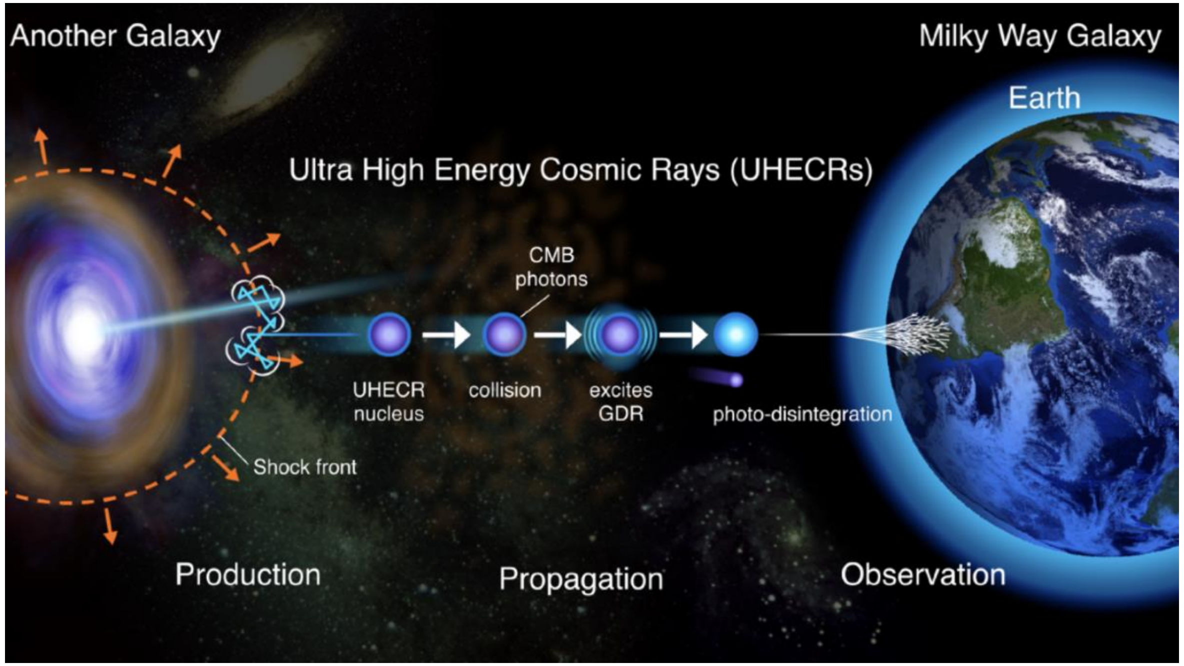
The measurement of gamma-decay in photo-nuclear reaction on ^{12}C、^{13}C for the PANDORA project

The University of Osaka
Yumaro Suzuki

PANDORA project

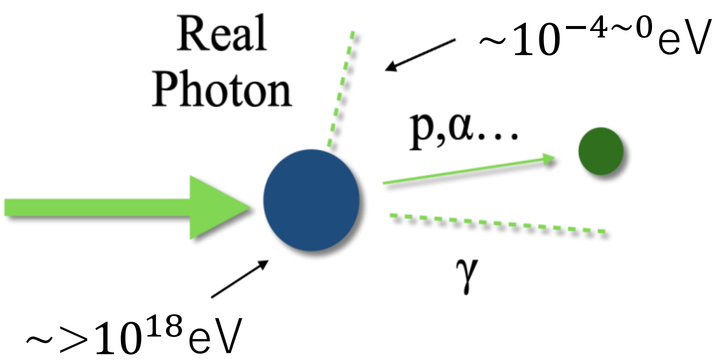
Research on photonuclear reaction of light nuclei to understand Ultra-high energy cosmic rays.



→ PANDORA project

Iso-Vector Giant Dipole Resonance (IVGDR) makes an important role in photonuclear reaction of UHECRs.

→ Nuclei which is IVGDR decays immediately emitting particles and gamma-rays.



Particle decay measurement (Si detector)

Gamma decay measurement ($LaBr_3$ detector)

Gamma decay measurement

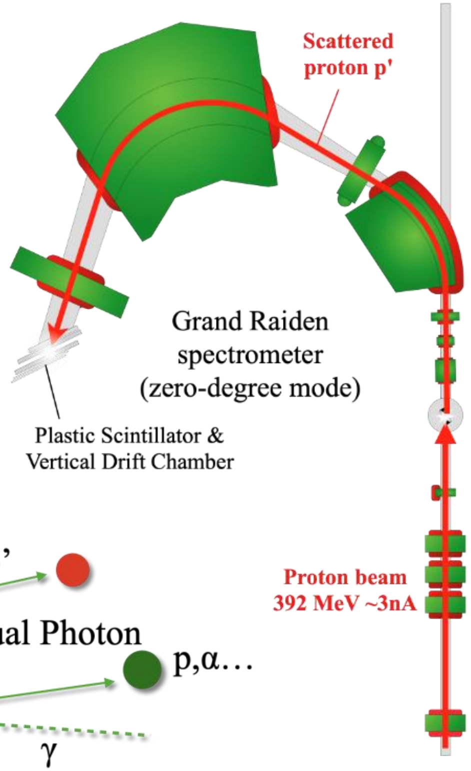
- Grand Raiden spectrometer (GR).

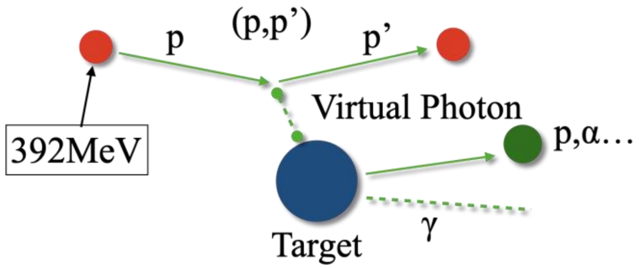
GR is a spectrometer that uses a magnetic field to separate the protons scattered after irradiation of a target by energy.

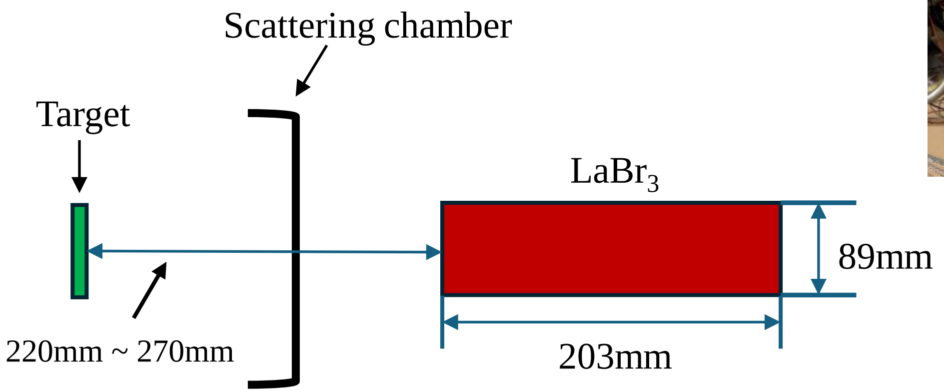
- $LaBr_3$ detector

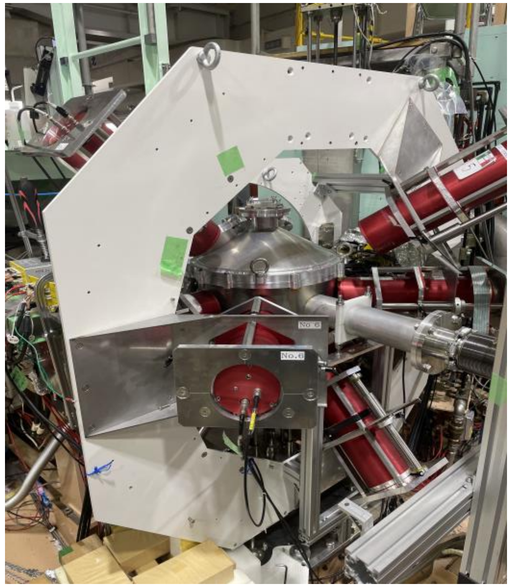
$LaBr_3$ detector is an inorganic scintillator.

We placed eight $LaBr_3$ detectors around the scattering chamber to detect the γ – ray.









Gamma decay measurement

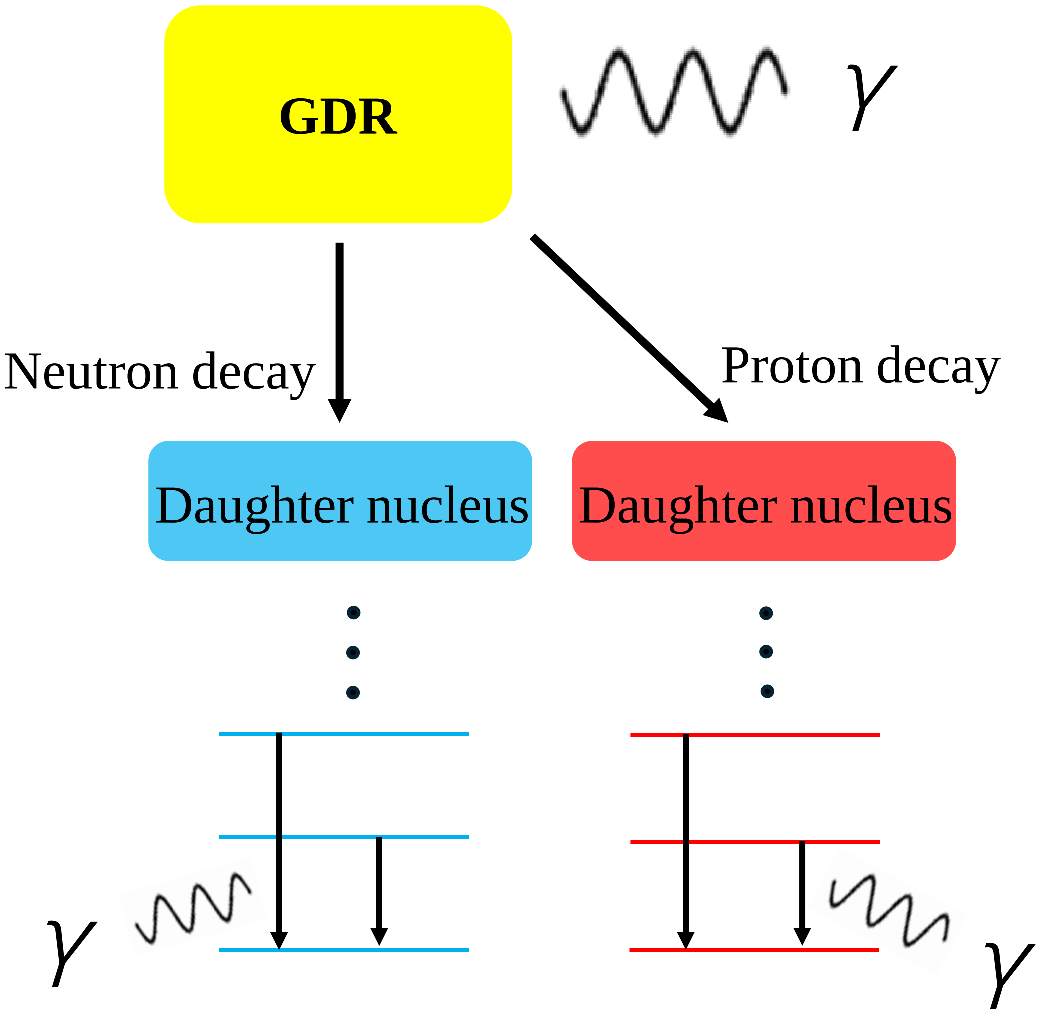
Gamma ray measurement

- Neutron decay branching ratios can be calculated
- Compare the proton decay result with the Si detectors
- Comprehensive study of gamma decay of Giant Resonance

