Using the clustering method to analyze multi-neutrons events

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Analysis and Detector Meeting of the BM@N Experiment at NICA
5 march 2025 г

Parameters of simulation and data analysis

Simulation:

- BOX generator
- Only neutrons with energies of 500, 1000, 2000, 4000 MeV
- 300k events
- HGNd 11x11 cells, 16 layers with copper absorber

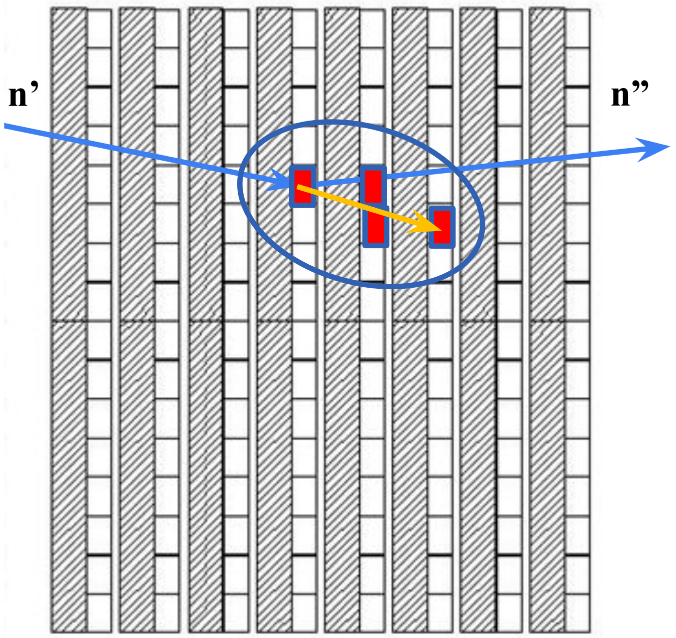
Minimum conditions for event selection:

- 2 triggered cells in the event with Edep > 3 MeV
- Number of cells in the cluster Nc > 1

$\lambda = 1$

eff(1)~exp(-x/Λ)~63%

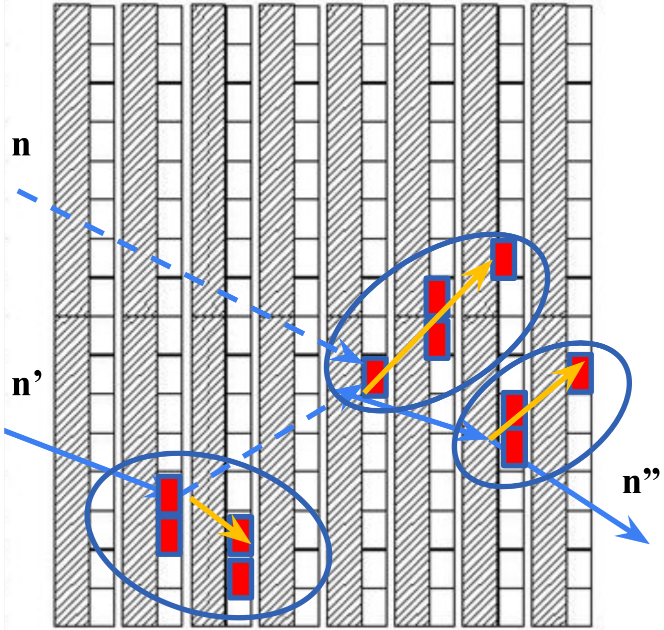
$N_{claster}/N_n$~Λ*exp(-x/Λ)~**0.63**



$\lambda = 3$

eff~exp(-x/Λ)~95%

$N_{claster}/N_n$~Λ*eff(1)~0.63*3~**2**

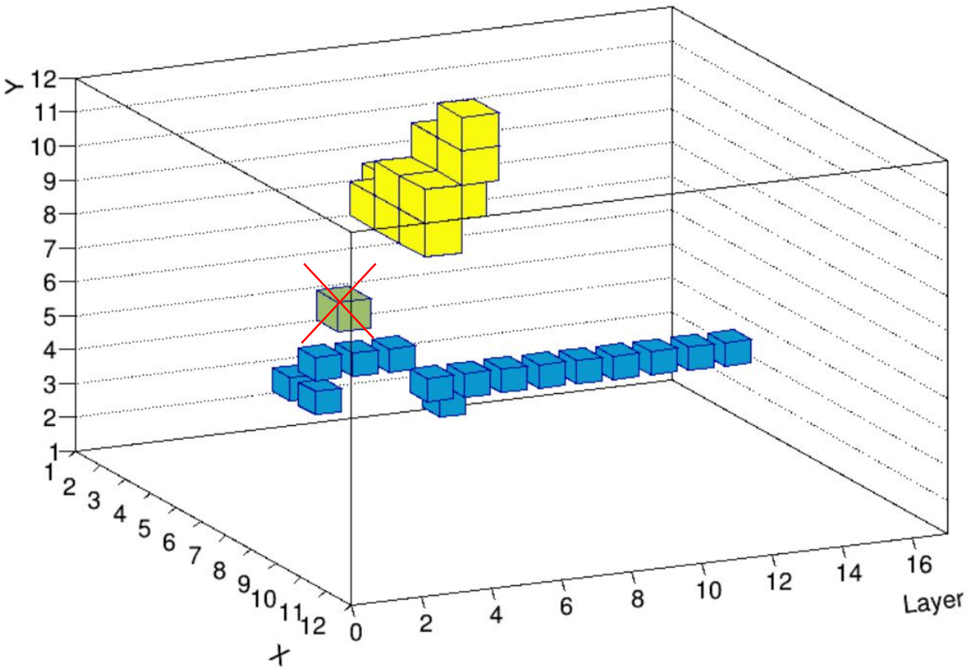


Clusterization

Depth first search algorithm (DFS).
All related cells are determined and clusters are formed

