

# Nuclear moments of isomeric states from deep-inelastic reactions. Is it doable?



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# Nuclear moments – what can we learn from them?



## Magnetic moment operator

$$\vec{\mu} = \sum_{k=1}^A g_l^{(k)} \vec{l}^{(k)} + \sum_{k=1}^A g_s^{(k)} \vec{s}^{(k)}$$

## Free-nucleon g factors

$$g_s^{\pi} = 5.585 \quad g_l^{\pi} = 1$$

$$g_s^{\nu} = -3.826 \quad g_l^{\nu} = 0$$

Most sensitive to  
M1 ("spin-flip") components

$$\left| l_{1+1/2}^{n-1} l_{1-1/2}^1; 1^+ \right\rangle$$

- ✓ valence particle configuration;
- ✓ first order core polarization (M1 excitations);

## Quadrupole moment operator

$$\bar{Q} = e \sum_{k=1}^A (3z_k^2 - r^2)$$

## Spectroscopic vs. intrinsic Q (model dependent)

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

## Intrinsic quadrupole moment

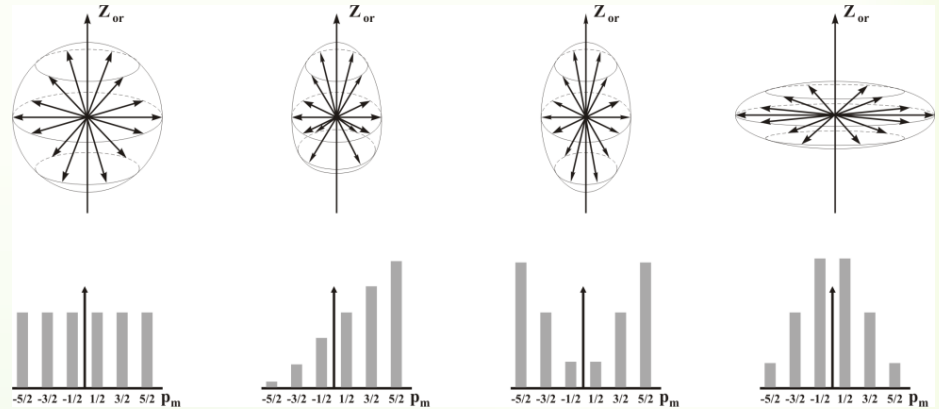
$$Q_0 = \frac{3}{\sqrt{5}\pi} e Z R^2 \beta \left\{ 1 + \pi^2 \left( \frac{a}{R} \right)^2 + \frac{2}{7} \sqrt{\frac{5}{\pi}} \beta \right\}$$

- ✓ nuclear deformation and effective charges;
- ✓ collective properties

# Experimental requirements for moment measurements of isomeric states



☞ Spin-aligned nuclear ensemble



☞ Fusion-evaporation reactions - alignment, well studied

☞ Projectile - fragmentation reactions – both alignment and polarization observed

- ☞  $^{43}\text{mSc}$  - W.-D. Schmidt-Ott *et al.*, ZPA350, 215 (1994)
- $^{67}\text{mNi}$ ,  $^{69}\text{mCu}$  - G. Georgiev *et al.*, JPG 28, 2993 (2002)
- $^{61}\text{mFe}$  - I. Matea *et al.*, PRL93, 142503 (2004)...
- ☞  $^{12}\text{B}$  - K. Asahi *et al.*, PLB 251, 488 (1990)

☞ Deep-inelastic reaction – what spin orientation could one get?

