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Can EFT help p+A scattering

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Office of Nuclear Physics
Exploring Nuclear Matter - Quarks to Stars

Observables in p+A elastic scattering

- p == proton or neutron
- A == spin-zero nucleus (closed shell)
- Independent vectors: $\vec{k}, \vec{k}', \ \vec{k} \times \vec{k}'$ or $\vec{k} \pm \vec{k}, \vec{k} \times \vec{k}'$
- Elastic scattering: |k| = |k'|
- Most general form of scattering amplitude
- spin-1/2 $\rightarrow$ spin-0: $A \cdot 1 + \vec{\sigma} \cdot \vec{C}$
- Assuming rotational invariance and parity conservation

$$M = A \cdot 1 + C\, \vec{\sigma} \cdot \left(\hat{k} \times \hat{k}' \right)$$
$$= A(k, \theta) + \underline{C(k, \theta)}\, \vec{\sigma} \cdot \hat{N}$$

Spin-flip amplitude

Explicitly:

- k and k' span scattering plane (x-z - plane)
- y-plane $\vec{\sigma}\cdot\widehat{N} = \sigma_y$
- With standard Pauli spinors:

$$\frac{d\sigma}{d\Omega}(\theta, +\widehat{y} \to +\widehat{y}) = \left|\chi_{+y}\left(A + C\sigma_y\right)\chi_{+y}\right| = \left|A + C\right|^2$$

$$\frac{d\sigma}{d\Omega}(\theta, +\widehat{y} \to -\widehat{y}) = 0$$

- **Unpolarized cross section:**
  - **Average of initial states and sum of all final states**

$$\frac{d\sigma}{d\Omega}(\theta) = \frac{1}{2}\left[\frac{d\sigma}{d\Omega}(\theta, i \to +\widehat{y}) + \frac{d\sigma}{d\Omega}(\theta, i \to -\widehat{y})\right]$$

$$= \left|A(\theta)\right|^2 + \left|C(\theta)\right|^2$$

Analyzing Power A_y

- Spin of the outgoing projectile is measured
- Incident beam is unpolarized

$$A_y = \frac{\frac{d\sigma}{d\Omega}(\theta, i \rightarrow +\hat{y}) - \frac{d\sigma}{d\Omega}(\theta, i \rightarrow -\hat{y})}{\frac{d\sigma}{d\Omega}(\theta, i \rightarrow +\hat{y}) + \frac{d\sigma}{d\Omega}(\theta, i \rightarrow -\hat{y})} = \frac{2\,\Re e\left(A^*(\theta)\,C(\theta)\right)}{|A(\theta)|^2 + |C(\theta)|^2}$$

⇒ Spin dependence out of the scattering plane

Spin rotation parameter Q

- Measures the rotation of the spin vector in the scattering plane
- +x $\rightarrow$ ±z

$$Q = \frac{\frac{d\sigma}{d\Omega}(\theta, \hat{x} \rightarrow +\hat{z}) - \frac{d\sigma}{d\Omega}(\theta, \hat{x} \rightarrow -\hat{z})}{\frac{d\sigma}{d\Omega}(\theta, \hat{x} \rightarrow +\hat{z}) + \frac{d\sigma}{d\Omega}(\theta, \hat{x} \rightarrow -\hat{z})} = \frac{2\,\Im m\left(A(\theta)C^{*}(\theta)\right)}{|A(\theta)|^{2} + |C(\theta)|^{2}}$$

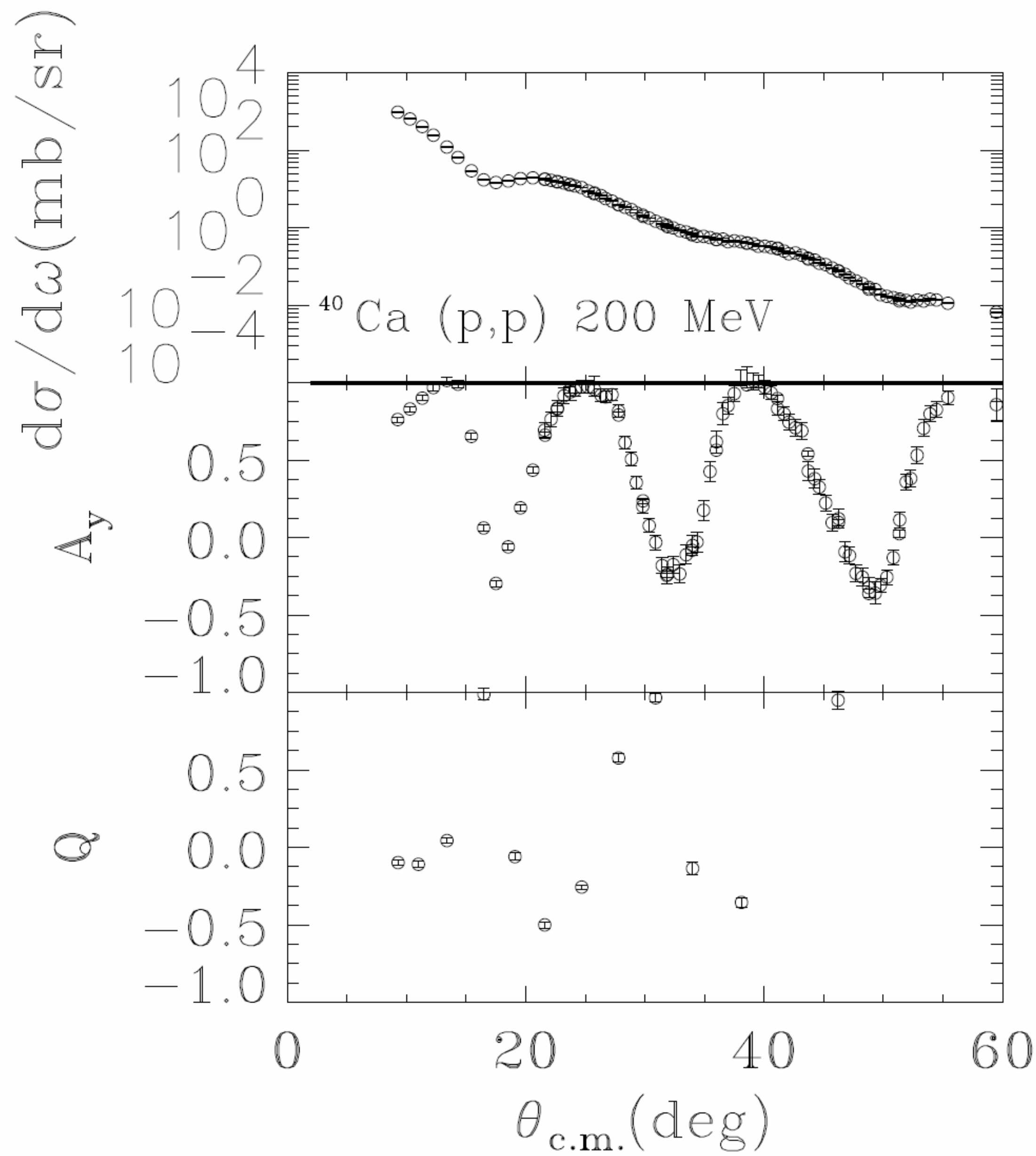
$\Rightarrow$ Spin dependence within the scattering plane

