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Laser spectroscopy and the nature of the shape transition at $N \approx 60$

Performed at JYFL, Jyväskylä, Finland

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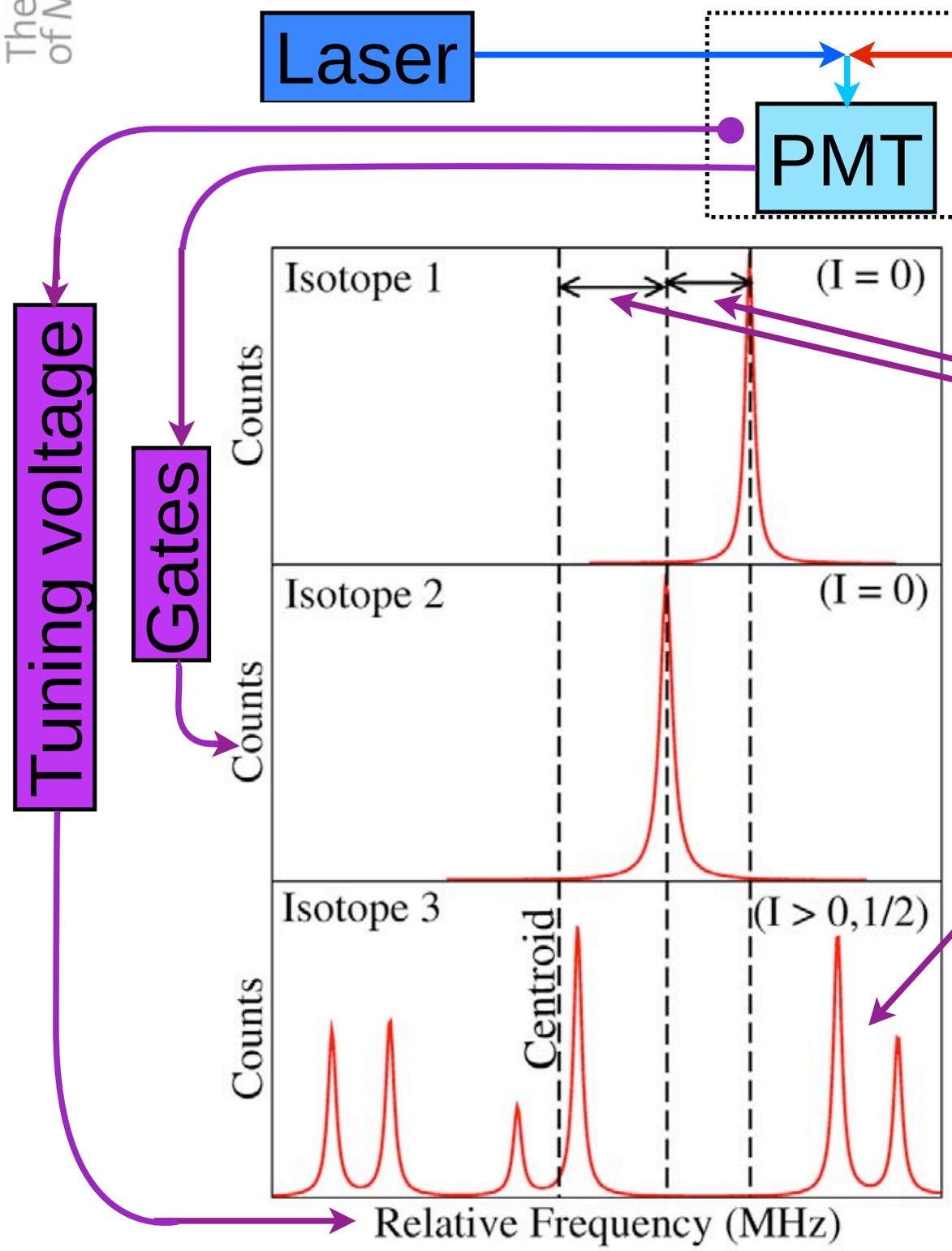
Introduction to laser spectroscopy



Isotope Shifts

→ $\delta\langle r^2 \rangle$

Hyperfine Structure

→ μ

→ Q_s → $\langle\beta_2\rangle$

→ Nuclear spin

(Sensitivity ~200 ions/sec)

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Properties obtained

Experimentally... $\delta\langle r^2\rangle$, μ, Q_s, I

...and may infer...

Size	Shape	Diffuseness
(Droplet model)	(Quadrupole term)	(assumed constant)

$$\langle r^2\rangle = \langle r^2\rangle_{\text{sph}}\left(1+\frac{5}{4\pi}(\langle\beta_2^2\rangle+\ldots)+3\sigma^2\right)$$

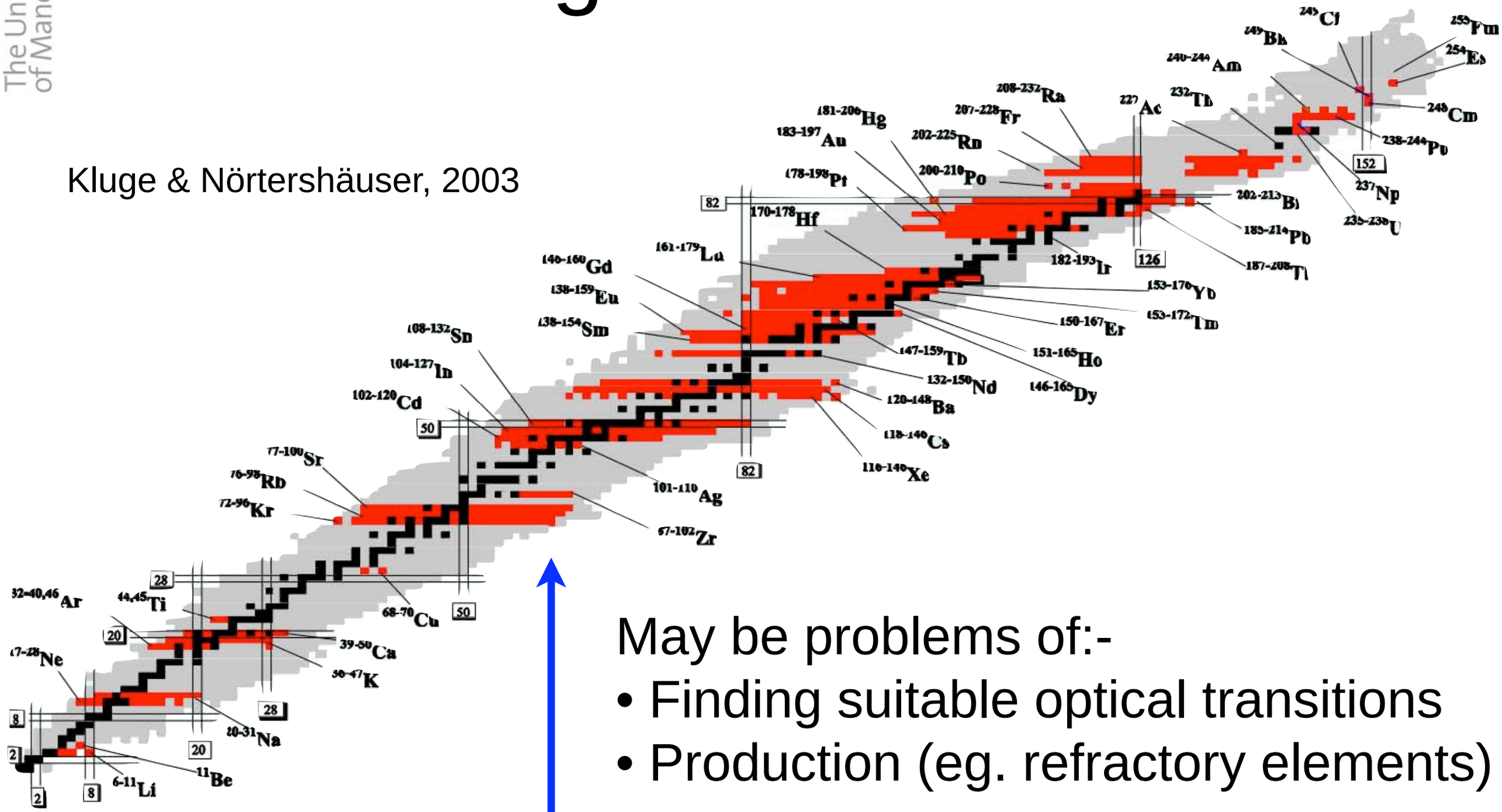
$$\langle\beta_2{}^2\rangle \neq \langle\beta_2\rangle^2$$

$$Q_0 \approx \frac{5Z\langle r^2\rangle_{\text{sph}}}{\sqrt{5\pi}}\langle\beta_2\rangle(1+0.36\langle\beta_2\rangle)$$

$$\beta^2_{\text{rms}} = \langle\beta_2\rangle^2+\left(\langle\beta_2{}^2\rangle-\langle\beta_2\rangle^2\right)=\beta^2_{\text{static}}+\beta^2_{\text{dynamic}}$$