There are many gamma rays

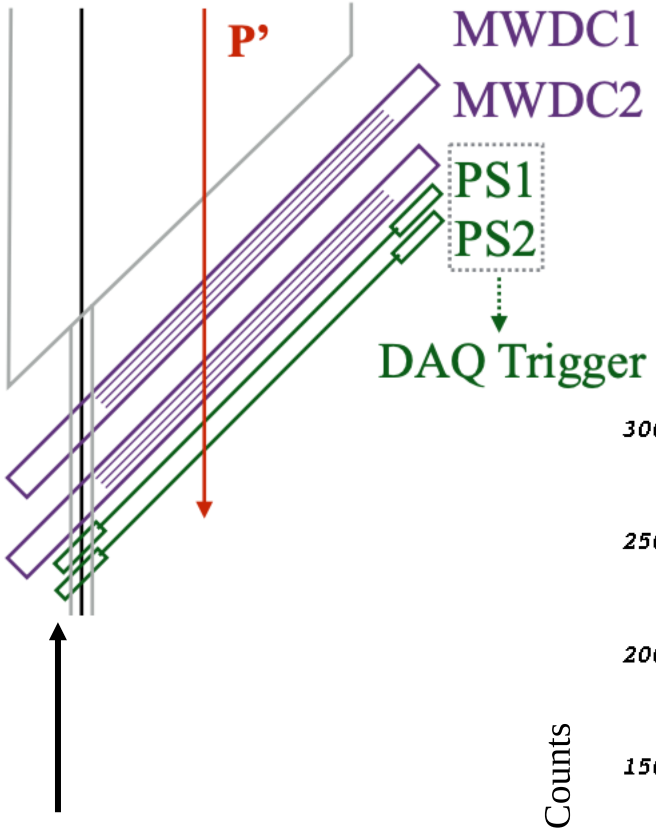
→ Direct decay from GDR

Gamma decay after particle decays

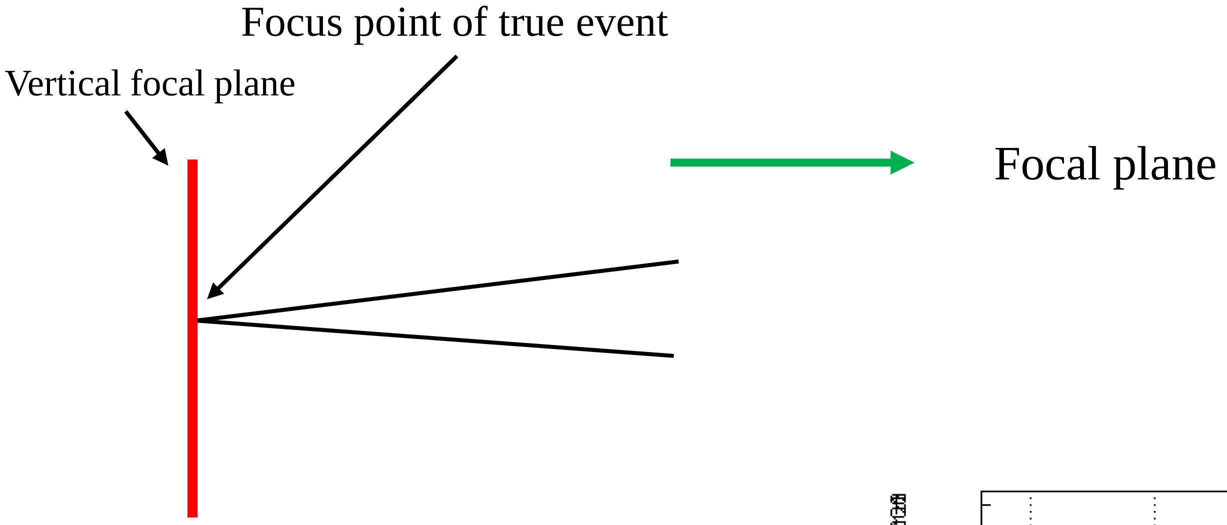


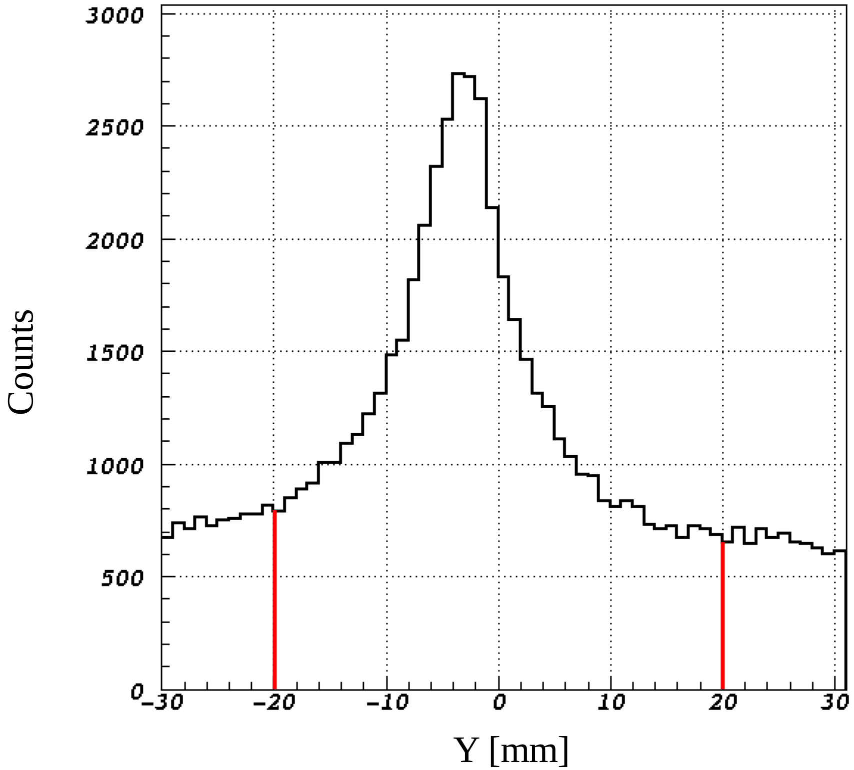
Preliminary result

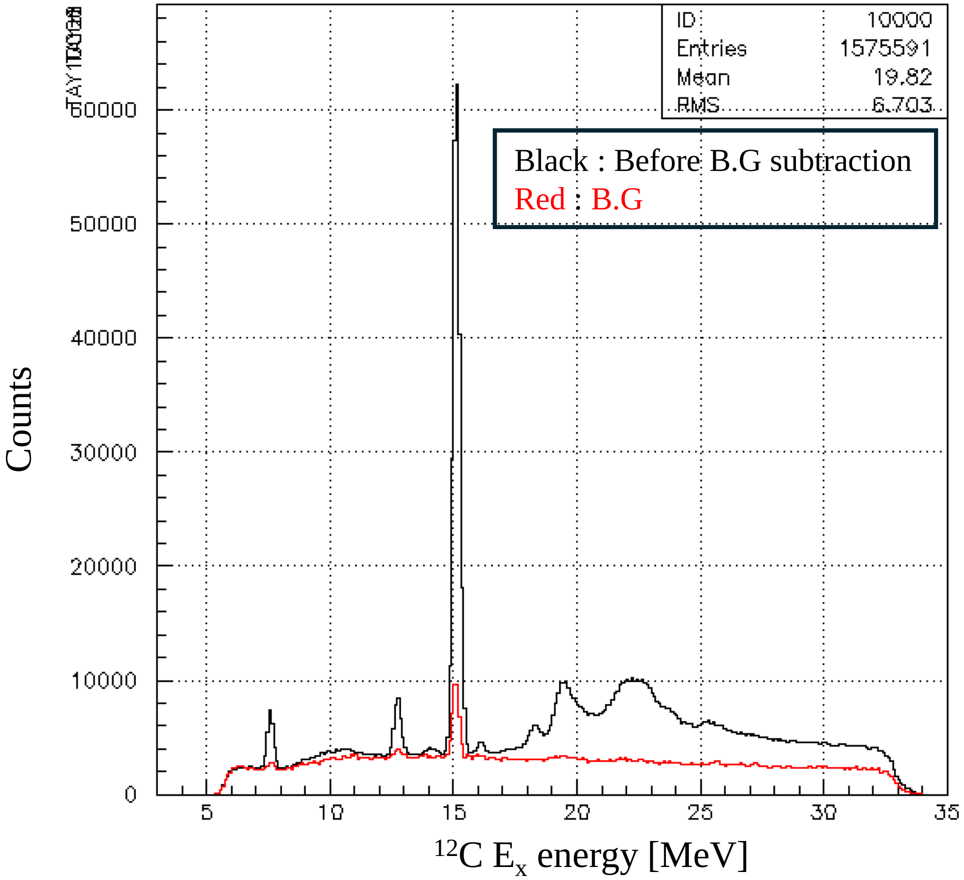
GR analysis



Proton ID by PS



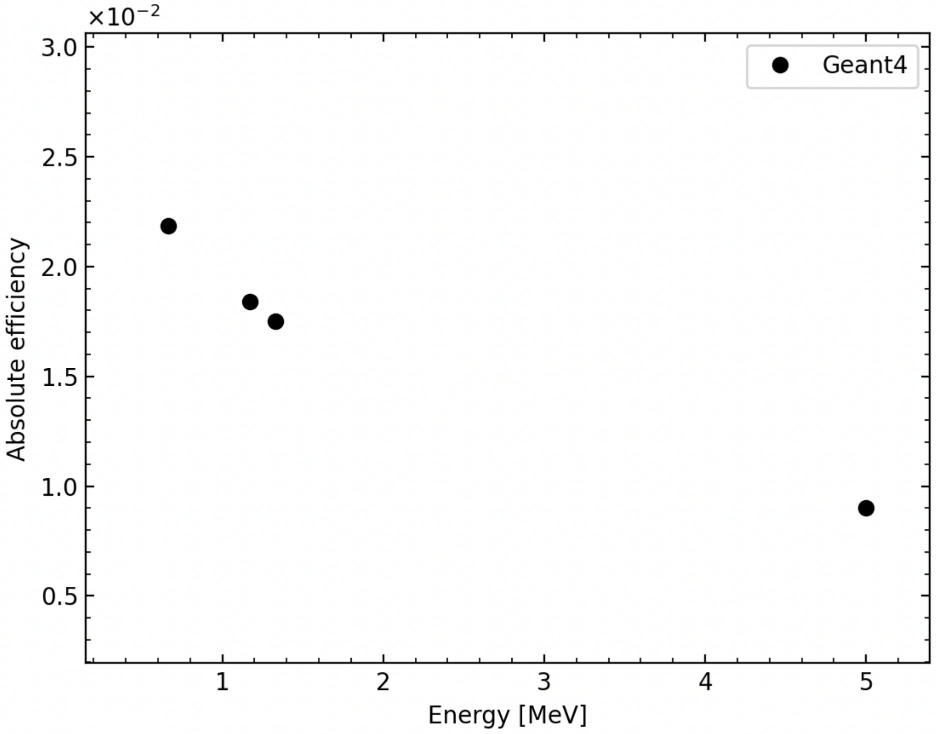




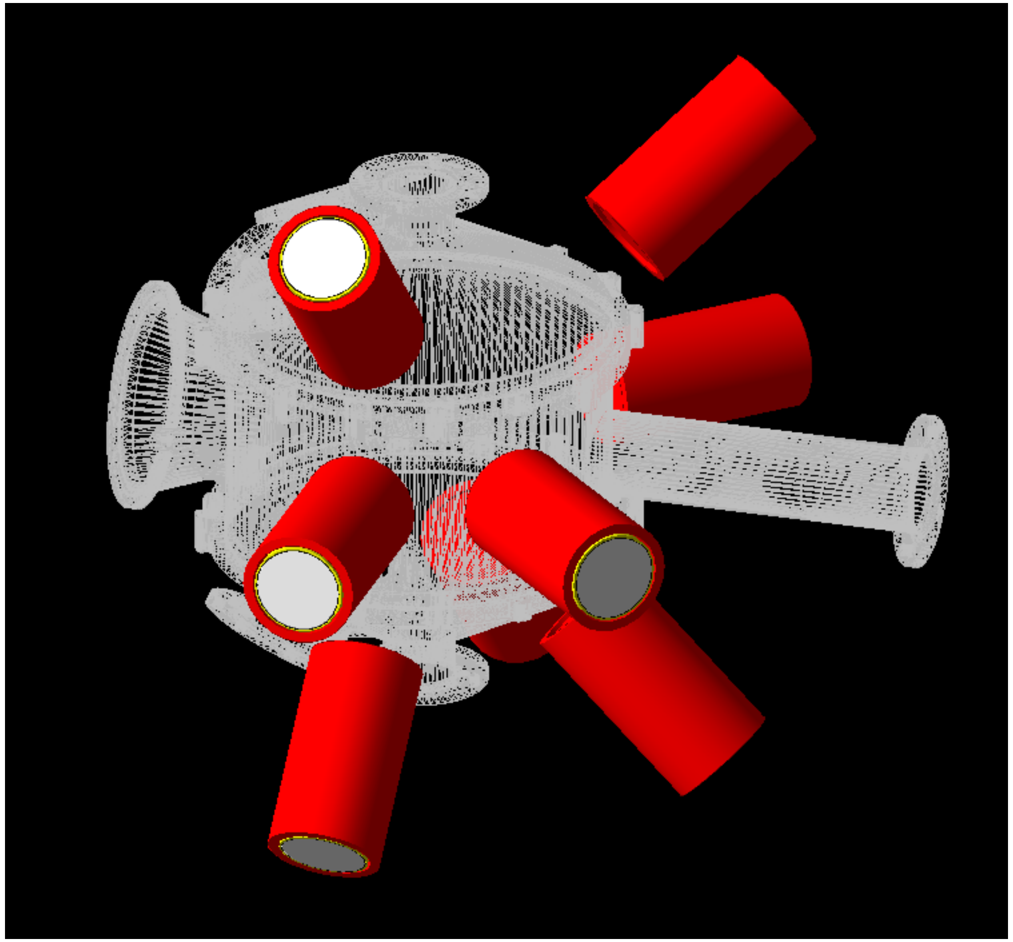
Branching ratio & Efficiency

Branching ratio

$$\frac{{}^{A}X(p,p'\gamma)\ counts}{{}^{A}X(p,p')\ counts} \times \frac{100}{efficiency}\ [\%]$$



Efficiency for full energy peak up to 5 MeV



^{12}C 0 degree

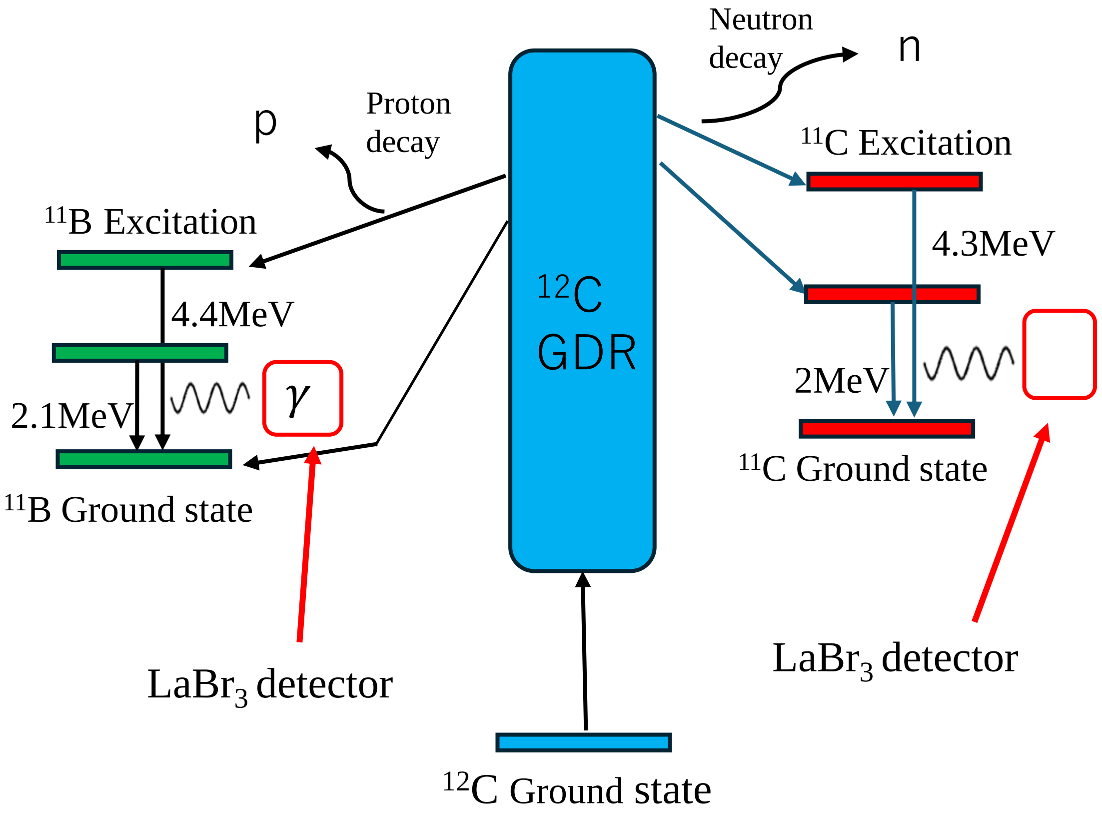
Branching ratio

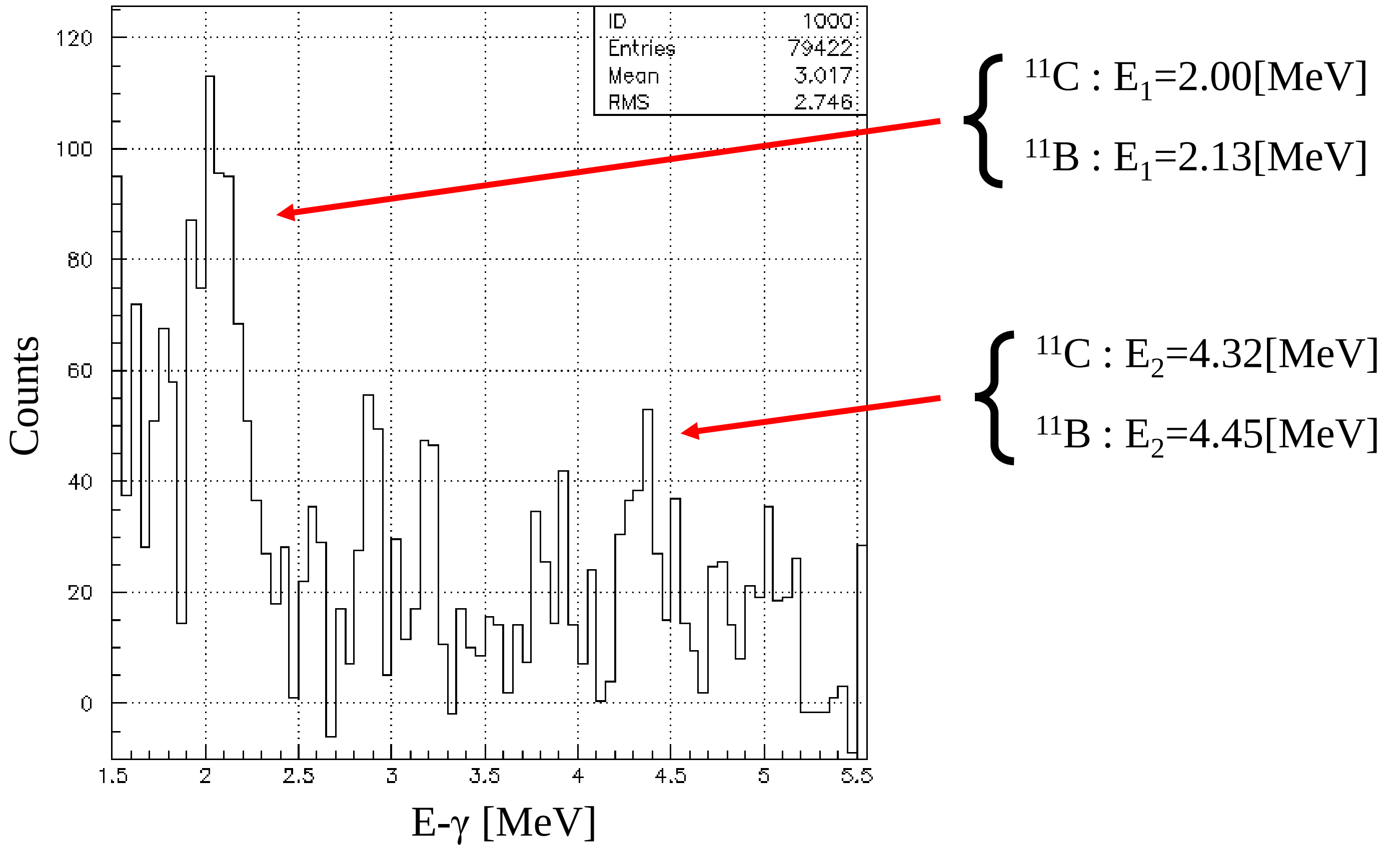
$$\frac{^{12}C(p,p'\gamma)\ counts}{^{12}C(p,p')\ counts} \times \frac{100}{efficiency}\ [\%]$$

Branching ratios

→ $^{11}C + ^{11}B : E_1 = 11.0\ [\%]$

$^{11}C + ^{11}B : E_2 = 7.2\ [\%]$

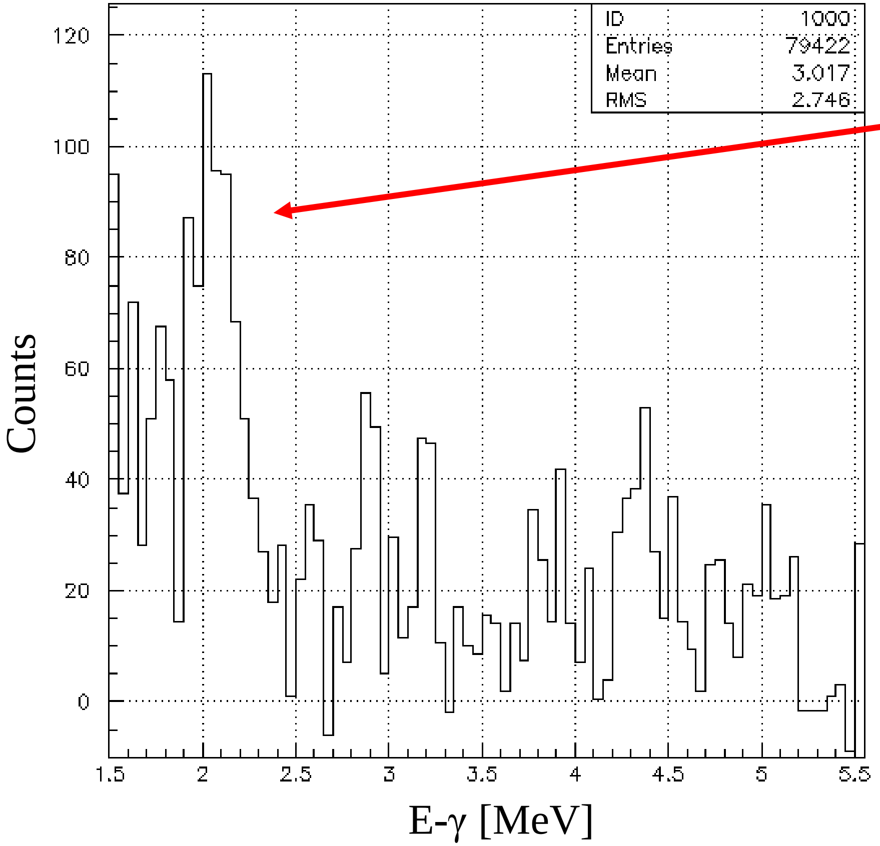




^{12}C 0 degree

Measurement of γ rays from giant resonances excited by the ^{12}C(p, p') reaction at 392 MeV and 0°

M. S. Reen,[1,*] I. Ou,[1] T. Sudo,[1] D. Fukuda,[1] T. Mori,[1] A. Ali,[1] Y. Koshio,[1] M. Sakuda,[1,†] A. Tamii,[2,‡] N. Aoi,[2] M. Yosoi,[2] E. Ideguchi,[2] T. Suzuki,[2] T. Yamamoto,[2] C. Iwamoto,[3] T. Kawabata,[4] S. Adachi,[5] M. Tsumura,[5] M. Murata,[5] T. Furuno,[5] H. Akimune,[6] T. Yano,[7] T. Suzuki,[8] and R. Dhir[9]

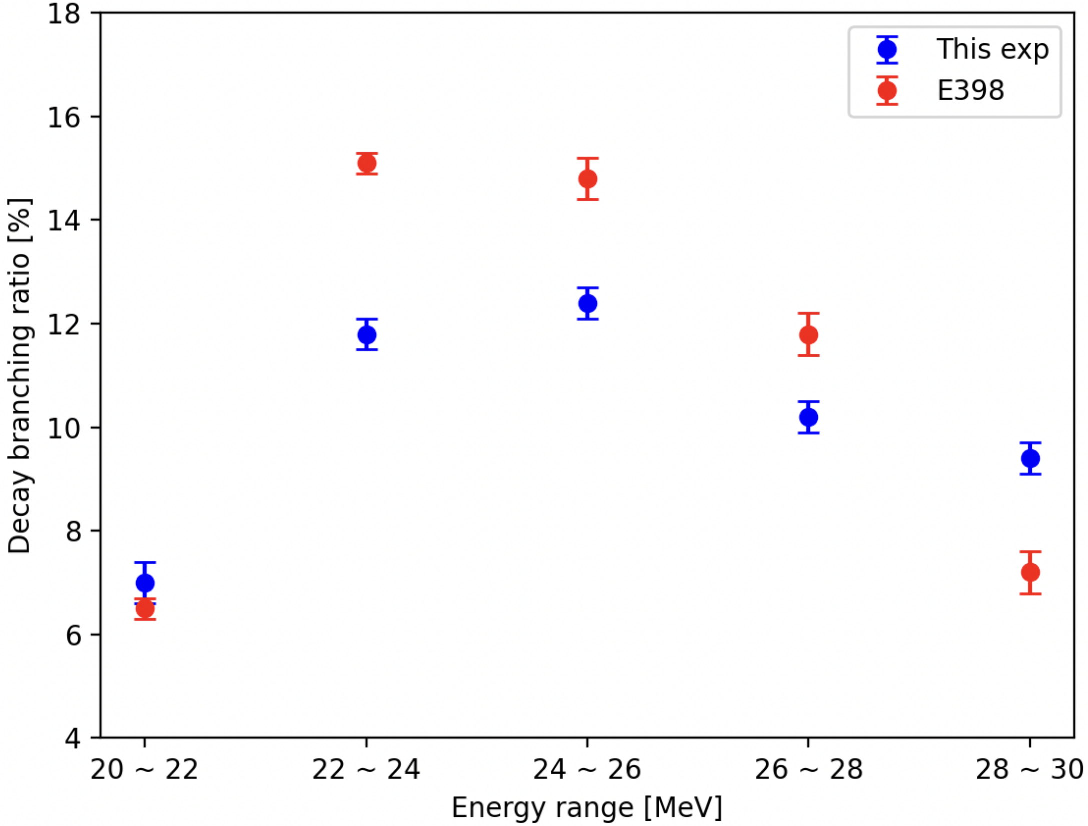


^{11}C : E_1=2.00[MeV]