Spin rotation parameter Q

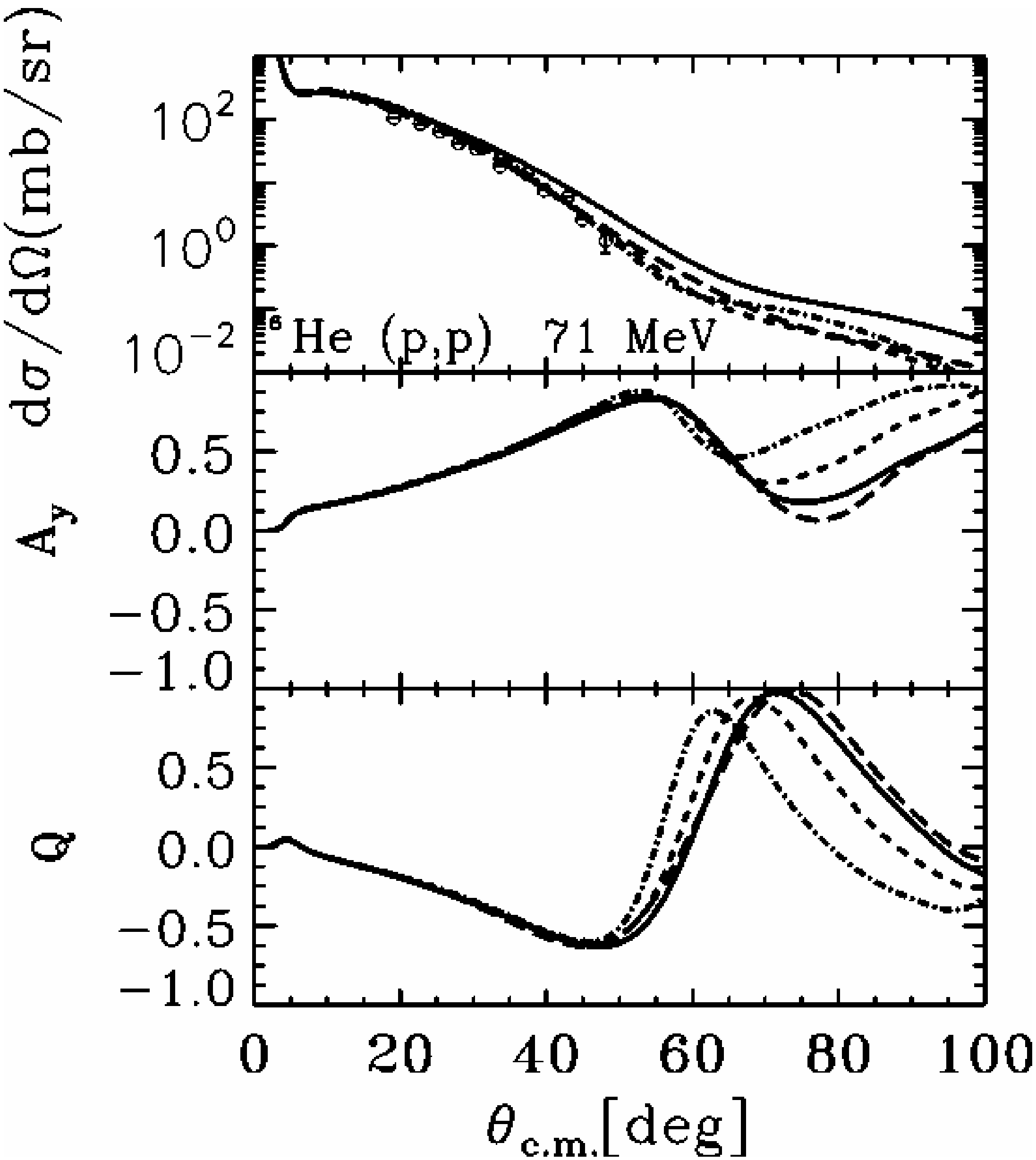
- Measures the rotation of the spin vector in the scattering plane
- $+x \to \pm z$

$$Q = \frac{\frac{d\sigma}{d\Omega}(\theta, \hat{x} \to +\hat{z}) - \frac{d\sigma}{d\Omega}(\theta, \hat{x} \to -\hat{z})}{\frac{d\sigma}{d\Omega}(\theta, \hat{x} \to +\hat{z}) + \frac{d\sigma}{d\Omega}(\theta, \hat{x} \to -\hat{z})} = \frac{2\,\Im m\left(A(\theta)C^*(\theta)\right)}{|A(\theta)|^2 + |C(\theta)|^2}$$

$\Rightarrow$ Spin dependence within the scattering plane


dσ/dω(mb/sr)
10^4
10^2
10^0
10^{-2}
10^{-4}
^{40}Ca (p,p) 200 MeV
A_y
0.5
0.0
−0.5
−1.0
Q
0.5
0.0
−0.5
−1.0
0
20
40
60
$\theta_{c.m.}$(deg)

