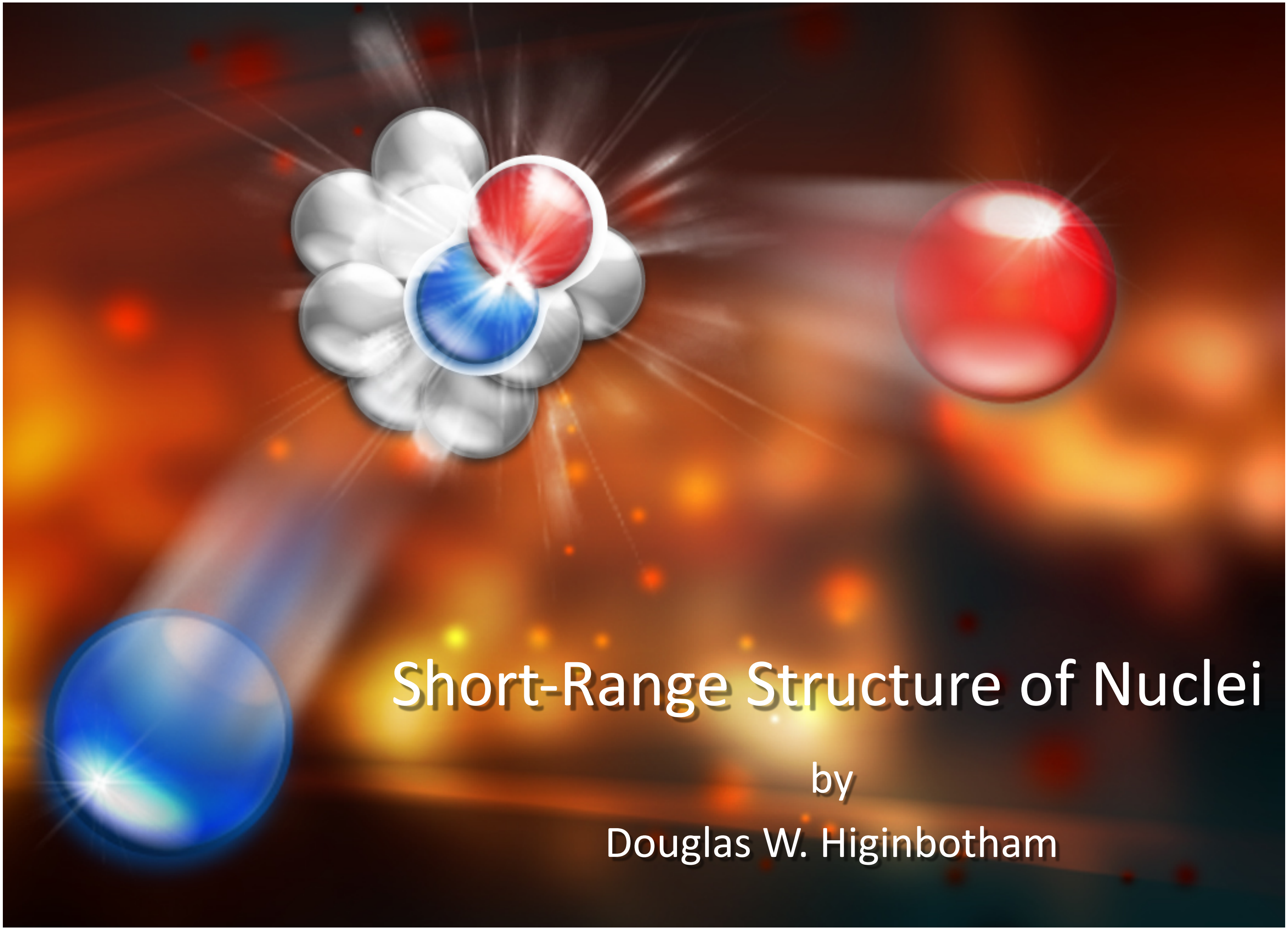


Short-Range Structure of Nuclei

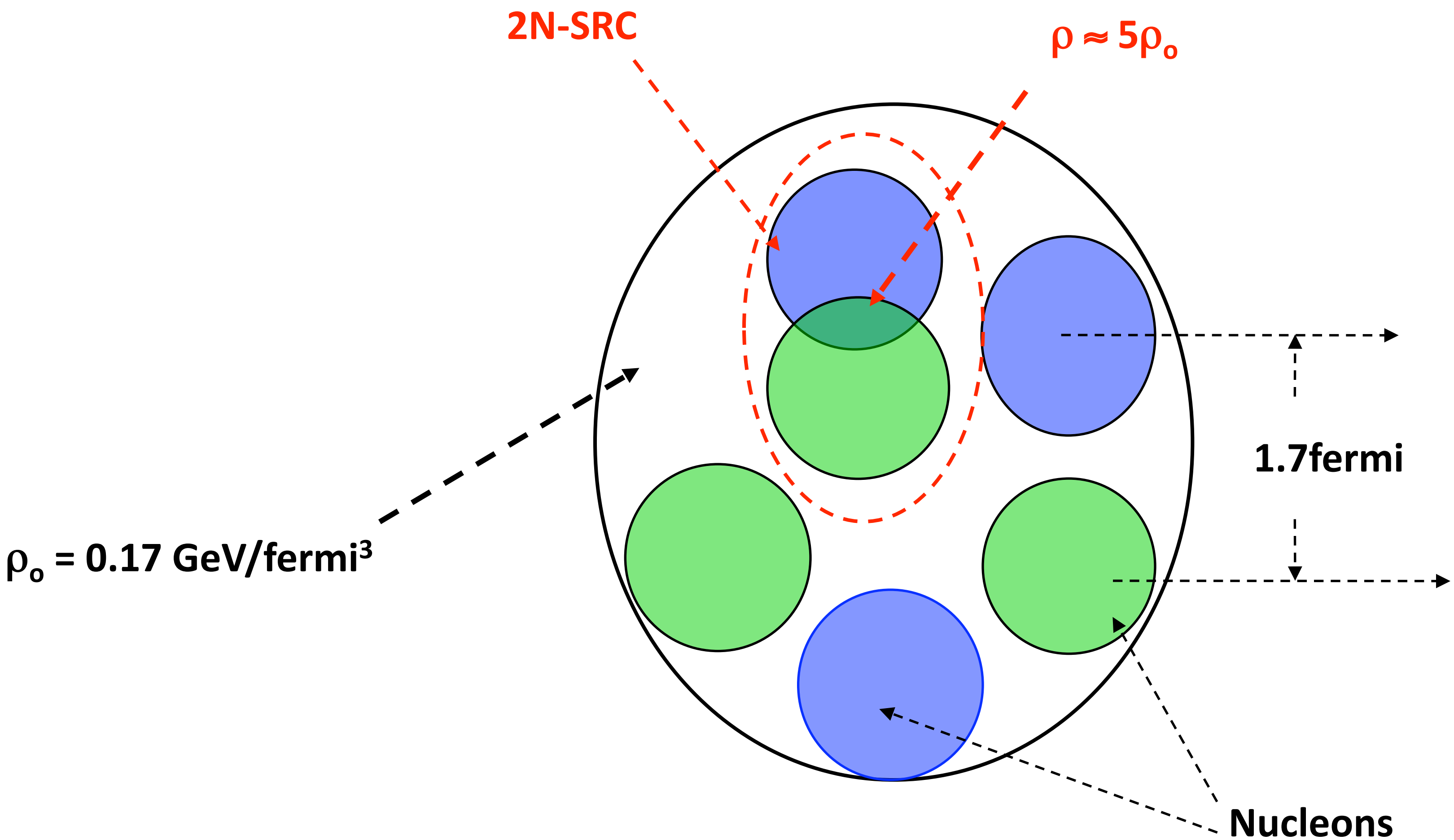
by

Douglas W. Higinbotham

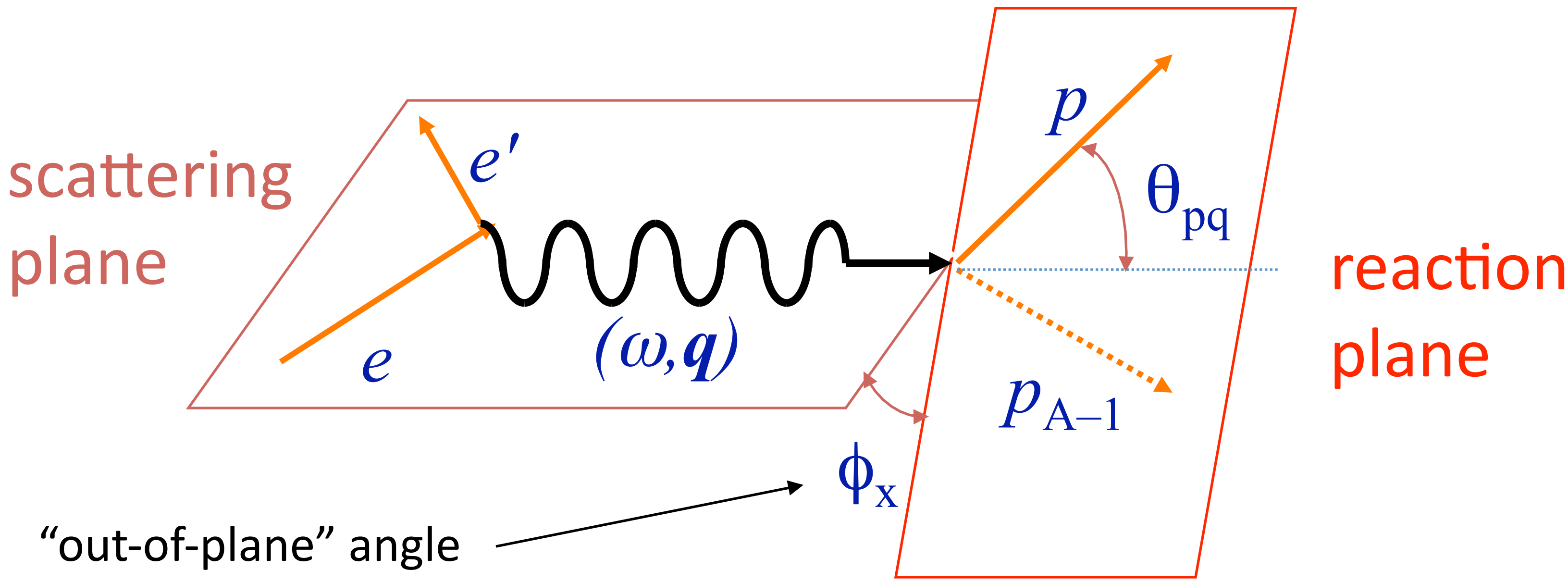
Outline of SRC Talks

- Monday Morning: History & Kinematics
- Monday Afternoon: Jefferson Lab Equipment (Tour after talk!) & Life Of An Experiment
- Tuesday Morning: Recent (e,e’) &(e,e’p) Results
- Tuesday Afternoon: Recent (e,e’pN) Results
- Wednesday: Future SRC Experiments

