Analysis of the ^{124}Xe nucleus electromagnetic dissociation in the Xe+CsI reaction

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on behalf of the HGNd group

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13 - 17 may

The aim of this work is to investigate the interaction of $^{124}Xe^{+54}$ ions with a CsI target with neutron emission at zero degrees in laboratory system.
In the nuclear electromagnetic interaction, the parity and spin of the system are preserved.

Expected reactions:

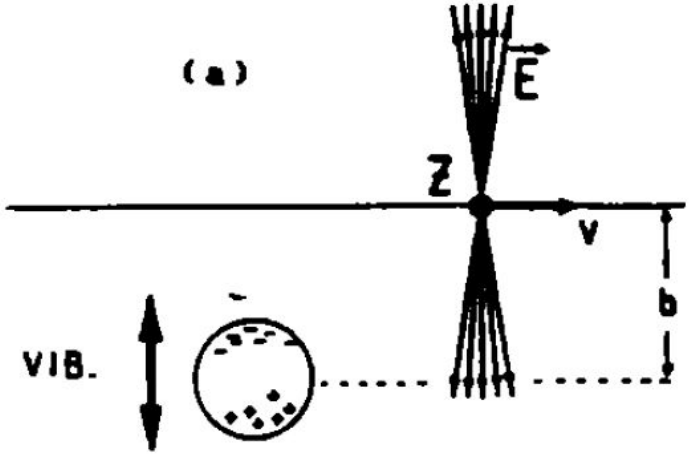
$$^{124}\mathrm{Xe}\ (0^+)+(^{108}\mathrm{CsI}^+)\rightarrow{}^{123}\mathrm{Xe}\ (1/2^+)\ +(^{108}\mathrm{CsI}^+)+\mathbf{n}(1/2^+)$$

$$^{124}\mathrm{Xe}\ (0^+)+(^{108}\mathrm{CsI}^+)\rightarrow{}^{123\mathrm{m}}\mathrm{Xe}\ (7/2^-)+(^{108}\mathrm{CsI}^+)+\mathbf{n}(1/2^+)$$

$$^{124}\mathrm{Xe}\ (0^+)+(^{108}\mathrm{CsI}^+)\rightarrow{}^{122}\mathrm{Xe}\ (0^+)\ +(^{108}\mathrm{CsI}^+)+\mathbf{2n}(0^+,1^+)$$

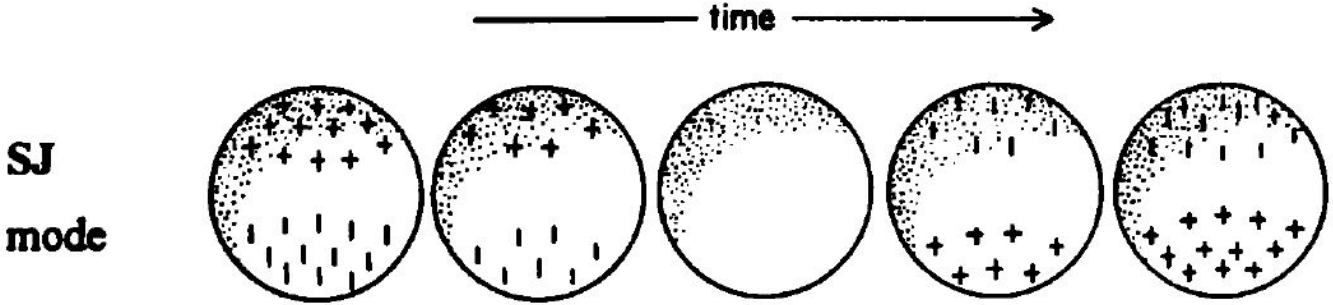
There is **no experimental data** for the presented reactions in the energy range 1-4 AGeV

Photoneutron Reactions on ^{129}Xe Nuclei and Their Electromagnetic Dissociation in Colliders, S.S. Belyshev, V.V. Varlamov, S.A. Gunin, Phys. Atom. Nuclei 83 (2020) 1–8, https://doi.org/10.1134/S1063778819060036 energy $\sqrt{s_{NN}}$ = 5.44 TeV



Schematic illustration of the electric field created by a relativistic heavy ion traveling on a straight line. There is an interaction with the charge of the target nucleus and the deflection of protons relative to the center of mass.
This electric field may excite the giant dipole resonance.

(G.P. Baur and C .A. Bertulani, Phys . Rep . 163 (1988) 299)

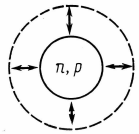


Shematic picture of the GDR in the Steinwedel and Jensen model.
(H.Steinwedel and J.H.D. Jensen, Z . Nat. 5a (1950) 413)

