Gamma-Gamma Angular Correlations With GRIFFIN

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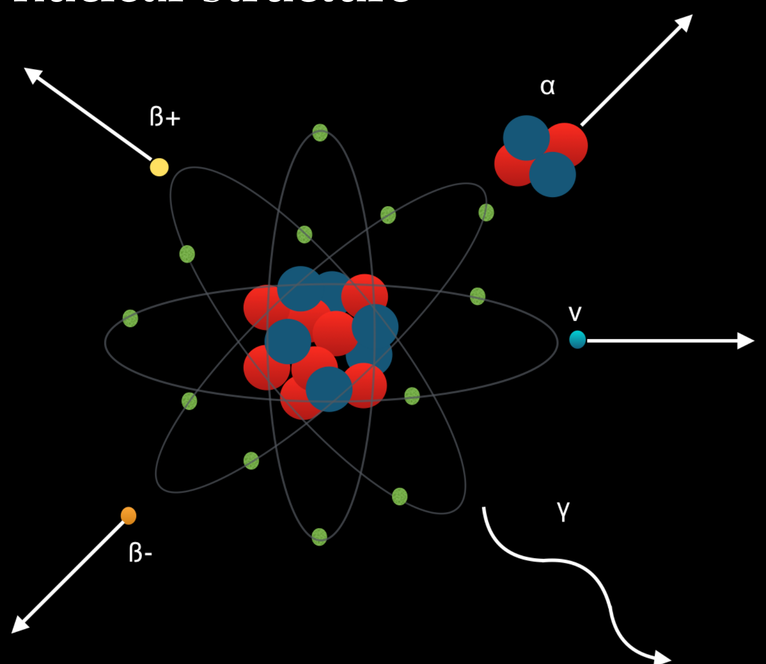
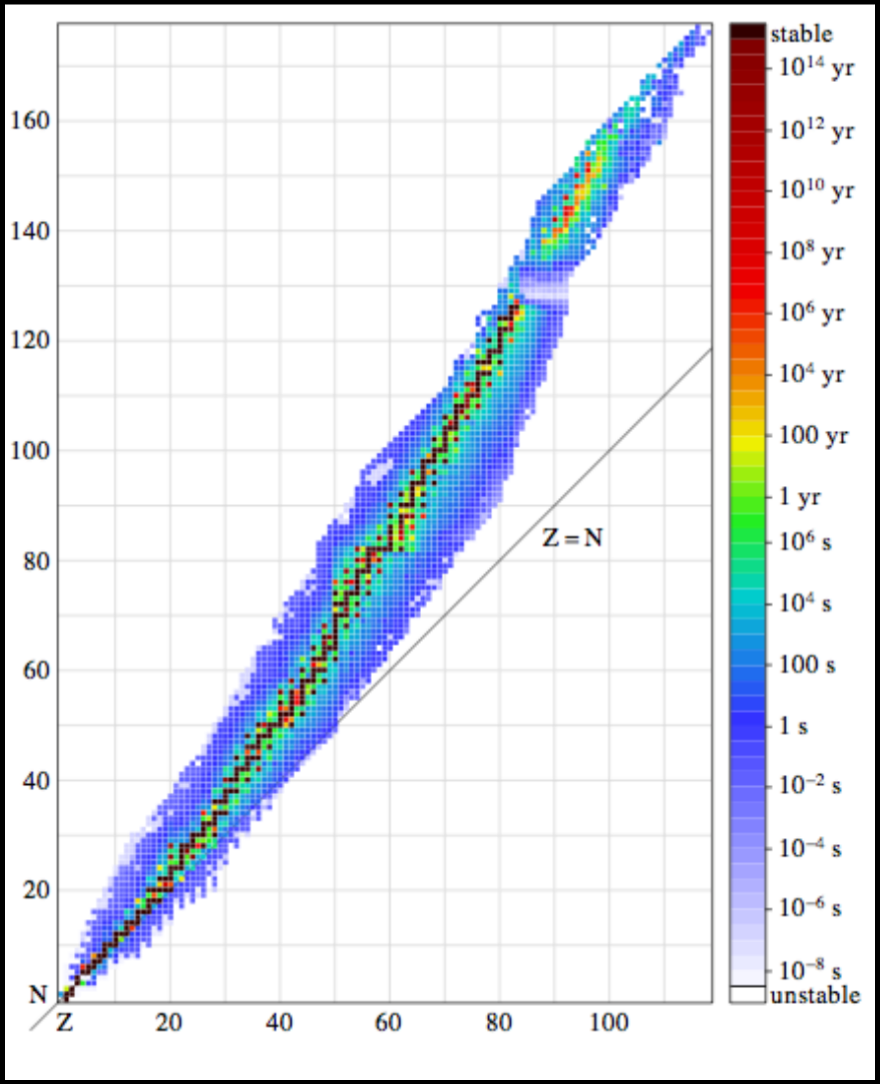
Introduction

- Goal is to further our understanding of rare and exotic isotopes created from the explosion of massive stars.
- Done by examining the evolution of matter through radioactive decay in order to understand nuclear structure

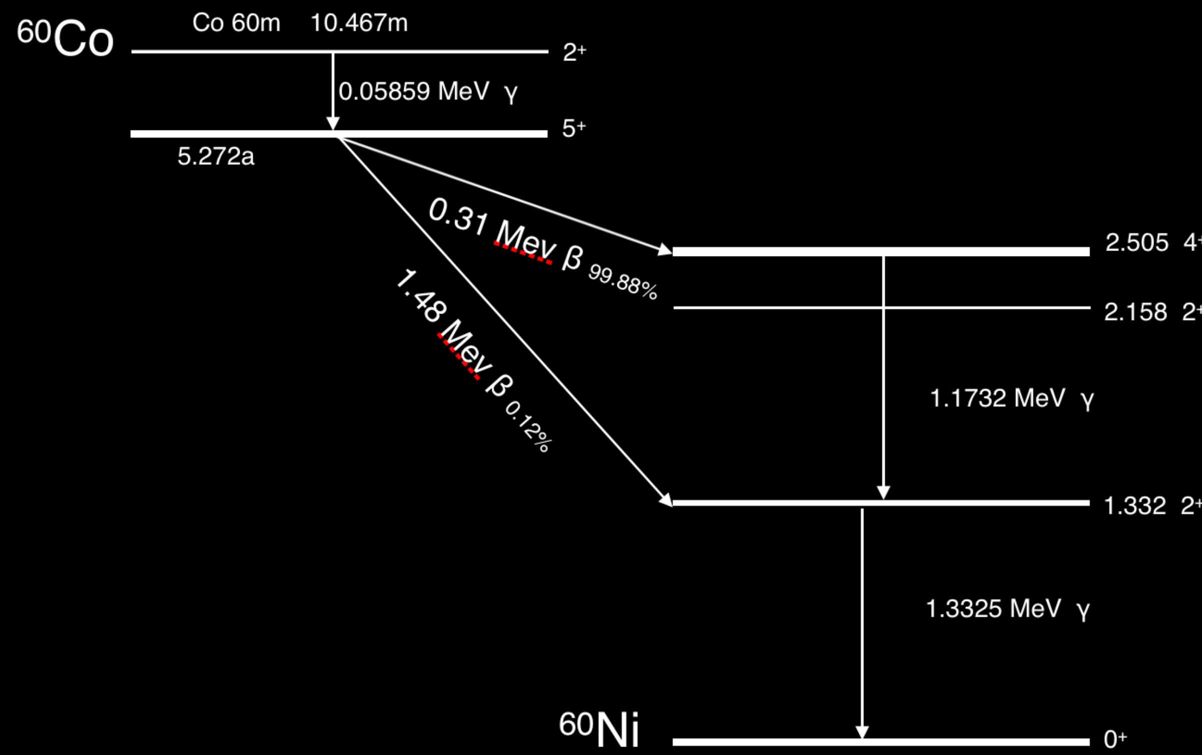


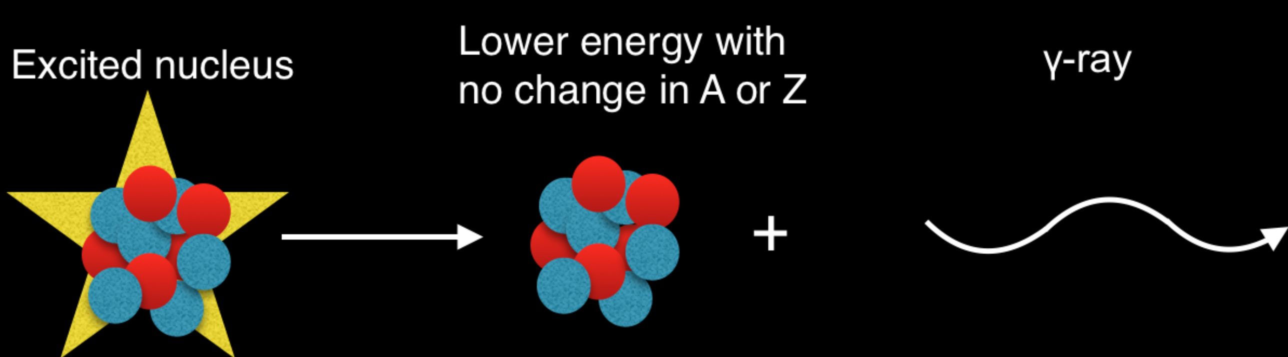


Excited States

- Generally the decay of a nucleus by the emission of an α or β will leave the daughter in an excited state.

- These nuclei can then de-excite by the emission of one or more γ-rays.





Single γ Emission

- If an excited nuclei emits only a single γ-ray without the presence of a magnetic field, the spatial distribution of the γ-ray must by isotropic.

- With any magnetic substate accessible a sum of distributions of all possible states must be carried out.