Example of cluster formation in two-neutron event

The clusters are separated by color

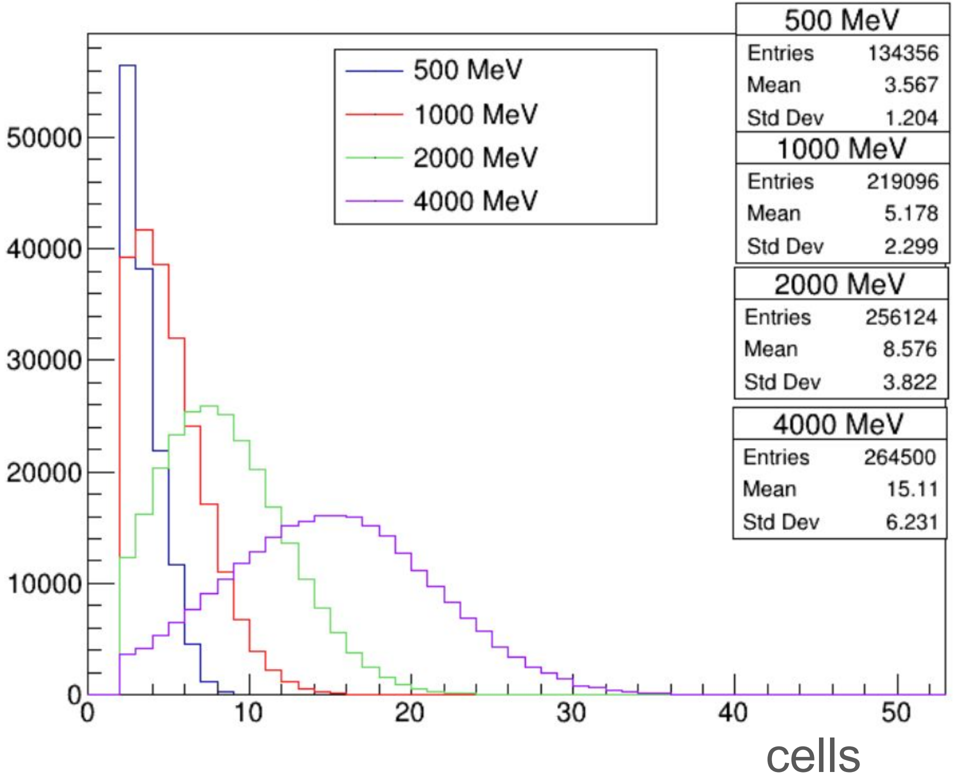


Efficiency HGNd for Nc > 1

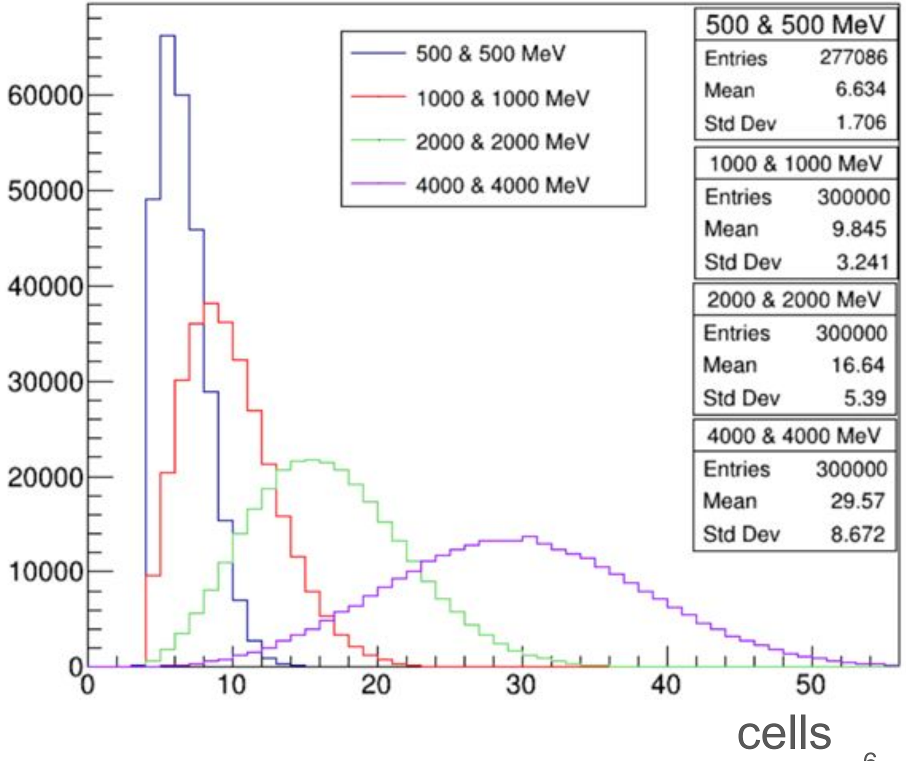
1n		
Energy, MeV	Ecells > 3 MeV, Ncells > 1 in **event**	Ecells > 3 MeV, Ncells > 1 in **cluster**
500	45 %	34 %
1000	73 %	64 %
2000	85 %	82 %
4000	88 %	88 %

