The experimental study of γ-ray decay patterns using DANCE

Presented at:
Compound Nuclear Reactions and Related Topics
October 22-26, 2007 Yosemite National Park, Fish Camp, CA

UCRL-PRES-235745

Undraa Agvaanluvsan
N-Division, Physical Sciences Directorate
Lawrence Livermore National Laboratory

This work is performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

Compound nuclear reactions – Resonances

Both **<u>Resolved and Unresolved Resonance Regions</u>** (RRR and URR) are important for compound nuclear reactions. In my opinion, RRR is in better shape (computation-wise).

This presentation focuses on the <u>resolved resonances</u> .
They are a challenge because:

1. Theoretically it is not possible to predict the exact locations and magnitudes of resonances, only their fluctuation properties are calculable. R-matrix codes are fit to resonance data.

2. In all media, neutrons slow down. Therefore for fast reactor applications, even though the flux for low energy neutron is low, it is impossible to eliminate neutron moderation, and cross section at resonances can be extremely large.

3. Reliable determination of their spin and parity is crucial for the level density, which in turn is used in nuclear reaction codes.

Therefore, experimental tools are valuable, some of them, indispensable.
e.g., long-flight paths such as ORELA

Overview

- Describe the experimental technique with DANCE
- Emphasize gating on

  (a) total energy, (b) multiplicity, (c) E_n

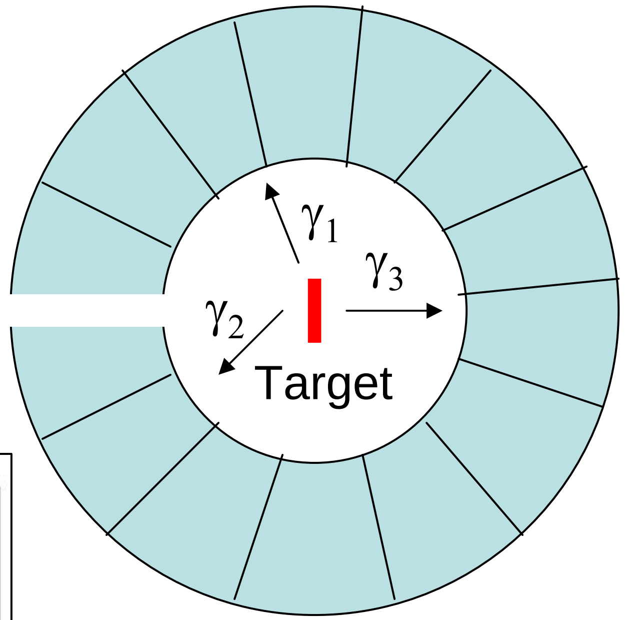
Then I will show data for the following nuclei:

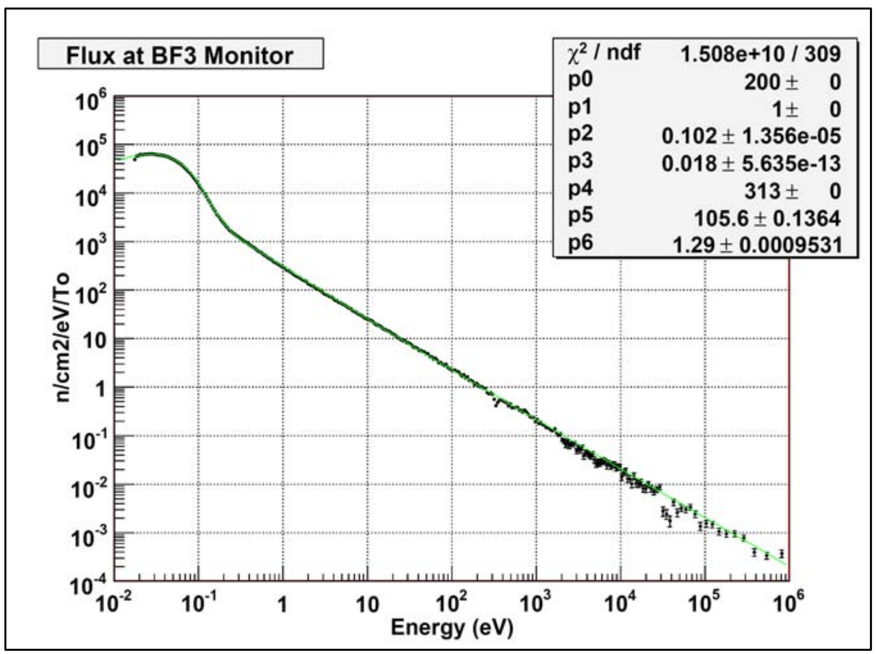
- $^{151}Eu(n,\gamma)$
- $^{152}Gd(n,\gamma)$
- $^{235}U(n,\gamma)$ – in most detail
- $^{241}Am(n,\gamma)$

DANCE – Experimental technique

The neutron energy is determined by the time-of-flight technique (20m)

Intense white neutron beam



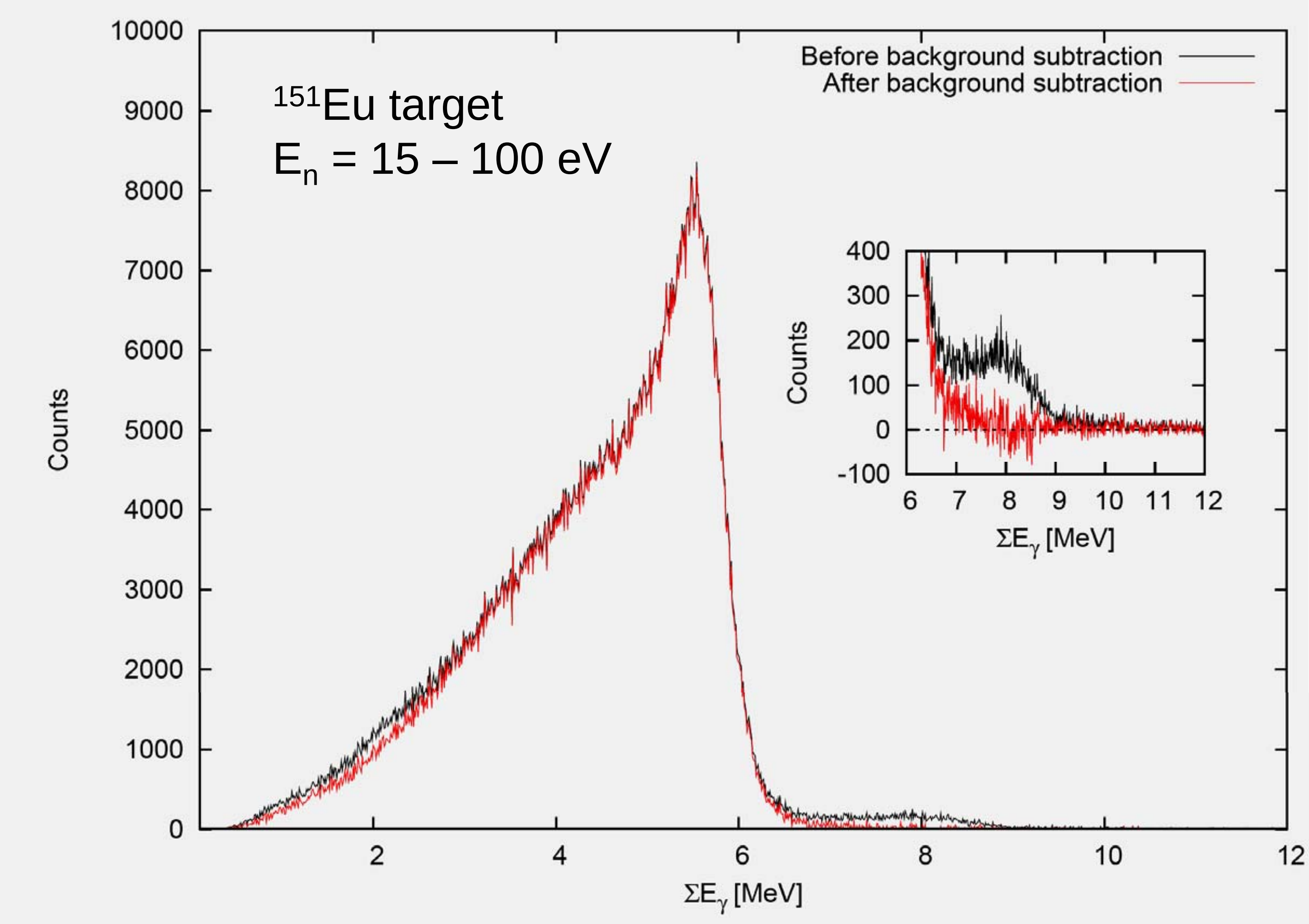


The DANCE array consists of 159 BaF_2 detectors and a ^2LiH sphere inside the array helps eliminate the neutron background.

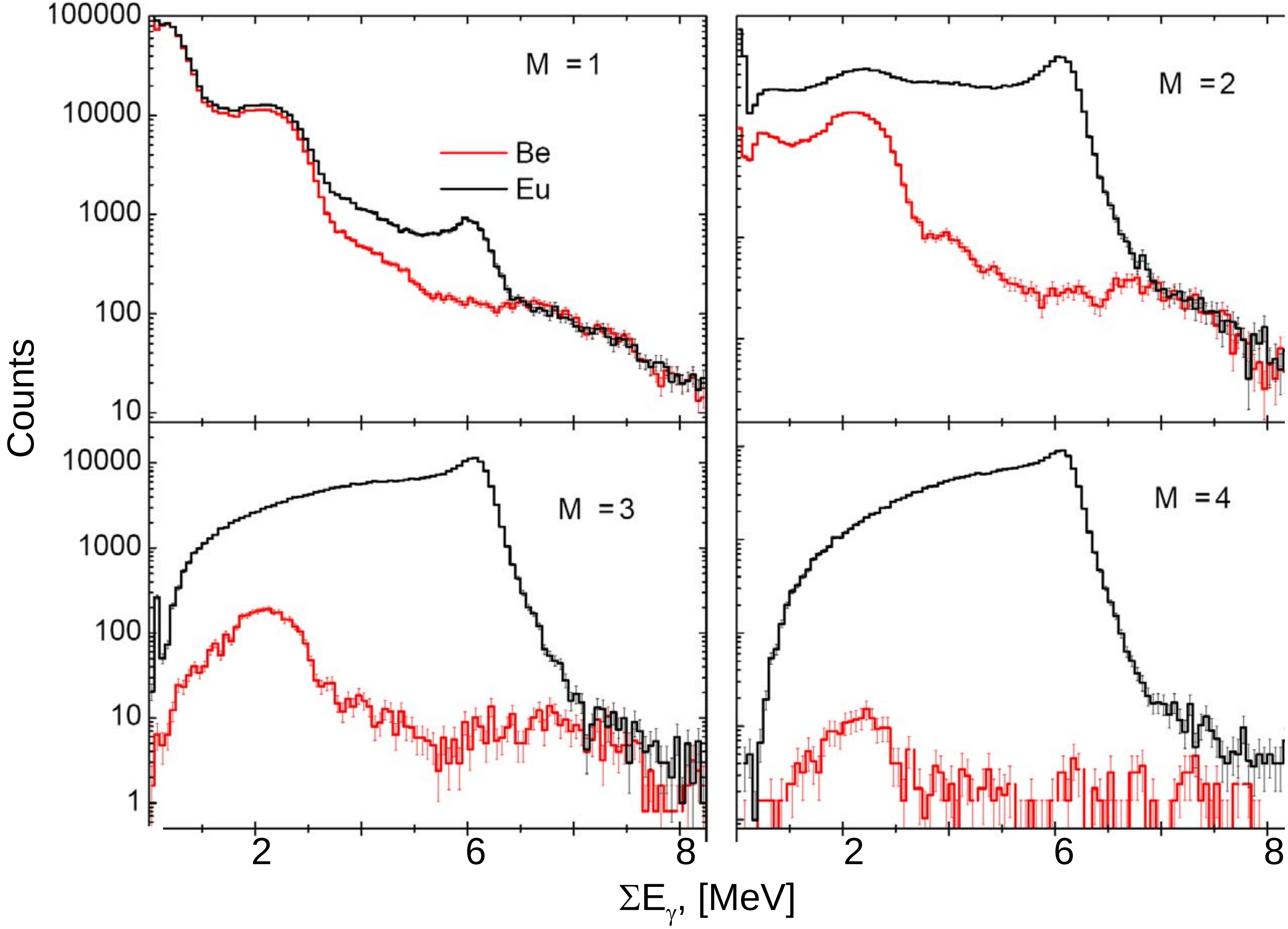
Detector for Advanced Neutron Capture Experiments (DANCE)

