Spin of resonances from the neutron capture experiment in rare-earth nuclei

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Outline

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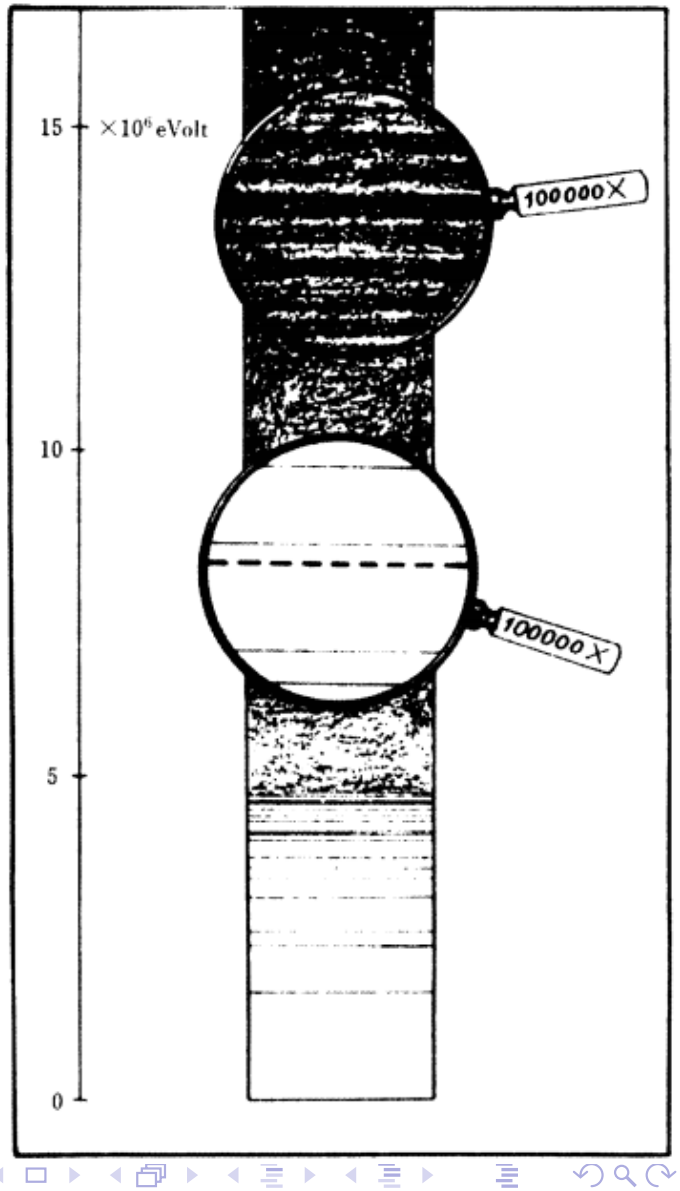
1. Introduction
   - Gamma decay
   - Neutron capture reaction
2. ^{161,163}Dy(n,γ) and ^{167}Er(n,γ) measurements
   - Experimental data reduction
3. Results
   - ^{161,163}Dy resonance spin assignment
   - ^{167}Er resonance spin assignment

Nuclear levels and gamma decay

Decay of levels at low excitation energies

- Often known experimentally
- Influence of "structure" effects
  - vibrations
  - rotational bands
  - ...
- Properties of individual levels predicted in models



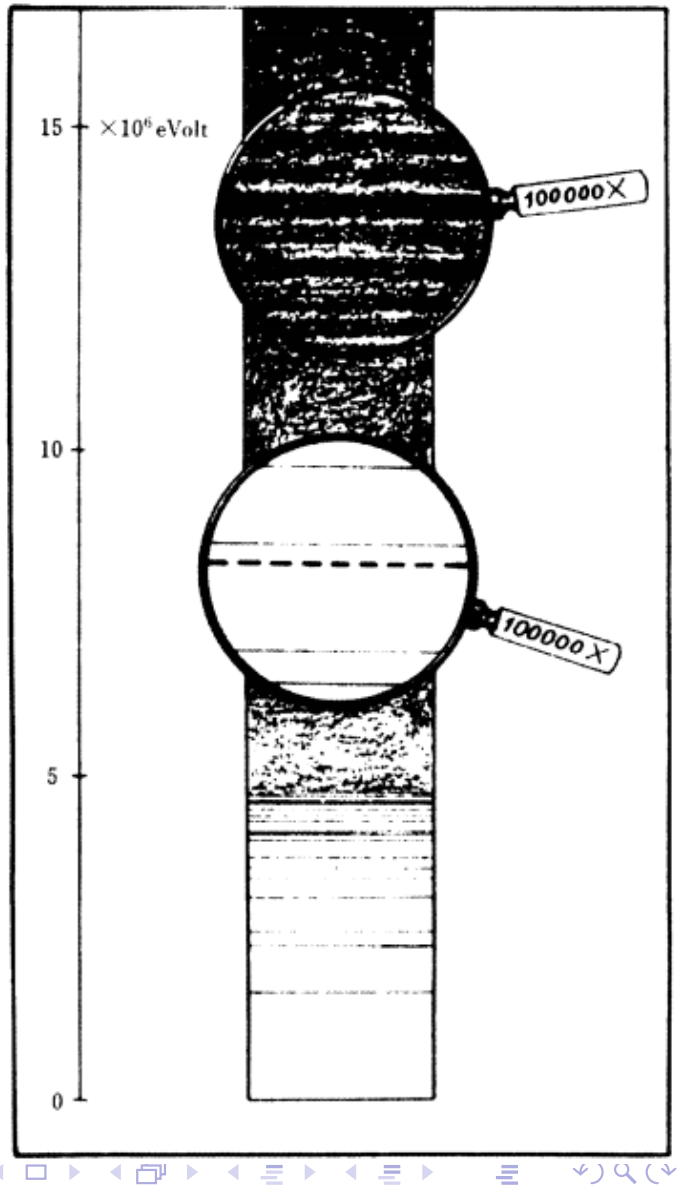
Nuclear levels and gamma decay

Decay of levels with increasing excitation energies

- Individual levels cannot be resolved
- Decay described by statistical approach
- Two average quantities
  - level density
  - photon γ-ray strength function
- Fluctuation properties
  - Porter-Thomas fluctuations of partial radiation widths
- Selection rules for electromagnetic transitions $\alpha \to \beta$ of type XL

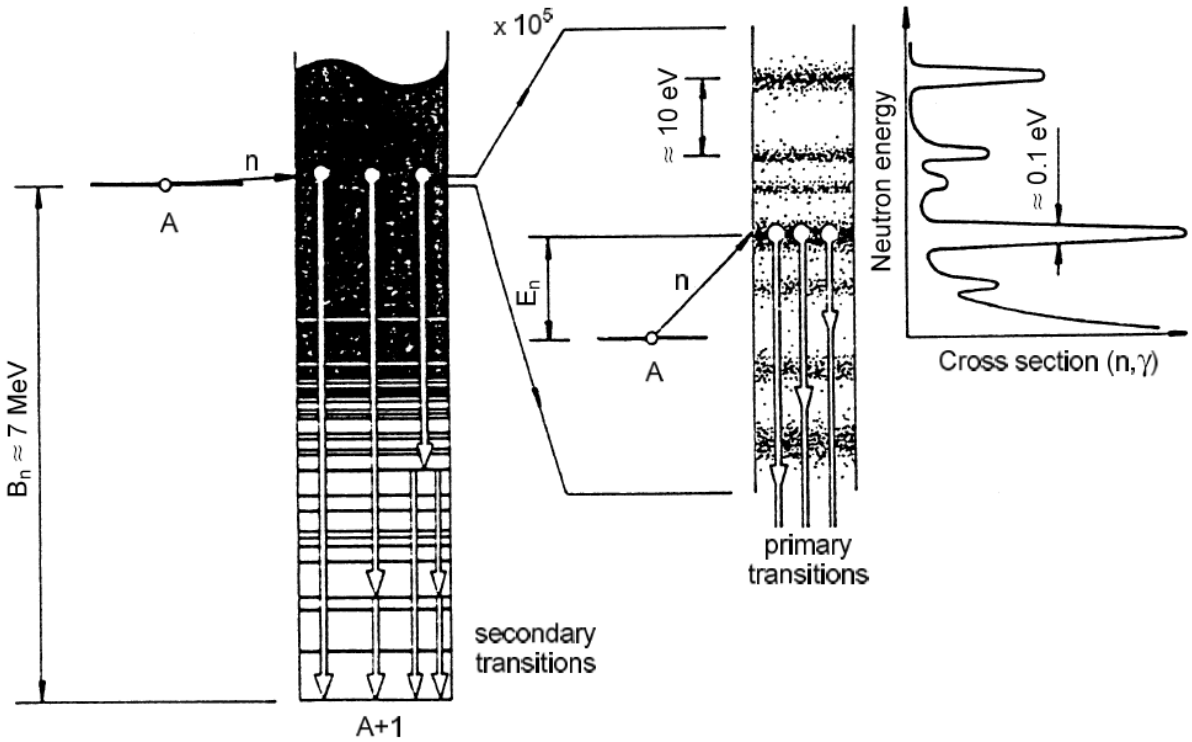
$$|J_\alpha - J_\beta| < L < J_\alpha + J_\beta$$

  - transitions with multipolarity $L > 2$ strongly suppressed



Neutron capture reaction

- Reaction $^{A}\mathrm{X}(\mathrm{n},\gamma)^{A+1}\mathrm{X}$
- Neutron captured in the nucleus, a neutron resonance is formed, followed by emission of gamma rays
- Average multiplicity of gamma cascades differs for different resonance spin $J = I \pm 1/2$ (s-wave resonances)



Los Alamos Neutron Science Center

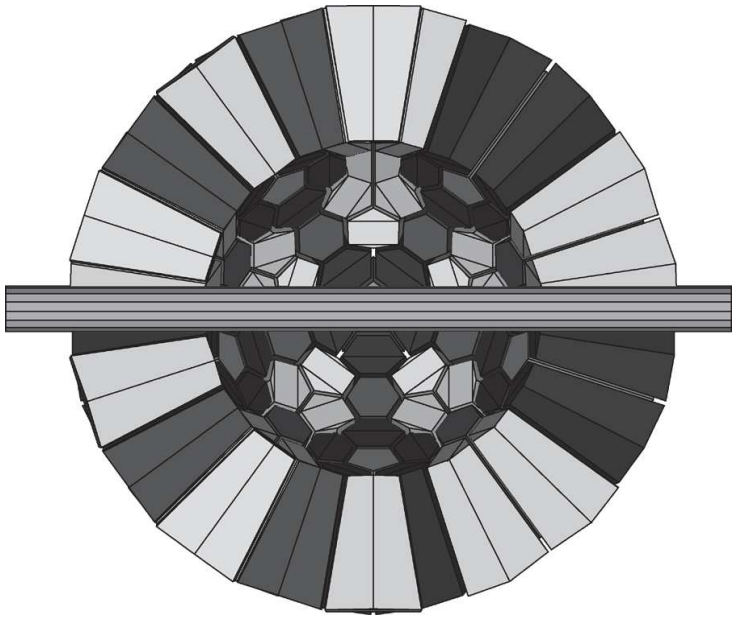
Neutron spallation source

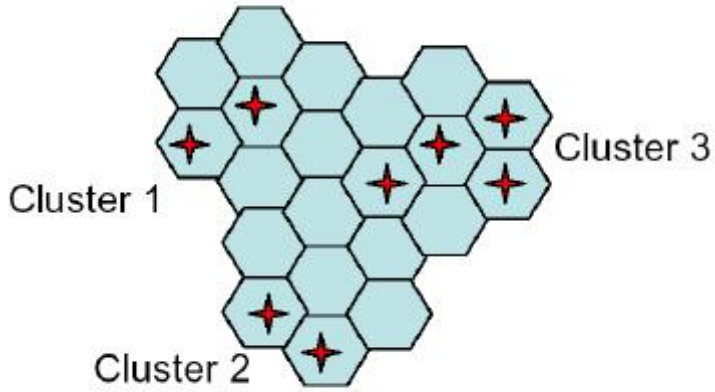
- 800 MeV protons from LINAC (7)
- 20 Hz repetition rate
- Pulse width ≈125 ns
- Moderated tungsten target in Lujan Neutron Scattering Center (1)
- ≈14 n's/proton, neutron energies from thermal up to several MeVs
- detector DANCE is on a 20 m flight path
- cca 1 cm beam after collimation

DANCE

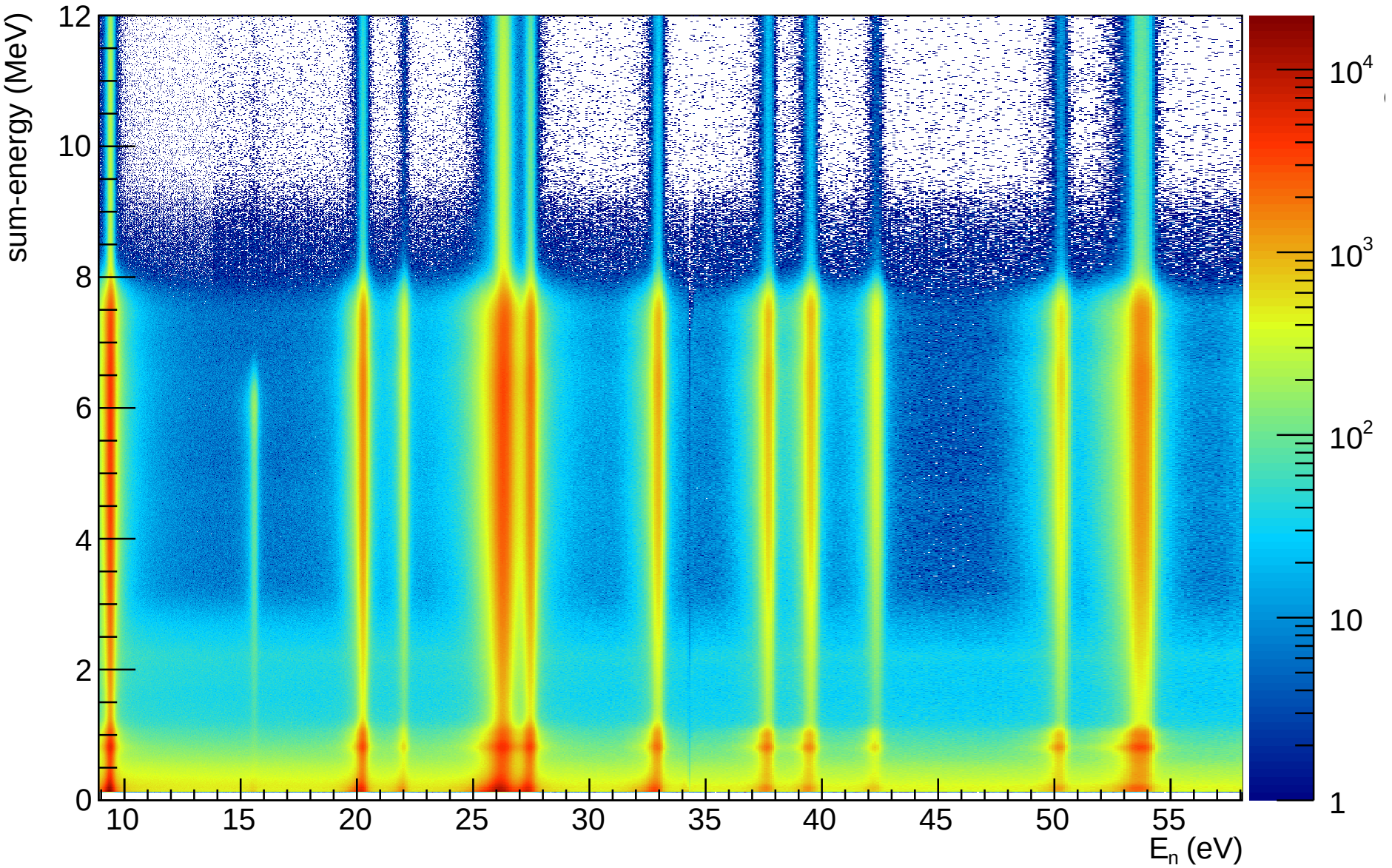
Detector for **A**dvanced **N**eutron **C**apture **E**xperiments

