Nucleon knockout reactions with heavy nuclei

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Brighton PRESPEC Meeting
12th January 2011

Nucleon knockout reactions

Removal of nucleons from a (secondary radioactive) beam at energies >80 MeV/nucleon on a light nuclear target (Be, Carbon)

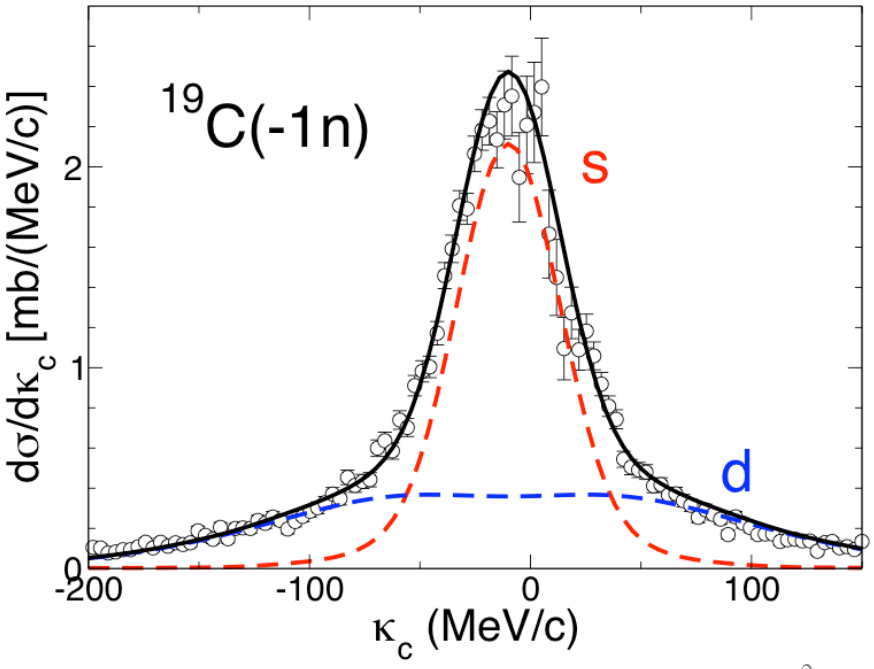
Halos: ^{15}C, ^{19}C, ^{27}P, ^{31}Ne
Magic numbers: ^{24}O, ^{42}Si
Exotic R_s: ^{23}Al, ^{23}Si, ^{27}P, ^{27}S

Absolute cross sections

- Cross section proportional to spectroscopic strength
- Suppression of spectroscopic strengths in asymmetric systems

