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Spectroscopic Factor Investigation in the $N=40$ Island of Inversion

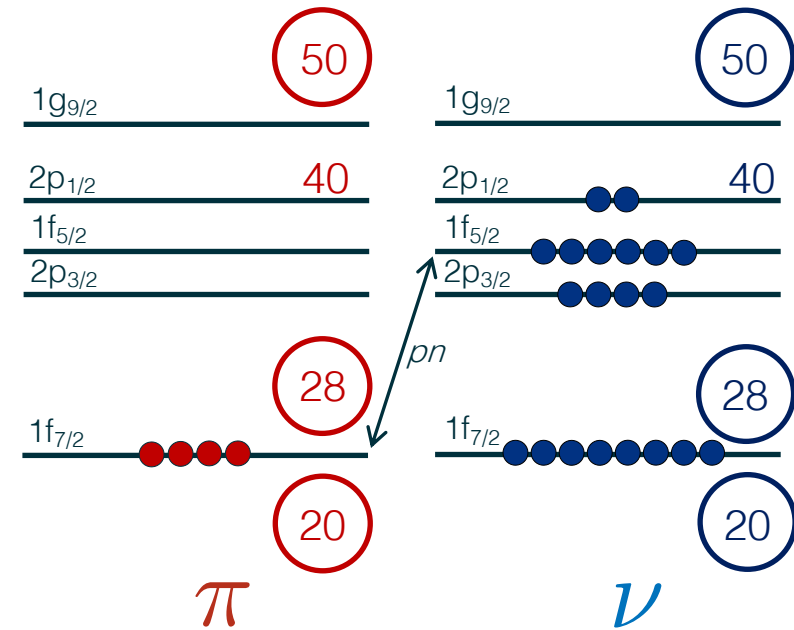
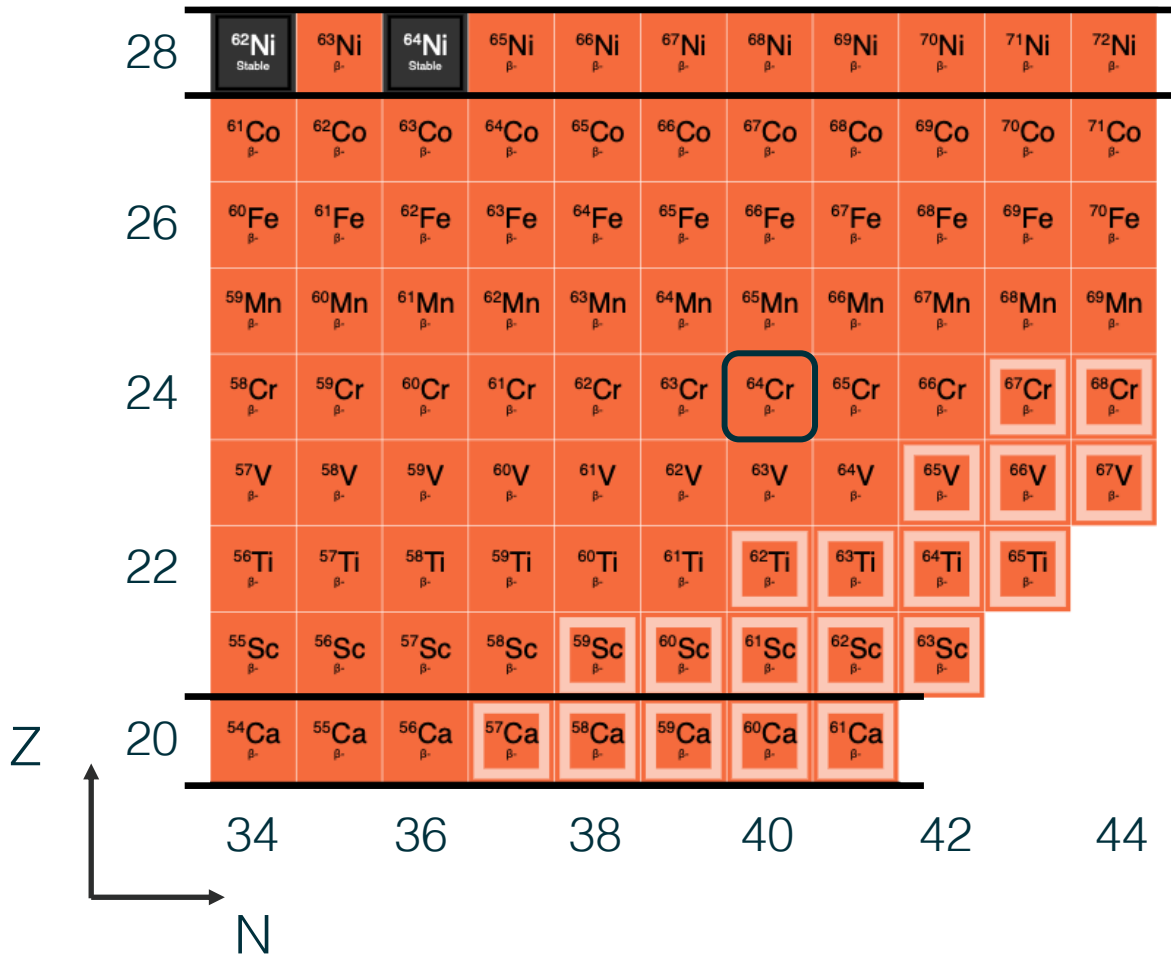
Carlotta Porzio