Short-Range Correlations



Kinematics



Four-momentum transfer: $Q^2 \equiv -q_\mu q^\mu = \boldsymbol{q}^2 - \omega^2 = 4ee' \sin^2\theta/2$

Missing momentum: $\boldsymbol{p}_{\mathrm{m}} = \boldsymbol{q} - \boldsymbol{p} = \boldsymbol{p}_{A-1} = -\boldsymbol{p}_0$

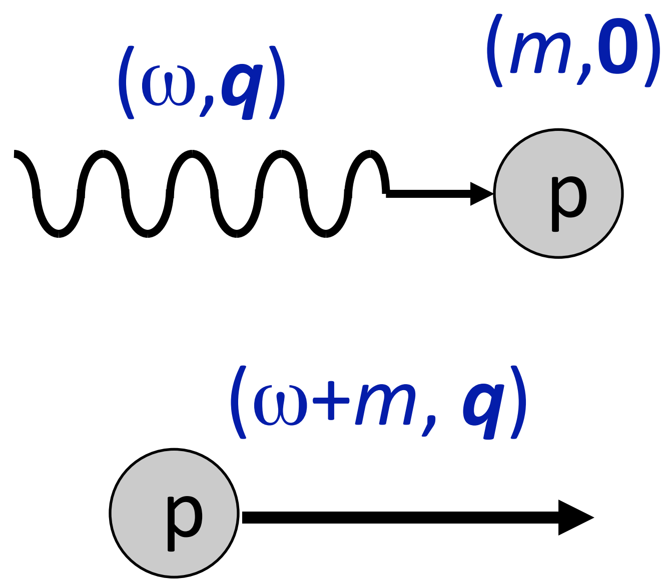
PWIA

Missing mass: $\varepsilon_{\mathrm{m}} = \omega - T_p - T_{A-1}$

Elastic Scattering from Proton

Before

After

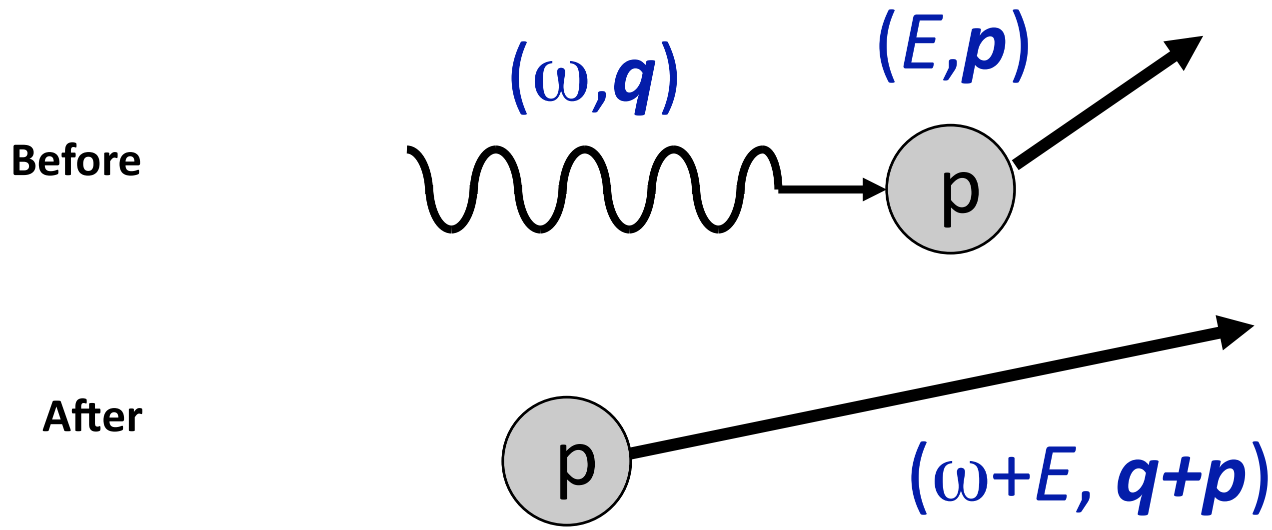


$$(\omega + m)^2 - \boldsymbol{q}^2 = m^2$$

$$\omega^2 + 2m\omega + m^2 - \boldsymbol{q}^2 = m^2$$

$$\omega = Q^2 / 2m$$

Elastic Scattering from Moving Proton



$$(\omega + E)^2 - (\boldsymbol{q}+\boldsymbol{p})^2 = m^2$$

$$\omega^2 + 2E\omega + E^2 - \boldsymbol{q}^2 - 2\boldsymbol{p}\bullet\boldsymbol{q} - \boldsymbol{p}^2 = m^2$$

$$Q^2 = 2E\omega - 2\boldsymbol{p}\bullet\boldsymbol{q}$$

$$\omega\,(E/m) = (Q^2/\,2m) + \boldsymbol{p}\bullet\boldsymbol{q}\,/\,m$$

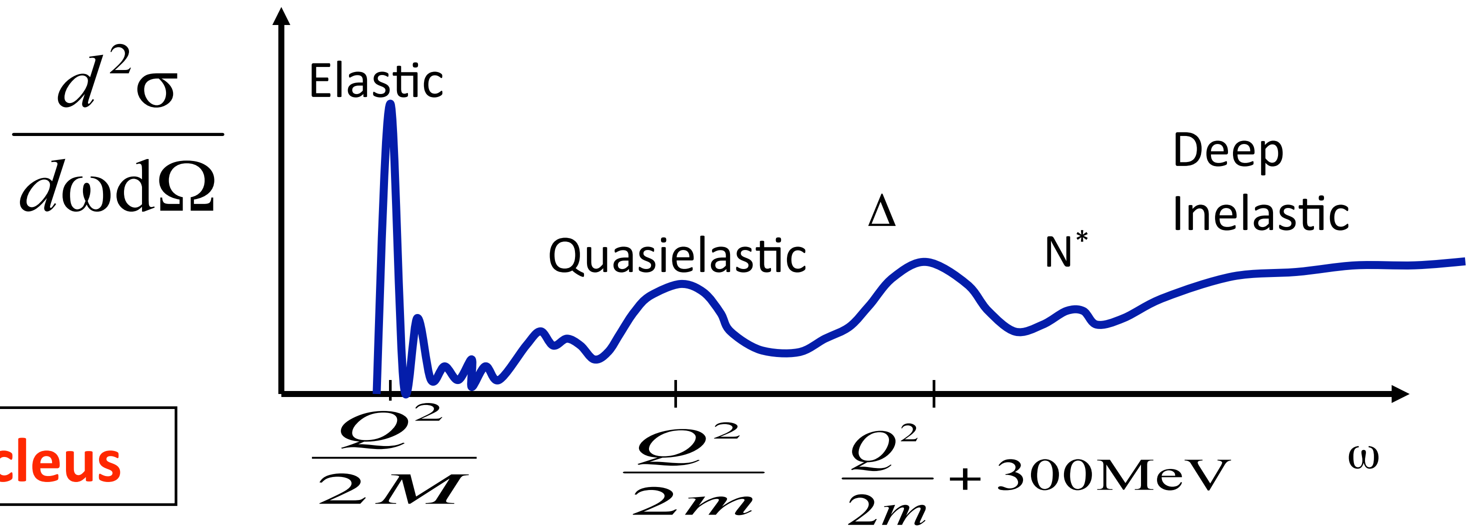
Quasi-elastic Electron Scattering

Scattering from nucleons within nucleus:

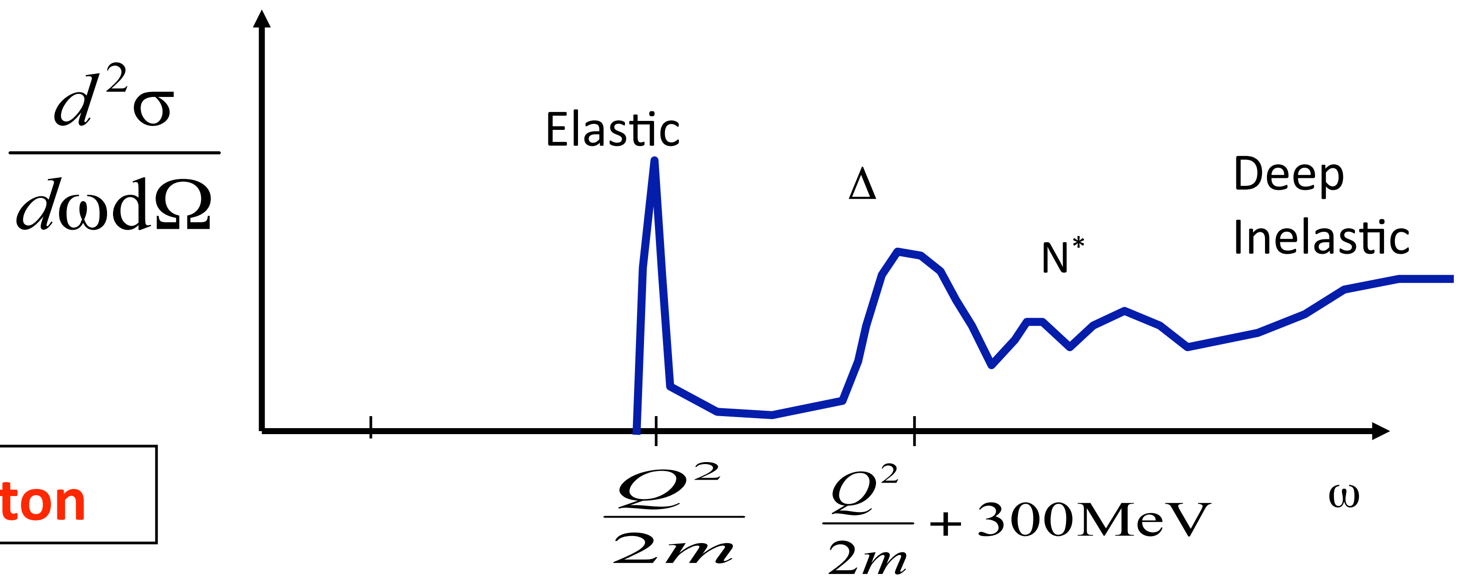
Expect peak at: $\omega \approx (Q^2/2m)$