# Spin-alignment in deep-inelastic reactions?



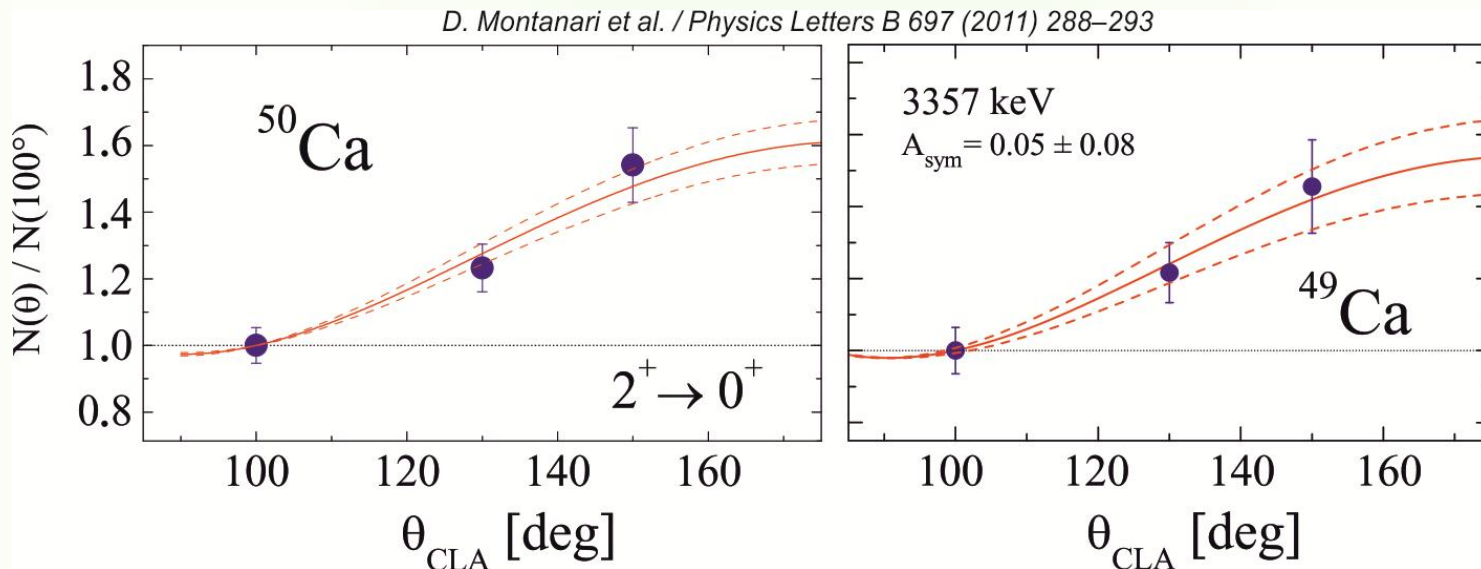
By 2008 - some initial reports: T. Pawlat *et al.*, LNL Annual Report (1994) 8

More recent results:

D. Montanari *et al.*, PLB 697, 288 (2011)

-  $^{48}\text{Ca}$  beam on  $^{64}\text{Ni}$  target;  $E_{\text{beam}} = 2 \cdot E_{\text{CB}}$

-  $^{49}\text{Ca}$  and  $^{50}\text{Ca}$  detected in PRISMA



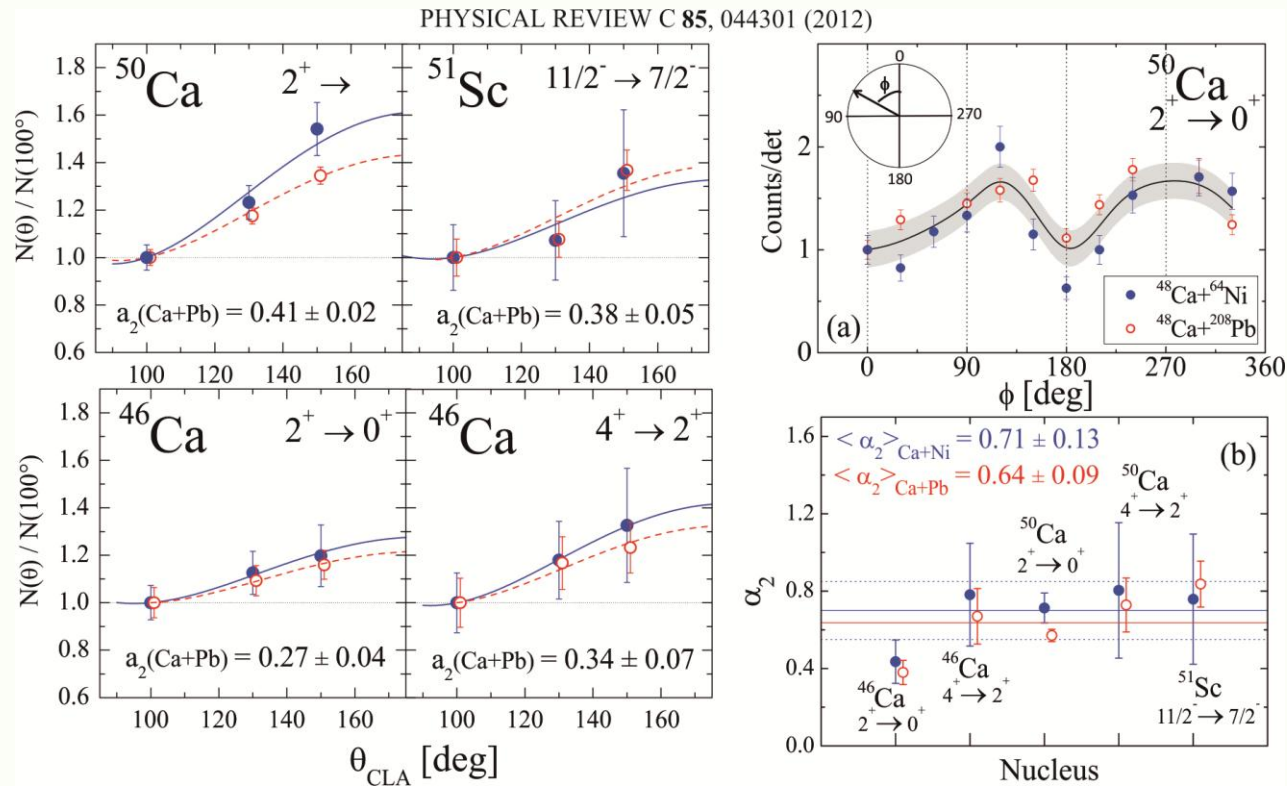
-  $\theta_{\text{CLA}}$  - with respect to PRISMA entrance!!!

