Neutron Spectroscopic Factors from transfer reactions with rare isotopes

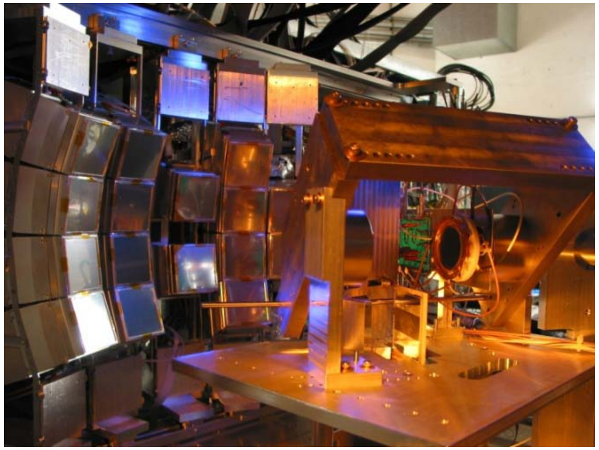
Survey: Extractions of Neutron Spectroscopic Factors using systematic approach from Transfer Reactions

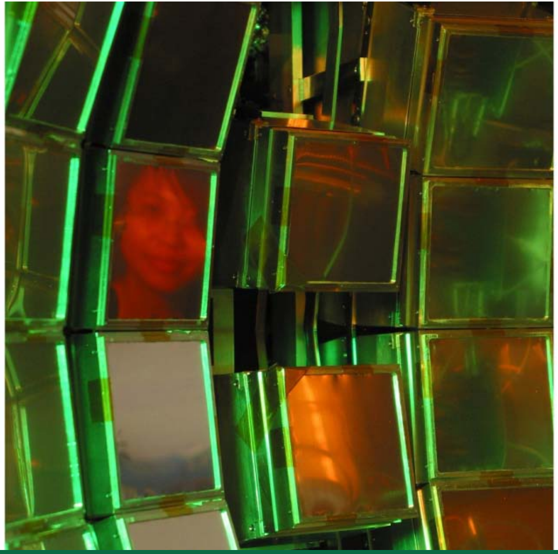
Experiment: ^{34,46}Ar(p,d) Transfer Reactions in Inverse Kinematics

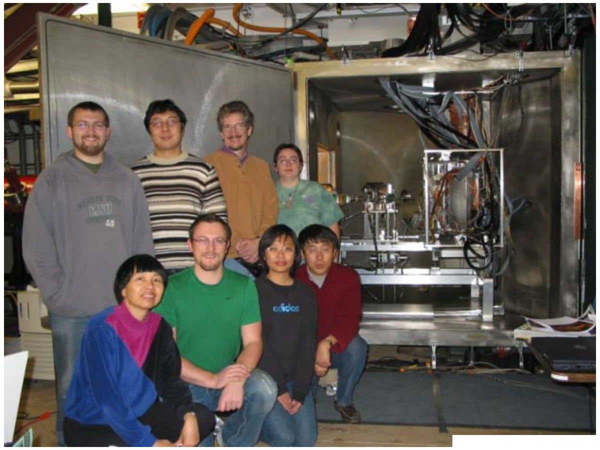
Thesis: Jenny Lee

^{56}Ni(p,d) & ^{56}Ni(d, ^{3}He) Transfer Reactions in Inverse Kinematics

Thesis: Alisher Sanetullaev; Tilak Ghosh (IUSSTF Fellow)







Betty Tsang
INT workshop on Reactions
Aug 8-13, 2011 Seattle, USA

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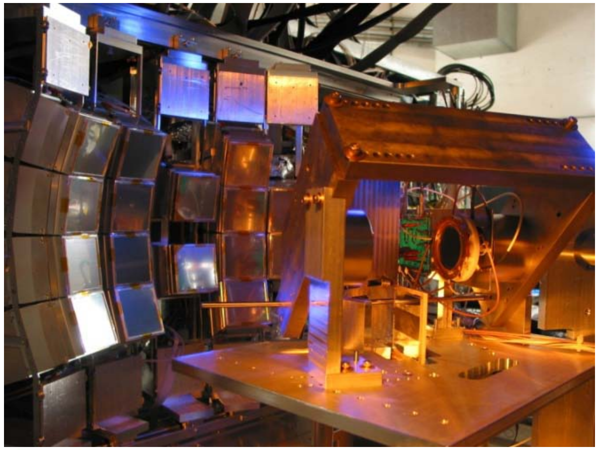
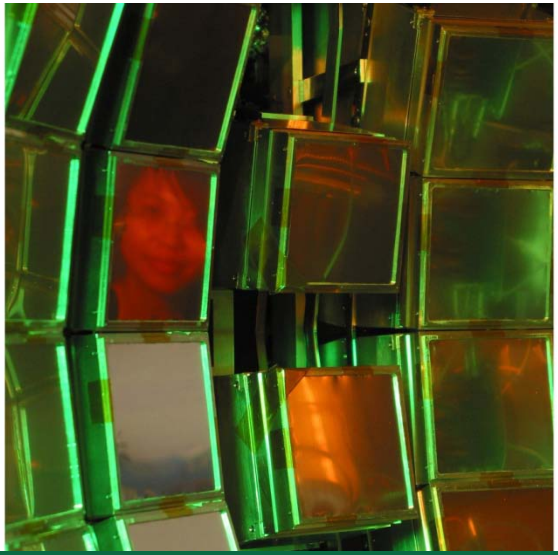
Experiment: ^{34,46}Ar(p,d) Transfer Reactions in Inverse Kinematics

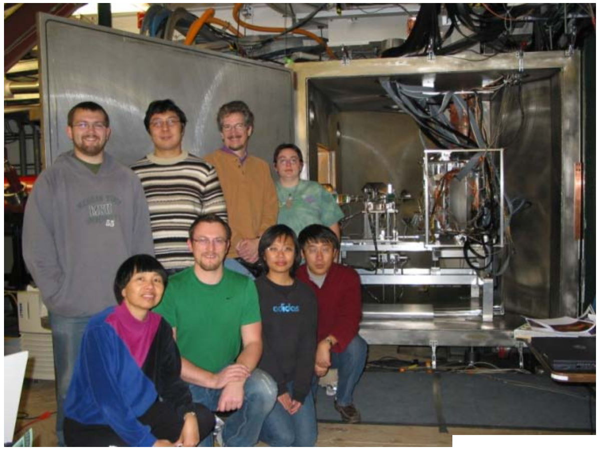
Asymmetry of nucleon-nucleon correlations

^{56}Ni(p,d) & ^{56}Ni(d, ^{3}He) Transfer Reactions in Inverse Kinematics

particle and hole states in ^{56}Ni







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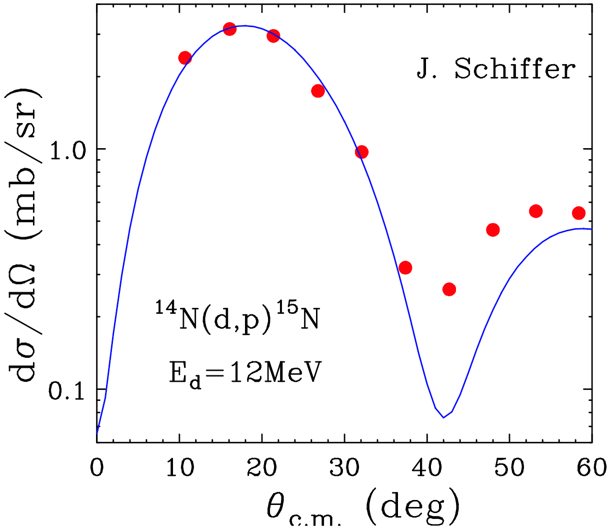
Many-body theory of $d + A(N,Z) \to B(N+1,Z) + p$

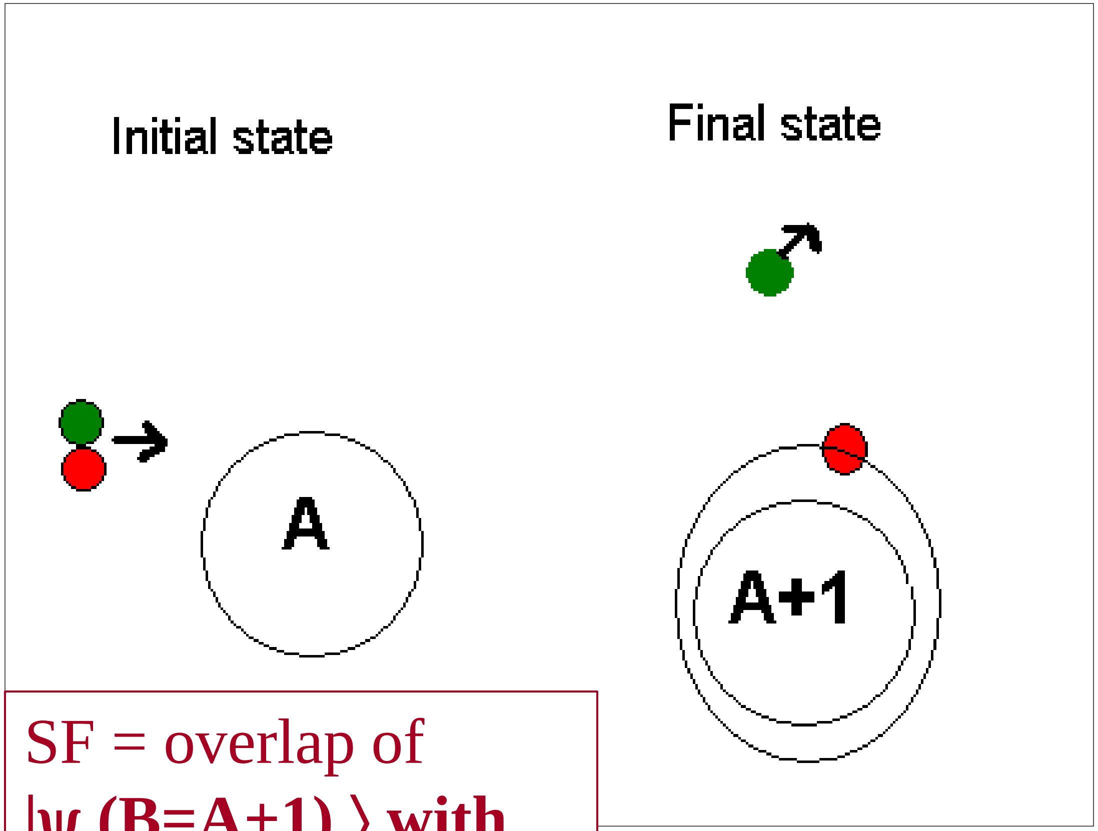
A(d,p)B ⟷ B(p,d)A

The reaction is dominated by 1-step direct transfer.

Elastic Scattering is the main process in the entrance and exit channels.

Adiabatic Distorted Wave Approximation





SF = overlap of
$|\psi\,(B=A+1)\rangle$ **with**
$|\psi\,(A)\rangle_{core} \otimes$ **n (ℓ j)**

$$S_{l,j} = \frac{\left(\frac{d\sigma}{d\Omega}\right)_{Expt}}{\left(\frac{d\sigma}{d\Omega}\right)_{ADWA}}$$

Systematic method (with minimal assumptions) to obtain consistent spectroscopic factors

$$\left(\frac{d\sigma}{d\Omega}\right)_{EXP} = SF_{EXP}\left(\frac{d\sigma}{d\Omega}\right)_{Theo}$$

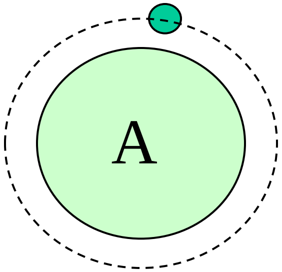
Johnson- Soper Adiabatic Distorted Wave Appro. (ADWA) to take care of d-break-up effects

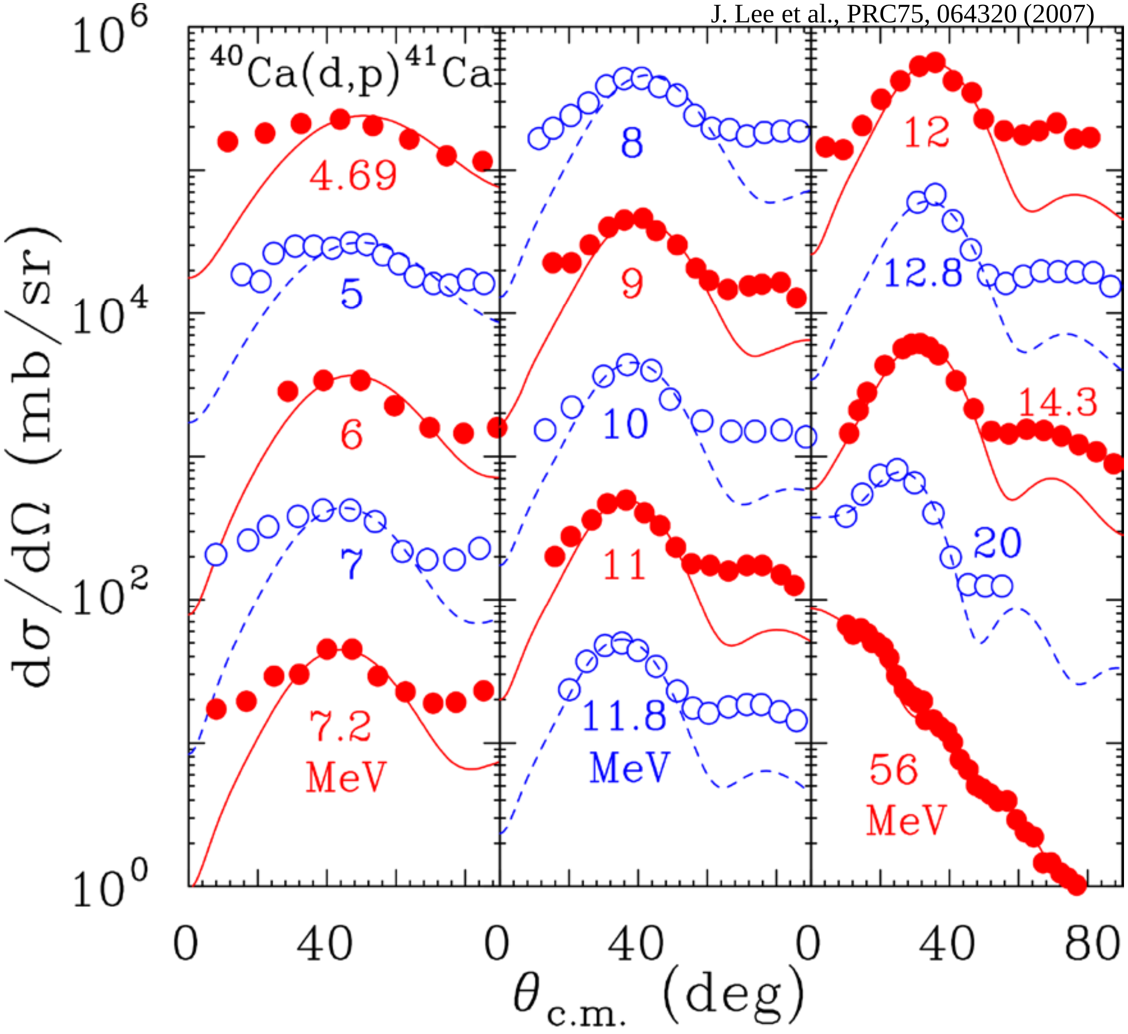
✓*Use global p and n optical potential with standardized parameters (CH89)*

✓ *n-potential : Woods-Saxon shape r_o=1.25 & a_o=0.65 fm; depth adjusted to reproduce experimental binding energy.*

→*Compute with TWOFNR code*

B=A+n





J. Lee et al., PRC75, 064320 (2007)

TWOFNR from Jeff Tostevin (University of Surrey)

Johnson & Soper, PRC1,976(1970)

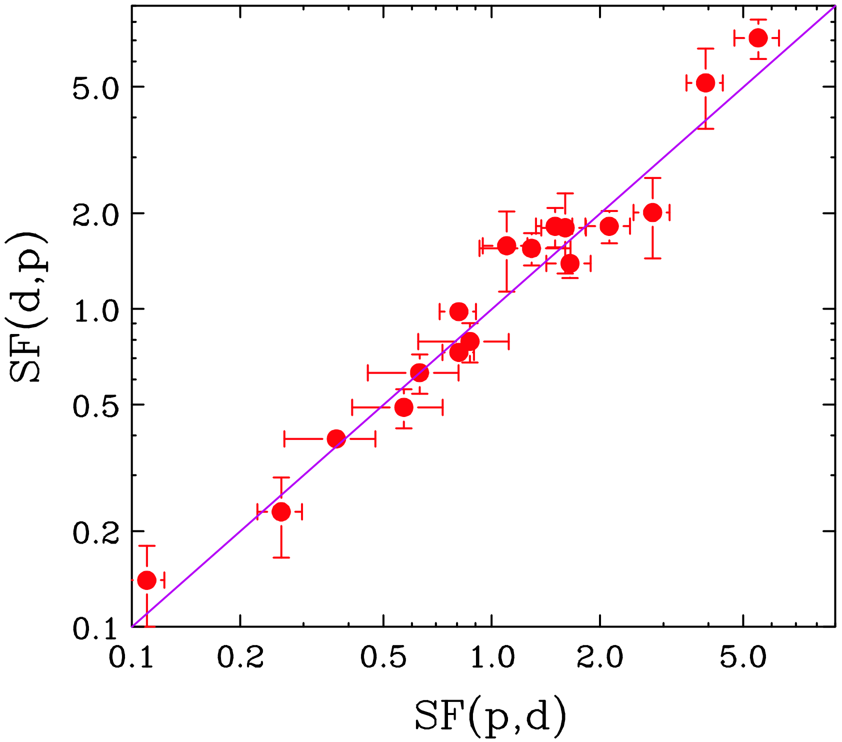
Quality Control

$\underline{B}$(p,d)A : SF$_+$; A(d,p)$\underline{B}$: SF$_-$

Ground-state to ground-state transition

→ SF$_+$= SF$_-$ (Detailed balance)

