BERKELEY LAB

Lawrence Berkeley National Laboratory

U.S. DEPARTMENT OF ENERGY

UNIVERSITY OF CALIFORNIA

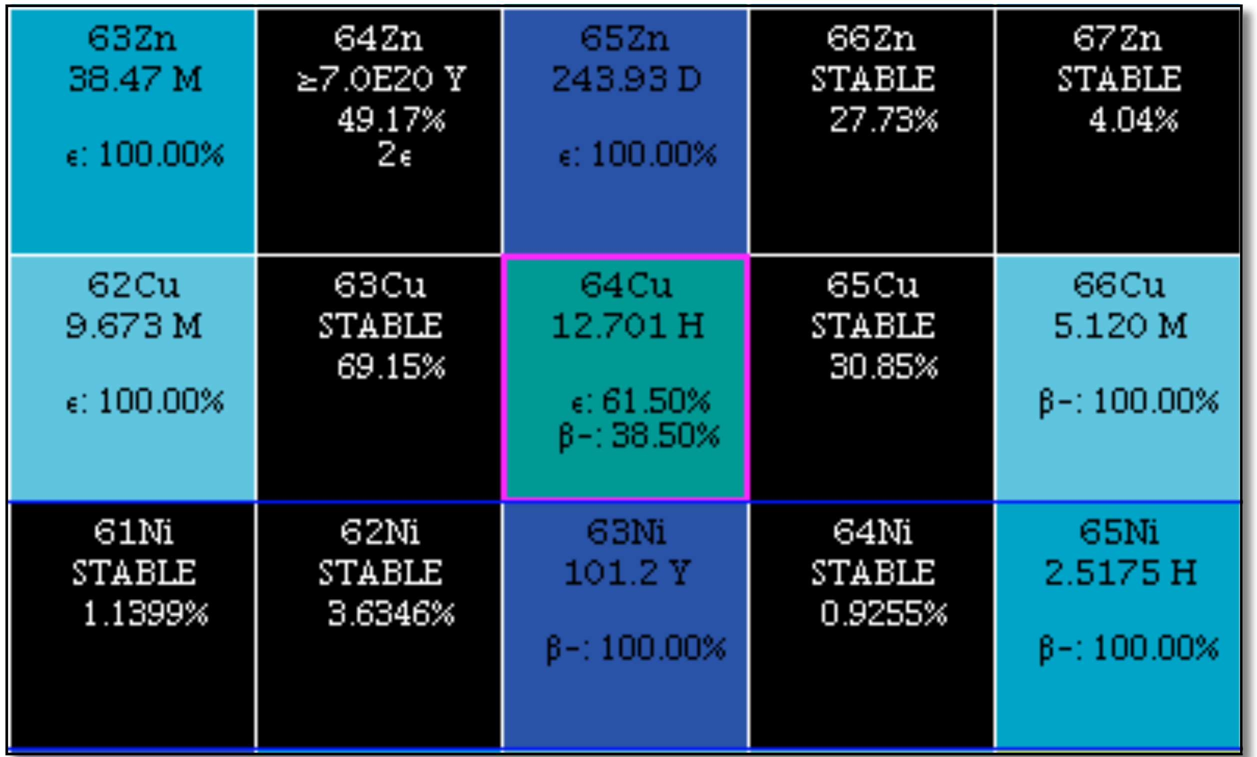
Thermal Neutron Capture of ^{64,66}Cu

Andrew M. Rogers
Nuclear Science Division
Lawerence Berkeley National Laboratory

USNDP / CSEWG
11-08-2012

Outline

- Introduction
  - Motivation and method
  - DICEBOX
- Experimental setup (Budapest research reactor)
- Preliminary analysis ^{65}Cu(n,γ)^{66}Cu
- Summary and outlook



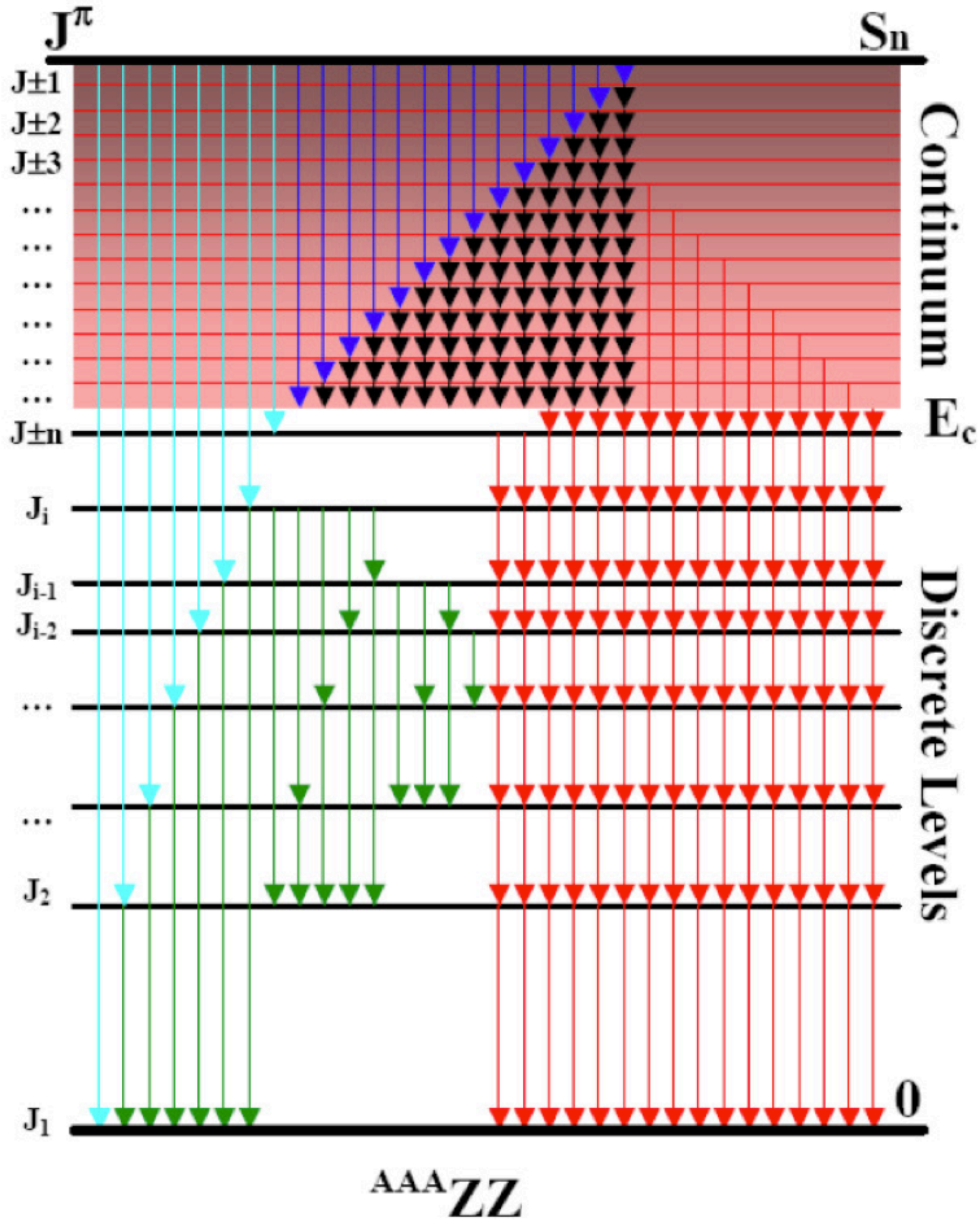
PRELIMINARY

Motivation and Method

- General improvements in the total radiative neutron-capture cross sections (σ_0).
- Constrain spins, search for new transitions, and etc..
- Method:
  - Experimental data of thermal (n,γ) cross sections on *elemental* Copper samples.
  - Generate simulated neutron capture decay schemes using the statistical decay code DICEBOX.
  - Compare measured *depopulation* from experiment to the *population* of levels generated by DICEBOX.

$$\sigma_0 = \Sigma\sigma_\gamma^{\mathrm{exp}}(\mathrm{g.s.}) + \Sigma\sigma_\gamma^{\mathrm{sim}}(\mathrm{g.s.})$$

