Prompt and delayed γ rays spectroscopy in the ^{68}Ni vicinity

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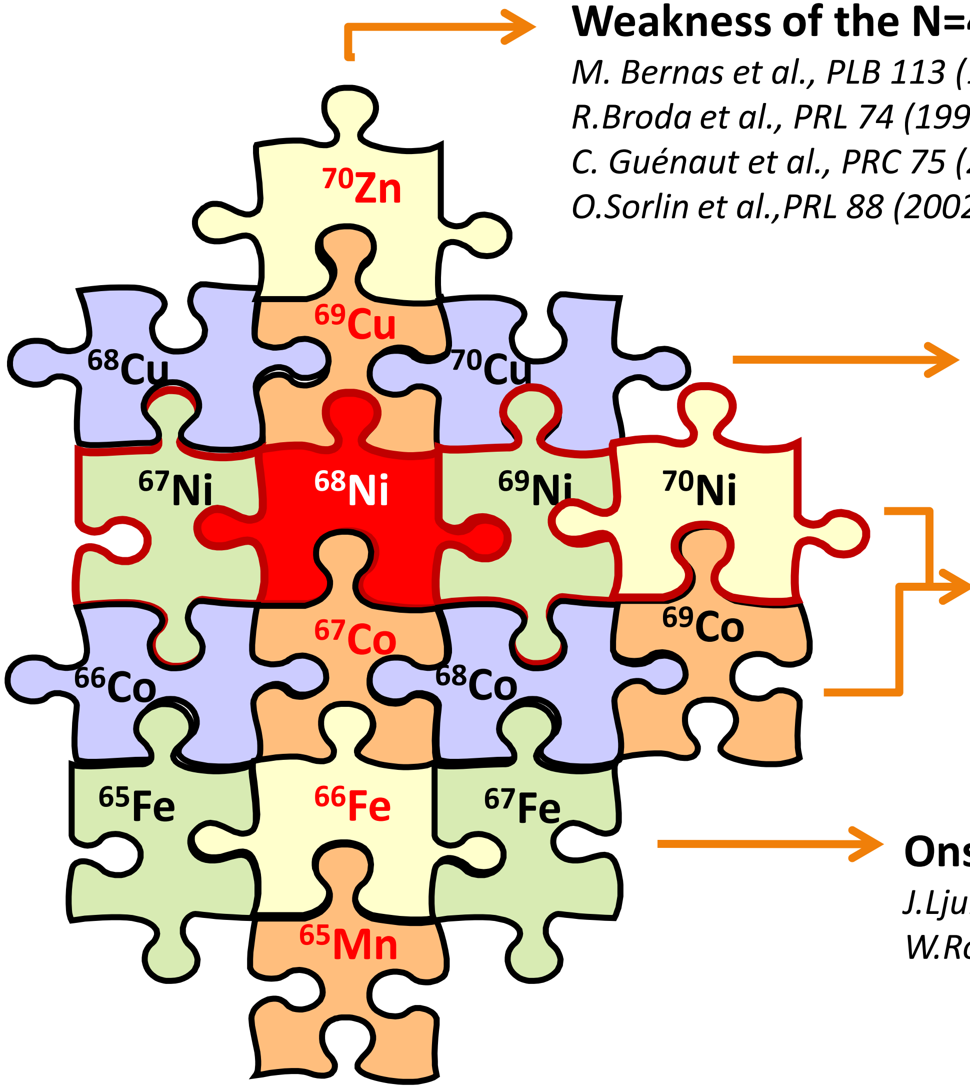
GANIL

European Gamma and Ancillary detectors Network
EGAN 2011 Workshop
Padova, 27-30 June

Introduction:



Weakness of the N=40 shell gap

M. Bernas et al., PLB 113 (1982)
R.Broda et al., PRL 74 (1995)
C. Guénaut et al., PRC 75 (2007)
O.Sorlin et al.,PRL 88 (2002)

Presence of single particle, collective and core-coupled states.

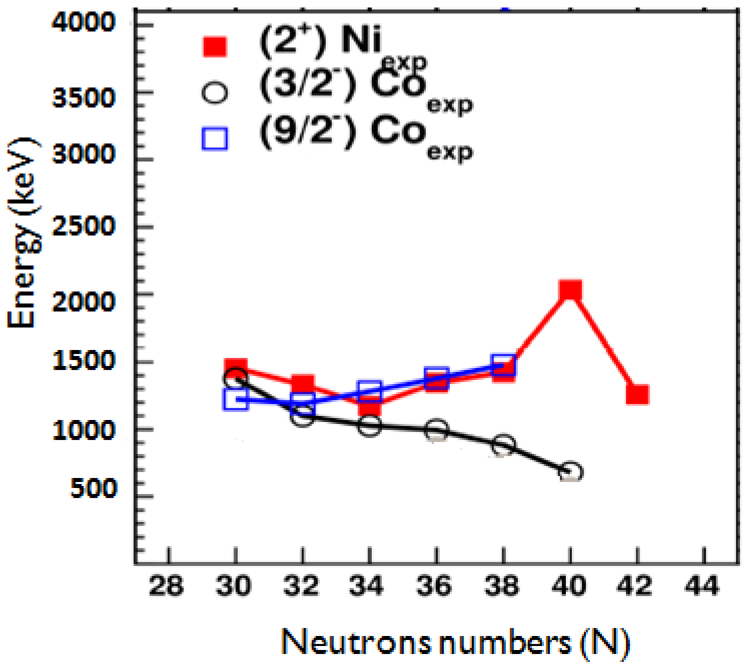
I.Stefanescu et al., PRL 100 (2008)

????

Onset of deformation in Fe isotopes

J.Ljungvall et al., PRC 81 (2010)
W.Rother et al., PRL 106 (2011)

Core-coupled states in cobalt isotopes ? :



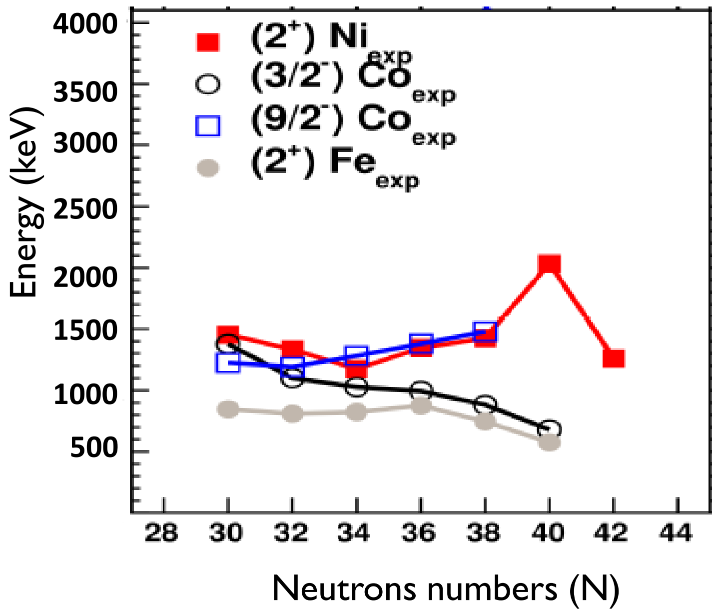
D.Pauwels et al., PRC 79, 2009

$$E(2^+, Ni) \simeq E(9/2^-, Co)$$

$$|7/2^- \ (Co) > \ \simeq \ |(1\pi f_{7/2})^{-1} > \otimes |0^+ \ (Ni) >$$

$$|9/2^- \ (Co) > \ \simeq \ |(1\pi f_{7/2})^{-1} > \otimes |2^+ \ (Ni) >$$

Core-coupled states in cobalt isotopes ? :



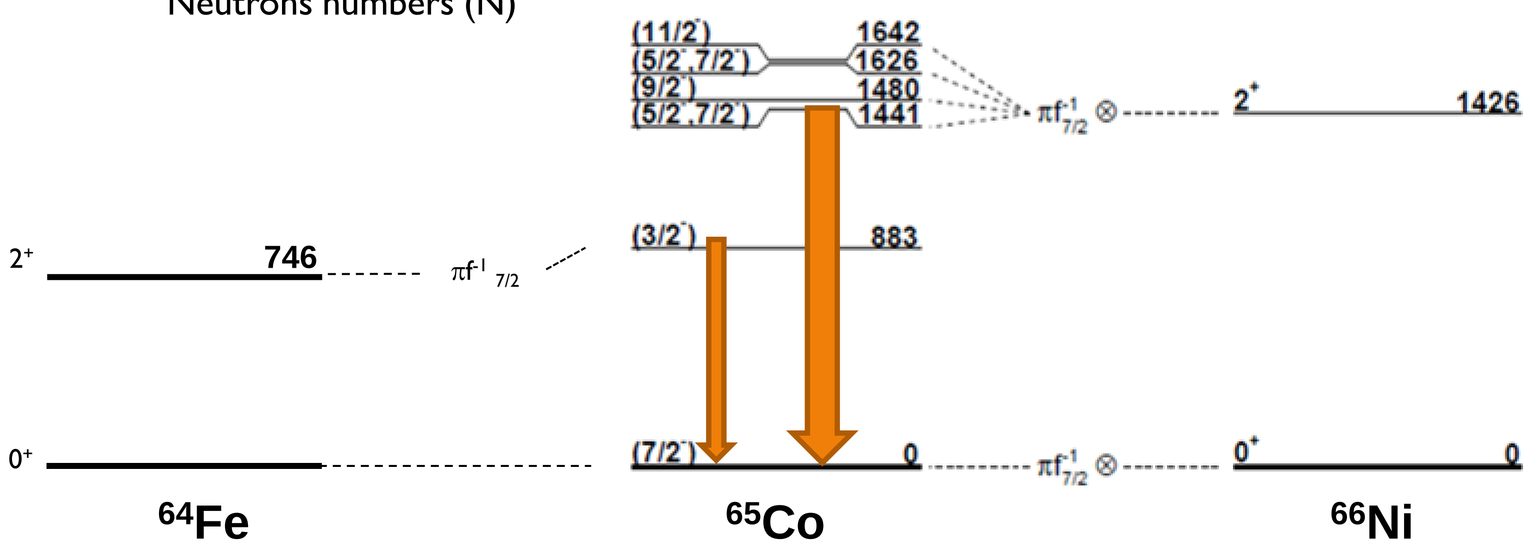
$$E(2^+, Ni) \simeq E(9/2^-, Co)$$

$$E(2^+, Fe) \simeq E(3/2^-, Co)$$

$$|7/2^- \ (Co) > \ \simeq \ |(1\pi f_{7/2})^{-1} > \otimes |0^+ \ (Ni) >$$

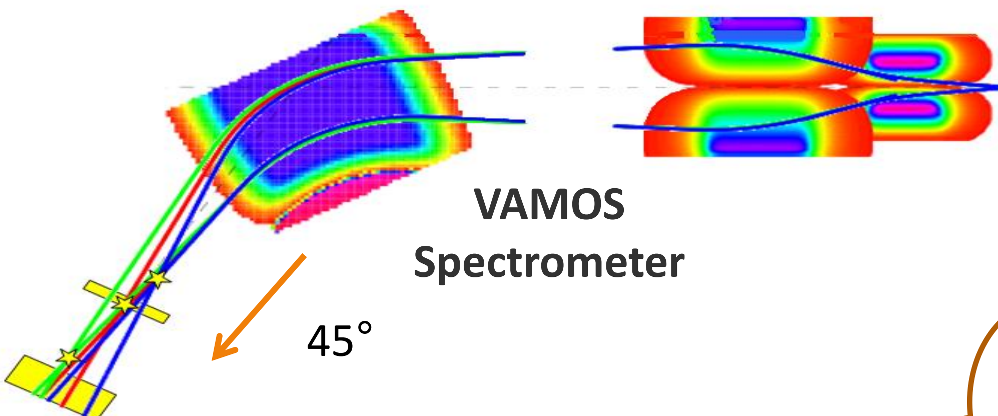
$$|9/2^- \ (Co) > \ \simeq \ |(1\pi f_{7/2})^{-1} > \otimes |2^+ \ (Ni) >$$

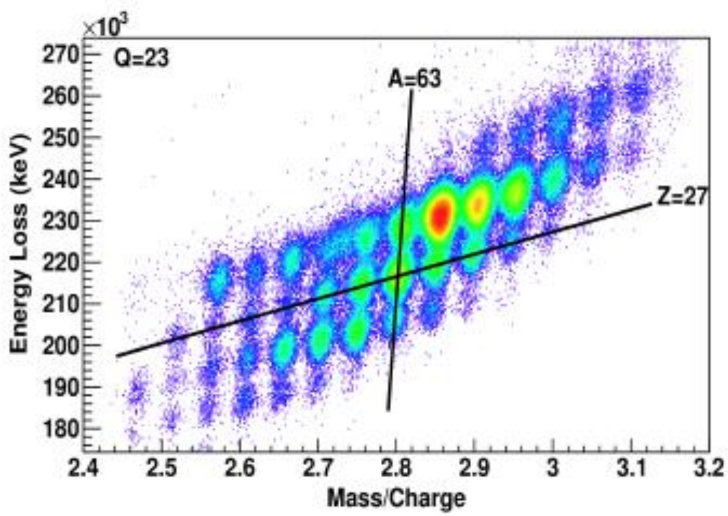
$$|3/2^- \ (Co) > \ \simeq \ |(1\pi f_{7/2}) > \ \otimes |2^+ \ (Fe) >$$



