Piotr Bednarczyk

Instytut Fizyki Jądrowej
im. Henryka Niewodniczańskiego
Polskiej Akademii Nauk

Quest for intruder band terminating states in the medium mass A 40 -60 shell model nuclei; challenge for experiments and theory

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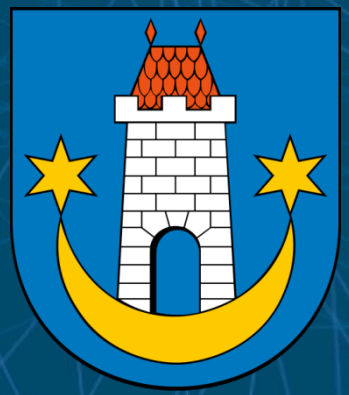
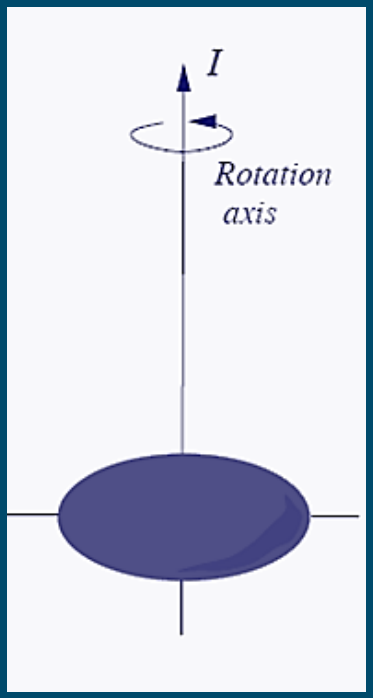


19th Nuclear Physics Workshop
"Marie & Pierre Curie"
Kazimierz, 2012

Origin of angular momentum in an atomic nucleus

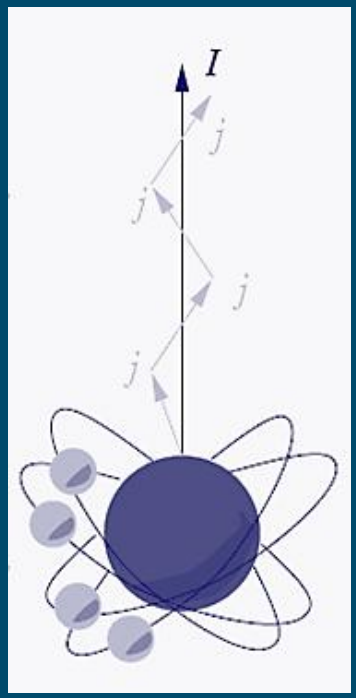
$I_{max} \approx fission\ limit$

$I_{max} = \sum j_i$



versus

Need for spectroscopic data close to I_{max}



- Regular rotational bands *E~I(I+1)*
- *„chaotic"* level distribution

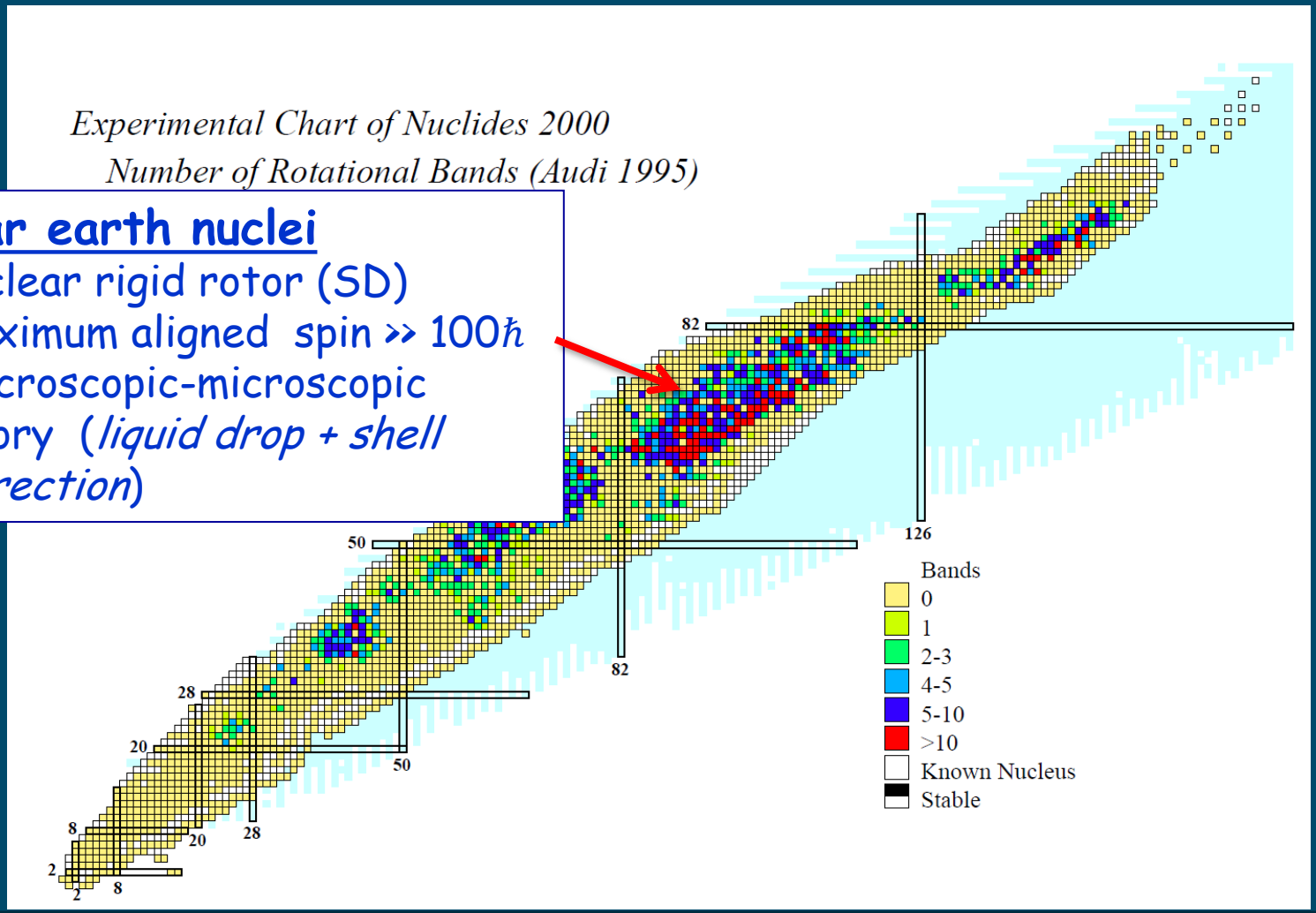
Quadrupole collectivity across the nuclear chart

Rear earth nuclei

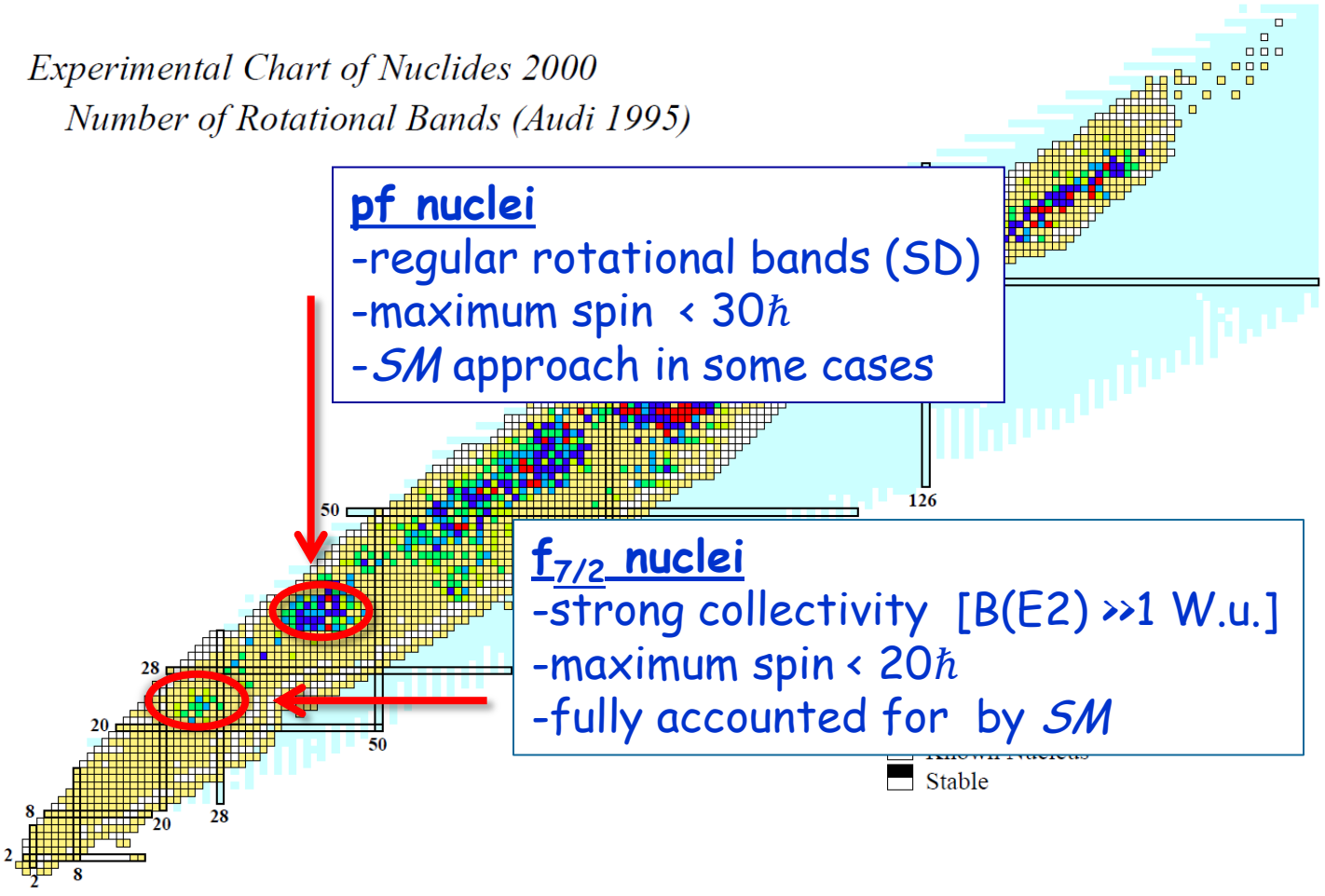
-nuclear rigid rotor (SD)

-maximum aligned spin >> 100ħ

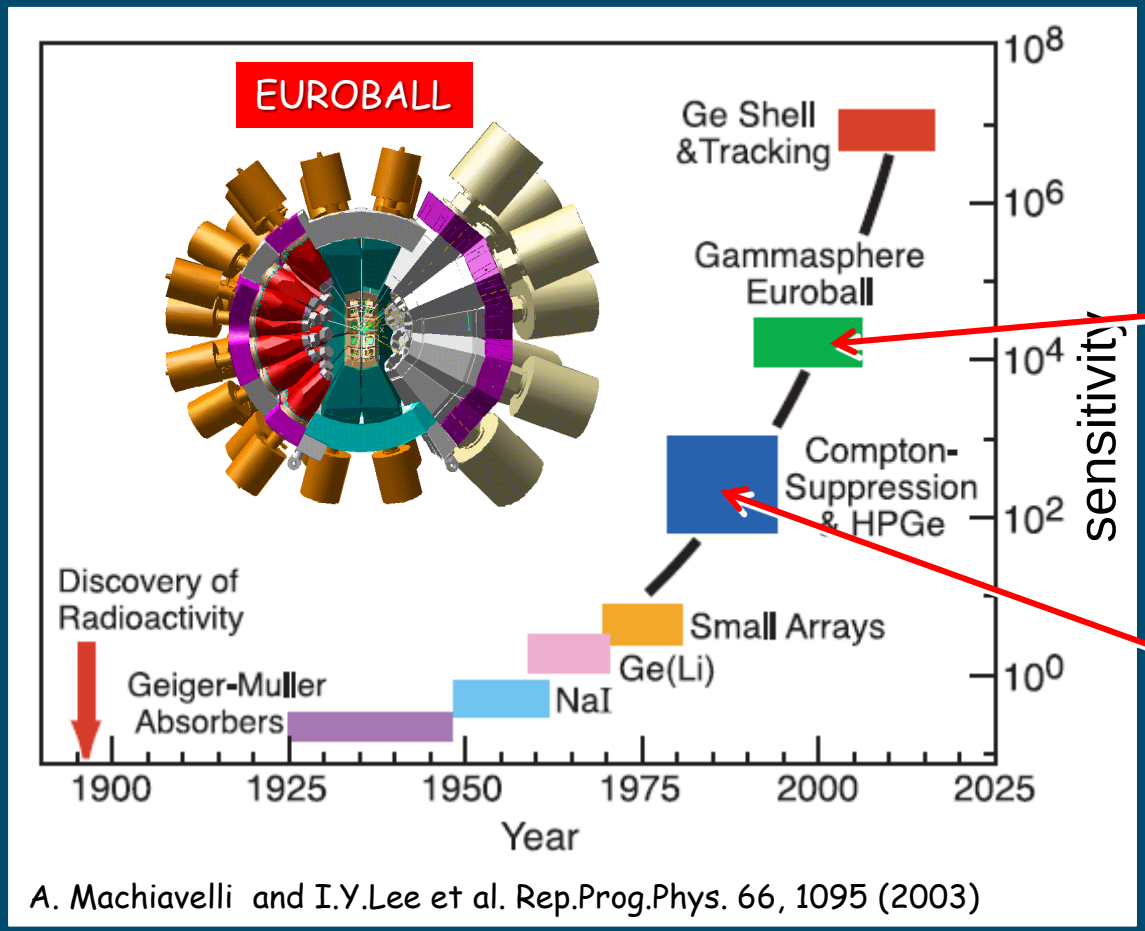
-macroscopic-microscopic theory (*liquid drop + shell correction*)



