Neutron Single Particle Strengths in Z = 20, 22, 24 Isotopes

Jiayan Phoenix, Dai
The Chinese University of Hong Kong

Supervisor: Prof. Betty Tsang
National Superconducting Cyclotron Laboratory
Michigan State University

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Content

- Background knowledge:
  - (1) Spectroscopic factor (SF) and its importance
  - (2) Motivation of this project

- Investigation of Ca, Ti, Cr isotopes by considering (d, p) transfer reaction
  - (1) Z=20, Ca41 → Ca43 → Ca45 → Ca47 evolution
  - (2) Comparison of <SF_ex> and SF_sm

- Conclusion

- Appendix:
  - (1) N=27, Ca47 → Ti49 → Cr51 evolution
  - (2) N=29, Ar47 → Ca49 → Ti51 → Cr53 evolution

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Spectroscopic Factor

- **Spectroscopic Factor:**

  It describes the orbital configurations of valence nucleons.

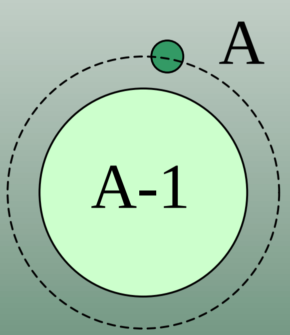
  Since it reveals the fundamental property of nuclides, it is independent of incident energies or involved reactions.

- **Experimental Spectroscopic Factor:**

- $$\left(\frac{d\sigma}{d\Omega}\right)_{ex} = SF\_ex \cdot \left(\frac{d\sigma}{d\Omega}\right)_{th}$$ **calculated by scattering theory, e.g. DWBA.**

obtained by systematic and consistent method.

measured by experiment



- **Theoretical Spectroscopic Factor:**

$$SF\_th = [\int \Phi(\vec{r})\, d\tau]^2, \text{where } \Phi(\vec{r}) = \left\langle \Psi^{A-1} \middle| \Psi^{A} \right\rangle$$

calculated by shell model with residual interaction included, “gx1a”.

If SF_th ≈ SF_ex, our theory explains the experiments very well.

If SF_th >> or << SF_ex, our theory needs modification; or experimental analysis needs revised.

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Shell Model

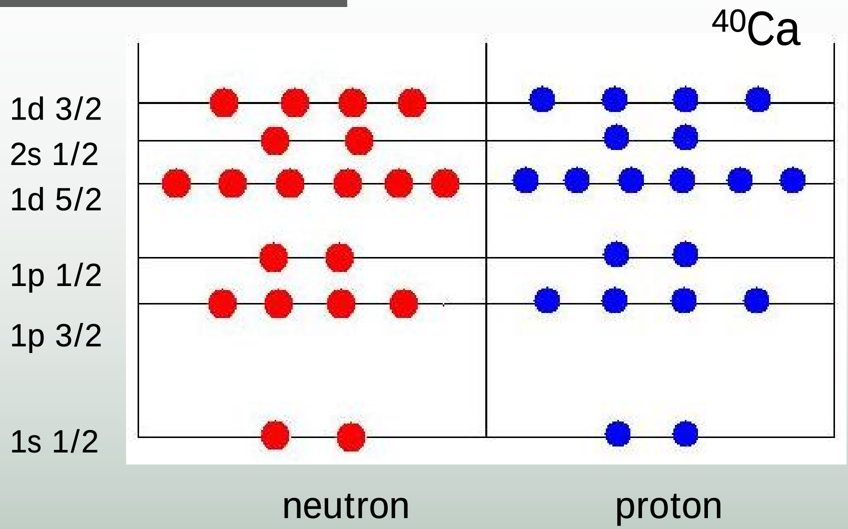
- Some nucleus are found to be more tightly bounded than others → number of protons/neutrons 2, 8, **20**, **28**, 50, 82, 126 (Magic Numbers) → origin of shell model.

- Analogous to the atomic electron model which uses the Pauli principle to describe the structure of electrons in terms of energy levels developed by in 1949.

- Like the electron configuration,

  (1) valence nucleons are moving in a mean field potential of the closed shell

  (2) having n, l, j principle quantum numbers.



From 40Ca using shell model:

1. Assuming spherical core
2. Using pairing interaction, maximal pairing
3. Adding residual interaction

Our shell model calculation is done by Oxbash (computer program) developed by Prof. Alex Brown et al. and Prof. Horoi's computer gx1a (full space) calculation.

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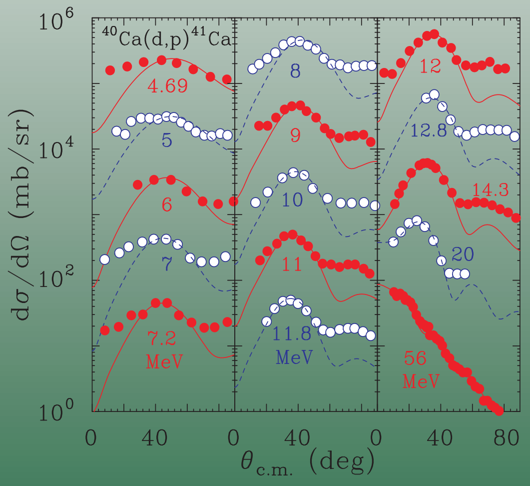
Experimental Spectroscopic Factor

- To extract spectroscopic factor by using consistent and systematic method to analyze all different experimental data.

$$\left(\frac{d\sigma}{d\Omega}\right)_{ex} = SF\_ex \cdot \left(\frac{d\sigma}{d\Omega}\right)_{th}$$

Measured by experiment

Calculated by TwoFNR (computer program) based on DWBA and Optical Model Potential



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- **(1) DWBA calculation with adiabatic approximation to take d-break-up into account.**
- **(2) Global optical potential with global optical model parameters.**
- **(3) Non-local and finite range corrections.**

TwoFNR developed by Prof. Jeff Tostevin

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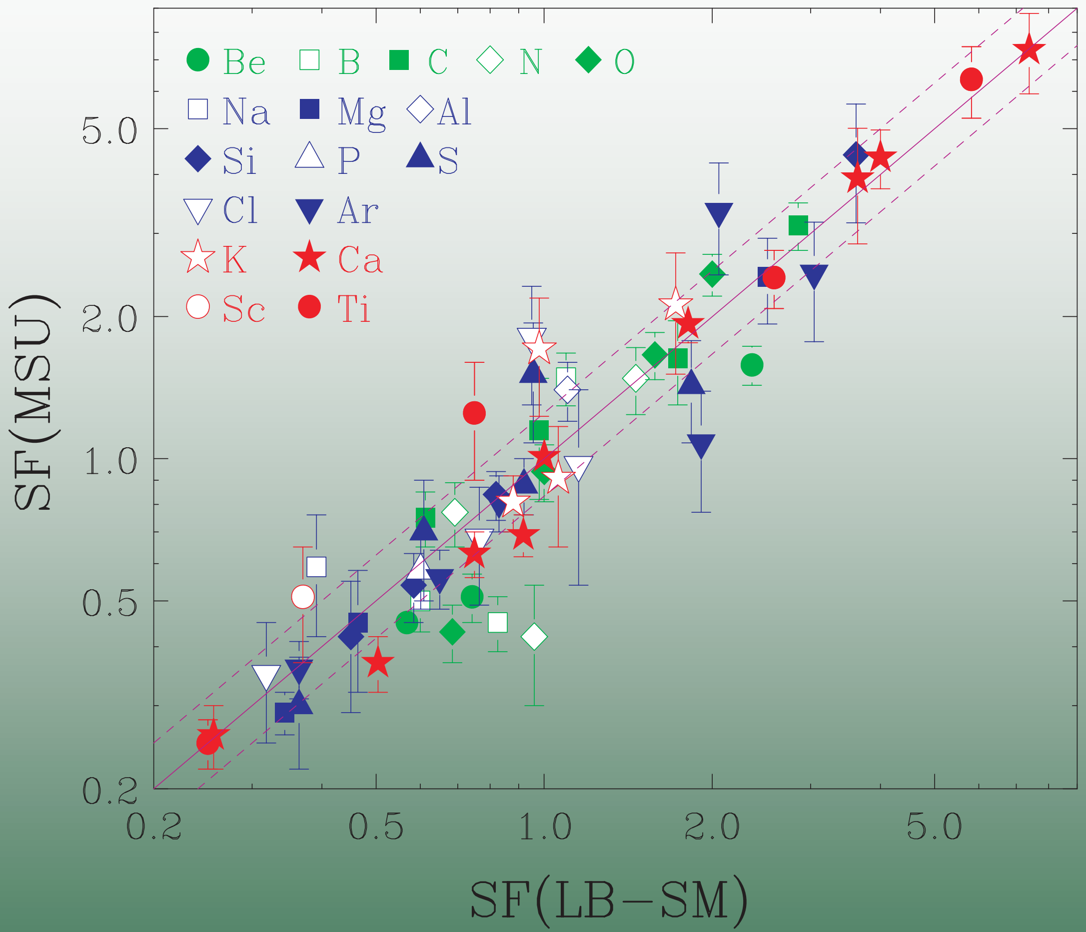
Comparisons with shell model predictions



Z=3	Li	6, 7, 8, 9
Z=4	Be	9, 10, 11
Z=5	B	10, 11, 12
Z=6	C	12, 13, 14, 15
Z=7	N	14, 15, 16
Z=8	O	16, 17, 18, 19
Z=9	F	19, 20
Z=10	Ne	21, 22, 23
Z=11	Na	24
Z=12	Mg	24, 25, 26, 27
Z=13	Al	27, 28
Z=14	Si	28, 29, 30, 31
Z=15	P	32
Z=16	S	32, 33, 34, 35, 37
Z=17	Cl	35, 36, 37, 38
Z=18	Ar	36, 37, 38, 39, 40, 41
Z=19	K	39, 40, 41, 42
Z=20	Ca	40, 41, 42, 43, 44,45, 47, 48, 49
Z=21	Sc	45, 46
Z=22	Ti	46, 47, 48, 49, 50,51
Z=23	V	51
Z=24	Cr	50, 51, 52, 53, 55

M.B. Tsang, et al, PRL95, 222501 (2005).