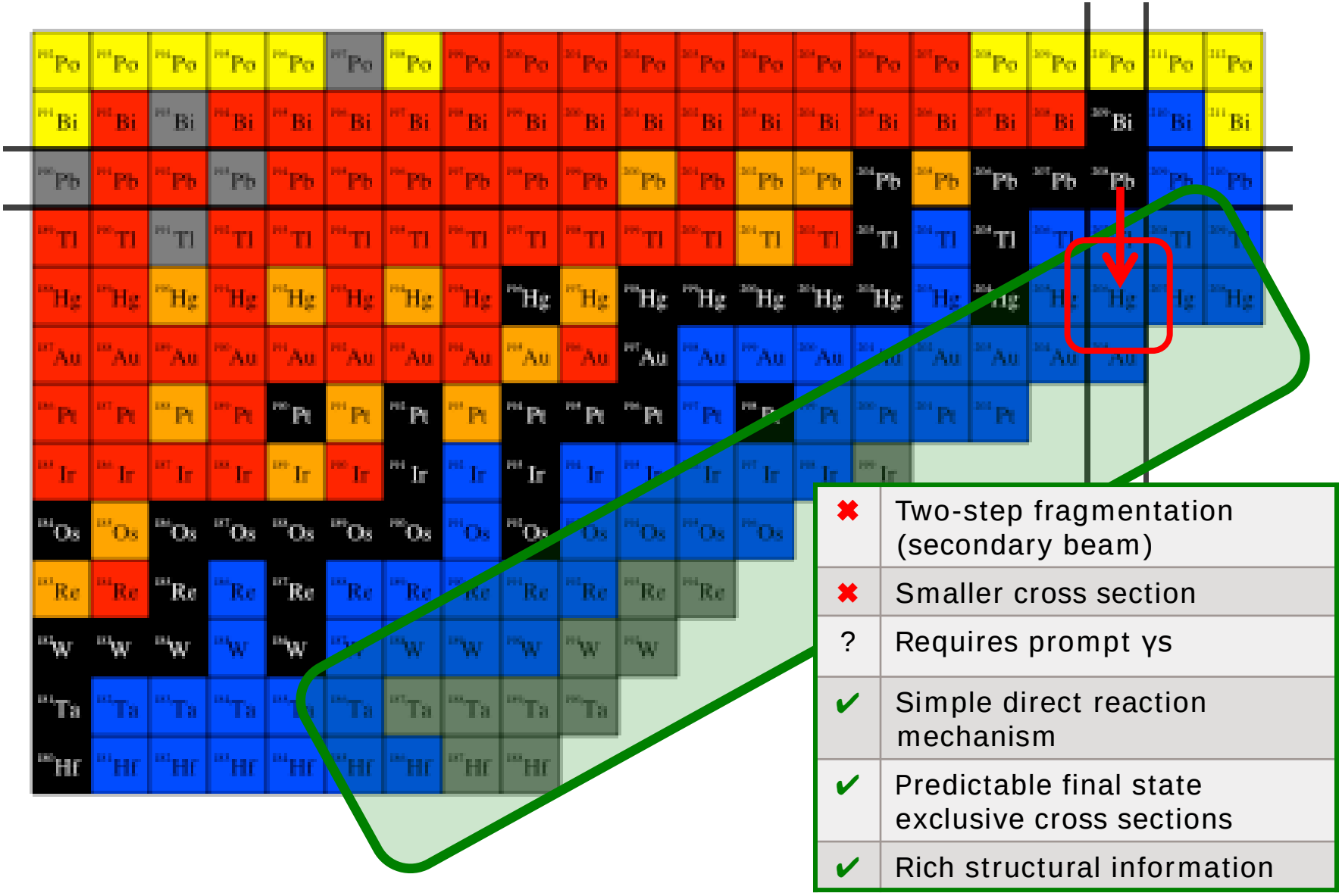
Momentum distributions

- Orbital angular momentum – final state spins, evolution of shell ordering
- Width increases with nucleon binding energy



Hansen *et al.*, Annu. Rev. Nucl. Part. Sci. 53, 219 (2003)

Knockout in heavy nuclei



✖	Two-step fragmentation (secondary beam)
✖	Smaller cross section
?	Requires prompt γs
✔	Simple direct reaction mechanism
✔	Predictable final state exclusive cross sections
✔	Rich structural information

Two-nucleon knockout

Two-nucleon overlap ($J_i=0$)

Two-nucleon amplitude (TNA)

$$\Psi_{JM} = \sum_{j_1 j_2} (-1)^{J-M} \frac{C(j_1 j_2 J)}{\sqrt{2J+1}} [\overline{\phi_{j_1} \otimes \phi_{j_2}}]_{JM}$$

Two-nucleon wave function

- Oxbash TNA using *khhe* interaction in proton [$2s_{1/2}$, $1d_{3/2}$, $0h_{11/2}$, $1d_{5/2}$, $0g_{7/2}$] model space, final state spin defined by valence nucleons: $j_1+j_2=J$
- Woods-Saxon radial wave functions, constrained by HF r.m.s. radii
- Optical-limit elastic S-matrices, density folding model, (HF calculations, reaction cross sections)