Broadened by Fermi motion: $\boldsymbol{p}\bullet\boldsymbol{q}/m$

Electron Scattering at Fixed Q^2

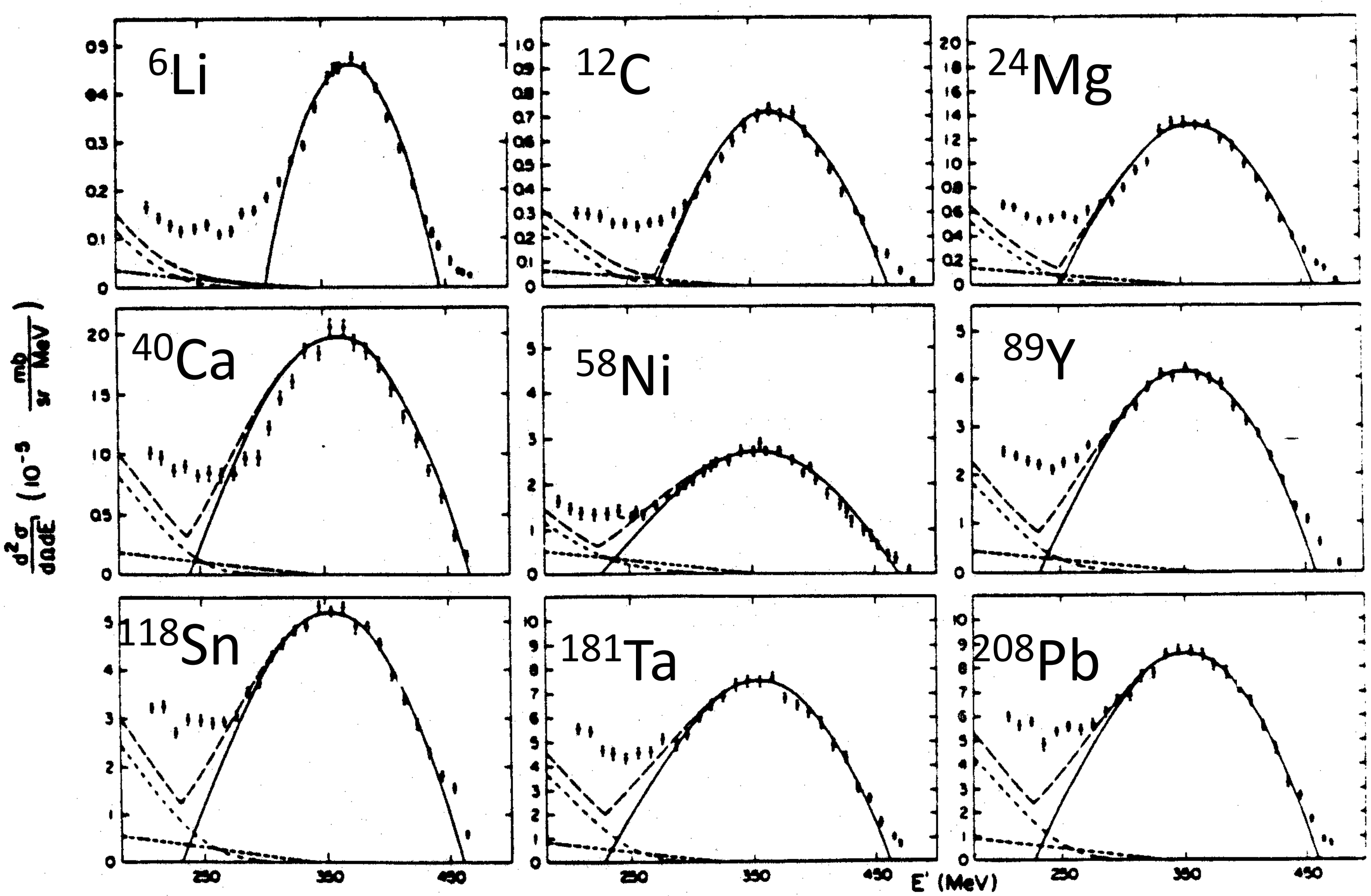


Nucleus



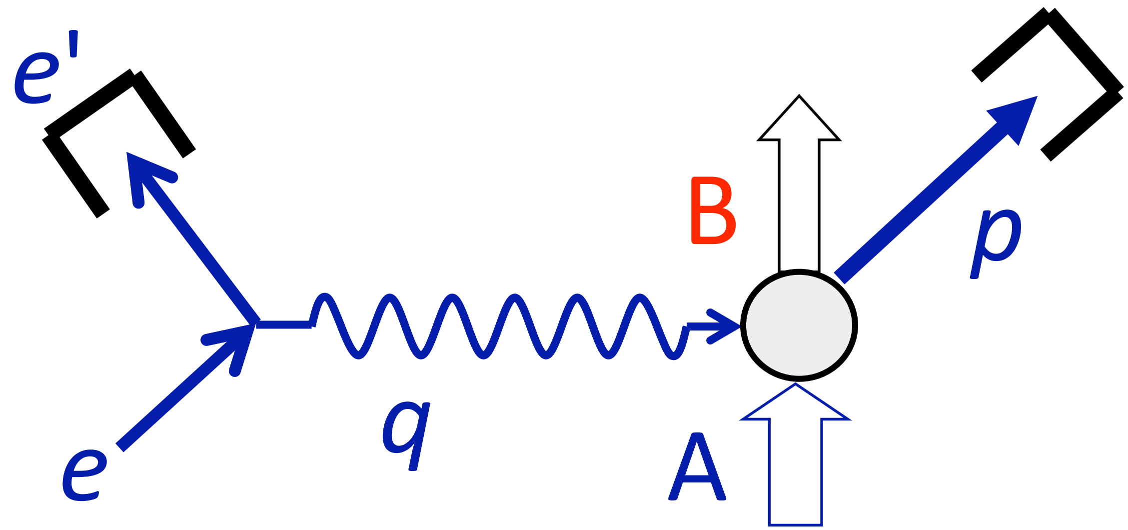
Proton

Quasi-elastic Electron Scattering Data



R.R. Whitney *et al.*, Phys. Rev. C **9**, 2230 (1974).