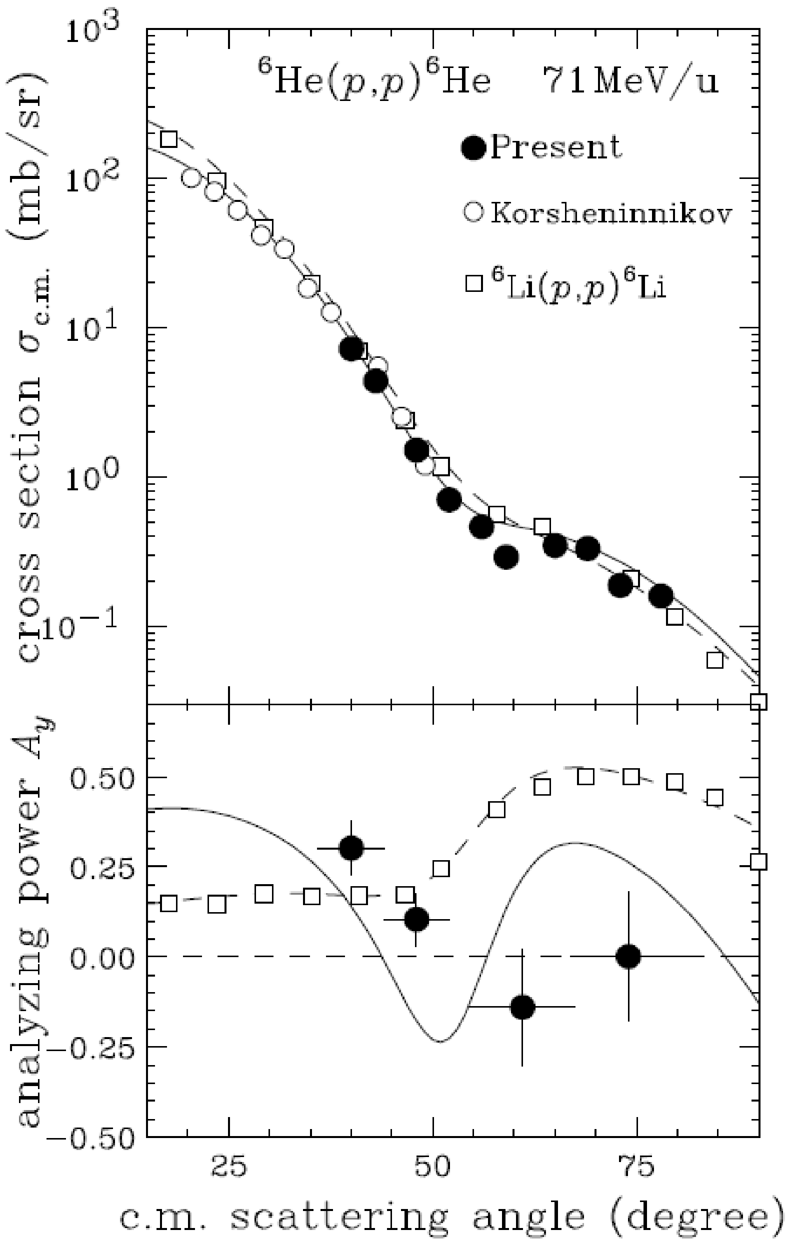
^{6}He + p



S.P. Weppner, O. Garcia, Ch. Elster

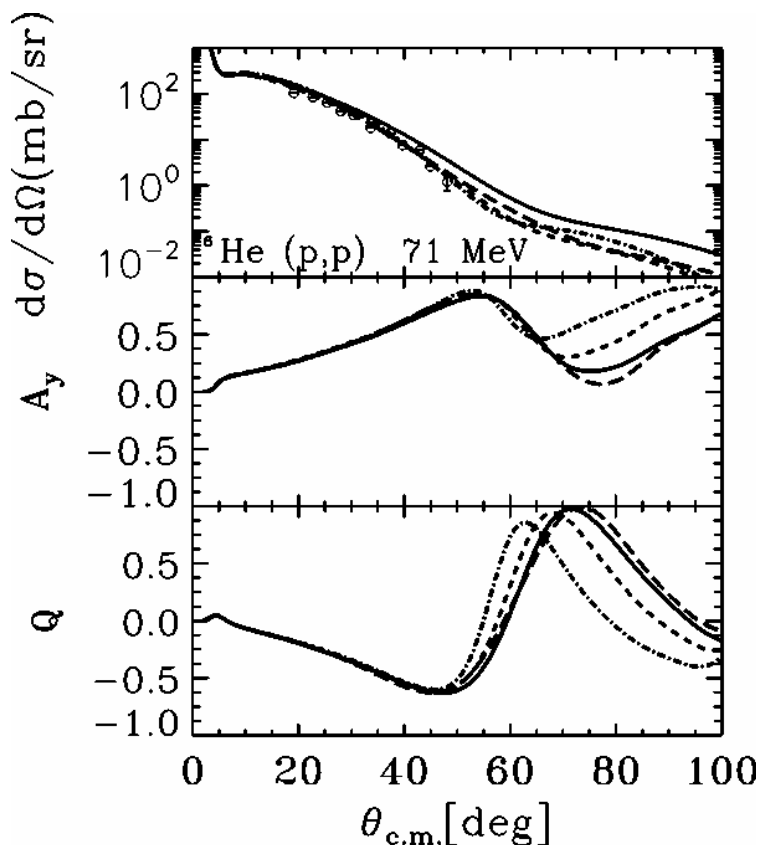
PRC 61, 044601(2000)

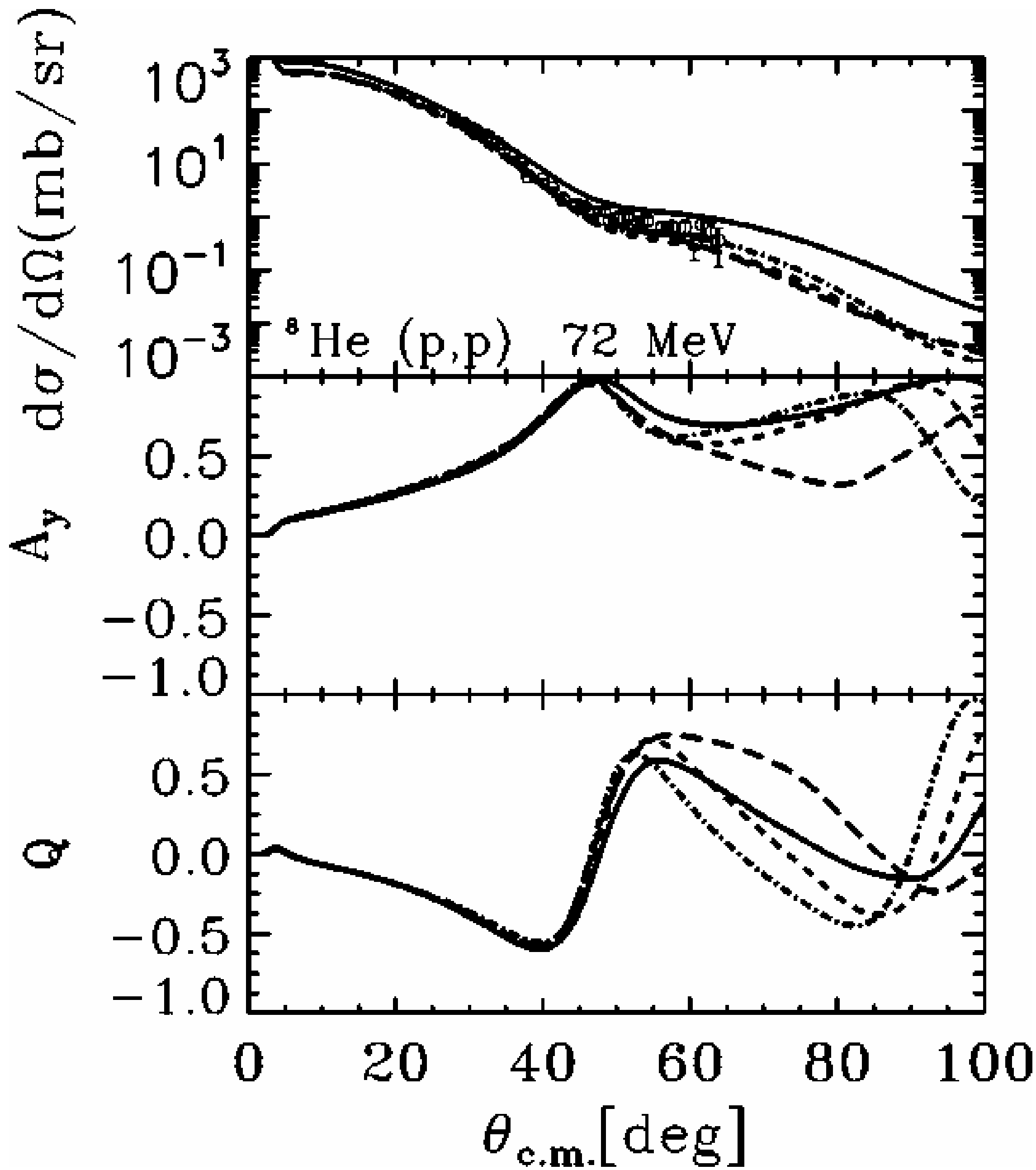
Simple densities, adjusted such that radius of ^{6}He is captured



Measurement:

M. Satano, H. Sakai et al.
Eur. Phys. J A25 255 (2005)





dσ/dΩ(mb/sr)
10^3
10^1
10^{-1}
10^{-3}
^{8}He (p,p) 72 MeV
A_y
0.5
0.0
−0.5
−1.0
Q
0.5
0.0
−0.5
−1.0
0
20
40
60
80
100
$\theta_{c.m.}$[deg]

Scattering: Lippmann-Schwinger Equation

- LSE: $T = V + V G_0 T$
- Hamiltonian: $H = H_0 + V$
- Free Hamiltonian: $H_0 = h_0 + H_A$
  - h_0: kinetic energy of projectile '0'
  - H_A: target hamiltonian with $H_A |\Phi\rangle = E_A |\Phi\rangle$
- V: interactions between projectile '0' and target nucleons 'i' $V = \Sigma^A_{i=0} v_{0i}$
- Propagator is (A+1) body operator
  - $G_0(E) = (E - h_0 - H_A + i\varepsilon)^{-1}$

