Gamma Ray Spectroscopy at ISAC (GRSI): Past, Present and Future

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

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

2025-09-20

Greg Hackman, TRIUMF

GRSI pre-history: My memories of working with Robert

- Great boss, mentor, friend
- Fun experiments & science:
  - ^{248}Cm Coulex (ANL-ND)
  - ^{142}Sm SD DSAM, ^{195}Hg SD (GS)
- He treats people right.
- Incredibly supportive of post-docs as colleagues and as friends, and in their subsequent careers
- P e e t ' s C o f f e e

The Past: GRSI in 1999

- Just Gordon at TRIUMF
- 8pi arrived in 2000

The Past: Robert was incredibly supportive of GRSI

TIGRESS progress reviews: Chair, 2003-2008

- Initial recommendation for funding 2003
- Subsequent (semi)annual reviews
- Valuable direction and advice to keep project on track
- Very effective advocate for us to rest of committee
  - esp. NSERC and particle-collider committee members

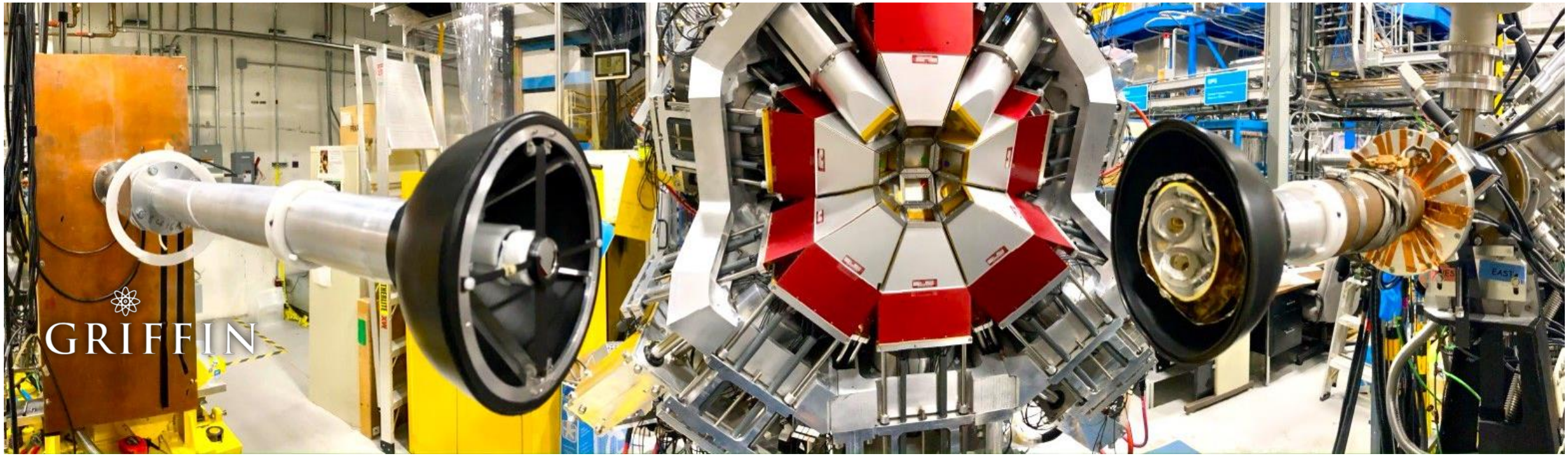
Advisory role

- Advisory Committee on TRIUMF (as mentioned by Ritu)
  - Always a strong advocate for ISAC & GRSI
- Advised on hiring plans
  - Build on-site team
  - Manage GRIFFIN install while TIGRESS operating

The Present: TIGRESS

- TIGRESS in front of EMMA
- 12 clovers when EMMA in use
- New Si arrays for EMMA astrophysics compatibility
- With EMMA pulled back: can install all 16 clovers
- Pictured below: CsI array with plunger (TIP)

The Present: GRIFFIN



- GRIFFIN fully instrumented
  - Tape system, Beta particle and conversion electron detectors from 8pi
  - LaBr for fast timing
  - Neutron detectors for e.g. ^{11}Li spectroscopy

- Upgrades in development
  - Replace beta detectors with highly segmented plastic with SiPM readout – construction well advanced
  - Replace 5-Si(Li) detectors with array of 8 for improved conversion electrons – design phase, cooling R&D

The Present: 8pi

- 8pi served admirably at TRIUMF 2000-2013
- Now at Simon Fraser U. in K. Starosta & C. Andreoi care
  - Occasionally, HPGe return to TRIUMF
  - Highly-charged ion x-rays (NEEC etc.)
  - Muonic x-rays

The Present: GRSI personnel in 2024

The Present: Some recent GRSI science highlights

- Some work we did with TIGRESS & GRIFFIN that Robert's support enabled
- And that he might have found interesting....

Shape coexistence and Inversion in n-rich A~60-70 nuclei

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Shape coexistence and the role of axial asymmetry in ^{72}Ge

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ABSTRACT

The quadrupole collectivity of low-lying states and the anomalous behavior of the 0_2^+ and 2_3^+ levels in ^{72}Ge are investigated via projectile multi-step Coulomb excitation with GRETINA and CHICO-2. A total of forty six $E2$ and $M1$ matrix elements connecting fourteen low-lying levels were determined using the least-squares search code, GOSIA. Evidence for triaxiality and shape coexistence, based on the model-independent shape invariants deduced from the Kumar–Cline sum rule, is presented. These are interpreted using a simple two-state mixing model as well as multi-state mixing calculations carried out within the framework of the triaxial rotor model. The results represent a significant milestone towards the understanding of the unusual structure of this nucleus.

nature physics

Article

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

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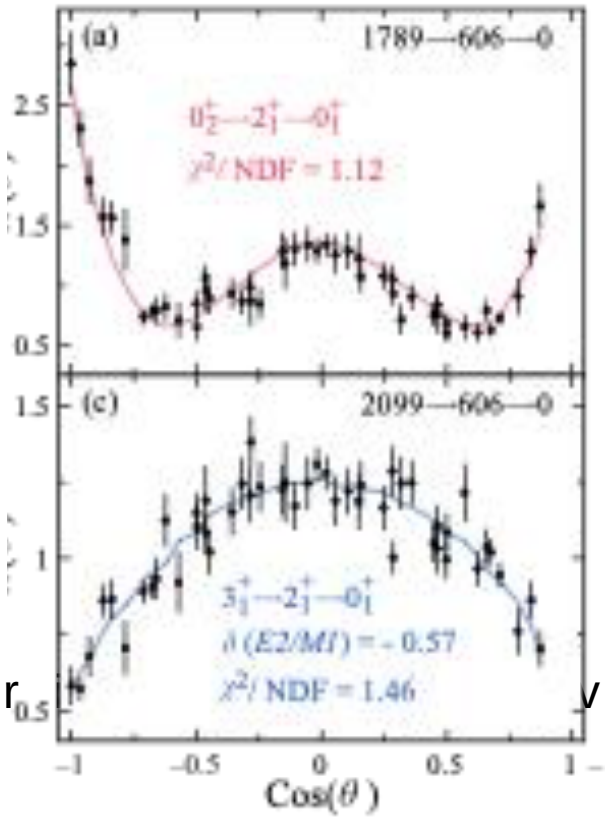
Check for updates

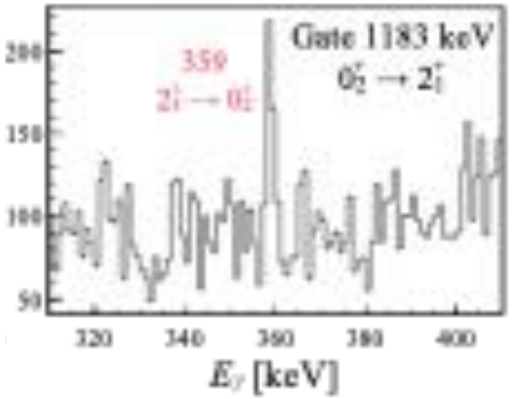
Alexandra Gade [1,2], Brenden Longfellow [3], Robert V. F. Janssens [4,5], Duc D. Dao [6], Frédéric Nowacki [6], Jeffrey A. Tostevin [7], Akaa D. Ayangeakaa [4,5], Marshall J. Basson [1,2], Christopher M. Campbell [8], Michael P. Carpenter [9], Joseph Chung-Jung [1,2], Heather L. Crawford [8], Benjamin P. Crider [10], Peter Farris [1,2], Stephen Gillespie [1], Ava M. Hill [1,2], Silvia M. Lenzi [11], Shumpei Noji [1], Jorge Pereira [1], Carlotta Porzio [8], Alfredo Poves [12], Elizabeth Rubino [1] & Dirk Weisshaar [1]

