Questions about nuclear structure: a study of ^{80}Ge

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GRIFFIN Collaboration

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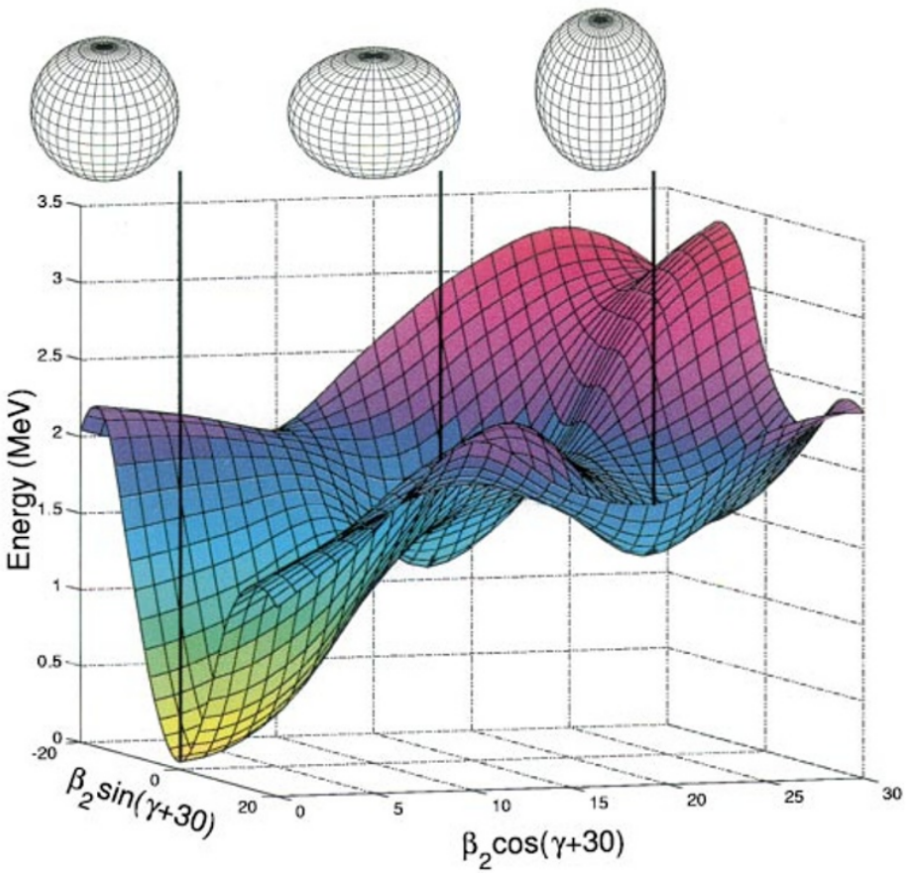
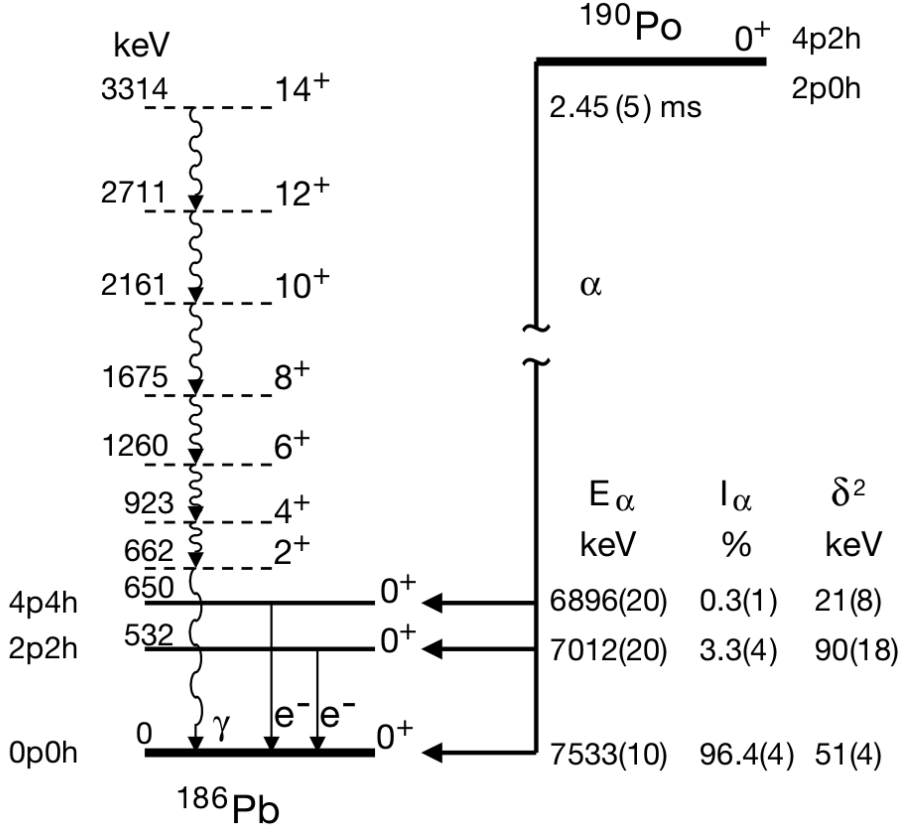
Shape coexistence



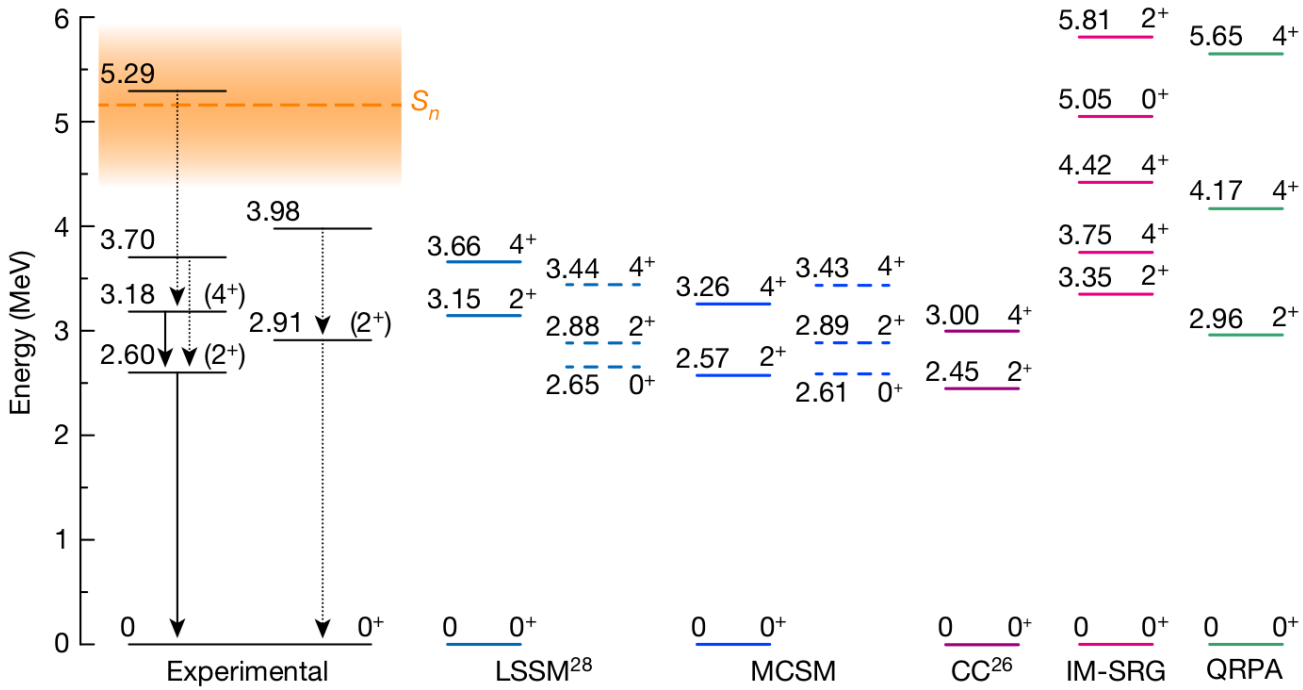


The observation of shape coexistence in ^{186}Pb was unprecedented.

Andreyev *et al.*, *Nature* 403, 430 (2000)

^{78}Ni: evidence for shape coexistence

A recent experiment probed the structure of doubly magic ^{78}Ni.

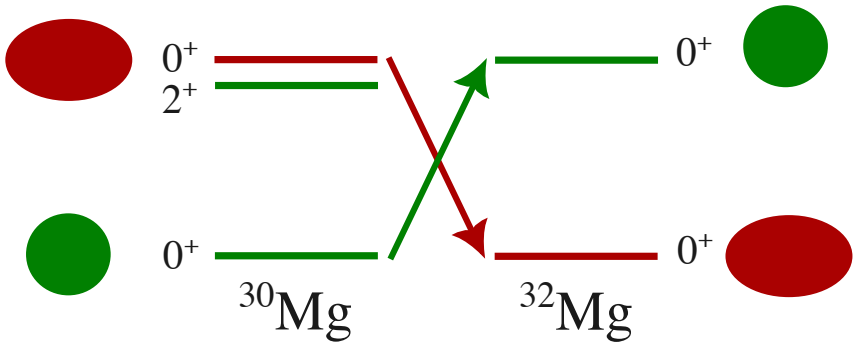


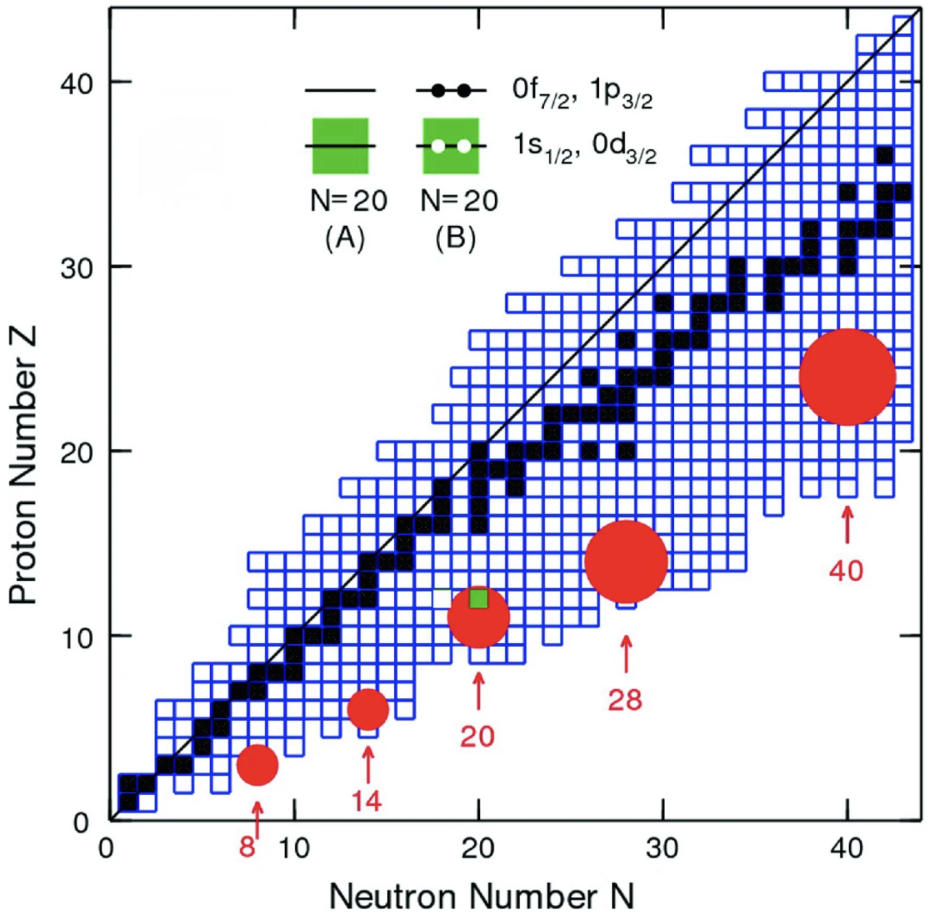
An excited 2^+ state was observed at only 0.31 MeV above the 2_1^+, suggesting shape coexistence in this nucleus.

Taniuchi, R. *et al.*, *Nature* 569 (2019) 53

Islands of Inversion

An inversion:
a sudden flipping of the states such that the spherical band is not longer the ground state band





Nowacki *et al.** proposed ^{78}Ni to be a portal to the fifth island of inversion.

