Octupole collectivity: Coulomb excitation of ^{224}Ra

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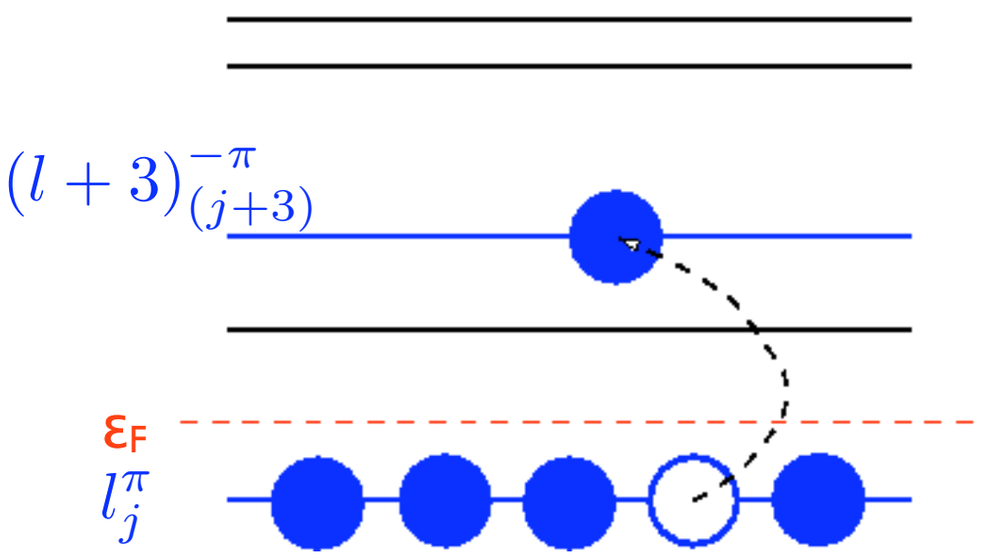
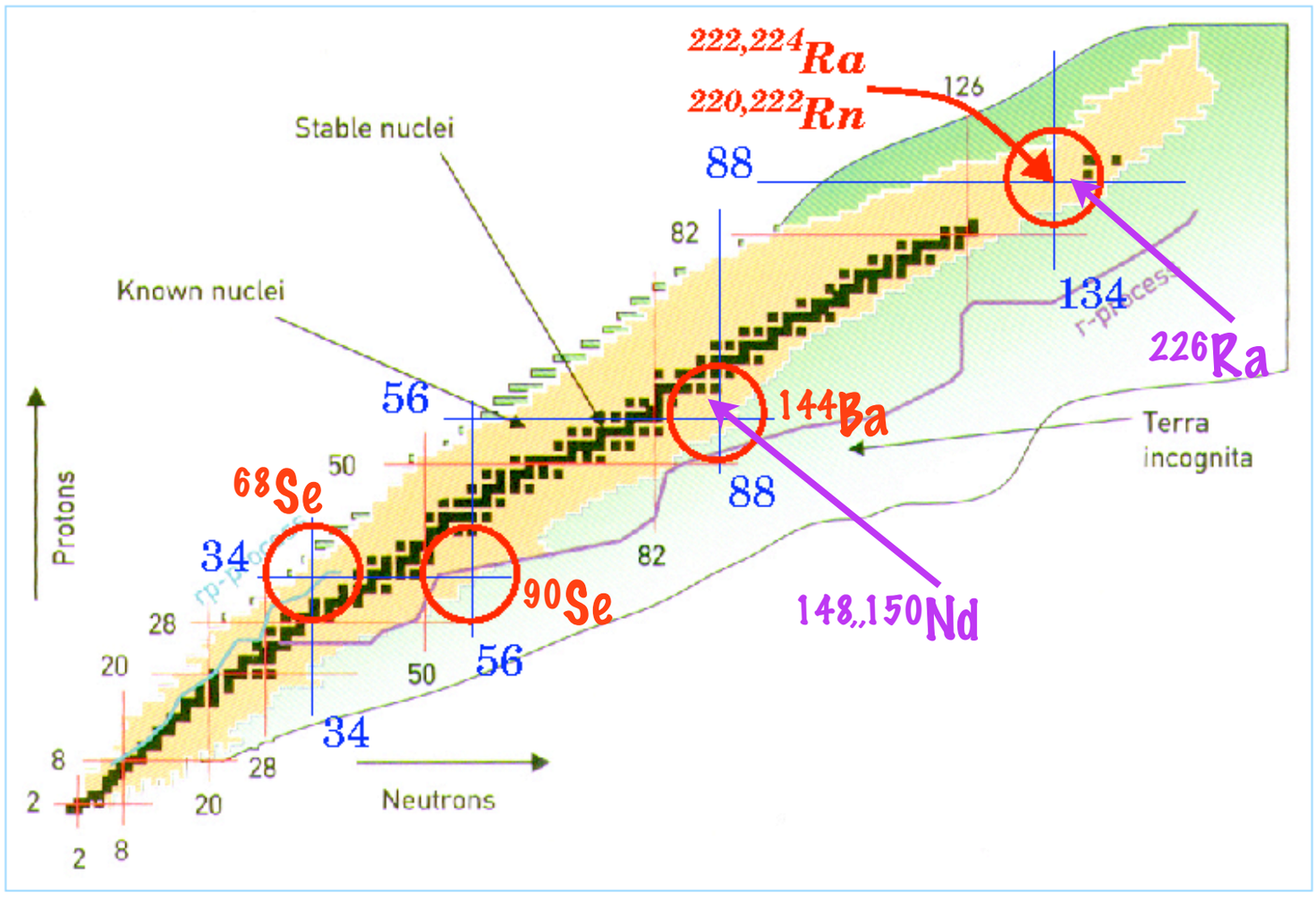
Octupole Collectivity

Octupole correlations enhanced at the magic numbers: **34, 56, 88, 134**

Microscopically...

Intruder orbitals of opposite parity and **ΔJ, ΔL = 3** close to the Fermi level





^{220,222}Rn and ^{222,224}Ra lie near Z=88, N=134

$$\pi\left(f_{7/2} \rightarrow i_{13/2}\right) \quad \nu\left(g_{9/2} \rightarrow j_{15/2}\right)$$

Octupole Collectivity

Macroscopically...

Nuclei take on a "pear" shape

Reflection asymmetric

- β_3-vibration
- β_2-deformation + β_3-softness
- Static β_3-deformation?

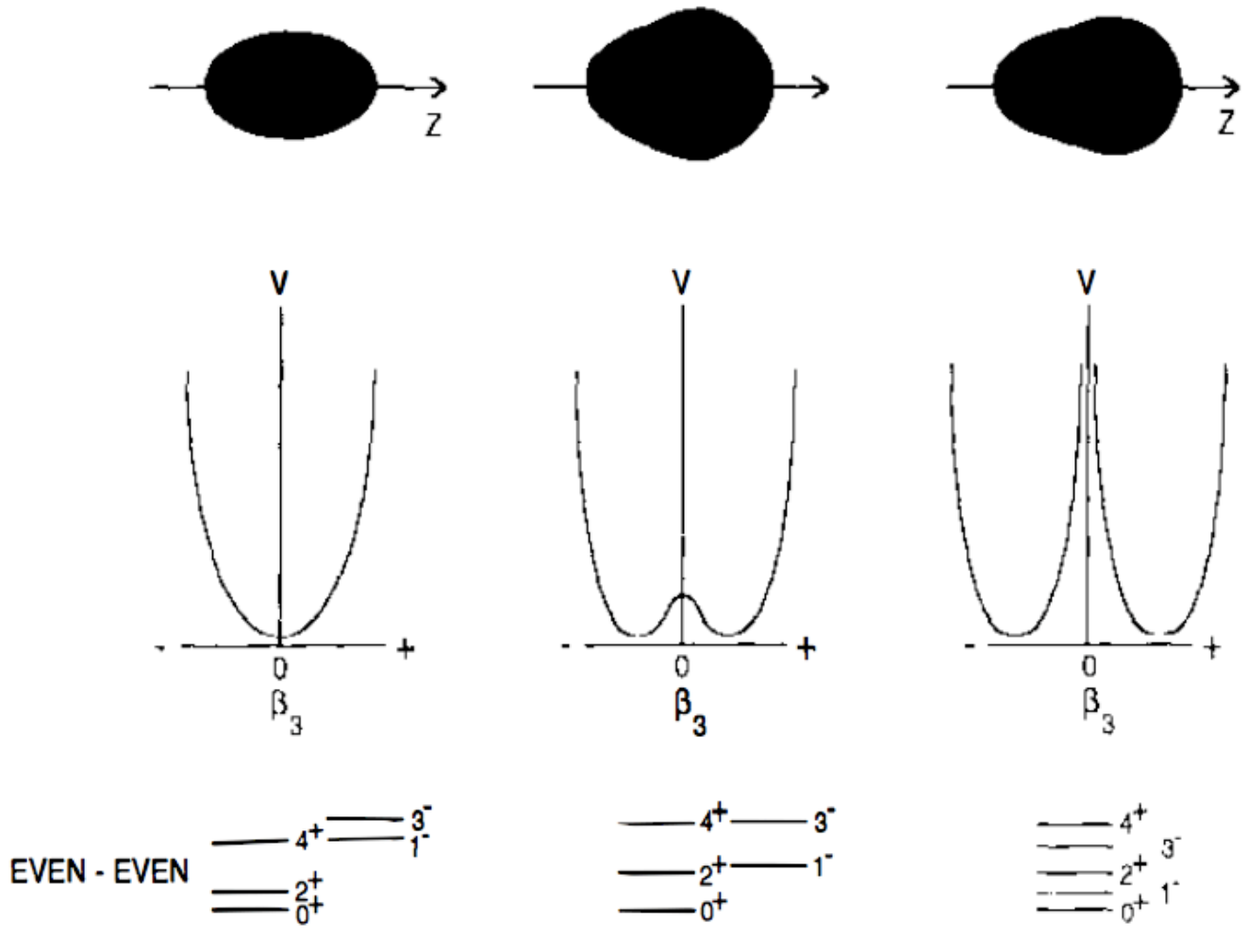


Image: I. Ahmed and P.A. Butler, Ann. Rev. Nucl. Part. Sci (1993) **43**

Signatures...

Odd-even staggering, negative parity

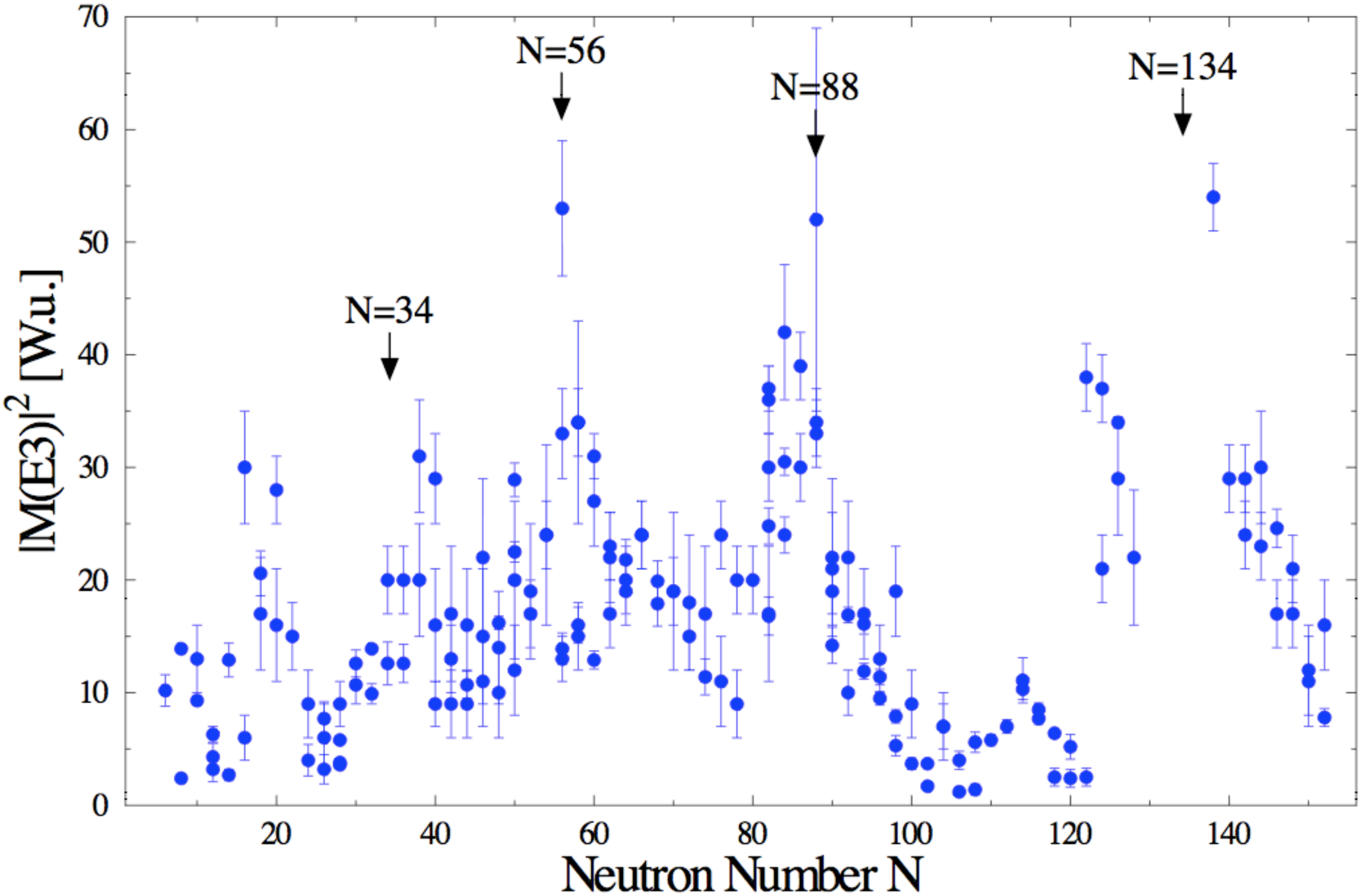
Parity doublets in odd-A nuclei

Enhanced E1 transitions

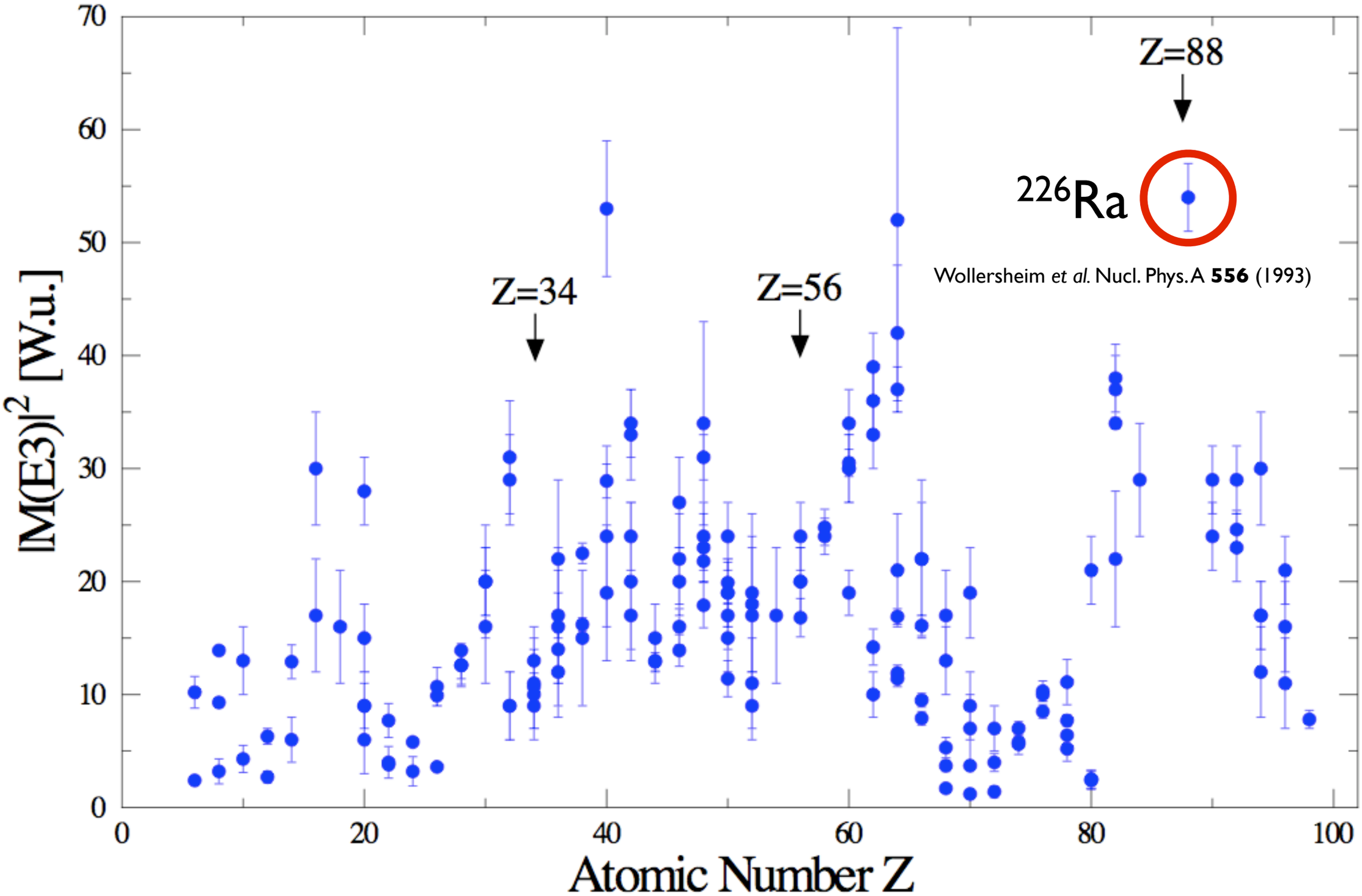
Large E3 strength → $B(E3; 0^+ \rightarrow 3^-) = < 0^+ || E3 || 3^- >^2$

2^L deformation -- β_L
L=2: Quadrupole, oblate/prolate shapes
L=3: Octupole, reflection asymmetry

