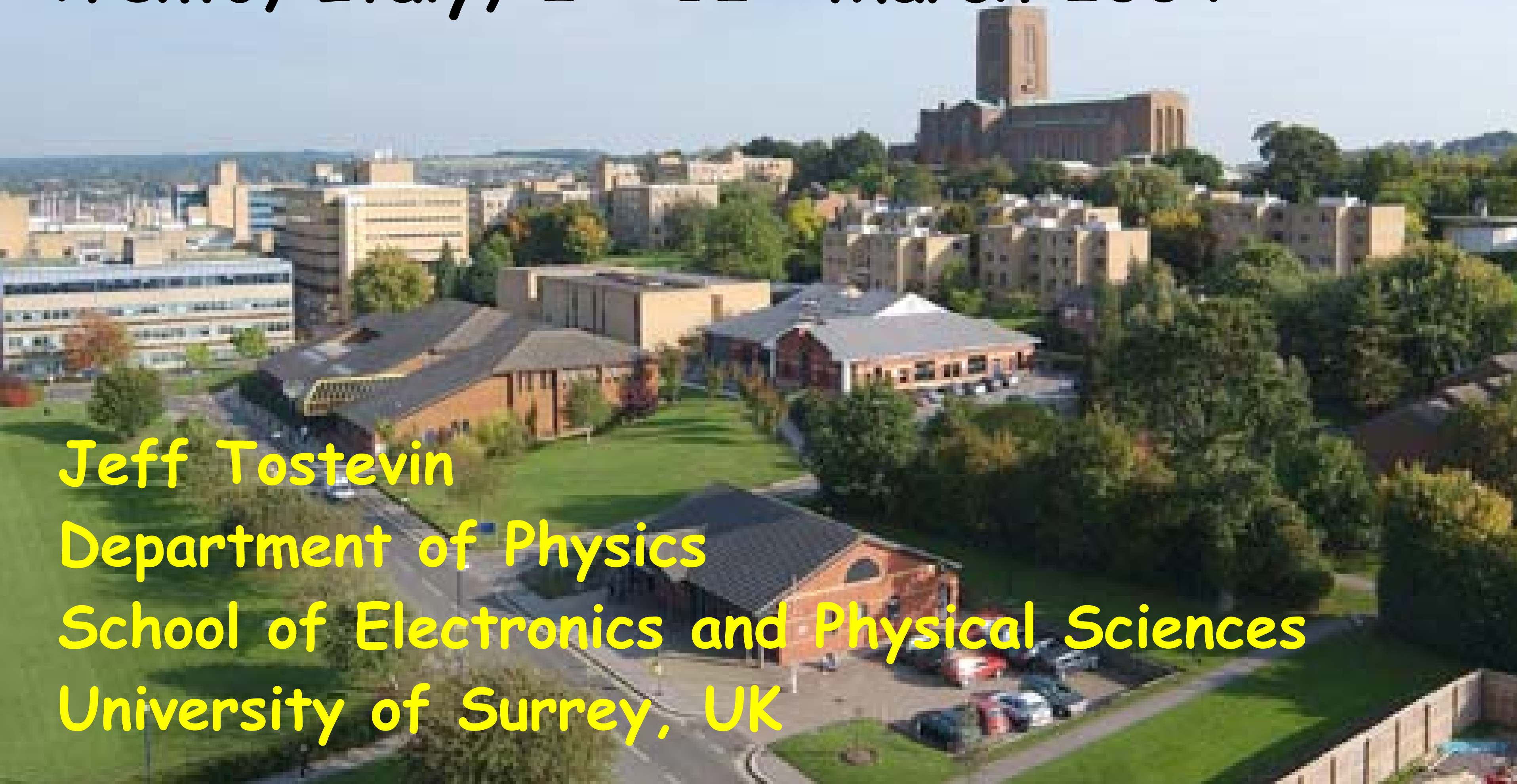
Methods and lessons from direct reaction theory

Spectroscopic Factors Workshop

Trento, Italy, 2^{nd}-12^{th} March 2004



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Direct (knockout, break-up, transfer) reactions – generics

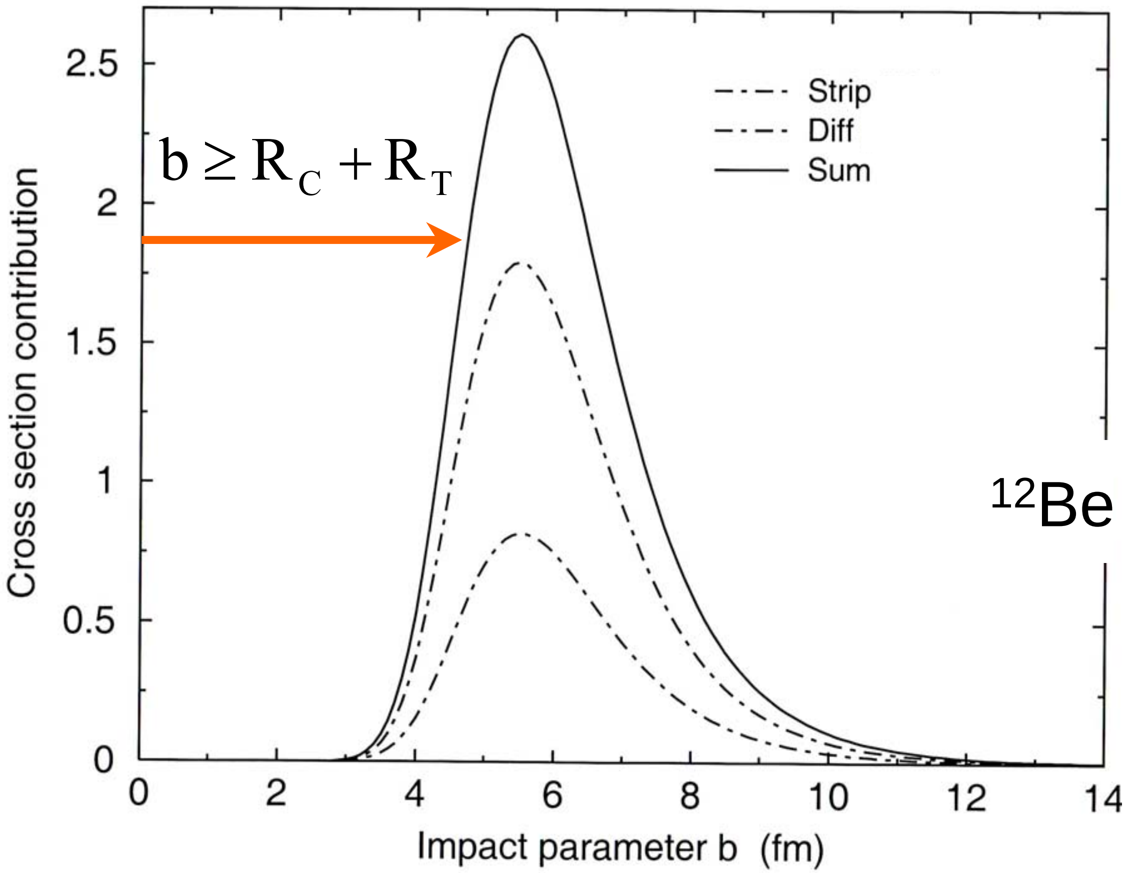
1) Reactions in which there is a minimal rearrangement, or excitation involving a very small number of active (*effective*) degrees of freedom of the projectile and/or target: single-particle (sp) or collective inelastic excitation, sp or cluster transfer – 'reactions are fast'

2) Reaction energies are such that average, effective (complex) interactions can be used between the reacting constituents – regions of high level density

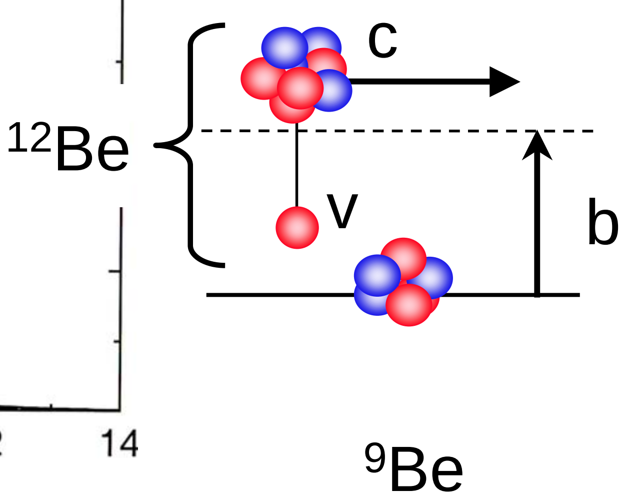
3) Because of complex effective interactions and short mean free paths, reactions are localised / dominated by interactions in the nuclear surfaces and by hence by peripheral and grazing collisions – 'so fast'

Surface localisation of knockout reactions

Intermediate energy: $^{12}Be + ^{9}Be \rightarrow ^{11}Be(gs) + X$, 80A MeV



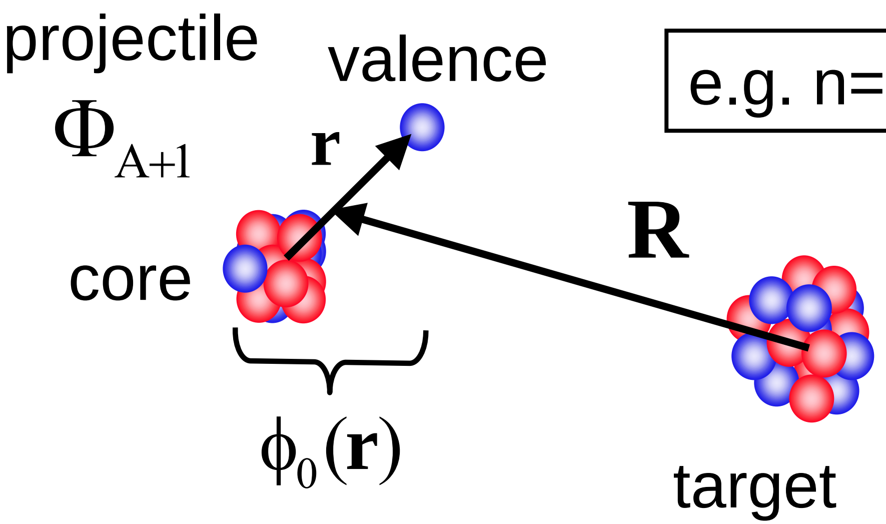
Eikonal theory: localisation provided by <u>core survival</u> requirement



Few-body reaction models for sp spectroscopy

There are no practical many-body reaction theories - we construct model ‘effective’ few-body models (n=2,3,4 …)

$$H = \underbrace{T_{\mathbf{r}} + V_{vc}}_{\text{projectile } H_p} + T_{\mathbf{R}} + \underbrace{V_{cT} + V_{vT}}_{U(\mathbf{r},\mathbf{R})}$$



e.g. n=3

Solve, as best we can, the Schrödinger equation:

$$H\Psi = E\Psi$$

(1) Dynamics – we need effective interactions

$$H = T_{\mathbf{r}} + V_{vc} + T_{\mathbf{R}} + \underbrace{V_{cT} + V_{vT}}$$

V_{vc}: binds projectile

$V_{cT} + V_{vT}$: effective (complex) interactions of c and v individually with target (nuclear + Coulomb potentials)

(a) From experiment: potentials fitted to available data for c+T or v+T scattering at the appropriate energy per nucleon