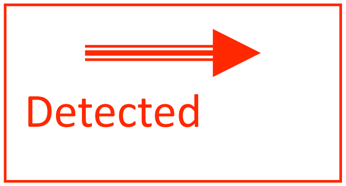
Basic A(e,e'p)B Experiment

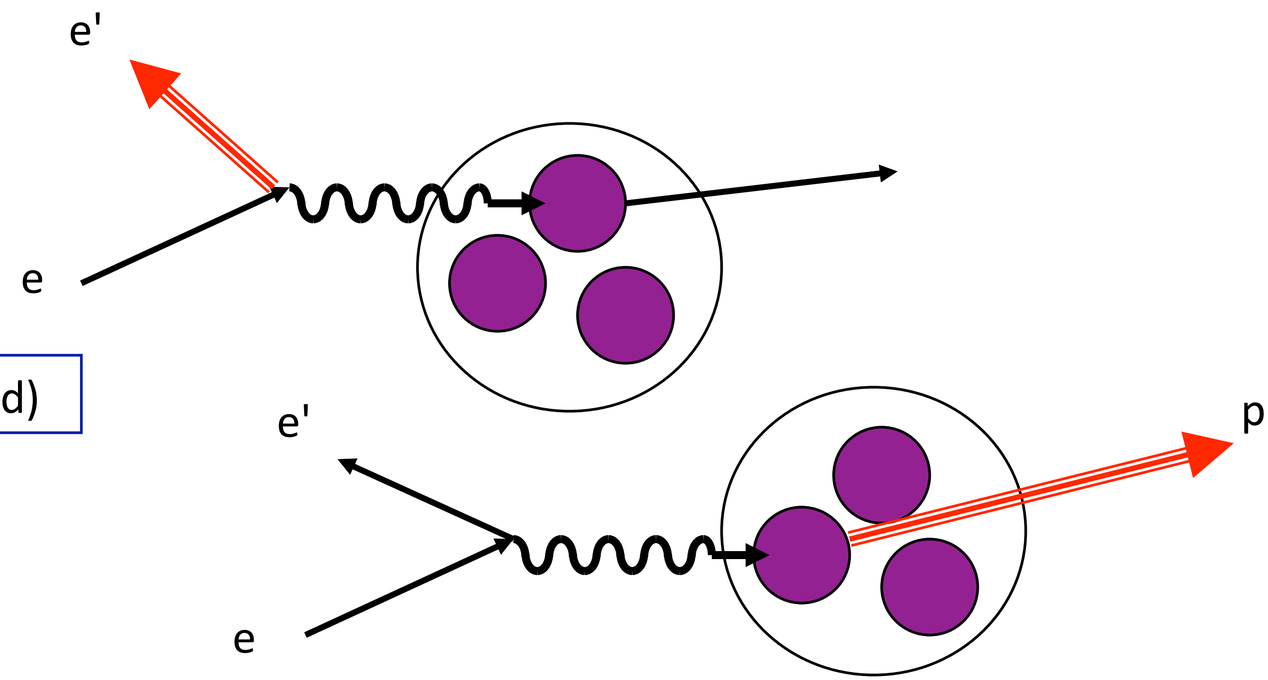


Know: *e* and A

Detect: *e'* and *p*

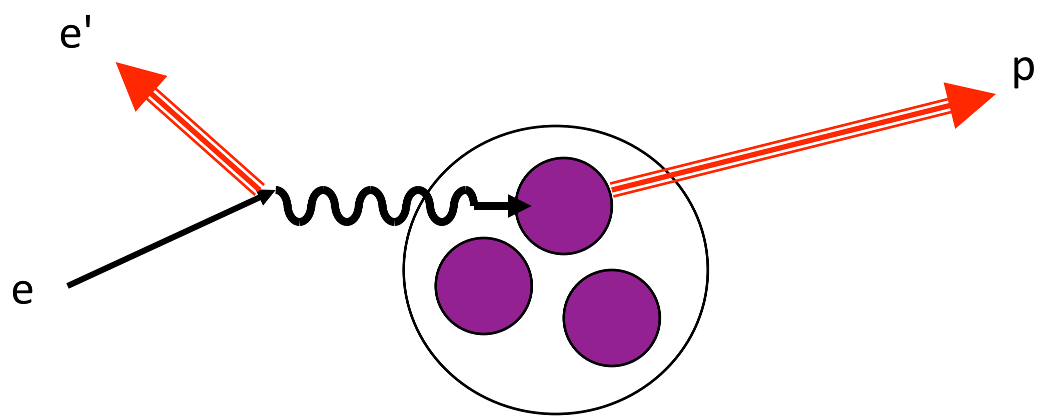
Missing momentum: $\boldsymbol{p}_{\mathrm{m}} = \boldsymbol{q} - \boldsymbol{p} = \boldsymbol{p}_{\mathrm{B}}$



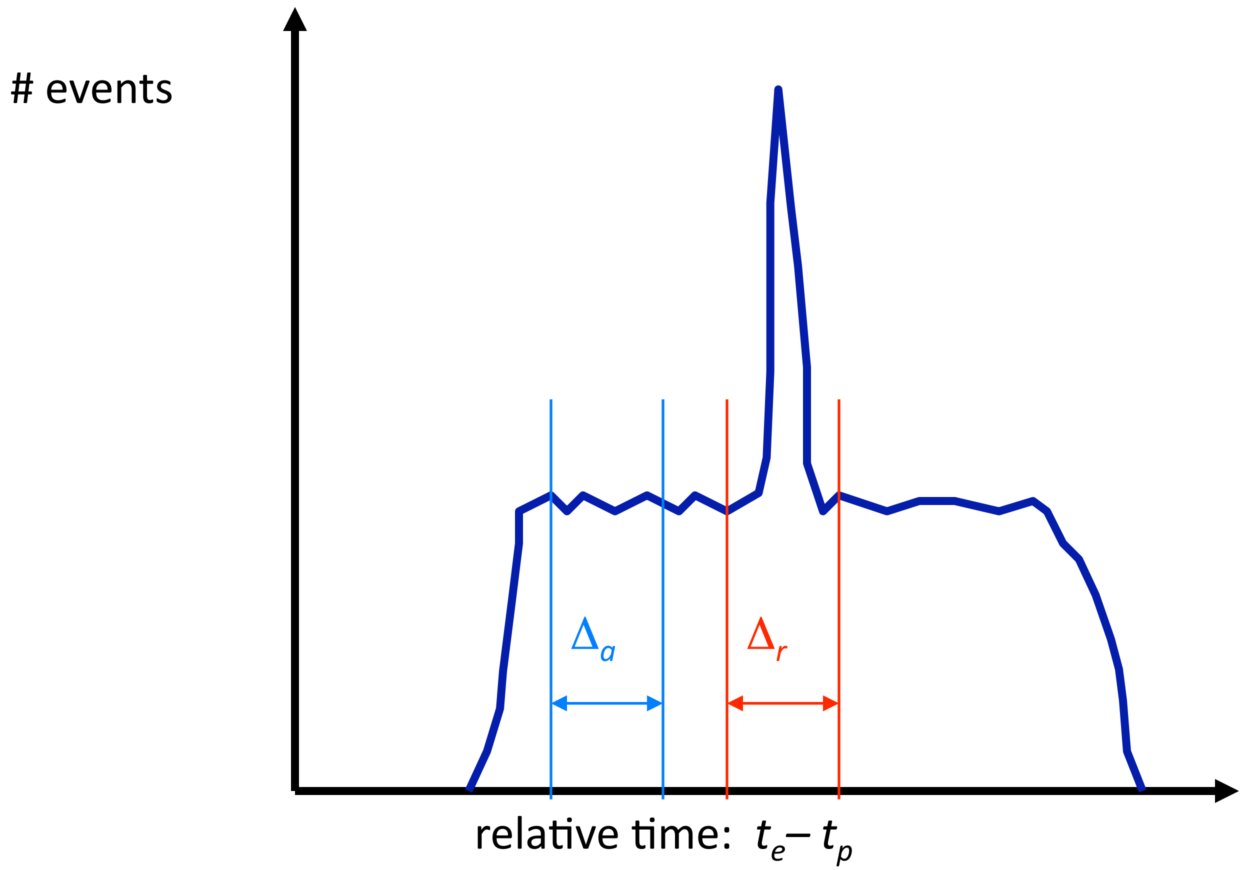


“accidental” (uncorrelated)

“real” (correlated)



Reals and Accidentals

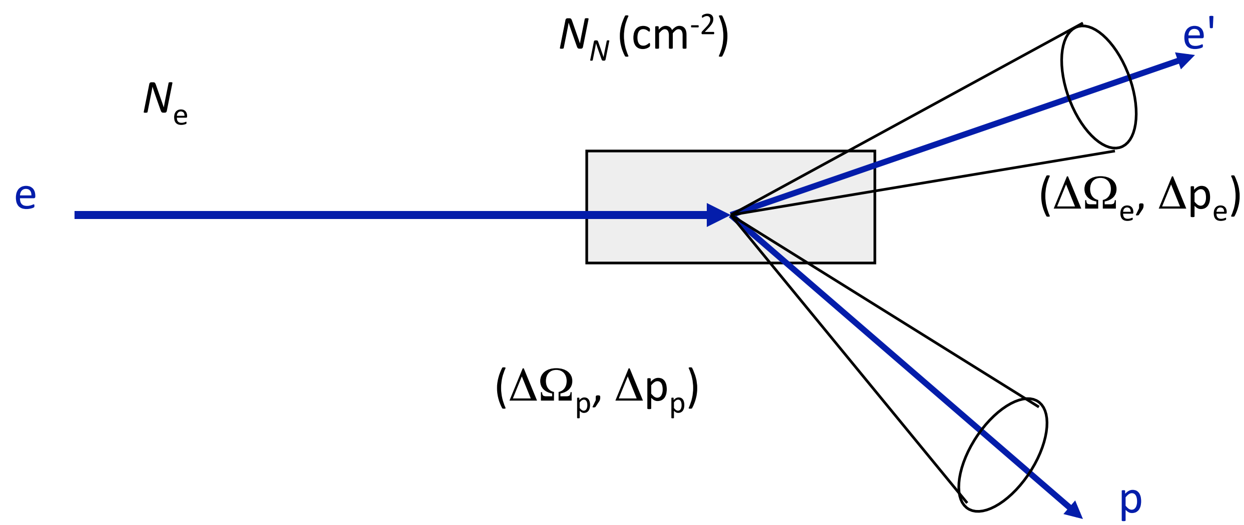


Accidentals Rate = $\boldsymbol{R_e \times R_p \times \Delta\tau/\mathrm{DF} \propto I^2\,\Delta\tau/\mathrm{DF}}$

Reals Rate = $\boldsymbol{R_{eep} \propto I}$

$\boldsymbol{S{:}N}$ = Reals/Accidentals $\propto$ $\boldsymbol{\mathrm{DF}\,/(\Delta\tau * I)}$

