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Towards fragmentation cross section in the FaziaZERO experiment: C+C reaction at 62 A·MeV

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1 experimental setup

2 Physics purpose

3 particle identification

4 fragmentation cross section

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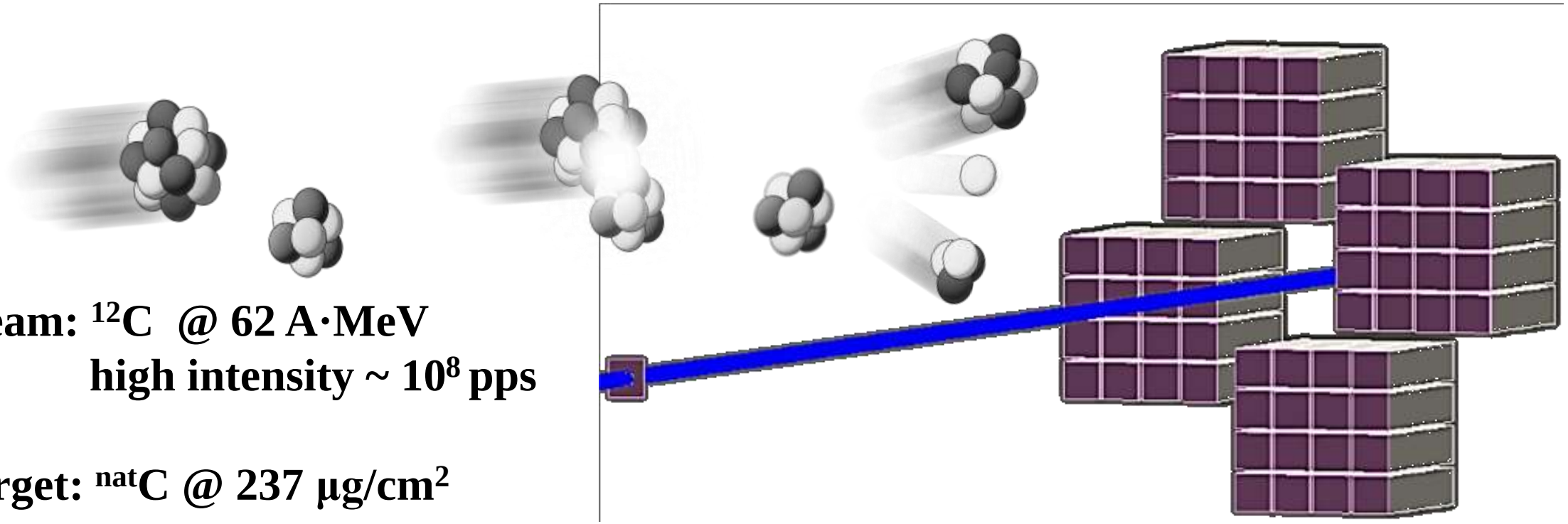
1 experimental setup

2 Physics purpose

3 particle identification

4 fragmentation cross section

Experimental setup



Beam: ^{12}C @ 62 A·MeV
high intensity ~ 10^8 pps

Target: ^{nat}C @ 237 μg/cm^2

Θ≈(2°，8°)

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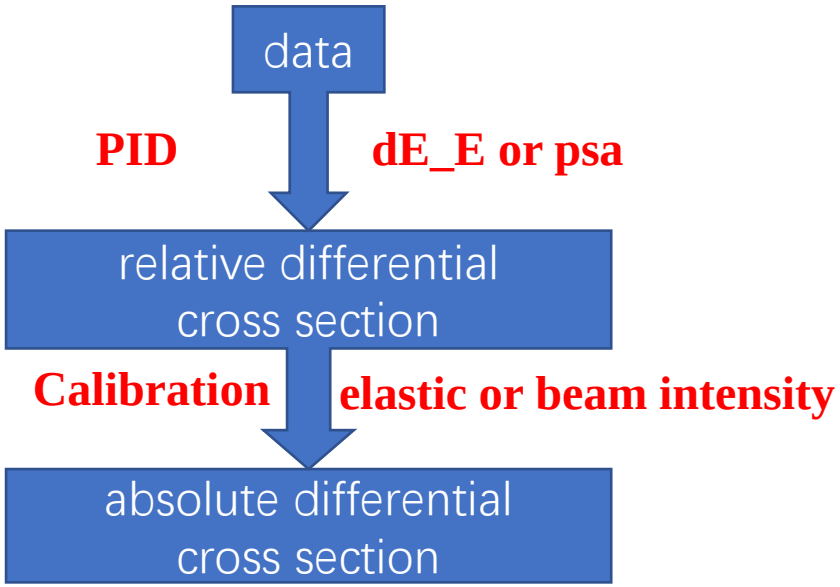
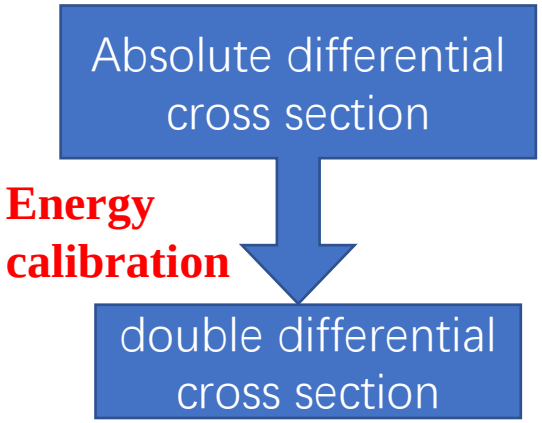
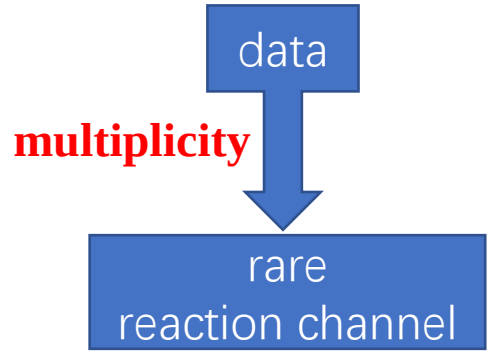
present		Future plan	
	process		
Heavy-Ion Cancer Therapy **Model comparison** ⋮	**significance**	**Model comparison** **Excitation energy spectrum**	**nuclear structure** **reaction mechanism**

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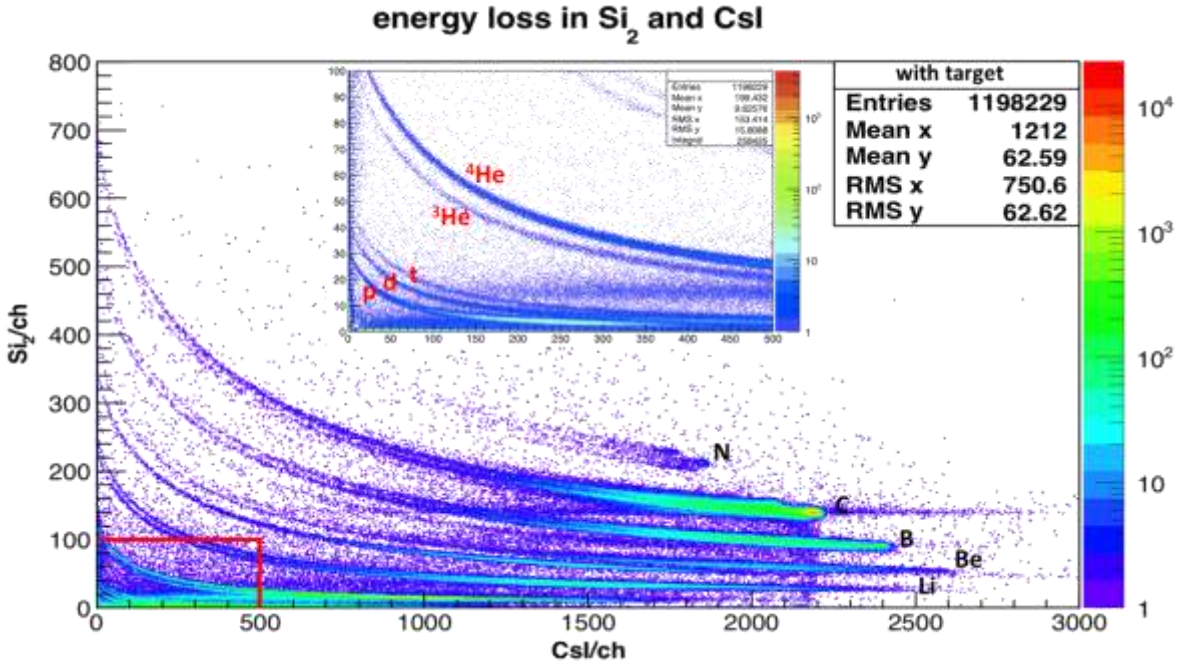
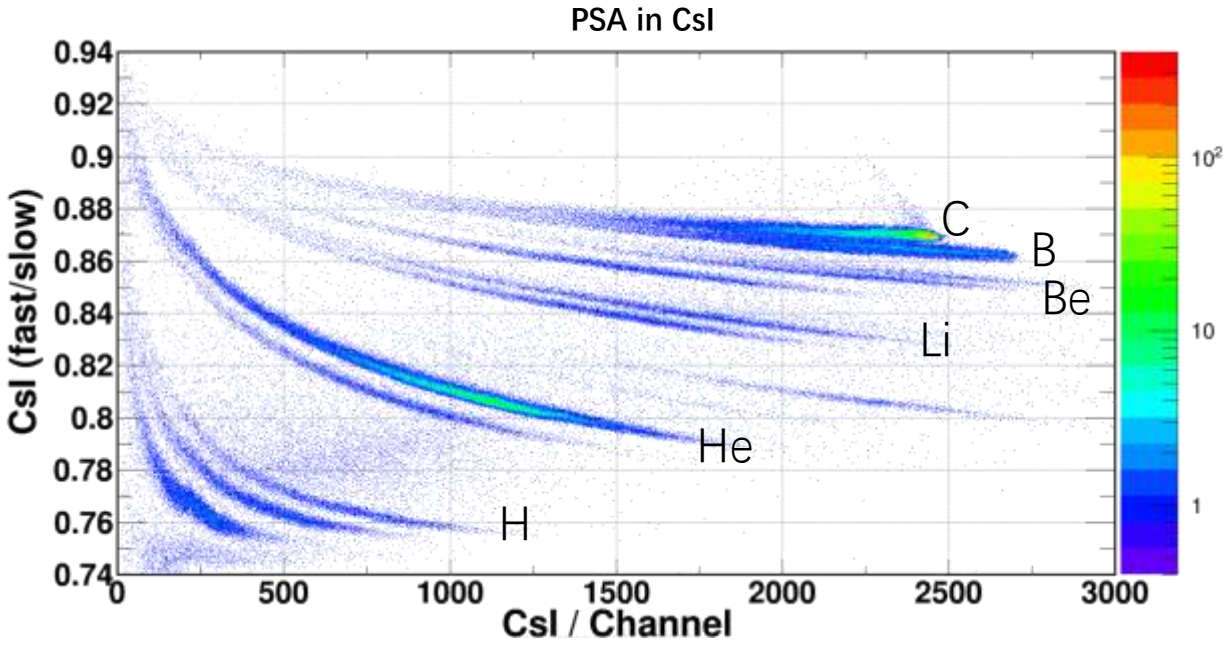
PID



E method



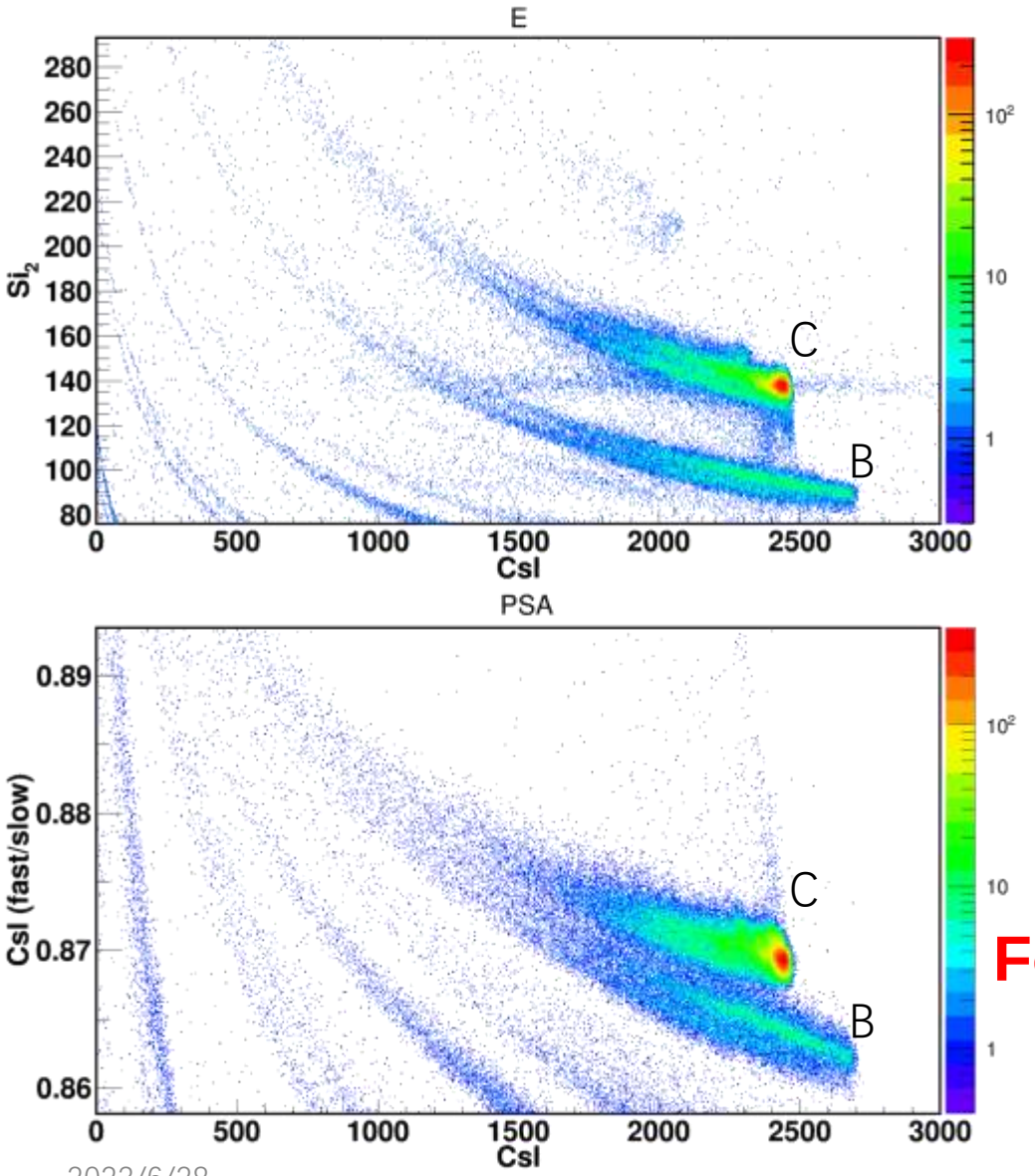
PSA method

There are two problems in the PID:

1、bad resolution of psa method for B and C isotopes.

2、IED(incomplete energy deposition) events

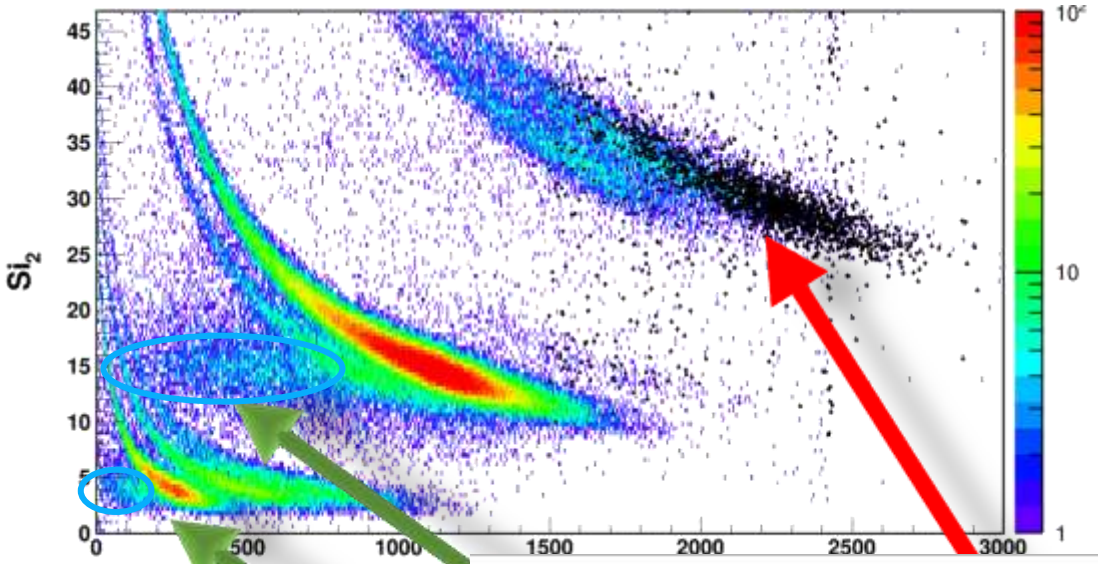
03 1)Bad resolution of psa for Boron & Carbon



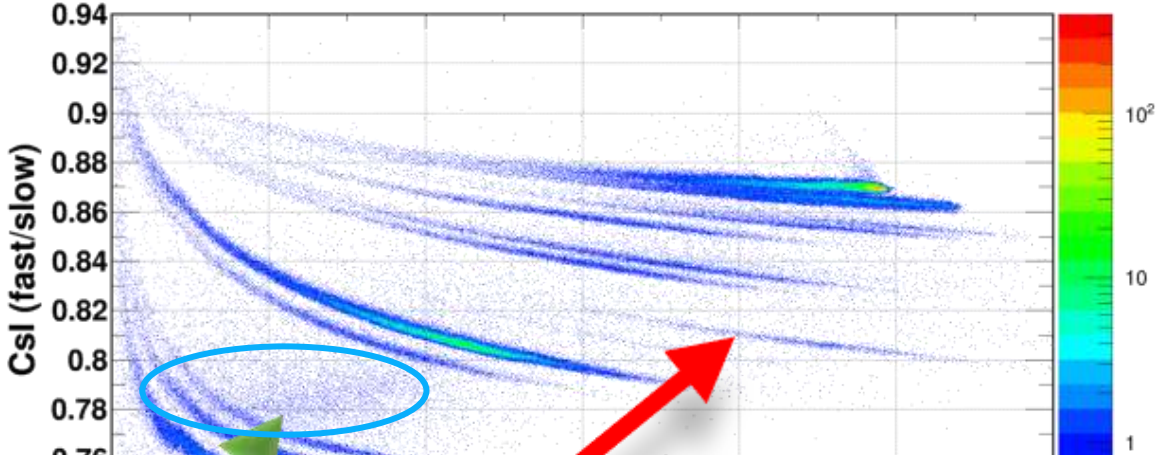
- PSA spectrum gets worse when CsI is smaller than 1500, but E spectrum doesn't.
- When counting C and B isotopes, E spectrum is more accurate than PSA spectrum.

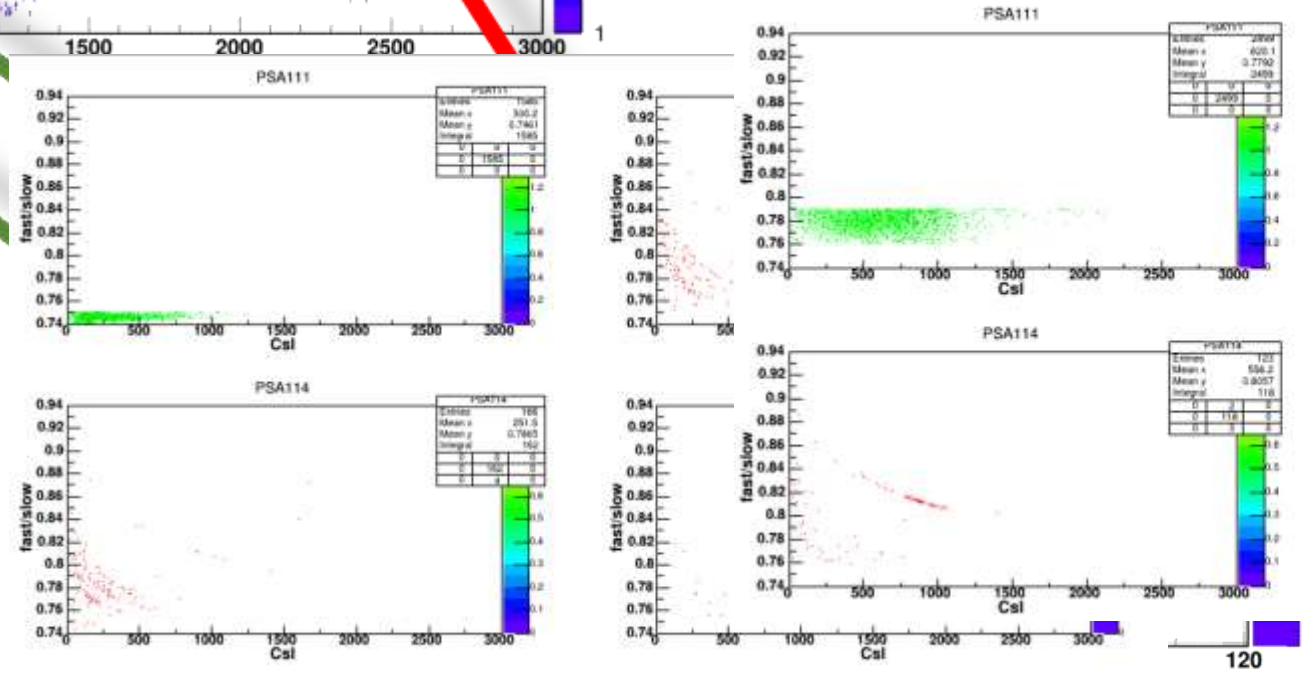
For Z>4 isotopes, E spectrum is more reliable.