Progress to date

Kluge & Nörtershäuser, 2003



May be problems of:-

- Finding suitable optical transitions
- Production (eg. refractory elements)

N=60

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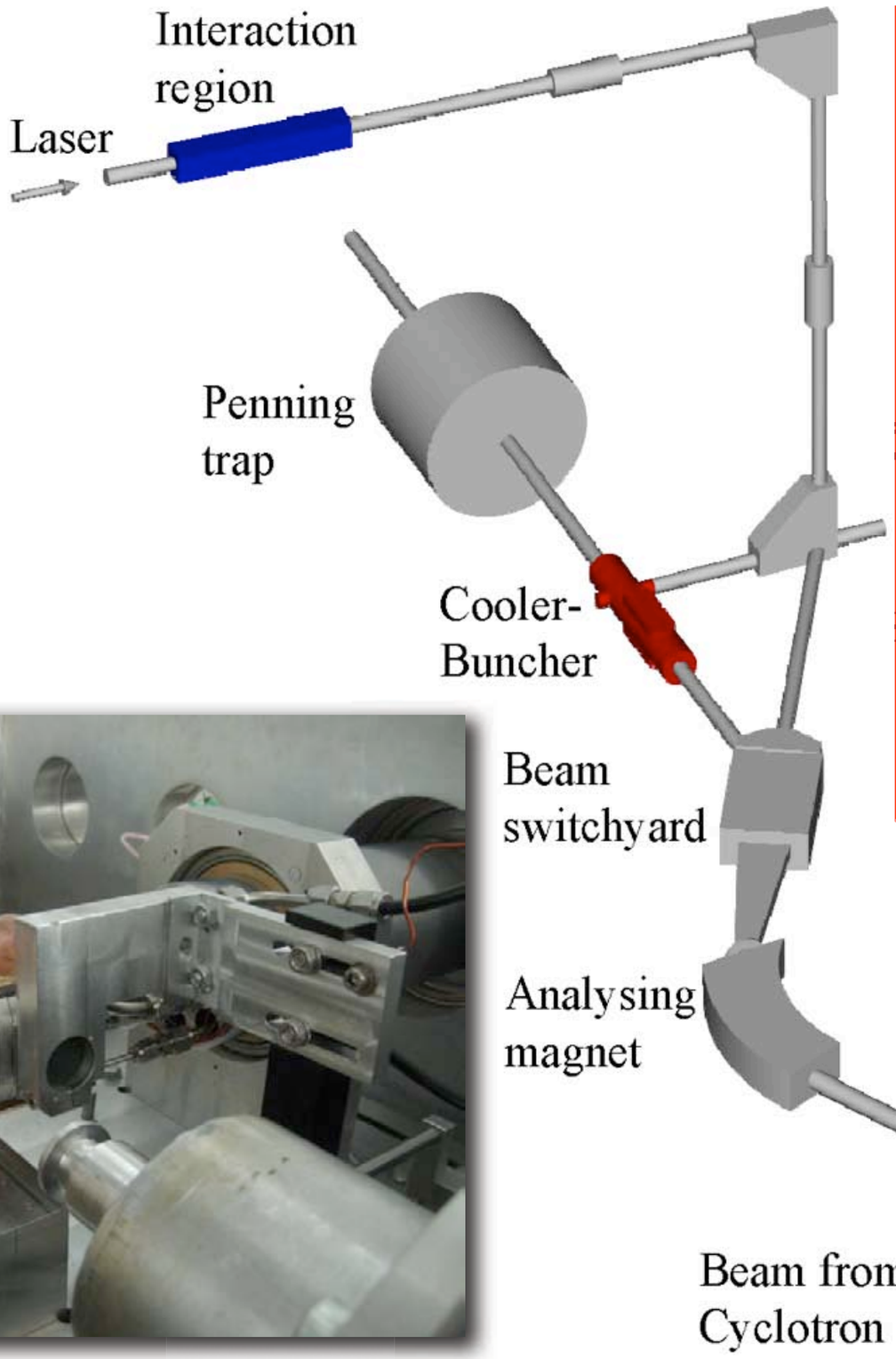
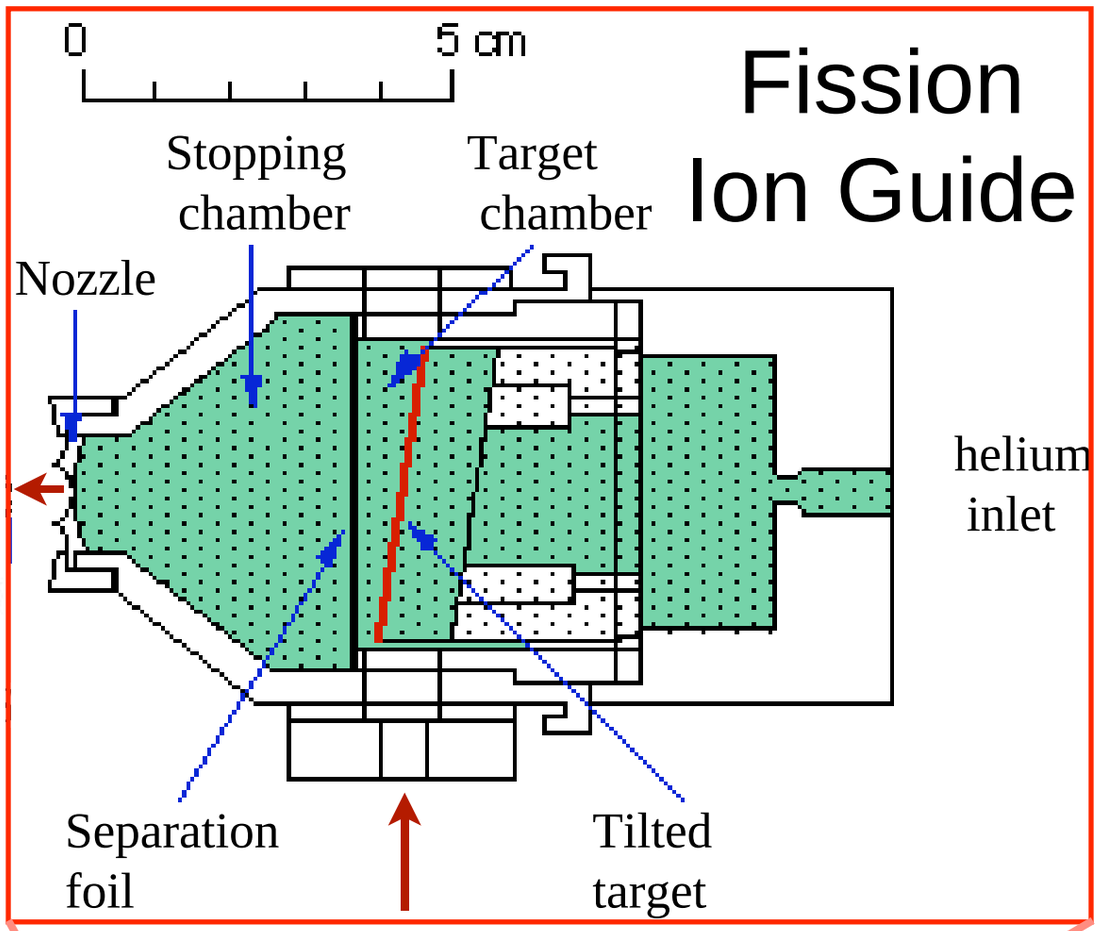
The JYFL IGISOL





