RELATION of MASSES and SPECTROSCOPIC OBSERVABLES to STRUCTURE

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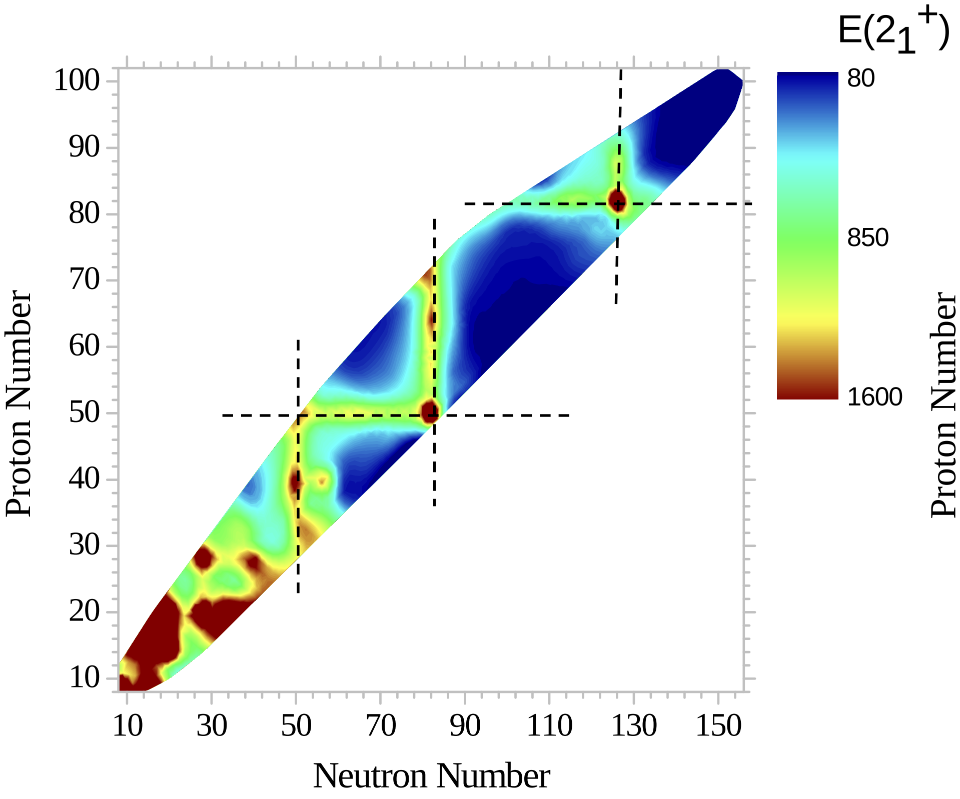
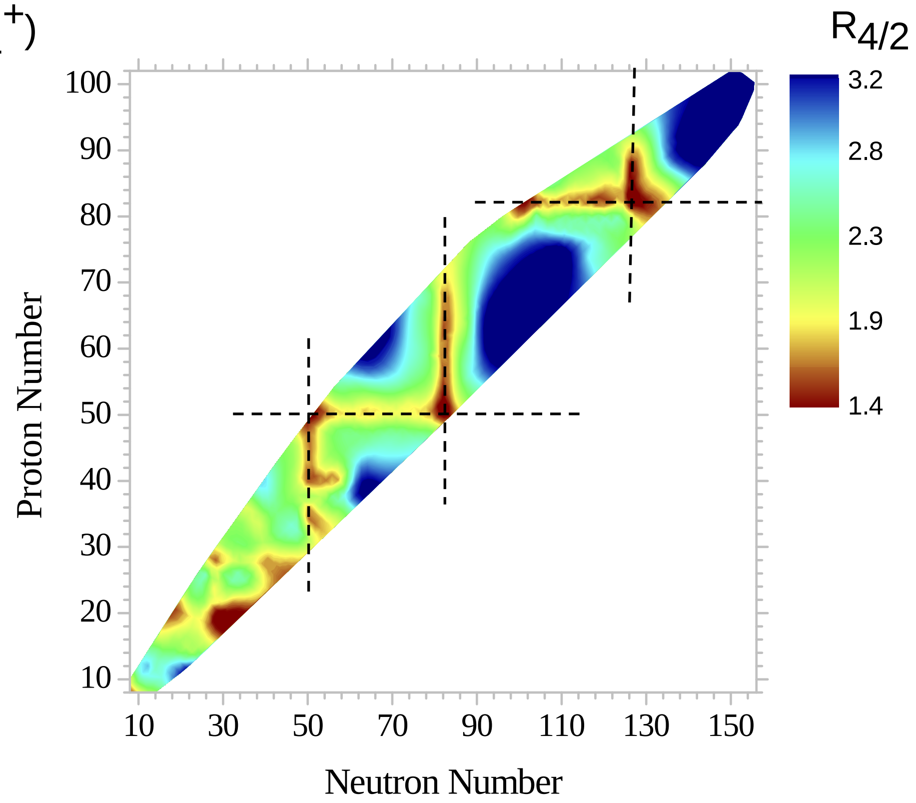
Broad perspective on structural evolution



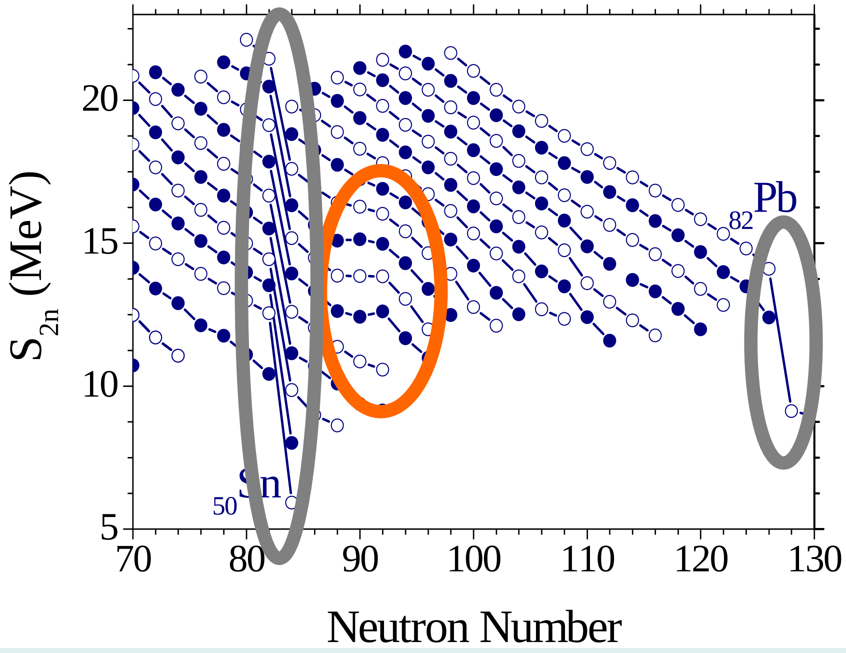


The remarkable regularity of these patterns is one of the beauties of nuclear systematics and one of the challenges to nuclear theory.

Whether they persist far off stability is one of the fascinating questions for the future

Nuclear Structure from Binding Energies

Masses – Nuclear Structure, Nucleon Interactions

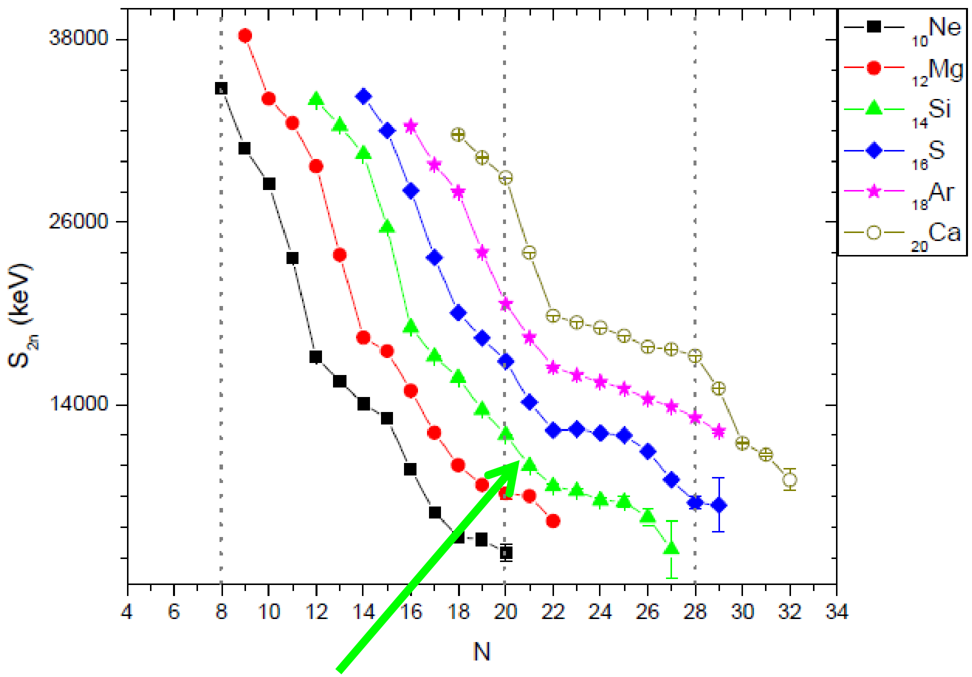


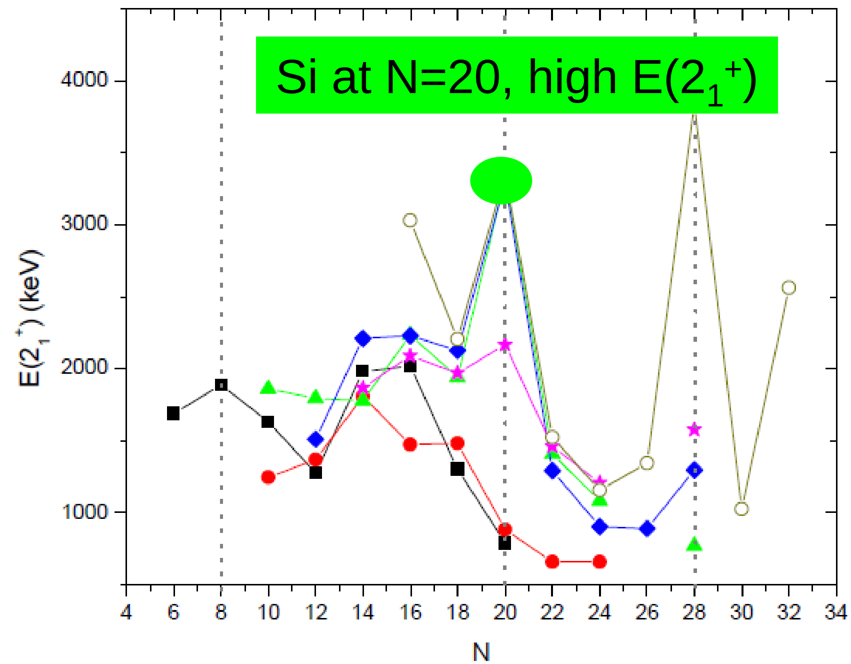
Key nuclear concepts that masses and binding energies can illuminate

