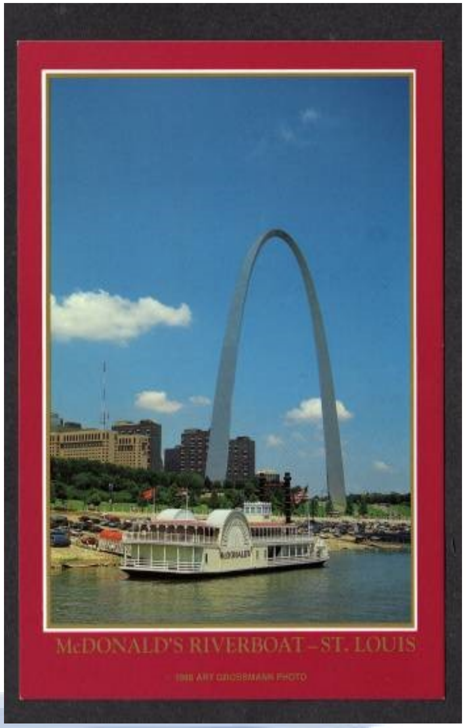
Studying proton and neutron correlations in the framework of the Dispersive Optical Model.

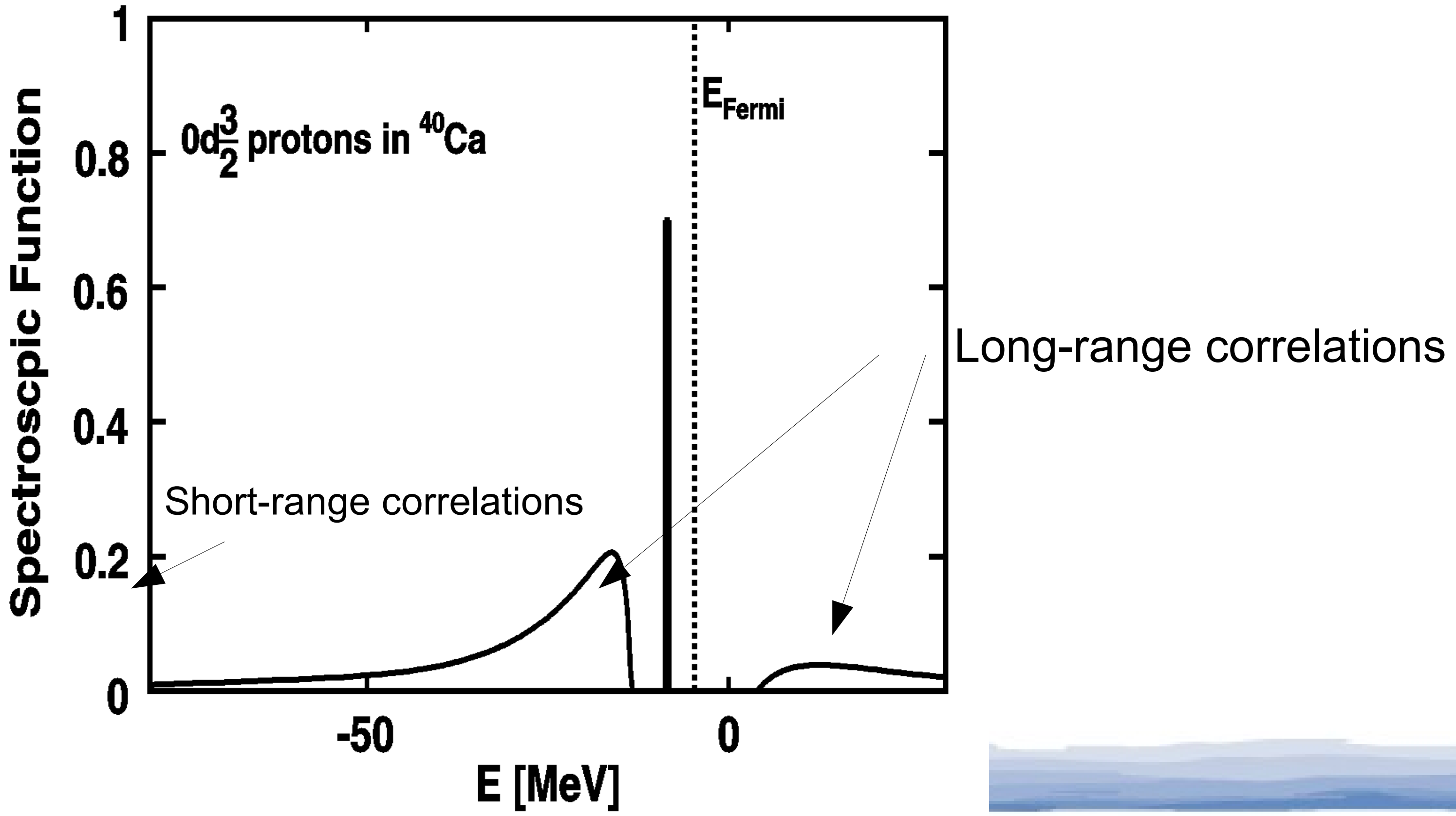
Robert Charity
Washington University in St. Louis

Trento, Italy, April 2010



Distribution of single particle strength

a) Only ~65% in the independent-particle-model energy
b) Strength distributed both above and before the Fermi energy due to long-range correlations. Couplings to collective modes.
c) Short-range correlations contributes to strength even further from the Fermi energy



Optical Model

a) real and imaginary potentials
b) calculates elastic scattering and reactions and total cross sections
c) Distorted waves for DWBA
d) Global fits available as functions of energy and Z,A
e) When optical-model potentials are extrapolated to negative energies, they do not reproduce single-particle energy levels.
f) We do not learn about nuclear structure from the standard OM

Dispersive optical Model

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Calculation of the Shell-Model Potential from the Optical-Model Potential

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(Received 6 August 1986)

a) Enforce causality. Dispersion relationships between real and imaginary part.
b) $E>E_F$ – nucleon OM potential = self energy Σ for A+1 system (particles).
c) $E<E_F$ – OM potential = self energy in the A-1 system (holes).
d) From self energy we can calculate single-particle energies, spectroscopic factors, Occupation probabilities, level widths, ...
e) Can use Mahaux approximations or solve the many-body Dyson equation.

The aim of this work is to constrain the self energy from reaction data.

optical model potential $U = V - iW$

$$V = \Re\Sigma(r, r', E) = \Re\Sigma(r, r', E_F) + \Delta V(r, E)$$

Where the dispersion correction is

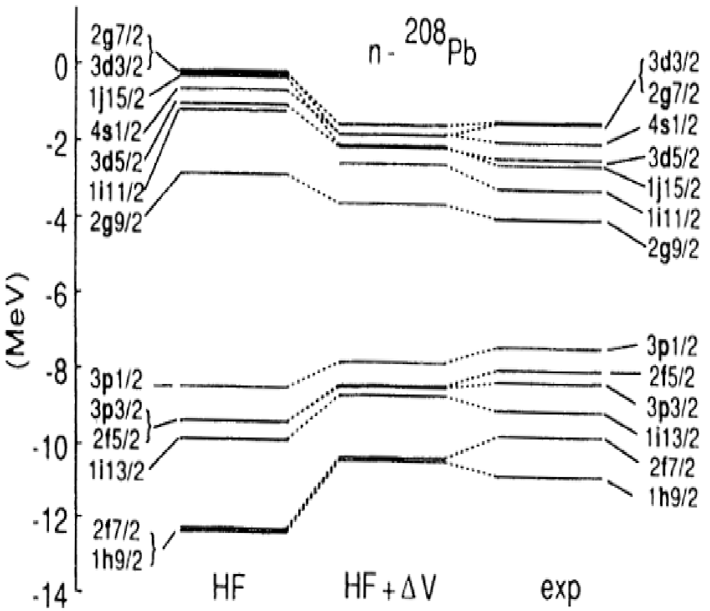
$$\Delta V(r, E) = \frac{1}{\pi} P \int_{-\infty}^{\infty} W \left(\frac{1}{\omega - E} - \frac{1}{\omega - E_F} \right) d\omega$$