^{11}B : E_1=2.13[MeV]

E398

- 392 MeV 0deg (p,p')
- ^{12}C target
- Gamma-decay measurement from GDR
- NaI scintillator



^{13}C 0 degree

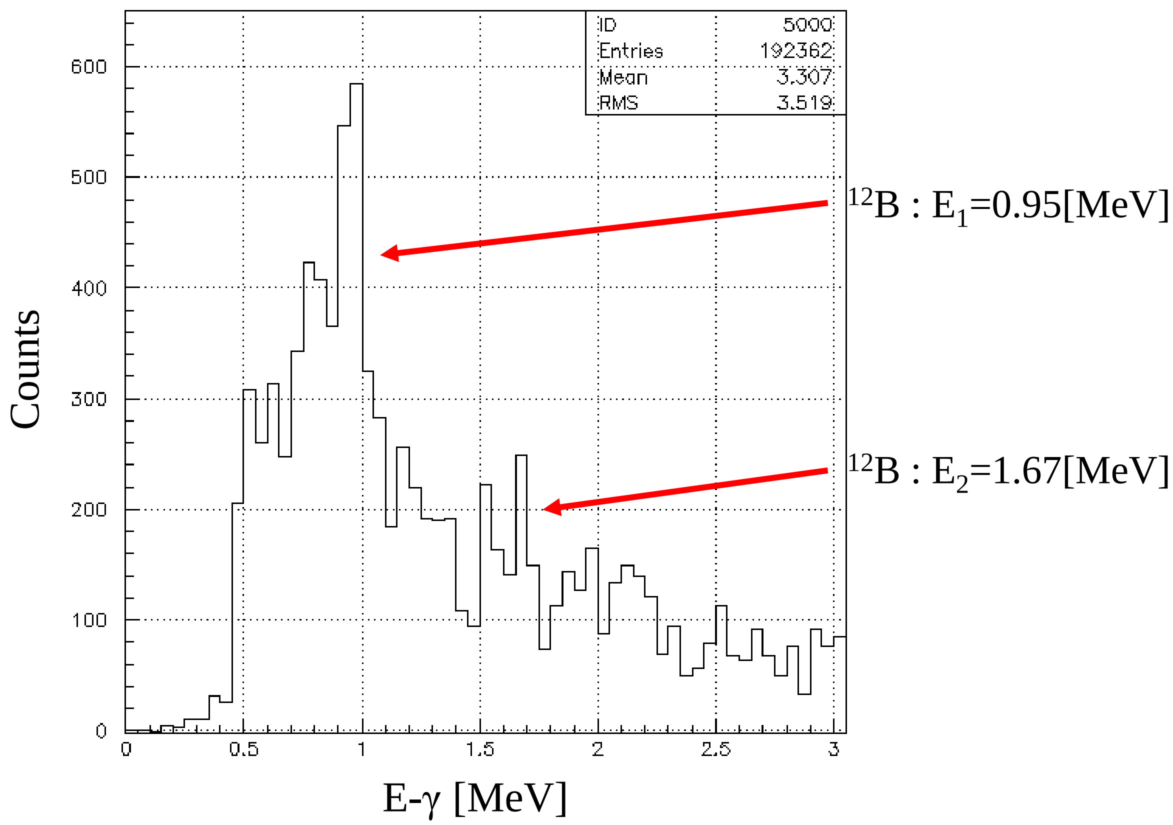
Branching ratio

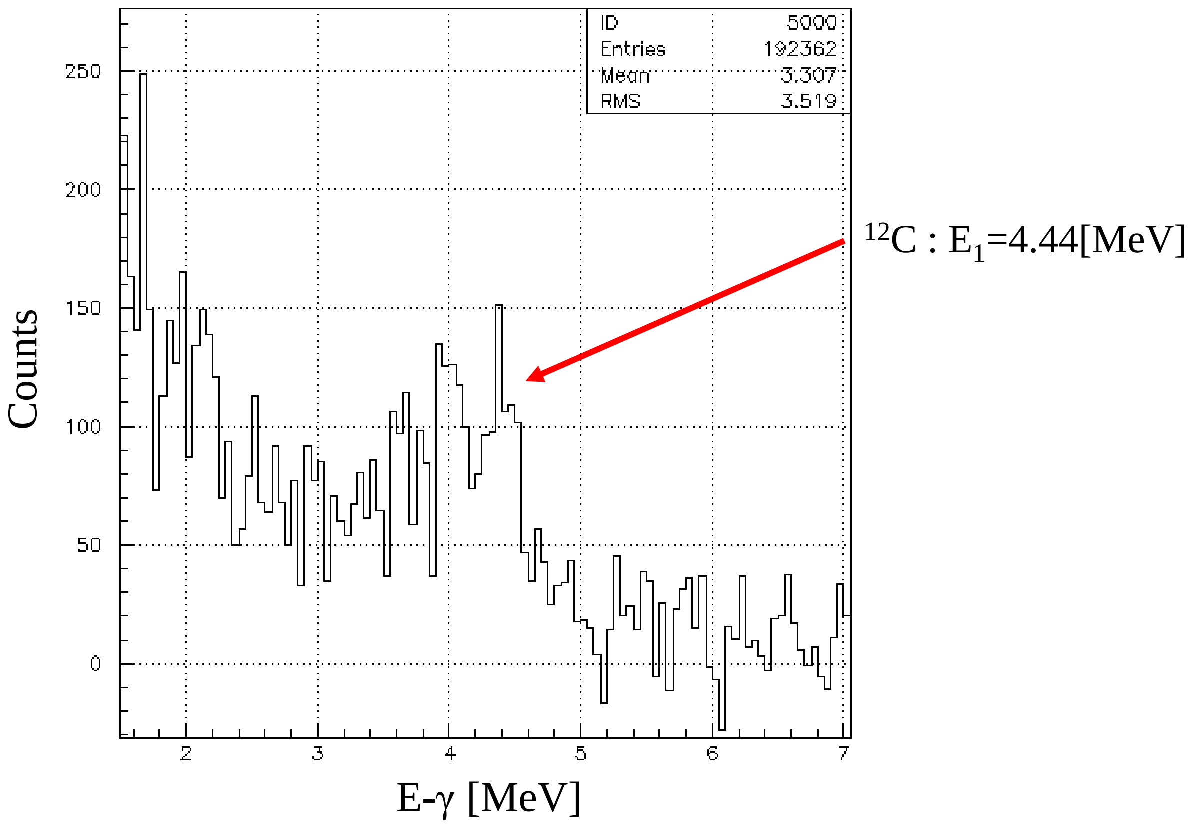
$$\frac{^{13}C(p,p'\gamma)\ counts}{^{13}C(p,p')\ counts} \times \frac{100}{efficiency}\ [\%]$$

Branching ratios

→ ^{12}C : E_1= 7.6[%]

^{12}B : E_1= 7.9[%] E_2= 2.3[%]





^{13}C 0 degree

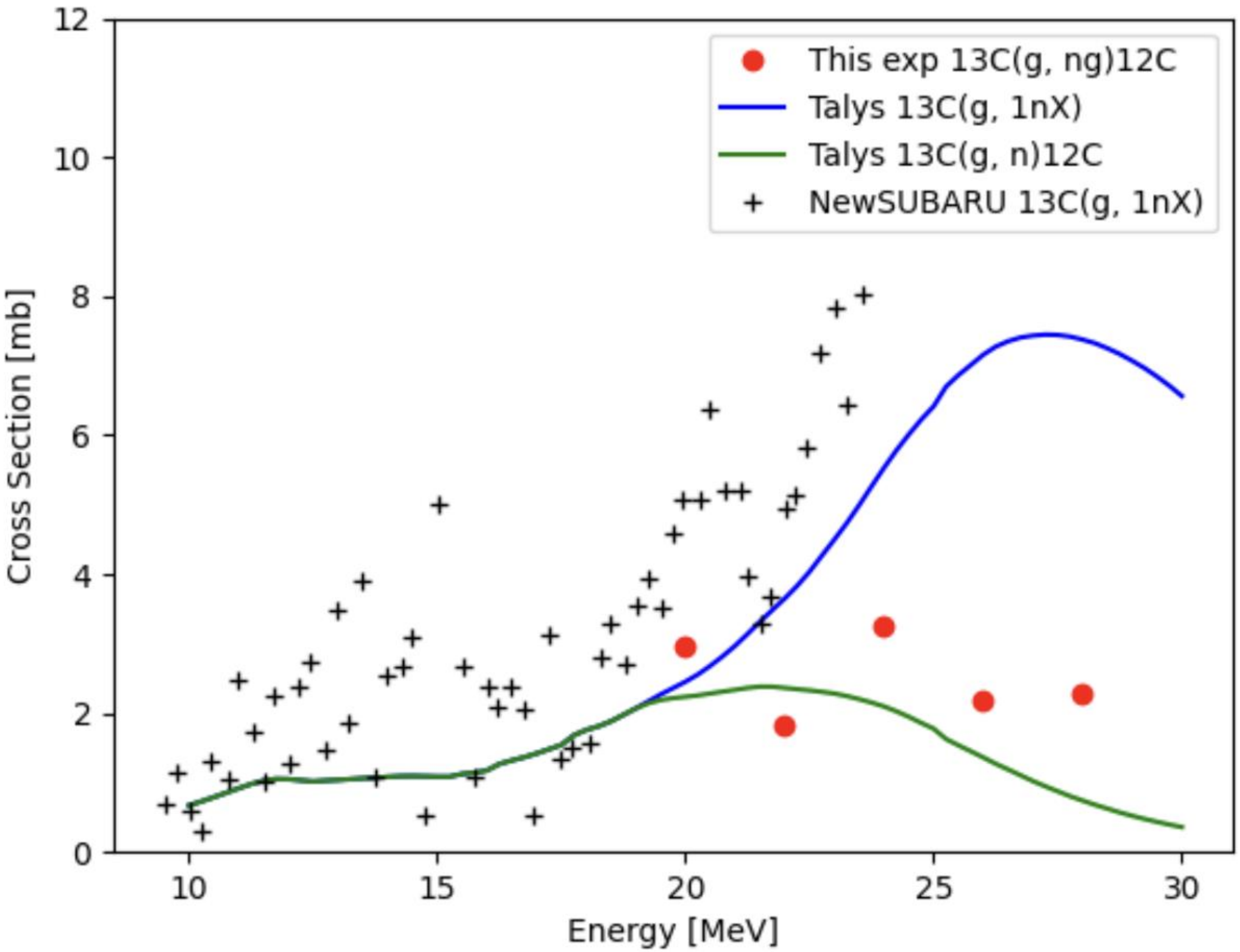
PHYSICAL REVIEW C **109**, 014617 (2024)

Photoneutron emission cross sections for ^{13}C

H. Utsunomiya,[1,2] S. Goriely,[3] M. Kimura,[4] N. Shimizu,[5] Y. Utsuno,[6,7] G. M. Tveten,[8,9] T. Renstrøm,[8,9] T. Ari-izumi,[1,10] and S. Miyamoto[11,12]

$$\int \frac{d^2\sigma}{dE d\Omega} d\Omega = \frac{1}{E} \int \frac{dN}{d\Omega} d\Omega \cdot \sigma_{abs}$$

$$\sigma_{(\gamma,ng)} = \sigma_{abs} \cdot Branch(\gamma, ng)$$



$S_{^{13}C}(p) = 17.53$ MeV
$S_{^{13}C}(n) = 4.95$ MeV

$S_{^{12}C}(p) = 15.60$ MeV
$S_{^{12}C}(n) = 18.72$ MeV

Summary

Summary

- Expected gamma-ray peaks appear in the analysis using the $LaBr_3$ detectors.

- Efficiency simulation on the Geant4 was done.

- Branching ratios and cross sections are roughly calculated.

→ Analysis on finite angle data and MDA is needed

Thank you

Presentation Backup

^{27}Al 0 degree

Branching ratio

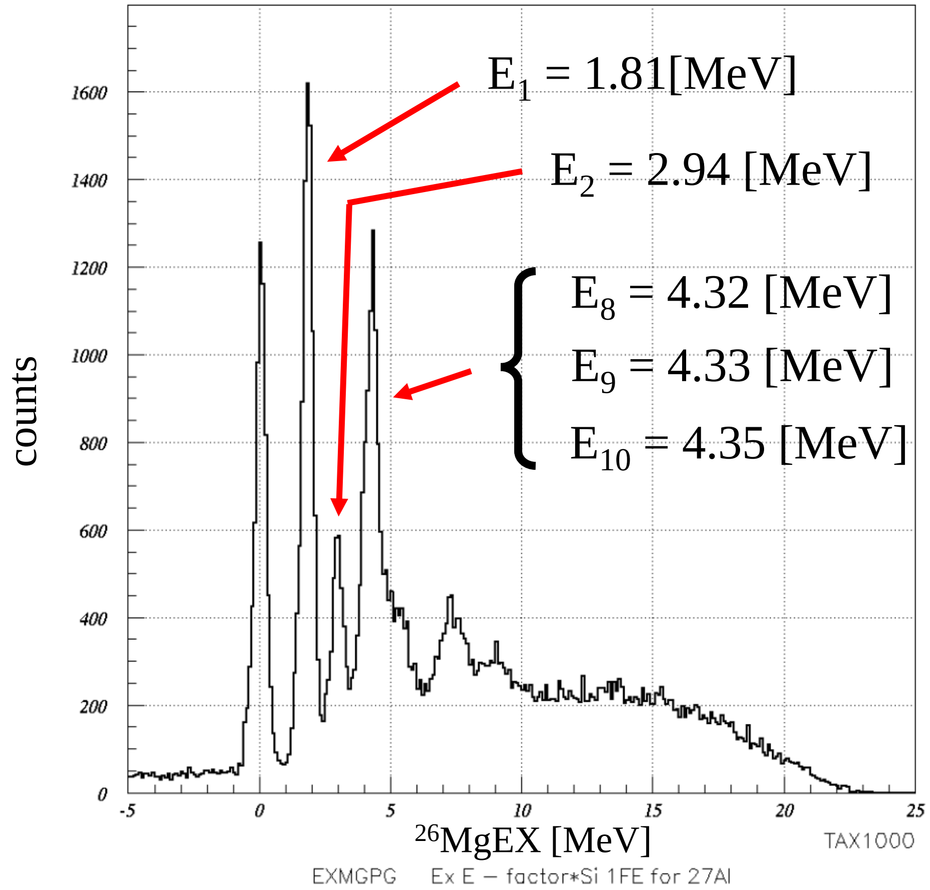
$$\frac{^{12}C(p,p'\gamma)\ counts}{^{12}C(p,p')\ counts} \times \frac{100}{efficiency}\ [\%]$$

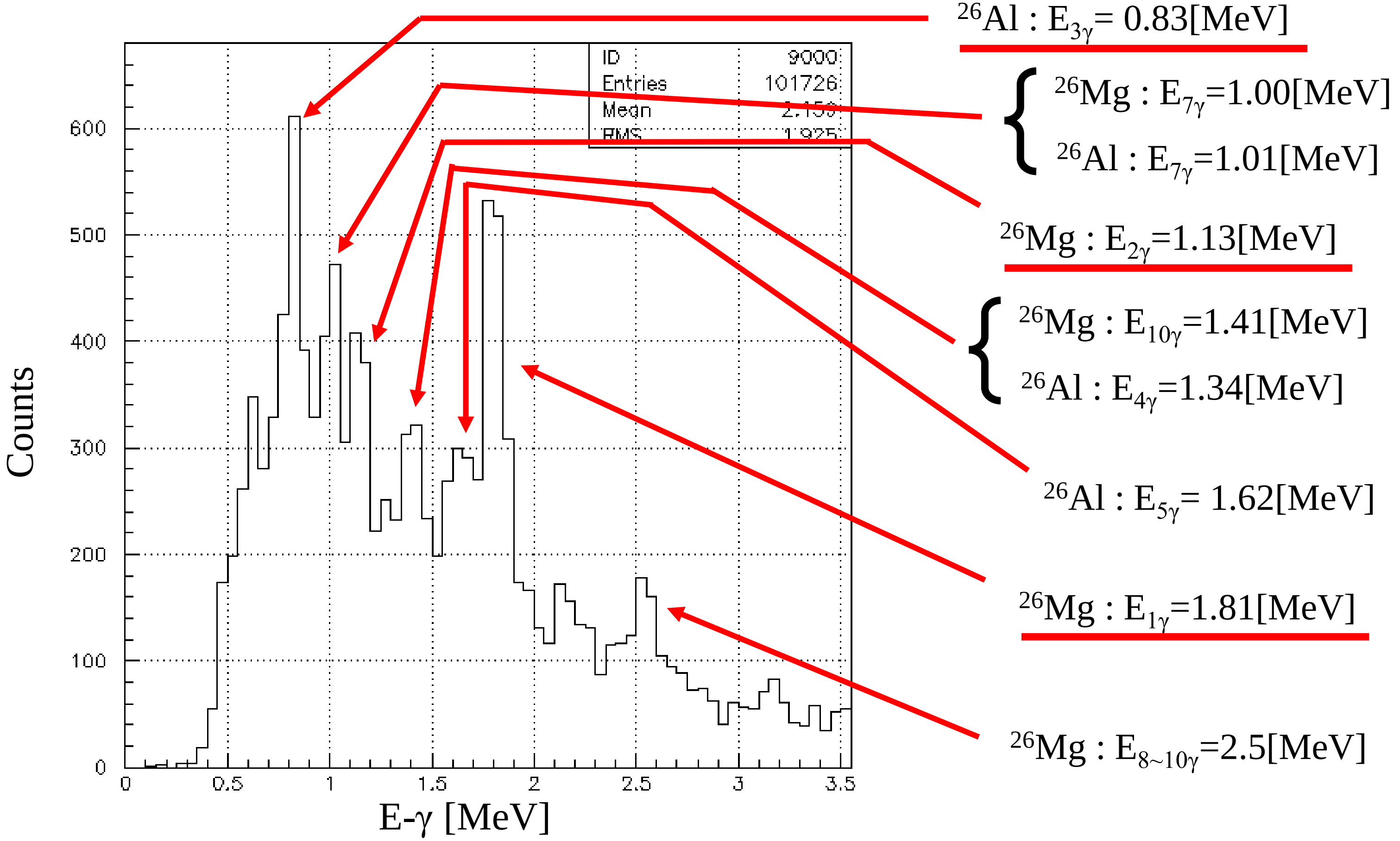
Branching ratios

→ ^{26}Al : E_3= 13.9[%]

^{26}Mg : E_1= 22.8[%] E_2= 8.4[%]