• Shell Structure
• Shape and phase changes, etc.
• Proton/Neutron shell gaps
• Pairing effects
• By removing the linear dependence in, for example, S_{2n} → isolate and amplify collective effects → much more sensitive tests of nuclear models
• Interactions between the last protons and neutrons

Structure for well known light nuclei

S_{2n} and $E(2_1^+)$ for Z ~ 16



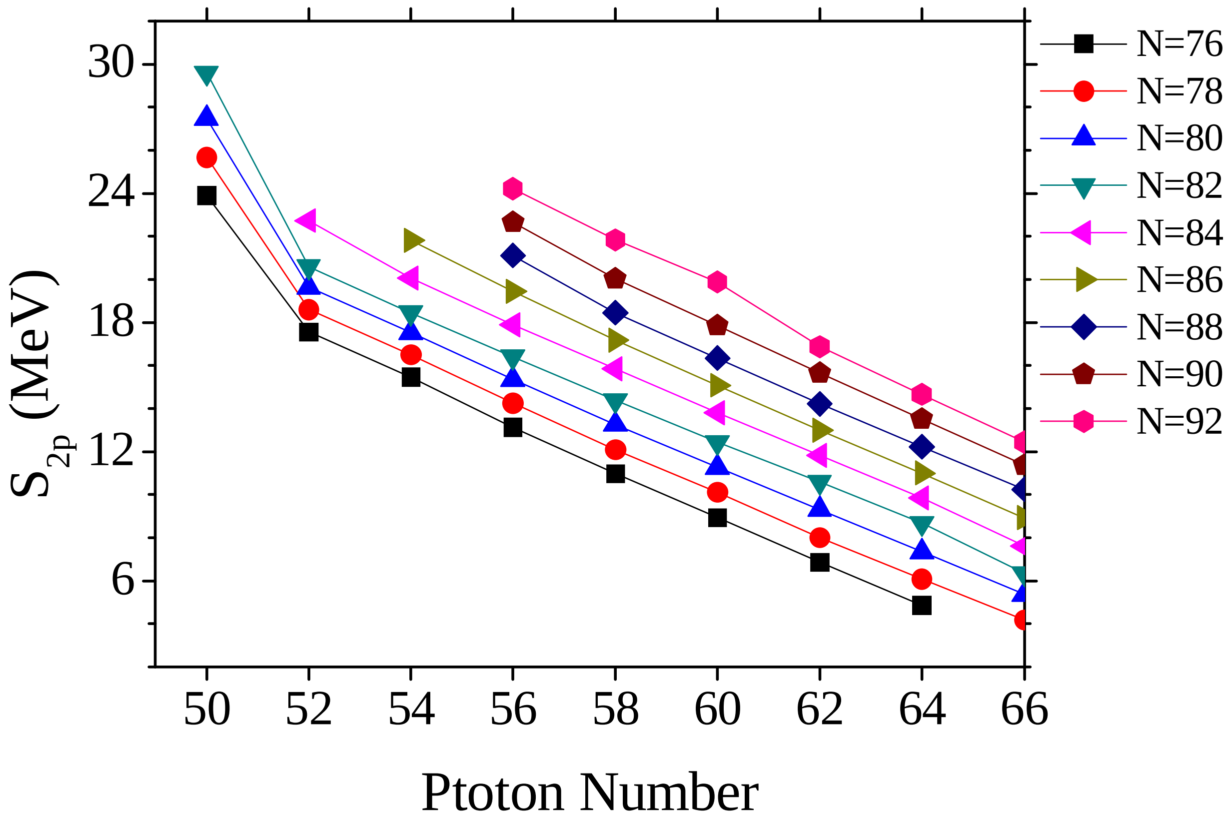


But no magic number effect for Si at N=20 ???

What is happening?

Study is in progress

S_{2p} - Z



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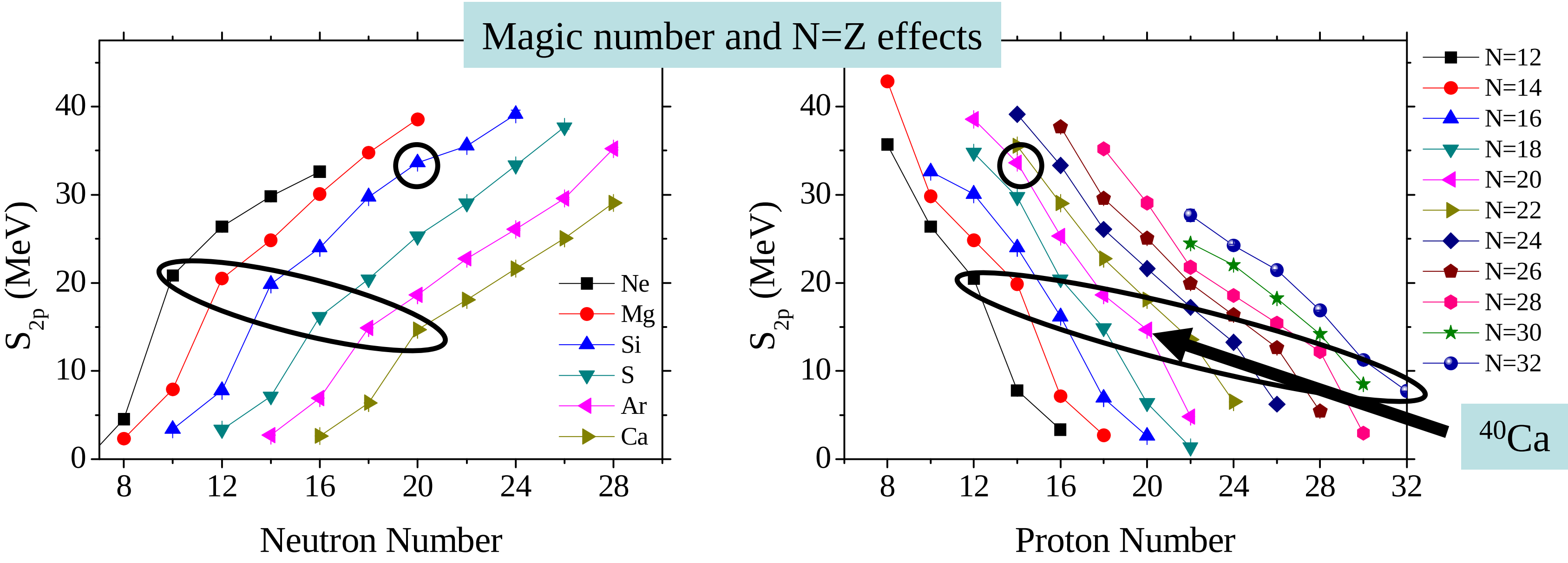
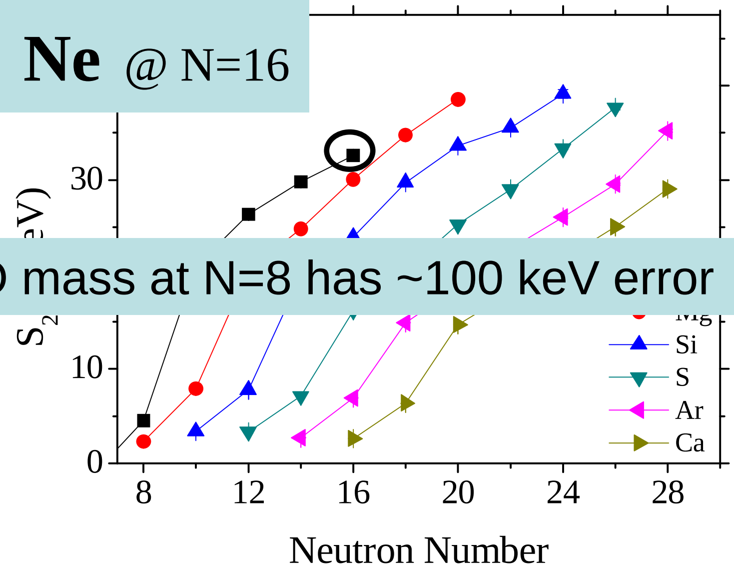
S_{2p} behavior

