11th Collaboration Meeting of the BM@N
Experiment at the NICA Facility

Measurement of neutron yields by a HGND prototype in ultra-peripheral and central Xe+CsI collisions at 0 degrees in Run8

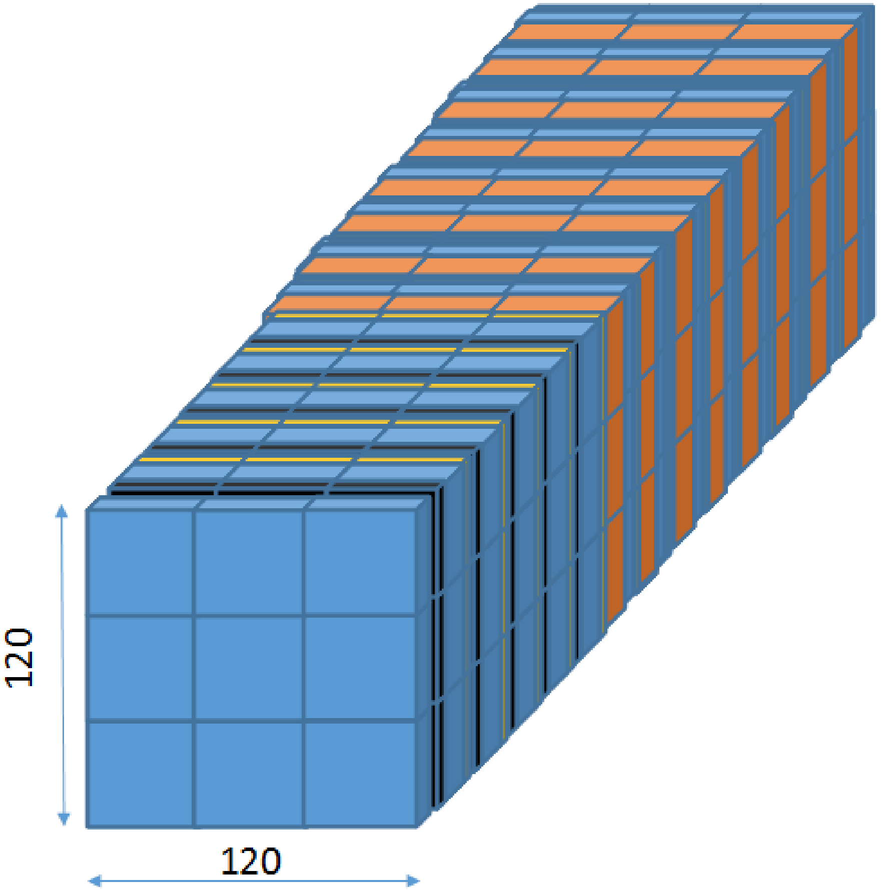
A. Zubankov on behalf of the HGND team

12.03.2024

Introduction

- The High Granular Neutron Time-of-Flight Detector (HGND) at the BM@N experiment is under development for measuring the energy of neutrons produced in nucleus-nucleus collisions.
- For the first time, small prototype of the HGND was used in Xe+CsI at 3.0 and 3.8 AGeV 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.
- The purpose of the research is to investigate neutron yields for electromagnetic dissociation (EMD) and nuclear interaction at 0 degrees by HGND prototype

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

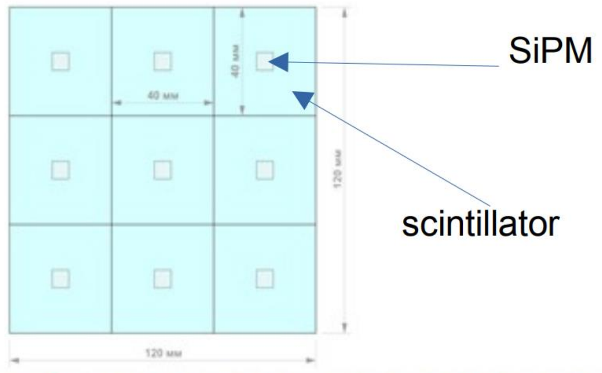
Scint. cell – 40 x 40 x 25 mm^3

Total number of cells – 9+45+81=135

Total size – 12 x 12 x 82.5 $см^3$

Total length ~ 2.5 λ_{int}

Average time resolution = 134±29 ps



Hamamatsu S13360- 6050PE

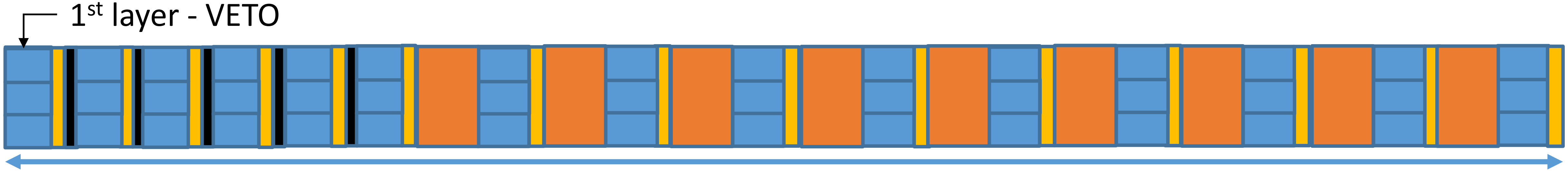
Photosensitive area – 6x6 mm^2

Number of pixels – 14400

Pixel size – 50 µm

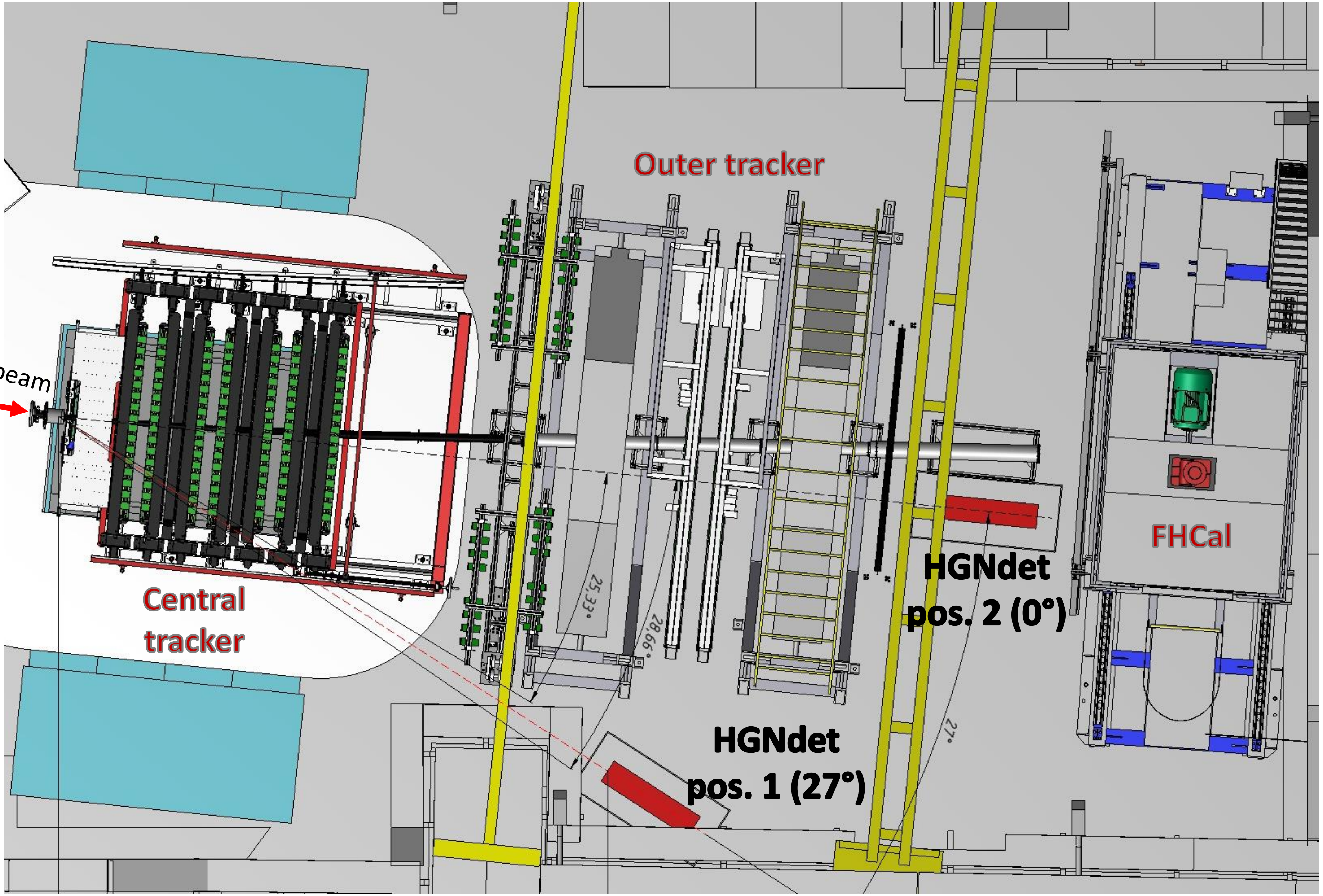
Gain – $1.7x10^6$

PDE – 40%



Necessary to separate showers from gamma quanta

HGND prototype in the Xe run of BM@N on Xe ion beam



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)

