Coulomb excitation of superdeformed states in ^{42}Ca

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Motivation

^{40}Ca

B(E2; $4^+ \rightarrow 2^+$) = 170 Wu (DSAM, GAMMASHPERE@ANL)
$\rightarrow$ β_2=0.6 – **superdeformation**

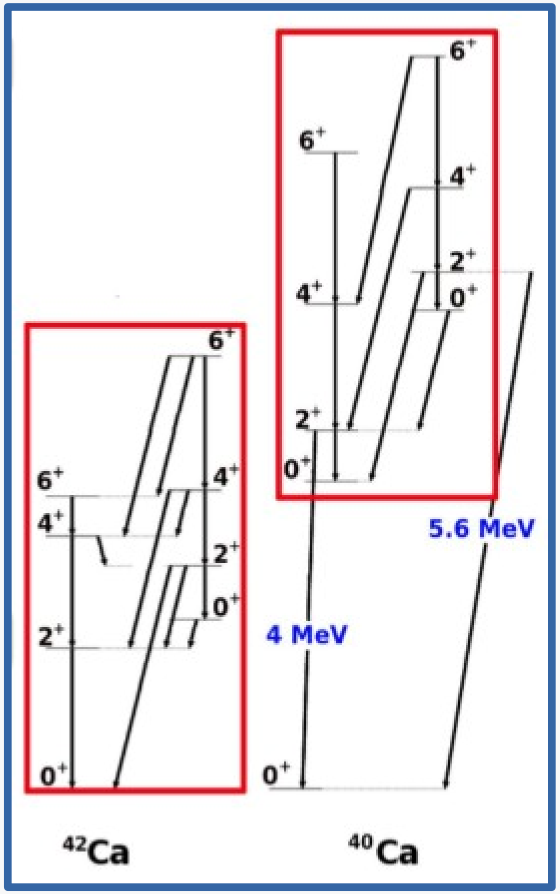
- E. Ideguchi et al., PRL 87, 222501 (2001)
- C.J. Chiara et al., PRC 67, 041303R (2003)

Superdeformed bands in A~40 mass region:

- ^{36}Ar: C.E.Svensson et al., PRL 85 (2000) 2693
- ^{38}Ar: D.Rudolph et al., PRC 65 (2002) 034305
- ^{40}Ar: E.Ideguchi et al., PLB 686 (2010) 18
- ^{44}Ti: D.C.O'Leary et al., PRC 61 (2000) 064314

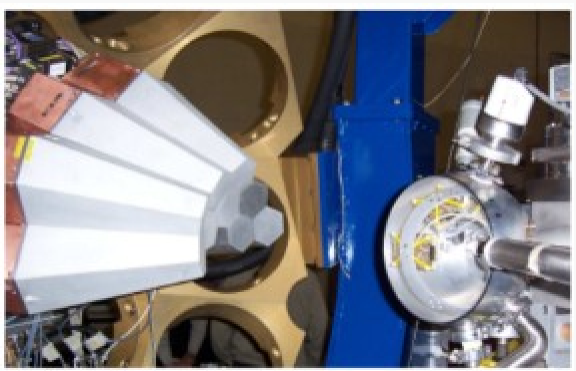
(in all cases β_2 between 0.4-0.6, axis ratio 3:2 - 2:1)