Analyzed by Y.Sasagawa





^{12}C 4.5 degrees

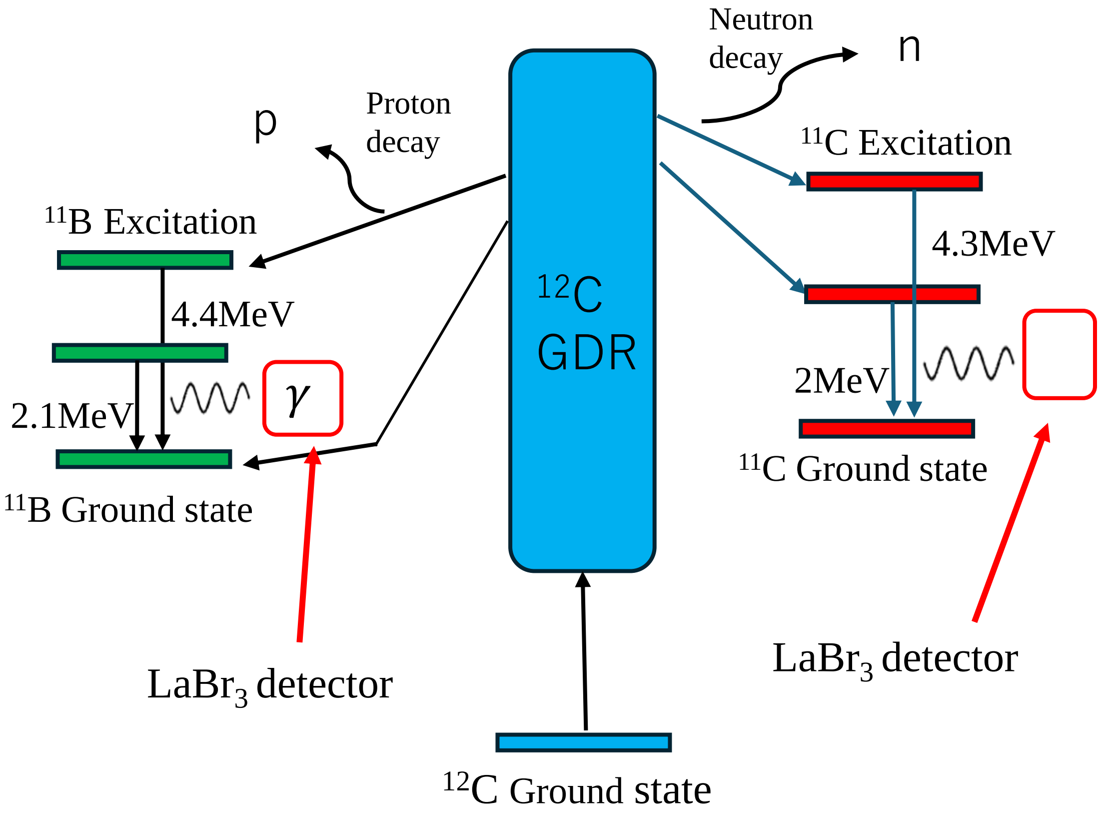
Branching ratio

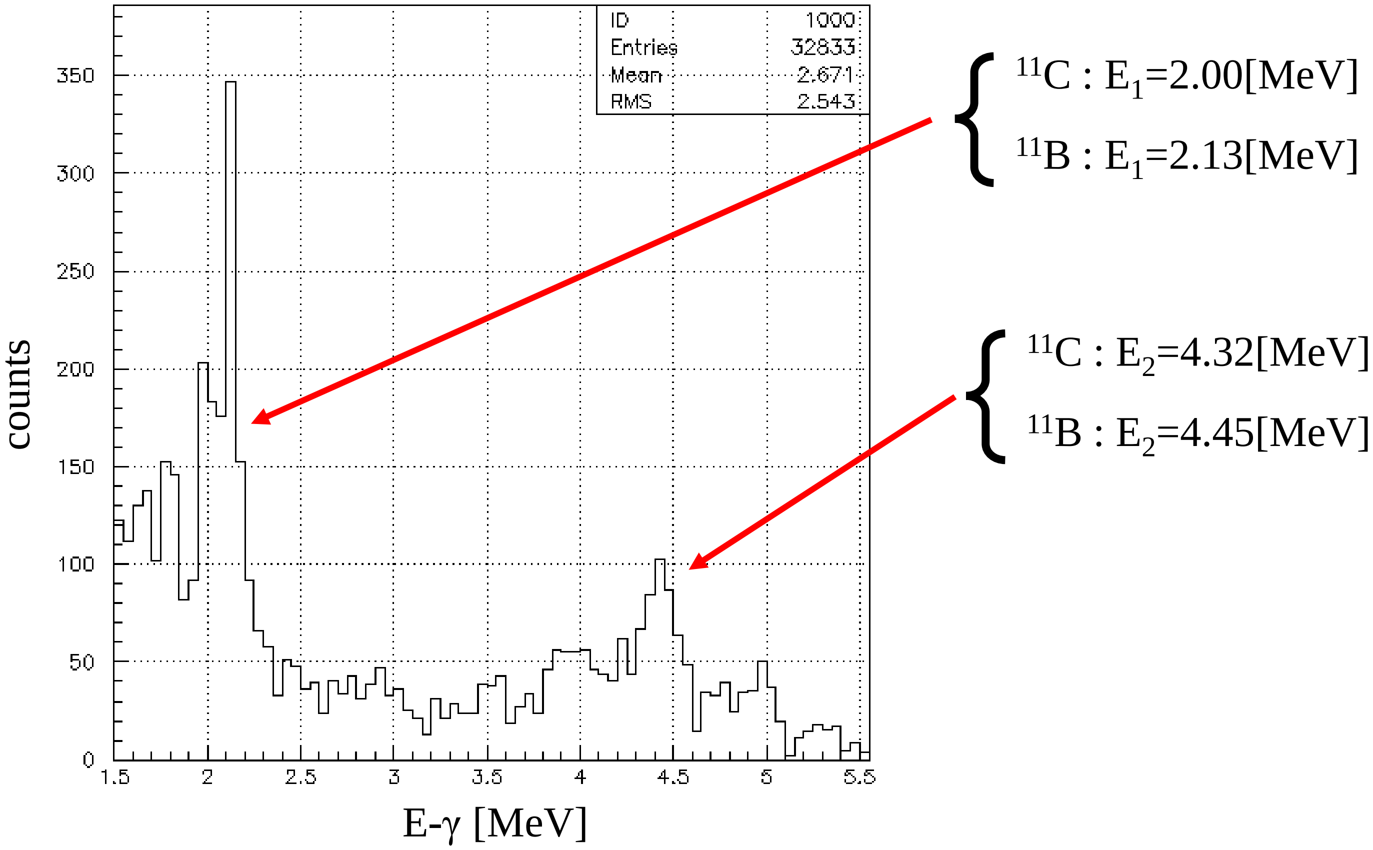
$$\frac{^{12}C(p,p'\gamma)\ counts}{^{12}C(p,p')\ counts} \times \frac{100}{efficiency}\ [\%]$$

Branching ratios

→ $^{11}C + {}^{11}B : E_1$=15.7 [%]

$^{11}C + {}^{11}B : E_2$= 10.5[%]



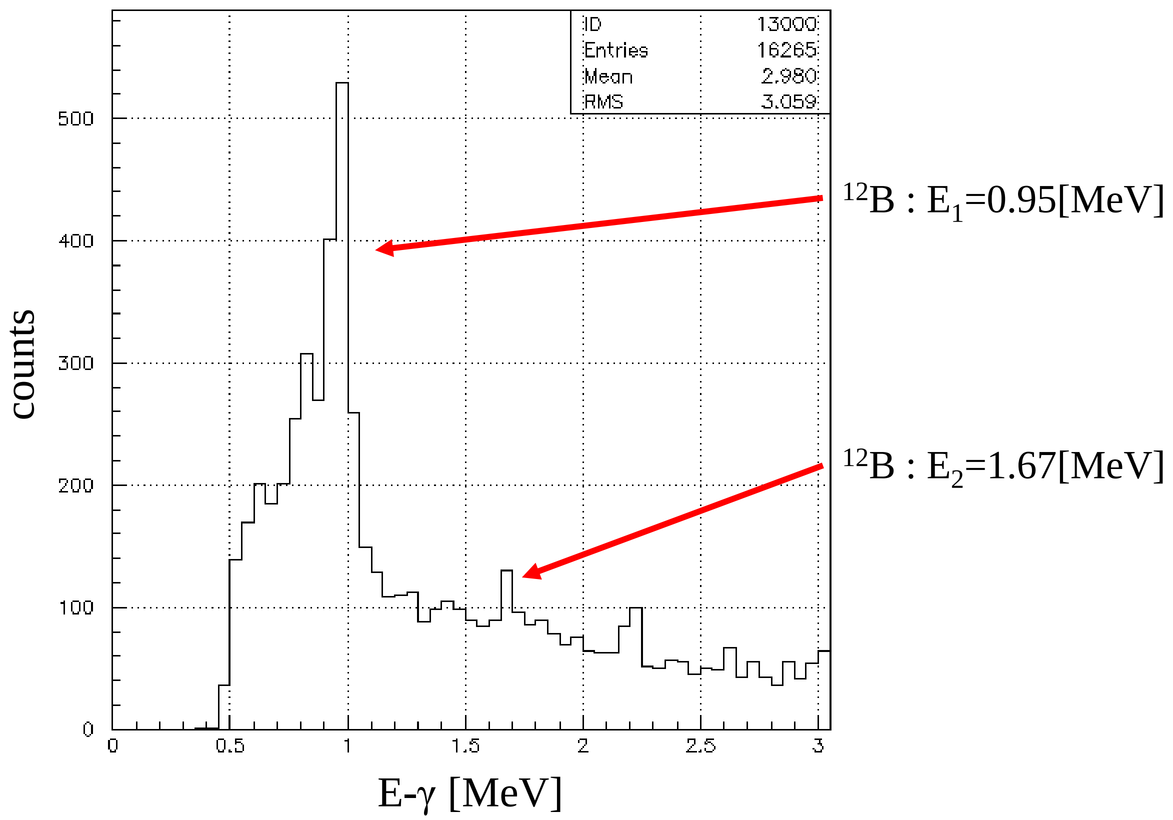


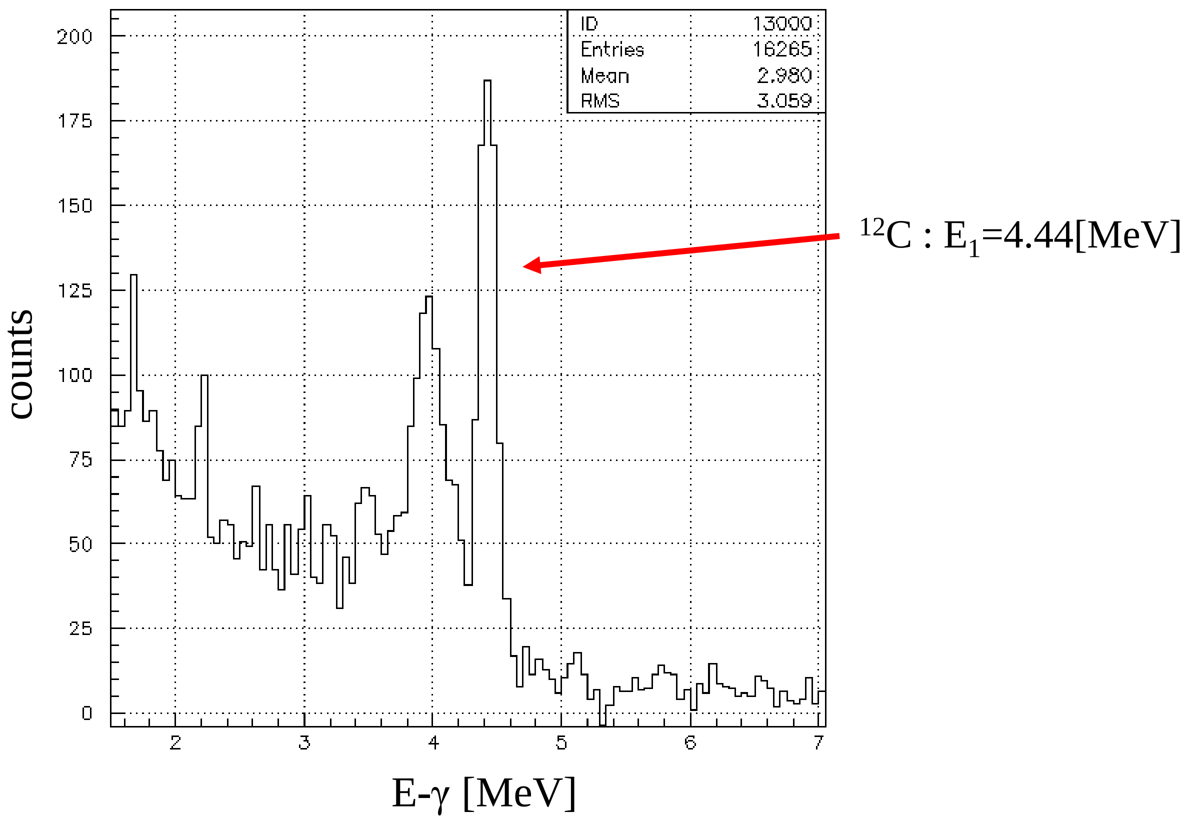
^{13}C 4.5 degrees

Branching ratio

$$\frac{^{13}C(p,p'\gamma)\ counts}{^{13}C(p,p')\ counts} \times \frac{100}{efficiency}\ [\%]$$

GR analysis has not been done yet



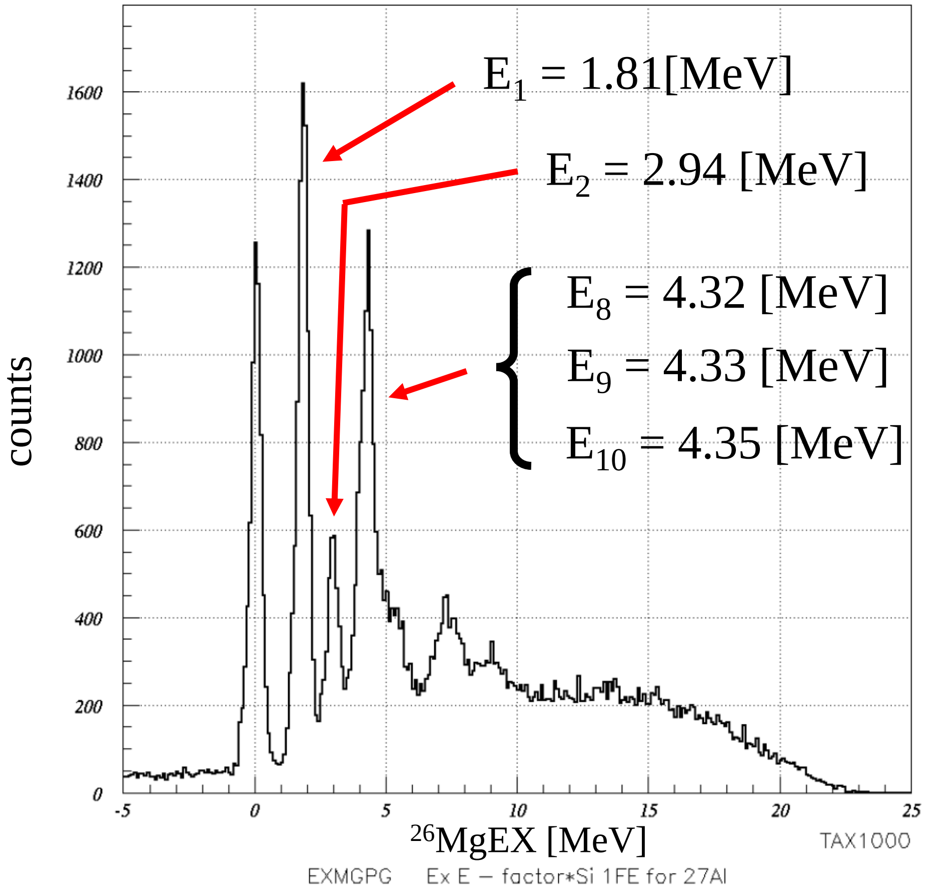


^{27}Al 4.5 degrees

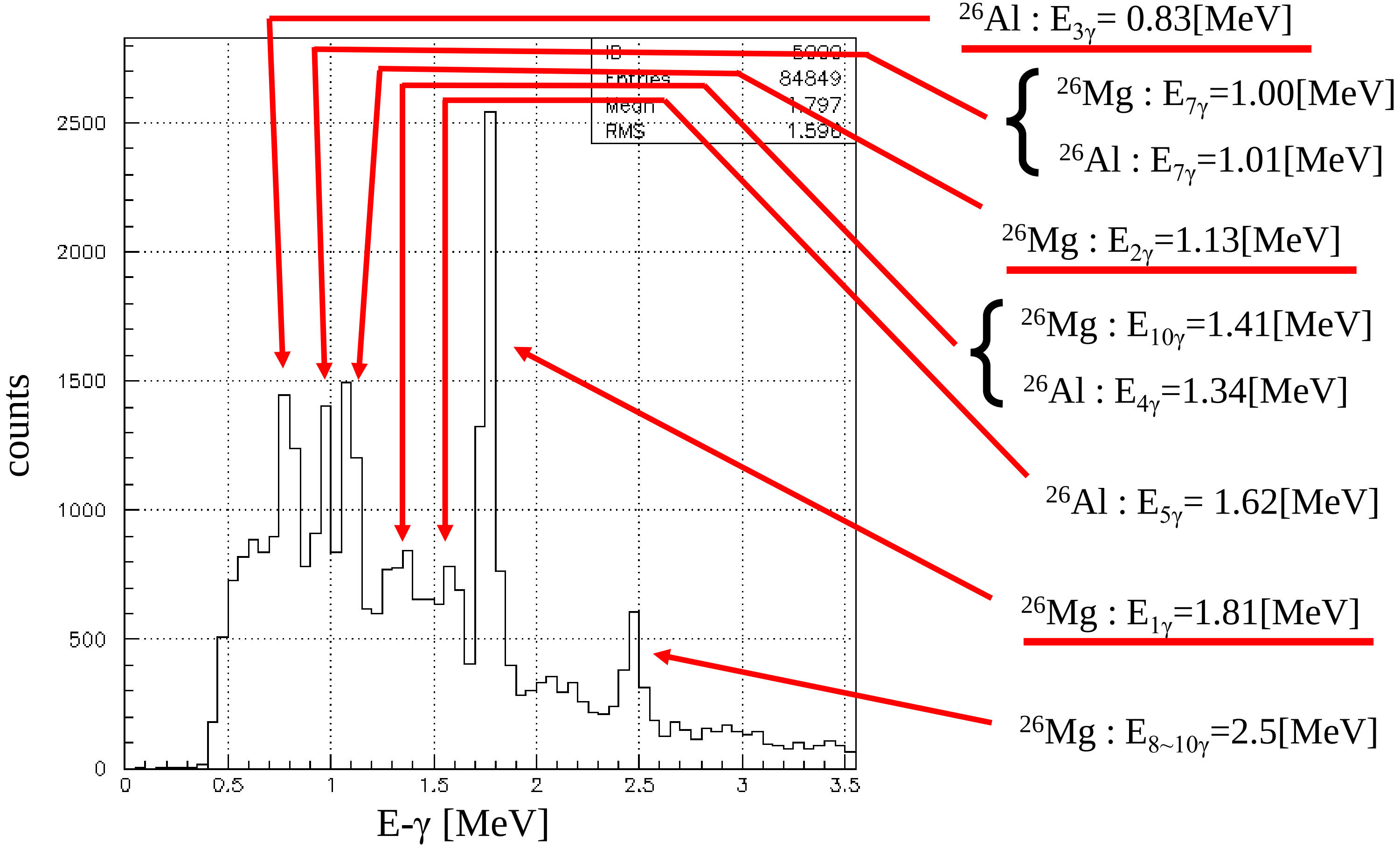
Branching ratio

$$\frac{^{12}C(p,p'\gamma)\ counts}{^{12}C(p,p')\ counts} \times \frac{100}{efficiency}\ [\%]$$