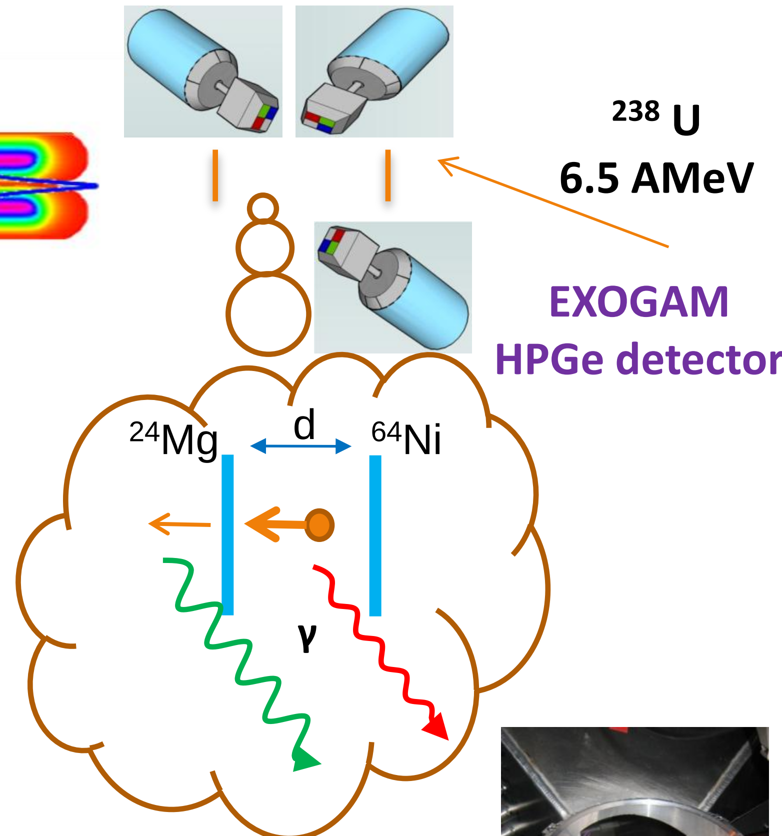
First experiment :
Lifetime measurement in $^{63,65}Co$

Reconstruction and identification of reaction products



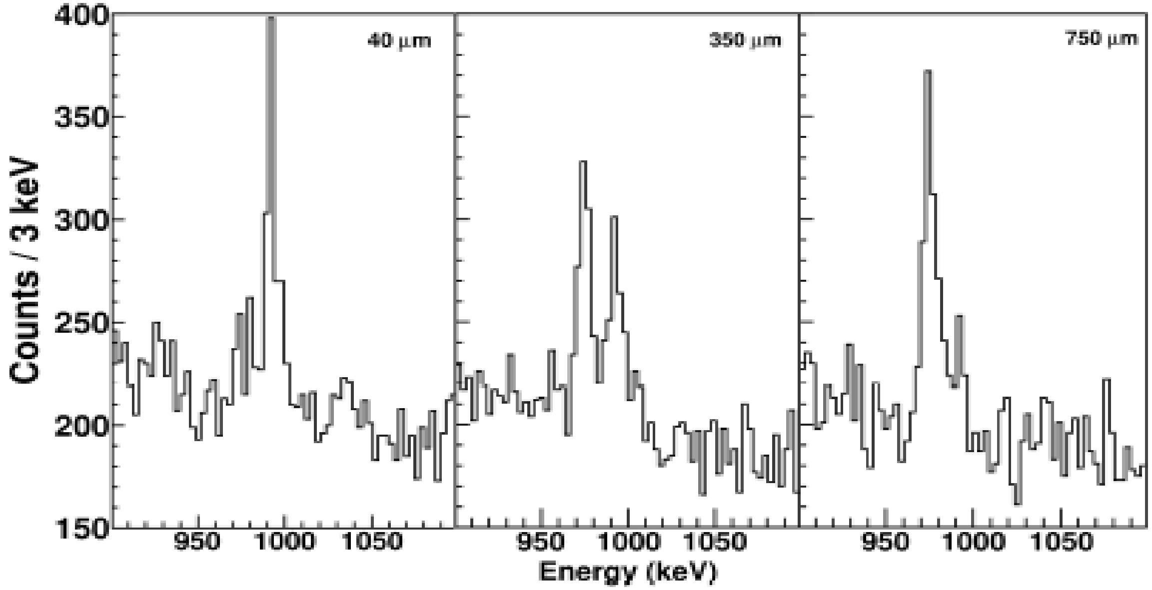


Identification of prompt gamma rays



Koeln plunger device

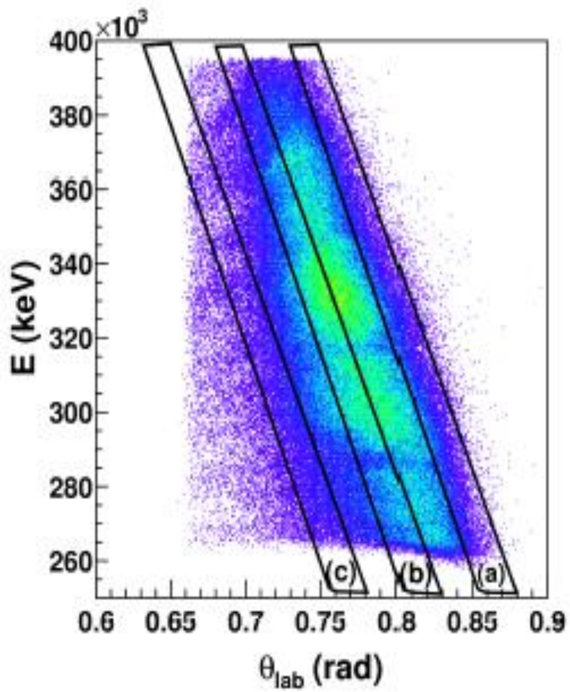
Lifetime measurement in ^{63,65}Co

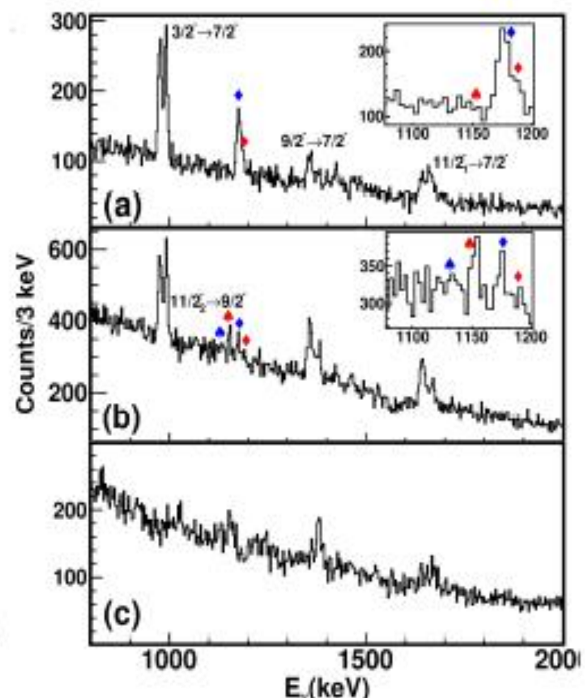


Transition Fe-like
$3/2^- \rightarrow 7/2^-$

→ simple extraction of the lifetime

$T_{1/2}$=15.4 (18)ps
B(E2)= 3.71(43) W.u





Transition Ni-like
$9/2^- \rightarrow 7/2^-$

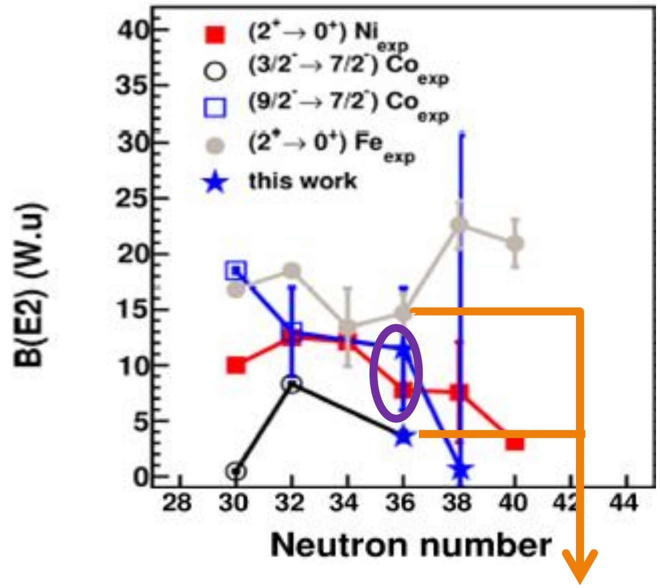
→ lifetime extracted by selection in excitation energy

$T_{1/2}$=0.9 (4)ps
B(E2)= 12.2(54) W.u

A. Dijon *et al,. PRC 83 (2011)*

Lifetime measurement in ^{63,65}Co

A. Dijon *et al.*, *PRC 83 (2011)*



B(E2; 3/2$^-$→7/2$^-$) in ^{63}Co << B(E2; 2$^+$→0$^+$) in Fe

B(E2; 9/2$^-$→7/2$^-$) in ^{63}Co compatible with the B(E2; 2$^+$→0$^+$) in ^{64}Ni

→ The core coupled model still valid at N=36 is consistent with this scenario :

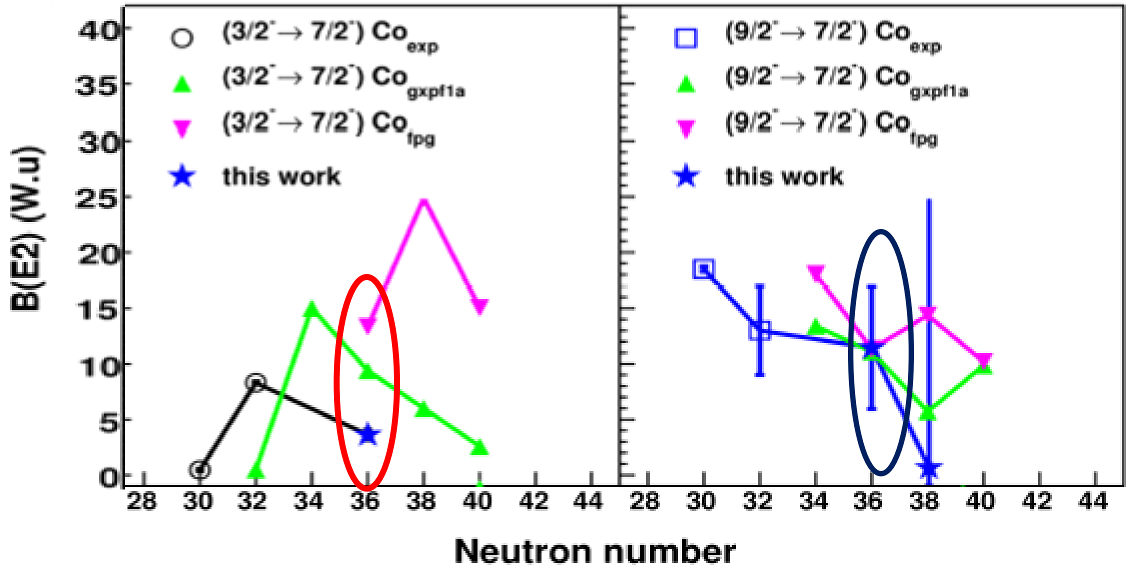
$$|7/2^- \ (Co)> \ \simeq \ |(1\pi f_{7/2})^{-1}> \otimes |0^+ \ (Ni)>$$

$$|9/2^- \ (Co)> \ \simeq \ |(1\pi f_{7/2})^{-1}> \otimes |2^+ \ (Ni)>$$

$$|3/2^- \ (Co)> \ \simeq \ |(1\pi f_{7/2})> \ \otimes |2^+ \ (Fe)>$$

Lifetime measurement in $^{63,65}Co$

A. Dijon *et al.*, *PRC 83 (2011)*



**Antoine code gxpf1a and fpg interactions*

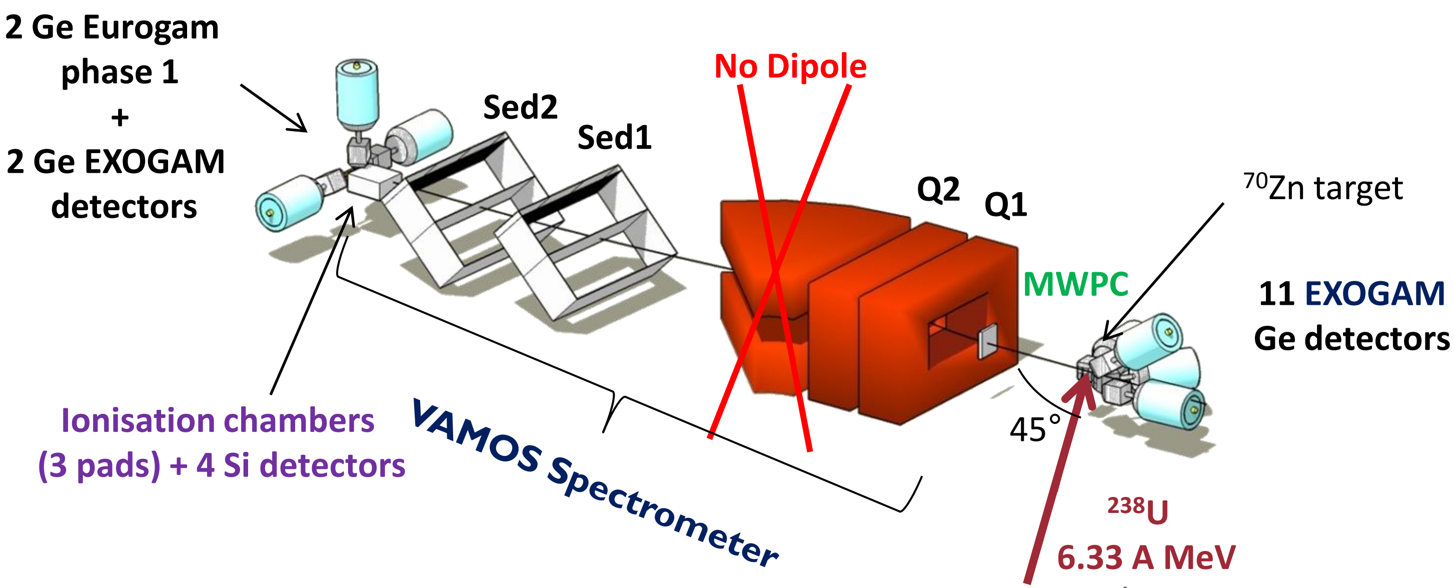
Theoretical B(E2; 9/2⁻→7/2⁻) = Experimental B(E2; 9/2⁻→7/2⁻)

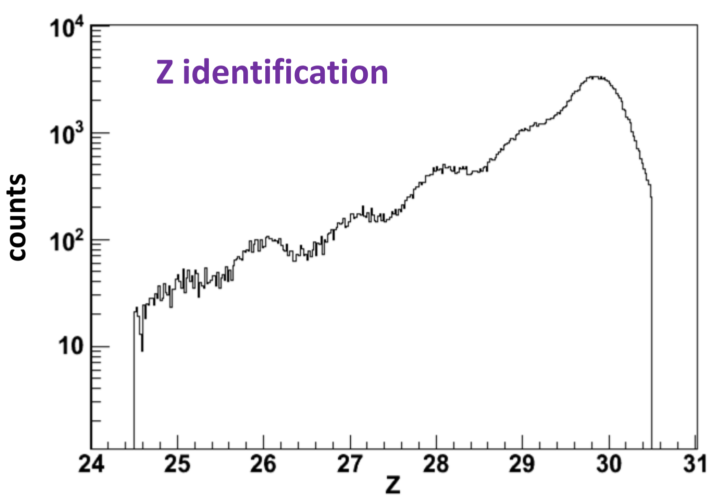
Theoretical lifetime a factor 10 lower →high value of B(M1)

B(E2; 3/2⁻→7/2⁻) not reproduced by the shell model calculations*

→ Attribute to a fragmentation of the wave function in our calculation.