Nuclei exitation

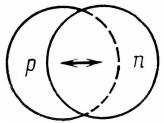
Pi/Pf=$(-1)^{-L}$

E0



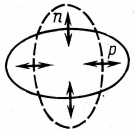
W=80$A^{-1/3}$MeV

E1



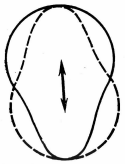
W=78$A^{-1/3}$MeV
Γ=3 -10MeV
9<A<203

E2



W=63$A^{-1/3}$MeV
Γ=6 - 3MeV
14<A<208

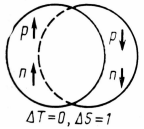
E3



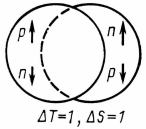
W=32$A^{-1/3}$MeV
Γ=2.2MeV
60<A<208

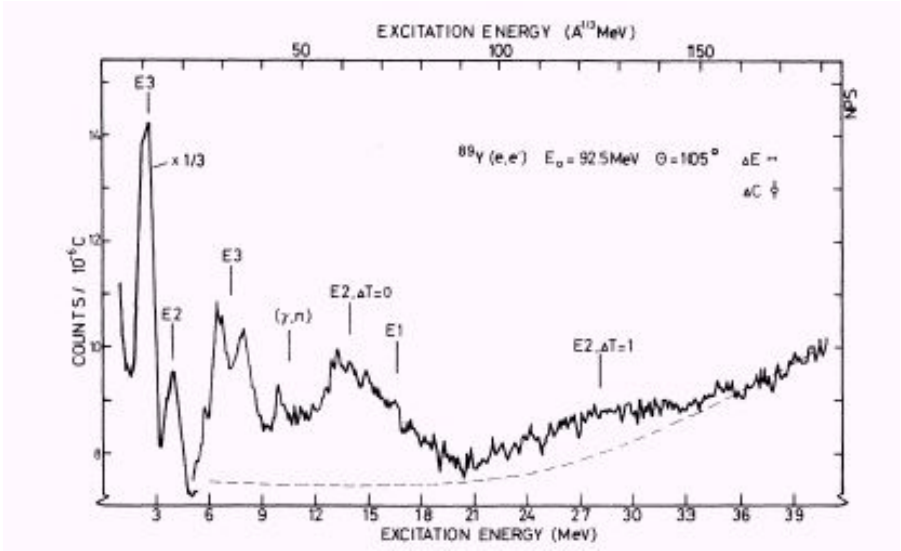
Pi/Pf=$(-1)^{-L+1}$

M1



M2





Spectrum of 92.5-MeV electrons scattered at 105º

When nuclei interact, in addition to the nuclear interaction, a giant dipole resonance E1, E3 is excited and the parity of the nucleus changes, so the reactions gives the following quantum numbers

$$^{124}Xe\ (0^+) + (^{108}CsI^+) \rightarrow ^{123}Xe\ (1/2^+) + (^{108}CsI^+) + \mathbf{n}(1/2^+) + E3$$

$P(^{124}Xe)=P(^{123}Xe)P(n)P(E3)$ $(+1)=(+1)*(+1)*(-1)$ - parity does not match (Reaction is suppressed)

$$^{124}Xe\ (0^+) + (^{108}CsI^+) \rightarrow ^{123m}Xe\ (7/2^-) + (^{108}CsI^+) + \mathbf{n}(1/2^+) + E3$$

$P(^{124}Xe)=P(^{123m}Xe)P(n)(E3)$ $(+1)=(-1)*(+1)*(-1)$ - parity matches **(Reaction is allowed)**

$$^{124}Xe\ (0^+) \rightarrow ^{122}Xe\ (0^+) + (^{108}CsI^+) + \mathbf{2n}(0^+,1^+) + E3$$

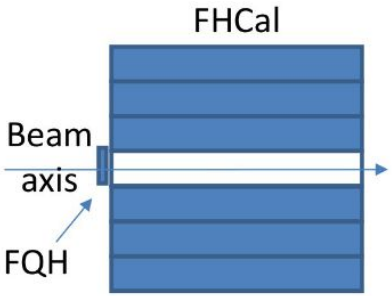
$P(^{124}Xe)=P(^{122}Xe)P(2n)(E3)$ $(+1)=(+1)*(+1)*(-1)$ - parity does not match (Reaction is suppressed)

The quantum numbers of the target nuclei ^{133}Cs (7/2+) and ^{127}I(5/2+) also have positive parity

If the reaction proceeds without exciting the GDR, we must register the same number of events with 1n and 2n
Otherwise, the reaction with two neutrons will be suppressed. (due to non-parity)

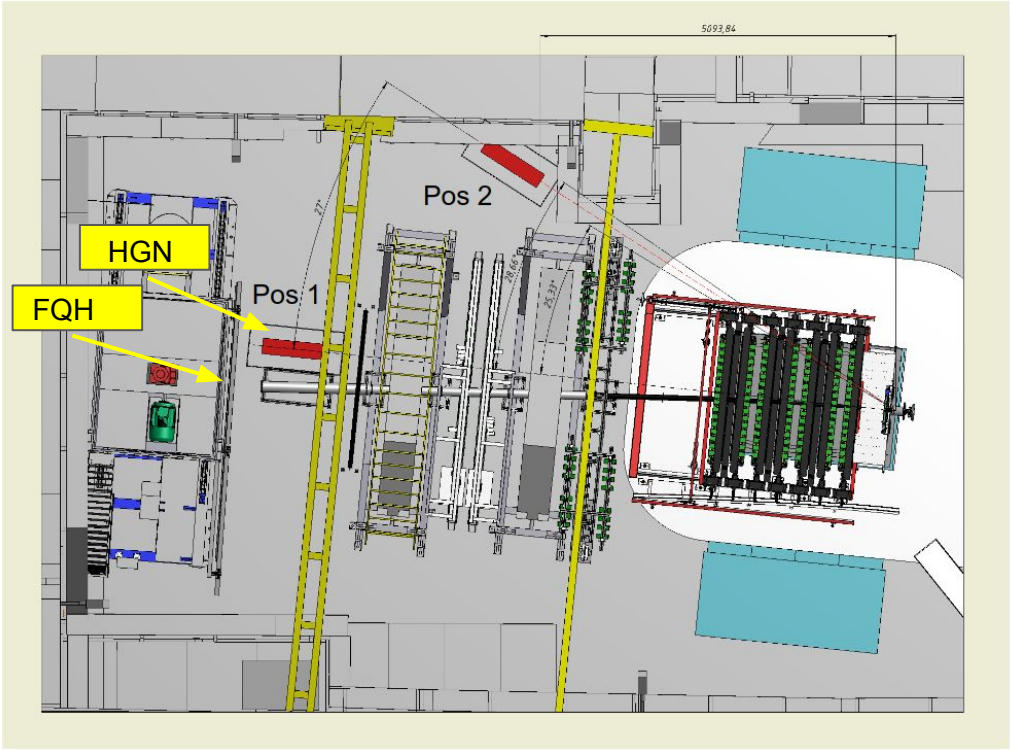
Schematic view

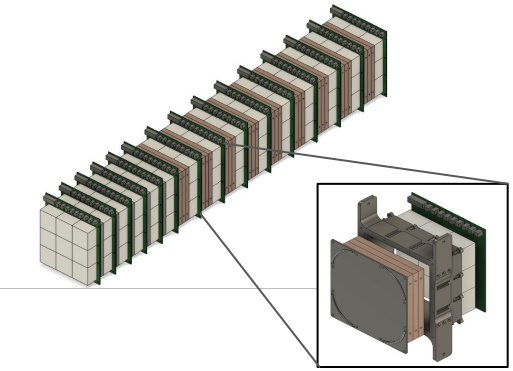
Position 0 degree



Forward
Quarz
Hodoscope

16 quartz strips
10x4x160mm^3





High
Granularity
Neutron
detector

15 layers
Veto + 5 Pb + 9 Cu
Scintillator cell
40 x 40 x 25 mm^3
135 readout channels

Data set conditions

The HGN detector at the 0° position has been adjusted (angle corresponds to ~0.7°):
Back part of the HGNd has been moved by 11 cm, the front by 10 cm towards the beam axis.