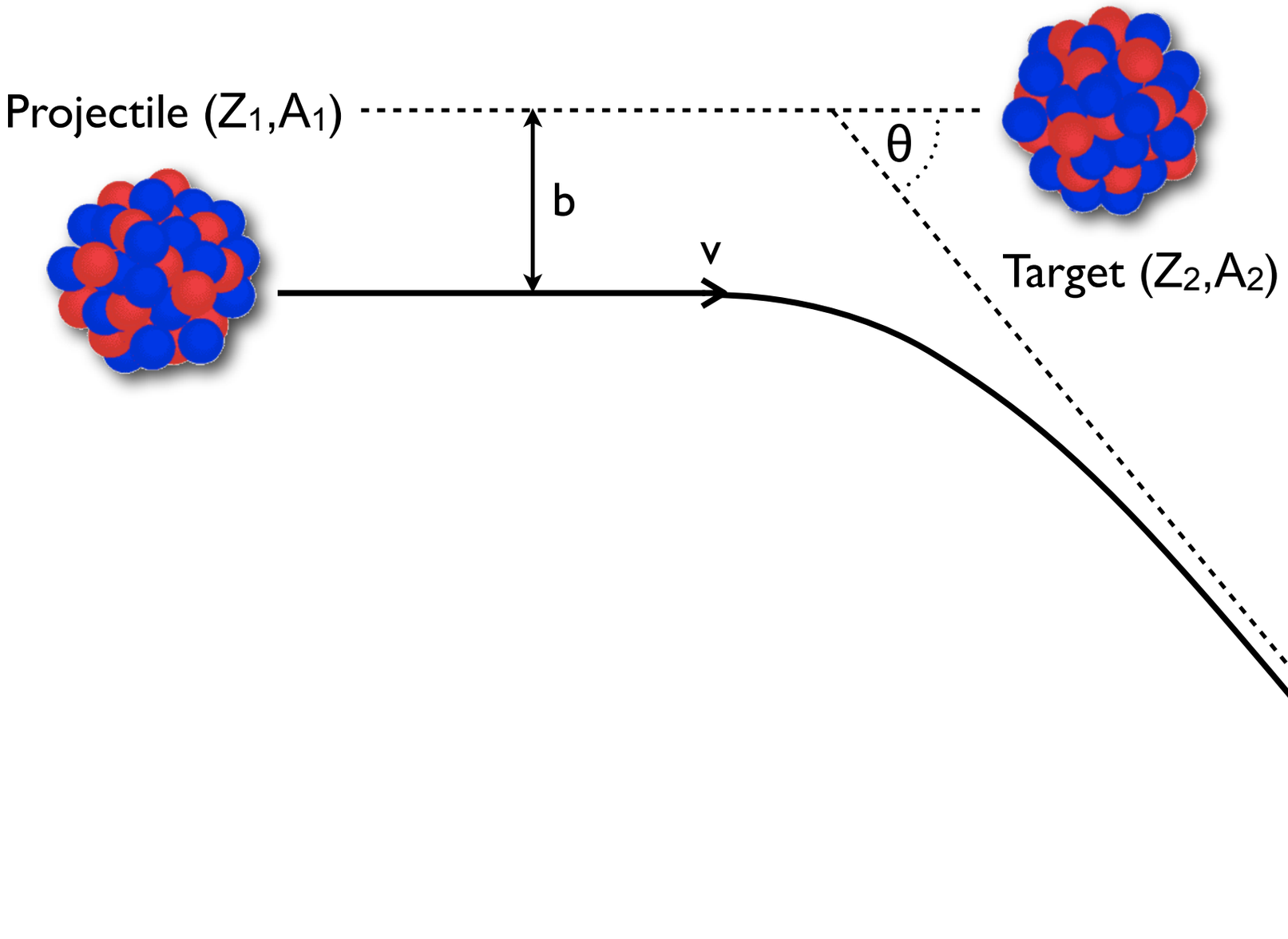
Octupole Collectivity



Octupole Collectivity



Coulomb Excitation



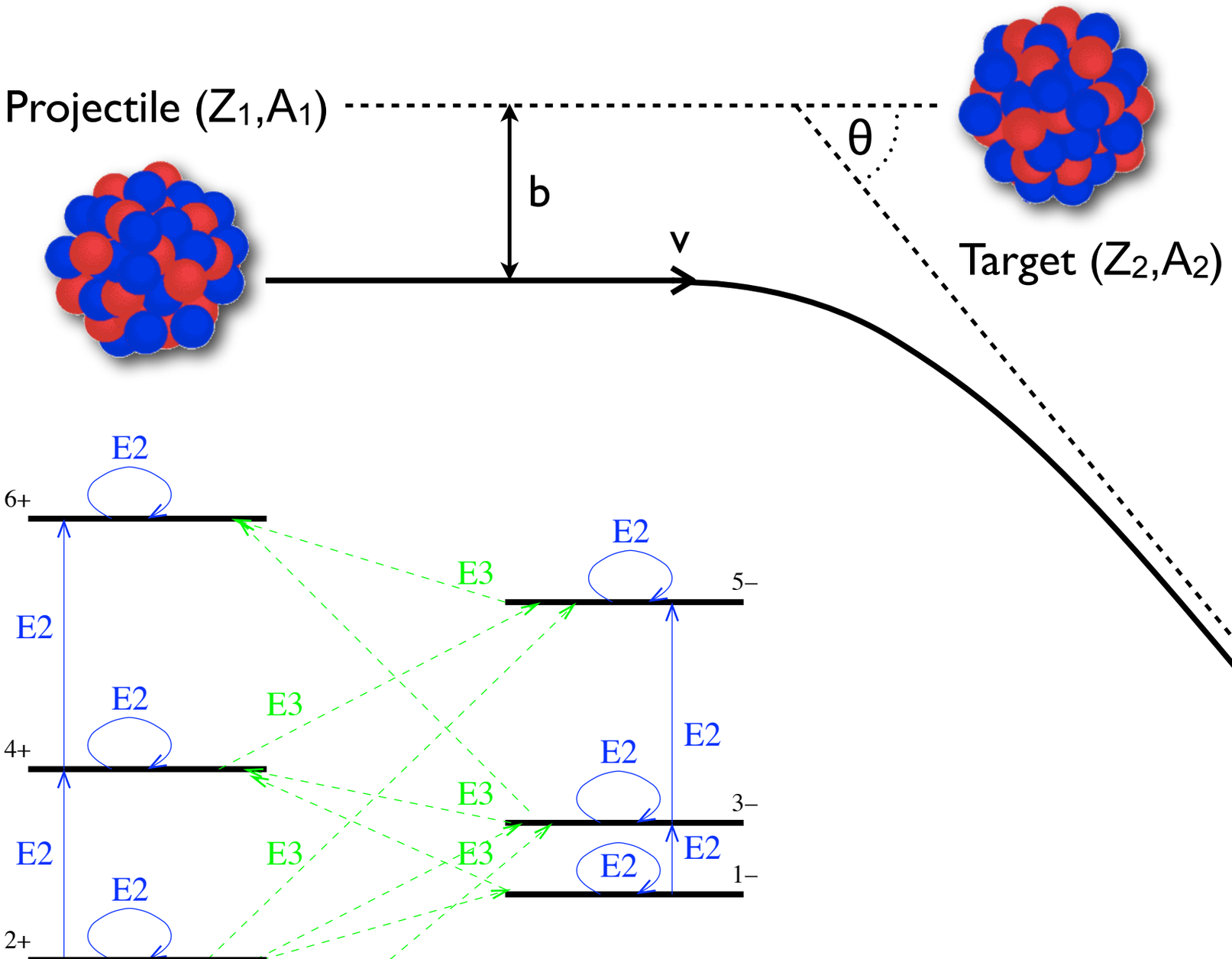
Sommerfeld parameter:

$$\eta = \frac{Z_1 Z_2 e^2}{\hbar v}$$

"Safe" Coulex:

$$\eta \gg 1$$

Coulomb Excitation



Sommerfeld parameter:

$$\eta = \frac{Z_1 Z_2 e^2}{\hbar v}$$

"Safe" Coulex:

$$\eta \gg 1$$

Reduced matrix elements: $< 0^+||E3||3^- >$

Isotope
Separation
On-
Line
D ..?
E ..?

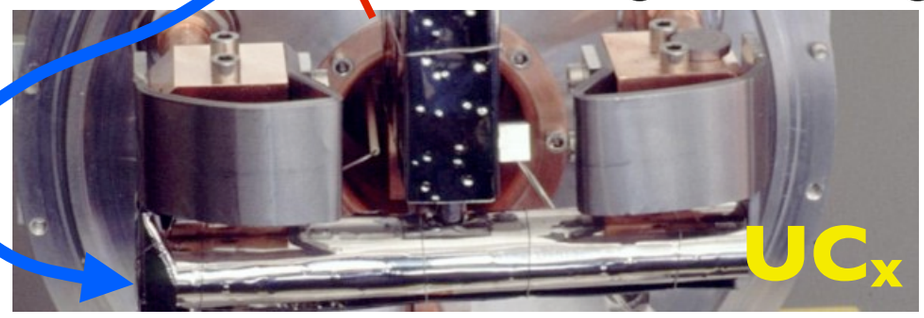
RIB
E-
Xperiment

Radioactive
Ion
Beam

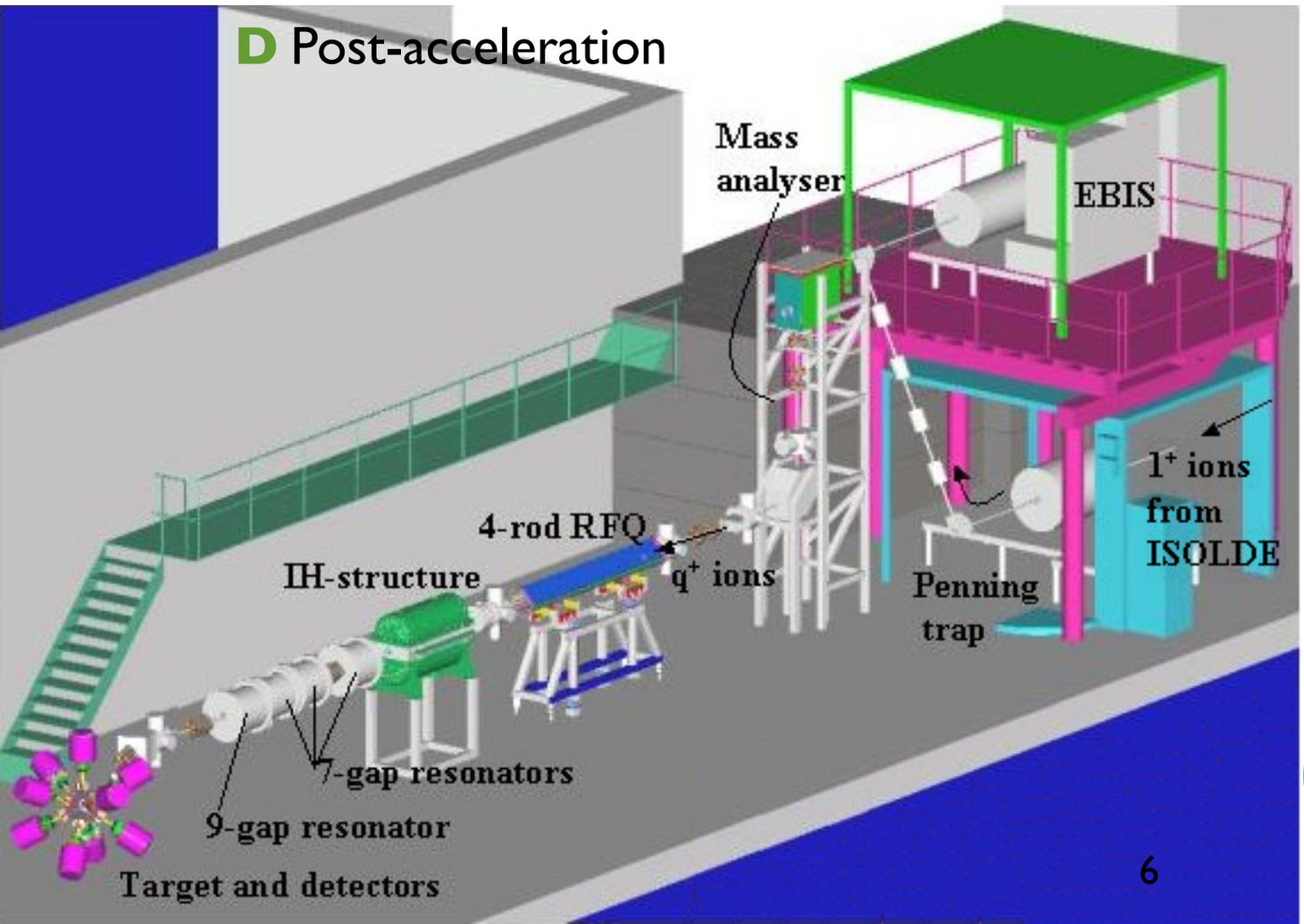
A 1.0 or 1.4GeV protons
from PS Booster

C
Mass separation
in HRS

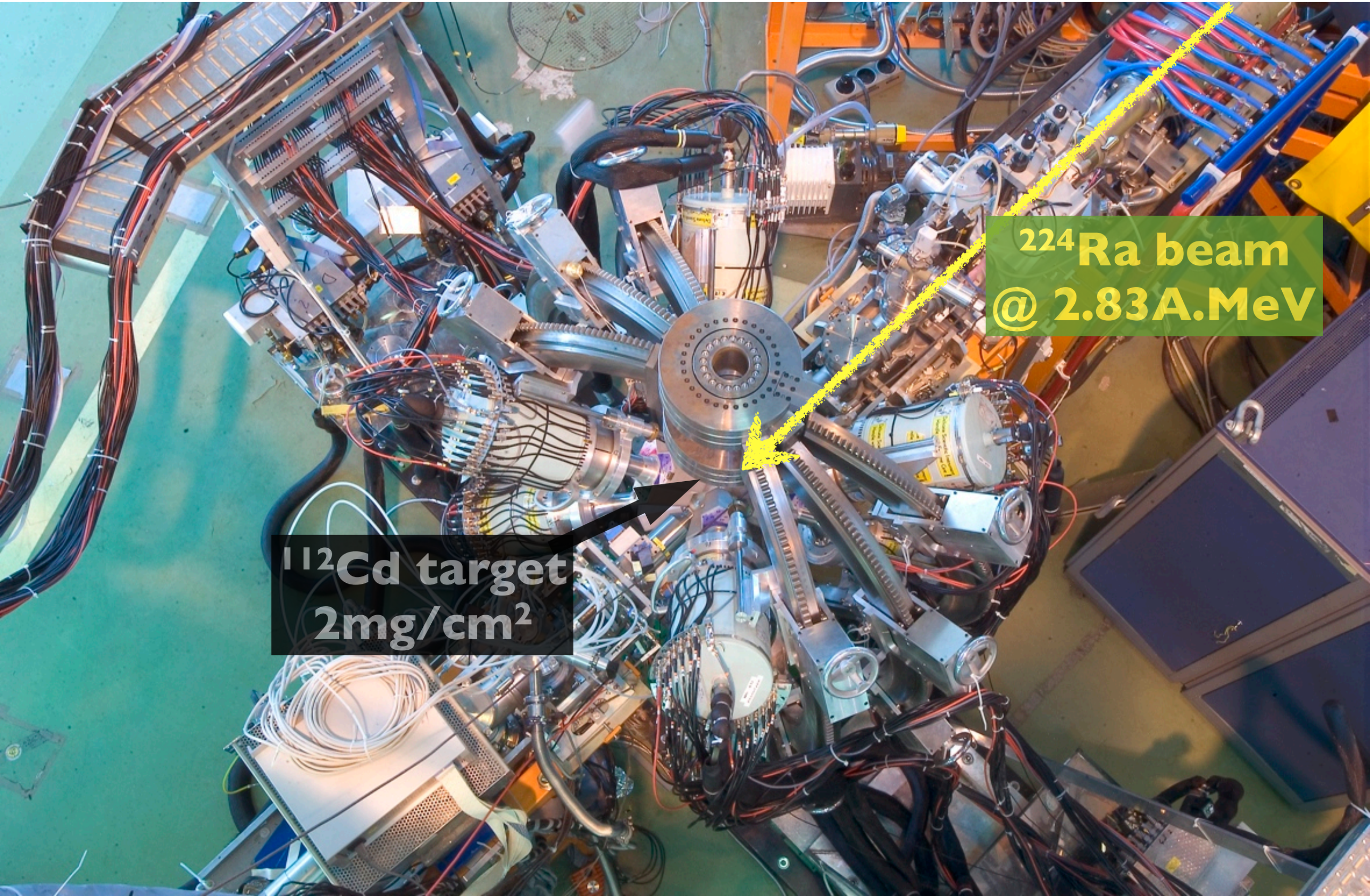
Heated tungsten line
B to ionise atoms
diffusing out of target