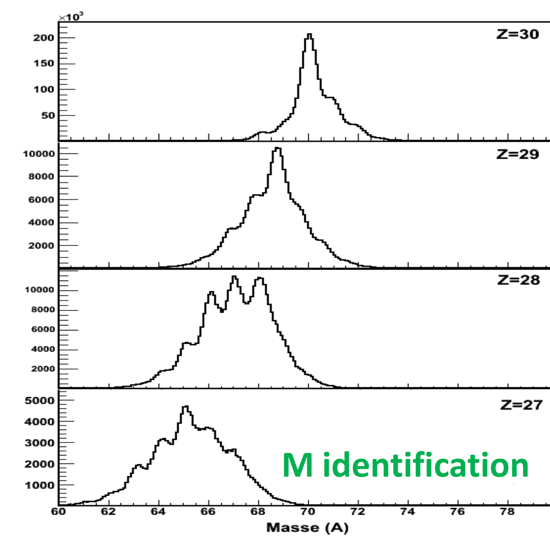
Second Experiment :
Prompt and delayed γ-ray spectroscopy





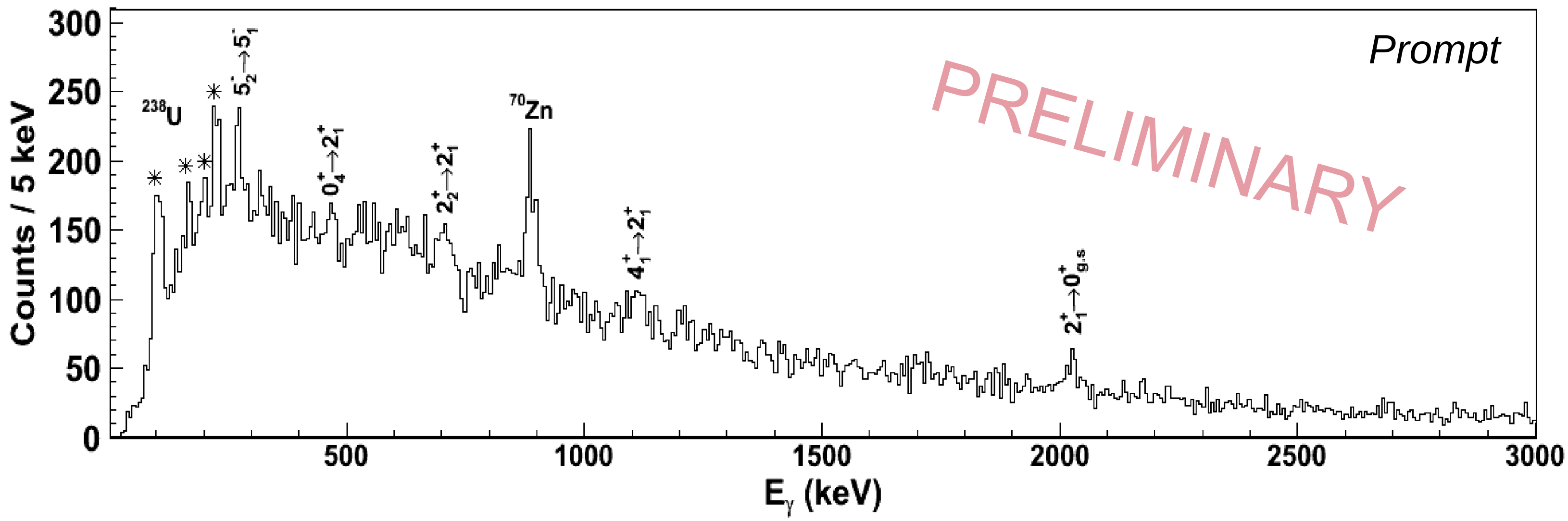
ΔM/M=1.2%

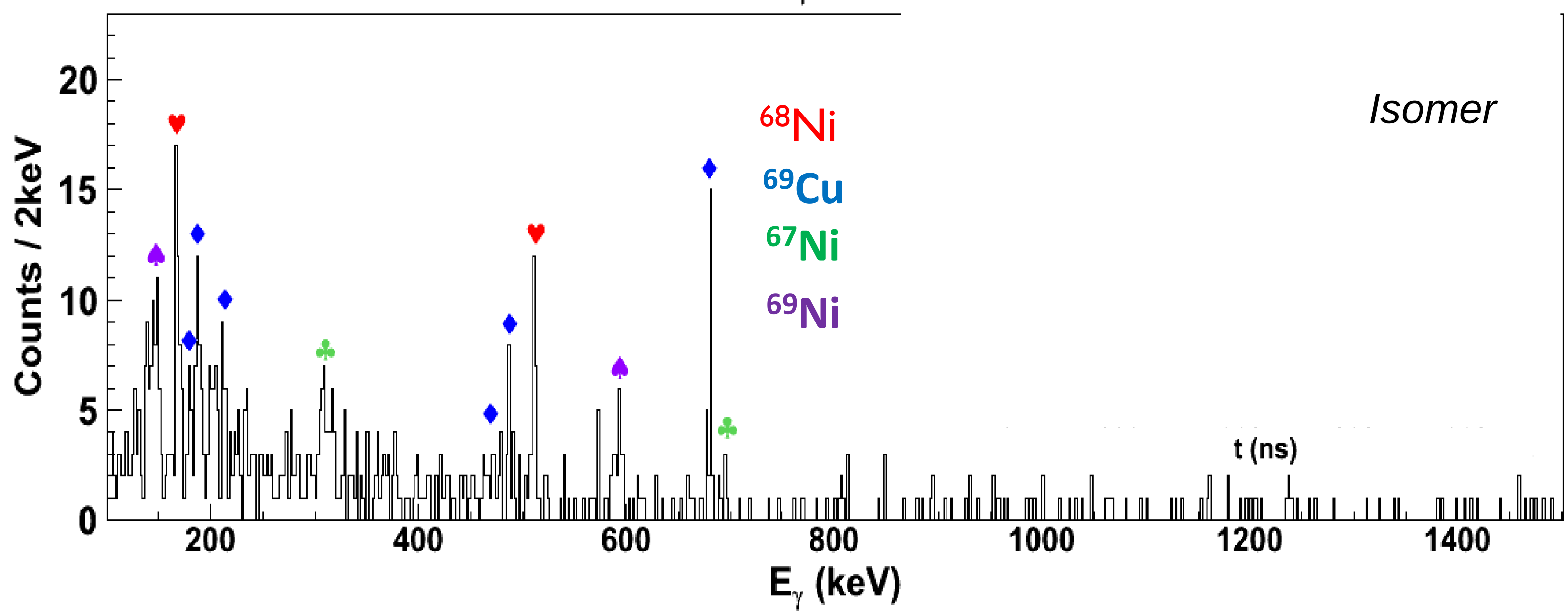
ΔZ/Z =1.1%



π(2p-2h) intruder state in ^{68}Ni

A. Dijon, *et al, in preparation*





Prompt and delay γ-ray spectroscopy

π(2p-2h) intruder state in ^{68}Ni

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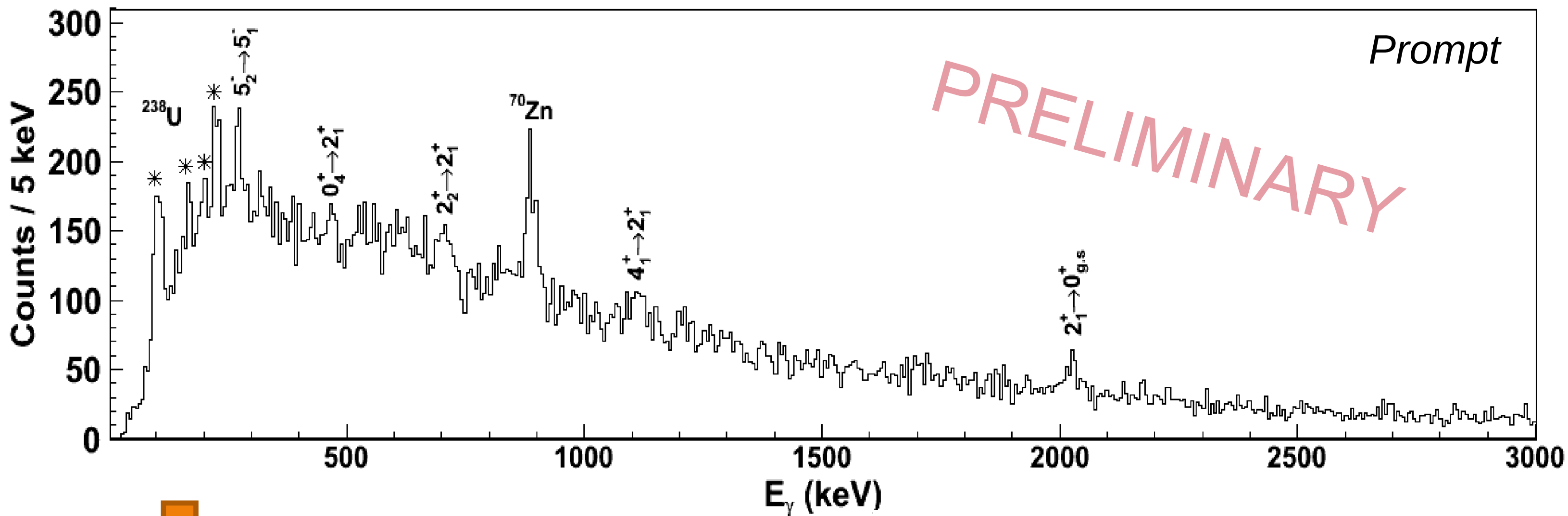
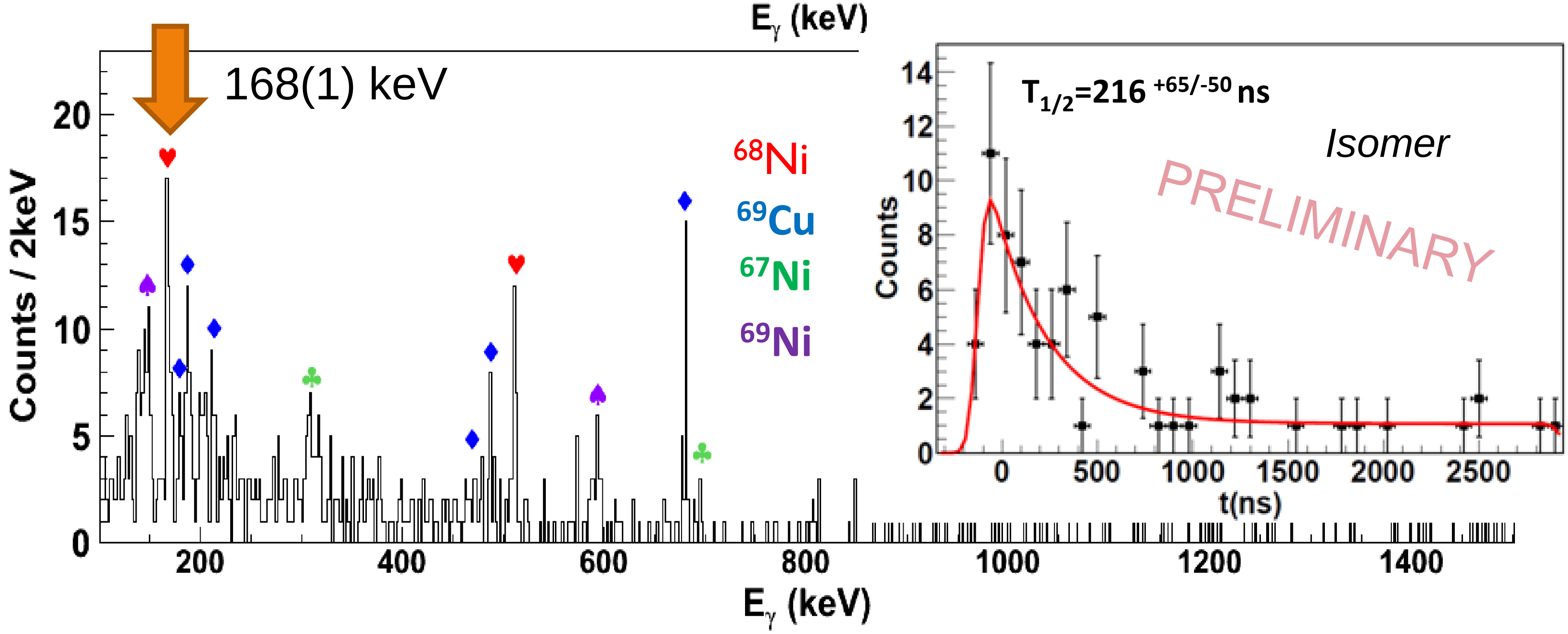
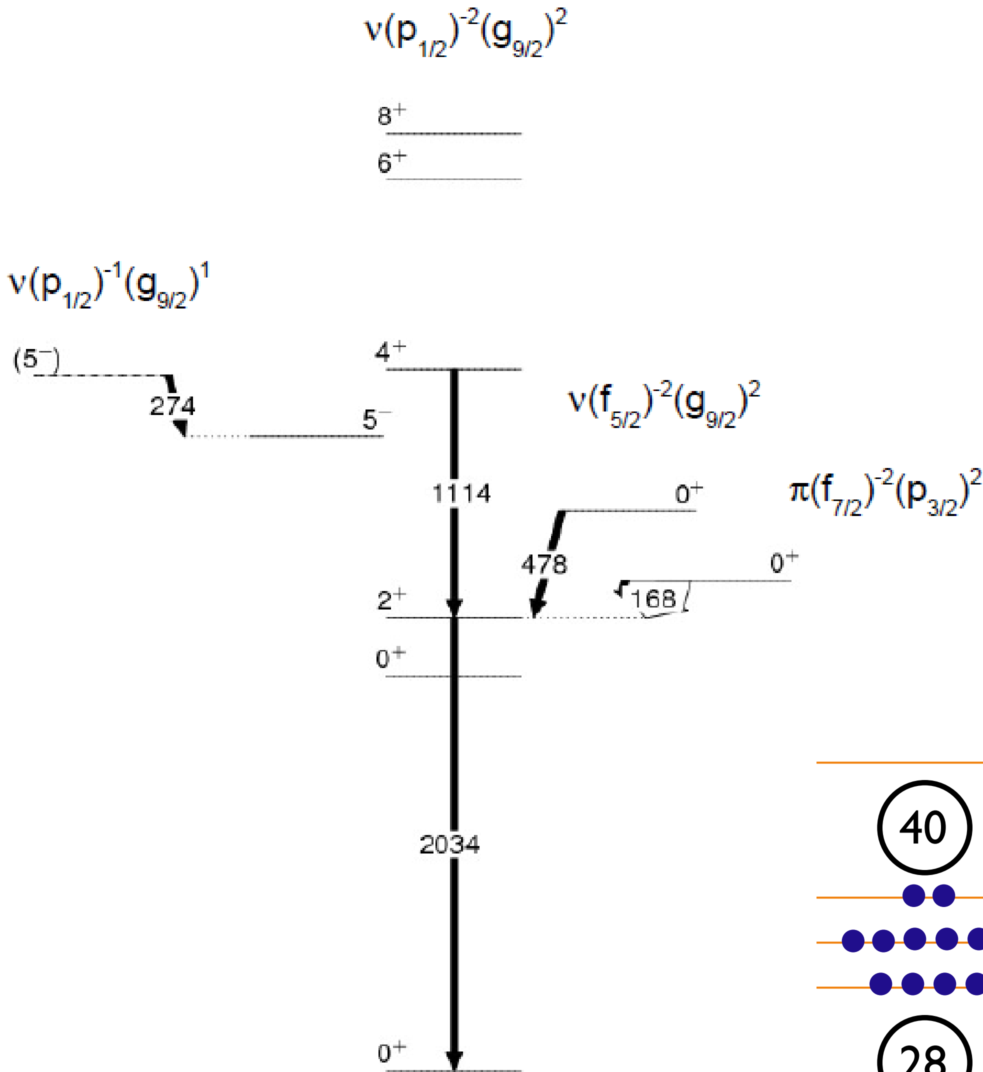
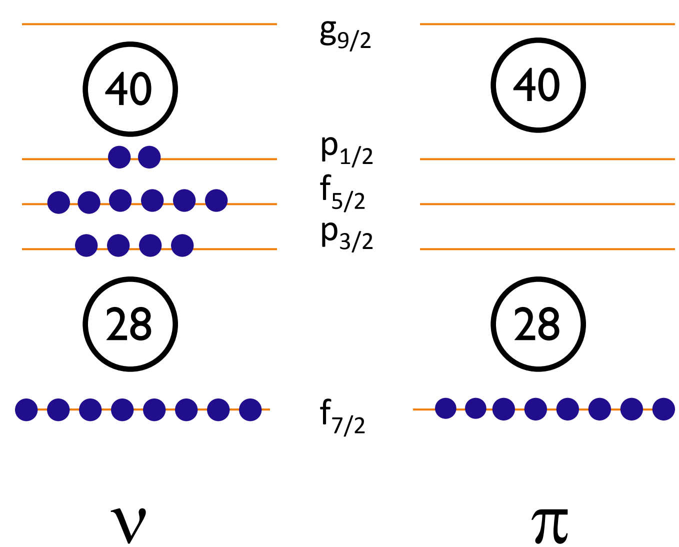