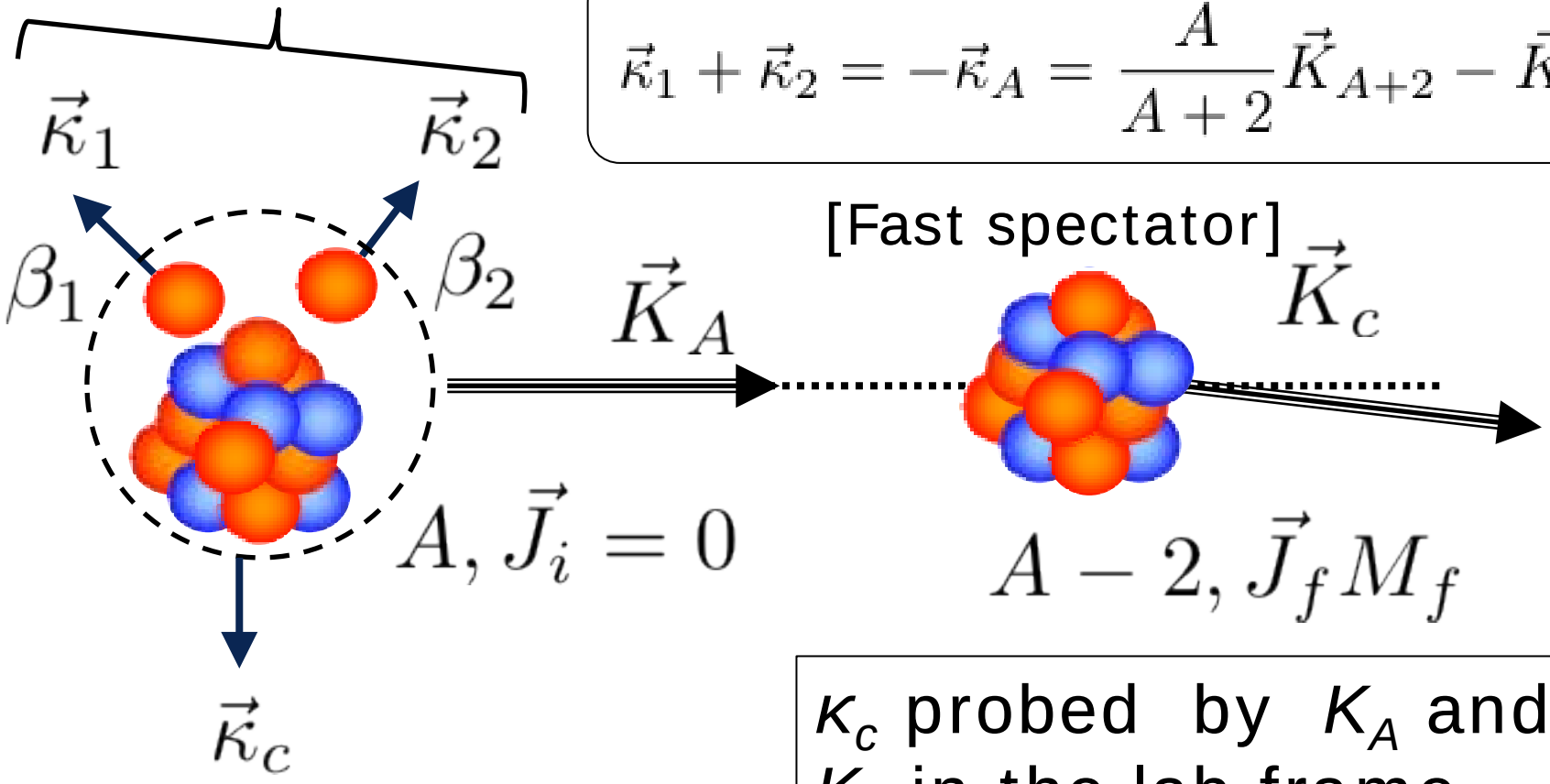
PRC 70, 064602 (2004); PRC 74, 064604 (2006);EPJ ST 150 67 (2007)

