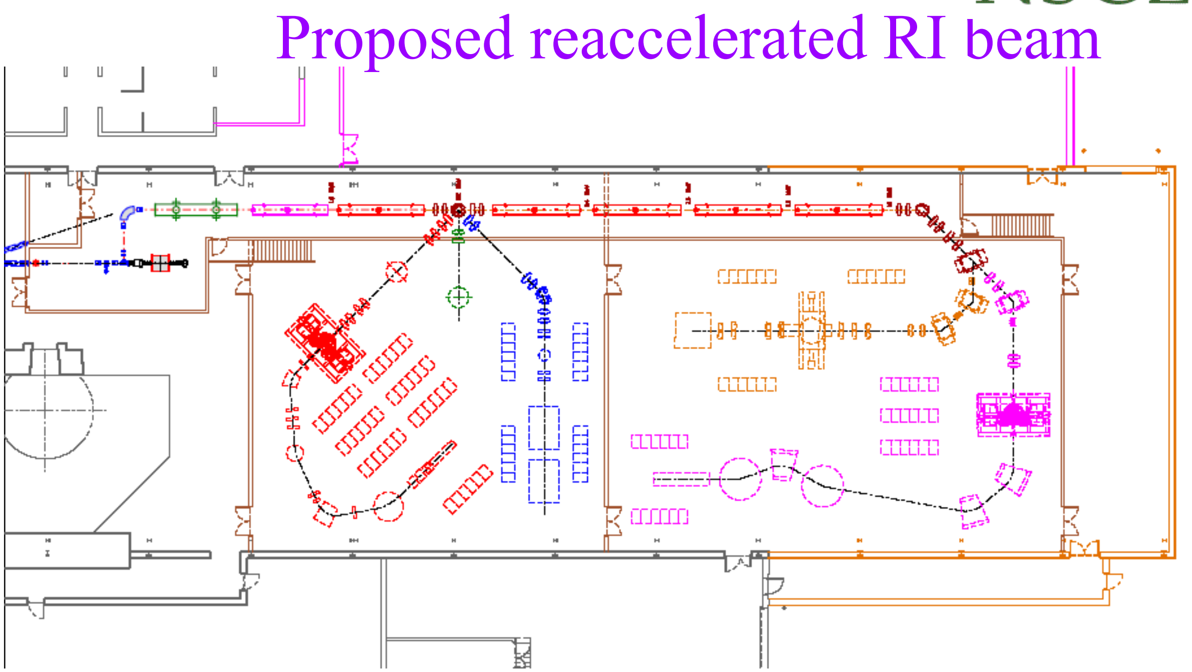
Extracting spectroscopic factors from 40 years of (p,d) and (d,p) data



USNDP
Annual Meeting
Nov 7-9, 2006

Betty Tsang

The National Superconducting Cyclotron Laboratory
@Michigan State University

The National Superconducting Cyclotron Laboratory

NSCL

Michigan State University

A national user facility for rare isotope research and education in nuclear science, astro-nuclear physics, accelerator physics, and societal applications

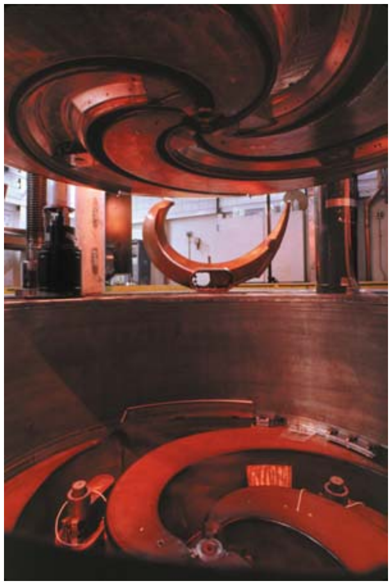
282 employees, incl. 51 undergraduate and 50 graduate students, 24 faculty

(as of March 05)

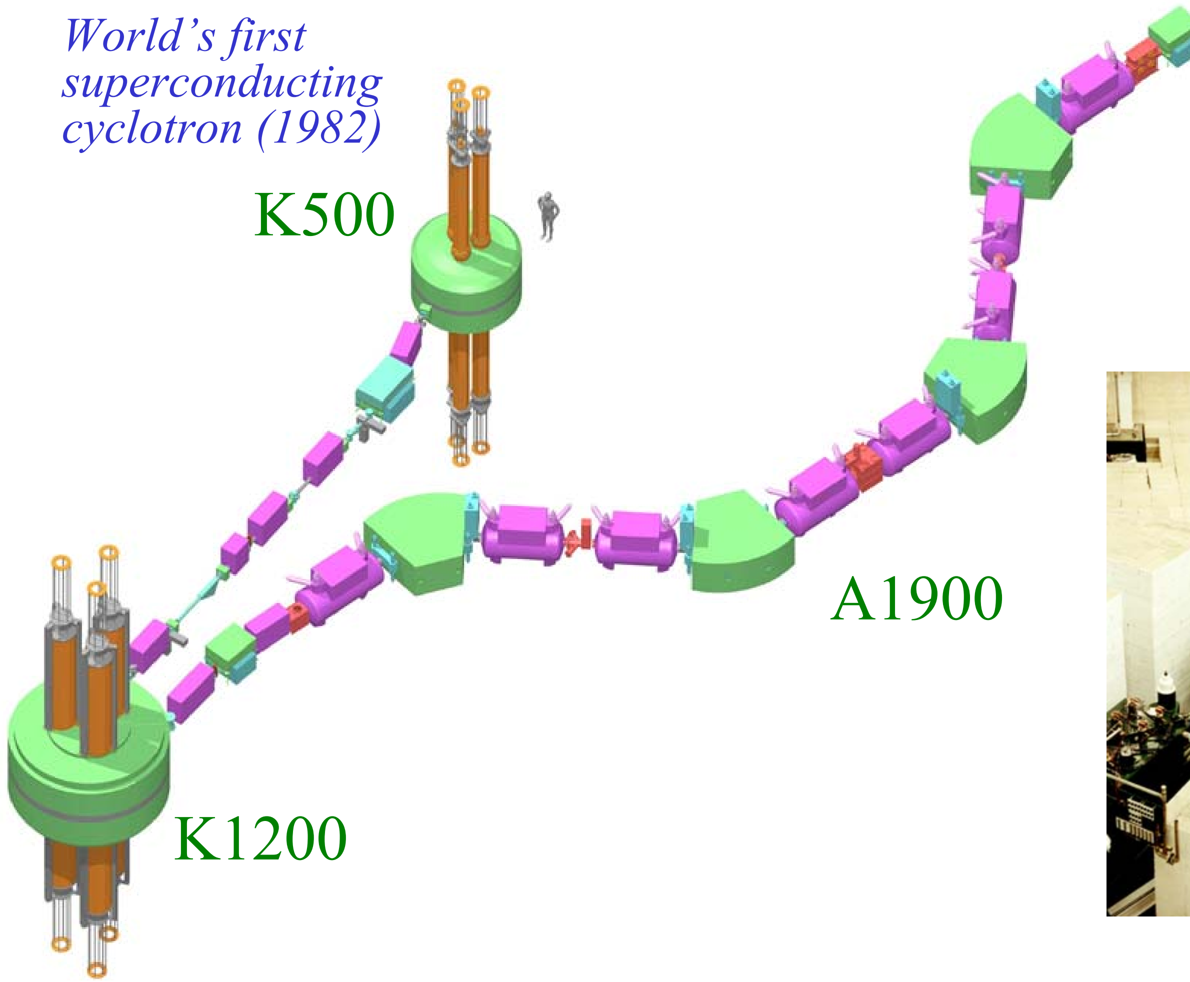
User group of over 600 CCF users

National Superconducting Cyclotron Laboratory

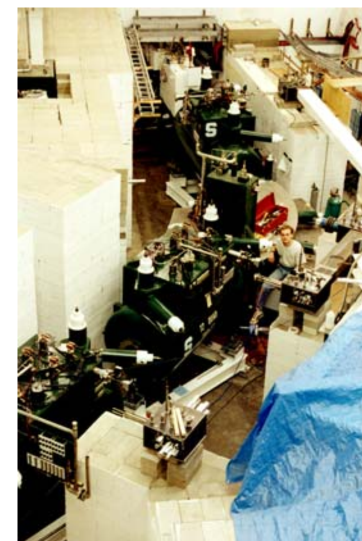
Coupled Cyclotron Facility (2000)



World's first superconducting cyclotron (1982)



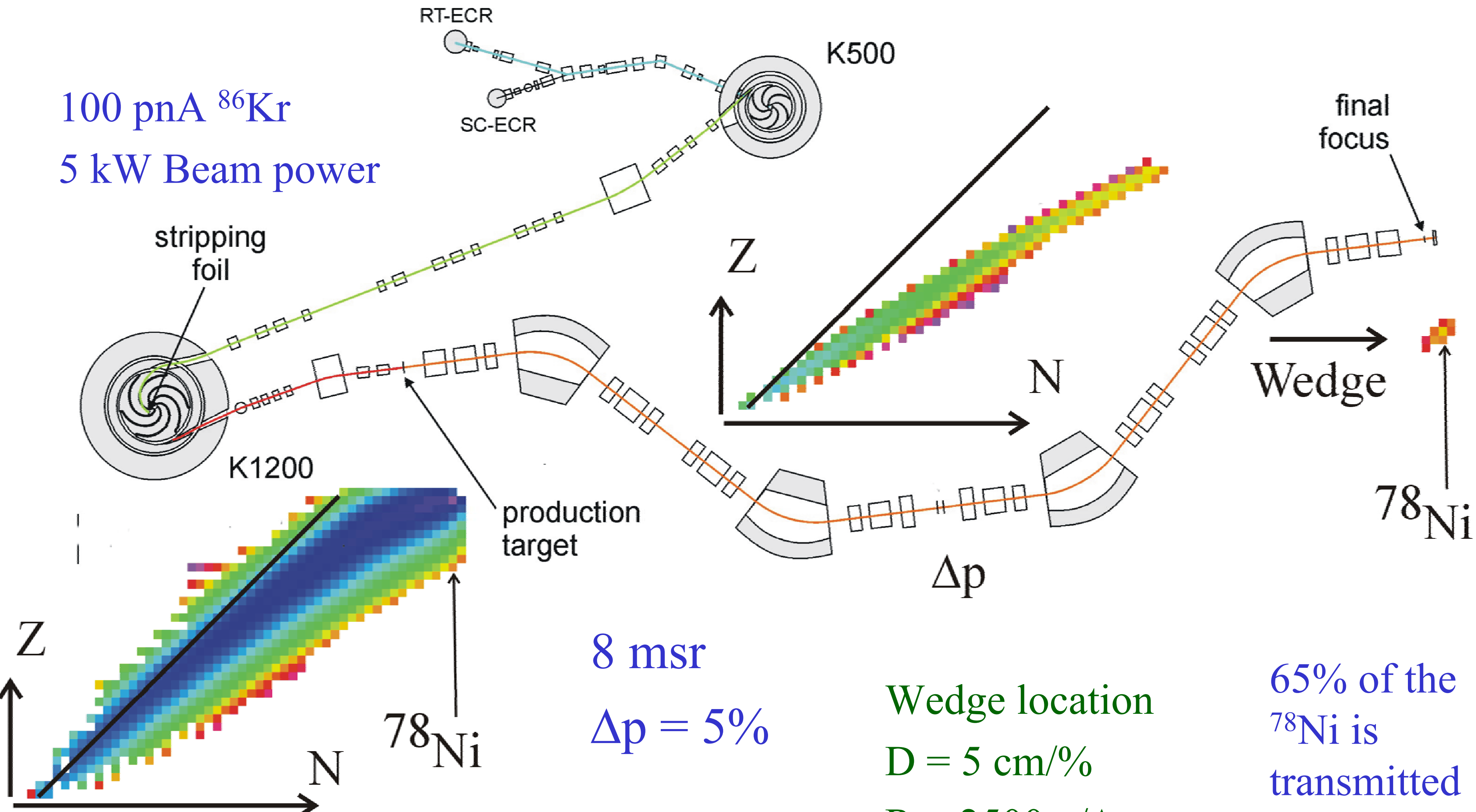
World's most powerful superconducting cyclotron (1989)



Example Fragment Separation Technique (NSCL)

100 pnA ^{86}Kr

5 kW Beam power



8 msr

$\Delta p = 5\%$

Wedge location

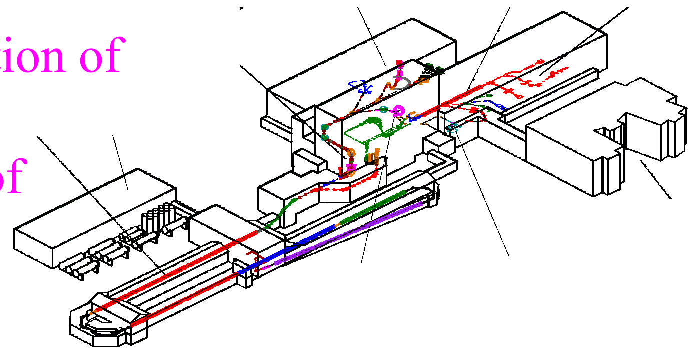
D = 5 cm/%

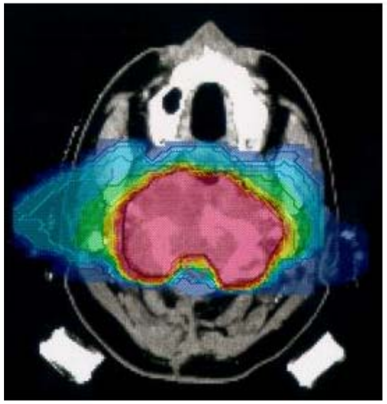
R = 2500 p/Δp

65% of the ^{78}Ni is transmitted

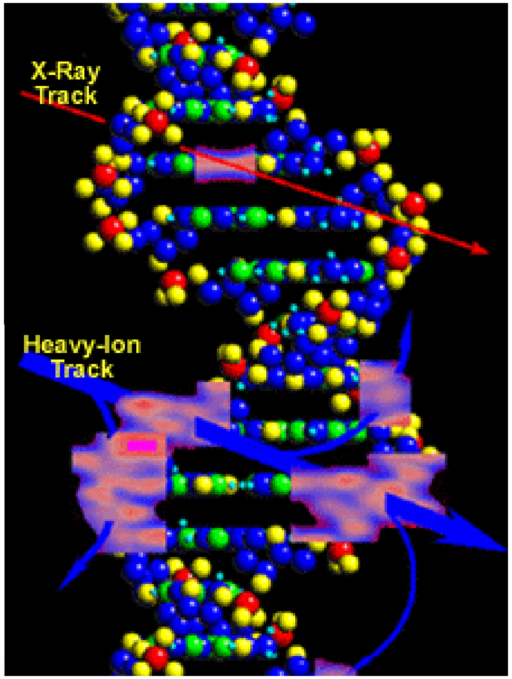
Projectile Fragmentation

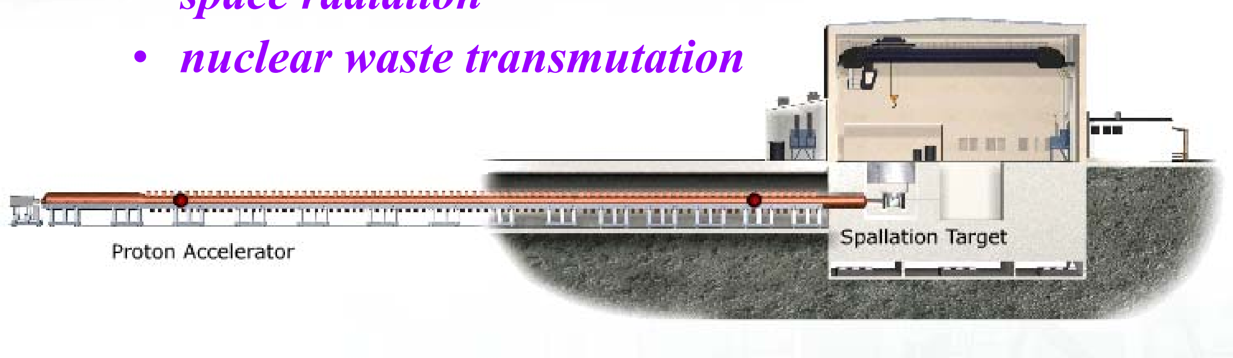
- Fundamental science
  - Mechanism in the production of rare isotopes
  - study of basic properties of atomic nuclei