π(2p-2h) intruder state in ^{68}Ni
Preliminary Interpretation

A. Dijon, *et al, in preparation*





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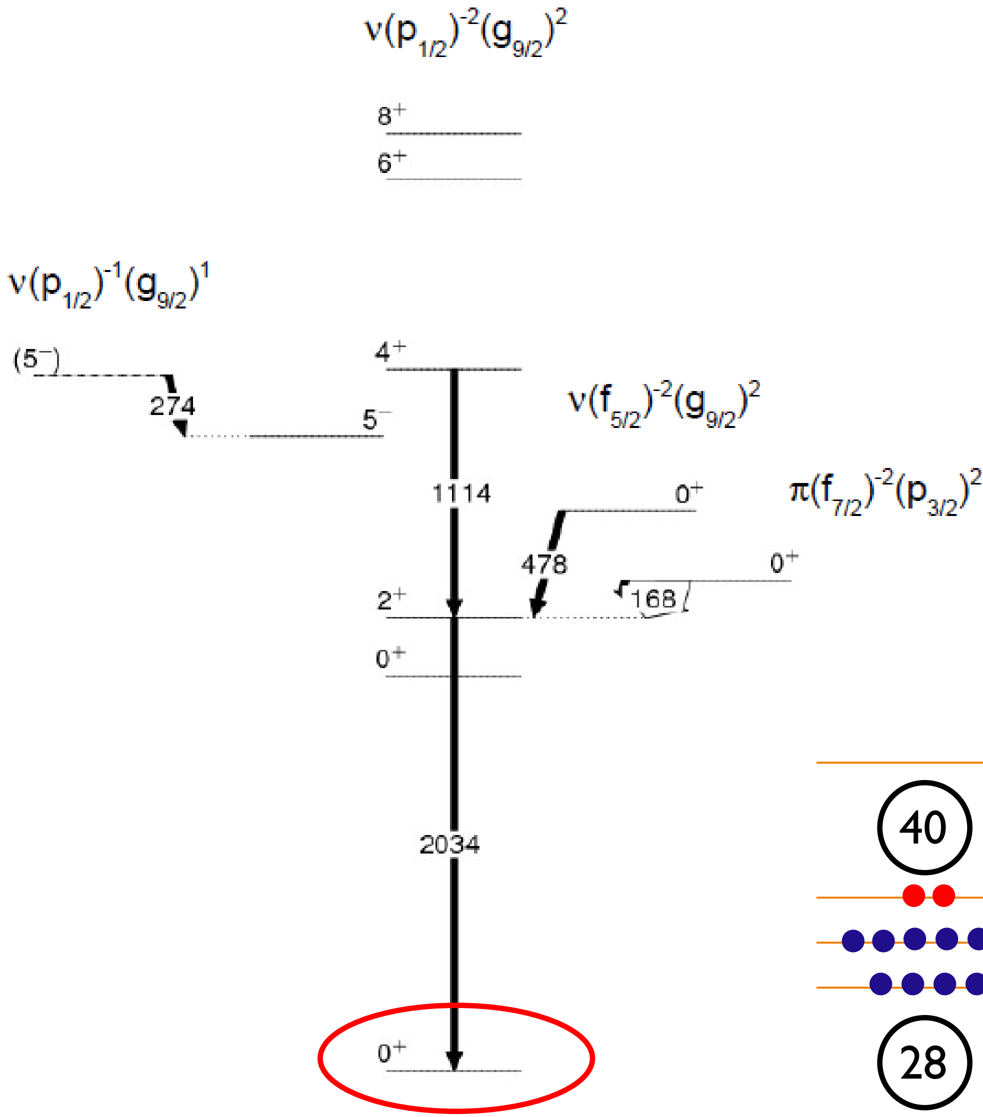
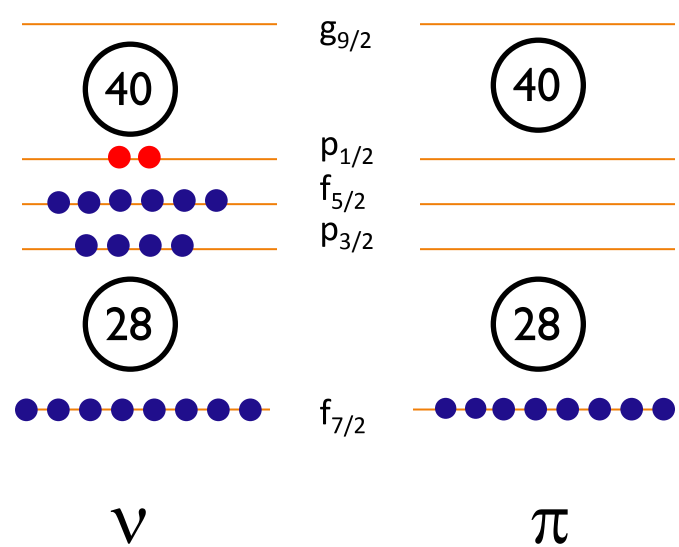
Preliminary Interpretation