ARIS 2023 – 8th June 2023



The $N=40$ Island of Inversion

<https://people.physics.anu.edu.au/~ecs103/chart/>

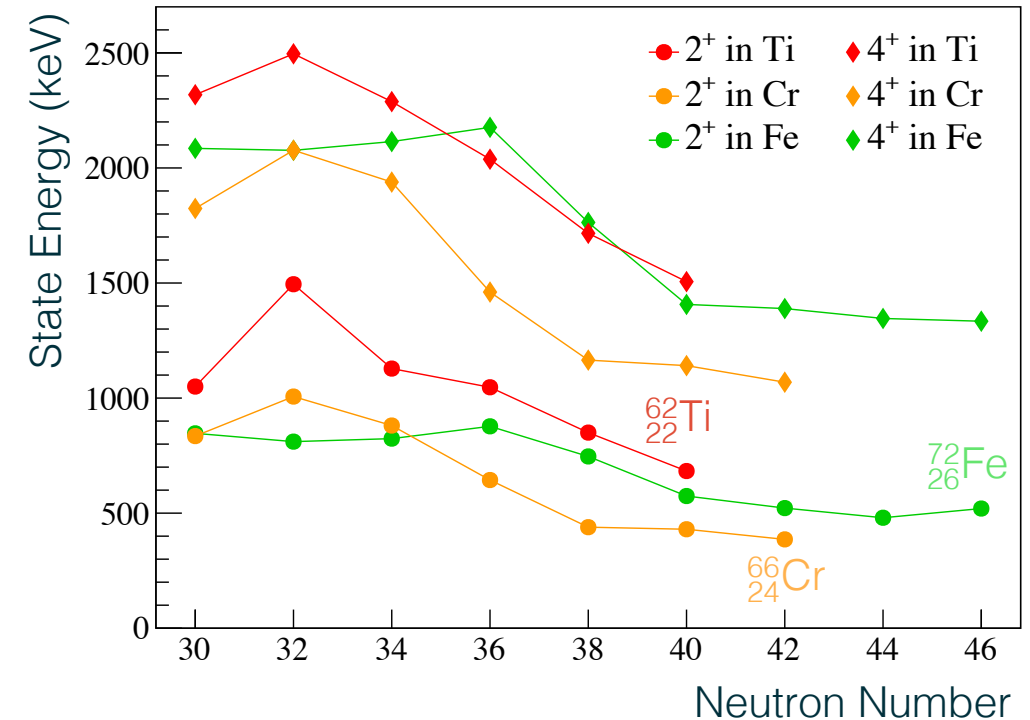


The $N=40$ Island of Inversion

Results from previous spectroscopic studies.

For the even-even nuclei:

- systematics of 2^+_1 and 4^+_1 state energies;
 - Santamaria et al., PRL 115 (2015) 192501
 - Cortés et al., PLB 800 (2020) 135071
- for the Fe and Cr isotopes, $B(E2; 2^+_1 \rightarrow 0^+_1)$ values up to ^{68}Fe and ^{64}Cr .
 - Crawford *et al.*, PRL 110 (2013) 242701

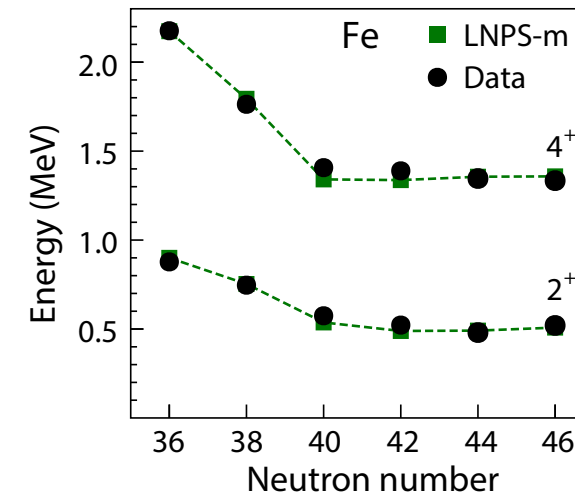
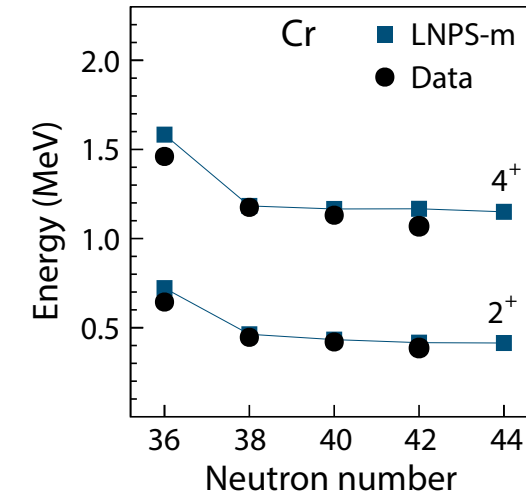


The $N=40$ Island of Inversion

Theoretical description.

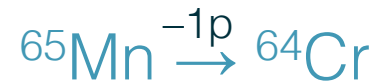
- Large-scale shell model calculations using the LNPS effective interaction well reproduce the energy systematics in the region.
- They also reproduce well $B(E2)$ values.
- They predict a deformation parameter $\beta_2 \sim 0.3$ (well deformed) for Cr and Fe nuclei around $N=40$.
- Also the Nilsson model provides a good description of the energy systematics.