Residue momentum distributions

$$\vec{j}_1 + \vec{j}_2 = \vec{J}_f$$

Distribution sensitive to J_f

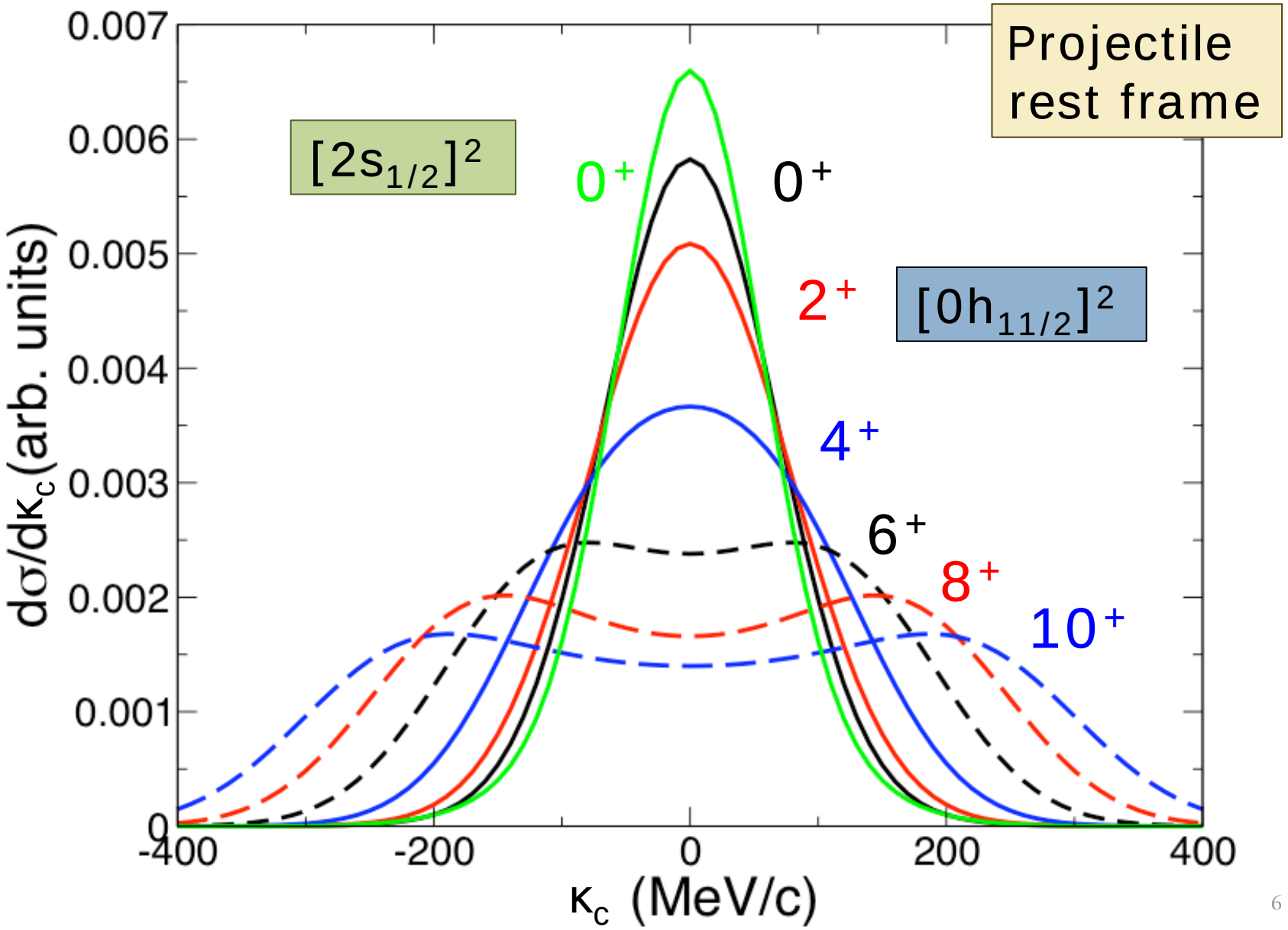
$$\vec{\kappa}_1 + \vec{\kappa}_2 = -\vec{\kappa}_A = \frac{A}{A+2}\vec{K}_{A+2} - \vec{K}_A$$



