Momentum distributions from intermediate energy two-nucleon knockout reactions

Direct Reactions with Exotic Beams, RIKEN, 30th May – 2nd June 2007

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Motivation – two-nucleon degrees of freedom

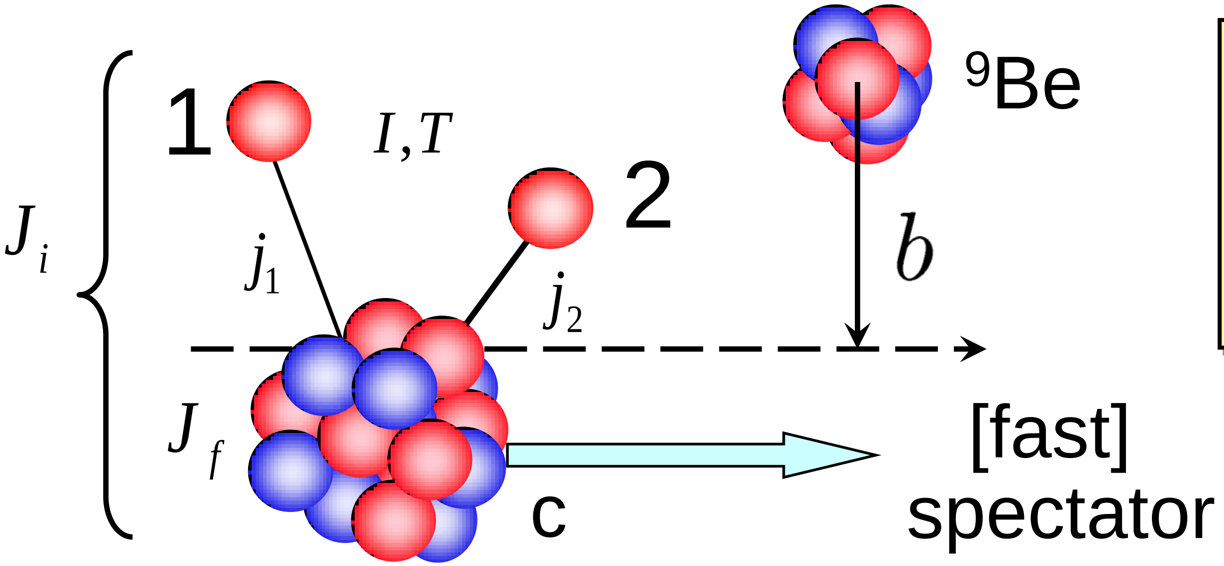
Can we observe experimentally, and understand theoretically, the effects of *correlations* of pairs of nucleons in exotic nuclei – and study these using simple nuclear reactions? (specifically, using fast secondary beams)

I will discuss the direct 2N knockout reaction mechanism:
(i) consider just one of the available experimental cases,
(ii) the sensitivity of the reaction to correlated pair properties.
Can this be exploited for spectroscopy of exotic systems?

Work in progress is looking at multi-proton knockout from ^{208}Pb - as a means of populating low seniority, high spin isomeric configurations in heavy neutron-rich systems