- Fast extraction (~1ms)
- Chemically non-selective

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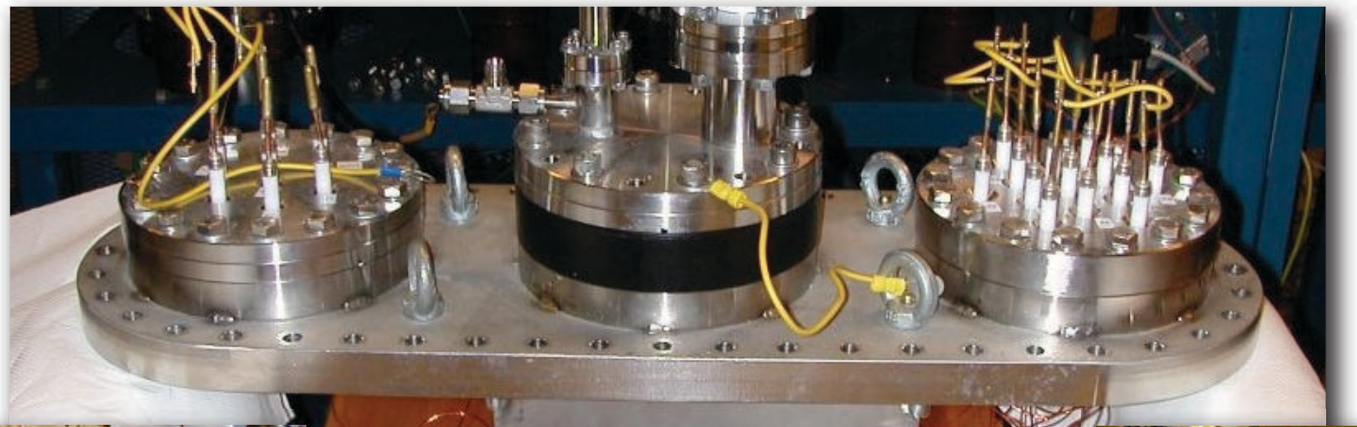
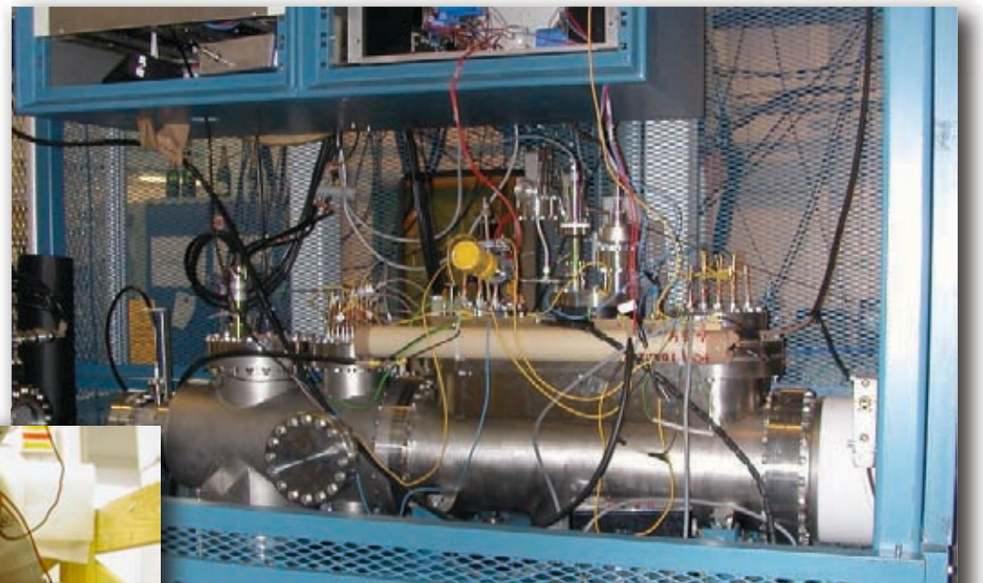
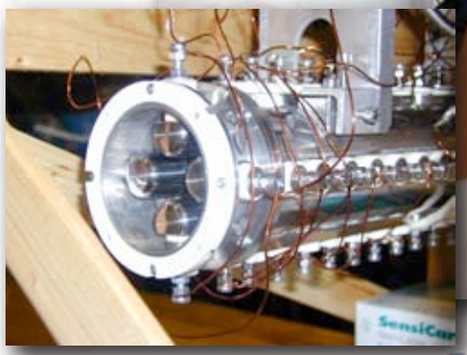
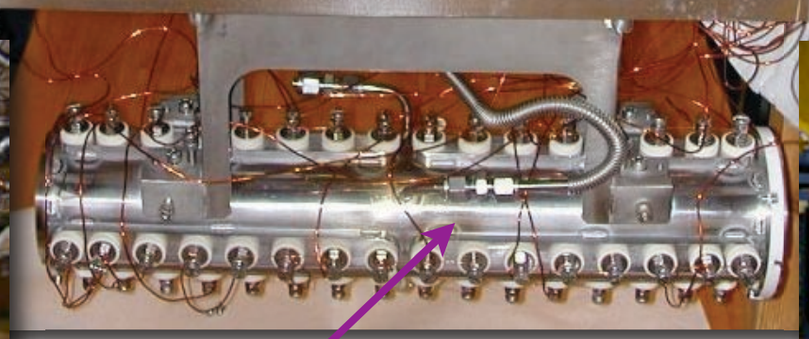
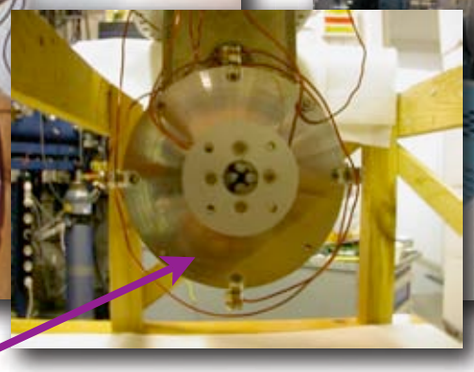
Ion beam cooling