- grazing angle =  $20^\circ$



☞ D. Montanari *et al.*, PRC 85, 044301 (2012)

☞ -  $^{48}\text{Ca}$  beam on  $^{208}\text{Pb}$  target;  $E_{\text{beam}} \sim 1.3 \cdot E_{\text{CB}}$



☞ Alignment  $\sim 70\%$  of the maximum possible

☞ Azimuthal angular distribution (?)

# Nuclear moments in DIC at LNL – the attempt



1 s	Kr72 17.2 s 0+	Kr73 27.0 s 5/2-	Kr74 11.50 m 0+	Kr75 4.3 m (5/2)+	Kr76 14.8 h 0+	Kr77 74.4 m 5/2+	Kr78 0+ *	Kr79 35.04 h 1/2-	Kr80 0+ *	Kr81 2.29E+5 y 7/2+	Kr82 0+ *	Kr83 9/2+ *	Kr84 0+ *	Kr85 10.756 y 9/2+ *	Kr86 0+ *
0 s	Br71 21.4 s 5/2-	Br72 78.6 s (3)+	Br73 3.4 m 1/2-	Br74 25.4 m (0,-1)	Br75 96.7 m 3/2-	Br76 16.2 h 1-	Br77 57.036 h 3/2-	Br78 6.46 m 1+	Br79 3/2- *	Br80 17.68 m 1+	Br81 3/2- *	Br82 35.30 h 5-	Br83 2.40 h 3/2-	Br84 31.80 m 2-	Br85 2.90 m 3/2-
9 s	Se70 41.1 m 0+	Se71 4.74 m 3/2-,5/2-	Se72 8.40 d 0+	Se73 7.15 h 9/2+	Se74 0+ *	Se75 119.779 d 5/2+	Se76 0+ *	Se77 1/2- *	Se78 0+ *	Se79 6.5E+4 y 7/2+	Se80 0+ *	Se81 18.5 m 3/2-	Se82 1.4E+20 y 0+ *	Se83 22.3 m 9/2+ *	Se84 3.1 m 0+ *
8 s	As69 15.2 m 5/2-	As70 52.6 m 4(+)	As71 65.28 h 5/2-	As72 26.0 h 2-	As73 80.30 d 3/2-	As74 17.77 d 2-	As75 3/2- *	As76 26.32 h 2-	As77 38.83 h 3/2-	As78 90.7 m 2-	As79 9.01 m 3/2-	As80 15.2 s 1+	As81 33.3 s 3/2-	As82 19.1 s (1+)	As83 13.4 s (5/2-,3/2-)
7 n	Ge68 270.82 d 0+	Ge69 39.05 h 5/2-	Ge70 0+ *	Ge71 11.43 d 1/2-	Ge72 0+ *	Ge73 9/2+ *	Ge74 0+ *	Ge75 82.78 m 1/2-	Ge76 0+ *	Ge77 11.30 h 7/2+	Ge78 88.0 m 0+	Ge79 19.1 s (1/2-)	Ge80 29.5 s 0+	Ge81 7.6 s (9/2+)	Ge82 4.60 s 0+
6 h	Ga67 3.2612 d 3/2-	Ga68 67.629 m 1+	Ga69 3/2- *	Ga70 21.14 m 1+	Ga71 3/2- *	Ga72 14.10 h 3-	Ga73 4.86 h 1+	Ga74 8.12 m (3-)	Ga75 126 s 3/2-	Ga76 32.6 s (3-)	Ga77 13.2 s (3/2-)	Ga78 5.09 s (3+)	Ga79 2.847 s (3/2-)	Ga80 1.697 s (3)	Ga81 1.221 s (5/2-)
5 d	Zn66 27.9 0+	Zn67 5/2- *	Zn68 18.8 0+	Zn69 56.7 m 1+	Zn70 5E+14 y 0+	Zn71 2.95 m 2-	Zn72 46.5 h 0+	Zn73 23.5 s (1/2)-	Zn74 96 s 0+	Zn75 10.2 s (7/2+)	Zn76 5.7 s 0+	Zn77 2.08 s (7/2+)	Zn78 1.47 s 0+	Zn79 995 ms 0+	Zn80 0.545 s 0+
4 h	Cu65 30.83 3/2-	Cu66 5.088 m 1+	Cu67 61.83 h 3/2-	Cu68 31.1 s 1+	Cu69 2.85 m 3/2-	Cu70 4.5 s (1+)	Cu71 19.5 s (3/2-)	Cu72 6.6 s 0+	Cu73 3.9 s 0+	Cu74 1.59 s 0+	Cu75 1.224 s 0+	Cu76 641 ms 0+	Cu77 469 ms 0+	Cu78 342 ms 0+	Cu79 188 ms 0+
3 y	Ni64 0.926 0+	Ni65 2.5172 h 5/2-	Ni66 54.6 h 0+	Ni67 21 s (1/2-)	Ni68 19 s 0+	Ni69 11.4 s 0+	Ni70 0+ *	Ni71 1.86 s 0+	Ni72 2.1 s 0+	Ni73 0.90 s 0+	Ni74 1.1 s 0+				