HGNd completely overlaps FHCal module No. 49 in this position

№ Run	Events	Target	Type	Comment
8281	999K	CsI (2%)	Physics	BT trigger beam position x=-7mm y=-14mm
8282	121K	Empty	Calibration	BT trigger beam position x=-7mm y=-14mm
8283	106K	Empty	Calibration	BT trigger beam position x=-12.4mm y=-12.2mm
8284	400K	CsI (2%)	Physics	BT trigger beam position x=-12.4mm y=-12.2mm

Trigger statistics

Beam time 30 min was allocated

Special runs

Beam position x=-7mm y=-14mm

Target **CsI(2%)**

BT trigger: 662453

Target **Empty**

BT trigger: 113959

Only
BEAM TRIGGER
for analysis

Additionally removed events with the remaining triggers from the analysis

2 data sets due to the deflection of the beam in target

Beam position x=-12.4mm y=-12.2mm

Target **CsI(2%)**

BT trigger: 275616

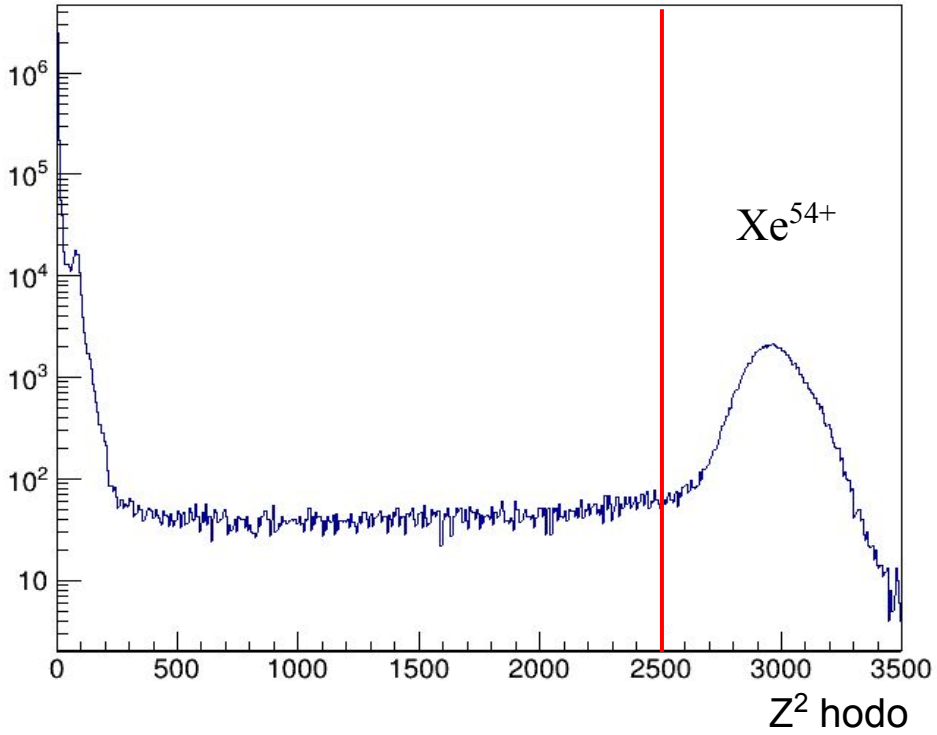
Target **Empty**

BT trigger: 99861

Total events: 938069 213820

Fragments charge distribution in FQH

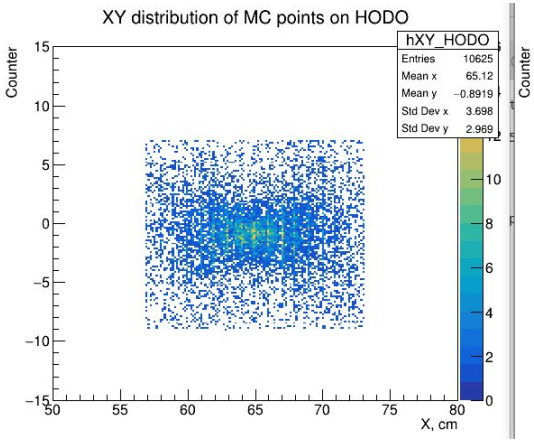
Charge cut > 2500

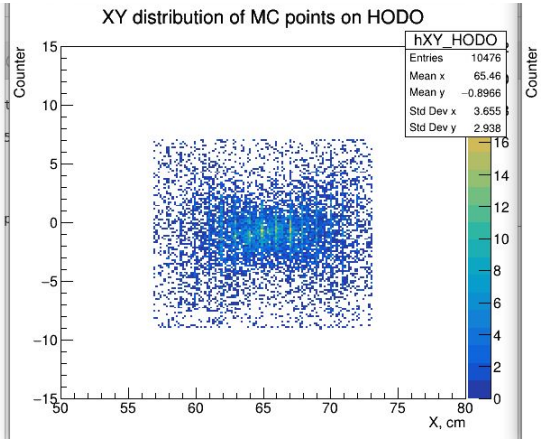


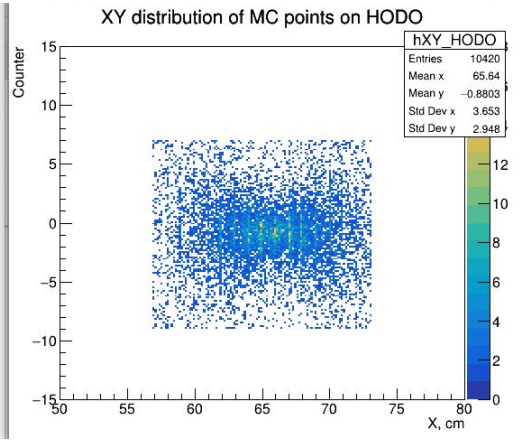
Simulation Xe beam in FQH with neutron emission

