CELEBRATING THE CAREER AND CONTRIBUTIONS OF ROBERT V. F. JANSSENS

Nuclear Physics Over The Years: From the high spin era to rare isotopes

Exploring N=32, 34 and 40 and the inverse-impact law

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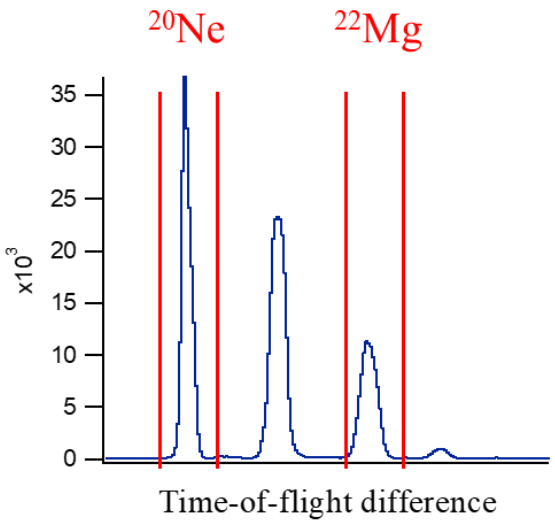
Outline

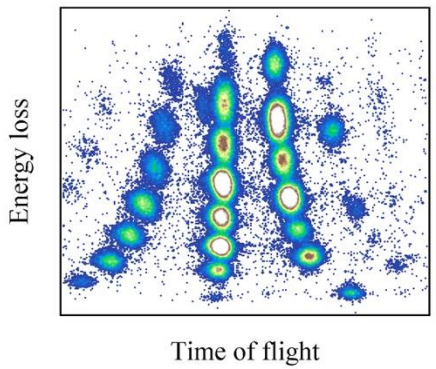
- 20+ years of collaboration on shell evolution
- Exploring shell evolution with Robert
  - Collectivity at *N*=32 and 34 – Intermediate-energy Coulomb excitation of neutron-rich Ti isotopes
    - Then and how far the field got since then
  - Knocking into *N*=32: Cross-shell excitations in ^{52}Ca
    - Then and the forefront now
  - Moving on to *N*=40 in Cr: The first spectroscopy of ^{64}Cr (2 x NSCL) and the first GRETINA paper at FRIB
- Trying to publish in PRL with Robert … or the inverse-impact law

The experimental scheme at MSU

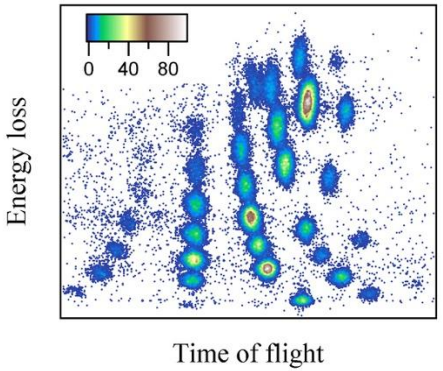
PID of the incoming beam via velocity difference



Reactions induced by ^{20}Ne



induced by ^{22}Mg

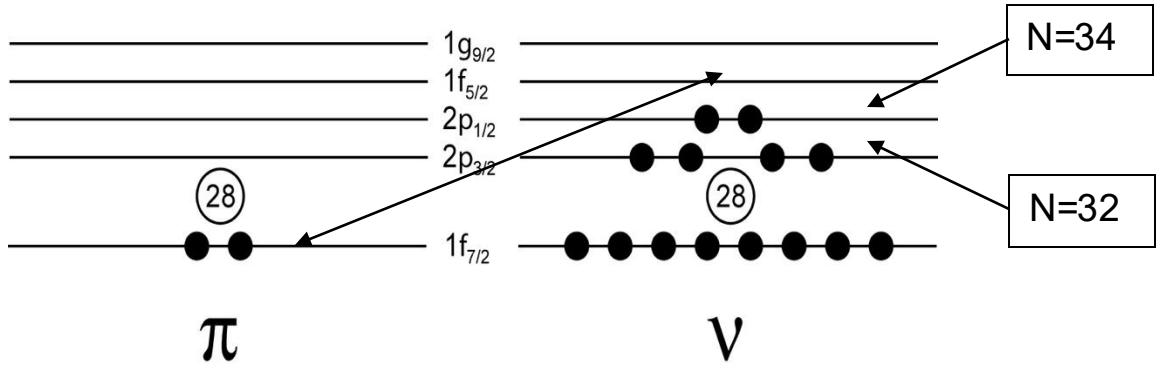


Driver accelerator

- Fragment separator
- Identification and beam transport
  - Stopped beam experiments
  - Fast beam experiments
    - Secondary reaction
    - Reaction product identification

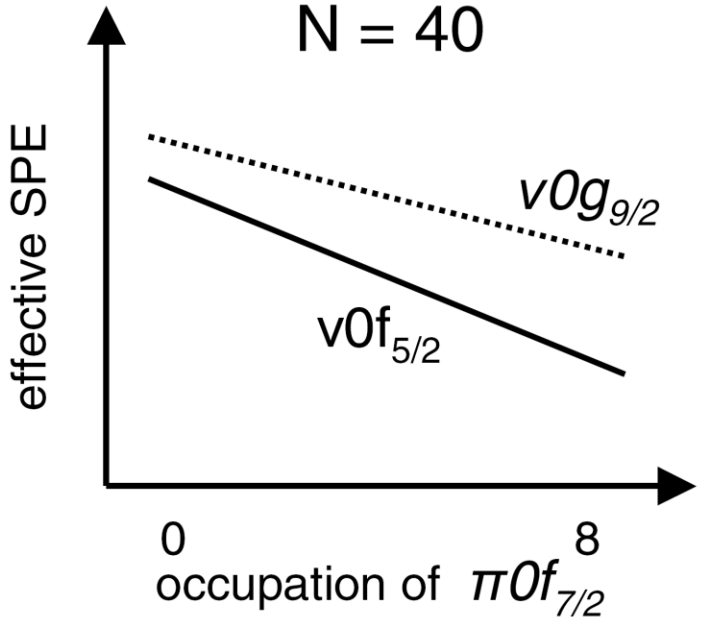
Shell evolution relevant to this talk

Monopole part of the tensor force



As protons are removed from the $\pi f_{7/2}$ shell (Ni → Ca):

- $\pi f_{7/2} - \nu f_{5/2}$ monopole interaction weakens
- $\nu f_{5/2}$ goes up in energy
- together with a large $p_{3/2}$-$p_{1/2}$ spin orbit splitting, possible shell gaps at *N=32* and *N=34*



Same monopole story: The attractive monopole part of the tensor force ($\pi f_{7/2}$ - $\nu f_{5/2}$) weakens as protons are removed from $\pi f_{7/2}$. The $\nu f_{5/2}$ orbit shifts up in energy and the gap between the $\nu f_{5/2}$ and $\nu g_{9/2}$ orbits is reduced, allowing neutron occupancy of the intruder $\nu g_{9/2}$ orbit already for nuclei with fewer than 40 neutrons

T. Otsuka *et al.*, PRL 95 232502 (2005)

Intermediate-energy Coulomb excitation at *N*=32 and 34

RAPID COMMUNICATIONS

PHYSICAL REVIEW C **71**, 041302(R) (2005)

Reduced transition probabilities to the first 2^+ state in ^{52,54,56}Ti and development of shell closures at $N = 32, 34$

D.-C. Dinca,[1,2] R. V. F. Janssens,[3] A. Gade,[2] D. Bazin,[2] R. Broda,[4] B. A. Brown,[1,2] C. M. Campbell,[1,2] M. P. Carpenter,[3] P. Chowdhury,[3,5] J. M. Cook,[1,2] A. N. Deacon,[6] B. Fornal,[4] S. J. Freeman,[6] T. Glasmacher,[1,2] M. Honma,[7] F. G. Kondev,[8] J.-L. Lecouey,[2] S. N. Liddick,[2,9] P. F. Mantica,[2,9] W. F. Mueller,[2] H. Olliver,[1,2] T. Otsuka,[10] J. R. Terry,[1,2] B. A. Tomlin,[2,9] and K. Yoneda[2]

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[2]*National Superconducting Cyclotron Laboratory, Michigan State University, East Lansing, Michigan 48824*
[3]*Physics Division, Argonne National Laboratory, Argonne, Illinois 60439*
[4]*Institute of Nuclear Physics, Polish Academy of Sciences, PL-31342 Cracow, Poland*
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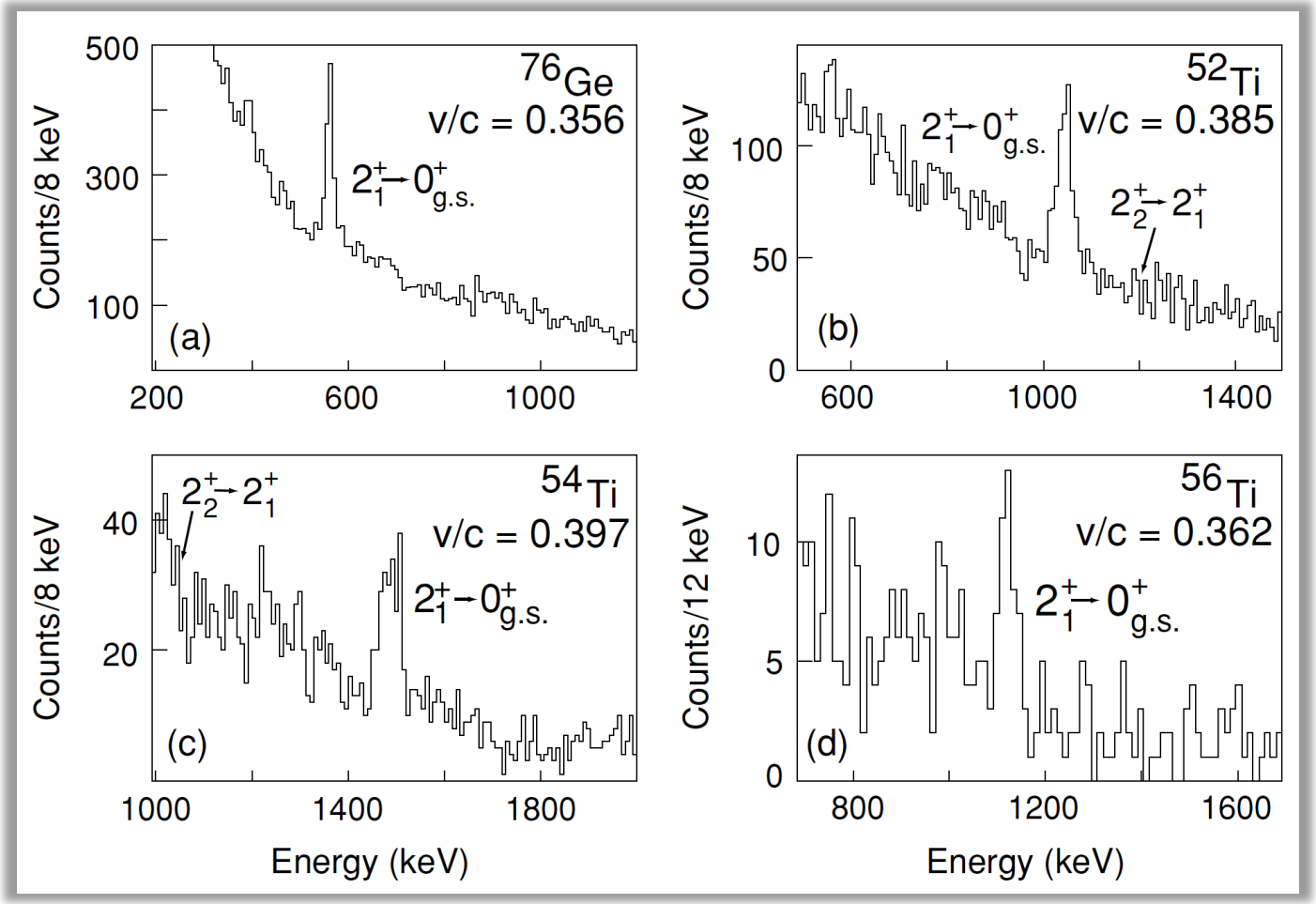
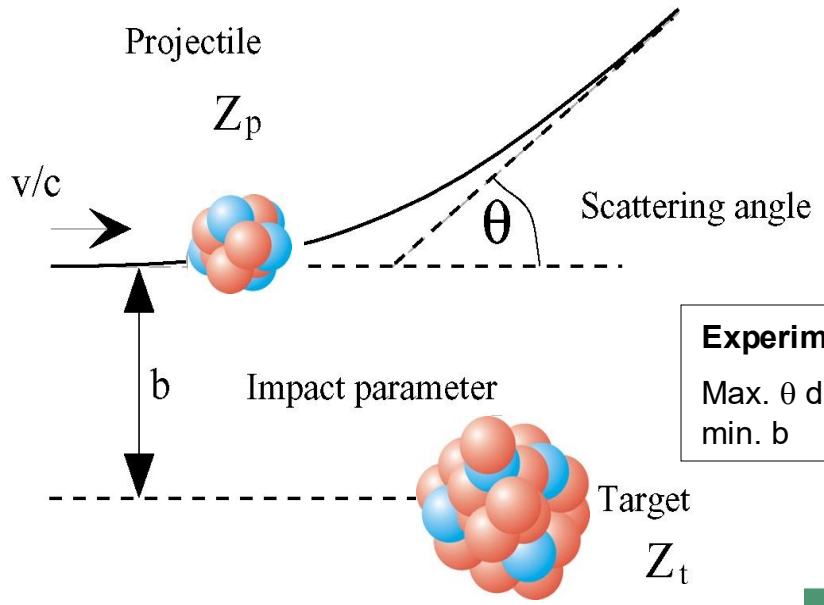
[6]*Department of Physics and Astronomy, Schuster Laboratory, University of Manchester, Manchester M13 9PL, United Kingdom*
[7]*Center for Mathematical Sciences, University of Aizu, Tsuruga, Ikki-machi, Aizu-Wakamatsu, Fukushima 965-8580, Japan*
[8]*Nuclear Engineering Division, Argonne National Laboratory, Argonne, Illinois 60439*
[9]*Department of Chemistry, Michigan State University, East Lansing, Michigan 48824*
[10]*Department of Physics and Center for Nuclear Study, University of Tokyo, Hongo, Tokyo 113-0033, Japan and RIKEN, Hirosawa, Wako-shi, Saitama 351-0198, Japan*