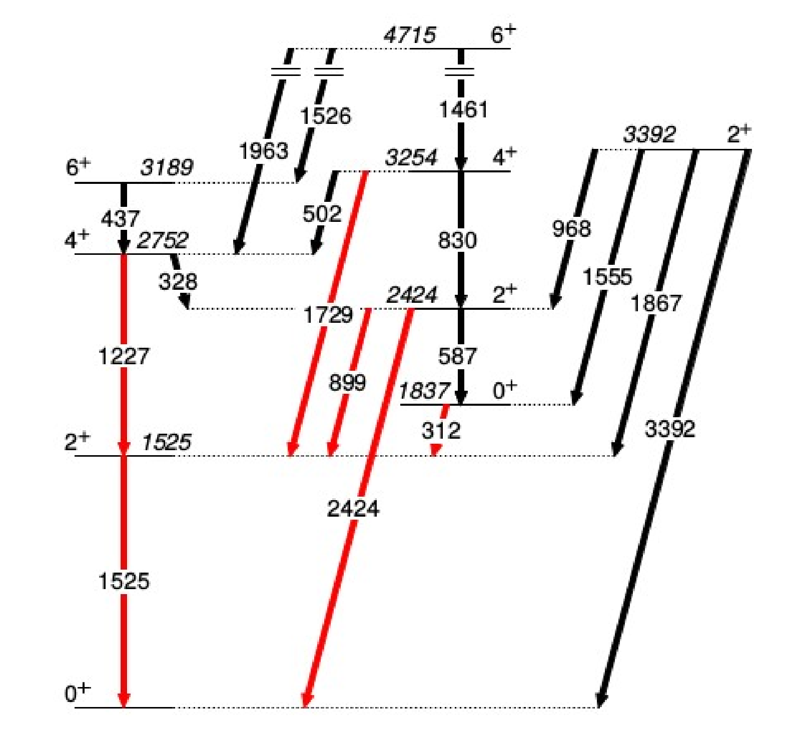
^{46}Ti GDR decay feedings states in ^{42}Ca