2004 SURE Talk by Jenny Lee

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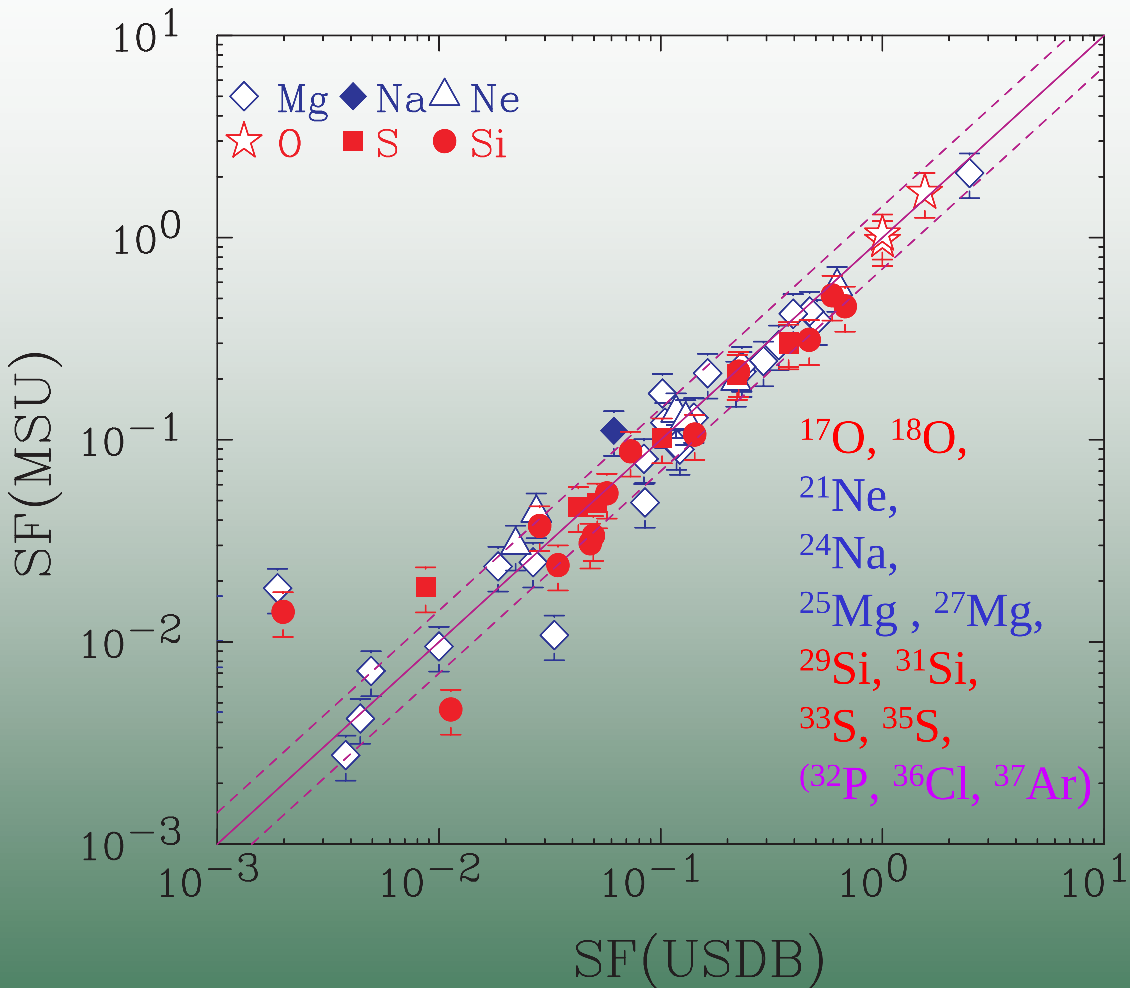
Excited States of sd shell nuclei



- The previous work was about ground state.
- For the excited states of sd shell nuclei, the agreement with shell model is within 30% uncertainty.
- 30% is also consistent with experimental uncertainties.

Data from Shichun Su, Jenny Lee and Betty Tsang

2006 SURE Talk by Shichun Su

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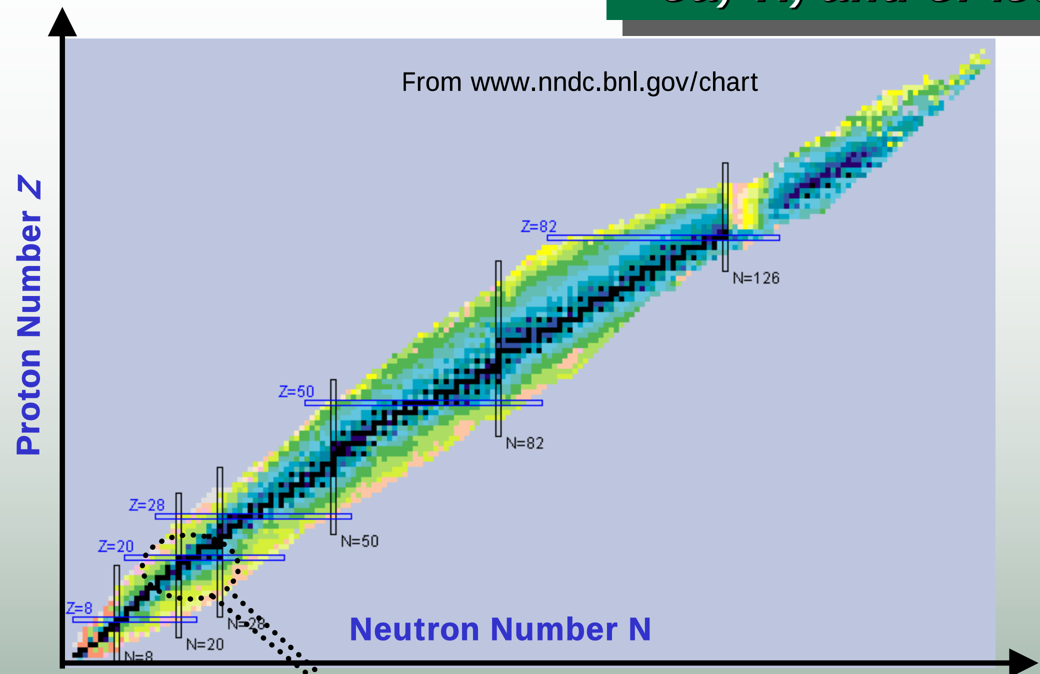
Ca, Ti, and Cr isotopes



- We study three regions:
- Fixed proton number Z=20, 41Ca, 43Ca, 45Ca and 47Ca
- Fixed neutron number N=27, 47Ca, 49Ti and 51Cr
- Fixed neutron number N=29, 47Ar, 49Ca, 51Ti and 53Cr

				Chromium	48Cr	49Cr	50Cr	51Cr	52Cr	53Cr	54Cr	55Cr
				Vanadium	47V	48V	49V	50V	51V	52V	53V	54V
				Titanium	46Ti	47Ti	48Ti	49Ti	50Ti	51Ti	52Ti	
		Scandium	43Sc	44Sc	45Sc	46Sc	47Sc	48Sc	49Sc	50Sc	51Sc	
Calcium	40Ca	41Ca	42Ca	43Ca	44Ca	45Ca	46Ca	47Ca	48Ca	49Ca	50Ca	
					Potassium	44K	45K	46K	47K	48K	49K	
					Argon	43Ar	44Ar	45Ar	46Ar	47Ar		

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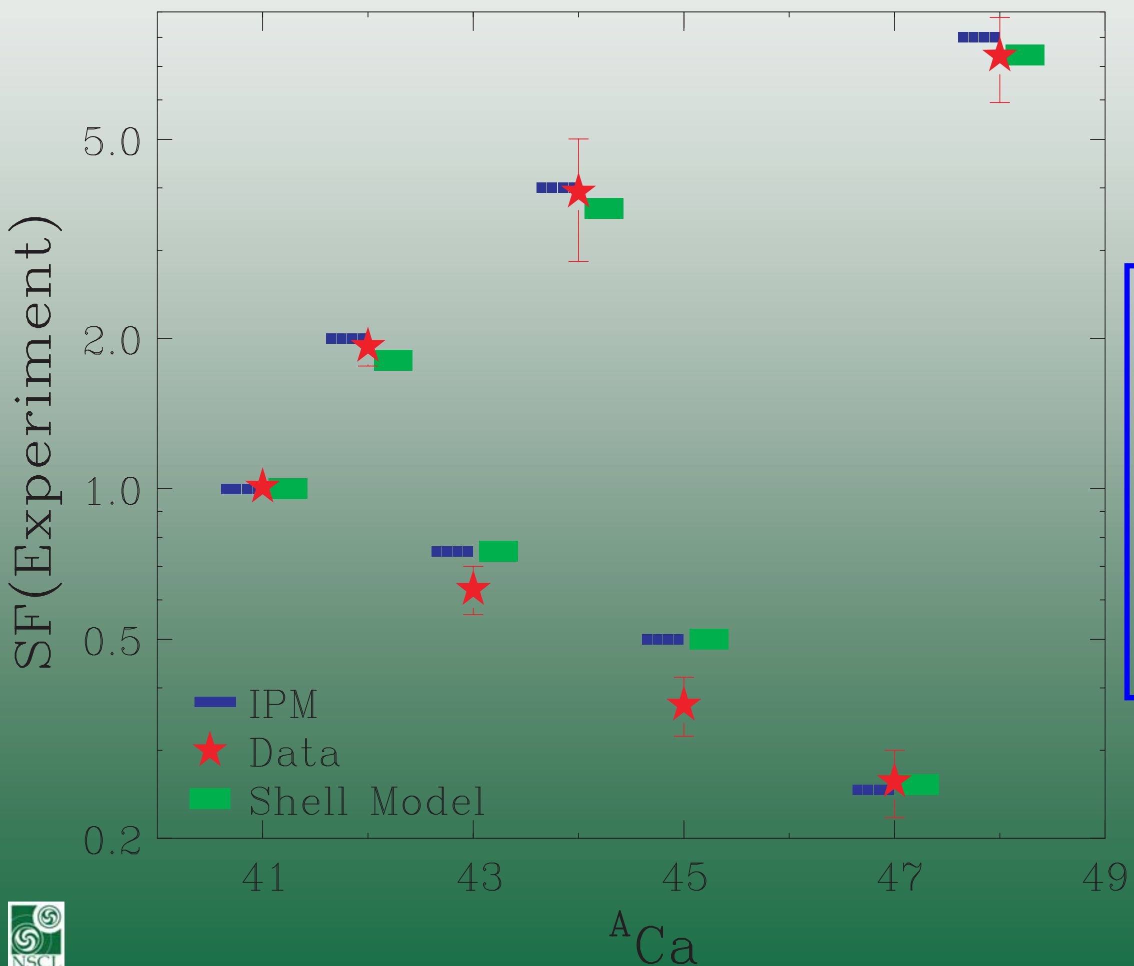
Previous Ca Isotopes' Ground State Study

- **Comparison with Large-Basis Shell Model (Oxbash) and Independent Particle Model (IPM) for Ca isotopes, ^{40}Ca – ^{48}Ca**

M.B. Tsang, et al, PRL95, 222501 (2005).