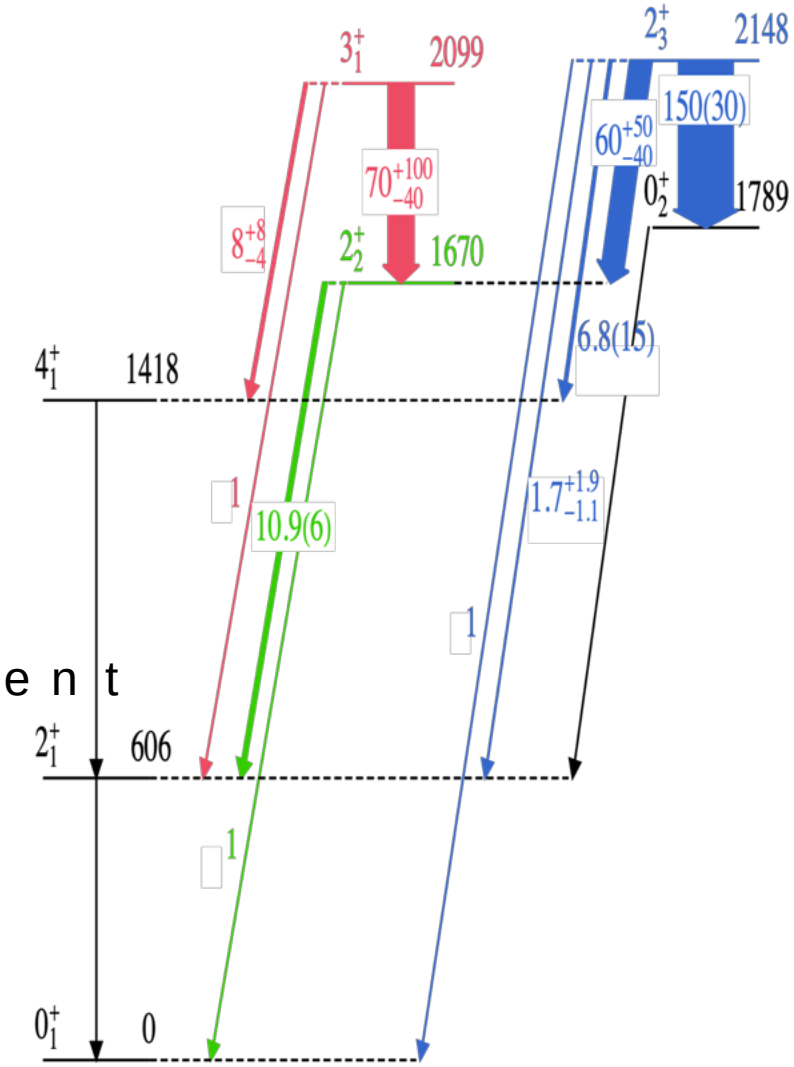
In recent decades, rare-isotope facilities have enabled the study of short-lived, neutron-rich nuclei. Their measured properties indicate that shell structure changes in the regime of unbalanced neutron-to-proton ratios compared with that of stable nuclei. In the so-called islands of inversion in the nuclear chart—around the neutron-rich nuclei ^{32}Mg, ^{42}Si and ^{64}Cr, for example—the textbook shell model predicts spherical shapes due to the respective magic neutron numbers of 20, 28 and 40 of these nuclei. However, nuclei in these regions turn out to be deformed in their ground states. Another hallmark of these islands is shape coexistence, where a nucleus assumes different shapes with excitation energy. Here we present evidence for this phenomenon from the observation of an excited 0^+ state in ^{62}Cr, two neutrons away from the heart of the island of inversion around neutron number $N = 40$. We use large-scale shell-model calculations to interpret the results, and we report extrapolations for the doubly magic nucleus ^{60}Ca.

^{74}Zn Axial Asymmetry and Configuration Coexistencef

- M. Rocchini, P.E. Garrett et al., PRL 130, 122502 (2023)
  - 5 RVFJ references
- N=40 Island of Inversion, Shape coexistence and triaxiality
- TRIUMF-ISAC-GRIFFIN , 1700/s ^{74}Cu discretionary beam time
  - During an "atmospheric" event
- – angular correlations: definite spins for four states
- New weak branches identified



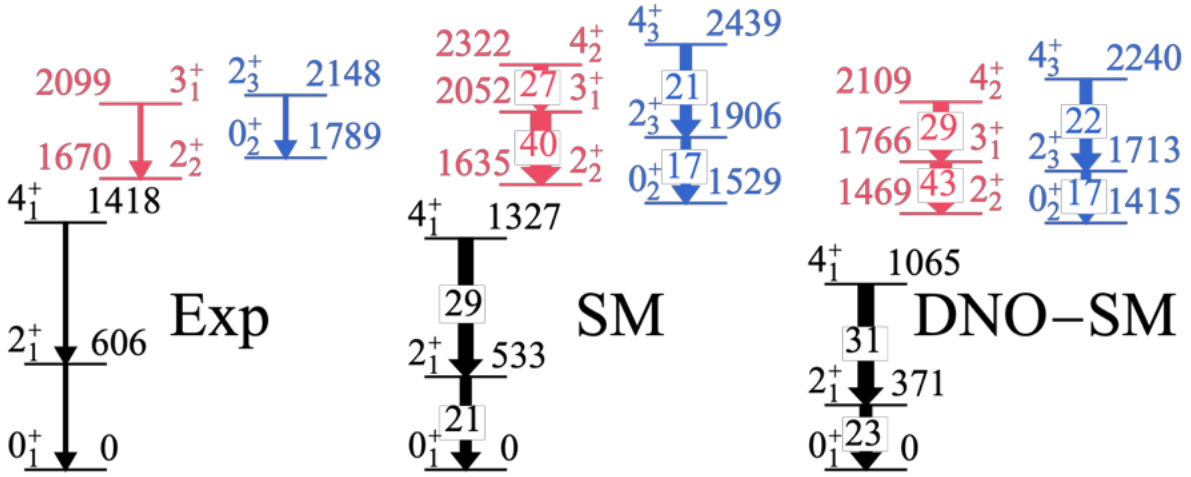


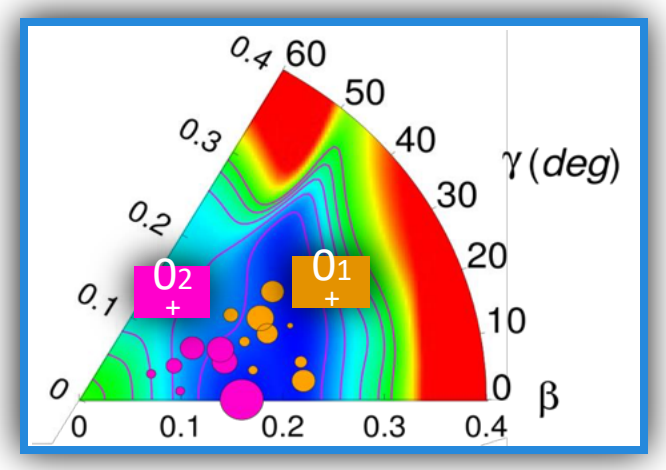


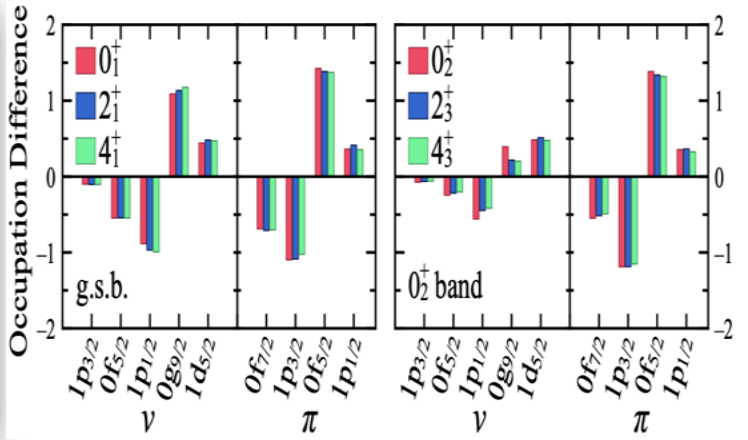
^{74}Zn Axial Asymmetry and Configuration Coexistence

Highlights from model interpretation:

- Good excitation energy, **relative** B(E2)
- Models suggest three rotational structures:
  - Ground: triaxial & prolate
  - First excited: triaxial and LESS prolate
  - Second excited: K=2
- Higher intruder $_{9}T_2$ occupation in ground than excited band – Inversion!
- Connects ^{64}Cr, $^{>78}$Ni IoIs