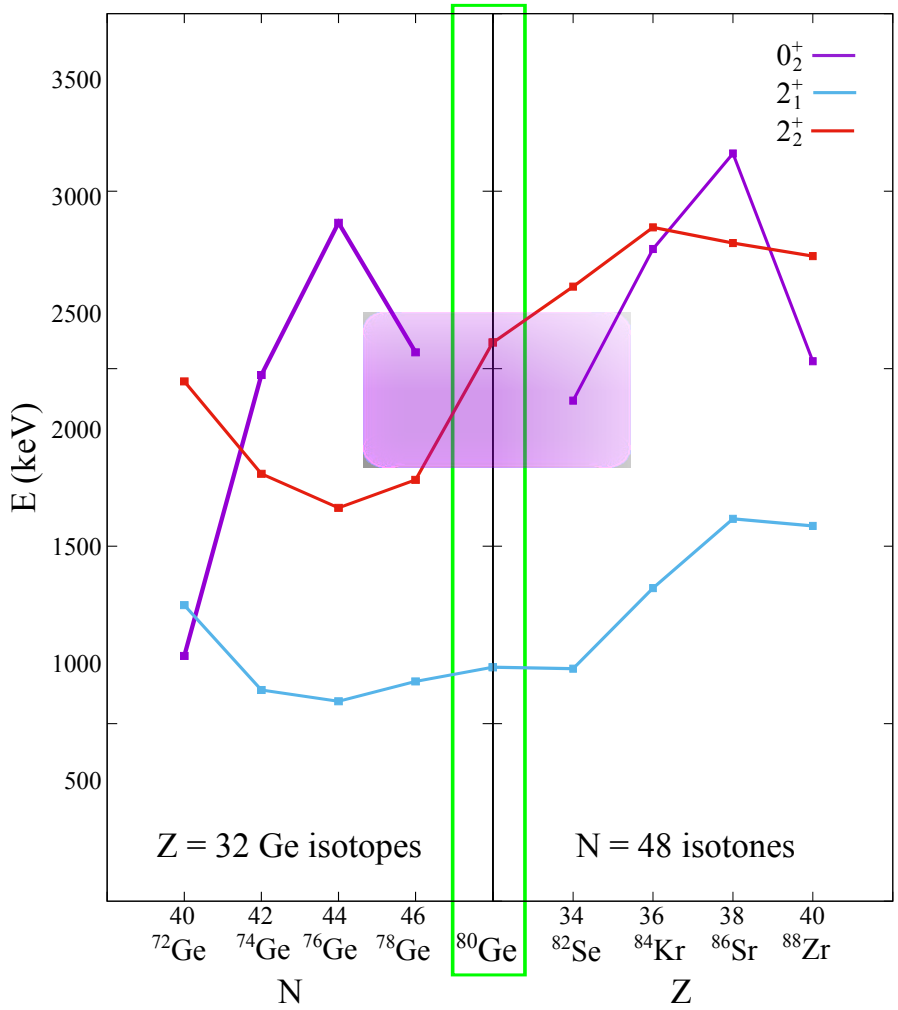
Brown, B. A. *RÁBIDA* 225 (2018)

Kröll, T. and Wimmer, K. *CERN Courier* (2011)

*Nowacki, F., Poves, A., Caurier, E. and Bounthong, B., *PRL* 117, 272501 (2016)

Coexistence in neighbouring nuclei

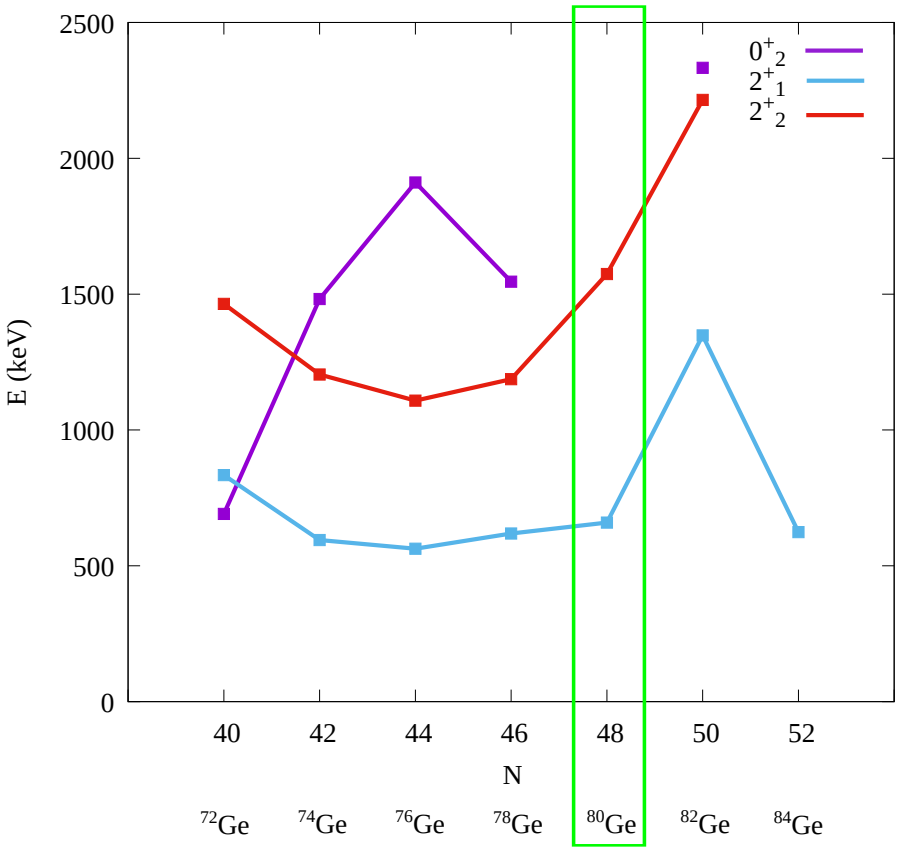
Exploring the regions around ^{78}Ni could uncover the shores of the island of inversion:
The case for ^{80}Ge

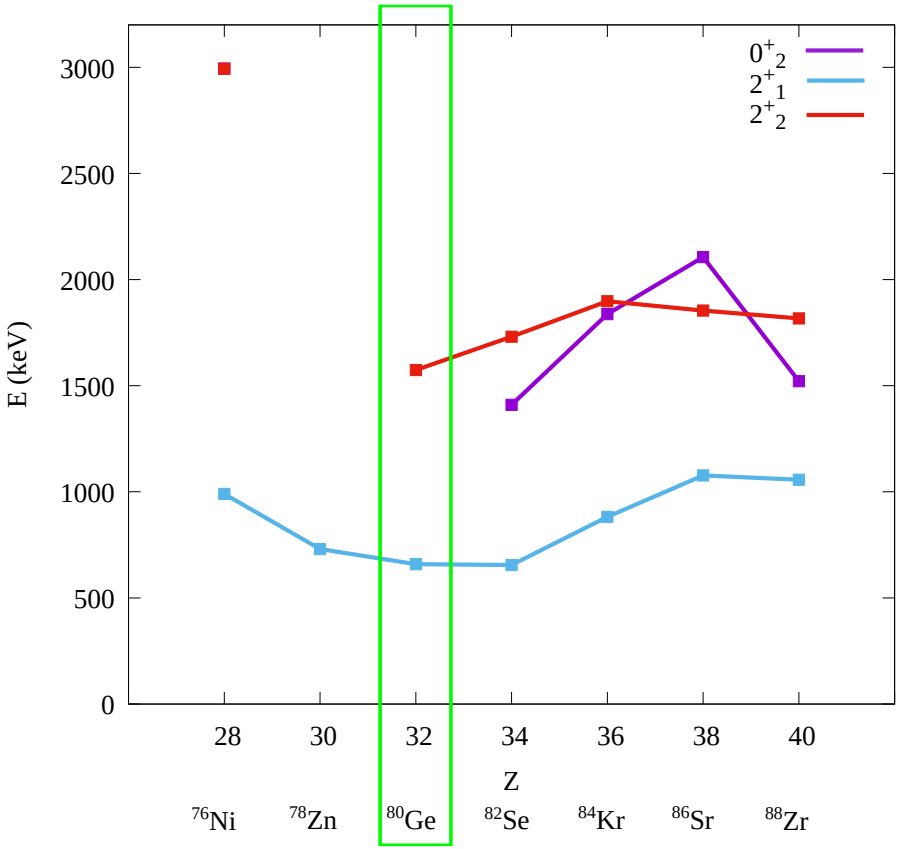


NNDC, Brookhaven National Laboratory

Coexistence in neighbouring nuclei

Does ^{80}Ge represent a boundary in the systematics?



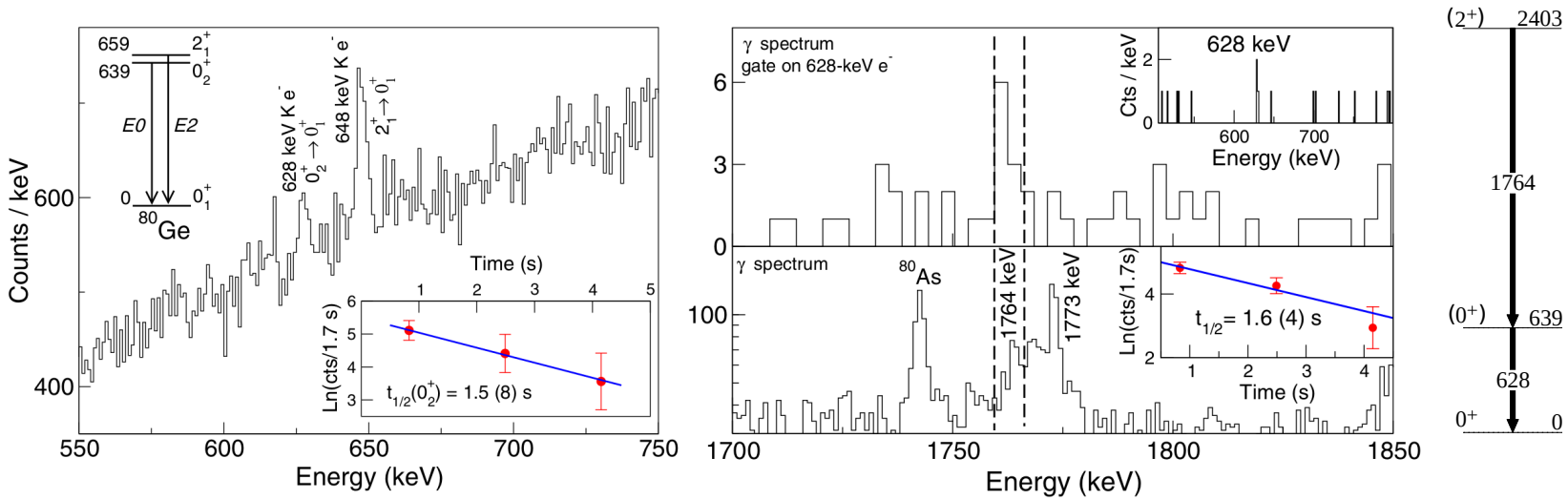


NNDC, Brookhaven National Laboratory

Low-lying Coexistence in ^{80}Ge

An experiment at ALTO reported a new state 0^+ state in ^{80}Ge at 639 keV, from observation of a conversion electron peak at 628 keV.

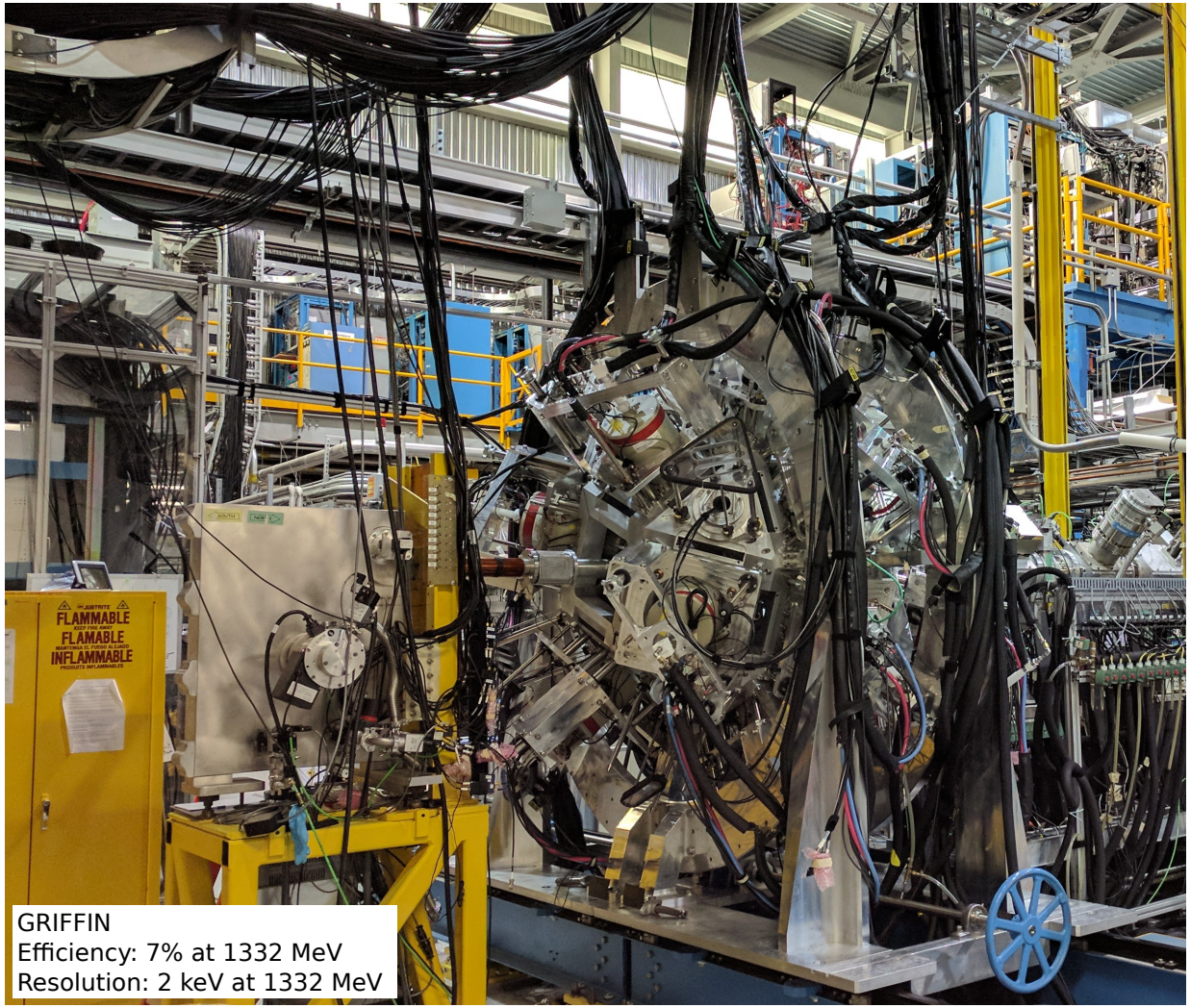
A coincidence was also observed between the 628-keV conversion electron and a 1764-keV γ-ray from a new state at 2403 keV.



