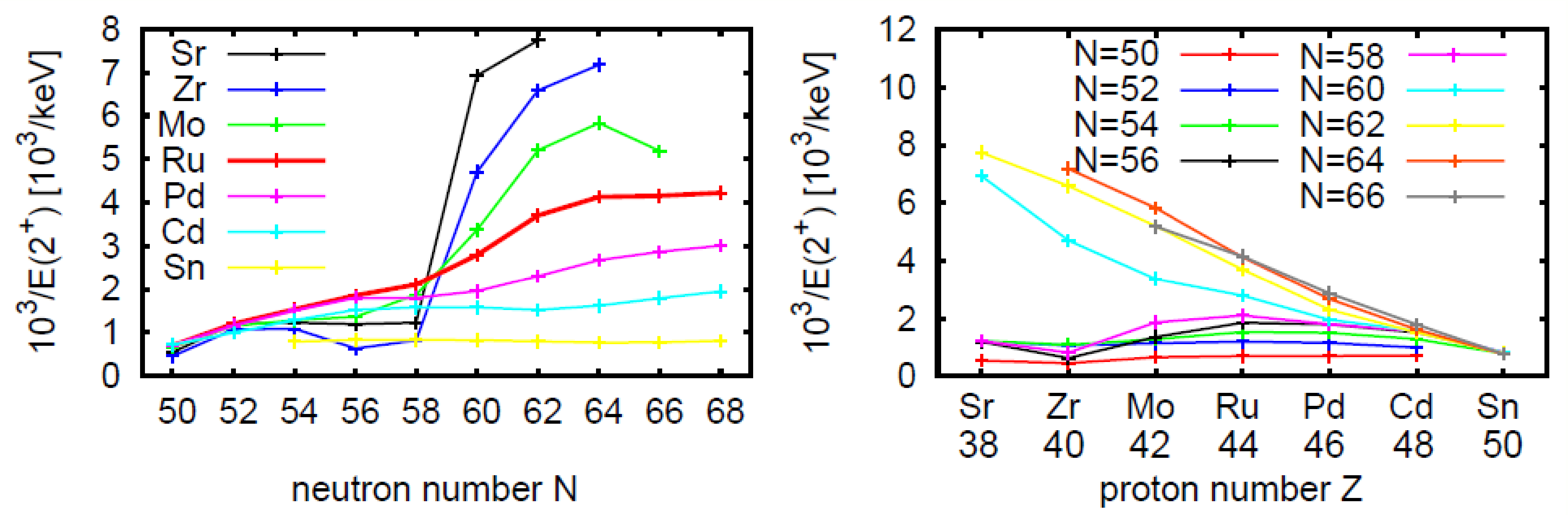
Yale

Overview:

- Evolution of Structure at A~100
- g-Plunger / TDRIV Technique for Simultaneous Lifetime and g Measurements
- Application to Pd, Ru, and Zr Isotopes
- Method explained on Pd's, Results ...

Some Challenges at A~100

fast vs gradual changes in deformation / collectivity



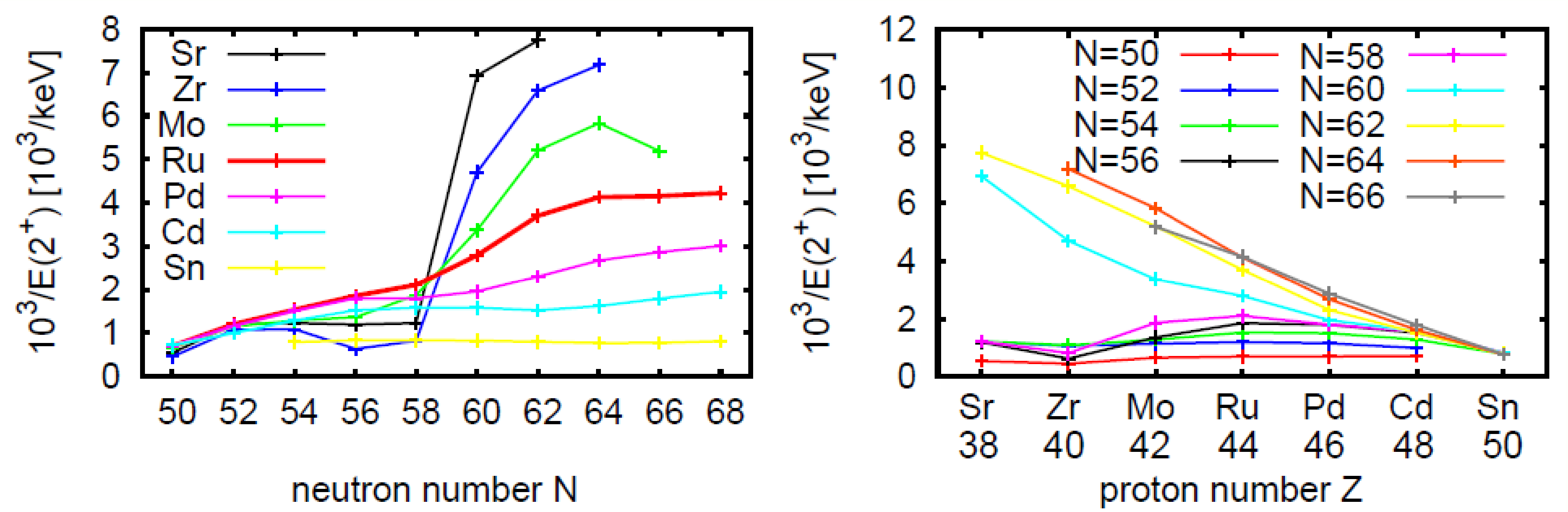
Sudden onset of deformation at N=60 for many isotopes.
(neutron sub-shells: N=56/58)

Ru Isotopes „separate” chains that show sudden increase of deformation and chains that evolve gradually / do not go deformed.

Proton sub-shell at Z=40 leads to p-n asymmetries

Some Challenges at A~100

fast vs gradual changes in deformation / collectivity



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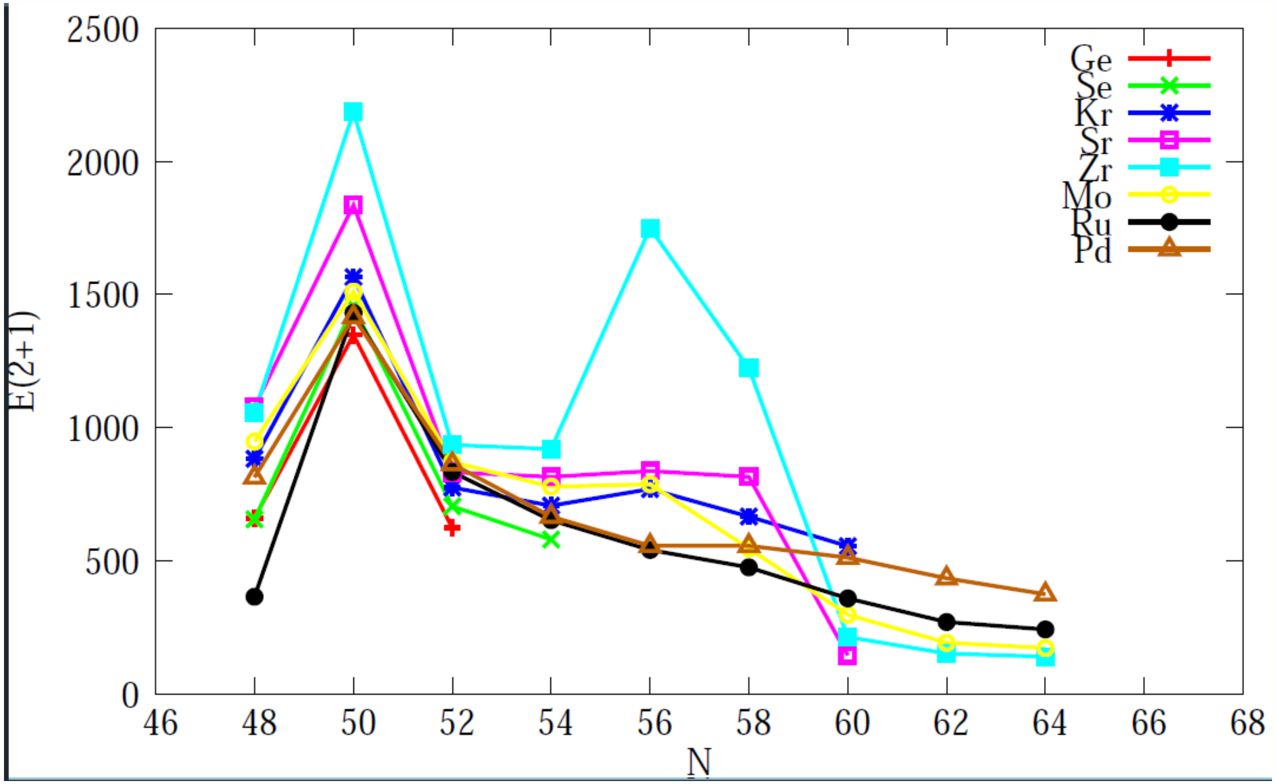
E(2_1^+) Systematics

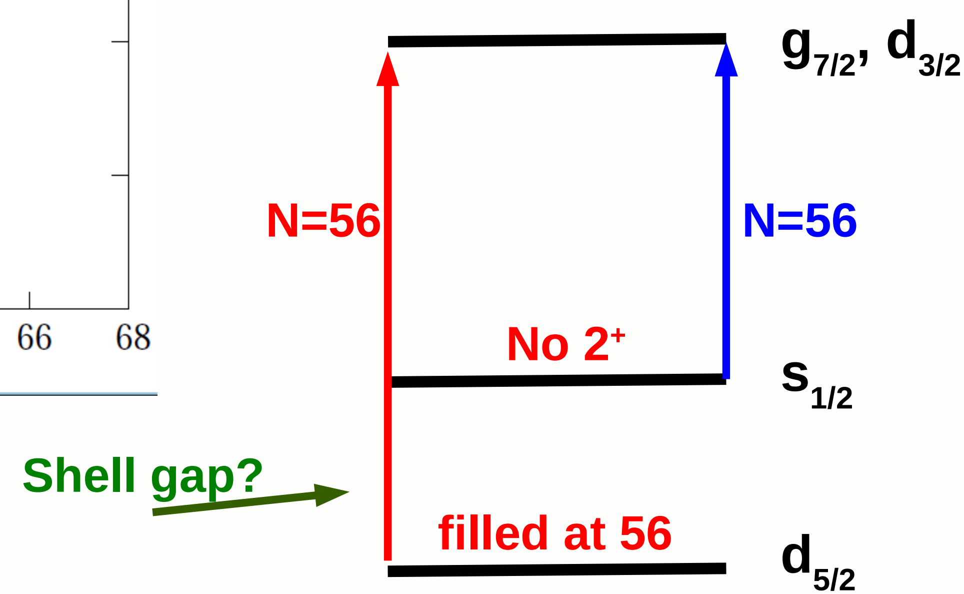


Function of N:
Zr: clear peak at N=56,58 in Zr
Sr: „peak” N=56, drop past 58
Kr: small peak at 56, smooth after
Se, Ge: ?????