DICEBOX

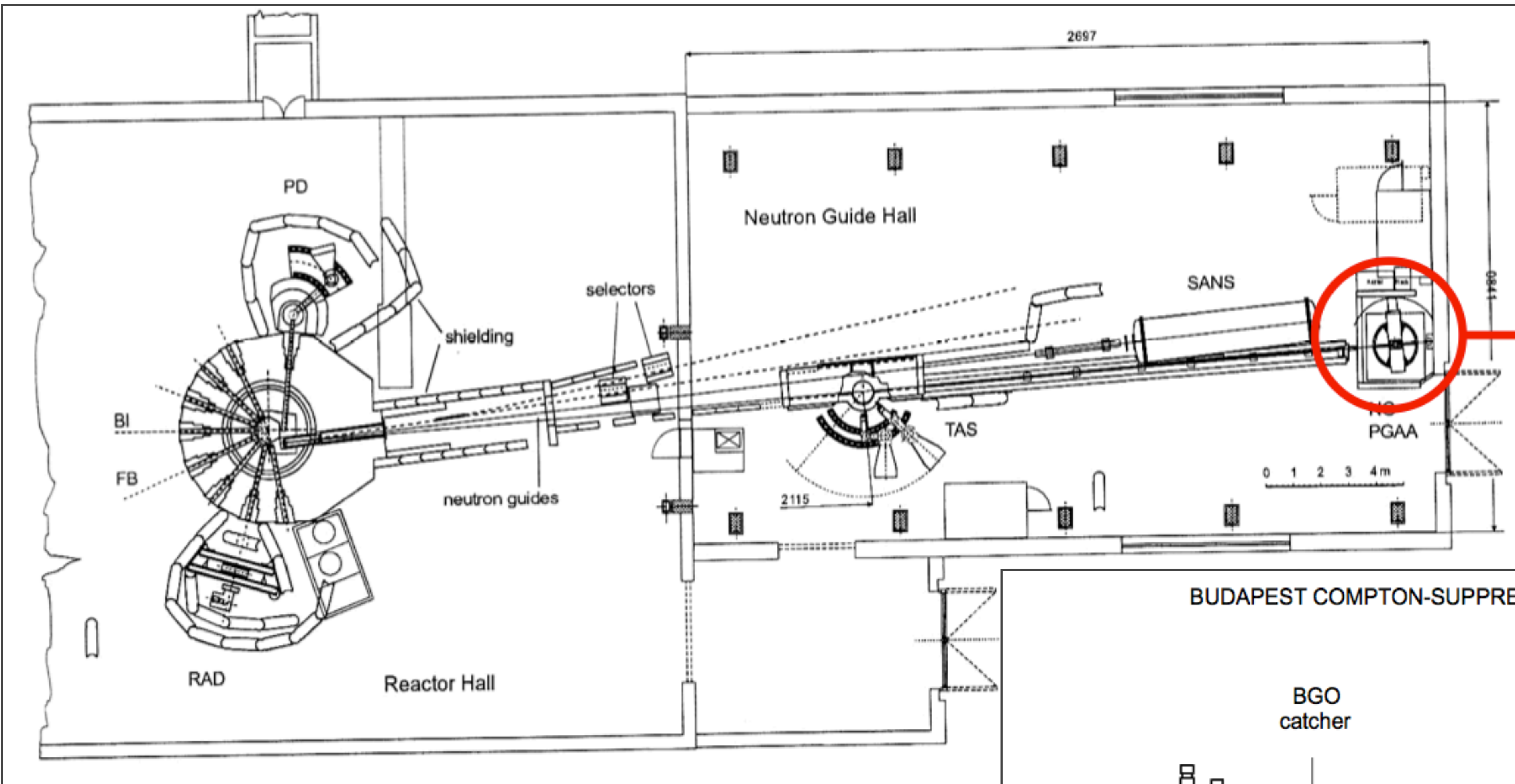


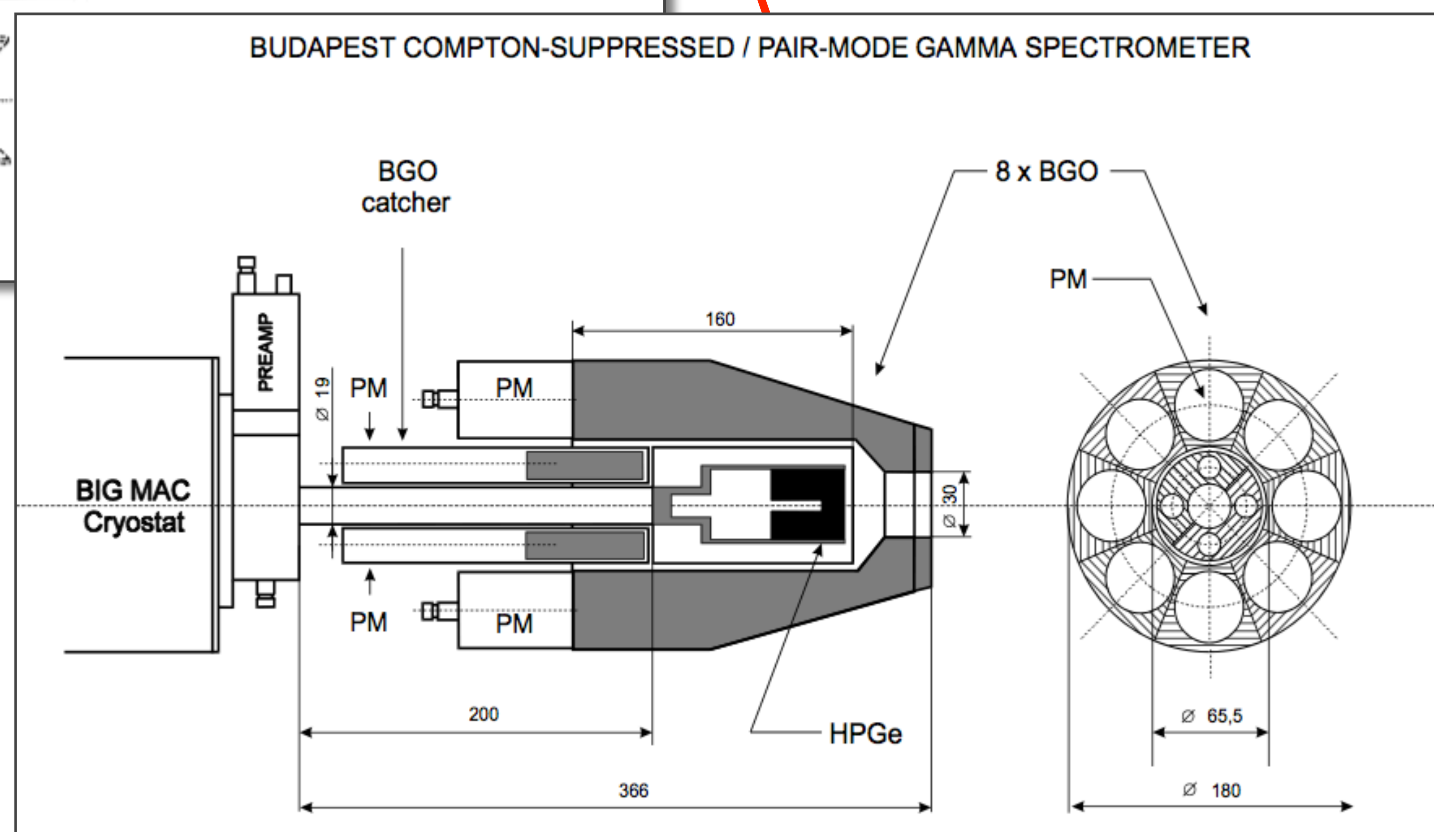
- Simulates spectra of nuclear *γ* cascades using Monte Carlo methods.
- Below a *critical energy*, E_{crit}, the spectrum is considered to be complete.
- Above E_{crit},
  - Sets of levels are generated from a known level-density formula $\rho(E,J^{\pi})$
  - Samples and incorporates uncertainties due to Porter-Thomas fluctuations.

Experimental setup - research reactor

- 10-MW Budapest research reactor
- Guided thermal-neutron beam
- Thermal flux: $\sim 10^6$ $cm^{-2}s^{-1}$
- Cold flux: $\sim 10^7$ $cm^{-2}s^{-1}$
- PGAA (Prompt Gamma Activation Analysis)
- Primary and secondary capture γ rays measured in low-background environment.
- No epithermal, fast, or high-energy neutrons!!!

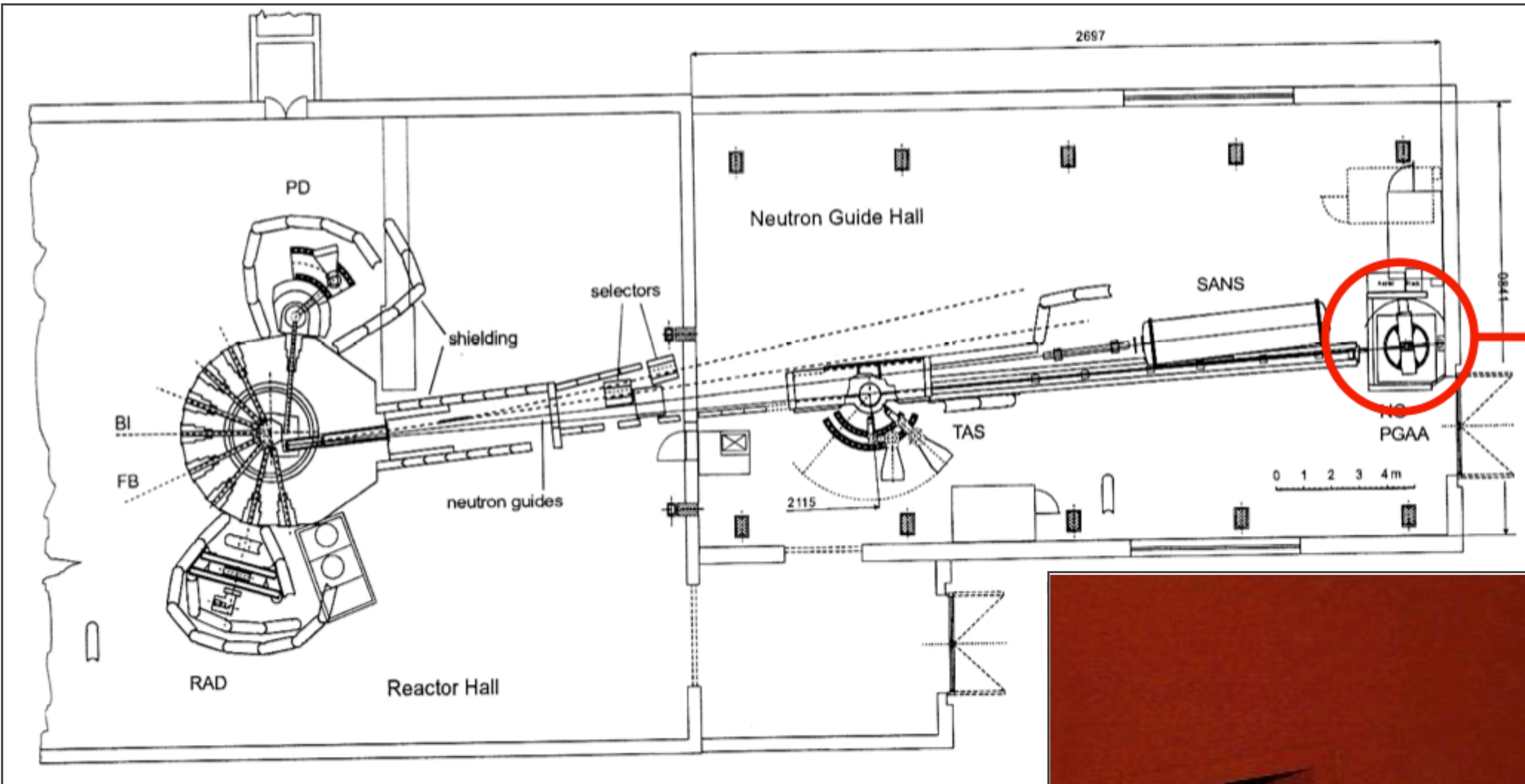
Experimental setup - beamline





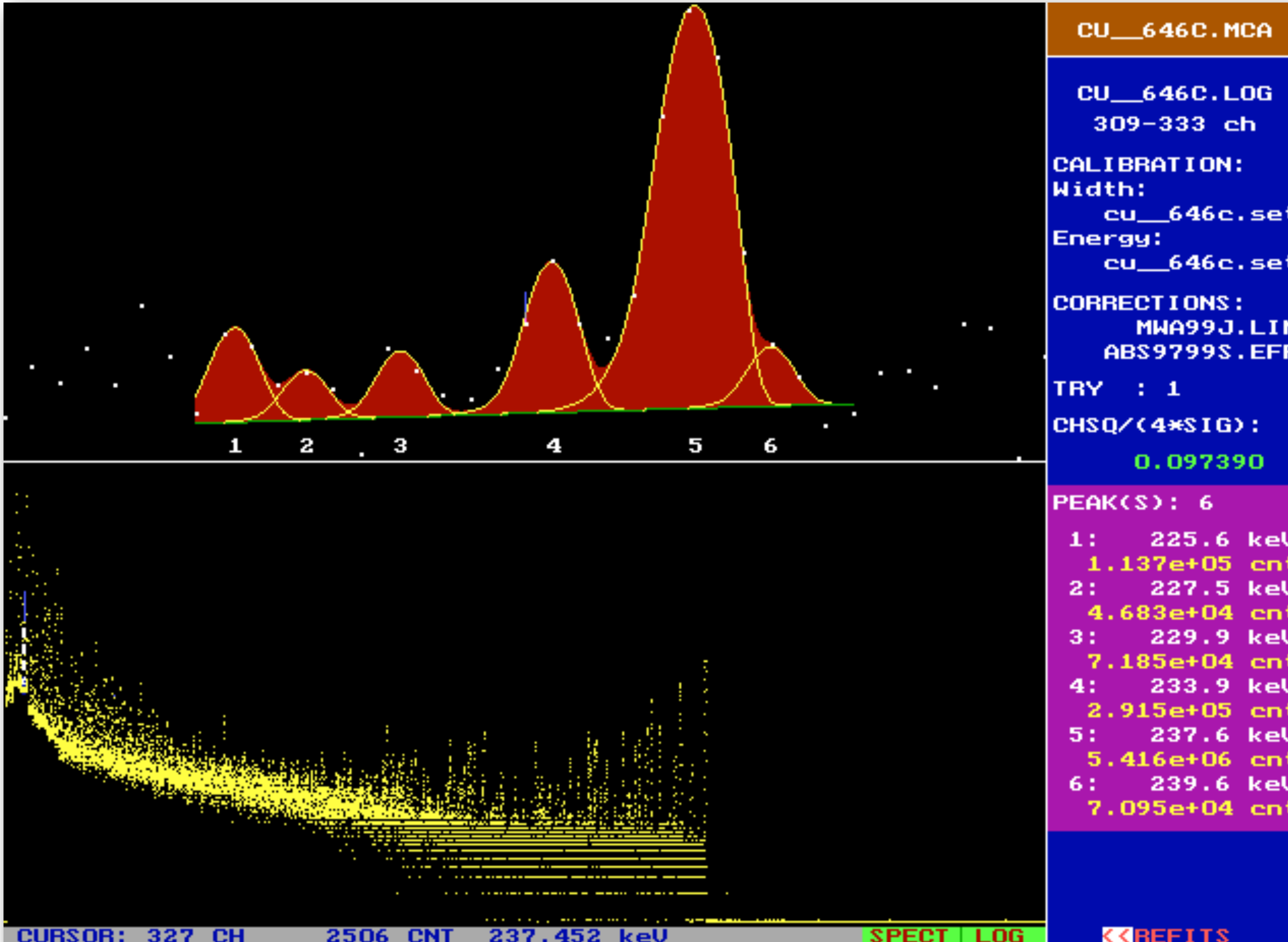
- Experimental setup is located ~35 m from the reactor wall.
- HpGe detector (closed-end coaxial) located ~23 cm from target.
- Compton-suppressed, shielded with BGO detectors.

