Role of the $\nu(g_{9/2})$ orbital in the Ni isotopes*

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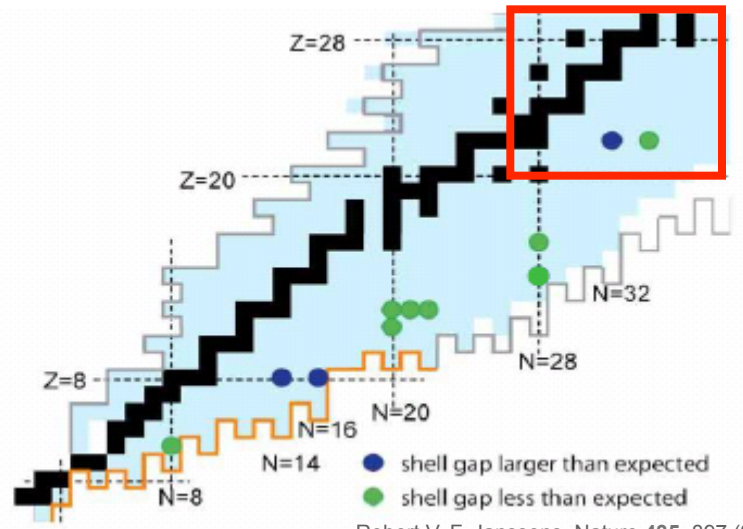
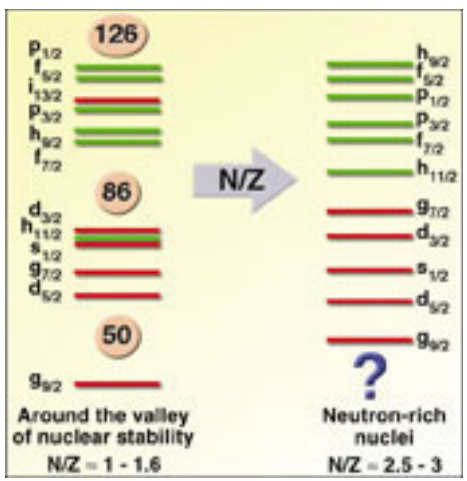
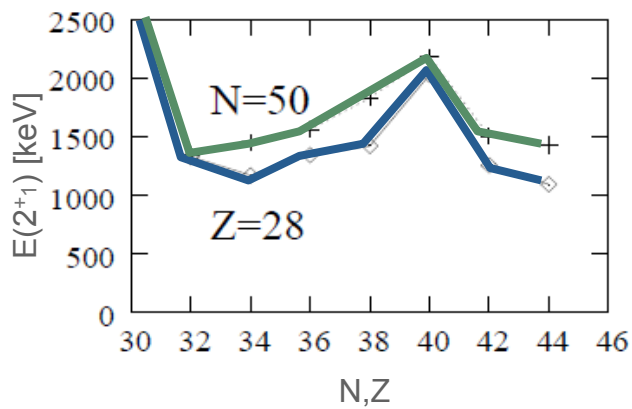
Investigation of the evolution of single particle structure in the A≈60 mass region

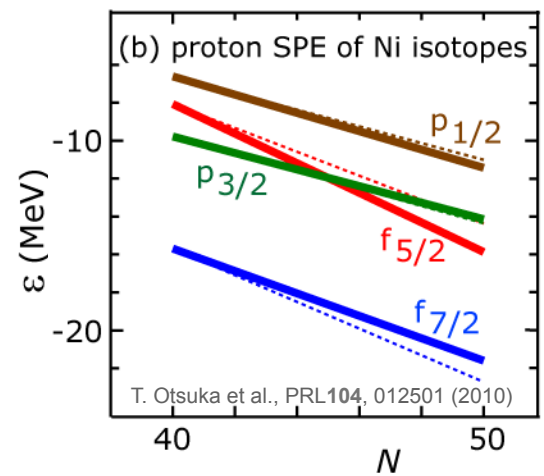


Robert V. F. Janssens, Nature **435**, 897 (2005)

- Single Particle Structure (SPS) is changing dramatically when going further away from the stable to more exotic nuclei
- Investigation of SPS in the A≈60 mass region (Cr-Fe-Ni-Zn) with emphasis on the influence of the $g_{9/2}$ orbital
- Experimental tools:
  - Transfer reactions with stable or fast radioactive beams
  - Coulomb excitation reactions with radioactive beams
  - Deep Inelastic reactions with beam energies above the Coulomb barrier (^{64}Ni,^{70}Zn+^{238}U @ 25% above Coulomb barrier)

