Nuclear Physics at the $N = Z$ Line

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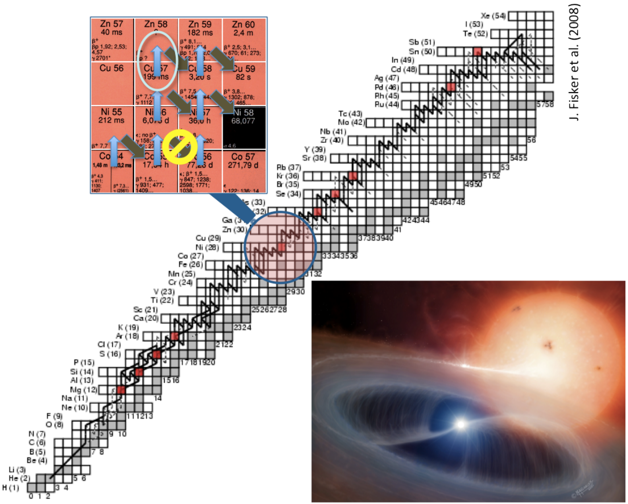
Outline

Nucleosynthesis along the $N = Z$ line

Nucleosynthesis in X-ray bursts

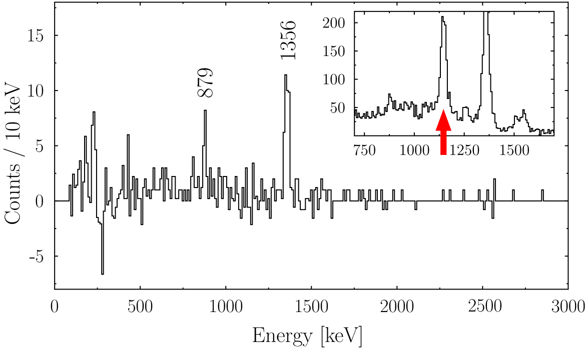
Analysis of X-ray burst light curves needs nuclear physics input

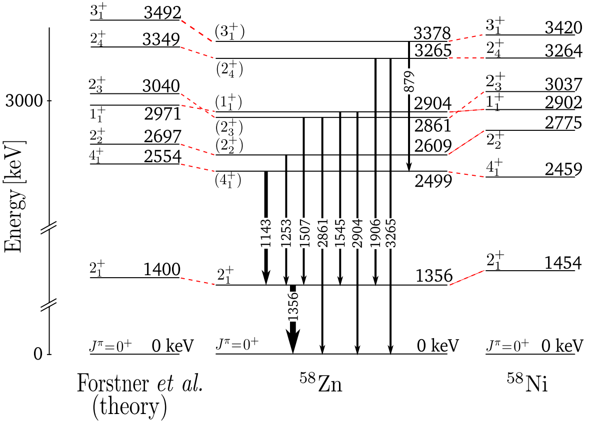
- *rp*-process nucleosynthesis slows down at waiting points
- Proton capture energetically disfavored
- Slow β^+ decay rate dictates flow
- Examples: ^{56}Ni, ^{64}Ge, ^{66}Se, ^{72}Kr
- Sensitivity studies show (p,γ) reaction rates very important
- Spectroscopy of excited states (often through surrogate reactions)
- Spectroscopic factors from mirrored reactions
- *Q*-values and masses are needed



Spectroscopy of ^{58}Zn

- ^{57}Cu(p,γ) reaction rate dominated by 2^+ resonances in ^{58}Zn
- First spectroscopy of ^{58}Zn





C. Langer et al., Phys. Rev. Lett. **113** (2014) 032502.

- Remaining uncertainty in the reaction rate dominated by *Q*-value

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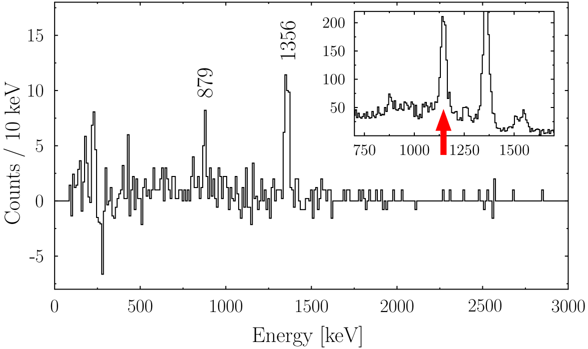
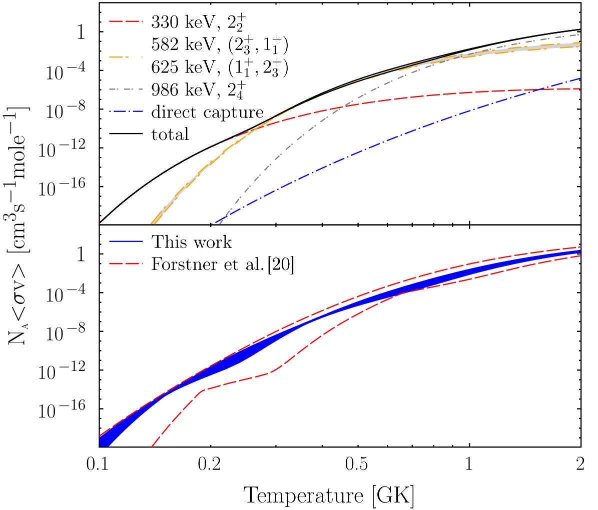




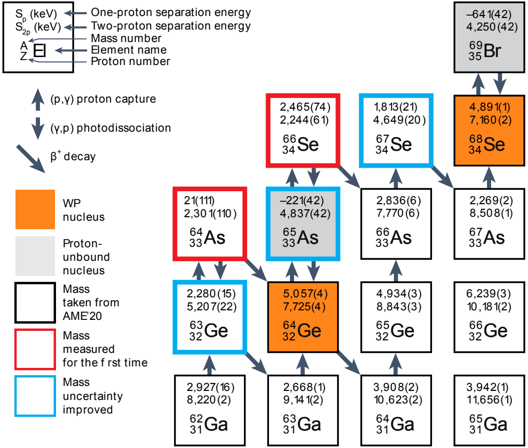
Uncertainty of reaction rate reduced by 3 orders of magnitude

C. Langer et al., Phys. Rev. Lett. **113** (2014) 032502.

- Remaining uncertainty in the reaction rate dominated by Q-value

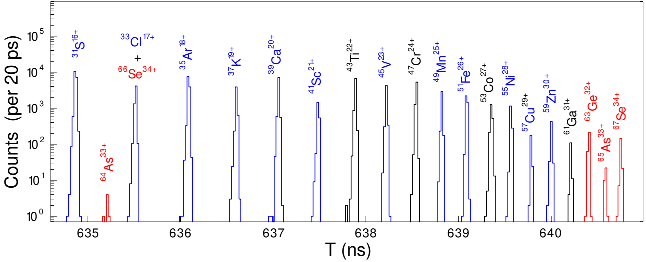
Waiting point ^{64}Ge

- Proton capture on ^{64}Ge leads to proton unbound ^{65}As

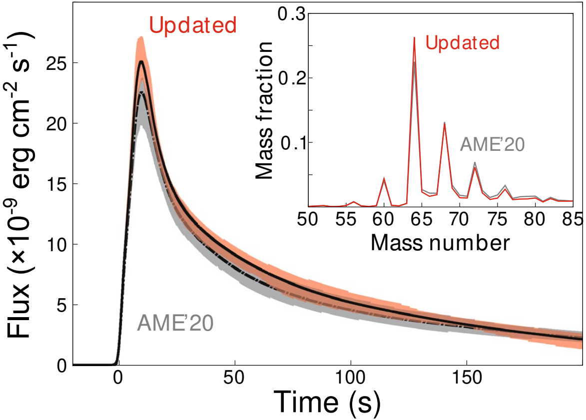


X. Zhou et al., Nature Physics **19** (2023) 1091.

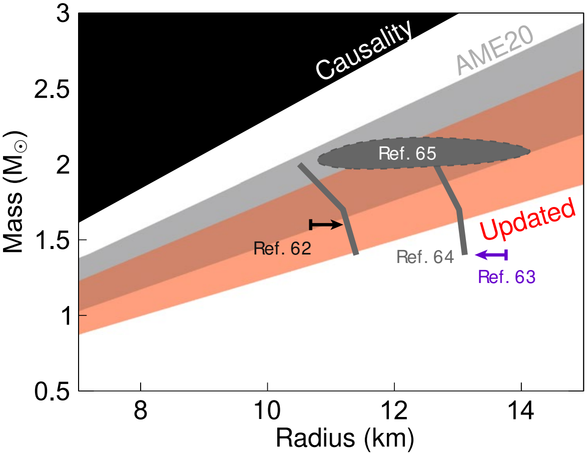
- Waiting points at ^{64}Ge ($T_{1/2} = 64$ s) and ^{66}Se ($T_{1/2} = 36$ s)
- Mass uncertainties limiting reliability for reaction rate calculation and X-ray burst light curves
- New measurements at cooler-storage ring CSR, Lanzhou
- Improved uncertainties and new values



Waiting point ^{64}Ge



- Less bound ^{65}As, stronger bound ^{66}Se stalled *rp*-process at the ^{64}Ge waiting point

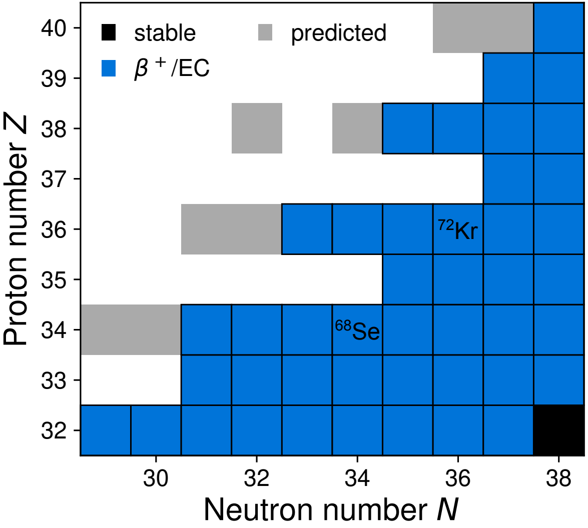


- X-ray burst luminosity allows to constrain distance and gravitational redshift $(1+z)$ of the burster

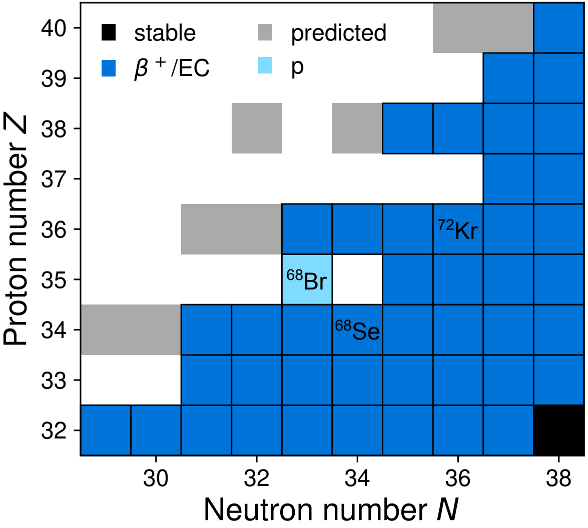
Limits on neutron-star compactness

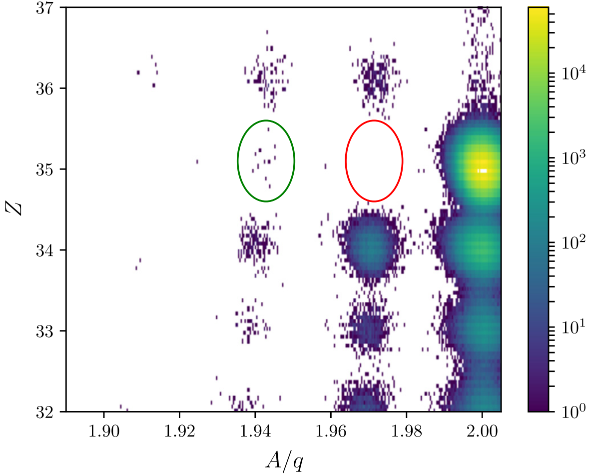
X. Zhou et al., Nature Physics **19** (2023) 1091.