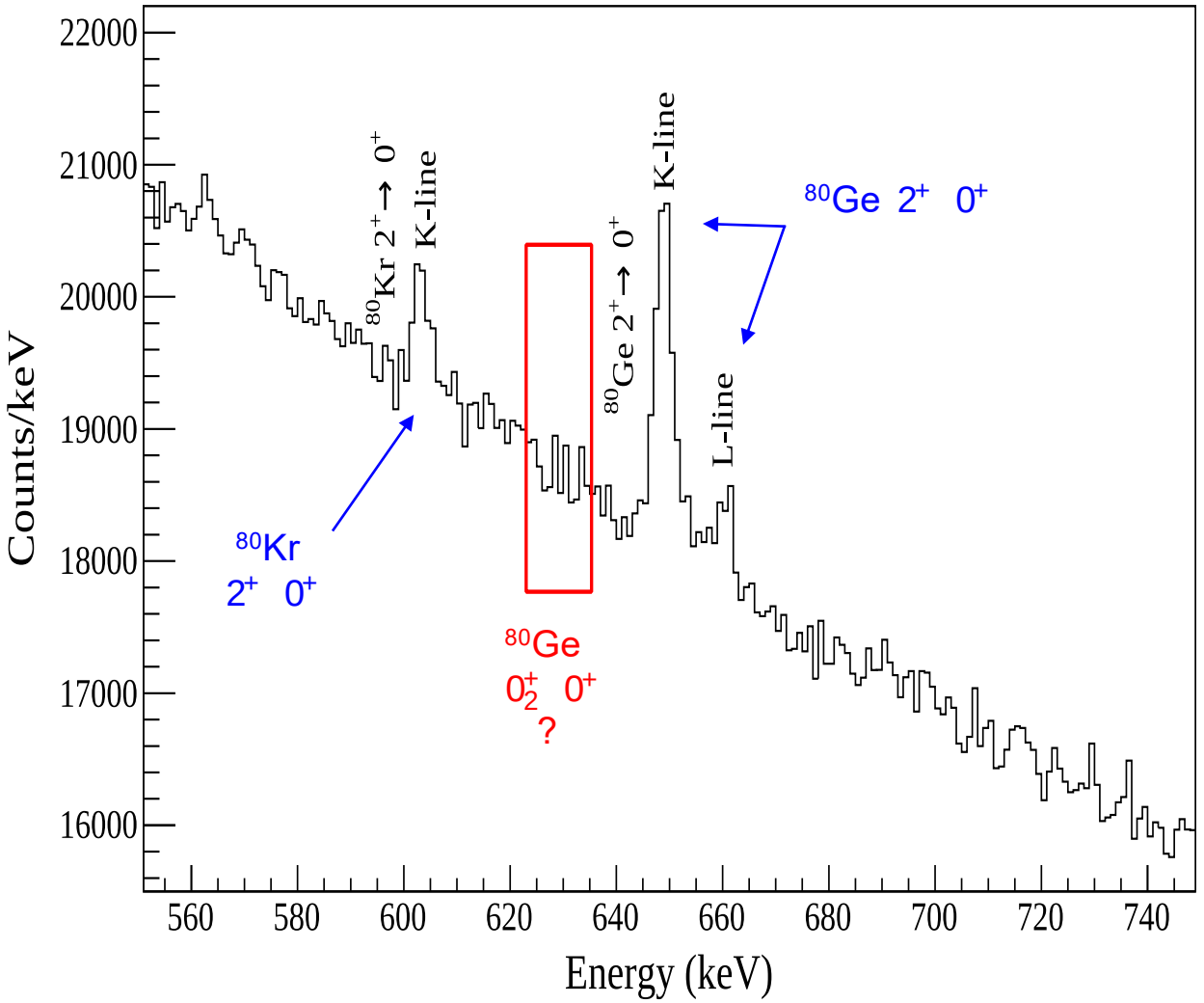






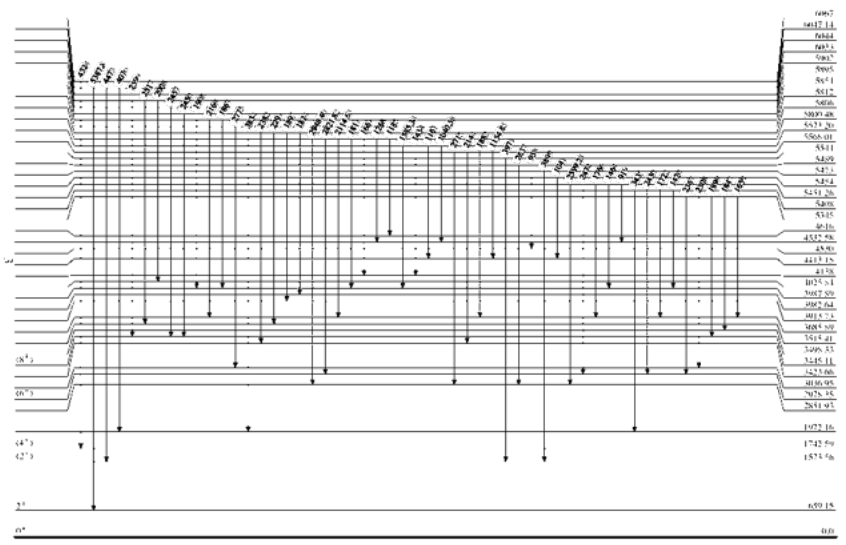
Quick diversion to (somewhat) related topic: ^{80}Ge shape (non)coexistence

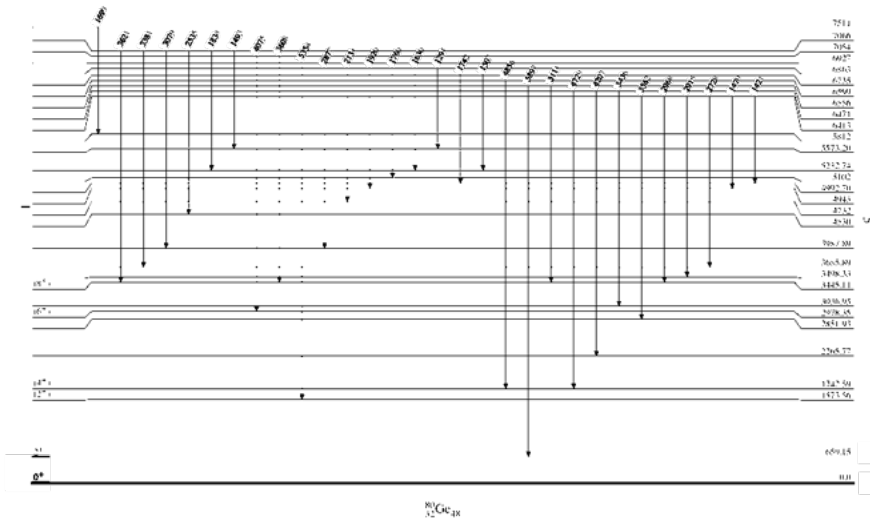
- F. Garcia et al, PRL 125, 172301 (2020)
- Conversion-electron spectra: no sign proposed low-lying 0+ state in ^{80}Ge
- Supporting gammas placed diffferenty
  - First reported Gottardo et al. PRL 116 182501 (2016)
  - Sekal e t a l . P R C 1 0 4 0 2 see it either
- Analysis continuing, Garcia & G. C. Ball .....

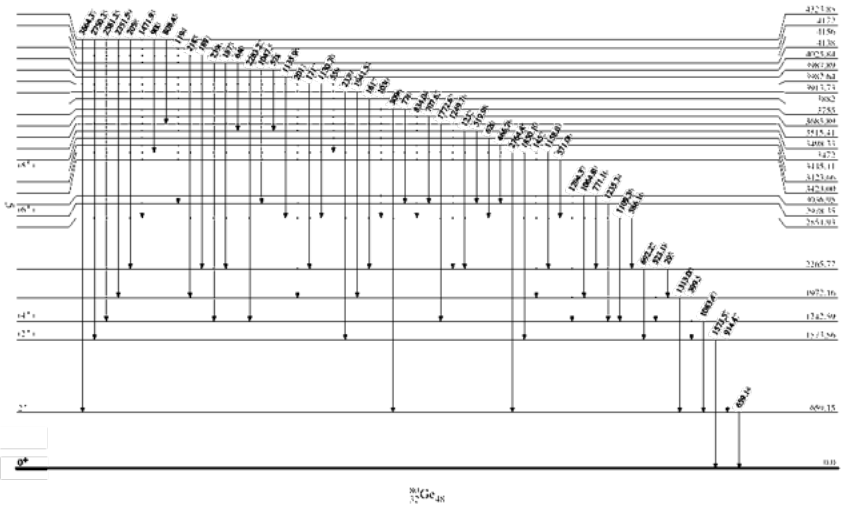


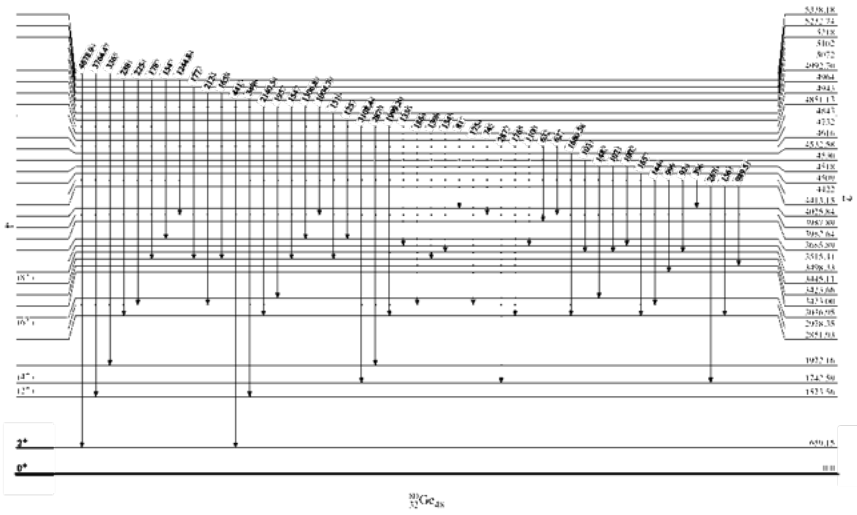
“Anyone who puts 300 levels on a

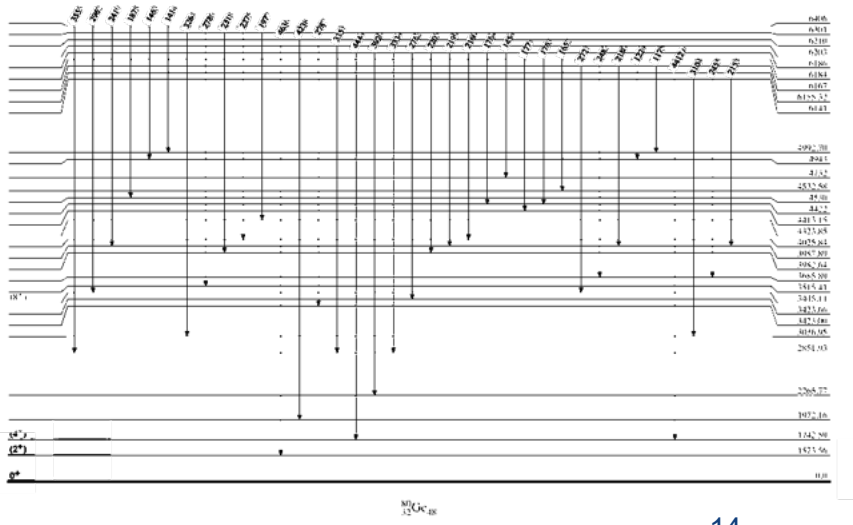
- 403 levels and 1143 transitions (!!!)
  - Just a small fraction shown here
- Motivation: GT strength
- ^{82}Se FRIB/DEGA data: 40,300 levels?











*G. Savard, priv. comm.