Experimental setup - beamline

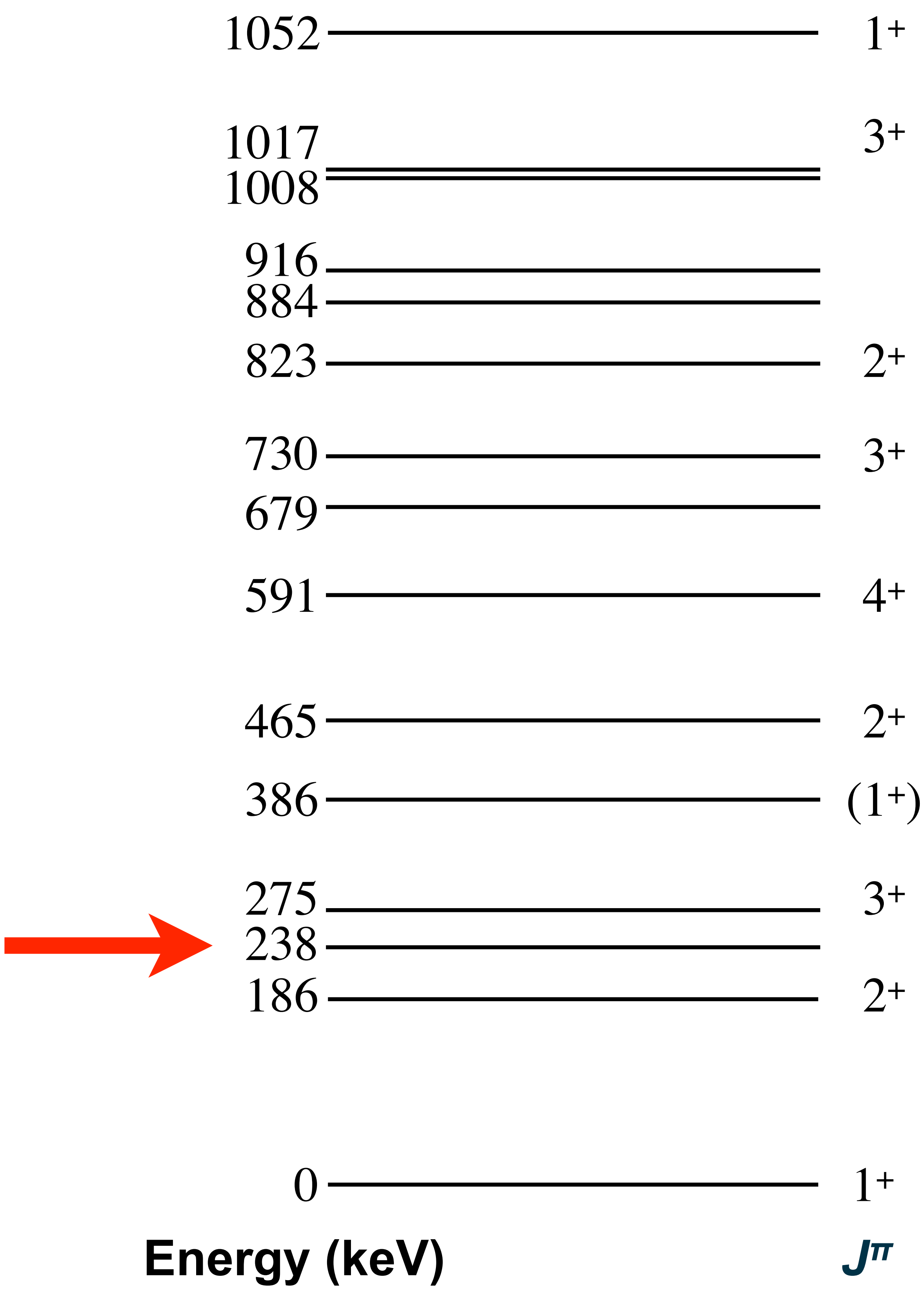


- Experimental setup is located ~35 m from the reactor wall.
- HpGe detector (closed-end coaxial) located ~23 cm from target.
- Compton-suppressed, shielded with BGO detectors.

Copper (n,γ) thermal-capture spectrum



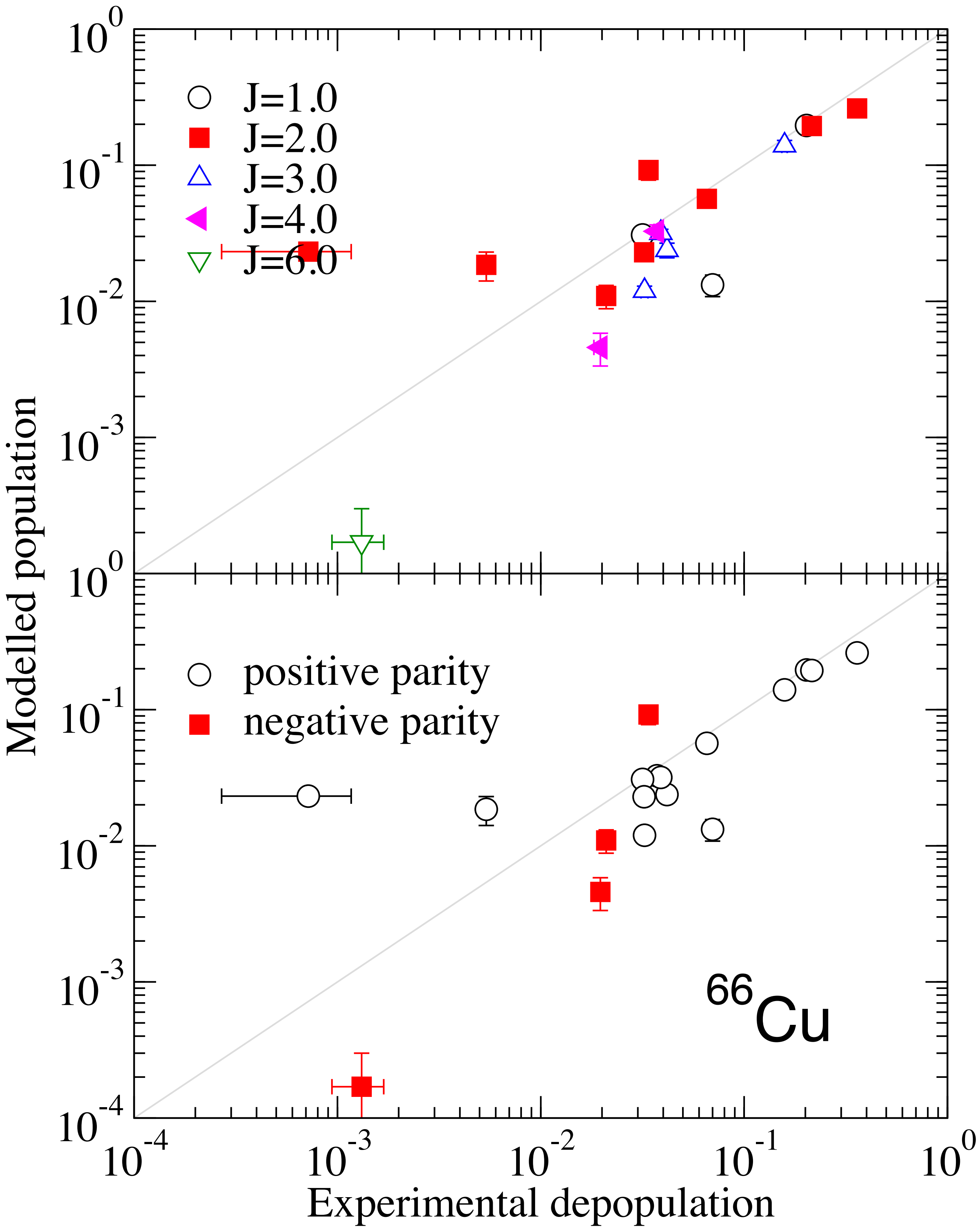
^{66}Cu ENSDF level scheme



- Last evaluation done in 2009.
- Low-lying 2nd excited state at 238 keV has unknown J^{π}.
- Total thermal-neutron capture cross section (*S.F. Mughabghab 2006*)

  σ_0 = 2.17±0.03 b
  S_n = 7066.7±0.8 keV
- ^{65}Cu spin state $3/2^-$
- RIPL: E_{crit} = 186 keV
  $J^{\pi} = 2^-$