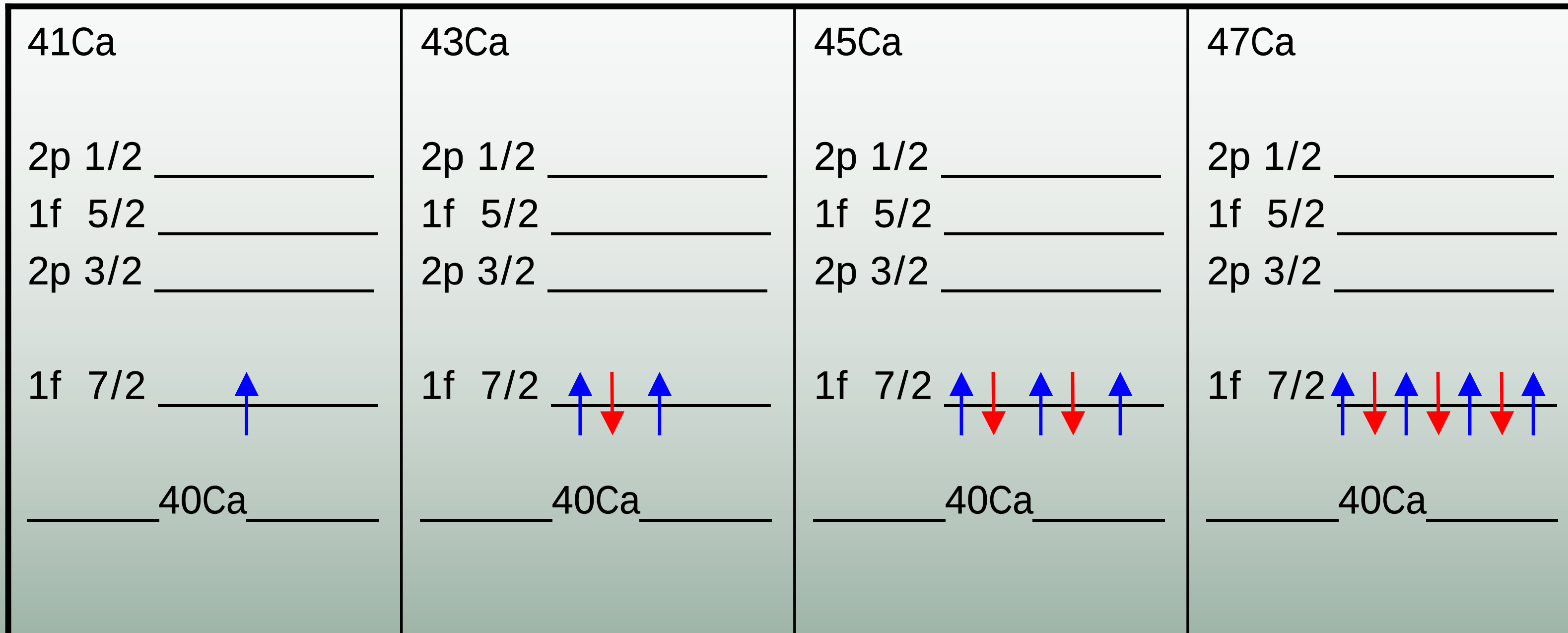
✓ SF's of ^{40}Ca-^{48}Ca isotopes are well described by a pairing interaction and agree very well with IPM and shell model.

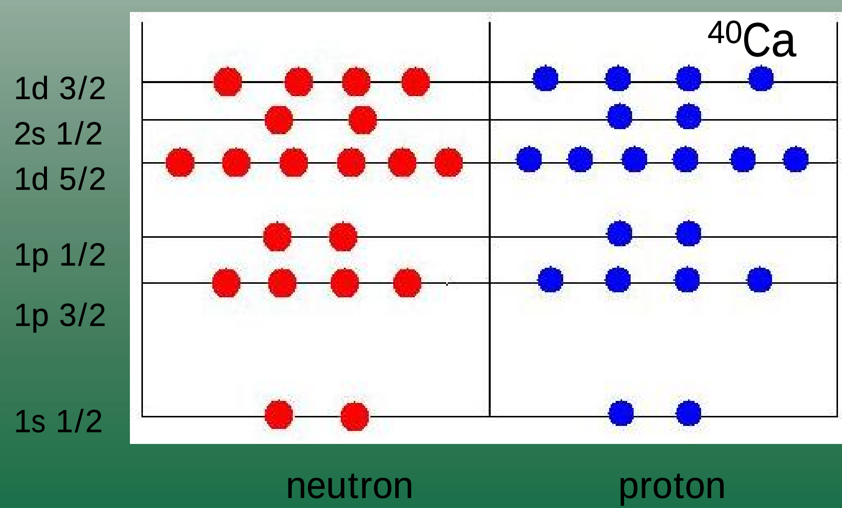
✓ The 1f$_{7/2}$ valance neutrons in Ca isotopes are good single particles with spherical cores.

Is this true also for excited state?

Ca Odd Isotopes

Neutron





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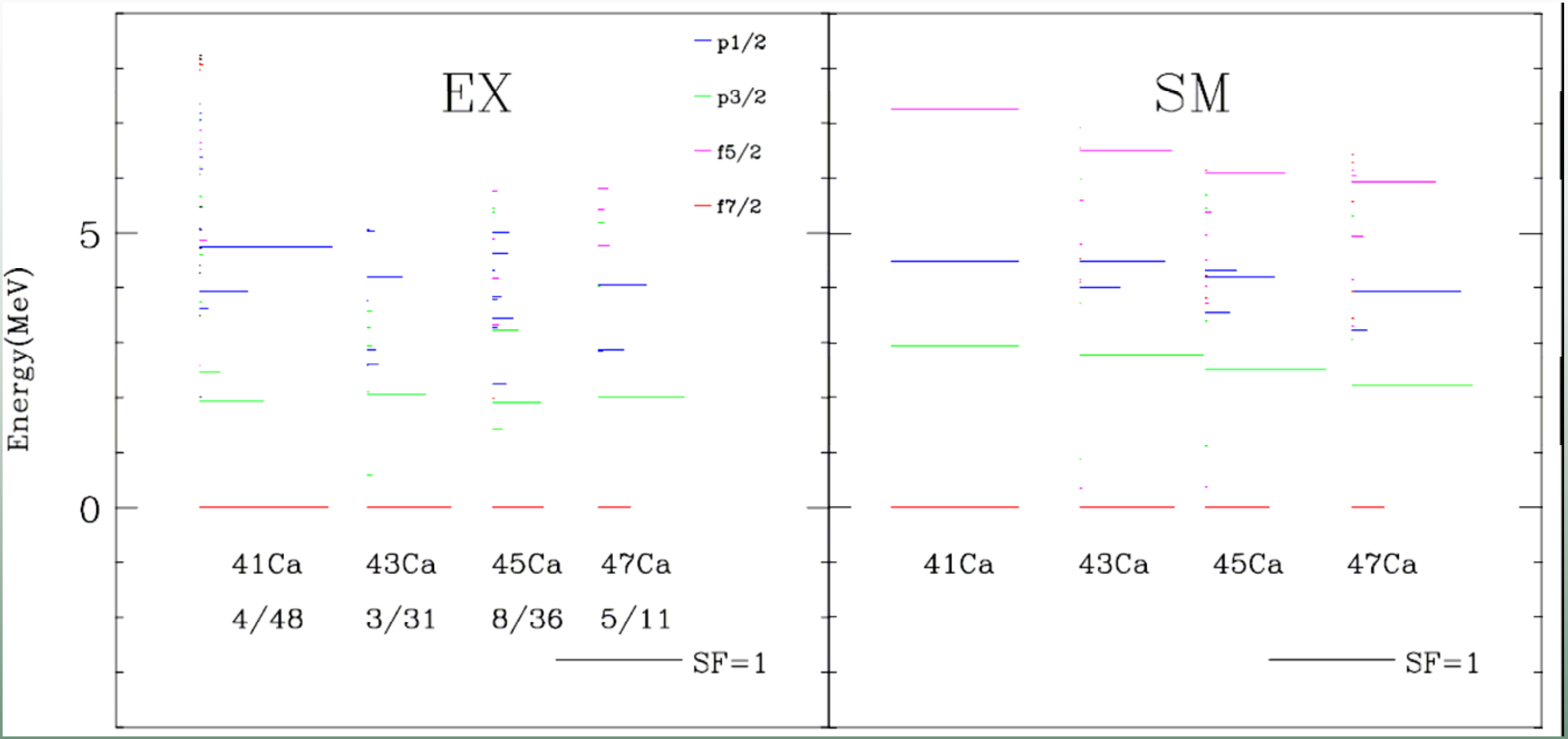
Z=20 Energy Level Plot



- For ground state, experimental results can be well explained by shell model.
- (SM) $N\uparrow$ → excited energy$\downarrow$, SF_sm$\downarrow$; (EX) $N\uparrow$ → can't easily tell the change in excited energy and <SF_ex> due to fragmentation of single particle strengths.
- (SM) $N\uparrow$ → fragmentation$\uparrow$; (EX) even for 41Ca, as for excited state, it has a fragmentation. → Spherical core assumption can't be well applied when talking about excited states.