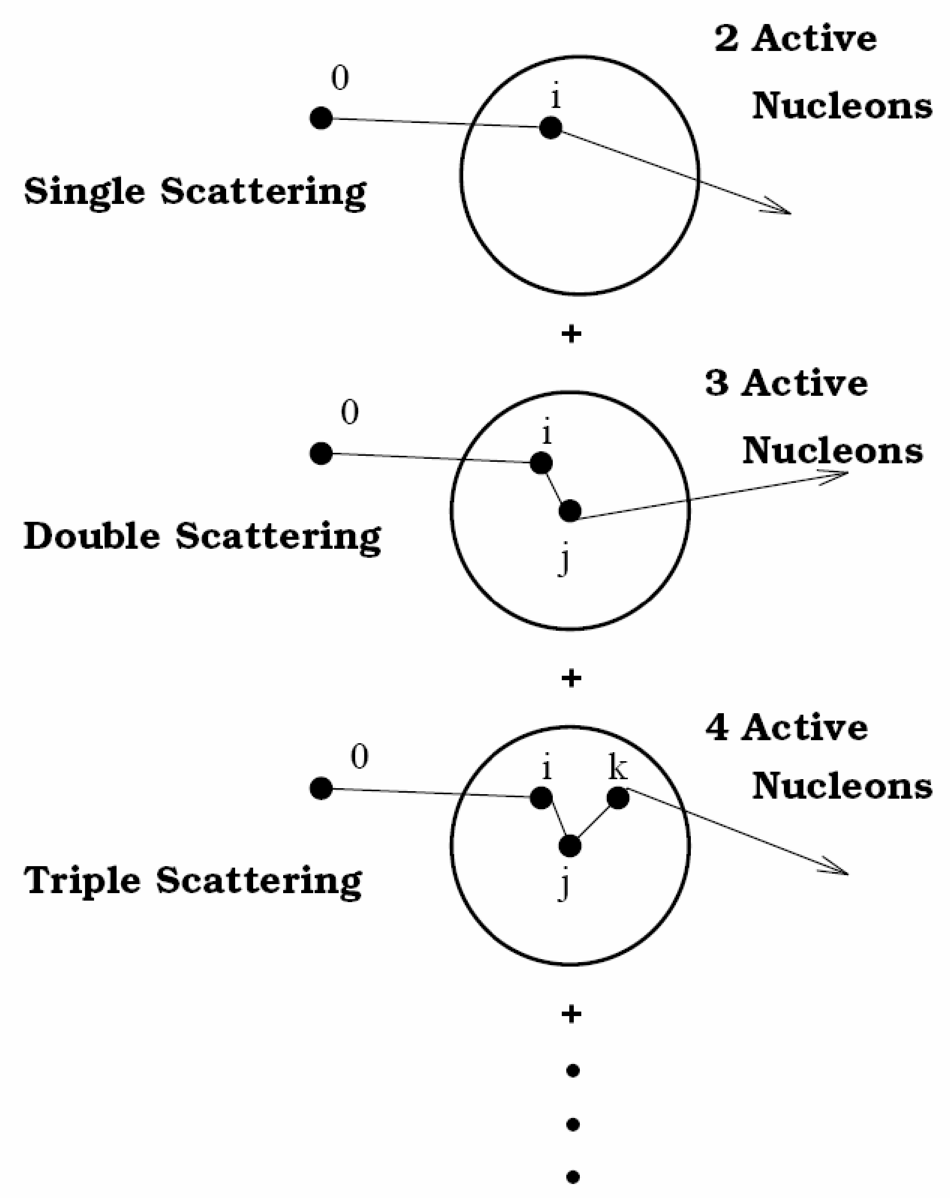
Standard Ansatz:

- $T = \Sigma^{A}_{i=0} T_{0i}$
  - with $T_{0i} = v_{oi} + v_{0i} G_0(E) T$

$$
\begin{aligned}
T_{0i} &= v_{0i} + v_{0i} G_0(E) \sum_j T_{0j} \\
&= v_{0i} + v_{0i} G_0(E) T_{0i} + v_{0i} G_0(E) \sum_{j \neq i} T_{0j} \\
(1 - v_{0i} G_0(E)) T_{0i} &= v_{0i} + v_{0i} G_0(E) \sum_{j \neq i} T_{0j} \\
T_{0i} &= t_{0i} + t_{0i} G_0(E) \sum_{j \neq i} T_{0j}.
\end{aligned}
$$

with $t_{0i} = v_{0i} + v_{0i} G_0(E)\, t_{0i}$

Spectator Expansion:



Written down by

Siciliano, Thaler (1977)

Picklesimer, Thaler (1981)

Spectator Expansion in eqs.

$$T = \sum_{i=1}^{A} t_{0i} \quad + \quad \sum_{i<j} (t_{ij} - t_{0i} - t_{0j})$$

Scattering from pairs

$$+ \quad \sum_{i<j<k} (t_{ijk} - t_{ij} - t_{ik} - t_{jk} + t_{0i} + t_{0j} + t_{0k}) + \ldots$$

2nd order term: $$t_{ij} = (v_{0i} + v_{0j}) + (v_{0i} + v_{0j}) G_0(E) t_{ij},$$

Single scattering approximation:

$$T = \sum_{i=1}^{A} T_{0i} \approx \sum_{i=1}^{A} t_{0i}.$$

Pauli Principle:

Antisymmetrize in active pairs

Elastic Scattering

- In- and Out-States have the target in ground state Φ_0
- Projector on ground state $P = |\Phi_0\rangle\langle\Phi_0|$
  - With $1=P+Q$ and $[P,G_0]=0$
- For elastic scattering one needs
- $P\,T\,P = P\,U\,P + P\,U\,P\,G0(E)\,P\,T\,P$
- Or
  - $\mathbf{T = U + U\,G_0(E)\,P\,T}$
  - $\mathbf{U = V + V\,G_0(E)\,Q\,U}$ $\Leftarrow$ **optical potential**

Standard: $\mathbf{U^{(1)}} \approx \Sigma^{A}_{i=0}\,\tau_{0i}$ (1st order)

with $\tau_{0i} = \mathbf{v}_{0i} + \mathbf{v}_{0i}\,\mathbf{G_0(E)}\,\mathbf{Q}\,\tau_{0i}$

$$\tau_{0i} = v_{0i} + v_{0i}\, G_0(E)\, Q\, \tau_{0i}$$

- $G_0(E) = (E - h_0 - H_A + i\varepsilon)^{-1}$ == (A+1) body operator
  - Standard **"impulse approximation":**
  - Average over $H_A \Rightarrow$ c-number
  - $\rightarrow G_0(e)$ ==: two body operator
- Deal with **Q**
  - Define "two-body" operator $\mathbf{t_{0i}^{free}}$ by
  - $\mathbf{t_{0i}^{free} = v_{0i} + v_{0i}\, G_0(e)\, t_{0i}^{free}}$
  - and relate via integral equation to τ_{oi}
  - $\tau_{oi} = t_{0i}^{free} - t_{0i}^{free}\, G_0(e)\, \tau_{oi}$ **[integral equation]**
  - Important for keeping correct iso-spin character of optical potential
  - $U^{(1)} = \Sigma^{A}_{i=1}\, \tau_{oi} =: N\, \tau_n + Z\, \tau_p$