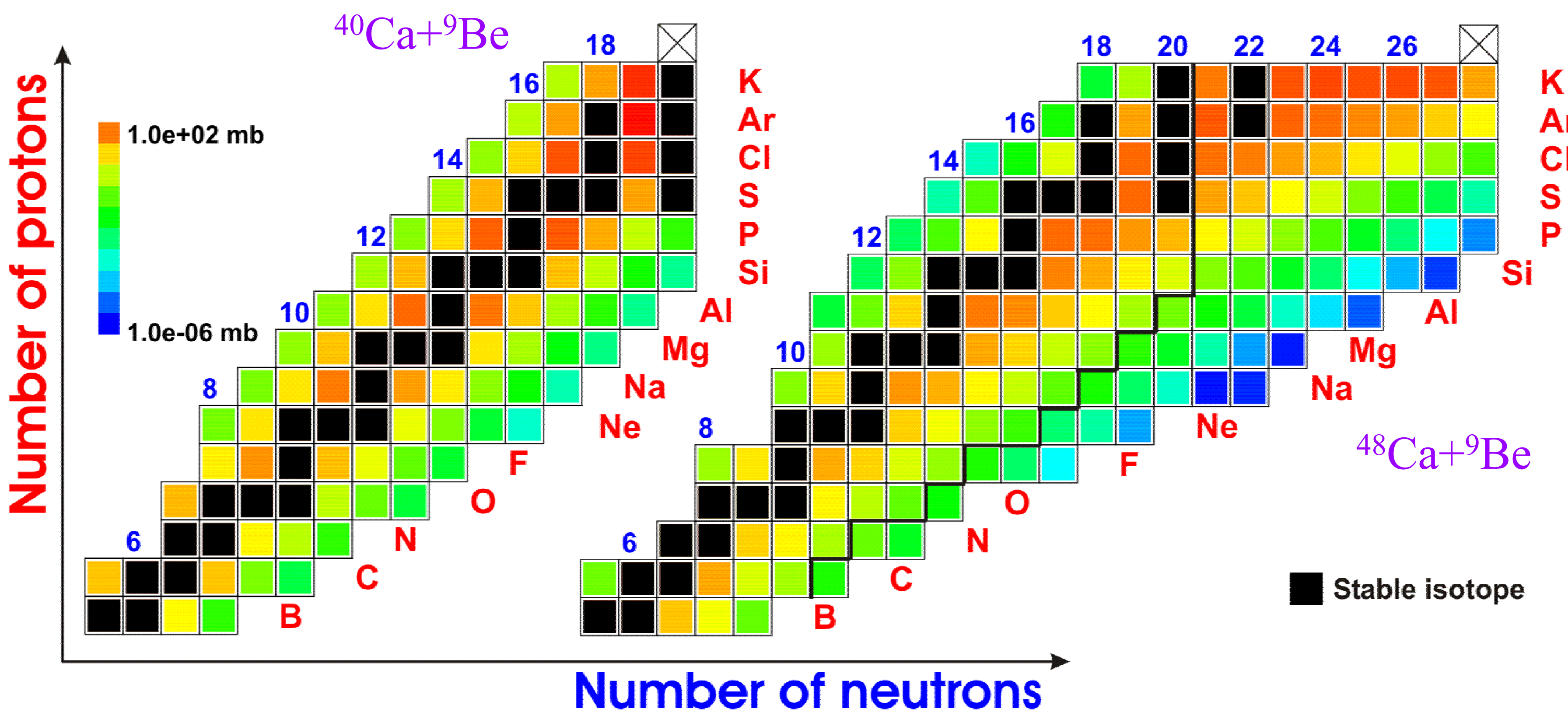


- Applications
  - Benchmark data needed to test simulation code.
    - ***Beam rate estimates for RI beam facilities***
    - ***Design high power accelerators***
    - ***tumor treatment***
    - ***space radiation***
    - ***nuclear waste transmutation***





Rare Isotope Production (Mocko thesis & PRC, in press)



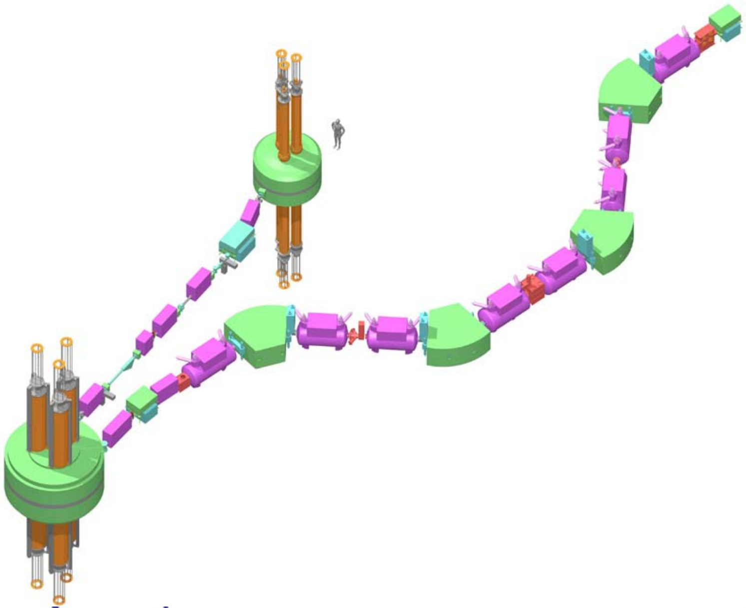
- *Nearly 2X more isotopes are produced in fragmentation of ^{48}Ca than ^{40}Ca.*

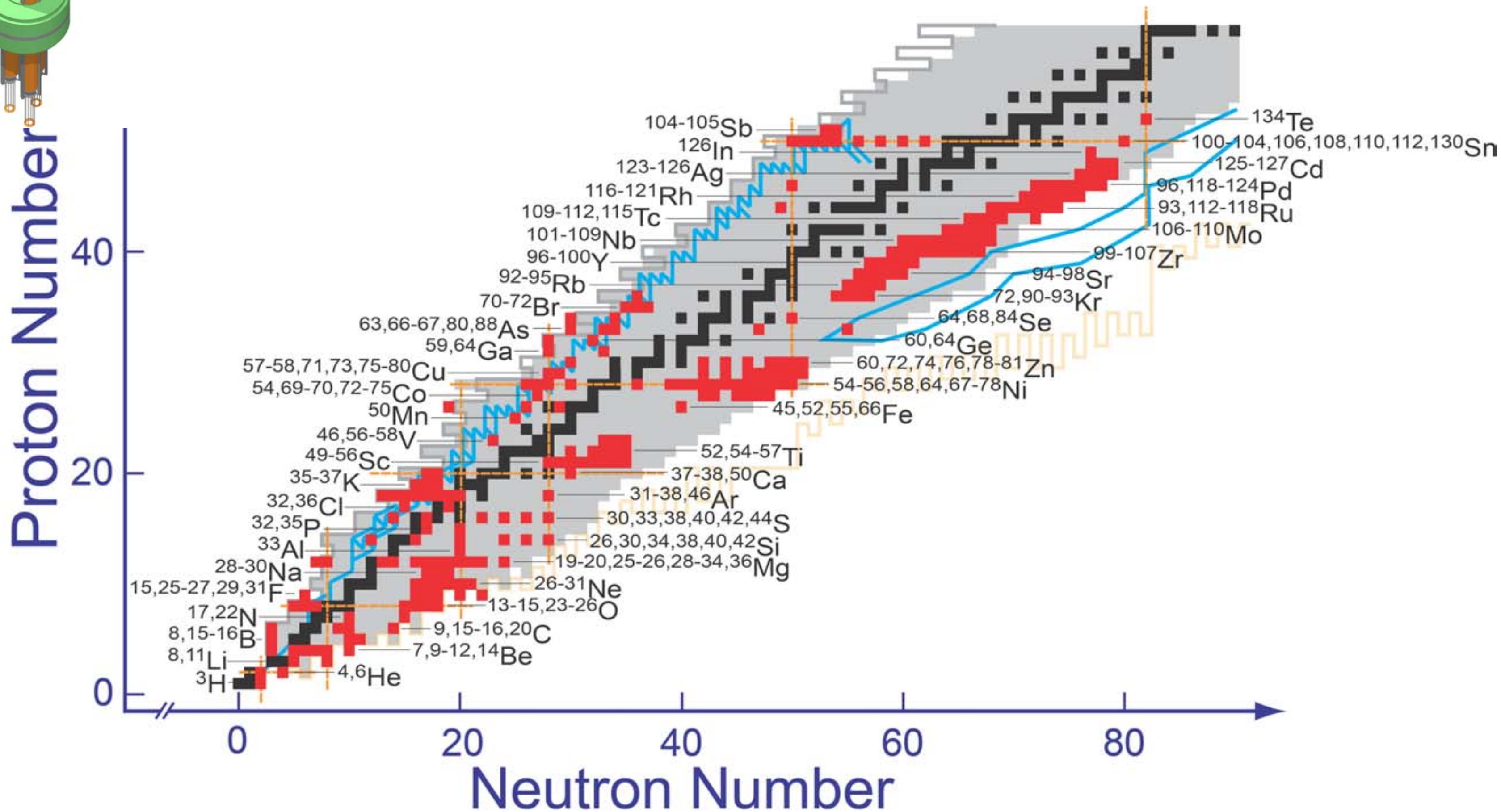
- *Primary beams: $^{40,48}Ca$, $^{58,64}Ni$ and unstable ^{68}Ni and ^{69}Cu beams.*
- *Data reveal deficiencies of EPAX parameterization.*
- *Improvement on theoretical understanding of the RI production mechanisms.*

NNDC data base for "fragmentation data"

Publication of cross-sections (Nuclear Data Sheets)

Rare Isotope Beams Produced with CCF/A1900





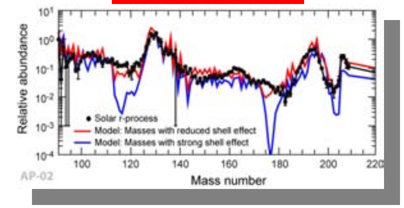
Sherrill (2006)

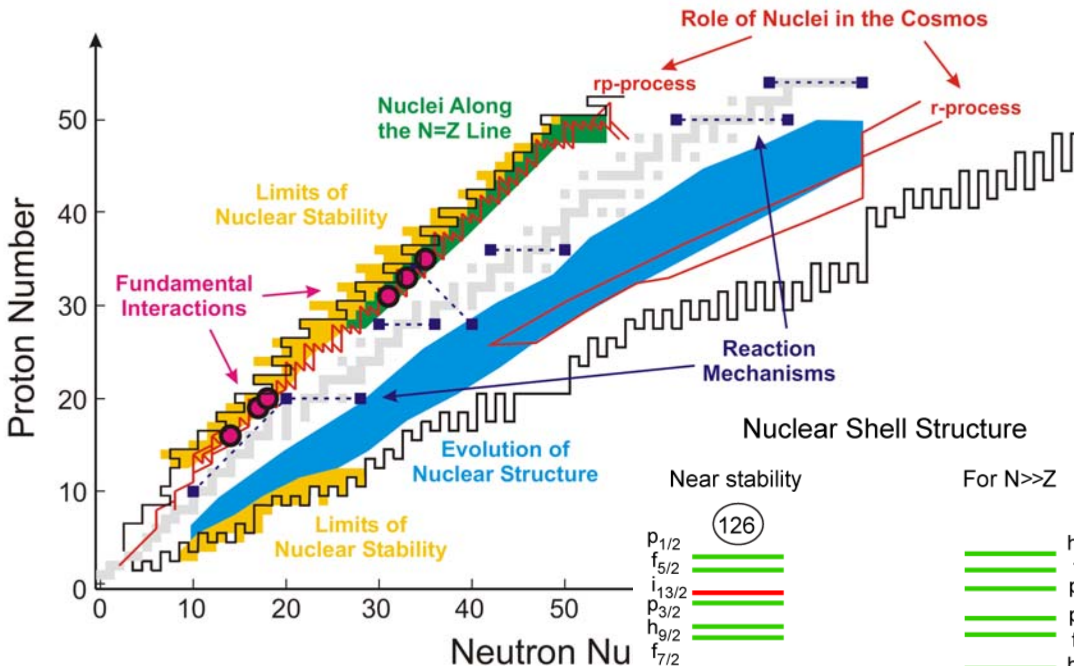
Nuclear Science at the NSCL

Where are the limits of nuclear stability?