- All γ-ray transitions are classified as electric or magnetic based on the multipolarity of the γ-ray

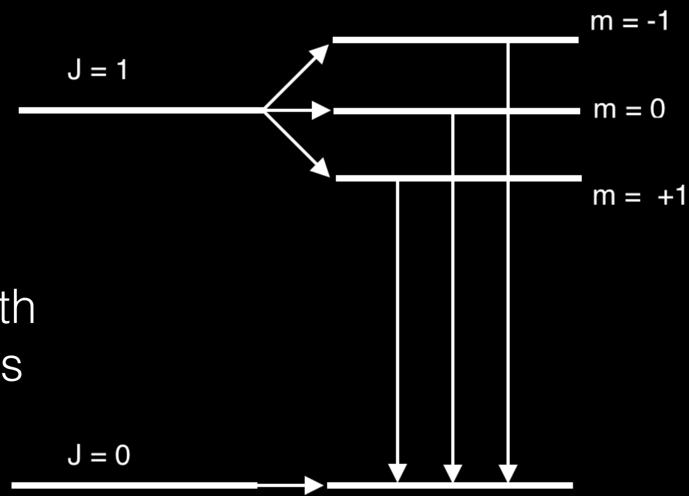
Parity selection rules:

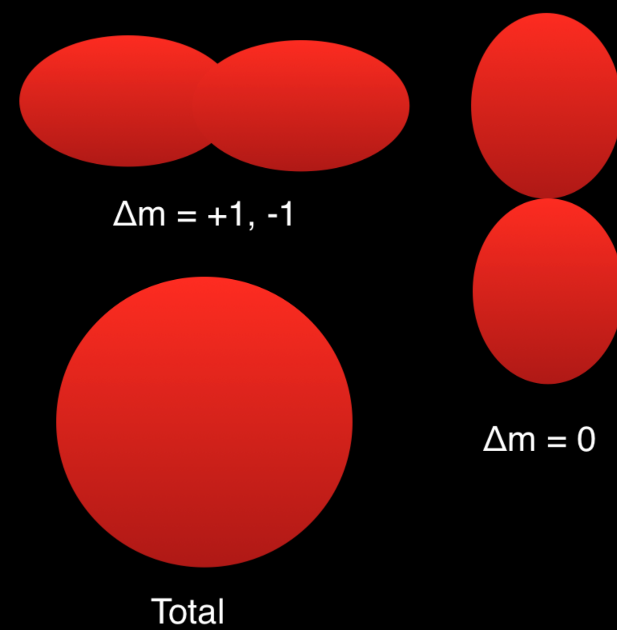
$$\pi(EL) = (-1)^{L}$$

$$\pi(ML) = (-1)^{L+1}$$

- Some transitions can be both if a range of multipolarities is possible, this leads to a mixing ratio

$$\delta = \frac{\langle J_f \mid EL \mid J_i \rangle}{\langle J_f \mid ML \mid J_i \rangle}$$



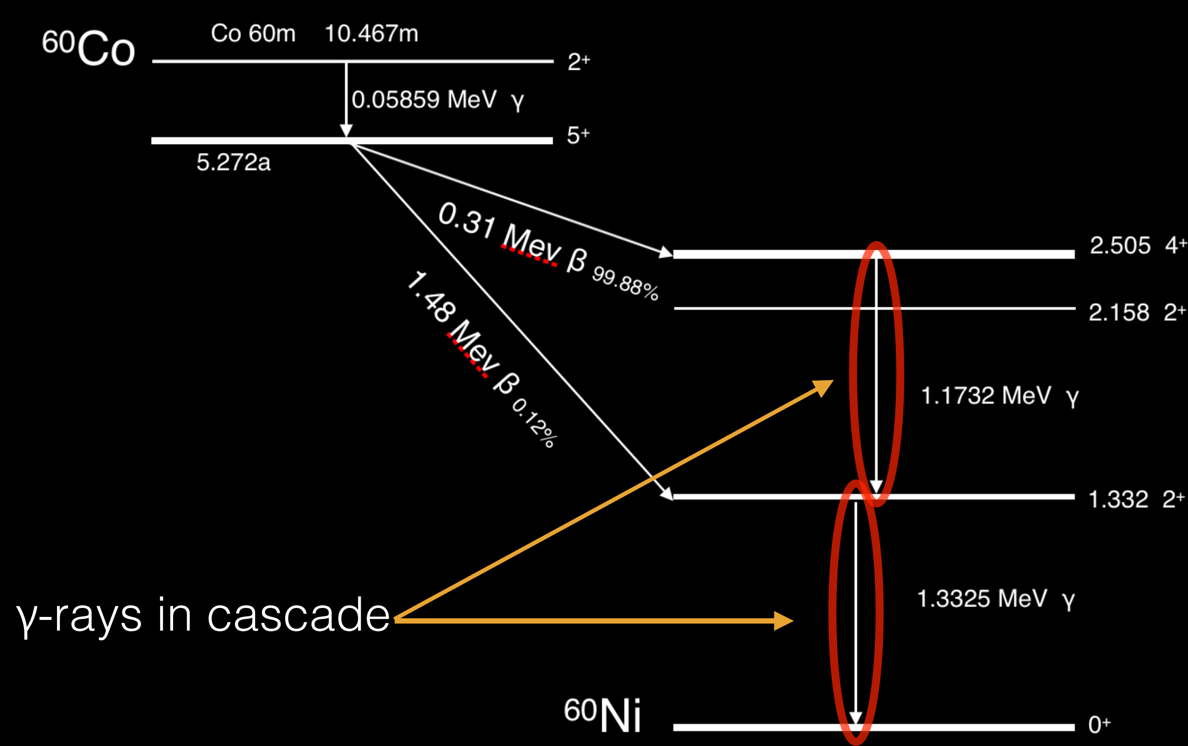


Cascades

- If a nucleus emits multiple γ-rays in rapid succession the spatial distribution of the second γ-ray will have an anisotropic distribution with respect to the first.

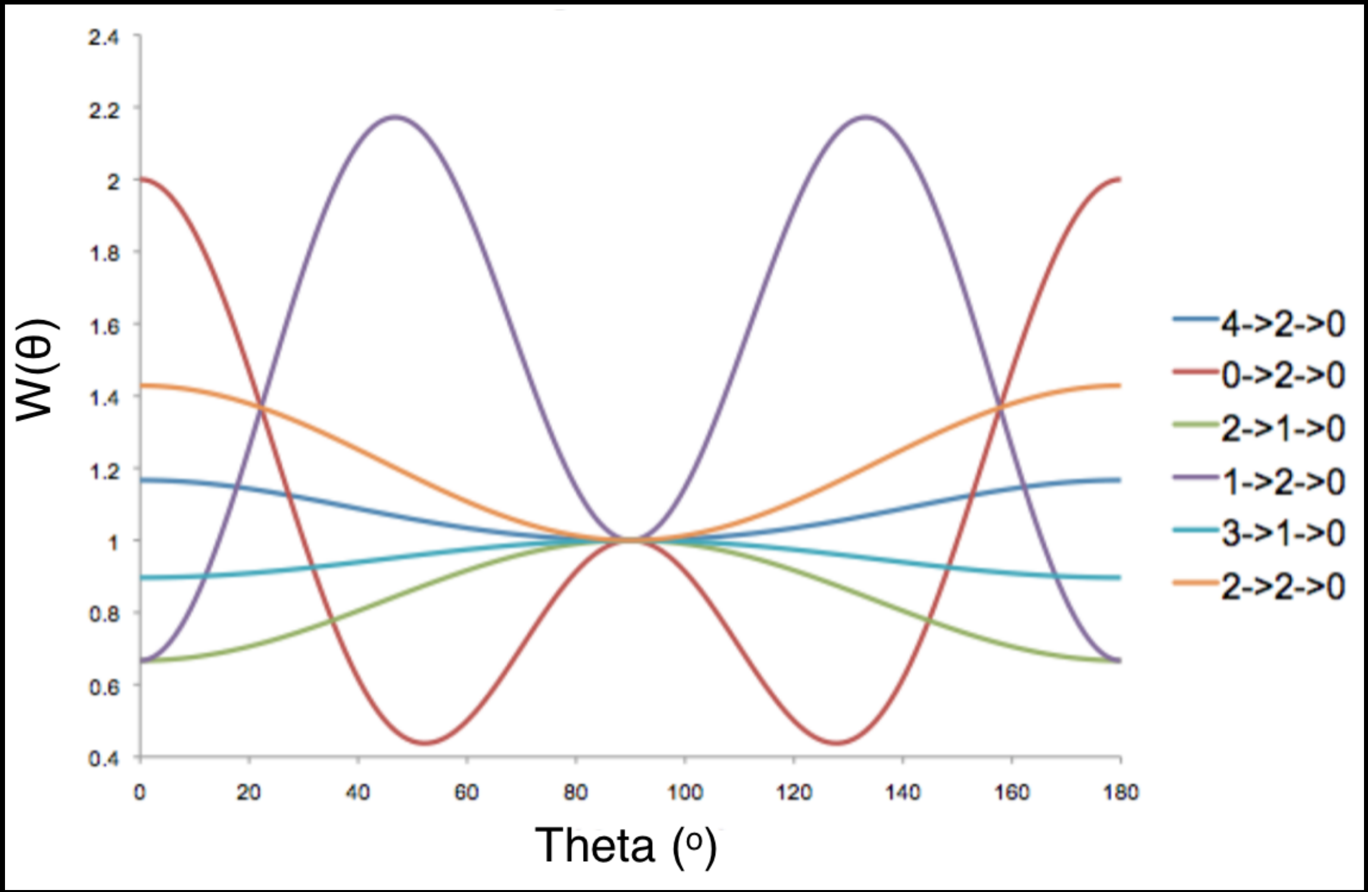
$$W(\Theta) = \sum_{k=0,k=even}^{2L} a_k P_k(\cos\Theta)$$

Here a_k are numerical coefficients based off of multipolarity of the γ-ray, nuclear spins of the states and the mixing ratio and $P_k(\cos\Theta)$ are the Legendre polynomials.



Anisotropy of Cascades

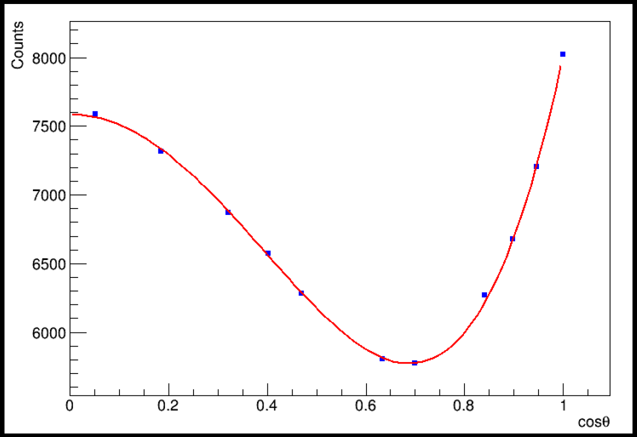
- Looking at some examples of different cascades it is clear that many appear to be very unique, thus making it possible to determine the spins and narrow down on mixing ratios for given transitions.



