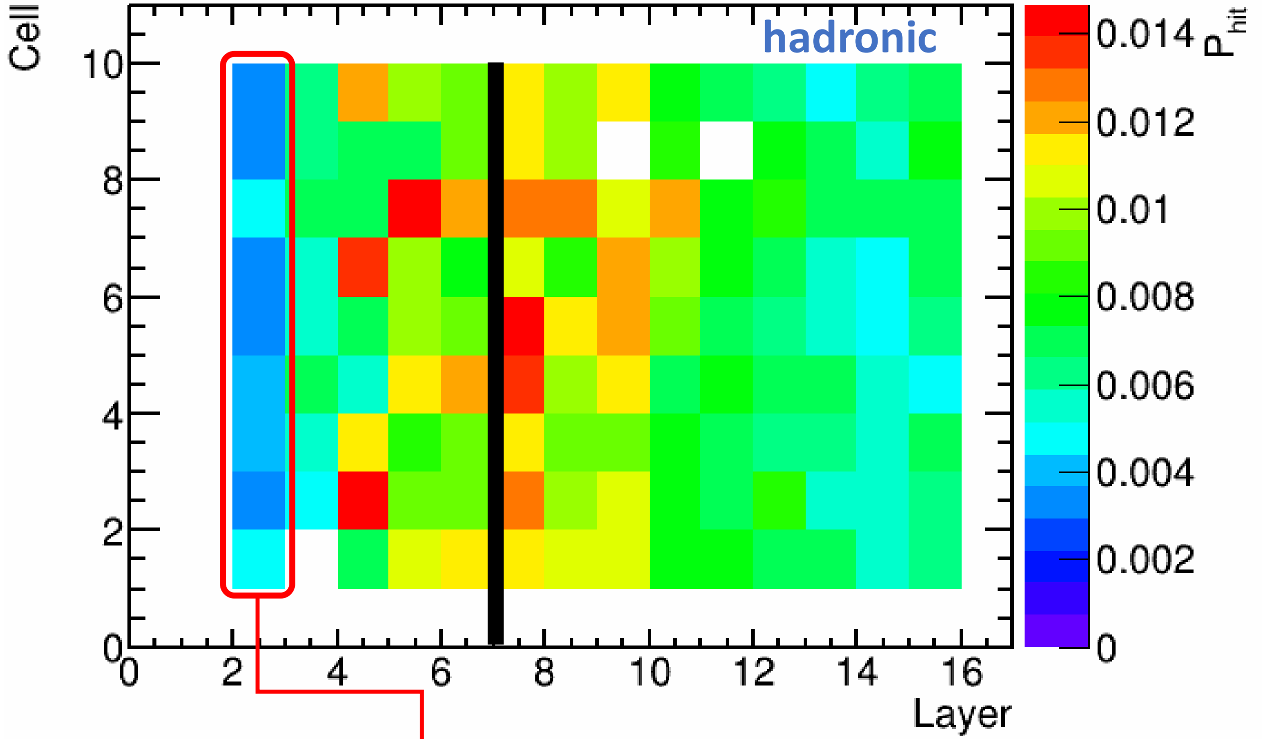


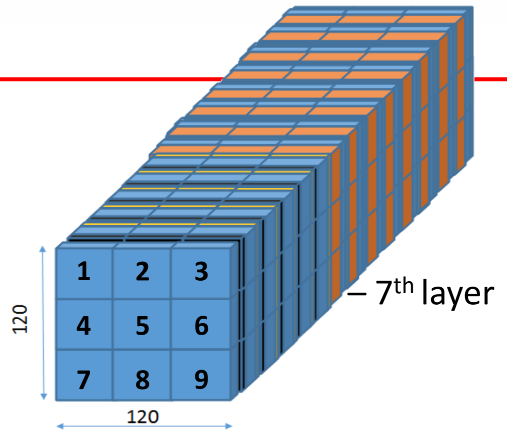
Fastest cells for EMD vs hadronic interactions

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}

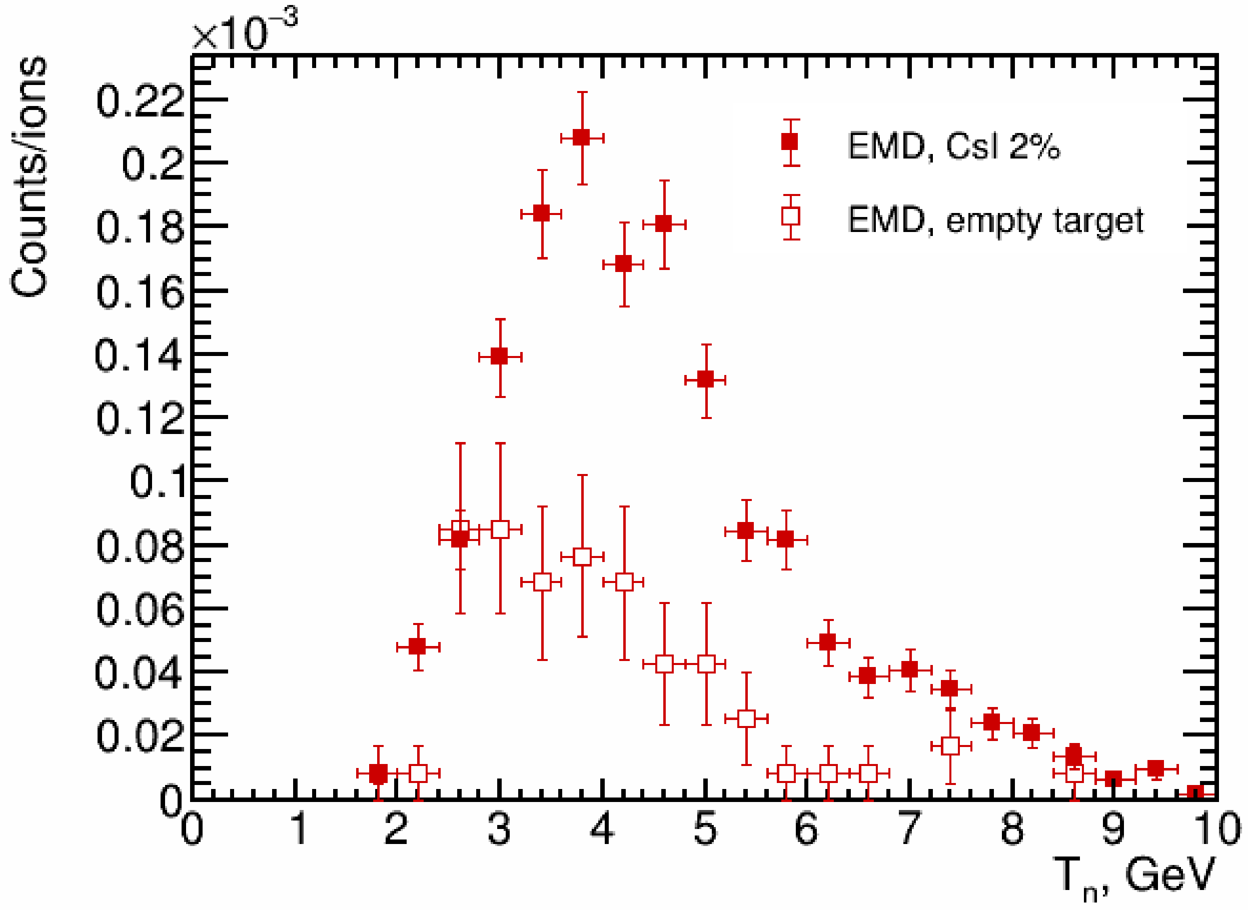
Most of the neutrons are deposited after the 7th layer for both EMD and nuclear interaction