D Post-acceleration



MINIBALL



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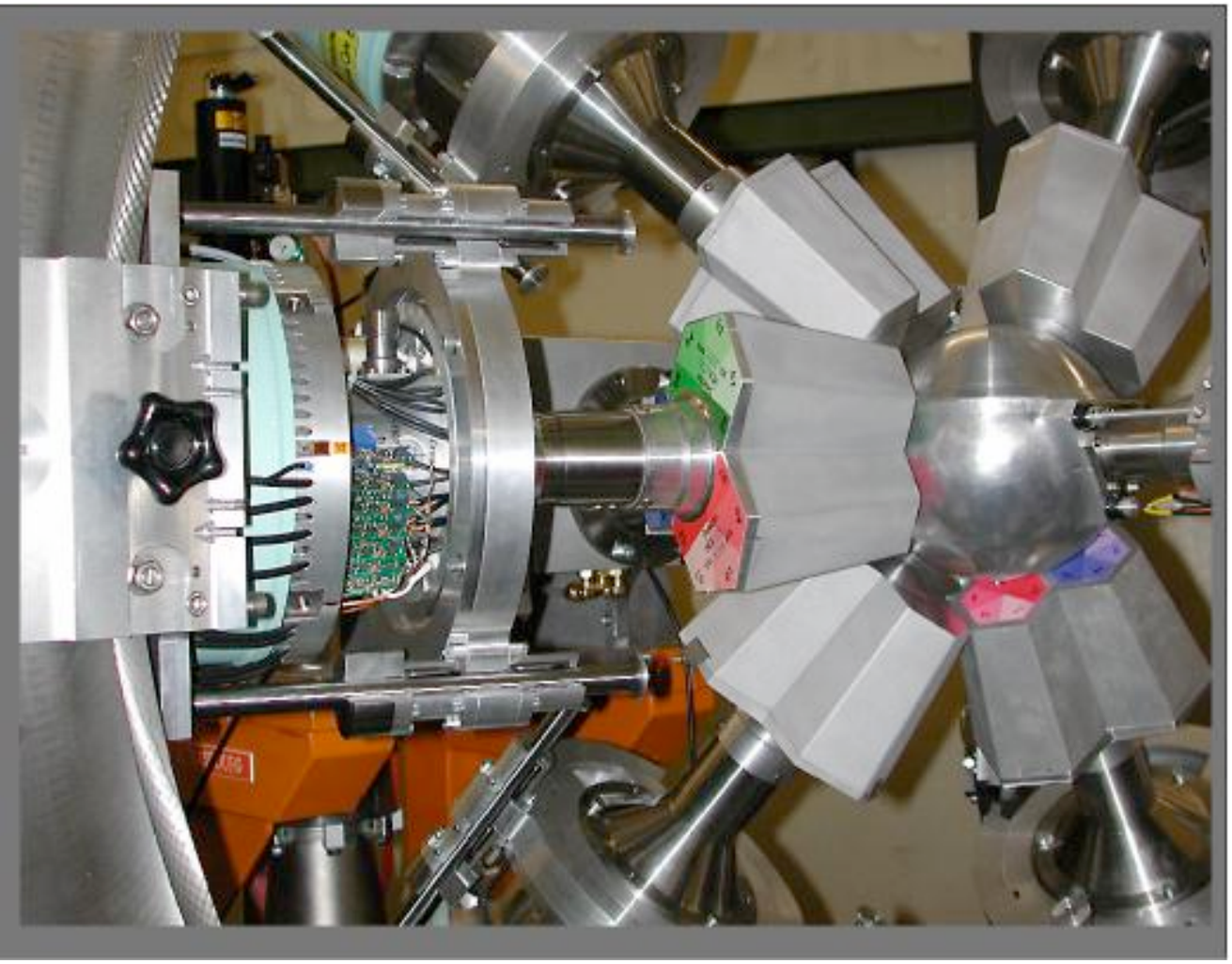
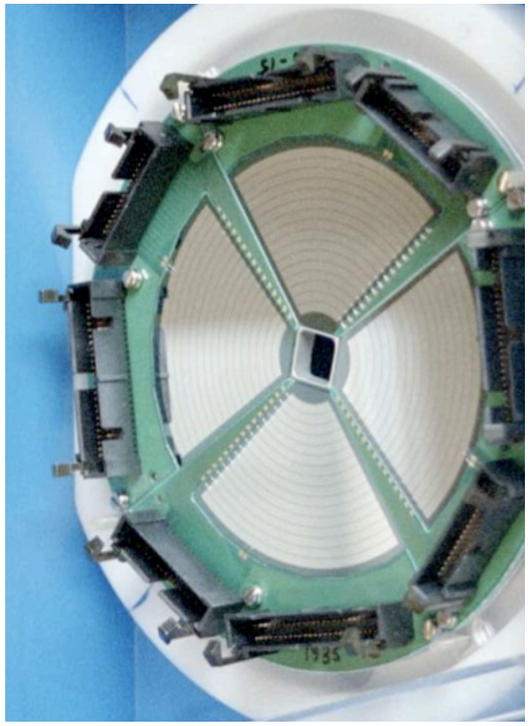
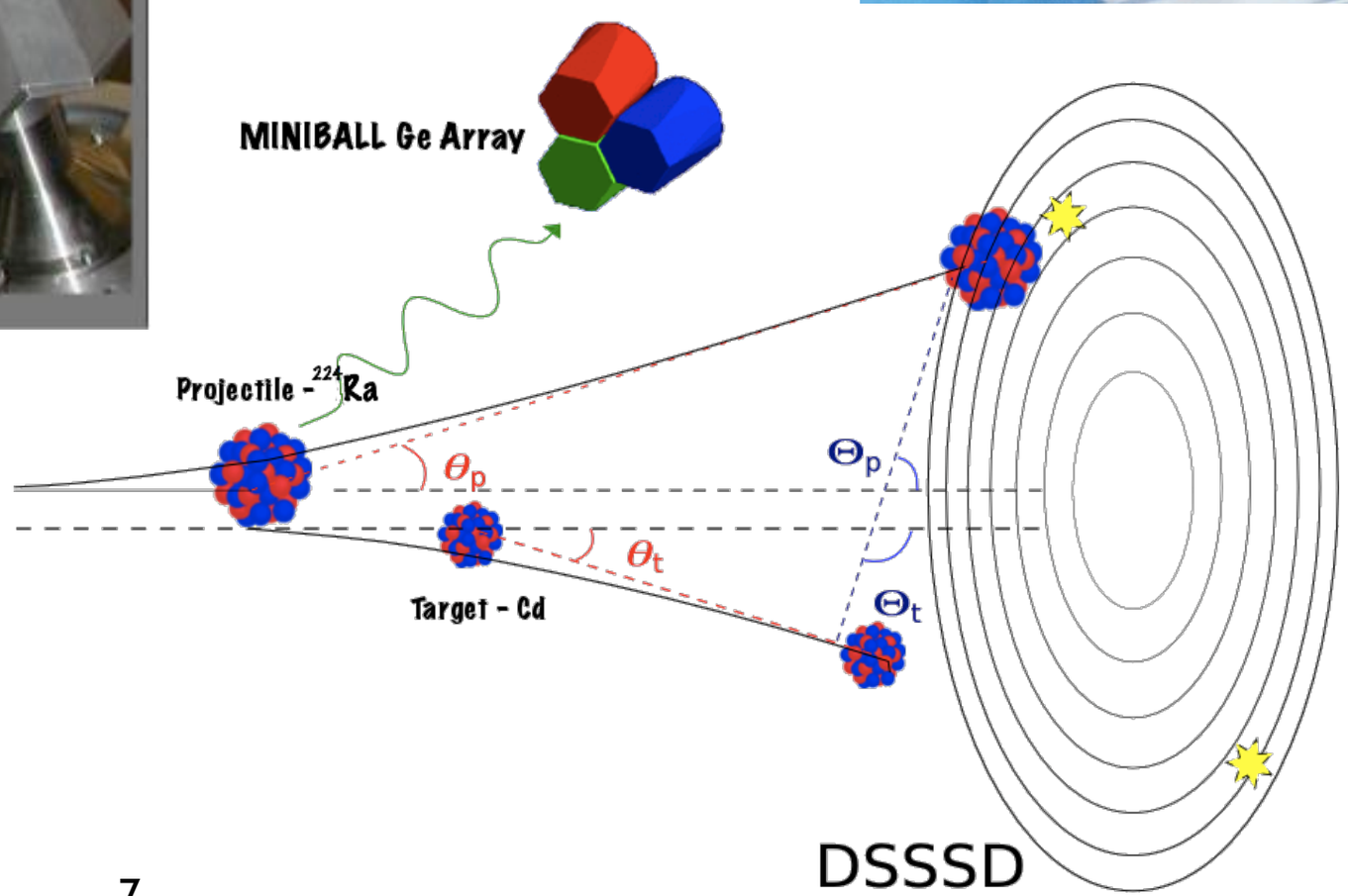


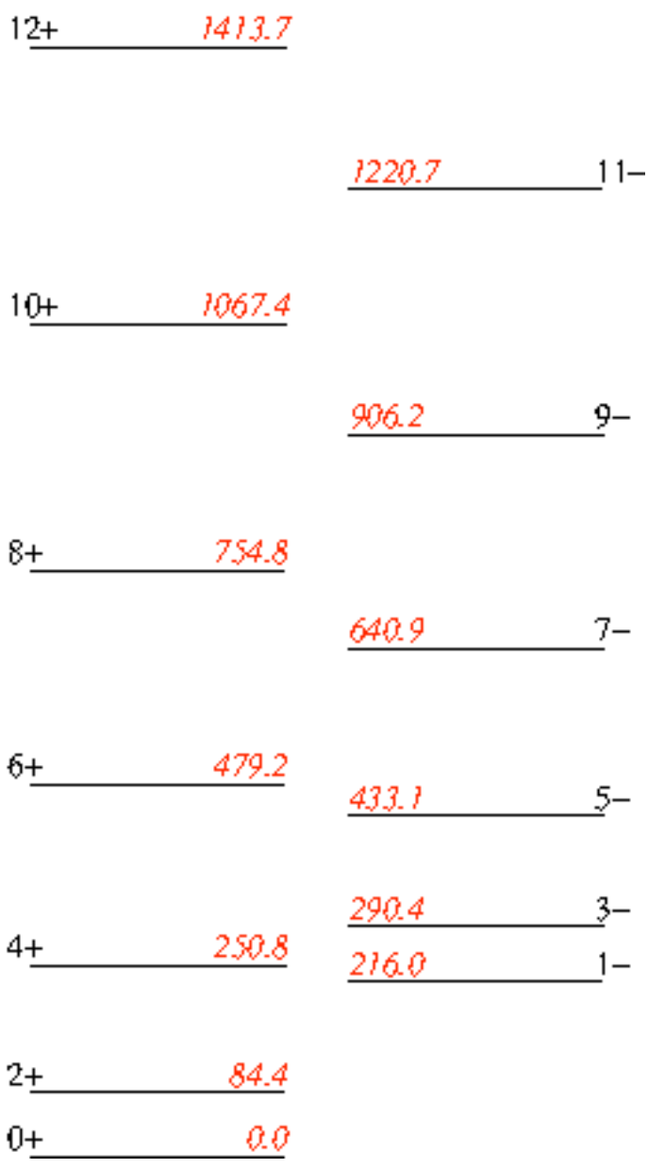
- Particle ID in a Double-Sided Si Strip Detector.
- Event by event Doppler correction.
- $17^\circ < \theta_{lab} < 54^\circ$



- Array of HPGe of 8 triple clusters
- 6-fold segmentation for positioning
- $\varepsilon > 7\%$ for 1.3MeV γ-rays



The experiment - ^{224}Ra



^{224}Ra

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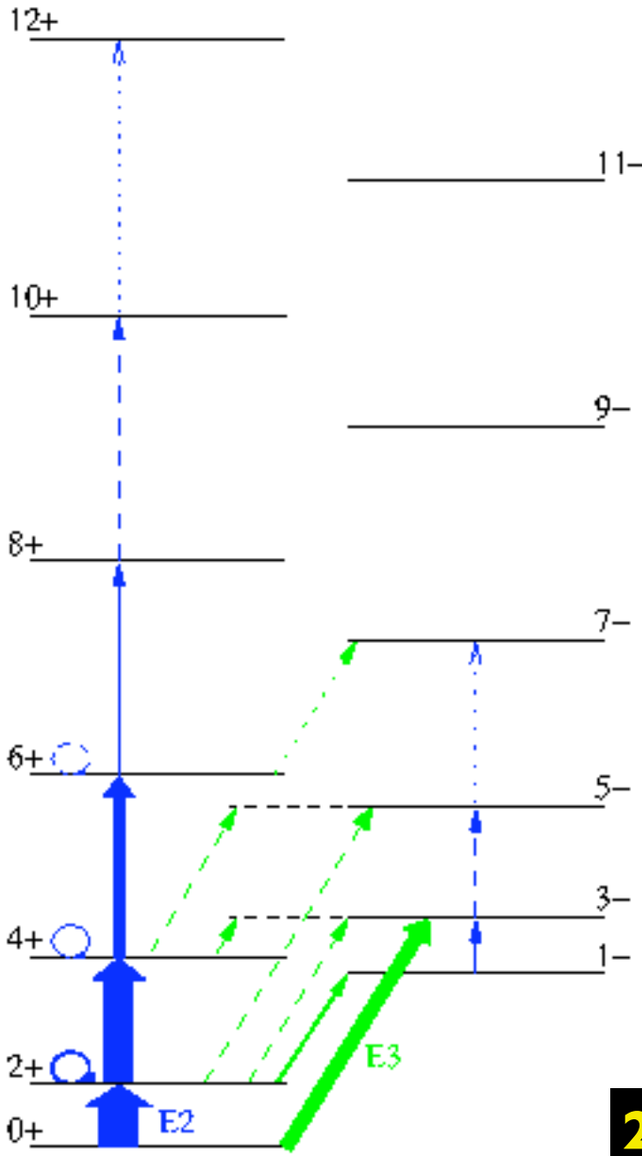
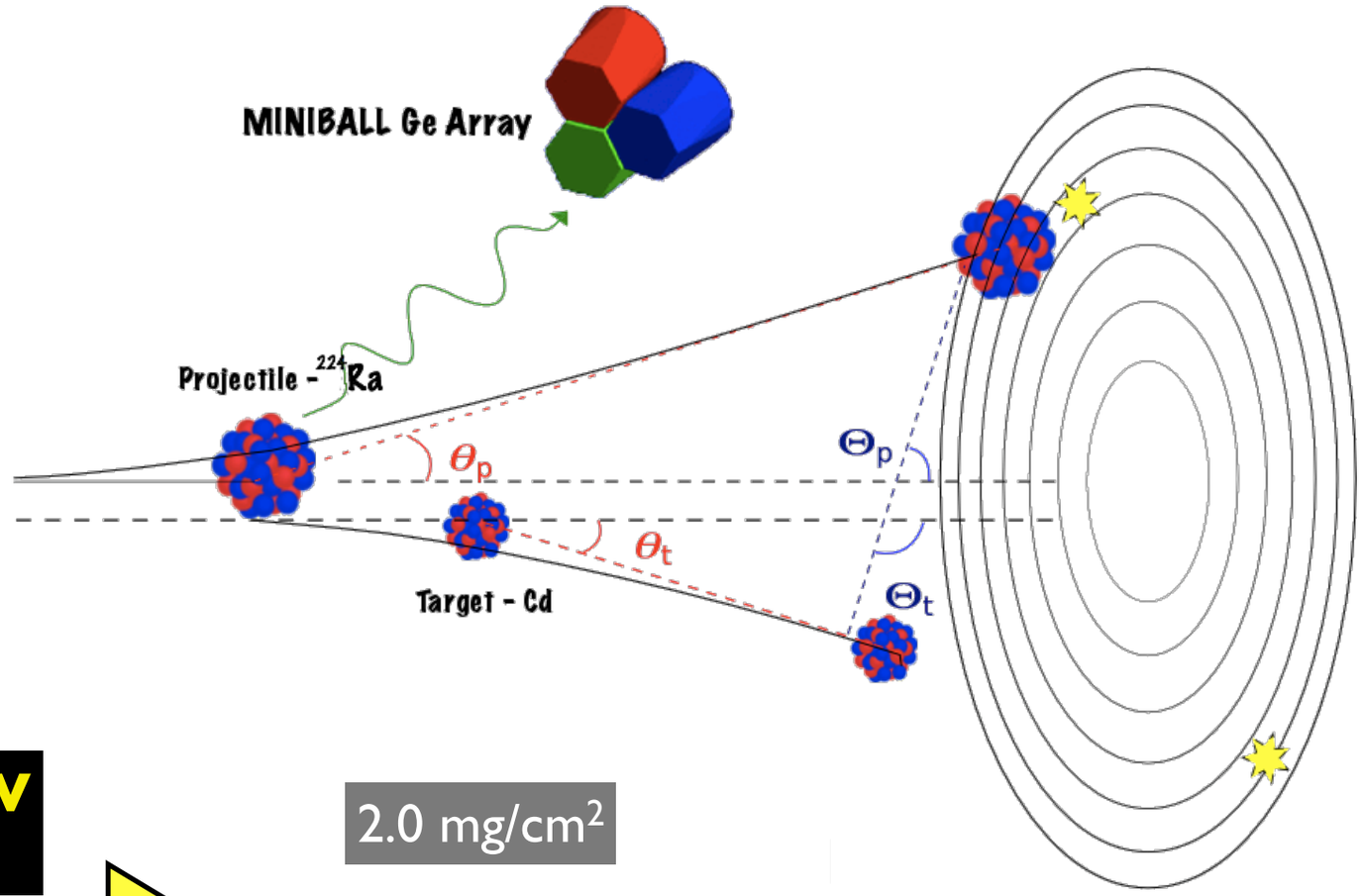




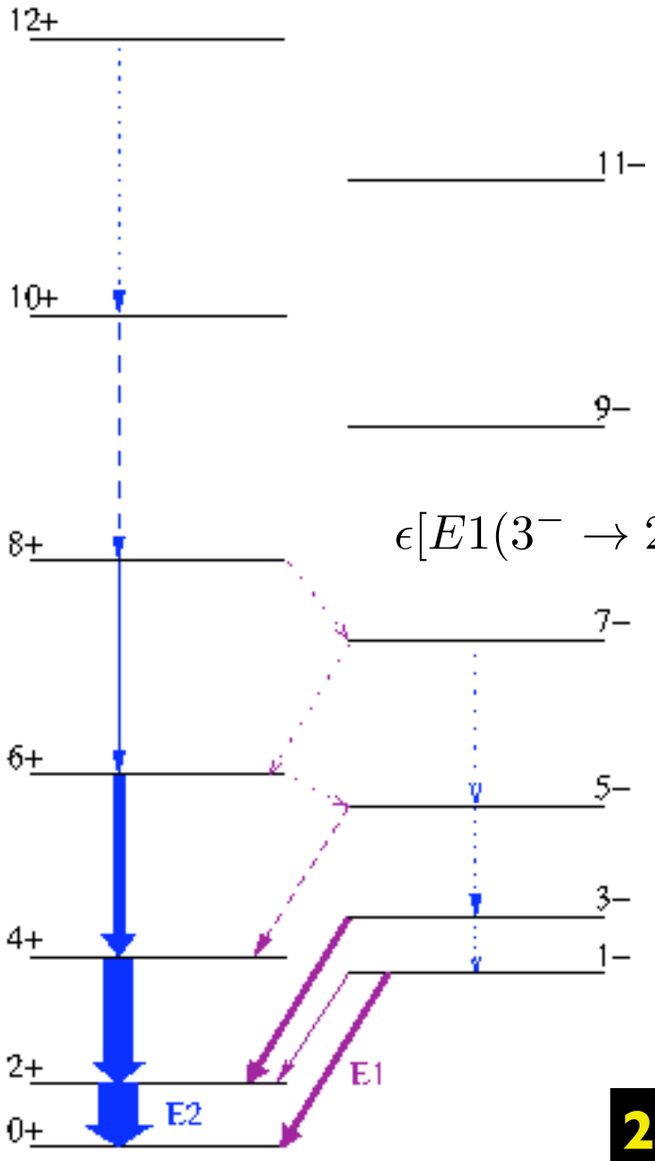
2.83 A.MeV
634 MeV

2.0 mg/cm^2

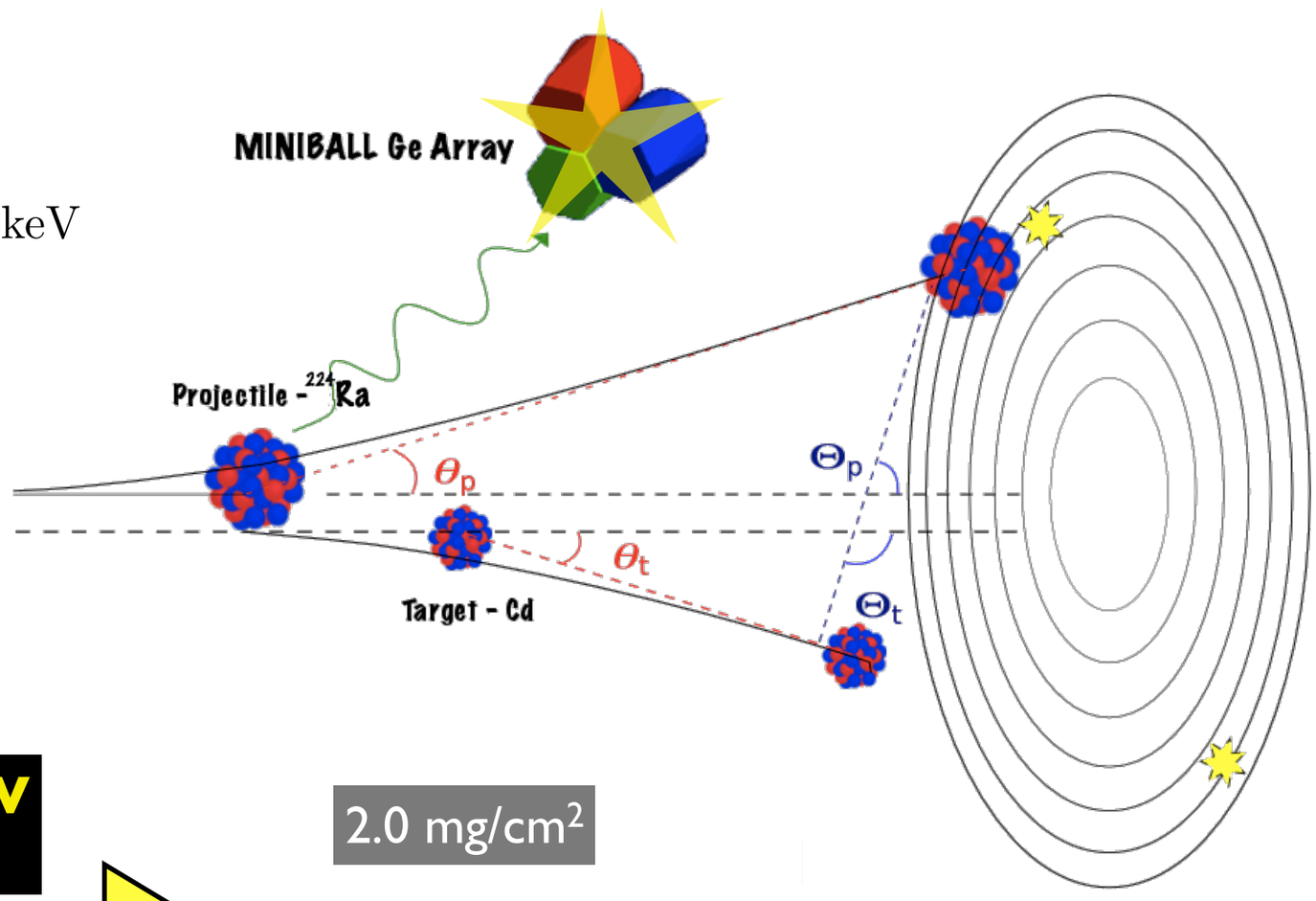
^{224}Ra → ^{112}Cd / ^{120}Sn

The experiment - ^{224}Ra

$$N[^{224}\mathrm{Ra}(3^-)] \propto Y[E1(3^- \rightarrow 2^+)]$$
$$\propto B(E3\uparrow; 0^+ \rightarrow 3^-)$$
$$+ \left\{B\left(E2\uparrow; 0^+ \rightarrow 2^+\right) \cdot B\left(E3\uparrow; 2^+ \rightarrow 3^-\right)\right\}$$
$$\propto \beta_3$$