Note: All of these correlation functions are symmetric about 90°.

Mixing Ratio Effects on Cascades

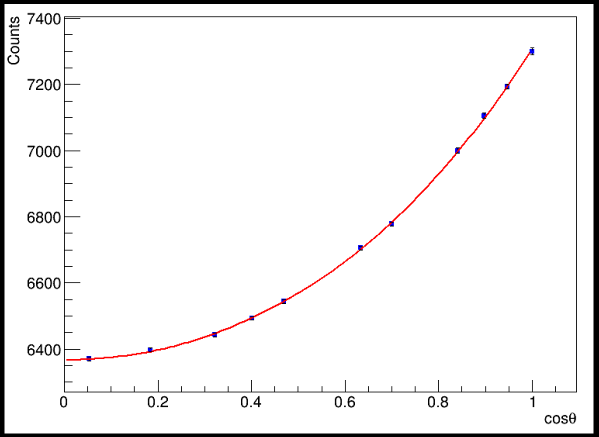
Looking at a $2^+ \longrightarrow 2^+ \longrightarrow 0^+$ decay and varying the mixing ratio it is quite visible how much the spatial distribution changes.



$\delta = 0$

$a_2 = 0.25$

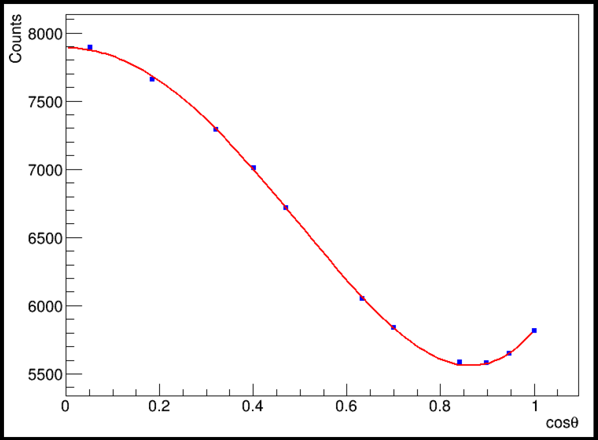
$a_4 = 0.00$



$\delta = 0.2$

$a_2 = 0.9669$

$a_4 = 0.0126$



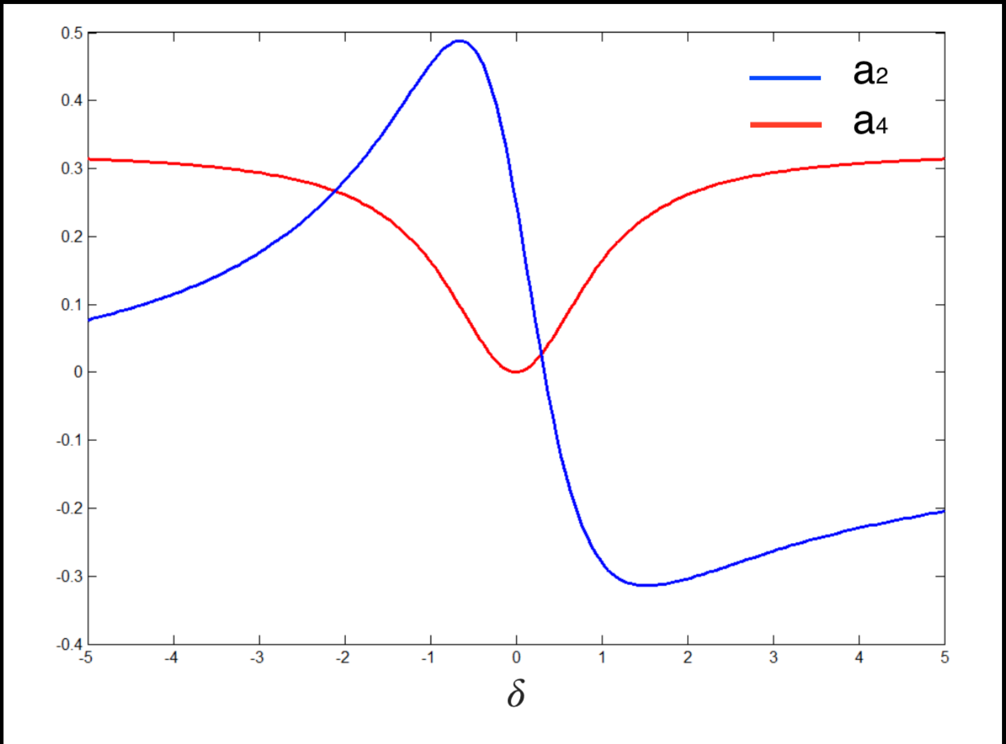
$\delta = 1$

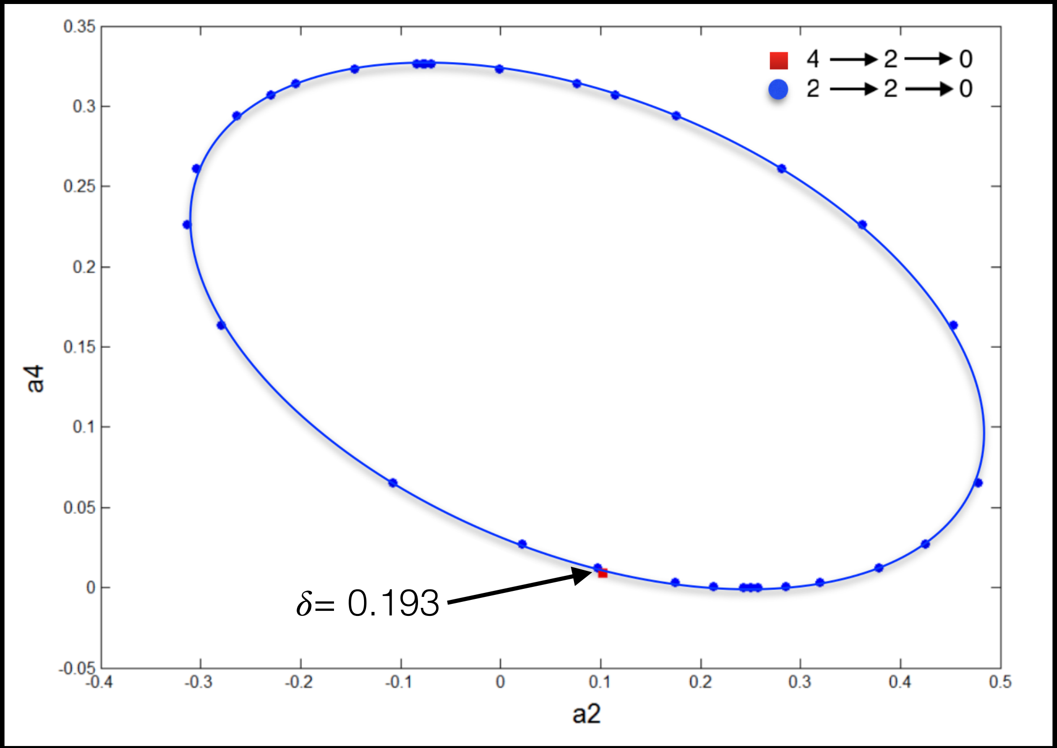
$a_2 = -0.2792$

$a_4 = 0.1633$

Issues Mixing Ratios Can Create

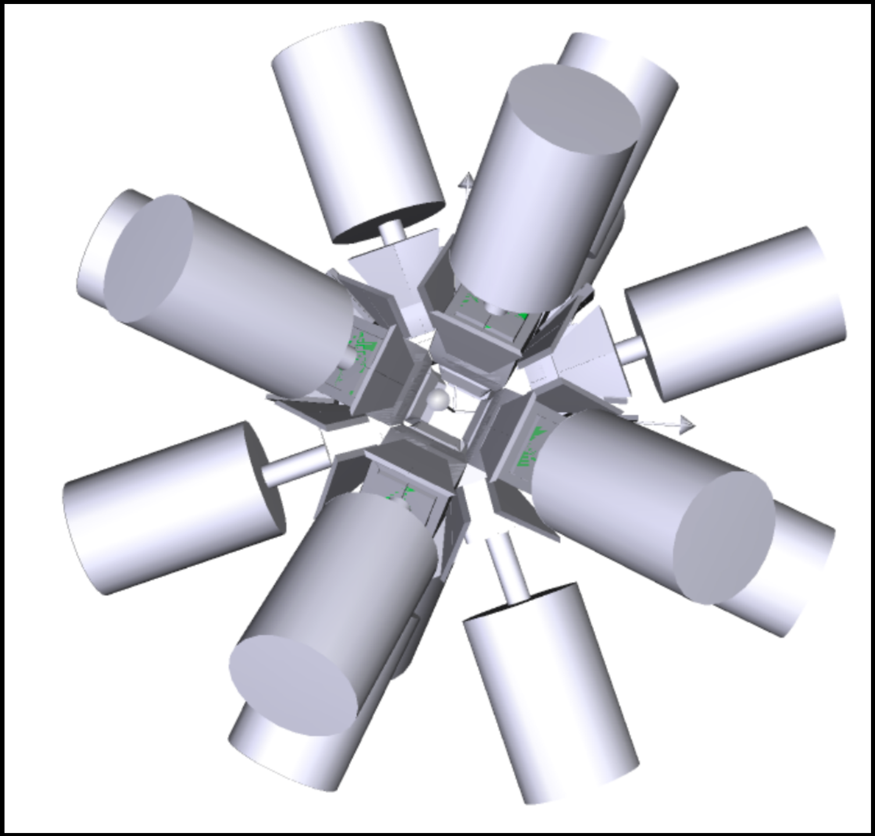
As the a_2 and a_4 values change they can become similar to other transitions making if difficult to discern spins for specific levels.

