Hard Break-Up of Two-Nucleons and QCD Dynamics of NN Interaction

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Nuclear QCD

- identyfy hard subprocess

- apply factorization

- apply pQCD to hard subprocess

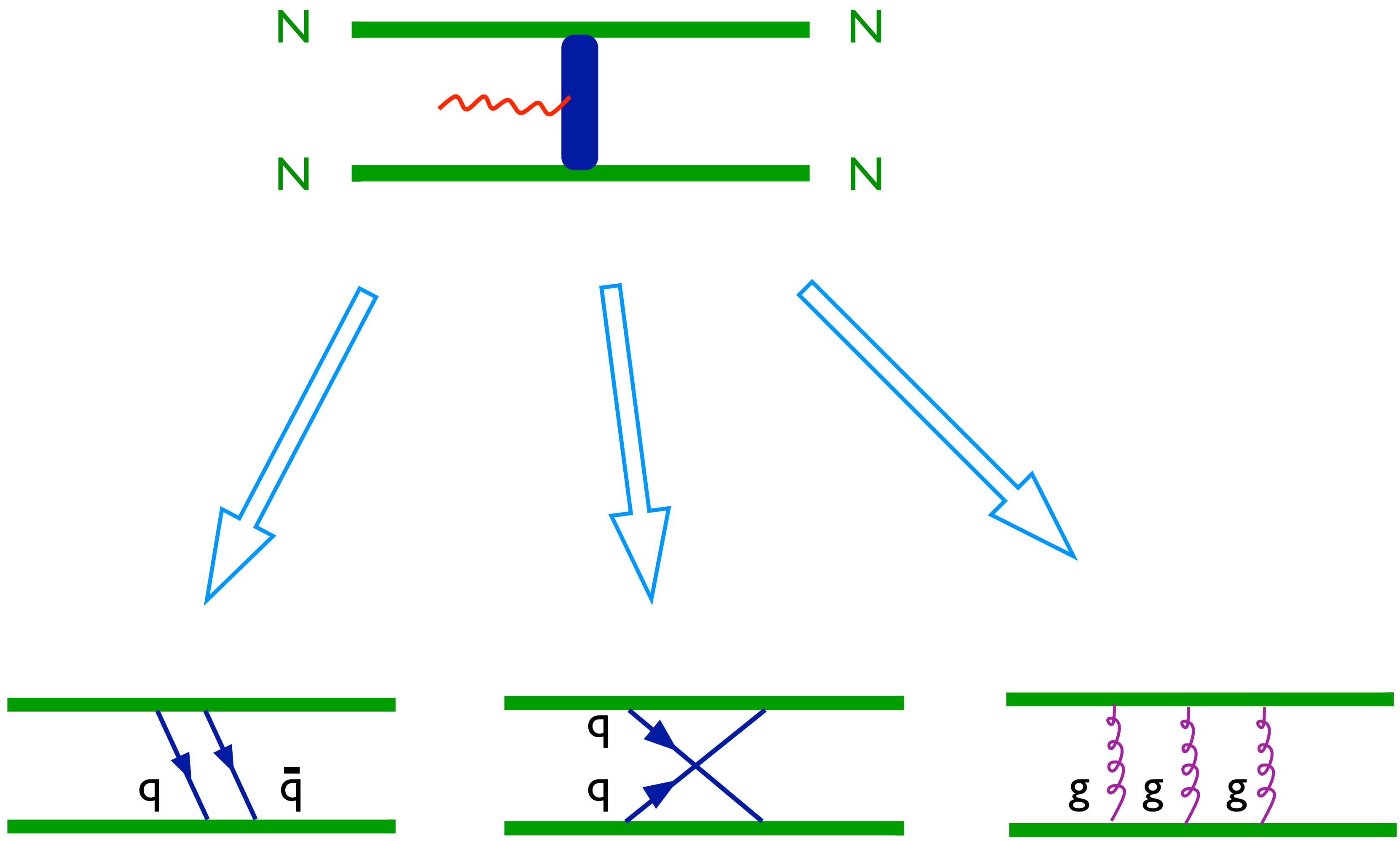
- express the soft part through measurable quatities as PDF's, hadronic amplitudes, FF and calculable nuclear wave functions

- obtain parameter free results

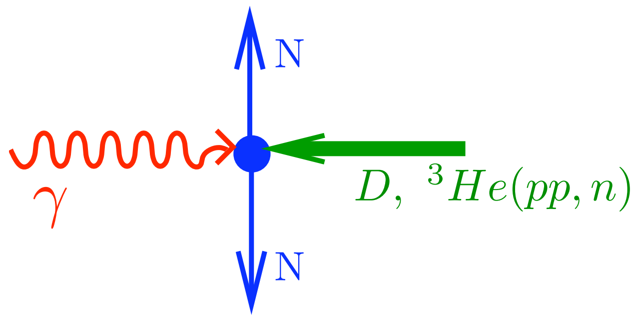
Nuclear QCD

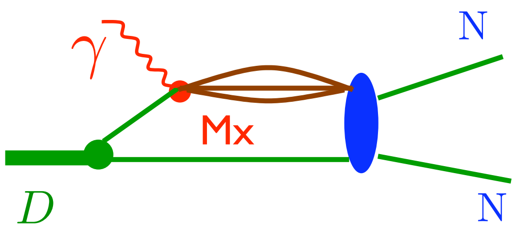
- EMC effect
- Formfactors of Few Nucleon Systems at high momentum transfer
- Color Transparency
- SRCs at Excitation Energies > 300 MeV
- DIS at x > 1
- High Energy Break up of two nucleons in Nuclei

and QCD Dynamics of NN Interaction


N
N
N
N
q
q̄
q
q
g
g
g

- Large CM angle disintegration of nuclei:





Brodsky, Chertock, 1976

Holt, 1990

Gilman, Gross, 2002

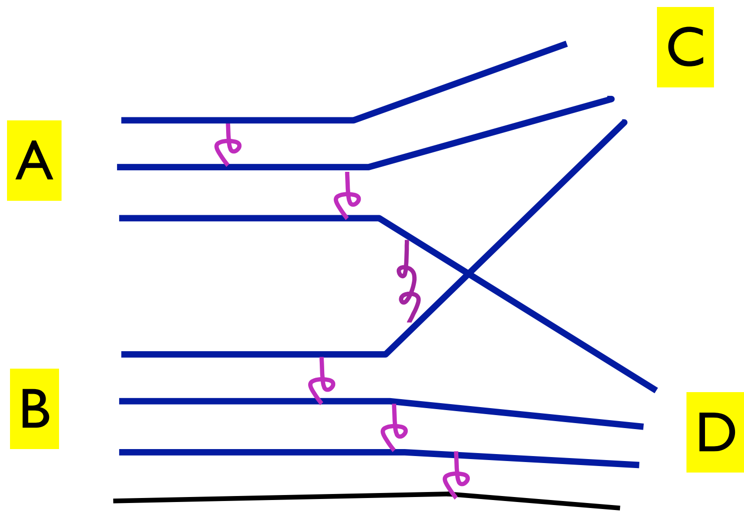
$$s = (k_\gamma + p_d)^2 = 2M_d E_\gamma + M_d^2$$

$$t = (k_\gamma - p_N)^2 = [cos\theta_{cm} - 1]\frac{s - M_d^2}{2}$$

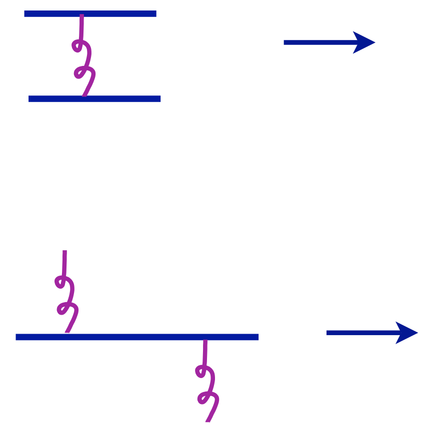
$$E_\gamma = 2 \text{ GeV},\ s = 12 \text{ GeV}^2,\ t\mid_{90^0} \approx -4 \text{ GeV}^2,\ M_x = 2 \text{ GeV}$$

$$E_\gamma = 12 \text{ GeV},\ s = 41 \text{ GeV}^2,\ t\mid_{90^0} \approx -18.7 \text{ GeV}^2,\ M_x = 4.4 \text{ GeV}$$

Consider A+B→C + D



additional $\frac{1}{s}$



$$\rightarrow f(\frac{t}{s})$$

$$\rightarrow \frac{1}{s}$$

$$A \sim F(\frac{t}{s}) \frac{1}{s^{\frac{n_A+n_B+n_C+n_D}{2}-2}}$$

Brodsky, Farrar 1975
Matveev, Muradyan, Takhvelidze, 1975

$$\frac{d\sigma}{dt} \approx \frac{|A|^2}{s^2} = F^2(\frac{t}{s}) \frac{1}{s^{n_A+n_B+n_C+n_D-2}}$$

$\gamma d \to pn$

Exclusive large-momentum-transfer scattering

• **Dimensional counting rule:**

$$\left.\frac{d\sigma}{dt}\right|_{AB\to CD} \propto S^{-(N=n_A+n_B+n_C+n_D-2)} f(\tfrac{t}{s})$$

For

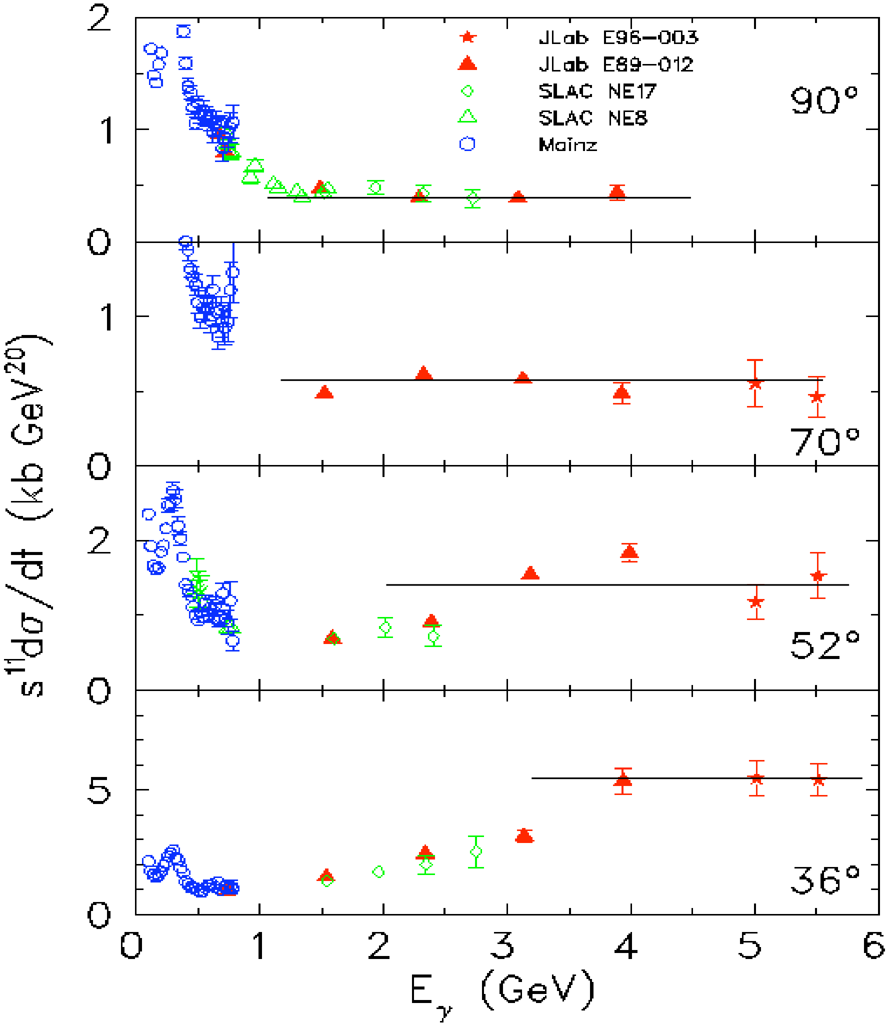
$$\gamma\, d \to p\,(high\ p_t) + n\,(high\ p_t)$$

N = 1 + 6 + 3 + 3 – 2 = 11

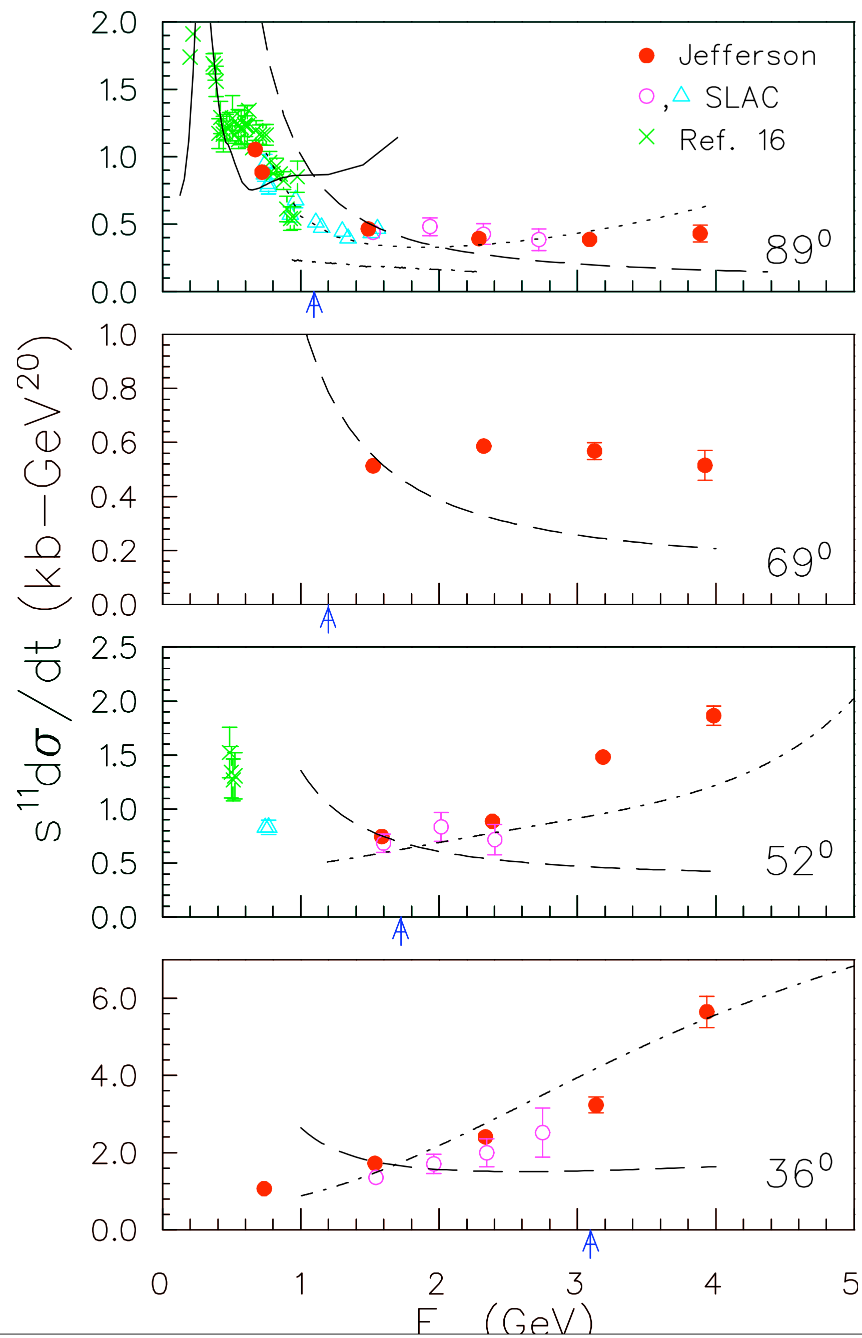
Notice:

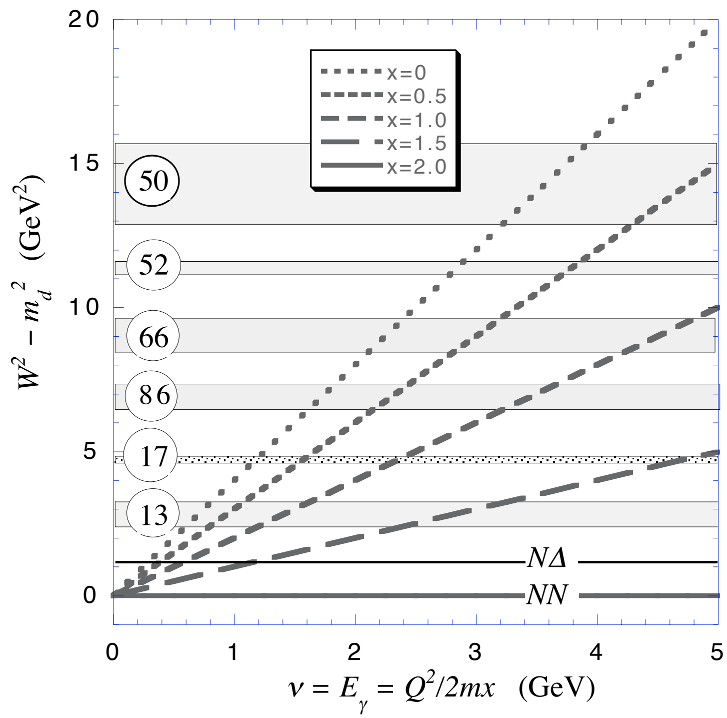
$$\frac{d\sigma}{dt}(E_\gamma = 1\,\mathrm{GeV/c}) \,/\, \frac{d\sigma}{dt}(E_\gamma = 4\,\mathrm{GeV/c}) \approx 10^4$$

scaling

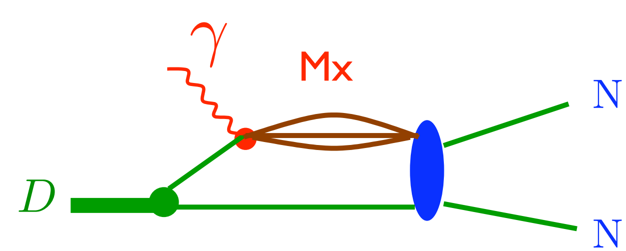


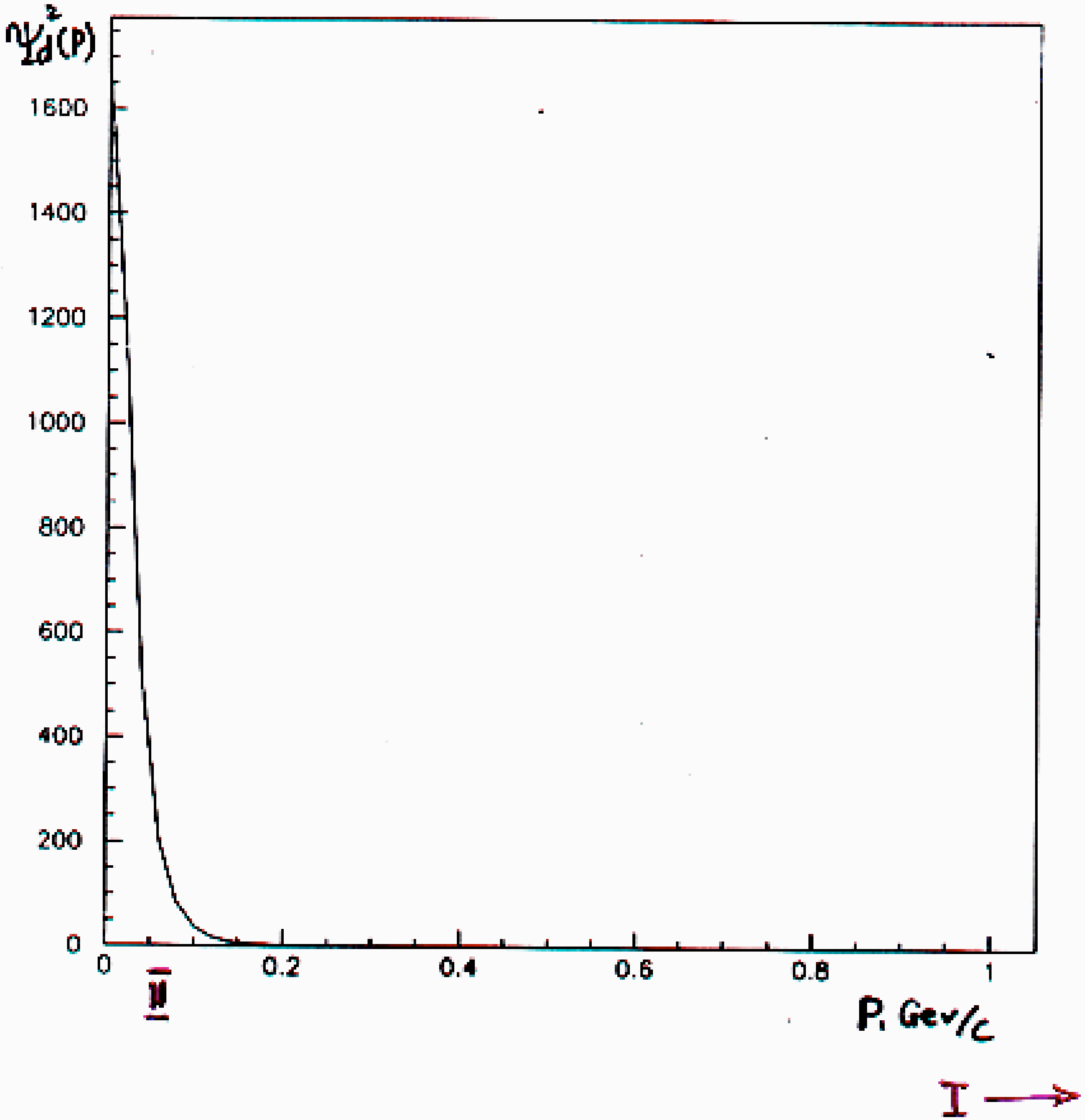
$\gamma d \rightarrow pn$





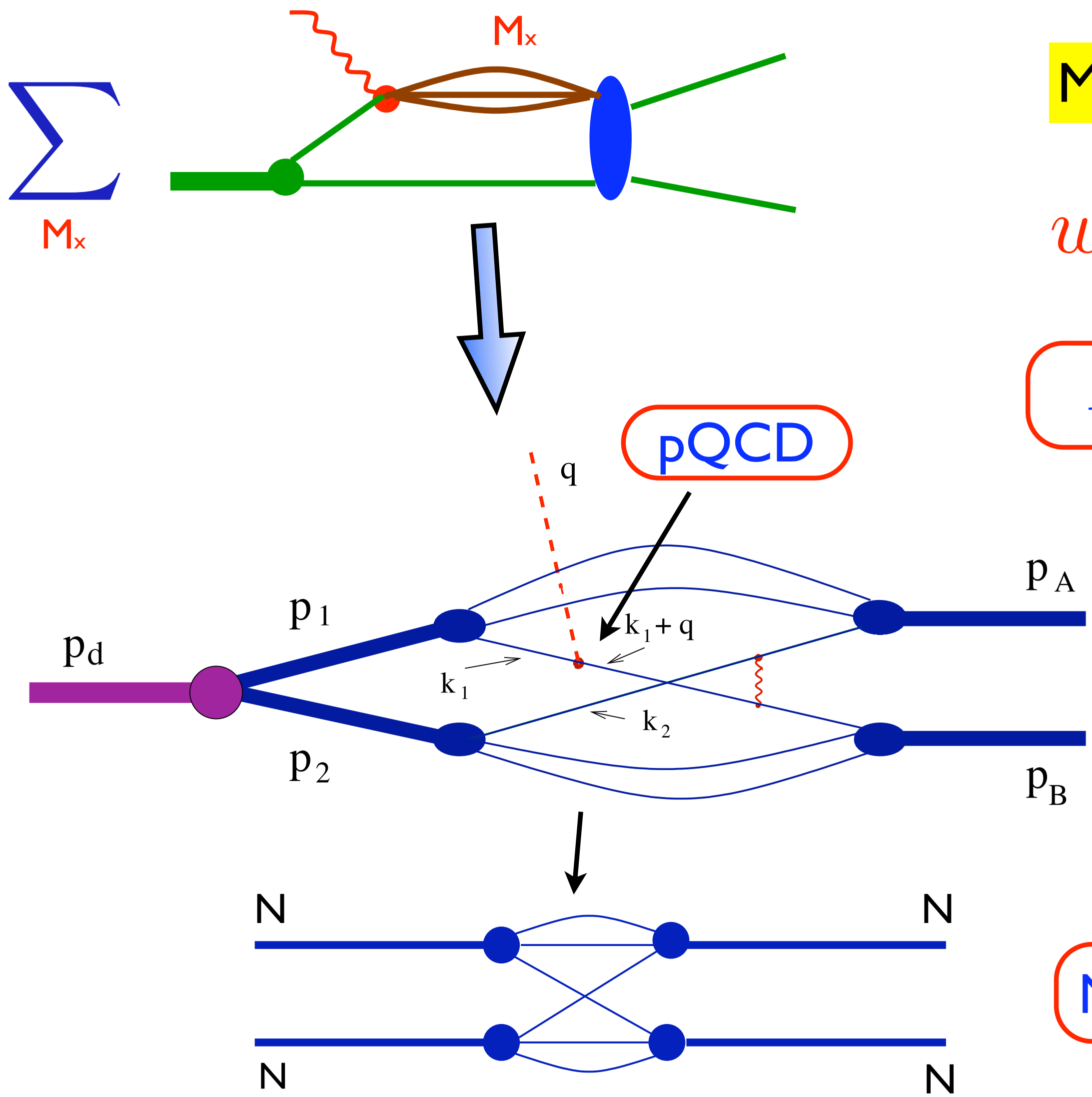
Gilman, Gross, 2002





$\Psi_d^2(P)$
1600
1400
1200
1000
800
600
400
200
0
0
0.2
0.4
0.6
0.8
1
P, Gev/c
I

Hard Rescattering Mechanism

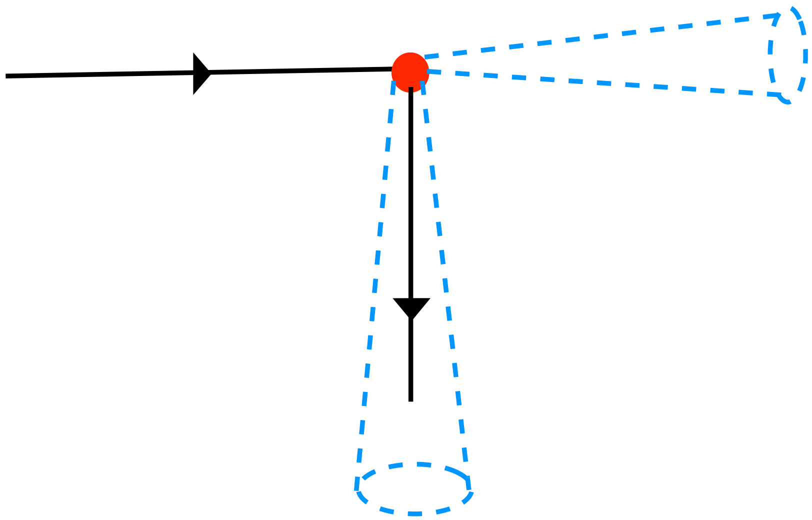


Mmax=w > 2 GeV

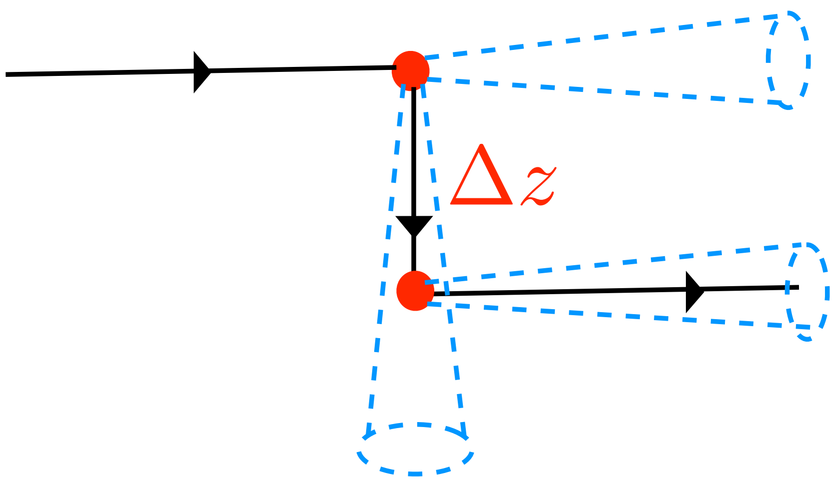
$$w \sim \sqrt{2 E_\gamma m_N}$$

$$E_\gamma \geq 2.5 \text{ GeV}$$

NN -amplitude



$$l_{regen} \sim \frac{k_{||}}{k_{\perp}^2}$$



$$l_{regen} > \Delta Z$$

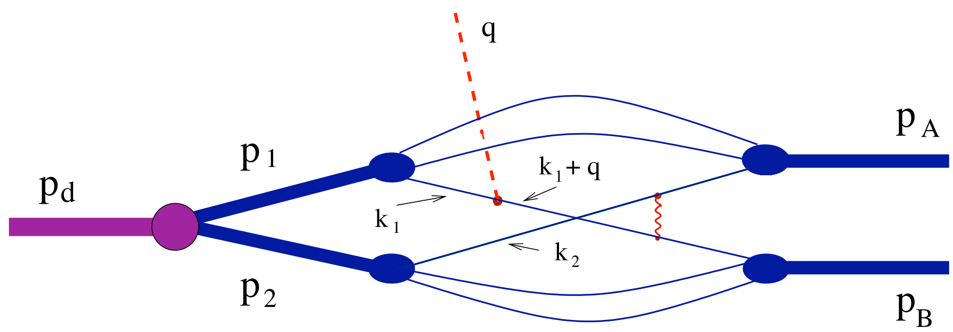
$$l_{regen} \approx E_\gamma R^2$$

E> 2.5GeV

Δz > 1fm

Landau, Pameranchuk, Migdal

Frankfurt, Miller, MS, Strikman
PRL 2000



$$T = -\sum_{e_q} \int \left(\frac{\psi_N^\dagger(x_2', p_{B\perp}, k_{2\perp})}{x_2'} \bar{u}(p_B - p_2 + k_2) \left[-igT_c^F \gamma^\nu\right] \right.$$

$$\left. \frac{u(k_1+q)\bar{u}(k_1+q)}{(k_1+q)^2 - m_q^2 + i\epsilon} \left[-ie_q \epsilon^\perp \cdot \gamma^\perp\right] u(k_1) \frac{\psi_N(x_1, p_{1\perp}, k_{1\perp})}{x_1} \right)$$

$$\left\{ \frac{\psi_N^\dagger(x_1', p_{A\perp}, k_{1\perp})}{x_1'} \bar{u}(p_A - p_1 + k_1) \left[-igT_c^F \gamma_\mu\right] u(k_2) \frac{\psi_N(x_2, p_{2\perp}, k_2}{x_2} \right.$$

$$G^{\mu\nu} \frac{\Psi_d(\alpha, p_\perp)}{1-\alpha} \frac{dx_1}{1-x_1} \frac{d^2 k_{1\perp}}{2(2\pi)^3} \frac{dx_2}{1-x_2} \frac{d^2 k_{2\perp}}{2(2\pi)^3} \frac{d\alpha}{\alpha} \frac{d^2 p_\perp}{2(2\pi)^3},$$

We use the reference frame where

$p_d = (p_{d0}, p_{dz}, p_\perp) \equiv (\frac{\sqrt{s'}}{2} + \frac{M_d^2}{2\sqrt{s'}}, \frac{\sqrt{s'}}{2} - \frac{M_d^2}{2\sqrt{s'}}, 0)$,

with $s = (q + p_d)^2$, $s' \equiv s - M_D^2$,

and the photon four-momentum is $q = (\frac{\sqrt{s'}}{2}, -\frac{\sqrt{s'}}{2}, 0)$.

-The knocked-out quark propagator.

$$(k_1 + q)^2 - m_q^2 = x_1 s' \left[\left(1 + \frac{1}{s'}(M_d^2 - \frac{m_n^2 + p_\perp^2}{1-\alpha}) \right) \alpha - \frac{x_1 m_R^2 + k_\perp^2 + m_q^2(1-x_1)}{(1-x_1)x_1 s'} - \frac{p_\perp^2 - 2p_\perp k_{1\perp}}{x_1 s'} \right] \quad (1)$$

-We are concerned with momenta such that $p_\perp^2 \ll m_N^2 \ll s'$ and $\alpha \sim \frac{1}{2}$ so we neglect terms of order $p_\perp^2, m_N^2/s' \ll 1$ to obtain:

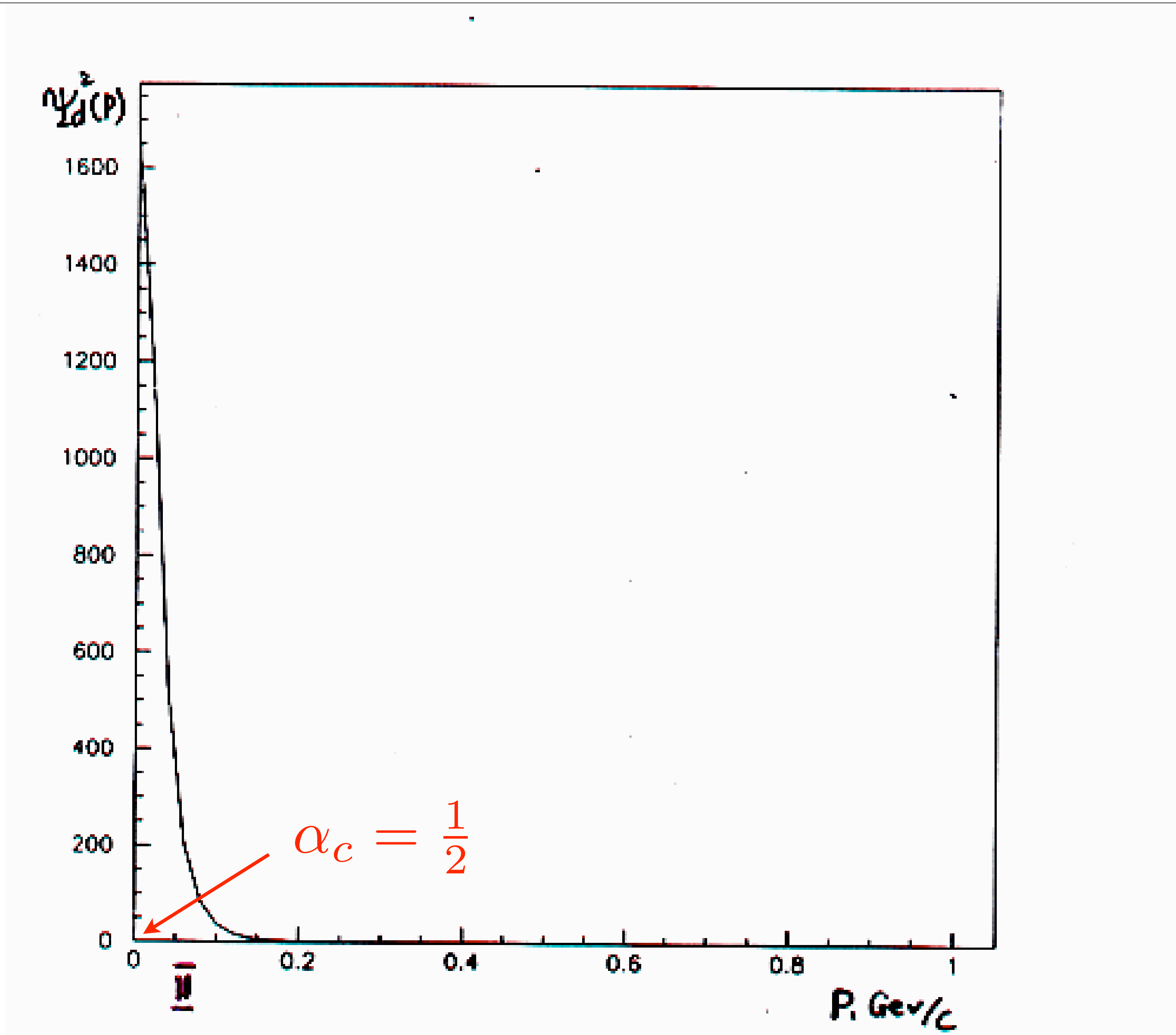
$$(k_1 + q)^2 - m_q^2 + i\epsilon \approx x_1 s'(\alpha - \alpha_c + i\epsilon),$$

$$\alpha_c \equiv \frac{x_1 m_R^2 + k_{1\perp}^2}{(1-x_1)x_1 \tilde{s}}. \quad (2)$$

looking for $\alpha_c \sim \frac{1}{2}$ contribution

Here $\tilde{s} \equiv s'(1 + \frac{M_d^2}{s'})$ and m_R is the recoil mass of the spectator quark-gluon system of the first nucleon.