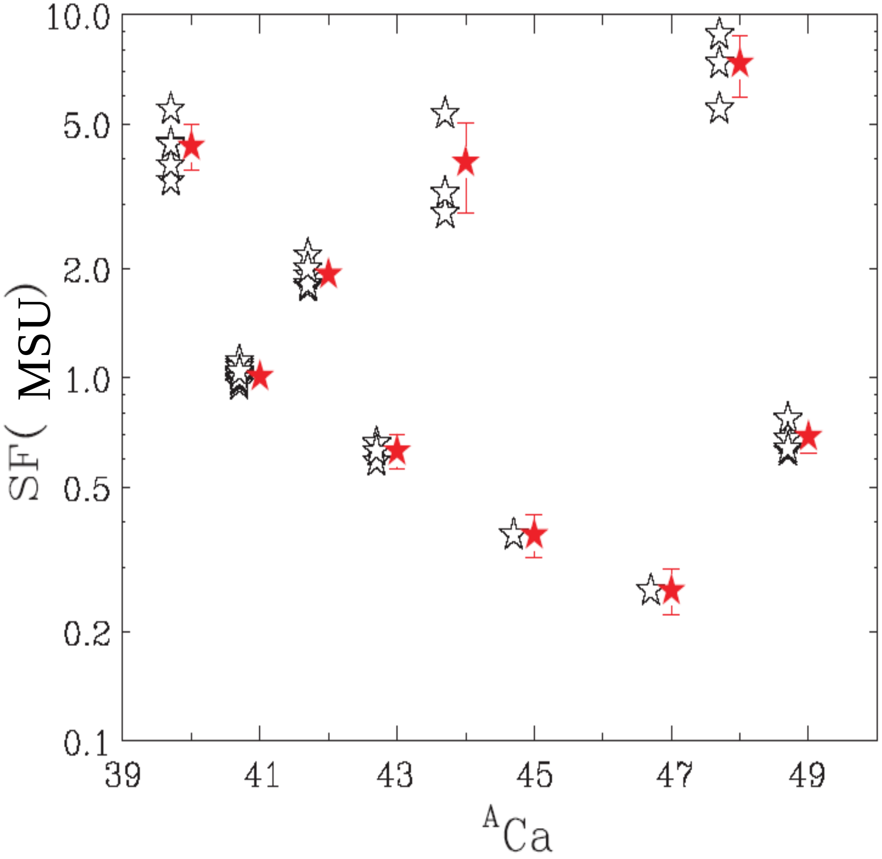
18 nuclei have both SF$_+$ and SF$_-$



-- SF$_+$ = SF$_-$ → Systematic method works

-- 20% uncertainty for each measurement

Uncertainties mainly come from experiment

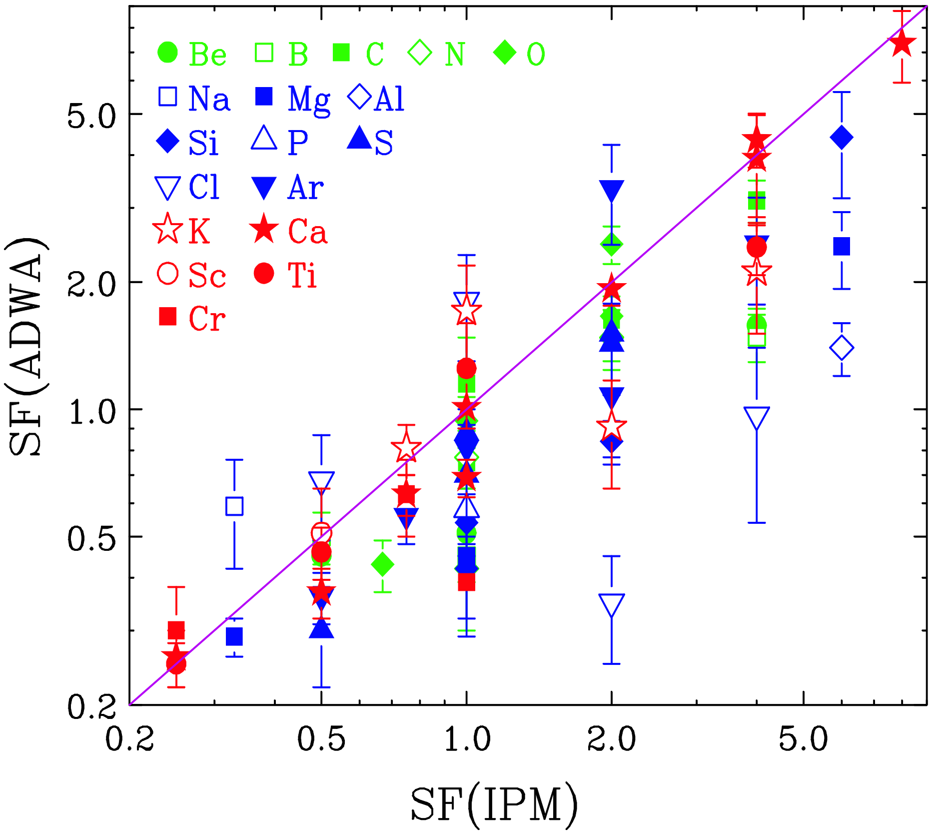


J. Lee et al, Phys. Rev. C75 (2007) 064320

Single Particle Nature of Valence Nucleons

SF=overlap of $|\psi\ (\mathrm{B})\rangle$ **with** $|\psi\ (\mathrm{A})\rangle_{\mathbf{core}} \otimes\ \mathbf{n}\ (\ell\ \mathbf{j})$

measures the orbital configuration of the valence nucleons



Textbook Example:

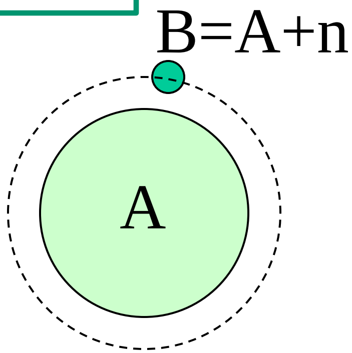
IPM (Austern, pg 291)

For n even

$$SF = n$$

For n odd

$$SF = 1 - \frac{n-1}{2j+1}$$



Single Particle Nature of Valence Nucleons

SF=overlap of $|\psi\,(B)\rangle$ with $|\psi\,(A)\rangle_{core} \otimes n\,(\ell\, j)$

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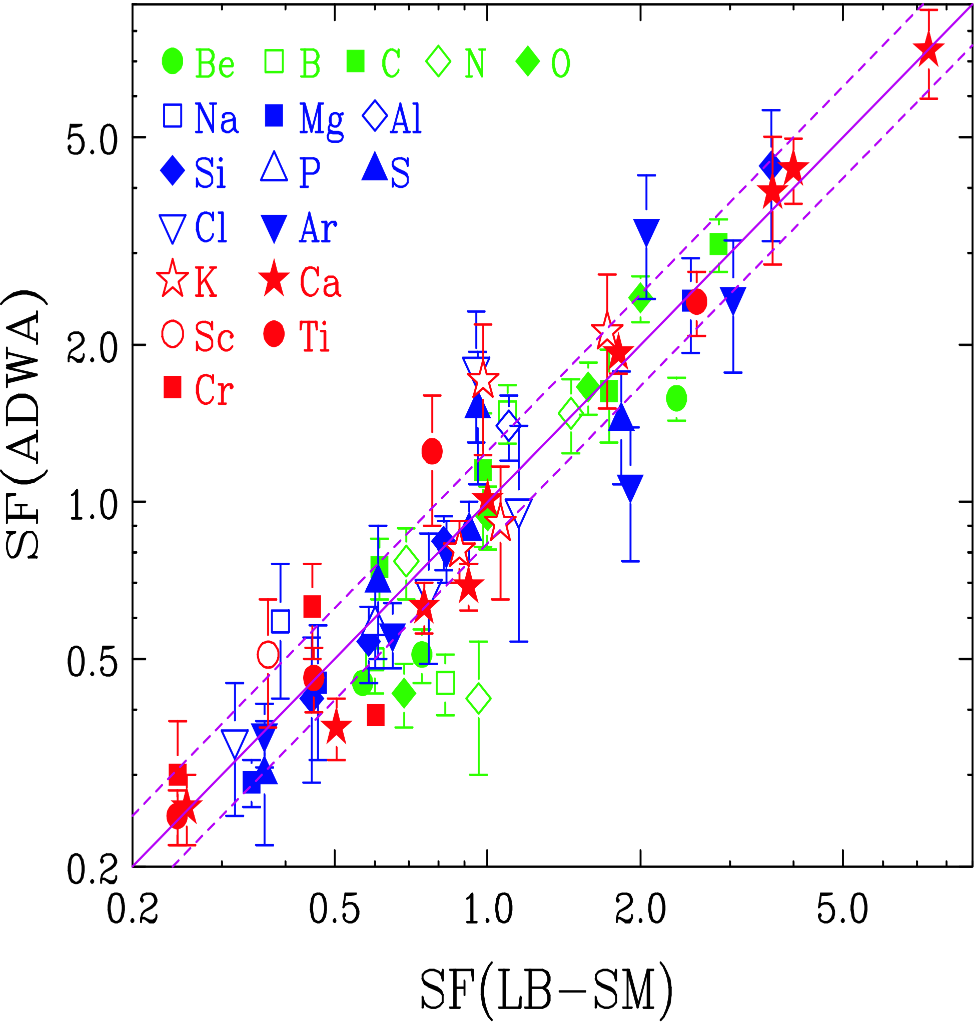
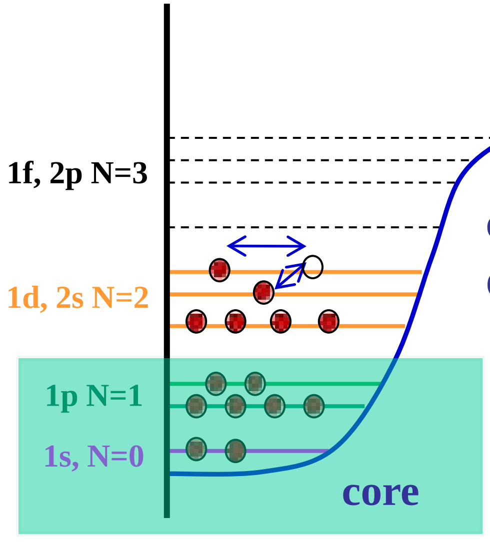




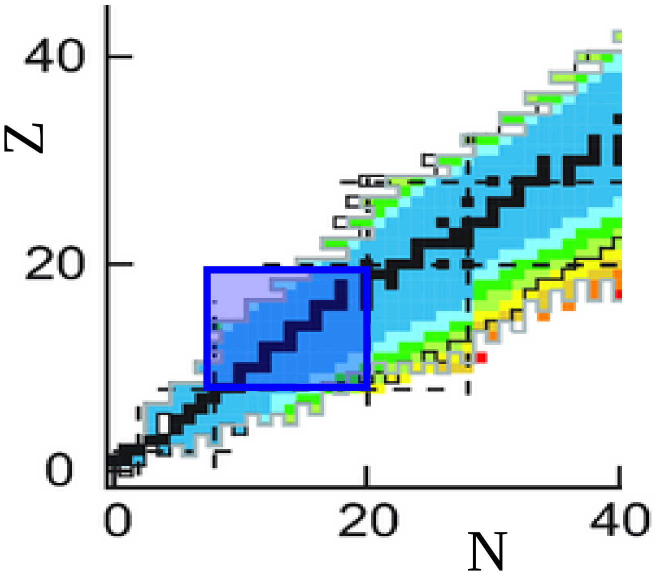
correlated motions of valence nucleons

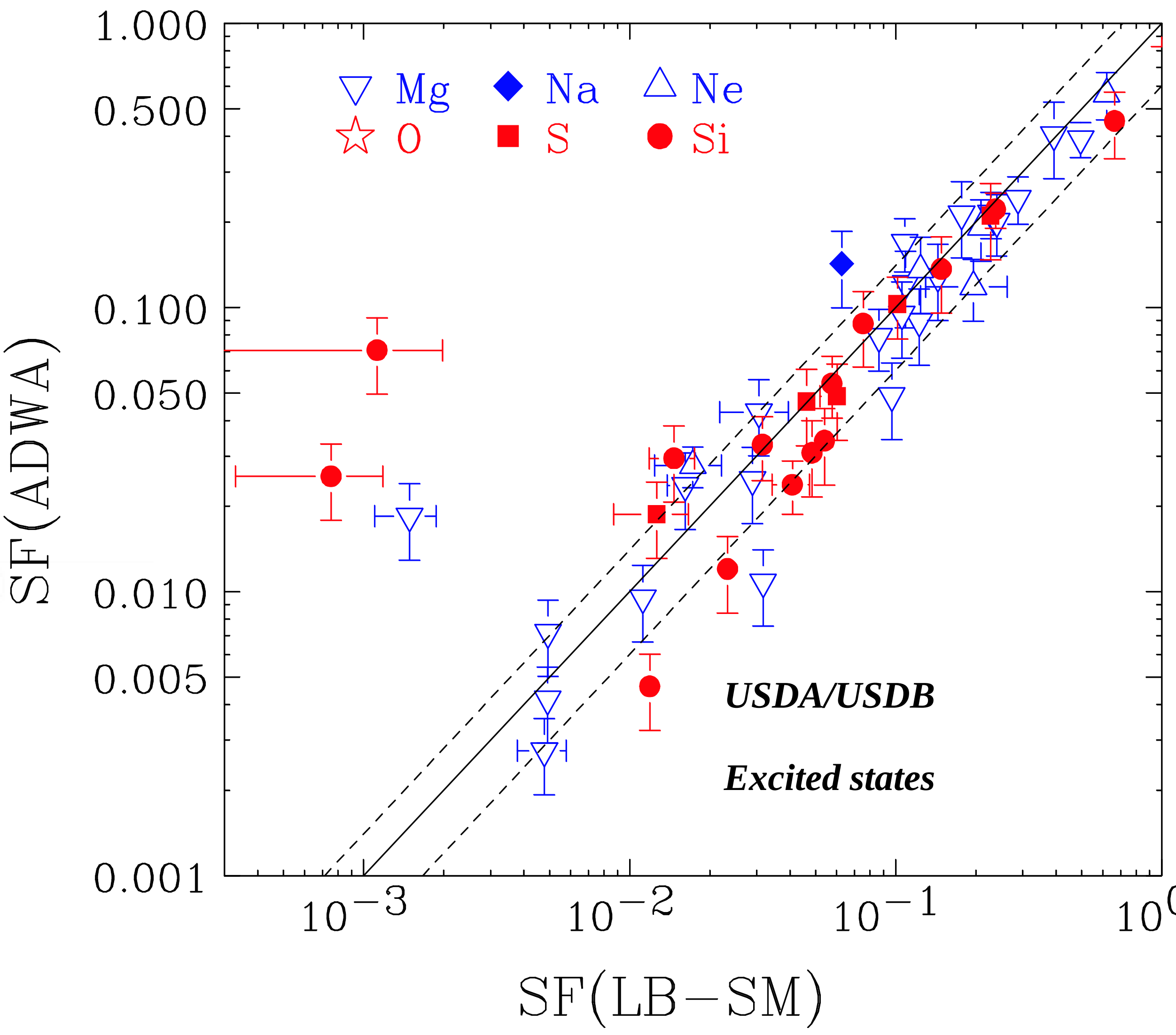
Large Basis Shell Model (LB-SM)

$$H = \underbrace{\sum_i \left(\frac{p_i^2}{2m} + U(r_i) \right)}_{\text{Mean field}} + \underbrace{\sum_{i<j} V_{NN}(r_i - r_j) - \sum_i U(r_i)}_{\text{Residual interactions}}$$

Mean field **Residual interactions**

Excited-state Spectroscopic Factors of sd shell nuclei



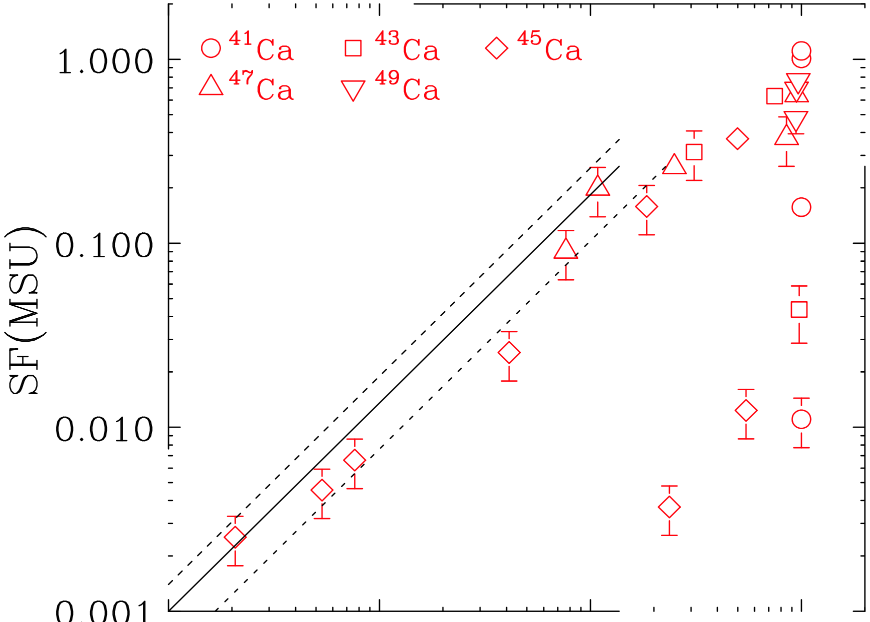


→the interaction (USDA/USDB) is well understood in sd shell

M.B. Tsang and J. Lee et al., PRL 95, 222501 (2005)