The nonlocal energy-independent term $\Re\Sigma(r, r', E_F)$

is often approximated by a local energy-dependent term $V_{HF}(r, E)$

e.g., Perey and Buck

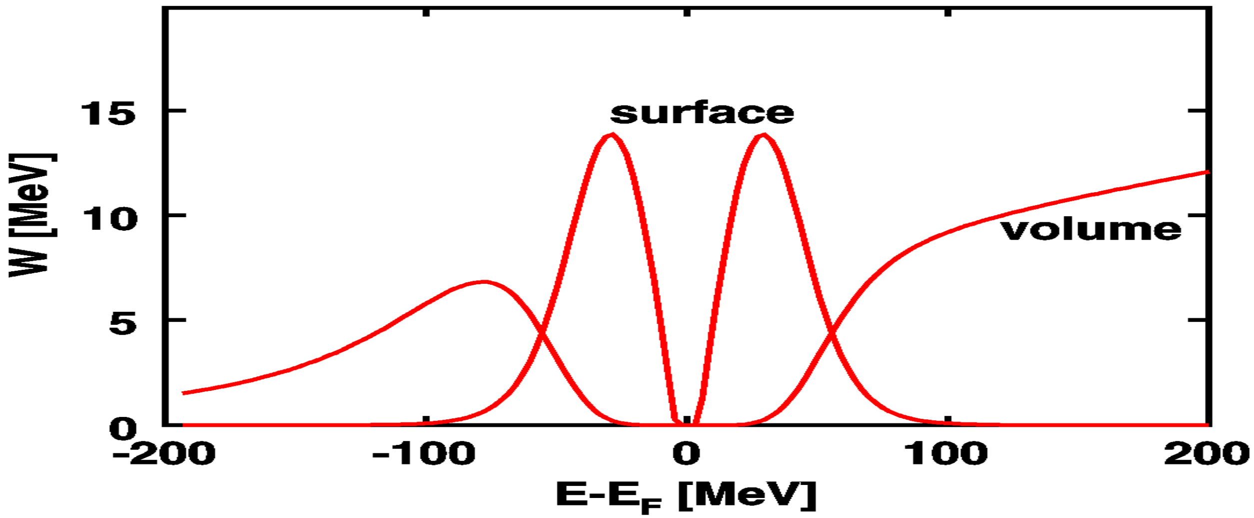
$$V(r, E) = V_{HF}(r, E) + \Delta V(r, E) + V_{coul}(r) + V_{SO}(r, E)$$



Mahaux+Sartor

Imaginary potential

$$W(r,E) = W_{surface}(r,E) + W_{volume}(r,E)$$



$W_{surface}$ – surface peaked imaginary pot. (Long-range correlations)
coupling to low-lying collective states and giants resonances

W_{volume} – volume peaked imaginary pot.(Short-range correlations)

This separation for E>0 is well known from analyzing elastic scattering data.

Energy dependence of imaginary potential is guided by nuclear-matter calculations

What do we learn from global optical-model fits to elastic scattering data. E<65 MeV

CH89 Varner et al. Physics Reports 201 (1991) 57
Bechetti and Greenlees PR 182 (1969)1190

$$V_{HF}=V^{0}_{HF}\pm\frac{N-Z}{A}V^{1}_{HF}$$ + proton,-neutrons (symmetry energy)

This form is based on the Lane potential. We would also expect

$$W_{volume}=W^{0}_{volume}\pm\frac{N-Z}{A}W^{1}_{volume}$$ (tensor interaction)

However in these global fits $W^{1}_{volume}=0$

But there is a large asymmetry dependence of the surface

$$W_{surface}=W^{0}_{surface}\pm\frac{N-Z}{A}W^{1}_{surface}$$ (justification?)

This suggests there are important asymmetry dependencies of the spectroscopic factors and occupation probabilities due to long-range correlations.
However, certainly for neutrons, there are little data to justify this dependence

We tried an $W_{surface} = W^0_{surface} \pm \frac{N-Z}{A} W^1_{surface}$ dependence.

But found this lead to problems for the neutrons. PRC 76 (2007) 044314.

Instead let the magnitude of the surface component be a free parameter for each system and separate value for protons and neutrons.

For the volume, we assume $W_{volume} = W^0_{volume} \pm \frac{N-Z}{A} W^1_{volume}$

Apart from these, we have 20 other parameters to describing the radial and energy dependencies of the real and imaginary potentials.

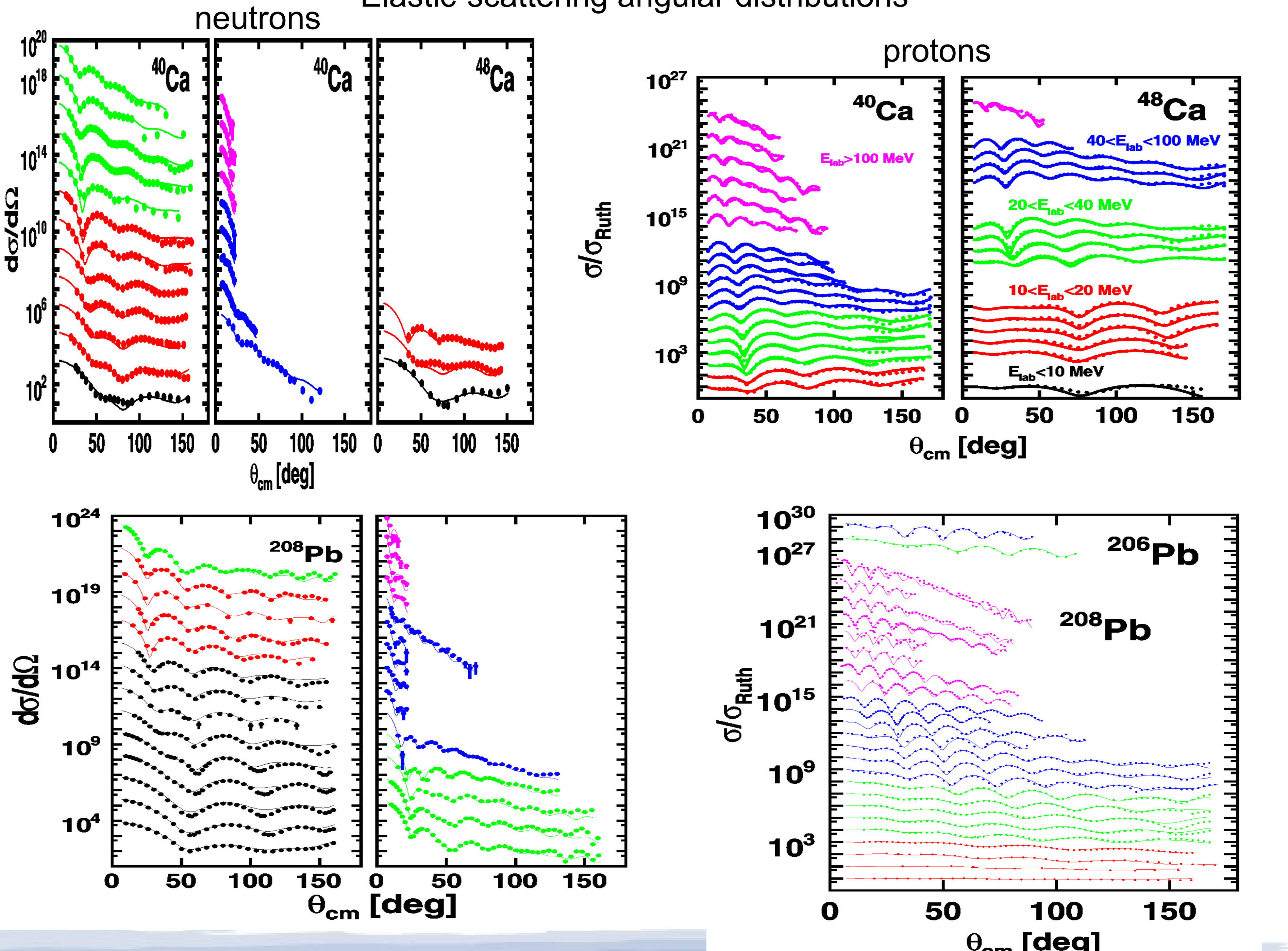
These are fitted with elastic scattering data, reaction and total cross sections data for positive energies < 200 MeV for 23 (p) and 12 (n) closed and doubled-closed shell nuclei Z=20,28,50,82 N=20,28,50,126

In addition for negative energies, we fit to single-particle energy levels and for a few systems we have r.m.s. radii and spectroscopic factors for (e,e'p) reactions.

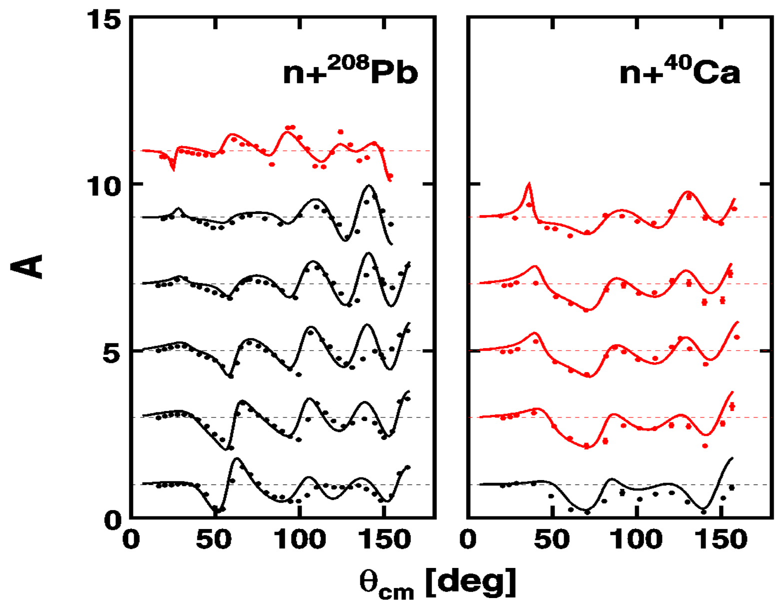
For ^{48}Ca, we have measured neutron elastic scattering (TUNL) and neutron total cross section data (LANSCE) using 3 g of ^{48}Ca borrowed from MSU.

