Hard photodisintegration of He^3

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2. HRM of ^3He
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   - Polarization Transfer
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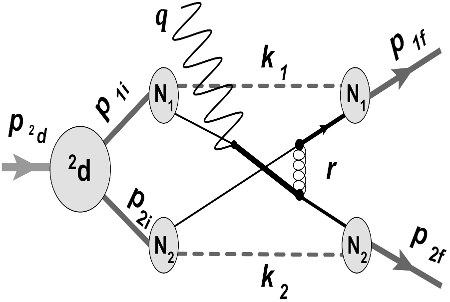
Hard photodisintegration of a nucleon pair



$\gamma + NN \rightarrow N + N$

- High energy photon absorbed by a NN system generating two nucleons at large transverse momentum.
- $s_{\gamma NN} \approx 4m_N^2 + 4E_\gamma m_N$, compare to $s_{NN} = 2m_N^2 + 2E \cdot m_N$ from $N + N \longrightarrow N + N$ processes.
- Moderate beam energies access hard kinematic regime, QCD degrees of freedom become evident.
- Potentially probes NN interaction.
- Studies can be extended to other baryonic channels,e.g.,$\gamma + NN \longrightarrow \Delta + \Delta$

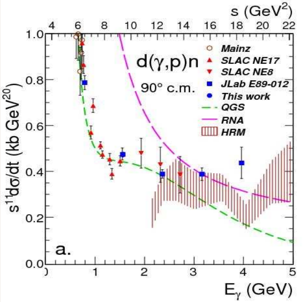
Hard rescattering model, HRM

L. Frankfurt et al.,Phys. Rev. Lett. 84, 3045 (2000)

- Through the HRM $d(\gamma, p)n$ amplitude results in a convolution of a hard process amplitude and a nuclear wave function,
  $\langle \lambda_{1f}, \lambda_{2f} \mid A \mid \lambda_\gamma, \lambda_d \rangle = -\frac{i[\lambda_\gamma]eQ_f\sqrt{2}(2\pi)^3}{\sqrt{2S'_{NN}}} \times$
  $\sum_{\lambda_{2i}} \int \langle \lambda_{2f}; \lambda_{1f} \mid T^{QIM}_{NN}(s_{NN}, t_N) \mid \lambda_\gamma; \lambda_{2i} \rangle \, \Psi^{\lambda_d \lambda_\gamma; \lambda_{2i}}_{d,NR}(\vec{p}_1, \vec{p}_2) m_N \frac{d^2 p_\perp}{(2\pi)^2},.$
- A parameter free cross section calculable through the input of experimental data,
  $\frac{\mathbf{d}\sigma^{\gamma \mathbf{d} \to \mathbf{pn}}}{\mathbf{dt}}(s, \theta_{c.m.}) = \frac{8\alpha}{9}\pi^4 \frac{1}{s'} C(\frac{\tilde{t}}{s})$
  $\times \frac{\mathbf{d}\sigma^{\mathbf{pn} \to \mathbf{pn}}}{\mathbf{dt}}(\mathbf{s}, \theta^{\mathbf{N}}_{\mathbf{c.m.}}) \times \left| \int \Psi^{NR}_d(p_z = 0, p_t) \sqrt{m_n} \frac{d^2 p_t}{(2\pi)^2} \right|^2$
- Angular distributions in pn elastic scattering data should be reflected by $\gamma + d \longrightarrow p + n$ data.

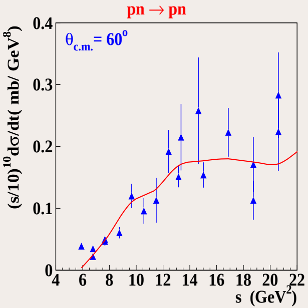
Energy Distribution

$\gamma + d \longrightarrow p + n$



I. Pomerantz et al. [JLab Hall A Collaboration], Phys. Lett. B 684, 106 (2010)

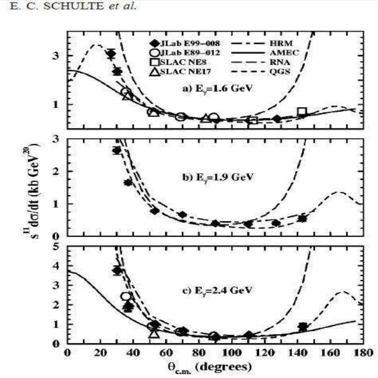
$p + n \longrightarrow p + n$



$\gamma(d,p)n \sim s^{-11}$ **for** $E_\gamma > 2GeV$, $s > 10\mathbf{GeV}^2$

Angular Distributions

$\gamma + d \to p + n$



Schulte et al., Phys.Rev.C66:042201,2002.