(Received 8 November 2004; published 15 April 2005)

Intermediate-energy Coulomb excitation of ^{52,54,56}Ti

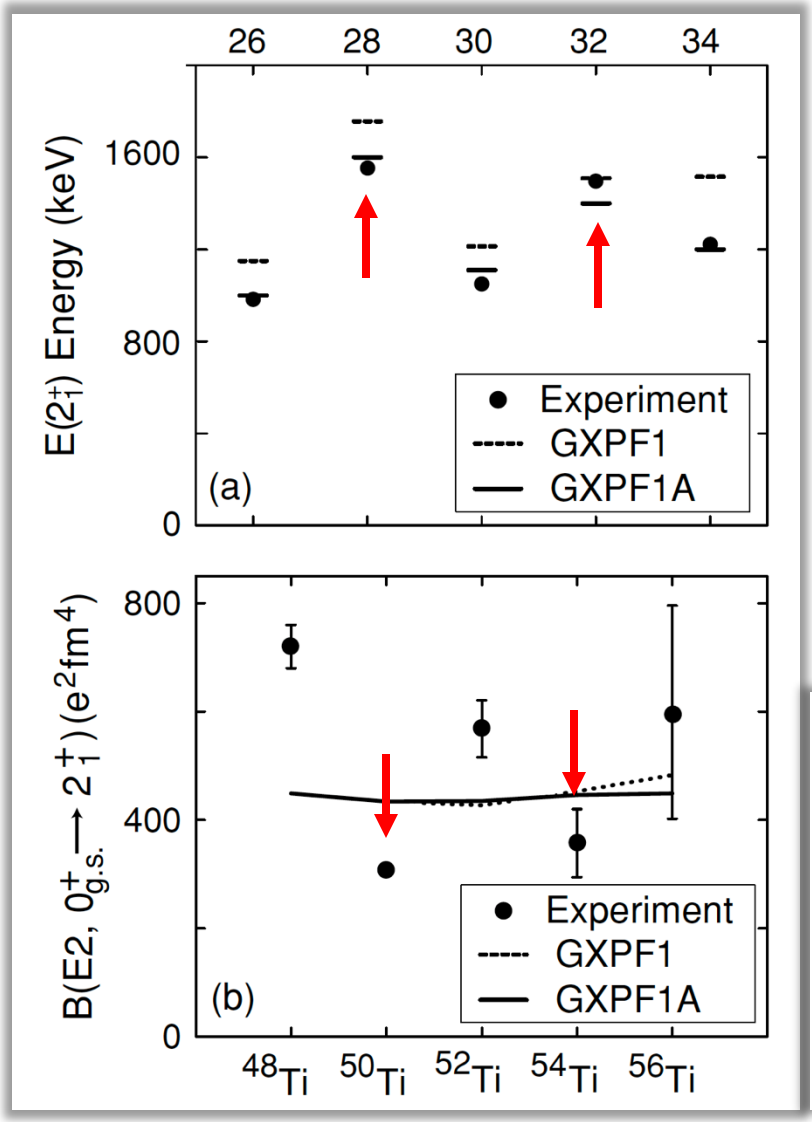


- Ti projectile beams are excited in the Coulomb field of a gold target at v/c>0.3
- Quadrupole-collective states are excited in a single step from the ground state → 2^+_1 in even-even nuclei
- Peak area → cross section → B(E2) value



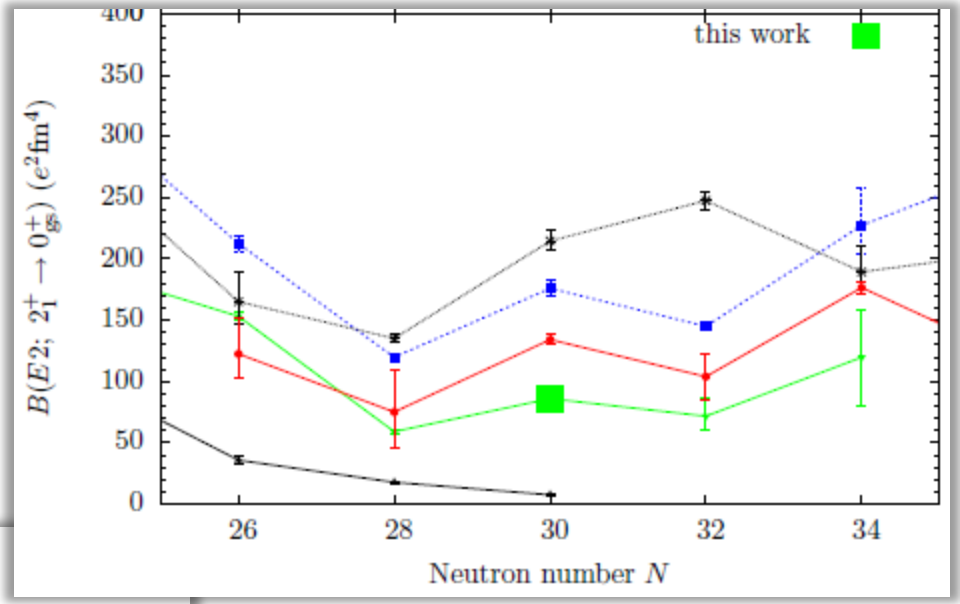
Experiment:
Max. θ determines min. b

Quadrupole collectivity in neutron-rich Ti isotopes



- Indeed, *N*=32 is a new magic number also according to the B(E2) values
- But no experimental evidence for an *N*=34 sub-shell closure in Ti
- **Astonishing:** No theory can reproduce staggering of the B(E2) values unless the SM effective charges are ad-hoc significantly tinkered with

On the experimental front: AGATA paper suggests that the ^{52}Ti B(E2) is lower and reduces the staggering (contradicts 2 experiments)



A. Goldkuhle *et al.*, PRC 100, 054317 (2019)

PHYSICAL REVIEW C **72**, 047302 (2005)

Isovector effective charge and the staggering of $2^+ \rightarrow 0^+$ transition probabilities in the titanium isotopes

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(Received 6 September 2005; published 27 October 2005)

In an effort to understand the magical status of $N = 32$ and $N = 34$ at the very neutron rich edge, experiments have been carried out in the titanium isotopes up to $A = 56$. The measured staggering of the $B(E2)$'s is not reproduced by the shell model calculations using the best effective interactions. We argue that this may be related to the choice of the isovector effective charge and to the value of the $N = 34$ neutron gap.

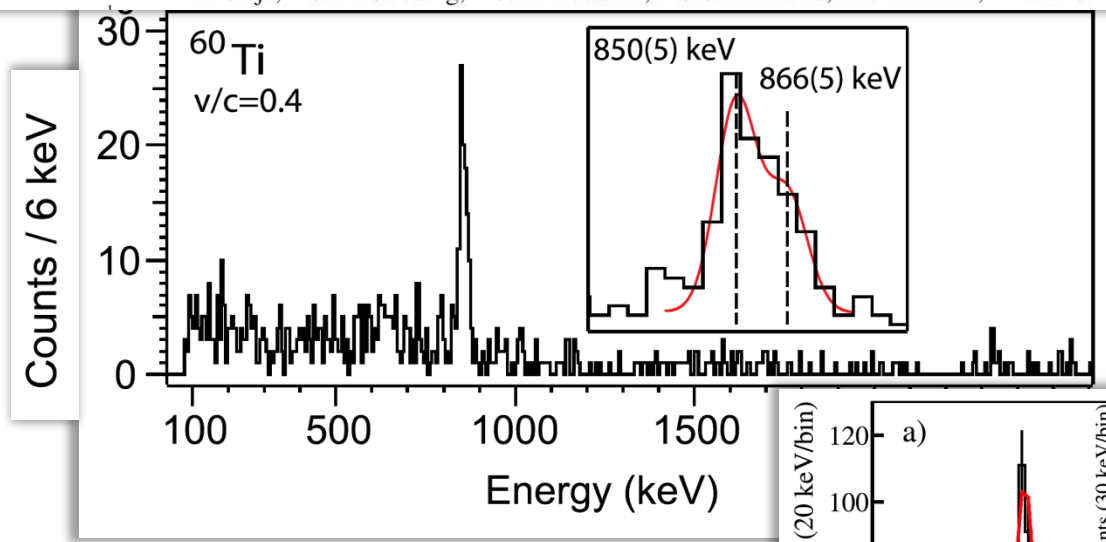
Now

First spectroscopy of ^{60}Ti (NSCL - 2014) and ^{62}Ti (RIBF - 2020)

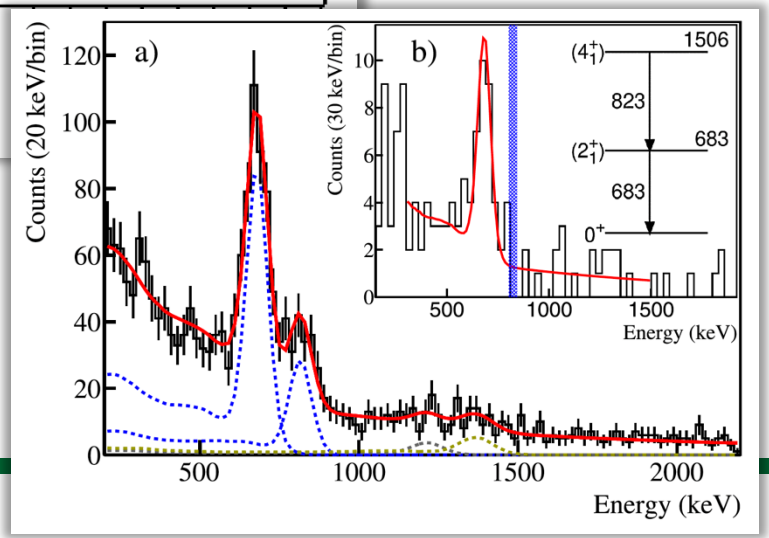
PRL 112, 112503 (2014) PHYSICAL REVIEW LETTERS week ending 21 MARCH 2014

Nuclear Structure Towards $N = 40$ ^{60}Ca: In-Beam γ-Ray Spectroscopy of ^{58,60}Ti

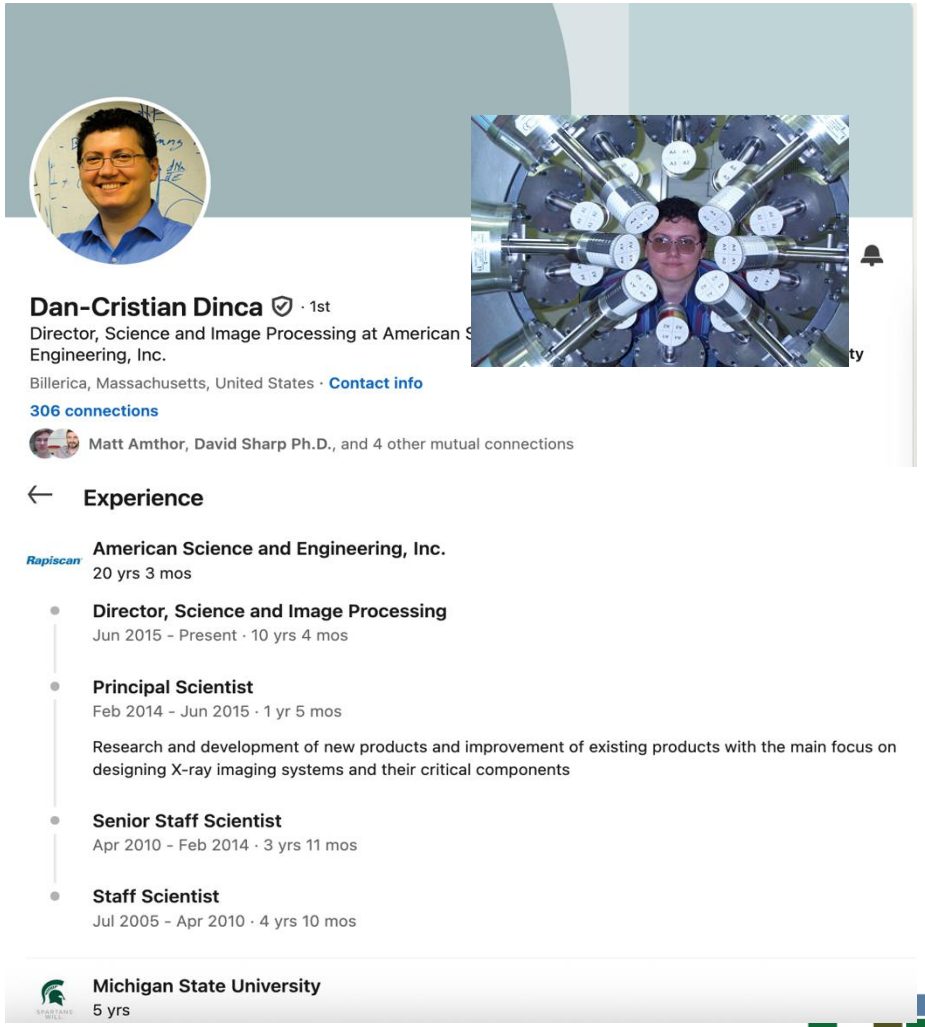
A. Gade,[1,2] R. V. F. Janssens,[3] D. Weisshaar,[1] B. A. Brown,[1,2] E. Lunderberg,[1,2] M. Albers,[3] V. M. Bader,[1,2] T. Baugher,[1,2] D. Bazin,[1] J. S. Berryman,[1] C. M. Campbell,[4] M. P. Carpenter,[3] C. J. Chiara,[5,3] H. L. Crawford,[4,*] M. Cromaz,[4] U. Garg,[6] C. R. Hoffman,[3] F. G. Kondev,[7] C. Langer,[1,8] T. Lauritsen,[3] I. Y. Lee,[4] S. M. Lenzi,[9] J. T. Matta,[6] F. Nowacki,[10] F. Recchia,[1,†] K. Sieja,[10] S. R. Stroberg,[1,2] J. A. Tostevin,[11] S. J. Williams,[1] K. Wimmer,[12,1] and S. Zhu[3]



M.L. Cortes *et al.*, PLB 800, 135071 (2020)



What happened to Dan-Cristian Dinca?



