Recent experiments probing isospin symmetry

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Introduction

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:

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

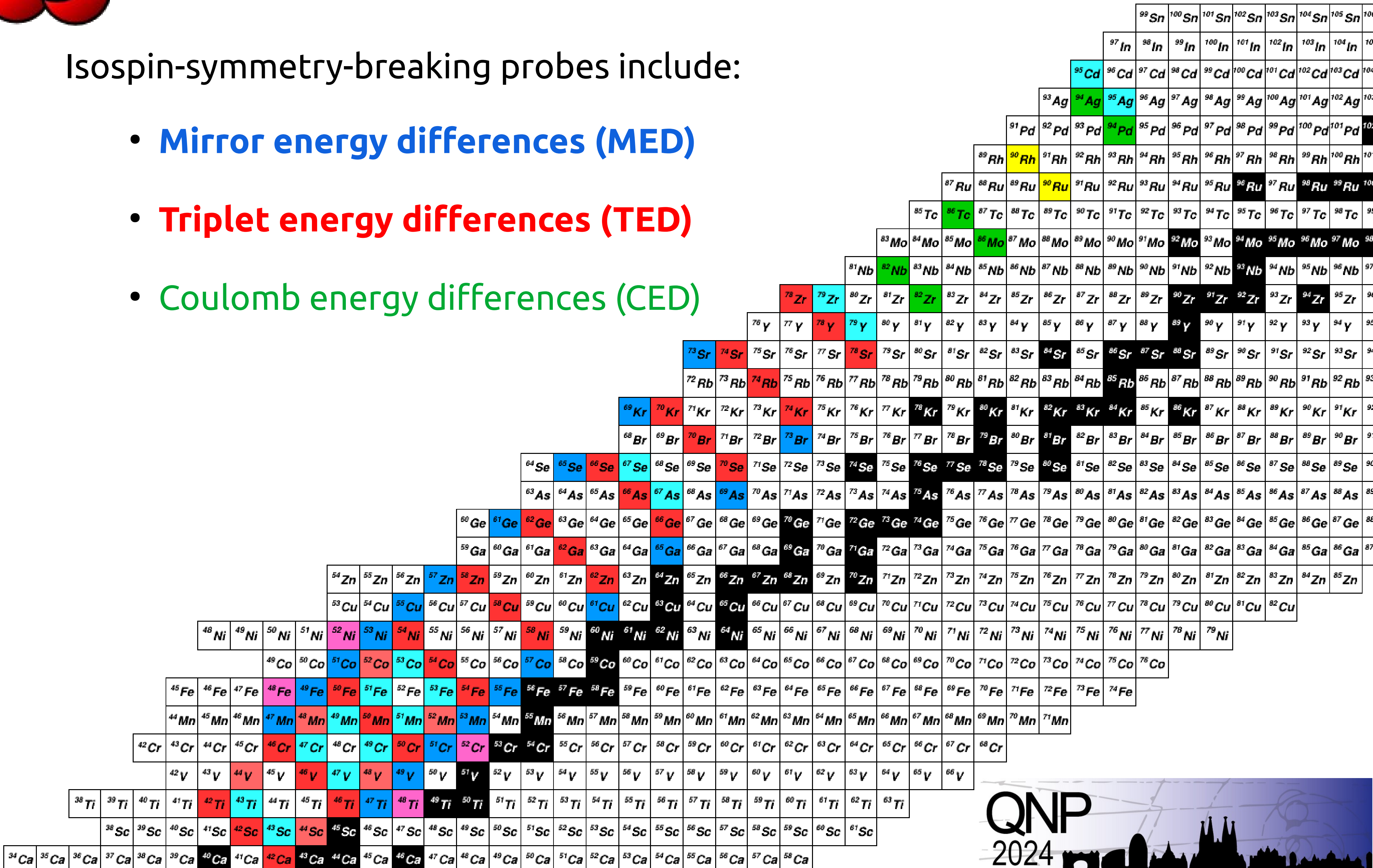
Hence, a nucleus can occupy states with a total isospin T values given by:

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

Isospin symmetry

Isospin-symmetry-breaking probes include:

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



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Experimental setup

JYVÄSKYLÄN YLIOPISTO
UNIVERSITY OF JYVÄSKYLÄ

Experimental setup

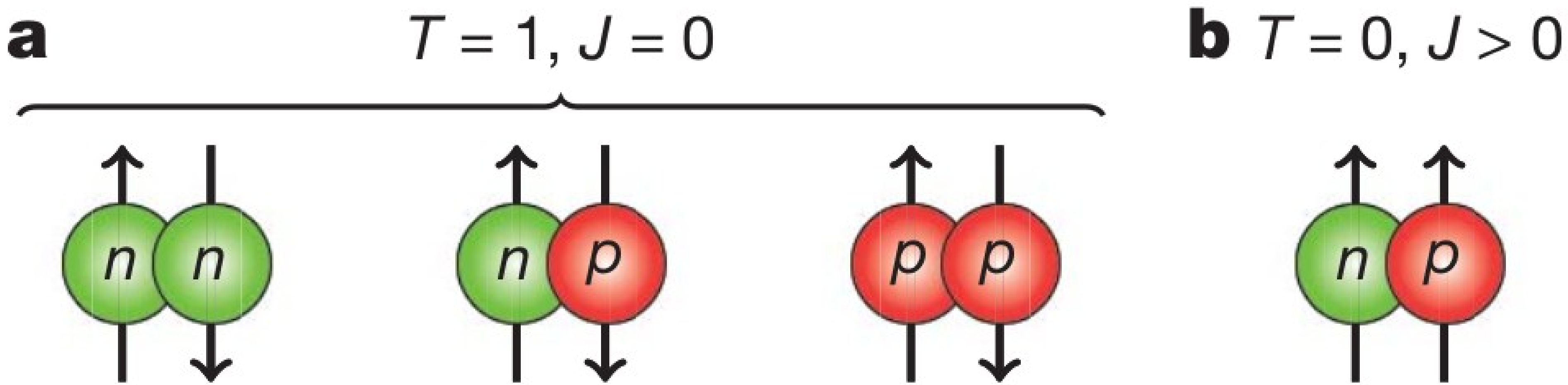
Fusion-evaporation reactions

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

In-beam spectroscopy of ^{94}Ag

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.
[8] E. Roeckl, Int. J. Mod. Phys. E 15, 2 (2006) 368-373.
[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]. β, β-delayed p and p
    - (21^+) [3] half life of 0.39(4) ms [4]