- LNPS: Lenzi *et al.*, PRC 82 (2010) 054301
- LNPS-m: Santamaria et al., PRL 115 (2015) 192501
- Figures from Gade, Physics 3 (2021) 1226



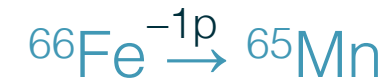
Proton Spectroscopic Factor Predictions

Large-scale shell model and Nilsson model calculations for proton spectroscopic factors tend to agree in some cases, but not all.



Final State	C ² S SM	C ² S Nilsson
0 ⁺ ₁	0.0	0.03
2 ⁺ ₁	0.59	0.58
4 ⁺ ₁	0.56	0.36
6 ⁺ ₁	0.0	0.02
*8 ⁺ ₁	0.04	0.0

*Not identified yet.



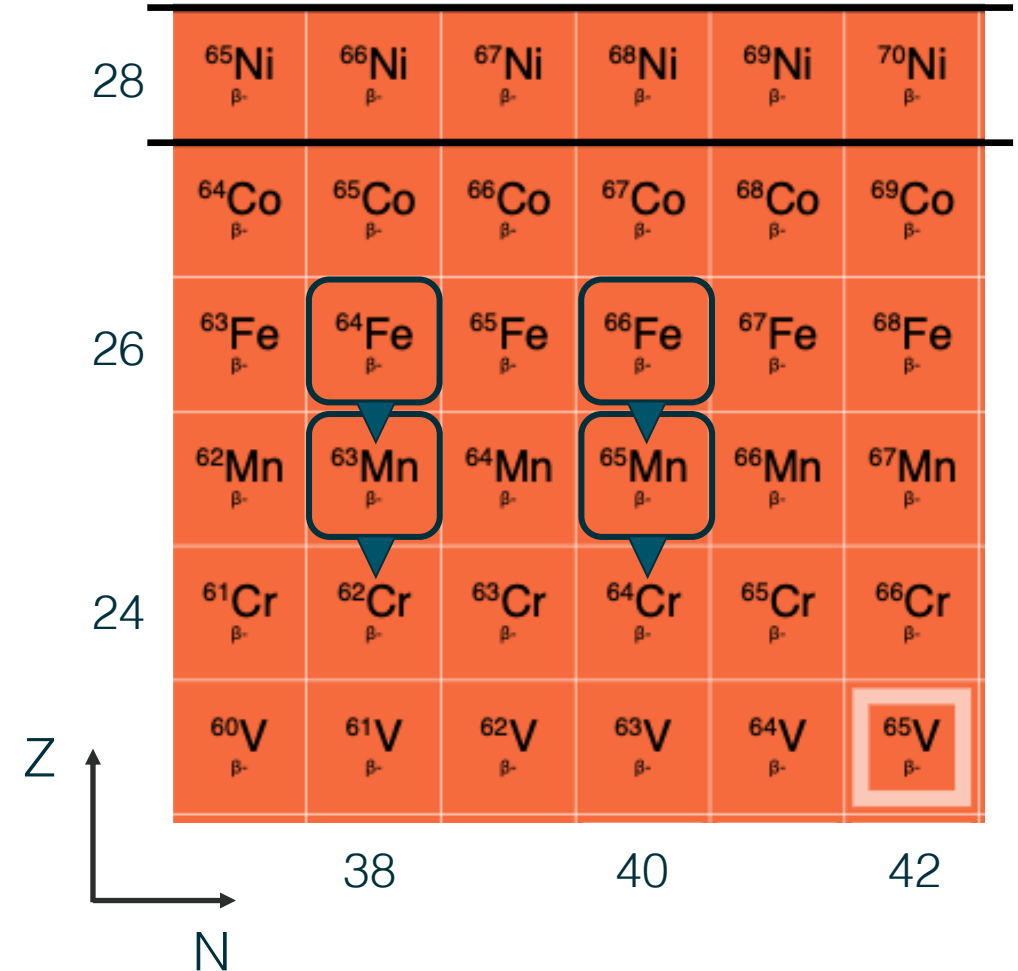
Final State	C ² S SM	C ² S Nilsson
5/2 ⁻ ₁	0.04	0.20
7/2 ⁻ ₁	3.25	1.80
*7/2 ⁻ ₂	0.71	1.69
*3/2 ⁻ ₁	0.13	0.20

*Not identified yet.

Probing Spectroscopic Factor via Proton Knockout Reactions

Experimental goals:

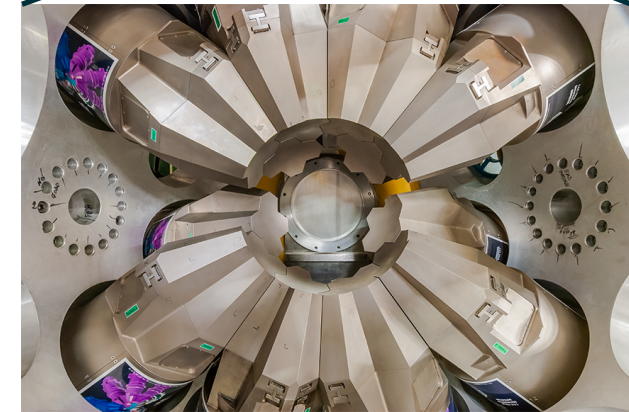
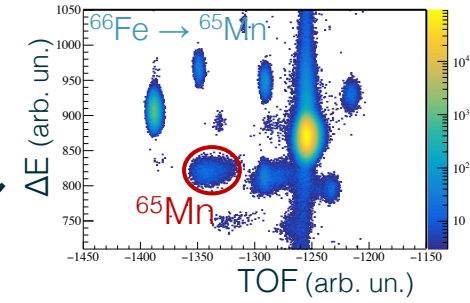
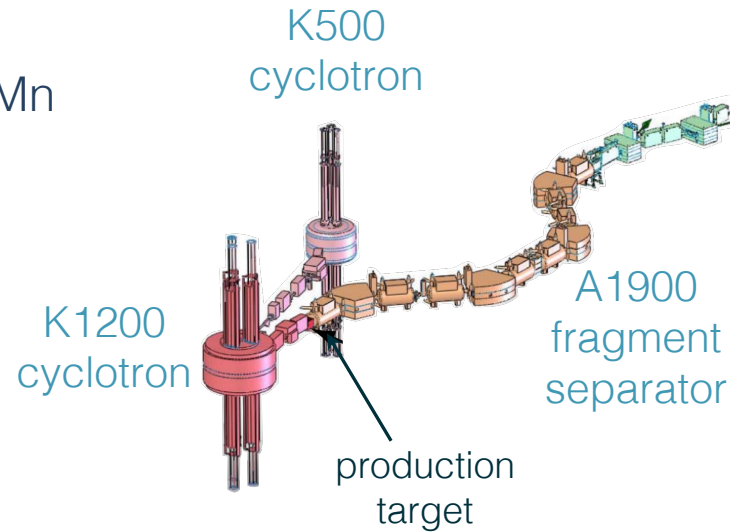
- determining the proton spectroscopic factors in $^{64,66}\text{Fe}$ and $^{63,65}\text{Mn}$ through one-proton knockout reactions
- expand the level scheme of the final nuclei



NSCL experiment E19019

at the NSCL Coupled Cyclotron Facility.

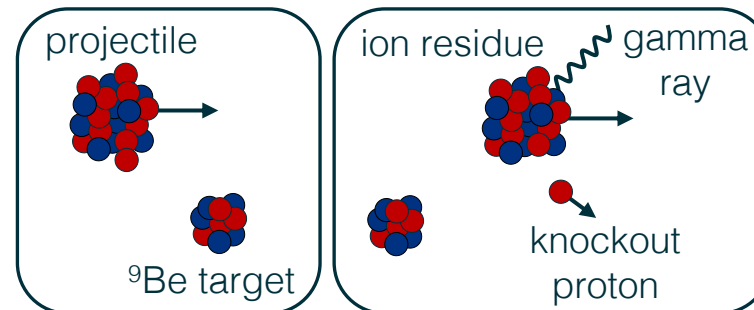
- Primary Beam ^{76}Ge ;
secondary beams $^{64,66}\text{Fe}$, $^{63,65}\text{Mn}$



https://people.nsl.msui.edu/~noji/gret_12det

^9Be target (1 mm) and
GRETINA (12 quads)

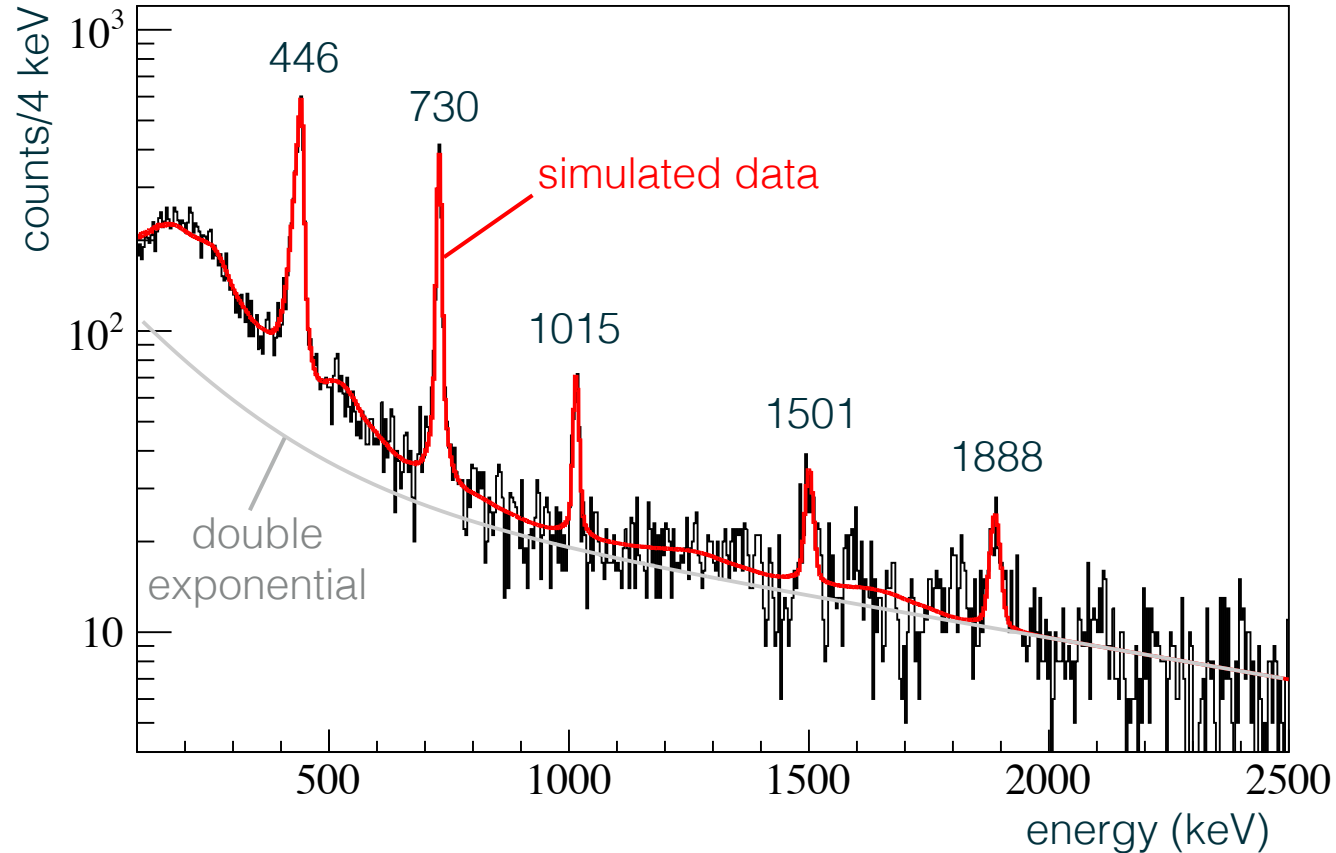
- Direct proton knockout
into Mn and Cr isotopes