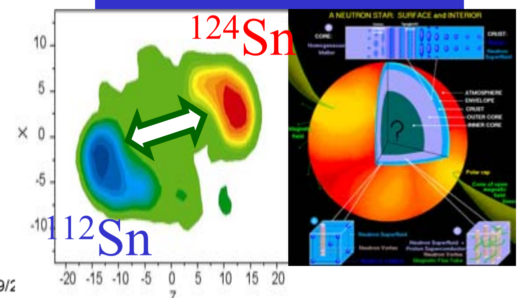
Properties N~Z nuclei r-p process

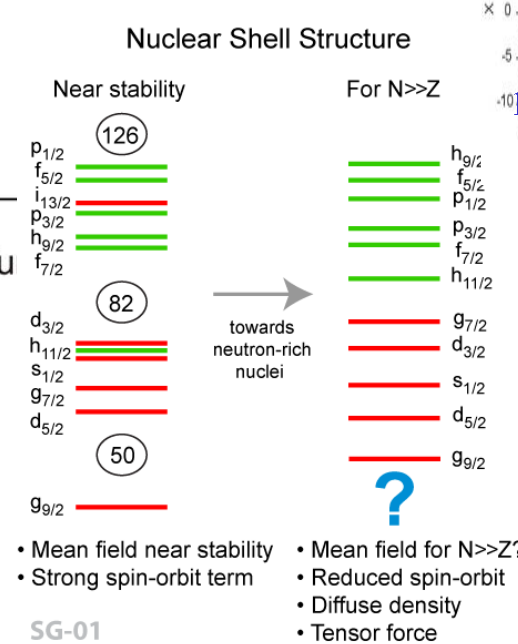
r-process

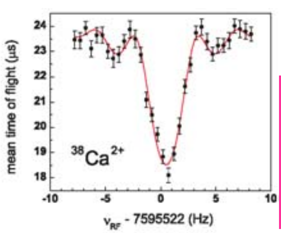




EOS of n-rich matter

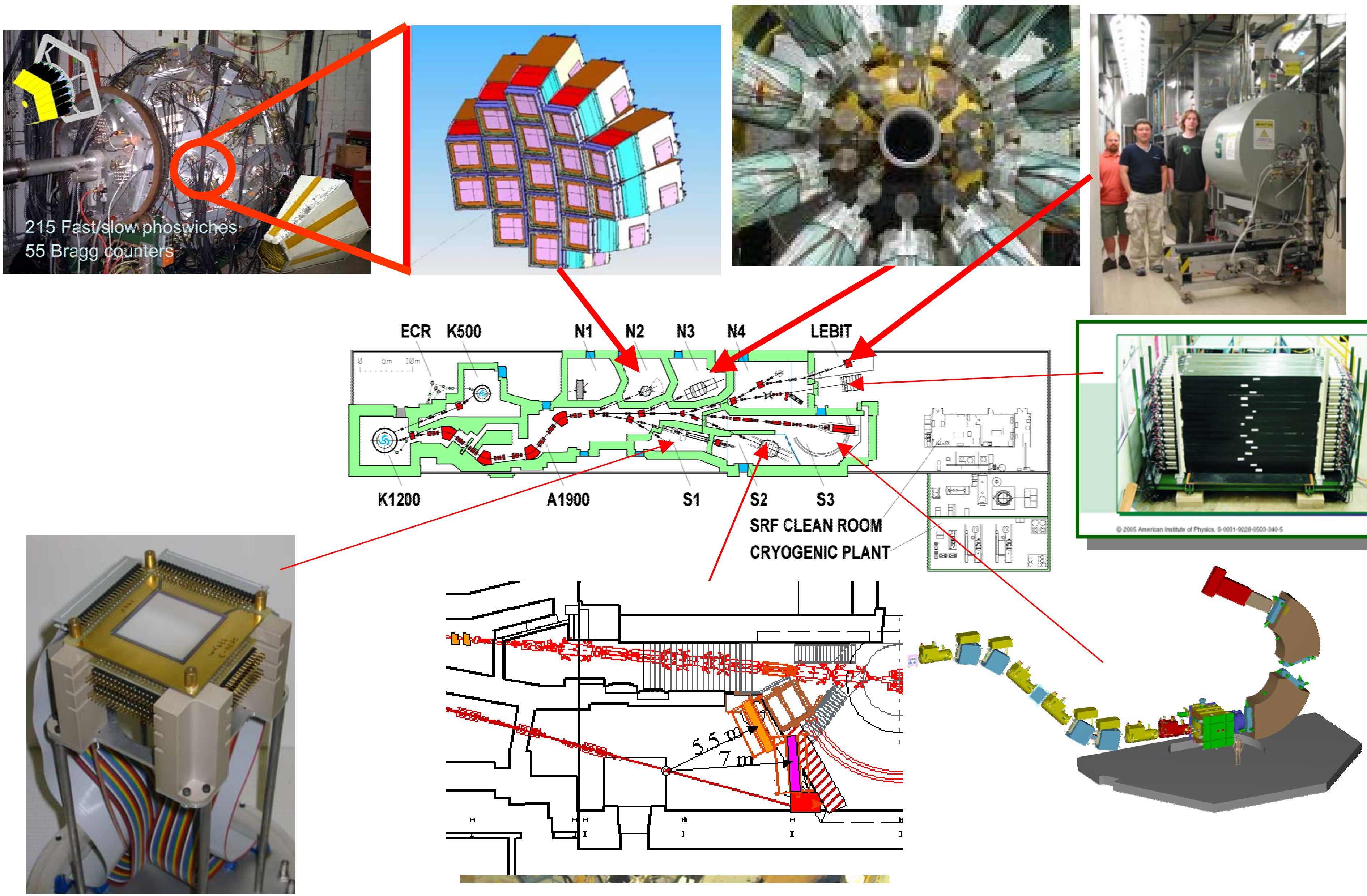




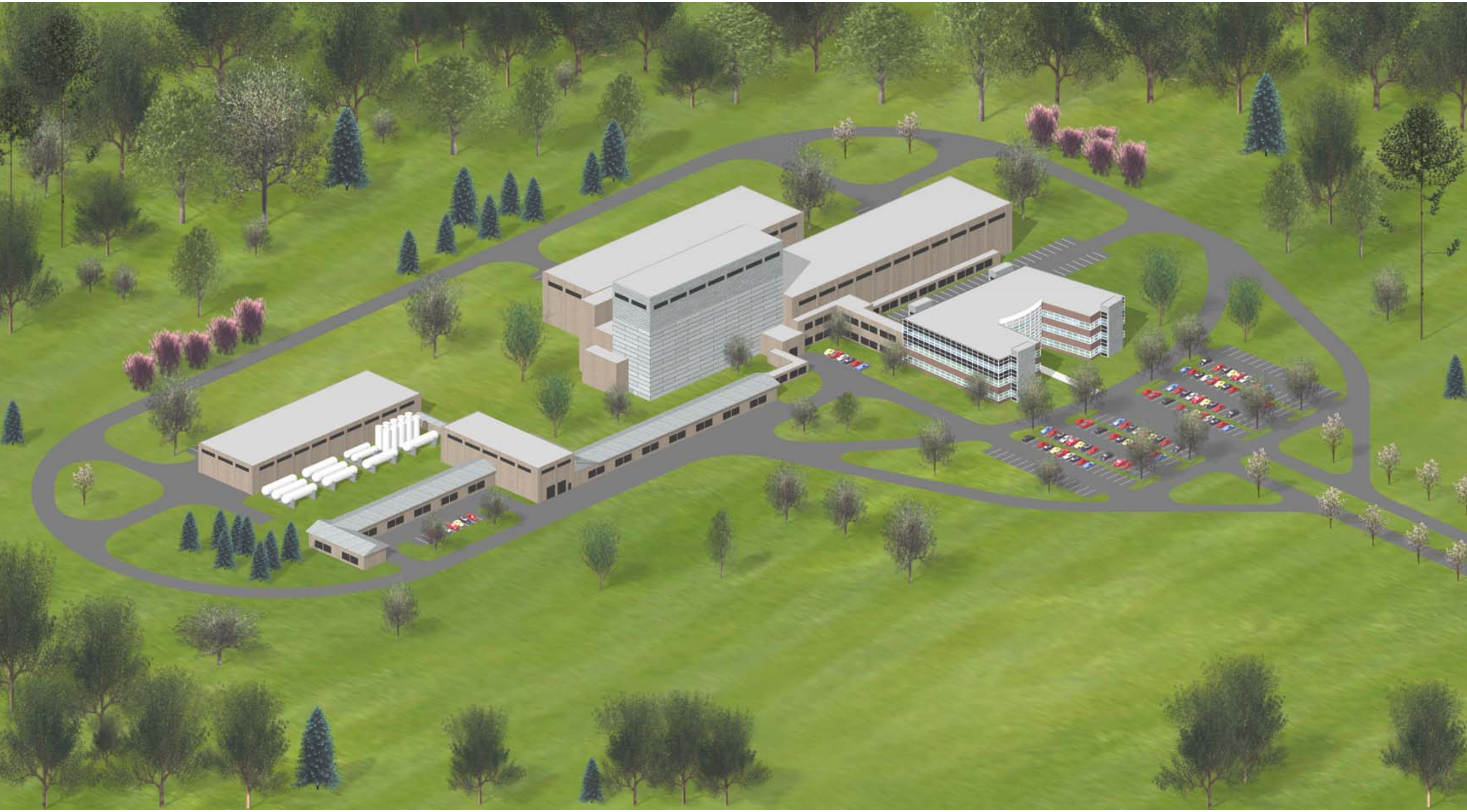


Is there physics beyond the standard model? Mass measurements

Experimental Areas at NSCL

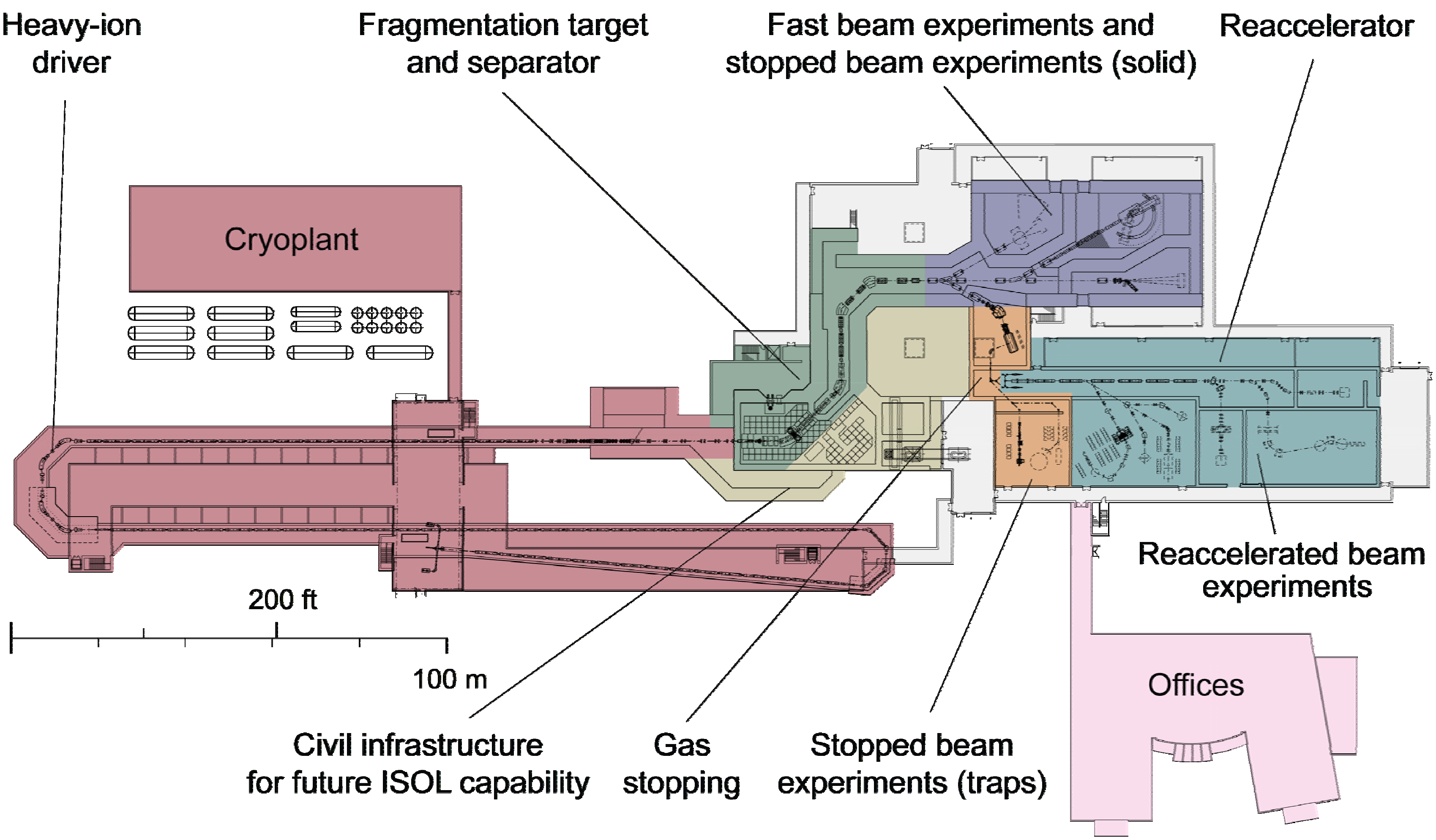


ISOTOPE SCIENCE FACILITY AT MSU
Developing Plans for the Future (10-Year Horizon)



ISF@MSU

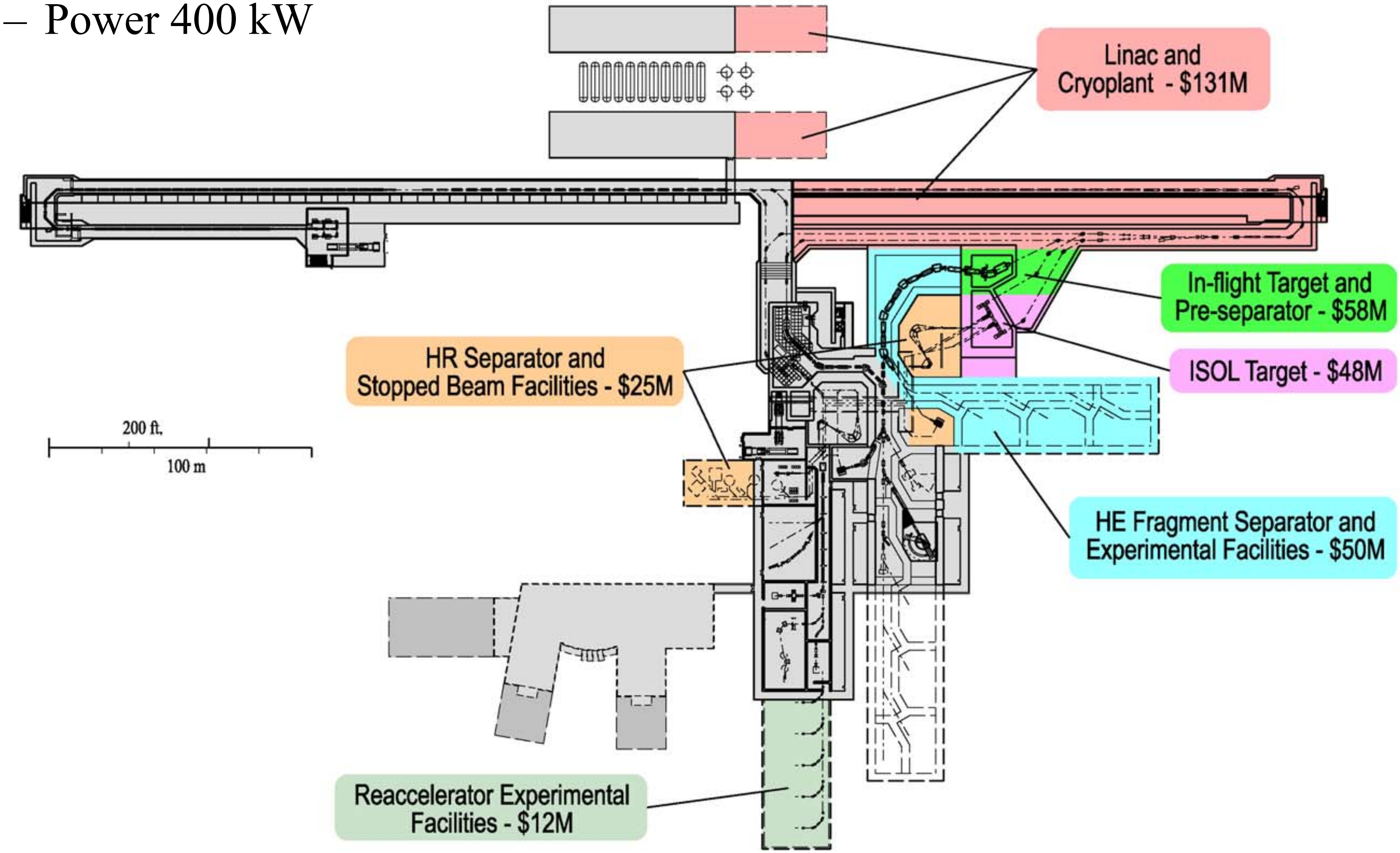
Large intensity gains (factors of 100-100,000) over current capability rare isotope beams with energies between 0 and 200 MeV/nucleon