Background

Two nucleon knockout, ~ 100 MeV per nucleon

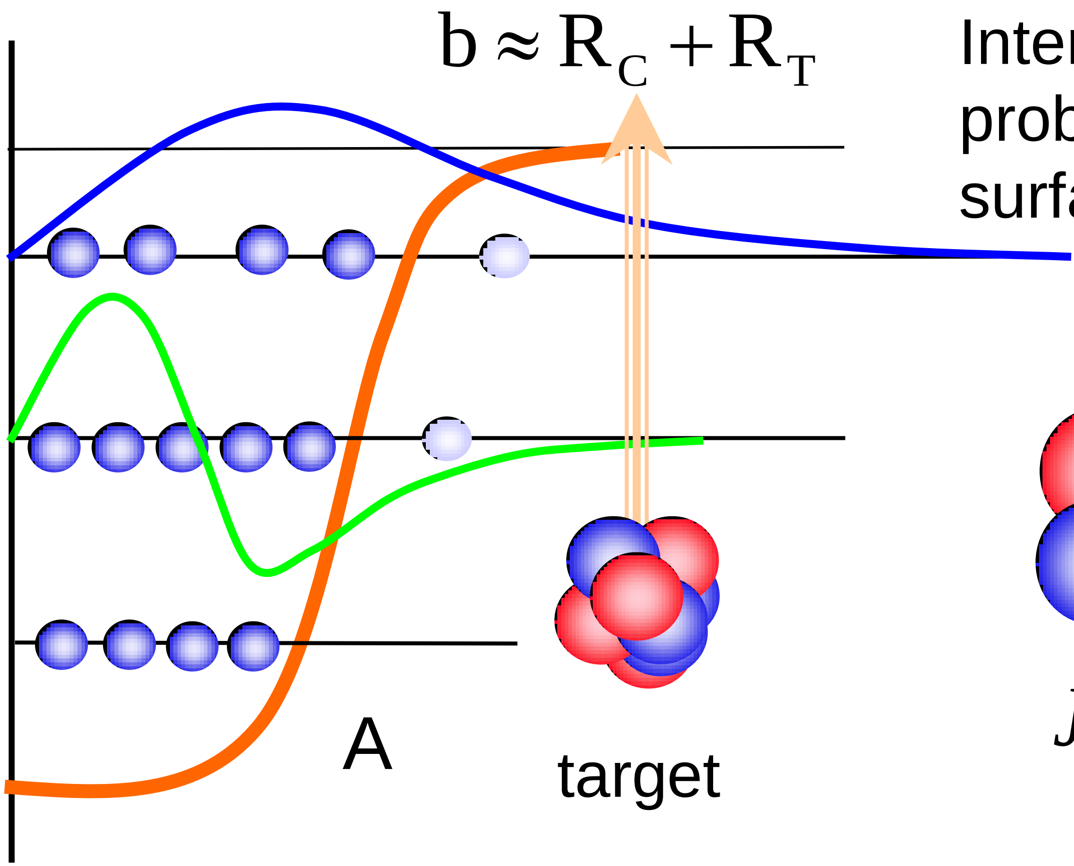


light nuclear target

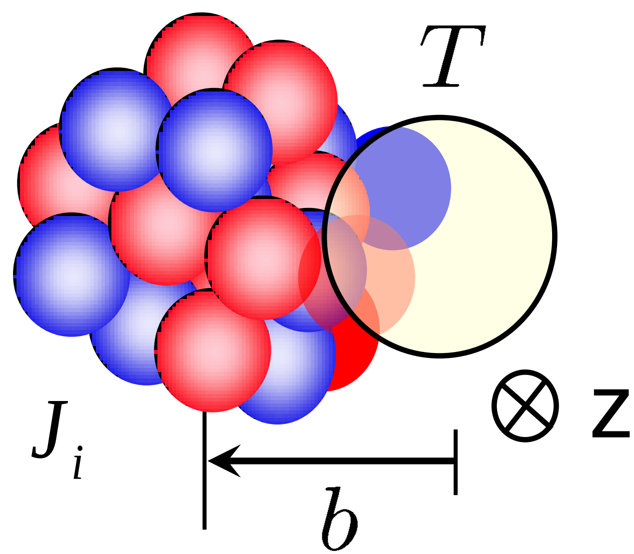
Experiments are inclusive (with respect to the target final states). Core final state measured – using gamma rays – whenever possible – and the momenta of the residues.

Cross sections are large and they include both:
Break-up (elastic) and stripping (inelastic/absorptive) interactions of the removed nucleon(s) with the target

Sampling the two-nucleon wave function



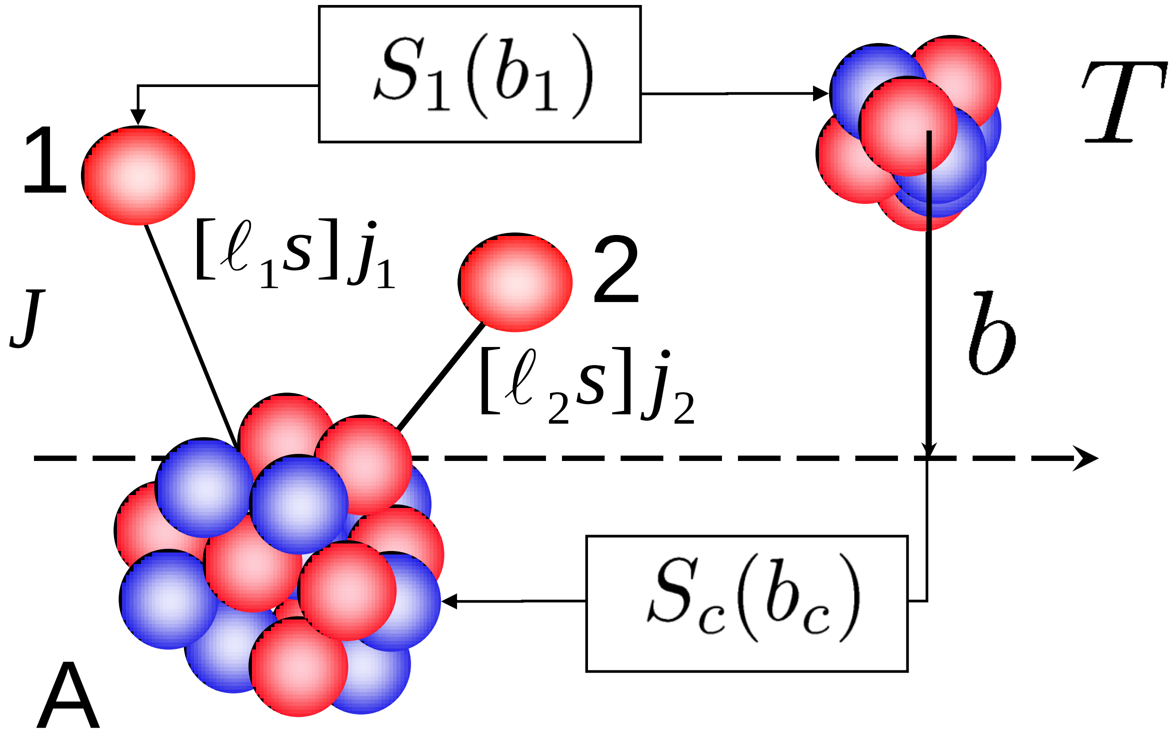
Interaction with the target probes wave functions at surface and beyond