1. A calorimeter which enables nearly total energy collection
2. Highly segmented therefore makes possible to identify the number of γ-rays in the cascade (multiplicity – M)
3. For each multiplicity, energy information can be obtained

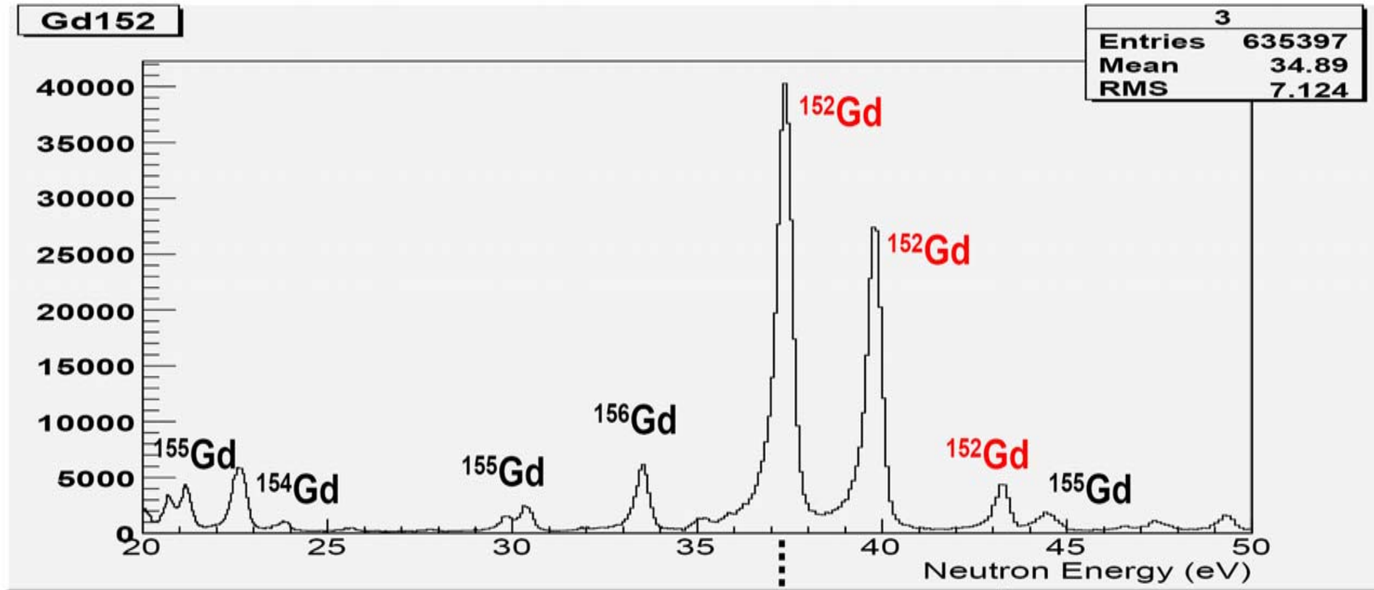
The total energy spectrum is obtained as a function of E_n



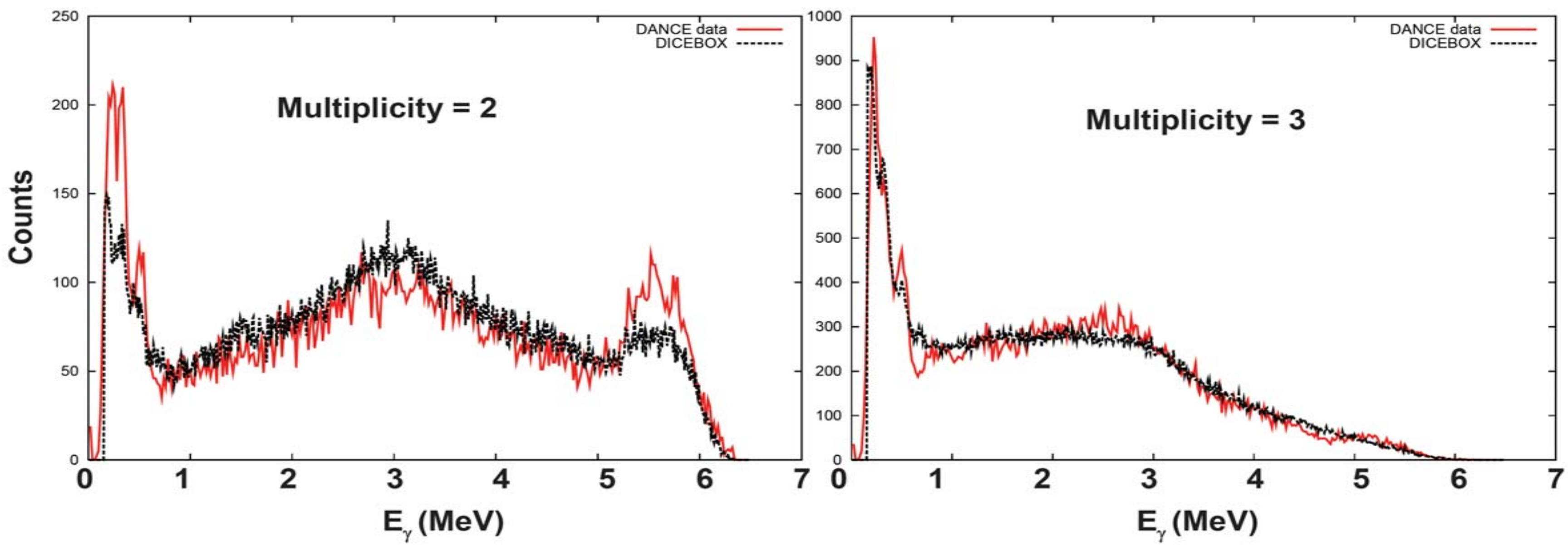
High segmentation -- each M can be separated



Gates set on the total energy, the neutron energy spectrum is obtained

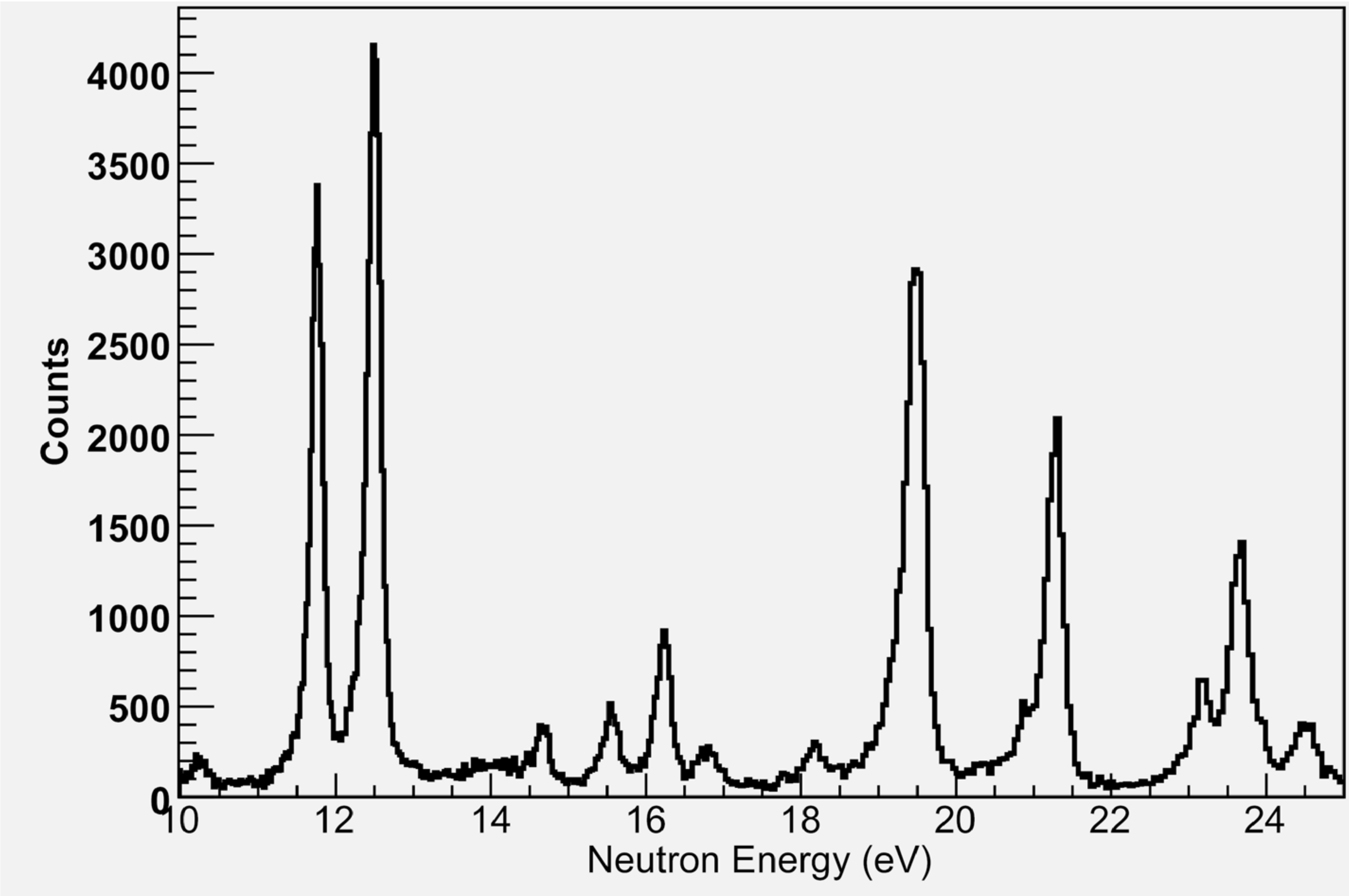


Neutron energy gate is set around well-separated s-wave ^{152}Gd resonance at E_n = 39.3 eV.

