ISOLDE Solenoidal Spectrometer

$^{79}\mathrm{Zn}^{gs,1/2+}(d,p)^{80}\mathrm{Zn}$

How the N=50 gap evolves close to ^{78}Ni ? How to characterise shape coexistence ?

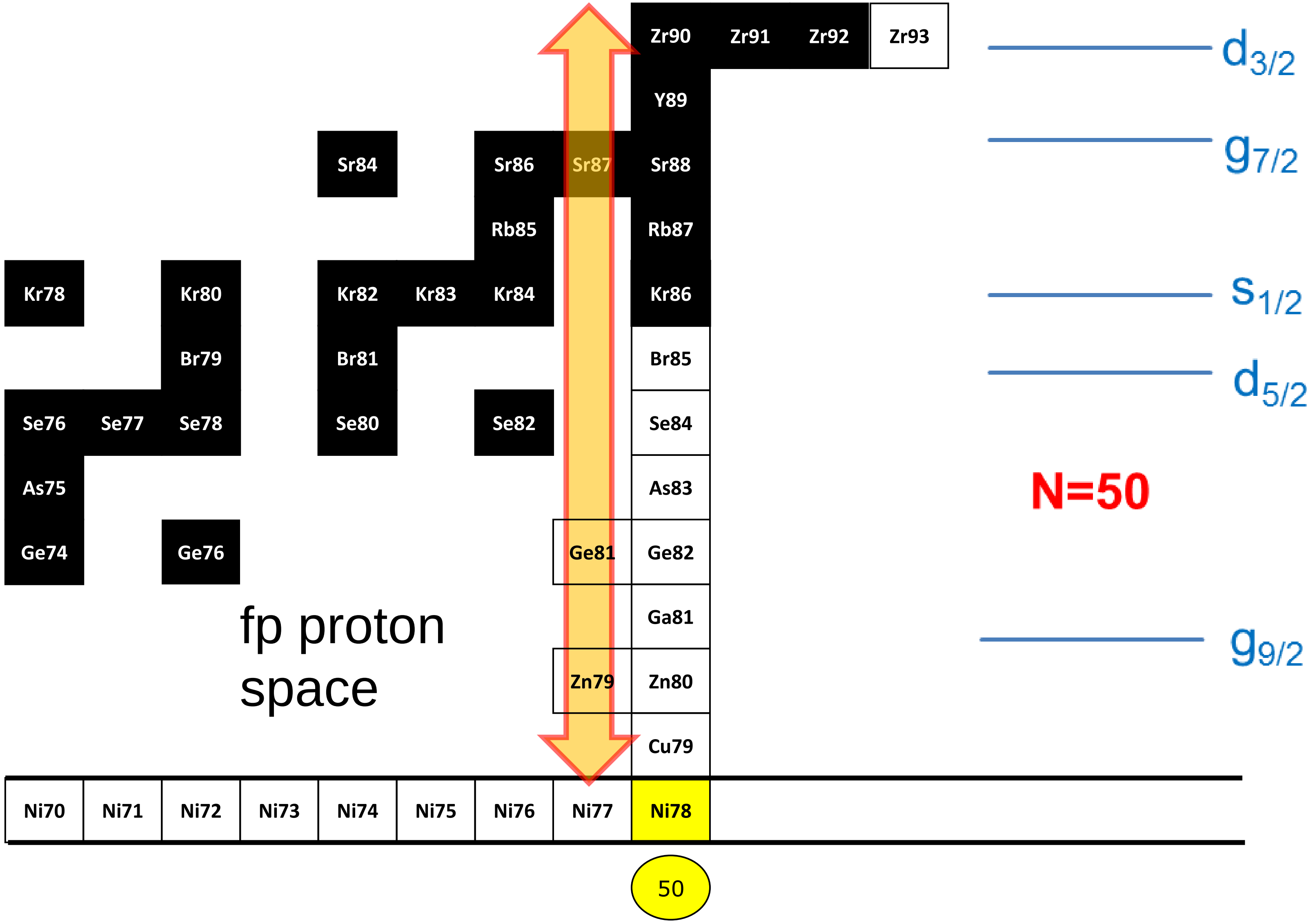
An ISS proposal

INFN Istituto Nazionale di Fisica Nucleare

A. Gottardo, L. Gaffeney
ISS collaboration

UNIVERSITY OF LIVERPOOL

The N=50 isotones towards ^{78}Ni



Zr90 Zr91 Zr92 Zr93

Y89

Sr84 Sr86 Sr87 Sr88

Rb85 Rb87

Kr78 Kr80 Kr82 Kr83 Kr84 Kr86

Br79 Br81 Br85

Se76 Se77 Se78 Se80 Se82 Se84

As75 As83

Ge74 Ge76 Ge81 Ge82

Ga81

Zn79 Zn80

Cu79

Ni70 Ni71 Ni72 Ni73 Ni74 Ni75 Ni76 Ni77 Ni78

50

$d_{3/2}$

$g_{7/2}$

$s_{1/2}$

$d_{5/2}$

N=50

$g_{9/2}$

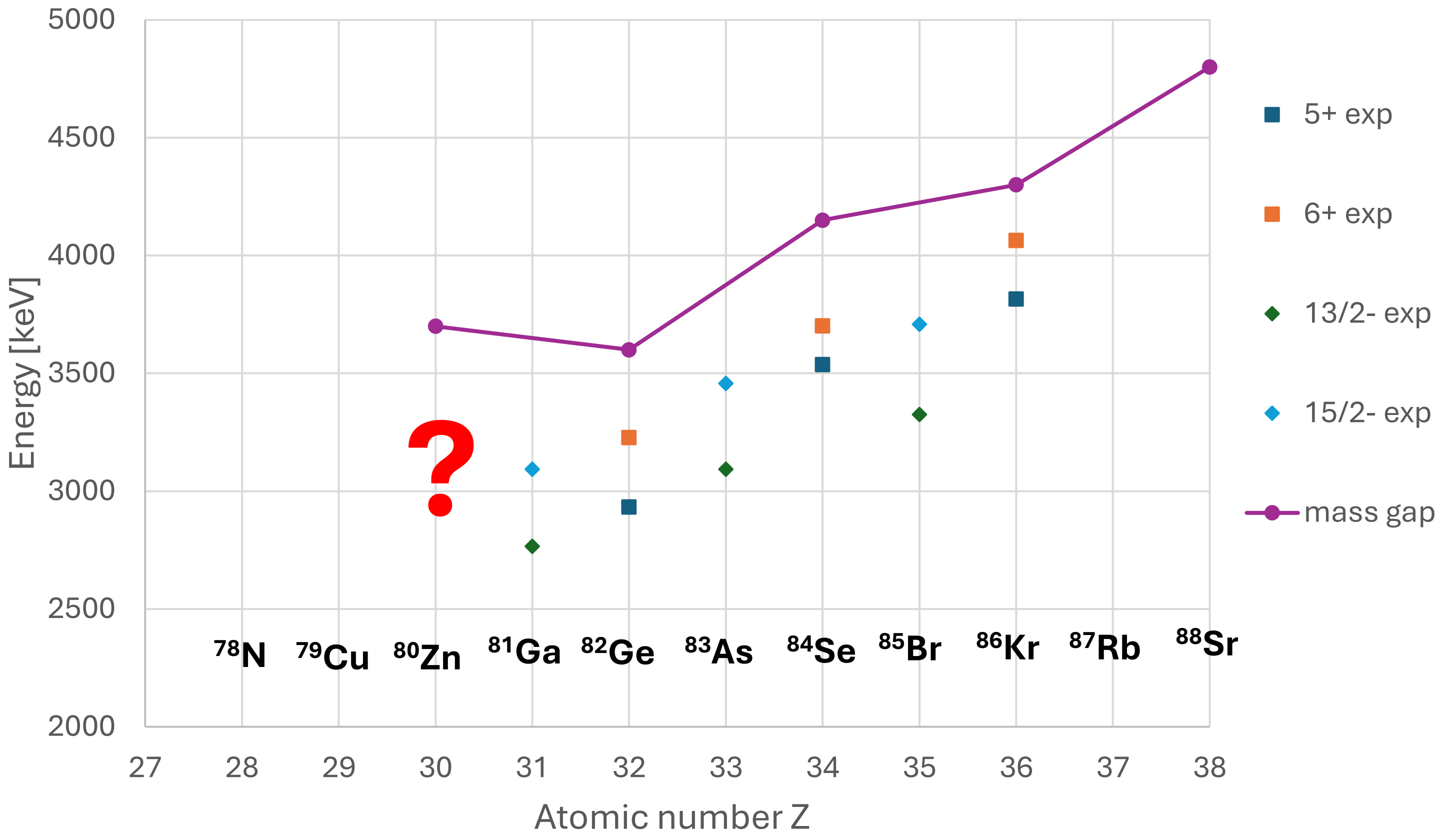
fp proton space

Quasi-SU(3) scheme: gds shells

Evolution of the N=50 gap

- **Mass gap**: from measured Sn values
- Quadratic behaviour of the shell gap