^{94}Ag transitions

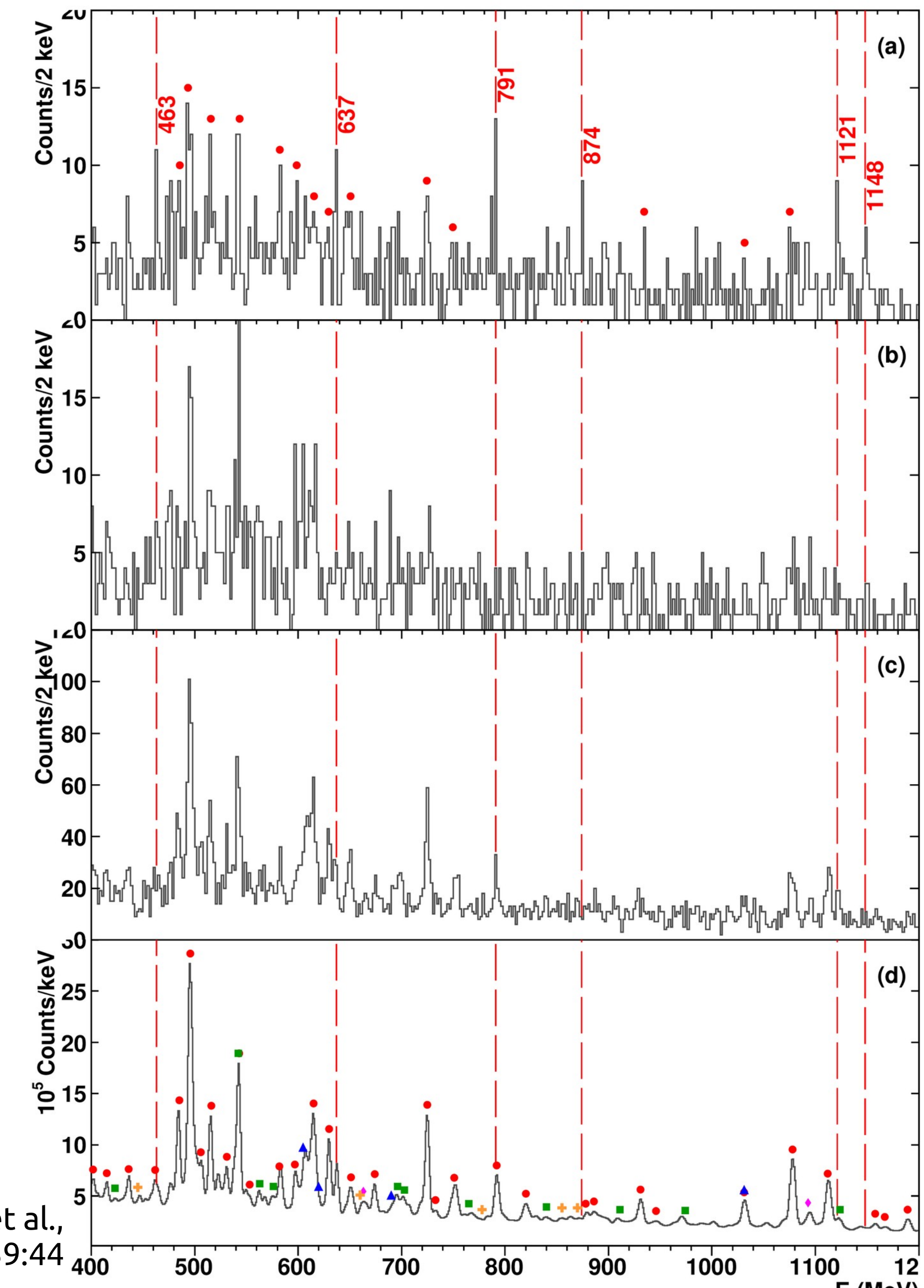
- 94Ag transitions were identified in the Doppler corrected γ-ray spectra for:
  - Prompt emission
  - short-lived A=94 fragments
    - decay within 60ms
  - One or less charged particles
  - High energy β
    - E > 3 MeV
- Comparison with spectra recorded for

