OAK RIDGE National Laboratory

Recent results within the sd and fpg shells

J.M. Allmond – ORNL

On behalf of the CLARION2-TRINITY and FDSi@FRIB Collaborations

ORNL is managed by UT-Battelle, LLC for the US Department of Energy

U.S. DEPARTMENT OF ENERGY

CLARION2-TRINITY @ FSU

T.J. Gray *et. al.*, NIM A **1041**, 167392 (2022)

Tim Gray

*Fully digital with XIA Pixie16

Liquid Drop Representation of Shape

$$r = R(1 + \beta_2 Y_{20} + \beta_3 Y_{30} + \ldots)$$

~0 for, e.g., Ti isotopes

Monopole term (volume)

$R = 1.2A^{1/3}$ or from other theory

$\beta_2^2 \sim \langle Q^2 \rangle$

Liquid Drop Representation of Shape

$$\langle r^2 \rangle = \langle r^2 \rangle_{sph} + \langle r^2 \rangle_Q$$

$$= (3/5)R^2 + (4\pi / 3Z^2R^2)\langle Q^2 \rangle$$

$$\delta\langle r^2 \rangle = \delta\langle r^2 \rangle_{sph} + \delta\langle r^2 \rangle_Q$$

$$\sim \delta\langle r^2 \rangle_{sph} + (4\pi / 3Z^2R^2)\delta\langle Q^2 \rangle$$

Liquid Drop Representation of Shape

Measurable

Measurable

$$\langle r^2 \rangle = \langle r^2 \rangle_{sph} + \langle r^2 \rangle_Q$$

$$= (3/5)R^2 + (4\pi / 3Z^2R^2)\langle Q^2 \rangle$$

Measurable

Measurable

$$\delta\langle r^2 \rangle = \delta\langle r^2 \rangle_{sph} + \delta\langle r^2 \rangle_Q$$

$$\sim \delta\langle r^2 \rangle_{sph} + (4\pi / 3Z^2R^2)\delta\langle Q^2 \rangle$$

Ground-State Deformation <Q^2>

Couple E2 operators to a frame-invariant quantity

$$\{E2 \times E2\}^0 = \frac{1}{\sqrt{5}} Q^2$$

Ground State

$$\langle s | \{E2 \times E2\}^0 | s \rangle = \frac{1}{\sqrt{2s+1}} \langle s \| \{E2 \times E2\}^0 \| s \rangle$$

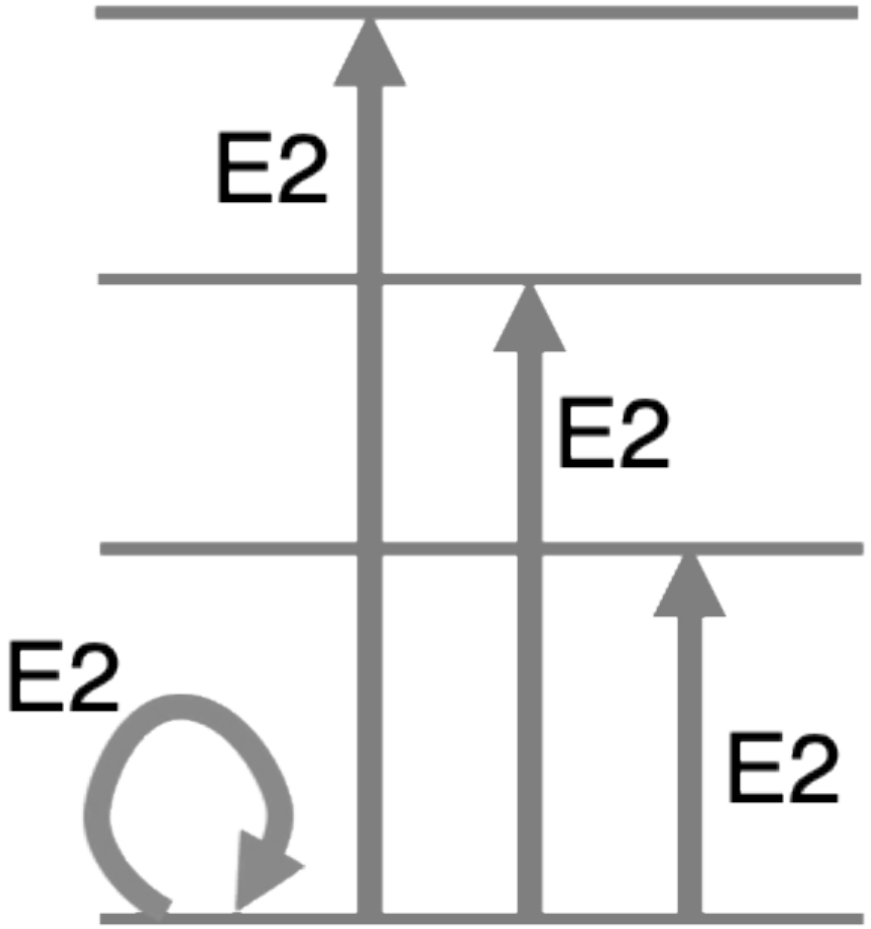
$$= \frac{1}{\sqrt{2s+1}} (-1)^{2s} \sum_r \langle s \| E2 \| r \rangle \langle r \| E2 \| s \rangle \begin{Bmatrix} 2 & 2 & 0 \\ s & s & r \end{Bmatrix},$$

Sum over intermediate states

K. Kumar, Phys. Rev. Lett. **28**, 249 (1972); D. Cline, Ann. Rev. Nucl. Part. Sci. **36**, 683 (1986).

Ground-State Deformation $\langle Q^2 \rangle$

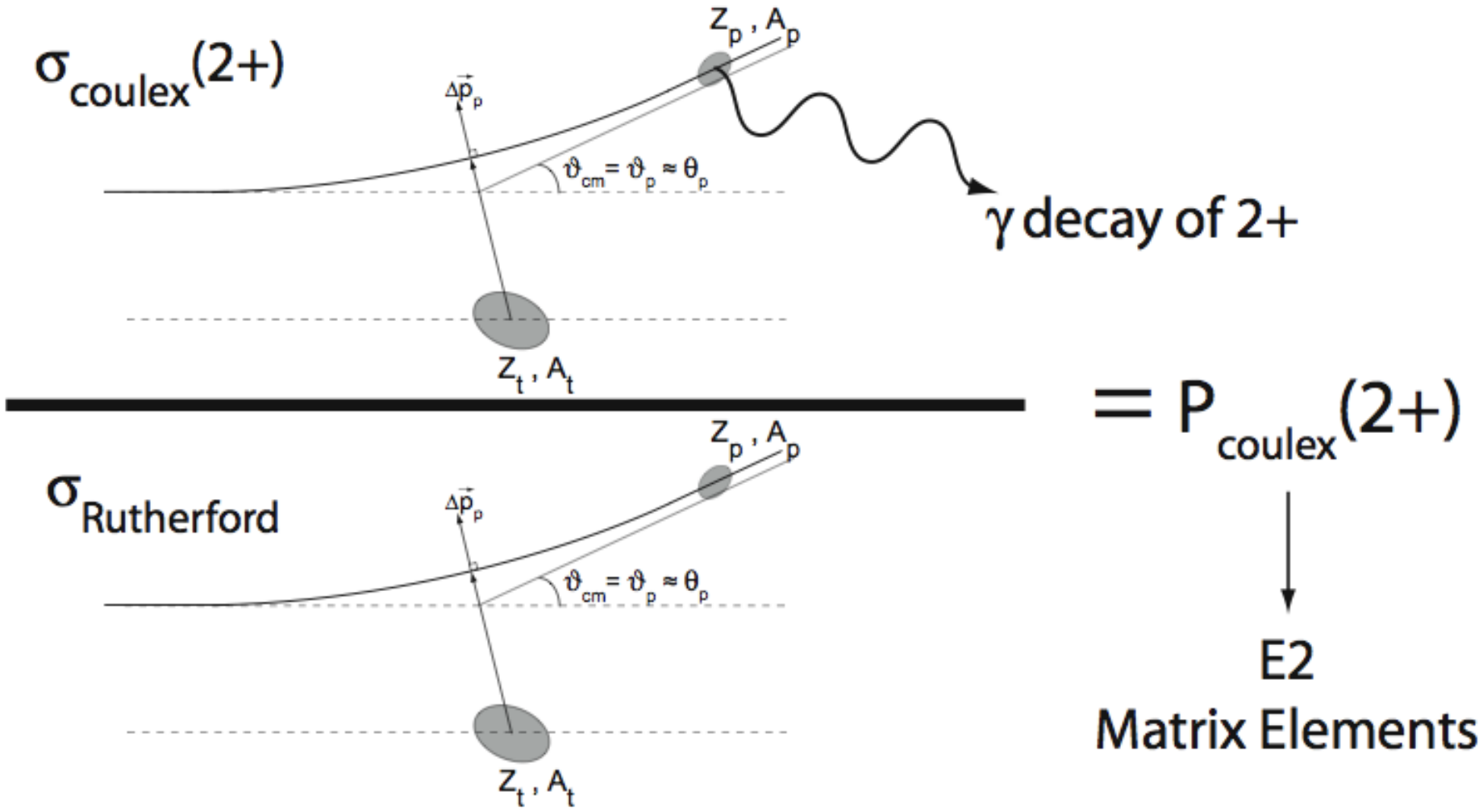
Essentially the B(E2) sum, with addition of **ground-state moment** term if spin is non-zero



K. Kumar, Phys. Rev. Lett. **28**, 249 (1972); D. Cline, Ann. Rev. Nucl. Part. Sci. **36**, 683 (1986).

Coulomb Excitation – E2 Moments

Coulomb excitation cross sections or probabilities let us determine E2 M.E.s and B(E2)s.



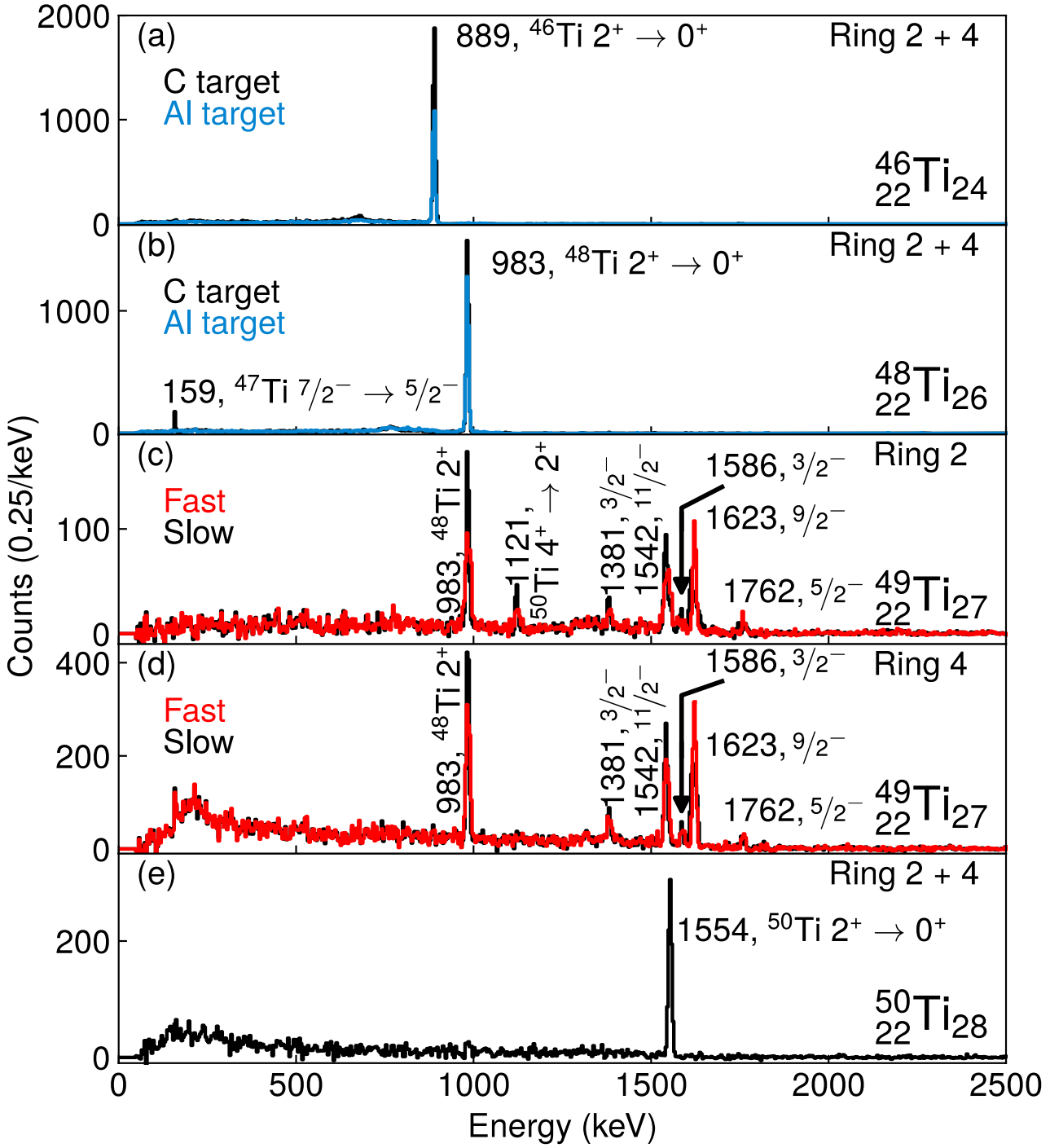
Single-Step Coulomb Excitation of ^{46,48,49,50}Ti