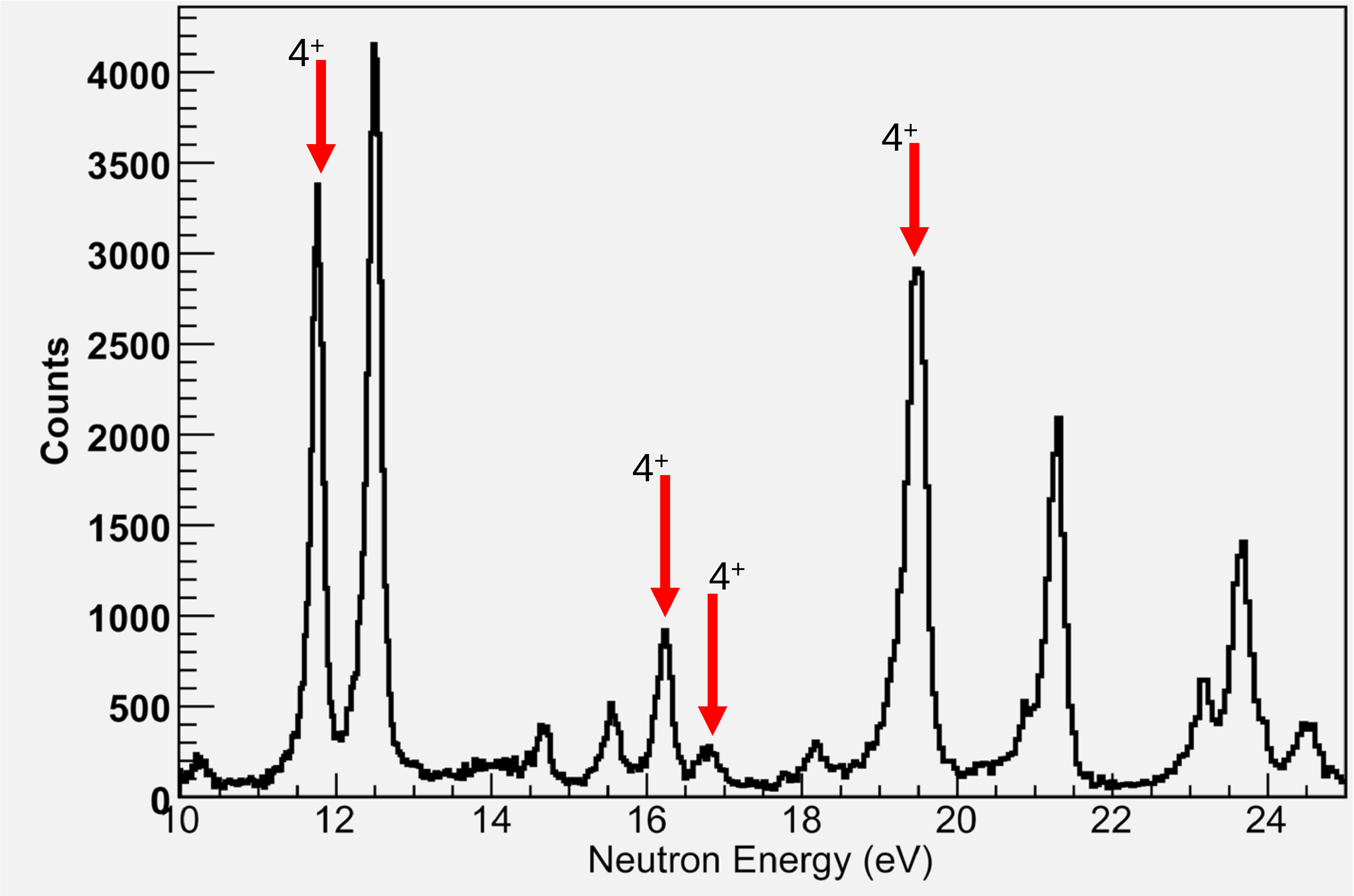


Courtesy of D. Dashdorj, NCSU

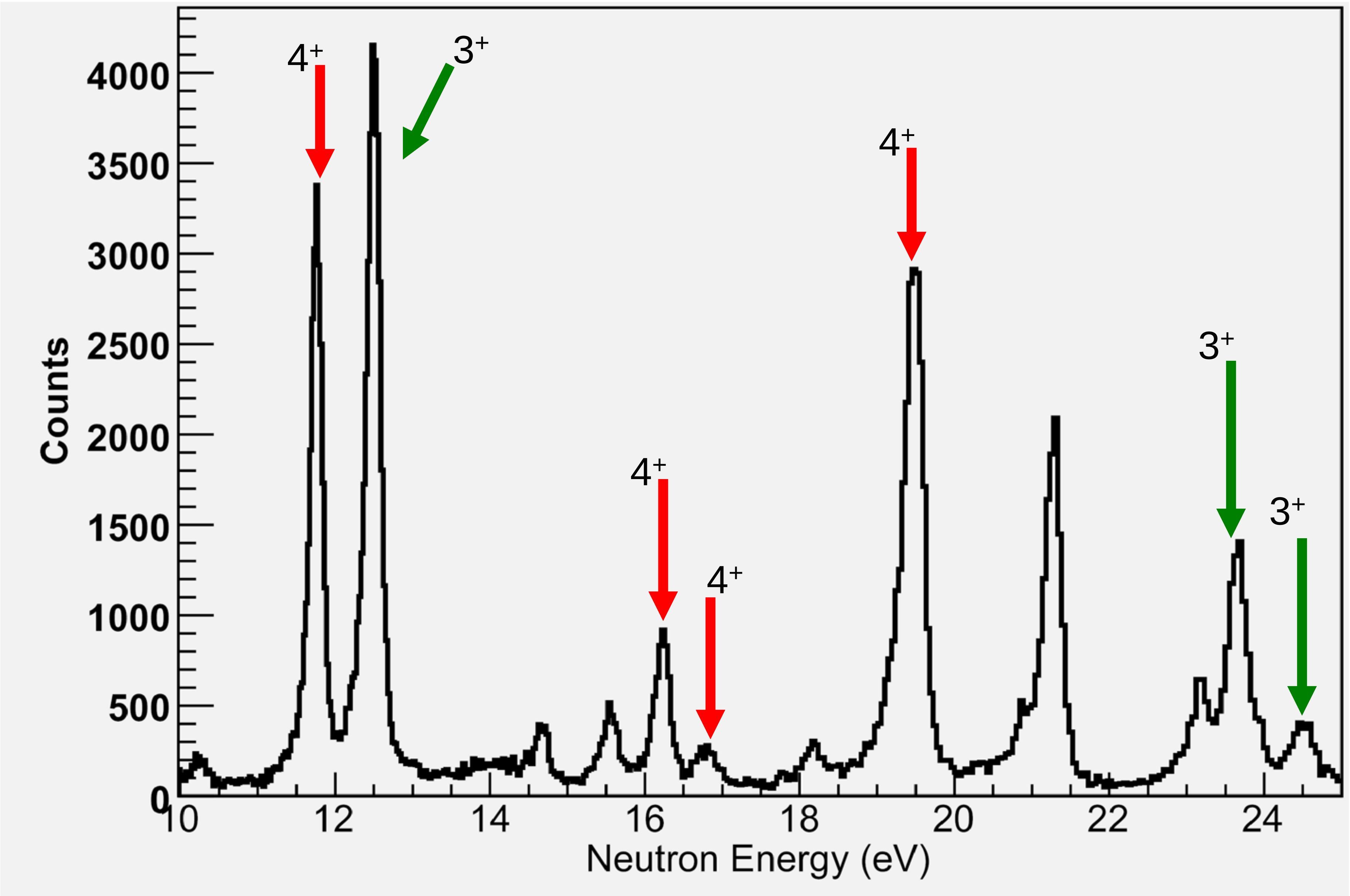
Neutron resonances of ^{235}U



Neutron resonances of ^{235}U



Neutron resonances of ^{235}U

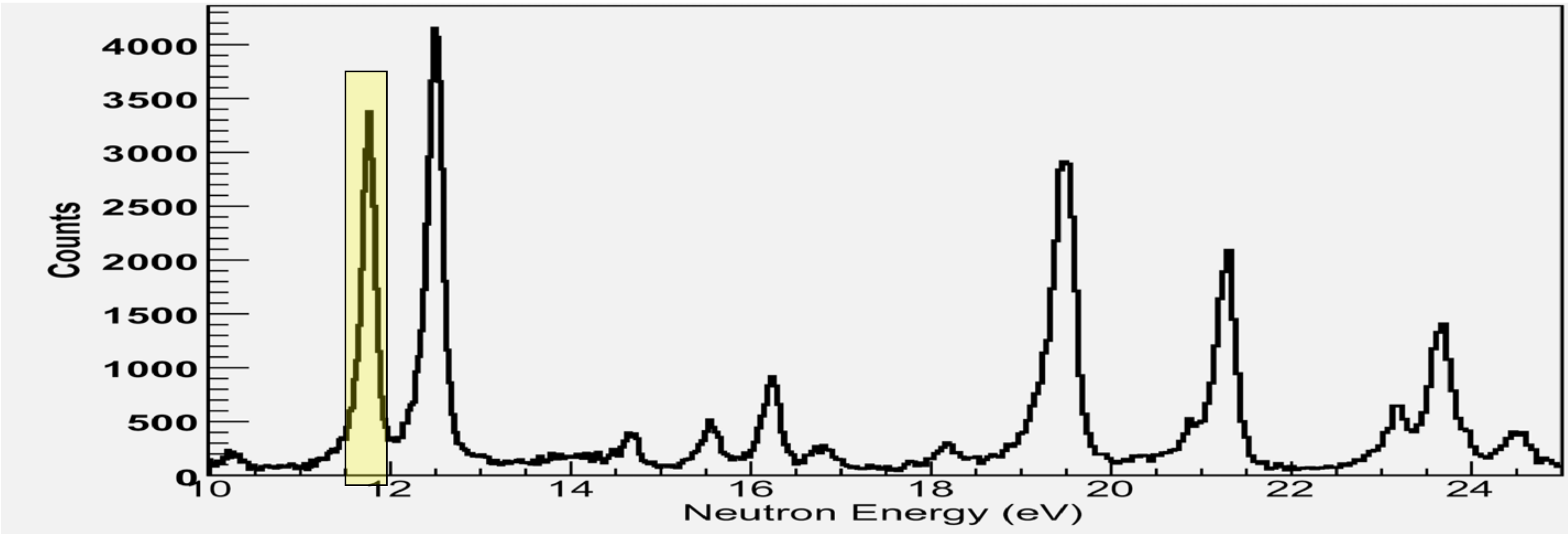


The application to reaction codes

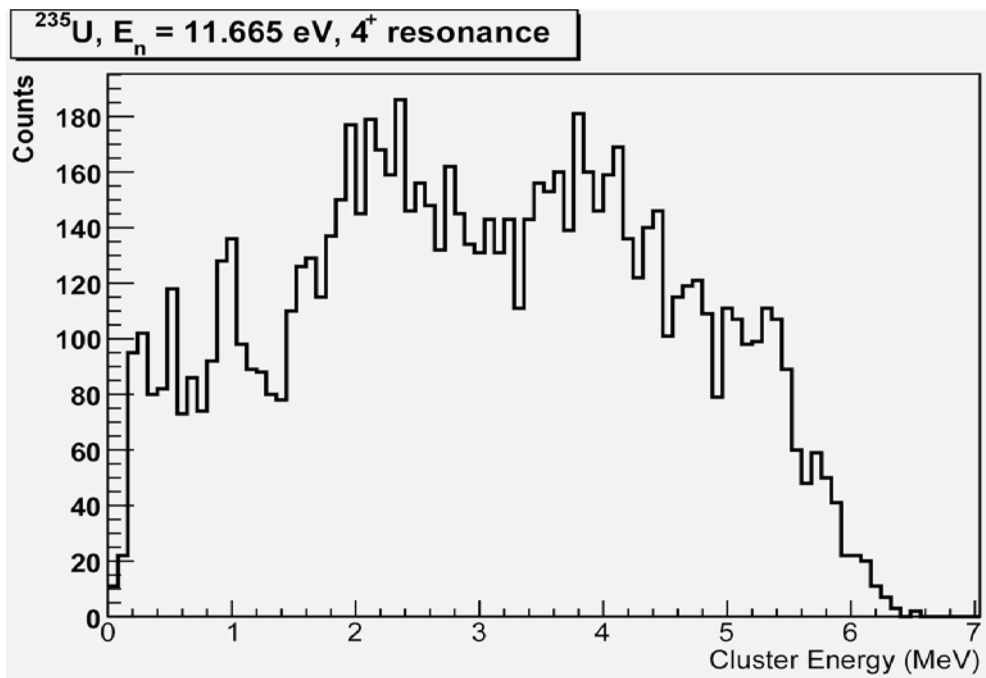
The s-wave resonance spacing D is needed for the calculation of the total level density (or for an “a” parameter) at the neutron binding energy. Therefore D needs to be accurate for the correct calculation of reaction rates.