  b) higher charged particle multiplicity

  c) Longer lived A=94 recoils

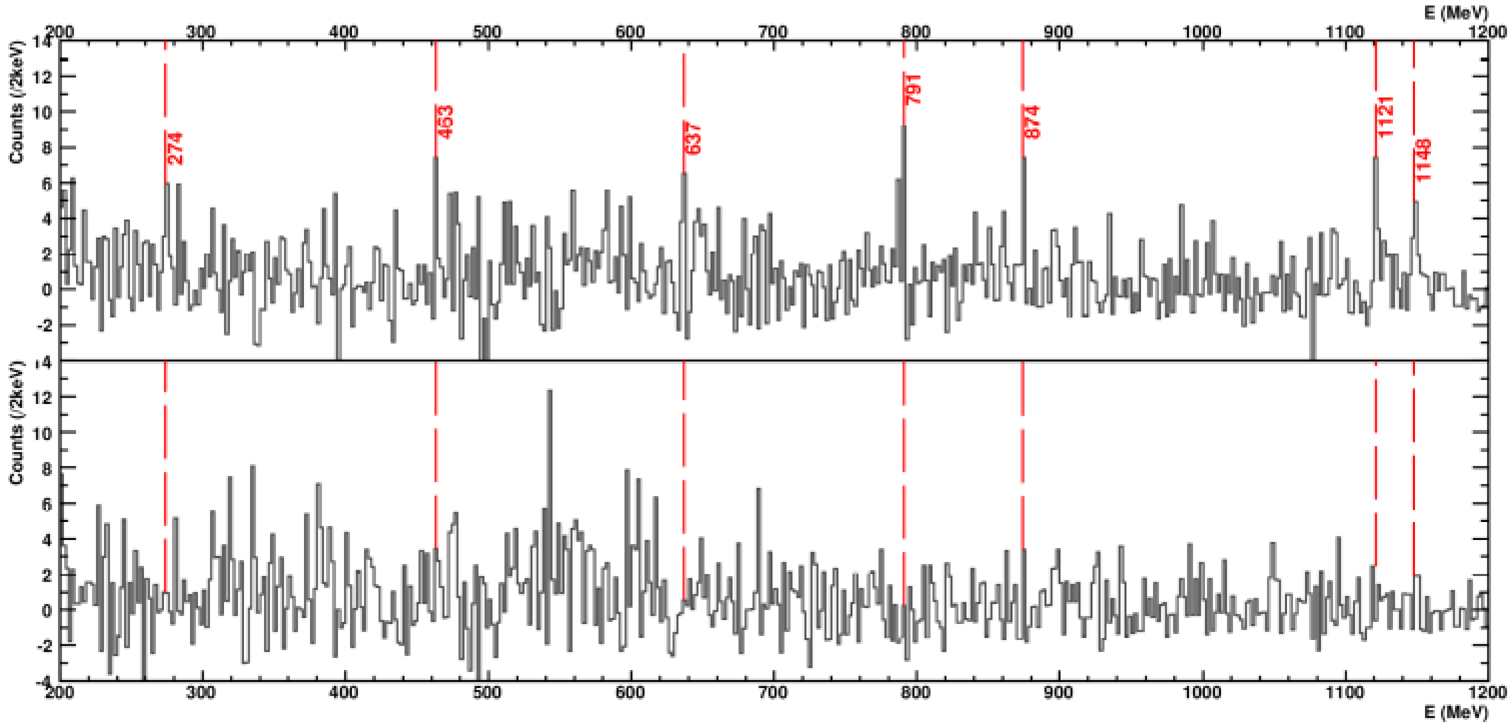
  - decay between 120 and 180 ms

  d) A=94 recoil



X. Pereira-Lopez et al.,
Eur. Phys. J. A (2023) 59:44

^{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.

X. Pereira-Lopez et al.,
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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.

- Most contaminants identified as γ from ^{94}**Ru**
  - evidence of ^{94}**Rh**, ^{94}**Tc** and ^{90}**Mo** also observed
- They come from either:
  - false correlations
  - misidentified p3n events

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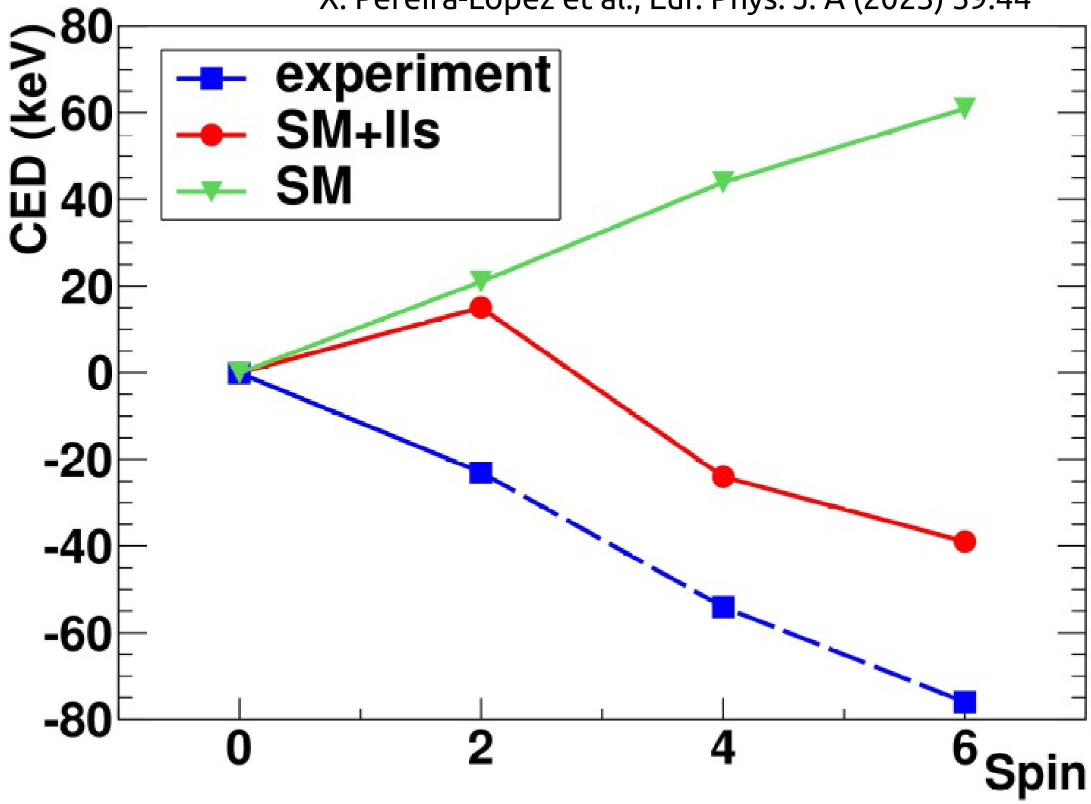
CEDs