Measurements for B(E2):

- Particle-Gamma / Particle
- Absolute Gamma efficiency
- Beam composition
- Stopping powers

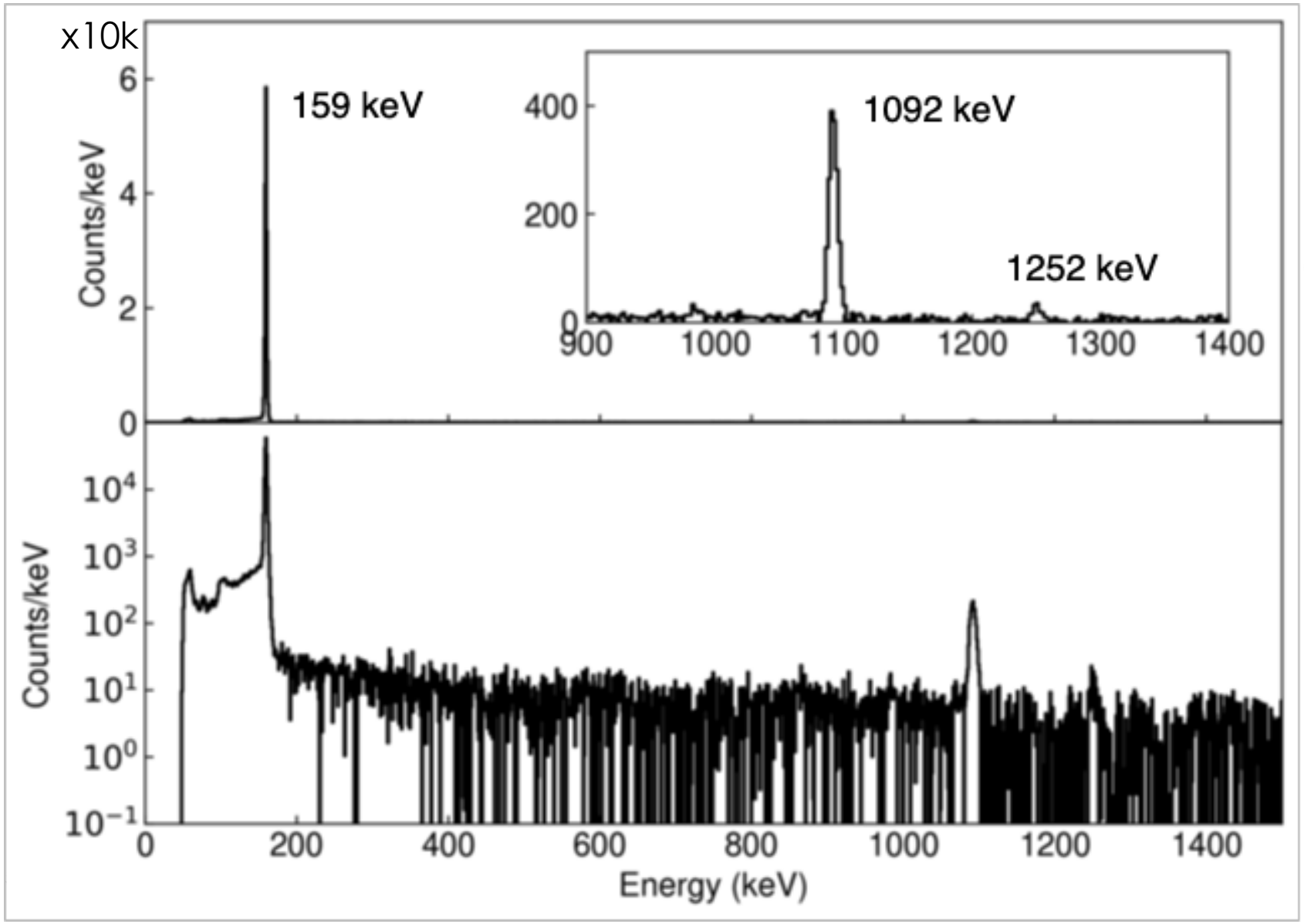
Tim Gray

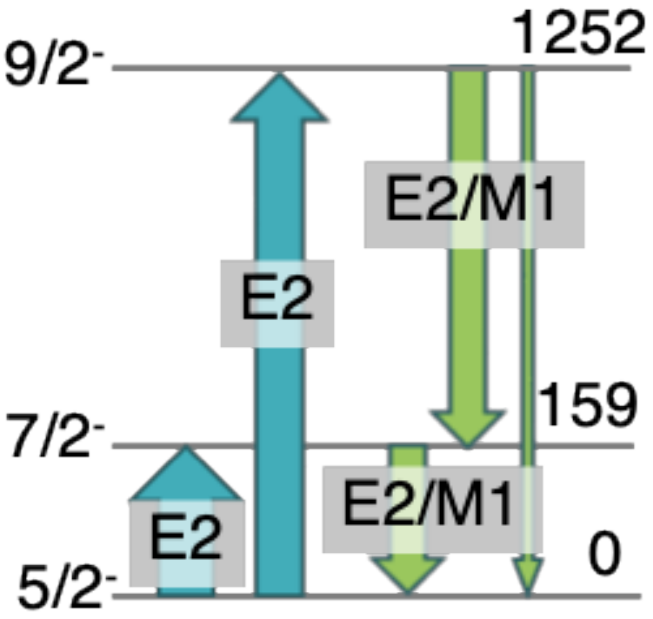
T.J. Gray *et al.*, PLB **855**, 138856 (2024)
w/ some calculations by Angela and Takayuki!



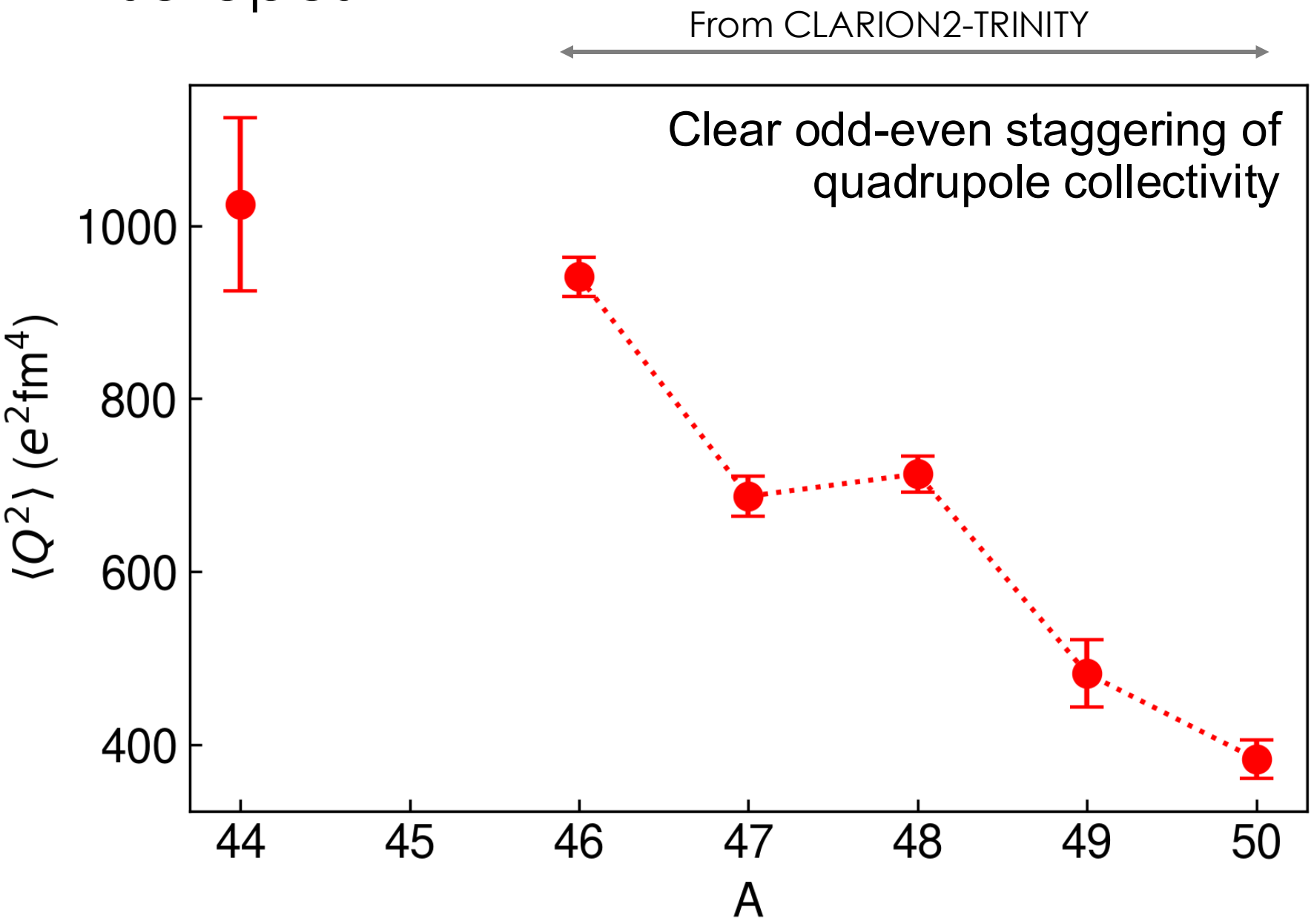
Finish the Ti Chain with Addition of ^{47}Ti