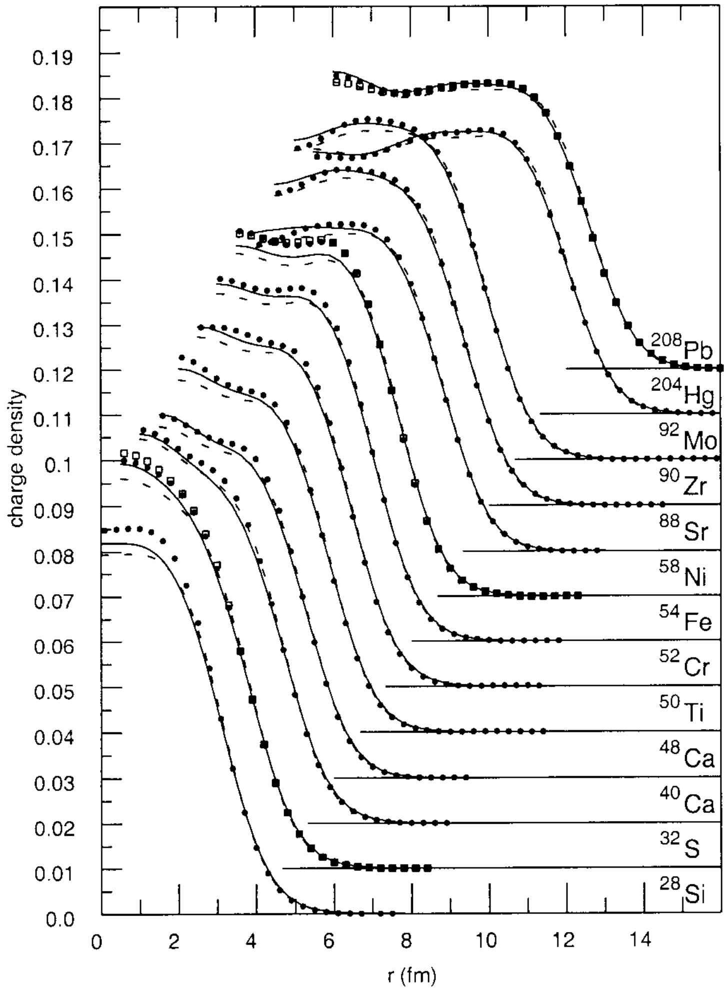
(b) From theory: multiple scattering or folding models, for example

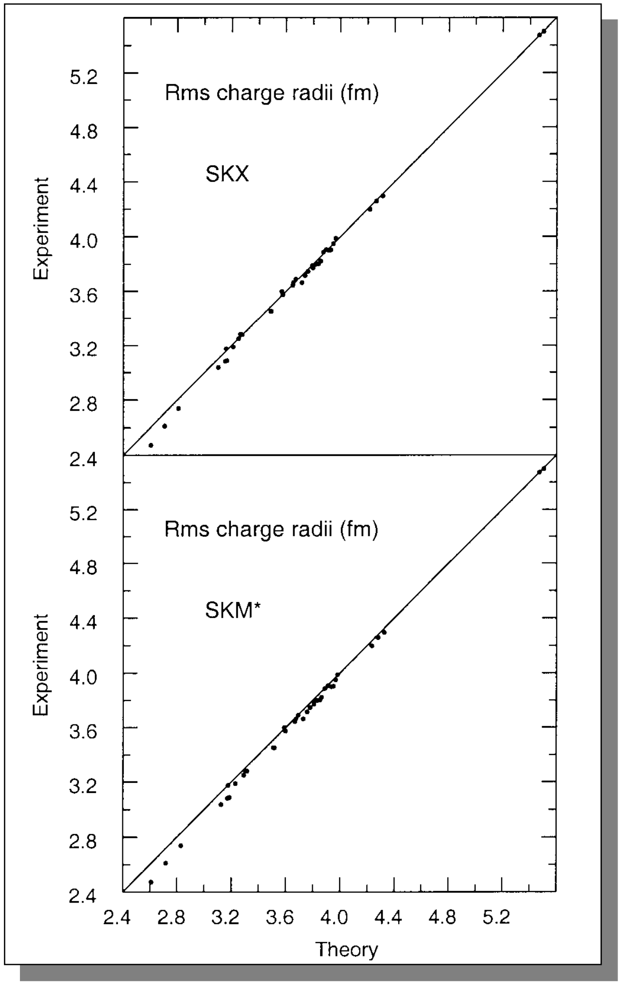
$$V_{cT}(R) = \int d\mathbf{r}_1 \int d\mathbf{r}_2 \, \rho_c(r_1)\, \rho_T(r_2)\, t_{NN}(\mathbf{R} + \mathbf{r}_2 - \mathbf{r}_1)$$

$\rho_c(r_1)\,\rho_T(r_2)$: constituent densities

$t_{NN}(\mathbf{R} + \mathbf{r}_2 - \mathbf{r}_1)$: nucleon-nucleon t-matrix or effective NN interaction

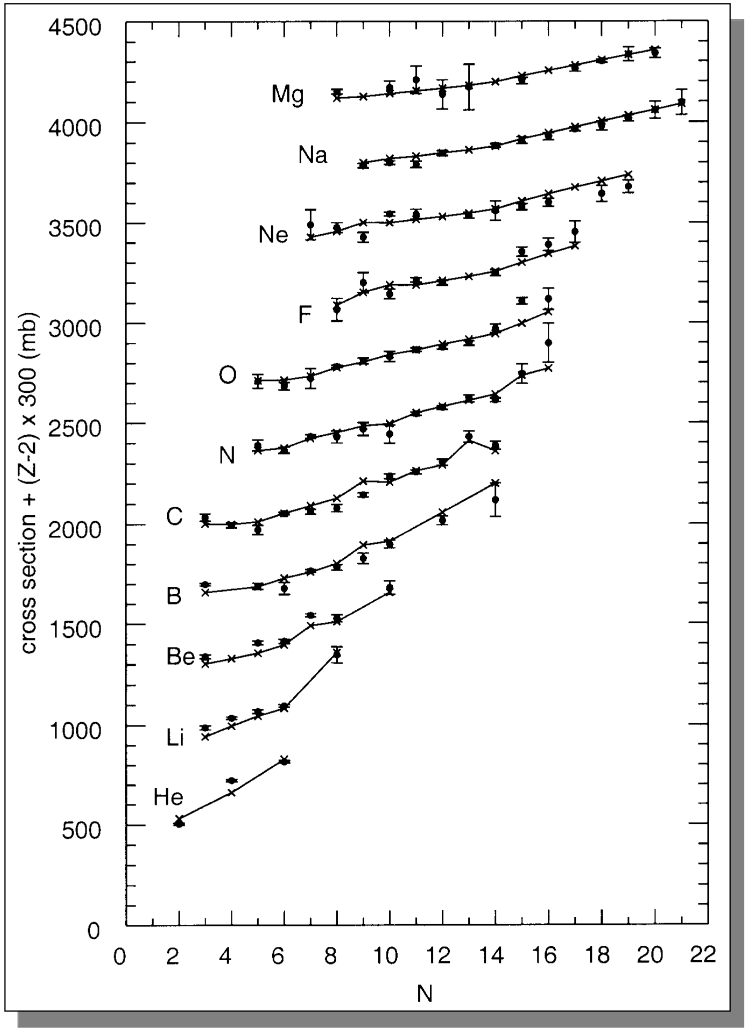
Skyrme Hartree-Fock radii and densities (1)

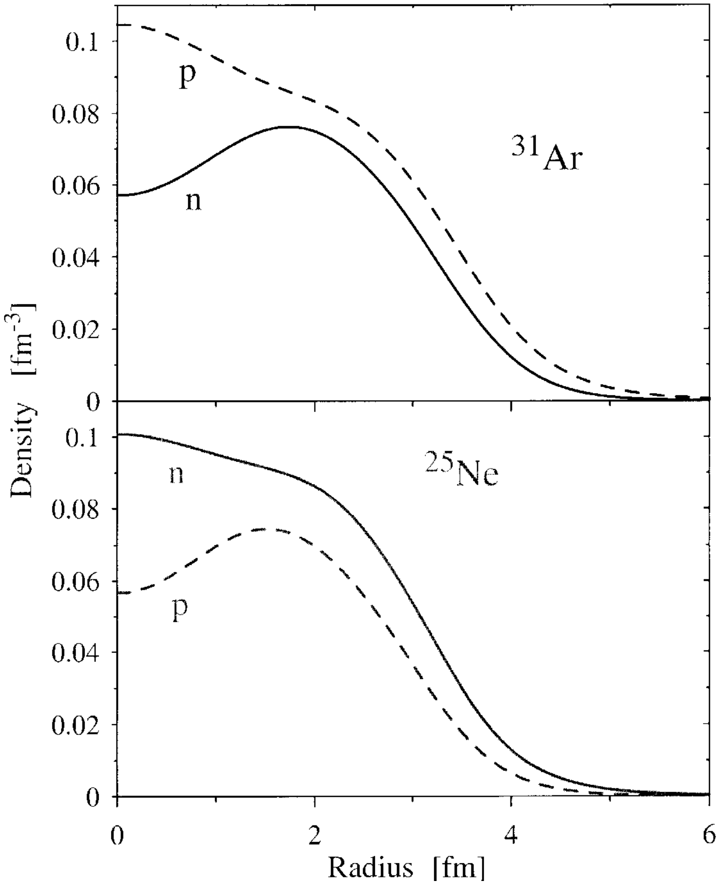




W.A. Richter and B.A. Brown, Phys. Rev. **C67** (2003) 034317

Skyrme Hartree-Fock radii and densities (2)



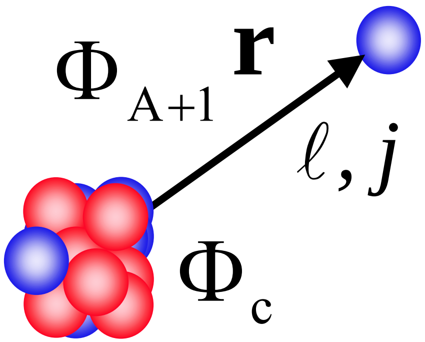


B.A. Brown, S. Typel, and W.A. Richter, Phys. Rev. **C65** (2002) 014612

(2) Structure – we need sp overlap integrals

Nucleon removal from Φ_{A+1} will leave mass A residue in the ground or an excited state - even in extreme sp model

More generally: amplitude for finding nucleon with sp quantum numbers ℓ,*j*, about core state Φ_c in Φ_{A+1} is



$$F^c_{\ell j}(\mathbf{r}) = \langle \mathbf{r}, \Phi_c \,|\, \Phi_{A+1} \rangle, \; S_N = E_{A+1} - E_c$$

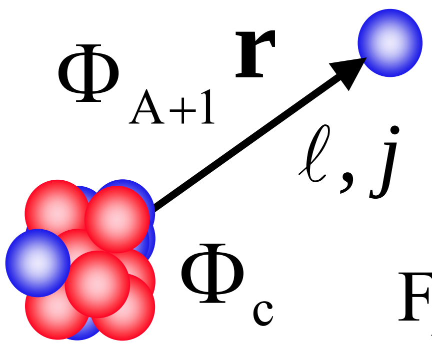
$$\int d\mathbf{r}\, |F^c_{\ell j}(\mathbf{r})|^2 = C^2 S(\ell j)$$

Spectroscopic factor - occupancy of the state

Usual to write

$$F^c_{\ell j}(\mathbf{r}) = \sqrt{C^2 S(\ell j)}\, \phi_0(\mathbf{r}); \quad \int d\mathbf{r}\, |\phi_0(\mathbf{r})|^2 = 1$$

(2) Structure – sensitivity to overlap integrals



$$F^{c}_{\ell j}(\mathbf{r}) = \langle \mathbf{r}, \Phi_c \,|\, \Phi_{A+1} \rangle, \;\; S_N = E_{A+1} - E_c$$

$$F^{c}_{\ell j}(\mathbf{r}) = \sqrt{C^2 S(\ell j)}\; \phi_0(\mathbf{r}) \,; \qquad \int d\mathbf{r}\, |\phi_0(\mathbf{r})|^2 = 1$$

Usually $\phi_0(\mathbf{r})$ calculated in a simple potential model, e.g. Woods-Saxon with 'reasonable' geometry; encompasses a mass of experimental systematics – use HF theory?

Major sensitivity of cross sections in transfer, break-up and knockout reactions is (linear in) $\langle r^2 \rangle^{1/2}$ of overlap

2N correlations - on single-nucleon overlaps

2N correlations in non-Borromean two-nucleon halo nuclei:

[A, A–1, A–2 nuclei all particle-stable]

A	$A-1$	$A-2$	$S_A(2N)$ (MeV)	$S_A(1N)$ (MeV)	$S_{A-1}(1N)$ (MeV)
^{12}Be	^{11}Be$(\frac{1}{2}^+)$	^{10}Be	3.670	3.170	0.500
^{12}Be	^{11}Be$(\frac{1}{2}^-)$	^{10}Be	3.670	3.490	0.180
^{15}B	^{14}B(1^-)	^{13}B	3.740	3.510	0.230
^{9}C	^{8}B(g.s.)	^{7}Be	1.433	1.296	0.137
^{16}C	^{15}C$(\frac{1}{2}^+)$	^{14}C	5.469	4.251	1.218
^{16}C	^{15}C$(\frac{5}{2}^+)$	^{14}C	5.469	4.991	0.478

+ many others

L.D. Blokhintsev, Bull. Acad. Russ. Sci. Phys. **65** (2001), 77.
N.K. Timofeyuk, L.D. Blokhintsev and J.A. Tostevin, Phys Rev C **68** (2003) 021601(R)

Past: DR analyses with light-ions: questions?