2)IED events:phenomenon



PSA

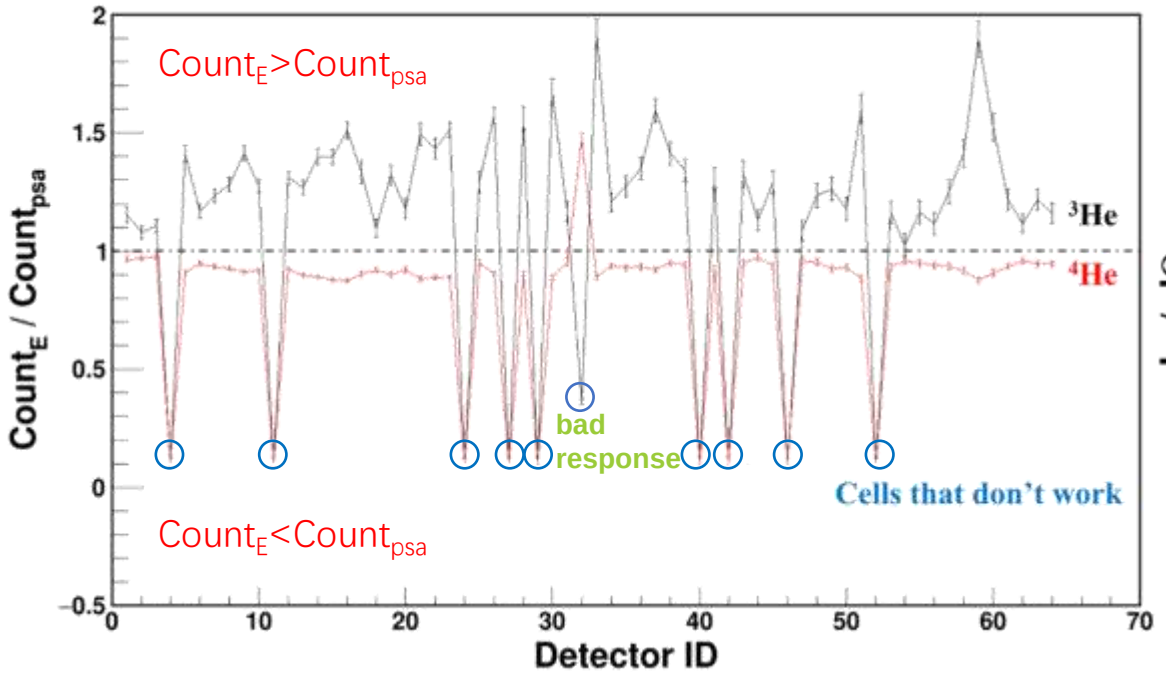


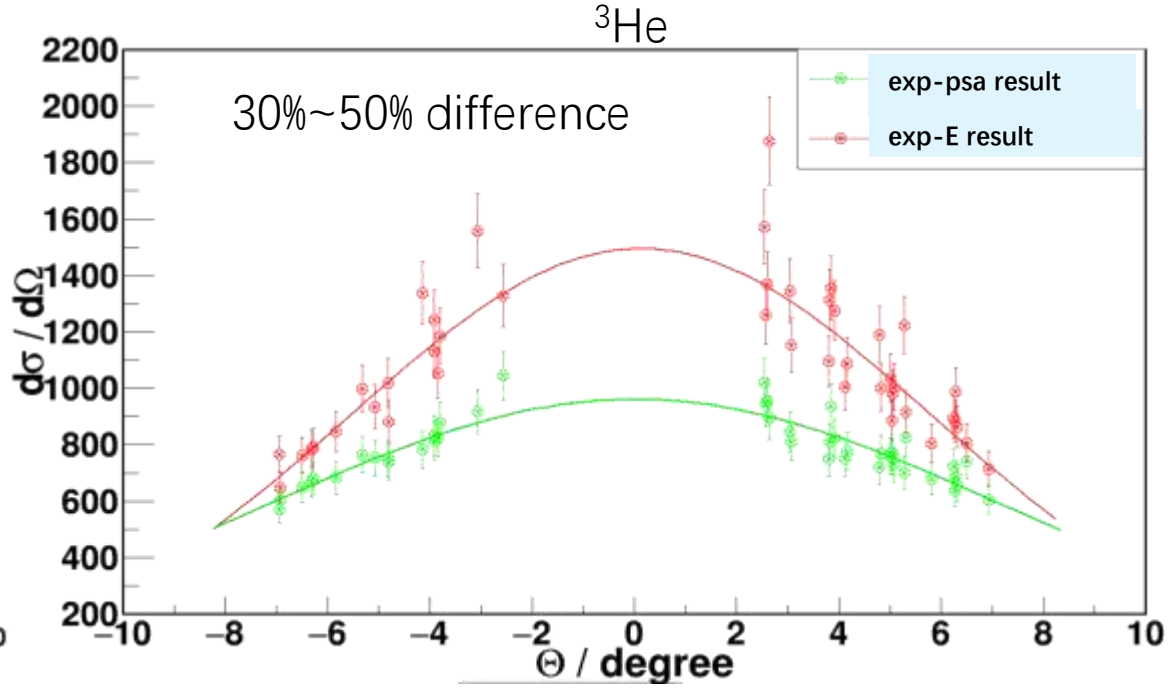


Si1 +Si2/ Channel

3)IED events: example

Influence of IED events





Check the response issue of the detector

for lower Z, psa method is better.

4)IED events: solution

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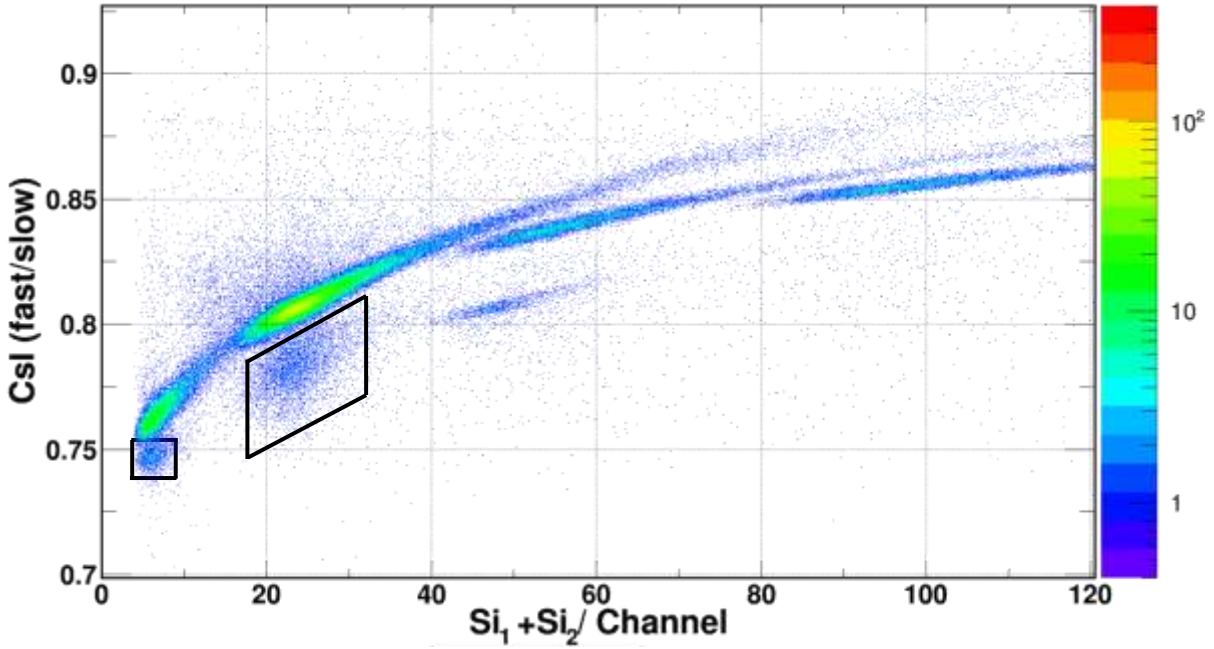
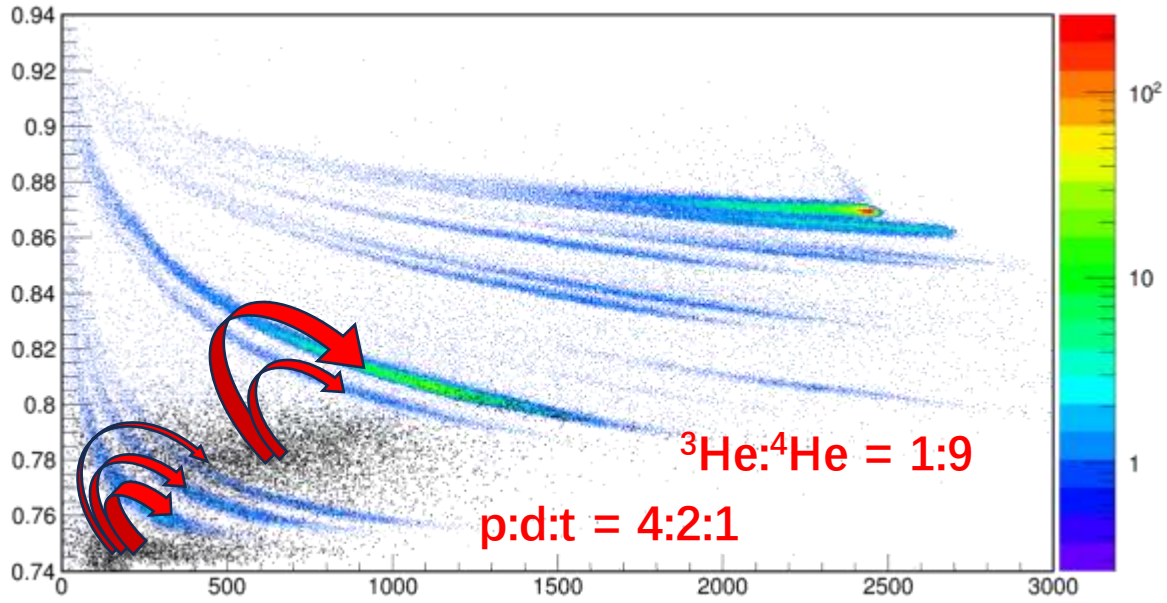
Deal with IED events





$$Counts^{tot}_{\alpha} = Counts^{psa}_{\alpha} + IED_{He} * ratio_{\alpha}$$

$$Counts^{tot}_{p} = Counts^{psa}_{p} + IED_{H} * ratio_{p} - IED_{He}$$

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Counting rules

Si_Si_CsI detectors are fired

For Z>4
$Counts_E$

For Z≤4
$Counts_{psa}$ ±IED(Z≤2)

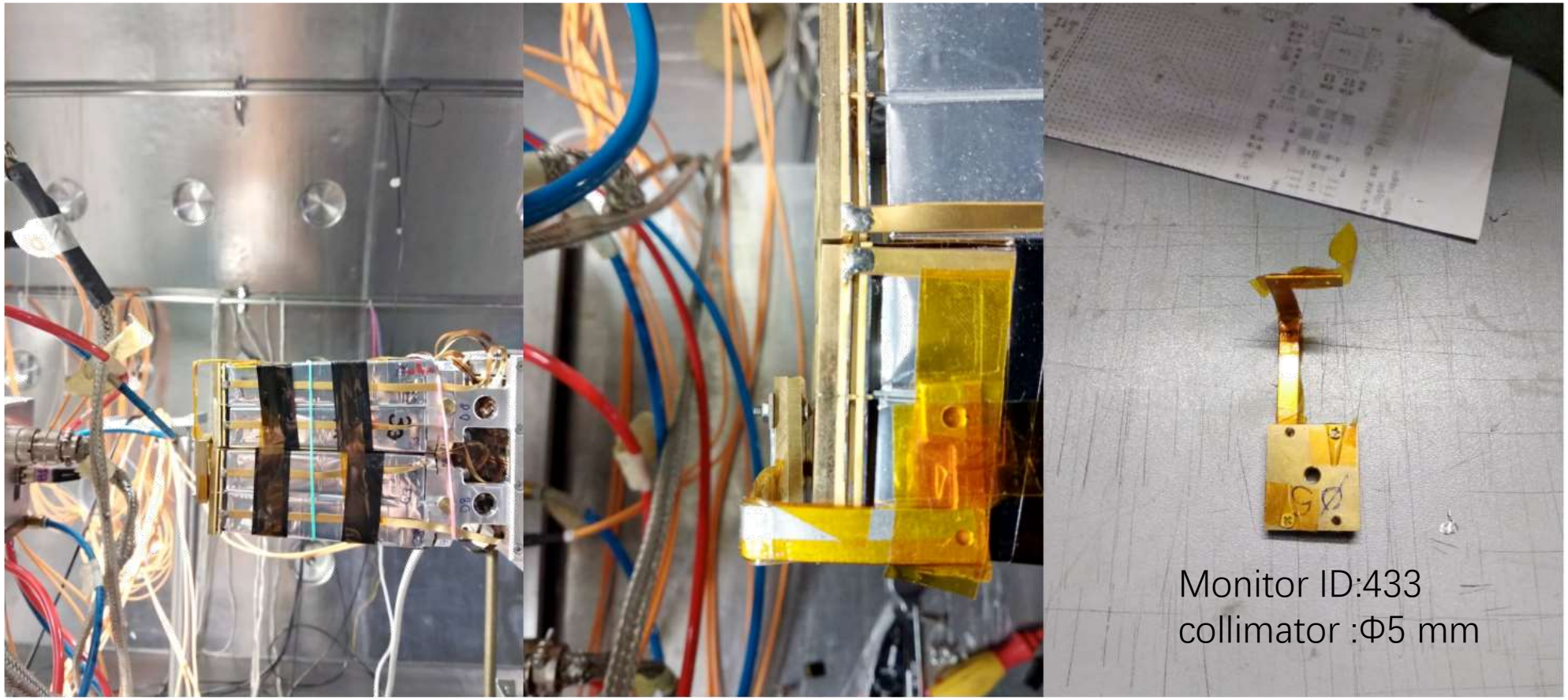
- E & PSA recognized 74.44%
  - $^{A}_{Z}E = {}^{A}_{Z}PSA$ 57%
  - psa!=E
    - Bad resolution 12%
    - IED 4%
- E recognized 16.25%
  - Bad resolution 13%
  - IED in && out 2%
- PSA recognized 3.95%
  - IED out 1%
  - IED in (si no response) 2%
- Nothing recognized 5.36%
  - IED out 1%
  - Stopped in Si 3%

95% events is confirmed

3% Stopped in Si

2% unrecognized

1）Elastic scattering monitor



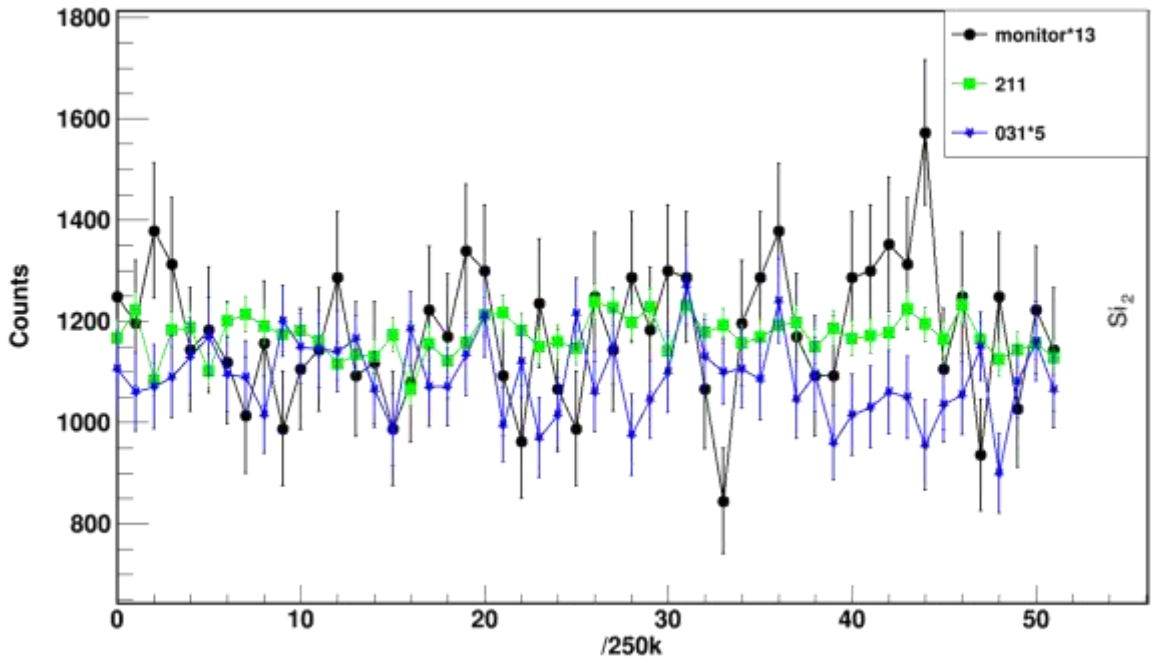
Detecting the number of 12C generated by elastic scattering

1) Elastic scattering monitor

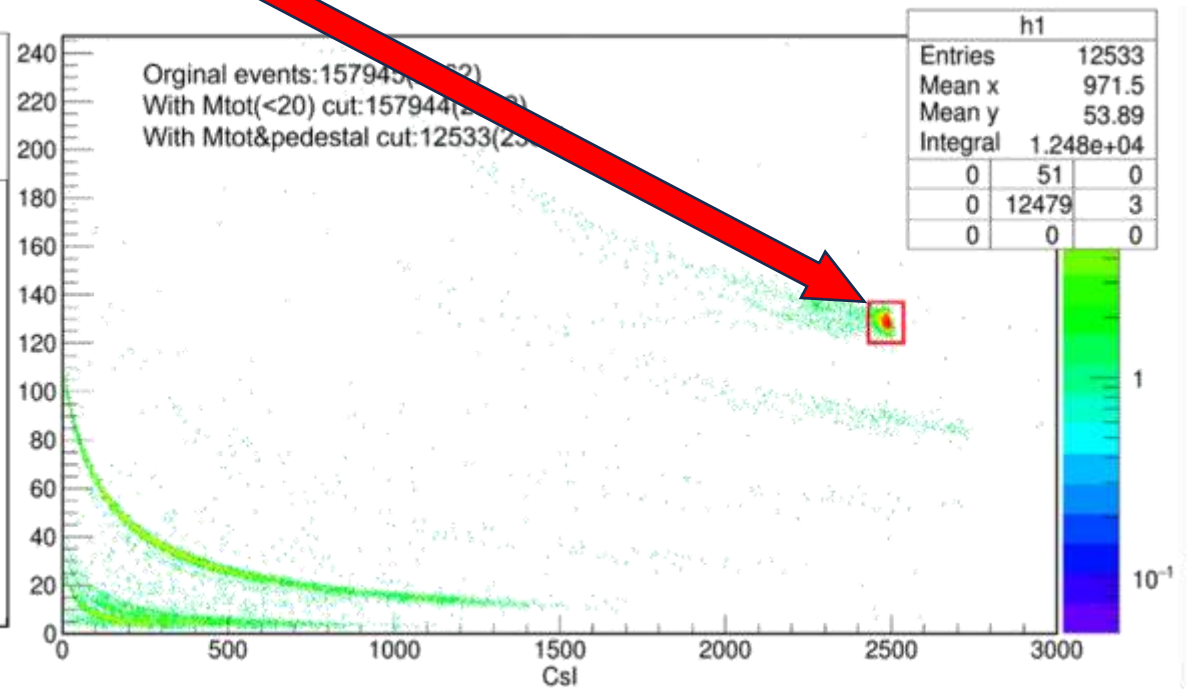
Is known from PID

?

$$\frac{d\sigma}{d\Omega} = \frac{N_\Omega}{(N_\Omega)_{elastic}}\left(\frac{d\sigma}{d\Omega}\right)_{elastic}$$