$p + n \to p + n$

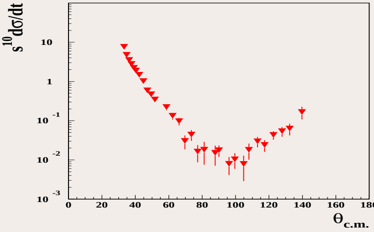
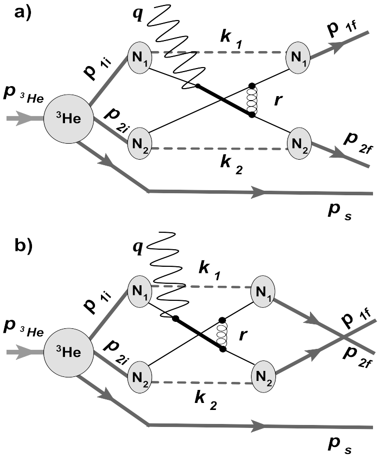


Figure: pn elastic scattering for p_{Lab}=8GeV/c

$^3He(\gamma NN)N_s$

S. J. Brodsky, et al., Phys. Lett. B578 (2004) 69.

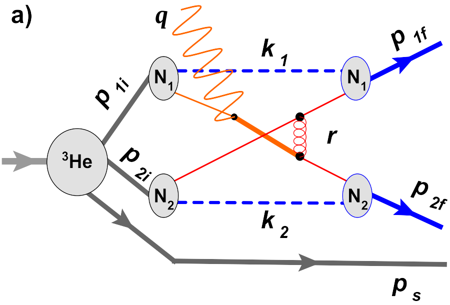


Reinforcing understanding of $\gamma(d,p)n$

- Different predictions from QCD models fitted to $d(\gamma,p)n$.
- Access to proton-proton breakup channel.
- Introduce spectator momentum distributions.

HRM of ^{3}He

S. J. Brodsky, et al., Phys. Lett. B578 (2004) 69.



- NN system with relative momentum $p_\perp << m_N$
- Low momentum p_s spectator nucleon N_s.
- $N = q_v + res.$
- The photon is absorbed by a valence quark of a nucleon from the NN system.
- γ triggers hard scattering off 2^{nd} valence quark.
- Two nucleons emerging at large transverse momentum.

Scattering Amplitude

$$\langle \lambda_{f1}, \lambda_{f2}, \lambda_s \mid A \mid \lambda_\gamma, \lambda_A \rangle =$$

$$(N1): \int \frac{-i\Gamma_{N_{1f}} i[\not p_{1f} - \not k_1 + m_q]}{(p_{1f} - k_1)^2 - m_q^2 + i\epsilon} iS(k_1) \cdots [-igT_c^F \gamma_\mu] \cdots$$

$$\frac{i[\not p_{1i} - \not k_1 + m_q](-i)\Gamma_{N_{1i}}}{(p_{1i} - k_1)^2 - m^2 + i\epsilon} \frac{d^4 k_1}{(2\pi)^4}$$

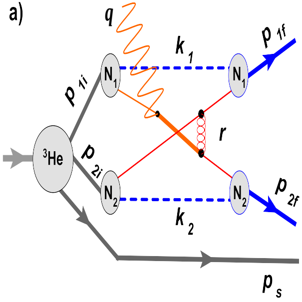
$$(\gamma q): \frac{i[\not p_{1i} - \not k_1 + q + m_q]}{(p_{1i} - k_1 + q)^2 - m_q^2 + i\epsilon} [-iQ_i e\epsilon^\perp \gamma^\perp]$$

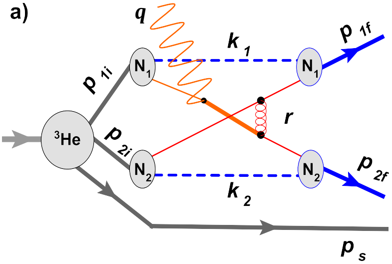
$$(N2): \int \frac{-i\Gamma_{N_{2f}} i[\not p_{2f} - \not k_2 + m_q]}{(p_{2f} - k_2)^2 - m_q^2 + i\epsilon} iS(k_2) \cdots [-igT_c^F \gamma_\nu]$$

$$\frac{i[\not p_{2i} - \not k_2 + m_q](-i)\Gamma_{N_{2i}}}{(p_{2i} - k_2)^2 - m^2 + \epsilon} \frac{d^4 k_2}{(2\pi)^4}$$

$$(^3He): \int \frac{-i\Gamma_{^3\mathrm{He}} \cdot \bar u_{\lambda_s}(p_s) i[\not p_{NN} - \not p_{2i} + m_N]}{(p_{NN} - p_{2i})^2 - m_N^2 + i\epsilon} \frac{i[\not p_{2i} + m_N]}{p_{2i}^2 - m_N^2 + i\epsilon} \frac{d^4 p_{2i}}{(2\pi)^4}$$

$$(g): \frac{id^{\mu,\nu}\delta_{ab}}{[(p_{2i} - k_2) - (p_{1i} - k_1) - (q - l)]^2 + i\epsilon}, \qquad (1)$$