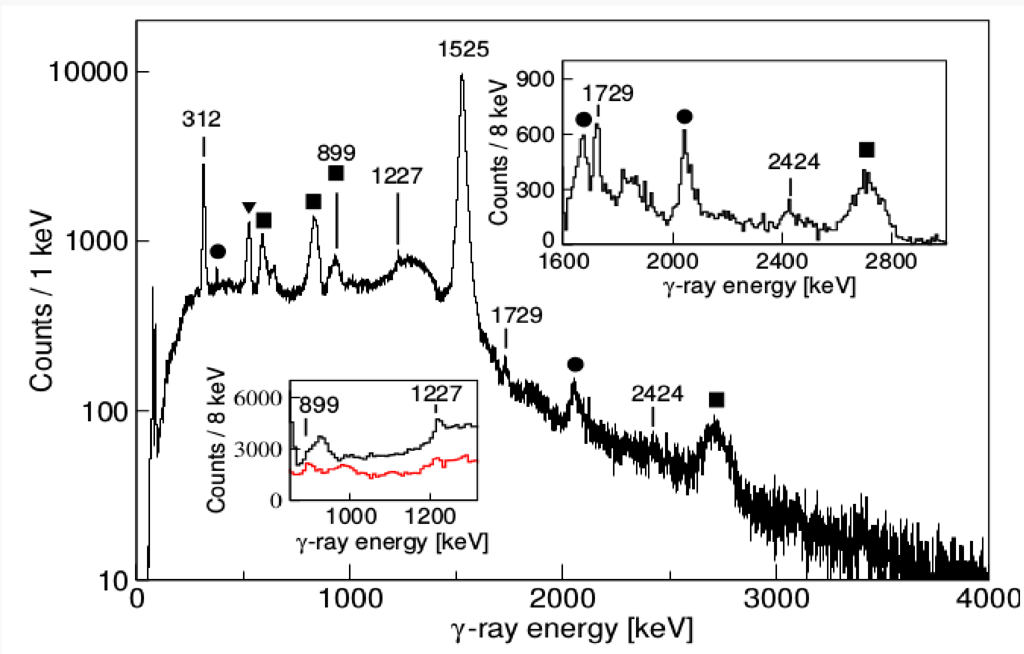
Coulomb excitation of ^{42}Ca

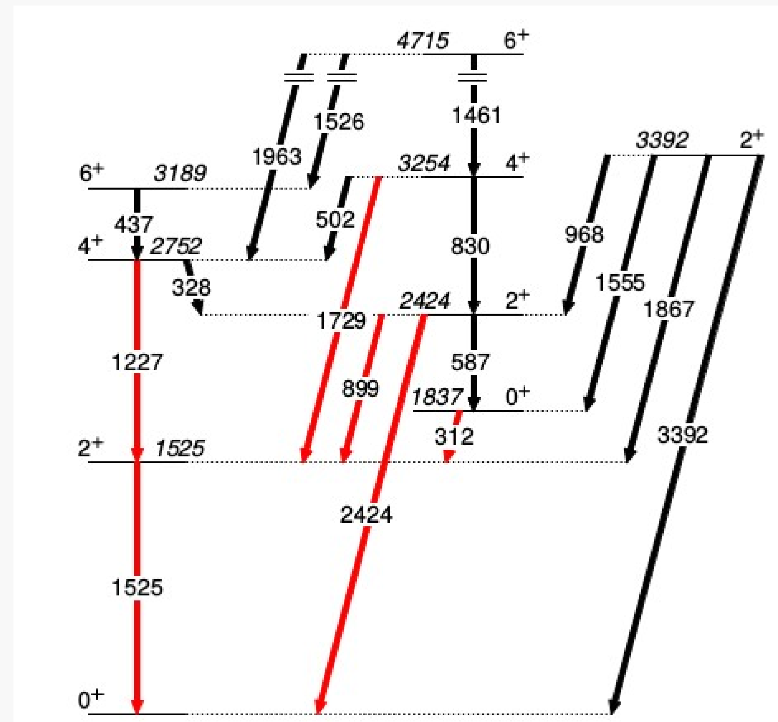
- Beam: ^{42}Ca, 170 MeV
- Targets:
  - ^{208}Pb, 1 mg/cm^2
  - ^{197}Au, 1 mg/cm^2
- AGATA: 3 triple clusters, 143.8 mm from the target
- DANTE: 3 MCP detectors, 100-144^o





Results – spectrum of ^{42}Ca

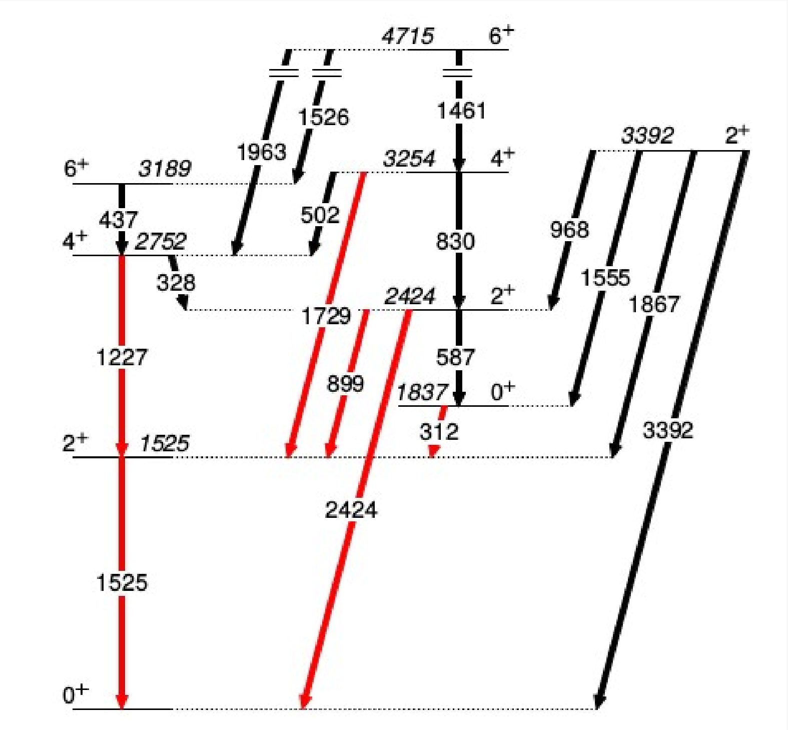




Results – GOSIA calculations

	$\langle I_i \| E2 \| I_f \rangle$ (e·fm²)	$B(E2)\downarrow$ (e²·fm⁴)	
$I_i^+ \rightarrow I_f^+$	Present	Present	Others
$2_1^+ \rightarrow 0_1^+$	$20.5^{+0.6}_{-0.6}$	84^{+5}_{-5}	80 (3)
$2_2^+ \rightarrow 0_1^+$	$-6.4^{+0.3}_{-0.3}$	$8.2^{+0.8}_{-0.8}$	19 (5)
$4_1^+ \rightarrow 2_1^+$	$24.3^{+1.2}_{-1.2}$	$66.0^{+6.5}_{-6.5}$	427 (128)
$0_2^+ \rightarrow 2_1^+$	$22.2^{+1.1}_{-1.1}$	493^{+49}_{-49}	576 (36)
$2_2^+ \rightarrow 2_1^+$	$-23.7^{+2.3}_{-2.7}$	112^{+22}_{-22}	146 (1)
$4_2^+ \rightarrow 2_1^+$	42^{+3}_{-4}	196^{+28}_{-37}	256 (93)
$6_1^+ \rightarrow 4_1^+$	$9.3^{+0.2}_{-0.2}$	$6.7^{+0.3}_{-0.3}$	6 (2)
$2_2^+ \rightarrow 0_2^+$	26^{+5}_{-4}	135^{+52}_{-42}	<520
$4_2^+ \rightarrow 2_2^+$	46^{+5}_{-6}	235^{+51}_{-61}	484 (189)