Criteria for selecting events with neutrons

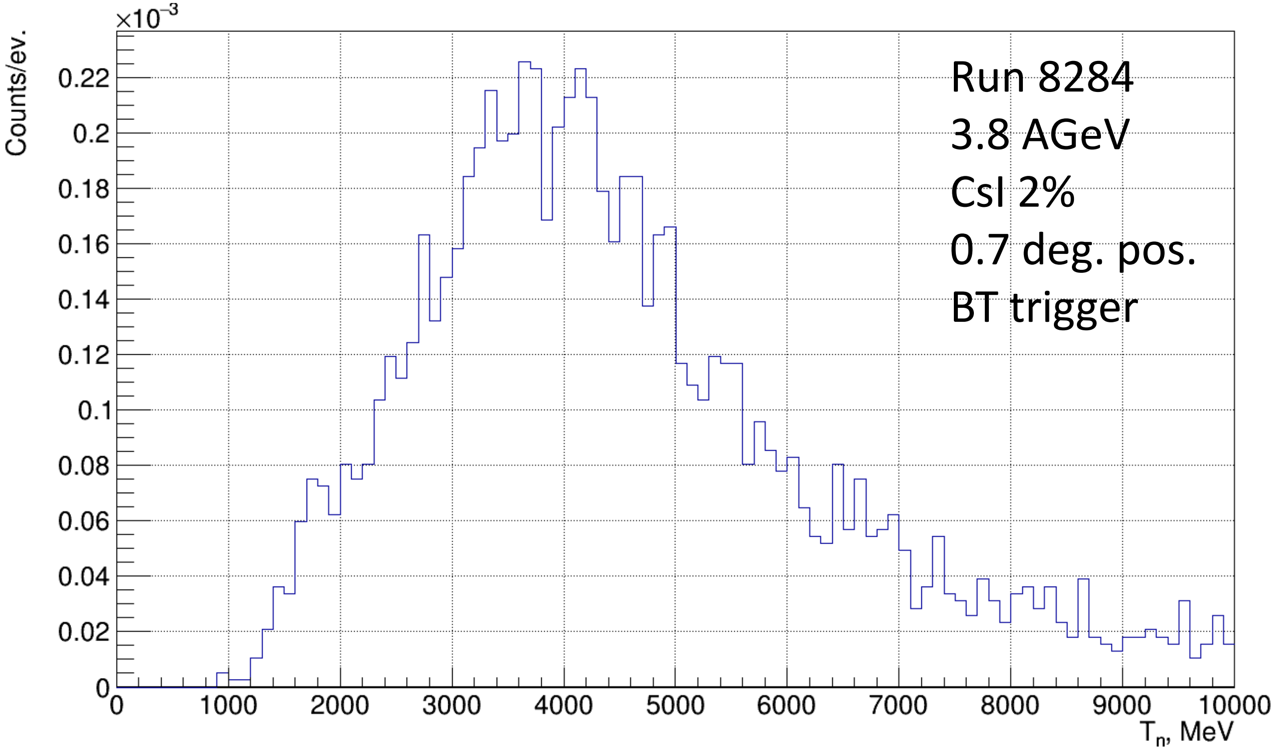
Reconstruction of energy by maximum velocity
(without efficiency correction)
Scaled by incident ion beam rate

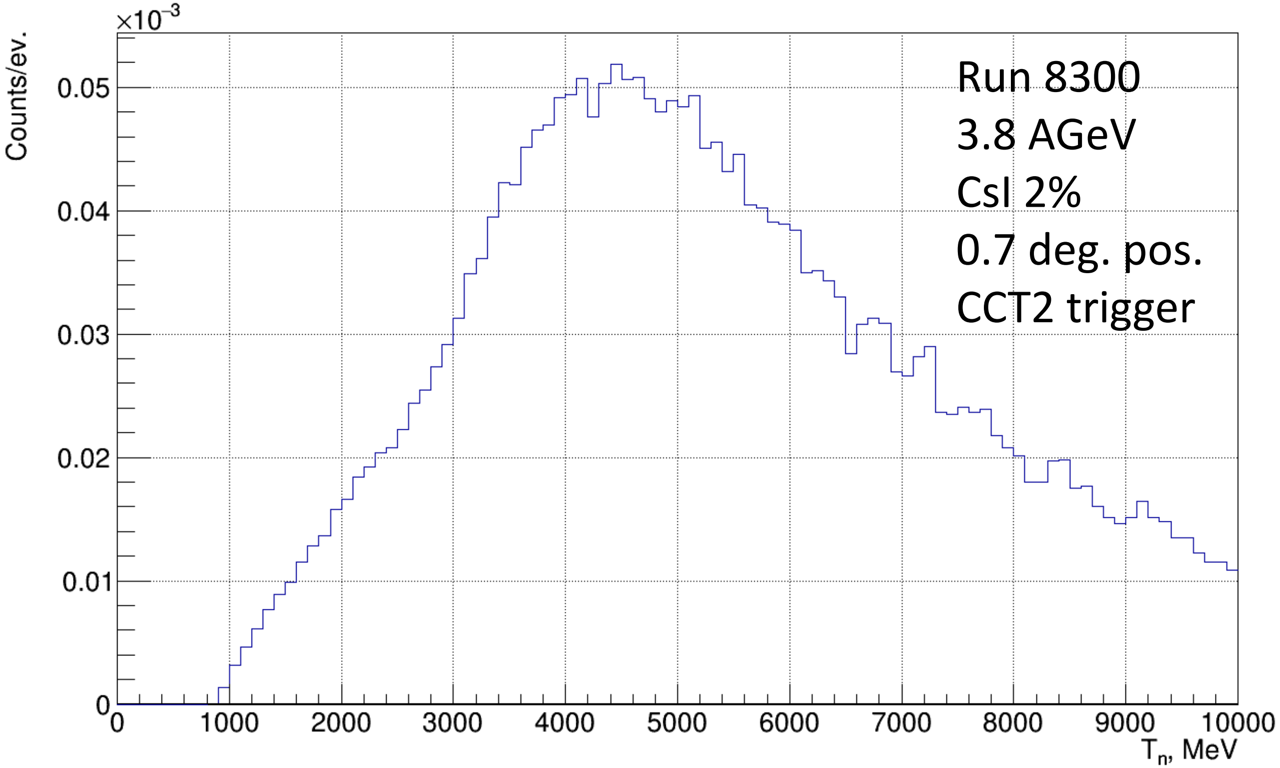
Ultra-peripheral collisions – EMD:

- 1 Xe ion, BC1S + **BT**
- Veto == 0, Ampl > 0.5 MIP, time cut 25-33 ns, >=2 cells in ev.
- Hodo Z^2>2500

Central collisions – Nuclear interaction:

- 1 Xe ion, BC1S + **CCT2**
- Veto == 0, Ampl > 0.5 MIP, time cut 25-33 ns, >=2 cells in ev.





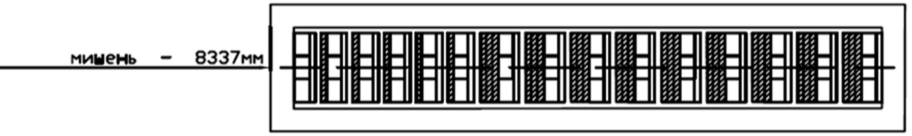
HGND prototype in 0 deg. vs 0.7 deg. positions

Since the beam is deflected near the target by a magnetic field, the HGND prototype position was adjusted from 0 to 0.7 deg.

Позиция - 2 (0 градусов)

(x=0, y=5.2, z=8337)

(Поворот HGN 0 градусов)

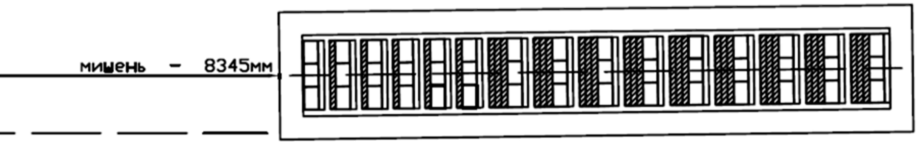


Run	n/ev. (BC1S+CCT2)	n/ions
0 deg.	**36.7%**	**0.29%**
0.7 deg.	**38.7%**	**0.32%**

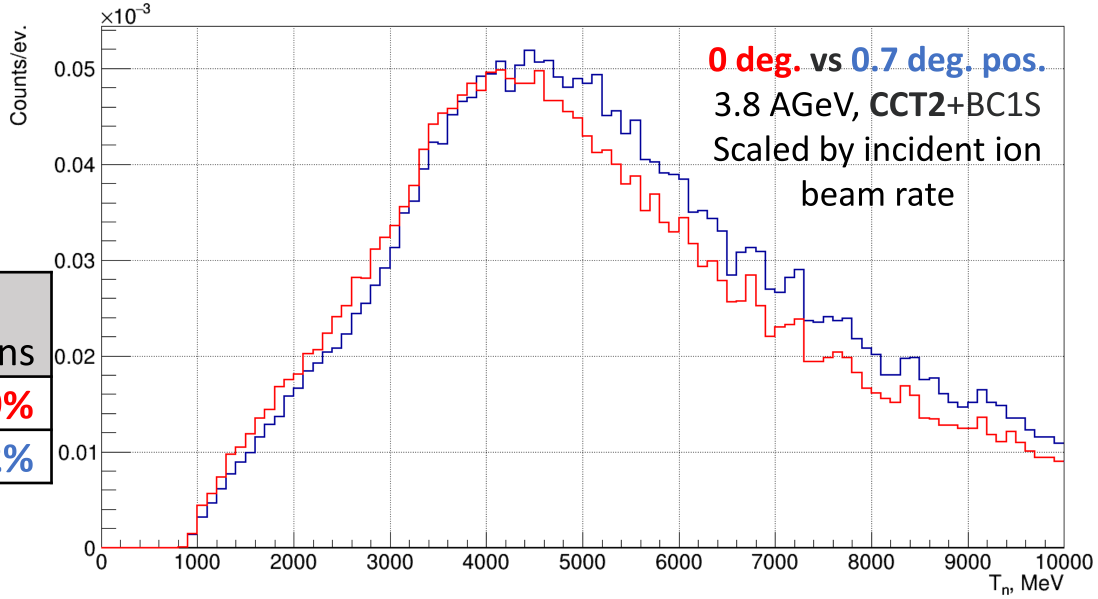
Позиция - 3 (0.7 градусов)

