DE LA RECHERCHE À L'INDUSTRIE

1. The N=28 region.
2. Coexistence at Z=16.
3. Perspectives & summary.

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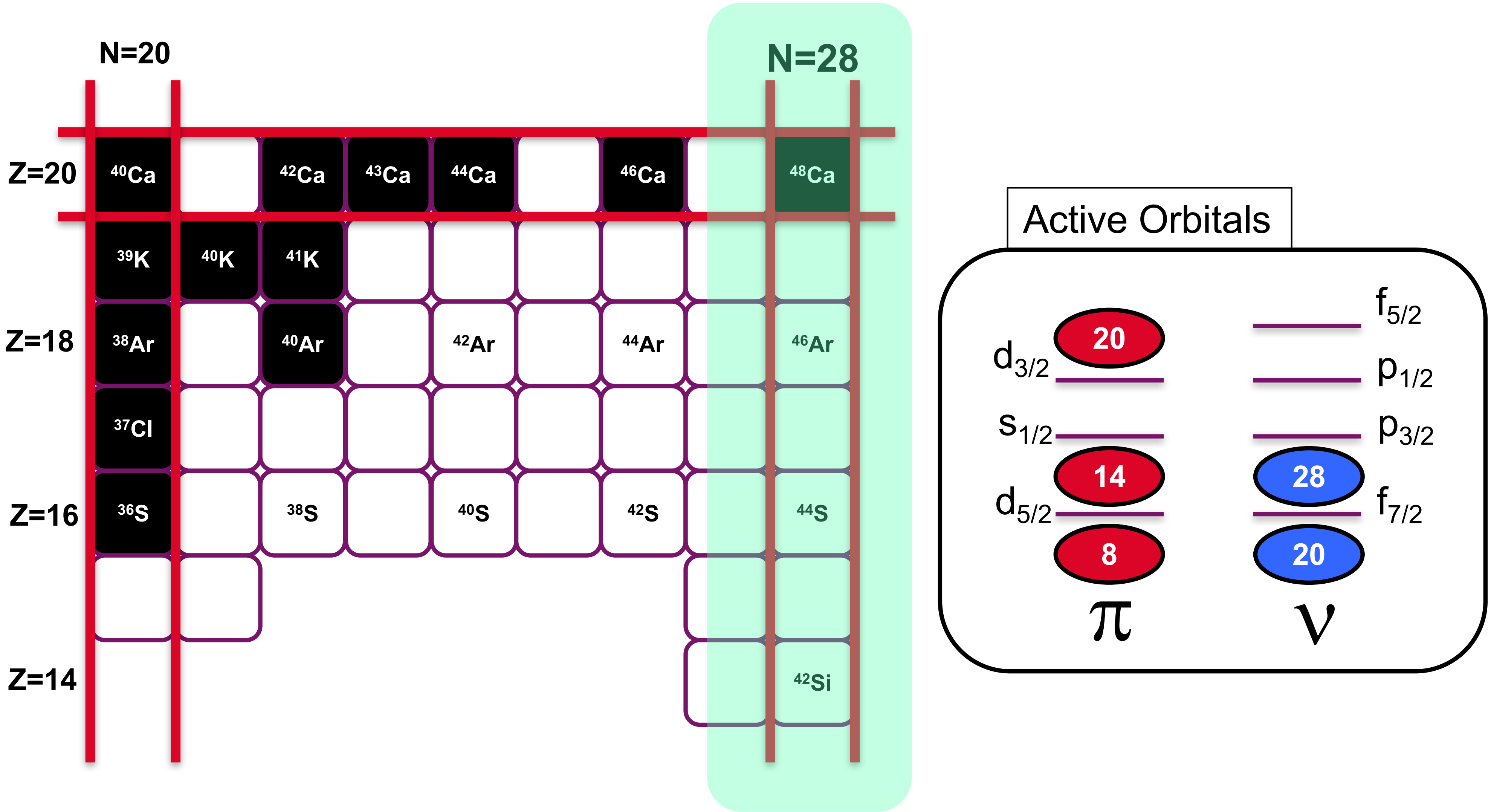
SHAPE TRANSITION & COEXISTENCE AROUND N=28

L. GAUDEFROY

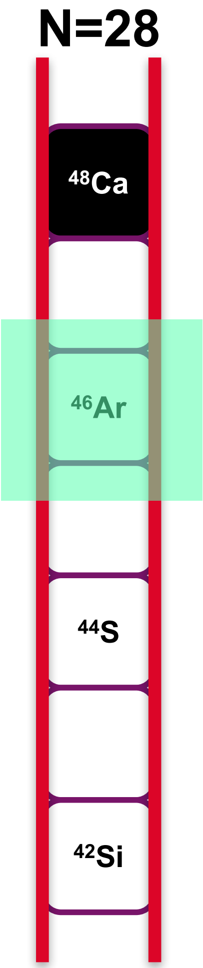
CEA-DAM

ESNT – October 2017

THE N=28 REGION

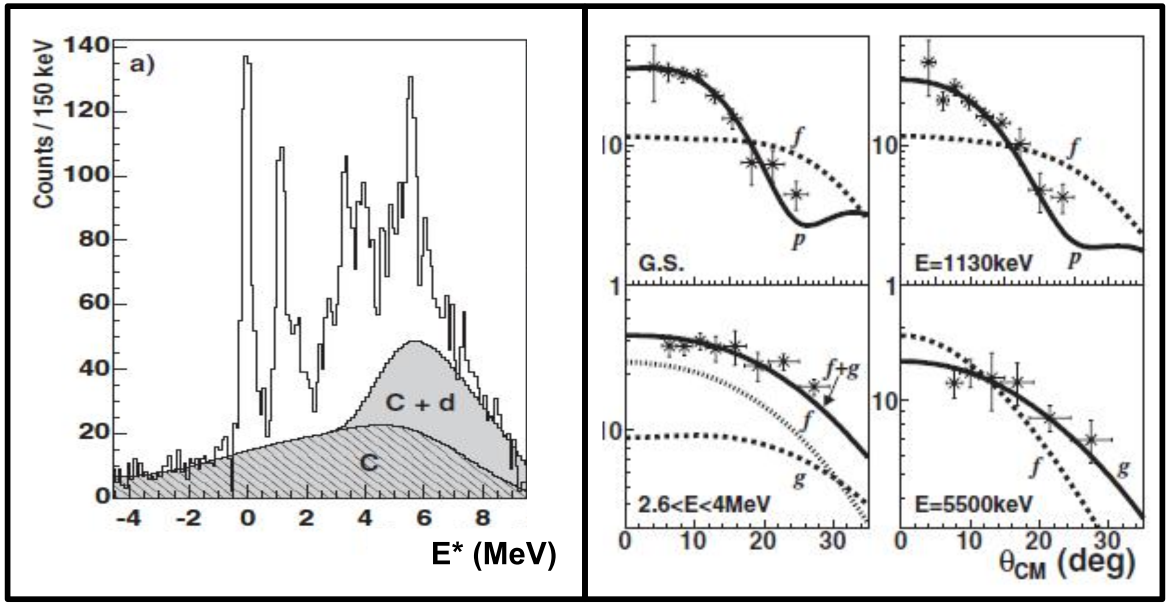


THE N=28 REGION – NEUTRON SIDE

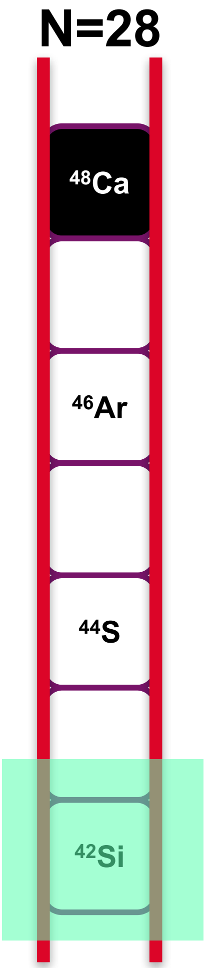


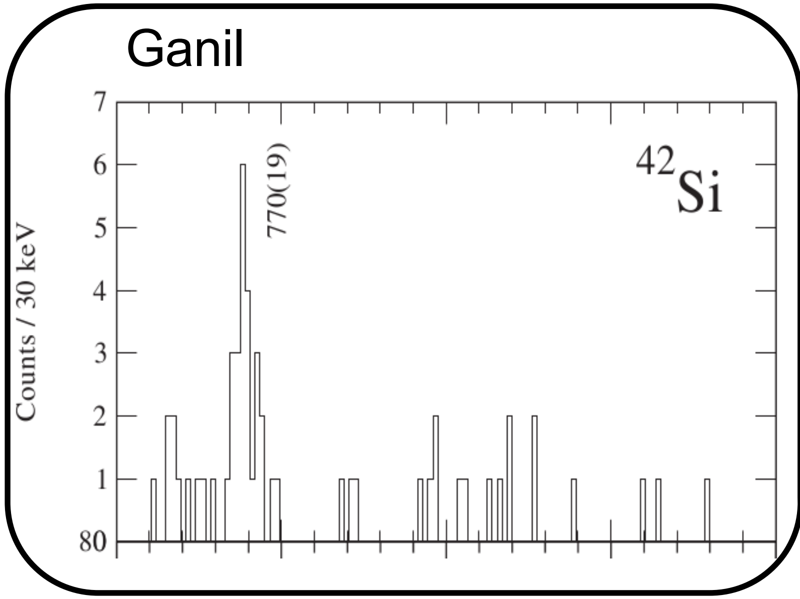
^{48}Ca :
Mass measurement ➔ Gap 4,8 MeV

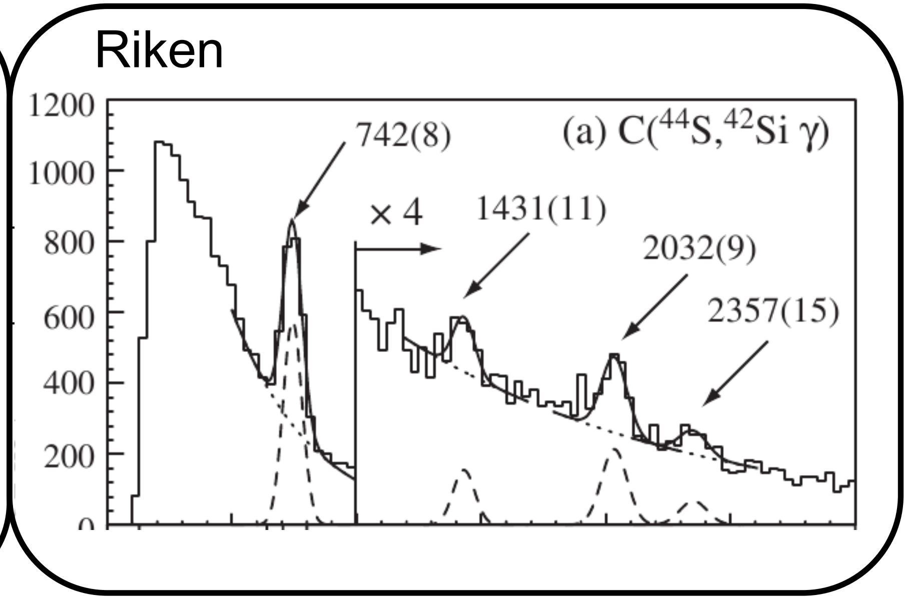
^{46}Ar :
(d,p) reaction ➔ Gap reduction by ~300 keV.
L. Gaudefroy et al., PRL **97**, 092501 (2006).