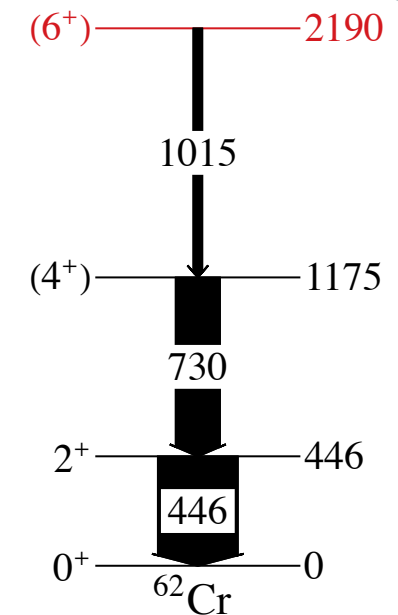
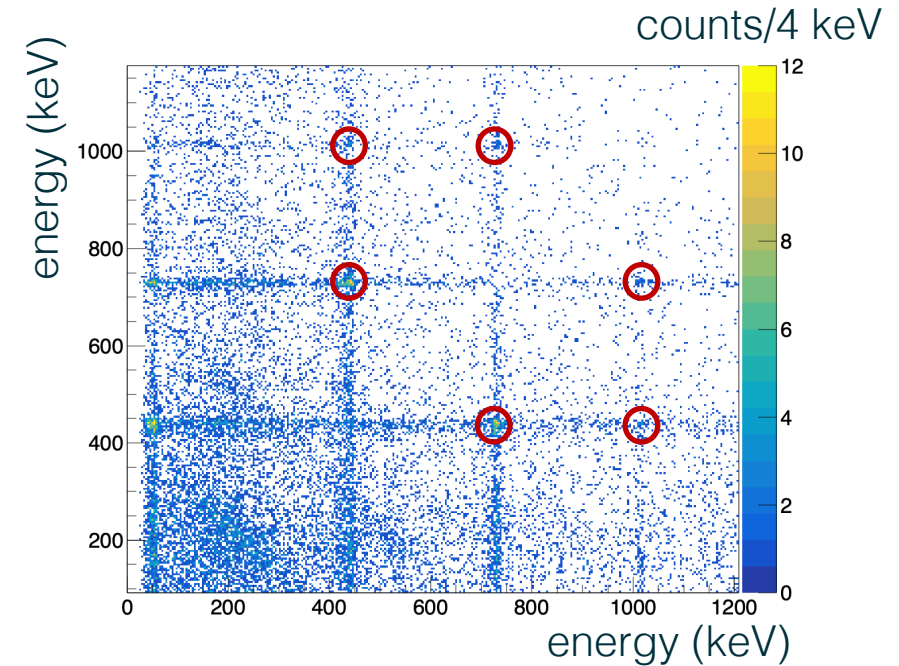
$$\sigma_{\text{exp},i} \propto C^2 S_i \cdot \sigma_{\text{sp},i}$$

- Paschalis *et al.*, NIM A 709 (2013) 44–55
- Bazin *et al.*, NIM B 204 (2003) 629–633