Proton cross-shell excitations in ^{52}Ca

RAPID COMMUNICATIONS

PHYSICAL REVIEW C **74**, 021302(R) (2006)

Cross-shell excitation in two-proton knockout: Structure of ^{52}Ca

A. Gade,[1,2] R. V. F. Janssens,[3] D. Bazin,[1] R. Broda,[4] B. A. Brown,[1,2] C. M. Campbell,[1,2] M. P. Carpenter,[3] J. M. Cook,[1,2] A. N. Deacon,[5] D.-C. Dinca,[1,2] B. Fornal,[4] S. J. Freeman,[5] T. Glasmacher,[1,2] P. G. Hansen,[1,2] B. P. Kay,[5] P. F. Mantica,[1,6] W. F. Mueller,[1] J. R. Terry,[1,2] J. A. Tostevin,[7] and S. Zhu[3]

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[3]*Physics Division, Argonne National Laboratory, Argonne, Illinois 60439, USA*

[4]*Institute of Nuclear Physics, Polish Academy of Science, PL-31342 Cracow, Poland*

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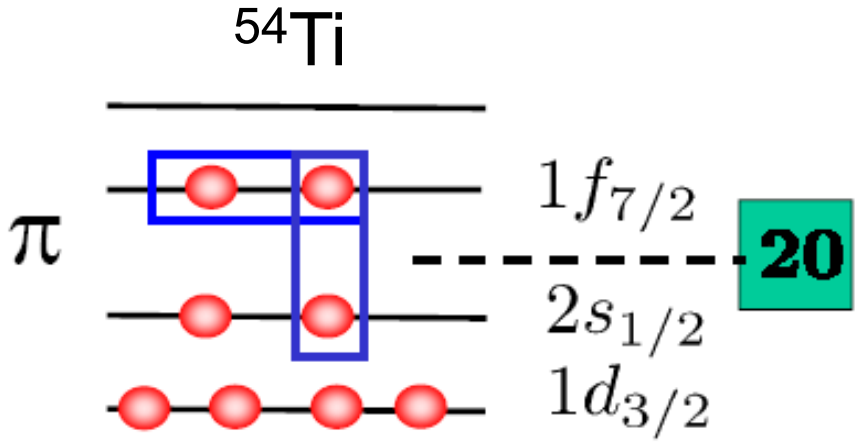
(Received 23 March 2006; published 16 August 2006)

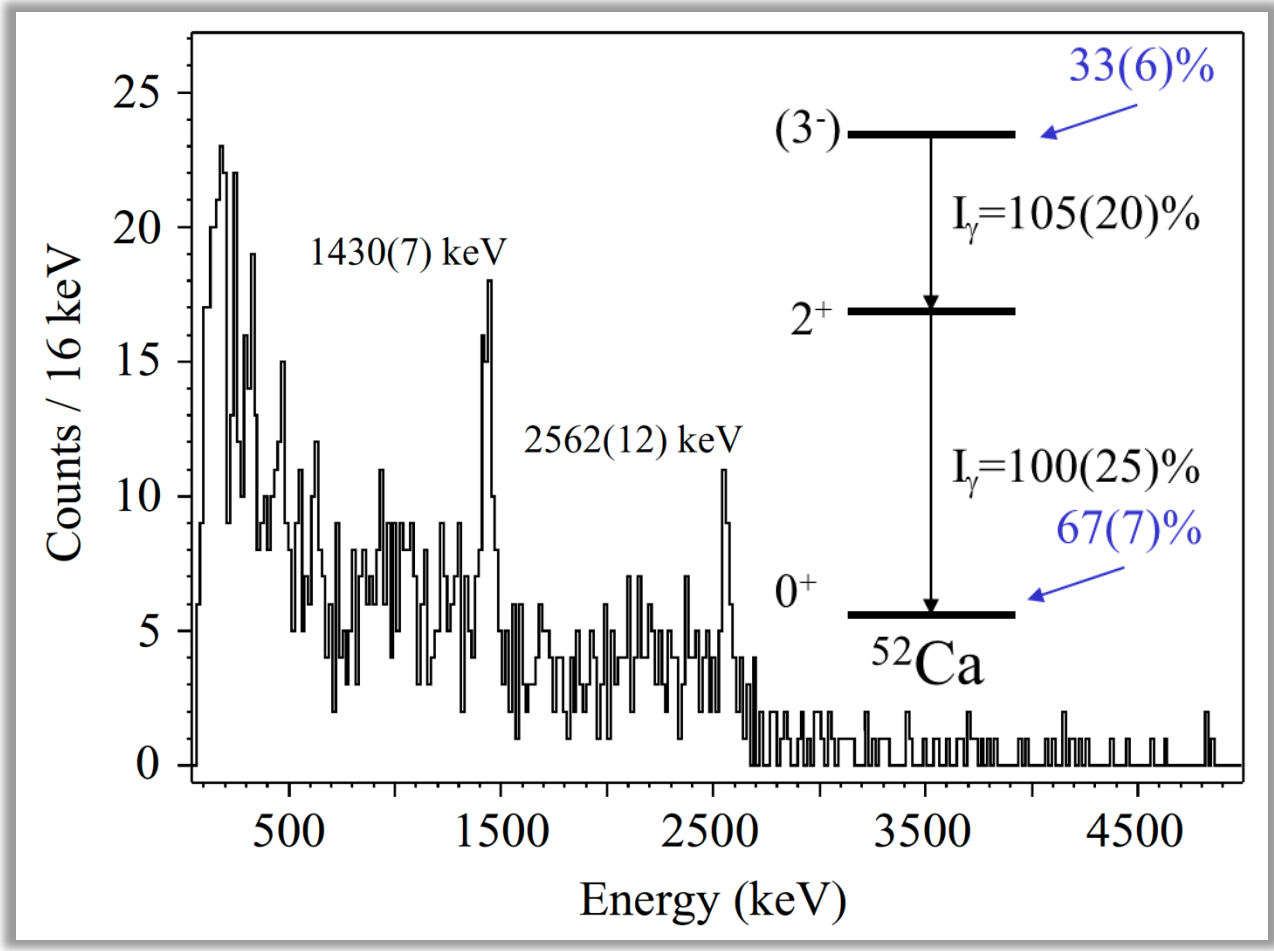
Two-proton knockout from ^{54}Ti to ^{52}Ca - Proton cross-shell excitation in a neutron-rich nucleus!



(i) Removal of two protons out of $f_{7/2}$ → population of the ground state of ^{52}Ca

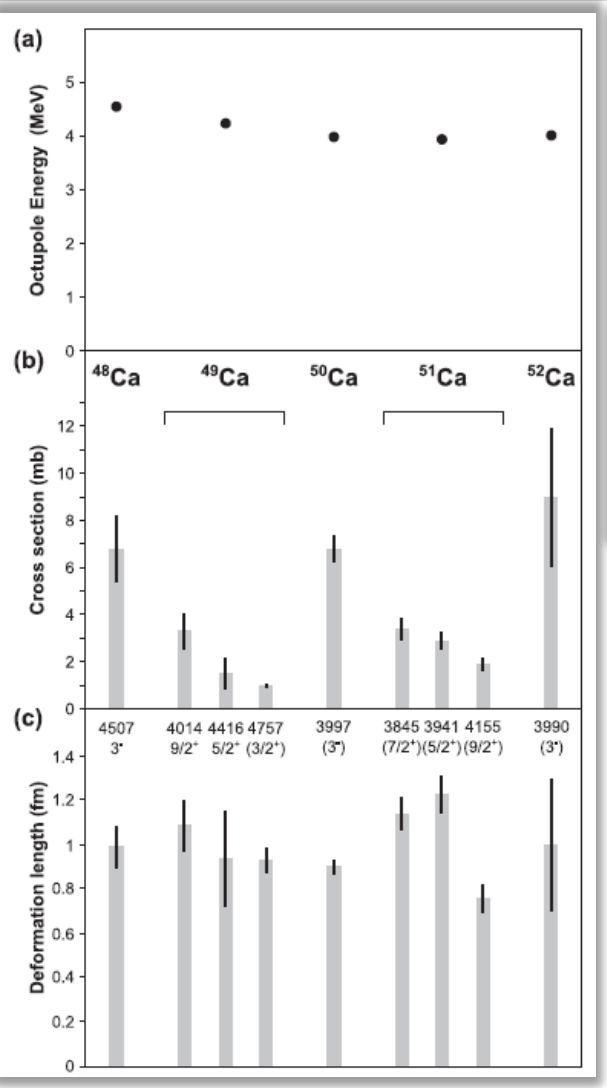
(ii) Removal of protons out of $f_{7/2}$ and $s_{1/2}$ or $f_{7/2}$ and $d_{3/2}$ → population of the 3^- state of ^{52}Ca

(iii) No direct population of the 2^+ state of ^{52}Ca → confirmation of *N=32* sub-shell gap (^{52}Ca 2^+: neutron *ph* excitation involving $\nu p_{1/2}$ and $\nu p_{3/2}$ and the *N=32* gap is strong enough to prevent such configurations in the gs of ^{54}Ti)



Now

B(E3) measured, ^{52}Ca a halo?!, the rise of the MR-TOFs, and energies claimed out to ^{58}Ca (if you believe it – I don't)



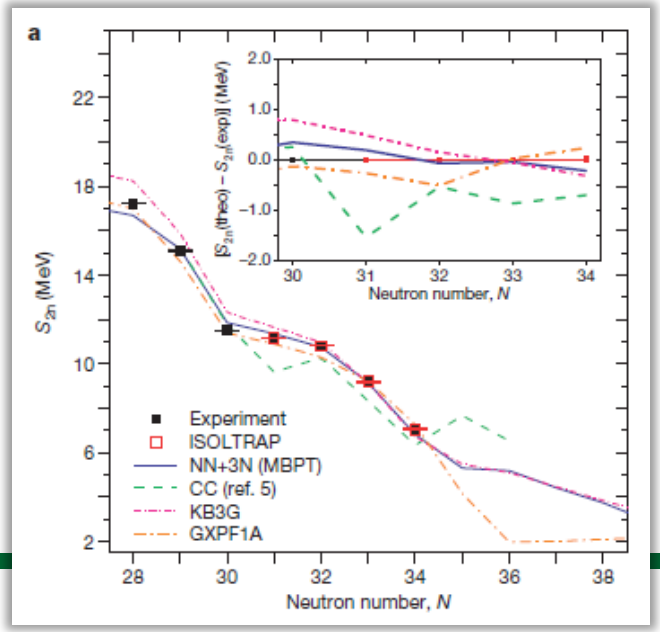
L. A.. Riley *et al.*, PRC 93, 044327 (2016)

PHYSICAL REVIEW LETTERS **129,** 262501 (2022)