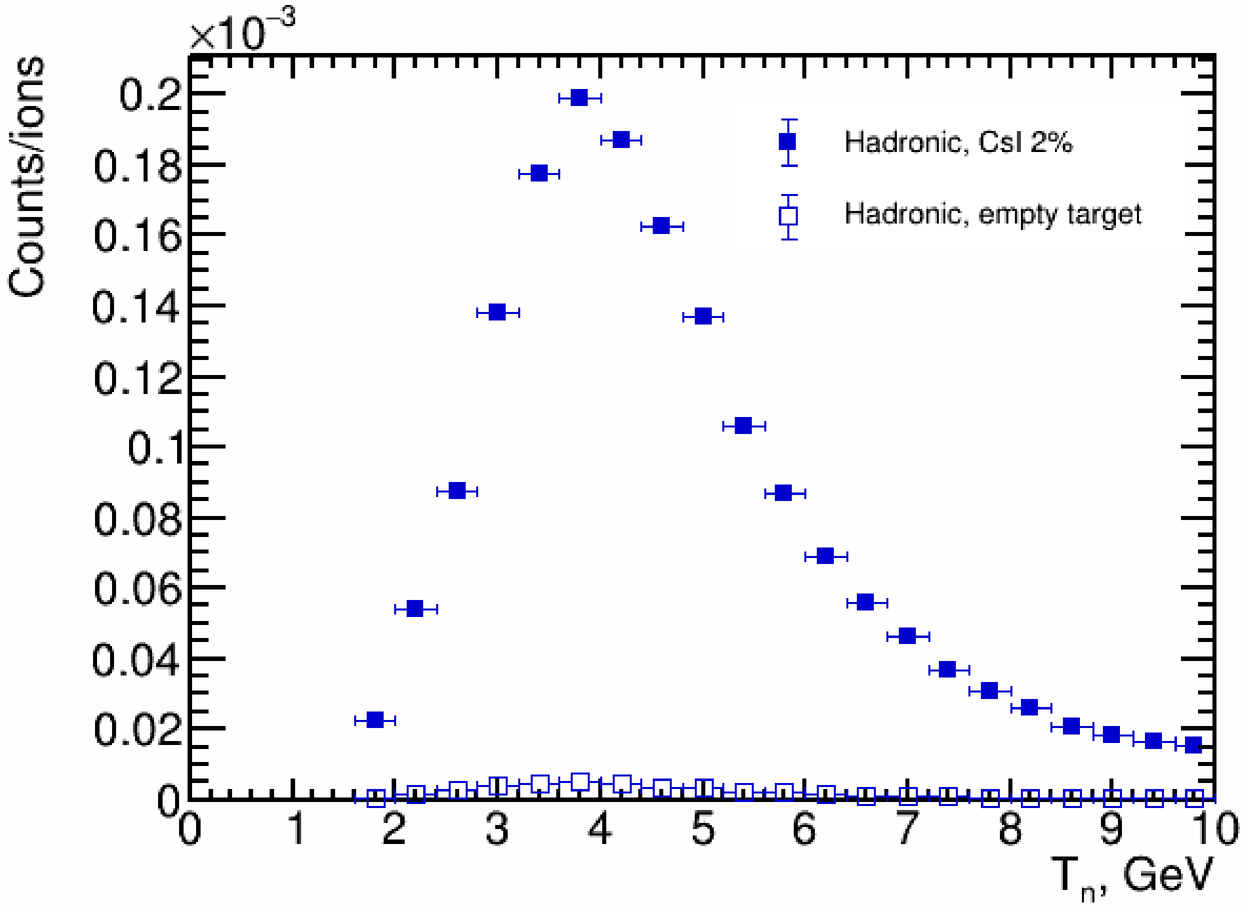
Empty target vs CsI 2%

Empty vs CsI 2%

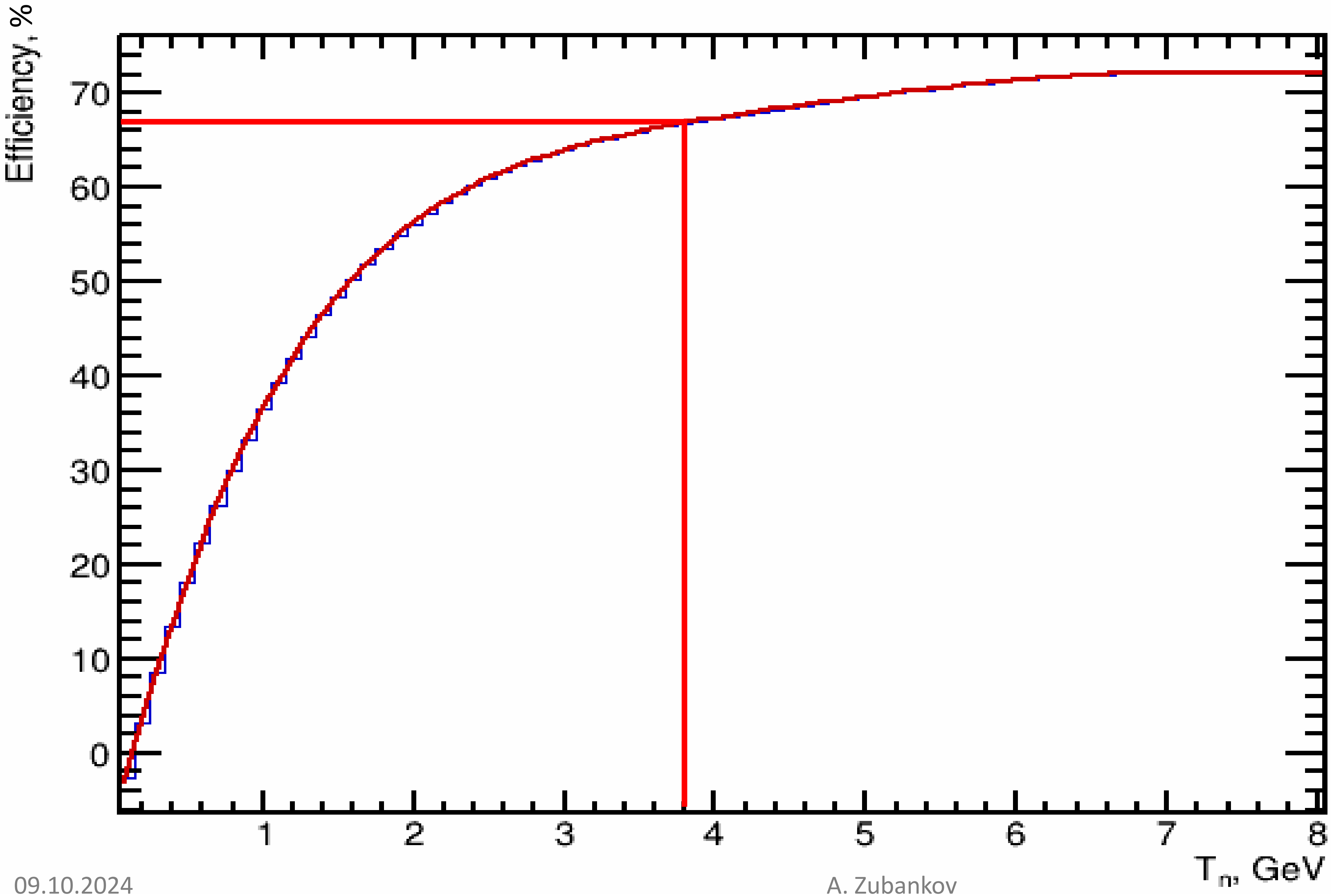
0.7 deg., 3.8 AGeV

Scaled by incident ion beam rate





HGND prototype efficiency for neutrons



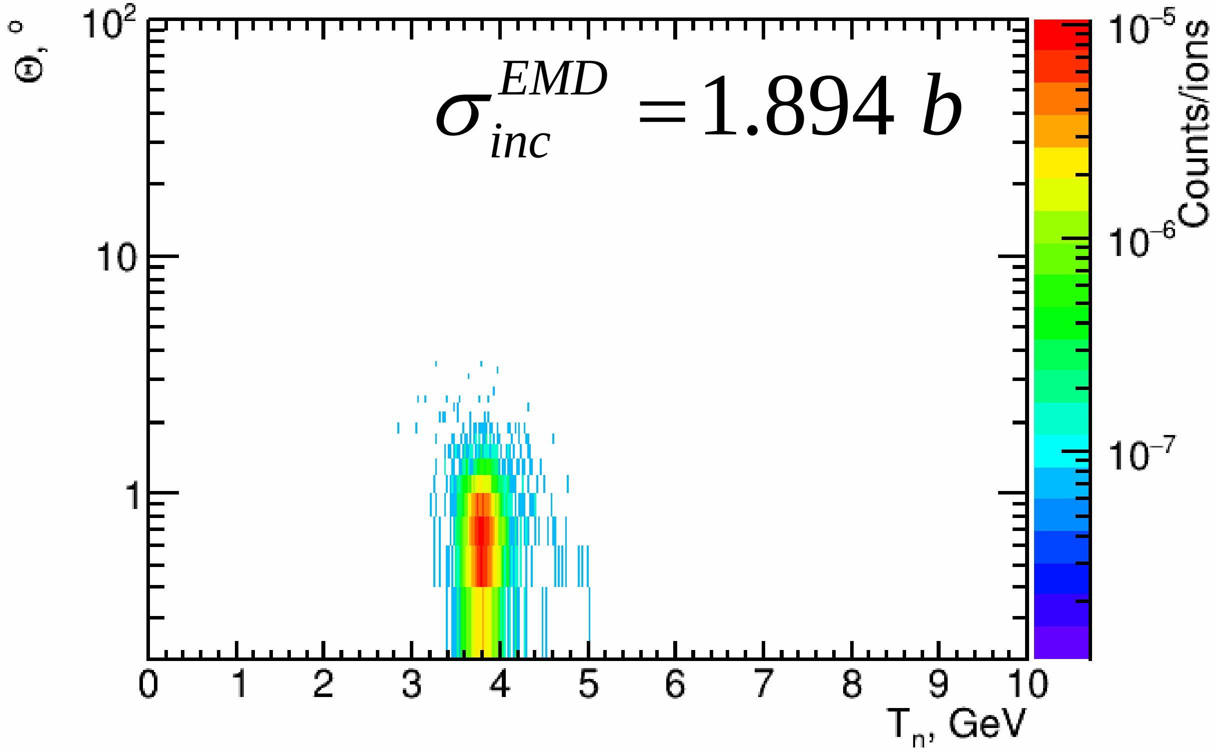
Box generator
Only neutrons

- VETO-cut
- γ-cut
- ToF cut

EMD vs Nuclear interaction in simulation

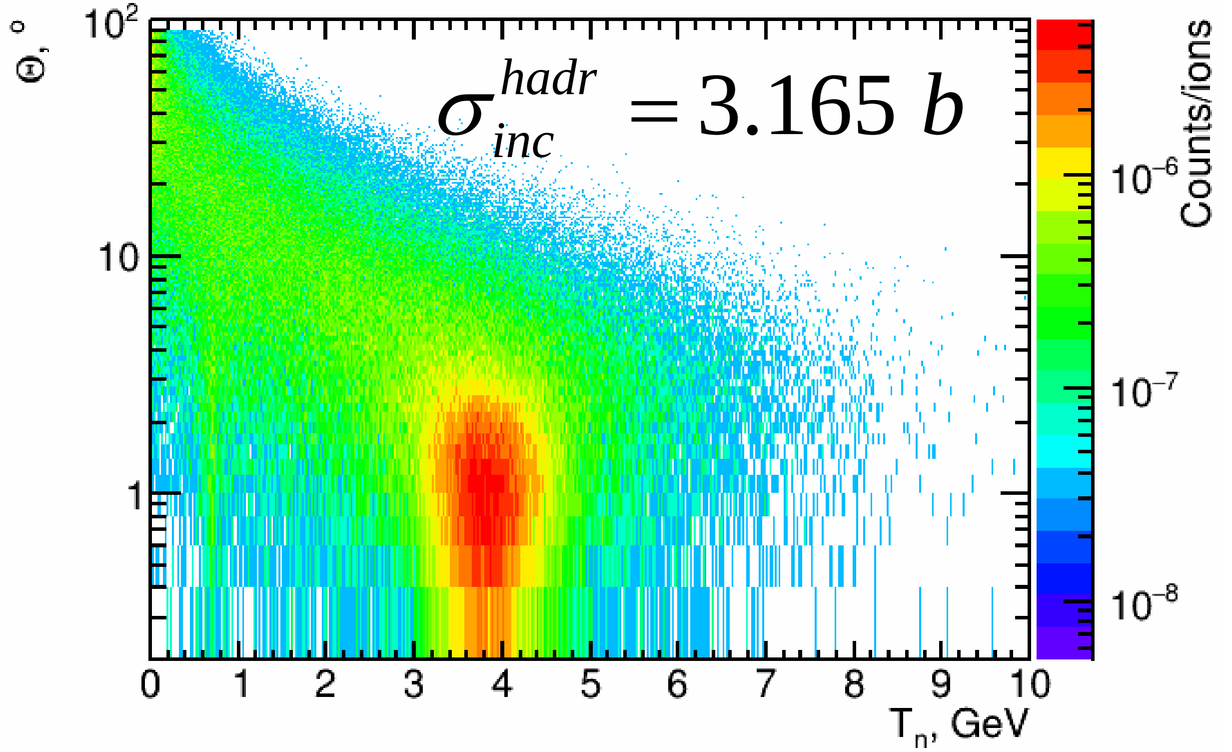
RELDIS*

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



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

^{131}Xe + Cs @ 3.8AGeV



Neutron multiplicity – **1.05**

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

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

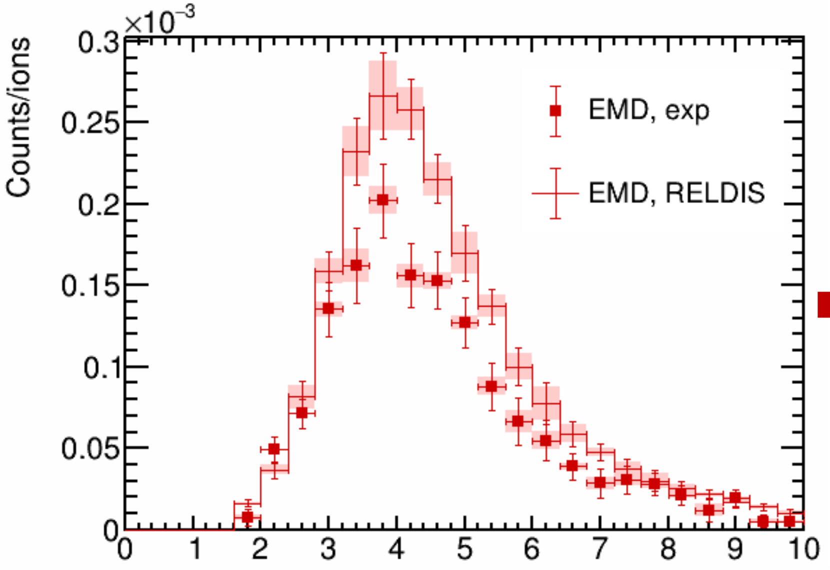
$$acc = \frac{N_{hit}}{N_{gen}} \qquad \varepsilon = \frac{N_{rec}}{N_{hit}}$$