Shell model overlaps – for 0^+ → heavy residue in state JM

$$F_{JM}(1,2) = \sum_{j_1 j_2} (-)^{J+M} C(j_1 j_2 J)/\hat{J}\,[\overline{\phi_{j_1 m_1} \otimes \phi_{j_2 m_2}}]_{J-M}$$

Sudden removal – eikonal model cross sections



$$\sigma = \frac{1}{2J+1} \sum_M \int d\vec{b}\, \langle F_{JM} | \hat{O}(c,1,2) | F_{JM} \rangle$$

$$\text{2N Stripping} : \hat{O}(c,1,2) = |S_c|^2 (1 - |S_1|^2)(1 - |S_2|^2)$$

J.A. Tostevin *et al.*, PRC 70 (2004) 064602 and PRC 74 (2006) 064604.

Must include all 2 nucleon removal mechanisms

$$\sigma_{abs} \quad \rightarrow \quad 1 - |S_c|^2 |S_1|^2 |S_2|^2$$

J.A. Tostevin *et al.*, PRC **74** (2006) 064604.

$$\begin{aligned} 1 \quad &= \quad [\, |S_c|^2 + \cancel{(1 - |S_c|^2)}\,] \\ &\times \quad [\, |S_1|^2 + (1 - |S_1|^2)\,] \\ &\times \quad [\, |S_2|^2 + (1 - |S_2|^2)\,] \end{aligned}$$

core survival and nucleon " removal "

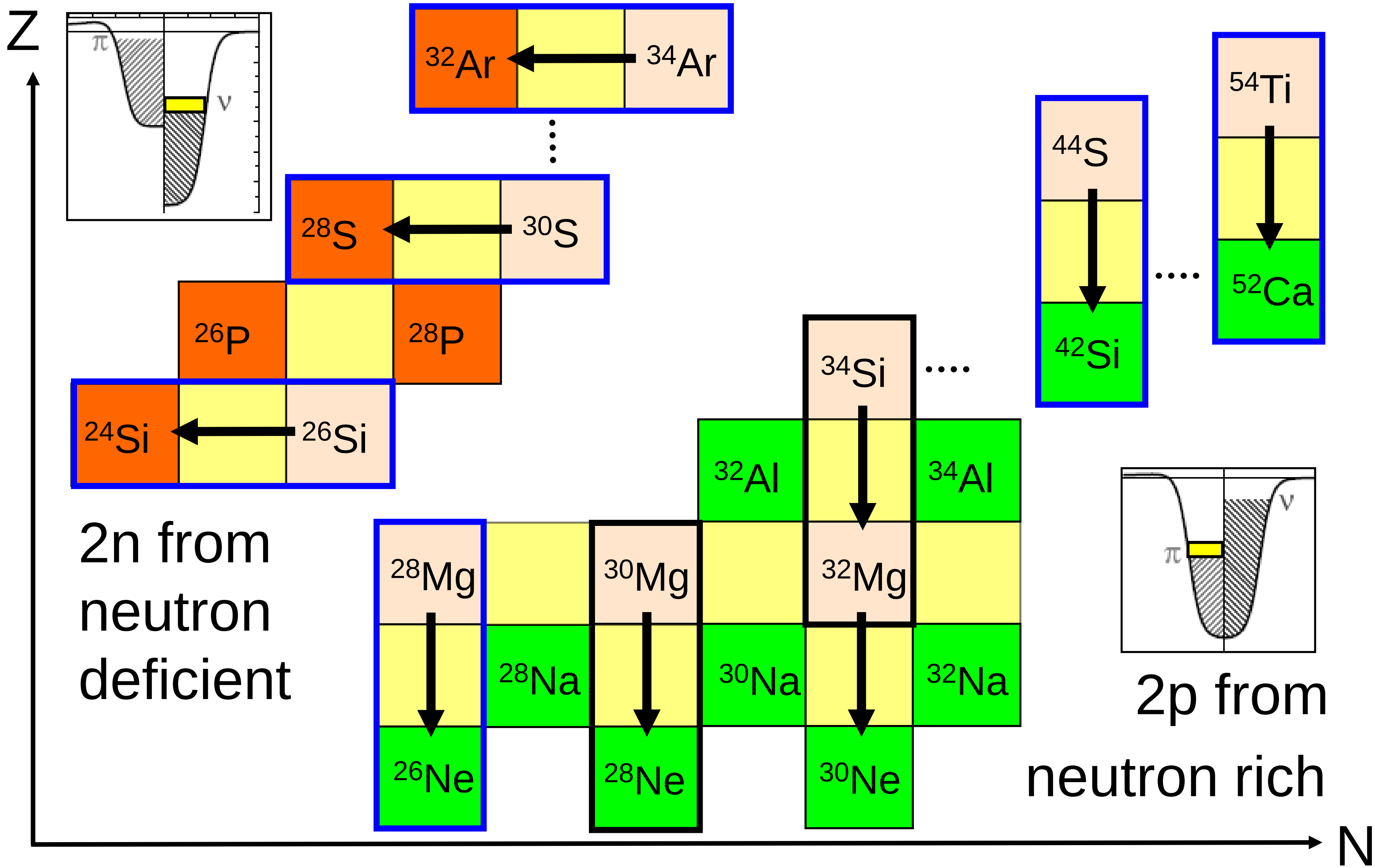
$$\begin{aligned} \sigma_{abs}^{\mathrm{KO}} \quad &\rightarrow \quad |S_c|^2 (1 - |S_1|^2)(1 - |S_2|^2) \\ &+ \quad |S_c|^2 |S_1|^2 (1 - |S_2|^2) \\ &+ \quad |S_c|^2 (1 - |S_1|^2) |S_2|^2 \end{aligned}$$