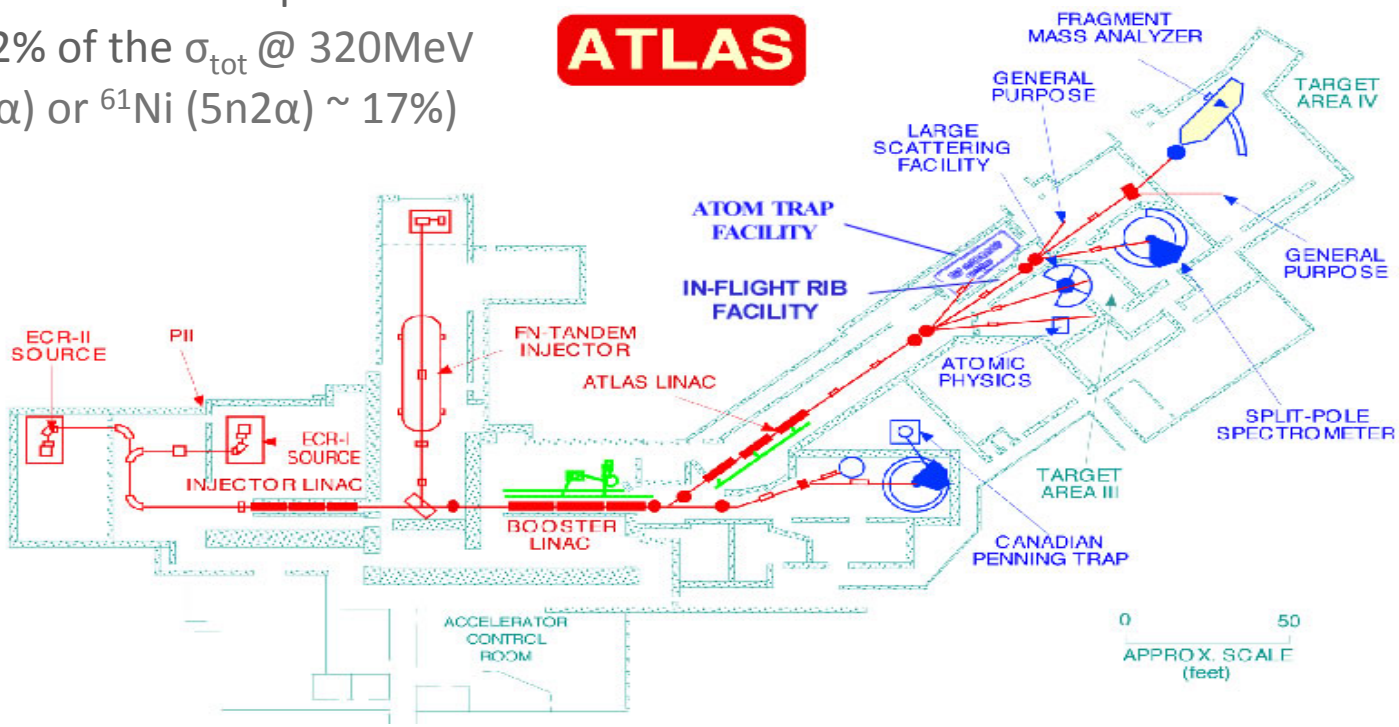




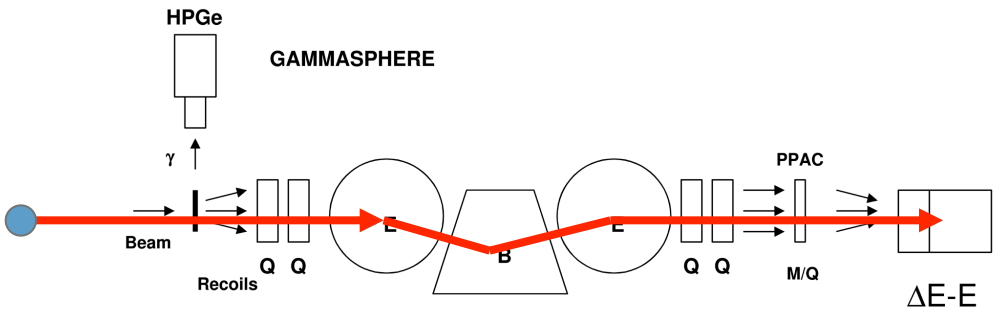


Experimental setup

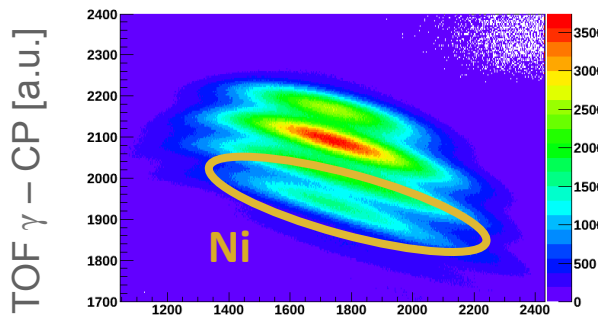
- ^{48}Ca beam @275, 290, 320 MeV (>200% above Coulomb barrier)
- Intensity ~ 200pnA
- Selfsupporting ^{26}Mg target, 0.973 mg/cm^2 thick
- ^{63}Ni is created in the 7n4p channel with only 2% of the σ_{tot} @ 320MeV (^{63}Cu (6npα) or ^{61}Ni (5n2α) ~ 17%)

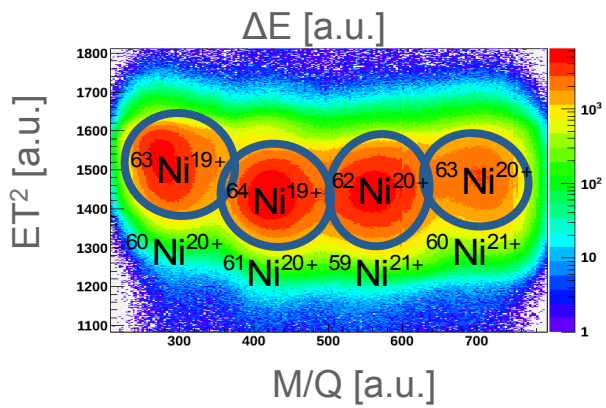


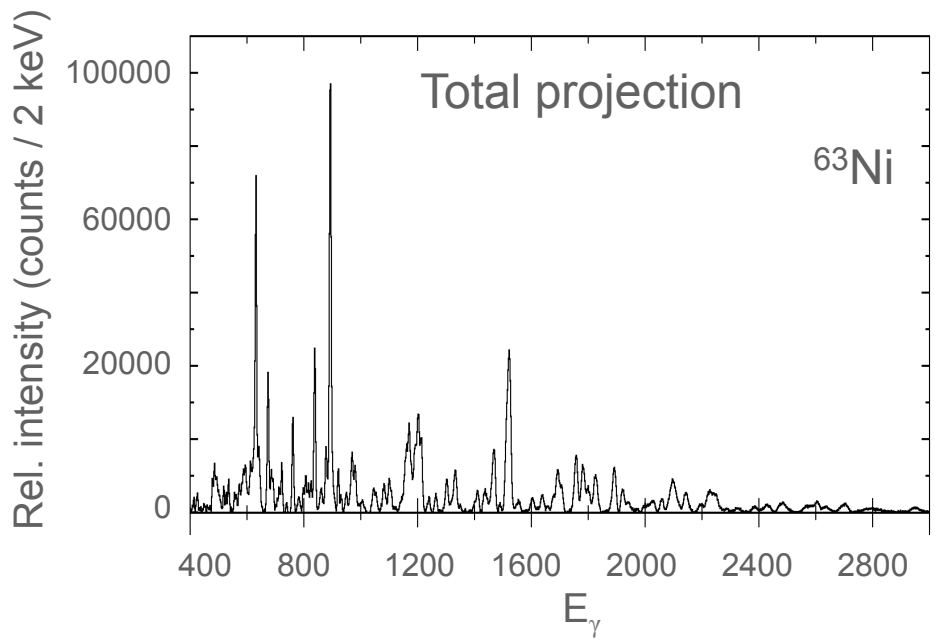
Experimental setup - Gammasphere + FMA



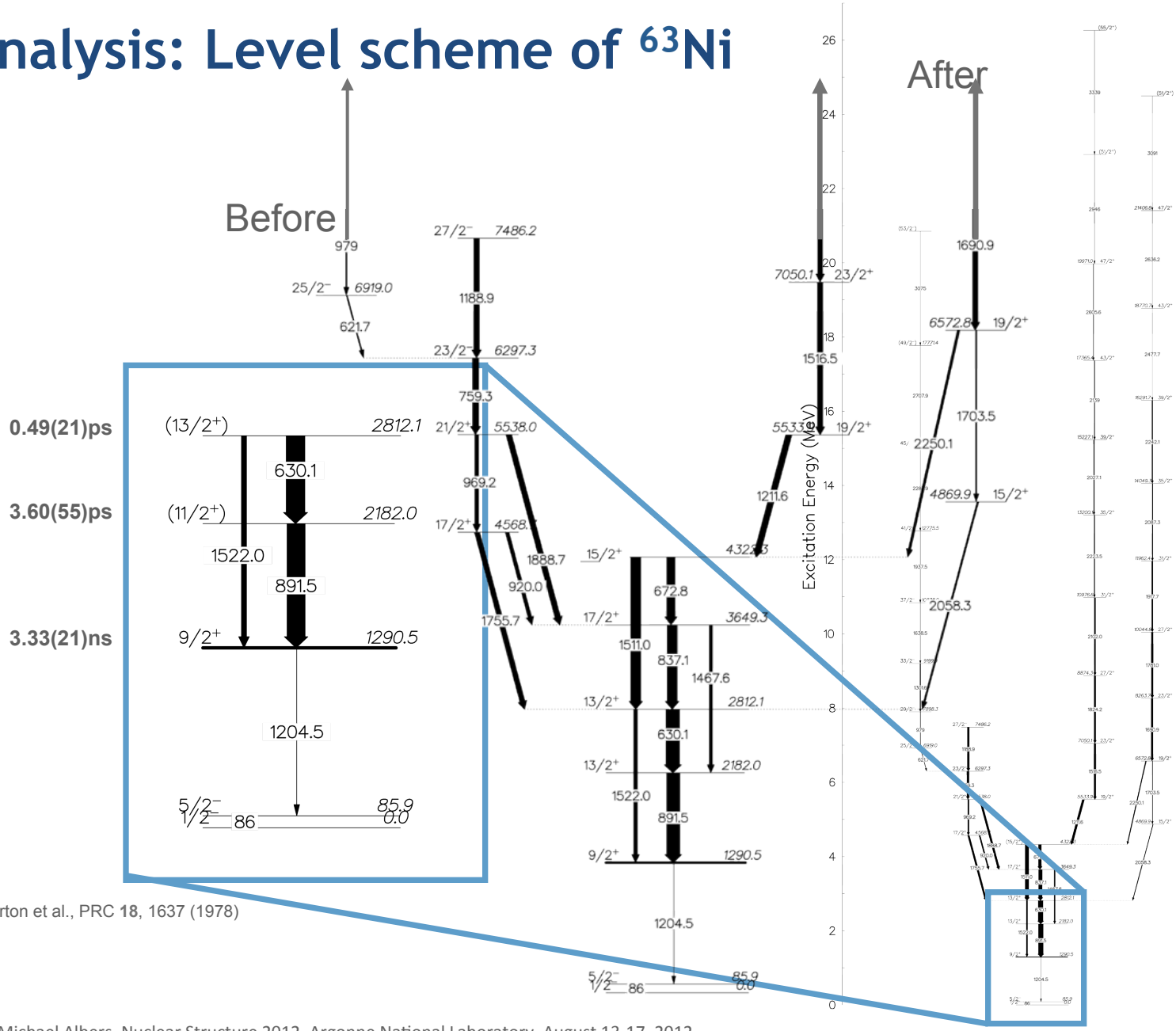
- Using Fragment Mass Analyzer for particle identification → PPAC detector in the focal plane ΔE-E telescope behind the focal plane
- Information from ΔE-E telescope used for Z determination
- TOF between γ-ray and event in FMA is used for M/Q determination