The binding electron of the K-shell electron in ^{80}Ge is 11 keV

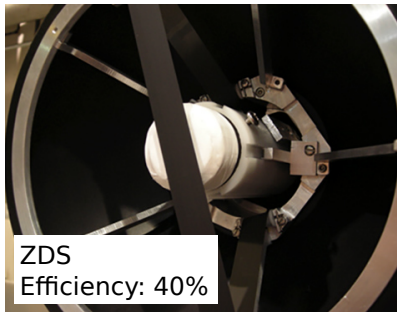
Gottardo, A. *et al.*, *PRL* 116, 182501 (2016)

GRIFFIN for β-decay spectroscopy

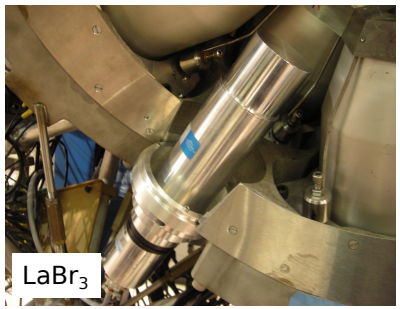


GRIFFIN
Efficiency: 7% at 1332 MeV
Resolution: 2 keV at 1332 MeV

PACES
Efficiency: ~2%



ZDS
Efficiency: 40%



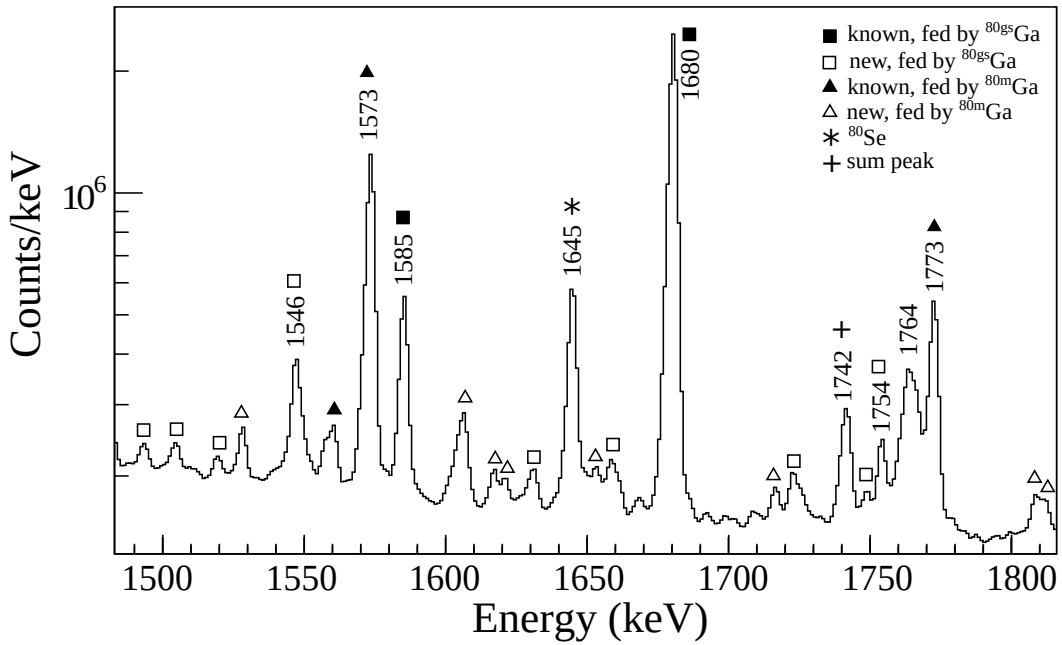
$LaBr_3$

Garnsworthy, A. B. *et al.*, *NIM A* 918,9 (2019)

Quality of the dataset

Experimental details:

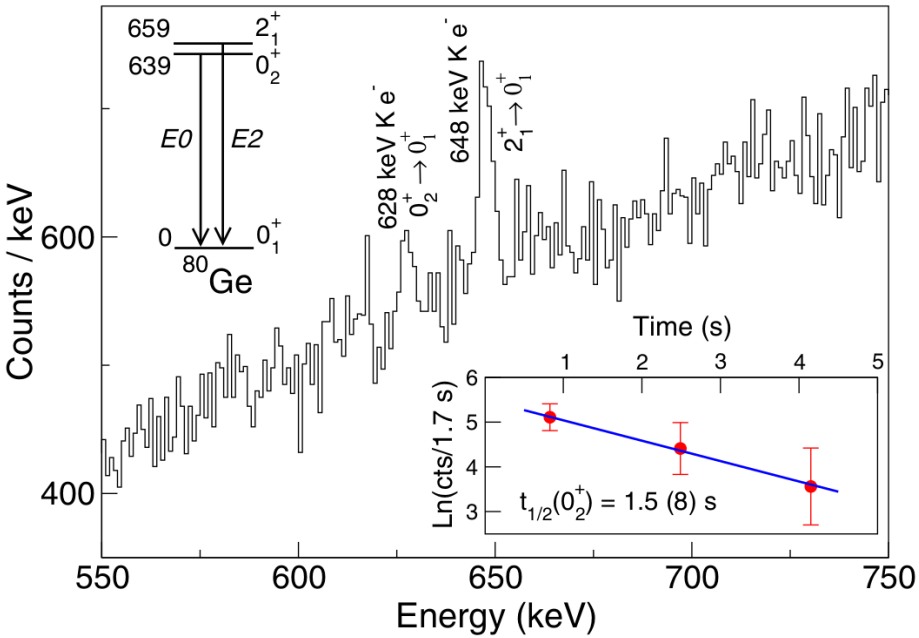
- ^{80}Ga β-decay to ^{80}Ge
- Run time: 51 hrs
- 78% ^{80}Rb contaminant
- 22% ^{80}Ga at 2×10^4 pps
- 6^- ^{80gs}Ga : 53%
- 3^- ^{80m}Ga : 46%

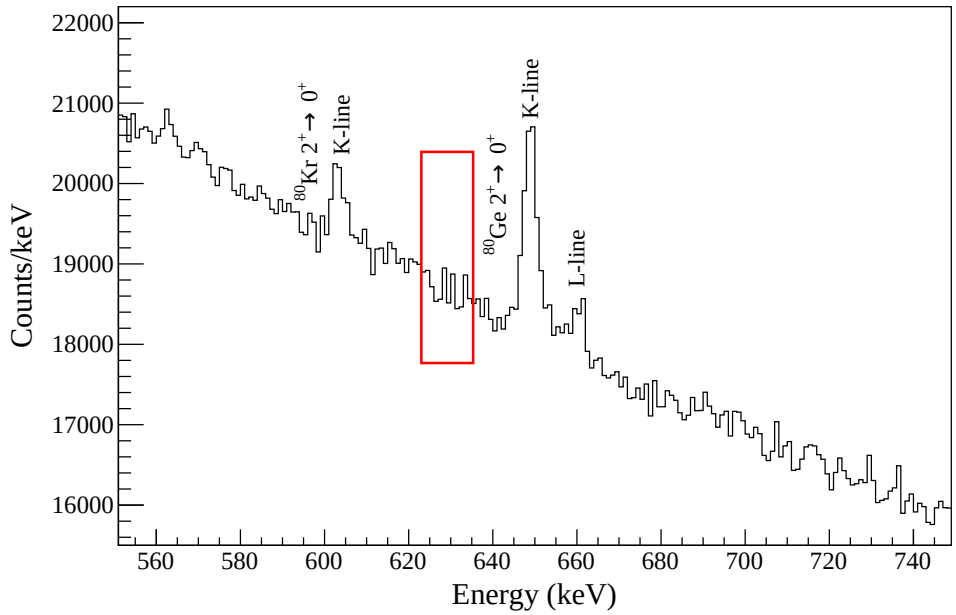


Garcia, F. H. *et al.*, *PRL* 125, 172501 (2020)

Contradictory Results

The GRIFFIN experiment used PACES, but did not detect the 628-keV conversion electron peak.





ALTO I^{628}: ~0.08%

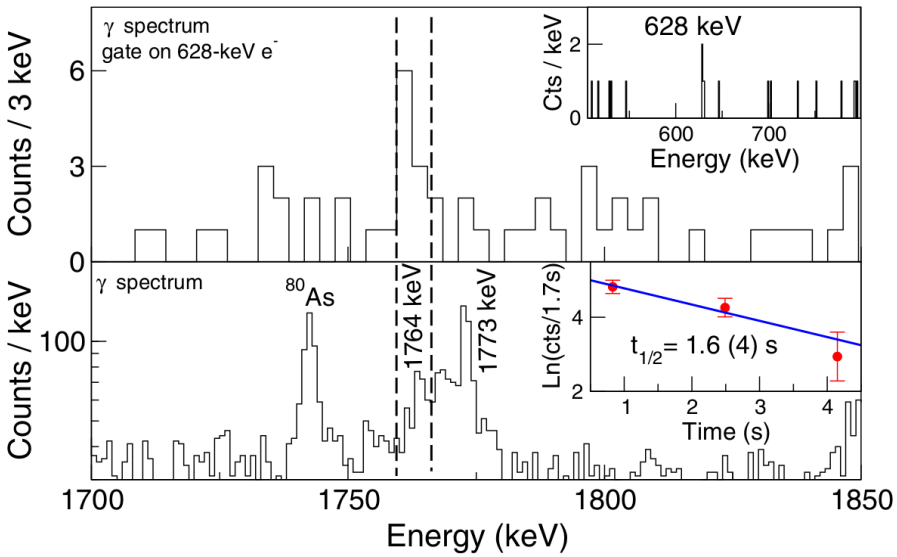
GRIFFIN 2σ limit: <0.02%

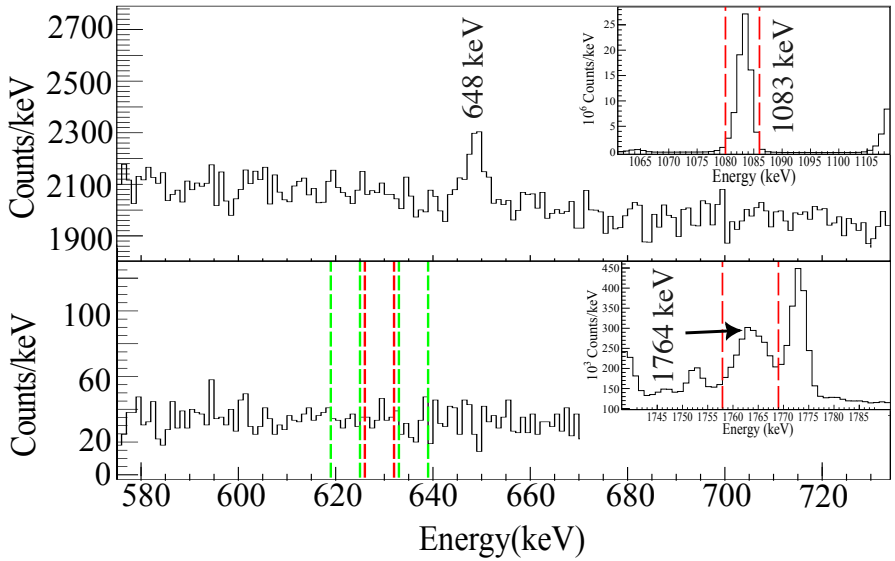
Gottardo, A. *et al.*, *PRL* 116, 182501 (2016)

Garcia, F. H. *et al.*, *PRL* 125, 172501 (2020)

Searching for transitions

Detection limits were calculated to verify non-observation.





ALTO I_{1764}/I_{1772}: 0.3

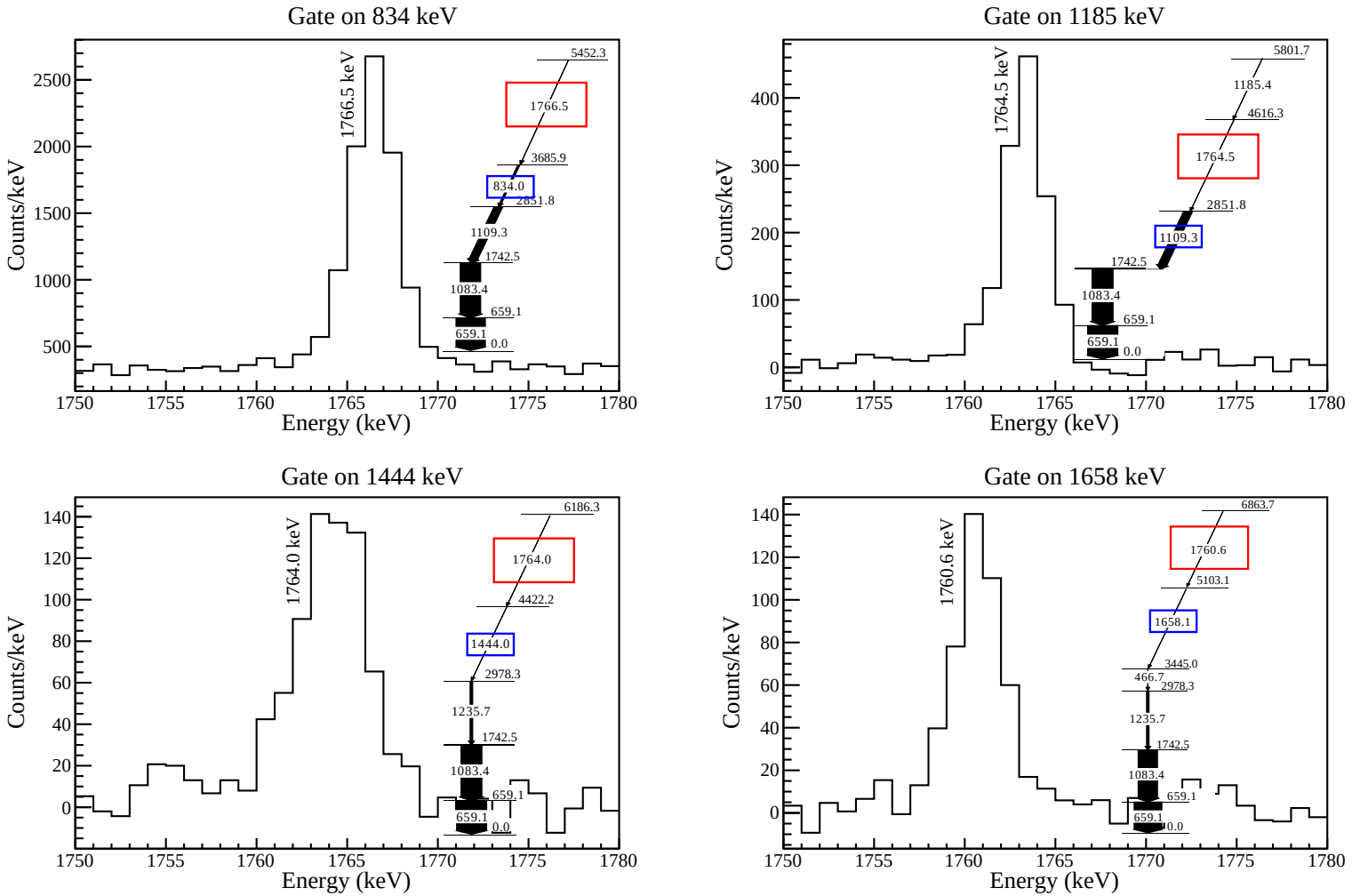
GRIFFIN I_{1764}/I_{1772} 2σ limit: 0.003