Quadrupole collectivity across the nuclear chart



Steady increase in γ-detection sensitivity



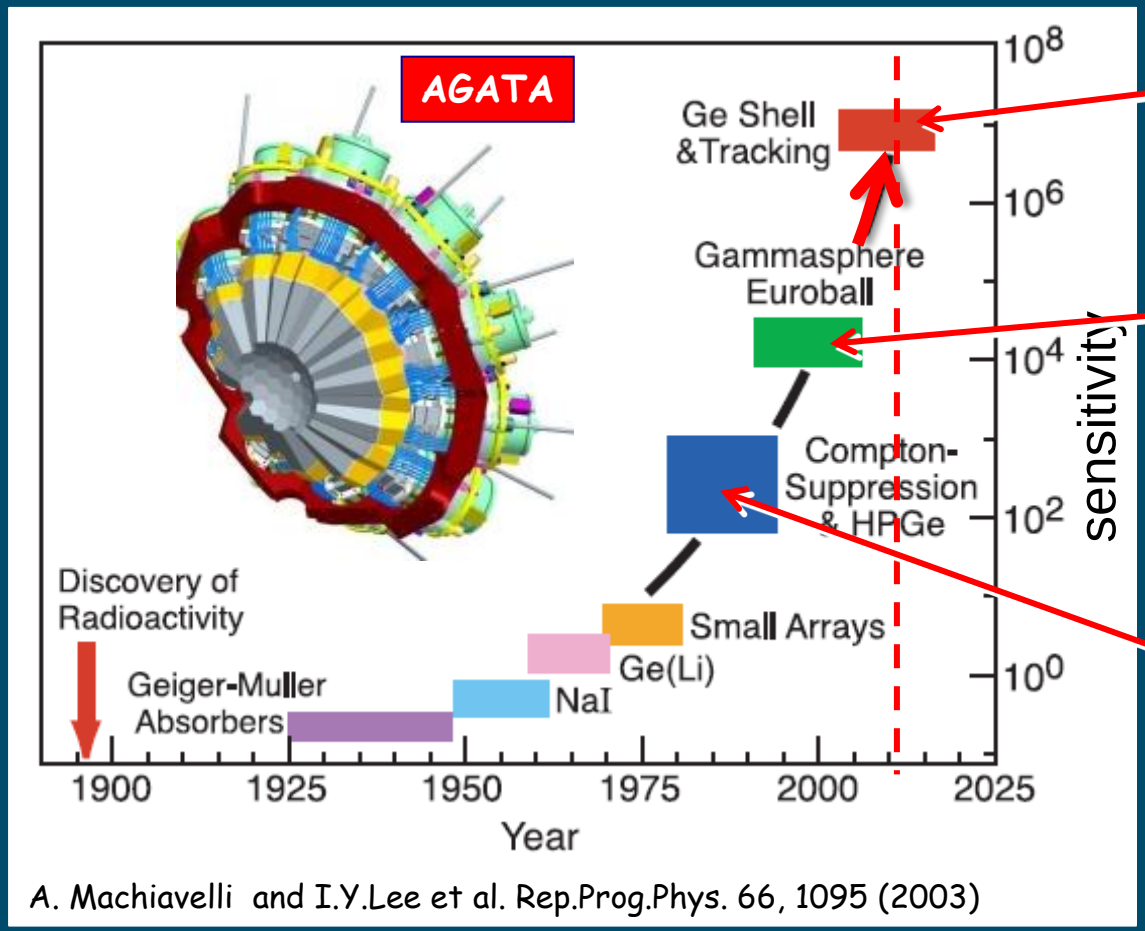
A. Machiavelli and I.Y.Lee et al. Rep.Prog.Phys. 66, 1095 (2003)

ultra high spin I~70ħ, terminating bands (^{158}Er)

E.Paul et al.,PRL 98, 012501 (2007)

superdeformation

Increase in γ-detection sensitivity



A. Machiavelli and I.Y.Lee et al. Rep.Prog.Phys. 66, 1095 (2003)

Gamma spectroscopy far from stability at radioactive beams (RIB)

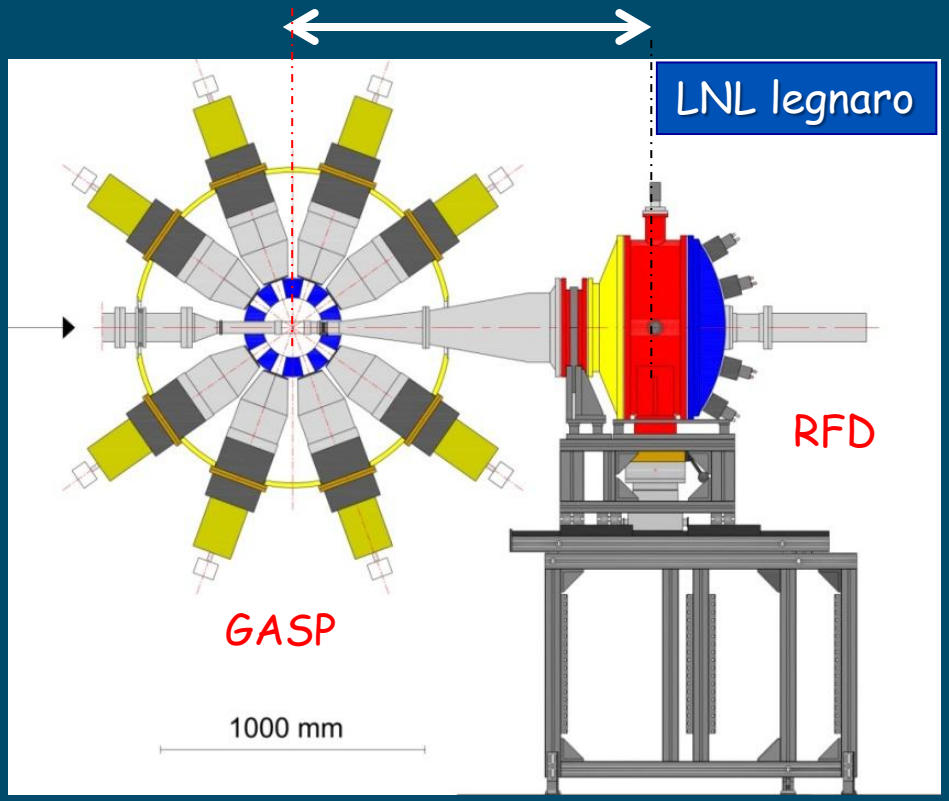
ultra high spin I~70ħ, terminating bands (^{158}Er)

superdeformation

Need for ancillary detectors

Recoil Filter Detector (Kraków)

$ToF \rightarrow v_{REC}$



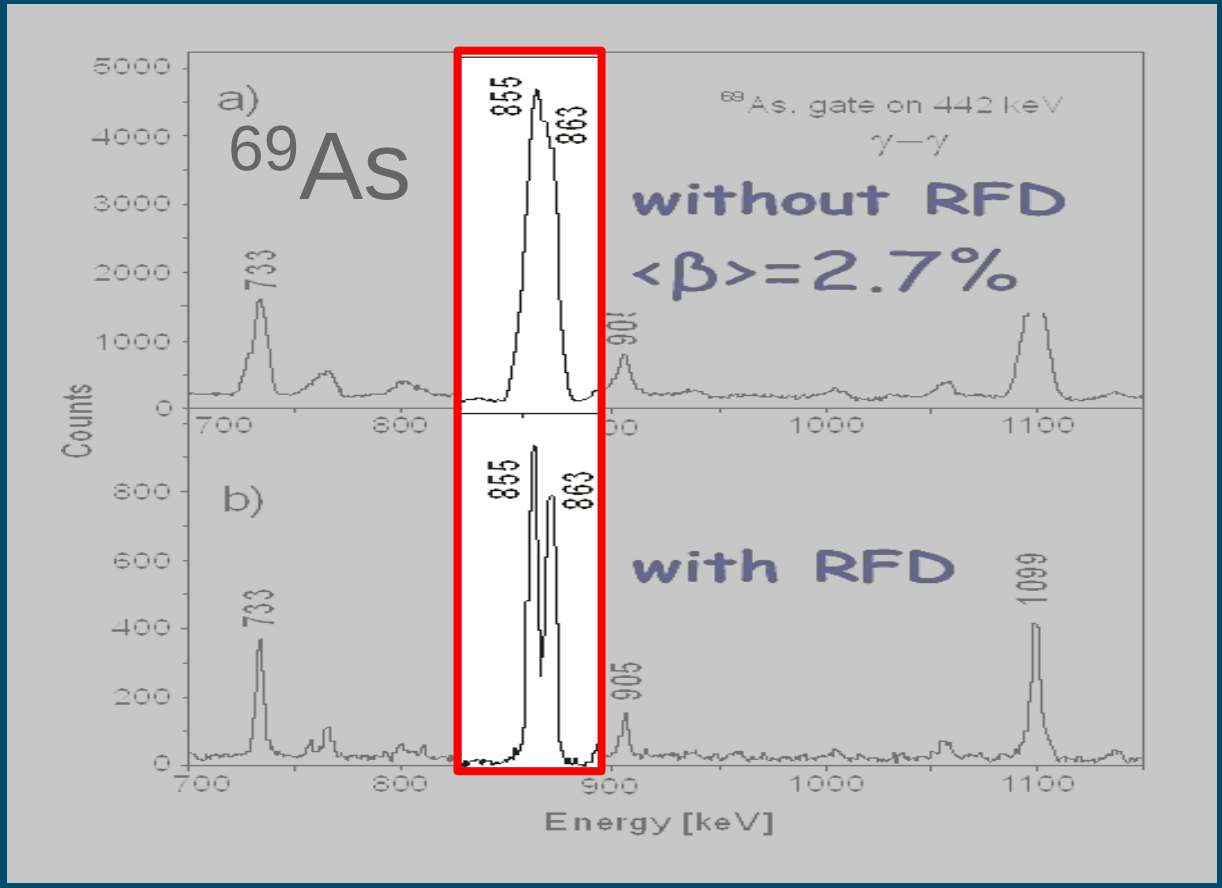
- RFD is a set of HI detectors. They pick up *Evaporation Residues* in coincidence with γ-rays
- Time-of-Flight technique allows to deduce actual velocity of every recoil and to filter out unwanted reaction channels:

scattered beam, coulex, fission

W. Męczyński et al., NIM A580, 1310 (2007)

Improvement in γ-spectra by a coincident recoil detection

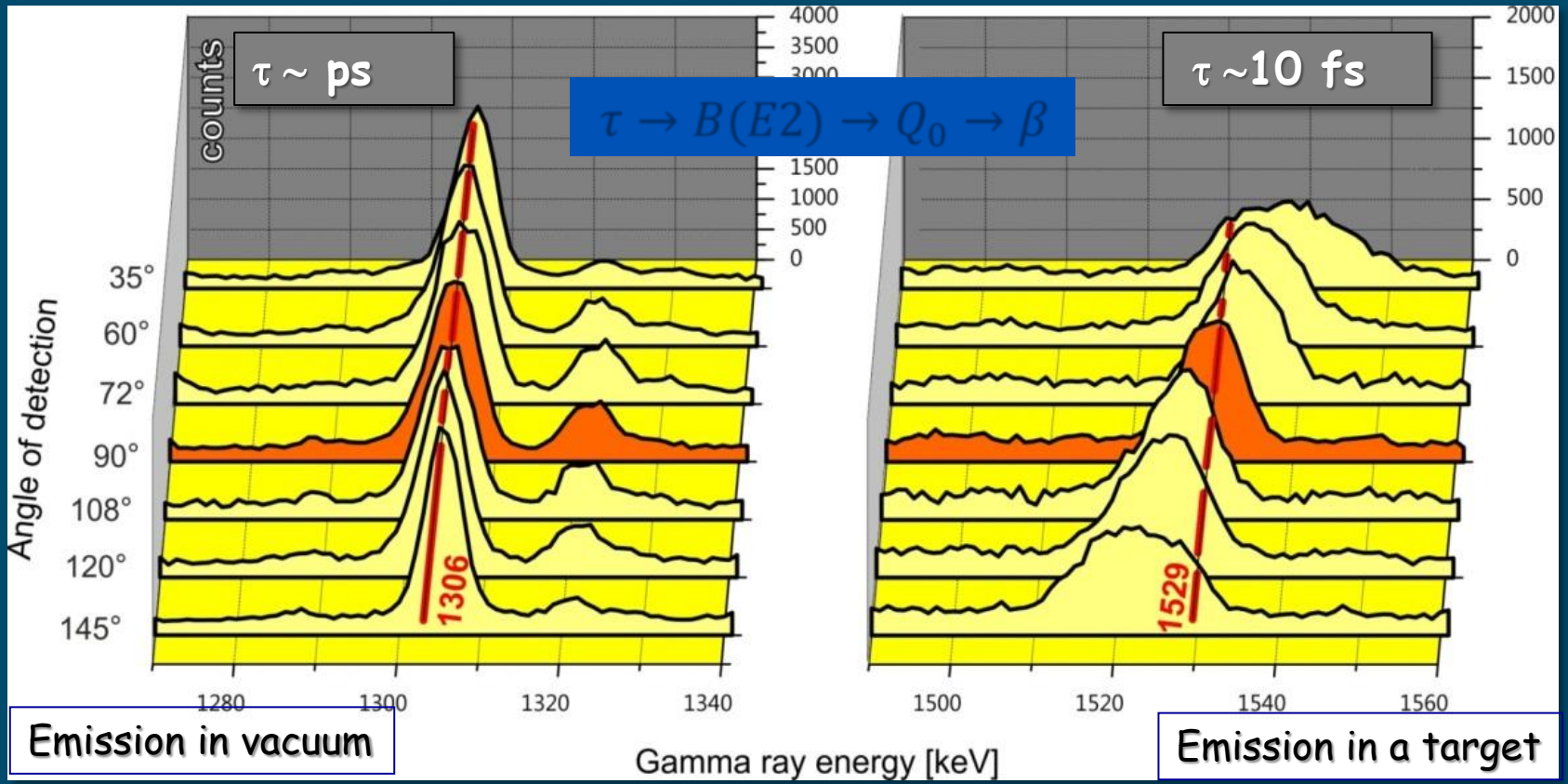
- Doppler broadening reduction



GASP + RFD (2009), ^{32}S (95MeV) + $^{40}Ca \rightarrow ^{72}Kr(CN)$

Improvement in γ-spectra by a coincident recoil detection

- Lifetime determination - lineshape analysis



GASP + RFD (2009), ^{32}S (95MeV) + $^{40}Ca \rightarrow ^{72}Kr(CN)$

Collective effects in light $f_{7/2}$ shell nuclei

At low spin / < 1980/:

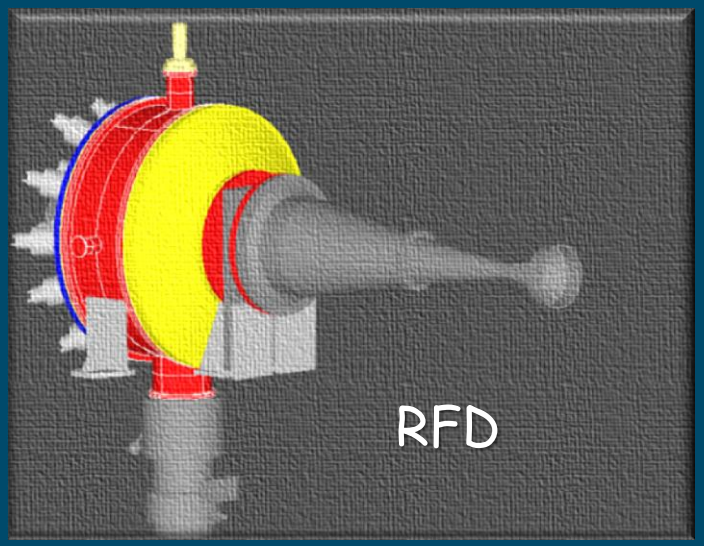
- Fast E2 transitions (tens W.u)
- Collective bands of unnatural parity (particle-hole states)

Experimental difficulties:

- fast recoil velocity
- high energy transitions

Break through /~2000/:

- Arrays of Ge detector arrays (GASP, EUROBALL, GAMASPHERE)
- Ancillary- particle and HI detectors



At high spin:

- Deformed, core excited states (up to I_{max}):
  $^{40\text{-}44}Ca$, $^{42\text{-}45}Sc$, $^{44\text{-}46}Ti$, $^{46,47}V$
- Superdeformation $^{36,38,40}Ar$, $^{40,42}Ca$, ^{44}Ti

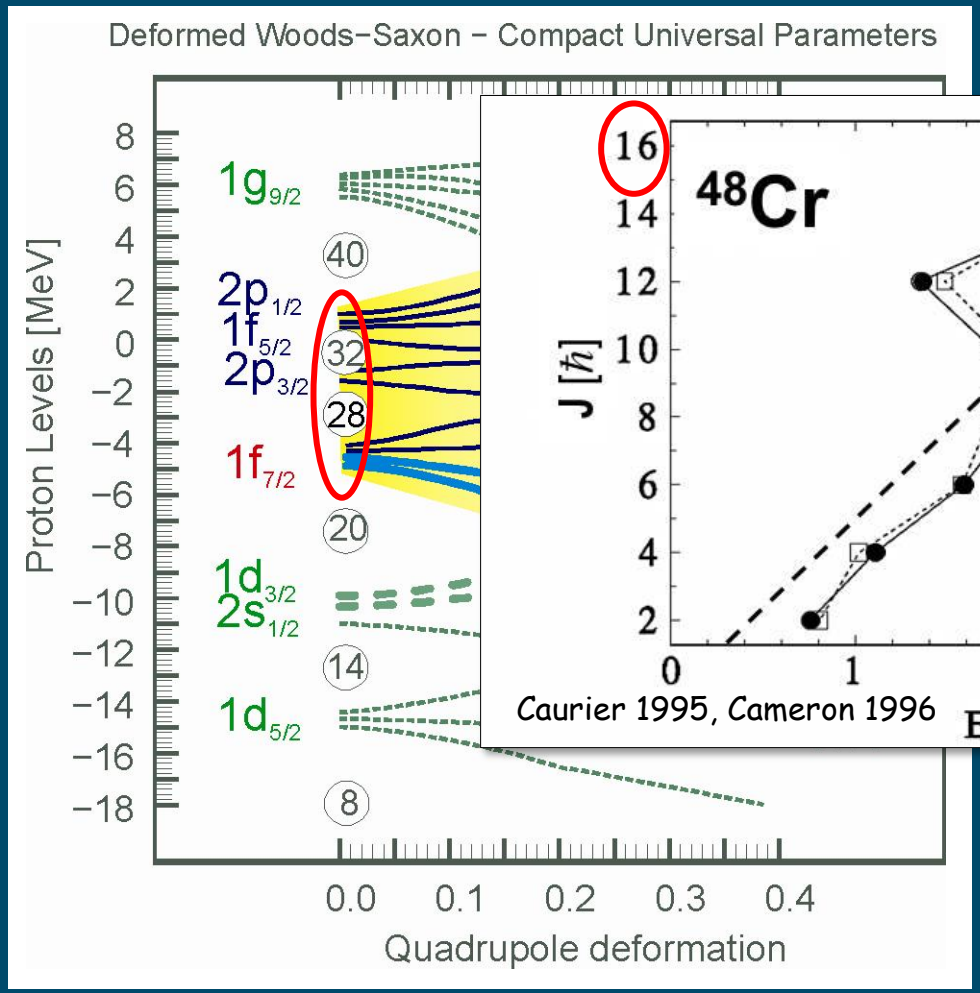
„Rotation" of ^{48}Cr

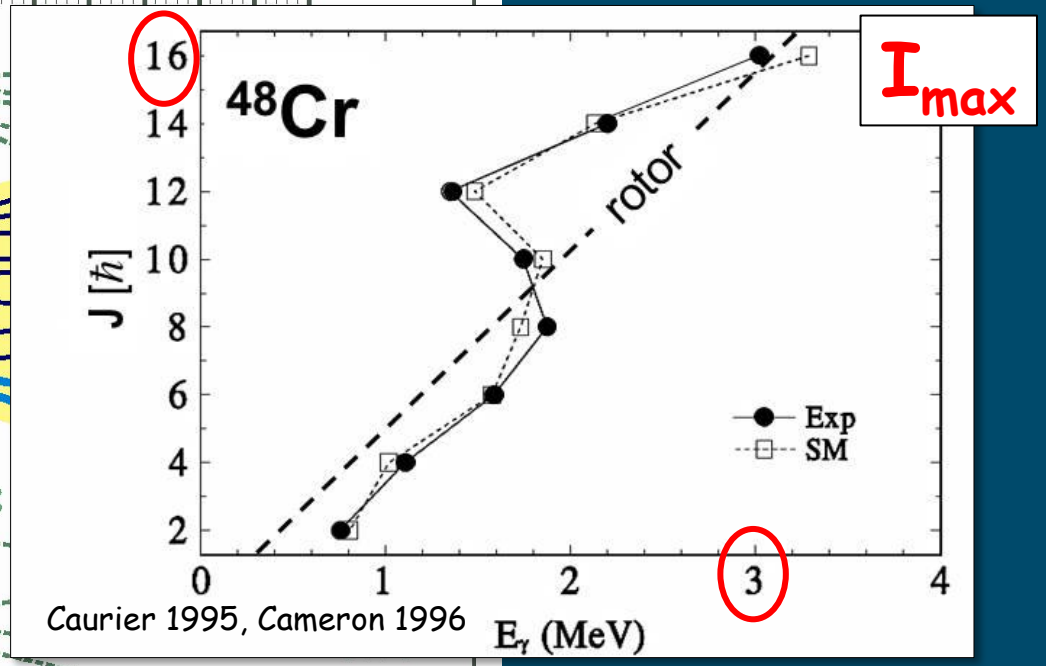
^{100}Sn

^{80}Zr

^{58}Ni

^{40}Ca





SM:

- extended ***fp*** shell
- effective interaction

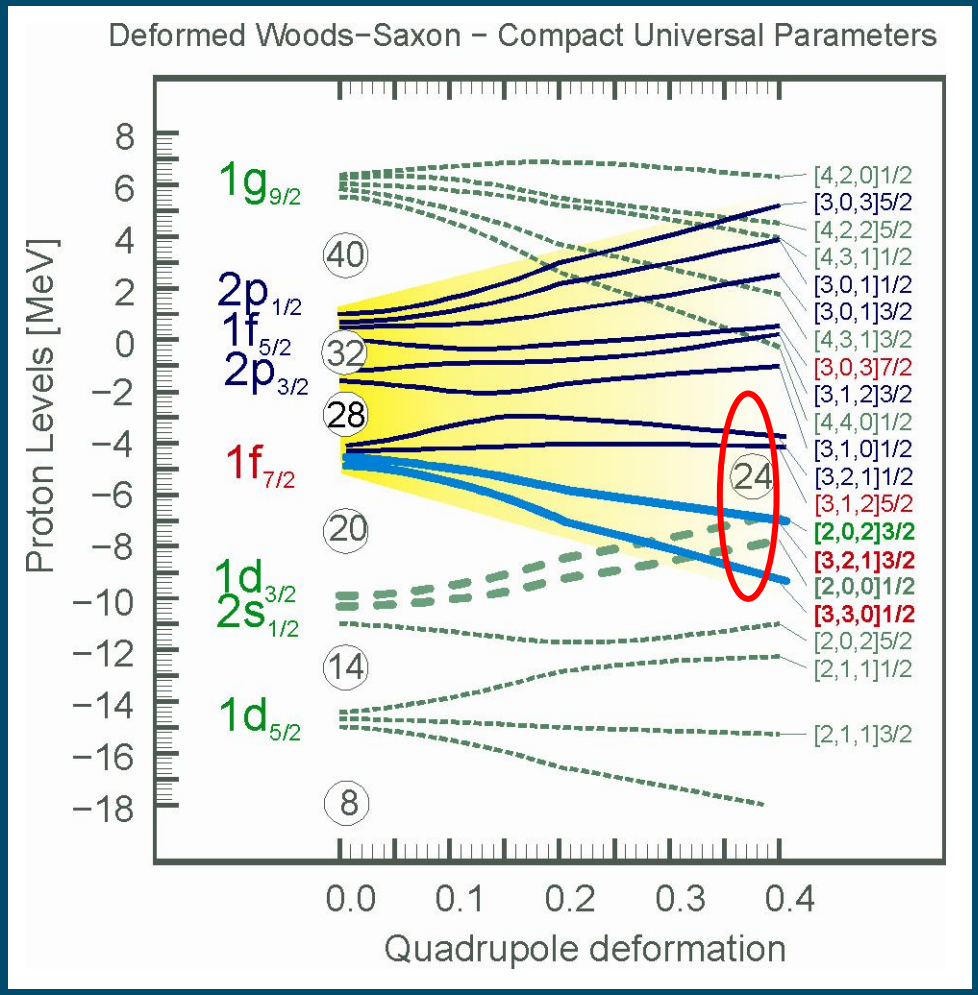
SM descroption of (super)deformation

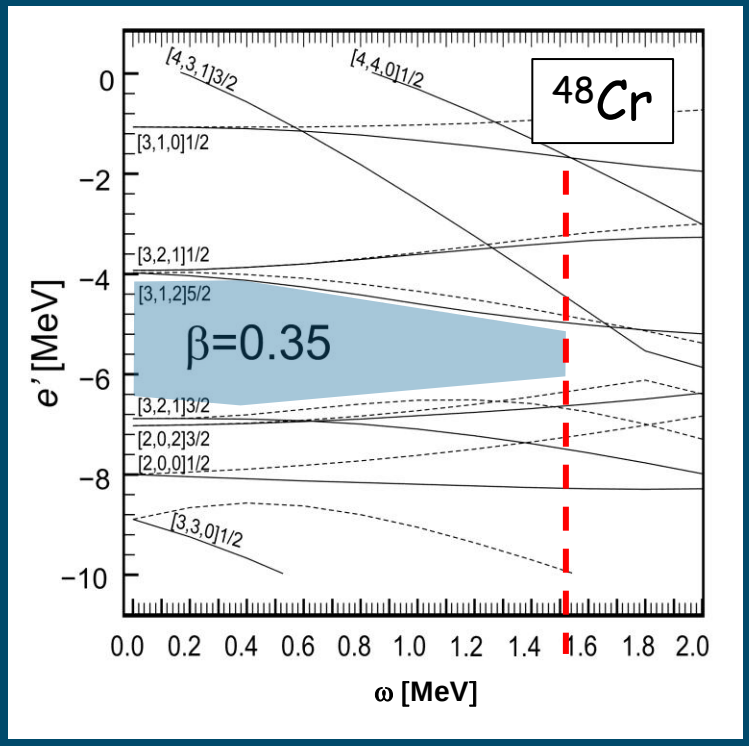
^{100}Sn

^{80}Zr

^{58}Ni

^{40}Ca





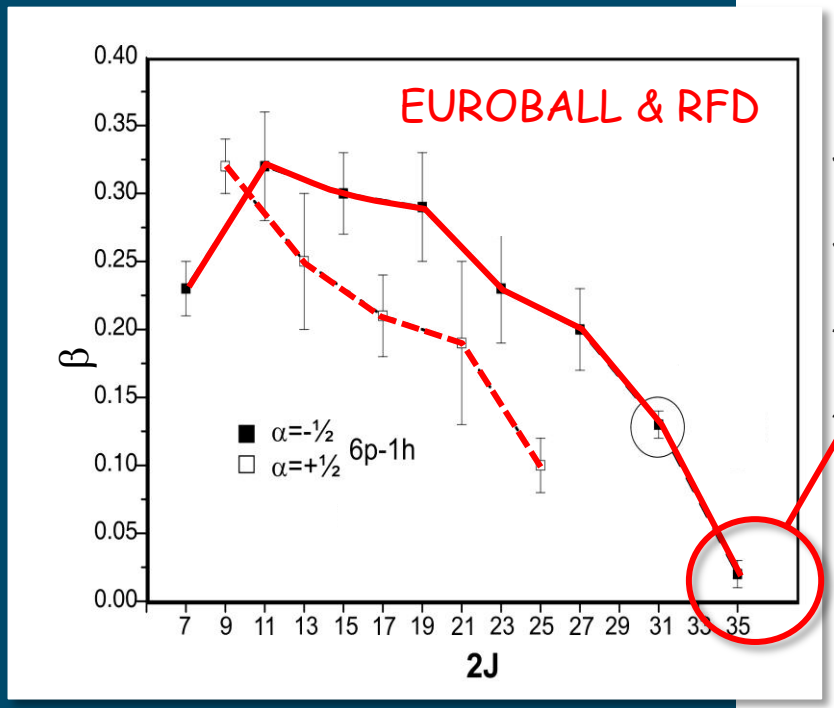
^{36}Ar, ^{40}Ca – *SD* bands (β~0.5)

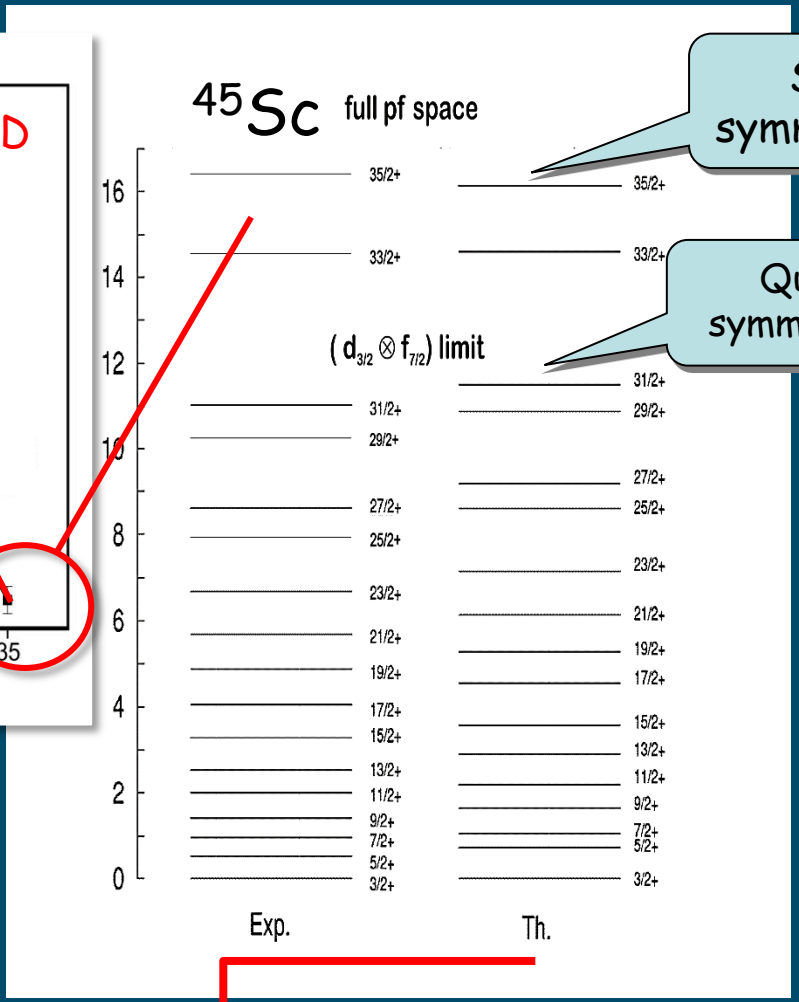
- **sd** 8 holes
- **fp** 4, 8 particles

Kazimierz Dolny

XIX NPW 2012

Deformation along the π = '+' p-h band in ^{45}Sc





Spherical symmetry states

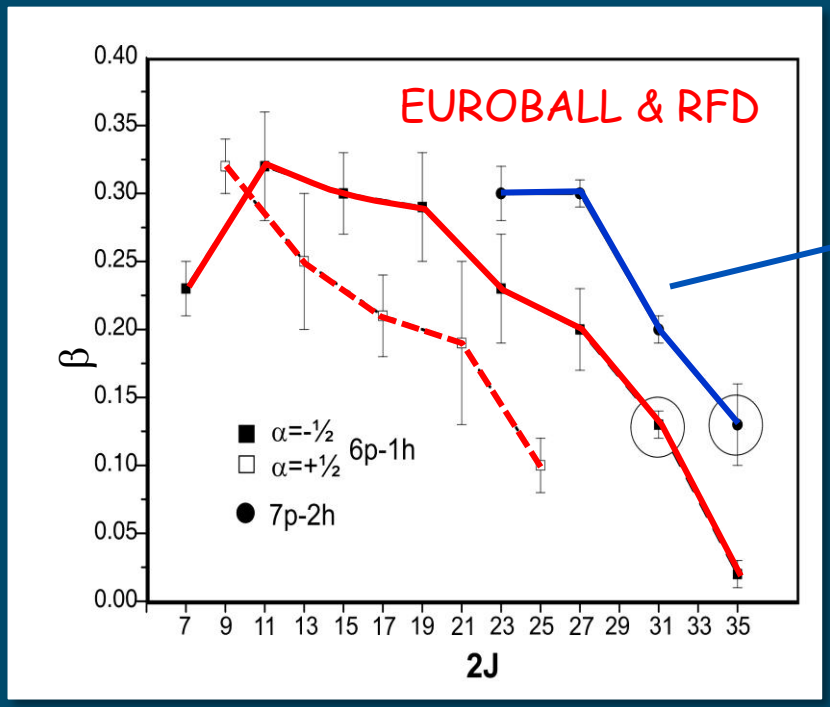
Quadrupole symmetry states

- *ANTOINE*
- *Interaction:*

  *KB3 (**pf**) + **sd** holes*
- $(sd)^{-1}(fp)^{6}$

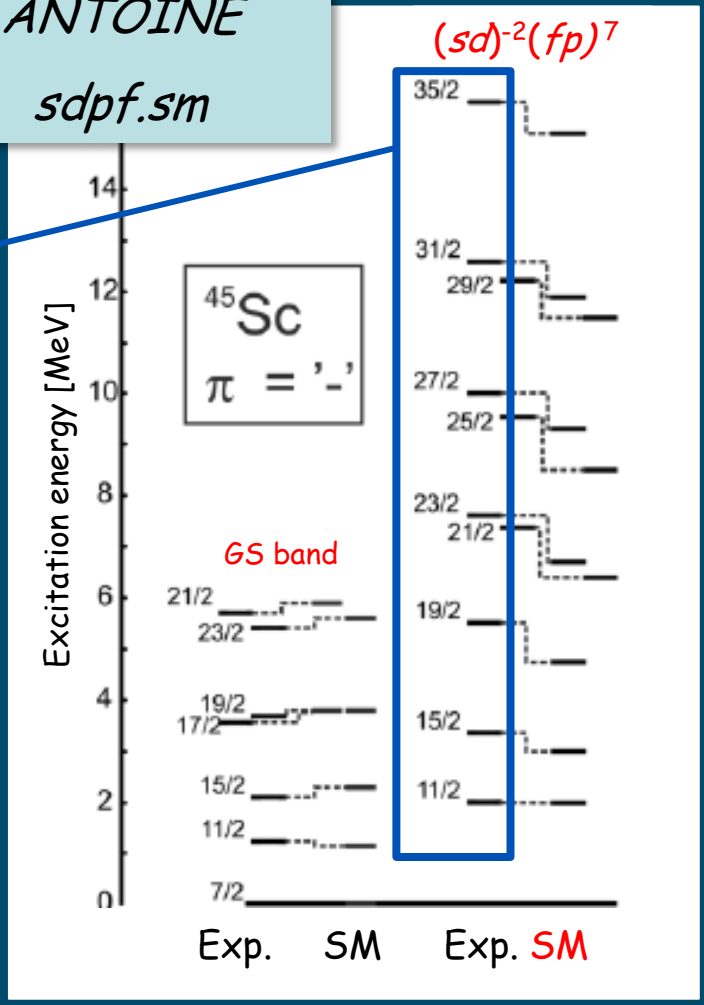
A.Poves et al., PRC58, 179 (1998)