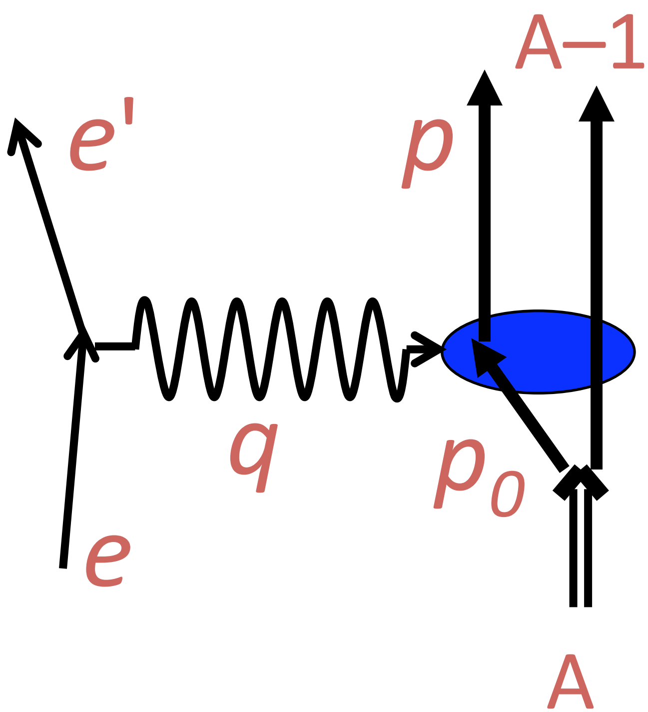
Extracting the Cross Section

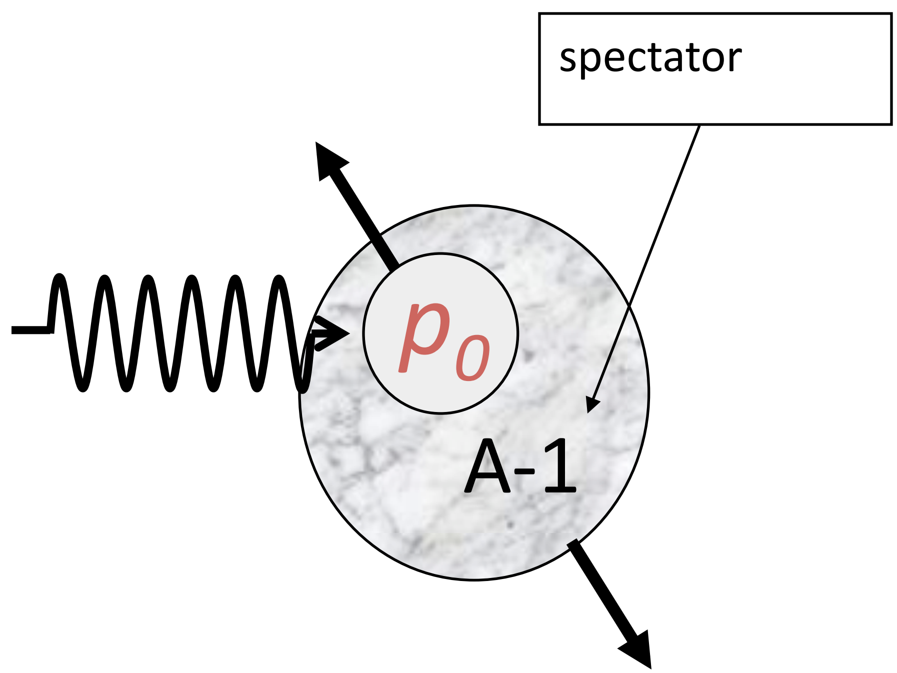


$$\left\langle \frac{d^6\sigma}{d\Omega_e d\Omega_p dp_e\, dp_p} \right\rangle = \frac{\text{Counts}}{N_e N_N \Delta\Omega_e \Delta\Omega_p \Delta p_e \Delta p_p}$$

Simple Theory Of Nucleon Knock-out

Plane Wave Impulse Approximation (PWIA)





$$\boldsymbol{q} - \boldsymbol{p} = \boldsymbol{p}_{\text{A-1}} = \boldsymbol{p}_{\text{m}} = -\boldsymbol{p}_{0}$$

Spectral Function

In nonrelativistic PWIA:

$$\frac{d^6\sigma}{d\omega\, d\Omega_e\, dp\, d\Omega_p} = K \boxed{\sigma_{ep}} \boxed{S(p_m, \varepsilon_m)}$$

e-p cross section

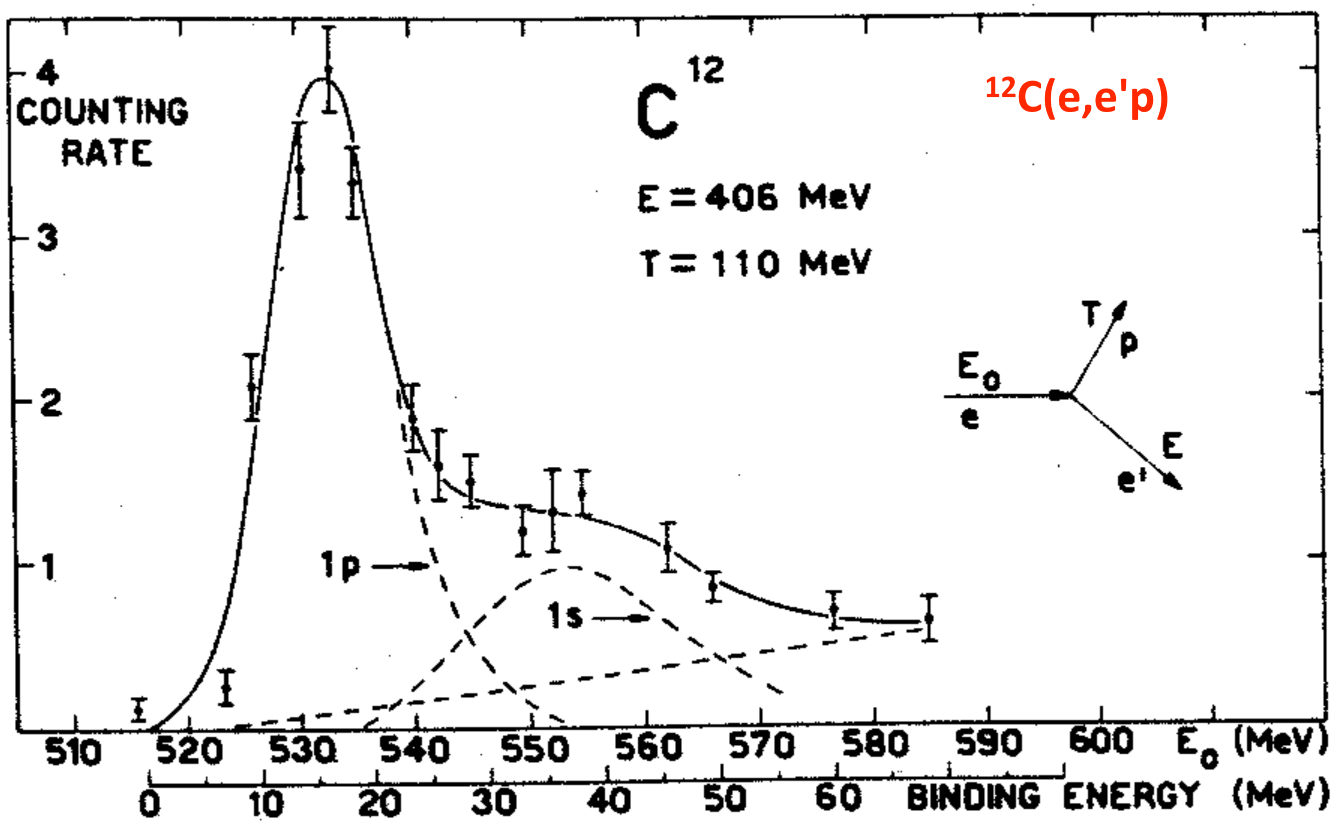
nuclear spectral function

For bound state of recoil system:

proton momentum distribution

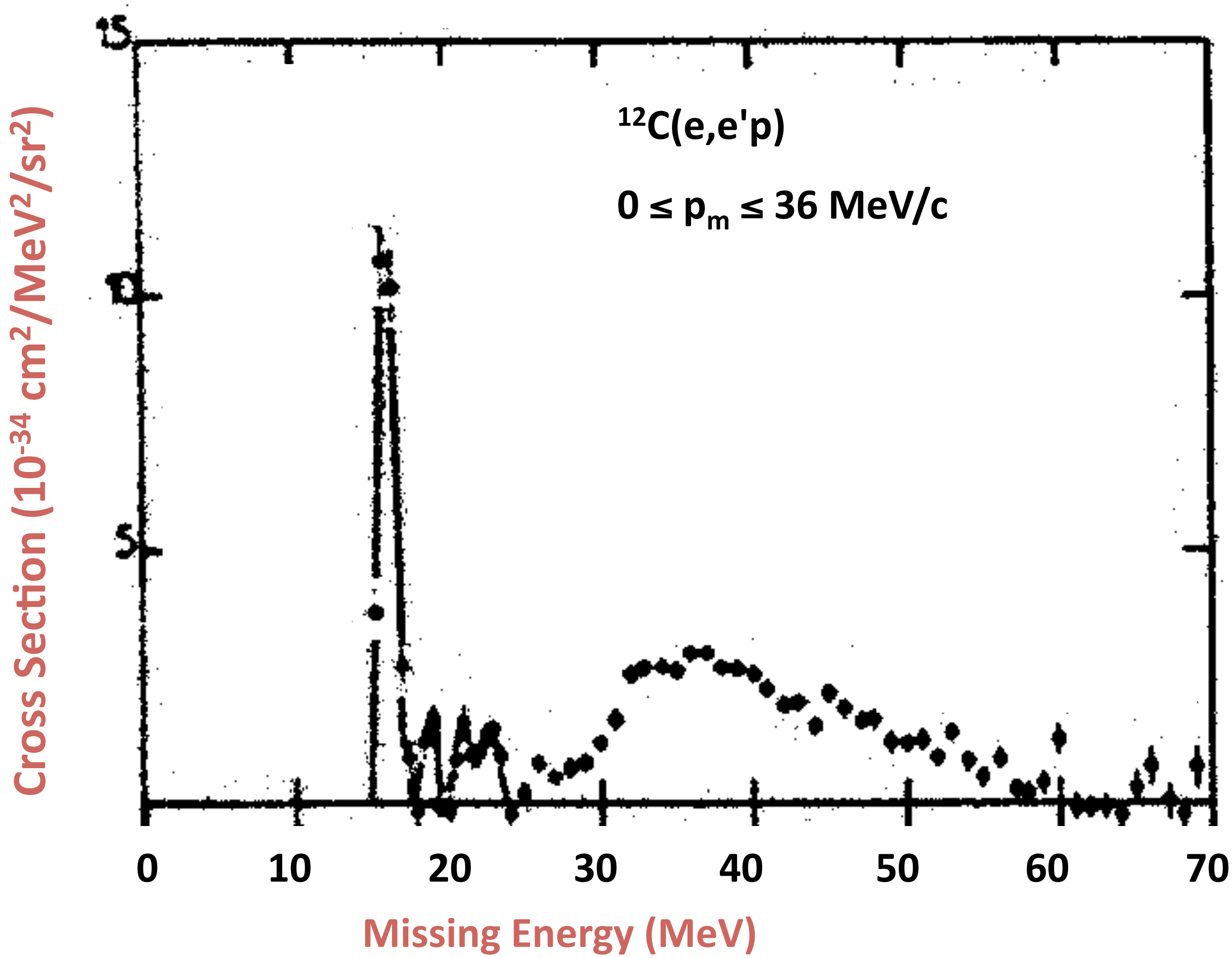
$$\rightarrow \frac{d^5\sigma}{d\omega\, d\Omega_e\, d\Omega_p} = K' \sigma_{ep} \boxed{\left|\Phi(p_m)\right|^2}$$