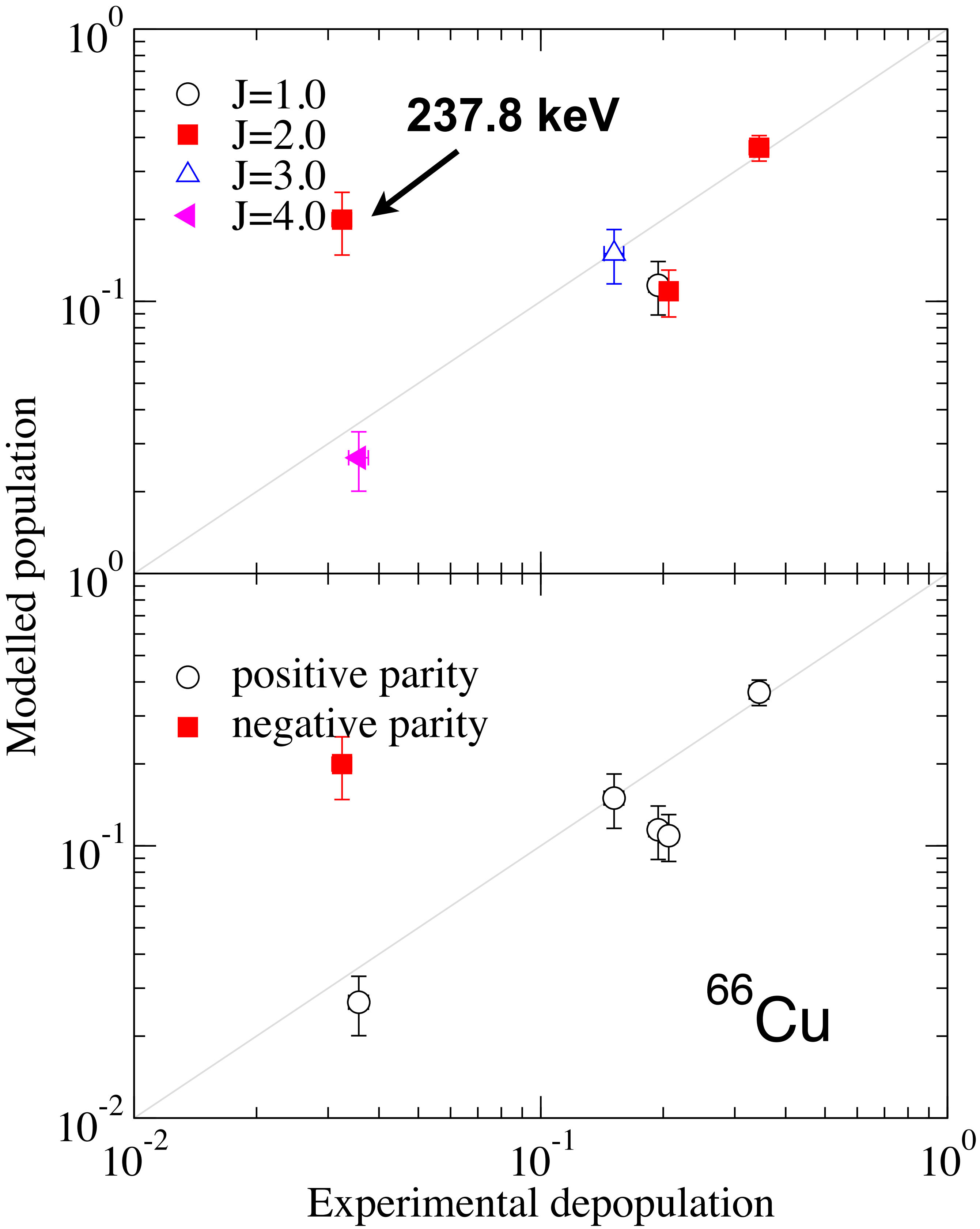
^{66}Cu DICEBOX: ENSDF and RIPL



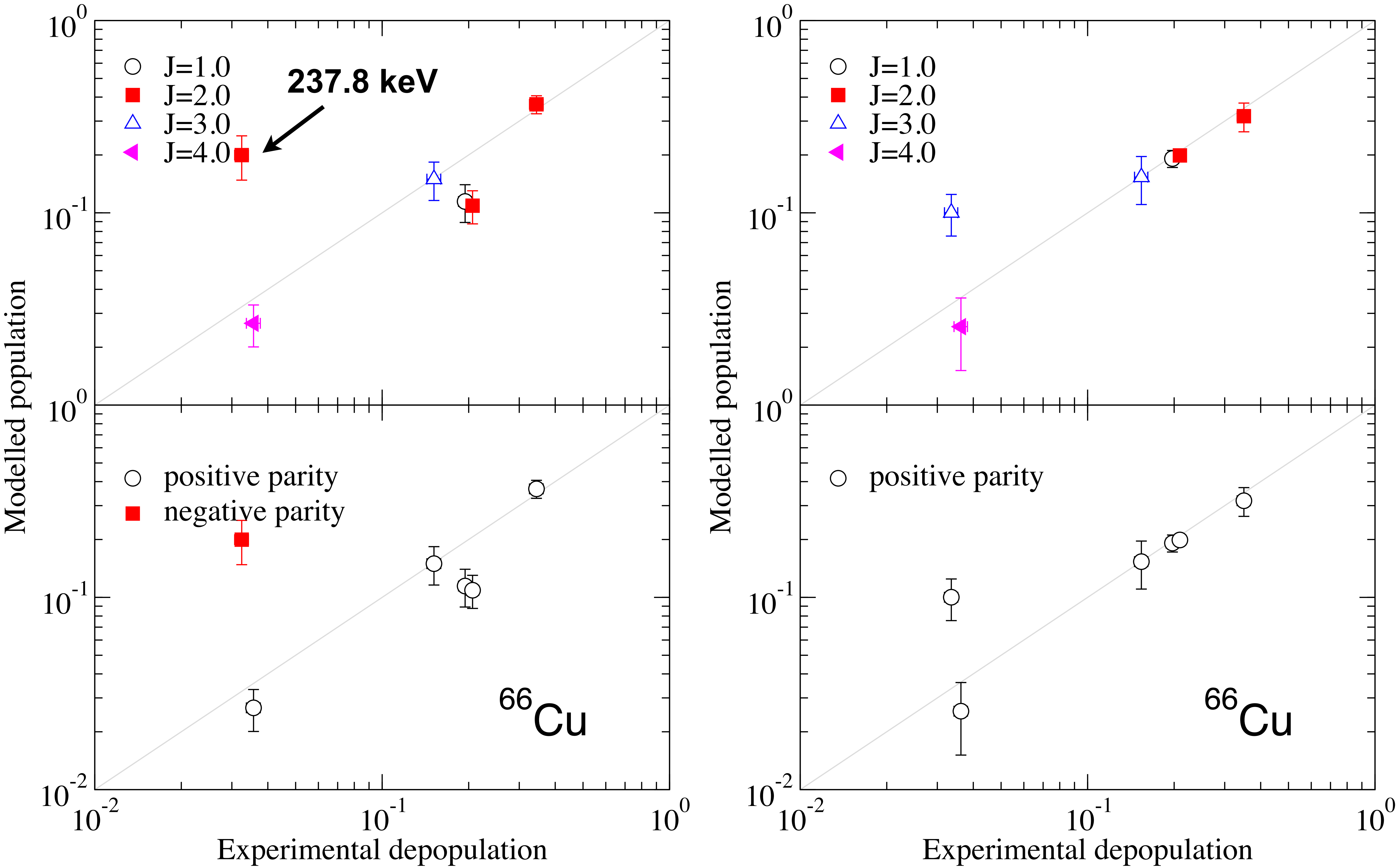
- Included 22 levels
- E_{crit} = 1547.4 keV
- Poorly reproduces the DICEBOX calculations.
- Total-capture cross section