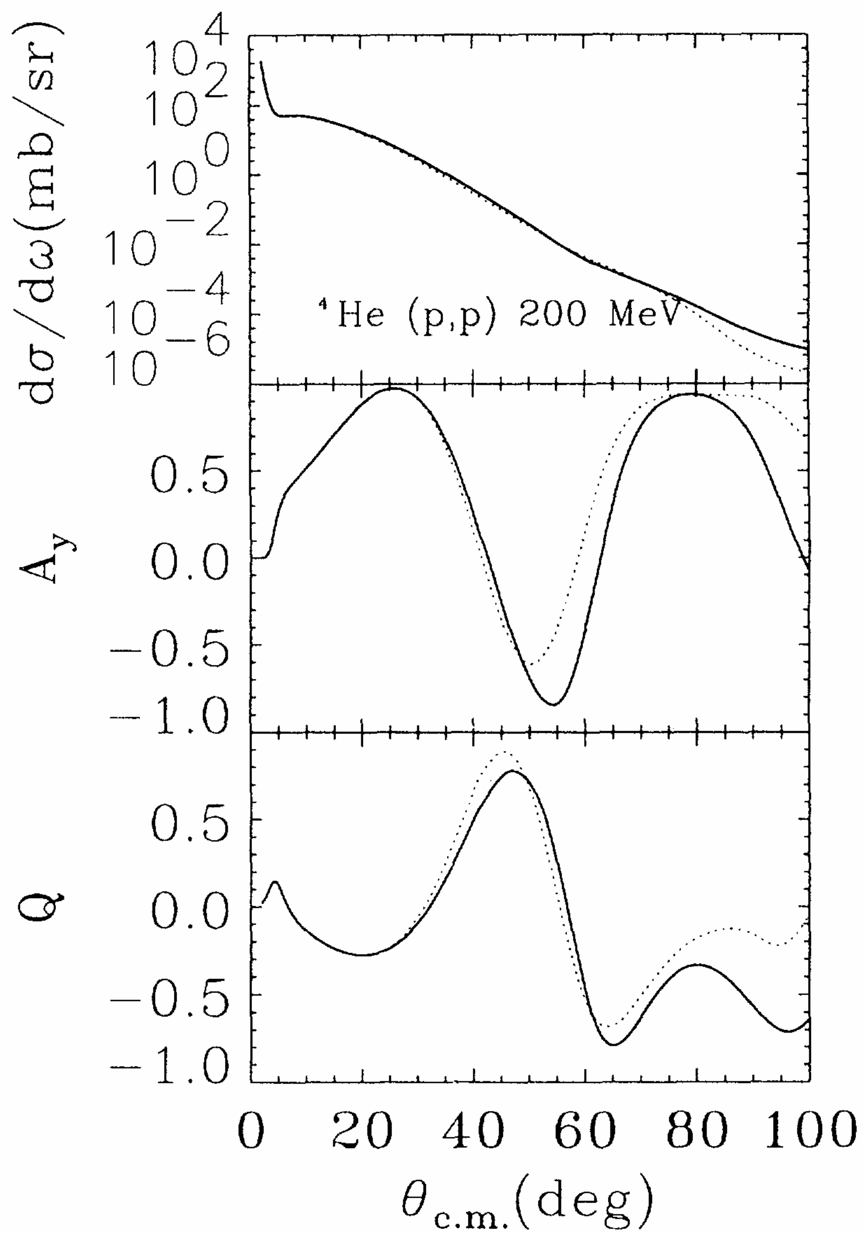
First order Watson optical potential

$$U^{(1)} = \Sigma^{A}{}_{i=1}\, \tau_{oi} =: \Sigma^{N}{}_{i=1}\, \tau_{n} + \Sigma^{P}{}_{i=1}\, \tau_{p}$$

- Important for treating N≠Z nuclei
- Be sensitive to proton vs. neutron scattering
- In general
  - $t_{pp} \neq t_{np}$
  - $\rho_p \neq \rho_n$
- These differences enter in a non-linear fashion into first order Watson optical potential

$$\tau_\alpha = t_\alpha - t_\alpha\, G_0{}^{\alpha}(e)\, \tau_\alpha\,, \quad \alpha=n,p$$

Isospin effects in elastic p+A scattering, Chinn, Elster, Thaler, PRC47, 2242 (1993)



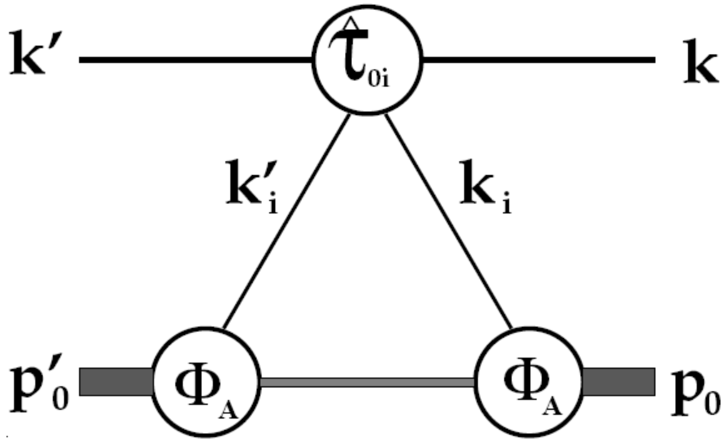
Solid: Watson

Dotted: $\tau = t$

More formal:

- Elastic scattering : $T_{el} = PUP + PUPG_0(E)PT_{el}.$
- First order Watson O.P.:

$$\langle \mathbf{k}' | \langle \phi_A | PUP | \phi_A \rangle \mathbf{k} \rangle \equiv U_{el}(\mathbf{k}', \mathbf{k}) = \sum_{i=n,p} \langle \mathbf{k}' | \langle \phi_A | \hat{\tau}_{0i}(\mathcal{E}) | \phi_A \rangle \mathbf{k} \rangle$$



$$\langle \hat{\tau}_{01} \rangle \equiv \langle \mathbf{k}' | \langle \phi_A | \hat{\tau}_{01}(\mathcal{E}) | \phi_A \rangle \mathbf{k} \rangle$$

Proton scattering: $U_{el}(\mathbf{k}', \mathbf{k}) = Z \langle \hat{\tau}_{01}^{pp} \rangle + N \langle \hat{\tau}_{01}^{np} \rangle$

Calculate: $$\langle \hat{\tau}_{01} \rangle \equiv \langle \mathbf{k}' | \langle \phi_A | \hat{\tau}_{01}(\mathcal{E}) | \phi_A \rangle \mathbf{k} \rangle$$

$$\langle \mathbf{k}_1 \mathbf{k}_2 \mathbf{k}_3 \mathbf{k}_4 ... \mathbf{k}_A | \phi_A \rangle = \delta(\mathbf{k}_1 + \mathbf{k}_2 + \mathbf{k}_3 + \mathbf{k}_4 ... + \mathbf{k}_A - \mathbf{p}_0) \langle \boldsymbol{\zeta_1 \zeta_2 \zeta_3 \zeta_4 ... \zeta_{A-1}} | \phi_A \rangle.$$

$$\langle \hat{\tau}_{01} \rangle = \int \prod_{j=1}^{A} d\mathbf{k}'_j \int \prod_{l=1}^{A} d\mathbf{k}_l \ \langle \phi_A | \zeta'_1 \zeta'_2 \zeta'_3 \zeta'_4 ... \zeta'_{A-1} \rangle \delta(\mathbf{p}' - \mathbf{p}'_0) \ \langle \mathbf{k}' \mathbf{k}'_1 | \hat{\tau}_{01}(\mathcal{E}) | \mathbf{k} \mathbf{k}_1 \rangle$$
$$\prod_{j=2}^{A} \delta(\mathbf{k}'_j - \mathbf{k}_j) \delta(\mathbf{p} - \mathbf{p}_0) \ \langle \zeta_1 \zeta_2 \zeta_3 \zeta_4 ... \zeta_{A-1} | \phi_A \rangle, \qquad (2.48)$$

With single particle density matrix :

$$\rho(\zeta'_{\mathbf{1}}, \zeta_{\mathbf{1}}) \equiv \int \prod_{l=2}^{A-1} d\zeta'_{\mathbf{l}} \int \prod_{j=2}^{A-1} d\zeta_{\mathbf{j}} \langle \phi_A | \zeta'_1 \zeta'_2 \zeta'_3 \zeta'_4 ... \zeta'_{A-1} \rangle \ \langle \zeta_1 \zeta_2 \zeta_3 \zeta_4 ... \zeta_{A-1} | \phi_A \rangle.$$

$$\langle \hat{\tau}_{01} \rangle = \int d\zeta'_{\mathbf{1}} \int d\zeta_{\mathbf{1}} \langle \mathbf{k}' \ \zeta'_{\mathbf{1}} + \frac{\mathbf{p}'_0}{A} | \hat{\tau}_{01}(\mathcal{E}) | \mathbf{k} \ \zeta_{\mathbf{1}} + \frac{\mathbf{p}_0}{A} \rangle \ \rho(\zeta'_{\mathbf{1}}, \zeta_{\mathbf{1}})$$
$$\delta(\frac{A-1}{A} \mathbf{p}'_0 - \zeta'_{\mathbf{1}} - \frac{A-1}{A} \mathbf{p}_0 + \zeta_{\mathbf{1}}).$$