- The integration over $k_{1\perp}$ in the region $k_{1\perp}^2 \sim \frac{(1-x_1)x_1\tilde{s}}{2} \gg x_1 m_R^2$ does provide $\alpha_c = \frac{1}{2}$.



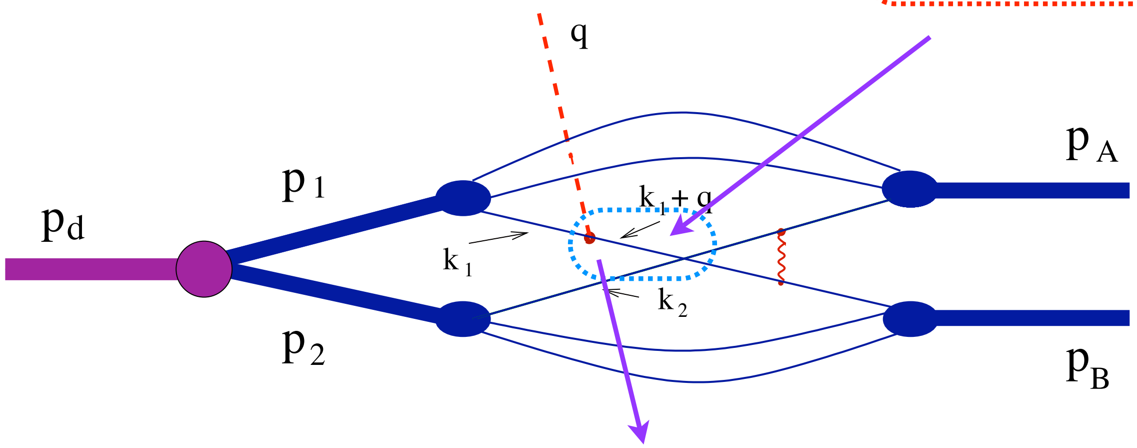
1600
1400
1200
1000
800
600
400
200
0
0
0.2
0.4
0.6
0.8
1
P, Gev/c
$\alpha_c = \frac{1}{2}$

$$x_1 = (1 - \frac{m_R^2}{\alpha_c s'}) \to 1$$

- Keeping only the imaginary part of the quark propagator (eikonal approximation) leads to $\alpha = \alpha_c$ and corresponds to keeping the contribution from the soft component of the deuteron wave function.

Next we calculate the photon-quark hard scattering vertex– $\bar{u}(k_1+q)[\gamma_\perp]u(k_1)$ and use Eq. (2) to integrate over α

-By taking into account only second term in the decomposition of struck quark propagator: $(\alpha - \alpha_c + \epsilon)^{-1} \equiv \mathcal{P}(\alpha - \alpha_c)^{-1} - i\pi\delta(\alpha - \alpha_c)$:



$$\bar{u}^\beta(k_1 + q)\left[-ie\epsilon^\mu(\lambda_\gamma)\gamma_\mu\right]u^\alpha(k_1) = ie_q 2\sqrt{2E_2 E1}(-\lambda_\gamma)\delta^{\beta,\alpha}\delta^{\lambda_\gamma,\alpha}$$

$$\langle \lambda_A, \lambda_B \mid A \mid \lambda_\gamma, \lambda_D \rangle = \sum_{(\eta_1,\eta_2),(\xi_2),(\lambda_1,\lambda_2)} \int \frac{e_q\sqrt{2}}{x_1\sqrt{s'}} \sqrt{[1-(1-\alpha_c)x_1](1-\alpha_c)x_1}$$
$$\left\{ \frac{\psi_N^{\dagger\lambda_B,\eta_2}(p_B, x_2', k_{2\perp})}{x_2'} \bar{u}_{\eta_2}(p_B - k_2)[-igT_c^F\gamma^\nu]\cdot u_{\lambda_\gamma}(p_1 - k_1 + q) \frac{\psi_N^{\lambda_1,\lambda_\gamma}(p_1, x_1, k_{1\perp})}{x_1} \times \right.$$
$$\left. \frac{\psi_N^{\dagger\lambda_A,\eta_1}(p_B, x_1', k_{1\perp})}{x_1'} \bar{u}_{\eta_1}(p_A - k_1)[-igT_c^F\gamma^\mu] u_{\xi_2}(p_2 - k_2) \frac{\psi_N^{\lambda_2,\xi_2}(p_2, x_2, k_2)}{x_2} G^{\mu,\nu}(r) \frac{dx_1}{1-x_1}\frac{d^2k_{1\perp}}{2(2\pi)^3}\frac{dx_2}{1-x_2}\frac{d^2k_{2\perp}}{2(2\pi)^3} \right\}$$
$$\frac{\Psi^{\lambda_D,\lambda_1,\lambda_2}(\alpha, p_\perp)}{(1-\alpha)\alpha}\frac{d^2p_\perp}{4(2\pi)^2}. \quad (1)$$

$$A_{pn}^{QIM} = \int \frac{\psi_N^\dagger(x_2', p_{B\perp}, k_{2\perp})}{x_2'} \bar{u}(p_B - p_2 + k_2)\left[-igT_c^F\gamma^\nu\right] u(k_1 + q) \frac{\psi_N(x_1, p_{1\perp}, k_{1\perp})}{x_1}$$
$$\frac{\psi_N^\dagger(x_1', p_{F\perp}, k_{1\perp})}{x_1'} \bar{u}(p_A - p_1 + k_1)\left[-igT_c^F\gamma_\mu\right] u(k_2) \frac{\psi_N(x_2, p_{2\perp}, k_{2\perp})}{x_2} \cdot G^{\mu\nu}$$
$$\times \frac{dx_1}{1-x_1}\frac{d^2k_{1\perp}}{2(2\pi)^3}\frac{dx_2}{1-x_2}\frac{d^2k_{2\perp}}{2(2\pi)^3} \quad (1)$$

Frankfurt, Sargsian, Strikman, Phys.Rev. Lett 2000

$$\langle \lambda_A, \lambda_B, | A_{Q_i} | \lambda_\gamma, \lambda_D \rangle = \sum_{(\eta_1,\eta_2),(\xi_2),(\lambda_1,\lambda_2)} \int \frac{eQ_i f(\theta_{cm})}{\sqrt{2s'}} \times$$

$$\langle \eta_2, \lambda_B | \langle \eta_1, \lambda_A | A^i_{QIM}(s, l^2) | \lambda_1, \lambda_\gamma \rangle | \lambda_2 \xi_2 \rangle \times \Psi^{\lambda_D, \lambda_1, \lambda_2}(\alpha_c, p_\perp) \frac{d^2 p_\perp}{(2\pi)^2} (1)$$

Notation used $| \lambda_{nucleon}, \lambda_{quark} \rangle$

Assuming $\lambda_1 = \lambda_\gamma$

Brodsky,Carlson,Lipkin Phys.Rev.D 1979
Farrar, Gottlieb,Sivers,Thomas Phys.Rev.D 1979

NN ⇒ NN

$$\langle a'b' | A^{NN}_{QIM} | ab \rangle = \frac{1}{2} \langle a'b' | \sum_{i \in a\ ,\ j \in b} [I_i I_j + \vec{\tau}_i \cdot \vec{\tau}_j] F_{i,j}(s,t) | ab \rangle$$

SU(6)

γnp ⇒ np

$$\langle a'b' | A^{Q}_{QIM} | ab \rangle \, |_{a,b \in D} = \frac{1}{2} \langle a'b' | \sum_{i \in a\ ,\ j \in b} [I_i I_j + \vec{\tau}_i \cdot \vec{\tau}_j](Q_i + Q_j) F_{i,j}(s,t) | ab \rangle = (Q_u + Q_d) \langle a'b' | A^{pn}_{QIM} | ab \rangle$$

$$(Q_u + Q_d) \langle a'b' | A^{pn}_{QIM} | ab \rangle = \frac{1}{3} \langle a'b' | A^{pn} | ab \rangle .$$

$$A^{pn}_{QIM} \approx A_{pn}$$

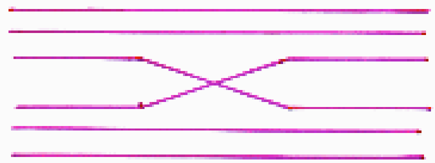
$$\langle p_{\lambda_A}, n_{\lambda_B} \mid A \mid \lambda_\gamma, \lambda_D\rangle = \sum_{\lambda_2} \frac{f(\theta_{cm})}{3\sqrt{2s'}} \times$$
$$\Big(\langle p_{\lambda_A}, n_{\lambda_B}|A_{pn}(s,t_n)|p_{\lambda_\gamma}, n_{\lambda_2}\rangle - \langle p_{\lambda_A}, n_{\lambda_B}|A_{pn}(s,u_n)|n_{\lambda_\gamma} p_{\lambda_2}\rangle\Big)$$
$$\int \Psi^{\lambda_D,\lambda_\gamma,\lambda_2}(\alpha_c, p_\perp)\frac{d^2p_\perp}{(2\pi)^2} \qquad (1)$$

$$\Psi^{\lambda_D,\lambda_1\lambda_2} = (2\pi)^{\frac{3}{2}}\Psi_{NR}^{J_D,\lambda_1,\lambda_2}\sqrt{m} = [u(k) + w(k)\sqrt{\tfrac{1}{8}}S_{12}]\xi_1^{\lambda_D,\lambda_1,\lambda_2}$$

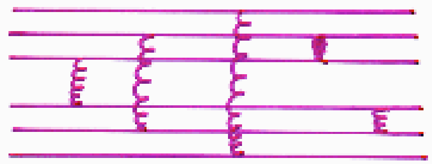
$$\frac{d\sigma^{\gamma d\to pn}}{dt} = \frac{8\alpha}{9}\pi^4 \cdot \frac{1}{s'}C(\frac{\tilde{t}}{s})\frac{d\sigma^{pn\to pn}(s,\tilde{t})}{dt}\left|\int \Psi_d^{NR}(p_z = 0, p_\perp)\sqrt{m_N}\frac{d^2p_\perp}{(2\pi)^2}\right|^2,$$

$$C(\tfrac{\tilde{t}}{s}) \mid_{\theta_{cm}=90} = 1$$

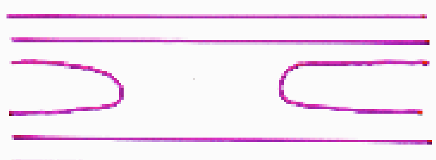
QIM



GLUON EXCHANGE



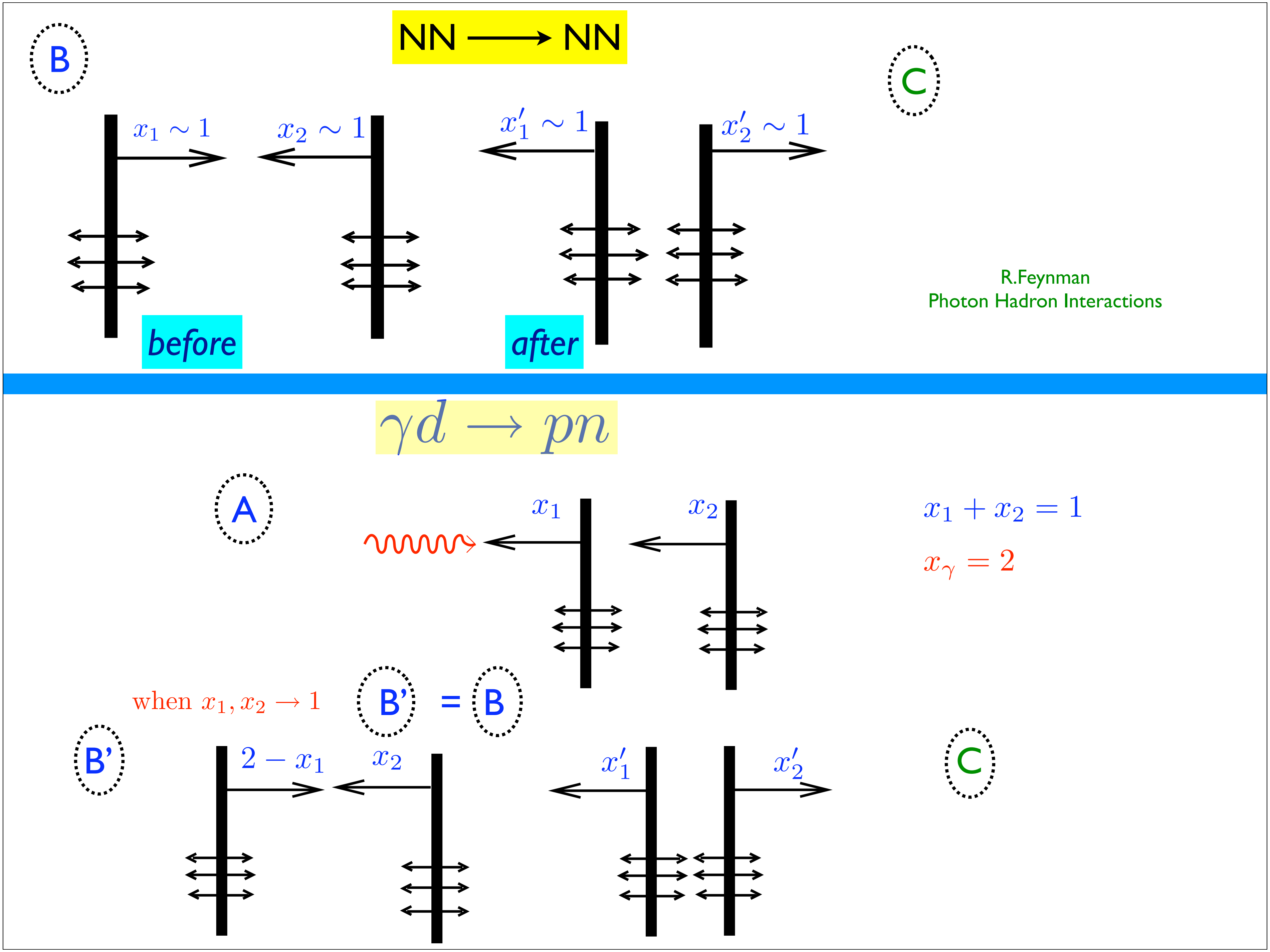
ANIHILLATION



≡ COMPARE $pp \to pp$ AND $p\bar{p} \to p\bar{p}$ CROSS SECTIONS

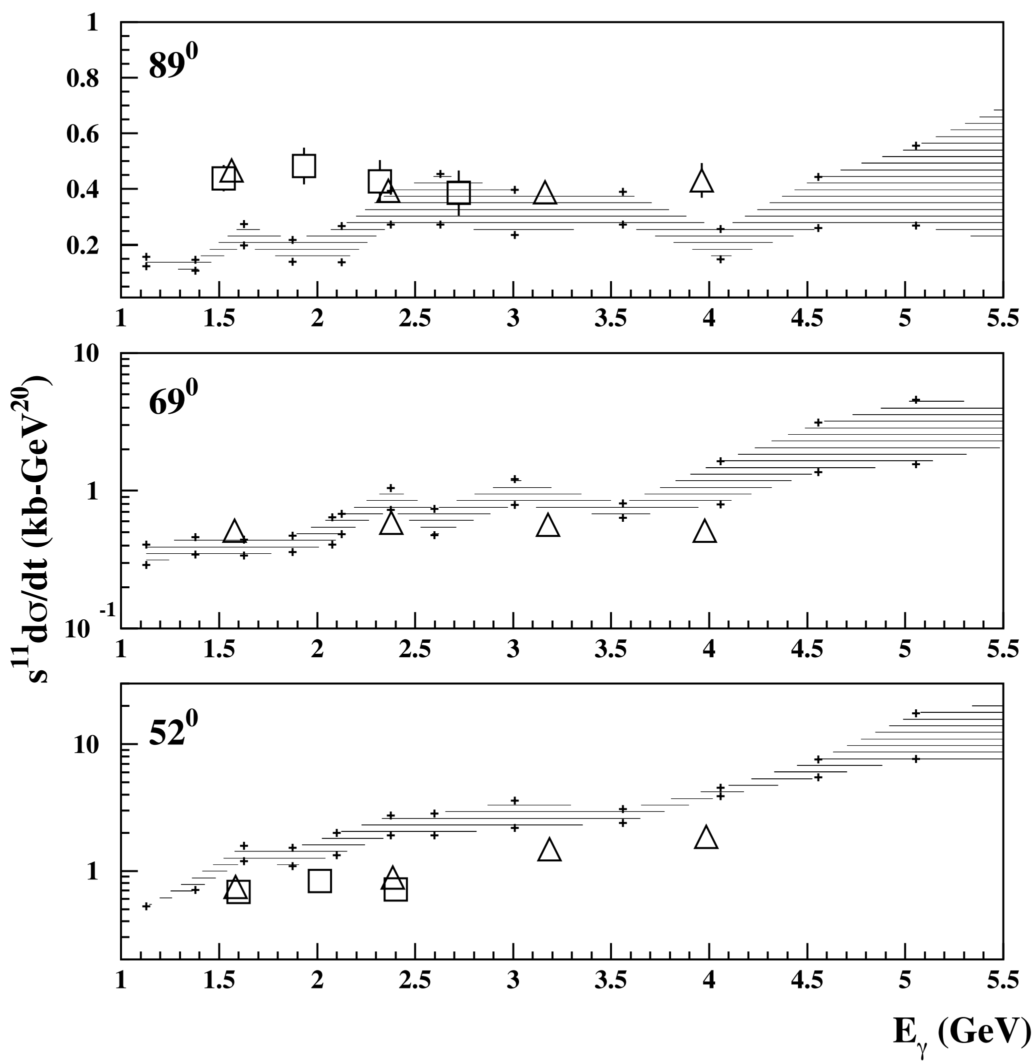
$$\frac{d\sigma^{\bar{p}p}/dt}{d\sigma^{pp}/dt} \sim 1.7 \text{ AT } \theta_{CM} \approx 0^\circ$$