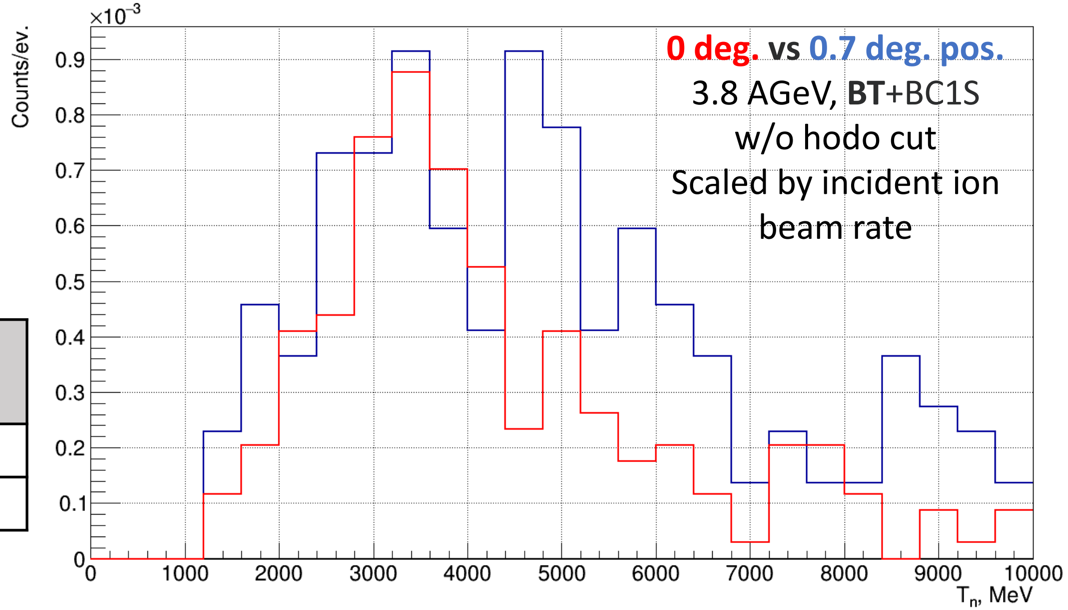
(x=100, y=5.2, z=8345)

(Поворот HGN 0.7 градусов)



Run	n/ev. (BC1S+BT)	n/ions
0 deg.	**1.59%**	**0.68%**
0.7 deg.	**2.35%**	**1.05%**





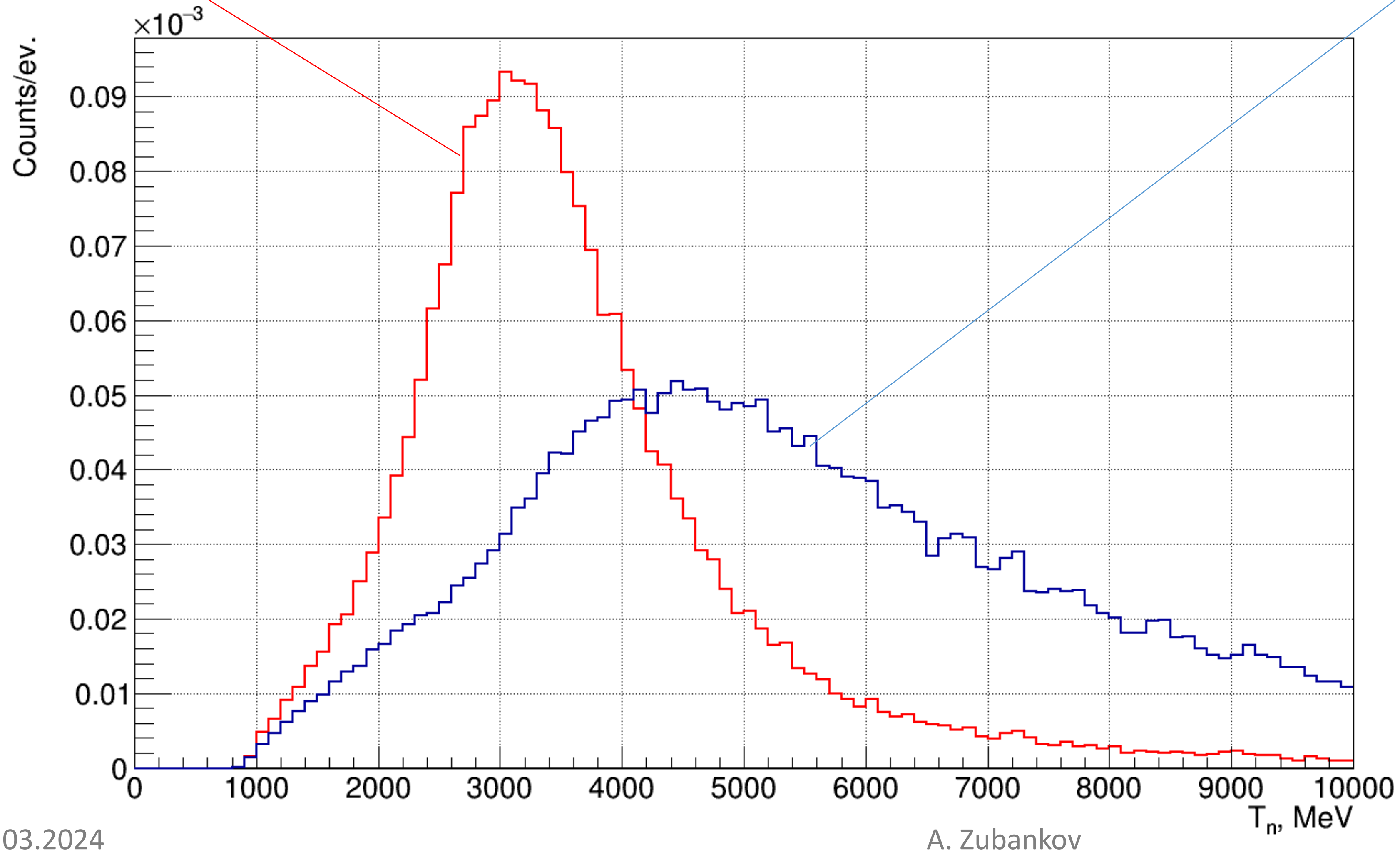
The proportion of detected spectator neutrons has increased

Nuclear interaction in 3.0 vs 3.8 AGeV runs

Run 8320 – **3 AGeV** CsI 2%
Total number of events – 579k
BC1S + CCT2 – 212k
n – 69k
Ions – 15k*2k

3 AGeV vs 3.8 AGeV
0.7 deg., CCT2+BC1S
Scaled by incident ion beam rate

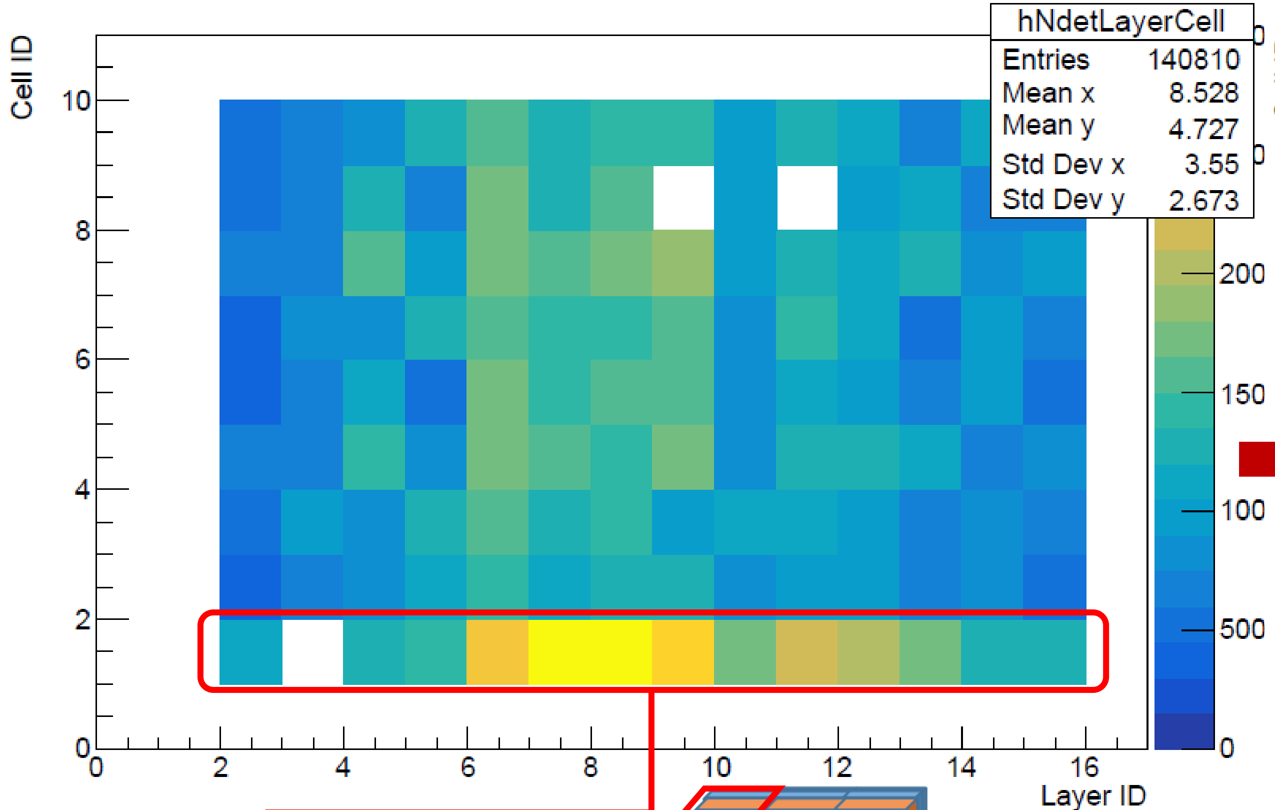
Run 8300 – **3.8 AGeV** CsI 2%
Total number of events – 1kk
BC1S + CCT2 – 364k
n – 141k
Ions – 22k*2k