Neutron Spectroscopic Factors for Ca Isotopes

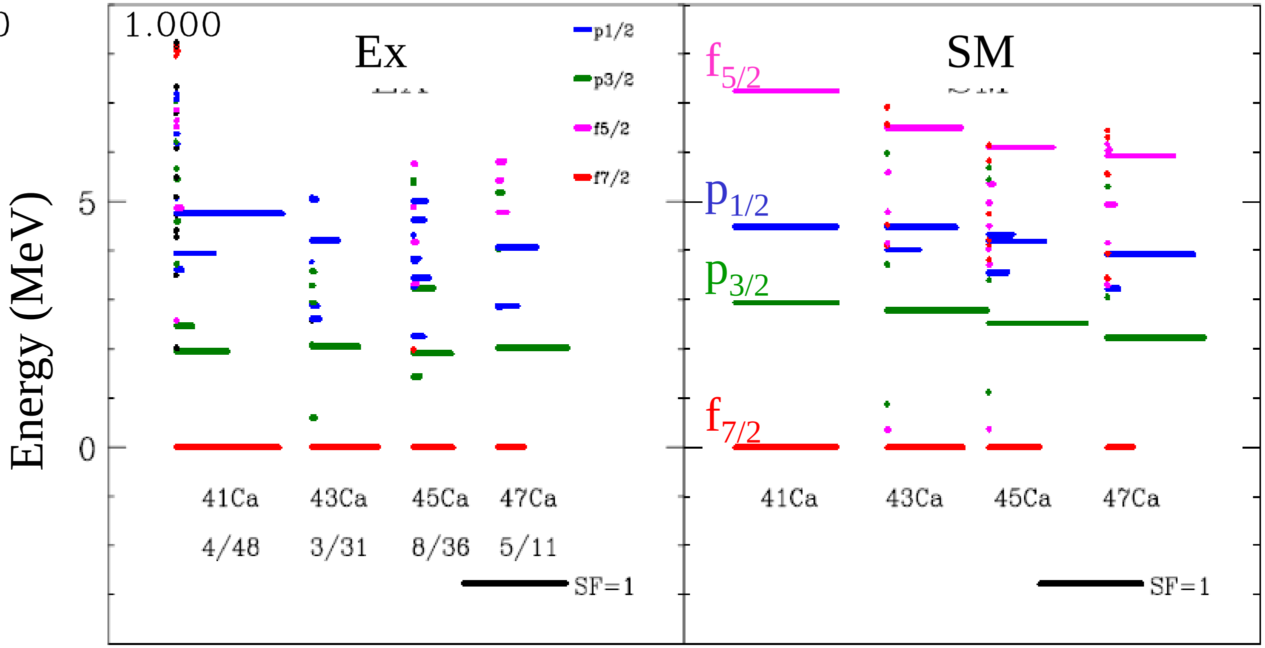
Phoenix Dai – 07’ CU-SURE



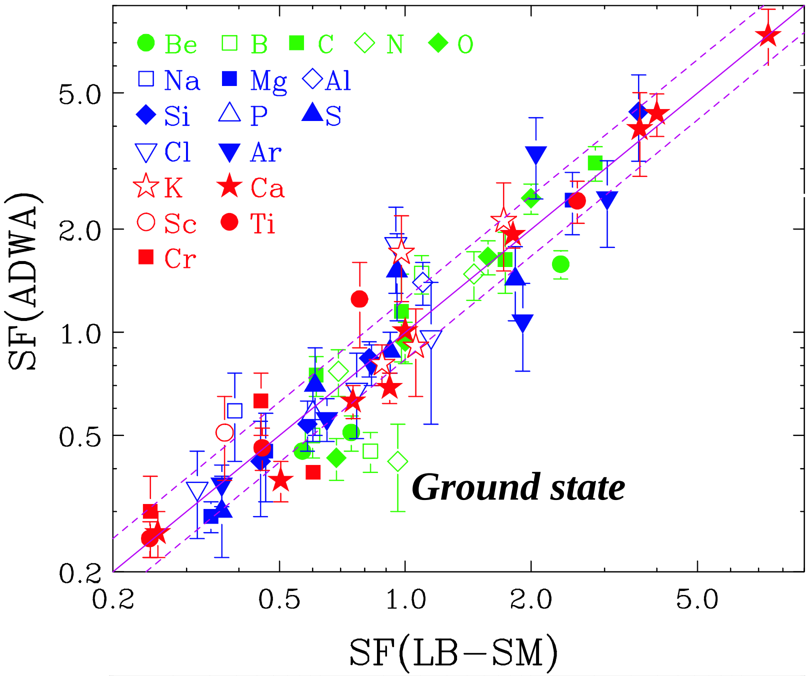
Shell Model – closed ^{40}Ca core: mainly single particle states

Experiment: Large fragmentation of excited states even for ^{41}Ca

Well known problem.
Can this be solved?



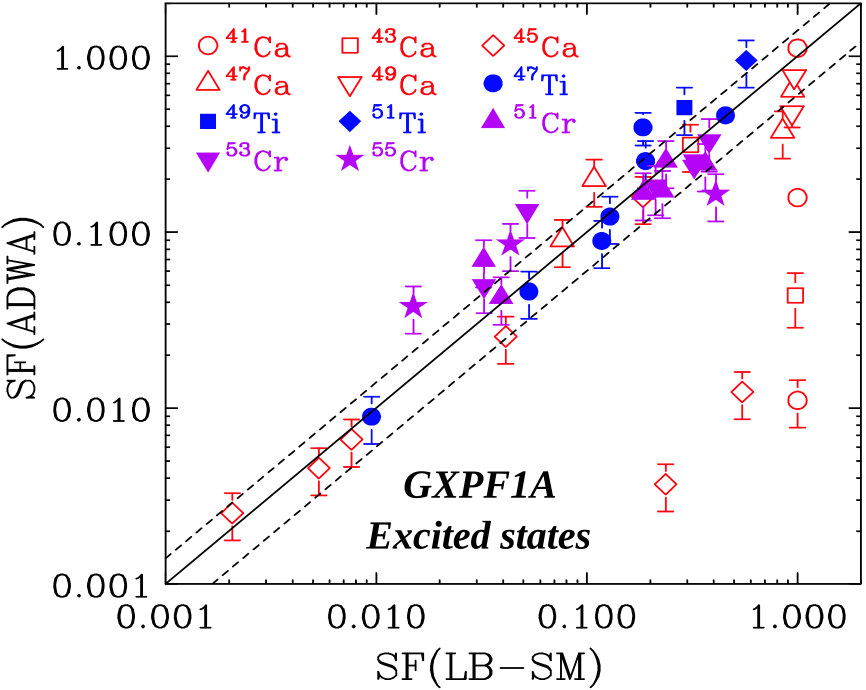
M.B. Tsang and J. Lee et al., PRL 95, 222501 (2005)

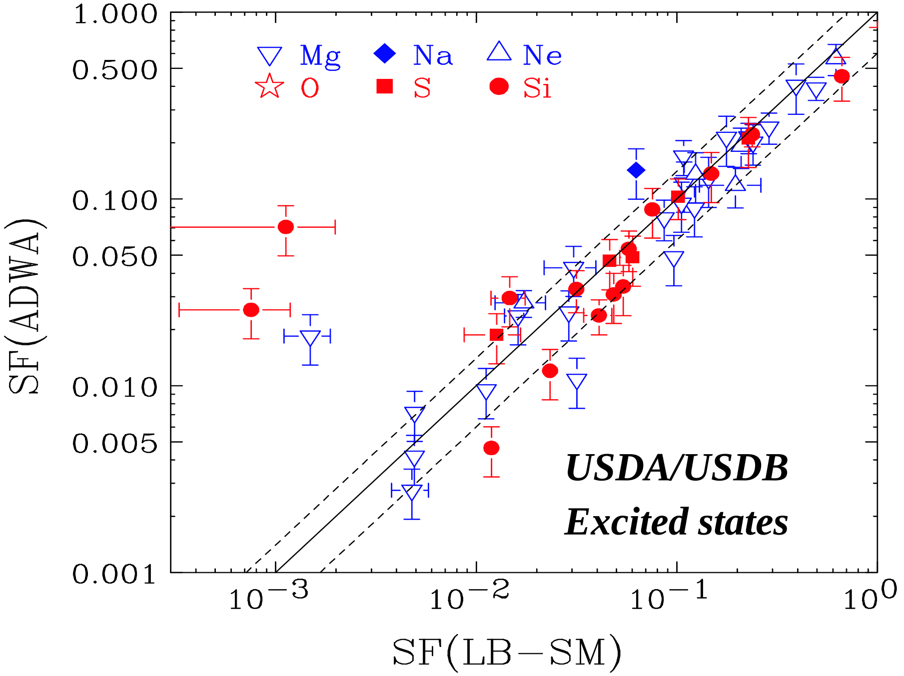


$SF_{EXP}=SF_{SM}$

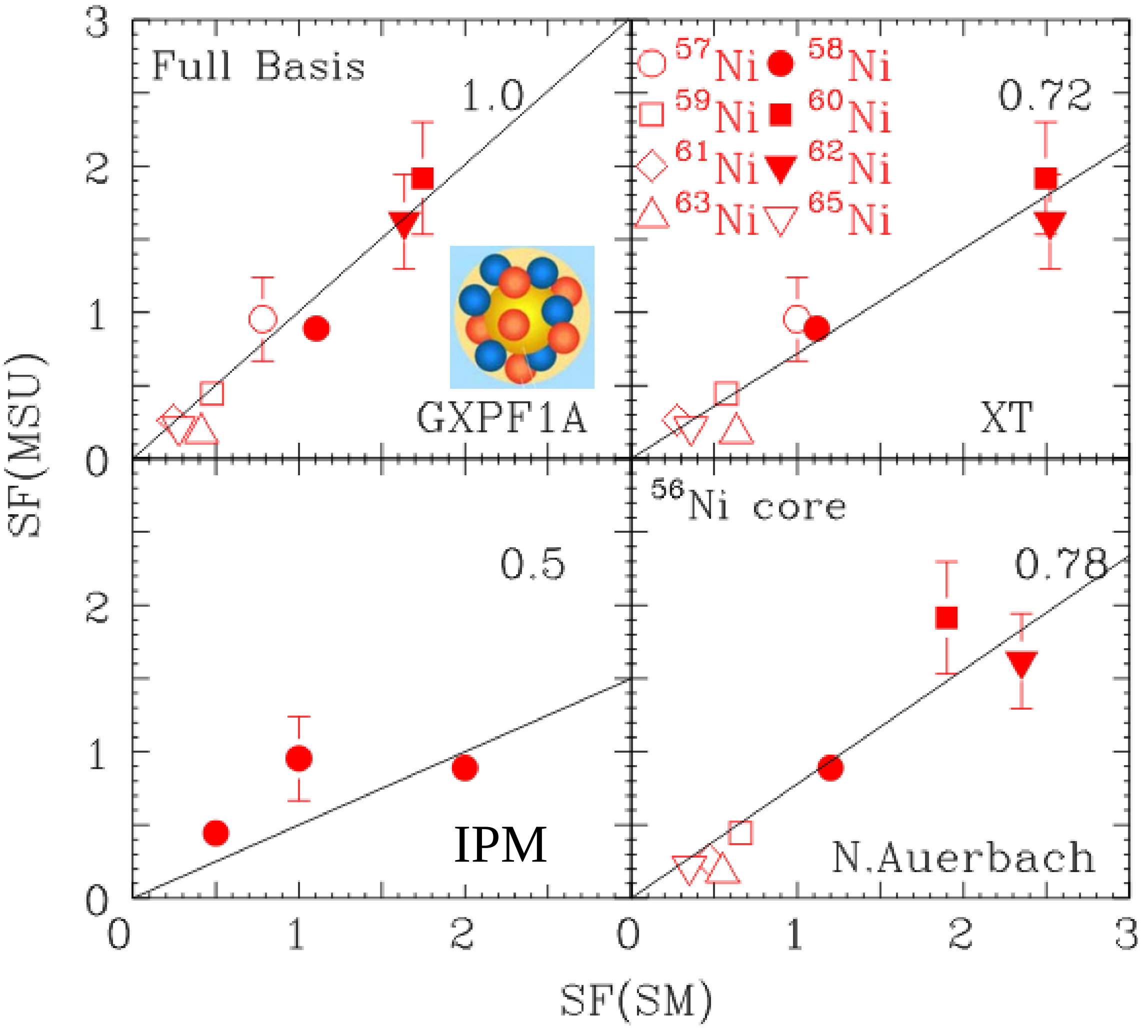
No short term NN correlations and other correlations included in SM.

Why the agreement?



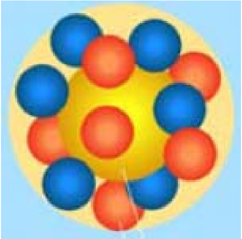


Ground State Neutron Spectroscopic Factors for Ni isotopes



^{56}Ni core

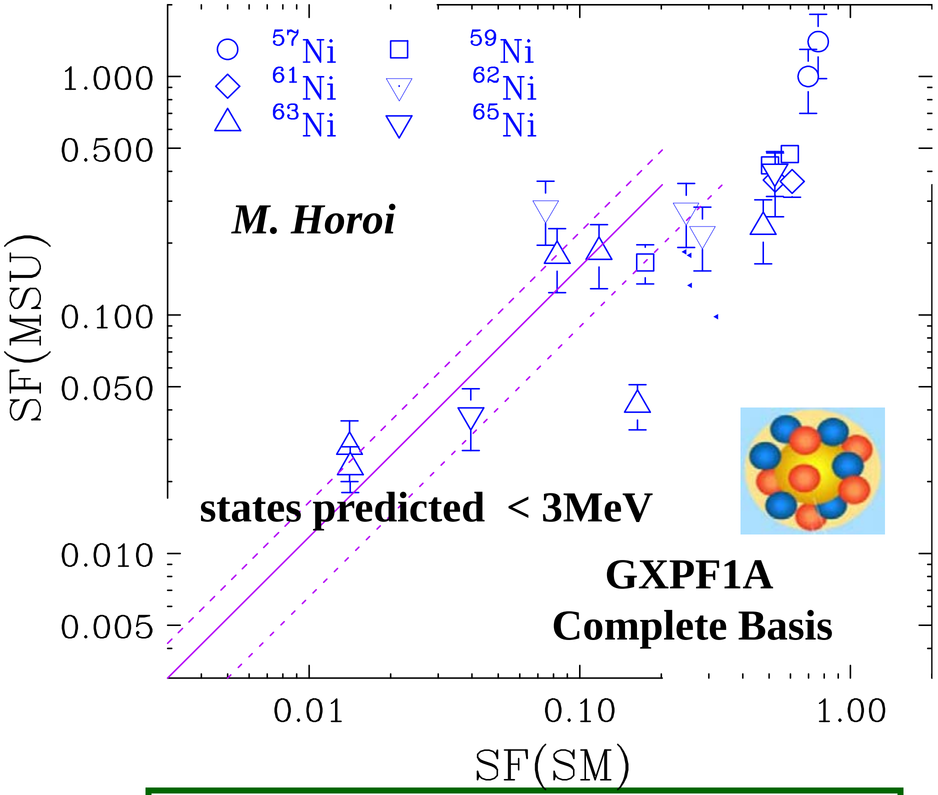
- IPM
- Auerbach interaction ('60)
- XT : T=1 effective interaction (derived for heavy Ni isotopes)

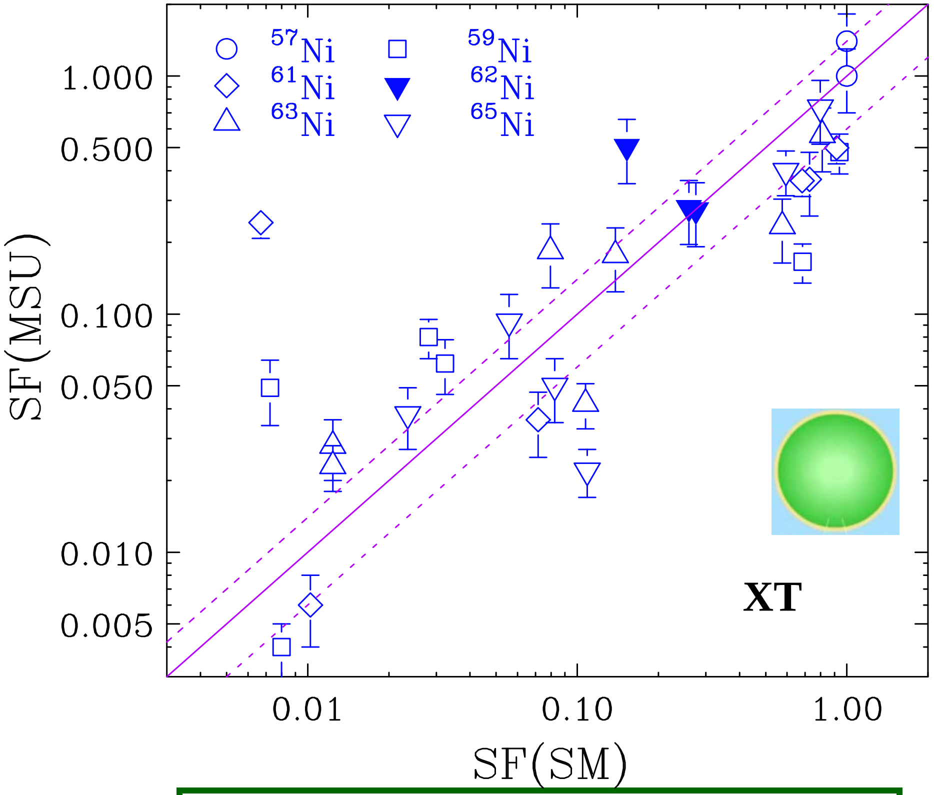


- ^{40}Ca core, in fp model space
- GXPF1A – complete basis →CPU intensive

Description of Ni isotopes requires full basis with ^{40}Ca core.

Neutron Spectroscopic Factors for Ni isotopes





• GXFP1A with full fp model space does not require ^{56}Ni shell closure → CPU intensive

•XT interaction uses ^{56}Ni shell closure → quick overall predictions of Ni nuclei.