Mo: small peak at 56, moderate drop after
Ru: nothing at 56, rise at 58, smooth after
Pd: smooth drop

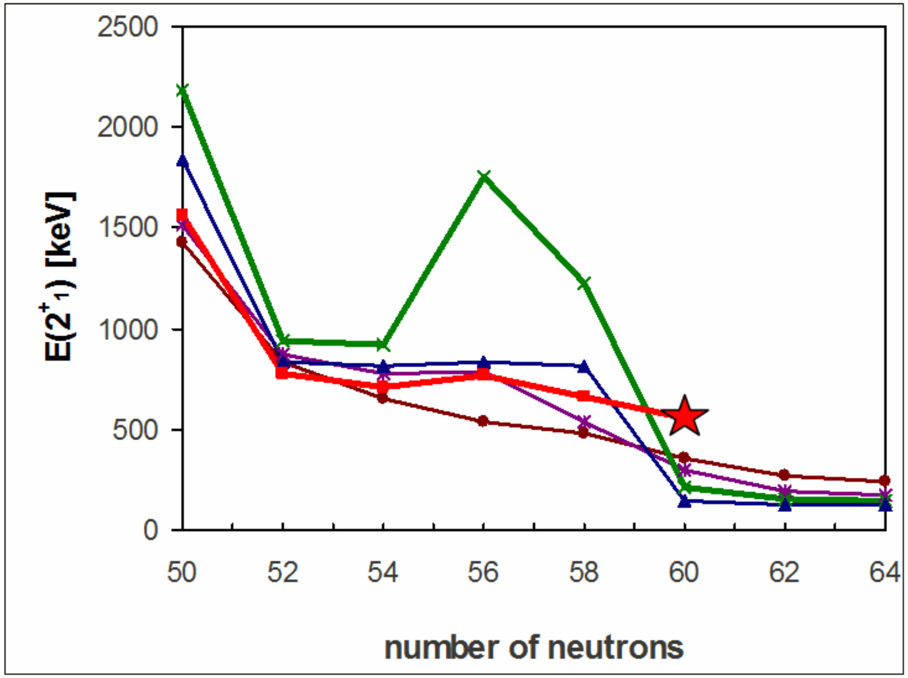
Weak coupling (p-n) was shown for Z~40, N<56 in prev. works

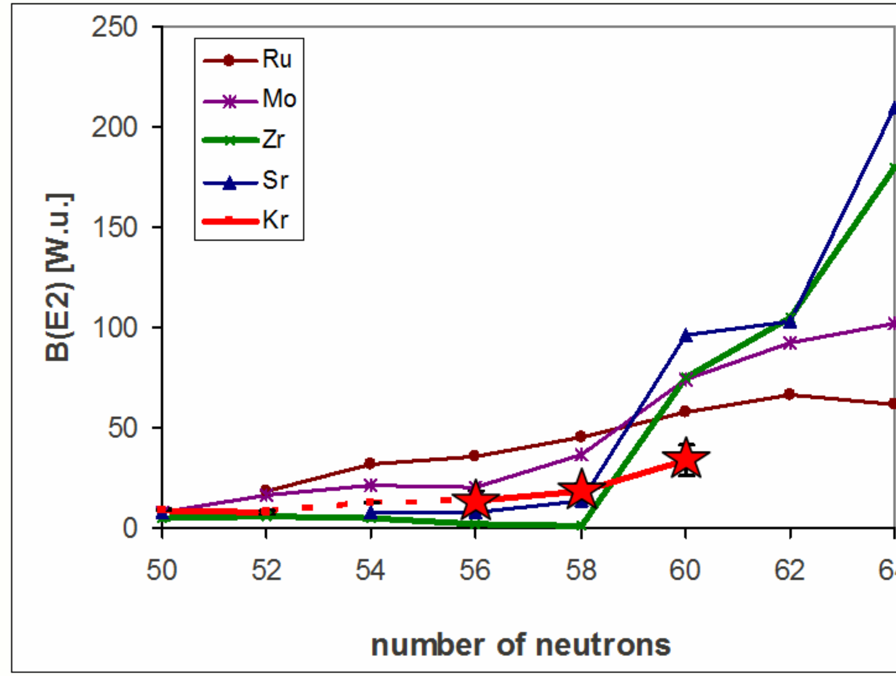
Assume it here -> E(2_1^+) depends mainly on SPEs

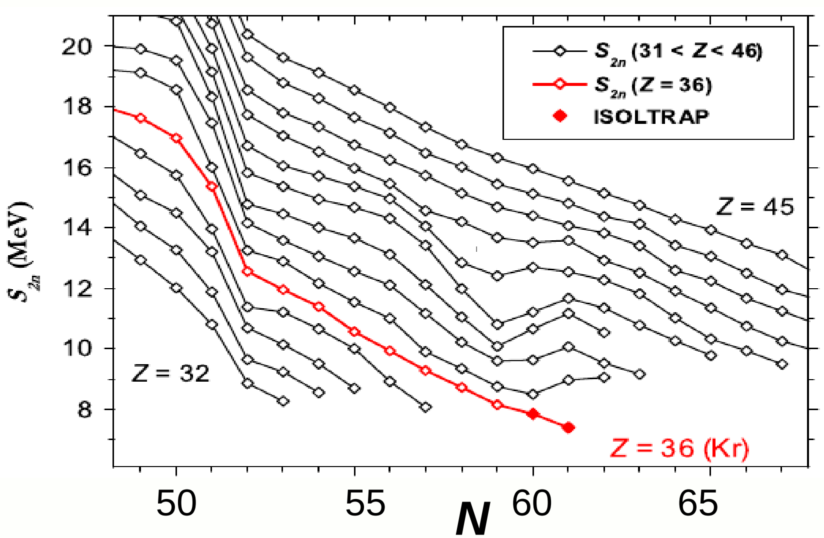


For Z>40 $ng_{7/2}$ fills and is lowered because of $pg_{9/2}$ -> gaps disappear

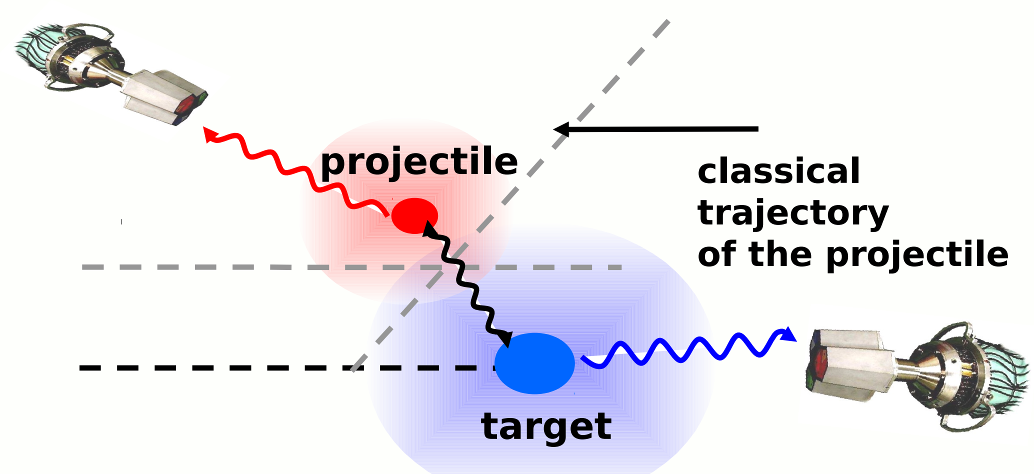
^{96}Kr at ISOLDE







Naimi er al PRL 105, 032502 (2010)



M.Albers *et al.*, PRL 108, 062701 (2012)

A ~ 100 Offerings / Challenges

A perfect testing ground for:

- **Nuclear Models (microscopic *and* macroscopic *or both*)**
- **Experimental Techniques (observables change quickly)**

Even in stable „well-studied" nuclei oddities occur:

- **Appearance / Disappearance of Vibrational (Phonon) Structures**
- **B(E2) Ratios that don't seem to make sense...**

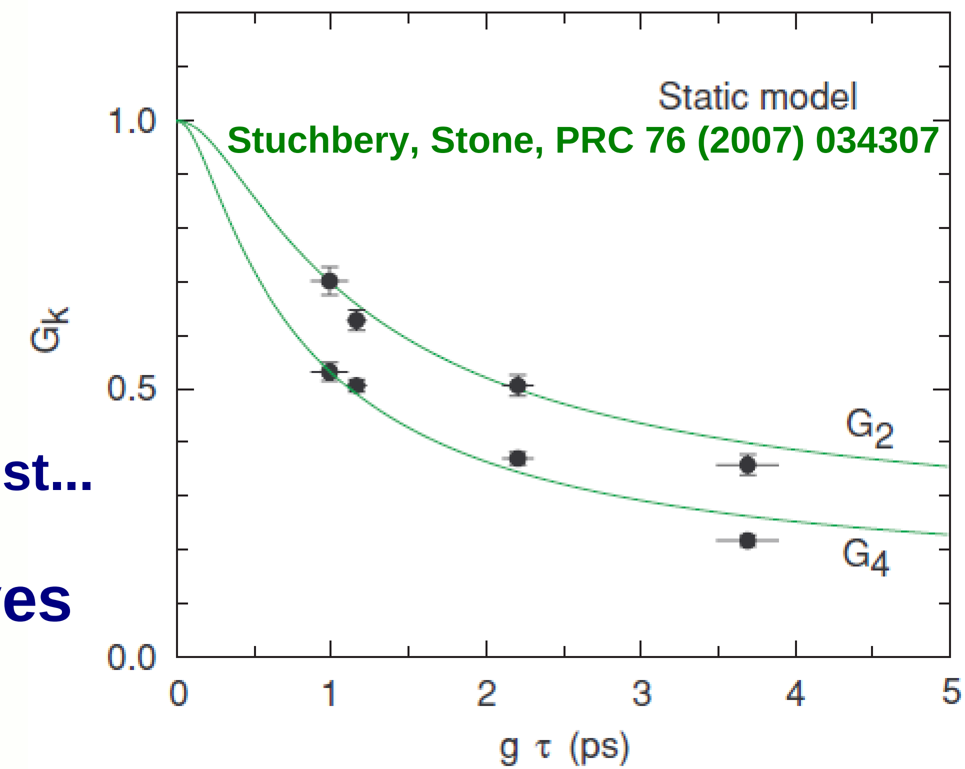
We need high-precision data, to resolve disagreements in literature data, and to provide meaningful tests of models.

Transient Field Technique exists, widely applied, so why?

→ TF needs to know the magnetic field, rely on parametrizations
→ target heating changes fields – can be a big problem
→ TF may not always work with RIBs
→ having another method at hand is *always* good for x-checks

Recoil Into Vacuum (RIV) was already re-introduced...

→ but – you need to know *a lot*: Lifetimes *and* g factors for a series of isotopes for calibration

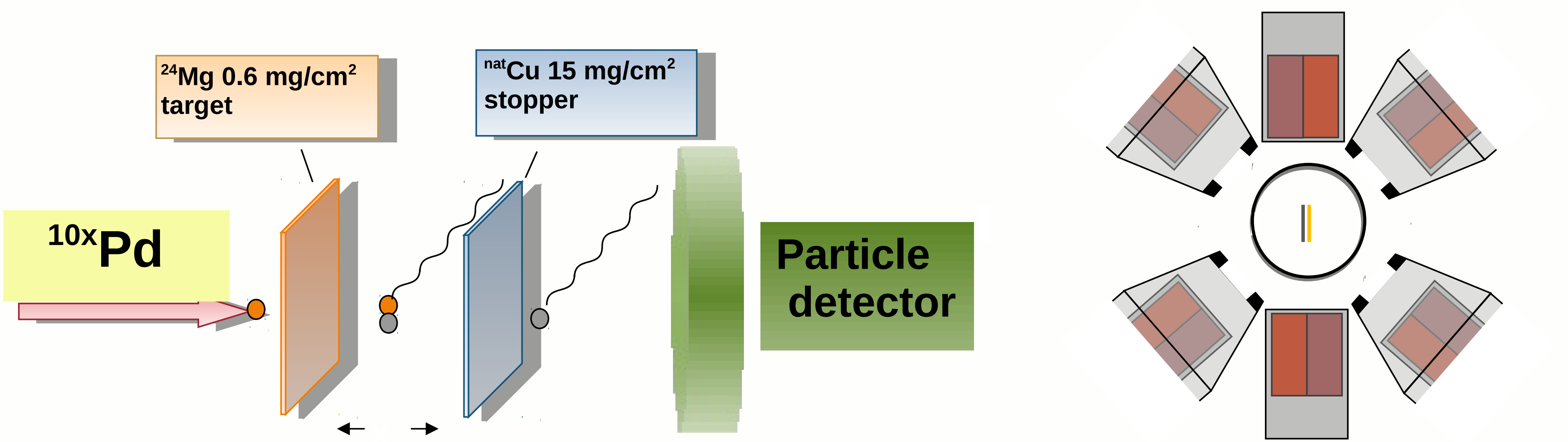


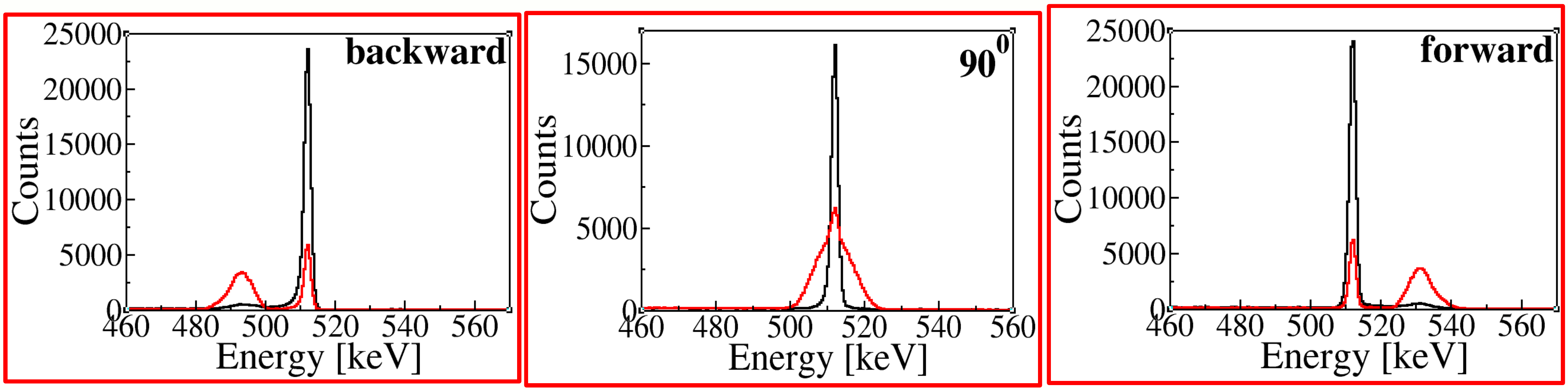
Theory aim:

→ calculate HF-Interaction (no more calibration necessary)
→ but: not much data available to test...

g-Plunger *simultaneously* gives lifetimes *and* g factors

g-Plunger: Pd Isotopes





High recoil velocity (v/c ~ 6 %)
-> large Doppler shift allows precise lifetime measurement

Intensity correction of γ rays

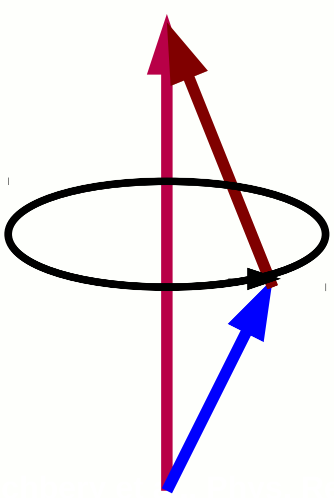
Attenuation coefficients (solid angle) of the detectors - Q

Solid angle of the particle detector – attenuation of the angular distribution

Lorentz boost $d\Omega/d\Omega' = (E\gamma/E\gamma_0)^2 = [1 + (E\gamma - E\gamma_0)/E\gamma_0]^2$

Nuclear Deorientation

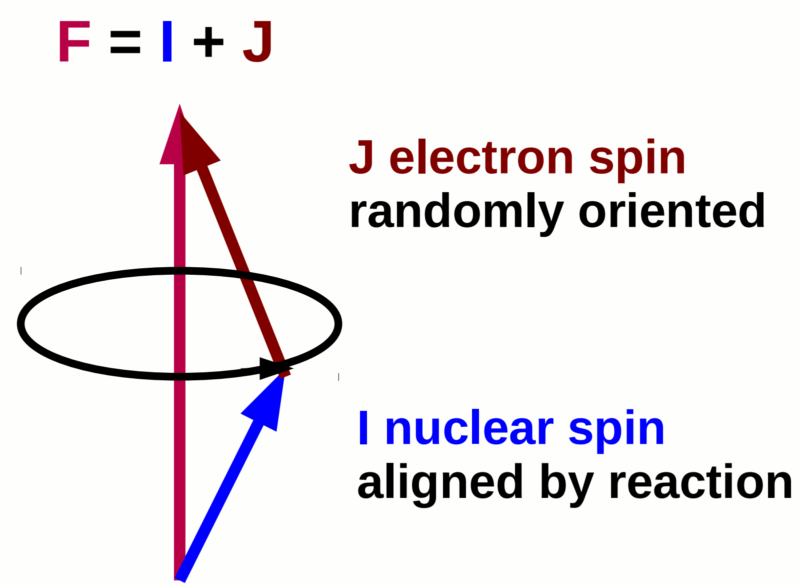
Hyperfine Interaction:
Precession of the nuclear spin I and the electron spin J about the total spin F



Nuclear Deorientation (RIV)

Make use of "Recoil Into Vacuum" (RIV)

=> Angular distribution is attenuated!
By precession of the nuclear spin due to the hyperfine interaction
→ deorientation coefficients.



$$W(\theta)=1+\Sigma_{i=2,4}\,G_i(t)\,Q_i\,B_i\,F_i\,P_i(\cos\theta)$$

G_i depend on magnetic moment (interacting with electrons)

$$G_k(t)=\alpha_k+(1-\alpha_k)\cdot\exp[-(g\cdot d)/(v\cdot C_k)]$$

⇒ 3 parameters: α_k, g, C_k

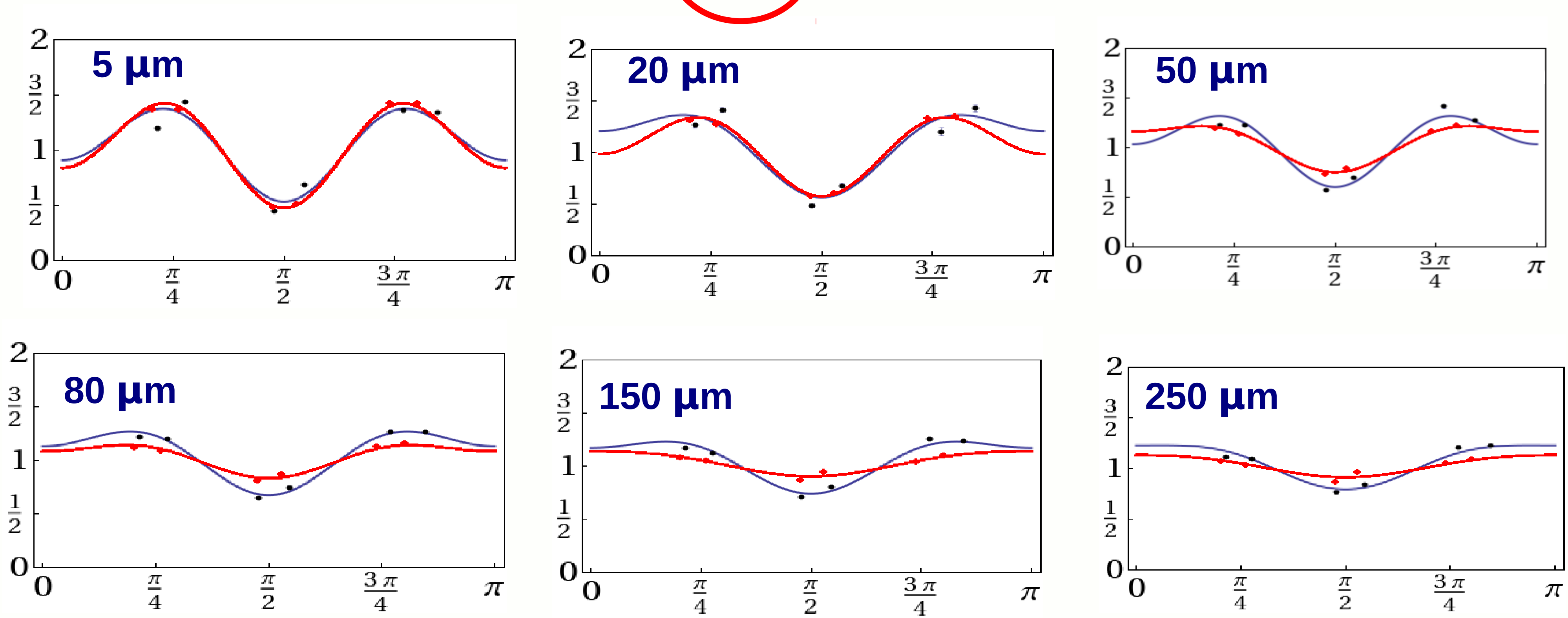
A. Stuchbery et al., PRC 76, 034307 (2007)

Distance dependent angular distribution:

$$\frac{A_{2/4}^{exp}}{A_{2/4}^{coulex}(d=0)}=G_{2/4}$$

Time-Dependent Angular Distribution (or: TDRIV)

$$W(\theta)=1+\sum_{i=2,4} G_i(t)\, Q_i\, B_i\, F_i\, P_i(\cos\theta)$$



- Doppler-shift
- Stopped

Example of experimental and theoretical calculation of angular distribution for the stopped and the Doppler shift component

g-Plunger TDRIV analysis

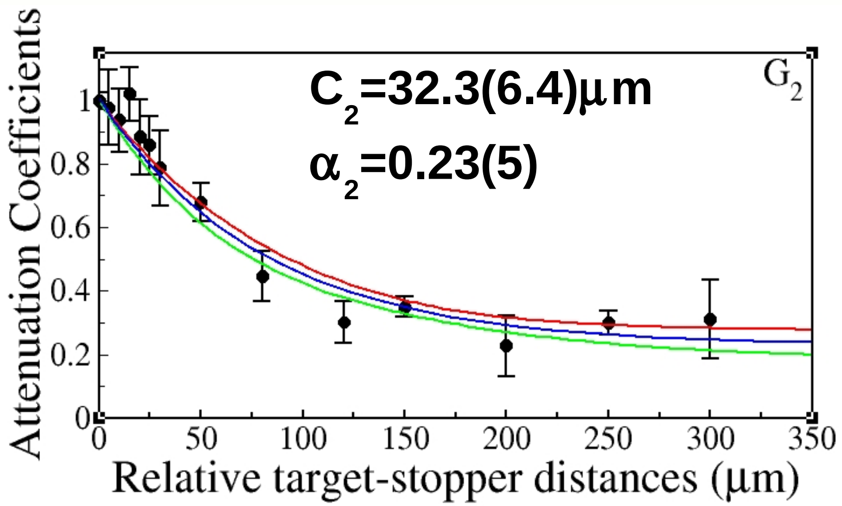
$$G_k(t)=\alpha_k+(1-\alpha_k)\cdot\exp[-(g\cdot(d-d_0)/(v\cdot C_k)]$$

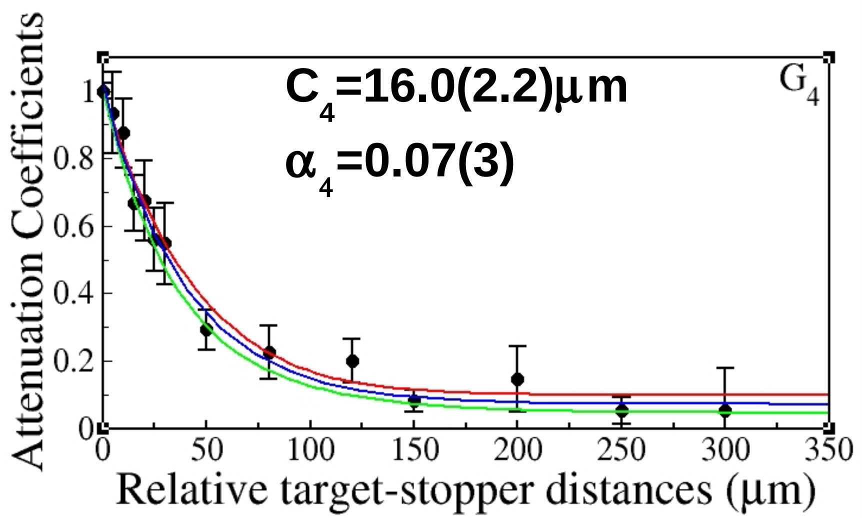
A. Stuchbery et al., PRC 76, 034307 (2007)

"calibrate" C_k of in one isotope with known g factor (^{106}Pd)

- measure the time dependent attenuation
- "calibrate" an isotopic chain

$$g(2_1^+;{}^{106}Pd)^{NNDC} = +0.398(21)$$





Relative g Factor Measurements

(The method **does not give the sign** of the g factor !)

		Reference	
Adopted value[1]	**+0.46(4)**	**+0.398(21)**	**+0.36(3)**
$g(2_1^+)$	**^{104}Pd**	**^{106}Pd**	**^{108}Pd**
This work	**|0.52(10)|**	**0.40(2)**	**|0.32(5)|**
IBM-2[2]	0.42	0.392	0.366
Shell-Model		0.5	

[1]Evaluated Nuclear Structure Data File
[2]Kim, Gelberg, Mizusaki, Otsuka, von Brentano, Nucl. Phys. A 604, 163 (1996)
[3]G. Gurdal et al., Phys. Rev. C 82, 064301 (2010); SM-Int: JJ45PN (Hjorth-Jensen), Ni-core, fpg, dg

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What is Right ??? (us of course...)