  σ_0 = 2.19±0.05 b

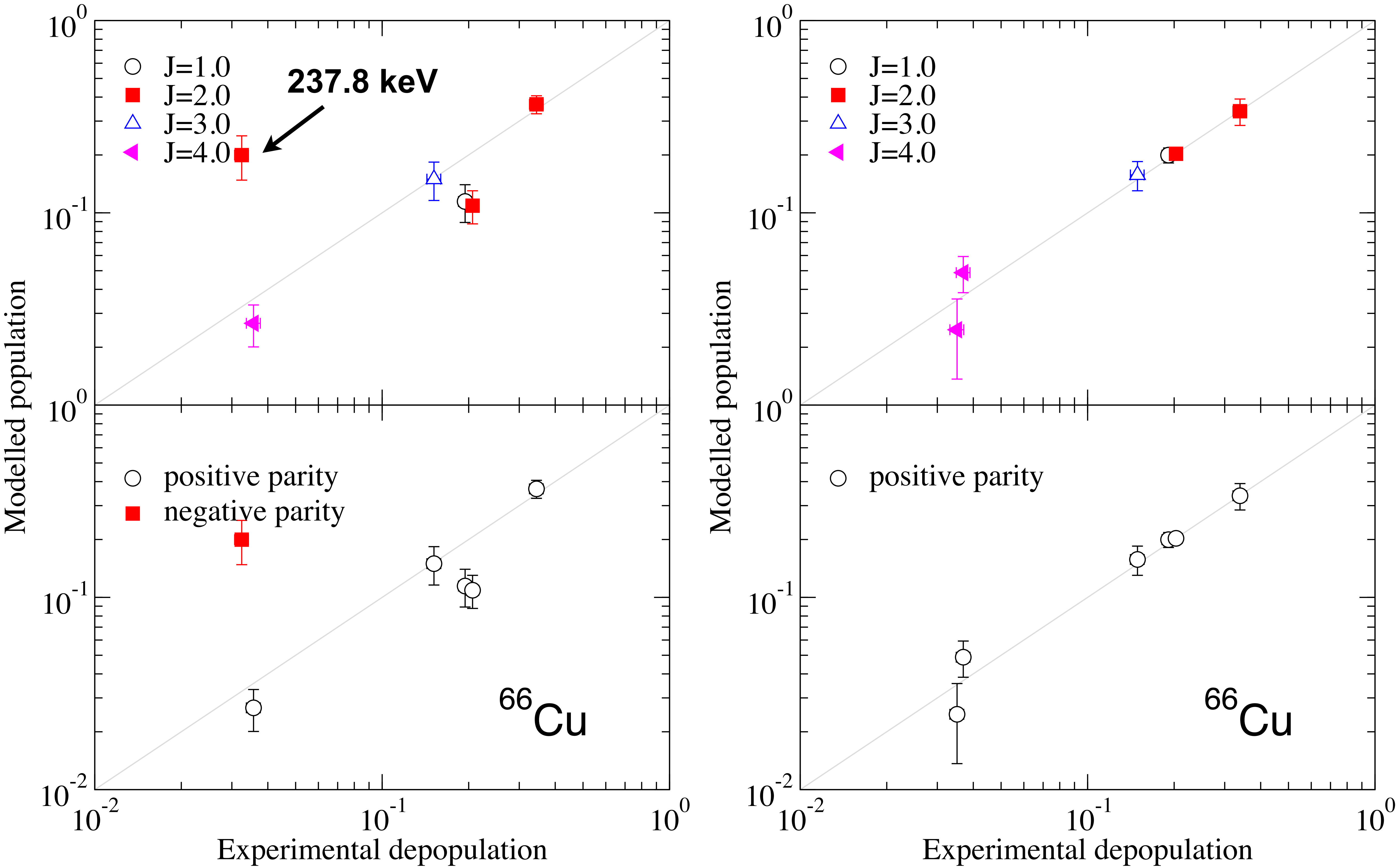
^{66}Cu DICEBOX: E_{crit} = 591 keV



^{66}Cu DICEBOX: E_{crit} = 591 keV

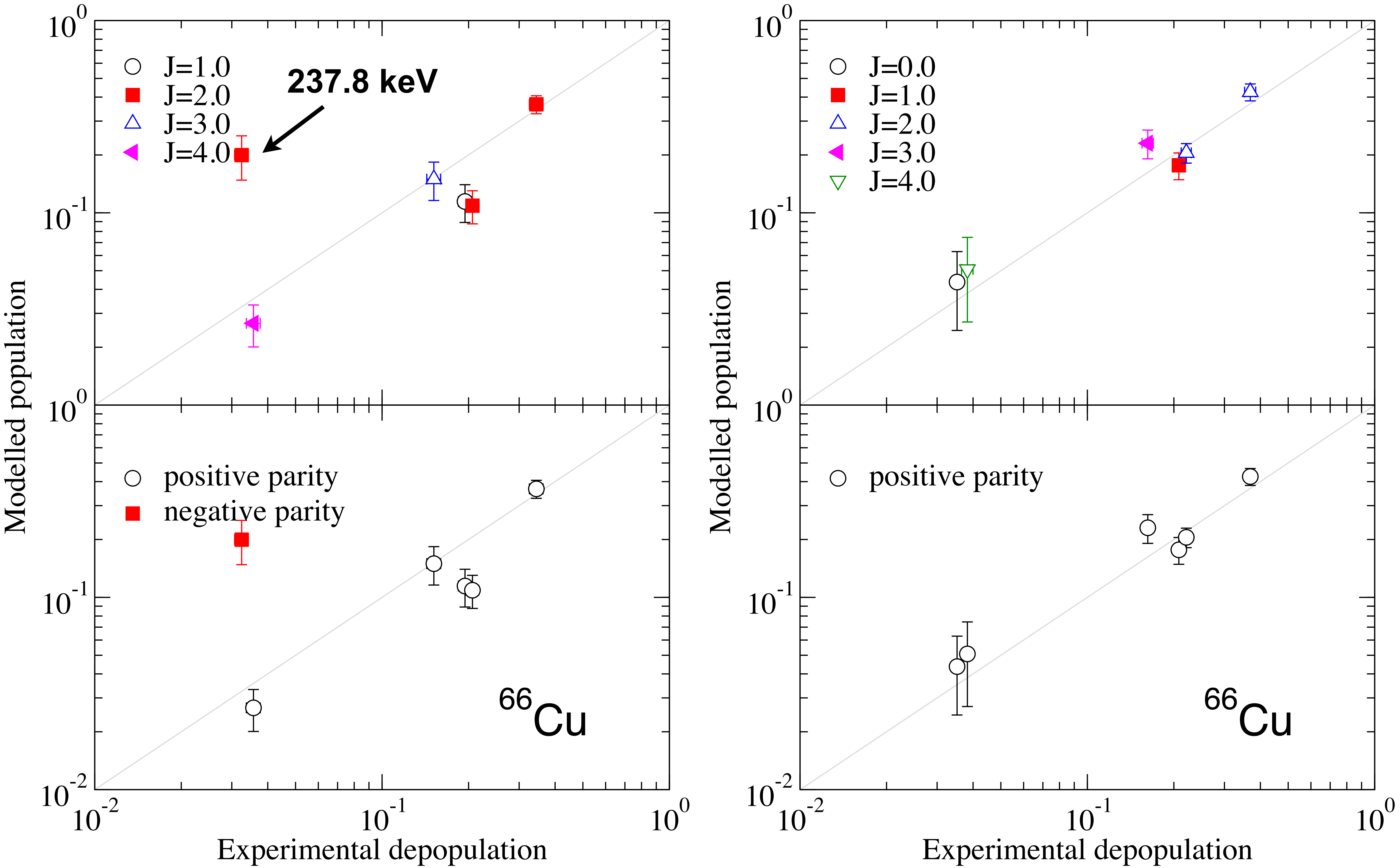


^{66}Cu DICEBOX: E_{crit} = 591 keV

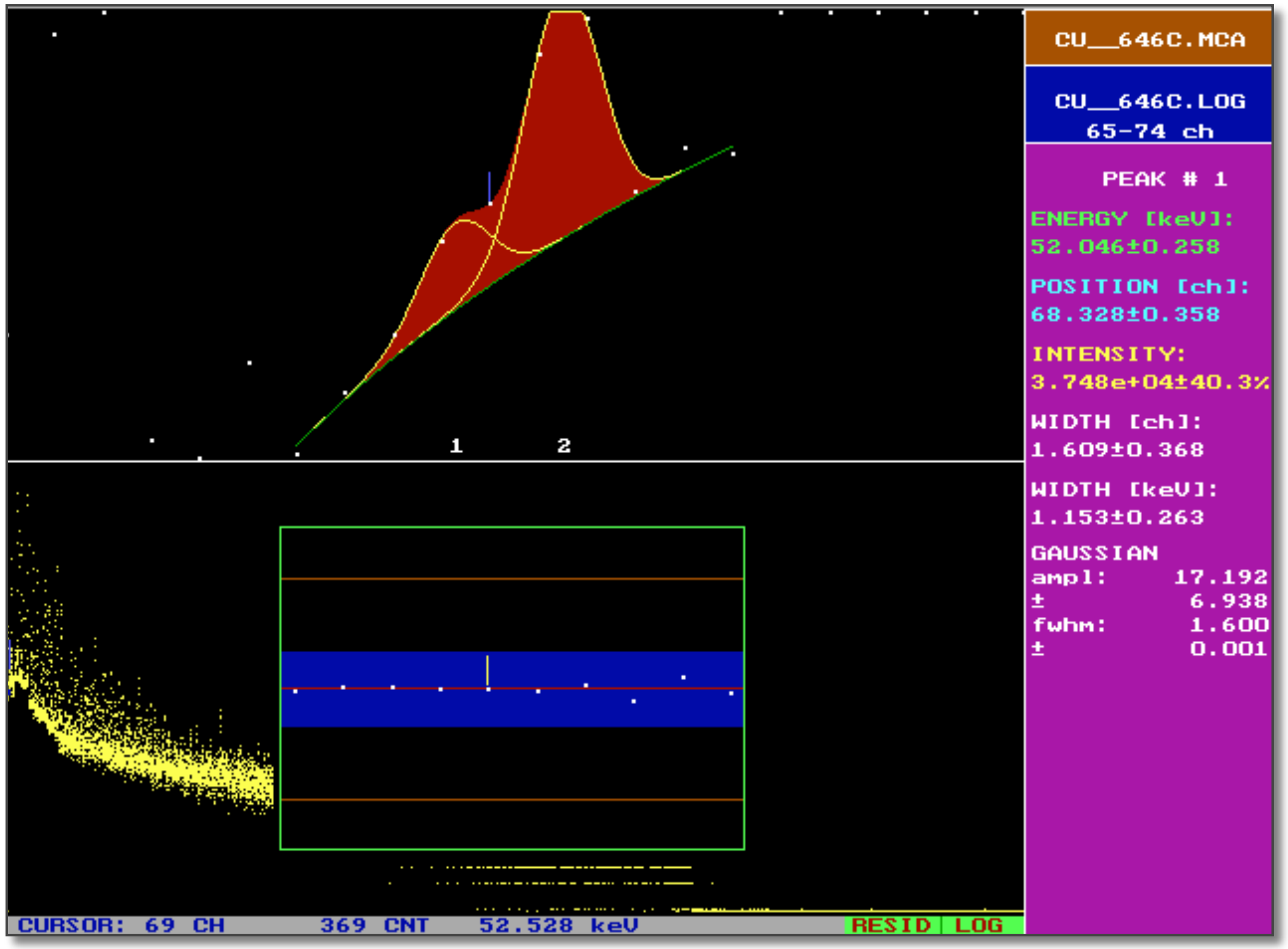


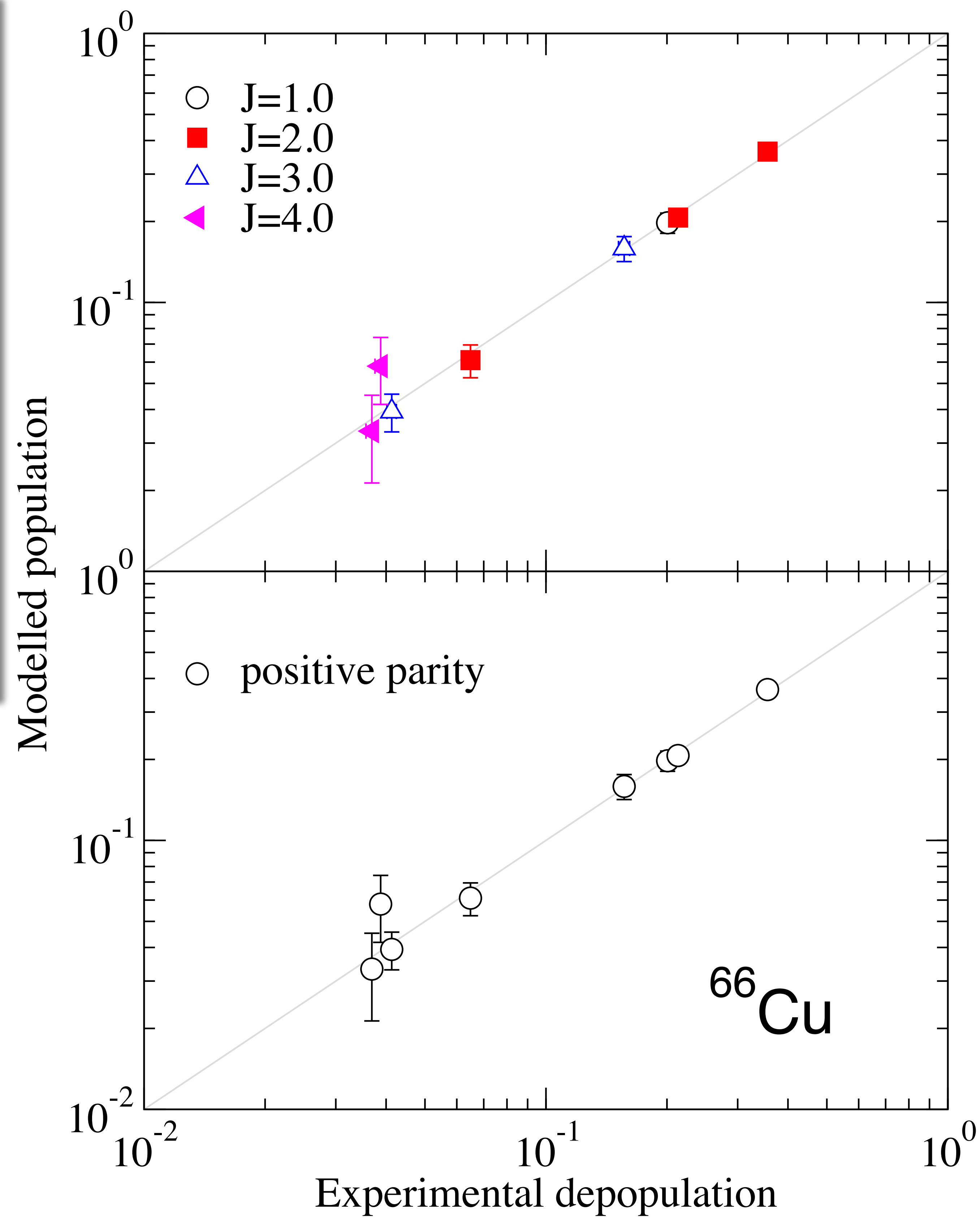
^{66}Cu DICEBOX: E_{crit} = 591 keV

BERKELEY LAB
Lawrence Berkeley National Laboratory



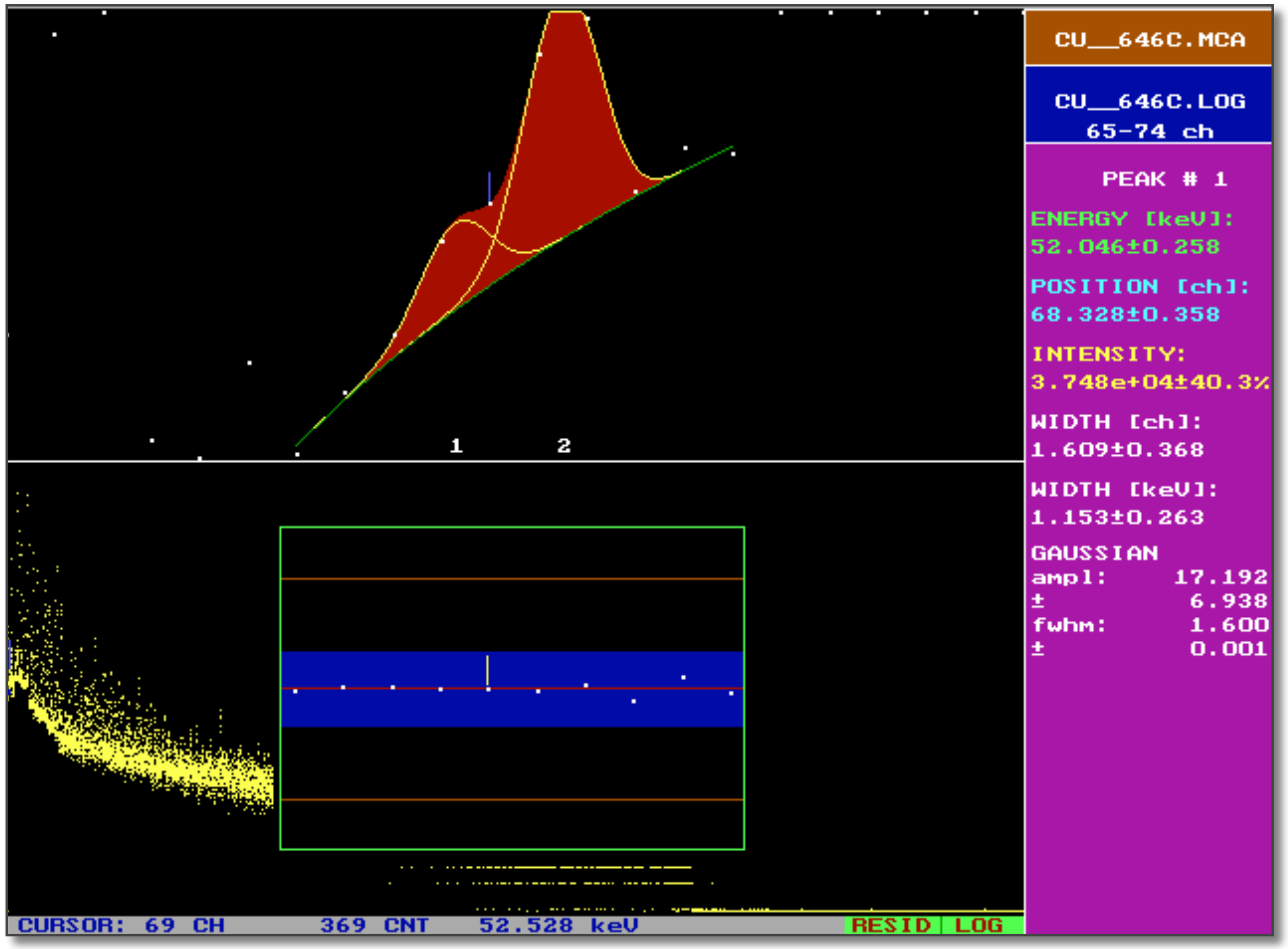