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

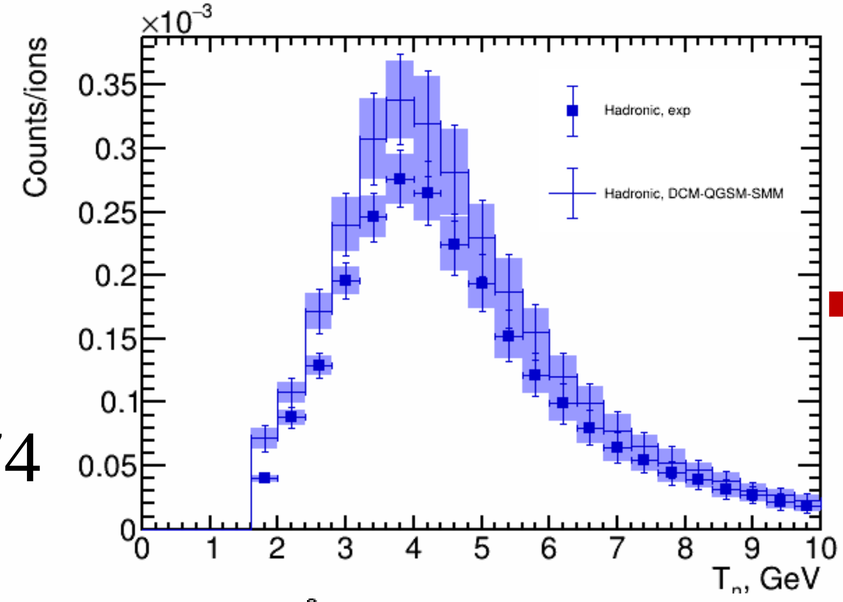
The difference in *acc* is explained by the considerably smaller angular distribution of neutron emission in EMD than in hadronic interactions.

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.