- **Spectroscopic gap**: from $5^+,6^+$ levels which are a $g_{9/2}$-$d_{5/2}$ N=50 core excitation
- Spectroscopy shows a decrease until Z=31

Phys. Rev. C **100**, 011301(R) (2019)

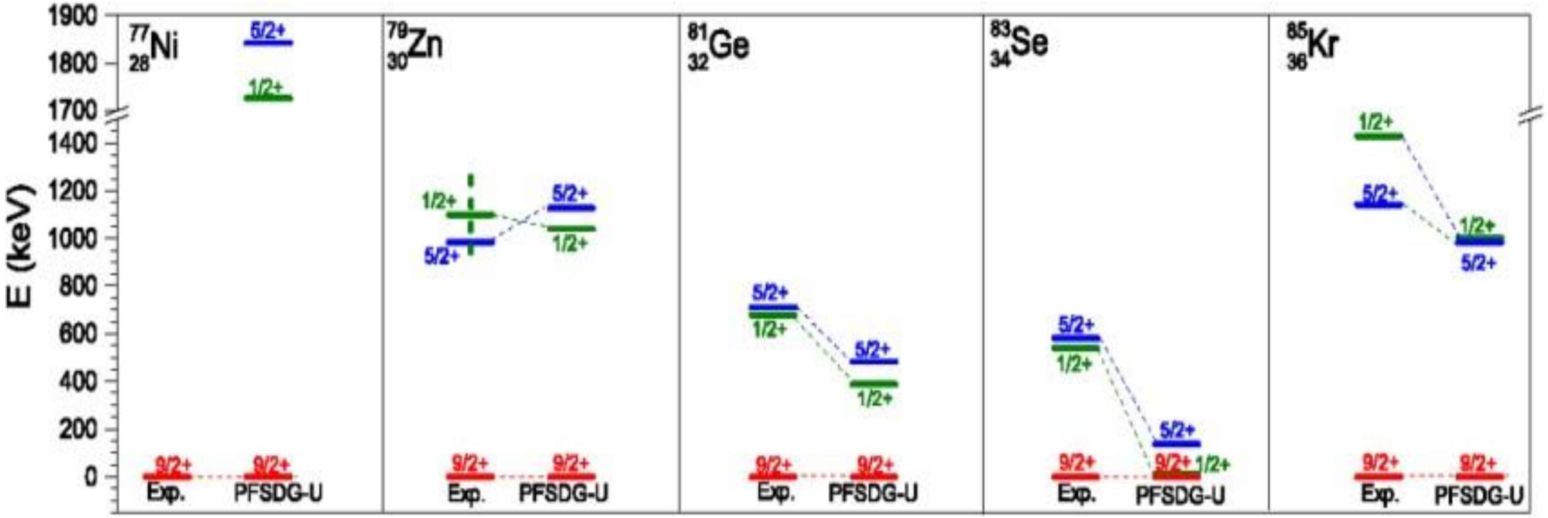


How does the spectroscopic N=50 gap evolve in ^{80}Zn ?
Is there the re-increase seen by mass measurements ?

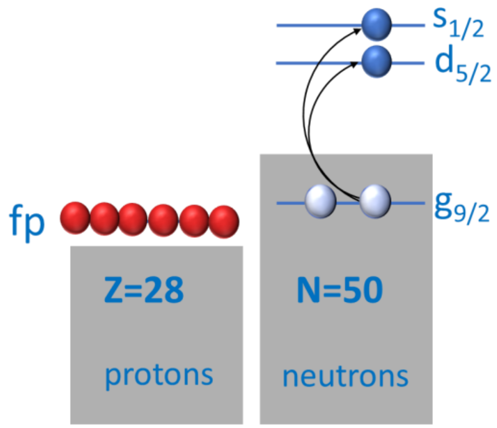
J. Hakala et al., Phys. Rev. Lett. 101, 052502 (2008)
S. Baruah et al., Phys. Rev. Lett. 101, 262501 (2008)
K. Heyde et al., Phys. Lett. B 176, 255 (1986).
T. Rzaca-Urban et al., Phys. Rev. C 76, 027302 (2007)

Shape coexistence towards and at ^{78}Ni

- Intruder 5/2$^+$, 1/2$^+$ states in N=49 isotones



C. Wraith et al., Phys. Lett. B 771 (2017) 385391



many particle – many hole across N=50

- Spherical gap :

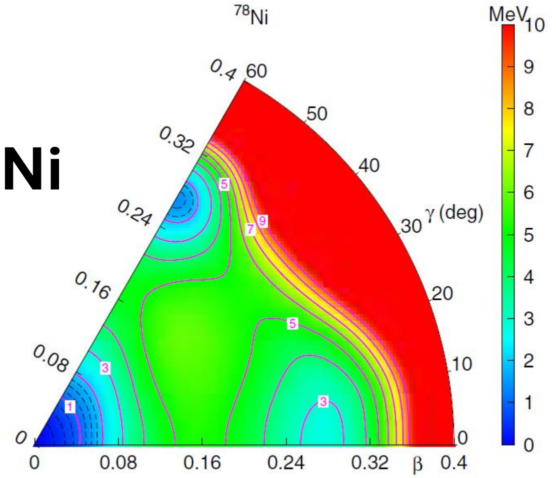
  energy cost ⬆

- Correlations by breaking the core:

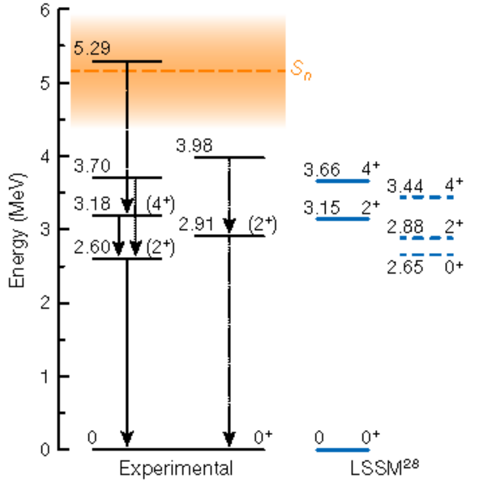
  energy gain ⬇

Prediction (and observation ?) of a well deformed 4p-4h intruder structure in ^{78}Ni

^{78}Ni

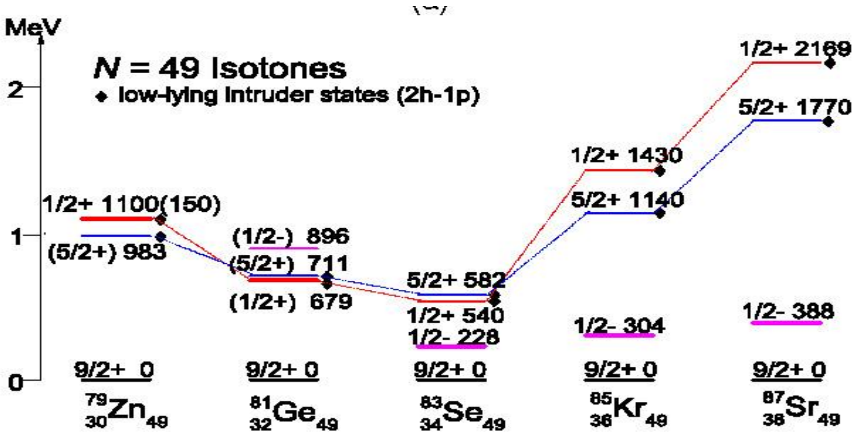


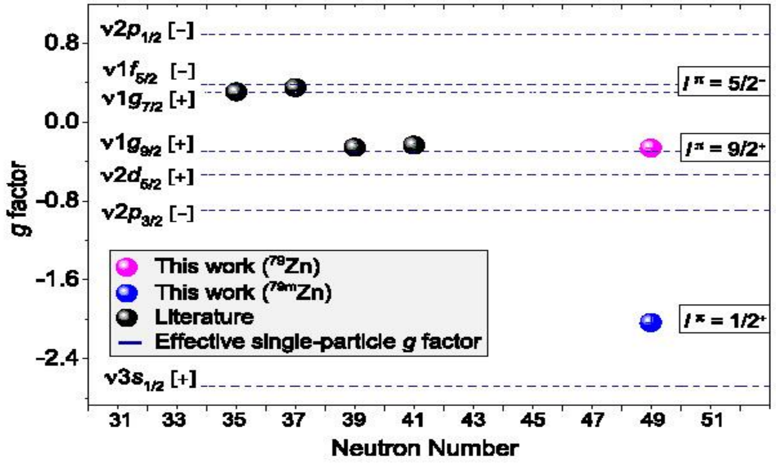
F. Nowacki et al., Phys. Rev. Lett. 117, 272501 (2016)



R. Taniuchi et al., Nature 569, 53–58 (2019)

What is known in ^{79,80}Zn (I)



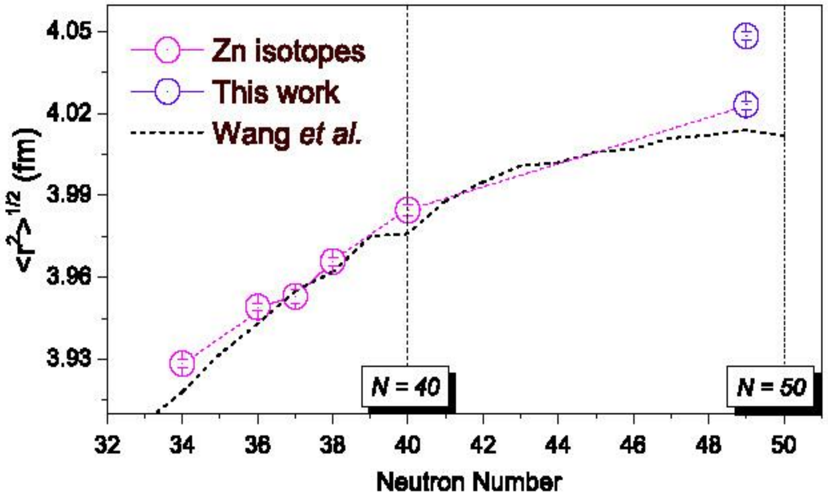


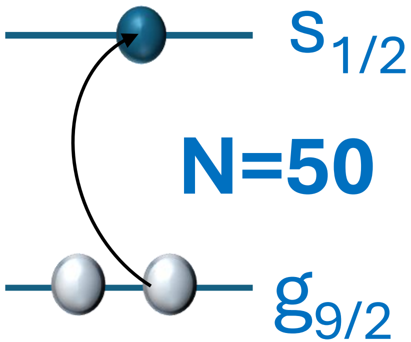
1. The 1/2$^+$ state in ^{79}Zn has a dominant ν($g_{9/2}^{-2}$ $s_{1/2}$) character

2. Large isomer shift. Large deformation (β~0.22) or large radius ?

$$\langle r^2 \rangle \approx \langle r^2 \rangle_0 \left(1 + \frac{5}{4\pi}\langle \beta^2 \rangle\right)$$

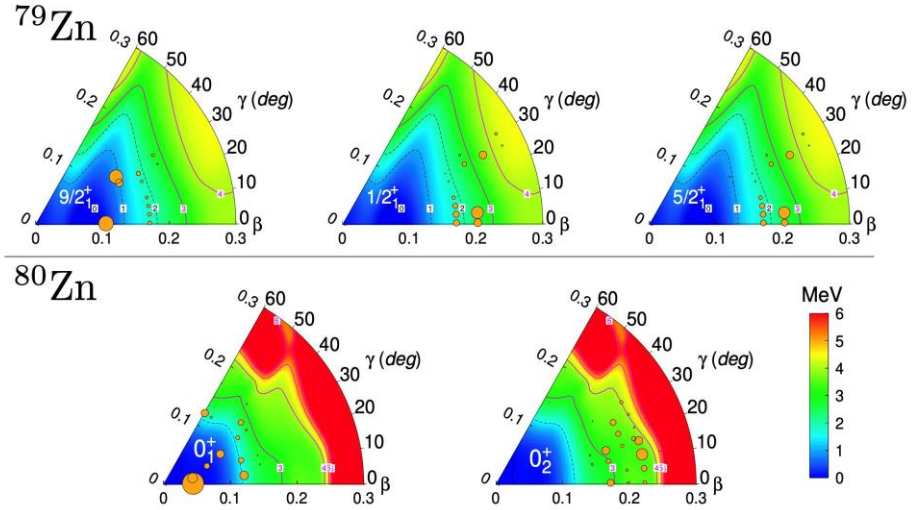
X. F. Yang et al. Phys. Rev. Lett. 116, 182502 (2016)