1 strip - 1 cm thickness

		-1n	-2n
MEAN X	65.12 cm	65.46 (+0.34cm)	65.64 (+0.52cm)







Primary beam

^{124}Xe

^{123}Xe

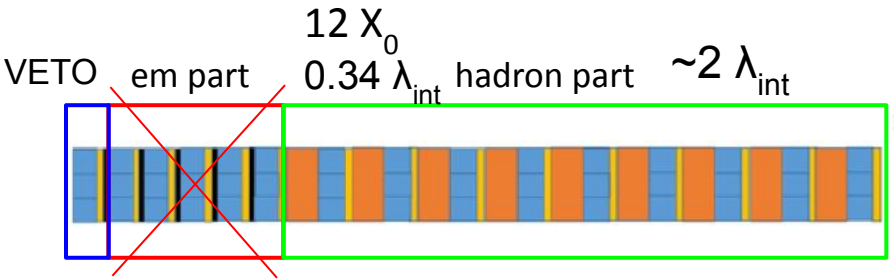
^{122}Xe

Beam position in FQH

Beam position in target	Beam position in FQH				Diff target - non target	
	CsI(2%) Target		**EMPTY** Target		Δ(mean)	Δ(fit)
	MEAN	FIT	MEAN	FIT		
x= -7 mm **y=** -14 mm	**8.714**	**9.208**	**8.424**	**8.923**	**0.290 cm**	**0.285 cm**
x= -12.4 mm **y=** -12.2 mm	**8.285**	**8.777**	**7.977**	**8.472**	**0.308 cm**	**0.305 cm**

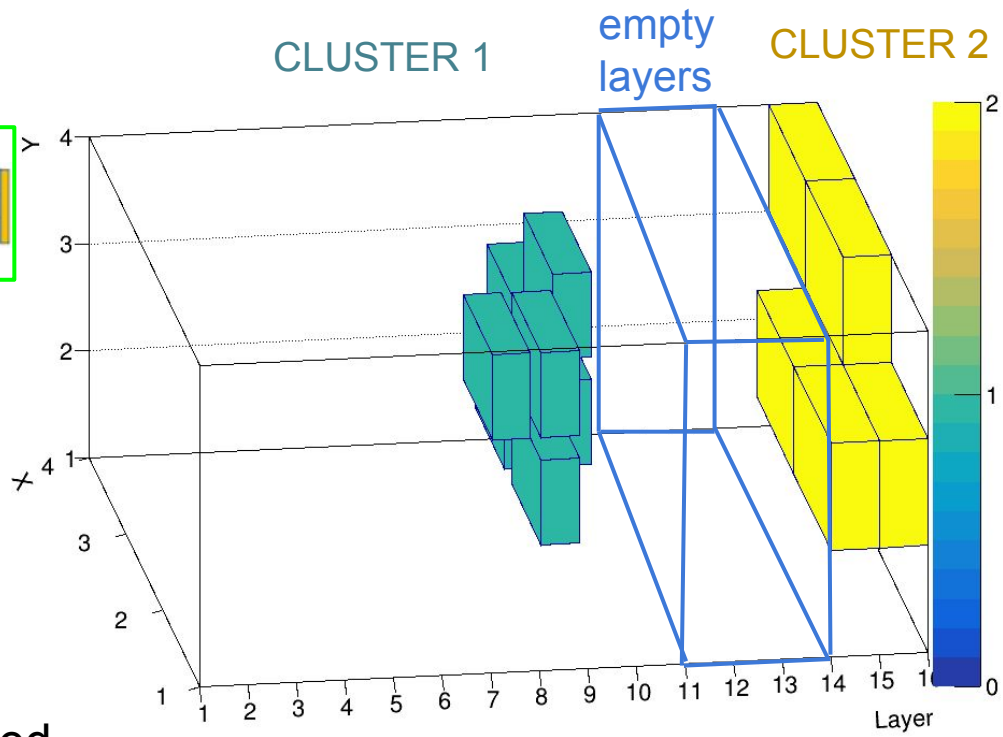
The presence of target leads to relative beam deflection on 0.3 cm associated with ionization energy losses in the target at 1.15 GeV
The total kinetic energy of ^{124}Xe E_k = 483 GeV

Clusterization in HGNd



- Only hadron part
- Without EM part to suppress gamma
- VETO to suppress charged particles