Analyzed by Y.Sasagawa



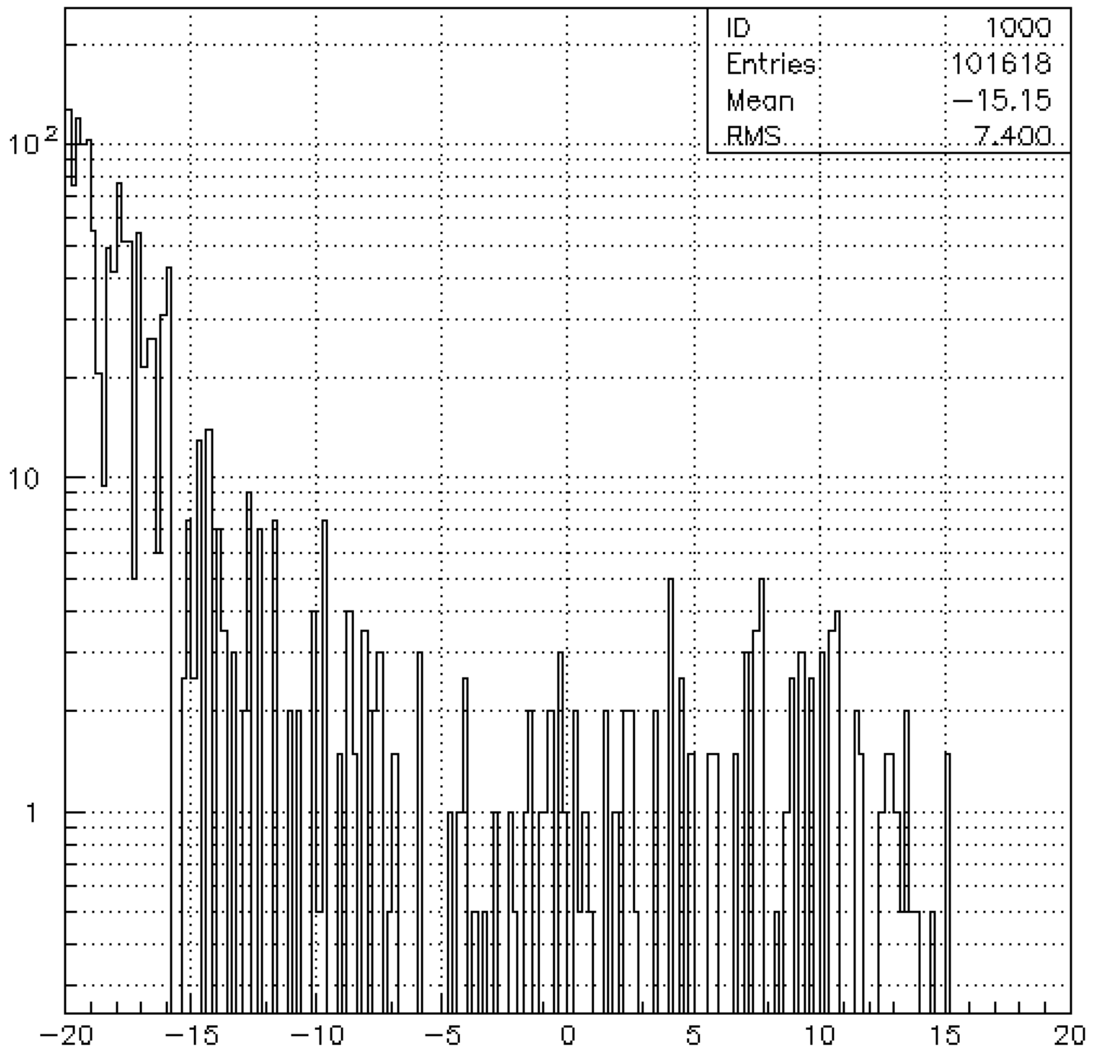
GR analysis has not been done yet

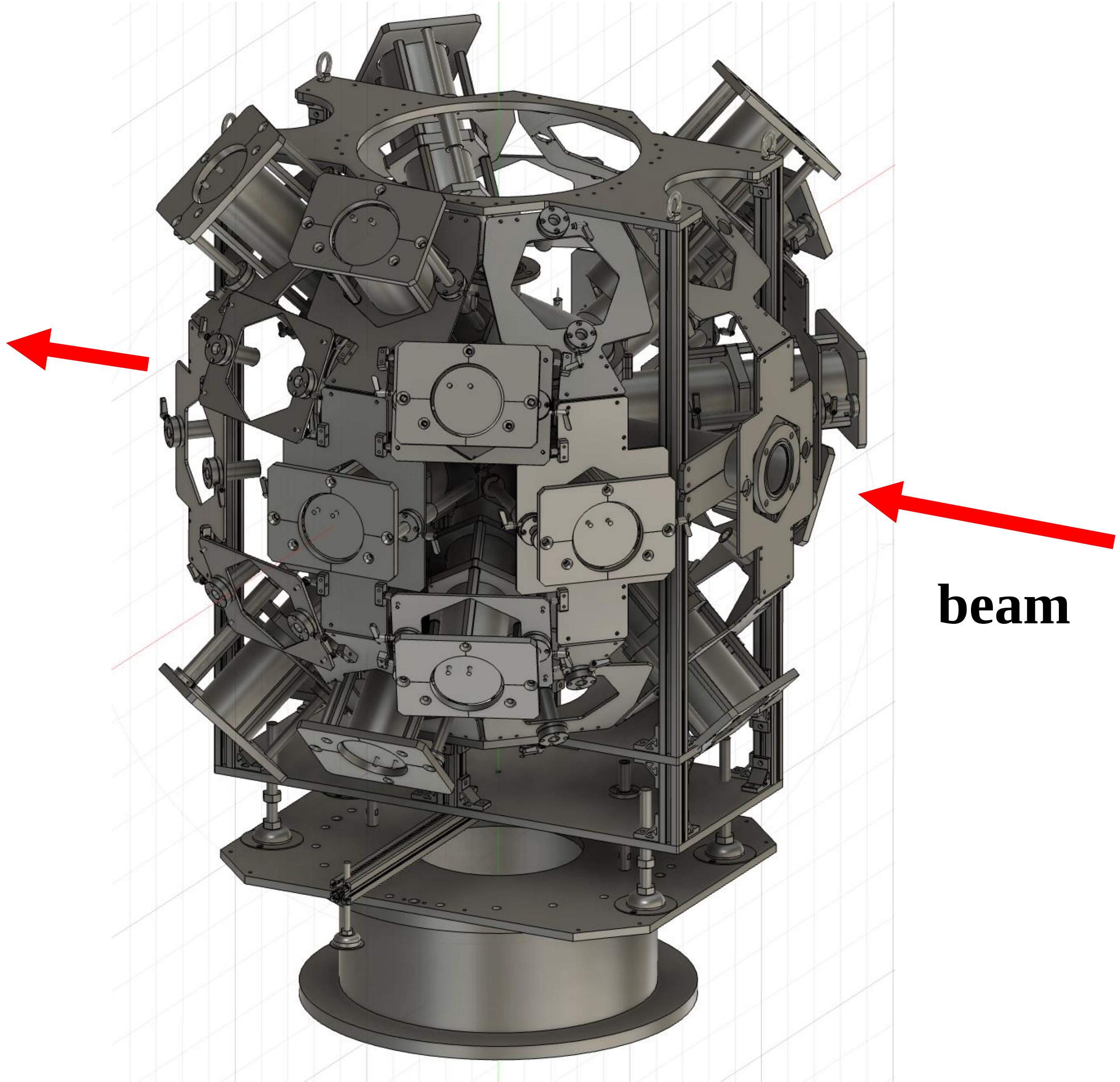


E(level) (keV)	XREF	J^π(level)	$T_{1/2}$(level)	E(γ) (keV)	I(γ)	M(γ)	Final Levels	
0	AB DE GHI K MNOP TU WX Za cdef ijklm opq stuvwxyz012345678	0+	STABLE					
4439.82 *21*	AB DE GHI K MNOP TU WXY a cdef ijklm opq stuvwxyz0123 5678	2+	10.8×10^{-3} eV *6* % IT = 100	4438.94	100	E2	0	0+
7654.07 *19*	AB DE GHIJK MNOP TUVWX a cdef ijkl nopqr uvwxyz0123 678	0+	9.3 eV *9* % IT = 4.16×10^{-2} % α ≈ 100	3213.79	100	E2	4439.82	2+
9641 *5*	DE GHIJ MNOP TUVWXY a cdef ijklmnopqr v xy 012 678	3−	46 keV *3* % α ≈ 100 % IT < 4.1×10^{-5}	9637	100	E3	0	0+
9870 *60*	ef k	2+	850 keV *85* % IT ≈ 7.1×10^{-6} % α ≈ 100					
9930 *30* ?	Z f k	0+	2710 keV *80*					
10.3E+3 *3* ?	AB N Z d i n v	(0+)	3.0 MeV 7 % α ≈ 100					
10847 *4*	D GH MN TUV X a def ijklmn pq x 2	1−	273 keV *5* % α ≈ 100					
11836 *4*	D GH MNO TUV XY a def ijkl n p x 2	2−	230 keV *8* % α ≈ 100 % IT > 0					
12400?	N	(5+,4−,6−,7+)	% α ≈ 100					
12710 *6*	AB GH MNOP TUVWXY a cde g ij l n p t vwxy 012	1+	18.1 eV *28* % IT = 2.2 % α = 97.8	8267 12703	15 *3* 100 *14*	M1 M1	4439.82 0	2+ 0+
13.3E3 *2* ?	G	4+	1.7 MeV *2*					
13316 *20*	I MN T V Y de kl n p x 2	4−	360 keV *43* % α ≈ 100 % IT > 0					
14079 *5*	GHI MN T a de g jkl nopq v x 0123 56 8	4+	272 keV *6* % α ≈ 100					
15110 *3*	B E MNOP TU XY a cde ij t vwx 012	1+	43.6 eV *10* % IT = 95.9 % α = 4.1	2400 4809 7453 10665 15100	1.5 *4* 4.2 *15* 2.83 *36* 2.49 *34* 100 *2*	M1 M1 M1 M1	12710 10.3E+3 7654.07 4439.82 0	1+ (0+) 0+ 2+ 0+
15440 *40*	a e hijk v	(2+)	1.77 MeV *20* % α ≈ 100					

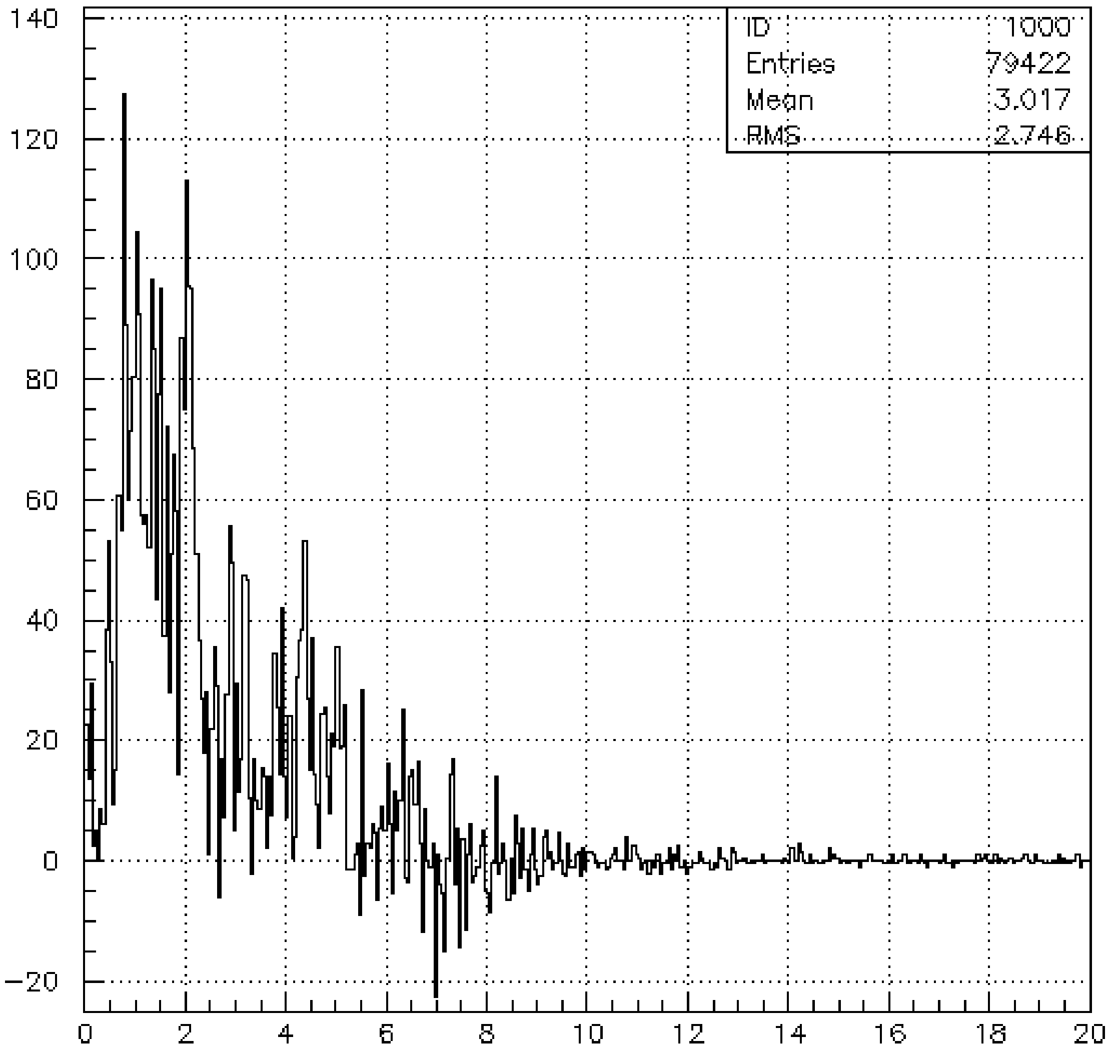
ELPIS

(Expanded $LaBr_3$ array for PANDORA Investigations with GR Spectrometer)





12C 0 degree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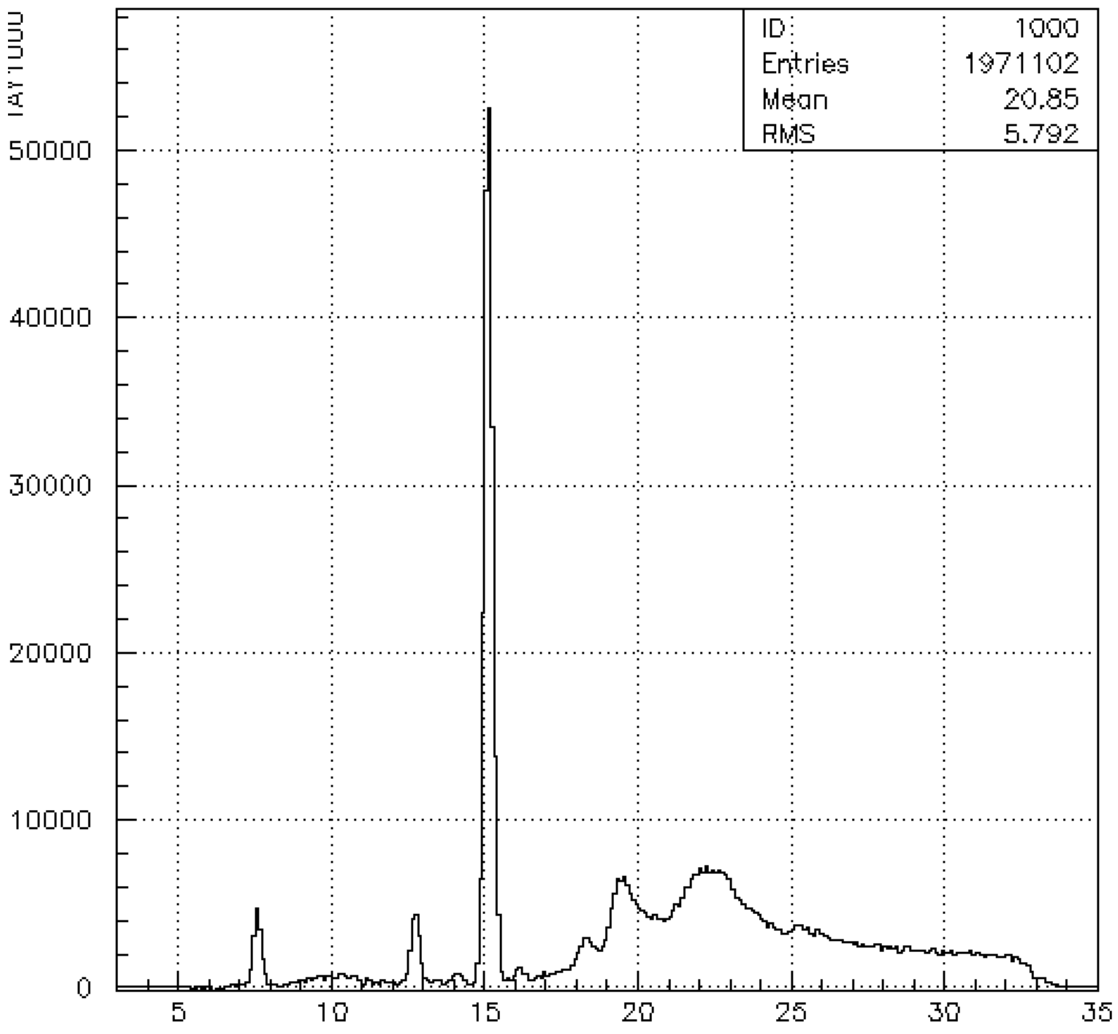
RMS 2.746


