Using Transfer Reactions for Nucleon Correlation Studies

One-nucleon Transfer Reactions

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

Experiment: $^{34,46}Ar(p,d)$ Transfer Reactions in Inverse Kinematics
→ Asymmetry Dependence of Neutron Correlations

Two-nucleon Transfer Reactions

Two-neutron: Systematic Calculations → Pairing properties of dilute neutron matter

Neutron-proton: Systematics of $(p,^{3}He)$ & $(^{3}He,p)$ Transfer in sd-shell nuclei
→ Baseline for np-pairing studies for N=Z nuclei

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RIKEN, Nishina Center

YKIS 2011, DCEN
Oct 24 , 2011

Nucleon Correlations using Direct Reactions

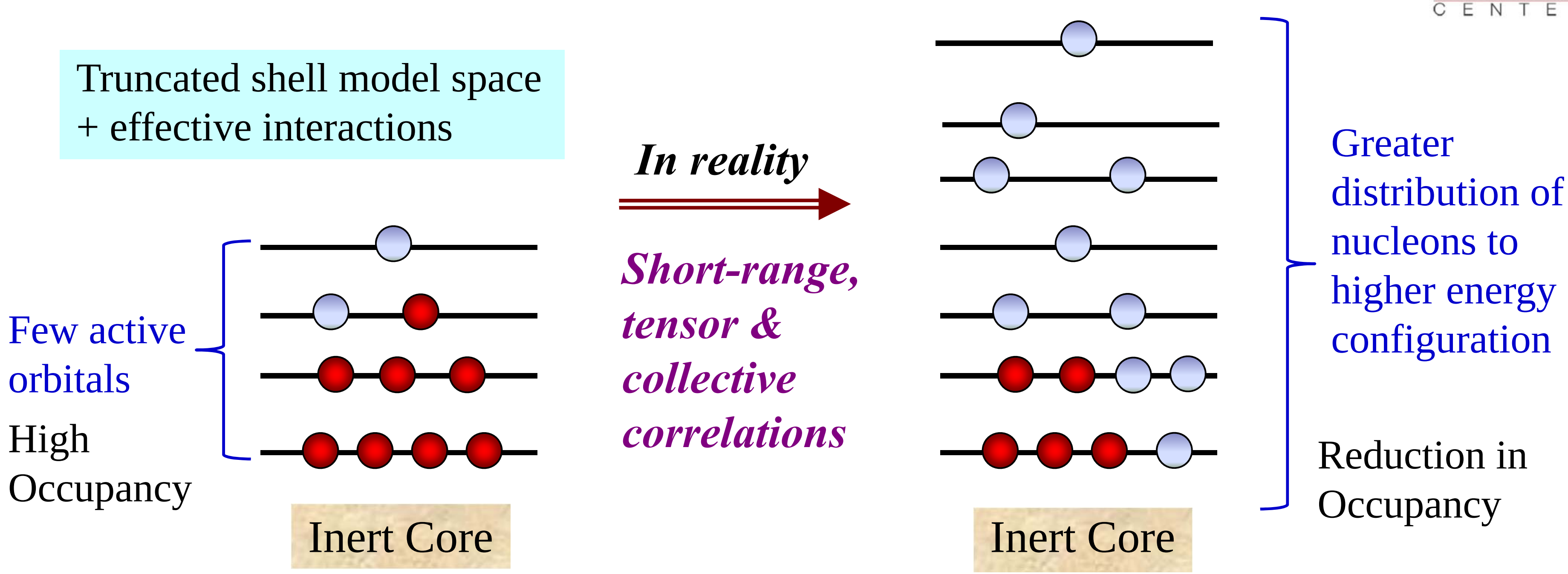
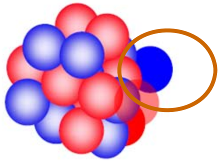


Figure courtesy: J.A. Tostevin

Probing the nuclear wave function

Removing nucleon from occupied orbital
→ ***Cross sections (probability)*** depend on the single-particle occupancy & overlap of many-body wave functions

Full Knowledge of Correlations → Complete Understanding of Nuclear Properties



Spectroscopic Factor (SF)

Cross Sections ✚ Reaction Model

➡ Spectroscopic Factors (expt)

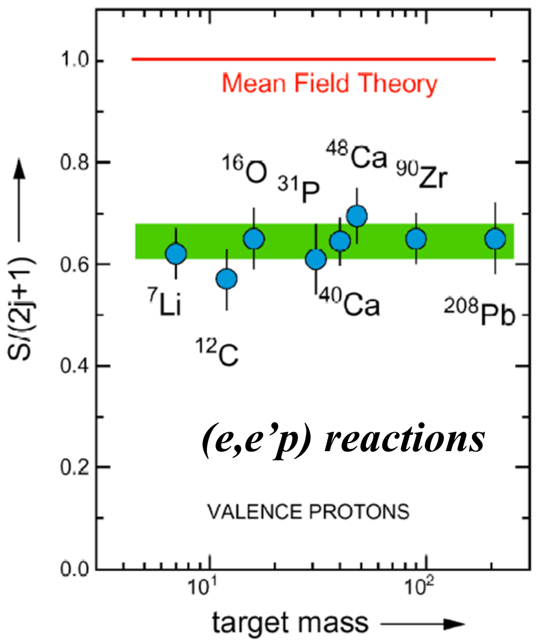
Quantify Occupancy → Correlation Effects

How much ? What is the Isospin Dependence of nucleon correlations?

How good the effective interaction in Shell Model for describing correlations ?

$SF_{exp}/SF_{SM} = 1$ **SM description is accurate**

$SF_{exp}/SF_{SM} < 1$ **Some correlations missing in the interactions ?**



(e,e'p) – Stable nuclei (near closed shell)

- ***Constant ~30-40% of SF reduction compared to theory***
- ***Correlations missing in shell-model interactions***

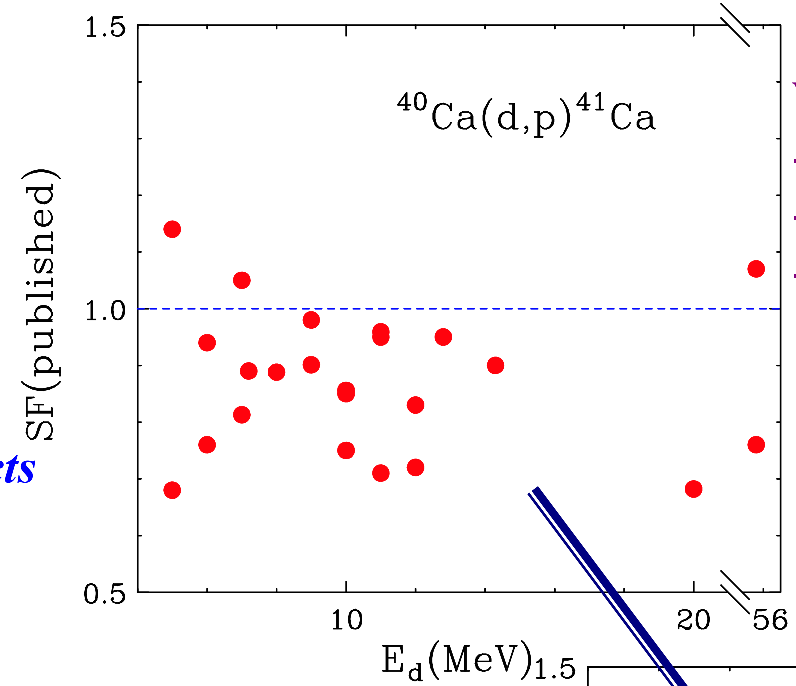
L. Lapikas, Nucl. Phys. A553, 297c (1993)

How about Transfer Reactions ?

Transfer Reactions -- long history (>50 years)
→ abundant data, but Problems in SF(expt) !

Experimental SF from Transfer Reactions

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



Well-known problem

- optical model potentials
- parameters
- reaction models

ADWA (consistent set)

✓ *Johnson-Soper (JS) Adiabatic Approximation takes care of d-break-up effects*

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

✓ *Include finite range & non-locality corrections*

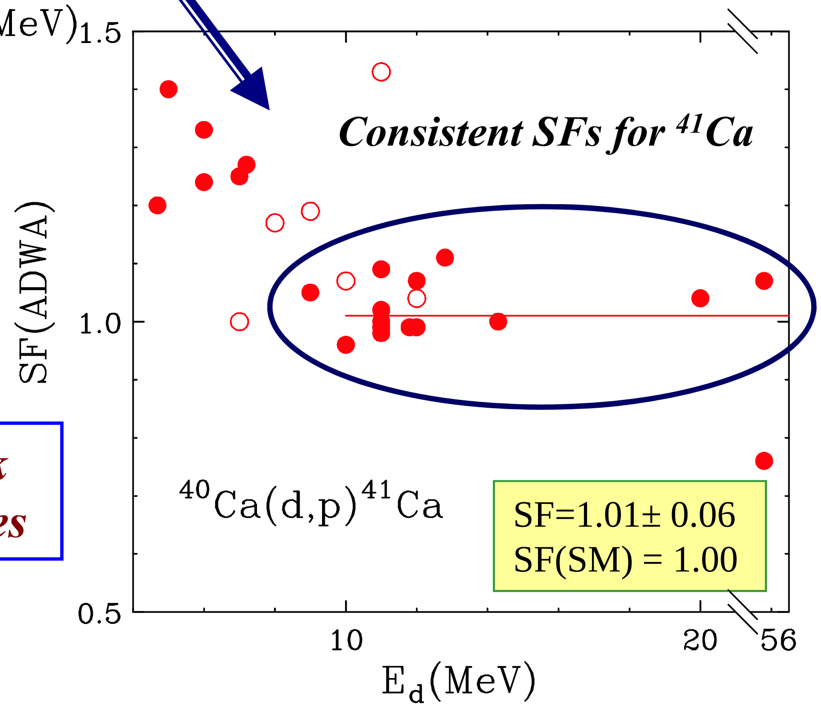
✓ *n-potential : Woods-Saxon shape r_o=1.25 & a_o=0.65 fm; depth adjusted to reproduce experimental binding energy*

TWOFNR, M. Igarashi et al.,

X.D. Liu et al., Phys Rev. C 69 (2004) 064313

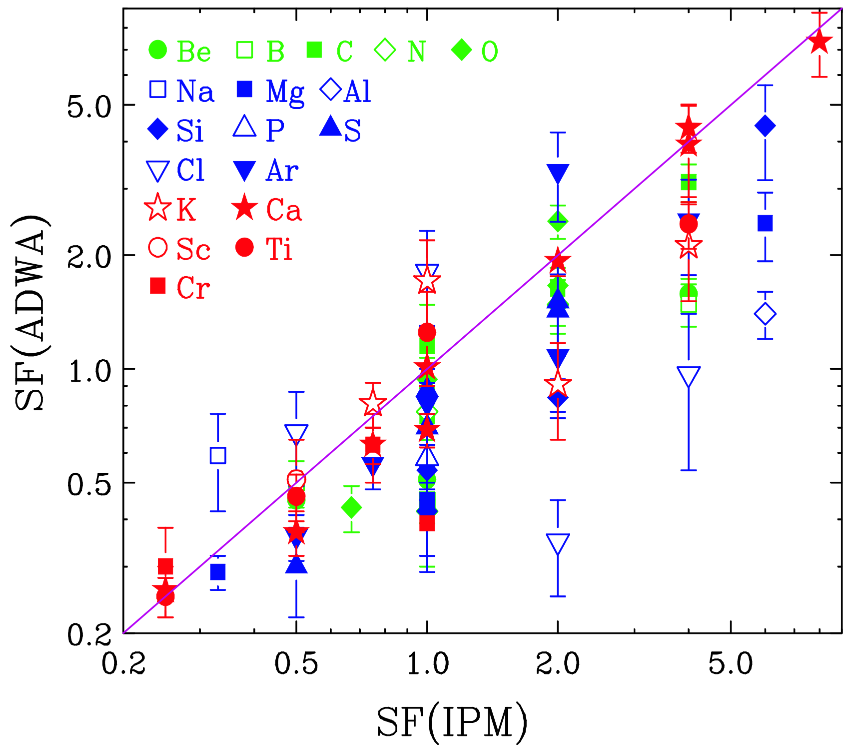
J. Lee et al., Phys. Rev. C75 (2007) 064320

Reliable Framework
→ Systematic Studies

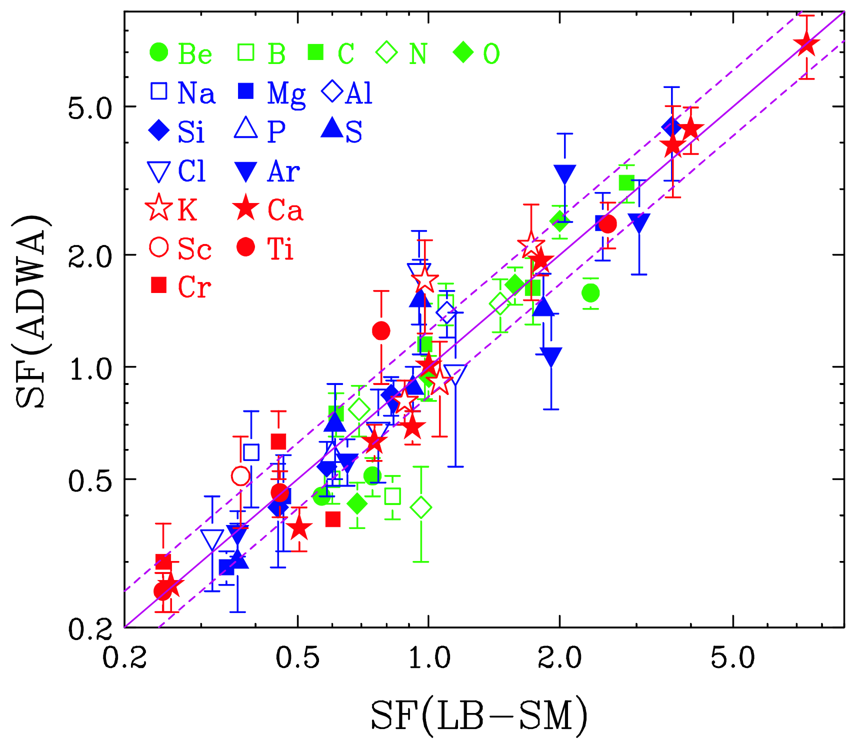


Ground-state Spectroscopic Factors of Z=3-24

IPM + Maximal pairing predictions



LB-SM predictions (Residual interactions → correlations)



- *Most extracted SFs less than IPM-plus-pairing predictions*
- *Absence of nucleon-nucleon correlations*

$$SF_{LB-SM} < SF_{IPM}$$

- ***Remarkable 20% agreement to the large-basis shell-model calculations***

M.B. Tsang and J. Lee et al., Phys. Rev. Lett. 95, 222501 (2005)

LB-SM code : Oxbash, Alex Brown (MSU)

Excited-state Spectroscopic Factors of sd-shell nuclei

NSCL

M.B. Tsang and J. Lee et al., Phys. Rev. Lett. 102, 062501 (2009)

Excited-state SFs of rare nuclei:

- ***rp process calculations***
- ***X-ray burst simulations***

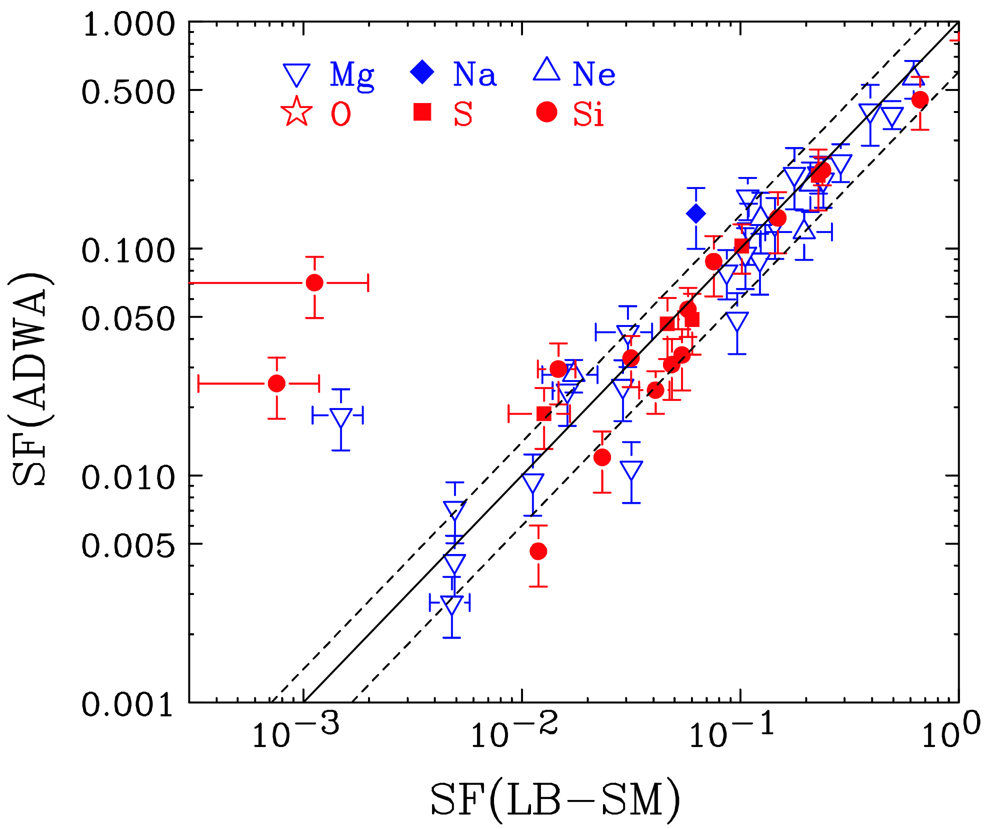
Not available in experiment

→ SFs from SM predictions

❖ ***SFs for excited states are very small (< 0.1)***

→Test the predictive power of Shell Model

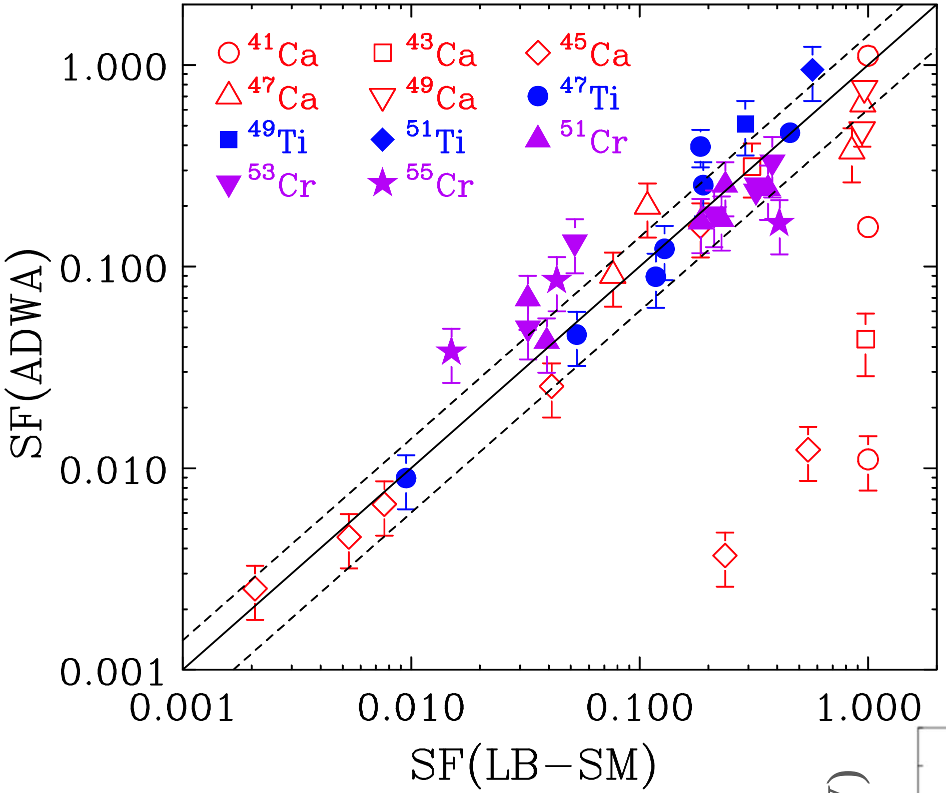
→Evaluate the latest interactions (USDA/USDB) in sd-shell region



SF > 0.002: 30% Agreement with Shell Model

SF < 0.002: SM calculations are not accurate

Neutron SFs for Ca, Ti, Cr isotopes

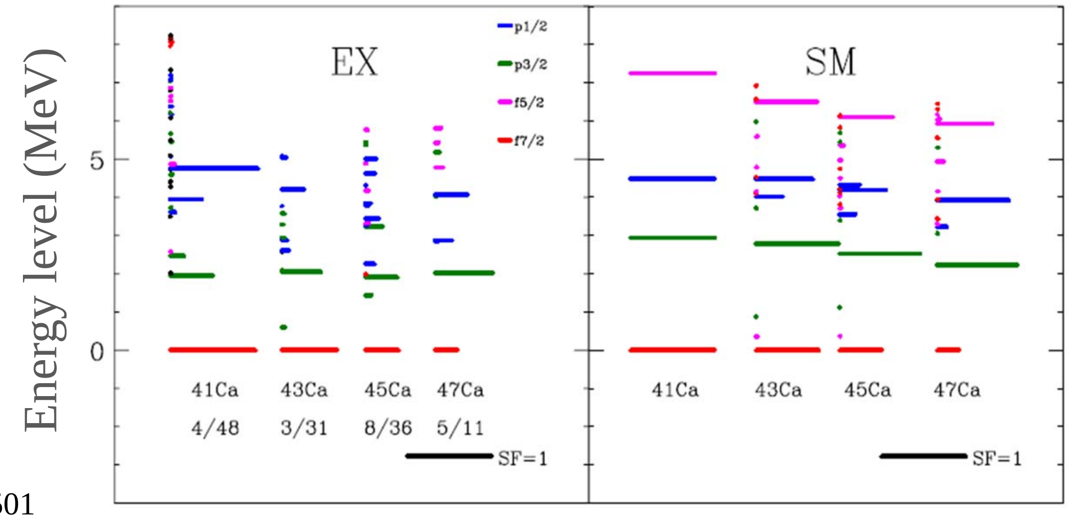


- Poor Shell Model predictions near ^{40}Ca → > 10 times larger than measured
- Not ^{40}Ca core + single particle → due to core excitation and fragmentation of states

Expt: Large Fragmentation of States

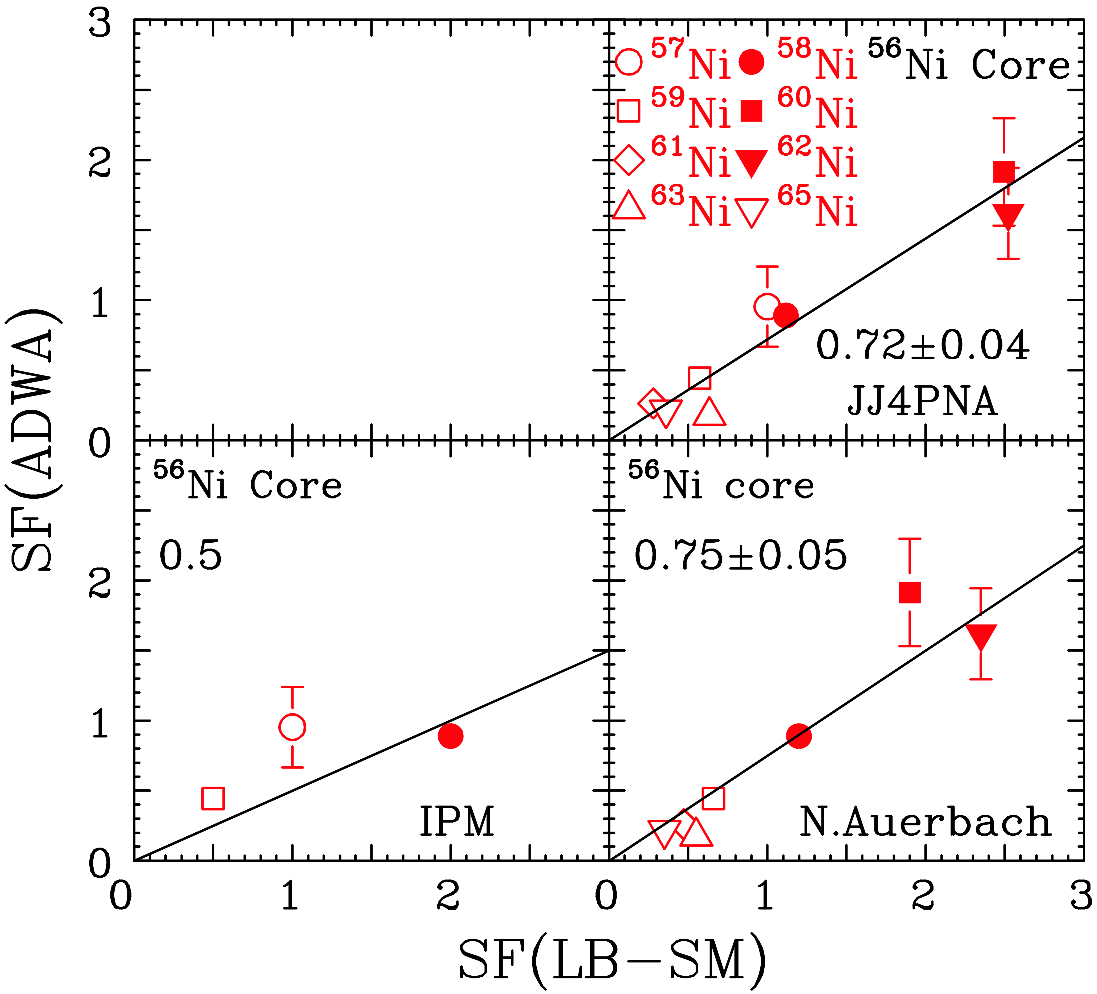
Shell-Model: Mainly Single Particle States

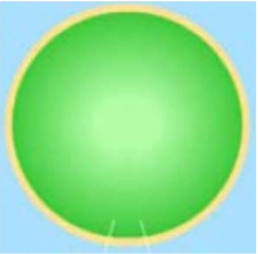
- **sd-pf model space with new interactions is needed**



M.B. Tsang and J. Lee et al., Phys. Rev. Lett. 102 (2009) 062501

Ground-state Neutron SFs for Ni isotopes



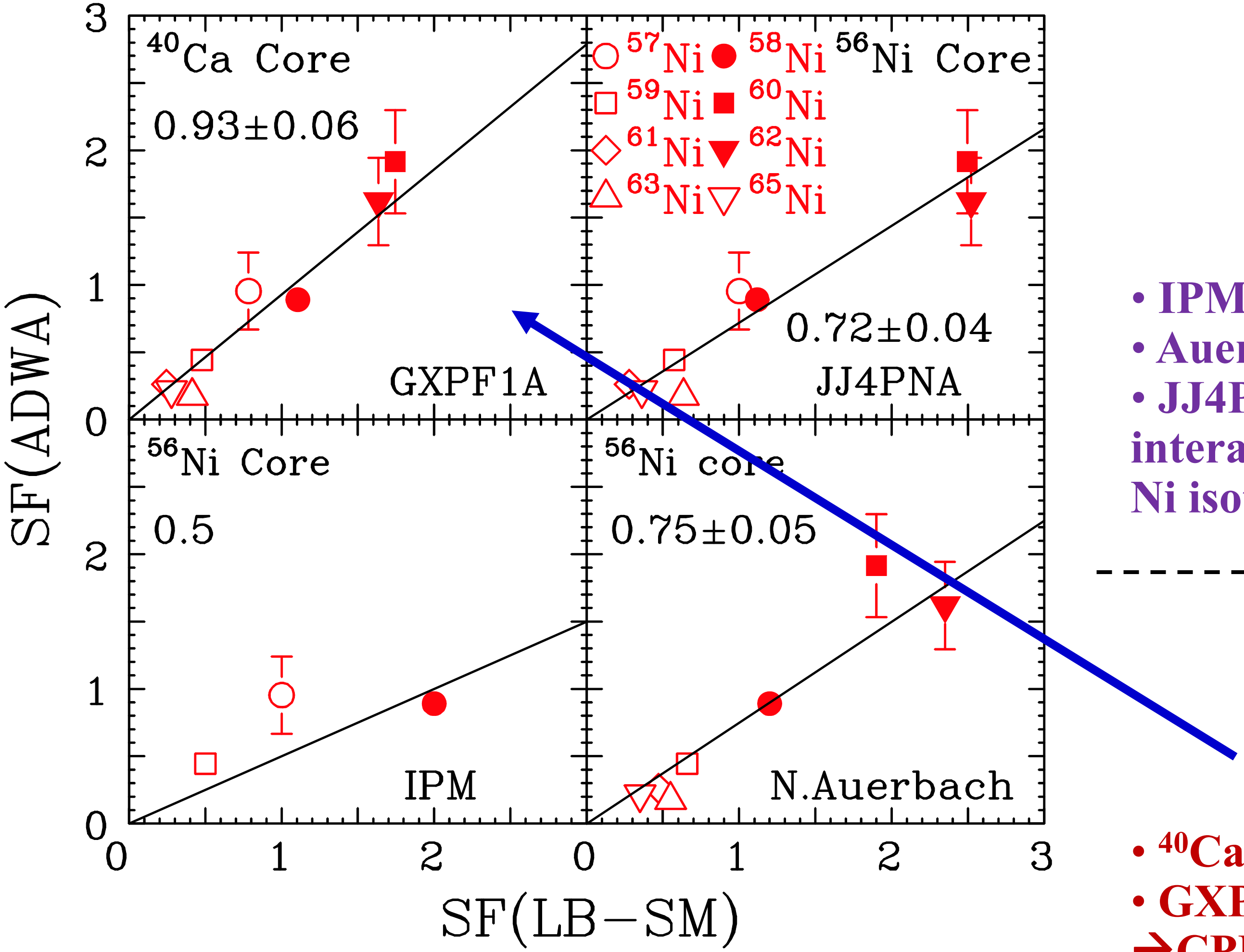


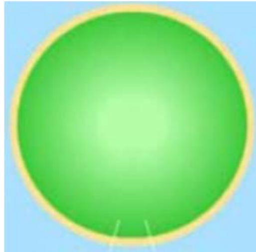
^{56}Ni core

- IPM
- Auerbach interaction ('60)
- JJ4PNA : T=1 effective interaction (derived for heavy Ni isotopes)

J. Lee and M.B. Tsang et al., Phys. Rev. C 79, 054611 (2009)

Ground-state Neutron SFs for Ni isotopes





^{56}Ni core

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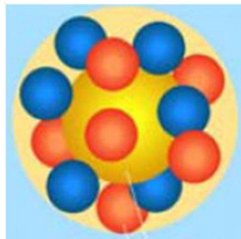
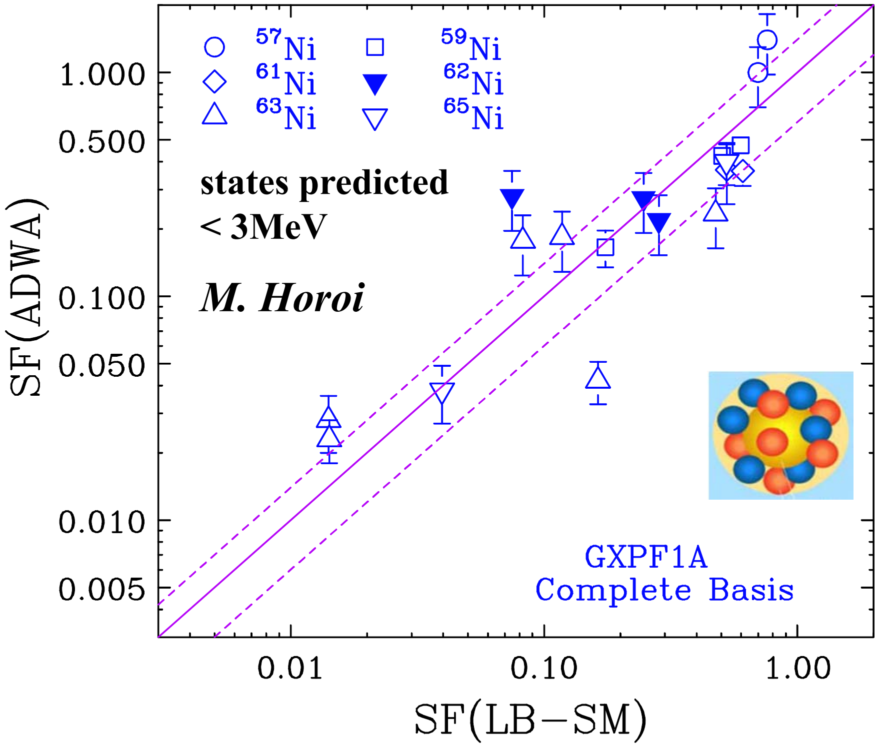