	$\langle 2_i^+ \| E2 \| 2_i^+ \rangle$ (e·fm²)	Q_{sp} (e·fm²)	
	Present	Present	Others
2_1^+	-16^{+9}_{-3}	-12^{+7}_{-2}	-19 (8)
2_2^+	-55^{+15}_{-15}	-42^{+12}_{-12}	



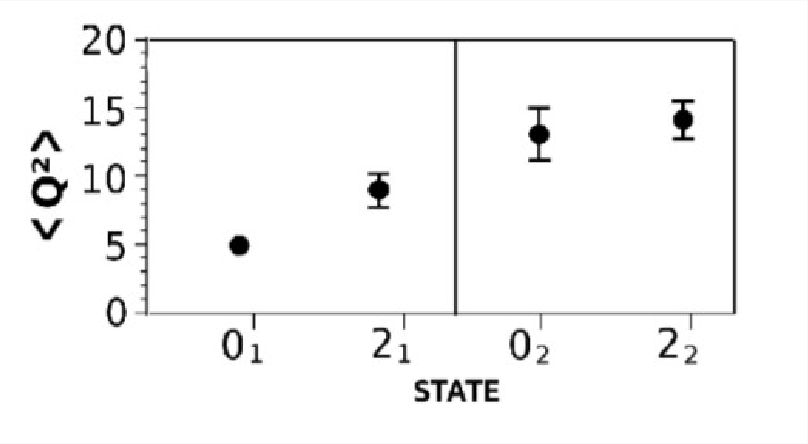
Discussion:
Quadrupole Sum Rules method

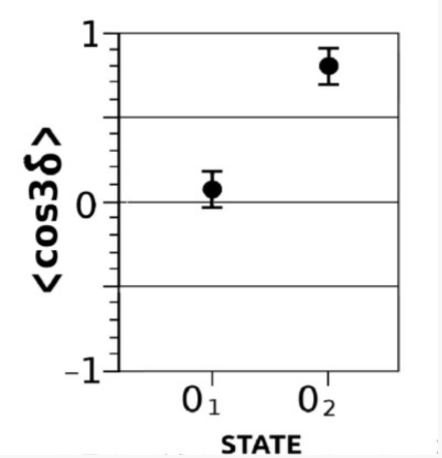
$$\frac{1}{\sqrt{5}}\langle Q^2\rangle = \frac{1}{\sqrt{2I_i+1}}\sum_t \langle i\|E2\|t\rangle\langle t\|E2\|f\rangle \begin{Bmatrix} 2 & 2 & 0 \\ I_i & I_f & I_t \end{Bmatrix}$$

$$\langle Q^3\cos(3\delta)\rangle = \mp\frac{\sqrt{35}}{\sqrt{2}}\frac{1}{\sqrt{2I_i+1}}\sum_{tu} \langle s\|E2\|u\rangle\langle u\|E2\|t\rangle\langle t\|E2\|s\rangle \begin{Bmatrix} 2 & 2 & 2 \\ I_s & I_t & I_u \end{Bmatrix}$$

state	$\langle Q^2\rangle_{exp}$
0_1^+	500 (20)
2_1^+	900 (100)
0_2^+	1300 (230)
2_2^+	1400 (250)

state	$\langle\cos(3\delta)\rangle_{exp}$
0_1^+	0.06 (10)
0_2^+	0.79 (13)