^{66}Cu DICEBOX results

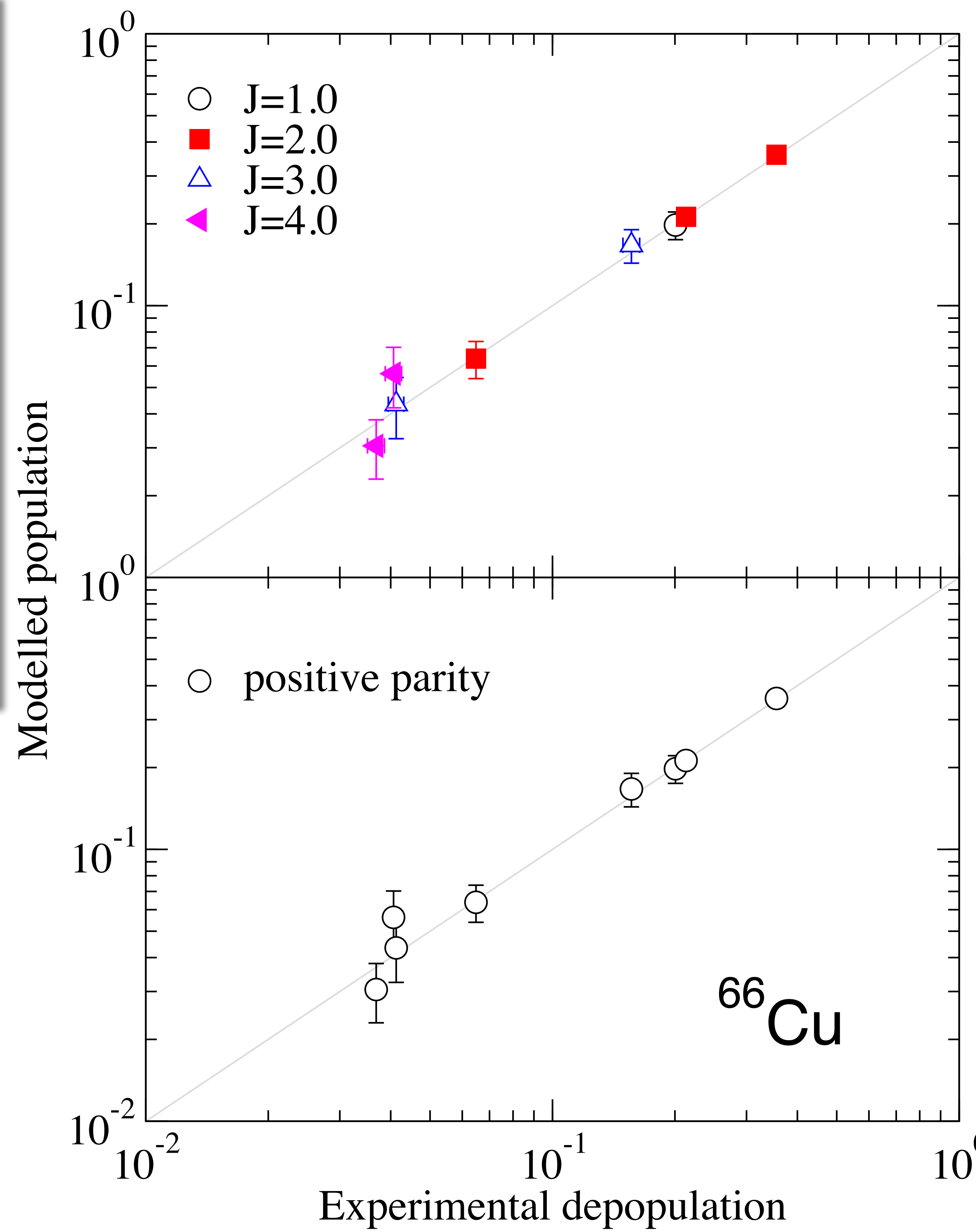




- Included 10 levels
- E_{crit} = 822.7 keV
- Indications of a new transition at 52 keV?
- σ_0 = 2.27±0.08 b **(2.17±0.03 b)**

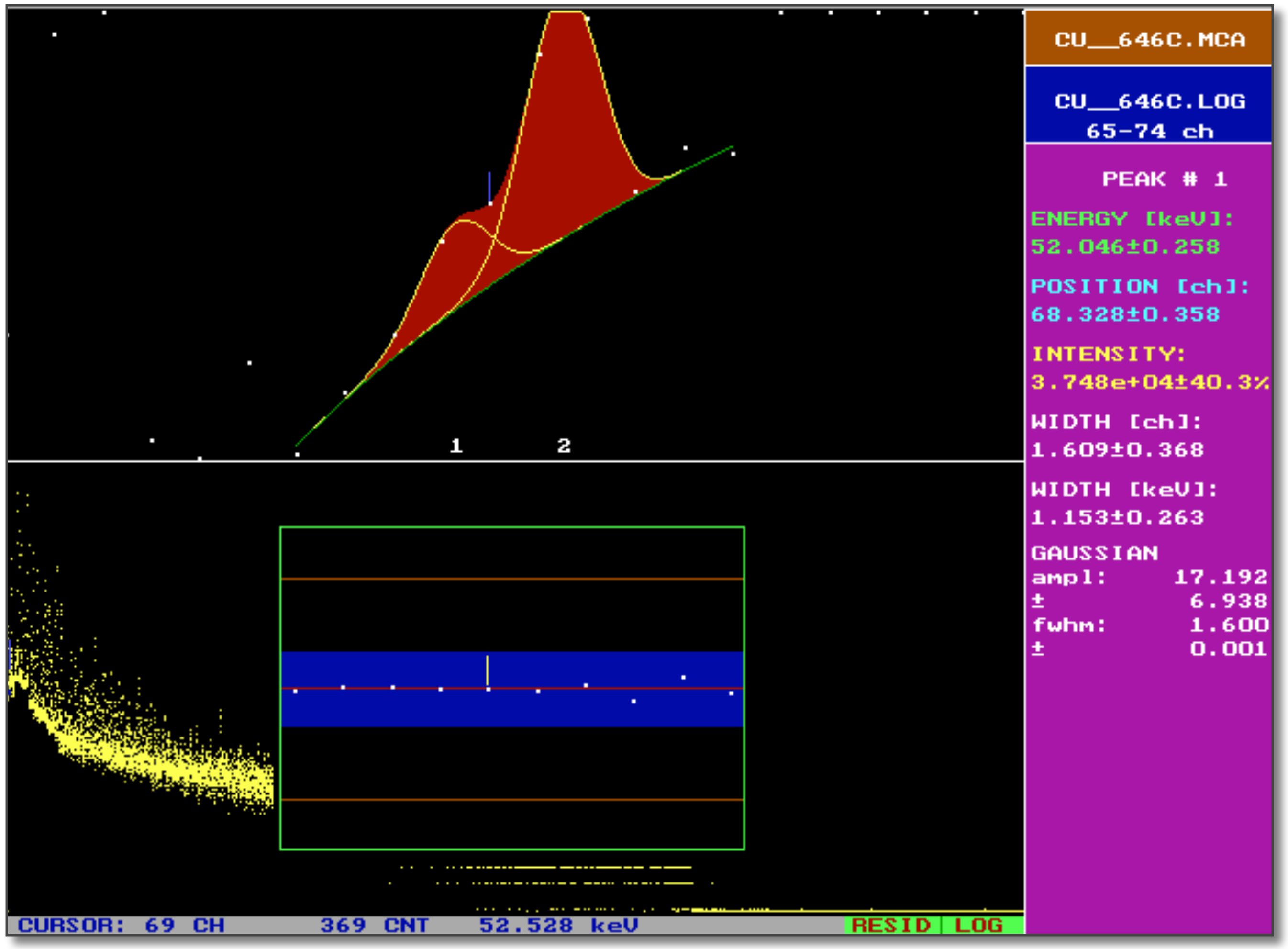
^{66}Cu DICEBOX results

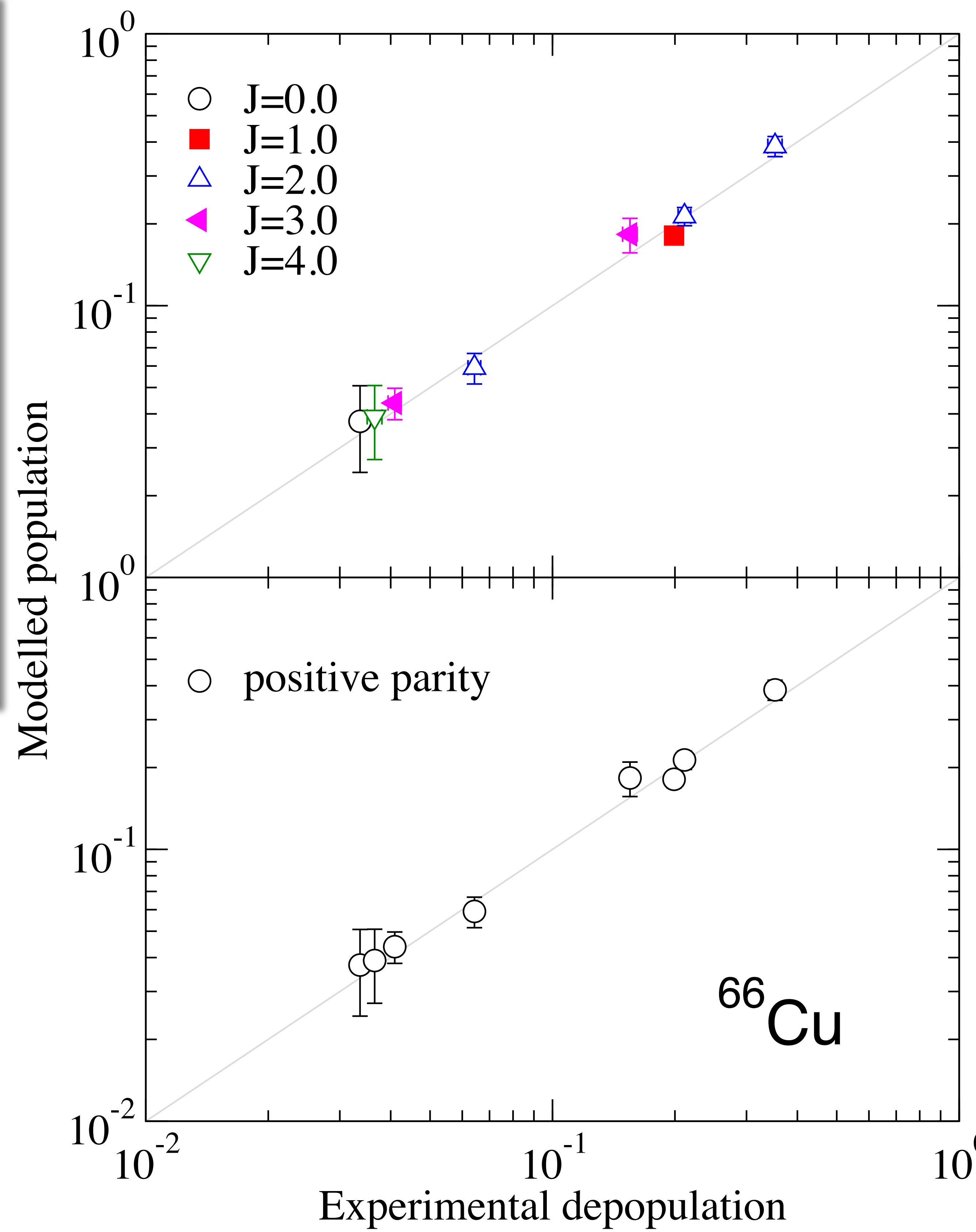




- Included 10 levels
- E_{crit} = 822.7 keV
- Indications of a new transition at 52 keV?
- σ_0 = 2.27±0.08 b **(2.17±0.03 b)**