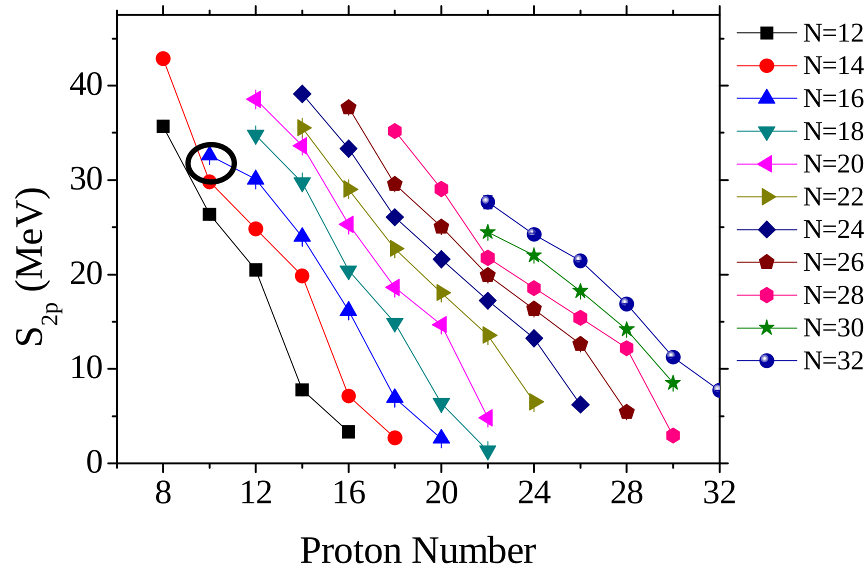


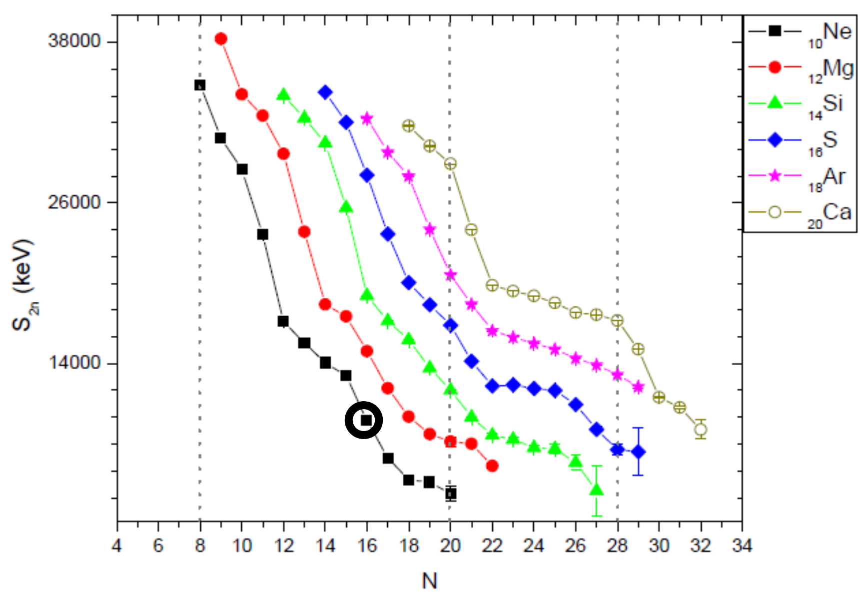
S_{2p} and S_{2n} behavior

? **Ne** @ N=16

$_8$O mass at N=8 has ~100 keV error

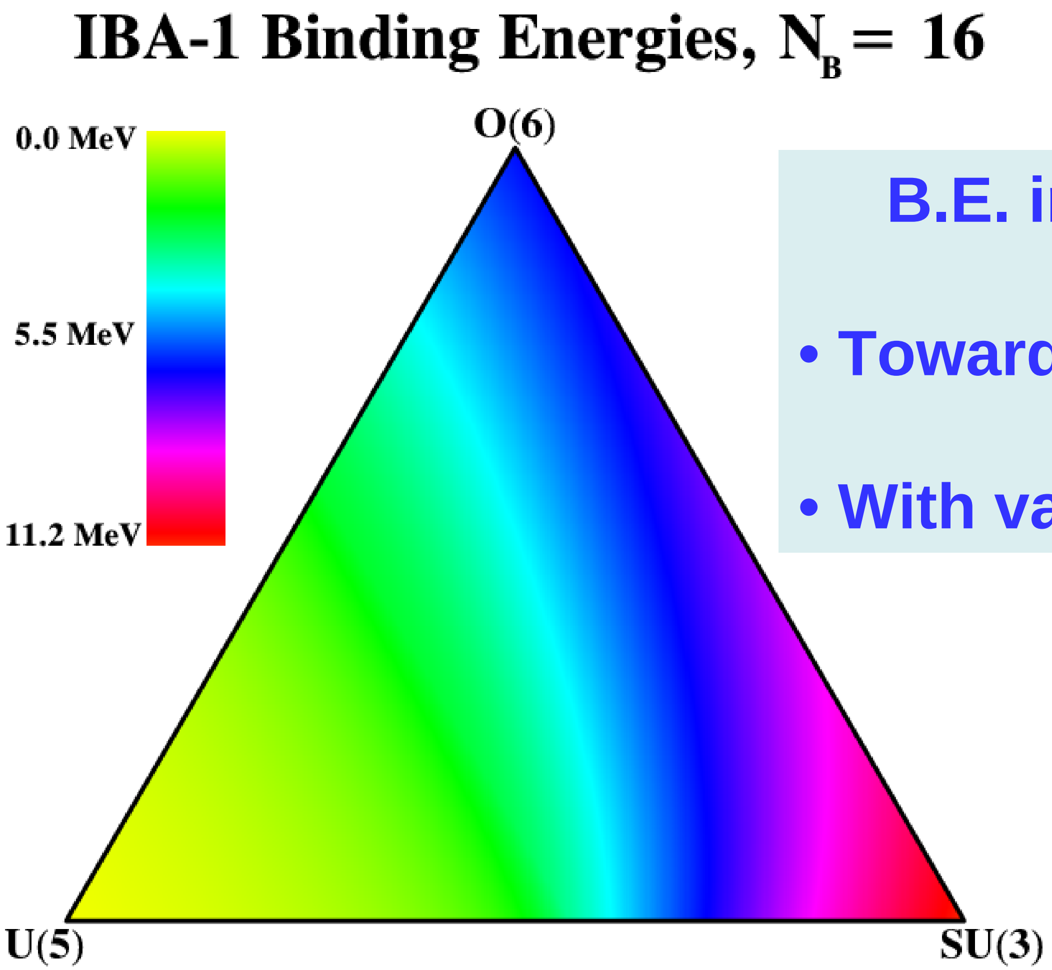






Relation between S_{2n} and $E(2^+)$ values

Masses, Binding, and Structure



B.E. increases rapidly:

- **Towards axial deformation**
- **With valence nucleons**

Cakirli, Casten, Winkler, Blaum and Kowalska, PRL **102**, 082501 (2009)

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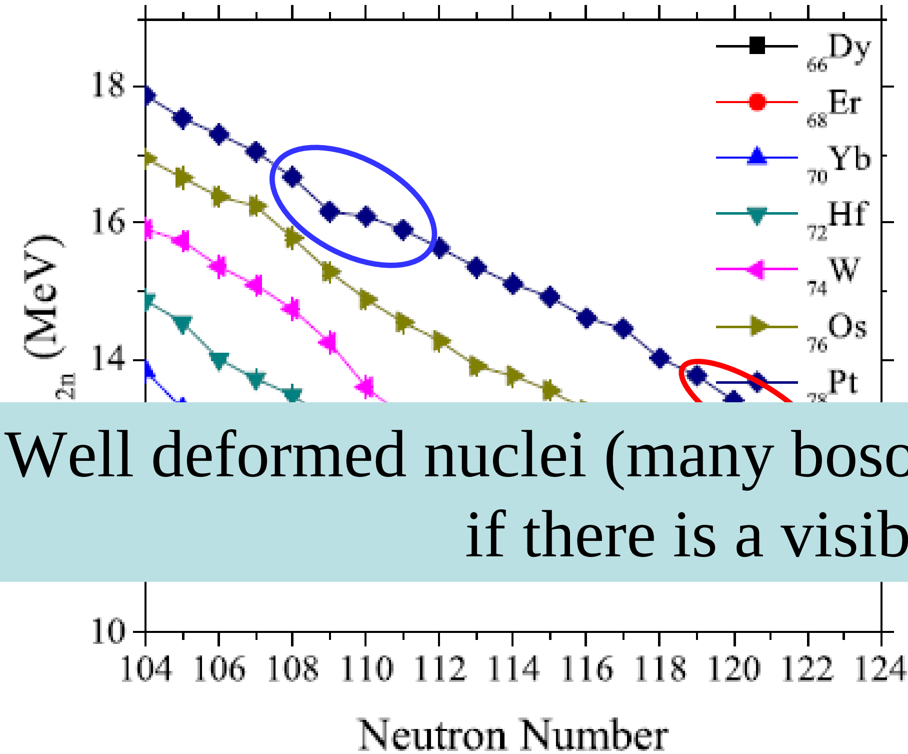
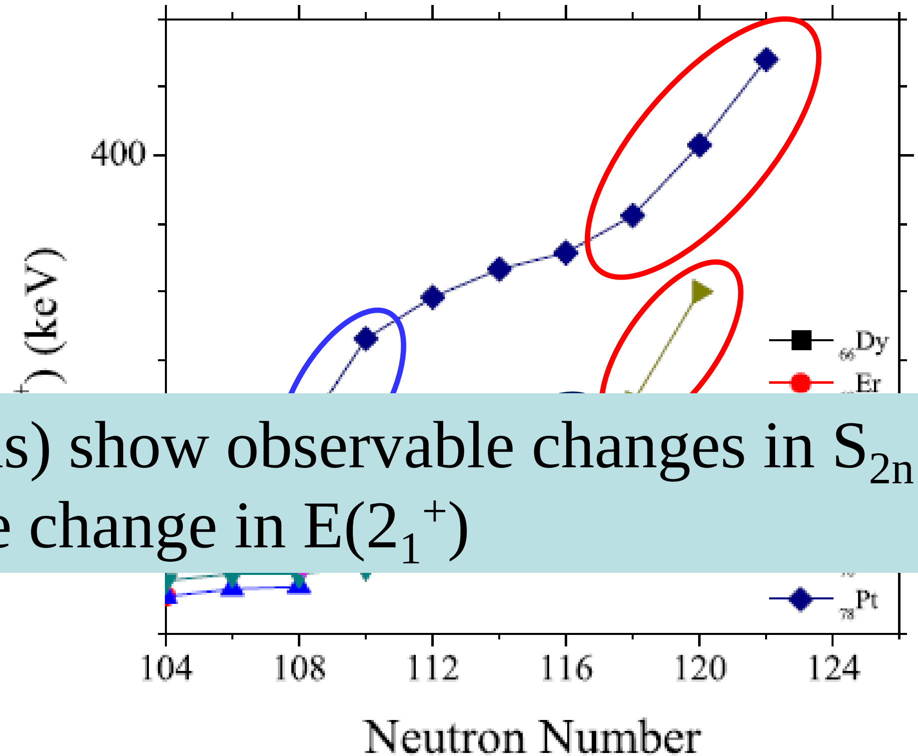
Relation between S_{2n} and $E(2^+)$ values