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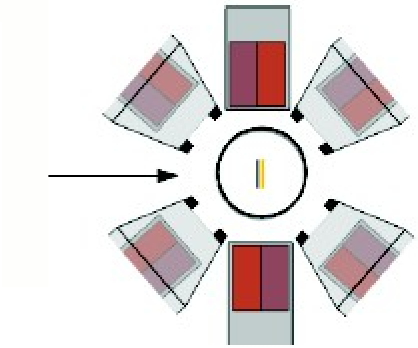
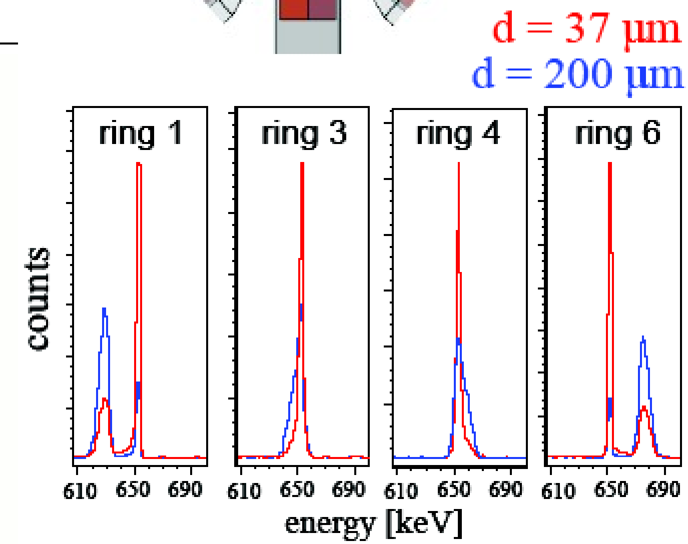
$\tau(2_1^+)$	^{104}Pd	^{106}Pd	^{108}Pd
Adopted value	**14.9(9)**	**17.6(6)**	**34.6(18)**
This work	**15.64(18)**	**19.87(14)**	**39.05(67)**

Even worse: **This change in τ will affect the g factor as well!**

isotope	E_{beam} [MeV]	$(v/c)_{\mathrm{av}}$	d_{min} [μm]	d_{max} [μm]	no. of distances
^{96}Ru	300	0.044 (1)	2	600	20
^{98}Ru	300	0.0450 (6)	3	450	15
^{104}Ru	322	0.0460 (8)	3	3600	29



simultaneous fit to experimental $G_k(d)$ of unshifted and shifted component to obtain α_k and Γ_k

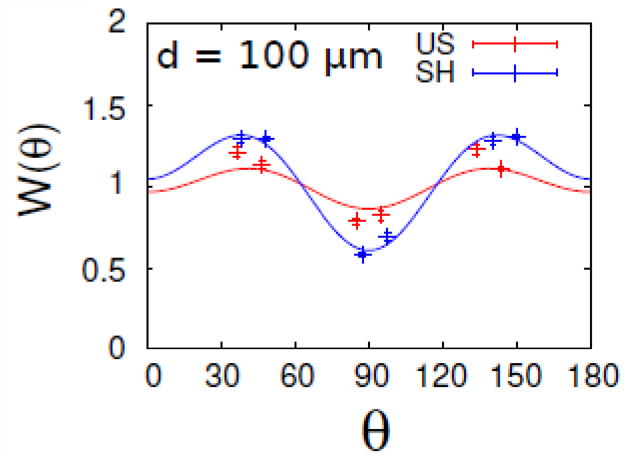


unshifted component:

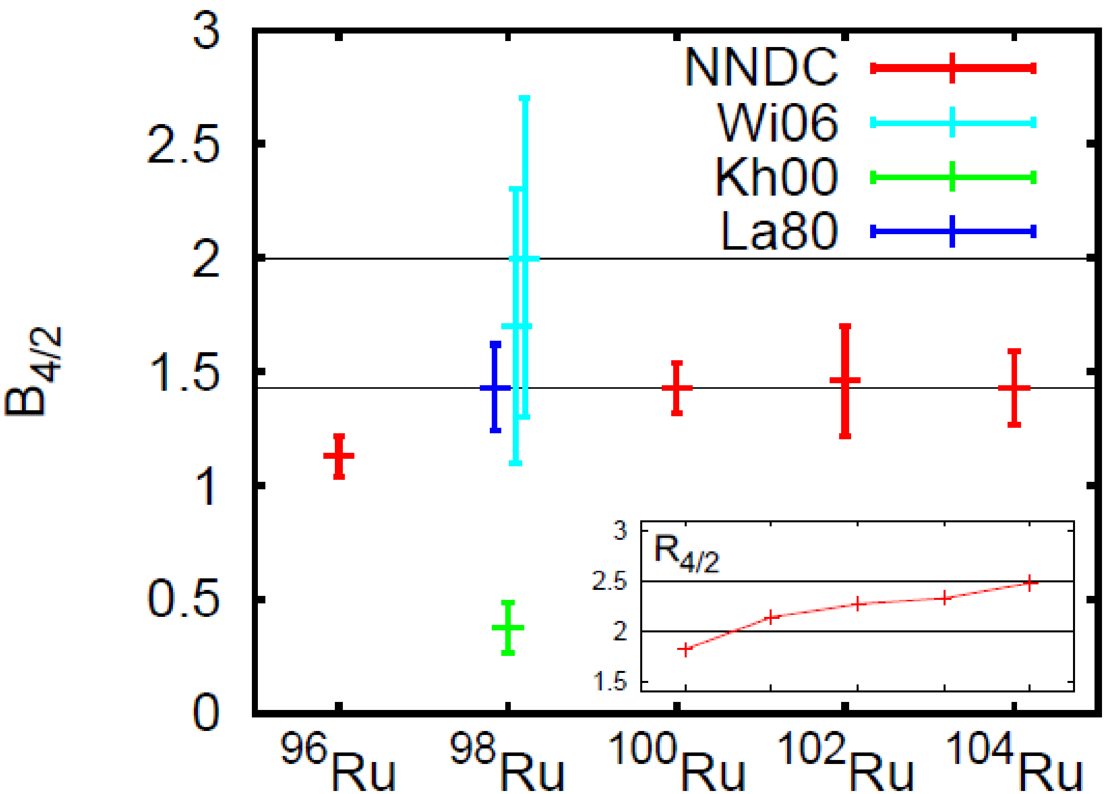
$$G_k(d) = \alpha_k + (1 - \alpha_k)\exp(-\Gamma_k d/v)$$

shifted component:

$$\tilde{G}_k^{(\tau)}(d) = \frac{\int_0^d G_k(x)\exp(-x/(v\tau))dx}{\int_0^d \exp(-x/(v\tau))dx}$$



Ru – Chain : $B_{4/2}$



- $B_{4/2} = \frac{B(E2; 4_1^+ \rightarrow 2_1^+)}{B(E2; 2_1^+ \rightarrow 0_1^+)}$
- geometrical limits:
  - $B_{4/2} = 2$: vibrational
  - $B_{4/2} = 1.43$: rotational
- discrepancy in ^{98}Ru due to conflicting lifetime measurements on the 4_1^+ lifetime

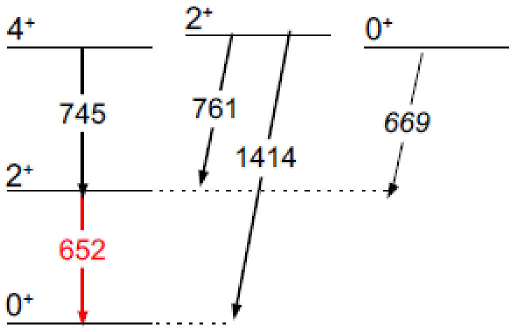
E. Williams *et al.*, PRC **74**, 024302 (2006).
B. Kharraja *et al.*, PRC **61**, 024301 (2000).
S. Landsberger *et al.*, PRC **21**, 588 (1980).

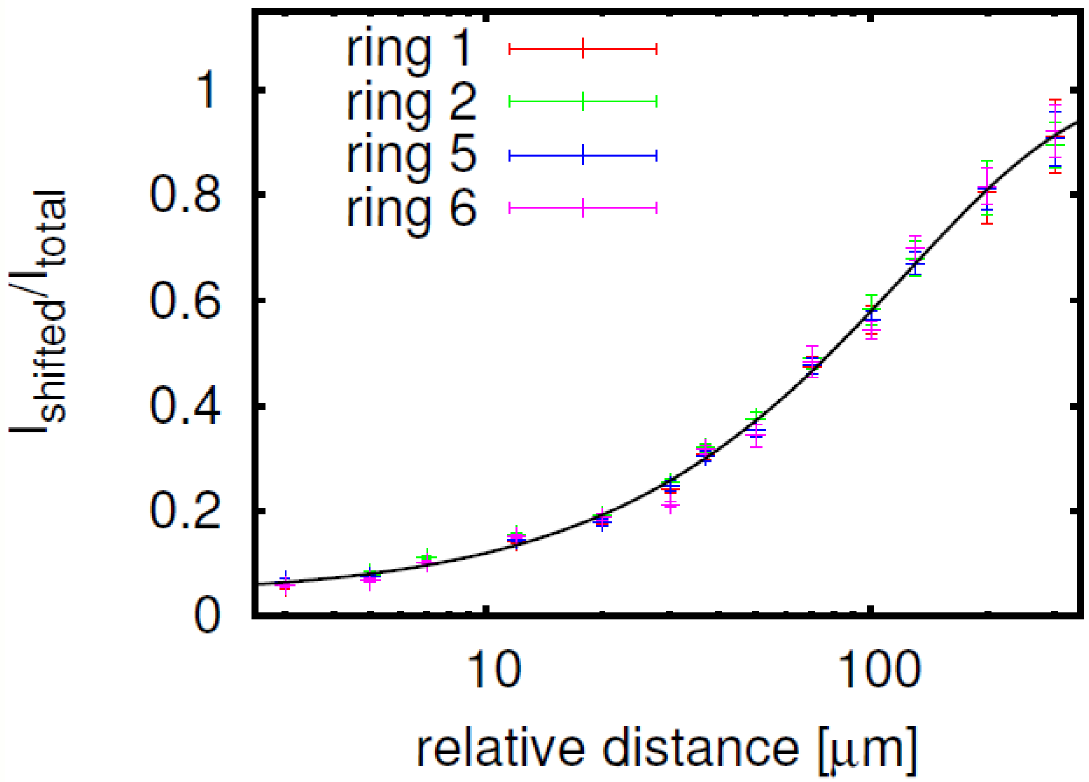
Desiree Radeck, DPG 2012

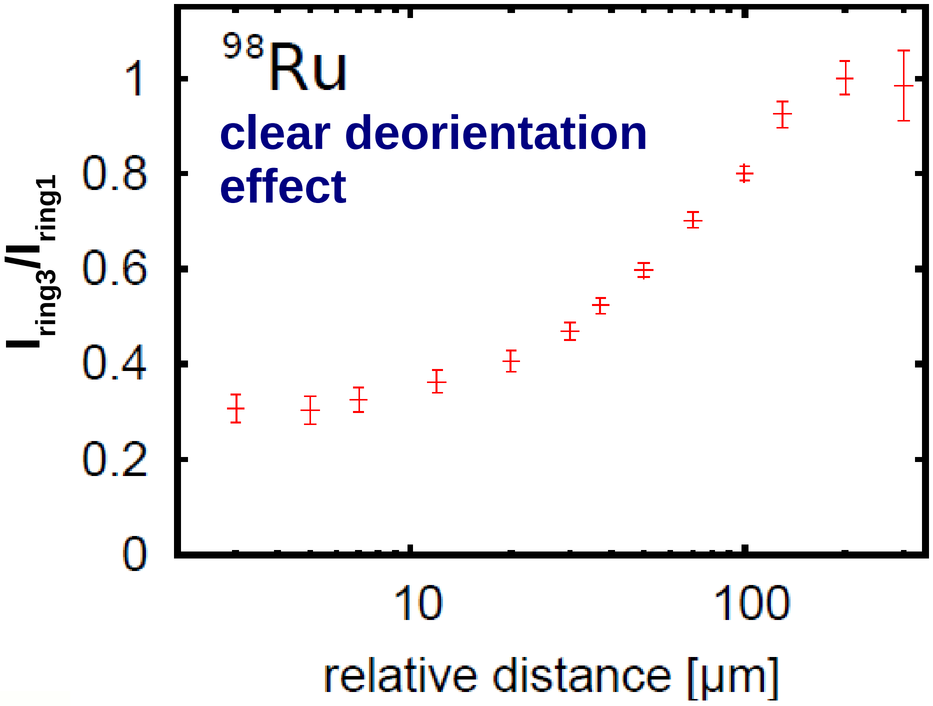
^{98}Ru Lifetimes: 2_1^+

Result:

$\tau(2_1^+) = 8.4(3)$ ps

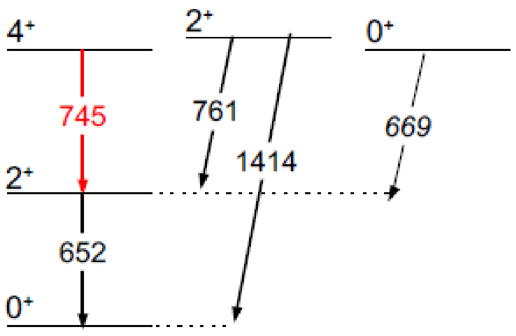


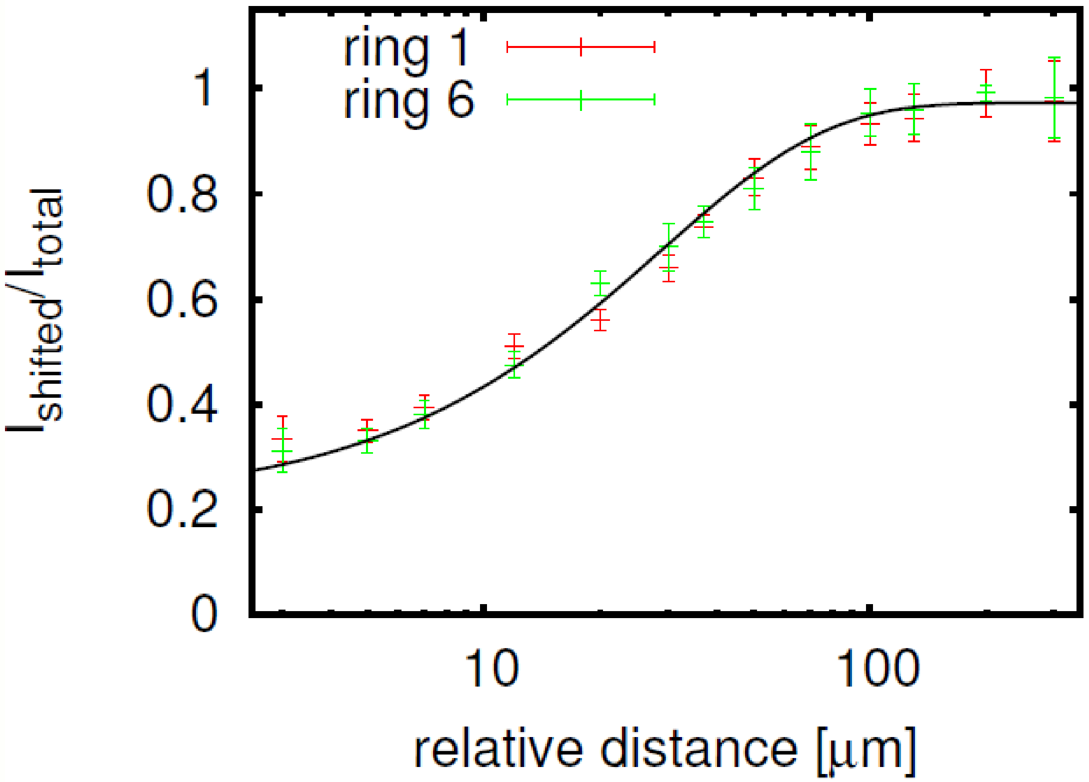


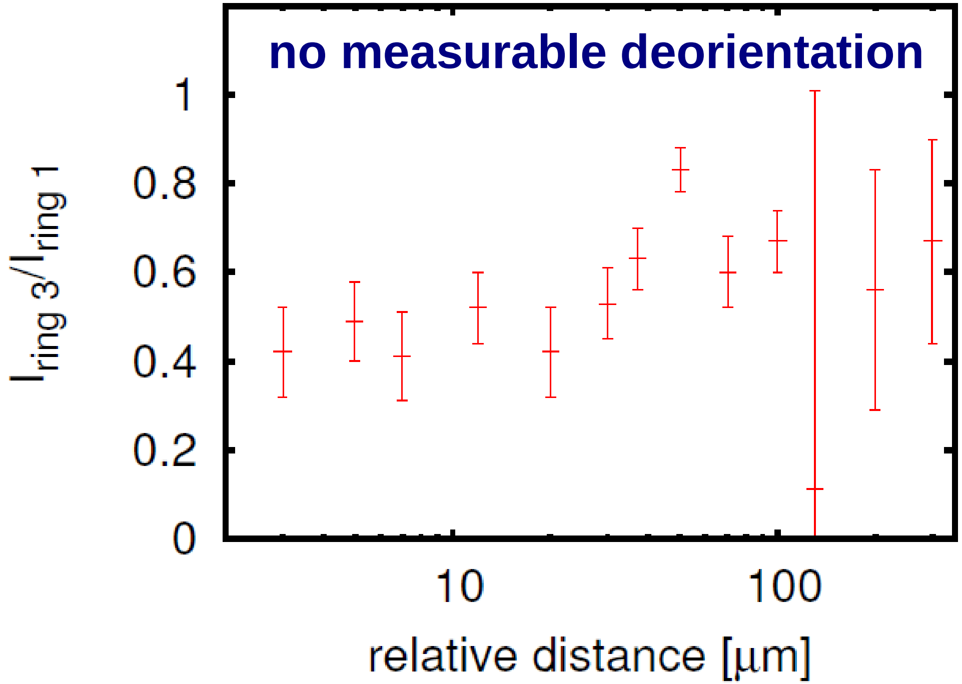


Result:

$\tau(4_1^+) = 2.3(2)$ ps



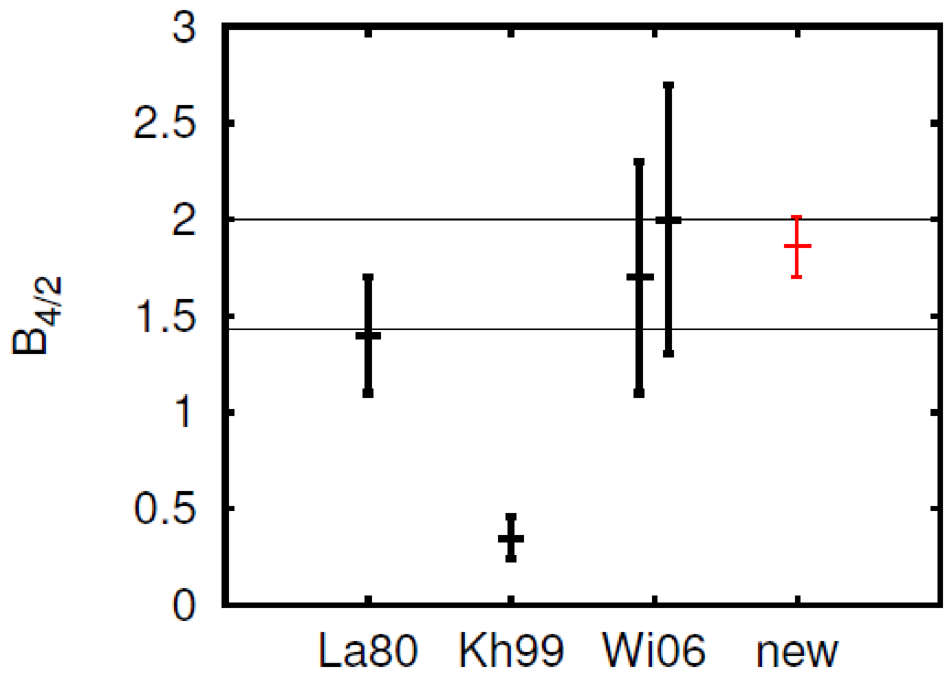




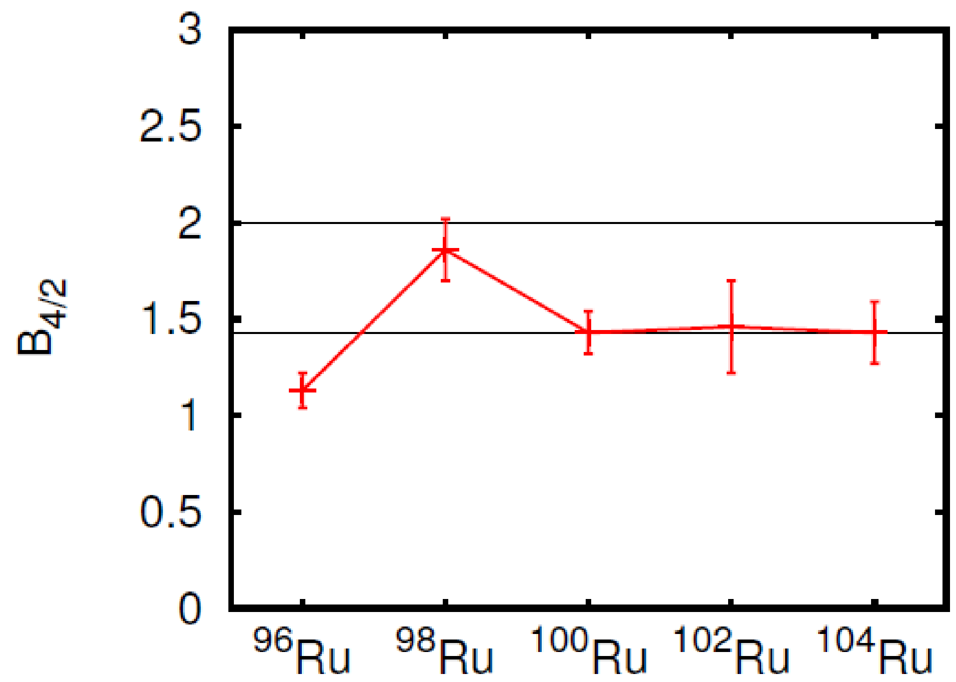
98Ru: $B_{4/2}$ Corrected (final!)