Define line cone momentum fractions: $\alpha = \frac{p_{2i}^+}{p_{NN}^+}$, $x^{(\prime)} = \frac{k_N^+}{p_{Ni(f)}^+}$,

and nuclear and nucleonic wave functions.
After performing loop integrations and using,

$$\not{p} + m \approx \sum_s u_s(p)\bar{u}_s(p),$$

for internal lines off mass-shell,the invariant amplitude is reduced to:

$$\begin{aligned}
\langle \lambda_{1f}, \lambda_{2f}, \lambda_s \mid A \mid \lambda_\gamma, \lambda_A \rangle = & \sum_{(\eta' s),(\lambda_i' s),(\zeta)} \int \left\{ \frac{\psi_N^{\dagger\lambda_{2f},\eta_{2f}}(p_{2f}, x_2', k_{2\perp})}{1 - x_2'} \bar{u}_{\eta_{2f}}(p_{2f} - k_2)[-igT_c^F\gamma^\nu] \right. \\
& \left. u_\zeta(p_{1i} - k_1 + q) \frac{\bar{u}_\zeta(p_{1i} - k_1 + q)[-iQ_i e\epsilon_\perp^{\lambda_\gamma}\gamma^\perp]u_{\eta_{1i}}(p_{1i} - k_1)}{(1 - x_1)s'(\alpha - (\alpha_c + i\epsilon))} \frac{\psi_N^{\lambda_{1i},\eta_{1i}}(p_{1i}, x_1, k_{1\perp})}{(1 - x_1)} \right\}_1 \times \\
& \left\{ \frac{\psi_N^{\dagger\lambda_{1f},\eta_{1f}}(p_{1f}, x_1', k_{1\perp})}{1 - x_1'} \bar{u}_{\eta_{1f}}(p_{1f} - k_1)[-igT_c^F\gamma^\mu]u_{\eta_{2i}}(p_{2i} - k_2) \frac{\psi_N^{\lambda_{2i},\eta_{2i}}(p_{2i}, x_2, k_{2\perp})}{(1 - x_2)} \right\}_2 \times \\
& G^{\mu,\nu}(r) \frac{dx_1}{x_1} \frac{d^2k_{1\perp}}{2(2\pi)^3} \frac{dx_2}{x_2} \frac{d^2k_{2\perp}}{2(2\pi)^3} \frac{\Psi_{^3\mathrm{He}}^{\lambda_A,\lambda_{1i},\lambda_{2i},\lambda_s}(\alpha, p_\perp, p_s)}{(1 - \alpha)} \frac{d\alpha}{\alpha} \frac{d^2p_\perp}{2(2\pi)^3} - (p_{1f} \longleftrightarrow p_{2f}), \qquad (2)
\end{aligned}$$

struck quark factor

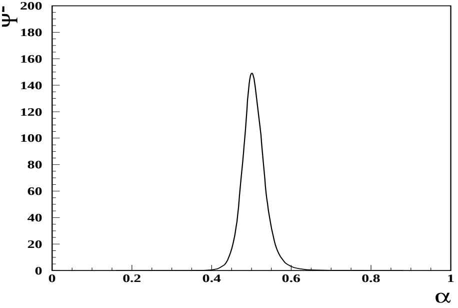
$$\frac{\bar{u}_\zeta(p_{1i}-k_1+q)[-iQ_ie\epsilon_\perp^{\lambda_\gamma}\gamma^\perp]u_{\eta_{1i}}(p_{1i}-k_1)}{(1-x_1)s'(\alpha-(\alpha_c+i\epsilon))} \approx \quad i\pi\delta(\alpha-\alpha_c)Q_ie\lambda_\gamma\sqrt{\frac{2(1-(1-x_1)(1-\alpha))}{s'(1-x_1)}}\delta_{\zeta\lambda_\gamma}\delta_{\eta_{1i}\lambda_\gamma}$$

$$\approx_{x_1\to 0} \quad i\pi\delta(\alpha-\alpha_c)Q_ie\lambda_\gamma\sqrt{\frac{2\alpha}{s'}}\delta_{\zeta\lambda_\gamma}\delta_{\eta_{1i}\lambda_\gamma}$$

where,

$$\alpha_c = 1+\frac{1}{s'_{NN}}\left[\tilde{m}_N^2-\frac{m_s^2(1-x_1)+m_q^2x_1+(k_1-x_1p_1)_\perp^2}{x_1(1-x_1)}\right].$$

- γ selects quark helicity.
- $\Psi_{^3He}$'s magnitude peaks sharply at $\alpha=\frac{1}{2}$, then set $\alpha_c=\frac{1}{2}$
- Restricted by α_c, $x_1\sim k_{1\perp}^2/s'$, then for large s', $x_1\approx 0$
  $\Rightarrow p_q \approx p_N$ and $\eta_q\approx\lambda_N$
- γ selects nucleon helicity.