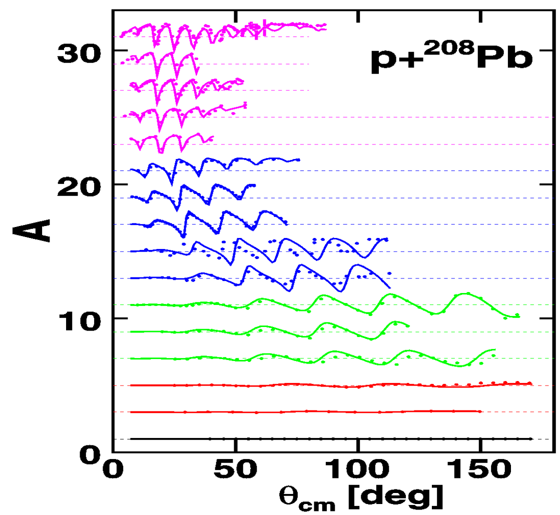
Otherwise from a large number of published and unpublished data sets.

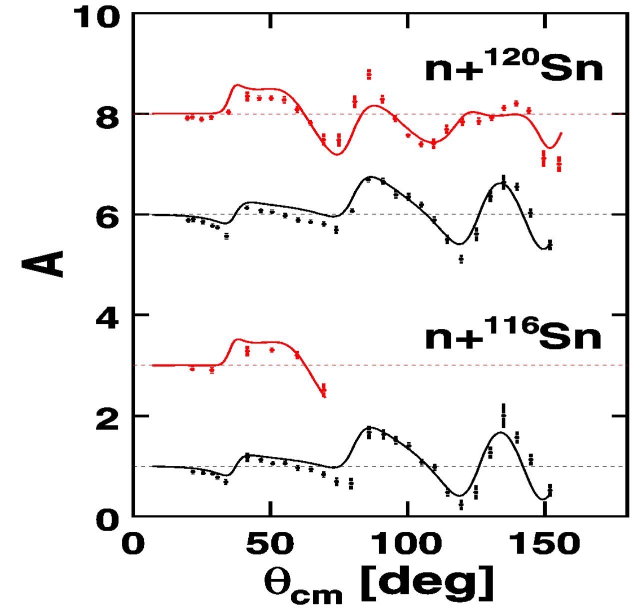
Elastic-scattering angular distributions