A. Dijon, *et al, in preparation*

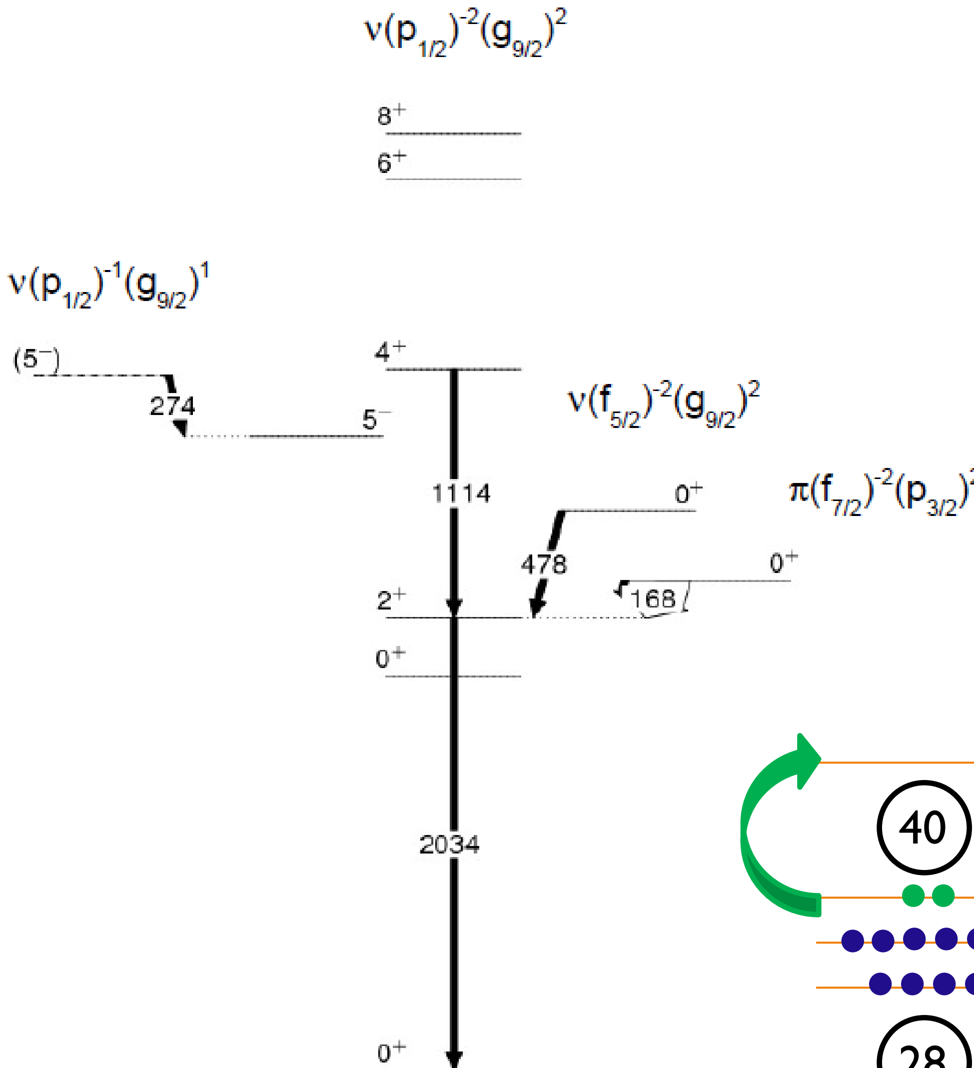


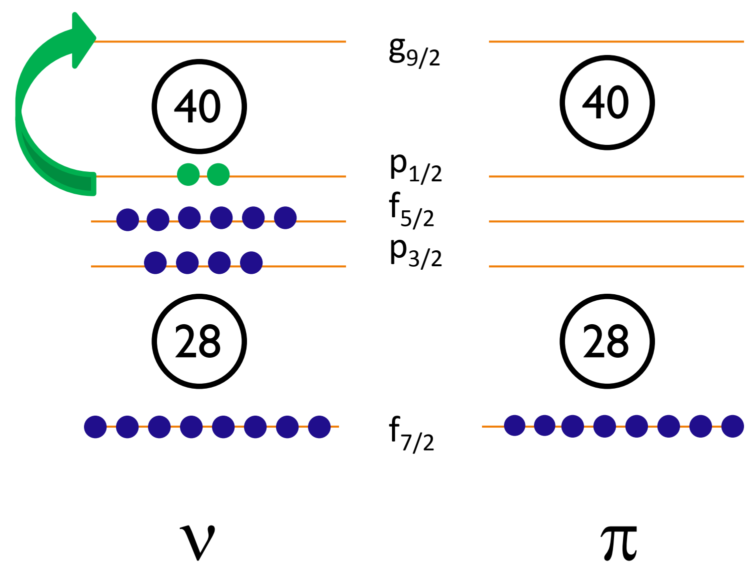


→ Ground state configuration

π(2p-2h) intruder state in ^{68}Ni
Preliminary Interpretation

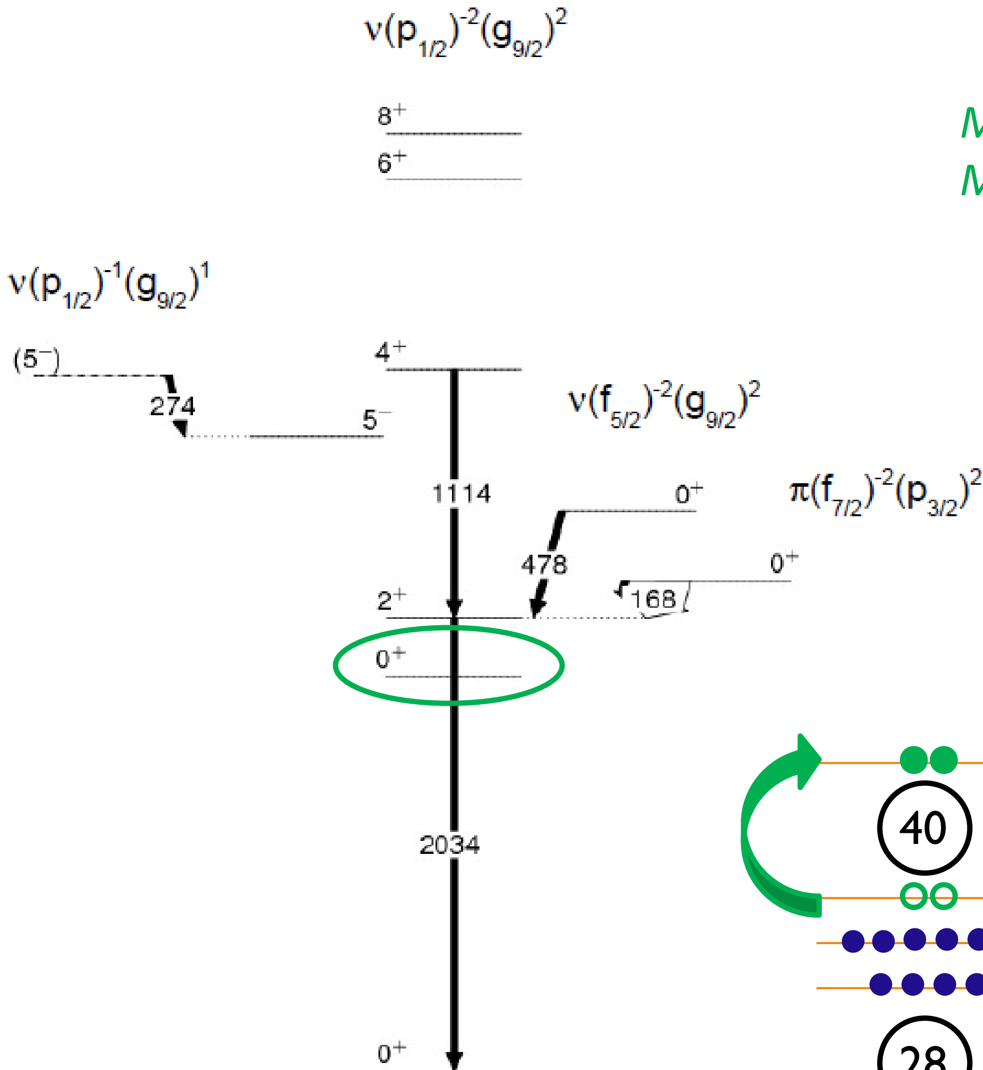
A. Dijon, *et al, in preparation*

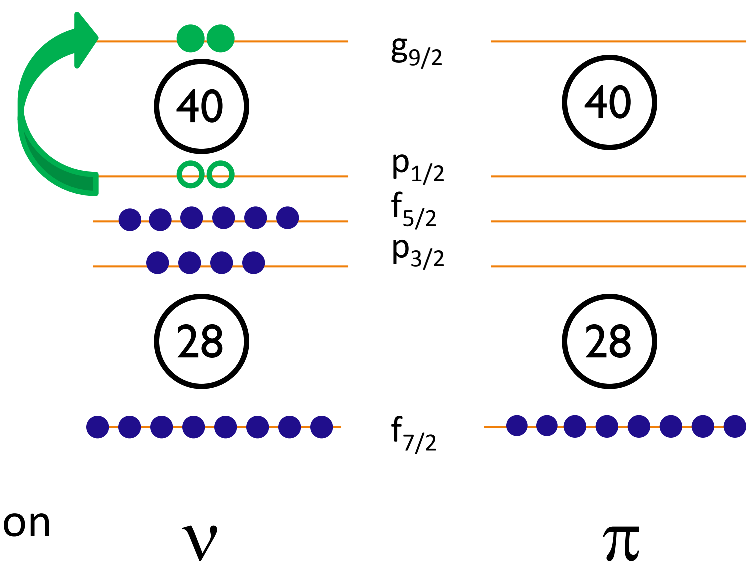




π(2p-2h) intruder state in ^{68}Ni
Preliminary Interpretation

M.Bernas et al., PLB 113 (1982)
M.Girod et al., PRC 37 (1988)

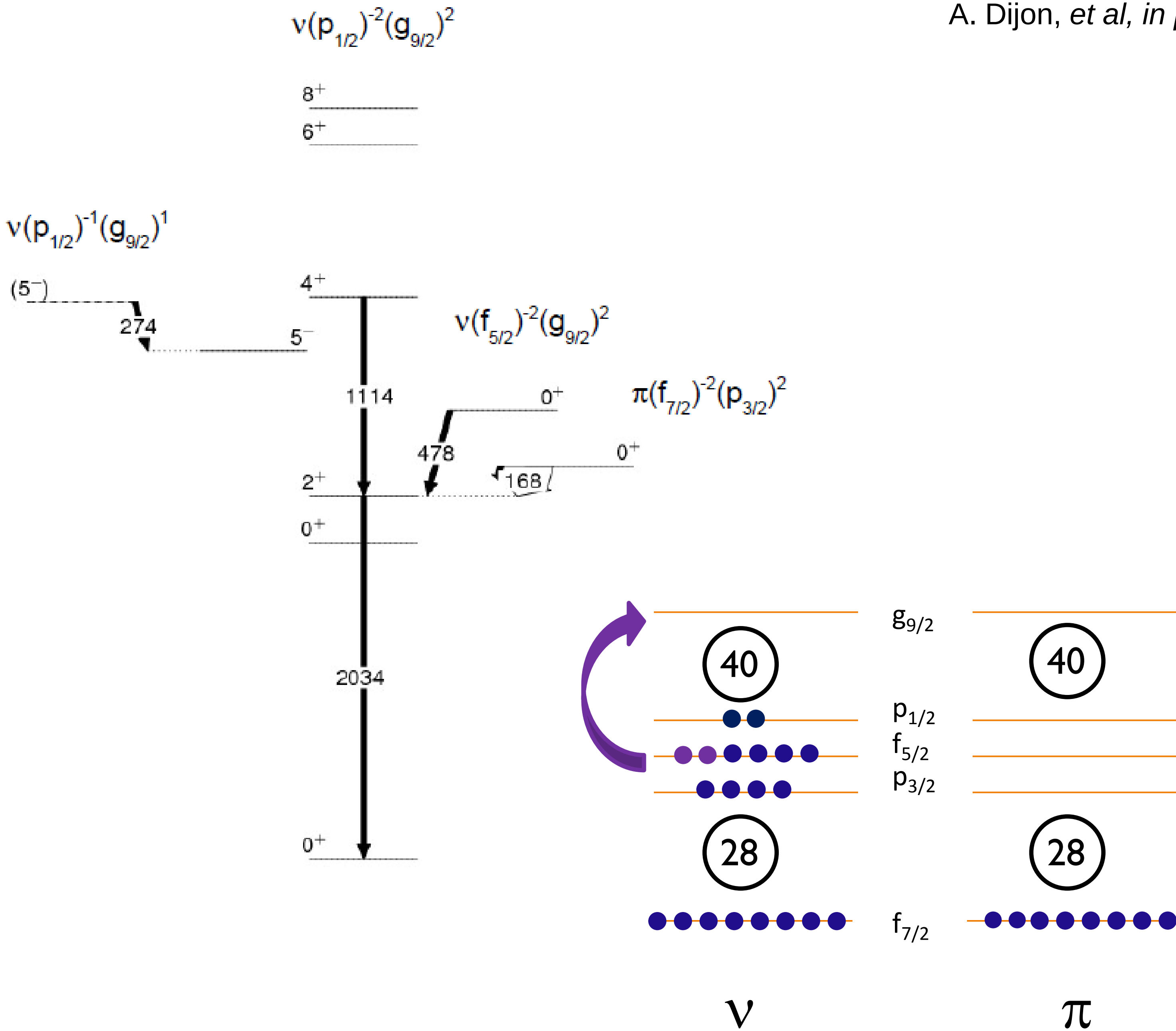




→First 0^+ excited state configuration

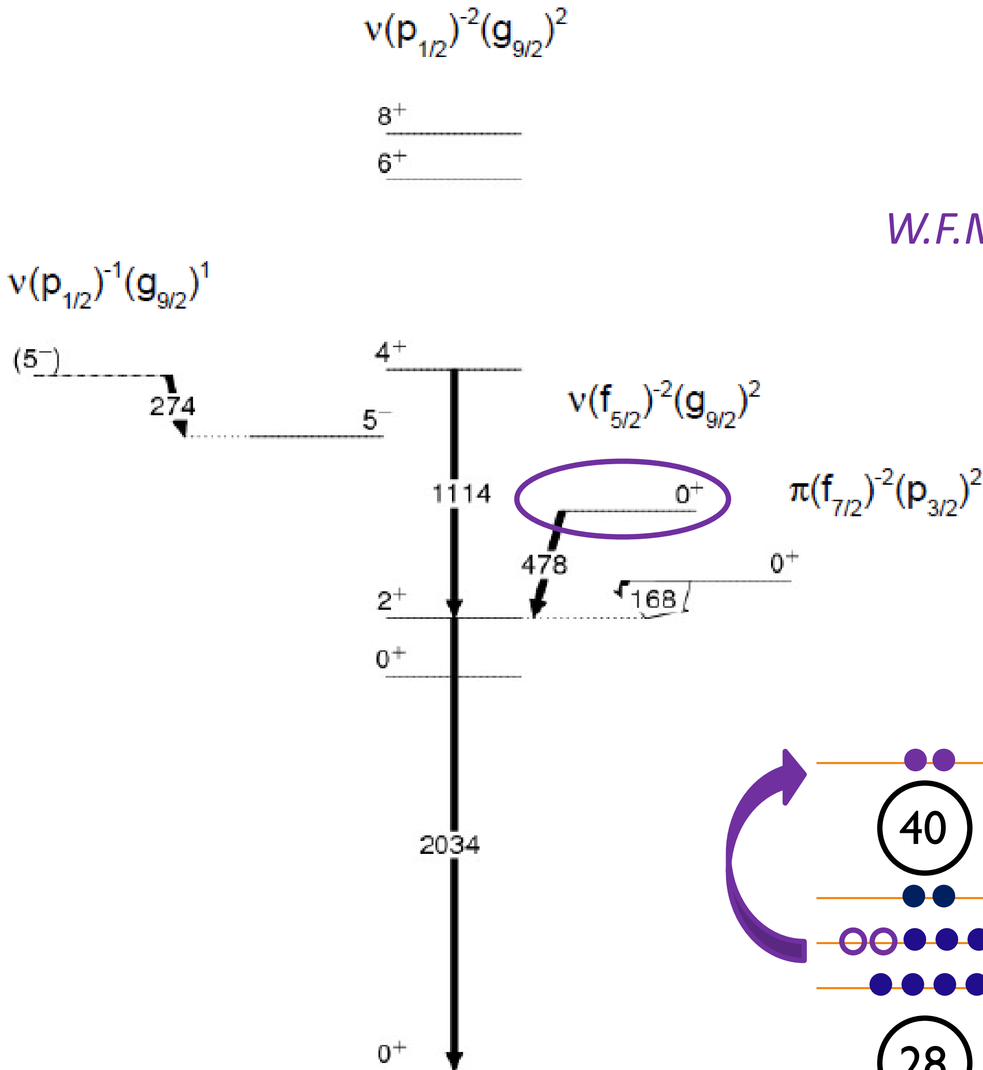
π(2p-2h) intruder state in ^{68}Ni
Preliminary Interpretation