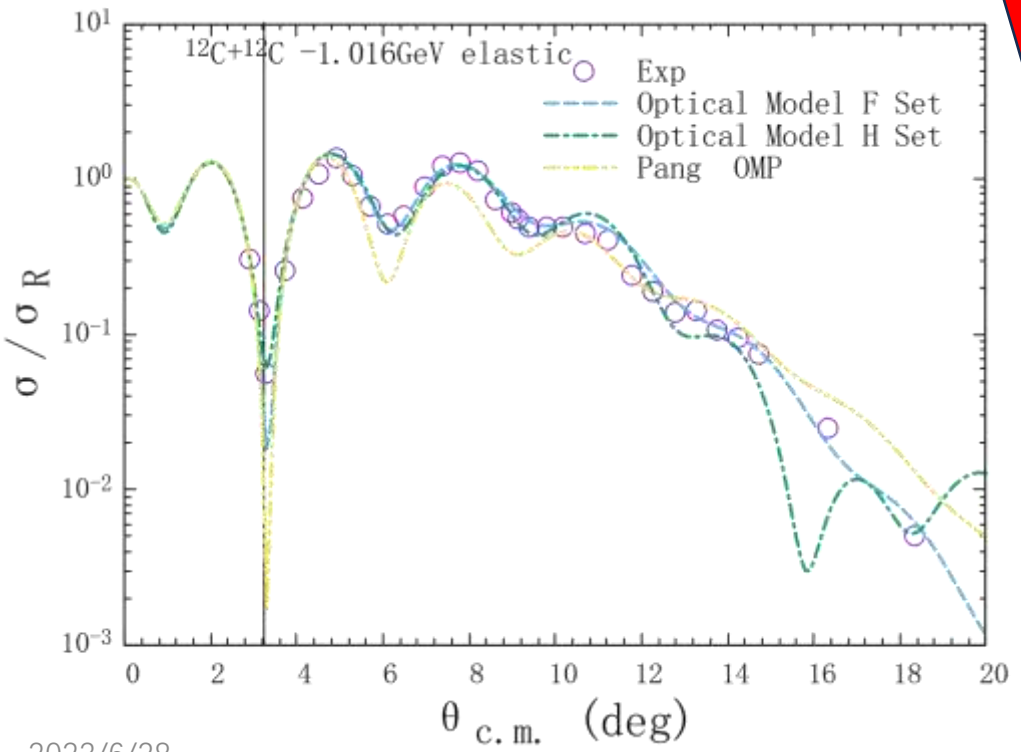
Stability check

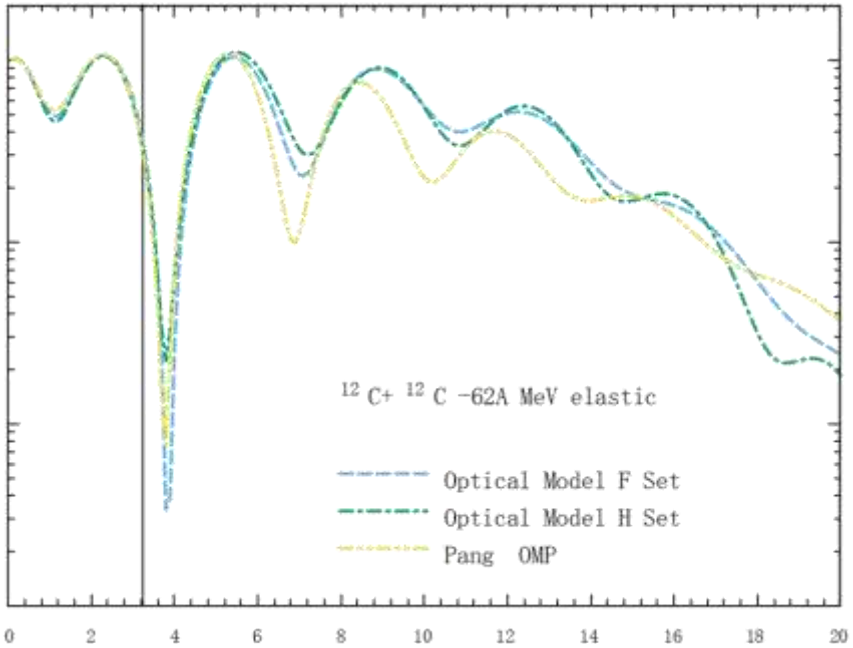


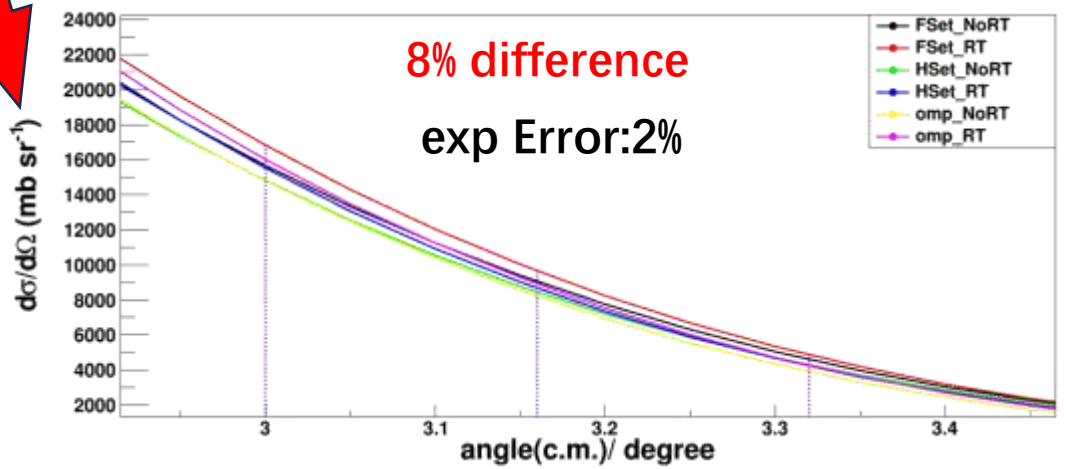
PID of the monitor

2) Elastic scattering cross section

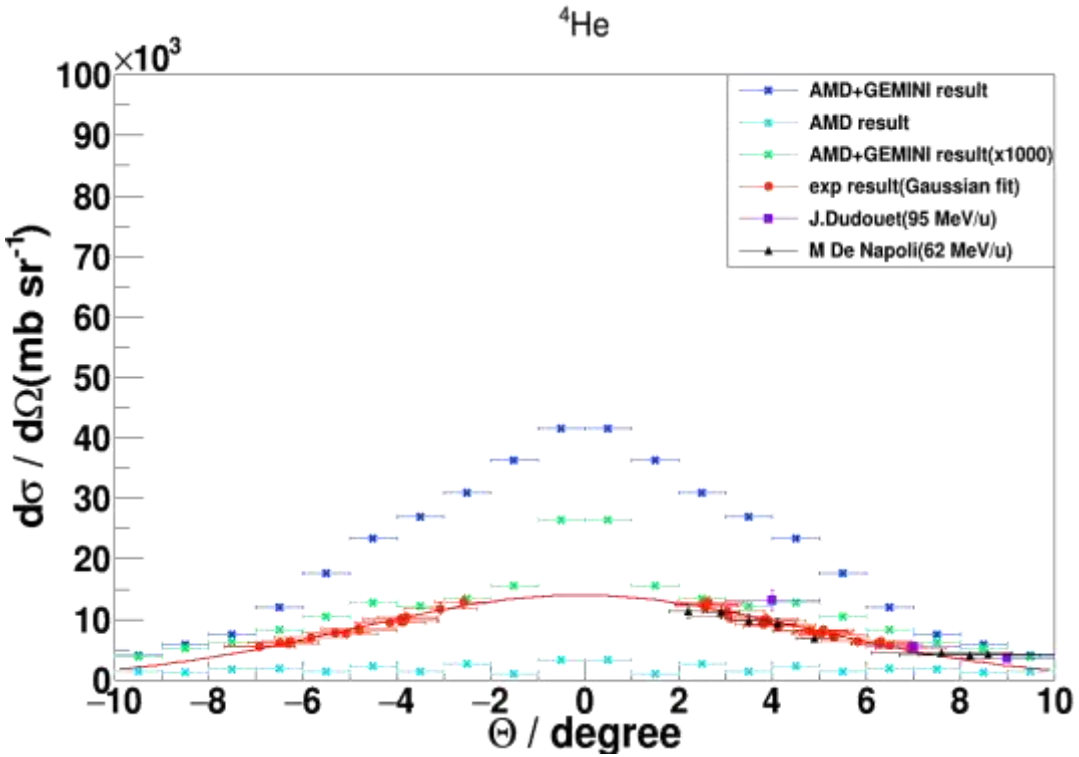
$$\frac{d\sigma}{d\Omega} = \frac{N_\Omega}{(N_\Omega)_{elastic}}\left(\frac{d\sigma}{d\Omega}\right)_{elastic}$$

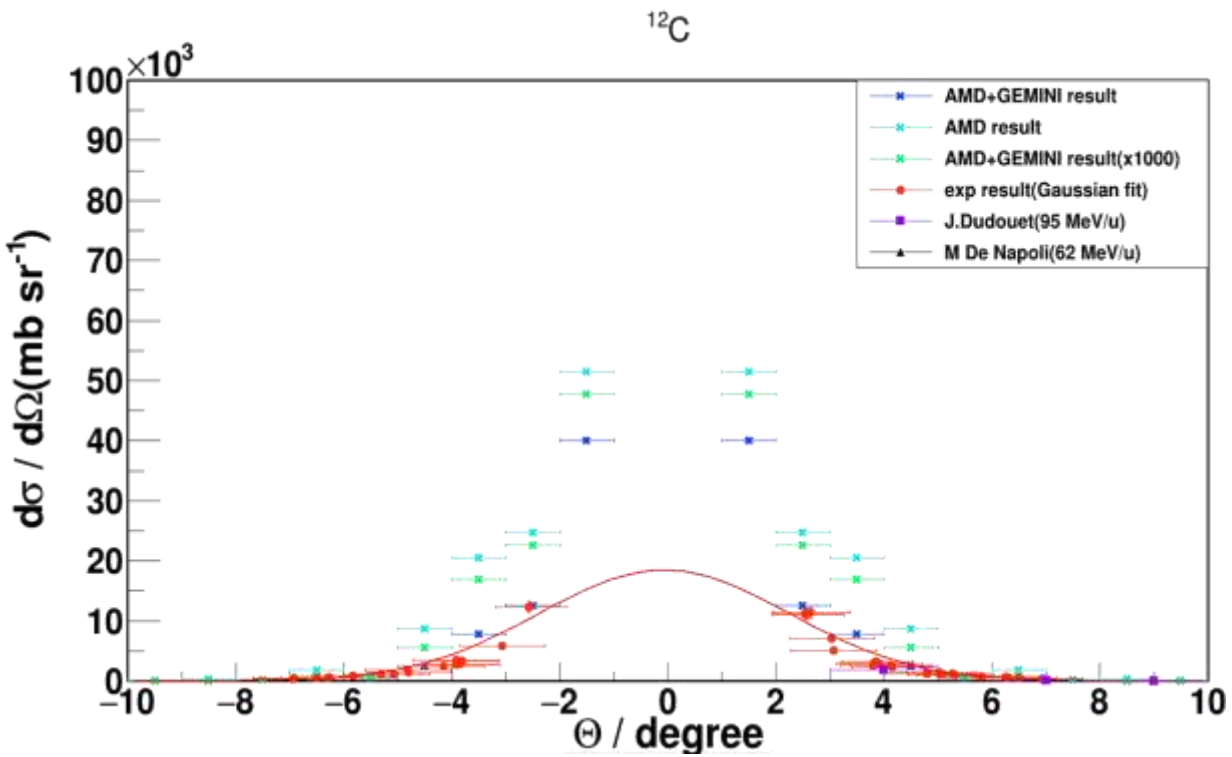






Fragmentation Cross Section





- **Red one** is the result of this experiment.

  Black & purple one is the result of others.

  ^{1}H ^{2}H ^{3}H ^{3}He ^{4}He ^{6}Li ^{7}Li ^{7}Be ^{9}Be
  ^{10}Be ^{10}B ^{11}B ^{10}C ^{11}C ^{12}C

- **Light blue one is the AMD result**

  dark blue one is the AMD+GEMINI(old rule) result.

  green one is the the AMD+GEMINI(new rule) **result.**

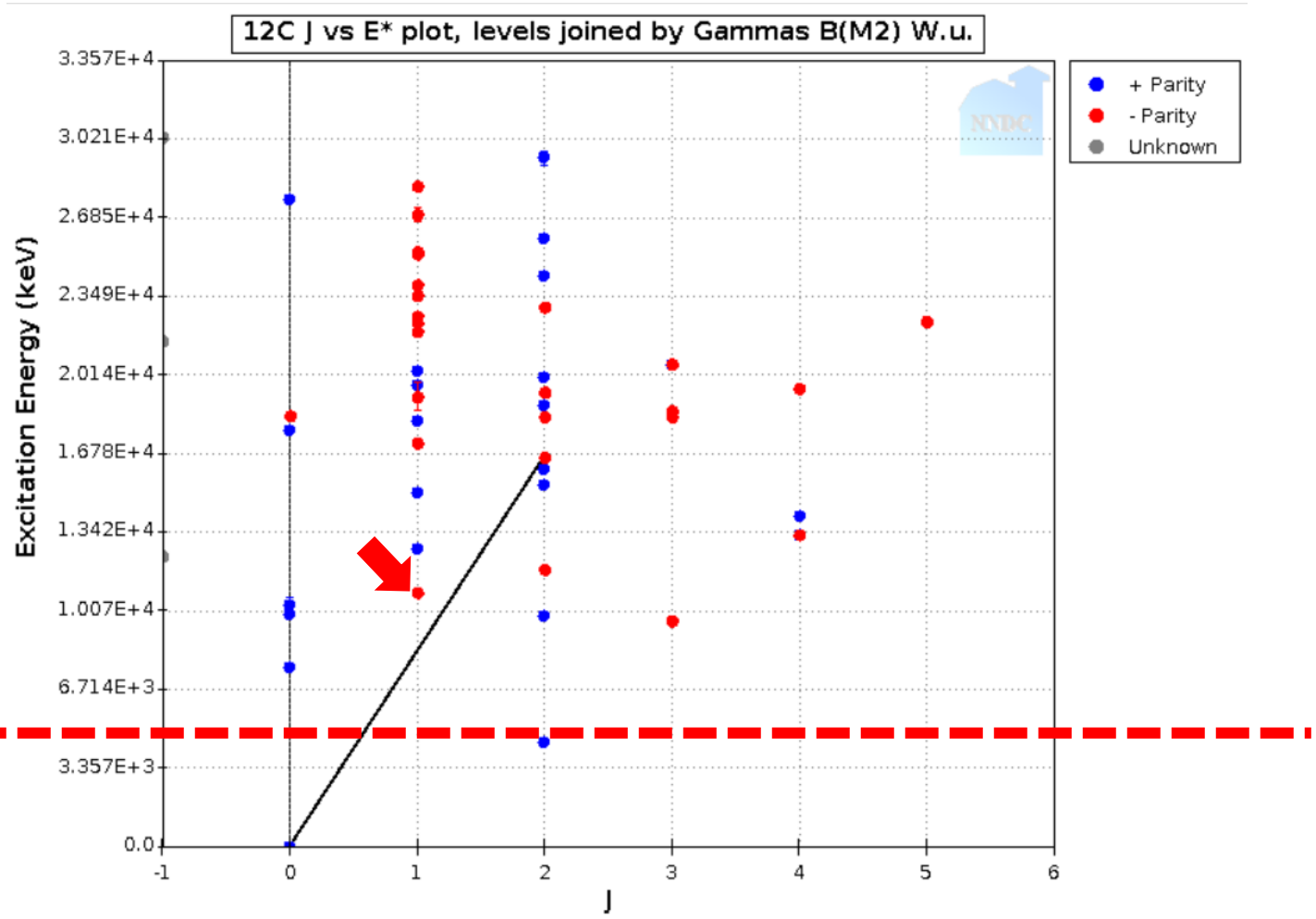
Green one shows better agreement with the experimental result.

Fragmentation Cross Section

J and E* take continuous values. Since the wave function is not an eigenstate of J and E*.

To start the statistical decay, the code has to choose one of the levels of the nucleus.

1. choosing J
2. choosing one of the levels smaller than E* of that J.



modified the algorithm to retry a lower J = J-1 if E* is lower than the lowest level for the chosen J.

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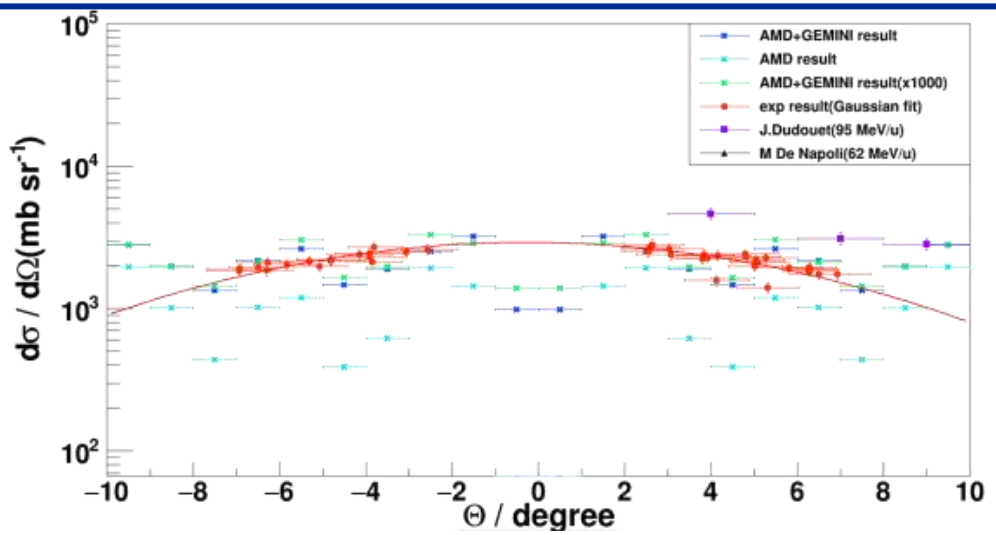
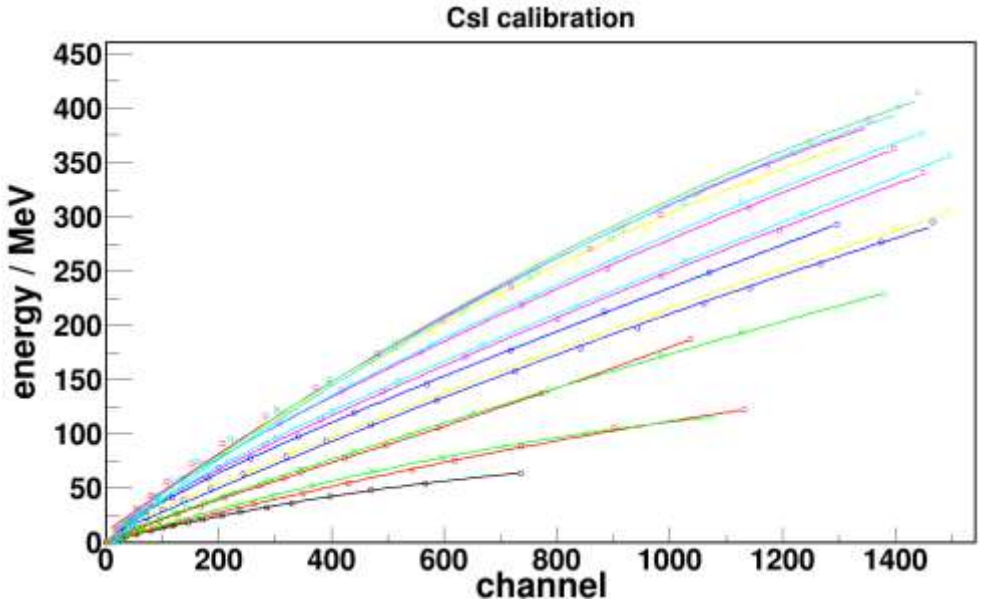
- Publish experimental data
- Finish energy calibration
- Look at rare reaction channels





Thanks for your listening

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Backup:
other FCS results

Fragmentation Cross Section

J and E* take continuous values.