- High efficiency, high segmented scintillator, 160 BaF_2 crystals
- Signals from crystals within a preset time window form a cascade
- Different 3D histograms available - E_n vs m vs E_{sum} and E_n vs m vs E_γ for certain E_{sum} intervals

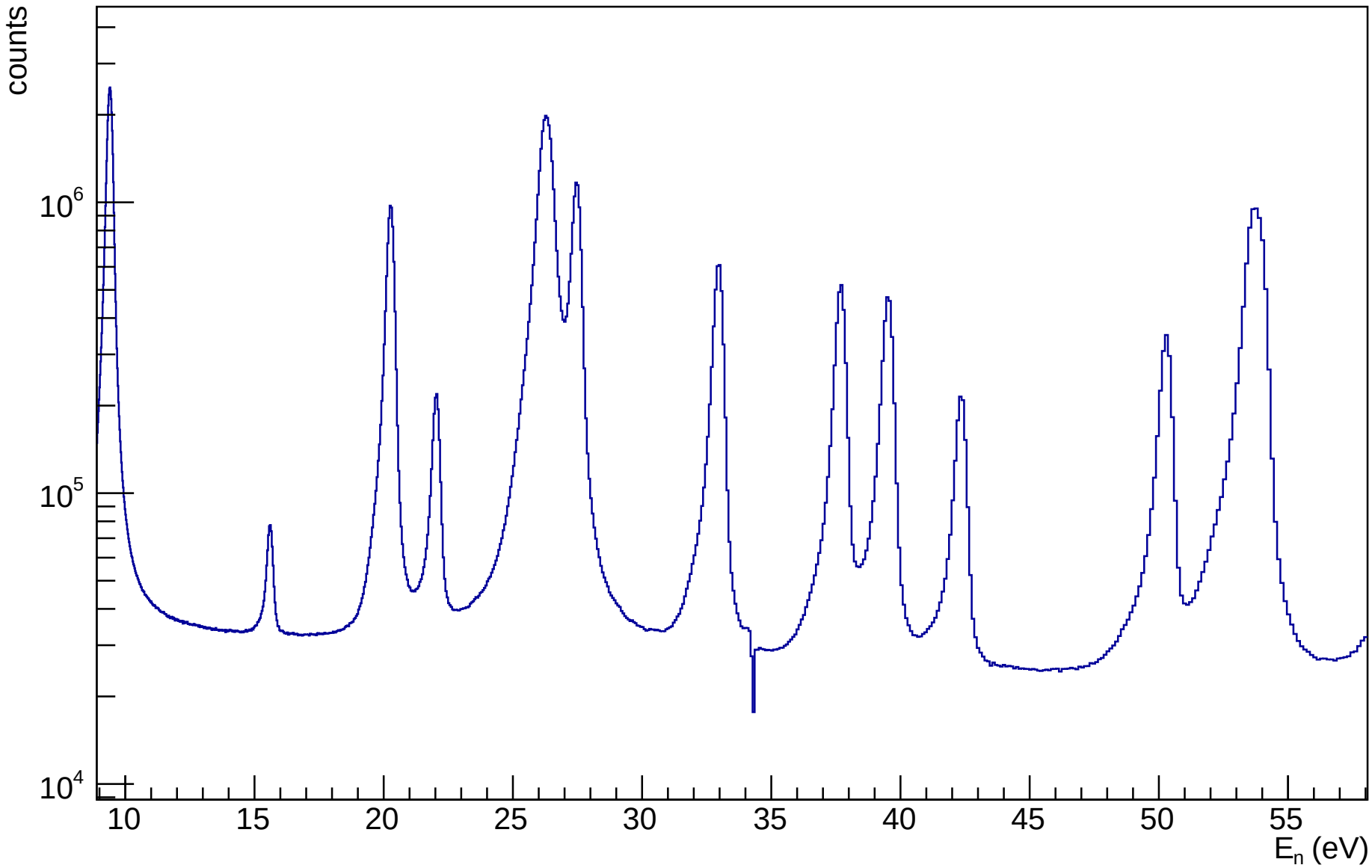




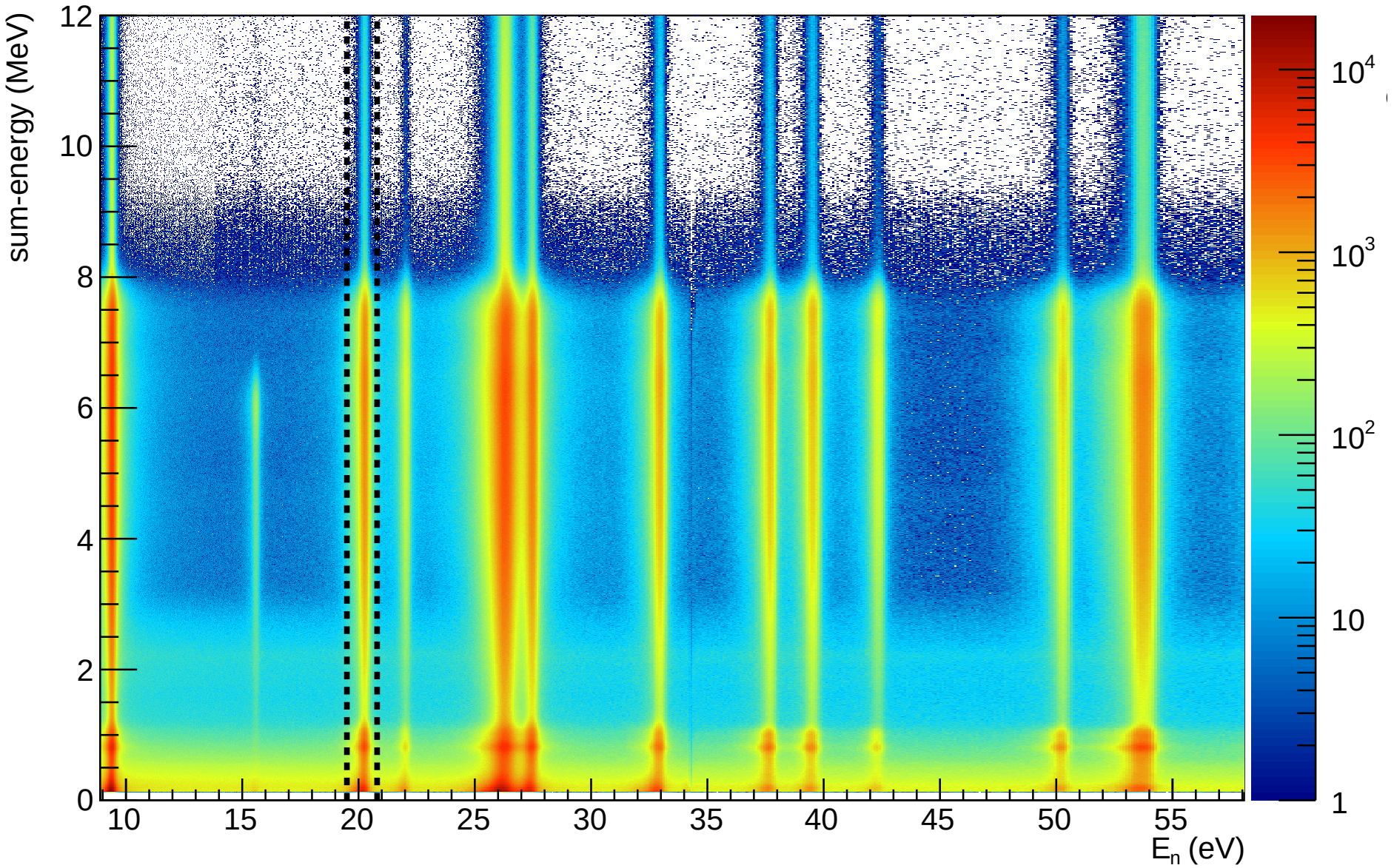
2D histogram E_n vs m vs E_{sum}, summed over all m, ^{168}Er



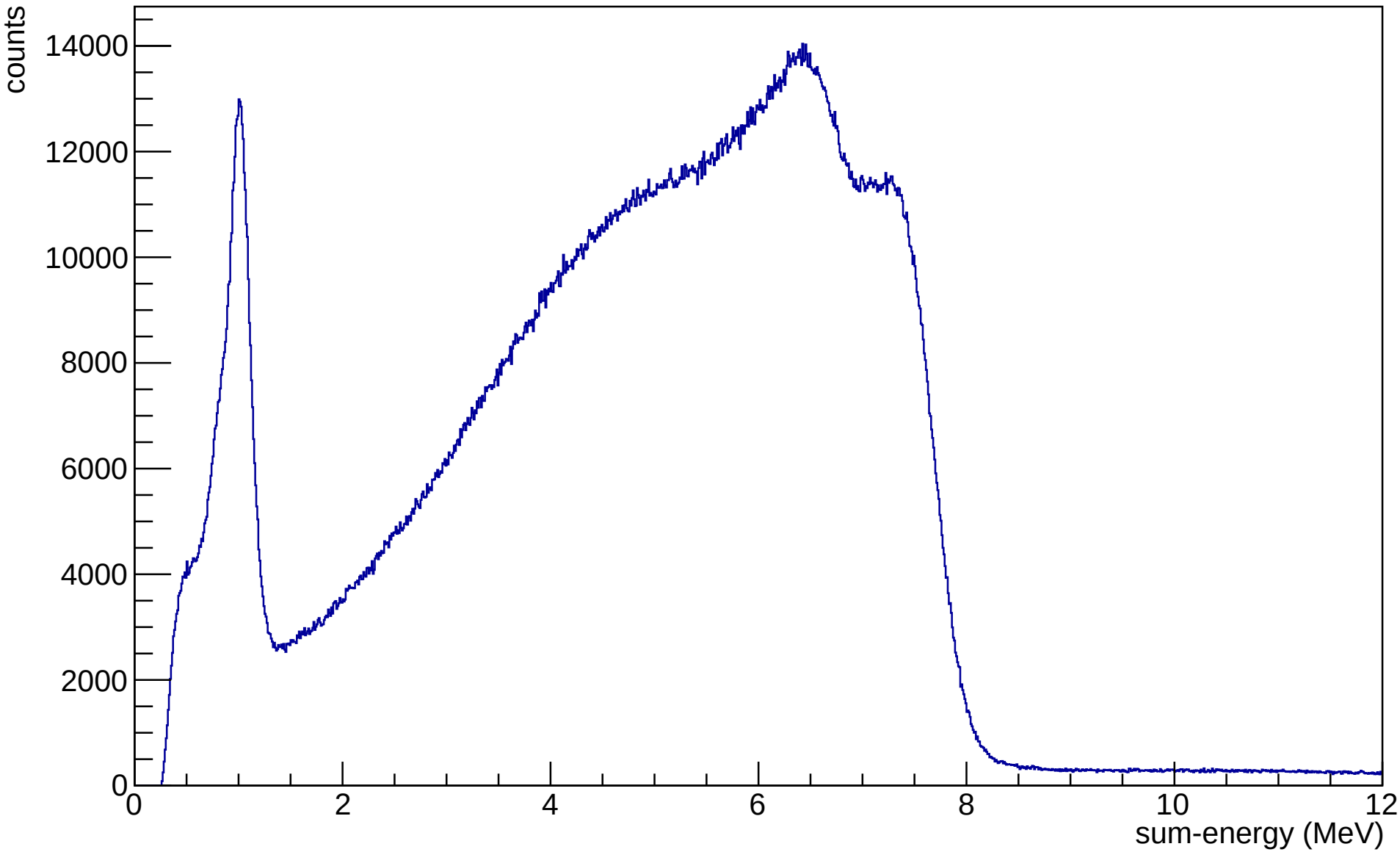
Projection onto E_n, time-of-flight spectrum