Number of cells in event

1 neutron

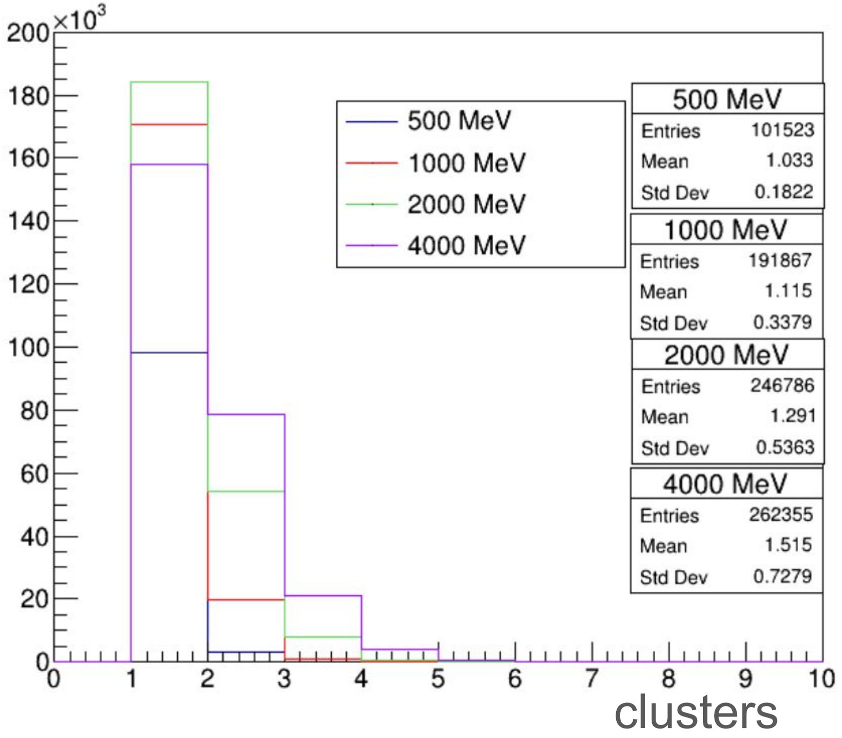


2 neutrons

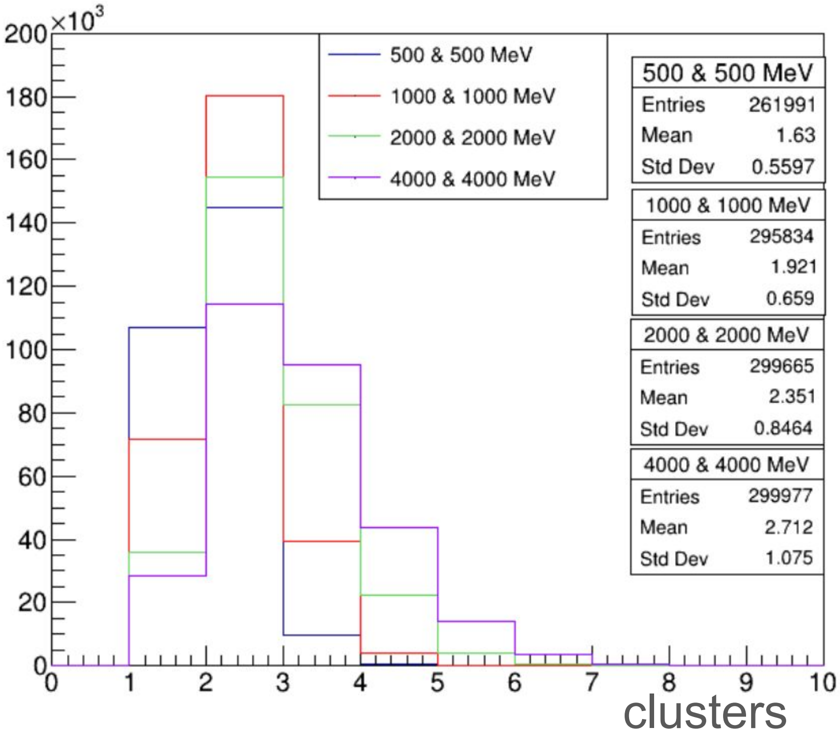


Number of clusters

1 neutron

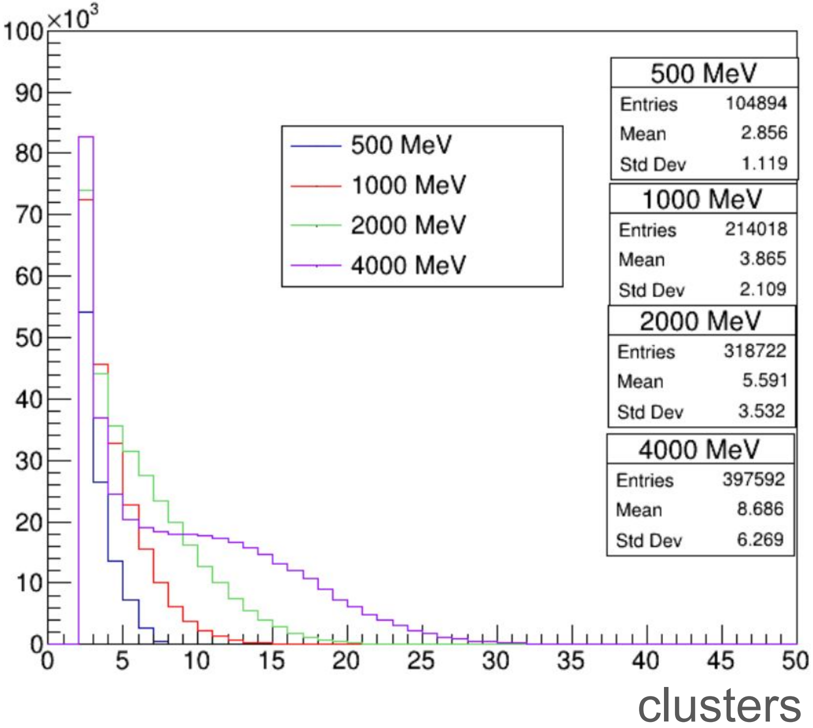


2 neutrons

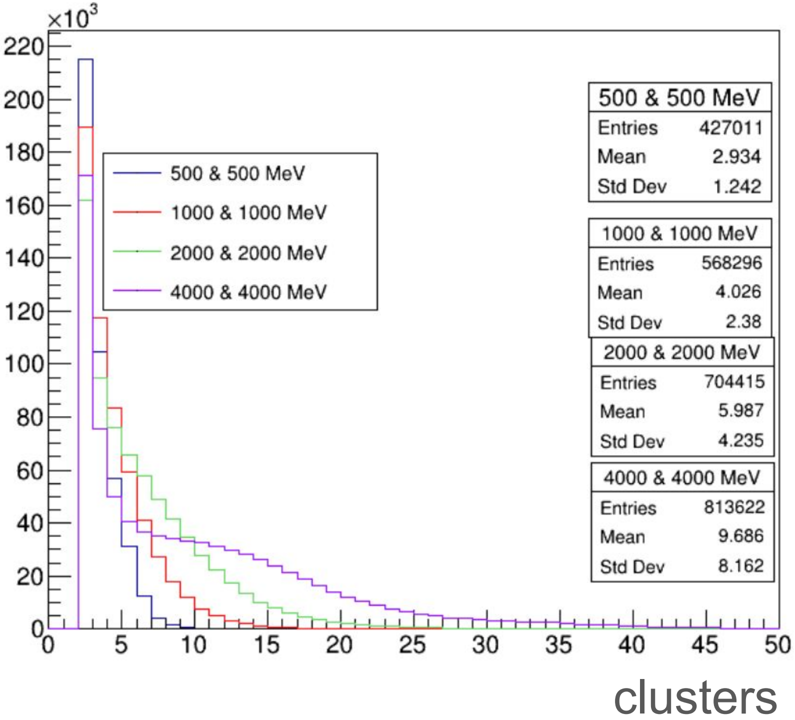


Number of cells in the cluster

1 neutron

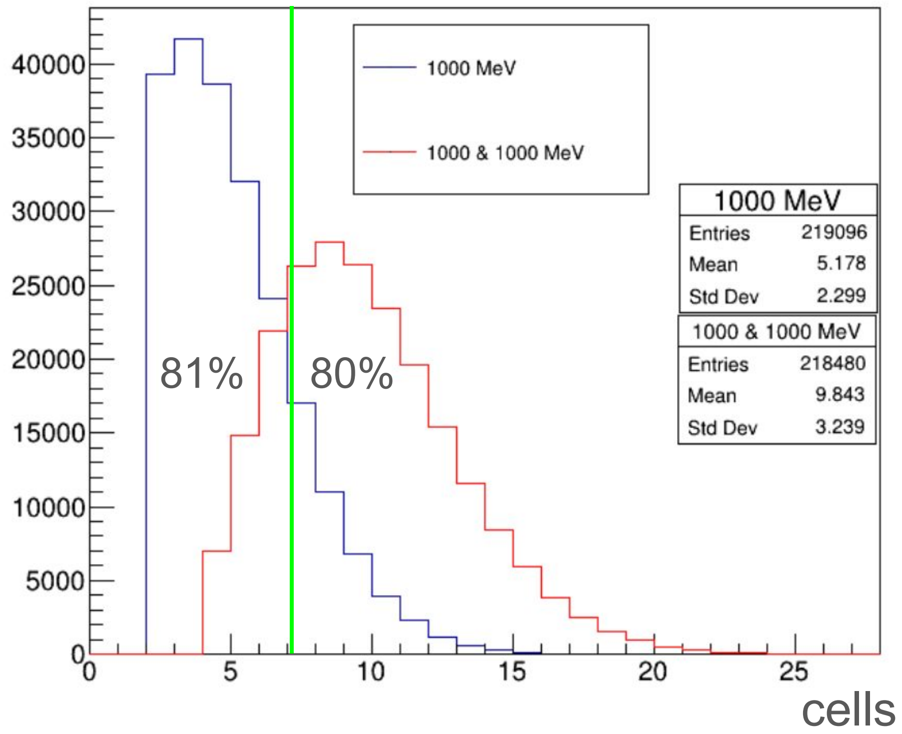


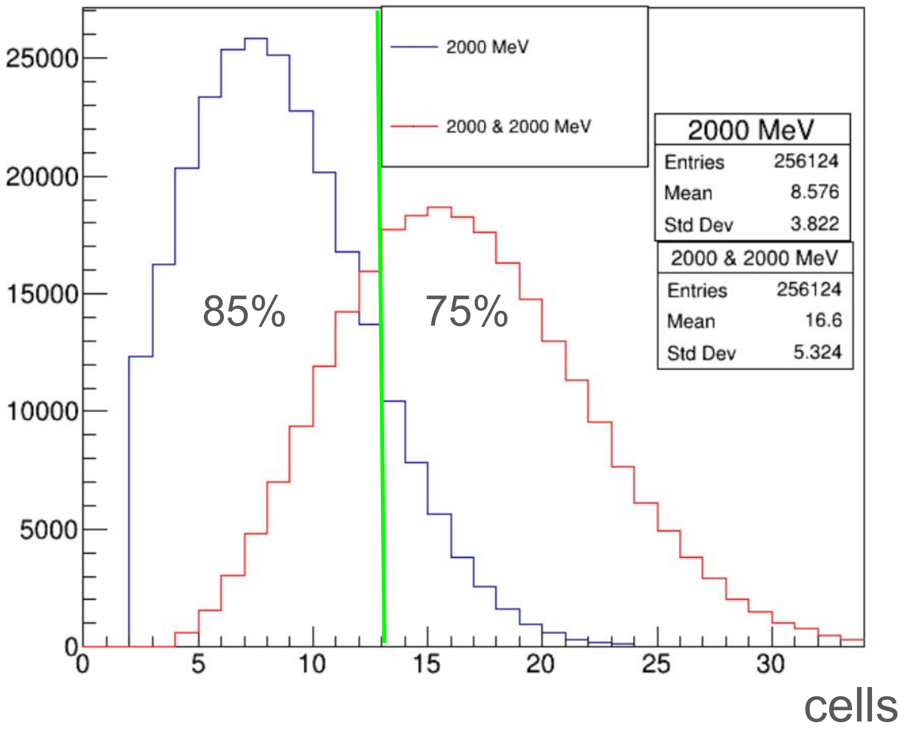
2 neutrons



The average value number of cells in cluster for 2 neutrons increases slightly, therefore, the clusters practically do not overlap.
The increase ranges from 3% to 10% (0.5 GeV) до 10% (4 GeV)