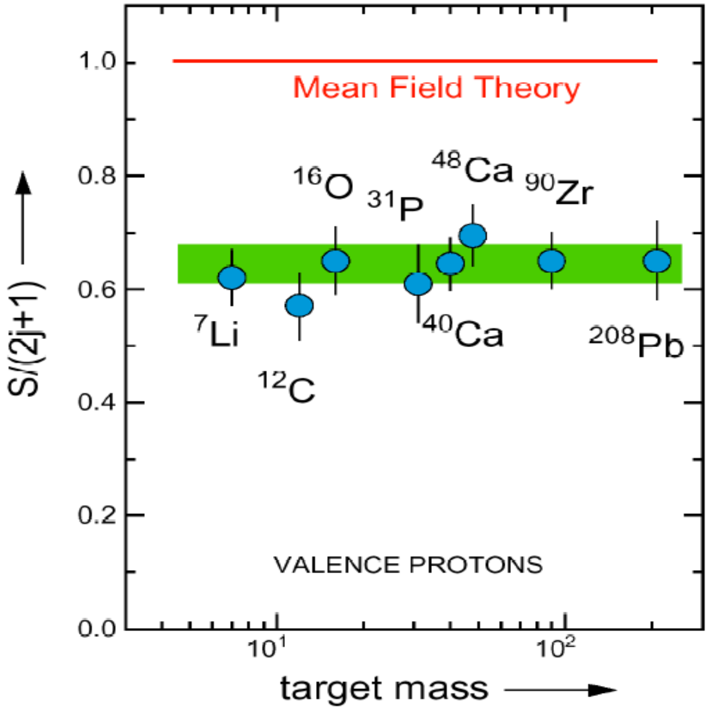
SF values agree to factor of 2 → cannot distinguish between two interactions

Interactions for gfp shell still need improvements

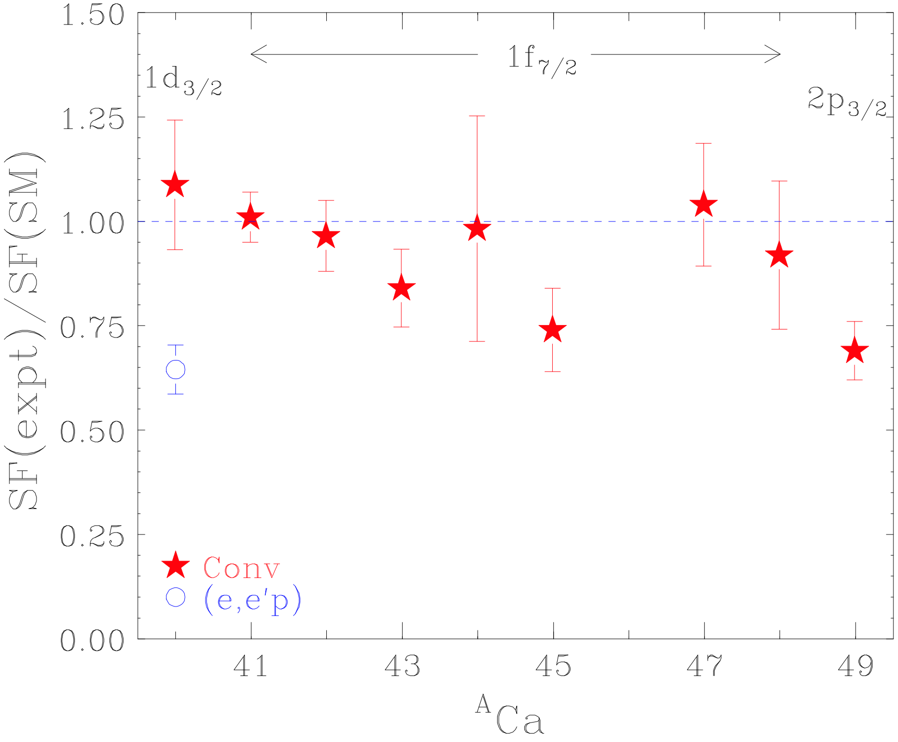
Need predictions of higher excited states

Quenching observed from (e,e'p) reactions

G.J.Kramer et al., Nucl. Phys. A 679, 267 (2001)



J. Lee et al, Phys. Rev. C 73 , 044608 (2006)



***<u>(e,e'p)</u>*: Proton SF values deduced from nuclei near closed shells are suppressed by 30-40% compared to IPM**

→ Correlation is beyond the residual interactions employed in the shell model.

Do transfer reactions yield absolute spectroscopic factors?

Deduced Spectroscopic factors constrained by Hartree-Fock calculations

1. Change the rms radius of the transferred neutron

No a priori justification to adopt fixed geometry for n-bound states with r_o=1.25 fm and a_o=0.65 fm

→Constrain the transferred neutron orbital rms radii with Hartree-Fock (HF) calculations

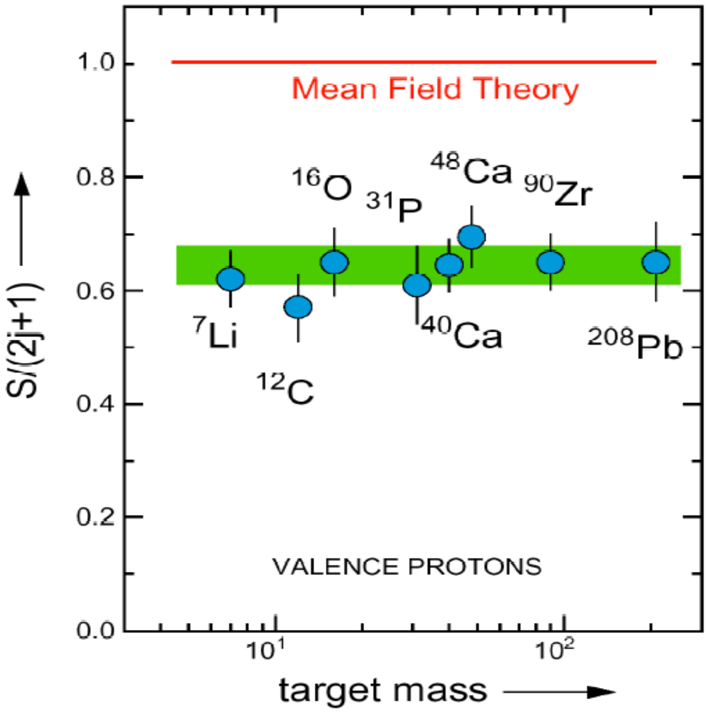
→15 % reduction in the spectroscopic factors

2. Adopt the global potentials derived from nuclear matter effective nucleon-nucleon potential (JLM)

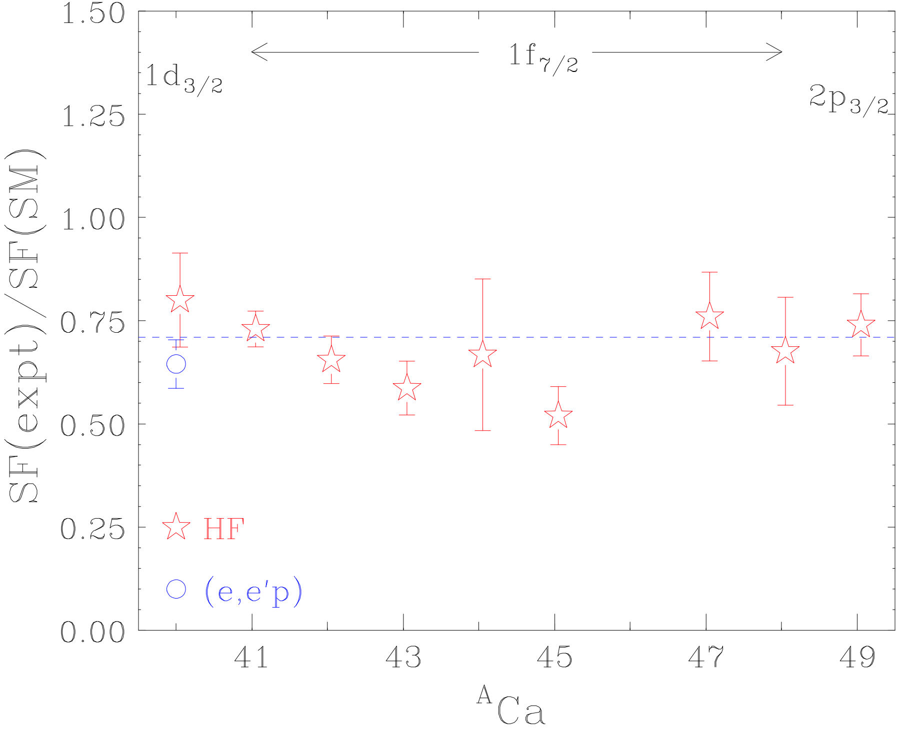
→Constrain the geometry of the nucleon optical potential with the target by HF calculations through target density

→Another 15 % reduction in the spectroscopic factors

Quenching observed from (e,e’p) reactions



G.J.Kramer et al., Nucl. Phys. A 679, 267 (2001)



J. Lee et al, Phys. Rev. C 73 , 044608 (2006)

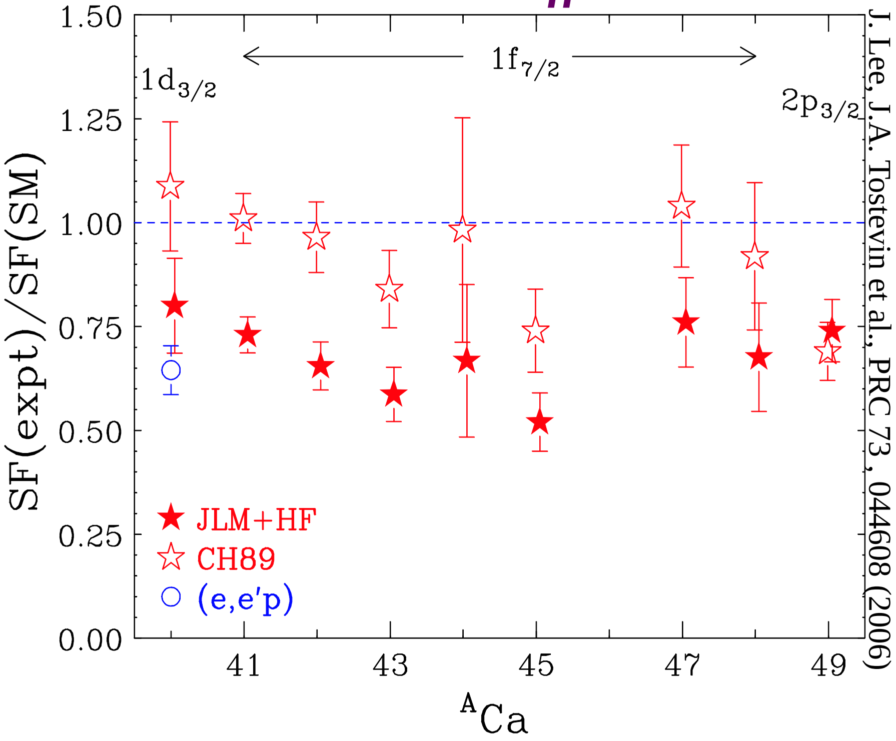
***(e,e’p)*: Proton SF values deduced from nuclei near closed shells are suppressed by 30-40% compared to IPM**

→ Correlation is beyond the residual interactions employed in the shell model.

As long as a systematic approach is used, relative SF can be obtained reliably over a wide range of nuclei

Suppression of Spectroscopic Factors in Transfer Reactions

Jeff Tostevin

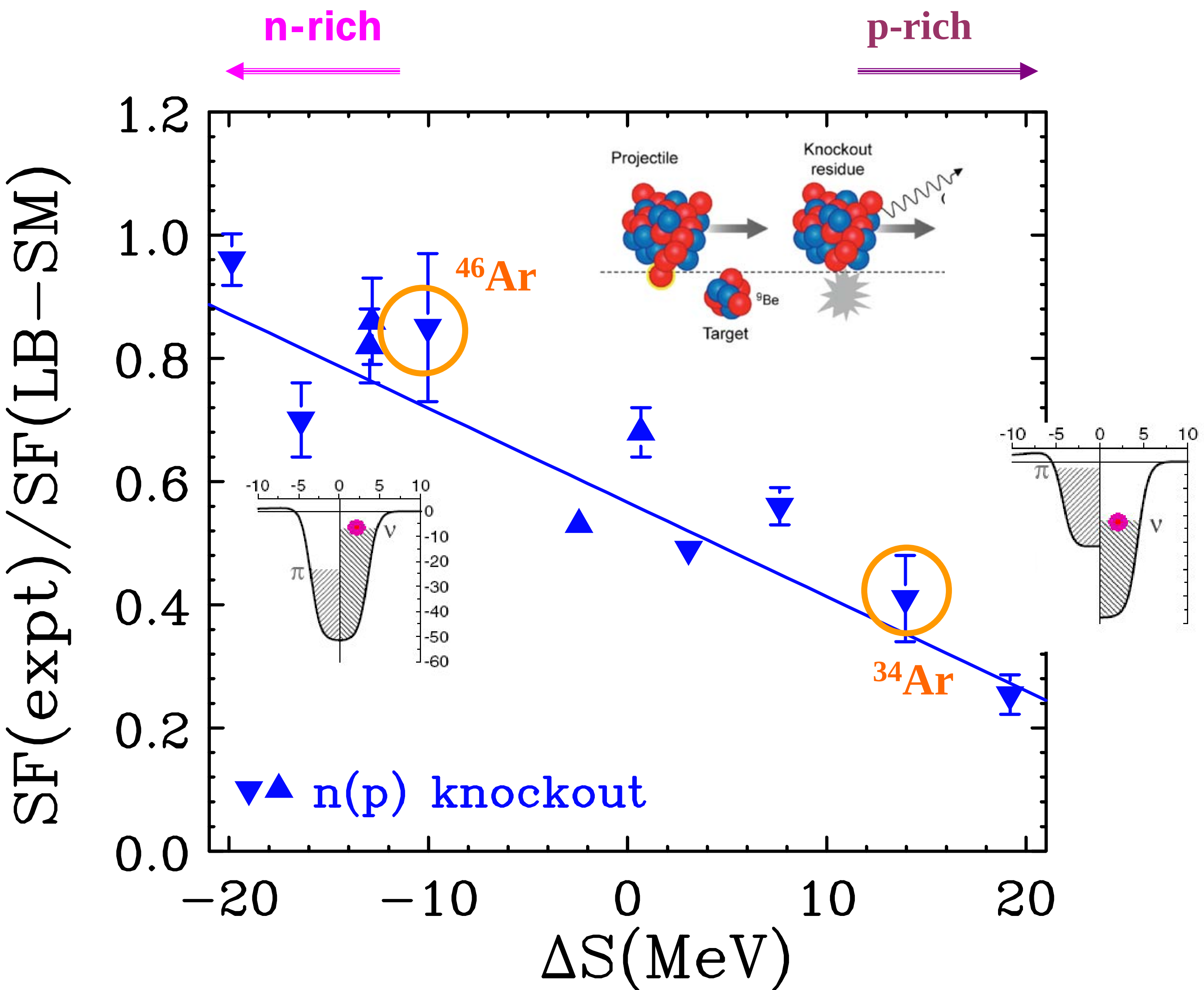


J. Lee, J.A. Tostevin et al., PRC 73, 044608 (2006)

Procedure has not been applied to excited states because of difficulties in calculating the HF geometry and density for excited states.

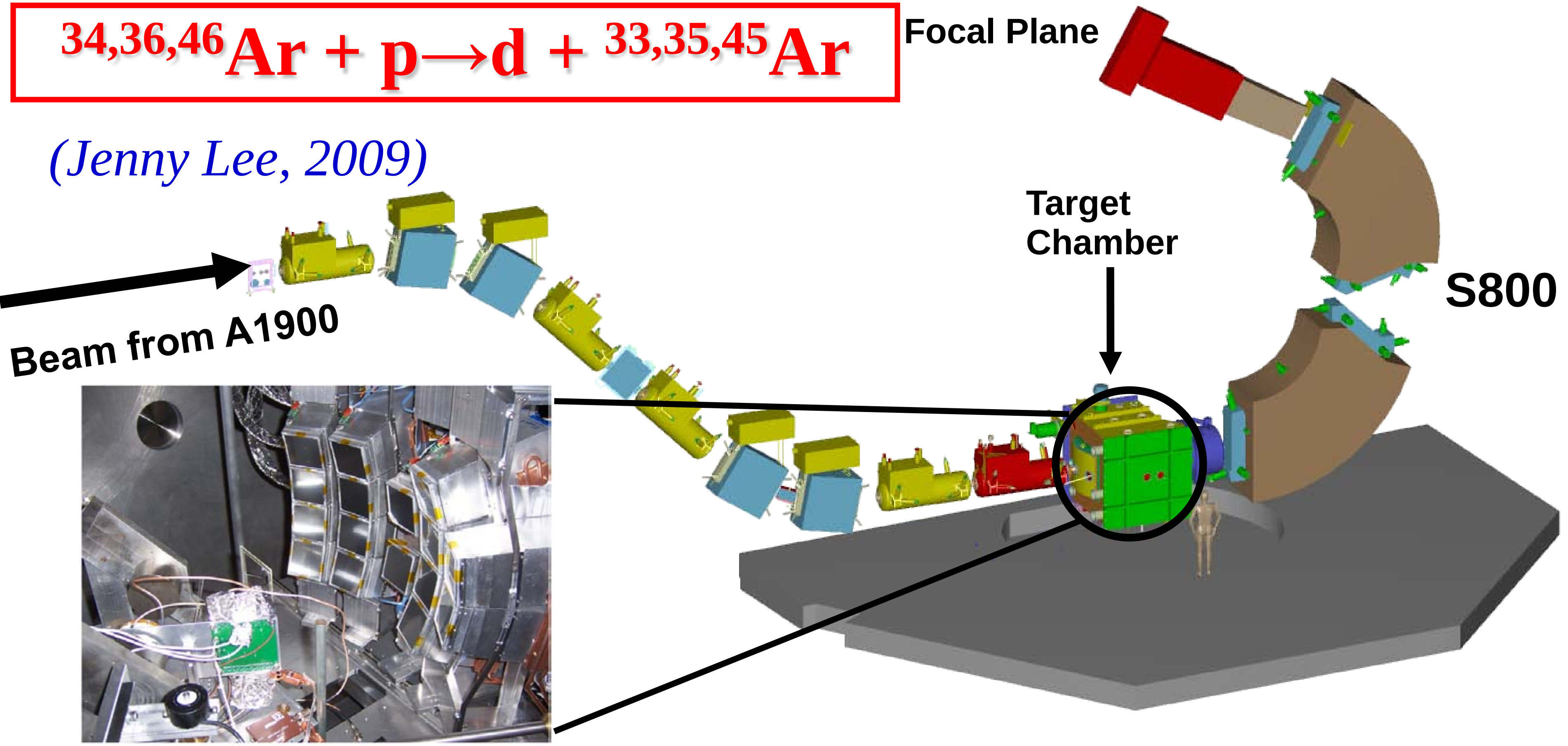
JLM optical potential + bound n-radii constrained with HF geometry → Overall ~30% reduction in SFs