ID 1000
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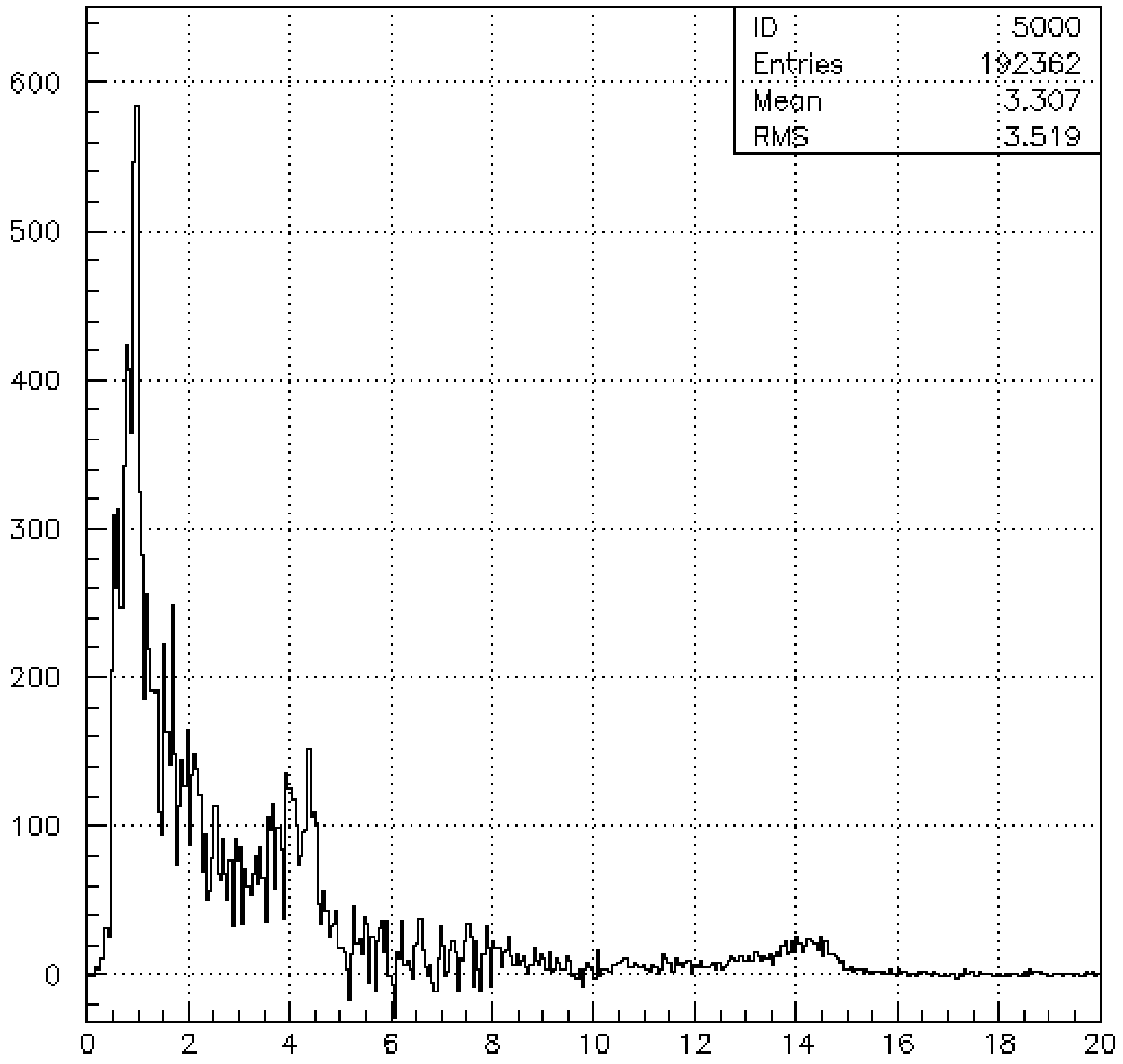
Mean 20.85
RMS 5.792

13C 0 degree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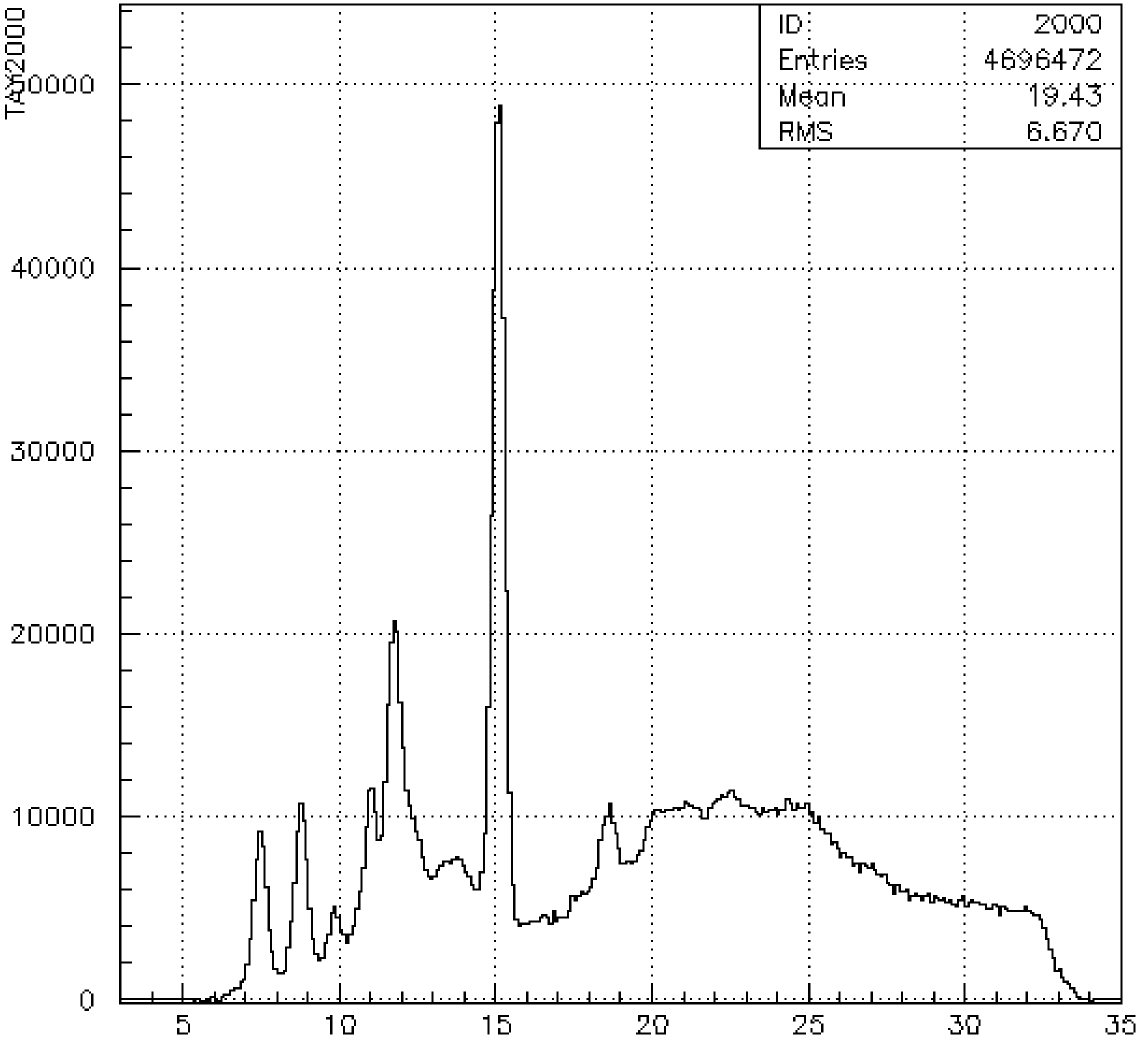
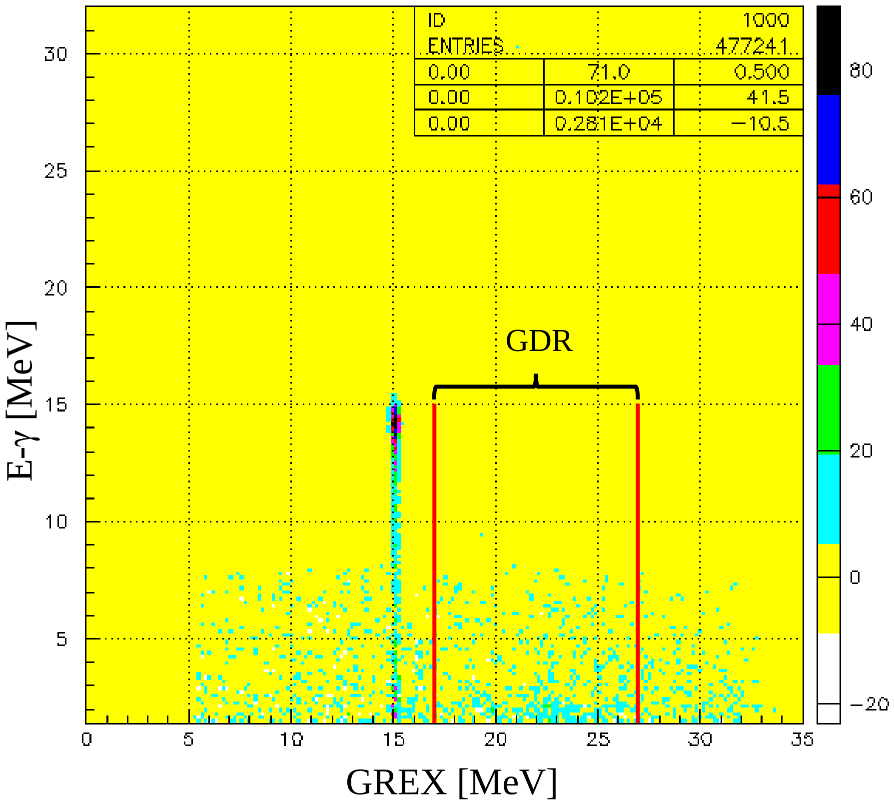
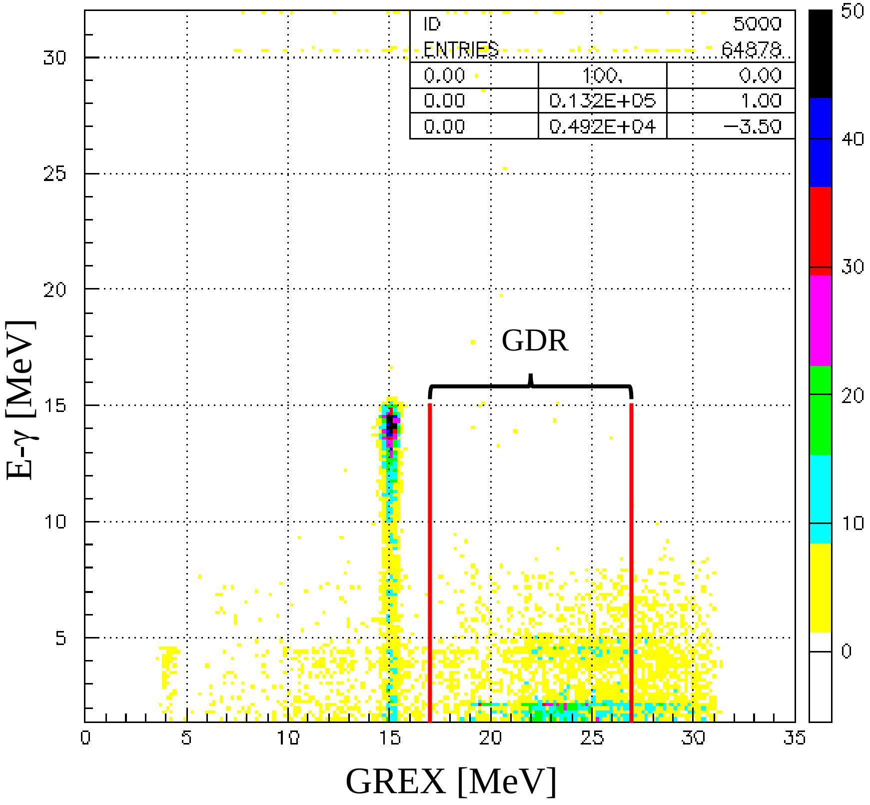
100
200
300
400
500
600
0 2 4 6 8 10 12 14 16 18 20


ID 2000
Entries 4696472
Mean 19.43
RMS 6.670
TAX2000
0
10000
20000
30000
40000
5 10 15 20 25 30 35