multi hole-particle *SM* approach



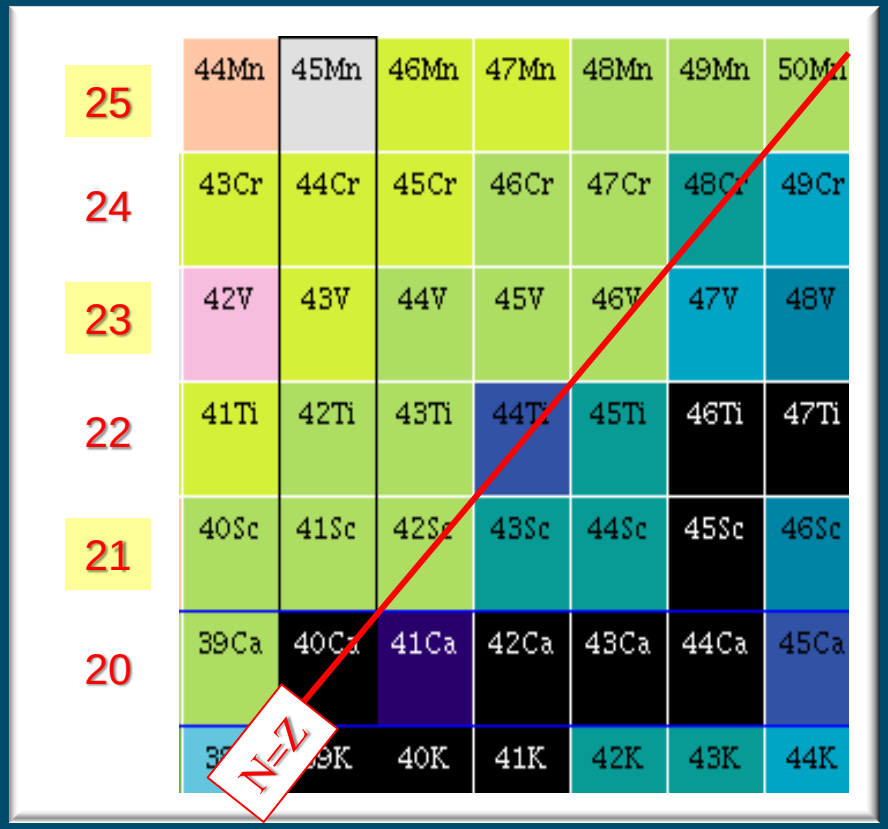
ANTOINE

sdpf.sm

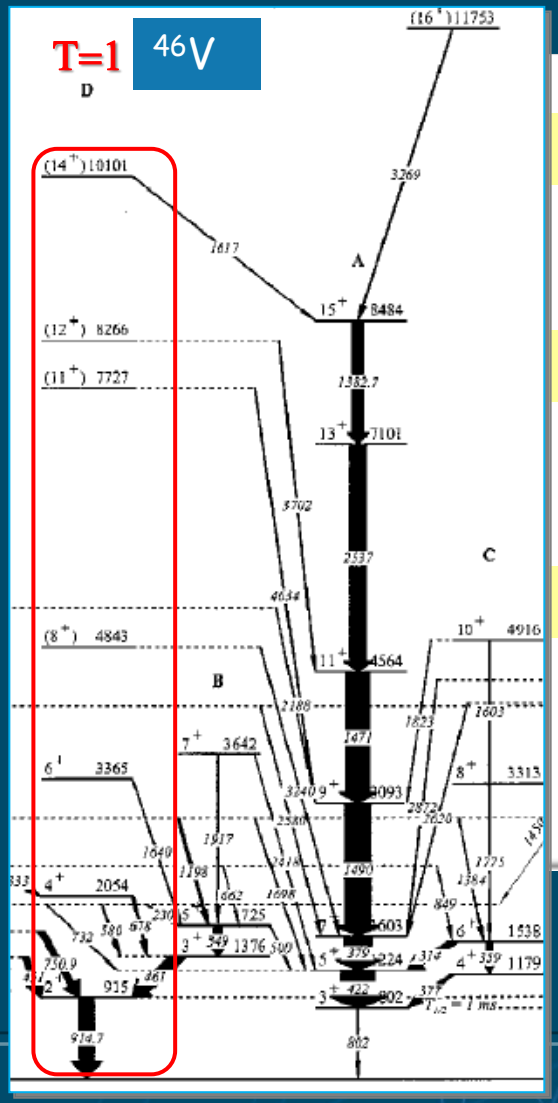


- same config. space for the GS and excited bands
- deformation increased by excitation of multiple holes

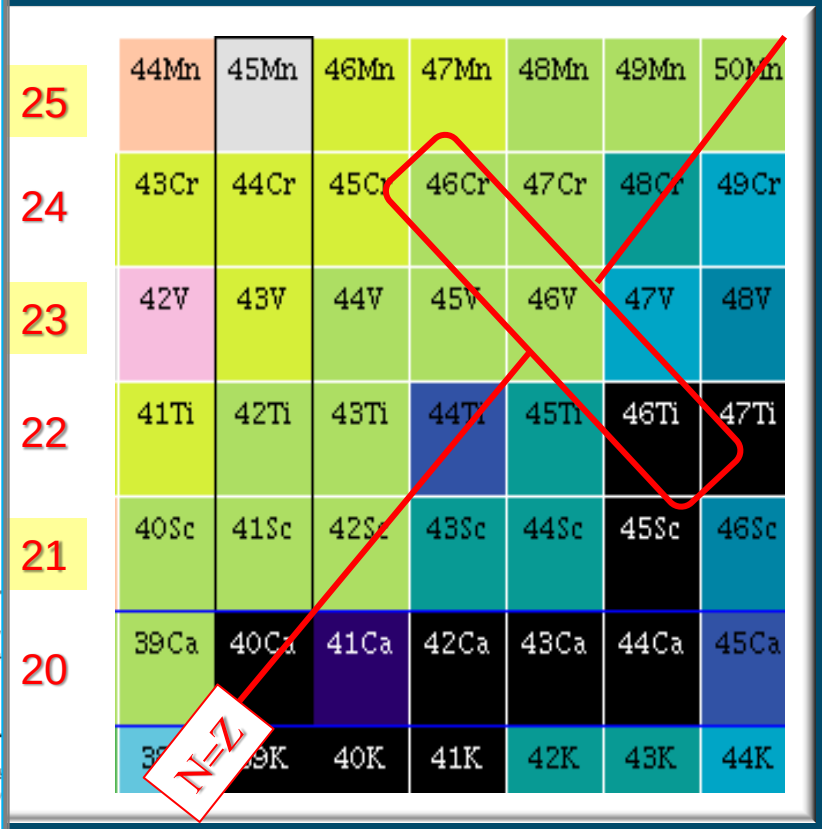
Izospin T=0, T=1 excitations in odd-odd N=Z nuclei



Izospin T=0, T=1 excitations in odd-odd N=Z nuclei

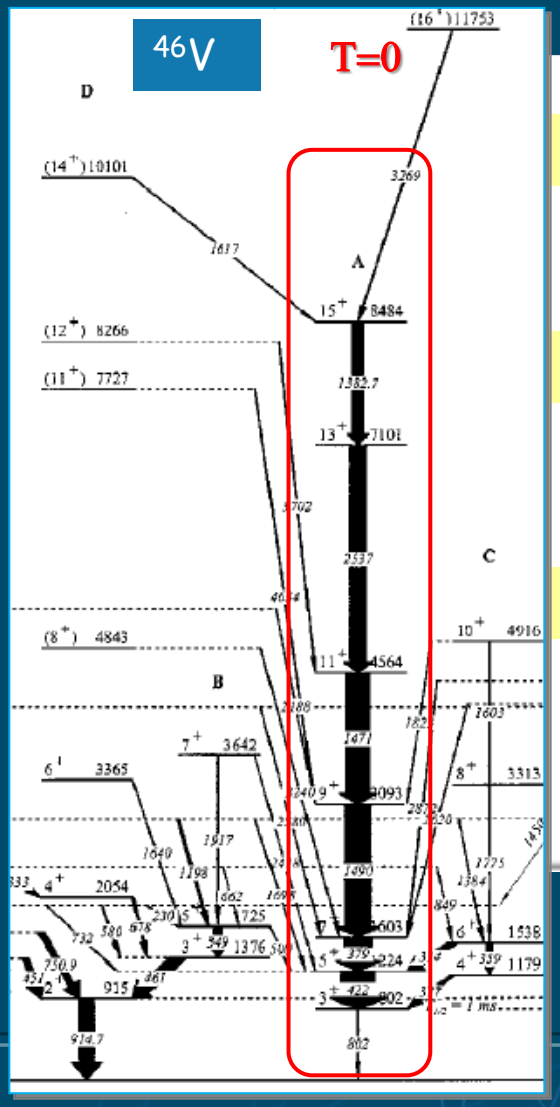


A=46, T=1 isospin triplet



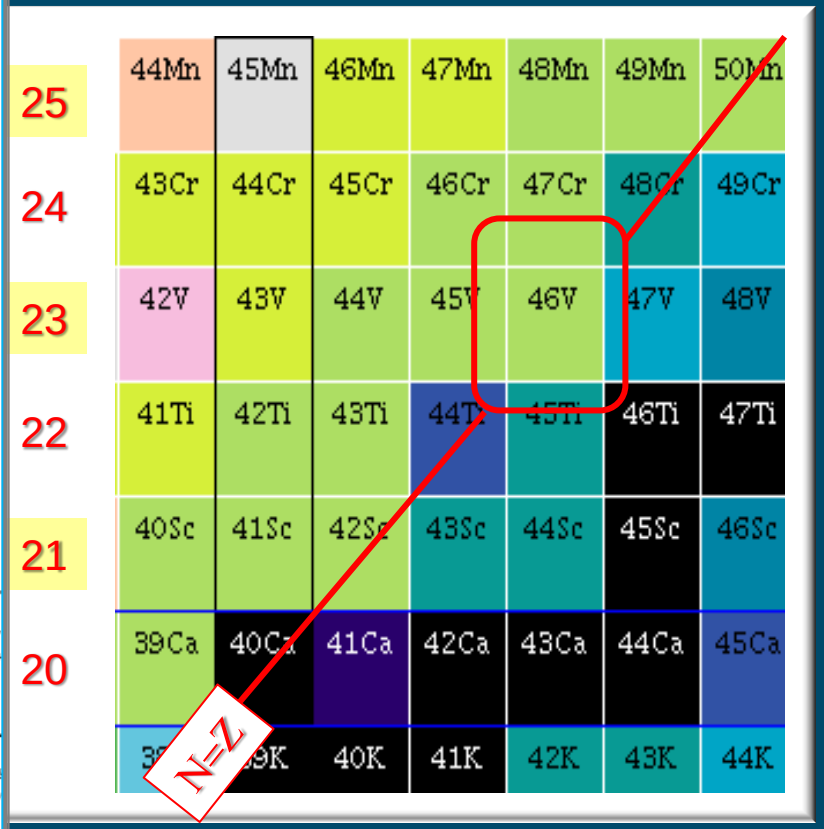
S.Lenzi Phys. Scr. T88, 100 (2000)