Discussion:
Quadrupole Shape Invariants

state	$\langle Q^2 \rangle_{exp}$
0_1^+	500 (20)
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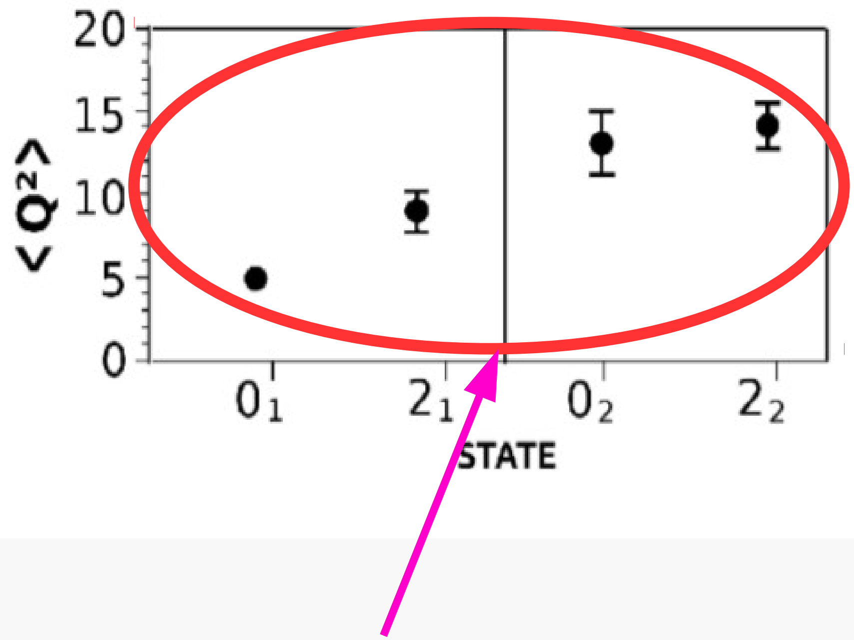

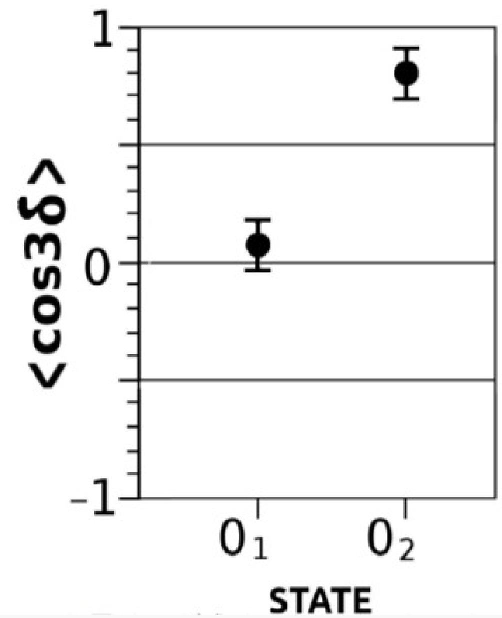

Increasing deformation in GSB and
stable in the side band

Discussion:
Quadrupole Shape Invariants

cos(3δ)~0.8 – slightly triaxial - prolate 0_2

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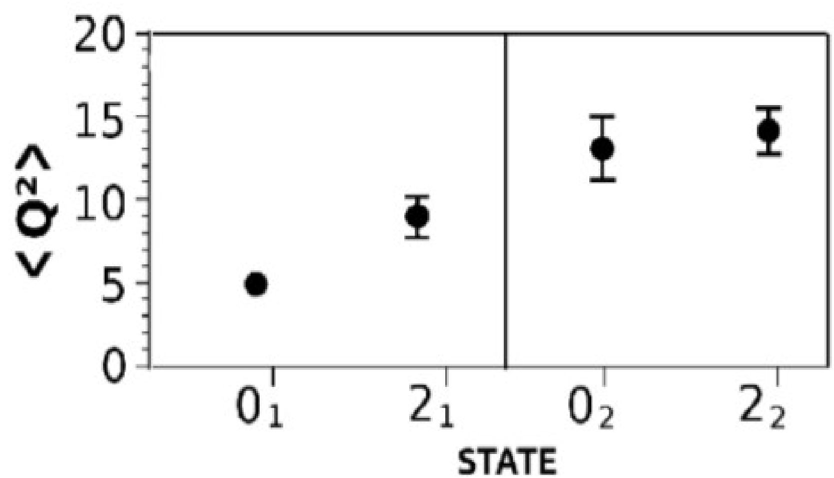