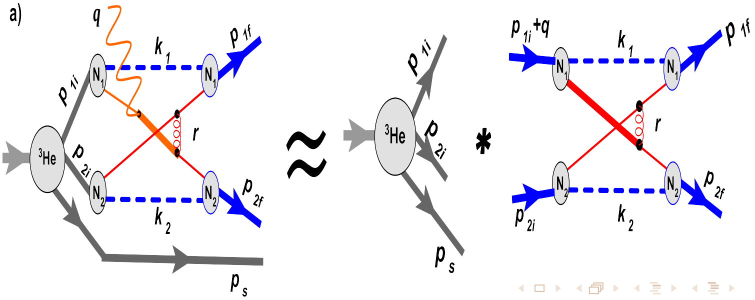


$$\langle \lambda_{1f}, \lambda_{2f}\lambda_s \mid A_i \mid \lambda_\gamma, \lambda_A\rangle = i[\lambda_\gamma]e \sum_{(\eta_{1f},\eta_{2f}),(\eta_{2i}),\lambda_{1i},\lambda_{2i}} \int \frac{Q_i}{\sqrt{2s'}}$$

$$\left[\left\{ \frac{\psi_N^{\dagger\lambda_{2f},\eta_{2f}}}{1-x_2'} \bar{u}_{\eta_{2f}}[-igT_c^F\gamma^\nu]\ u_{\eta_{1i}} \frac{\psi_N^{\lambda_{1i},\eta_{1i}}}{(1-x_1)} \right\} \times \right.$$

$$\left\{ \frac{\psi_N^{\dagger\lambda_{1f},\eta_{1f}}}{1-x_1'} \bar{u}_{\eta_{1f}}[-igT_c^F\gamma^\mu]u_{\eta_{2i}} \frac{\psi_N^{\lambda_{2i},\eta_{2i}}}{(1-x_2)} \right\}$$

$$\left. G^{\mu,\nu} \frac{dx_1}{x_1}\frac{d^2k_{1\perp}}{2(2\pi)^3}\frac{dx_2}{x_2}\frac{d^2k_{2\perp}}{2(2\pi)^3}\right] \Psi_{^3He}^{\lambda_A,\lambda_{1i},\lambda_{2i}}(\alpha = \frac{1}{2}, p_{2\perp})\frac{d^2p_{2\perp}}{(2\pi)^2}.$$



Accounting for all possible quark interchange diagrams we obtain,

$$\langle \lambda_{1f}, \lambda_{2f}, \lambda_s \mid M \mid \lambda_\gamma, \lambda_A \rangle = \frac{i[\lambda_\gamma] e \sqrt{2} (2\pi)^3}{\sqrt{2S'_{NN}}} \times$$
$$\Bigg\{ Q_F^{N_1} \sum_{\lambda_{2i}} \int \langle \lambda_{2f}; \lambda_{1f} \mid T_{NN}^{\mathrm{QIM}}(s_{NN}, t_N) \mid \lambda_\gamma; \lambda_{2i} \rangle \Psi^{\lambda_A}_{^3\mathrm{He,NR}}(\vec{p}_1, \lambda_\gamma; \vec{p}_2, \lambda_{2i}; \vec{p}_s, \lambda_s) m_N \frac{d^2 p_\perp}{(2\pi)^2} +$$
$$Q_F^{N_2} \sum_{\lambda_{1i}} \int \langle \lambda_{2f}; \lambda_{1f} \mid T_{NN}^{\mathrm{QIM}}(s_{NN}, t_N) \mid \lambda_{1i}; \lambda_\lambda \rangle \Psi^{\lambda_A}_{^3\mathrm{He,NR}}(\vec{p}_1, \lambda_{1i}; \vec{p}_2, \lambda_\gamma; \vec{p}_s, \lambda_s) m_N \frac{d^2 p_\perp}{(2\pi)^2} \Bigg\} \tag{3}$$

where charge factors Q_F are introduced such that,

$$\sum_{i \in N} Q_i^N \langle a' b' \mid T_{NN,i}^{\mathrm{QIM}} \mid ab \rangle \quad = \quad Q_F^N \cdot \langle a' b' \mid T_{NN}^{\mathrm{QIM}} \mid ab \rangle$$

For the quark interchange NN amplitudes we choose NN helicity amplitudes labeled as follows:

$$
\begin{aligned}
<+,+|T_{NN}^{\mathrm{QIM}}|+,+> &= \phi_1 \\
<+,+|T_{NN}^{\mathrm{QIM}}|+,-> &= \phi_5 \\
<+,+|T_{NN}^{\mathrm{QIM}}|-,-> &= \phi_2 \\
<+,-|T_{NN}^{\mathrm{QIM}}|+,-> &= \phi_3 \\
<+-|T_{NN}^{\mathrm{QIM}}|-+> &= -\phi_4.
\end{aligned}
\tag{4}
$$