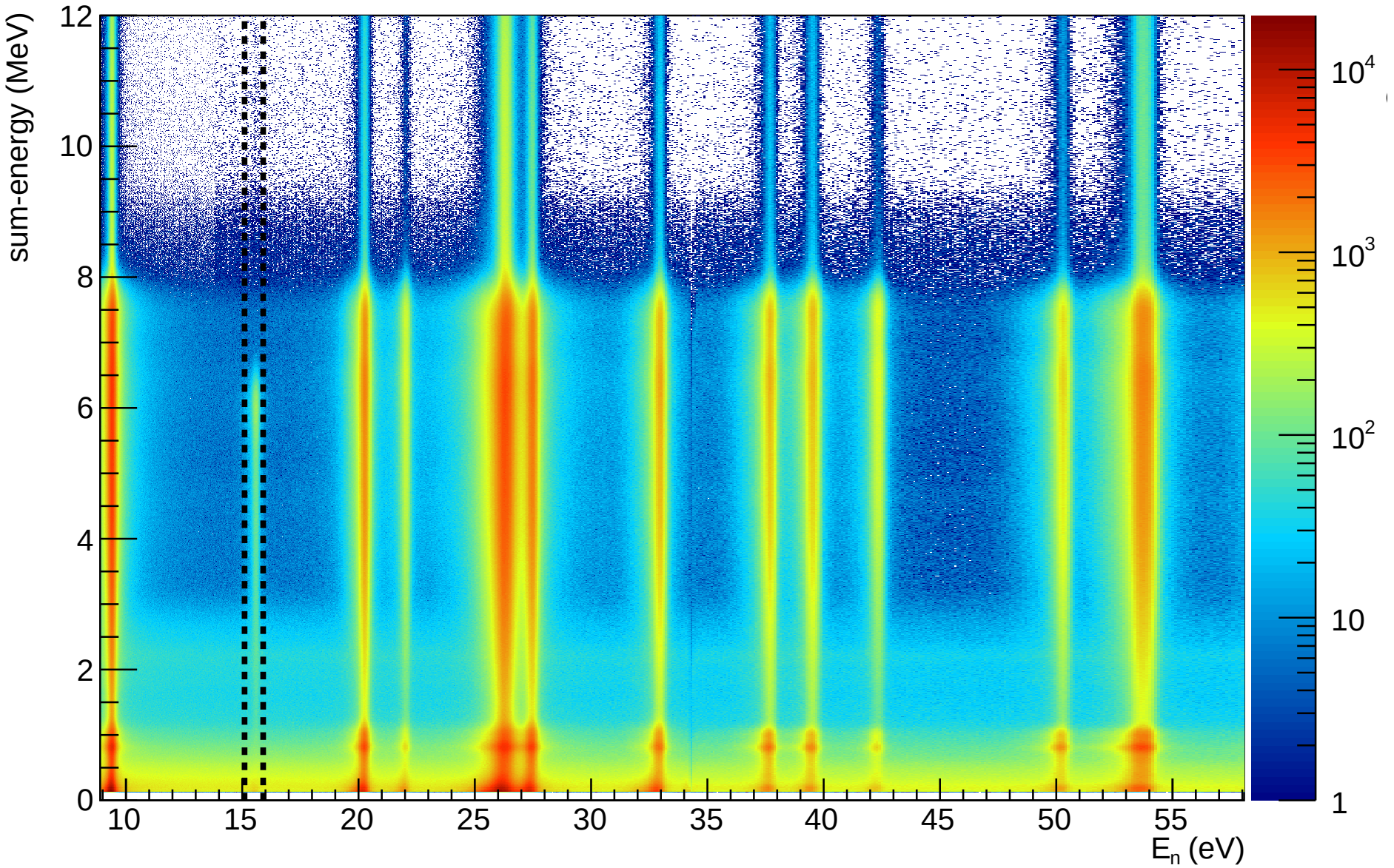
A specific resonance is chosen



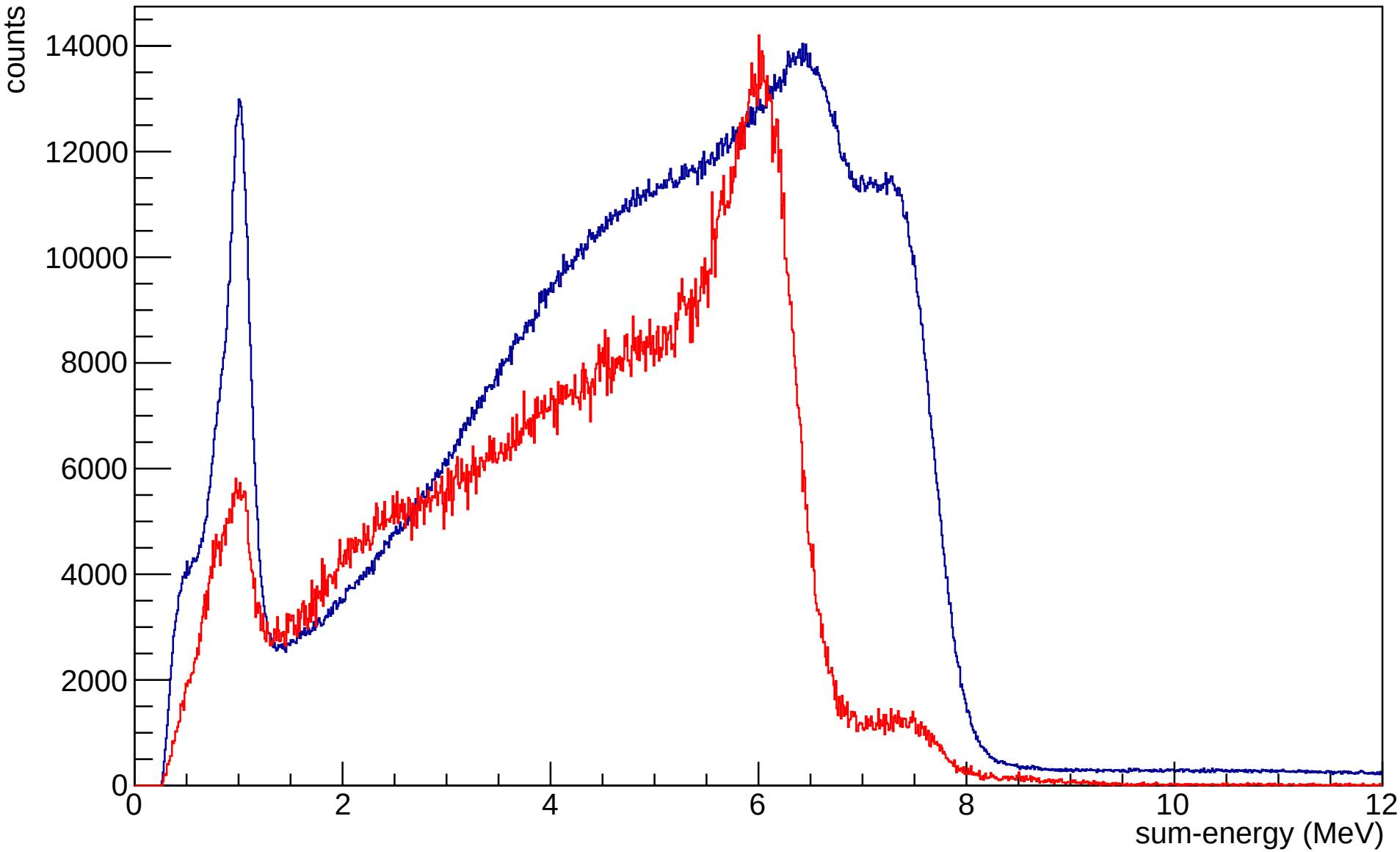
Projection onto E_{sum}, sum-energy spectrum



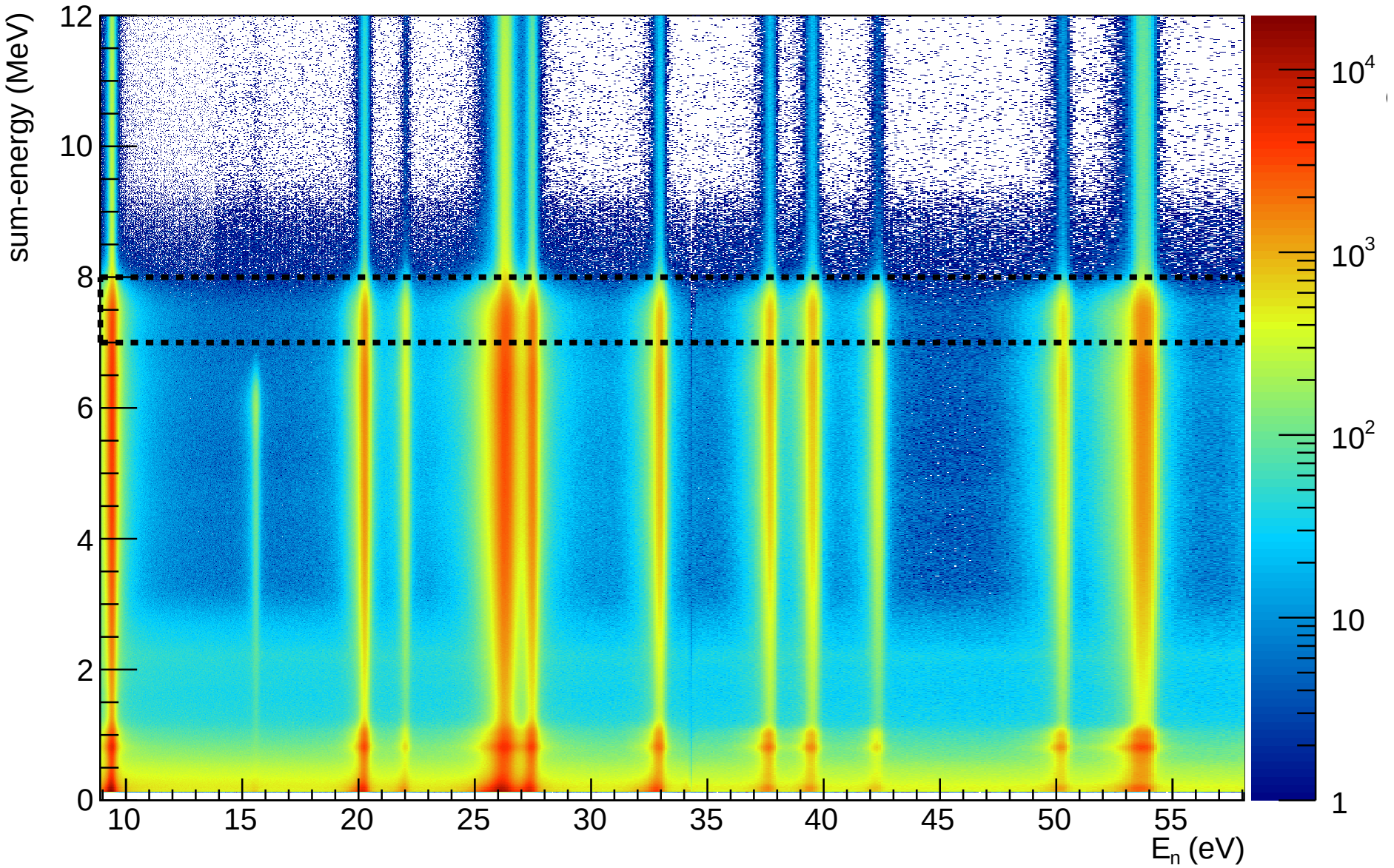
Another resonance is chosen



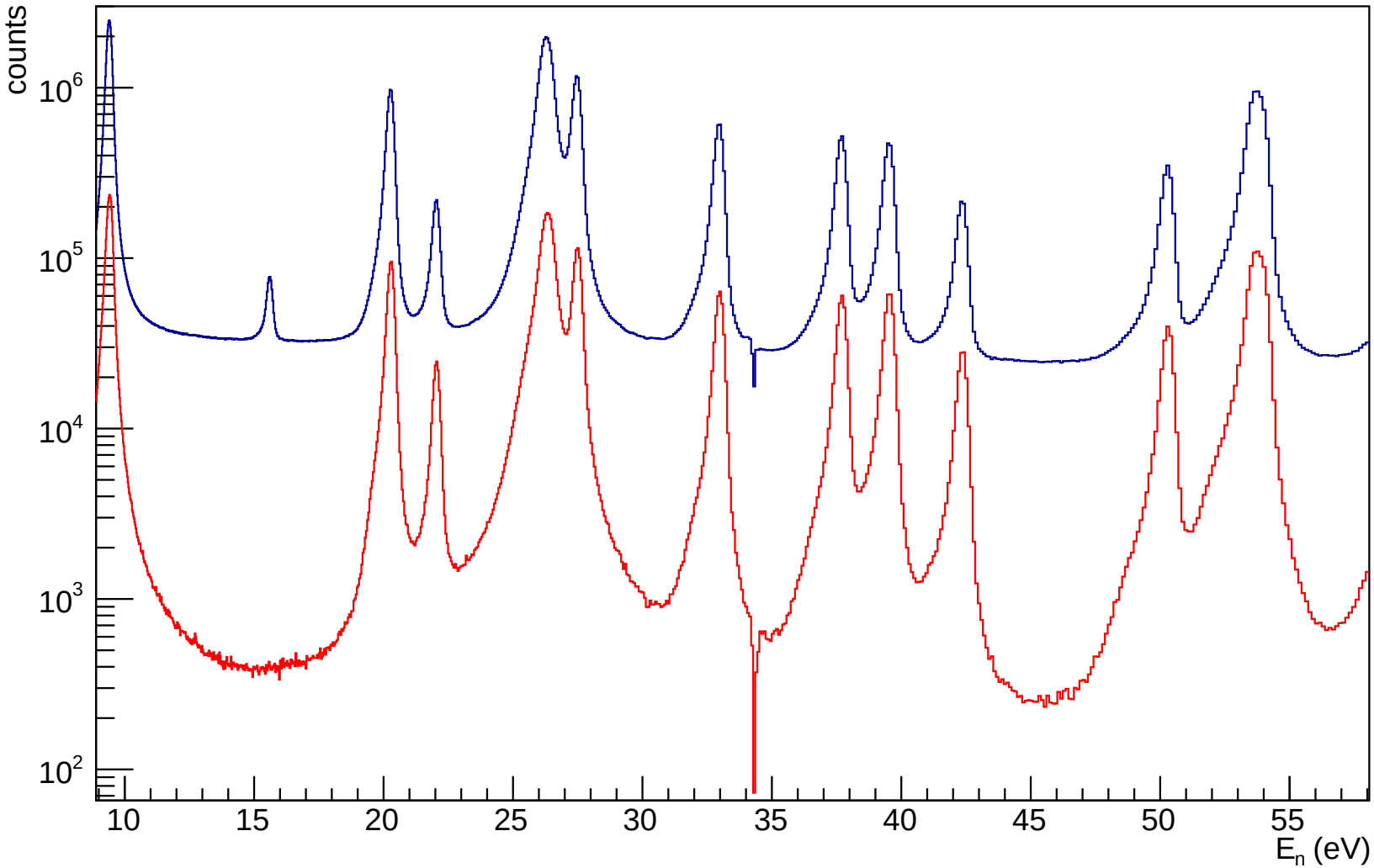
Comparison of sum-energy spectra, ^{168}Er vs ^{167}Er isotope



Gate on sum-energy is applied



Comparison of gated and ungated yields



Resonance spin assignment

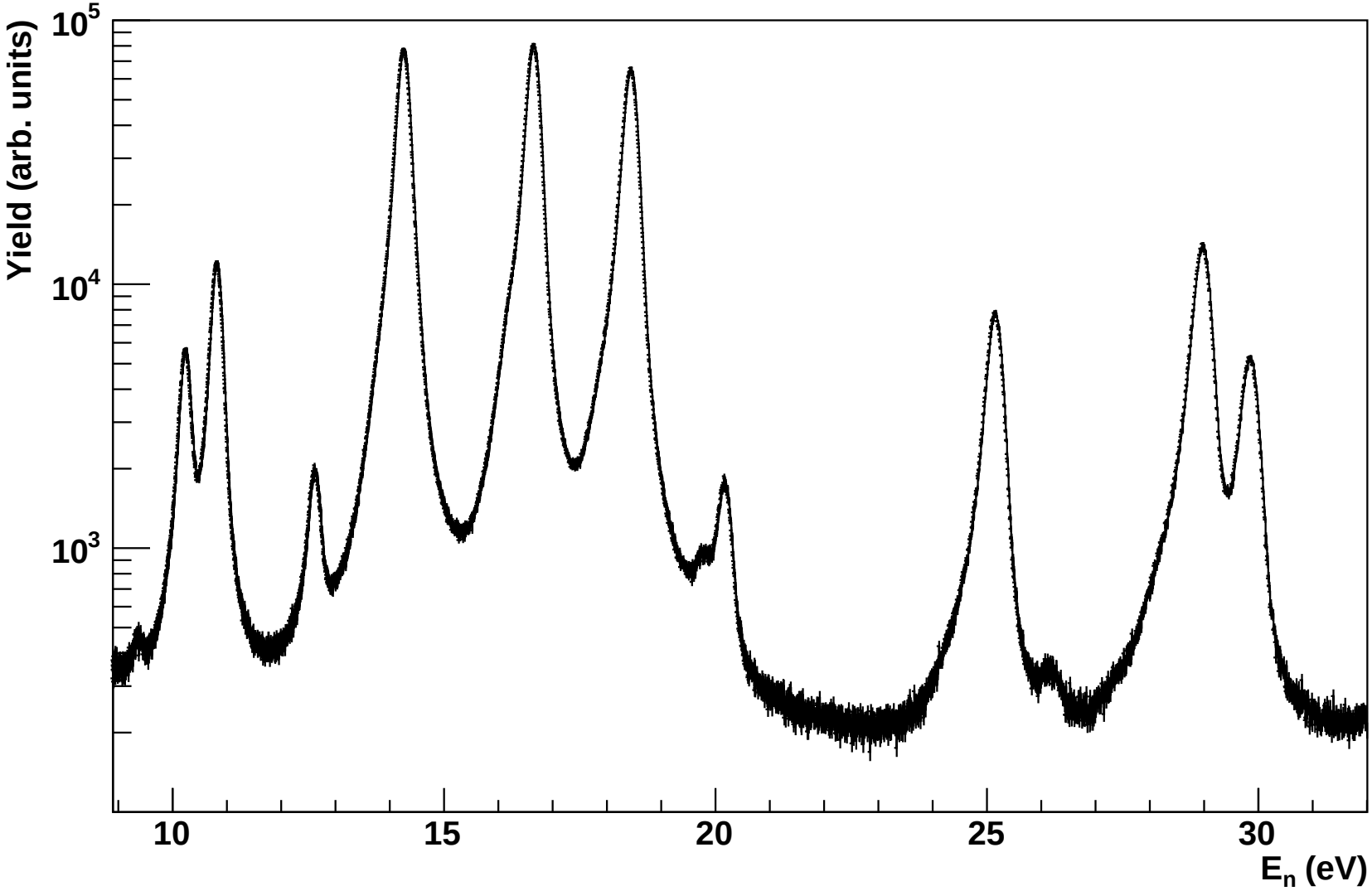
Used method by Bečvář et. al. published in NIM A 647, 73 (2011) *Optimized γ-multiplicity-based spin assignments of s-wave neutron resonances*

Yield (as a function of E_n) is assumed in form:

$$Y(E_n) = Y(E_n)_{J=I+\frac{1}{2}} + Y(E_n)_{J=I-\frac{1}{2}} + (Y(E_n)_{\mathrm{background}}),$$

where the partial yields are obtained bin-by-bin by least square fit of **multiplicity** vector $\vec{m}$ in given bin using so-called multiplicity **prototypes**.