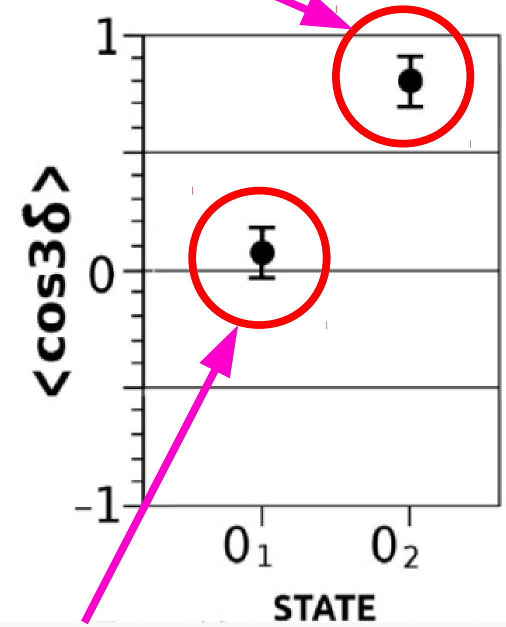

cos(3δ)~0 – triaxial GS

Discussion:
Quadrupole Shape Invariants

cos(3δ)~0.8 – slightly triaxial - prolate 0_2

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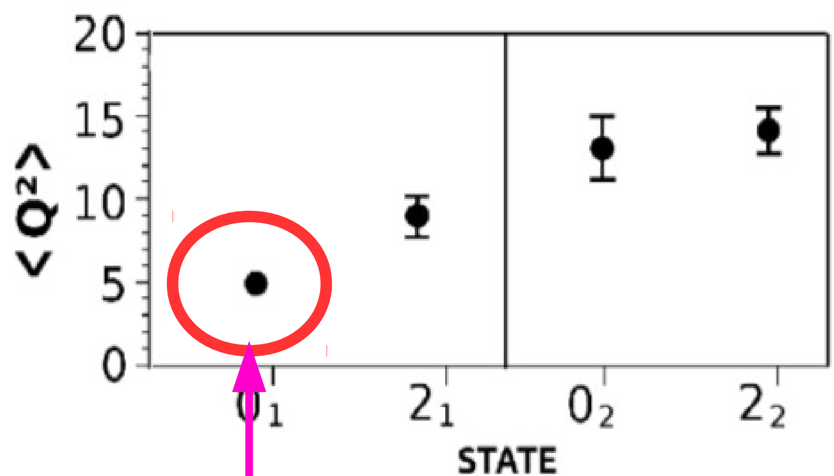
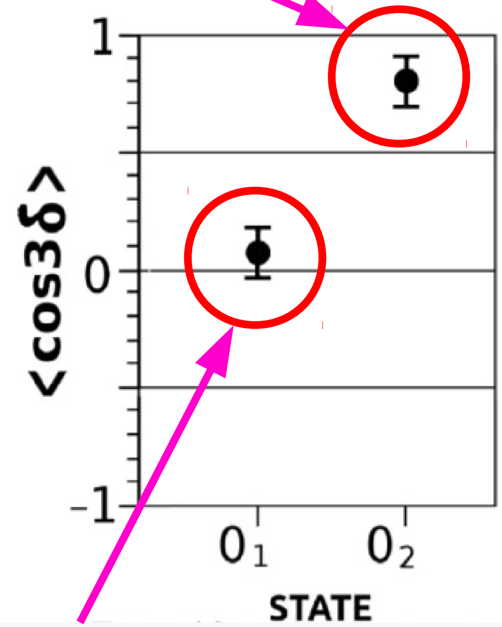




Non-zero deformation of the ground state?

cos(3δ)~0 – triaxial GS??
In spherical ^{40}Ca region?