Sandbanks beyond the proton drip-line



Sandbanks beyond the proton drip-line





K. Wimmer et al., Phys. Lett. B **795** (2019) 266.

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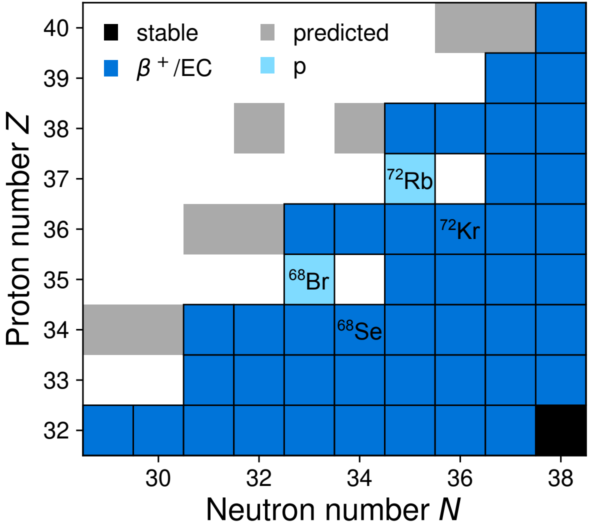
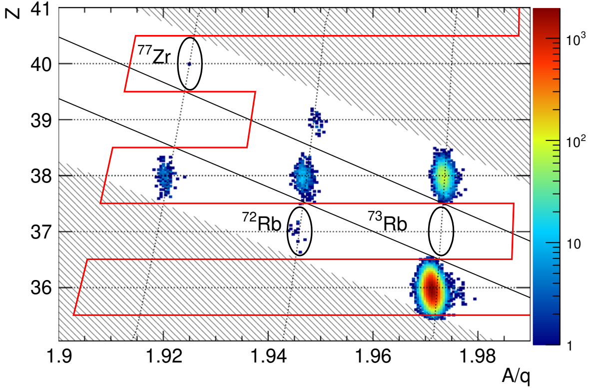




K. Wimmer et al., Phys. Lett. B **795** (2019) 266,
H. Suzuki et al., Phys. Rev. Lett **119** (2017) 192503.

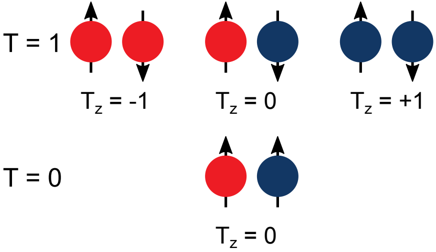
- Odd-odd ^{68}Br and ^{72}Rb longer lived than less proton-rich neighbors ($T_{1/2} \sim 100$ ns)

Influence on *rp*-process nucleosynthesis needs to be explored

Isospin symmetry

Isospin symmetry

- Neutron and proton: two representations of the nucleon with isospin $t_z = \pm 1/2$
- Led to the concept of quarks as constituents



- Two nucleon system in $T = 0$ and 1 channel: explains deuteron $J^{\pi} = 1^{+}$
- Strong interaction independent of isospin or charge $V_{np} = (V_{pp} + V_{nn})/2$
- Symmetric under exchange of protons and neutrons $V_{pp} = V_{nn}$

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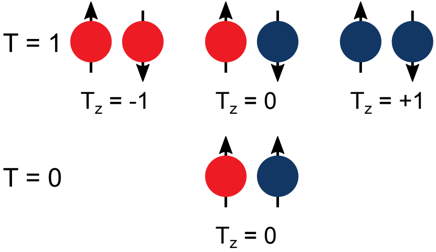

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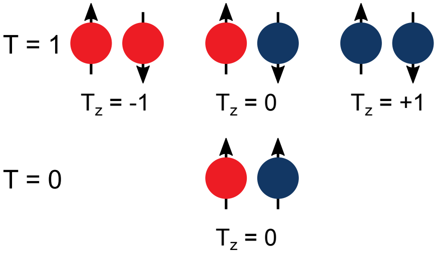

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- Violated by electromagnetic effects
- Light quark mass difference $m_u \neq m_d$
  $\rightarrow$ free neutron is unstable
- Relative proton-neutron mass difference 0.0013
  $\rightarrow$ symmetry breaking is small
- *nn*, *pp*, and *np* scattering length are different

In nuclei:

- Exactly degenerate energies of isobaric multiplets
- Pure isospin quantum numbers
- No isospin mixing in nuclear states
- Identical wave functions for the members of an isobaric multiplet

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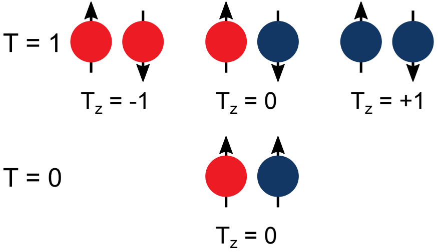

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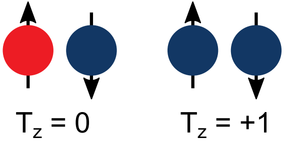
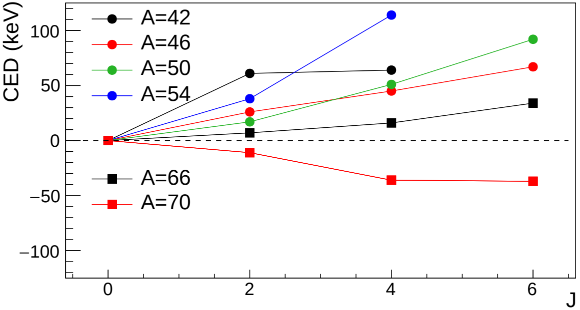
Anomaly at A = 70

- Coulomb energy differences between $T = 1$ states:

$$\mathrm{CED}(J^\pi) = E(J^\pi, T_z = 0) - E(J^\pi, T_z = 1)$$





G. de Angelis et al., Eur. Phys. J. A **12** (2001) 51,
B. S. Nara Singh et al., Phys. Rev. C **75** (2007) 061301.

- CED rise as a function of spin in the *sd* and *fp* shell
- $A = 70$ isobars show anomalous Coulomb energy differences
- Weakly bound: reduction of Coulomb repulsion due to spatial extension of proton wave functions
- However, negative CED only occur in $A = 70$ isotones
- May be explained by a shape change between ^{70}Se and ^{70}Br

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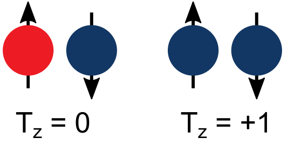

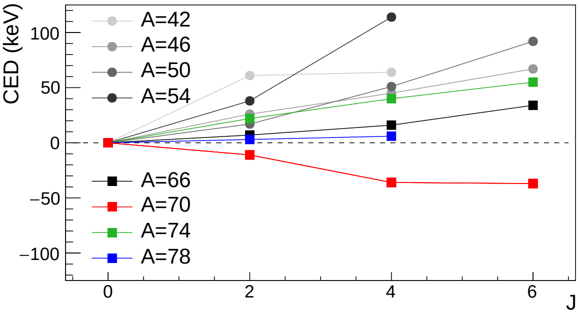

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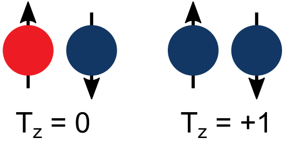

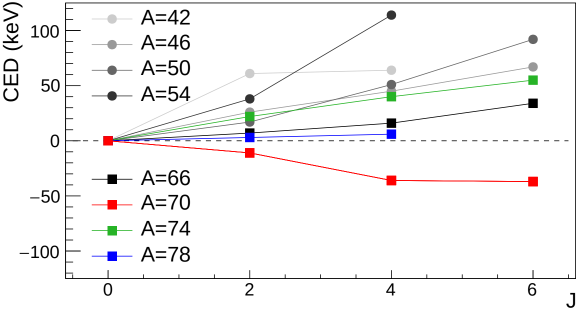

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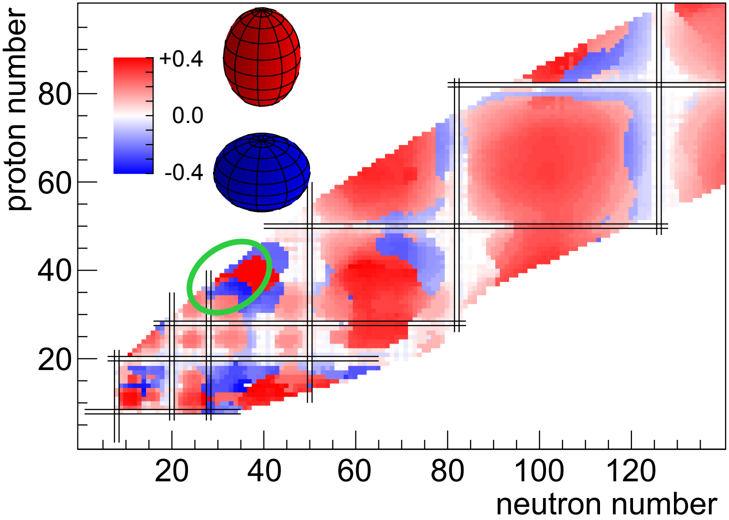
$\rightarrow$ Further lowering of states for $T_z = -1$ nucleus ^{70}Kr expected

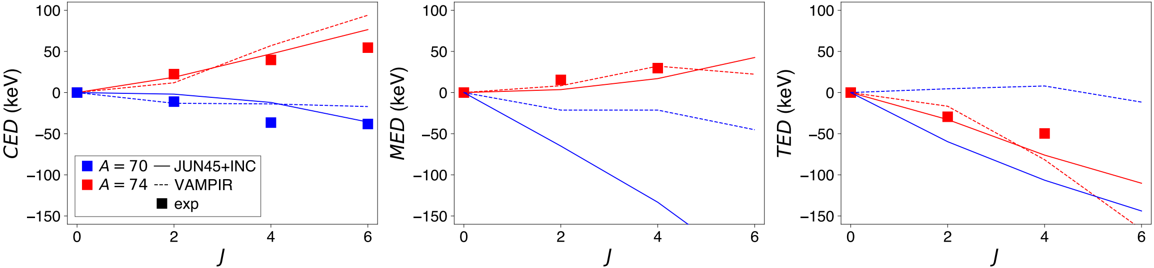
Predicted shapes of nuclei

- Predicted deformation parameters using finite-range droplet macroscopic model



P. Möller et al., At. Data Nucl. Data Tables **109** (2016) 1.

Energy differences of the $A = 70$ triplet



A. Petrovici, Phys. Rev. C **91** (2015) 014302, K. Kaneko et al., Phys. Rev. Lett. **109** (2012) 092504, J. Henderson et al., Phys. Rev. C **90** (2014) 051303(R), D. M. Debenham et al., Phys. Rev. C **94** (2016) 054311, K. Wimmer et al., Phys. Lett. B **785** (2018) 441, G. L. Zimba et al. Phys. Rev. C **110** (2024) 024314.