Island of Inversion and Cross-Shell Excitations

PHYSICAL REVIEW C **82**, 034305 (2010)

Cross-shell excitations near the "island of inversion": Structure of ^{30}Mg

A. N. Deacon,[1,*] J. F. Smith,[2] S. J. Freeman,[1] R. V. F. Janssens,[3] M. P. Carpenter,[3] B. Hadinia,[2] C. R. Hoffman,[4,†] B. P. Kay,[3] T. Lauritsen,[3] C. J. Lister,[3] D. O'Donnell,[2,‡] J. Ollier,[2,‡] T. Otsuka,[5,6] D. Seweryniak,[3] K.-M. Spohr,[2] D. Steppenbeck,[1,§] S. L. Tabor,[4] V. Tripathi,[4] Y. Utsuno,[7] P. T. Wady,[2] and S. Zhu[3]

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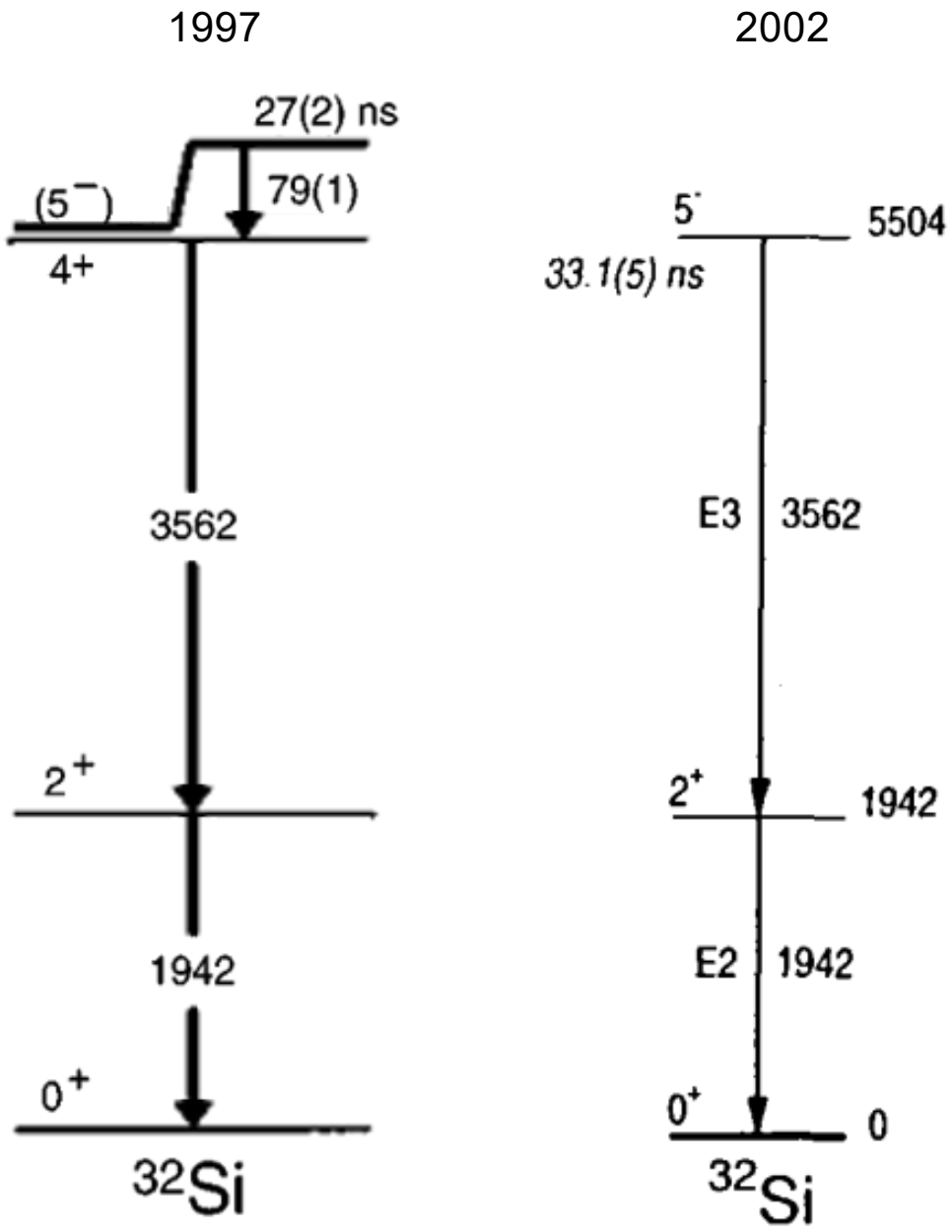
(Received 18 June 2010; published 7 September 2010)

Excited states in ^{30}Mg have been populated to $\sim 6\hbar$ and 5 MeV excitation energy with the ^{14}C(^{18}O,2p) reaction. Firm spin assignments for states with $J > 2\hbar$ have been made in this nucleus. The level scheme is compared to shell-model calculations using the Universal *sd* effective interaction and the Monte Carlo shell model method. Calculations employing a full *sd* model space fail to reproduce the observed levels. The results indicate that excitations across the $N = 20$ gap are required at relatively low excitation energy to achieve a description of the data. The incorporation of the $f_{7/2}$ and $p_{3/2}$ orbitals into the model space gives improved results but indicate the need for further refinement of the models to reproduce the observed spectra.

- N=18, Z=12
- ^{14}C(^{18}O,2p)^{30}Mg
- (radioactive target)
- FMA+GS
- Let's go protons up to ....

The case of ^{32}Si

- N=18, Z=14
- 5^- isomeric state
- could arise from $(0d_{3/2})^{-1}(0f_{7/2})^{1}$ configuration
- ~46 ns mean lifetime
- Disagreement on placement & decay of 5^-, placement of 4^+_1



^{32}Si

- ^{22}Ne @ 56 MeV on ^{nat}C targets, DSAM-style and self-supporting
- TIP CsI(Tl) array inside TIGRESS
  - J. Williams et al. NIM A 939 1 (2019).
- 2-CsI-1-Ge filter with waveforms
- Offline PID to select ^{12}C(^{22}Ne,2p)^{32}Si
- Lifetimes from DSAM, electronic timing
- Also DCO & polarization for of transitions

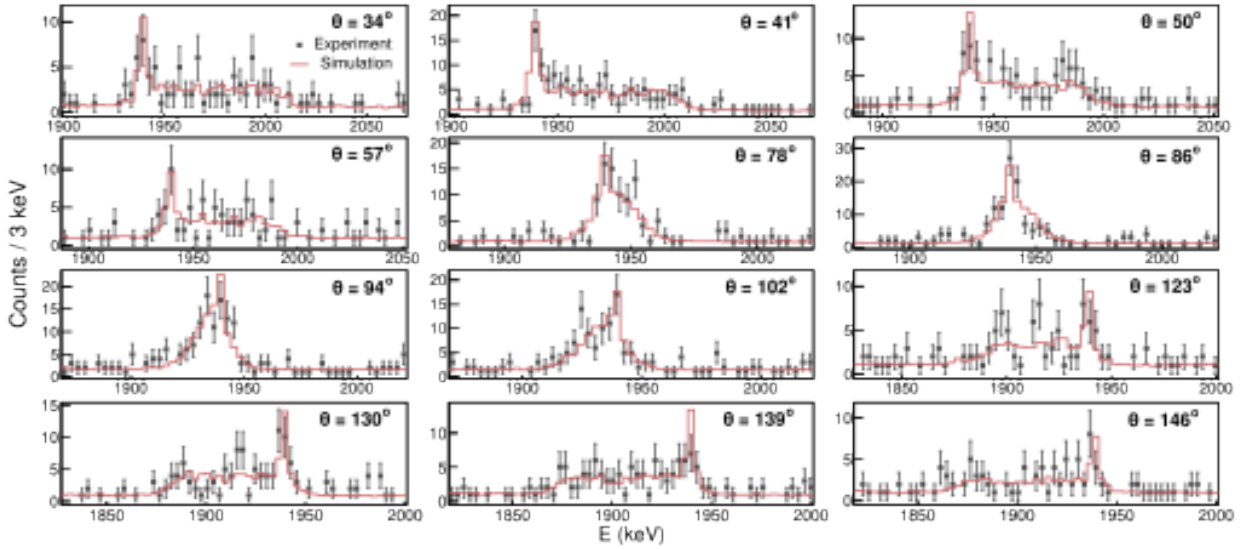


FIG. 5. Comparison of the 1942.06(6) keV DSAM lineshape (gated on the feeding 3940.1(12) keV transition) to GEANT4-based simulations assuming τ_{mean} = 800 fs for the 2_1^+ level of ^{32}Si.

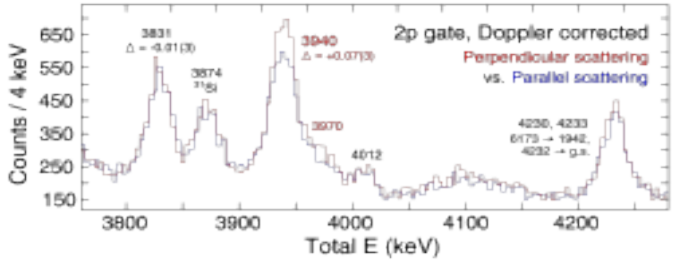


FIG. 6. Doppler-corrected 2p (^{32}Si) gated γ singles spectrum for events which Compton scatter either in a perpendicular (red) or parallel (blue) direction with respect to the reaction plane, in the vicinity of the 3940.1(12) keV transition.