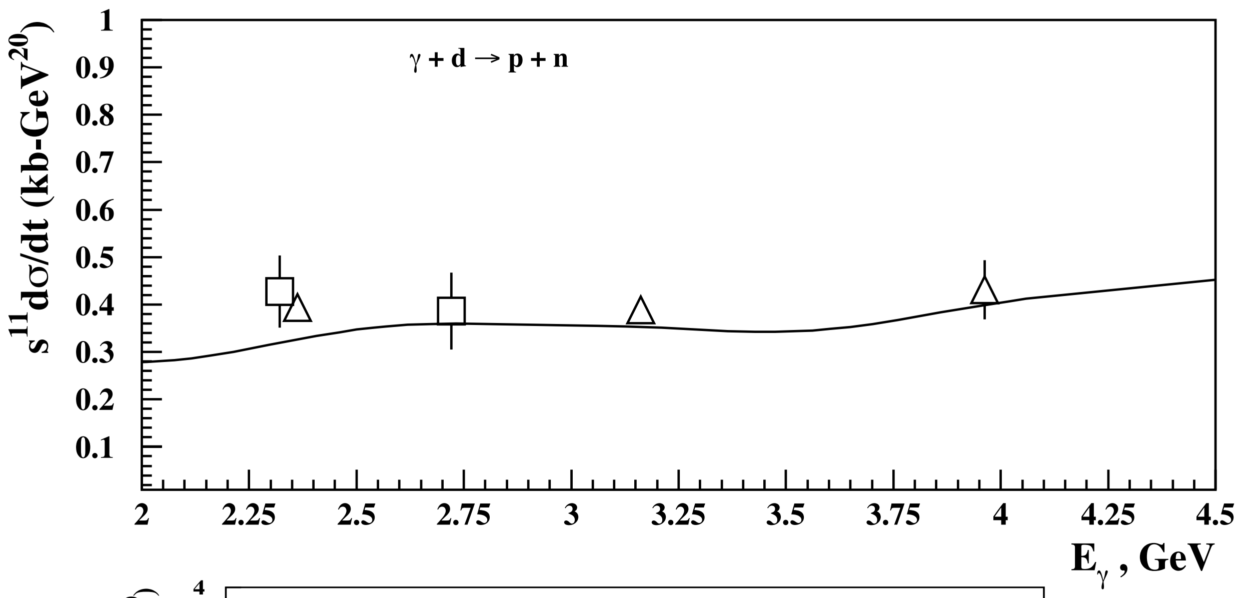
$$\sim 0.025 \text{ AT } \theta_{CM} = 90^\circ$$


NN ⟶ NN
B
C
$x_1 \sim 1$
$x_2 \sim 1$
$x_1' \sim 1$
$x_2' \sim 1$
before
after
R.Feynman
Photon Hadron Interactions
$\gamma d \to pn$
A
x_1
x_2
$x_1 + x_2 = 1$
$x_\gamma = 2$
when $x_1, x_2 \to 1$
B' = B
B'
$2 - x_1$
x_2
x_1'
x_2'
C

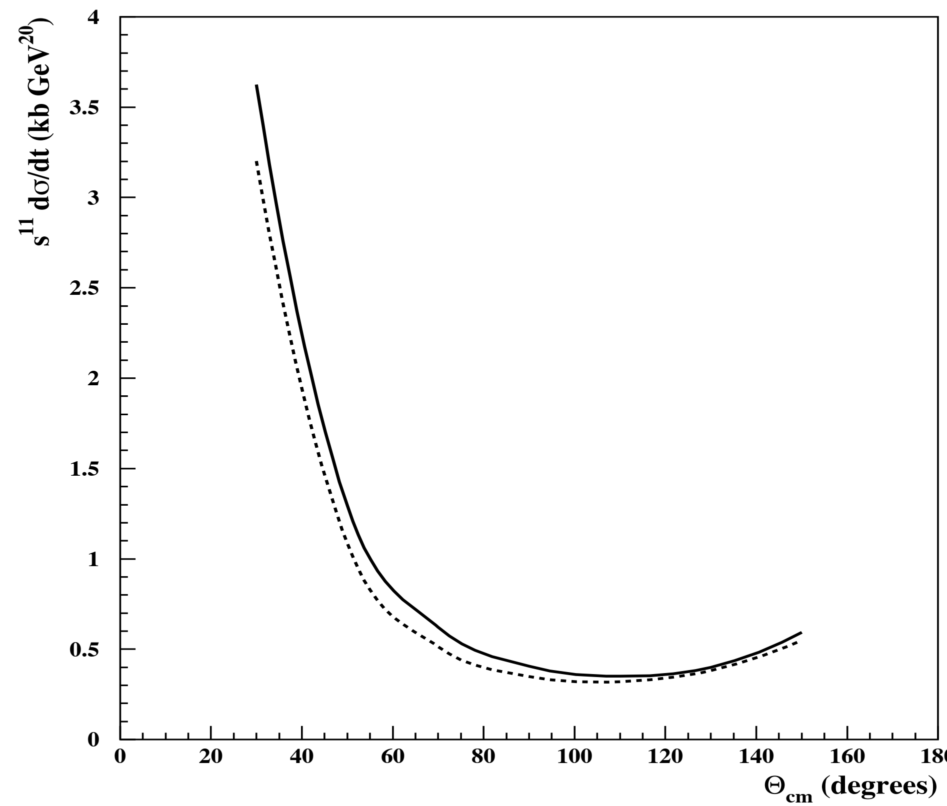
Frankfurt, Miller, M.S. Sargsian
PRL 2000

$$\frac{d\sigma^{\gamma d\to pn}}{dt} = \frac{8\alpha}{9}\pi^4 \cdot \frac{1}{s'} C(\frac{\tilde{t}}{s}) \frac{d\sigma^{pn\to pn}(s,\tilde{t})}{dt} \left| \int \Psi_d^{NR}(p_z=0,p_\perp)\sqrt{m_N}\frac{d^2p_\perp}{(2\pi)^2}\right|^2,$$

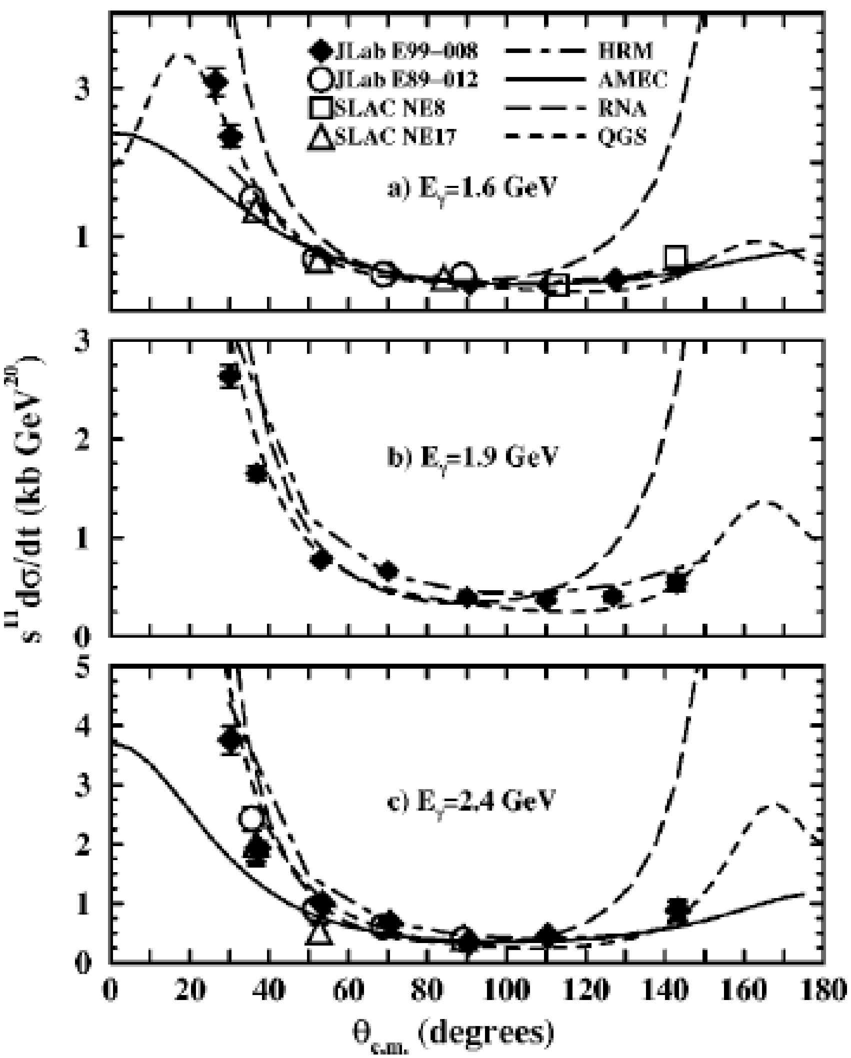




γ + d → p + n
$s^{11}d\sigma/dt$ (kb-GeV^{20})
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
2
2.25
2.5
2.75
3
3.25
3.5
3.75
4
4.25
4.5
E_γ , GeV



$s^{11}d\sigma/dt$ (kb GeV^{20})
4
3.5
3
2.5
2
1.5
1
0.5
0
0
20
40
60
80
100
120
140
160
180
Θ_{cm} (degrees)


JLab E99–008
JLab E89–012
SLAC NE8
SLAC NE17
HRM
AMEC
RNA
QGS
a) E_γ=1.6 GeV
b) E_γ=1.9 GeV
c) E_γ=2.4 GeV
$s^{11}d\sigma/dt$ (kb GeV^{20})
$\theta_{c.m.}$ (degrees)

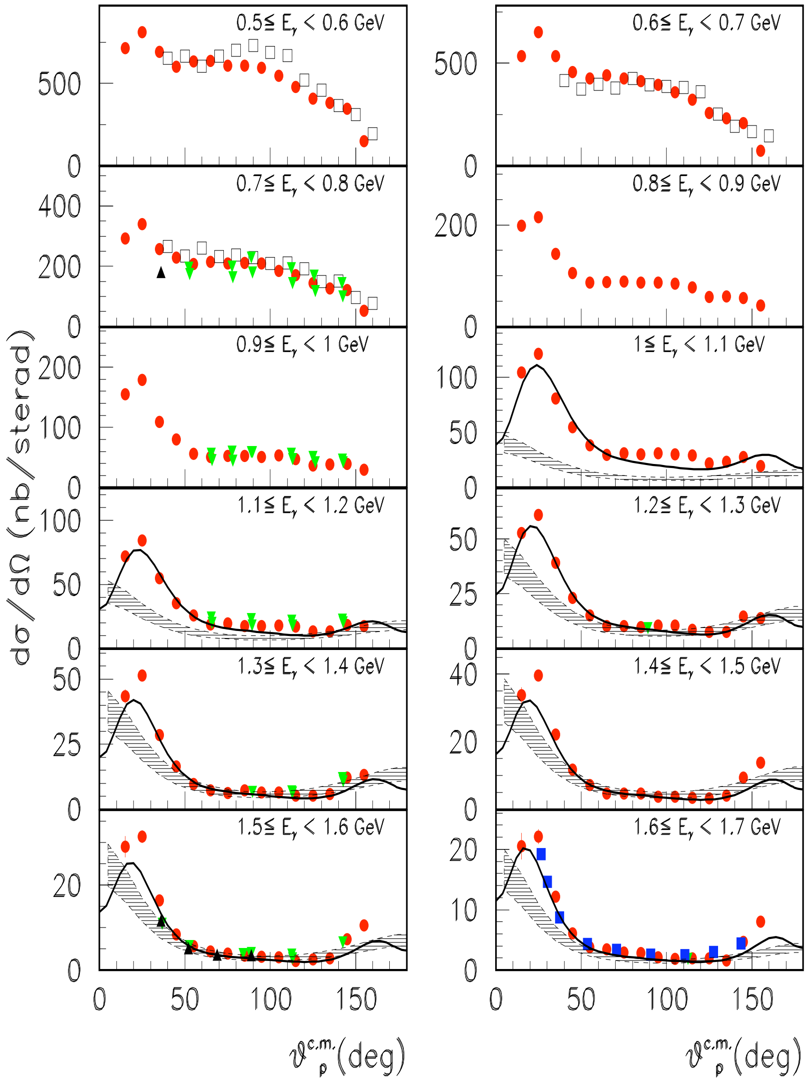


FIG. 7: (Color) Angular distributions of the deuteron photodisintegration cross section measured by the CLAS (full/red circles) in the incident photon energy range 0.50 – 1.70 GeV. Results from Mainz [26] (open squares, average of the measured values in the given photon energy intervals), SLAC [5, 6, 7] (full/green down-triangles), JLab Hall A [10] (full/blue squares) and Hall C [8, 9] (full/black up-triangles) are also shown. Error bars represent the statistical uncertainties only. The solid line and the hatched area represent the predictions of the QGS [18] and the HRM [27] models, respectively.

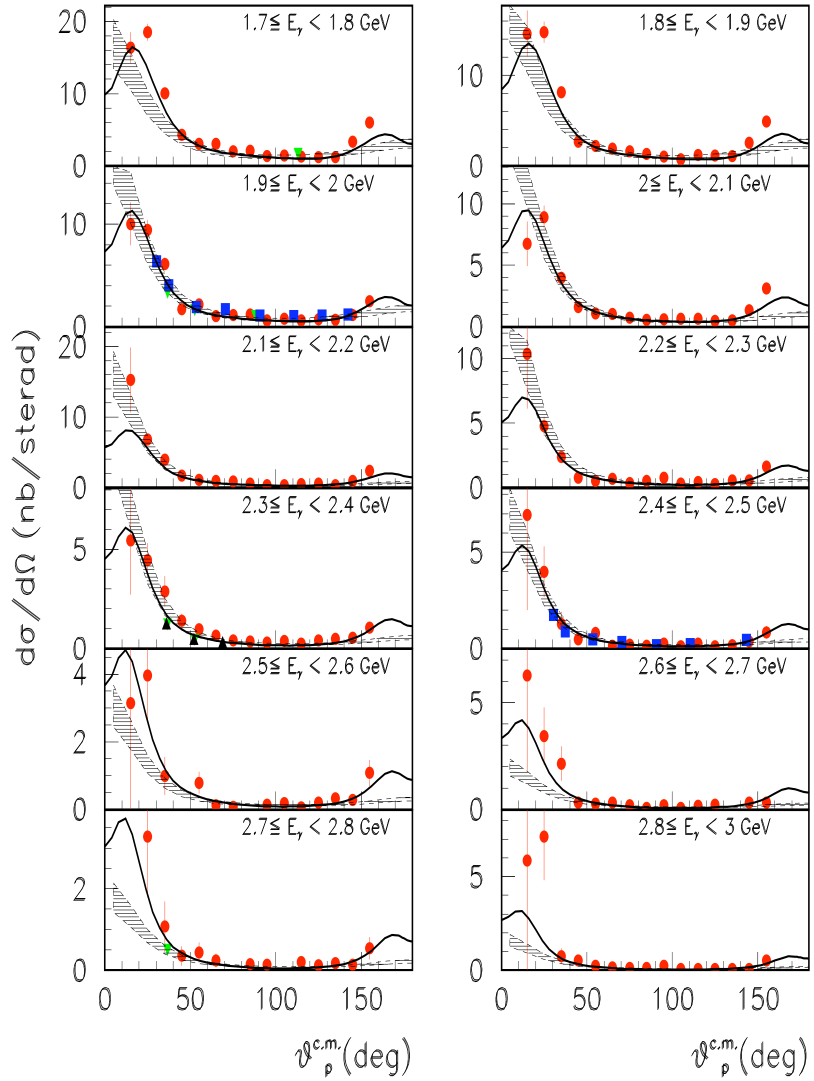


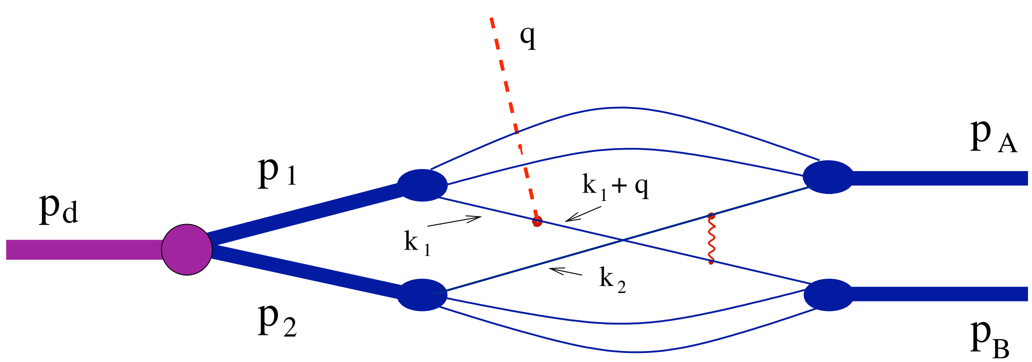
FIG. 8: (Color) Same as Fig. 7 for photon energies 1.7 – 3.0 GeV.