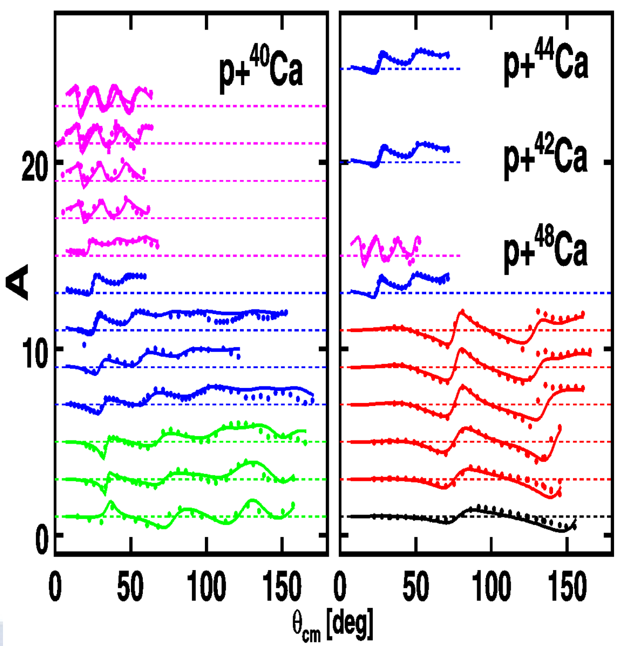


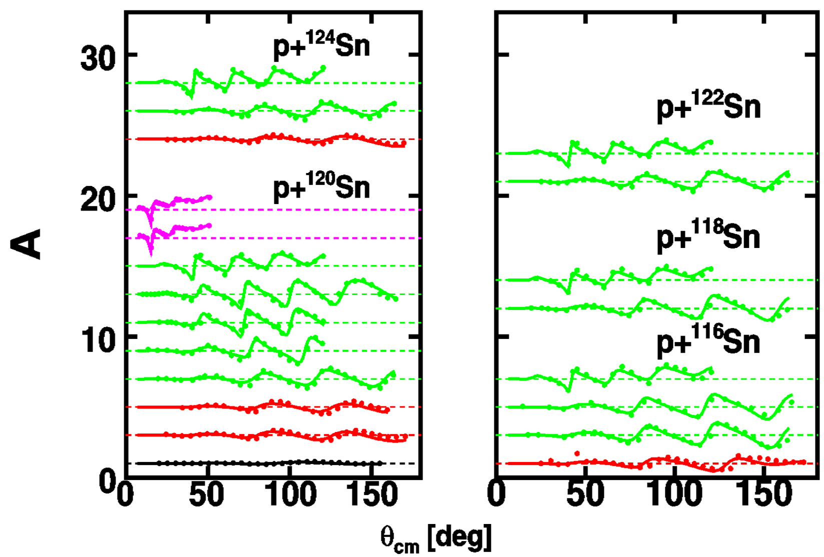
ANALYZING POWERS



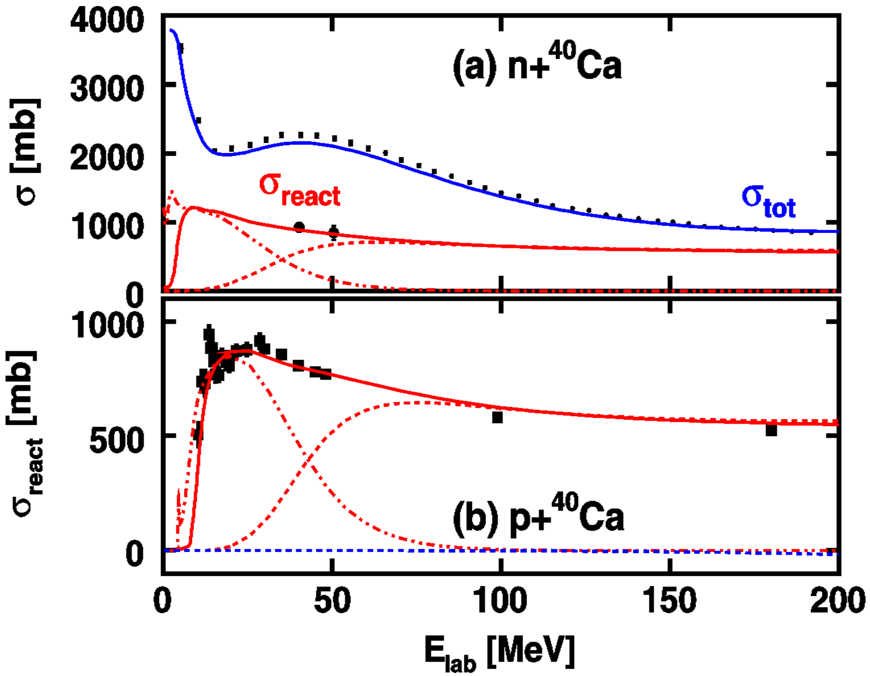


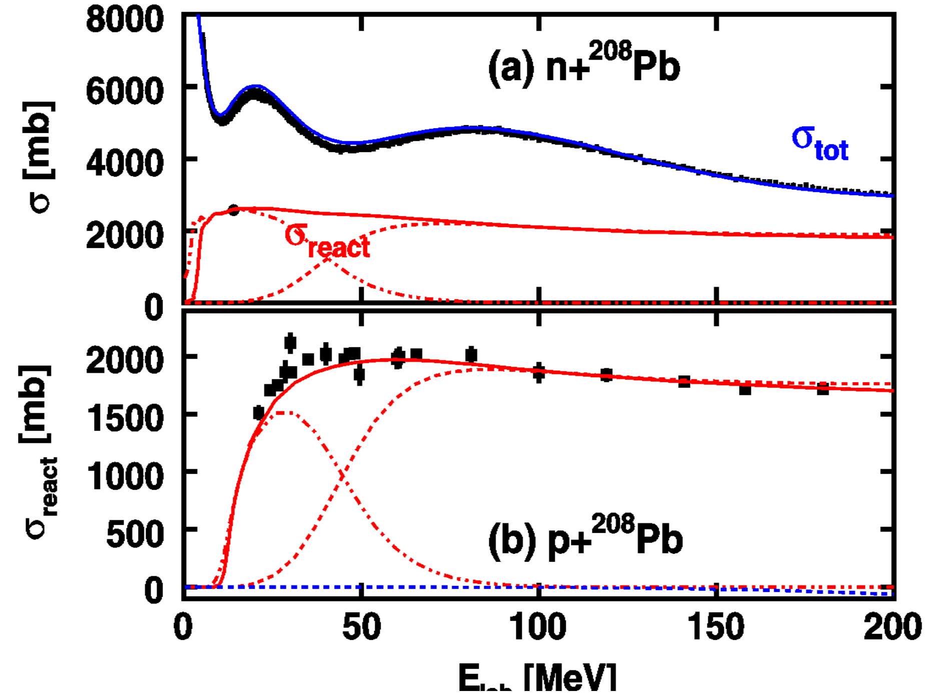




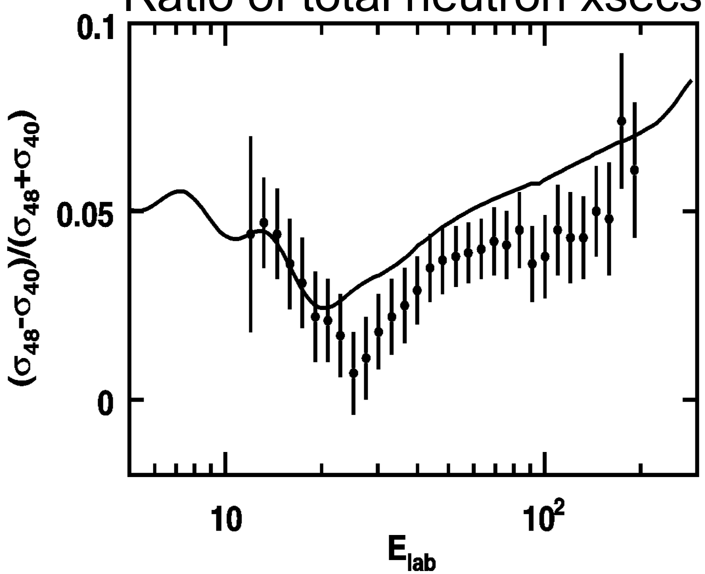


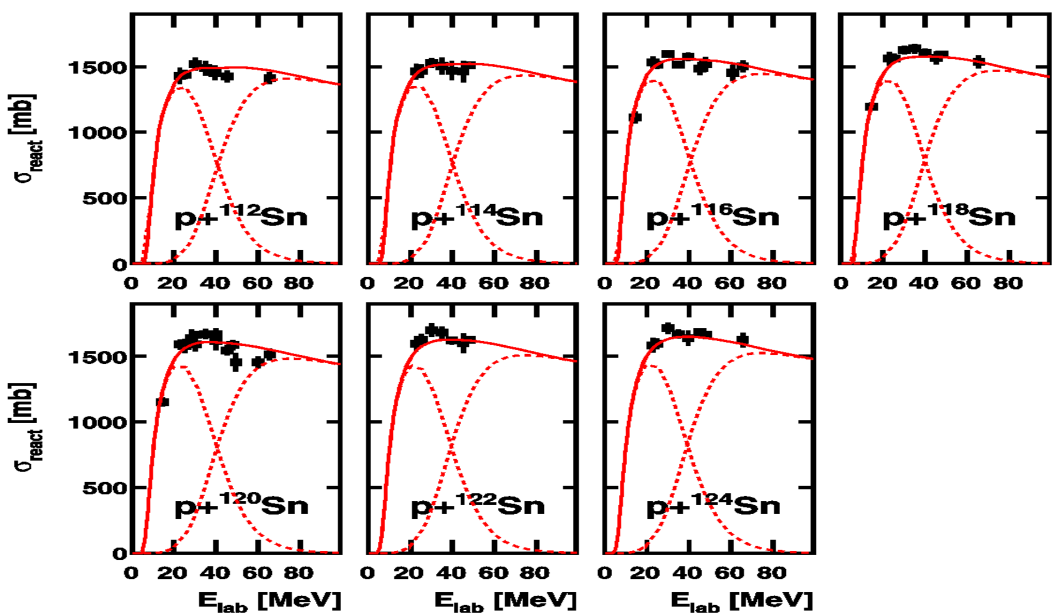
Total and reaction cross sections



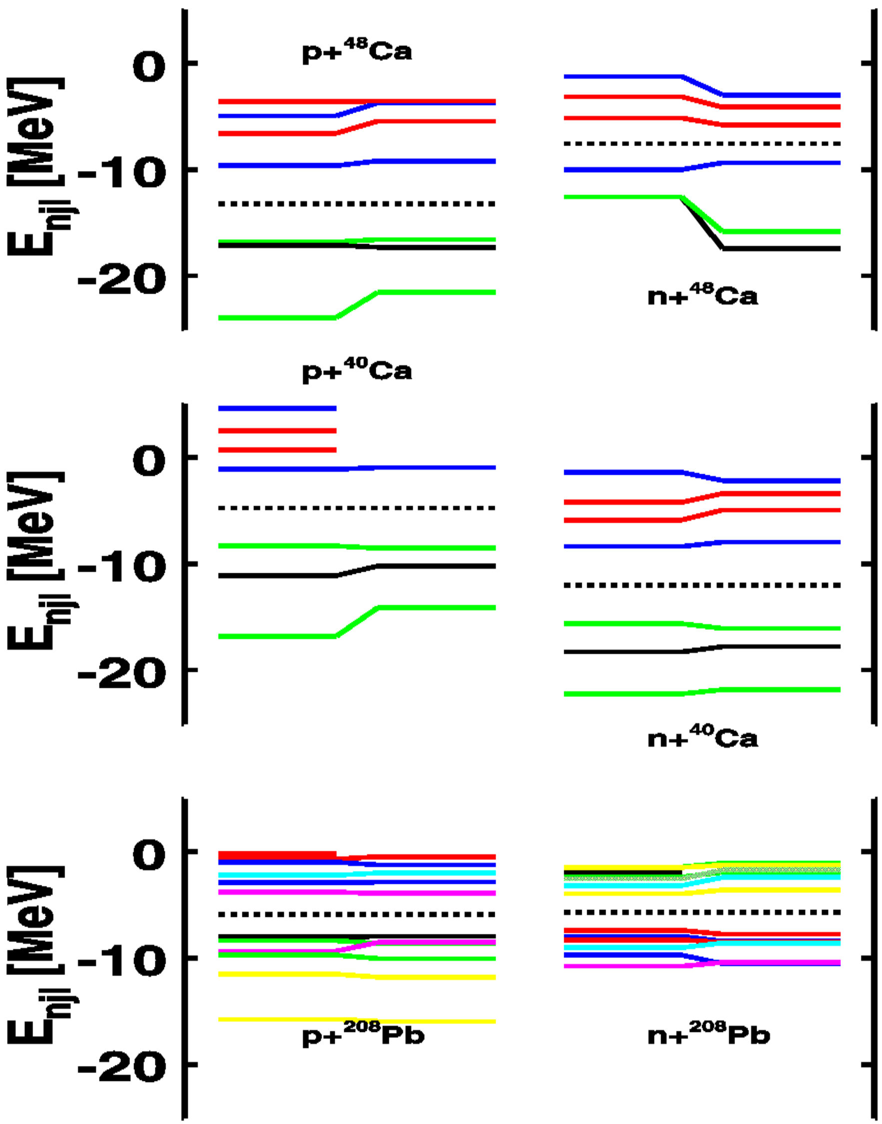


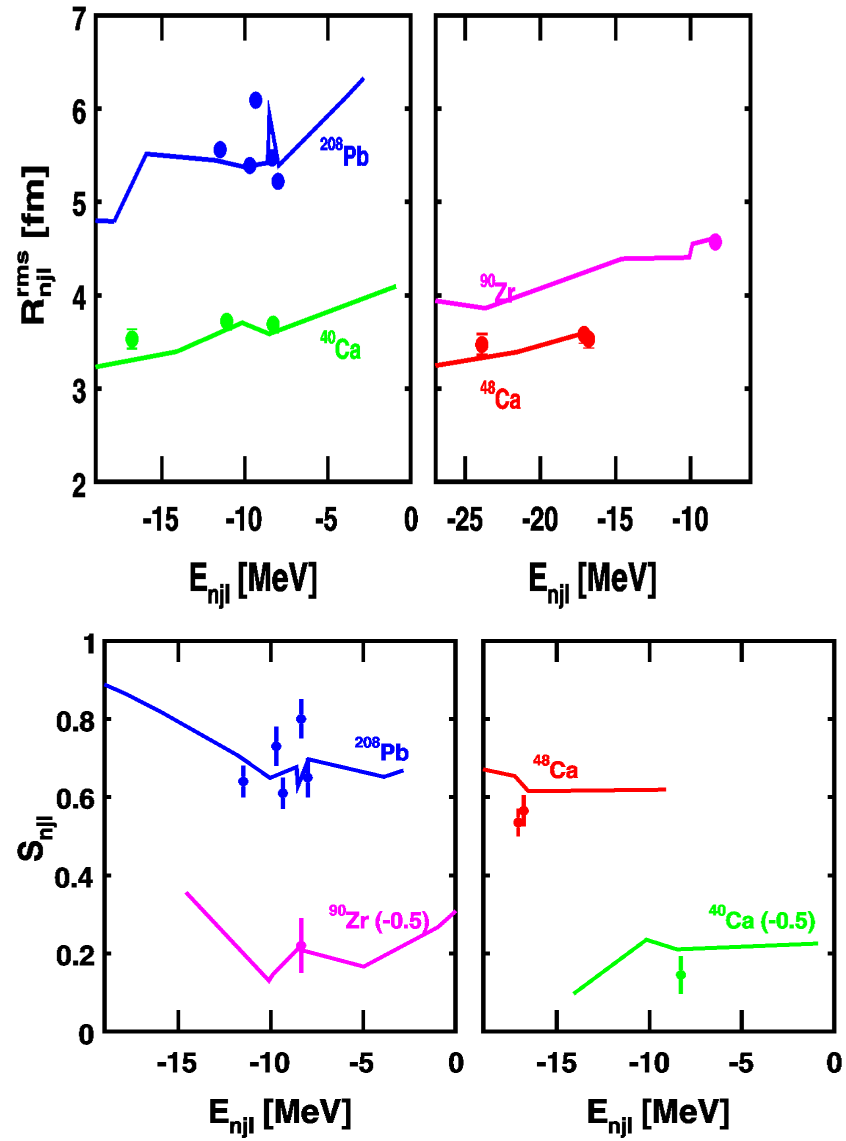