Izospin T=0, T=1 excitations in odd-odd N=Z nuclei

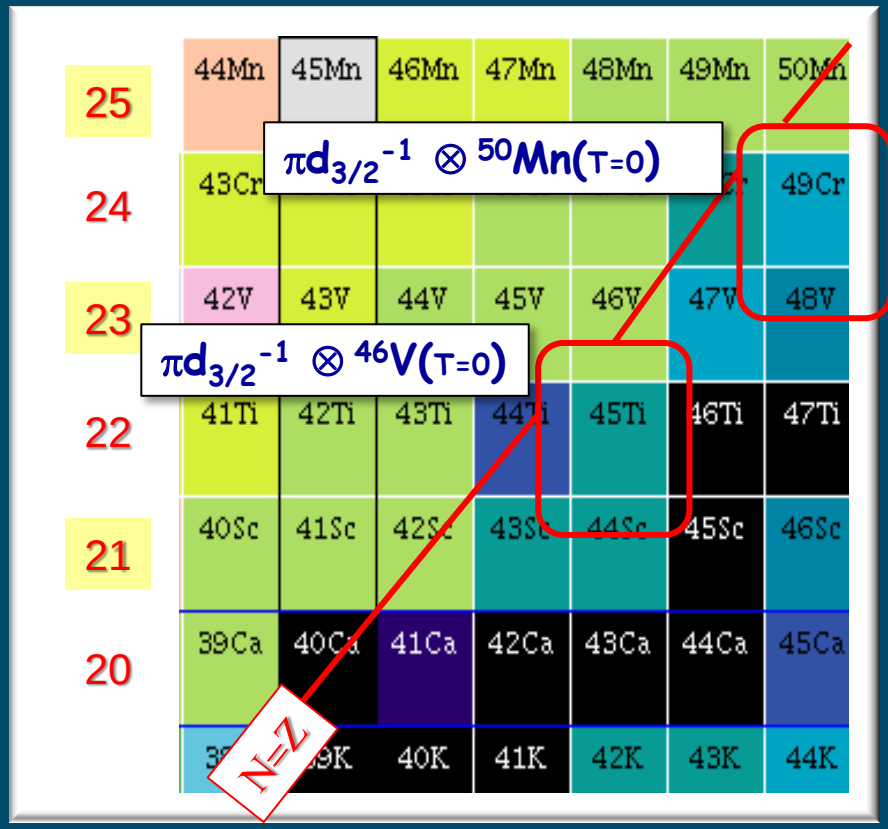


S.Lenzi Phys. Scr. T88, 100 (2000)

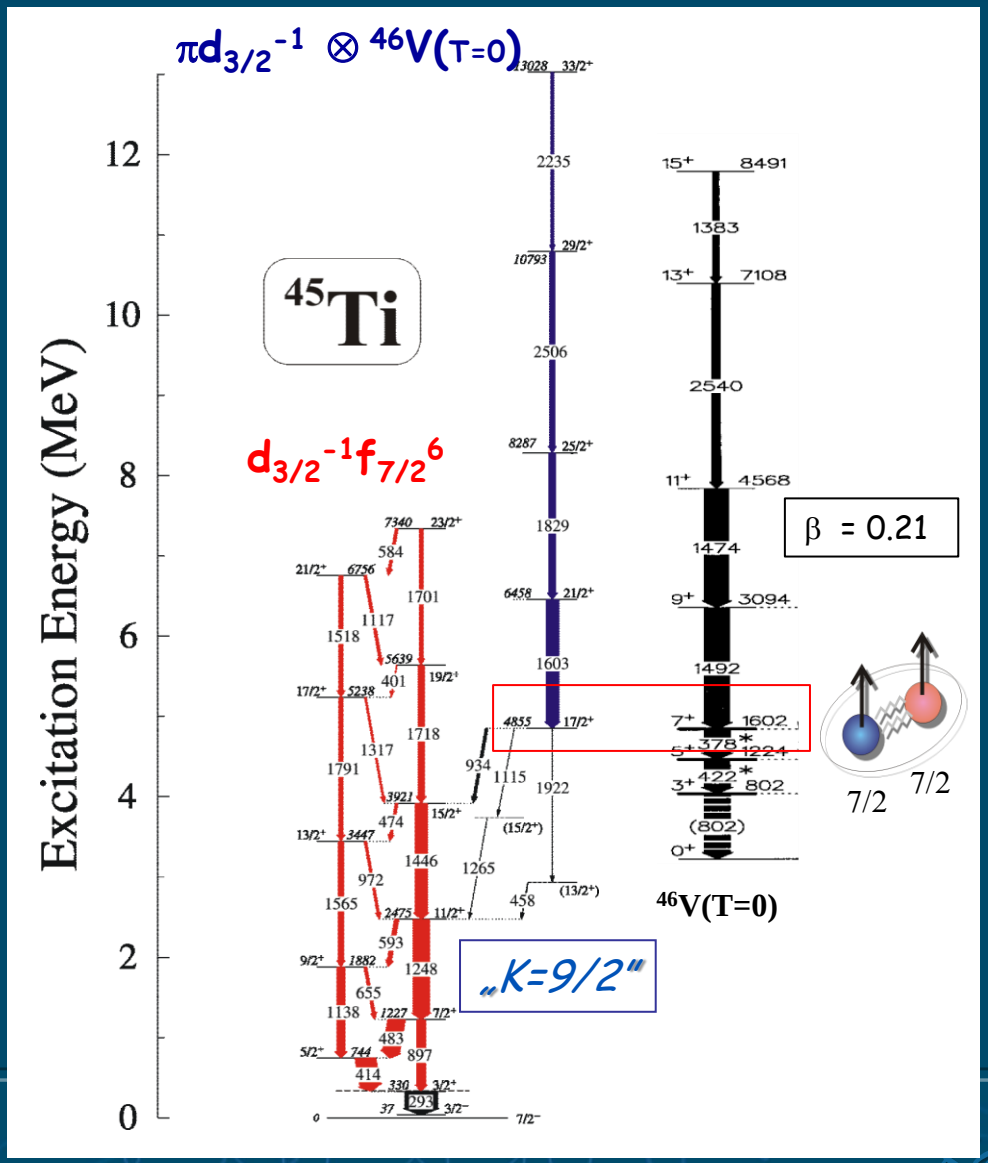
^{46}V, T=0 isospin singlet



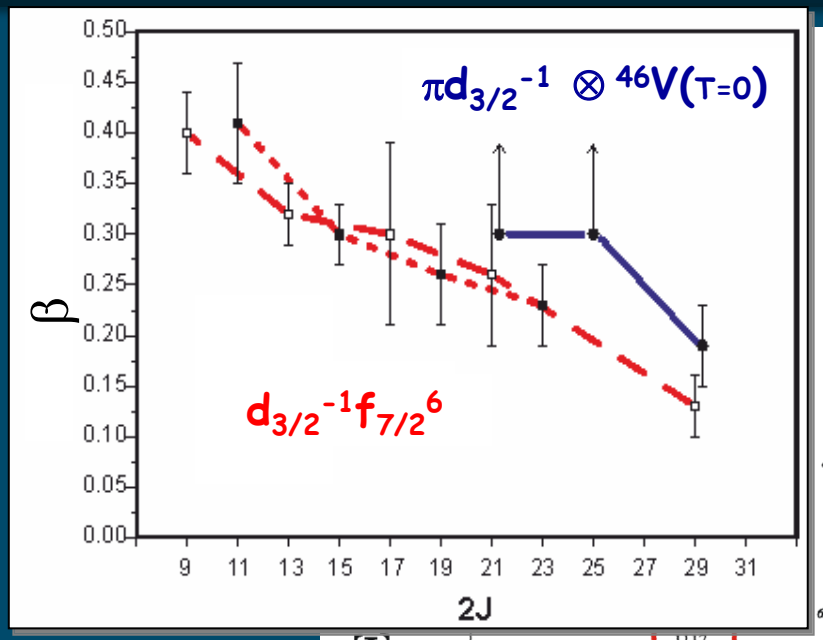
$(p\text{-}n)_{fp}$ T=0 coupling in odd-A N=Z+1 nuclei



$(p\text{-}n)_{fp}$ T=0 coupling in odd-A N=Z+1 nuclei

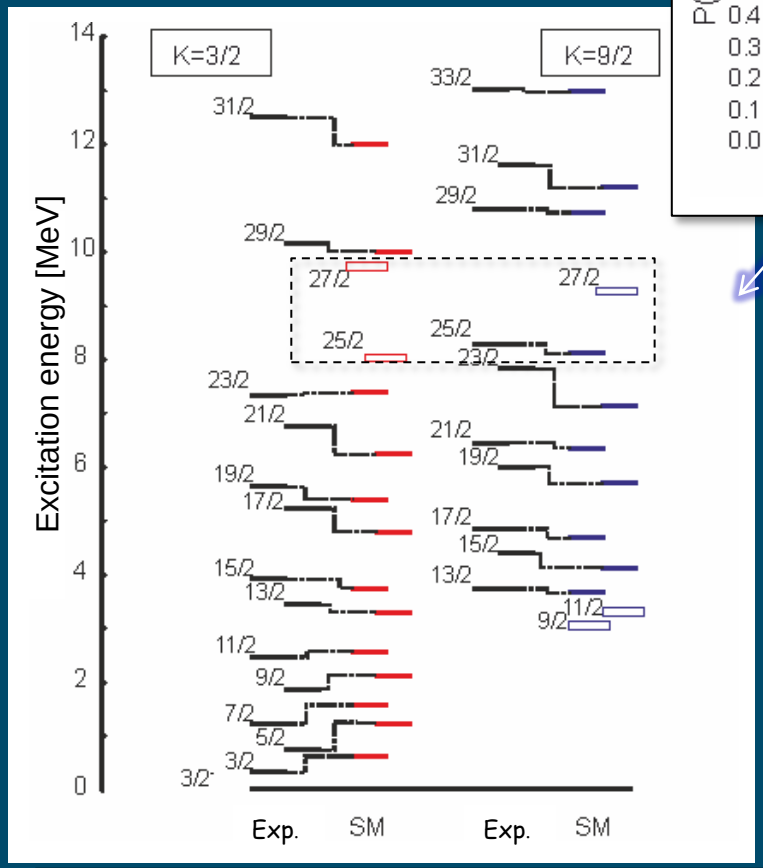


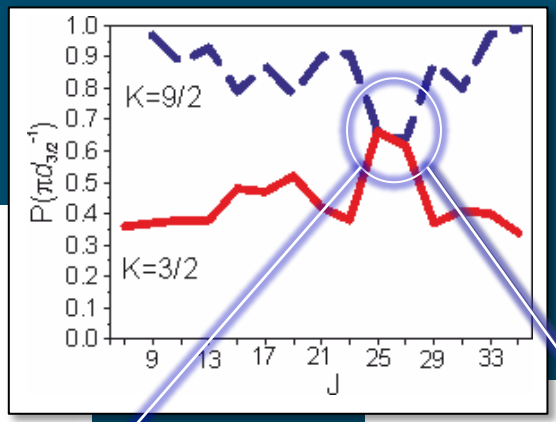
$(p\text{-}n)_{fp}$ T=0 coupling in odd-A N=Z+1 nuclei