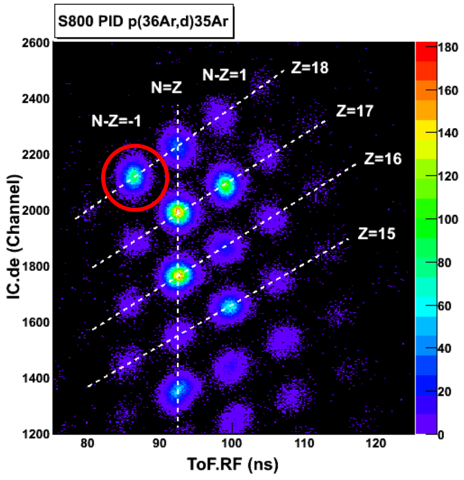
Asymmetry dependence of neutron correlations in knock out reactions

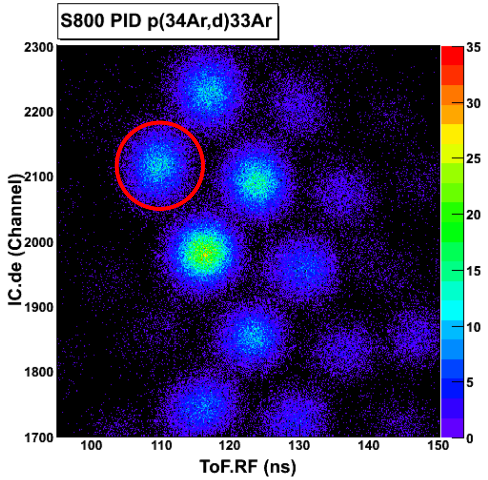


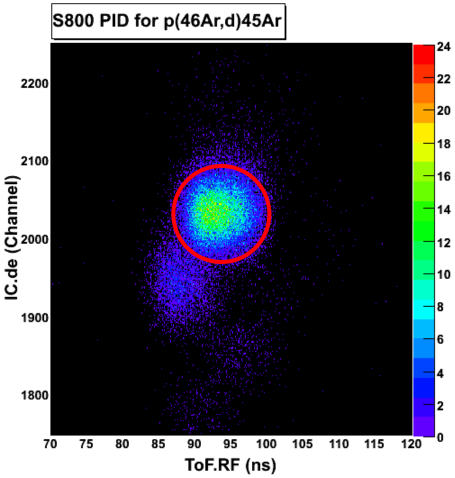
$^{34,36,46}\mathrm{Ar} + p \rightarrow d + {}^{33,35,45}\mathrm{Ar}$

(Jenny Lee, 2009)

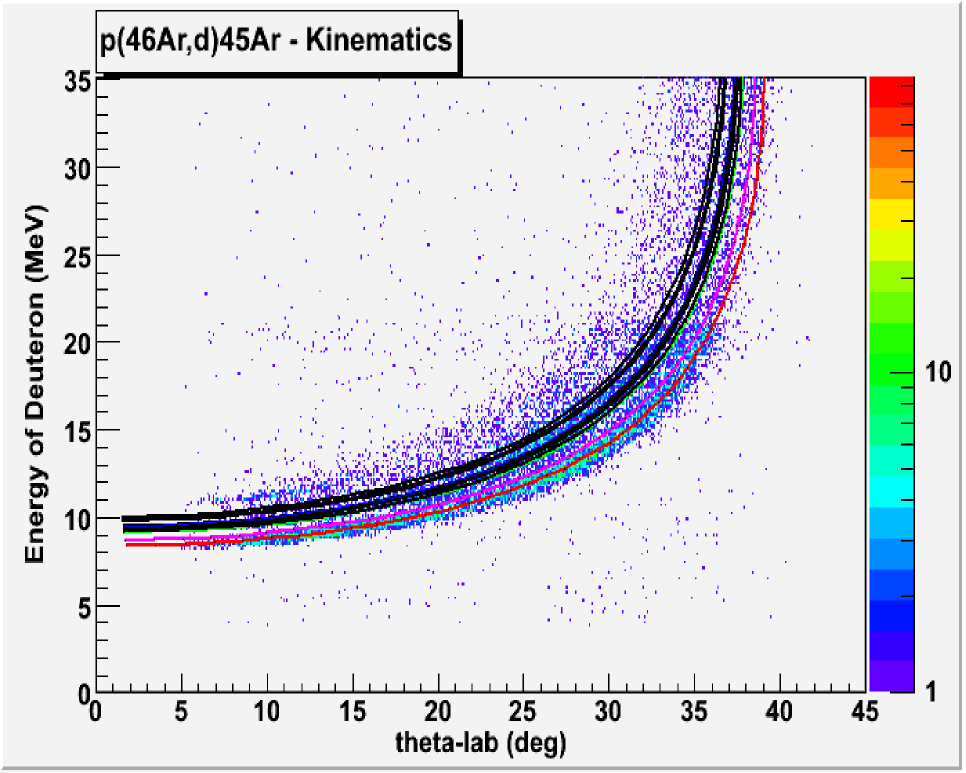


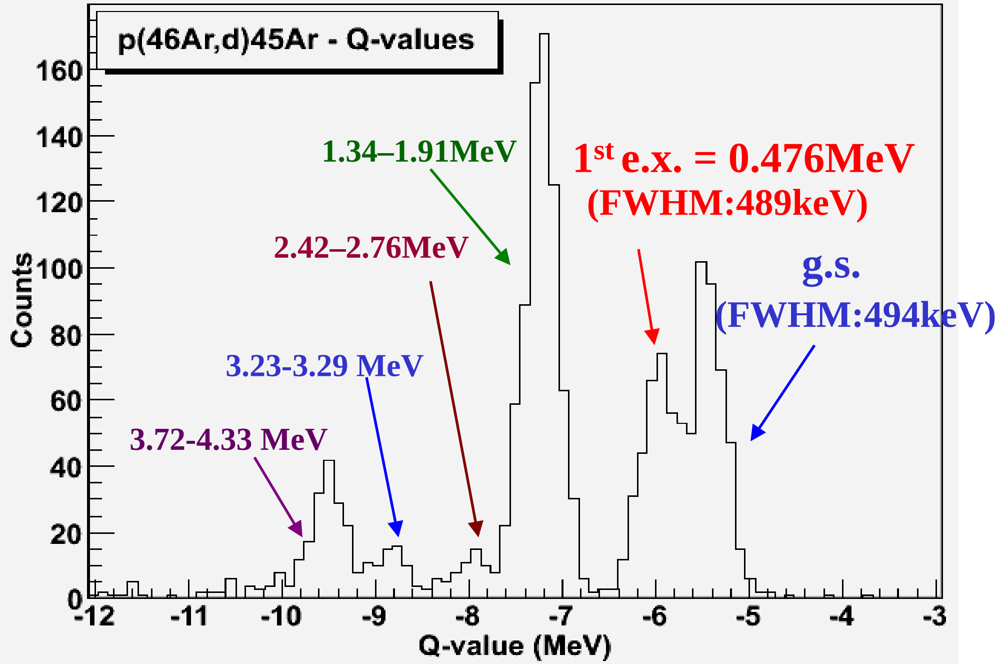

S800 PID p(36Ar,d)35Ar


S800 PID p(34Ar,d)33Ar


S800 PID for p(46Ar,d)45Ar

$p(^{46}Ar,d)^{45}Ar$





1.34–1.91MeV

1^{st} e.x. = 0.476MeV
(FWHM:489keV)

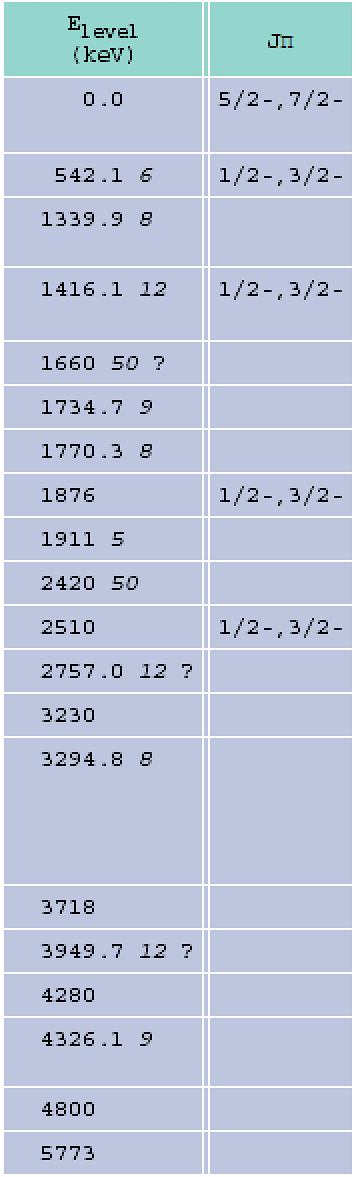
2.42–2.76MeV

g.s.
(FWHM:494keV)

3.23-3.29 MeV

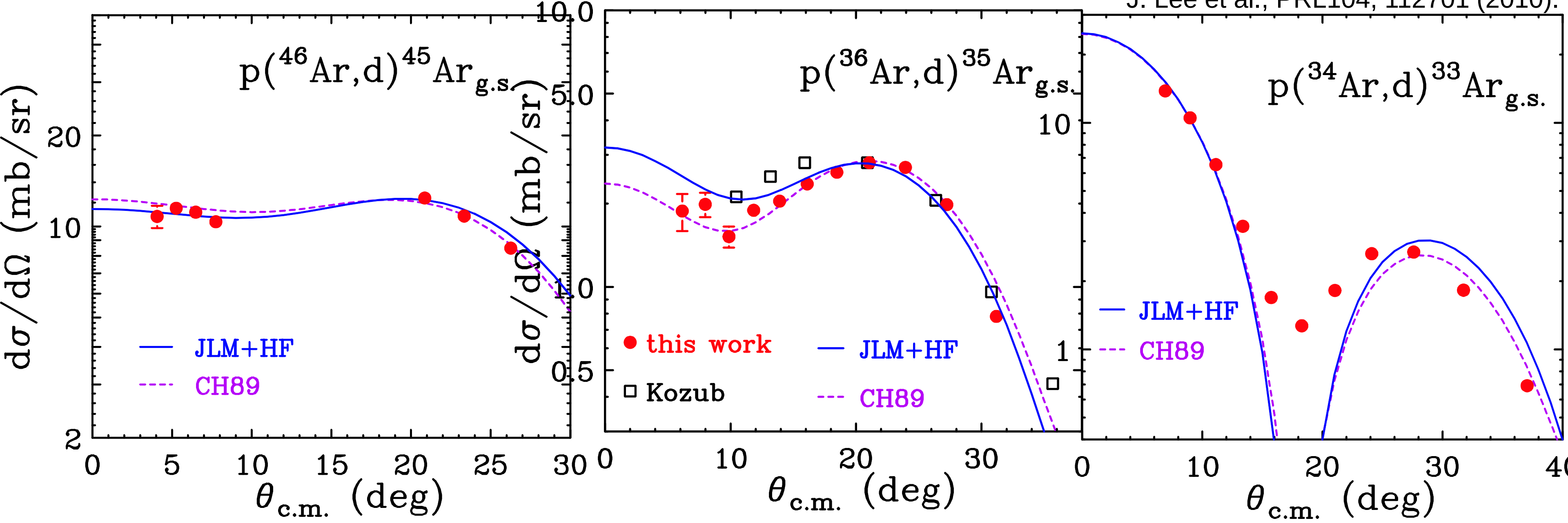
3.72-4.33 MeV

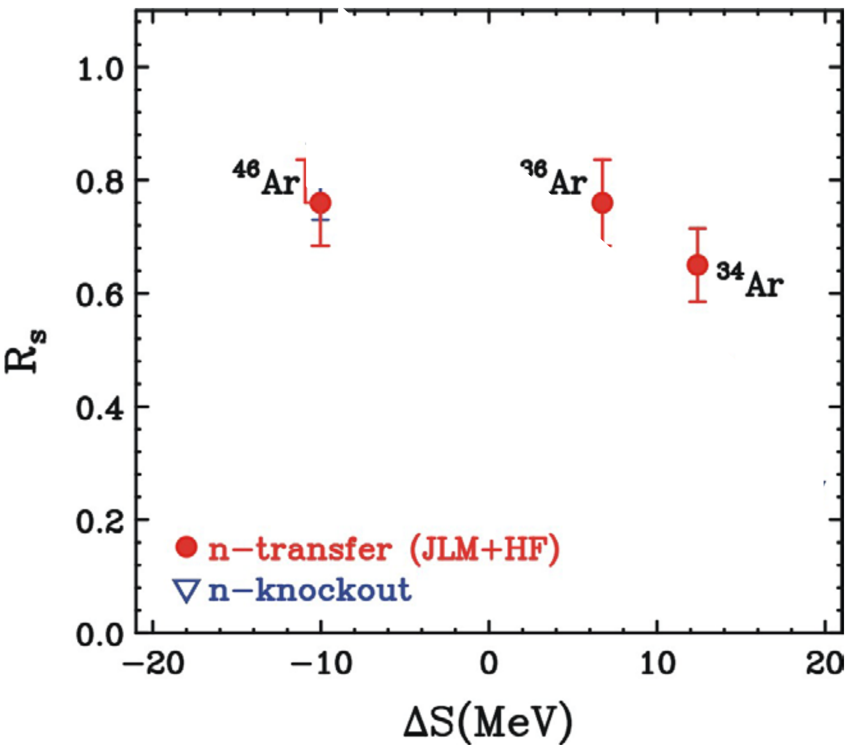
(NNDC)

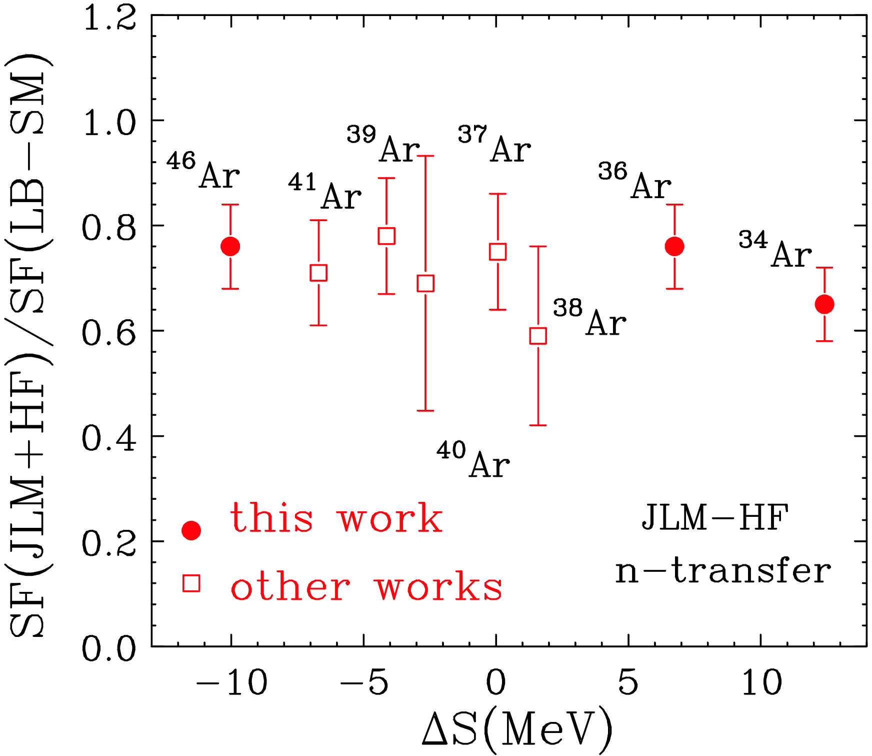


E level (keV)	Jπ
0.0	5/2-,7/2-
542.1 *6*	1/2-,3/2-
1339.9 *8*	
1416.1 *12*	1/2-,3/2-
1660 *50* ?	
1734.7 *9*	
1770.3 *8*	
1876	1/2-,3/2-
1911 *5*	
2420 *50*	
2510	1/2-,3/2-
2757.0 *12* ?	
3230	
3294.8 *8*	
3718	
3949.7 *12* ?	
4280	
4326.1 *9*	
4800	
5773	