Optimized γ-multiplicity-based spin assignment



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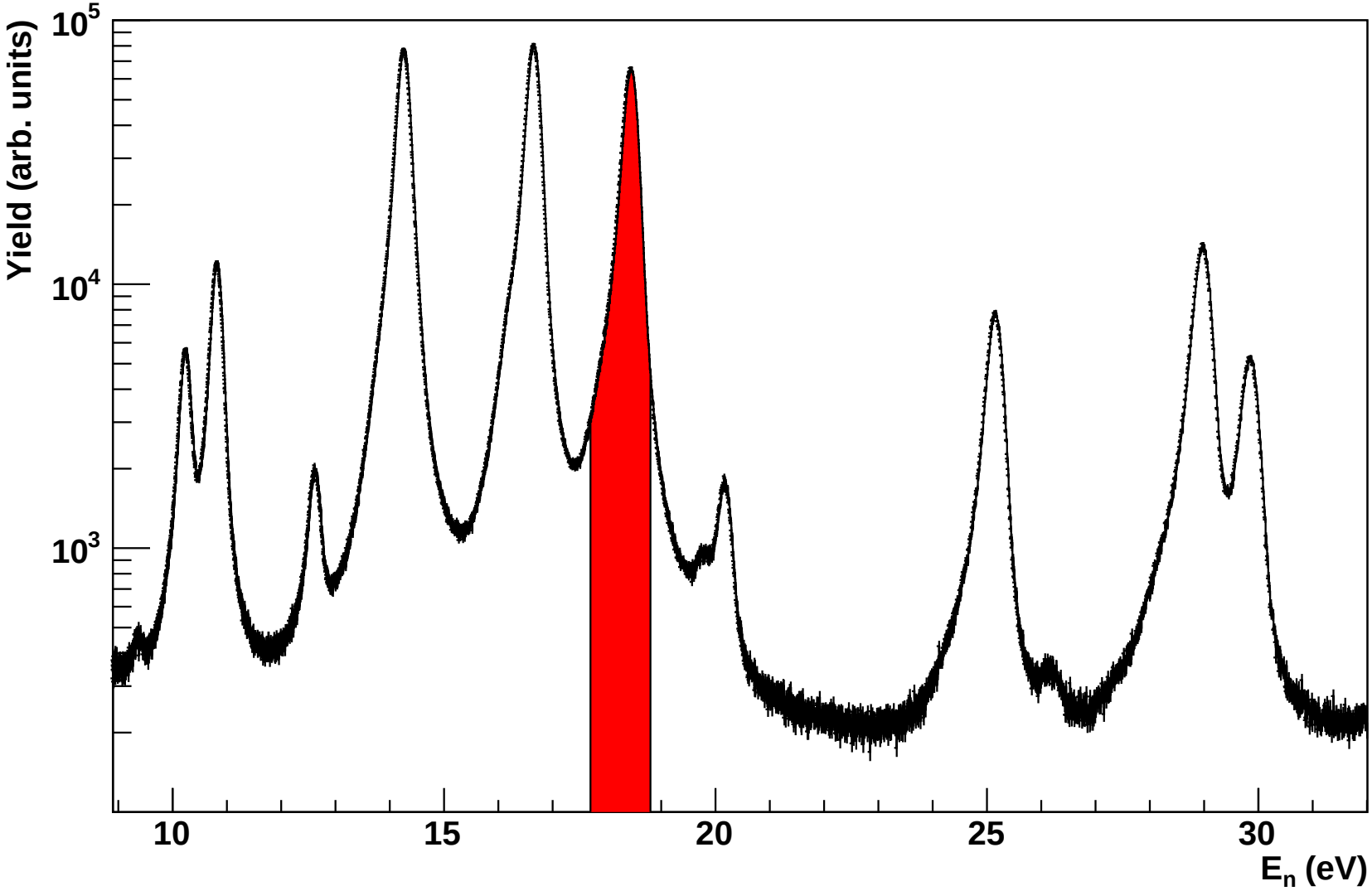

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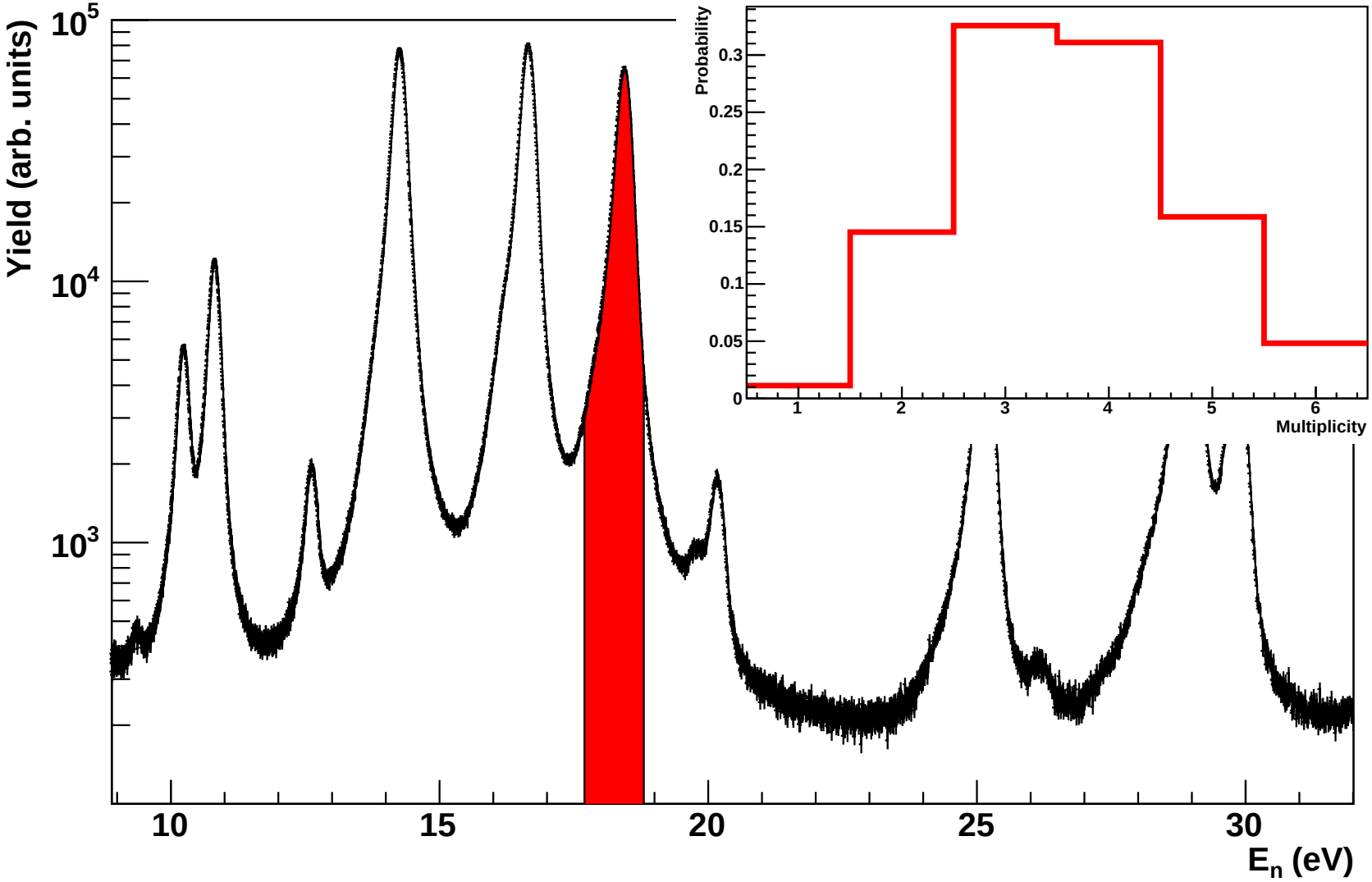

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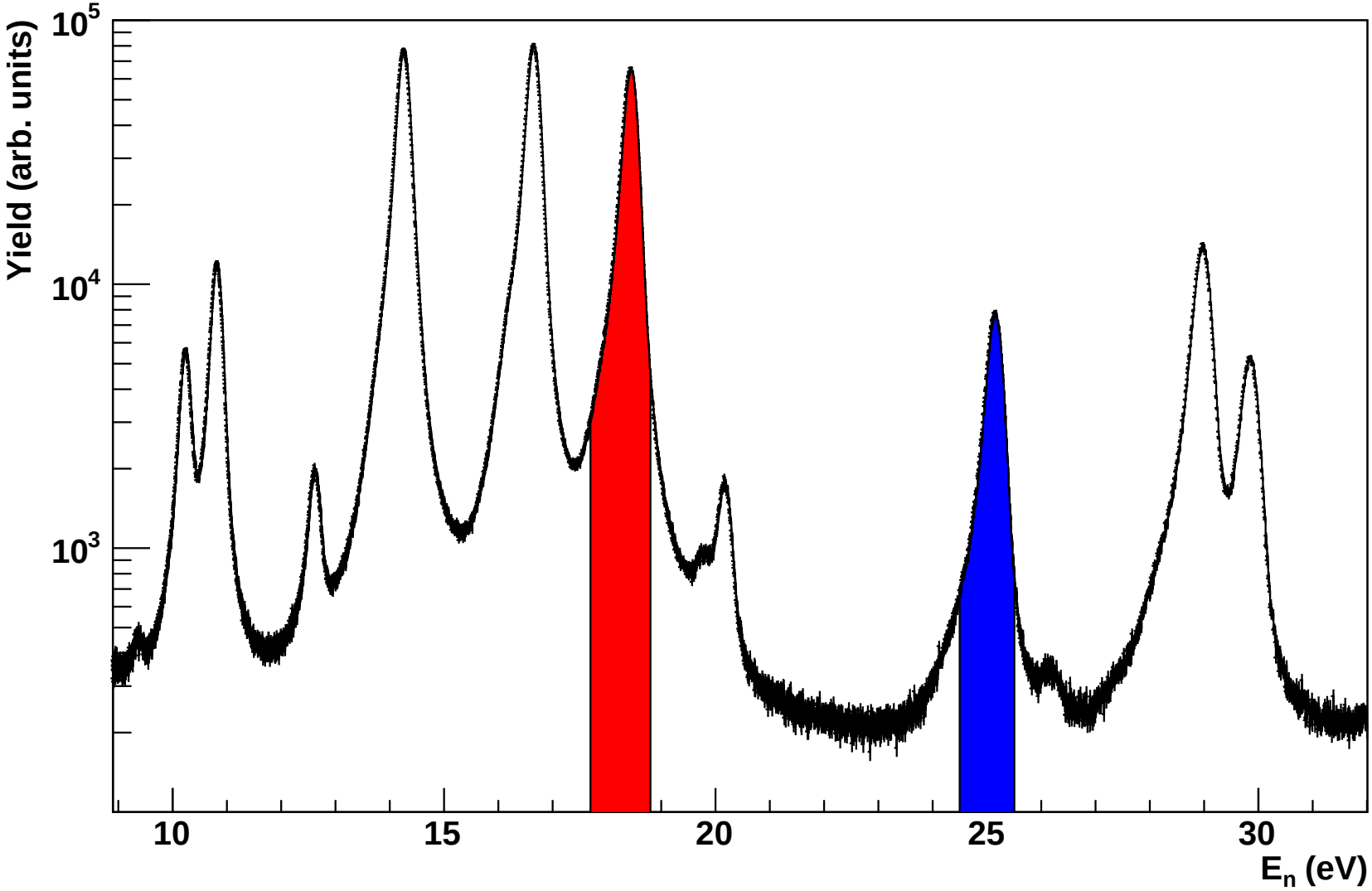

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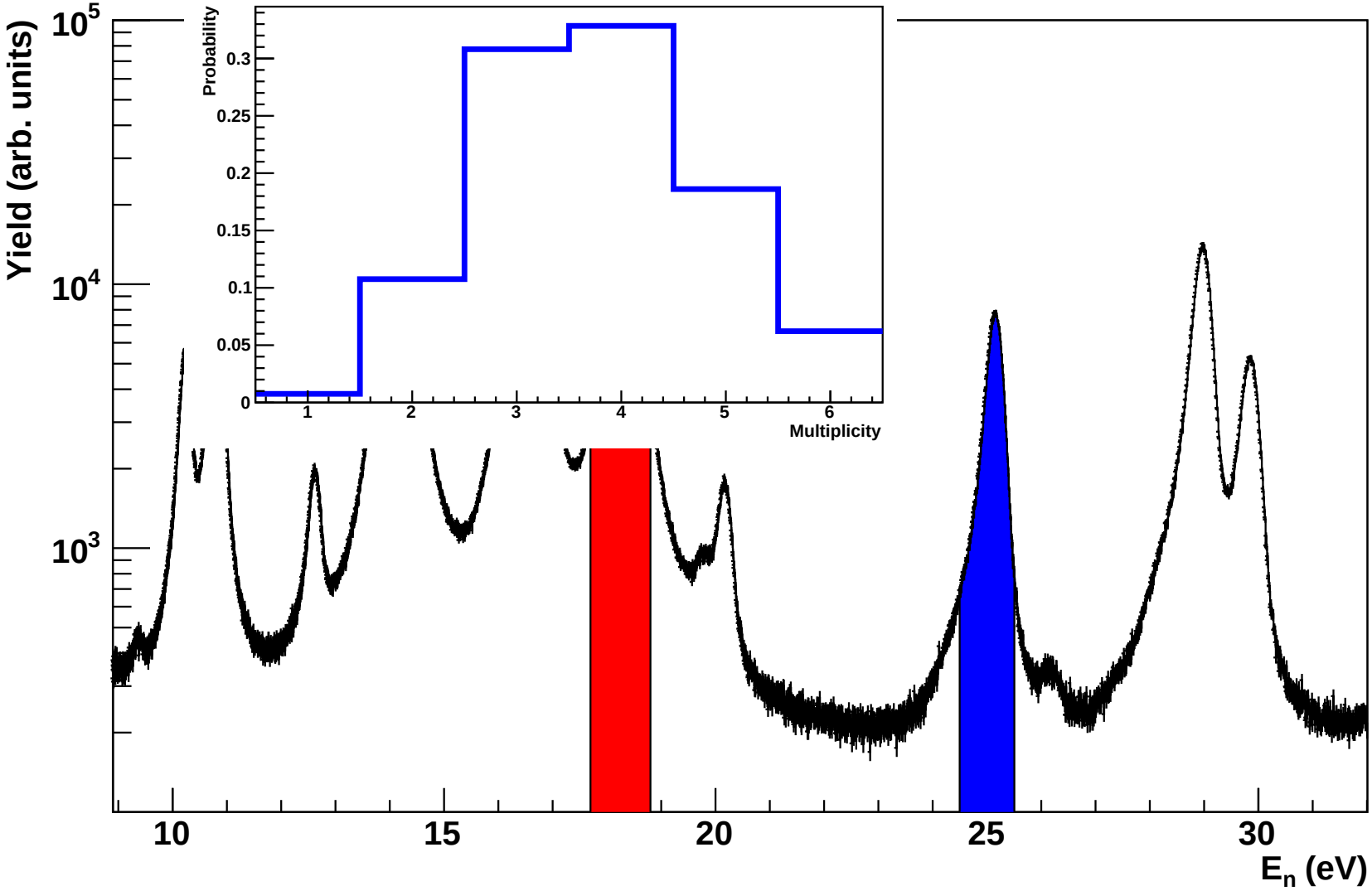