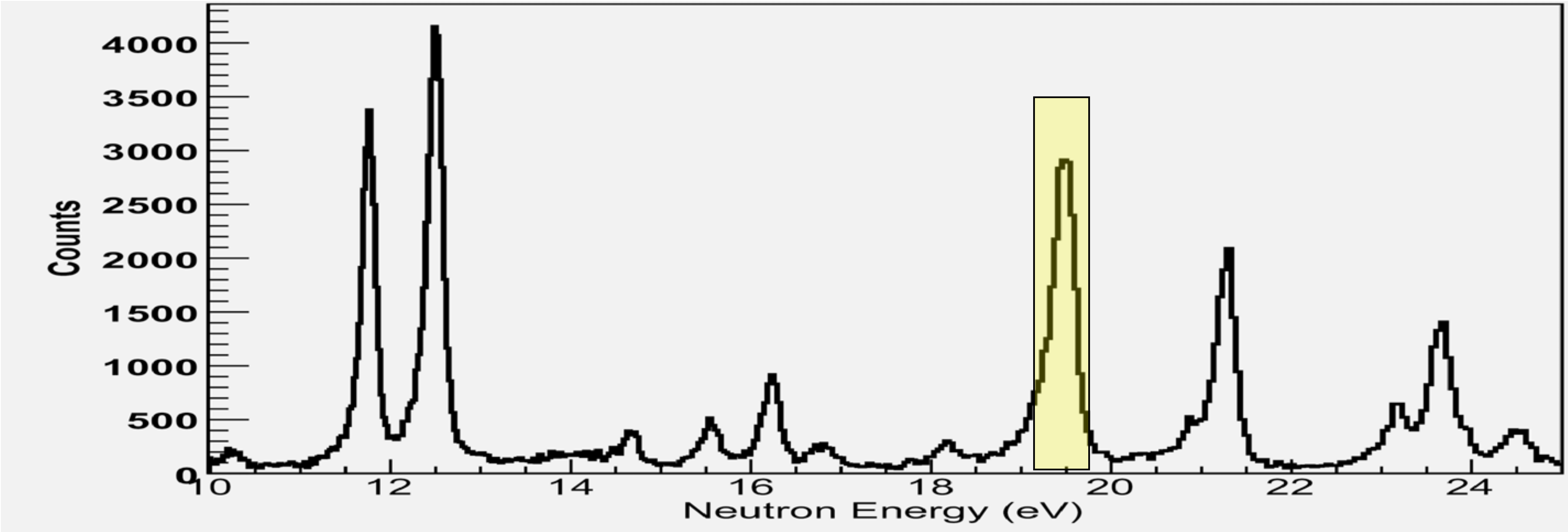
For ^{235}U, the target spin is $7/2^+$.

The s-wave resonances have spins 3^+ or 4^+.

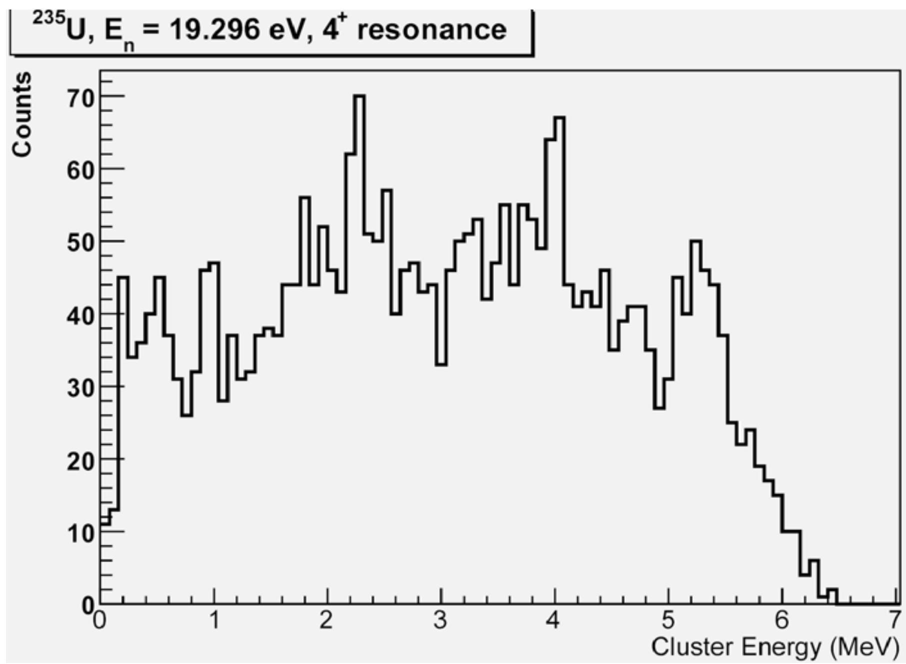

Counts
0
500
1000
1500
2000
2500
3000
3500
4000
10
12
14
16
18
20
22
24
Neutron Energy (eV)

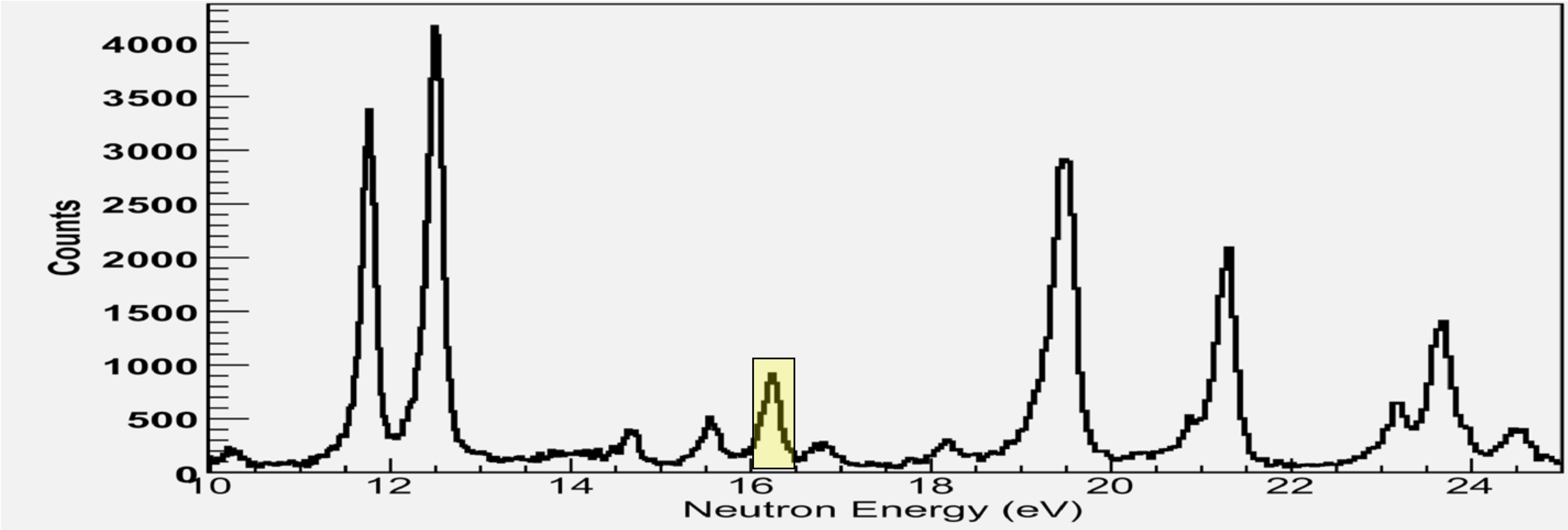
4^+


^{235}U, E_n = 11.665 eV, 4^+ resonance
Counts
0
20
40
60
80
100
120
140
160
180
0
1
2
3
4
5
6
7
Cluster Energy (MeV)

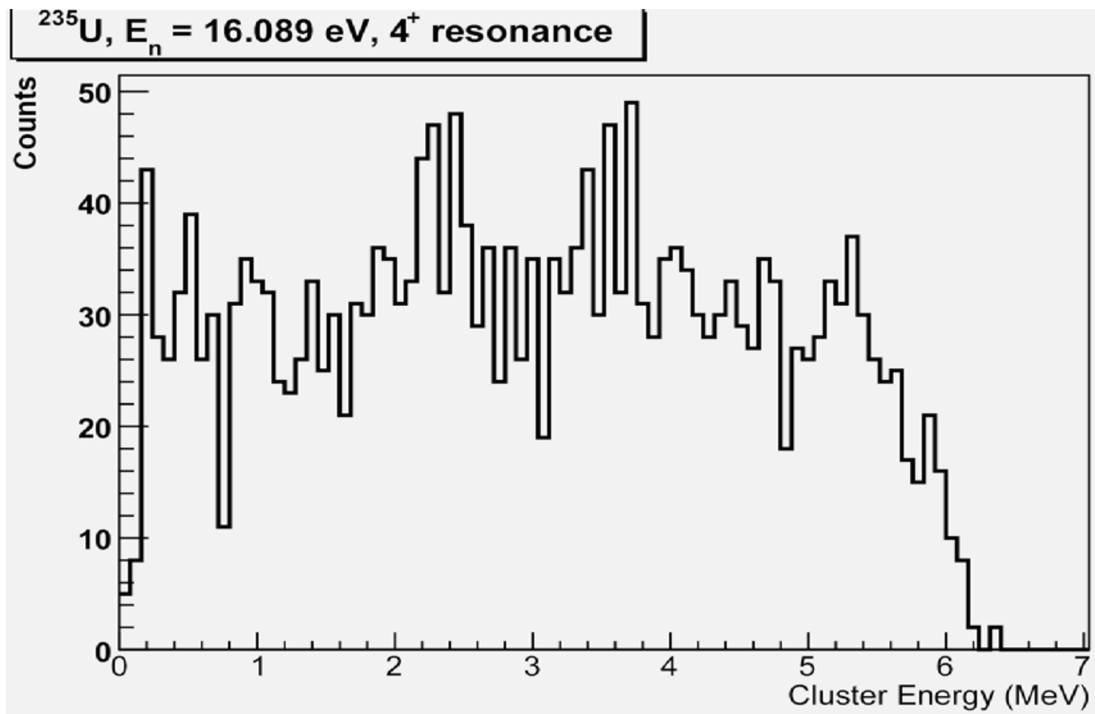

Counts
0
500
1000
1500
2000
2500
3000
3500
4000
10
12
14
16
18
20
22
24
Neutron Energy (eV)

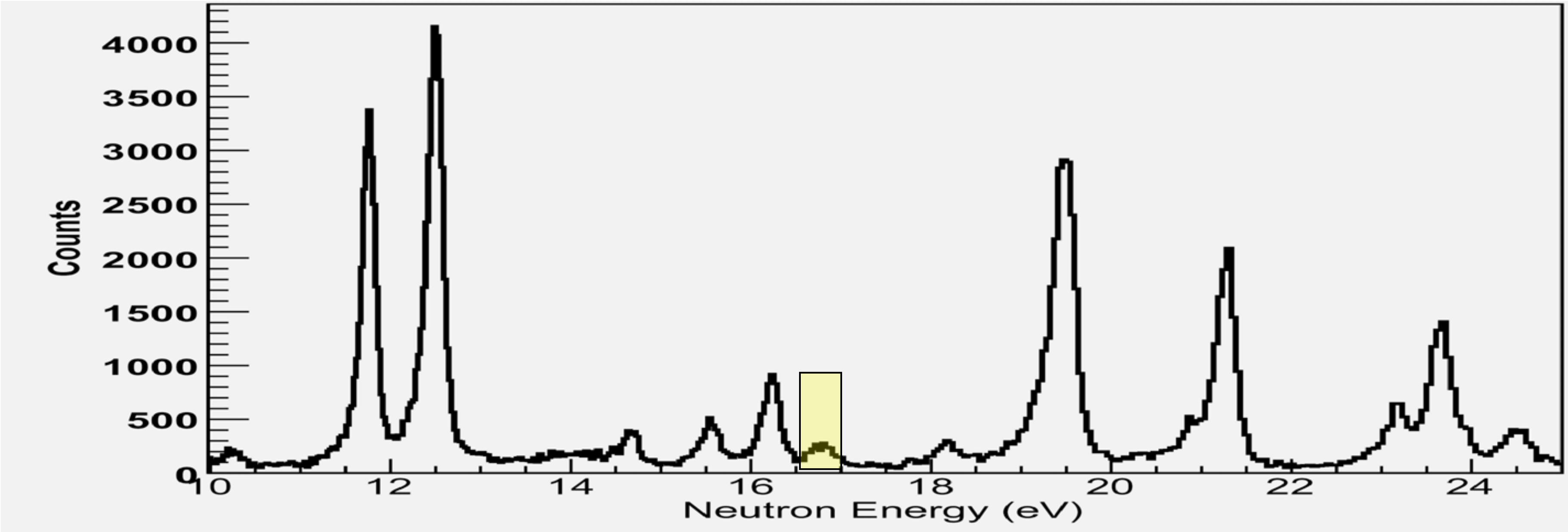
4^+


^{235}U, E_n = 19.296 eV, 4^+ resonance
Counts
0
10
20
30
40
50
60
70
0
1
2
3
4
5
6
7
Cluster Energy (MeV)