- Large positive contribution from monopole components leads to positive MED for $A = 74$, large negative spin-orbit component to negative MED for $A = 70$
- Negative TED due to the fact that the excitation energy of the odd-odd $T_z = 0$ nucleus is larger than either of the even-even isobars, proton-neutron pairing
- $A = 70$ anomaly can be understood without invoking any “exotic” physics

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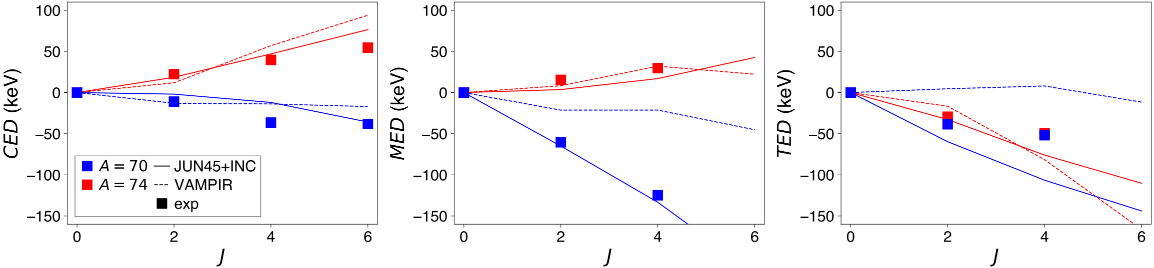

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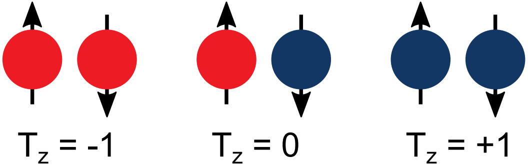
Energies alone do not probe the wave function, we need another observable to test the symmetry

Isospin symmetry of matrix elements



Charge independence of the nuclear interaction implies

- Exactly degenerate energies of isobaric multiplets
- Pure isospin quantum numbers and no isospin mixing
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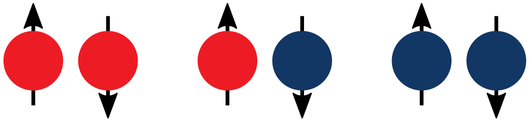

$T_z = -1$ $T_z = 0$ $T_z = +1$

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- Determine multipole matrix elements from measured $B(E2)$ values

$$M_{p/n} = \langle J_\mathrm{f} || \sum_{p/n} r^\lambda Y_\lambda(\Omega) || J_\mathrm{i} \rangle$$

$$B(E2;\ J_\mathrm{i} \to J_\mathrm{f}) = \frac{|\langle J_\mathrm{f} || E2 || J_\mathrm{i} \rangle|^2}{2J_\mathrm{i}+1} = \frac{M_p^2(E2)}{2J_\mathrm{i}+1}$$

- In isospin representation:

$$M_{n/p} = \frac{1}{2}\left(M_0(T_z) \pm M_1(T_z)\right)$$

- Assuming isospin symmetry:

$$M_p(T_z) = \frac{1}{2}\left(M_0 - M_1 \cdot T_z\right)$$

A. M. Bernstein, V. R. Brown, and V. A. Madsen, Phys. Rev. Lett. **42** (1979) 425.

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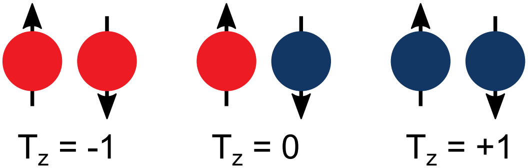

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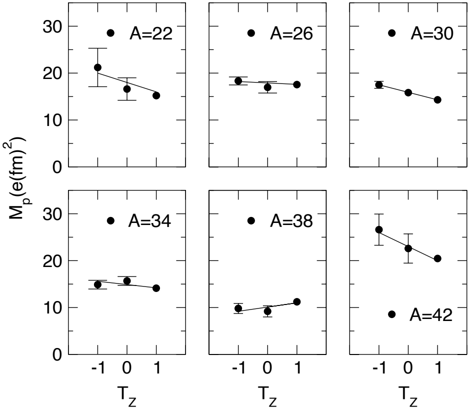
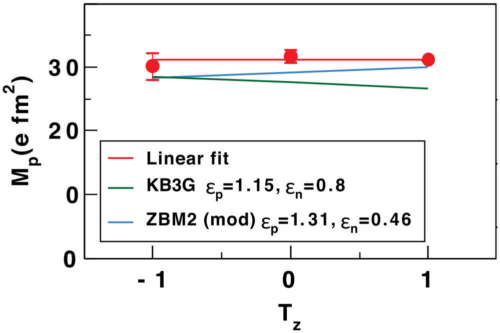
Isospin purity of T = 1 states

- $M_p(T_z)$ should be linear if isospin is conserved



F. M. Prados Estévez et al., Phys. Rev. C **75** (2007) 014309.

- Well tested for nuclei up to $A = 46$



A. Boso et al., Phys. Lett. B **797** (2019) 134835.

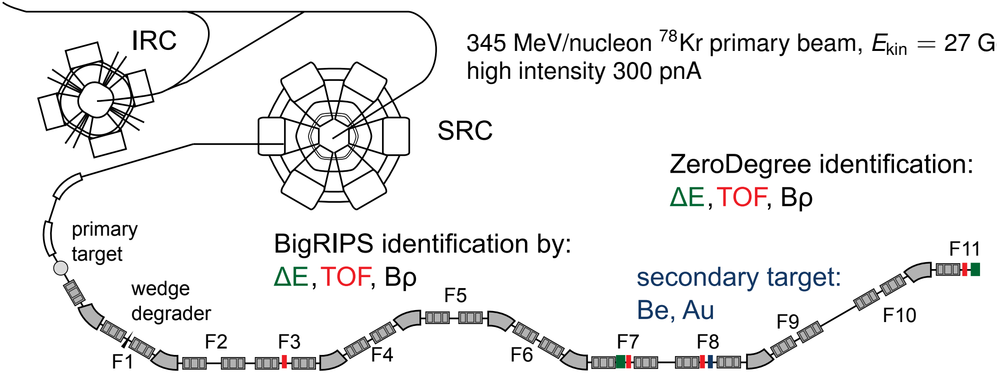
- No $B(E2)$ data on $T_z = -1$ nuclei beyond $A = 54$

K. L. Yurkewicz et al., Phys. Rev. C **70** (2004) 054319.

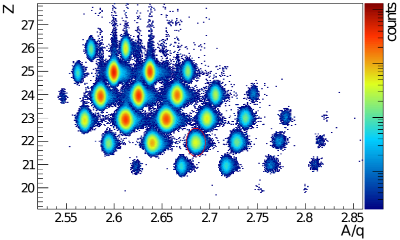
Different experiments and techniques used for different isobars
→ need for a consistent approach

In-beam spectroscopy at the RIBF

345 MeV/nucleon ^{78}Kr primary beam, $E_{\mathrm{kin}} = 27$ GeV
high intensity 300 pnA



- Fragmentation or fission of intense primary beam
- Particle identification by $B\rho - \Delta E -$ TOF:
  intensity ^{70}Kr only 15 pps
- Secondary reaction target at F8 surrounded by γ-ray detectors
- Identification after target:
  ZeroDegree spectrometer in large acceptance mode



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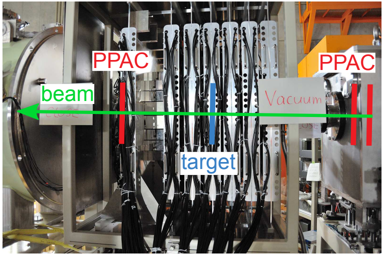
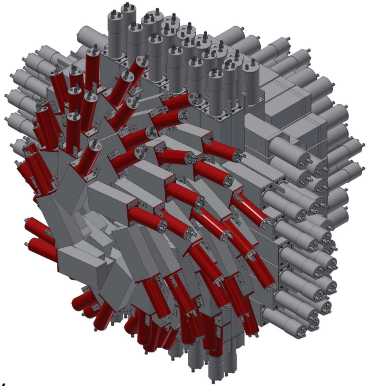
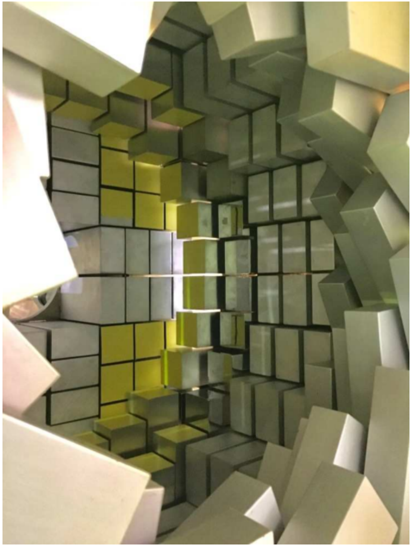


S. Takeuchi et al.,
Nucl. Instr. Meth. **A 763** (2014) 596.

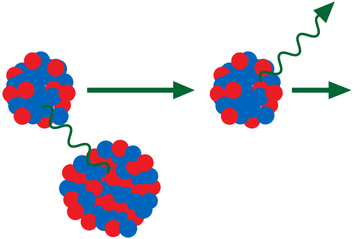




- 226 NaI(Tl) detectors
- Intrinsic resolution 7 % at 1 MeV
- In-beam resolution $\sim$ 10 % at 150 *A*MeV
- Efficiency $\sim$ 20 % at 1 MeV (before add-back)
- Beam tracking by PPACs

Coulomb excitation at relativistic energies

- Excitation of the projectile in the electromagnetic field of a high-Z target
- Absorption of virtual photon
- At relativistic energies one-step excitation is limited to (first) 2^+ states
- Measure cross section from de-excitation yield
- Nuclear excitation also contributes and interferes
- Developed consistent analysis approach for relativistic Coulomb excitation K. Wimmer et al., Eur. Phys. J. A **56** (2020) 159.