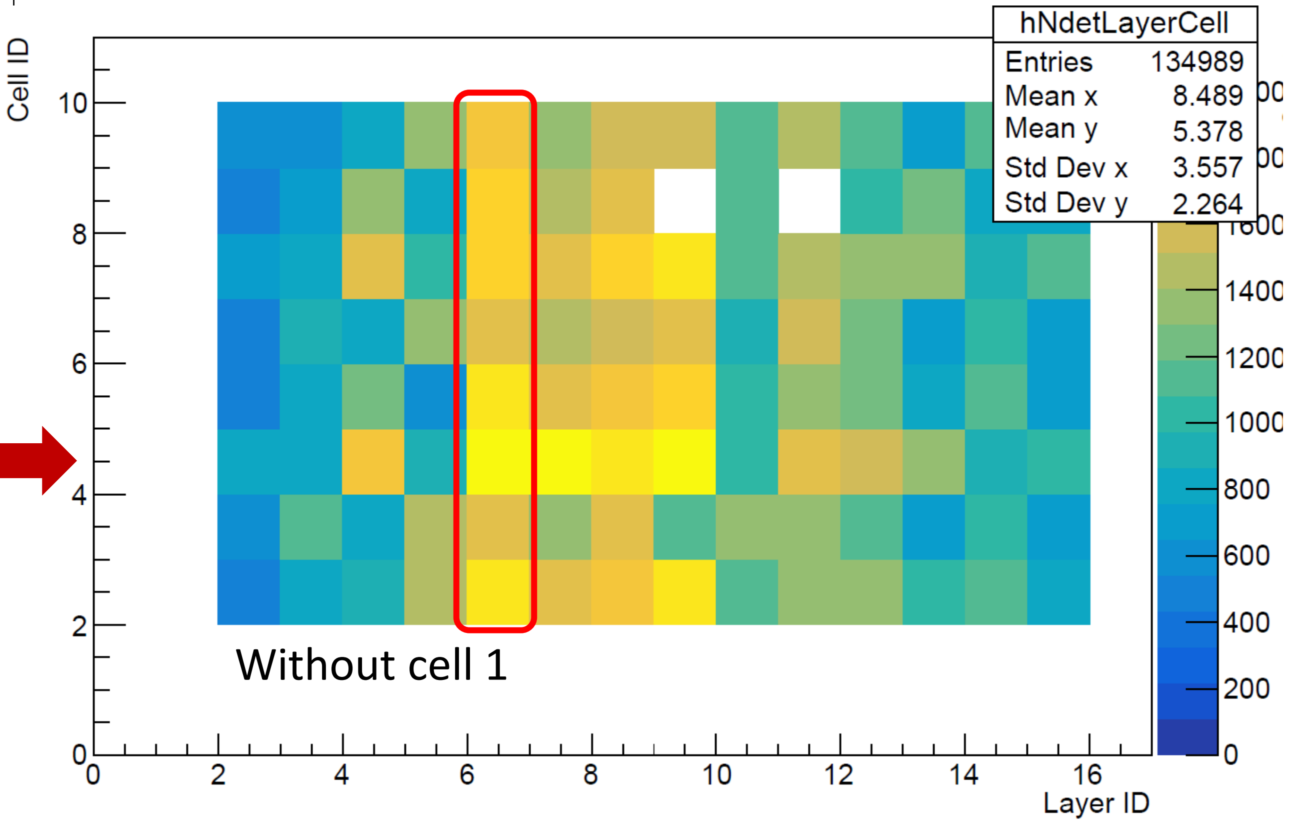


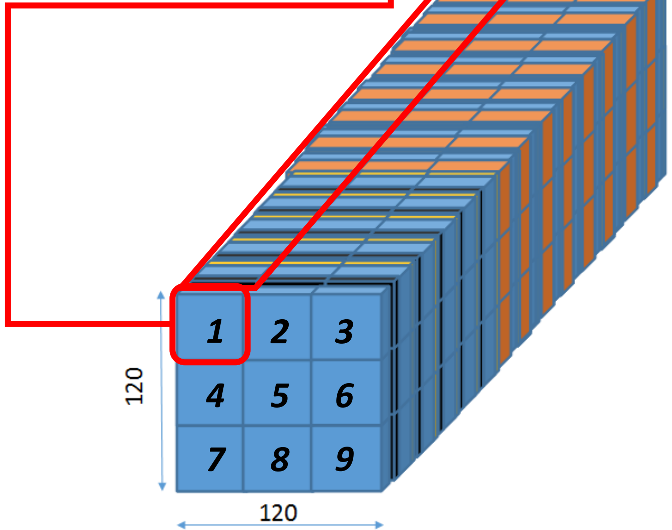
Run	n/ev. (BC1S+CCT2)	n/ions
3 AGeV	**32.5%**	**0.23%**
3.8 AGeV	**38.7%**	**0.32%**

Calibration performed on 3.8 AGeV data gives a peak in correct position for 3 AGeV runs

Fastest cells for Nuclear interaction



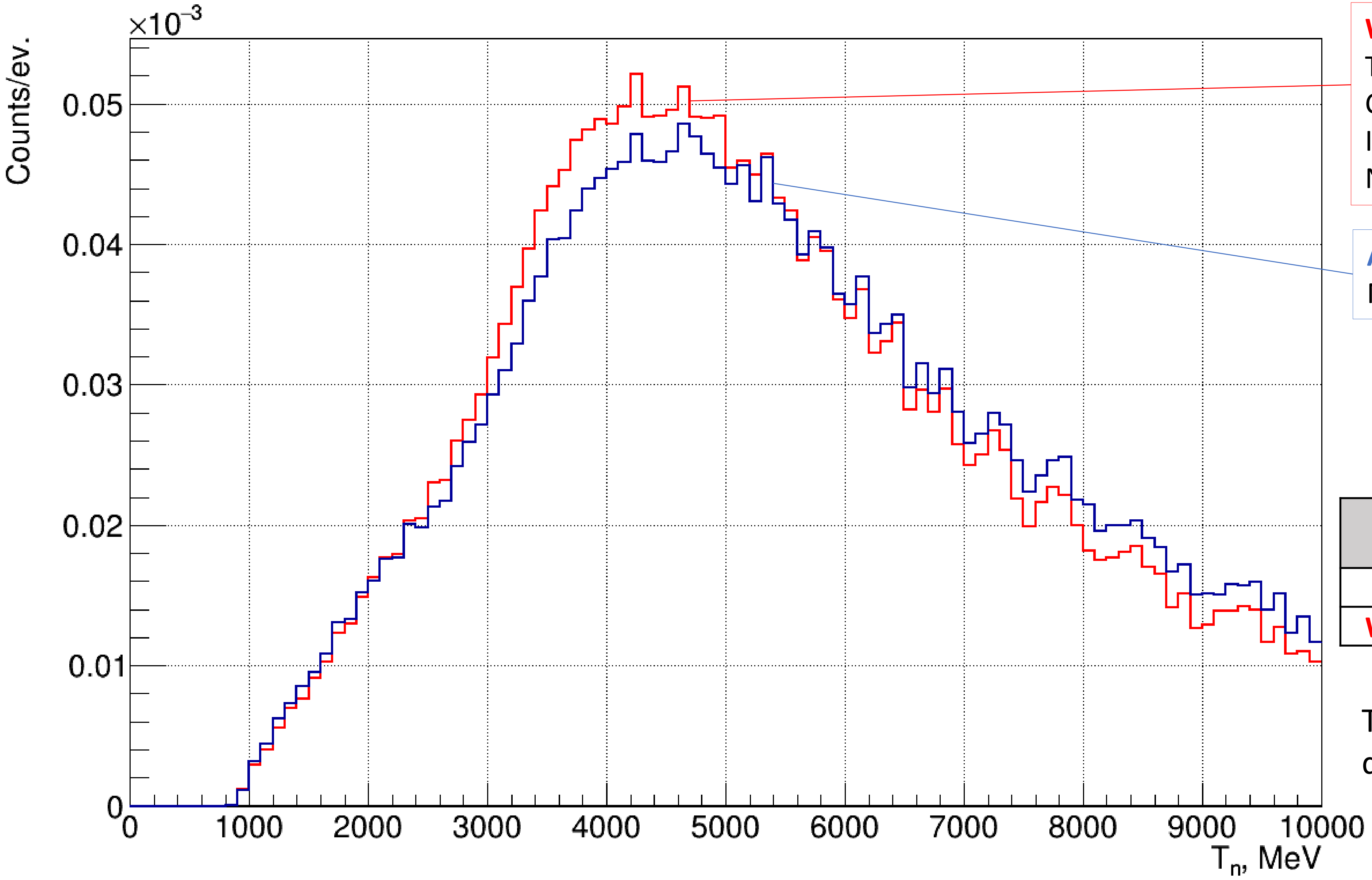




Cell 1 was not considered to get rid of the background

Most of the neutrons are deposited after the 6th layer

Nuclear interaction w/o cell 1



W/o cell 1
Total number of events – 1kk
CCT2 + BC1S – 364k
Ions – 22k*2k
Number of neutrons – 135k