- γ-γ was not possible.
- Based on comparison with ^{94}Pd
  - 791, 874 and 637 keV in ^{94}Ag

    analog states of
  - 814, 905 and 659 keV in ^{94}Pd
- Negative CEDs
  - Observed only for ^{70}Br-^{70}Se
- Compared to SM calculations
  - JUN45, fpg model space
  - decresing trend
  - ~35 keV shift

X. Pereira-Lopez et al., Eur. Phys. J. A (2023) 59:44



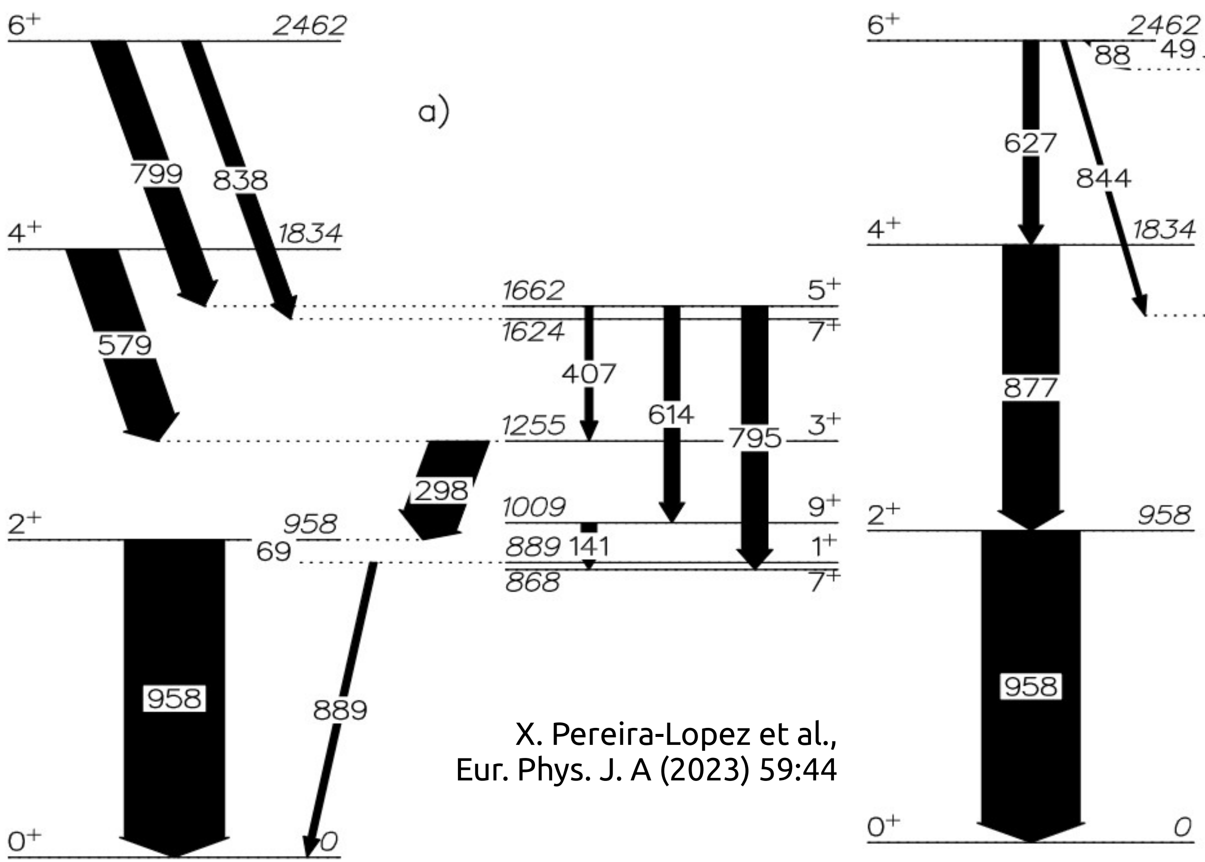
*CEDs as function of J between tentatively assigned T=1 levels in ^{94}Ag and analog states in ^{94}Pd. **Experimental values** in blue squares, **SM model prediction** in red circles.*

Shell model predictions

- SM suggest that we should only see $2^+ \rightarrow 0^+$ T=1 decay.
- 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

- Further work is required



X. Pereira-Lopez et al.,
Eur. Phys. J. A (2023) 59:44

⁹⁴Ag 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.