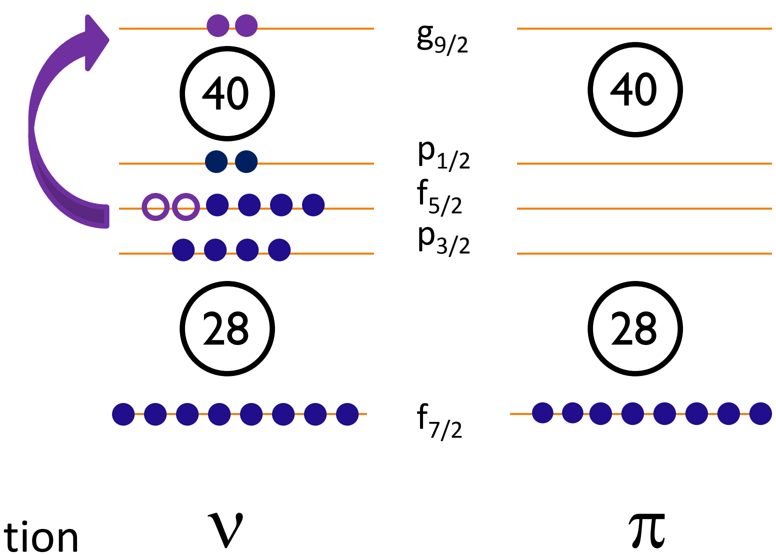
A. Dijon, et al, in preparation



π(2p-2h) intruder state in ^{68}Ni
Preliminary Interpretation

W.F.Mueller et al., PRC 61 (2000)