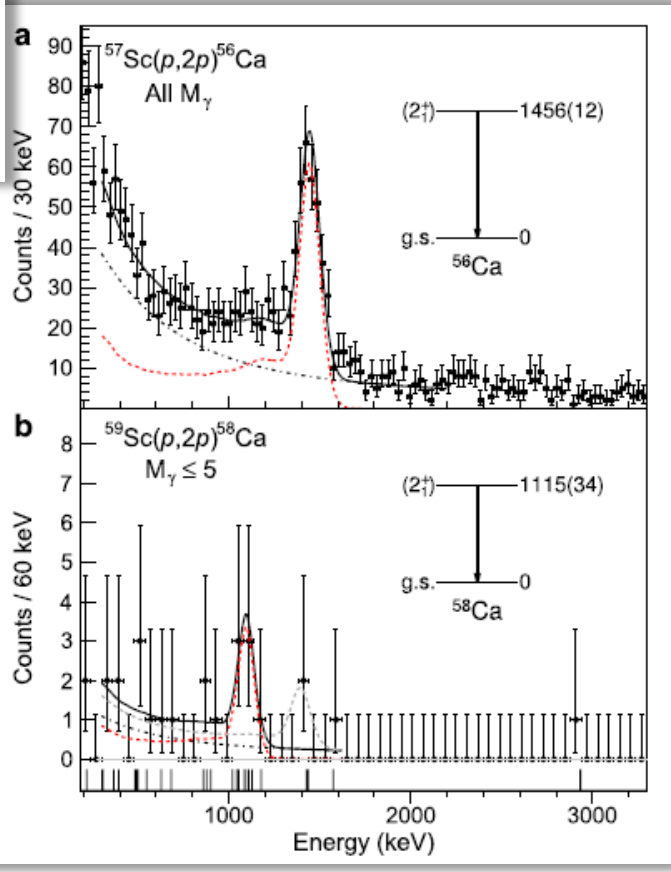
Extended $p_{3/2}$ Neutron Orbital and the $N=32$ Shell Closure in ^{52}Ca

M. Enciu,[1,*] H. N. Liu,[1,2,3,†] A. Obertelli,[1,4,5] P. Doornenbal,[5] F. Nowacki,[6] K. Ogata,[7,8] A. Poves,[9] K. Yoshida,[10] N. L. Achouri,[11] H. Baba,[5] F. Browne,[5] D. Calvet,[4] F. Château,[4] S. Chen,[12,5,13] N. Chiga,[5] A. Corsi,[4] M. L. Cortés,[5] A. Delbart,[4] J-M. Gheller,[4] A. Giganon,[4] A. Gillibert,[4] C. Hilaire,[4] T. Isobe,[5] T. Kobayashi,[14] Y. Kubota,[5,15] V. Lapoux,[4] T. Motobayashi,[5] I. Murray,[16,5] H. Otsu,[5] V. Panin,[5] N. Paul,[4,17] W. Rodriguez,[5,18,19] H. Sakurai,[5,20] M. Sasano,[5] D. Steppenbeck,[5] L. Stuhl,[15,21,22] Y. L. Sun,[4,1] Y. Togano,[23,5] T. Uesaka,[5] K. Wimmer,[20,5] K. Yoneda,[5] O. Aktas,[3] T. Aumann,[1,24] L. X. Chung,[25] F. Flavigny,[16,11] S. Franchoo,[16] I. Gasparic,[26,1,5] R.-B. Gerst,[27] J. Gibelin,[11] K. I. Hahn,[28,22] D. Kim,[28,5,22] Y. Kondo,[29] P. Koseoglou,[1,24] J. Lee,[12] C. Lehr,[1] P. J. Li,[12] B. D. Linh,[25] T. Lokotko,[12] M. MacCormick,[16] K. Moschner,[27] T. Nakamura,[29] S. Y. Park,[28,22] D. Rossi,[1] E. Sahin,[30] P.-A. Söderström,[1] D. Sohler,[21] S. Takeuchi,[29] H. Toernqvist,[1,24] V. Vaquero,[31] V. Wagner,[1] S. Wang,[32] V. Werner,[1,33] X. Xu,[12] H. Yamada,[29] D. Yan,[32] Z. Yang,[5] M. Yasuda,[29] and L. Zanetti[1]

F. Wienholtz *et al.*, Nature 498, 346 (2013)



S. Chen *et al.*, PLB 843, 138025 (2005)



First spectroscopy of ^{64}Cr at NSCL (SeGA)

… and again a decade later with GRETINA

RAPID COMMUNICATIONS

PHYSICAL REVIEW C **81**, 051304(R) (2010)

Collectivity at $N = 40$ in neutron-rich ^{64}Cr

A. Gade,[1,2] R. V. F. Janssens,[3] T. Baugher,[1,2] D. Bazin,[1] B. A. Brown,[1,2] M. P. Carpenter,[3] C. J. Chiara,[3,4] A. N. Deacon,[5] S. J. Freeman,[5] G. F. Grinyer,[1] C. R. Hoffman,[3] B. P. Kay,[3] F. G. Kondev,[6] T. Lauritsen,[3] S. McDaniel,[1,2] K. Meierbachtol,[1,7] A. Ratkiewicz,[1,2] S. R. Stroberg,[1,2] K. A. Walsh,[1,2] D. Weisshaar,[1] R. Winkler,[1] and S. Zhu[3]

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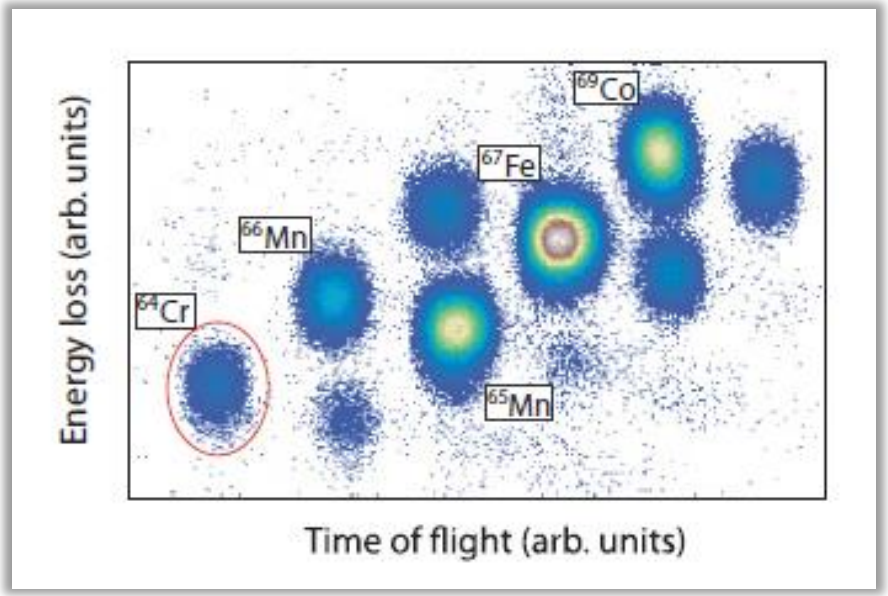
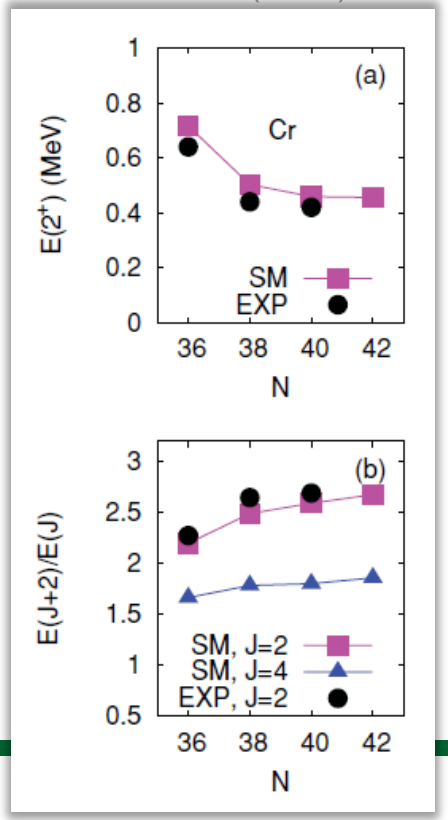
(Received 19 March 2010; published 28 May 2010)

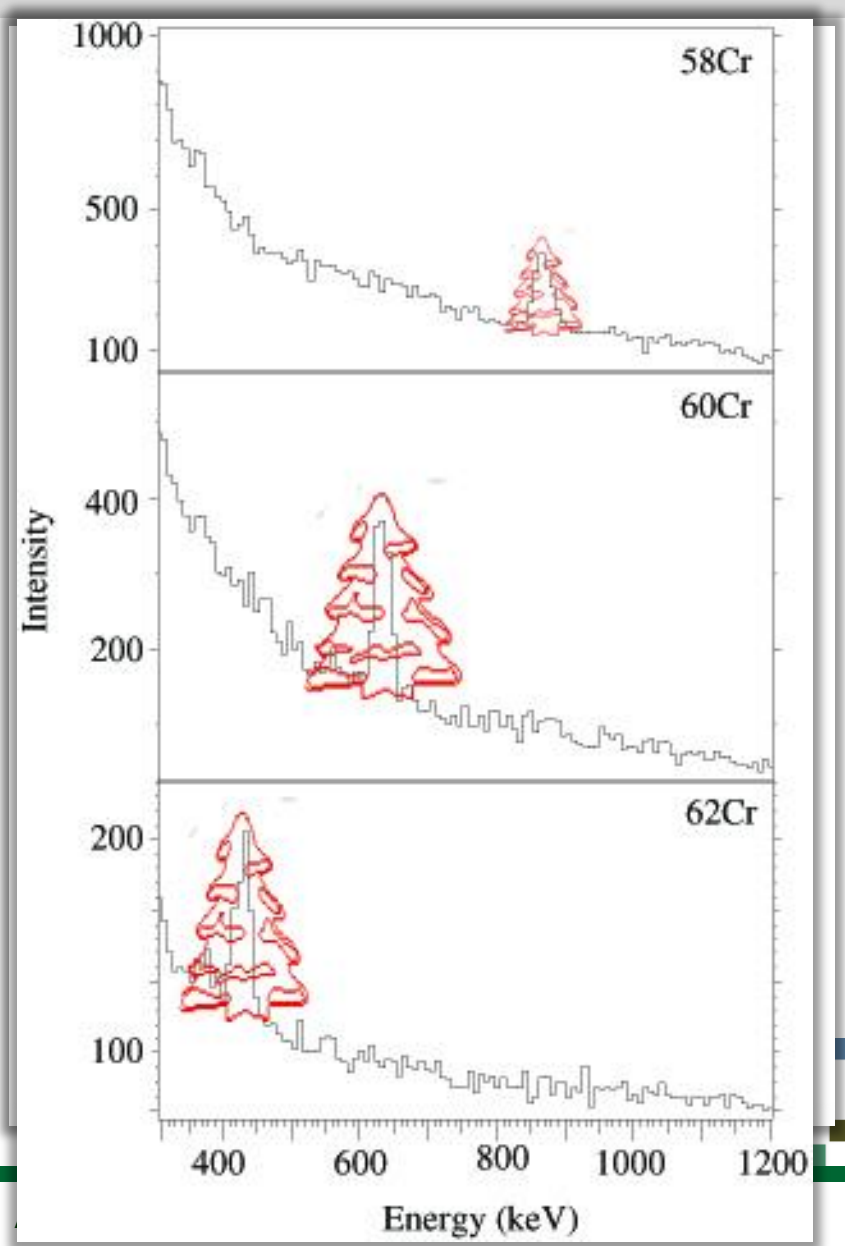
Accidental first spectroscopy of ^{64}Cr in inelastic scattering off Be

- Was supposed to be an experiment where we go on different reaction settings and explore the neutron-rich Fe and Cr nuclei via spectroscopy following knockout, fragmentation …
- However, had ^{64}Cr in the massive cocktail beam and saw that ^{64}Cr seems to be excited in inelastic scattering off Be
- Changed plans, stayed on inelastic scattering and did that for ^{60,62,64}Cr and got the Fe's for free

S. Lenzi *et al.*, PRC 82, 054301 (2010)

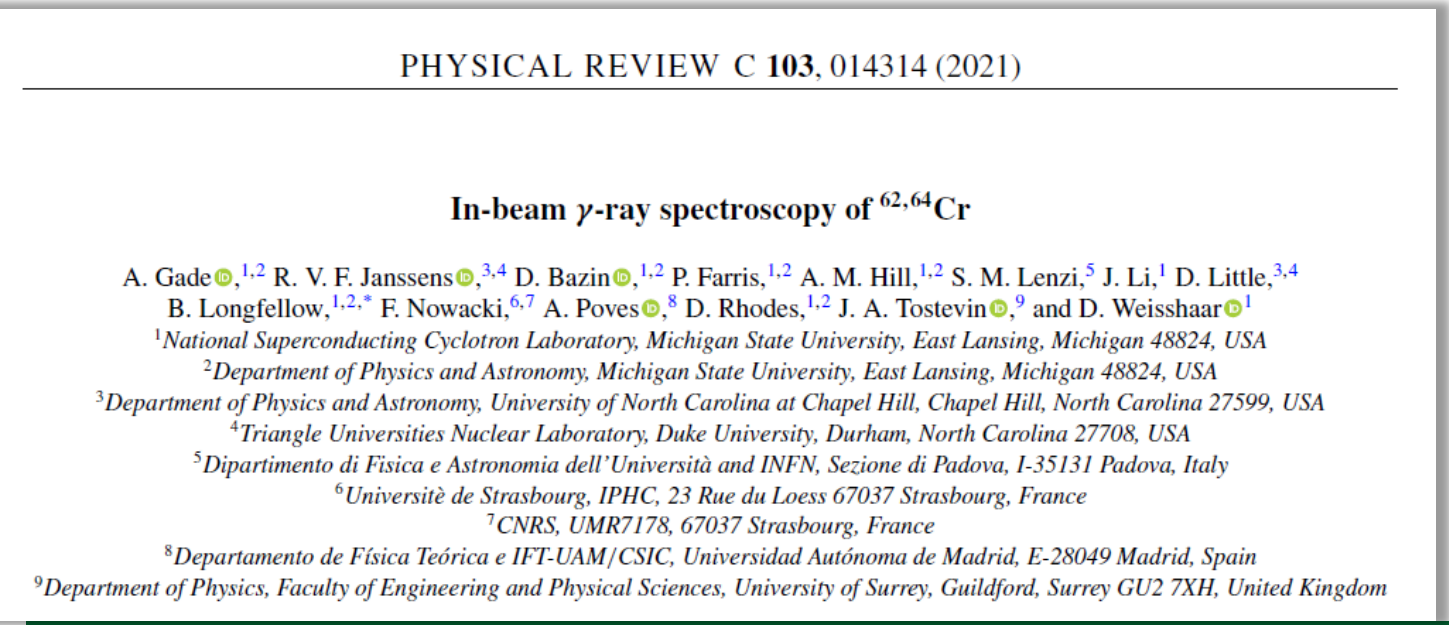






^{64}Cr reloaded … With GRETINA and 11 years later

- Most detailed spectroscopy then on ^{62}Cr and ^{64}Cr
- Afforded by arge increase if ^{82}Se primary beam intensity and GRETINA
- Collaboration with Silvia Lenzi and Alfredo Poves