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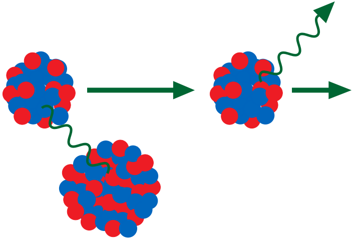
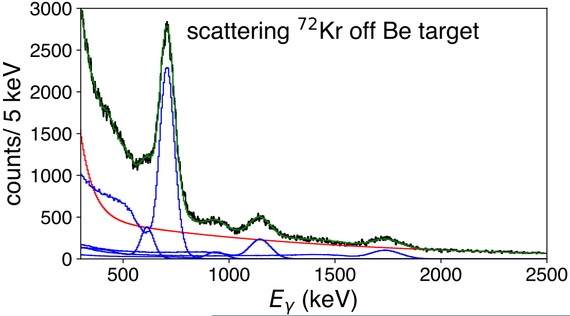
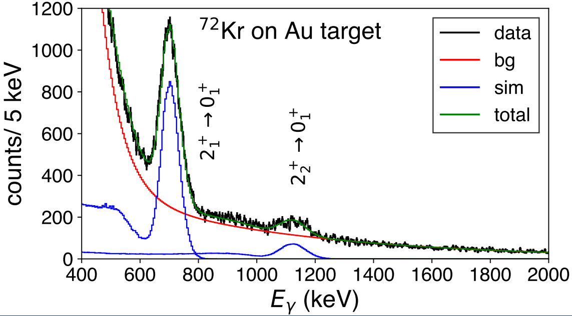
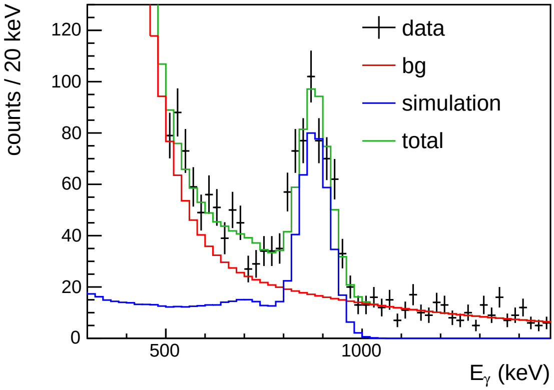


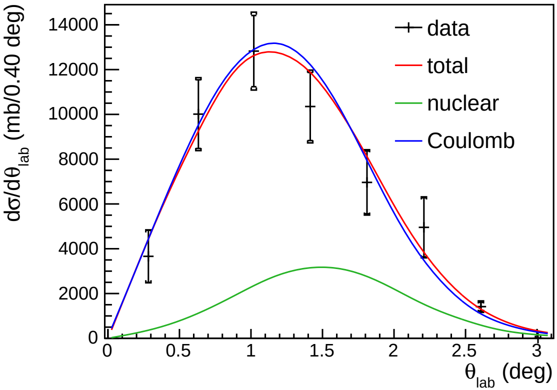
K. Wimmer et al., Eur. Phys. J. A **56** (2020) 159.





Coulomb excitation of ^{70}Kr





K. Wimmer et al., Phys. Lett. B **785** (2018) 441.

- Excitation energy of ^{70}Kr: $E(2^+) = 884$ keV
- Nuclear deformation length from Be target data: $\beta_N = 0.22(4)$
- Feeding corrections estimated from ^{72}Kr and ^{68}Se, and theoretical calculations
- $B(E2\uparrow) = 2726(294)_{\text{stat.}}(224)_{\text{syst.}}(258)_{\text{theo.}}$ e^{2}fm^4
  or $\beta_C = 0.25(2)$

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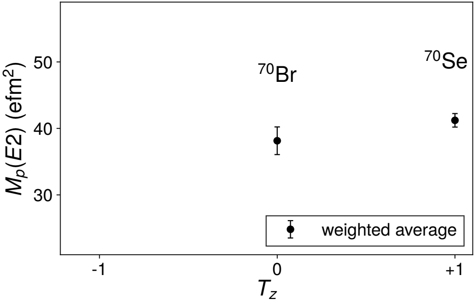

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J. Ljungvall et al., Phys. Rev. Lett. **100** (2008) 102502,
A. J. Nichols et al., Phys. Lett. B **733** (2014) 52.

- Linear fit with:

$$M_p(T_z) = \frac{1}{2}(M_0 - M_1 \cdot T_z)$$

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C. Morse et al., Phys. Lett. B. **787** (2018) 198.

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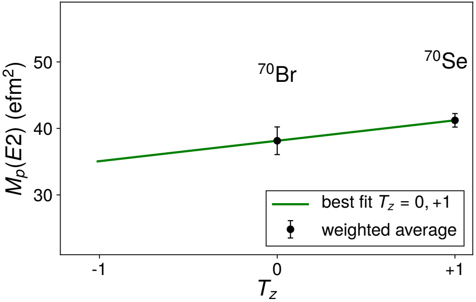

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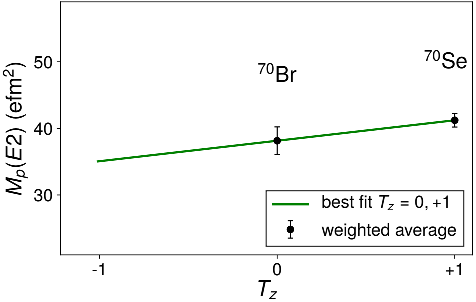

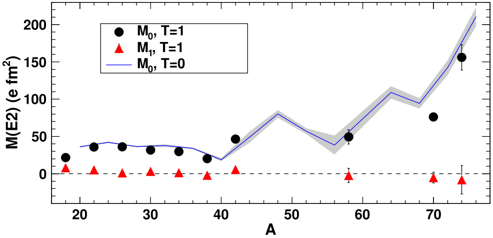

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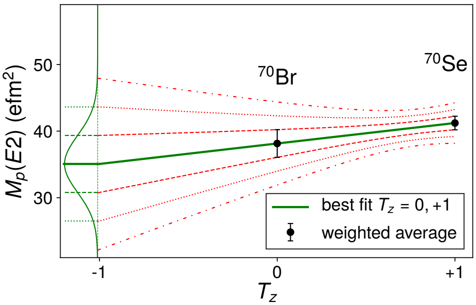

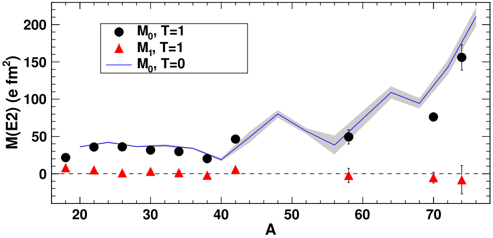

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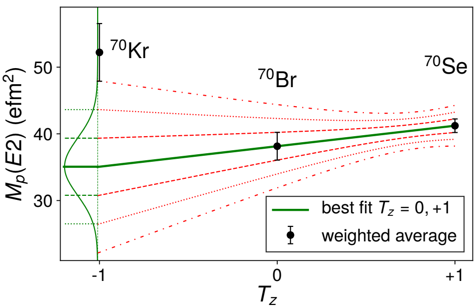

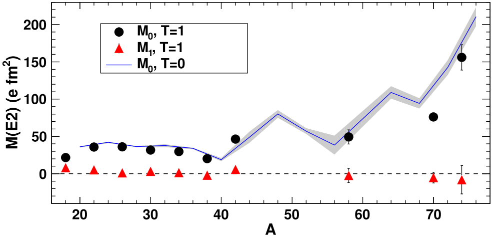

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Sign of deviation from isospin symmetry in $A = 70$ triplet

K. Wimmer et al., Phys. Rev. Lett. **126** (2021) 072501.

Shapes of the A = 70 triplet

- ^{70}Se is oblate deformed
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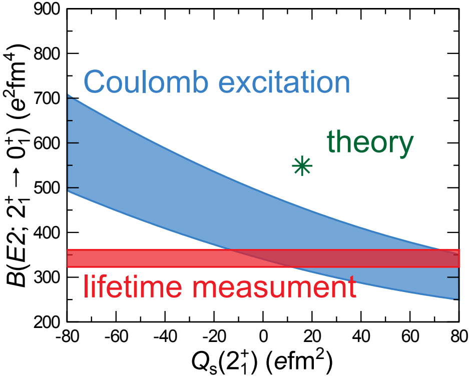

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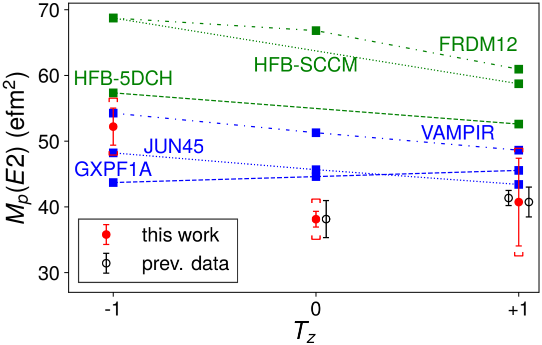

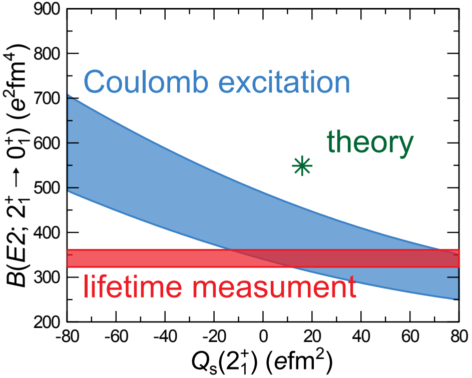

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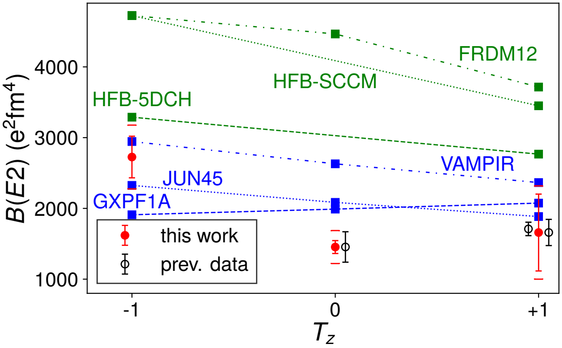