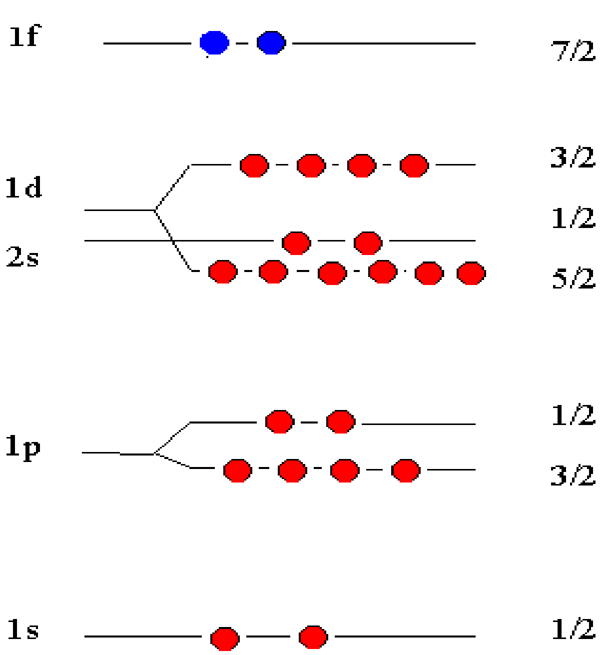
ISF Upgrade Options

Modular, expandable capacity to meet future science needs

- Multi-user capability, flexible science-driven selection of upgrade elements
  - Energy/nucleon: 400 MeV ^{238}U, 539 MeV ^{129}Xe, 864 MeV ^{3}He, 1122 MeV ^{1}H
  - Power 400 kW



Extracting spectroscopic factors from 40 years of (p,d) and (d,p) data



Magic number

N=20

N=8

N=2

^{42}Ca

Spectroscopic Factors: measure the single particle nature of the valence nucleons.

Properties of Single Particle

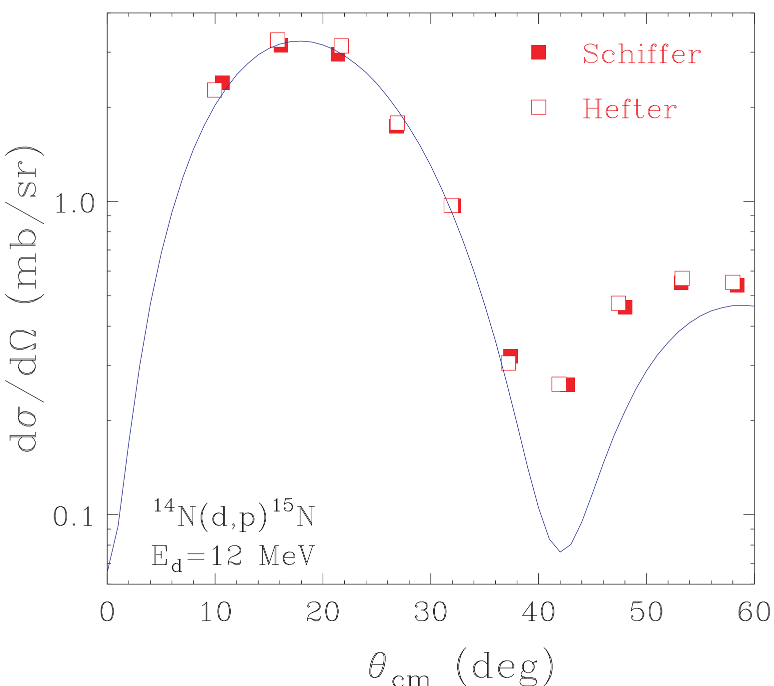
Experimental SF :

$$S_{gs} = \frac{\left(\frac{d\sigma}{d\Omega}\right)_{EX}}{\left(\frac{d\sigma}{d\Omega}\right)_{RM}}$$

$\Rightarrow$ **Spectroscopic factor(SF)**

measures the orbital configuration of the valence nucleons.

Independent Particle Model (IPM), SF represents how good can we describe the nucleus as a single particle plus a core.



$$S_{exp}/S_{IPM} = 1$$

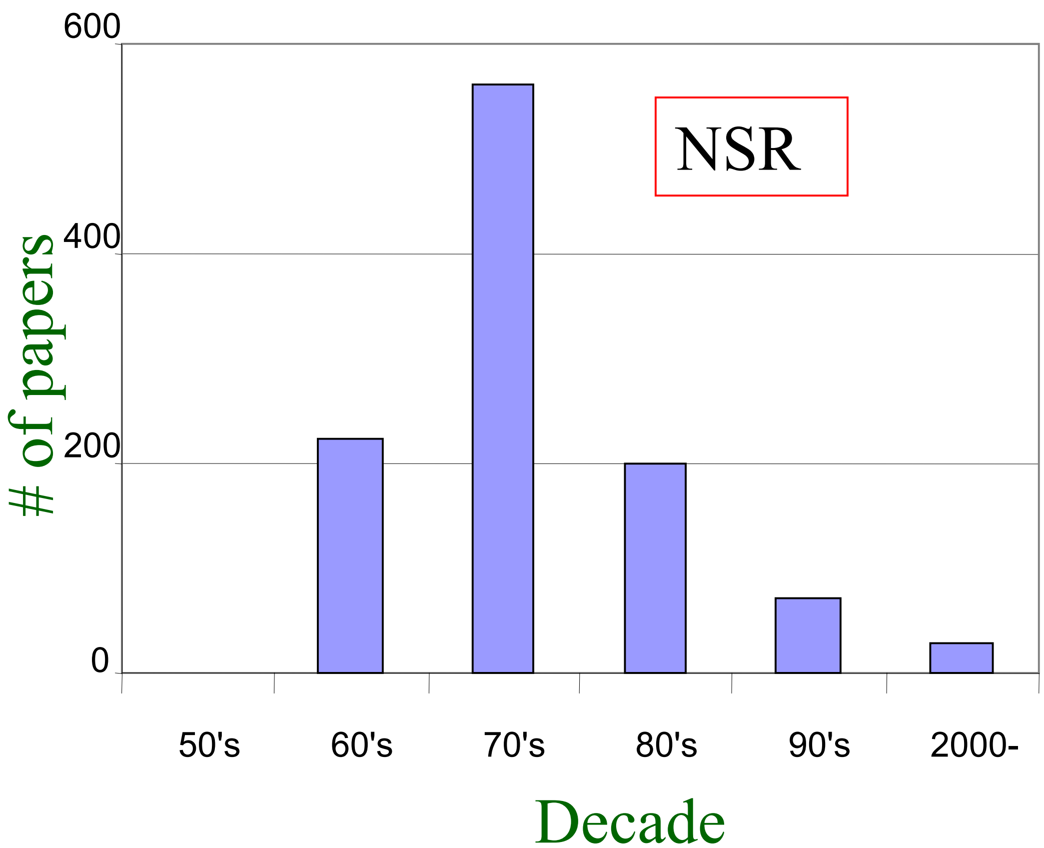
Orbital description is accurate

$$S_{exp}/S_{IPM} < 1$$

Valence nucleon occupies more than one orbit →LBSM.

Spectroscopic Studies from (p,d) & (d,p) transfer reactions

SF is one of the important properties to understand the structure of the rare nuclei.



Pros:

✓*We know the exact state of the nucleon transferred.*

✓*Good understanding of the experimental technique and reaction theory (DWBA) & beyond*

✓*Lots of data from past 40 years (NSR).*

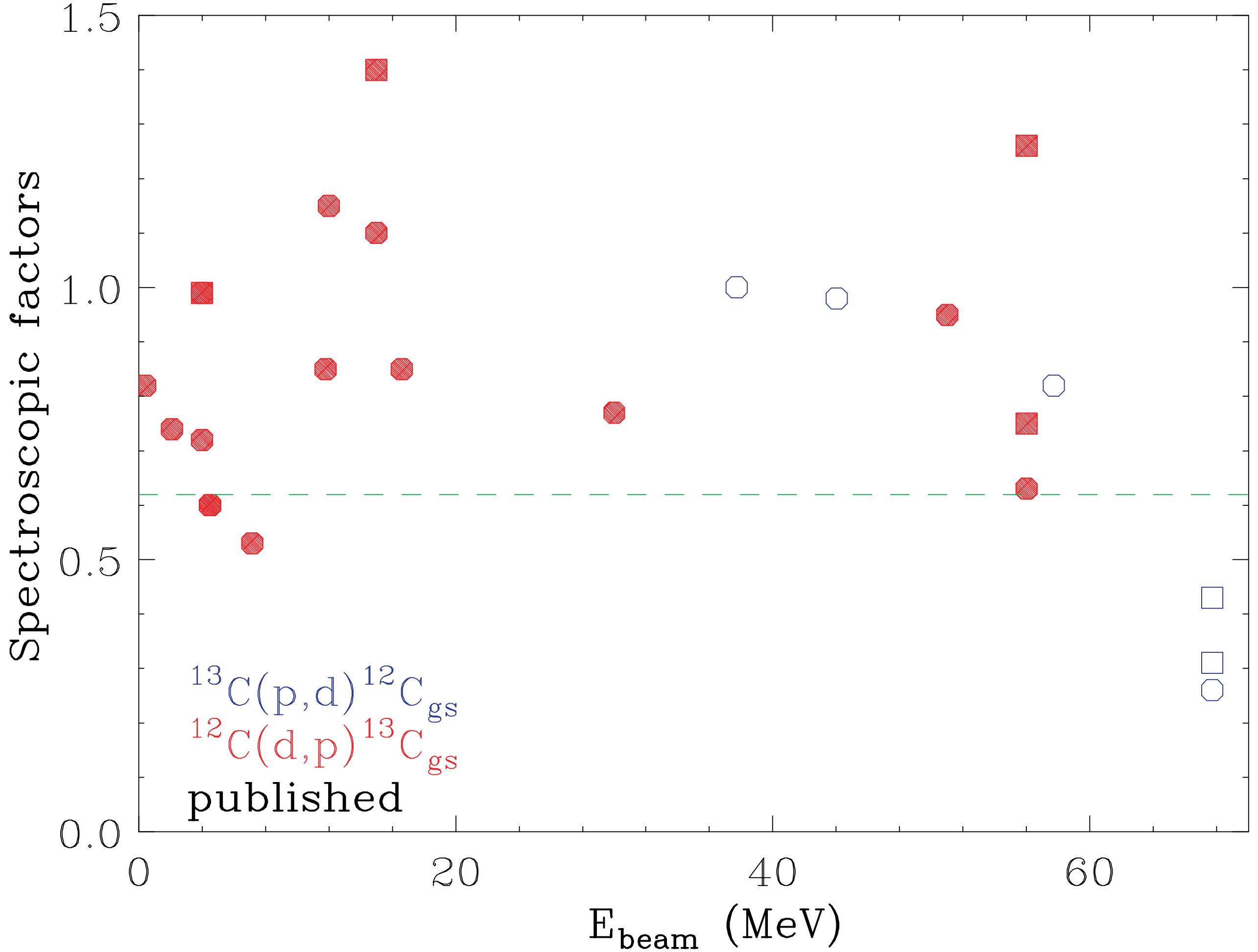
Cons:

✘ *Do we measure the "absolute" spectroscopic factors?*

✘ *Data appear to give inconsistent results*

Spectroscopic Factors from literatures

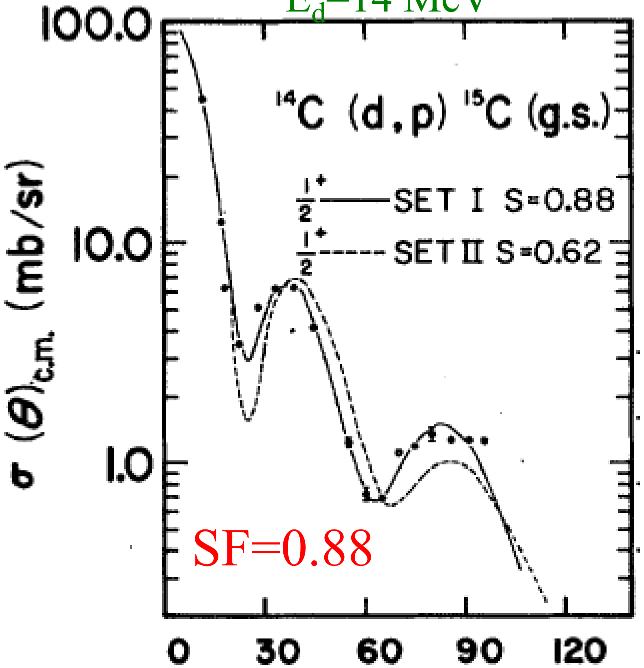
Example: $1p_{1/2}$ neutron SF in $^{13}C = {}^{12}C+n$



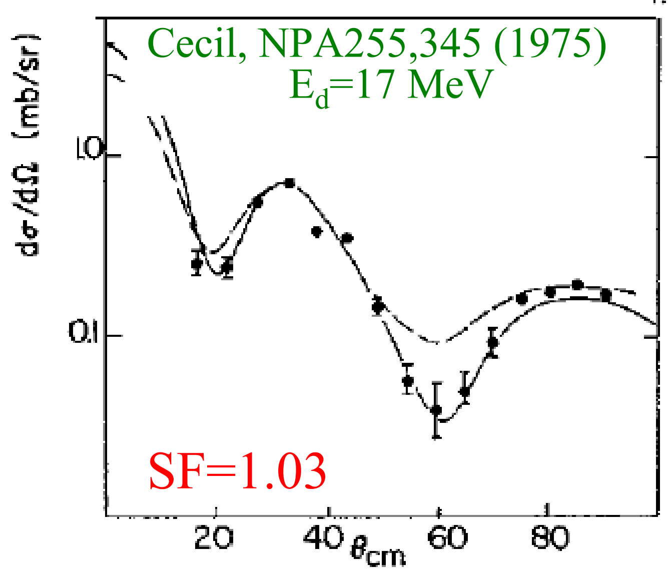
- ***Published spectroscopic factors show large fluctuations from analysis to analysis***