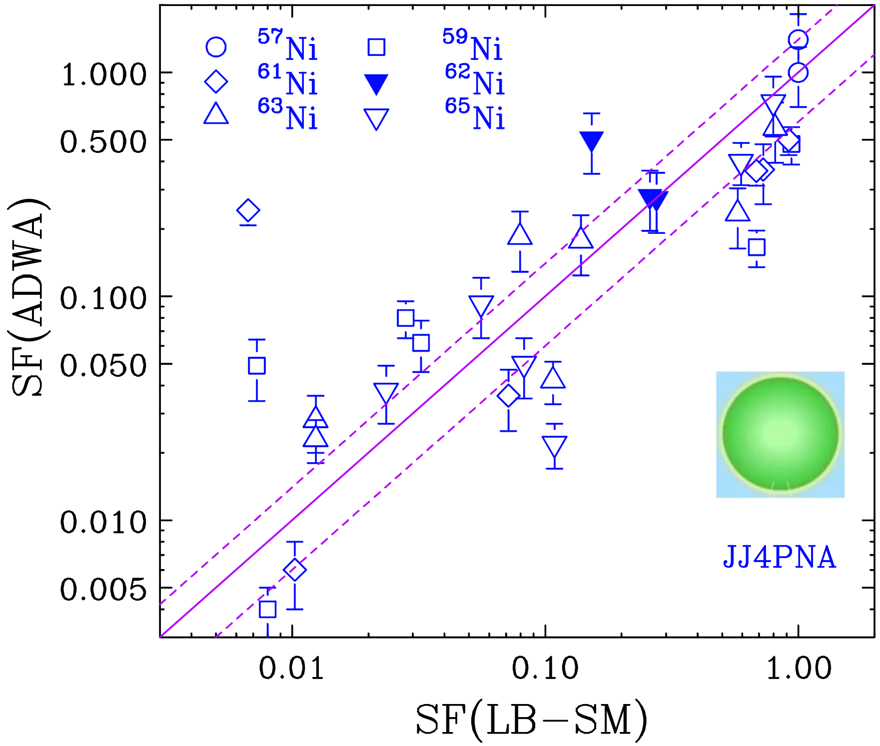
- ^{40}Ca core, in fp model space
- GXPF1A – complete basis →CPU intensive

- ➢ ^{56}Ni is not a good closed core
- ➢ Description of Ni isotopes requires ^{40}Ca core

J. Lee and M.B. Tsang et al., Phys. Rev. C 79, 054611 (2009)

Excited-state Neutron SFs for Ni isotopes





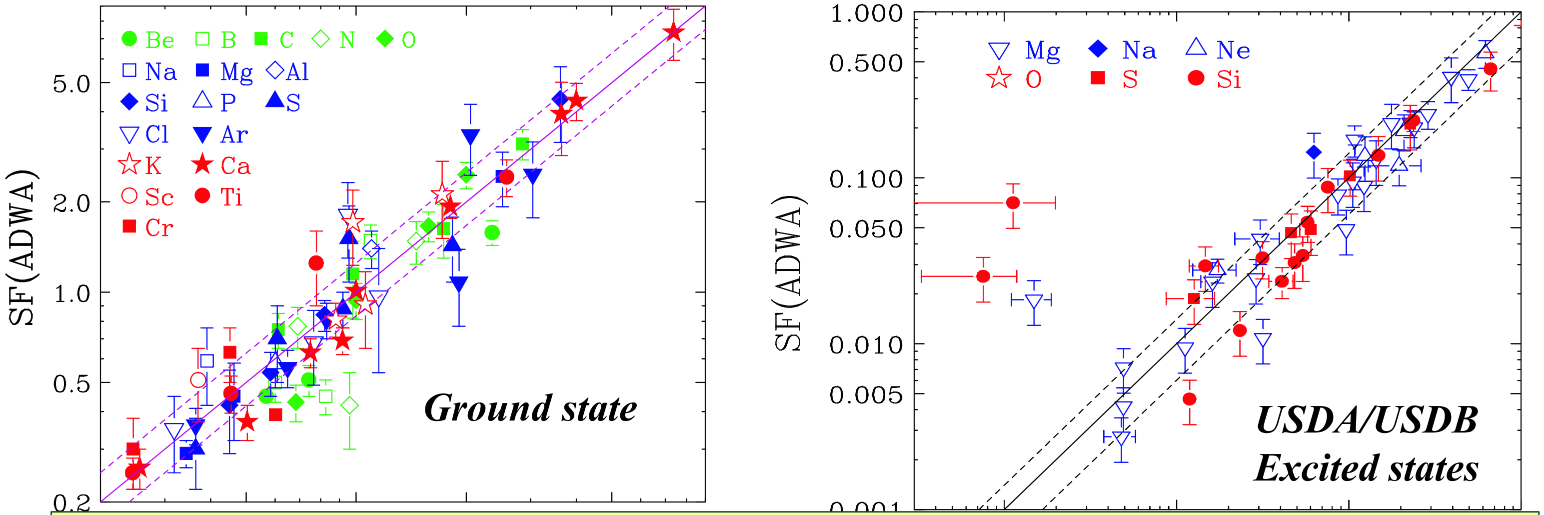
- **GXFP1A with full fp model space does not require ^{56}Ni shell closure → CPU intensive**

- **JJ4PNA interaction uses ^{56}Ni shell closure → much less CPU demanding**

SF values agree to factor of 2 → cannot distinguish between two interactions
Data uncertainties: 20-30 % → Interactions for fpg shell still need improvements

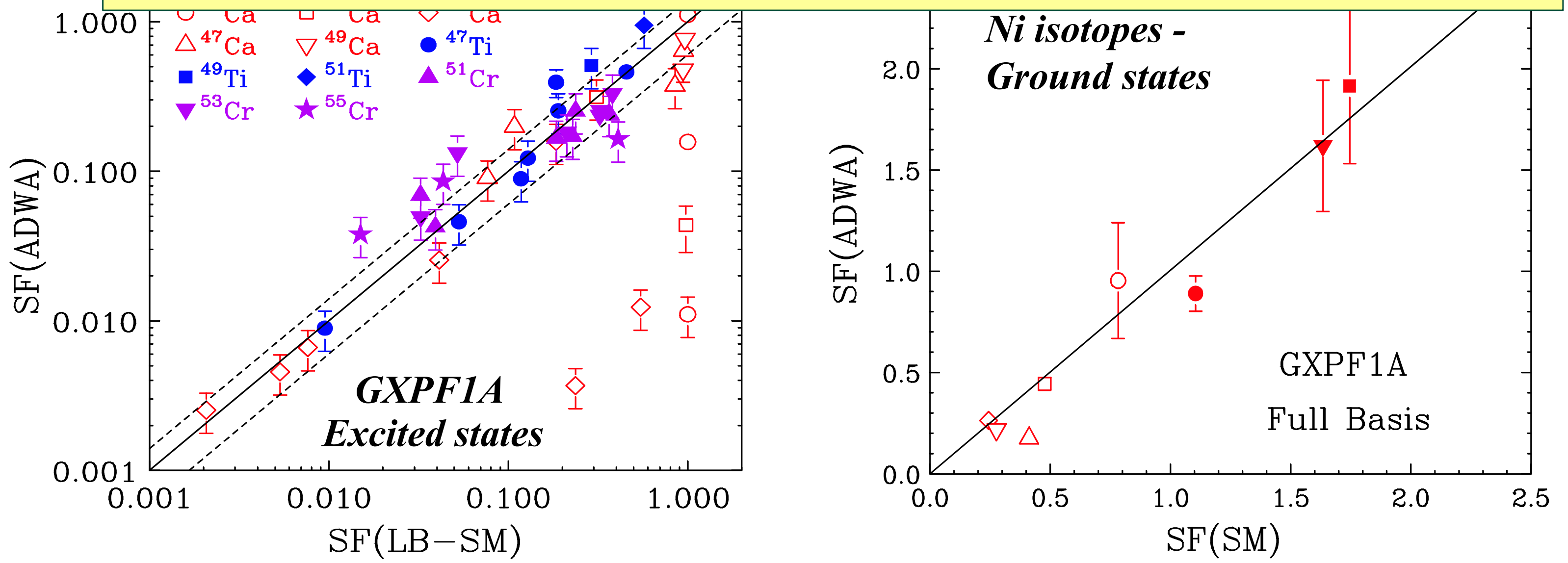
M.B. Tsang and J. Lee et al., Phys. Rev. Lett. 102, 062501 (2009)
J. Lee and M.B. Tsang et al., Phys. Rev. C 79, 054611 (2009)

Survey of Spectroscopic Factor (Transfer Reactions)

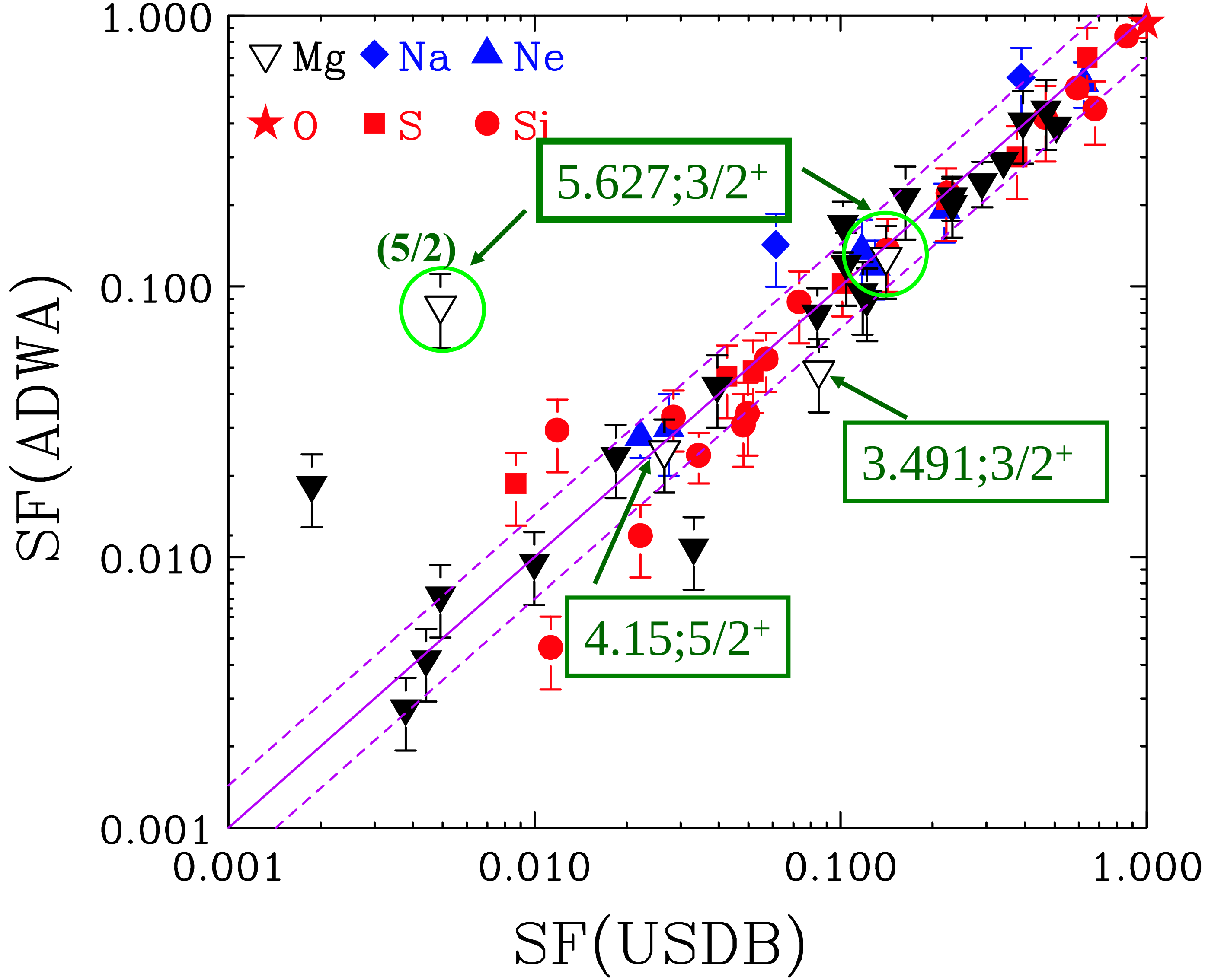


Reaction Model: CH89 + ro=1.25 fm with minimum assumption

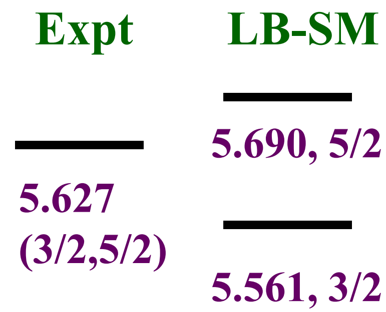
→ consistent SF(expt) with Shell Model



Confirmation of Spin Assignment from Systematics

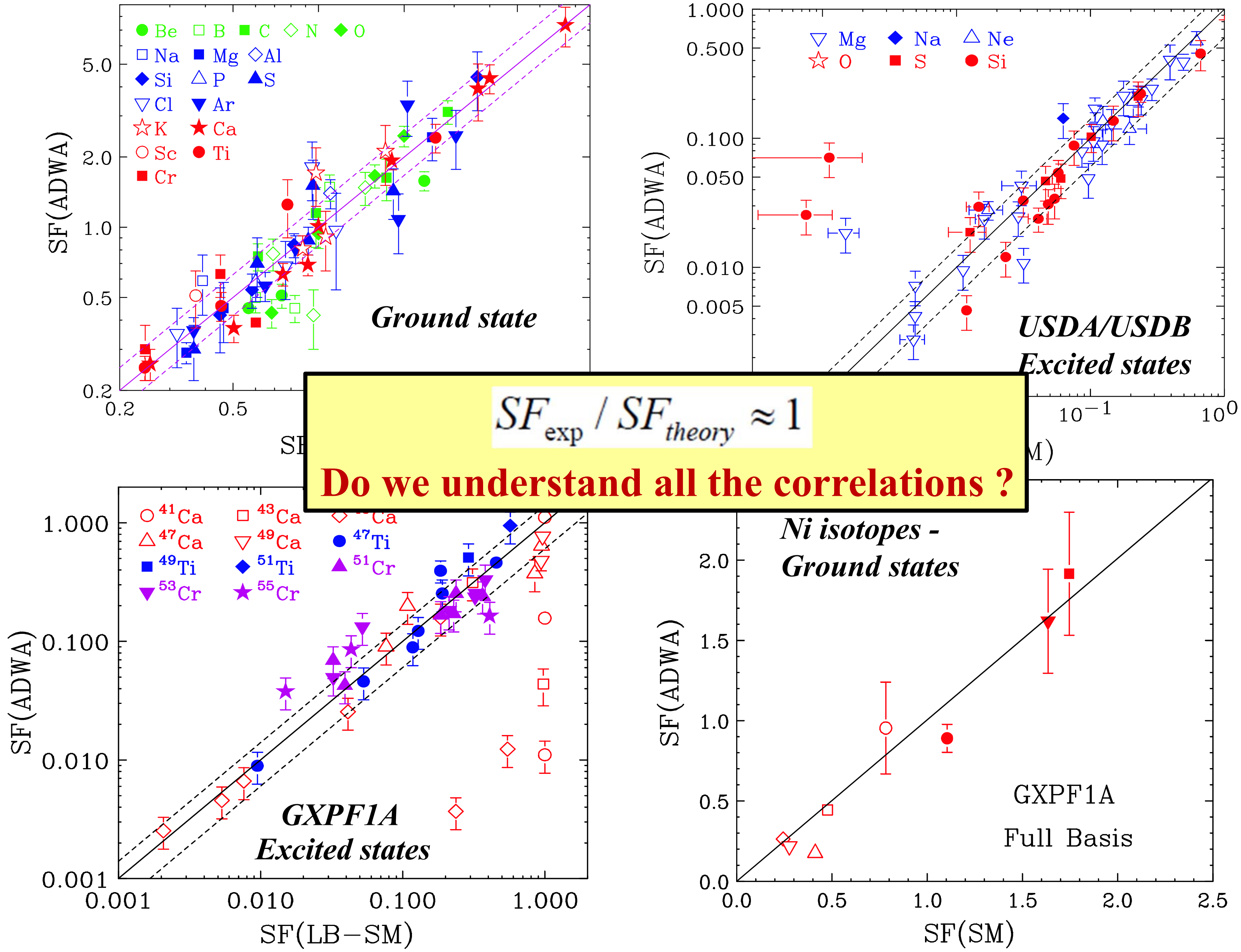


J^{π} assignment
^{27}Mg (NNDC):
$(3/2,5/2)^{+}$



M.B. Tsang and J. Lee et al., Phys. Rev. Lett. 102 (2009) 062501

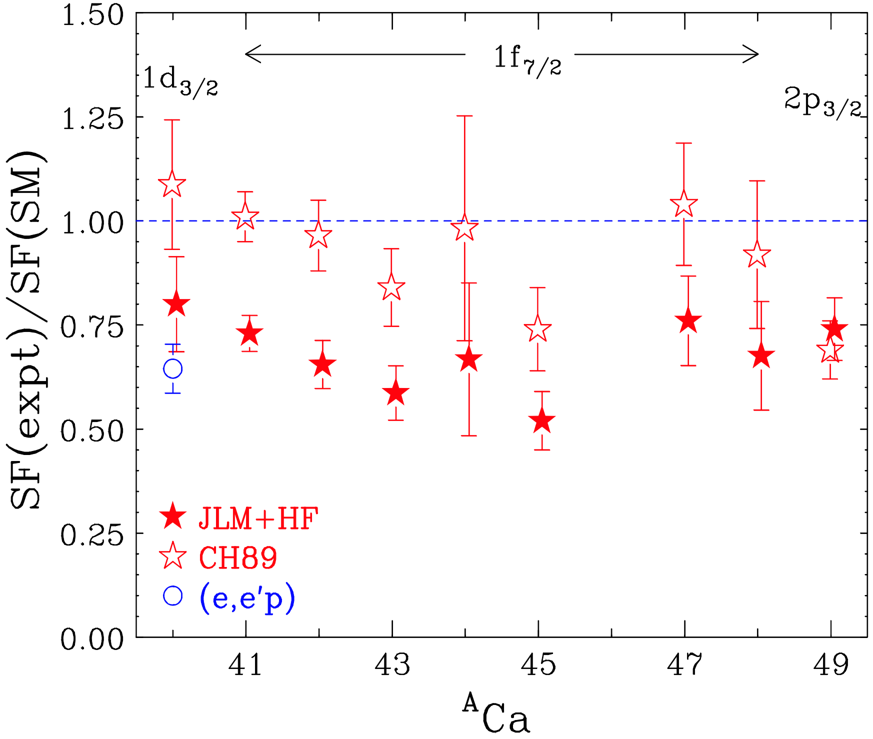
Survey of Spectroscopic Factor (Transfer Reactions)



$$SF_{exp} / SF_{theory} \approx 1$$

Do we understand all the correlations ?