All other helicity combinations can be related to the above amplitudes through the parity and time-reversal symmetry. The cross section of a NN scattering is defined as

$$
\frac{d\sigma^{NN\to NN}}{dt} = \frac{1}{16\pi}\frac{1}{s(s-4m_N^2)}\frac{1}{2}(|\phi_1|^2+|\phi_2|^2+|\phi_3|^2+|\phi_4|^2+4|\phi_5|^2).
$$

Then for NN breakup in ^3He, using the antisymmetry of the ^3He ground state wave function we have,

$$\langle +,+,\lambda_s \mid A \mid +,\lambda_A\rangle = B\int \left[Q_F\phi_5\Psi^{\lambda_A}_{^3He}(+,-,\lambda_s) + Q_F\phi_1\Psi^{\lambda_A}_{^3He}(+,+,\lambda_s)\right] m_N \frac{d^2p_\perp}{(2\pi)^2}$$

$$\langle +,-,\lambda_s \mid A \mid +,\lambda_A\rangle = B\int \left[(Q_F^{N_1}\phi_3 + Q_F^{N_2}\phi_4)\Psi^{\lambda_A}_{^3He}(+,-,\lambda_s) - Q_F\phi_5\Psi^{\lambda_A}_{^3He}(+,+,\lambda_s)\right] \times m_N \frac{d^2p_\perp}{(2\pi)^2}$$

$$\langle -,+,\lambda_s \mid A \mid +,\lambda_A\rangle = B\int \left[-(Q_F^{N_1}\phi_4 + Q_F^{N_2}\phi_3)\Psi^{\lambda_A}_{^3He}(+,-,\lambda_s) + Q_F\phi_5\Psi^{\lambda_A}_{^3He}(+,+,\lambda_s)\right] \times m_N \frac{d^2p_\perp}{(2\pi)^2}$$

$$\langle -,-,\lambda_s \mid A \mid +,\lambda_A\rangle = B\int \left[Q_F\phi_5\Psi^{\lambda_A}_{^3He}(+,-,\lambda_s) + Q_F\phi_2\Psi^{\lambda_A}_{^3He}(+,+,\lambda_s)\right] m_N \frac{d^2p_\perp}{(2\pi)^2}$$

where $B = \frac{ie\sqrt{2}(2\pi)^3}{\sqrt{2s'_{NN}}}$.

Then for the averaged squared amplitude one obtains,

$$|\bar{\mathcal{M}}|^2 = \frac{e^2 2(2\pi)^6}{2s'_{NN}}\frac{1}{2}\{2Q_F^2|\phi_5|^2 S_0 + Q_F^2(|\phi_1|^2 + |\phi_2|^2)S_{12} + \left[(Q_F^{N_1}\phi_3 + Q_F^{N_2}\phi_4)^2 + (Q_F^{N_1}\phi_4 + Q_F^{N_2}\phi_3)^2\right] S_{34}\} \quad (6)$$

where $Q_F = Q_F^{N_1} + Q_F^{N_2}$ and S_{12}, S_{34}, and S_0 are partially integrated nuclear spectral functions:

$$S_{12}(t_1, t_2, \alpha, \vec{p}_s) = N_{NN} \sum_{\lambda_1=\lambda_2=-\frac{1}{2}}^{\frac{1}{2}} \sum_{\lambda_3=-\frac{1}{2}}^{\frac{1}{2}} \left| \int \Psi^{\frac{1}{2}}_{^3\mathrm{He,NR}}(\vec{p}_1, \lambda_1, t_1; \vec{p}_2, \lambda_2, t_2; \vec{p}_s, \lambda_3) m_N \frac{d^2 p_\perp}{(2\pi)^2} \right|^2, \quad (7)$$

$$S_{34}(t_1, t_2, \alpha, \vec{p}_s) = N_{NN} \sum_{\lambda_1=-\lambda_2=-\frac{1}{2}}^{\frac{1}{2}} \sum_{\lambda_3=-\frac{1}{2}}^{\frac{1}{2}} \left| \int \Psi^{\frac{1}{2}}_{^3\mathrm{He,NR}}(\vec{p}_1, \lambda_1, t_1; \vec{p}_2, \lambda_2, t_2; \vec{p}_s, \lambda_3) m_N \frac{d^2 p_\perp}{(2\pi)^2} \right|^2 \quad (8)$$

and

$$S_0 = S_{12} + S_{34}. \quad (9)$$

Assuming the massless approximation for the interchanging quarks, their corresponding helicities are conserved during the hard subprocess, leading to the vanishing of NN amplitudes that don't conserve helicity, i.e.,

$$\begin{aligned}\phi_2 &= 0\\ \phi_5 &= 0\end{aligned}$$

then for NN scattering,

$$\frac{d\sigma^{NN\to NN}}{dt} = \frac{1}{16\pi}\frac{1}{s(s-4m_N^2)}\frac{1}{2}(|\phi_1|^2+|\phi_3|^2+|\phi_4|^2), \tag{10}$$

while for NN breakup

$$\begin{aligned}|\bar{\mathcal{M}}|^2 = \quad & \frac{e^2 2(2\pi)^6}{2s'_{NN}}\frac{1}{2}\left\{Q_F^2(|\phi_1|^2)S_{12}+\right.\\ & \left.\left[(Q_F^{N_1}\phi_3+Q_F^{N_2}\phi_4)^2+(Q_F^{N_1}\phi_4+Q_F^{N_2}\phi_3)^2\right]S_{34}\right\}\end{aligned} \tag{11}$$