Cluster - area of the detector separated by empty layer and number of cells > 1

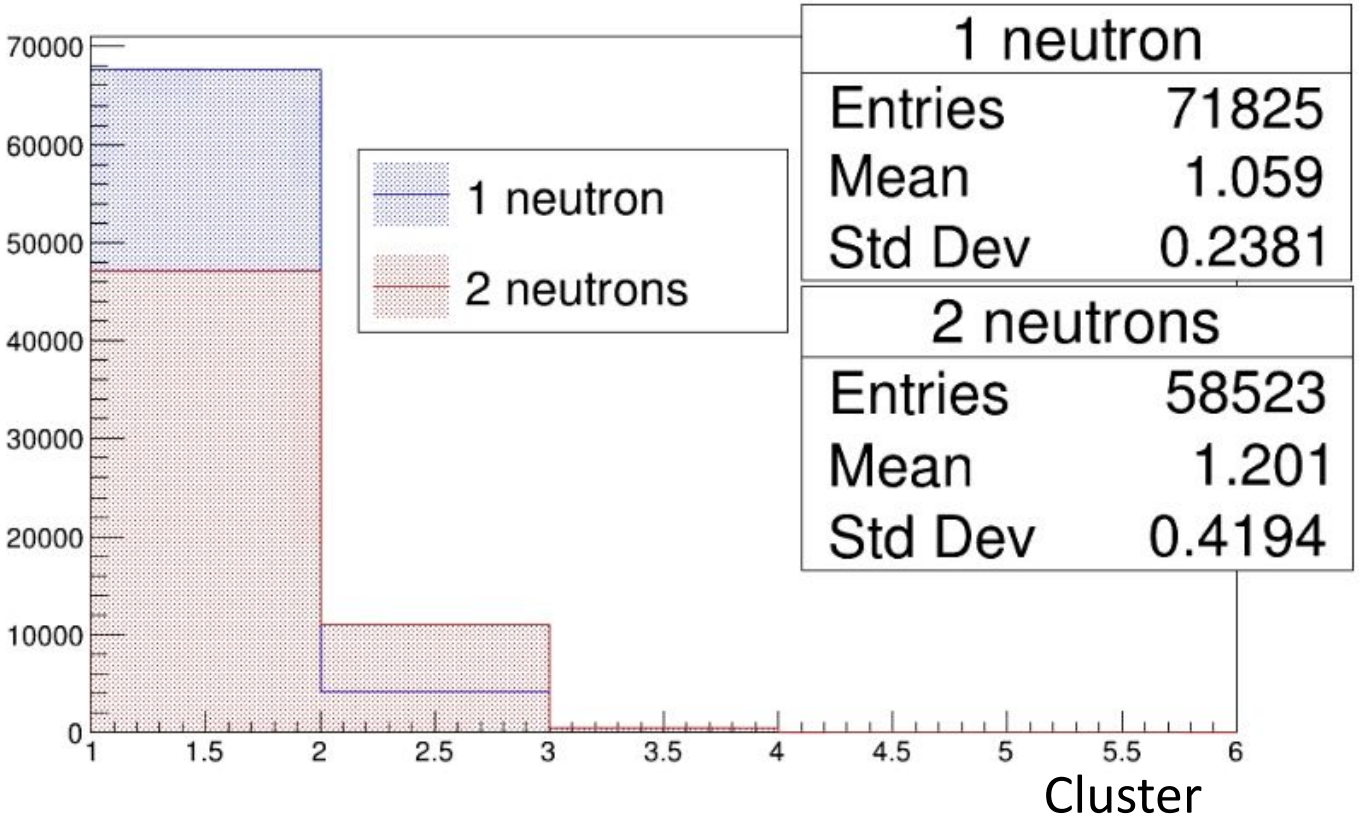


Simulation

Box generator

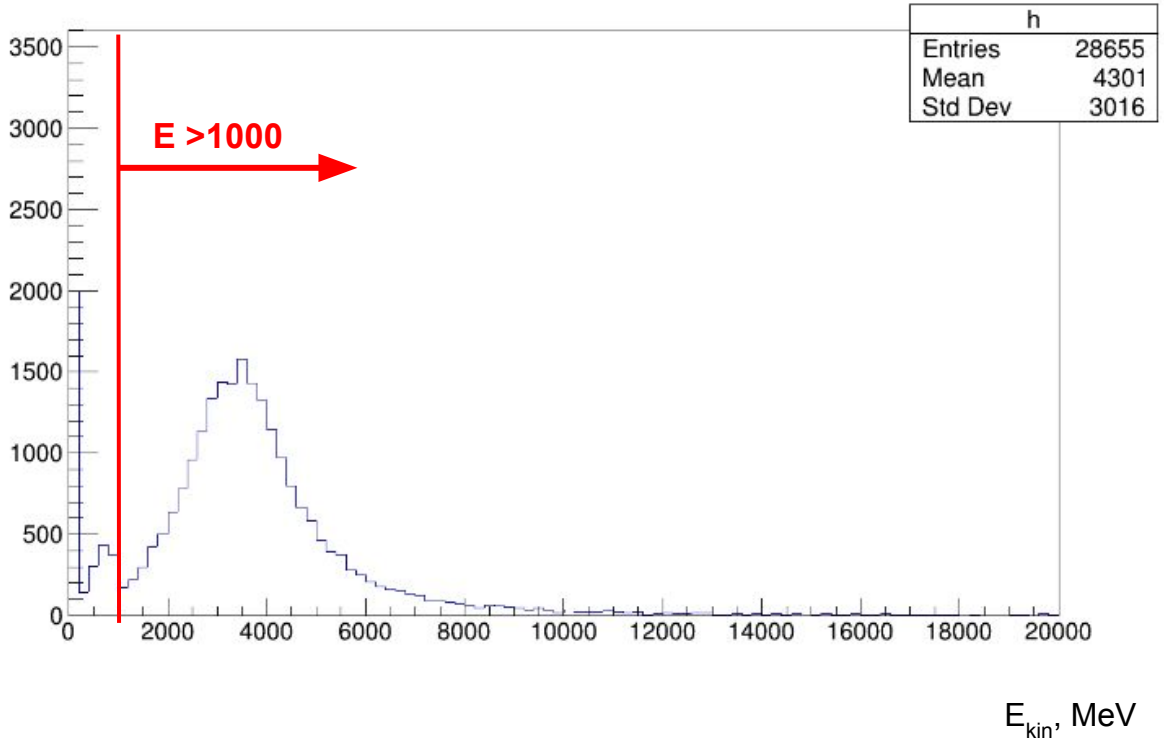
Only primary neutrons
100k events

The efficiency of neutron detector for two neutron events is lower than for single neutron events due to the specific of the selection algorithm



Experimental data

Neutron kinetic energy by the fastest cell in the cluster



Experimental data

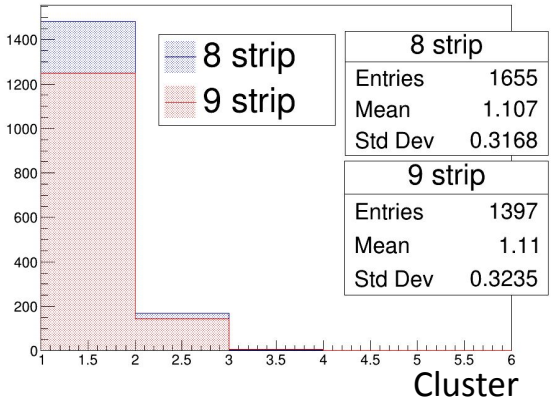
No correlation between the number of clusters and the beam deflection.