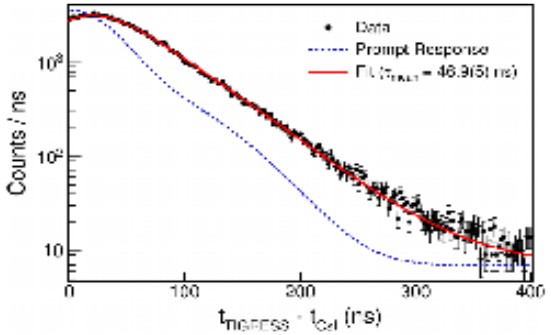
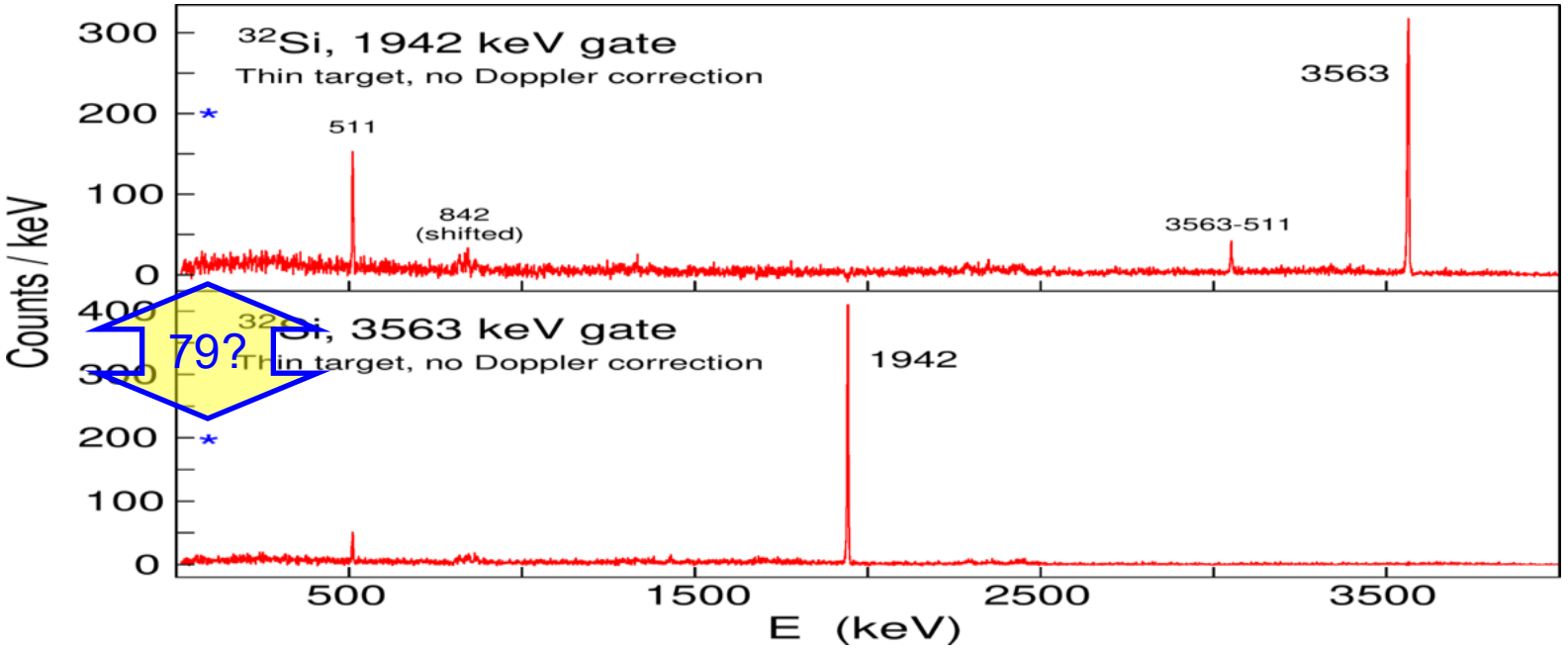
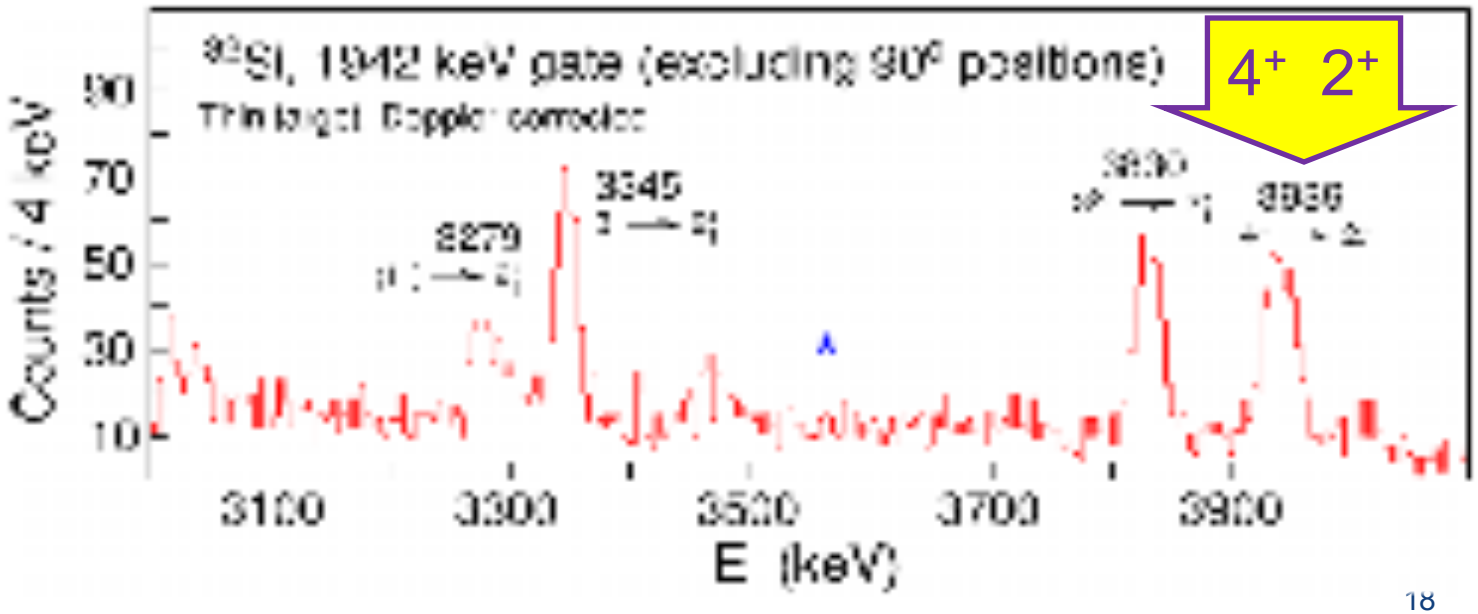


FIG. 4. Background subtracted TIGRESS-CsI timing distribution for the 3562.84(14) keV transition in ^{32}Si.

^{32}Si

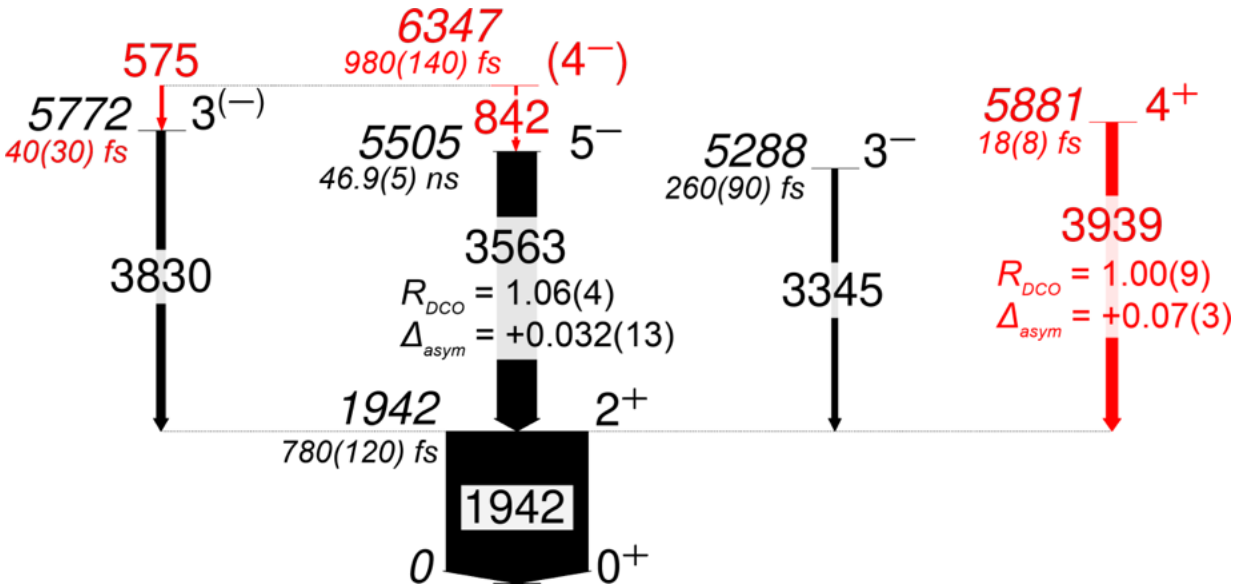
- No evidence of 79 keV transition in proton-proton-gamma-gamma coincidence
  - Should be about 200 counts high
- Evidence for 4^+ state at higher energy than 5^-