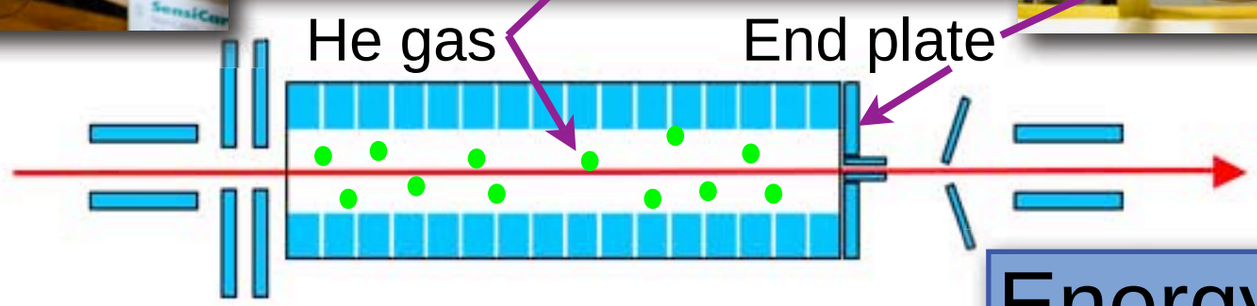


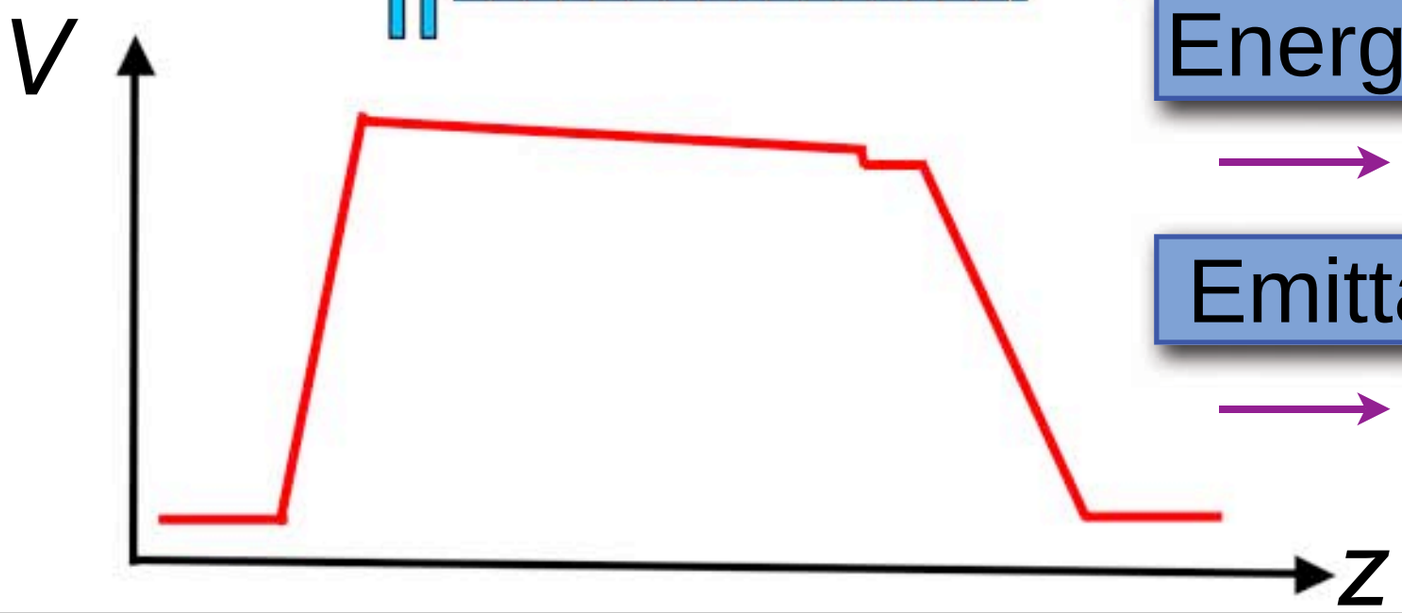












Energy spread: 100→1eV

→ Less spectral broadening

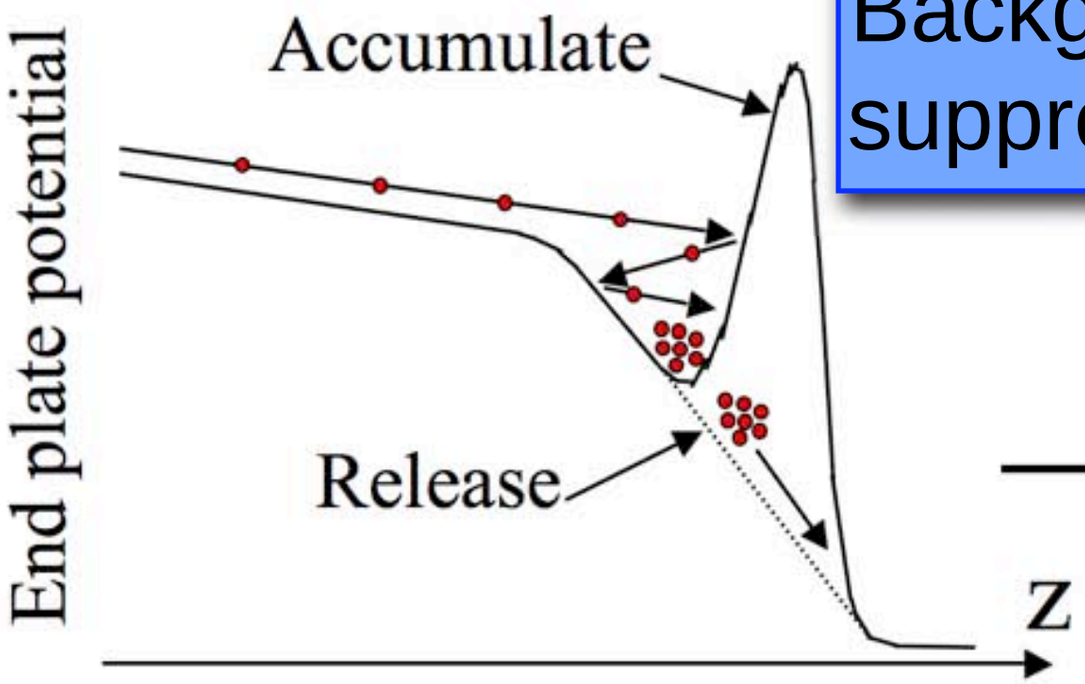
Emittance→3π.mm.mrad

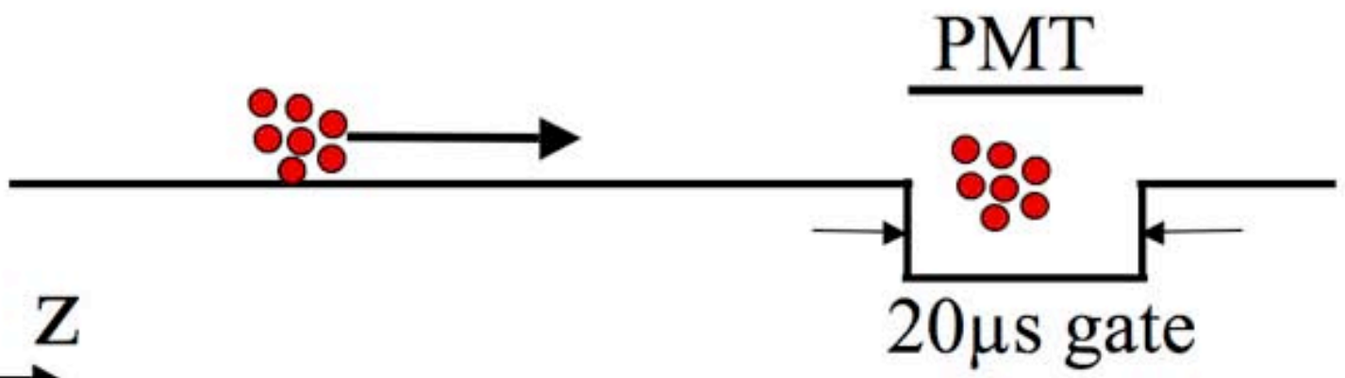
→ Better laser-ion overlap

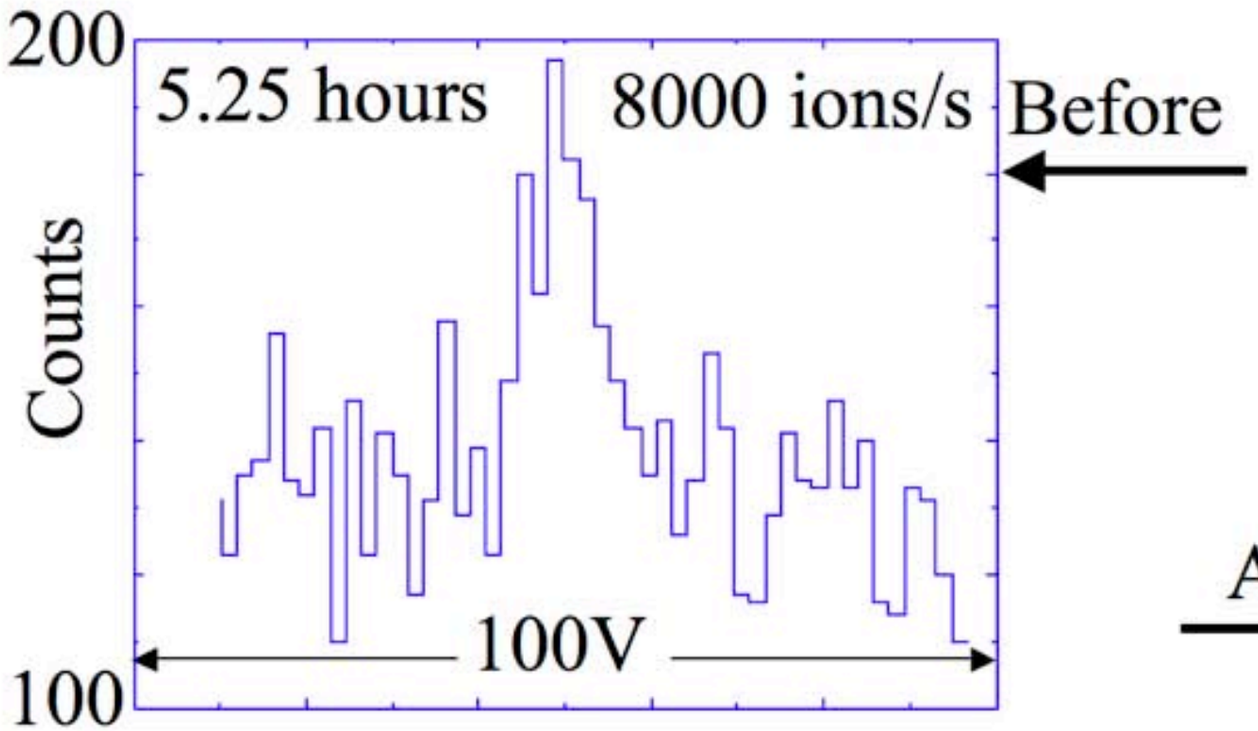
Reduced peak skewing

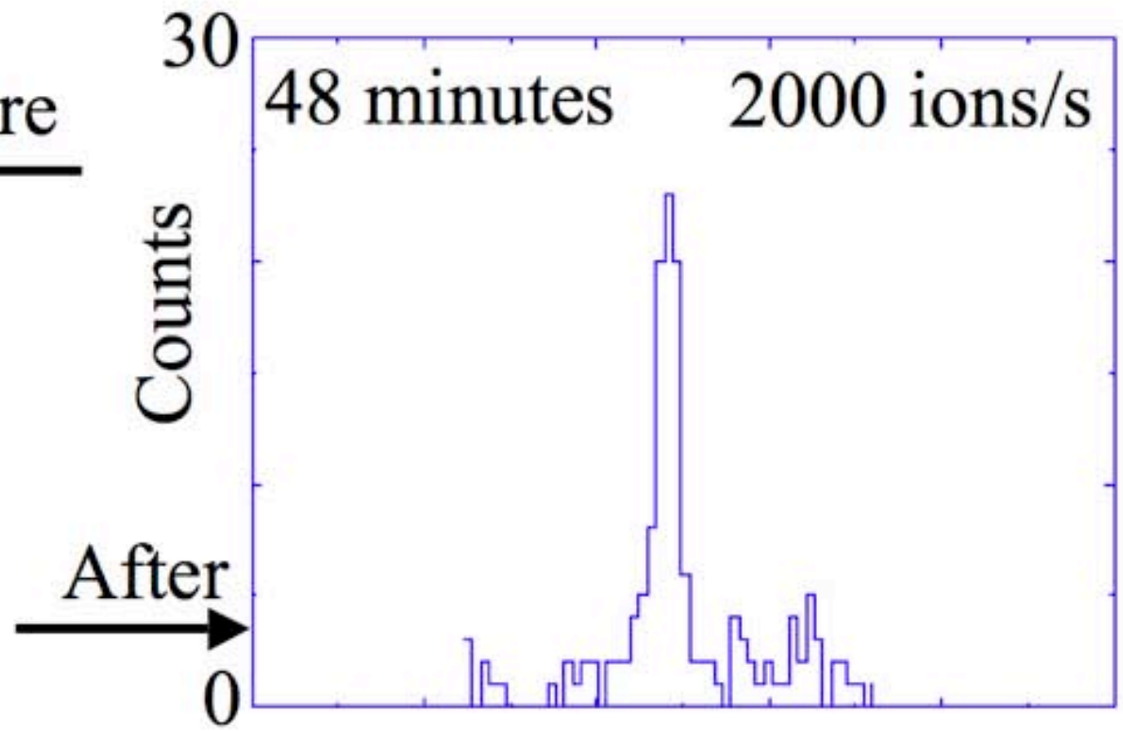
Ion beam bunching

$$\text{Background suppression} = \frac{\text{200ms accumulation}}{\text{20µs gate width}} \sim 10^4$$