Specifics of Hard Rescattering Model

Helicity Selection Rule

- Photon selects nucleon in the nucleus with helicity = to its own

- Due to dominance of Helicity Conserving amplitudes in NN scattering, photon helicity will propogate to the helicty of one of the final nucleons.

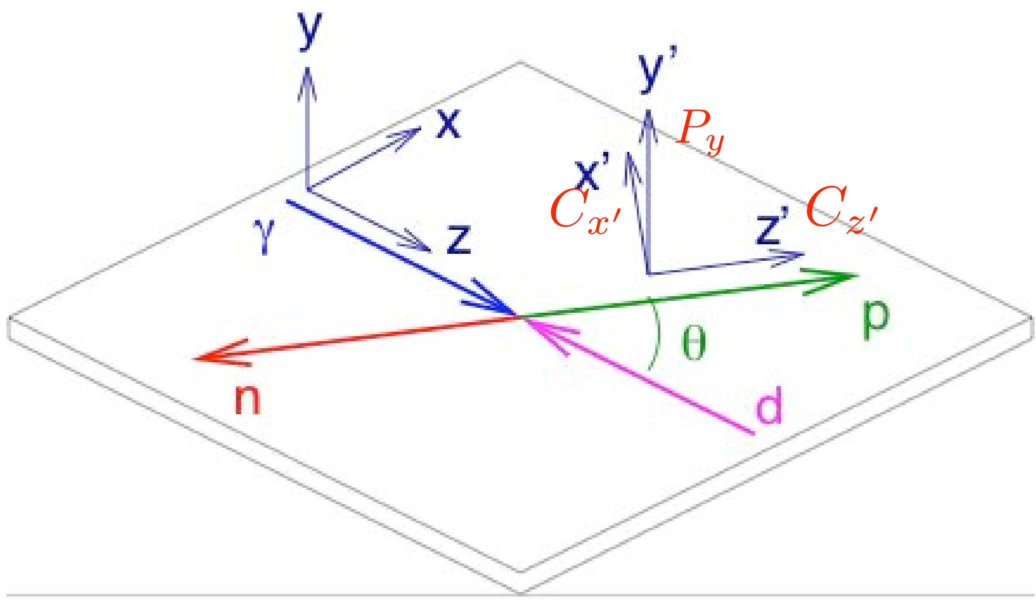


Polarization Observables

$$\langle p_{\lambda_A}, n_{\lambda_B} \mid A \mid \lambda_\gamma, \lambda_D \rangle = \sum_{\lambda_2} \frac{f(\theta_{cm})}{3\sqrt{2s'}} \times$$

$$\left(\langle p_{\lambda_A}, n_{\lambda_B} | A_{pn}(s, t_n) | p_{\lambda_\gamma}, n_{\lambda_2} \rangle - \langle p_{\lambda_A}, n_{\lambda_B} | A_{pn}(s, u_n) | n_{\lambda_\gamma} p_{\lambda_2} \rangle \right)$$

$$\int \Psi^{\lambda_D, \lambda_\gamma, \lambda_2}(\alpha_c, p_\perp) \frac{d^2 p_\perp}{(2\pi)^2}$$



Gilman, Gross, 2002

$$P_y = -\frac{2Im\left\{\phi_5^\dagger[2(\phi_1+\phi_2)+\phi_3-\phi_4]\right\}}{2|\phi_1|^2+2|\phi_2|^2+|\phi_3|^2+|\phi_4|^2+6|\phi_5|^2}$$

$$C_{x'} = \frac{2Re\left\{\phi_5^\dagger[2(\phi_1-\phi_2)+\phi_3+\phi_4]\right\}}{2|\phi_1|^2+2|\phi_2|^2+|\phi_3|^2+|\phi_4|^2+6|\phi_5|^2}$$

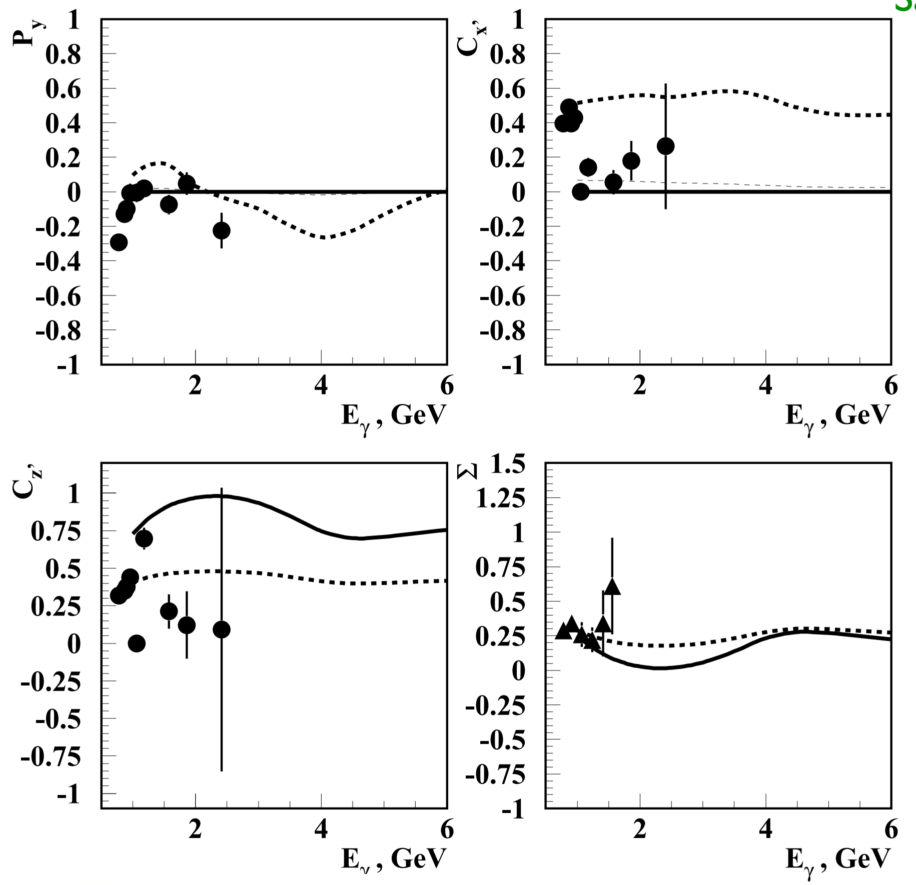
$$C_{z'} = \frac{2|\phi_1|^2-2|\phi_2|^2+|\phi_3|^2-|\phi_4|^2}{2|\phi_1|^2+2|\phi_2|^2+|\phi_3|^2+|\phi_4|^2+6|\phi_5|^2}$$

$$\Sigma = \frac{2Re\left[|\phi_5|^2-\phi_3^\dagger\phi_4\right]}{2|\phi_1|^2+2|\phi_2|^2+|\phi_3|^2+|\phi_4|^2+6|\phi_5|^2},$$

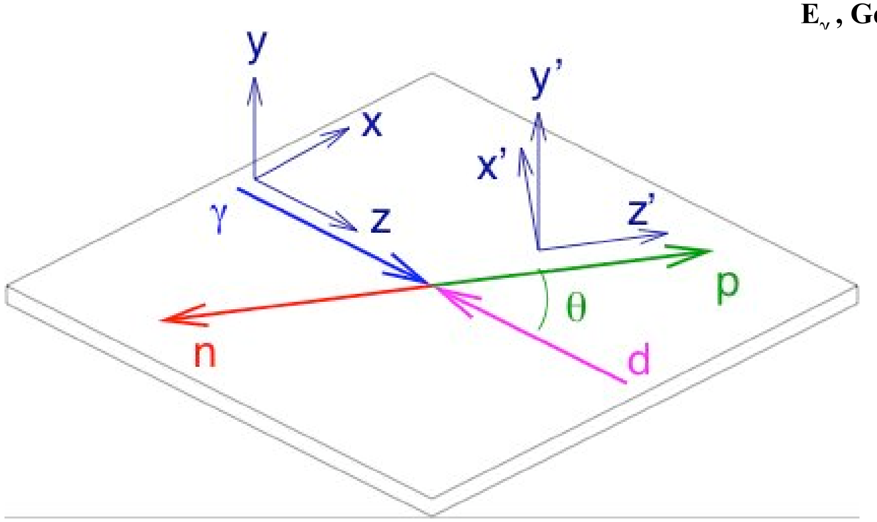
$$\begin{aligned}
\phi_1(s,t_n,u_n) &= \langle +,+ \mid A_{pn} \mid +,+\rangle \\
\phi_2(s,t_n,u_n) &= \langle +,+ \mid A_{pn} \mid -,-\rangle \\
\phi_3(s,t_n,u_n) &= \langle +,- \mid A_{pn} \mid +,-\rangle \\
\phi_4(s,t_n,u_n) &= \langle +,- \mid A_{pn} \mid -,+\rangle \\
\phi_5(s,t_n,u_n) &= \langle +,+ \mid A_{pn} \mid +,-\rangle. \qquad (1)
\end{aligned}$$

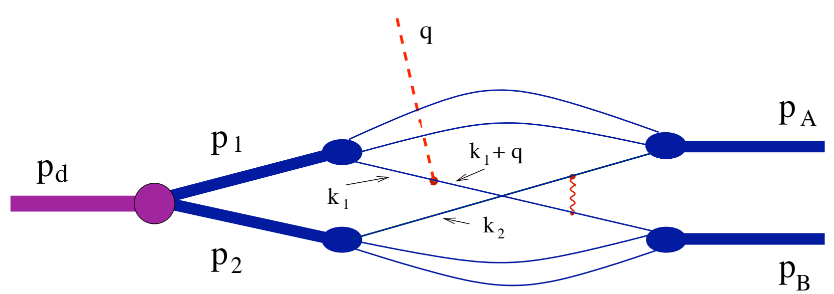
$$|\phi_1| \geq |\phi_3|, |\phi_4| > |\phi_5| > |\phi_2|.$$

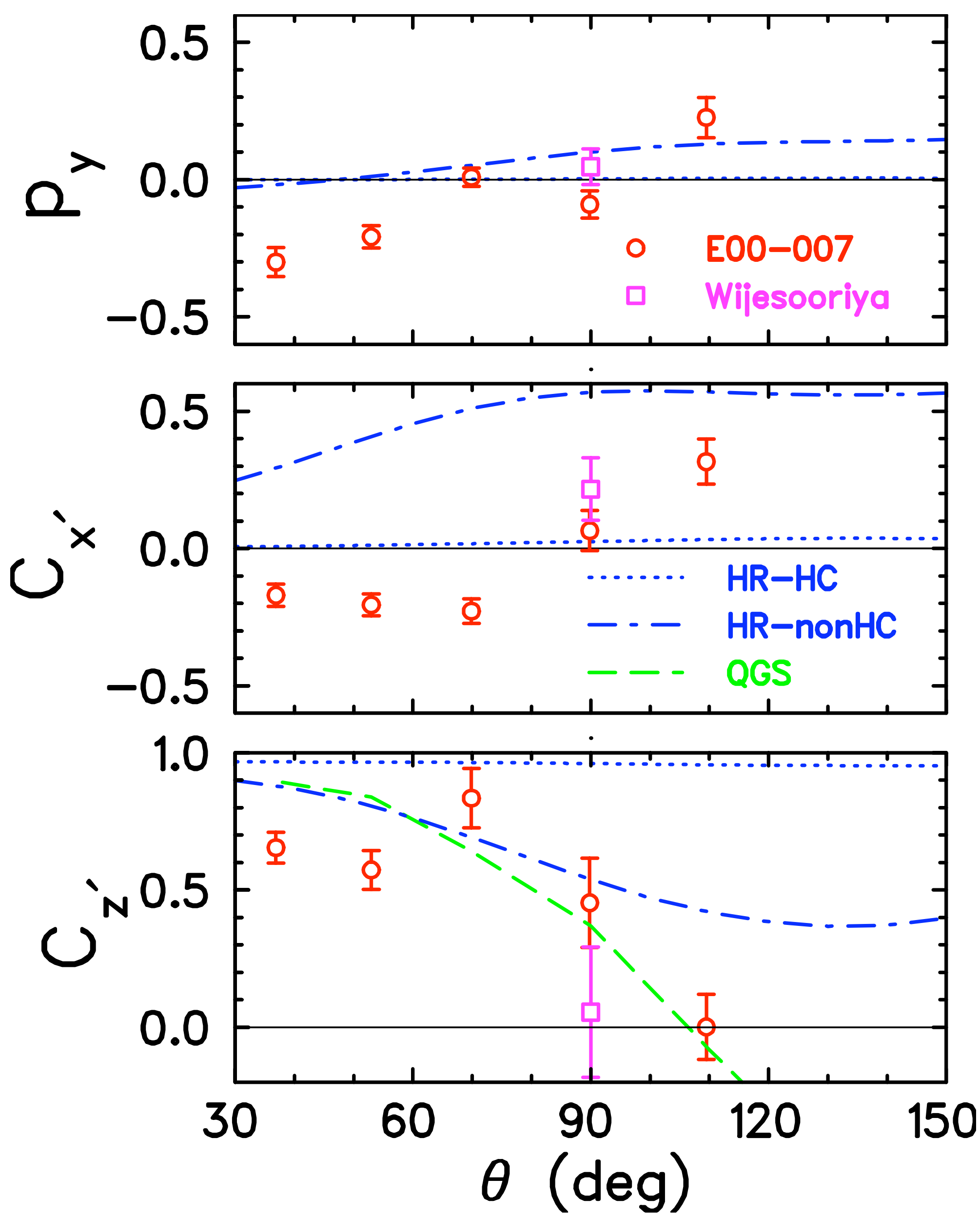
Sargsian, Phys. Lett. B 2004



$$C_{z'} = 0.5 \div 1.0$$

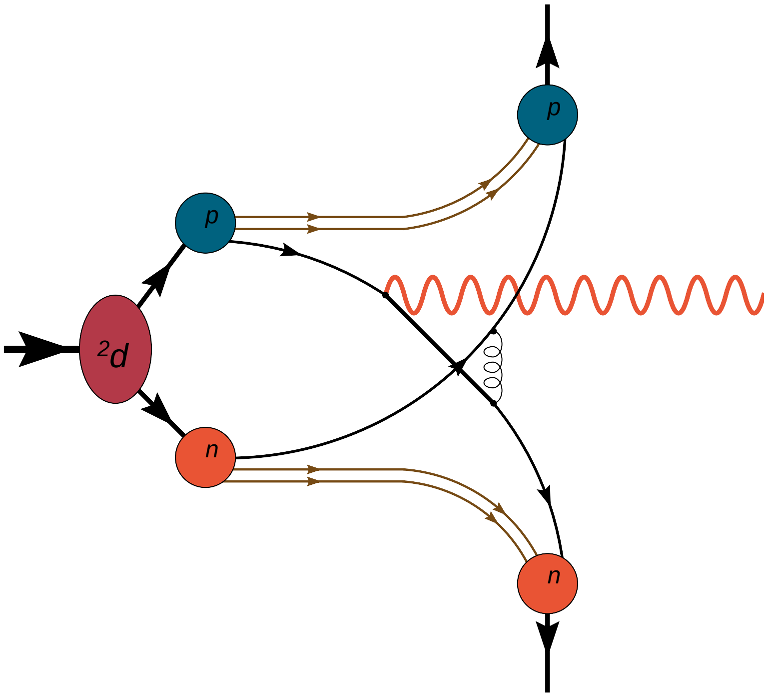




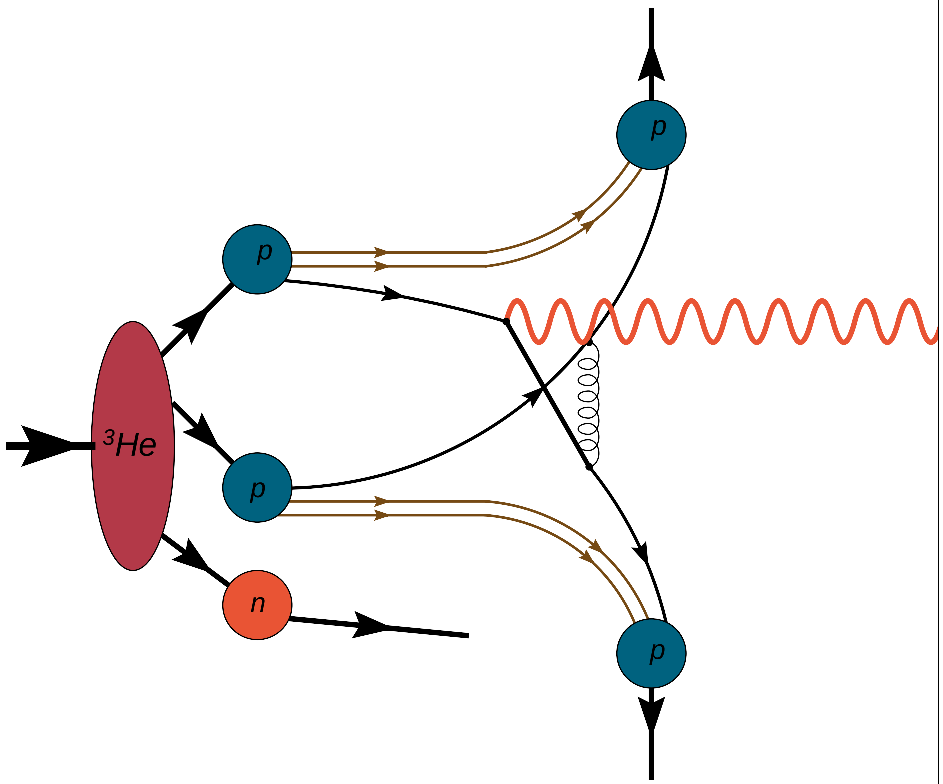


Jiang et al, PRL2007

Break up of pn from the deuteron



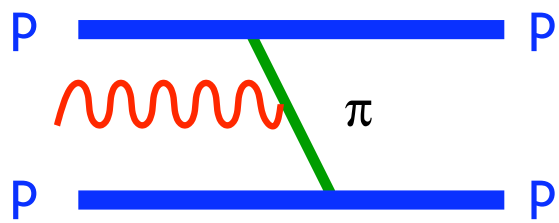
Break up of pp from Helium 3



- Hard Photodisintegration of pp pair: $\gamma +^3 He \rightarrow pp + n$

What is known?