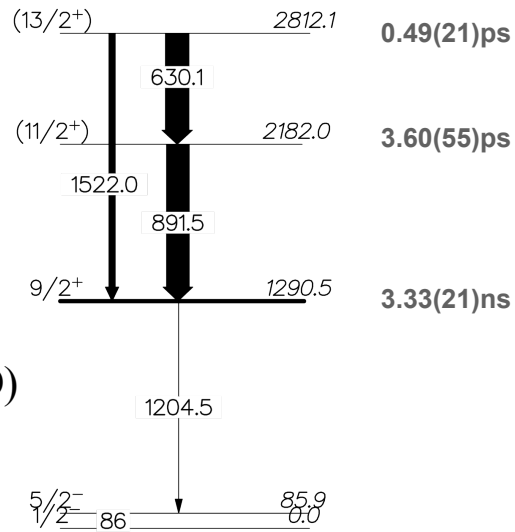


Analysis: Level scheme of ^{63}Ni



E.K. Warburton et al., PRC **18**, 1637 (1978)

Singles angular distributions + gated DCO

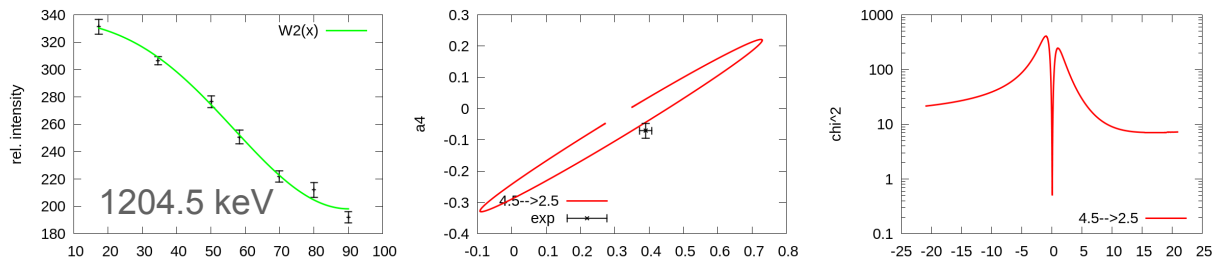


- The design of Gammasphere allows the combination of detectors under same angles relativ to the beam axis and relativ to 90°:
  - **r1 : 17.3° + 162.7°**
  - **r2 : 34.6° + 145.4°**
  - r3 : 50.1° + 129.9°
  - r4 : 58.3° + 121.7°
  - r5 : 69.8° + 110.2°
  - **r6 : 80.0° + 100.0°**
  - **r7 : 90.0°**

DCO
} Fwd/Bwd
} 90°

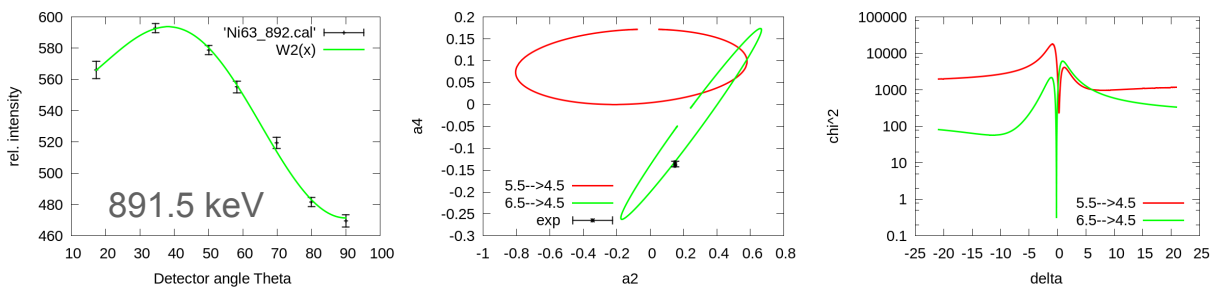
$$P(\Theta) = a_0 + a_2 \cdot P_2(\Theta) + a_4 \cdot P_4(\Theta)$$

$$R_{DCO} = \frac{I(any \mid FWD/BWD)}{I(any \mid 90°)}$$



I_i=9/2+, E3/**M2**

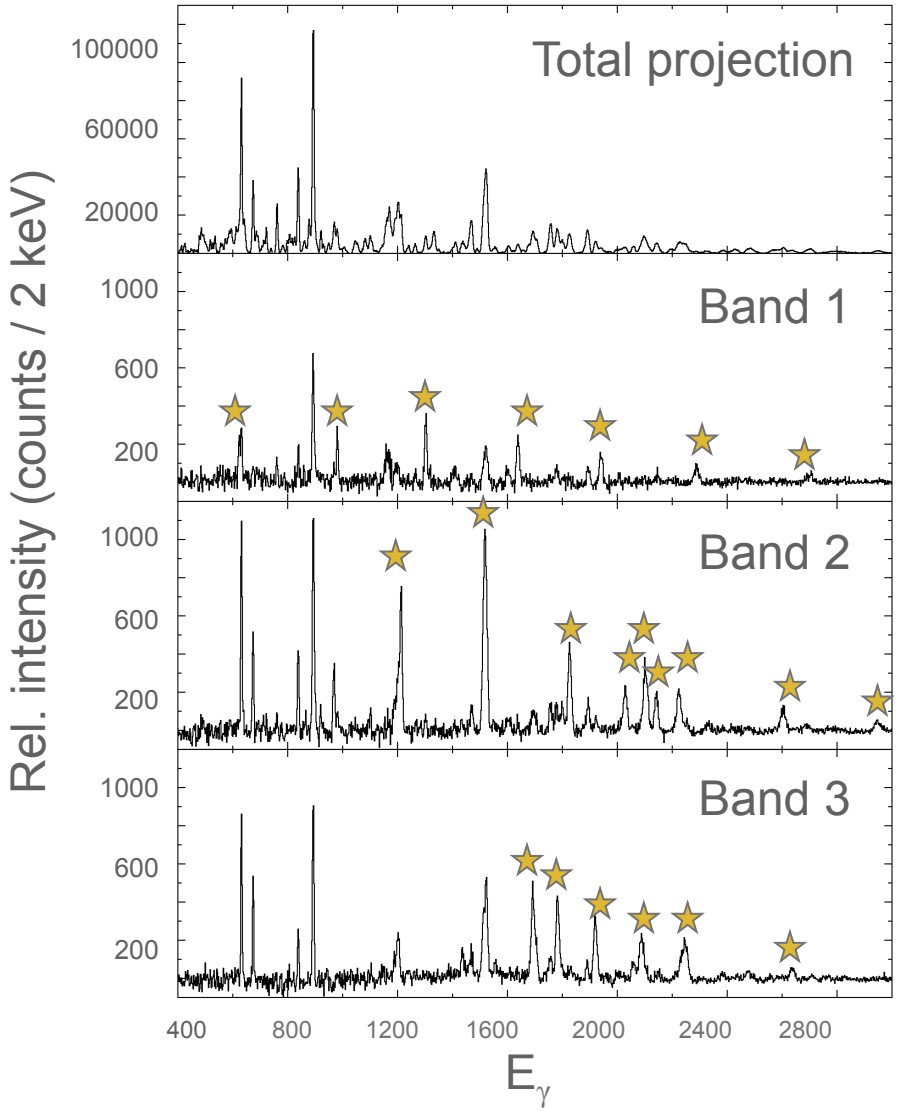
R_{DCO}=1.33(7)