Gottardo, A. *et al.*, *PRL* 116, 182501 (2016)

Garcia, F. H. *et al.*, *PRL* 125, 172501 (2020)

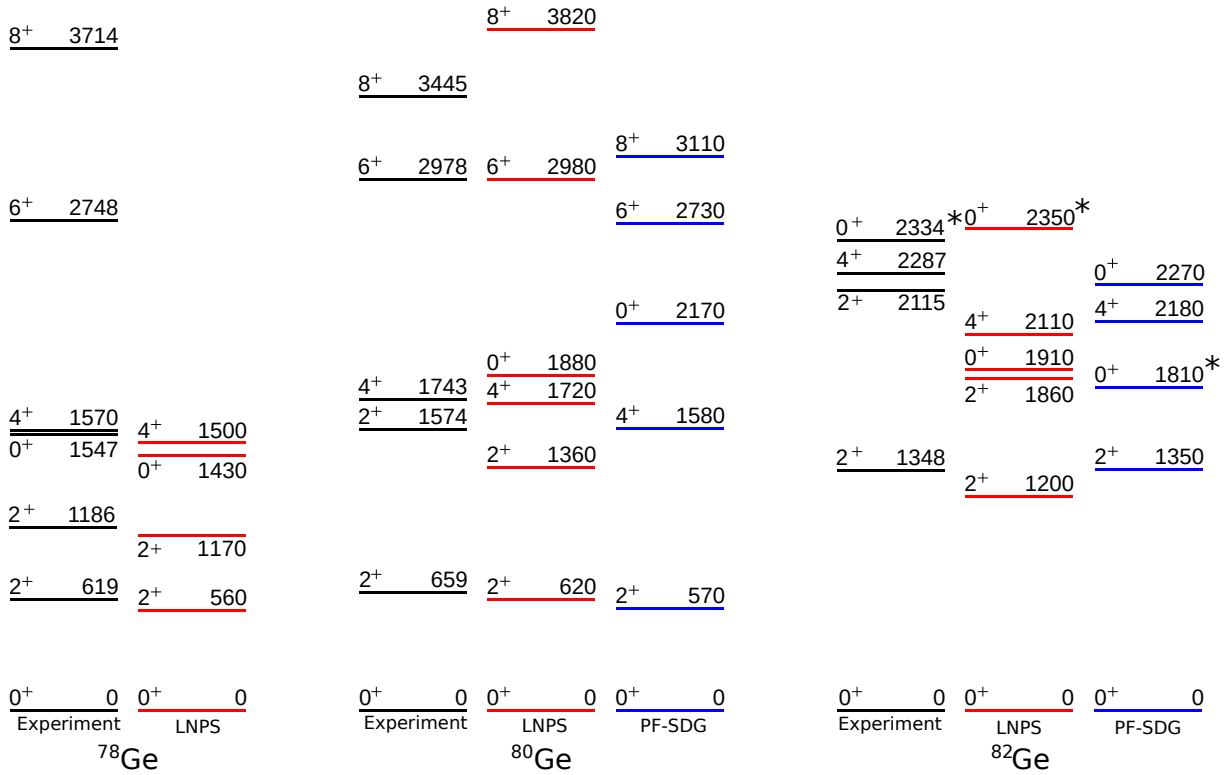
1764-keV γ-ray

Distinguished by GRIFFIN, the broad peak at 1764 keV is in fact four different transitions (red), observed in different gates (blue);



Theoretical considerations

To compliment the experimental results, large-scale shell model calculations were performed, which were able to reasonably predict intruder configurations in neighbouring isotopes.



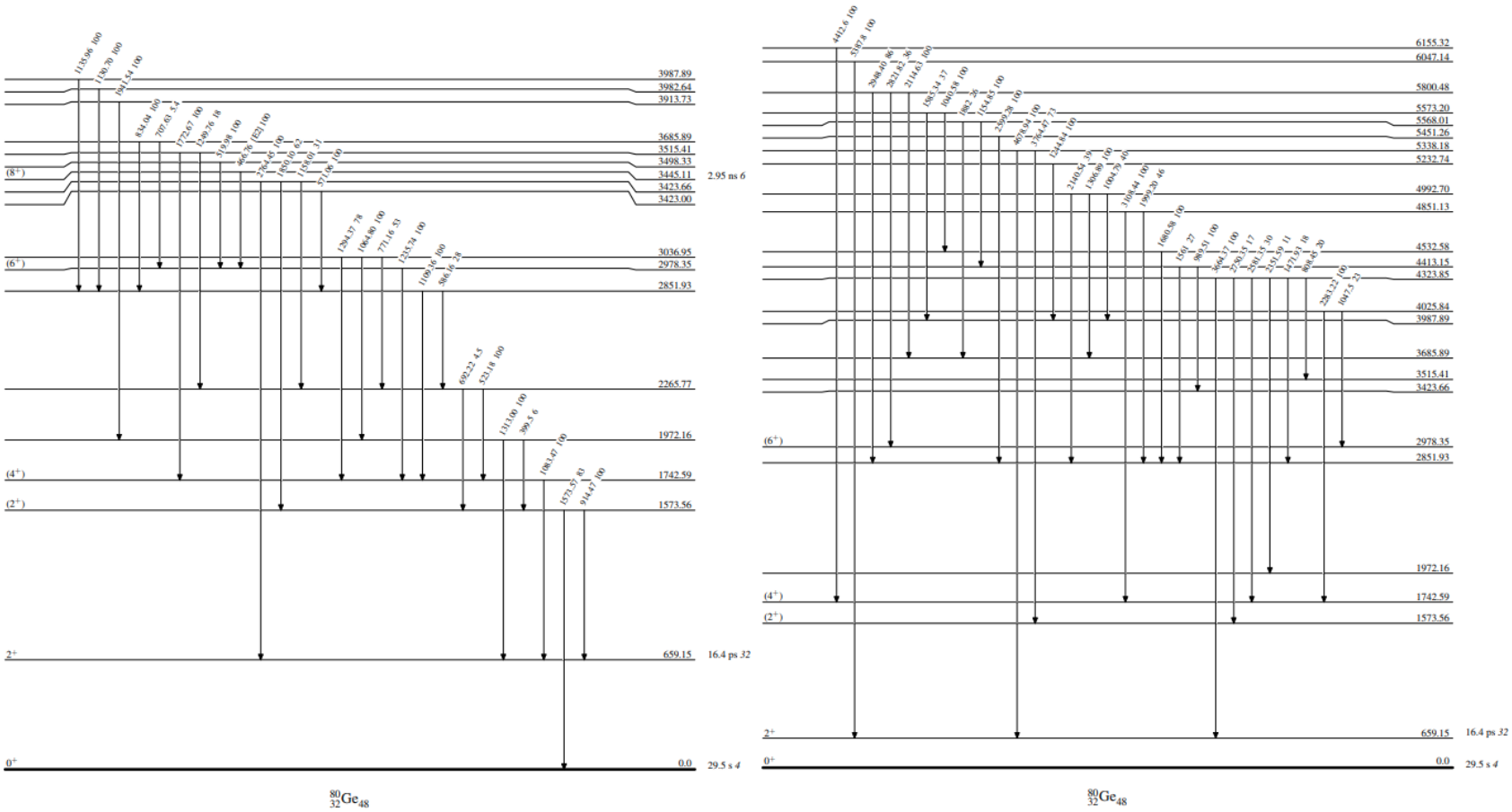
Garcia, F. H. *et al.*, *PRL* 125, 172501 (2020)

Lenzi, S., Nowacki, F. Poves, A. and Sieja, K. *PRC* 82, 054301 (2010)

Nowacki, F., Poves, A., Caurier, E. and Bounthong, B., *PRL* 117, 272501 (2016)

Current status ^{80}Ge in NNDC

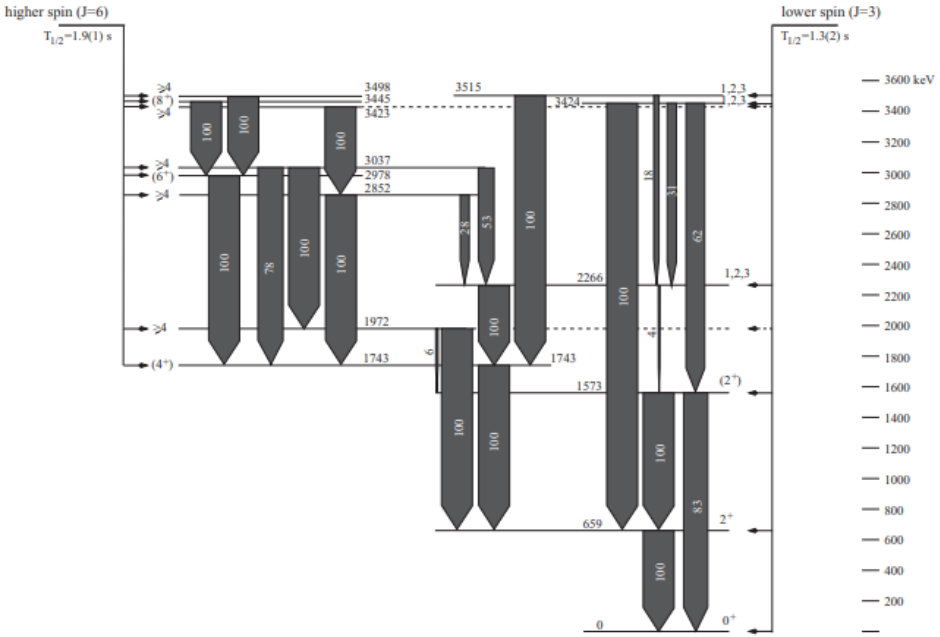
Evaluated in 2005 and shows 32 levels and 56 transitions



NNDC, Brookhaven National Laboratory

Recent studies: ALTO (2013)

ALTO produced both 6^- ground and 3^- isomeric states in ^{80}Ga, populating excited states in ^{80}Ge, placing 21 transitions and 14 states



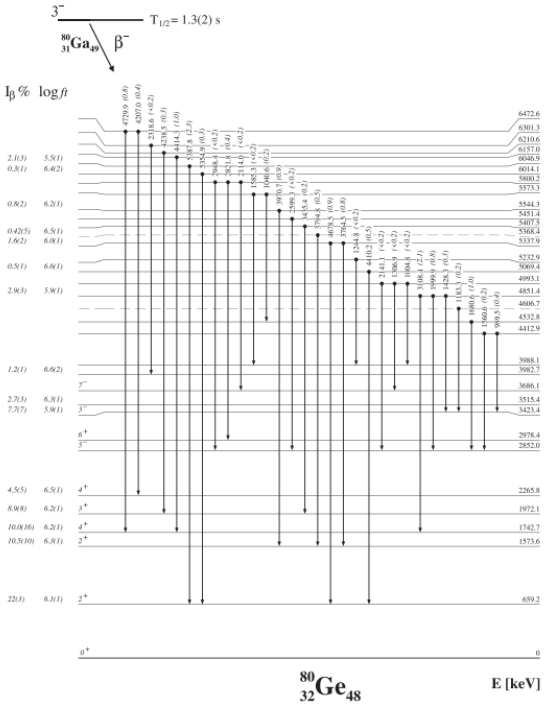
- Photofission
- Yield: 9.4×10^3 pps
- ^{80gs}Ga: 48% / ^{80m}Ga: 52%
- 2 HPGe
- ϵ (1.3 MeV): 1.4%

Concluded that the level scheme was fragmented due to the spins of the parents states and were able to separate the feeding of excited states

Verney, D. *et al.*, *PRC* 87, 054307 (2013)

Recent studies: ISOLDE (2021)

ISOLDE produced largely only the 3^- isomeric state in ^{80}Ga, precluding the fragmentation challenge identified by ALTO and observd 79 transitions and 42 states



- 0^+ ground state in ^{80}Zn decayed to ^{80}Ga 3^-
- Yield: 2×10^4 pps
- 2 HPGe
- ϵ_{rel}: 60%
- Plastic scintillator for β-tagging
- $LaBr_3$ for fast timing

Corroborated the results that the 0_2^+ at 639 keV did not exist

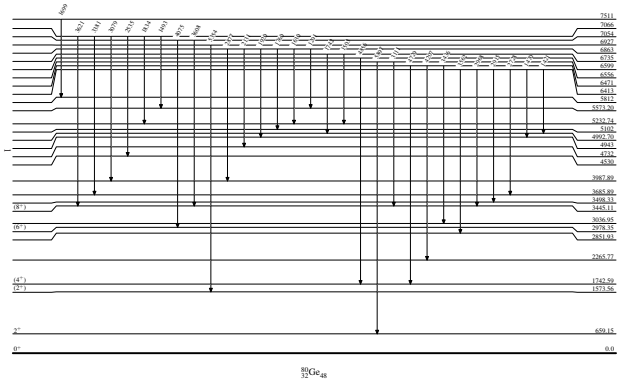
Sekal, S. *et al.*, *PRC* 104, 024317 (2021)

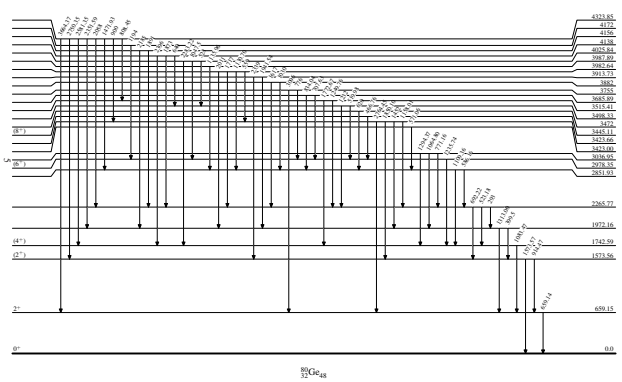
GRIFFIN data on ^{80}Ge

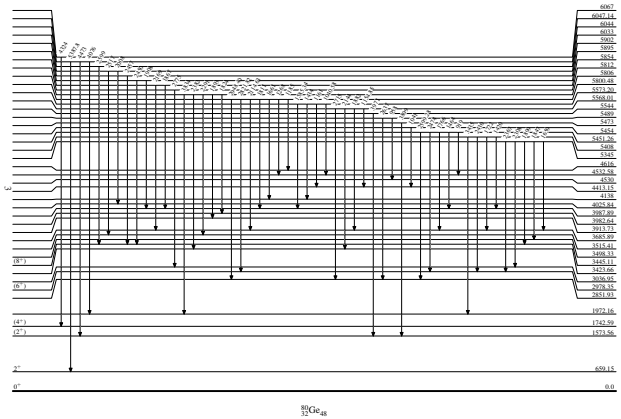
Spectroscopic analysis is nearing the end. The dataset is quite rich.