From Summer 2024 with all 5 Rings of TRINITY

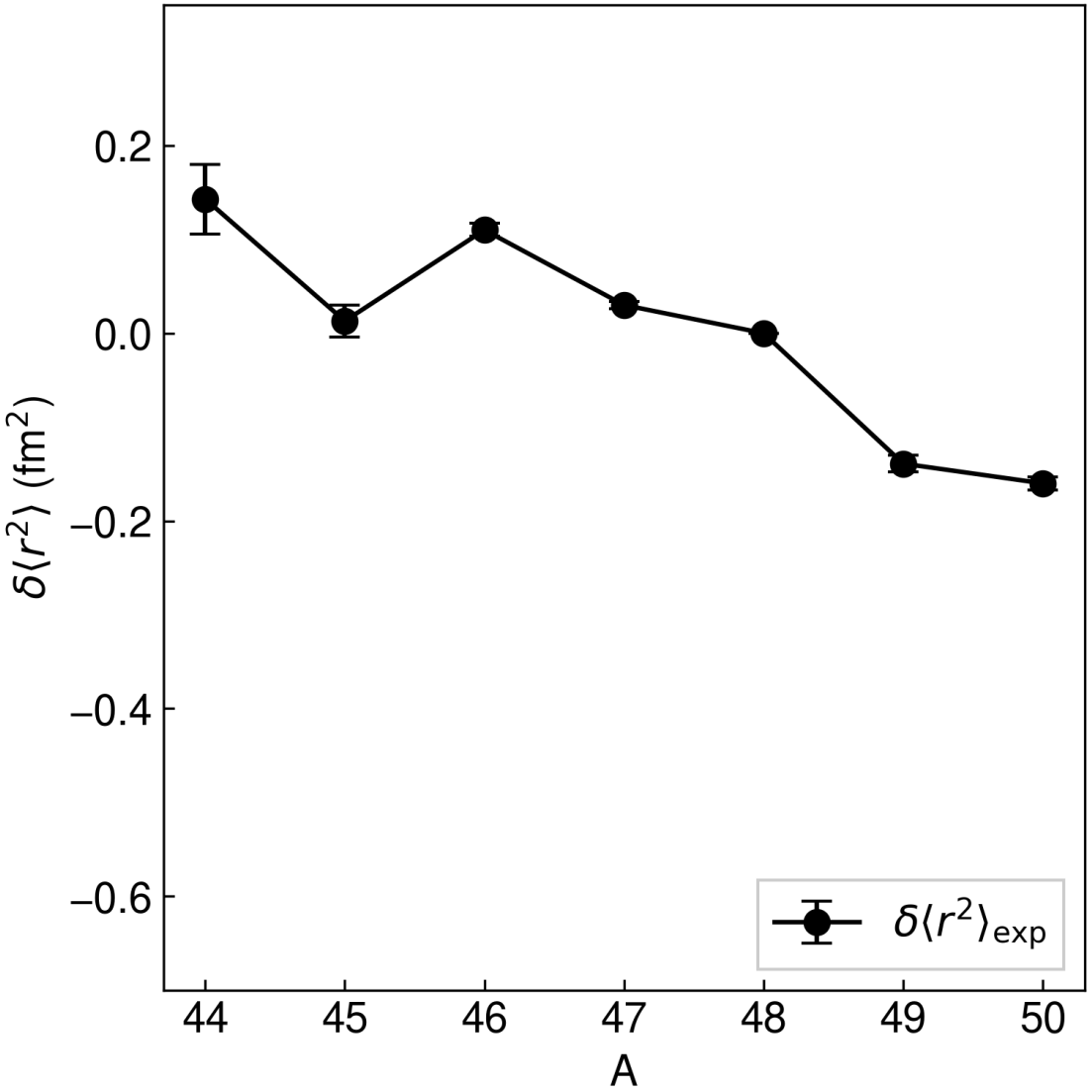


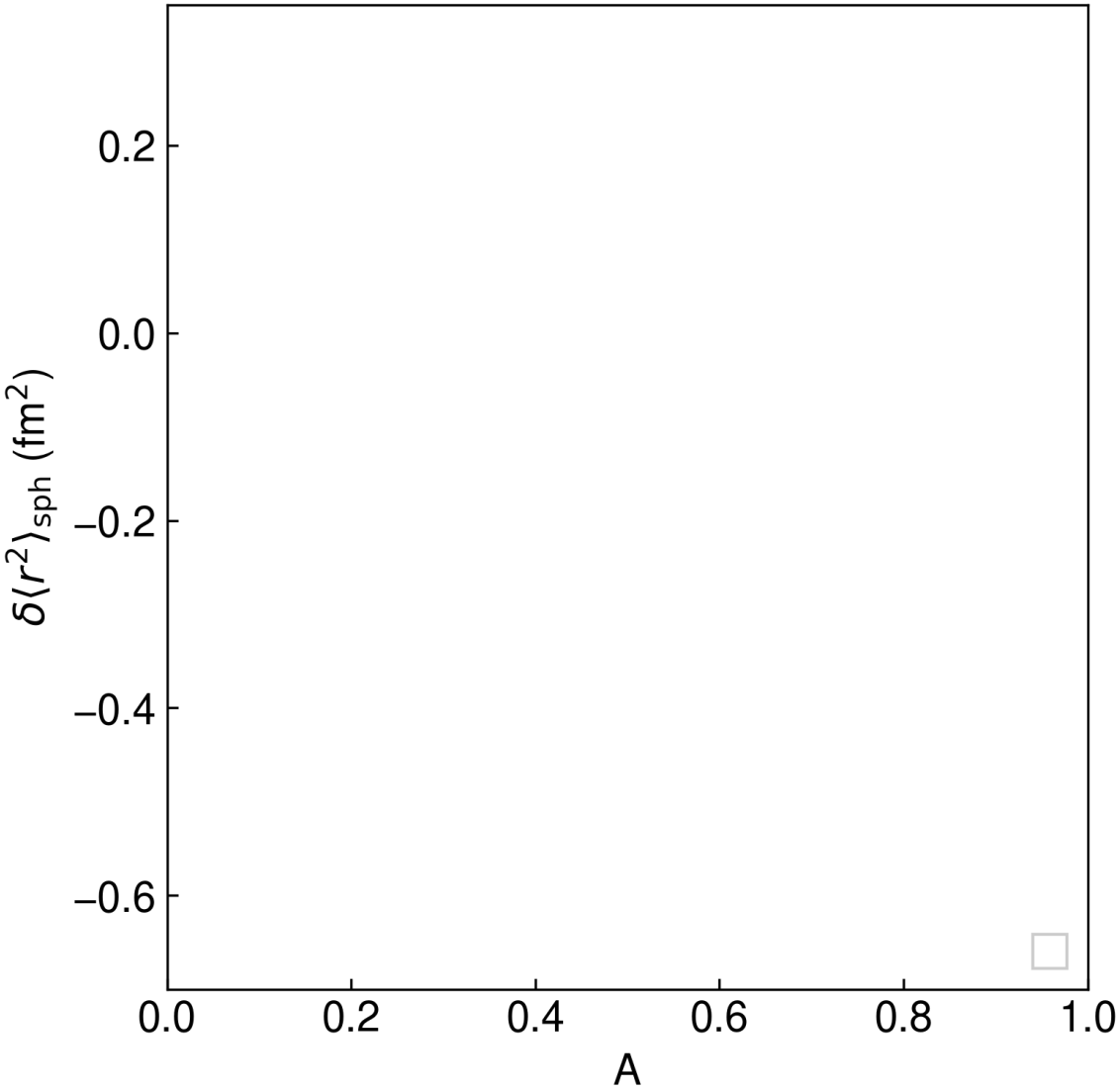


<Q^2> of Ti Isotopes



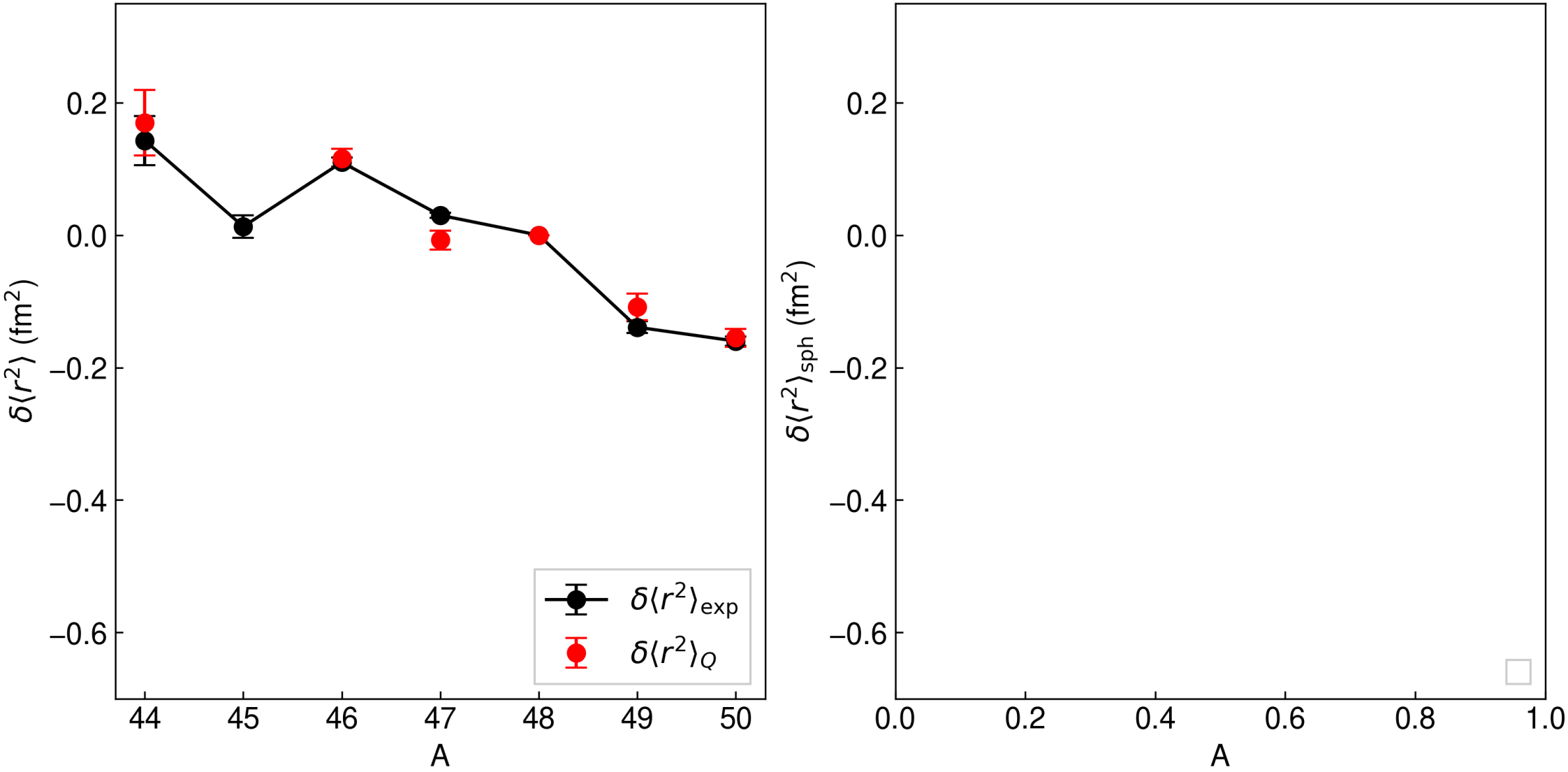
Ti Isotope Shifts → Differences in $\langle r^2 \rangle$





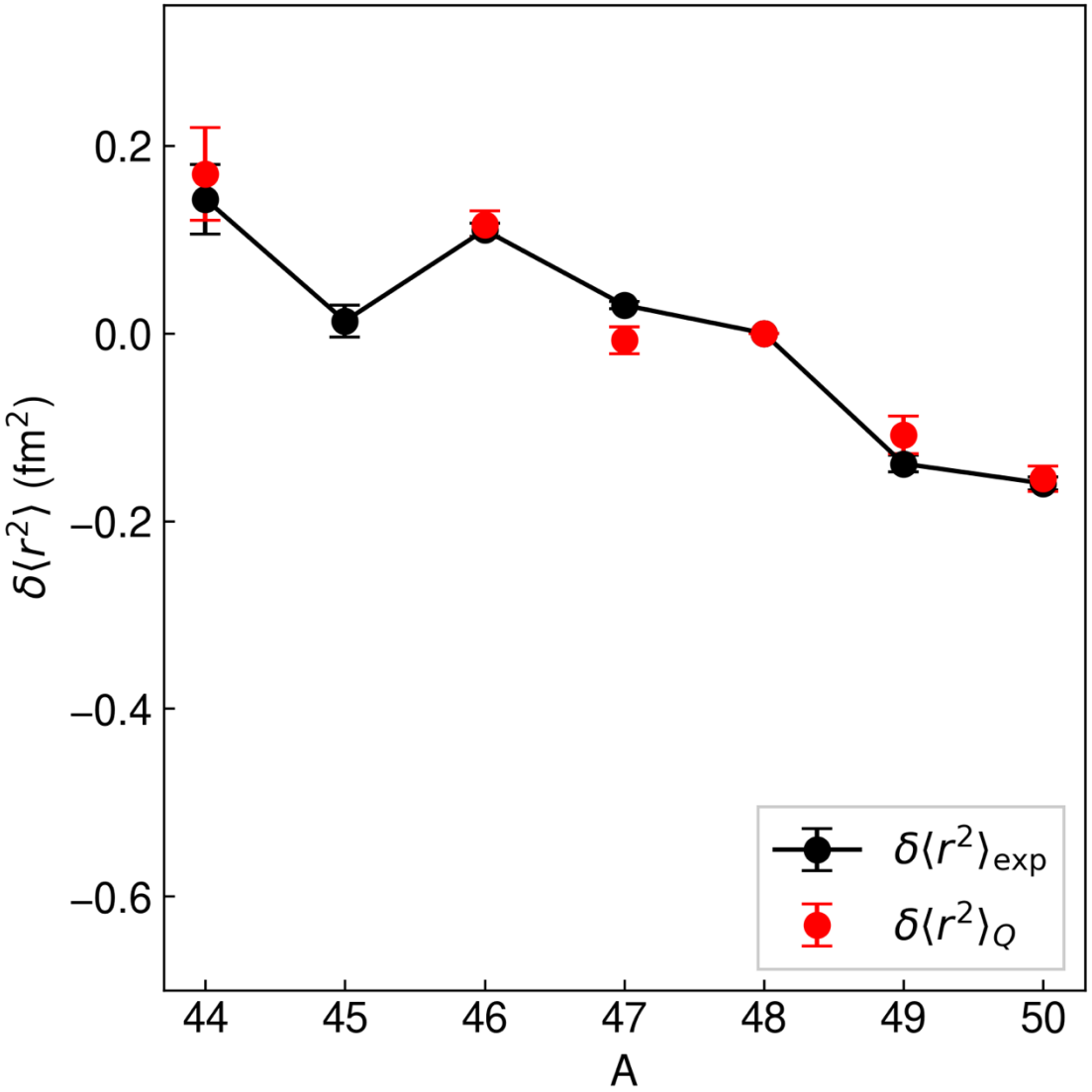
[Atomic Data and Nuclear Data Tables 99 (2013) 69–95] [Phys. Rev. C **102**, 054302]