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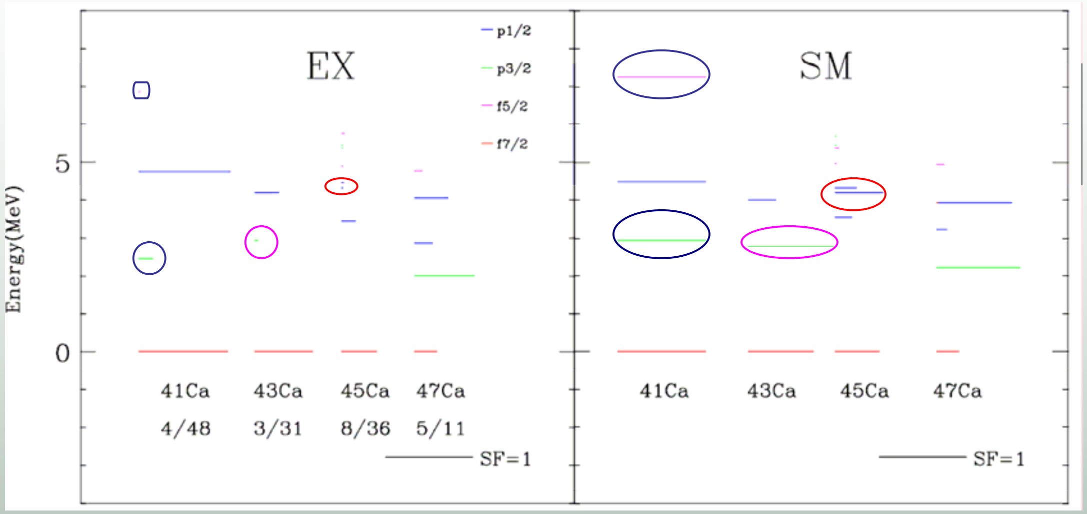
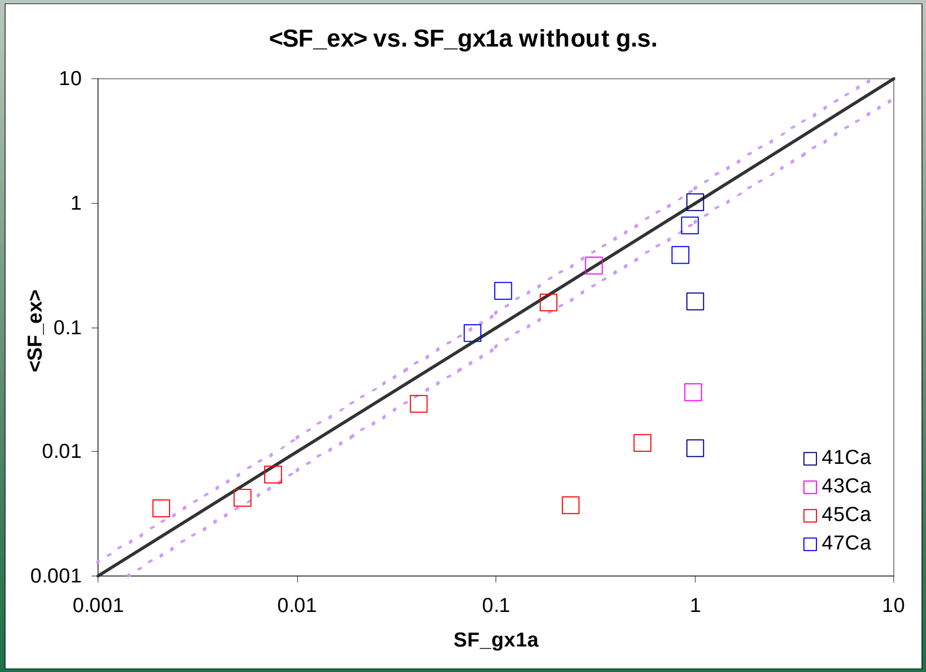
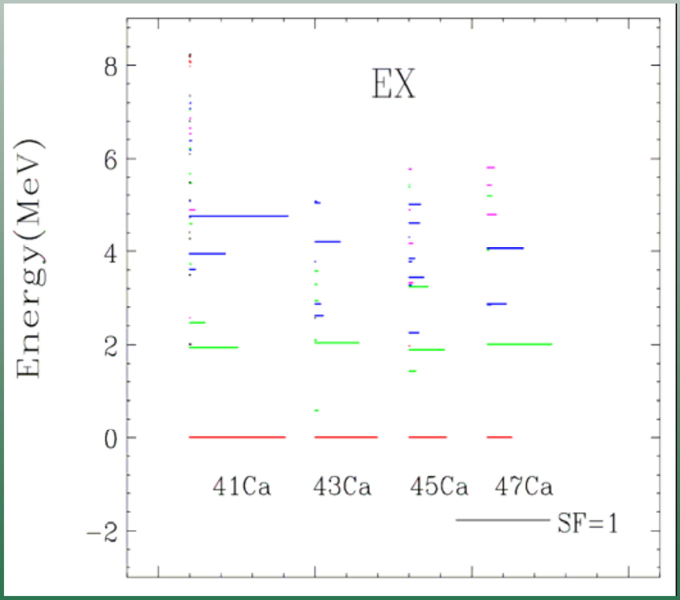
Comparison Between Different Plots of Odd Ca



Only a few states can be compared in the below plot due to inability of shell model to predict these states.





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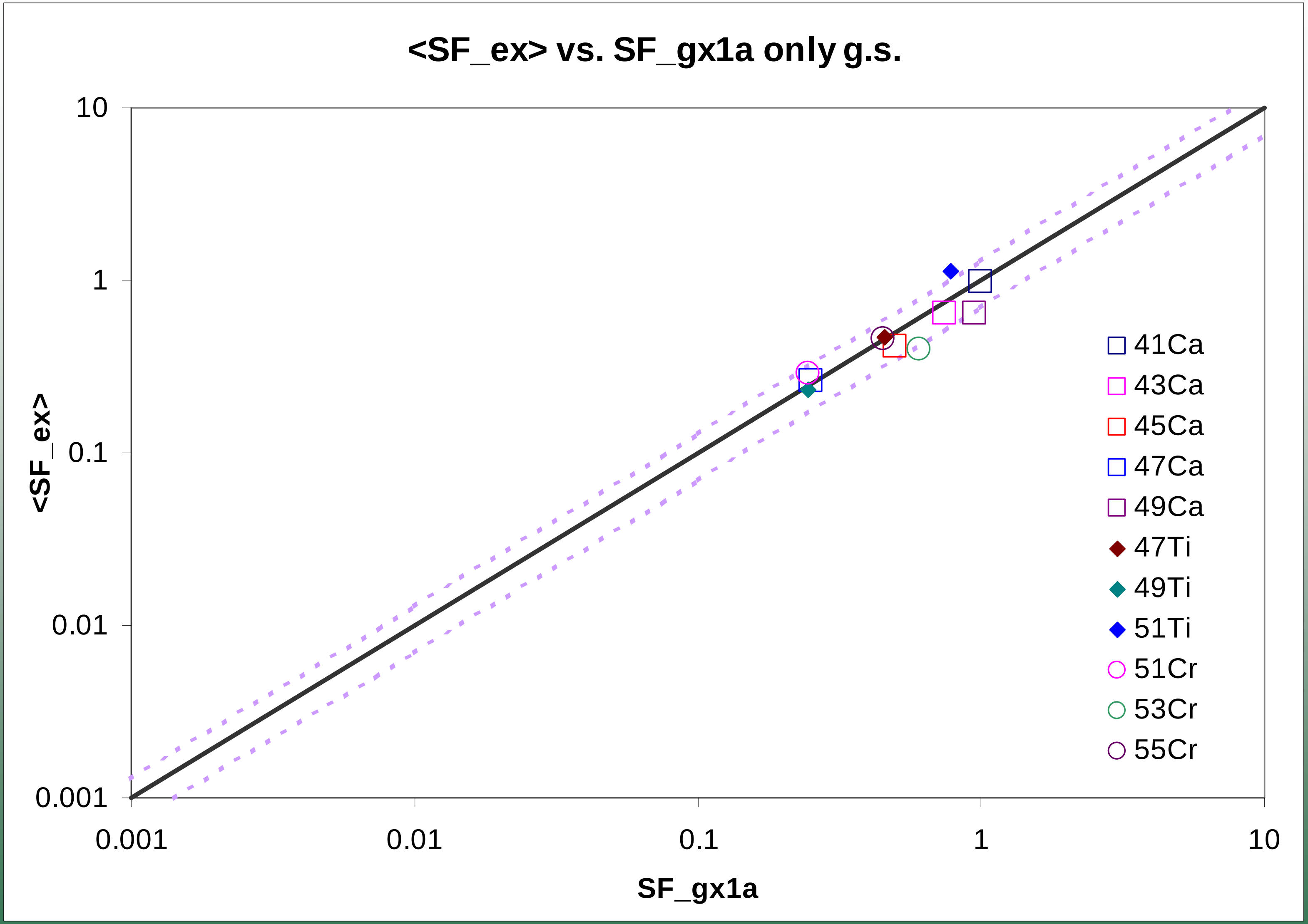
<SF_ex> vs. SF_sm only g.s.



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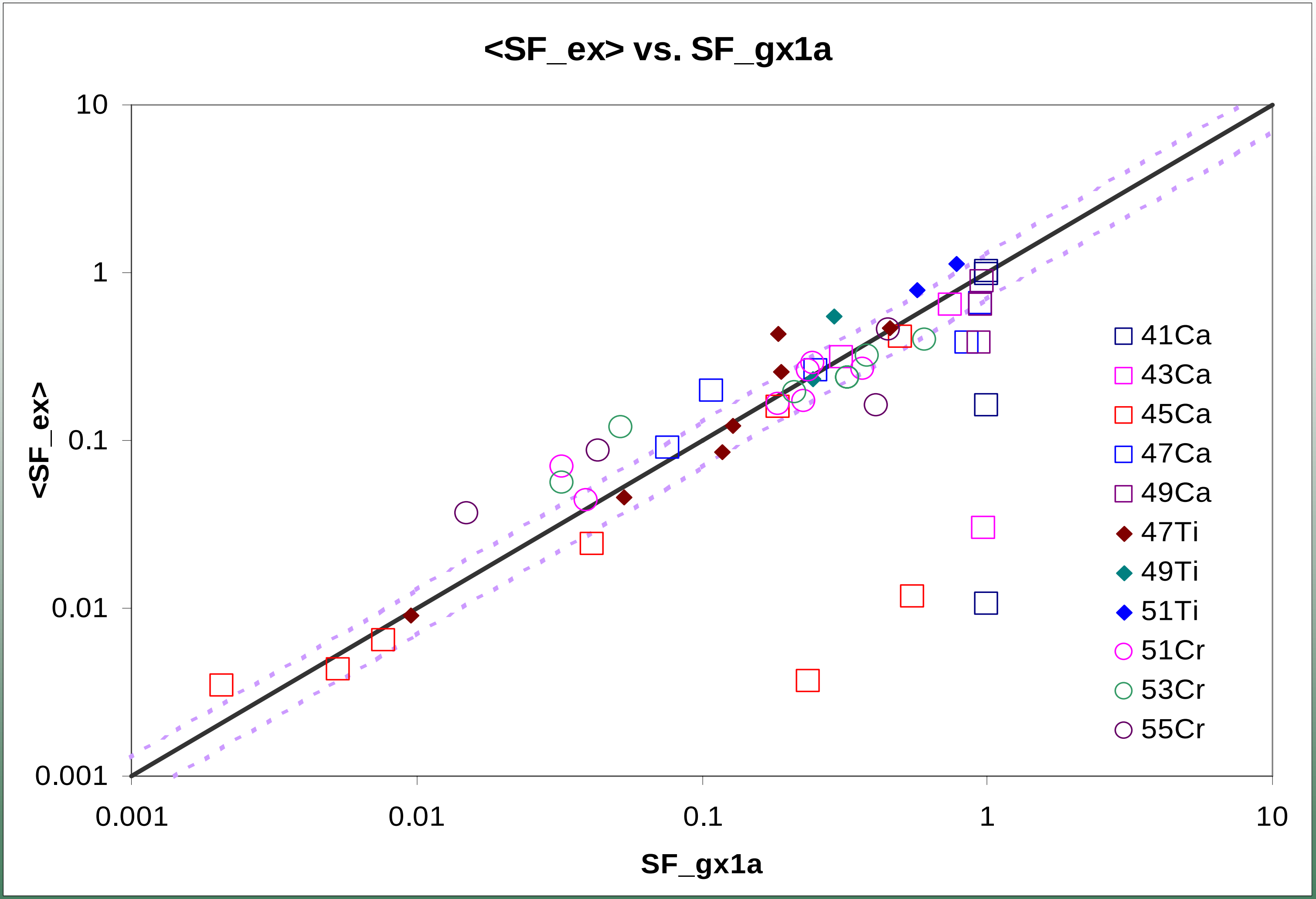
<SF_ex> vs. SF_sm



- Why there are points whose <SF_ex> is much less than corresponding SF_gx1a?
- These states contain fragmentation while the corresponding states calculated in shell model mainly reflect single particle states.