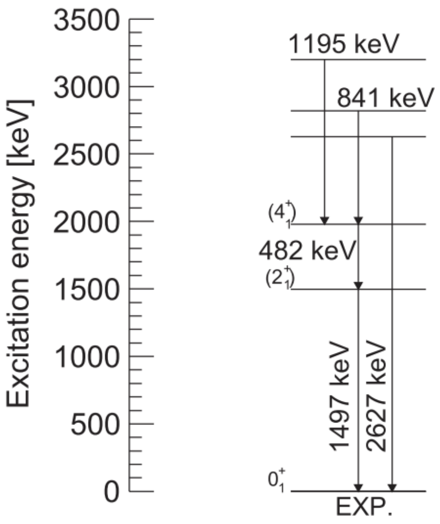
What is known in ^{79,80}Zn (II)

- Mass measurement at ISOLDE measured the exact energy of the $1/2^+$ isomer (943 keV)
- Mixed ISOL beam: ^{79}Zn gs + ^{79}Zn $1/2^+$ (7%)
- Shell-model calculations point to the same deformed intruder structure in ^{79,80}Zn
- In ^{80}Zn, only the 2^+ and 4^+ states are known



discrete nonorthogonal shell-model

L. Nies et al., Phys. Rev. Lett. 131, 222503, 2023

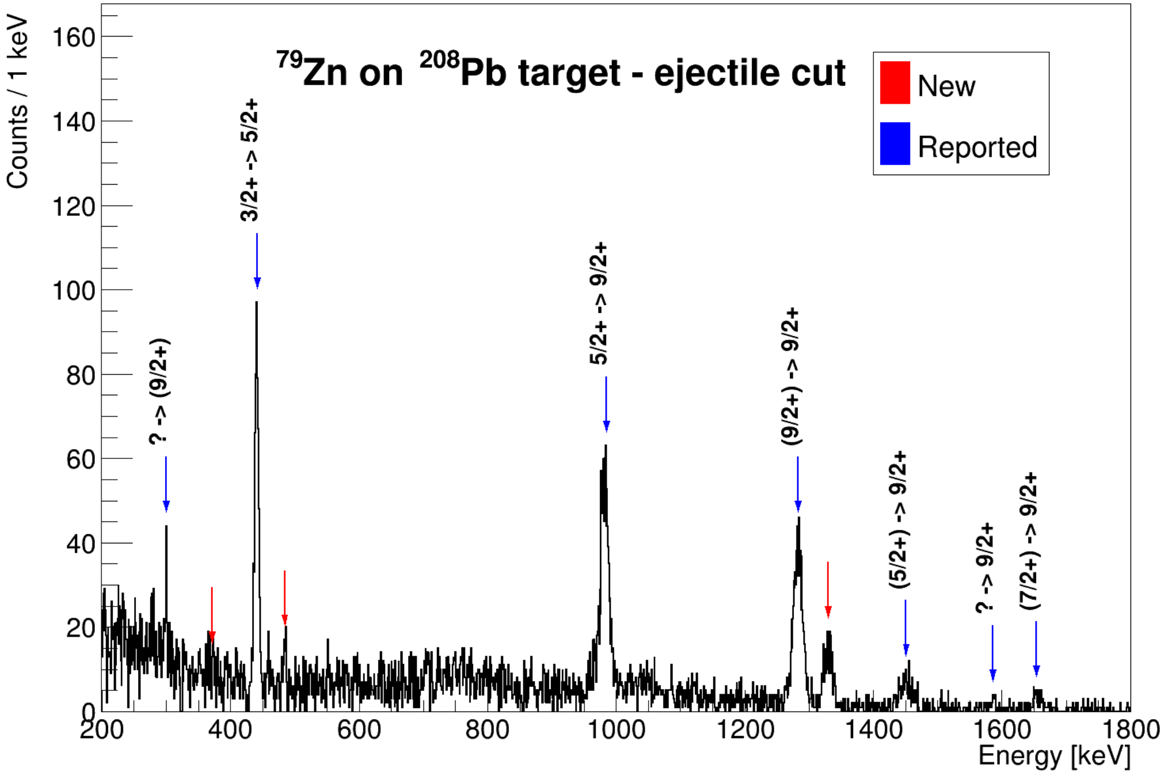


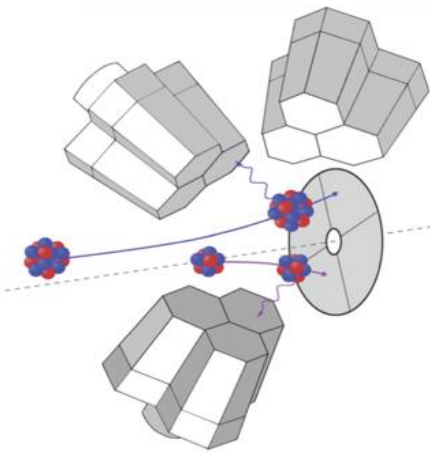
2^+ discovered at ISOLDE ! Phys. Rev. Lett. **99**, 142501 (2007)

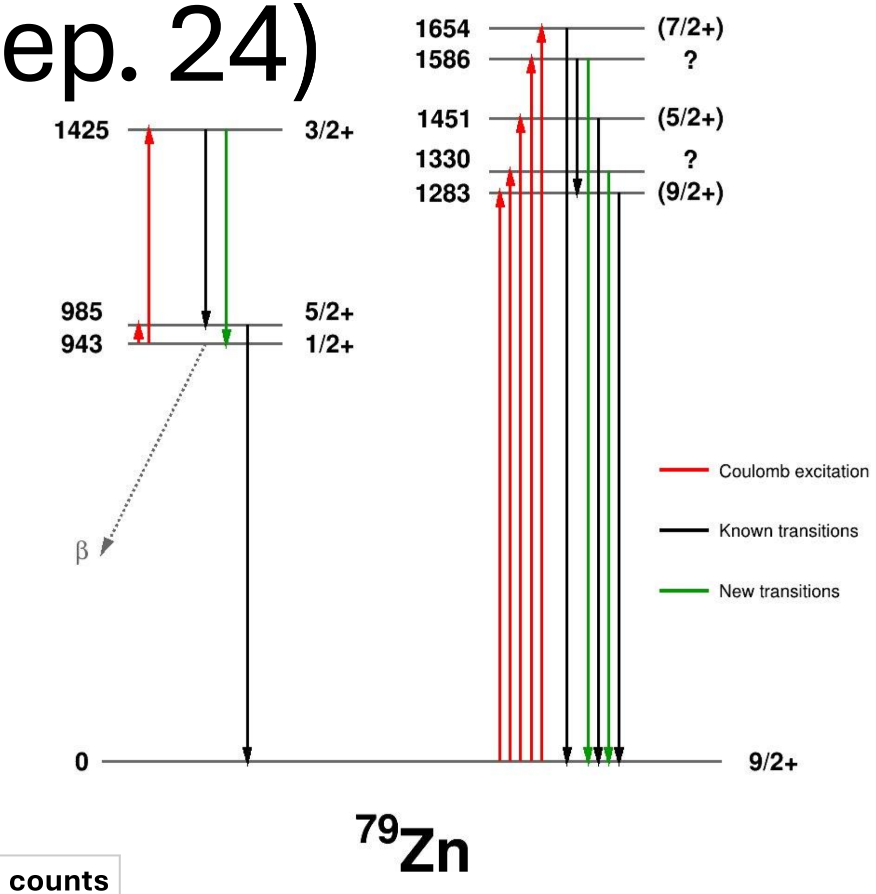
Phys. Rev. C 93, 024320 (2016)