D. Radeck, VW et al., PRC 85 (2012) 014301

^{98}Ru:



Ru isotopes with $52 \leq N \leq 60$:



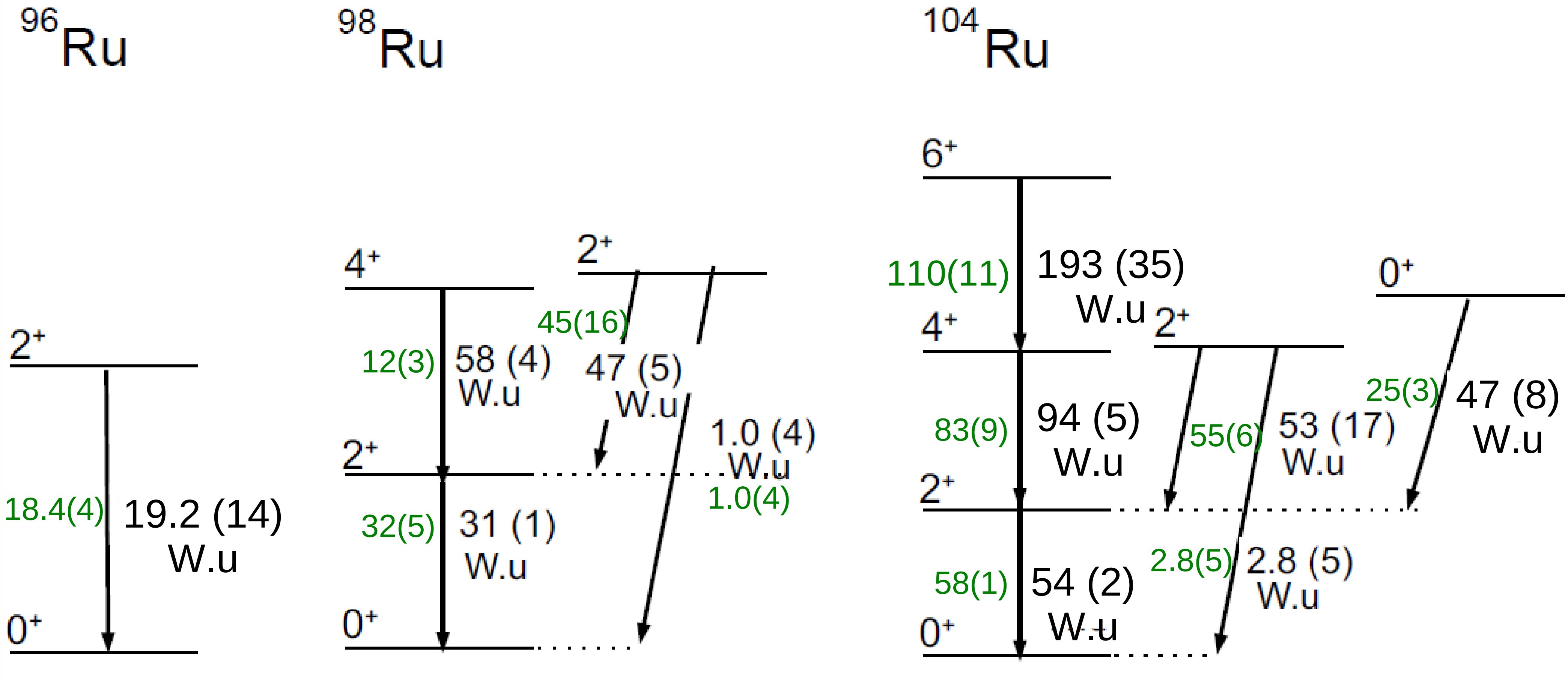
La80: S. Landsberger *et al.*, PRC **21**, 588 (1980).
Kh00: B. Kharraja *et al.*, PRC **61**, 024301 (2000).
Wi06: E. Williams *et al.*, PRC **74**, 024302 (2006).

Looks perfectly vibrational – too good in fact...

Harmonic Oscillator: $B_{4/2} = 2$

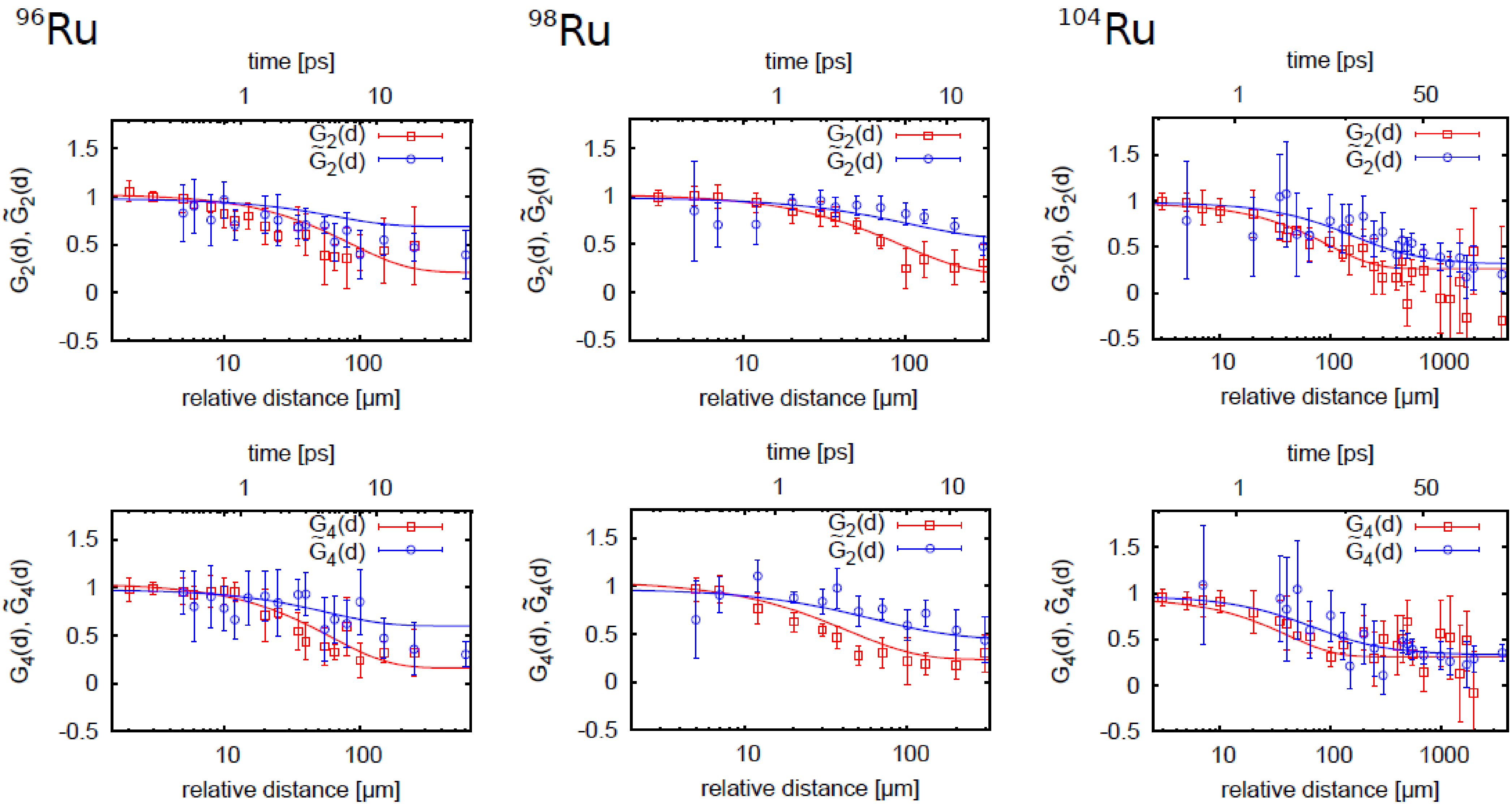
IBM (finite N): $B_{4/2} \sim 1.5$

Ru – Chain B(E2)'s



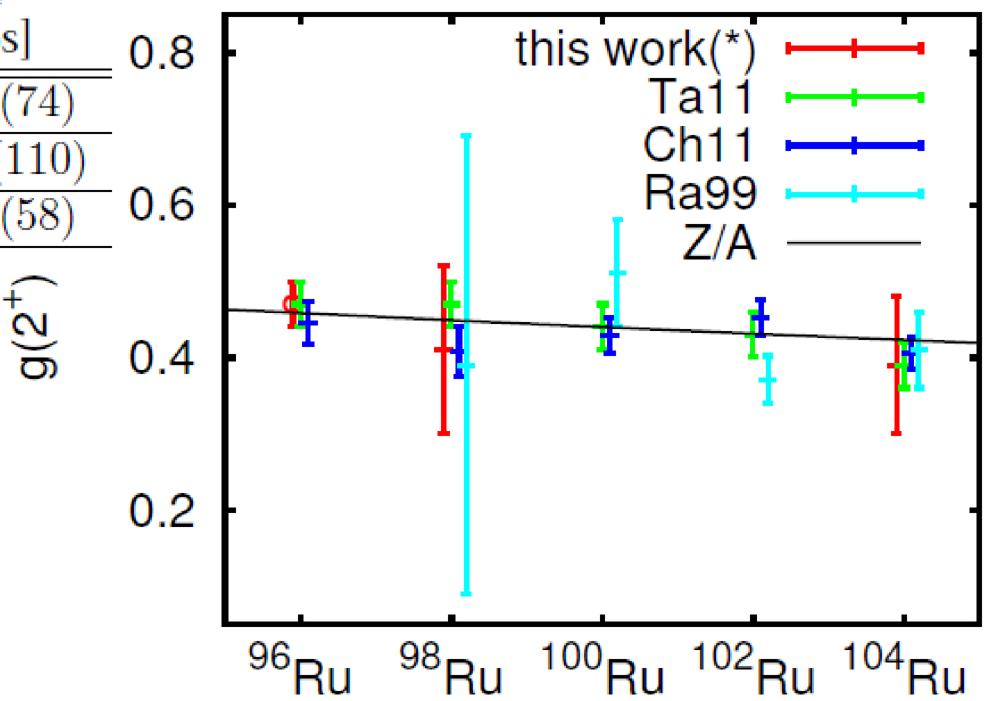
Literature values in green, present values (preliminary) in black

Simultaneous fit for each Isotope



Ru: g Factor Results (prelim.)

	α_2	Γ_2 [1/ps]	α_4	Γ_4 [1/ps]
^{96}Ru	0.21 (11)	0.177 (84)	0.19 (8)	0.330 (74)
^{98}Ru	0.18 (11)	0.142 (31)	0.24 (13)	0.314 (110)
^{104}Ru	0.26 (5)	0.138 (27)	0.31 (6)	0.309 (58)



nucleus	g relative	$g(2_1^+)$
^{96}Ru	1.00(29)	0.47(3)*
^{98}Ru	0.88(29)	0.41(11)
^{104}Ru	0.84(23)	0.39(9)

(* value from [Ta11])

(* H.I. calibrated with ^{96}Ru)

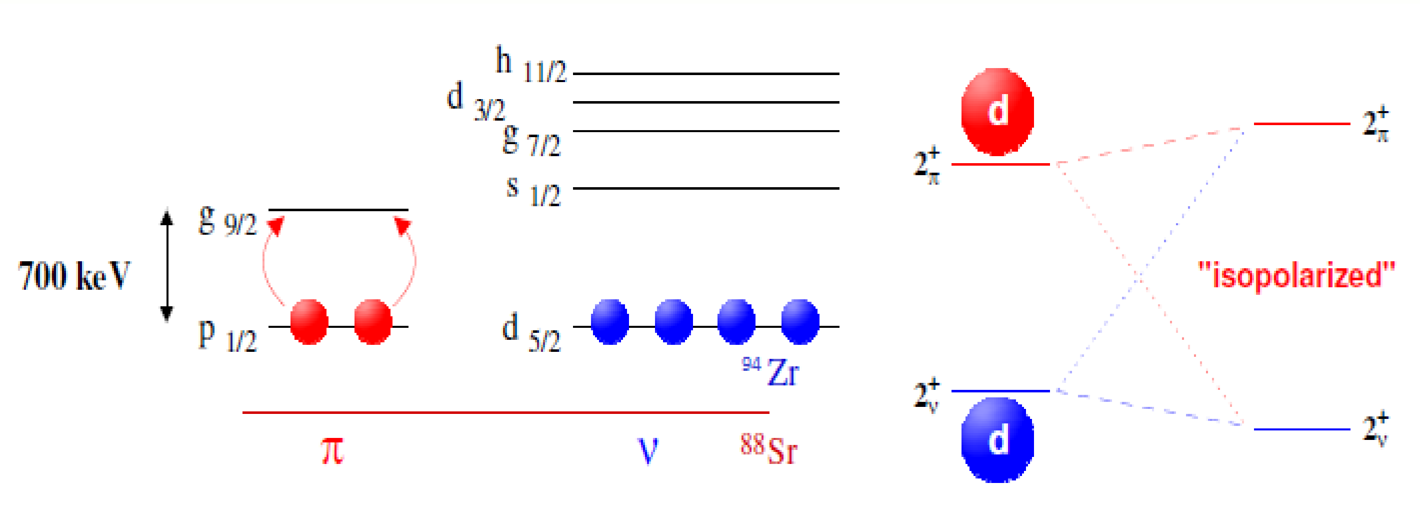
P. Raghavan, At. Nucl. Data Tabl. **42** (1999).
M.J. Taylor *et al.*, PRC **83**, 044315 (2011).
S.K. Chamoli *et al.*, PRC **83**, 054318 (2011).

