CGS17

# In-beam γ-ray spectroscopy of $^{94}$Ag

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# Isospin

Observation of similar behaviour of p and n under the nuclear force

- Charge independence $$V_{np}=\frac{V_{pp}+V_{nn}}{2}$$
- Charge symmetry $$V_{pp}=V_{nn}$$

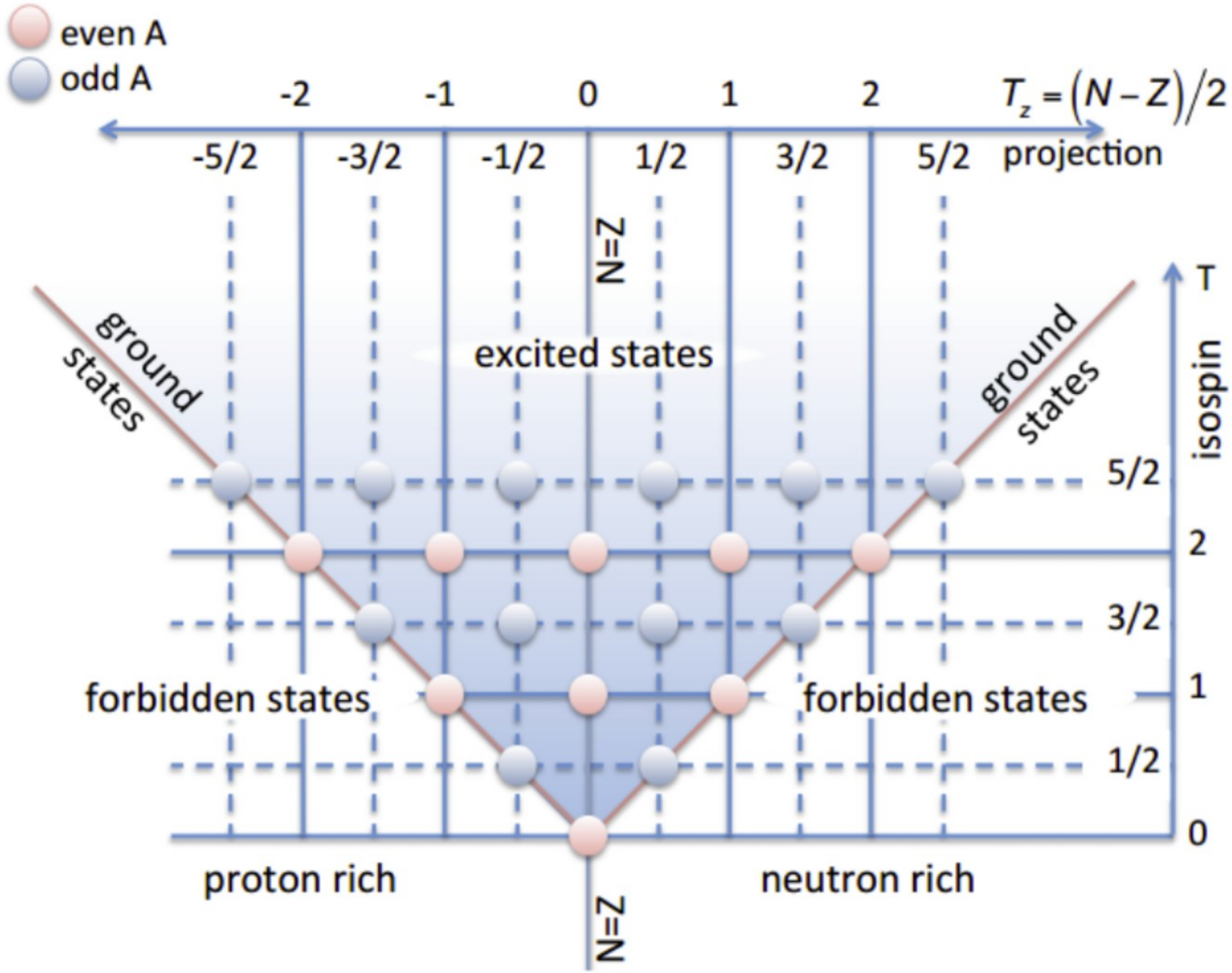
**Isospin:** p and n considered states of the same particle (*nucleon*) with different projections of the isospin quantum number $t_z$. The total isospin projection $T_z$ of a nucleus will be:

$$T_z=\sum^{A} t_z=\frac{N-Z}{2}$$

Hence, a nucleus can occupy states with a total isospin T values given by:

$$\frac{|N-Z|}{2}\leqslant T\leqslant\frac{|N+Z|}{2}$$

# Bentley isospin triangle

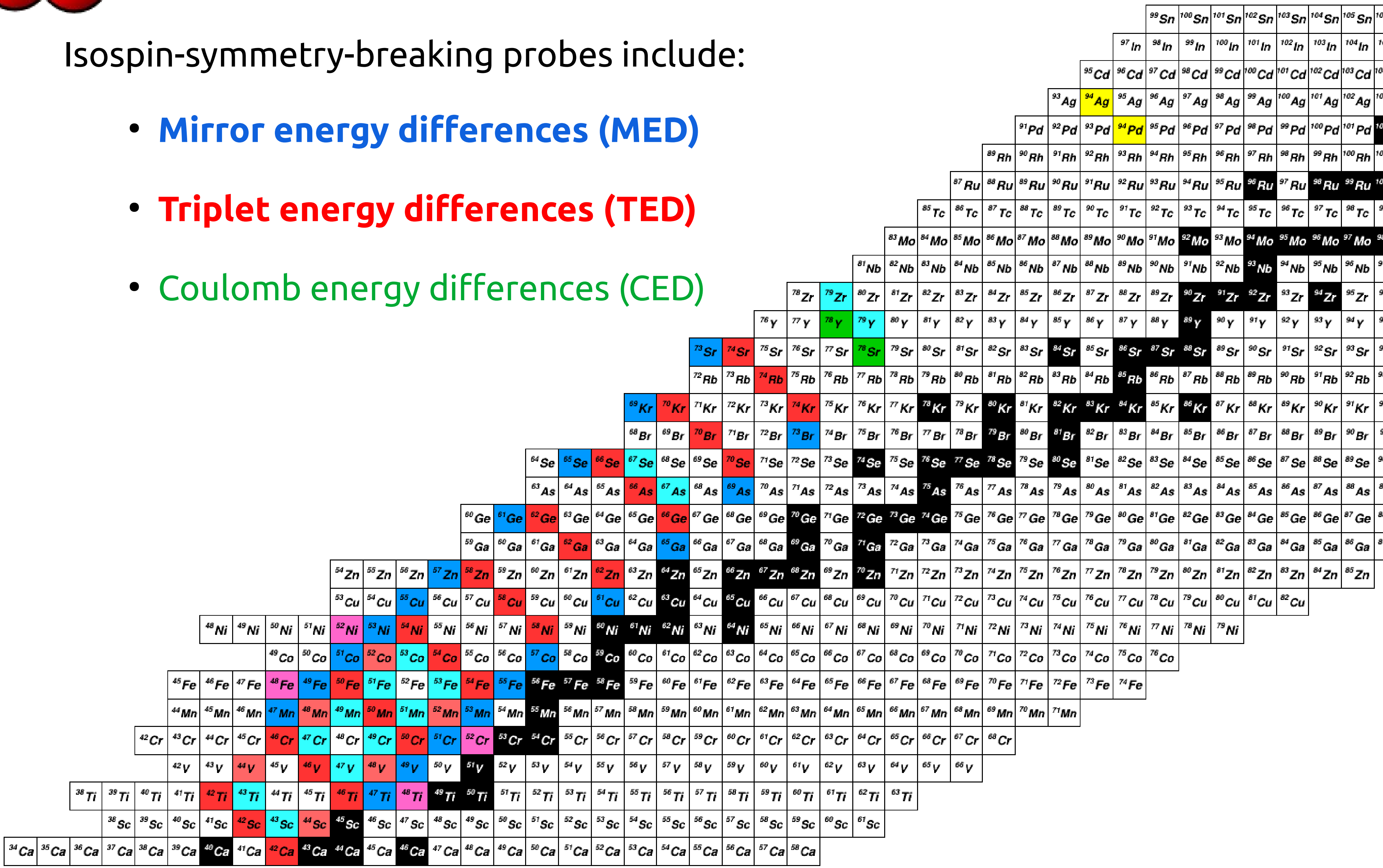



*Bentley Isospin triangle* displaying possible T states for a nucleus with a given $T_z$

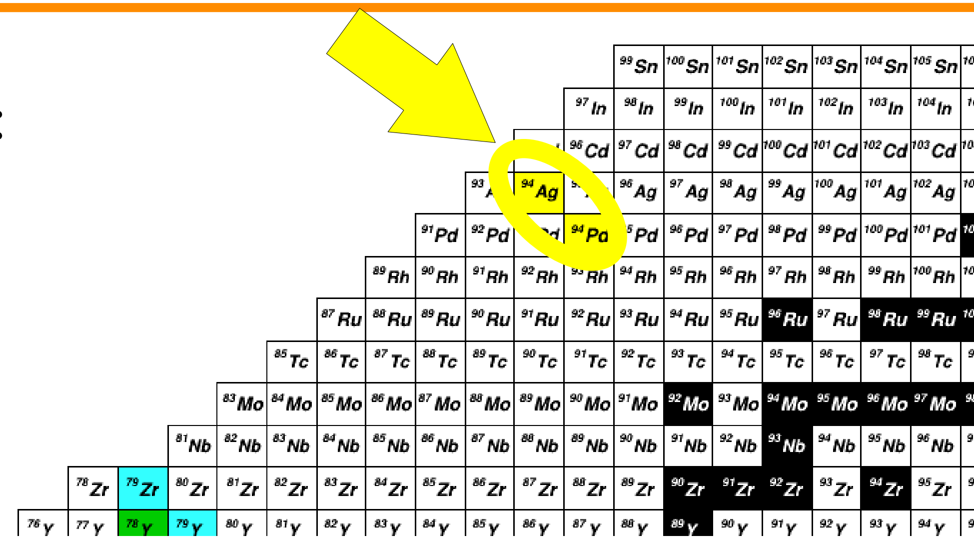
# Isospin symmetry

Isospin-symmetry-breaking probes include:

- **Mirror energy differences (MED)**
- **Triplet energy differences (TED)**
- Coulomb energy differences (CED)