Deflection in each selection is 1cm

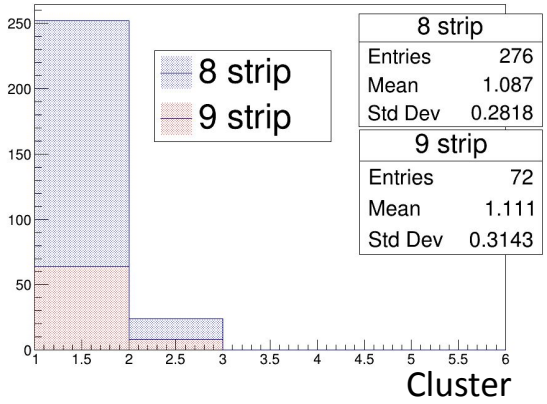
The number of clusters is close to the simulation predictions, and one neutron is emitted

Beam position x=-7mm y=-14mm

Target **CsI(2%)**

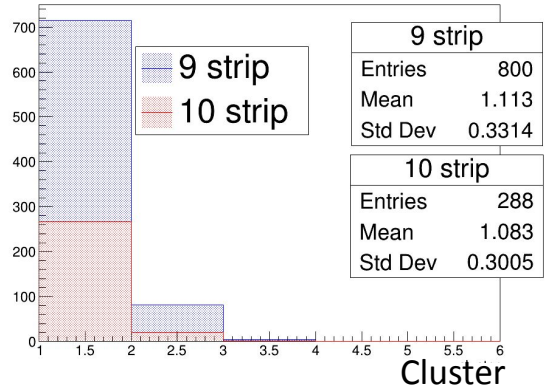


Target **Empty**

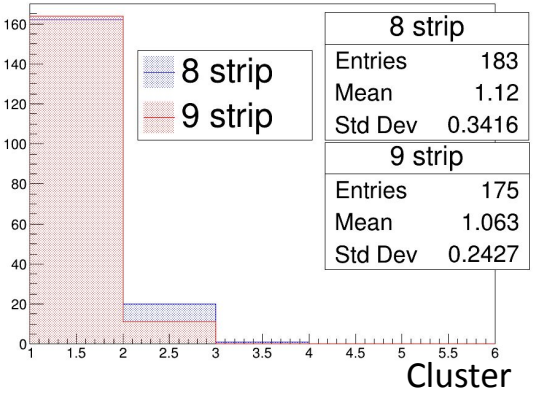


Beam position x=-12.4mm y=-12.2mm

Target **CsI(2%)**



Target **Empty**



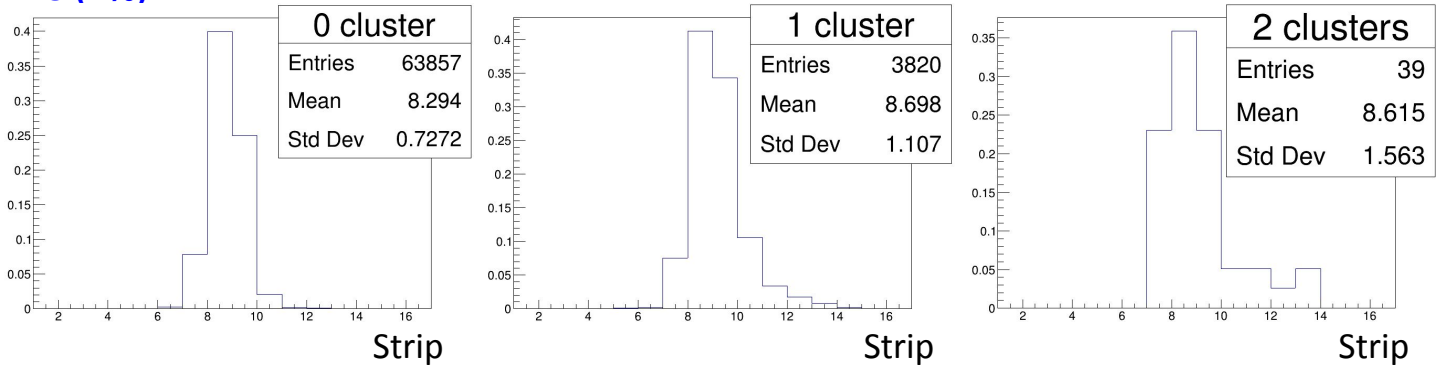
Beam position in FQH

Target **CsI(2%)**

Beam position x=-7mm y=-14mm

Strip position (cm)

0 cluster 8.294 ±0.003 cm
1 cluster 8.698 ±0.018 cm
2 clusters 8.615 ±0.25 cm

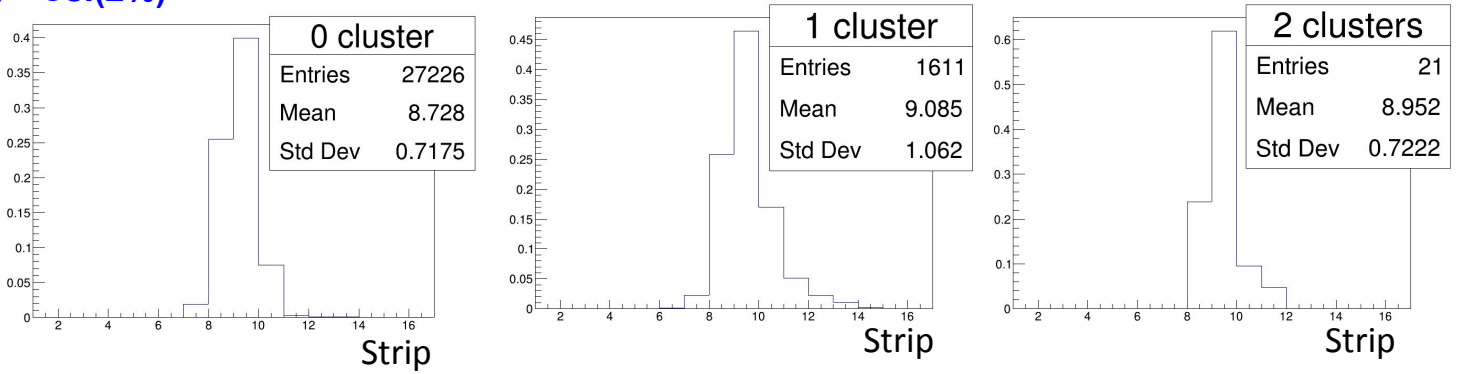


Target **CsI(2%)**

Beam position x=-12.4mm y=-12.2mm

Strip position (cm)