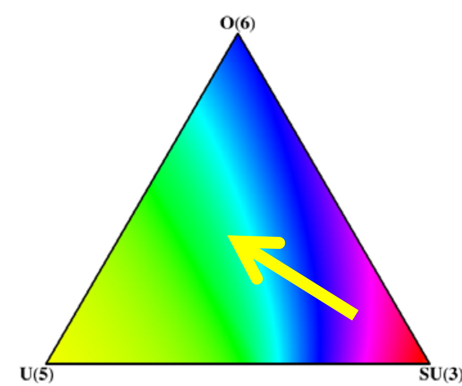




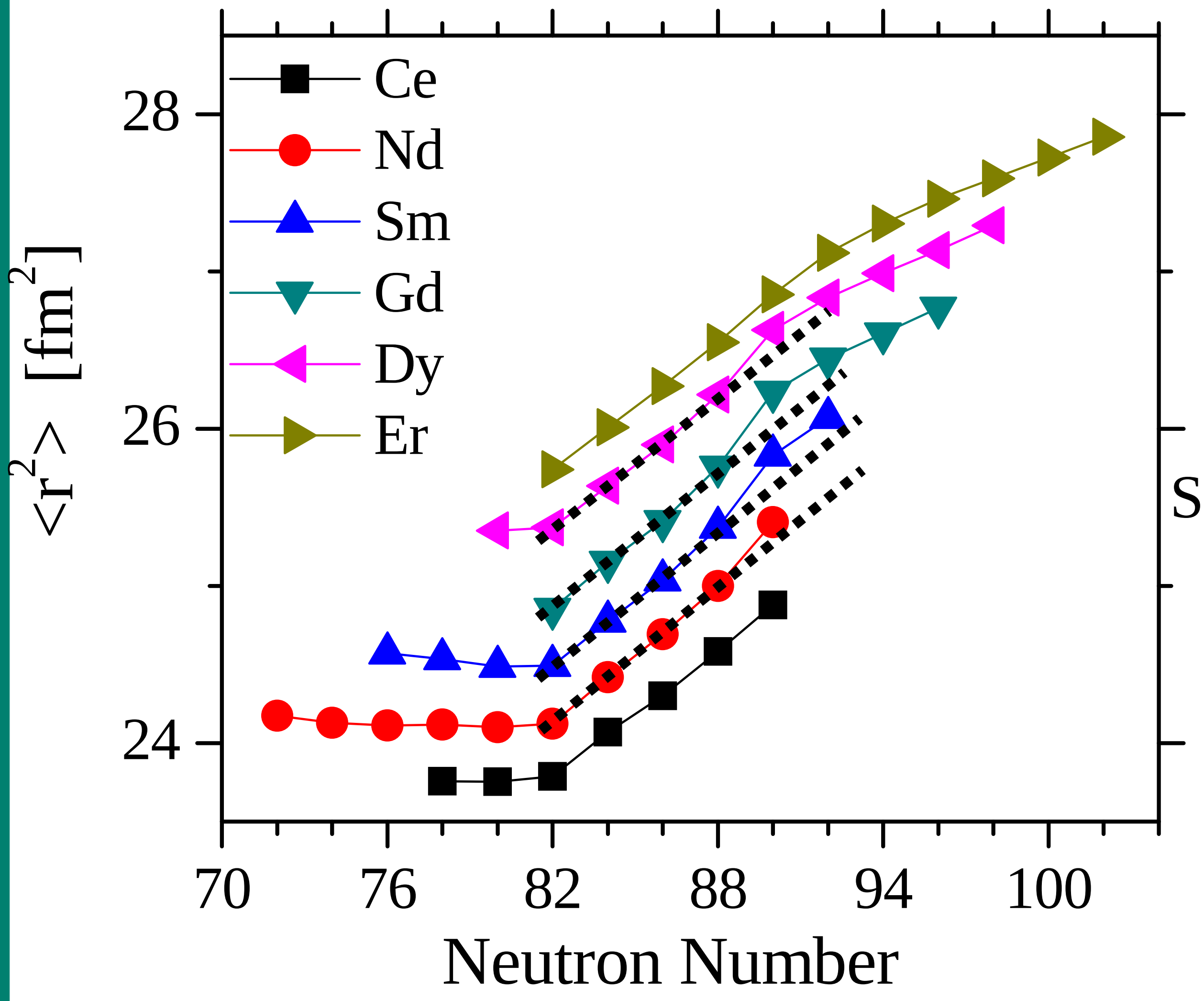
Well deformed nuclei (many bosons) show observable changes in S_{2n} if there is a visible change in $E(2_1^+)$

D. Shubina, R.B Cakirli et al., to be published

- W, light Pt deformed, 18 and 20 valence nucleons
- n-rich Os, Pt transitional, 12 and 10 valence nucleons
- Hence changes in S_{2n} in latter substantially reduced
- S_{2n} is sensitive both to structure and the val. nucl. #



$\langle r^2 \rangle$ for the rare-earth nuclei



Change on slope

Sudden deformation

N~90

Shape transitions

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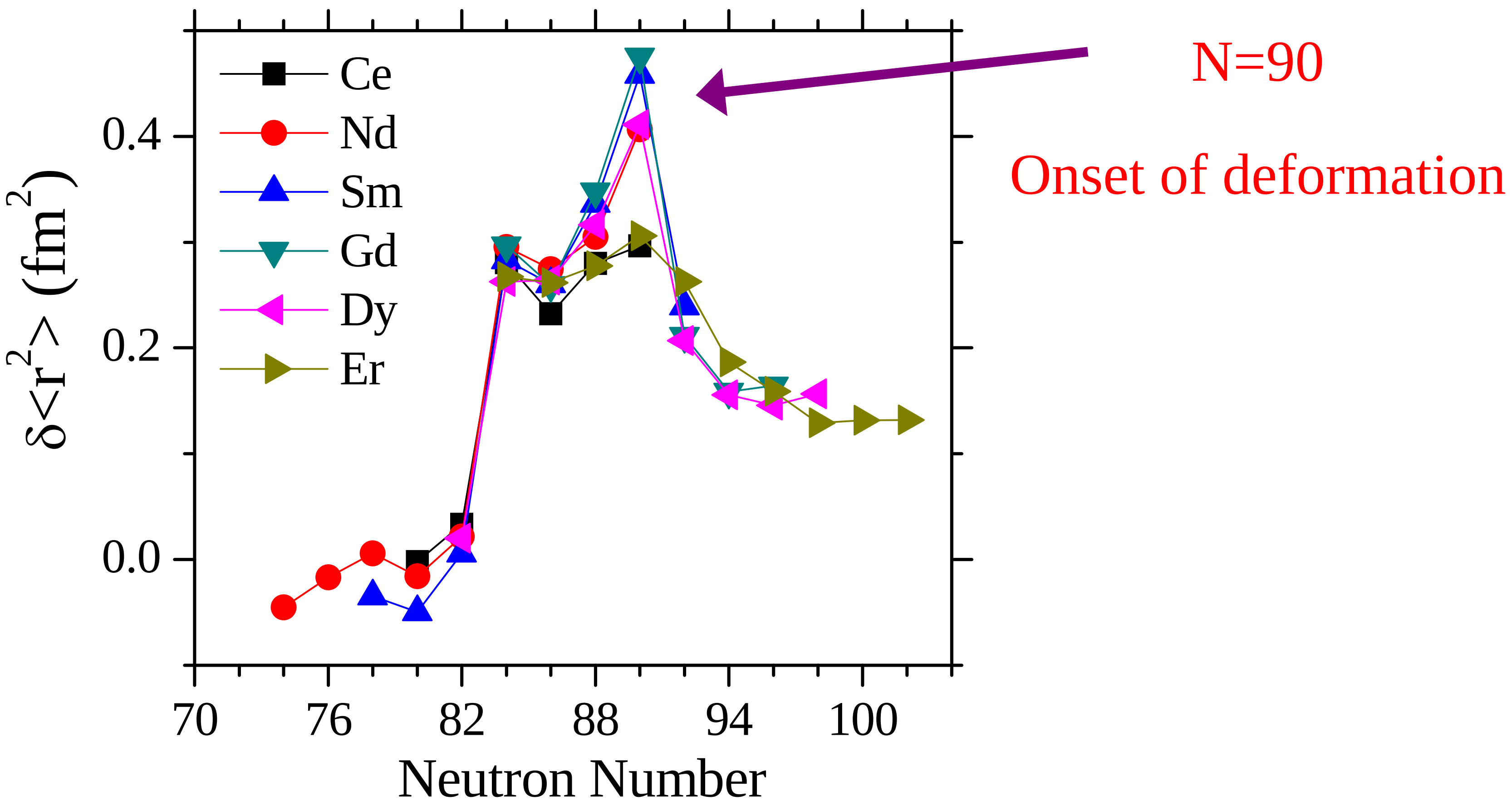
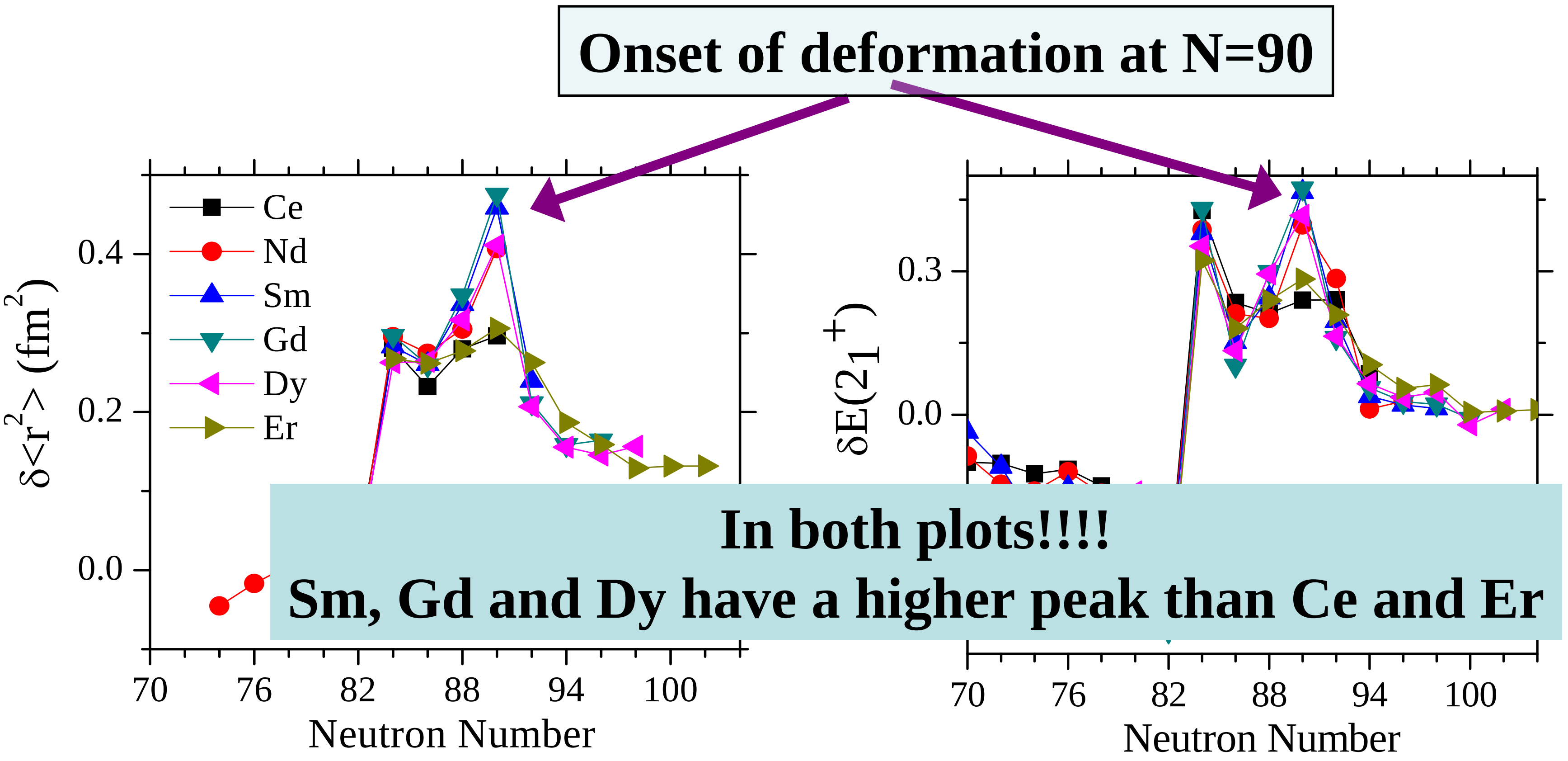
Differential observables (isotope shifts)