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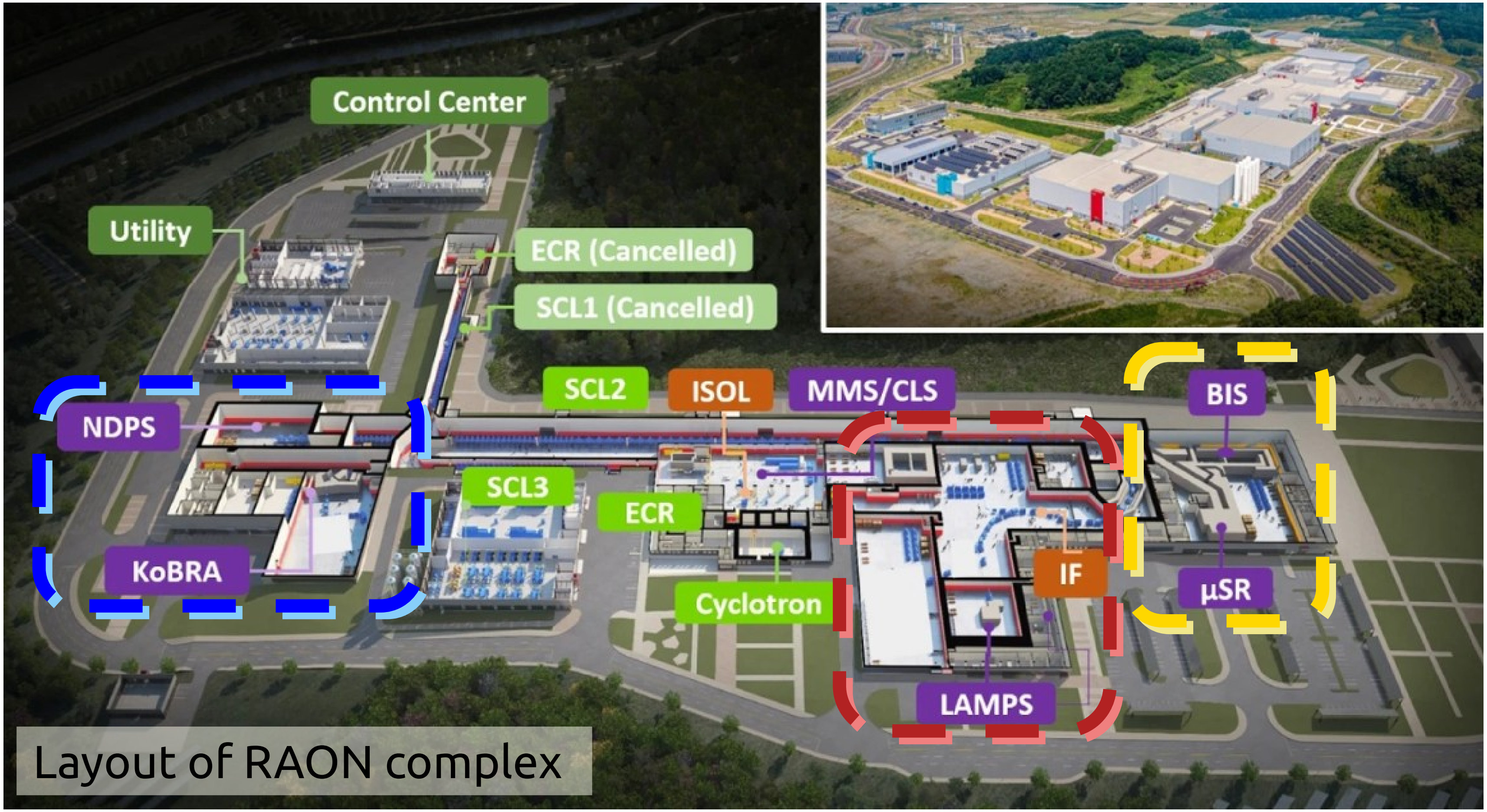
Conclusions

- Seven γ-ray transitions 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.
    - They represent the first observation of γ-ray transitions from ^{94}Ag excited states.
- Results compared with neighbouring T=1 isobar nucleus ^{94}Pd.
- CEDs are extracted and discussed with shell model calculations.
    - Level scheme remains unclear.
- Future experiments to locate 7^{+} T=0 isomer may provide important information on this regard.