Suppression of SFs in Transfer Reactions



CH89 + ro=1.25 fm with minimum assumption
→ consistent SF(expt) with Shell Model

Microscopic Input in Reaction Model

→ JLM potential & Hartree-Fock (SK20)

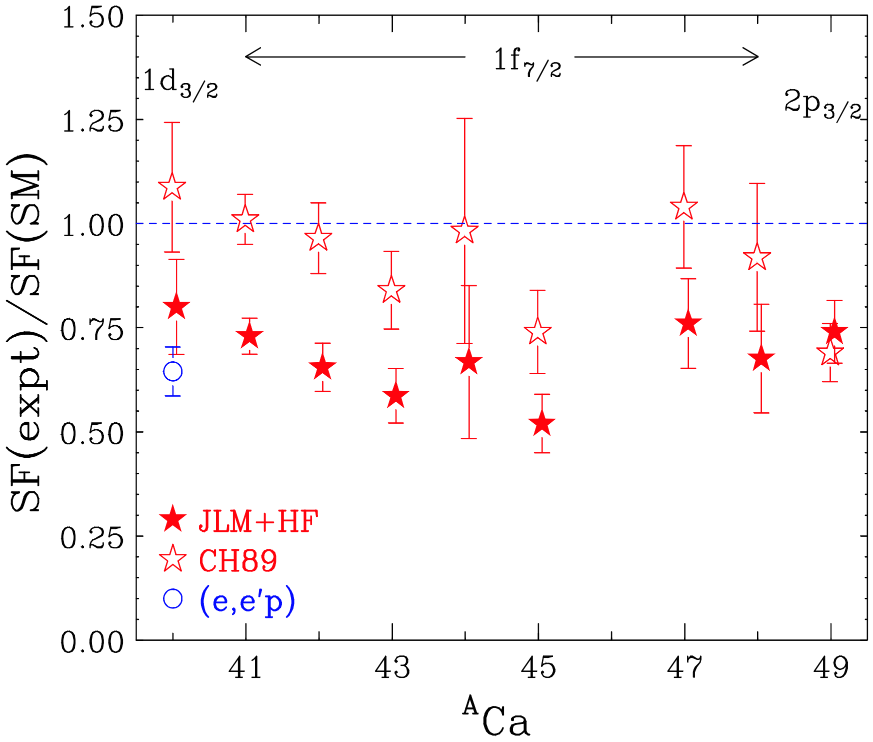
r_o=1.25 fm → HF rms radius

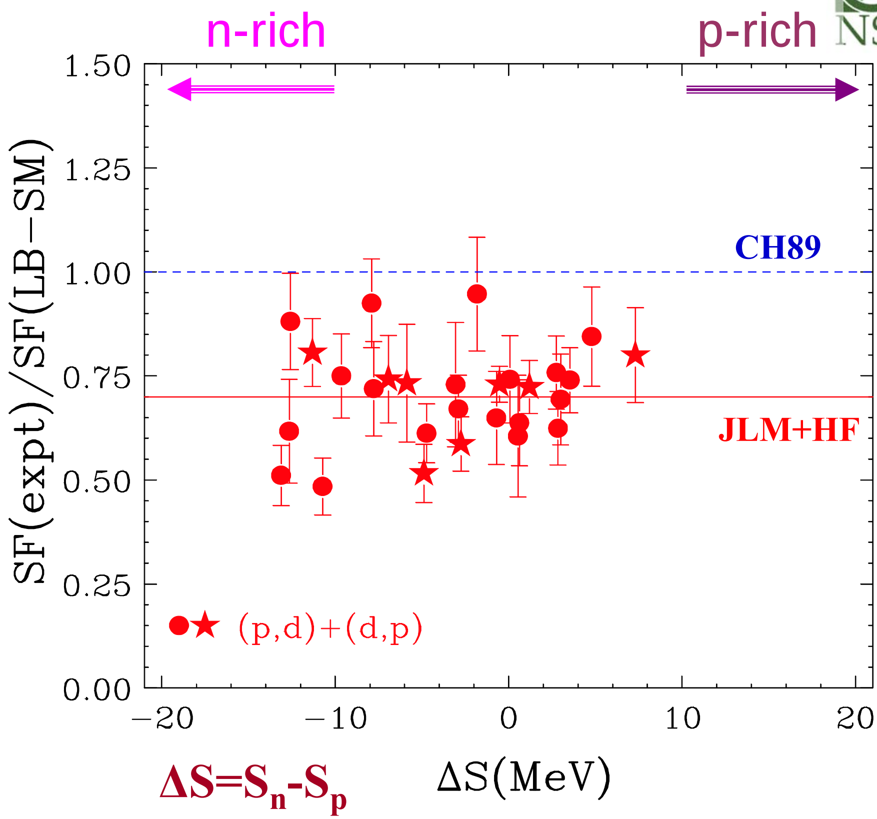
Global CH89 → JLM + HF densities

Constant ~30% reduction in SFs

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

Suppression of SFs in Transfer Reactions





$\Delta S = S_n - S_p$

Constant ~30% reduction in SFs

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

Different sets of consistent parameters → different normalizations

- ***Transfer reactions do not yield <u>absolute</u> SF ; Systematic approach → <u>relative</u> SF can be obtained <u>reliably</u> over a wide range of nuclei***
- ***Nuclear structure purpose → Relative normalized SFs***

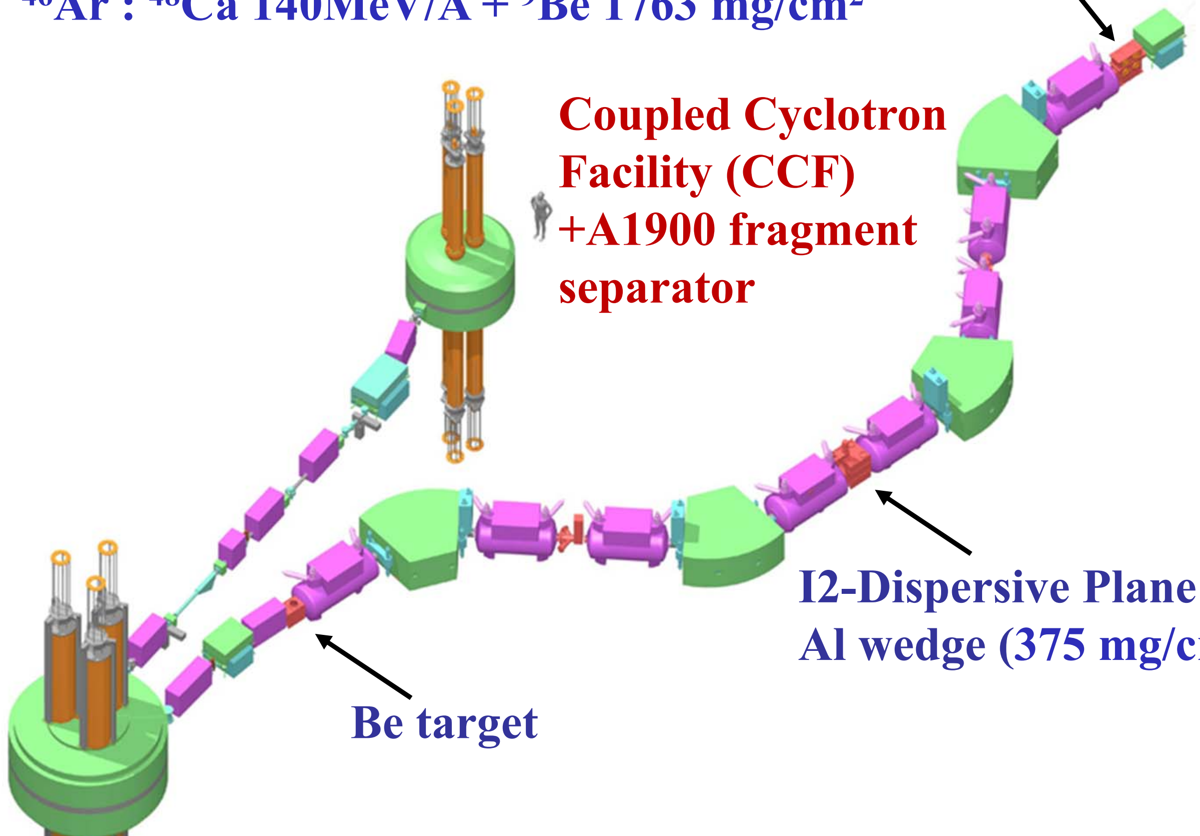
Isospin Dependence of Neutron Correlations

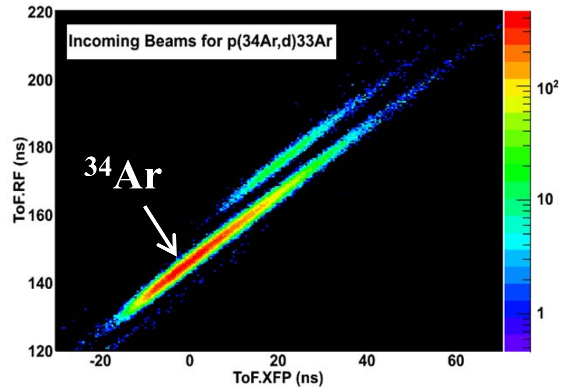
$^{34,36,46}Ar + p \rightarrow d + ^{33,35,45}Ar$

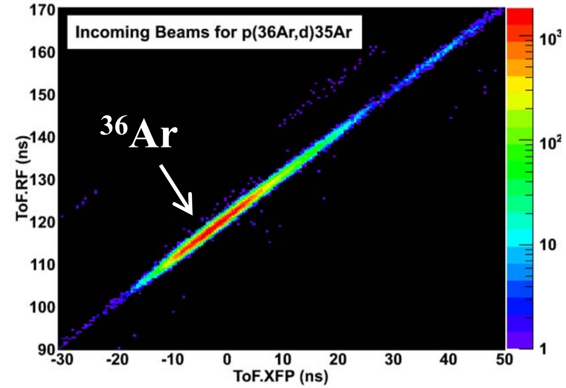
Inverse kinematics at 33MeV/A

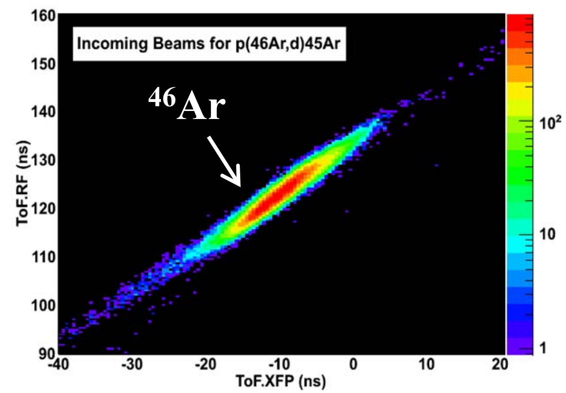
^{34}Ar : ^{36}Ar 150MeV/A + ^{9}Be 1480 mg/cm^2

^{46}Ar : ^{48}Ca 140MeV/A + ^{9}Be 1763 mg/cm^2









<u>Beam PID</u>: Time-of-flight of the extended focal plane and radio-frequency (RF) of K1200 cyclotron

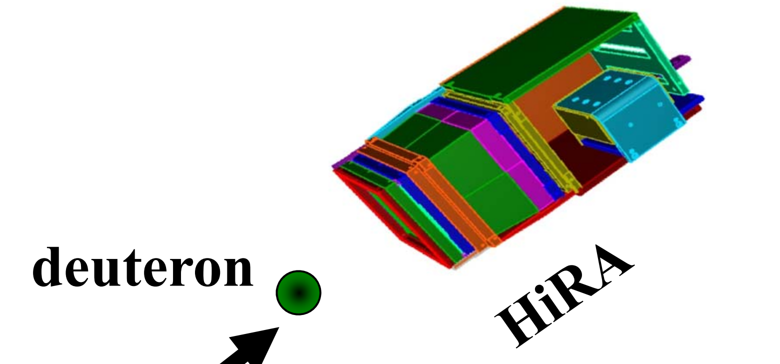
Isospin Dependence of Neutron Correlations

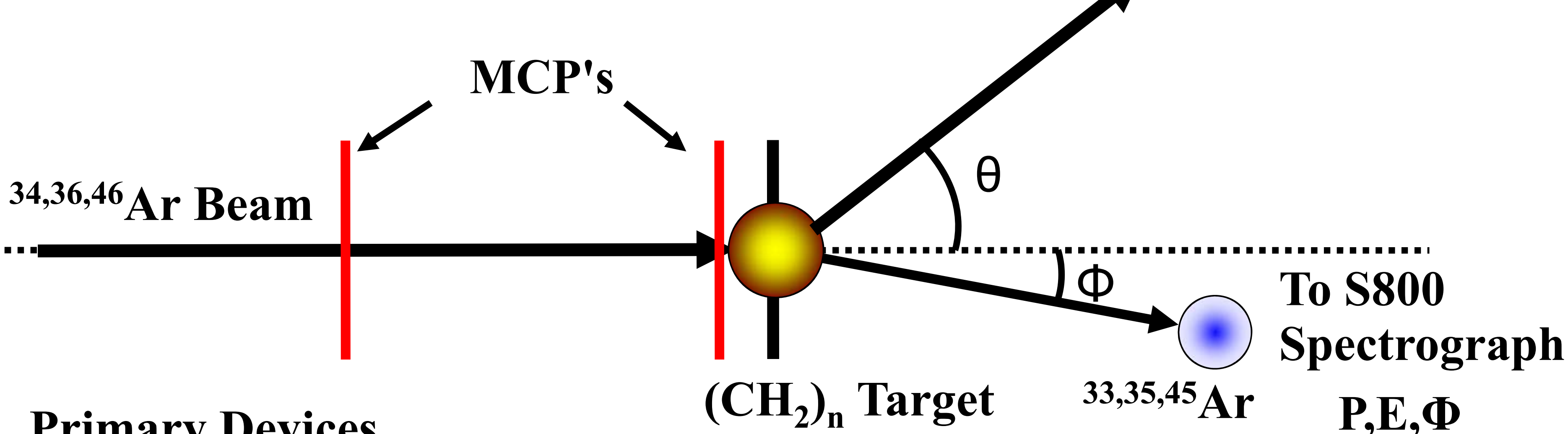
$^{34,36,46}Ar + p \rightarrow d + ^{33,35,45}Ar$