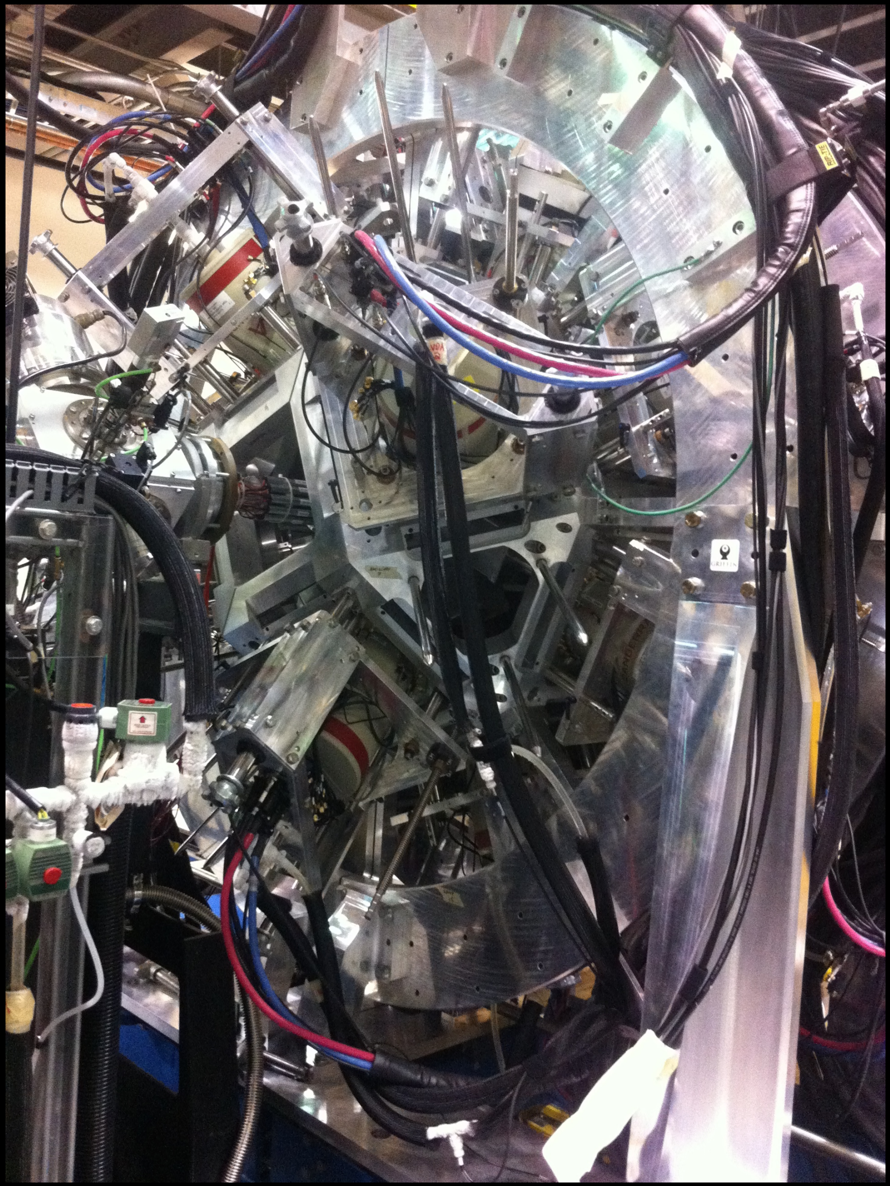


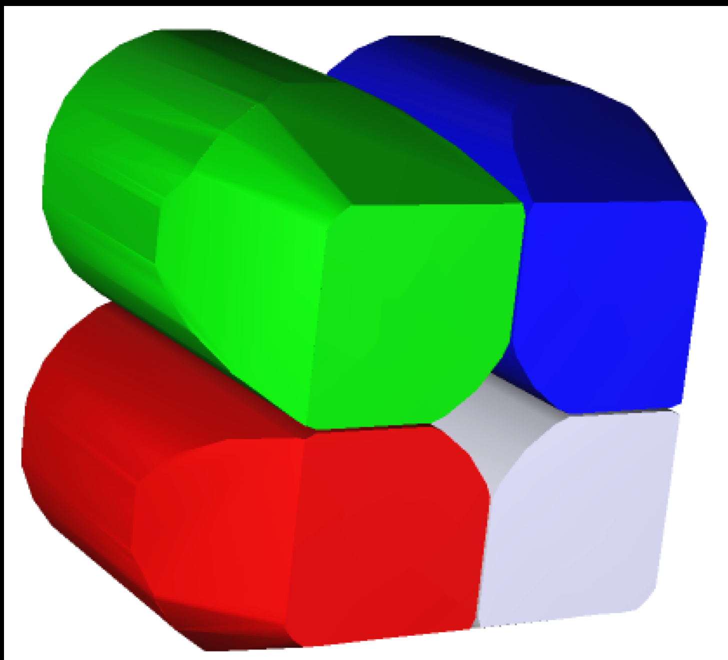


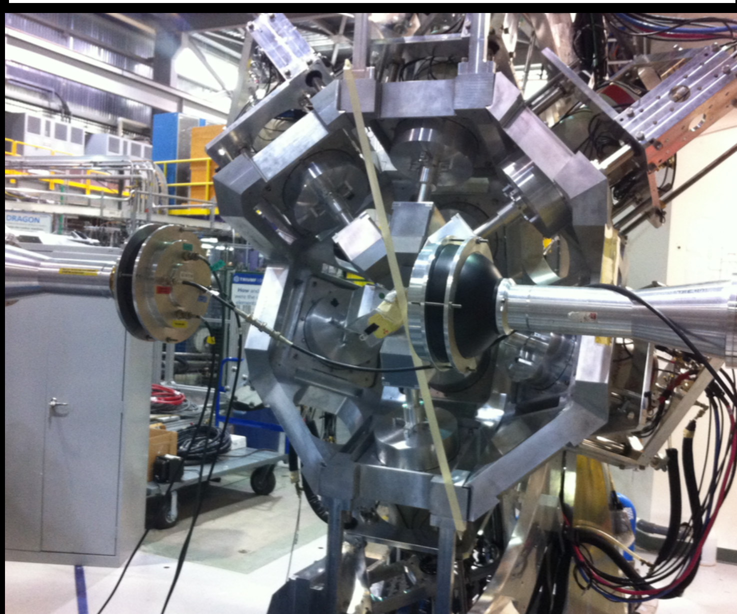
How This Is Done

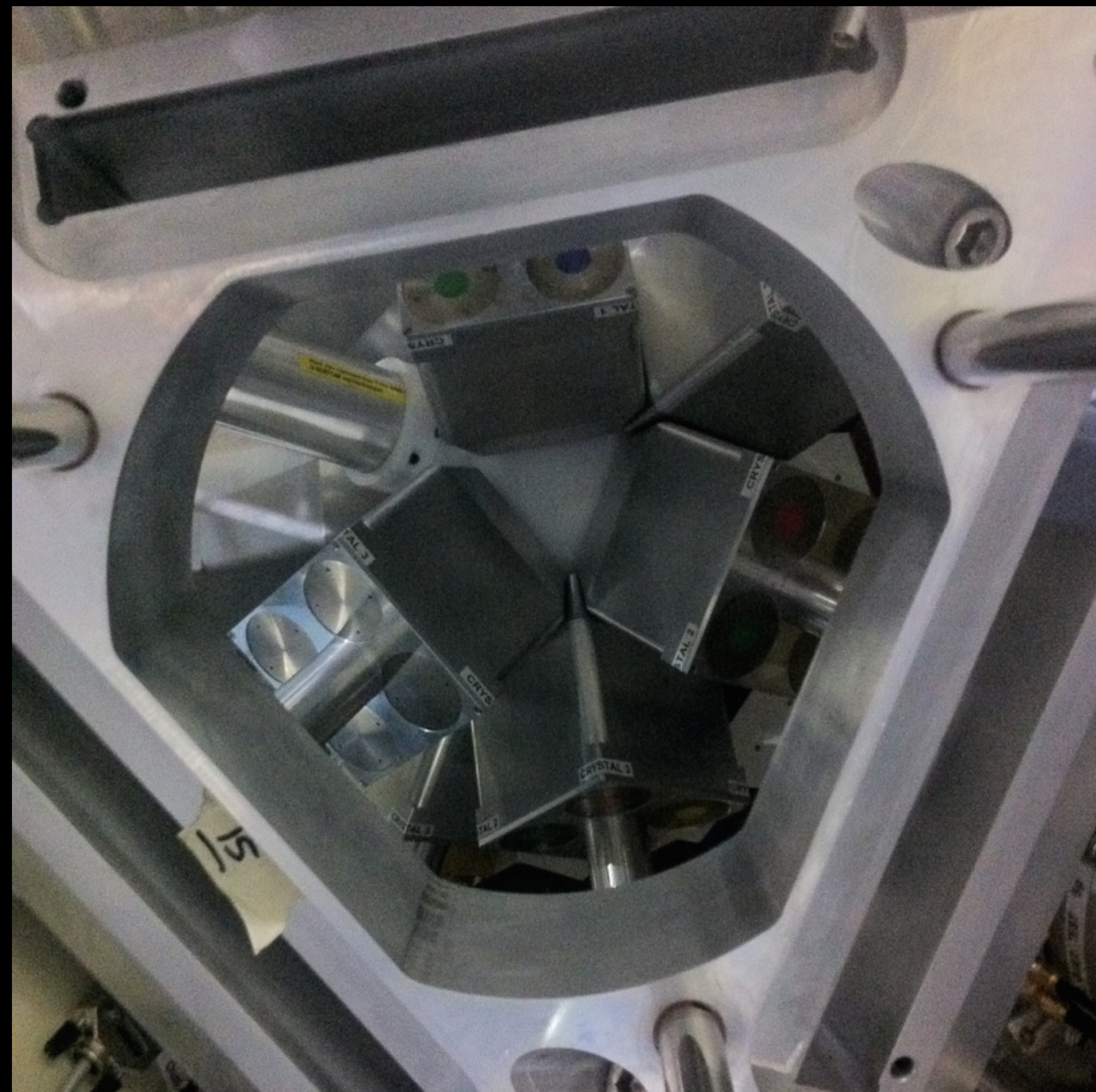
- Use Gamma-Ray Infrastructure For Fundamental Investigations of Nuclei.
- Contains 16 large-volume clover detectors.