Future experiments

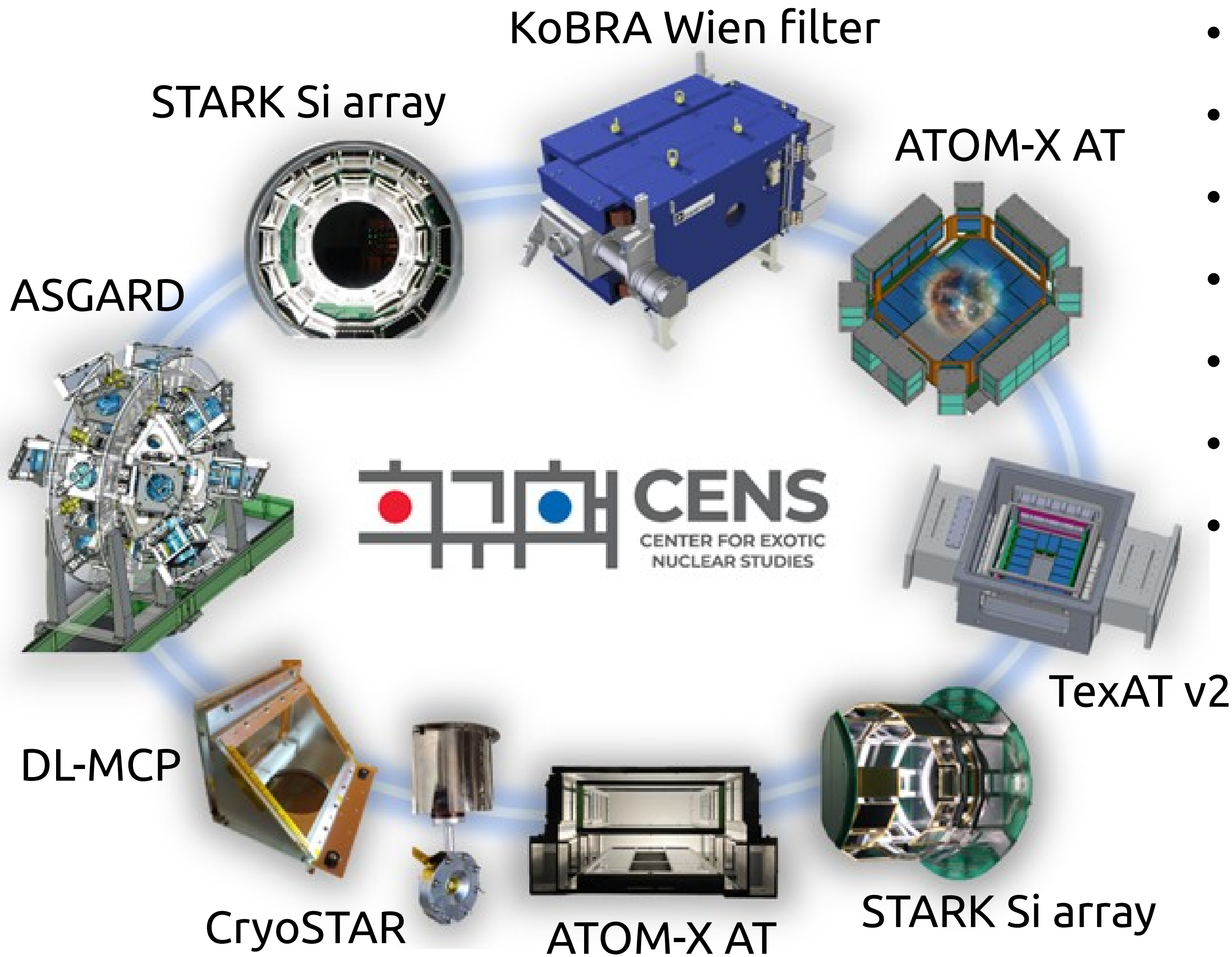
RAON

RAON is the new RIB accelerator facility built in Korea, expected to provide RIBs via ISOL and IF production methods. First beam (stable) already delivered last May, first stable-beam experiments currently ongoing.



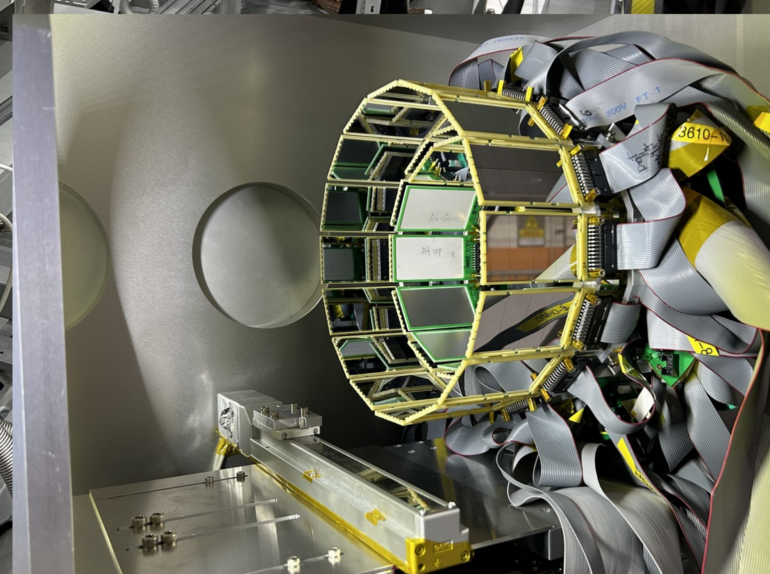
Layout of RAON complex

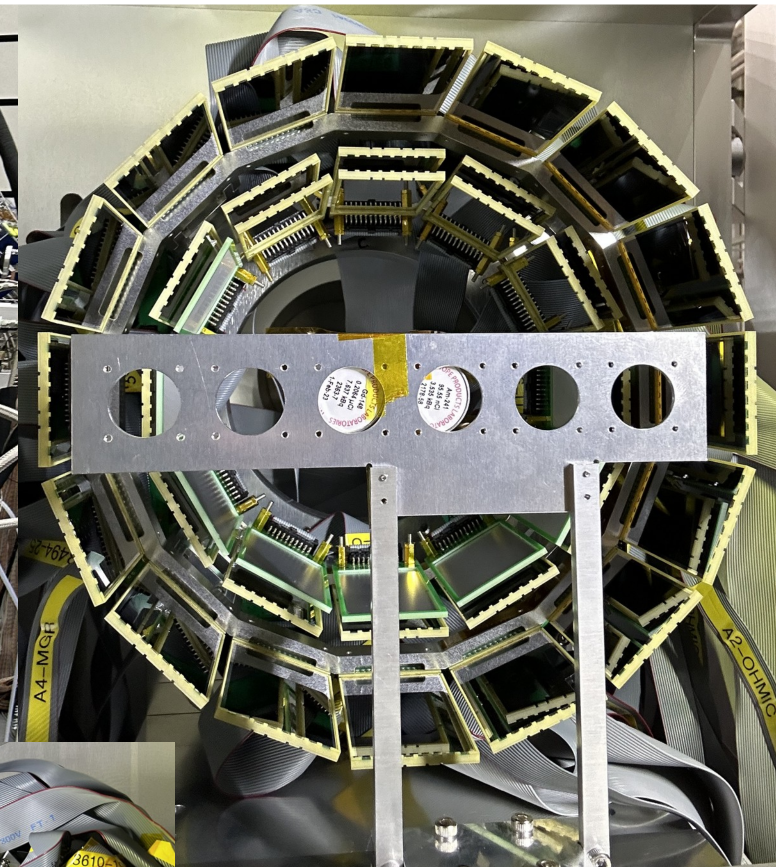
CENS Detector development



- KHALA LaBr3 array
- Decay station
- ICE detector system
- Plunger device
- Beam PID
- Liquid Organic Scintillator
- Gas Jet Target system
- And more…