Number of cells in event



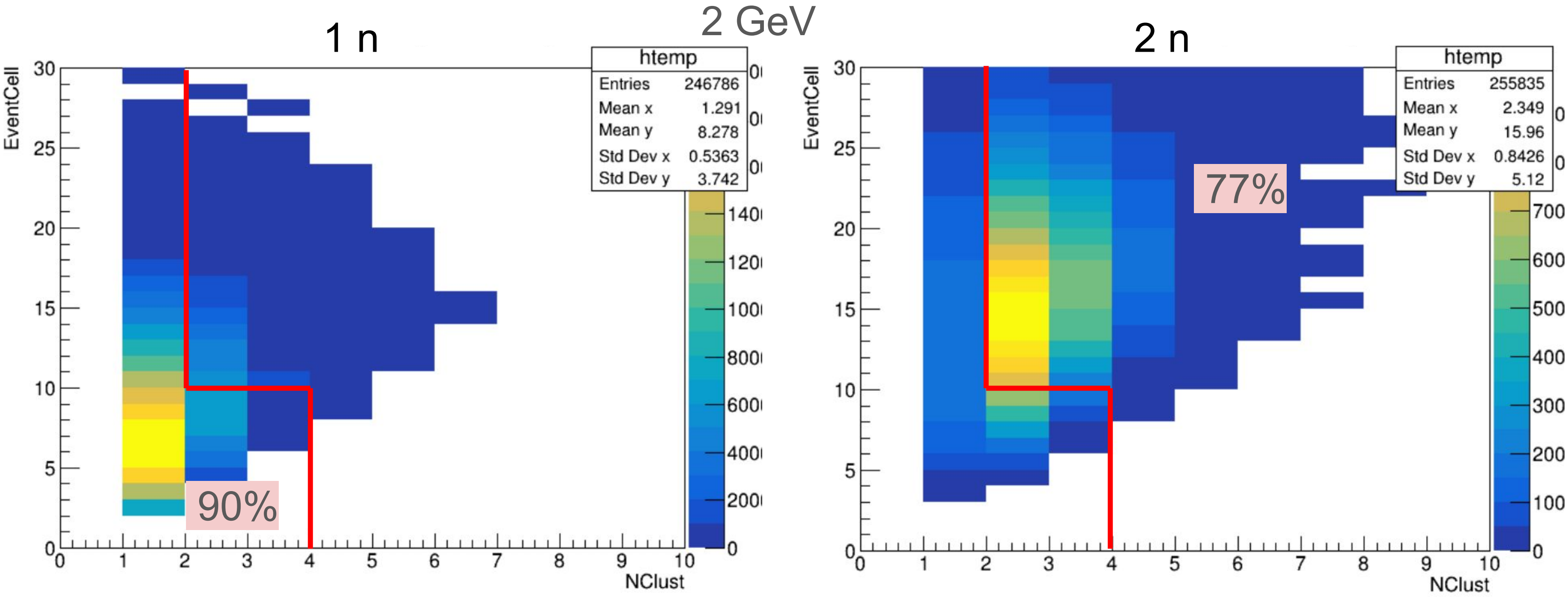


Average number of cells in event

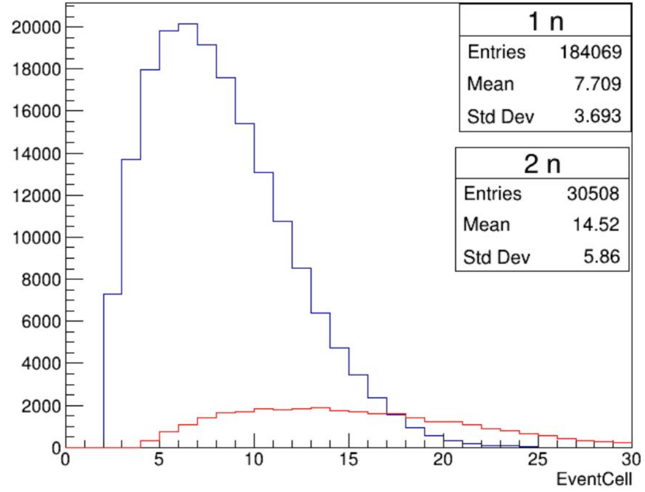
1n		
Energy		rms
500	3.07	1.2
1000	4.68	2.3
2000	8.08	3.82
4000	14.61	6.23

2n		
Energy		rms
500 & 500	6.13	1.71
1000 & 1000	9.35	3.24
2000 & 2000	16.14	5.39
4000 & 4000	29.13	8.75

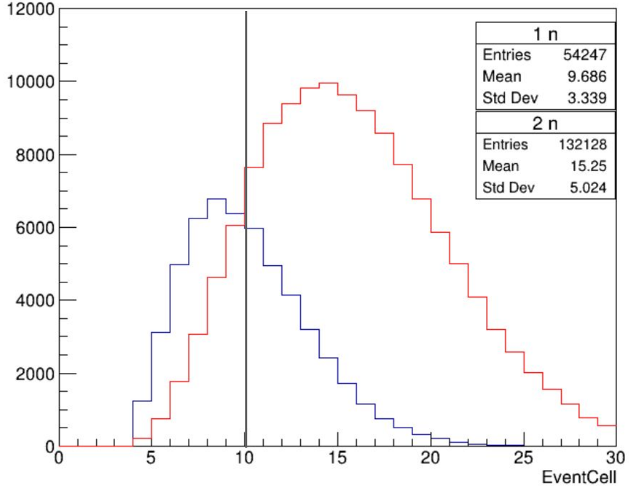
Number of cells in event VS number of clusters



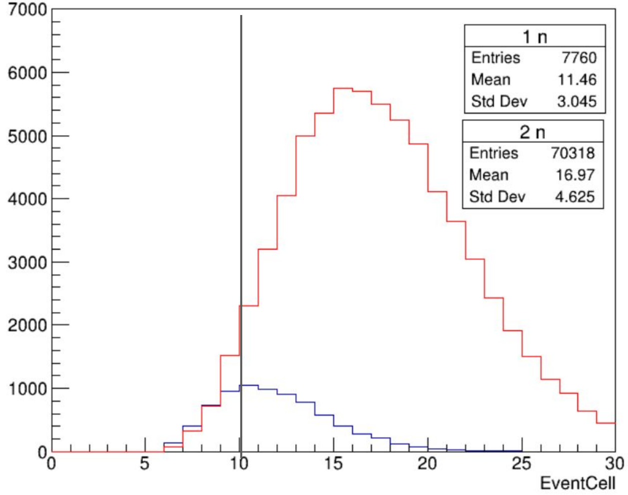
The contribution from 2n to 1n is 4.6%, because 2n is about 20% of 1n.
The contribution of 1n to 2n is 43%.