Ratio of total neutron xsecs



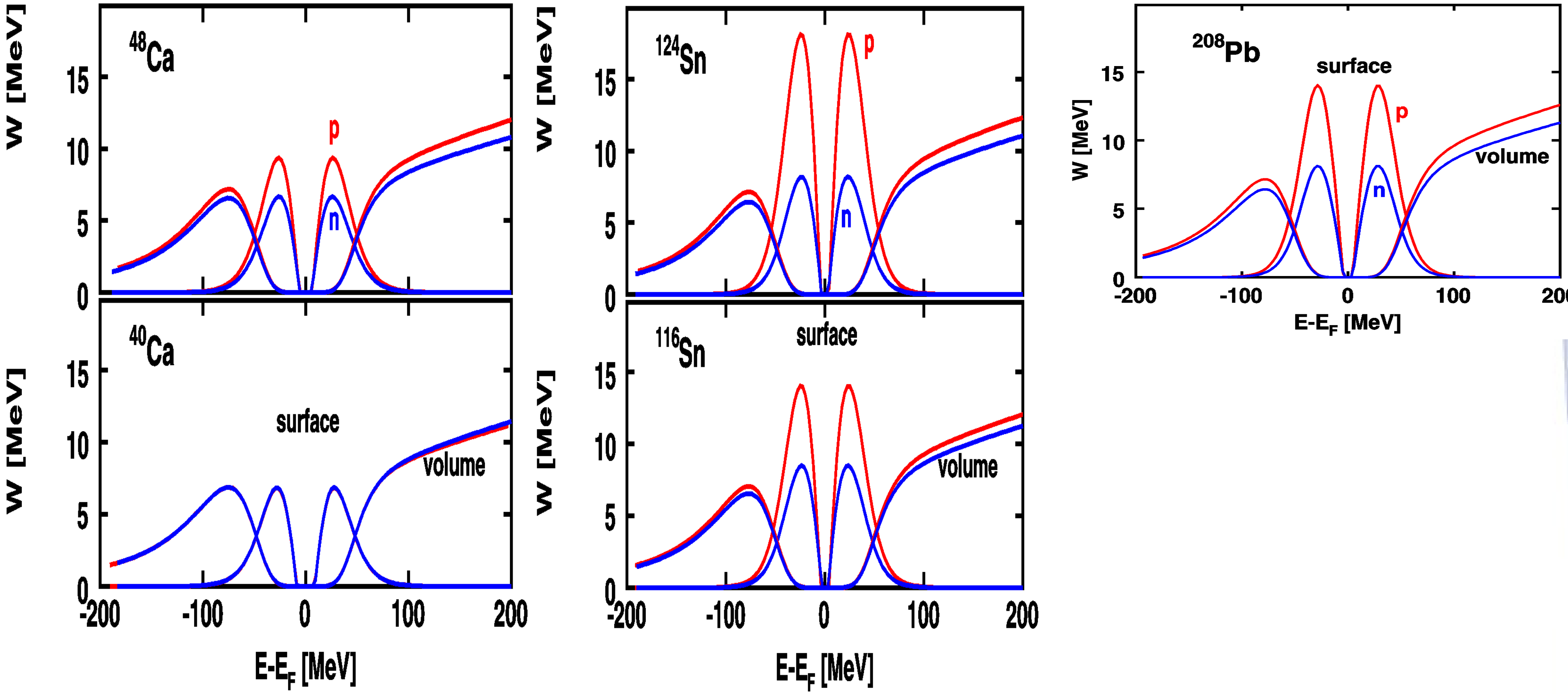


Negative energy data





From (e,e'p) data

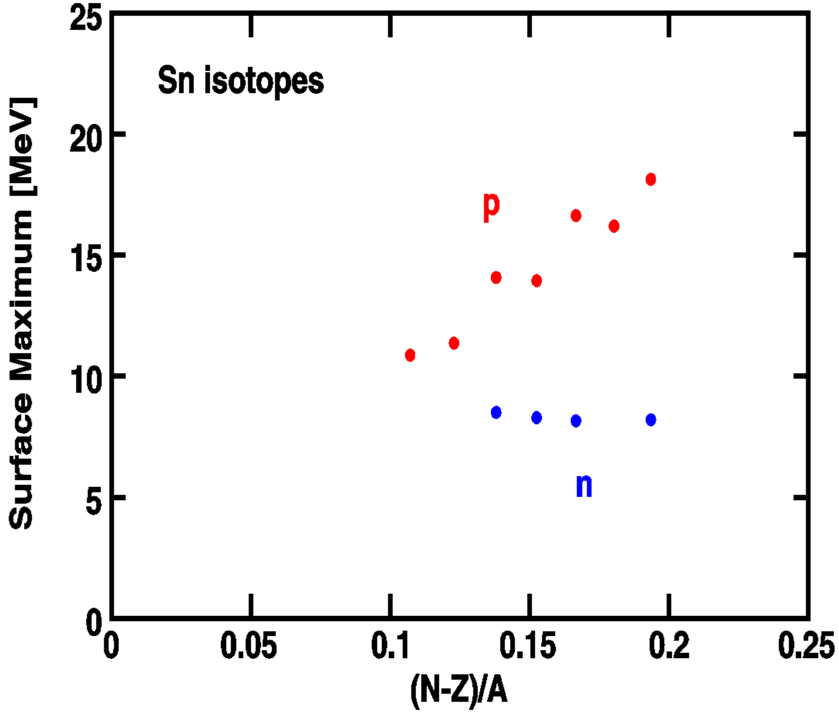


Volume – small asymmetry dependence $W_{volume} = W^0_{volume} \pm \frac{N-Z}{A} W^1_{volume}$

Neutron surface – no strong dependencies on *A* or *(N-Z)/A*

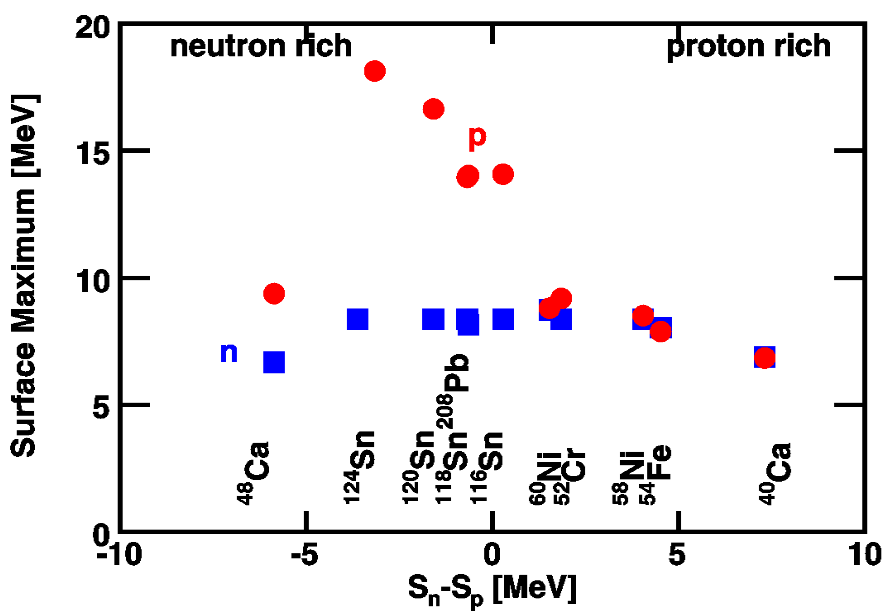
Proton surface – increases with neutron richness