RAON experimental setup





STARK Si telescope

Experimental setup at KoBRA beamline in RAON

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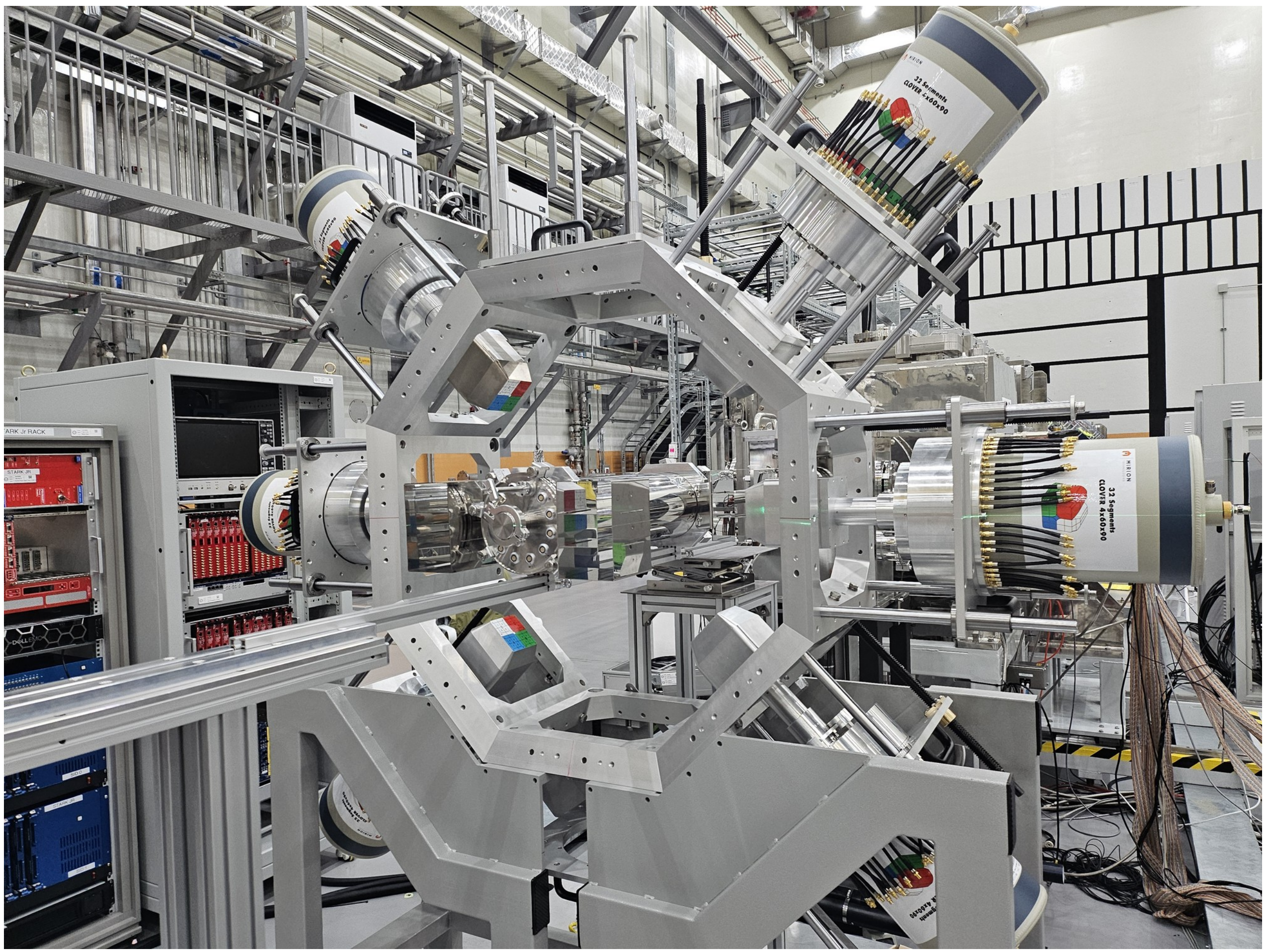
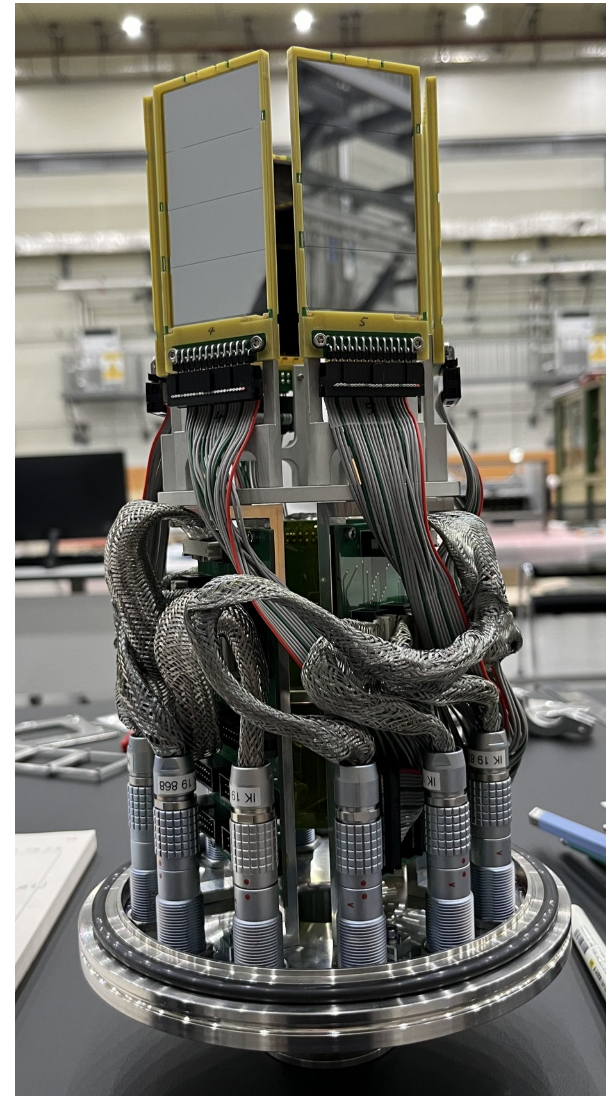
RAON experimental setup