IS646: ^{79}Zn Coulex at ISOLDE (Sep. 24)

- Coulex on both gs and isomeric 1/2+ state







Energy	Eff. corr. counts
300.5	495
441.6	4562
484.8	468
983.5	9709
1283.5	9439
1331.5	3291
1449.7	2212
1582.5	316
1656	922

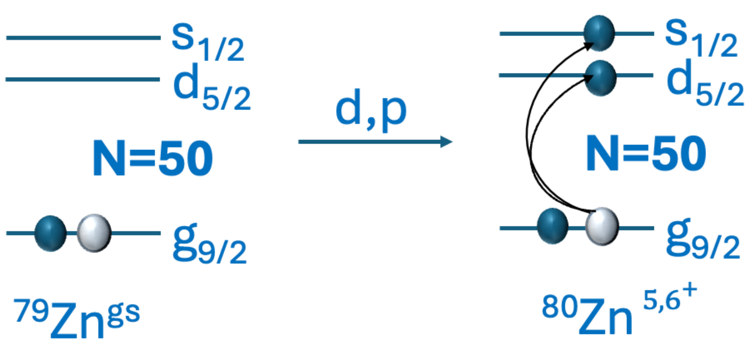
$1/2^+$ Coulex
$\sim 1.0 \cdot 10^4$

GS Coulex
$\sim 1.6 \cdot 10^4$

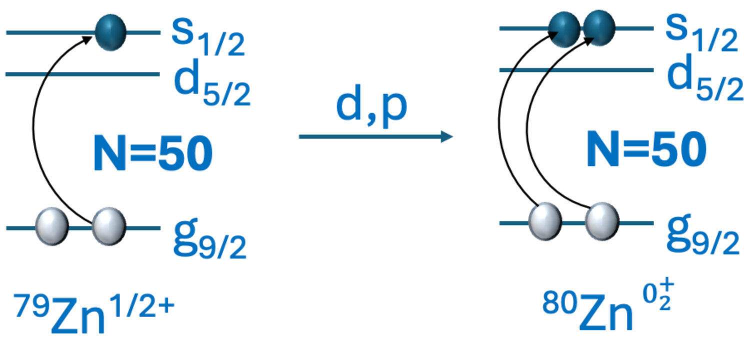
- Large Coulex on the $1/2^+$ isomer: rotational band(K=1/2)-like structure

What we can learn from $^{79}\mathrm{Zn}^{gs,1/2+}(d,p)^{80}\mathrm{Zn}$

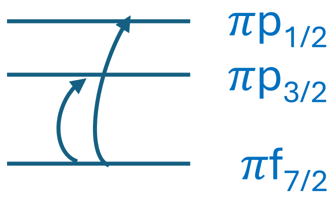
Transfer on the ^{79}Zn 9/2^{+} gs



Transfer on the ^{79}Zn 1/2^{+} isomer



When N=50 is broken, more proton excitations

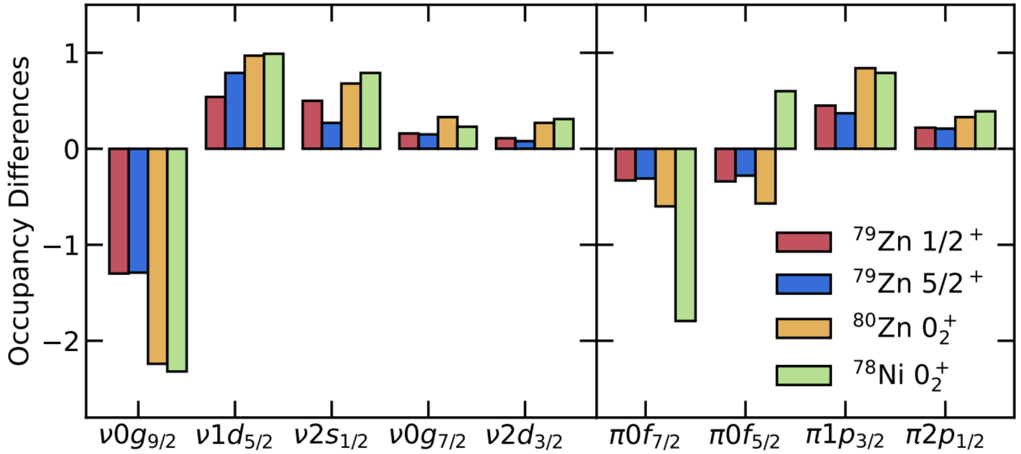


Discovery potential:

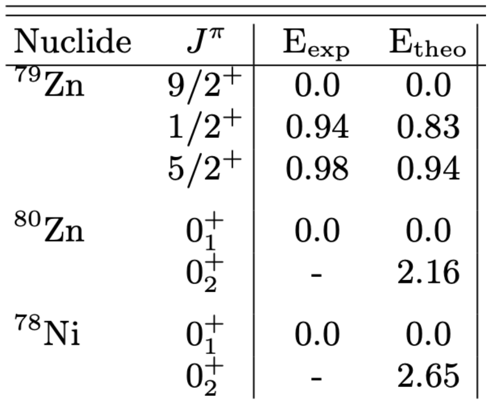
- (d,p) on the ^{79}Zn gs will populate the 5^{+}, 6^{+} breaking the core with ℓ=0,2 : $g_{9/2}$-$d_{5/2}$, $g_{9/2}$-$s_{1/2}$
- (d,p) on the ^{79}Zn 1/2^{+} will populate the intruder 0_2^{+} breaking the core with ℓ=0: $(g_{9/2})^{-2}\ (s_{1/2})^{2}$, $(g_{9/2})^{-2}\ (d_{5/2})^{2}$