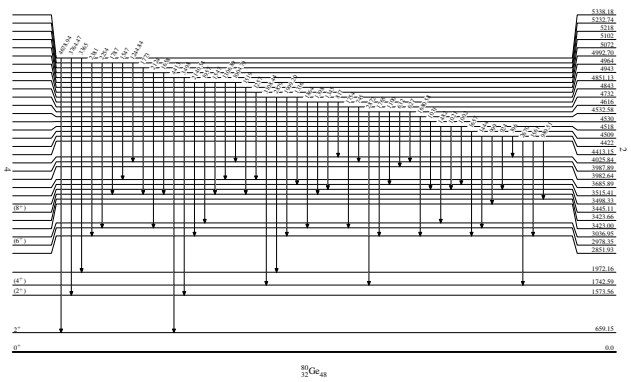
Highlights:
- ~1000 newly observed transitions
- ~350 newly observed excited states

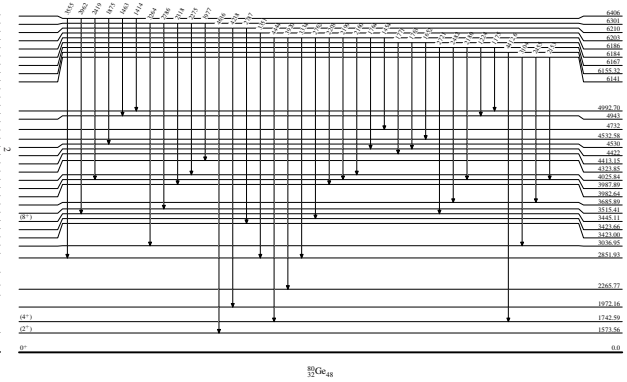
Next steps:
- Sorting level contributions
- β-feeding analysis for tentative spins
- logFT and B(GT) calculations











Update: 1764-keV γ-ray

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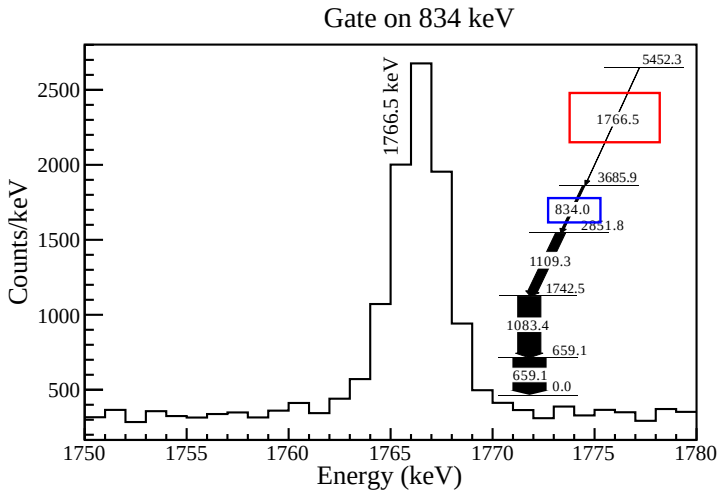

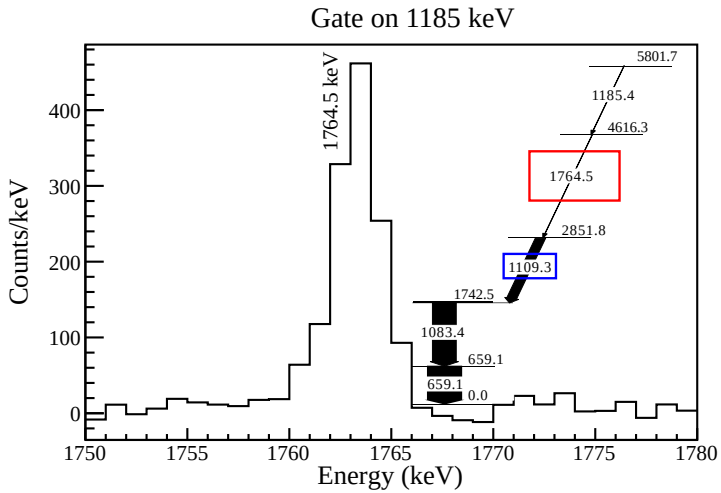

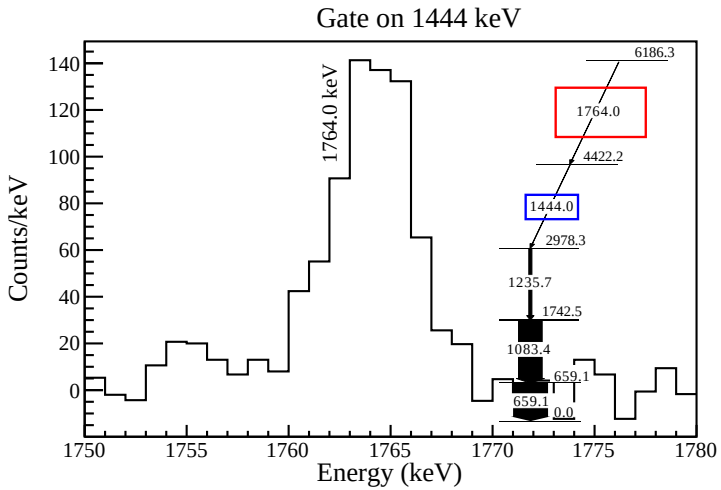

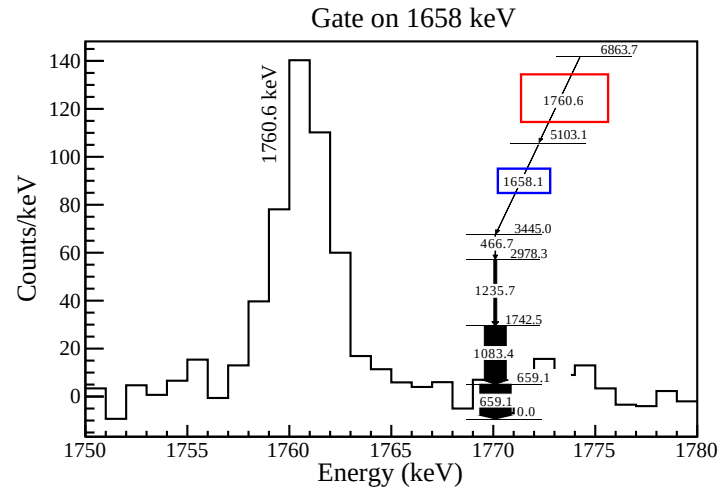

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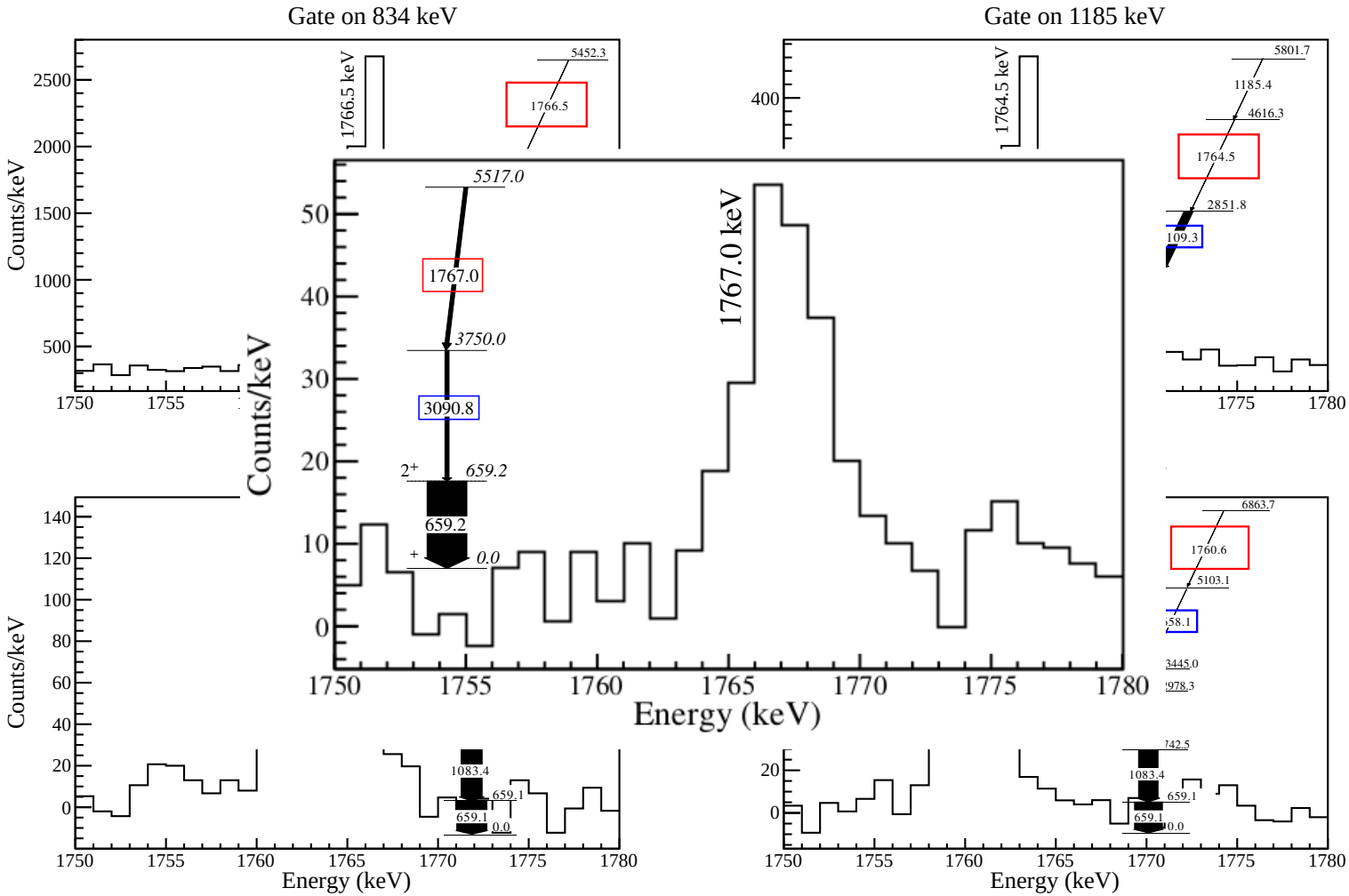
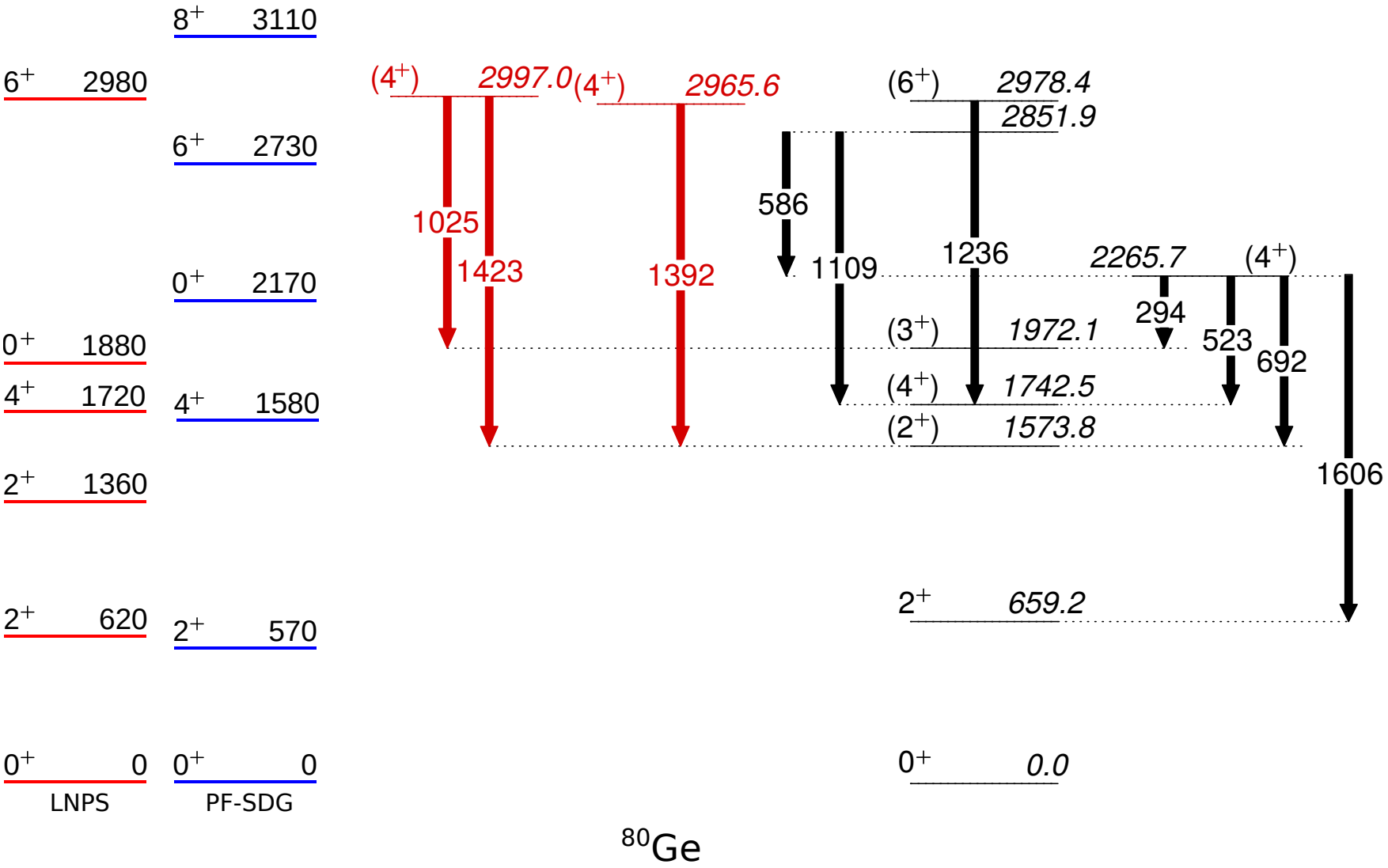