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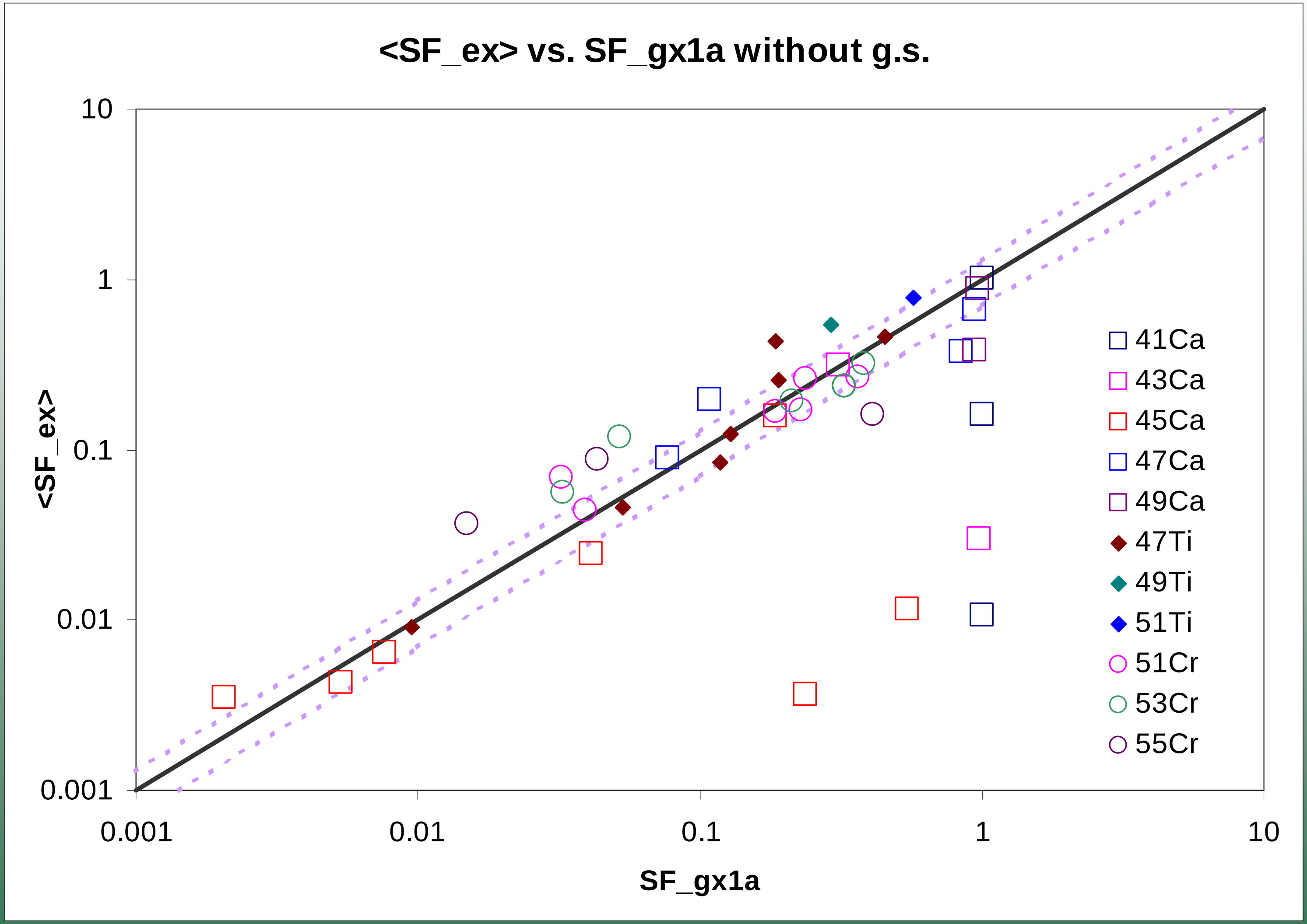
<SF_ex> vs. SF_sm without g.s.



Conclusion

- From <SF_ex> vs. SF_sm plot, we can see the agreement between experiment and theory overall is good, but not as good as sd shell.

- For 41Ca, it used to be considered as a perfect spherical core according to the ground state data; but concerning to experimental work, it is found that excited state of 41Ca has much more fragmentation, far from single particle state.

- Also for other odd Ca isotopes, the states turn out to be more fragmented than predicted theoretically.

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Acknowledgement

- Many thanks to Prof. Tsang for her instructions with a lot of physics insights and her guidance on which direction I should follow.

- Many thanks to Jenny Lee for her always warm-hearted helps and being patient to provide me a lot of explanations.

- Many thanks to Prof. Horoi for his help with the theoretical calculations on Ti, and Cr.

- Many thanks to Prof. Brown and his student to give some time to attend the meeting to offer precious insights and comments.

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Thank you very much!

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Appendix: Ti and Cr involved

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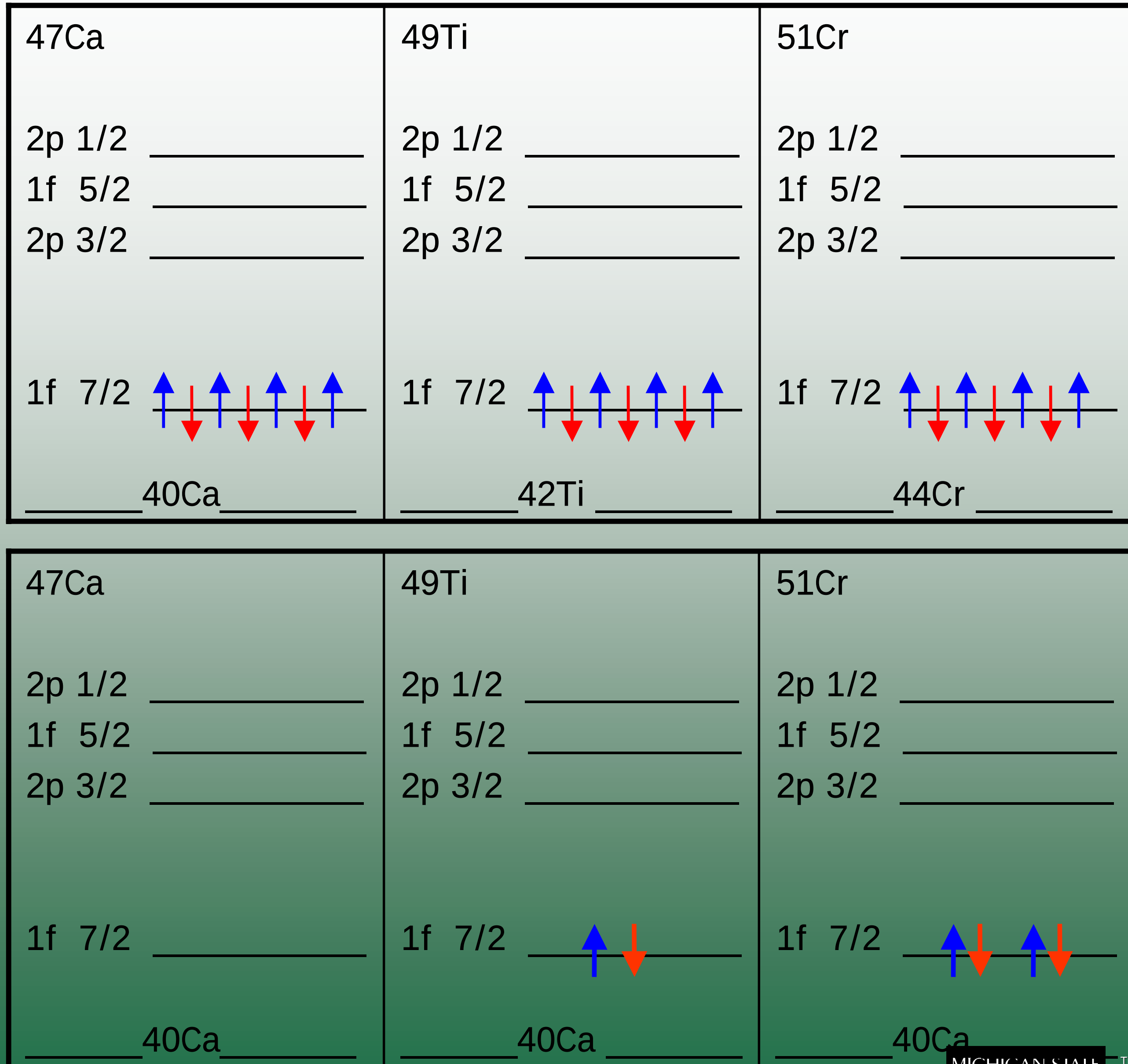
N=27