All cells
Number of neutrons – 141k

Run	n/ev.	n/ions
All cells	**38.7%**	**0.32%**
W/o cell 1	**37.0%**	**0.31%**

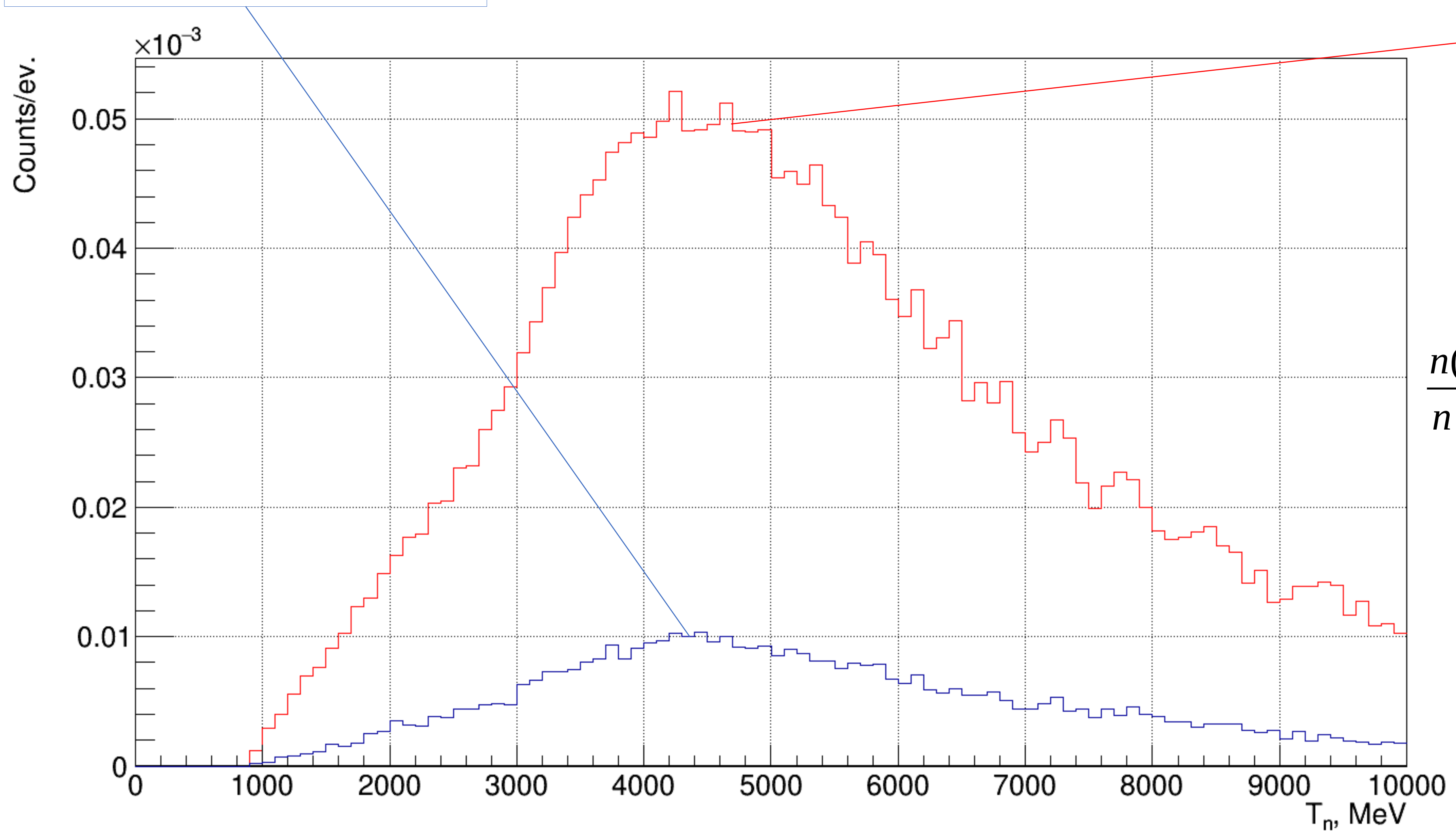
The number of neutrons decreased by <5% after such cut

Empty target vs CsI 2% for nuclear interaction

Total number of events – 304k
CCT2 + BC1S – 75.5k
n – 30.3k
Ions – 26.6k*2k

Empty vs CsI 2%
0.7 deg., 3.8 AGeV, **CCT2**+BC1S
Scaled by incident ion beam rate

Total number of events – 1kk
CCT2 + BC1S – 364k
n – 135k
Ions – 22k*2k

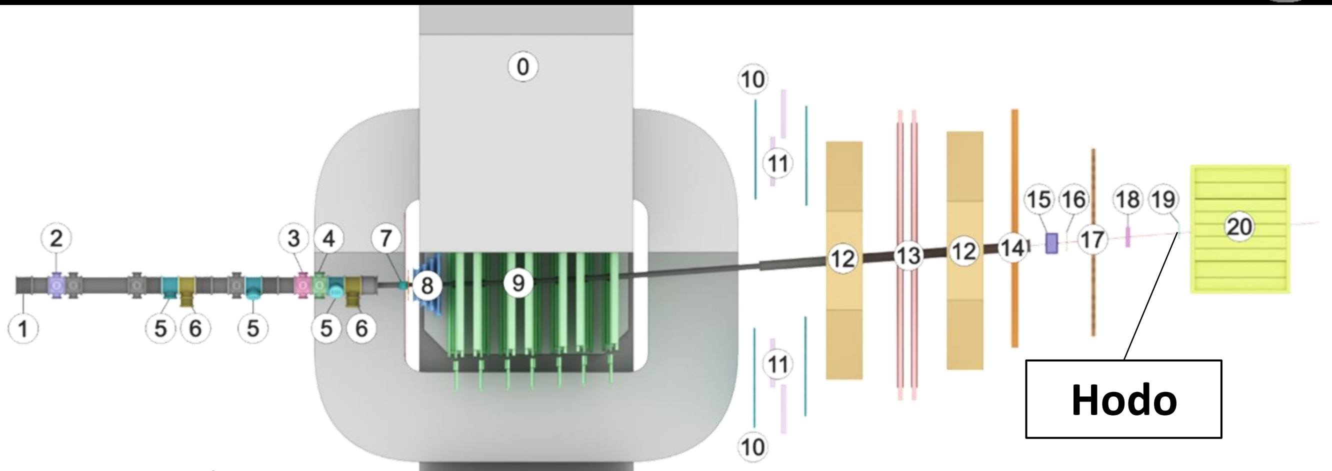


$$\frac{n(CsI\ 2\%)}{n(Empty)} \cdot \frac{i(Empty)}{i(CsI\ 2\%)} = 5.39 \pm 0.05$$