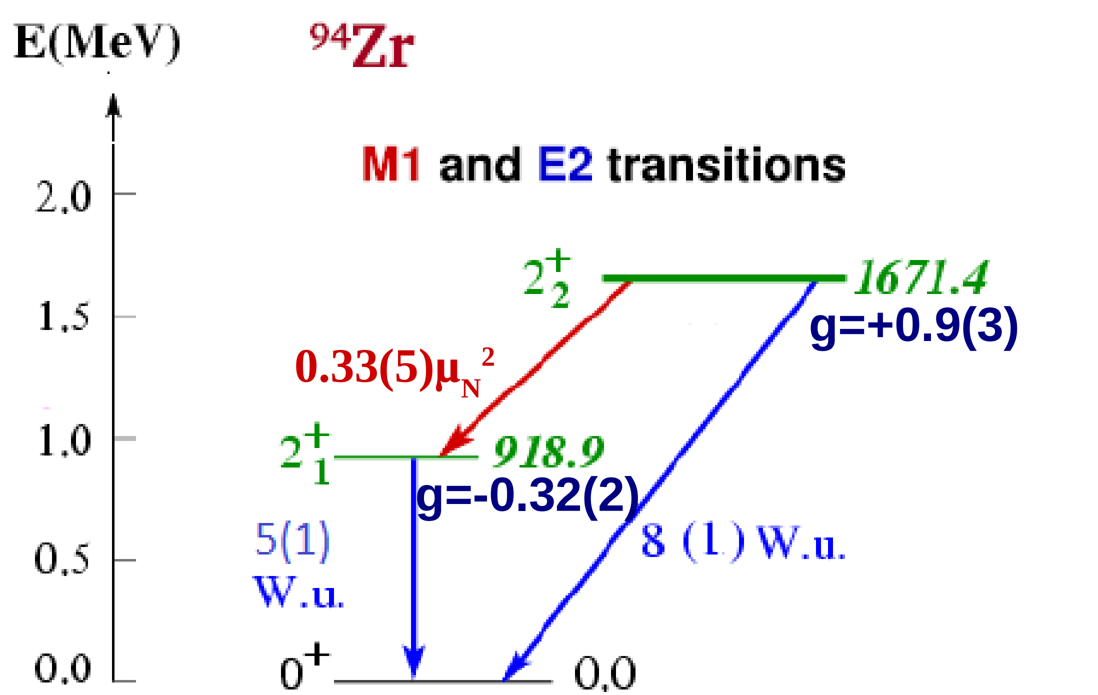
-> very nice agreement with Literature (and Z/A ...) even for the most deformed (104)

Desiree Radeck, DPG 2012

Strong p-n Polarization: ^{92,94}Zr

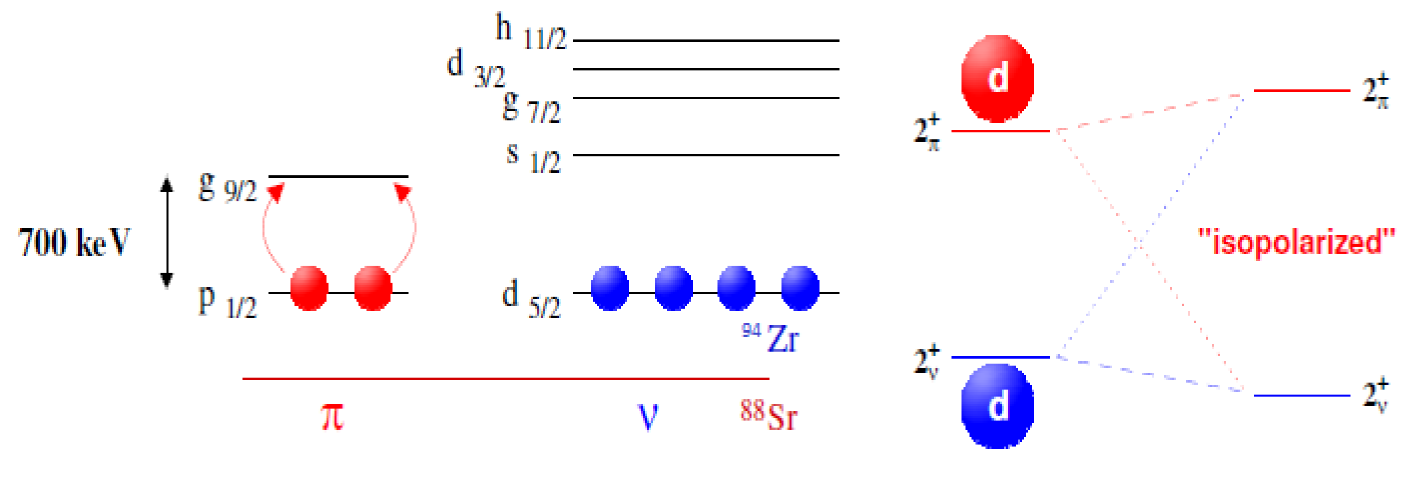
^{92,94}Zr similar



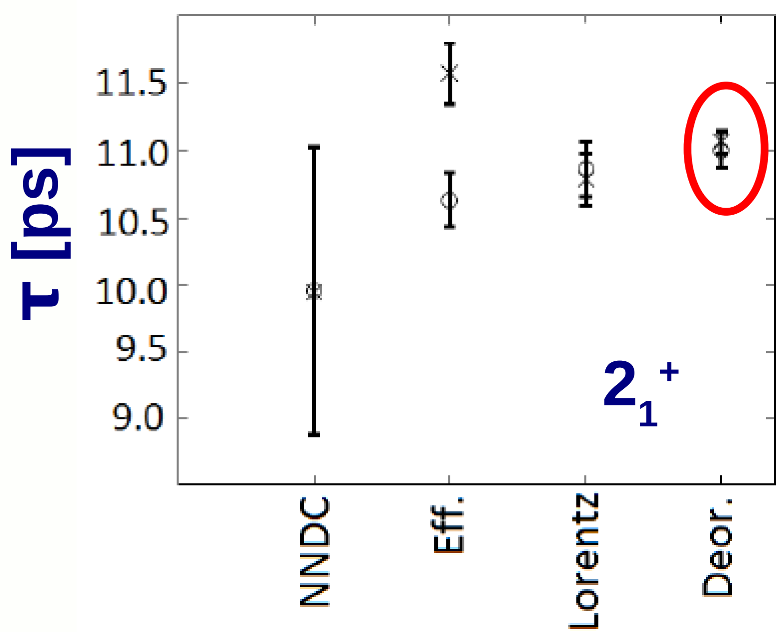


V. Werner et al., PRC 78, 031301 (2008)
E. Elhami et al., PRC 75, 011301 (2007)

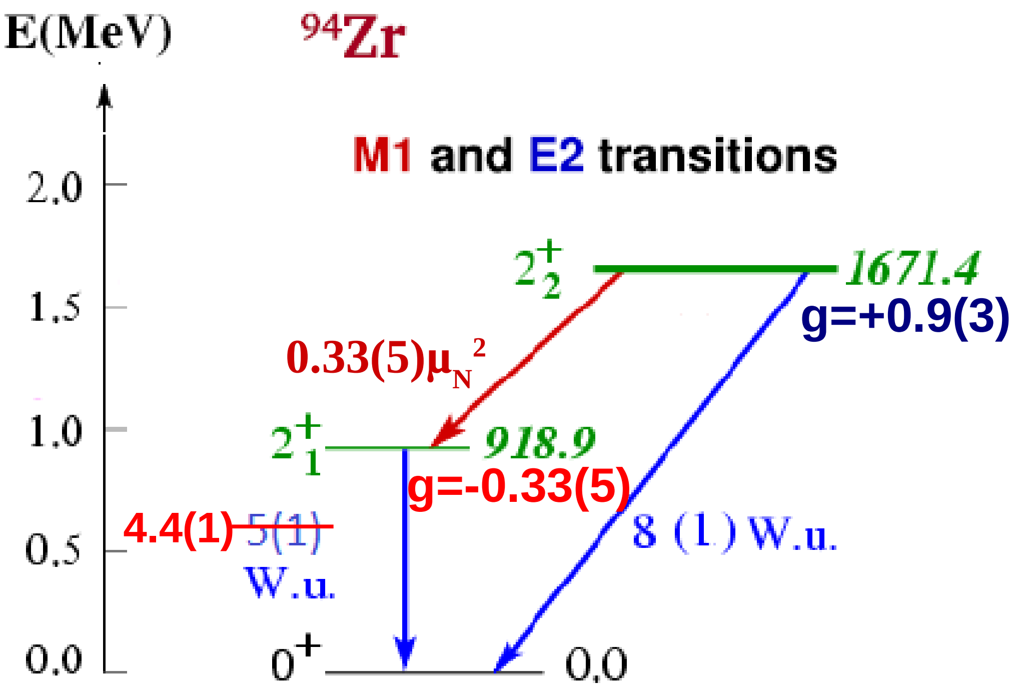
Strong p-n Polarization: $^{92,94}Zr$



$^{92,94}Zr$ similar



New plunger data Yale



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Strong p-n Polarization: $^{92,94}Zr$

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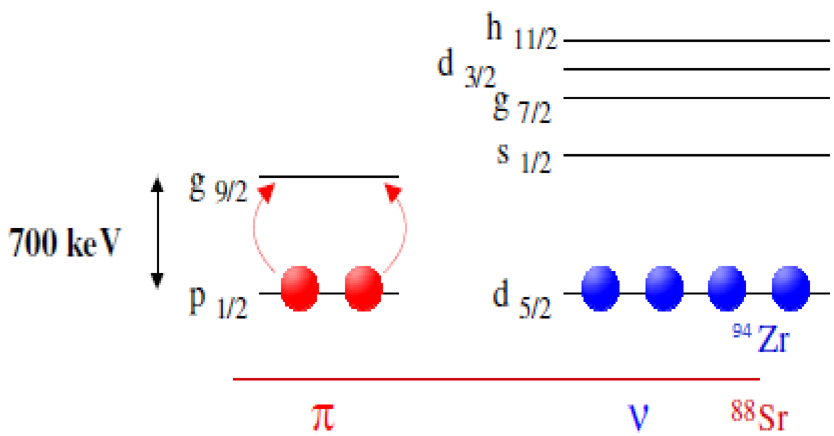
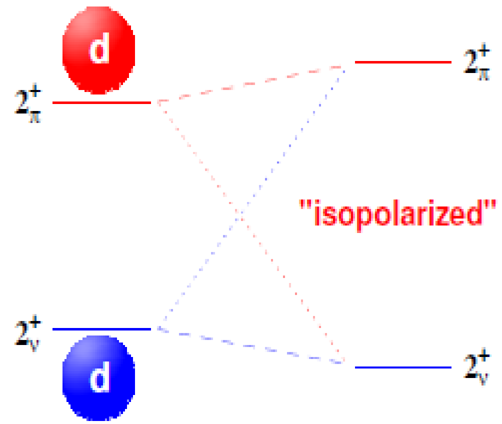
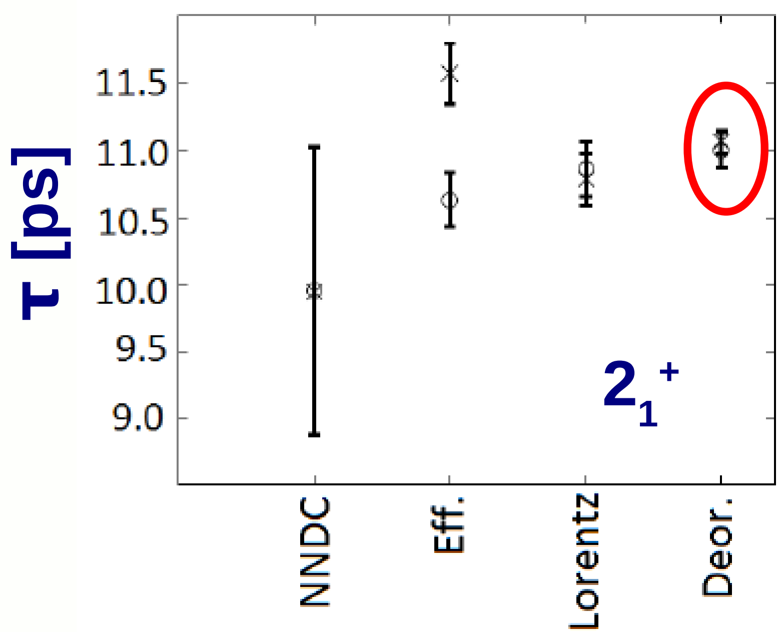
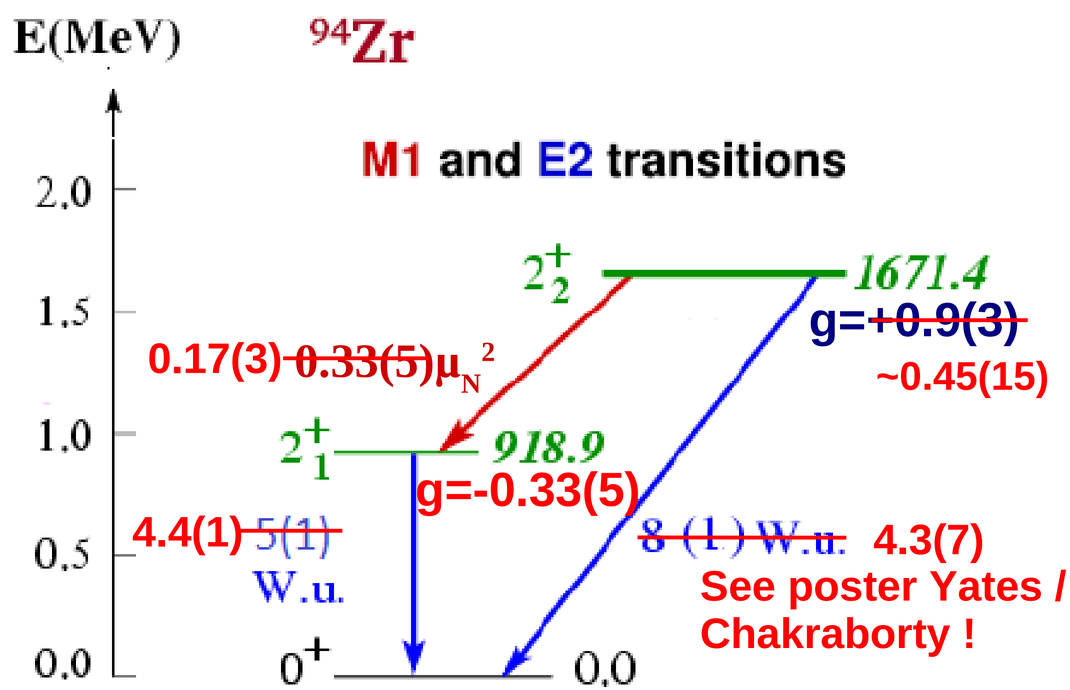