0_1 β=0.26(2) and γ=29(2)°

0_2 β=0.43(2) and γ=13(6)°

Discussion:
Shape parameters

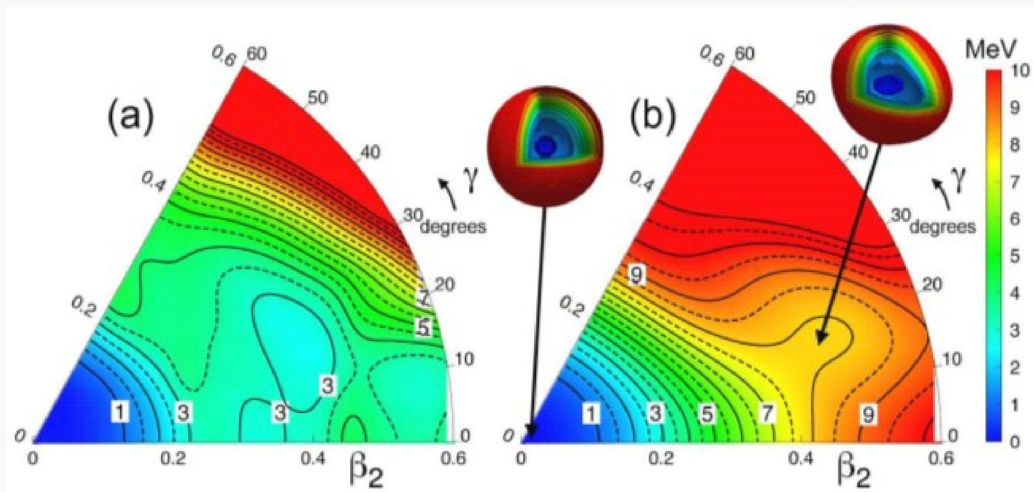
Non-zero Q^2 for the ground state could be caused by **fluctuations** around the spherical shape so the maximum triaxiality could be the effect of averaging over **<u>all possible quadrupole shapes</u>**. If so, **the dispersion of Q^2 , $\sigma(Q^2)$, should be comparable to Q^2 value**

$$\sigma(Q^2) = \sqrt{\langle Q^4 \rangle - \langle Q^2 \rangle^2}$$

Insufficient experimental data
Theoretical predictions and the full set of ME from the SM and BMF calculations

Discussion:
Shape parameters

We use the theoretical predictions and the full set of ME from the calculations:
- Large Scale Shell Model (F. Nowacki, H. Naidja - Strasbourg)
- Beyond Mean Field (T. Rodriguez - Madrid)



Both approaches predict:

0_1 - SPHERICAL

0_2 - TRIAXIAL/PROLATE

Discussion:
Shape parameters

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state	$\langle Q^2\rangle_{exp}$	$\langle Q^2\rangle_{SM}$	$\sigma(Q^2)_{SM}$	$\langle Q^2\rangle_{BMF}$	$\sigma(Q^2)_{BMF}$
0_1^+	500 (20)	240	470	100	250
2_1^+	900 (100)	250	490	100	310
0_2^+	1300 (230)	1200	500	1900	520
2_2^+	1400 (250)	1130	500	1900	300

state	$\langle\cos(3\delta)\rangle_{exp}$	$\langle\cos(3\delta)\rangle_{SM}$	$\langle\cos(3\delta)\rangle_{BMF}$
0_1^+	0.06 (10)	0.34	0.34
0_2^+	0.79 (13)	0.67	0.49

0_1 - SPHERICAL with large fluctuations around minimum

0_2 - SLIGHTLY TRIAXIAL/PROLATE shape

K. Hadynska-Klek et al., accepted in PRL

Summary

- the properties of low-lying states in ^{42}Ca were studied using low-energy Coulomb excitation – 0^+, 2^+ and 4^+ states observed in both bands
- the quadrupole deformation parameters of the $0^+$and 2^+ states in GSB and SDB in ^{42}Ca were determined from the measured reduced matrix elements
- the results were compared with SM and BMF calculations
- the non-zero deformation of the ground state has been attributed to the fluctuations around the spherical shape
- a large static deformation of β=0.43(2) and β=0.45(2), for $0_2^+$and 2_2^+ was observed, proving the superdeformed character of the side band
- the cos(3δ) parameter measured for 0_2 brings the first experimental evidence for non-axial character of SD bands in the A∼ 40 mass region