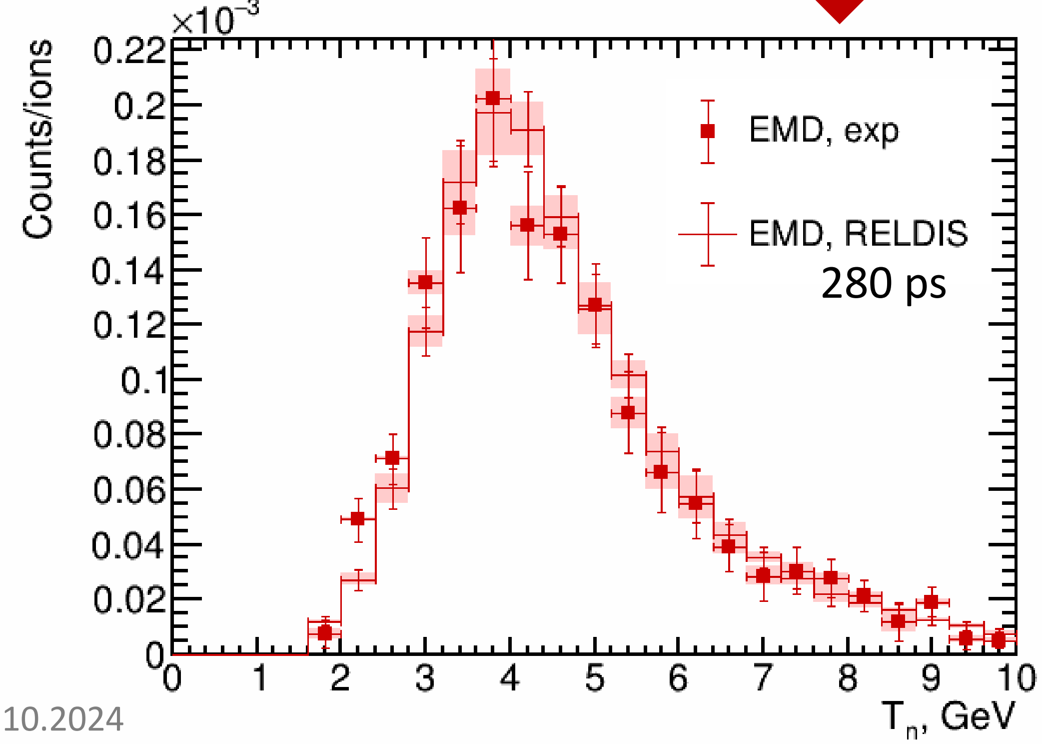
EMD vs Nuclear interaction

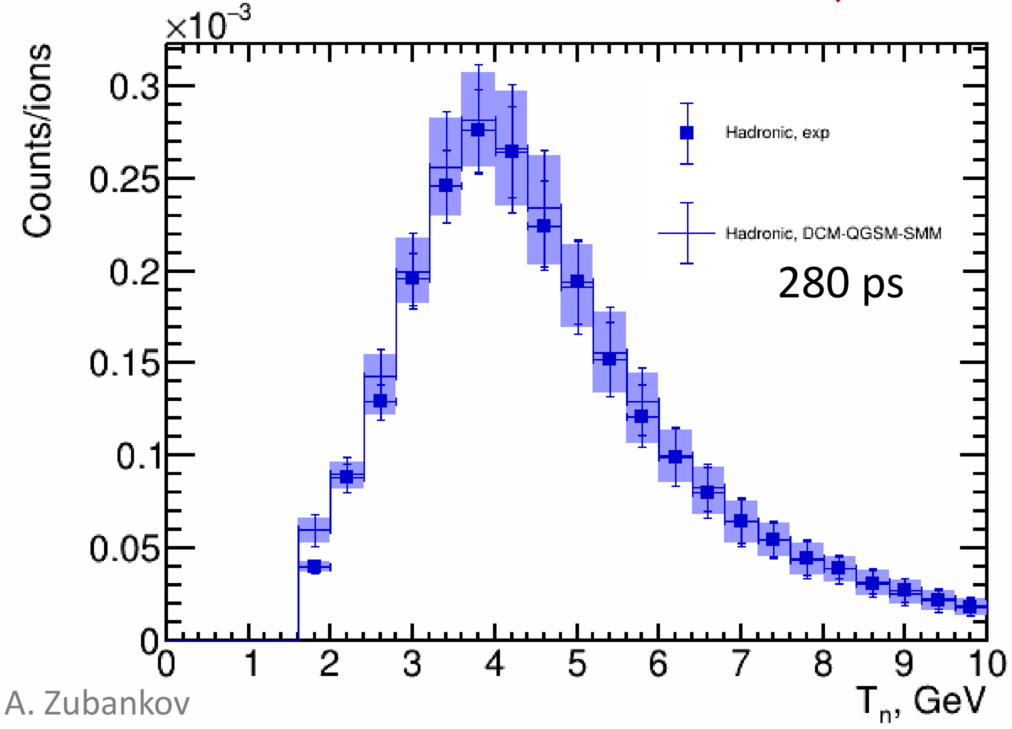


$$k_{EMD} \approx 0.74$$

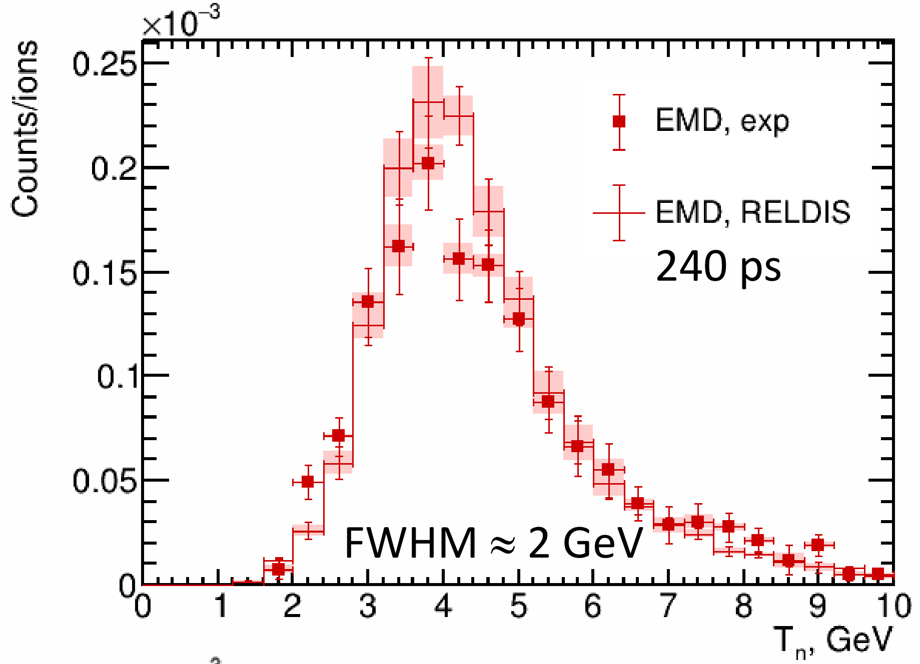


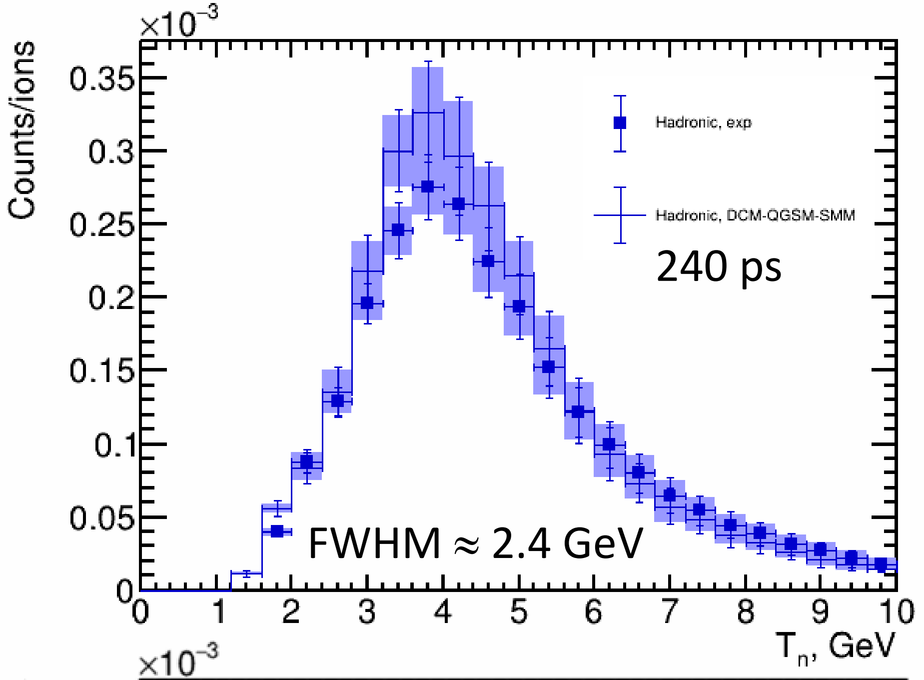
$$k_{hadr} \approx 0.83$$

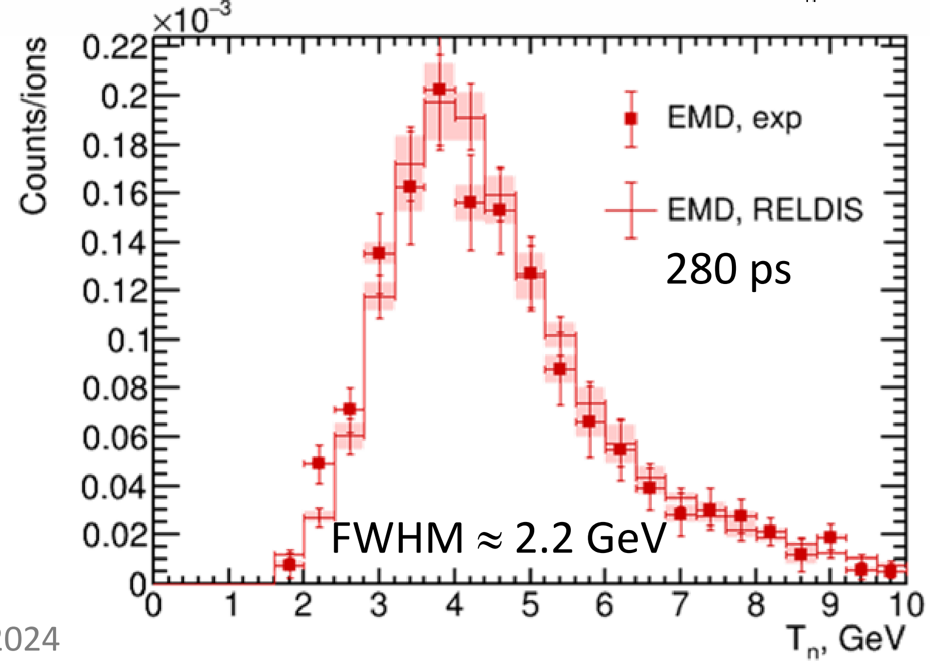


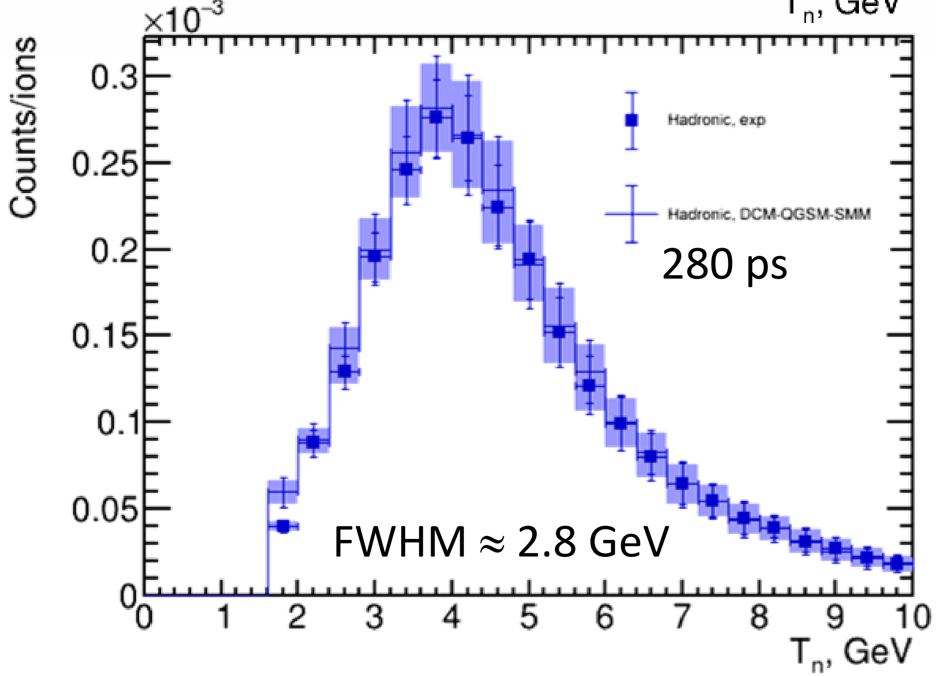


Time resolution









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

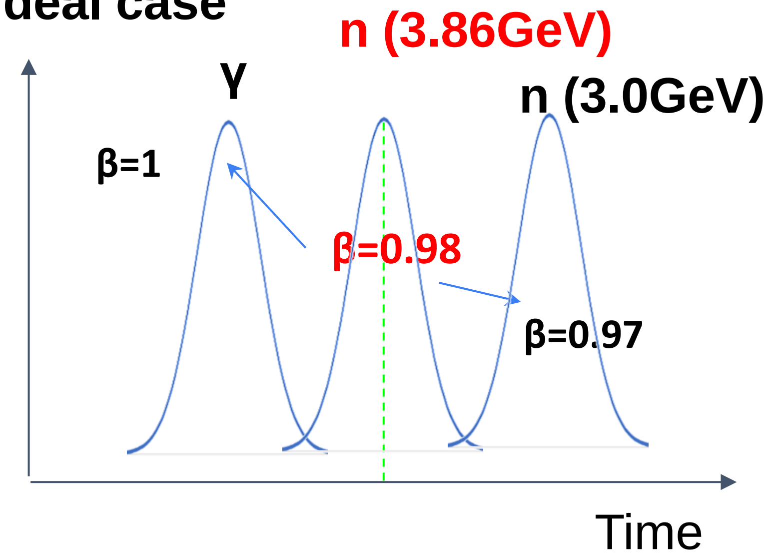
- The acceptances and efficiencies of the HGND prototype to neutrons from the hadronic interaction and EMD were studied.
- The ratio of neutron yields from a hadronic interactions to EMD is 1.70±0.16±0.25, which is close to the simulation – 1.73±0.01±0.17.
- EMD in the BM@N experiment can be used as 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.
- The paper is being prepared for submission to JINST

Thank you for your attention!