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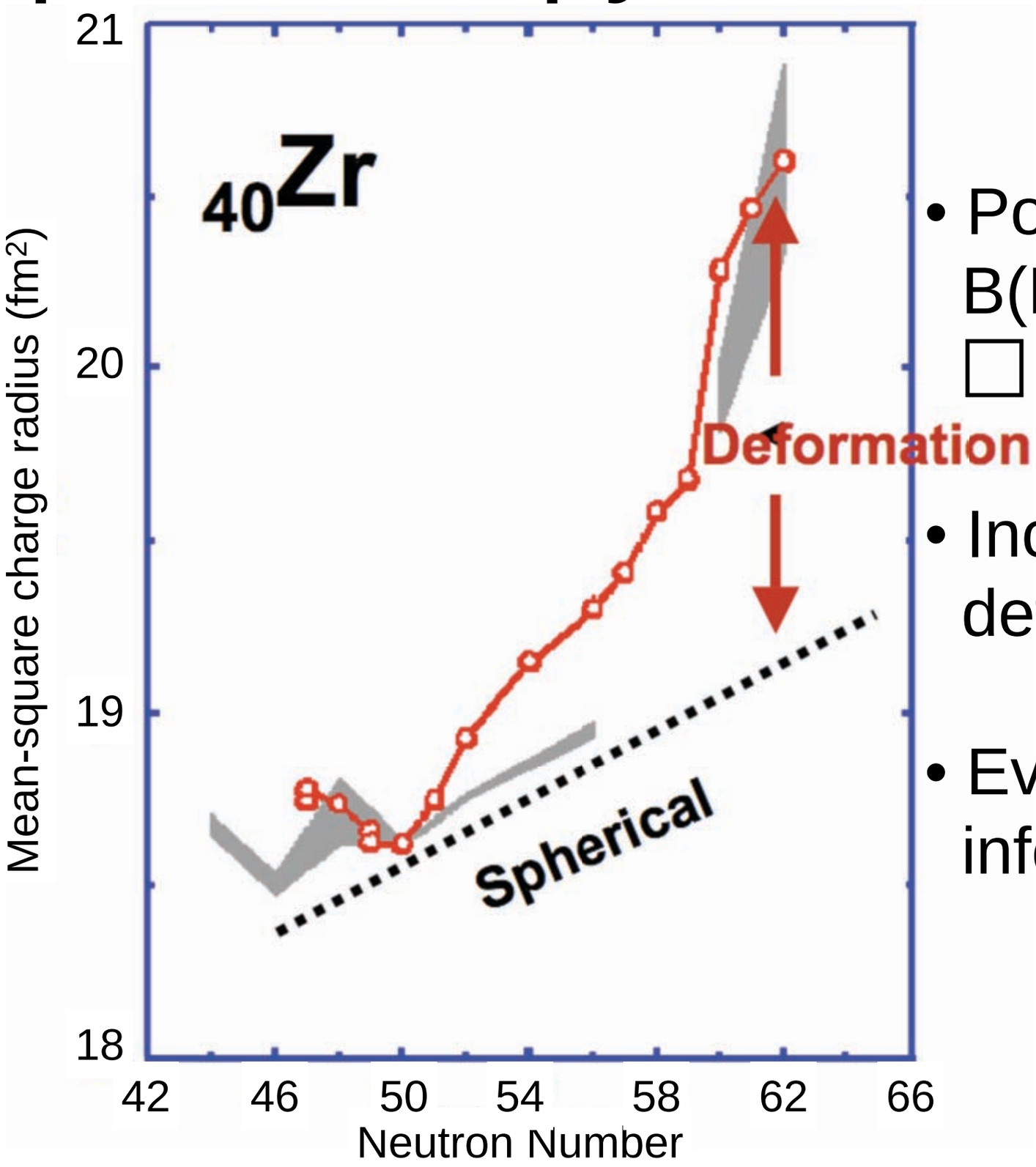
Spectroscopy of zirconium (Z=40)



- Poor match with B(E2)-derived values
  - ☐ missing strengths?
- Inclusion of octupole deformation does not help
- Even-Z element and little information from Q_s

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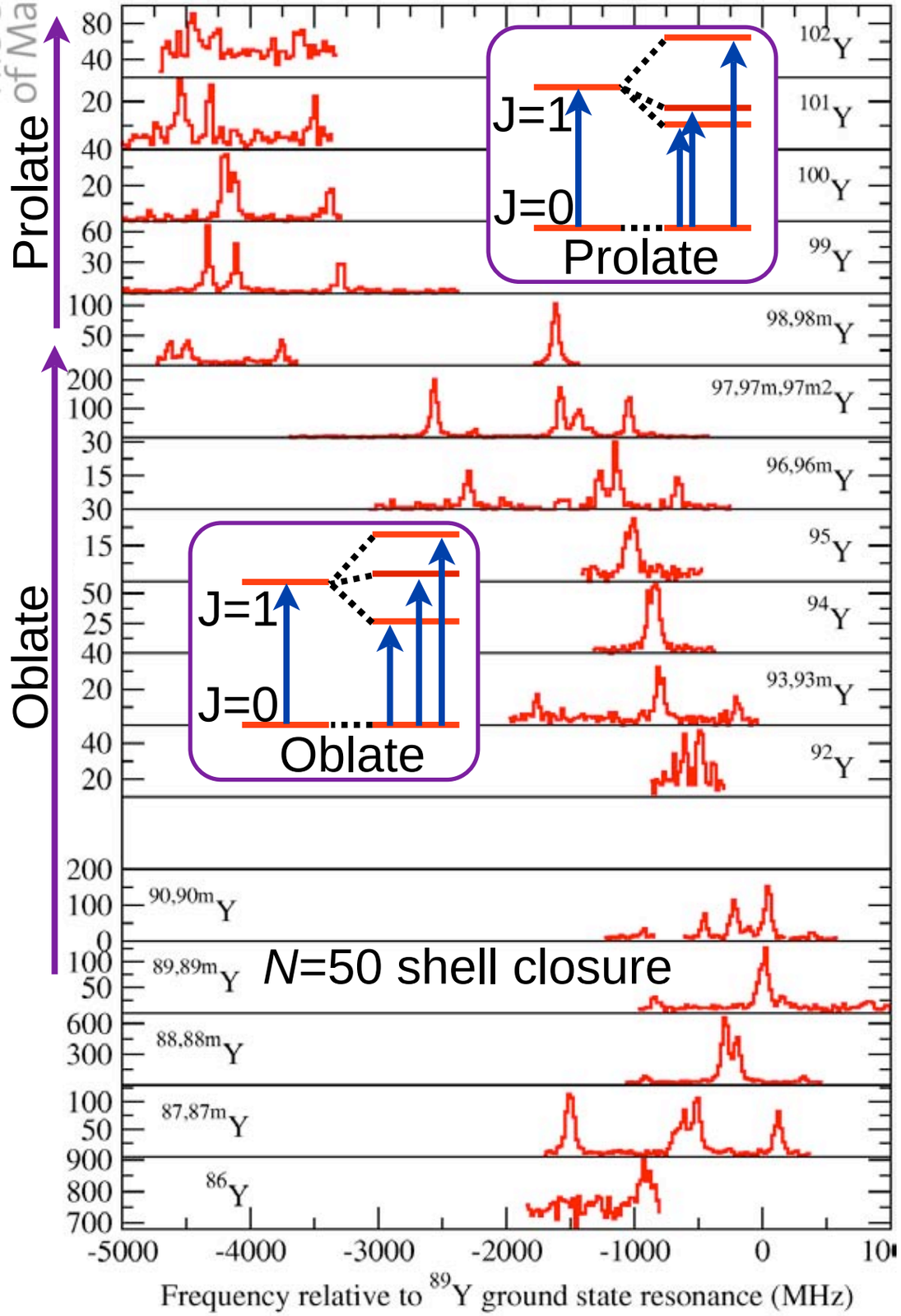
Spectroscopy of yttrium (Z=39)