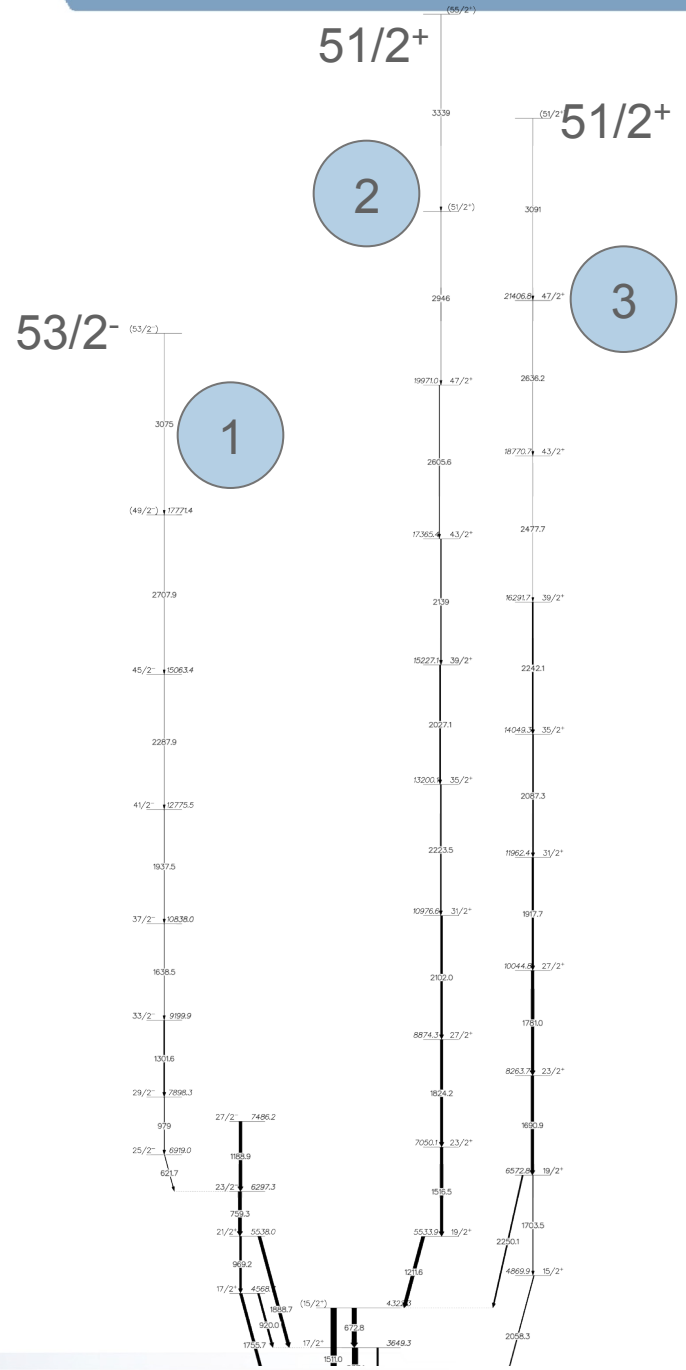


I_i=13/2+, M3/**E2**

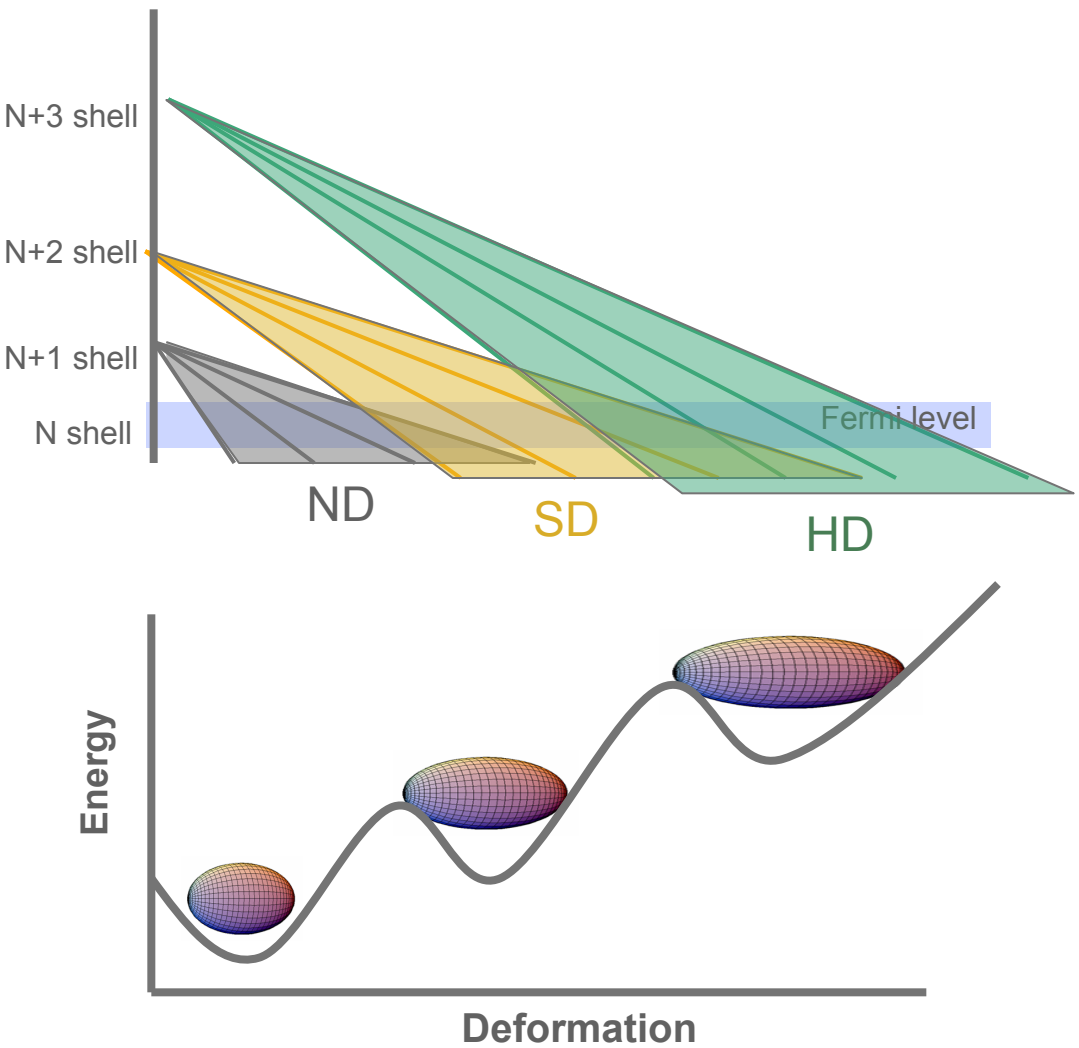
R_{DCO}=1.19(3)