Inverse kinematics at 33MeV/A

Goal: neutron spectroscopic factors

Observables: deuteron differential cross sections





Primary Devices

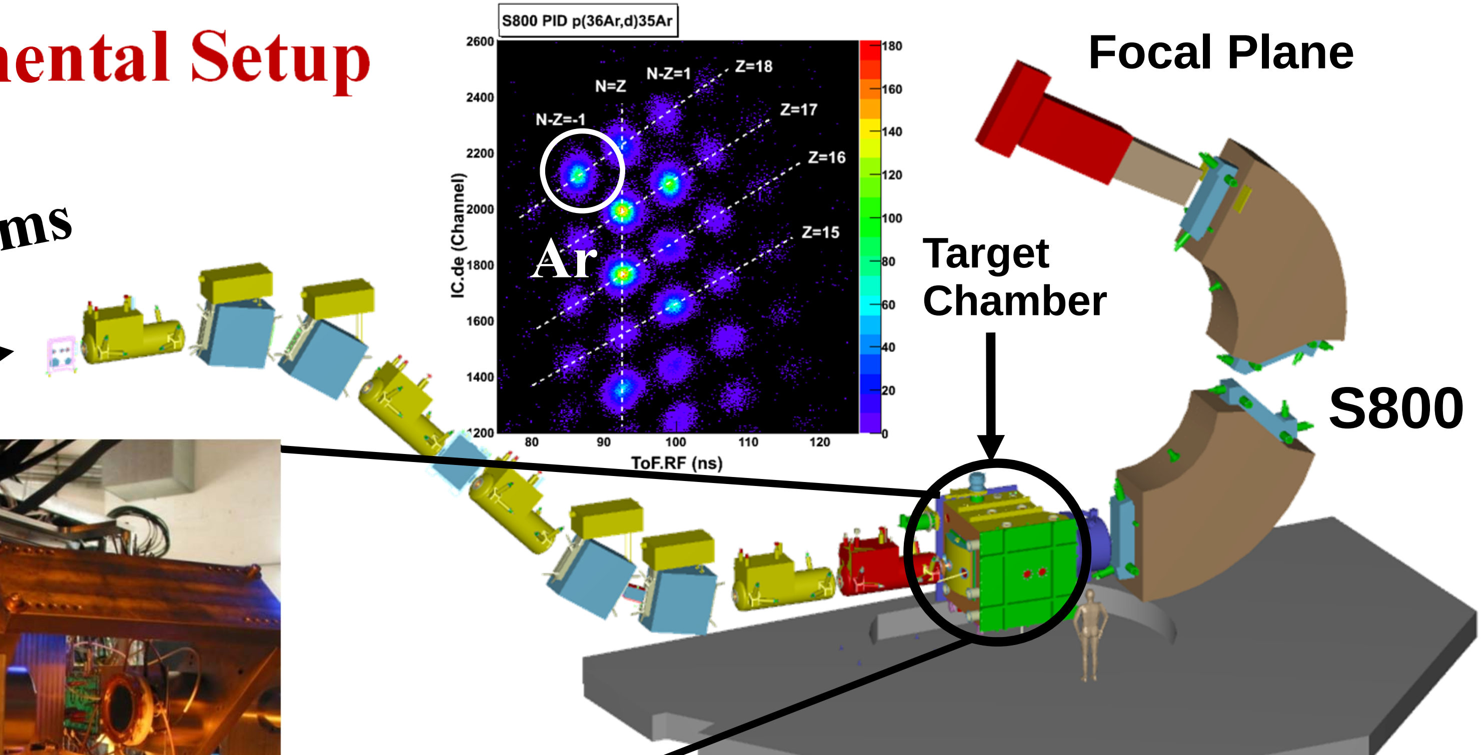
1. **H**i**gh** **R**esolution **A**rray
2. S800 Spectrograph
3. **M**icro-**C**hannel **P**lates

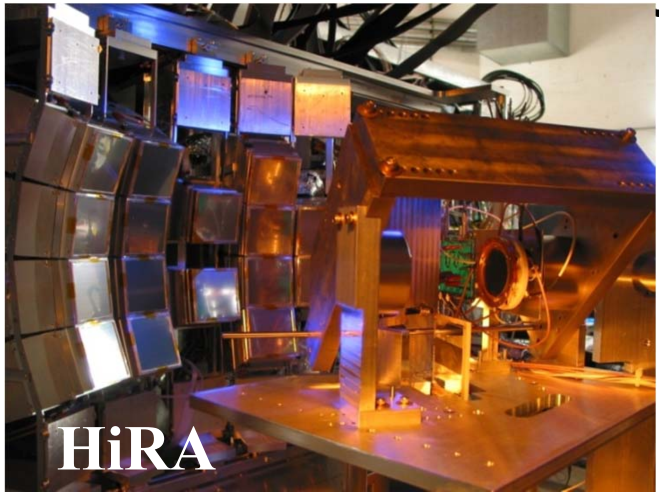
✓ *Complete kinematics measurement*

✓ *First transfer reaction experiment using HiRA with S800 + MCP at NSCL*

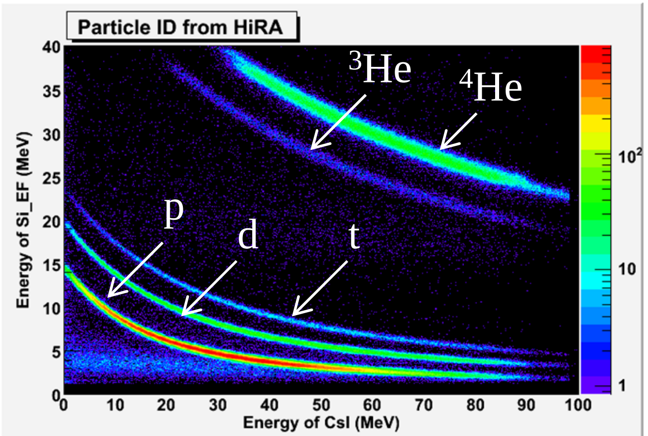
Experimental Setup

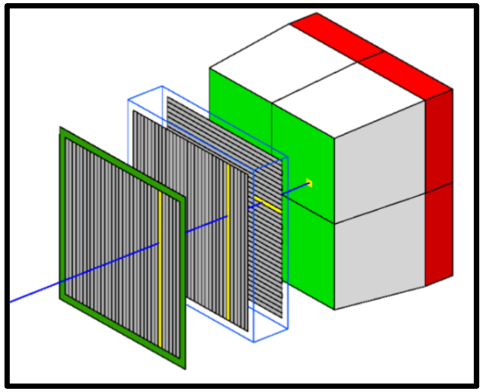
^{34,36,46}Ar Beams





State-of-the-art detectors
excellent particle identification

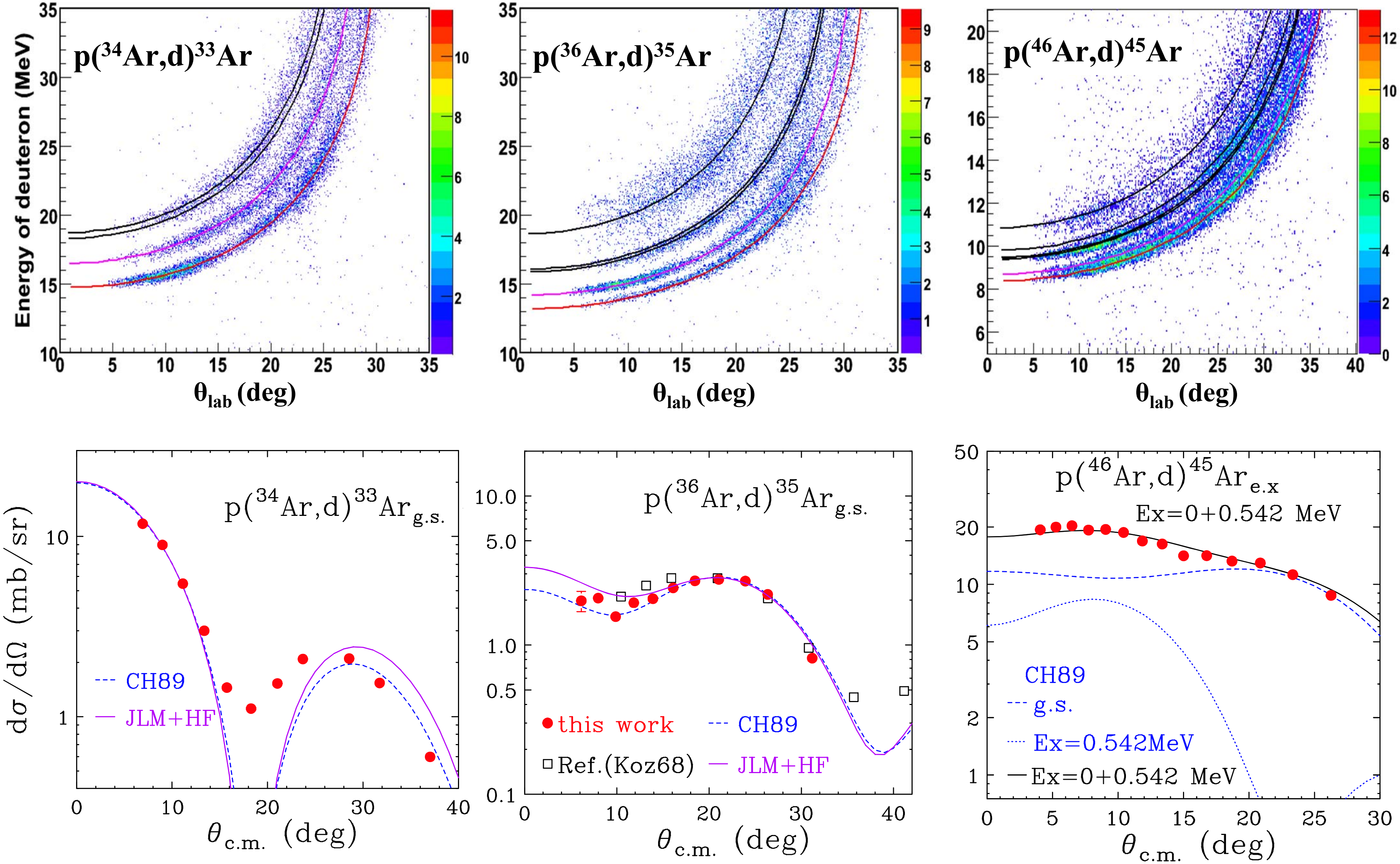




16 HiRA telescopes – efficiency ~30-40%

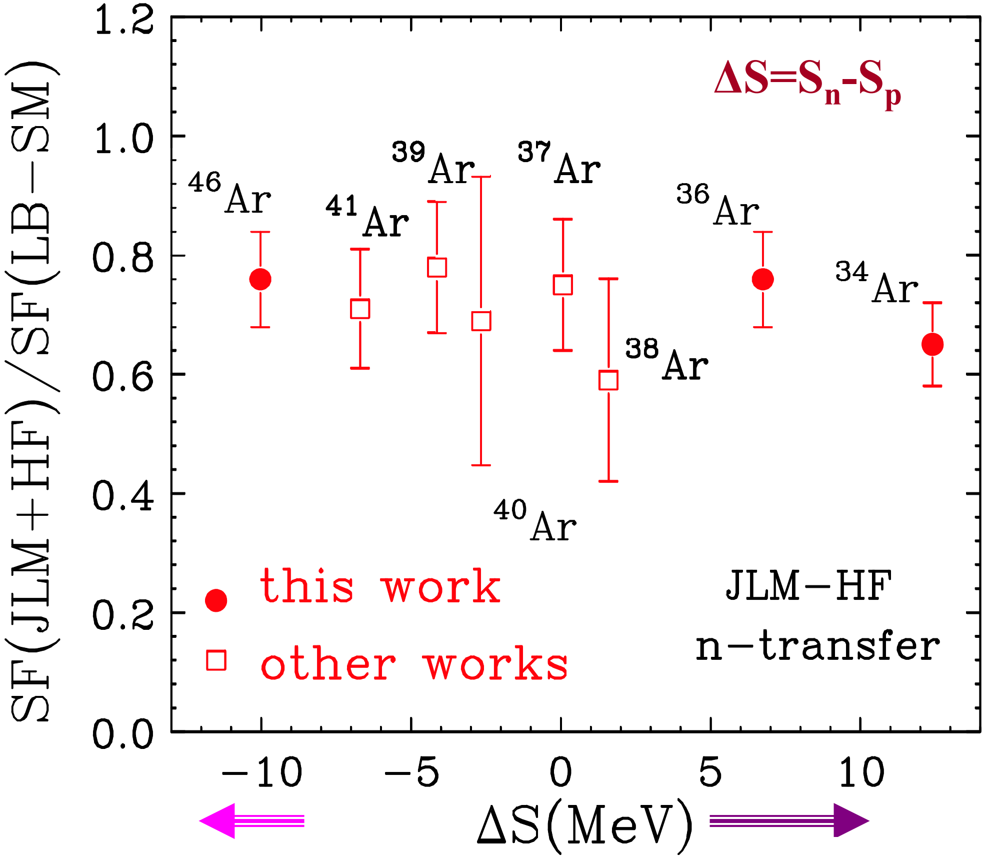
✓*1024 pixels (2mm x2mm)*
✓*0.16° at 35 cm setup*

Experimental Results



J. Lee et al., Phys. Rev. Lett 104, 112701 (2010)
J. Lee et al., Phys. Rev. C 83, 014606 (2011)

Isospin Dependence of Nucleon Correlations

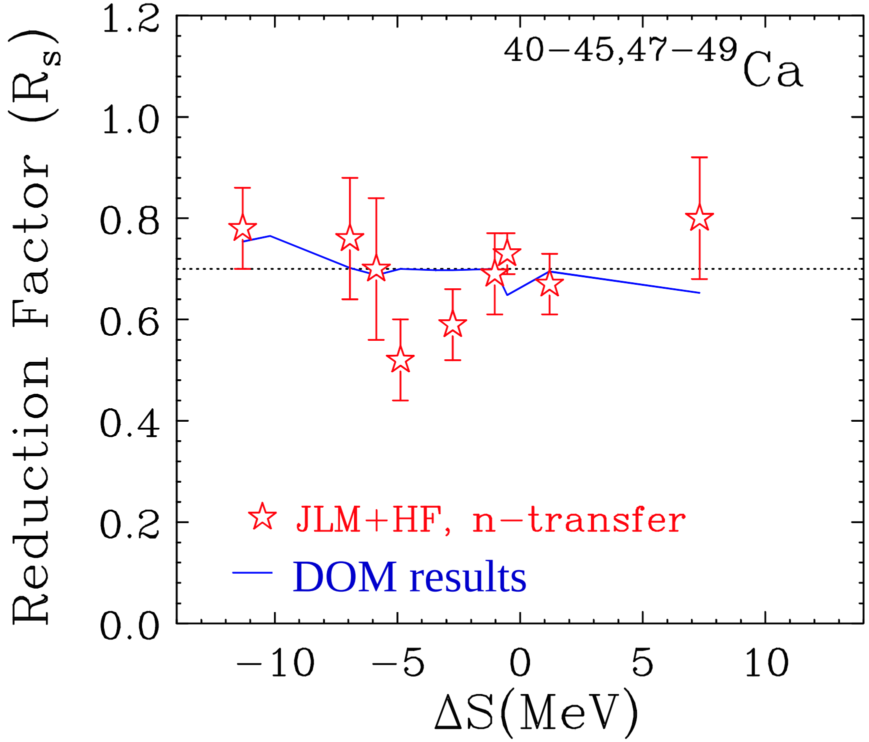


$^{34,36,46}Ar + p \rightarrow d + {}^{33,35,45}Ar$

✓ Follow the established systematics (e.g. $^{40-49}$Ca isotope chain)

Dispersive Optical Model (DOM)
(elastic-scattering & bound-level data for $^{40-49}$Ca)

R.J. Charity et al., Phys. Rev. C 76 , 044314 (2007)

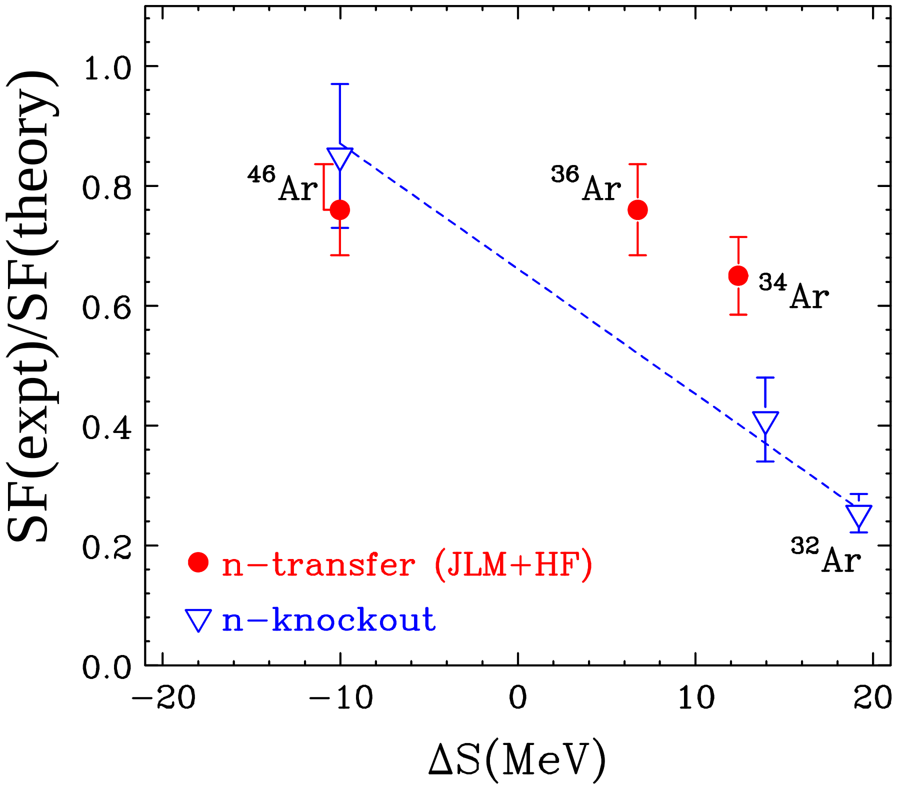


Transfer Reactions:

Weak Isospin Dependence of nucleon correlations

J. Lee et al., Phys. Rev. Lett 104, 112701 (2010)
J. Lee et al., Phys. Rev. C 83, 014606 (2011)

Isospin Dependence of Nucleon Correlations



Q: Isospin Dependence ?