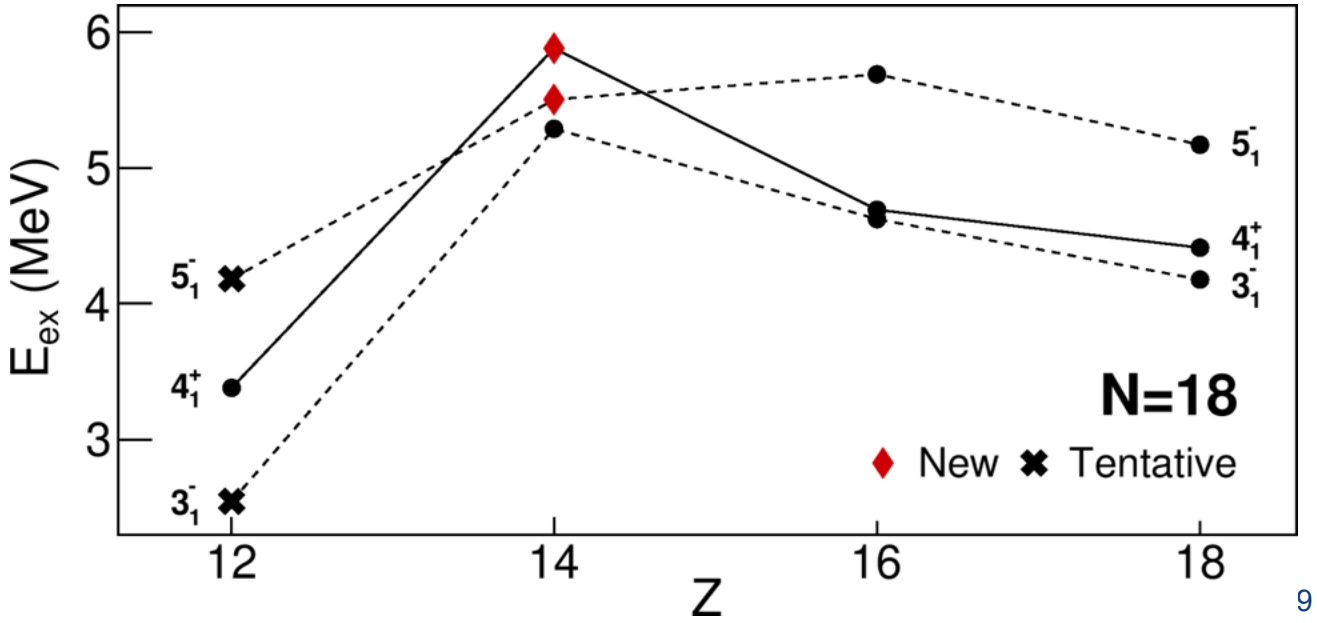




^{32}Si

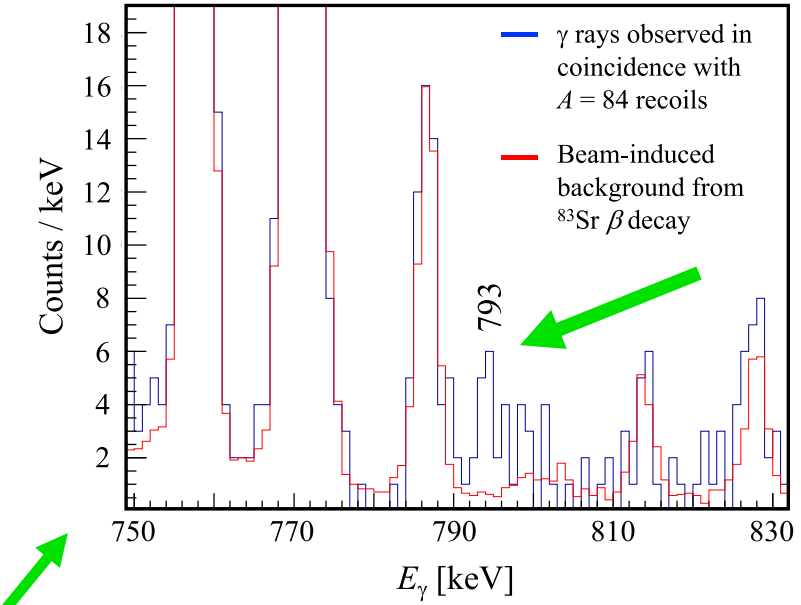
- 4+ anomalously high compared to other N=18 isotones
- 5- i s e s s e n t i a l l y
  - Yes I know the 3- is below it
- Z=14 subshell closure effect?
  - J. Williams et al., NIM A 939 1 (2019); PRC 108 L051305 (2023); PRC 112 014318 (2025)

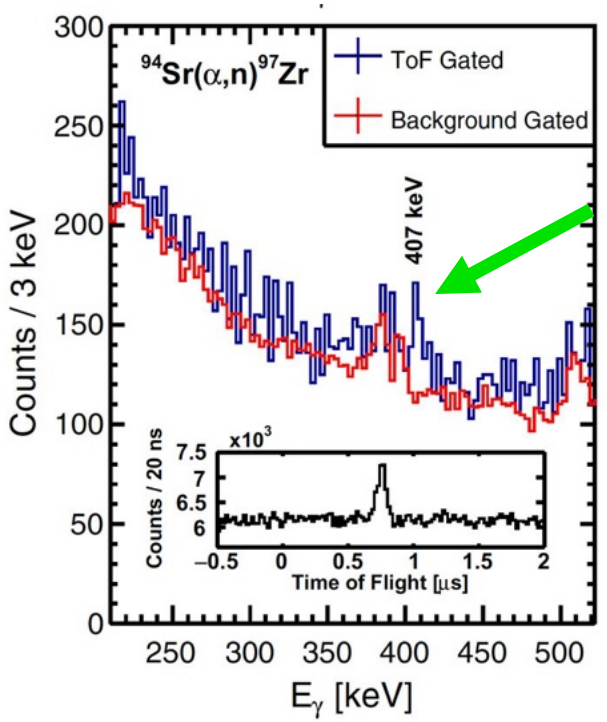




TIGRESS@EMMA

- TIGRESS moved in front of EMMA recoil separator in 2019 ... Since then ...
- >55% TIGRESS experiments with EMMA
- >50% explicitly astrophysics-motivated measurements
- Includes direct measurements
- ^{83}Rb(p,): G. Lotay, S. Gillespie, M. Williams et al. PRL 127 112701 (2021), M. Williams et al. PRC 107 035803 (2023)
- ^{94}Sr(α ,n)γ weak -process: M. Williams, C. Angus et al., PRL 134 107 035803 (2023)



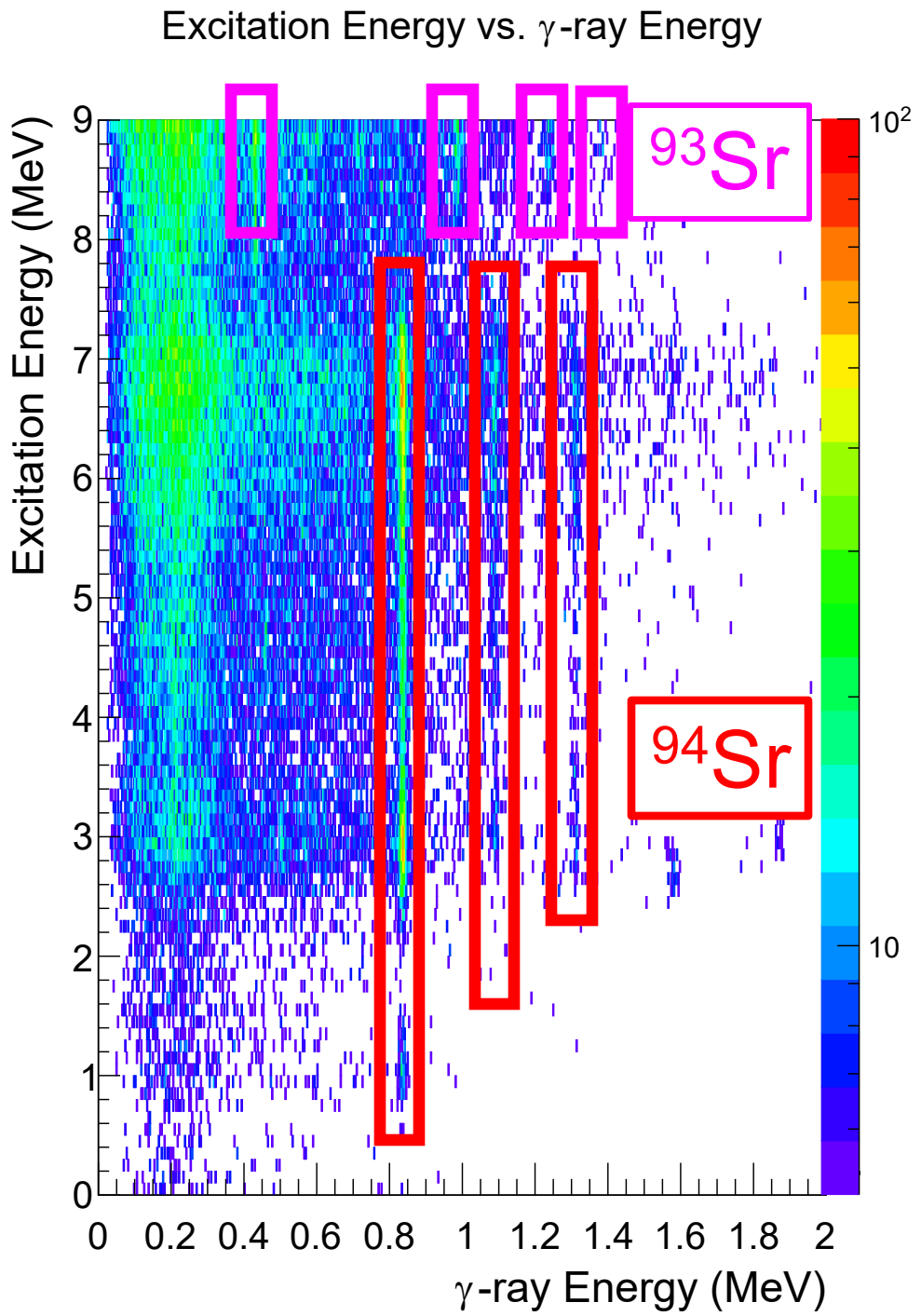


GRIFFIN@DRAGON: More GRSI "astr

- GRIFFIN subarray surrounding DRAGON gas target
  - Replaces BGO ball
  - Pulled back for visibility, they get pushed much closer
- F. Saraz, Enhancement of the $^{20}Ne(p,\ )$ reaction rate due to the presence of a barely-bound $1/2^+$ state in ^{21}Na —a case study of the impact of excited halo states in nuclear astrophysics"
- E_{cm} 300, 550 keV data taken, under analysis

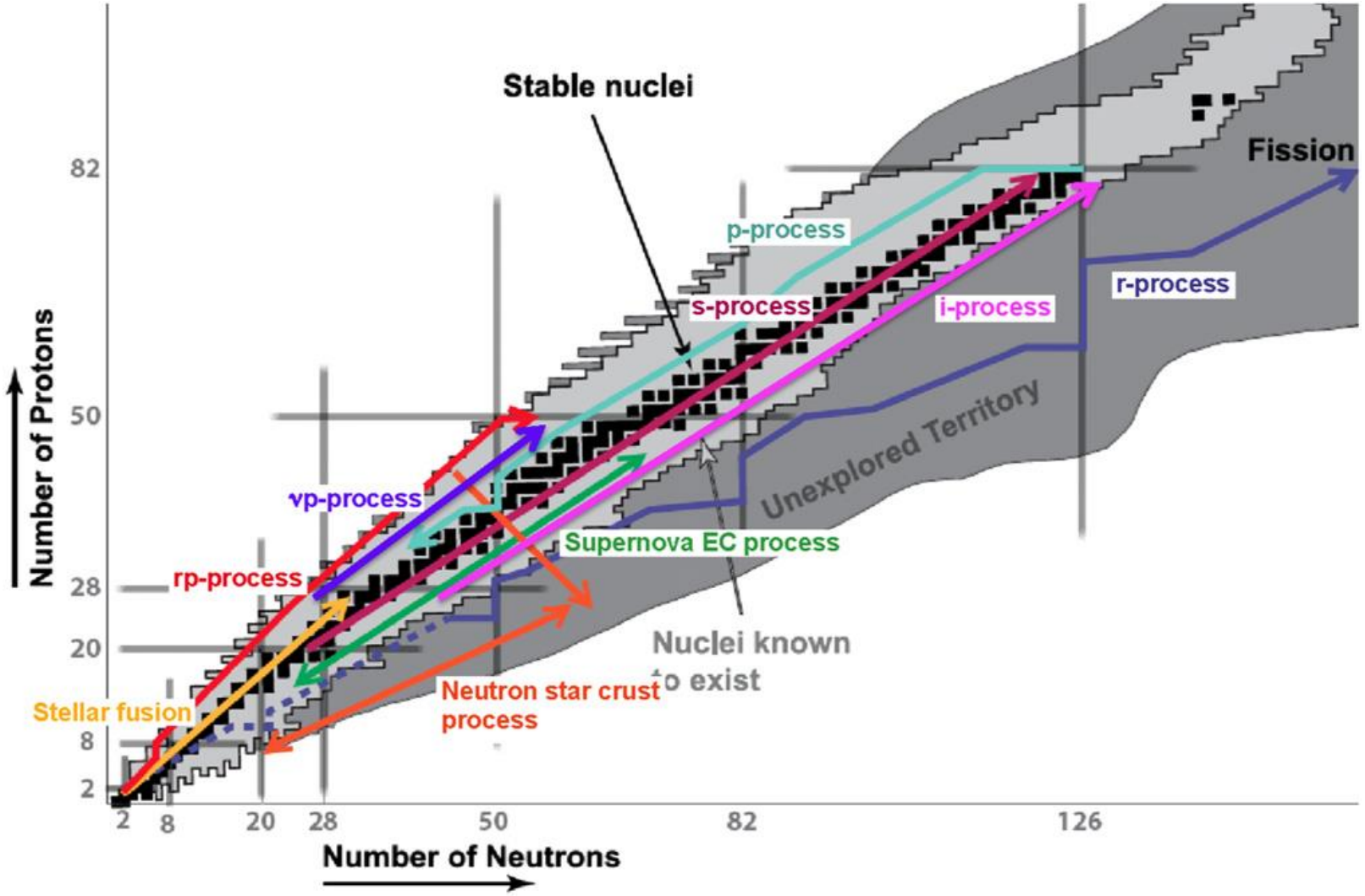
^{93}Sr(d,p)