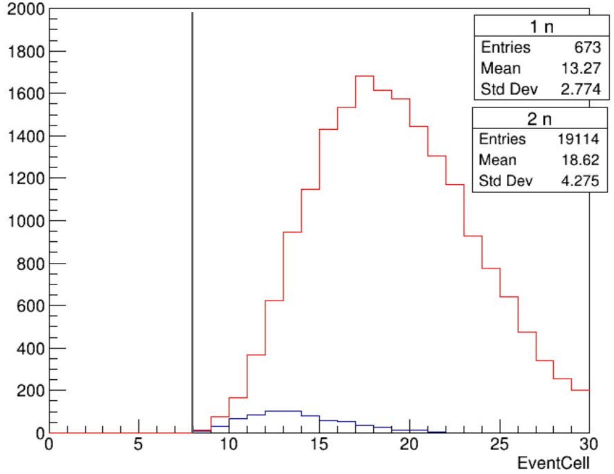
1cluster



2clusters



3clusters



4clusters

Average number of clusters in event

1n		
Energy	N clusters	rms
500	1.03	0.18
1000	1.12	0.34
2000	1.29	0.54
4000	1.52	0.73

2n		
Energy	N clusters	rms
500 & 500	1.63	0.56
1000 & 1000	1.92	0.66
2000 & 2000	2.35	0.85
4000 & 4000	2.71	1.08

Merging clusters

Light cone check

Algorithm:

1. Cluster number, speed(V_{fast}) and time (T_{fast}) of fastest cell in the event are stored
2. Find the cell with minimum time (T_i) in each cluster
3. Check possibility of correlation between clusters

   The cells from (1) and (2) are analyzed

   $dist = sqrt((X_i-X_{fast})^2 + (Y_i-Y_{fast})^2 + (Z_i-Z_{fast})^2)$

   $dt = T_{fast} - T_i$

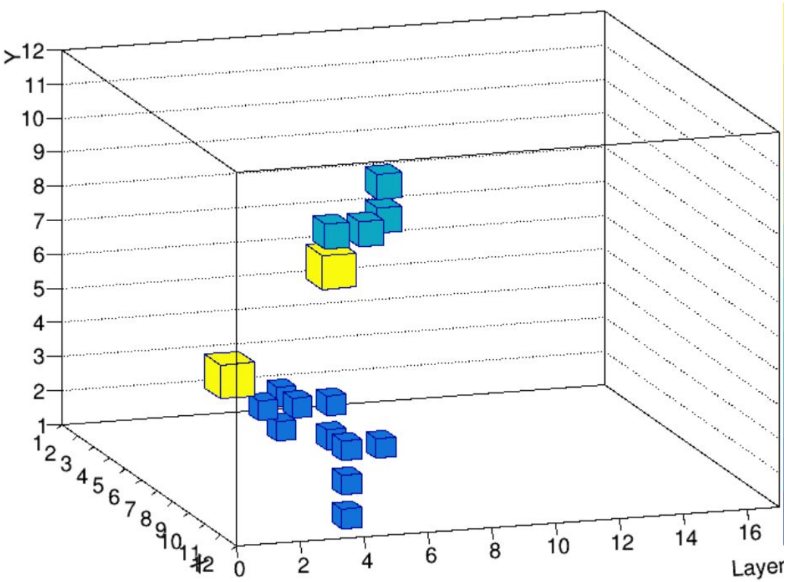
   Condition for merging clusters

$$\mathbf{(dist / V_{fast}) = dt \pm \Delta t}$$

where **Δt** - error in determining time and coordinates

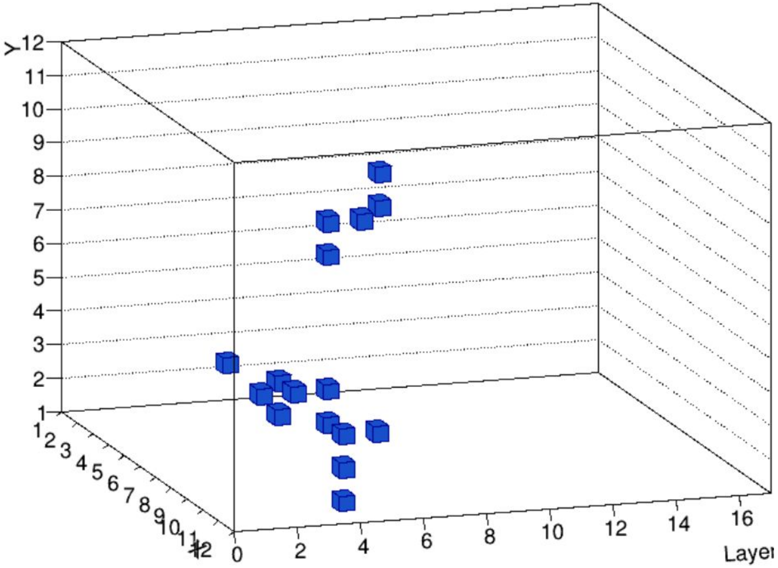
Example of applying condition to light cone

1 neutron 4 GeV



Yellow indicates the cells with the minimum time in the cluster

After applying the condition to the light cone



Average number of clusters in event

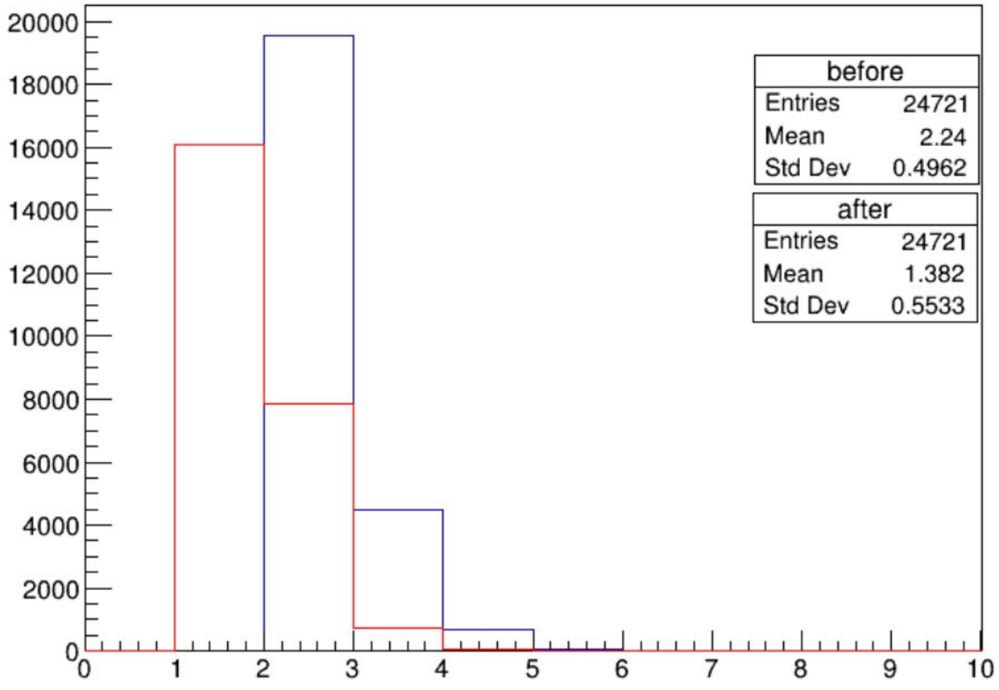
1n				
Energy		rms	T cut	rms
500	1.03	0.18	1.01	0.1
1000	1.12	0.34	1.04	0.2
2000	1.29	0.54	1.10	0.33
4000	1.52	0.73	1.18	0.45