0 cluster 8.728 ±0.004 cm
1 cluster 9.085 ±0.027 cm
2 clusters 8.952 ±0.158 cm



The values for the two cluster events are underestimated due to the selection criteria
Two clusters events have large errors, so more detailed study is required.

Beam position in FQH

Beam position in target		Beam position in FQH				Δ(mean)
		CsI(2%) Target		**EMPTY** Target		
		MEAN (cm)	EVENTS	MEAN (cm)	EVENTS	
x= -7 mm y= -14 mm	**0 cluster**	**8.296 ±0.003**	63800	**7.963**	10960	**0**
	1 clusters	**8.741 ±0.018**	3820	**8.202**	410	**0.45 ±0.02 cm**
	2 clusters	**8.618 ±0.250**	39	**-**	-	**0.32 ±0.25 cm**
x= -12.4 mm y= -12.2 mm	**0 cluster**	**8.727 ±0.004**	27230	**8.411**	9530	**0**
	1 clusters	**9.128 ±0.027**	1610	**8.711**	380	**0.4 ±0.03 cm**
	2 clusters	**8.92 ±0.158**	21	**-**	-	**0.19 ±0.16 cm**

The difference in the beam position between events without cluster formation and single cluster events is **0.44 ±0.02 cm**

double clusters events is **0.28 ±0.22 cm**

The beam deflection is the same in both cases within the error limits

Evaluation of the cross section

Calculations based on

В.С.Барашенков «Сечения взаимодействия частиц и ядер с ядрами», Дубна 1993.

$$\sigma_{tot}(T,A_b,A_t)=\sigma_0(T)(A_b^{1/3}+A_t^{1/3})^2$$

$$\sigma_0(T)=34.5T^{0.06}\,(mb)$$

$$T=3.896*124=483,1GeV$$

Evaluation of the total cross section $^{124}Xe+CsI(2\%)$ *(3.9GeV/nuc)*

$$\boldsymbol{\sigma_{tot}(T,A_b,A_t)=34.5*483.1^{0.06}*(124^{1/3}+130^{1/3})^2=\ 5\ barn}$$

Beam trigger		
with target	938069	N_{tot}= 18651
c >=1 cluster	5490	σ_{tot}(dA>1)~1.48b
w/o target	213820	N_{tot}= 4251
c >=1 cluster	790	σ_{tot}(dA>1)~0.9b

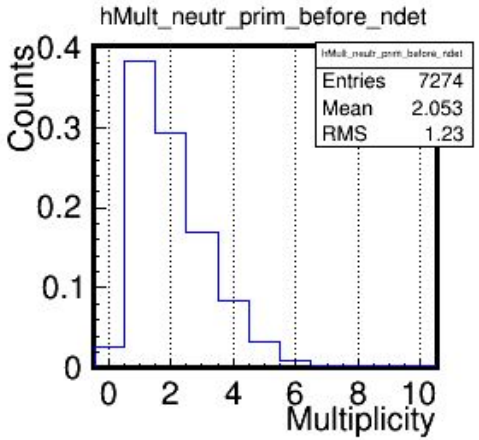
The cross sections in relation to the total nuclear cross section

σ (dA>1)~1.48±0.9 (1.55±0.96) **(2.16±1.35) barn**

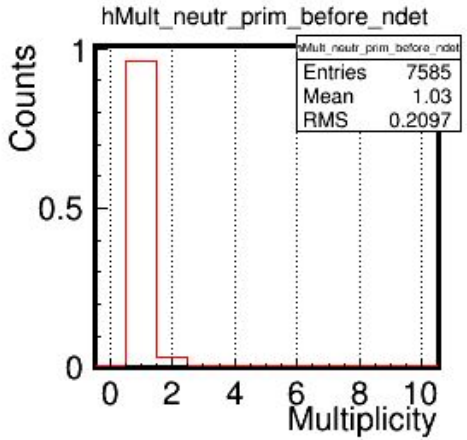
Correction: **w/o** for acceptance detection efficiency

Primary neutrons multiplicity distributions at vacuum wall before HGNd prototype

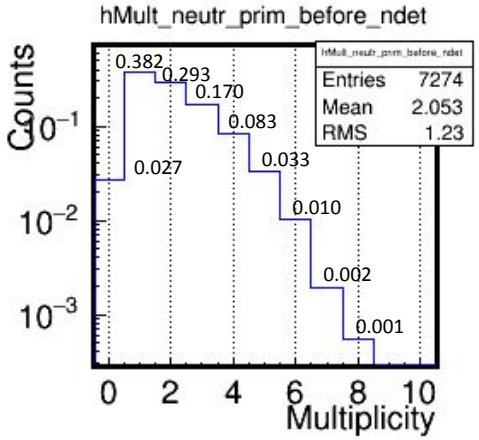
DCM-QGSM-SMM (10000ev)

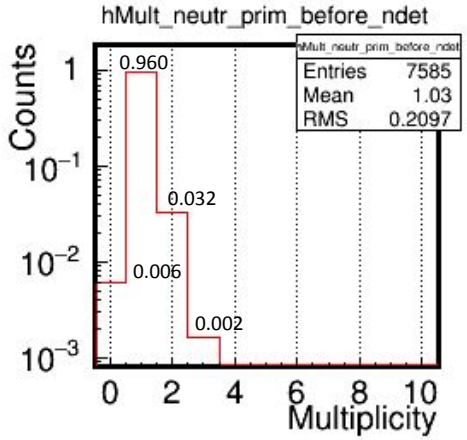


RELDIS (10000 ev)



Linear scale





Log scale

Geometry:
Vacuum in cave
Target, Hodo, vacuum
Wall
With field

HGNd position:
X = 10 cm
Y = 0.52 cm
Z = 838 cm
rotY = 0.7 deg

DCM-QGSM-SMM
RELDIS

Conclusions

Analysis based on the beam deflection in FQH shows that the $^{124}Xe^{+54}$ disintegration reaction proceeds with the emission of single neutron. The average number of experimental measured clusters is 1.1 and from simulation is 1.06.