Band structure



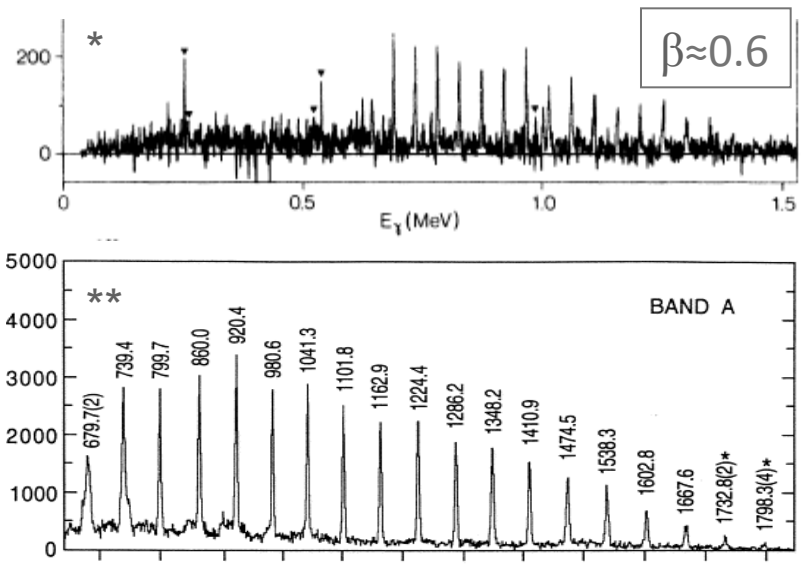


Superdeformation



- First discrete SD band discovered in ^{152}Dy in 1986 by P. Twin *et al.*

  constant level spacing of ~47keV



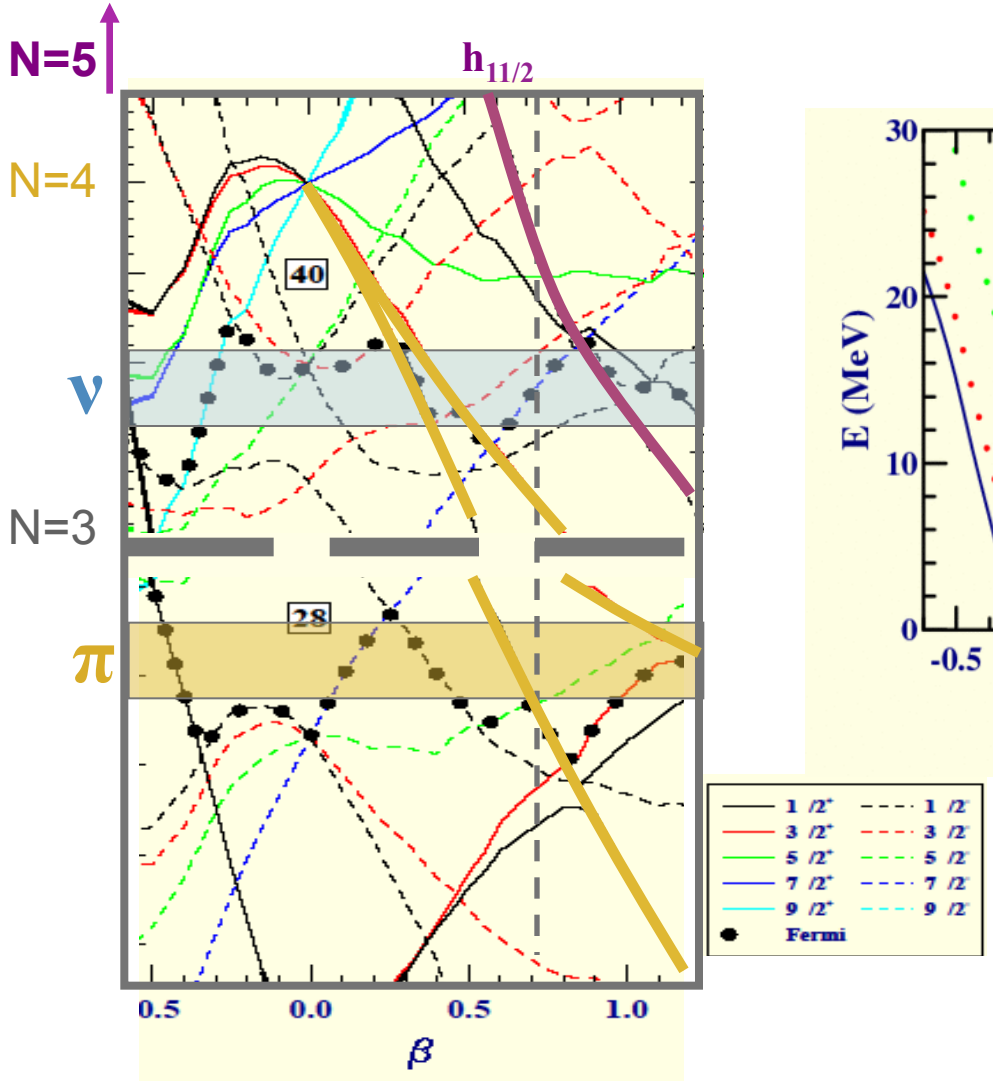
- Today: Many confirmed observations of SD bands all over the nuclear chart, i.e.,

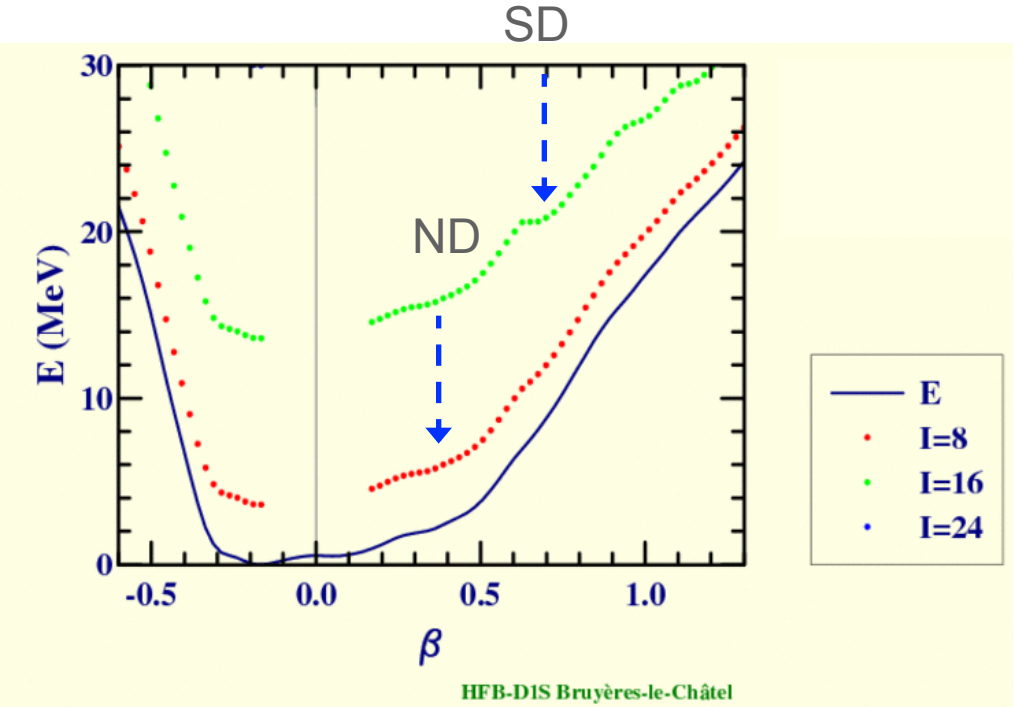
  ^{20}Ne – ^{62}Zn – ^{132}Ce – ^{152}Dy – ^{192}Hg – ^{245}Bk

  (1.7:1) (1.5:1) (1.5:1) (2:1) (1.7:1) (2:1)

* P. Twin *et al.*, PRL 57, 811 (1986)
** T. Lauritsen *et al.*, PRL 88, 042501, (2002), PRL 89, 282501 (2002)

Superdeformation in ^{63}Ni?