Shell-model predictions

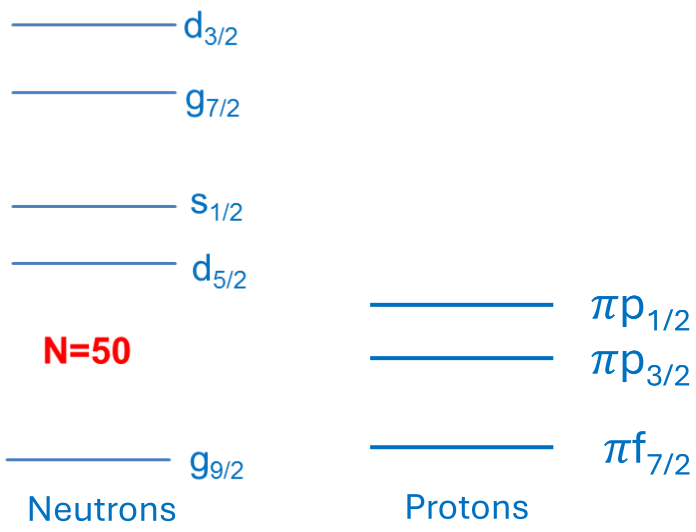
L. Nies et al., Phys. Rev. Lett. 131, 222503, 2023, PFSDG-U



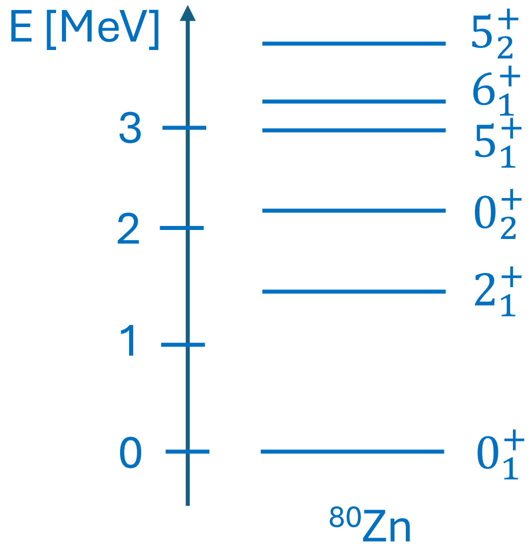
Difference of occupancies among the excited states and the gs in ^{79,80}Zn, ^{78}Ni



Nuclide	J^π	E_{exp}	E_{theo}
^{79}Zn	$9/2^+$	0.0	0.0
	$1/2^+$	0.94	0.83
	$5/2^+$	0.98	0.94
^{80}Zn	0_1^+	0.0	0.0
	0_2^+	-	2.16
^{78}Ni	0_1^+	0.0	0.0
	0_2^+	-	2.65

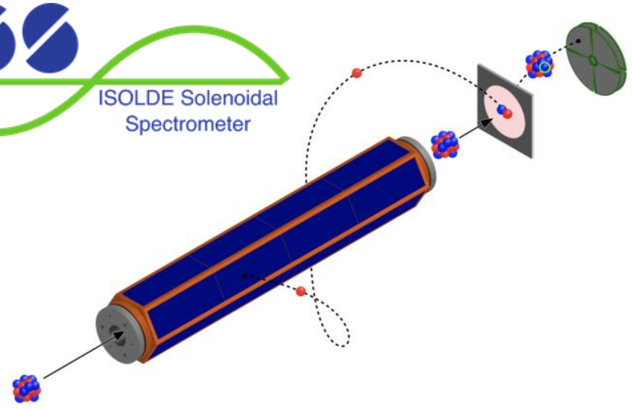


- Simplified interaction breaking only the N=50 core (GWB from Oxbash library)



- Shell-model calculations support the schematic shell-model picture
- From the interaction, we get the level energies and SF to simulate the reactions

Proposed measurement on ISS: 21 shifts of beam on target

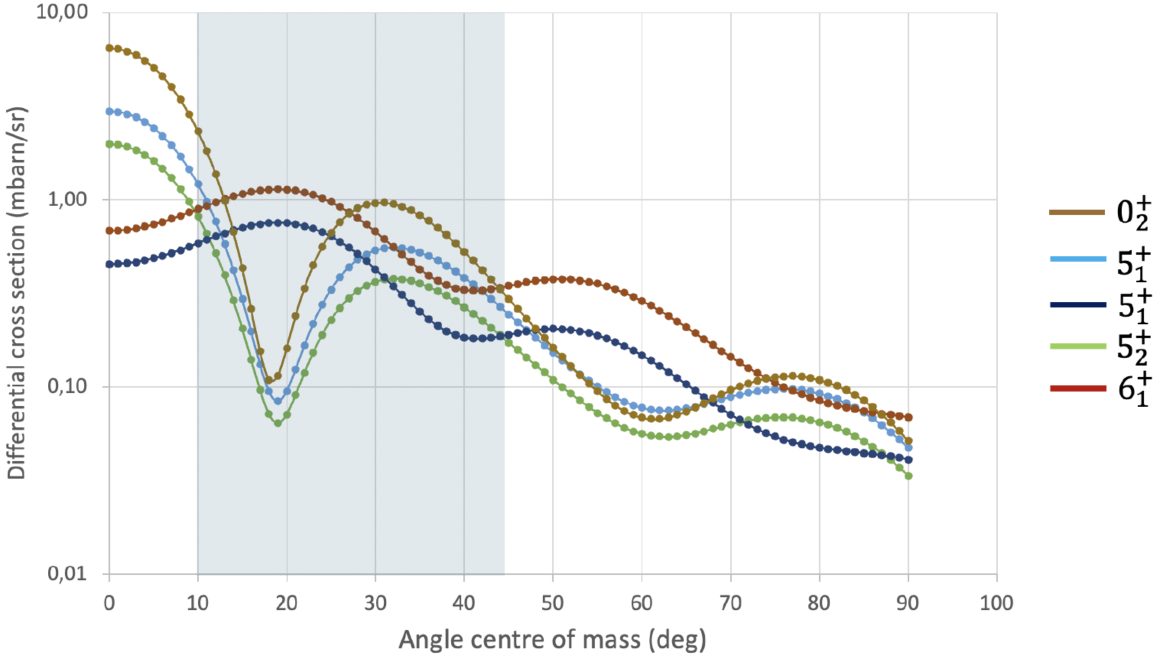


- ^{79}Zn$^{gs,1/2+}$(d,p)^{80}Zn reaction at 6 MeV/u (to enhance ℓ=0 transfer on ISS)
- Isolde Solenoid Spectrometer (with IC chamber)
- ℓ=0,2 transfer are the only ones with sizeable cross sections at this energy
- SF are in the order 0.1-0.2 for the states of interest
- Statistics request driven by isomeric ratio in ^{79}Zn beam (1/2$^+$ beam is ~ 10% of the 9/2$^+$ beam)