- $^{A}Z + n \rightarrow {}^{A+1}Z +$ n-capture reactions on radioactive beams for r- and i-processes
- Well known (and frequently used): (d,p) surrogate reactions
- ^{93}Sr(d,p)^{94}Sr*, TIGRESS+Si array SHARC
  - Explicitly an astrophysics experiment
  - Standalone –EMMA pulled back
  - Outgoing channels ^{94}Sr+ and ^{93}Sr+n+
  - A. Richard, R. Hughes leading surrogate analysis
  - D. Yates et al. structure analysis in preparation (submission this year)



The future of GRSI

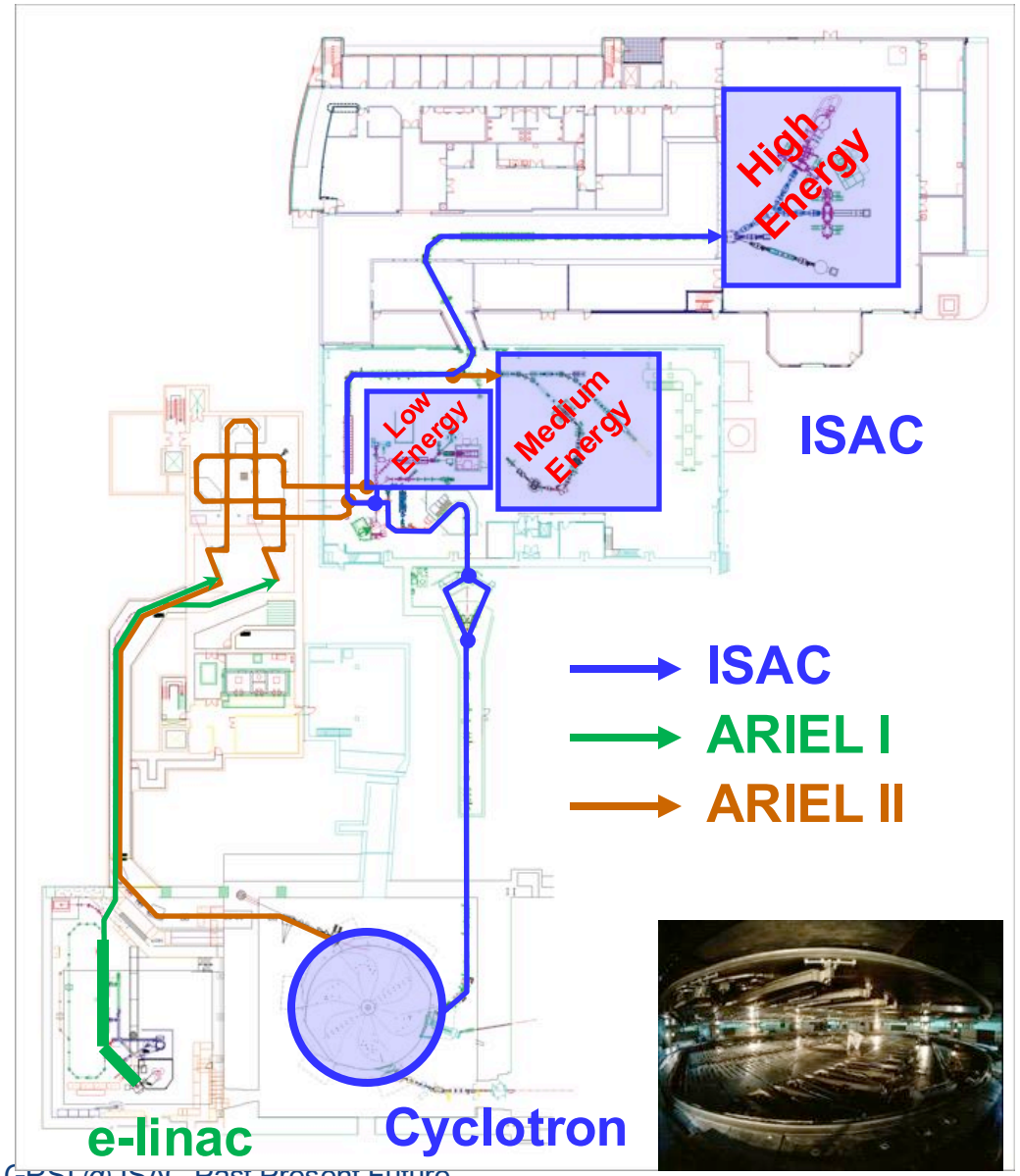
- TIGRESS@EMMA evolving towards more astrophysics
- Many GRIFFIN experiments also *r*-process related
  - And even one with accelerated RIB
- Will be enabled by ARIEL



H. Schatz, JPG 43.6 064001 (2016)

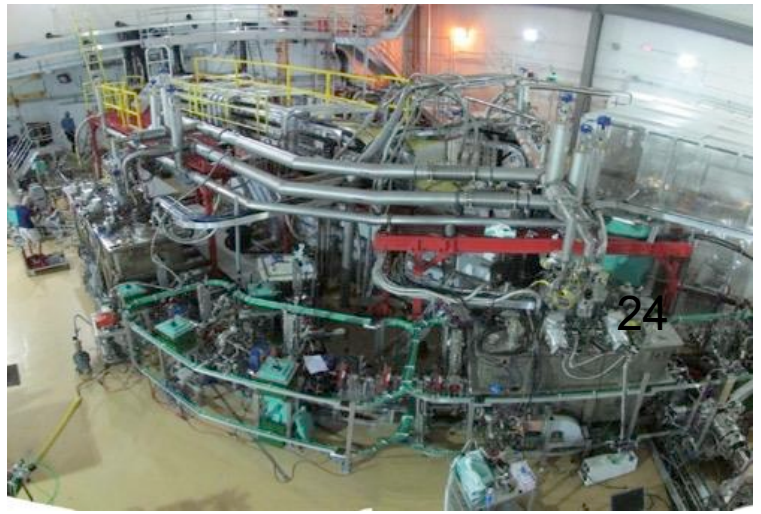
(anyone who puts 9 nucleosynthesis processes on a slide....)

Future directions, ARIEL



- ARIEL goal: 3 radioactive beams to experiments at same time
  - 2 low-energy, 1 accelerated
  - E.g. 1 each mass, decay, reaction measurements
- New 30 MeV e-linac for photofission on UCx
  - n-rich nuclei with no spallation background
- New proton beamline for spallation/fission
  - Also n-rich from UCx
  - But not necessarily exclusively
- New high-resolution separator, EBIS charge breeder
- Maintain existing ISAC infrastructure