2N stripping

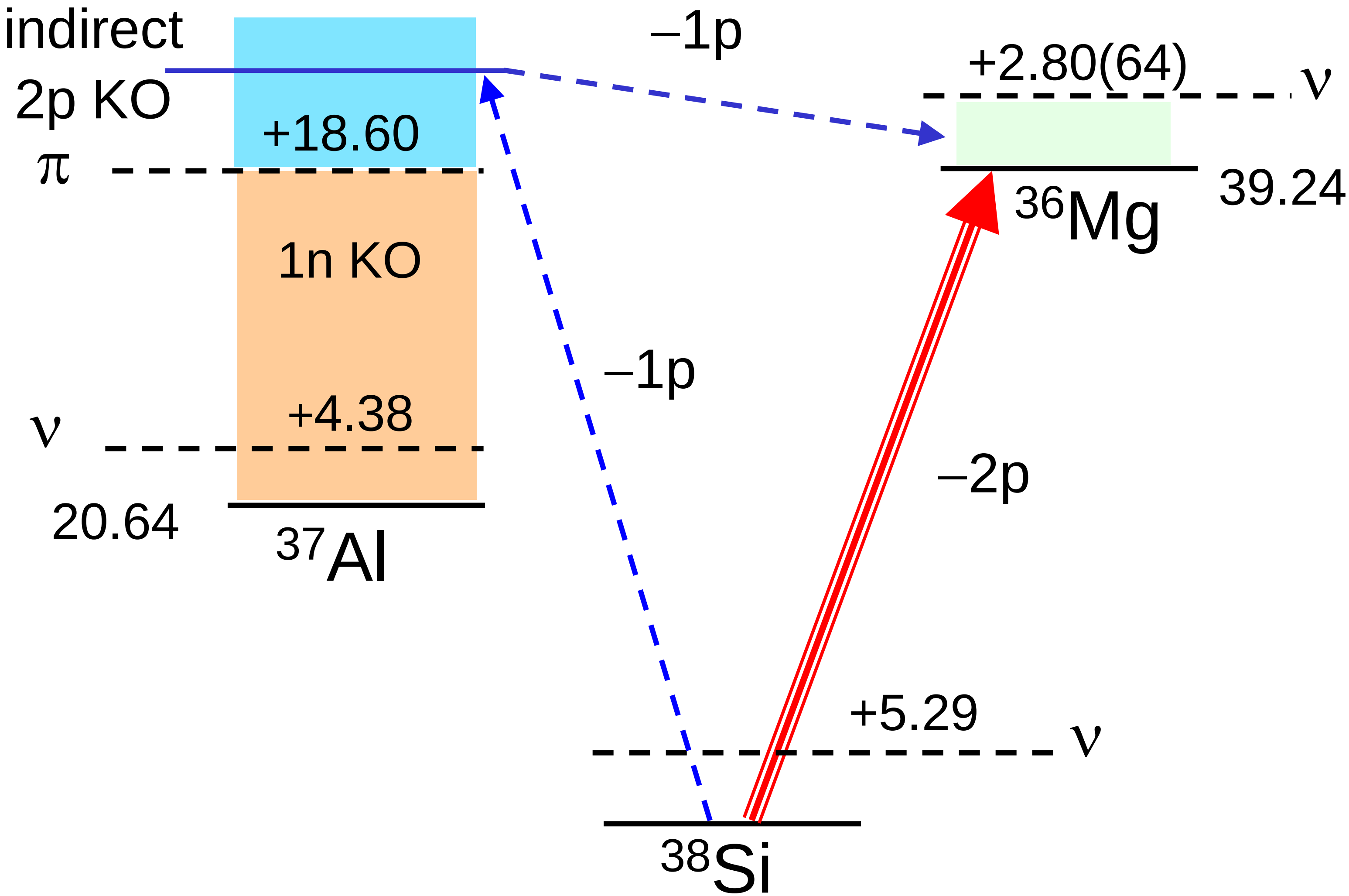
1N stripped
1N diffracted

$$+ \text{ 2N diffraction