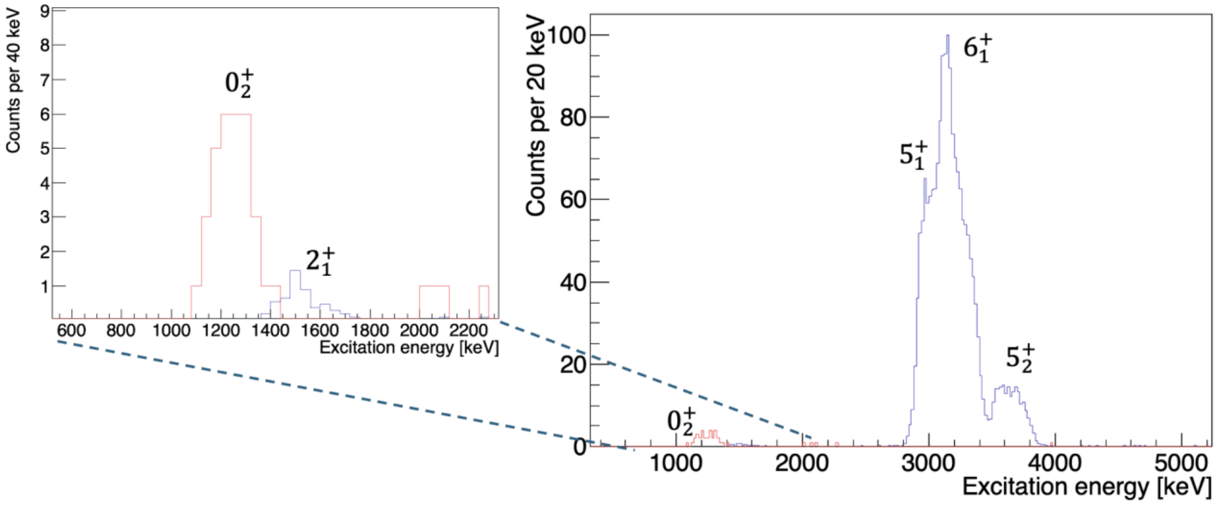
^{80}Zn state	(d,p) on	SF	Cross section [mb]	Statistics in 7 days
5^+_1	^{79}Zn^{gs} ℓ=0,2	~0.1 ➡	2.5	~700
6^+_1	^{79}Zn^{gs} ℓ=2	~0.1 ➡	2.5	~700
5^+_2	^{79}Zn^{gs} ℓ=0	~0.04 ➡	0.7	~200
0^+_2	^{79}Zn$^{1/2+}$ ℓ=0	~0.2 ➡	1.5	~40

Simulation of the ISS results

- Monte Carlo simulation with a 300 μg/cm^2 CD2 target
- Rough idea on how the excitation spectra might look like
- A thinner target (100-150 μg/cm^2) will be ready to be used during the experiment looking at near-line spectra



Excitation energy assuming transfer on gs for Q-value



- ISS angular coverage will allow one to disentangle the transferred ℓ

Conclusions, TAC comment

- ^{79}Zn$^{gs,1/2+}$(d,p)^{80}Zn reaction at 6 MeV/u with the ISS setup

- The request is for **24 shifts of beam time**:
  - 21+1 shifts (optmisation setup) of ^{79}Zn at 6 MeV/u + 2 shifts of stable beam

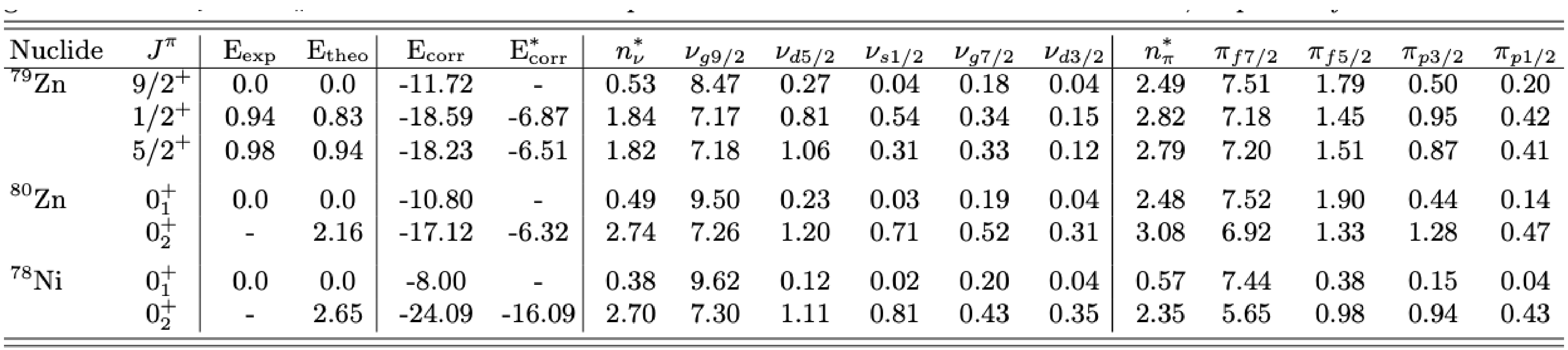
- TAC comment: we measured a 8 · 10^4 pps beam intensity in IS646 from Rutherford (I_p=2 μA).
  Even if the accelerated beam current is lower (~2-4 · 10^4 pps) we should still measure level energies and have an idea of SF.

- What we will extract: state energies, transferred ℓ from $\frac{d\sigma}{d\Omega}$, spectroscopic factors (at least relative).

- These results will constrain/challenge current shell-model Hamiltonians to describe ^{78}Ni,
  - N=50 gap size from spectroscopic data in the ^{78}Ni region (5^+,6^+ states in ^{80}Zn)
  - shape coexistence in the ^{78}Ni region (0_2^+ state in ^{80}Zn)