Better Variables:

$$\mathbf{k} = \mathbf{K} - \frac{1}{2}\mathbf{q} \qquad \zeta_1 = \mathbf{P} + \frac{A-1}{2A}\mathbf{q}$$

$$\mathbf{k}' = \mathbf{K} + \frac{1}{2}\mathbf{q} \qquad \zeta_1' = \mathbf{P} - \frac{A-1}{2A}\mathbf{q}.$$

$$\langle \hat{\tau}_{01} \rangle = \langle \frac{1}{2}(\mathbf{K} - \mathbf{P} + \frac{2A-1}{2A}\mathbf{q} - \frac{\mathbf{p}_0'}{A}) | \hat{\tau}_{01}(\hat{\mathcal{E}}) | \frac{1}{2}(\mathbf{K} - \mathbf{P} - \frac{2A-1}{2A}\mathbf{q} - \frac{\mathbf{p}_0}{A}) \rangle$$
$$\rho(\mathbf{P} - \frac{A-1}{2A}\mathbf{q}, \mathbf{P} + \frac{A-1}{2A}\mathbf{q}). \tag{2.59}$$

$$U_{el}(\mathbf{q}, \mathbf{K}) = \sum_{i=n,p} \int d\mathbf{P} \hat{\tau}_{0i}(\mathbf{q}, \frac{1}{2}(\frac{A+1}{A}\mathbf{K} - \mathbf{P}), \hat{\mathcal{E}}) \; \rho_i(\mathbf{P} - \frac{A-1}{2A}\mathbf{q}, \mathbf{P} + \frac{A-1}{2A}\mathbf{q})$$

$$\hat{\mathcal{E}} = E_{NA} - \frac{(\mathbf{k} + \mathbf{k}_1)^2}{4m} = E_{NA} - (\frac{(\frac{A-1}{A}\mathbf{K} + \mathbf{P})^2}{4m})$$

Full-Folding Optical Potential

$$U_{el}(\mathbf{q},\mathbf{K}) = \sum_{i=n,p} \int d\mathbf{P}\,\hat{\tau}_{0i}(\mathbf{q}, \frac{1}{2}(\frac{A+1}{A}\mathbf{K}-\mathbf{P}), \hat{\mathcal{E}})\ \rho_i(\mathbf{P}-\frac{A-1}{2A}\mathbf{q}, \mathbf{P}+\frac{A-1}{2A}\mathbf{q})$$

Depends on |q|, |K|, $\cos(\theta)_{qK}$

Stored on grids 80x80x5 for low energies
. and 360x360x5 for high energies

Study of approximations and simplifications (like fixed energy ε, on-shell density ….) to get to "text-book" expression for optical potential

$$U(q) = t(q)\ \rho(q)$$

See Thesis Stephen Weppner @ www.phy.ohiou.edu/~elster/HE6

NN amplitude $f_{NN}(k'k;E) = C \langle k' | t_{NN}(E) | k \rangle$

Variables (E,k',k,φ) ⇒ (E, q, K, θ)

with $q = k' - k$

. $K = ½ (k' + k)$

Invariant I_α	Amplitude A_α		
$\mathbb{1}$	$A\,(q, \mathcal{K}, \vec{q}\cdot\vec{\mathcal{K}})$		
$(\vec{\sigma}_1 + \vec{\sigma}_2)\cdot\vec{w}$	$C\,(q, \mathcal{K}, \vec{q}\cdot\vec{\mathcal{K}})$		
. . . .	. . . .		
$\vec{\sigma}_1\cdot\vec{w}\quad \vec{\sigma}_2\cdot\vec{w}$	$B\,(q, \mathcal{K}, \vec{q}\cdot\vec{\mathcal{K}})$		$M\,(\ldots)$
$\vec{\sigma}_1\cdot\hat{q}\quad \sigma_2\cdot\hat{q}$	$E\,(q, \mathcal{K}, \vec{q}\cdot\vec{\mathcal{K}})$	or	$G\,(\ldots)$
$\vec{\sigma}_1\cdot\hat{\mathcal{K}}\quad \vec{\sigma}\cdot\hat{\mathcal{K}}$	$F\,(q, \mathcal{K}, \vec{q}\cdot\vec{\mathcal{K}})$		$H\,(\ldots)$
	(Wolfenstein)		(Hoshizaki)
$(\vec{\sigma}_1\cdot\hat{q}\,\vec{\sigma}_2\cdot\hat{\mathcal{K}} + \vec{\sigma}_1\cdot\hat{\mathcal{K}}\,\vec{\sigma}_2\cdot\hat{q})\;\vec{q}\cdot\vec{\mathcal{K}}$	$D\,(q, \mathcal{K}, \vec{q}\cdot\vec{\mathcal{K}}) = 0$ on-shell		

Densities used in 1997:

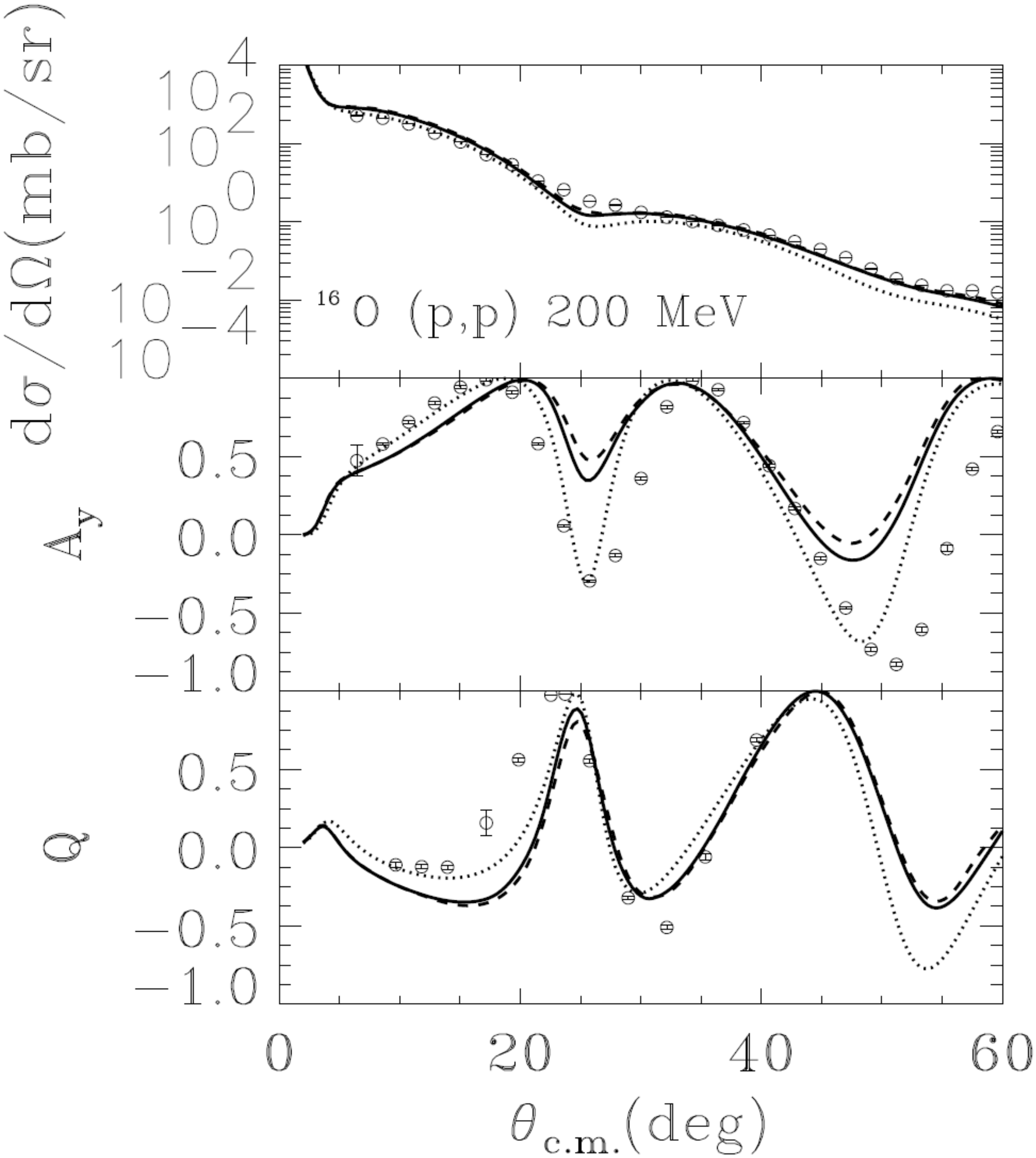
- Dirac-Hartree

$$\rho_{t_z}(\mathbf{r}',\mathbf{r}) = \sum_{n\nu}\left[\frac{G_{n,\nu,t_z}(r')}{r'}\frac{G_{n,\nu,t_z}(r)}{r} + \frac{F_{n,\nu,t_z}(r')}{r'}\frac{F_{n,\nu,t_z}(r)}{r}\right]\frac{2J+1}{2l+1}\sum_{m_l} Y_l^{*m_l}(\hat{\mathbf{r}}')Y_l^{m_l}(\hat{\mathbf{r}}).$$