contributions} \approx 6 - 8\%$$

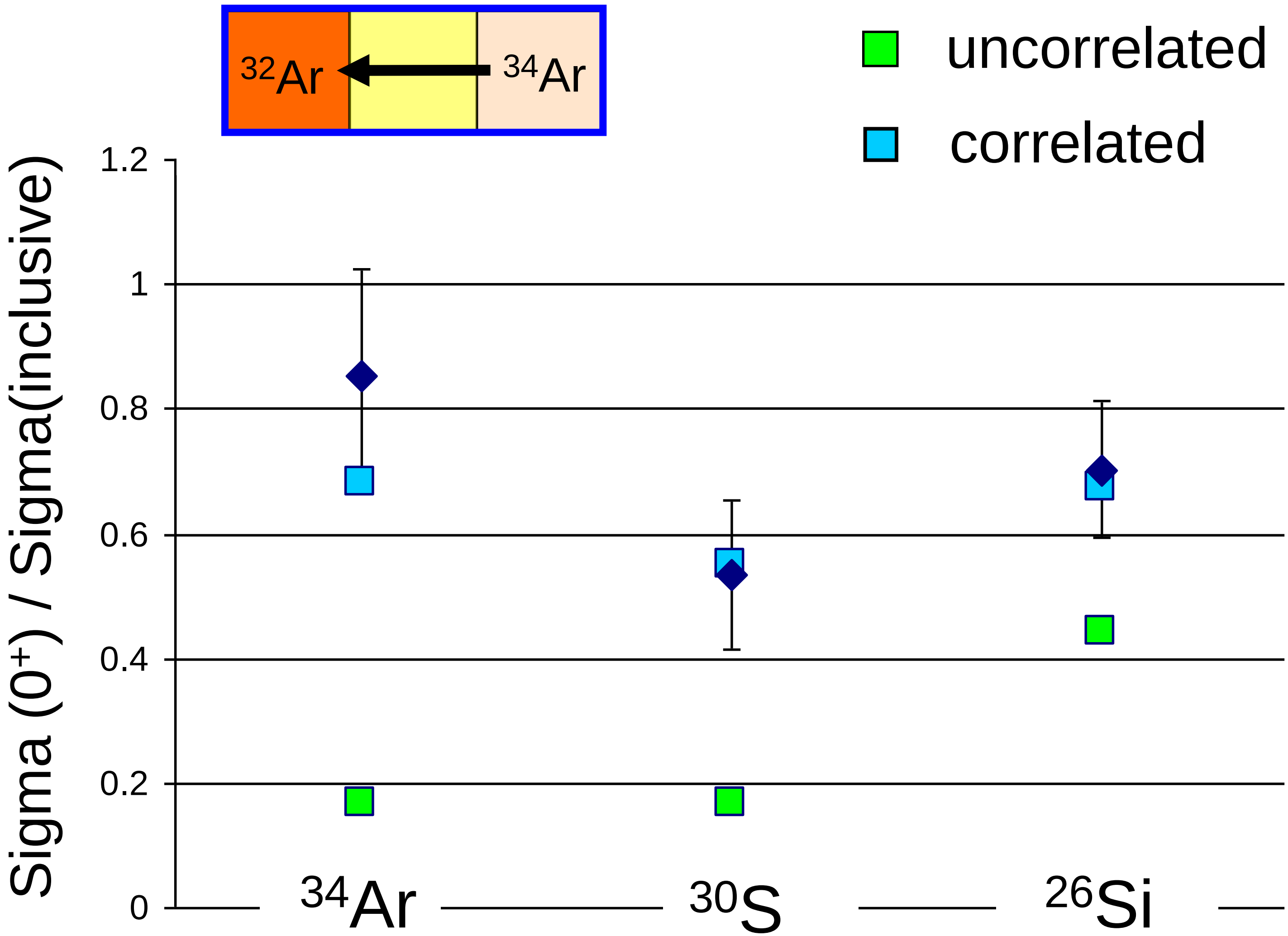
Two nucleon knockout – direct reaction set