1964: Frascati Synchrotron



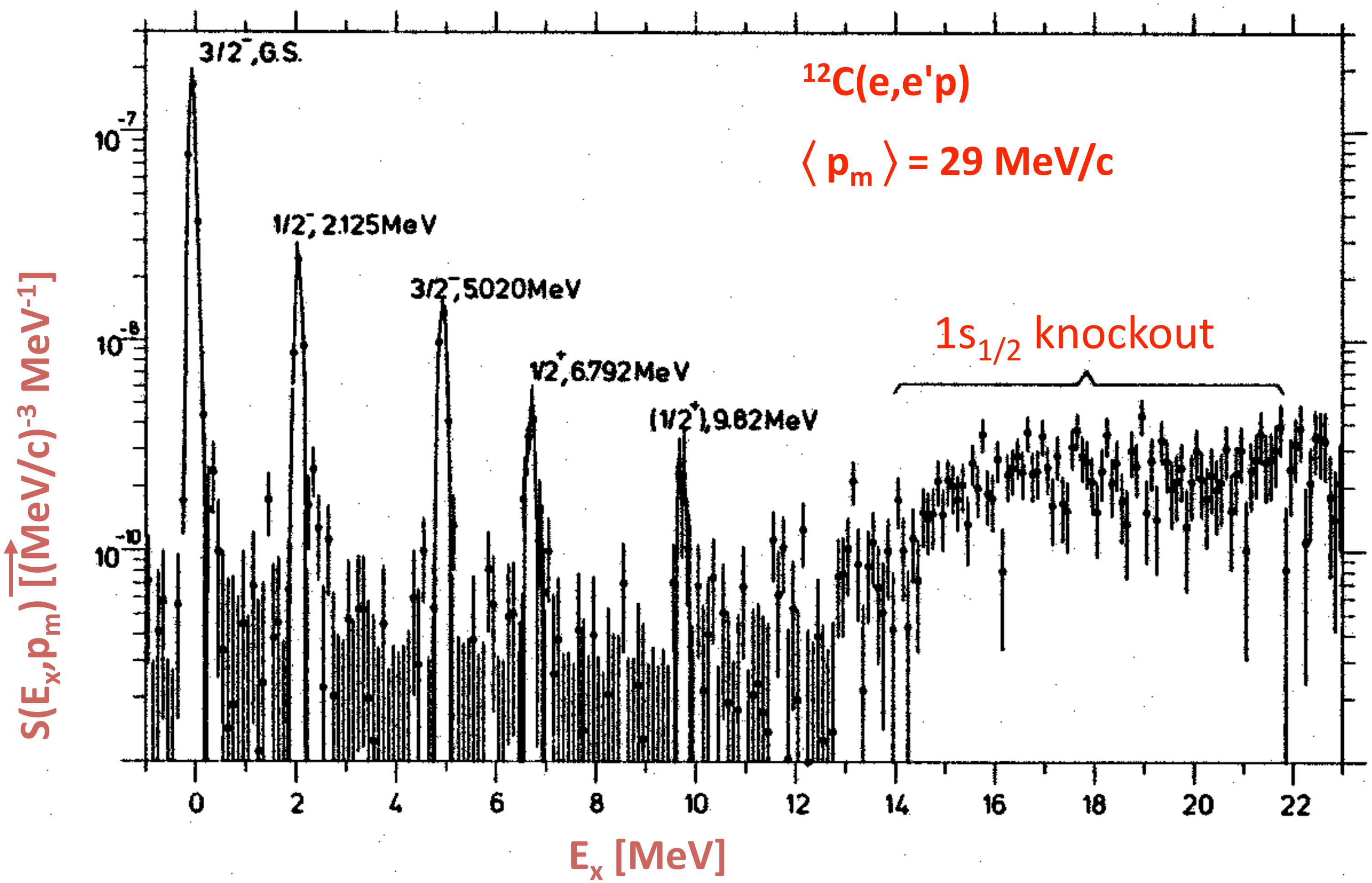
U. Amaldi, Jr. *et al.*, Phys. Rev. Lett. **13**, 341 (1964).

1976: Saclay



J. Mougey *et al.,* Nucl. Phys. **A262**, 461 (1976).

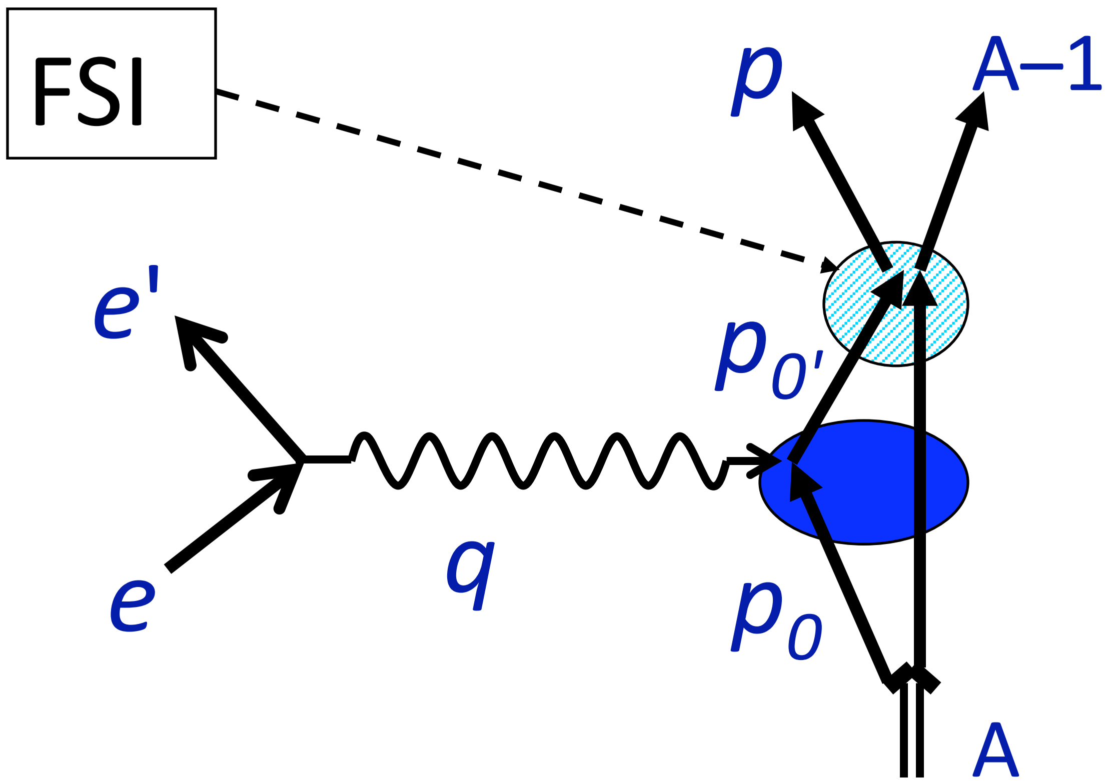
1988: NIKHEF



G. van der Steenhoven *et al.*, Nucl. Phys. **A484**, 445 (1988).

Reaction Mechanisms

Example: Final State Interactions (FSI)



$$\boxed{\vec{q} - \vec{p} = \vec{p}_{A-1} \neq \vec{p}_0}$$

Improve Theory

Distorted Wave Impulse Approximation (DWIA)

$$\frac{d^6\sigma}{d\Omega_e d\Omega_p dp\, d\omega} = K\, \sigma_{ep} \boxed{S^D(p_m, \varepsilon_m, p)}$$