Levels in the 2 MeV energy range



Level spins are still tentative

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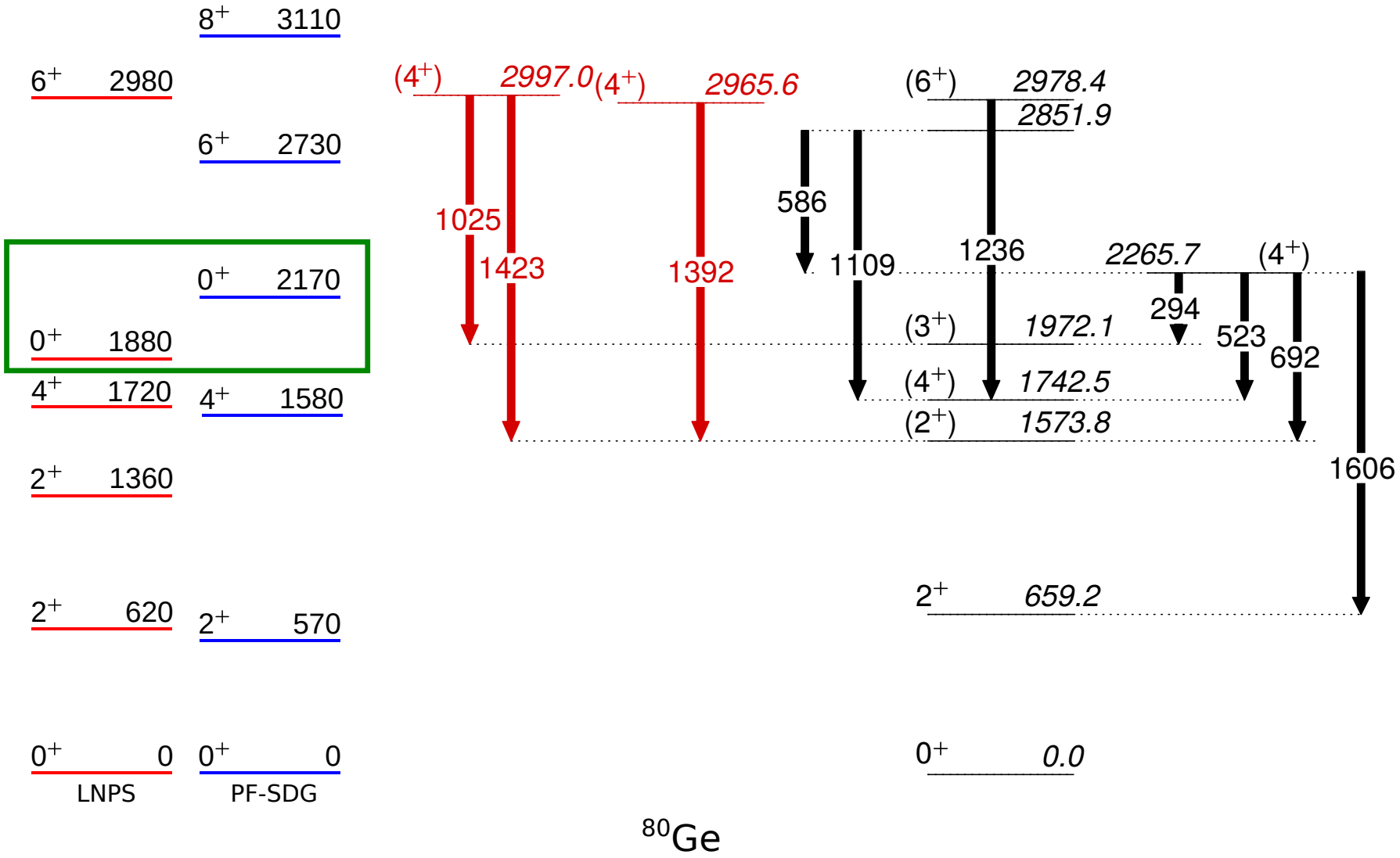

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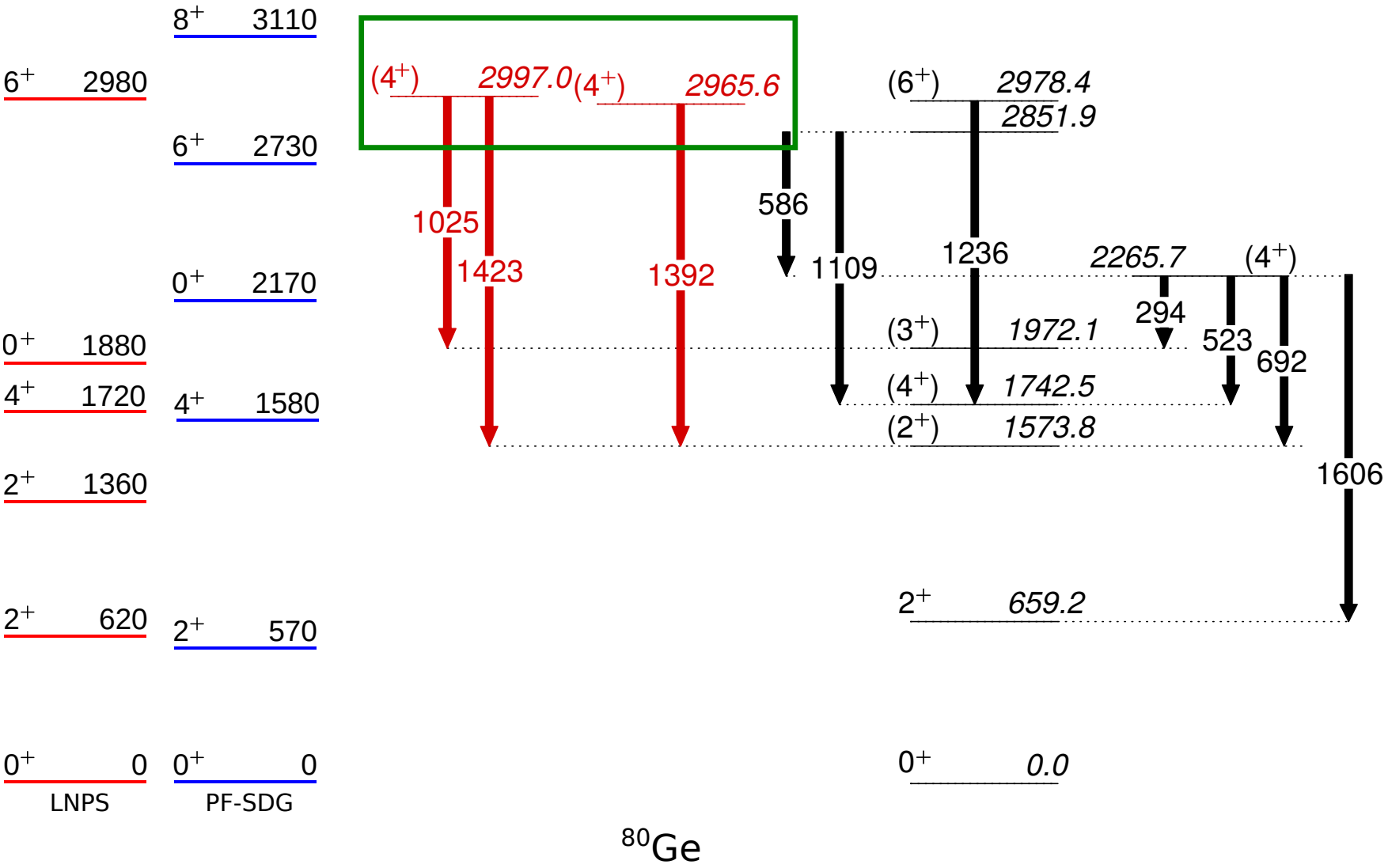
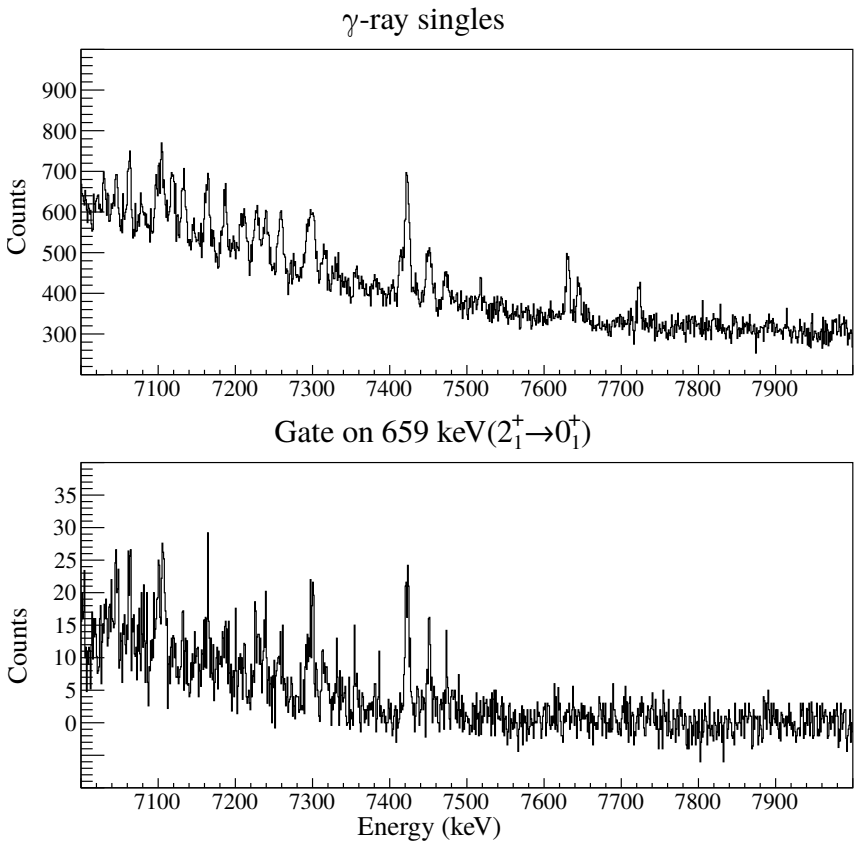


Level spins are still tentative

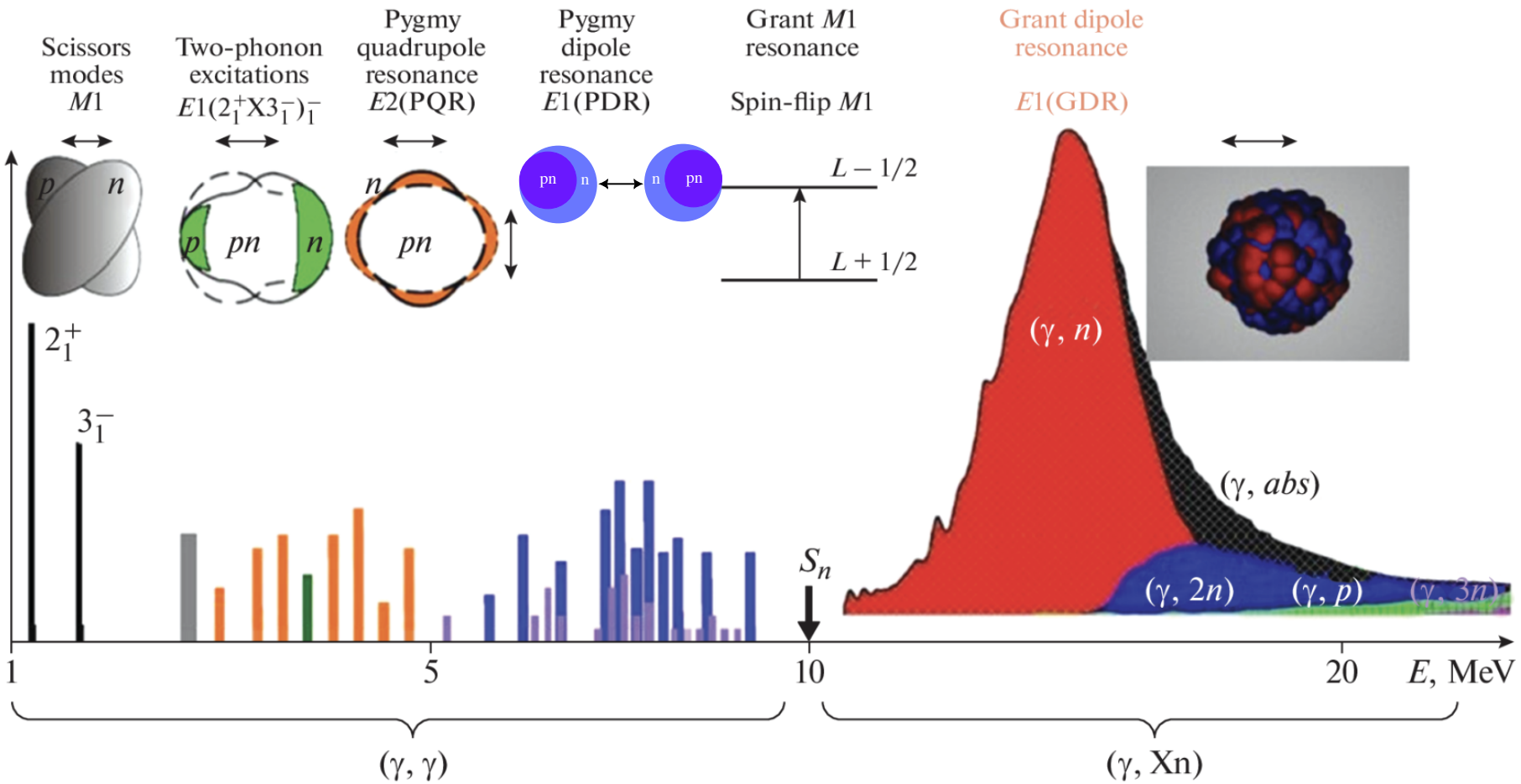
Levels above S_n

A number of levels have been identified above the neutron separation energy of ^{80}Ge (8.08 MeV).