$$\epsilon[E1(3^- \rightarrow 2^+)] = 206.0\mathrm{keV}$$



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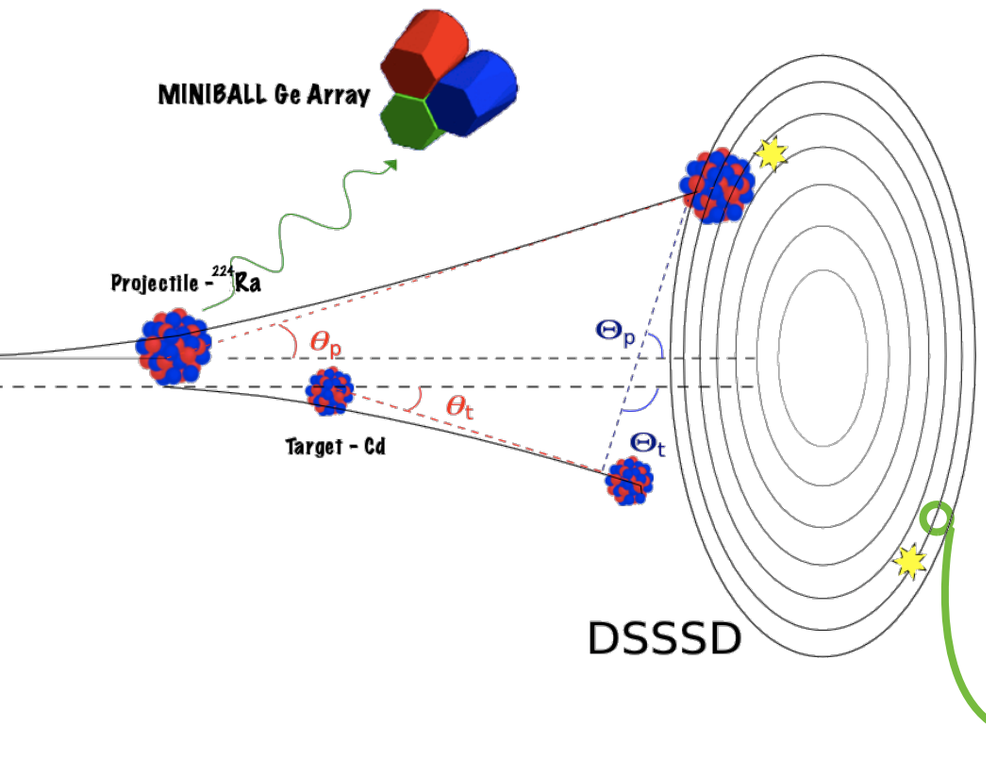
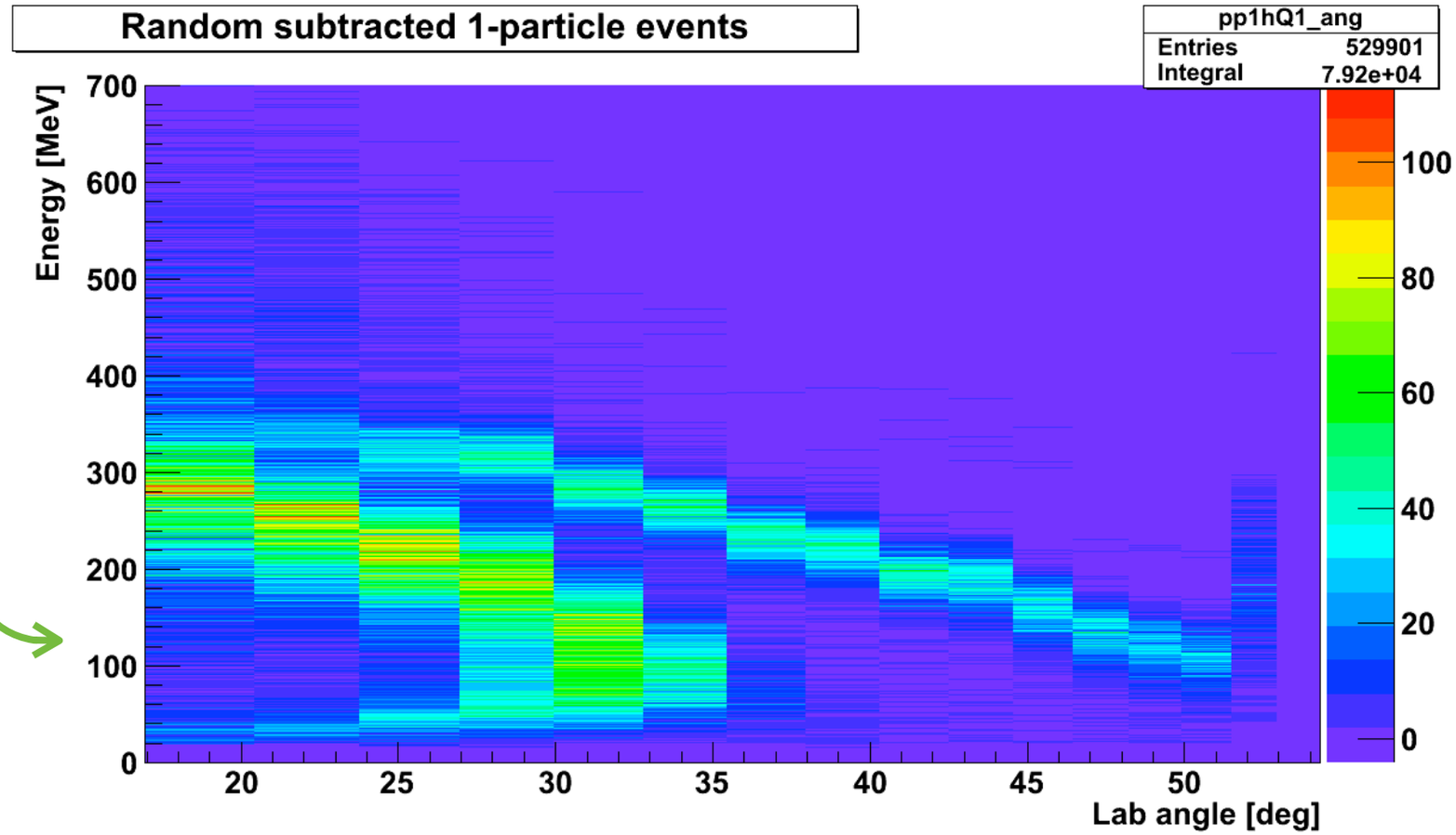
Analysis - ^{224}Ra





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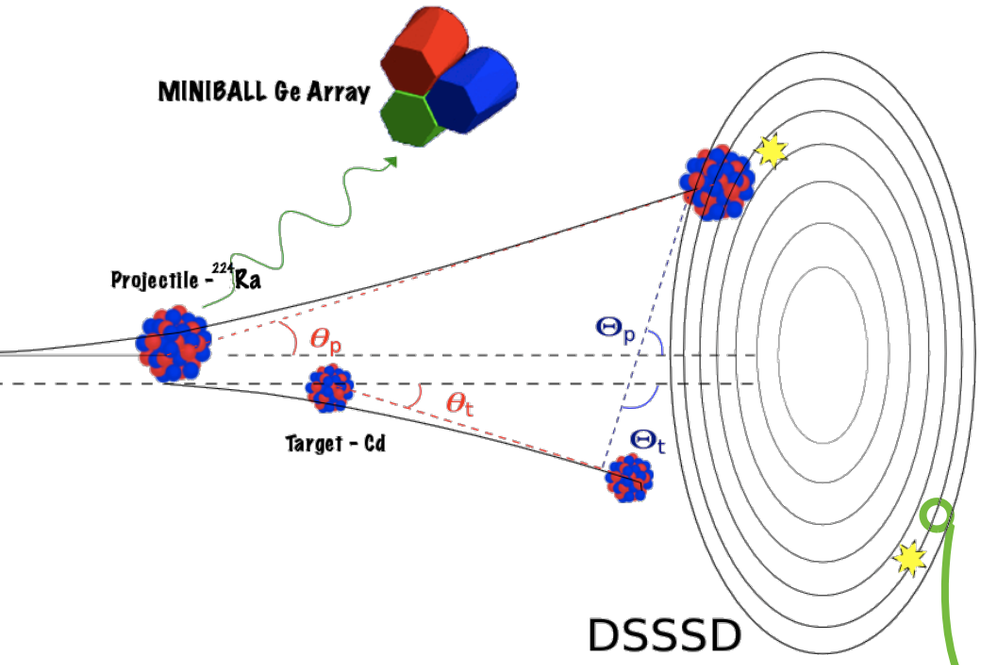

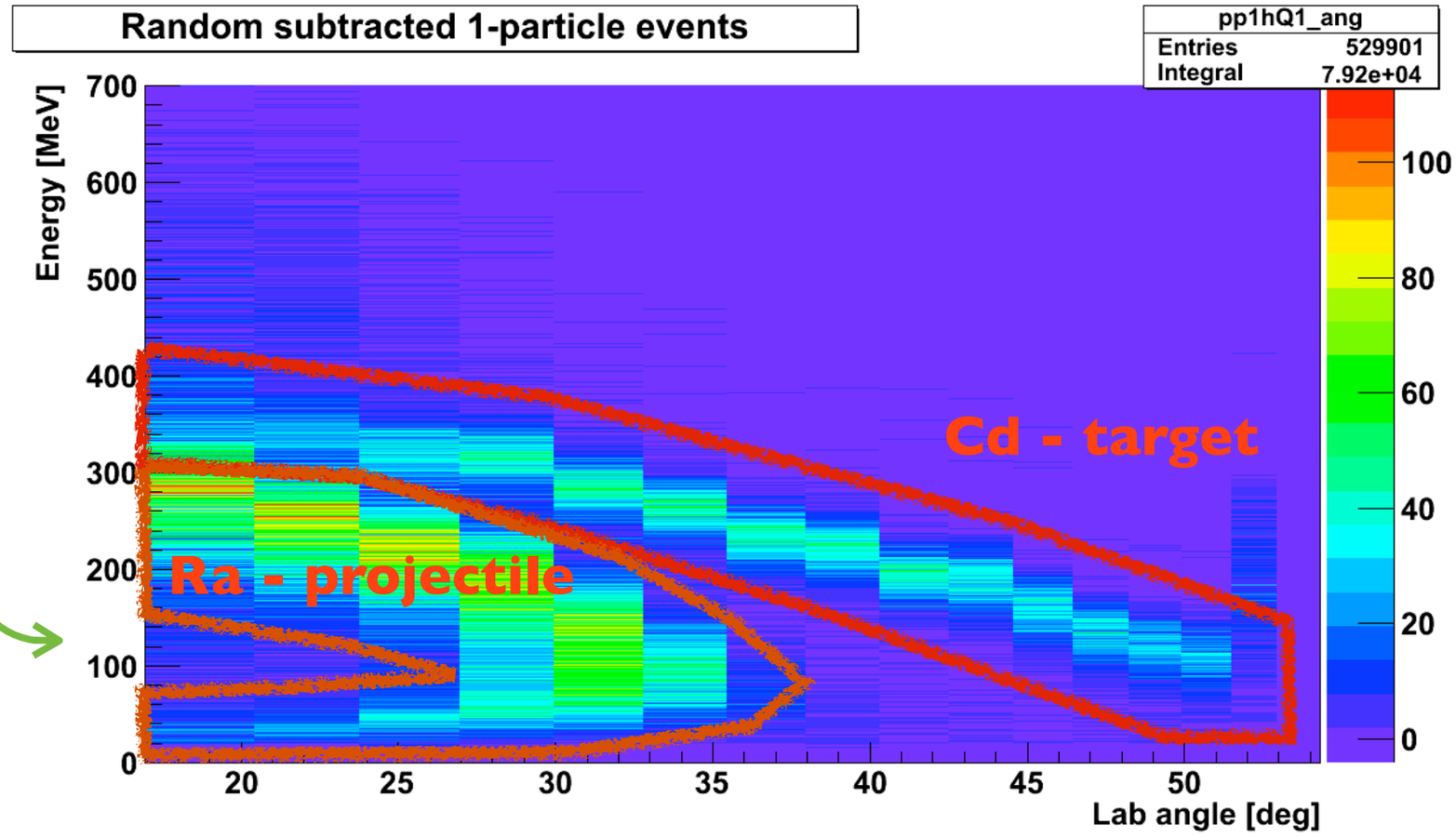

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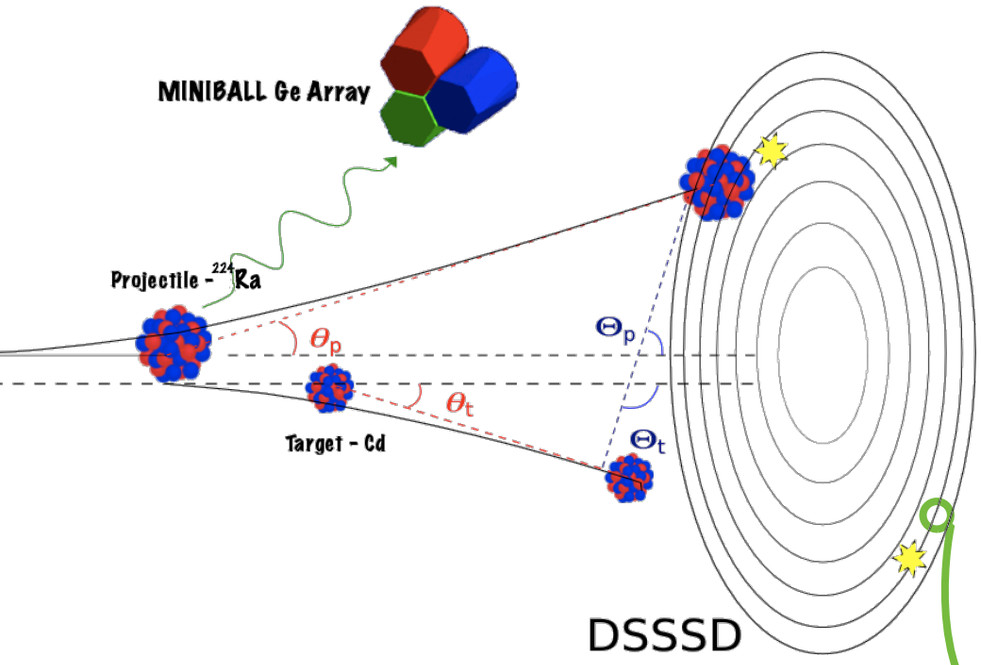