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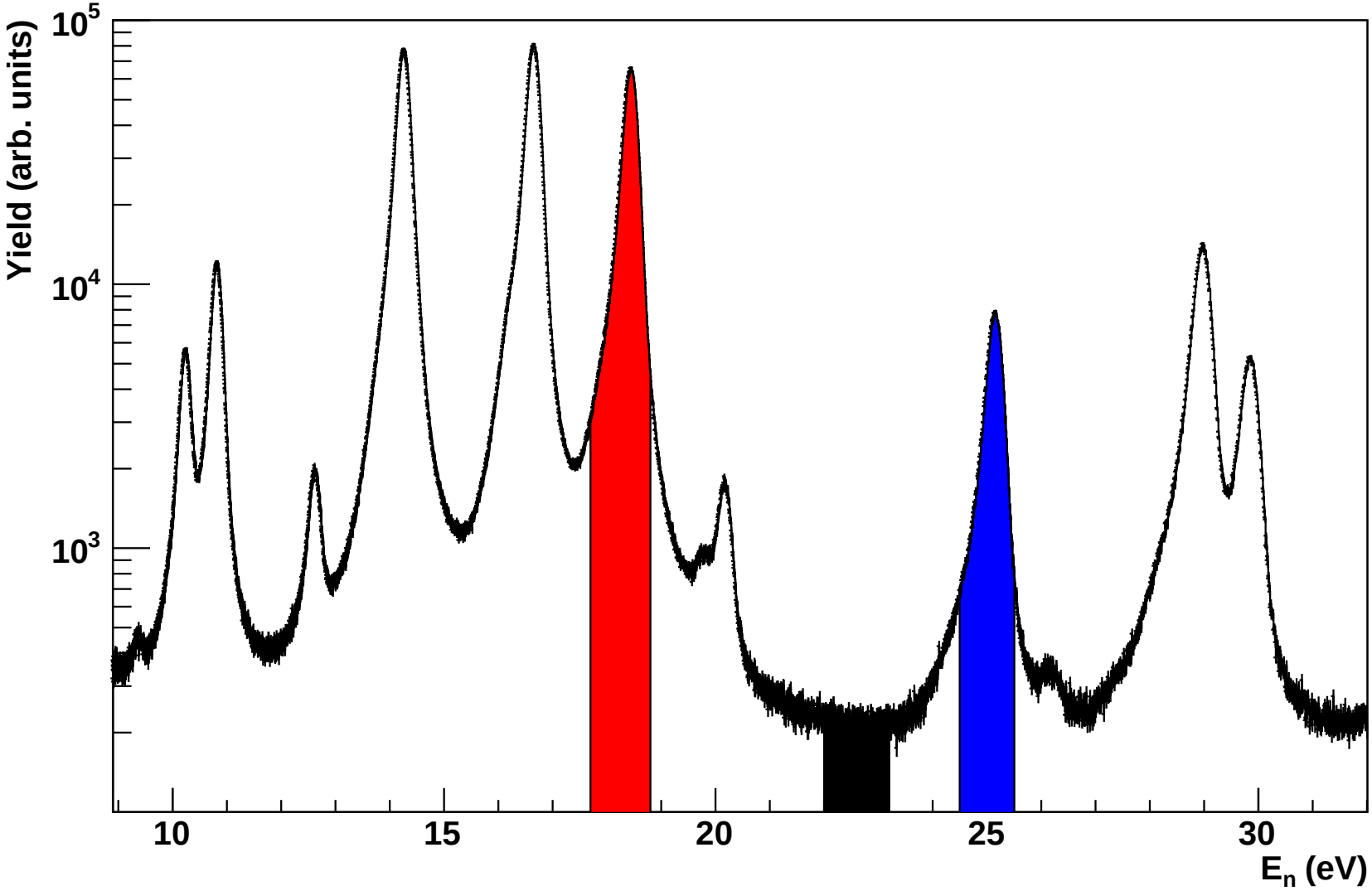

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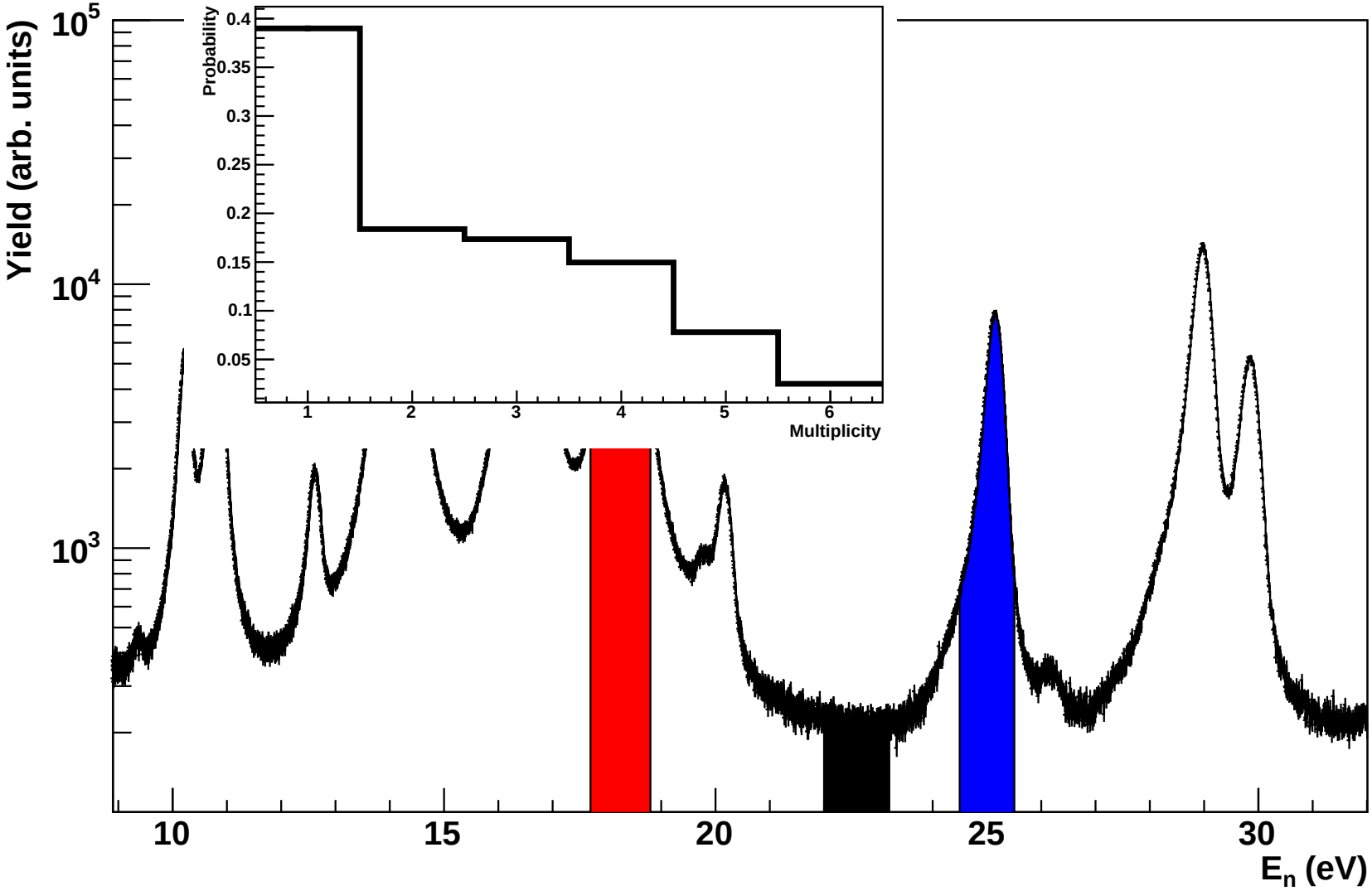
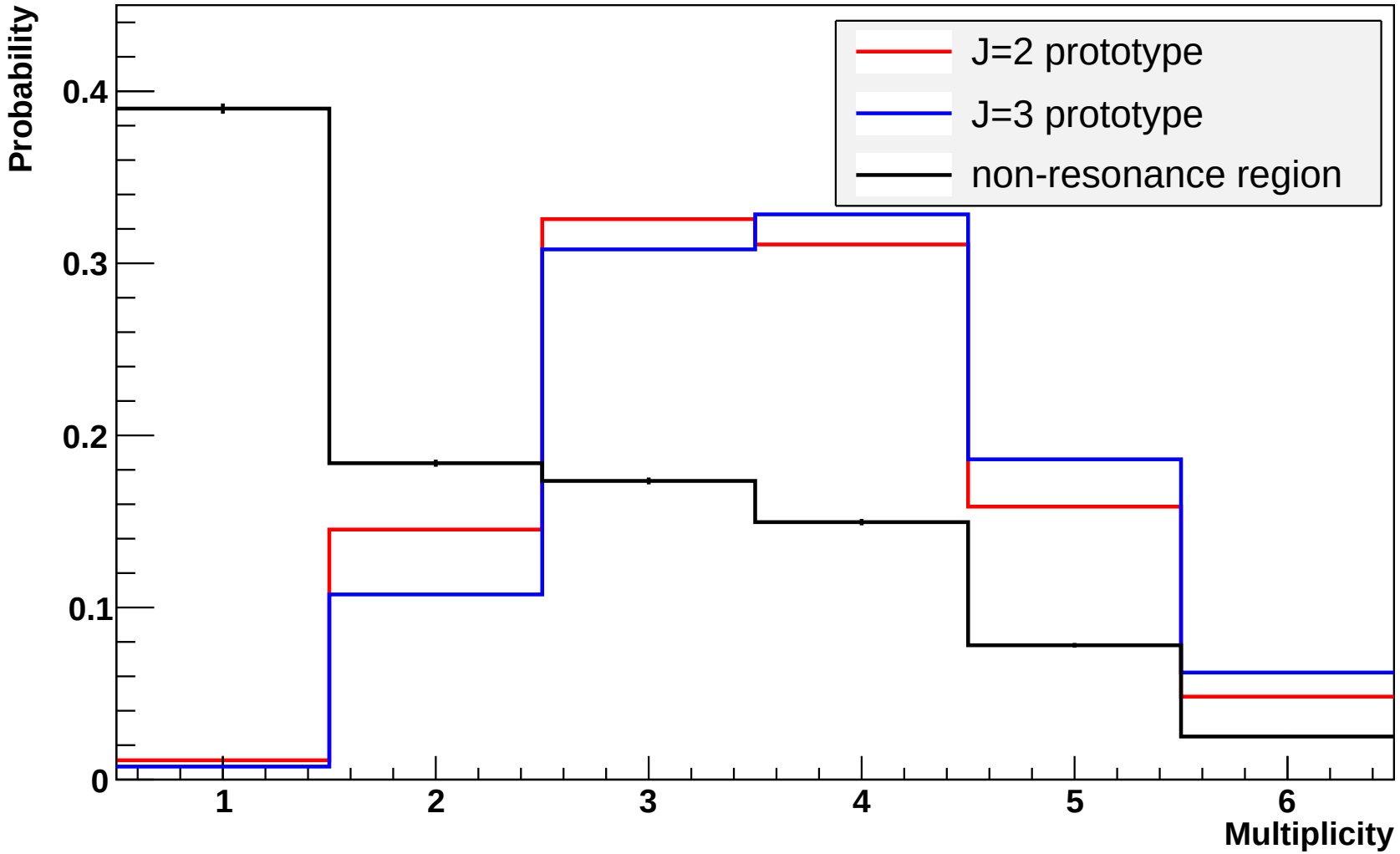
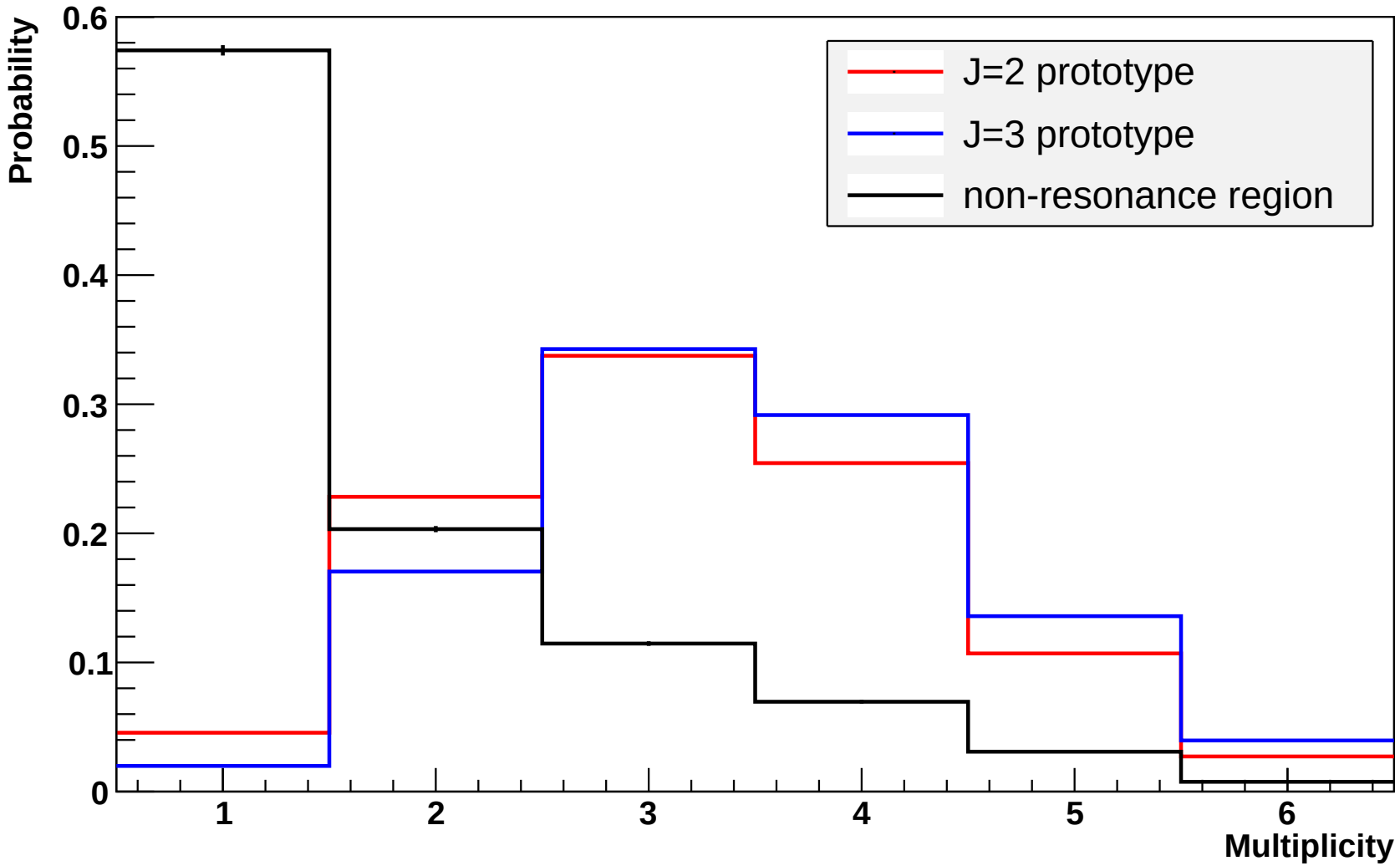