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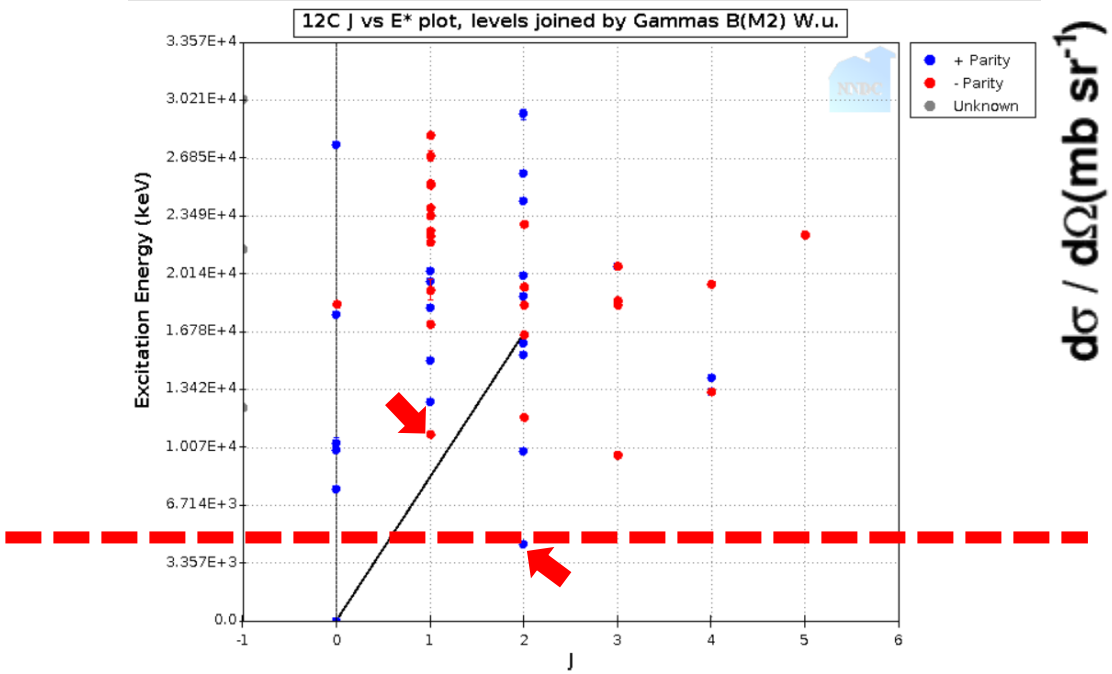
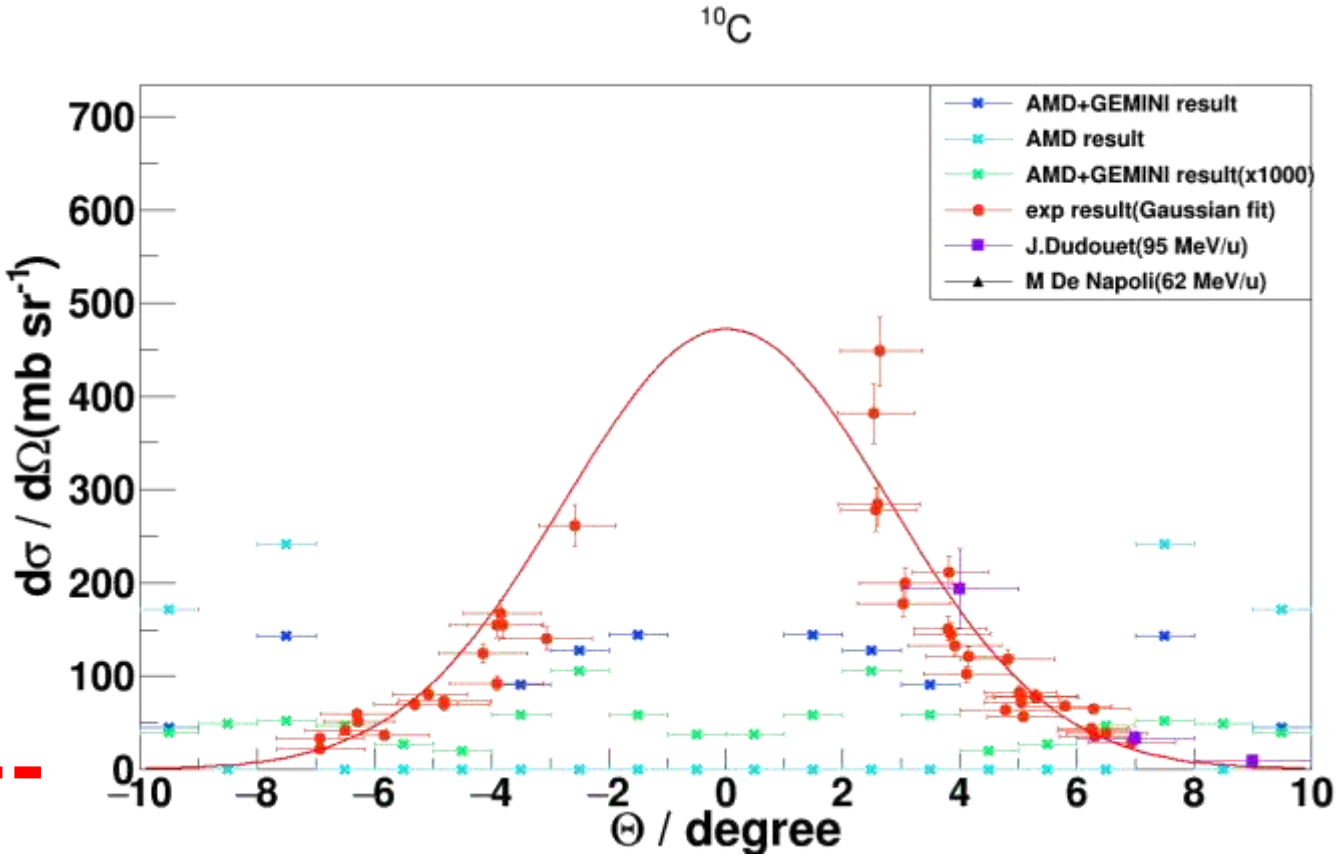
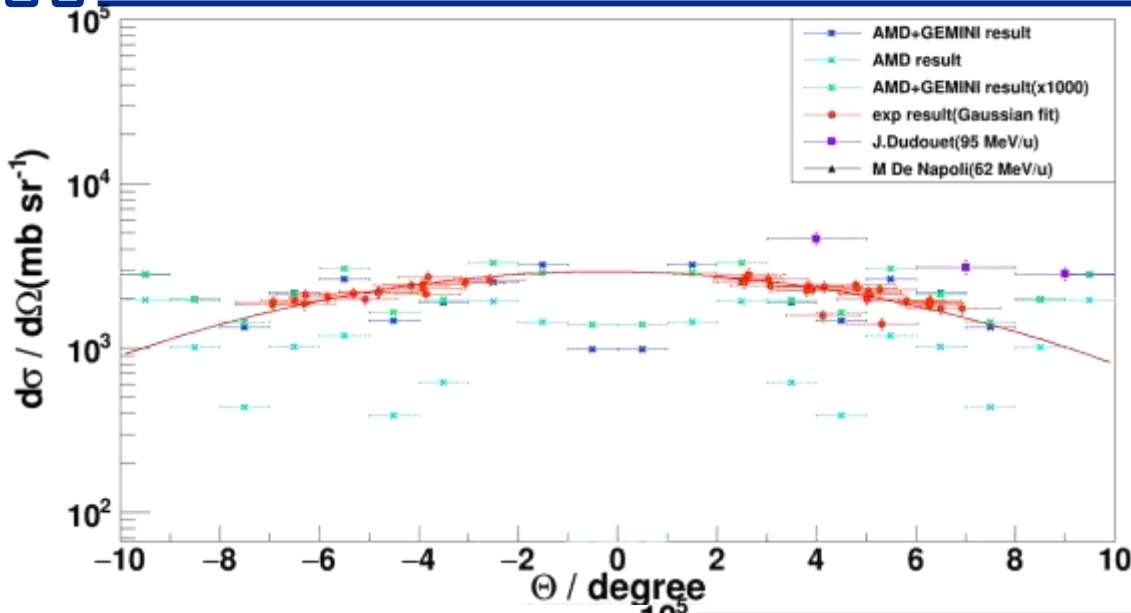


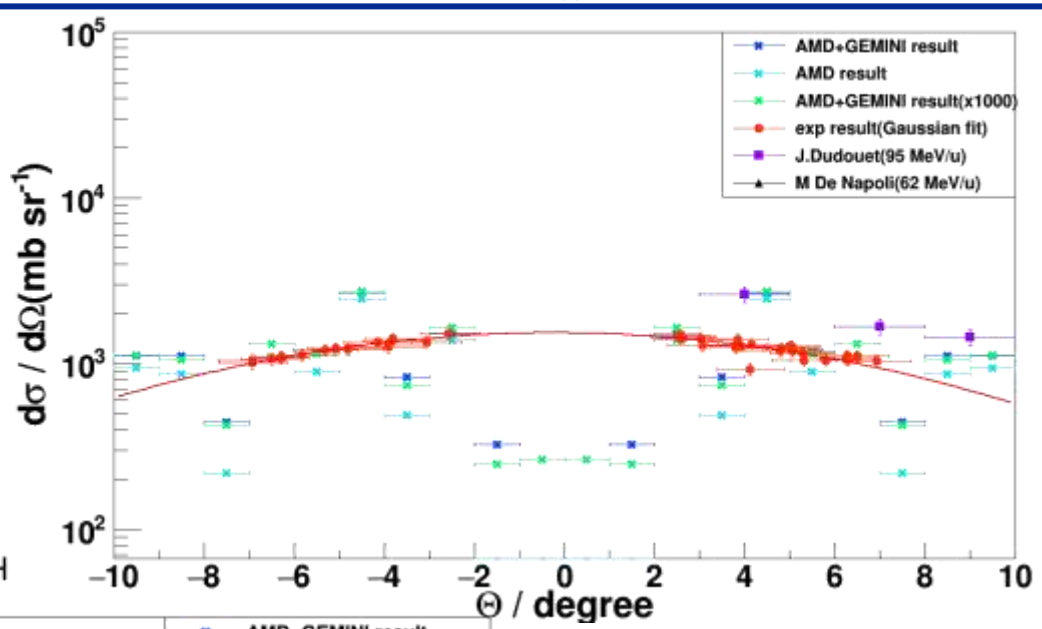


modified the algorithm to retry a lower J = J-1 if E* is lower than the lowest level for the chosen J.

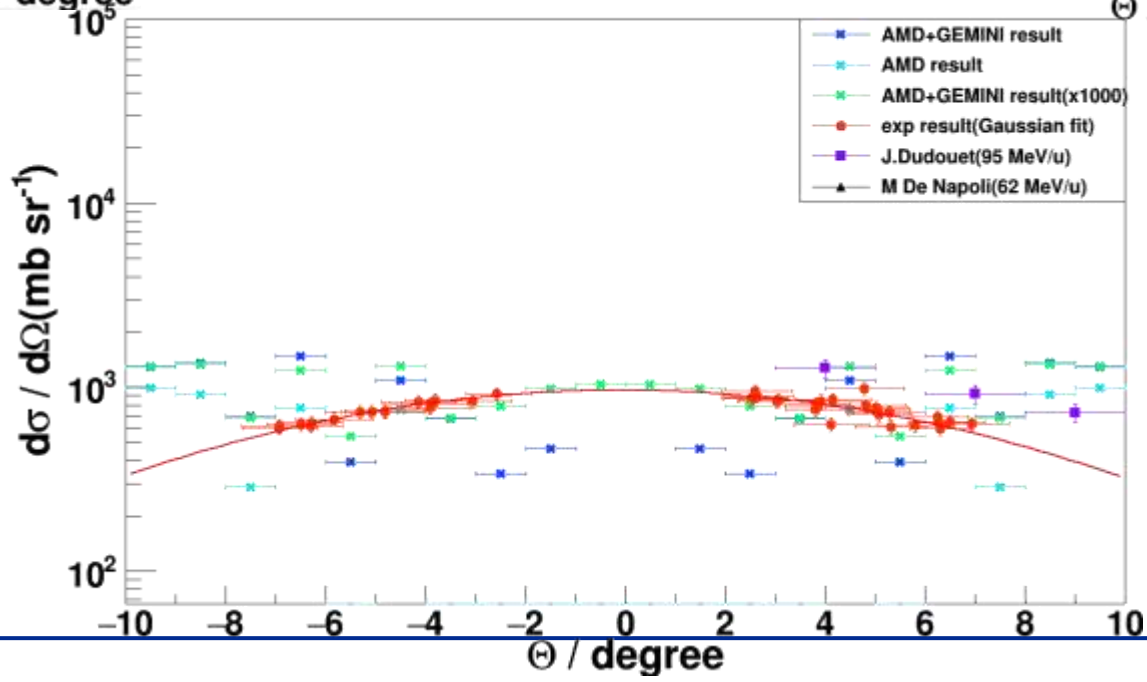
^{1}H


AMD+GEMINI result
AMD result
AMD+GEMINI result(x1000)
exp result(Gaussian fit)
J.Dudouet(95 MeV/u)
M De Napoli(62 MeV/u)
dσ / dΩ(mb sr⁻¹)
Θ / degree

^{2}H


AMD+GEMINI result
AMD result
AMD+GEMINI result(x1000)
exp result(Gaussian fit)
J.Dudouet(95 MeV/u)
M De Napoli(62 MeV/u)
dσ / dΩ(mb sr⁻¹)
Θ / degree

^{3}H


AMD+GEMINI result
AMD result
AMD+GEMINI result(x1000)
exp result(Gaussian fit)
J.Dudouet(95 MeV/u)
M De Napoli(62 MeV/u)
dσ / dΩ(mb sr⁻¹)
Θ / degree

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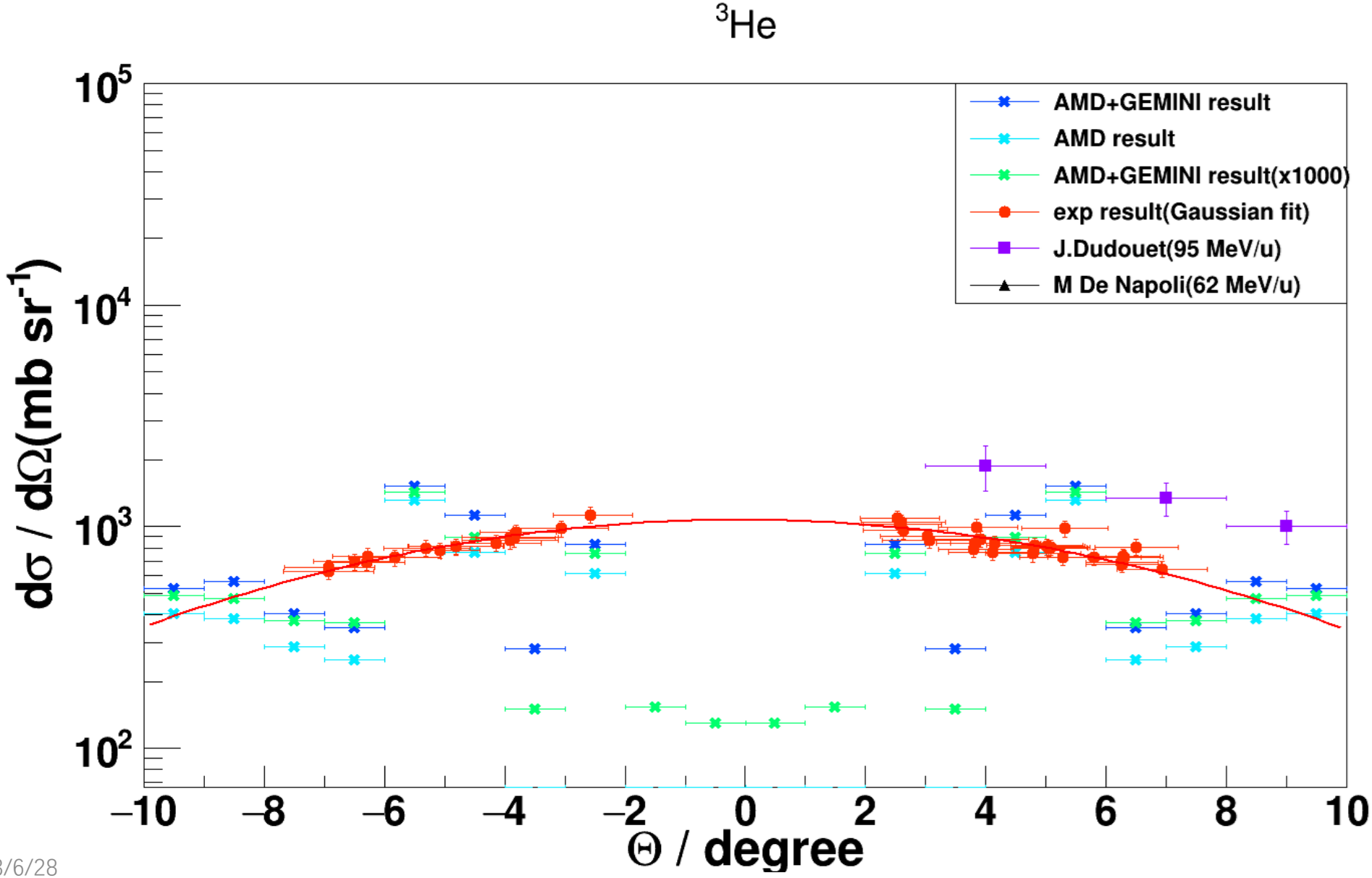
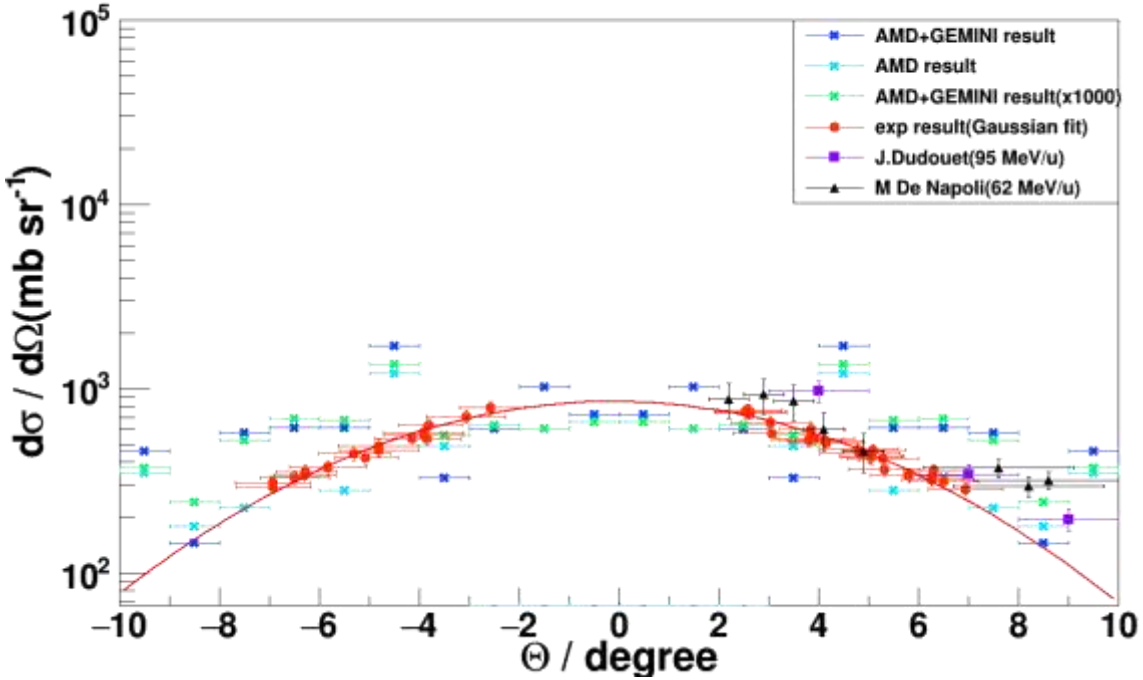
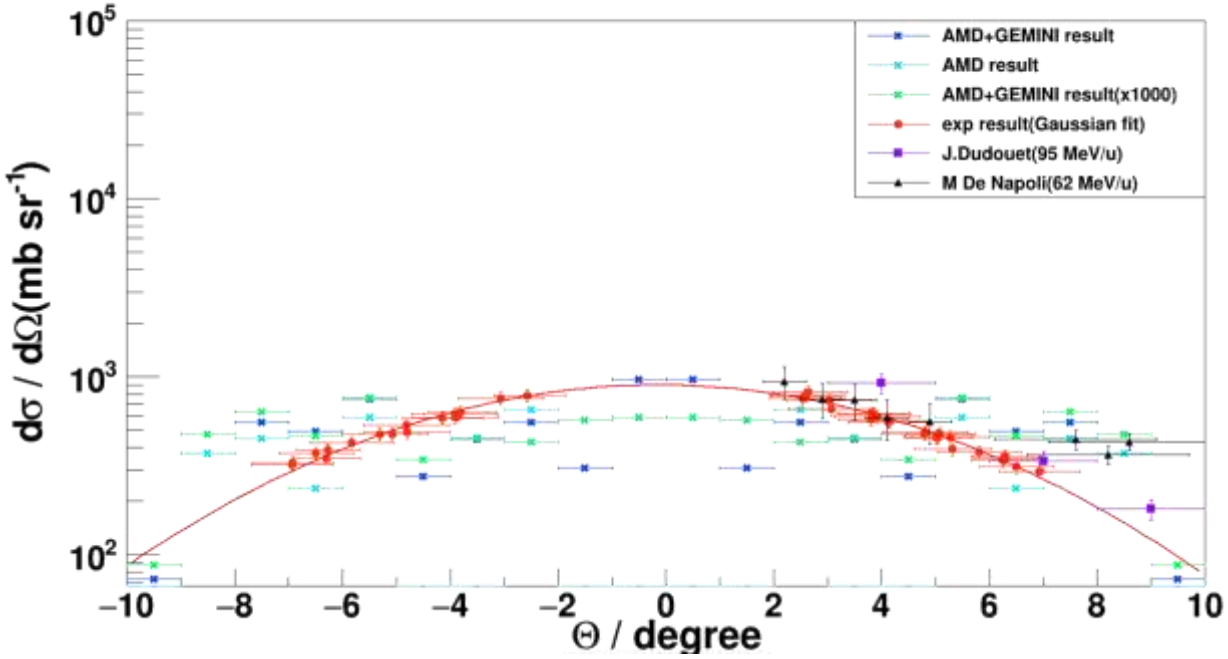


^{6}Li


AMD+GEMINI result
AMD result
AMD+GEMINI result(x1000)
exp result(Gaussian fit)
J.Dudouet(95 MeV/u)
M De Napoli(62 MeV/u)
dσ / dΩ(mb sr^{-1})
Θ / degree

^{7}Li


AMD+GEMINI result
AMD result
AMD+GEMINI result(x1000)
exp result(Gaussian fit)
J.Dudouet(95 MeV/u)
M De Napoli(62 MeV/u)
dσ / dΩ(mb sr^{-1})
Θ / degree