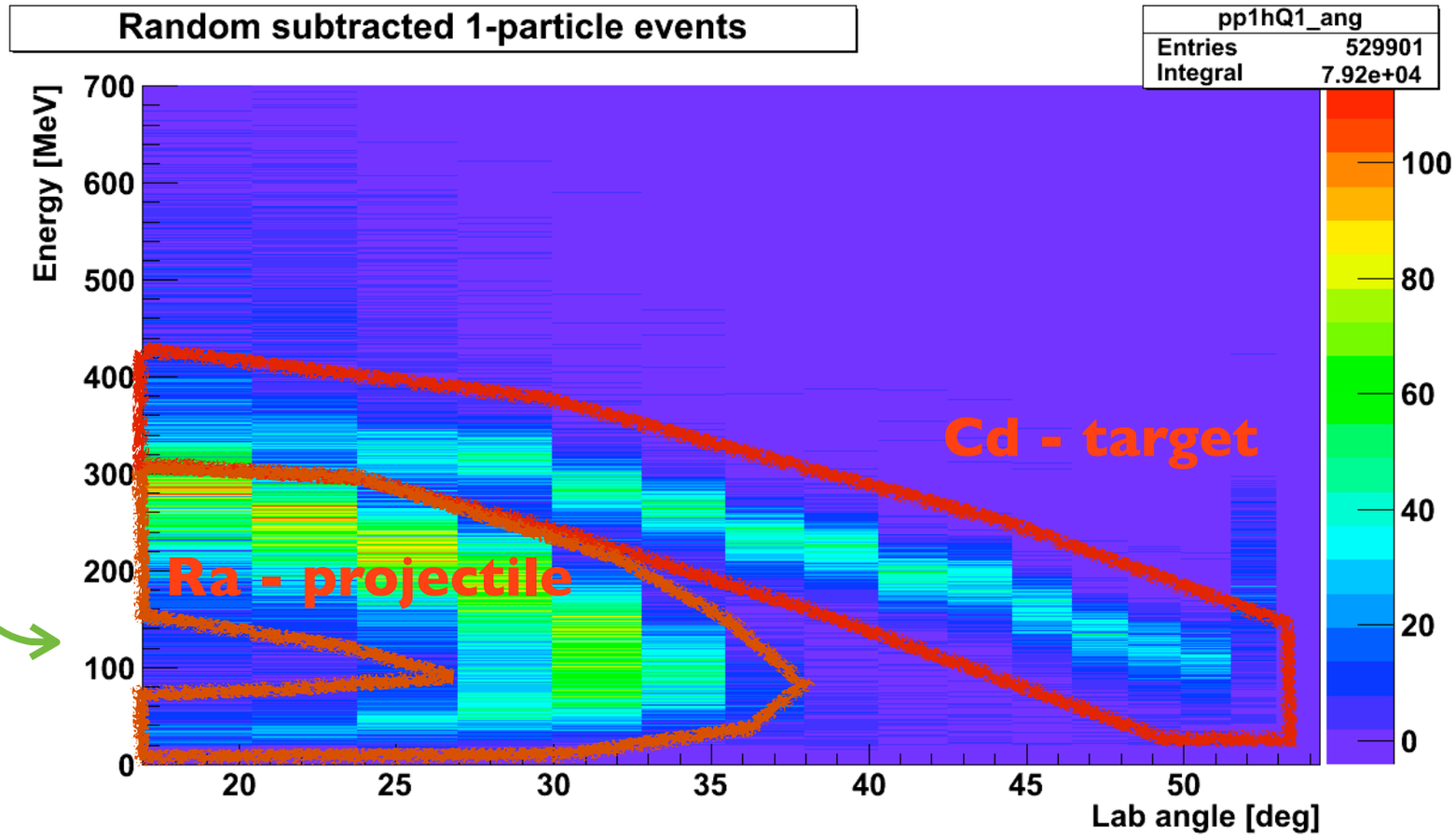

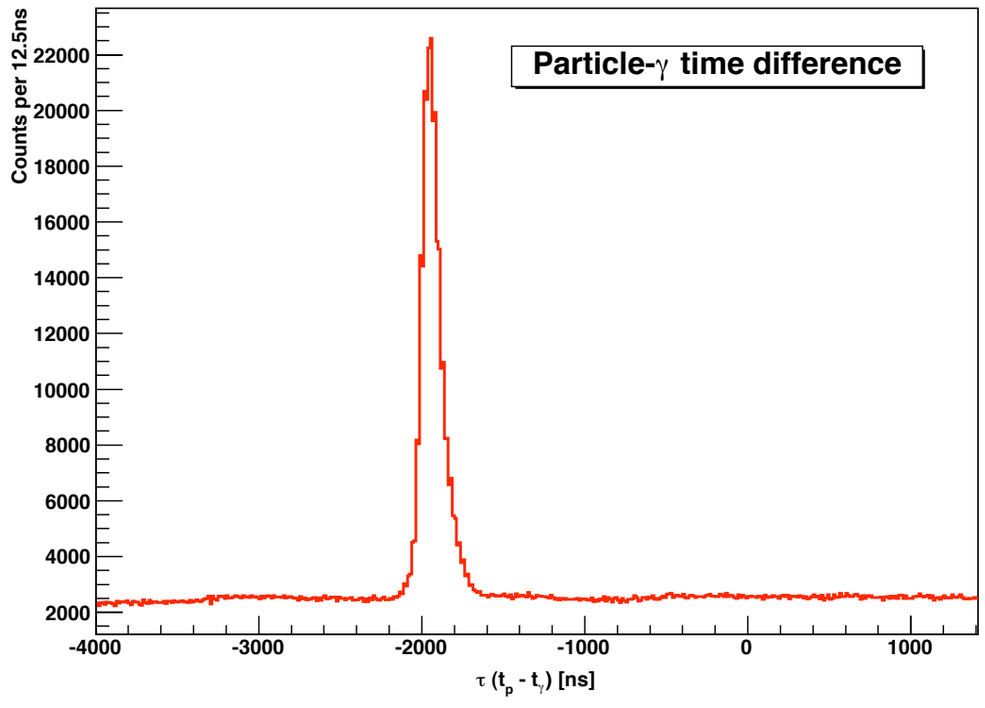

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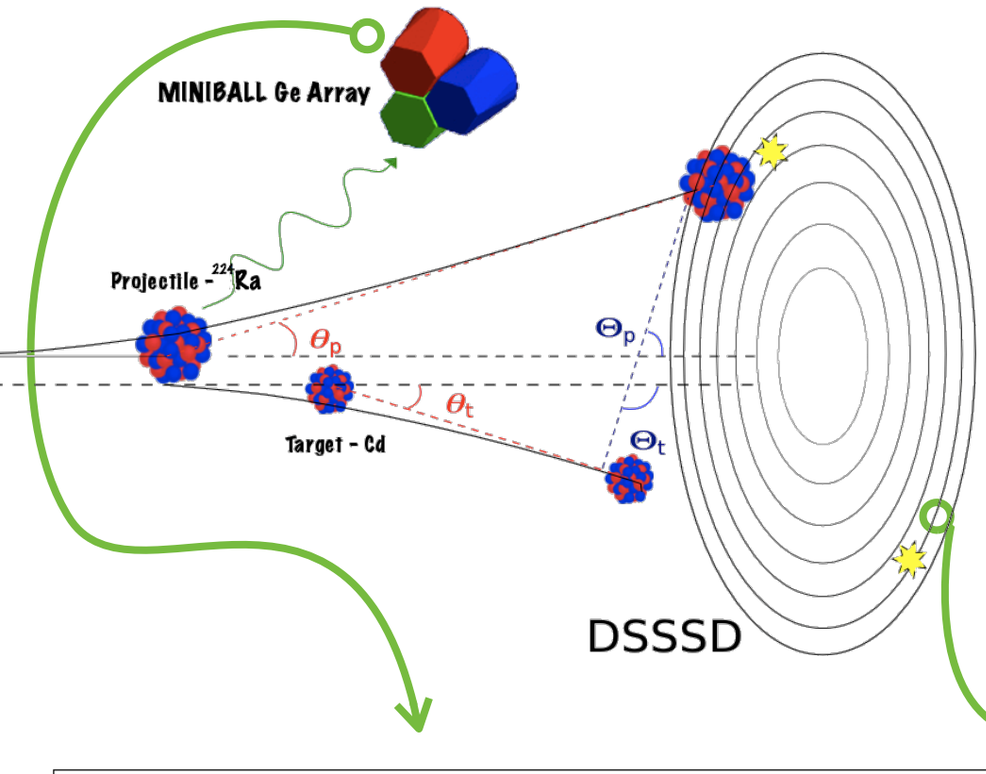

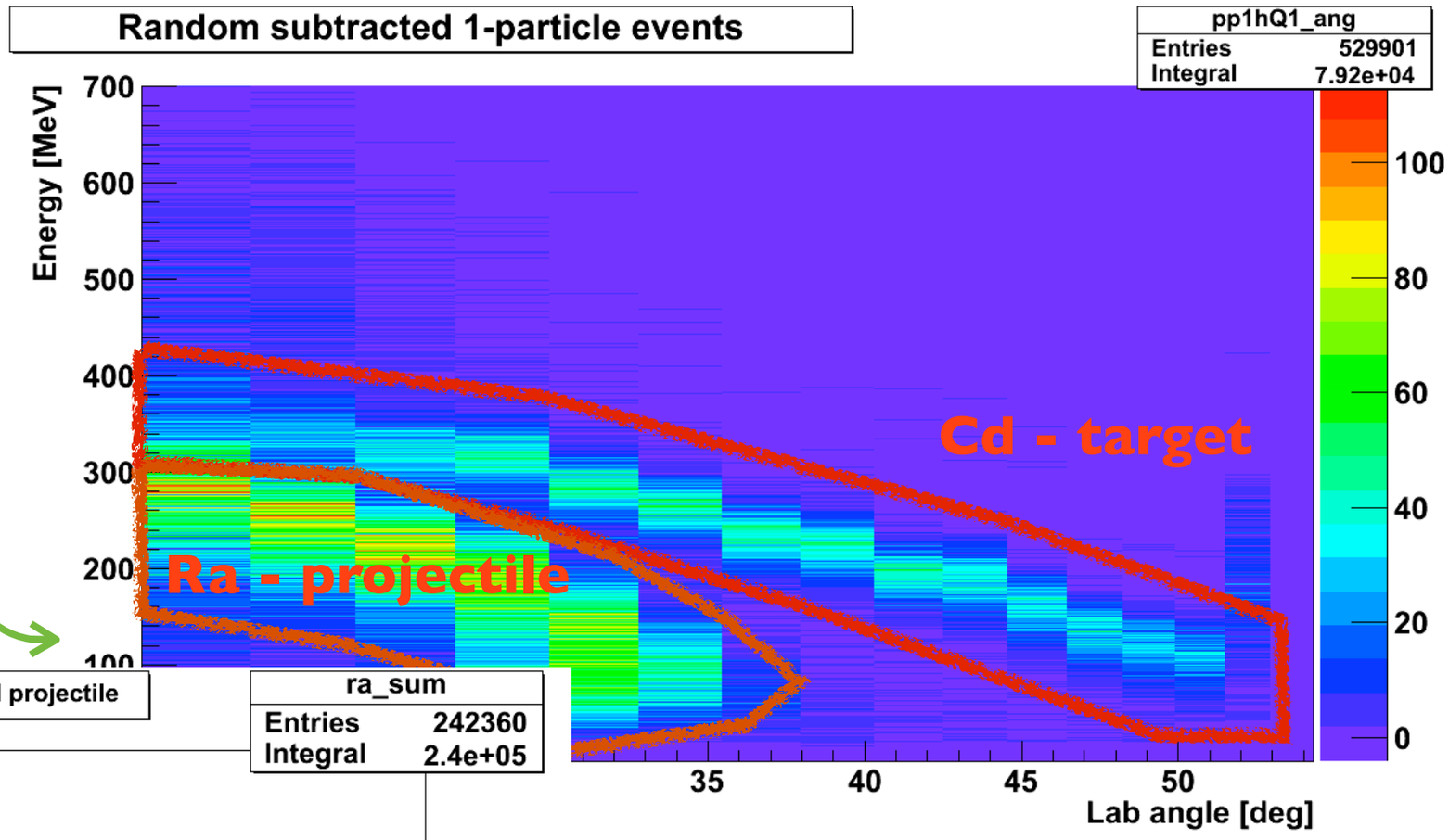

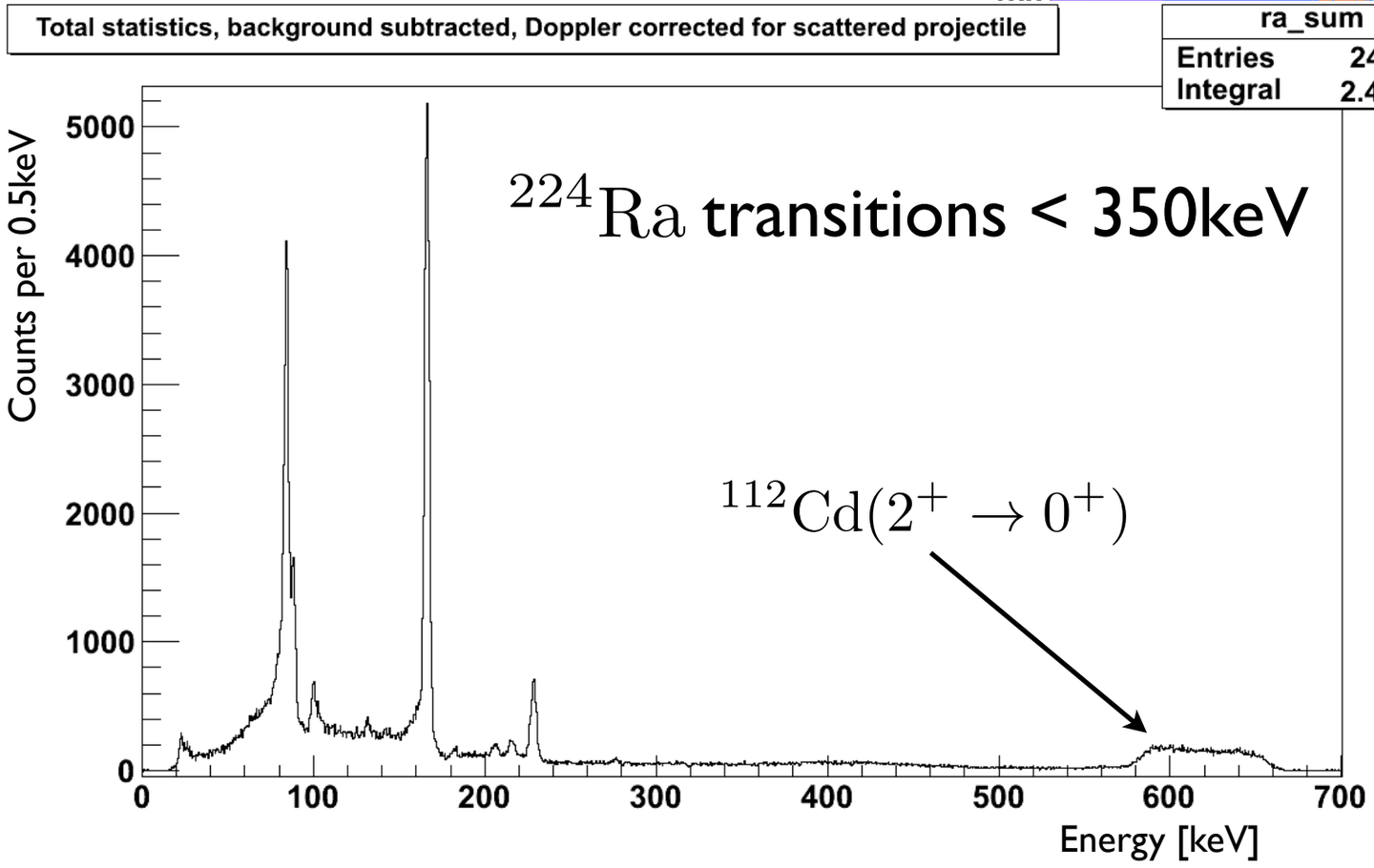

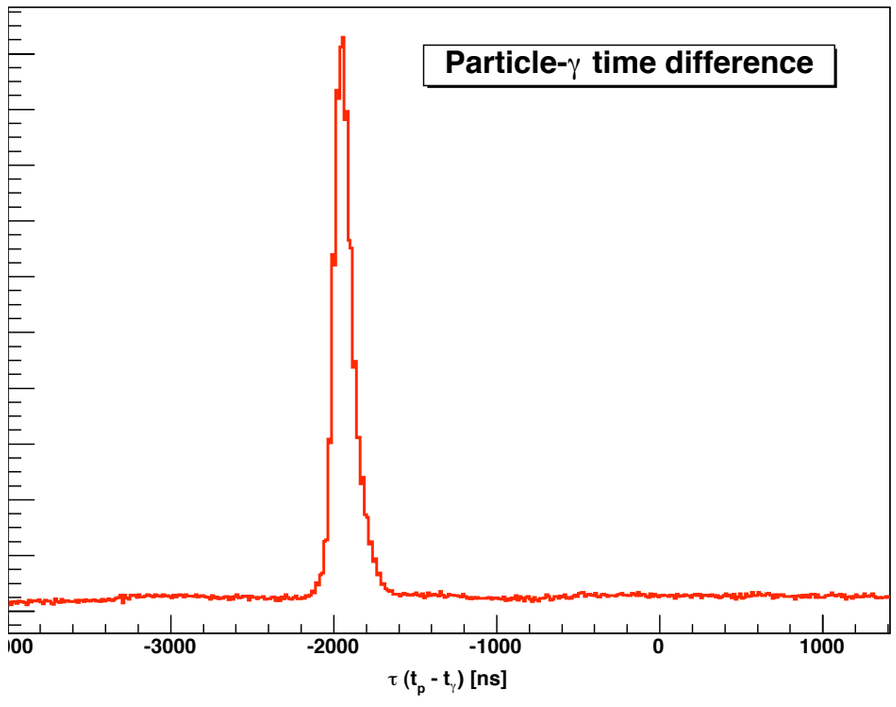

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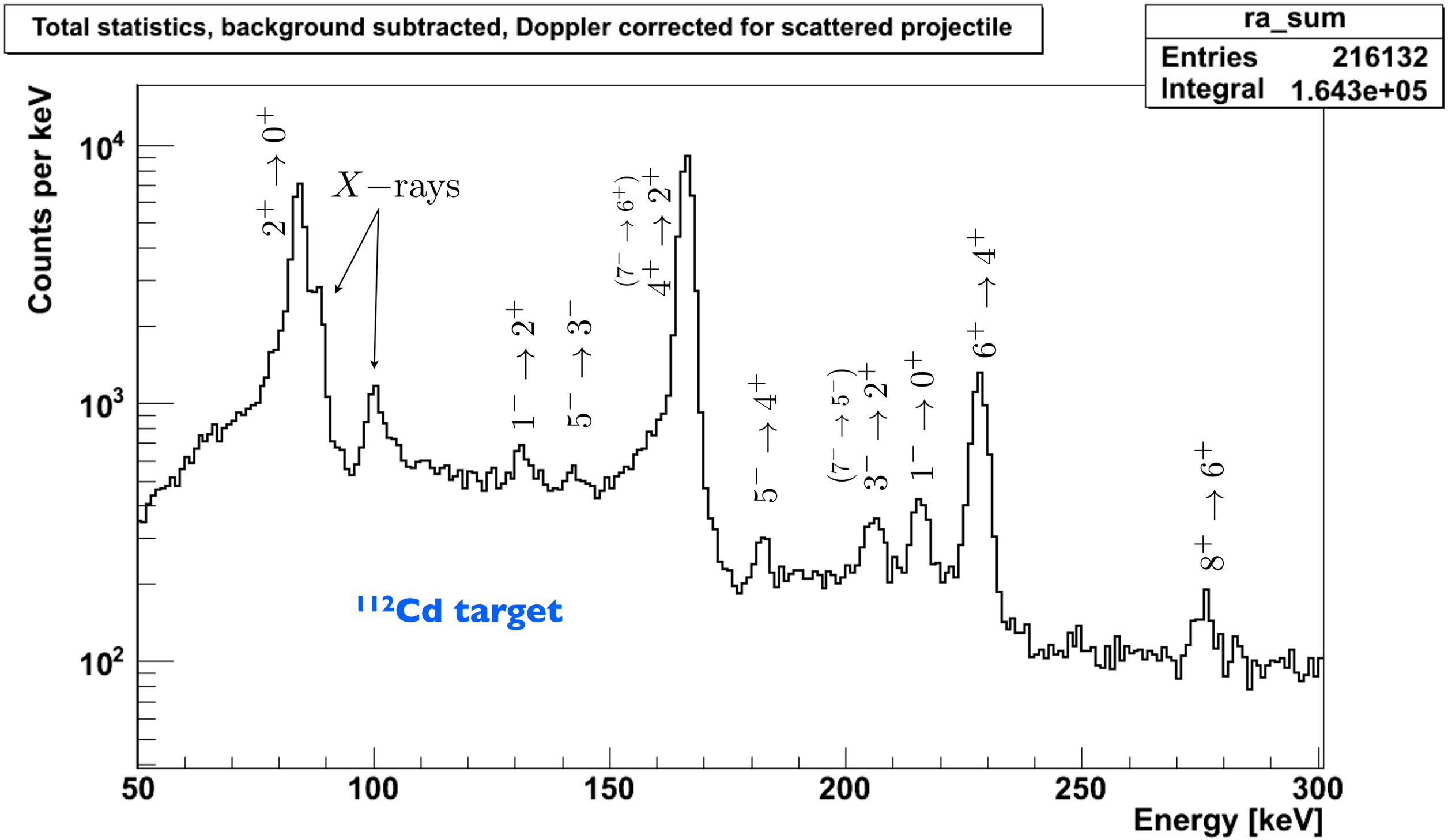

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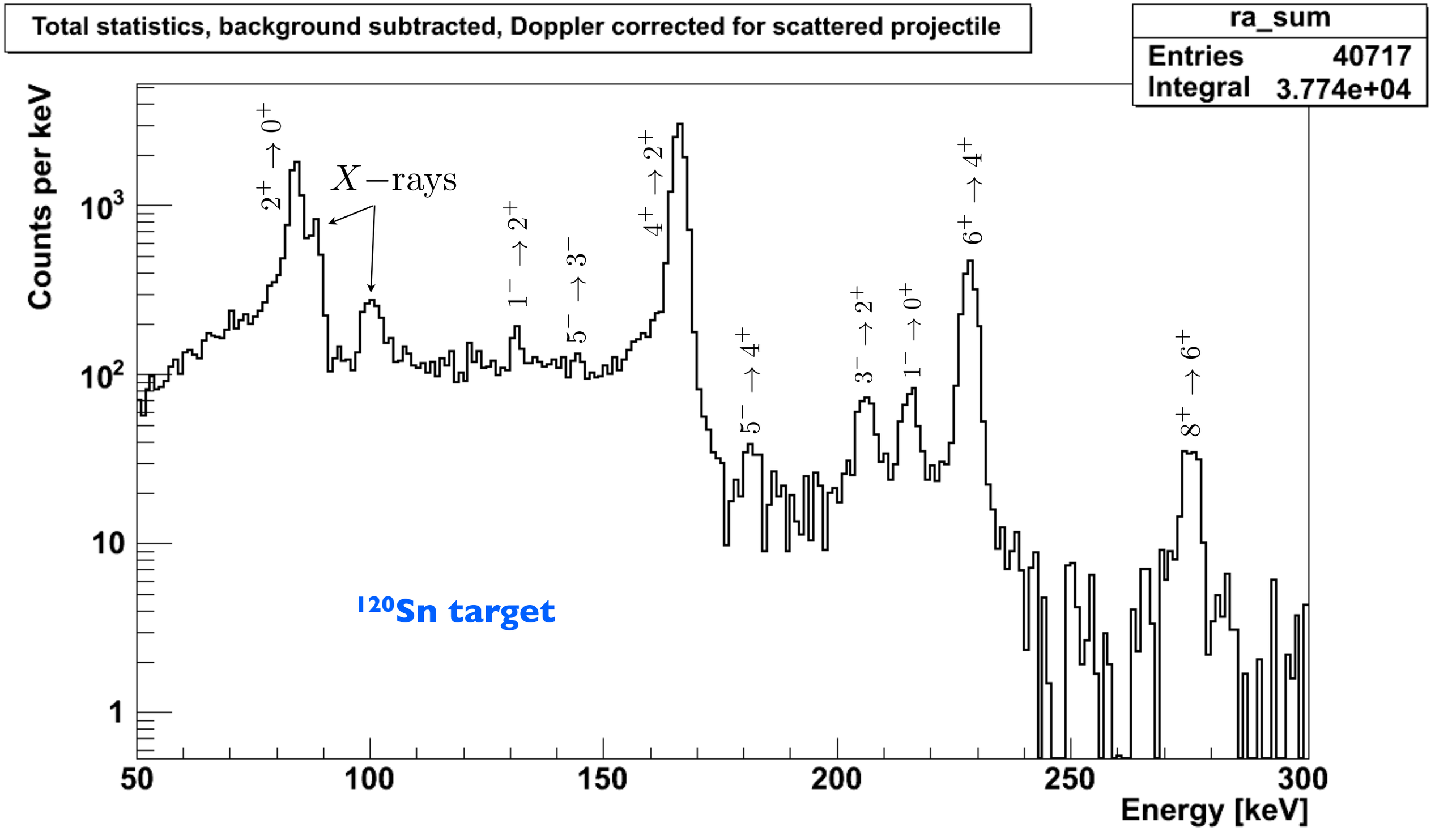