Neutron

Proton



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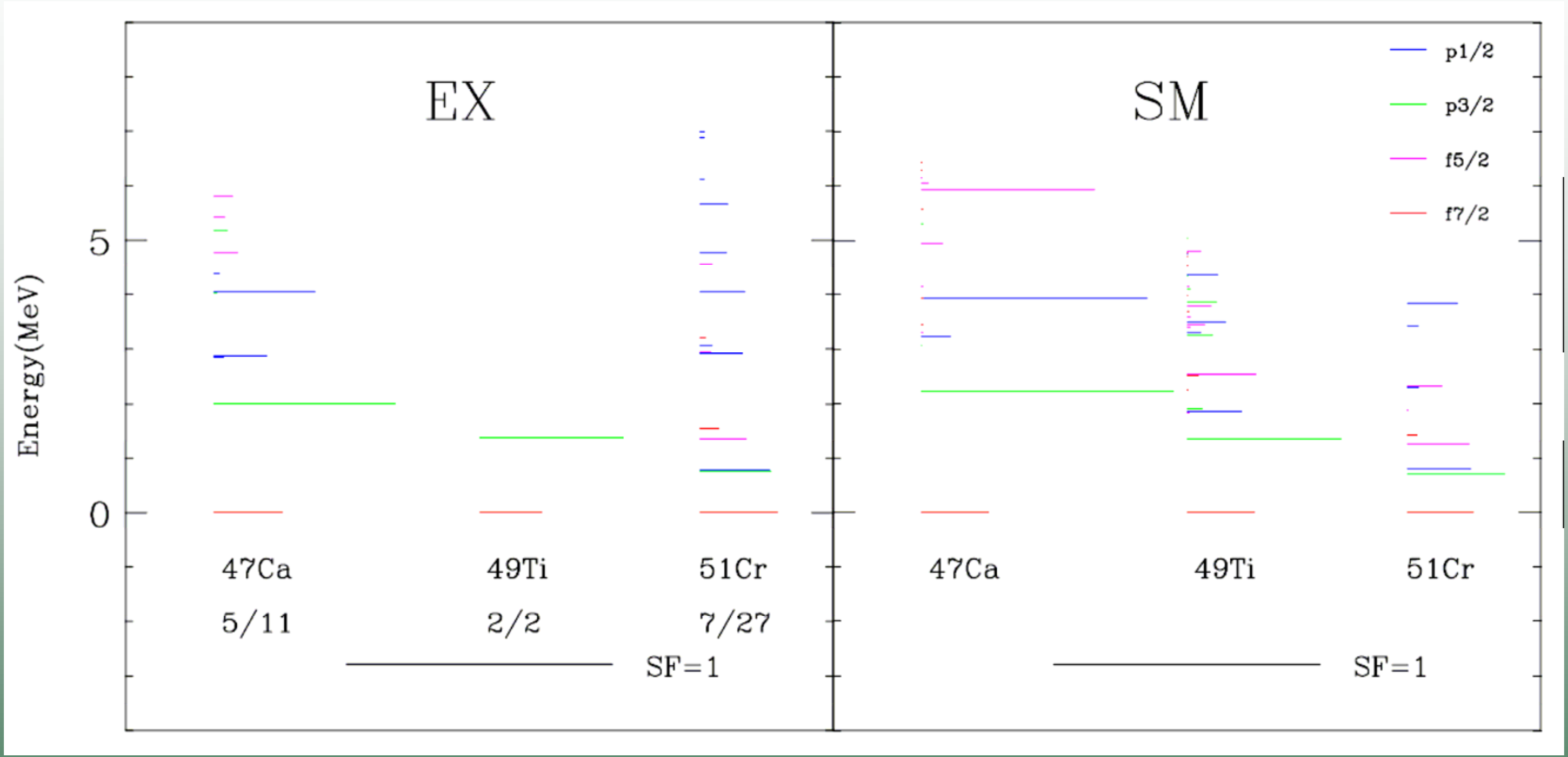
N=27 Energy Level Plot



- For ground state, <SF_ex> can be well explained by SF_sm.
- For excited state of 47Ca, <SF_ex> turns out to be smaller than SF_sm.
- For 51Cr, experimental results have more fragmentation than shell model predicted.

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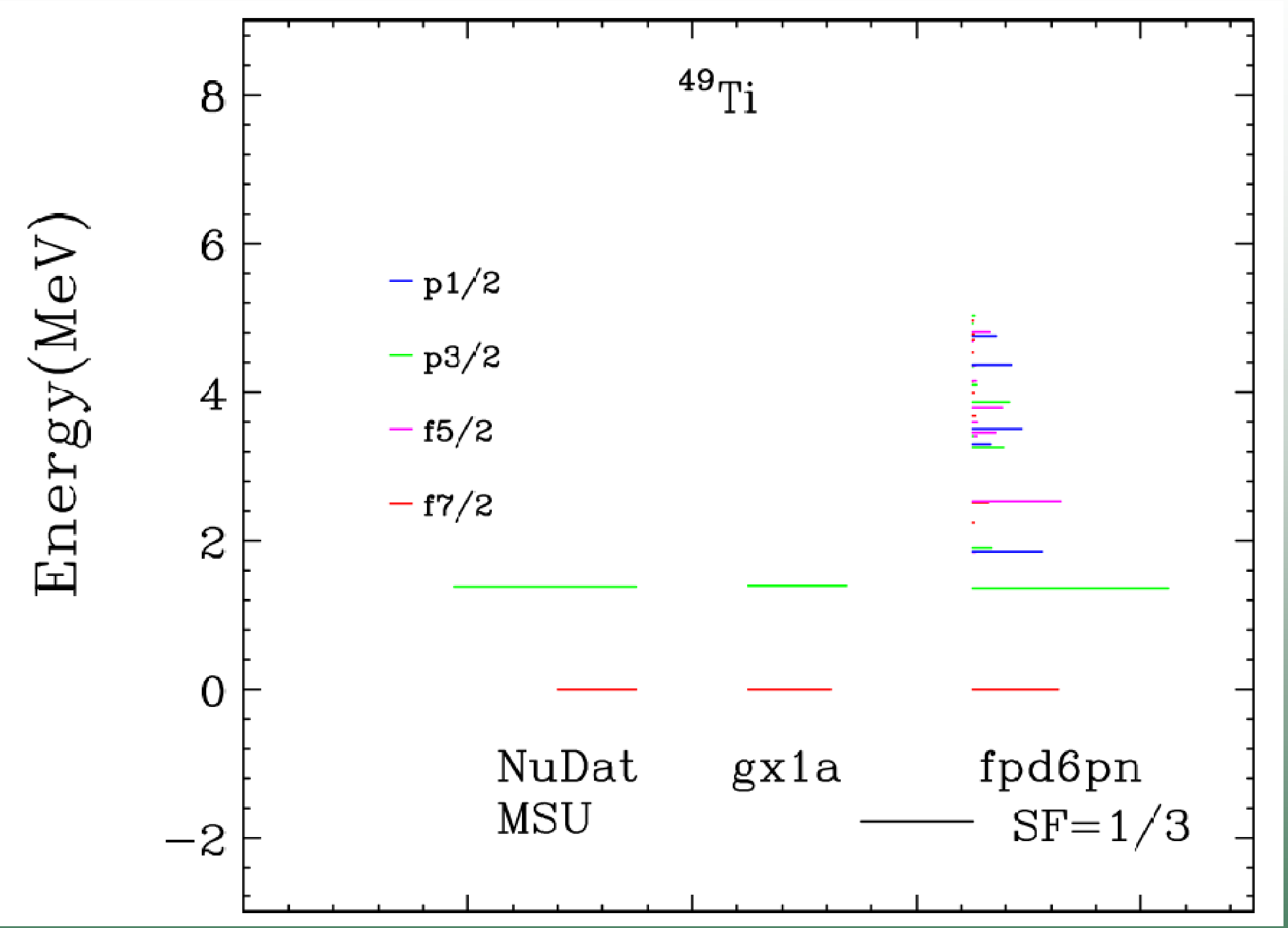
49Ti



- Only two states are shown due to insufficient experimental information.
- Theoretically, more states can be calculated. Here fpd6pn reaction was used to do the calculation. Experimentally, more states can also be measured.

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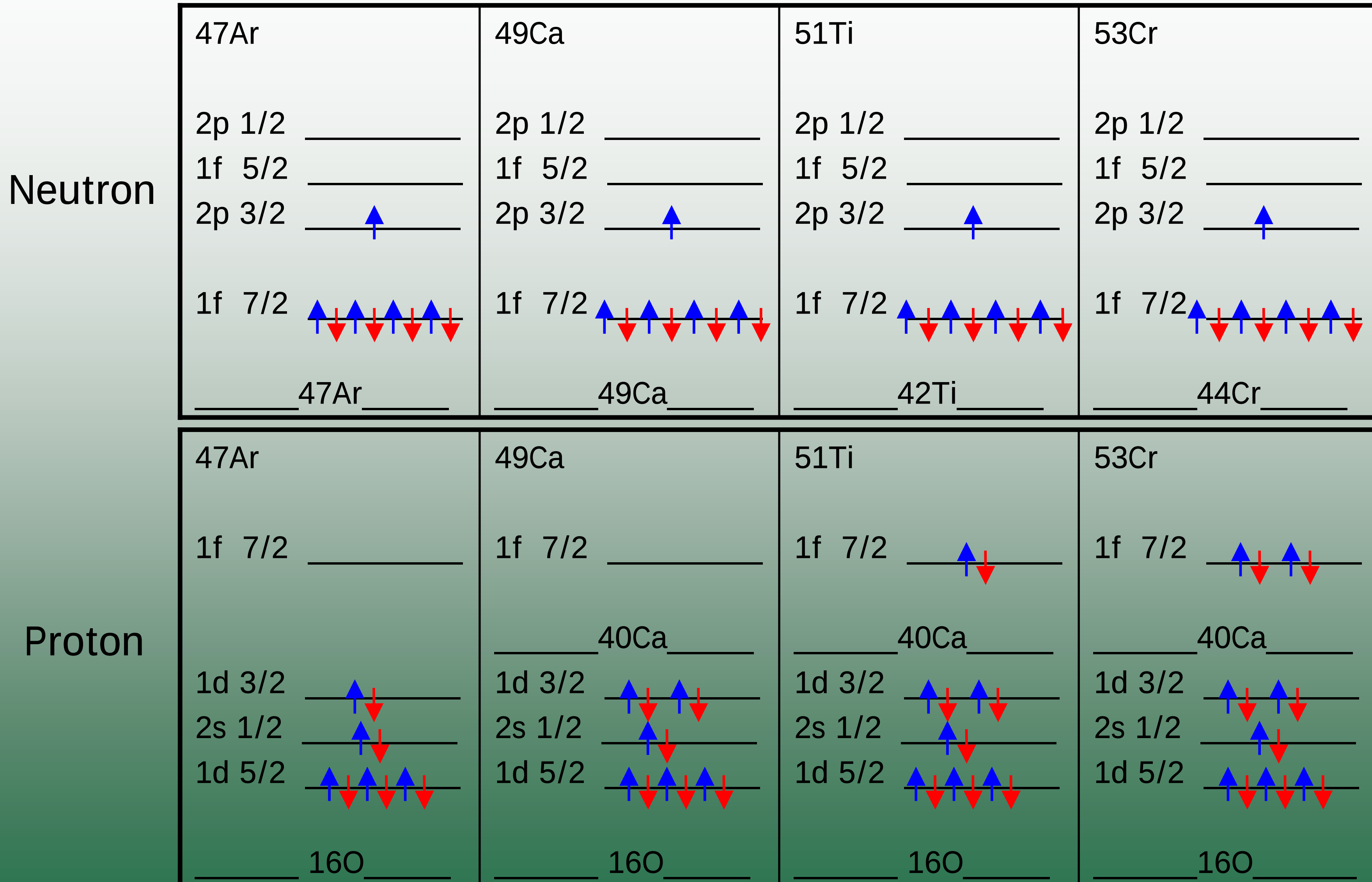
N=29