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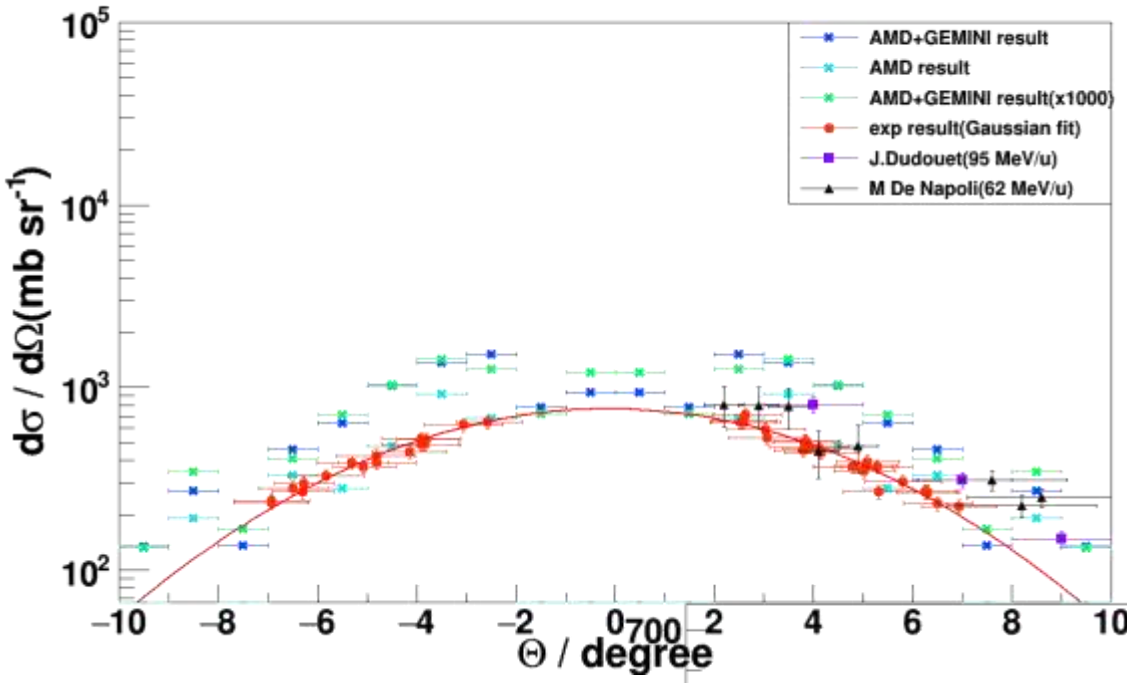
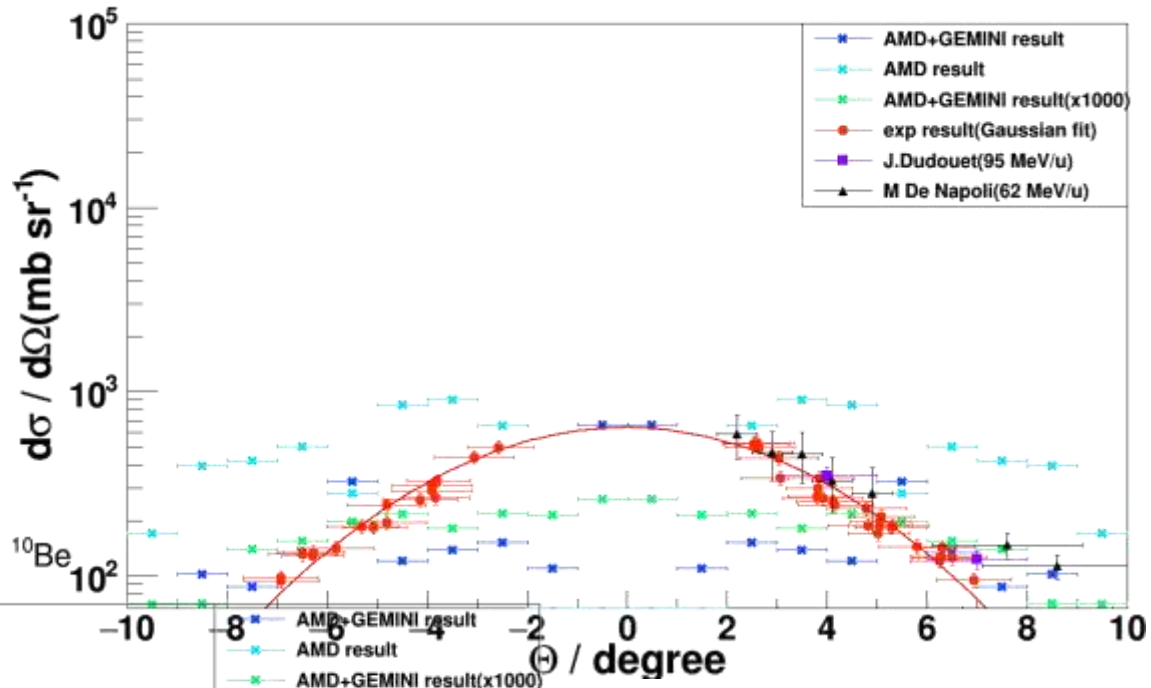
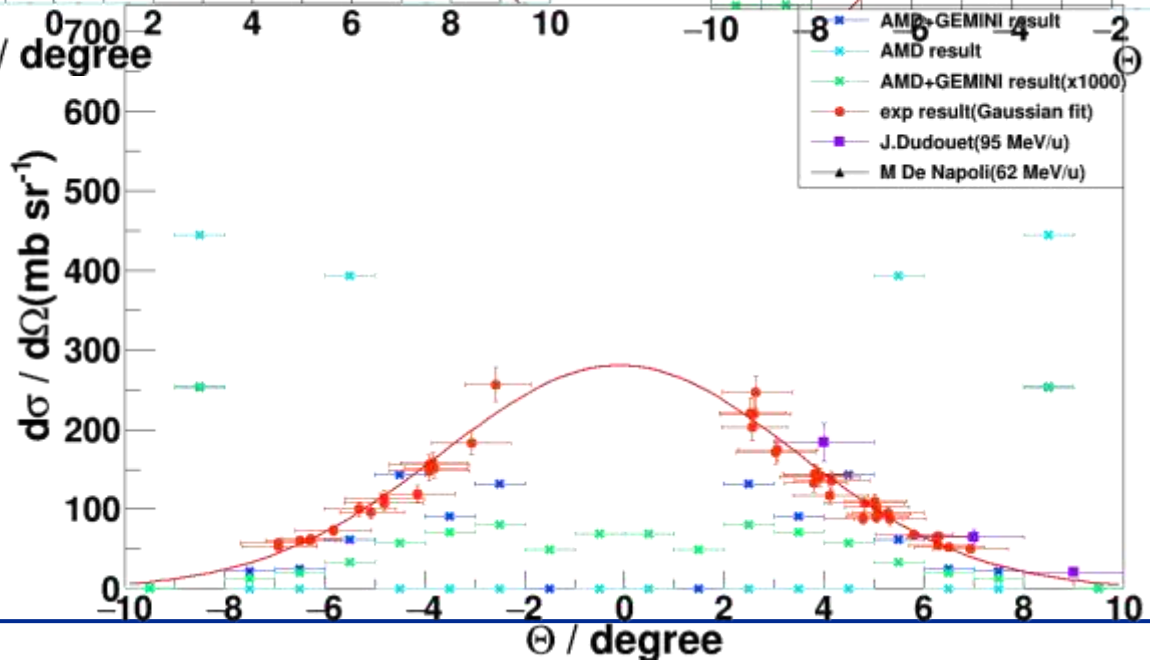
^{7}Be

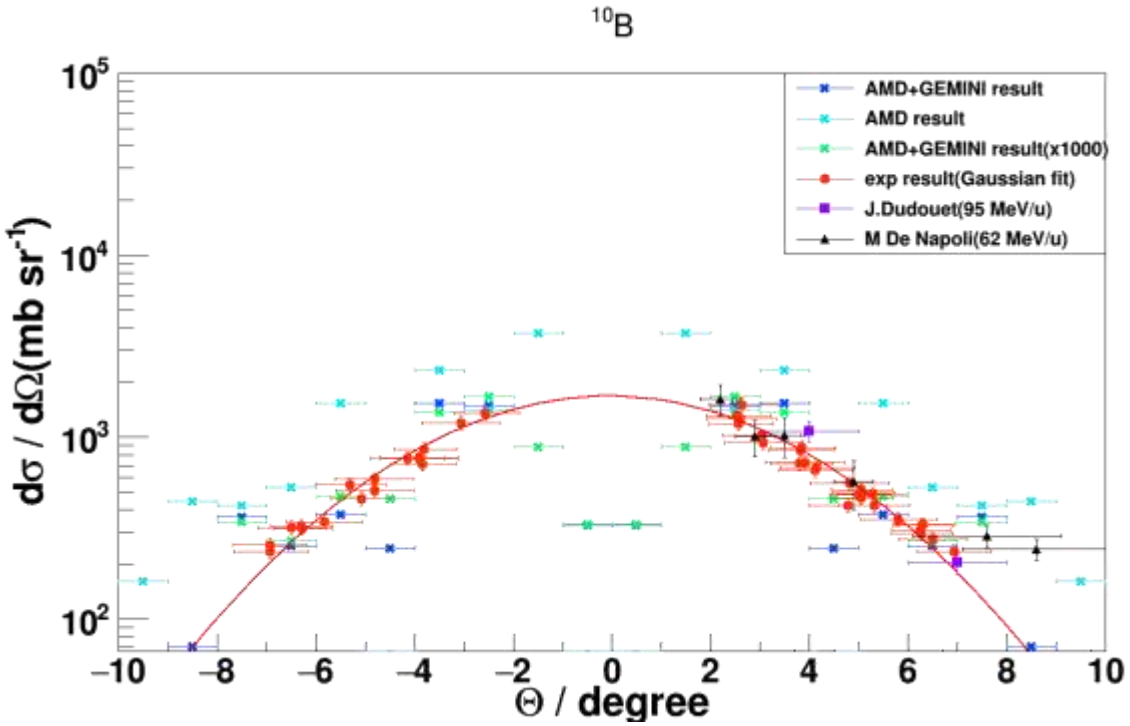


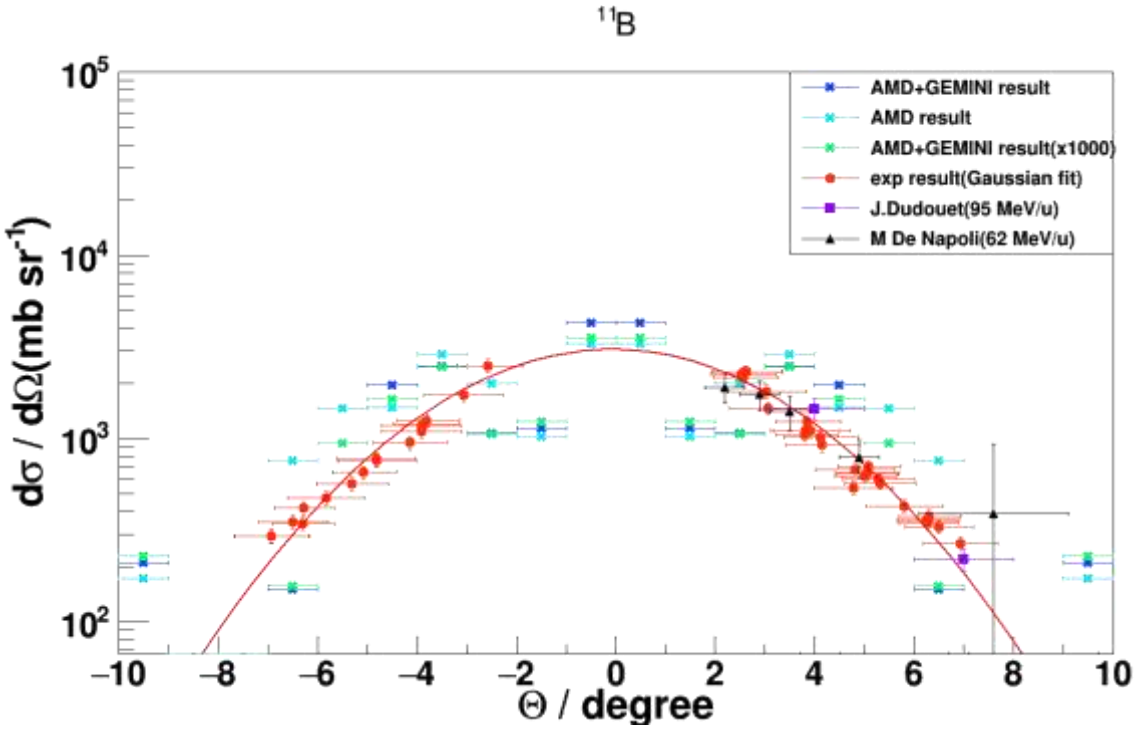
^{9}Be



^{10}Be




^{10}B
AMD+GEMINI result
AMD result
AMD+GEMINI result(x1000)
exp result(Gaussian fit)
J.Dudouet(95 MeV/u)
M De Napoli(62 MeV/u)
dσ / dΩ(mb sr^{-1})
Θ / degree


^{11}B
AMD+GEMINI result
AMD result
AMD+GEMINI result(x1000)
exp result(Gaussian fit)
J.Dudouet(95 MeV/u)
M De Napoli(62 MeV/u)
dσ / dΩ(mb sr^{-1})
Θ / degree

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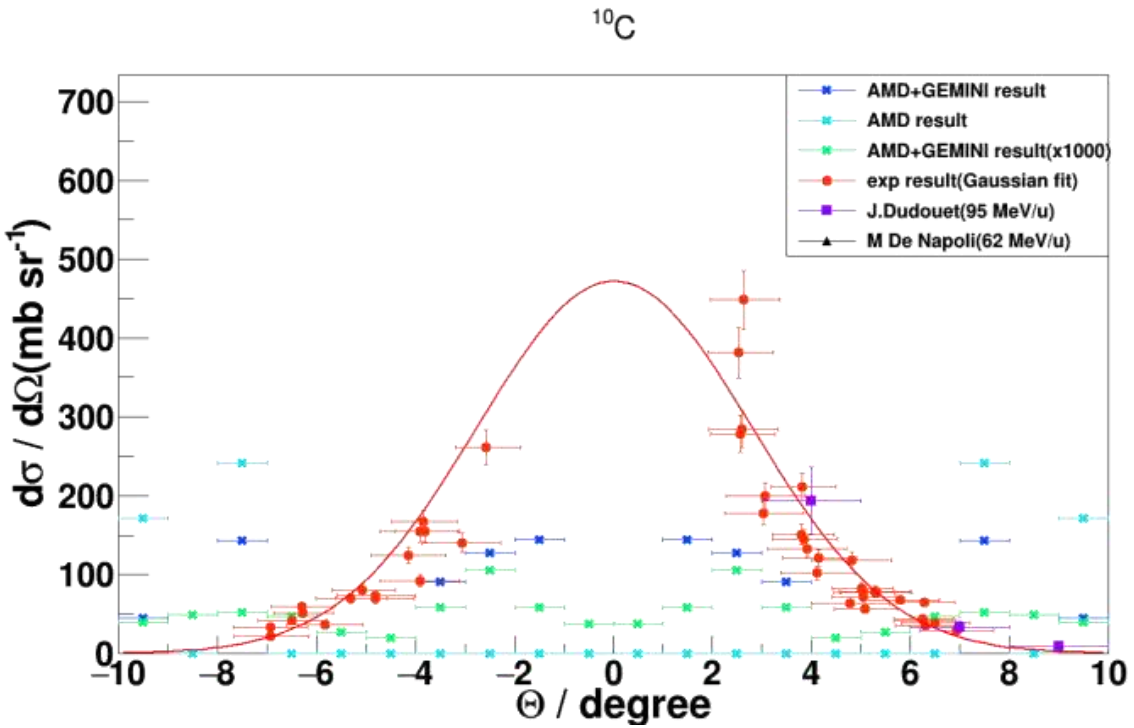

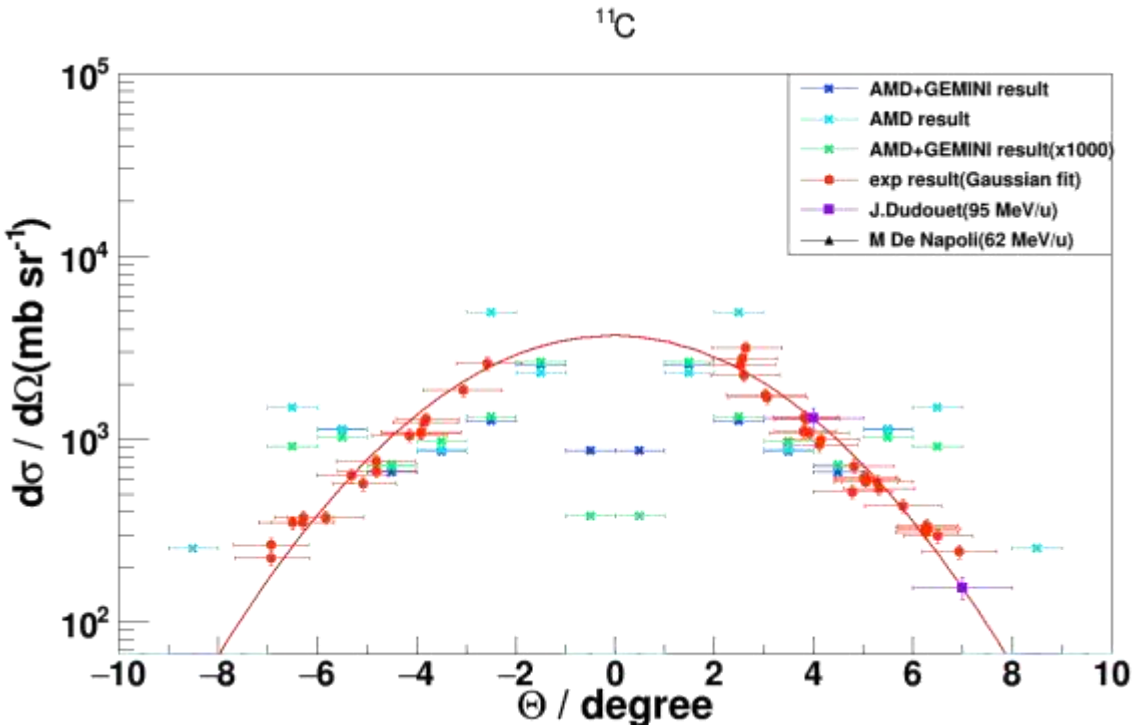

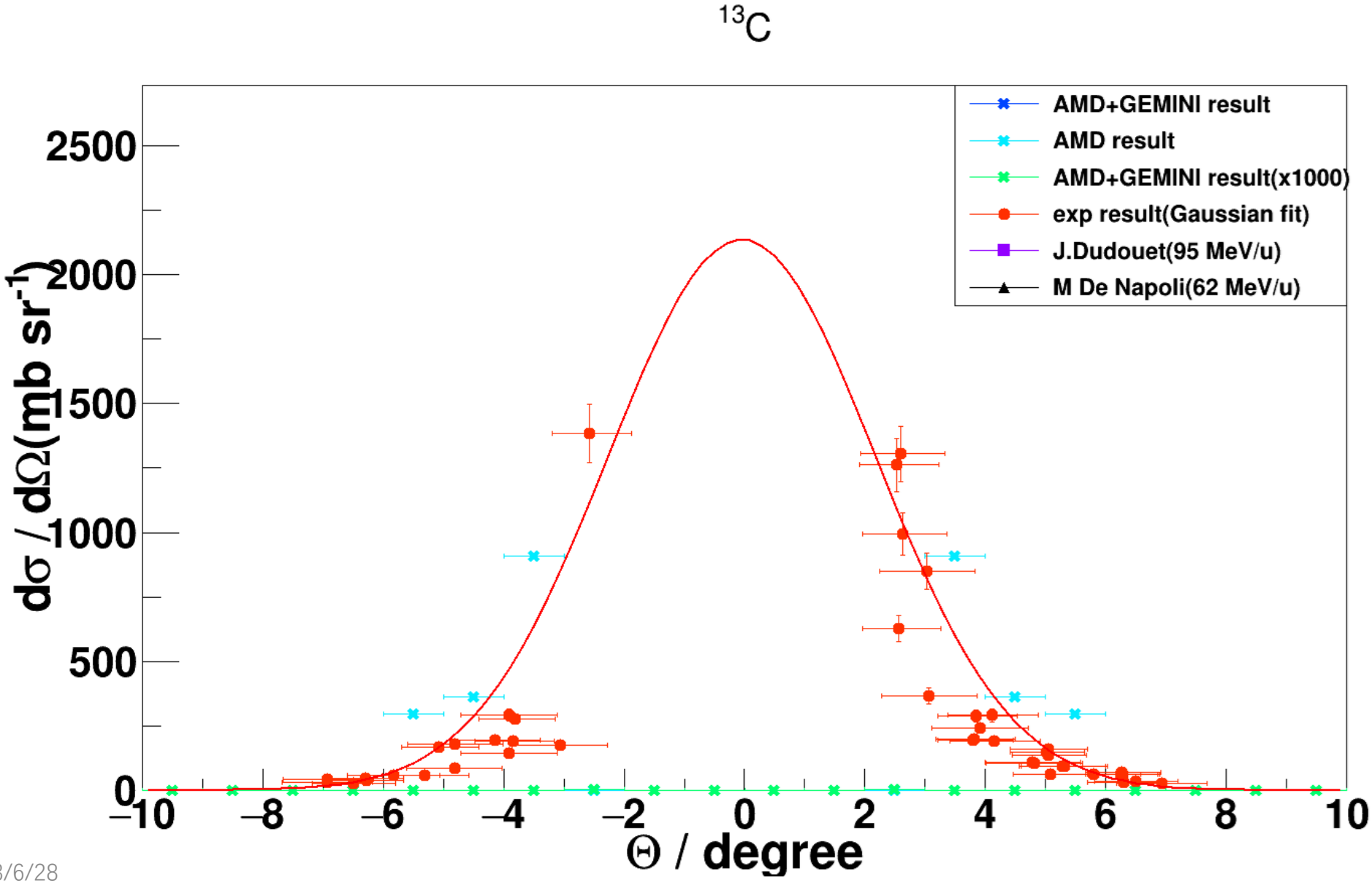
^{13}C
AMD+GEMINI result
AMD result
AMD+GEMINI result(x1000)
exp result(Gaussian fit)
J.Dudouet(95 MeV/u)
M De Napoli(62 MeV/u)
dσ / dΩ(mb sr^{-1})
2500
2000
1500
1000
500
0
−10
−8
−6
−4
−2
0
2
4
6
8
10
Θ / degree