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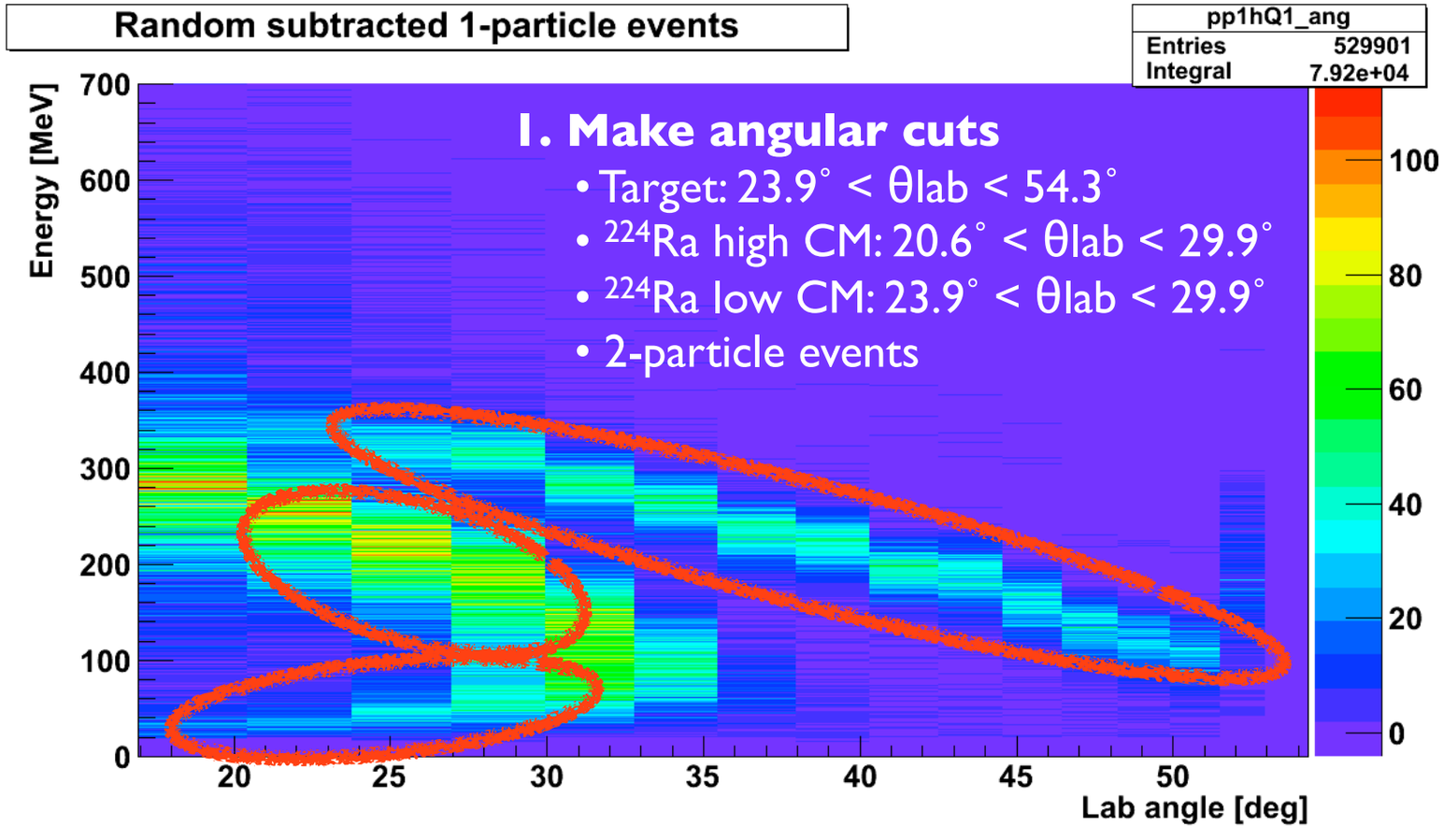

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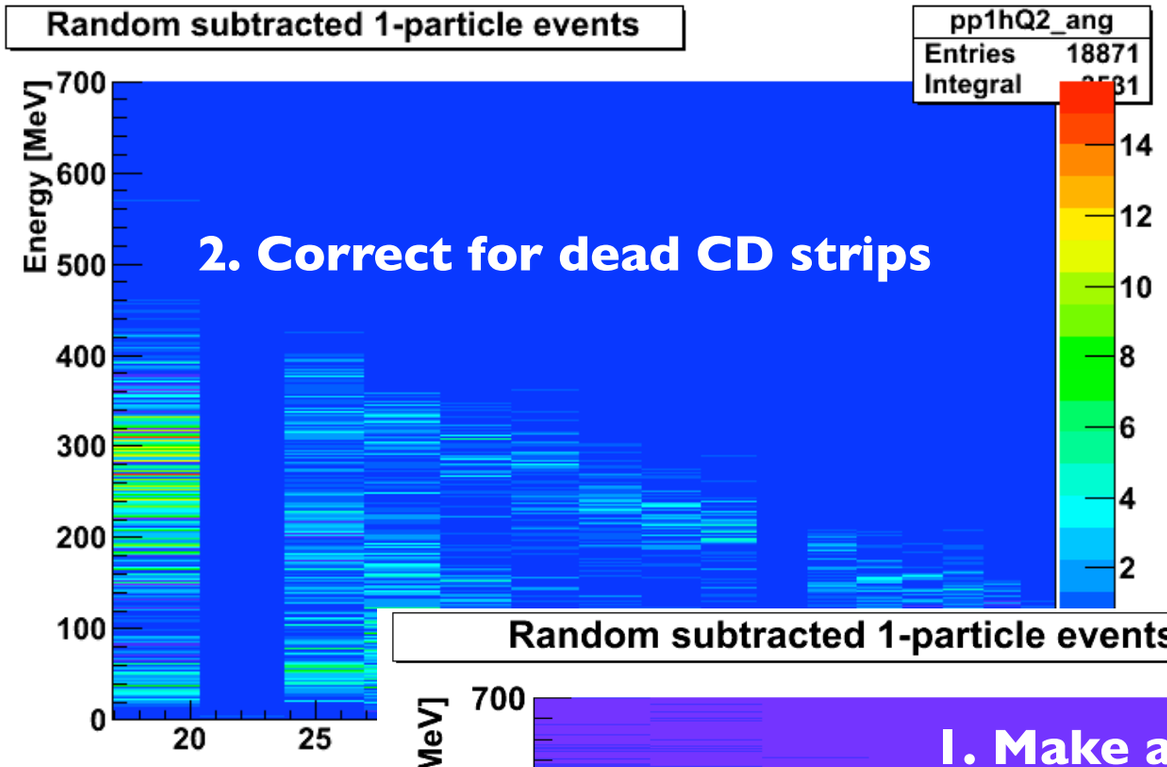

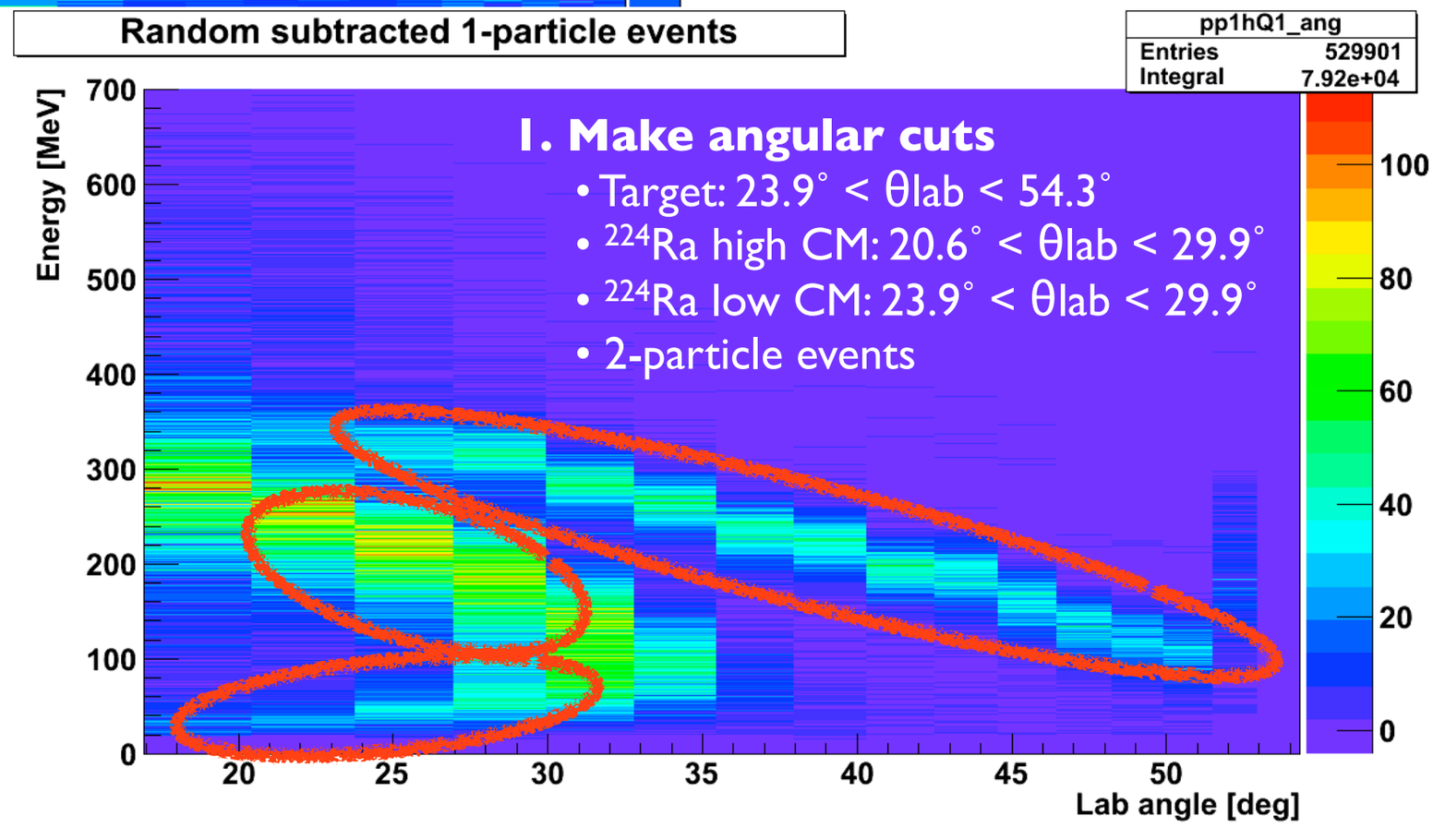

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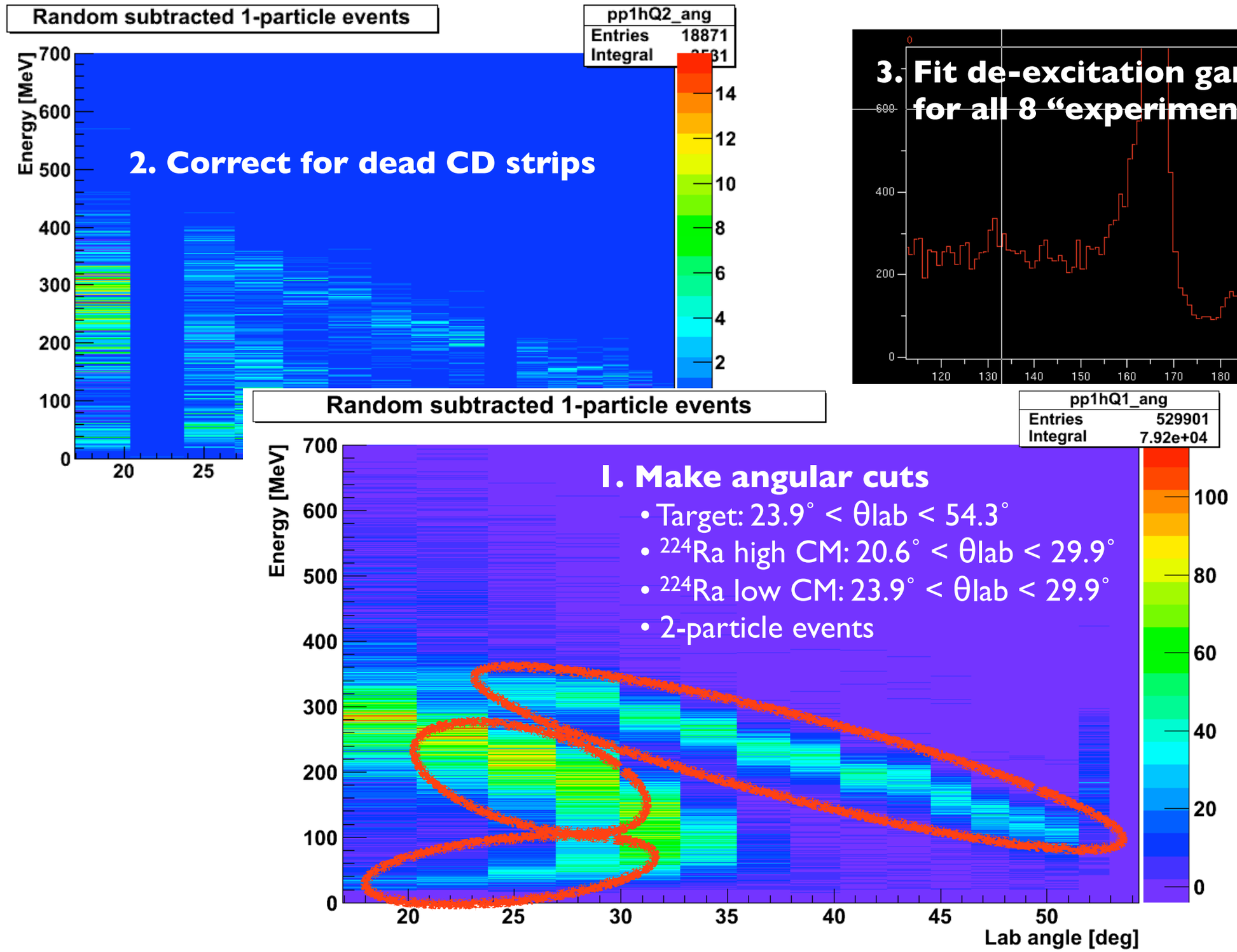
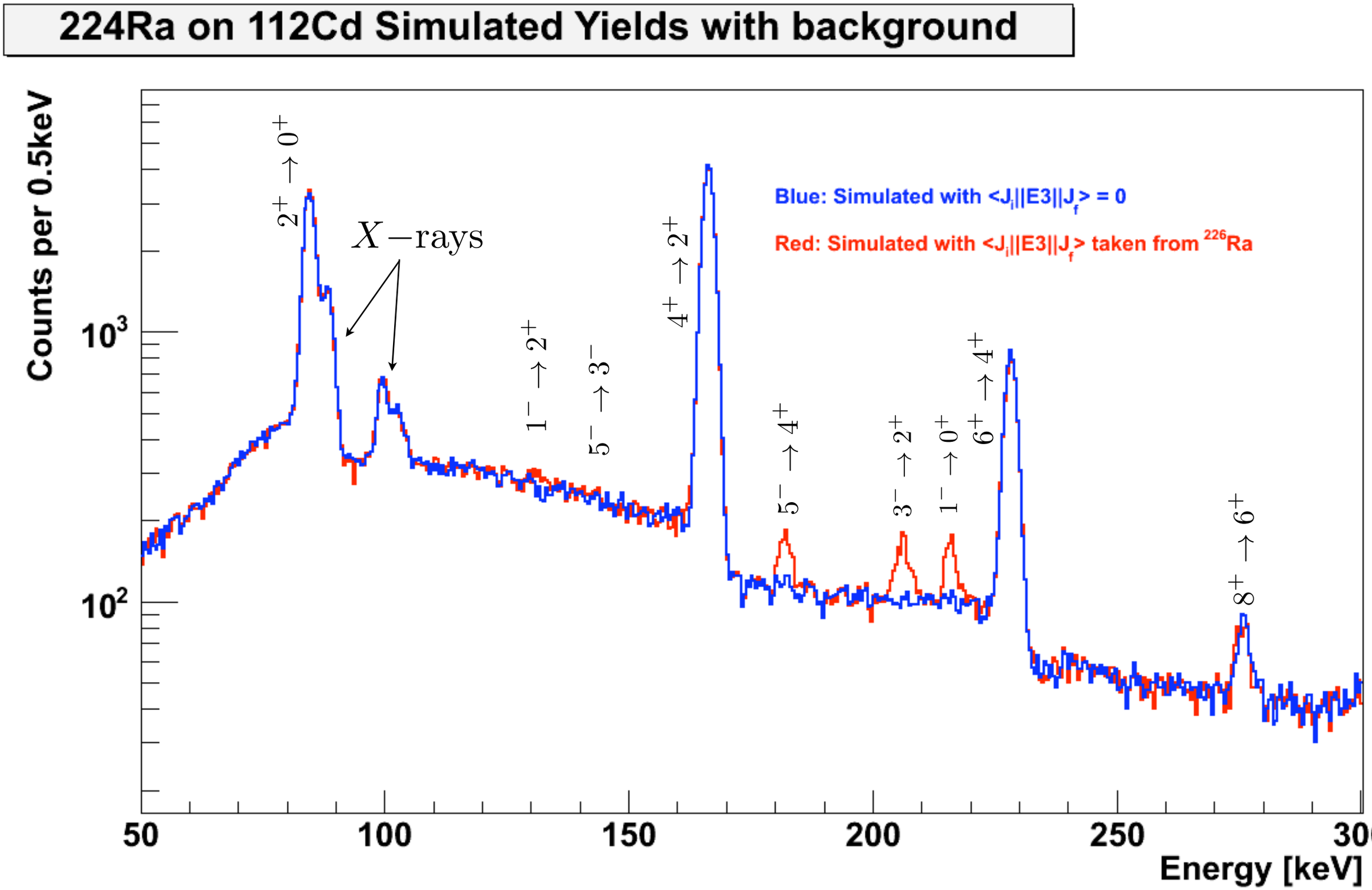