"Distorted" spectral function

p-shell l=1

s-shell l=0

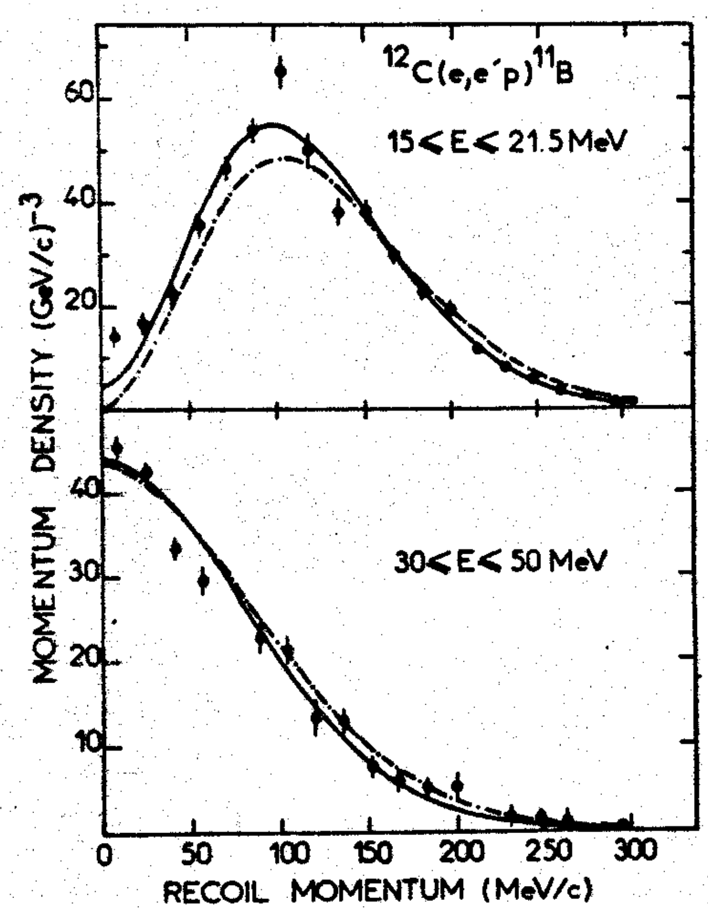
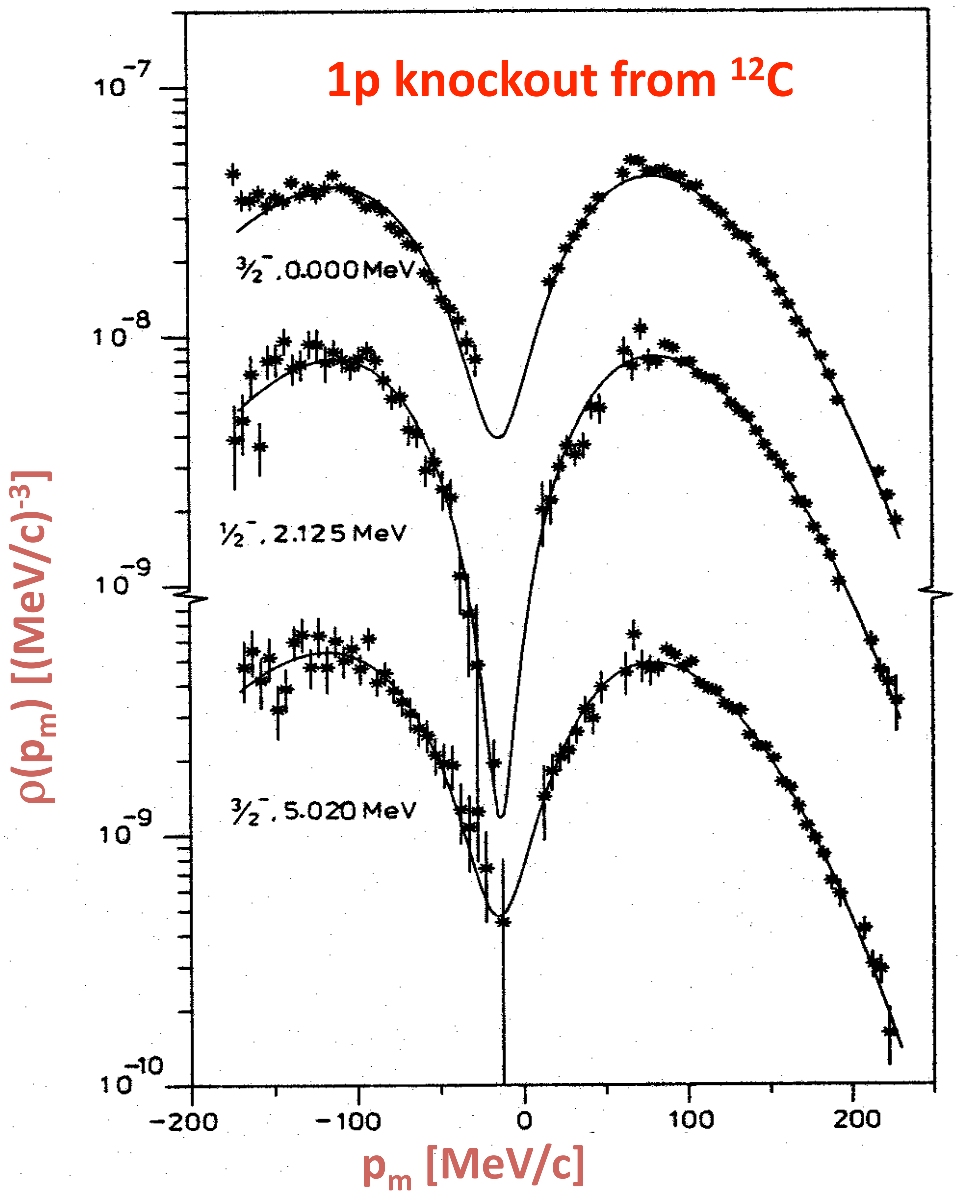


Fig. 10. Momentum distribution from $^{12}C(e, e'p)$; (a) $15 \leqq E \leqq 21.5$ MeV and (b) $30 \leqq E \leqq 50$ MeV. The solid and dashed lines represent DWIA and PWIA calculations respectively, with normalization obtained by a fit to the data.

$^{12}C(e,e'p)^{11}B$

Saclay Linac, France

J. Mougey *et al.,* Nucl. Phys. **A262**, 461 (1976).



$^{12}C(e,e'p)^{11}B$

DWIA calculations give correct shapes, but:

Missing strength observed.

NIKHEF

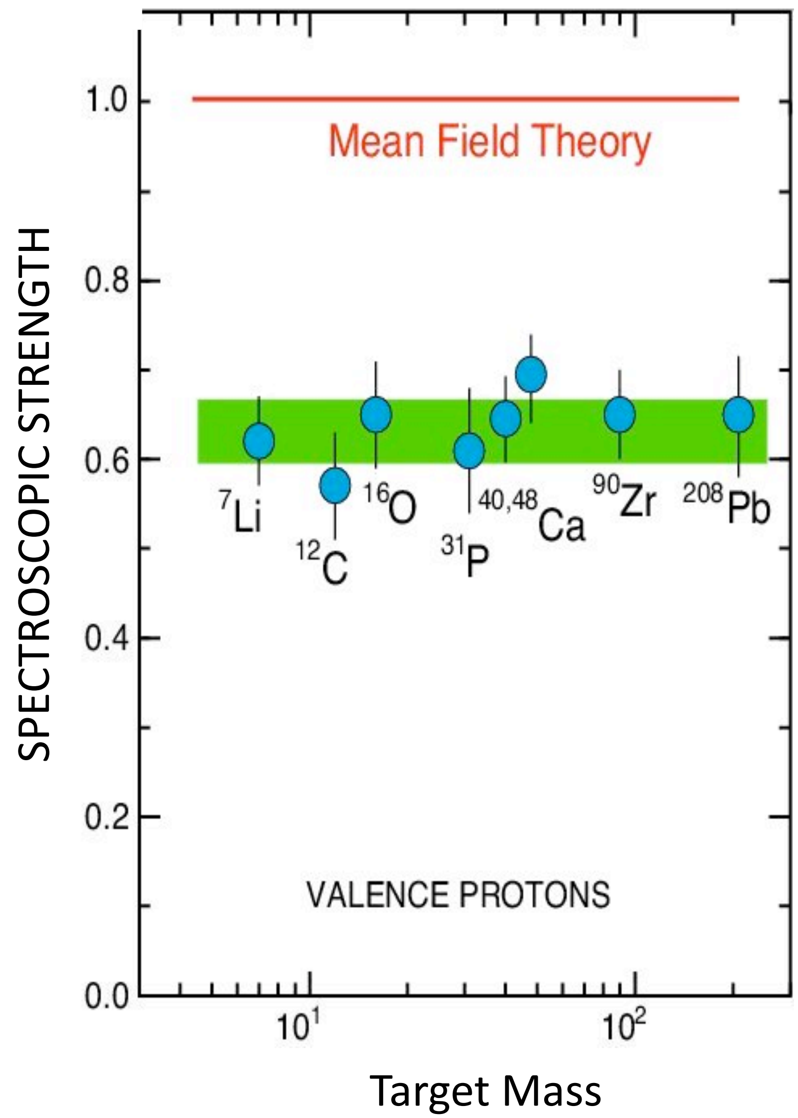
G. van der Steenhoven, *et al.,* Nucl. Phys. **A480**, 547 (1988).

Results from (e,e'p) Measurements

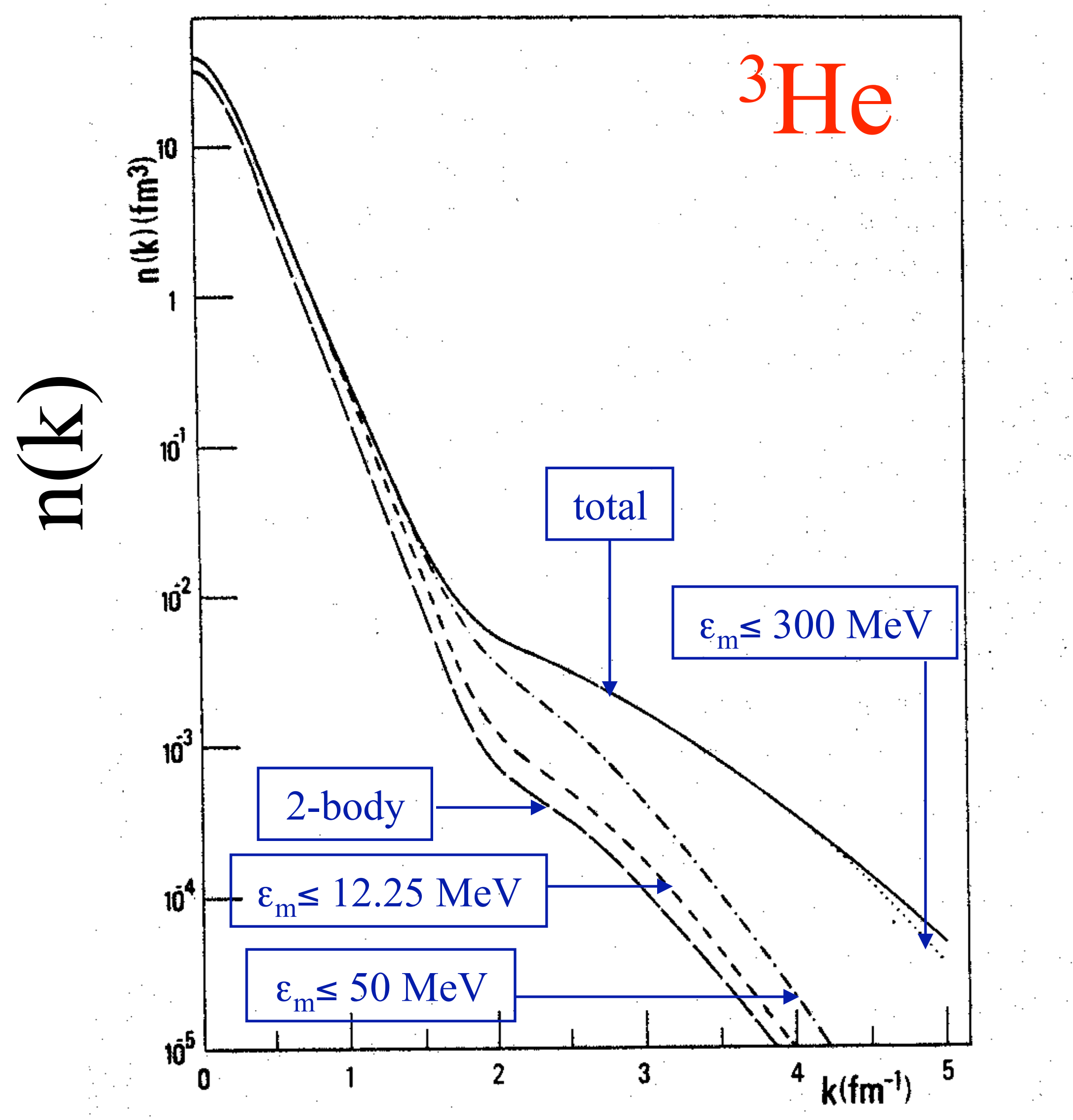
Independent-Particle Shell-Model
is based upon the assumption that each nucleon moves independently in an average potential (mean field) induced by the surrounding nucleons

The (e,e'p) data for knockout of valence and deeply bound orbits in nuclei gives spectroscopic factors that are 60 – 70% of the mean field prediction.