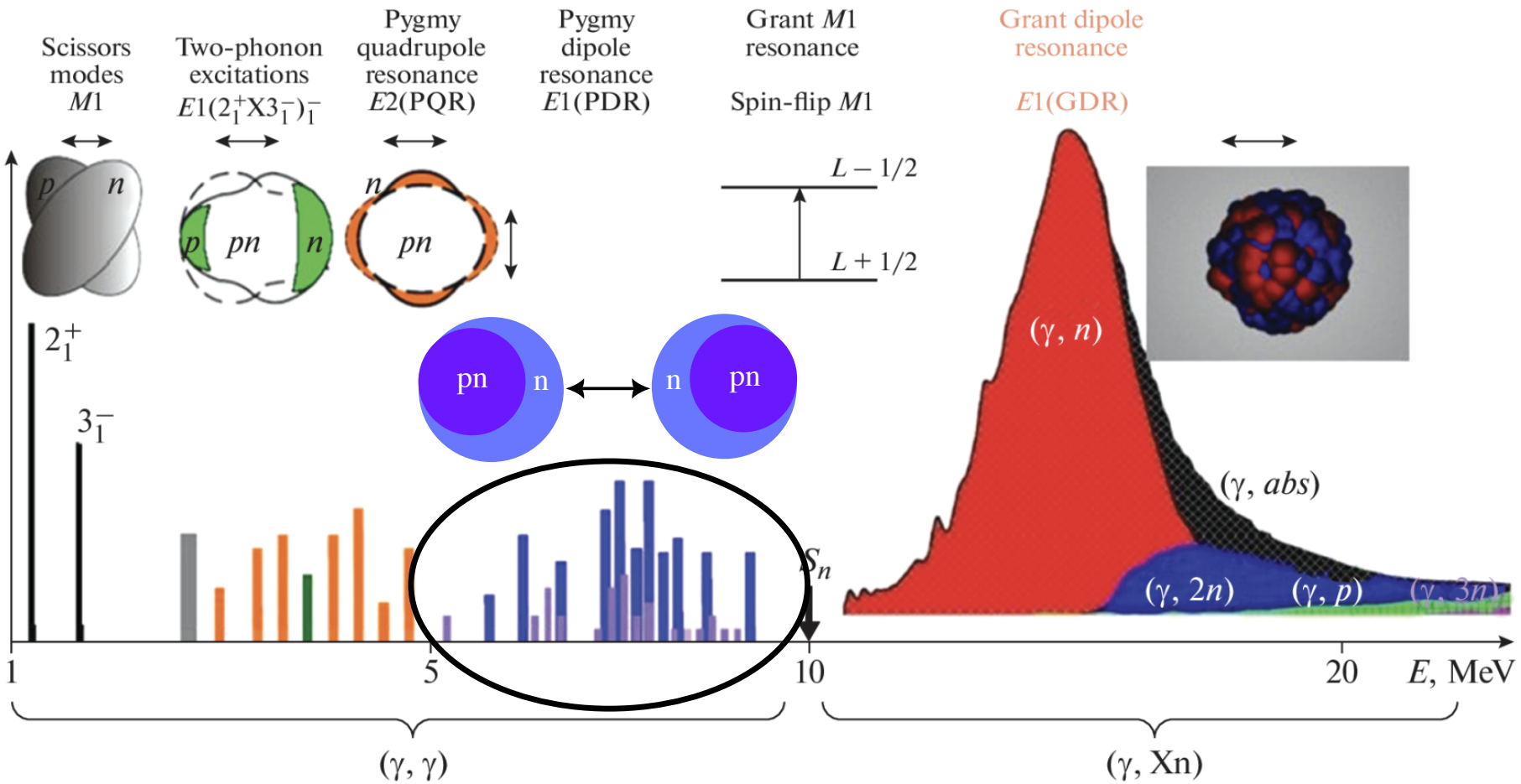
E_i (keV)	E_γ (keV)	E_f (keV)
8111.1	7451.9	659.2
8112.5	6370.0	1742.5
8129.5	6387.0	1742.5
8132.6	7473.4	659.2
8132.9	5154.7	2978.2
8135.5	6393.0	1742.5
8160.0	5894.3	2265.7
	6188.1	1972.1
8181.0	6439.0	1742.5
	6208.4	1972.1
8195.1	6223.0	1972.1
8208.9	6236.8	1972.1
8211.5	6469.8	1742.5
8217.2	5951.5	2265.7
8265.7	6525.0	1742.5
8278.5	6536.0	1742.5
8281.2	5303.0	2978.2
8294.5	6552.0	1742.5
8343.8	5365.6	2978.2
8390.3	5412.1	2978.2
8519.2	5541.0	2978.2

Pygmy Dipole Resonances



Kamerdzhiev, S.P. & Shitov, M.I. Moscow Univ. Phys. 79 (2024) 191–199

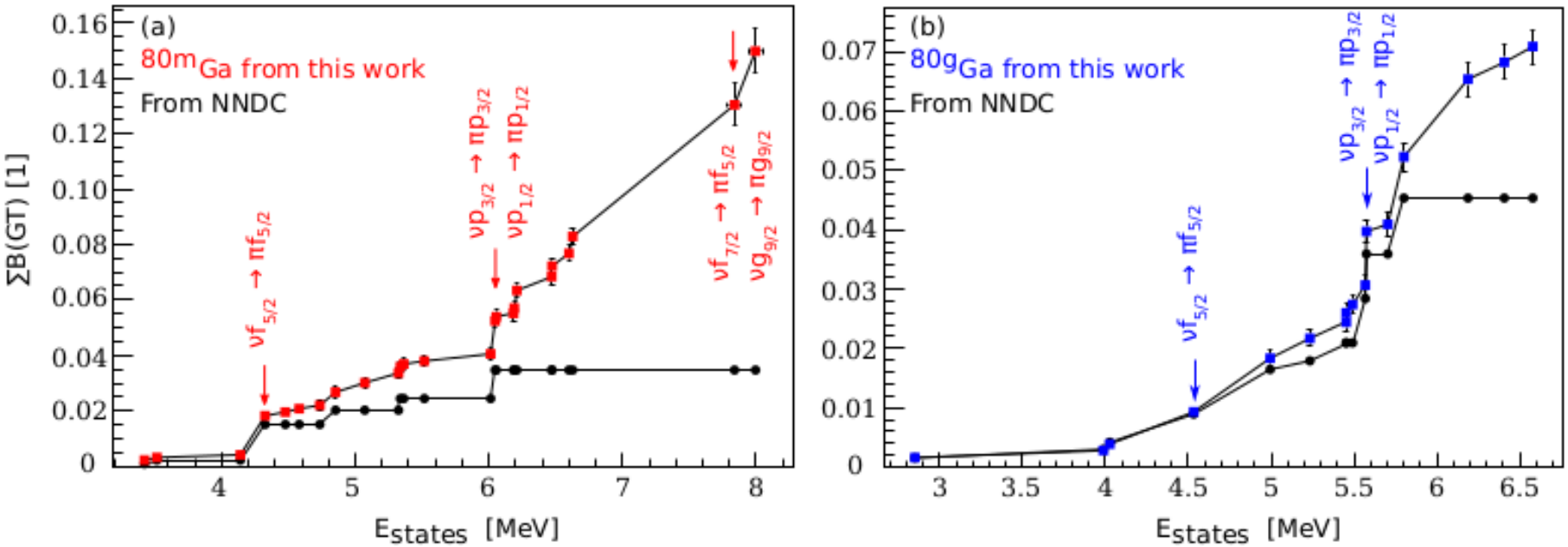
Pygmy Dipole Resonances



Kamerdzhiev, S.P. & Shitov, M.I. Moscow Univ. Phys. 79 (2024) 191–199

B(GT) strength & evidence for PDR

A jump structure in the B(GT) values was quoted as evidence for pygmy dipole resonance behaviour



Li, R. *et al.*, doi.org/10.48550/arXiv.2405.20490 (2024)

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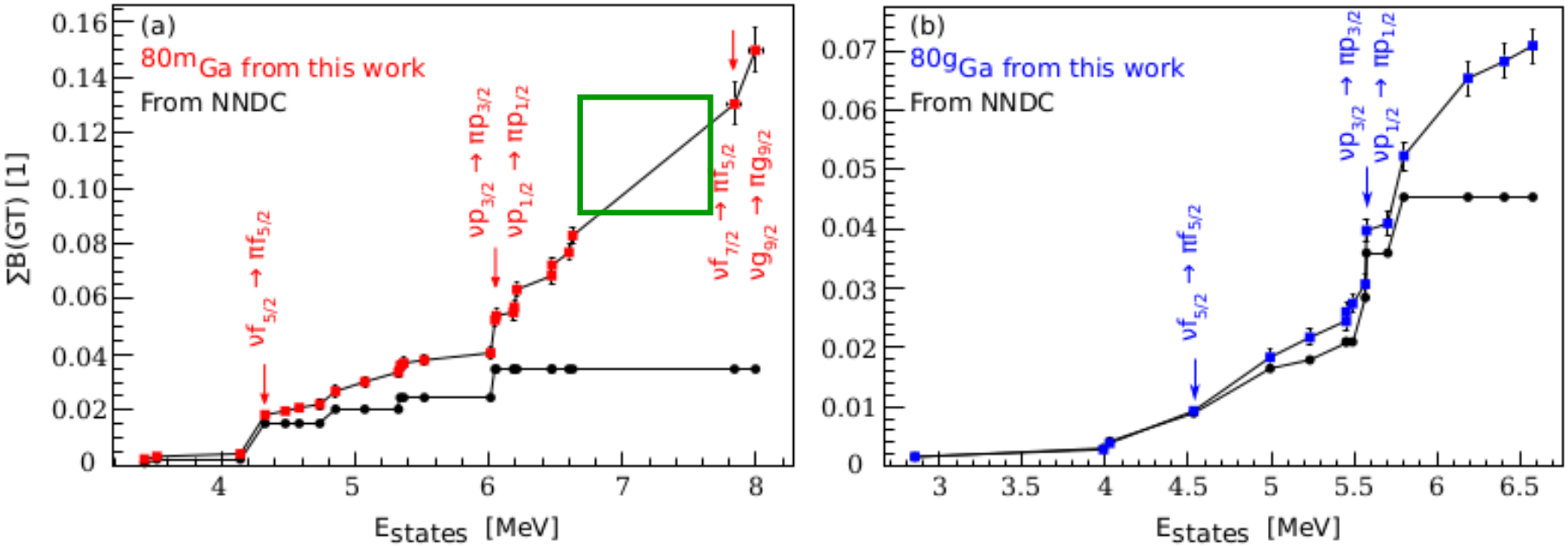
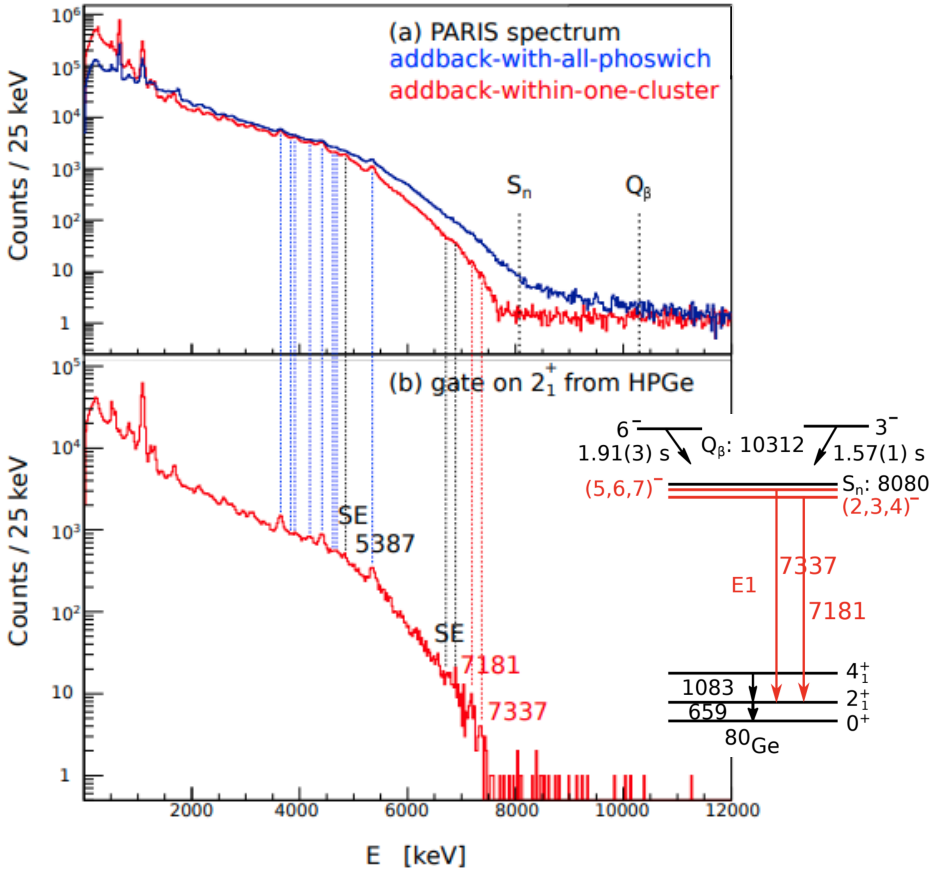
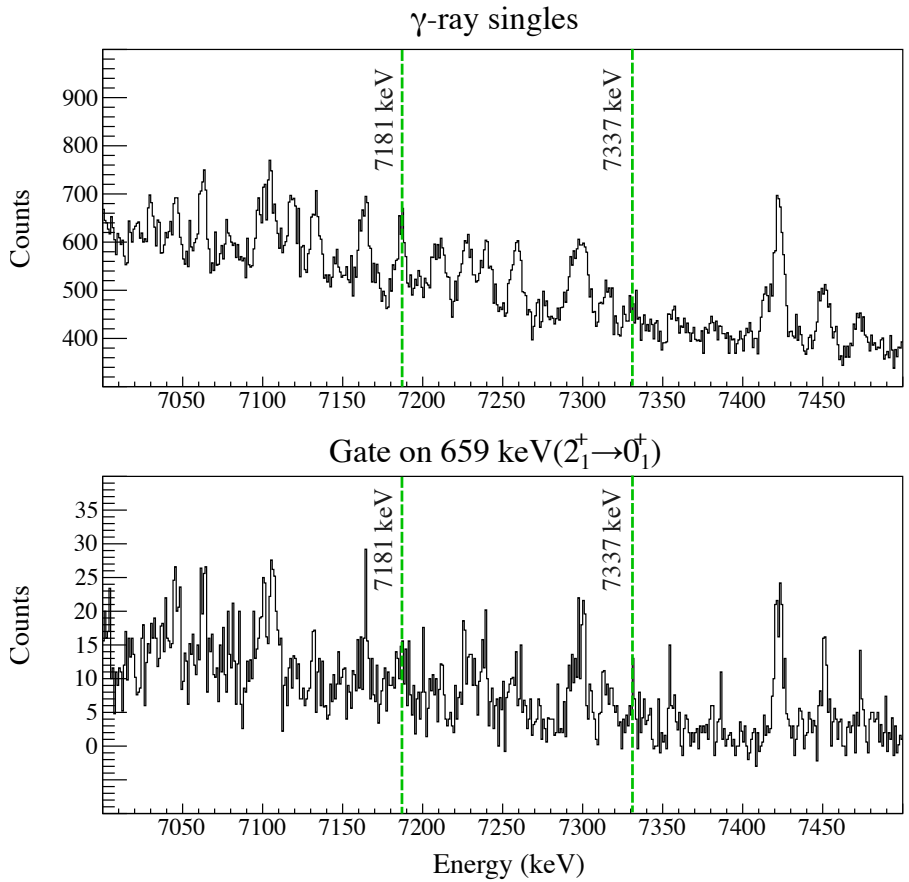