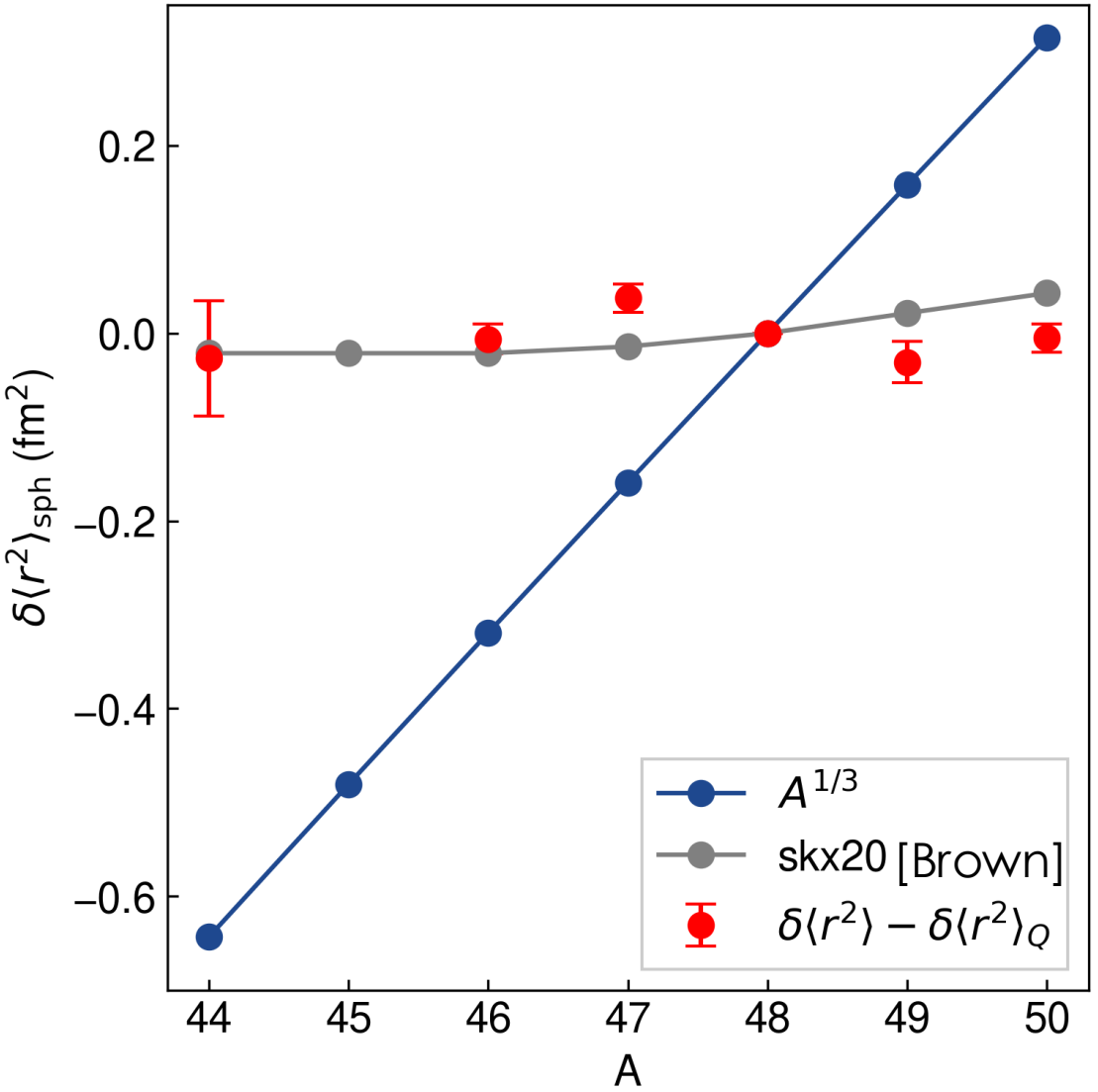
Ti Isotope Shifts → Differences in $\langle r^2 \rangle$



[Atomic Data and Nuclear Data Tables 99 (2013) 69–95] [Phys. Rev. C **102**, 054302]

Ti Isotope Shifts → Differences in <r^2>

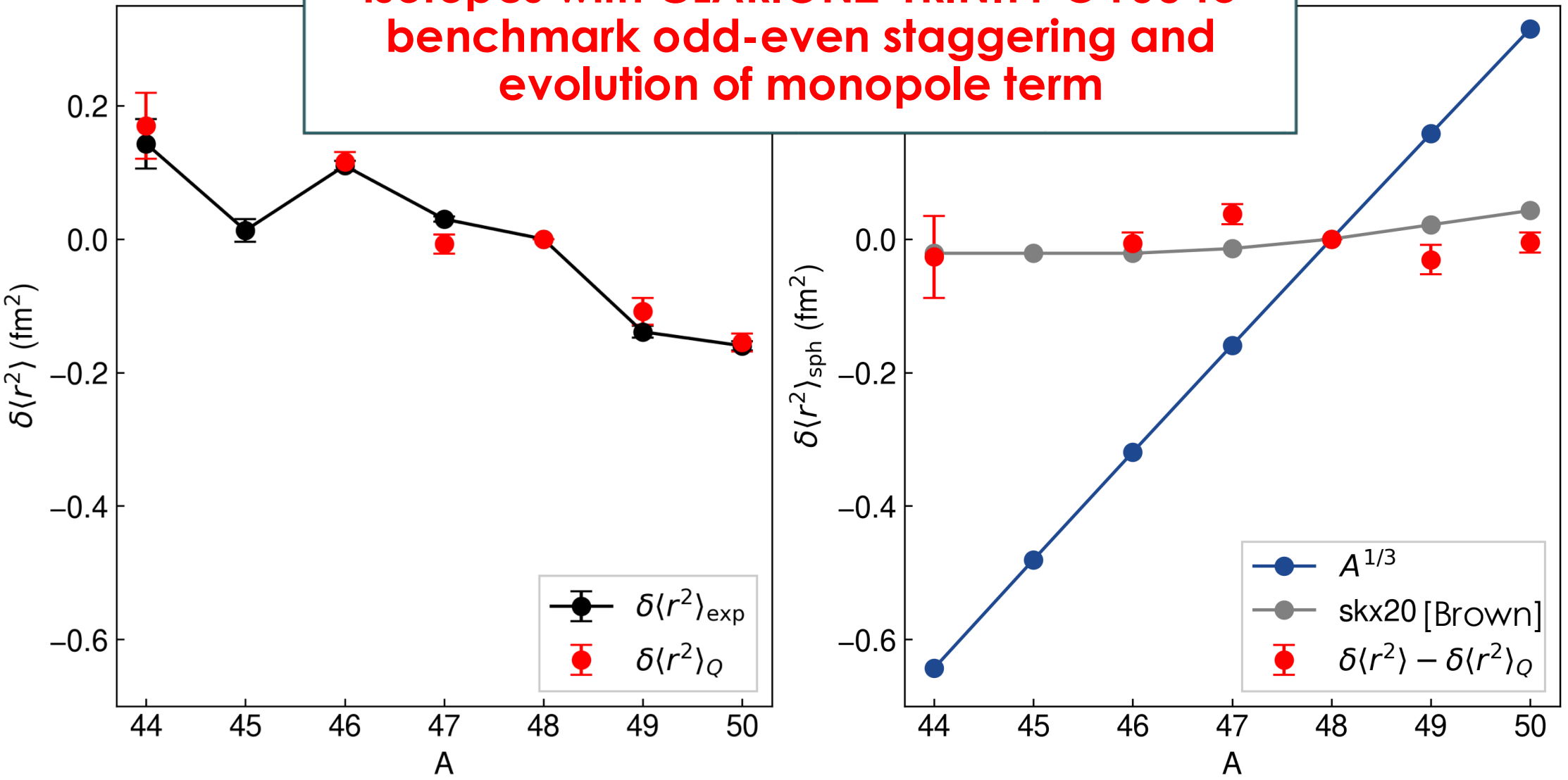




[Atomic Data and Nuclear Data Tables 99 (2013) 69–95] [Phys. Rev. C **102**, 054302]

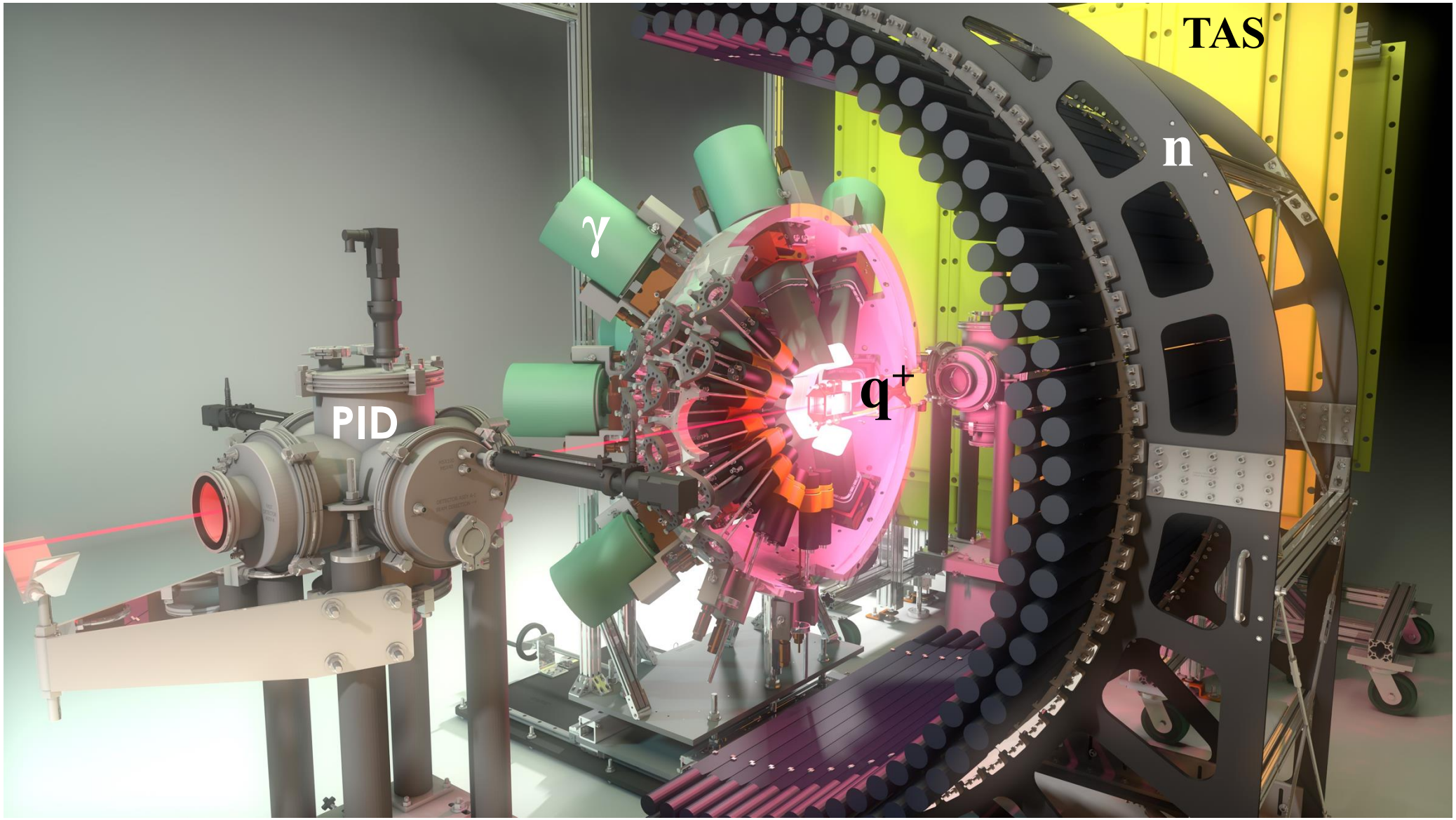
Ti Isotope Shift

Will measure all stable Ca, Cr, Fe, Ni isotopes with CLARION2-TRINITY @ FSU to benchmark odd-even staggering and evolution of monopole term



[Atomic Data and Nuclear Data Tables 99 (2013) 69–95] [Phys. Rev. C **102**, 054302]