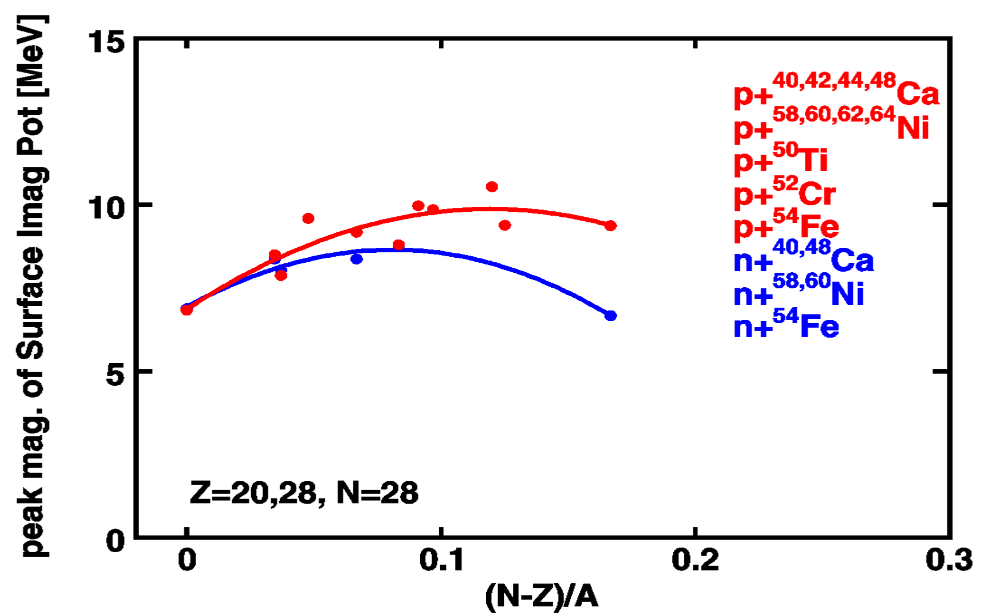
Asymmetry dependence of surface imaginary potential



Does not follow $W_{sur} = W_0 \pm \frac{N-Z}{A} W_1$

More complicated function





Spectroscopic factors

$$S_{n,l,j} = \int_0^\infty dr \frac{\left|u_{n,l,j}(r)^2\right|}{1 - \frac{d\,\Delta V(r,E)}{dE} / \left(1 - \frac{dV_{HF}(r,E)}{dE}\right)}$$