Direct two-proton knockout: $^{38}Si \rightarrow {}^{36}Mg$



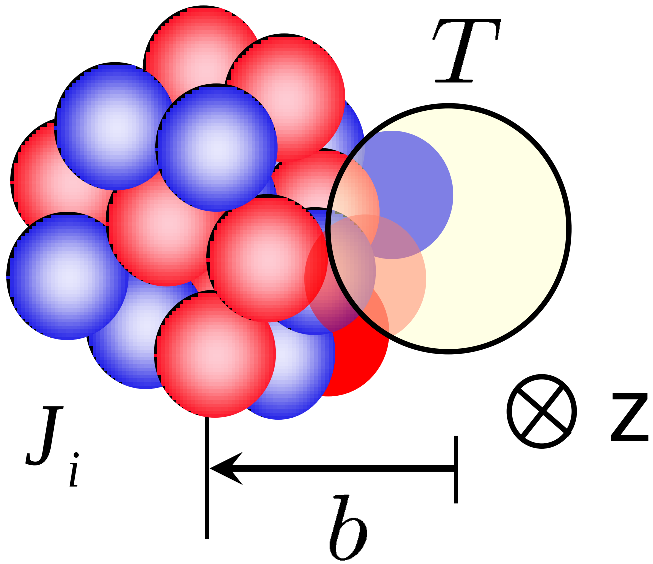
Two-neutron removal – g.s. branching ratios

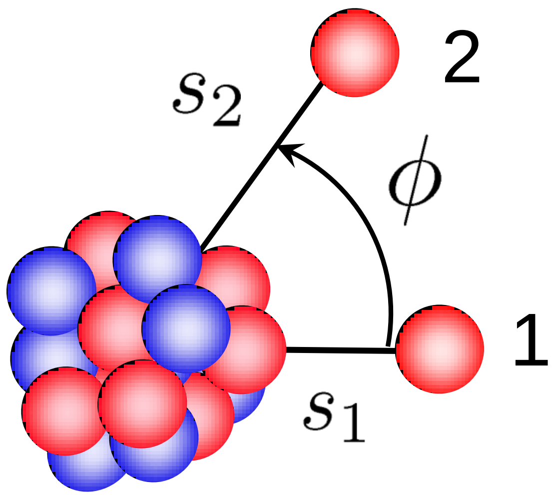


K. Yoneda *et al*., PRC 74 (2006) 021303(R)

Momentum distributions

Look at momentum content of sampled volume





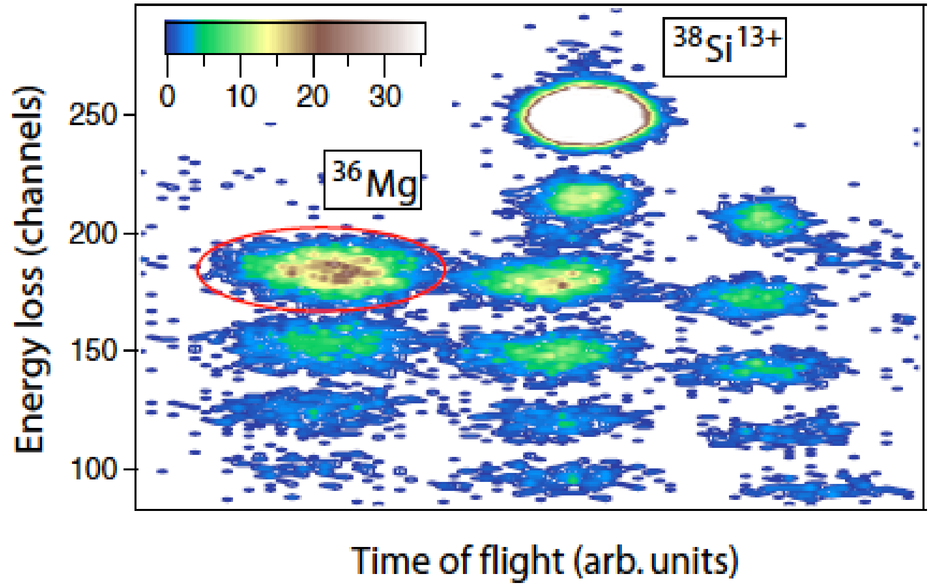
Probability of a residue with parallel momentum *K*

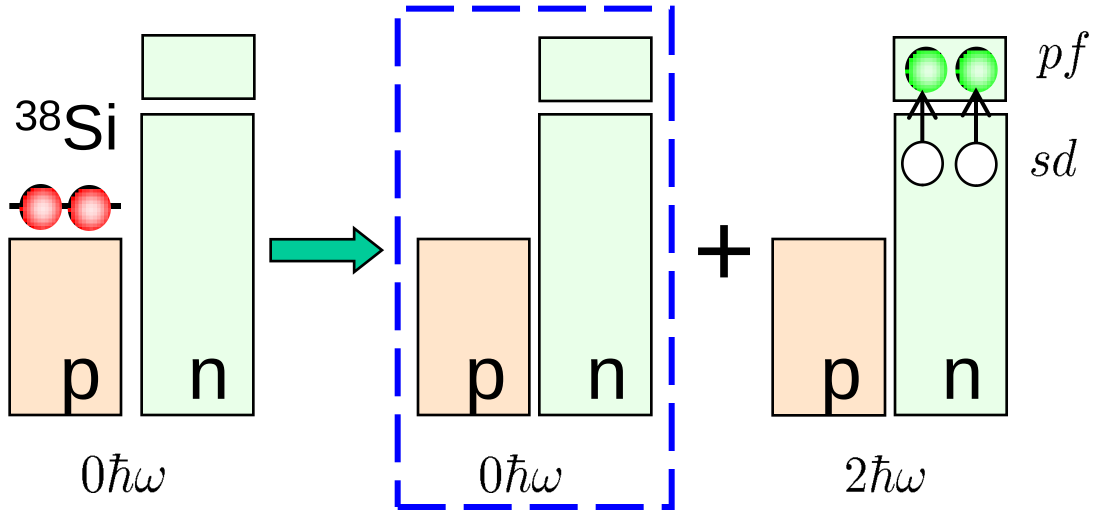
$$P(K,\vec{s}_1,\vec{s}_2) = \sum_M \Big\langle \int dk_1 \int dk_2\ \delta(K+k_1+k_2) \times \Big| \int dz_1 \int dz_2\, e^{ik_1 z_1} e^{ik_2 z_2} F_{JM}(1,2) \Big|^2 \Big\rangle_{sp}$$