$$\delta\langle r^2\rangle_N = \langle r^2\rangle_N - \langle r^2\rangle_{(N-2)}$$



Brix Kopfermann plot

Differential results



$$\delta E(2_1^+)_N = [\ E(2_1^+)_{(N-2)} - E(2_1^+)_{(N)}\ ] / [\ E(2_1^+)_{(N-2)} + E(2_1^+)_N\ ]$$

like a normalization

$<r^2>$

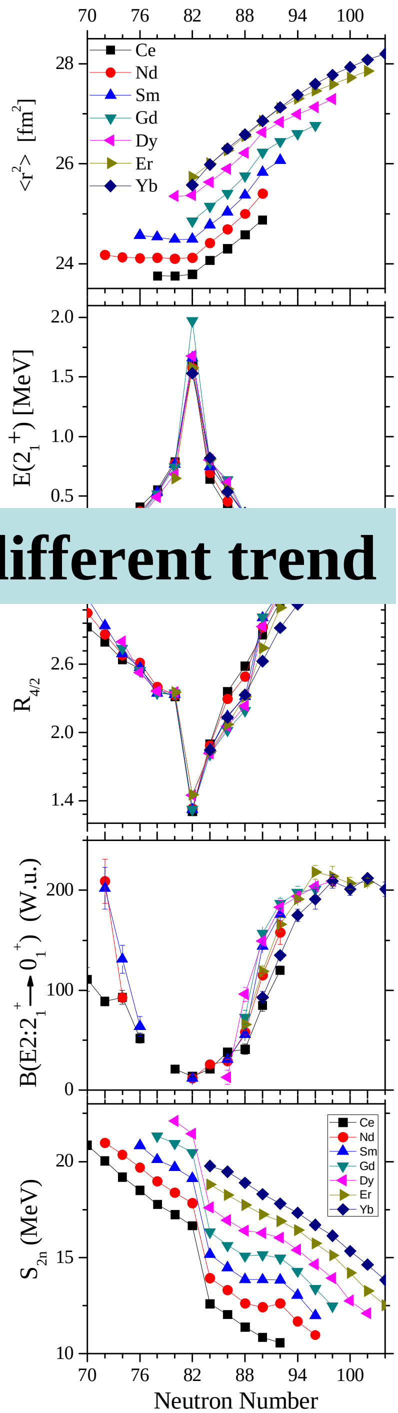
$E(2_1^+)$

Each plot has a different trend

$R_{4/2}$

B(E2)

S_{2n}



Summary

- Masses and structure – sensitively, subtly correlated.
- Why don't we see N=20 shell effect in S_{2n} for Si?
- What is happening for Ne at N=16?
- Well deformed nuclei (many bosons) show changes in S_{2n} if there is a visible change in $E(2_1^+)$
- Striking correlations of differential observables representing single particle motion, nuclear radii and collective observables -- to our knowledge, not recognized heretofore. New way of looking at structural changes (in particular, exotic nuclei).
- Deviations from the differential results can be used to highlight anomalous behavior or possibly spot data worthy of remeasurements (for $\langle r^2 \rangle$, spectroscopic observables, masses)

Collaborators

Rick Casten
Klaus Blaum
Ryan Winkler
Yuri Litvinov
Daria Shubina and ESR-GSI

Humboldt Foundation

THANK YOU

BACKUPS

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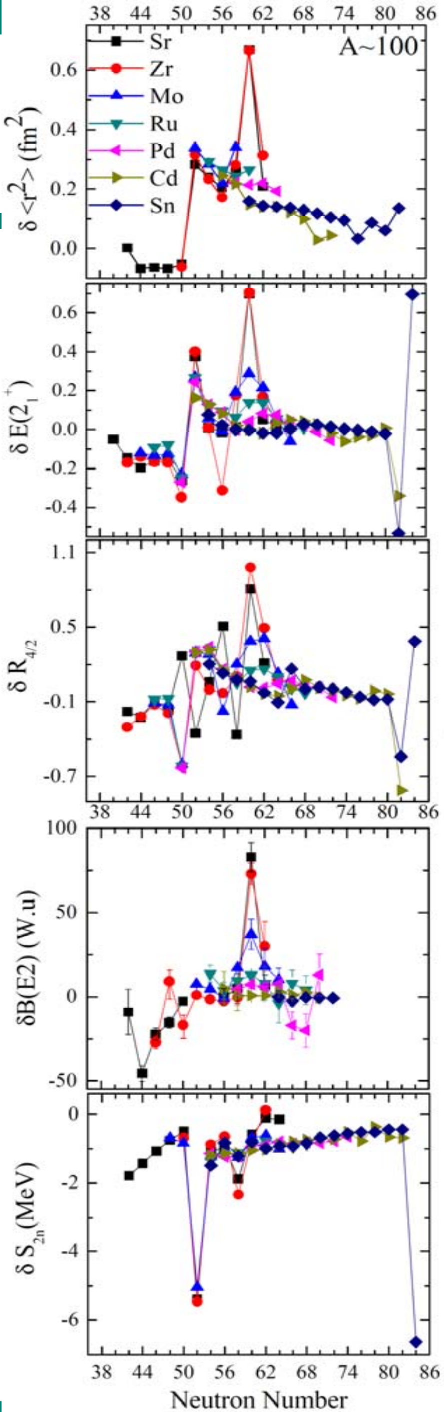
$\delta\langle r^2\rangle$