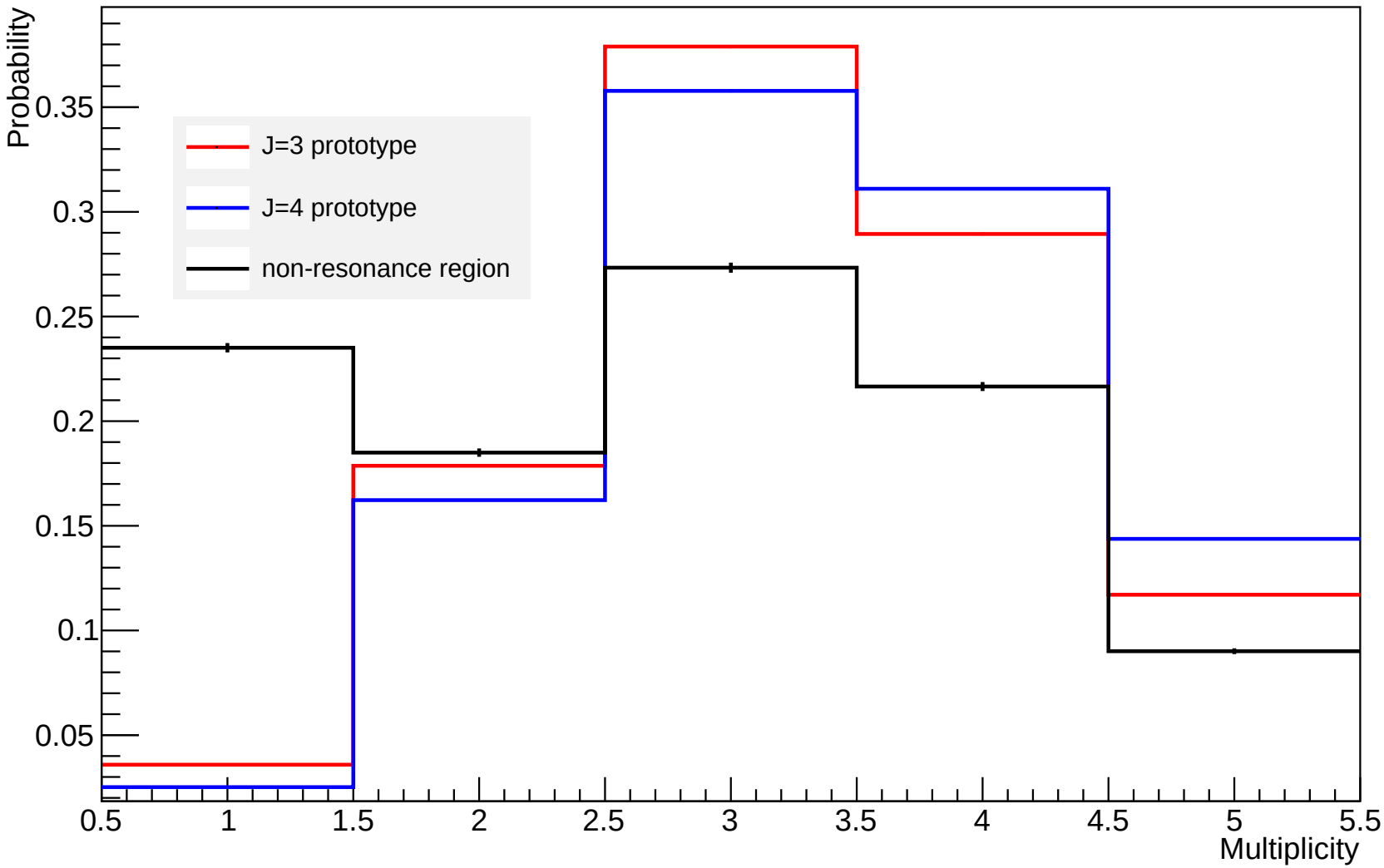
Multiplicity prototypes in ^{161}Dy



Multiplicity prototypes in ^{163}Dy



Multiplicity prototypes in ^{167}Er



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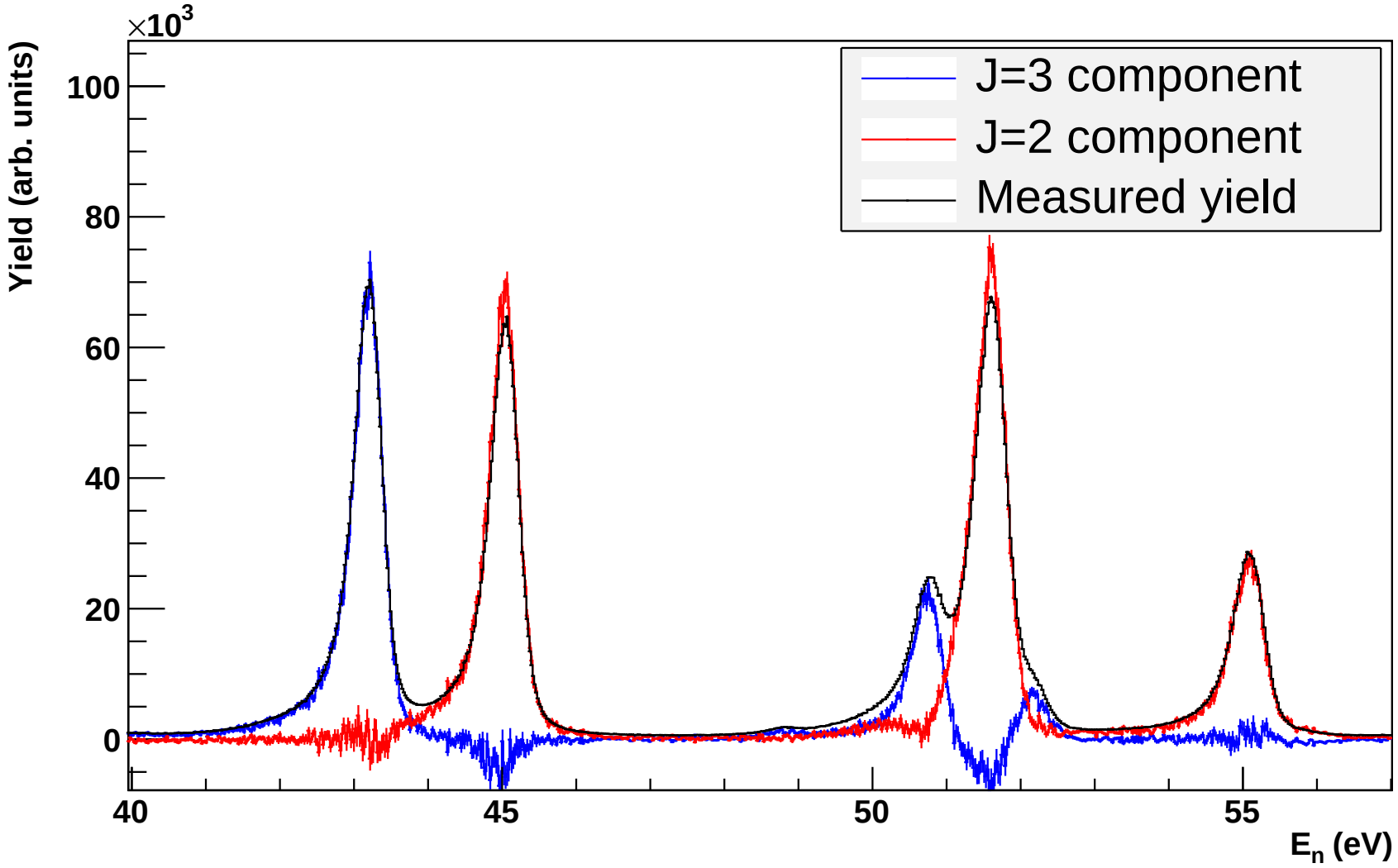
Confirmation of spin on a few non-prototype resonances

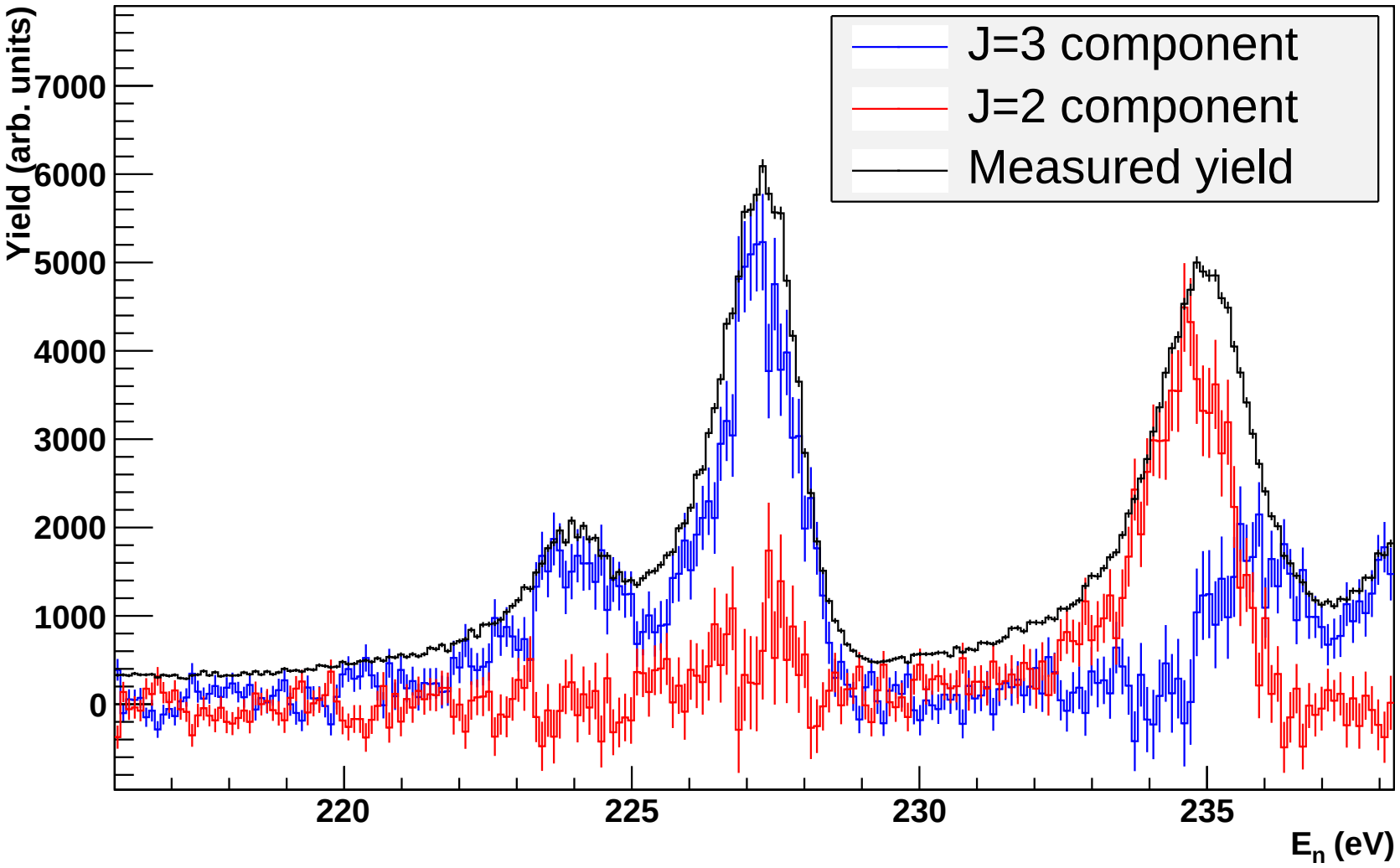


Results for resonance spins in ^{161}Dy

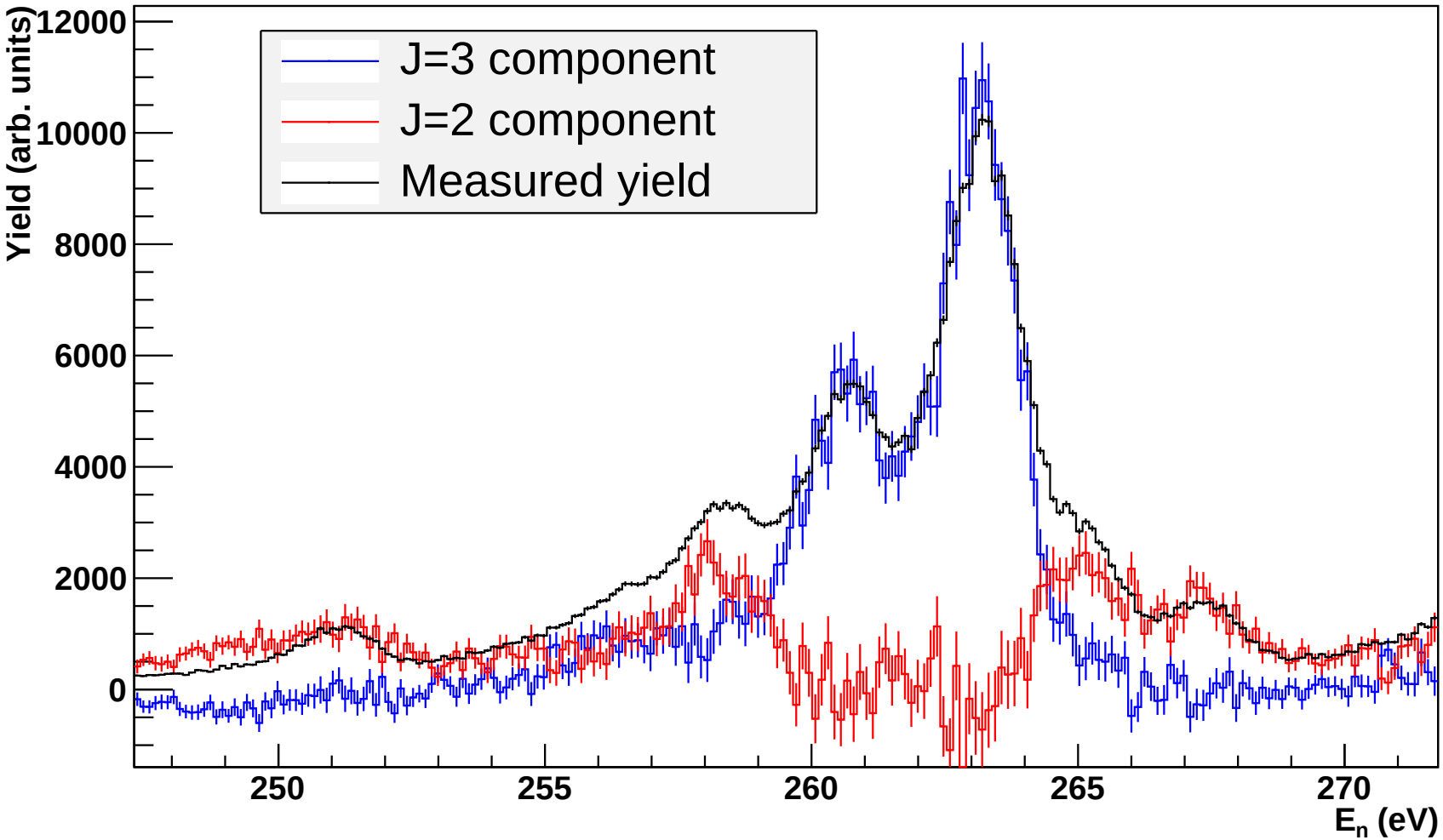
Works up to $\approx$ 440 eV.
Overall good agreement with Atlas of N. Res. by S.F.Mughabghab.
For 114 resonances in ^{161}Dy:

- 24 new assignments - from unknown J to J=2 or J=3
- 1 reassignment - 91.12 eV seems to be J=2 rather than J=3
- several possible close dublets that need futher investigation with help of DICEBOX/GEANT4