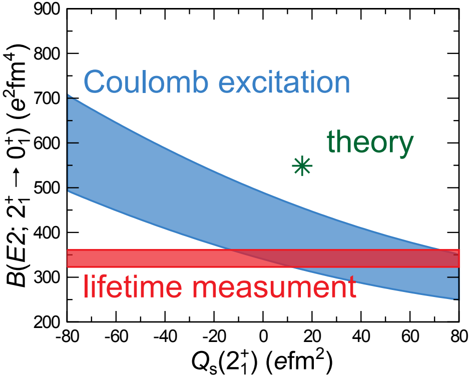

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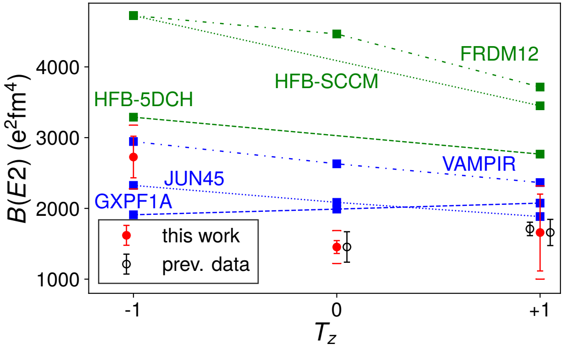
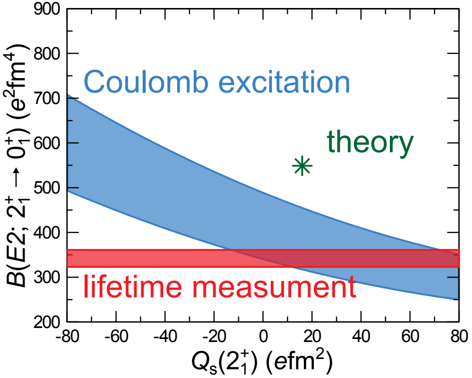


Shape change in the mirror nuclei ^{70}Se and ^{70}Kr



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- Heaviest isospin triplet where all three matrix elements are experimentally known
- $M_p(E2;\ 0_1^+ \rightarrow 2_1^+)$ value of ^{70}Kr significantly larger than in ^{70}Se
- 3σ deviation from the extrapolation of a linear relation ship $M_p(T_z)$

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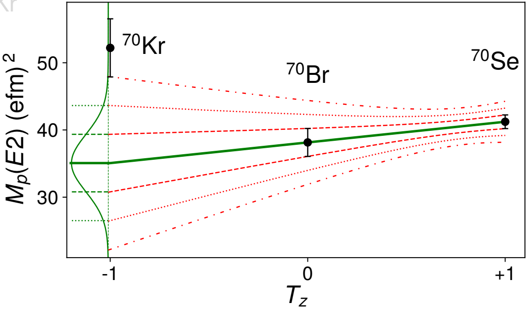

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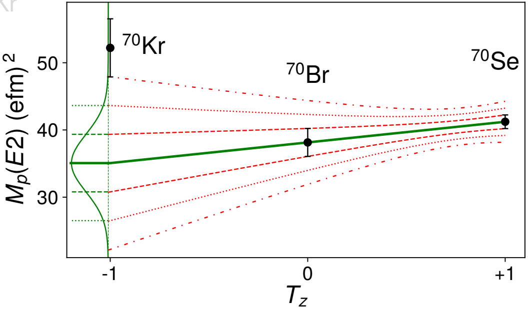

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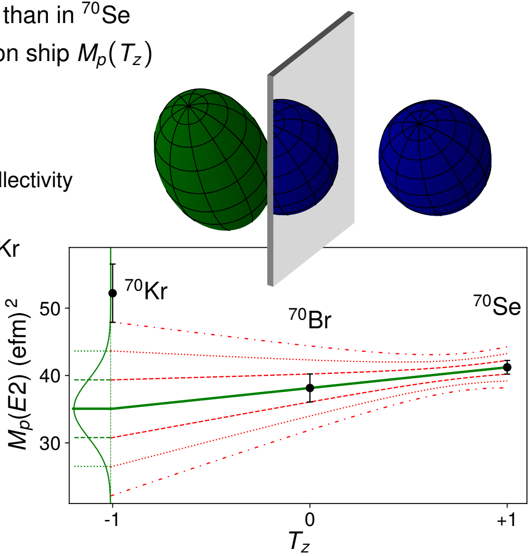

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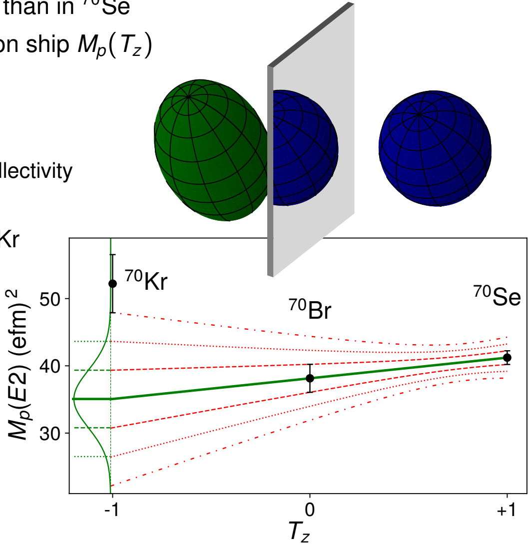
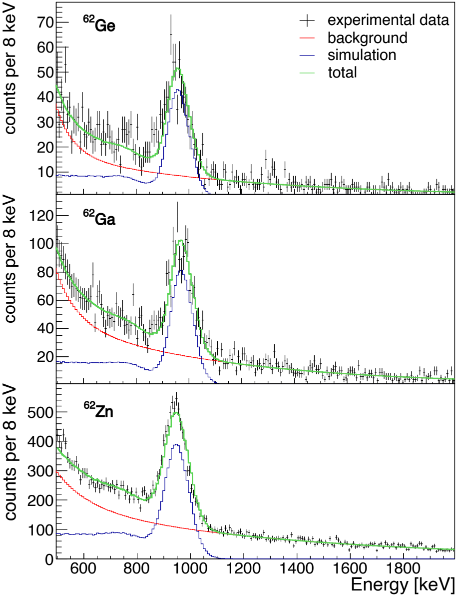


Precision test of isospin symmetry

- Systematic uncertainties from different measurements
  $\longrightarrow$ use same technique for all three members of a triplet
- New experiment: Coulomb excitation of $A = 62$, $T = 1$ triplet using identical target, beam energy, and detector
- Cancellation of systematic uncertainties



T. Hüyük et al., in prep.

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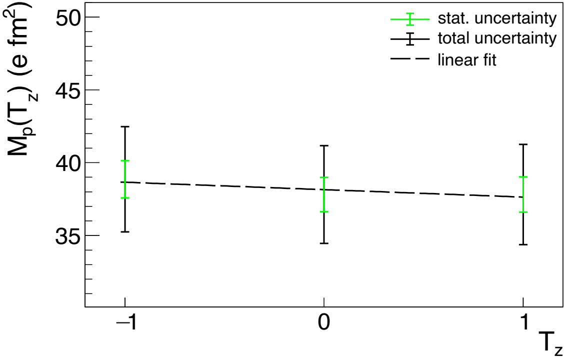

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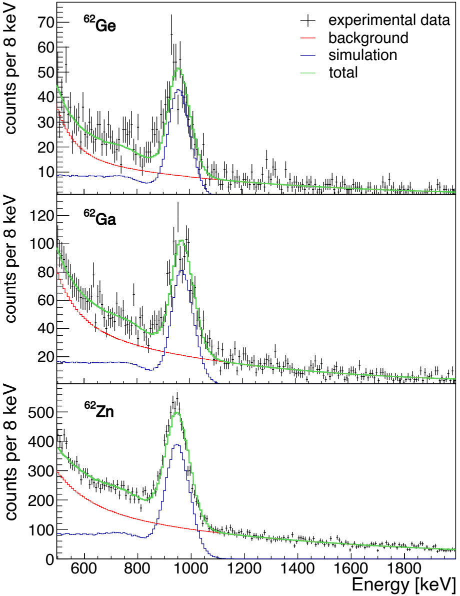

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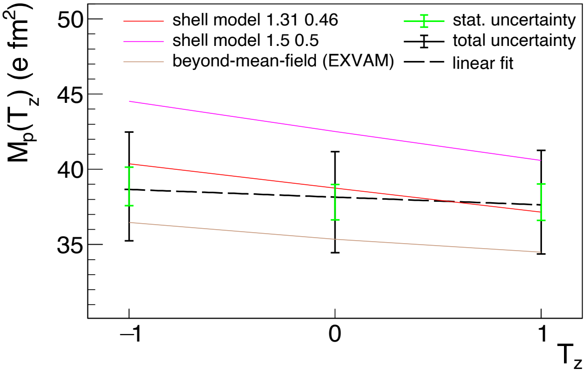

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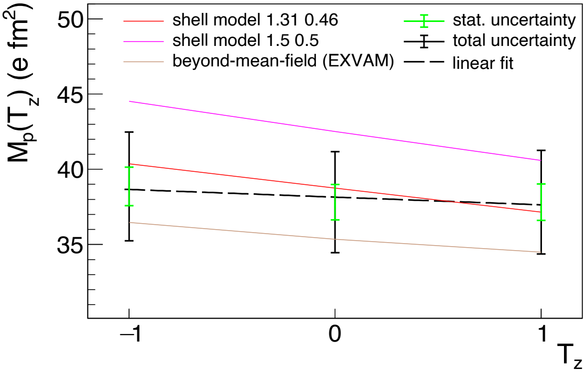

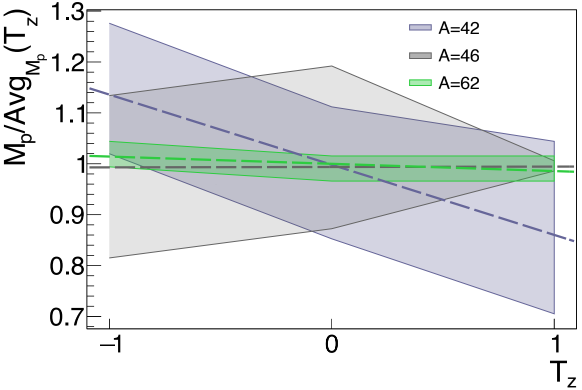

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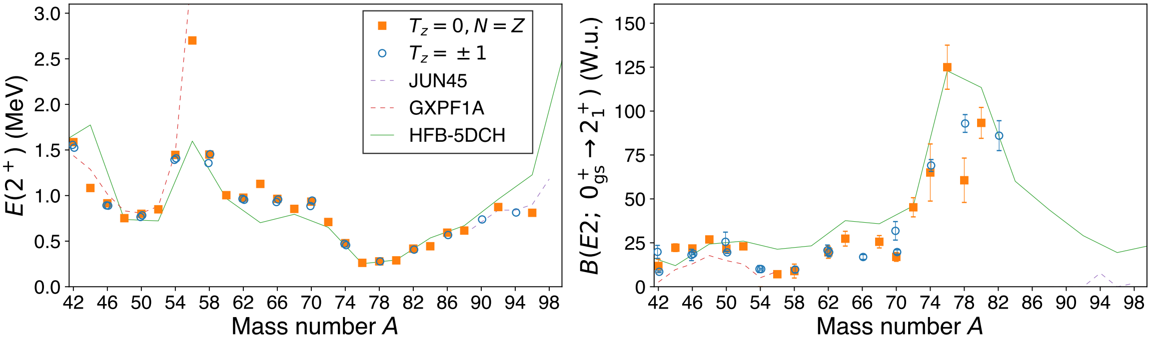
Precision experiment with radioactive beams

T. Hüyük et al., in prep.

Deformation and collectivity at N $=$ Z

What changes for $A = 70$?