- Rich in isomers I > 1/2

- J=0 → J=1 electronic transition

→ 3 peaks (maximum) for each nuclear state

→ $\delta\langle r^2\rangle$, μ, Q_s (but *not* the spin)

- ^{98m}Y (N=59) well deformed

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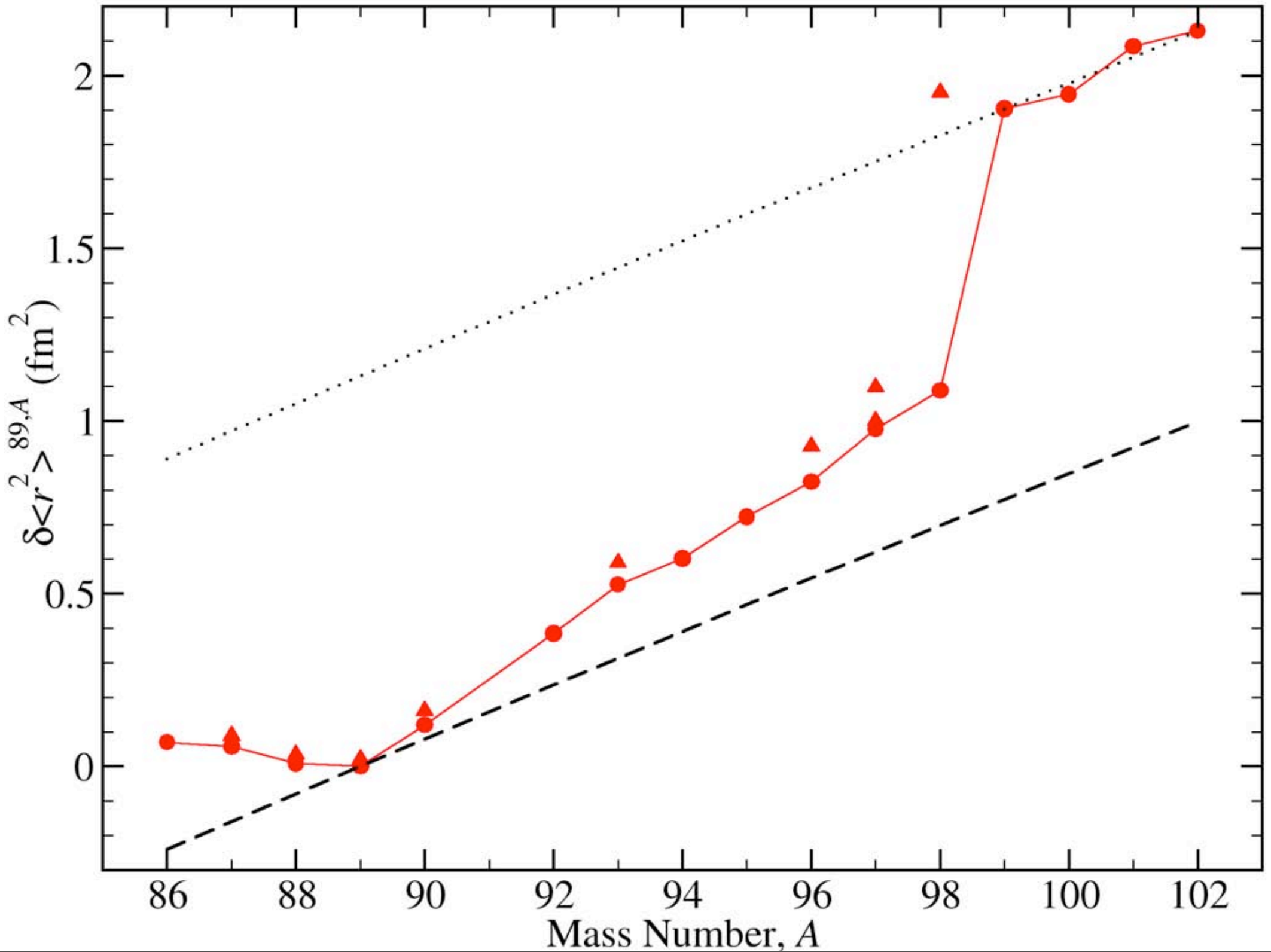
Yttrium charge-radii



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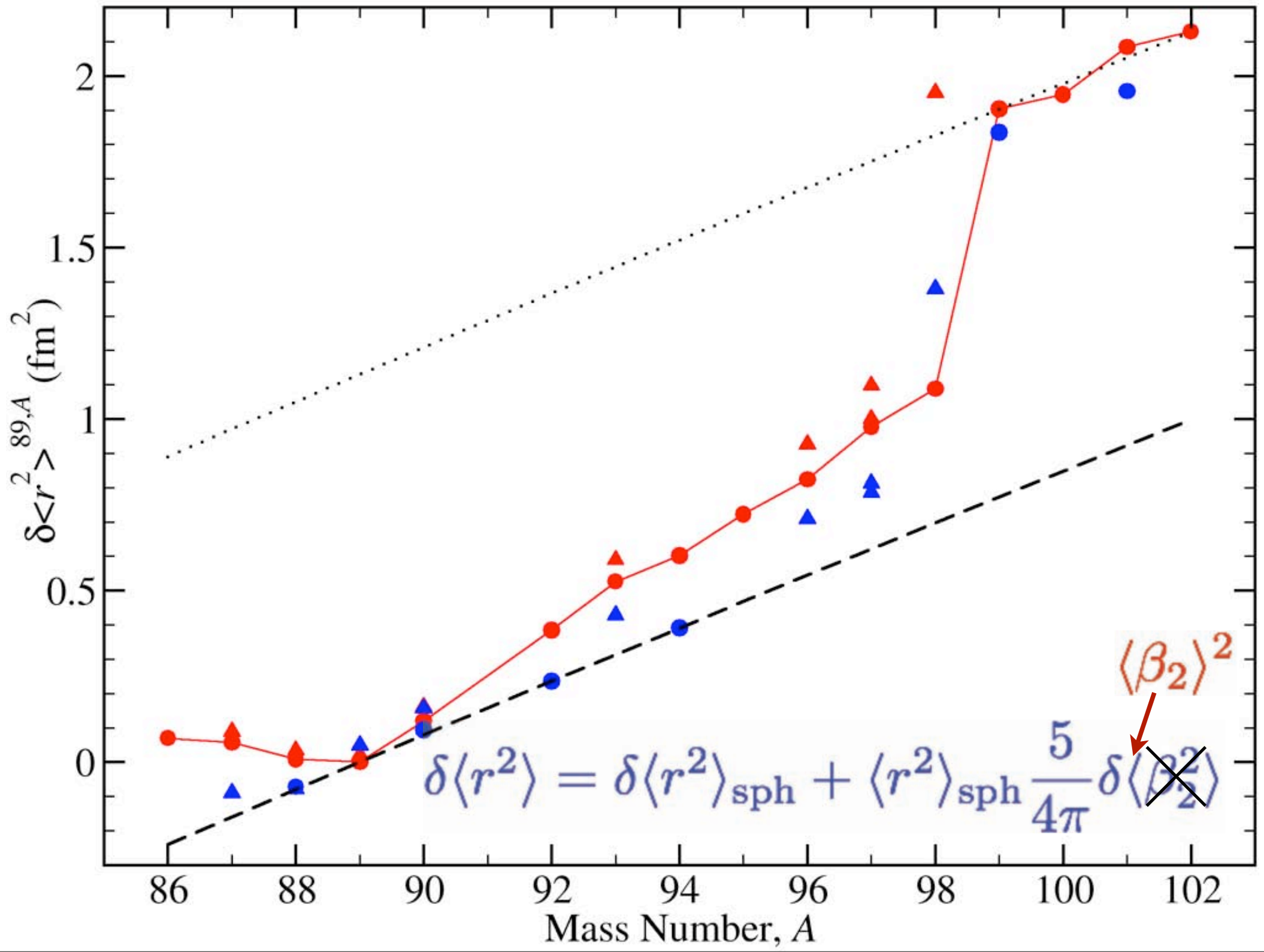
Droplet model analysis