J. Lee et al., PRL104, 112701 (2010).

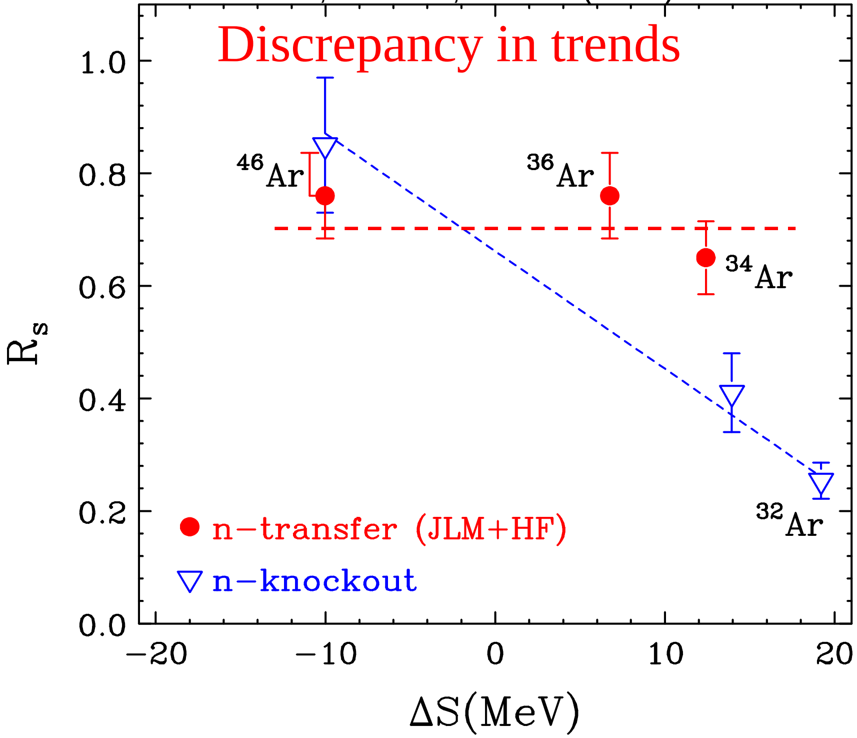




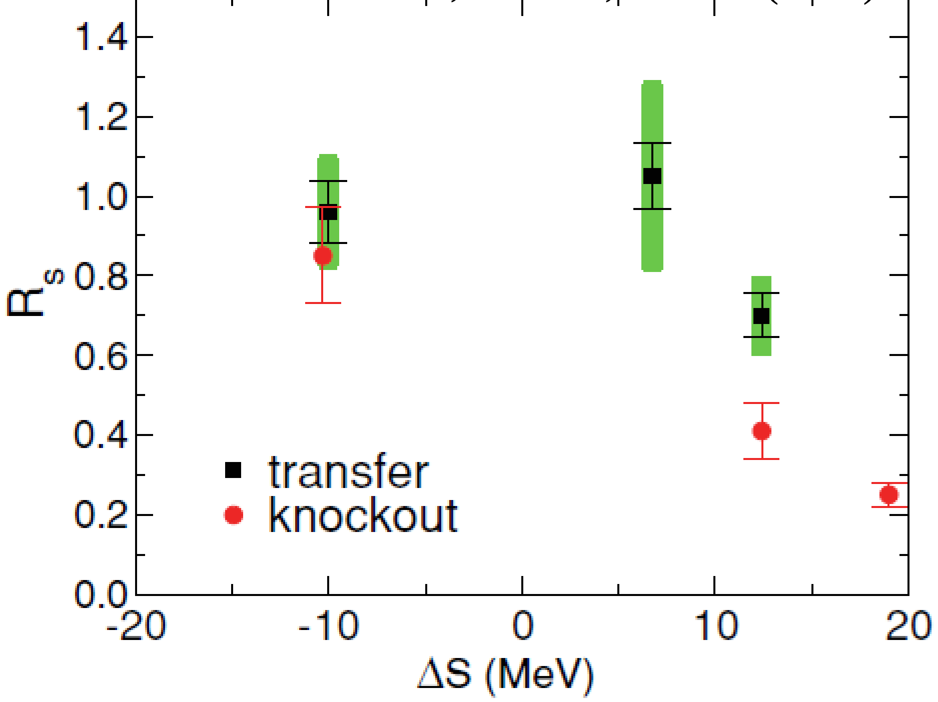


Errors in Reaction theories using Feddeev Calculatiosns

J. Lee et al., PRL104, 112701 (2010).

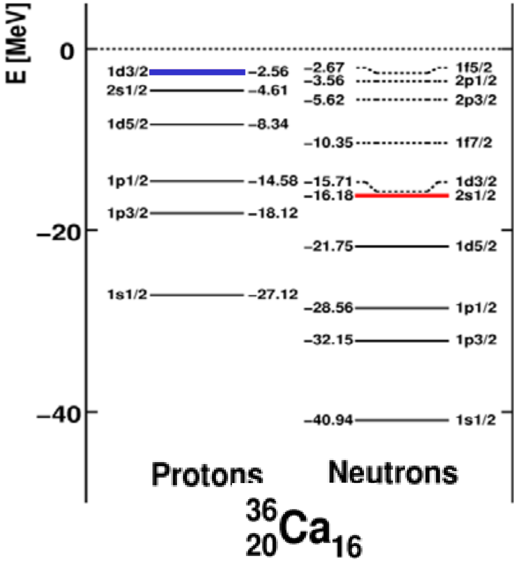

Discrepancy in trends

Nunes, PRC 83, 034610 (2011)



Equivalent reaction theory errors should be obtained in knockout reactions using the 3-body Feddeev calculations

Single Nucleon Knockout of ^{36}Ca
Rebecca Shane – Wash U results



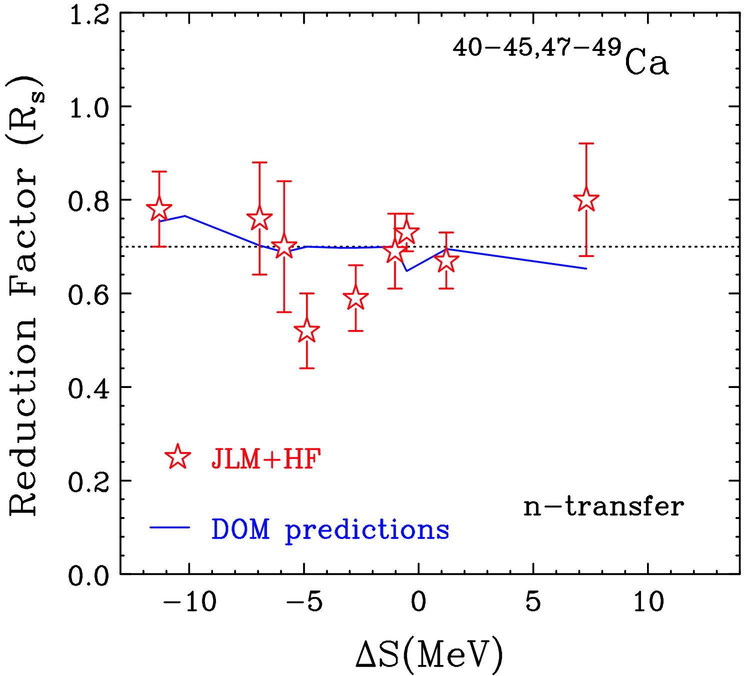
Knockout Cross Sections

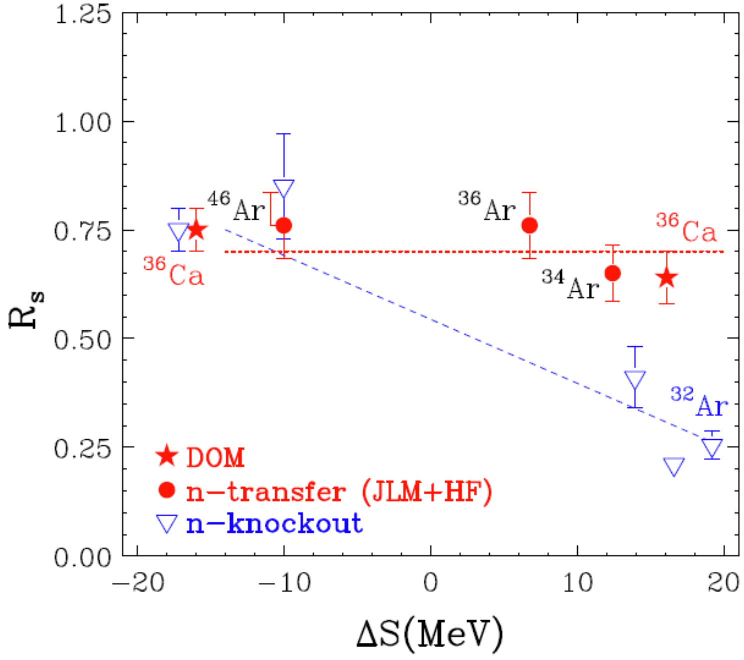
$$N_{knockout} \sim \sigma_{exp}(nl)_{targ} N_{beam}$$

Residue	σ_{exp} (mb)	σ_{thy} (mb)	$R_s = \sigma_{exp}/\sigma_{thy}$	SF_{knock}	SF_{DOM}
^{35}K ($d_{3/2}$)	51.1 ± 2.6	64.6	0.83	*0.75*	*0.7-0.8*
^{35}Ca ($s_{1/2}$)	5.03 ± 0.46	22.22	0.24	*0.21*	*0.64*

Results are consistent with prior knockout analyses

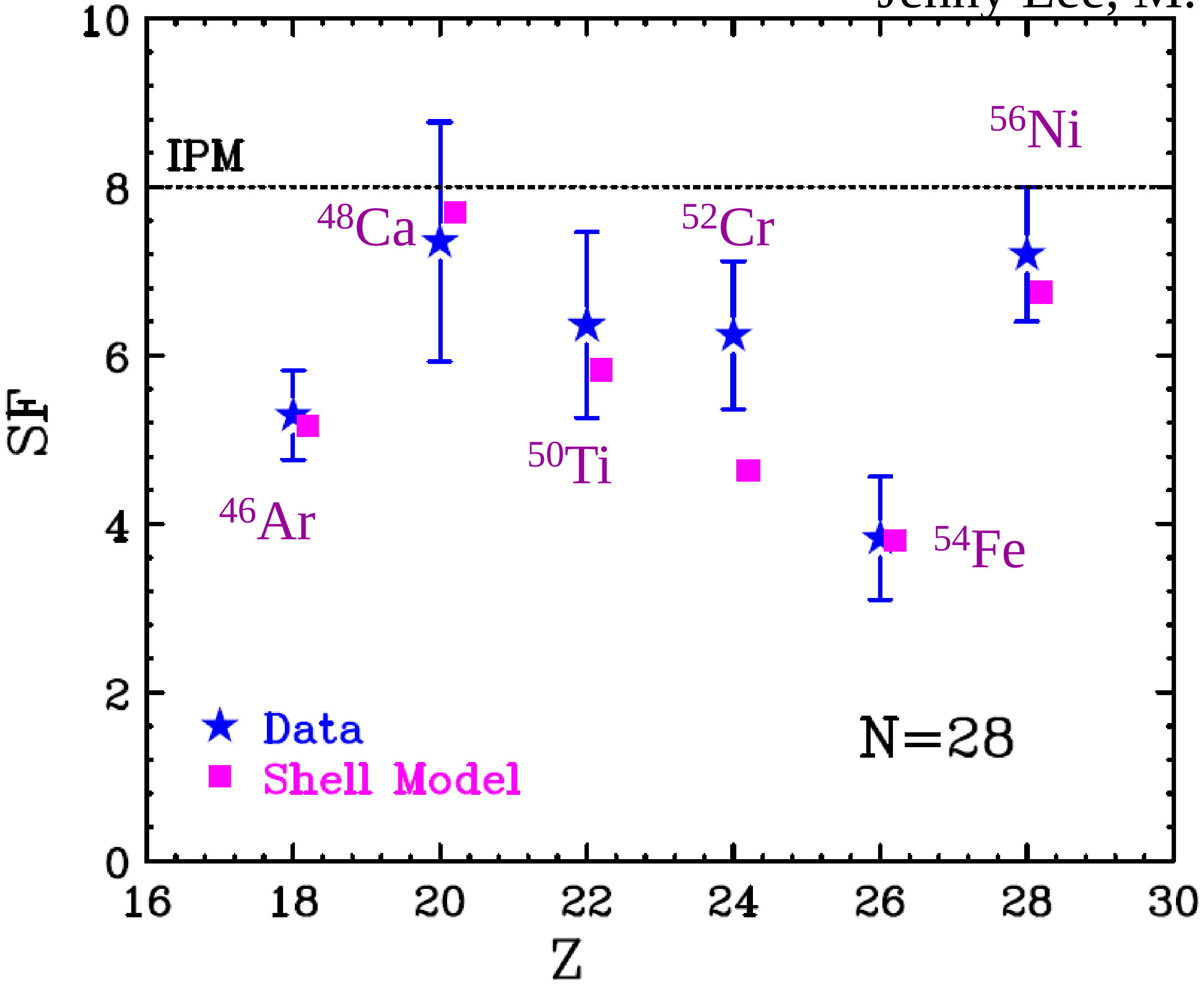
Very different SF from DOM fits





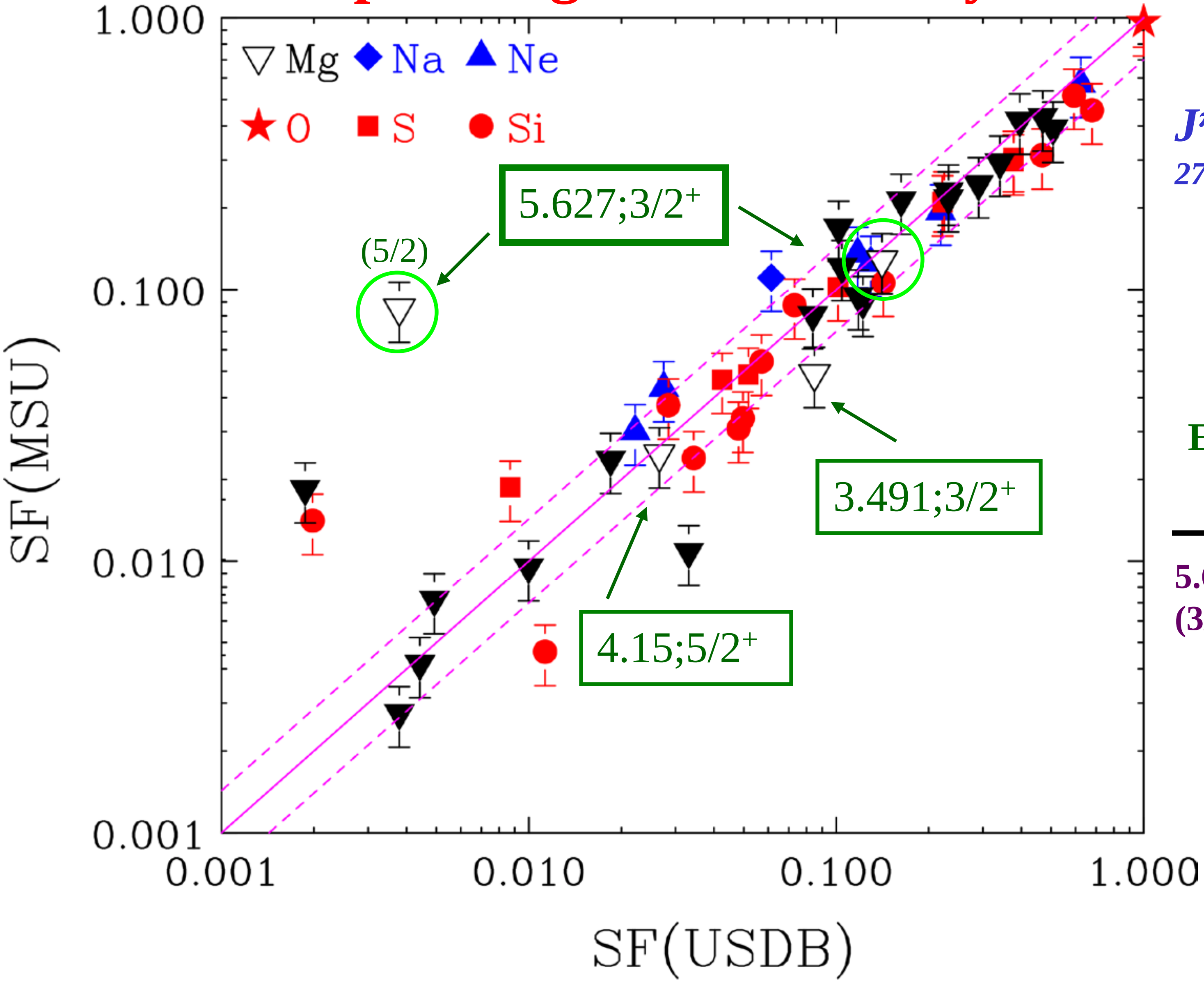
Neutron correlations in N=28 isotones (add more protons)

Jenny Lee, M. Horoi



^{54}Fe; n's feel the effect most strongly when 2 p's are removed

Nuclear structure study with (p,d) reactions
Spin assignments from Systematics



J^{π} assignment
^{27}Mg (NUDAT):

(3/2,5/2)$^{+}$

Expt **SM**

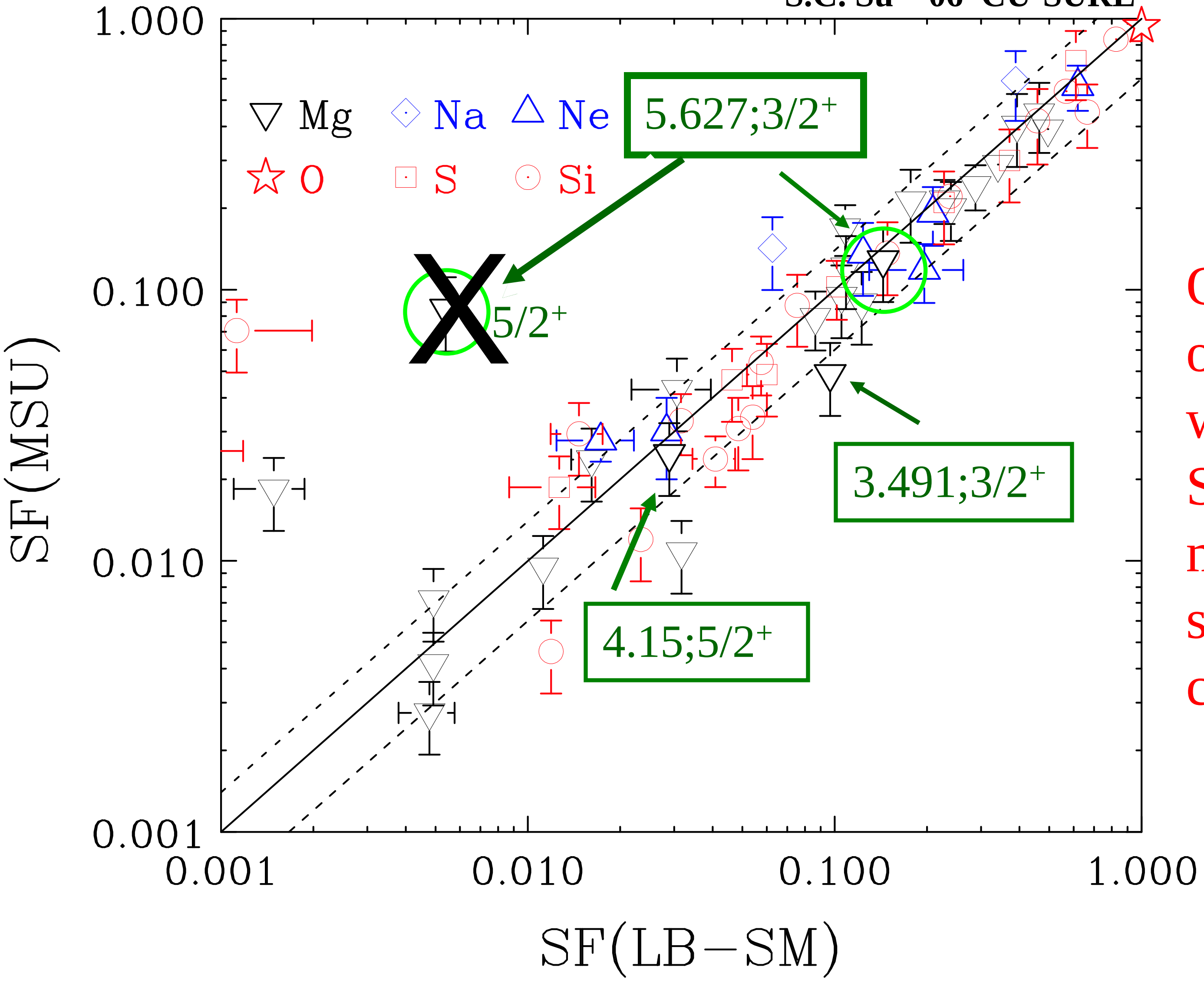
5.454, 3/2

5.627
(3/2,5/2)