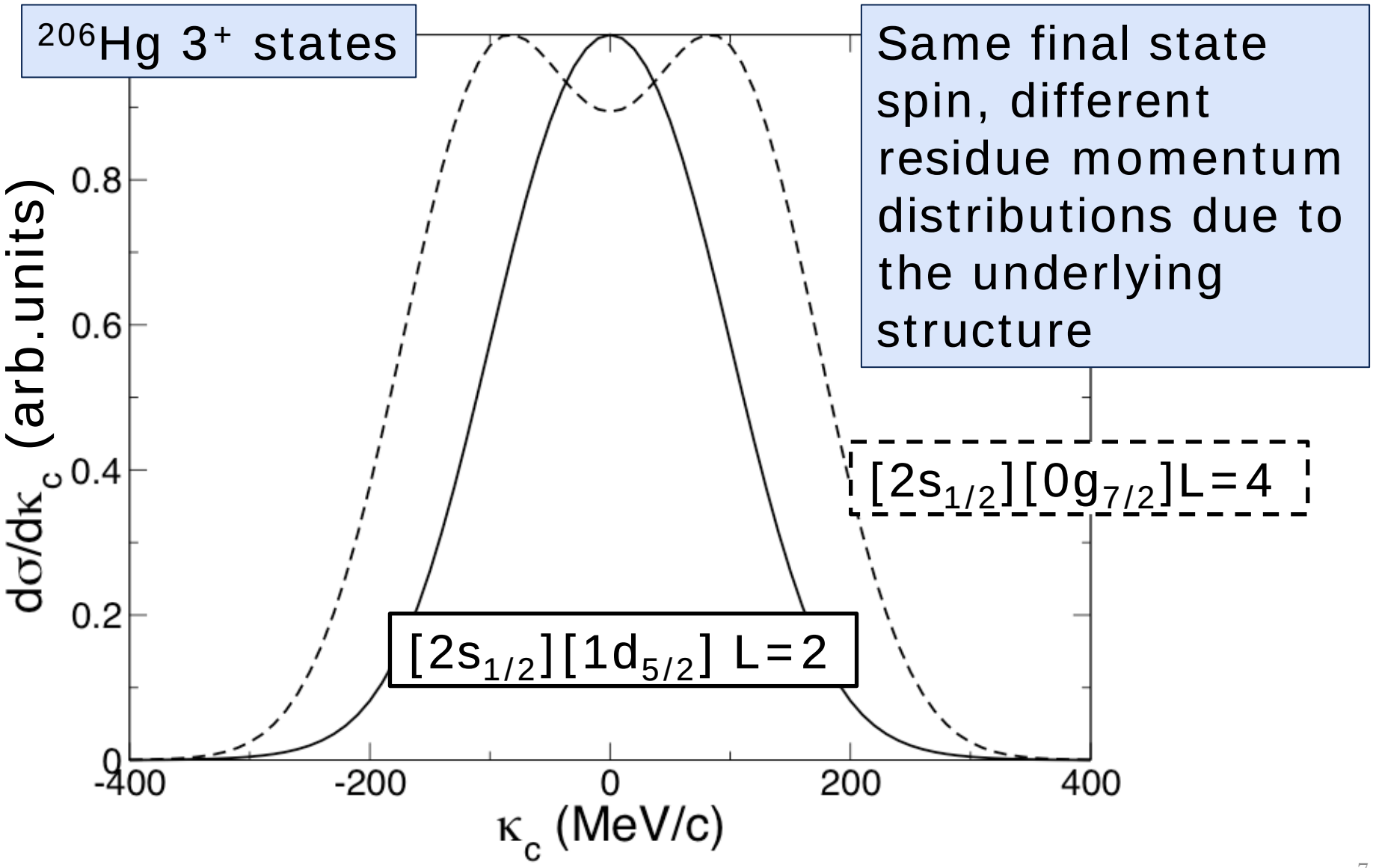
κ_c probed by K_A and K_c in the lab frame

[PRL 102, 132502 (2009); PRC 79, 064621 (2009)]