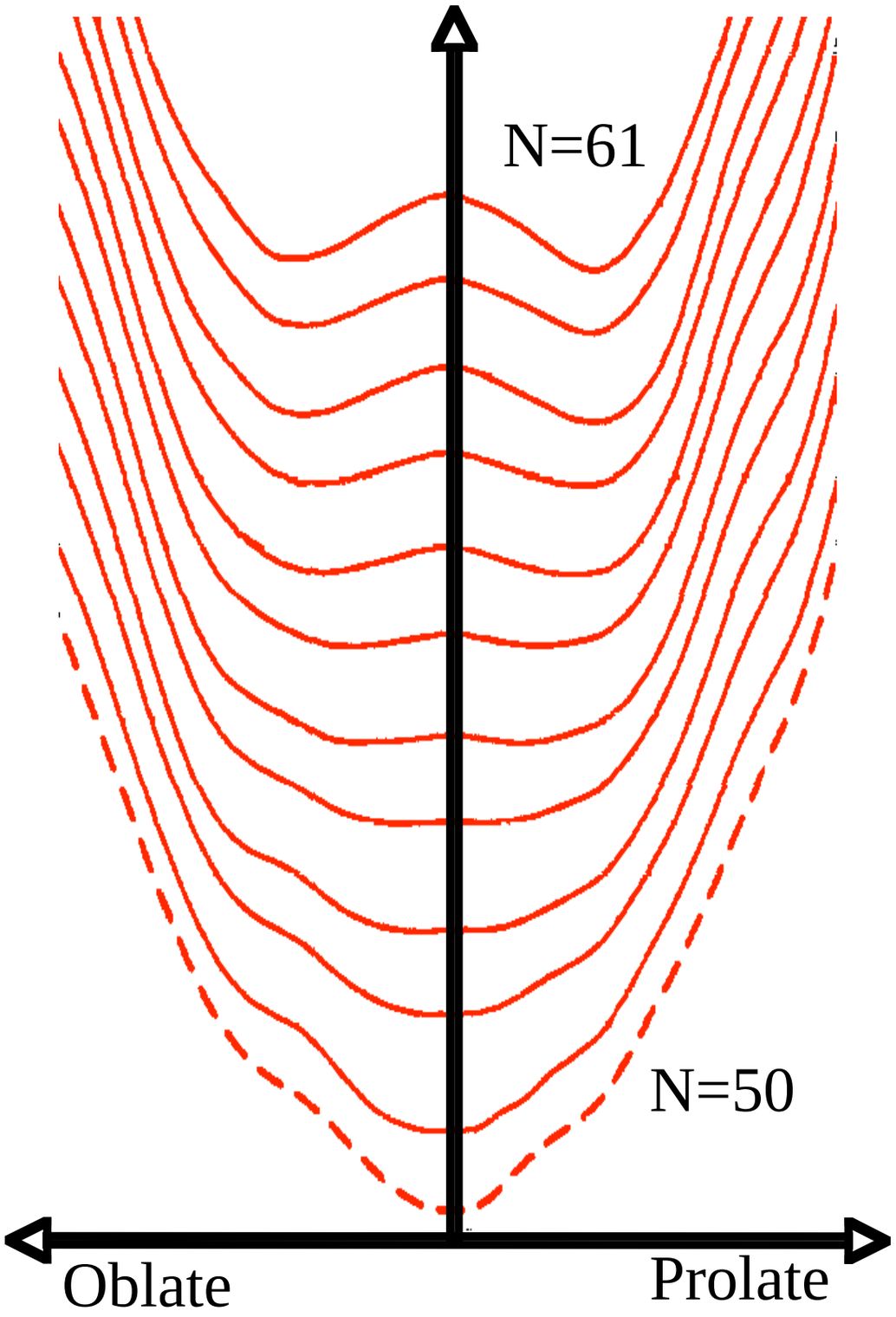


Potential energy surfaces

Potential well splits
(strong prolate favourable)

Potential well flattens
(increases β_2-softness)

Near-spherical nuclei



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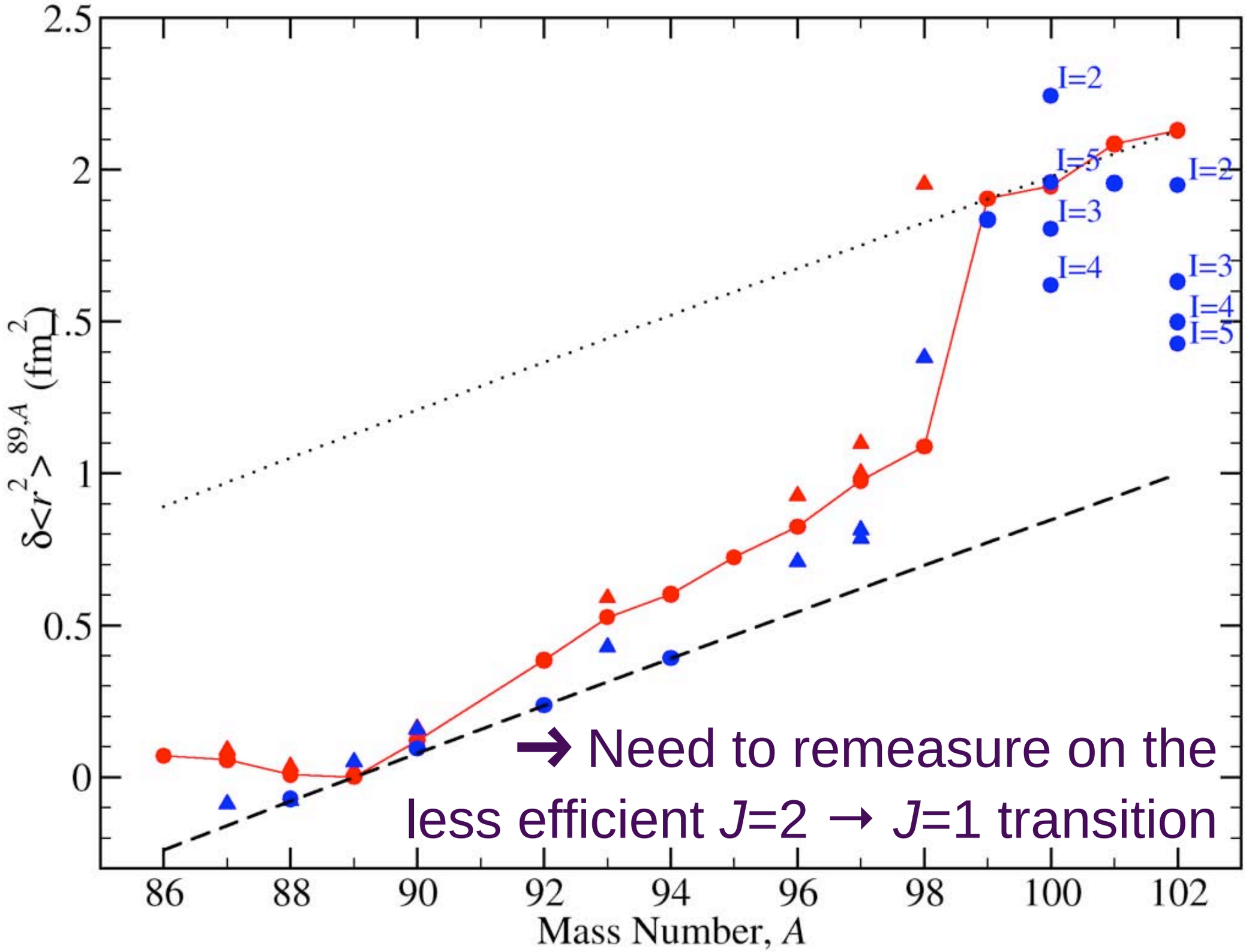
Charge radii (A=100,102)