1) How important is it to take account of the loosely bound nature of the deuteron/triton/^{3}He and three-body break-up channels in direct reactions and how can one treat these 'practically'?
2) How accurate are first-order (BA, DWBA) approaches, and the spectroscopic information (spectroscopic factors B(E2)'s, deformations and angular momentum assignments) deduced, as a test of structure models?
3) How do we treat the required single-particle overlaps of many-body wave functions? (often assumed known)
4) How does one best deal with sensitivity of direct reaction calculations to the assumed effective interactions?

Present: ingredients/questions with exotic beams:

1) It is vital to take into account non-perturbatively the loosely bound nature of exotic nuclei and their break-up channels in calculations of reaction observables

2) How accurate is the spectroscopic information (spectroscopic factors) deduced from approximate few-body models as a test of structure models?

3) How to / can we (?) obtain 'practically' the required single-particle overlaps from realistic many-body wave functions of the best structure theory?

4) How should we best choose the assumed effective interactions between reacting constituents? – we should make best use of theoretical models – sizes, densities.

Eikonal theory reveals bare requirements

Reaction mechanism complications stripped away:

dynamics

$$S_{\alpha\beta}(b) = \langle \phi_\beta \mid S_c(b_c)\, S_v(b_v) \mid \phi_\alpha \rangle$$

structure

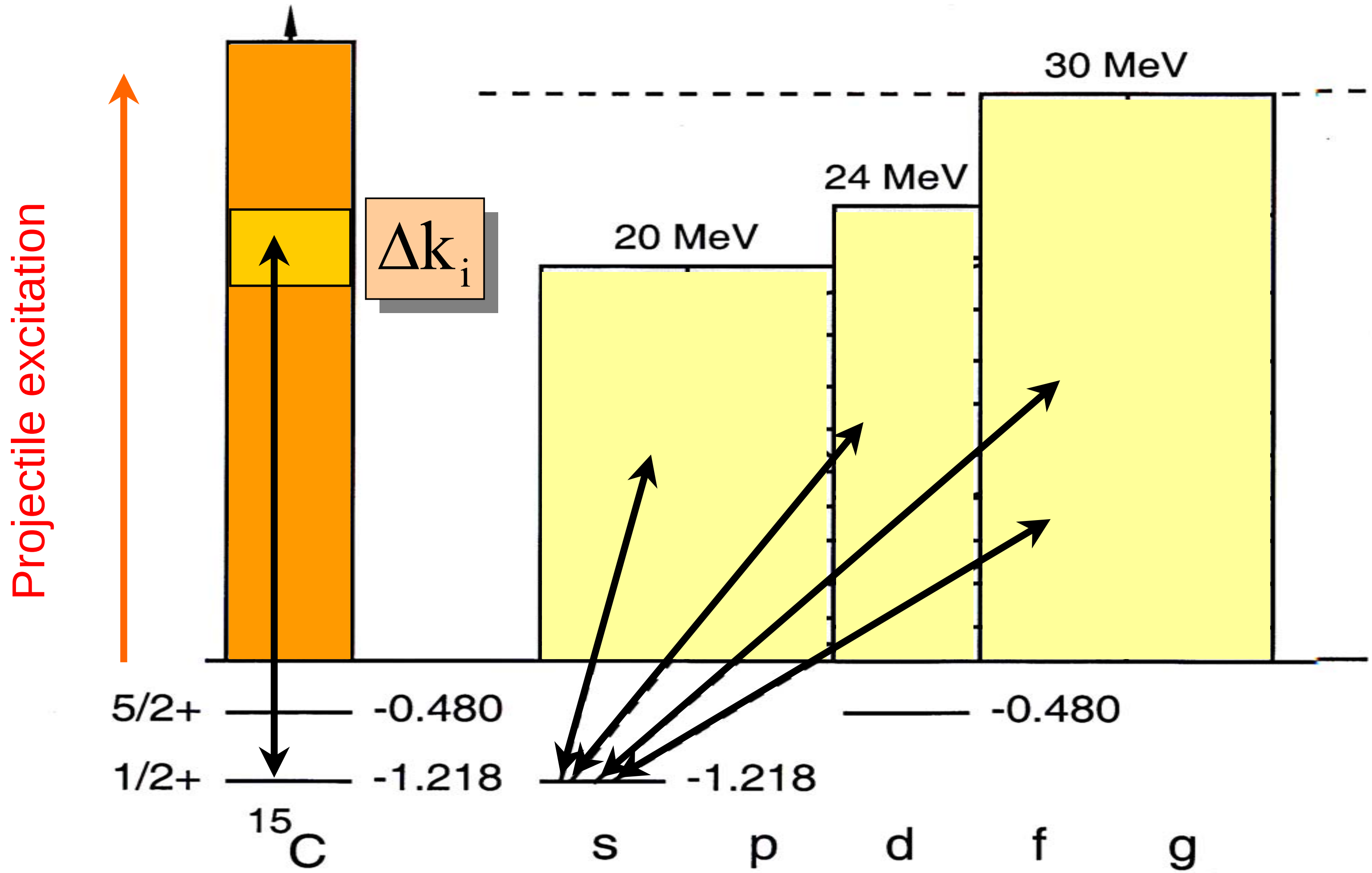
Can use overlaps from the best available few- or many-body sp wave functions <u>if can be provided/extracted</u> in a suitable form

<u>More generally,</u>

$$S_{\alpha\beta}(b) = \langle \varphi_\beta \mid S_1(b_1)\, S_2(b_2) \ldots\ldots\ S_n(b_n) \mid \varphi_\alpha \rangle$$

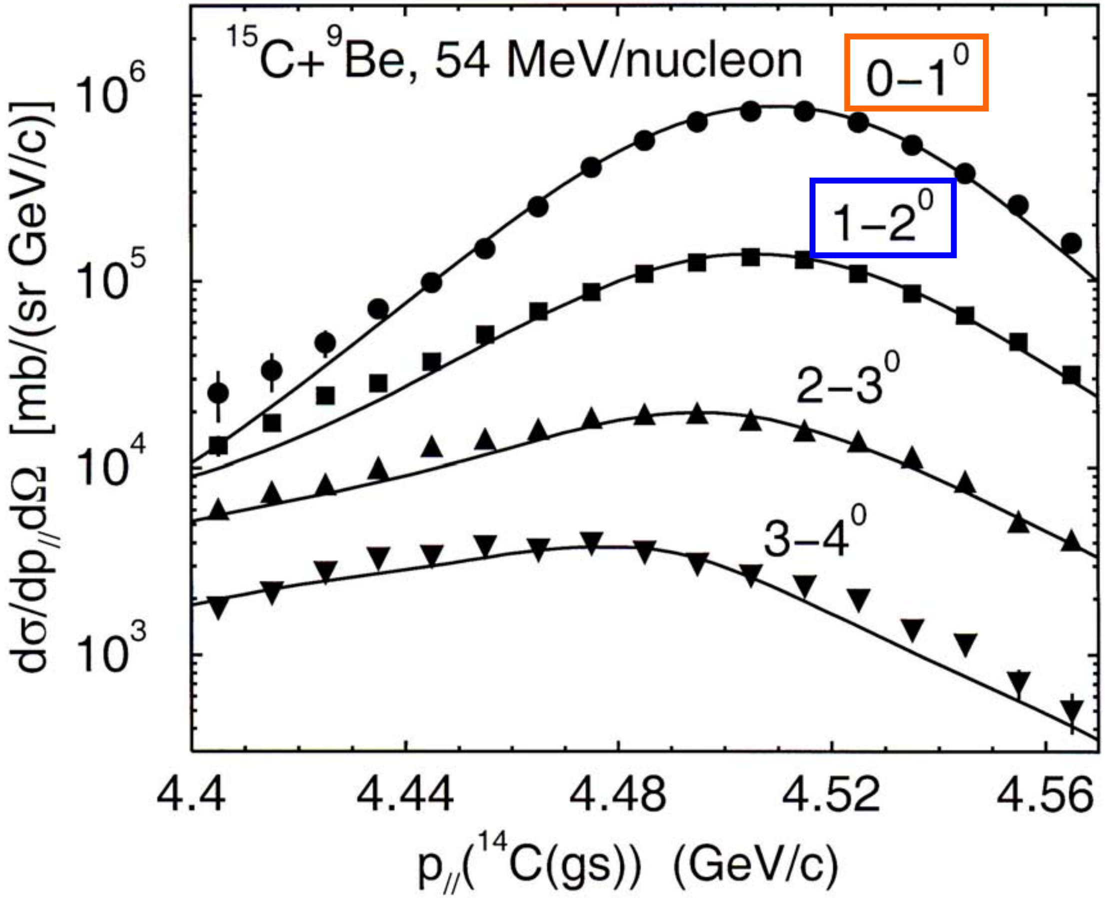
for any choice of 1,2 ,3, ….. n clusters if φ is available

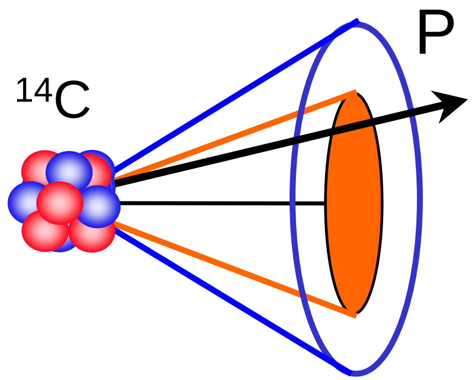
The continuum-coupled channels methodology



UniS

Core fragment differential cross sections - CDCC





these yields almost entirely due to diffractive dissociation

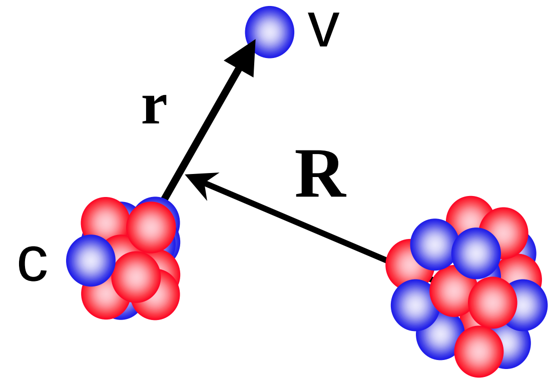
$^{9}Be\ (^{15}C,^{14}C(gs))\ X$

J.A. Tostevin et al, PRC **66** (2002) 024607

Adiabatic/sudden approximation – few-bodies

The time-dependent equation is

$$\mathrm{H}\Psi(\mathbf{r},\mathbf{R},\mathrm{t}) = i\hbar\frac{\partial\Psi}{\partial \mathrm{t}}$$



and can be written

$$\Psi(\mathbf{r},\mathbf{R},\mathrm{t}) = \Lambda\,\Phi(\mathbf{r}(\mathrm{t}),\mathbf{R}),\quad \mathbf{r}(\mathrm{t}) = \Lambda^{+}\,\mathbf{r}\,\Lambda$$

$\Lambda = \exp\{-i(\mathrm{H}_\mathrm{p}+\varepsilon_0)\mathrm{t}/\hbar\}$ and where

$$[\mathrm{T}_\mathrm{R} + \mathrm{U}(\mathbf{r}(\mathrm{t}),\mathbf{R}) - \varepsilon_0]\Phi(\mathbf{r}(\mathrm{t}),\mathbf{R}) = i\hbar\frac{\partial\Phi}{\partial \mathrm{t}}$$

Adiabatic step <u>assumes</u>

$\mathbf{r}(\mathrm{t}) \approx \mathbf{r}(0) = \mathbf{r}$ = fixed or $\Lambda = 1$ for the collision time $\mathrm{t}_{\mathrm{coll}}$

Adiabatic equation

$$[\mathrm{T}_\mathrm{R} + \mathrm{U}(\mathbf{r},\mathbf{R})]\Phi(\mathbf{r},\mathbf{R}) = (\mathrm{E}+\varepsilon_0)\Phi(\mathbf{r},\mathbf{R})$$