2n				
Energy		rms	T cut	rms
500 & 500	1.63	0.56	1.49	0.52
1000 & 1000	1.92	0.66	1.7	0.58
2000 & 2000	2.35	0.85	1.97	0.68
4000 & 4000	2.71	1.08	2.15	0.84

The number of clusters after applying the condition

1 neutron

Energy 2 GeV



clusters

Analysis of 10% of single-neutron events in selected area from two-neutron events

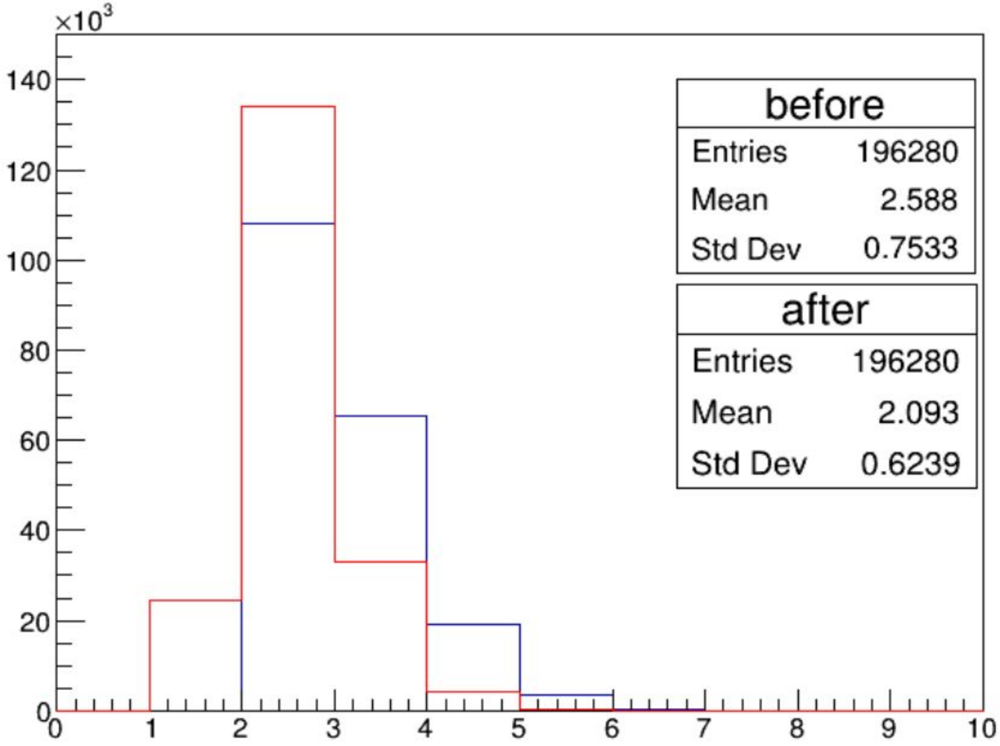
Before
24721 / 246786 = 10%

After
(24721-16103) / 246786 = 4%

The number of clusters after applying the condition

2 neutrons

Energy 2 GeV



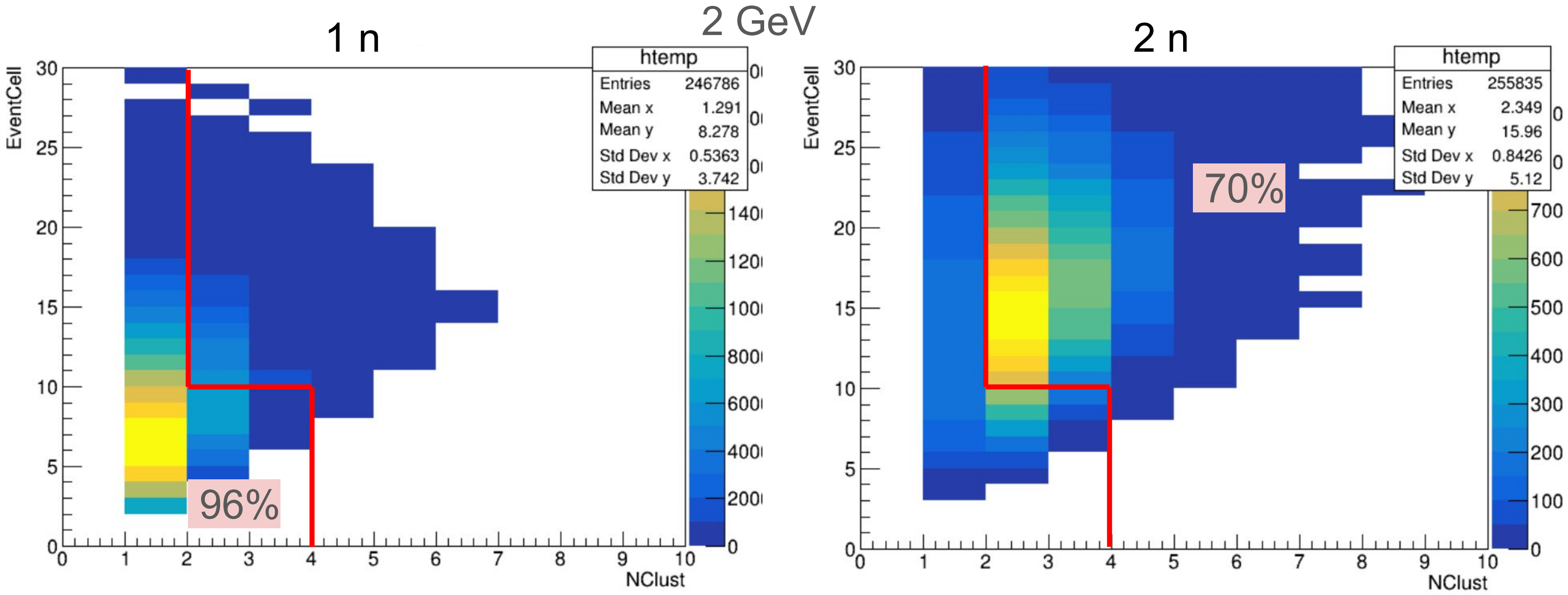
clusters

Analysis of 77% of two-neutron events in selected area from two-neutron events

Before
196279 / 255836 = 77%

After
(196279 - 24433) / 246786 = 70%

Number of cells in event VS number of clusters



The contribution from 2n to 1n is 6%, because 2n is about 20% of 1n.
The contribution of 1n to 2n is 13%.