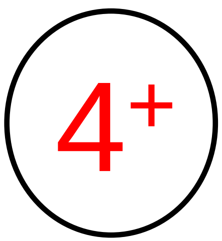

Counts
4000
3500
3000
2500
2000
1500
1000
500
0
10
12
14
16
18
20
22
24
Neutron Energy (eV)

4+

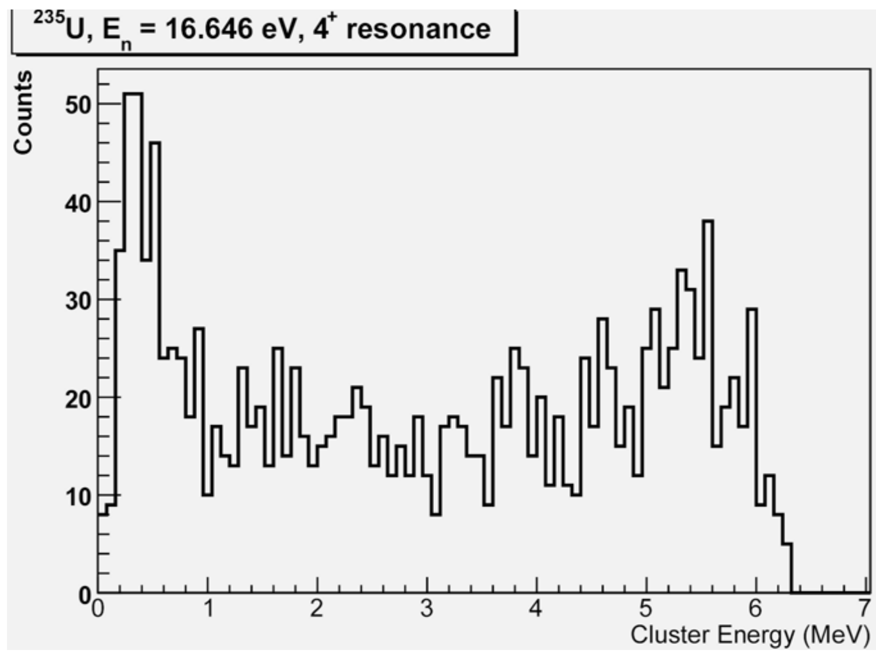

^{235}U, E_n = 16.089 eV, 4^+ resonance
Counts
50
40
30
20
10
0
0
1
2
3
4
5
6
7
Cluster Energy (MeV)



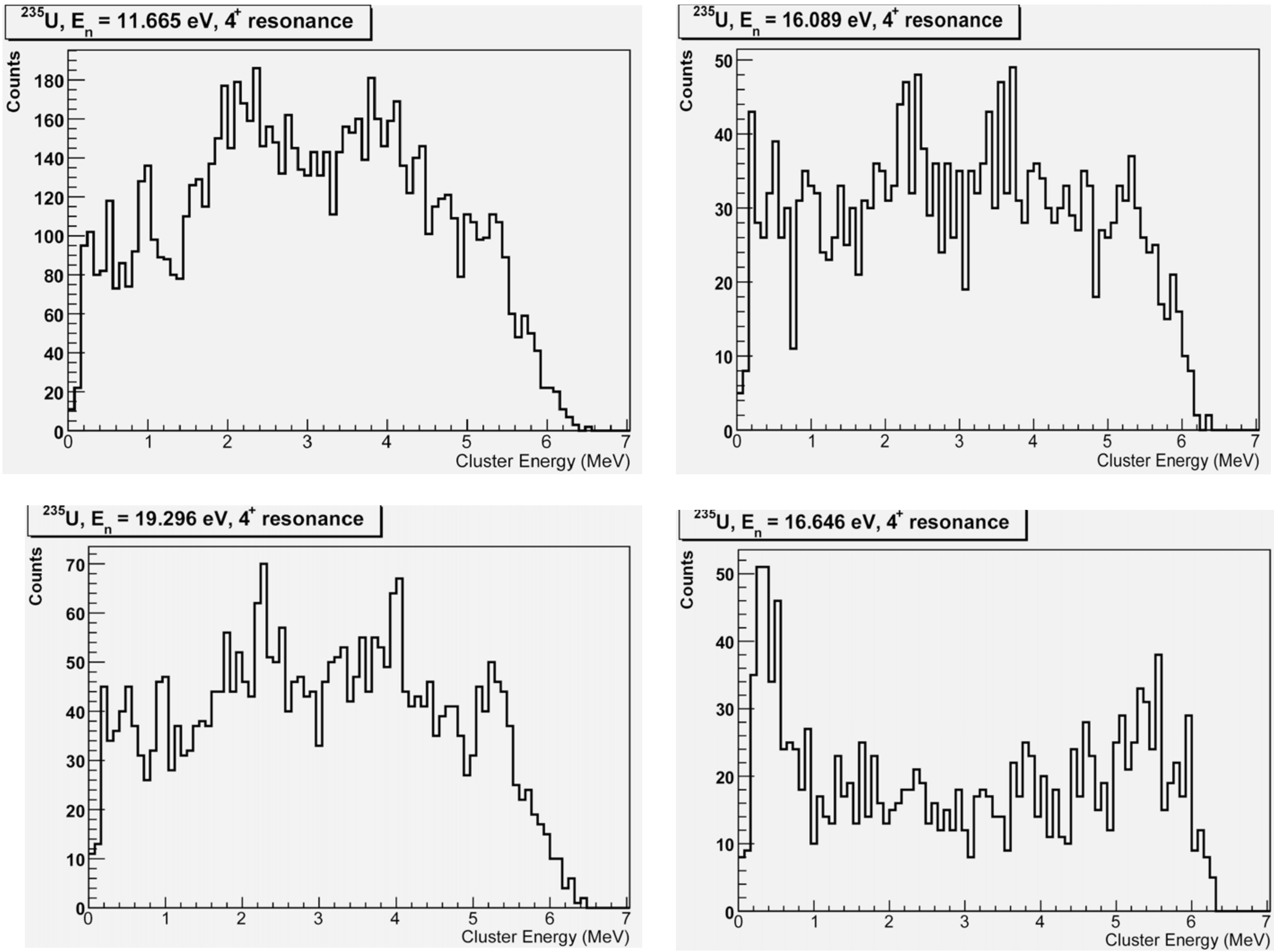
Counts
4000
3500
3000
2500
2000
1500
1000
500
0
10
12
14
16
18
20
22
24
Neutron Energy (eV)



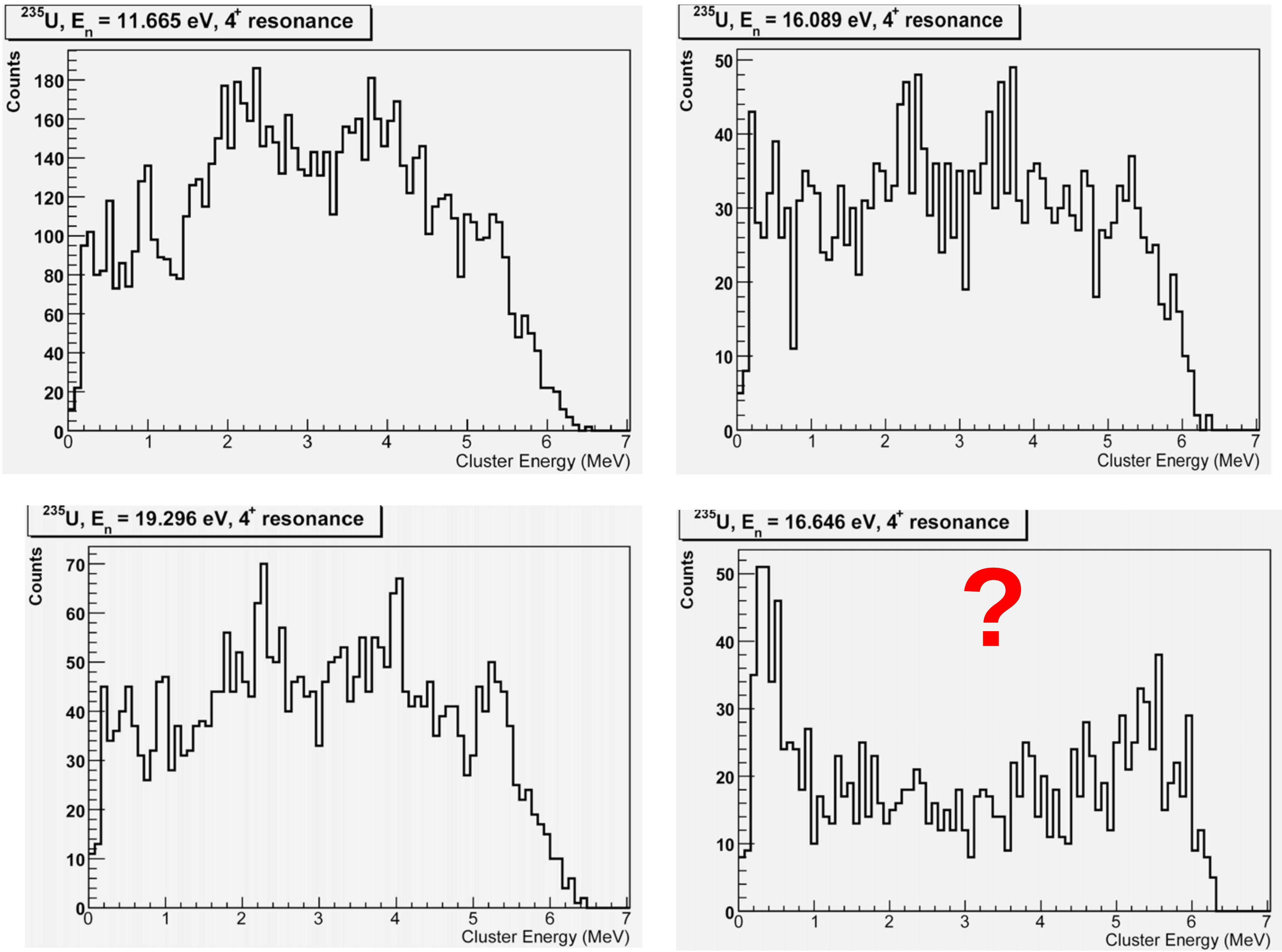
4+



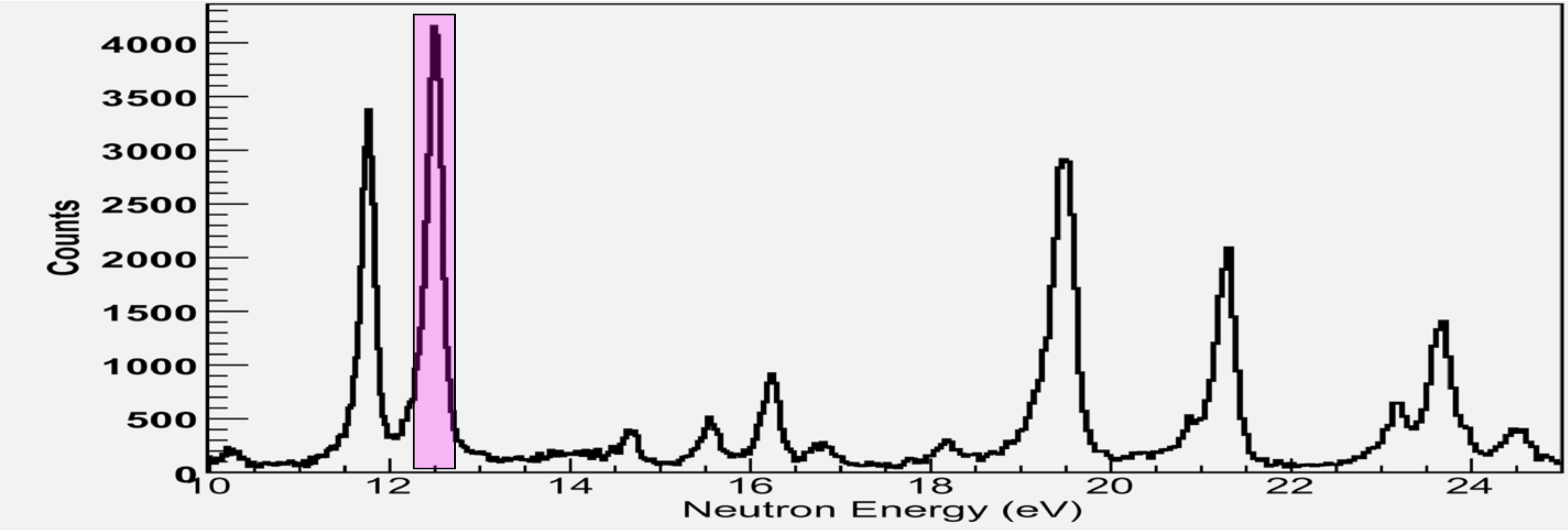
235U, En = 16.646 eV, 4+ resonance
Counts
50
40
30
20
10
0
0
1
2
3
4
5
6
7
Cluster Energy (MeV)