New plunger data Yale



V. Werner et al., PRC 78, 031301 (2008)
E. Elhami et al., PRC 75, 011301 (2007)

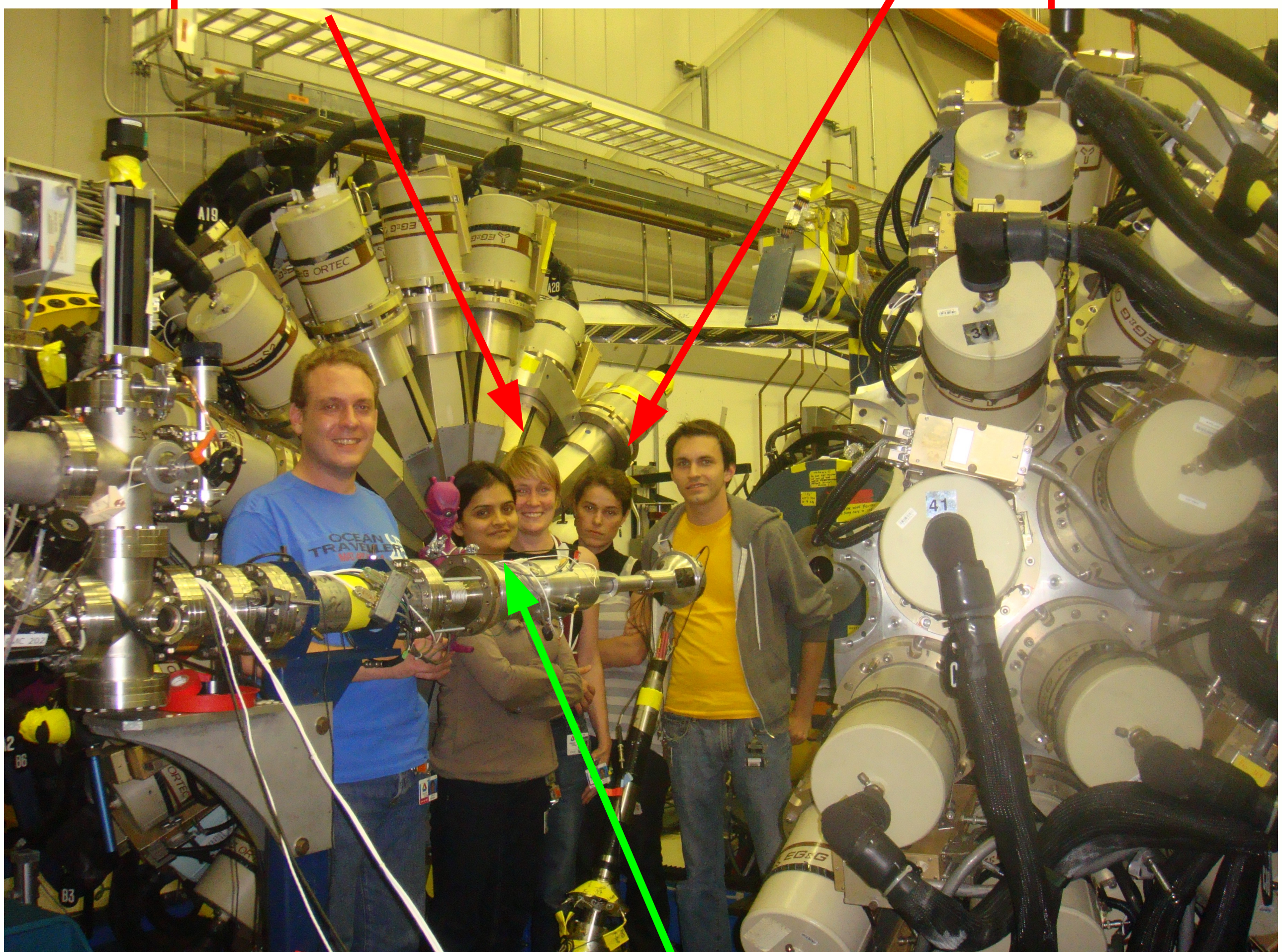
Thank you !

Yale

Those who did most of the work:

Desiree Radeck, GS (Yale/Cologne)
Ru isotopes

Gabriela Ilie, PD
Pd isotopes



Matt Hinton, MS (Yale/Surrey)
Zr isotopes

See Poster Farheen Naqvi: $^{138/142}$Ce g-Plunger; first time with Gammasphere !!!

New Plunger design finally started w. Cologne for CB energy RIBs (CARIBU-ATLAS)

Thank you !

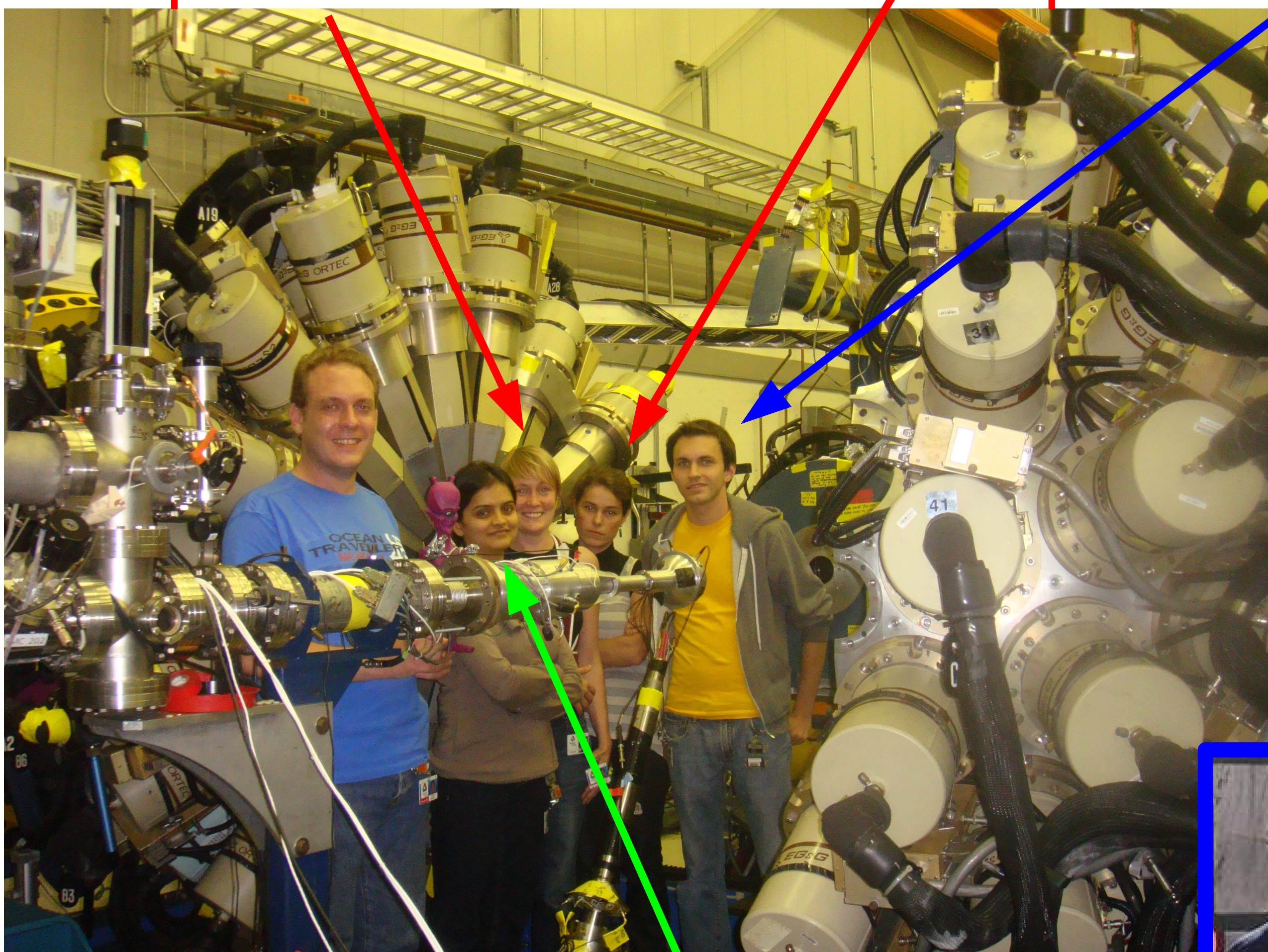
Those who did most of the work:

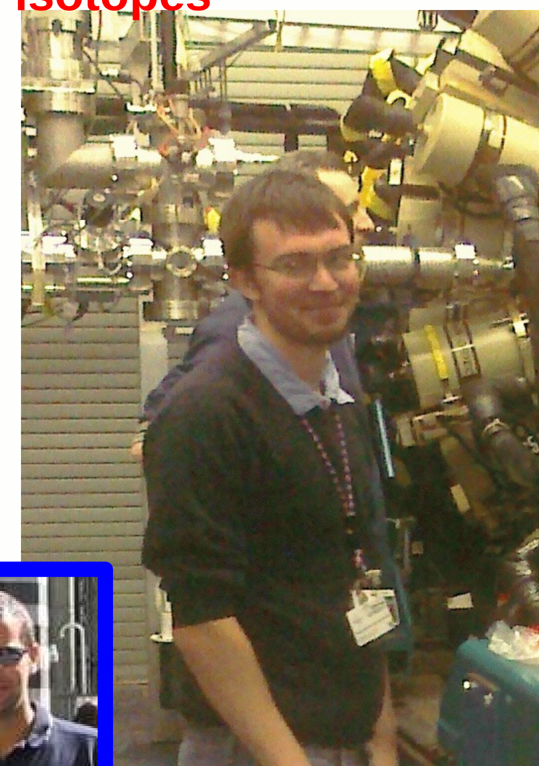
Desiree Radeck, GS (Yale/Cologne)
Ru isotopes

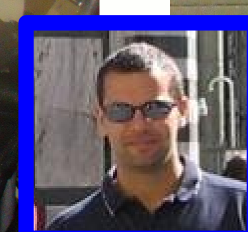
Gabriela Ilie, PD
Pd isotopes

Nathan Cooper, GS
no g's, but much news on ^{76}Se/As/Ge -> see poster!

Matt Hinton, MS (Yale/Surrey)
Zr isotopes







Christian Bernards, PD -> poster on SUSY ~Hg-Au

See Poster Farheen Naqvi: $^{138/142}$Ce g-Plunger; first time with Gammasphere !!!