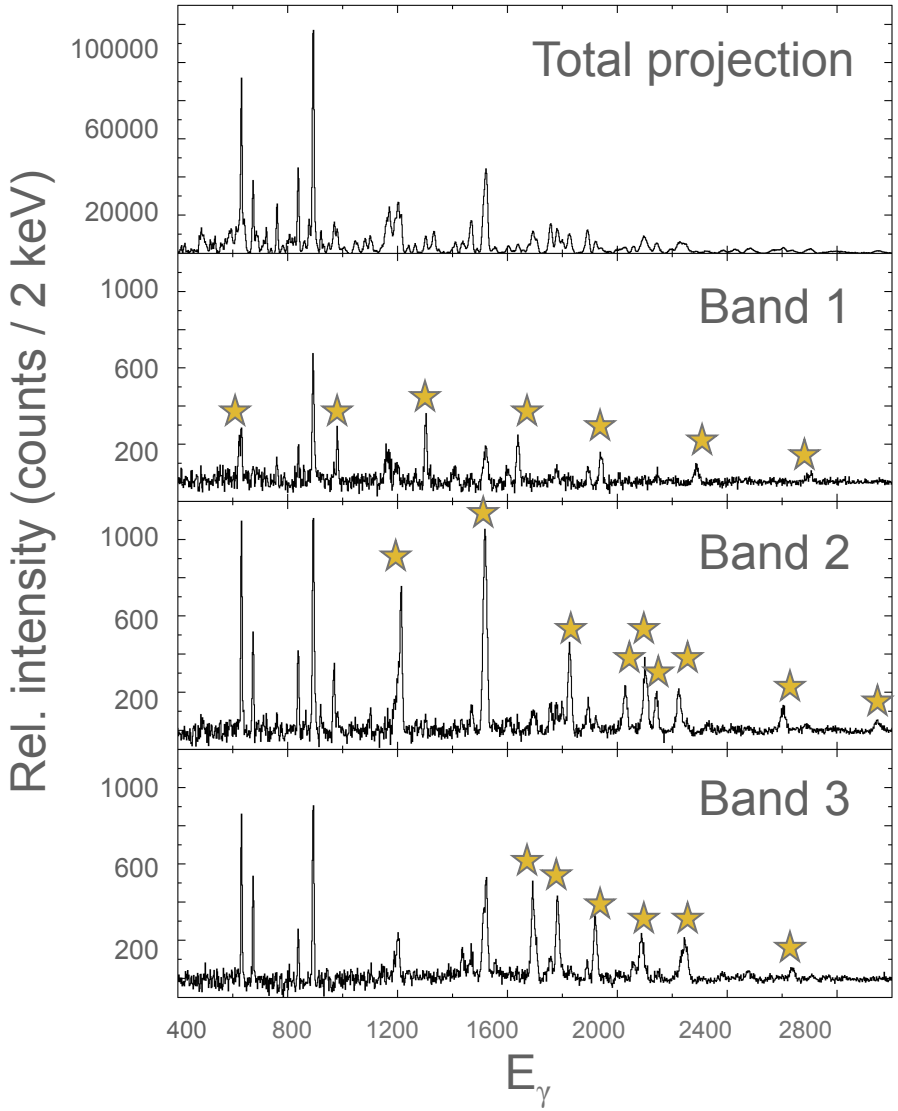


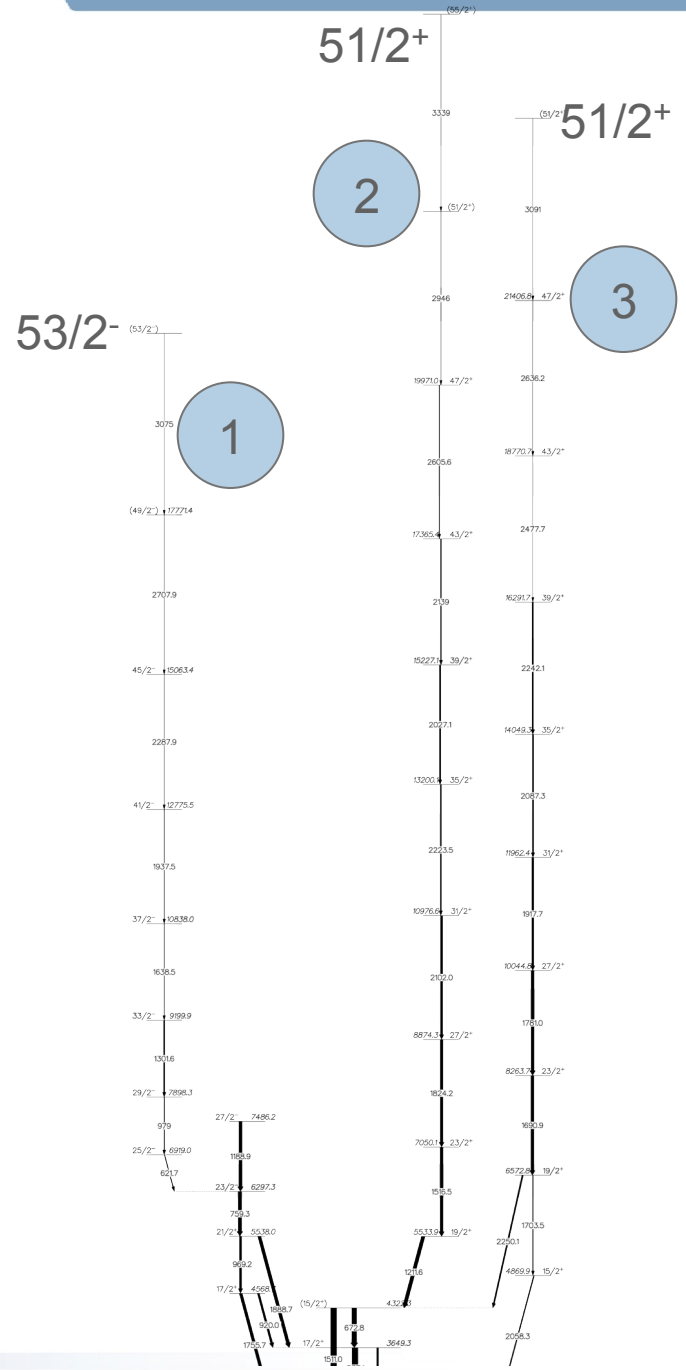


- Downsloping of **1/2+[440]** and **3/2+[431]** induce „normal deformation“
- Downsloping of **1/2-[550]** might induce superdeformation?

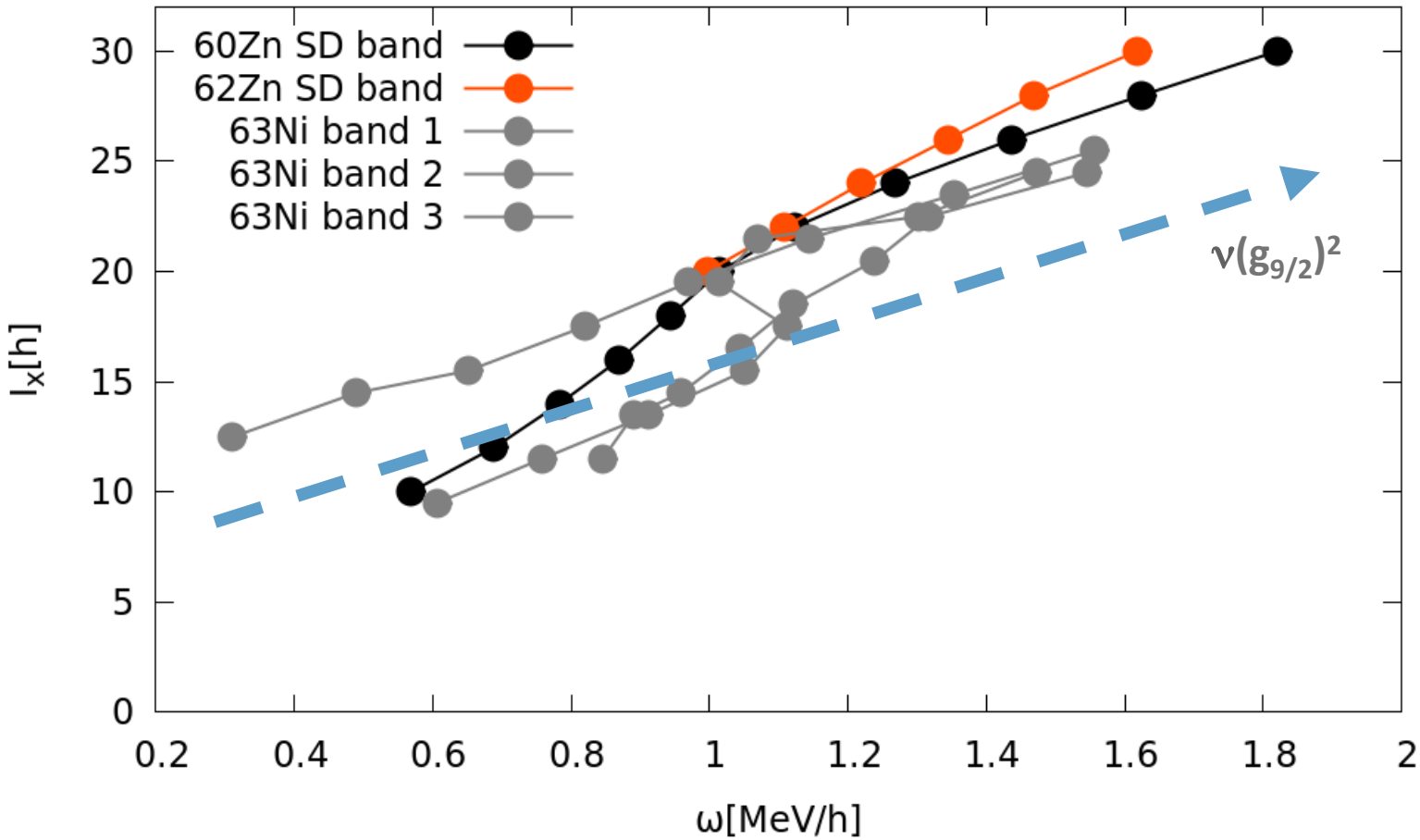
http://www-phynu.cea.fr/science_en_ligne/carte_potentiels_microscopiques/noyaux/zz28/zz28nn35all_eng.html

Band structure





I_x vs. rotational frequency ω



^{60}Fe: A. Deacon et al., PRC76, 054303 (2007)
^{62,64}Ni: C.R. Hoffman *et al.*, to be published
^{60,62}Zn: C.E.Svensson et al., PRL79, 1233, (1997); PRL82,3400 (2002)