Li, R. *et al.*, doi.org/10.48550/arXiv.2405.20490 (2024)

High Energy transitions as evidence for PDR

Two high energy γ-rays observed to decay to the 659-keV 2_1^+ may point to pygmy dipole resonance





Li, R. *et al.*, doi.org/10.21203/rs.3.rs-3169781/v1 (2023)

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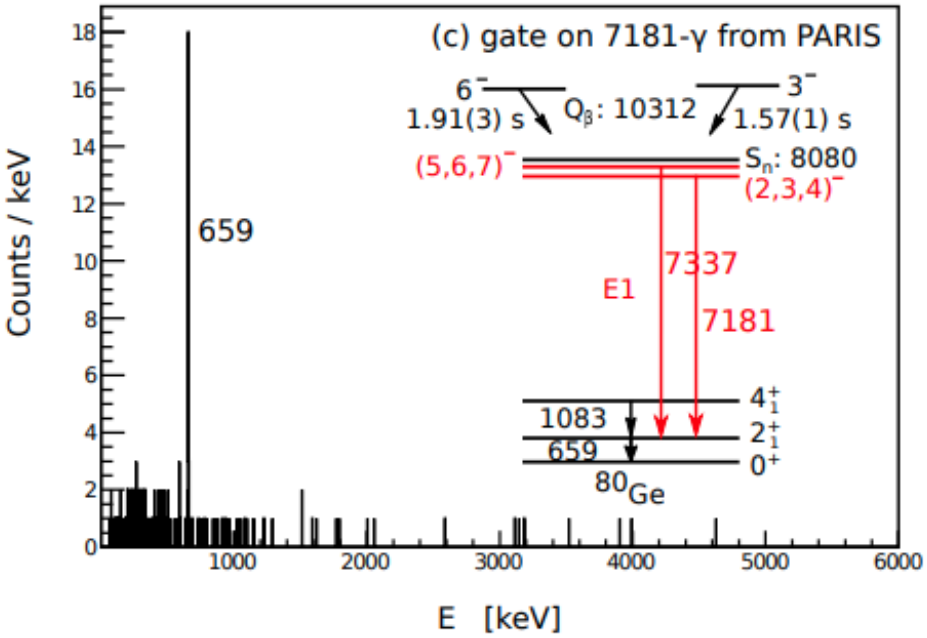

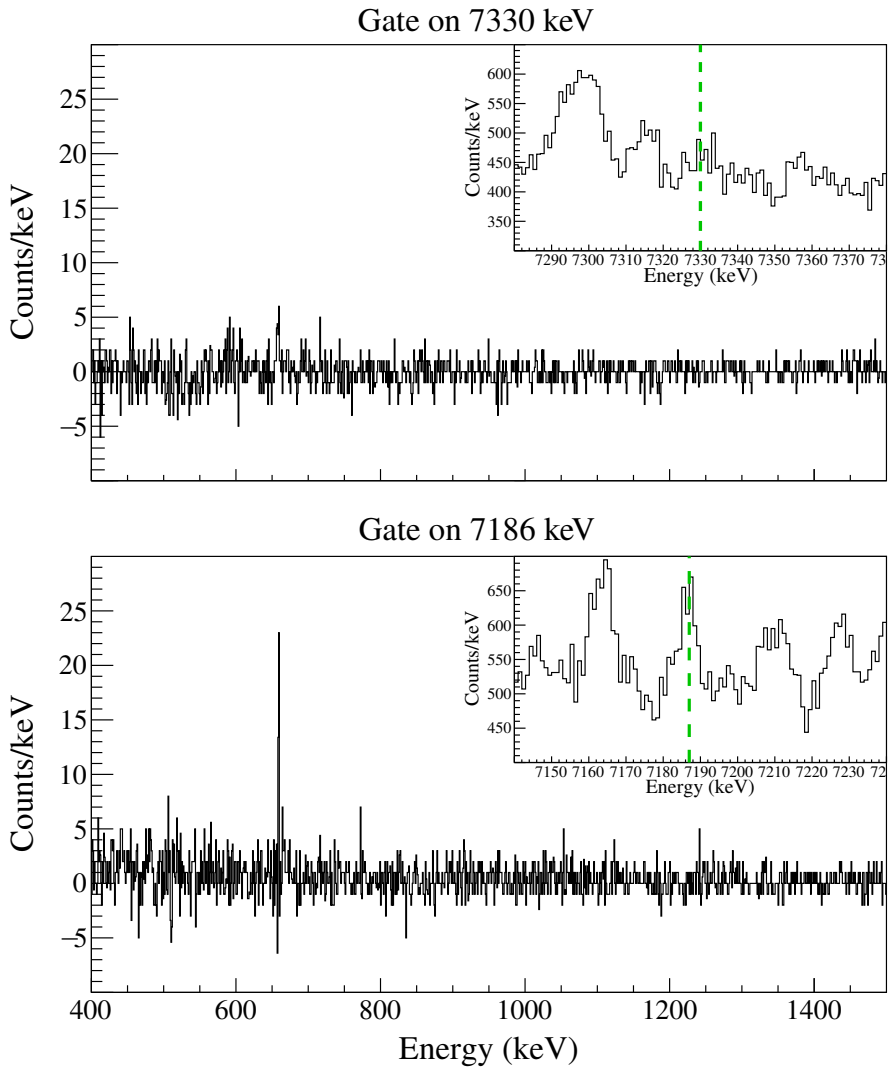

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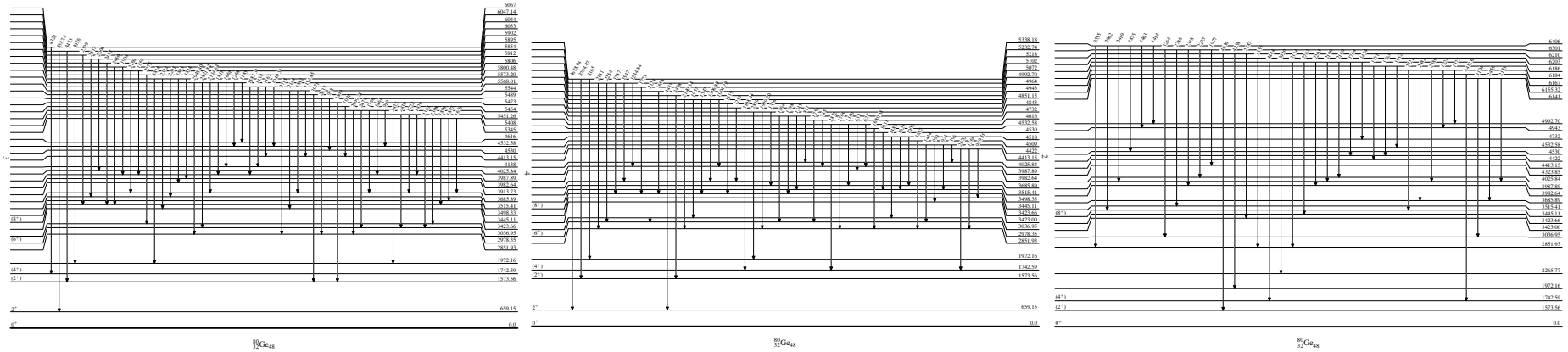
Conclusions and outlook

Massive impact to the region around ^{80}Ge:

- Shape coexistance questions
- Features at the shore of the island of inversion
- Investigations of pygmy dipole resonance



One thousands transitions, one thousand and one implications?

SFU
C. Andreoiu, A. Bell, I. Djianto, M. Gascoine, K. Ortner, P. Spagnoletti, K. Raymond, K. Whitmore

TRIUMF
G. C. Ball, N. Bernier, S. Bhattacharjee, M. Bowry, A. B. Garnsworthy, I. Dillman, G. Hackman, A.N. Murphy, B. Olaizola, R. Umashankar, J. Williams, D. Yates

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Thank you

^{80}Ge experiment comparisons

GRIFFIN

- ISOL: p^+ reactions
- Yield: 2.4×10^4 pps
- ^{80gs}Ge: 53% / ^{80m}Ge: 46%
- 15 HPGe
- ϵ (1.3 MeV): 8%
- 5 Si(Li)
- 10 plastic scintillators

Gottardo *et al.*

- Photofission
- Yield: $\sim 10^4$ pps
- 1 HPGe
- ϵ (1.3 MeV): 0.7%
- 1 Si(Li)
- 1 plastic scintillator

Verney *et al.*

- Photofission
- Yield: 9.4×10^3 pps
- ^{80gs}Ge: 48% / ^{80m}Ge: 52%
- 2 HPGe
- ϵ (1.3 MeV): 1.4%

Isomeric Component calculation - I

A major concern that presented itself during the analysis was the quantity of each of the ground state and isomer of ^{80}Ge in the beam.

The $6(^-)$ g.s. and 22.4 keV $3(^-)$ isomer in ^{80}Ga are known to β-decay. ENSDF only shows the $3(^-)$ isomer β-decaying, but there is a high lying (8^+) in ^{80}Ge that has a non-zero β-feeding intensity. This can only be fed by the ground state in ^{80}Ga.

Isomeric Component calculation - II

To prove we had a comparable isomeric mixture, we chose two independent states to examine:

- (2^+) 1573-keV state fed only by the $3(^-)$ ^{80m1}Ga
- (8^+) 3445-keV state fed only by the $6(^-)$ ^{80gs}Ga

We compared the β-feeding intensities in our experiment and those in ENSDF and discovered a decrease of 0.66 in feeding of the 1573-keV state and an increase of 1.55 to the 3445-keV state.

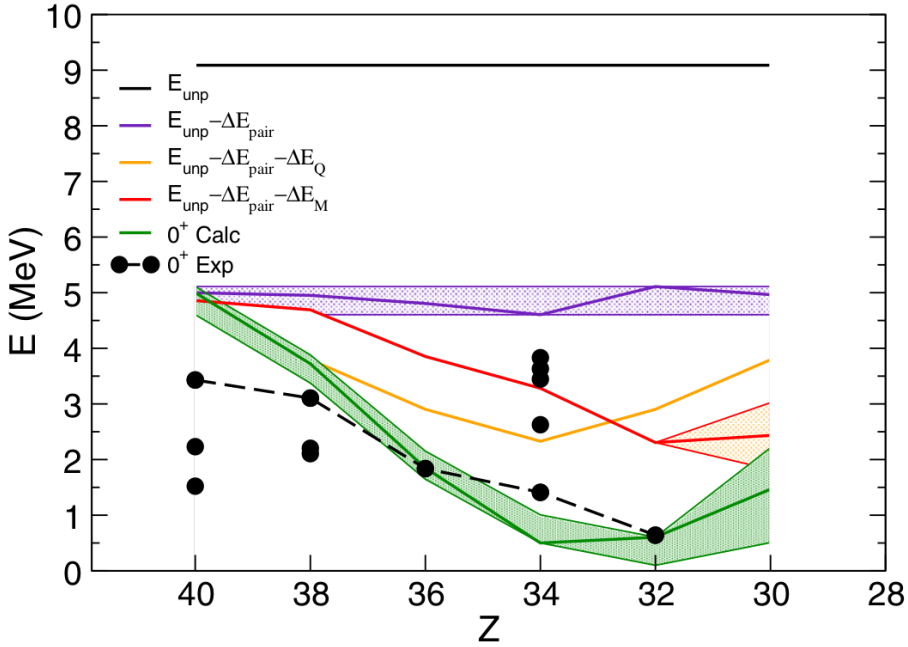
Given the ENSDF set contains a beam composition of 62% of the (3^-) isomer, we calculate a value of 41% of the same component.

Based on the data in the paper, ALTO observed 52% of ^{80m1}Ga in their beam.

Theoretical Interpretation - ALTO

The authors also employed theoretical models to show lowering of the 0_2^+ in context of different energy contributions.

The theoretically calculated value was in good agreement with their experimentally observed value.



Gottardo, A. *et al.*, *PRL* 116, 182501 (2016)