Mahaux and Sartor

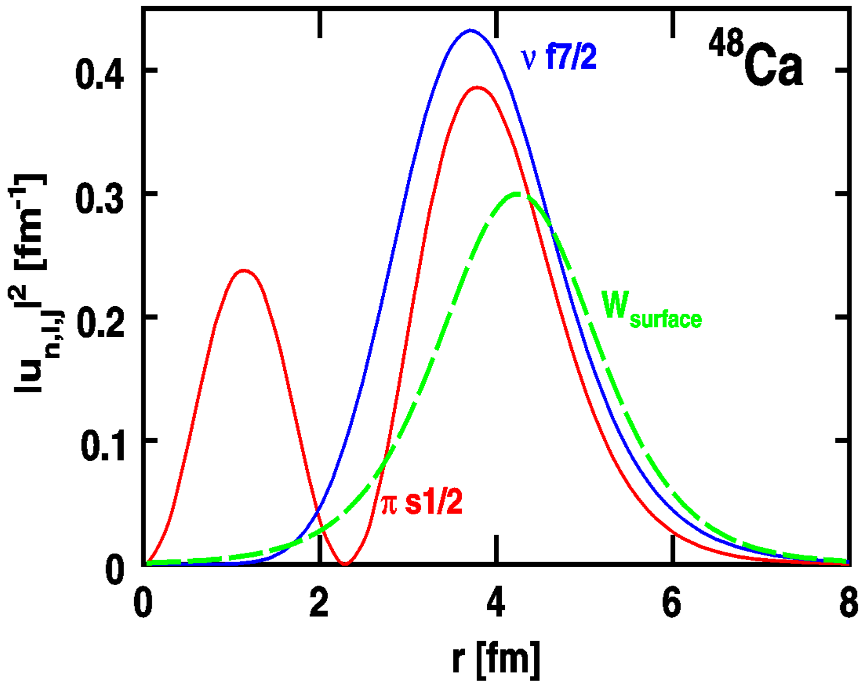
^{48}Ca

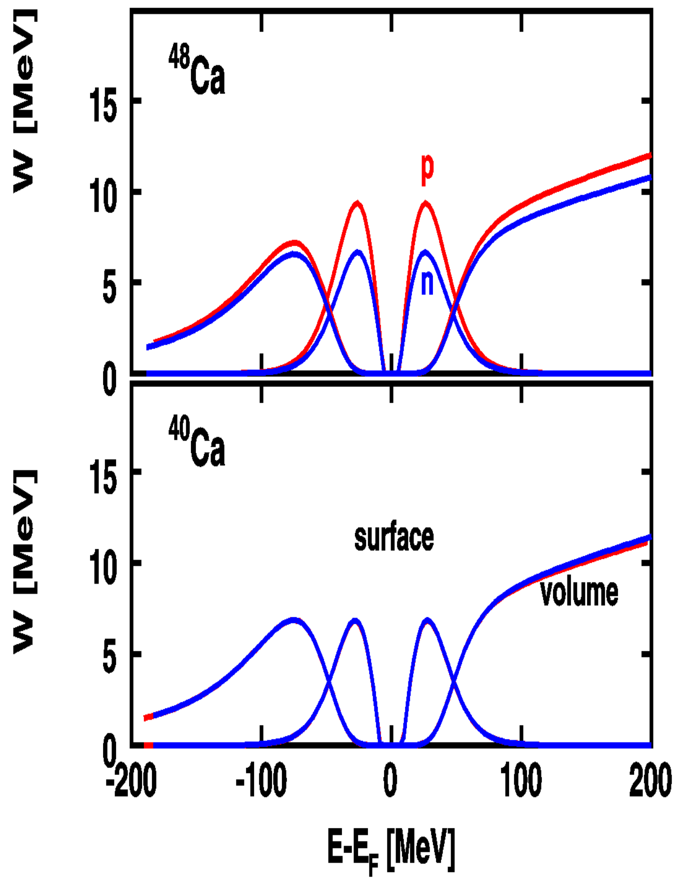
Valence hole levels

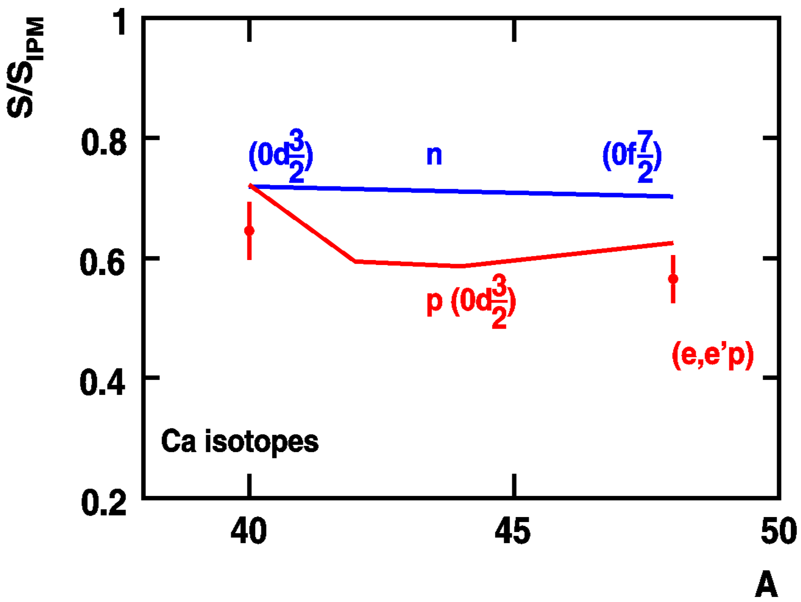
$\nu f7/2$ $S/S_{IPM} = 0.70$

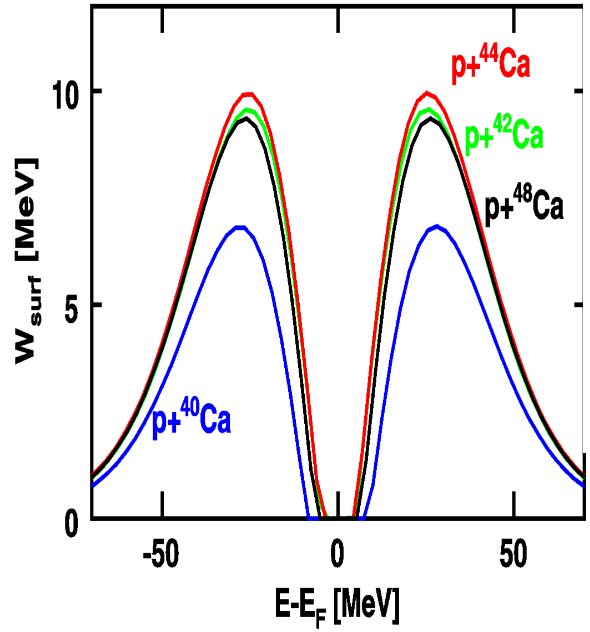
$\pi s1/2$ $S/S_{IPM} = 0.66$

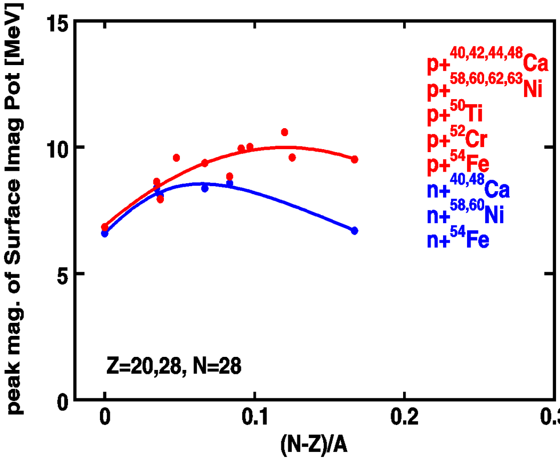
$\pi d\,3/2$ $S/S_{IPM} = 0.63$





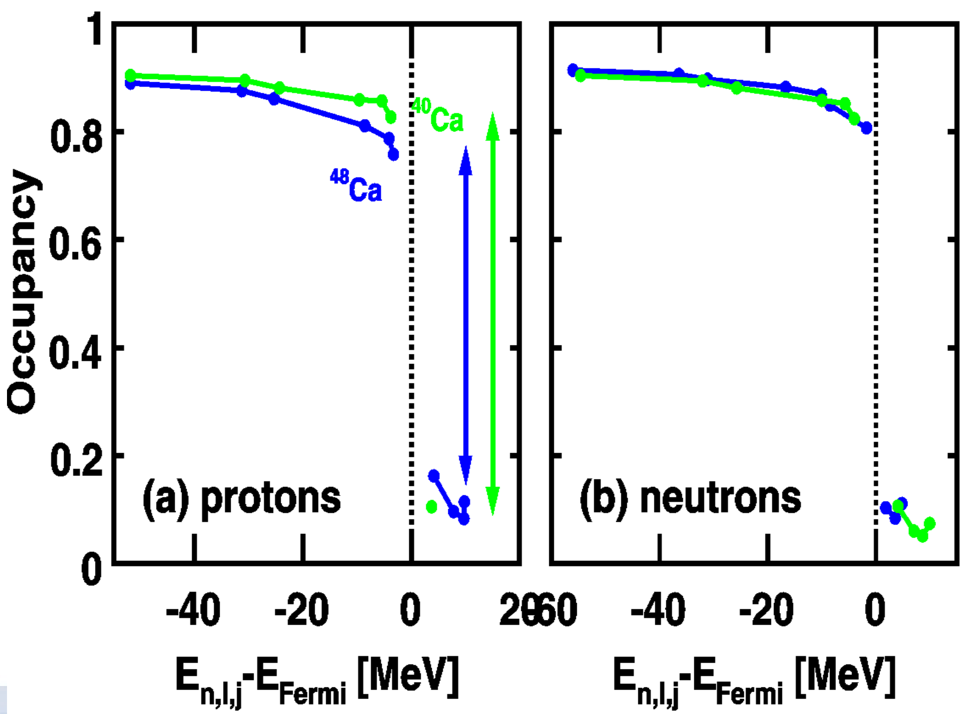


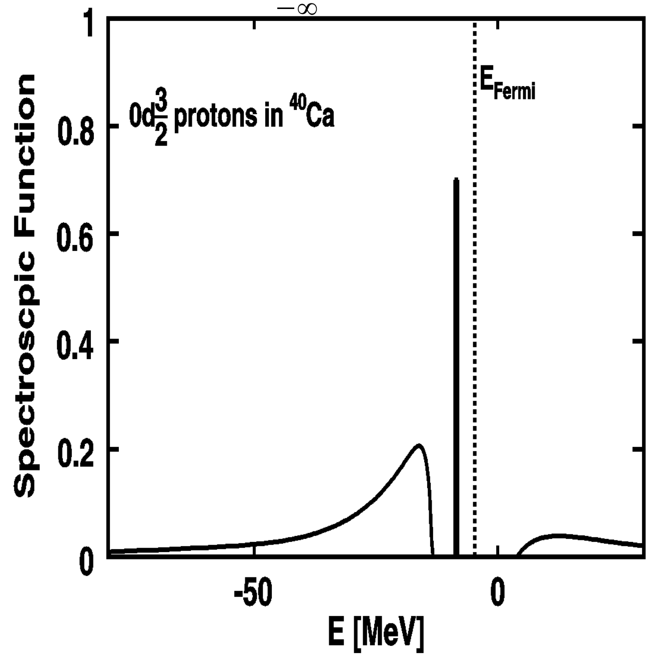


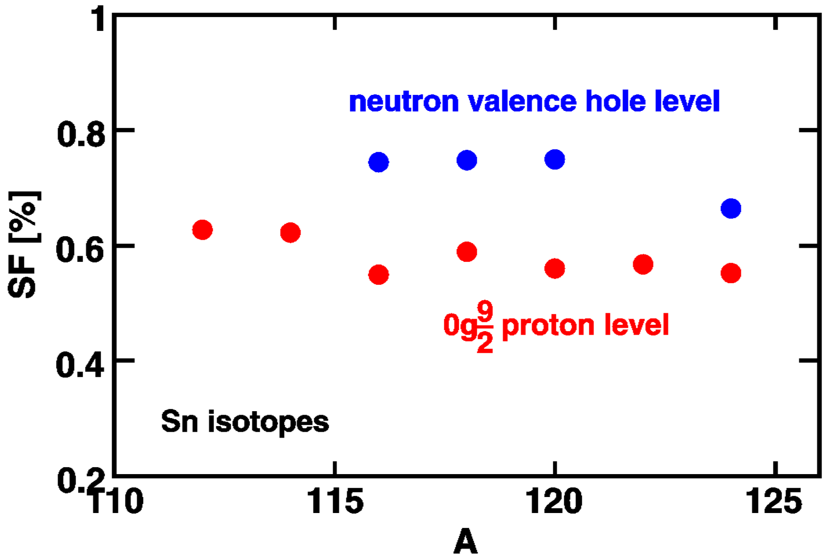


Valence-hole spectroscopic factors

$$Occupancy = \int_{-\infty}^{E_{Fermi}} SpectFunct(E)\, dE$$

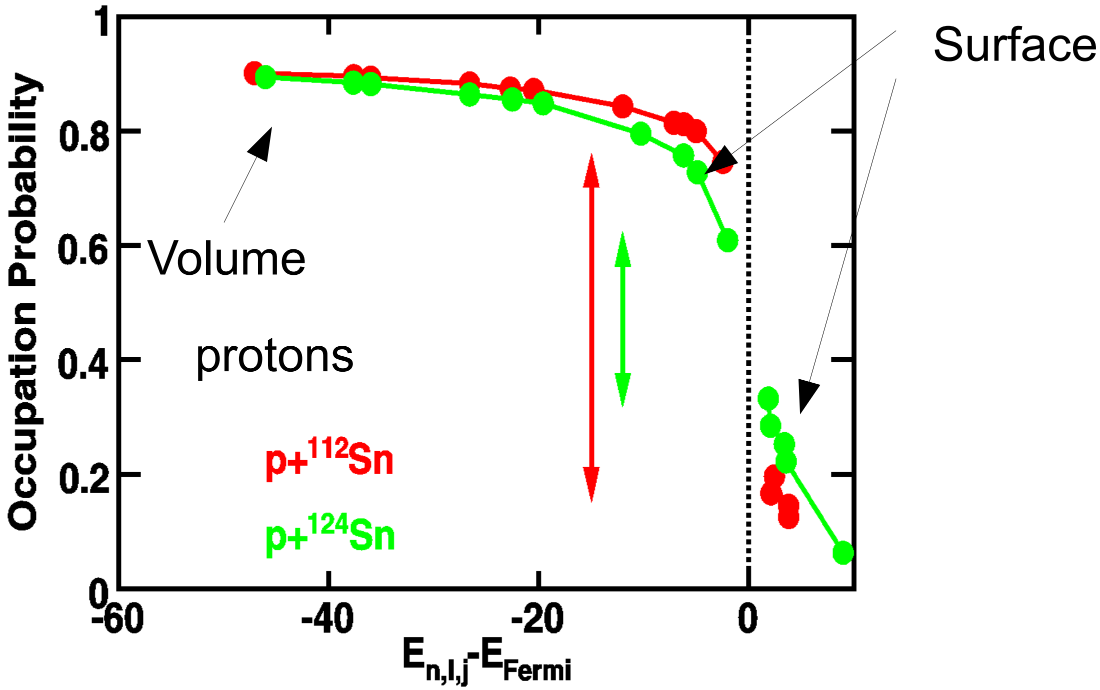


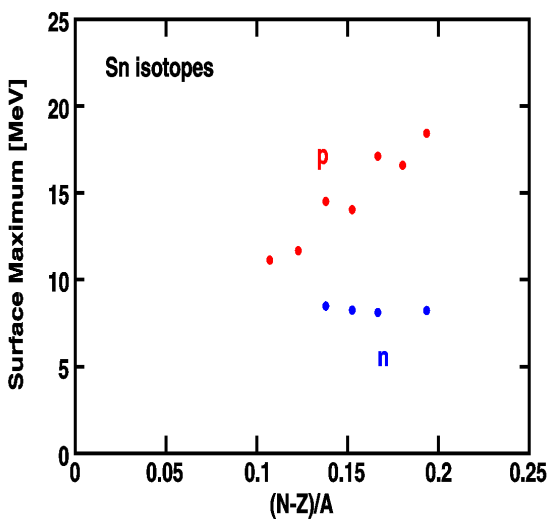




Small changes in SF/SF$_{IPM}$ as a function of neutron richness.