# Isospin symmetry




Isospin-symmetry-breaking probes include:

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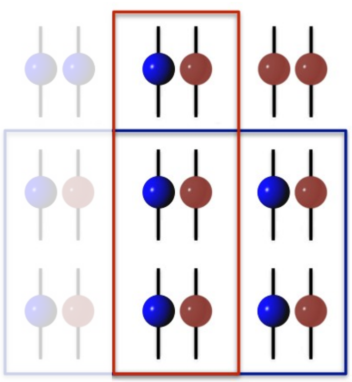

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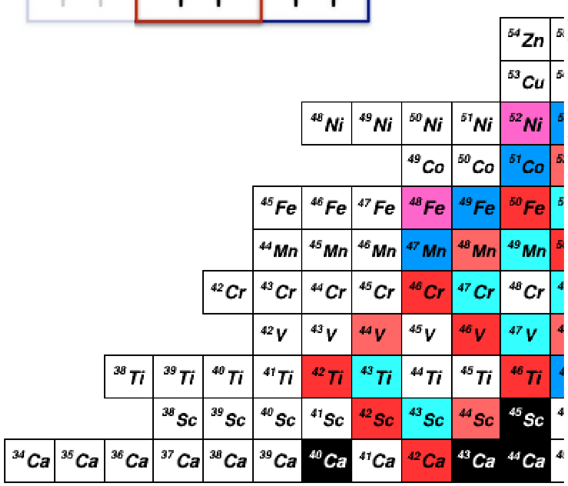
## In-beam $\gamma$-ray spectroscopy of $^{94}$Ag

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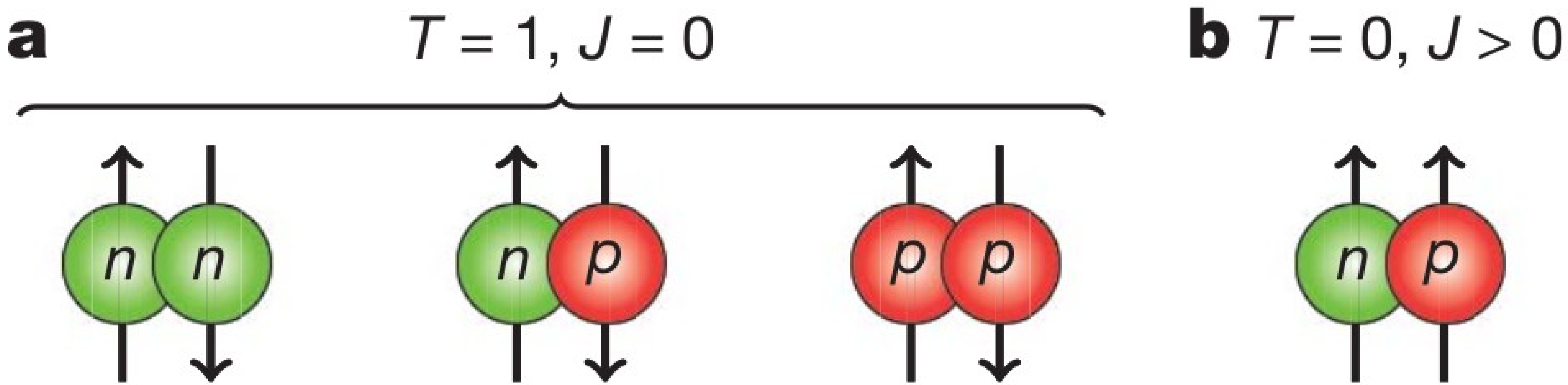
# Nucleon pairing

- Like-nucleon pairing (nn and pp) is the dominant pairing correlation.
- In N~Z systems, np pairings are possible.




- Evidence of spin-aligned T=0 np pairing is elusive.
  - Rotational alignment in $^{88}$Ru
  - Yrast sequence in $^{92}$Pd B. Cederwall et al., Nature 461, (2011) 6871.

    - Theory studies suggested similar effect in N=Z A>90 $^{94}$Ag and $^{96}$Cd

G.J.Fu, J.J Shen, Y.M. Zhao and A. Arima, PRC 87 (2013) 044312
Z.X.Xu, C. Qi, J. Blomqvist, R.J. Liotta and R. Wyss, Nucl. Phys. A 877 (2012) 51-58
S. Zerguine and P. Van Isacker, PRC 83 (2011) 064314.

# Current knowledge on $^{94}$Ag

- Several experimental studies have been focused on $^{94}$Ag:


[1] J. Park et al., PRC 99, 034313 (2019).
[2] K. Moschner et al., EPJ web conf. 93, (2015) 01024.
[3] M. La Commara et al., Nucl. Phys. A 708 (2002) 167-180.
[4] I. Mukha et al., PRC 70 (2004) 044311.
[5] I. Mukha et al., PRL 95 (2005) 022501.
[6] K. Schmidt et al., Z. Phys. A 350 (1994) 99-100.
[7] C. Plettner et al., Nucl. Phys. A 733 (2004) 20-36.
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[9] O.L. Pechenaya et al., PRC 76 (2007) 011304(R).
[10] T. Kessler et al., Nucl. Instrum. Methods PRB 266 (2008) 4420-4424.
[11] A. Kankainen et al., PRL 101 (2008) 142503.
[12] K. Kaneko et al., AIP Conference Proceedings 1090 (2009) 611.
[13] J. Cerny et al., PRL 103 (2009) 152502.
[14] David G. Jenkins, PRC 80 (2009) 054303.
[15] I. Mukha et al., arXiv:1008.5346 [nucl-ex] (2009).
[16] Mamta Aggarwal, PLB 693 (2010) 489-493.