Analysis based on the number of clusters shows that the $^{124}Xe^{+54}$ disintegration reaction proceeds with the emission of single neutron. The deflection for one cluster is **0.44 ±0.02 cm**, and for two clusters is **0.28 ±0.22 cm.** The beam deflection is the same in both cases within the error limits.

$$^{124}Xe\ (0^+) + (^{108}CsI^+) \rightarrow {}^{123m}Xe(7/2^-) + (^{108}CsI^+) + n(1/2^+) + E3 \quad \text{registered}$$

$$^{124}Xe\ (0^+) + (^{108}CsI^+) \rightarrow {}^{122}Xe\ (0^+) + (^{108}CsI^+) + \mathbf{2n}(0^+,1^+) \quad \text{not detected}$$

The nuclear **cross-section estimate with correction** for acceptance and efficiency of the neutron detector is **σ(dA>1)~2.16±1.35 barn**, where 1.35 barn is systematic error estimate from empty target. The **RELDIS model** gives estimate of **1.9 barn.**

Information about the cross-section can be used for the BM@N trigger system and for the luminosity determination in the NICA collider.

Special thanks to Mikhail Kapishin for providing beam time

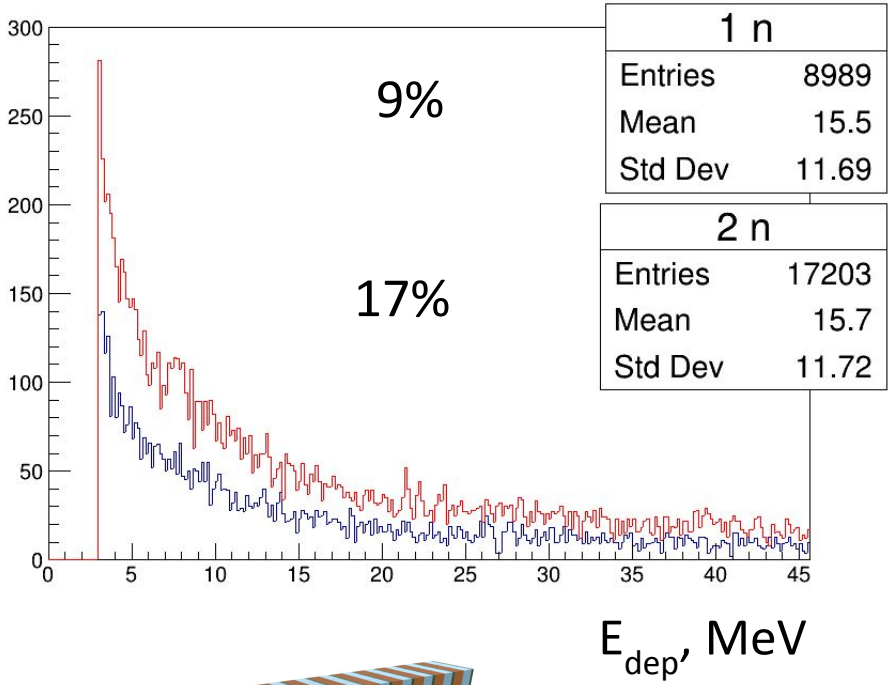
Thank you for your attention

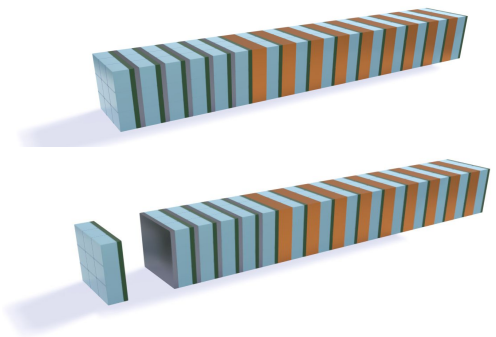
Energy deposition in veto layer

Primary neutrons

Ekin 3.86 GeV
100k events
Edep > 3 MeV

From backscattering





Option: to shift the veto layer

I.A. Pshenichnov, U.A. Dmitrieva

"Emission of forward nucleons by 129Xe in UPC at √SNN = 5.44 TeV: Preliminary data vs RELDIS"

Production of $^{126,127,128}_{54}Xe$

RELDIS:
Total single EMD: 50.6 b

Mutual EMD: 0.69 b

^{129}Xe (1/2+)

Residual nucleus from beam C	ZNC	ZNA	$\sigma \pm \sigma_{fit\_err} \pm \sigma_{stat\_err}$ (barns) normalized to RELDIS	σ_{RELDIS} (barns)	
^{128}Xe	1n	Xn	22.51 ± 0.06 ± 0.06 = 22.51 ± 0.08	21.44 ± 0.05	(0+)
^{127}Xe	2n	Xn	6.04 ± 0.03 ± 0.03 = 6.04 ± 0.05	4.65 ± 0.02	(1/2+)
^{126}Xe	3n	Xn	2.64 ± 0.03 ± 0.02 = 2.64 ± 0.04	1.2 ± 0.01	(0+)

Errors are only from fitting procedure (e.g. due to parameter correlations) and purely statistical ($1/\sqrt{n_{events}}$ for each neutron peak), same for RELDIS.

No corrections for acceptance or detection efficiency yet ...