- $A = 62$ triplet well in shell-model regime

K. Wimmer, P. Ruotsalainen, S.M. Lenzi et al., Phys. Lett. B **847** (2023) 138249.

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R. D. O. Llewellyn et al., Phys. Rev. Lett. **124** (2020) 152501.

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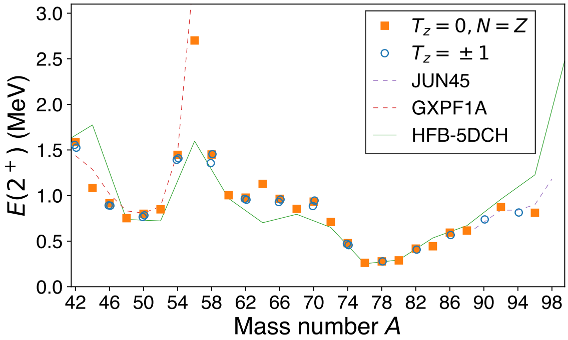

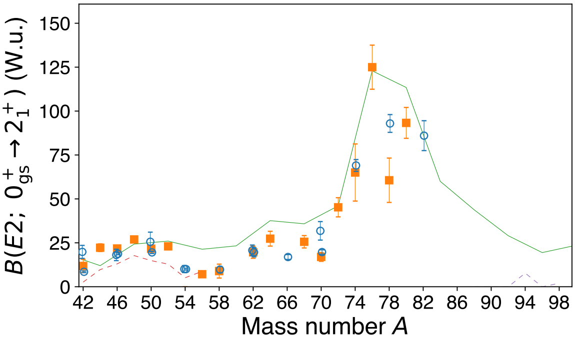

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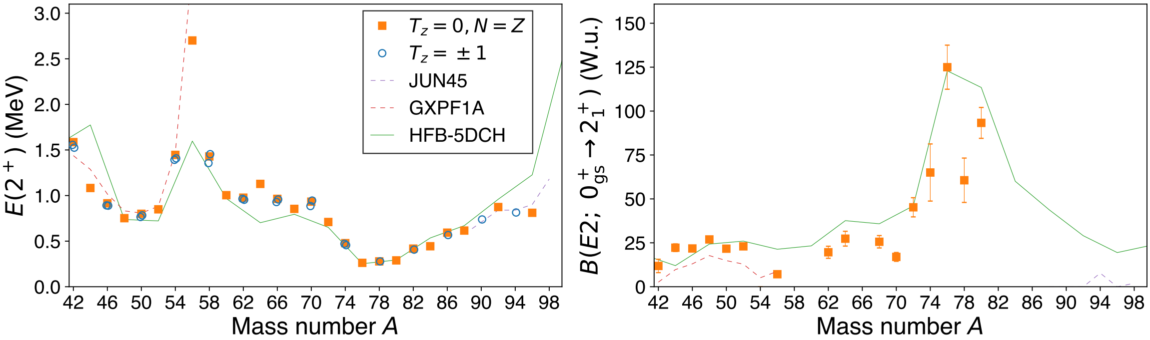

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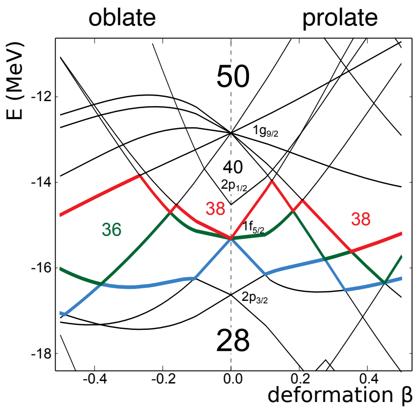


- Nuclei around $A = 80$ are very strongly deformed
- Small changes in the single-particle structure can lead to drastic change in deformation
- Contribution of p orbitals to radial Coulomb term quenched due to decrease in radius

A. Fernández et al., Phys. Lett. B **823** (2021) 136784.

- Coulomb interaction depends on spatial configuration of protons
- ^{70}Kr currently out of reach for shell model calculations
  required model space is at least $pf_{5/2}g_{9/2}$, but excitations beyond 50 and below 28 are required to appropriately model the collectivity

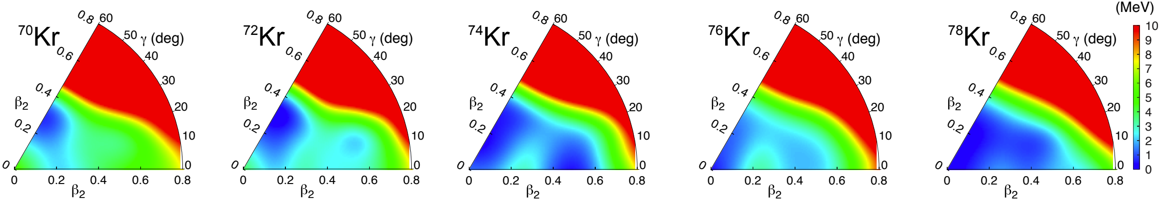
- Fully microscopic description of the deformation in the region yet to be attained

In a region where deformation and collectivity rise, a small change in the configuration of protons and neutrons can cause large difference in shape

Shape coexistence

Shape coexistence in Kr isotopes

- Proton-rich Kr ($Z = 36$) isotopes show a variety of shapes
- Self-consistent beyond mean-field calculations of potential energy surface



T. R. Rodríguez, Phys. Rev. C **90** (2014) 034306.

- Spherical ^{76,78}Kr
- Degenerate minima in ^{74}Kr: shape coexistence and mixing

E. Clement et al., Phys. Rev. C **75** (2007) 054313.

- ^{72}Kr: oblate ground state and rapid oblate - prolate transition with increasing spin

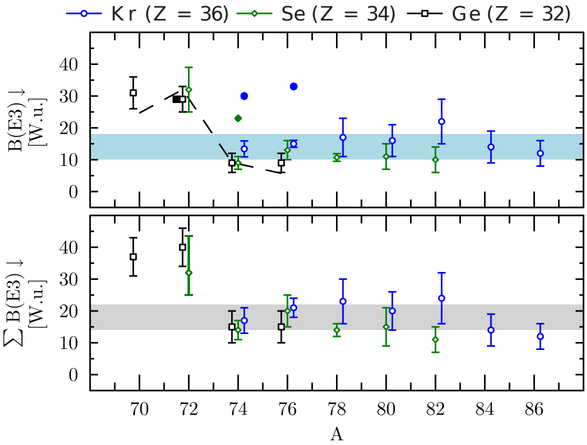
A. Gade et al., Phys. Rev. Lett. **95** (2005) 022502, H. Iwasaki et al., Phys. Rev. Lett. **112** (2014) 142502.

- Second minimum: excited 0^+ state in ^{72}Kr with large difference in deformation

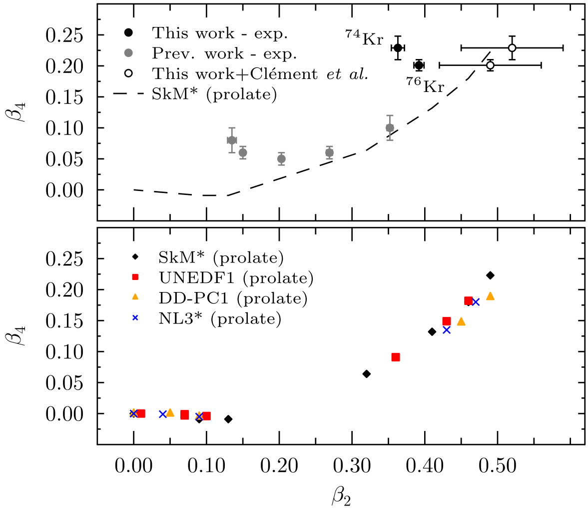
E. Bouchez et al., Phys. Rev. Lett. **90** (2003) 082502.

- Prediction for ^{70}Kr: oblate deformed

Higher order deformation



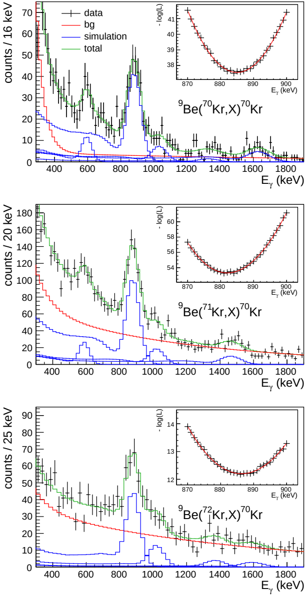
M. Spieker et al., Phys. Rev. C **106** (2022) 054305.



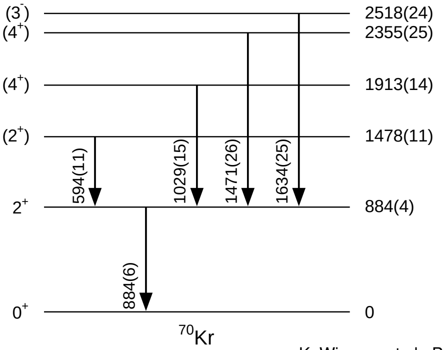
M. Spieker et al., Phys. Lett. B **841** (2023) 137932.

- Large octupole and hexadecupole deformation inferred from inelastic scattering

Shape coexistence at N = Z − 2?



- Inelastic scattering of ^{70}Kr on Be target
- One- and two-neutron removal reaction from ^{71,72}Kr
- Likely-hood fit to obtain γ-ray transitions energies

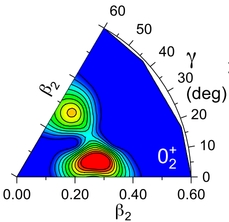


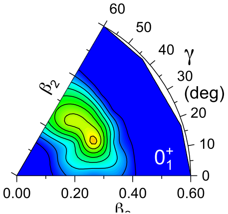
K. Wimmer et al., Phys. Lett. B **785** (2018) 441.

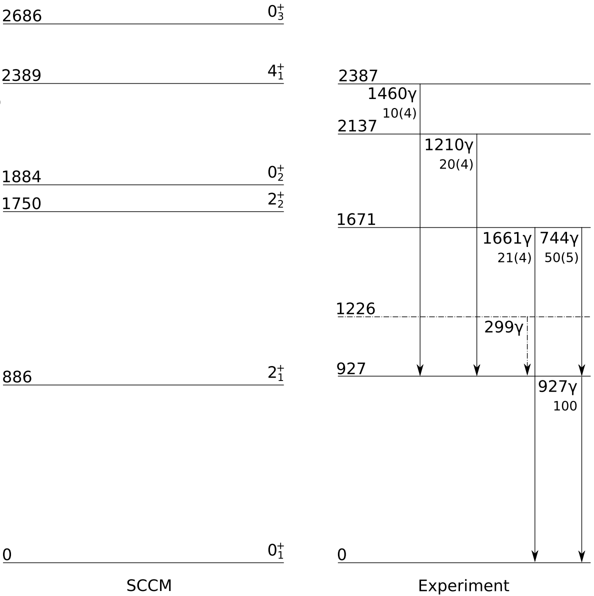
Coexisting excited band in ^{70}Kr

0^+ states still missing in ^{70}Se and ^{70}Kr

Shape coexistence at N = Z − 2?