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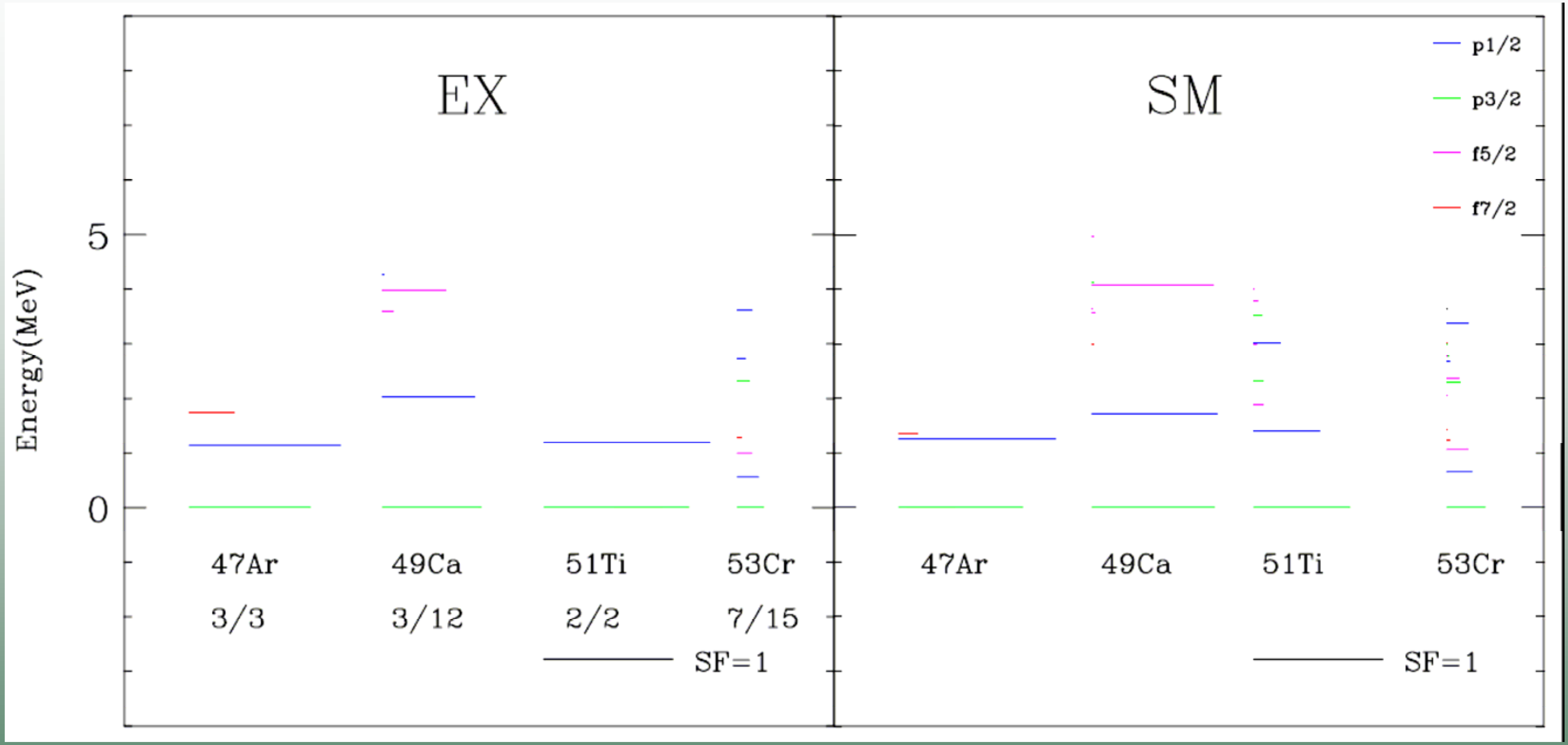
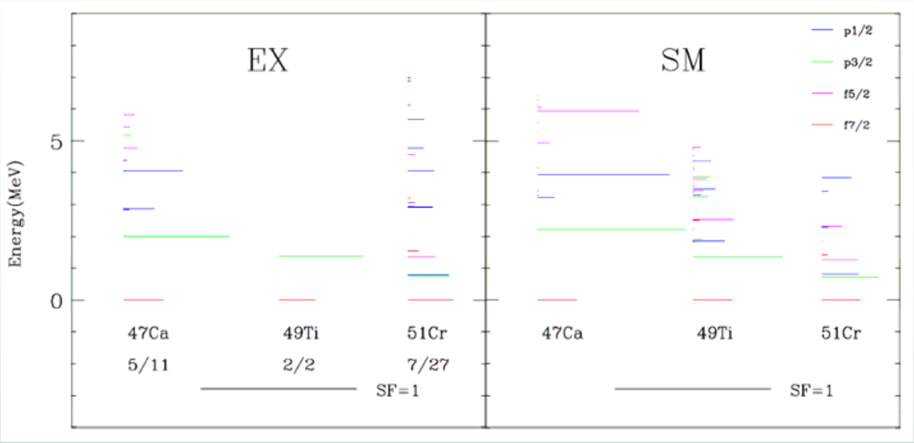
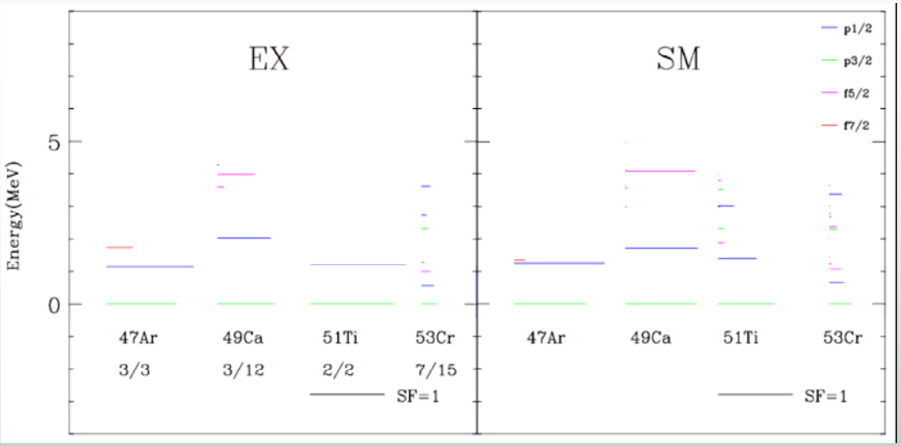
N=29 Energy Level Plot

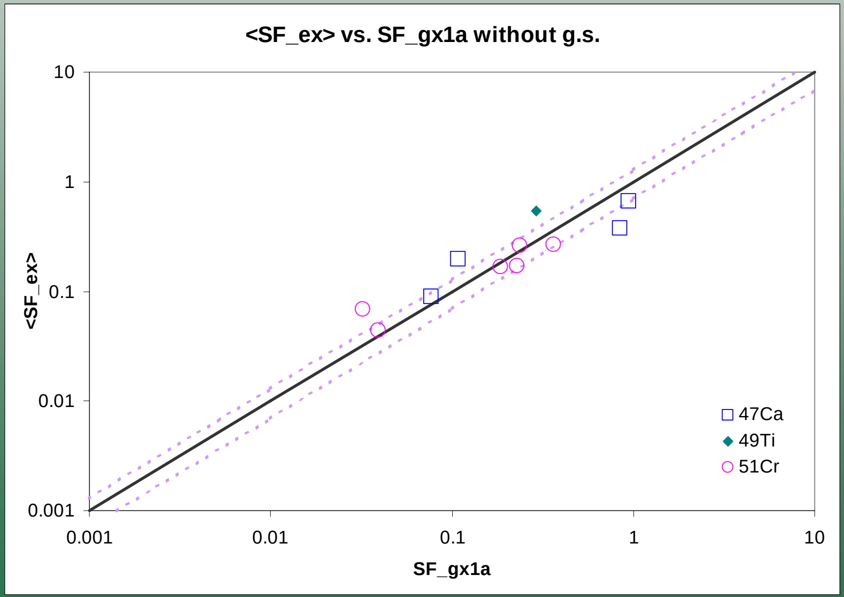


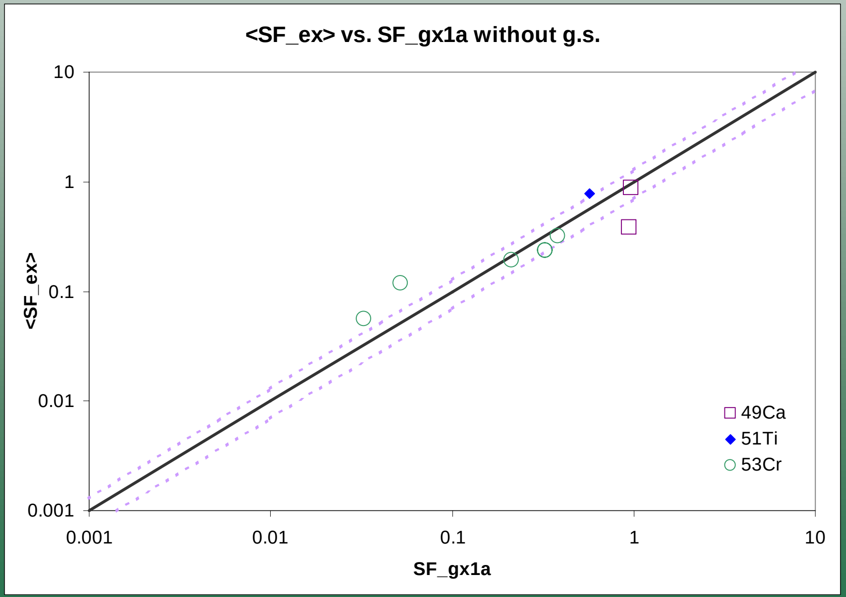
- The trend shown in experimental results is similar as predicted in shell model.
- From 49Ca to 53Cr, we observe that when Z=20 increase to Z=24, 53Cr is more fragmented.

Comparison Between Different Plots of N=27 and N=29









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Conclusion

- For N=27 and N=29 (except for 47Ar), when proton number increases, the excited energy level decreases, and corresponding spectroscopic factor decreases.

- 47Ar's first excited energy compared with 49Ca is even lower, is because it doesn't have a closed core.

- For N=27 and N=29, when proton number increases, excited state is more fragmented, e.g. 51Cr, 53Cr.