THE N=28 REGION – NEUTRON SIDE







^{42}Si :

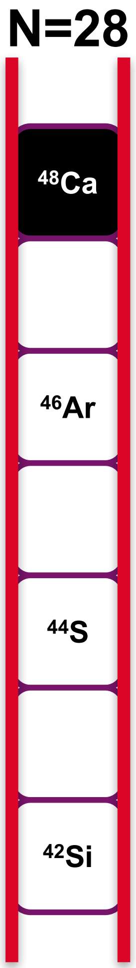
In-beam γ-Spectroscopy ➔ Low E(2^{+}_{1}) = 742 keV.

B. Bastin et al., PRL **99**, 022503 (2007).

Riken ➔ $R_{4/2}$=2,93 , i.e. well-deformed rotor.

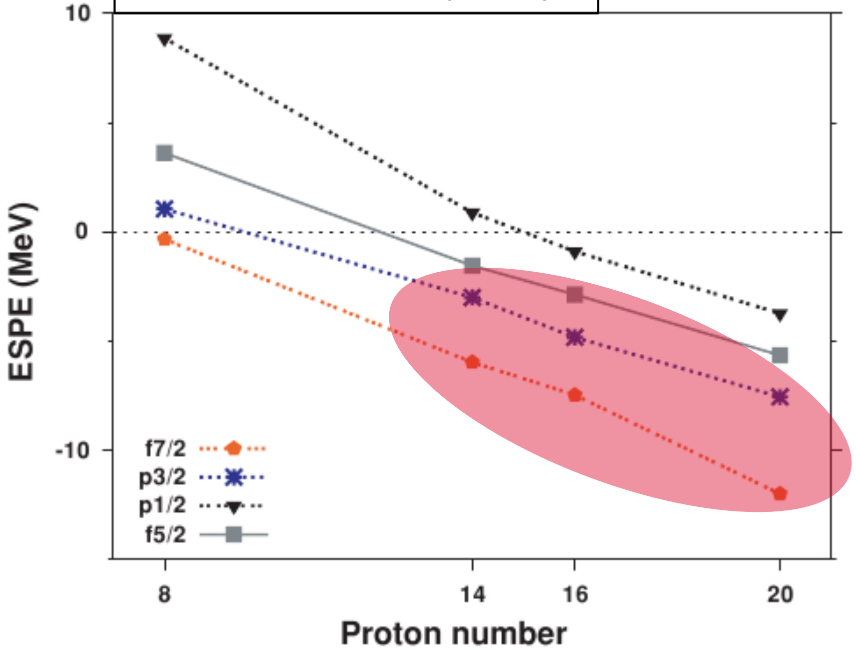
S. Takeuchi et al., PRL **109**, 182501 (2012).

THE N=28 REGION – NEUTRON SIDE

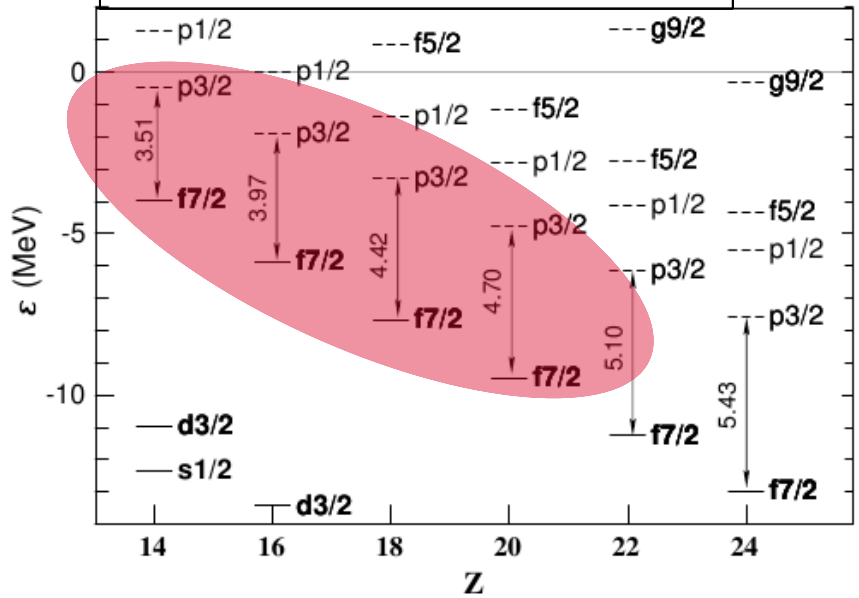


N28 gap reduction from Z=20 down to Z=14:
- ➔ by about 300keV every 2 proton.
- ➔ Well accounted for by SM and MF approaches.

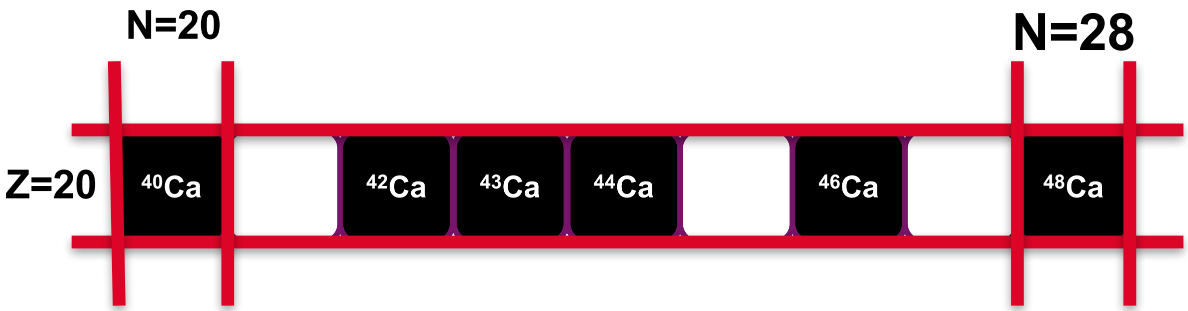
F. Nowacki and A. Poves
PRC **79**, 014310 (2009).

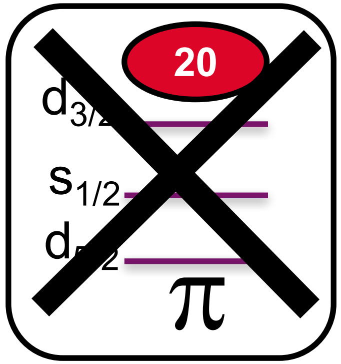


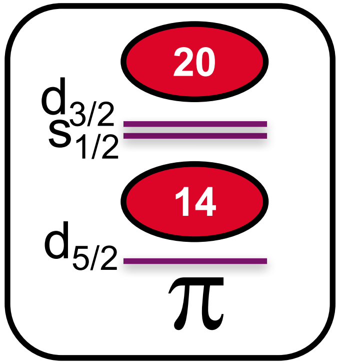
S. Péru et al., EPJA **9**, 35 (2000).

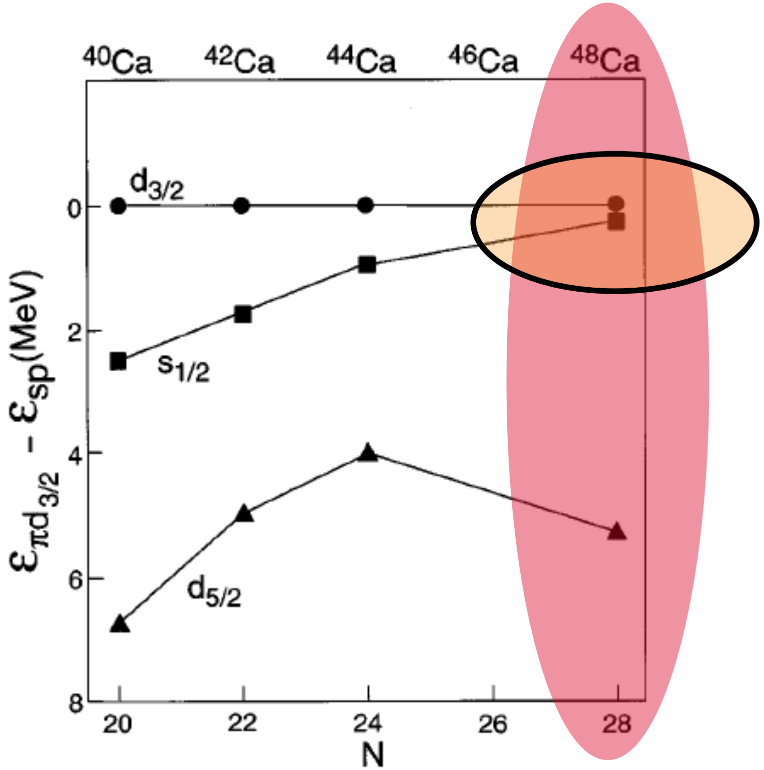


THE N=28 REGION – PROTON SIDE



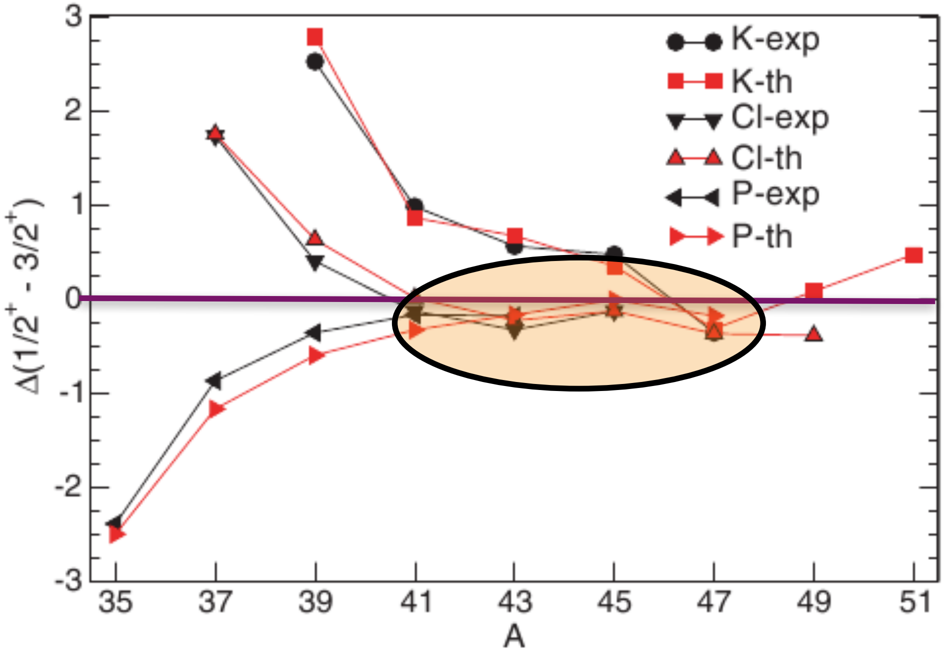






P.D. Cottle and K.W. Kemper PRC 58, 3761 (1998).