High spins in ^{45}Ti - SM results

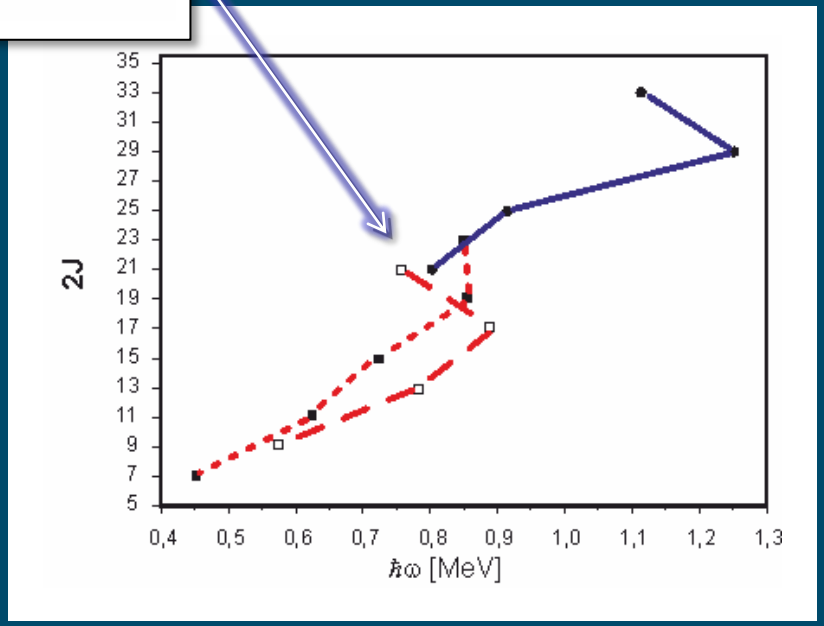
- *ANTOINE*
- *sdpf.sm*





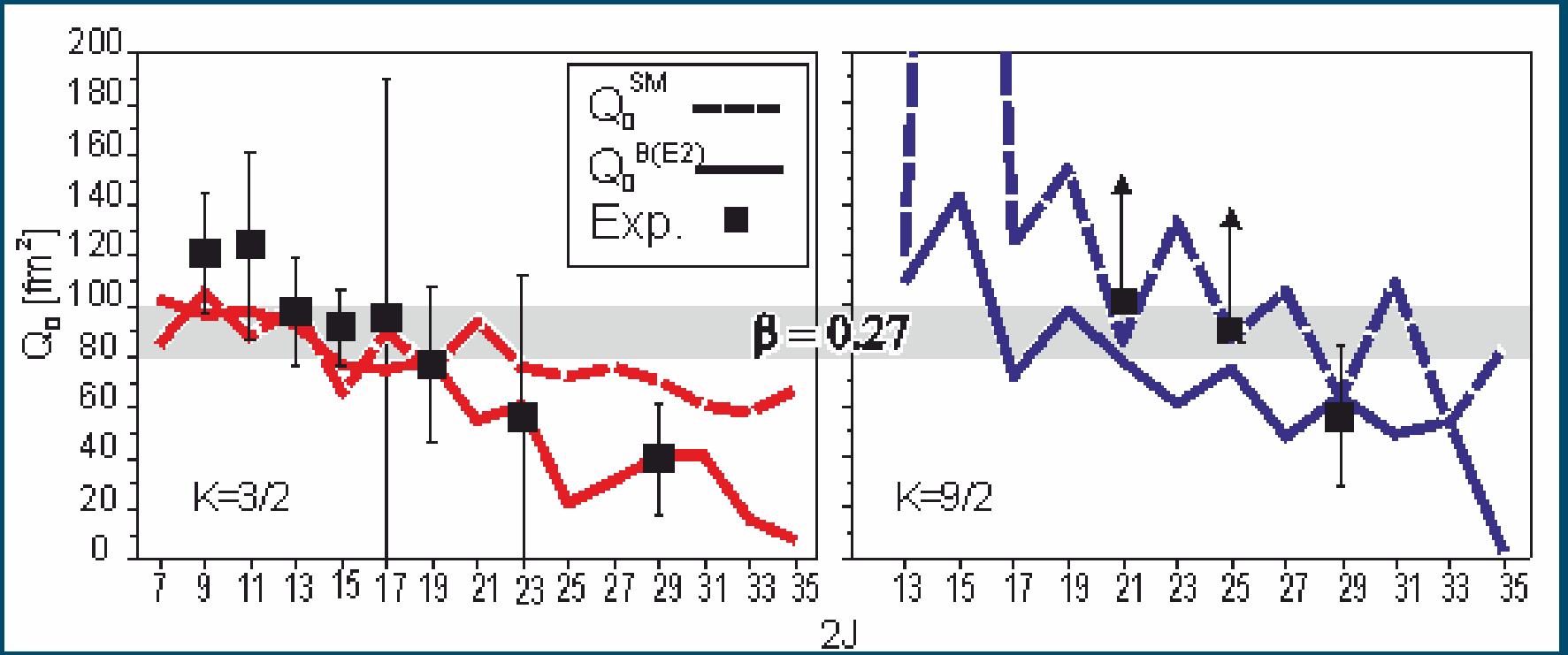
π hole (^{46}V analogue)

π,ν hole (mixed)



Deformation driven high spin structure of ^{45}Ti

quadrupole deformation (SM view): if $Q_0(Q_{spec}) = Q_0(B(E2))$



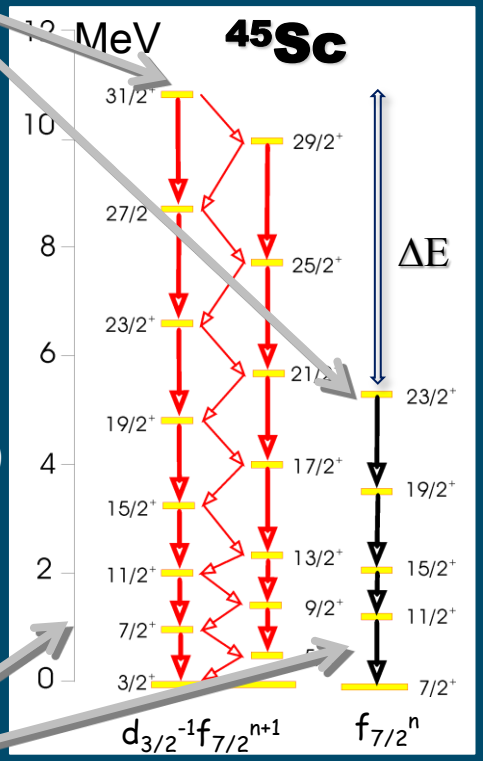
- increase of deformation at HS due to isospin degree of freedeom

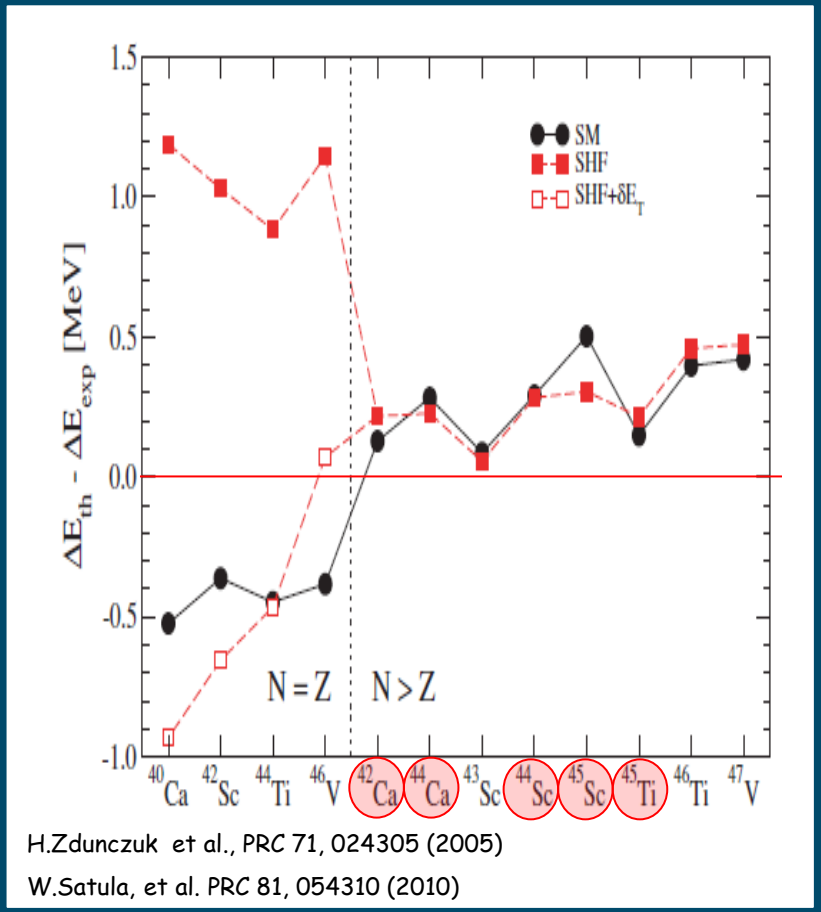
Test of *EDF* components at band termination

TS-spherical meanfield

$\Delta E(SO) =$

$E_{ex}(d_{3/2}^{-1} f_{7/2}^{n+1}) - E_{ex}(f_{7/2}^{n})$





H.Zdunczuk et al., PRC 71, 024305 (2005)

W.Satula, et al. PRC 81, 054310 (2010)

GS-resid. interactions -quadrupole field

Towards heavier (more collective) systems

At high rotational frequencies pairing correlations are considerably quenched and can often be neglected. A most interesting nuclear region is the one with $A \sim 60$ ($N \approx Z \approx 30$), where a large variety of rotational structures such as (smooth) terminating, highly deformed, and superdeformed (SD) rotational bands are expected to be observed up to very high rotational frequencies in the same nucleus.

A. V. Afanasjev, I. Ragnarsson, P. Ring

PHYSICAL REVIEW C, VOLUME 59, NUMBER 6, JUNE 1999

Structure of ^{69}As

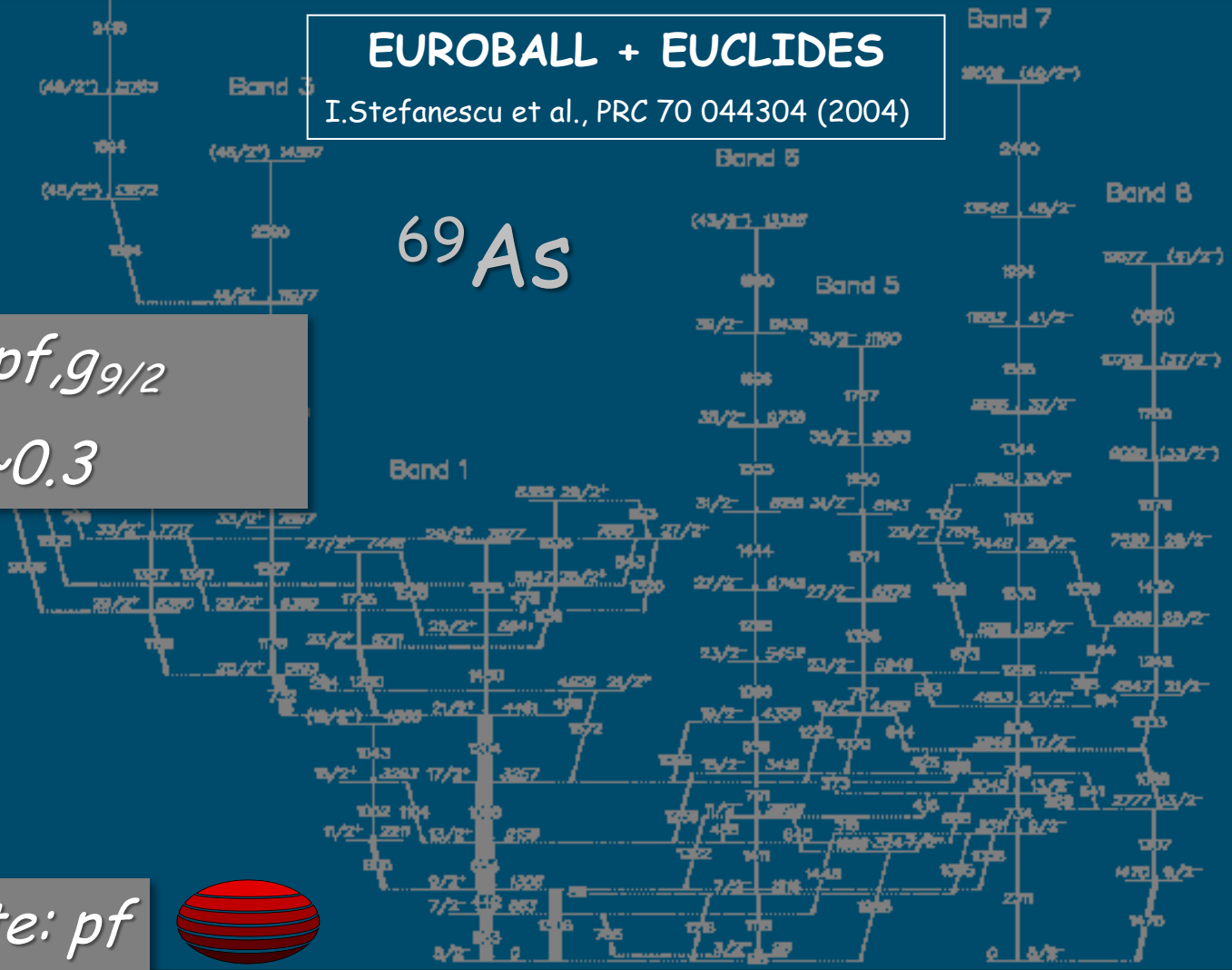
EUROBALL + EUCLIDES

I.Stefanescu et al., PRC 70 044304 (2004)