Backup

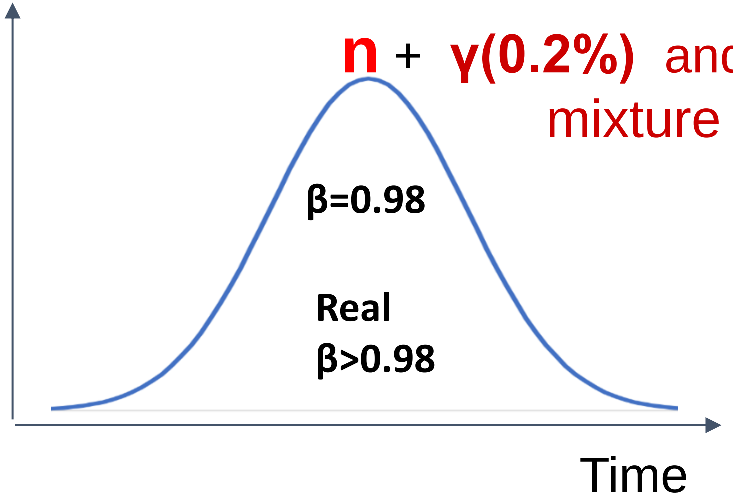
HGND calibration

Ideal case

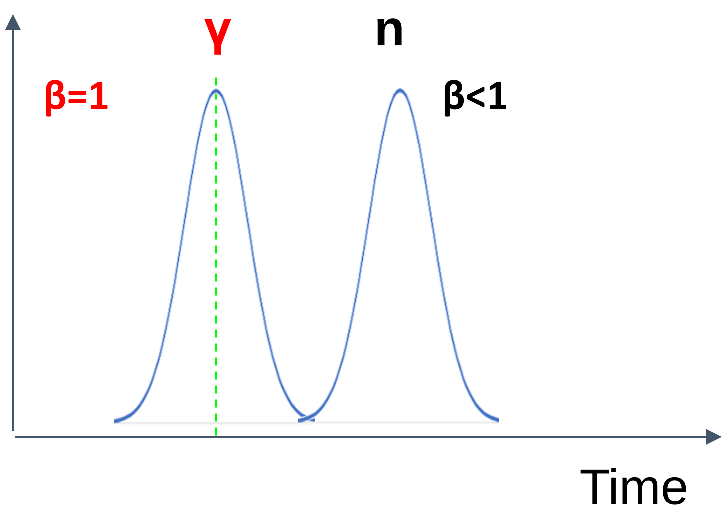


Calibration on neutrons

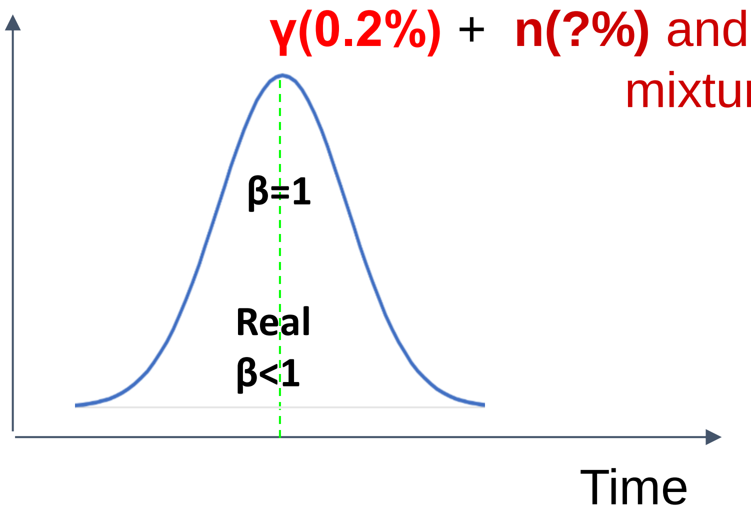
Real data



Calibration on neutrons



Calibration on photons

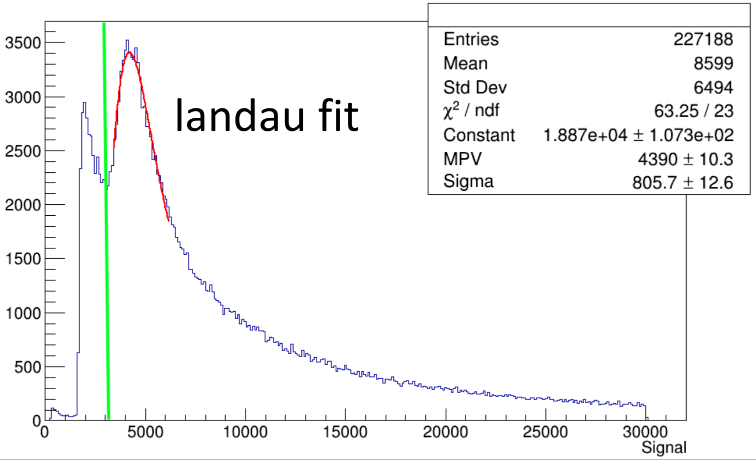


Calibration on photons is possible up to 8 layer

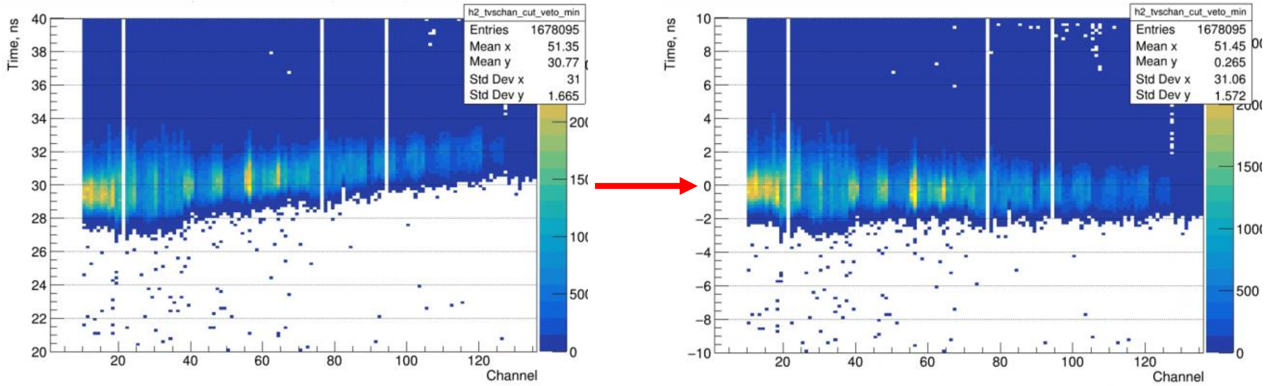
HGND calibration

1. Amplitude normalization

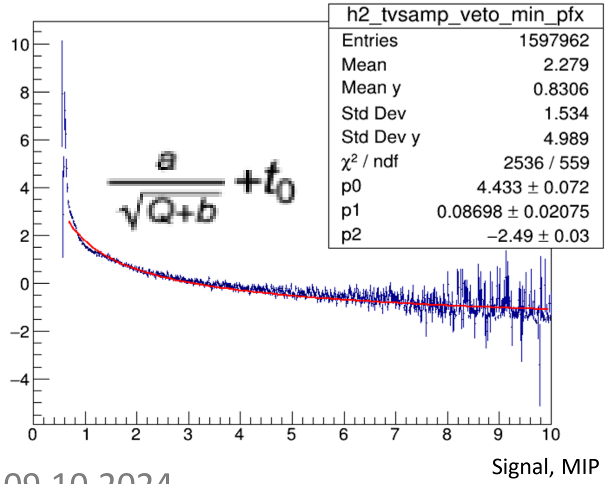
$$Ampl = Ampl \cdot \frac{1}{MPV}$$



2. Time shift for all channels by the average fit value