- Gogny
- Harmonic Oscillator (home-brew)

$$\rho_s(\mathbf{q},\mathbf{P}) = \frac{4\pi}{\nu_s}e^{-(P^2/\nu_s+q^2/4\nu_s)},$$

$$\rho_p(\mathbf{q},\mathbf{P}) = \frac{2}{3}\frac{4\pi}{\nu_p}(P^2/\nu_p - q^2/4\nu_p)e^{-(P^2/\nu_p+q^2/4\nu_p)}$$



Solid: fixed ε

Dashed: integrated ε and ⟨H_A⟩=0 MeV

Dotted: integrated ε and ⟨H_A⟩= -8 MeV

$$\tau_{0i} = v_{0i} + v_{0i}\, G_0(E)\, Q\, \tau_{0i}$$

- $G_0(E) = (E - h_0 - H_A + i\varepsilon)^{-1}$ == (A+1) body operator
  - Standard **"impulse approximation":**
  - Average over $H_A \Rightarrow$ c-number
  - $\rightarrow G_0(e)$ ==: two body operator
- Deal with **Q**
  - Define "two-body" operator $\mathbf{t_{0i}^{free}}$ by
  - $\mathbf{t_{0i}^{free} = v_{0i} + v_{0i}\, G_0(e)\, t_{0i}^{free}}$

Exact

  - and relate via integral equation to τ_{oi}
  - $\tau_{oi} = t_{0i}^{free} - t_{0i}^{free}\, G_0(e)\, \tau_{oi}$ **[integral equation]**
  - Important for keeping correct iso-spin character of optical potential
  - $U^{(1)} = \Sigma^{A}_{i=1} \tau_{oi} =: N\, \tau_n + Z\, \tau_p$

Propagator (A+1) body operator:
$G_0(E) = (E - h_0 - H_A + i\varepsilon)^{-1}$

$$H_A = h_i + \sum_{j \neq i}^{A} v_{ij} + H^i$$

Chinn, Elster, Thaler
PRC 48, 2956 (1993)

h_i : kinetic energy of nucleon i

v_{ij} : interaction potential between i and j

H^i : (A-1) Hamiltionian $\rightarrow \langle H^i \rangle \equiv \varepsilon^i \equiv$ c-number

$\langle \Sigma_{j\neq i}{}^{A} v_{ij} \rangle \equiv U_i \equiv$ mean field

$\varepsilon^i + \varepsilon_i = \langle H_A \rangle = 0$

Two-body operator via construction:

$$G_0(E_i, i)^{-1} = \left(E - \varepsilon^i\right) - h_0 - h_i - U_i$$

$$E_i \equiv E - \left[\varepsilon^i + \varepsilon_i\right] + \varepsilon_i$$

$$\tilde{t}_{0i} = v_{0i} + v_{0i}\, G_0(E_i, i)\, \tilde{t}_{0i}$$

$$t_{0i}^{free} = v_{0i} + v_{0i}\, g_0(e)\, t_{0i}^{free}$$

e = arbitrary for now

$$\tilde{t}_{0i} = t_{0i}^{free} + t_{0i}^{free} \left[G_0(E_i, i) - g_0(e) \right] \tilde{t}_{0i}$$

Resolvent Identities:

$$G_0(E_i, i) - g_0(e) = G_0(E_i, i)\left[g_0(e)^{-1} - G_0^{-1}(E_i, i) \right] g_0(e)$$

$$= G_0(E_i, i)\left[e - h_0 - h_i - (E_i - h_0 - h_i - U_i) \right] g_0(e)$$

for $e = E_i$ $$= G_0(E_i, i)\, U_i\, g_0(E_i)$$

$$= g_0(E_i)\, T_i(E_i)\, g_0(E_i)$$

with $T_i(E_i) = U_i + U_i g_0(E_i) T_i(E_i)$

$$\tilde{t}_{0i}(E_i) = t_{0i}^{free}(E_i) + t_{0i}^{free}(E_i) g_0(E_i) T(E_i) g_0(E_i) \tilde{t}_{0i}(E_i)$$

$$= t_{0i}^{free}(E_i) + \quad \omega_{0i}(E_i) \quad g_0(E_i) \tilde{t}_{0i}(E_i)$$

$$\boxed{\tilde{t}_{0i}(E_i) = t_{0i}^{free}(E_i) + \Delta_{0i}}$$

$$\Delta_{0i} = \omega_{0i}(E_i) g_0(E_i) \tilde{t}_{0i}(E_i)$$

$$= t_{0i}^{free}(E_i) g_0(E_i) T(E_i) g_0(E_i) \tilde{t}_{0i}(E_i)$$

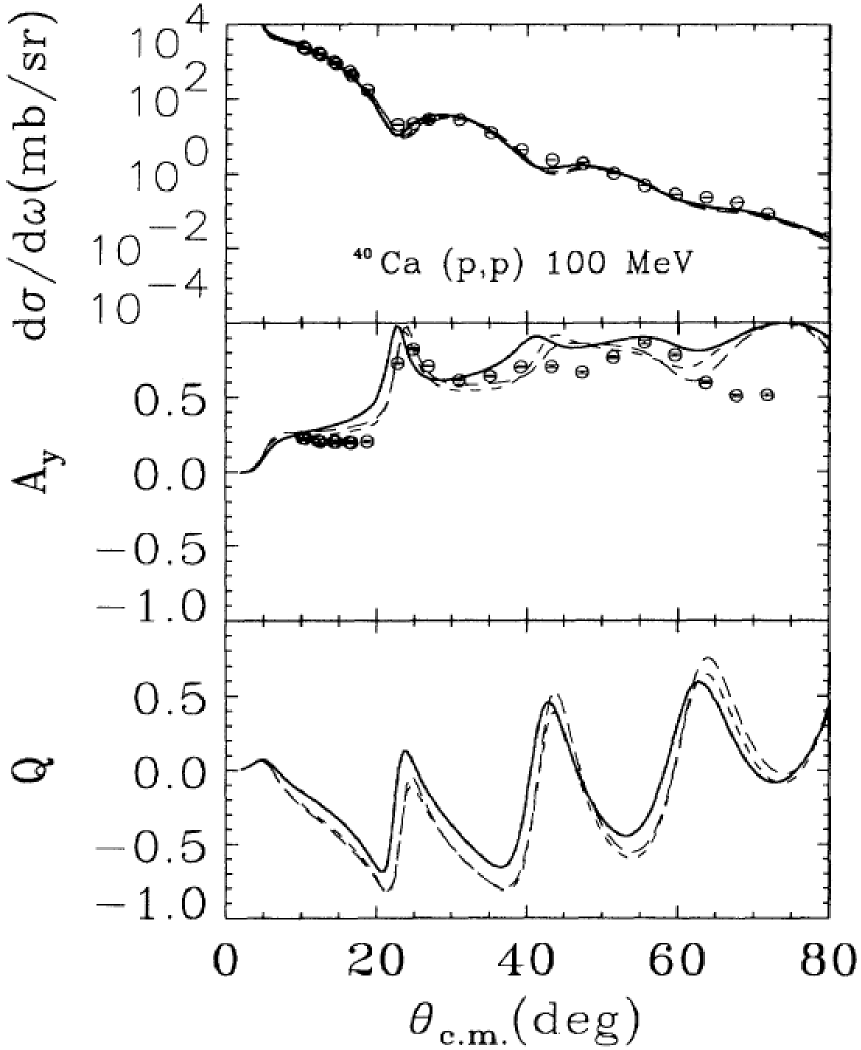
$$= t_{0i}^{free}(E_i) g_0(E_i) \quad \eta_{0i}(E_i)$$