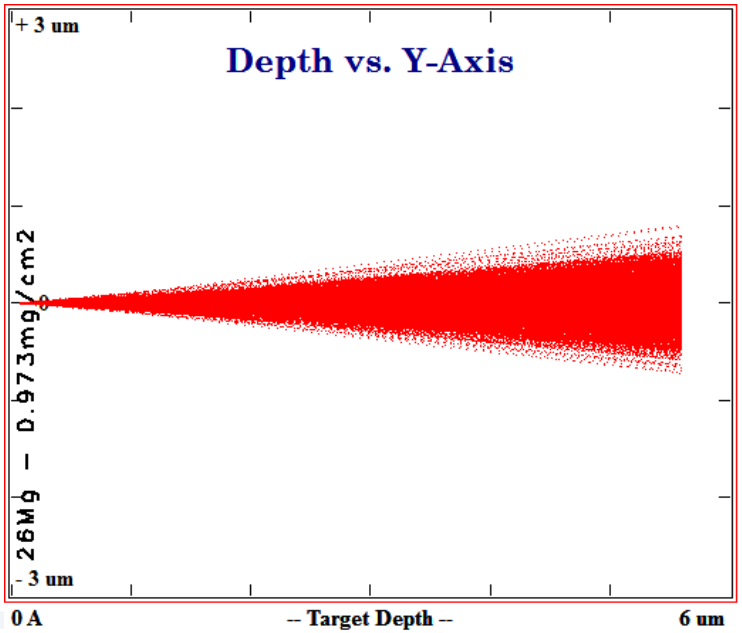
Lifetime Analysis – thin target DSAM

1. Simulate the fusion-evaporation process in the ^{26}Mg target by Monte-Carlo simulation using computer code SRIM, including the energy loss of each ^{63}Ni nucleus in the ^{26}Mg target including electronic and nuclear stopping

2. Use the computer code Wlife4 by F. Moore to simulate theoretical F(τ) values, depending on the three parameters Q_T (transitional quadrupole moment), Q_{SF} (transitional quadrupole moment of a sidefeeding band) and T_{SF} ("one-step" feeding delay):

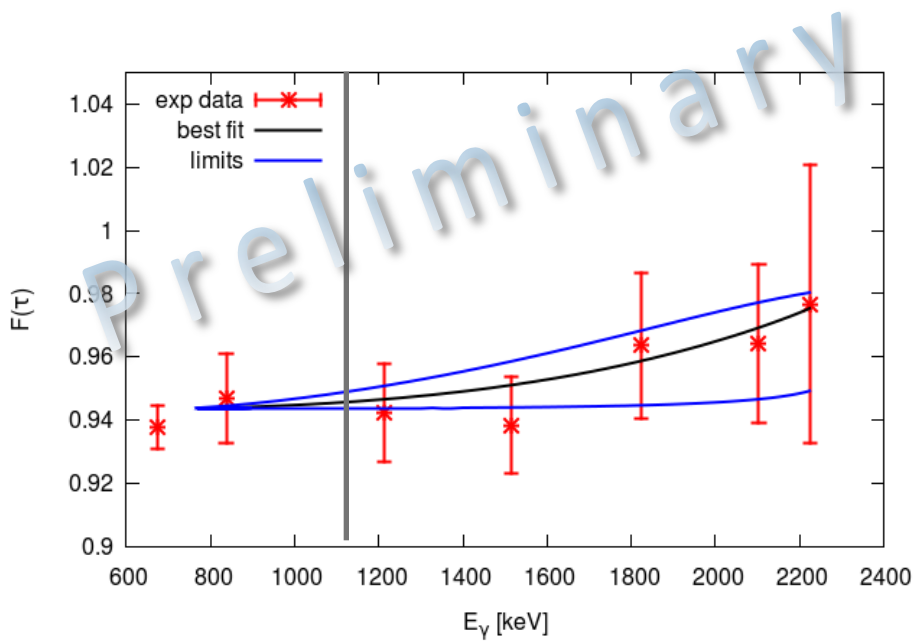
   - a constant Q_T for all γ-ray transitions within the band
   - a quadrupole moment of a possible sidefeeding rotational band Q_{SF} of the same size as the Q_T
   - a delay T_{SF} accounting for unobserved feeding on top of the rotational band

$$F(\tau)_{\exp} = \frac{\beta(t)}{\beta_{\max}} = \frac{v(t)}{c \cdot \beta_{\max}} = \frac{E_{\gamma,F} - E_{\gamma,B}}{E_0(\cos\Theta_F - \cos\Theta_B) \cdot \beta_{\max}}$$