^{69}As

HS states: pf,$g_{9/2}$

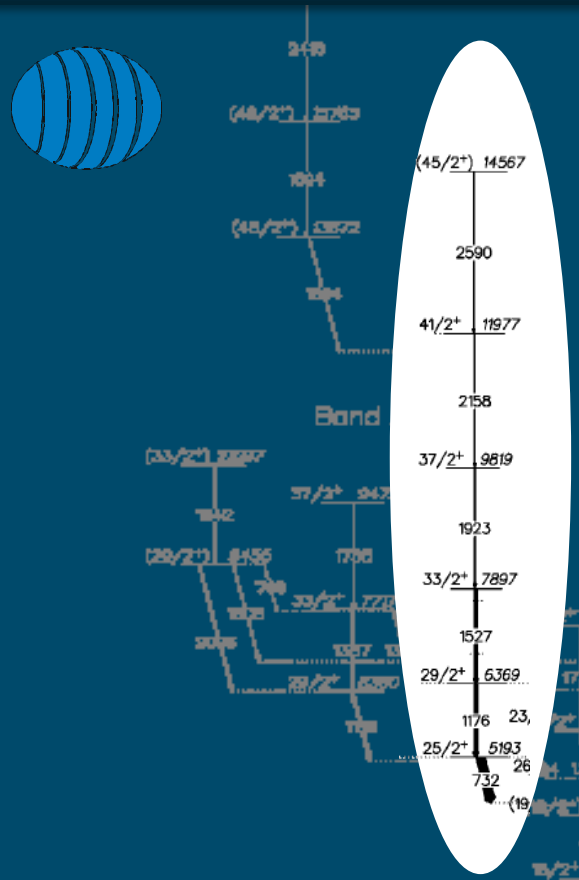
- *γ-soft, β~0.3*



ground state: pf

- *oblate*

Structure of ^{69}As



^{69}As

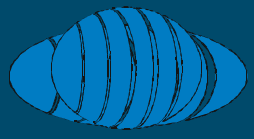
CNS:

I.Stefanescu et al., PRC 70 044304 (2004)

SM: $\pi(g_{9/2})^1\ \nu(g_{9/2})^2$, $I_{max}=49/2$

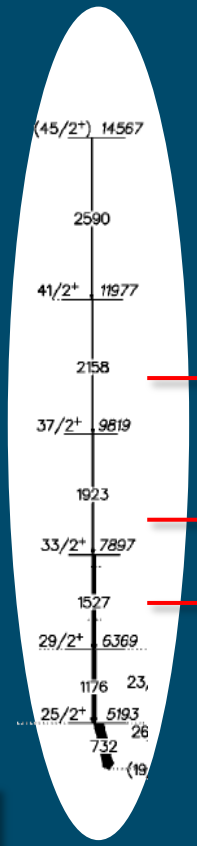
M.Hasegawa, et al., PRC 72, 064320 (2005)

Is ^{69}As superdeformed ?

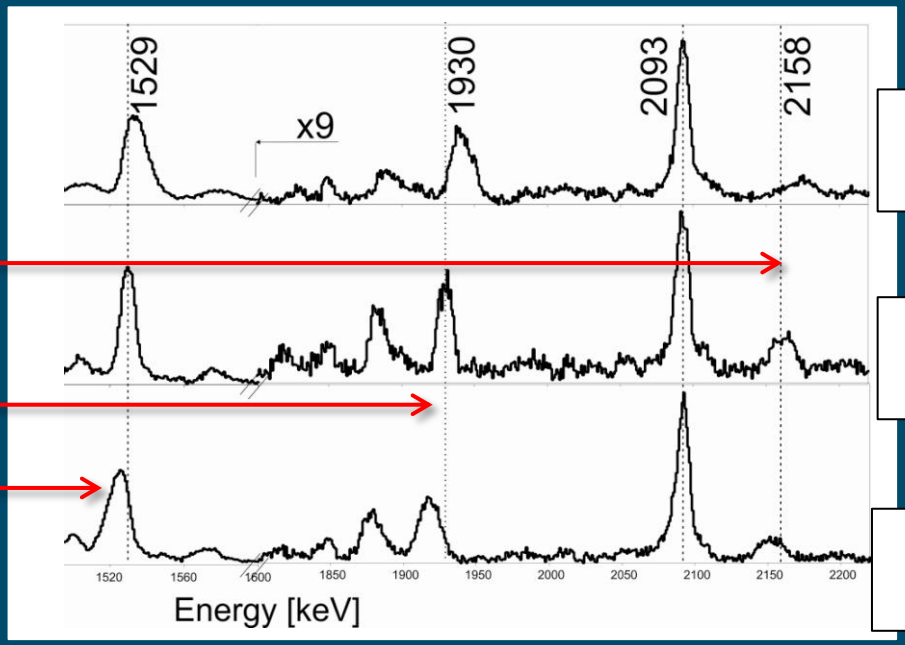


Similar to *SD* in ^{68}Ge

- holes in ^{56}Ni core must be involved



M.Matejska-Minda et al., APP (2013)



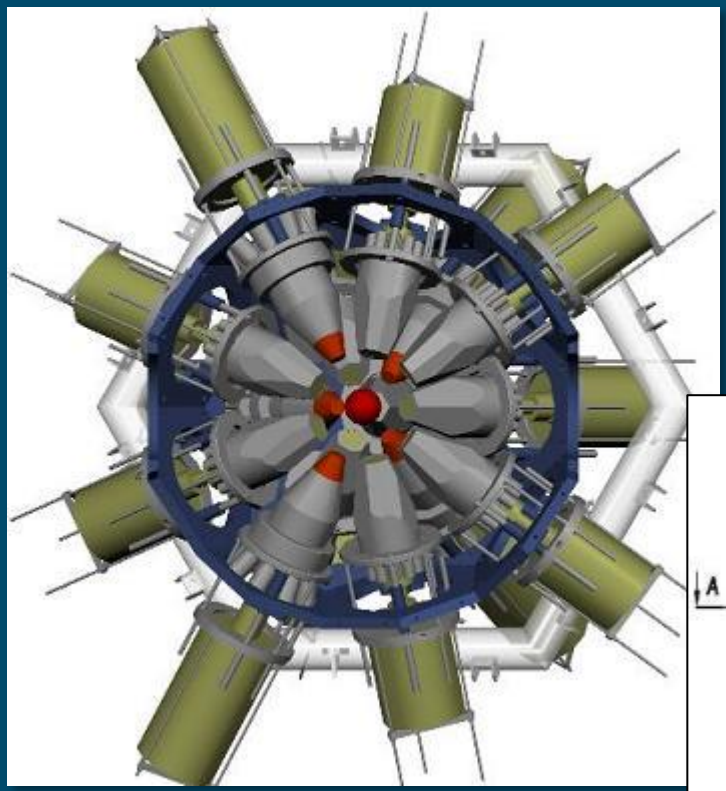
GASP + RFD (2009)

^{32}S (95MeV) + ^{40}Ca

τ <40 fs $\rightarrow$ β>0.5

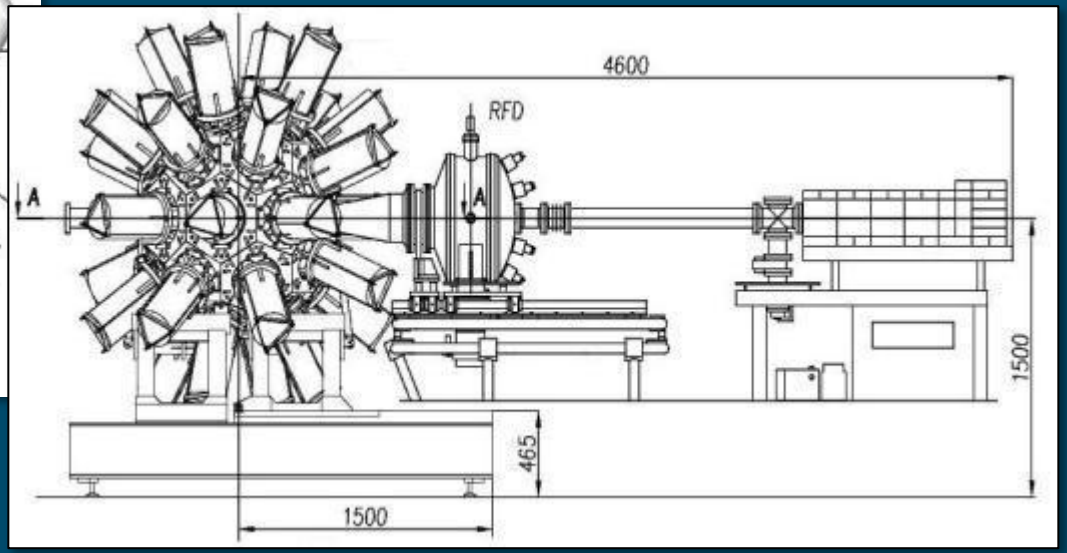
The interpretation needs to be reconsidered

Prospects: EAGLE, HIL, Warsaw



- 30 HPGe ACS detectors
- ε_γ=(1%-4%)

- *Lifetimes along rotational bands in fp nuclei*



Prospects: GALILEO LNL, Legnaro

- 30 GASP detectors
- 10 triple (EB) clusters
- ε_γ ~8%

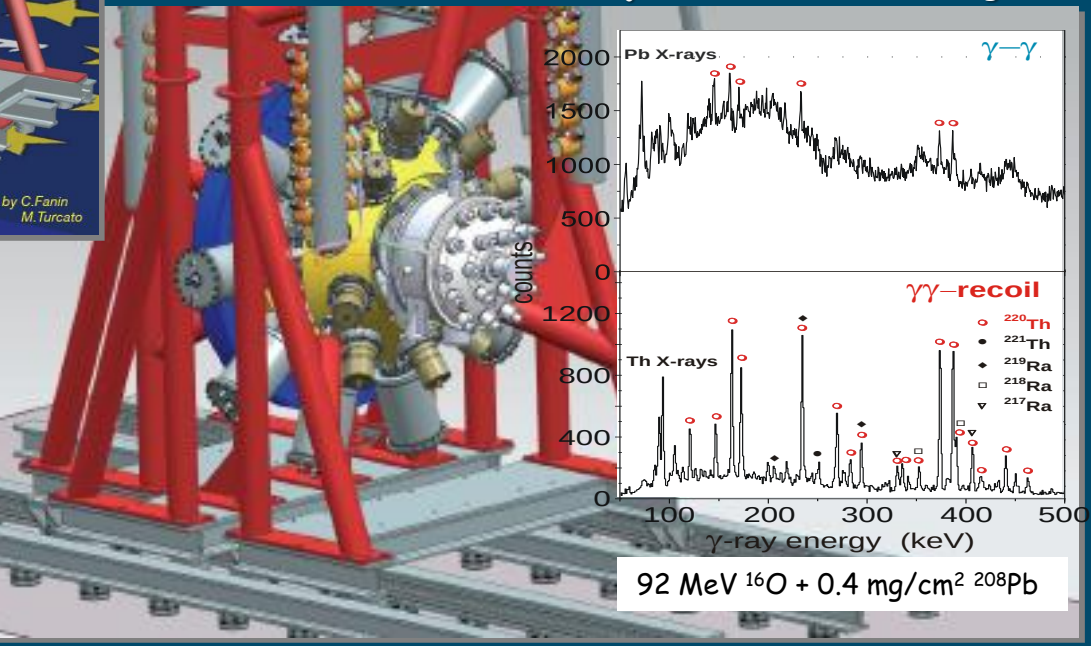
Far geometry

- *Ultra-HS in n-rich Ba isotops, proof of principle studies (follow up at SPIRAL2 RIB)*

Close geometry

- *HS Spectroscopy of very heavy nuclei A>>200*

Rejection of a fission background



92 MeV ^{16}O + 0.4 mg/cm^2 ^{208}Pb

Acknowledges

IFJ PAN, Kraków

P.Bednarczyk, M.Ciemała*, B. Fornal, J. Grębosz, M. Kmiecik, M.Krzysiek*, A. Maj, M.Matejska-Minda*, W.Męczyński, J.Styczeń, M.Zięblíński

*student PhD

IPHC, Strasbourg

D.Curien et al. (experiment)

F.Nowacki et al. (theory)

Preparation for new facilities:

LNL-INFN, Legnaro-Padova

C. Ur et al.

University and INFN, Milano

S.Leoni et al.

HIL, Warszawa

J. Srebrny et al.

GANIL, Caen

Ch. Schmitt et al.