GOSIA Simulation - ^{224}Ra



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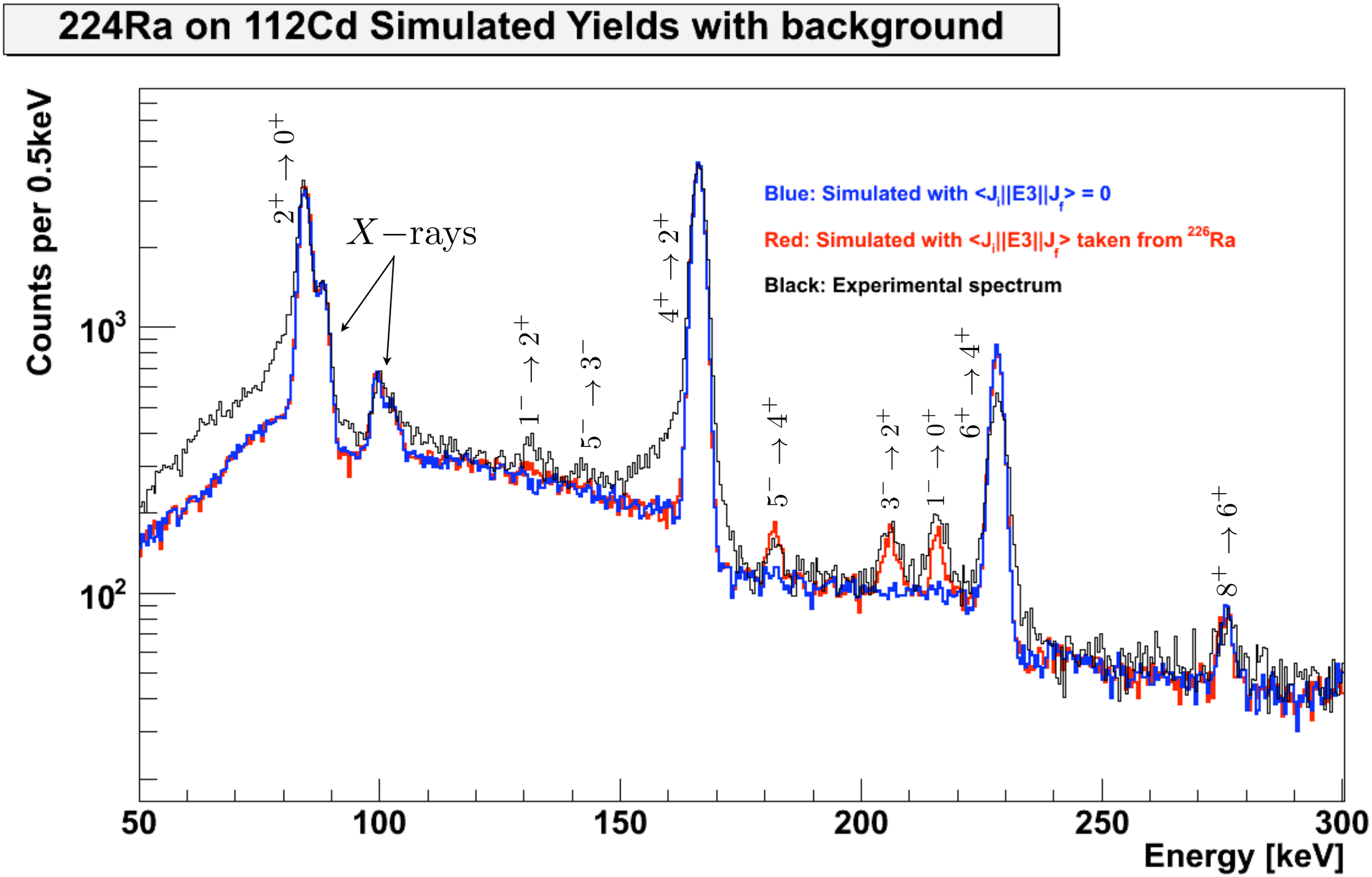
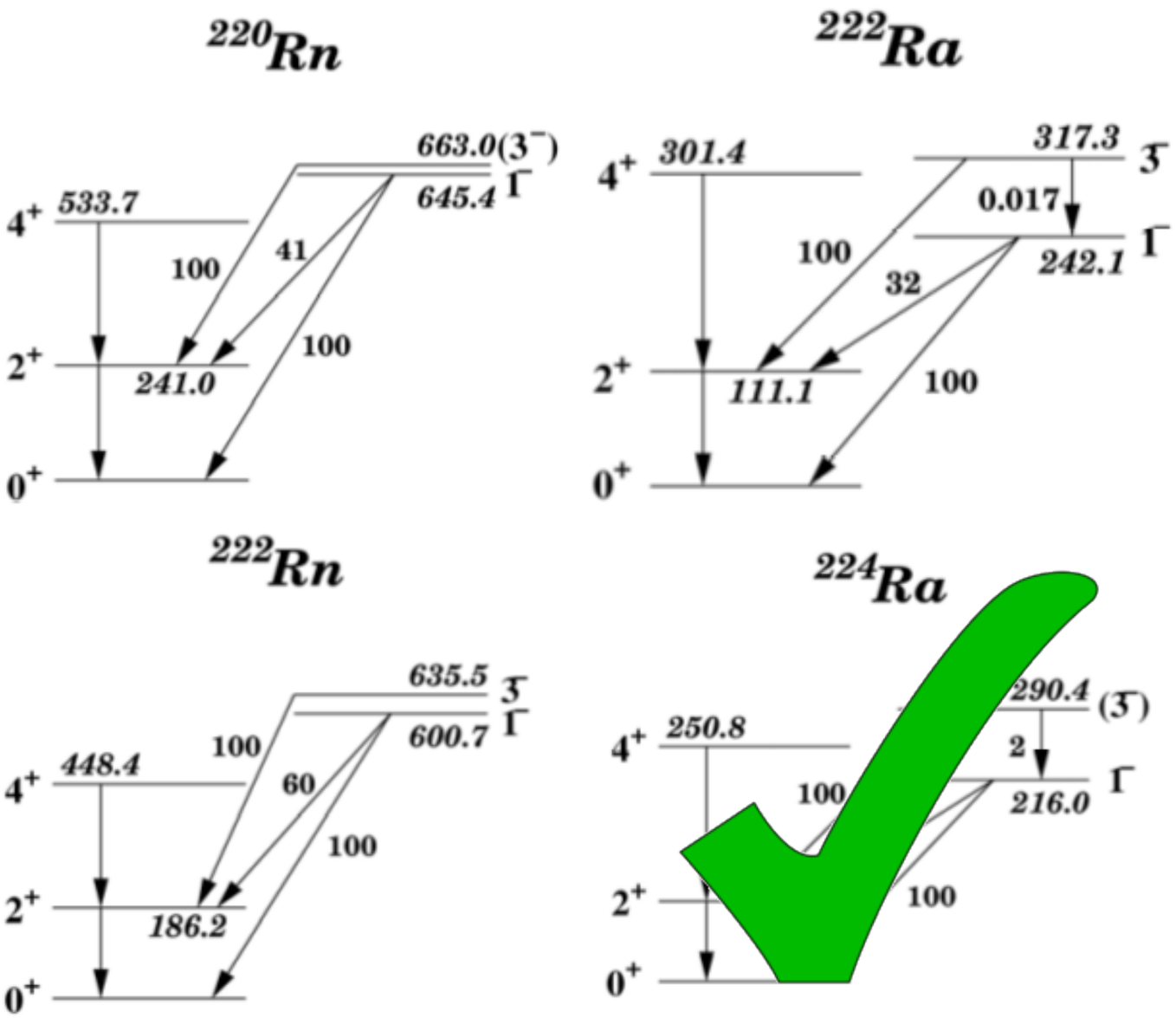


Outlook and “to do”s

Extract B(E3; $0^+ \rightarrow 3^-$) !!

Outlook and "to do"s

Proposal included ^{220,222}Rn and ^{222}Ra



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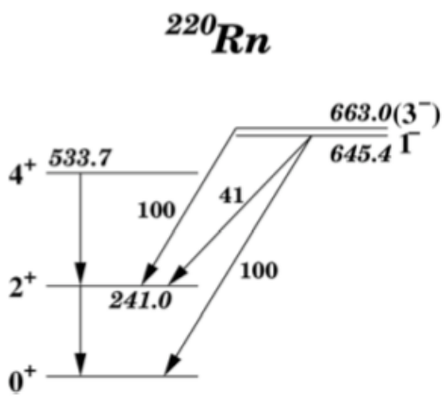
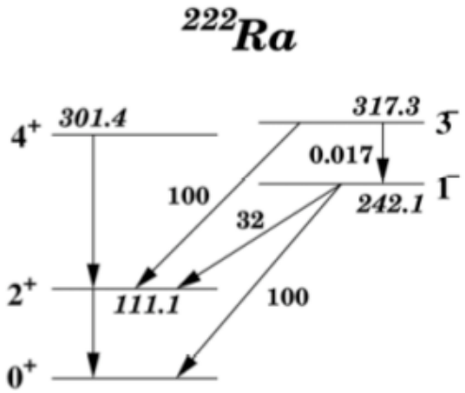
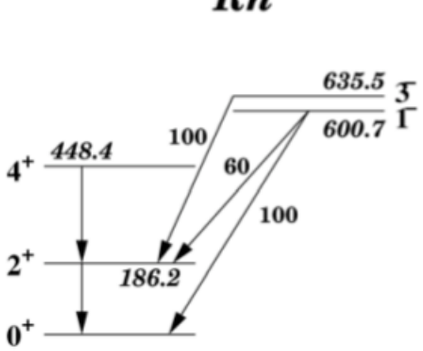
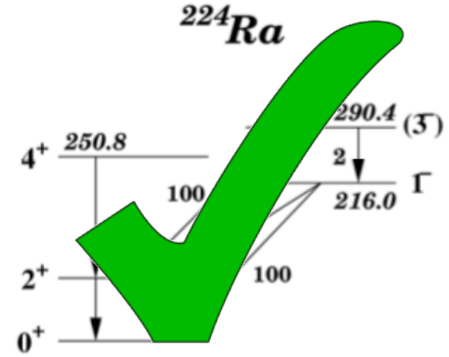


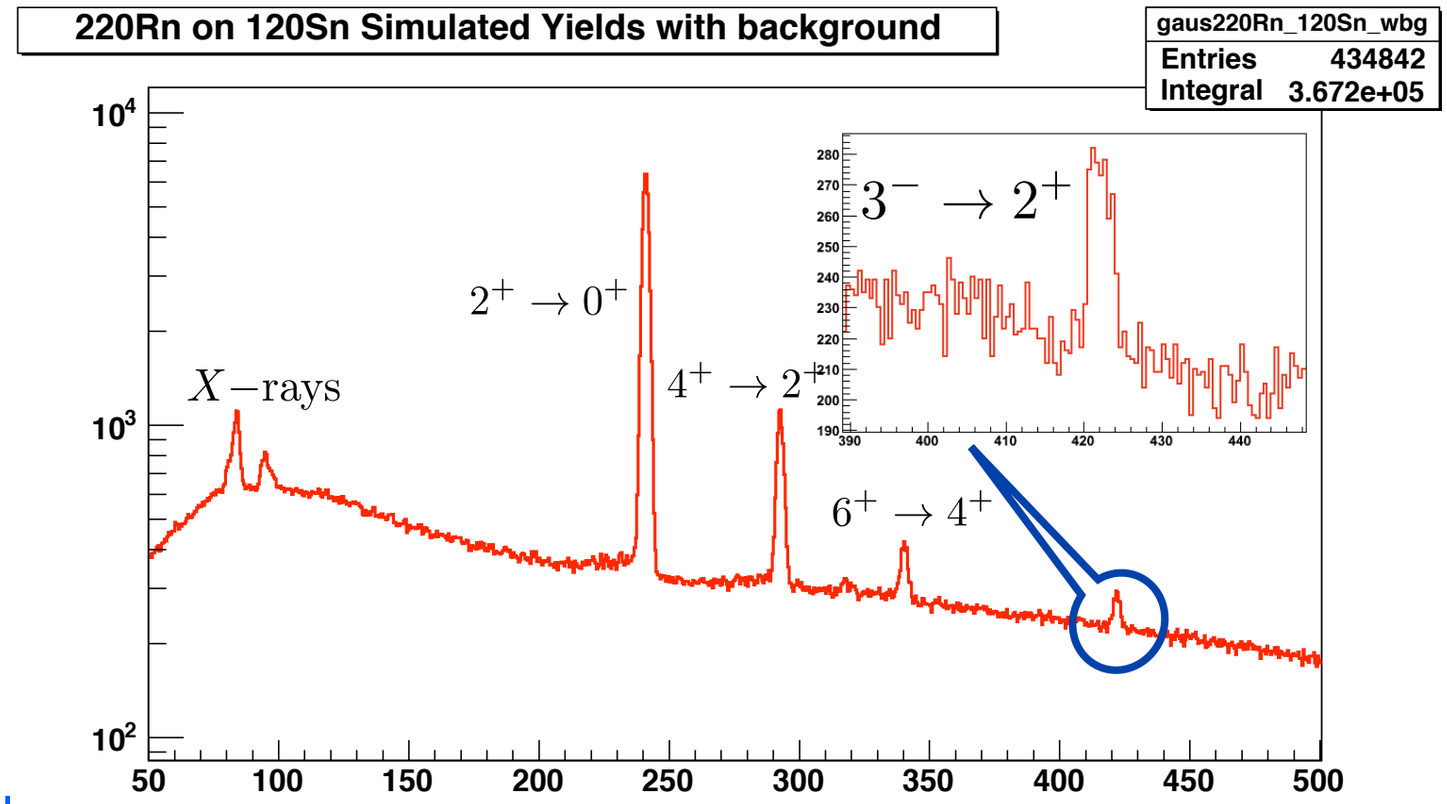






Extract B(E3; $0^+ \rightarrow 3^-$) !!

^{220}Rn to be studied in July 2011

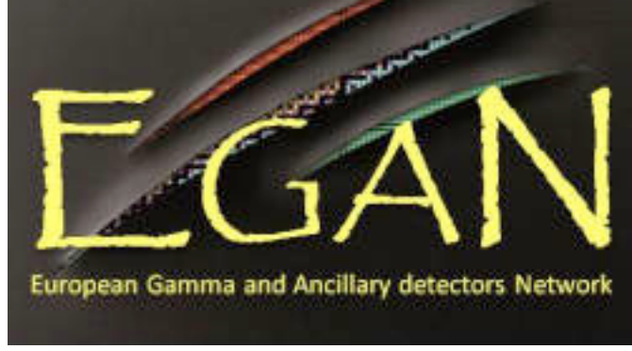


Note on Rn nuclei:

3^- higher in energy, σ is smaller
More time (events) needed

To be continued...

Collaborators



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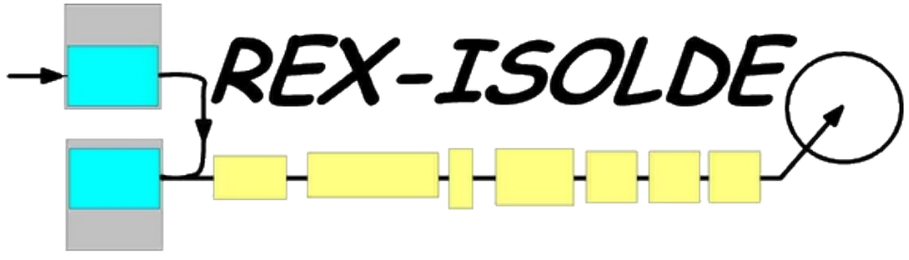
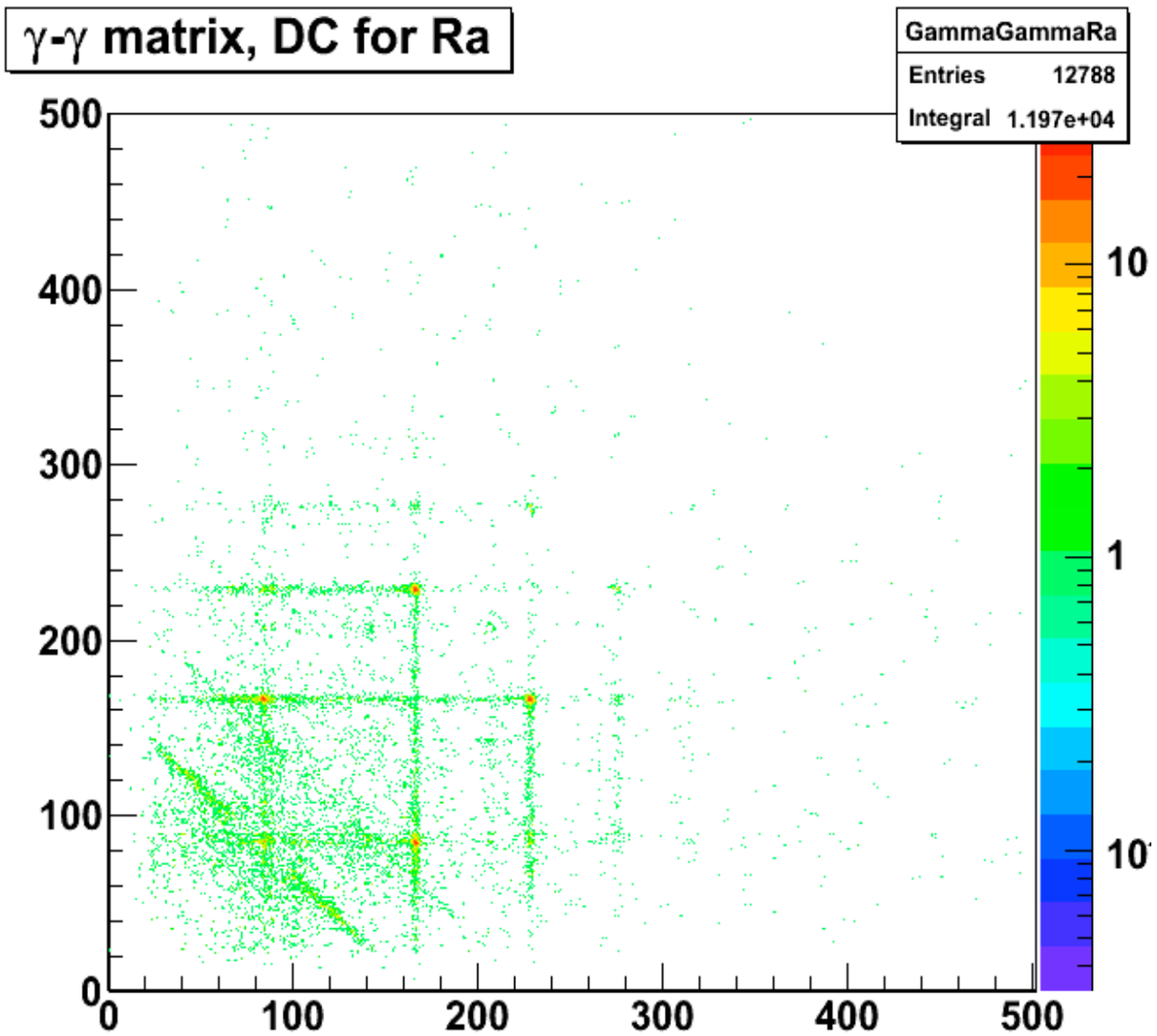
T. Grahn — **University of Jyväskylä, Finland**
M. Zielinska — **HIL University of Warsaw, Poland**