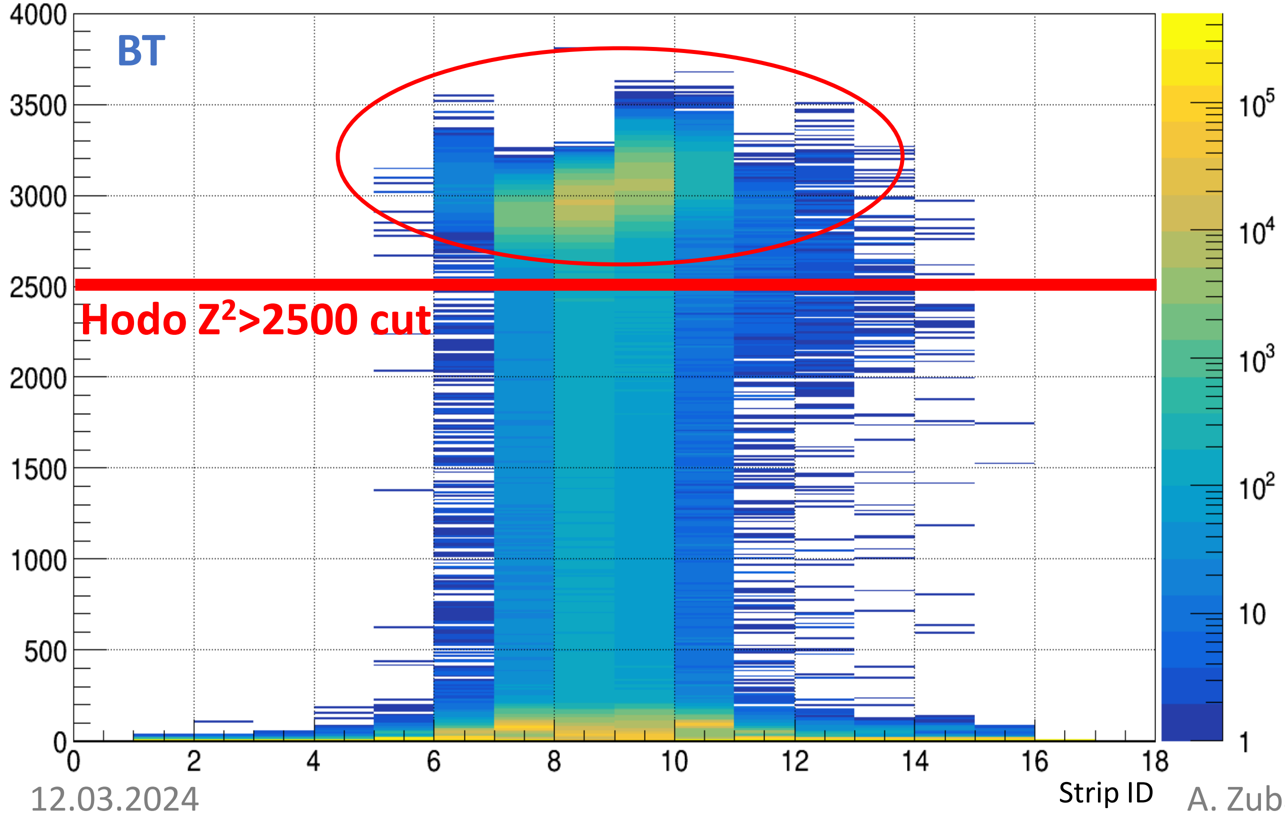
EMD – cut on Hodo

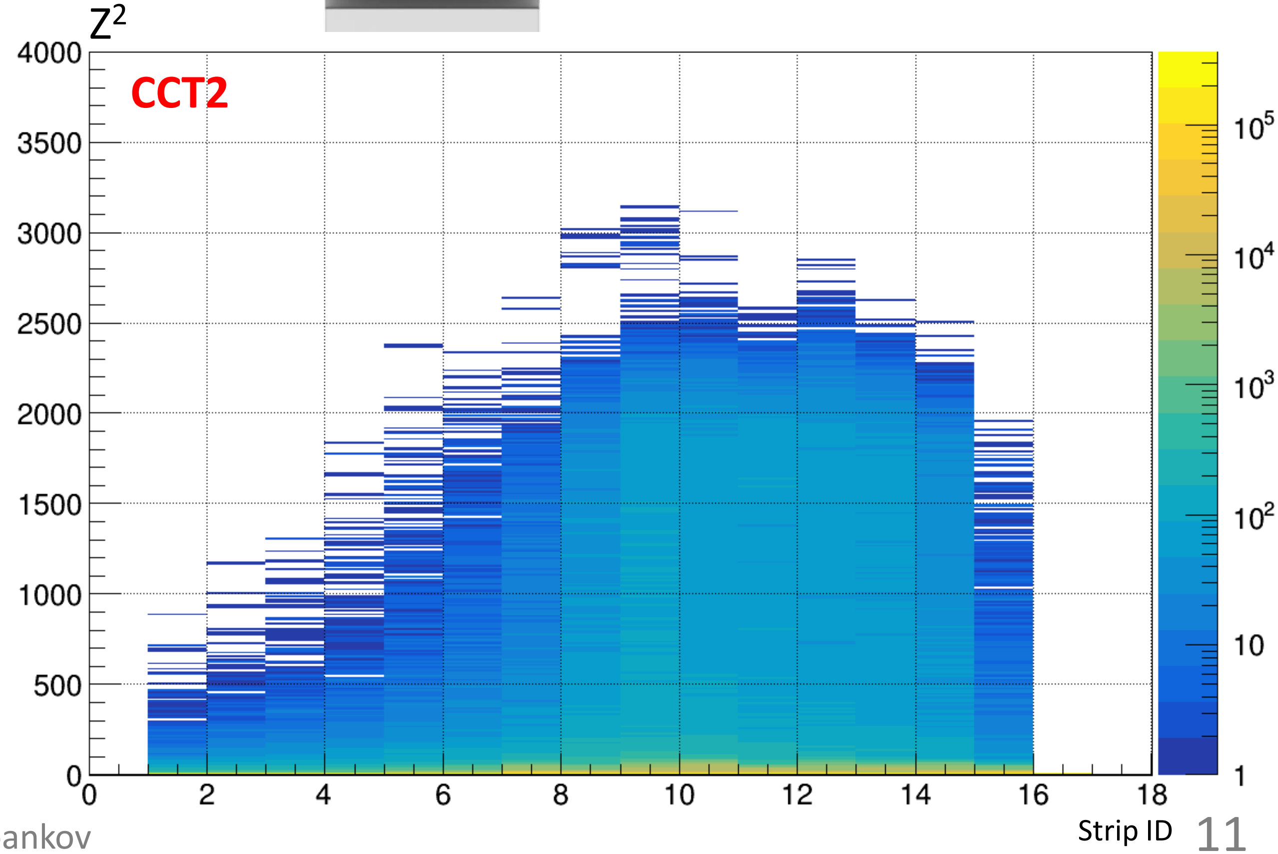
Comparison of nuclear interaction (CCT2) with electromagnetic dissociation (BT) on Hodoscope

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



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



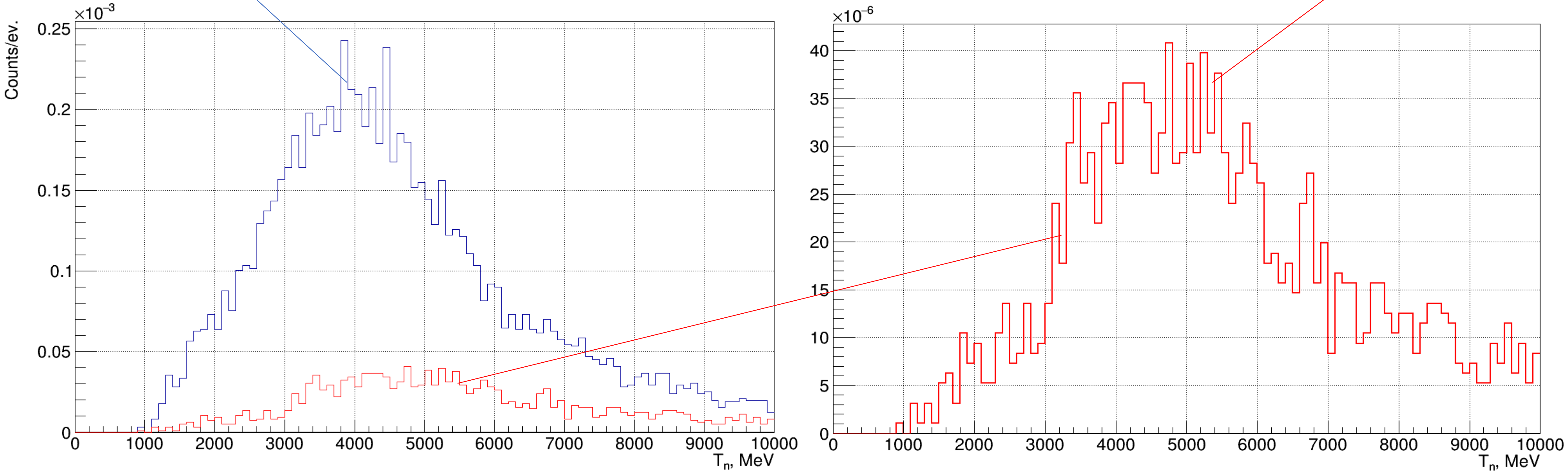


Hodo Z^2>2500 for ultra-peripheral collisions

Total number of events – 994k
BT + BC1S – 496k
n – 8481
Ions – 496k

Hodo Z^2>2500 vs **w/o**
0.7 deg., 3.8 AGeV, **BT**+BC1S
Scaled by incident ion beam rate