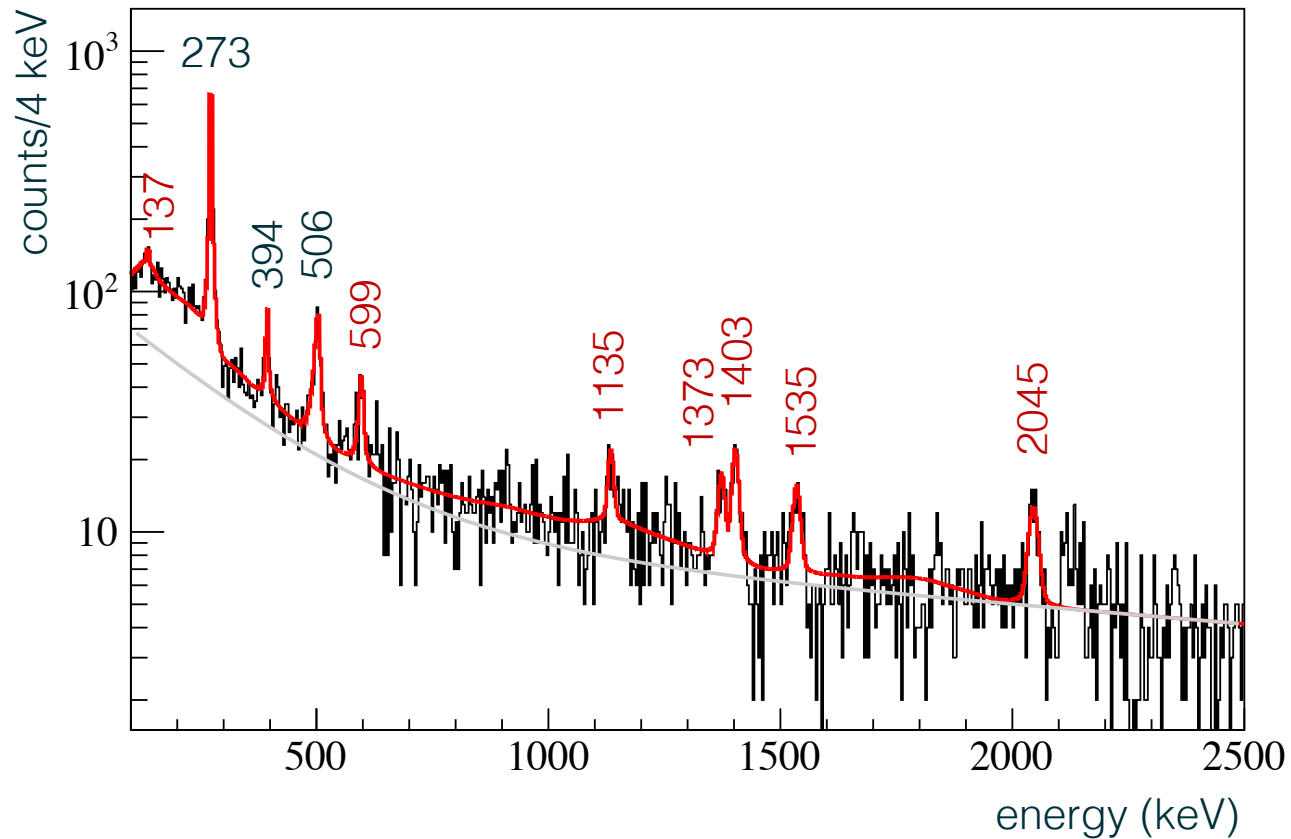
^{62}Cr gamma-ray spectrum from ^{63}Mn



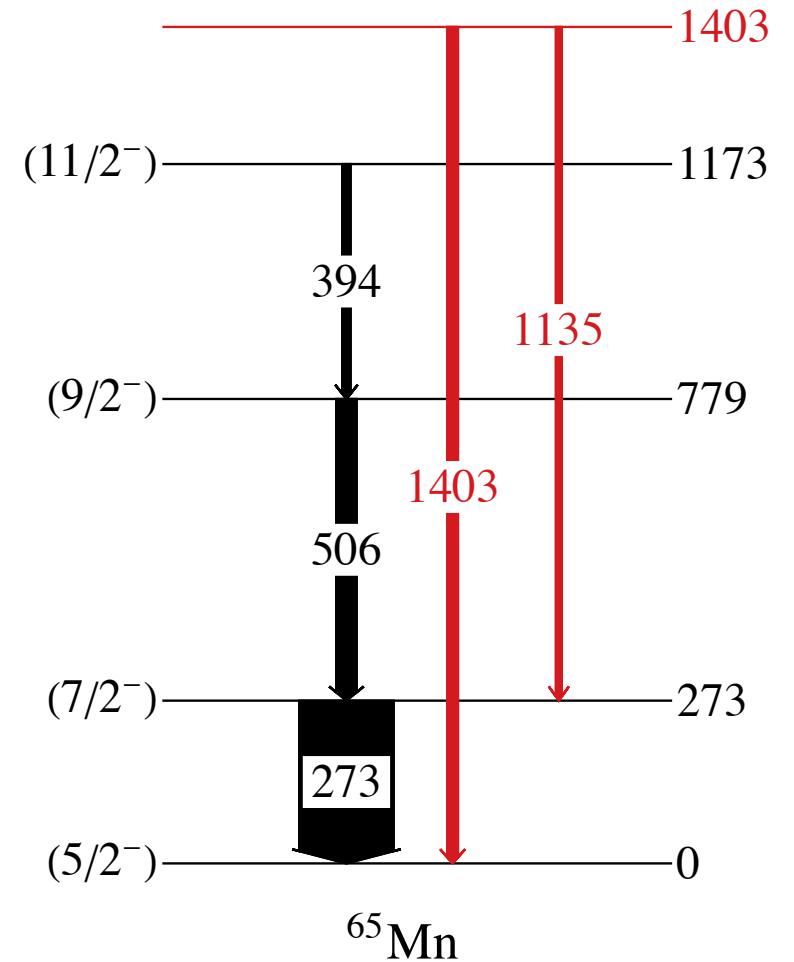
- Braunroth *et al.*, PRC 92 (2015) 034306
- Gade *et al.*, PRC 103 (2021) 014314