Conclusions: Considering the most difficult cases of registration of two-neutron events, in which the neutrons are not separated by arrival time (close in energy), it is determined that:

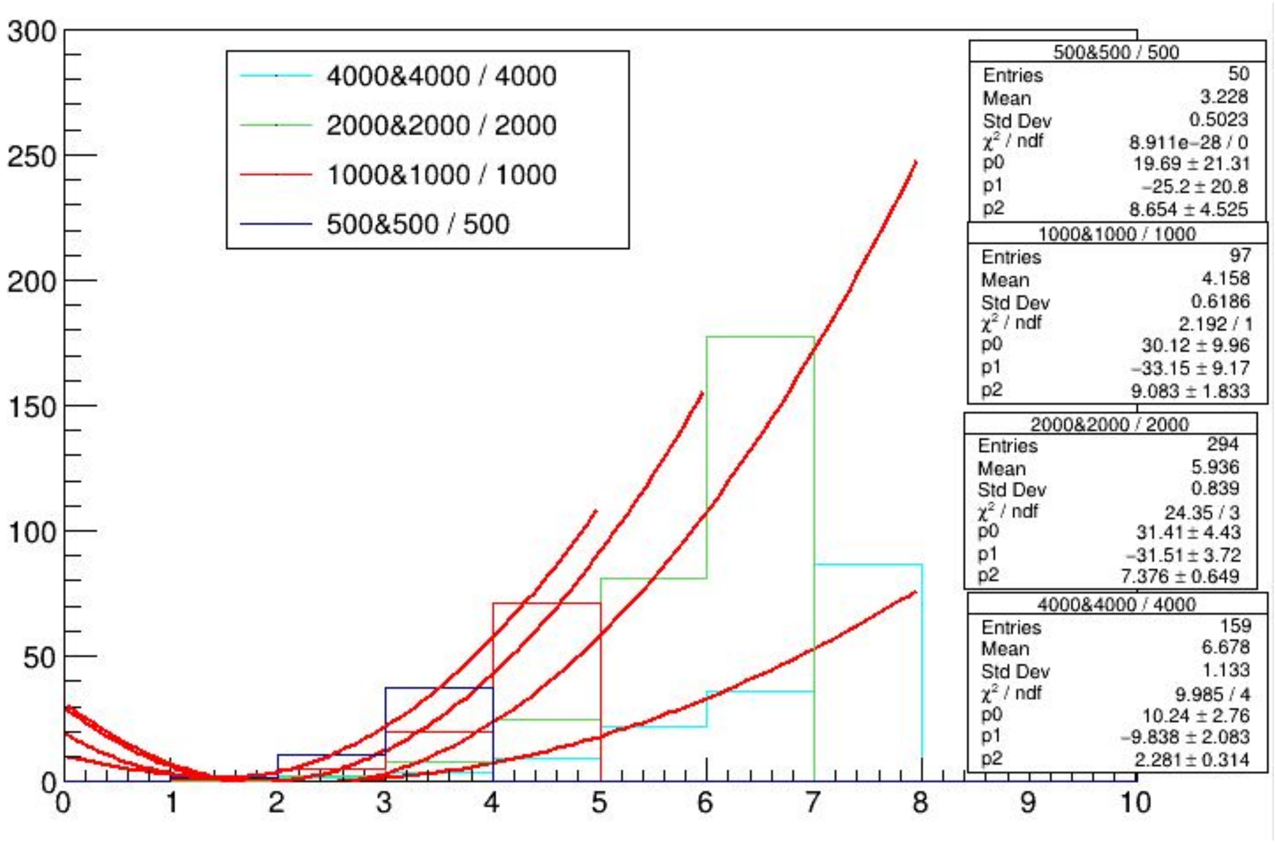
1. Clusterization and analysis of number of cells and clusters in event makes it possible to identify one neutron in event in 96% of cases.
   The systematic contribution from two-neutron events is about 6%

2. The same method makes it possible to identify two-neutron events in 70% of cases.

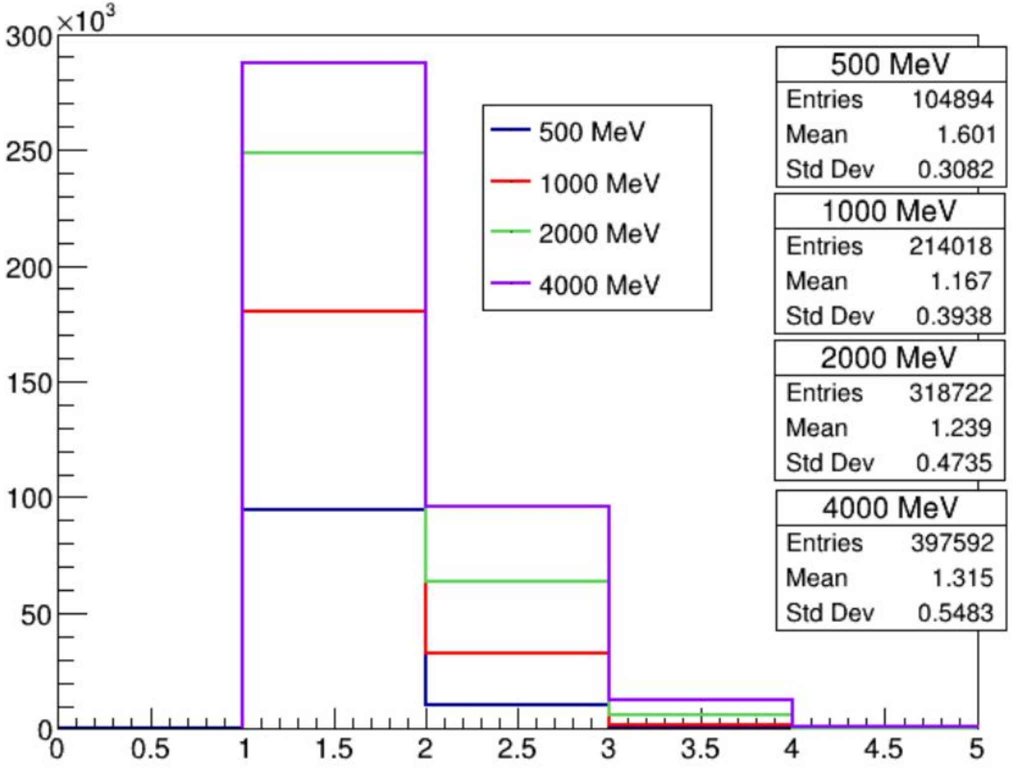
   The systematic error from the contribution of single-neutron events to two-neutron events is about 13%

backup

The ratio of number of clusters from 2 neutrons to clusters from 1 neutron



The position (relative to beginning of the cluster) of the fastest cell(by time) in the cluster