PHYSICAL REVIEW C **103**, 014314 (2021)

In-beam γ-ray spectroscopy of ^{62,64}Cr

A. Gade,[1,2] R. V. F. Janssens,[3,4] D. Bazin,[1,2] P. Farris,[1,2] A. M. Hill,[1,2] S. M. Lenzi,[5] J. Li,[1] D. Little,[3,4] B. Longfellow,[1,2,*] F. Nowacki,[6,7] A. Poves,[8] D. Rhodes,[1,2] J. A. Tostevin,[9] and D. Weisshaar[1]

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[6]*Universitè de Strasbourg, IPHC, 23 Rue du Loess 67037 Strasbourg, France*
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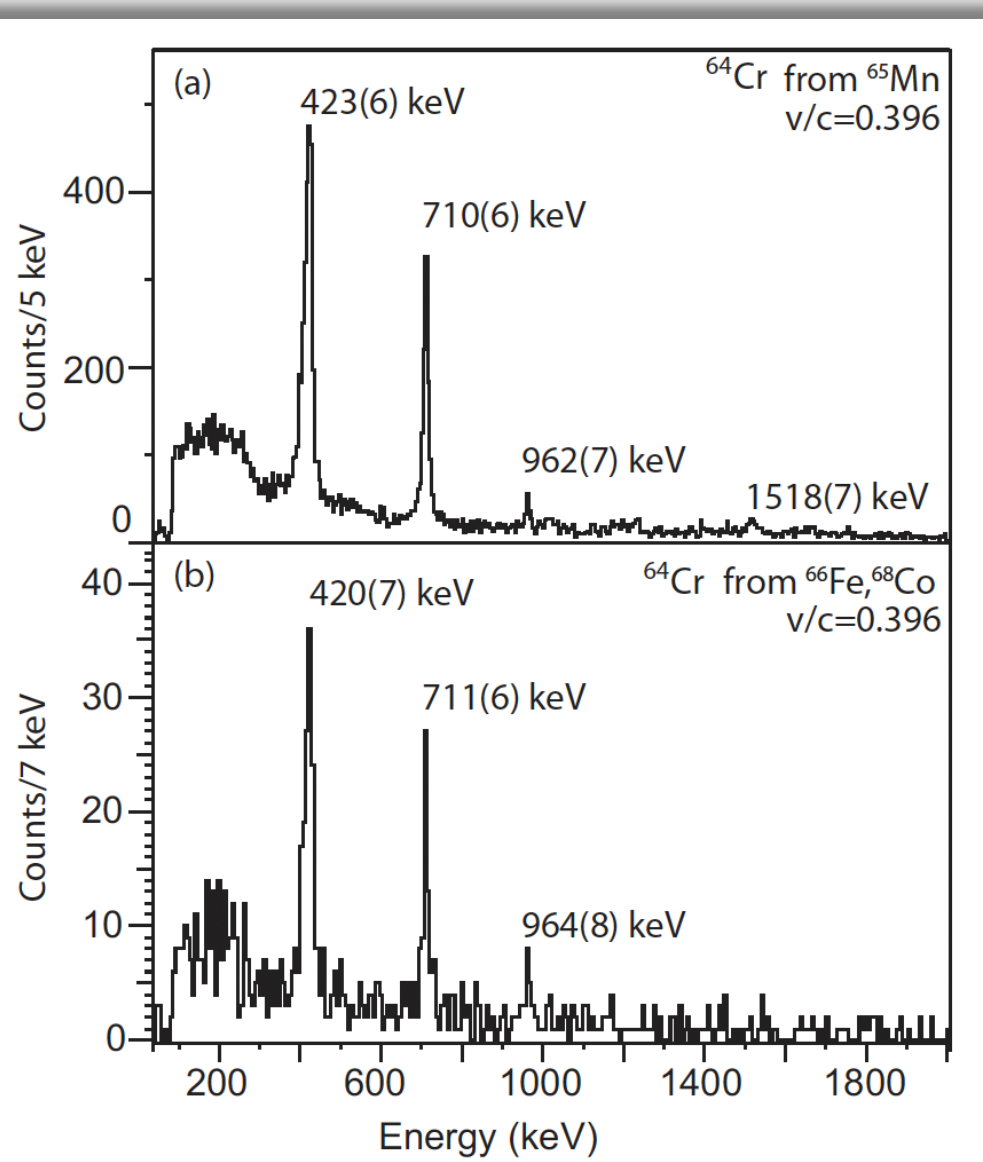
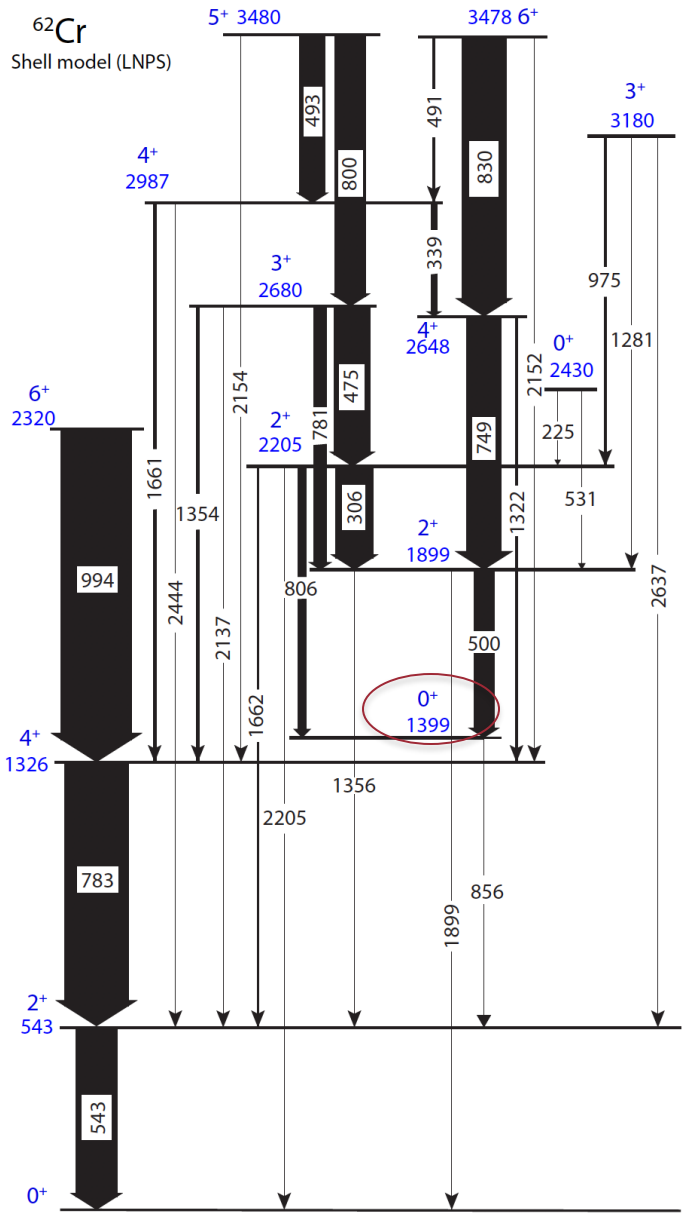
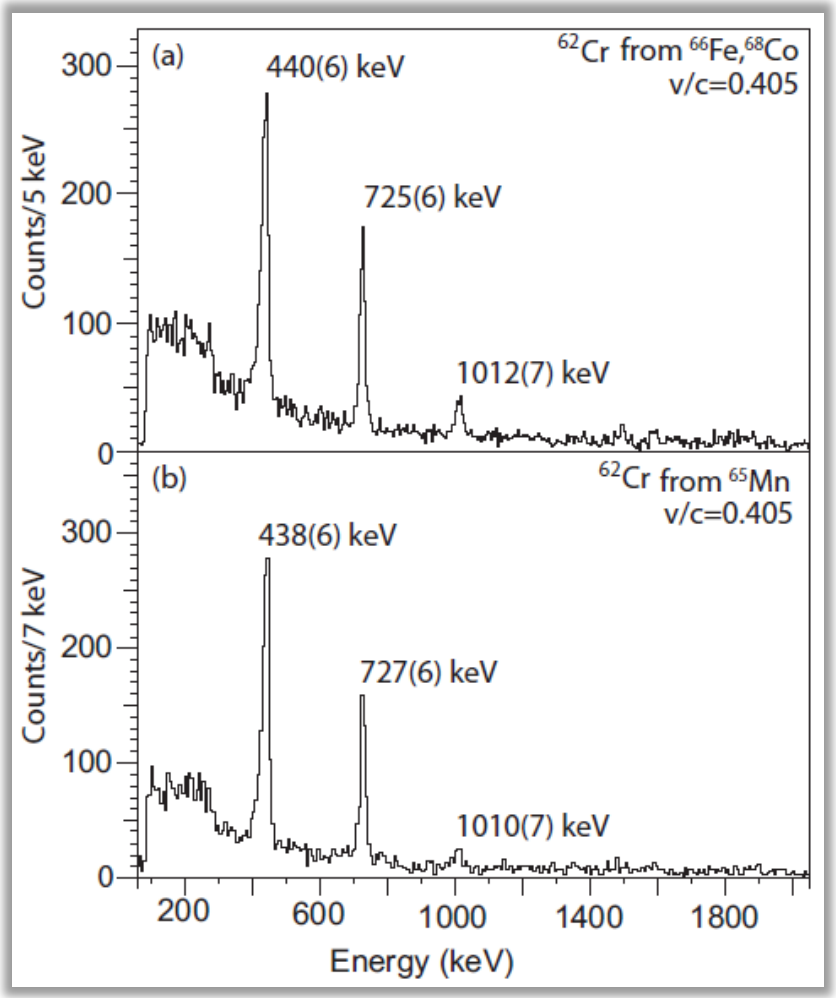


Who ordered that?

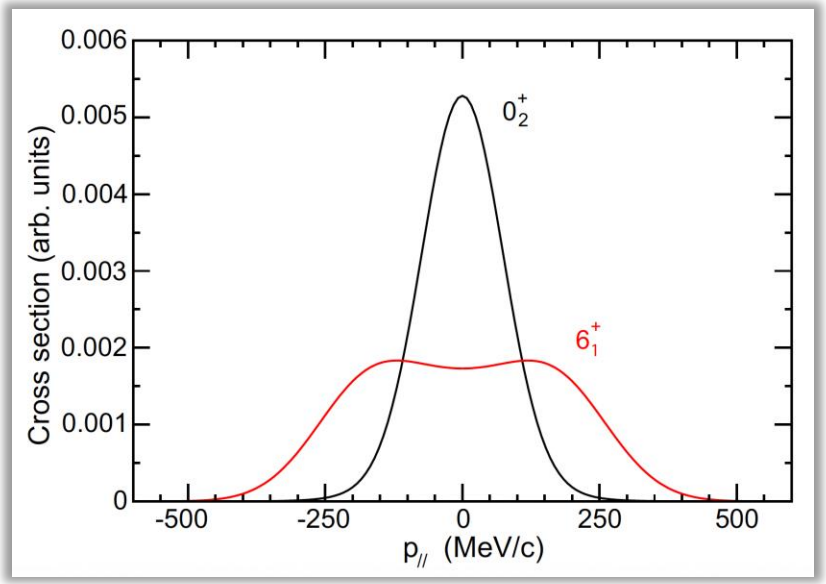
Interesting collective structures predicted in the *N=40* Island of Inversion



- **Goal:** Find the predicted 0^+ band head and maybe the other collective structure



Already proposed in the spectroscopy paper:
Find the 0^+ in the ^{64}Fe-2p



Now: The first GRETINA experiment at FRIB

nature physics

Article

https://doi.org/10.1038/s41567-024-02680-0

In-beam spectroscopy reveals competing nuclear shapes in the rare isotope ^{62}Cr