Total number of events – 994k
BT + BC1S – 496k
n – 1834
Ions – 496k

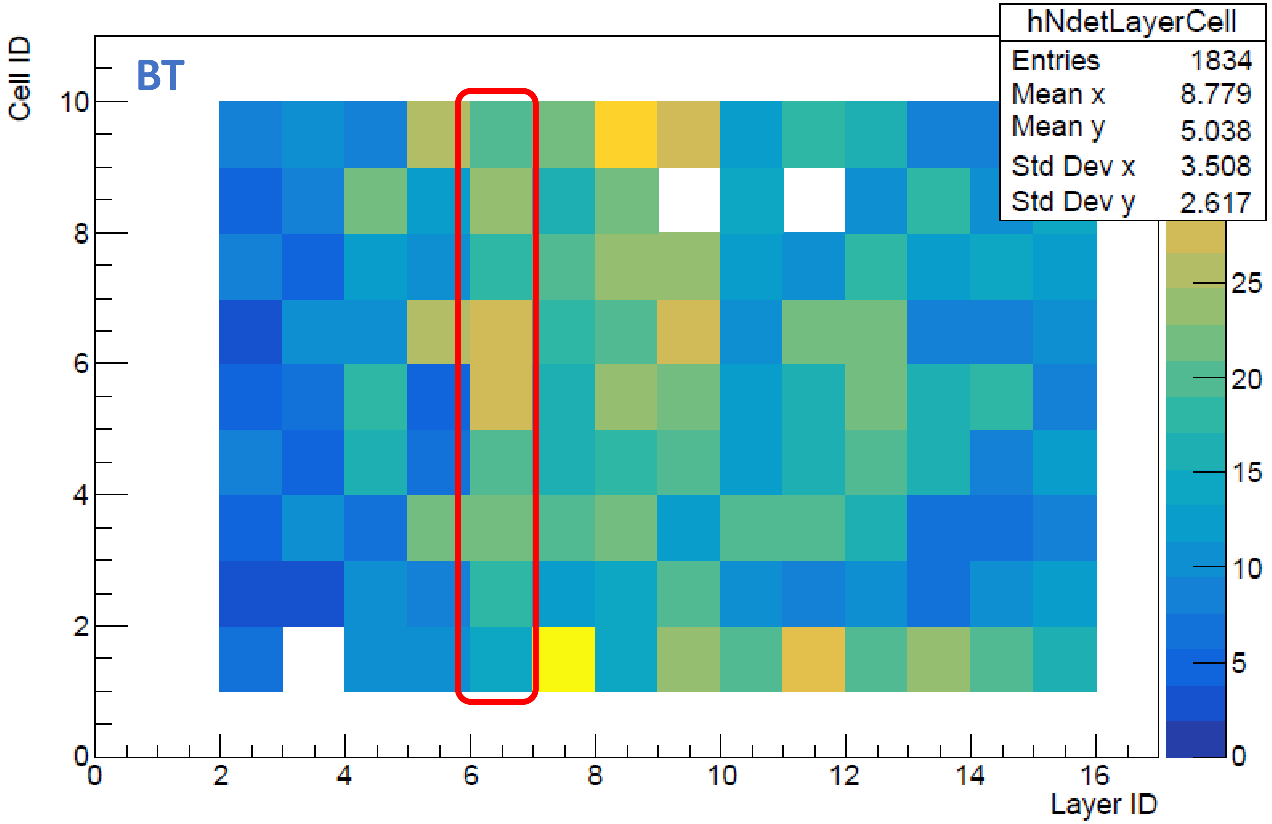


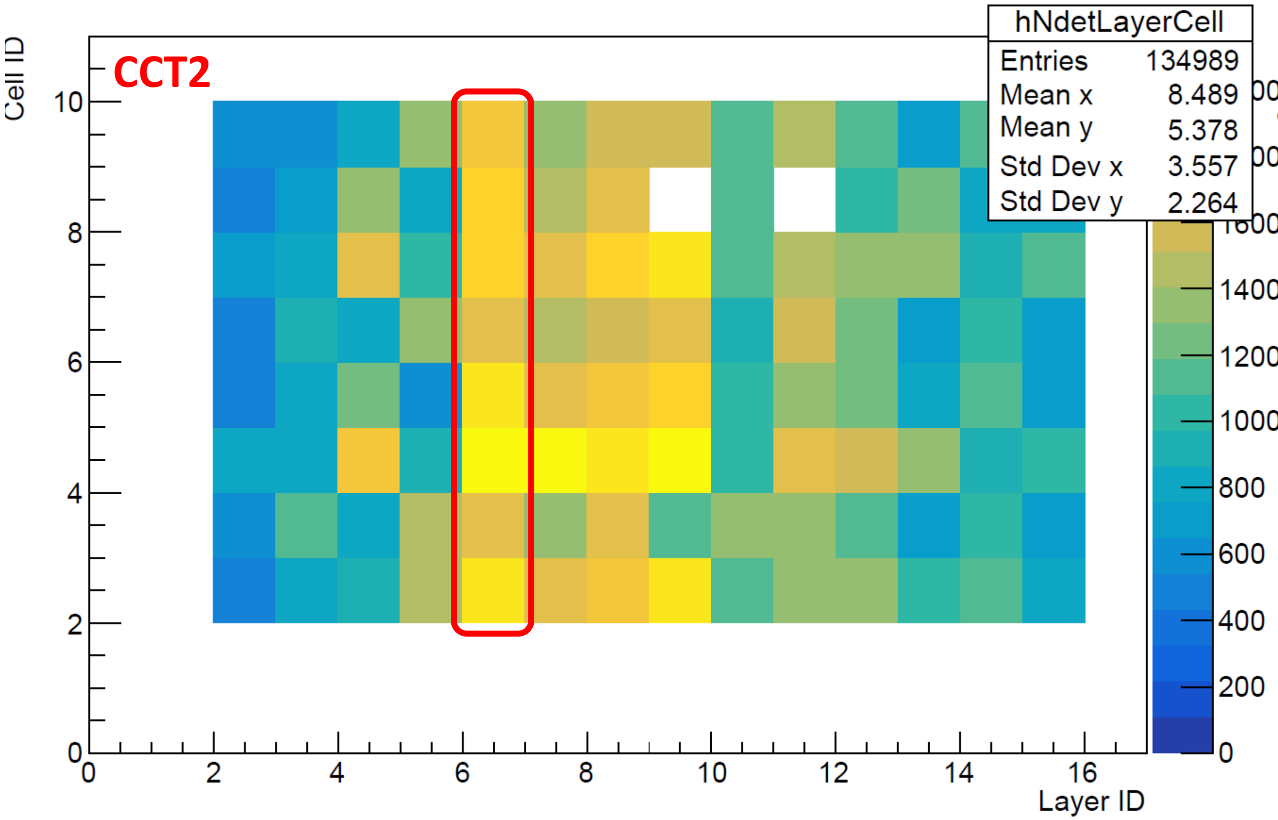
$$\frac{n(cut)}{n\left(w/o\right)} = 0.22 \pm 0.01$$

Fastest cells for EMD vs Nuclear interaction

Comparison of nuclear interaction (CCT2) with electromagnetic dissociation (BT)

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

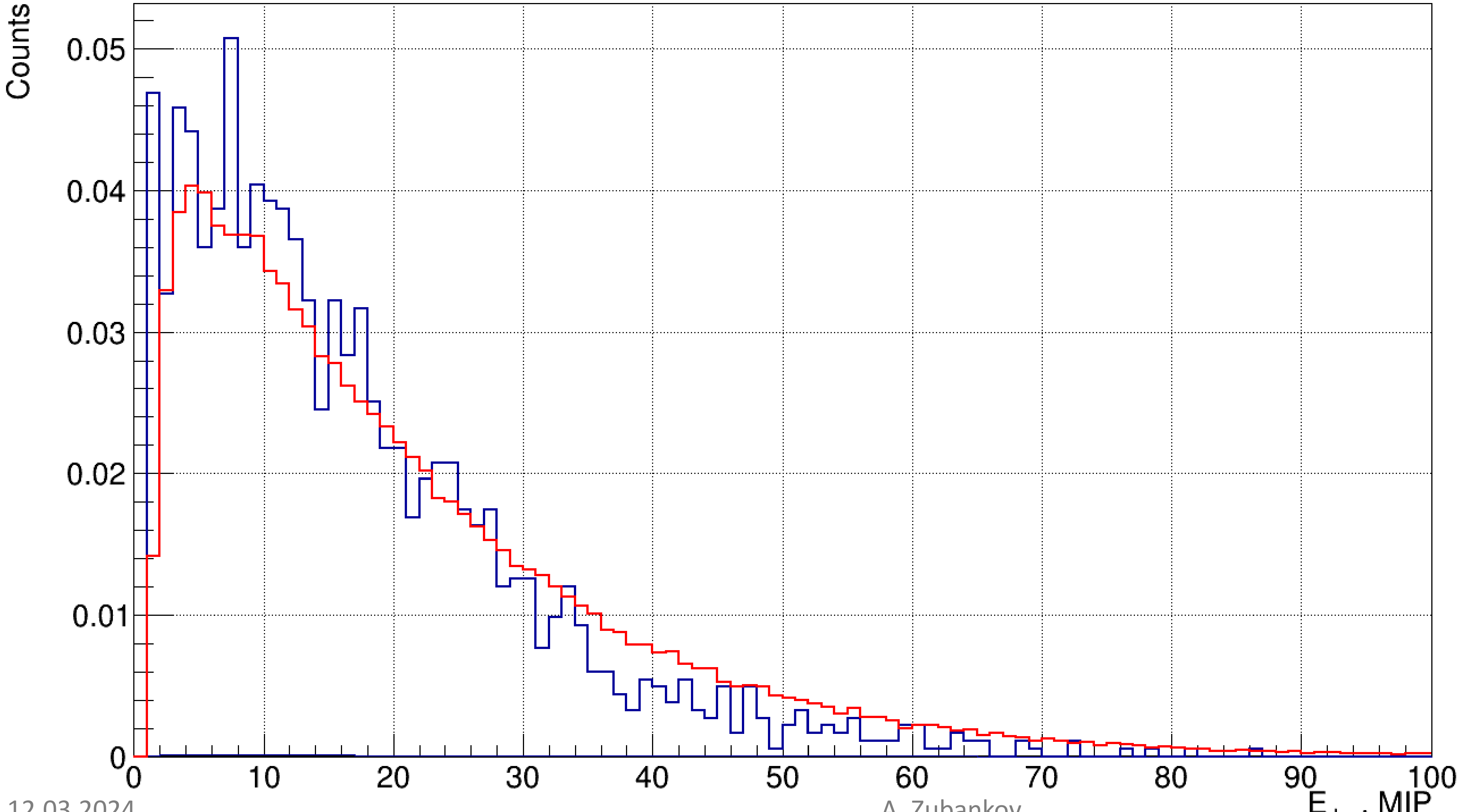




Most of the neutrons are deposited after the 6th layer
for both EMD and nuclear interaction

Deposited energy for EMD vs Nuclear interaction

Comparison of nuclear interaction (CCT2) with
electromagnetic dissociation (BT)
Run 8281 (BT) vs 8300 (CCT2) 3.8 AGeV



Deposited energy looks similar for EMD and nuclear interaction

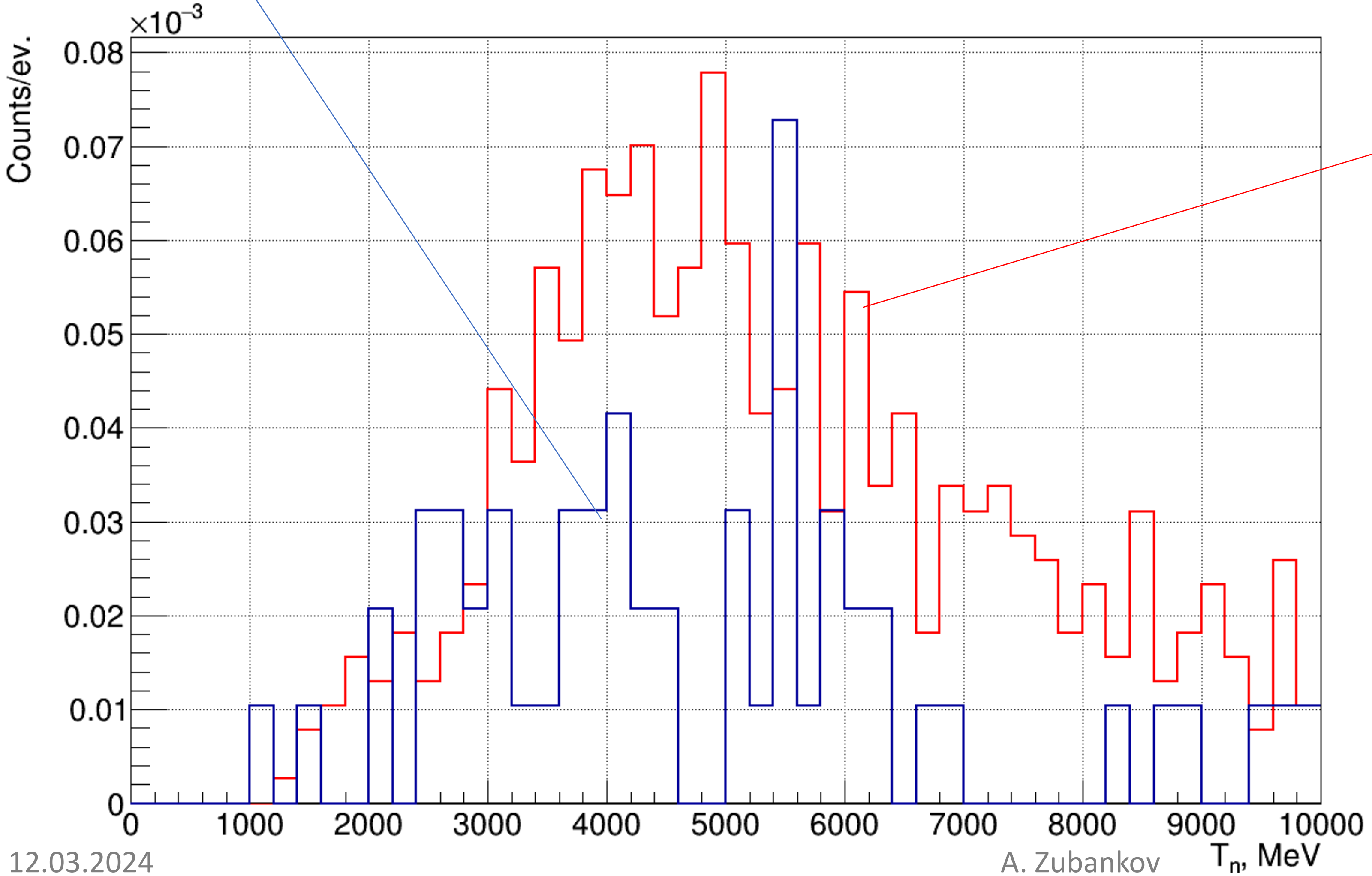
In both cases neutrons are observed

Empty target vs CsI 2% for EMD

Empty
Total number of events – 100k
BT + BC1S – 62k
n – 70
Ions – 96k

Runs 8284 CsI 2% vs 8283 Empty
0.7 deg., 3.8 AGeV, **BT**+BC1S
Scaled by incident ion beam rate
BT trigger, beam pos.: x=-12.4 mm y=-12.2 mm