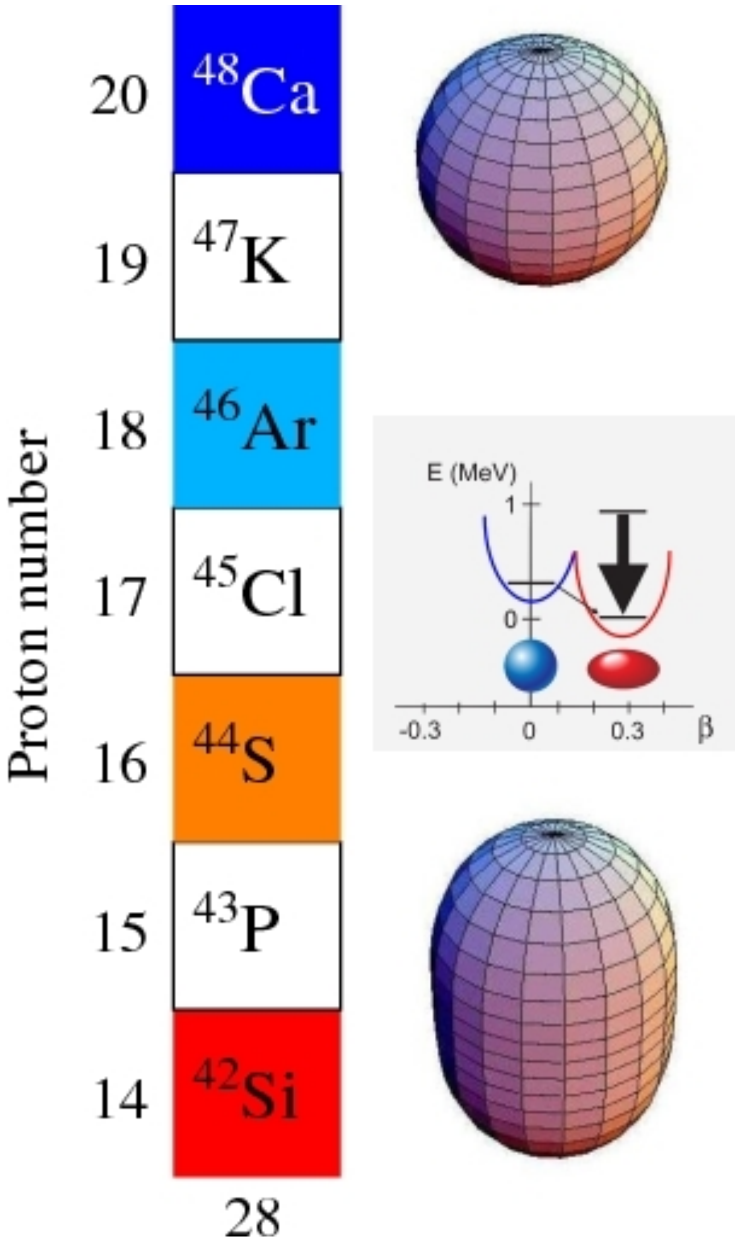
P. Doll et al., NPA 263, 210 (1976).



F. Nowacki and A. Poves PRC **79**, 014310 (2009).

A. Gade et al., PRC **74**, 034322 (2006).

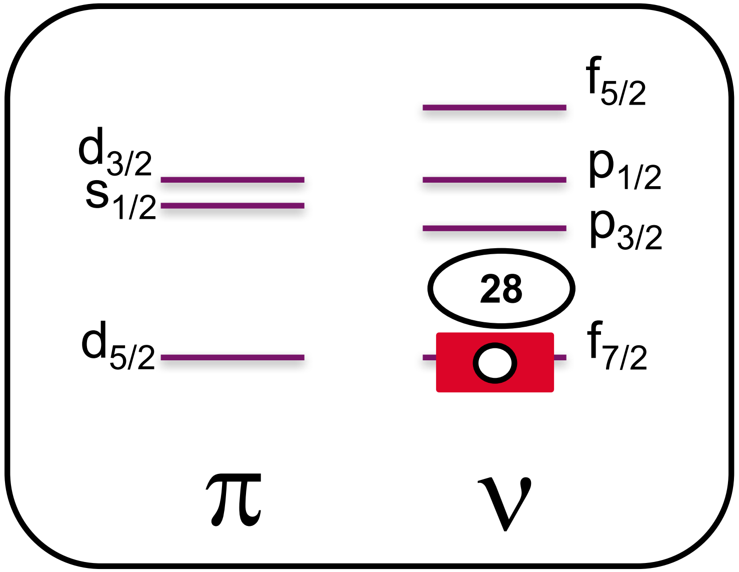
THE N=28 REGION

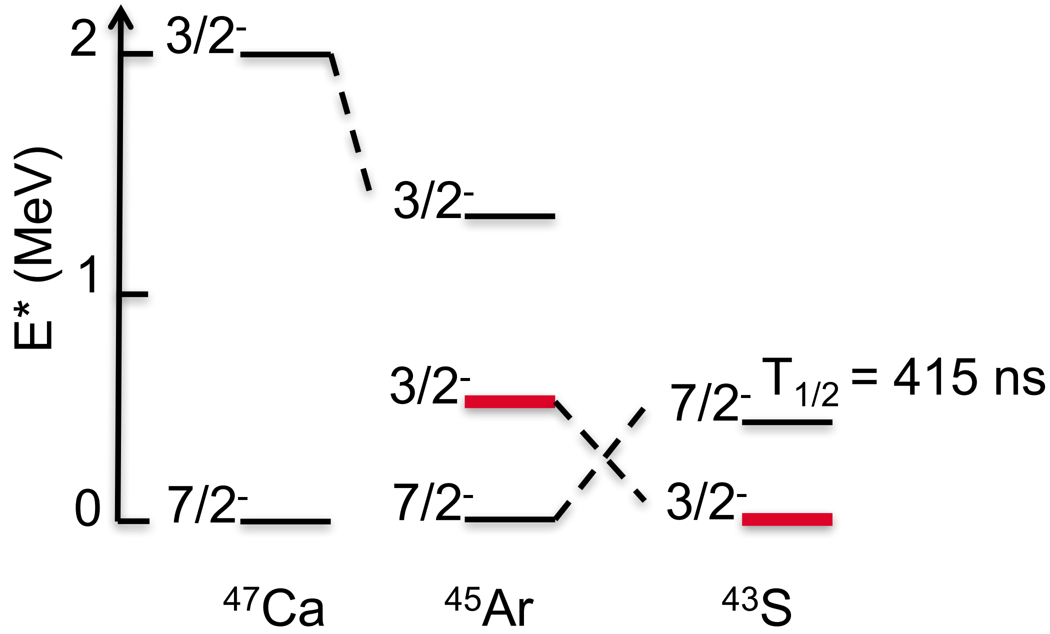


- Reduction of neutron gap with N/Z.
- Near degeneracy of proton $s_{1/2}$ – $d_{3/2}$ orbits.
- Both favor quadrupole collectivity mandatory to understand structure evolution.
- Spherical/deformed shape transition : Ca ➔ Si.
- **Transitional nature of sulfur isotopes.**

ON THE WAY TOWARD ^{43}S

Structure of N=27 isotones :





^{47}Ca : Single particle states.
Evaluated Nuclear Structure Data File.

^{45}Ar : $3/2^-_1$ state ➔ Intruder.
Favored by about 2MeV (correlation energy) with respect to $7/2^-$.
L. Gaudefroy et al., PRC **78,** 034307 (2008).

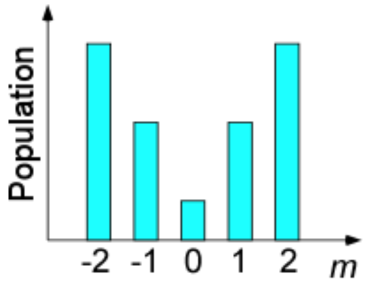
^{43}S : Intruder state ➔ GS.
$7/2^-_1$ ➔ Isomer.
} Shape coexistence?
F. Sarazin et al., PRL 84, 5062 (2000); L. Gaudefroy et al., PRL 109, 202503 (2012).

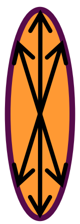
NUCLEAR MOMENTS OF ^{43m}S

Principle of the measurement :

Orientation → Perturbation → Anisotropie

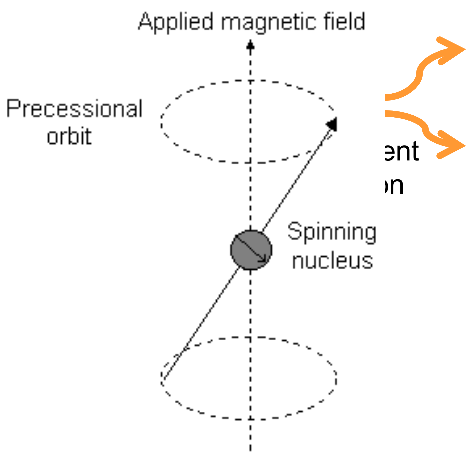
Spin alignement :
fragm. reaction



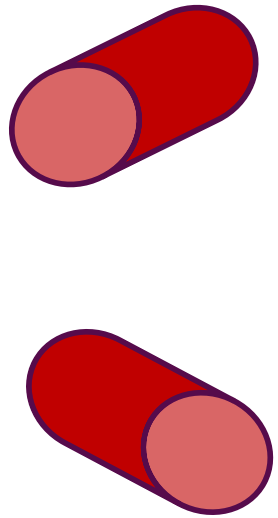


Implantation
appropriate host

- $B \perp Z_{or} \Rightarrow \omega_L$
- $V_{zz} \perp Z_{or} \Rightarrow \omega_Q$