Hard pn Breakup

- For large angle pn scattering $\phi_3 \approx \phi_4$,
- while for pn breakup $Q_F^{pn} = \frac{1}{3}$,
- and for ^3He ground state $S_{12}^{pn} \approx S_{34}^{pn} \approx \frac{S_0^{pn}}{2}$,

yielding,

$$\mid \bar{M} \mid^2 = \frac{(eQ_{F,pn})^2(2\pi)^6}{s'_{NN}} 16\pi s_{NN}(s_{NN} - 4m_N^2) \frac{d\sigma^{pn\to pn}(s_{NN}, t_N)}{dt_N} \frac{S_0^{pn}}{2}, \tag{12}$$

and for the differential cross section,

$$\frac{d\sigma^{\gamma^3He\to(pn)p}}{dt\frac{d^3p_s}{E_s}} = \alpha Q_{F,pn}^2 16\pi^4 \frac{S_0^{pn}(\alpha = \frac{1}{2}, \vec{p}_s)}{2} \frac{s_{NN}(s_{NN} - 4m^2)}{(s_{NN} - p_{NN}^2)_{NN}^2(s - M_{^3He}^2)} \frac{d\sigma^{pn\to pn}(s_{NN}, t_N)}{dt_N},$$

(

Hard pp Breakup

- For pp scattering, $\phi_4 \sim -\phi_3$ for large $\theta_{c.m}$.
- From exclusion principle and S state dominance of the nuclear wave function, $S_{12}^{pp} << S_{34}^{pp}$,
- with $Q_F^{pp} = \frac{5}{3}$,

for pp breakup,

$$|\bar{\mathcal{M}}|^2 = \frac{(e^2 2(2\pi)^6}{2s'_{NN}} \frac{1}{2} \left\{ 2Q_F^{pp}(|\phi_3| - |\phi_4|)^2 S_{34} \right\}. \tag{14}$$

Then, for the corresponding differential cross section,

$$\frac{d\sigma^{\gamma^3He\to(pp)n}}{dt\frac{d^3p_s}{E_s}} = \alpha Q_{F,pp}^2 16\pi^4 S_{34}^{pp}(\alpha = \frac{1}{2}, \vec{p}_s)\frac{2\beta^2}{1+2C^2}\frac{s_{NN}(s_{NN} - 4m_N^2)}{(s_{NN} - p_{NN}^2)^2(s - M_{^3\mathrm{He}}^2)} \times \frac{d\sigma^{pp\to pp}(s_{NN}, t_N)}{dt}, \tag{15}$$

where,

$$C^2 = \frac{\phi_3^2}{\phi_1^2} \approx \frac{\phi_4^2}{\phi_1^2},$$

and,

$$\beta = \frac{|\phi_3| - |\phi_4|}{|\phi_1|}, \tag{16}$$

- $$\frac{d\sigma^{\gamma\, ^3He\to(pn)p}}{dt\,\frac{d^3p_s}{E_s}} = \alpha Q^2_{F,pn} 16\pi^4 \frac{S_0^{pn}(\alpha=\frac{1}{2},\vec{p}_s)}{2} \frac{s_{NN}(s_{NN}-4m^2)}{(s_{NN}-p^2_{NN})^2_{NN}(s-M^2_{^3He})} \frac{d\sigma^{pn\to pn}(s_{NN},t_N)}{dt_N},$$

- $$\frac{d\sigma^{\gamma\, ^3He\to(pp)n}}{dt\,\frac{d^3p_s}{E_s}} = \alpha Q^2_{F,pp} 16\pi^4 S_{34}^{pp}(\alpha=\frac{1}{2},\vec{p}_s) \frac{2\beta^2}{1+2C^2} \frac{s_{NN}(s_{NN}-4m_N^2)}{(s_{NN}-p^2_{NN})^2(s-M^2_{^3\mathrm{He}})} \times \frac{d\sigma^{pp\to pp}(s_{NN},t_N)}{dt},$$