- New excited states in ^{66}Se
- SCCM calculations show rough agreement with data
- Coexisting triaxial-deformed configurations
- Ground-state band more oblate
- Excited band more prolate

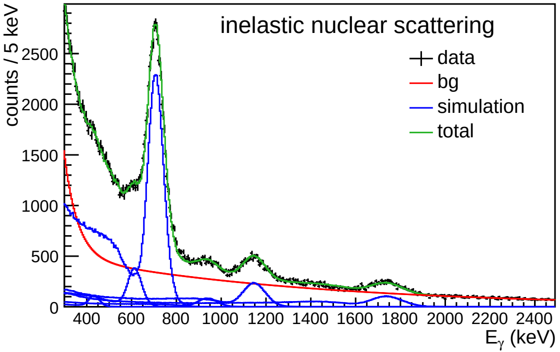
Z. Elekes et al.,
Phys. Lett. B **844** (2023) 138072.

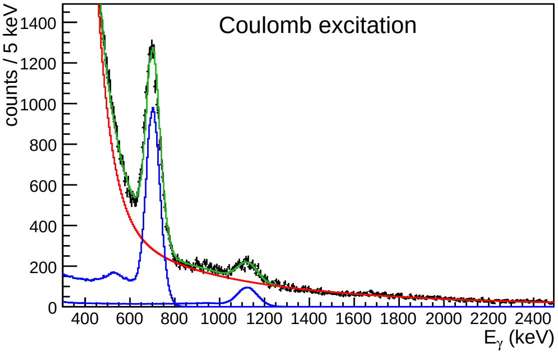
Relativistic Coulomb excitation of ^{72}Kr

- High-spin ^{72}Kr level scheme well known from fusion evaporation reactions

N. S. Kelsall et al., Phys. Rev. C **64** (2001) 024309, S. M. Fisher et al., Phys. Rev. C **67** (2003) 064318.

- Excited states in ^{72}Kr populated in inelastic scattering off Be and Au targets





- Four new transitions observed
- 1148(5) keV transition also in Coulomb excitation → new 2^+ state
- 947(7) keV transition in coincidence → new 4^+ state

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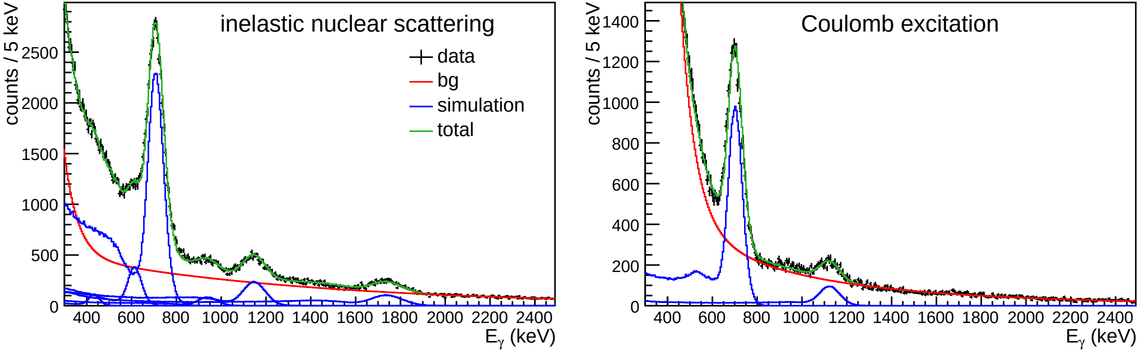

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Two-band mixing model

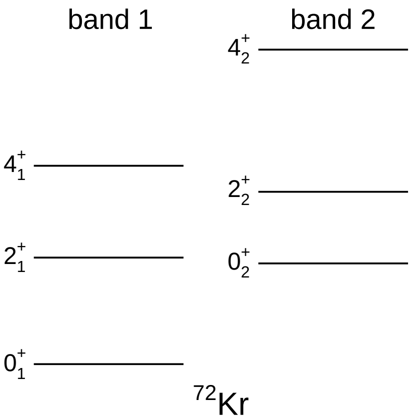
- Physical $J^\pi = 0^+, 2^+$, and 4^+ states are mixture of pure prolate and oblate configurations:

$$|J_1^+\rangle = +a_J|J_p^+\rangle + b_J|J_o^+\rangle$$
$$|J_2^+\rangle = -b_J|J_p^+\rangle + a_J|J_o^+\rangle$$

- Yrast band prolate deformed at high spin

R. B. Piercey et al., Phys. Rev. Lett. **47** (1981) 1514.

- Extrapolation using variable moment of inertia $I = I_0 + \omega^2 I_1$
$\rightarrow$ unperturbed energies



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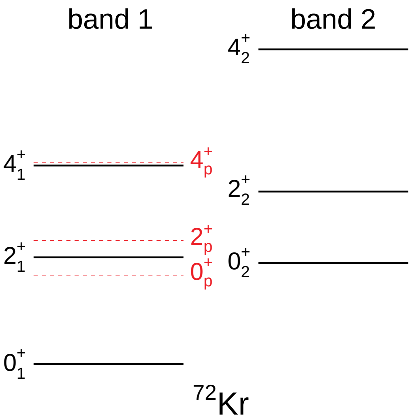

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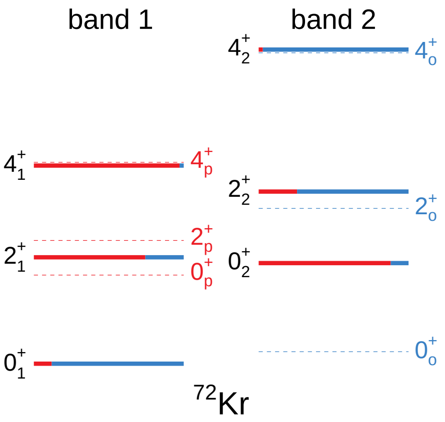
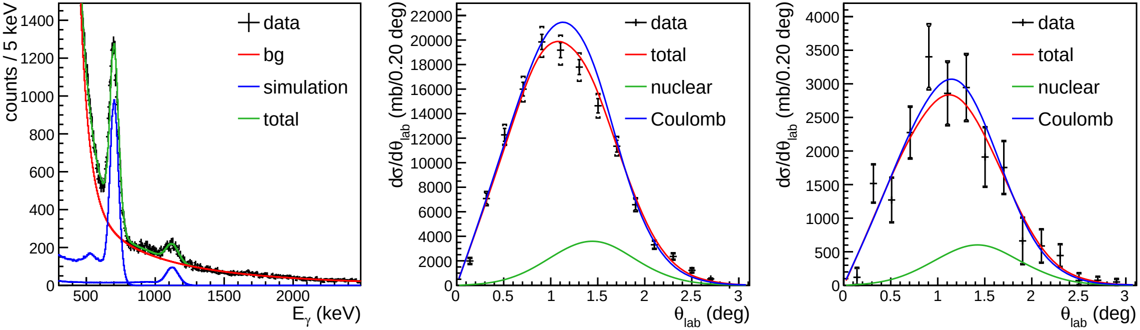


E. Bouchez et al., Phys. Rev. Lett. **90** (2003) 082502.

- ground state oblate dominated
- New 2_2^+ and 4_2^+ states allow to extend the mixing analysis
- Inversion with oblate ground state, rapid transition towards prolate yrast states
- In agreement with interpretation of $B(E2;\ 4_1^+ \rightarrow 2_1^+)$

H. Iwasaki et al., Phys. Rev. Lett. **112** (2014) 142502.

Results for ^{72}Kr



- Nuclear deformation length and *E*2 matrix elements obtained from comparison with FRESCO (DWCC) calculations

state	β_N	β_C	$B(E2\uparrow)$ (e^2fm^4) this	prev.
2_1^+	0.309(2)(9)(8)	0.296(3)(11)(13)	$4023(81)_{stat.}(290)_{syst.}(380)_{theo.}$	4997(647) 4050(750)
2_2^+	0.123(4)(5)(3)	0.112(3)(4)(5)	$665(39)_{stat.}(58)_{syst.}(63)_{theo.}$	-

A. Gade et al., Phys. Rev. Lett. **95** (2005) 022502, H. Iwasaki et al., Phys. Rev. Lett. **112** (2014) 142502.

Different deformation → shape coexistence

Transition strengths in the mixing model

- So far, only energies are considered to obtain a, b_J:
  $b_0^2 = 0.881$, $b_2^2 = 0.256$, and $b_4^2 = 0.028$
- Matrix elements (transitions between the pure configurations are forbidden)

$$
\begin{aligned}
\langle 2_1^+ || E2 || 0_1^+ \rangle &= b_0 b_2 \langle 2_\mathrm{o}^+ || E2 || 0_\mathrm{o}^+ \rangle + a_0 a_2 \langle 2_\mathrm{p}^+ || E2 || 0_\mathrm{p}^+ \rangle \\
\langle 2_2^+ || E2 || 0_1^+ \rangle &= b_0 a_2 \langle 2_\mathrm{o}^+ || E2 || 0_\mathrm{o}^+ \rangle - a_0 b_2 \langle 2_\mathrm{p}^+ || E2 || 0_\mathrm{p}^+ \rangle \\
\langle 4_1^+ || E2 || 2_1^+ \rangle &= b_2 b_4 \langle 4_\mathrm{o}^+ || E2 || 2_\mathrm{o}^+ \rangle + a_2 a_4 \langle 4_\mathrm{p}^+ || E2 || 2_\mathrm{p}^+ \rangle \\
\langle 0_2^+ || E0 || 0_1^+ \rangle &= a_0 b_0 \left(\langle 0_\mathrm{o}^+ || E0 || 0_\mathrm{o}^+ \rangle - \langle 0_\mathrm{p}^+ || E0 || 0_\mathrm{p}^+ \rangle \right)
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- Matrix elements (transitions between the pure configurations are forbidden)
- 4^+ states pure $a_4 = 1$, deformation β from reduced transition probability

$$\begin{aligned} B(E2;\ J_i \rightarrow J_f) &= \frac{5}{16\pi}\left(eQ_0\right)^2 \left|\langle J_i K_i 20 | J_f K_f \rangle\right|^2 \\ Q_0^{\mathrm{o/p}} &= ZR^2 \frac{3}{\sqrt{5\pi}} \left(\beta_{\mathrm{o/p}} + 0.36\beta_{\mathrm{o/p}}^2\right) \end{aligned}$$

$$\begin{aligned} B(E2;\ 2_1^+ \rightarrow 0_1^+) &= \left(\frac{3e}{4\pi}R^2 Z\right)^2 \left|\langle 2020|00\rangle\right|^2 \left[b_0 b_2 (1+0.36\beta_{\mathrm{o}})\beta_{\mathrm{o}} + a_0 a_2 (1+0.36\beta_{\mathrm{p}})\beta_{\mathrm{p}}\right]^2 \\ B(E2;\ 2_2^+ \rightarrow 0_1^+) &= \left(\frac{3e}{4\pi}R^2 Z\right)^2 \left|\langle 2020|00\rangle\right|^2 \left[b_0 a_2 (1+0.36\beta_{\mathrm{o}})\beta_{\mathrm{o}} - a_0 b_2 (1+0.36\beta_{\mathrm{p}})\beta_{\mathrm{p}}\right]^2 \\ B(E2;\ 4_1^+ \rightarrow 2_1^+) &= \left(\frac{3e}{4\pi}R^2 Z\right)^2 \left|\langle 4020|20\rangle\right|^2 \left[a_2 (1+0.36\beta_{\mathrm{p}})\beta_{\mathrm{p}}\right]^2 \\ \rho^2(E0;\ 0_2^+ \rightarrow 0_1^+) &= \left(\frac{3e}{4\pi}Z\right)^2 a_0^2 b_0^2 \left(\beta_{\mathrm{o}} - \beta_{\mathrm{p}}\right)^2 \end{aligned}$$