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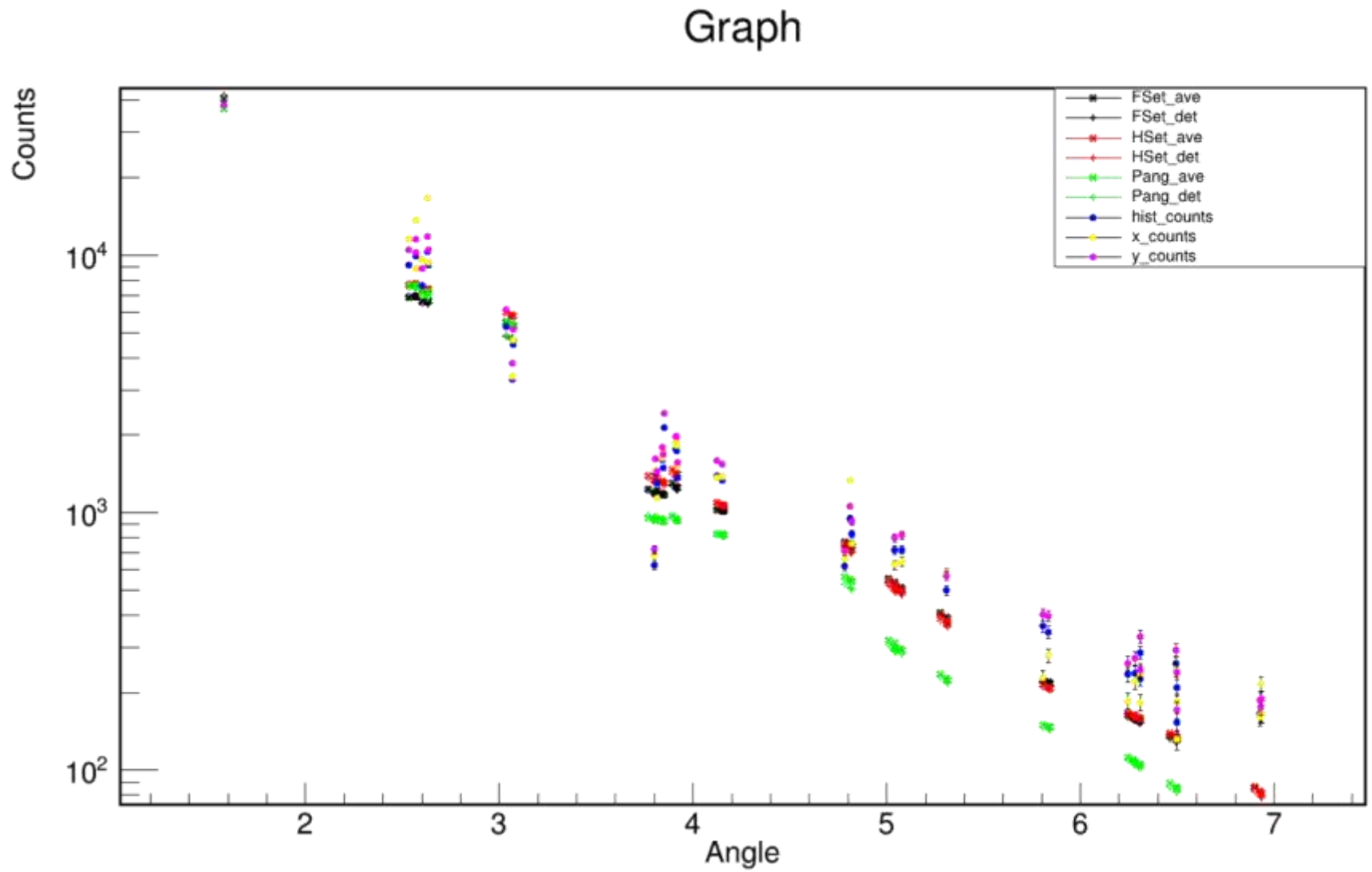
Backup:
other ESCS results


Graph
Counts
10^4
10^3
10^2
2
3
4
5
6
7
Angle
FSet_ave
FSet_det
HSet_ave
HSet_det
Pang_ave
Pang_det
hist_counts
x_counts
y_counts

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Backup: Evaporation

^{11}C

$^{10}B+p$ 20%

$^{9}B+d$ Missed ^{9}B

$^{8}Be+^{3}He$ Missed ^{8}Be

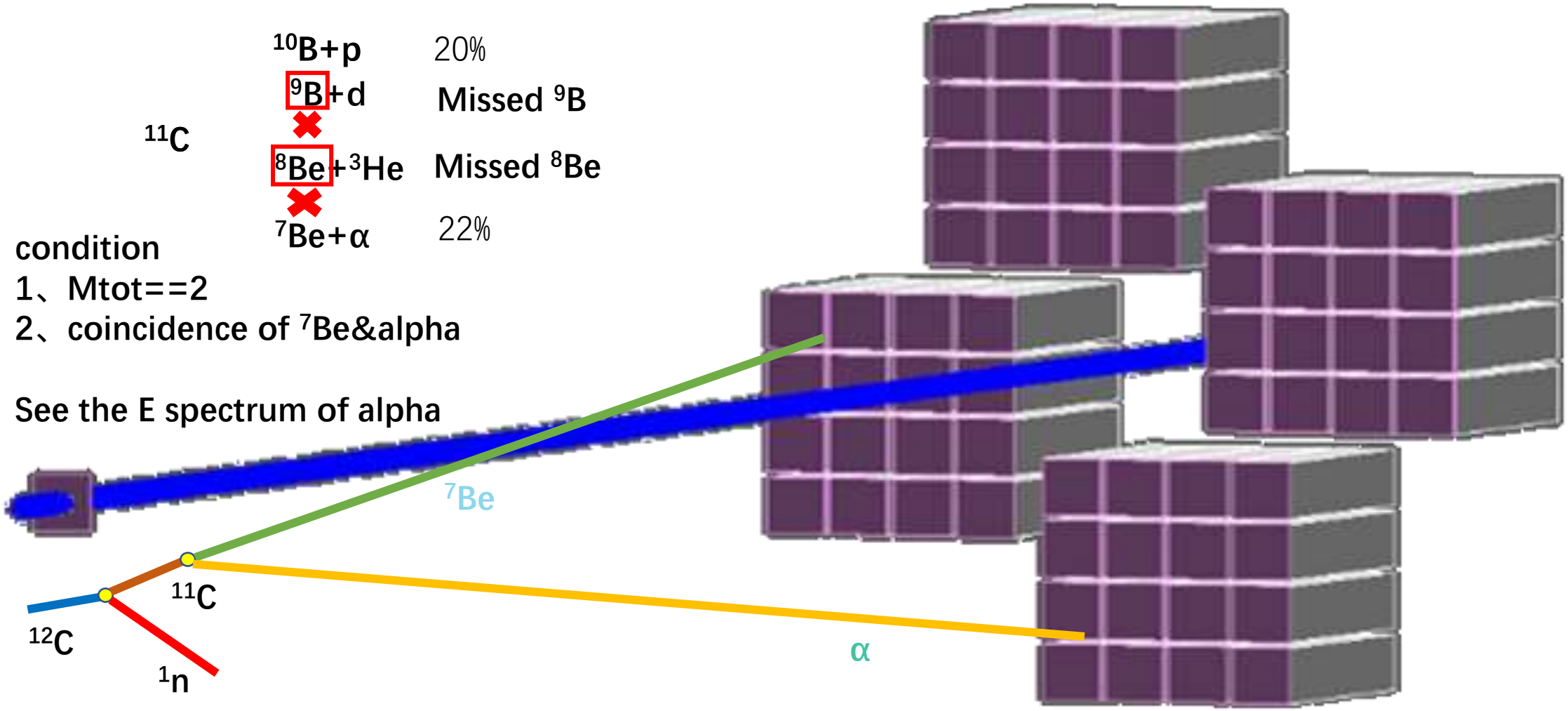
$^{7}Be+\alpha$ 22%

condition

1、Mtot==2

2、coincidence of ^{7}Be&alpha

See the E spectrum of alpha



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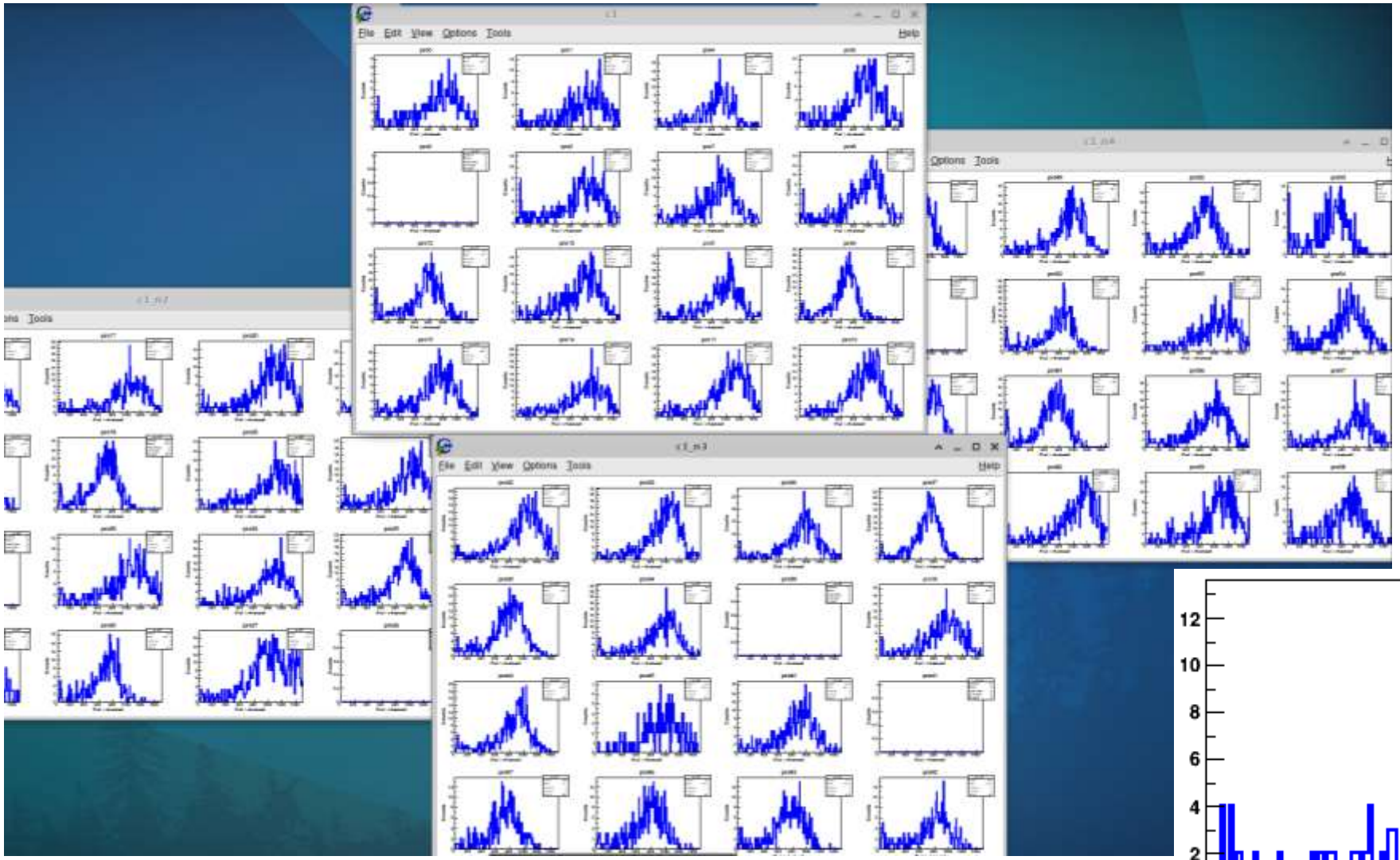

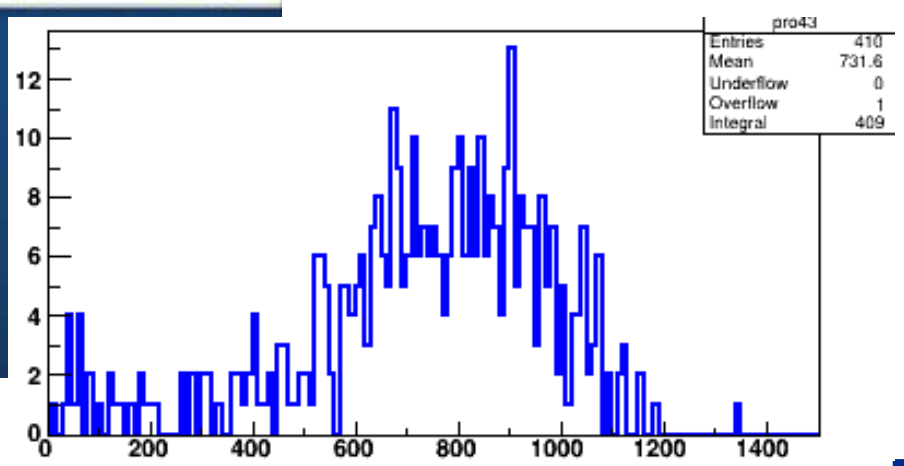

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Backup:
ESCS theory

Theory: scattering theory
Software: Fresco

```
12C-12C, 62 AMeV
NAMELIST
 &FRESCO  hcm= 0.0010 rmatch= 30.0
     jtmin= 0.0   jtmax=400.0 absend= 0.0001
     thmin= 0.050 thmax=120.0   thinc=0.010
         ips= 0.0010
     iso=' ' nnu=36 maxl= 0 minl=  0 mtmin= 8 epc= 0.0010
     treneg= 3 cdetr= 0 xstabl= 1 nlpl= 0  smats=2
     elab = 744.0 /

 &PARTITION namep='12C'  massp= 12.0 zp=6   nex= 1 pwf=T
            namet='12C' masst= 12.0 zt=6  qval= 0.0000 /
 &STATES jp= 0.0 ptyp= 1 ep= 0.0000  cpot= 1
         jt= 0.0 ptyt= 1 et= 0.0000 /
 &partition /

 &pot kp= 1 type= 0  p(1:3)= 12.00  12.00   1.2 /
 &pot kp= 1 type= 1  p(1:6)= 50.0  1.2  0.755  42.2  1.2  0.755  /

 &pot /

 &overlap /

 &COUPLING /
```

W-S potential

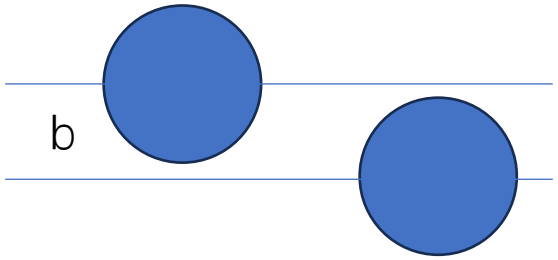
TABLE 1

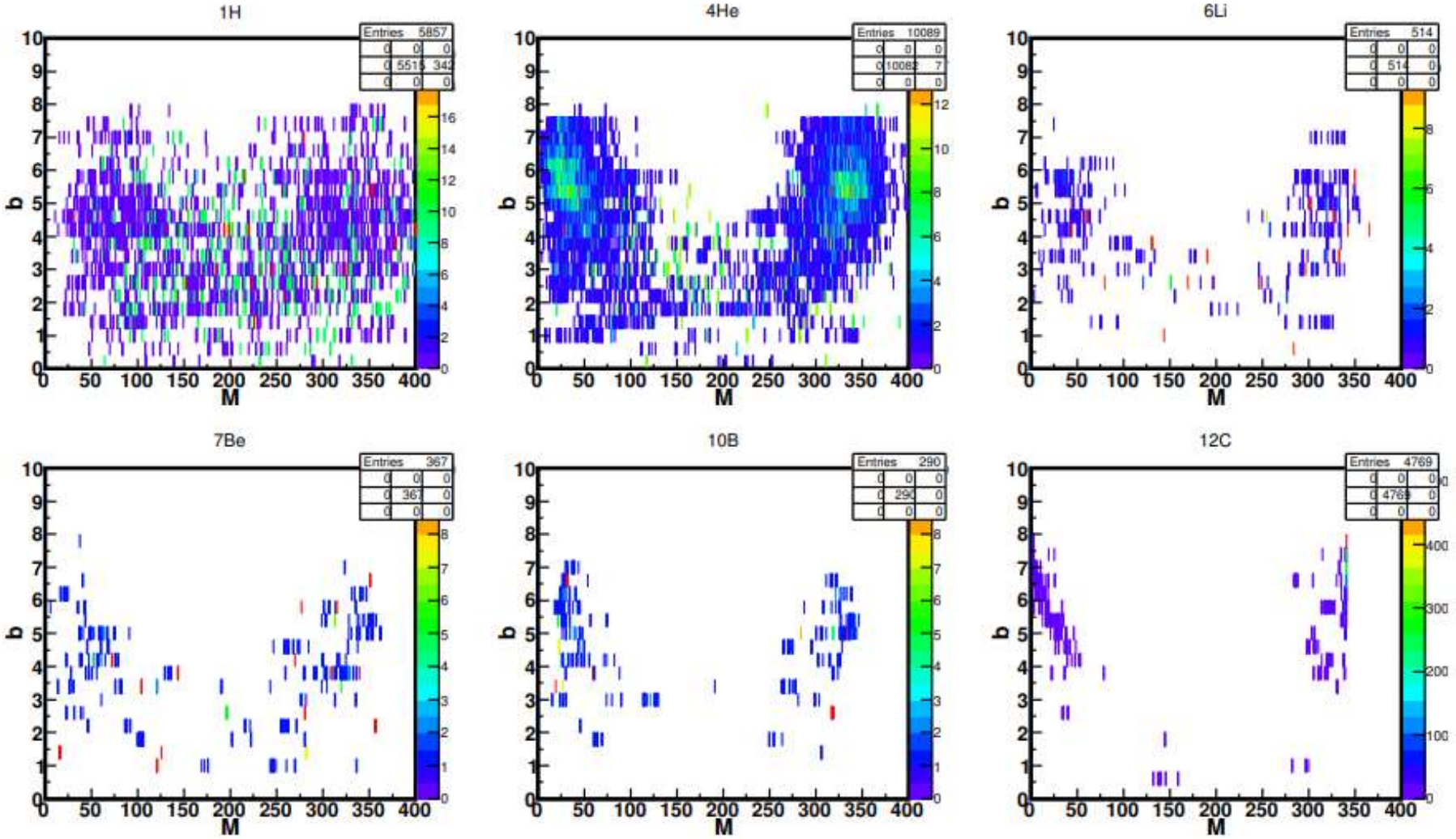
Optical-model parameters obtained from the analysis of $^{12}C+^{12}C$ elastic-scattering data at 1016 MeV, for fixed values of the real well depth

	V (MeV)	r (fm)	a (fm)	W (MeV)	r' (fm)	a' (fm)	σ_R (mb)	χ^2/N
A	15	1.29	0.57	37.80	1.03	0.46	966	12
B	40	1.03	0.67	34.20	1.00	0.55	971	9.3
C	60	0.91	0.71	39.13	0.95	0.63	995	7.3
D	80	0.83	0.75	40.57	0.91	0.72	1027	5.1
E	100	0.77	0.84	47.35	0.95	0.59	1005	3.6
F	120	0.71	0.84	34.02	0.96	0.69	1040	2.3
G	140	0.67	0.90	45.10	0.96	0.58	1001	2.3
H	200	0.55	0.98	43.11	0.99	0.53	994	3.7
I	300	0.41	1.06	47.68	0.98	0.53	1007	4.8

The last two columns give the calculated reaction cross section and the minimum chi-squared per point value obtained in the search.