M. M. Sargsian and C. Granados, Phys. Rev. C 80, 014612 (2009)

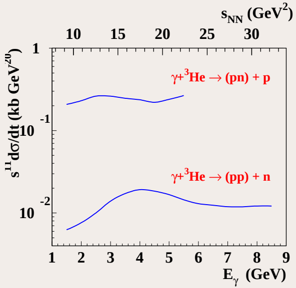
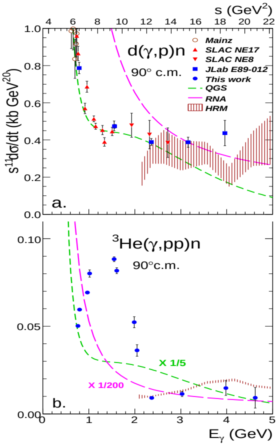
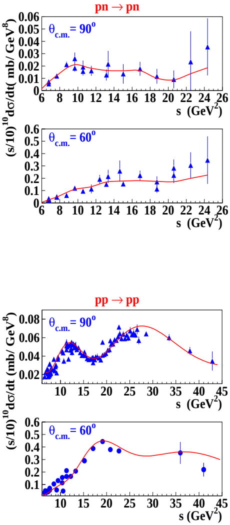
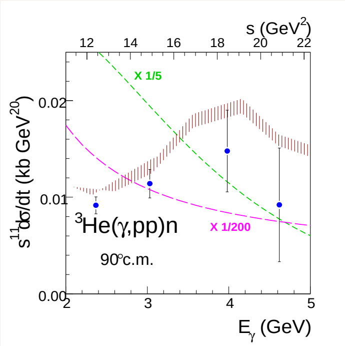


Figure: Energy dependence of s^{11} weighted differential cross sections at 90^o c.m. angle scattering in "γ-NN" system. In these calculations one integrated over the spectator nucleon momenta in the range of 0-100 MeV/c.

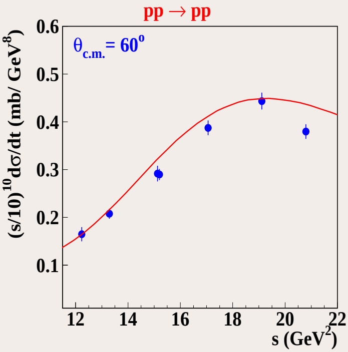




I. Pomerantz et al. [JLab Hall A Collaboration], Phys. Lett. B 684, 106 (2010) [arXiv:0908.2968 [nucl-ex]]



I. Pomerantz(2010)

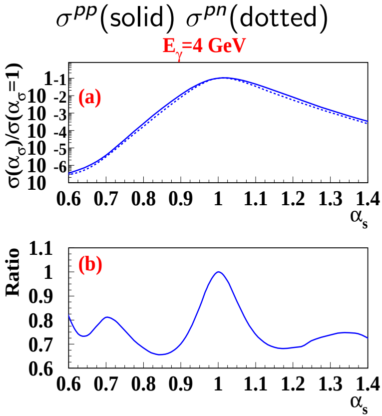


- HRM calculated $^3He(\gamma pp)n$ energy distribution in agreement with experimental data.
- Note

$$s\sigma^{^3He(\gamma pp)n}(s) \sim \sigma^{pp}(s)$$

Spectator Momentum Distributions

M. M. Sargsian and C. Granados, Phys. Rev. C 80, 014612 (2009)



$$\alpha_s \equiv \frac{E_s - p_{s,z}}{M_A/A} = \alpha_A - \alpha_{NN}$$

with

$$s_{NN} = M_{NN}^2 + E_\gamma m_n \alpha_{NN}.$$

- Asymmetry around $\alpha = 1$ due to s^{-11} dependence.
- *pp* distribution broader than *pn*.
- **R** drops around $\alpha = 1$ from the suppression of same helicity two proton components of the nuclear wave function at small momenta

Polarization Transfer

M. M. Sargsian and C. Granados, Phys. Rev. C 80, 014612 (2009)

$$C_{z'} = \frac{\sum\limits_{\lambda_{2f},\lambda_s,\lambda_a} \left\{ |\langle +, \lambda_{2f}, \lambda_s \mid M \mid +, \lambda_A \rangle|^2 - |\langle -, \lambda_{2f}, \lambda_s \mid M \mid +, \lambda_A \rangle|^2 \right\}}{\sum\limits_{\lambda_{1f}\lambda_{2f},\lambda_s,\lambda_a} |\langle \lambda_{1f}, \lambda_{2f}, \lambda_s \mid M \mid +, \lambda_A \rangle|^2}. \quad (17)$$

Then

$$C_{z'} = \frac{(|\phi_1|^2 - |\phi_2|^2)S^{++} + (|\phi_3|^2 - |\phi_4|^2)S^{+-}}{2|\phi_5|^2 S^{+} + (|\phi_1|^2 + |\phi_2|^2)S^{++} + (|\phi_3|^2 + |\phi_4|^2)S^{+-}}, \quad (18)$$

with,

$$S^{\pm,\pm}(t_1, t_2, \alpha, \vec{p}_s) =$$
$$\sum_{\lambda_A=-\frac{1}{2}}^{\frac{1}{2}} \sum_{\lambda_3=-\frac{1}{2}}^{\frac{1}{2}} \left| \int \Psi^{\lambda_A}_{^3\mathrm{He,NR}}(\vec{p}_1, \lambda_1 = \pm\frac{1}{2}, t_1; \vec{p}_2, \lambda_2 = \pm\frac{1}{2}, t_2; \vec{p}_s, \lambda_3) m_N \frac{d^2 p_{2,\perp}}{(2\pi)^2} \right|^2 \quad (19)$$

and $S^{+} = S^{++} + S^{+-}$.