^{208}Pb(-2p) $[0h_{11/2}]^2$ Distribution



Sensitivity to underlying structure

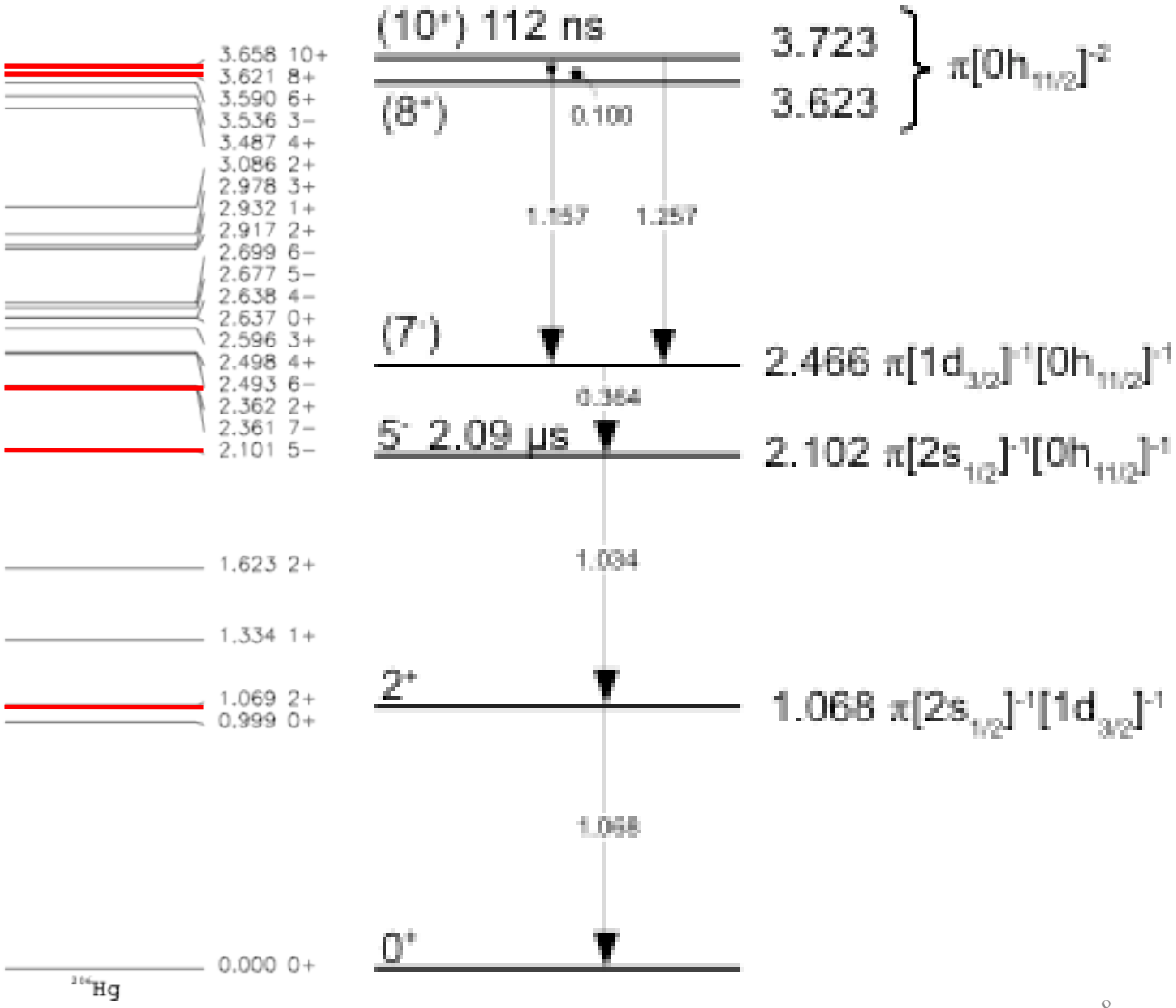


^{208}Pb(-2p): RISING Isomer Decay

Many states are expected to be populated, with σ~0.1 mb.

Density of states much higher than in light nuclei.

Most states unobserved – isomer decay only



PRC 65, 064604 (2001); PRL 87, 212501 (2001)

^{208}Pb(-2p): Isomeric ratios

Reasonable agreement once feeding is included

- Unobserved feeding?
- Cuts on momentum, affects high-spin states?

$$R_I = \frac{\sigma_I}{\sigma_T} = \frac{\int dK_A\, \sigma_I(K_A)}{\int dK_A\, \sigma_T(K_A)}$$