→ Need to remeasure on the less efficient J=2 → J=1 transition

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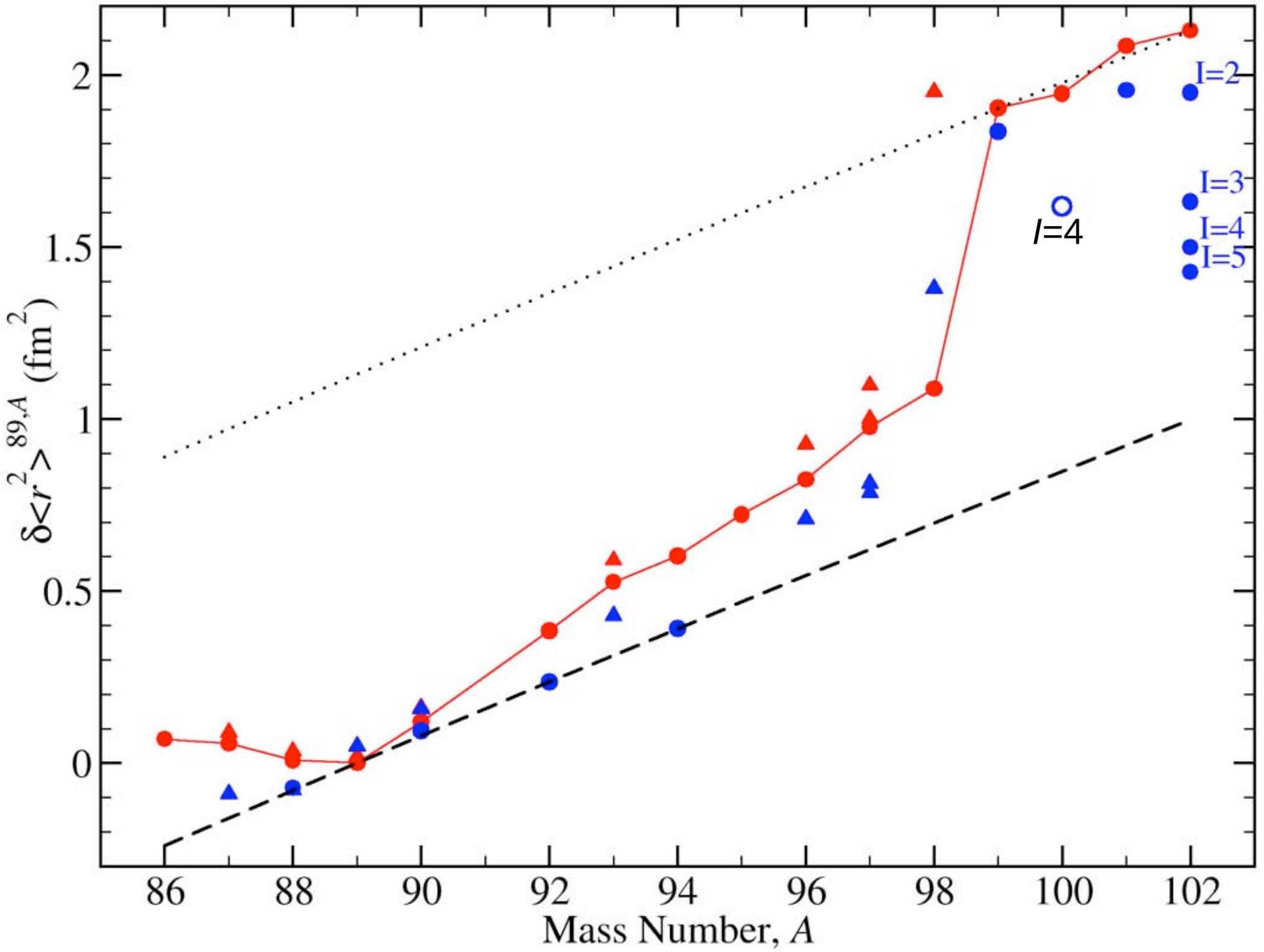
Charge radii (A=100,102)



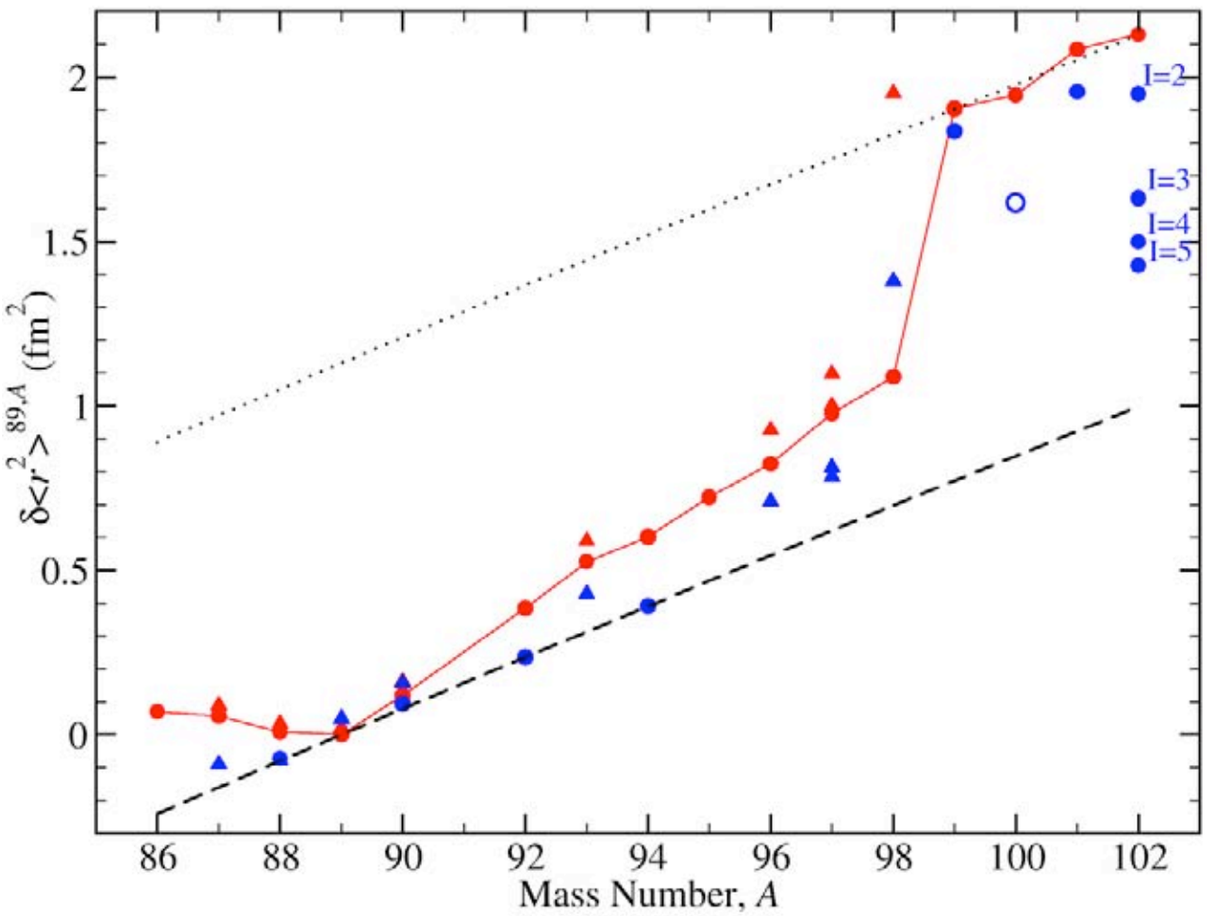
Possibilities....

- Problem with the projection?

$$Q_0 = Q_s \frac{(I+1)(2I+3)}{I(2I-1)}$$

- *A*=100 (and heavier even-*A* *i*sotopes) are 98m-like?

- Has an *isomeric* state been observed instead?



Conclusions

- Spectroscopy performed on 25 isotopes and isomers (I >1/2) of yttrium, across N=60 shape change

- Yields $\delta\langle r^2\rangle$, μ (I > 0), Q_s (I > 1/2).

- Weak, but increasing, oblate deformation before the shape change, with increasing β-softness.

- ^{98m}Y lies at extreme point before transformation to rigid prolate shape at ^{99,101}Y

- ^{100}Y less clear - which state observed?

- Spectroscopy of Niobium (Z=41)

The Collaboration

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