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Check for updates

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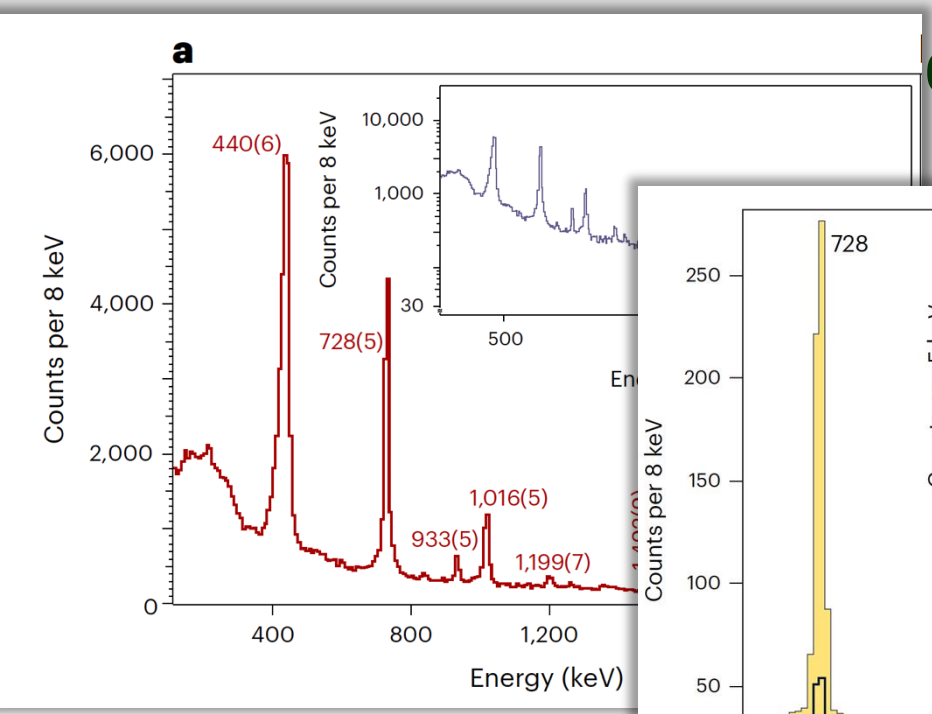
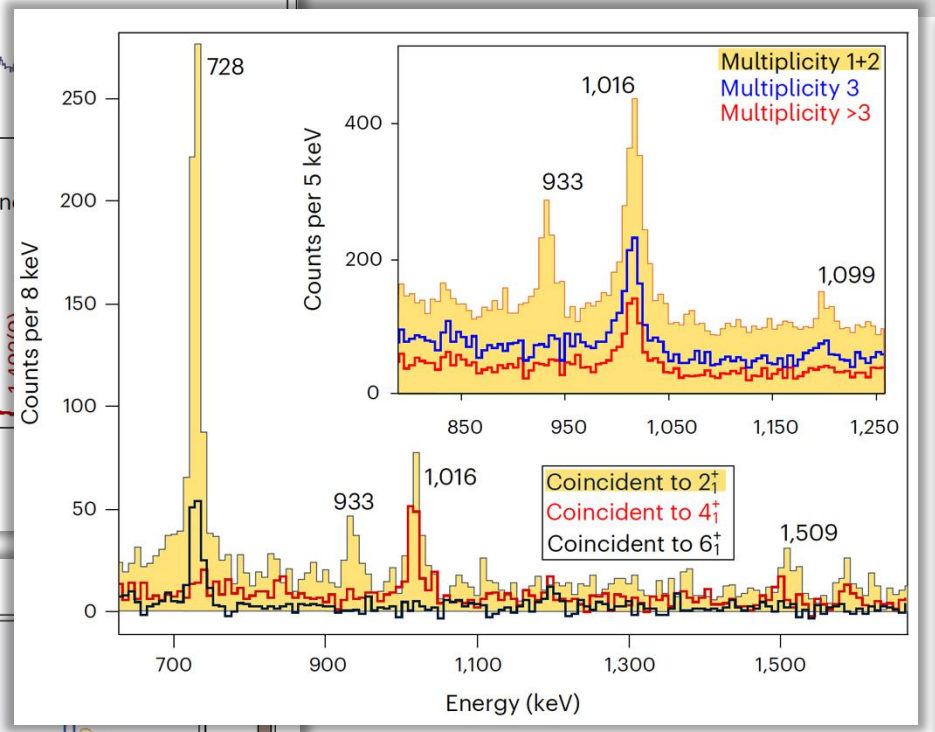
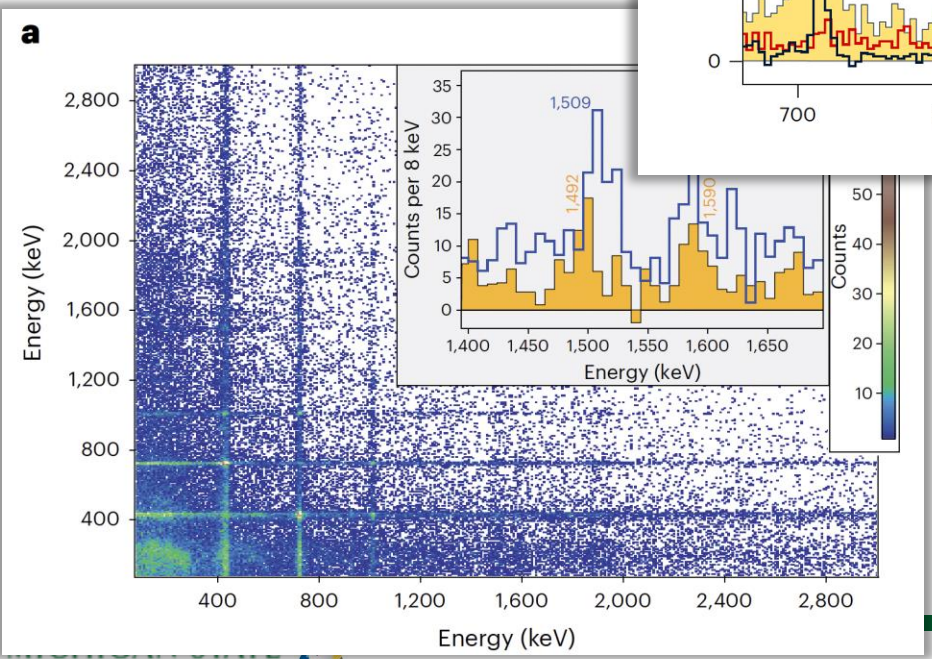
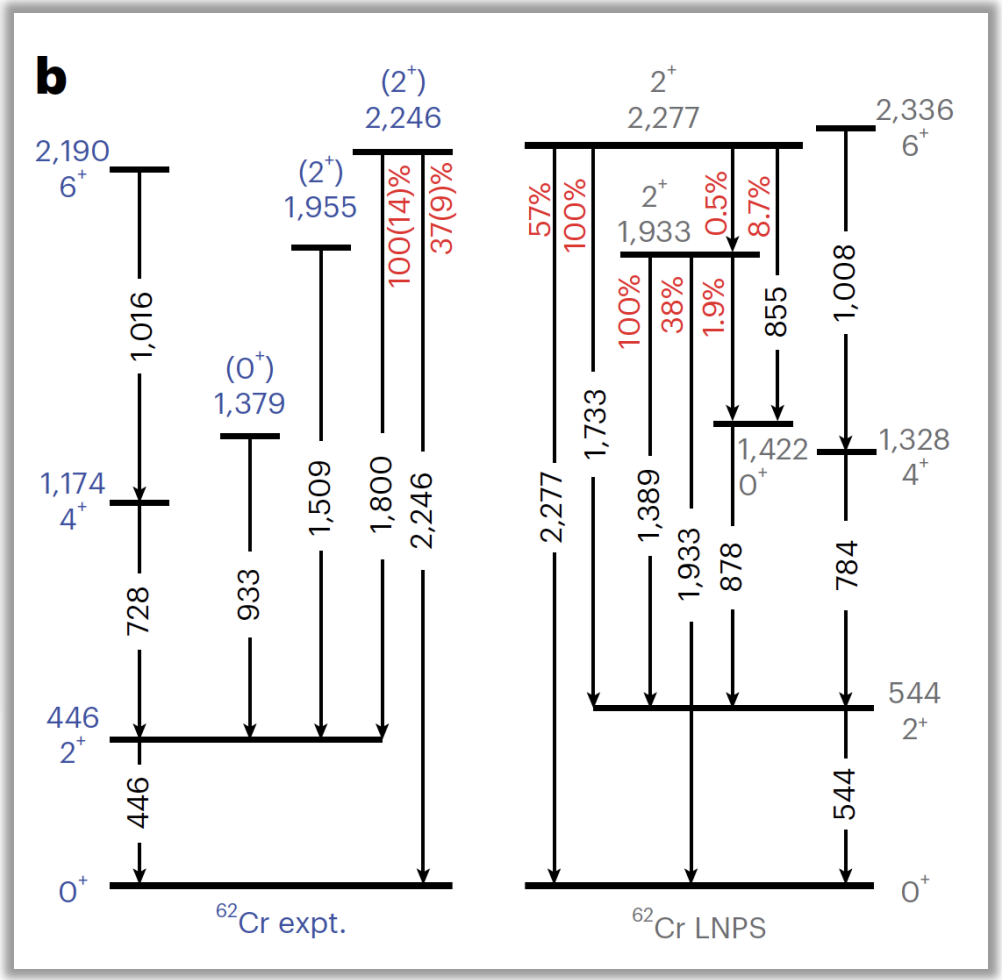
^{64}Fe-2p at at FRIB





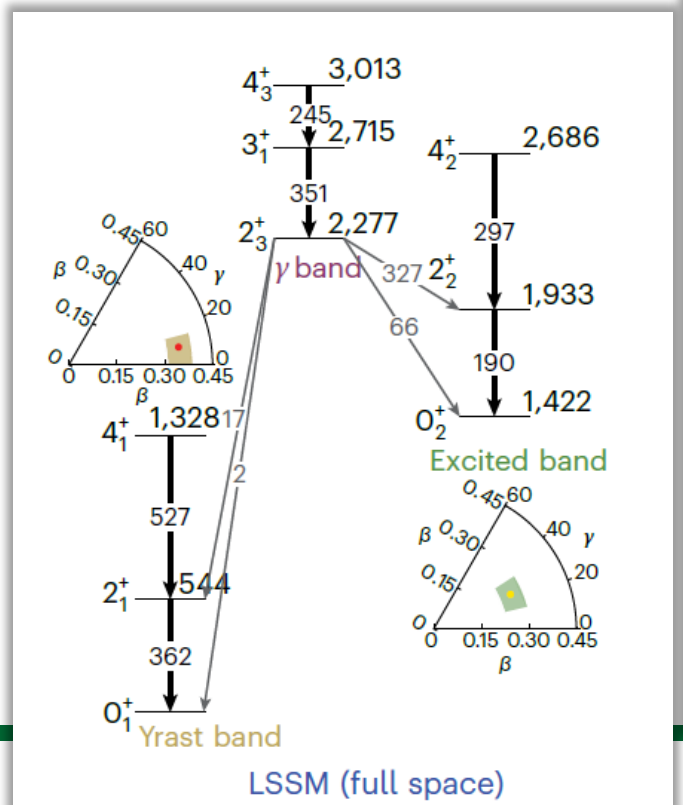


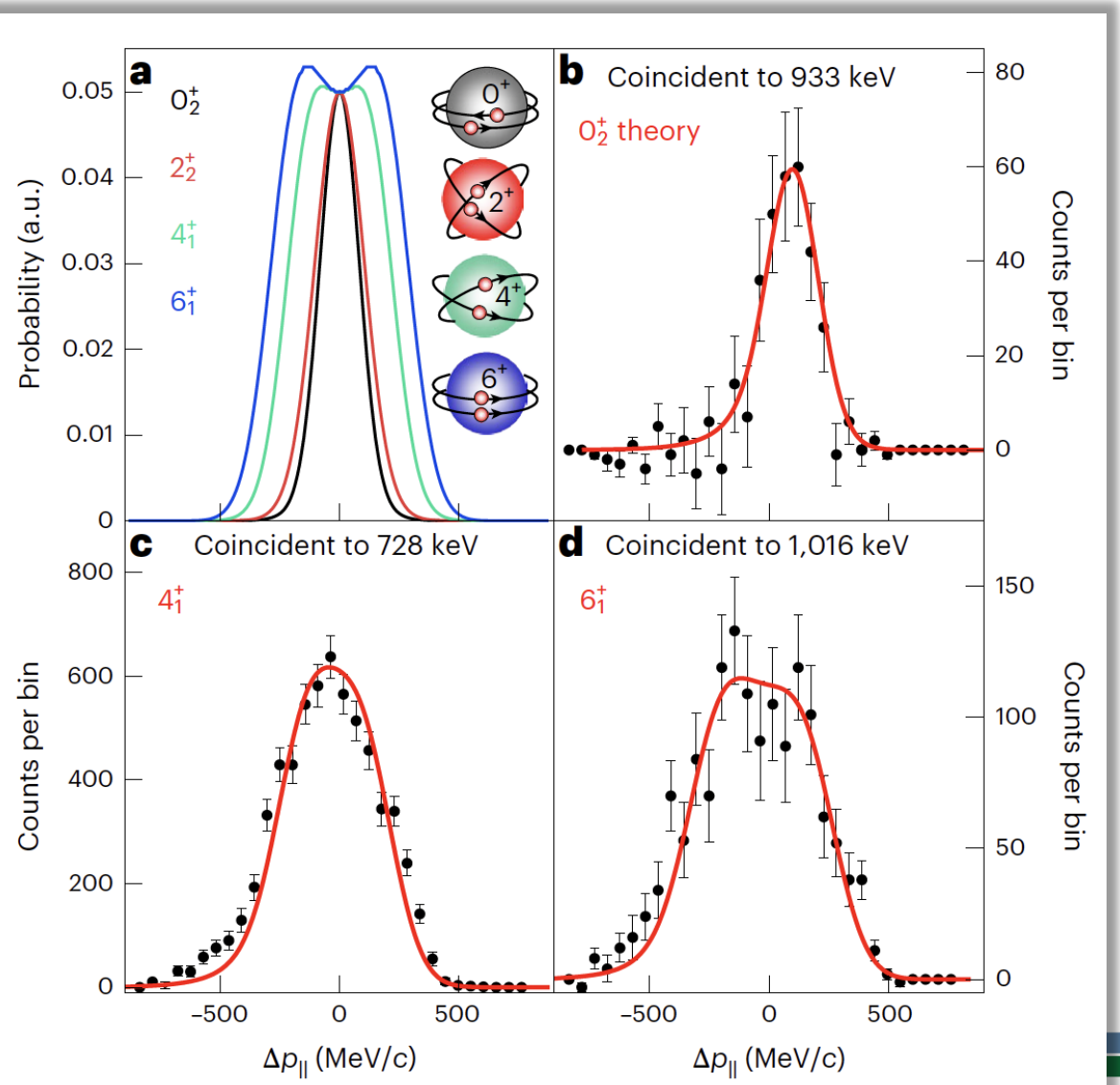


Understanding ^{62}Cr via two-nucleon knockout

- For the states where the transitions are free-standing, have ok peak-to-background ratios, and feeding is manageable, the momentum distributions extracted confirm total angular momentum assignments
  - 4^+_1 and 6^+_1 assignments confirmed
  - 0^+_2 assignment convincing, but 2^+_2 cannot be excluded