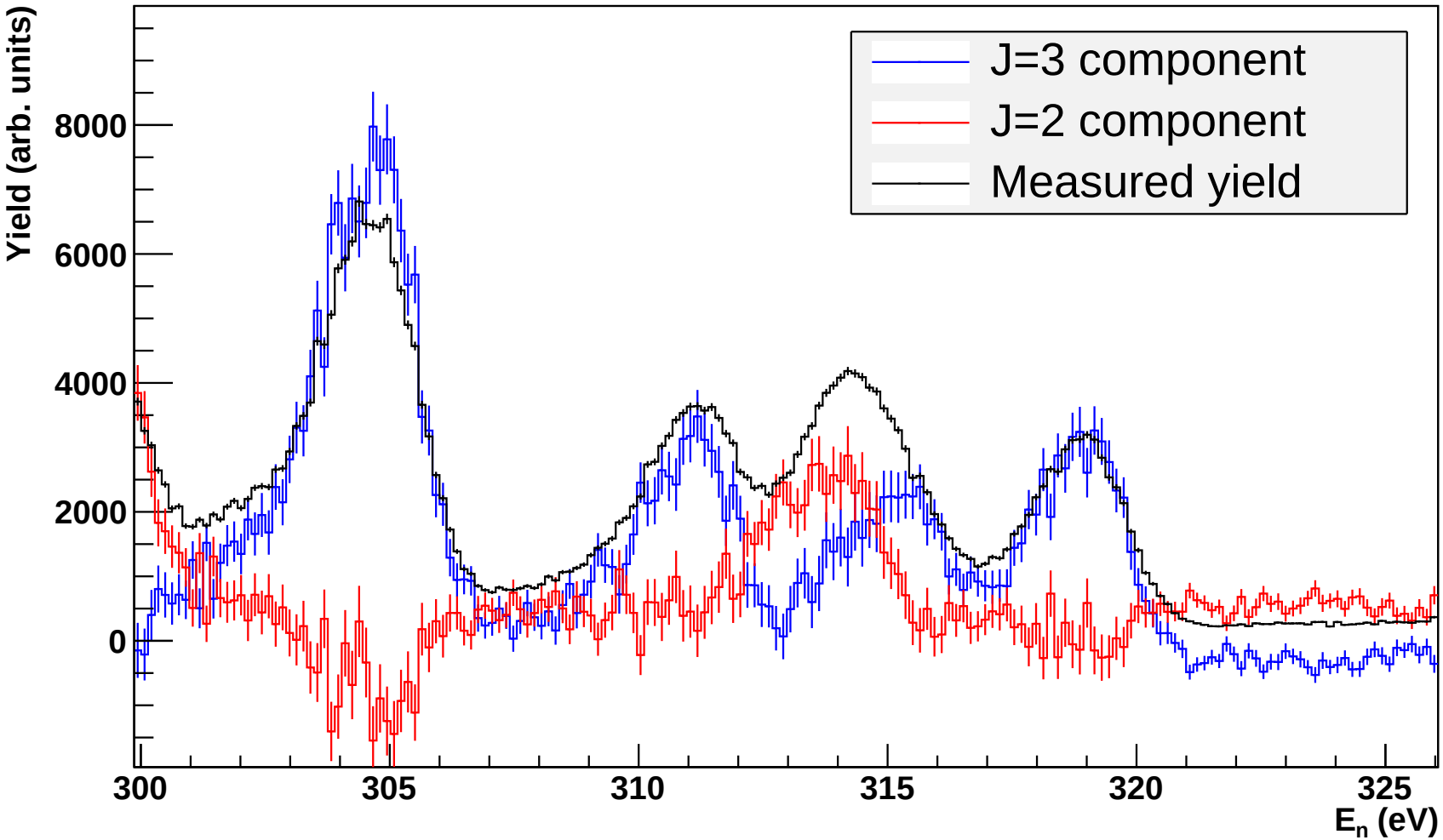
224.43 eV resonance assigned the spin of J=3



256.81 eV and 267.81 eV resonances are J=3,2 respectively



314.78 eV and 315.76 eV resonances are J=2,3 respectively

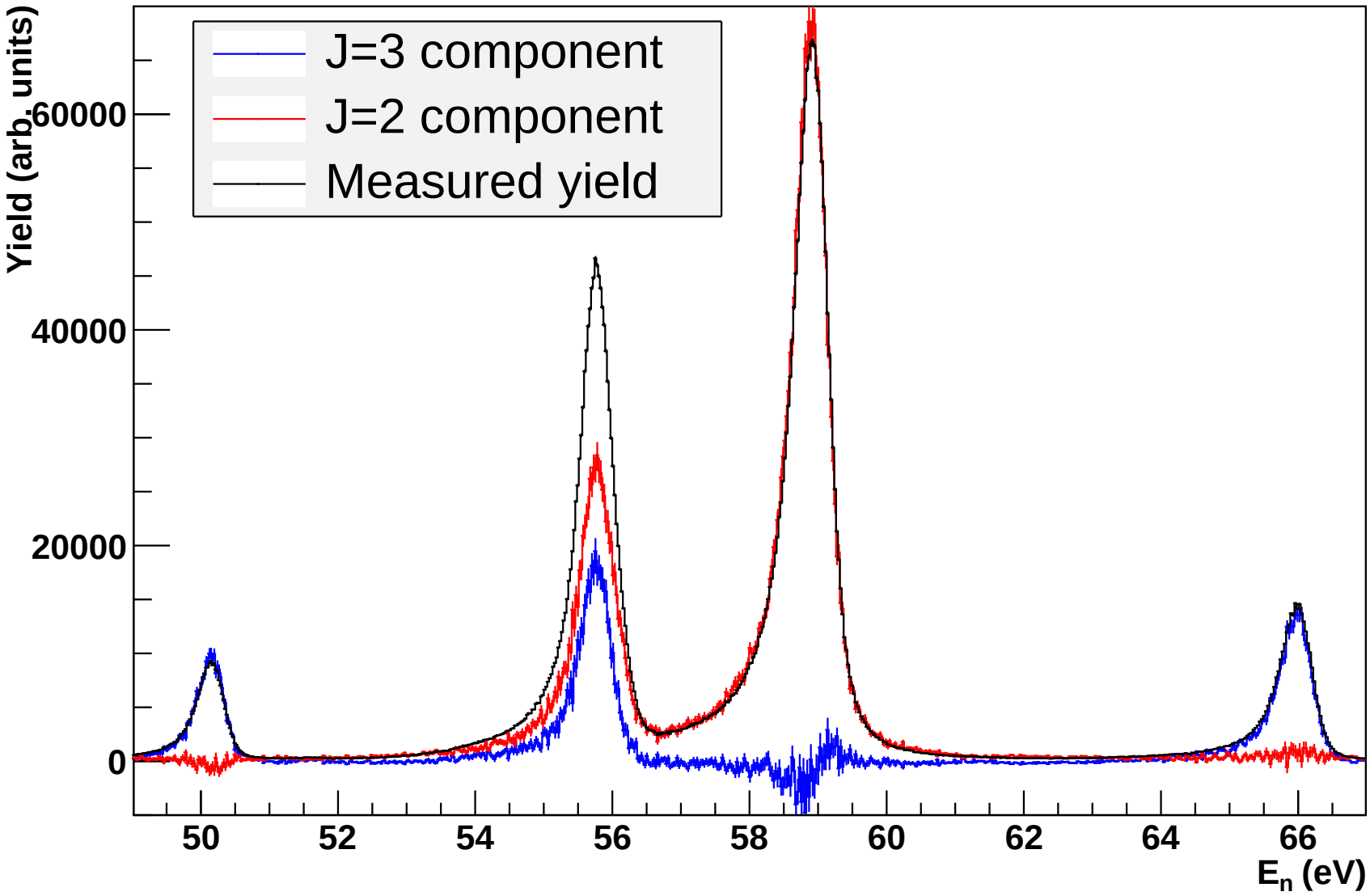


Results for resonance spins in ^{163}Dy

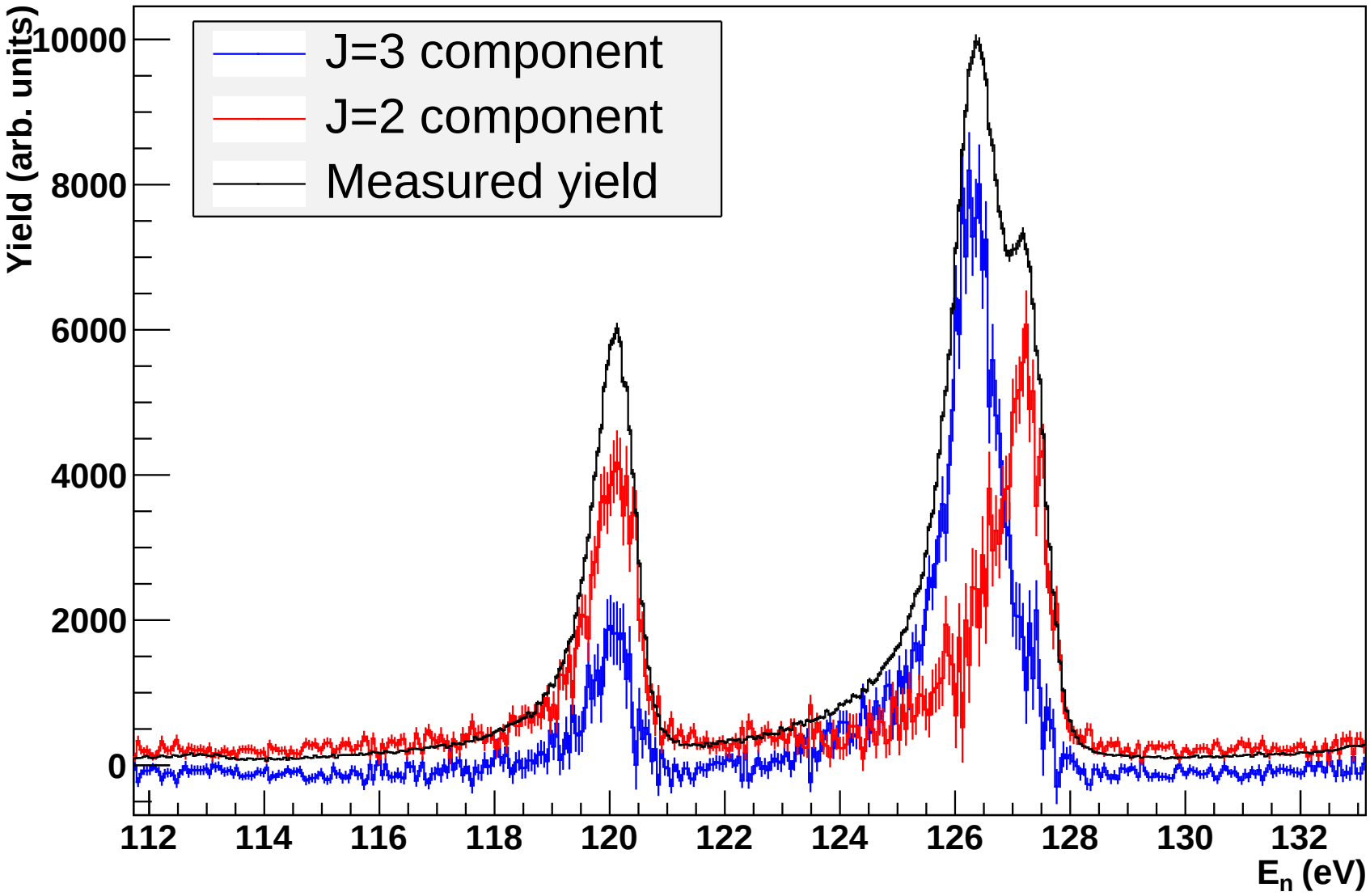
Works up to $\approx$ 950 eV.
Overall good agreement with Atlas of N. Res. by S.F.Mughabghab.
For 102 resonances in ^{163}Dy:

- 5 new assignments - from unknown J to J=2 or J=3
- 6 reassignments - from J=2 to J=3 and vice versa
- several possible close dublets that need futher investigation with help of DICEBOX/GEANT4
- several weak resonances remain inconclusive due to low statistics

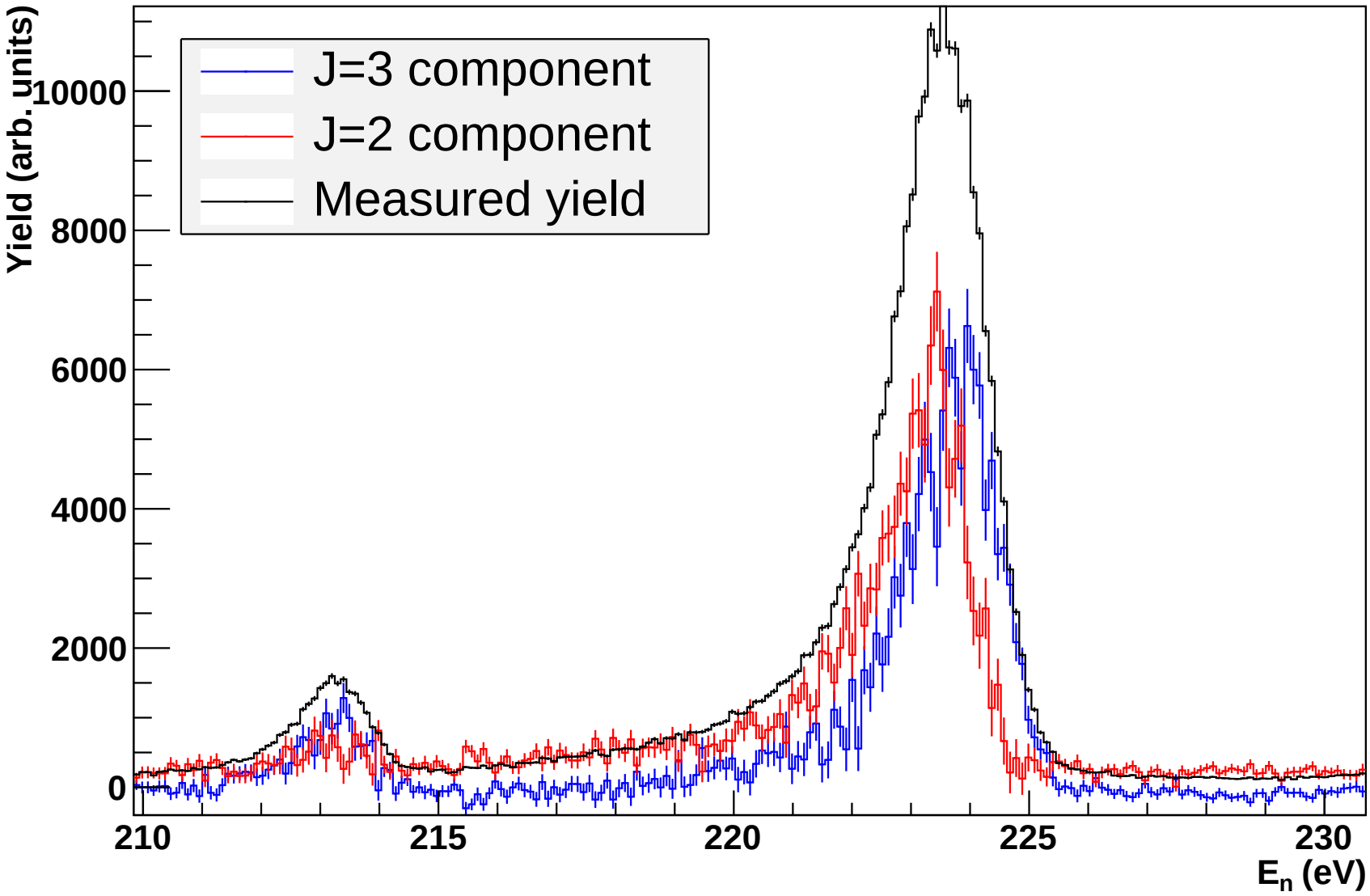
Confirmation of spin on a few non-prototype resonances