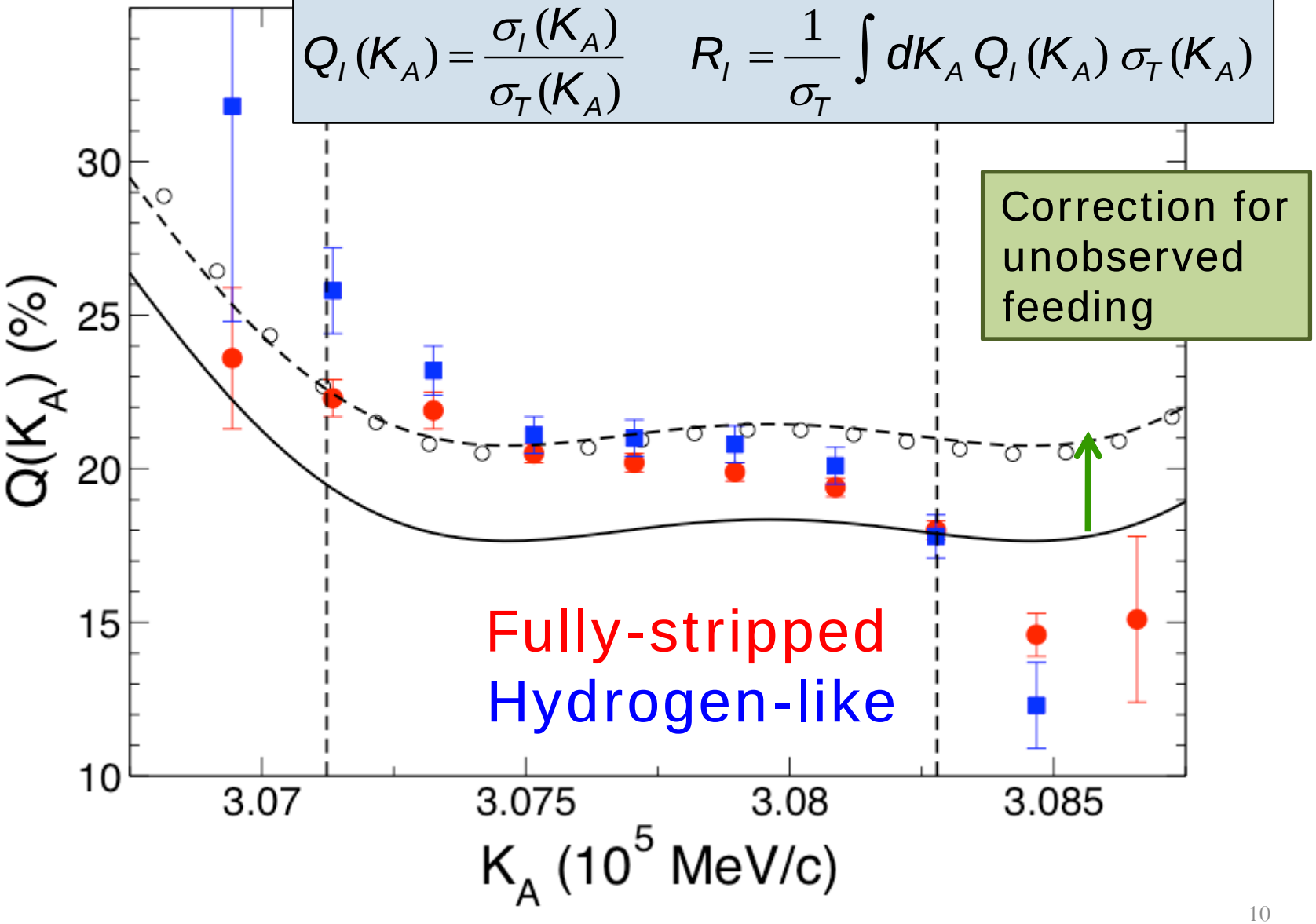
$$\sigma(K_A) \equiv \frac{d\sigma}{dK_A}$$

Isomeric state	Isomeric ratio, R_I (%)
5^- (exp)	21.9(+1.2,-2.9)
5^- (theory)	4.8
5^- (theory: 5^-, 7^-, 8^+, 10^+)	18.8 [Unobserved feeding?]
10^+ (exp)	3.1(+1.0,-1.2)
10^+ (theory)	4.7 [Differential cutting by slit?]

PRC 78, 061302 (2008); Int. J. Mod. Phys. E 18, 1002 (2008); PRC 80, 064608 (2009)

^{206}Hg differential isomeric ratios

$$Q_I(K_A) = \frac{\sigma_I(K_A)}{\sigma_T(K_A)} \qquad R_I = \frac{1}{\sigma_T}\int dK_A\, Q_I(K_A)\,\sigma_T(K_A)$$