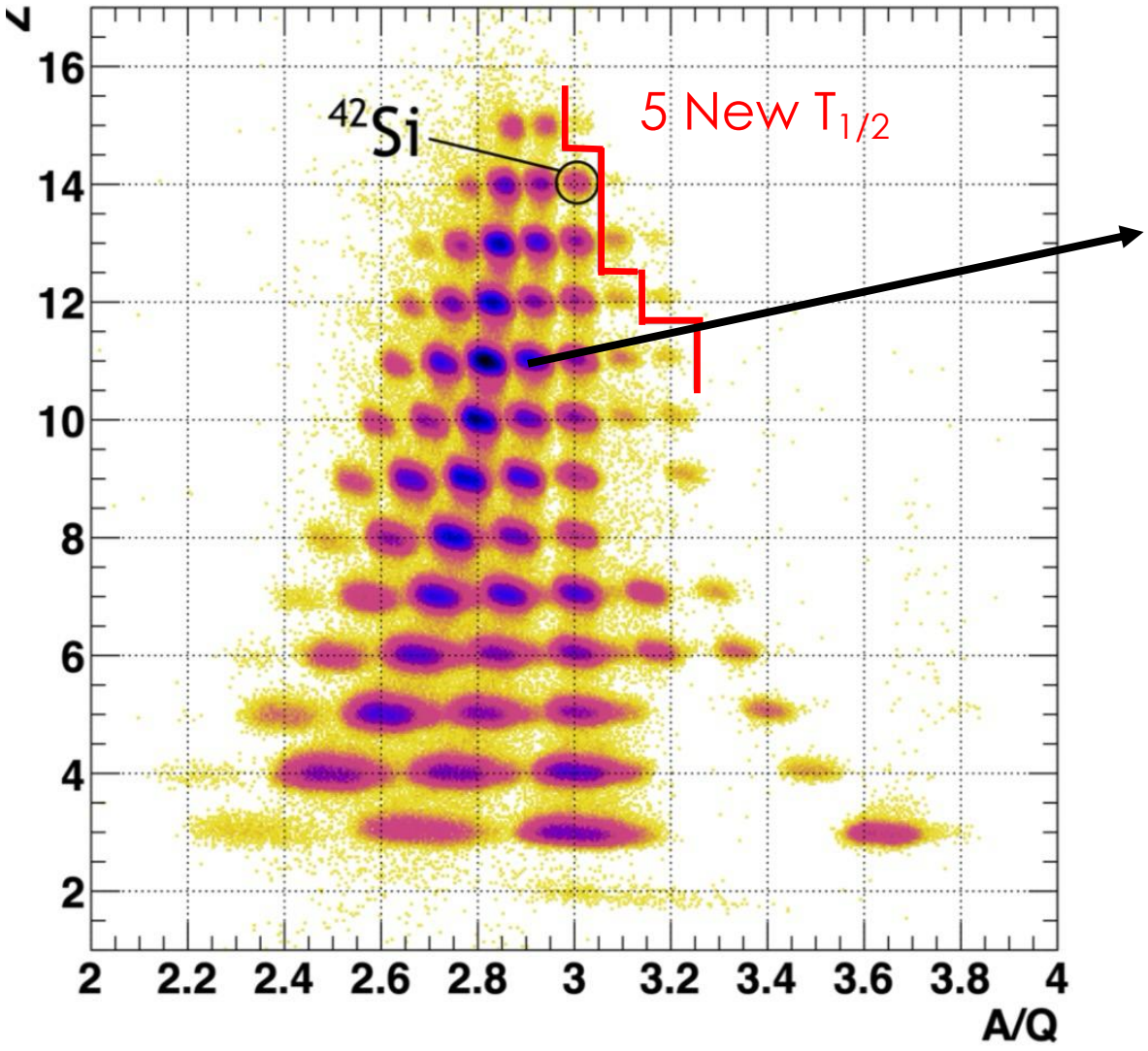
FDSi @ FRIB



Exotic N=20-28 Region

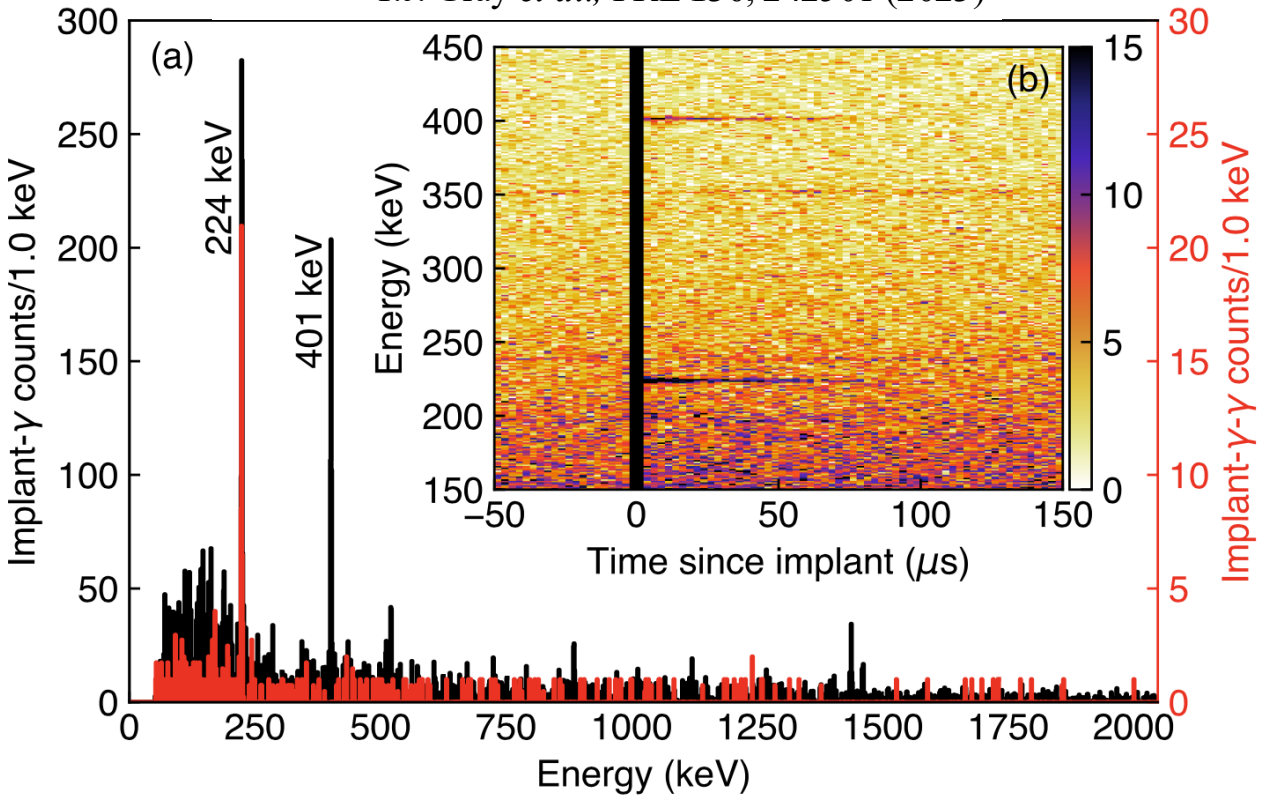
PI = Heather Crawford (LBNL)

H.L Crawford *et al.*, PRL **129**, 212501 (2022)



New Beam Isomer in ^{32}Na

T.J. Gray *et al.*, PRL **130**, 242501 (2023)



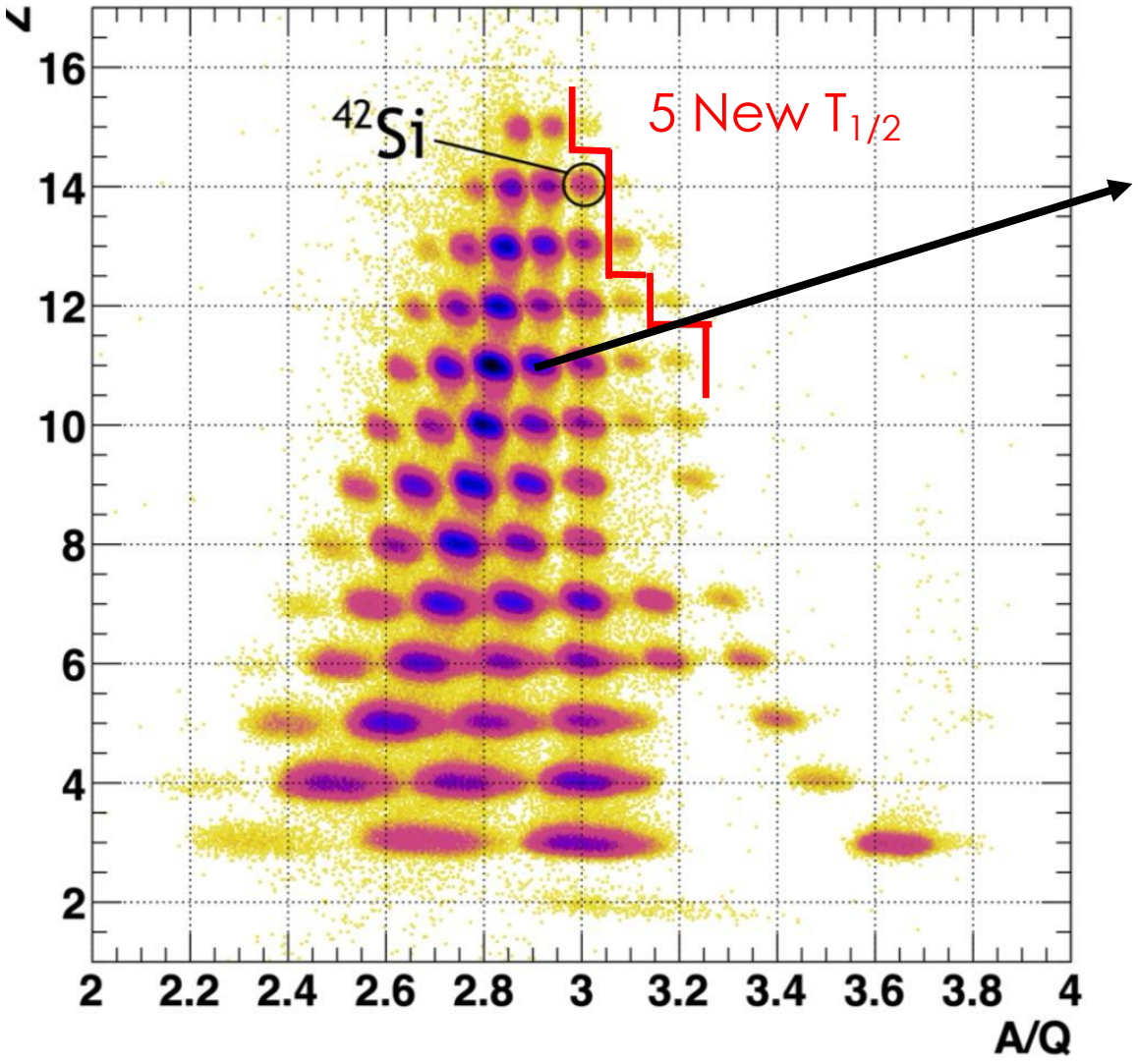
delayed gamma singles

gammas gated on 401 keV

Exotic N=20-28 Region

PI = Heather Crawford (LBNL)

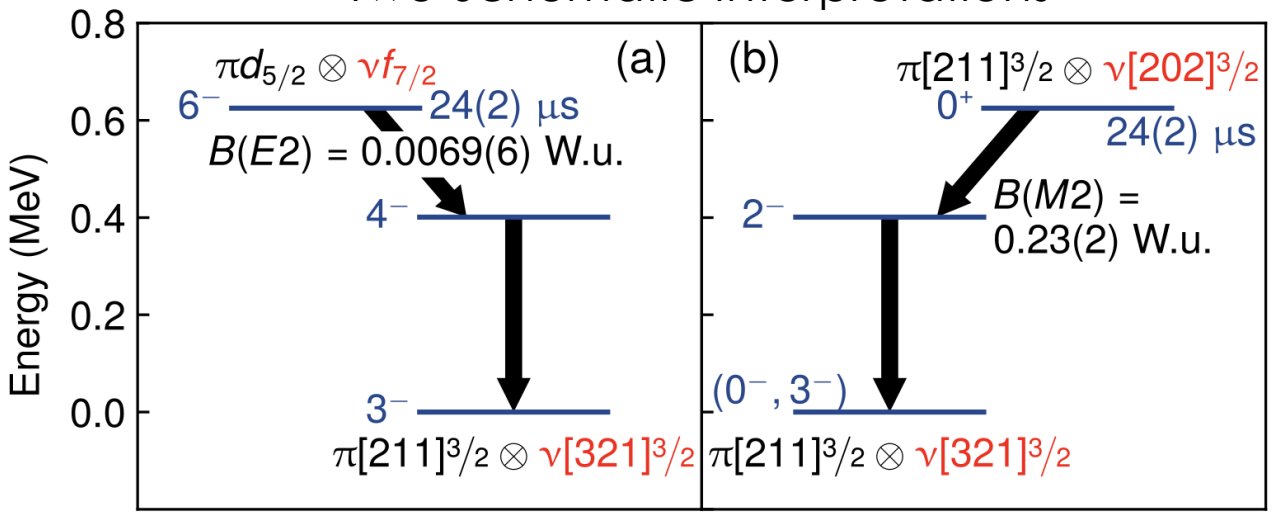
H.L Crawford *et al.*, PRL **129**, 212501 (2022)