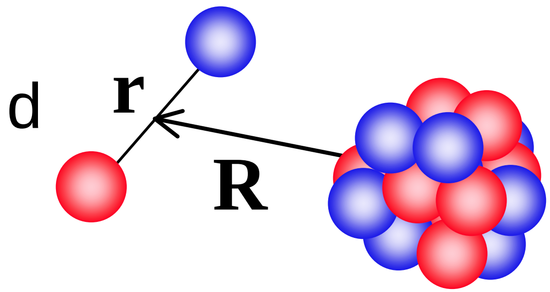
requires

$$(\mathrm{H}_\mathrm{p}+\varepsilon_0)\mathrm{t}_{\mathrm{coll}}/\hbar \ll 1$$

Models for transfer reactions: e.g. (d,p)

$$T_{dp} = \left\langle \chi_p^{(-)}(\mathbf{r}_p)\phi_n(\mathbf{r}_n) \middle| V_{np} \middle| \Psi_{\mathbf{K}}^{(+)}(\mathbf{r},\mathbf{R}) \right\rangle$$

note $|\mathbf{r}| \leq$ range of V_{np}



$$[T_{\mathbf{R}} + U(\mathbf{r},\mathbf{R}) + H_d - E]\,\Psi_{\mathbf{K}}^{(+)} = 0$$

$$H_d \to -\varepsilon_0\,, \quad \Psi_{\mathbf{K}}^{(+)} \to \Psi_{\mathbf{K}}^{AD}$$

$$[T_{\mathbf{R}} + U(\mathbf{r},\mathbf{R}) - E_0]\,\Psi_{\mathbf{K}}^{AD} = 0$$

DWBA ($|\mathbf{r}| \leq$ range of ϕ_0)

$$\Psi_{\mathbf{K}}^{(+)} \to \phi_0(\mathbf{r}) \left\langle \phi_0(\mathbf{r}) \middle| \Psi_{\mathbf{K}}^{(+)} \right\rangle_{\mathbf{r}}$$

$$= \phi_0(\mathbf{r})\,\chi_{\mathbf{K}}^{(+)}(\mathbf{R})$$

elastic scattering

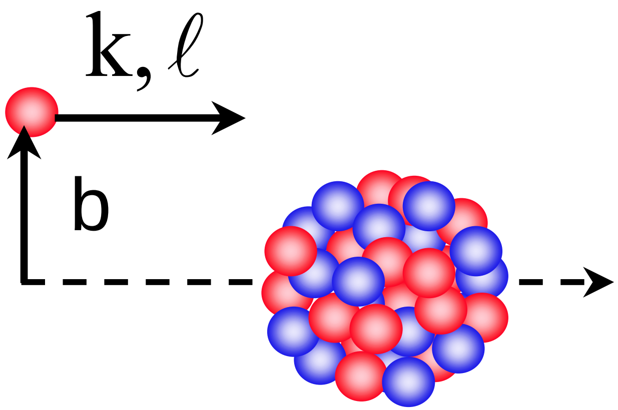
ADIABATIC ($|\mathbf{r}| \leq$ range of V_{np})

$$\Psi_{\mathbf{K}}^{AD} \approx \phi_0(\mathbf{r})\,\tilde{\chi}_{\mathbf{K}}^{AD}(\mathbf{R})$$

$$[T_{\mathbf{R}} + \tilde{V}(\mathbf{R}) - E_0]\,\tilde{\chi}_{\mathbf{K}}^{AD} = 0$$

$$\tilde{V}(\mathbf{R}) = \frac{\left\langle \phi_0 \,|\, V_{np} U(\mathbf{r},\mathbf{R}) \,|\, \phi_0 \right\rangle}{\left\langle \phi_0 \,|\, V_{np} \,|\, \phi_0 \right\rangle} \approx U(\mathbf{r}=0,\mathbf{R})$$

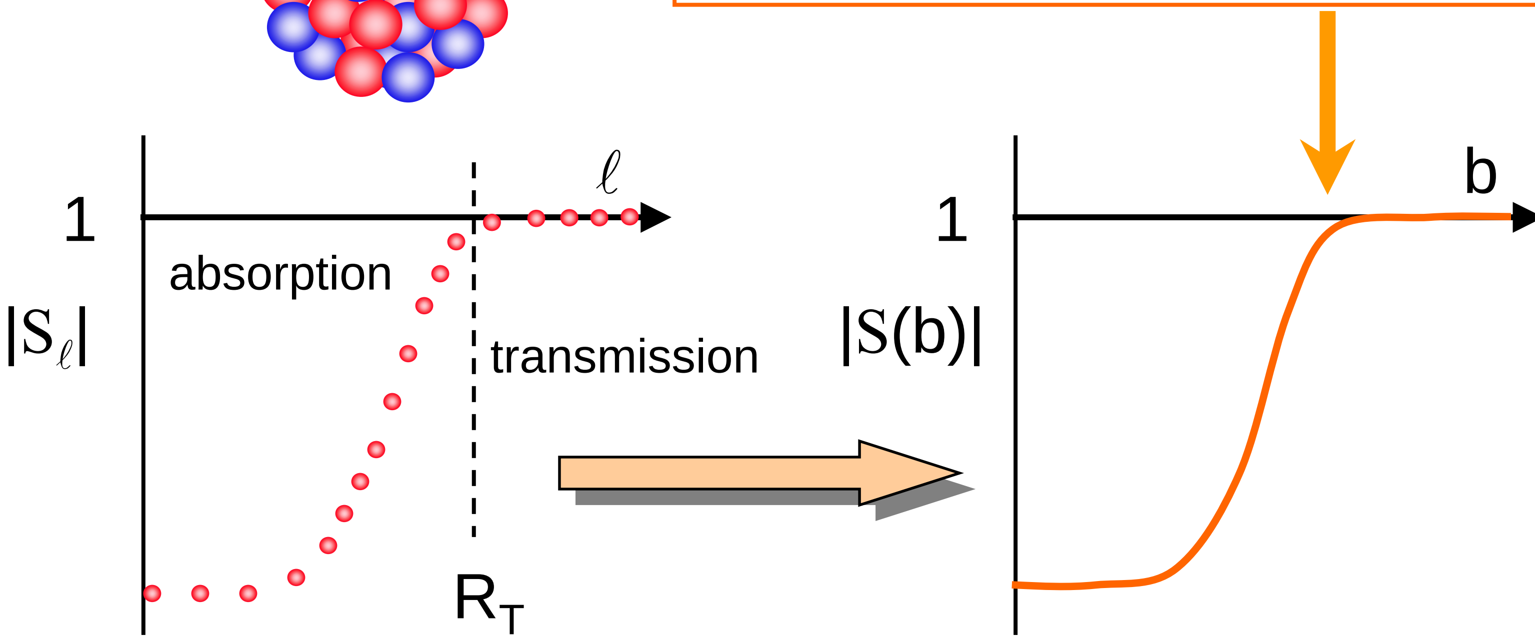
Large number of semi-classical methods



b=impact parameter

for high energy/or large mass, semi-classical ideas are good

$kb \cong \ell$, actually $\Rightarrow \ell + 1/2$

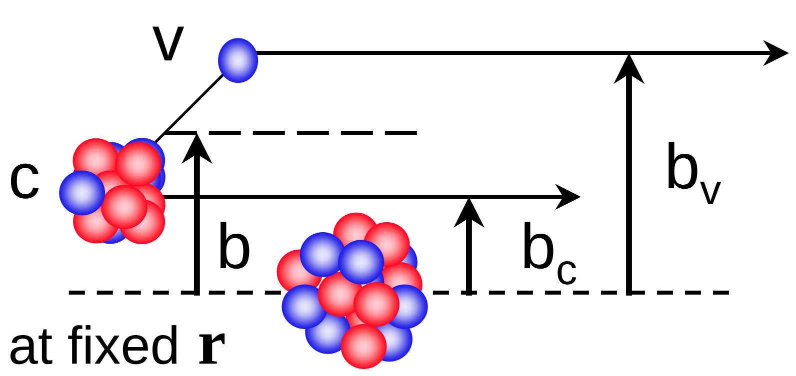


Few-body eikonal model – adiabatic, trajectories

Modulation function after collision, $\omega(\mathbf{r},\mathbf{R}) = S_c(b_c)\, S_v(b_v)$

$$\Psi_{\mathbf{K}}^{\rm Eik}(\mathbf{r},\mathbf{R}) \rightarrow e^{i\mathbf{K}\cdot\mathbf{R}}\, S_c(b_c)\, S_v(b_v)\, \phi_\alpha(\mathbf{r})$$

with S_c and S_v the eikonal approximations to the S-matrices for the independent scattering of c and v from the target



at fixed $\mathbf{r}$

adiabatic

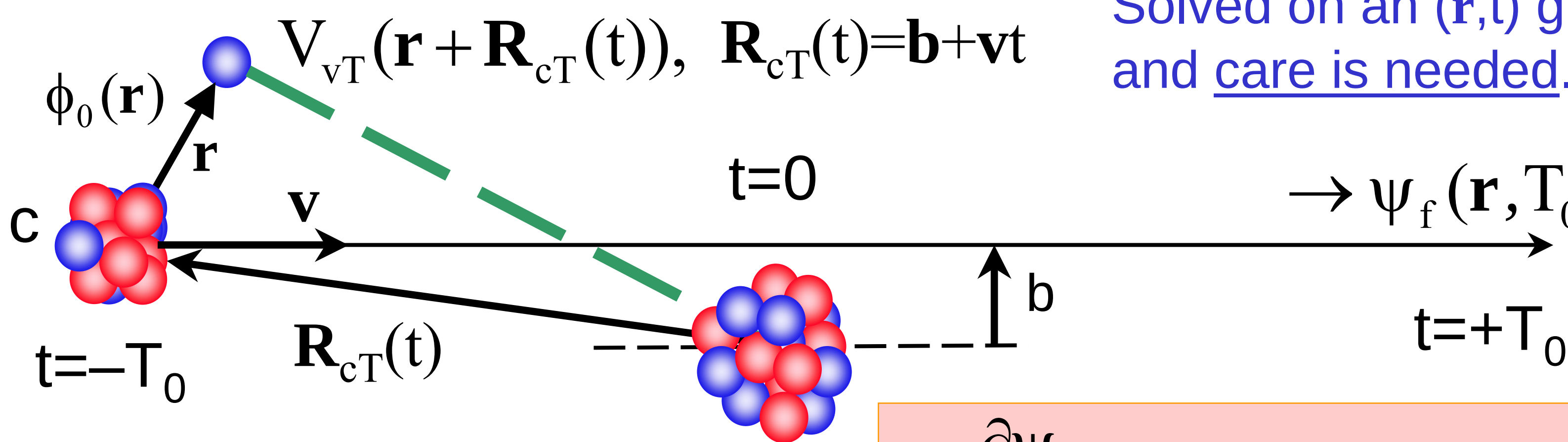
So, inelastic amplitude (S-matrix) for the scattering of the projectile at an impact parameter b - i.e. The amplitude that it emerges in state $\varphi_\beta(\mathbf{r})$ is

$$S_{\alpha\beta}(b) = \langle \phi_\beta \,|\, S_c(b_c)\, S_v(b_v) \,|\, \phi_\alpha \rangle$$

Non-adiabatic - but trajectory based

Time-dependent (finite difference) solution of the valence particle motion - assuming the heavy core, or c.m., follows a trajectory: [See: Bertsch and Esbensen, Baur and Typel, Suzuki, Melezhik and Baye]

Solved on an $(\mathbf{r},t)$ grid and care is needed.



Not exact - but non-adiabatic
Dynamics of V_{cT} is not included and no energy transfer/sharing between core and internal motion.
For heavy targets - Coulomb path

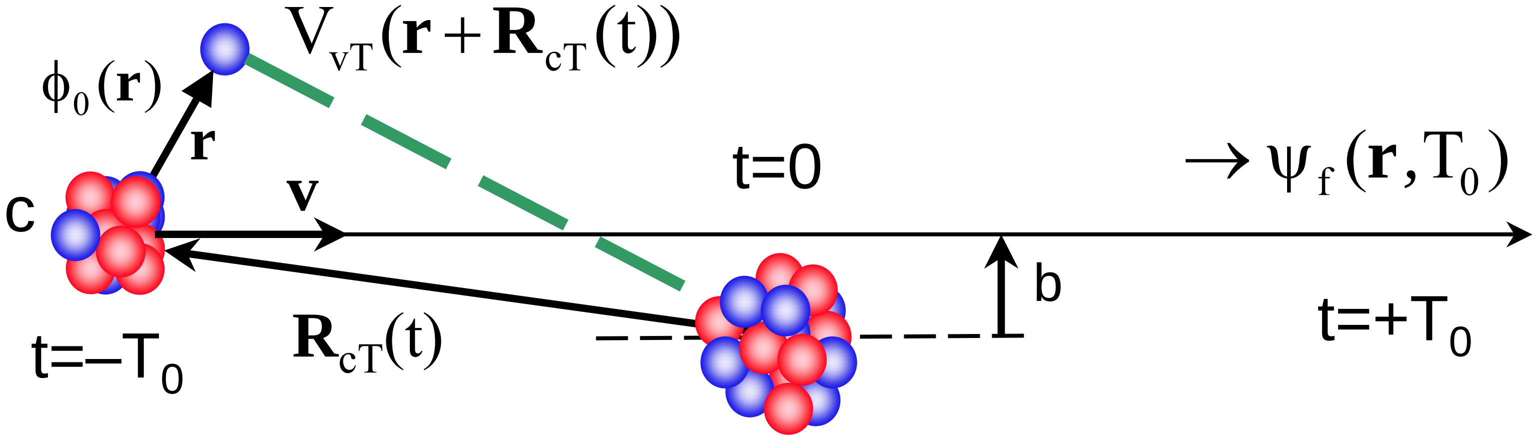
$$i\hbar\frac{\partial\psi}{\partial t}=(H_p+V_{vT})\psi(\mathbf{r},t)$$

as $t\to-\infty$ $\psi(\mathbf{r},t)\to\phi_0(\mathbf{r})$

$t\to+\infty$ $\psi(\mathbf{r},t)\to\psi_f(\mathbf{r},T_0)$

Transfer to the continuum approximation

Related transfer to the continuum model is due to Angela Bonaccorso , David Brink and others (this meeting). Using additional approximations (asymptotic forms of wave function) the time-dependent finite difference solution is avoided in favour of largely analytic approach.