- However, current knowledge is limited to:
  - $0^+$ ground state, half life of 27(2) ms [1,2]
  - Two isomeric states:
    - $(7^+)$ [3] half life of 0.50(1) ms [1,4] located at 6.7 MeV [5]. $\beta$, $\beta$-delayed p and p
    - $(21^+)$ [3] half life of 0.39(4) ms [4]

# Experimental setup

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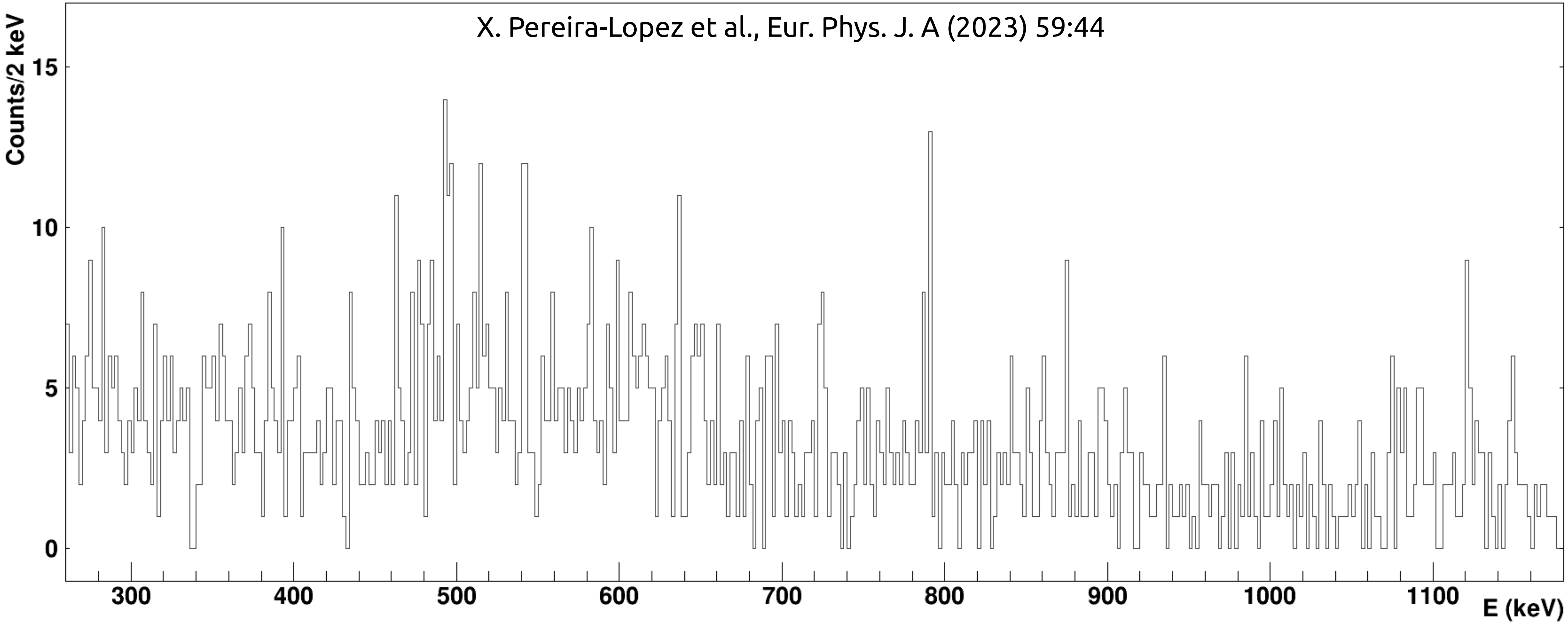
# Experimental setup

Fusion-evaporation reaction $^{40}Ca(^{58}Ni,p3n)^{94}Ag$


- All detector signals are time stamped to allow temporal correlations.