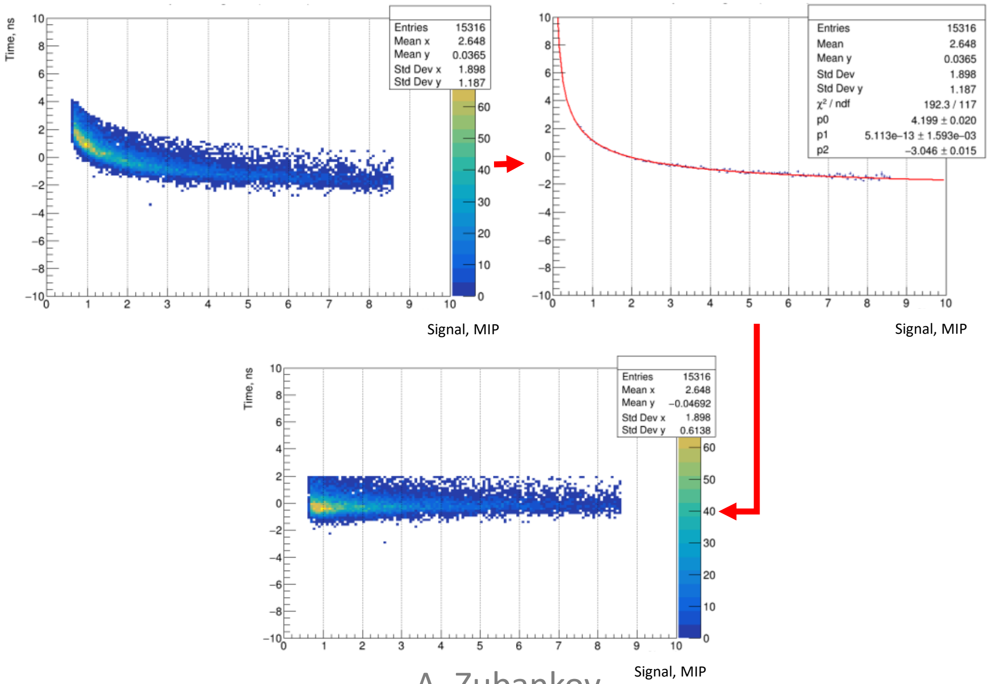


3. Determination of parameters of the approximating function for all channels & time limit

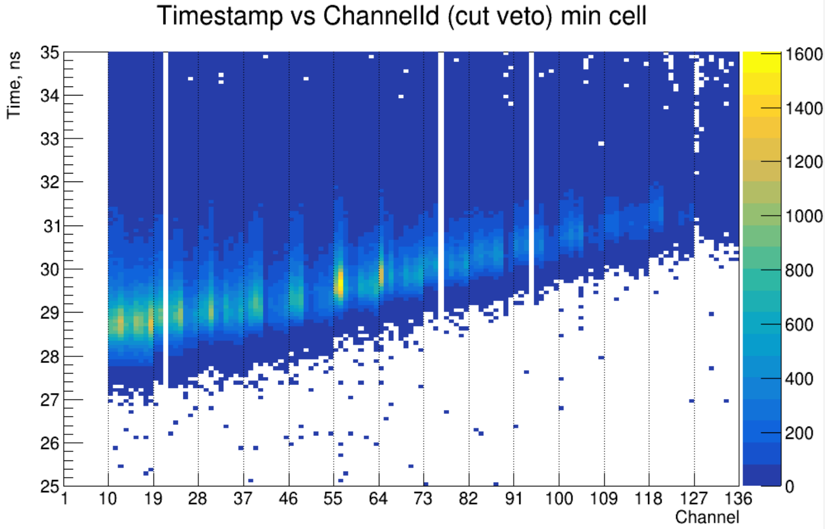


$$\frac{a}{\sqrt{Q+b}} + t_0$$

4. Time-amplitude correction

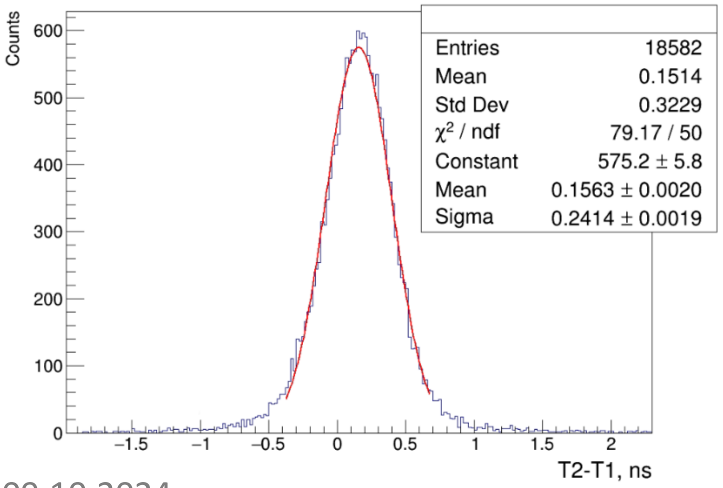


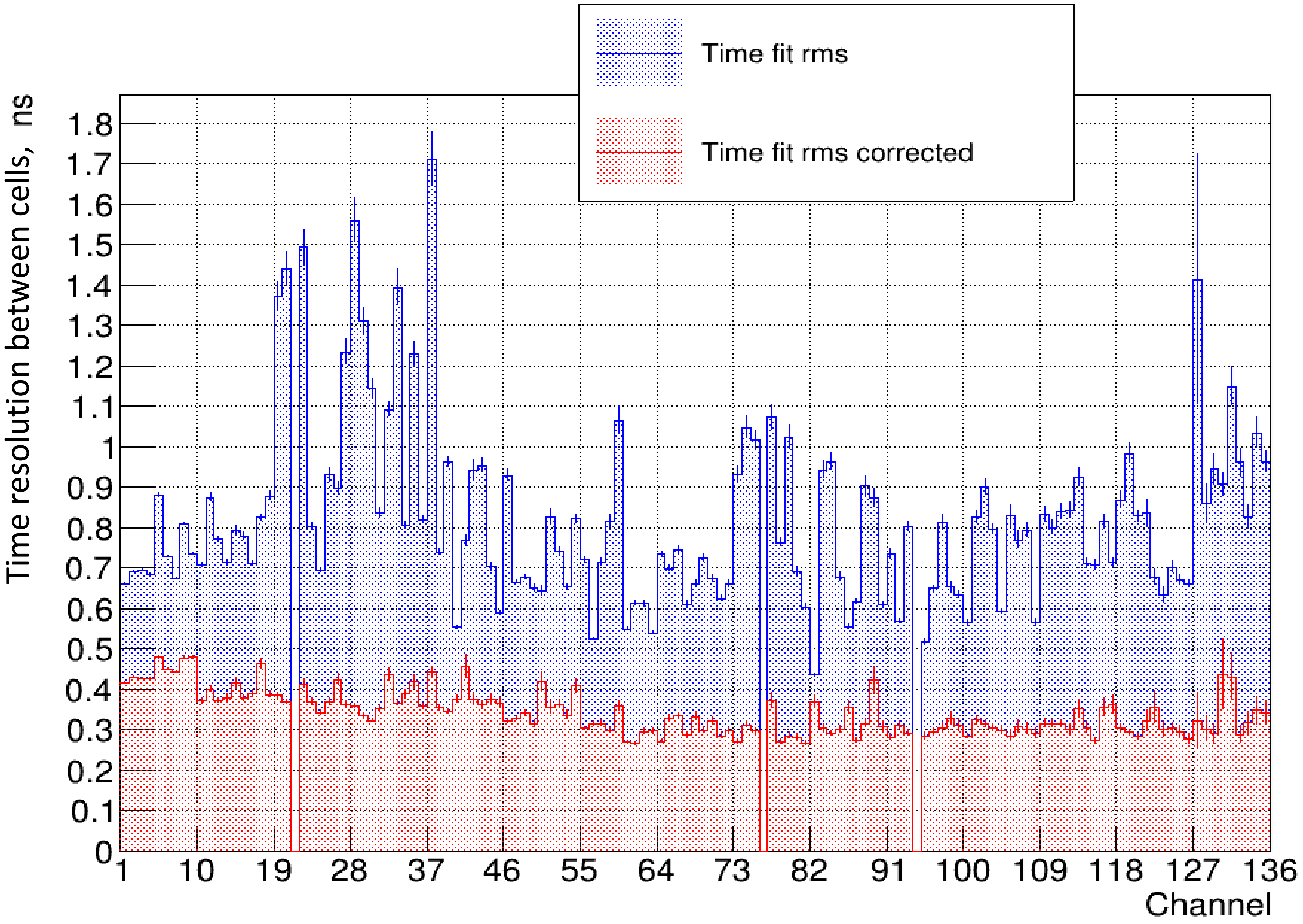
5. Time shift



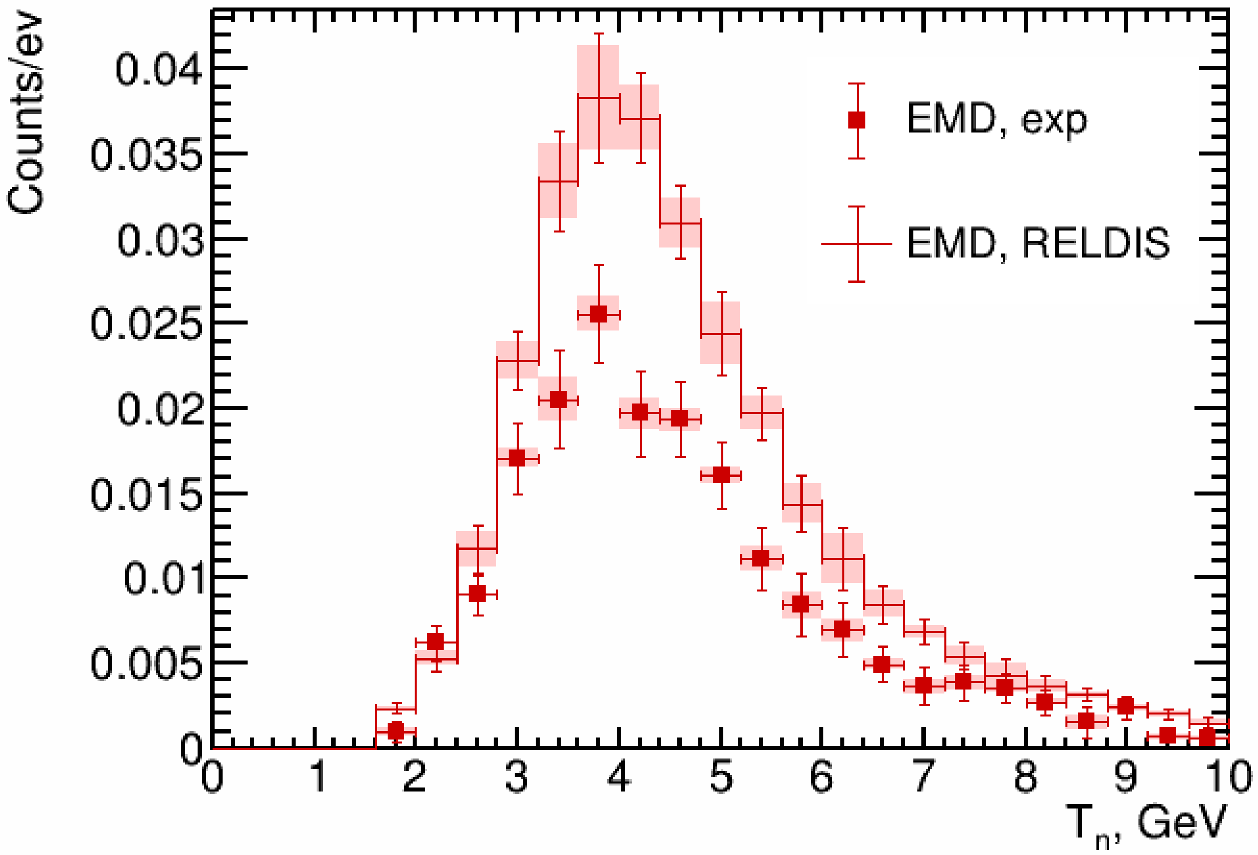
HGND calibration

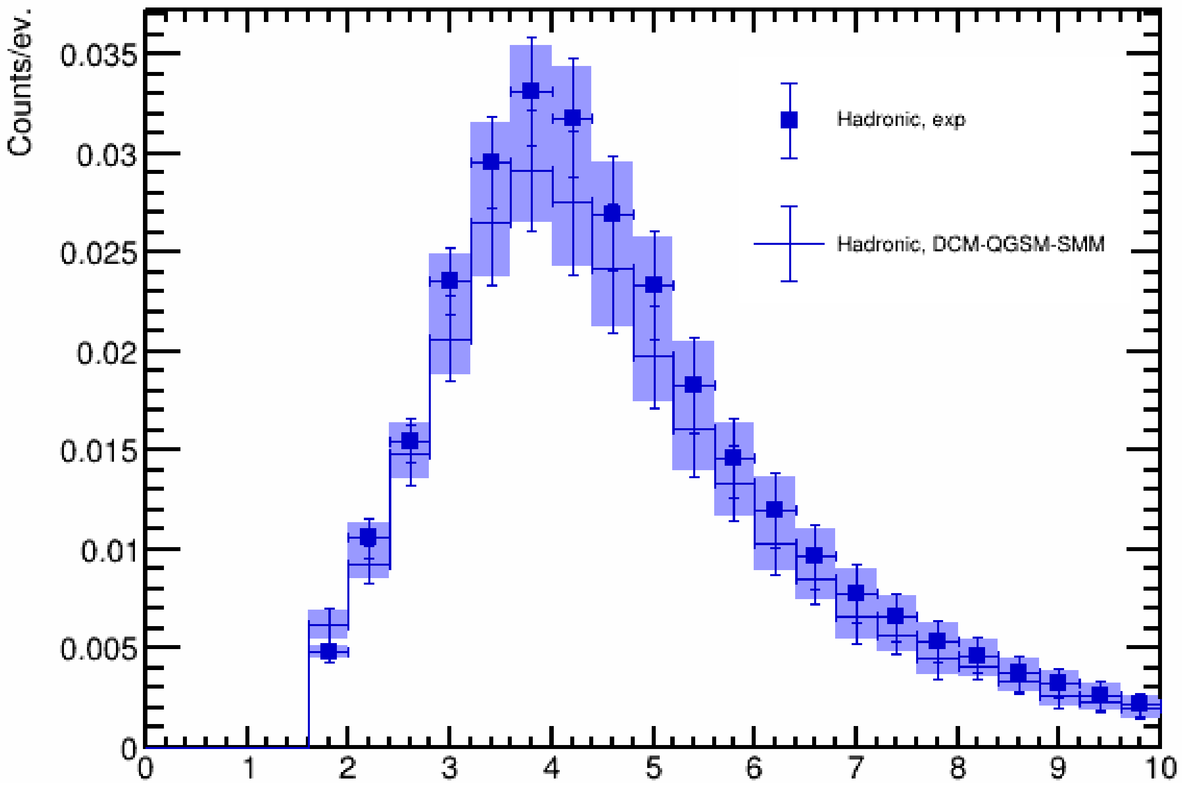
Time-amplitude correction of signals made it possible to get rid of the dependence of time on signal amplitude, which improved the time resolution by ~2.4 times.