Not exact - but non-adiabatic
Dynamics of V_{cT} is not included
and no energy transfer/sharing
between core and internal motion.

$$i\hbar\frac{\partial\psi}{\partial t}=(H_p+V_{vT})\psi(\mathbf{r},t)$$

as $t\rightarrow-\infty \quad \psi(\mathbf{r},t)\rightarrow\phi_0(\mathbf{r})$

What is the state of the reaction theory?

Do the different theories agree for the same structure and effective interaction inputs?

Theorists will (sometimes/always?) argue the details but where fair tests and comparisons have been carried out and domains of approximations overlap – answer is YES

Structure inputs – overlaps
Dynamics – effective interactions

Transfer reactions: choice of distorting potentials

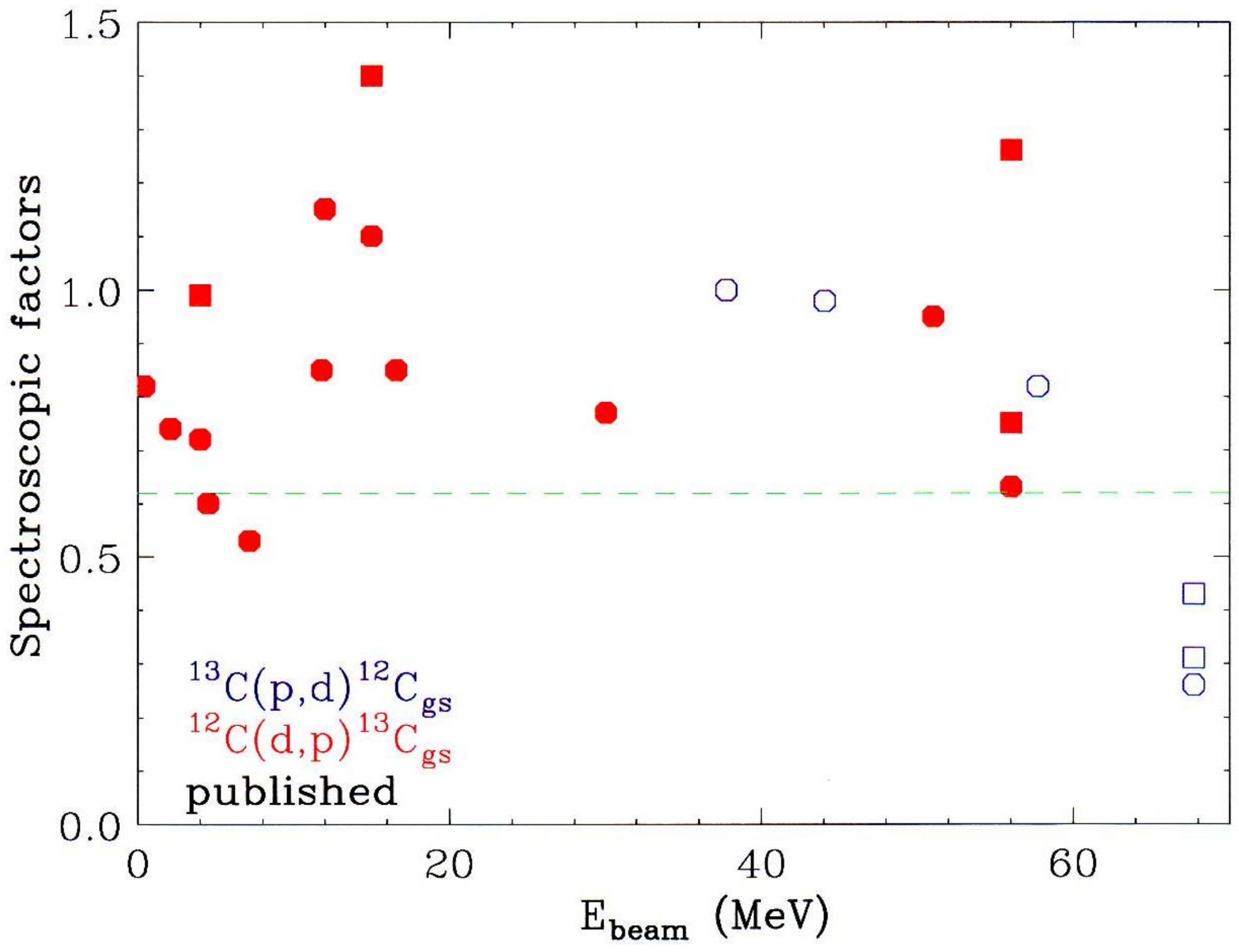
It used to be thought that the best procedure is to measure the elastic scattering by the target nucleus of the incident projectiles and that by the final nucleus of the outgoing particles, all at the proper energies, and then to fit the elastic data as well as possible with optical model potentials. These potentials were then to be used as input to DWBA calculations.

Experience has shown that a more sensible procedure is to use distorting parameters which are appropriate for a wider range of target nuclei and energies. Emphasis on accurate fitting of data on one or two nuclei tends to optimize the fit by selecting a peculiar (and perhaps unphysical) set of parameters.

M.H. Macfarlane and J.P. Schiffer, Nucl. Spectroscopy and Reactions, Vol B, pp 169

What should we use? – appeal to theory

Spectroscopic factors from individual analyses

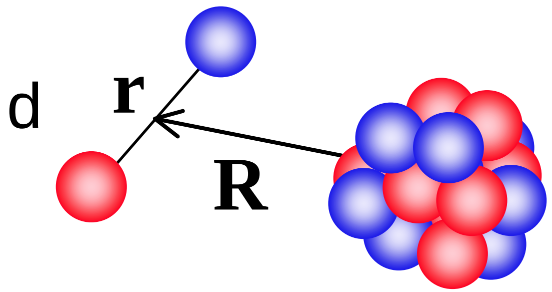


X. Liu, M. Famiano, B. Tsang, W. Lynch and J.A. Tostevin (2003), in progress

Adiabatic model for transfer reactions: e.g. (d,p)

$$T_{dp} = \left\langle \chi_p^{(-)}(\mathbf{r}_p)\phi_n(\mathbf{r}_n) \middle| V_{np} \middle| \Psi_{\mathbf{K}}^{(+)}(\mathbf{r},\mathbf{R}) \right\rangle$$

note $|\mathbf{r}| \leq$ range of V_{np}



$$[T_{\mathbf{R}} + U(\mathbf{r},\mathbf{R}) + H_d - E]\,\Psi_{\mathbf{K}}^{(+)} = 0$$

$$H_d \rightarrow -\varepsilon_0\,,\quad \Psi_{\mathbf{K}}^{(+)} \rightarrow \Psi_{\mathbf{K}}^{AD}$$

DWBA $(|\mathbf{r}| \leq \text{range of } \phi_0)$

$$\Psi_{\mathbf{K}}^{(+)} \rightarrow \phi_0(\mathbf{r}) \left\langle \phi_0(\mathbf{r}) \middle| \Psi_{\mathbf{K}}^{(+)} \right\rangle_{\mathbf{r}}$$

$$= \phi_0(\mathbf{r})\,\chi_{\mathbf{K}}^{(+)}(\mathbf{R})$$

d elastic scattering

ADIABATIC $(|\mathbf{r}| \leq \text{range of } V_{np})$

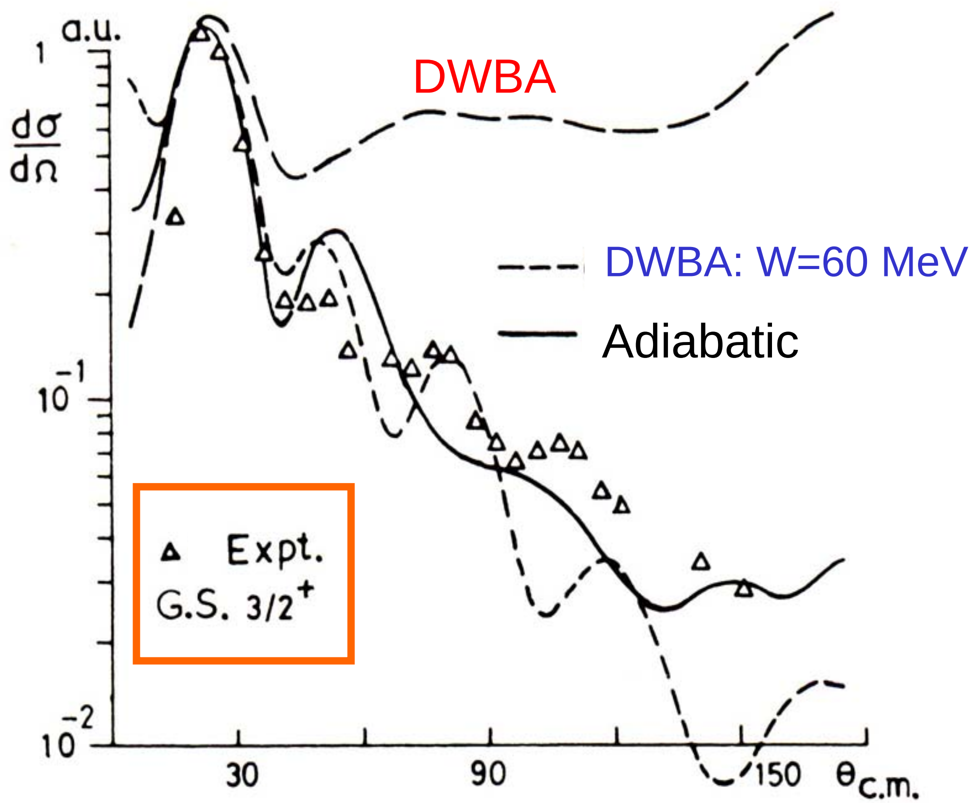
$$\Psi_{\mathbf{K}}^{AD} \approx \phi_0(\mathbf{r})\,\tilde{\chi}_{\mathbf{K}}^{AD}(\mathbf{R})$$

$$[T_{\mathbf{R}} + \tilde{V}(\mathbf{R}) - E_0]\,\tilde{\chi}_{\mathbf{K}}^{AD} = 0$$

$$\tilde{V}(\mathbf{R}) \approx V_n(R) + V_p(R)$$

Key outcomes for transfer reactions - spectroscopy

$^{40}Ca(p,d)^{39}Ca$, 30.5 MeV



Increased reflection at nuclear surface - less diffuse ‘deuteron’ channel potential