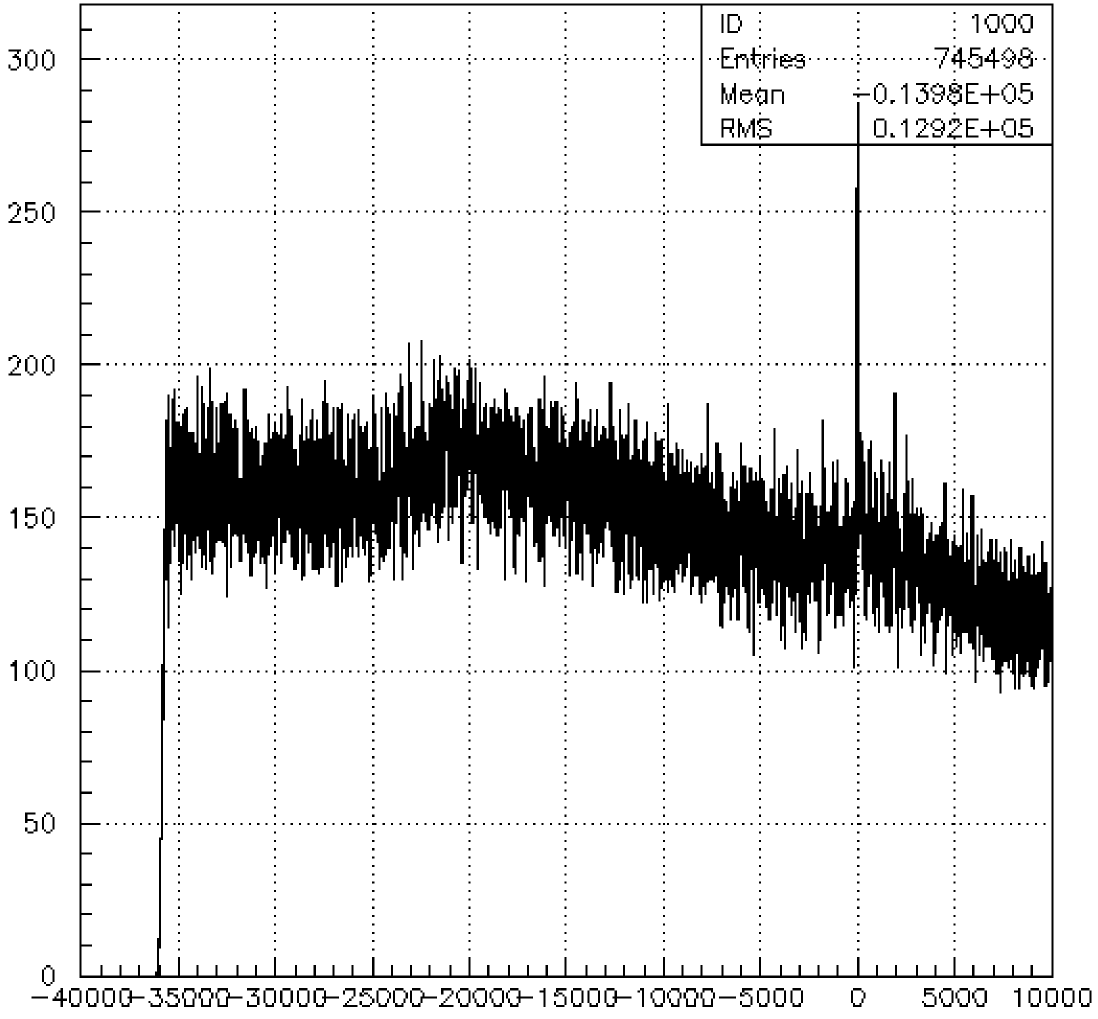
12C 0 degree



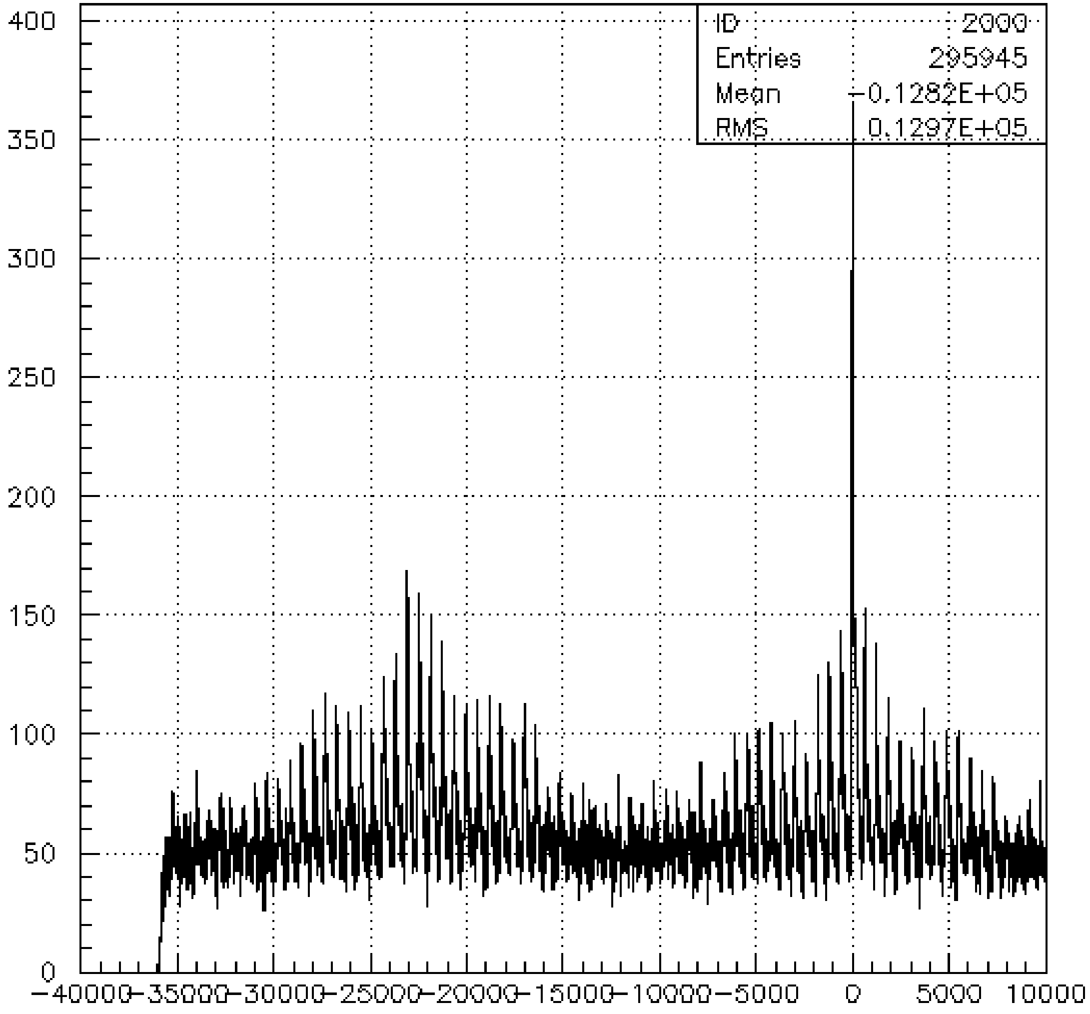
12C 0 degree



TDC data



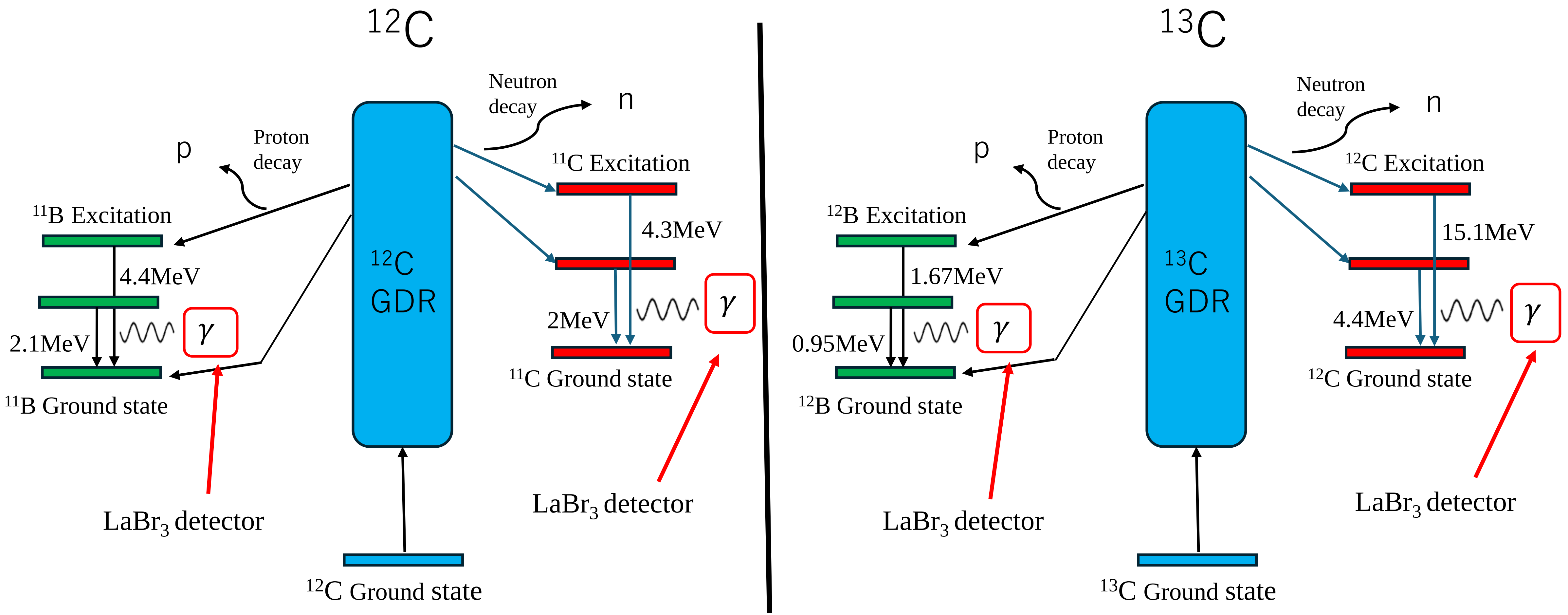
ID 1000
Entries 745498
Mean -0.1398E+05
RMS 0.1292E+05
300
250
200
150
100
50
0
-40000 -35000 -30000 -25000 -20000 -15000 -10000 -5000 0 5000 10000



ID 2000
Entries 295945
Mean -0.1282E+05
RMS 0.1297E+05
400
350
300
250
200
150
100
50
0
-40000 -35000 -30000 -25000 -20000 -15000 -10000 -5000 0 5000 10000

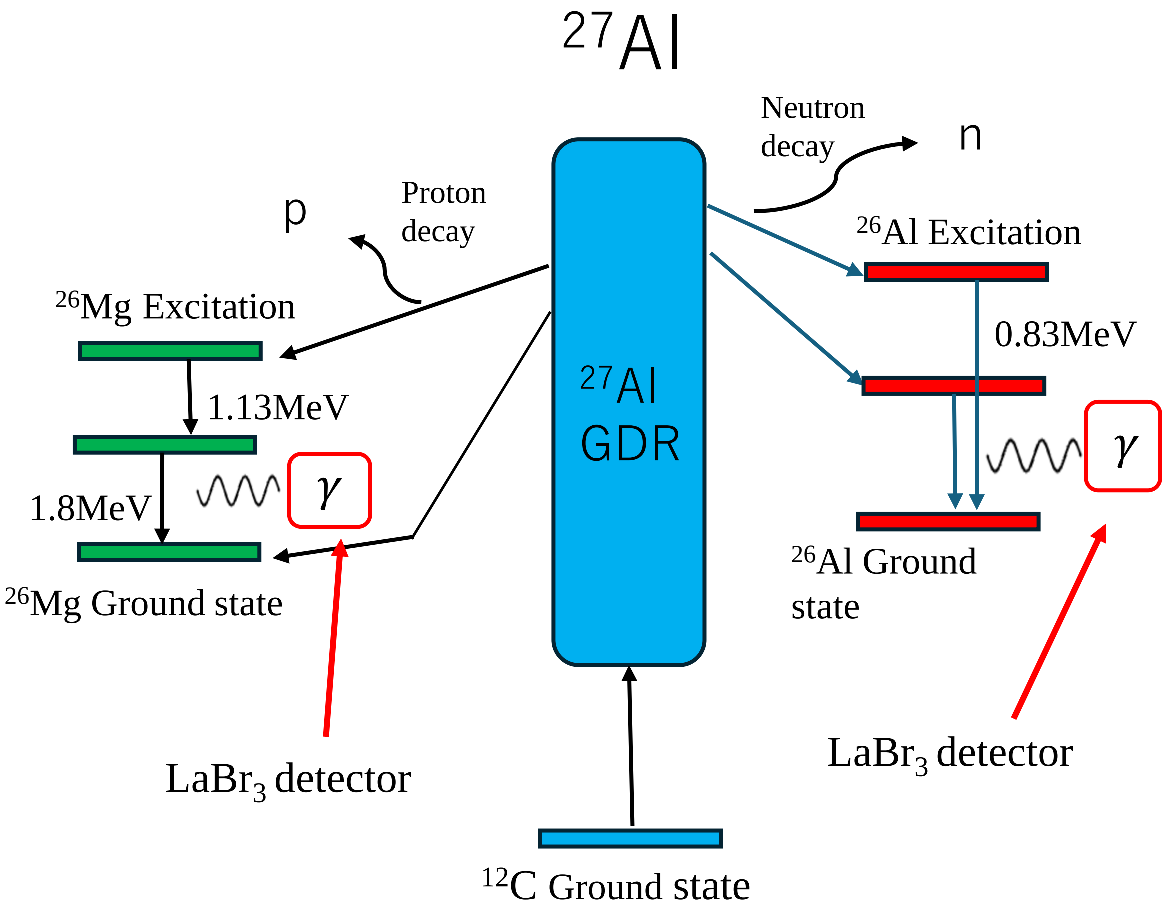
GDR & decays

Targets : ^{12}C, ^{13}C Scattering angles : 0° , 4.5° GDR : 17 ~ 27 MeV



GDR & decays

Targets : ^{27}Al　　Scattering angles : 0°, 4.5°　　GDR : 15 ~ 25 MeV



Proton decay (^{26}Mg)

S(p) = 8.3 MeV

GDR : 15 ~ 25 MeV

XREFs ☑ | J^{π} ☑ | $T_{1/2}$/Decay ☑ | E(γ) ☑ | I(γ) ☑ | M(γ) ☑ | Final Levels ☑

E(level) (keV)	XREF	J^{π}(level)	$T_{1/2}$(level)	E(γ) (keV)	I(γ)	M(γ)	Final Levels	
0.0	ABCDEFGHI KLM OPQRSTU	0+	STABLE					
1808.74 *4*	AB DE GHI KLM OPQR TU	2+	476 fs *21*	1808.68 *4*	100	E2	0.0	0+
2938.33 *4*	AB E GHI KLM OPQR TU	2+	141 fs *8*	1129.61 *4* 2938.15 *5*	100.0 *6* 10.7 *6*	M1+E2 E2	1808.74 0.0	2+ 0+
3082.9 *20*	E			1274.1 *20*	100		1808.74	2+
3420.2 *17*	E			1611.4 *17*	100	D+Q	1808.74	2+
3564.9 *19*	E			1756.1 *19*	100		1808.74	2+
3588.56 *9*	E GHI KLM OPQR TU	0+	6.45 ps *48*	1779.74 *8*	100	E2	1808.74	2+
3941.57 *4*	A E GHI KL OP R TU	3+	0.83 ps *12*	1003.25 *4* 2132.71 *4*	100.0 *16* 61.3 *16*	M1+E2 M1	2938.33 1808.74	2+ 2+
4318.89 *5*	A E GHI L OPQR TU	4+	272 fs *16*	1380.88 *18* 2510.01 *5*	1.85 *11* 100 *2*	 [E2]	2938.33 1808.74	2+ 2+
4332.52 *5*	A E GHI LM OPQR U	2+	20 fs *3*	1394.28 *7* 2523.69 *6* 4332.2 *3*	19.3 *10* 100.0 *13* 7.6 *8*	 [E2]	2938.33 1808.74 0.0	2+ 2+ 0+
4350.09 *4*	A E G I L OPQR	3+	105 fs *28*	409.4 *5* 1411.72 *4* 2541.18 *6*	0.041 *25* 93 *4* 100 *4*	 M1+E2 M1+E2	3941.57 2938.33 1808.74	3+ 2+ 2+
4644.9 *13*	E			2836.0 *13*	100	D+Q	1808.74	2+

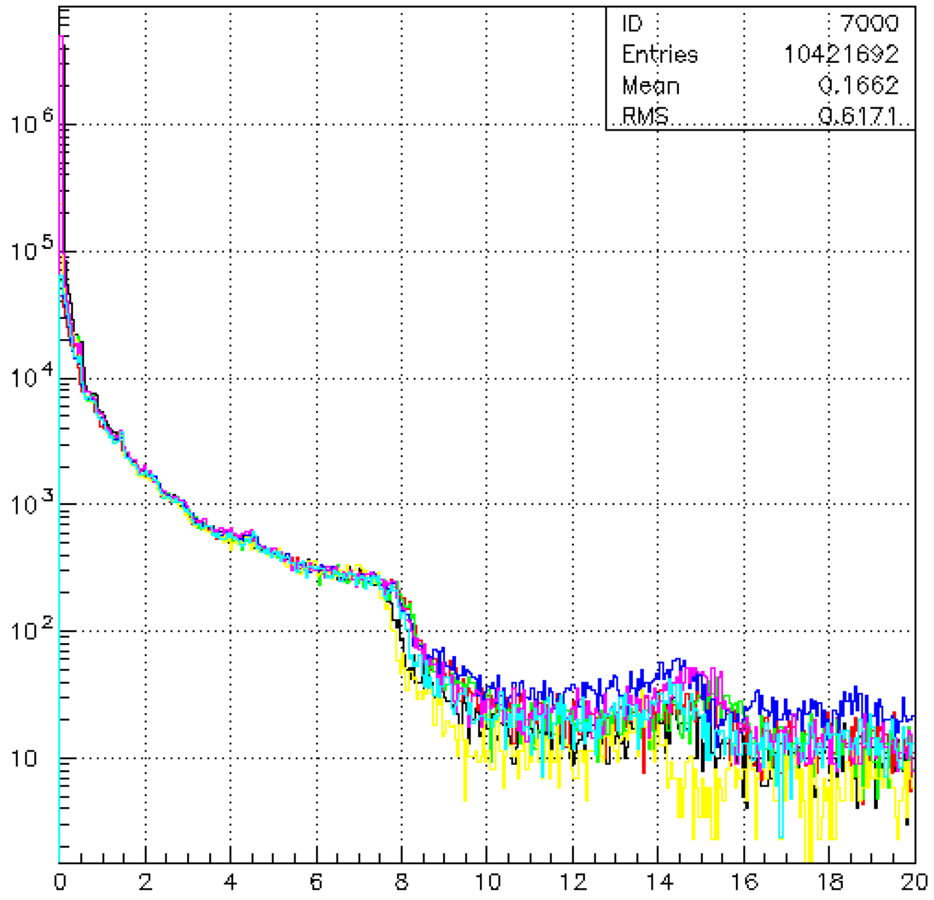
Proton decay (^{26}Al)

S(n) = 13.1 MeV

GDR : 15 ~ 25 MeV

E(level) (keV)	XREF	J^{π}(level)	$T_{1/2}$(level)	E(γ) (keV)	I(γ)	M(γ)	Final Levels	
0.0	ABCDEFGHIJKLMNOP	5+	$7.17\times10^{+5}$ y 24 % ε = 100					
228.305 13	AB DEFGHIJKLMNO	0+	6.3460 s 8 % ε = 100					
416.852 3	A D FGHIJKLMNOP	3+	1.20 ns 1	416.848	100	[E2]	0.0	5+
1057.739 12	A CD FGHIJKLMNOP	1+	25 fs 5	829.3 4	100	M1	228.305	0+
1759.034 8	A CD FGHIJ LMN P	2+	3.8 ps 6	701.285 1342.145	2.0 1 100.0 1		1057.739 416.852	1+ 3+
1850.62 3	A D FGH JKLMNOP	1+	32 fs 3	1433.73 1622.0 7	0.7 1 100.0 1	[E2] M1	416.852 228.305	3+ 0+
2068.86 5	CD FG J LMNOP	(4+)	310 fs 50	1651.95 2068.77	100.0 15 44.9 15	 (M1+)E2	416.852 0.0	3+ 5+
2069.47 3	D FGH J LMNOP	(2+)	14 fs 2	218.85 310.43 1011.71 1652.56 1841.09	0.053 13 0.23 3 100.0 12 28.4 11 4.0 5	[M1] [M1] [M1] [M1] E2	1850.62 1759.034 1057.739 416.852 228.305	1+ 2+ 1+ 3+ 0+
2071.64 4	A CD FG JKLMNOP	1+	367 fs 69	221.02 1654.73 1842.8 7	0.045 11 11.9 10 100 1	 [E2] M1	1850.62 416.852 228.305	1+ 3+ 0+
2365.150 18	CD FGH J LM OP	3+	0.8 ps 2	295.678 606.108 1307.375 1948.219 2365.034	100 2 2.90 10 26.9 8 64.7 20 1.75 8	[M1] [E2] [E2]	2069.47 1759.034 1057.739 416.852 0.0	(2+) 2+ 1+ 3+ 5+

Calibration



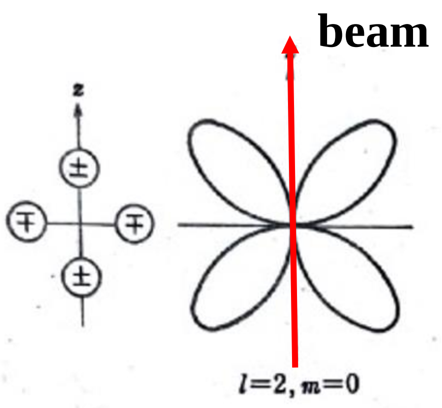
$LaBr_3$ setup on next experiment

2^{nd} PANDORA experiment

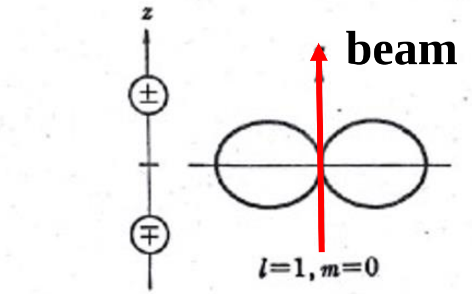
The number of $LaBr_3$ detectors will be 16.

Angles : 45°, 90°, 112.5°, 135°

4 detectors for each angle.