235U, En = 11.665 eV, 4+ resonance
Counts
Cluster Energy (MeV)
235U, En = 16.089 eV, 4+ resonance
Counts
Cluster Energy (MeV)
235U, En = 19.296 eV, 4+ resonance
Counts
Cluster Energy (MeV)
235U, En = 16.646 eV, 4+ resonance
Counts
Cluster Energy (MeV)

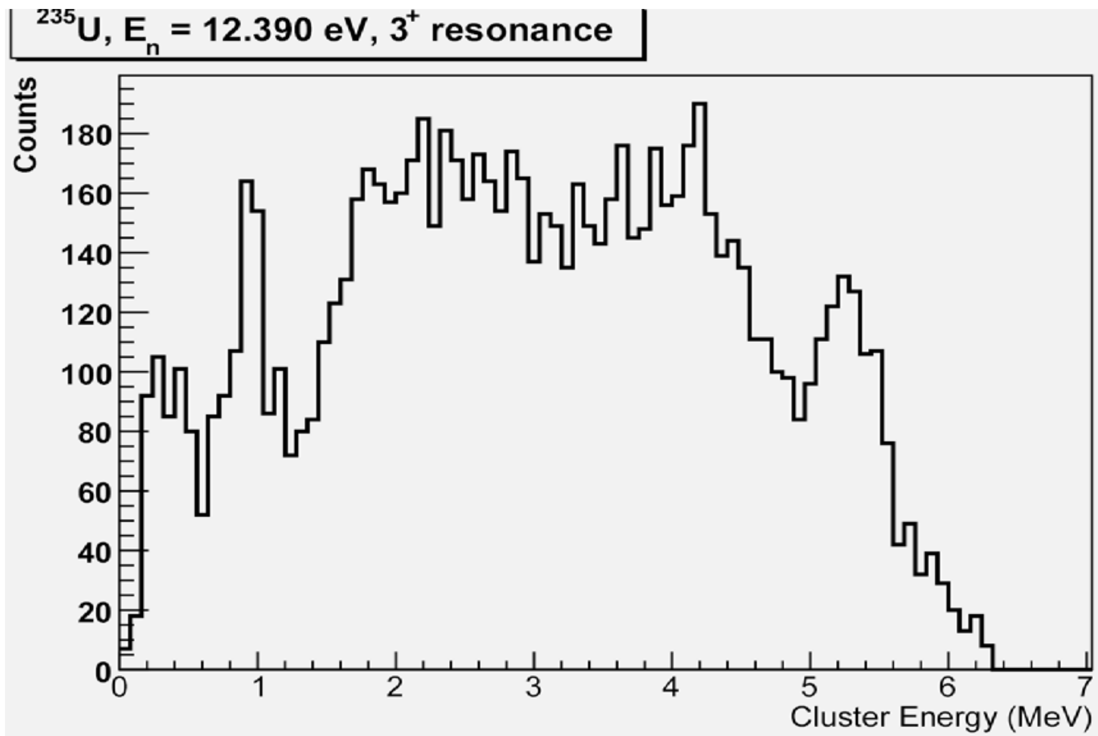


235U, En = 11.665 eV, 4+ resonance
Counts
Cluster Energy (MeV)
235U, En = 16.089 eV, 4+ resonance
Counts
Cluster Energy (MeV)
235U, En = 19.296 eV, 4+ resonance
Counts
Cluster Energy (MeV)
235U, En = 16.646 eV, 4+ resonance
Counts
?
Cluster Energy (MeV)

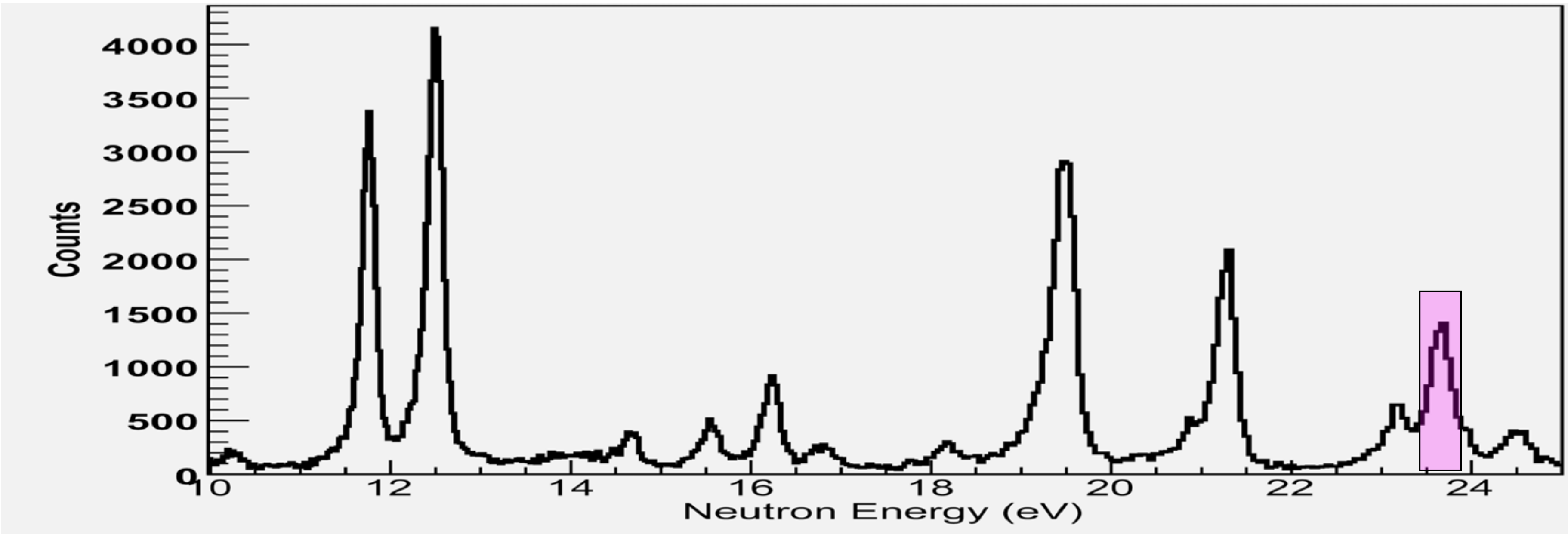


Counts
4000
3500
3000
2500
2000
1500
1000
500
0
10
12
14
16
18
20
22
24
Neutron Energy (eV)

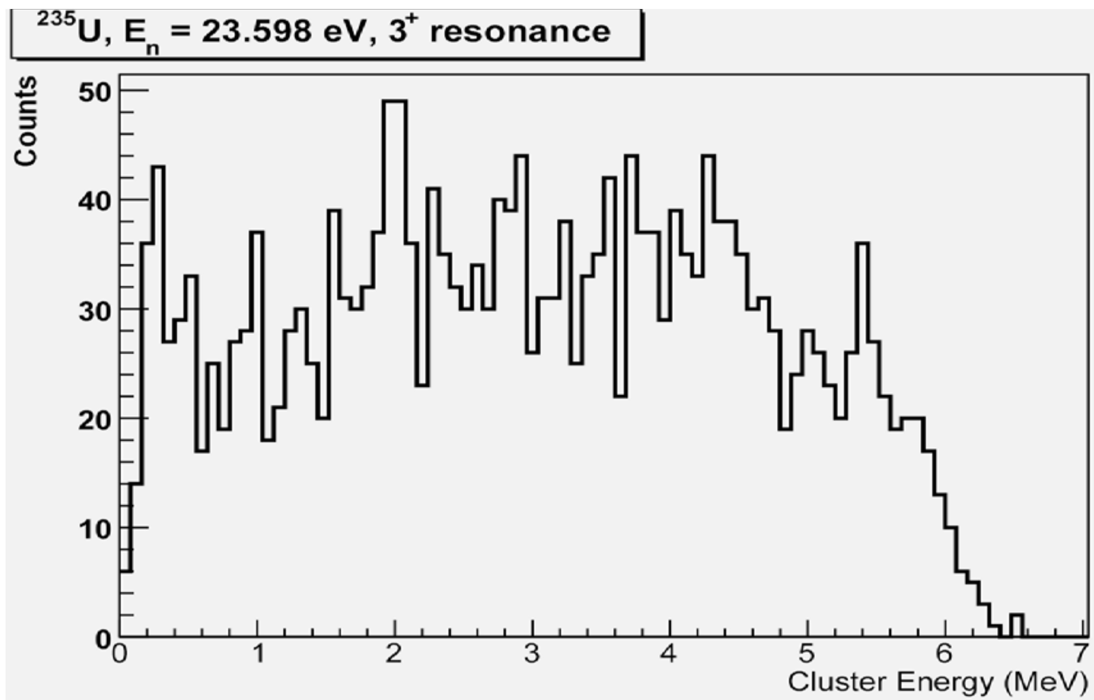
3+

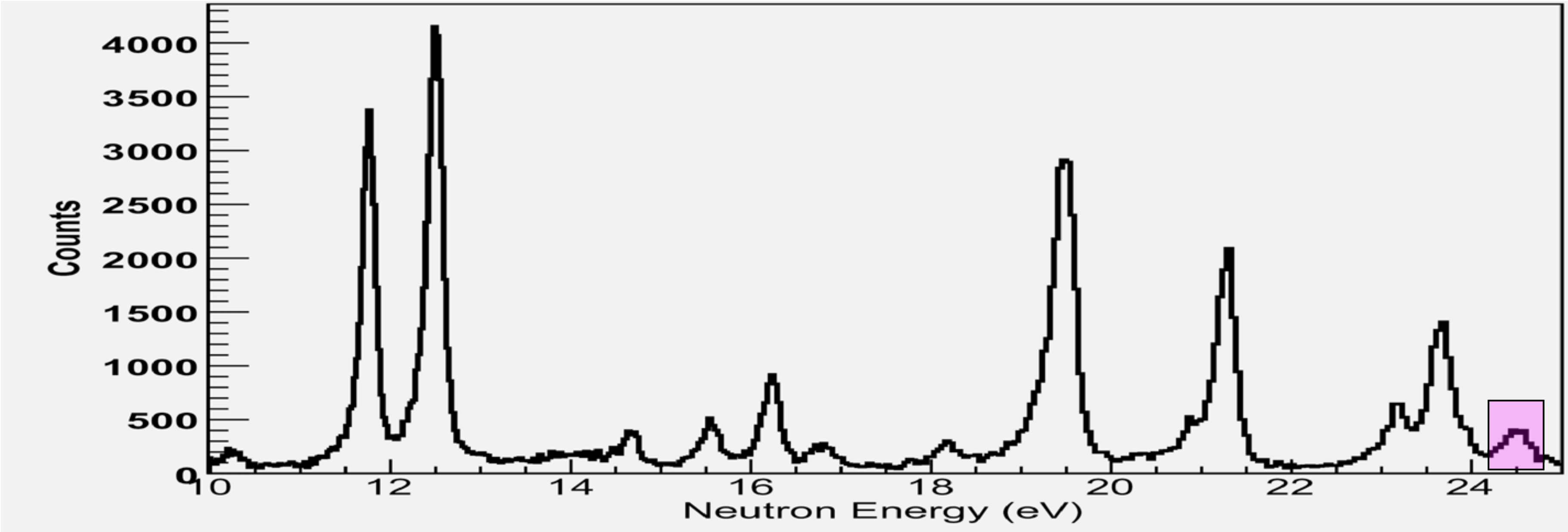


235U, En = 12.390 eV, 3+ resonance
Counts
180
160
140
120
100
80
60
40
20
0
0
1
2
3
4
5
6
7
Cluster Energy (MeV)