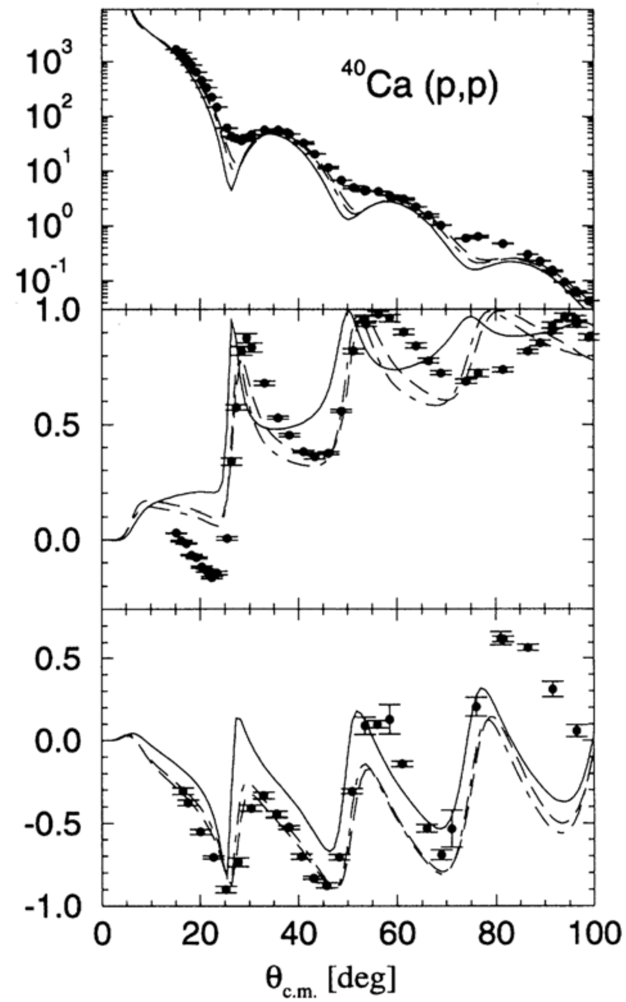
with $\boxed{\eta_{0i}(E_i) = \omega_{0i}(E_i) + \omega_{0i}(E_i) g_0(E_i) \eta_{0i}(E_i)}$

Modification of propagator $G_{0:}$

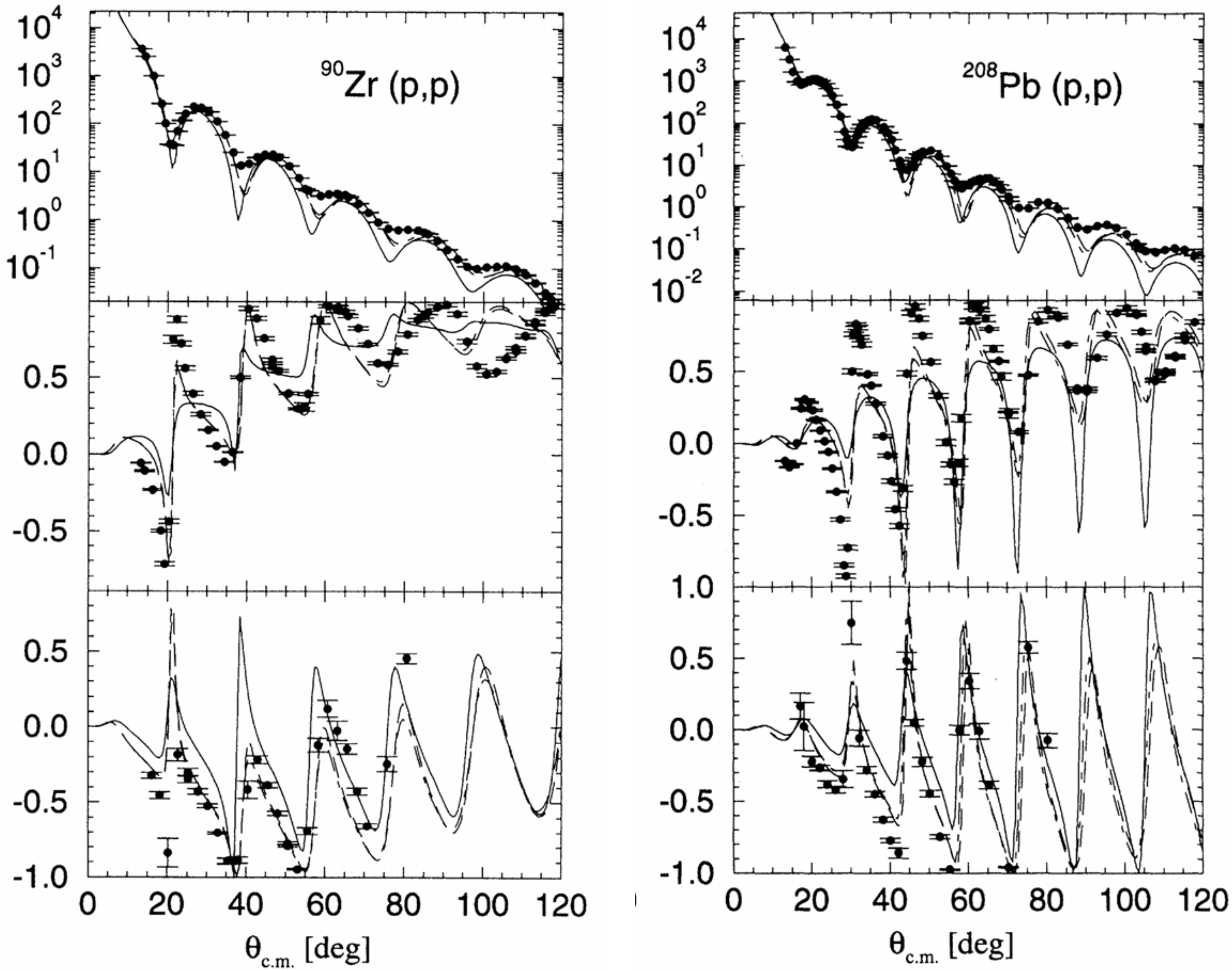
- Choose mean field potential U_i (consistent with density)
- Solve integral equation for T_{0i}
- Construct $\omega_{0i}(E_i)$
  - Approximation: variables are not "right"
  - i.e. ω_{0i} (k'_0, k'_i, k_0, k_i) – needed ω_{0i} $(k'_0 - k'_i, k_0 - k_i)$
- Solve integral equation for $\eta_{0i}(E_i)$
- Construct Δ_{0i}
- Add Δ_{0i} to $t_{0i}^{free} \rightarrow \tilde{t}_{0i}$
- Fold $\tilde{t}_{0i}$ with the nuclear density matrix
- Solve integral equation for Watson first order potential

65 MeV





65 MeV



^{90}Zr (p,p)
^{208}Pb (p,p)
10^4
10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
0.5
0.0
-0.5
1.0
-1.0
0
20
40
60
80
100
120
$\theta_{c.m.}$ [deg]