EMD vs Nuclear interaction

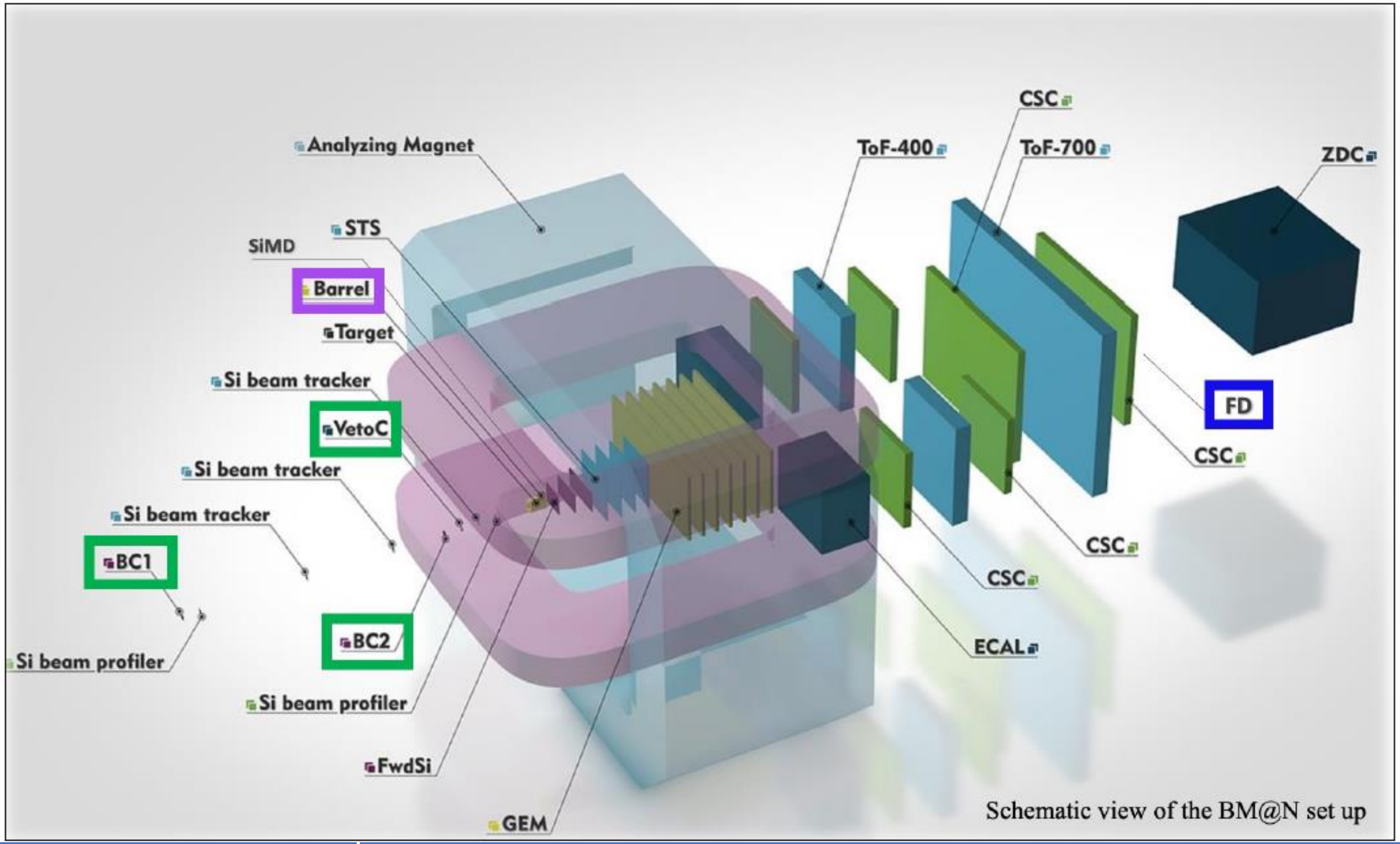




BC1, VC, BC2

BD

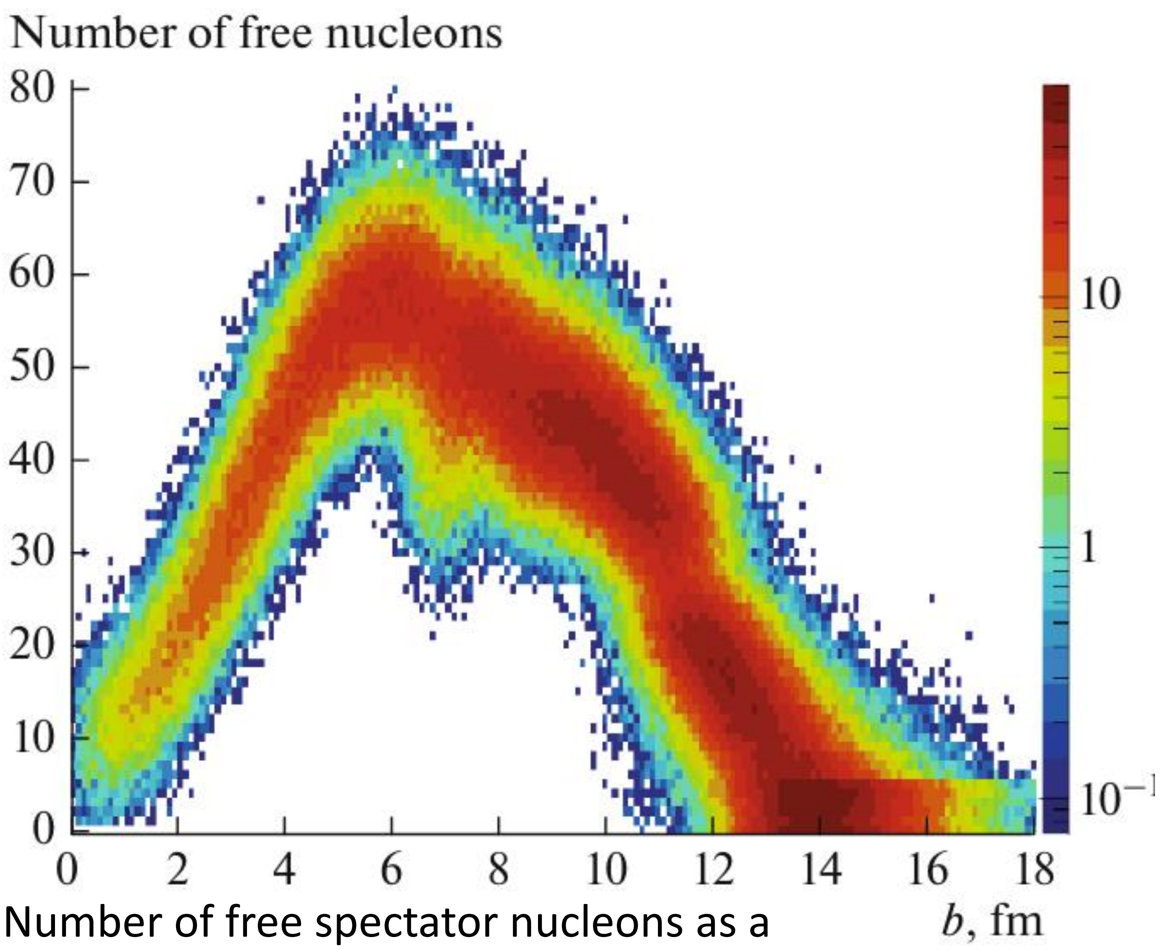
FD



Schematic view of the BM@N set up

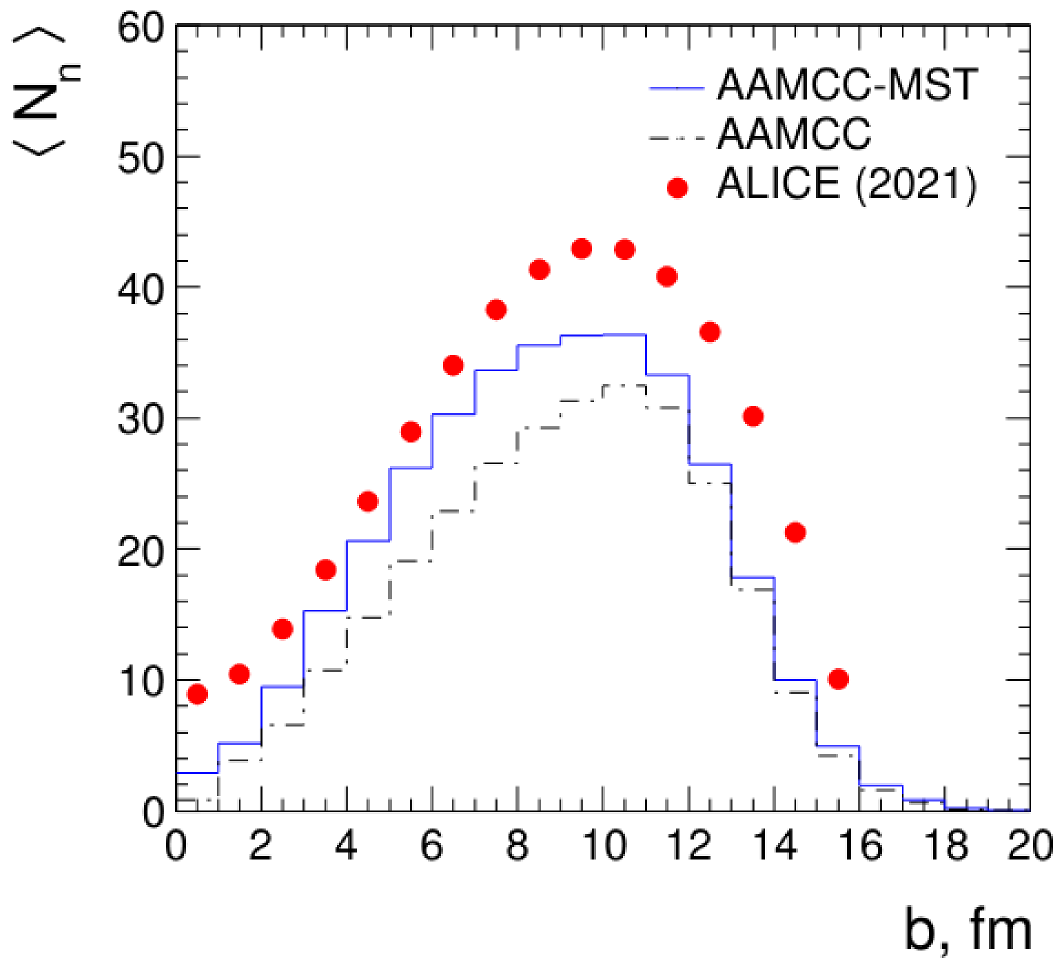
Trigger type	Trigger logic
Beam Trigger (BT)	BT = BC1 * BC2 * !VC
Min. Bias Trigger (MBT)	MBT = BT * !FD
Centrality Trigger 1 (CCT1)	CCT1 = BT * BD
Centrality Trigger 2 (CCT2)	CCT2 = MBT * BD

Nuclear interaction



Number of free spectator nucleons as a function of the impact parameter in collisions between ^{197}Au nuclei at NICA at $\sqrt{s_{NN}}$ = 5 GeV