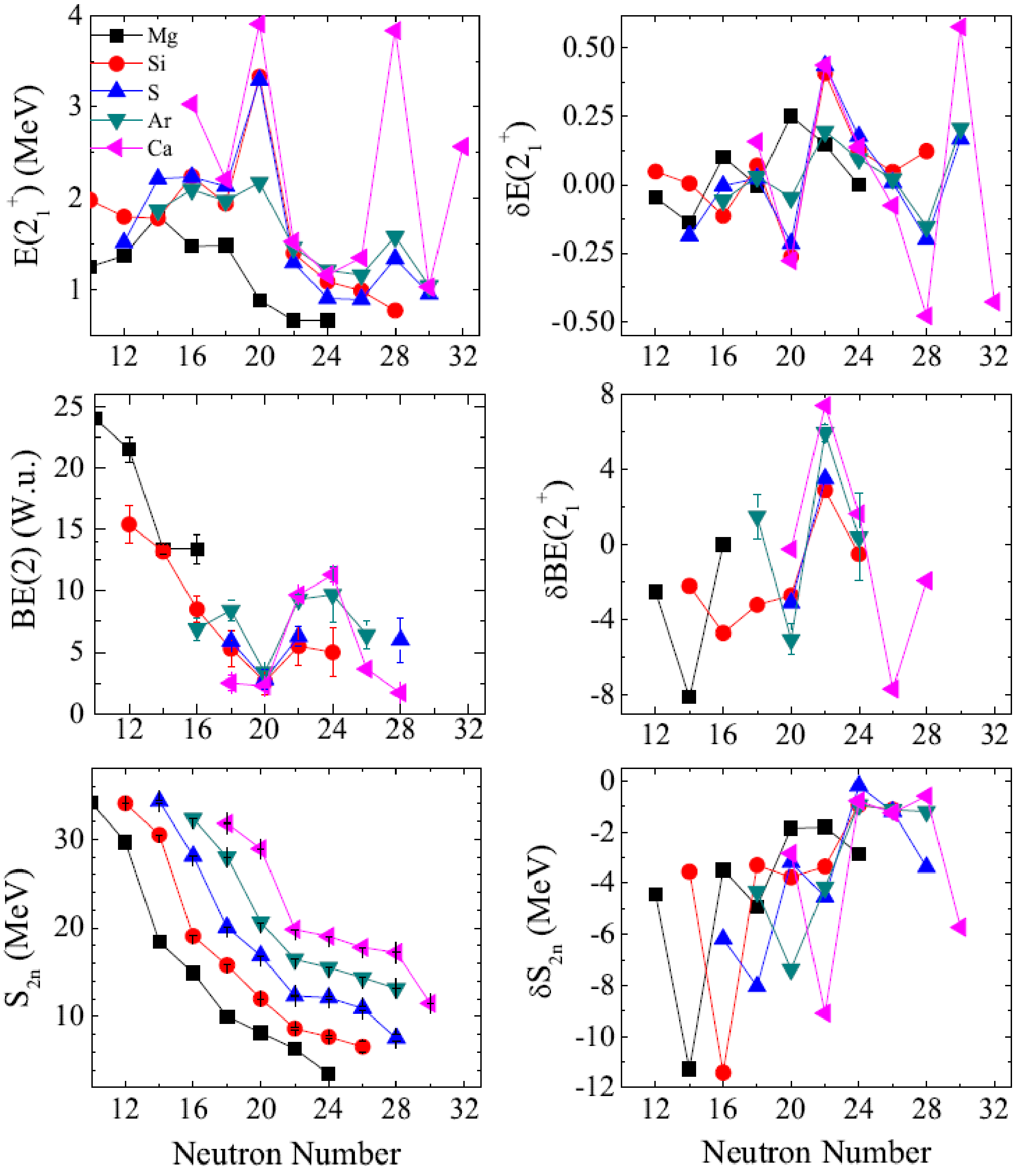
$\delta E(2_1^+)$

$\delta R_{4/2}$

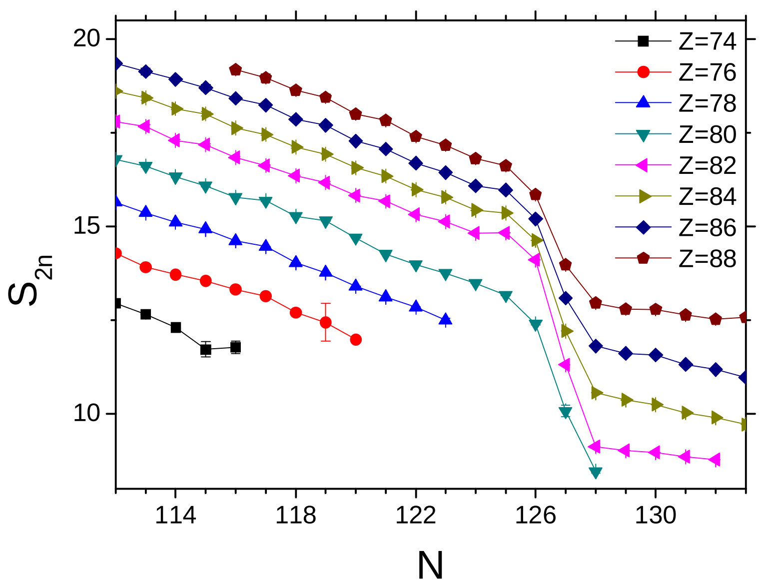
$\delta B(E2)$

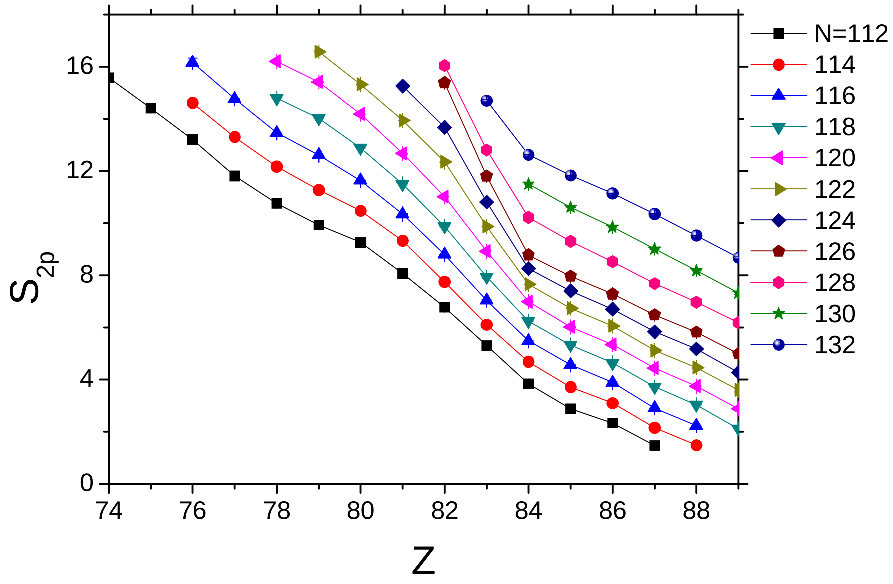
δS_{2n}

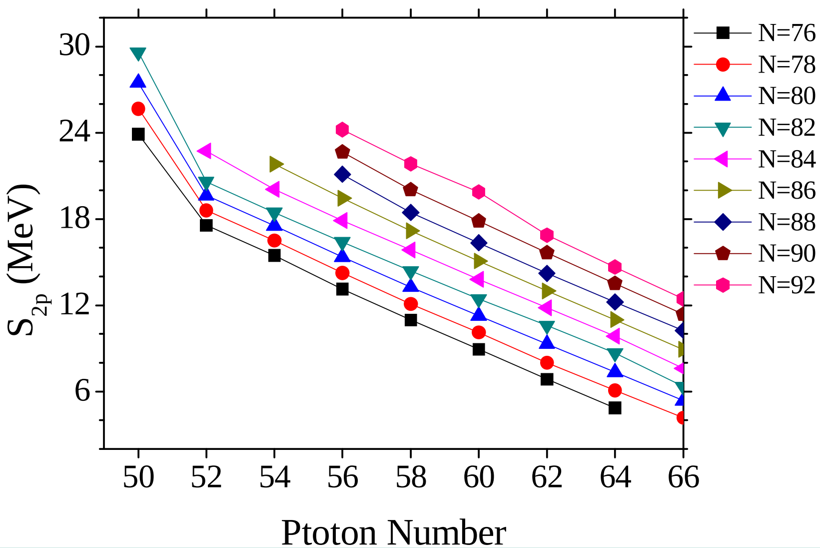



Mg
Si
S
Ar
Ca
E(2$_1^+$) (MeV)
δE(2$_1^+$)
BE(2) (W.u.)
δBE(2$_1^+$)
S_{2n} (MeV)
δS_{2n} (MeV)
Neutron Number
Neutron Number

S_{2n} and S_{2p}







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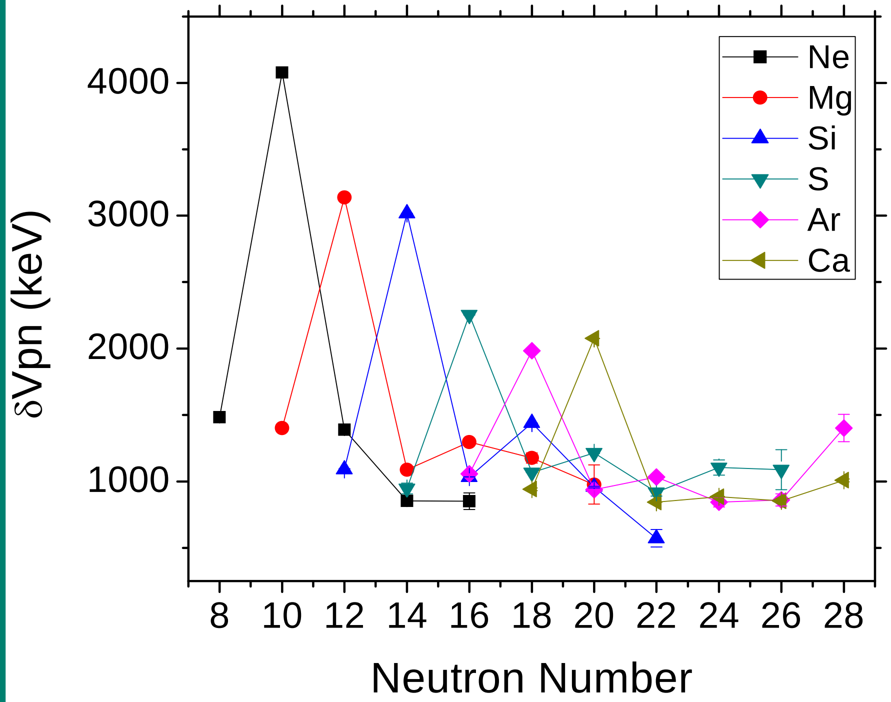
δV_{pn} has singularities for N = Z in light nuclei



- Wigner energy, related to SU(4), spin-isospin symmetry. Physics is high overlaps of the last proton and neutron wave functions when they fill identical orbits.
- Expected to vanish in heavy nuclei due to: Coulomb force for protons, spin-orbit force which brings UPOs into different positions in each shell and protons and neutrons occupying different major shells.

Another useful observables
masses, charge radii

Nuclear Radii

Mean square of charge radius → $\langle r^2 \rangle$ → fm^2

↓

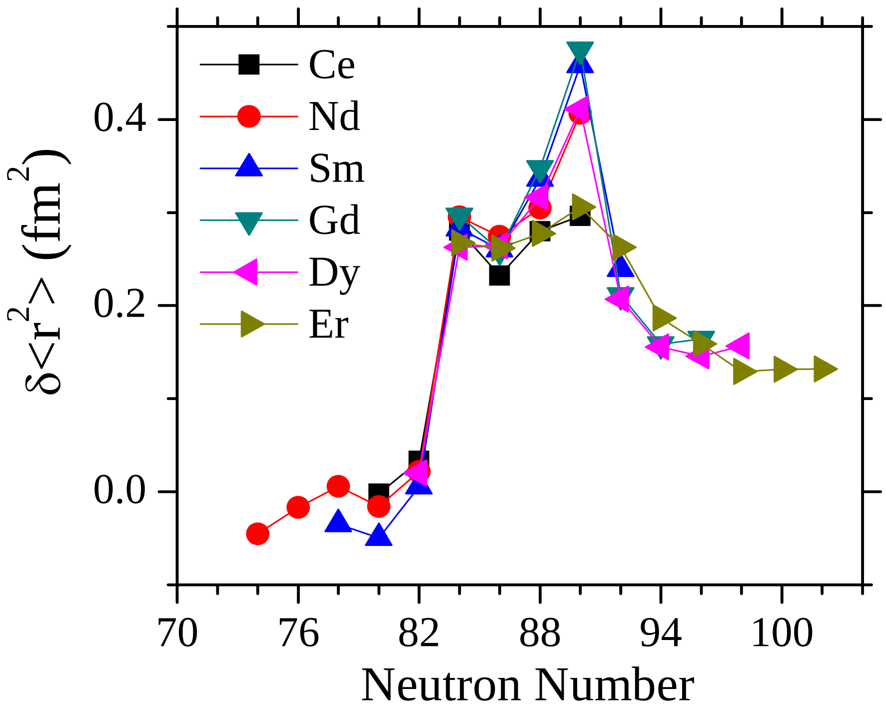
Deformed nuclei have larger radius → sudden increase in $\langle r^2 \rangle$