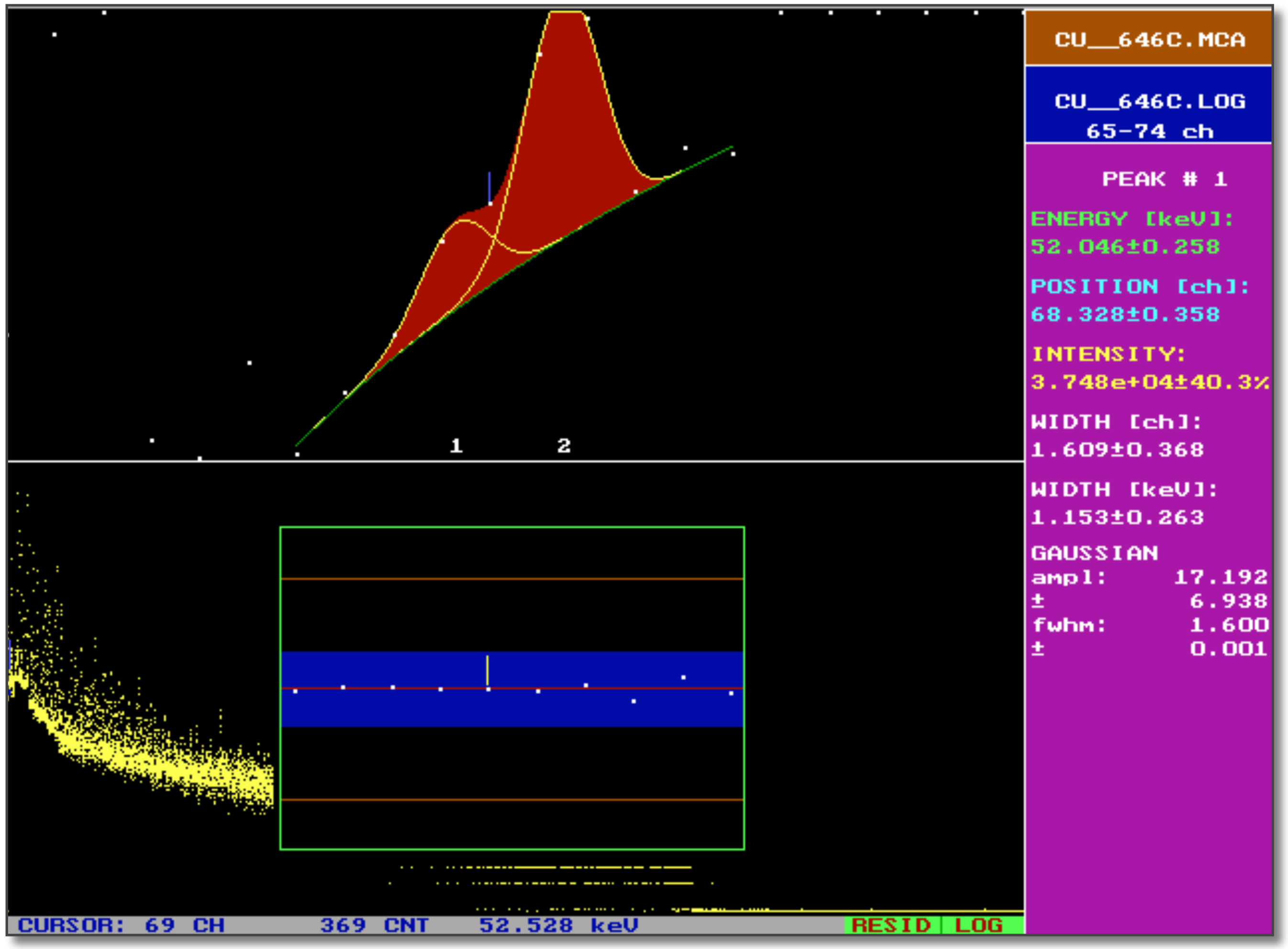
^{66}Cu DICEBOX results

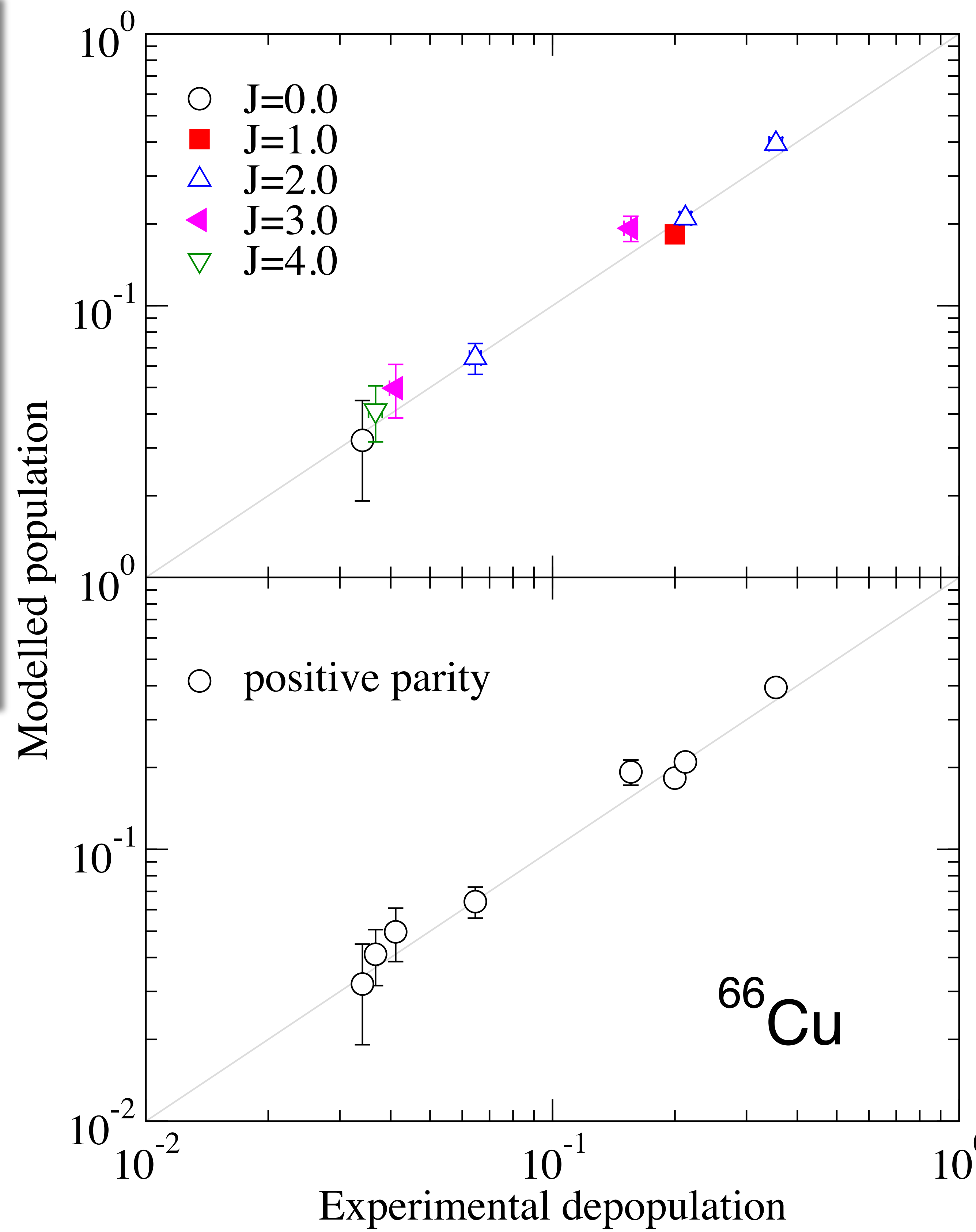




- Included 10 levels
- E_{crit} = 822.7 keV
- Indications of a new transition at 52 keV?
- σ_0 = 2.27±0.08 b **(2.17±0.03 b)**