5.404, 5/2

S.C. Su (Chinese University of Hong Kong) – 06' SURE program

Nuclear structure study with (p,d) reactions
Spin assignments from Systematics



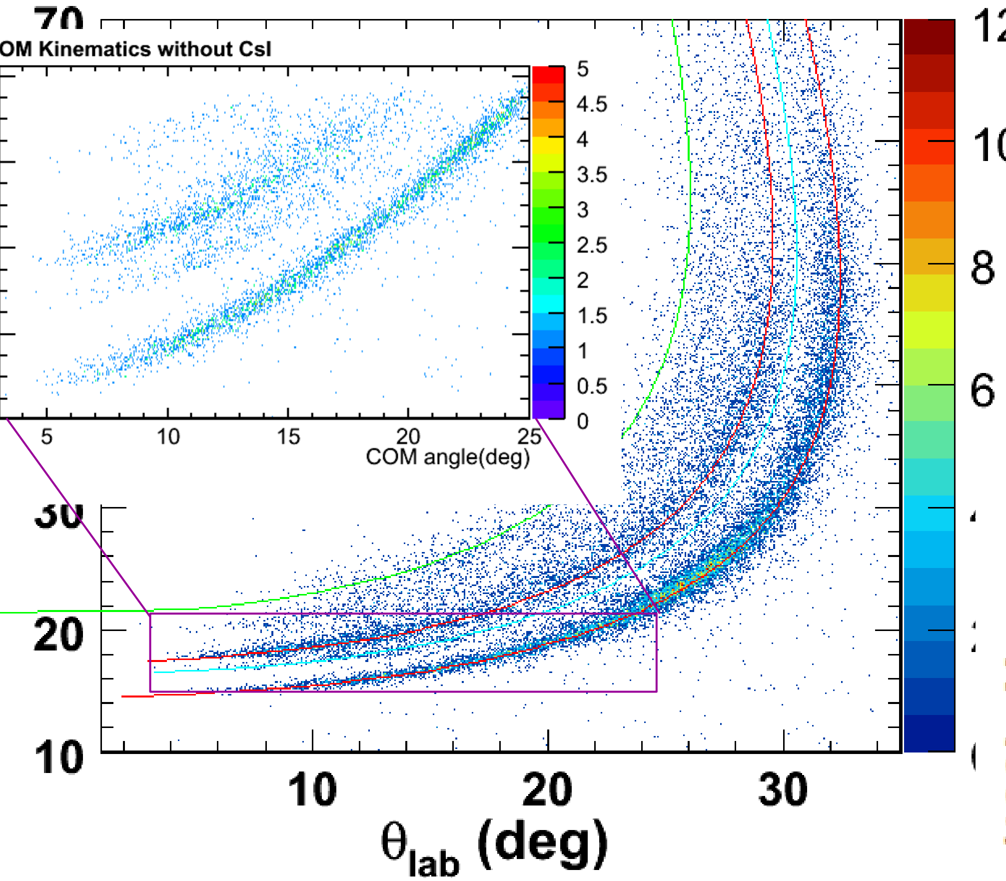
S.C. Su – 06’ CU-SURE

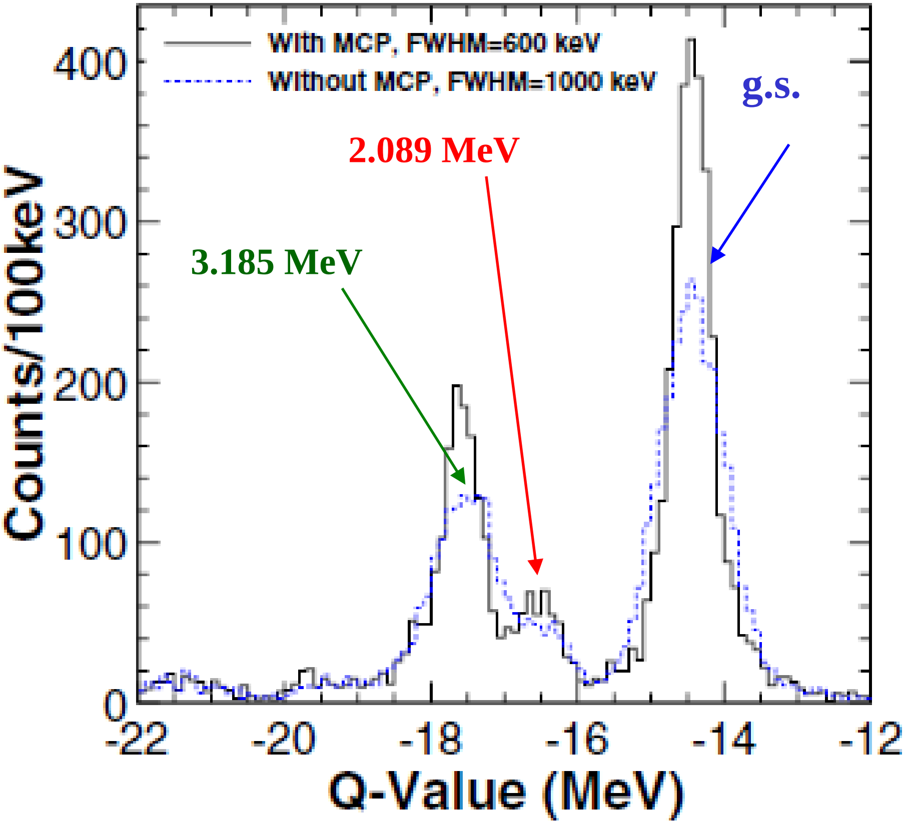
Only about 30% of the states with extracted SF can be matched to states from SM calculations.

Kinematics and Q-Value

$p(^{56}Ni, d)^{55}Ni$; E/A~37 MeV

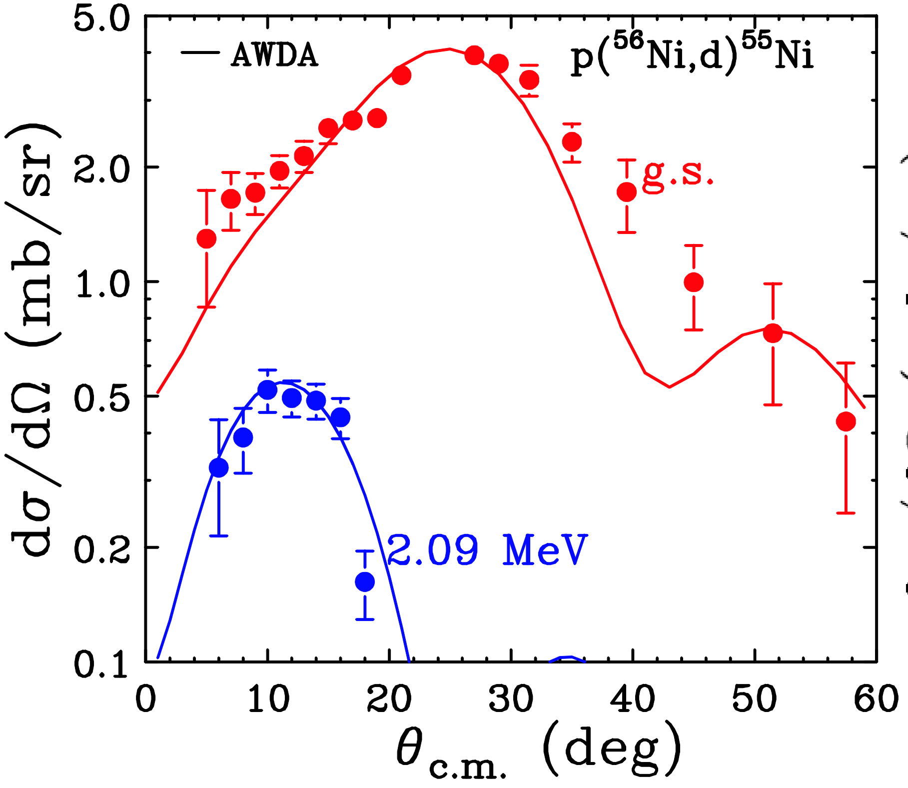
Thesis: Alisher Sanetullaev



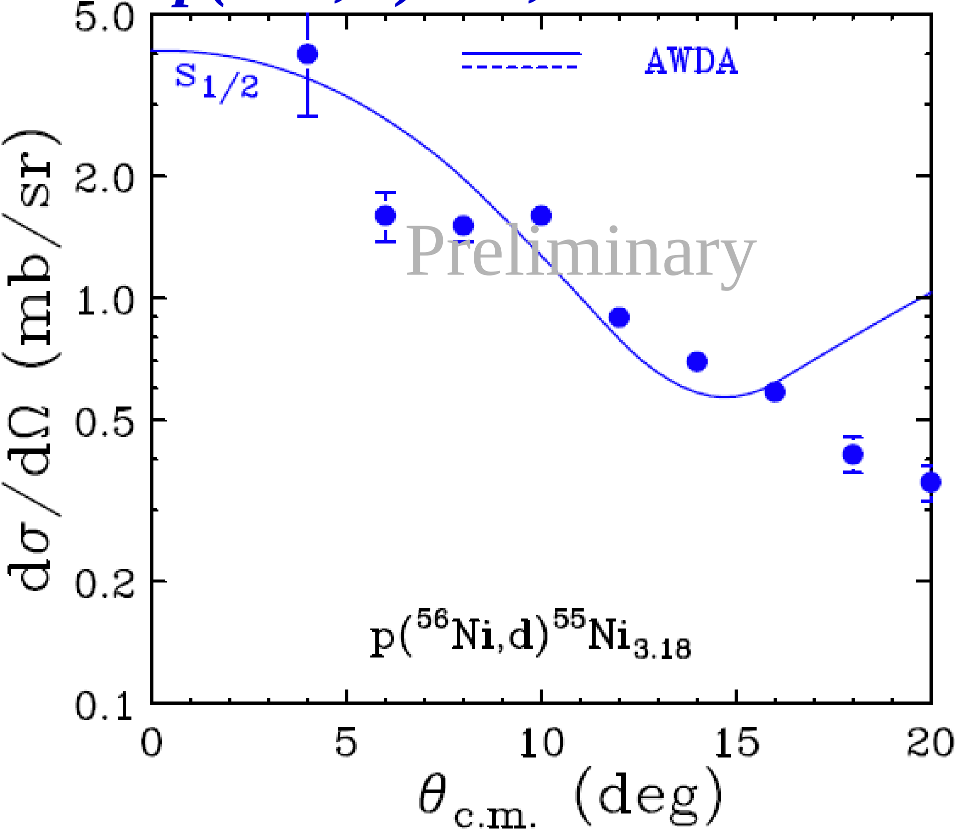


Corrections for beam positions and beam angles using MCP are important to improve the energy resolutions of the data.

Angular Distributions



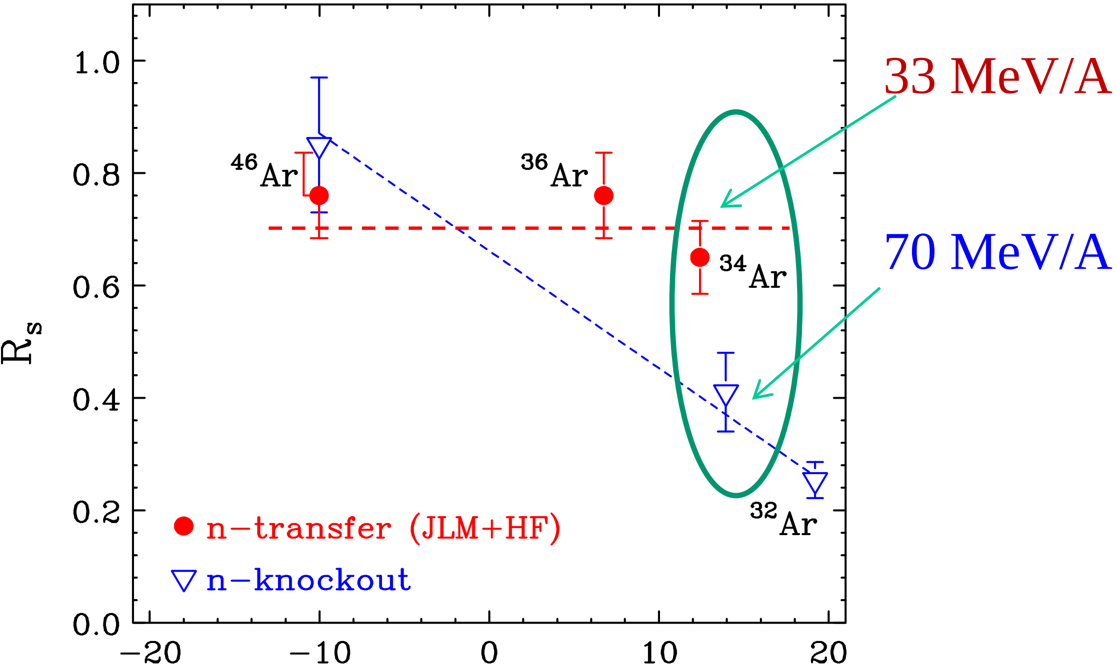
p(^{56}Ni, d)^{55}Ni; E/A~37 MeV



Need theoretical predictions for 3.18 MeV state.

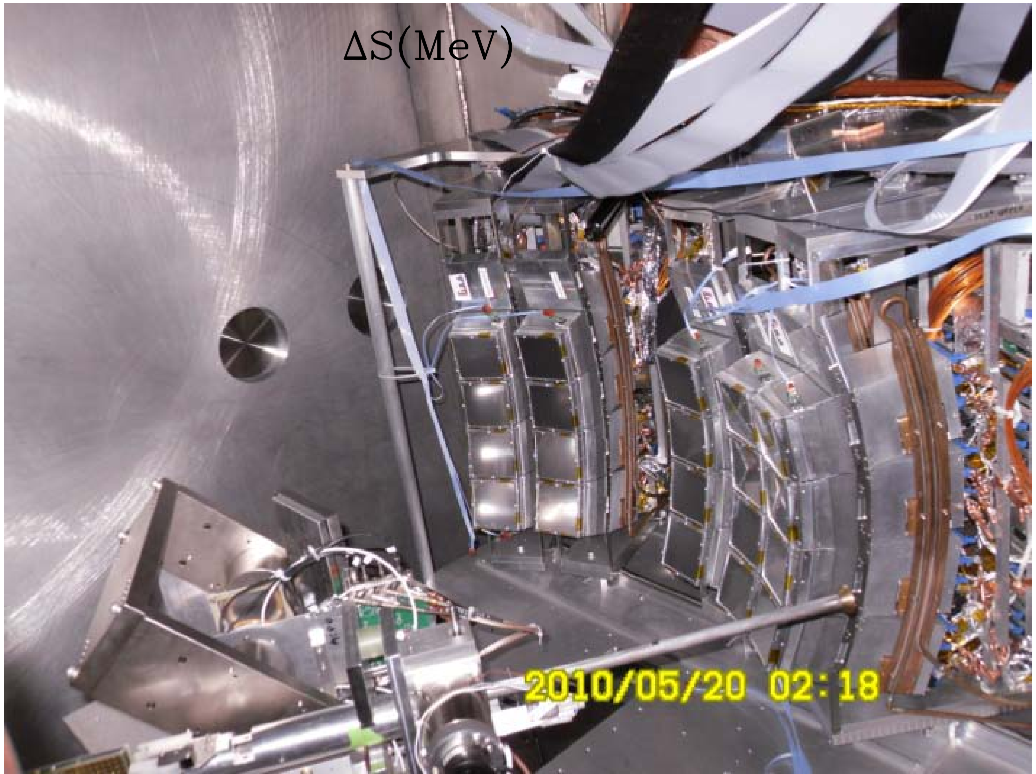
Alisher Sanetullaev, Thesis: 2011

	lj^π	SF(ex)	SF(SM)
g.s.	**$1f_{7/2}^{-}$**	**7.0±0.7**	**6.78**
2.09 MeV (unknown)	**$p_{3/2}^{-}$**	**0.12±0.03**	**0.18**
3.18 MeV (verify)	**$s_{1/2}^{+}$**	**0.25±0.05**	**?**



33 MeV/A

70 MeV/A



Upcoming Results

MSU + VECC collaboration

E/A=37 MeV
^{56}Ni + p→d + ^{55}Ni
E/A=80 MeV
^{56}Ni + p→d + ^{55}Ni

Comparison of proton and neutron spectroscopic factors in ^{56}Ni

MSU + VECC collaboration

E/A=80 MeV
^{56}Ni + p→d + ^{55}Ni
^{56}Ni+ d→^{3}He + ^{55}Co

Proton Spectroscopic Factor:

$^{3}\mathrm{He}+\mathrm{A}(\mathrm{N},\mathrm{Z}) \rightarrow \mathrm{B}(\mathrm{N}, \mathrm{Z}+1)+\mathrm{d}$

$\mathrm{d}+\mathrm{A}(\mathrm{N},\mathrm{Z}) \rightarrow \mathrm{B}(\mathrm{N}, \mathrm{Z}+1)+\mathrm{n}$ (n is difficult to detect)

SF = overlap of **$|\psi$ (B=A+1) $\rangle$ with $|\psi$ (A) $\rangle_{\text{core}}$ $\otimes$ p(ℓ j)**

The reaction is dominated by 1-step direct transfer.