Backup:
B_value


b


1H
Entries 5857
4He
Entries 10089
6Li
Entries 514
7Be
Entries 367
10B
Entries 290
12C
Entries 4769
b
M

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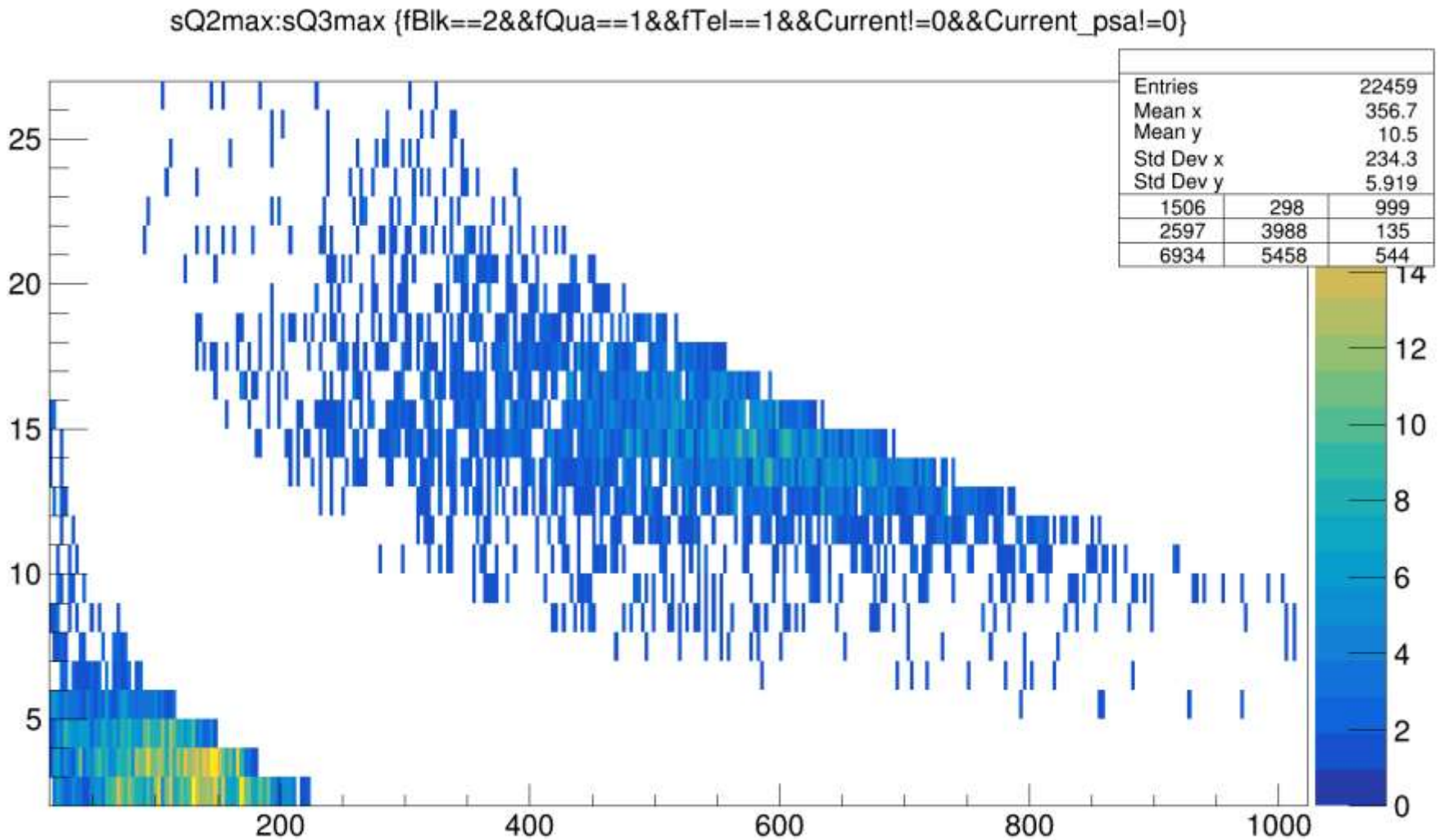
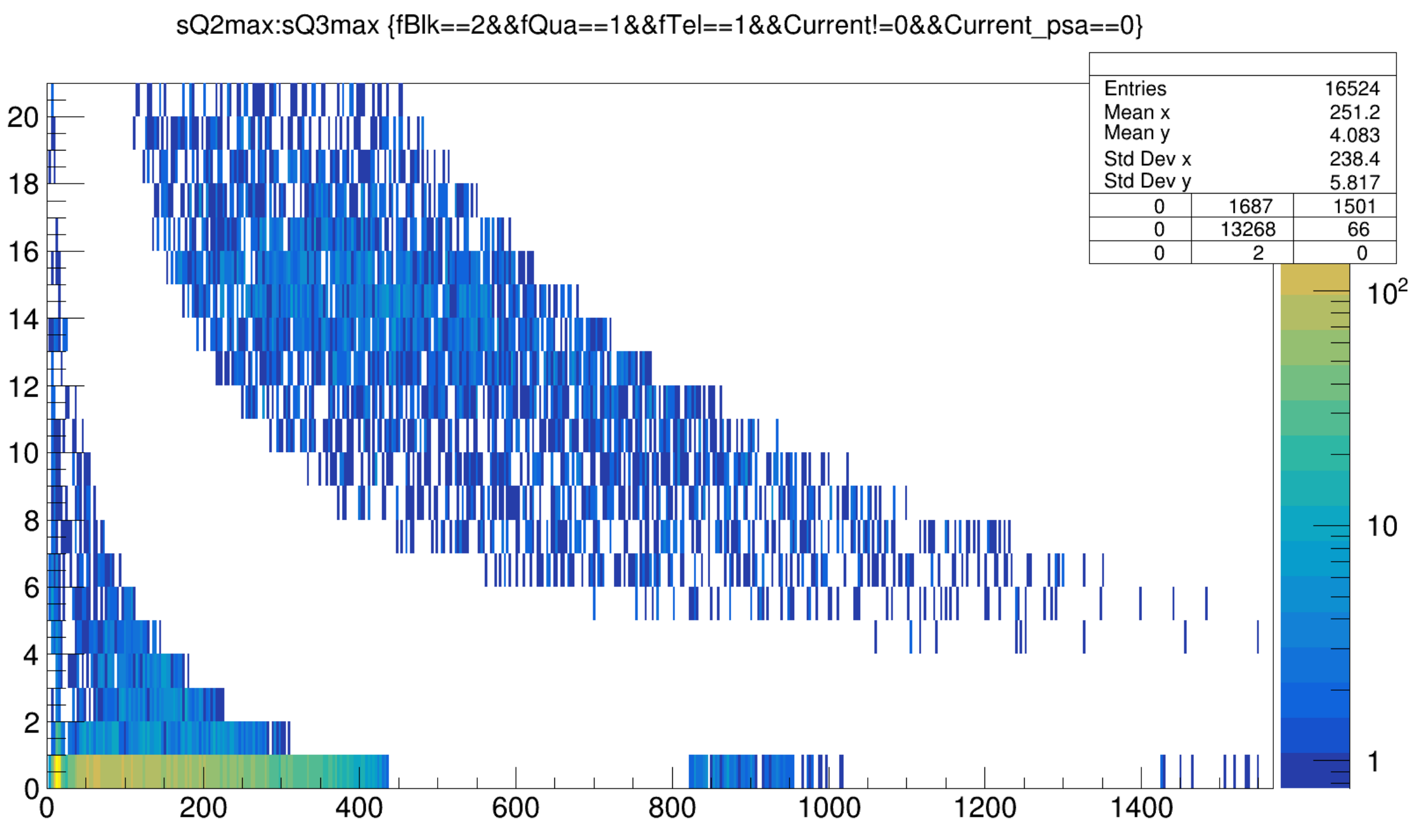
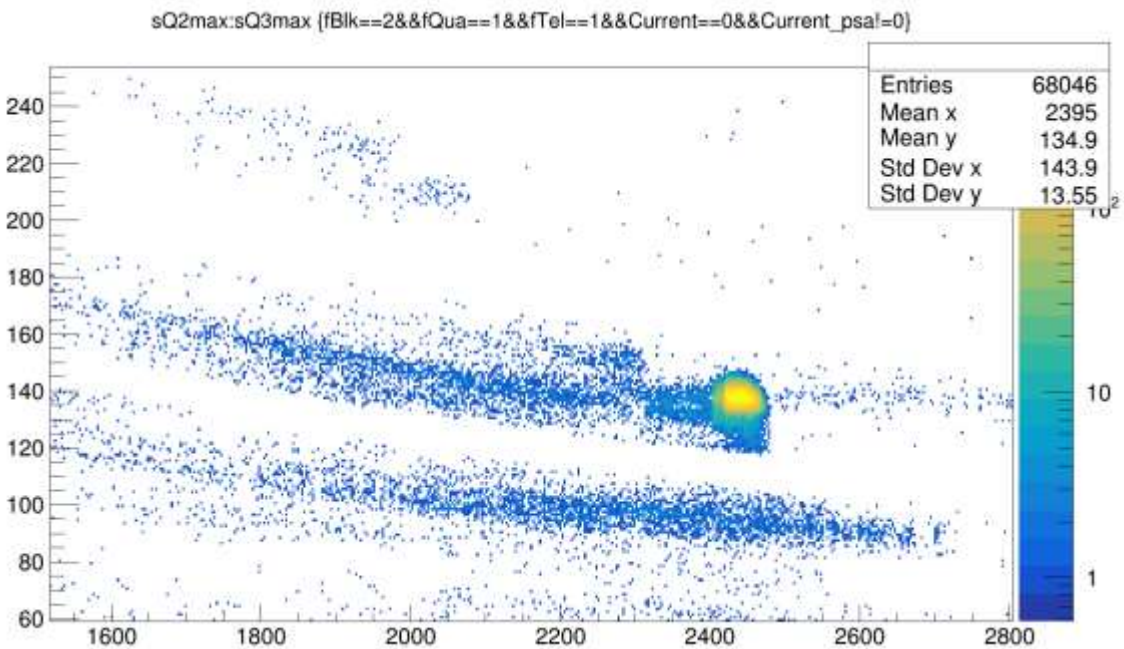
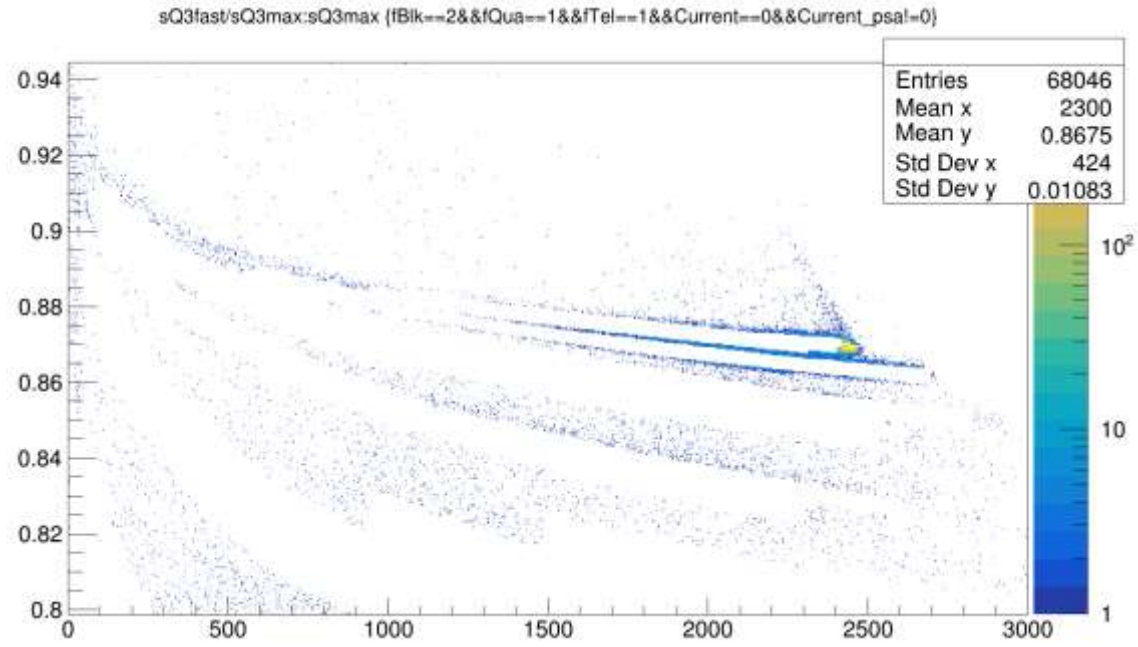
Backup:
Counting rule


sQ2max:sQ3max {fBlk==2&&fQua==1&&fTel==1&&Current!=0&&Current_psa!=0}
Entries 22459
Mean x 356.7
Mean y 10.5
Std Dev x 234.3
Std Dev y 5.919
1506 298 999
2597 3988 135
6934 5458 544
25
20
15
10
5
200
400
600
800
1000
14
12
10
8
6
4
2
0


sQ2max:sQ3max {fBlk==2&&fQua==1&&fTel==1&&Current!=0&&Current_psa==0}
Entries 16524
Mean x 251.2
Mean y 4.083
Std Dev x 238.4
Std Dev y 5.817
0 1687 1501
0 13268 66
0 2 0
0 2 4 6 8 10 12 14 16 18 20
0 200 400 600 800 1000 1200 1400
1 10 10^2


sQ2max:sQ3max {fBlk==2&&fQua==1&&fTel==1&&Current==0&&Current_psa!=0}
Entries 68046
Mean x 2395
Mean y 134.9
Std Dev x 143.9
Std Dev y 13.55
240
220
200
180
160
140
120
100
80
60
1600
1800
2000
2200
2400
2600
2800
10
1


sQ3fast/sQ3max:sQ3max {fBlk==2&&fQua==1&&fTel==1&&Current==0&&Current_psa!=0}
Entries 68046
Mean x 2300
Mean y 0.8675
Std Dev x 424
Std Dev y 0.01083
0.94
0.92
0.9
0.88
0.86
0.84
0.82
0.8
0
500
1000
1500
2000
2500
3000
10
1

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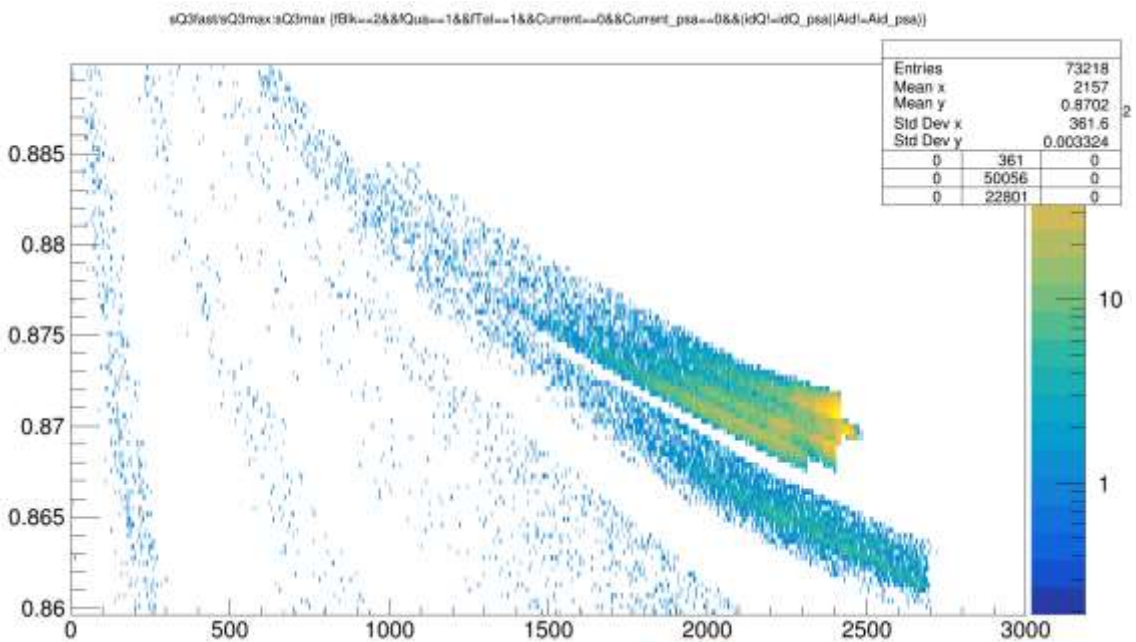

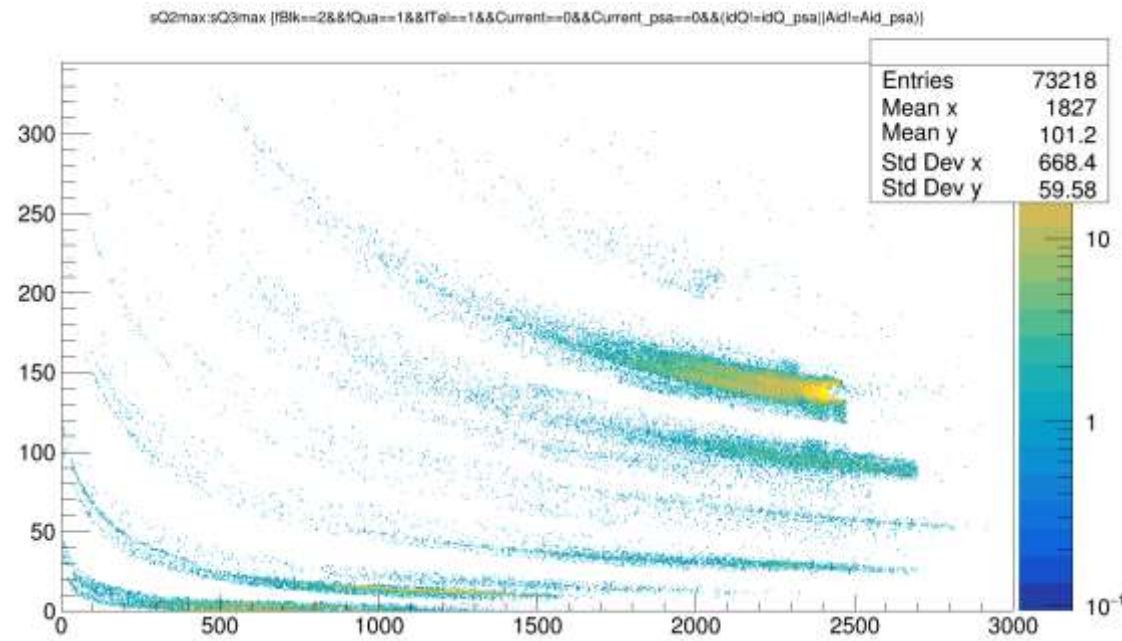

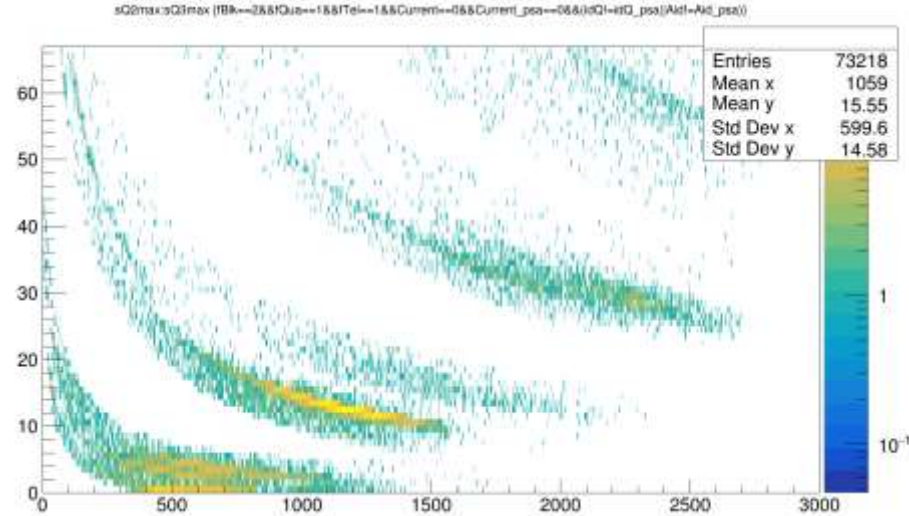

both good	311684	psa==E	238466		
		psa!=E	73218	on C,B	48615
				On H,He	16448
E good	68046	kali_error	54342		
		same as below	8000		
psa good	16524	he out	3473		
		h out	633		
		si no response	9094		
		else(z>2)	2499		
no good	22459	he out	2495		
		h out	2113		
		csi no response	10969		
		In	4500		

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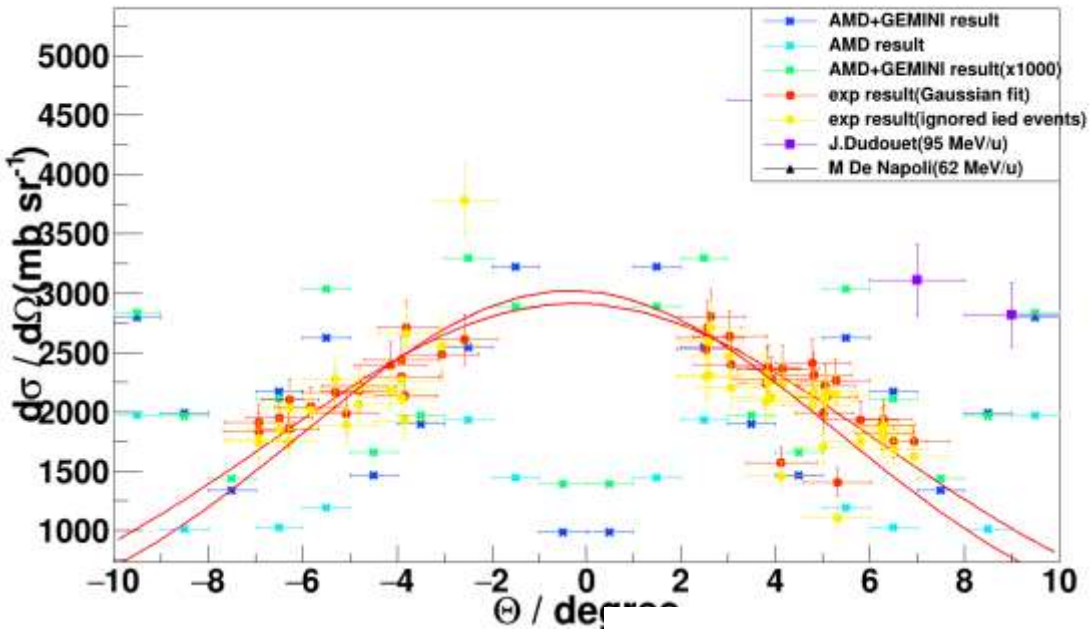
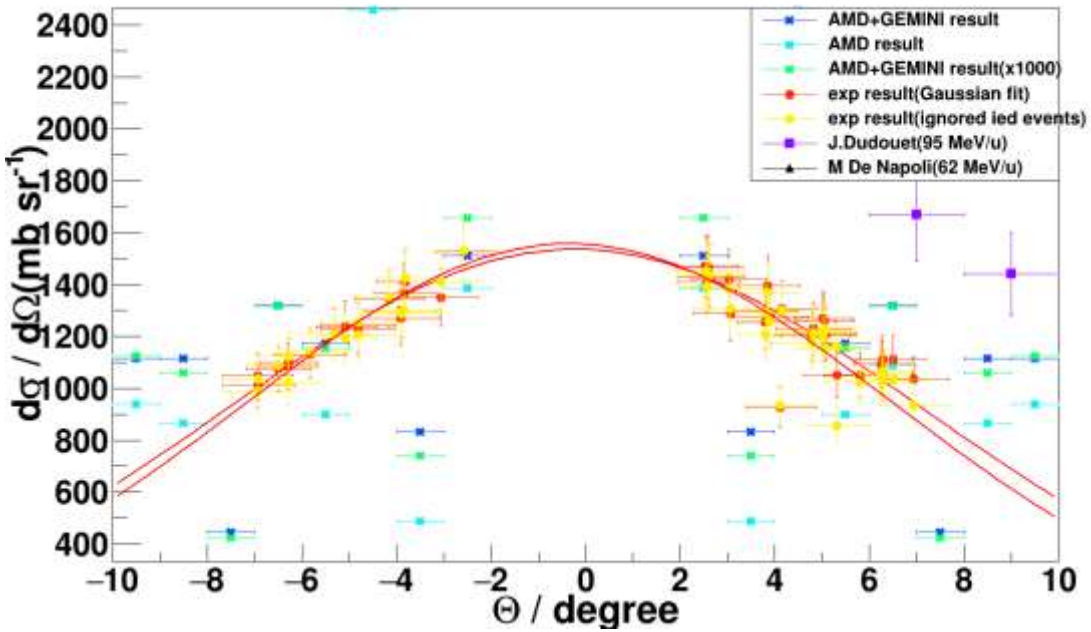
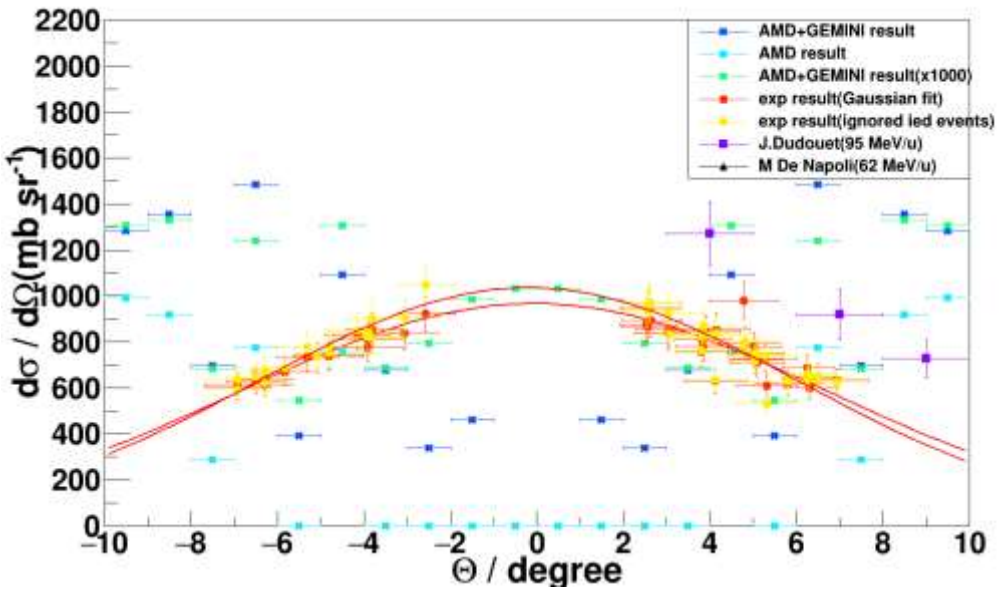
^{1}H