cells

Momentum analysis

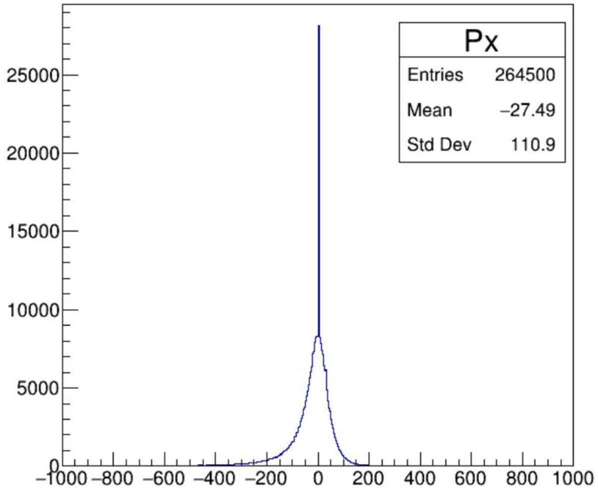
Algorithm

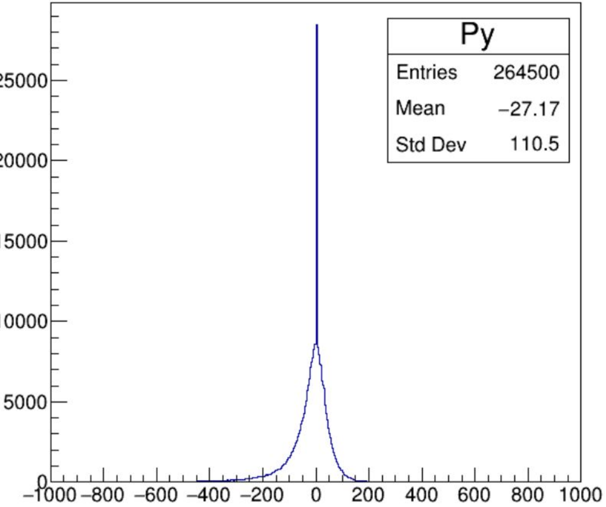
The coordinates of the vertex in each cluster are determined.
The distance and time between each cell and the vertex are determined.
Get the velocity V_x, V_y, V_z
Find the P_x, P_y, P_z for the cluster

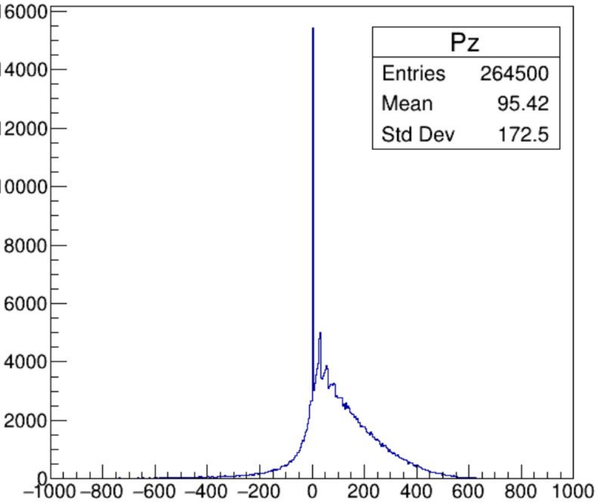
$$P_x = m(V_{1x}+V_{2x}+..)$$
$$P_y = m(V_{1y}+V_{2y}+..)$$
$$P_z = m(V_{1z}+V_{2z}+..)$$

If momentum of the i-th cluster reduces the total transverse momentum of the cluster, then we merge the clusters

Px, Py, Pz of cluster







Average number of clusters in event

1n						
Energy		rms	T cut	rms	P cut	rms
500	1.03	0.18	1.01	0.1	1.01	0.1
1000	1.12	0.34	1.04	0.2	1.03	0.17
2000	1.29	0.54	1.10	0.33	1.08	0.28
4000	1.52	0.73	1.18	0.45	1.12	0.36

2n						
Energy		rms	T cut	rms	P cut	rms
500 & 500	1.63	0.56	1.49	0.52	1.4	0.51
1000 & 1000	1.92	0.66	1.7	0.58	1.55	0.57
2000 & 2000	2.35	0.85	1.97	0.68	1.71	0.67
4000 & 4000	2.71	1.08	2.15	0.84	1.8	0.77

Слипшиеся кластеры от разных нейтронов

Среднее кол-во ячеек в событии

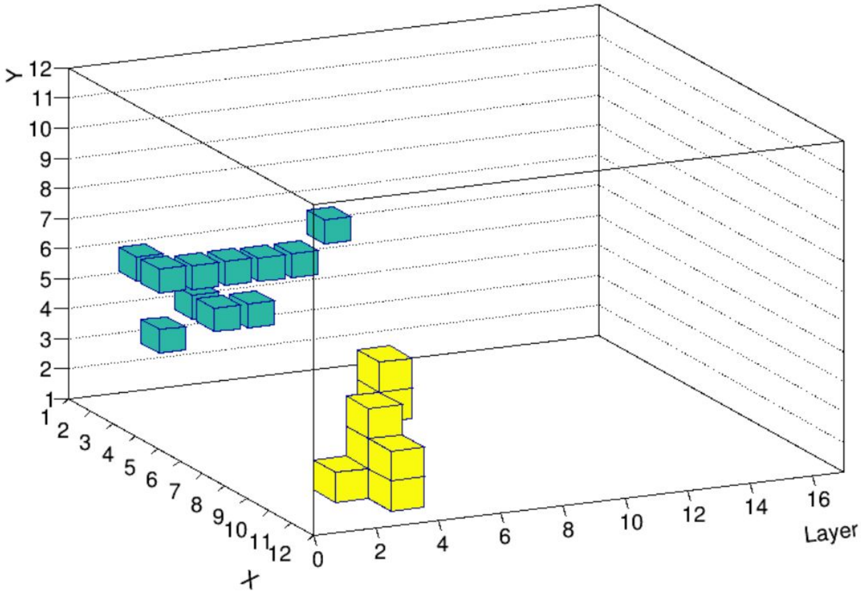
1n		
Energy		rms
500	3.07	1.2
1000	4.68	2.3
2000	8.08	3.82
4000	14.61	6.23

2n		
Energy		rms
500 & 500	6.13	1.71
1000 & 1000	9.35	3.24
2000 & 2000	16.14	5.39
4000 & 4000	29.13	8.75

Среднее кол-во ячеек в кластере

1n	
Energy	
500	2.86
1000	3.87
2000	5.59
4000	8.69

2n	
Energy	
500 & 500	2.93
1000 & 1000	4.03
2000 & 2000	5.99
4000 & 4000	9.69



Y
12
11
10
9
8
7
6
5
4
3
2
1
1 2 3 4 5 6 7 8 9 10 11 12
X
0 2 4 6 8 10 12 14 16
Layer

Среднее кол-во ячеек в кластере

1n	
Energy	
500	2.86
1000	3.87
2000	5.59
4000	8.69

2n	
Energy	
500 & 500	2.93
1000 & 1000	4.03
2000 & 2000	5.99
4000 & 4000	9.69

Эффективность, в %

1n			2n		
Energy	(2 cells > 3 MeV)	(>1 cells in cluster)	Energy	(2 cells > 3 MeV)	(>1 cells in cluster)
500	45	34	500 & 500	75	57
1000	73	64	1000 & 1000	94	87
2000	85	82	2000 & 2000	98	97
4000	88	88	4000 & 4000	99	98

Среднее кол-во ячеек в кластере

1n		
	кол-во слоев	
Energy	8	16
500	2.82	2.86
1000	3.66	3.87
2000	5.15	5.59
4000	7.92	8.87

2n		
Energy	кол-во слоев	
	8	16
500 & 500	2.86	2.90
1000 & 1000	3.80	3.98
2000 & 2000	5.51	5.93
4000 & 4000	8.81	9.56

Среднее кол-во ячеек в событии

1n		
Energy	N cells	rms
500	3.57	
1000	5.18	
2000	8.58	
4000	15.11	

2n	
Energy	N cells
500 & 500	4.09
1000 & 1000	7.46
2000 & 2000	14.14
4000 & 4000	26.08