Answer: Short-Range Correlations?



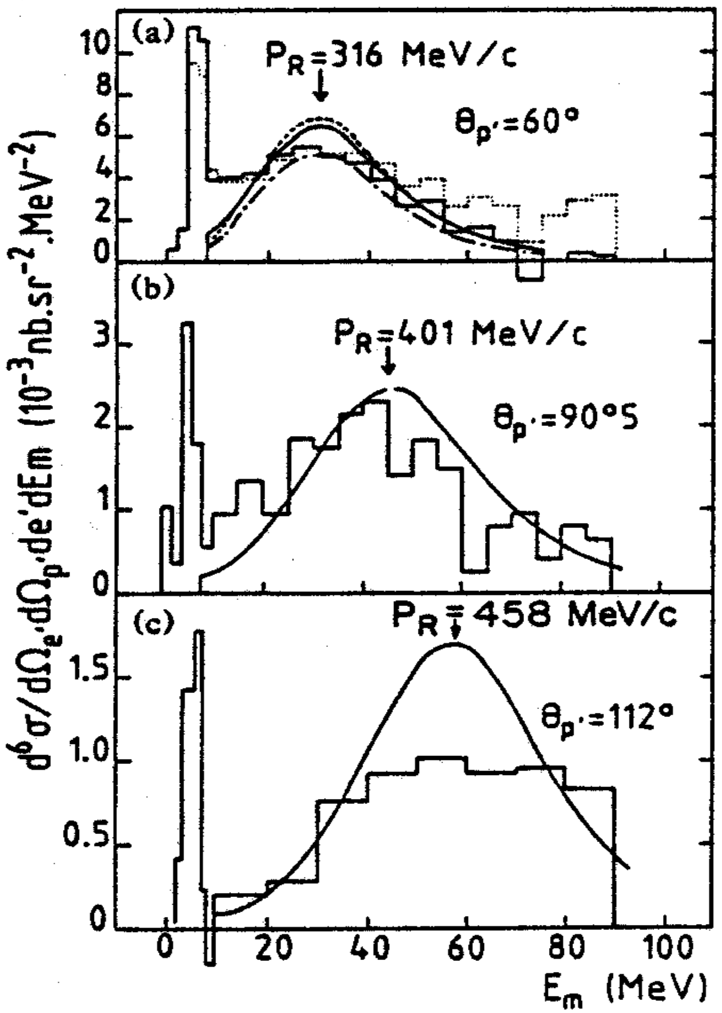
Jefferson Lab



SRC dominate high k (=p_m) and are related to large values of ε_m.

C. Ciofi degli Atti, E. Pace and G. Salmè, Phys. Lett. **141B**, 14 (1984).

^{3}He(e,e'p)



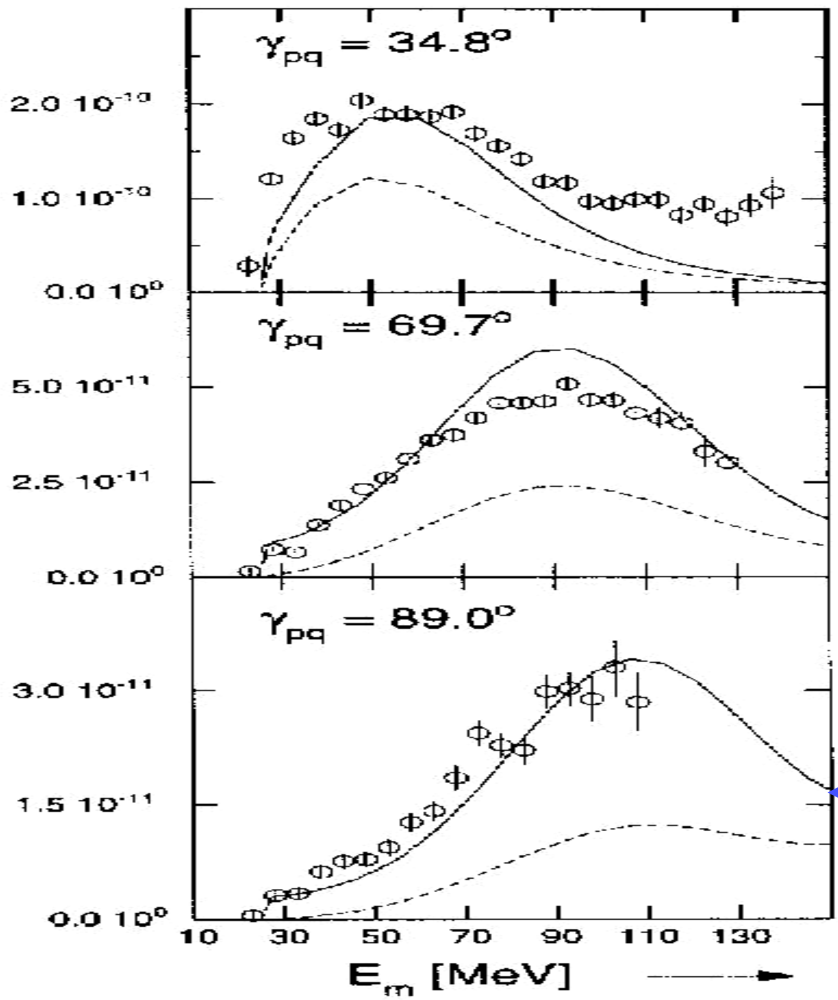
Calculations by Laget:
dashed=PWIA
dot-dashed=DWIA
solid=DWIA+MEC

Arrows indicate expected position for correlated pair.

Saclay

C. Marchand *et al.,* Phys. Rev. Lett. **60**, 1703 (1988).

^{4}He(e,e'p)



Laget: full

Laget: no MEC/IC

Peak roughly tracks kinematics of knockout of correlated 2N pair

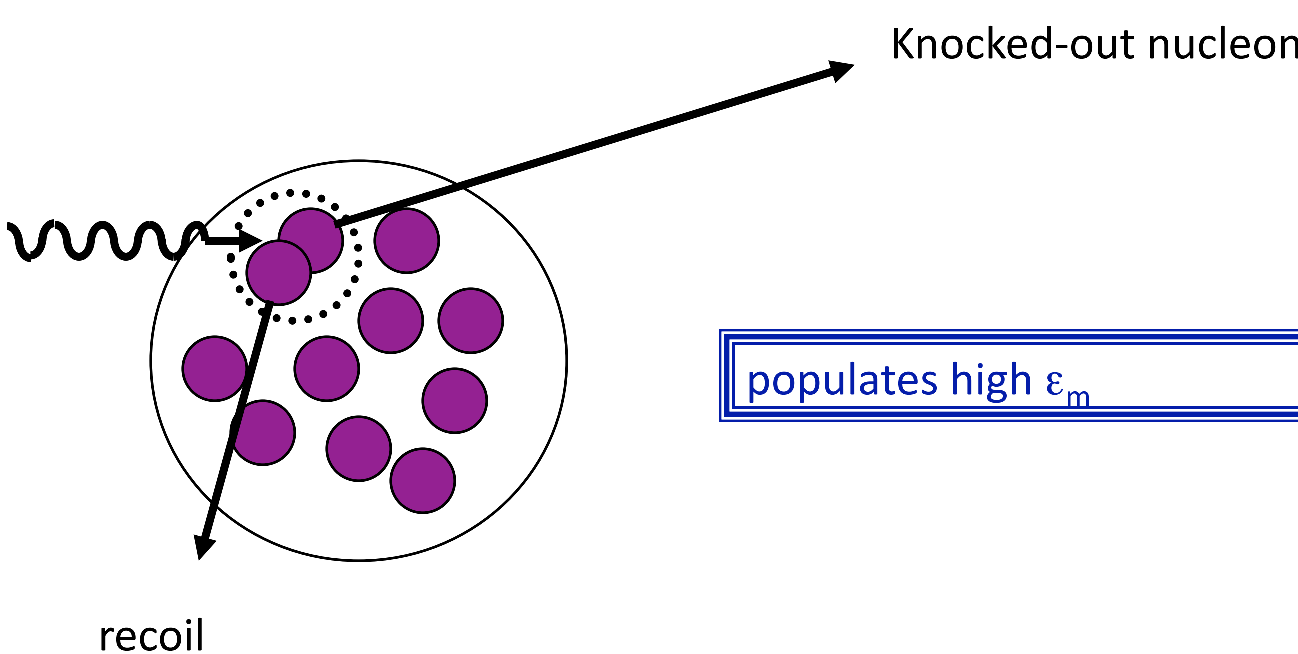
$$E_m \approx \frac{A-2}{A-1}\frac{p_m^2}{2m} + E_{thr}$$

AmPS NIKHEF-K

J.J. van Leeuwe *et al.*, Nucl. Phys. **A631**, 593c (1998).

Summary

- (e,e'p) sensitive probe of single-particle orbits.
- (FSI) must be accounted for to reproduce shape of spectral function.
- Missing strength in valence orbits, even after accounting for FSI
- At high P_m significant strength found in cross sections.
- Short-Range Correlations?!



populates high ε_m