New Beam Isomer in ^{32}Na

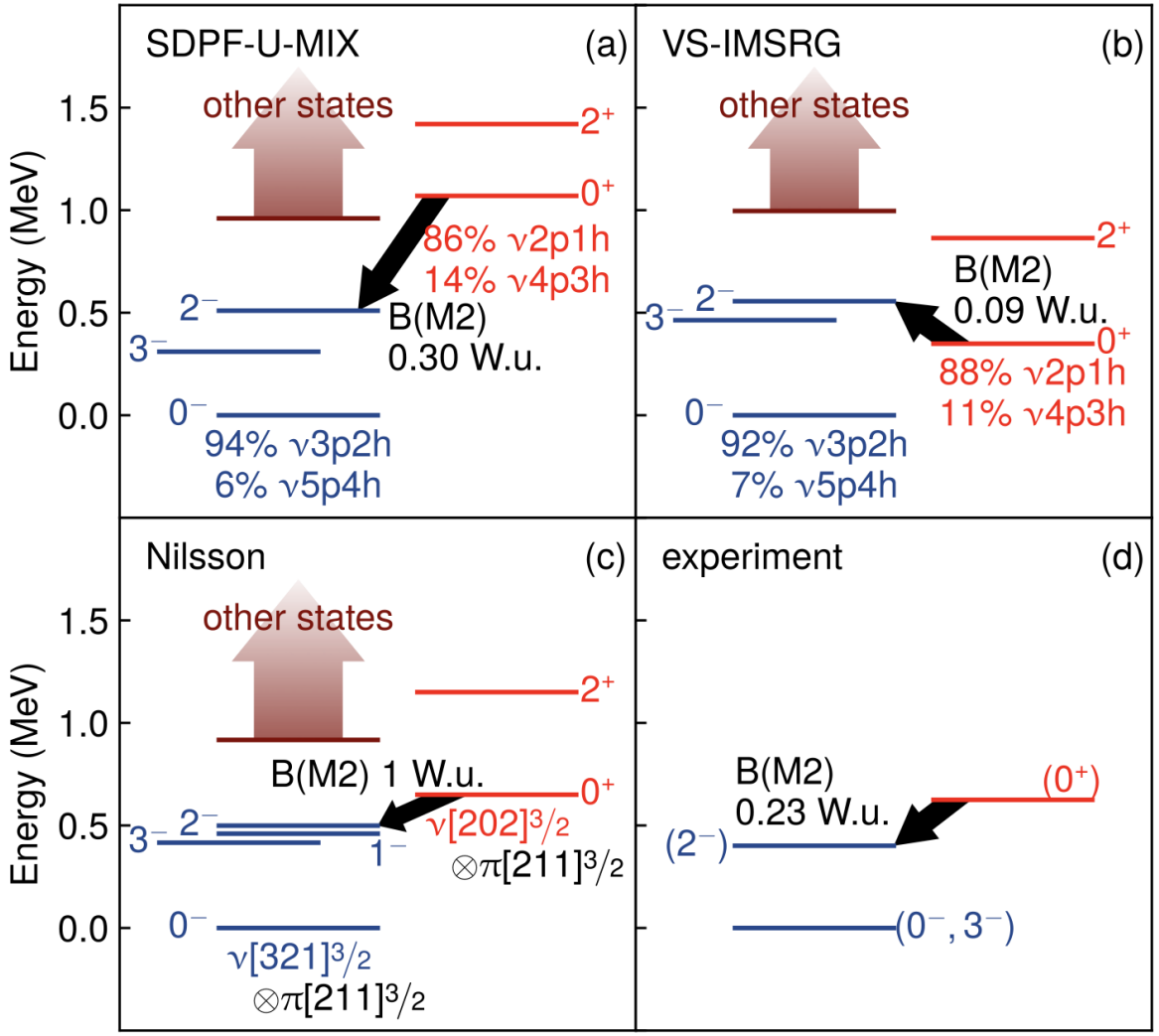
T.J. Gray *et al.*, PRL **130**, 242501 (2023)

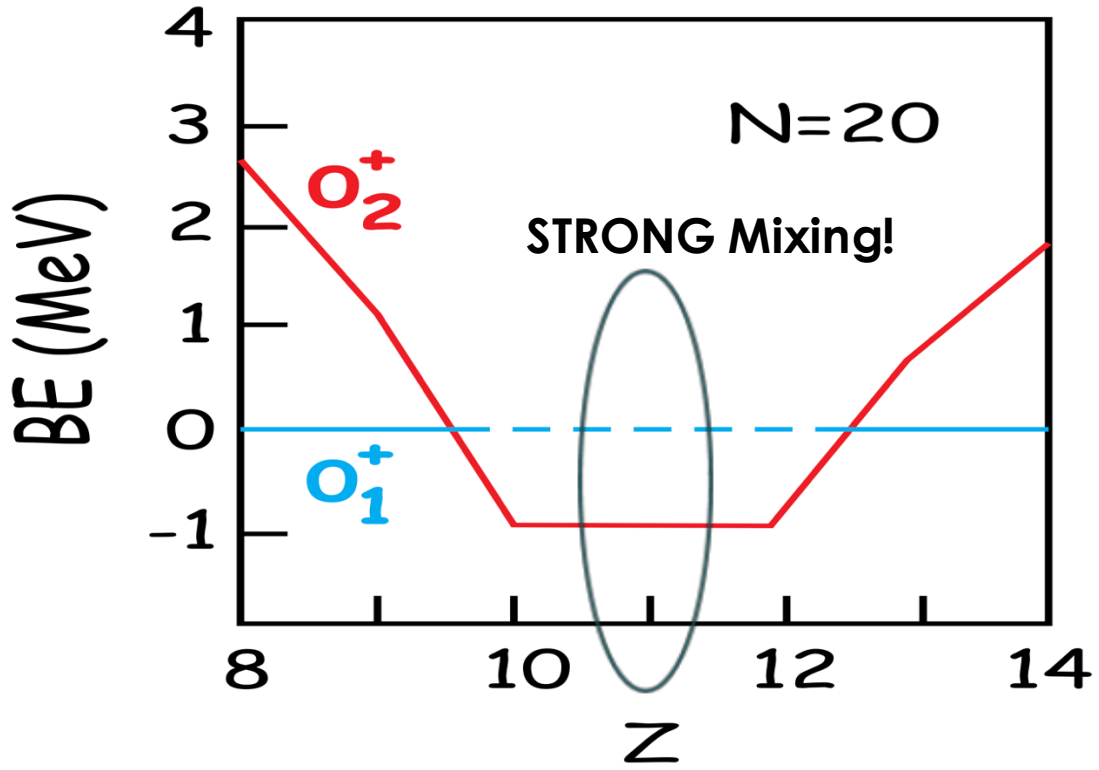
Two Schematic Interpretations



Spherical-Deformed or Deformed-Deformed

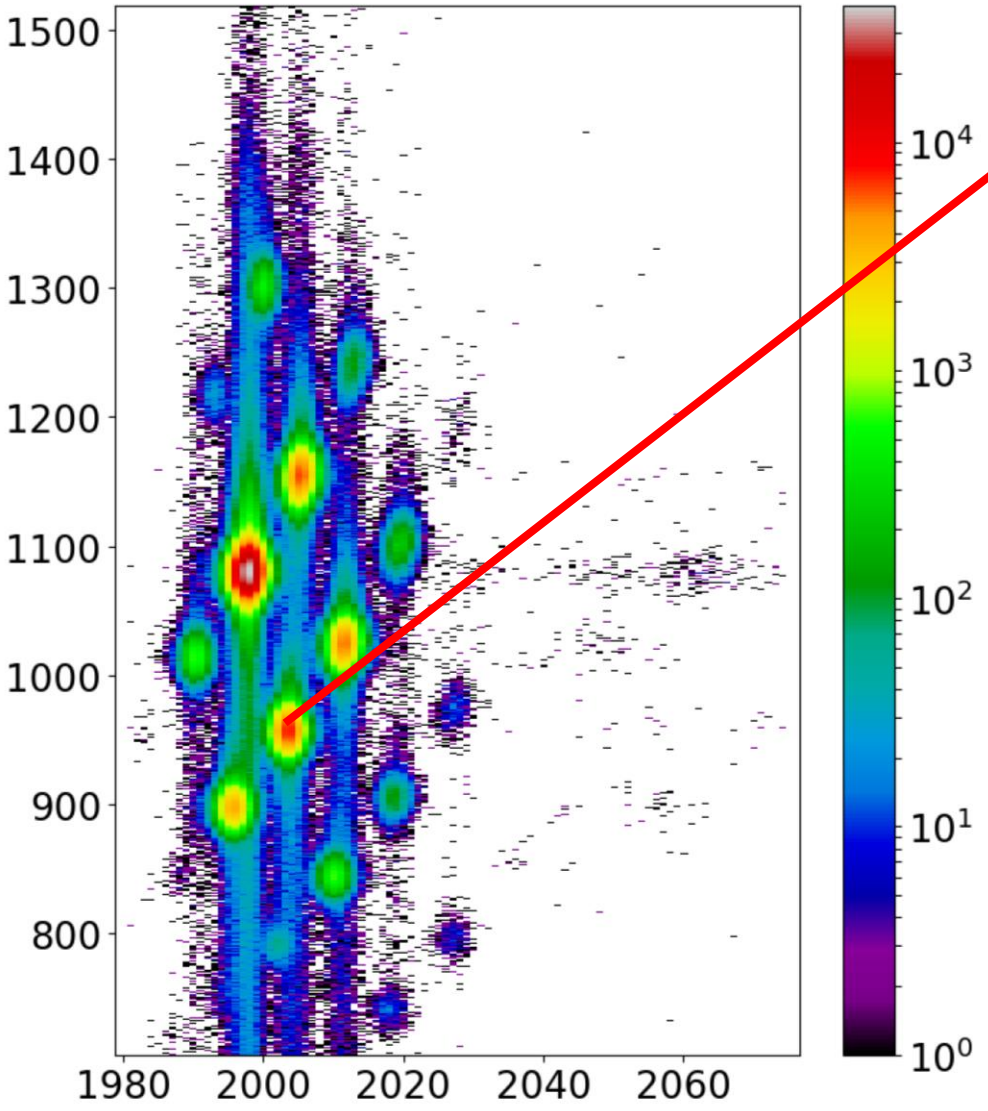
Theory on ^{32}Na Consistent with Deformed Spin/K Isomer

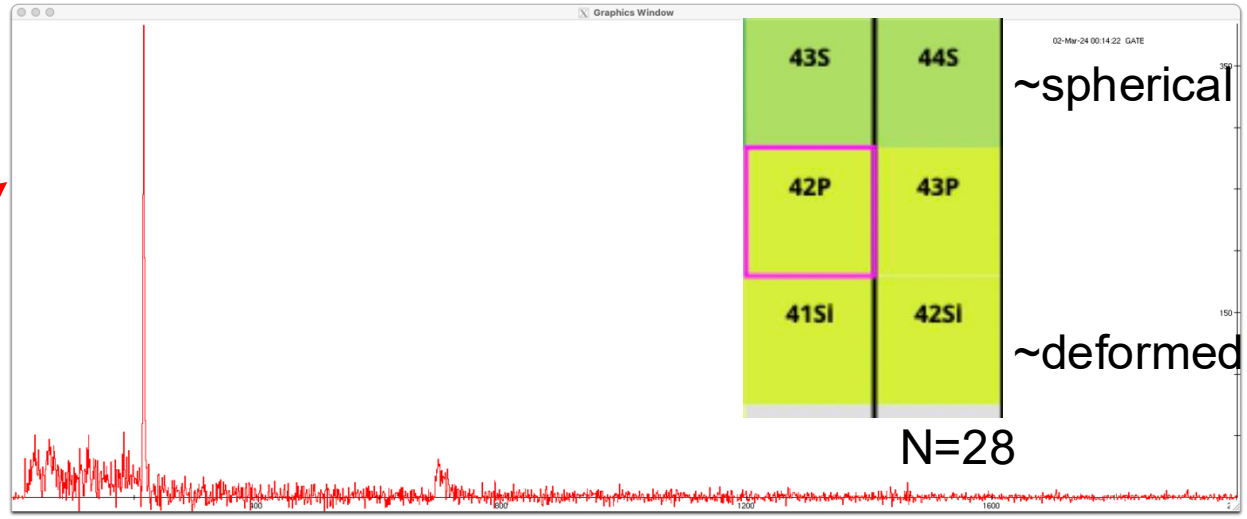




T.J. Gray *et al.*, PRL **130**, 242501 (2023)
w/ some calculations by Alfredo and Takayuki!