Z. Phys. A. 250, 215 (1994); PRC 63, 064609 (2001)

Conclusions/Further work

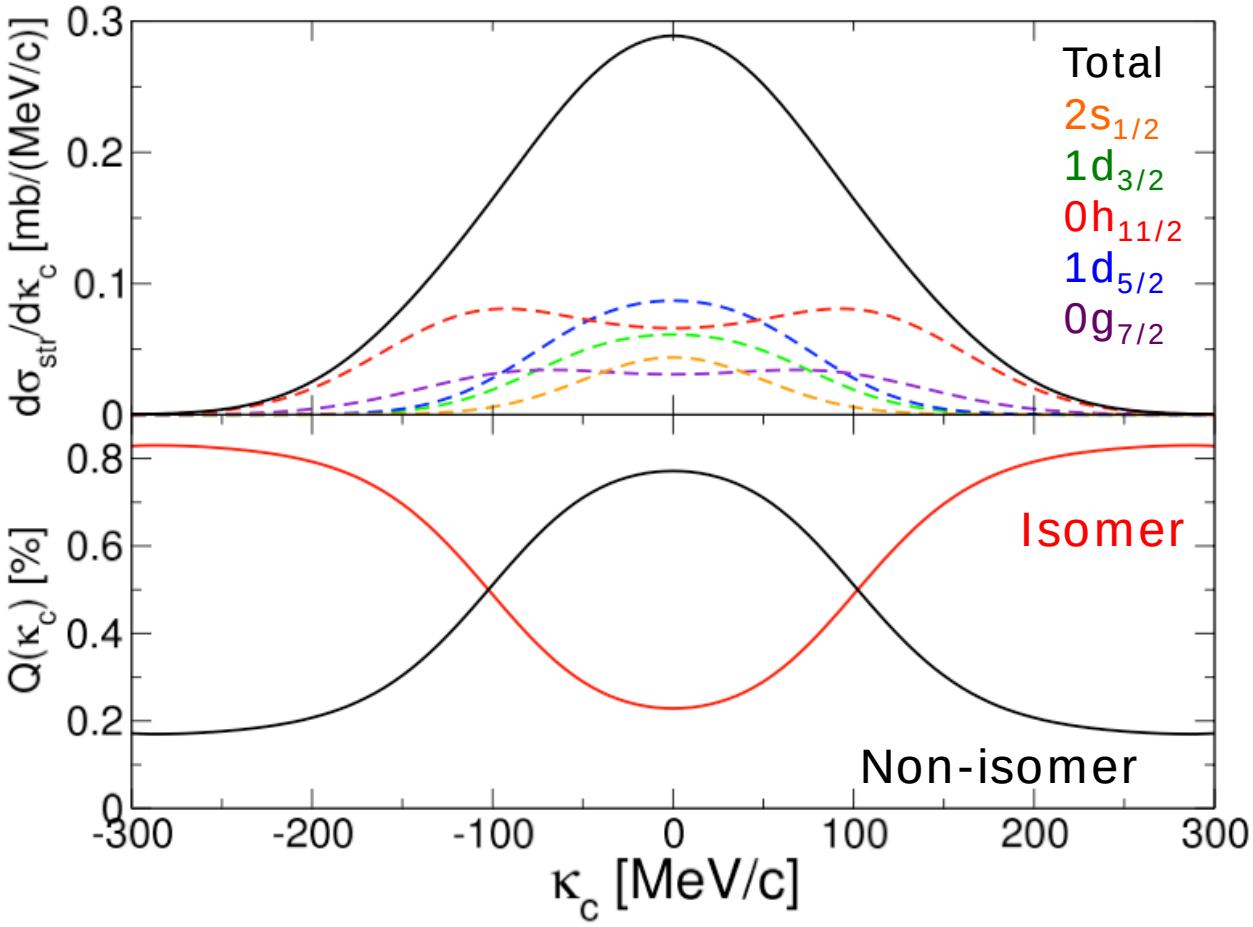
- Full exploitation of the mechanism requires prompt gamma rays…
- … and ideally final state exclusive residue momentum distributions
- Tests of mechanism – single nucleon knockout (using thin target) e.g. ^{208}Pb(-1p) --> ^{207}Tl, secondary reactions with “isomeric” beam?
- Deformed nuclei requires theoretical development, structure and reaction dynamics

^{208}Pb(-1p): test case?

Isomer: 1.33 s proton $[0h_{11/2}]^{-1}$ hole state at 1.348 MeV
Simple: five proton-hole states populated
Large cross section (~10s of mb)
Thin target: sensitivity of isomeric ratio to momentum

Momentum distribution

Population fraction



Acknowledgements

J. A. Tostevin, P. H. Regan
Zs. Podolyak, S. J. Steer

B. A. Brown

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NSCL

UK STFC Grants EP/D003628 and ST/F012012
UK EPSRC Grant EP/P503892/1