Transfer reactions: Weak

p(^{34,36,46}Ar,d) at 33 MeV/A

NSCL

J. Lee et al., Phys. Rev. Lett 104, 112701 (2010)

Knockout reactions: Yes & Strong

A. Gade et al., Phys. Rev. C 77, 044306 (2008) & reference therein

Systematic difference between two probes !

Inconsistency → Incomplete understanding in underlying reaction mechanism

Transfer Reaction

✓ *^{34,46}Ar(p,d) at 70 MeV/A @ MSU (approved – MSU)*

- same energy as knockout reactions

- same SF from transfer at higher energy ? **(reliability and applicability of model)**

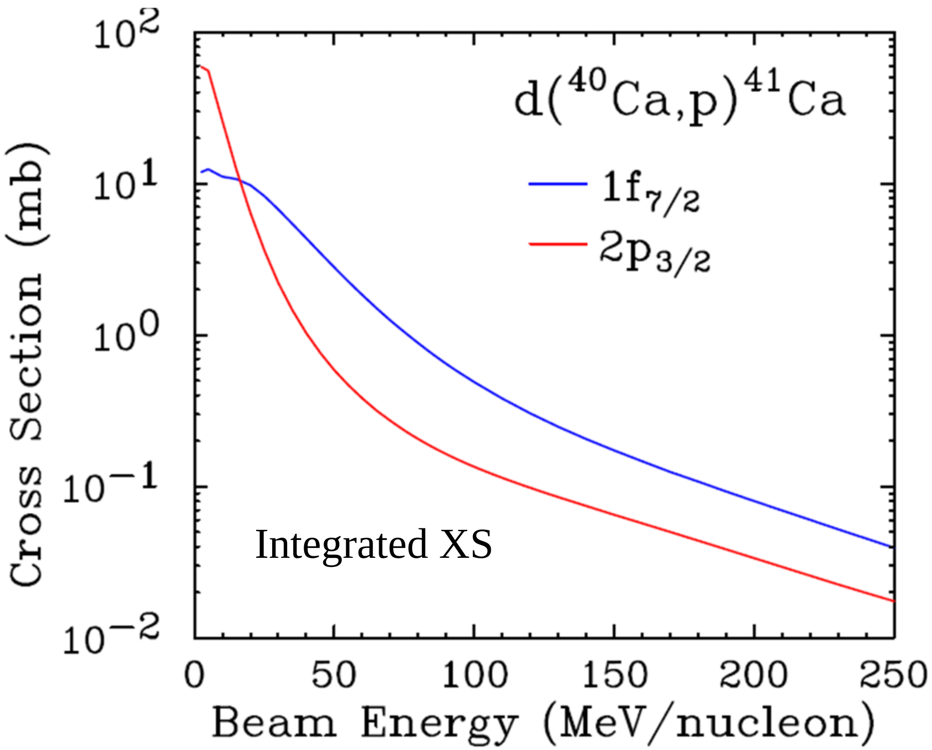
Energy-Degraded Beam

→ *compromise: beam quality & statistics – determines beam energy used*

Knockout Reaction ?

→ Experiments proposed

Transfer Reactions – Experimental Challenges



- Small reaction cross sections (~ 1 mb)

- Intensity required ~ 10^3 - 10^4 s^{-1}

- Cross sections drop rapidly with energy

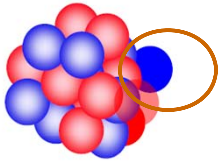
- Low Energy reactions

→ limit the experimental reach of transfer reactions

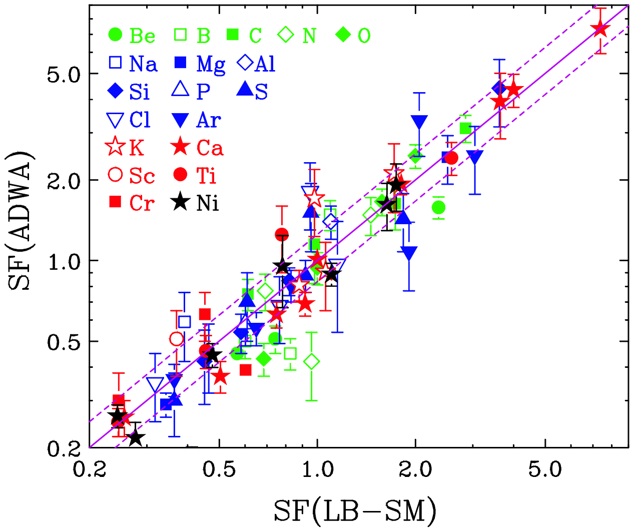
Energy-degraded intense beams

→ Large energy spread of the beams

Sensitivity to what part of nucleon correlations → Reaction energy



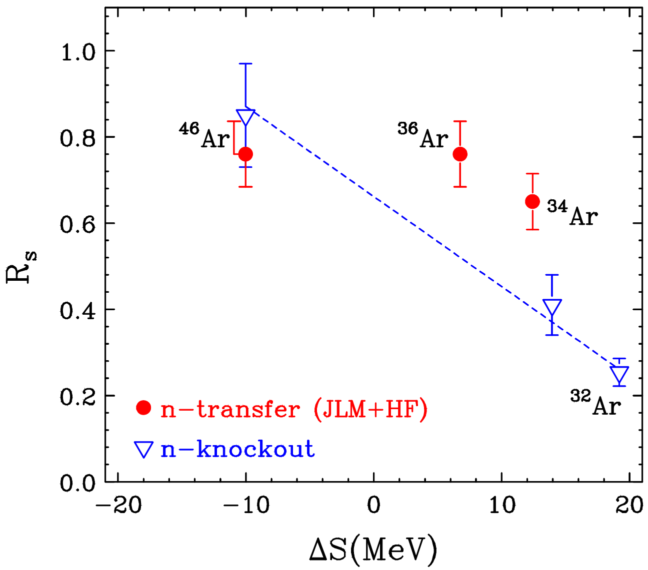
Summary I : One-Nucleon Transfer



Analyzed > 2000 measured angular distributions systematically using CH89 potential and conventional n-bound state parameters → Spectroscopic Factors

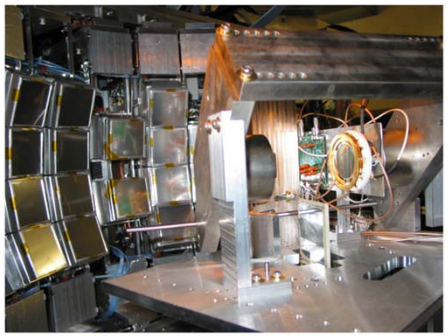
88 g.s. & 565 excited-state SFs → Compare to shell model (Oxbash) to test the residual interactions

Benchmark and Essential framework to understand structure information using transfer reactions



p(^{34}Ar,d) ^{33}Ar & p(^{46}Ar,d) ^{45}Ar

NSCL



n-SF -- No strong dependence of neutron correlations on asymmetry

Intriguing questions:
Reaction mechanisms of transfer and knockout reactions

Pairing Correlations Using Transfer Reactions

Two-like nucleon Transfer Reaction

Similarity between pairing field and 2-body transfer operator

Two-nucleon transfer reactions like (t,p) or (p,t) → specific tool to probe T=1 pair correlations

Ground-state composed of BCS pairs, two-nucleon transfer cross sections enhanced

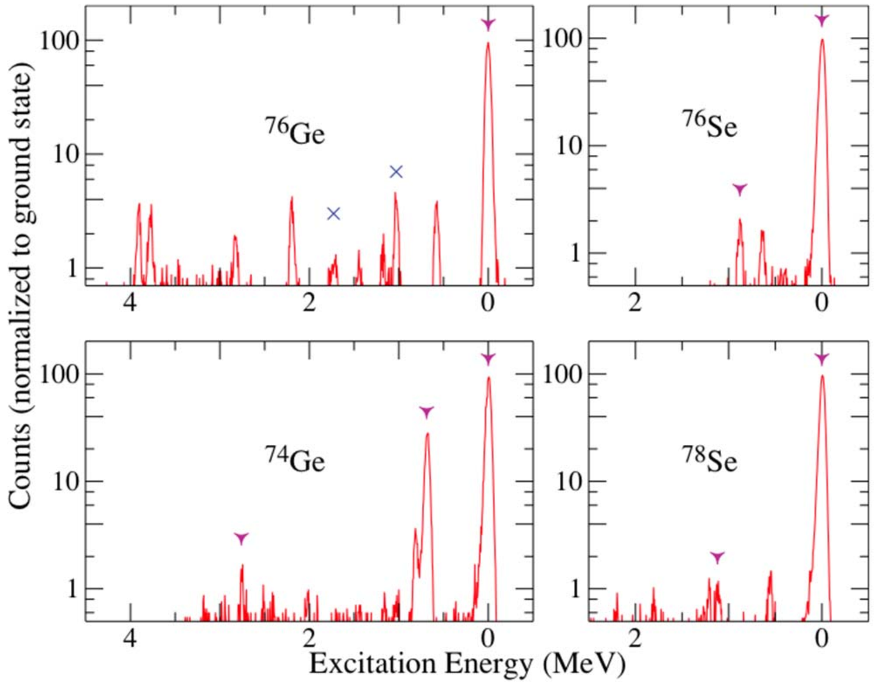
R.A. Broglia et al., Adv. Nucl. Phys. 6, 287 (1973)

^{76}Ge & ^{76,78}Se(p,t) strength: predominately to the ground states → simple BCS paired states

How to get more quantitative + systematic knowledge of *nn-pairing ?*

Spectra from (p,t) reactions

S.J. Freeman *et al*. PRC **75** 051301(R) (2007)

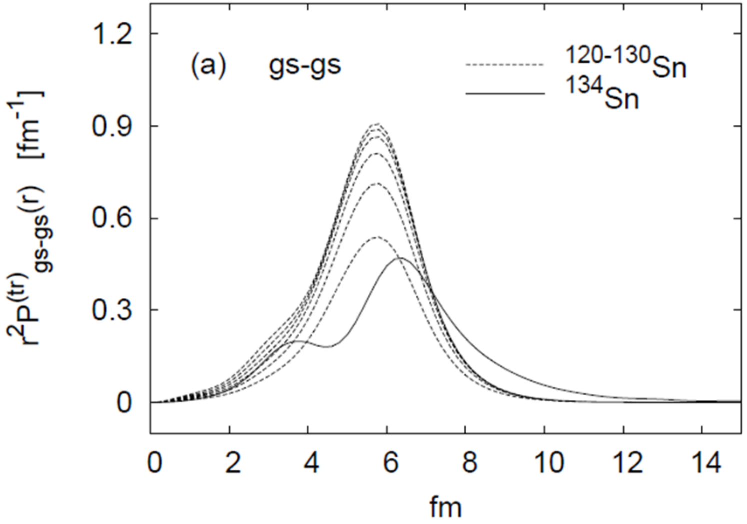


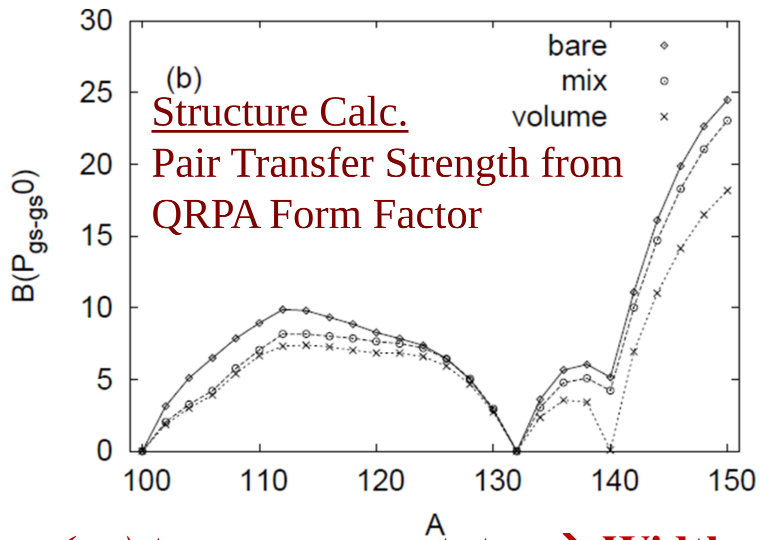
nn-pairing in *Sn* Isotopes

Pair Transition density – Skyrme HFB + QRPA approach

M. Matsuo et al., PRC 82, 024318 (2010)

H. Shimoyama, M. Matsuo, paper submitted





***(p,t)* to resonance states → Width**

Another useful observables ?

How to see & interpret these *nn*-pairing structure in Transfer Reaction ?

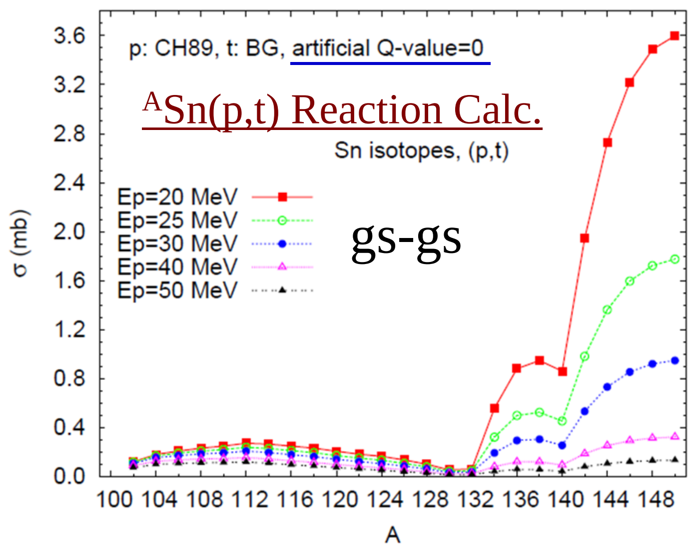
Insight → First Step: Systematic Reaction Calc.