- **STARK Jr:** Compact configuration designed for charged particles and γ-ray coincidences
- **ASGARD:** 16 HPGe clovers



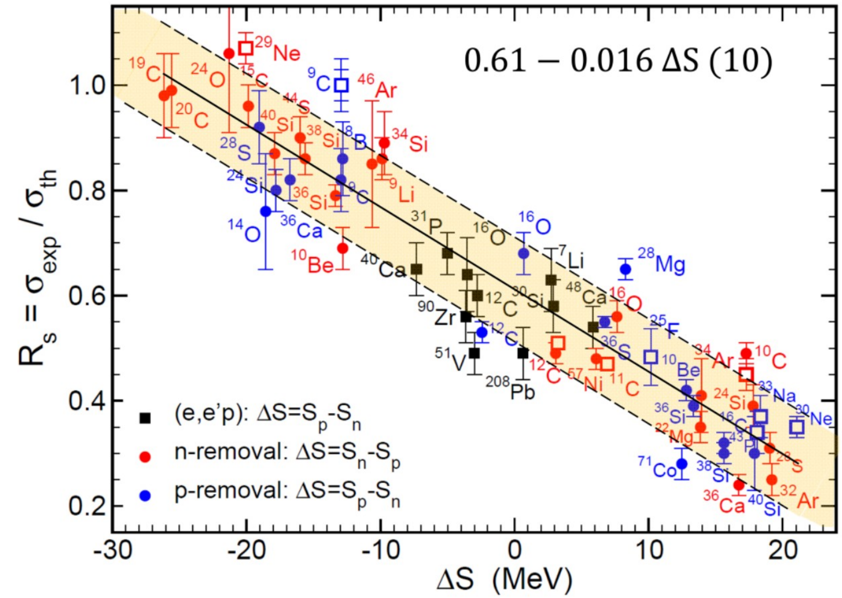


One-nucleon removal reactions

Systematics of σ_{exp} for one-nucleon removal reactions at intermediate energies:

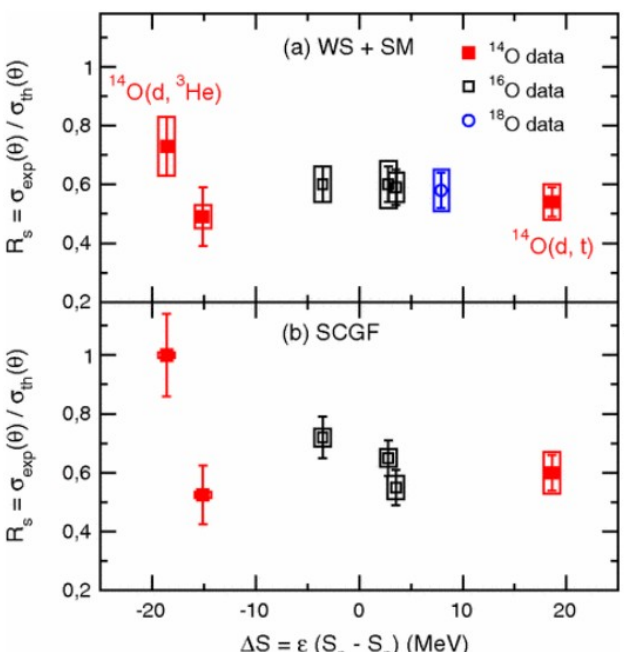
- Supression strongly dependent on the asymmetry of the separation energies.

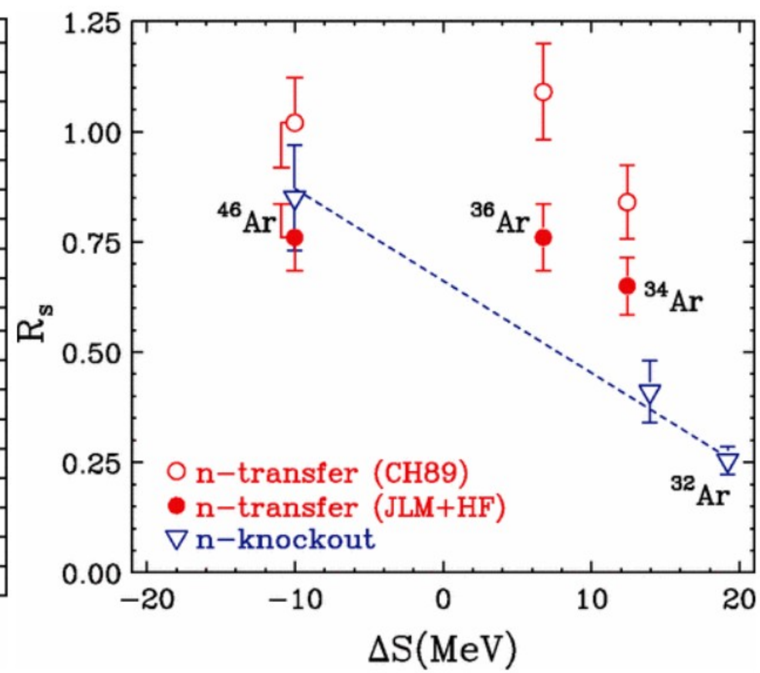
J.A. Tostevin and A. Gade, Phys. Rev. C 103 (2021) 054610



Intriguing consequences for mirror reactions:

- Isospin symmetry suggest similar σ_{exp}





On the other hand, this dependence was not observed in oxygen nor argon isotopes at low energies.

F. Flavigny et al., PRL 110 (2013) 122503.
Jenny Lee et al., PRL 104 (2010) 112701.

Study of ^{19}Ne and ^{19}F via mirror reactions ^{20}Ne(d,t) and (d,^{3}He)

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Thank you!