$^{14}C(d,p)^{15}C$

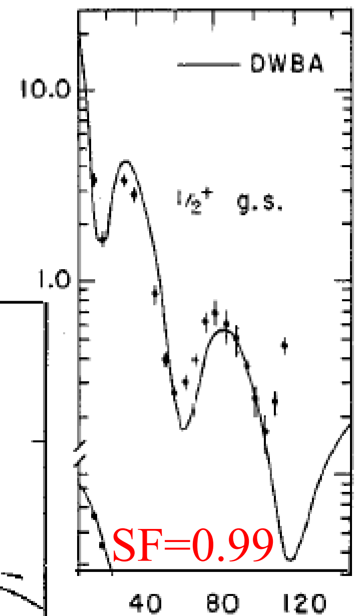
Goss, PRC12,1730 (1975)
E_d=14 MeV



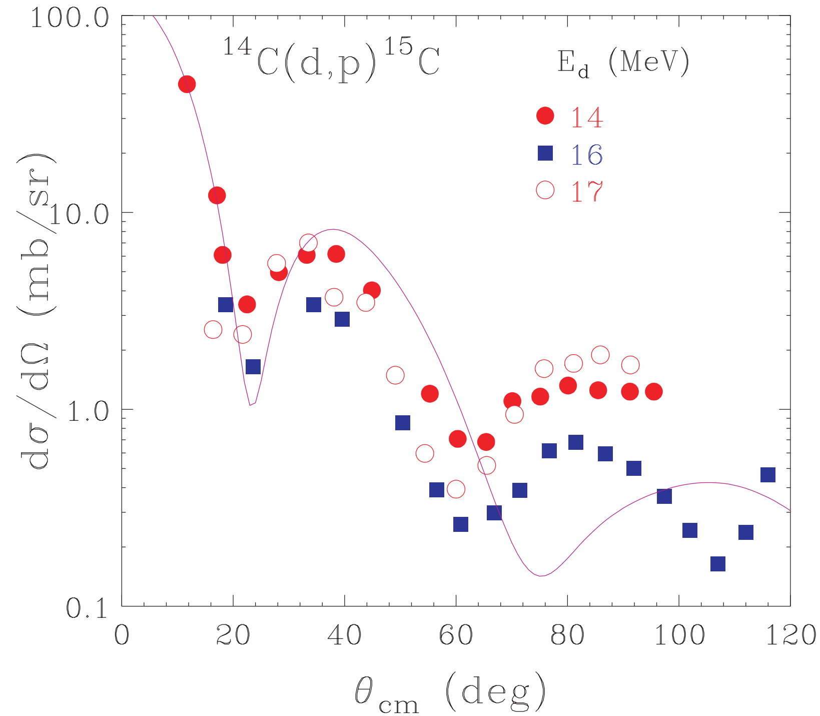
Cecil, NPA255,345 (1975)
E_d=17 MeV



E_d=16 MeV



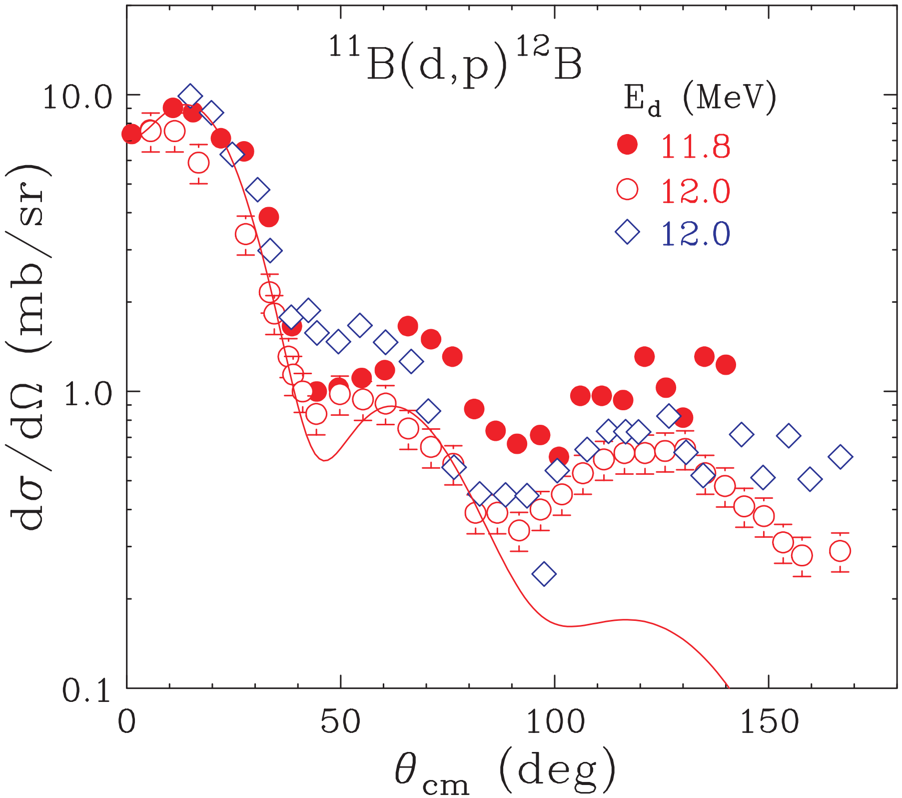
Murillo, NPA579, 125 (1994)

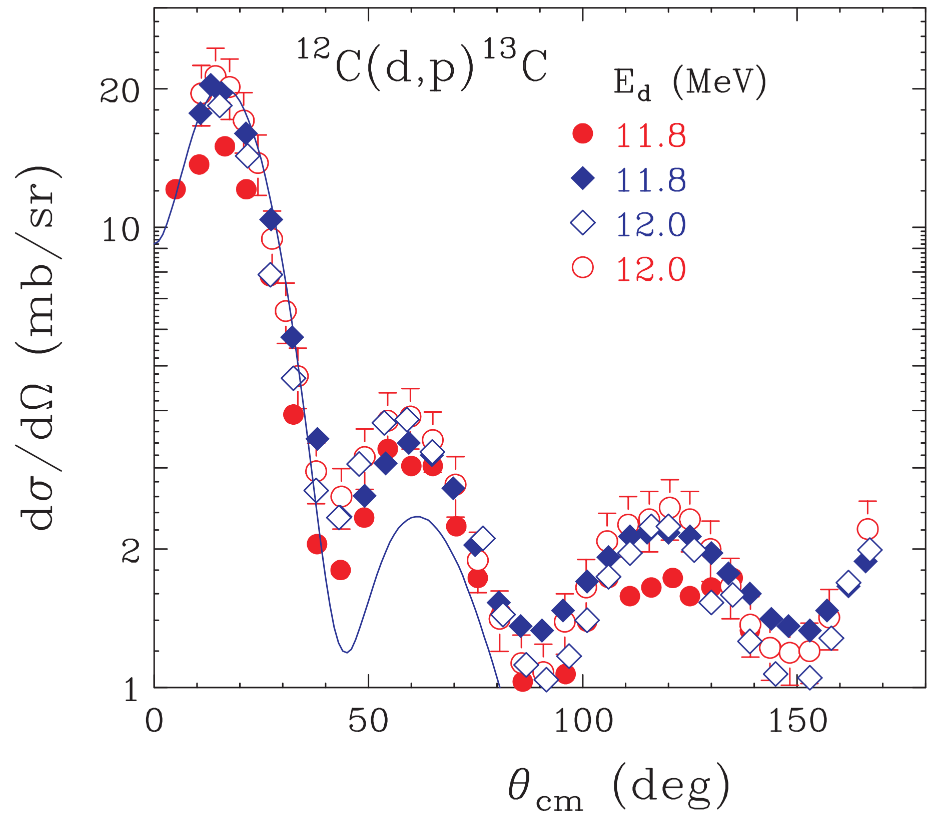


The data differ by factor of 2 but SF's are nearly the same by varying the input parameters!!

Discrepancies between data sets

Quoted experimental uncertainties are 6-20%





J. P. Schiffer et al., Phys. Rev. 164, 1274 (1967).
Z. H. Liu et al., Phys. Rev. C 64, 034312 (2001).
D.Fick, J,NUK,19,693 (1974) (EXFOR).

J. P. Schiffer et al., Phys. Rev. 164, 1274 (1967)
Z. H. Liu et al., Phys. Rev. C 64, 034312 (2001).
J. Lang et al., Nucl. Phys. A477, 77 (1988).
U.Schmidt-Rohr et al., Nucl. Phys. 53, 77 (1964).

Quality control from independent measurements

TWOFNR (Tostevin)

Soper-Johnson Adiabatic Approximation to take care of d-break-up effects.

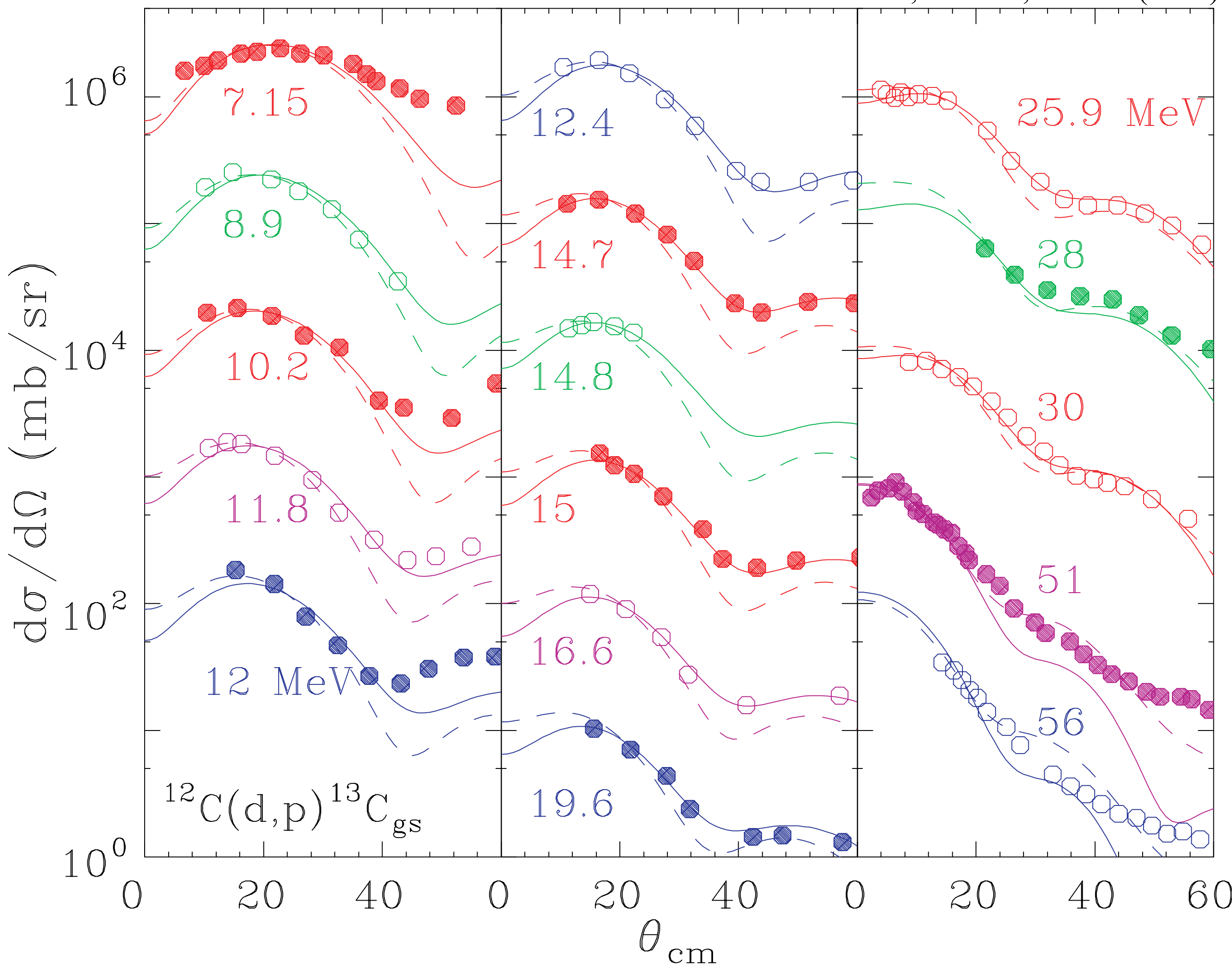
Use global p and n optical potential with standardized parameters (CH89)

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

Include finite range & non-locality corrections

$^{12}C(d,p)^{13}C_{gs}$

Liu et al, PRC **69**, 064313 (2004)



SF=0.75±0.10; SF(SM) = 0.62

Apply the technique to a large data set

Ground state n-spectroscopic factors for 80 nuclei

Tsang et al, PRL **95**, 222501 (2005)

Jenny Lee, 2004
SURE student

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
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

Quality Control ?

80 nuclei from Li to Cr (~ 430 angular distributions)