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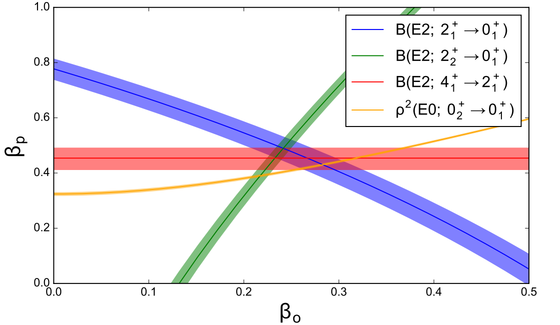
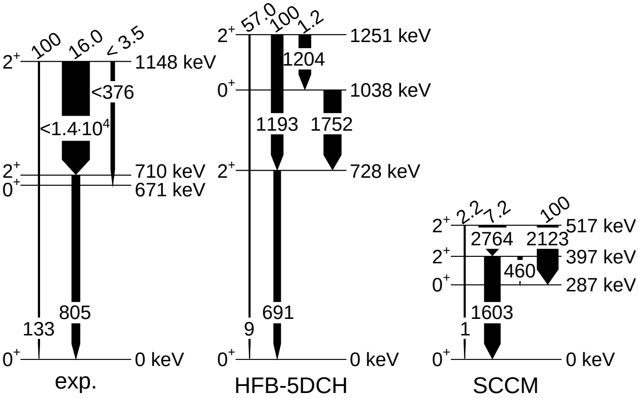
- Equation system with many possible signs
- Using $a_0^2 = 0.256$, $a_2^2 = 0.744$ from the energies
- Overlap in the region $\beta_{\mathrm{o}} = 0.24$ and $\beta_{\mathrm{p}} = 0.45$
- Shape coexistence and mixing

K. Wimmer et al., Eur. Phys. J. A **56** (2020) 159.



Comparison to theoretical calculations



- Beyond mean field calculations using Gogny D1S interaction
- HFB-5DCH calculations
  J. P. Delaroche et al., Phys. Rev. C **81** (2010) 014303.
- SCCM method
  T. R. Rodríguez, Phys. Rev. C **90** (2014) 034306.
- Both in expanded spaces

- Reproduce $B(E2;\ 2_1^+ \rightarrow 0_1^+)$ rather well
- HFB-5DCH calculations over predict the 0_2^+ energy
- Moderately oblate 2_1^+ and stronger prolate deformation for 2_2^+
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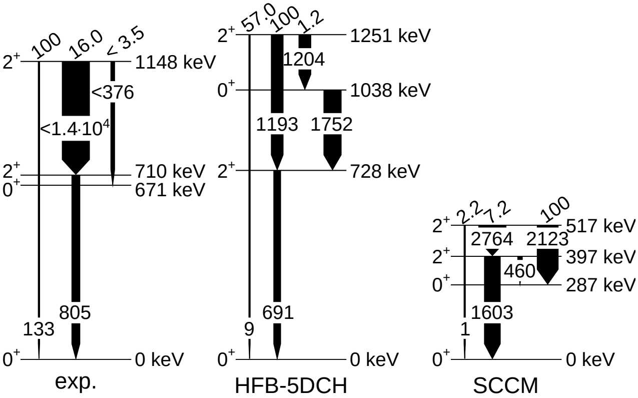

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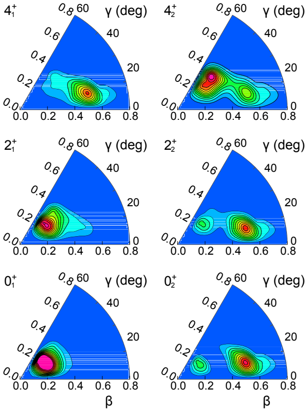
Probability densities (HFB-5DCH method) and collective wave functions (SCCM)



K. Wimmer et al., Eur. Phys. J. A **56** (2020) 159.

- 5DCH: 0_1^+ and 2_1^+ oblate, transition to prolate for 4_1^+
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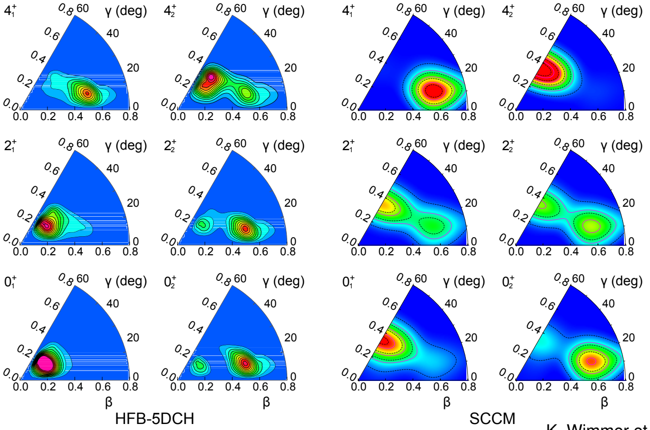

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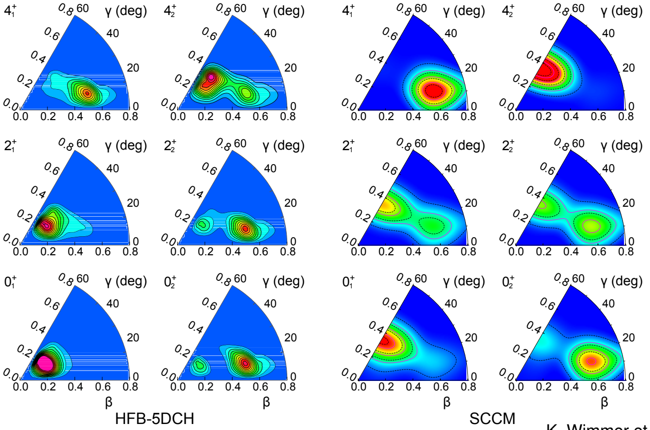

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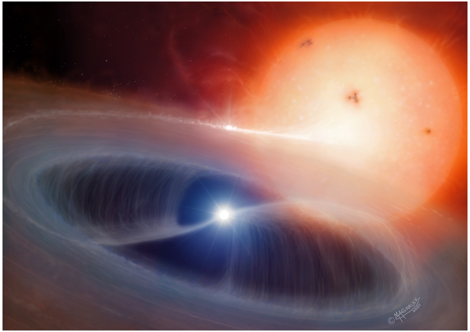
Coexistence and shape change along yrast band

Summary: Nuclei at $N = Z$

- Their properties influence nucleosynthesis
- Mass measurements and proton-capture reactions
- Lifetimes of proton-unbound nuclei



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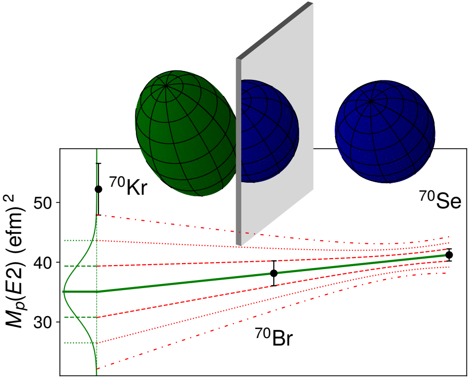

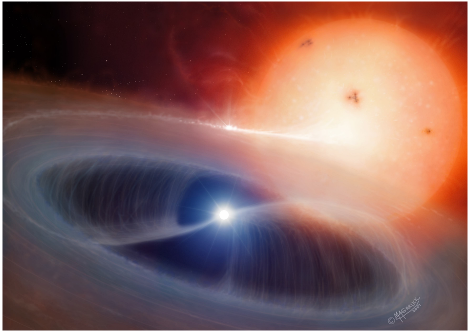

- Isospin symmetry of multipole matrix elements violated at $A = 70$
- Shape change in the mirror nuclei ^{70}Se and ^{70}Kr
- Symmetry preserved in $A = 62$ system
- Interesting region of large ground state deformation

Collaboration

RIBF94

W. Korten, T. Arici, P. Doornenbal, P. Aguilera, A. Algora, T. Ando, H. Baba, B. Blank, A. Boso, S. Chen, A. Corsi, P. Davies, G. de Angelis, G. de France, D. Doherty, J. Gerl, R. Gernhäuser, D. Jenkins, A. Jungclaus, S. Koyama, T. Motobayashi, S. Nagamine, M. Niikura, A. Obertelli, D. Lubos, B. Rubio, E. Sahin, H. Sakurai, T. Saito, L. Sinclair, D. Steppenbeck, R. Taniuchi, V. Vaquero, R. Wadsworth, and M. Zielinska

RIBF151

S.M. Lenzi, A. Poves, T. Hüyük, F. Browne, P. Doornenbal, T. Koiwai, T. Arici, M. Bentley, M. L. Cortés, N. Imai, A. Jungclaus, N. Kitamura, B. Longfellow, R. Lozeva, B. Mauss, D. Napoli, M. Niikura, X. Pereira-Lopez, F. Recchia, P. Ruotsalainen, R. Taniuchi, S. Uthayakumaar, V. Vaquero, R. Wadsworth, and R. Yajzey

U Tokyo, RIKEN, CEA Saclay, GSI, U Giessen, CCEN, U Valencia, U Bordeaux, INFN Padova, U York, INFN Legnaro, GANIL, TU München, CSIC Madrid, U Olso, U Padova, UA Madrid, CNS Tokyo, NSCL, CSNSM, U Jyväskylä

Thank you for your attention