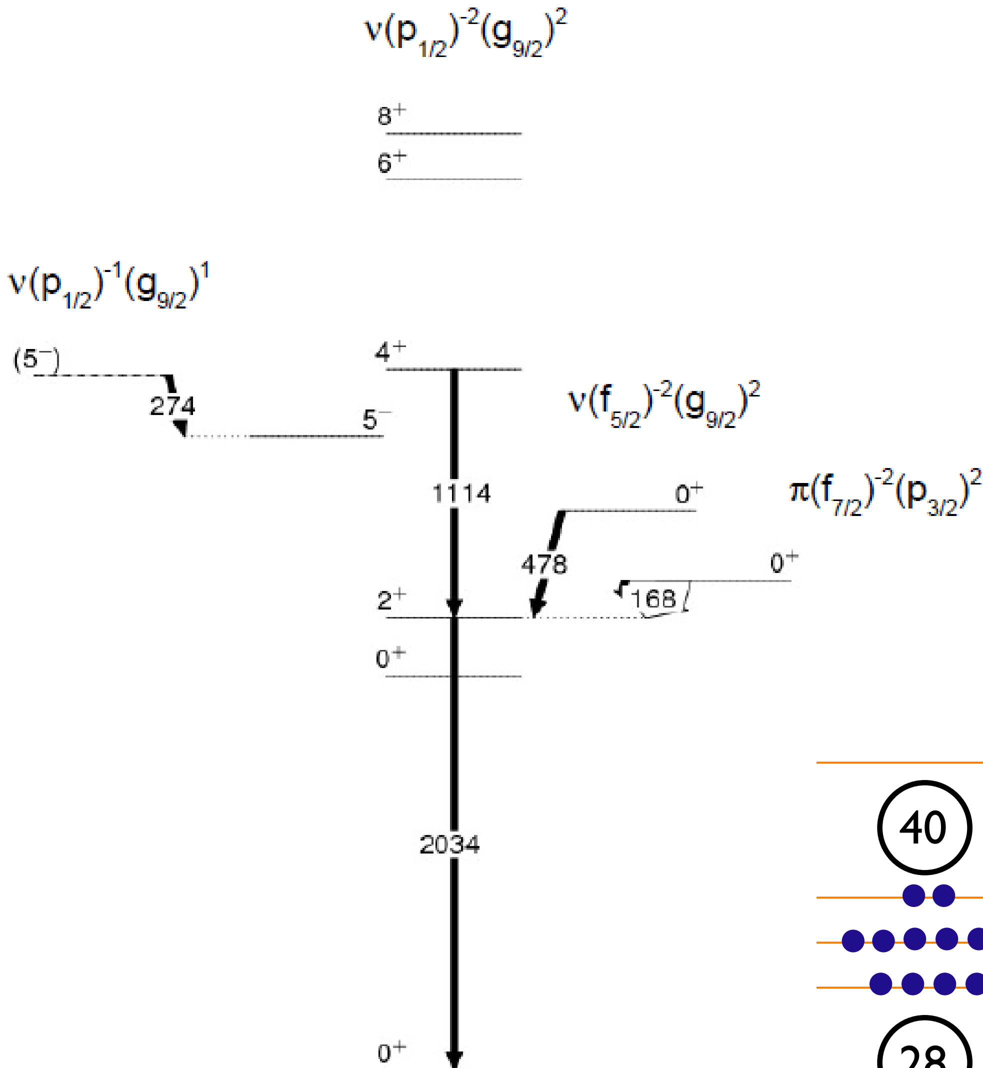


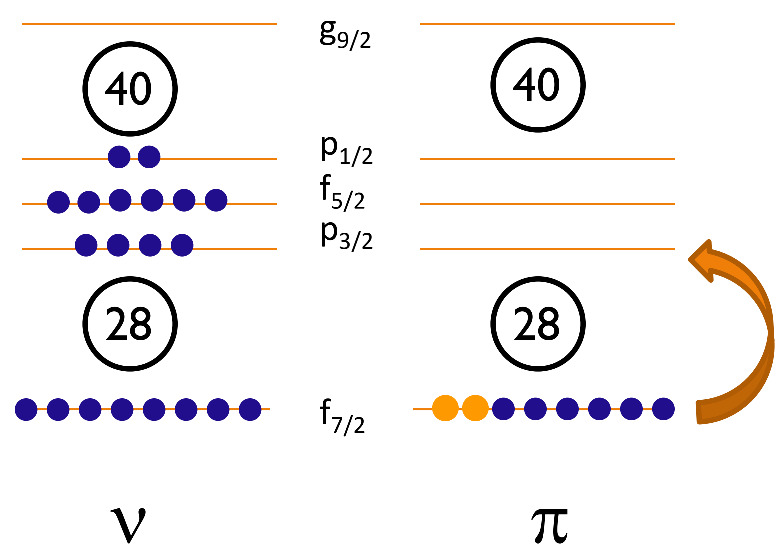


→Third 0+ excited state configuration

π(2p-2h) intruder state in ^{68}Ni
Preliminary Interpretation

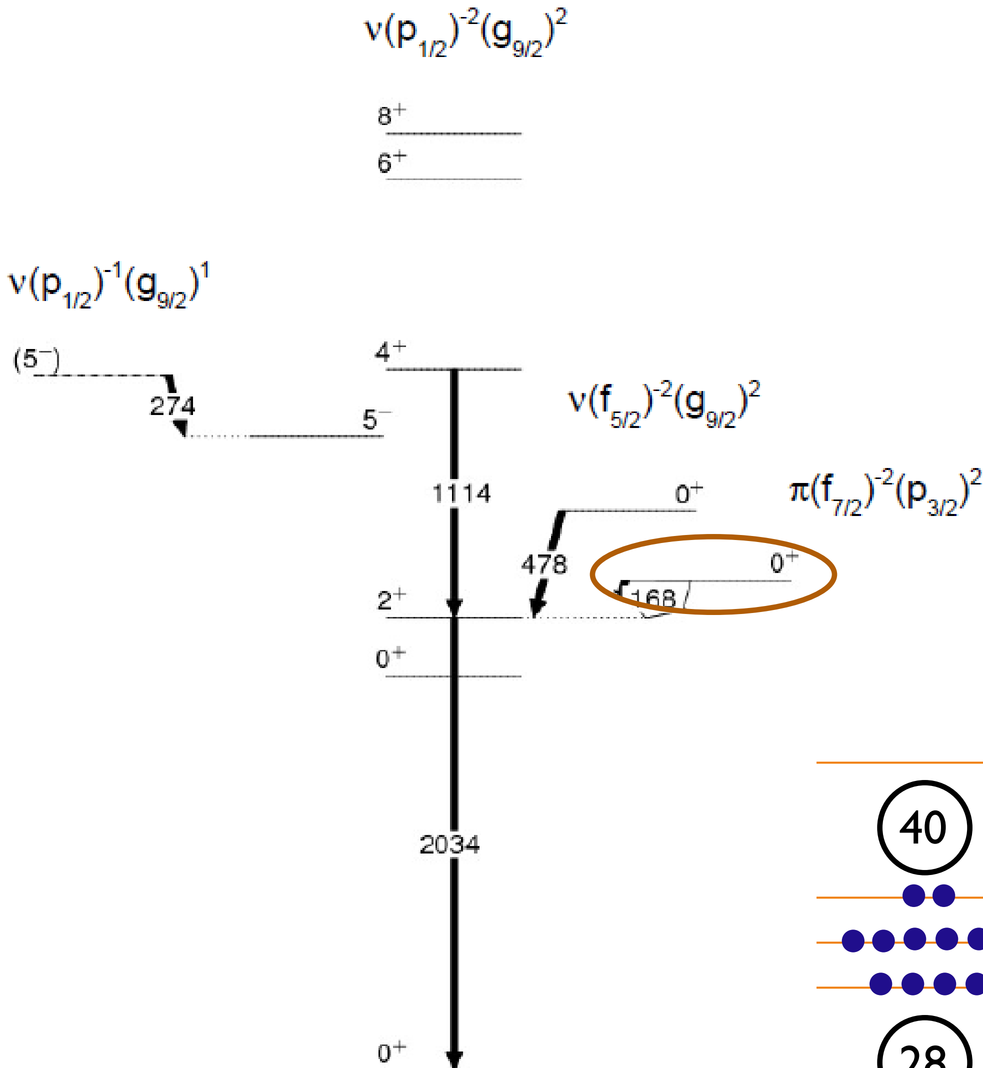
A. Dijon, *et al, in preparation*

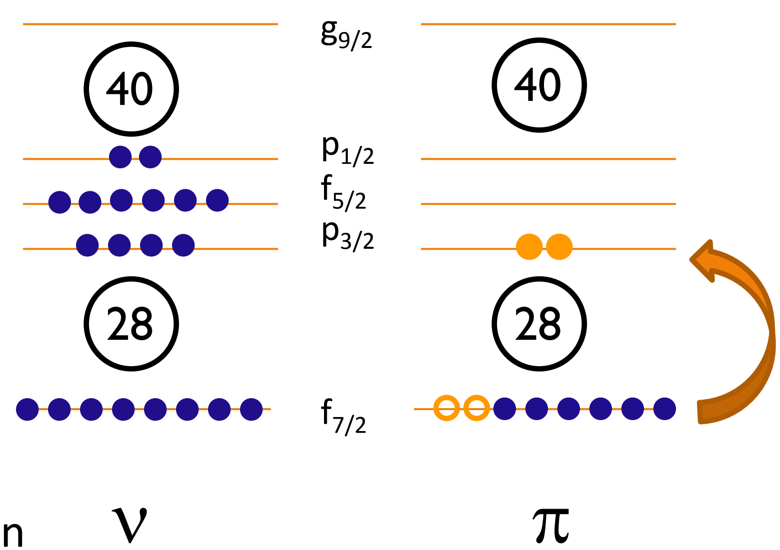




π(2p-2h) intruder state in ^{68}Ni
Preliminary Interpretation

A. Dijon, *et al, in preparation*

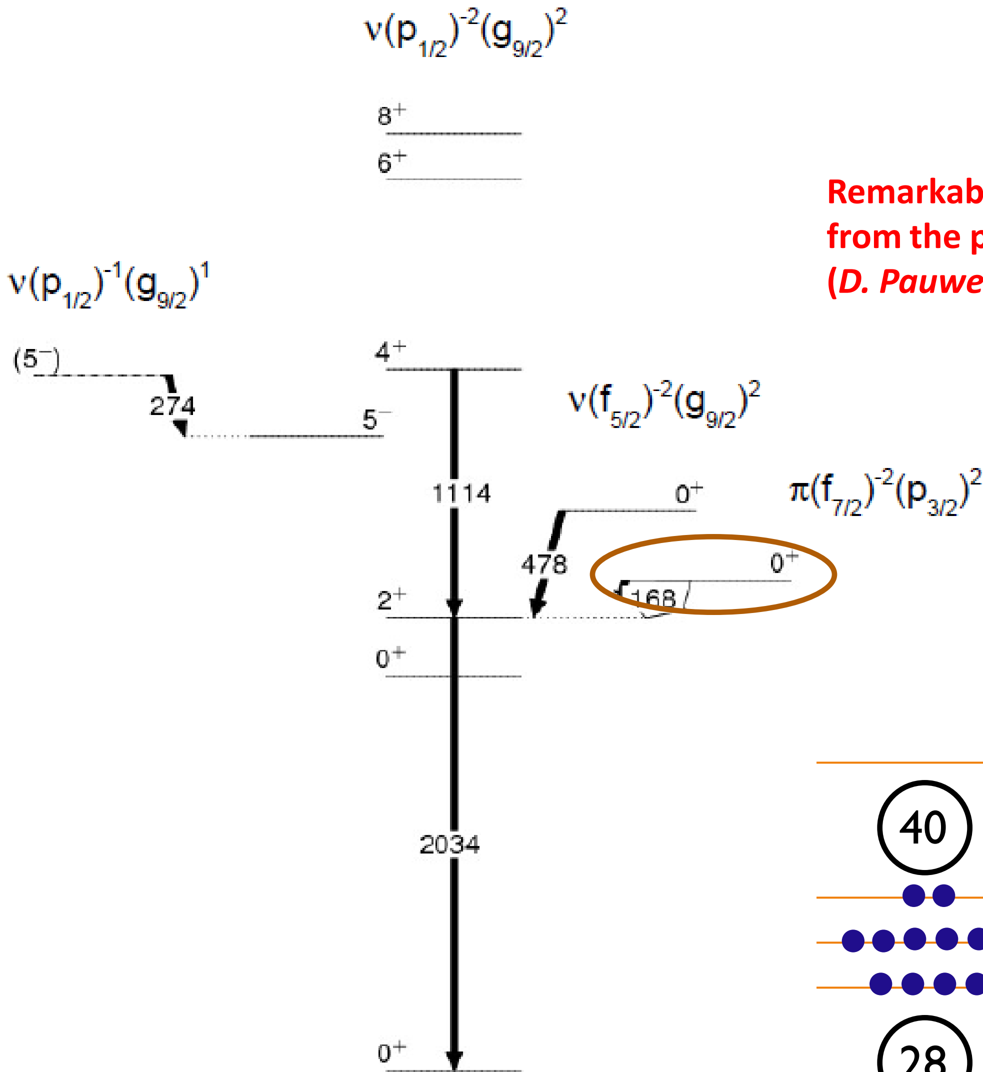




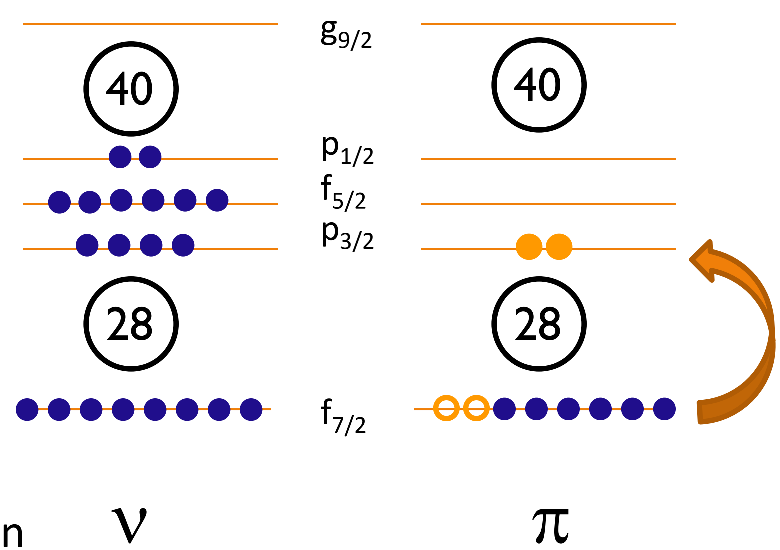
→Second 0⁺ excited state configuration

π(2p-2h) intruder state in ^{68}Ni
Preliminary Interpretation

A. Dijon, *et al, in preparation*



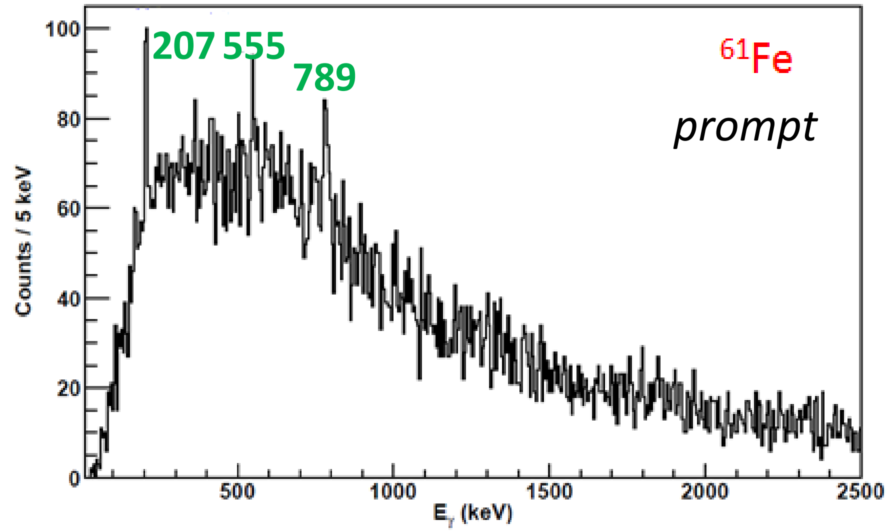
Remarkable agreement with the predicted position from the p(1p-2h) in ^{67}Co and p(2p-1h) in ^{69}Cu (*D. Pauwels et al, PRC 82, 027304 (2010)*)

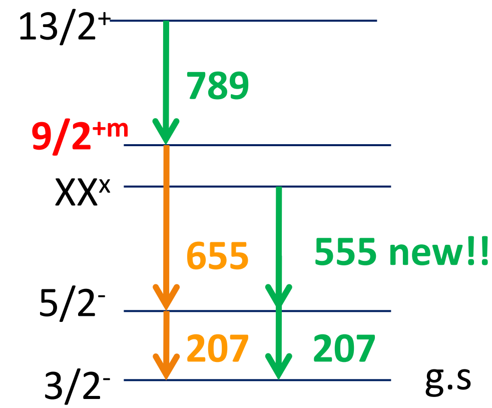


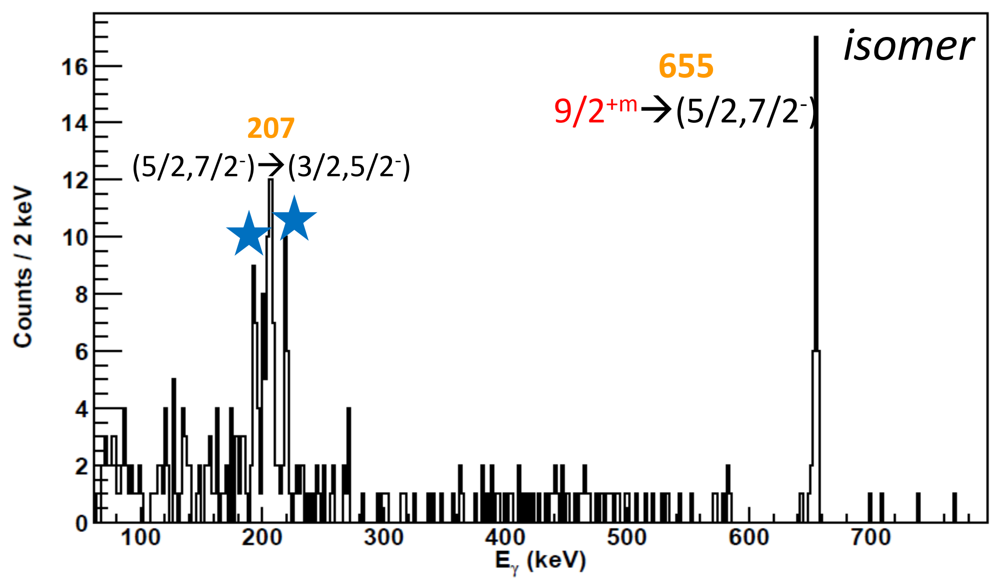
→Second 0^+ excited state configuration

Prompt and delay γ-ray spectroscopy

Others preliminary results :







Isomer 9/2$^+$:

$T_{1/2}$= 233 (17) ns

$T_{1/2}$= 250 (10) ns (NNDC)

… systematic up to ^{67}Fe….

A. Dijon, *et al, in preparation (2)*

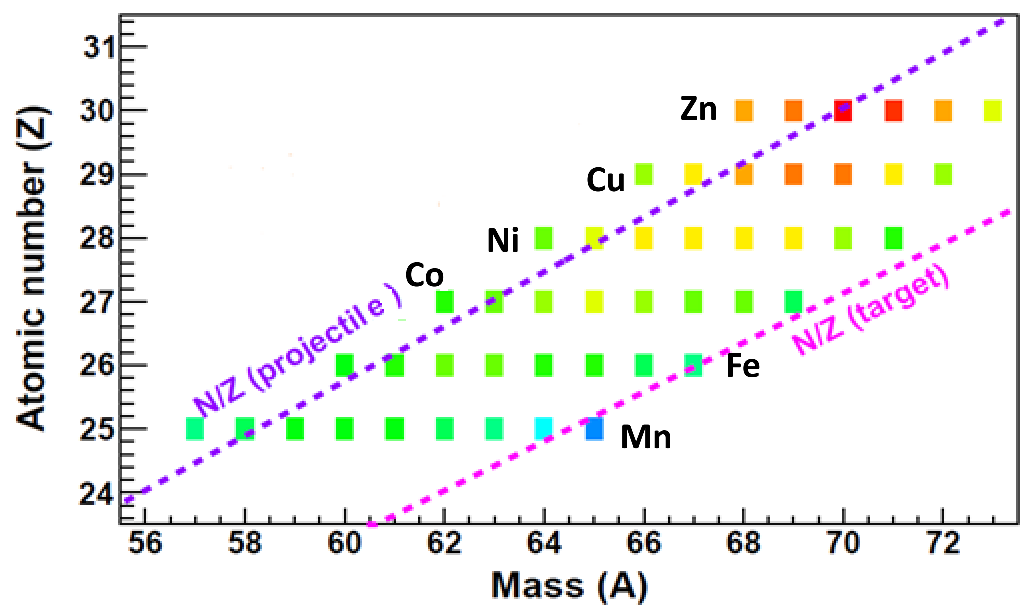
Conclusion and perspectives

Lifetime measurement in ^{63,65}Co have shown :

- ❑ 9/2$^-$ and 3/2$^-$ states in Co agree with the core-coupled model up to N=36.
- ❑ Comparisons with SM underline a too much fragmented wave function.

Isomer spectroscopy :

- ❑ Observation of the 2p-2h proton intruder state in ^{68}Ni in perfect agreement with the predicted position from the p(1p-2h) in ^{67}Co and p(2p-1h) in ^{69}Cu
  →Shape isomer in ^{68}Ni ?
- ❑ New γ prompt and isomer?



… to be continued …

Collaboration

PHYSICAL REVIEW C **83**, 064321 (2011)

Lifetime measurements in ^{63}Co and ^{65}Co

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(Received 28 February 2011; published 21 June 2011)

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(Dated: May 19, 2011)

Fragmentation of the wave function in our calculation :

- **Experimental scenario of the wave function :**

$$|7/2_1^-(\mathrm{Co})\rangle \approx |(1\pi f_{7/2})^{-1} \times 0_1^+(\mathrm{Ni}); 7/2\rangle,$$

$$|9/2_1^-(\mathrm{Co})\rangle \approx |(1\pi f_{7/2})^{-1} \times 2_1^+(\mathrm{Ni}); 9/2\rangle,$$

$$|3/2_1^-(\mathrm{Co})\rangle \approx |1\pi f_{7/2} \times 2_1^+(\mathrm{Fe}); 3/2\rangle,$$

- **Theoretical wave function :**

$$\begin{aligned}|7/2_1^-\rangle \approx\ & 0.62|(1\pi f_{7/2})^{-1} \times 0_1^+(\mathrm{Ni}); 7/2\rangle \\ & \pm 0.38|(1\pi f_{7/2})^{-1} \times 2_1^+(\mathrm{Ni}); 7/2\rangle \\ & \pm 0.23|(1\pi f_{7/2})^{-1} \times 2_2^+(\mathrm{Ni}); 7/2\rangle + \cdots,\end{aligned}$$

$$\begin{aligned}|9/2_1^-\rangle \approx\ & 0.61|(1\pi f_{7/2})^{-1} \times 2_1^+(\mathrm{Ni}); 9/2\rangle \\ & \pm 0.31|(1\pi f_{7/2})^{-1} \times 4_2^+(\mathrm{Ni}); 9/2\rangle \\ & \pm 0.25|(1\pi f_{7/2})^{-1} \times 2_2^+(\mathrm{Ni}); 9/2\rangle + \cdots,\end{aligned}$$

$$\begin{aligned}|3/2_1^-\rangle \approx\ & 0.55|1\pi p_{3/2} \times 0_1^+(\mathrm{Fe}); 3/2\rangle \\ & \pm 0.19|1\pi p_{3/2} \times 0_2^+(\mathrm{Fe}); 3/2\rangle \\ & \pm 0.18|1\pi p_{1/2} \times 2_2^+(\mathrm{Fe}); 3/2\rangle + \cdots.\end{aligned}$$

Fragmentation of the wave function in our calculation

In a shell-model calculation, expansions of the type

$$|J_i\rangle = \sum_{jL_k} c^{J_i}_{jL_k} |j \times L_k; J\rangle, \quad (5)$$

where $|J_i\rangle$ is a state in an odd-mass nucleus formed by coupling a particle in orbital j to even-even core states $|L_k\rangle$, can be obtained by computing spectroscopic factors. The coefficients $c^{J_i}_{jL_k}$ are found from

$$\left(c^{J_i}_{jL_k}\right)^2 \approx \frac{1}{\langle n_j\rangle} \frac{\langle J_i||a^\dagger_j||L_k\rangle^2}{2J+1}, \quad (6)$$

where the reduced matrix element of the creation operator in orbital j and the occupancy $\langle n_j\rangle$ of this orbital for the state $|J_i\rangle$ are given by the shell-model code. If we wish to express a shell-model state $|J_i\rangle$ as a hole in orbital j coupled to an even-even core,