# $^{94}$Ag transitions

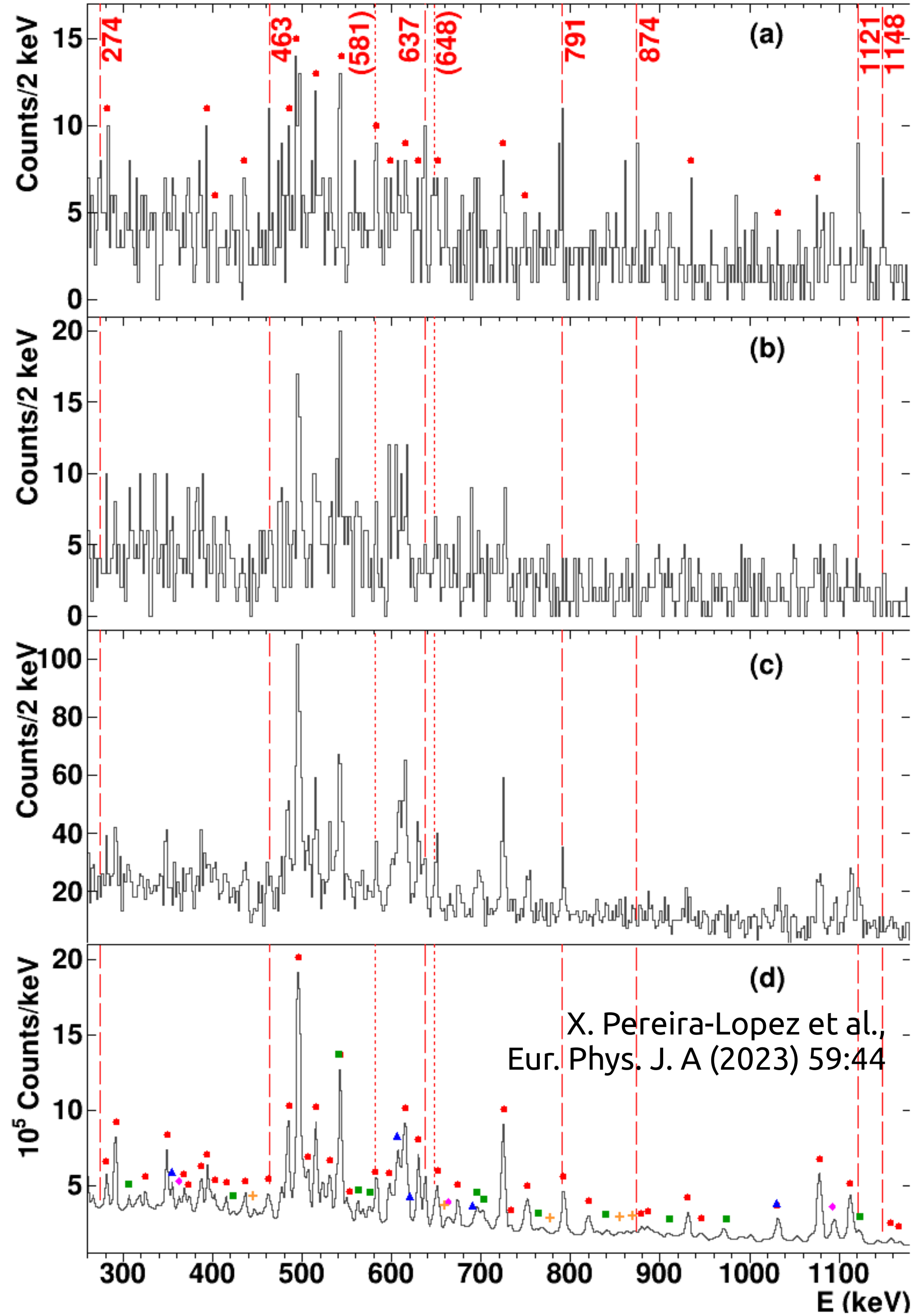
- $^{94}$Ag transitions were identified in the Doppler corrected γ-ray spectra for:
  - Prompt emission
  - short-lived A=94 fragments (decay within 60ms)
  - One or less charged particles
  - High energy β (E > 3 MeV)



# $^{94}$Ag transitions

- Comparison with spectra recorded for
  - b) higher charged particle multiplicity
  - c) Longer lived A=94 recoils
    - - decay between 120 and 180 ms
  - d) A=94 recoil

- γ-rays at 273, 463, 637, 791, 874, 1121 and 1148 keV seem to grow respect to other A=94 contaminants when gating on the reaction channel leading to $^{94}$Ag.
  - Most contaminants are $^{94}$**Ru** transitions.
    - - evidence of $^{94}$**Rh**, $^{94}$**Tc** and $^{90}$**Mo**
  - They come from either:
    - - false correlations
    - - misidentified p3n events