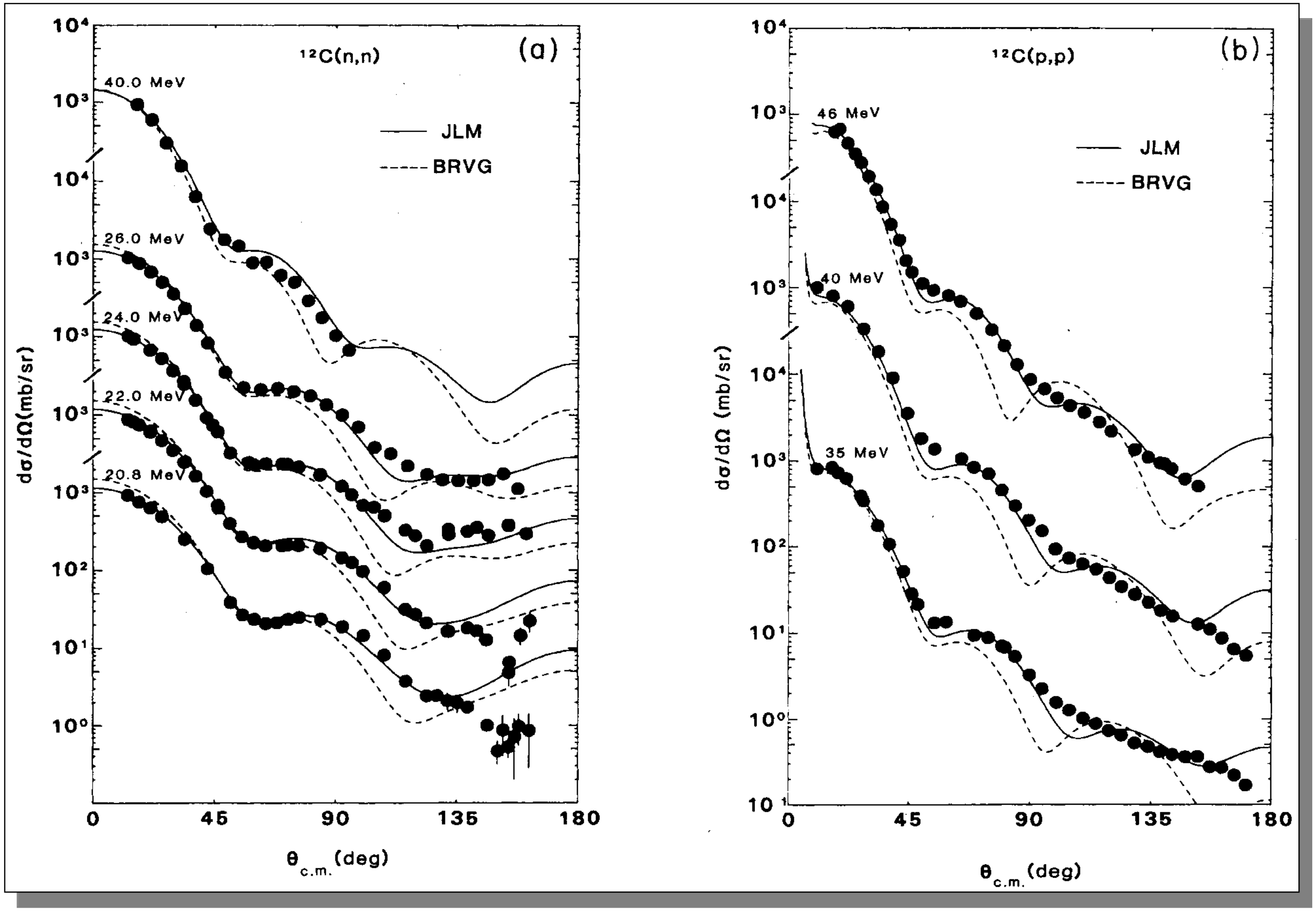
Greater surface localisation - L-space localisation

Less nuclear volume contribution and less sensitivity to optical model parameters

More consistent sets of deduced spectroscopic factors

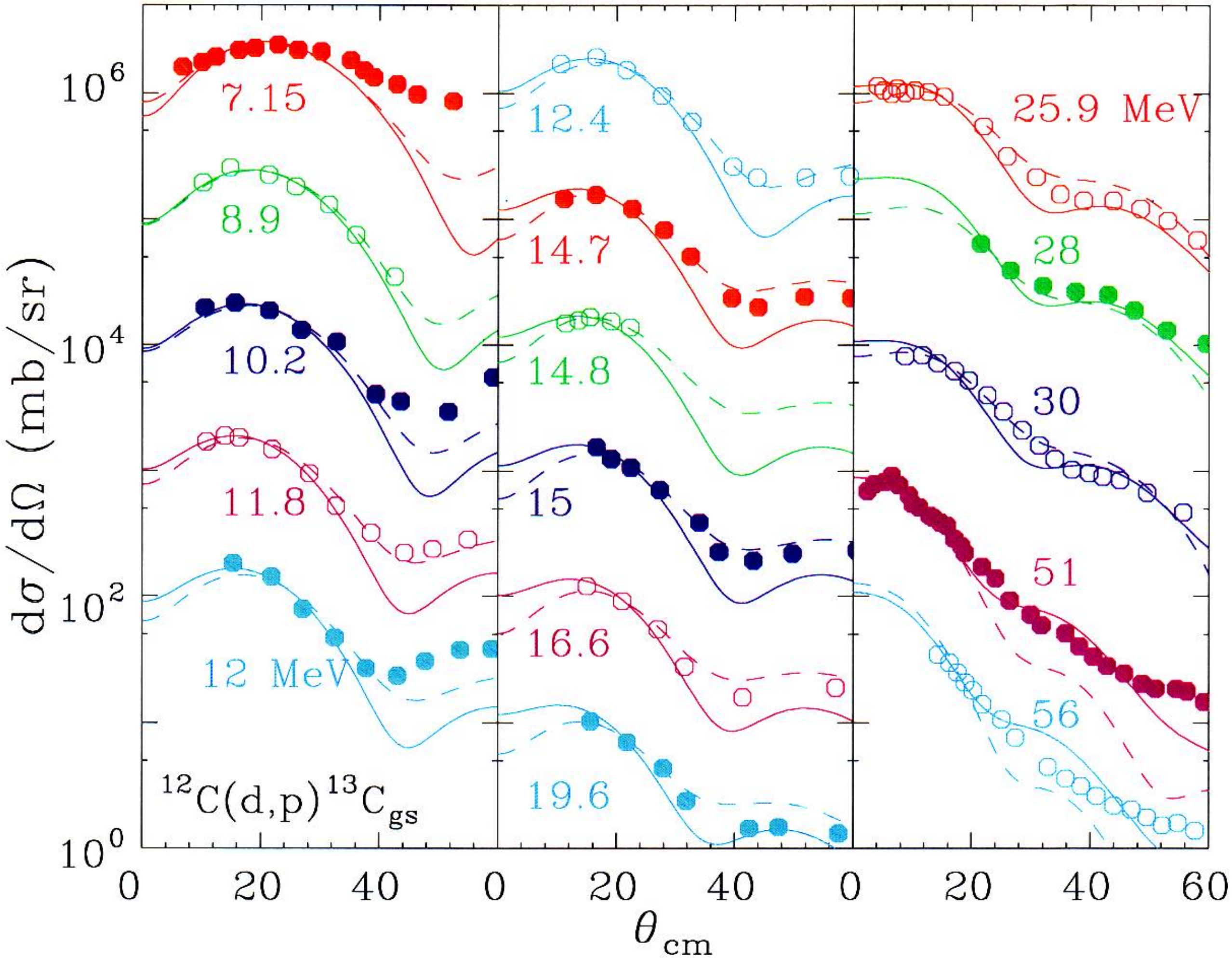
J.D. Harvey and R.C. Johnson, Phys. Rev.C **3** (1971) 636

Microscopic nucleon optical potentials - JLM



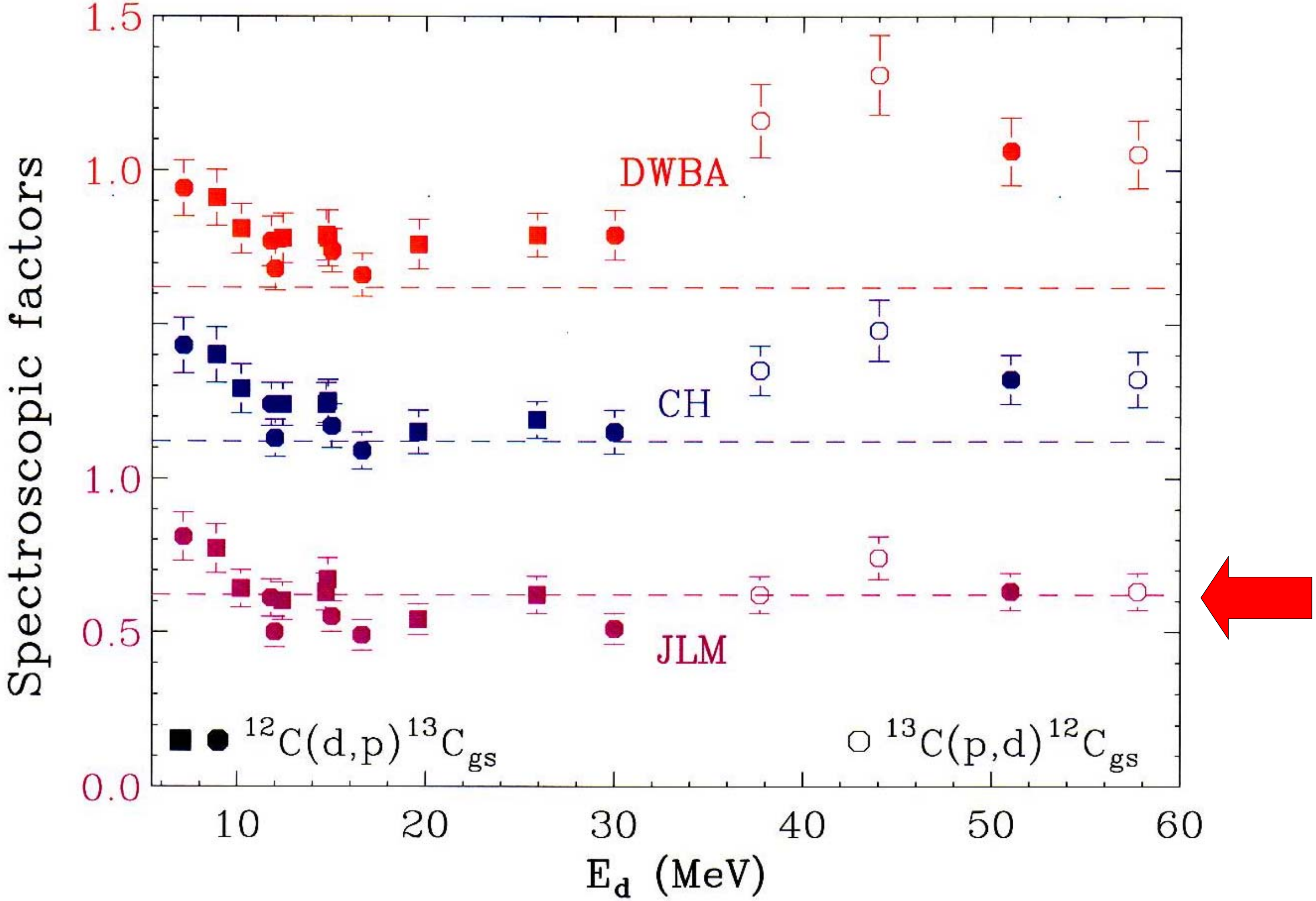
J.S. Petler et al. Phys. Rev. C **32** (1985), 673

Consistent analyses of transfer reaction data



X. Liu, M. Famiano, B. Tsang, W. Lynch and J.A. Tostevin (2003), submitted

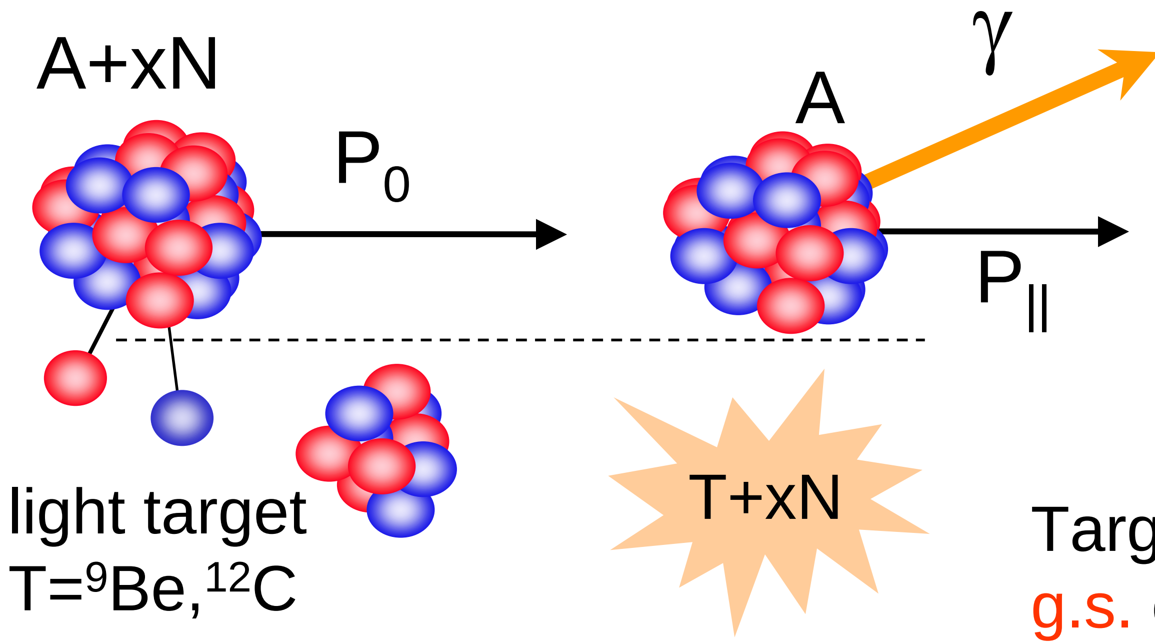
Spectroscopic factors – consistent inputs