S_n 80 nuclei
(p,d) : S_+ 47 nuclei
(d,p) : S_- 56 nuclei

(p,d) & (d,p) 18 nuclei

A+p→B+d S_+

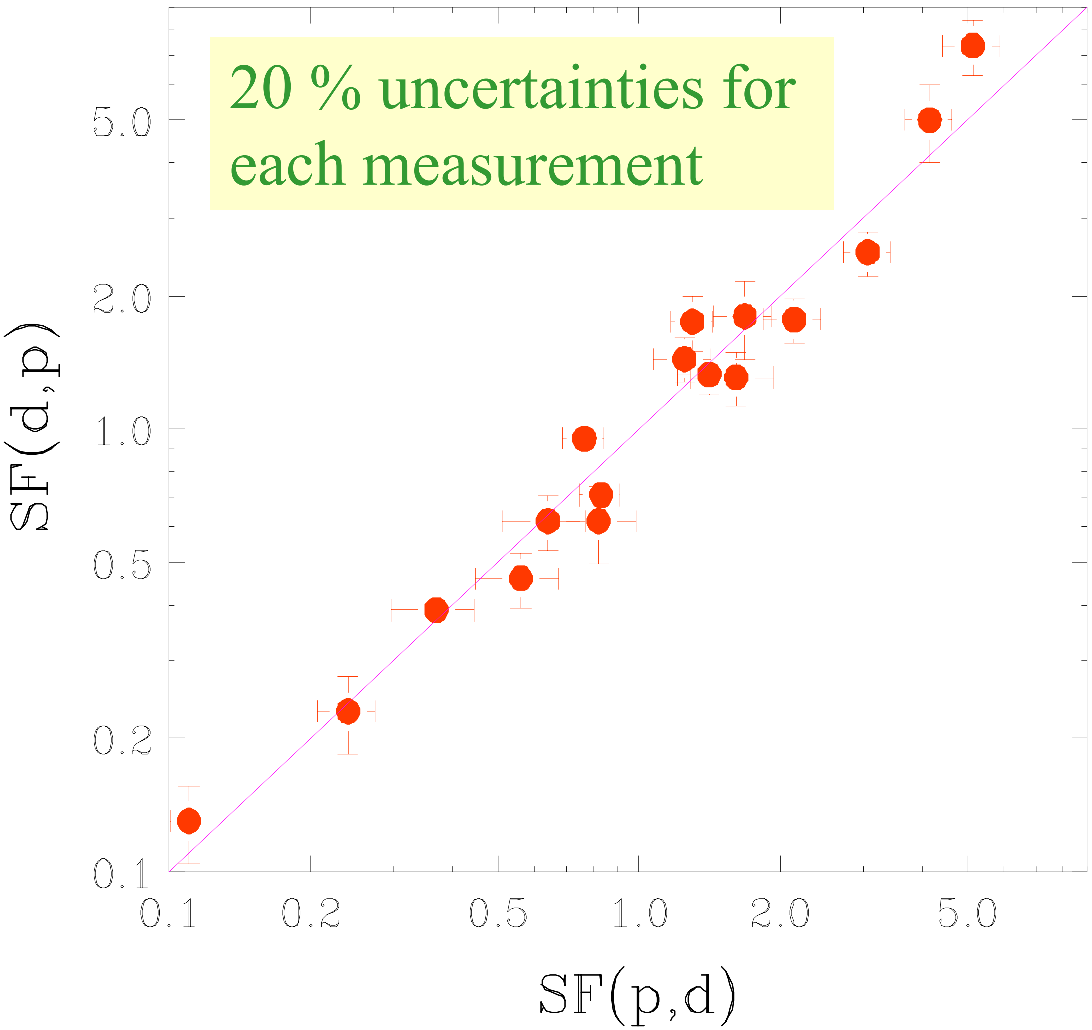
B+d→A+p S_-

Equivalent processes $S_+ = S_-$

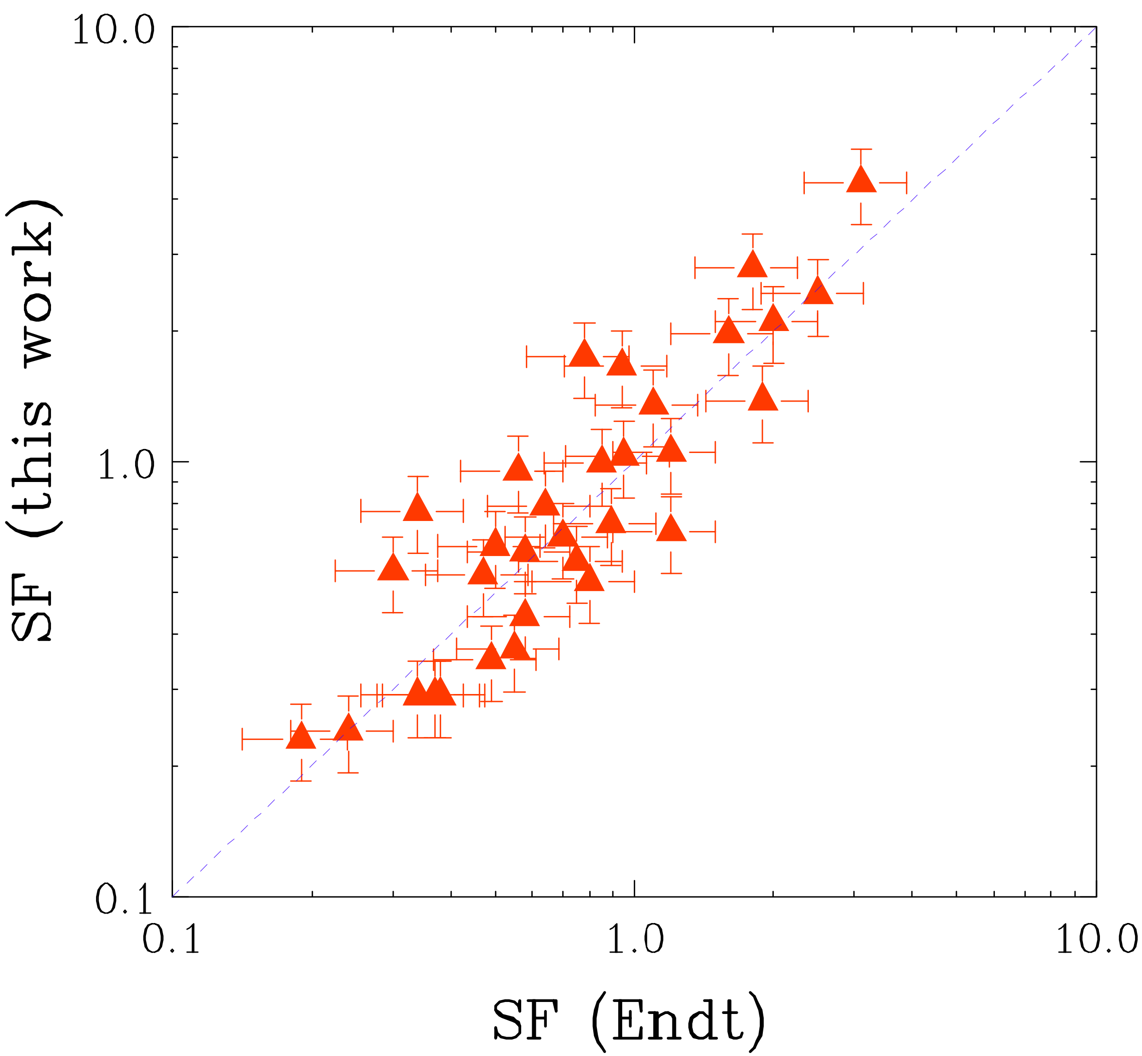
18 nuclei

⇒Self consistency checks

⇒Assign uncertainties



Comparison with Endt's (Atomic Data and Nuclear Tables 19, 23 (1977)) best SF values in A=21-44 region



Endt's SF:

✓ uncertainty : ***25% [(p,d), (d,p), (d,t), (^{3}He, α)]***

50 % for (d,p) and (p,d) reactions only)

✓ removal of normalization uncertainties

✓ mainly based on communication with authors

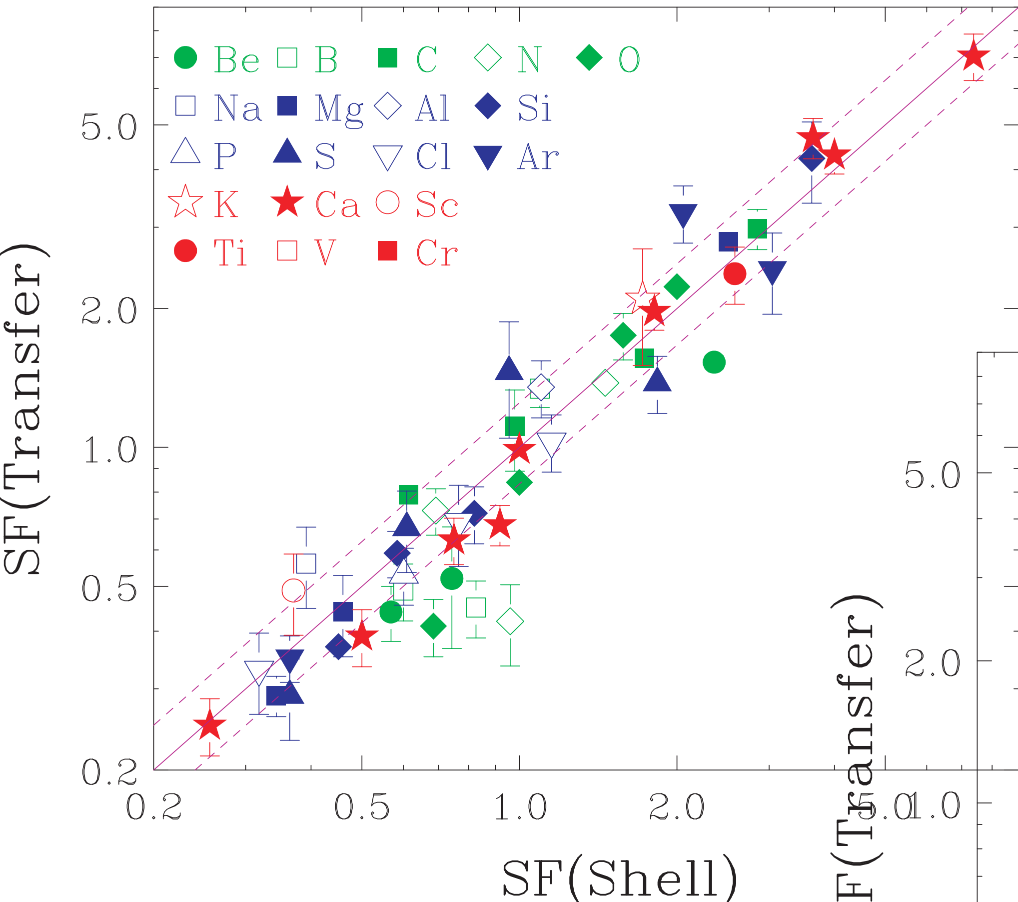
Our SF :

✓ uncertainty : < 20 %

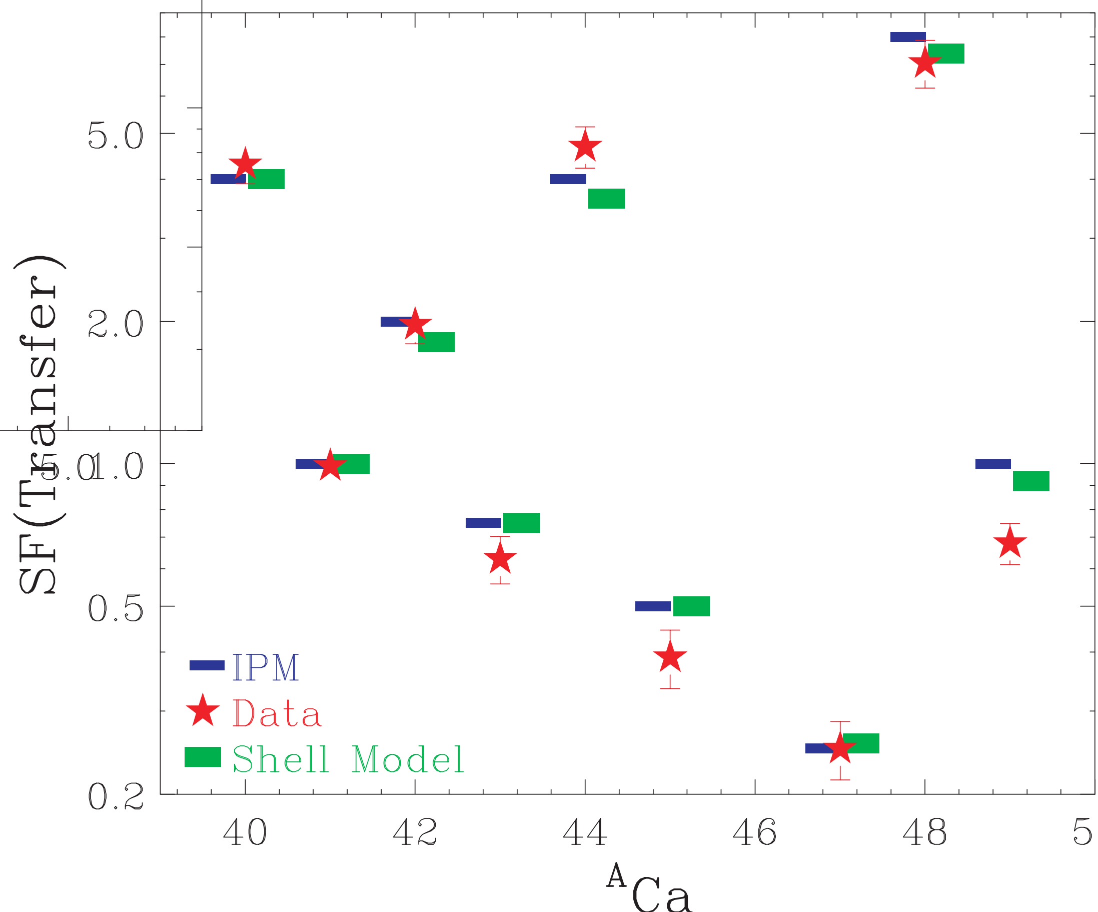
✓ re-analysis by consistent method and parameters

✓ can be applied to other data.

Compare with LB-Shell Model (Oxbash, B.A. Brown)



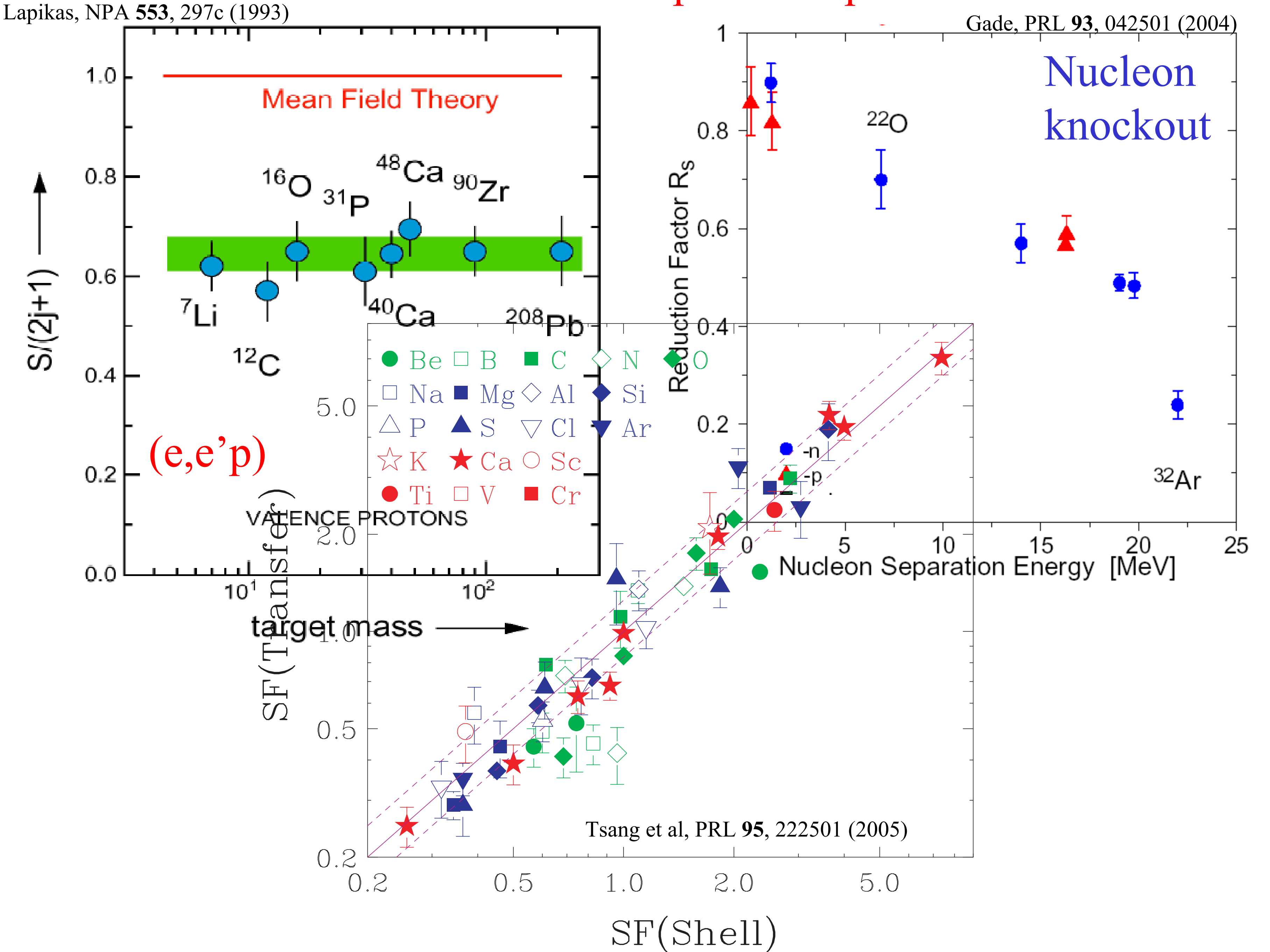
Austern's values were predicted 40 years ago