One-step transfer + QRPA Form Factor

Planned: Two-step Calculations

TWOFNR, M. Igarashi et al.,

Calc: D.Y. Pang (Peking), Y. Aoki (Tsukuba)

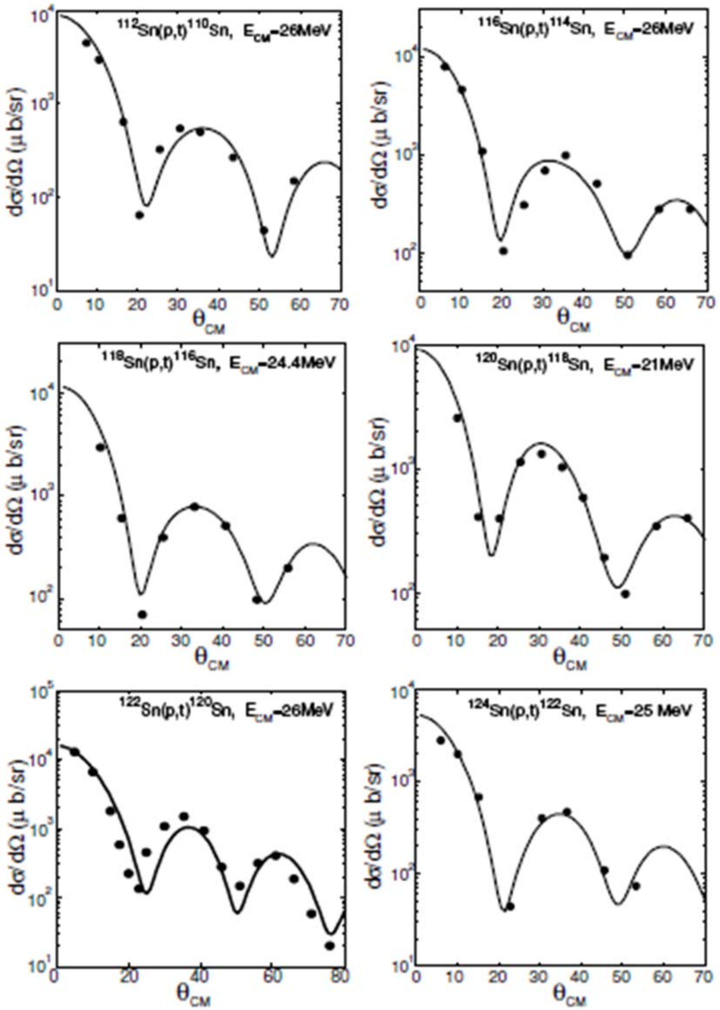


Reaction Calc: 0_2^+ & 2_1^+ (in progress)

Advanced 2*n* Transfer Calculations

Calculation of ***absolute (p,t)*** cross sections:

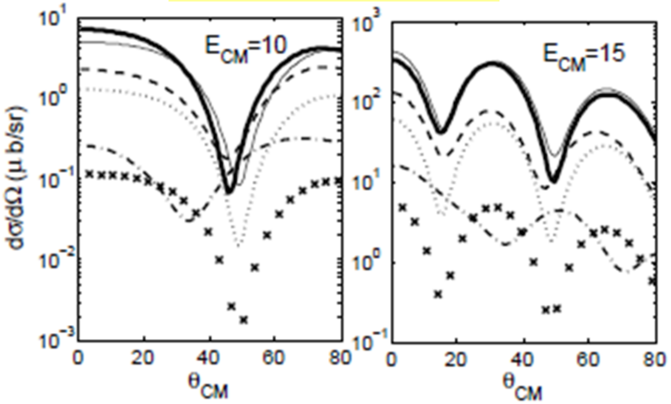
- Proper pairing interaction
- Multistep & All Terms



G. Potel et al., Phys. Rev. Lett. 107, 092501 (2011)

	σ(μb)			
	5.11 MeV	6.1 MeV	10.07 MeV	15.04 MeV
total	1.29×10^{-17}	3.77×10^{-8}	39.02	750.2
successive	9.48×10^{-20}	1.14×10^{-8}	44.44	863.8
simultaneous	1.18×10^{-18}	8.07×10^{-9}	10.9	156.7
non–orthogonal	2.17×10^{-17}	7.17×10^{-8}	22.68	233.5
non–orth.+sim.	1.31×10^{-17}	3.34×10^{-8}	3.18	17.4
pairing	1.01×10^{-19}	6.86×10^{-10}	0.97	14.04

^{132}Sn(p,t)^{130}Sn



Q: Best reaction energy for 2N-transfer expt. ?

Energy region → large cross sections & good control of reaction mechanism (calculation).

Q: Other probe (^{18}O,^{16}O) etc → Structure ?

Ans: from Reliable Reaction Calc.

Neutron-Proton Pair Correlations

In nuclei: 4 types of Pairs

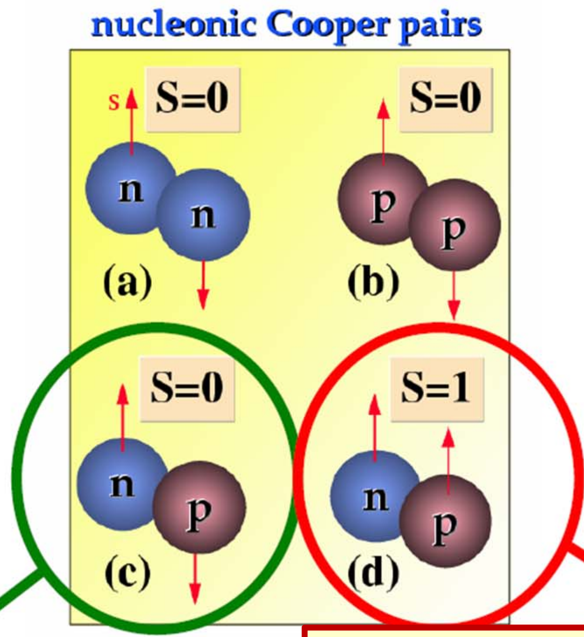
Isovector (T=1, S=0) nn, pp, np pair

np should be similar to nn & pp

Isoscalar (T=0, S=1) np pair (deuteron-like)

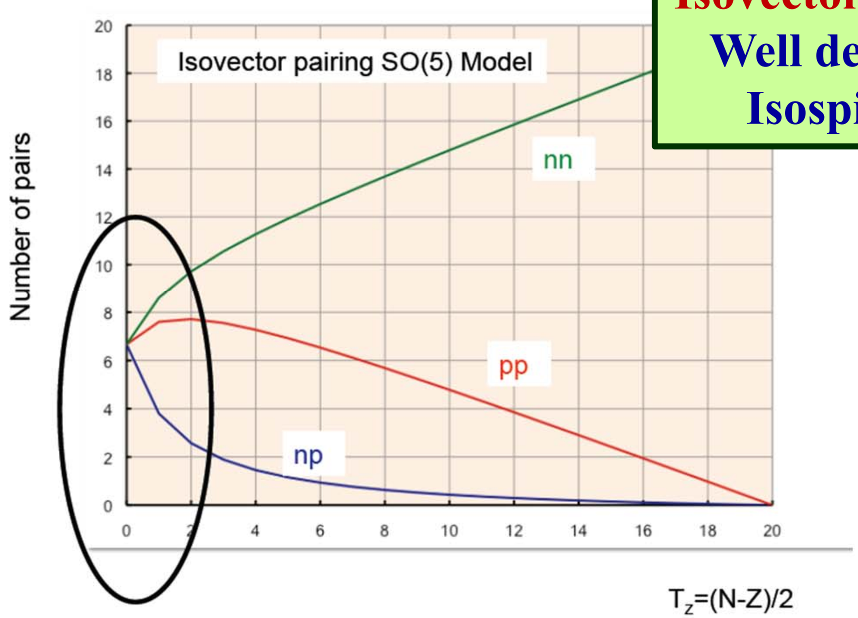
→ *new phase of nuclear matter*

Theoretical & experimental efforts since 60's → Contradicting opinions & results !



Isovector (T=1) np-pairing
Well defined from the Isospin Symmetry

Isoscalar (T=0) np-pairing
A lot of uncertainties !!



N=Z unique system for np-pairing studies !

Previous Observables for *np*-pairing

Extra Binding Energy of N=Z nuclei
"Wigner Energy"

PHYSICAL REVIEW C, VOLUME 61, 041303(R)

Is there np pairing in $N=Z$ nuclei?

A. O. Macchiavelli, P. Fallon, R. M. Clark, M. Cromaz, M. A. Deleplanque, F. S. Stephens, C. E. Svensson, K. Vetter, and
Nuclear Science Division, Lawrence Berkeley National Laboratory,
(Received 15 April 1999; published 10 March

The binding energies of even-even and odd-odd $N=Z$ nuclei are compared. After correcting for the symmetry energy we find that the lowest $T=1$ state in odd-odd $N=Z$ nuclei is as bound as the ground state in the neighboring even-even nucleus, thus providing evidence for isovector np pairing. However, $T=0$ states in odd-odd $N=Z$ nuclei are several MeV less bound than the even-even ground states. We associate this difference with the $T=1$ pair gap and conclude from the analysis of binding energy differences and blocking arguments that there is no evidence for an isoscalar (deuteronlike) pair condensate in $N=Z$ nuclei.

T(T+1) – simple symmetry energy

Physics Letters B 393 (1997) 1–6

Competition between $T=0$ and $T=1$ pairing in proton-rich nuclei

W. Satuła [a,b,c,d], R. Wyss [a]
[a] The Royal Institute of Technology, Physics Department Frescati, Frescativägen 24, S-104 05 Stockholm, Sweden
[b] Joint Institute for Heavy Ion Research, Oak Ridge, TN 37831, USA
[c] Department of Pl
[d] Institute of Theoretical Ph
Received 26 Au

Abstract

A cranked mean-field model with two-body $T=1$ and $T=0$ pairing interactions is presented. Approximate pro onto good particle-number is enforced via an extended Lipkin-Nogami scheme. Our calculations suggest the simul presence of both $T=0$ and $T=1$ pairing modes in $N=Z$ nuclei. The transitions between different pairing ph discussed as a function of neutron/proton excess, T_z, and rotational frequency, $\hbar\omega$. The additional binding energy d $T=0$ np-pairing correlations, is suggested as a possible microscopic explanation of the Wigner energy term in nuclei.

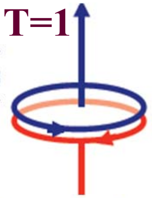
Mean-field term T^2 as symmetry energy, T as np pairing

Proof of existence of T=0 pairing collectivity using B.E. depends on interpretations

J. Dobaczewski, arXiv:nucl-th/0203063v1

Rotational properties (high-spin aspect): moments of inertia, alignments

T=1



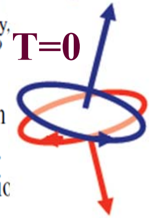
VOLUME 87, NUMBER 13 PHYSICAL REVIEW LETTERS 24 S

Alignment Delays in the $N=Z$ Nuclei ^{72}Kr, ^{76}Sr, and ^{80}Zr

S. M. Fischer,[1] C. J. Lister,[2] D. P. Balamuth,[3] R. Bauer,[4] J. A. Becker,[4] L. A. Bernstein,[4] M. P. Carpent N. Fotiades,[6] S. J. Freeman,[5] P. E. Garrett,[4] P. A. Hausladen,[3] R. ... J. Schwartz,[2] D. Svelnys,[1] D. G. Sarantites,[8] D. Se

Coriolis effect

T=0



The ground state rotational bands of the $N=Z$ nuclei ^{72}Kr, ^{76}Sr, and ^{80}Zr have been the angular momentum region where rotation alignment of particles is normally expected. the moments of inertia of these bands we have observed a consistent increase in the rotatic required to start pair breaking, when compared to neighboring nuclei. ^{72}Kr shows the most marked effect. It has been widely suggested that these "delayed alignments" arise from np-pairing correlations. However, alignment frequencies are very sensitive to shape degrees of freedom and normal pairing, so the new experimental observations are still open to interpretation.

PHYSICAL REVIEW C **67**, 064318 (2003)

Unravelling the band crossings in ^{68}Se and ^{72}Kr: The quest for $T=0$ pairing

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(Received 13 March 2003; published 27 June 2003)

... suggested to contain information on $T=0$ neutron- ... momentum states in the $N=Z$ ... populated through of these ... higher spin, and has resolved ... extended to spin $J=26$ and a new band crossing ... into three bands, each of which has irregularities in its moment of inertia ... ments indicate that the two high-spin bands have very different shapes. Similar, sharp ... established in both nuclei. A comparison of these data with recent measurements of $N=Z+2$ nuclei ^{70}Se and ^{74}Kr allowed the issue of "delayed alignments" to be addressed in detail. No clear-cut evidence for any delay was found.

Change Experimental Observables from static properties → dynamic counterparts !

Neutron-Proton Transfer Reactions

PRL 94, 162502 (2005) PHYSICAL REVIEW LETTERS week ending 29 APRIL 2005

Deuteron Transfer in $N = Z$ Nuclei

P. Van Isacker,[1] D. D. Warner,[2] and A. Frank[3]

[1]*Grand Accélérateur National d'Ions Lourds, B.P. 55027, F-14076 Caen Cedex 5, France*
[2]*CCLRC Daresbury Laboratory, Daresbury, Warrington WA4 4AD, United Kingdom*
[3]*Instituto de Ciencias Nucleares, UNAM, Apdo. Postal 70-543, 04510 México, D.F. Mexico*

(Received 14 September 2004; published 29 April 2005)

T=0 (T=1) pairing:
enhanced transfer probabilities
$0^+ \rightarrow 1^+$ ($0^+ \rightarrow 0^+$) levels

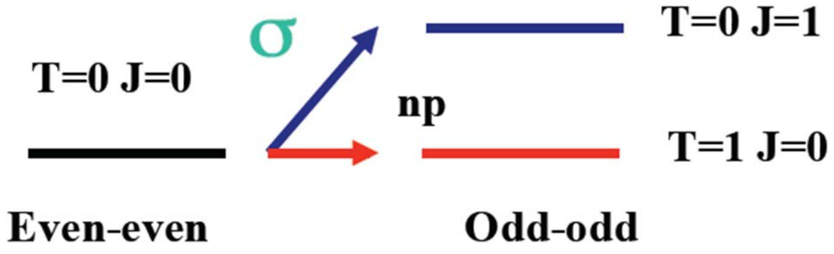
Interacting Boson Model (IBM-4)

TABLE I. Predicted deuteron-transfer intensities C_T^2 between even-even (EE) and odd-odd (OO) $N = Z$ nuclei in the SU(4) ($b/a = 0$) and $U_T(3) \otimes U_S(3)$ ($|b/a| \gg 1$) limits.

Limit	Reaction	$C^2_{T=0}$	$C^2_{T=1}$
$b/a = 0$	$EE \rightarrow OO_{T=0}$	$\frac{1}{2}(N_b + 6)$	0
	$EE \rightarrow OO_{T=1}$	0	$\frac{1}{2}(N_b + 6)$
	$OO_{T=0} \rightarrow EE$	$\frac{1}{2}(N_b + 1)$	0
	$OO_{T=1} \rightarrow EE$	0	$\frac{1}{2}(N_b + 1)$
$b/a \ll -1$	$EE \rightarrow OO_{T=0}$	$N_b + 3$	0
	$EE \rightarrow OO_{T=1}$	0	3
	$OO_{T=0} \rightarrow EE$	$N_b + 1$	0
$b/a \gg +1$	$EE \rightarrow OO_{T=0}$	3	0
	$EE \rightarrow OO_{T=1}$	0	$N_b + 3$
	$OO_{T=1} \rightarrow EE$	0	$N_b + 1$

T=0 stronger

T=1 stronger



Reactions

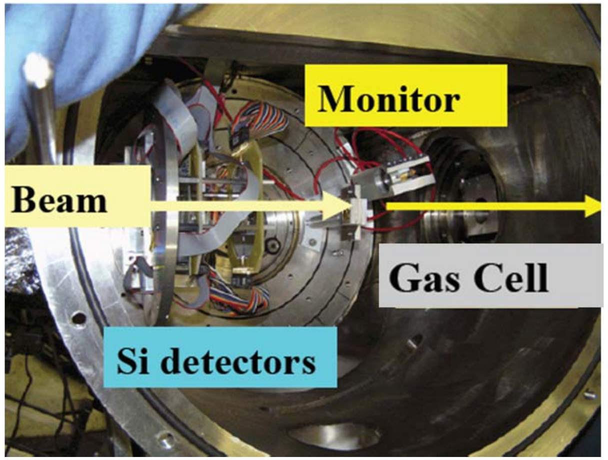
(p, ^{3}He), (^{3}He,p) ΔT=0,1
(d,α), (α,d) ΔT=0
(α, ^{6}Li), (^{6}Li,α) ΔT=0

Measure the np transfer cross section to T=1 and T=0 states

Absolute σ(T=1) and σ(T=0) – character and strength of the correlations

σ(T=1) /σ(T=0) – interplay of T=1 and T=0 pairing modes

np-Transfer Reactions using Radioactive Beams



- **Proof of Principle (LBNL) – successfully completed**

  ^{3}He(^{44}Ti,p) @ 4.5 AMeV at ATLAS

- **Approved experiments at ISAC2**

  ^{48}Cr, ^{72}Kr – (^{3}He,p) ***LBNL, ANL, TRIUMF***

- **Plan:** ReA3/NSCL using AT-TPC (LBNL)

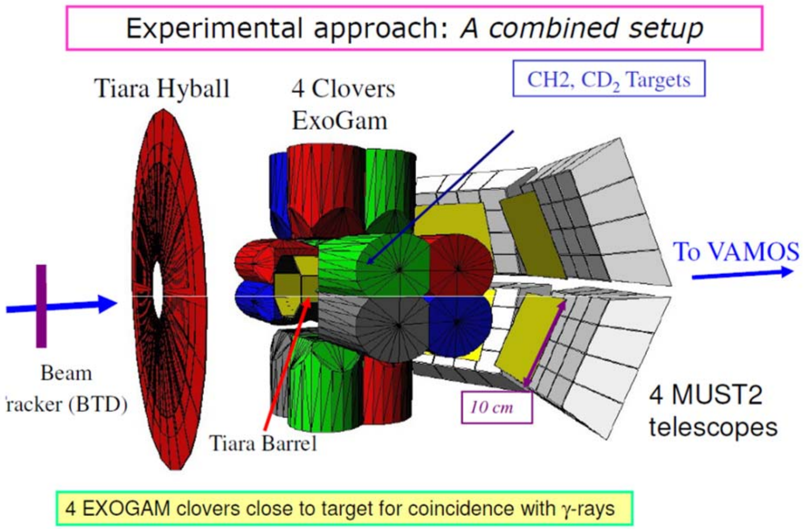
- **Approved experiments at GANIL**

  ^{48}Cr, ^{56}Ni -- (d, α) @ ~30 AMeV

Insight / physics of *np*-pairing ?