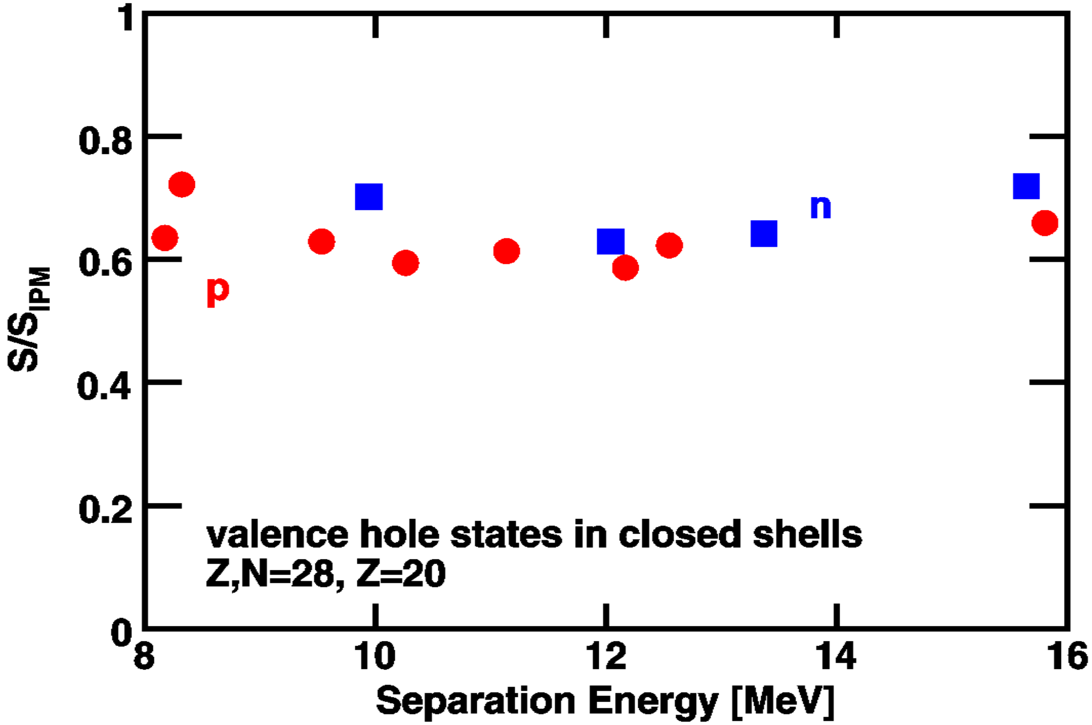
More consistent with transfer-reaction than knockout-reaction systematics.

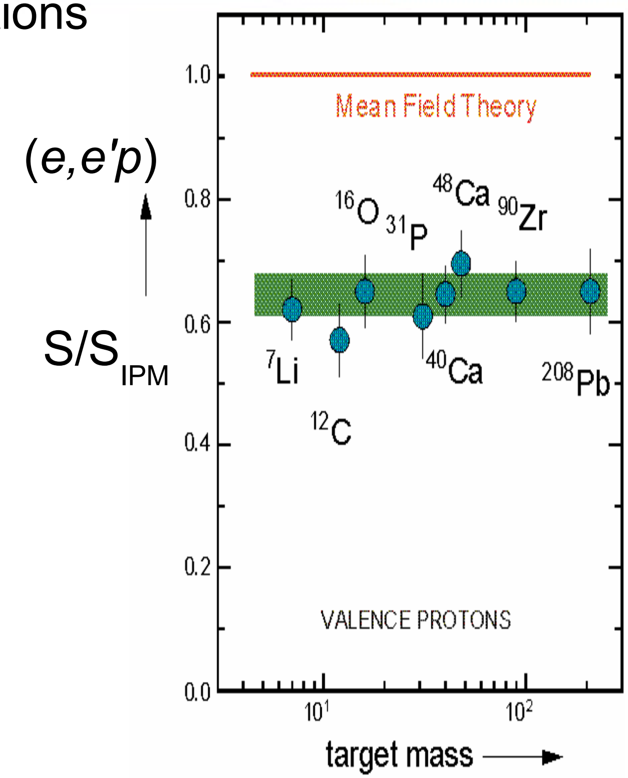


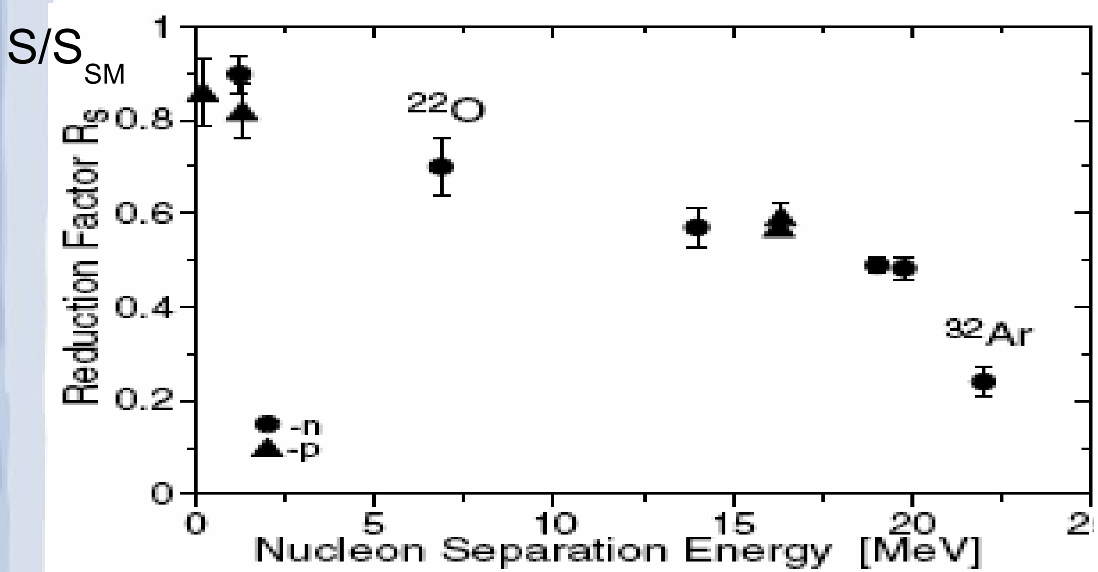


Sn isotopes

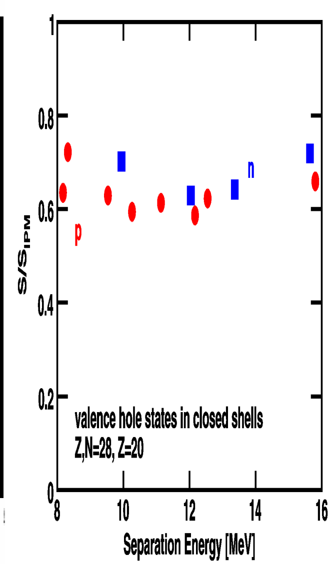
Comparison with knockout and (e,e'p) reactions







Gade et al PRL 93 (2004)042501



We do not see a strong dependence as suggested by the knockout reactions. Consistent with recent transfer reactions studies. (Betty Tsang)

Application of the DOM to (*p,d*) and (*d,p*) reactions.

In the calculation of the differential cross sections in the adiabatic model of Johnson and Soper [PRC 1 (1969) 976] you need:

a) wavefunction
b) spectroscopic factor
c) proton and neutron potentials

All of these can be obtained from the DOM and thus we can include such data into our fits, or make predictions based on present fits. (Waldecker, Nunes, Dickhoff)

Similarly with (p,2p) and (e,e'p) data.

The DOM thus is a framework for which you can incorporate a large number of different types of reaction data and deduce structure information.

Summary

J. Mueller
L.G. Sobotka
W. Dickhoff
R. Shane
S. Waldecker

a) The Dispersive Optical Model is a useful framework for studies of proton and neutron correlations.

b) Reaction data can be used to constrain the nucleon self energy

c) Strong asymmetry dependencies of proton surface imaginary potential, but weaker dependence for neutrons

d) volume imaginary potential has a weak asymmetry dependence.

e) These dependencies give rise to **modest** asymmetry dependencies of the spectroscopic factors and occupation probabilities.

f) The Dispersive Optical Model is a useful framework that can incorporation elastic-scattering data, total and reaction cross section, (*d,p*), (*p,d*), (*p,2p*), (*e,e'p*) data in is analysis.

g) With data from larger ranges of asymmetries, we can hope to extrapolate the potential to the drip lines and predict the spectroscopic properties.

h) Extend proton elastic-scattering studies with radioactive beams in the future

i) Need more neutron data on separated isotopes

j) Use nonlocal potentials in DOM analyses (van Neck)