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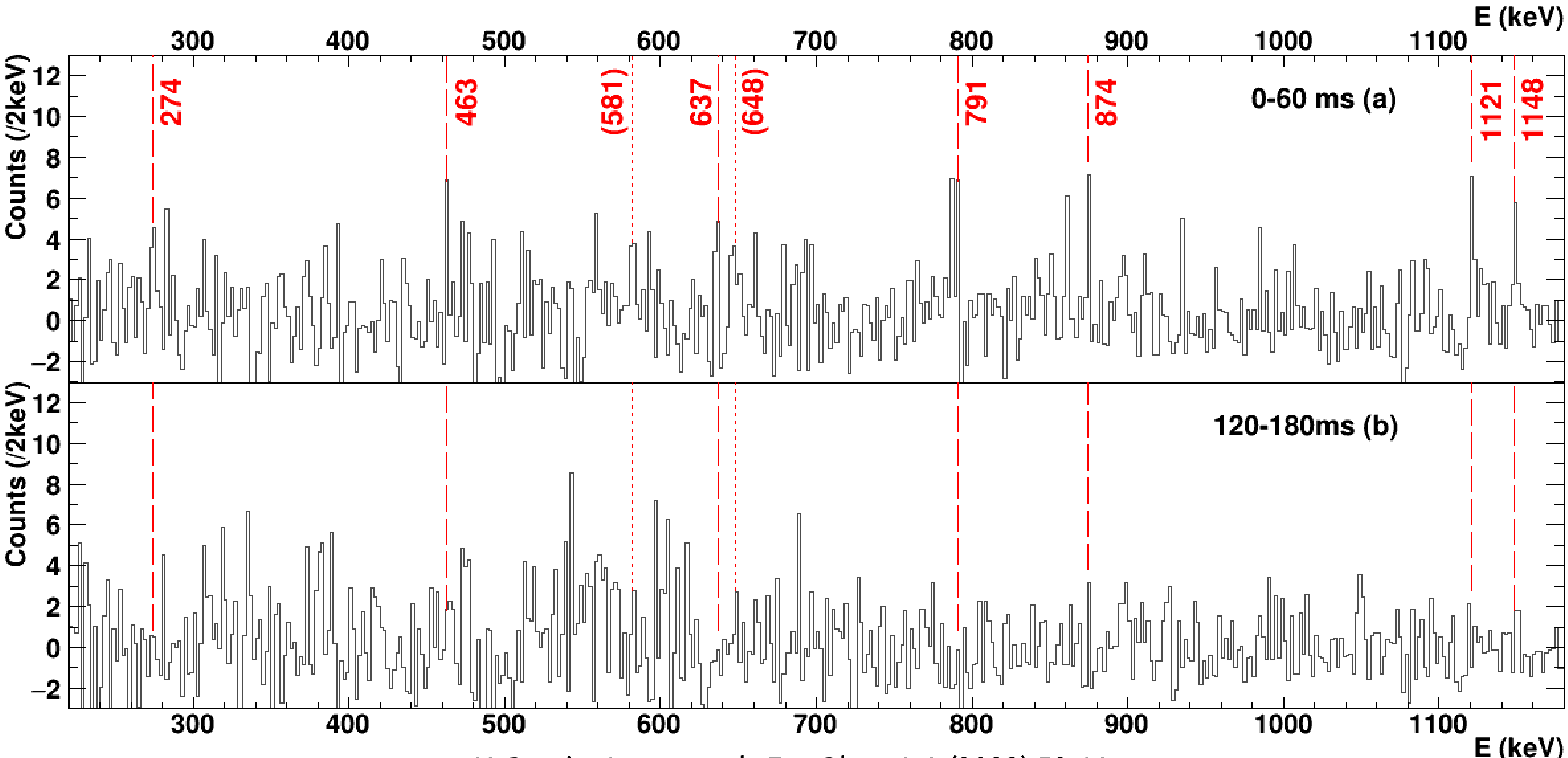
# $^{94}$Ag transitions

*Background substracted Doppler corrected spectra for prompt γ-rays for A=94 recoils decaying withing 60ms (a) or 120-180ms (b), in coincidence with a high energy β and rejecting events with 2 or more charged particles in JYtube.*

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# $^{94}$Ag transitions

- Comparison with spectra recorded for
  - b) higher charged particle multiplicity
  - c) Longer lived A=94 recoils
    - - decay between 120 and 180 ms
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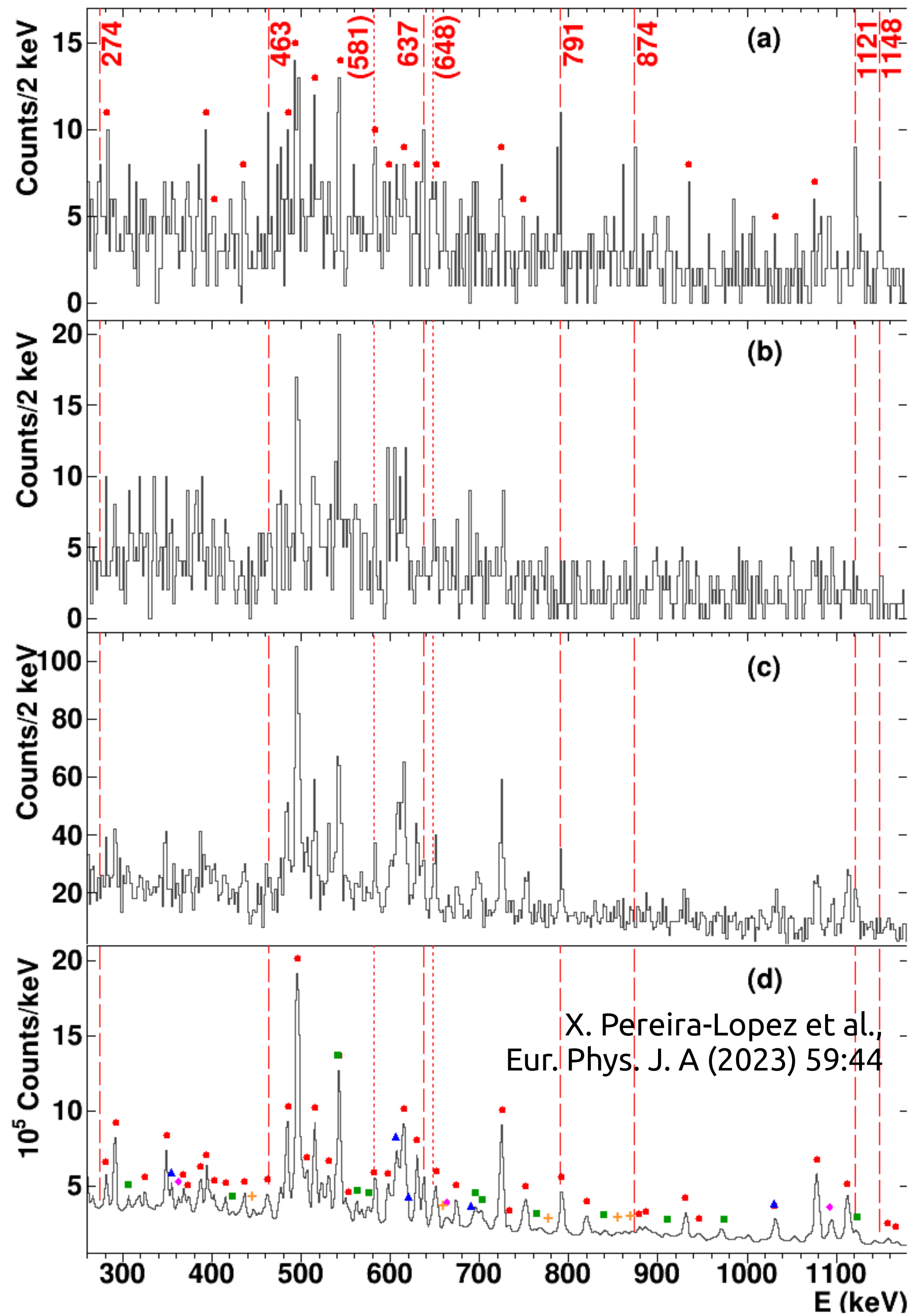
γ-rays observed in this work are associated with a short lived A=94 nucleus, produced via one charged particle evaporation channel and whose half-life is consistent with currently accepted value for $^{94}$Ag ground state β-decay.