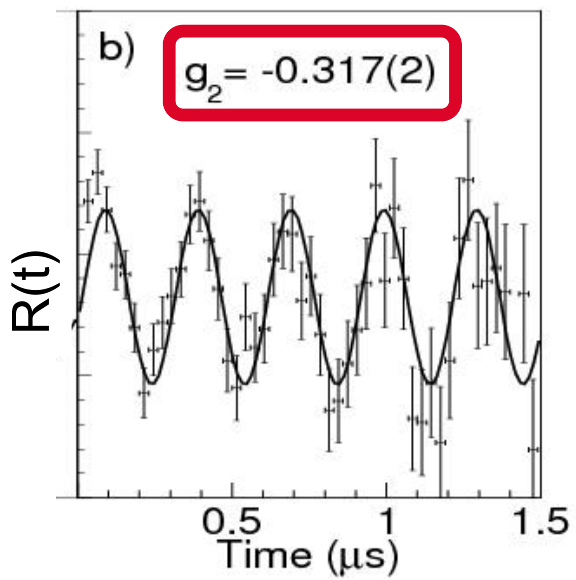


Ge detector for 320 keV γ-ray

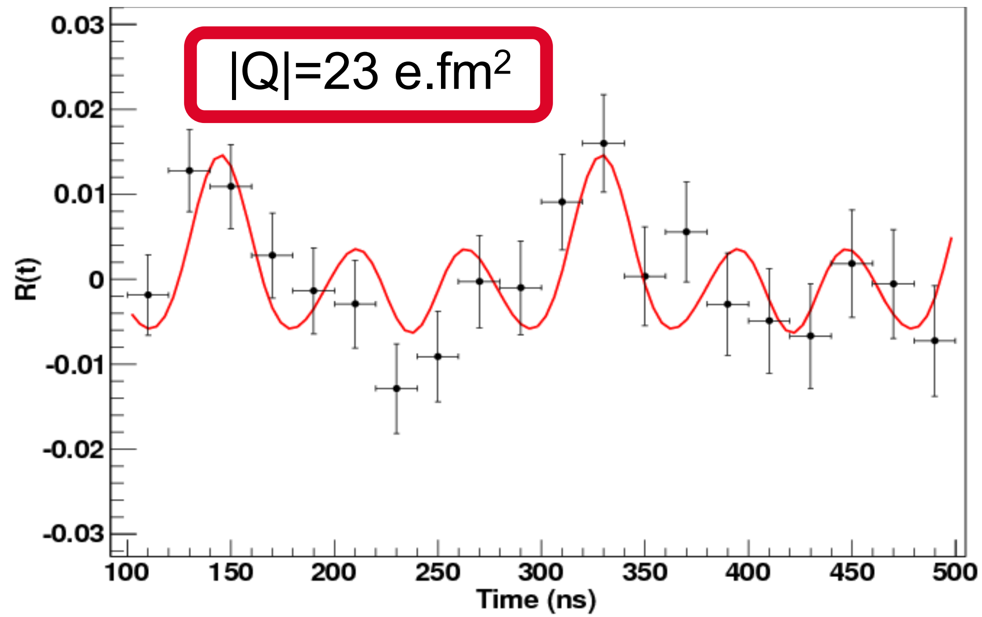


➔ **g-factor @ GANIL & Q-moment @ RIKEN**

NUCLEAR MOMENTS OF ^{43M}S



L. Gaudefroy et al., PRL **102**, 092501 (2009).



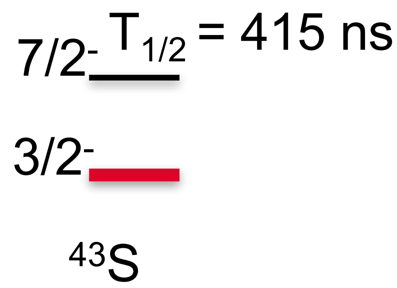
R. Chevrier et al., PRL **108**, 162501 (2012).

g-factor @ GANIL:

- ➔ Sign & Amplitude : $J^{\pi}=7/2^{-}$.
- ➔ $T_{1/2}$=415(5)ns, E2 transition : GS=$3/2^{-}$
- ➔ Hindrance factor 7/2->3/2 : 20.

Q-moment @ RIKEN:

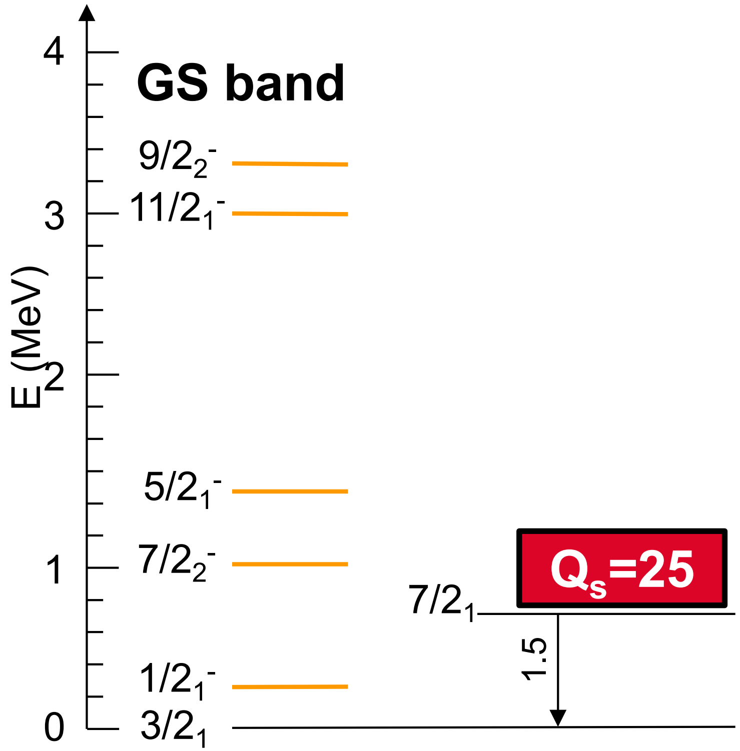
- ➔ Q=23, significantly higher than SP value (4 $e.fm^2$).



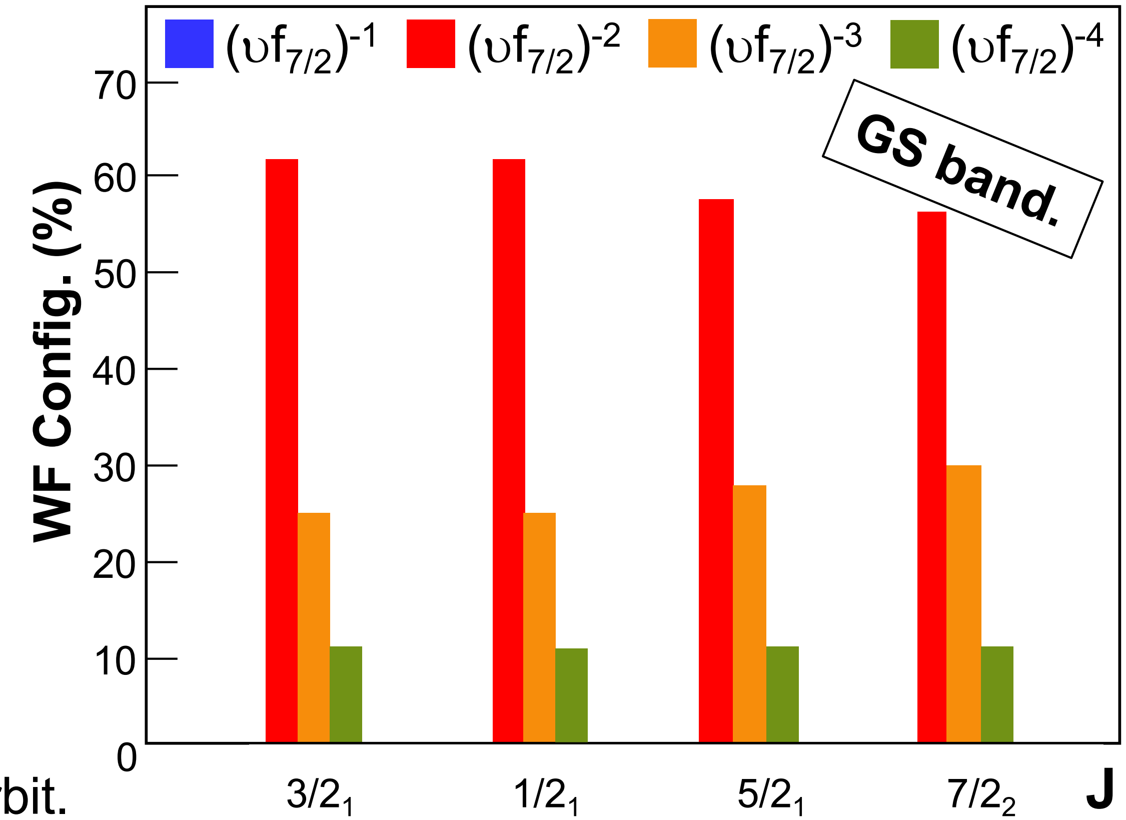
<u>SM calculations</u> :

ANTOINE : E. Caurier, IReS, Strasbourg 1989-2002.

SDPF-U: F. Nowacki and A. Poves, PRC**79**, 014310 (2009).



K=1/2 decoupled GS band on $p_{3/2}$ orbit.



➔Clear evidence for intrinsic WF.

- GS axial (prolate – β=0,3) band.
- Isomer not member of the band.
- Q-moment of isomer well reproduced.

Shape of the isomer?

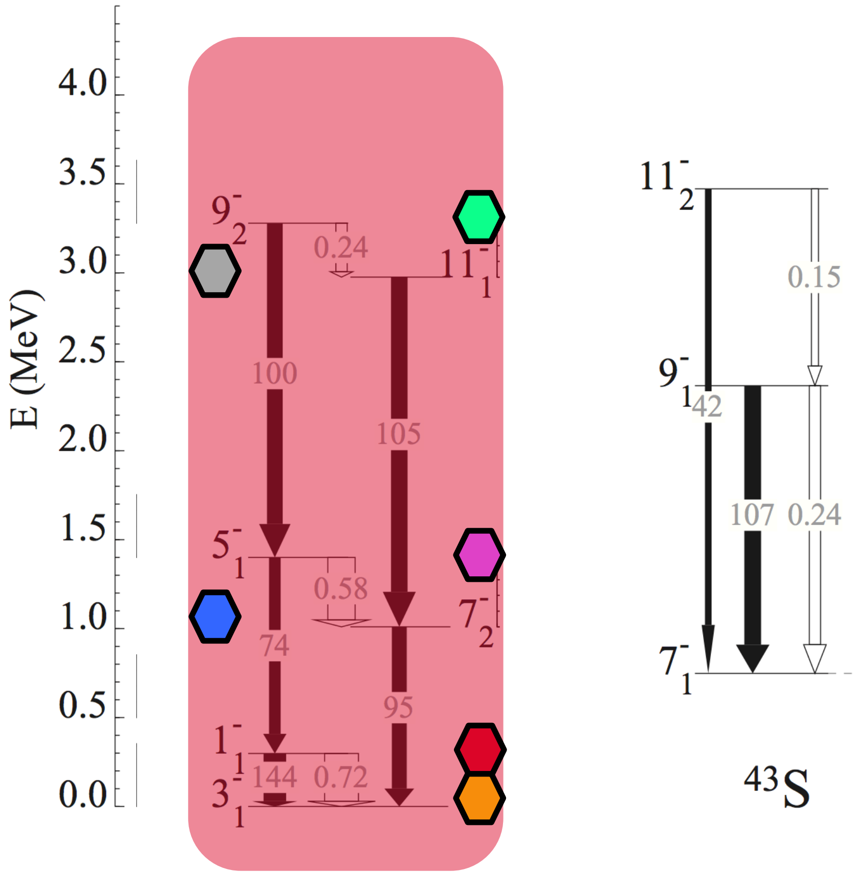
^{43}S SM SHAPE PARAMETERS

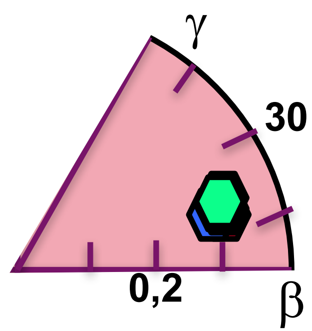
E2 Rotational Invariants :

K. Kumar, PRL**28**, 249 (1972).

$$Q^2_i = \langle s|P^{(2)}|s\rangle = \frac{1}{\sqrt{5}}\frac{1}{2I_s+1}\sum_t M_{sr}^2,$$

$$Q^3_i \cos(3\gamma) = \langle s|P^{(3)}|s\rangle = \frac{-1}{2I_s+1}(-)^{2I_s} \times \sum_{rt}\begin{Bmatrix} 2 & 2 & 2 \\ I_s & I_r & I_t \end{Bmatrix} M_{sr}M_{rt}M_{ts},$$





- Axial prolate GS Band.