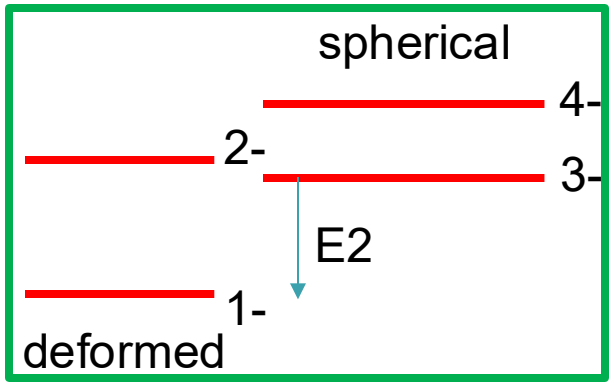
New μs Isomer at N=28 Shape Crossing – $^{42}P_{27}$

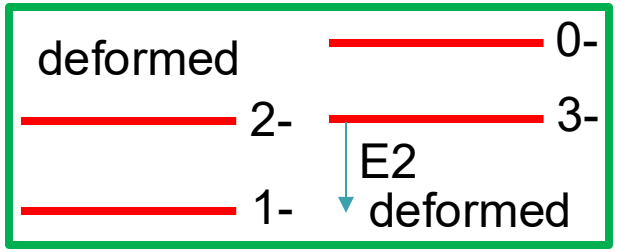


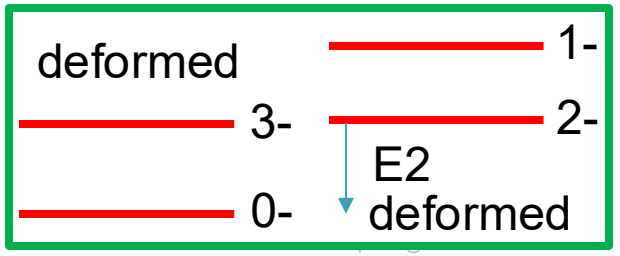


Schematic Scenarios

- Need Calculations!
- Strong Shape mixing like N=20 region?

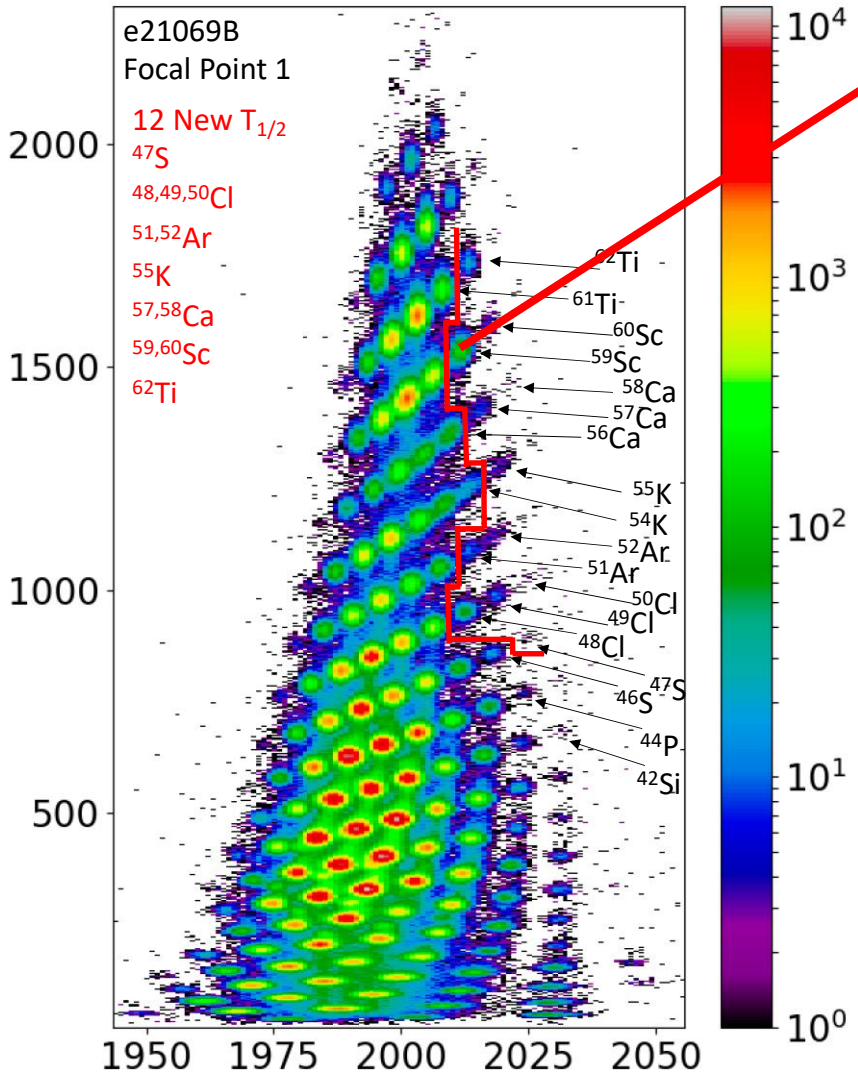




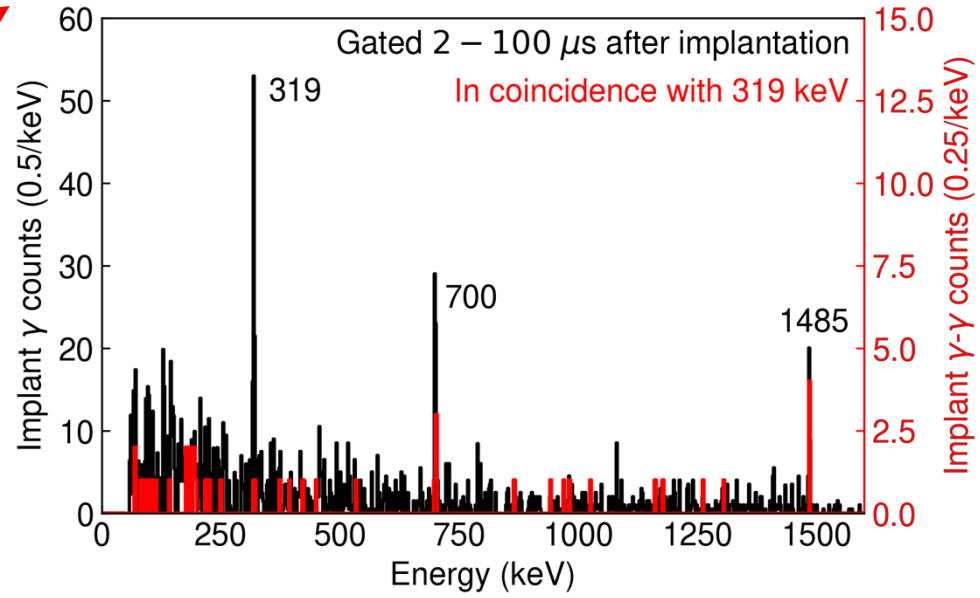


Exotic Ca Region

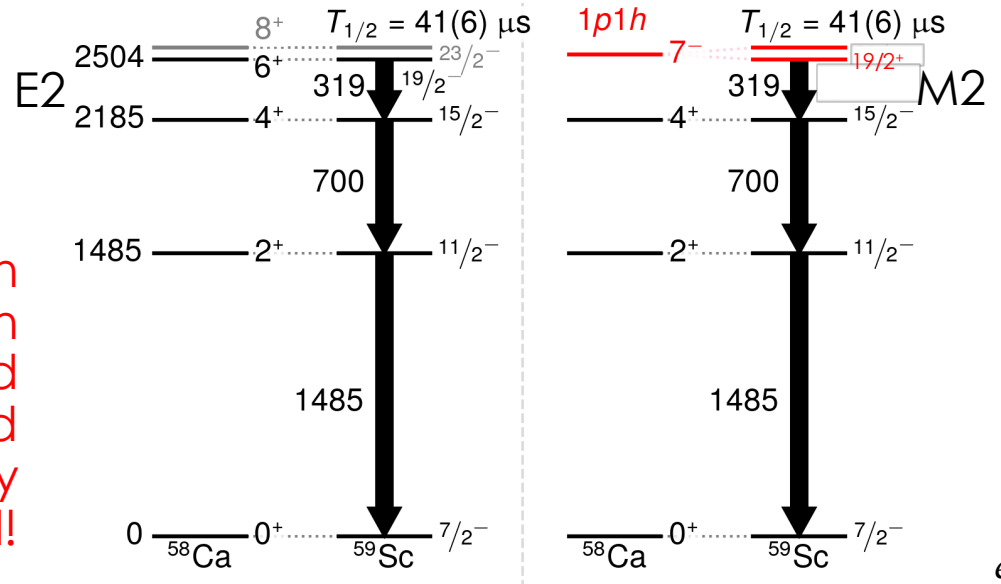
PI = Wei Jia Ong (LLNL)



New Beam Isomer in $^{59}Sc_{38}$



$\nu g_{9/2}$ seniority isomer OR $\nu g_{9/2}$ 1p-1h isomer

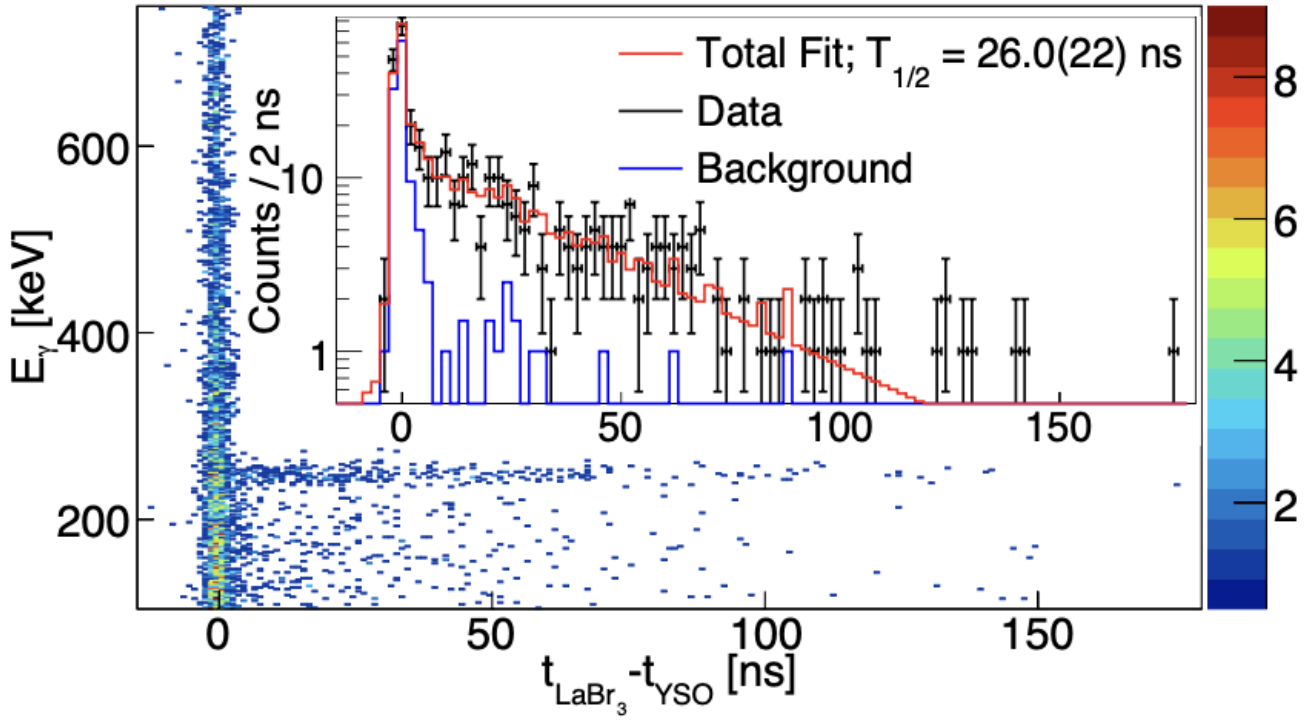


Theory in progress with 1p-1h and weakened N=40 currently favored!