Preliminary results of the lifetime analysis

Band 2

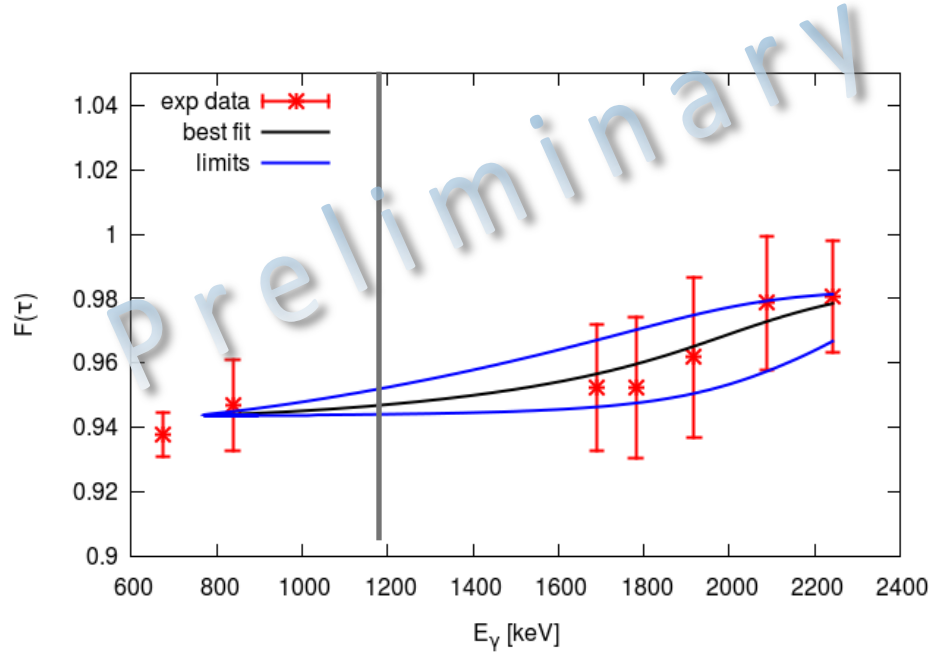


$$Q_T = Q_{SF} = 1.9^{+1.1}_{-1.0} \pm 0.19\ \text{eb}$$

$$T_{SF} = 0.1\,\text{fs}$$

$$\Rightarrow \beta = 0.30^{+0.17}_{-0.20}$$

Band3

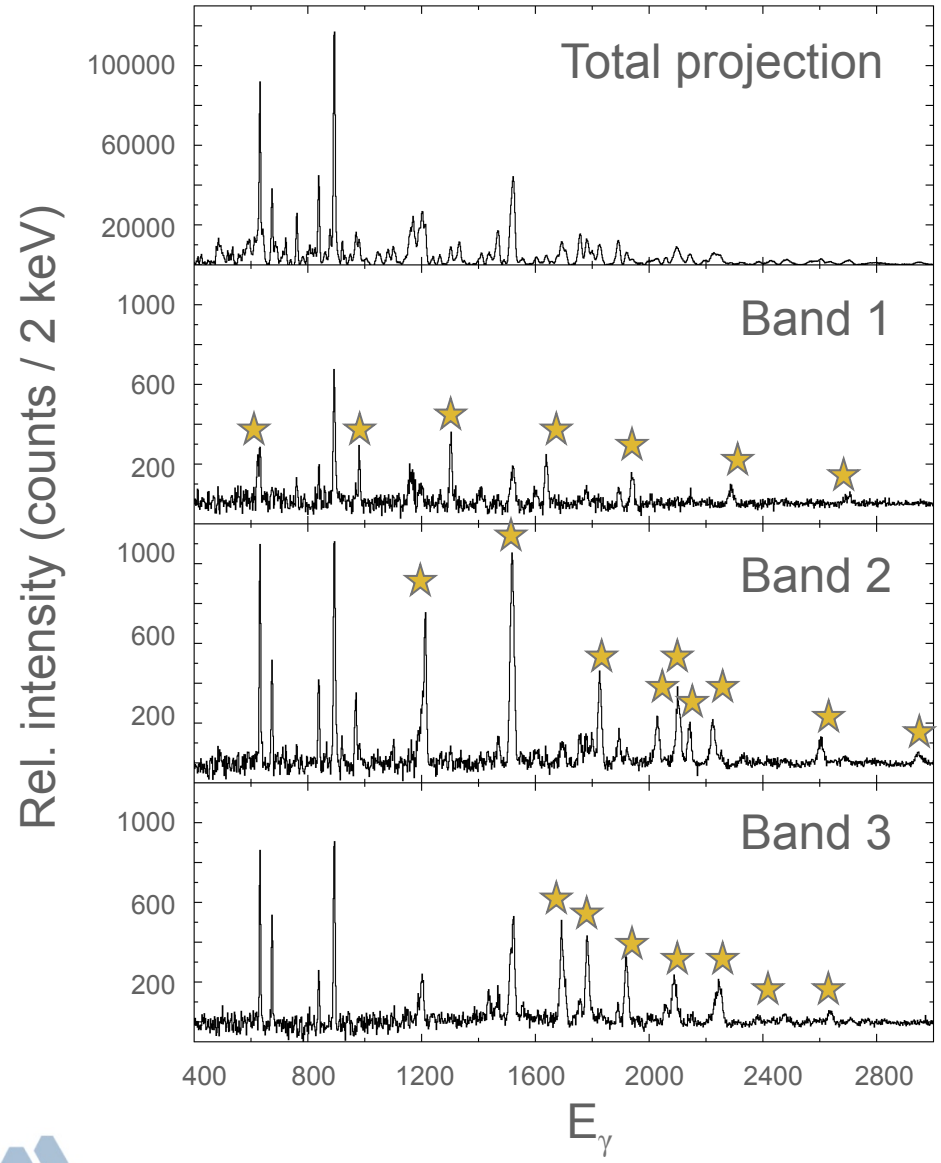


$$Q_T = Q_{SF} = 2.4^{+1.4}_{-0.9} \pm 0.24\ \text{eb}$$

$$T_{SF} = 0.1\,\text{fs}$$

$$\Rightarrow \beta = 0.37^{+0.23}_{-0.18}$$

Lifetime analysis



Deformation parameters:

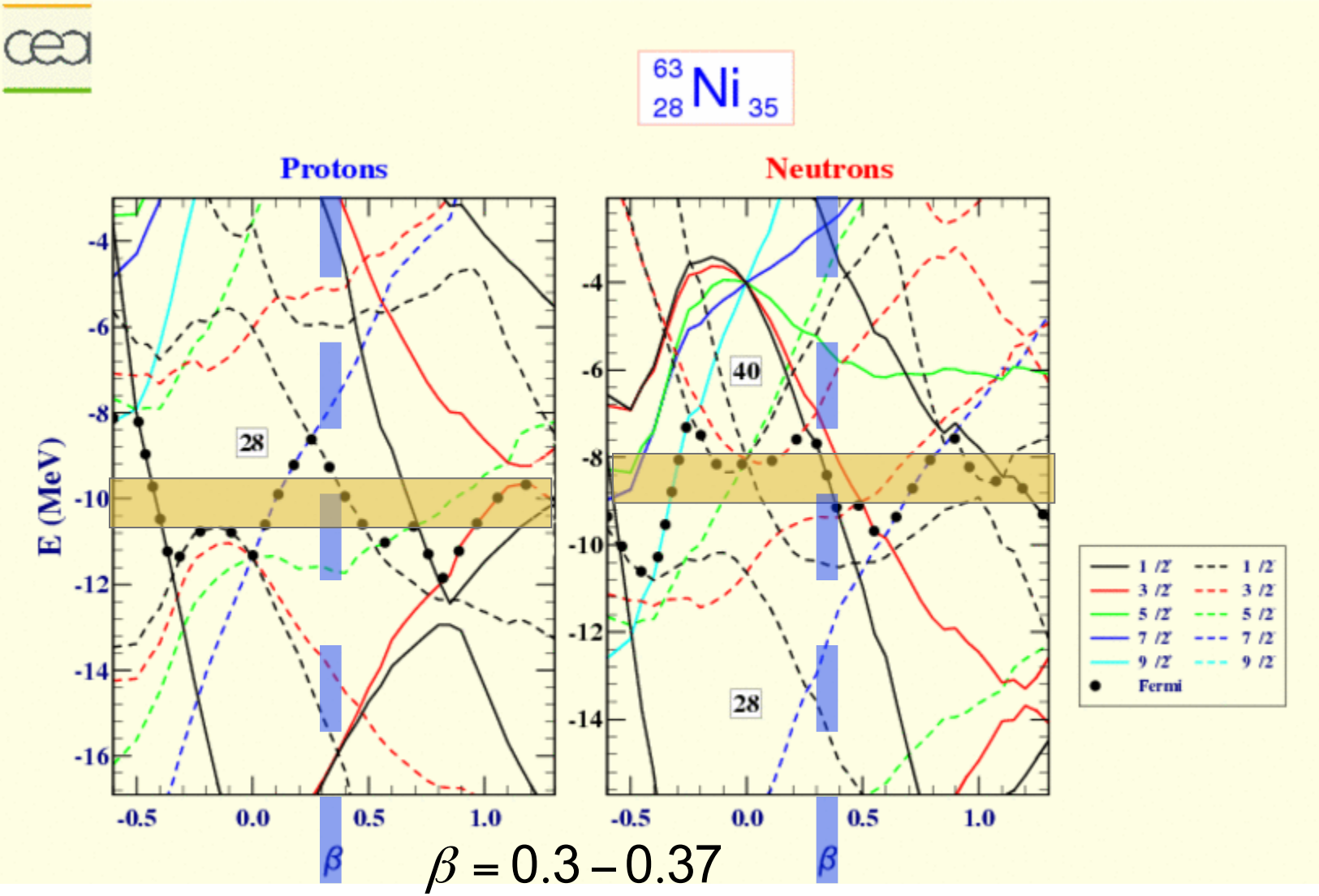
- ^{59}Ni β = 0.22(4)
  β = 0.26(9)
- ^{63}Ni $\beta = 0.30^{+0.17}_{-0.20}$
  $\beta = 0.37^{+0.23}_{-0.18}$
- ^{60}Zn β = 0.47(7) SD
- ^{61}Zn β = 0.5(7) SD
- ^{62}Zn β = 0.15
  β = 0.2
  β = 0.45(9) SD
- ^{65}Zn β = 0.43(5) SD
  β = 0.35(5)

$$Q_T = Q_{SF} = 1.9^{+1.1}_{-1.0} \pm 0.19 \text{ eb}$$
$$T_{SF} = 0.1 \text{ fs}$$
$$\Rightarrow \beta = 0.30^{+0.17}_{-0.20}$$

$$Q_T = Q_{SF} = 2.4^{+1.4}_{-0.9} \pm 0.24 \text{ eb}$$
$$T_{SF} = 0.1 \text{ fs}$$
$$\Rightarrow \beta = 0.37^{+0.23}_{-0.18}$$

C.E.Svensson et al., PRL79, 1233, (1997); PRL80, 2558 (1998); PRL82,3400 (2002)
C.-H. Yu et al., PRC60, 031305 (1999);PRC62, 041301(R) (2000); PRC65, 061302(R) (2002)

Constrained Hartree-Fock-Bogoliobov



$\beta = 0.3 - 0.37$

http://www-phynu.cea.fr/science_en_ligne/carte_potentiels_microscopiques/noyaux/zz28/zz28nn35all_eng.html

Summary

- Level scheme of ^{63}Ni was significantly extended up to level energies of $\approx$ 26 MeV and level spins up to 53/2 $\hbar$
- Multipolarities of emitted γ–rays were determined based on angular distribution and DCO analyses
- Transitional quadrupole moments and deformation parameters were extracted for two of the three deformed bands based on "thin target DSAM" indicating "large" deformation

Thank you!