Polarization Transfer

$$C_{z'} = \frac{(|\phi_1|^2 - |\phi_2|^2)S^{++} + (|\phi_3|^2 - |\phi_4|^2)S^{+-}}{2|\phi_5|^2 S^{+} + (|\phi_1|^2 + |\phi_2|^2)S^{++} + (|\phi_3|^2 + |\phi_4|^2)S^{+-}}, \tag{20}$$

Through previous assumptions for *pp* and *pn* breakup,

$$C_{z'}^{pp} \approx \frac{|\phi_3|^2 - |\phi_4|^2}{|\phi_3|^2 + |\phi_4|^2} \sim 0, \tag{21}$$

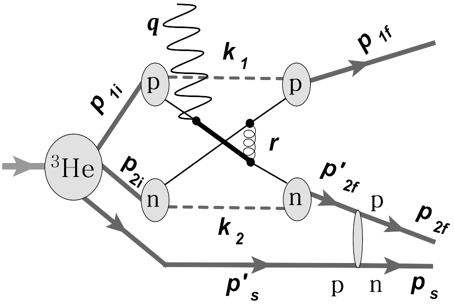
and,

$$C_{z'}^{pn} \approx \frac{|\phi_1|^2 + |\phi_3|^2 - |\phi_4|^2}{|\phi_1|^2 + |\phi_3|^2 + |\phi_4|^2} \sim \frac{2}{3}, \tag{22}$$

Summary

- Large angle high energy breakup of a NN system in ^3He has been studied in *pp* and *pn* breakup channels within the framework of the QCD hard rescattering model,HRM.
- HRM predicted energy dependencies, in accordance with counting rules, agree with recent experimental observations.
- Calculated HRM $^3He(\gamma pp)n$ differential cross section at $\theta^{NN}_{c.m.} = 90^o$ agrees well with experimental data without the introduction of adjustable parameters. (Note suppression from $|\phi_3| - |\phi_4|$ factor with respect to *pn* breakup).
- HRM predicts a broader spectator's momentum distribution for *pp* breakup in relations to *pn* breakup.
- From the HRM, $C^{pp}_{z'}$ is suppressed in relation to $C^{pn}_{z'}$

Three-body/two-step reaction



- Dominant at low to intermediate beam energies ($E_\gamma \sim 200$MeV).
- HRM amplitude does not interfere with two-body/one-step amplitude.
- HRM cross section scales like s^{-12} at large energies from second rescattering.

Introducing the light-cone wave function of ^{3}He [?, ?, ?]

$$\Psi^{\lambda_A,\lambda_1,\lambda_2,\lambda_s}_{^3\mathrm{He}}(\alpha, p_\perp) = \frac{\Gamma^{\lambda_A}_{^3\mathrm{He}}\bar{u}_{\lambda_1}(p_{NN}-p)\bar{u}_{\lambda_2}(p)\bar{u}_{\lambda_s}(p_s)}{M^2_{NN} - \frac{m_N^2+p_\perp^2}{\alpha(1-\alpha)}} \quad (23)$$

defining quark wave function of the nucleon as

$$\Psi^{\lambda,\eta}_N(p,x,k_\perp) = \frac{u^\lambda_N(p)\Gamma_N\bar{u}_\eta(p-k)\psi^\dagger_s(k)}{m_N^2 - \frac{m_s^2(1-x)+m_q^2x+(k_\perp-xp_\perp)^2}{x(1-x)}} \quad (24)$$

L.L. Frankfurt and M.I. Strikman, Phys. Rep. 76, 214 (1981)

$$\Psi_{^3\mathrm{He}}(\alpha, p_\perp, \alpha_s, p_{s,\perp}) = \sqrt{2}(2\pi)^3 m_N \Psi_{^3\mathrm{He,NR}}(\alpha, p_\perp, \alpha_s, p_{s,\perp}) \quad (25)$$

A. Nogga A. Kievsky, H. Kamada, W. Gloeckle, L. E. Marcucci, S. Rosati and M. Viviani, Phys. Rev. C 67, 034004 (2003).

SU(6)Helicity Amplitudes

For *pp* scattering:

Farrar et al.,(1979).

$$\begin{aligned}
\phi_1(\theta_{CM}) &= 144f(\theta_{CM}) + 144f(\pi - \theta_{CM}) \\
\phi_2(\theta_{CM}) &= 0 \\
\phi_3(\theta_{CM}) &= 56f(\theta_{CM}) + 68f(\pi - \theta_{CM}) \\
\phi_4(\theta_{CM}) &= -68f(\theta_{CM}) - 56f(\pi - \theta_{CM}) \\
\phi_5(\theta_{CM}) &= 0
\end{aligned} \tag{26}$$