E-linac and electron beamline
Sept. 2014

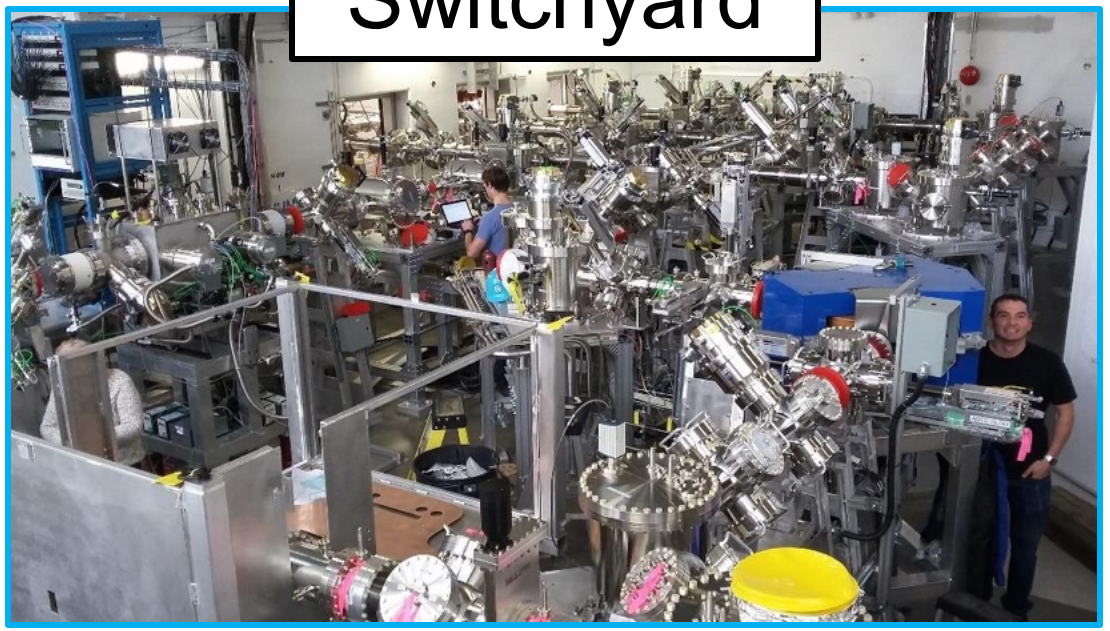


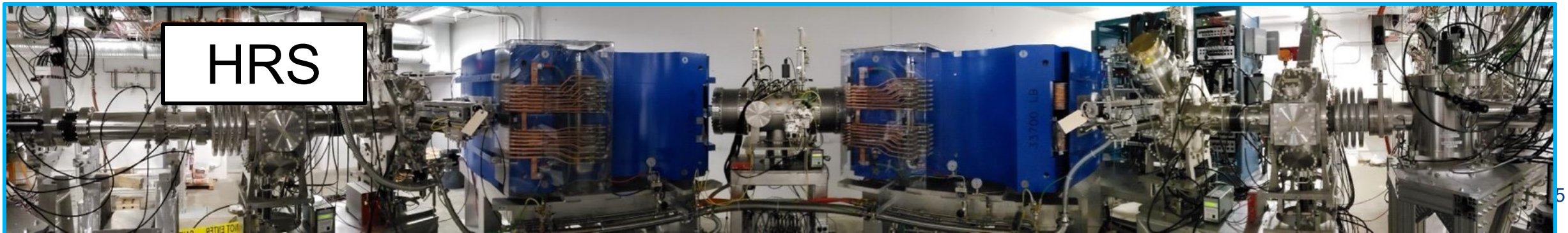
Future directions, ARIEL

- Where is ARIEL at?
- Electronic linac: completed, commissioning underway.
- with science along the way at beam dump
  - N.L. Ford et al.,J. Med. Imaging. 12 014002 (2025)
  - Darklight (e , e) data taking 2025

- RIB switchyard, yield station, High Resolution Separator functioning
- Resonant laser ion source, hot cells installed

Switchyard



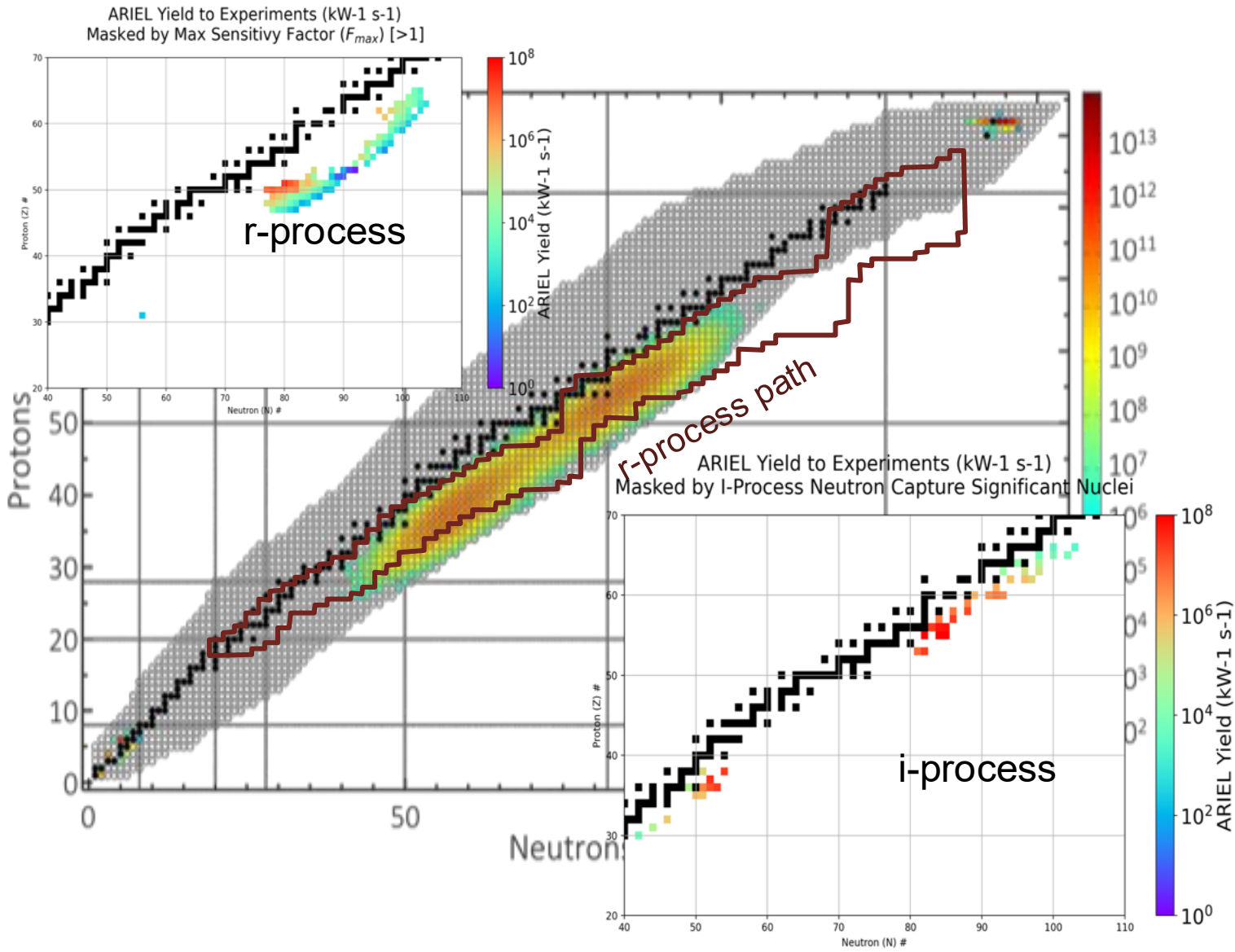


Future directions, ARIEL

- Major RIB targetry fabrication and installation in 2026
- Start ramping up beam on target 2027
- Will enable indirect *r*- and *i*-process experiments with some of our first beams (and maybe direct?)

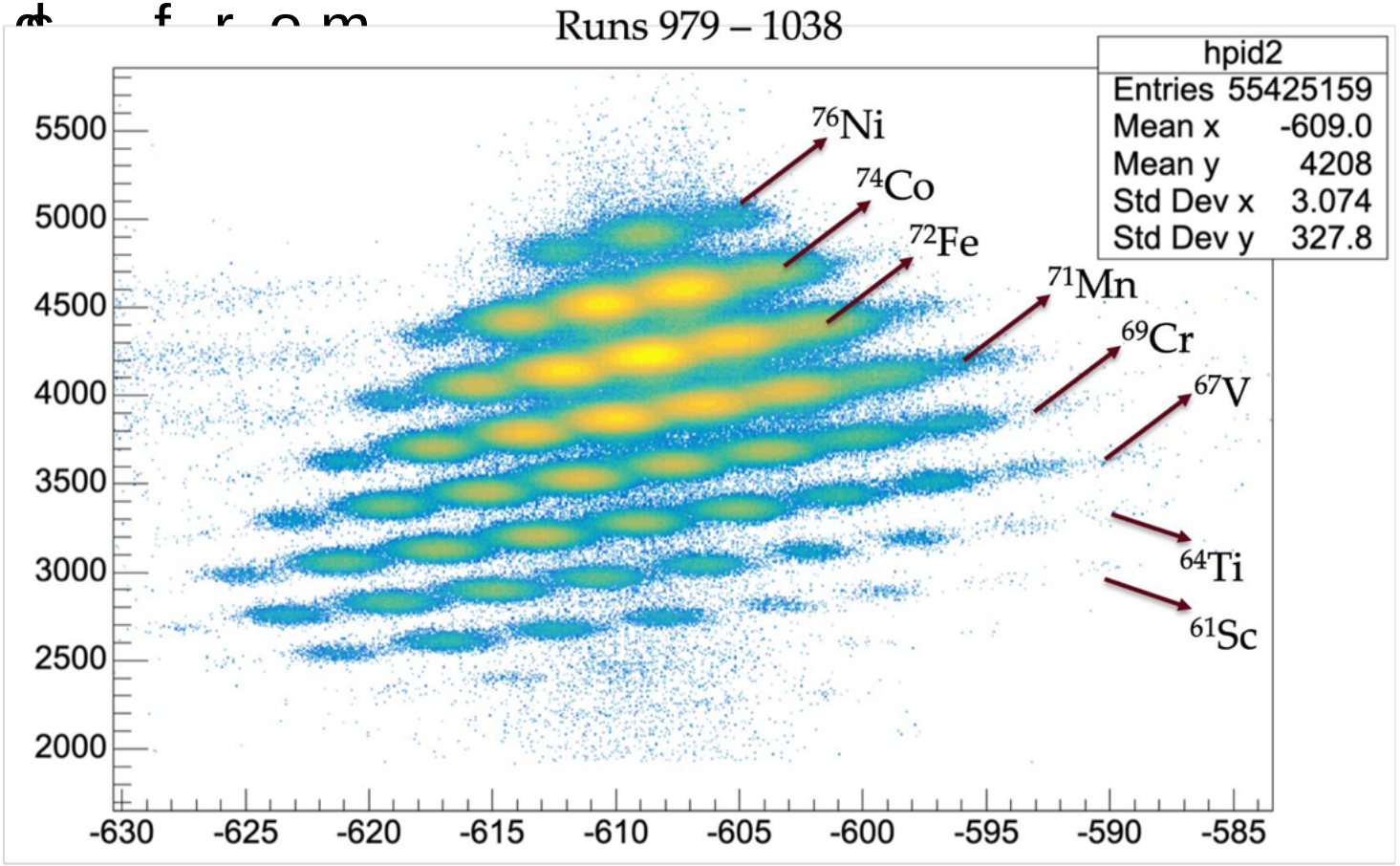
- TIGRESS, GRIFFIN, GRSI looking forward to it

photo-fission yields in uranium target



Robert's retirement plan?

- All my "mentors" from a decade ago mentors are still going strong
  - Gordon's 40Ge
  - Jim Waddington still contemplating ^{149}Gd SD staggering
- ~100 nuclei in this data set
- My prediction: by 2035 Robert & co will have published 40,300 published levels
  - Probably sooner



TRIUMF

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