Elastic Scattering is the main process in the entrance and exit channels.

Distorted Wave Born Approximation (DWBA)

$$S_{l,j} = \frac{\left(\frac{d\sigma}{d\Omega}\right)_{Expt}}{\left(\frac{d\sigma}{d\Omega}\right)_{DWBA}}$$

Need Optical Model potentials for ^{3}He, d & n

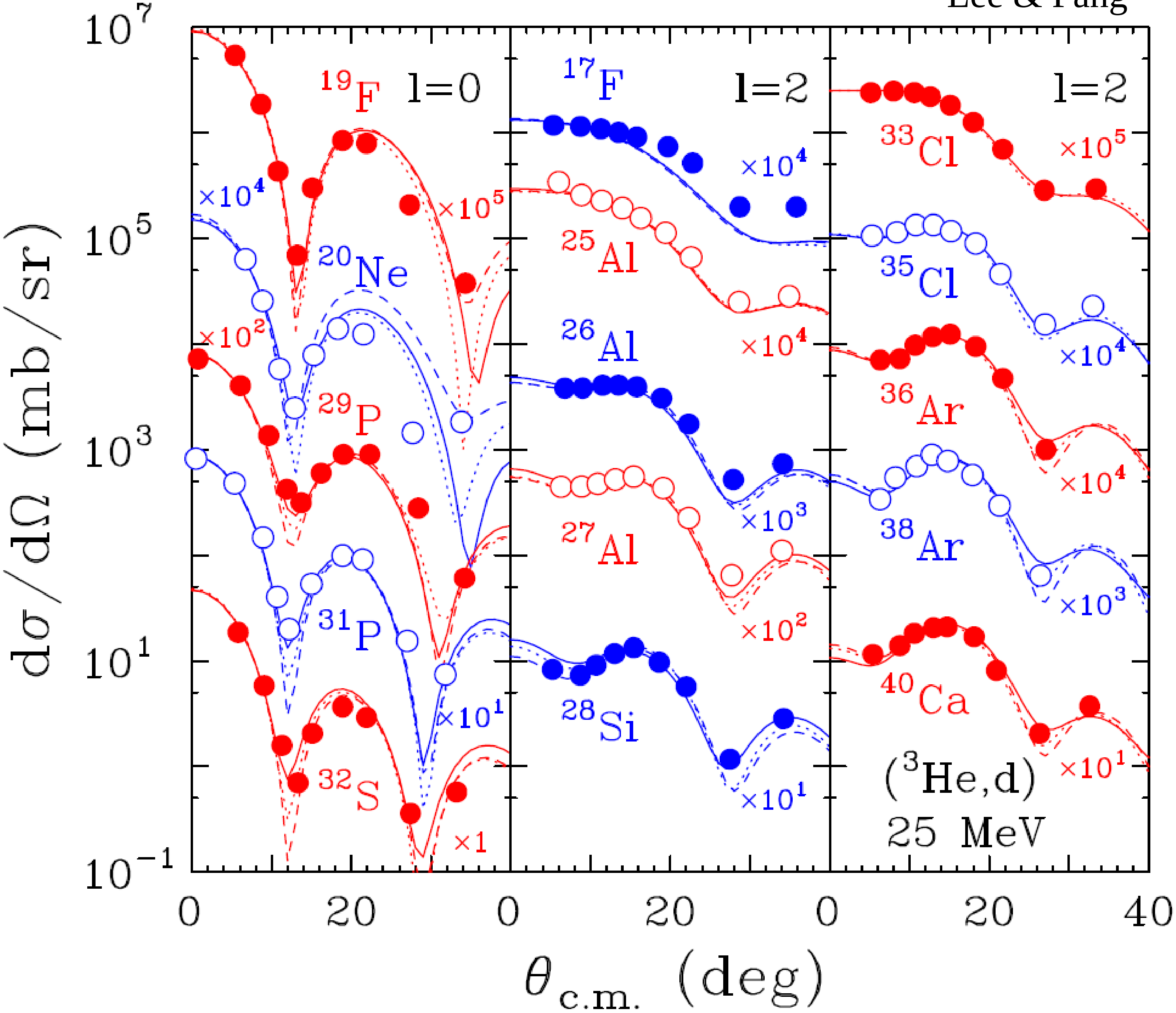
^{3}He potential : Becchetti-Greenlees (B-G); GDP08; microscopic

d potentials: Daehnick

p potentials: Woods-Saxon, ro=1.25 fm, ao=0.65 fm

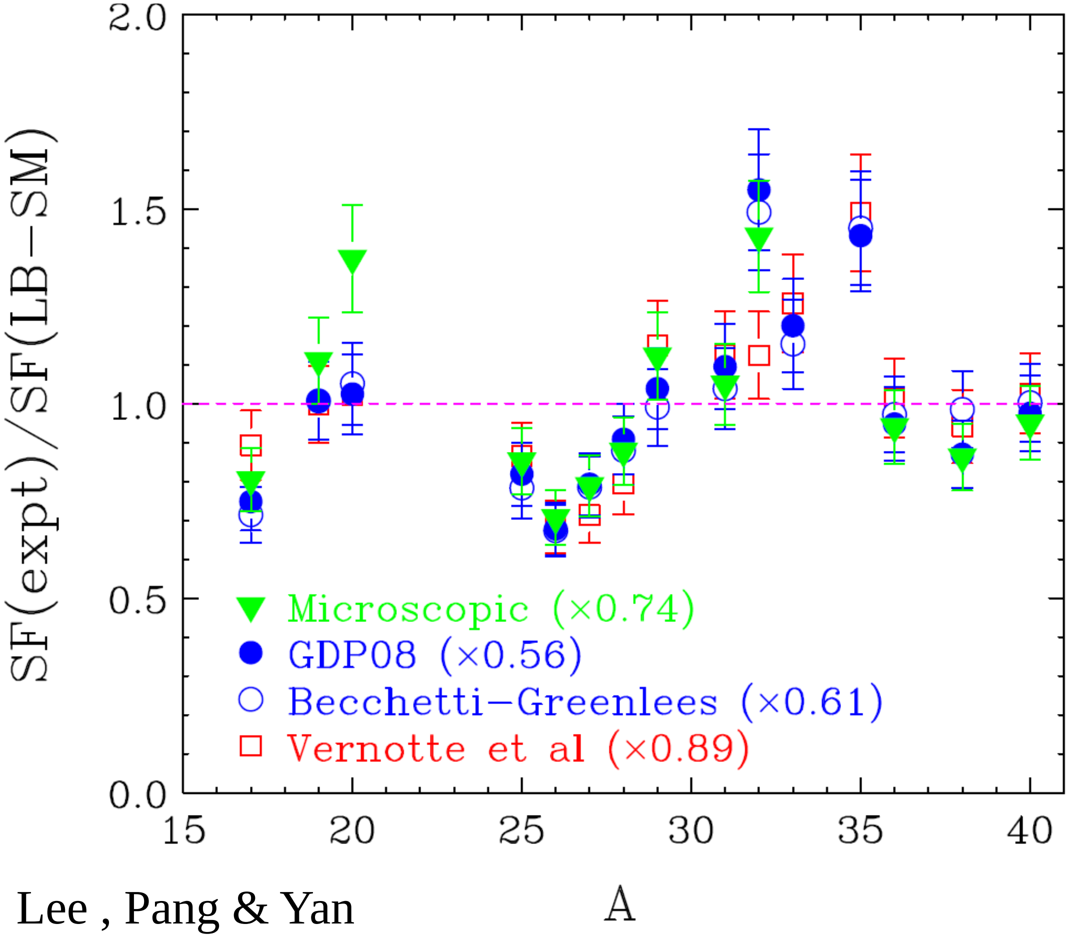
Fits to ^{3}He+(A-p)→d+A

Lee & Pang



Systematics of proton SFs

^{17}F, ^{19}F, ^{20}Ne, ^{25}Al, ^{26}Al, ^{27}Al, ^{28}Si, ^{29}P, ^{31}P, ^{32}S, ^{33}Cl, ^{35}Cl, ^{35}Ar, ^{36}Ar, ^{40}Ca



Lee , Pang & Yan

The p SF-systematics is not as consistent as the n-SF systematics.

Extracted SF are larger than SM(SF).

Different potentials have different normalization factors

±50% fluctuations.

Theoretical input and collaborations are welcome.

Physics with HiRA

NSCL
Washington University in St.Louis

HiRA core collaboration

Bill Lynch, Betty Tsang, Zibi Chajecki, Daniel Coupland, Tilak Ghosh, Rachel Hodges, Micha Kilburn, Jenny Lee, Fei Lu, Andy Rogers, Alisher Sanetullaev, Jack Winkelbauer, Mike Youngs (Mark Wallace, Frank Delaunay, Marc VanGoethem)

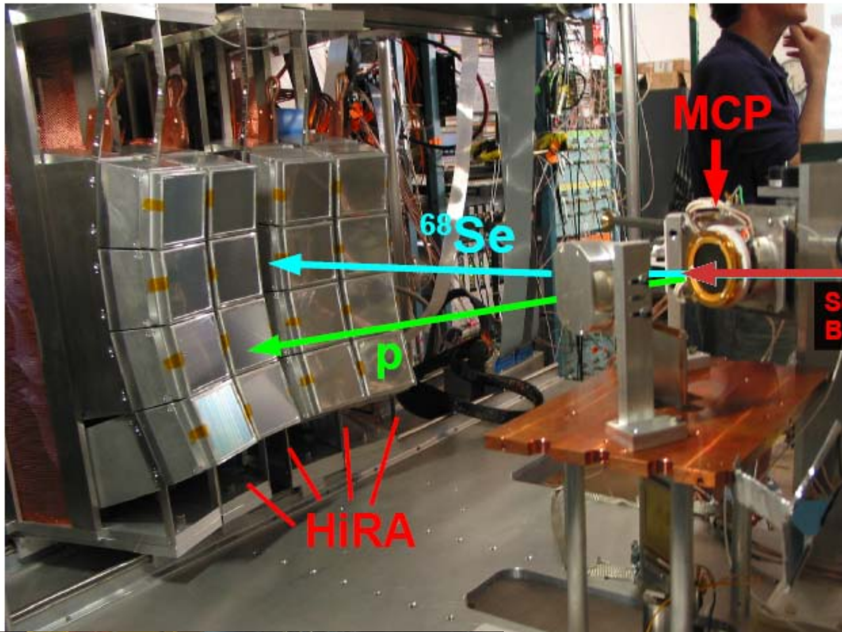
WU in St. Louis ***Bob Charity, Jon Elson, Lee Sobotka***

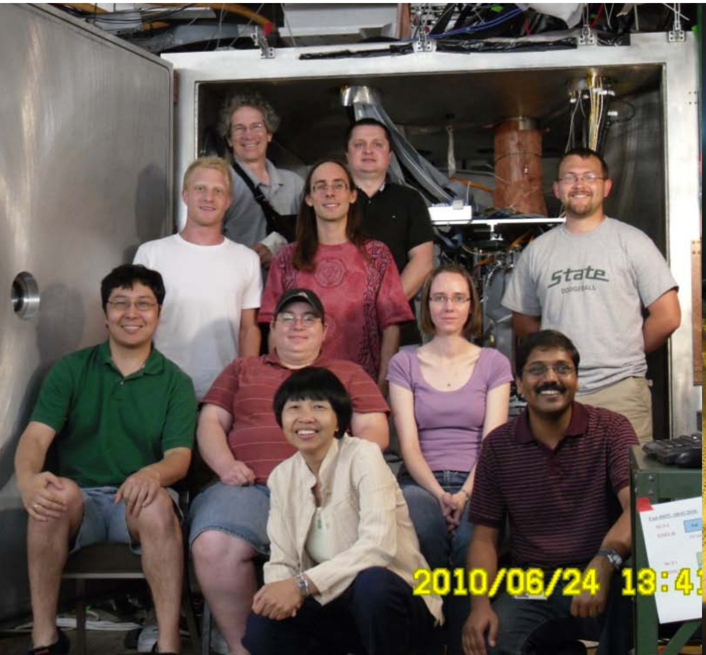
Indiana University ***Romualdo deSouza, Sylvie Hudan,***

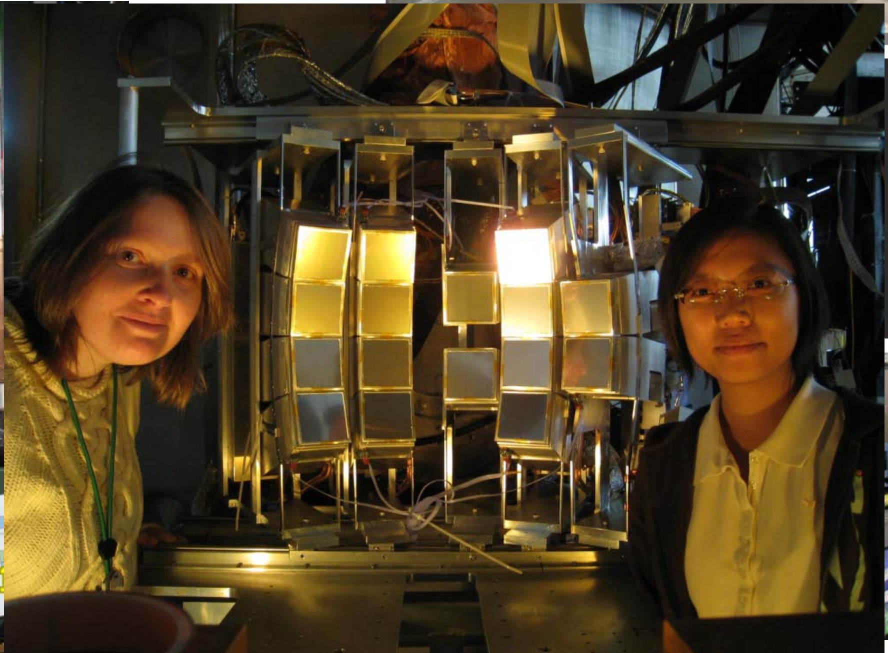
INFN, Milan ***Arialdo Moroni***

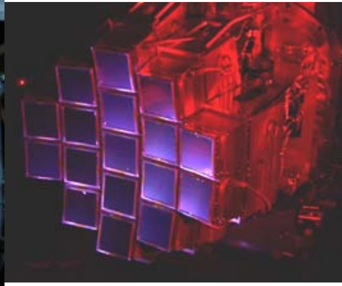
Western Michigan University ***Mike Famiano,***

ORNL ***Dan Shapira***









Homework Problems– Summary of questions/requests

1. Can SF for excited states in nuclei near closed shell nuclei be predicted with better accuracy?
2. Are there explanations why the SFs extracted using the "standard parameter" set with AWDA agree with LBSM predictions?
3. Better residual interactions are needed for gfp shell in predicting the SFs of the excited states. We also need predictions for higher excited states for the gfp shell nuclei.
4. We need a procedure to apply the HF geometry constraints for the excited states.
5. Is there explanation for the consistent discrepancies between knockout and transfer reactions?
6. Where are the missing strength of the states strongly quenched in knock out reactions?
7. We need errors in knockout reaction theories using the 3-body Feddeev calculations as in PRC83, 034610(2011).

Homework Problems– continued

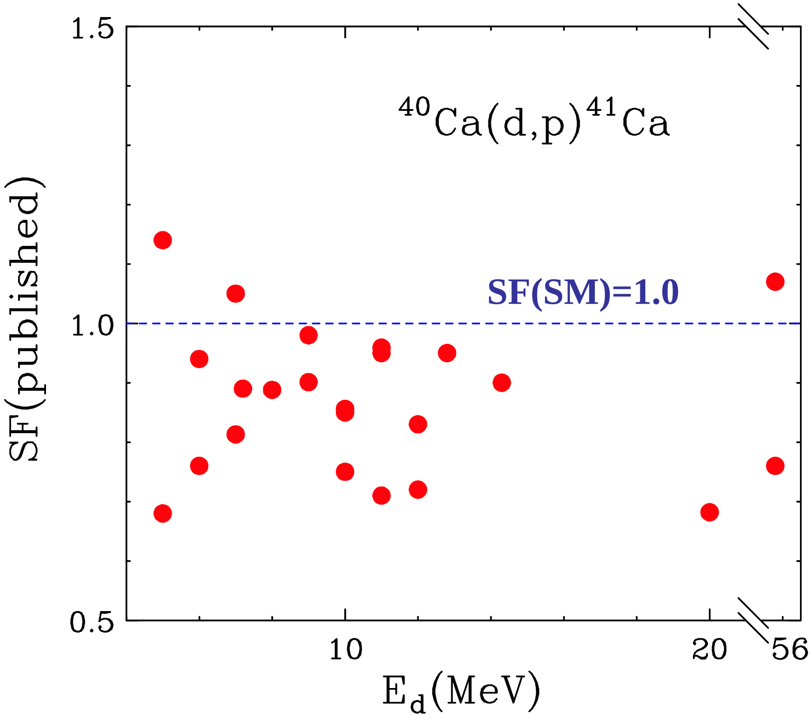
8. Typically, only a small number of states predicted by the shell model can be matched to the experimental results. Can this situation be improved?

10. For proton-SF, we need better theoretical guidance in choosing or deriving ^{3}He OM parameters.

11. Can a model similar to AWDA approach be developed for (^{3}He,d) & (^{3}H,d) reactions?

Discussion Slide

Is elastic scattering data for individual data set the best way to get the optical model potential parameters?



Different sets of parameters were used for the same reaction yield different results.

Need systematic approach including global OM potentials

J. Lee et al., PRC75, 064320 (2007)