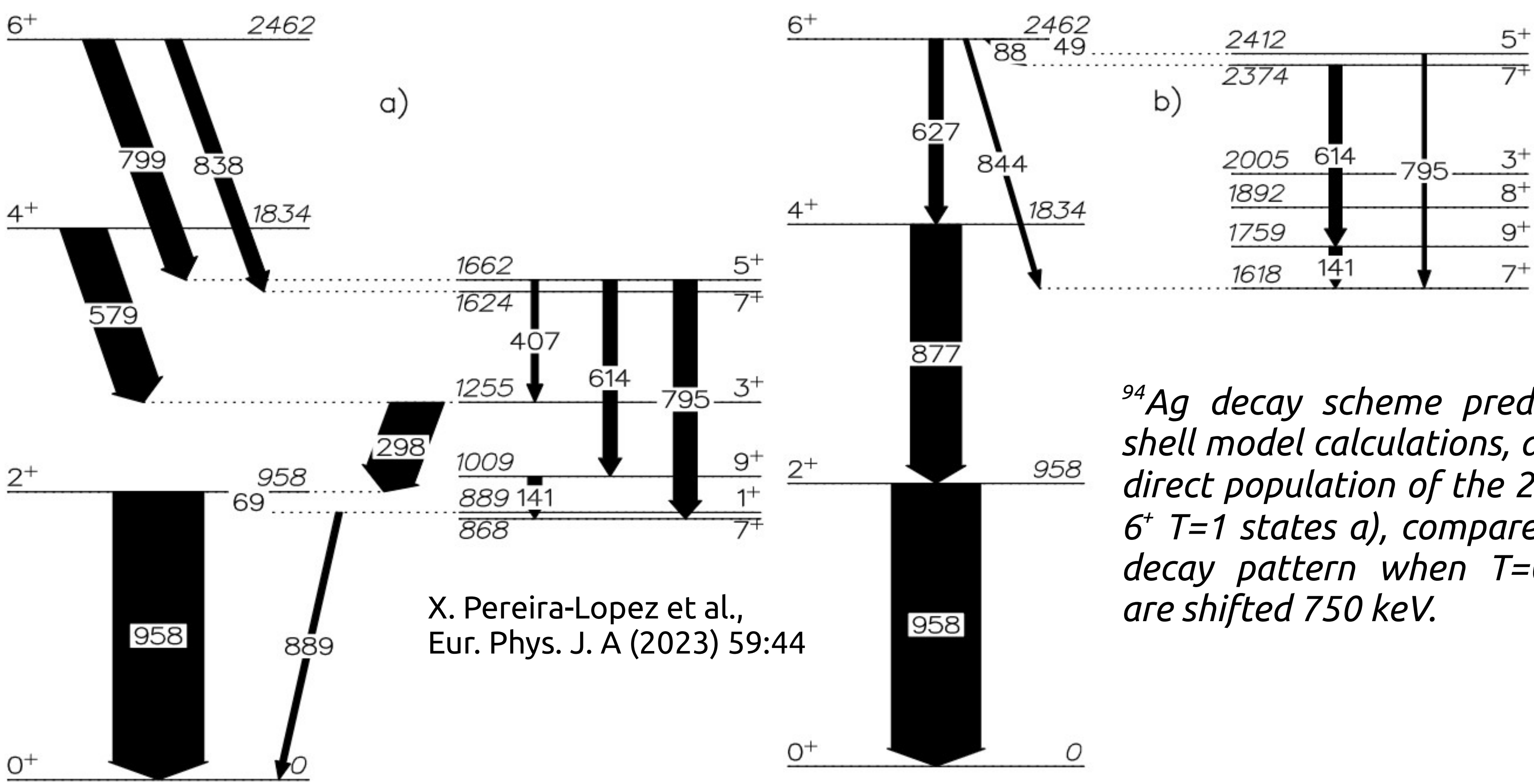



- Not enough statistics for γ-γ analysis.