T.J. Gray *et al., in prep*

B(E2;$1^+ \rightarrow 3^+$) in ^{54}Sc and Universal sd + fp Effective Charges

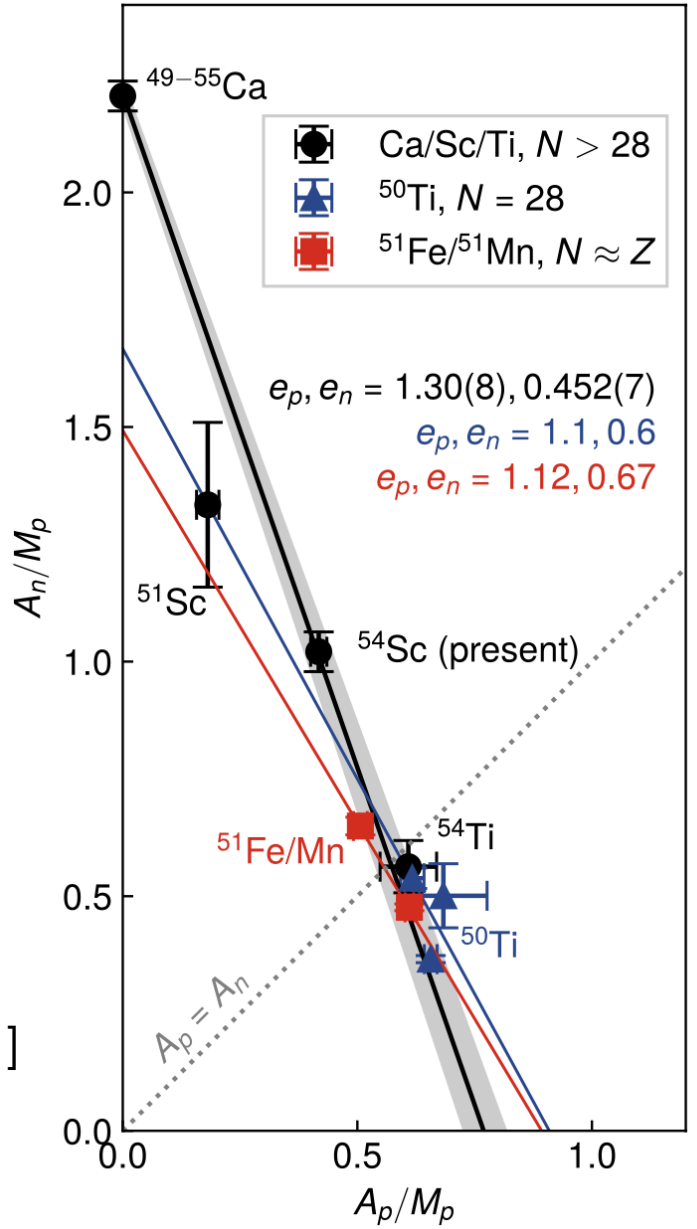
$\pi f_{7/2} \otimes \nu f_{5/2} \rightarrow \pi f_{7/2} \otimes \nu p_{1/2}$ = **$\nu f_{5/2} \rightarrow \nu p_{1/2}$ in weak coupling limit**



"No evidence for changes in the effective charges due to an isospin or orbital dependence is found."

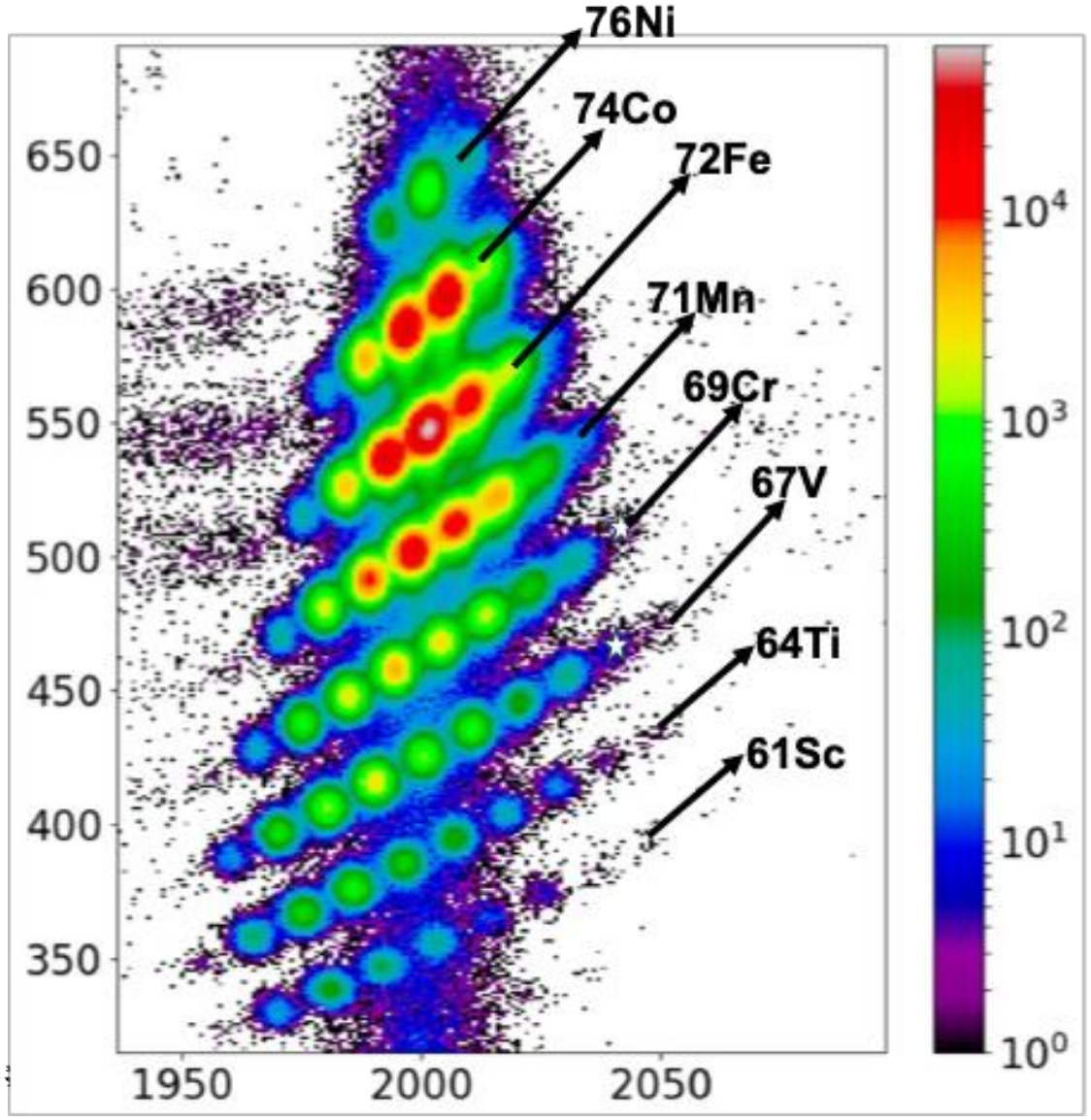
fp shell charges = 1.30(8), 0.452(7) [present]
sd shell charges = 1.36(5), 0.45(5) [PRC **78**, 064302 (2008)]
Microscopic Thy = 1.31 , 0.46 [PRC **54**, 1641 (1996)]

T.H. Ogunbeku *et al.*,
Submitted to PRL (2025), w/ some calculations by Angela, Takayuki, and Alex

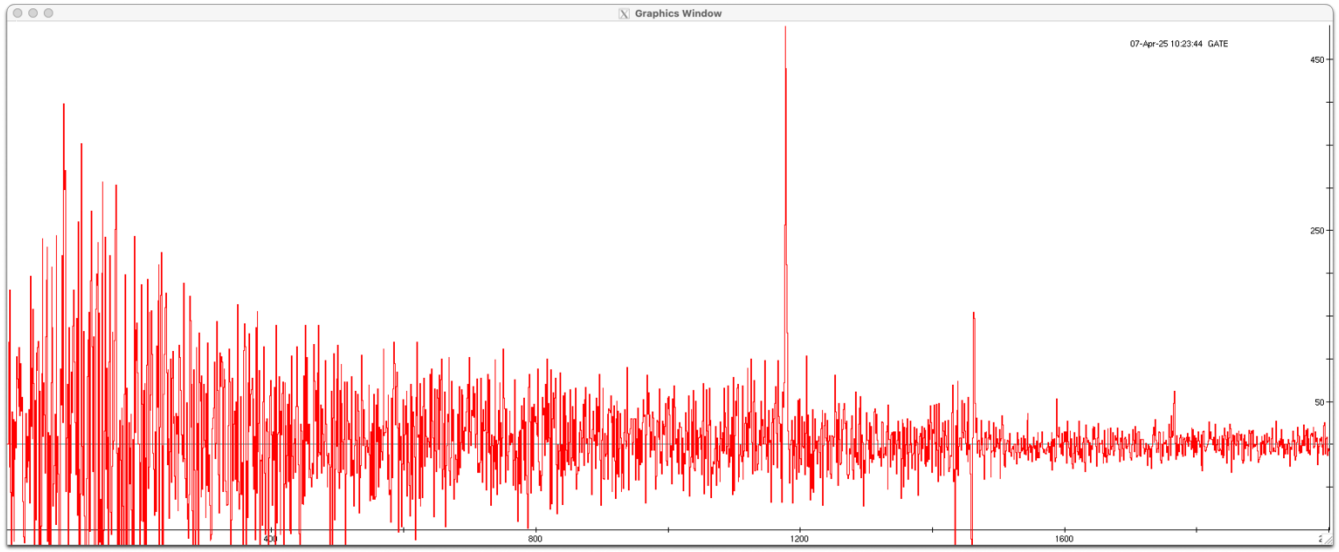


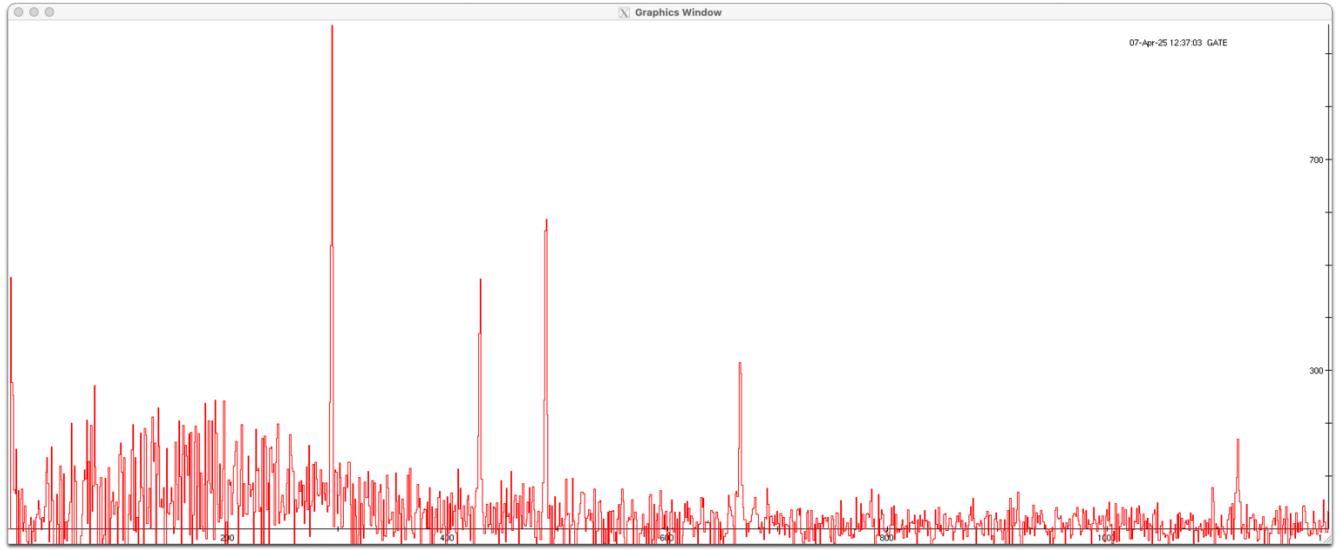
Exotic N=40 Region

PI = Ben Crider – Miss. State



New Beam Isomers from March 2025 Experiment!





D. Scriven
et al., in prep

Thank you

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with the U.S. Department of Energy