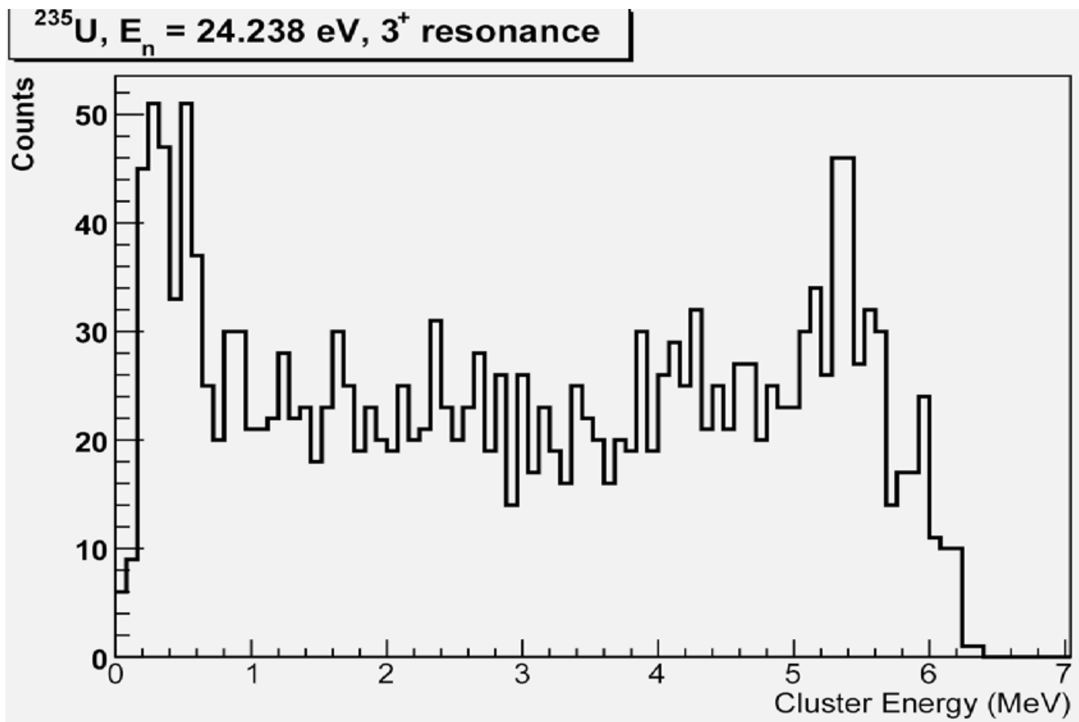

Counts
0
500
1000
1500
2000
2500
3000
3500
4000
10
12
14
16
18
20
22
24
Neutron Energy (eV)

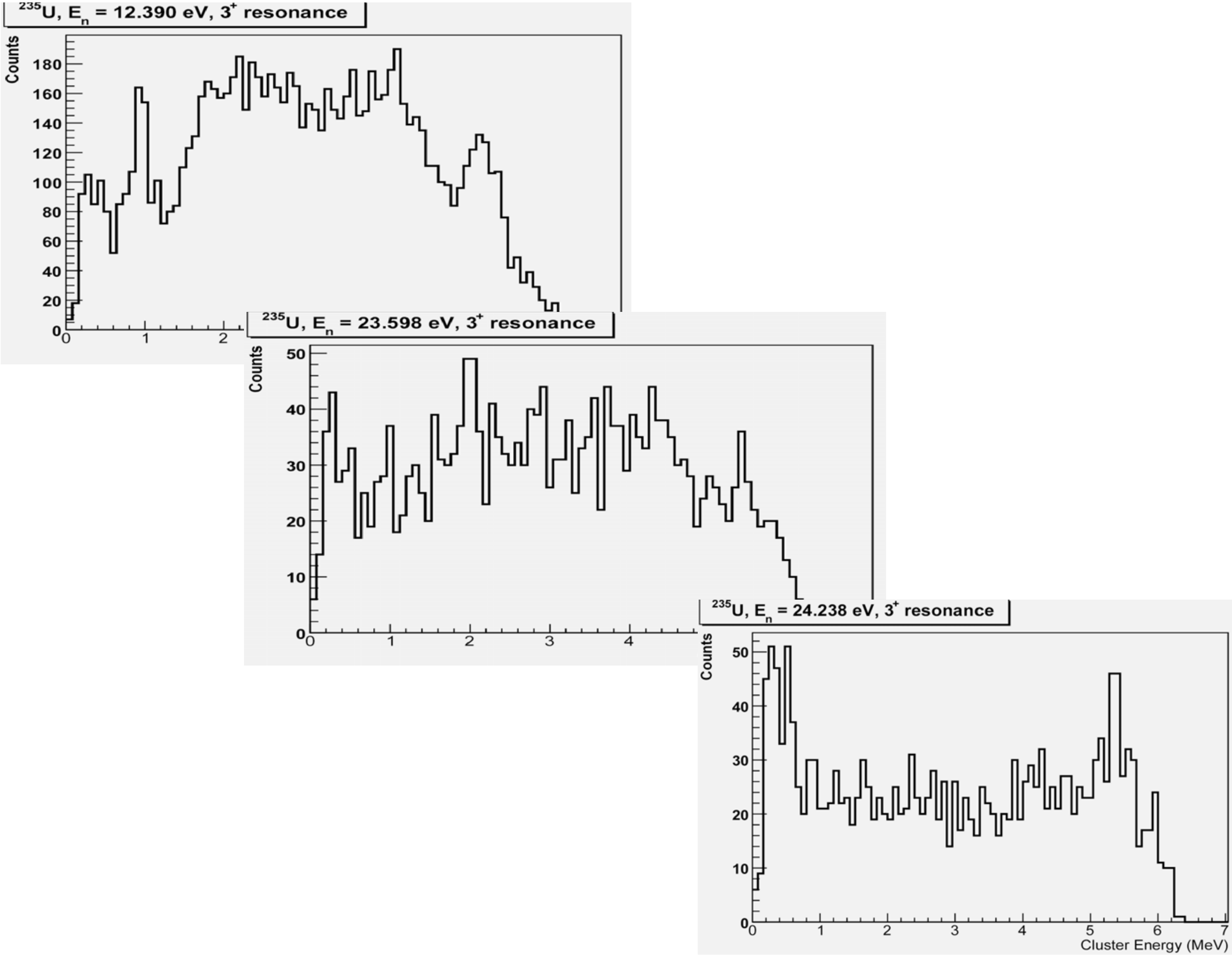
3+


235U, En = 23.598 eV, 3+ resonance
Counts
0
10
20
30
40
50
0
1
2
3
4
5
6
7
Cluster Energy (MeV)

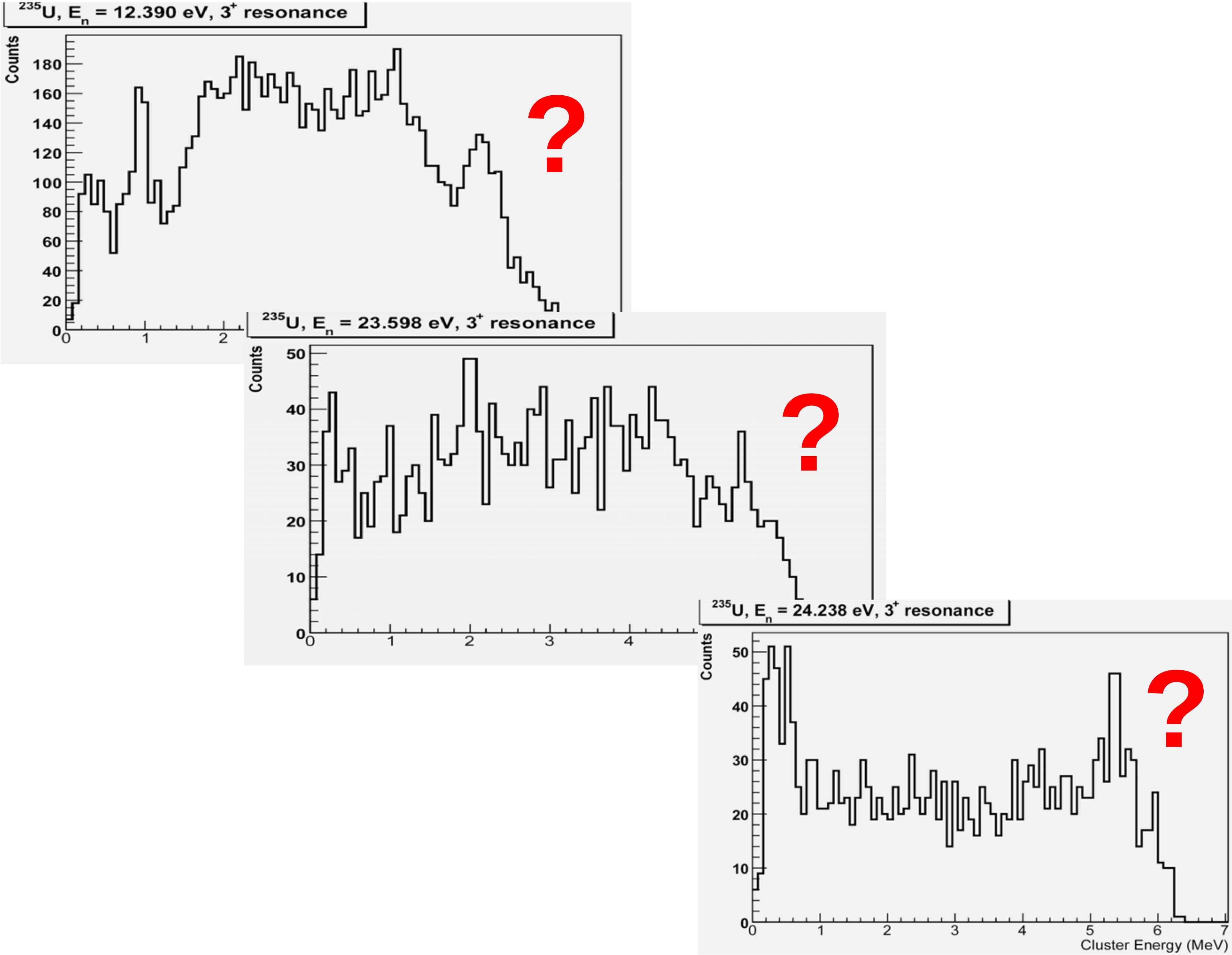

Counts
0
500
1000
1500
2000
2500
3000
3500
4000
10
12
14
16
18
20
22
24
Neutron Energy (eV)

3^+


^{235}U, E_n = 24.238 eV, 3^+ resonance
Counts
0
10
20
30
40
50
0
1
2
3
4
5
6
7
Cluster Energy (MeV)