Good agreement with most isotopes

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

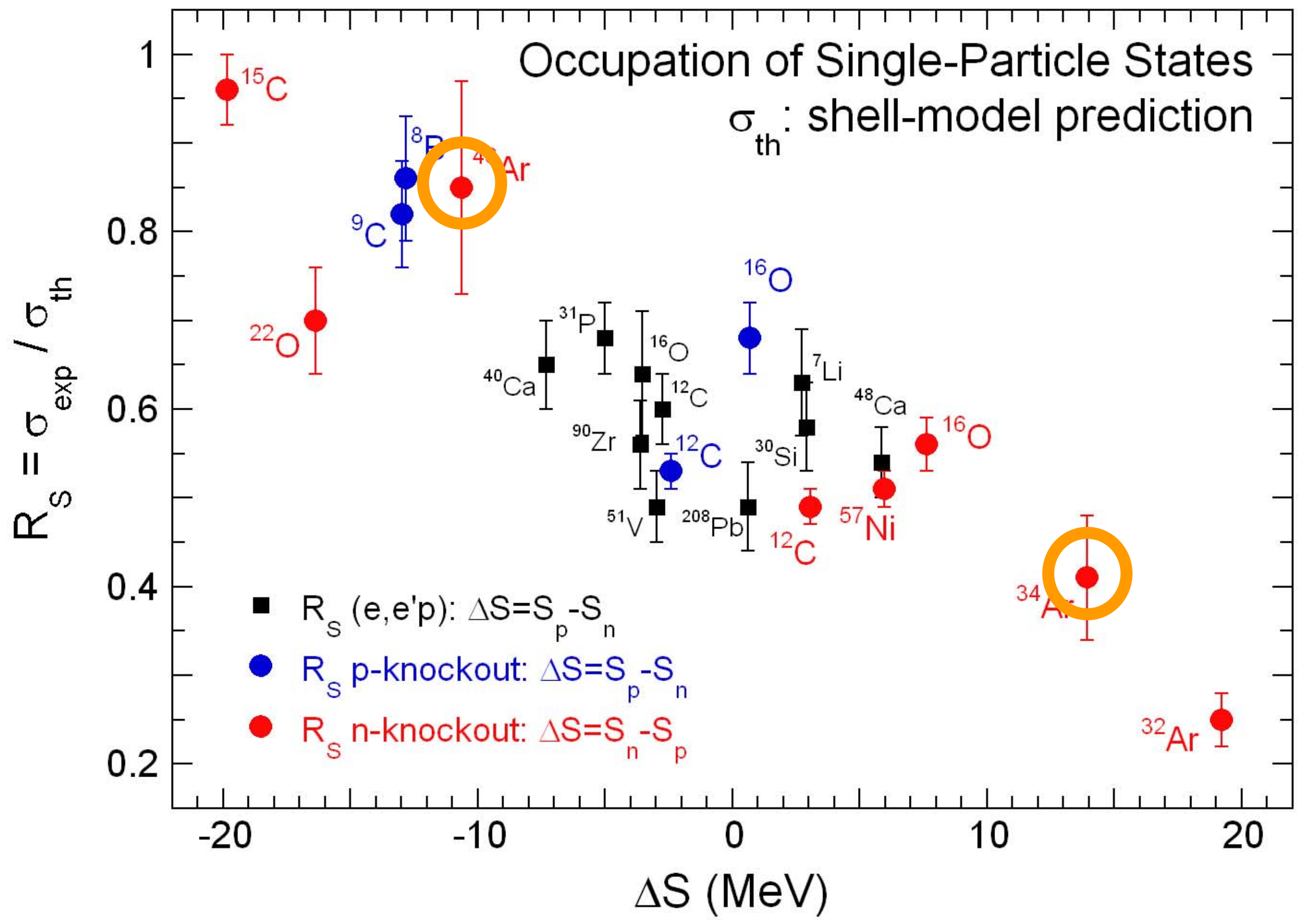
Measurements of Spectroscopic Factors



Measurements of Spectroscopic Factors

SF values and trends should be the same independent of measurement methods, i.e. (e,e'p), nucleon knockout and transfer reactions should give same SF values.

Lee, PRC73, 044608 (2006); Gade, PRL **93**, 042501 (2004)



Approved experiments : **p(^{46}Ar, d)^{45}Ar; p(^{34}Ar, d)^{33}Ar – to study possible quenching effects in strong and weakly bound neutrons in rare isotopes.**

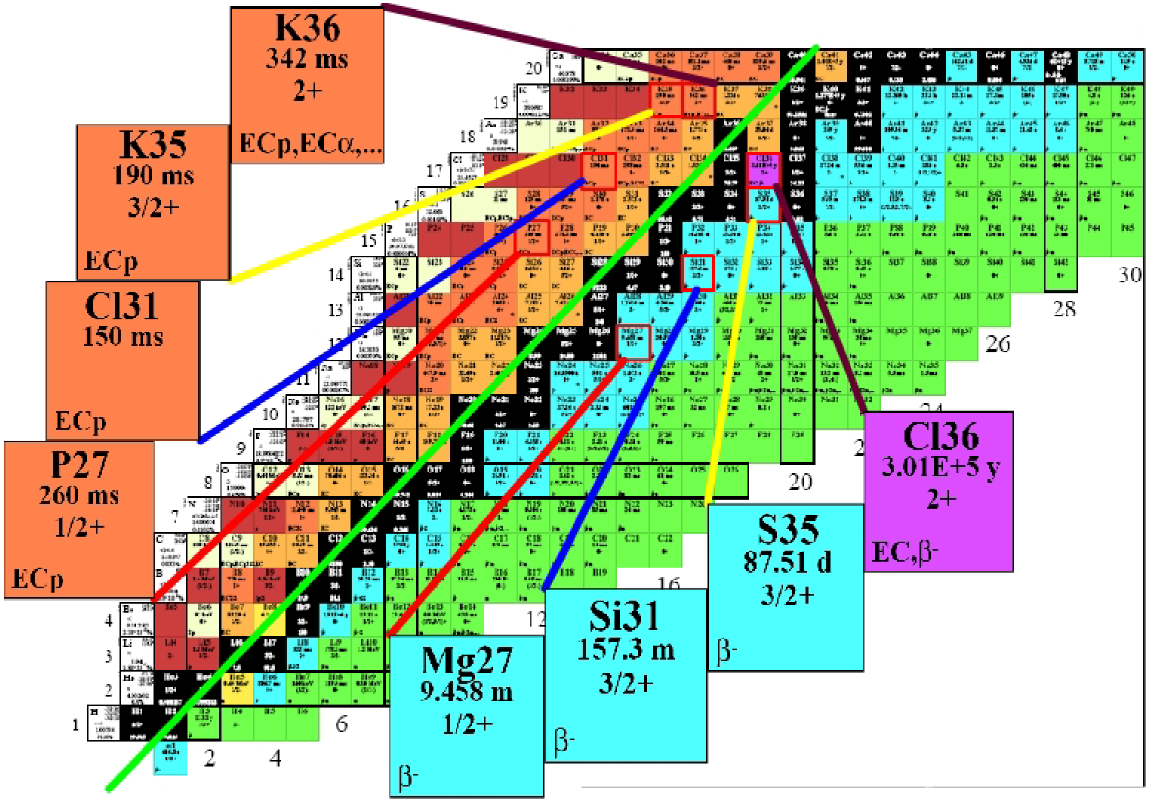
SF's of excited states for ^{27}Mg, ^{30}Si, ^{31}Si, ^{35}S & ^{36}Cl

- The (unstable) mirror nuclei **^{27}P, ^{30}S ,^{31}Cl, ^{35}K & ^{36}K** are of astrophysical importance in nucleosynthesis processes.

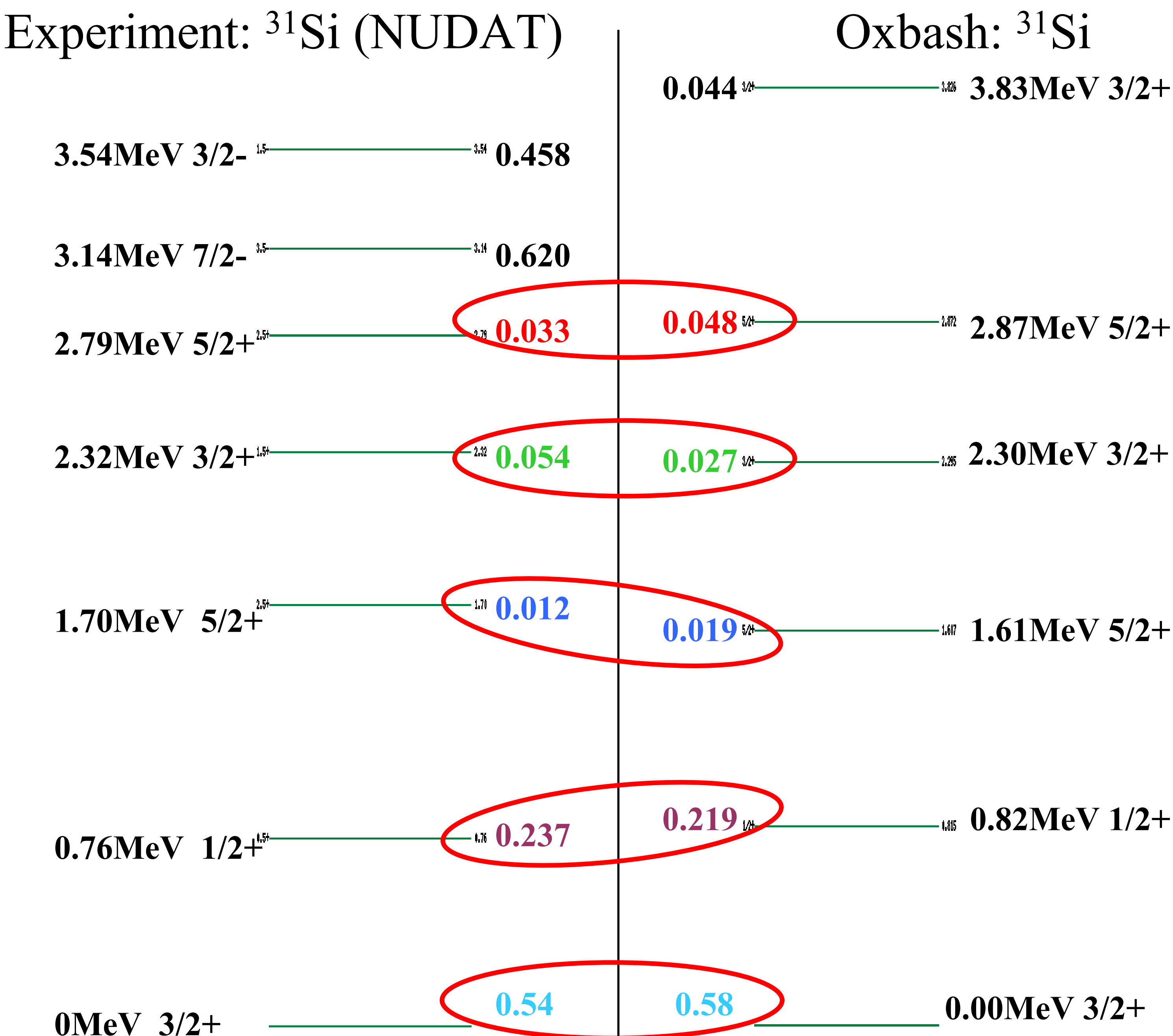
- no experimental (SF) data exist so reaction rates (and energy levels) rely on shell model calculations.

•Important to establish the accuracies of these calculations by comparing SF data to predictions.