# Shell model predictions

- Shell model calculations using JUN45 interaction in the fpg model space.
  - Dominant decay patterns assuming direct population of the $2^+$, $4^+$ and $6^+$ T=1 states
- However, if T=0 lie 750 keV higher, E2 sequence from $6^+$ becomes dominant.
- Location of T=0 strongly influenced by np aligned $g_{9/2}$ matrix element.

Z.X.Xu, C. Qi, J. Blomqvist, R.J. Liotta and R. Wyss, Nucl. Phys. A 877 (2012) 51-58

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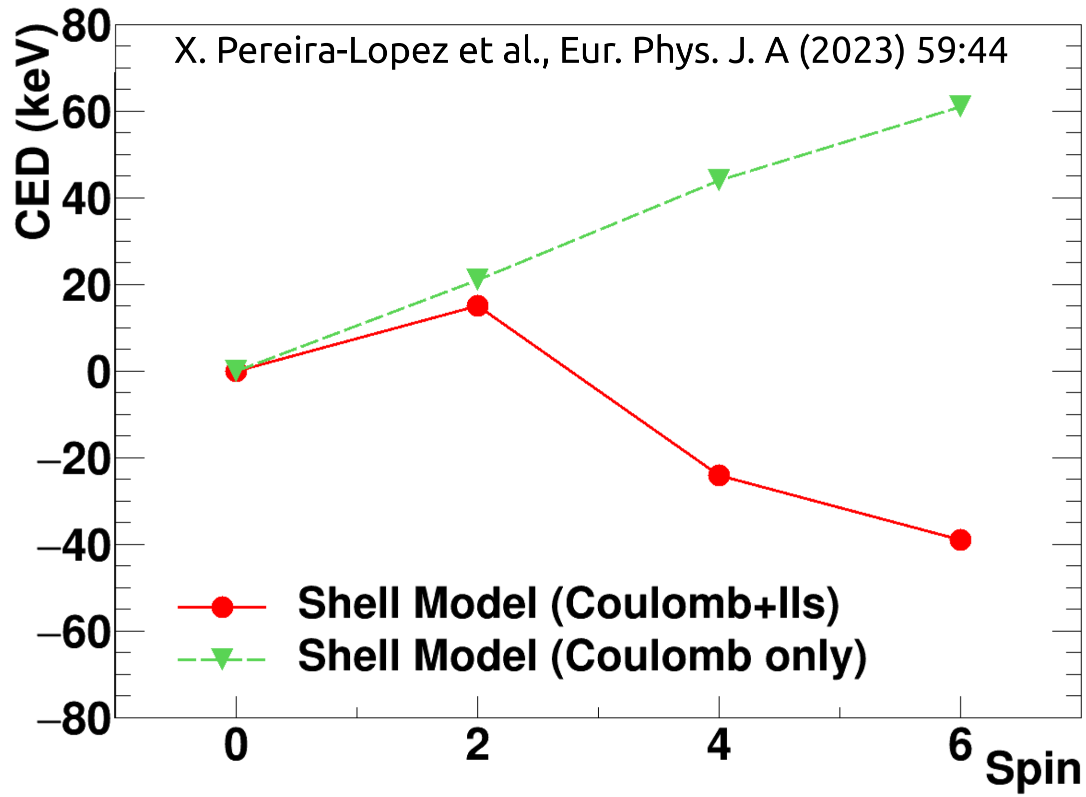
*$^{94}$Ag decay scheme predicted by shell model calculations, assuming direct population of the $2^+$, $4^+$ and $6^+$ T=1 states a), compared to the decay pattern when T=0 states are shifted 750 keV.*

# CEDs

- Based on comparison with $^{94}$Pd
  - 791, 874 and 637 keV in $^{94}$Ag
    tentative analog of
  - 814, 905 and 659 keV in $^{94}$Pd
- Negative CEDs
  - Observed only for $^{70}$Br-$^{70}$Se
- Compared to SM calculations
  - decresing trend
  - ~35 keV shift
- SM cast doubts on this tentative assignment




*CEDs as function of J between tentatively assigned T=1 levels in $^{94}$Ag and analog states in $^{94}$Pd.* ***Shell model predictions with and without single particle monopole effects*** *in red circles and green triangles.*

# Conclusions

- Seven γ-ray transitions observed are associated with a short lived A=94 nucleus, produced via one charged particle evaporation channel and whose half-life is consistent with accepted value for $^{94}$Ag ground state β-decay.
    - First observation of γ-ray transitions from $^{94}$Ag excited states.
    - Level scheme remains unclear.
- Shell model calculations were presented, showing the separation between T=1 and T=0 strongly influences the decay pattern.
    - Work required to determine the relative position of T=0 and T=1 states.
        - provide insight into the np spin-aligned pairing in this nucleus
- Possible correspondence between observed transitions and analogue states in neighbouring T=1 isobar nucleus $^{94}$Pd is discussed.
    - Shell model predicted CEDs are presented.

# Collaborators

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