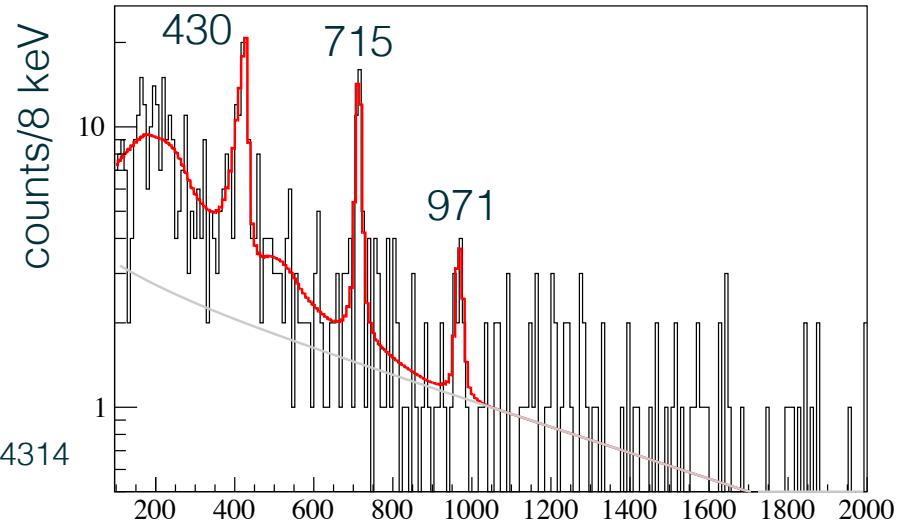
^{65}Mn gamma-ray spectrum from ^{66}Fe



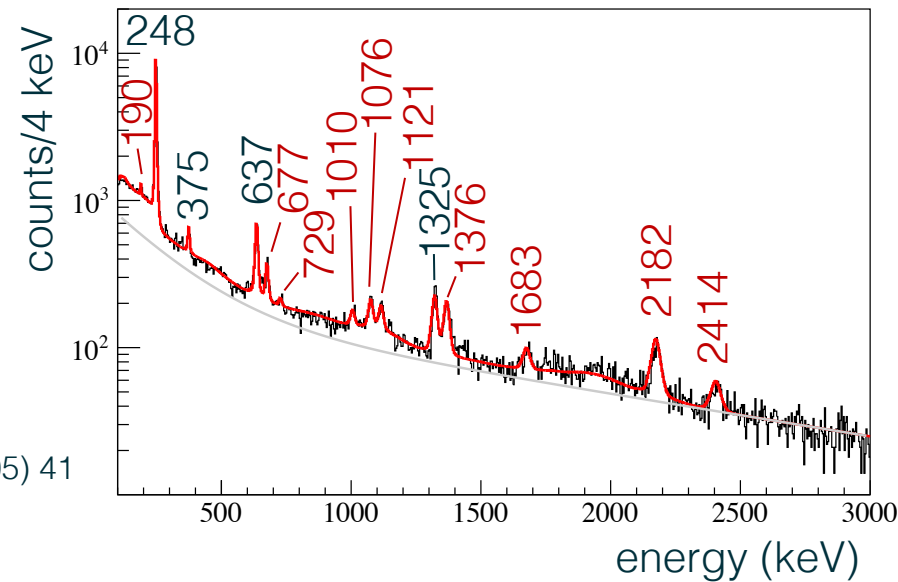
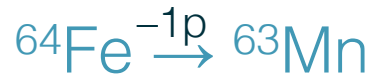
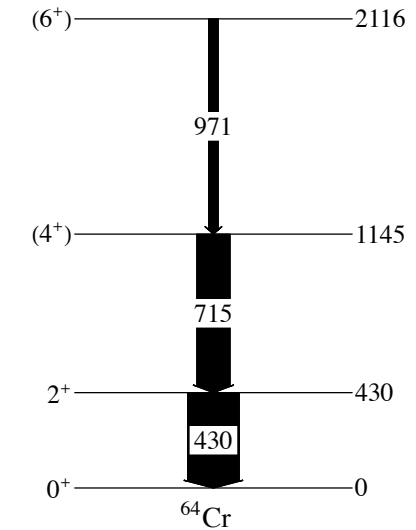
► Liu *et al.*, PLB 784 (2018) 392



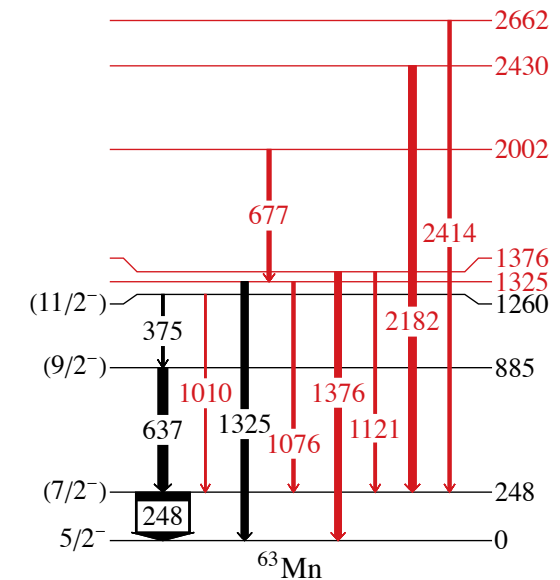
^{64}Cr and ^{63}Mn gamma-ray spectra



► Gade *et al.*, PRC 103 (2021) 014314



► Liu *et al.*, PLB 784 (2018) 392
 ► Gaudefroy *et al.*, EPJ A 23 (2005) 41



Preliminary Results



Final State	C ² S SM	C ² S Nilsson	$\sigma_{\text{exp},i}$ [mb]
0^+_1	0.0	0.03	$0.8(3.1)_{\text{stat}}$
2^+_1	0.59	0.58	$4(2)_{\text{stat}}$
4^+_1	0.56	0.36	$5(2)_{\text{stat}}$
6^+_1	0.0	0.02	$1.8(1.2)_{\text{stat}}$
$*8^+_1$	0.04	0.0	—

*Not identified yet.