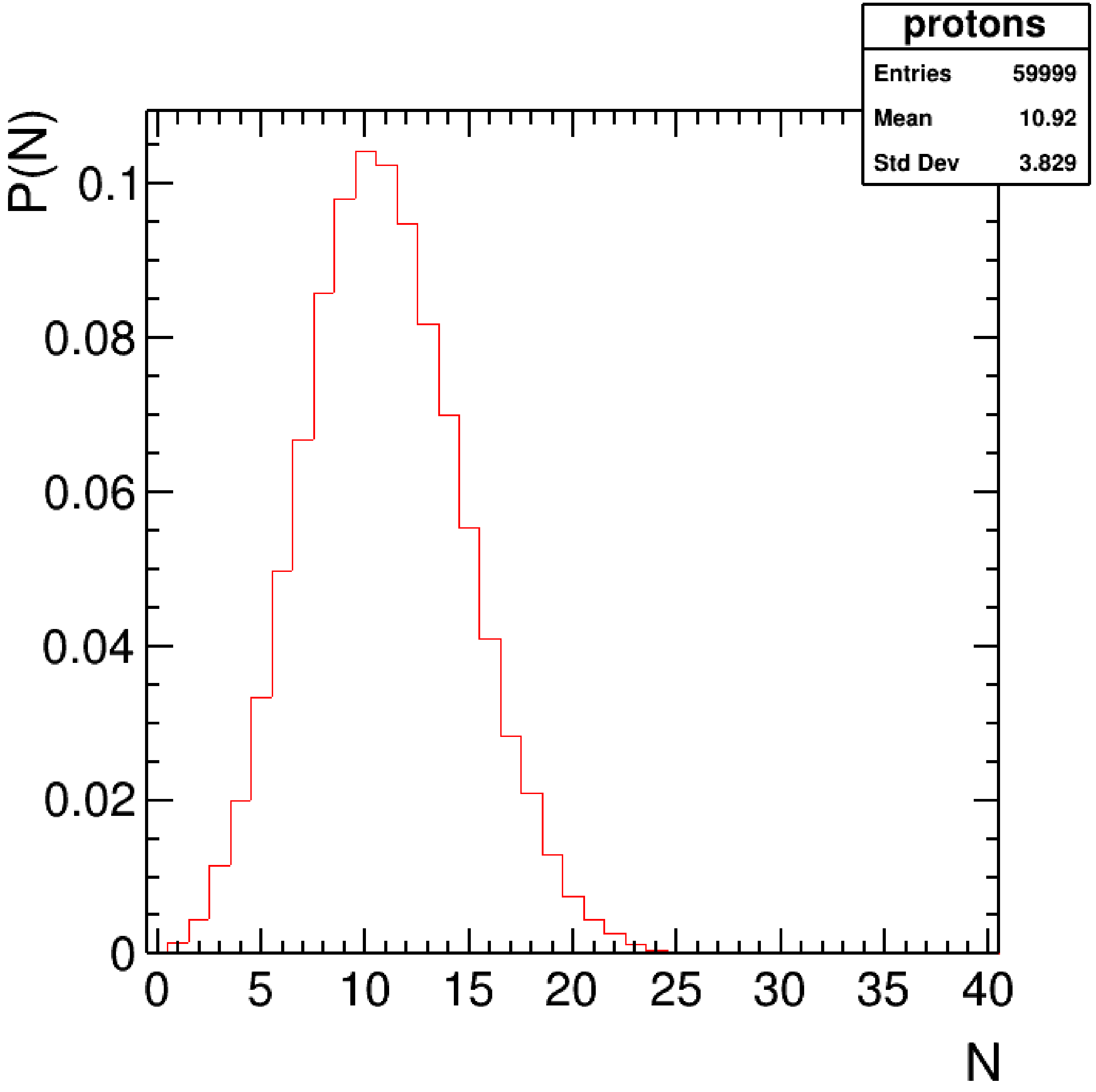
A. Svetlichnyi & I. Pshenichnov, Formation of Free and Bound Spectator Nucleons in Hadronic Interactions between Relativistic Nuclei. *Bulletin of the Russian Academy of Sciences: Physics* **2020**, 84 (8), 911–916.

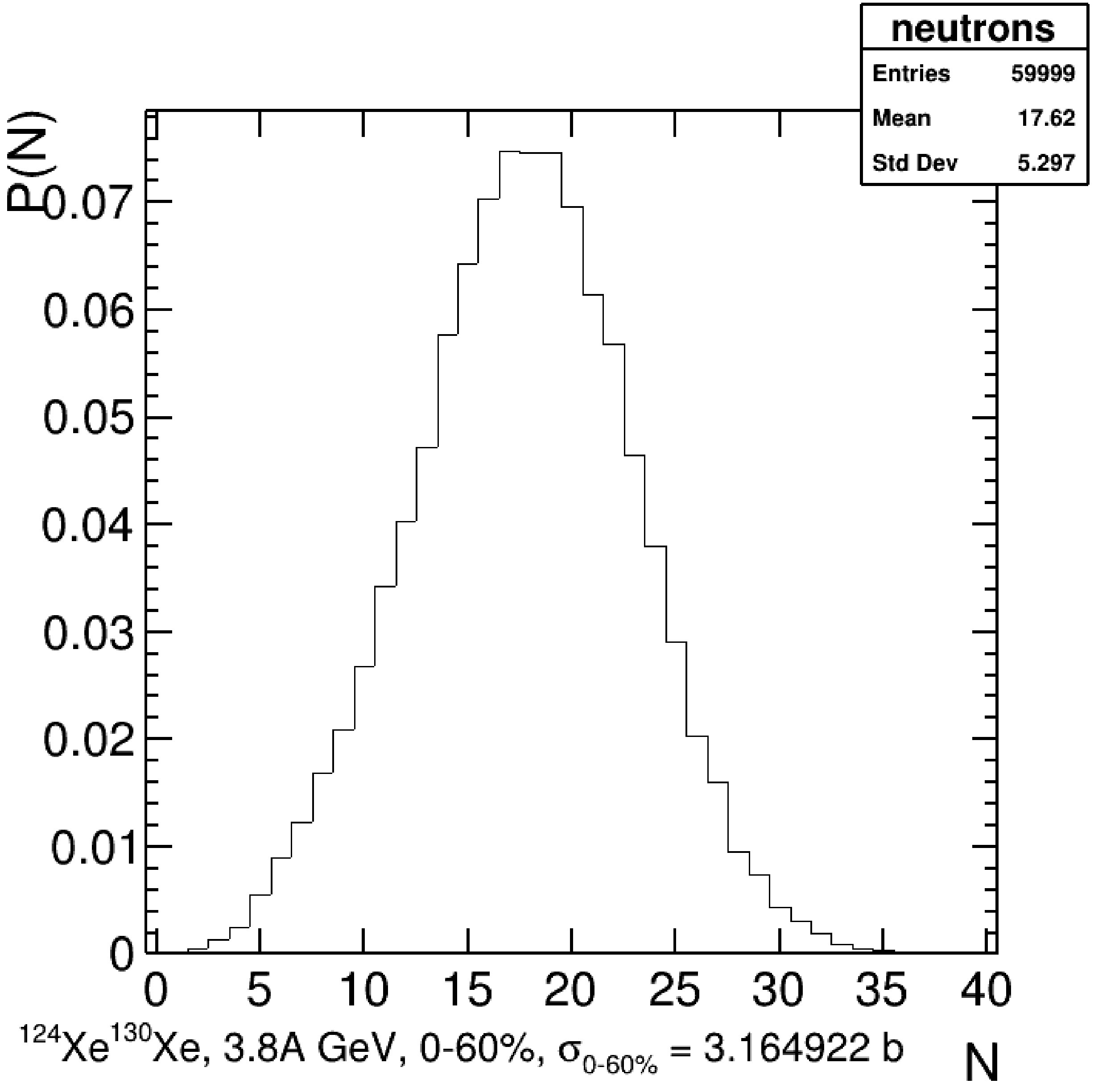


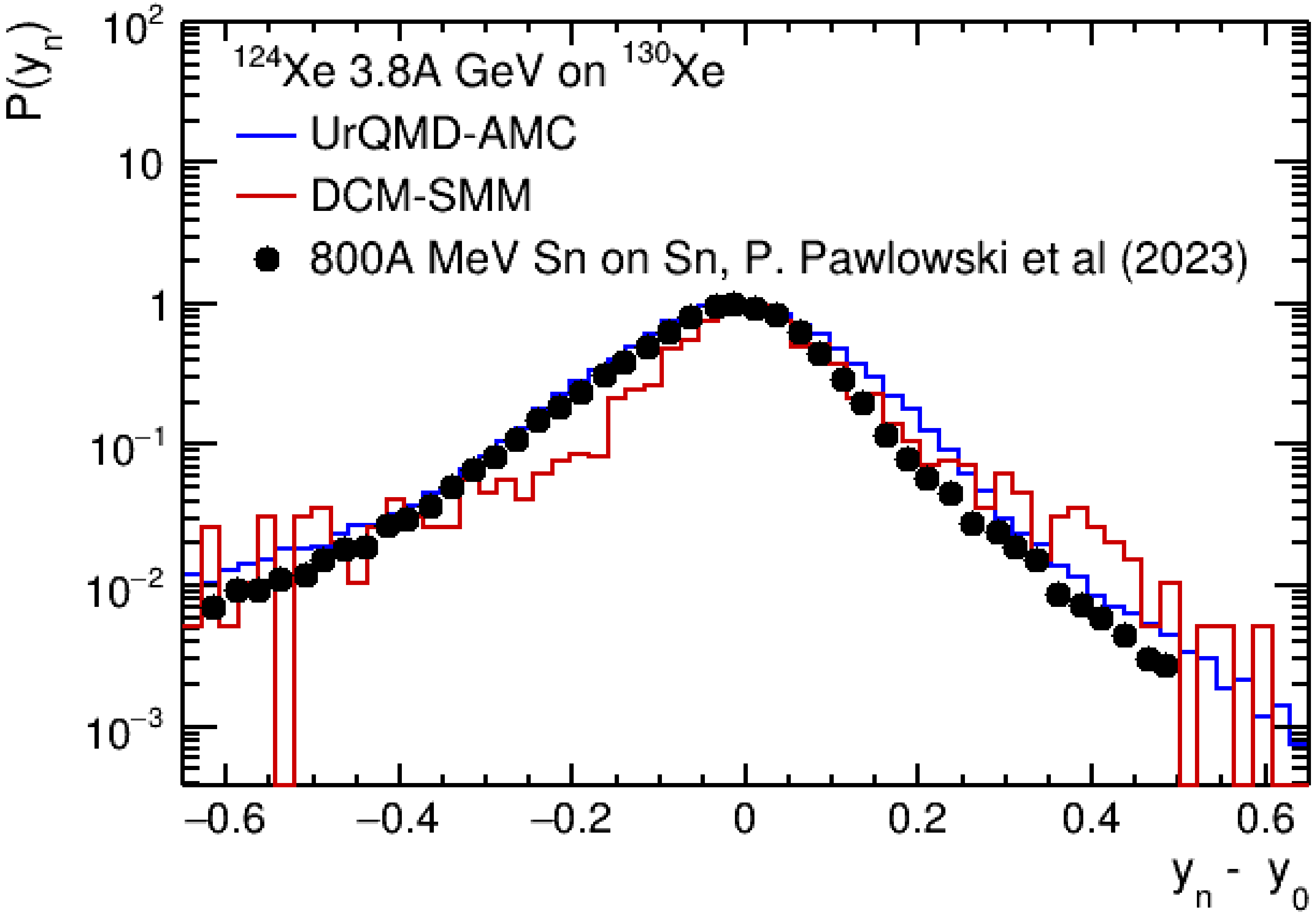
Average multiplicities of neutrons in ^{208}Pb–^{208}Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV as functions of the collision impact parameter

Nepeivoda, R. et al., Pre-Equilibrium Clustering in Production of Spectator Fragments in Collisions of Relativistic Nuclei. *Particles* **2022**, 5, 40–51.

Nuclear interaction







P(y_n)
10^2
10
1
10^−1
10^−2
10^−3
124Xe 3.8A GeV on 130Xe
UrQMD-AMC
DCM-SMM
800A MeV Sn on Sn, P. Pawlowski et al (2023)
−0.6
−0.4
−0.2
0
0.2
0.4
0.6
y_n - y_0