for $E_\gamma \leq 0.5 GeV$

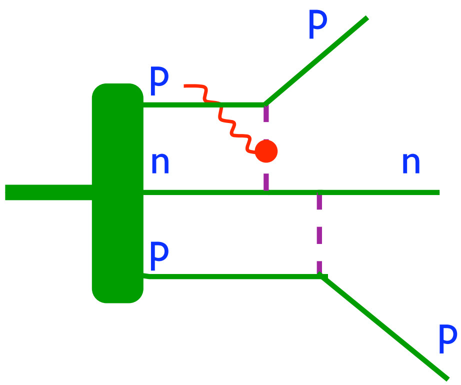


~ 0

$\sigma_{\gamma pp} \ll \sigma_{\gamma pn}$

- Three Body Processes are Dominant

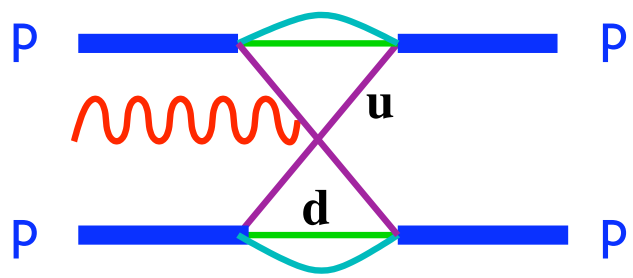
Laget, Nucl.Phys. 1989



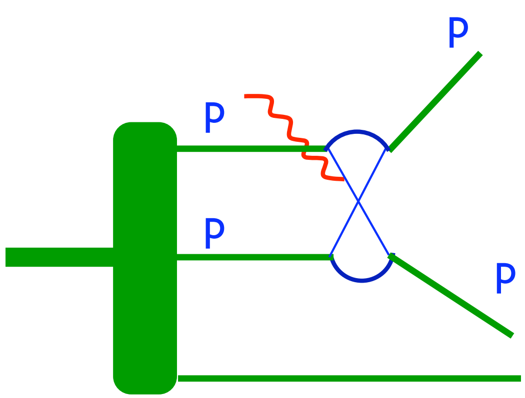
$$\frac{\sigma(\gamma^3 He \rightarrow pp)}{\sigma(\gamma^3 He \rightarrow pn)} \approx 1\%$$

- Hard Photodisintegration of pp pair: $\gamma +^3 He \rightarrow pp + n$

In High Energy Limit

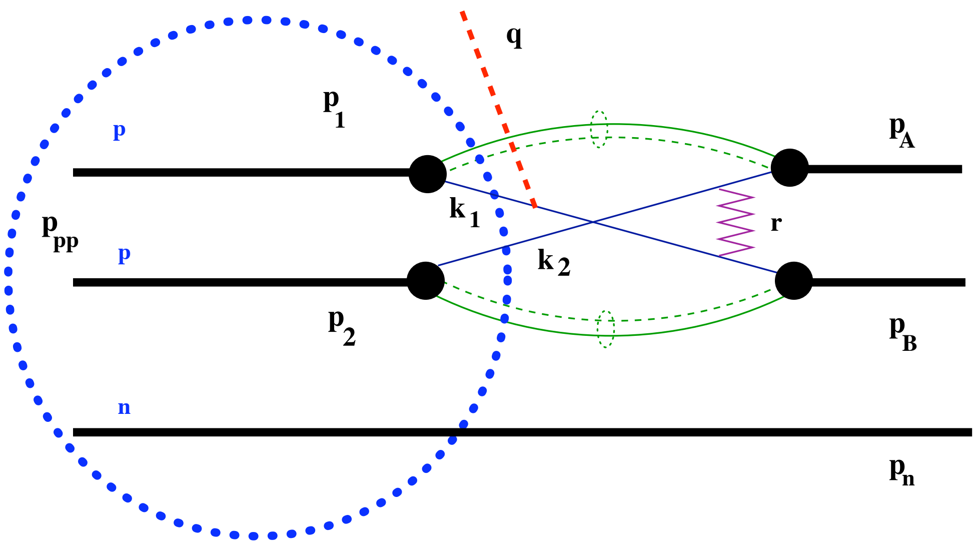


- Two Body Processes may Dominate again



Hard Disintegration of pp from 3He

Brodsky, Frankfurt, Gilman,Hiller,
Miller,Piasetzky,M.S. Strikman
Phys.Lett. B 2003



$$\frac{d\sigma}{dt d^3p_n} = \left(\frac{14}{15}\right)^2 \frac{8\pi^4\alpha_{EM}}{s - M^2_{^3\text{He}}} \; \frac{d\sigma^{pp}(s_{pp}, t_N)}{dt} \frac{1}{2} \left| \sum_{spins} \int \Psi^{^3\text{He}}(p_1, p_2, p_n) \sqrt{M_N} \frac{d^2 p_{2T}}{(2\pi)^2} \right|^2 ,$$

where $s = (P_\gamma + P_{^3\text{He}})^2$, $t = (P_p - P_\gamma)$ $s_{pp} = (P_\gamma + P_{^3\text{He}} - P_n)^2$, and $t_N = (p_a - \alpha p_{pp})^2 \approx \frac{1}{2}t$.

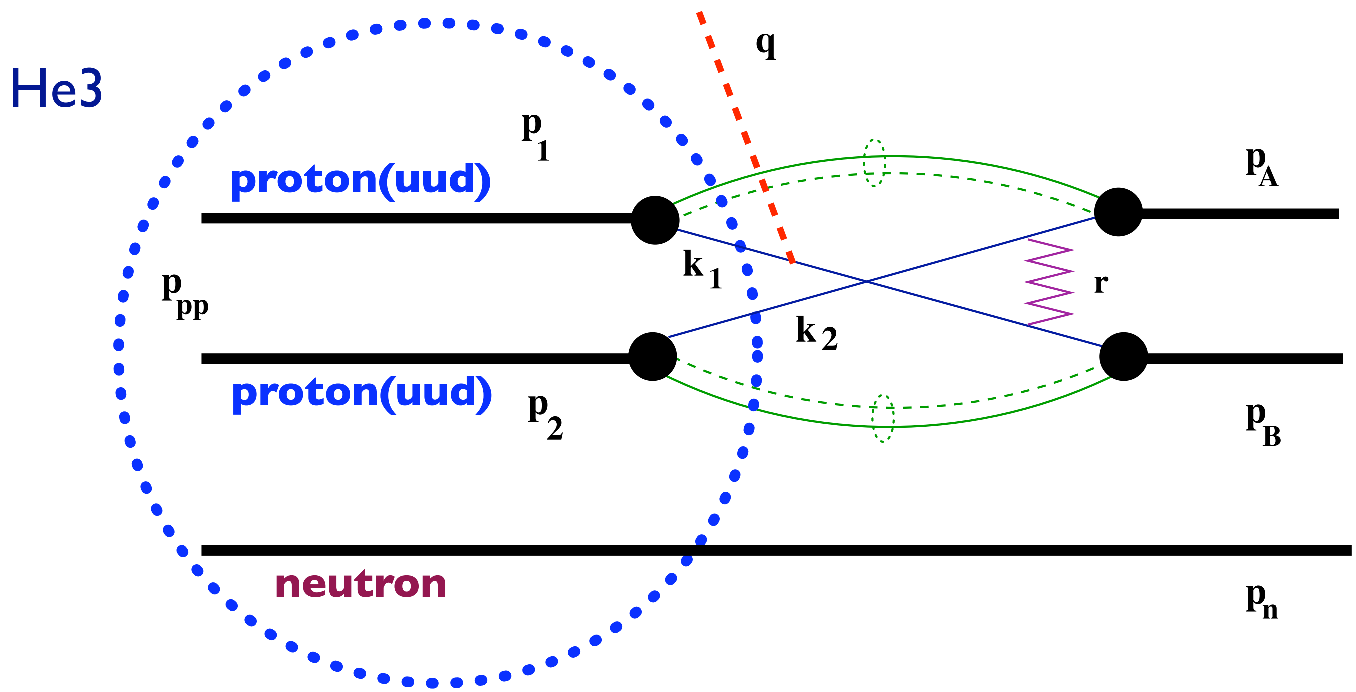
- Hard Photodisintegration of pp pair:

MS, Carlos Granados, in progress

$$\langle \lambda_A, \lambda_B \mid A_{Q_i} \mid \lambda_\gamma, \lambda_{pp} \rangle = \sum_{\lambda_2} \int \frac{ef(\theta_{cm})}{\sqrt{2s'}} Q_i \cdot \langle \lambda_A, \lambda_B | A^i_{QIM}(s, l^2) | \lambda_\gamma, \lambda_2 \rangle \Psi^{\lambda_{pp}, \lambda_\gamma, \lambda_2}(\alpha_c, p_\perp) \frac{d^2 p_\perp}{(2\pi)^2}$$

$$\langle a'b' | A^Q_{QIM} | ab \rangle \mid_{a,b \in pp} = \frac{1}{2} \langle a'b' | \sum_{i \in a\ ,\ j \in b} [I_i I_j + \vec{\tau}_i \cdot \vec{\tau}_j](Q_i + Q_j) F_{i,j}(s,t) | ab \rangle = \frac{14}{15} \langle a'b' | A^{pp}_{QIM} | ab \rangle$$

$$A^{pp}_{QIM} \approx A_{pp}$$



$$|\bar{A}|^2 = const \cdot \frac{1}{2}\left[\phi_1^2 S_1 + (\phi_3^2 + \phi_4) S_{34}\right]$$

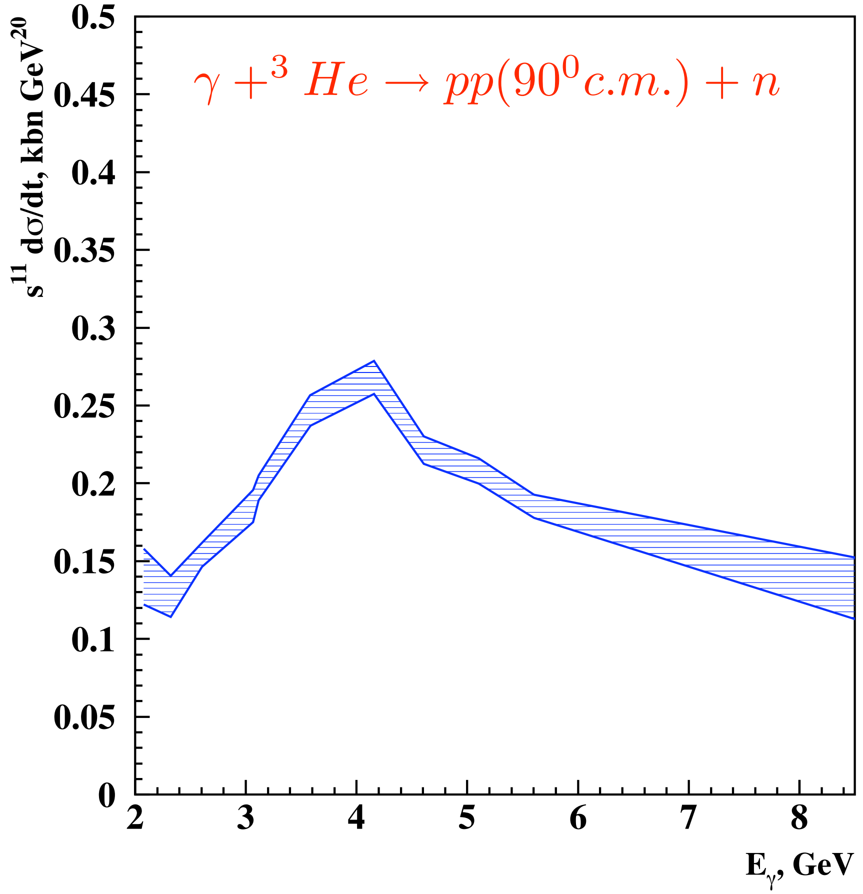
$$S_1 = \sum_{\lambda_1=\lambda_2, \lambda_3=-\frac{1}{2}}^{\frac{1}{2}} \left| \int \psi^{\frac{1}{2}}_{3\,He}(\lambda_1, \lambda_2, \lambda_3) m \frac{d^2 p_{2\perp}}{(2\pi)^2} \right|^2$$

$$S_{34} = \sum_{\lambda_1=-\lambda_2, \lambda_3=-\frac{1}{2}}^{\frac{1}{2}} \left| \int \psi^{\frac{1}{2}}_{3\,He}(\lambda_1, \lambda_2, \lambda_3) m \frac{d^2 p_{2\perp}}{(2\pi)^2} \right|^2$$

$$\begin{aligned}
\phi_1(s, t_n, u_n) &= \langle +, + \mid A_{pn} \mid +, + \rangle \\
\phi_2(s, t_n, u_n) &= \langle +, + \mid A_{pn} \mid -, - \rangle \\
\phi_3(s, t_n, u_n) &= \langle +, - \mid A_{pn} \mid +, - \rangle \\
\phi_4(s, t_n, u_n) &= \langle +, - \mid A_{pn} \mid -, + \rangle \\
\phi_5(s, t_n, u_n) &= \langle +, + \mid A_{pn} \mid +, - \rangle .
\end{aligned} \quad (1)$$

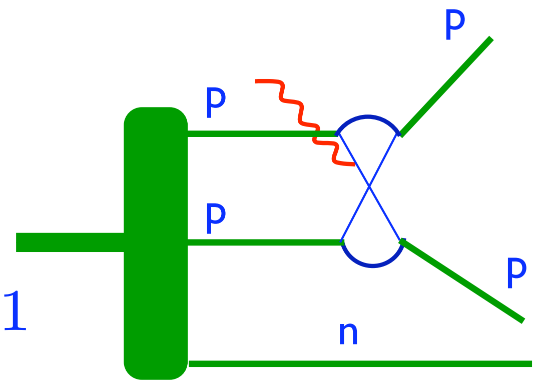
$$\frac{d\sigma}{dt d^3 p_n} = \left(\frac{14}{15}\right)^2 \frac{16\pi^4\alpha}{S - M^2_{^3He}} \left(\frac{2c^2}{1+2c^2}\right) \frac{d\sigma^{pp}}{dt}(s_{pp}, t_n) \frac{S_{34}}{E_n}$$

$$c = \frac{|\phi_{3,4}|}{|\phi_1|} \sim \frac{1}{2}$$

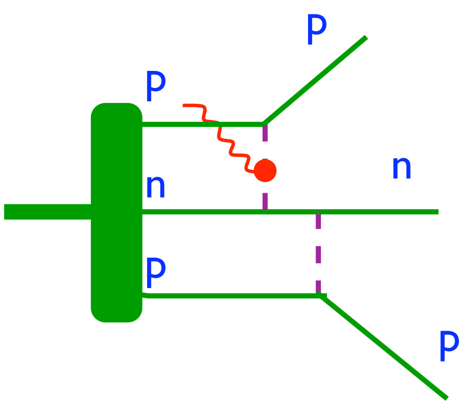


What Can be Checked

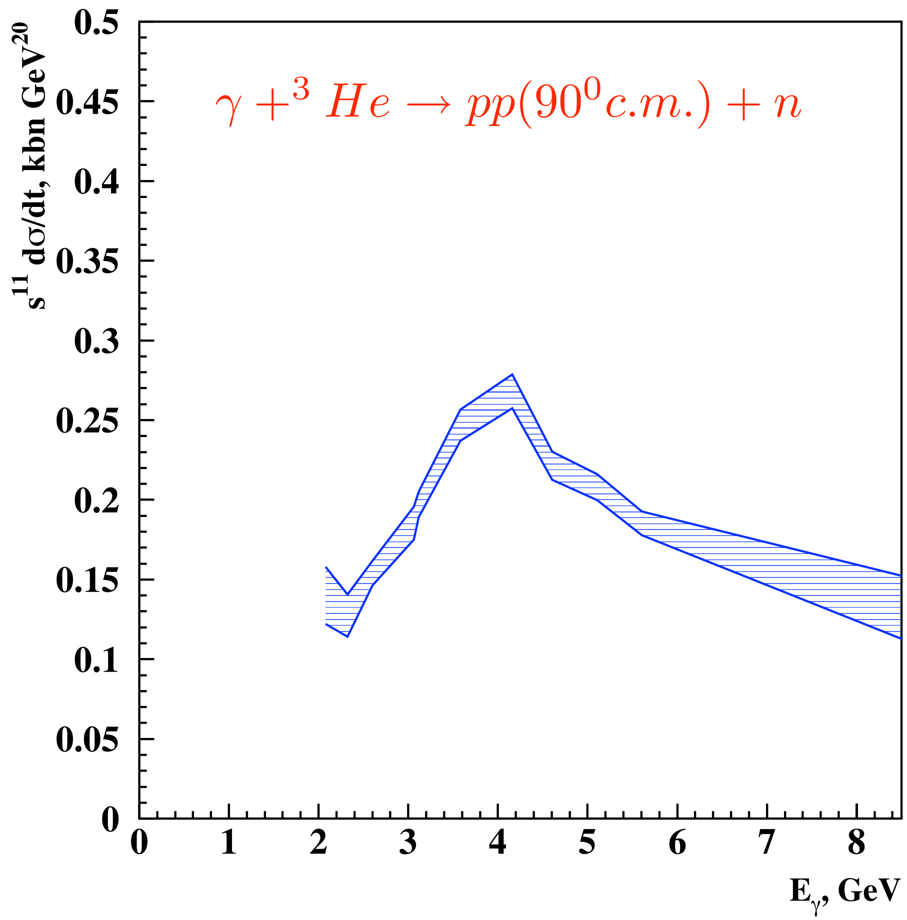
(I) Transition from 3-step to 2-step processes