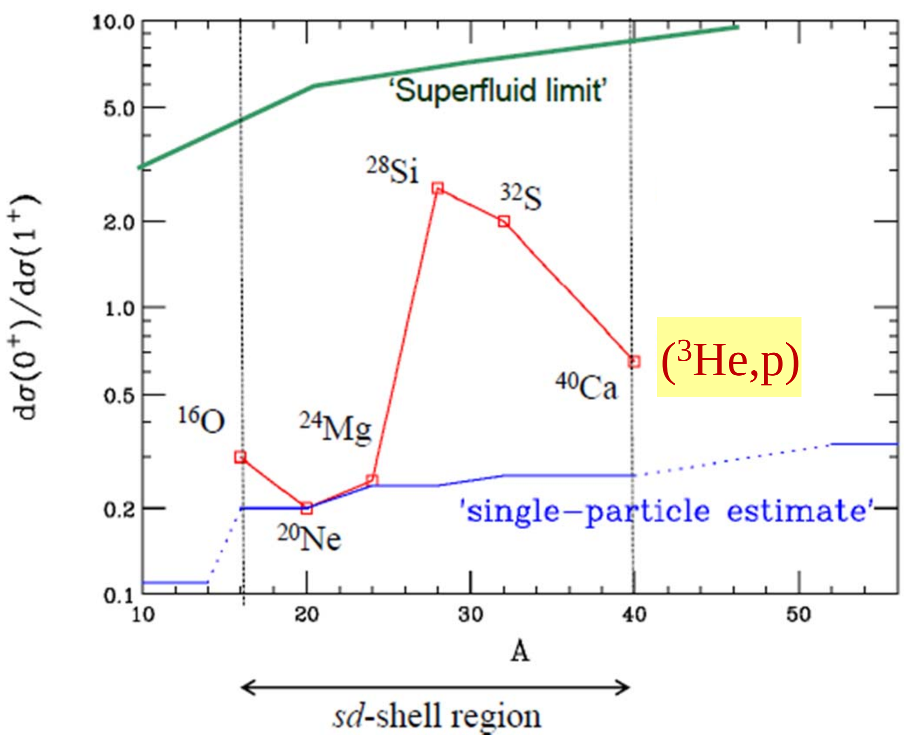
Methodology / framework established ?

Physics from light *N*=*Z* stable nuclei ?



Systematics of T=0 & T=1 *np*-pairing in *sd*-shell

N=Z nuclei in sd-shell



Ratio of cross section (T=1/ T=0)
- reducing systematic effects of absolute normalization

from A. Macchiavelli *(LBNL)*

Shiro Yoshida, NP 33, 685 (1962)

Superfluid limit ~ $(2\Delta_{T=1}/G)^2$

Single-particle estimate ~ (spin)x(^{3}He)x(LS -> jj)

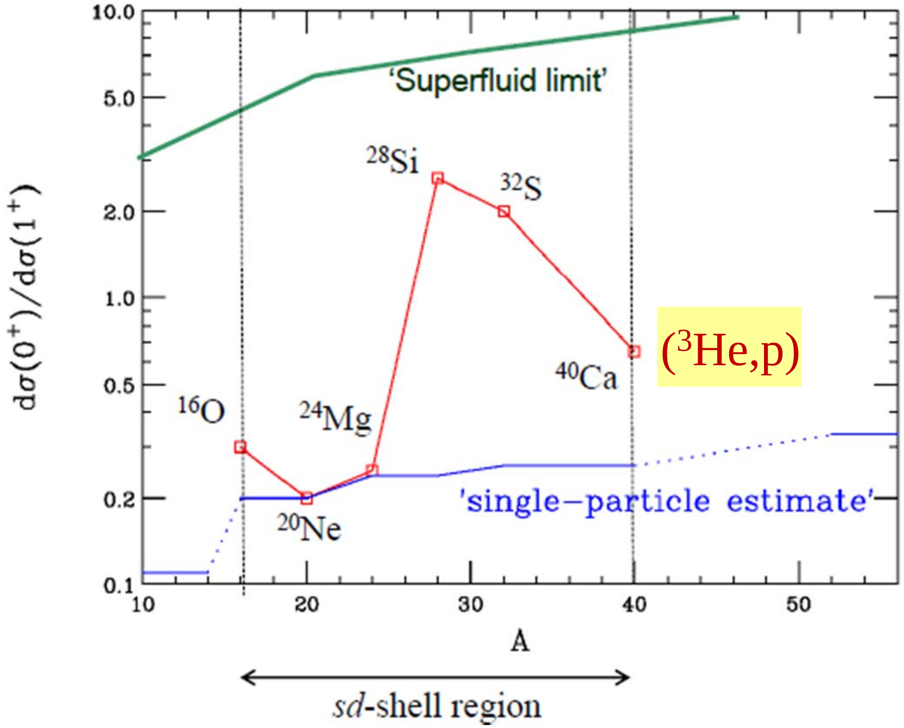
Inconsistencies in the trends (*sd*-shell):

- **Closed-shell nuclei ^{16}O, ^{40}Ca NOT follow single-particle estimate ?**
- **No intuitive understanding – ^{20}Ne, ^{24}Mg follow single-particle prediction ?**
- **Doubtful increase of > a factor of 10 from ^{24}Mg to ^{28}Si ?**

Need systematic measurements dedicated to *np*-pairing studies !

Systematics of T=0 & T=1 *np*-pairing in *sd*-shell

N=Z nuclei in sd-shell

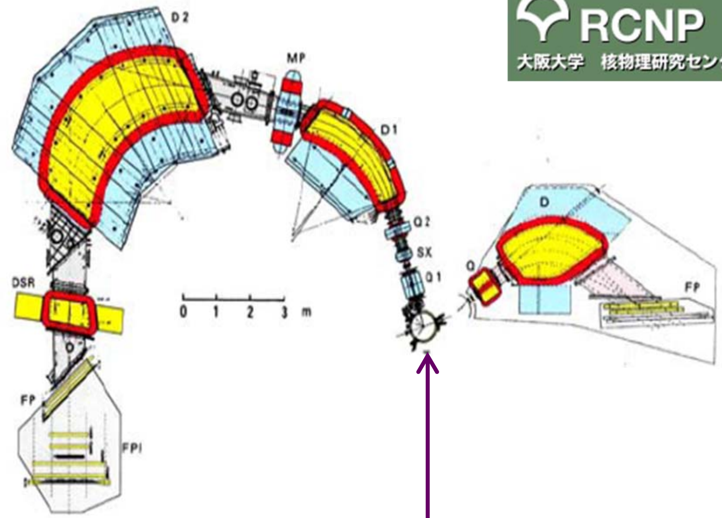


Systematic measurements spanning ***sd*-shell** nuclei – approved RCNP E365

<u>^{24}Mg(^{3}He,p), ^{32}S(^{3}He,p) – Oct, 2011</u>

^{24}Mg(p,^{3}He), ^{28}Si(p,^{3}He) & ^{40}Ca(p,^{3}He)

Grand Raiden
→ Outgoing particles

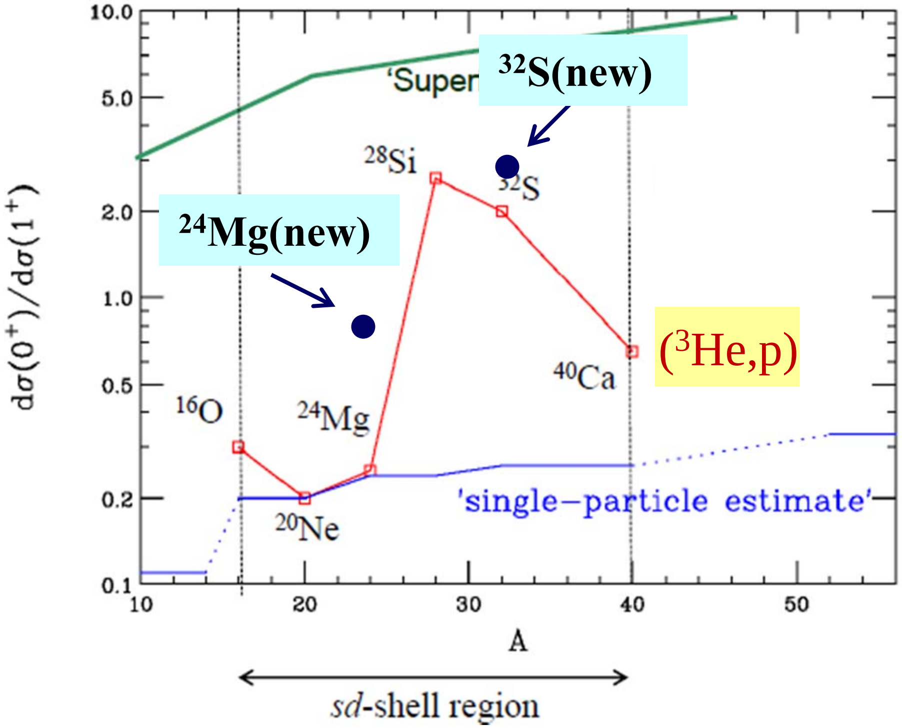


65 MeV proton /
25 MeV ^{3}He beams

Framework & Baseline -- studies of np pairing in heavier N=Z nuclei (RI Beams)

Systematics of T=0 & T=1 *np*-pairing in *sd*-shell

N=Z nuclei in sd-shell

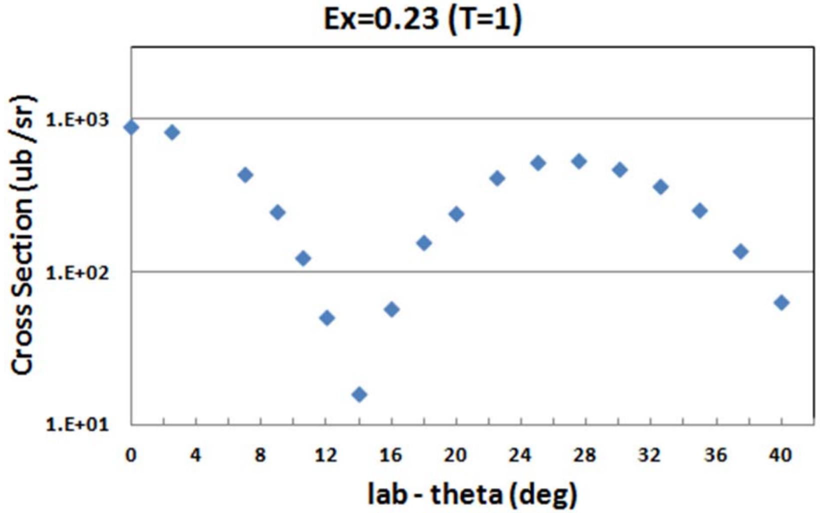


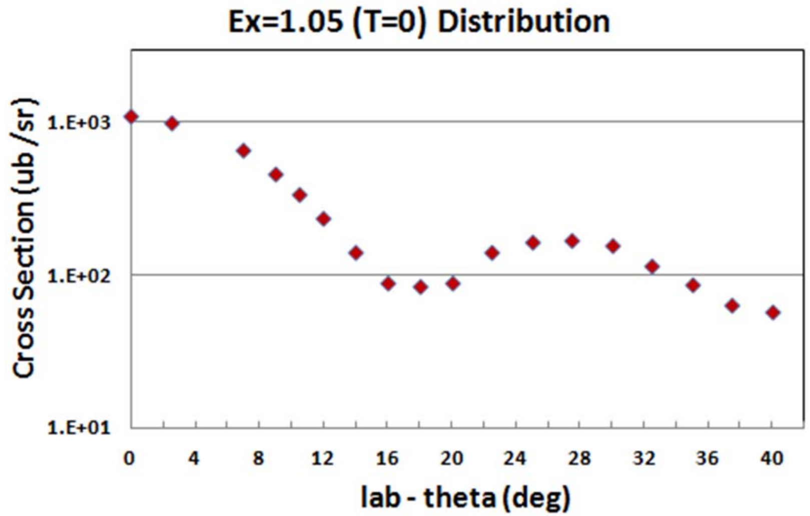
→ *Comparison at 0°*
(online results – very preliminary)

Also one-nucleon transfer data
→ *Intermediate States*

^{24}Mg(^{3}He,p) @ 25 MeV

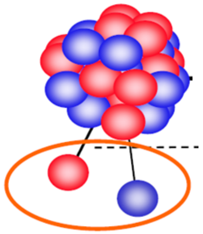
Online Results





RCNP
大阪大学 核物理研究センター

np-Transfer Reactions – Stable *N*=*Z* nuclei



New Structure of *np*-pairing:

- transfer amplitudes from SM / pair operators
- matrix elements from spherical/ projected SM
- formulating *np*-pairing using QRPA
- including T=0 *np*-pairing based on MF / SLAP

Insight

Structure Input :
many-body wave functions
& transition matrix density

⇒ Reaction Model → Calc. Cross Sections

⇕

Expt. Cross Sections

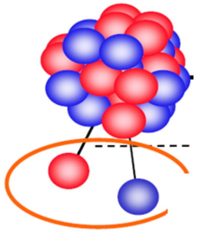
Nature

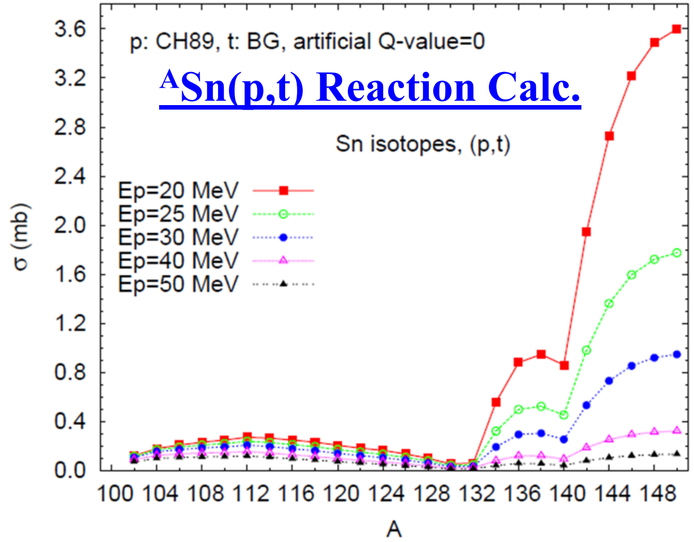
Data

I.J. Thompson (LLNL): Full one-step & two-step transfer reaction calculations (FRESCO)

Framework / Baseline -- studies of np pairing in heavier N=Z nuclei (RI Beams)

Summary II : Two-Nucleon Transfer

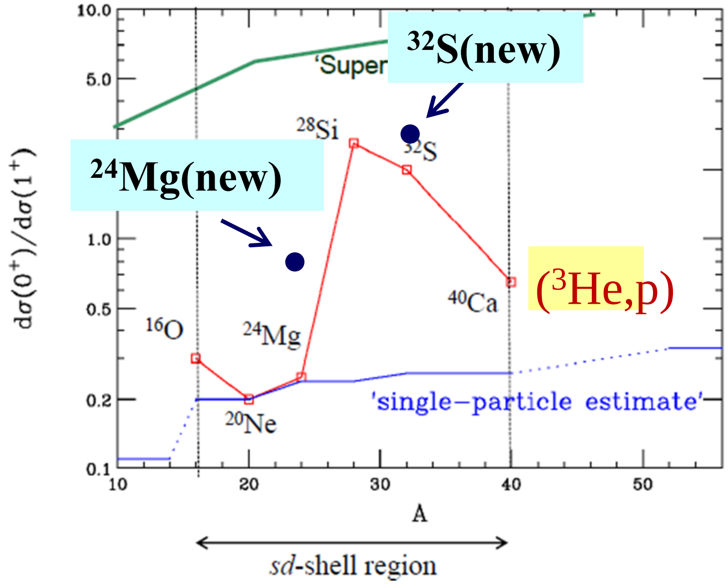




***2n*-transfer** → **Sensitivity to pairing properties of dilute neutron matter**

Reliable Calculations
→ Experimental planning
(eg. Best reaction energy)

N=Z nuclei in sd-shell



***np*-transfer** → **Dynamical Effects of np-pairing**

Systematic measurements in *sd*-shell nuclei

Benchmark & Baseline of *np*-pairing research