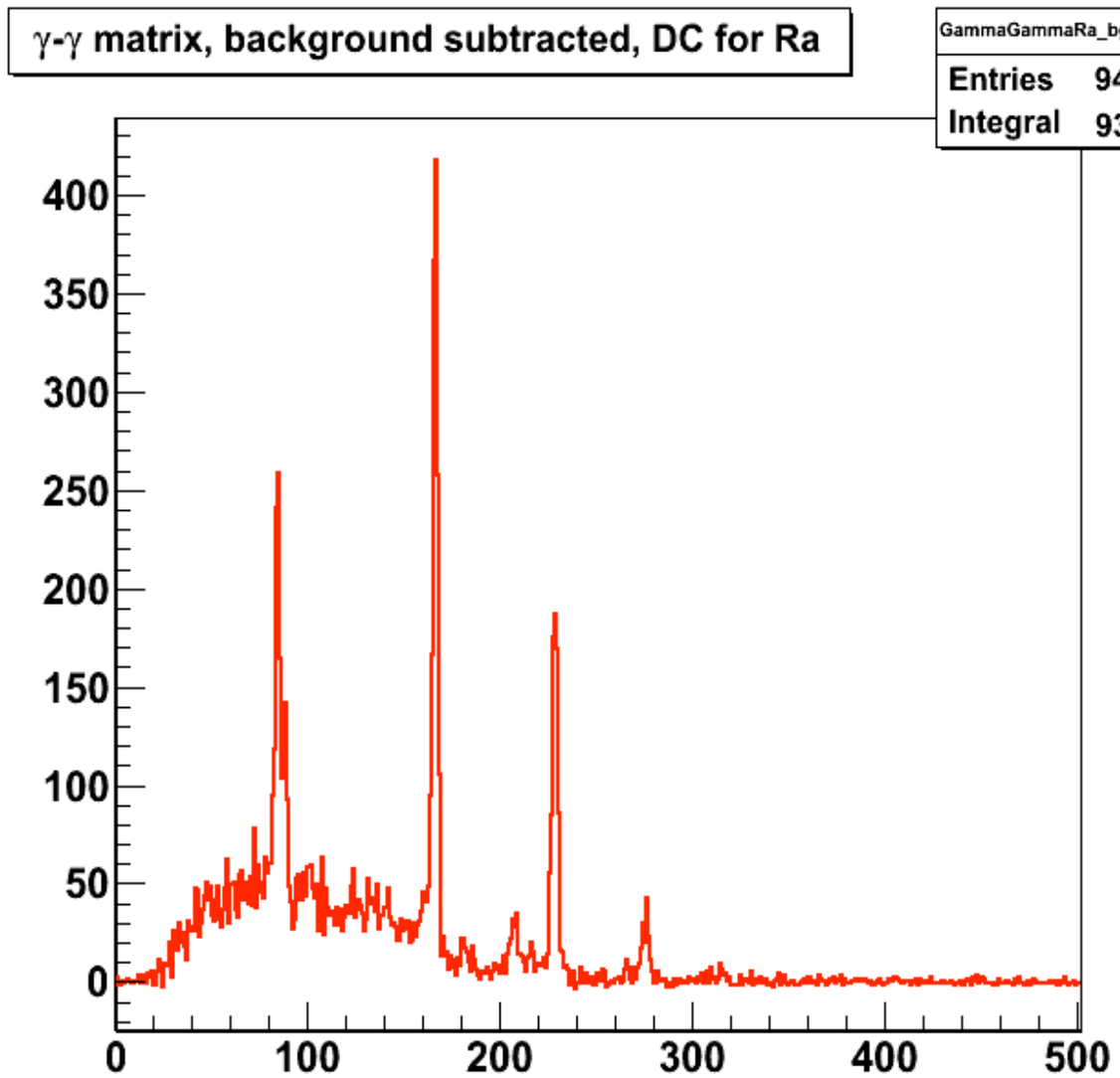
and the ISOLDE and MINIBALL collaborations

Thank you!



Gamma-Gamma Matrix - ^{224}Ra





Gosia Analysis

75 Matrix elements -- 74 experimental data points

"Experiment"	**Number and type of data**
Multi-nucleon transfer[1,2] ^{226}Ra(^{58}Ni,^{60}Ni)^{224}Ra ^{232}Th(^{136}Xe,^{128}Te)^{224}Ra Alpha, alpha-prime[3] ^{226}Ra(α,α'2n)^{224}Ra Alpha-decay[4] ^{228}Th → α	Branching ratios (1^-, 3^-, 5^-, 7^-) **-- 4** (+3 limits)
Delayed-coincidence[5,6]	Lifetimes (2^+, 4^+) **-- 2**
Cd(/Sn) only detection $23.9^\circ < \theta_{lab} < 54.3^\circ$	γ-ray yield **-- 9 + 8**
Ra, high CoM branch $20.6^\circ < \theta_{lab} < 29.9^\circ$	γ-ray yield **-- 9 + 7**
Ra, low CoM branch $23.9^\circ < \theta_{lab} < 29.9^\circ$	γ-ray yield **-- 9 + 9**
2-particle events $17.1^\circ < \theta_{lab} < 54.3^\circ$	γ-ray yield **-- 9 + 8**
Total	**74**

Huge parameter space - Reduce number of matrix elements by using rigid rotor

$$< I||E\lambda||I' >= (2I+1)^{\frac{1}{2}}(I0\lambda0|I'0)Q_\lambda a_\lambda$$

[1] Poynter *et al.,* Phys. Lett. B **232**, 447 (1989)
[2] J.F.C. Cocks *et al.,* Nucl. Phys. A **645**, 61 (1999)
[3] Marten-Tölle *et al.,* Z. Phys. A **336**, 27 (1990)
[4] W. Kurcewicz, *et al.,* Nucl. Phys. A **289** (1977)
[5] W.R. Neal and H.W. Kraner, Phys. Rev. **137**, **B**1164 (1965)
[6] H. Ton *et al.,* Nucl. Phys. A **155**, 235 (1970)

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"Experiment"	**Number and type of data**
Multi-nucleon transfer[1,2] ^{226}Ra(^{58}Ni,^{60}Ni)^{224}Ra ^{232}Th(^{136}Xe,^{128}Te)^{224}Ra Alpha, alpha-prime[3] ^{226}Ra(α,α'2n)^{224}Ra Alpha-decay[4] ^{228}Th → α	Branching ratios (1^-, 3^-, 5^-, 7^-) **-- 4** (+3 limits)
Delayed-coincidence[5,6]	Lifetimes (2^+, 4^+) **-- 2**
Cd(/Sn) only detection 23.9° < θ_{lab} < 54.3°	γ-ray yield **-- 9 + 8**
Ra, high CoM branch 20.6° < θ_{lab} < 29.9°	γ-ray yield **-- 9 + 7**
Ra, low CoM branch 23.9° < θ_{lab} < 29.9°	γ-ray yield **-- 9 + 9**
2-particle events 17.1° < θ_{lab} < 54.3°	γ-ray yield **-- 9 + 8**
Total	**74**

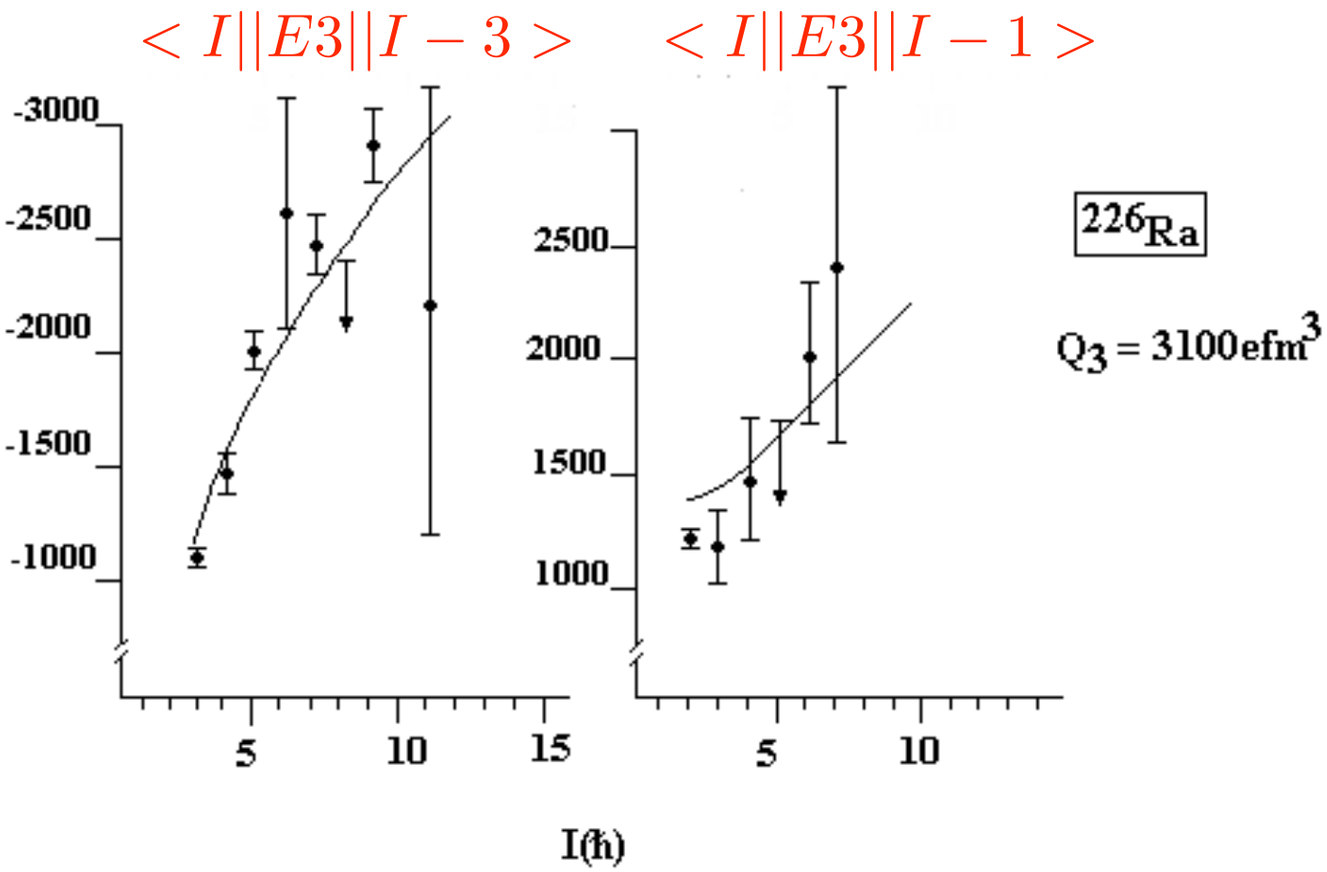
Huge parameter space - Reduce number of matrix elements by using rigid rotor

$$< I||E\lambda||I' >= (2I+1)^{\frac{1}{2}}(I0\lambda0|I'0)Q_\lambda a_\lambda$$

- Q_1 coupled for states $I_i > 6\hbar$ — -6 MEs
- Q_2 coupled for states $I_i > 6\hbar$ — -10 MEs
- Q_3 coupled for states $I_i > 5\hbar$ — -15 MEs
- All E4 matrix elements fixed — -19 MEs
- Free: 25 matrix elements + 6 normalisation constants = **31** free parameters in fit

[1] Poynter *et al.,* Phys. Lett. B **232**, 447 (1989)
[2] J.F.C. Cocks *et al.,* Nucl. Phys. A **645**, 61 (1999)
[3] Marten-Tölle *et al.,* Z. Phys. A **336**, 27 (1990)
[4] W. Kurcewicz, *et al.,* Nucl. Phys. A **289** (1977)
[5] W.R. Neal and H.W. Kraner, Phys. Rev. **137**, **B**1164 (1965)
[6] H. Ton *et al.,* Nucl. Phys. A **155**, 235 (1970)

Gosia Analysis

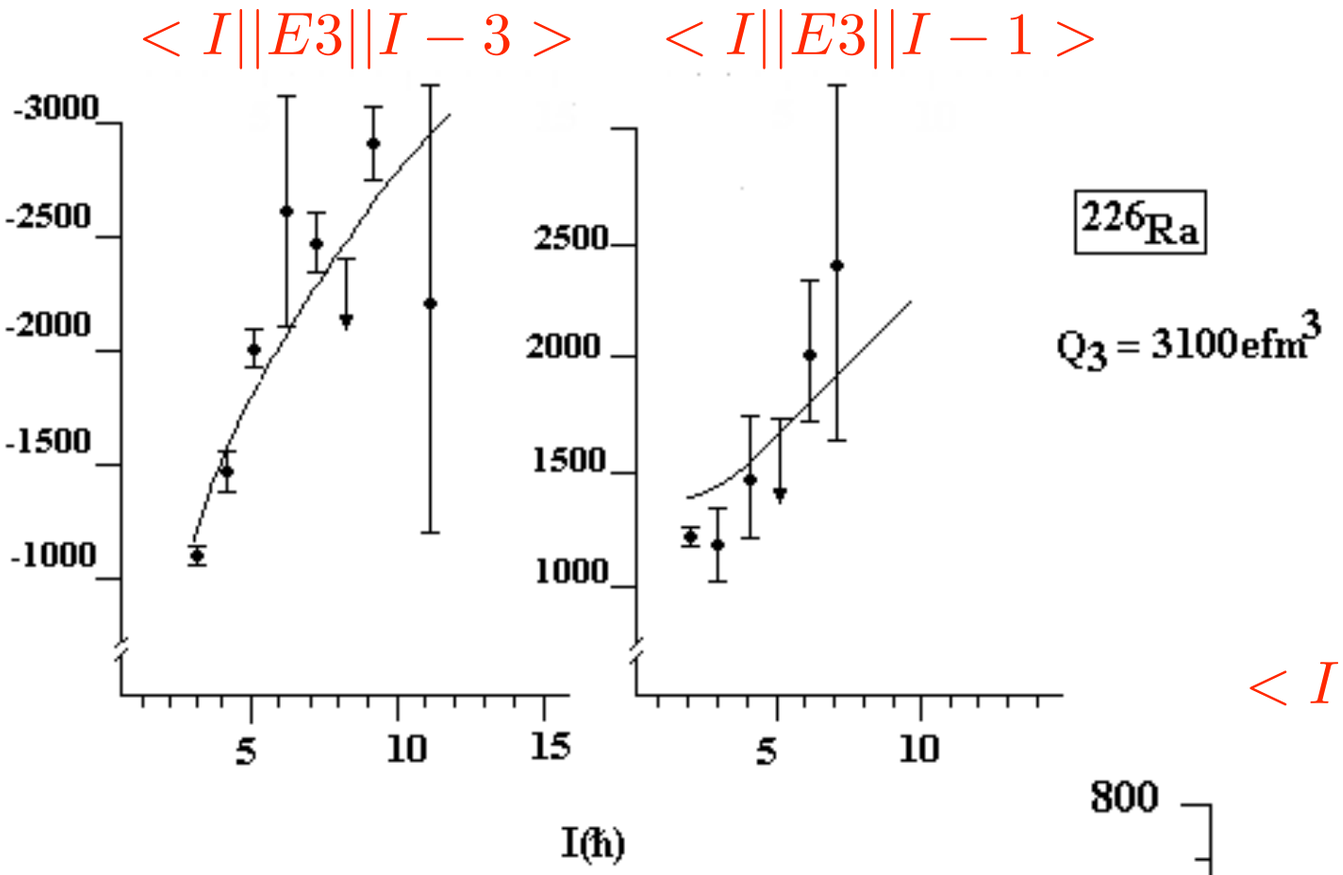


Measured E3 matrix elements [e·fm^3]

Stretched: $< I||E3||I-3 >$
Un-stretched: $< I||E3||I-1 >$

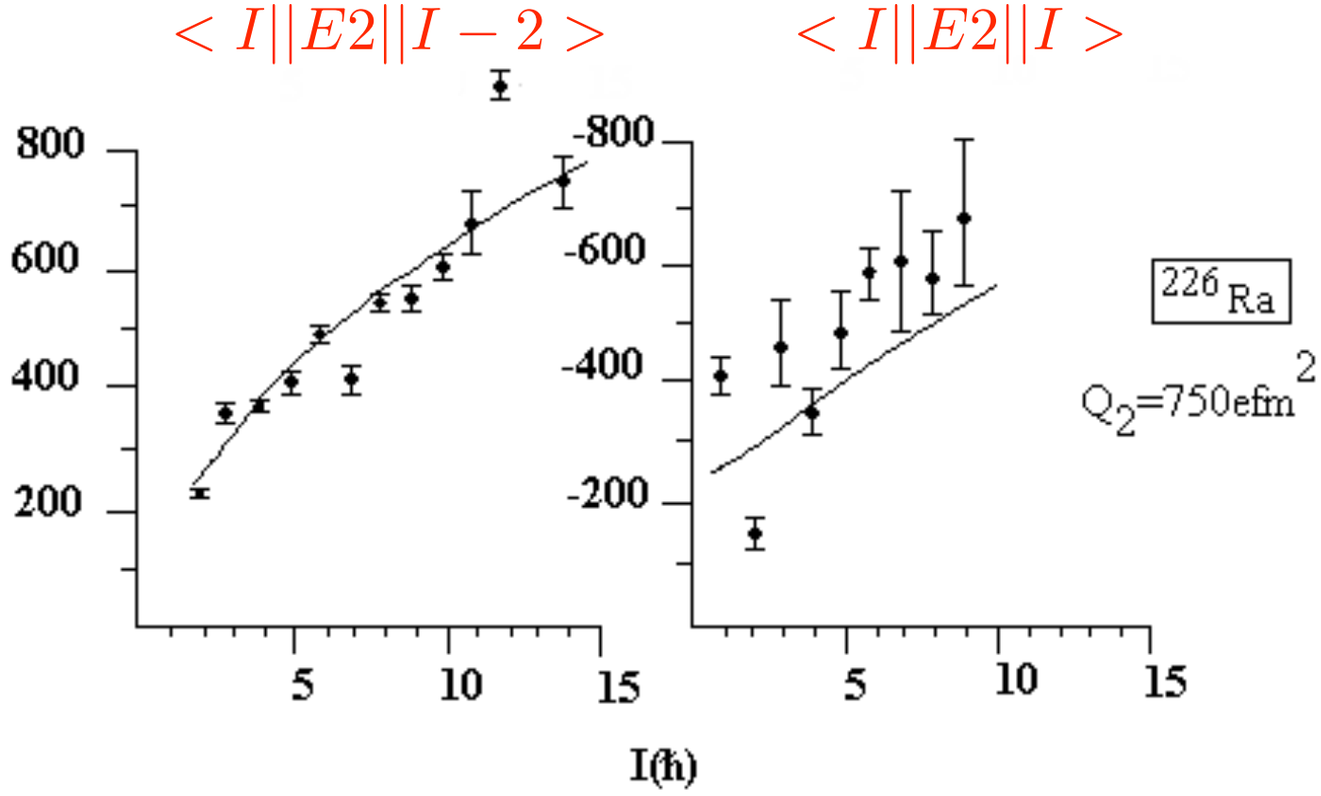
[Ref] H. J. Wollersheim *et al.,* Nucl. Phys. A **556**, 261 (1993)

Gosia Analysis



Measured E3 matrix elements [e·fm^3]

Stretched: $< I||E3||I-3 >$
Un-stretched: $< I||E3||I-1 >$



Measured E2 matrix elements [e·fm^2]

Transitional: $< I||E2||I-2 >$
Diagonal: $< I||E2||I >$

[Ref] H. J. Wollersheim *et al.*, Nucl. Phys. A **556**, 261 (1993)