$\sim s^{-11}$

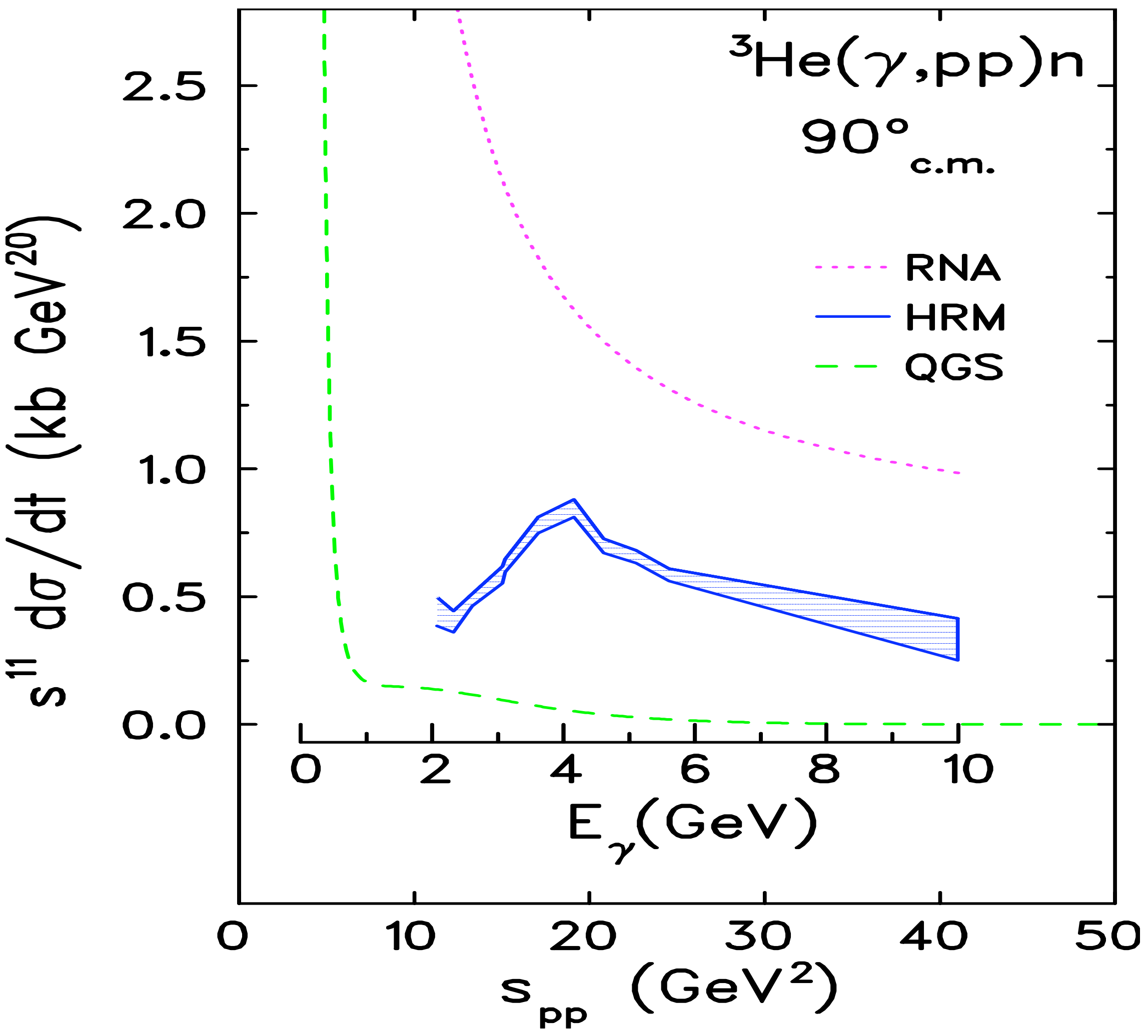


$\sim s^{-13}$



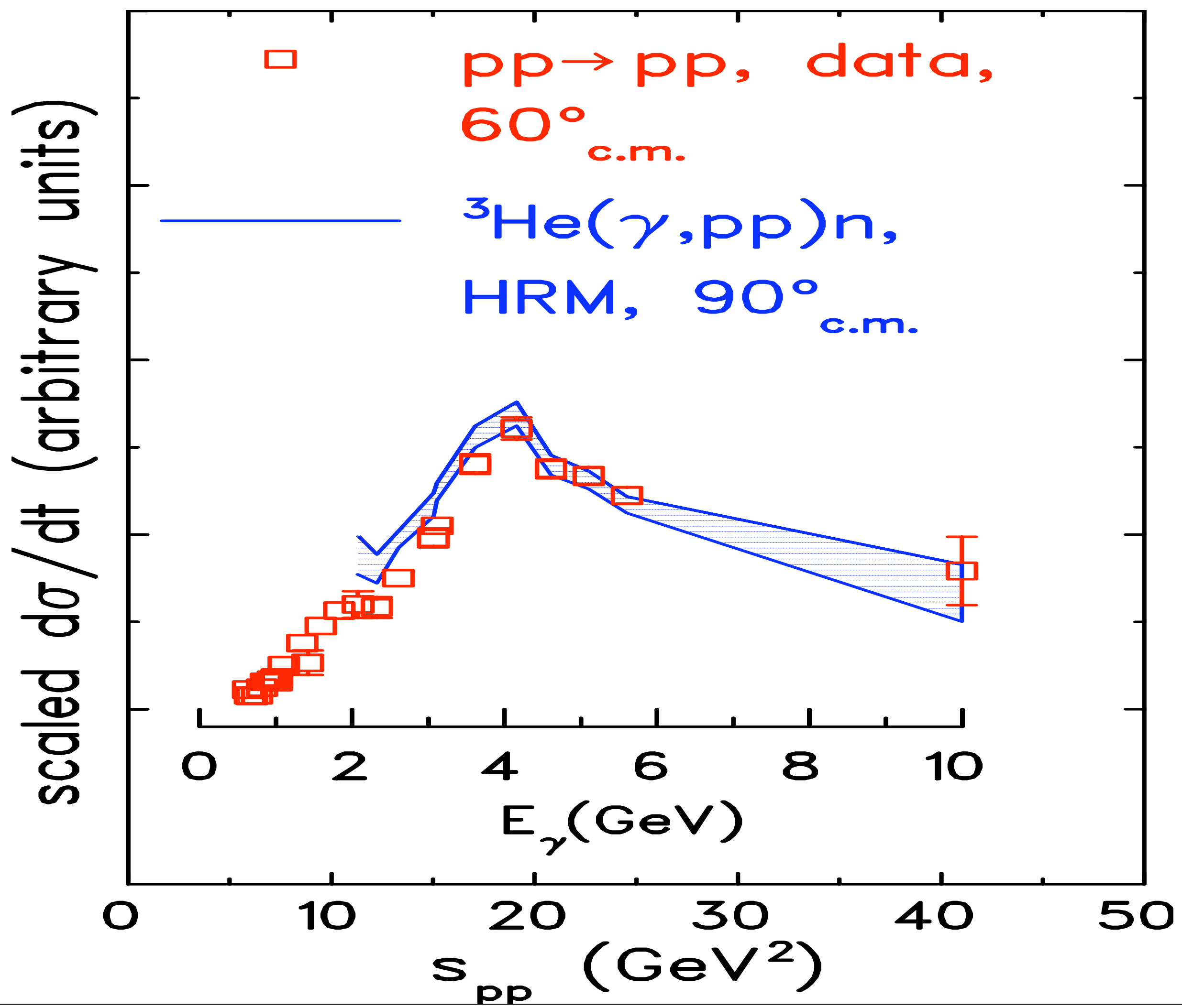
What Can be Checked

(II) Absolute Cross Section



What Can be Checked

(III) The Shape of the Energy Dependence



What Can be Checked

(IV) Polarization Observables

$$\langle \lambda_A, \lambda_B \mid A_{Q_i} \mid \lambda_\gamma, \lambda_{pp} \rangle = \sum_{\lambda_2} \int \frac{ef(\theta_{cm})}{\sqrt{2s'}} Q_i \cdot \langle \lambda_A, \lambda_B | A^i_{QIM}(s, l^2) | \lambda_\gamma, \lambda_2 \rangle \Psi^{\lambda_{pp}, \lambda_\gamma, \lambda_2}(\alpha_c, p_\perp) \frac{d^2 p_\perp}{(2\pi)^2}$$

$$P_y = -\frac{2Im\left\{\phi_5^\dagger[2(\phi_1+\phi_2)+\phi_3-\phi_4]\right\}}{2|\phi_1|^2+2|\phi_2|^2+|\phi_3|^2+|\phi_4|^2+6|\phi_5|^2}$$

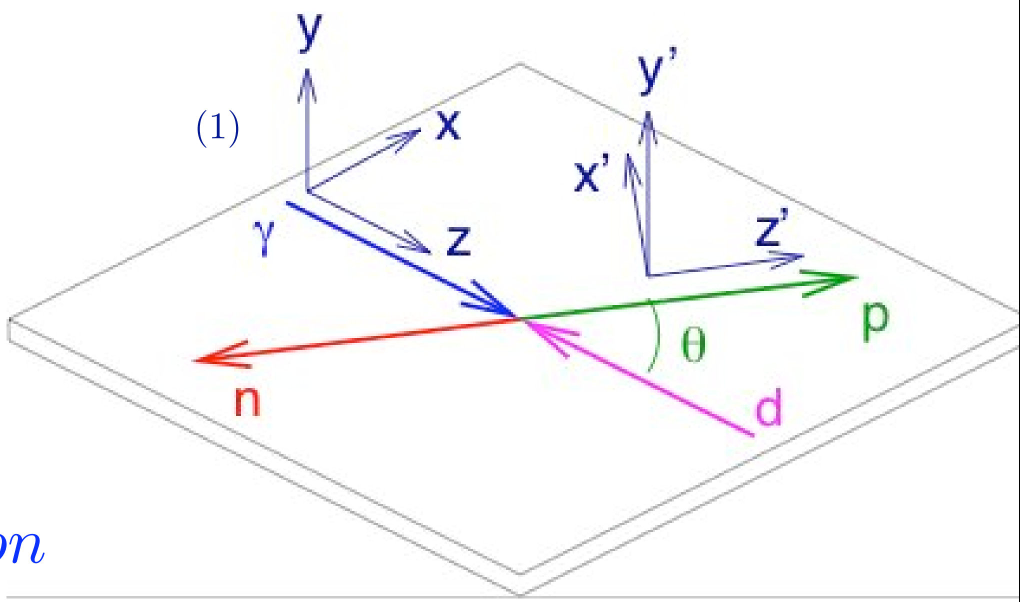
$$C_{x'} = \frac{2Re\left\{\phi_5^\dagger[2(\phi_1-\phi_2)+\phi_3+\phi_4]\right\}}{2|\phi_1|^2+2|\phi_2|^2+|\phi_3|^2+|\phi_4|^2+6|\phi_5|^2}$$

$$C_{z'} = \frac{2|\phi_1|^2-2|\phi_2|^2+|\phi_3|^2-|\phi_4|^2}{2|\phi_1|^2+2|\phi_2|^2+|\phi_3|^2+|\phi_4|^2+6|\phi_5|^2}$$

$$\Sigma = \frac{2Re\left[|\phi_5|^2-\phi_3^\dagger\phi_4\right]}{2|\phi_1|^2+2|\phi_2|^2+|\phi_3|^2+|\phi_4|^2+6|\phi_5|^2},$$

Helicity Selection Rule

(1)

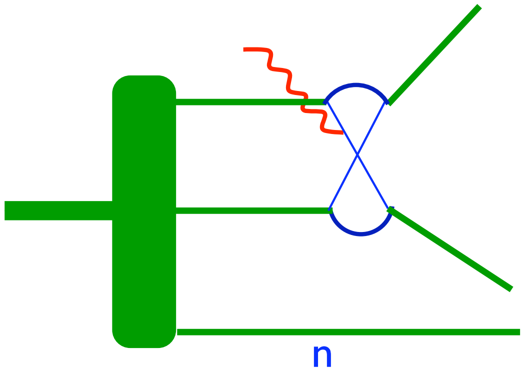


$$C_{z'} = 0!$$

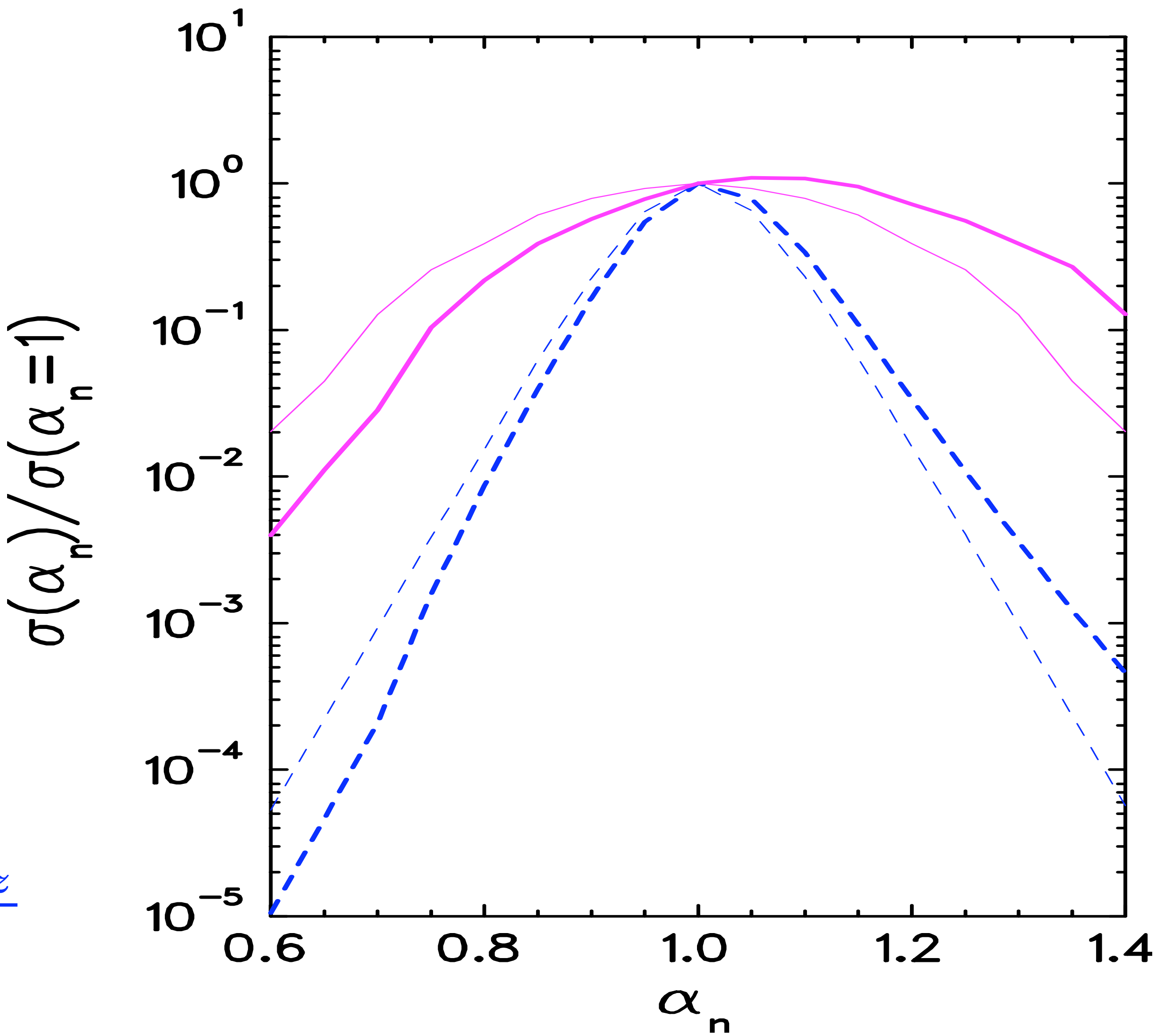
$$C_{z'} = 0.5 \div 1.0 \text{ for } \gamma d \to pn$$

What Can be Checked

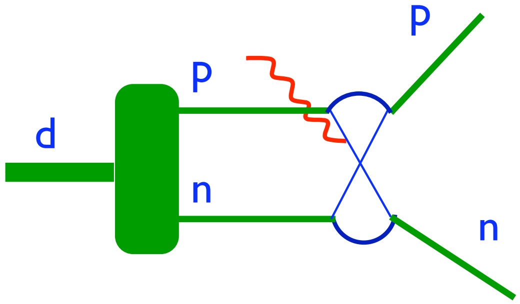
(V) Angular Distribution of Spectator Neuteron

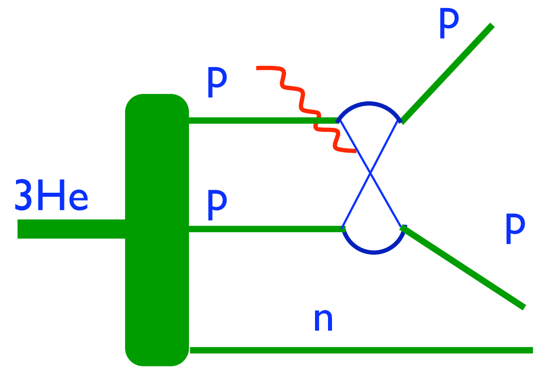


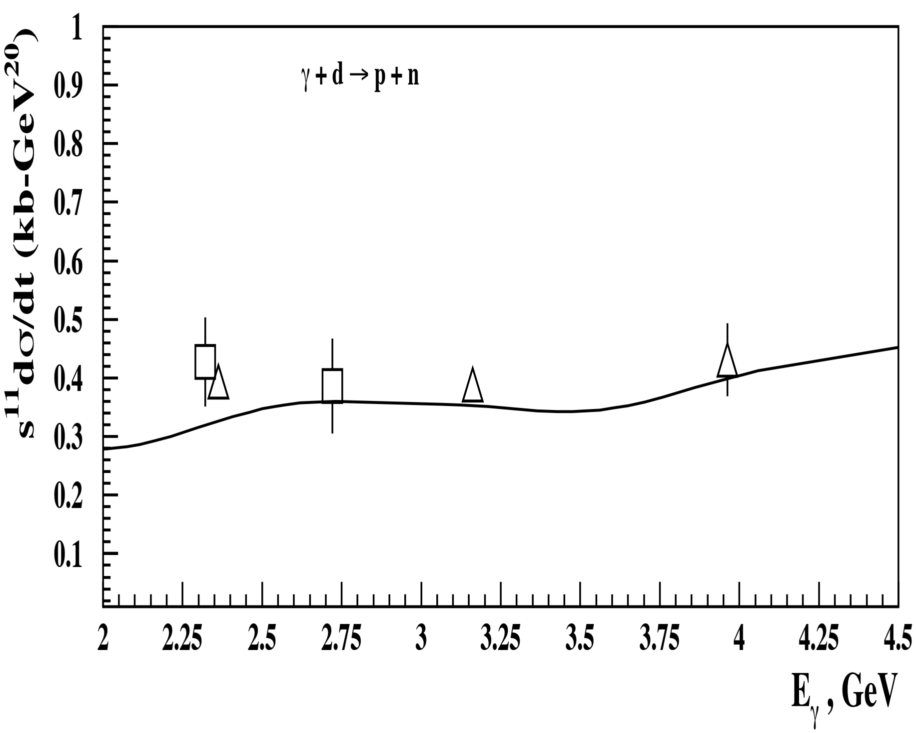
$$\alpha_n = \frac{E_n - p_{n,z}}{m_N}$$