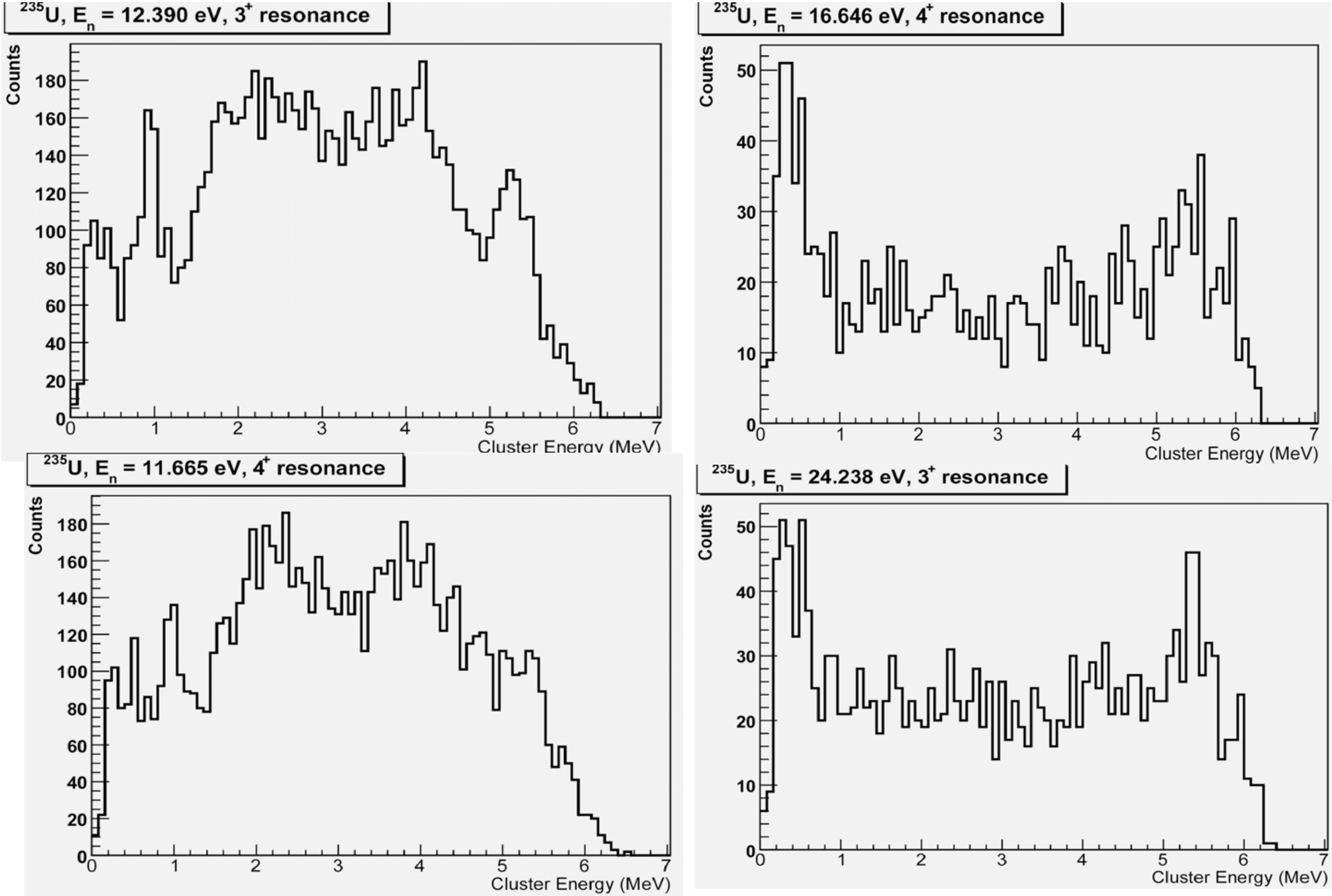


235U, En = 12.390 eV, 3+ resonance
Counts
235U, En = 23.598 eV, 3+ resonance
Counts
235U, En = 24.238 eV, 3+ resonance
Counts
Cluster Energy (MeV)

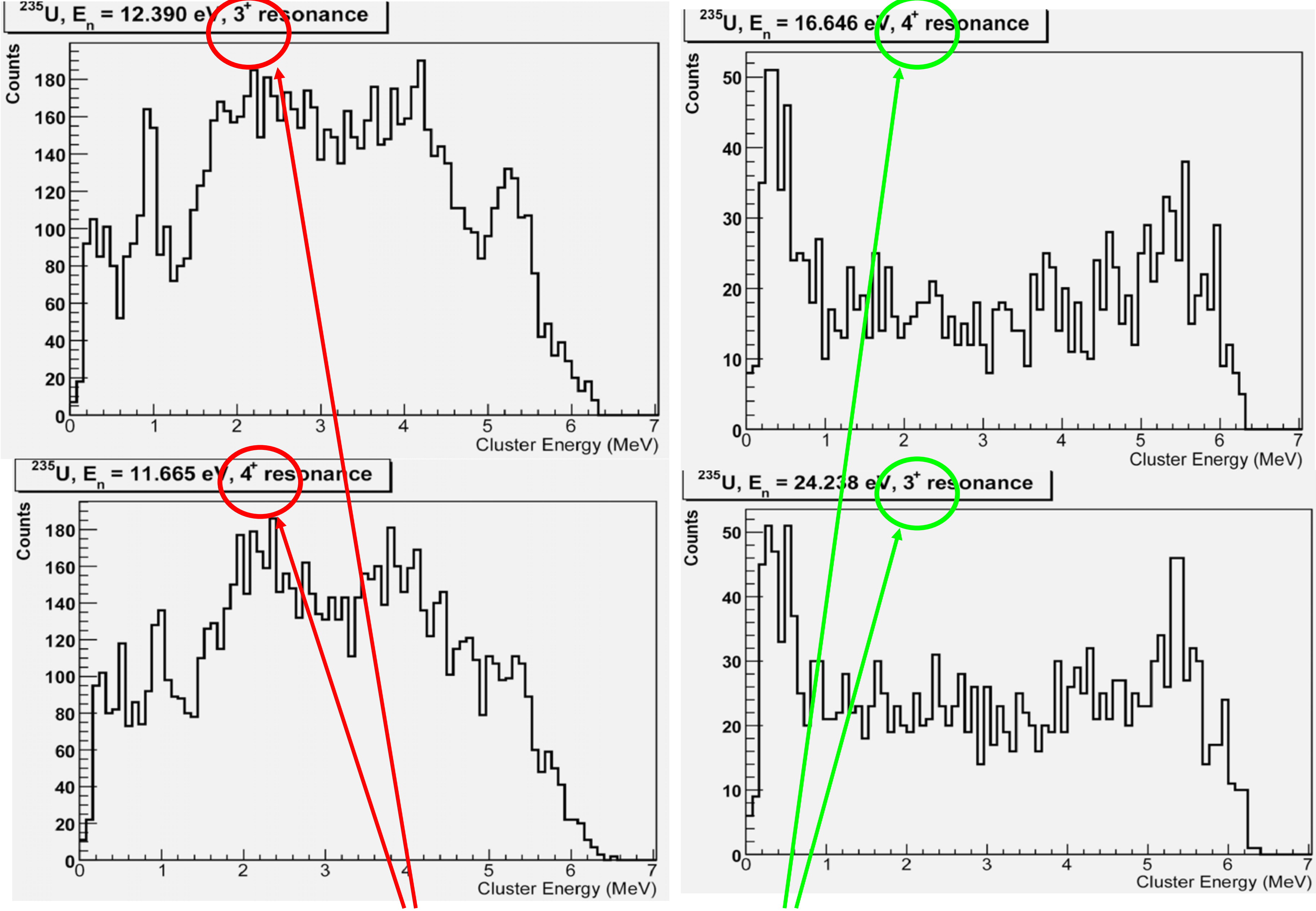


^{235}U, E_n = 12.390 eV, 3^+ resonance
Counts
?
^{235}U, E_n = 23.598 eV, 3^+ resonance
Counts
?
^{235}U, E_n = 24.238 eV, 3^+ resonance
Counts
?
Cluster Energy (MeV)

What happens if I rearrange?



They can be sorted into two distinct shapes.



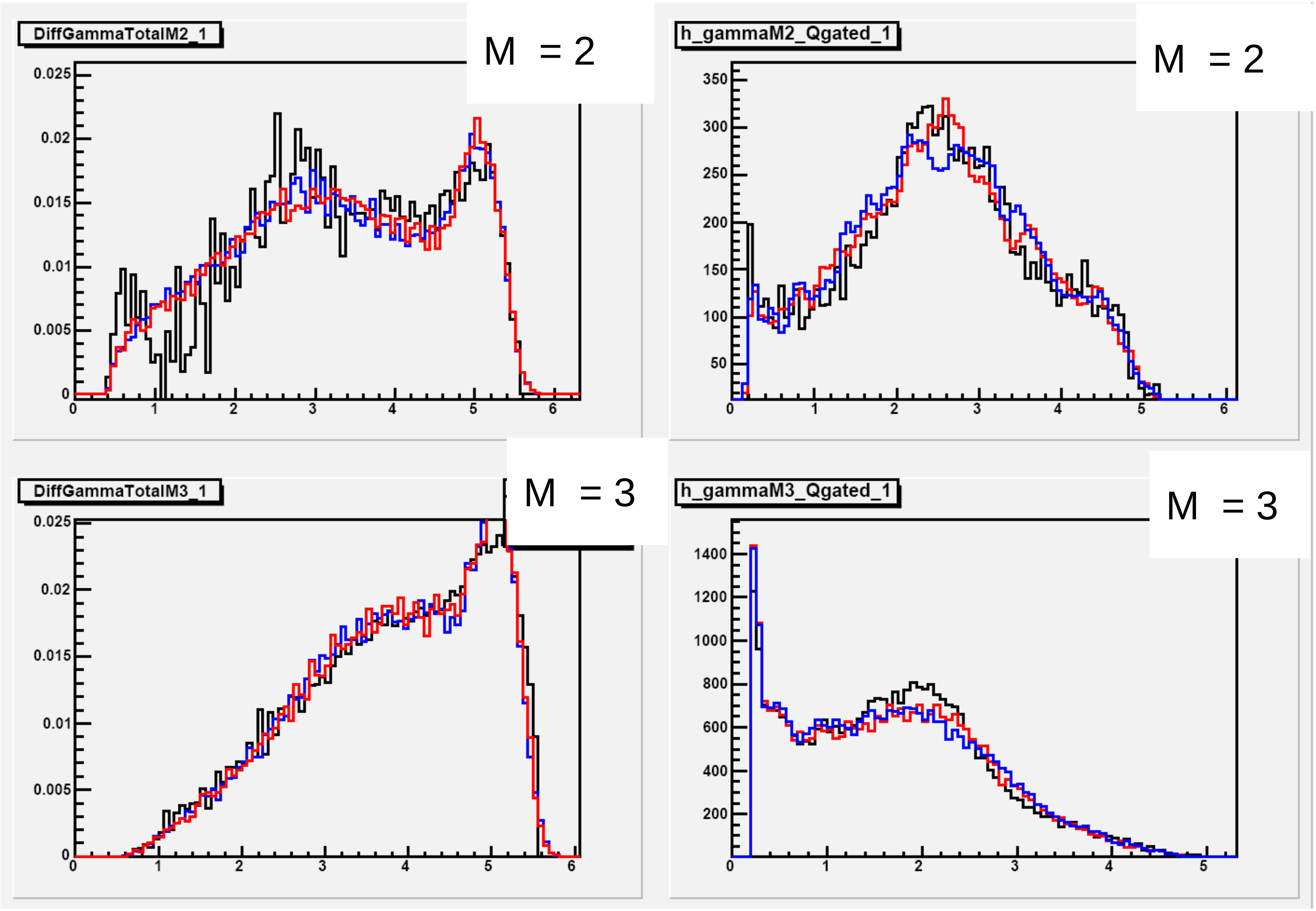
Which one is correct?

J^{π}? Correlation with other channels?

So, we may be able learn something about the ^{235}U resonance decay by looking at the spectral shape.

How about other actinides? How do their spectral shapes look?

^{241}Am(n,γ), 3^{-} resonance



ΣE_γ, [MeV] E_γ, [MeV]

Courtesy of M. Jandel, LANL

____ DANCE data, ___, ___ simulations

Summary

Even for the well-studied nuclei such as ^{235}U many questions remain

Spectral shapes provide additional constraints for understanding of γ- ray cascade, therefore, improving the reaction codes (especially for calculation of n,γ reaction)

Spectral shapes are a useful (new) tool to study resonance spin and parity

After 70 years since the first neutron resonance was measured, a struggle is far from over!! But optimists try …

Thanks to my collaborators:

J.A. Becker, W.E. Parker, C.Y. Wu,
Lawrence Livermore National Laboratory

T.A. Bredeweg, A. Couture, R.C. Haight, M. Jandel, J.M. O'Donnell,
R. Rundberg, J.M. Wouters, J.L. Ullmann, D.J. Vieira,
Los Alamos National Laboratory

G.E. Mitchell, B. Baramsai, R. Chankova, A. Chyzh, D. Dashdorj,
C. Walker,
North Carolina State University

F. Becvar, M. Krticka,
Charles University in Prague, Czech Republic

E. Sharapov,
Joint Institute of Nuclear Research, Dubna, Russia

E. Algin,
Eskisehir Osmangazi University, Turkey