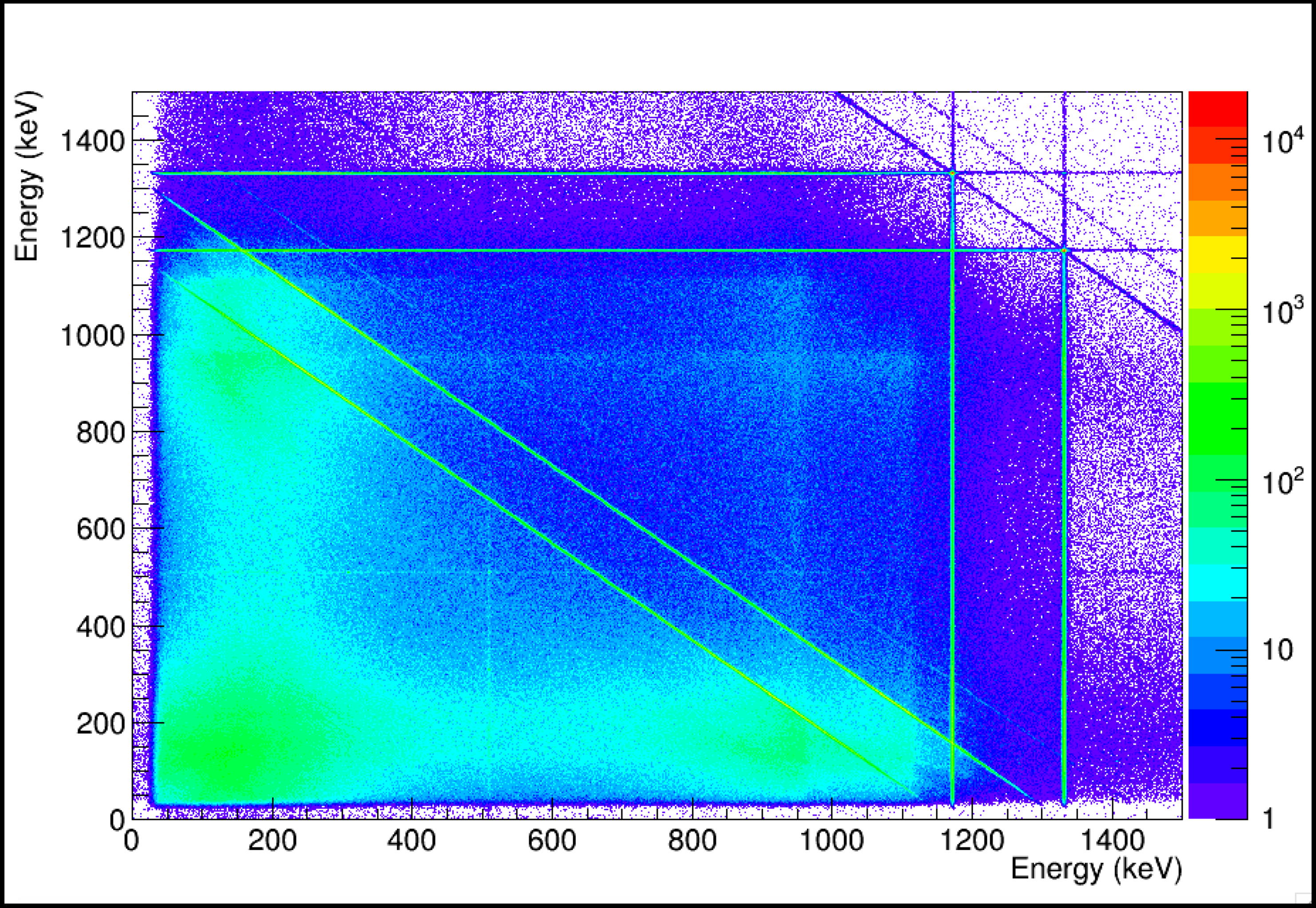


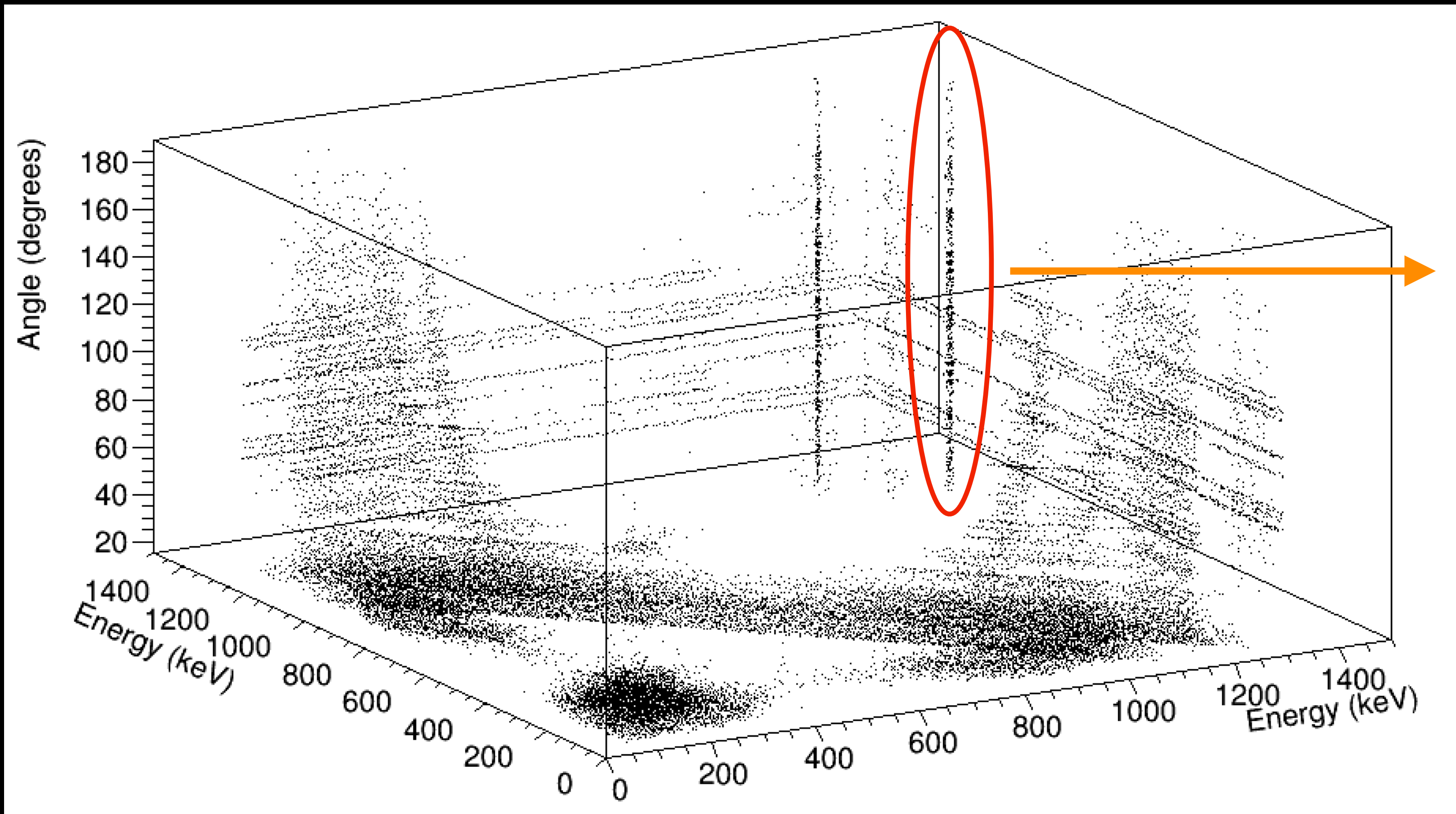




Extracting Correlations

- Plot of a symmetric γ-γ matrix for ^{60}Co with the 1.17 MeV and 1.33 MeV γ-rays.
- A lot of scattering between neighbouring (close) crystals.





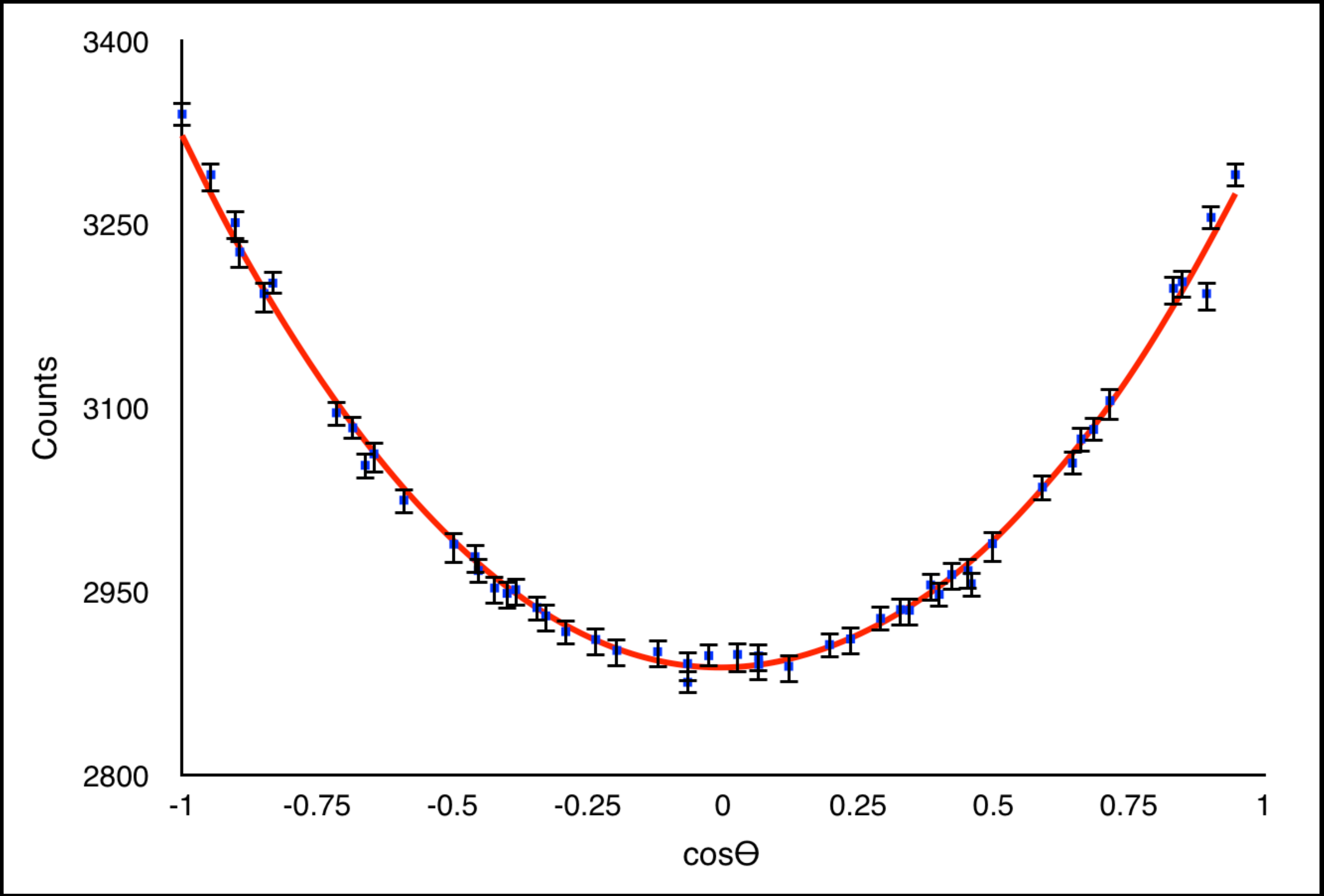
Correlation information we wish to extract