- Deformation in βγ according to Kumar-Cline invariants extracted from the conventional shell model (LNPS effective interaction)
- Interesting case of shape coexistence

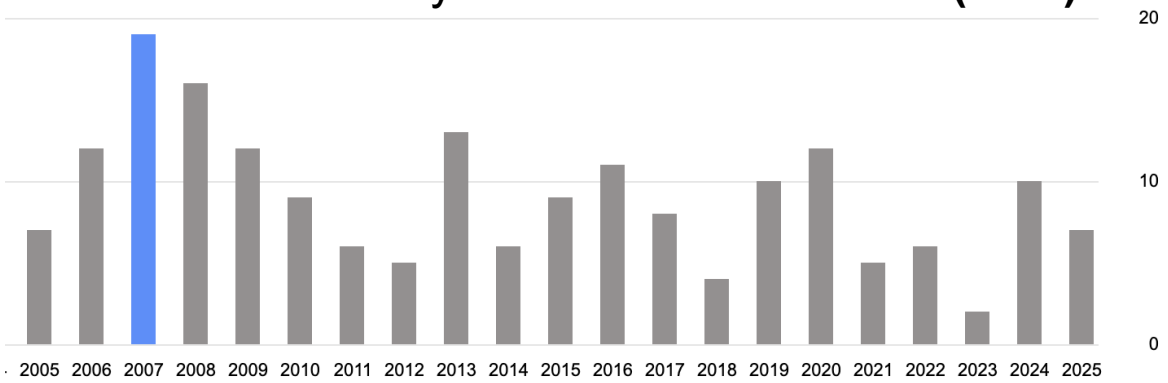




Trying to publish in PRL with Robert … or the inverse-impact law

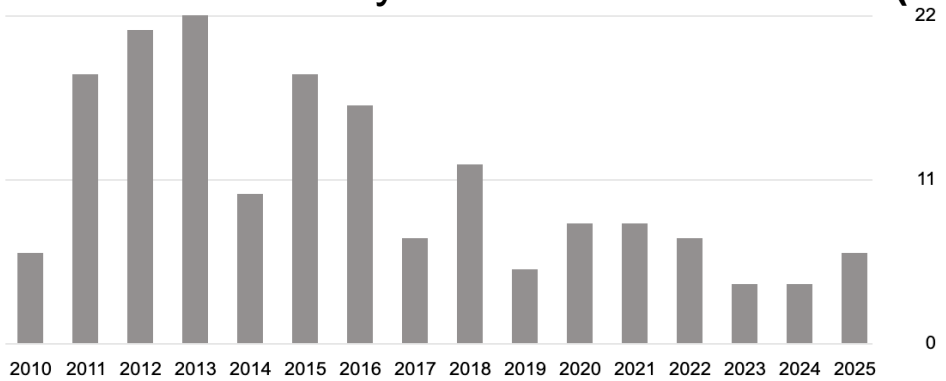
^{54,56}Ti Citations per year

IF=#total citations/#years= 193/20=**9.65>8.1(PRL)**



^{64}Cr Citations per year

IF=#total citations/#years= 172/15=**11.5>8.1(PRL)**



- Impact factor for a journal: IF(year2)=#citations(years 1+2)/2
- Newest for PRL: IF(2023)=8.1
- Here, for a paper: IF= #total citations/#years

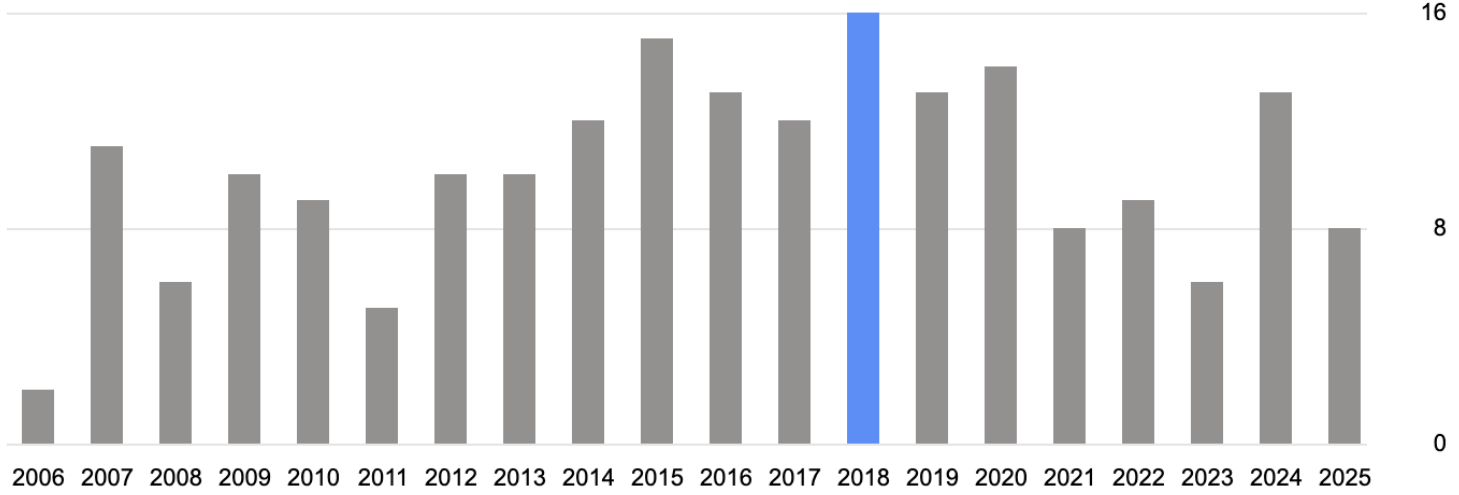
Inverse-impact Law: Publishing with RVFJ

(i) 3 out of 4 papers from our collaboration submitted to PRL became PRC rapids due to “lack of general interest/impact”

(ii) All of these rapids may exceed PRL in impact and some of them for 20 years!

^{52}Ca Citations per year

IF=#total citations/#years= 203/19=**10.68>8.1(PRL)**



Thanks for 20+ years of fantastic collaboration and friendship + thoughts at the end

- In US academia, one needs famous senior colleagues to write an obscene number of letters for all sorts of occasions – Thanks, Robert, for writing a few tens of them for me
- Nuclear Physics is a team sports and will starve without collaborations such as ours

Hoping for continued scientific adventures and the occasional, enjoyable conference experience - my GRC lobster will always have your name on it!

Thank you!

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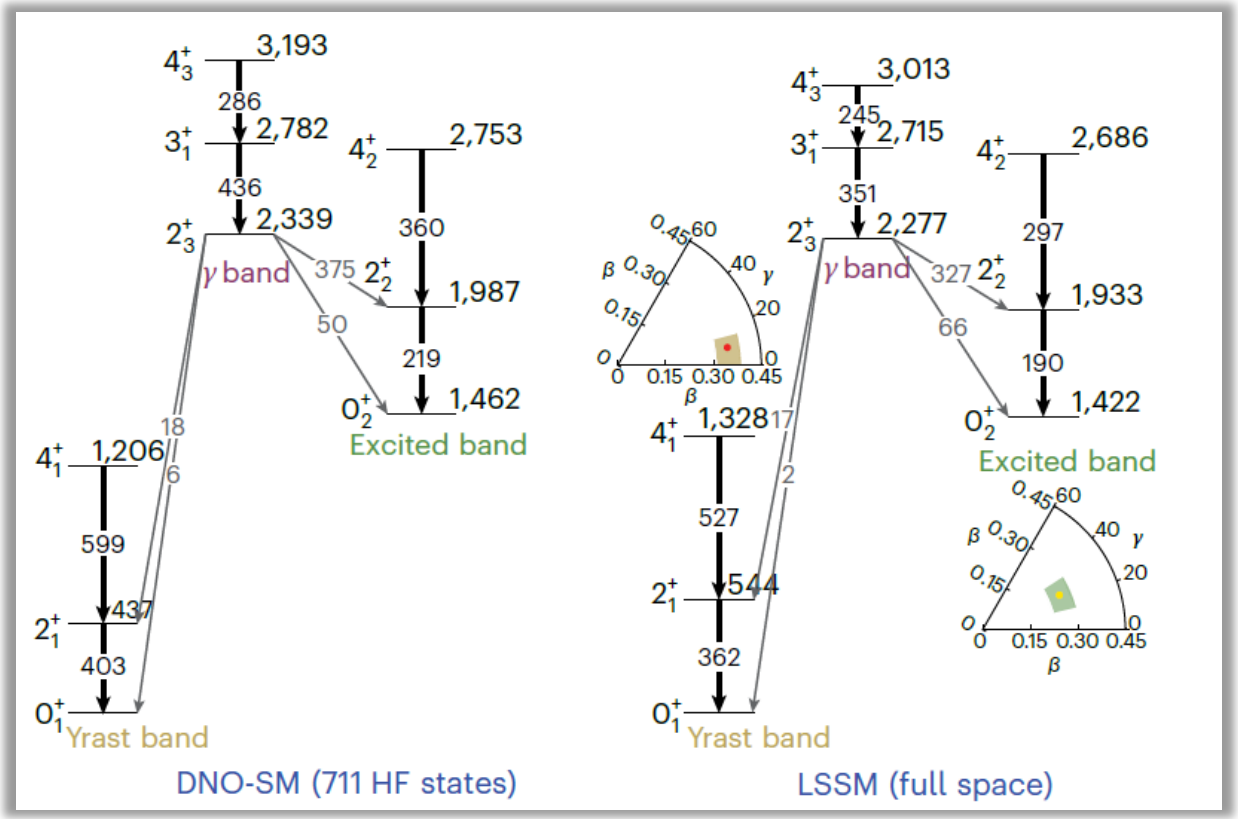
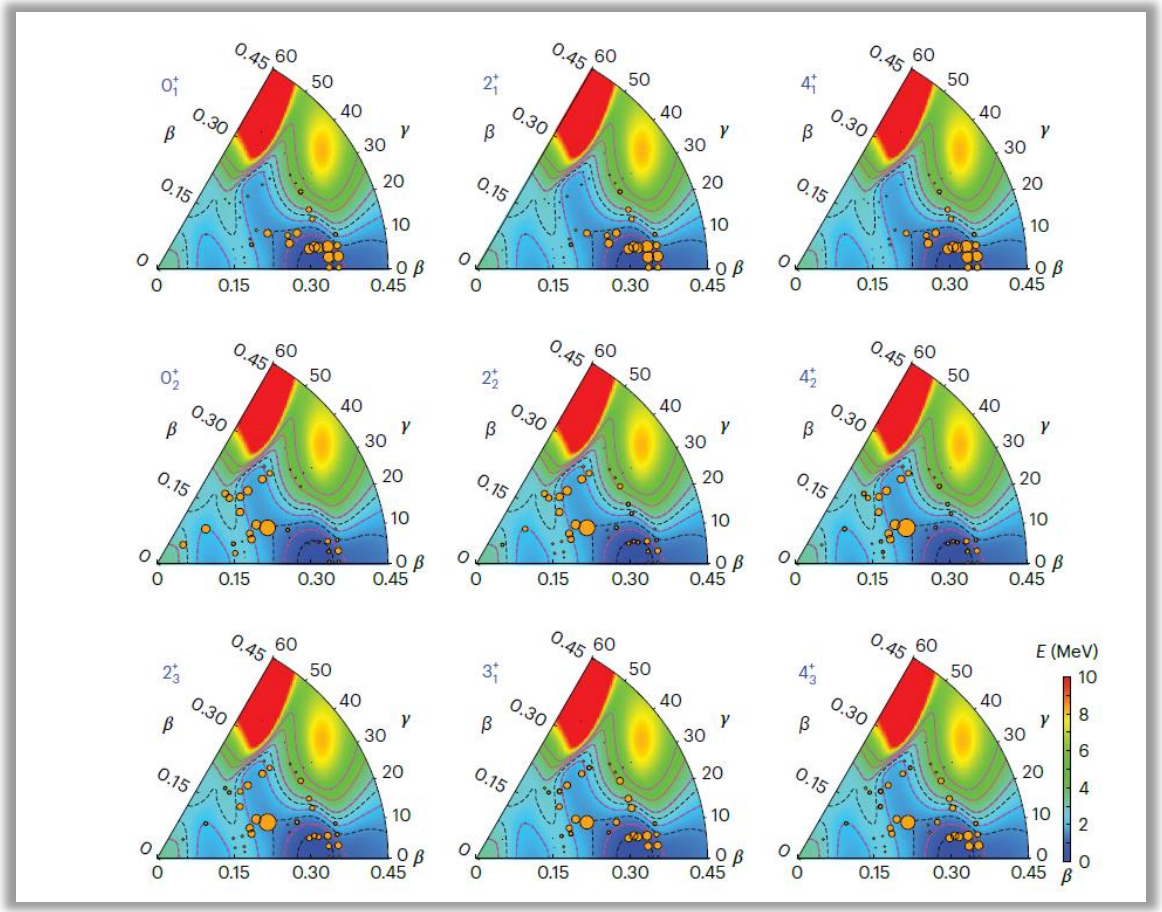
Analyzing the shapes of ^{62}Cr