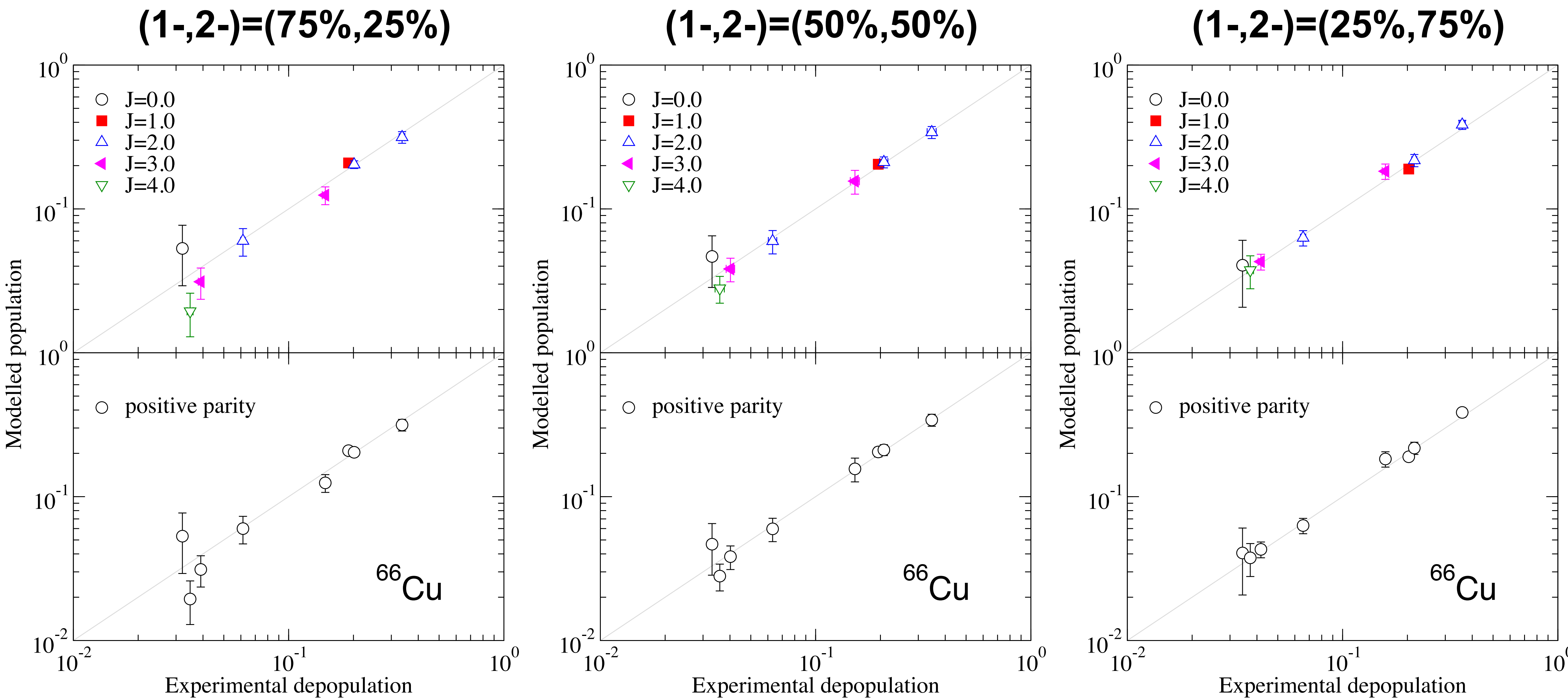
^{66}Cu DICEBOX results





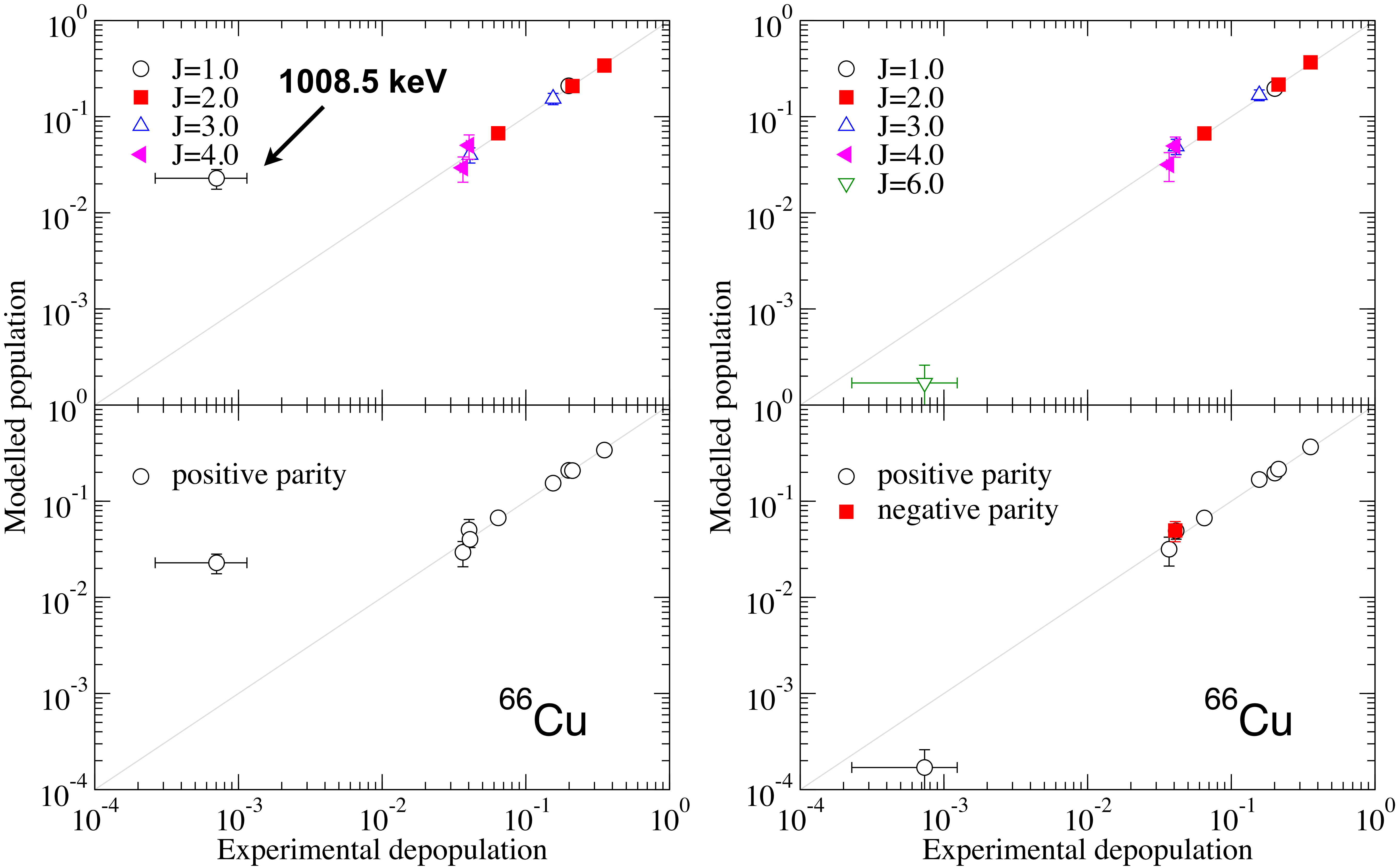
- Included 10 levels
- E_{crit} = 822.7 keV
- Indications of a new transition at 52 keV?
- σ_0 = 2.27±0.08 b **(2.17±0.03 b)**

^{66}Cu DICEBOX capture-state spin fraction

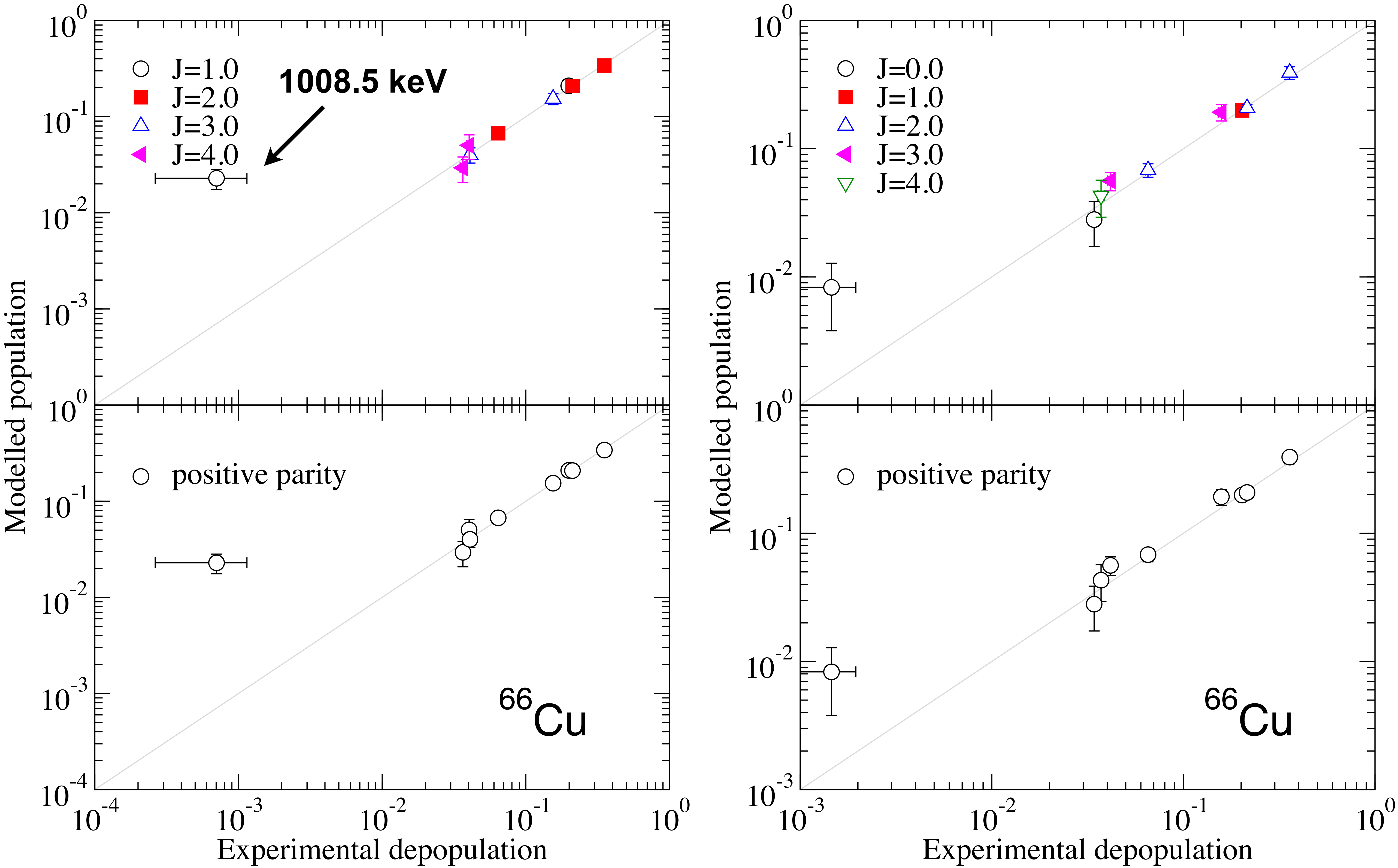


- Consistent with a dominant $J^{\pi}=2^{-}$ (99%) capture state fraction.
- In agreement with thermal neutron-capture measurements of *M.G. Delfini et al. Nuclear Physics* ***A404*** *(1983)*

^{66}Cu DICEBOX results: E_{crit} = 1009 keV



^{66}Cu DICEBOX results: E_{crit} = 1009 keV



Summary and outlook

- Low-lying 2nd excited state is consistent with a spin assignment of J=0.
- 386-keV excited state tentative 1^+ assignment.
- Consistency between the experimental data and simulated cascades for E_{crit} = 823 keV and possibly raised to 1009 keV.
- Good agreement of total thermal capture cross section with previous measurements.

$$\sigma_0 = 2.27 \pm 0.08 \text{ b} \quad \mathbf{(2.17 \pm 0.03 \text{ b})}$$

- Explore the effects of additional models and parameters.
- Continue analysis for $^{63}Cu(n,\gamma)^{64}Cu$

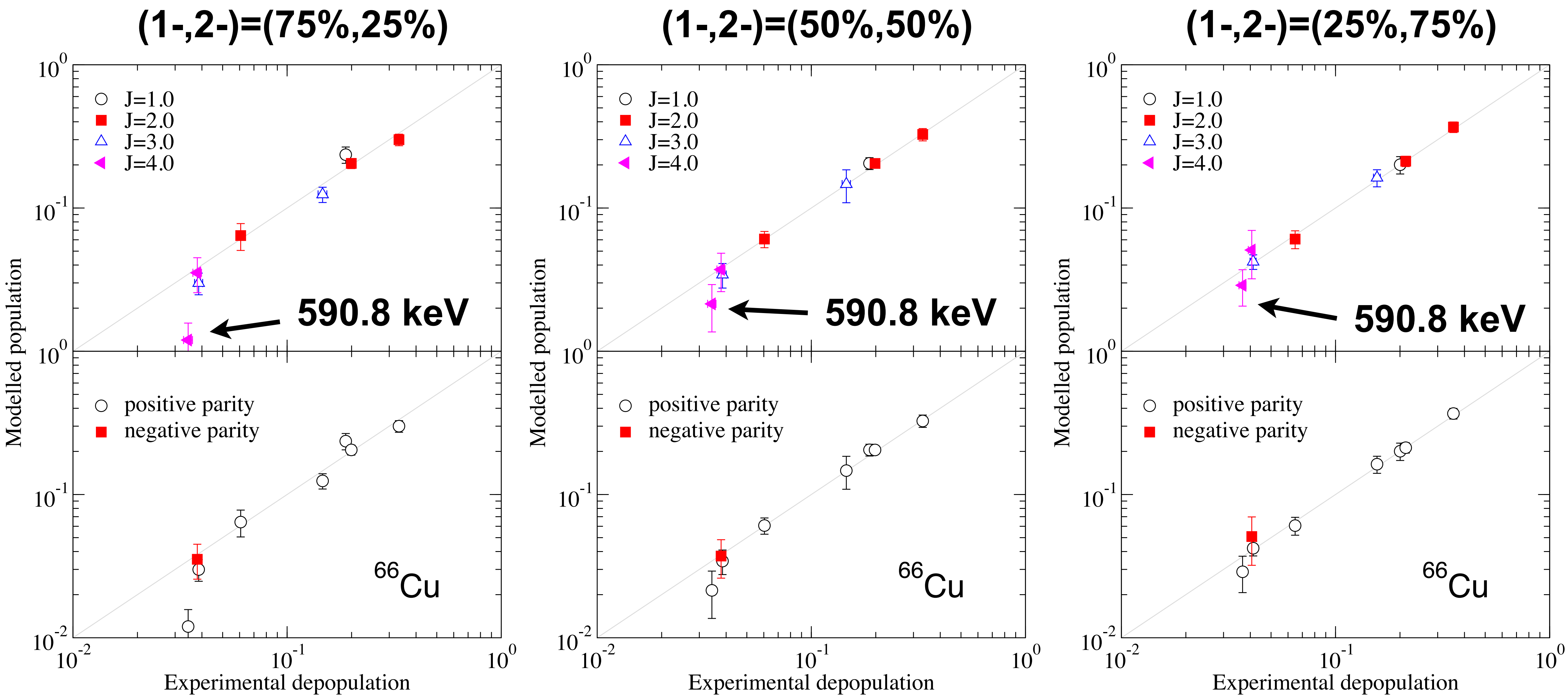
Acknowledgements

LBL: R.B. Firestone, A.M. Hurst, M.S. Basunia

LLNL: B.W. Sleaford, N.C. Summers, and J.E. Escher

ISI Budapest: Zs. Revay, L. Szentmiklosi, and T. Belgya

^{66}Cu DICEBOX capture-state spin fraction



- Consistent with a dominant $J^{\pi}=2^{-}$ (99%) capture state fraction.
- In agreement with thermal neutron-capture measurements of *M.G. Delfini et al. Nuclear Physics **A404** (1983)*

^{66}Cu DICEBOX capture-state spin fraction

(1-,2-)=(75%,25%) (1-,2-)=(50%,50%) (1-,2-)=(25%,75%)

- Consistent with a dominant $J^{\pi}=2^{-}$ (99%) capture state fraction.
- In agreement with thermal neutron-capture measurements of *M.G. Delfini et al. Nuclear Physics* ***A404*** *(1983)*