- The 2D γ-γ matrix is expanded in the z direction with respect to the opening angle to create a 3D angular correlation cube.

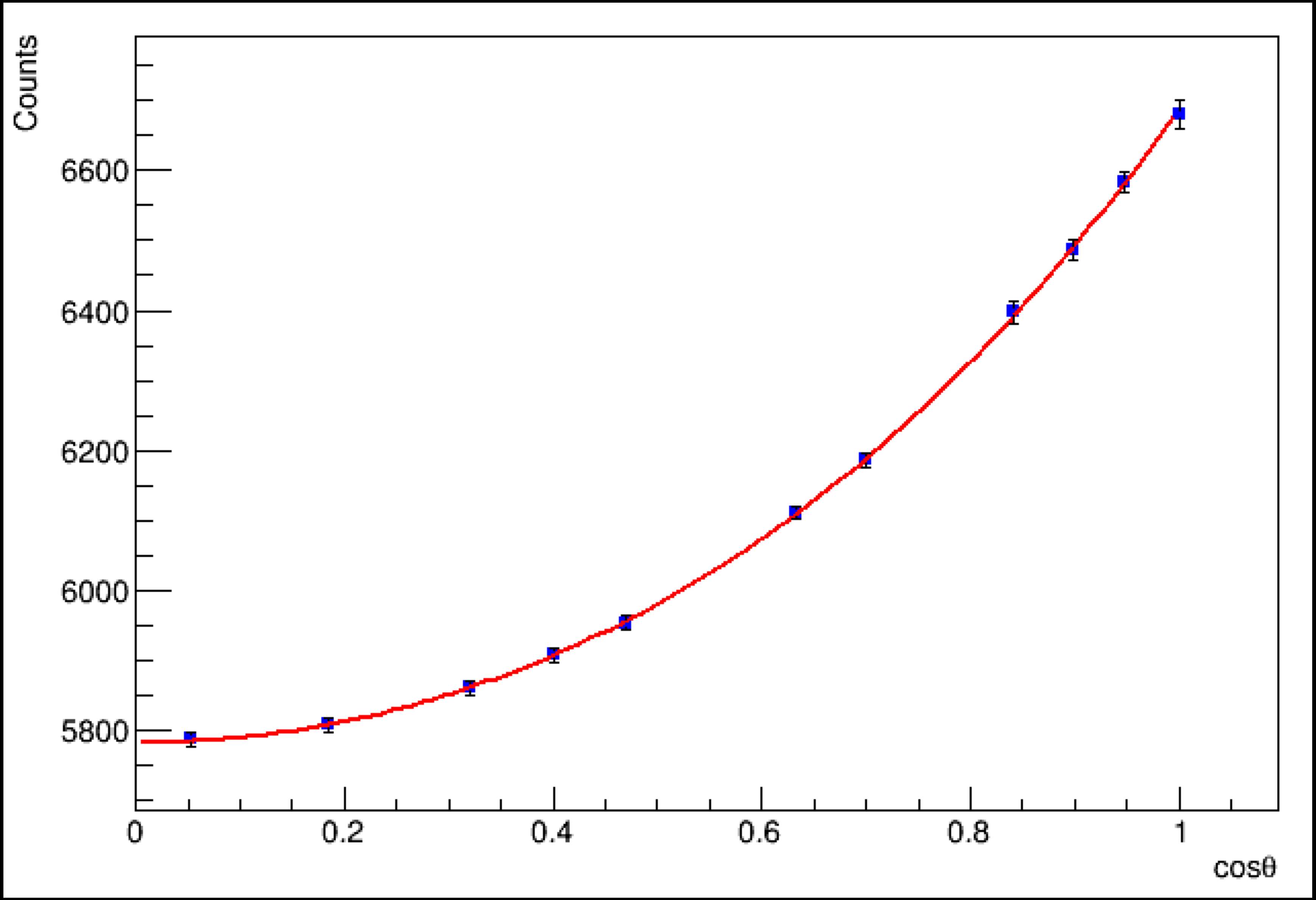
Angular Correlations

One billion simulated events to produce the angular correlation including 51 (ignoring the sum peak) unique open angles for the GRIFFIN array.

- Simulation of well known $4^+ \longrightarrow 2^+ \longrightarrow 0^+$ cascade in ^{60}Co