J. A. Tostevin, EPJ A, in press, and Acta Physica Polonica B 38 (2007) 1195

Example: Island of Inversion extends to ^{36}Mg?

1) Insufficient yield for, e.g. secondary beam inelastic scattering
2) Parent for beta decay, ^{37}Na, is particle unbound
3) So, use 2p removal from n-rich (sd-shell) parent, ^{38}Si

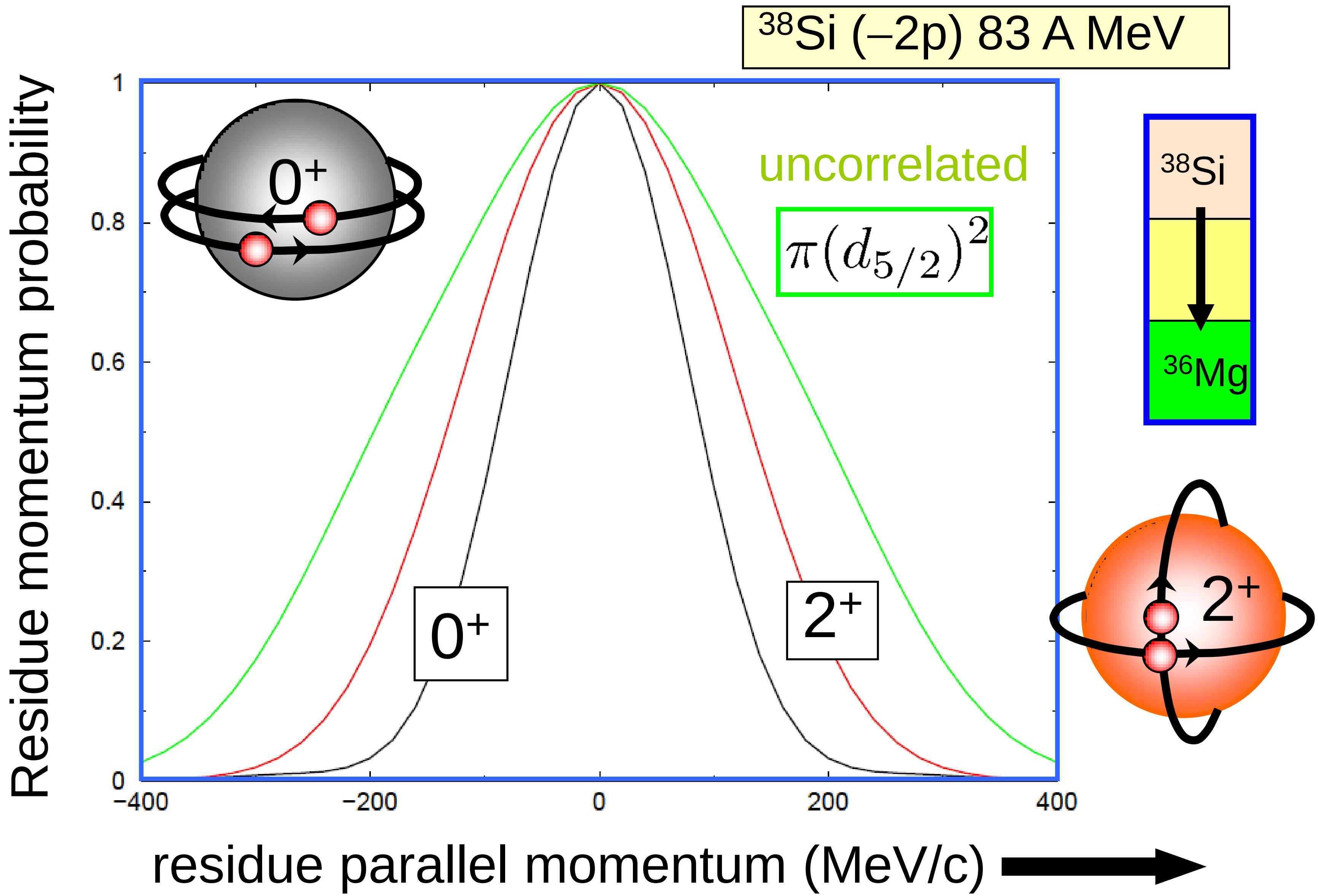




Monte-Carlo shell model calculations: SDPF-M interaction of Utsono, Otsuka *et al*.