CsI 2%
Total number of events – 399k
BT + BC1S – 194k
n – 681
Ions – 385k



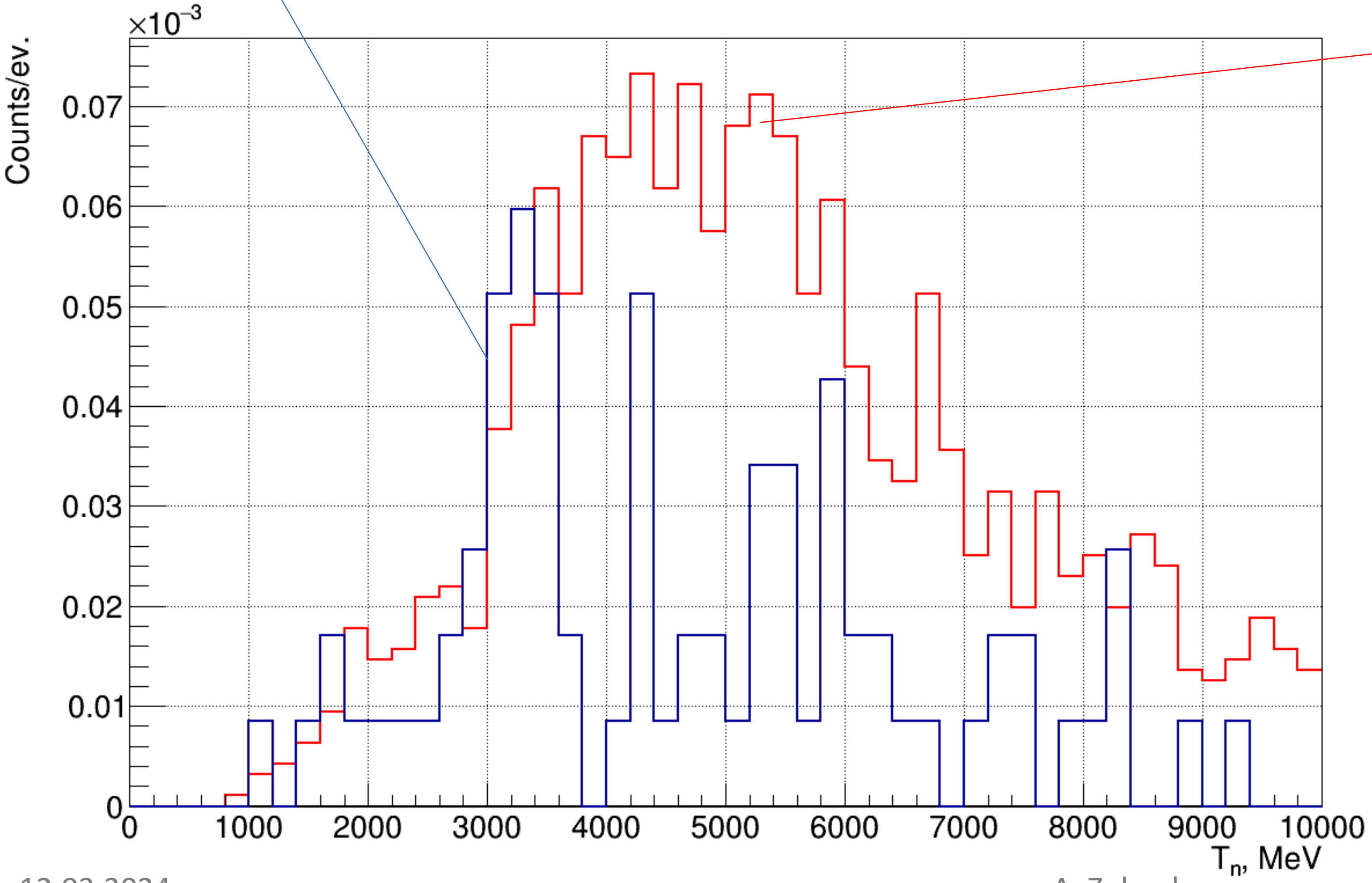
$$\frac{n(CsI\ 2\%)}{n(Empty)} \cdot \frac{i(Empty)}{i(CsI\ 2\%)} = 2.43 \pm 0.40$$

Empty target vs CsI 2% for EMD

Empty
Total number of events – 121k
BT + BC1S –74k
n – 86
Ions – 117k

Runs 8281 CsI 2% vs 8282 Empty
0.7 deg., 3.8 AGeV, **BT**+BC1S
Scaled by incident ion beam rate
BT trigger, beam pos.: x=-7 mm y=-14 mm

CsI 2%
Total number of events – 994k
BT + BC1S – 496k
n – 1834
Ions – 956k



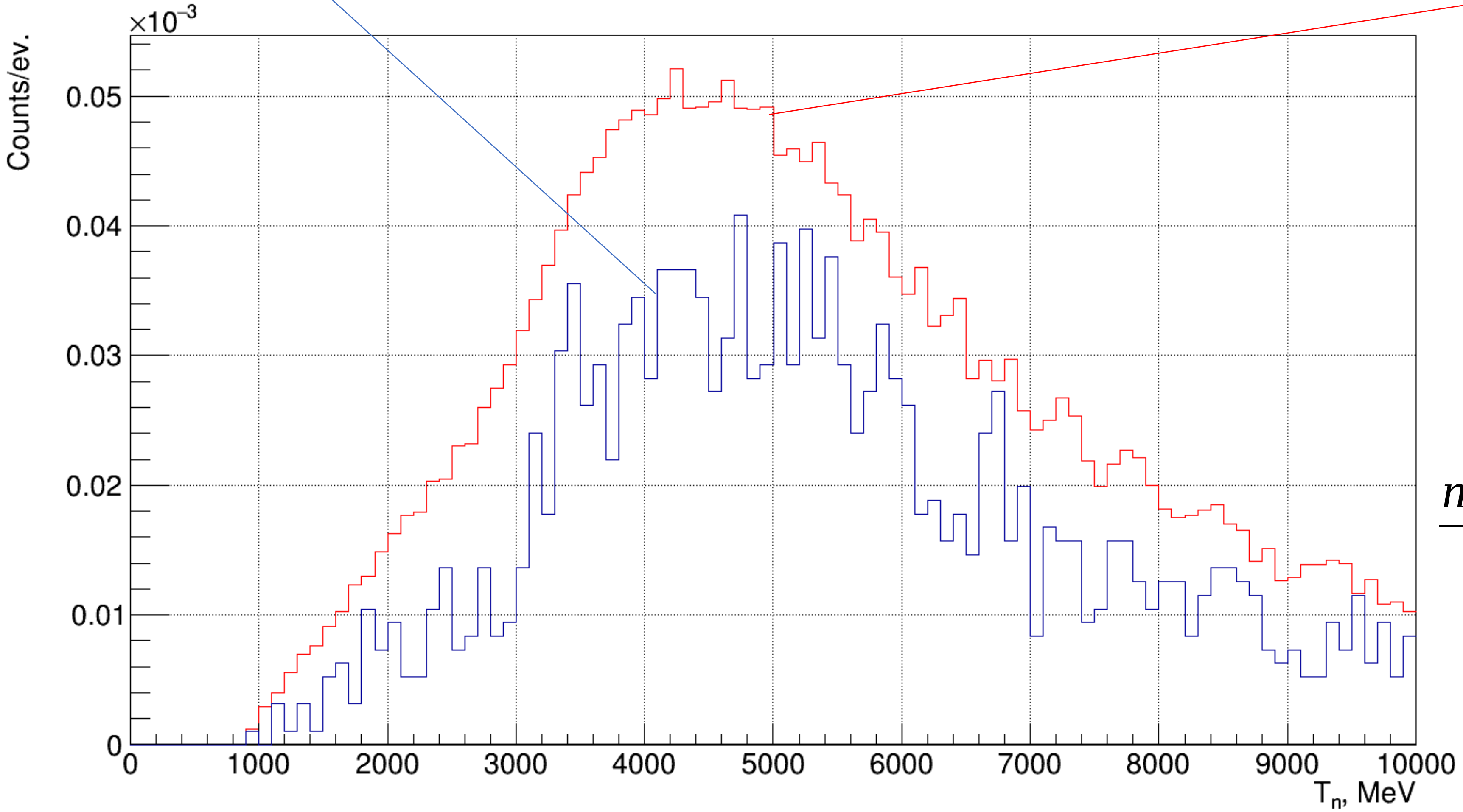
$$\frac{n(CsI\ 2\%)}{n(Empty)}\cdot\frac{i(Empty)}{i(CsI\ 2\%)} = 2.61\pm0.35$$

EMD vs Nuclear interaction

Total number of events – 994k
BT + BC1S – 496k
n – 1834
Ions – 956k

Comparison of nuclear interaction (CCT2)
with electromagnetic dissociation (BT)
Run 8284 (BT) vs 8300 (CCT2)
0.7 deg., 3.8 AGeV
Scaled by incident ion beam rate

Total number of events – 1kk
CCT2 + BC1S – 364k
n – 135k
Ions – 22k*2k



Run	n/ev.	n/ions
BT	**0.37%**	**0.19%**
CCT2	**37.0%**	**0.31%**

$$\frac{n(CCT2)}{n(BT)}\cdot\frac{i(BT)}{i(CCT2)} = 1.60\pm0.04$$

Conclusions

- Calibration performed on 3.8 AGeV data gives a peak in correct position for 3 AGeV runs
- The neutron response is the same for both nuclear interaction and EMD
- Nuclear interaction produces 1.6 times more neutrons per ion than EMD in the HGND prototype at 0.7 deg. position
- Neutron yields from a nuclear interaction with a target are 5.4 times greater than without a target
- Neutron yields from EMD with a target are 2.5 times greater than without a target

Thank you for your attention!