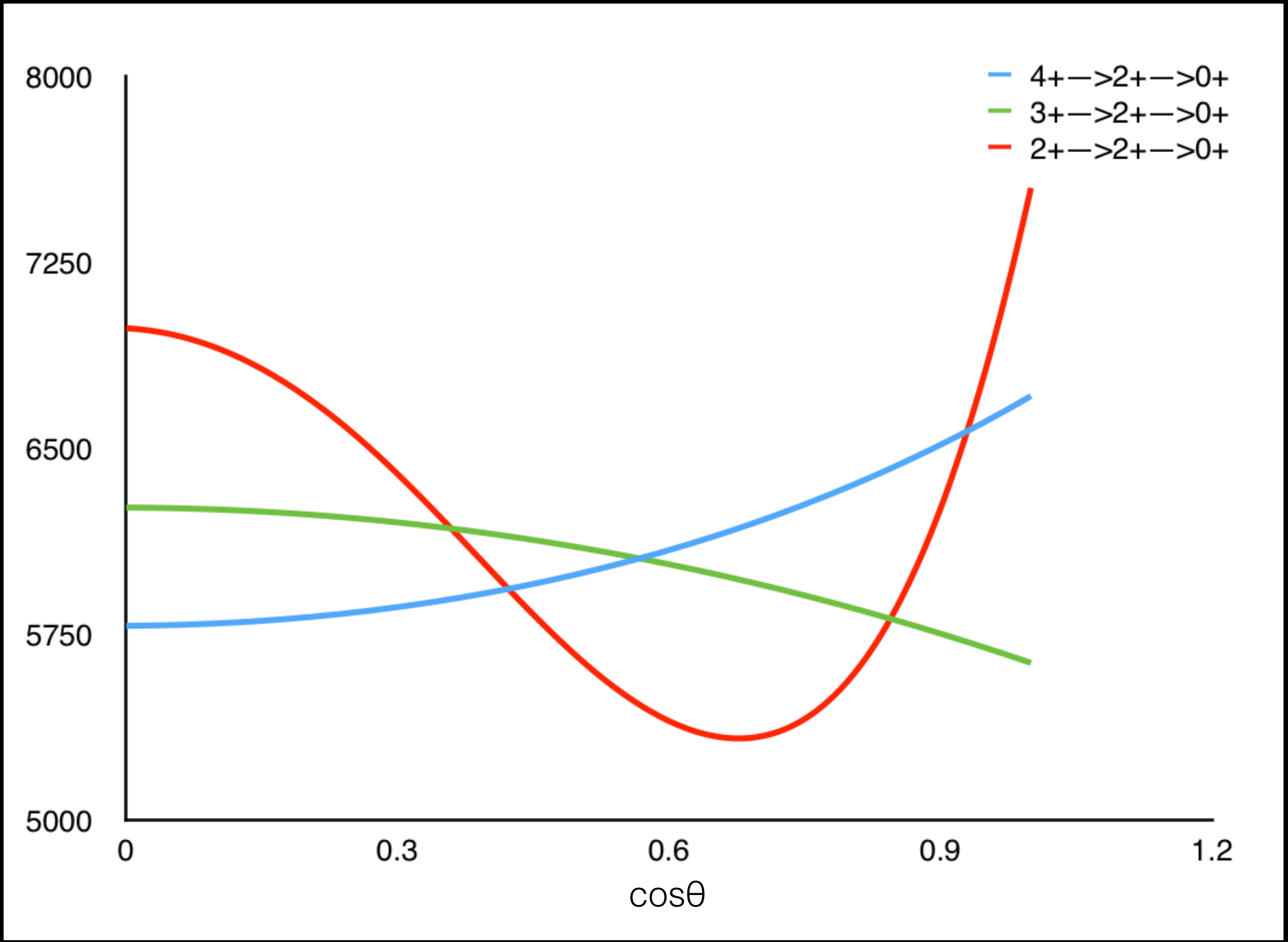
Folding the Data



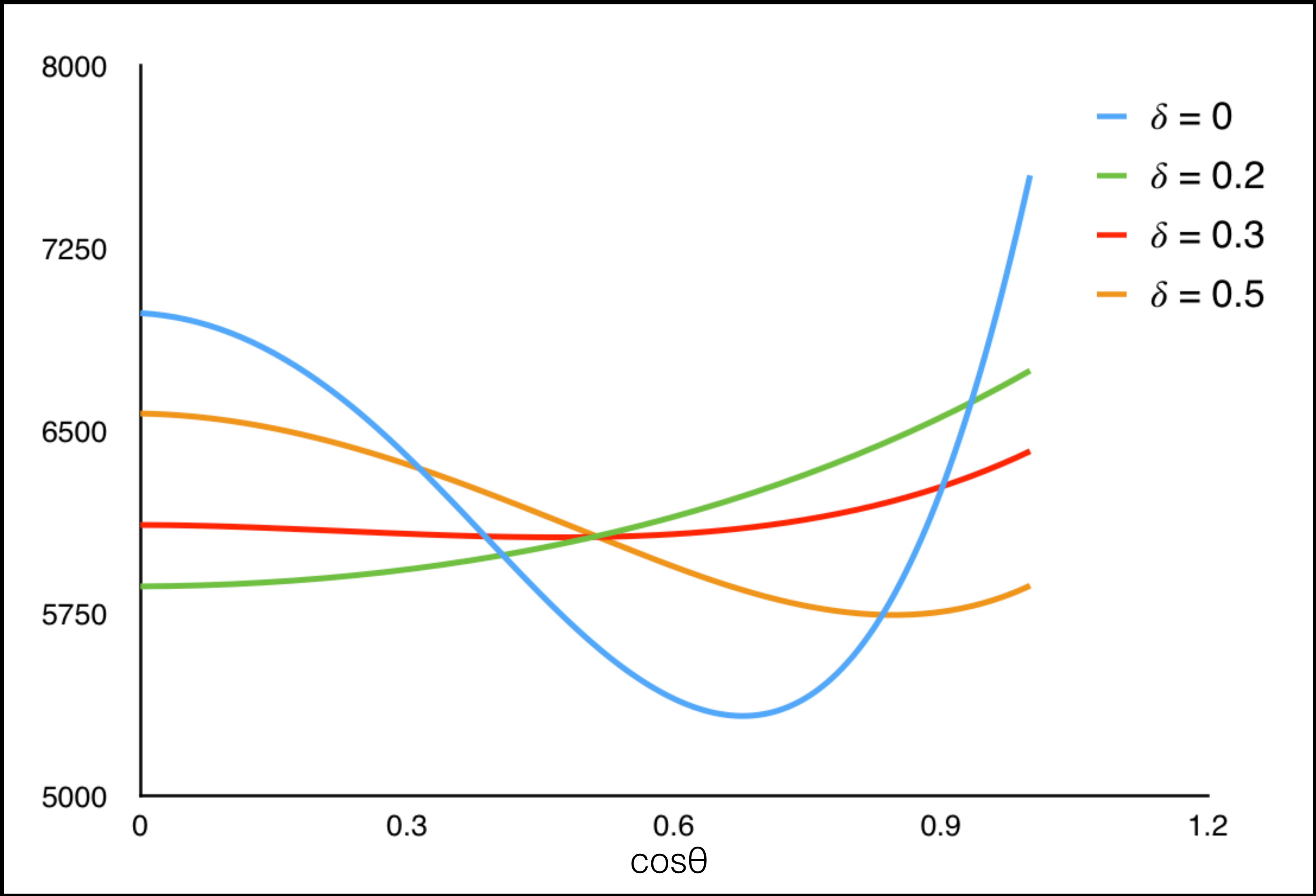
The same simulation with angles combined

Templates

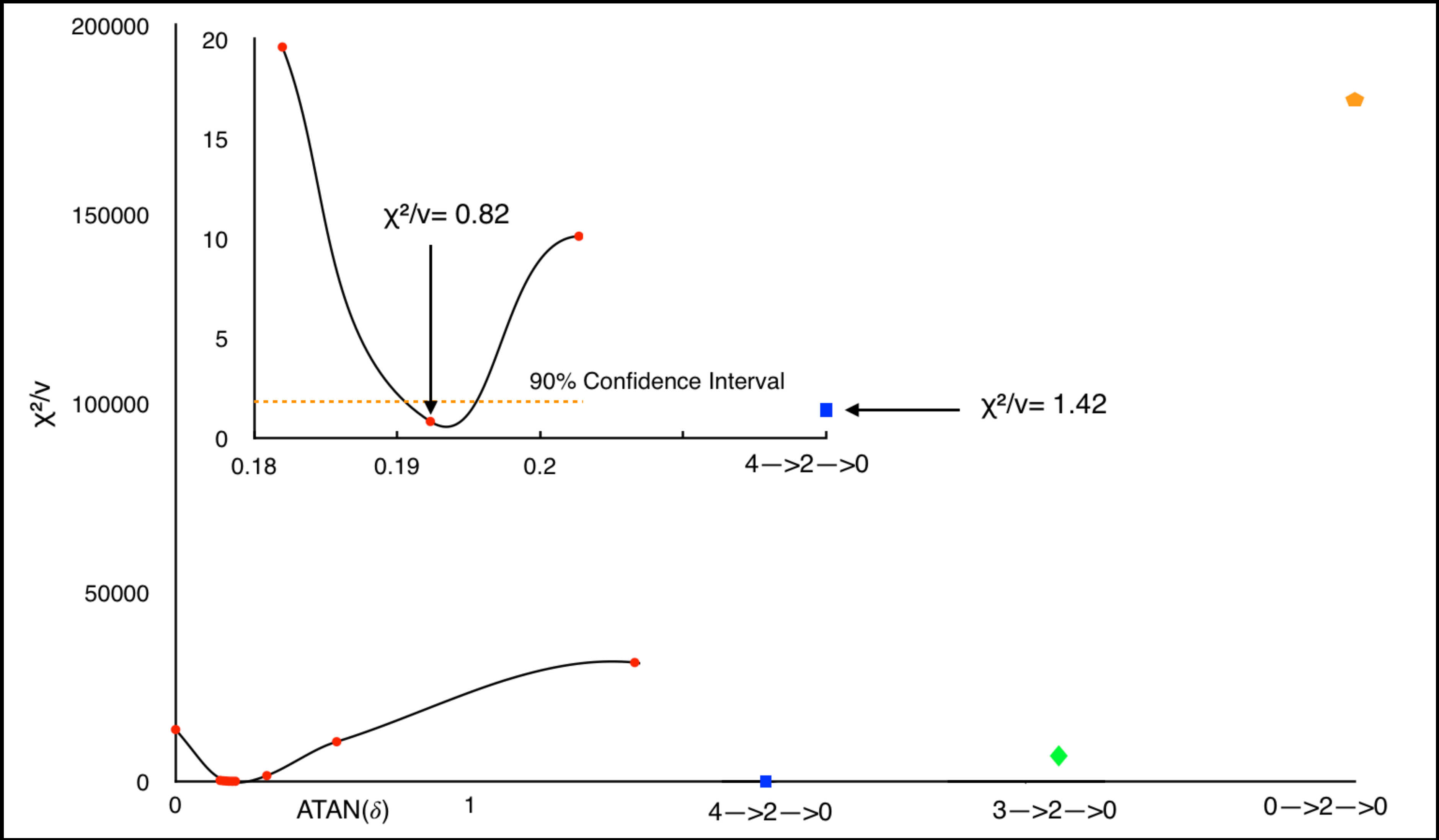
- With high statistic simulations templates can be made for different cascades.
- Can be clearly distinguished from each other.



- Also in the case of the $2^+ \longrightarrow 2^+ \longrightarrow 0^+$ cascade there can be mixing ratios causing different angular correlations.