R. Chevrier and L. Gaudefroy, PRC **89**, 051301(R) (2014).

^{43}S SM SHAPE PARAMETERS

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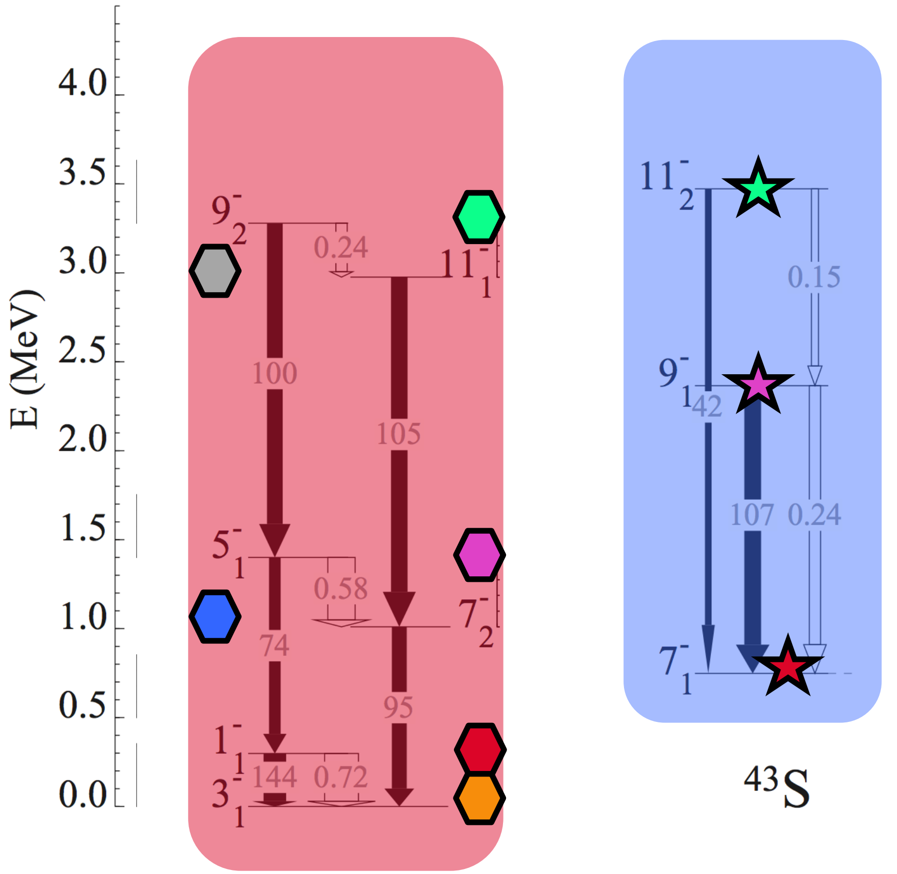
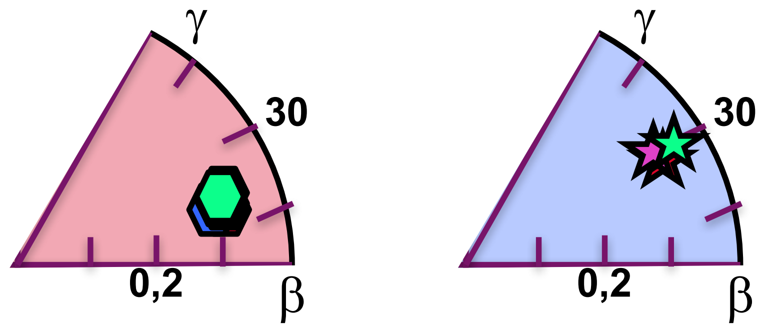




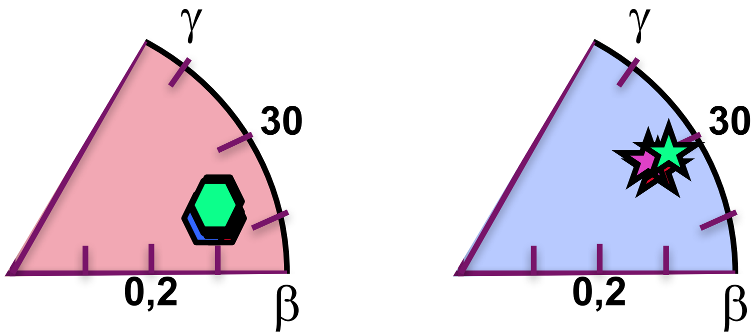
- Axial prolate GS Band.
- Triaxial structure on isomer.

R. Chevrier and L. Gaudefroy, PRC **89**, 051301(R) (2014).

^{43}S THEORETICAL COHERENCE

SM approach:

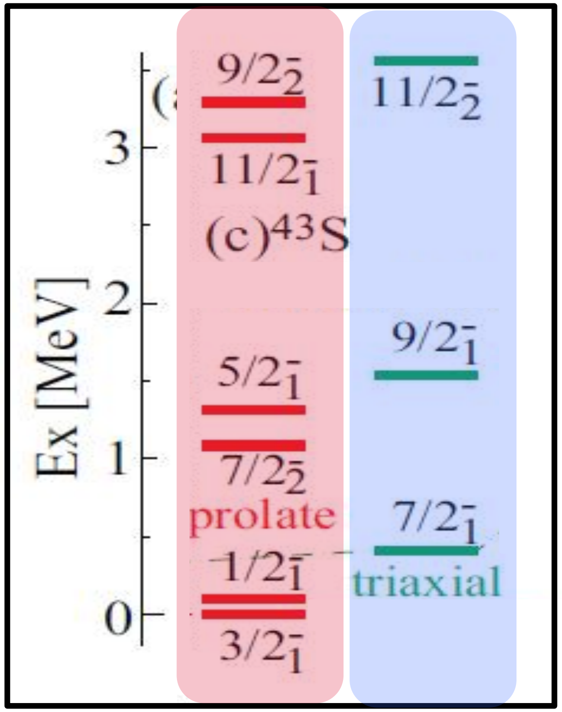
R. Chevrier and L.G., PRC **89**, 051301(R) (2014).

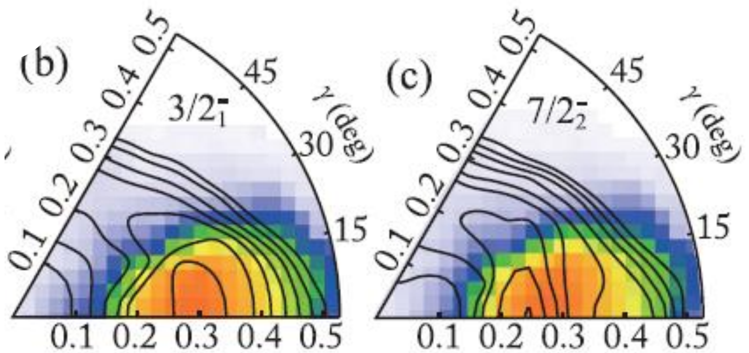


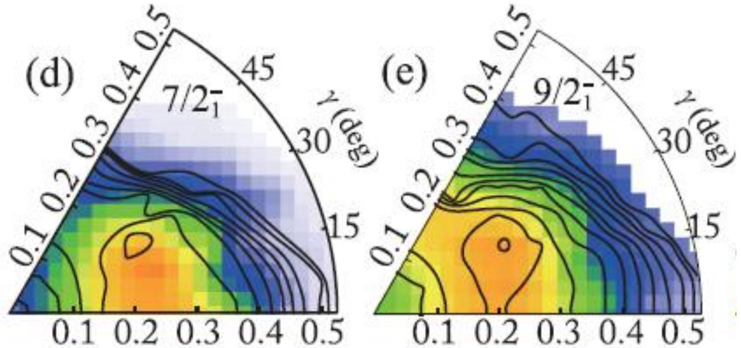
- Axial prolate GS Band.
- Triaxial structure on isomer.

AMD approach with D1S Gogny:

M. Kimura et al., PRC **87**, 011301(R) (2013).







See also : Y. Utsuno et al., PRL **114**, 032501 (2015).

➔ Same conclusions with BMF approx. to SM.

COEXISTENCE AT N=28 : ^{44}S

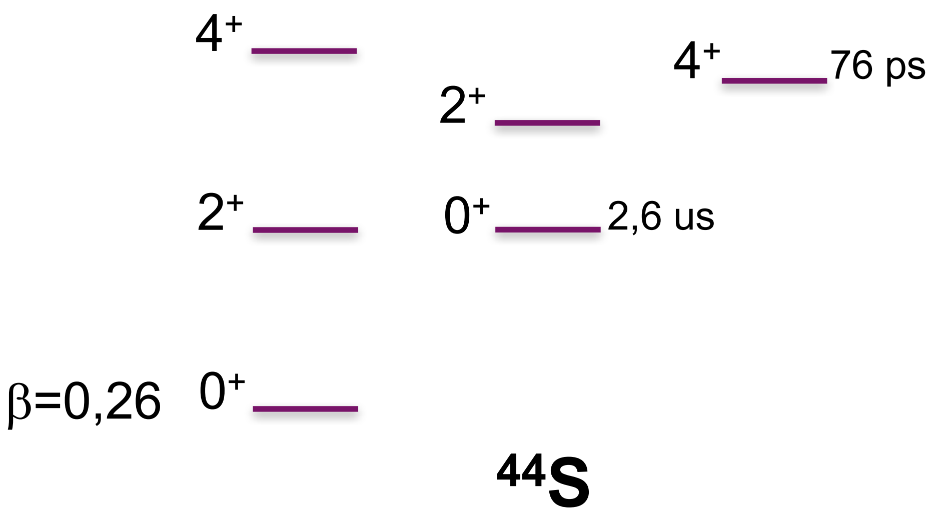
➔ 1993 : Suggestion of N=28 erosion from short β-decay half-life of ^{44}S.
O. Sorlin et al., PRC **47**, 2941 (1993).

➔ 1996 : Deformation in ^{44}S (β=0.26) from B(E2).
T. Glasmacher et al., PLB **395**, 163 (1997).

➔ 2005 : Observation of 0^+_2 state – coexistence?
S. Grévy et al., EPJA **25**, 111 (2005).

➔ 2010 : ρ^2(E0 0^+_2 -> 0^+_1) – Sphe./Def. shape coexistence.
C. Force et al., PRL **105**, 102501 (2010).