Duc D. Dao, Frederic Nowacki, Silvia Lenzi, Alfredo Poves

Duc D. Dao, Frederic Nowacki



Deformation in βγ according to Kumar-Cline invariants extracted from the conventional shell model (LNPS effective interaction)



βγ planes according to the discrete non-orthogonal shell model

Excursion: Shape of longitudinal momentum distribution encodes final-state total angular momentum

PHYSICAL REVIEW C **101**, 031303(R) (2020)

Rapid Communications

Two-neutron knockout as a probe of the composition of states in ^{22}Mg, ^{23}Al, and ^{24}Si

B. Longfellow,[1,2] A. Gade,[1,2] J. A. Tostevin,[3] E. C. Simpson,[4] B. A. Brown,[1,2] A. Magilligan,[1,2] D. Bazin,[1,2] P. C. Bender,[1,*] M. Bowry,[1,†] B. Elman,[1,2] E. Lunderberg,[1,2] D. Rhodes,[1,2] M. Spieker,[1,‡] D. Weisshaar,[1] and S. J. Williams[1,§]

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PHYSICAL REVIEW C **79**, 064621 (2009)

Longitudinal momentum distributions of the reaction residues following fast two-nucleon knockout reactions

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PRL **102,** 132502 (2009) PHYSICAL REVIEW LETTERS week ending 3 APRIL 2009

Two-Nucleon Knockout Spectroscopy at the Limits of Nuclear Stability

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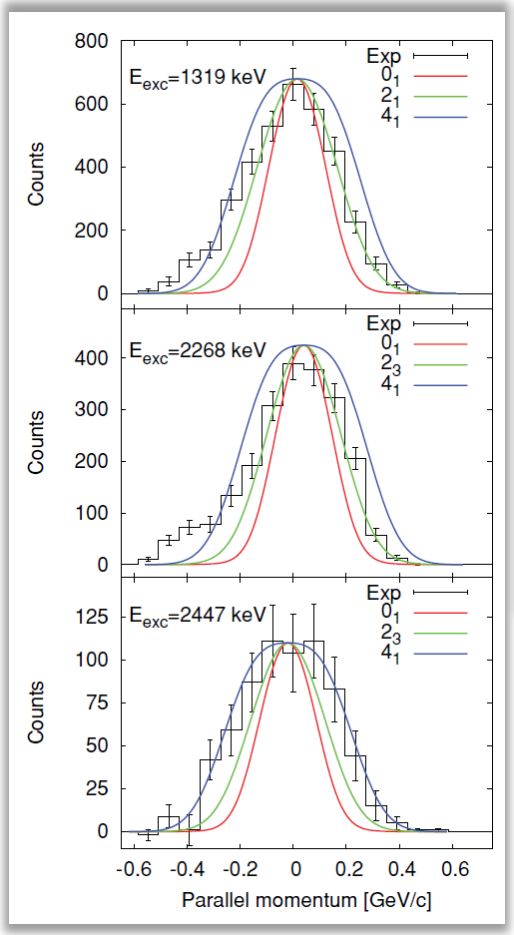
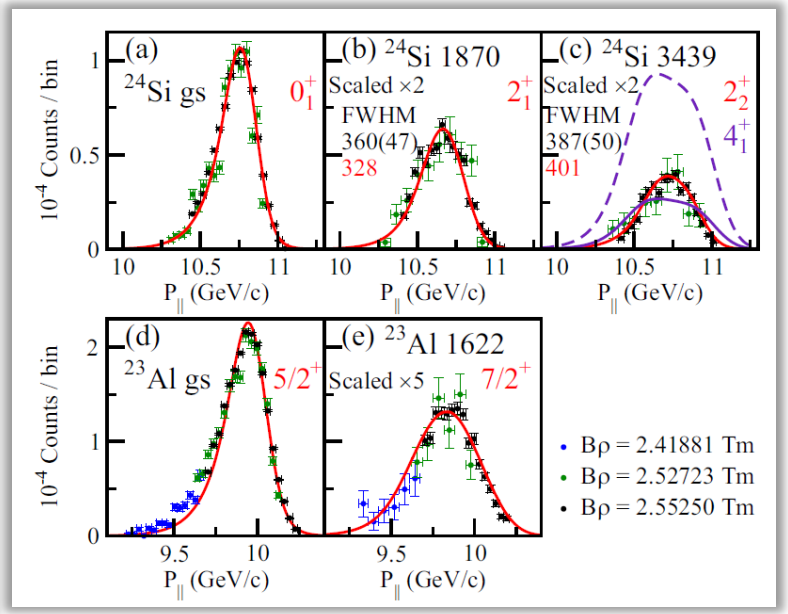
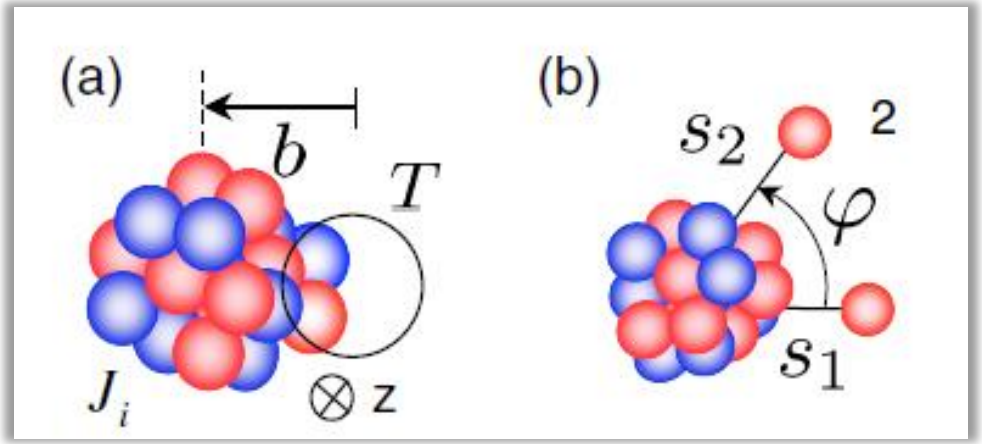


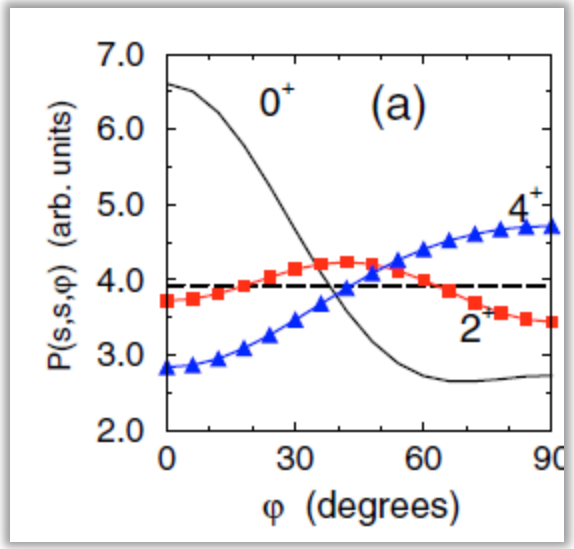
D. Santiago-Gonzalez *et al.*, PRC 83, 061305(R) (2011)

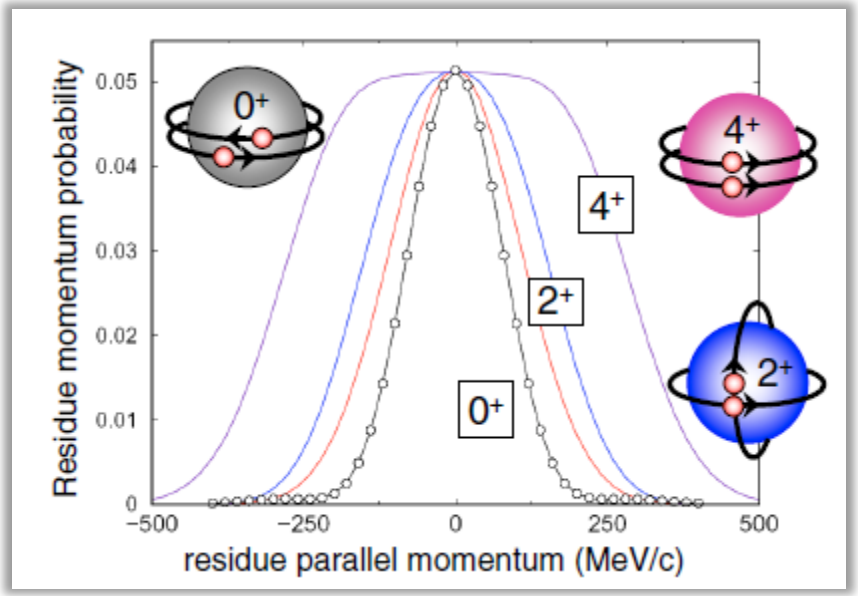


B. Longfellow *et al.*, PRC 101, 031303(R) (2020)

Momentum distributions in two-nucleon knockout







Eur. Phys. J. Special Topics **150**, 67–70 (2007)

DOI: 10.1140/epjst/e2007-00268-6

THE EUROPEAN PHYSICAL JOURNAL SPECIAL TOPICS

Reaction spectroscopy at fragmentation beam energies – recent advances in studies of two-nucleon removal

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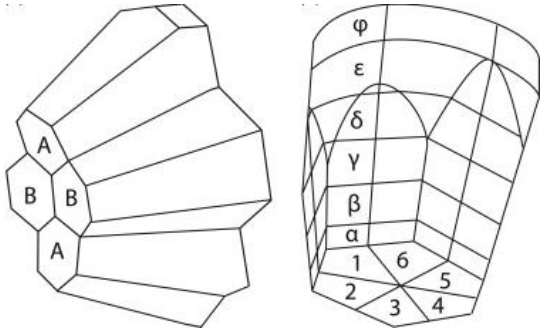
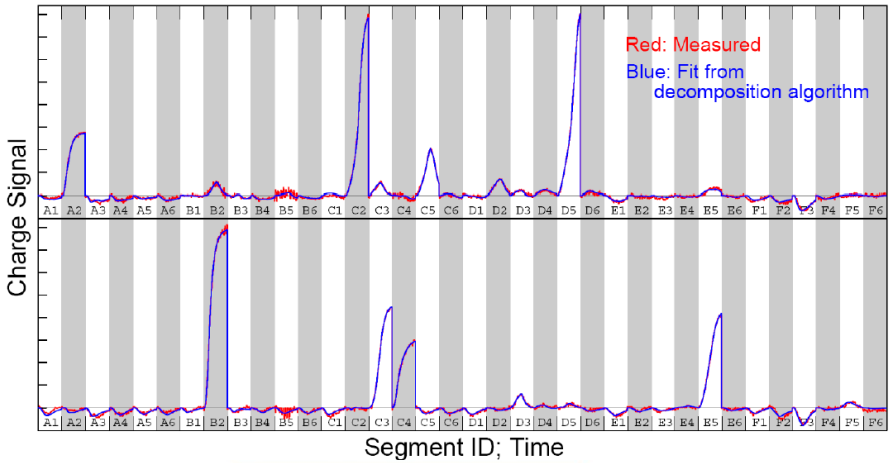
γ rays emitted in flight are Doppler shifted – needed for reconstruction: Velocity and emission angle

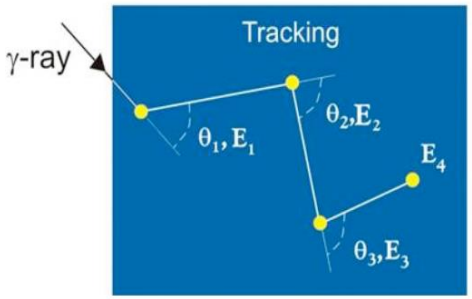
Segmented HP Ge detectors



Signal decomposition from digitizer traces



Determine precise location and sequence of γ-ray interaction points



Doppler-reconstruction of γ rays emitted in flight