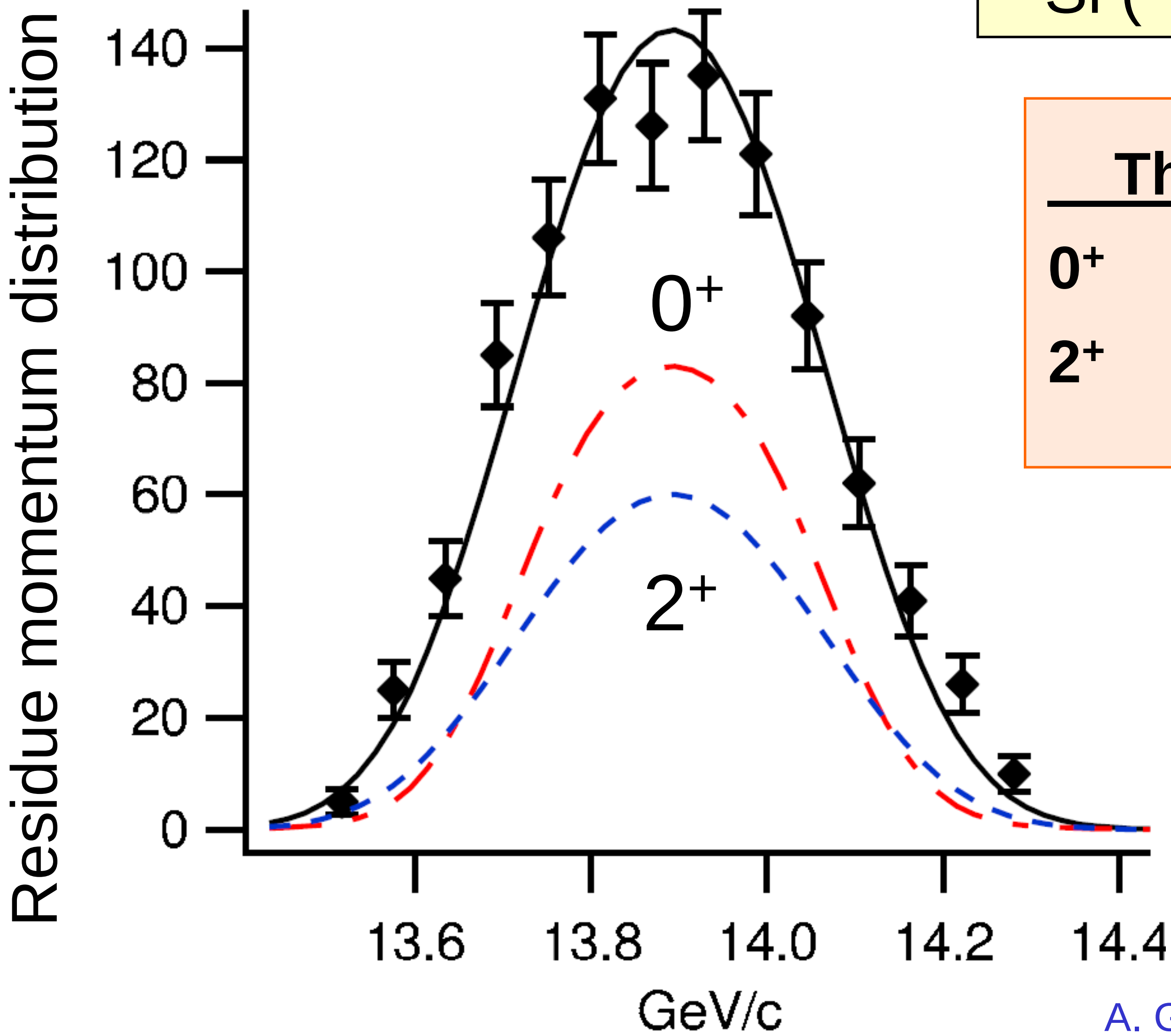
A. Gade et al., to be published

Two proton knockout from $^{38}Si \rightarrow {}^{36}Mg(0^+,2^+)$



Two proton knockout from $^{38}Si \rightarrow {}^{36}Mg(0^+,2^+)$

^{38}Si (–2p) 83 A MeV



	Theory	Expt.
0^+	56%	58(7)%
2^+	44%	42(7)%

A. Gade et al., to be published

Summary

At fragmentation energies (~100 MeV/u) reaction theory is sufficiently accurate to make quantitative predictions to test structure model predictions.

Two neutron/proton knockout data – reveal sensitivity to correlated configurations in the 2N wave functions.

It is predicted that there is valuable structure information to be gained from final-state-exclusive residue momentum distribution measurements. First data sets look very promising.

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NSCL