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Appendix

- IPM assumption:
- (1) 40Ca is a spherical core
- (2) pairing interaction, maximal pairing

$$S = n$$ for even n

$$S = 1 - \frac{n-1}{2j+1}$$ for odd n

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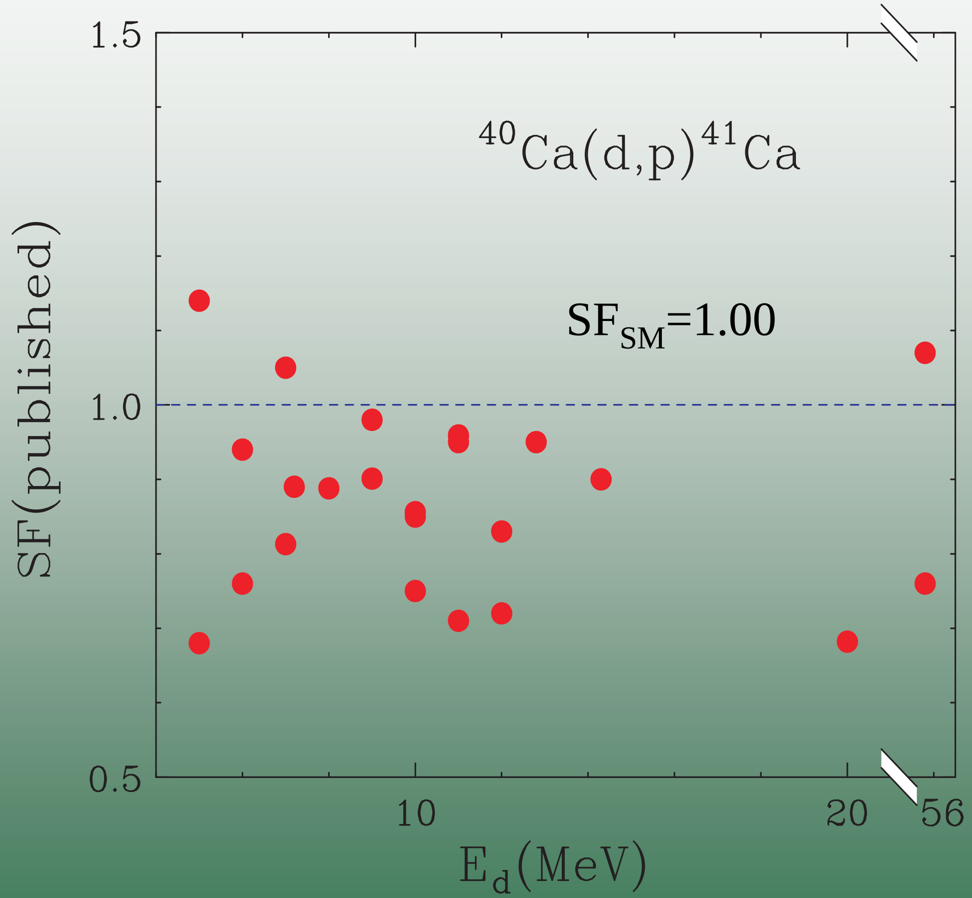
Previous Experimental Spectroscopic Factor

Example: $1f_{7/2}$ neutron SF in $^{41}Ca = ^{40}Ca+n$
Data from Jenny Lee



$$\left(\frac{d\sigma}{d\Omega}\right)_{ex} = SF\_ex \cdot \left(\frac{d\sigma}{d\Omega}\right)_{th}$$

Depending on experimental data analysis

- Do all the experiments using the same method to analyze their data?

No. Why?

They used different parameters to obtain spectroscopic factor.

So, what shall we do?

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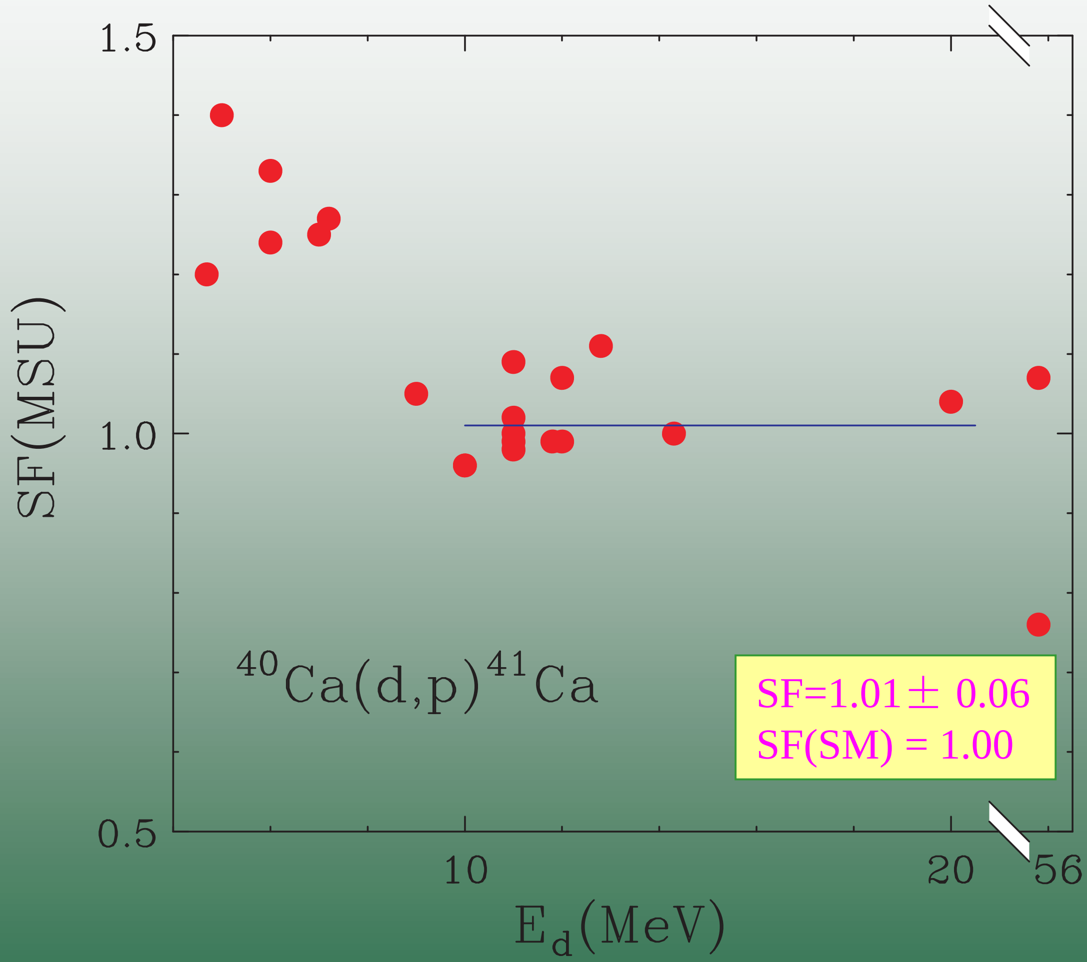
After Adopting Consistent Method

Consistent spectroscopic factors for ^{41}Ca



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- For incident energy less than 10 MeV, compound nuclear effect are dominant.
- Extracted spectroscopic factors for 41Ca ground state in different experiments are much more consistent with each other, and match well with prediction by shell model.

It provides a more reliable link between theory and experiments.

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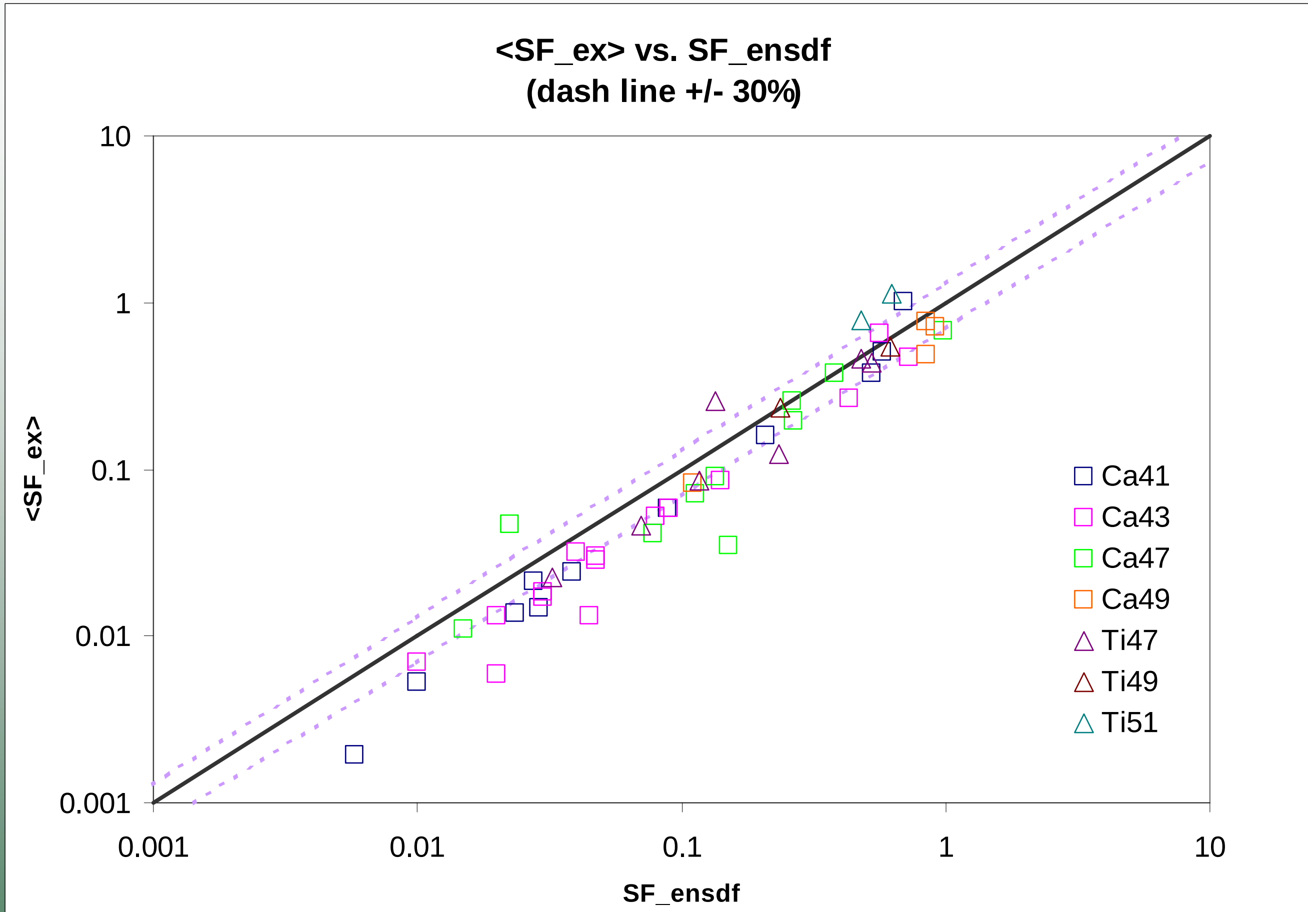
<SF_ex> vs. SF_ensdf



(1) <SF_ex> in general matches with SF_ensdf → reasonable result.

(2) More experiments used vs. Only one or two adopted

(3) Consistent and systematic method vs. Directly using paper values

- ENSDF (Evaluated Nuclear Structure Data File, www.nndc.bnl.gov/ensdf) is a database which contains evaluated nuclear structure and decay information for over 2900 nuclides. It's updated on a continuous basis.

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