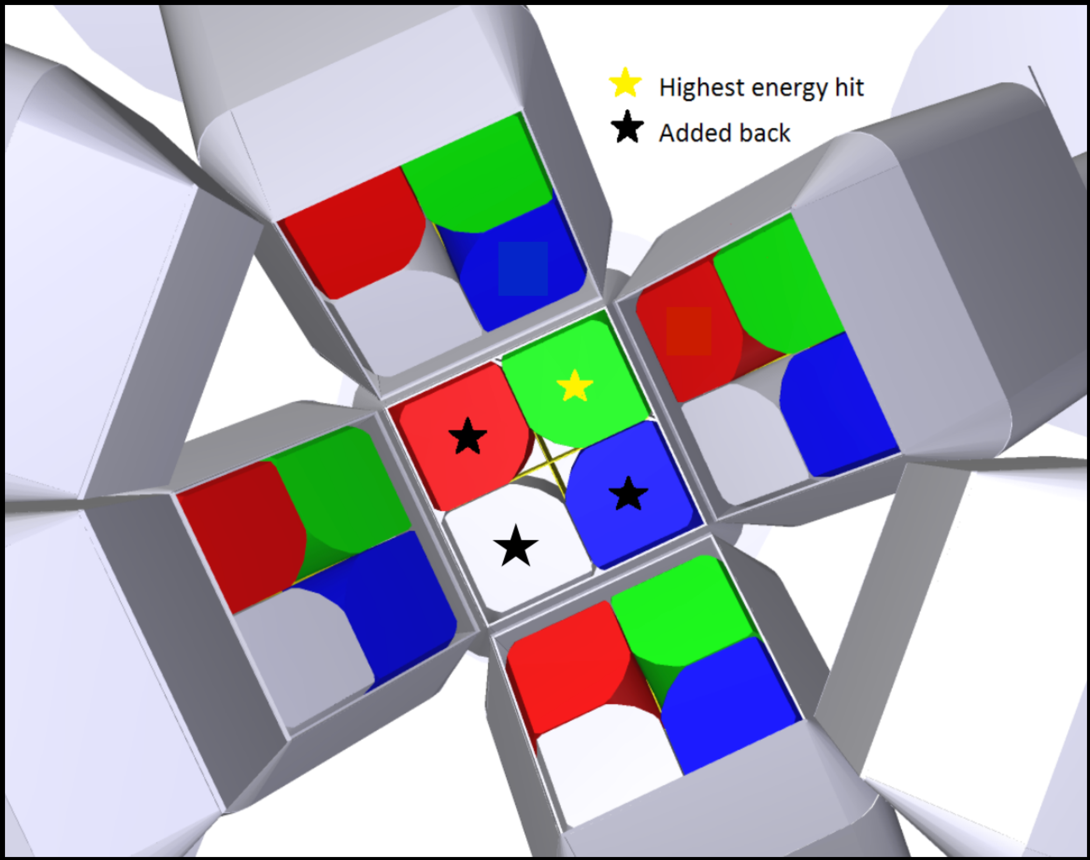


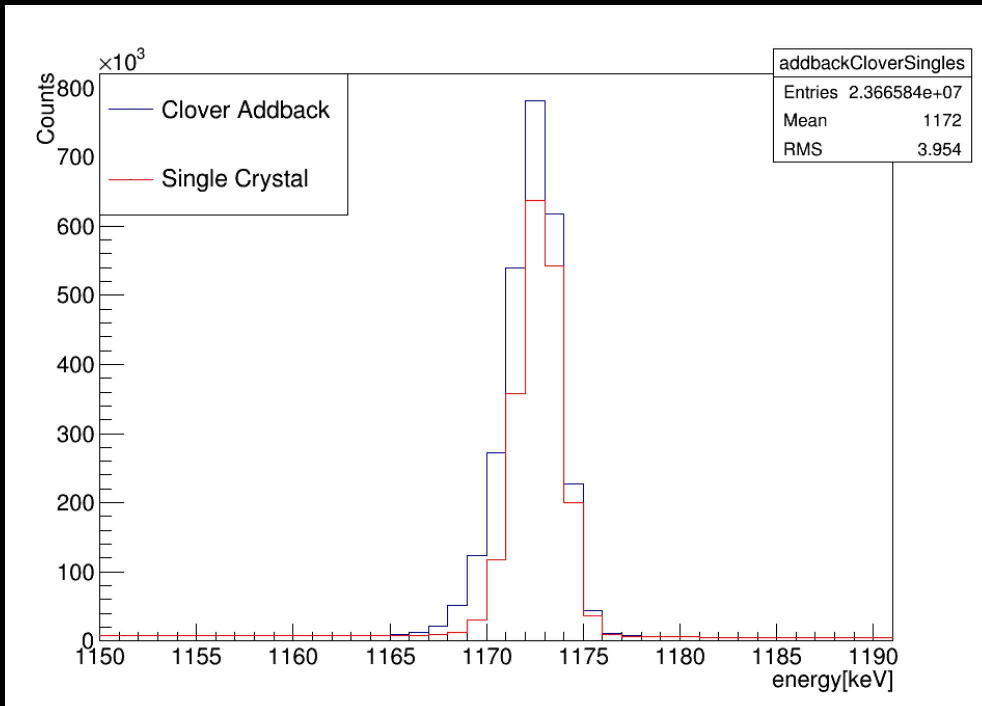
- Many cascades are able to be disregarded but in this case some cannot as they have nearly identical angular correlation coefficients, and hence correlations.

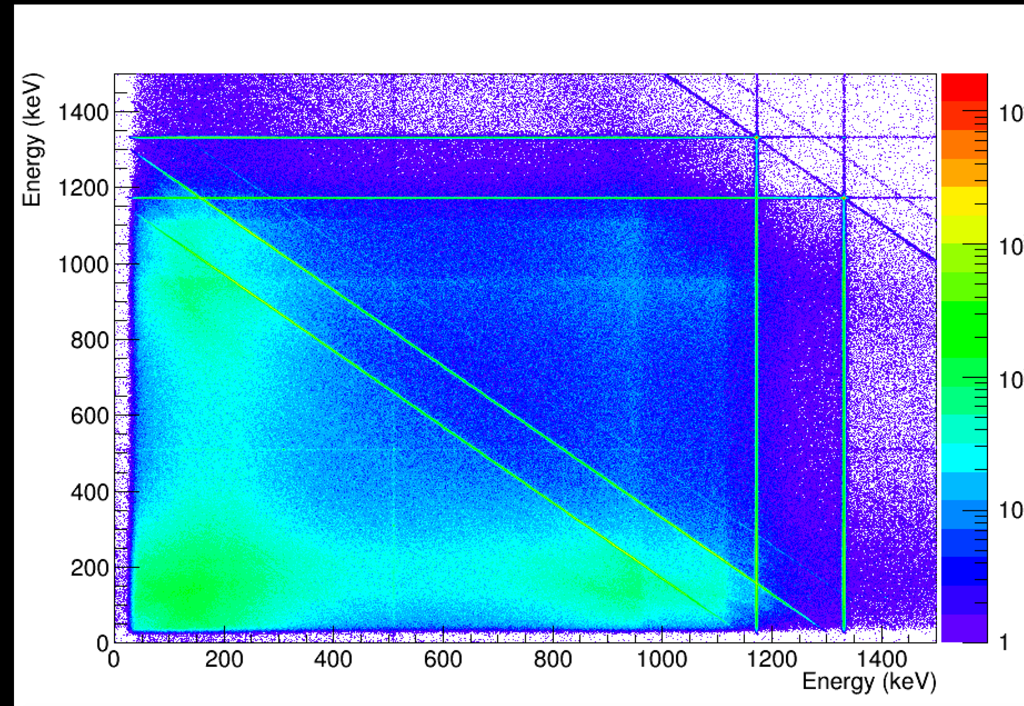


Addback

- All previous plots have been using single crystal method.
- Wish to explore different methods of addback.
- When using addback for angular correlations you gain photopeak efficiency but lose angular resolution and some angles.
- Hence, only few neighbouring crystals can be used when looking at angular correlations.

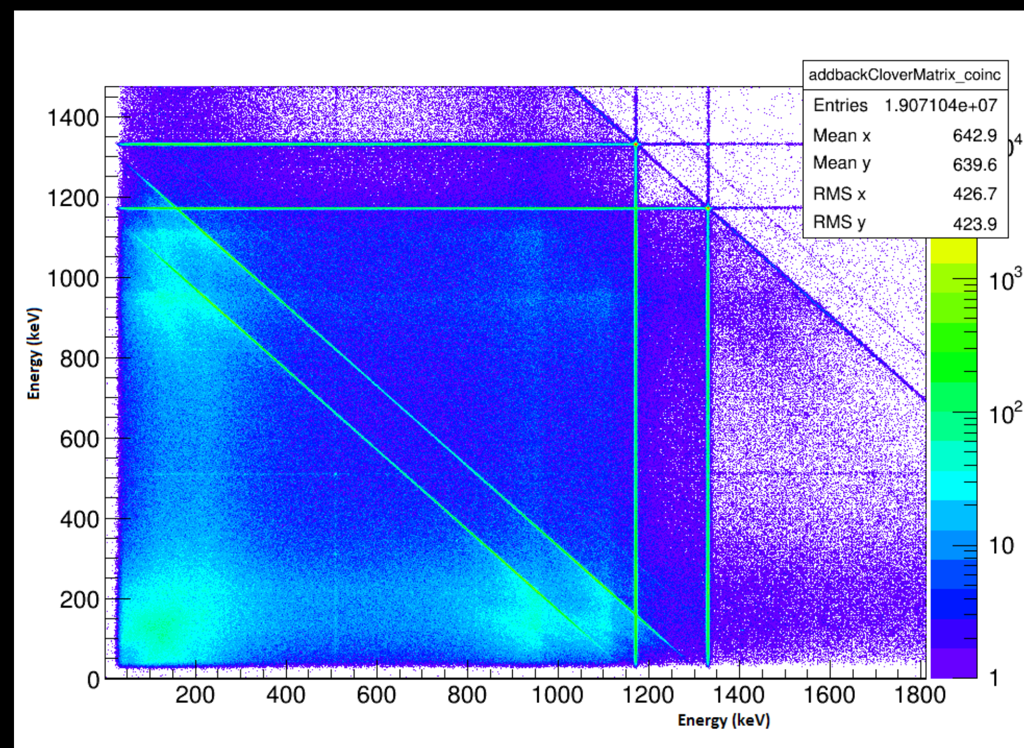






Above is the gain in photopeak efficiency is seen in the 1.17 MeV γ-ray.

To the right is the γ-γ coincident matrices for single crystal (top) and addback (bottom) methods.



Future Work

- Finish addback simulation analysis.
- Analyze experimental data sets with ^{60}Co and ^{152}Eu have just been taken (one week ago).
- Test the different distances GRIFFIN can be placed from the implant site.
- Increase precision of measurements with the addition of efficiency corrections.

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Thank You!

TRIUMF

NSERC CRSNG

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The coefficients of the $\gamma_1 - \gamma_2$ angular distribution have the form:

$$a_k = A_k(\gamma_1)B_k(\gamma_2)$$

$$A_k(\gamma_1) = \frac{1}{1+\delta_1^2}(f_k(L_1, L_1, J_i, J_f) + 2\delta_1 f_k(L_1, L_1', J_i, J_f) + \delta_1^2 f_k(L_1', L_1', J_i, J_f))$$

$$B_k(\gamma_2) = \frac{1}{1+\delta_2^2}(f_k(L_2, L_2, J_i, J_f) + 2\delta_2 f_k(L_2, L_2', J_i, J_f) + \delta_2^2 f_k(L_2', L_2', J_i, J_f))$$

With the f_k coefficients represented by the following if fully aligned:

$$f_k(L_1, L_1', J_i, J_f) = B_k(J_i)F_k(L_1, L_1', J_i, J_f)$$

$$F_k(L_1, L_1', J_i, J_f) = (-1)^{J_f - J_i - 1}(2J_i + 1)^{\frac{1}{2}}(2L_1 + 1)^{\frac{1}{2}}(2L_1' + 1)^{\frac{1}{2}} \times (L_1 1 L_1' - 1|k0)W(J_i J_i L_1 L_1'; kJ_f)$$

$$B_k(J_i) = (-1)^{J_i}(2J_i + 1)^{\frac{1}{2}}(J_i 0 J_i 0|k0) \text{ for integer spin.}$$

$$B_k(J_i) = (-1)^{J_i - \frac{1}{2}}(2J_i + 1)^{\frac{1}{2}}(J_i \tfrac{1}{2} J_i - \tfrac{1}{2}|k0) \text{ for half integer spin.}$$

With $W(J_i J_i L_1 L_2; kJ_f)$ being the Racah W-coefficient which deals with cases that involve three sources of angular momentum.