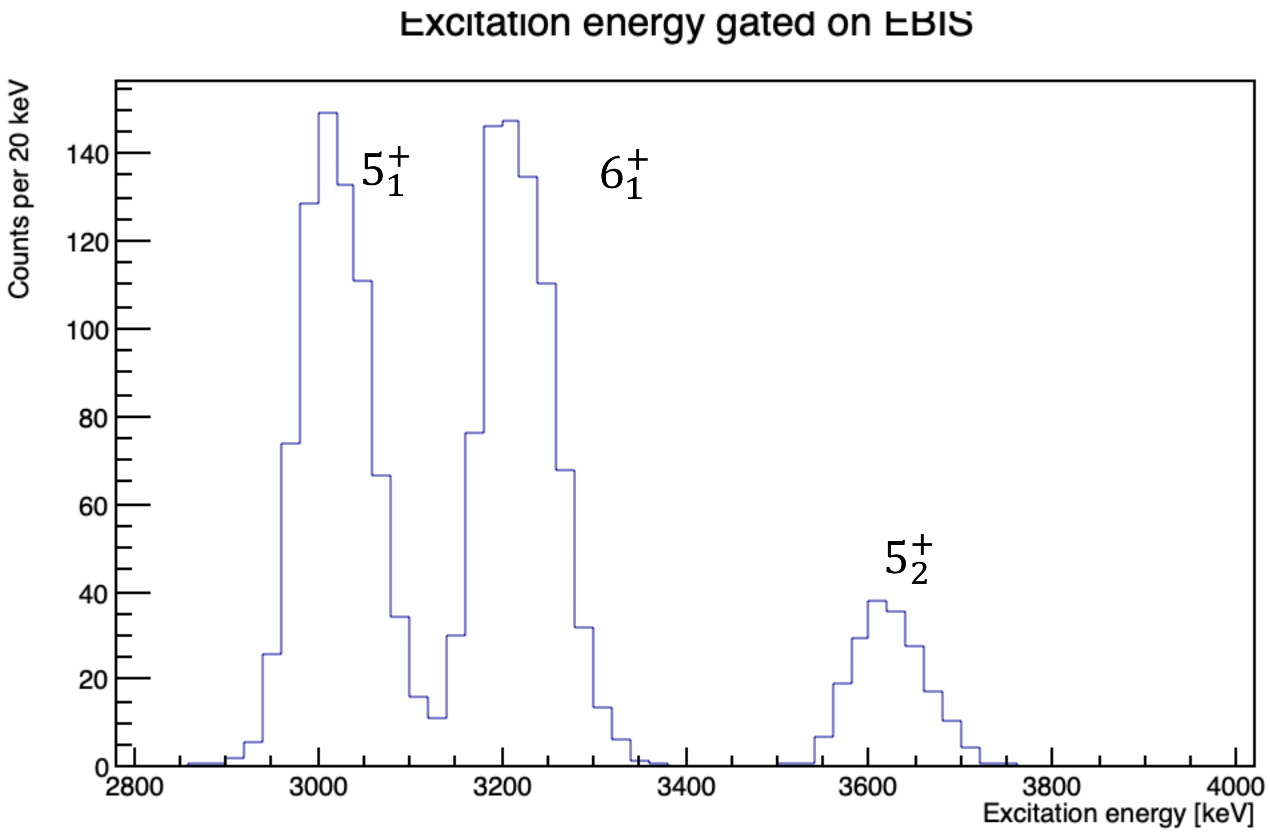
Thank for your attention !

Shell-model PFSDG-U

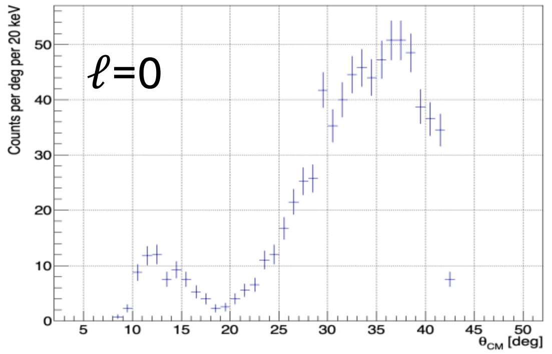


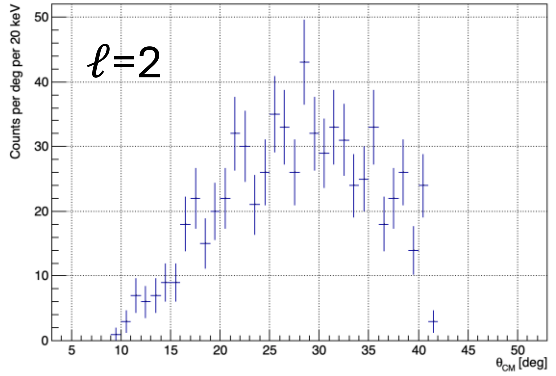
Nuclide	J^π	E_{exp}	E_{theo}	E_{corr}	E^*_{corr}	n^*_ν	$\nu_{g9/2}$	$\nu_{d5/2}$	$\nu_{s1/2}$	$\nu_{g7/2}$	$\nu_{d3/2}$	n^*_π	$\pi_{f7/2}$	$\pi_{f5/2}$	$\pi_{p3/2}$	$\pi_{p1/2}$
^{79}Zn	$9/2^+$	0.0	0.0	-11.72	-	0.53	8.47	0.27	0.04	0.18	0.04	2.49	7.51	1.79	0.50	0.20
	$1/2^+$	0.94	0.83	-18.59	-6.87	1.84	7.17	0.81	0.54	0.34	0.15	2.82	7.18	1.45	0.95	0.42
	$5/2^+$	0.98	0.94	-18.23	-6.51	1.82	7.18	1.06	0.31	0.33	0.12	2.79	7.20	1.51	0.87	0.41
^{80}Zn	0^+_1	0.0	0.0	-10.80	-	0.49	9.50	0.23	0.03	0.19	0.04	2.48	7.52	1.90	0.44	0.14
	0^+_2	-	2.16	-17.12	-6.32	2.74	7.26	1.20	0.71	0.52	0.31	3.08	6.92	1.33	1.28	0.47
^{78}Ni	0^+_1	0.0	0.0	-8.00	-	0.38	9.62	0.12	0.02	0.20	0.04	0.57	7.44	0.38	0.15	0.04
	0^+_2	-	2.65	-24.09	-16.09	2.70	7.30	1.11	0.81	0.43	0.35	2.35	5.65	0.98	0.94	0.43

Thinner target 100-150 μg/cm^2



- To be used in case after a few days of thick target to help disentagle the 5^+,6^+ states at around 3 MeV.





Fusion-evaporation backround

- We intend to use the ionisation chamber and perform event-by-event recoil coincidences,
- we have the 68Ni spectrum to give an idea of the background level with similar mass and similar beam intensity. In this case, we did not use the ionisation chamber, so background will be lower for 79Zn.

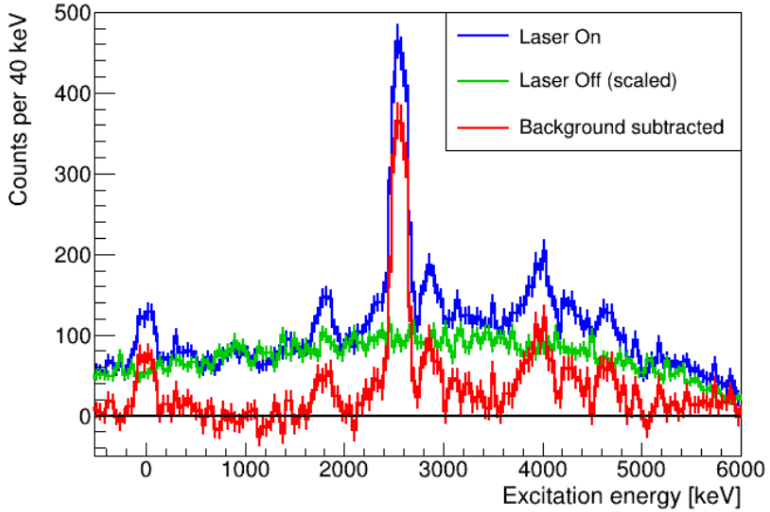


FIG. 1. Detected protons as a function of the calculated excitation energy in ^{69}Ni. Data with short release times blocked and lasers on, containing Ni- and Ga-induced events, are shown in blue. Scaled Ga-only background measurement is shown in green (short release times allowed and lasers off). The background-subtracted data are shown in red.