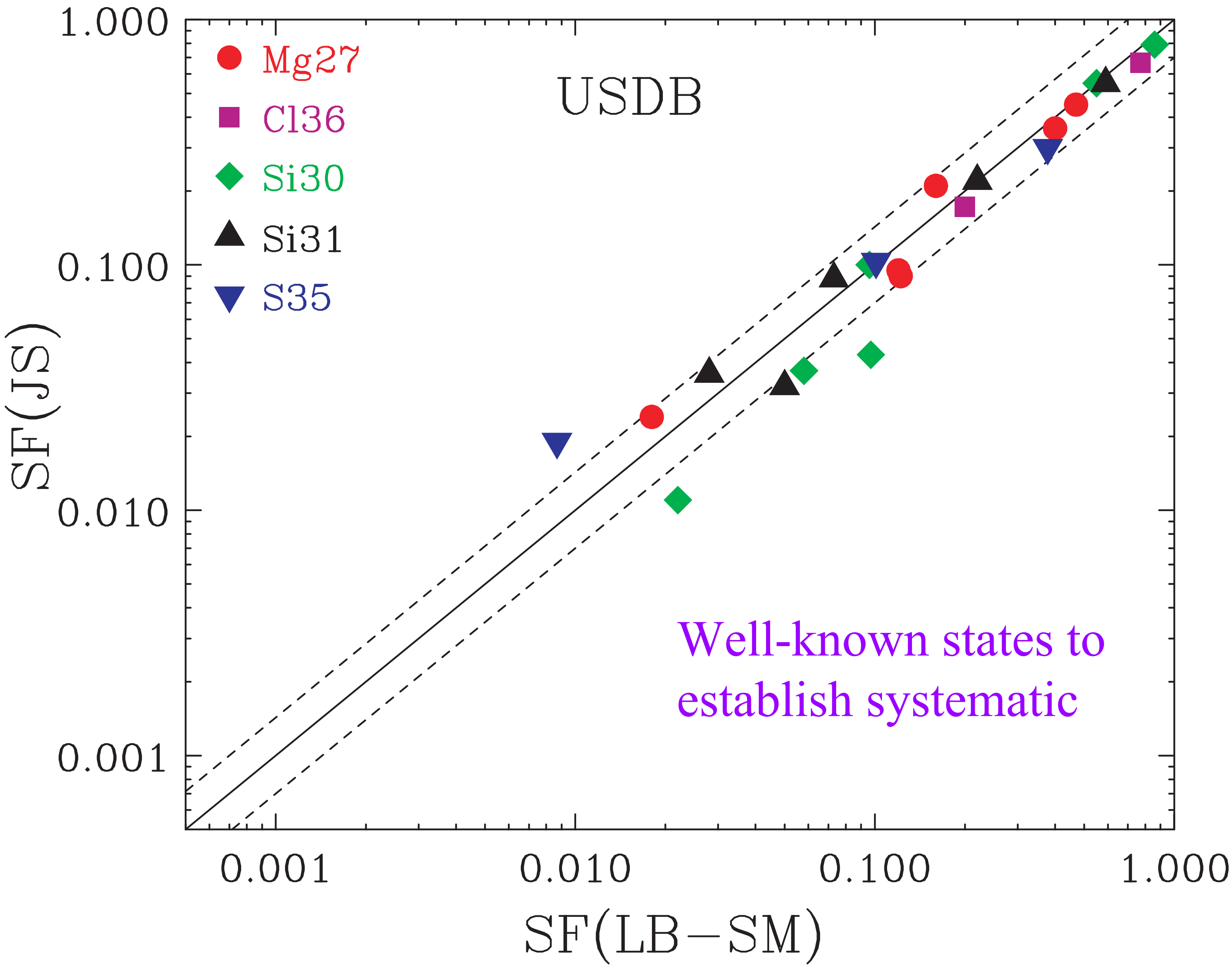
Shi Chun Su, 2006 SURE student



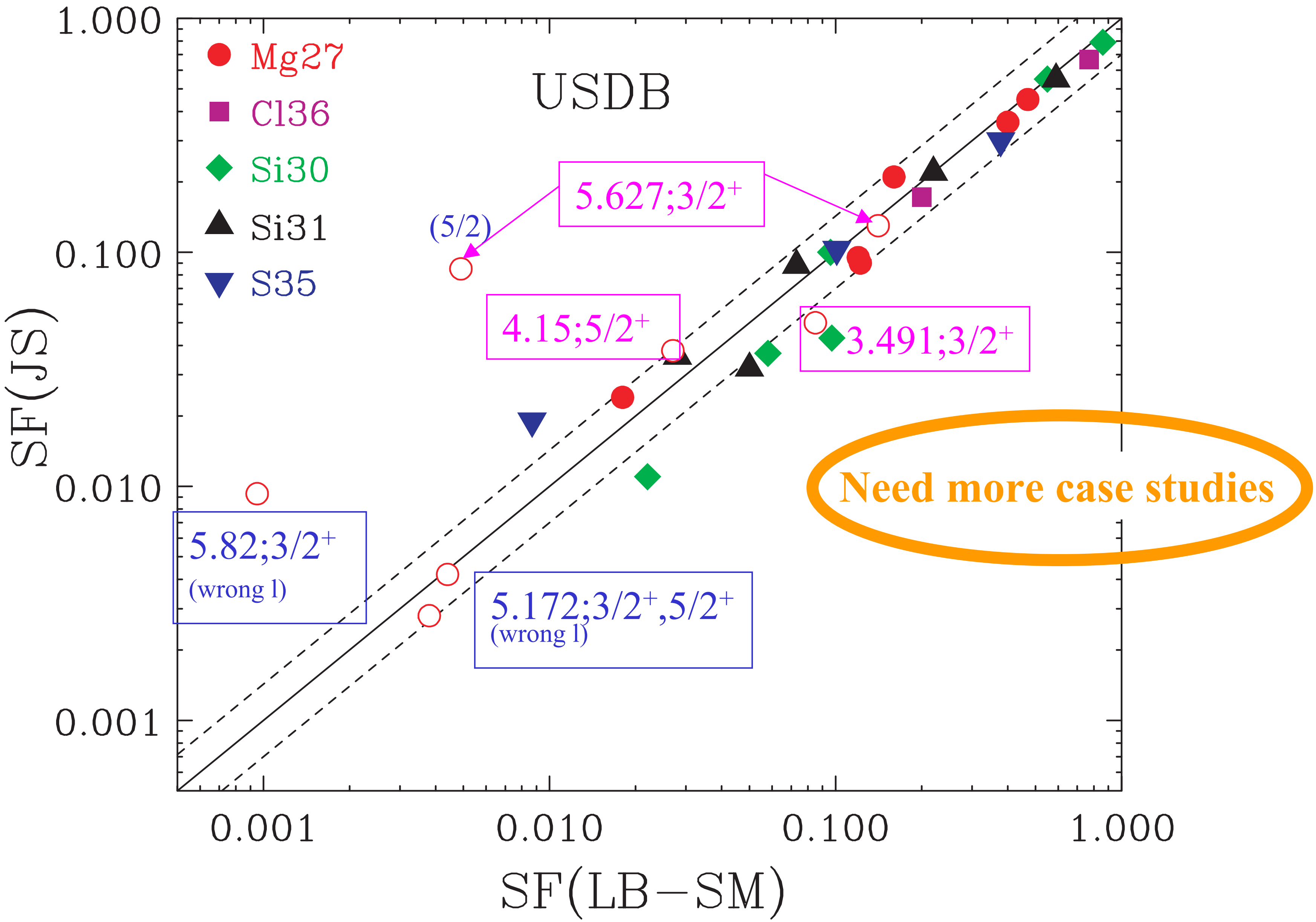
^{31}Si (mirror nuclei: ^{31}Cl) T=3/2 Sn= 6.587 MeV



Comparisons to LB-SM (oxbash, B.A. Brown) calculations



Spin assignment from Systematics with SM



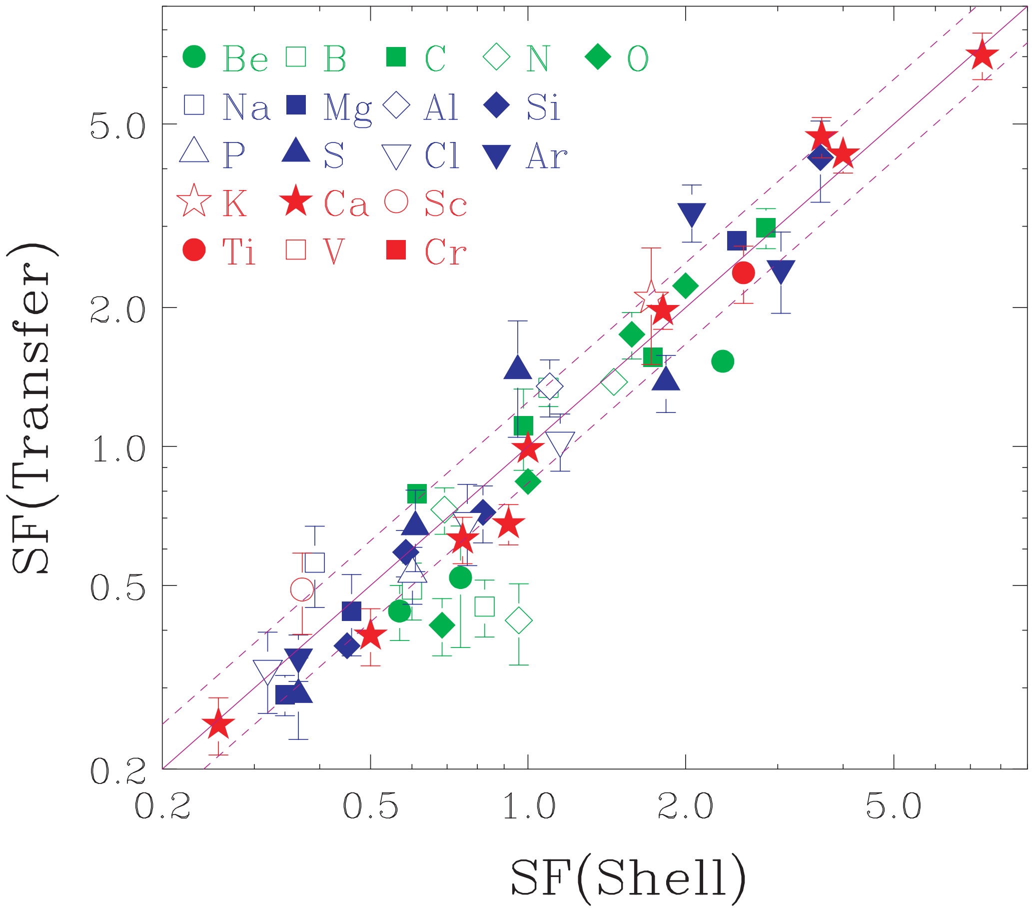
Summary

1. ***Last SF review was done by Endt in 1977. A new review of SF values is overdue with more data, better reaction models and better SM calculations; → gives directions for rare-isotope research.***

Summer Undergraduate Research Experience, Chinese University of Hong Kong, (SURE) students

Jenny Lee (2004, ground states)

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



Summary

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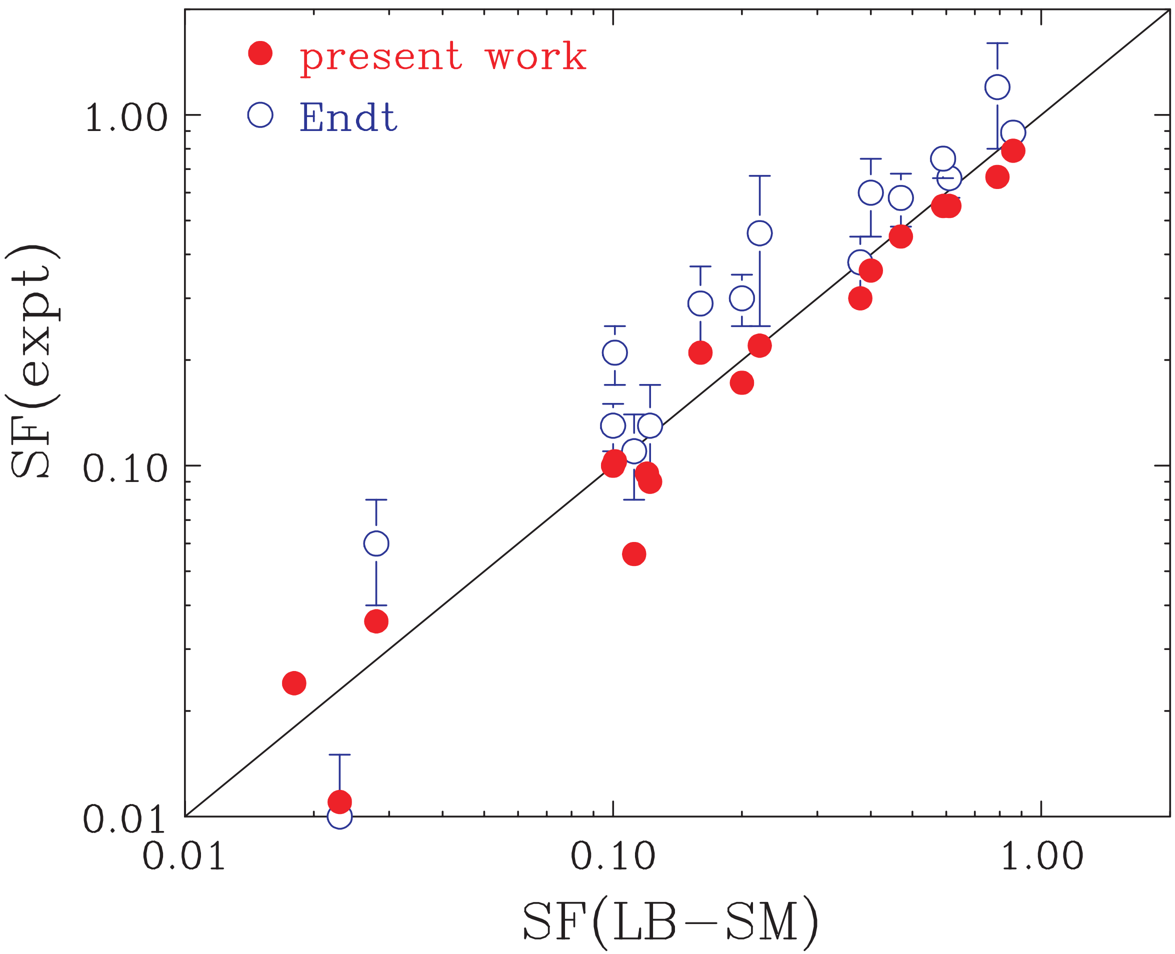
Jenny Lee (2004, ground states)

Shi Chun Su (2006, excited states)



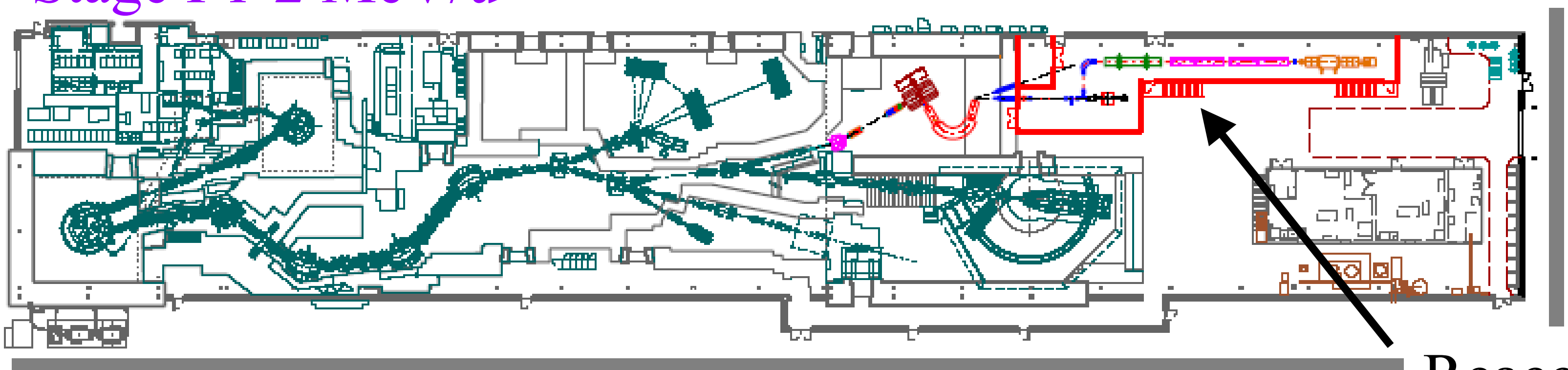
Summary/Suggestions

1. ***Last SF review was done by Endt in 1977. A new review of SF values is overdue with more data, better reaction models and better SM calculations; → gives directions for rare-isotope research.***
2. ***Include projectile fragmentation cross-sections in NuDat as in spallation cross-sections.***
3. ***Publications in Nuclear Data Sheets?***
4. ***Direct inclusion of large sets of data from PRC, NP etc.***
5. ***Search, search , search …incorporate google search engine in the data base?***

NSCL Reacceleration Stage Options

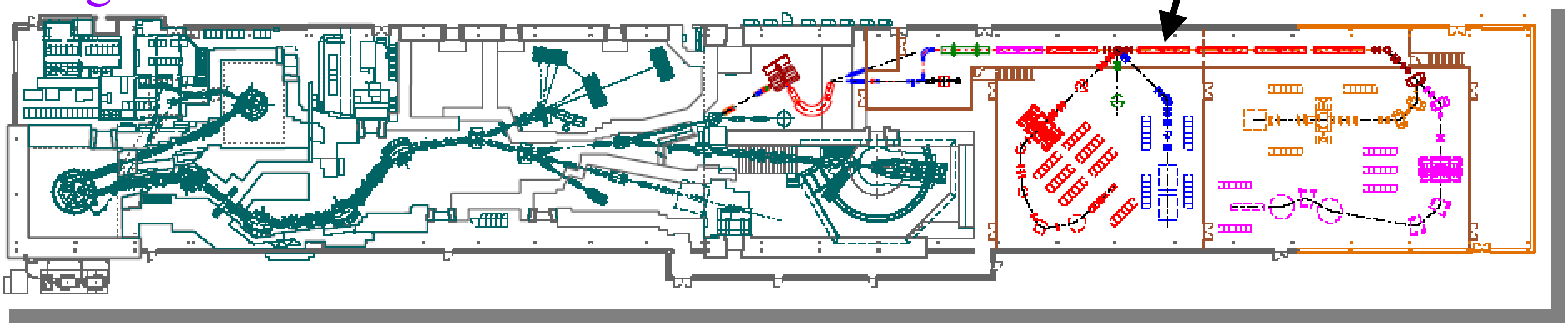
A1900/ Cyclotron Stopper/ Charge Breeder/ RFQ/ LINAC

Stage I 1-2 MeV/u



Reaccelerated beam area

Stage II 12 MeV/u



In near future, transfer reactions will become an important and unique tool to understand structure and reaction mechanism.