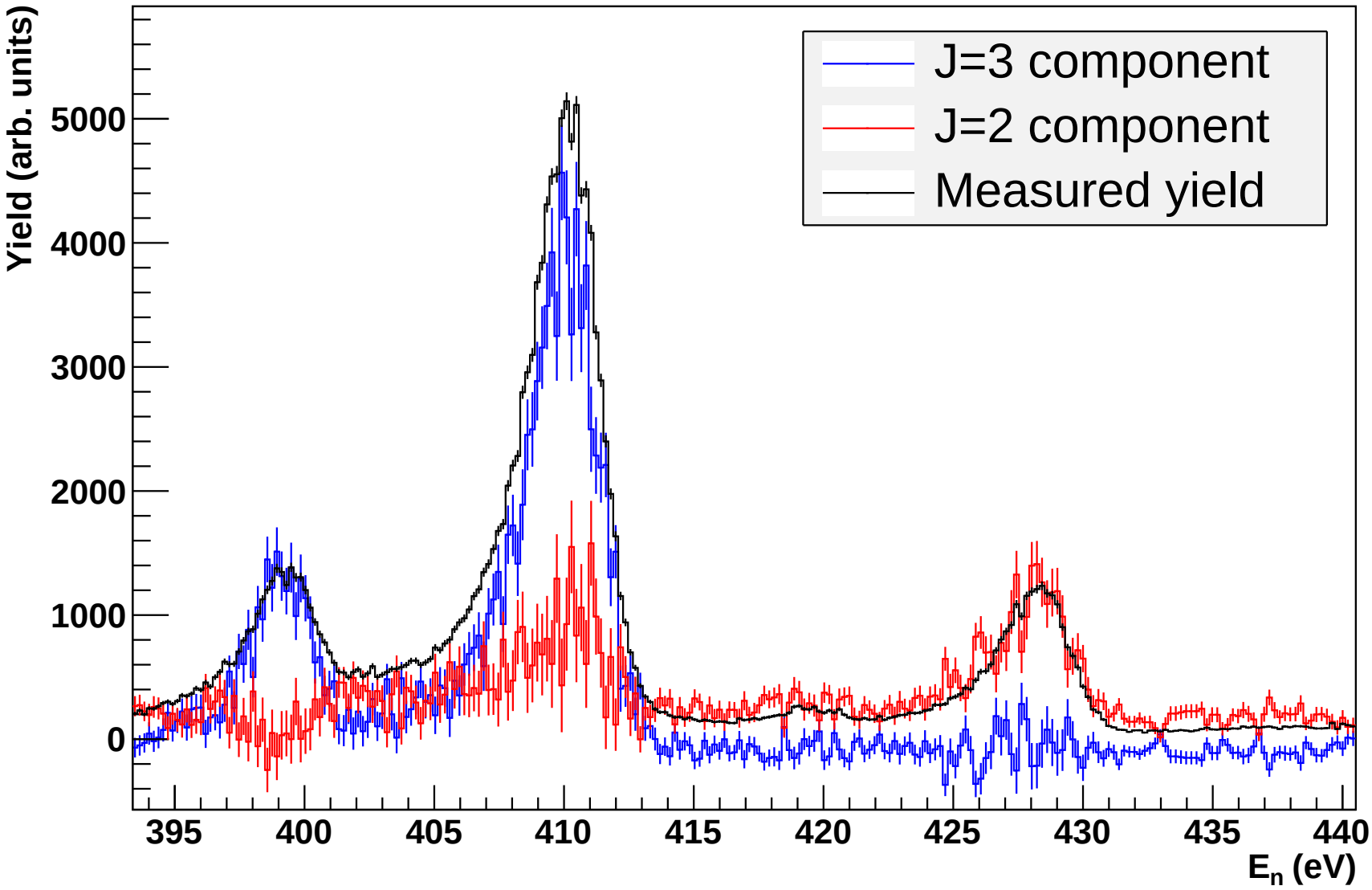
127.46 eV is J=2 not J=3, possible dublet at ≈ 120.33 eV



224.15 eV is not single J=2 resonance but dublet



411.08 eV is J=3 rather than J=2

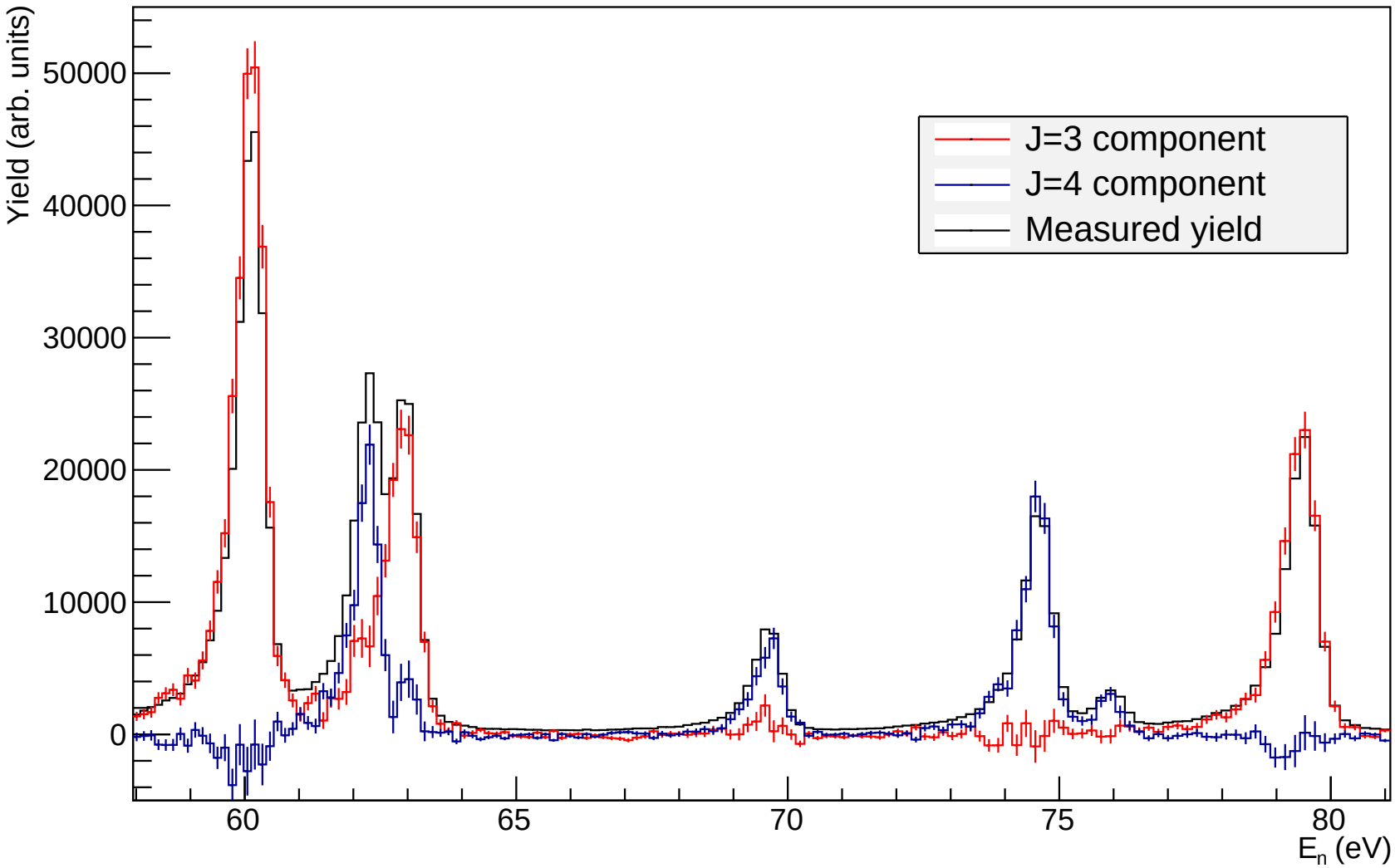


Preliminary results for resonance spins in ^{167}Er

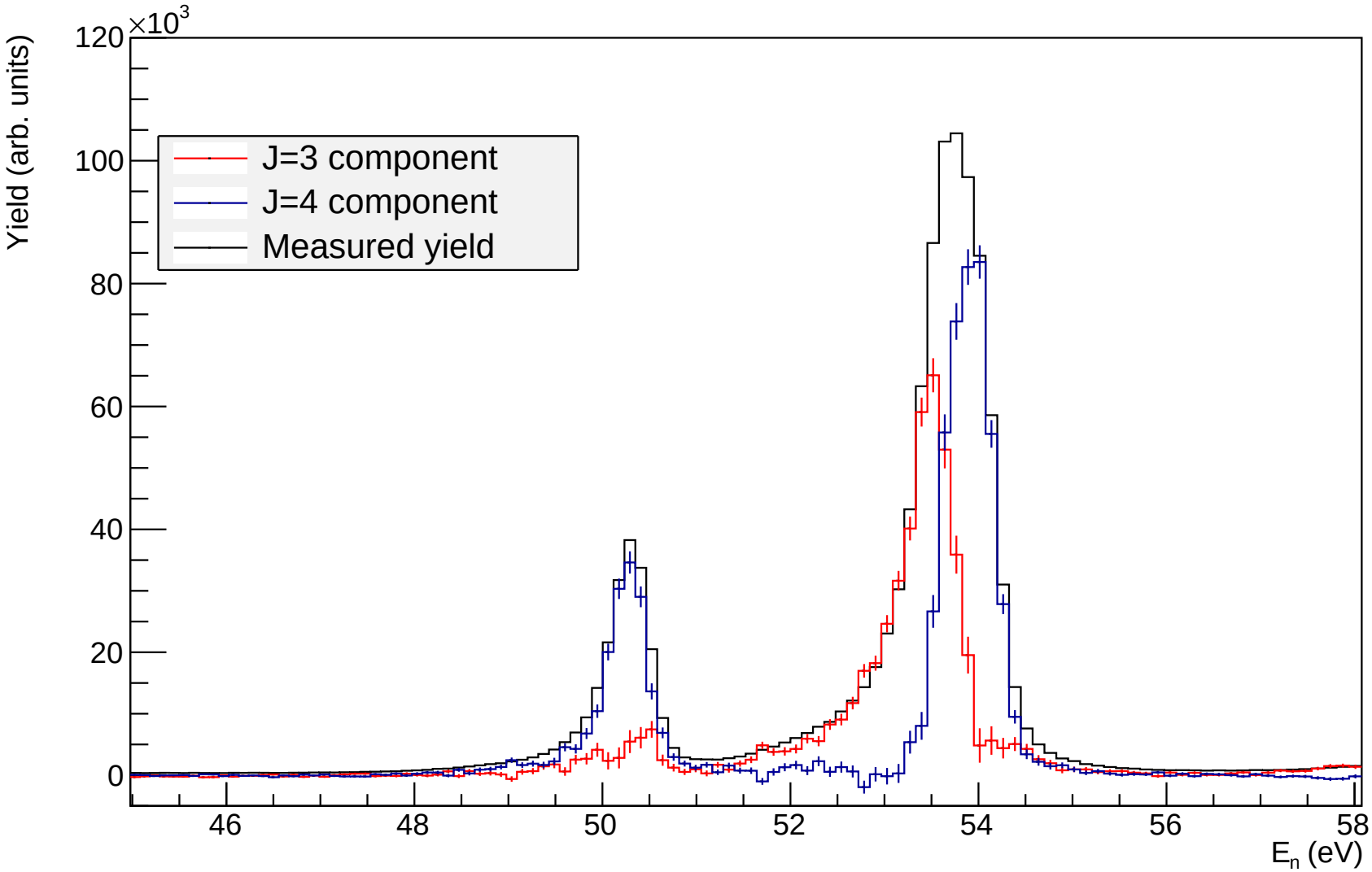
Overall good agreement with Atlas of N. Res. by S.F.Mughabghab.
For 60 resonances in ^{167}Er:

- 3 new assignments - from unknown J to J=3 or J=4
- 4 reassignments - from J=3 to J=4 and vice versa
- several possible close dublets that need futher investigation with help of DICEBOX/GEANT4
- several weak resonances remain inconclusive due to low statistics

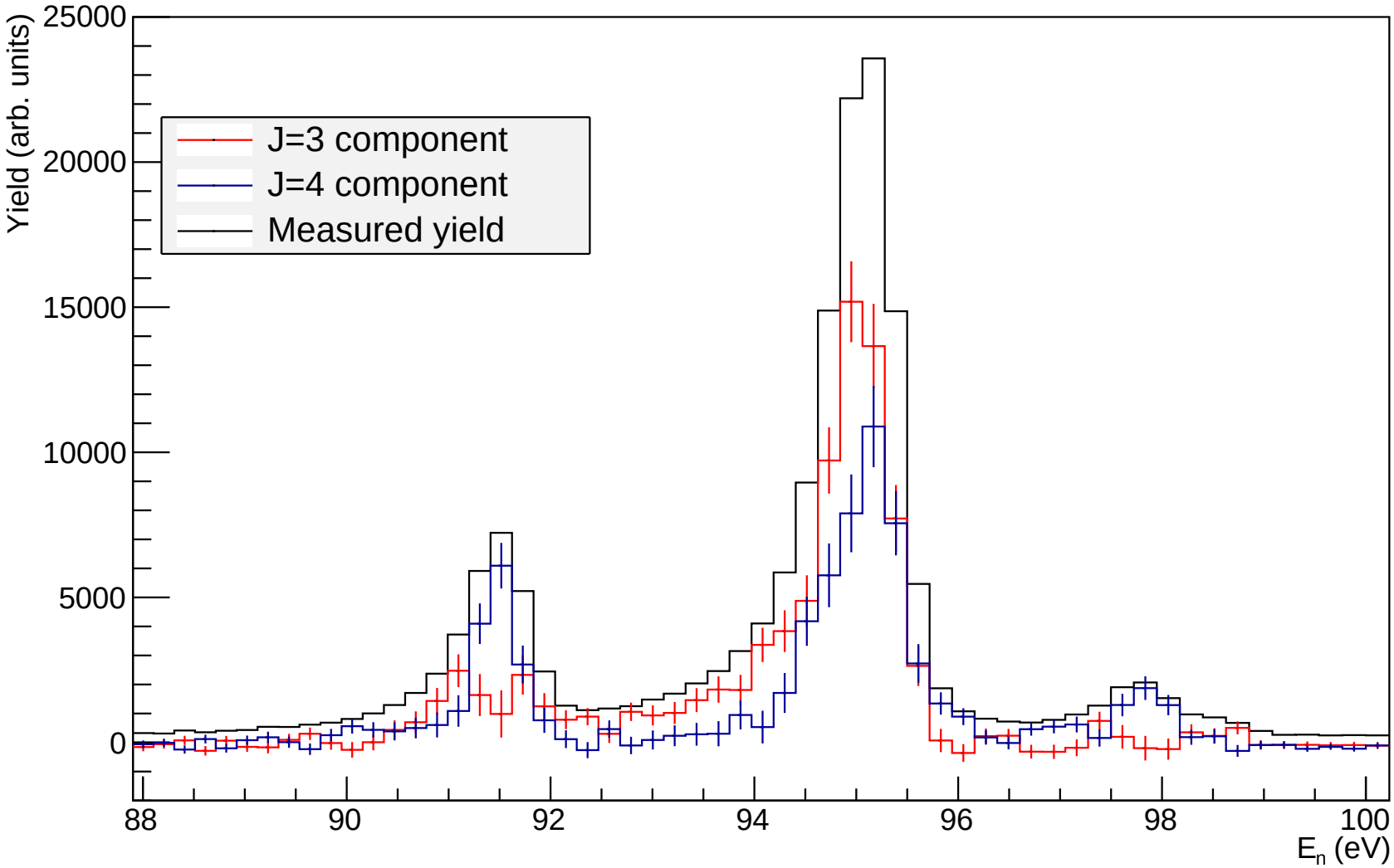
Confirmation of spin on a few non-prototype resonances



Possible dublet at ≈ 53.6 eV



Another dublet at ≈ 94.8 eV



Conclusion and future outlook

- Spin assignment in ^{161,163}Dy and ^{167}Er was carried out
- Overall good agreement with tabulated values
- Resonance spins important for our future ^{167}Er analysis (MSC spectra)