X. Liu, M. Famiano, B. Tsang, W. Lynch and J.A. Tostevin (2003), submitted

One- and two-nucleon knockout reactions

Peripheral collisions (E ≥ 50A MeV; MSU, RIKEN, GSI)



heavy mass A residue
is detected,
<u>with</u> coincident
γ-ray detection

Target T left in
g.s. or excited state

<u>Direct from the projectile perspective</u>

Events contributing will be both <u>break-up</u> and <u>stripping</u> both of which leave a mass A residue in the final state

Absorptive cross sections - target excitation

Since our effective interactions are complex all S(b) include the effects of absorption due to inelastic channels → $|S(b)|^2 \leq 1$

$$\sigma_{abs} = \sigma_R - \sigma_{diff} = \int d\mathbf{b}\ \langle \phi_0 \,|\, \underbrace{1 - |S_c S_v|^2}\, |\, \phi_0 \rangle$$

$$\left\{ \begin{array}{ll} |S_v|^2 (1-|S_c|^2) + & \text{v survives, c absorbed} \\ |S_c|^2 (1-|S_v|^2) + & \text{v absorbed, c survives} \\ (1-|S_v|^2)(1-|S_v|^2) & \text{v absorbed, c absorbed} \end{array} \right.$$

stripping of v from projectile exciting the target. c scatters at most elastically with the target

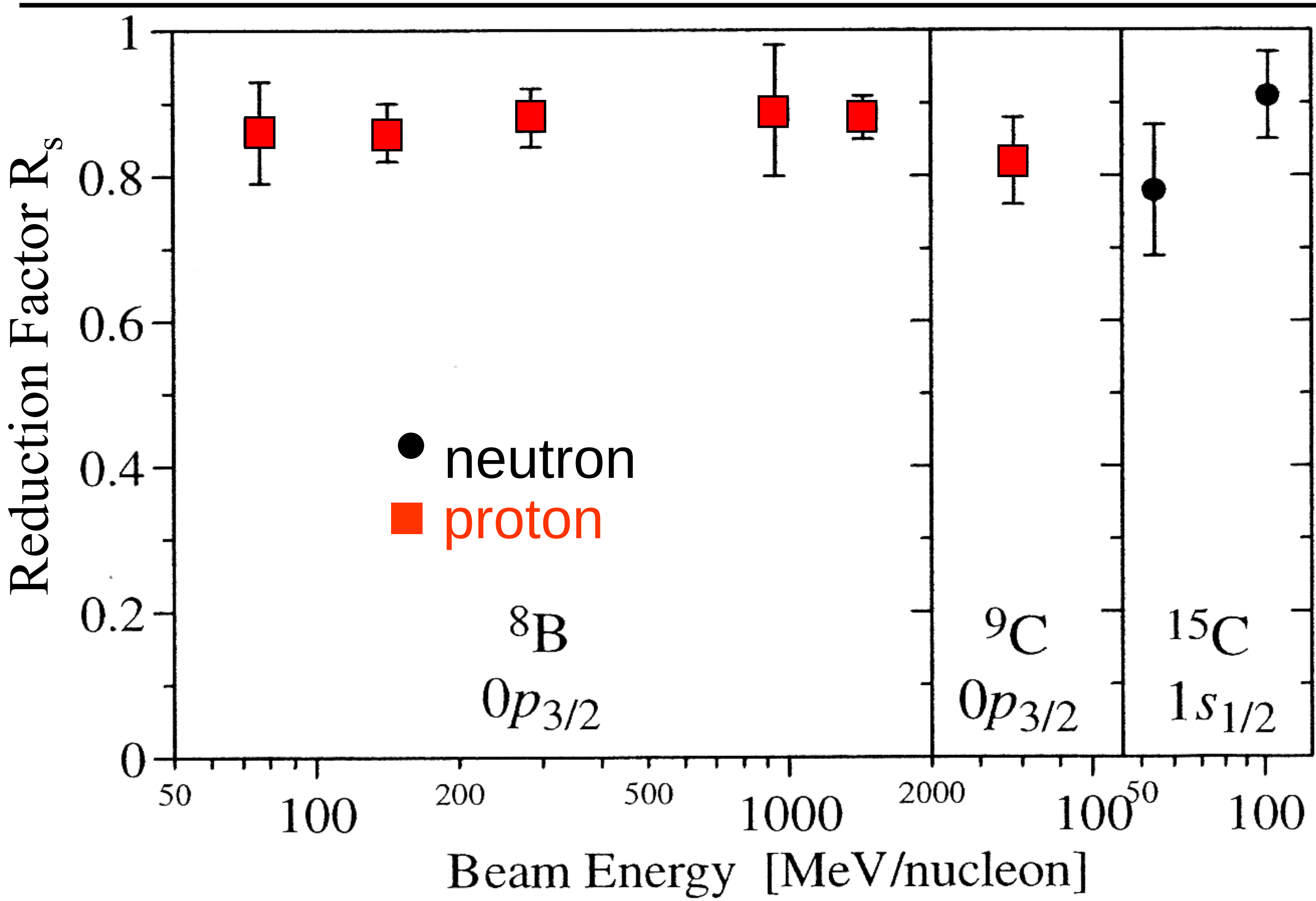
$$\sigma_{strip} = \int d\mathbf{b}\ \langle \phi_0 \,||\, S_c|^2 (1-|S_v|^2) \,|\, \phi_0 \rangle$$

Related equations exist for the differential cross sections, etc.

Choice of two-body distorting interactions

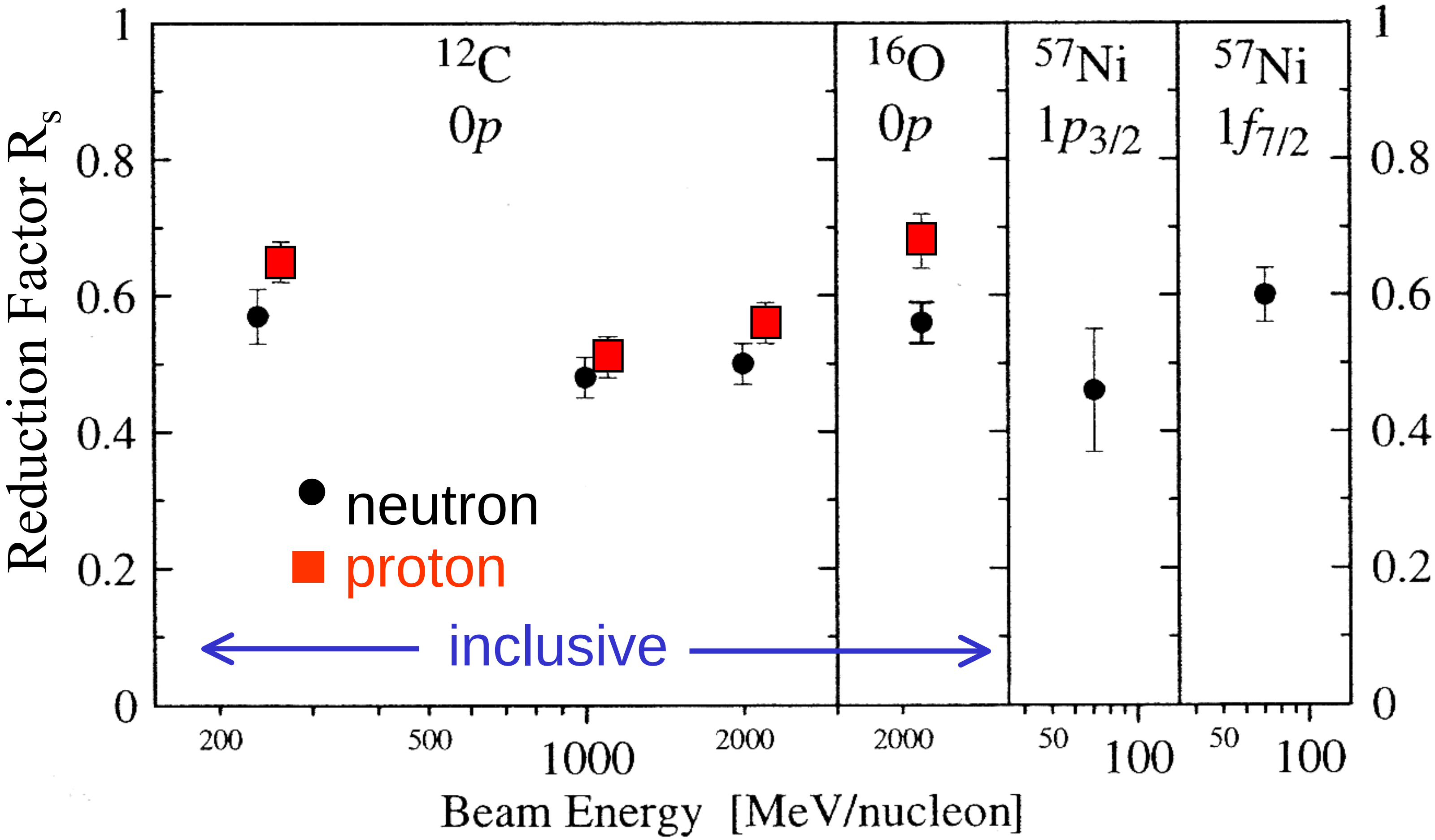
- Work at MSU has used the same energy range (60 – 100 MeV/nucleon) and the same light nuclear target (^{9}Be) combination – systematics across many data sets
- Need nucleon – ^{9}Be S-matrices over limited energy. Can use JLM or other absorptive t_{NN} effective interaction consistent with n+^{9}Be reaction cross section (split between diffractive and stripping mechanisms depends on this choice – but not their sum)
- Core-target systems are black (highly absorptive). Calculated using '$t_{NN}\rho\rho$' double folding model to incorporate realistic sizes and surface geometries – gives results consistent with two-body σ_R(core)

Weakly bound states – with good statistics



P.G. Hansen and J.A.Tostevin, ARNPS **53** (2003), 219

More strongly bound states – deep hole states



P.G. Hansen and J.A.Tostevin, ARNPS **53** (2003), 219

Neutron removal from the N=16 isotones

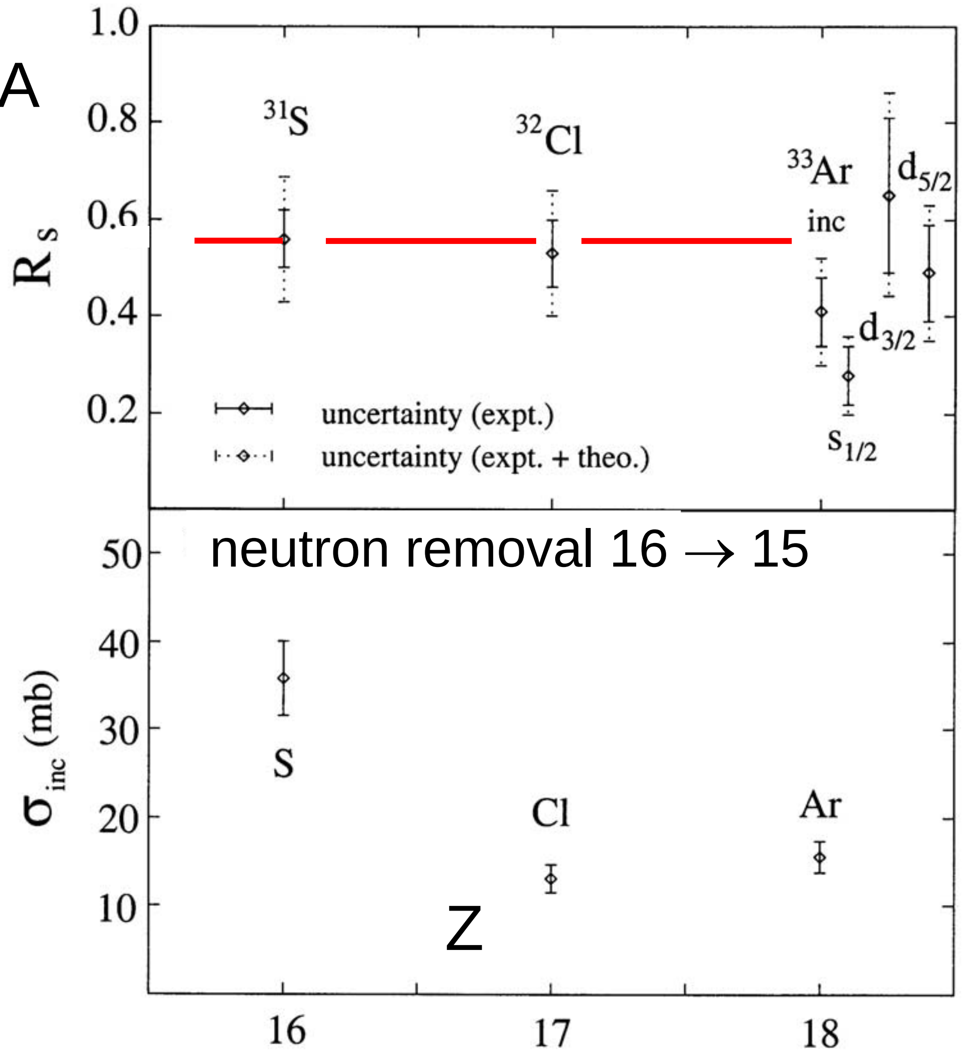
E_{beam} = 63, 66, 70 MeV/A

Deep hole-states:

$S_n(^{32}S)$ = 15.04 MeV

$S_n(^{33}Cl)$ = 15.74 MeV

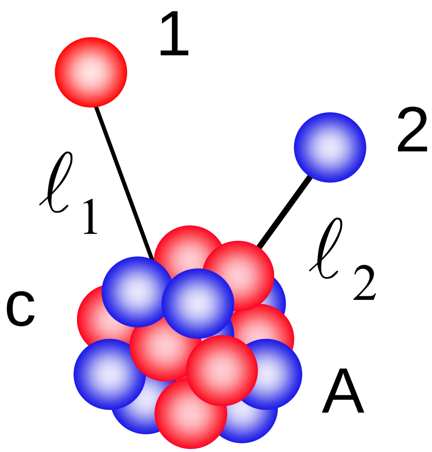
$S_n(^{34}Ar)$ = 17.07 MeV



Alexandra Gade et al., PRC, in the press

Direct two nucleon knockout – 2N correlations?

$$\sigma_{\text{strip}} = \sigma_{-2\text{N}} = \int d\mathbf{b}\ \langle \phi_0 \,||\, S_c|^2 (1-|S_1|^2)(1-|S_2|^2)\,|\,\phi_0 \rangle$$



Estimate assuming removal of a pair of uncorrelated nucleons -

$$\phi_0(A,\mathbf{r}_1,\mathbf{r}_2) = \Phi_c(A)\phi_{\ell_1}(\mathbf{r}_1)\phi_{\ell_2}(\mathbf{r}_2)$$

$$\sigma_{\text{strip}} \Rightarrow \sigma_{\text{strip}}(\ell_1 \ell_2)$$

contribution from direct 2N removal σ_{-2N}

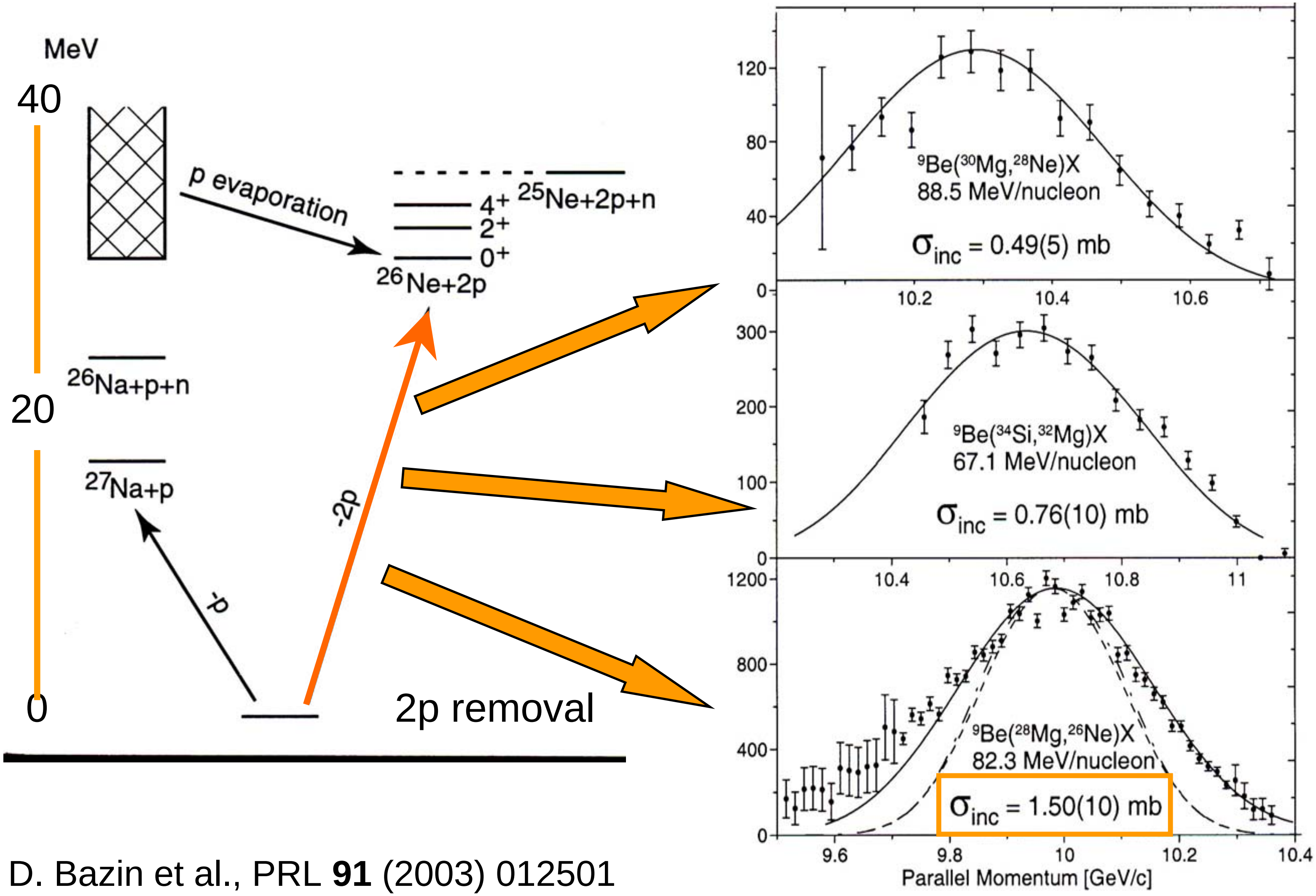
p particles ℓ_α

q particles ℓ_β

$$\sigma_{-2N} = \frac{p(p-1)}{2}\sigma_{\text{strip}}(\ell_\alpha \ell_\alpha) + \frac{q(q-1)}{2}\sigma_{\text{strip}}(\ell_\beta \ell_\beta) + pq\,\sigma_{\text{strip}}(\ell_\alpha \ell_\beta)$$

D. Bazin et al., PRL **91** (2003) 012501

Two proton knockout from neutron rich nuclei

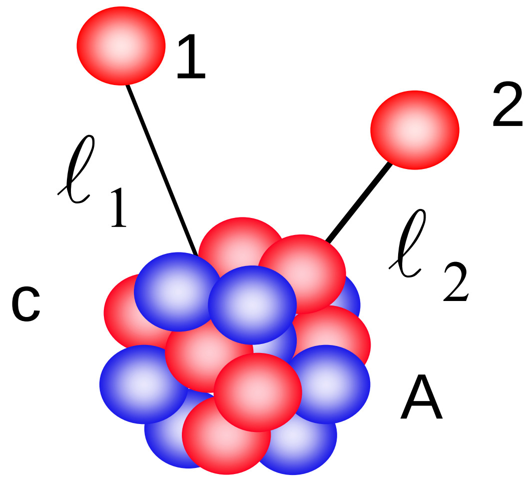


D. Bazin et al., PRL **91** (2003) 012501

Two proton removal from n-rich – (i) uncorrelated

$^{28}Mg \rightarrow ^{26}Ne$(inclusive)

D. Bazin et al., PRL **91** (2003) 012501



Assuming $(1d_{5/2})^4$ then

$$\sigma_{-2N} = \frac{4(4-1)}{2}\sigma_{strip}(22) \approx 1.8\,mb$$

Expt: 1.50(1) mb

$$\sigma_{strip}(22) = 0.29\text{ mb}$$

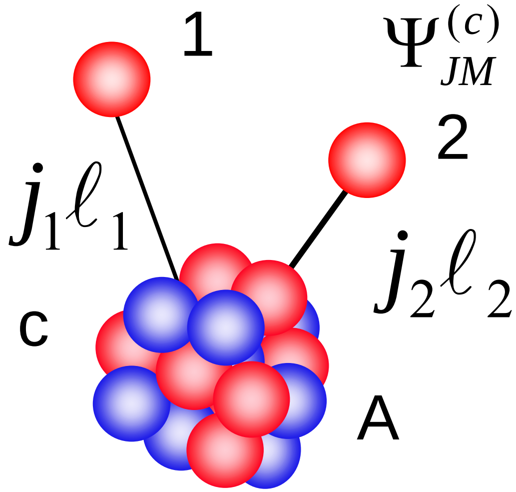
$$\sigma_{strip}(02) = 0.32\text{ mb}$$

$$\sigma_{strip}(00) = 0.35\text{ mb}$$

There is now no factorisation!!

Two proton removal from n-rich – (ii) correlated

$$\sigma_{\text{strip}} = \frac{1}{2J+1}\sum_{M\,c}\int d\mathbf{b}\ \langle \Psi_{JM}^{(c)} \,||\, S_c|^2 (1-|S_1|^2)(1-|S_2|^2) \,|\, \Psi_{JM}^{(c)} \rangle$$



$$\Psi_{JM}^{(c)} = \sum_{\alpha\, I} C_{\alpha}^{JIc} [[\overline{\phi_{j_1\ell_1}(1) \otimes \phi_{j_2\ell_2}(2)]}_I \otimes \phi_c]_{JM}$$

$$\alpha \equiv (j_1\ell_1, j_2\ell_2)$$

$^{28}Mg \rightarrow {}^{26}Ne(0^+)$

$C(2s_{1/2})^2 = -0.305$

$C(1d_{3/2})^2 = -0.301$

$C(1d_{5/2})^2 = -1.05$

There is now no factorisation!!

J.A. Tostevin et al., RNB6 proceedings, in press

Cross sections – correlated and uncorrelated

$^{28}Mg \rightarrow ^{26}Ne(0^+, 2^+, 4^+)$ S = σ(in mb) / 0.29

	S_{th} unc.	S_{exp}	S_{th} corr.	σ_{exp} (mb)	σ_{th} (mb)
0^+	1.33	**2.4(5)**	**1.83**	0.70(15)	0.53
2^+	1.67	**0.3(5)**	**0.55**	0.09(15)	0.16
4^+	3.00	**2.0(3)**	**1.79**	0.58(9)	0.52
2^+	-	**0.5(3)**	**0.76**	0.15(9)	0.22

Inclusive cross section (in mb) **1.50(10)** **1.43**

J.A. Tostevin, G. Podolyák, et al., in preparation

No suppression?

Test case - earlier data from Berkeley (~10%)

2N removal from ^{12}C
B.A. Brown, 2N amplitudes

Kidd et al., Phys Rev C **37** (1988) 2613

Energy/nucleon	250 MeV	1.05 GeV	2.10 GeV
$^{12}C \rightarrow {}^{10}Be$ (2p) S(2p)=27.18 MeV	**5.82 mb** **5.88**	**5.33 mb** **5.30(30)**	**5.15 mb** **5.81(29)**
$^{12}C \rightarrow {}^{10}C$ (2n) S(2n)=31.84 MeV	**4.26 mb** **5.33(81)**	**3.91 mb** **4.44(24)**	**3.84 mb** **4.11(22)**

J.A. Tostevin et al., RNB6 proceedings, in press and in preparation