$^{80}\text{Se}$  beam 338 MeV (1.3  $E_{\text{CB}}$ )

$^{70}\text{Zn}$  – thick target  
4 coaxial Ge detectors  
GAMPE setup

Aiming at:  $^{69}\text{mCu}$ ;  $^{79}\text{mAs}$

Observed:  $^{144}\text{mGd}$  and  $^{142}\text{mSm}$

No traces of  $^{69}\text{mCu}$  or  $^{79}\text{mAs}$

Tb145 (1/2+) *	Tb146 8 s 1+ *	Tb147 1.7 h (1/2+) *	Tb148 60 m 2- *	Tb149 4.118 h 1/2+ *	Tb150 3.48 h (2-) *	Tb151 17.609 h 1/2(+) *	Tb152 17.5 h 2- *
EC	EC	EC	EC	EC,α	EC,α	EC,α	EC,α
Gd144 4.5 m 0+ *	Gd145 23.0 m 1/2+ *	Gd146 48.27 d 0+ *	Gd147 38.06 h 7/2- *	Gd148 74.6 y 0+ *	Gd149 9.28 d 7/2- *	Gd150 1.79E+6 y 0+ *	Gd151 124 d 7/2- *
EC	EC	EC	EC	α	EC,α	α	EC,α
Eu143 2.63 m 5/2+ *	Eu144 10.2 s 1+ *	Eu145 5.93 d 5/2+ *	Eu146 4.59 d 4- *	Eu147 24.1 d 5/2+ *	Eu148 54.5 d 5- *	Eu149 93.1 d 5/2+ *	Eu150 35.8 y 5(-) *
EC	EC	EC	EC	EC,α	EC,α	EC	EC
Sm142 72.49 m 0+ *	Sm143 8.83 m 3/2+ *	Sm144 0+ *	Sm145 340 d 7/2- *	Sm146 1.03E+8 y 0+ *	Sm147 1.06E+11 y 7/2- *	Sm148 7E+15 y 0+ *	Sm149 2E15 y 7/2- *
EC	EC	3.1	α	α	α	α	α
Pm141 20.90 m 5/2+ *	Pm142 40.5 s 1+ *	Pm143 265 d 5/2+ *	Pm144 363 d 5- *	Pm145 17.7 y 5/2+ *	Pm146 5.53 y 3- *	Pm147 2.6234 y 7/2+ *	Pm148 5.370 d 1- *
EC	EC	EC	EC	EC,α	EC,β-	β-	β-



# Conclusions

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- ✧ Significant spin alignment available from deep-inelastic reactions - both with **thin target** (+spectrometer) and **thick target** experiments (see talk of N. Cieplicka)
- ✧ Tick-target experiment not possible without **gamma-gamma** coincidences even for lighter beam/target combination (no fission contribution)
- ✧ Still to be investigated what are the limits and the best approach for similar experiments

# Collaboration

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- ❧ CSNSM, Orsay – G. Georgiev, C. Sotty, E. Fiori
- ❧ IFJ, Krakow – B. Fornal, A. Maj, M. Kmiecik, N. Cieplicka, M. Matejska-Minda
- ❧ LNL, Legnaro – **C. Ur**, F. Brandolini, S. Lenzi, D. Napoli
- ❧ INRNE, Sofia – D.L. Balabanski, L. Atanasova, P. Detistov
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- ❧ IPHC, Strasbourg – R. Lozeva
- ❧ IPN, Orsay – F. Azaiez, S. Franchoo