➔ 2017 : High K isomer 4^+_1 state : Triple shape coexistence.
J.J. Parker et al., PRL **118**, 052501 (2017).
First reported in D. Santiago-Gonzales et al., PRC **83,** 061305 (R) (2011).



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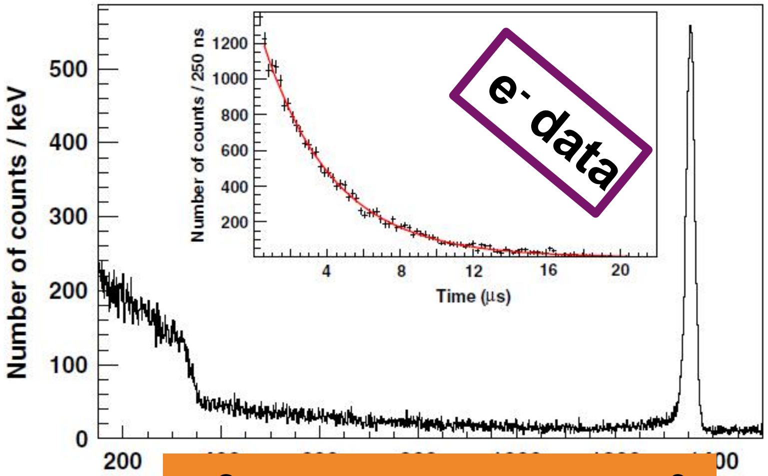
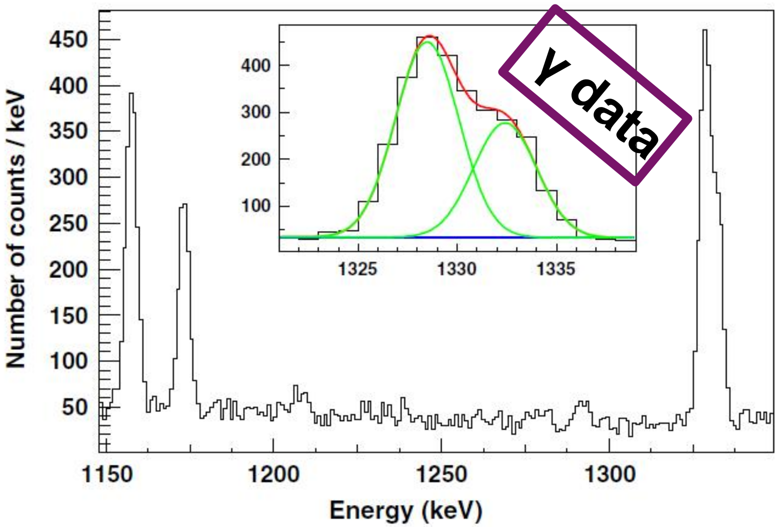
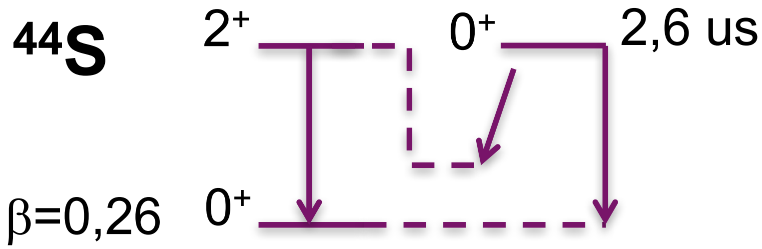
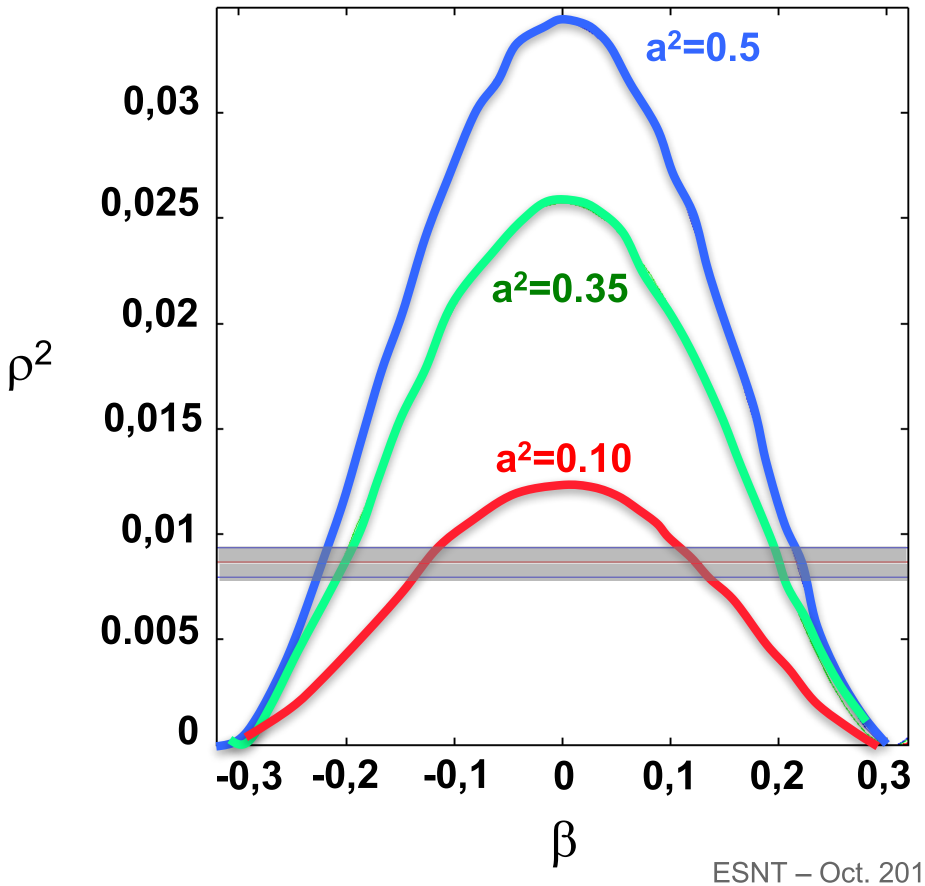
C. Force et al., PRL**105**, 102501 (2010).



$\rho^2(E_0) = 8{,}7(7)\ .\ 10^{-3}$



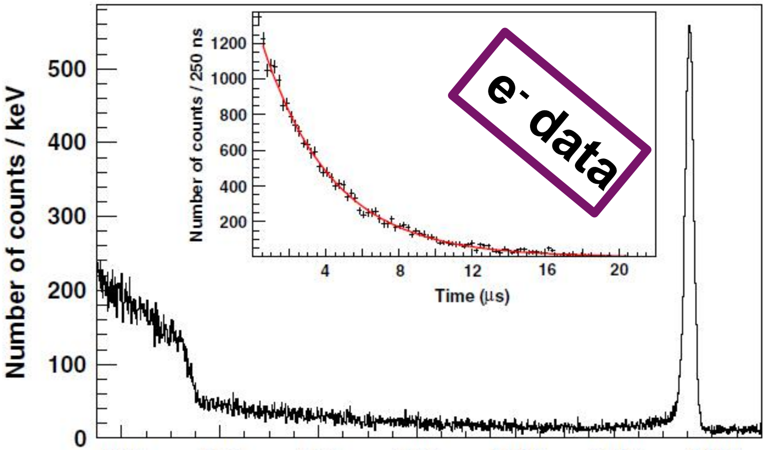




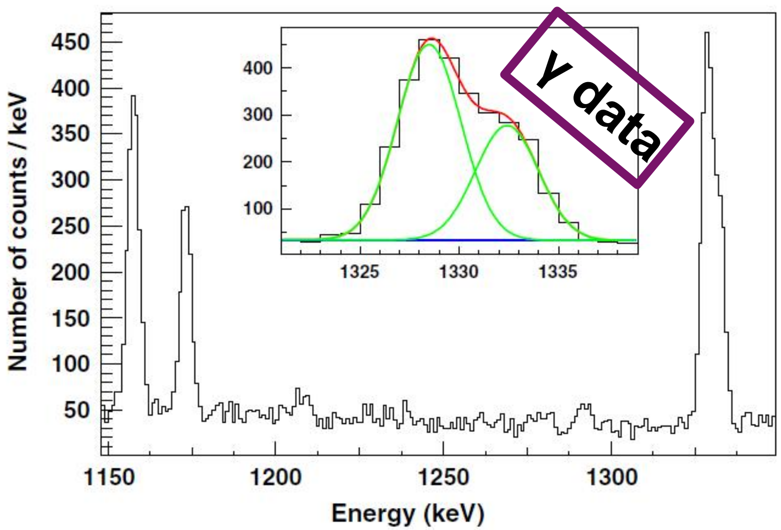
γ AND e^- SPECTROSCOPY

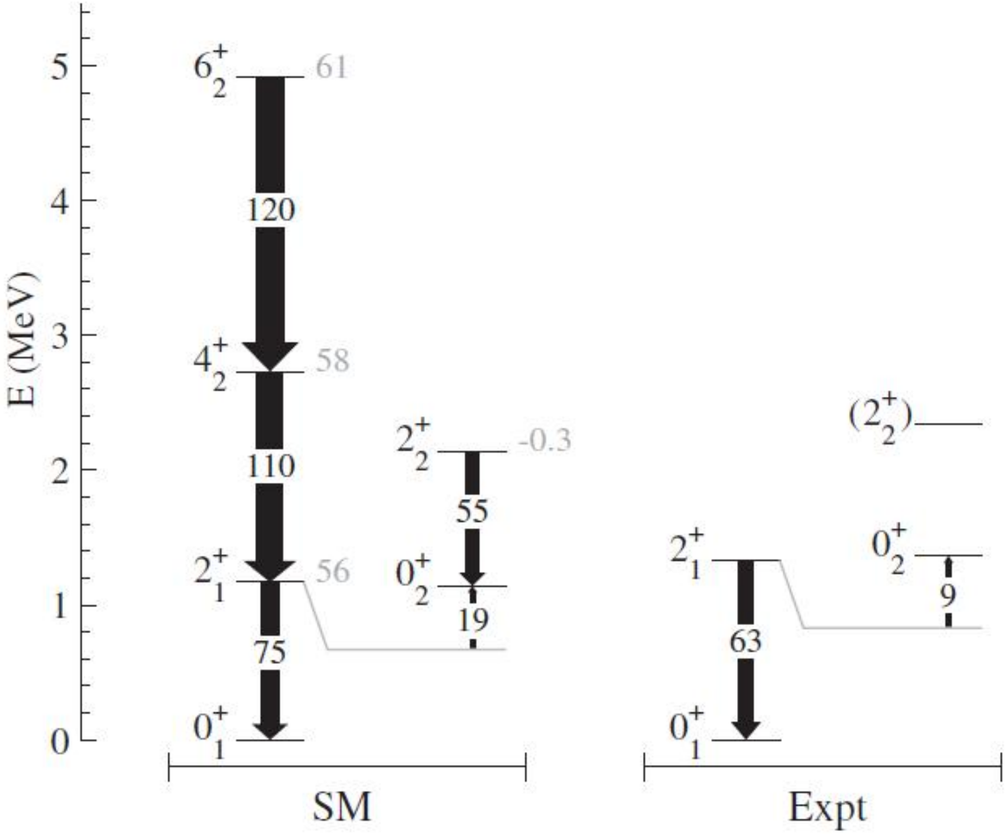
GANIL

C. Force et al., PRL**105**, 102501 (2010).



$\rho^2(E_0) = 8,7(7) . 10^{-3}$





SM calculations:

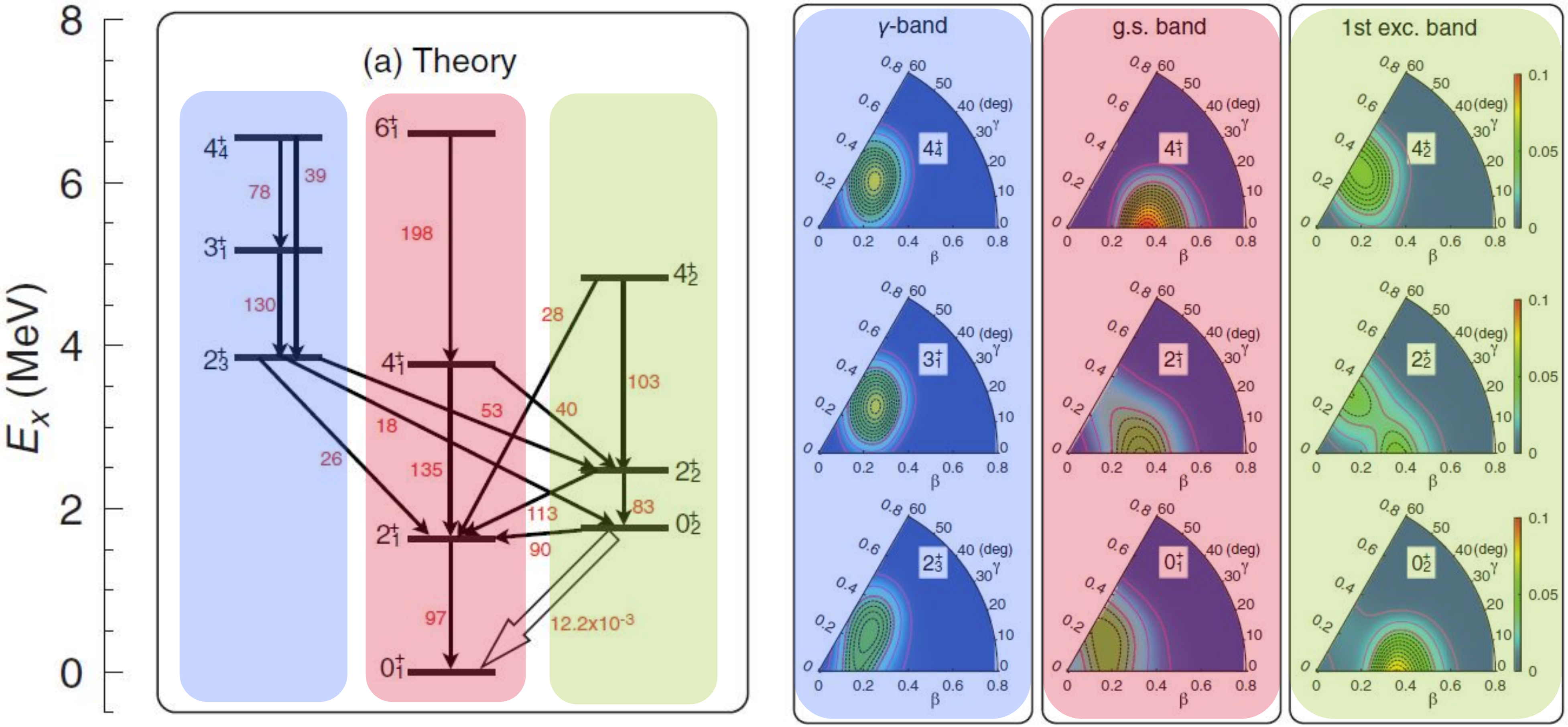
- GS band; prolate; β=0,25.
- $Q_{SM}(2^+_2)$=-0,3 e.fm^2.

➔**Prolate/Spherical shape coexistence in ^{44}S.**

^{44}S : MEAN FIELD RESULTS

- HFB + GCM + AM Projection – D1S Gogny

T. R. Rodriguez and J. L. Egido, PRC **84**, 051307(R) (2011)

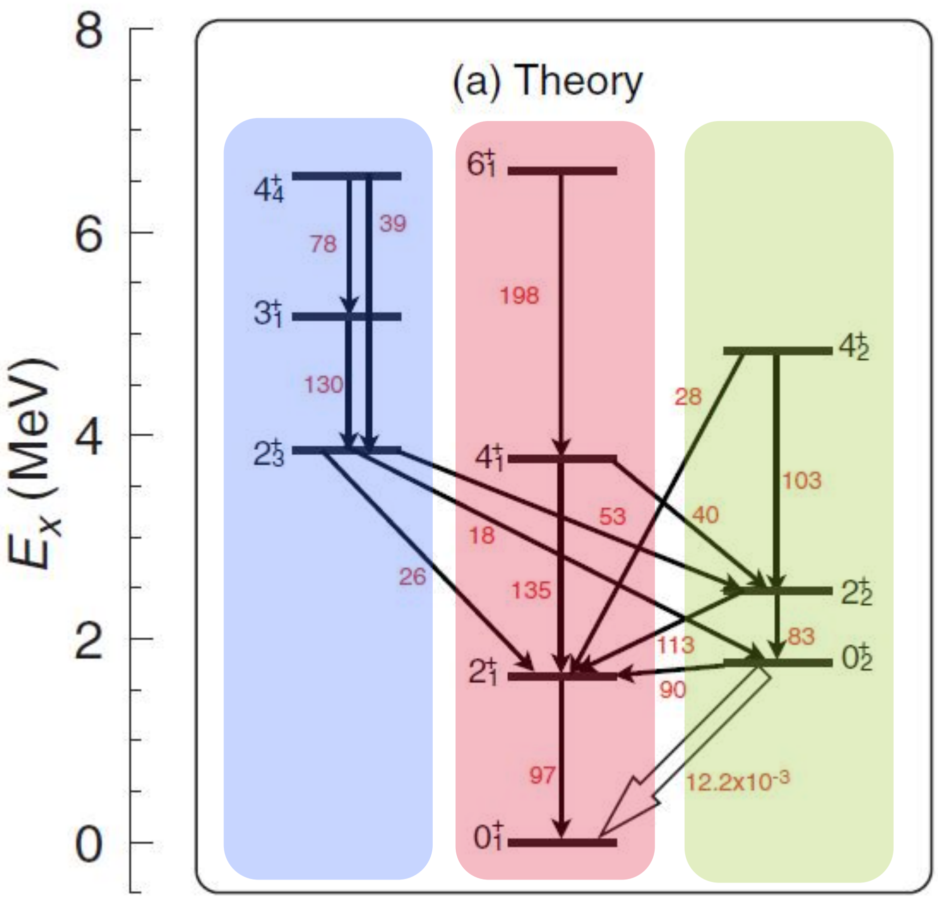


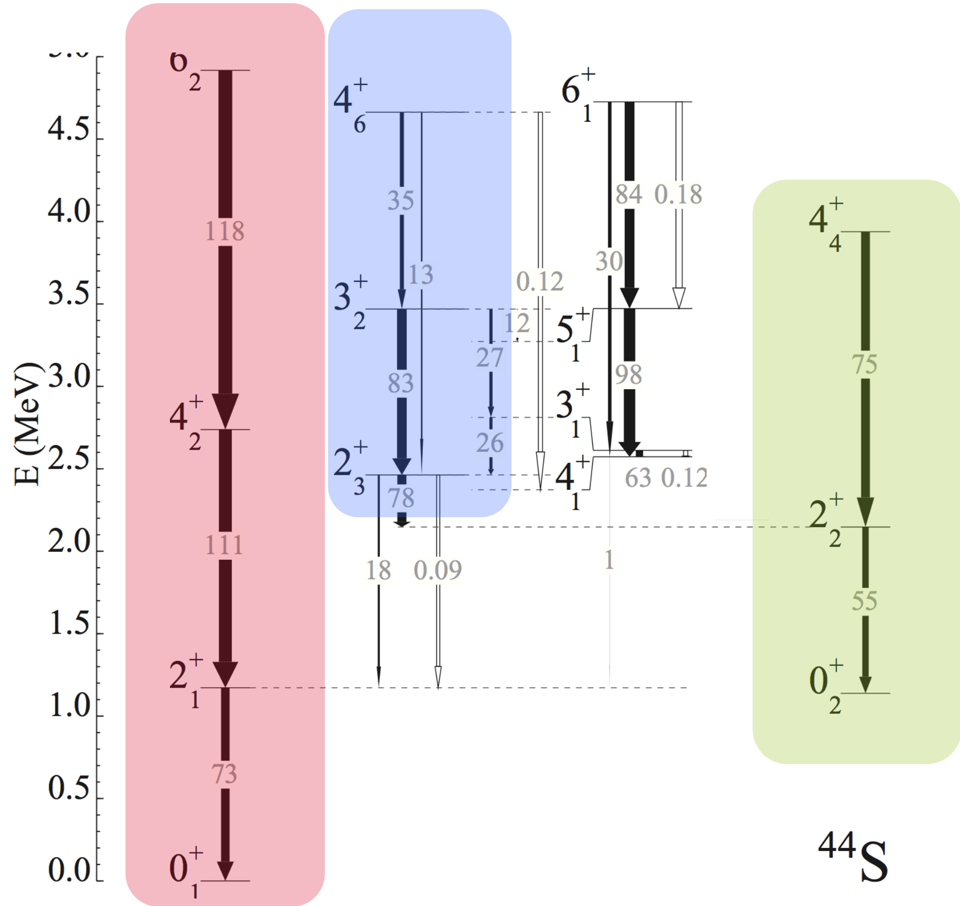
- GS band ➔ toward prolate.
- Excited band ➔ Shape evolution.

➔ ^{44}S : Deformed/Deformed Shape coexistence.