$\sigma_{\text{exp},i}$ [mb]
$0.6(7)_{\text{stat}}(+0_{-0.8})_{\text{syst}}$
$4.9(5)_{\text{stat}}(+0_{-1.6})_{\text{syst}}$
$4.9(4)_{\text{stat}}(+0_{-1.6})_{\text{syst}}$
$1.2(1)_{\text{stat}}(8)_{\text{syst}}$
—



Final State	C ² S SM	C ² S Nilsson	$\sigma_{\text{exp},i}$ [mb]
$5/2^-_1$	0.04	0.20	$4.4(3)_{\text{stat}}(+0_{-1.5})_{\text{syst}}$
$7/2^-_1$	3.25	1.80	$3.0(2)_{\text{stat}}(+0_{-1.5})_{\text{syst}}$
$*7/2^-_2$	0.71	1.69	—
$*3/2^-_1$	0.13	0.20	—
$9/2^-_1$			$0.5(1)_{\text{stat}}(5)_{\text{syst}}$
$11/2^-_1$			$0.36(6)_{\text{stat}}(+0.45_{-0.36})_{\text{syst}}$
?			$0.7(2)_{\text{stat}}(7)_{\text{syst}}$

$$\sigma_{\text{exp},i} \propto C^2S_i \cdot \sigma_{\text{sp},i}$$

Summary and Outlook

- The $N=40$ Island of Inversion is under investigation via proton knockout reactions along the $N=38$ and 40 isotonic chains.
- The experiment aims to benchmark large-scale shell model and Nilsson model calculations, which provide different predictions for proton spectroscopic factors.
- The analysis of four reactions is ongoing:
 - exclusive cross sections
 - parallel momentum distributions to investigate new state spins and parities
- Spectroscopic factors will be extracted via a comparison with calculated theoretical cross sections (J. Tostevin).

Thank You



Lawrence Berkeley National Laboratory
H. Crawford, C. Campbell, R. Clark, M. Cromaz, P. Fallon,
A. Frotscher, A. O. Macchiavelli, C. Santamaria



NSCL and MSU
A. Gade, D. Bazin, D. Weisshaar, B. Longfellow, J. Li,
D. Rhodes, M. Hill, P. Farris, S. Biswas



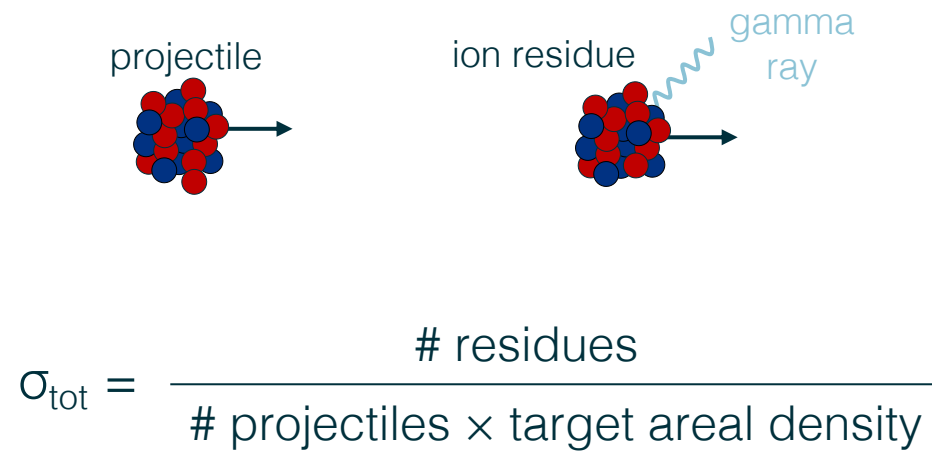
Universidad Autónoma de Madrid
A. Poves



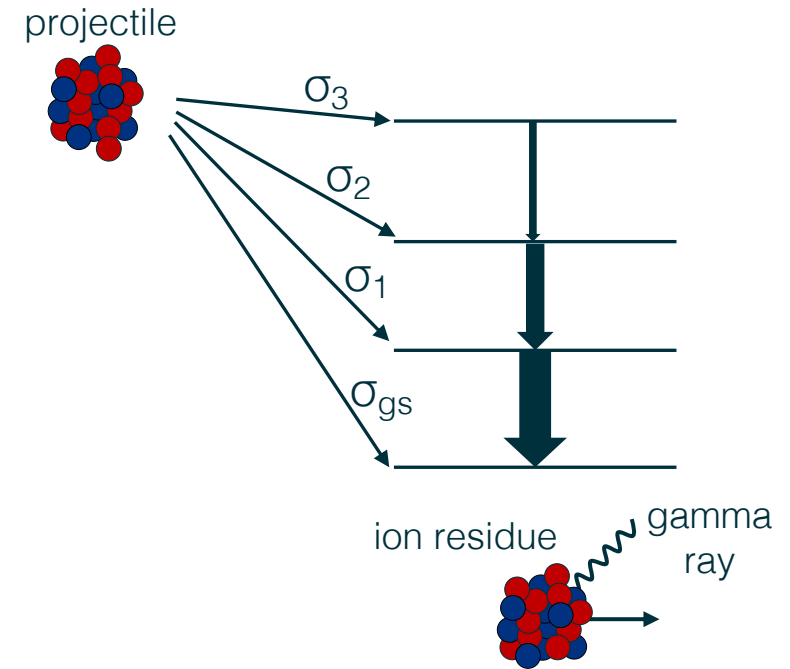
Università degli Studi di Padova and INFN
S. Lenzi

Measuring Cross Sections

Inclusive cross section:



Exclusive cross sections:



$$\sigma_{\text{exp},i} \propto C^2 S_i \cdot \sigma_{\text{sp},i}$$

The Particle Identification