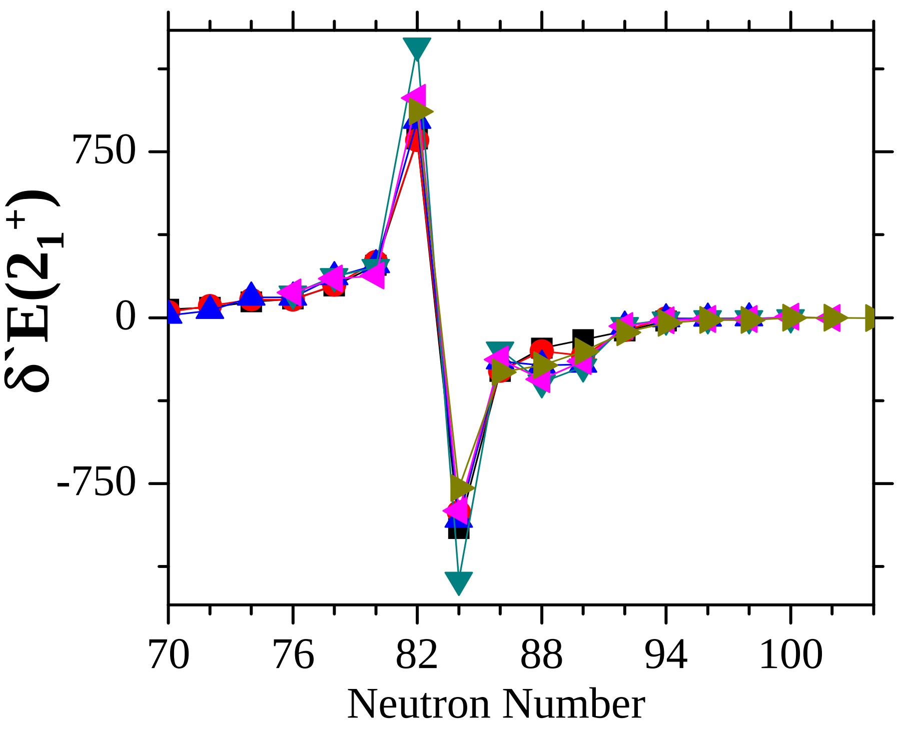
Different ways to understand structural changes with $\langle r^2 \rangle$

- $\langle r^2 \rangle$ as a function of Z or/and N
- Differential observables (**isotope shifts**) as function of Z or/and N

Differential observables with $E(2_1^+)$

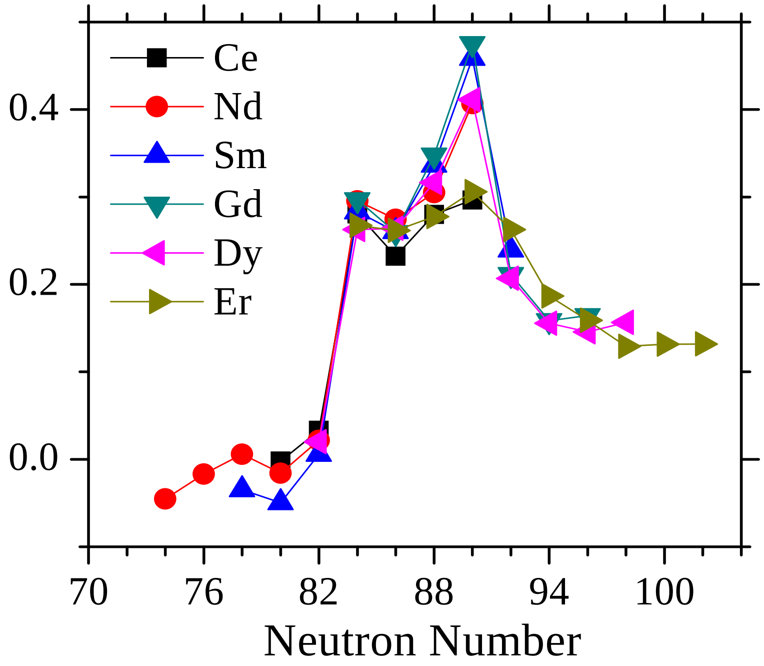
$$\delta`E(2_1^+)_N = E(2_1^+)_N - E(2_1^+)_{(N-2)}$$

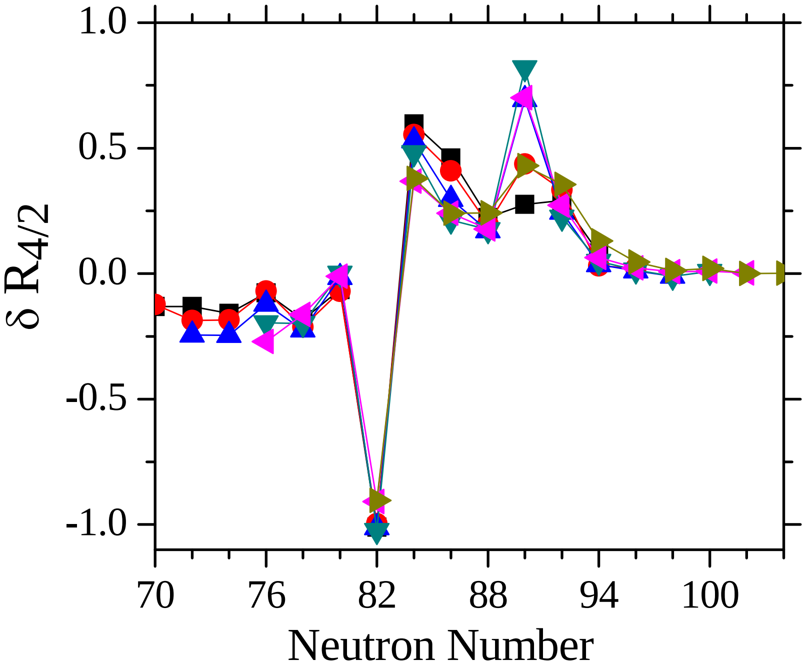




With $R_{4/2}$

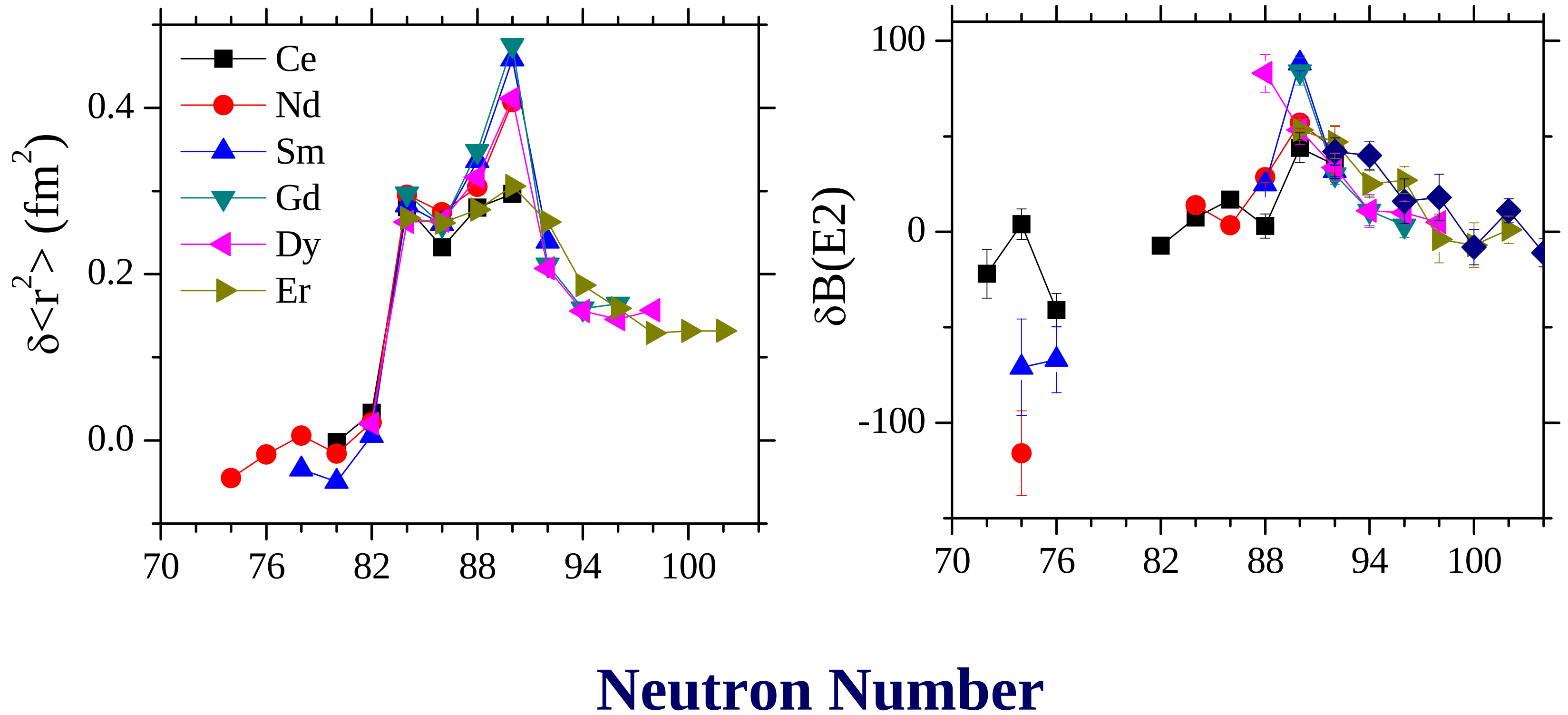
$$\delta R_{4/2} = R_{4/2\,(N)} - R_{4/2\,(N-2)}$$