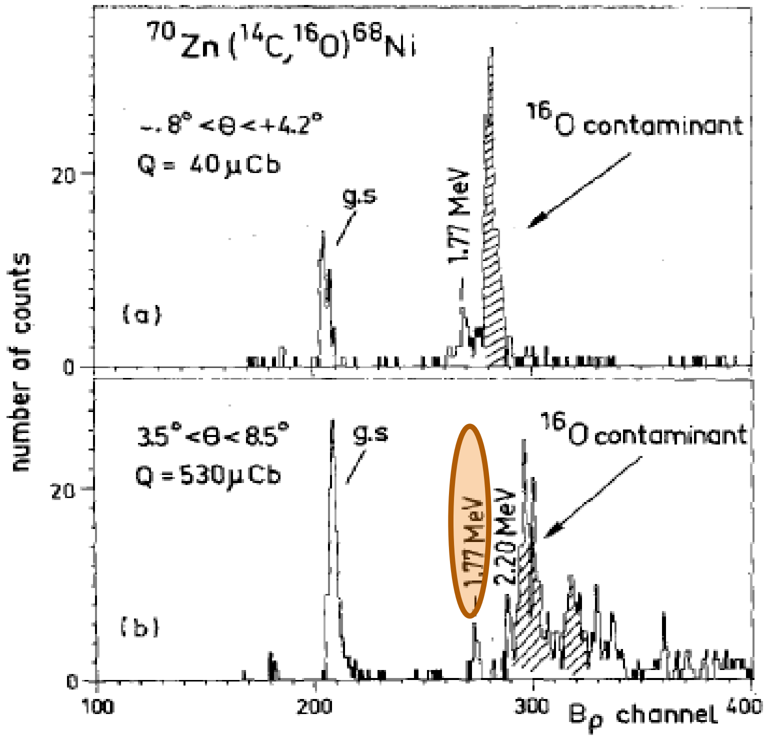
$$|J_i\rangle = \sum_{jL_k} c^{J_i}_{j^{-1}L_k} |j^{-1} \times L_k; J\rangle, \quad (7)$$

the expression for the coefficients $c^{J_i}_{j^{-1}L_k}$ is

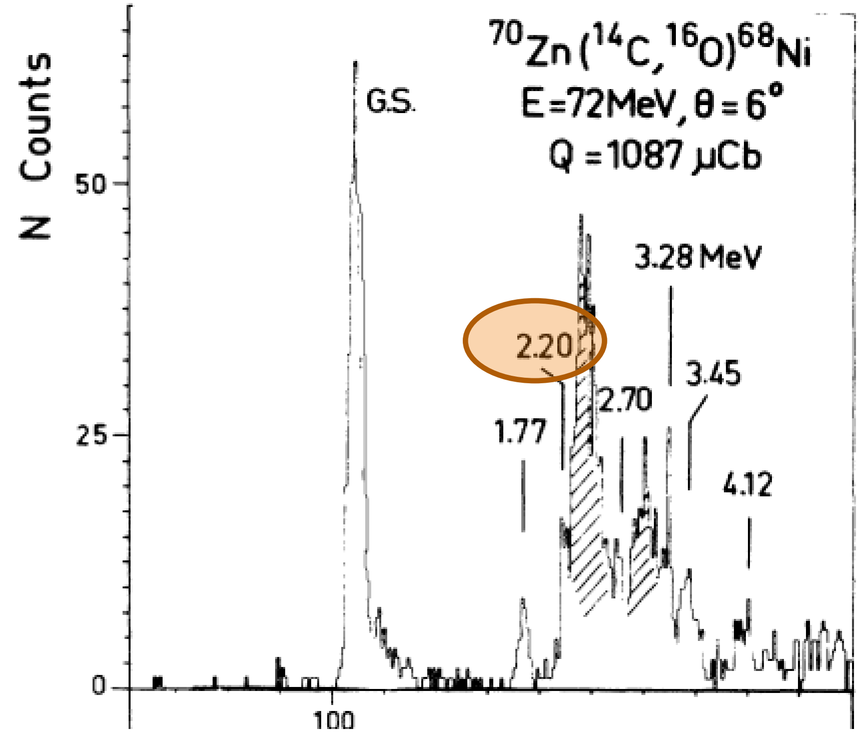
$$\left(c^{J_i}_{j^{-1}L_k}\right)^2 \approx \frac{1}{\langle \bar{n}_j\rangle} \frac{\langle L_k||a^\dagger_j||J_i\rangle^2}{2J+1}, \quad (8)$$

where $\langle \bar{n}_j\rangle$ is the "emptiness" of orbital j for the state $|J_i\rangle$, $\langle \bar{n}_j\rangle = 2j + 1 - \langle n_j\rangle$.

A 0^+ state ? : Looking at the past ...



M. Bernas et al PLB B113,(1982)

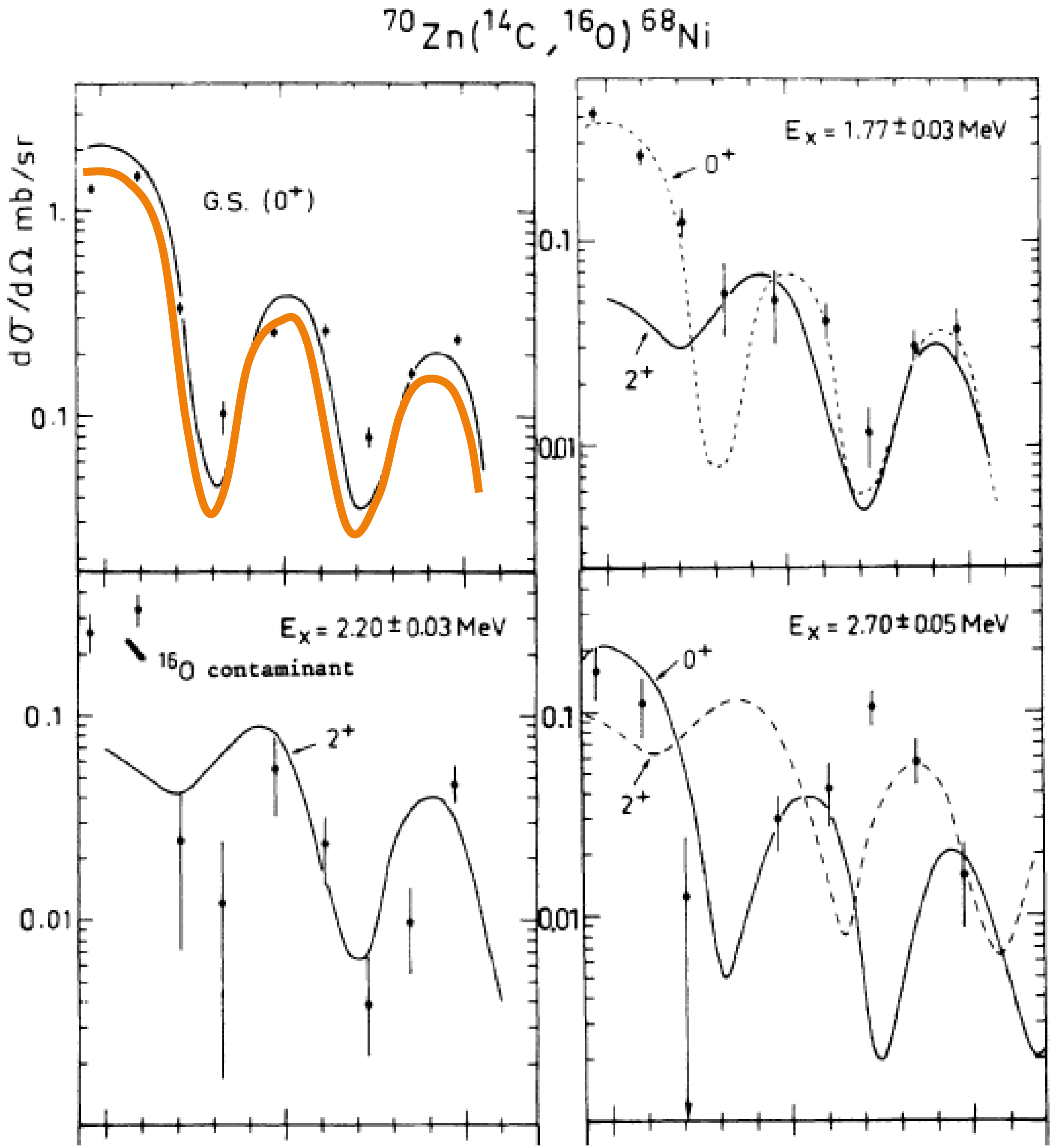


M. Girod et al PRC 37 (1988)

Remember, at this time the 2^+ at 2033 keV was not known :

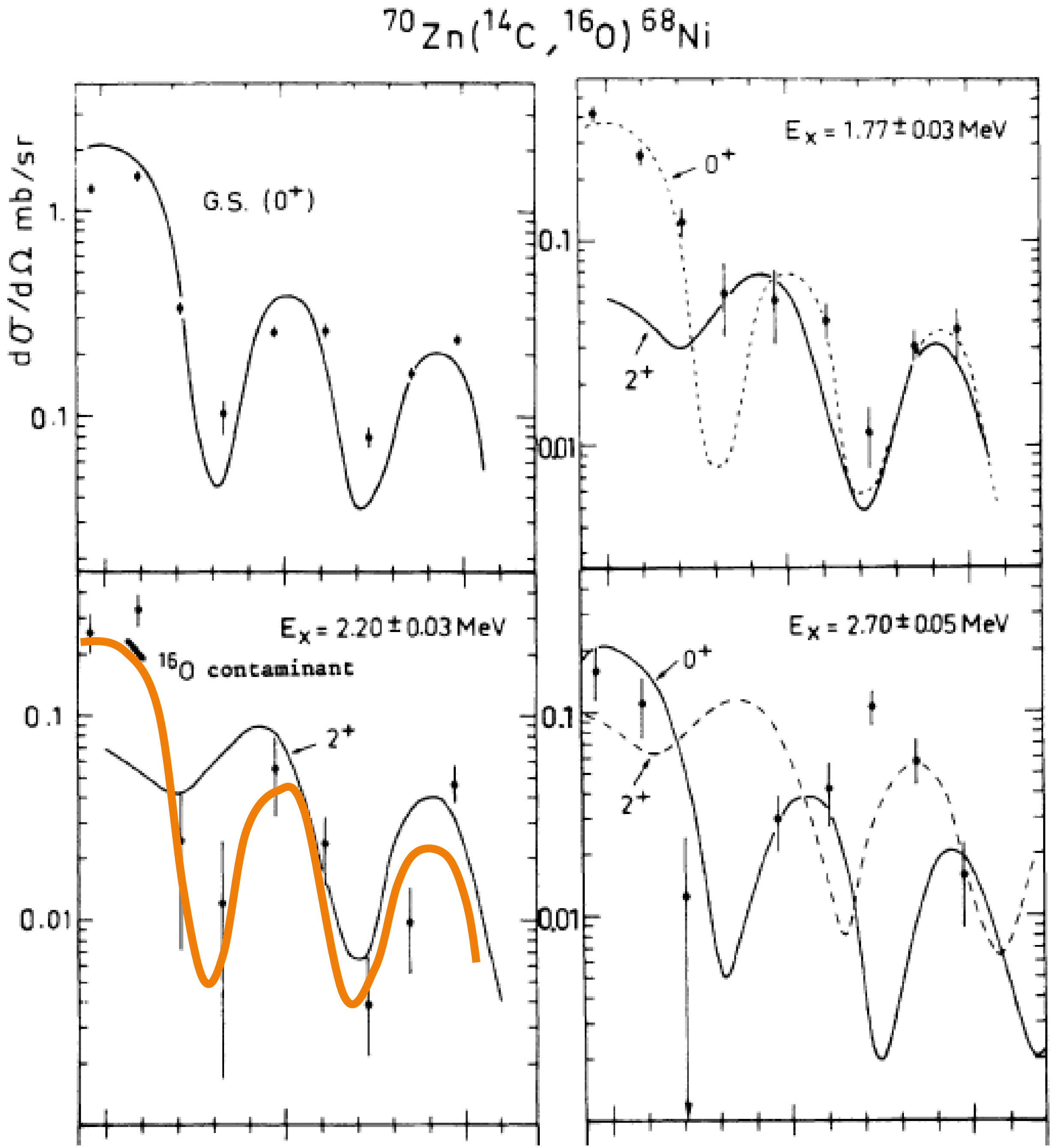
the 2.20(3) MeV state interpreted as a the 2^+_1 state

A 0^+ state ? : Looking at the past …



M. Girod et al PRC 37 (1988)

A 0^+ state ? : Looking at the past …



M. Girod et al PRC 37 (1988)

PHYSICAL REVIEW C **82**, 027304 (2010)

Pairing-excitation versus intruder states in ^{68}Ni and ^{90}Zr

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(Received 25 May 2010; published 12 August 2010)

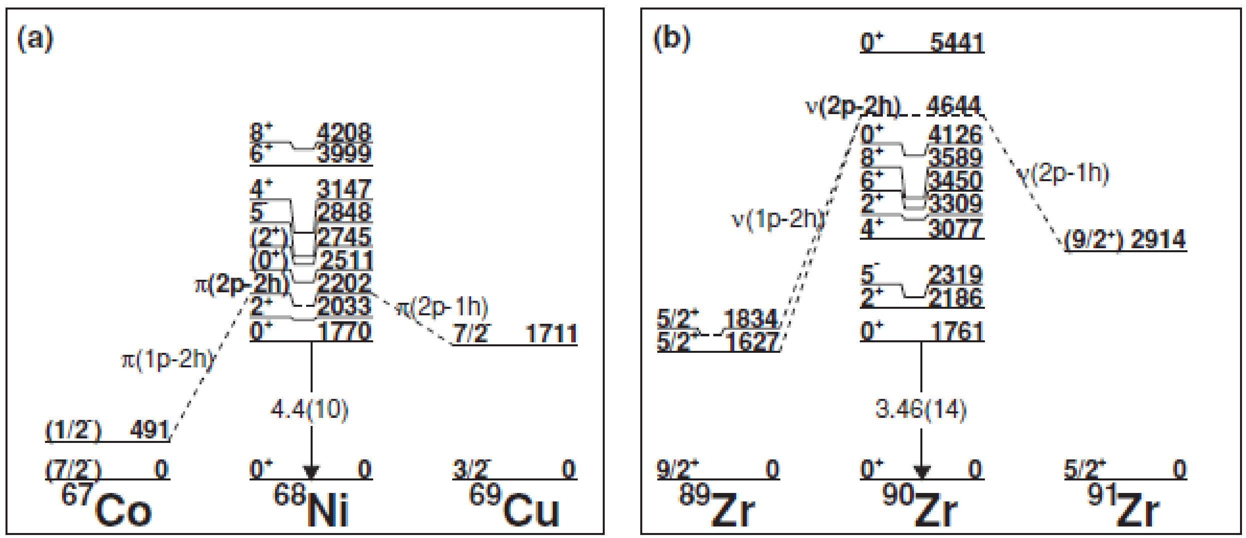

FIG. 1. Low-energy structure of (a) ^{68}Ni and (b) ^{90}Zr [2,14–16]. The arrows denote $\rho^2(E0)\times10^3$ transition strengths [17]. The estimated excitation energies of the respective π and ν(2p-2h) configurations, based on 1p-2h and 2p-1h excitation energies of the $Z\pm1$ and $N\pm1$ nuclei [18–24], respectively, are represented by the dashed lines.