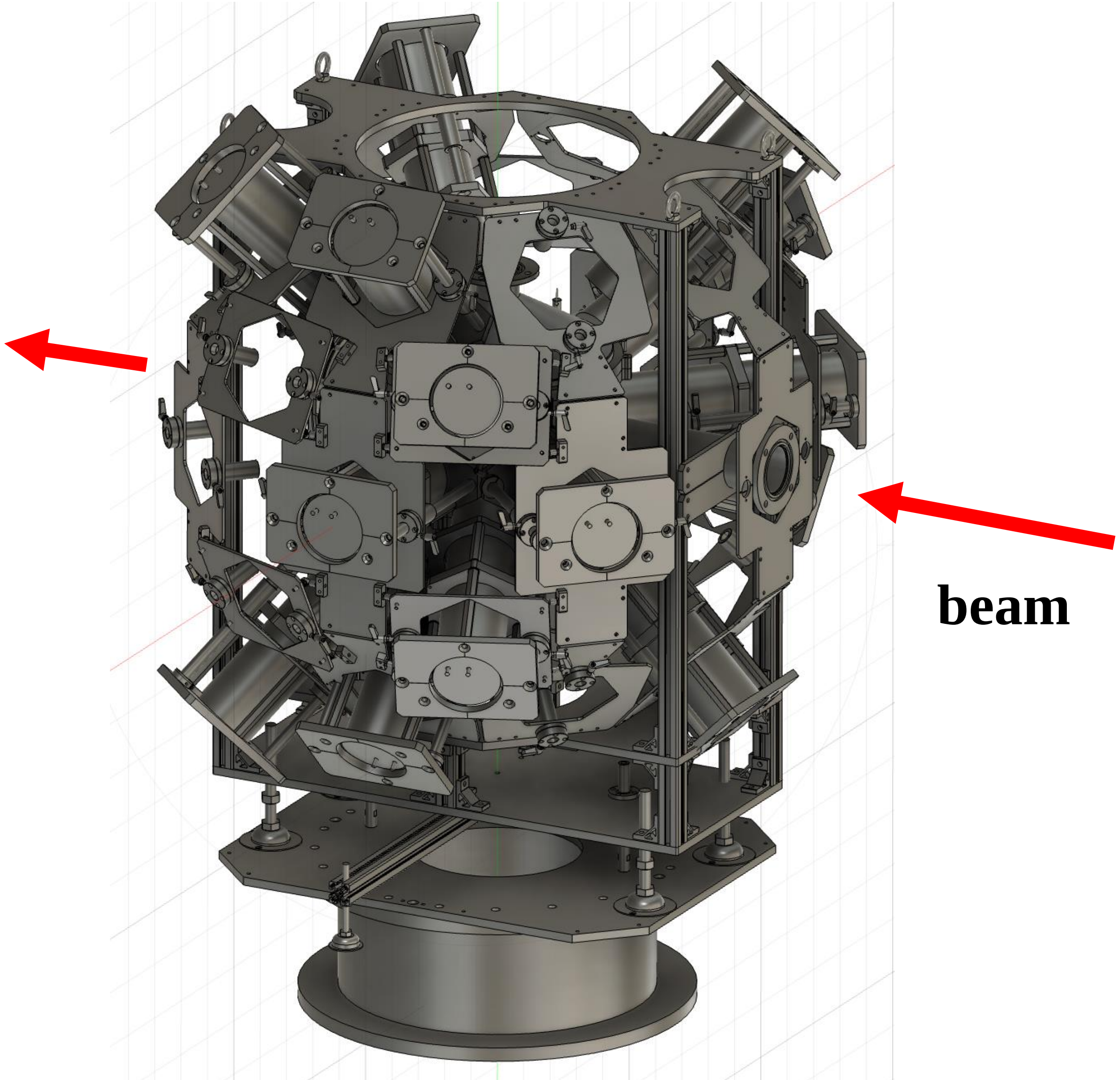
E2, M2 gamma ray



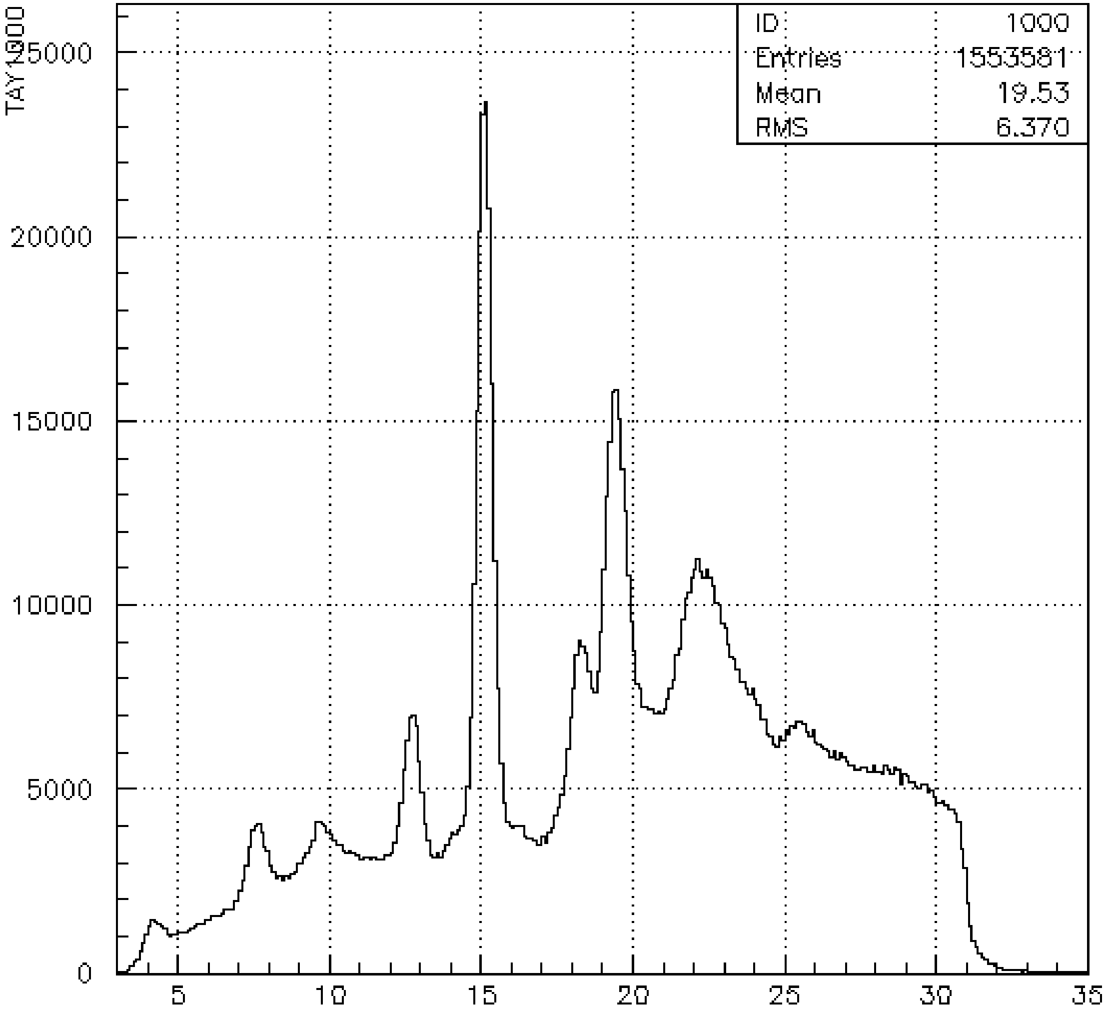
E1, M1 gamma ray

ELPIS

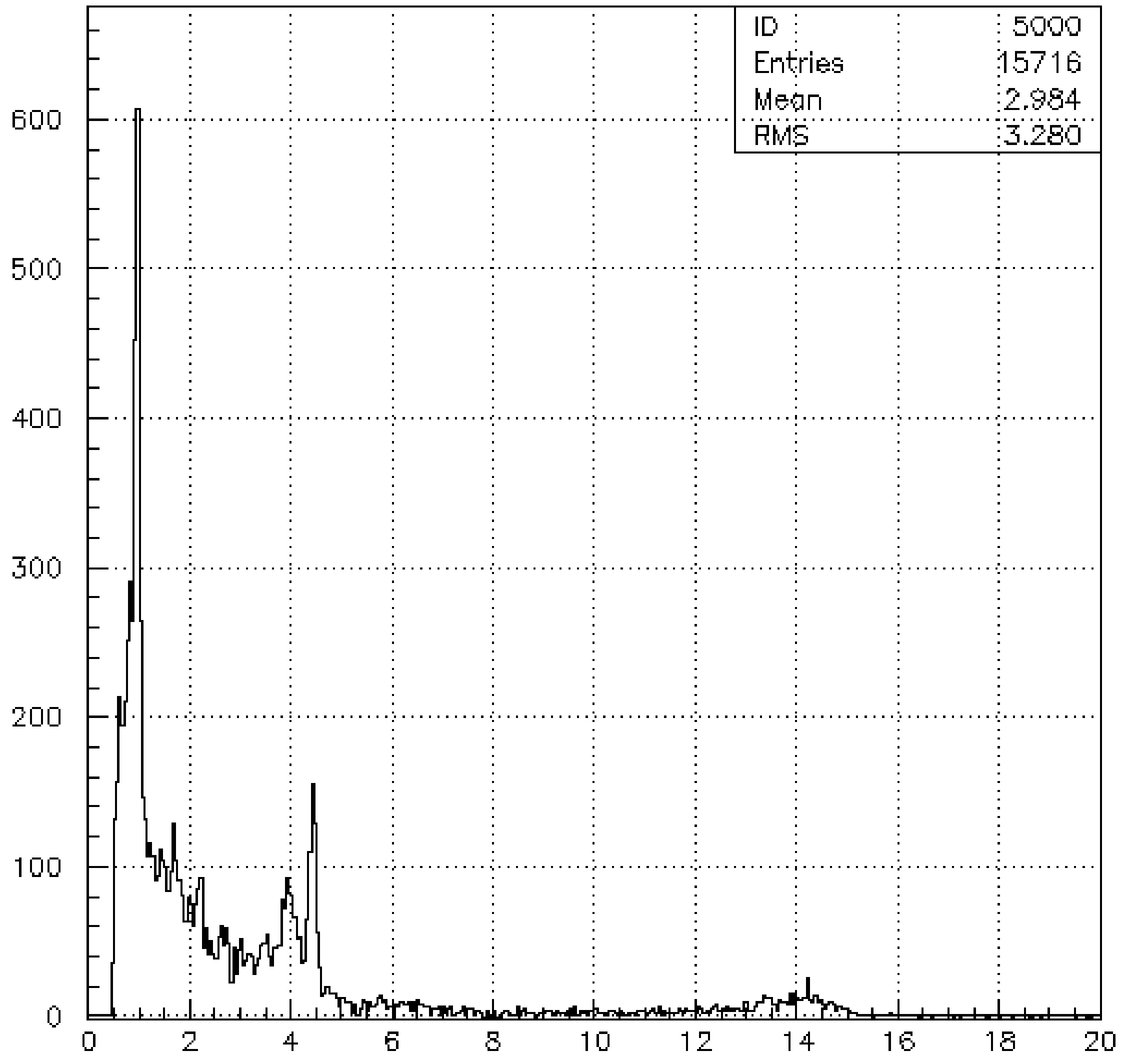
(Expanded $LaBr_3$ array for PANDORA Investigations with GR Spectrometer)

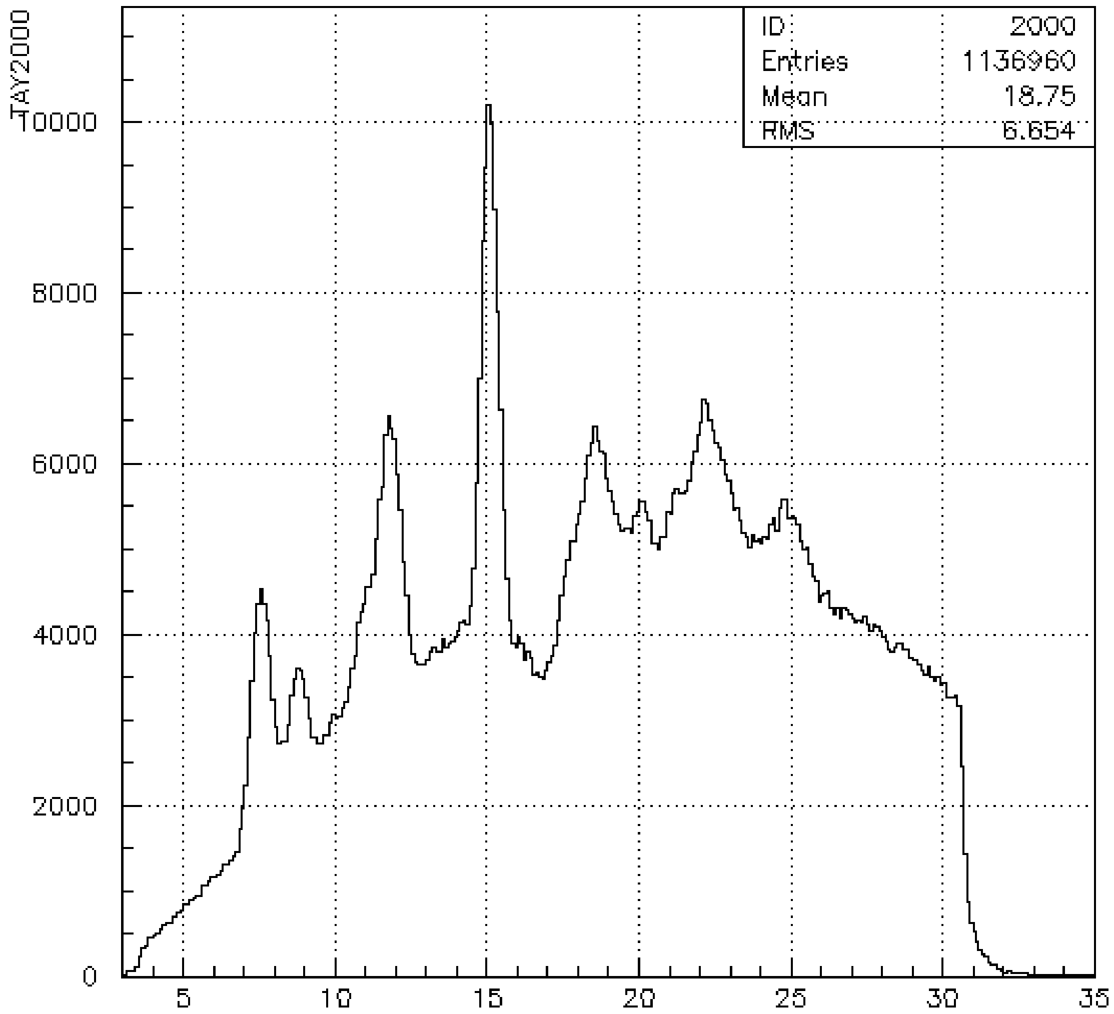


12C 4.5 degrees

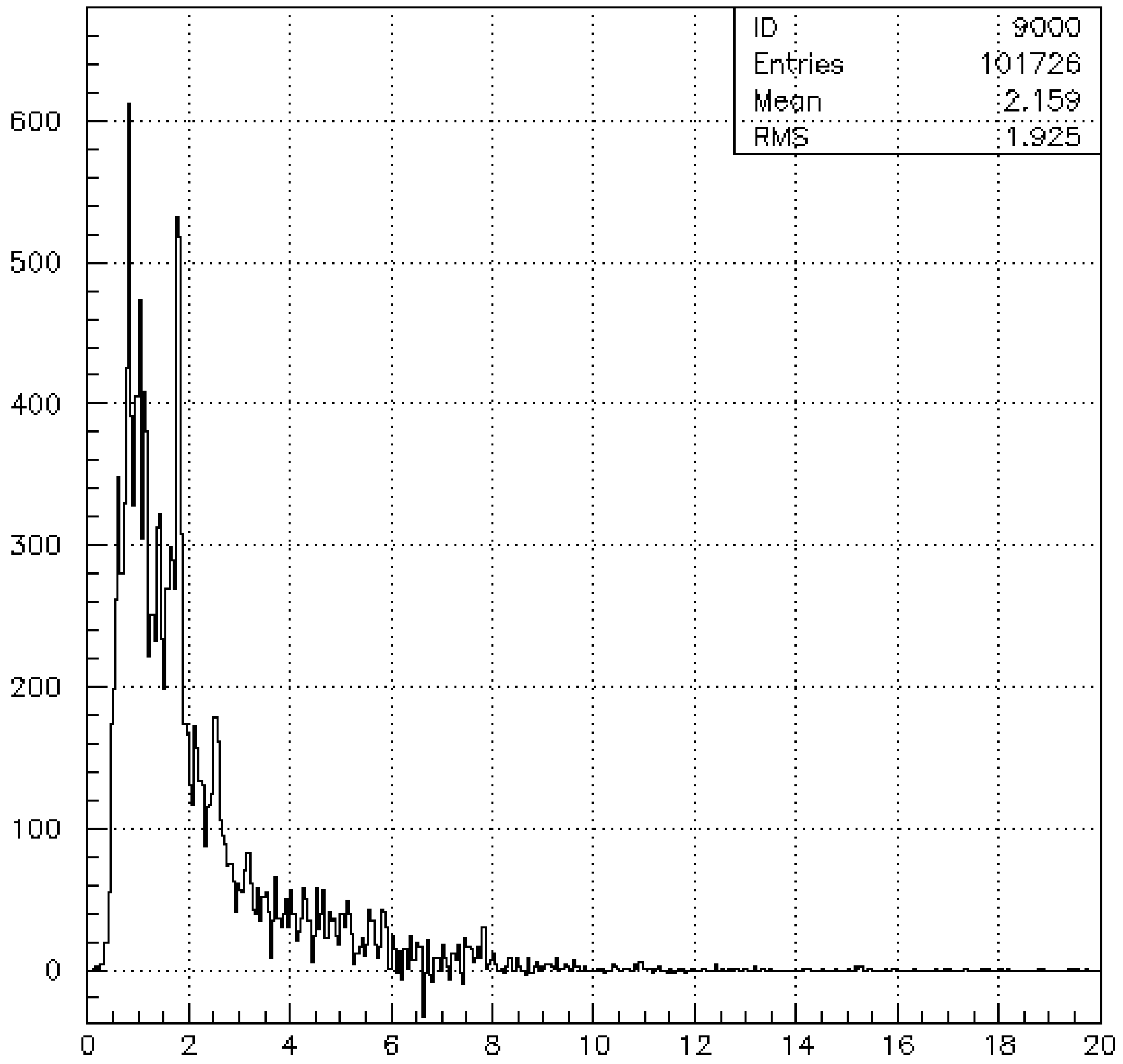


13C 4.5 degrees

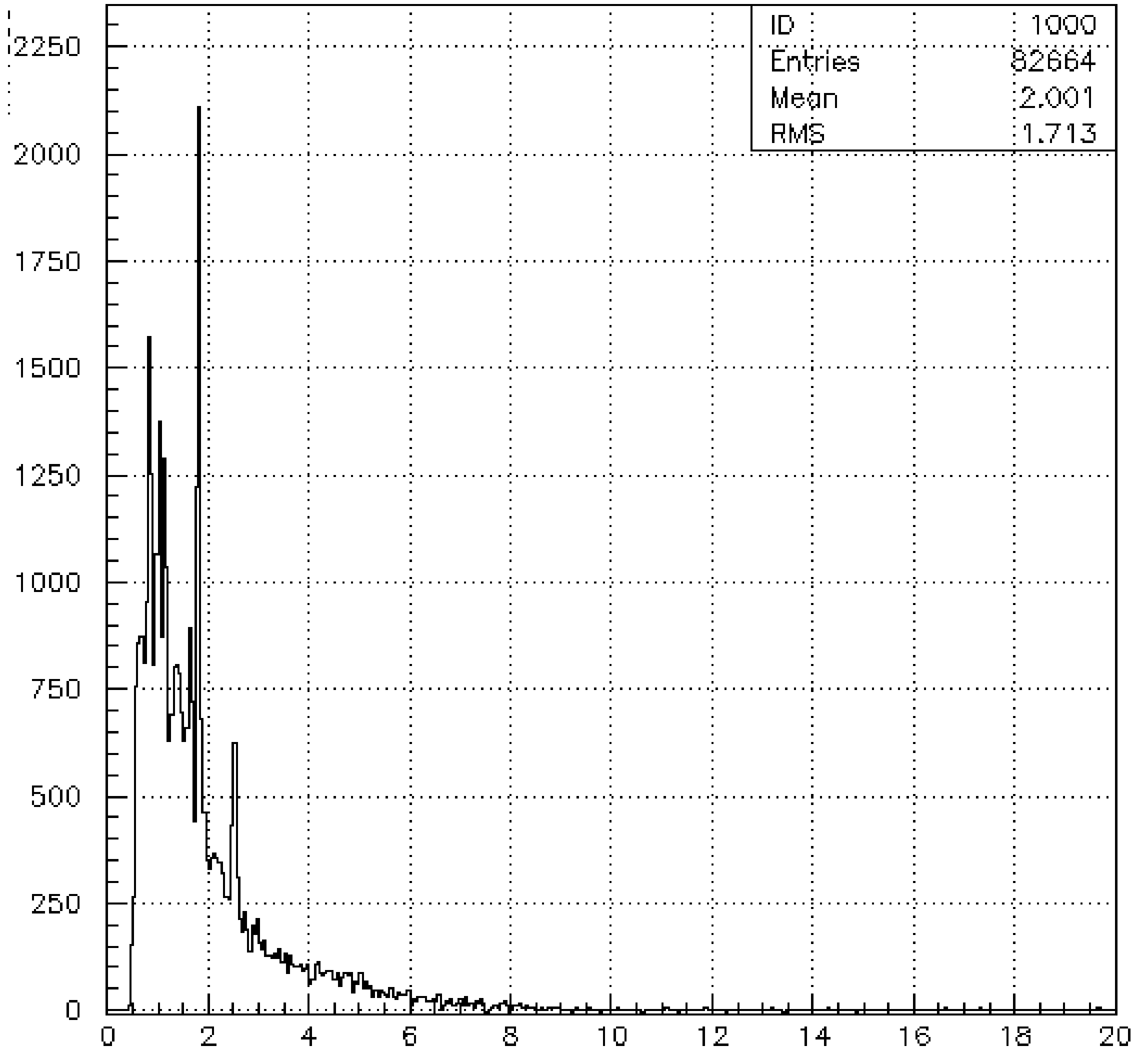




27Al 0 degree



27Al 4.5 degrees



Branching ratios & Efficiency

Branching ratio

$$\frac{{}^{A}X(p,p'\gamma)\ counts}{{}^{A}X(p,p')\ counts} \times \frac{100}{efficiency}\ [\%]$$

detector efficiency @ 15.1 MeV

$$\frac{Number\ of\ 15.1\ MeV\ \ \gamma-ray}{Number\ of\ 15.1\ MeV\ excited\ state \times 0.873} = 0.014$$

Efficiency was roughly calculated using the results of another thesis.

Renormalized multiplying by ratio