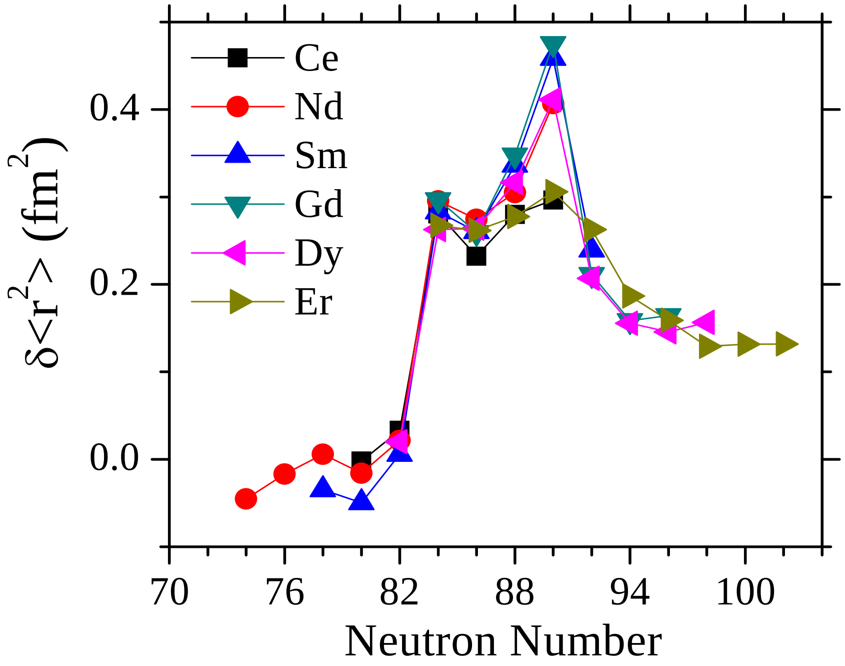
With B(E2; $2_1^+ \rightarrow 0_1^+$)

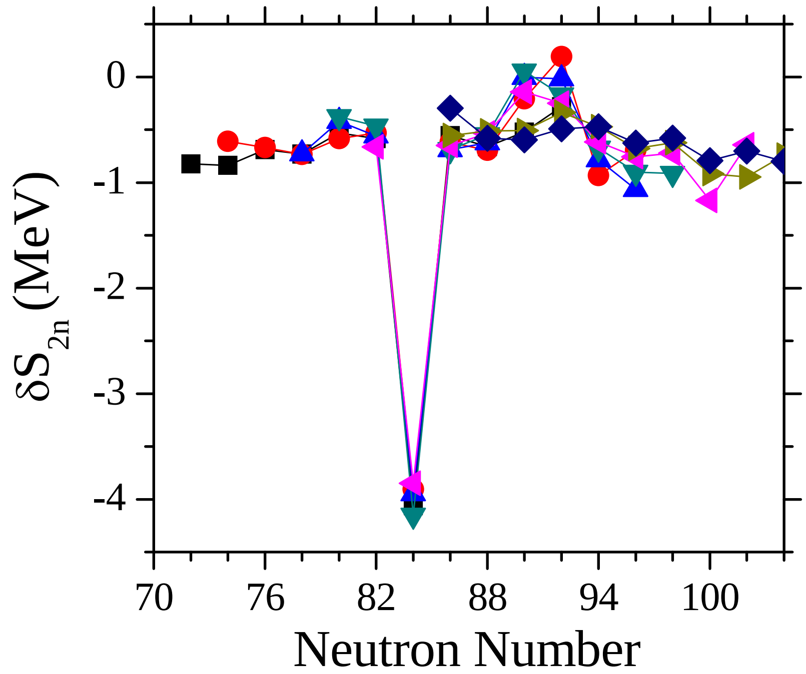
$$\delta B(E2) = B(E2)_{(N)} - B(E2)_{(N-2)}$$



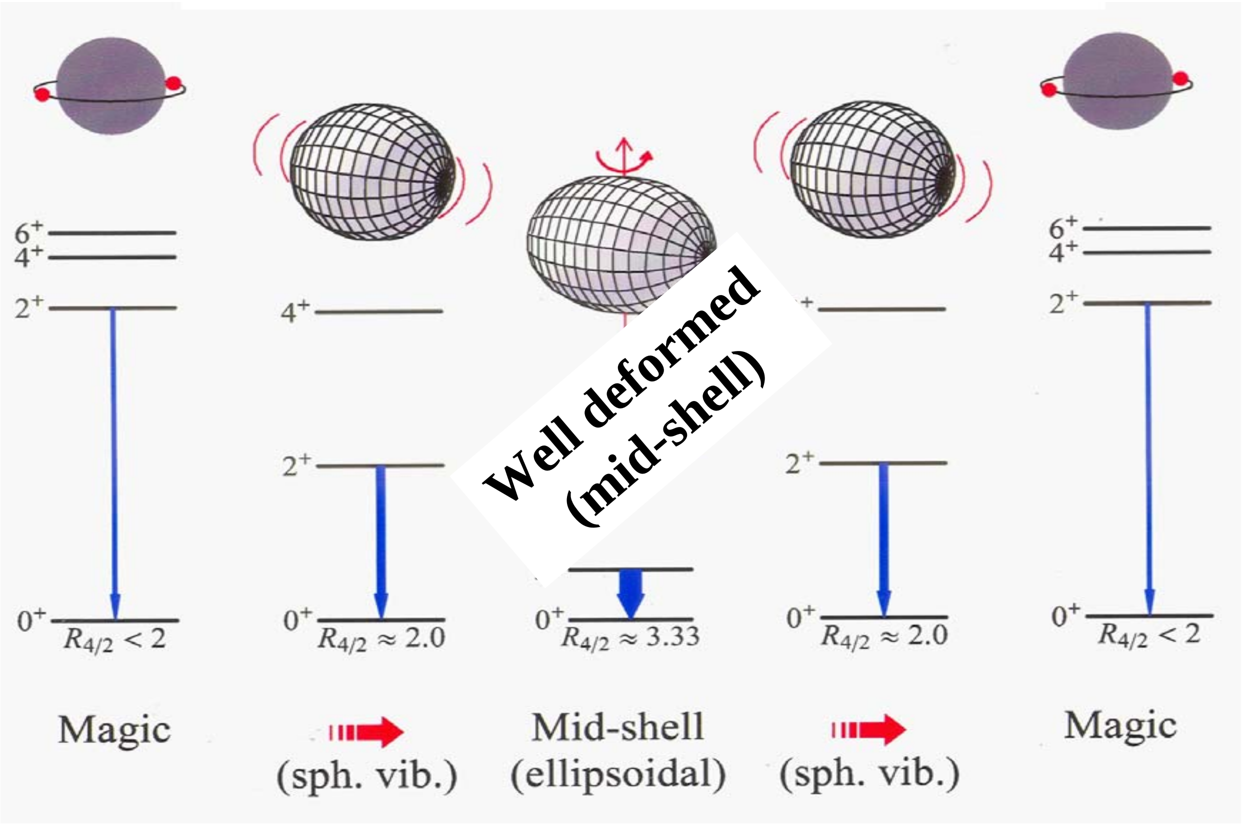
With S_{2n}

$$\delta S_{2n} = S_{2n(N)} - S_{2n(N-2)}$$





Evolution of Nuclear Structure (as a function of valence nucleon number)



Useful Observables for structure

$E(2_1^+)$

$B(E2: 2^+ \rightarrow 0^+)$

$R_{4/2} = E(4_1^+) / E(2_1^+)$

$\langle r^2 \rangle$

Separation Energies (masses)

Origin of collectivity – Residual interactions, especially among the valence protons and neutrons

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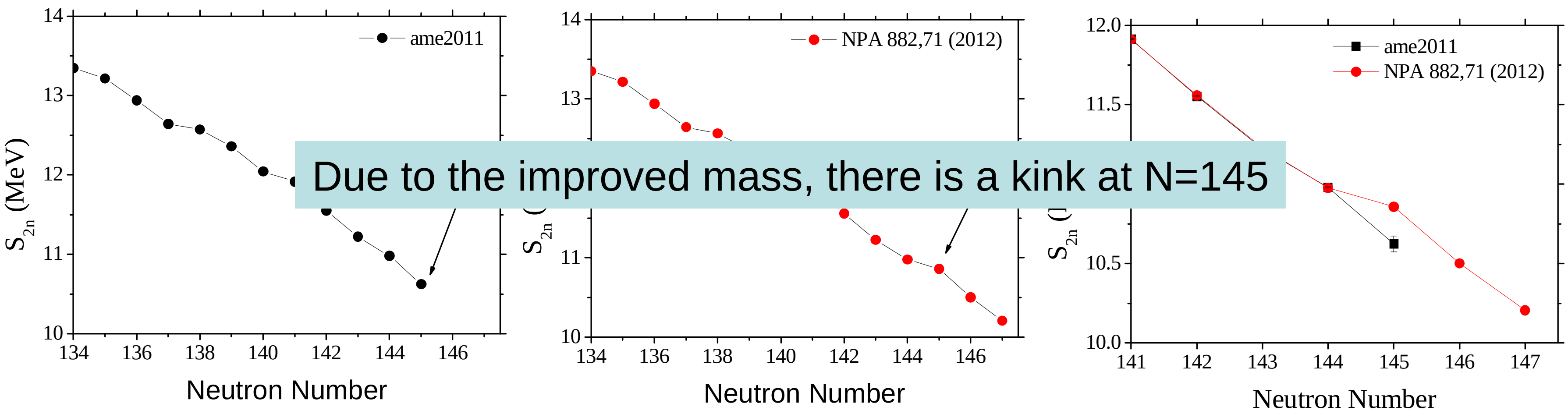
…need to be careful about the interpretation

- NPA, 882, 71 2012 by L.Chen et al.

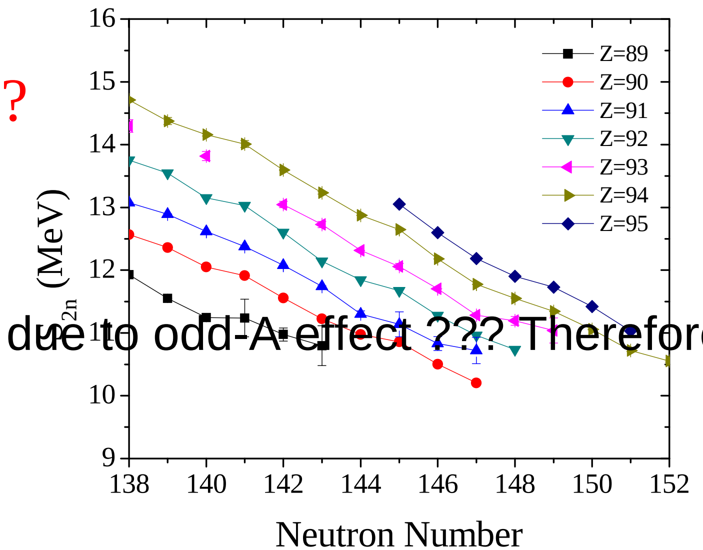
Before the ^{235}Th mass improvement

After the improvement



Due to the improved mass, there is a kink at N=145

Flattening at N=145 ?



QUESTION – due to odd-A effect ??? Therefore we see the kink ??