^{44}S : THEORETICAL COHERENCE

T. R. Rodriguez and J. L. Egido,PRC **84**, 051307(R) (2011)





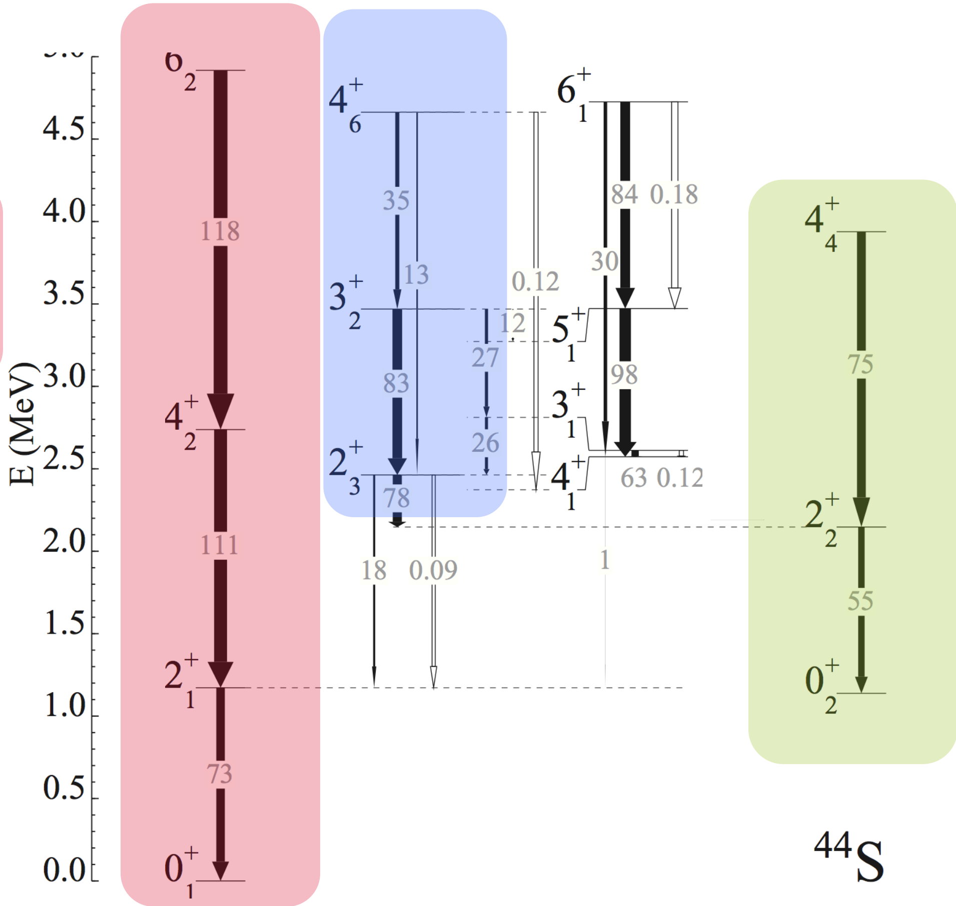
R. Chevrier and L. Gaudefroy, PRC **89**, 051301(R) (2014).

➔ Also good agreement on shape parameters.

^{44}S : THEORETICAL COHERENCE

Shape parameters from E2 invariants.

J^π	Q_i (e fm^2)	β	γ (deg)	$\sigma(\gamma)$ (deg)
0_1^+	70	0.31	28	8
2_1^+	72	0.32	24	8
4_2^+	67	0.30	16	7
6_2^+	62	0.28	12	7
0_2^+	68	0.30	20	6
2_2^+	66	0.29	30	8
4_4^+	65	0.29	31	8
2_3^+	64	0.29	34	7
3_2^+	65	0.29	29	8
4_6^+	60	0.27	34	10
3_1^+	65	0.29	26	4
4_1^+	65	0.30	26	5
5_1^+	63	0.28	26	4
6_1^+	61	0.27	28	3

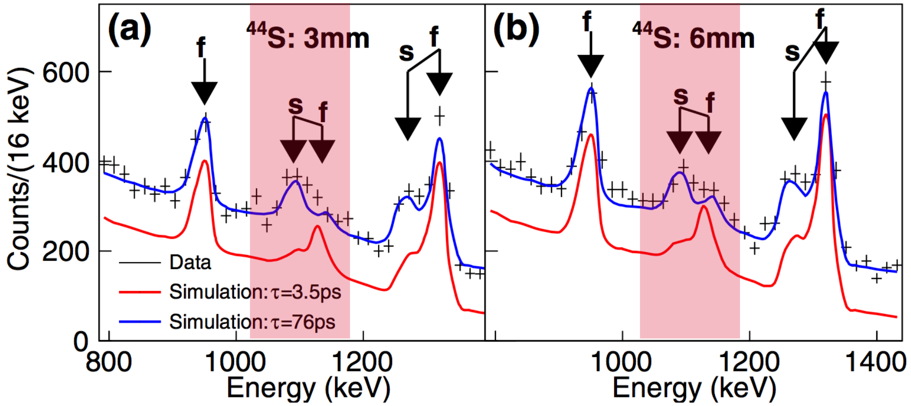


R. Chevrier and L. Gaudefroy, PRC **89**, 051301(R) (2014).

^{44}S : K=4 EXCITED BAND

MSU – Recoil-distance method

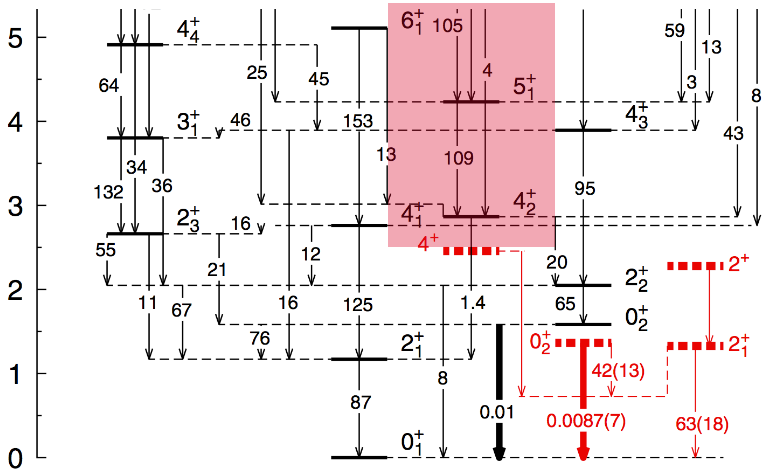
J.J. Parker et al., PRL **118**, 052501 (2017).



✓ $4^+ \to 2^+$ transition : 76ps.

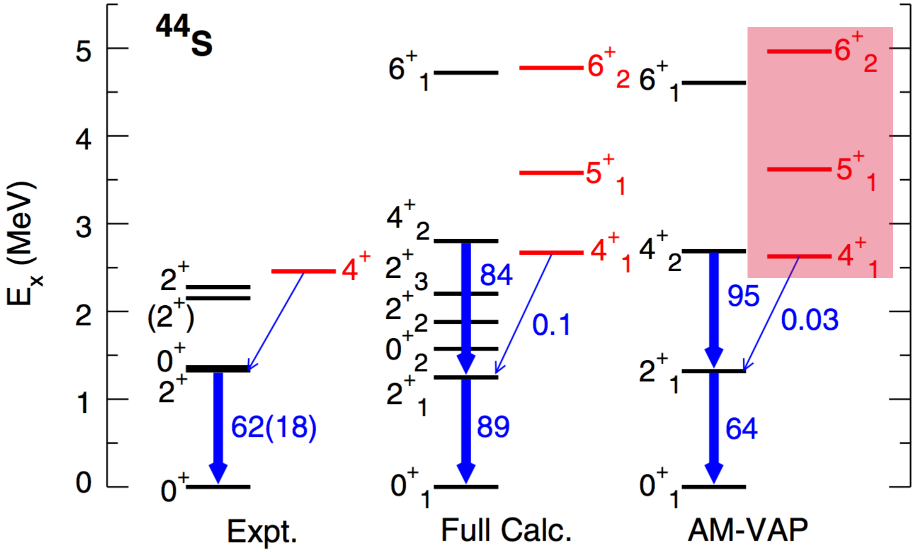
BMF – Collective + SP

J.L. Egido et al., PRL **116**, 052502 (2016).



BMF-SM

Y. Utsuno et al., PRL **114**, 032501 (2015).

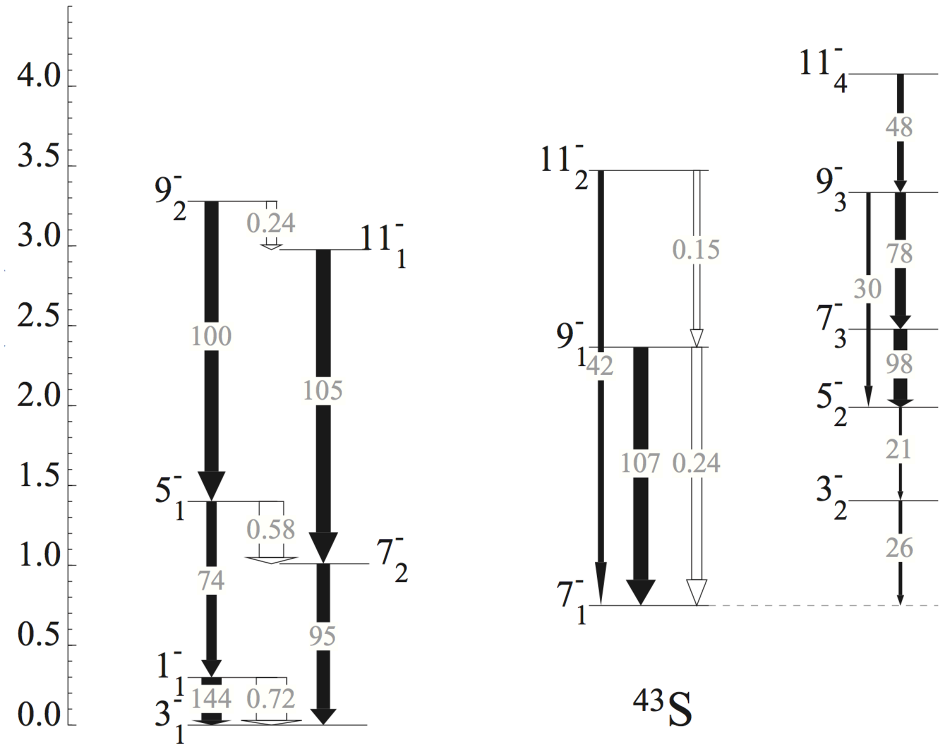


I^{π}_{σ}	|K| 0	1	2	3	4	5	6	β	γ
0_1^+	1.00							0.24	33
2_1^+	0.98	0.00	0.01					0.26	23
4_2^+	0.92	0.08	0.00	0.00	0.00			0.28	14
6_1^+	0.76	0.23	0.01	0.00	0.00	0.00	0.00	0.28	13
4_1^+	0.00	0.00	0.00	0.07	0.93			0.23	28
5_1^+	0.00	0.00	0.01	0.08	0.85	0.07		0.23	24
6_2^+	0.00	0.01	0.01	0.14	0.80	0.04	0.00	0.23	26

Low lying high K isomer.

SHAPE COEXISTENCE AT N=28

- N=28 ➔ Shape transition from Ca to Si/Mg.
- Complex coexistence features at Z=16.
- Large impact of triaxial degree of freedom.
- Convergence of all theoretical descriptions (BMF, AMD, SM).



- ^{42}S (d,p) good probe for GS rotational band.
  B. Elbek et al., Adv. Nucl. Phys. 3, 259 (1969).
- Spectroscopy of ^{43}S of interest.
- $3/2^-$ intruder GS also predicted in ^{41}Si.
- Oblate/prolate shape coexistence predicted in ^{42}Si.
  F. Nowacki and A. Poves, PRC**79**, 014310 (2009).