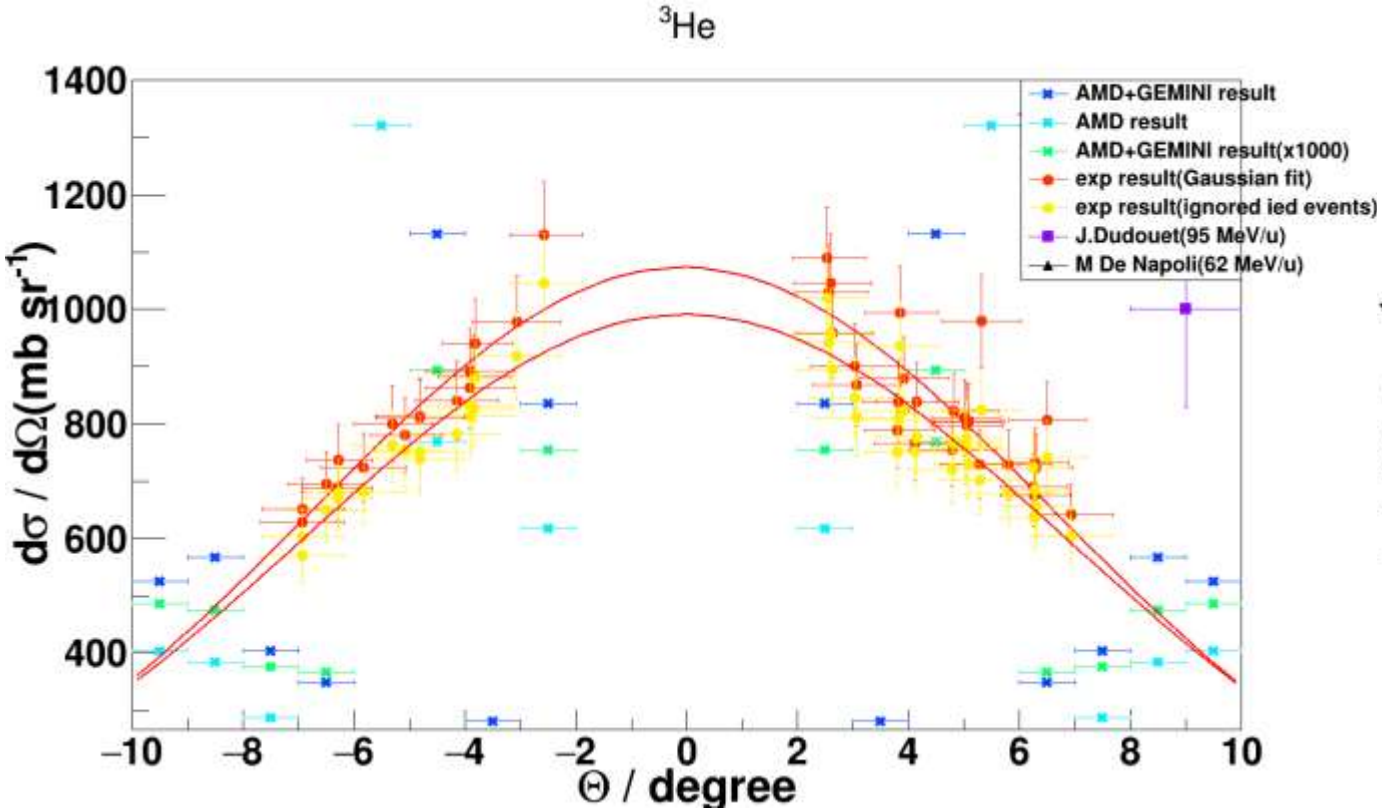


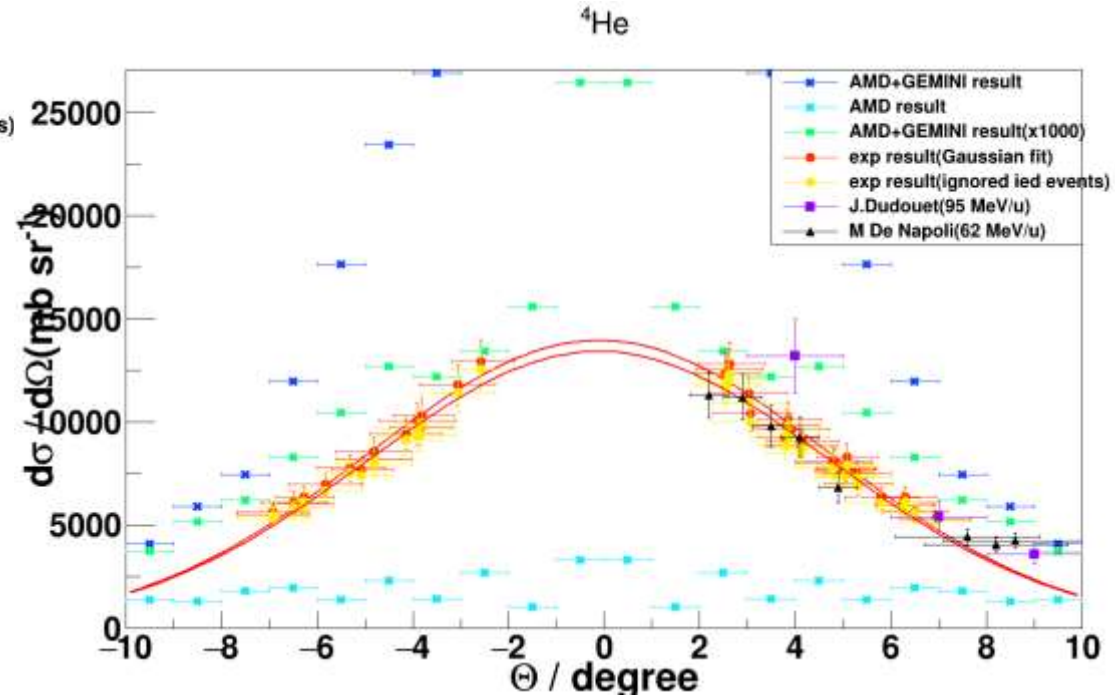
^{2}H



^{3}H




^{3}He
AMD+GEMINI result
AMD result
AMD+GEMINI result(x1000)
exp result(Gaussian fit)
exp result(ignored ied events)
J.Dudouet(95 MeV/u)
M De Napoli(62 MeV/u)
dσ / dΩ(mb sr^{-1})
Θ / degree


^{4}He
AMD+GEMINI result
AMD result
AMD+GEMINI result(x1000)
exp result(Gaussian fit)
exp result(ignored ied events)
J.Dudouet(95 MeV/u)
M De Napoli(62 MeV/u)
dσ / dΩ(mb sr^{-1})
Θ / degree

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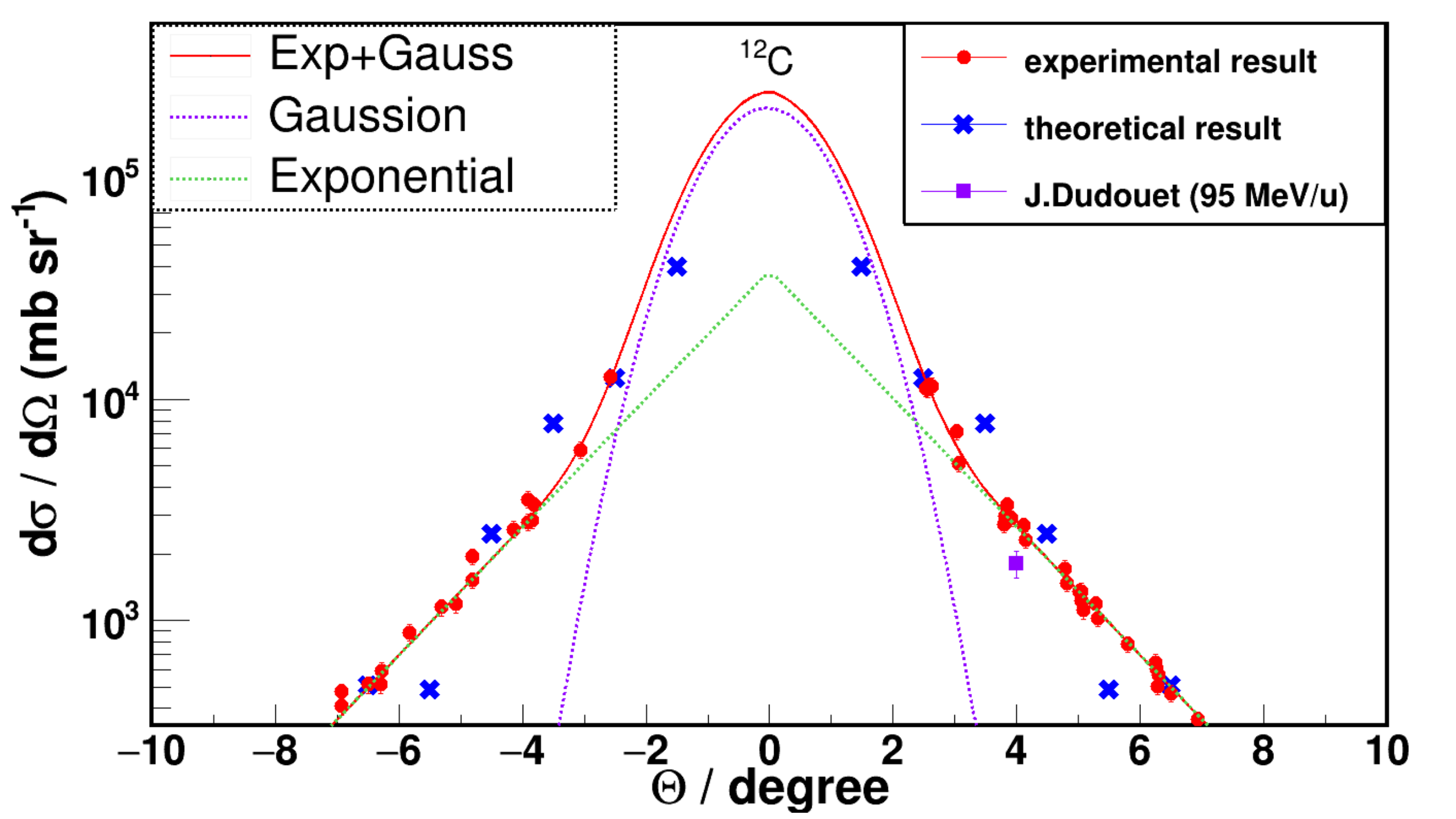
Backup:
Beam calibration

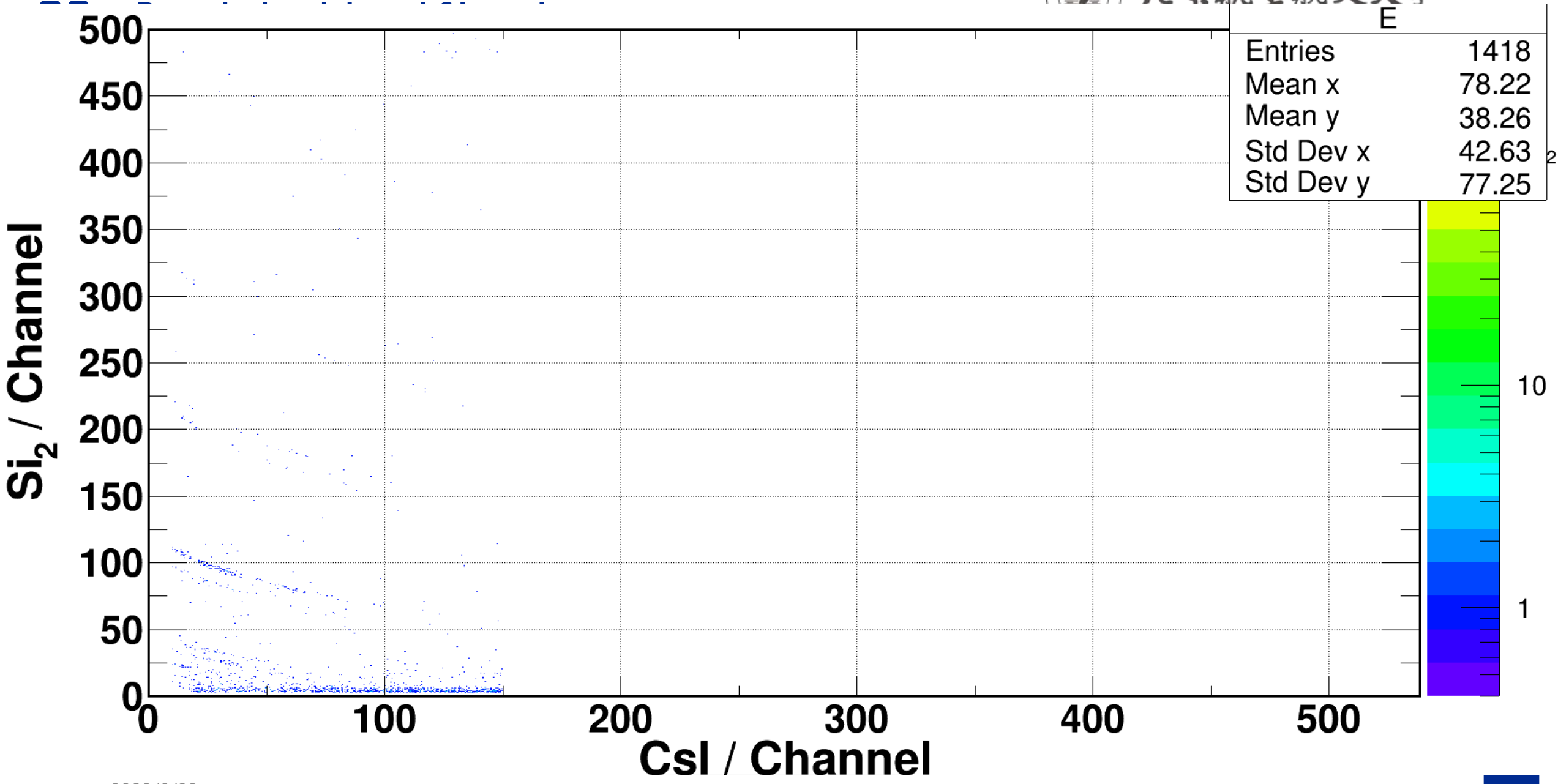
18% difference

file	omega	3.16 degree	escs(c.m.) / mb/sr	escs/ mb/sr	Counts	measuring time	Ibeam(epA)	reference value(epA)
1000-1099	5.96246E-06	pang	8502.479297	34009.9172	1663	83	132.9656561	145
1000-1099	5.96246E-06	Hset	8565.48457	34261.9383	1663	83	131.9875984	
1000-1099	5.96246E-06	Fset	9408.303016	37633.2121	1663	83	120.1638314	

file	omega	3.16 degree	escs(c.m.) / mb/sr	escs/ mb/sr	Counts	measuring time	Ibeam(epA)	reference value(epA)
1100-1199	5.96246E-06	pang	8502.479297	34009.9172	1918	87	146.3034859	145
1100-1199	5.96246E-06	Hset	8565.48457	34261.9383	1918	87	145.227319	
1100-1199	5.96246E-06	Fset	9408.303016	37633.2121	1918	87	132.217506	

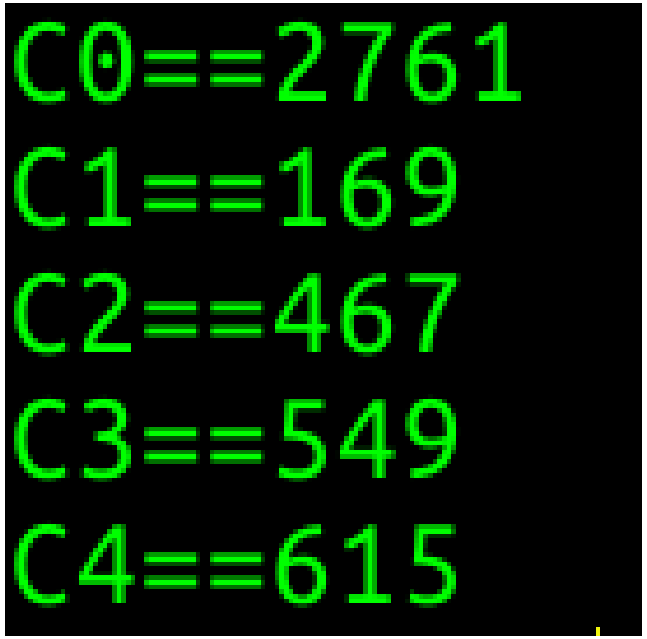
file	omega	3.16 degree	escs(c.m.) / mb/sr	escs/ mb/sr	Counts	measuring time	Ibeam(epA)	reference value(epA)
1319-1437	5.96246E-06	pang	8502.479297	34009.9172	2397	83	191.6528428	160
1319-1437	5.96246E-06	Hset	8565.48457	34261.9383	2397	83	190.2430989	
1319-1437	5.96246E-06	Fset	9408.303016	37633.2121	2397	83	173.2006638	


Exp+Gauss
Gaussion
Exponential
^{12}C
experimental result
theoretical result
J.Dudouet (95 MeV/u)
dσ / dΩ (mb sr^{-1})
10^5
10^4
10^3
−10
−8
−6
−4
−2
0
2
4
6
8
10
Θ / degree


E
Entries 1418
Mean x 78.22
Mean y 38.26
Std Dev x 42.63
Std Dev y 77.25
Si2 / Channel
CsI / Channel
0
50
100
150
200
250
300
350
400
450
500
0
100
200
300
400
500
1
10

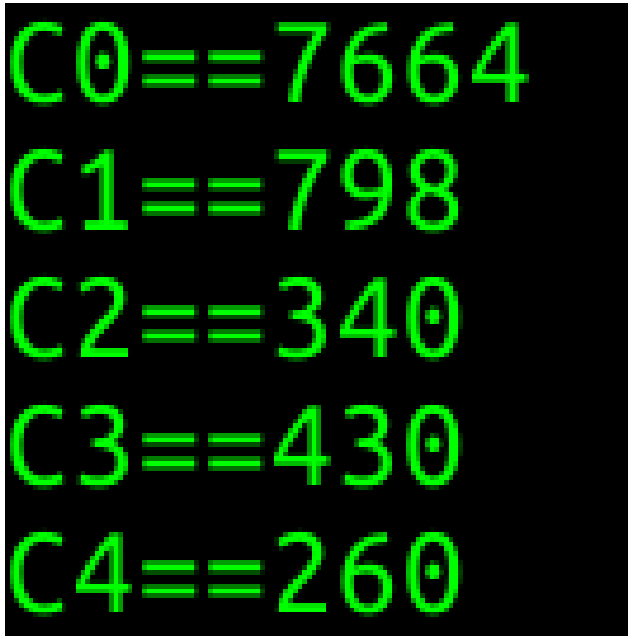
C0:E spe recognized
C1:E spe recognized while psa spe failed
C2: E and psa spe recognized while psa recognized as other isotopes
C3:E spe didn't recognize as proton but psa does.
C4:E spe failed recognizing but psa does.

^{3}H



6.12%
16.91%
19.88%
22.27%

^{1}H



10.41%
4.44%
5.61%
3.39%