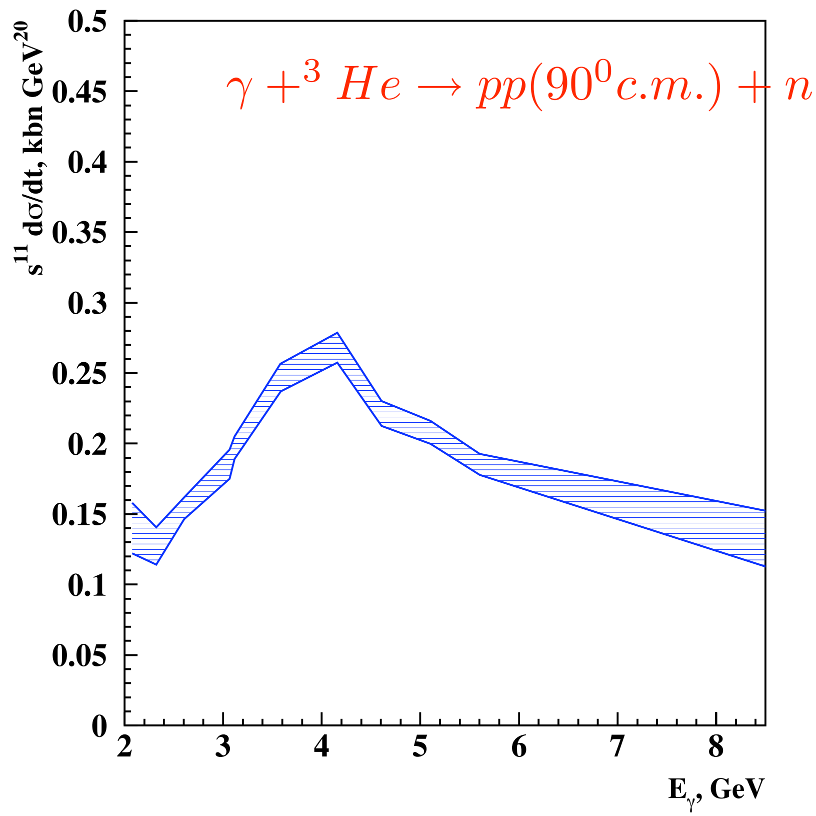


QCD Dynamics of NN Interaction

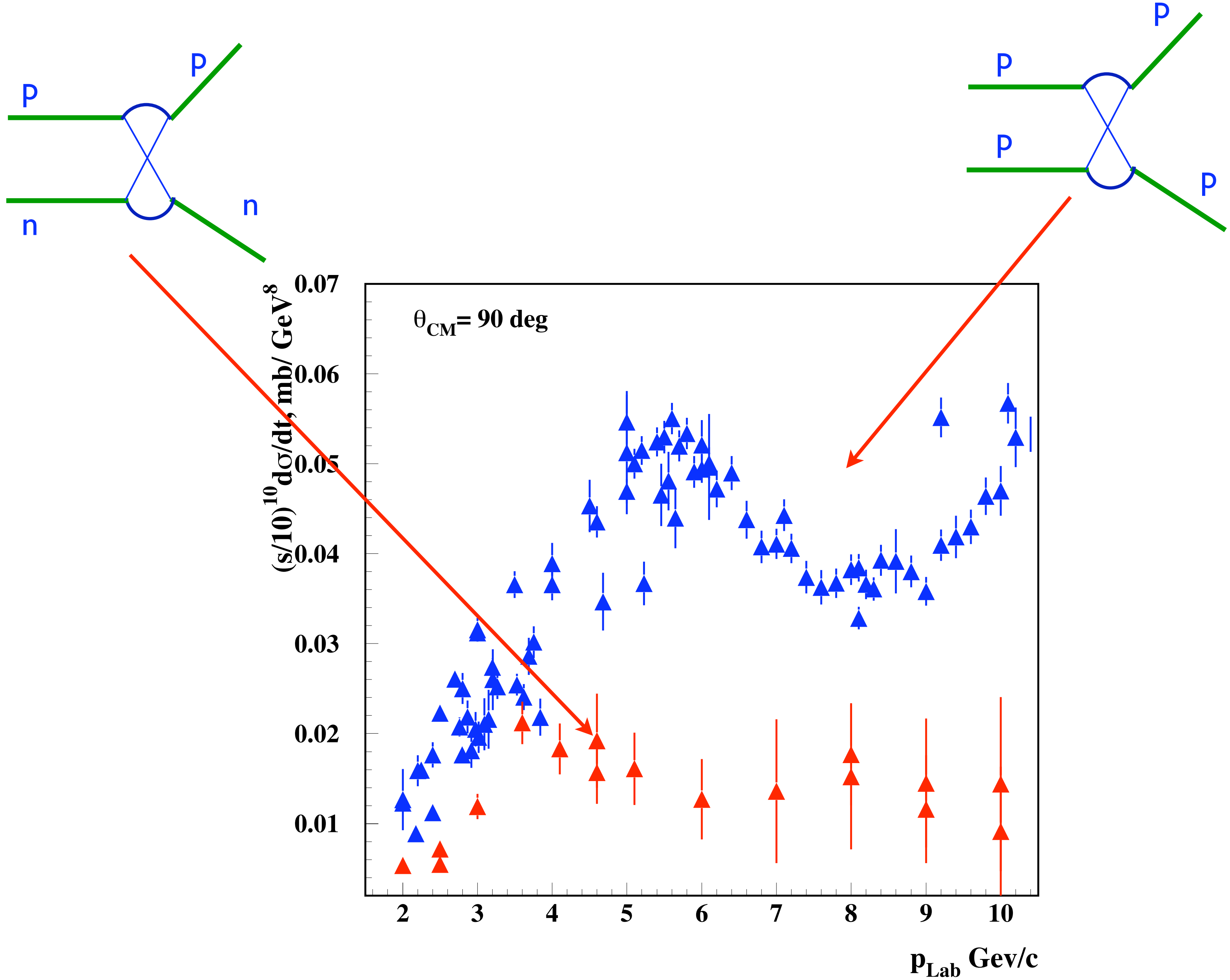




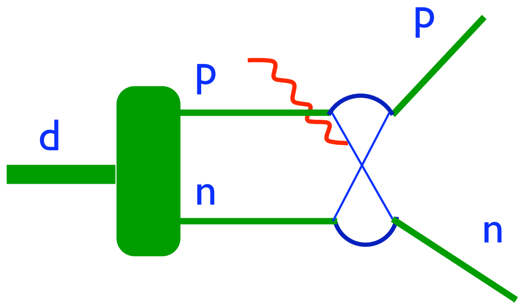


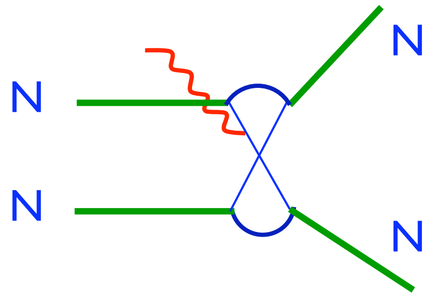


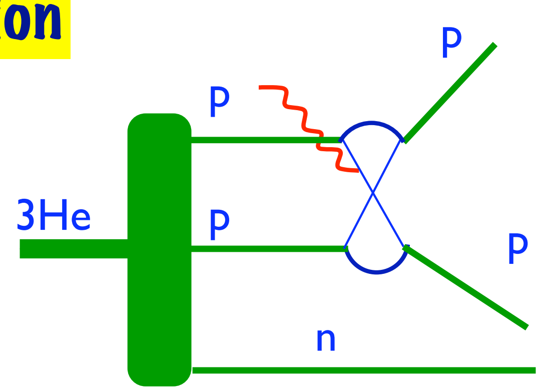
QCD Dynamics of NN Interaction



QCD Dynamics of NN Interaction







Brodsky,Carlson,Lipkin Phys.Rev.D 1979
Farrar Goetltieb, Sivers,Thomas Phys.Rev. D1979

NN ⇨ NN

$$\langle a'b'|A^{NN}_{QIM}|ab\rangle = \frac{1}{2}\langle a'b'|\sum_{i\in a\ ,\ j\in b}[I_iI_j + \vec{\tau_i}\cdot\vec{\tau_j}]F_{i,j}(s,t)|ab\rangle$$

SU(6)

γNN ⇨ NN

$$\langle a'b'|A^{Q}_{QIM}|ab\rangle\ |_{a,b\in D} = \frac{1}{2}\langle a'b'|\sum_{i\in a\ ,\ j\in b}[I_iI_j+\vec{\tau_i}\cdot\vec{\tau_j}](Q_i+Q_j)F_{i,j}(s,t)|ab\rangle = (Q_u+Q_d)\langle a'b'|A^{pn}_{QIM}|ab\rangle$$

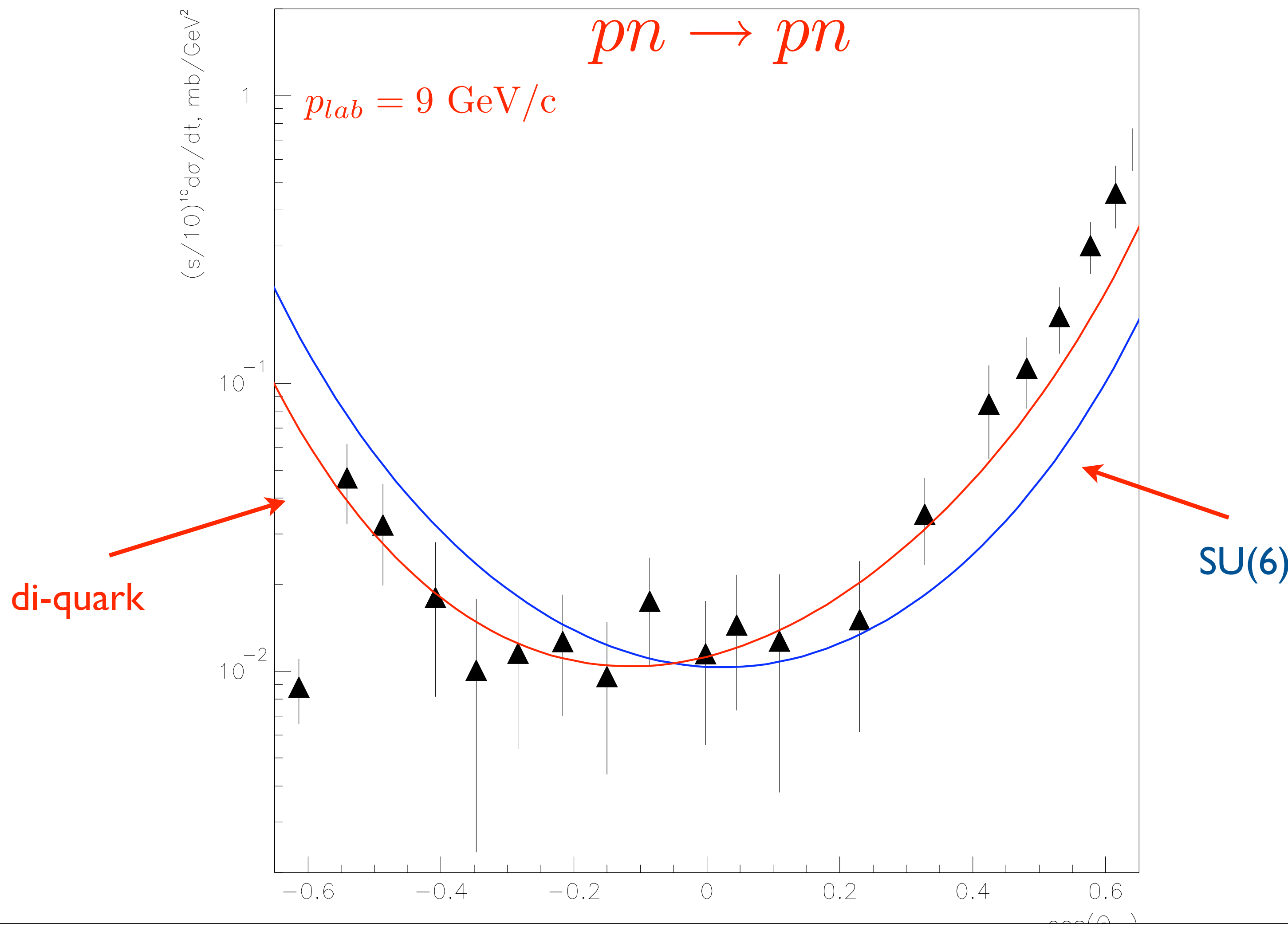
$$\langle a'b' \mid A^{\gamma pn\to pn}_{QIM} \mid ab\rangle = \frac{1}{3}\langle a'b' \mid A^{pn\to pn}_{QIM} \mid ab\rangle$$

$$\langle a'b' \mid A^{\gamma pp\to pp}_{QIM} \mid ab\rangle = \frac{14}{15}\langle a'b' \mid A^{pp\to pp}_{QIM} \mid ab\rangle$$

QCD Dynamics of NN Interaction

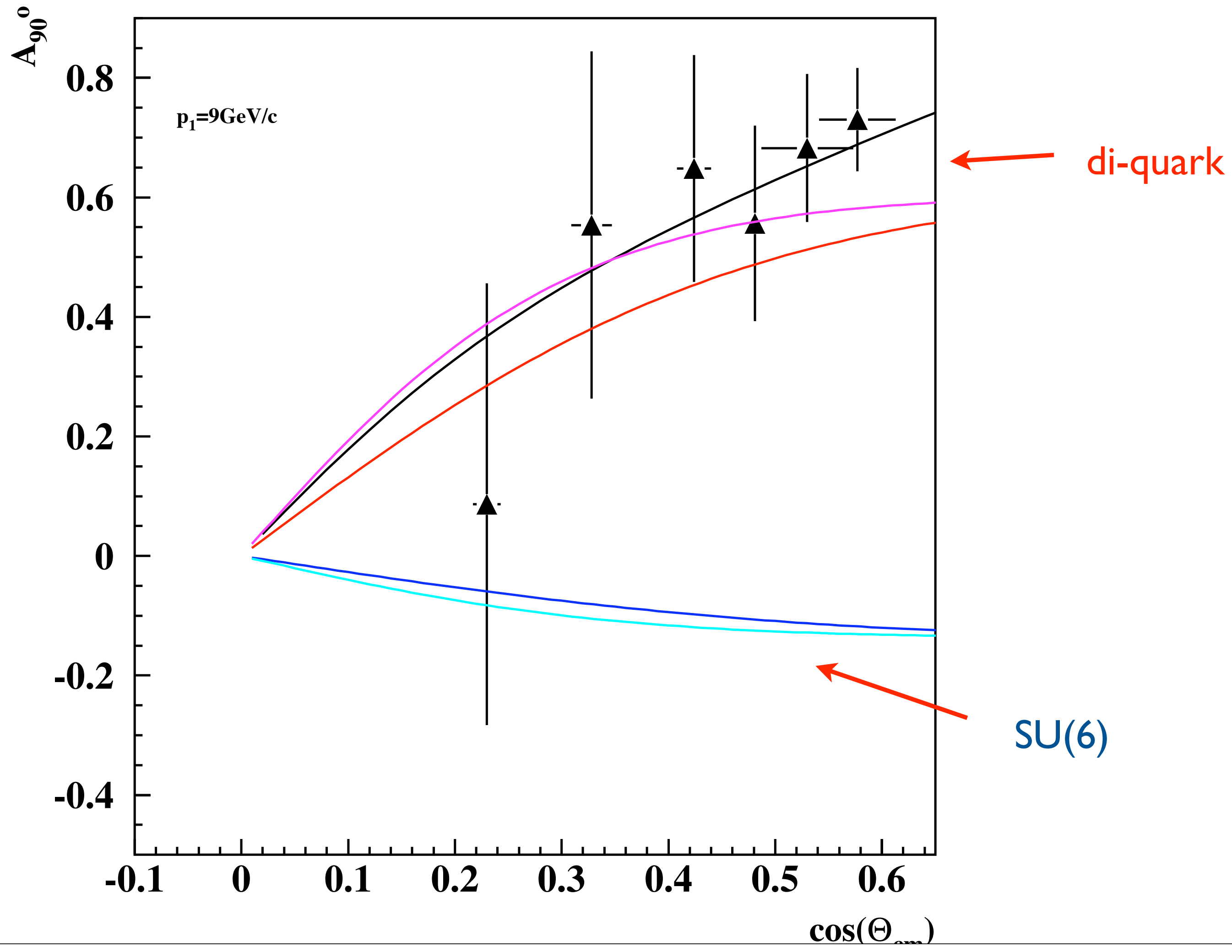
How good is SU(6)?

Granados, Sargsian in progress



QCD Dynamics of NN Interaction

How good is SU(6)?



QCD Dynamics of NN Interaction

In Diquark Model

$$\langle a'b' \mid A_{QIM}^{\gamma pn\to pn} \mid ab\rangle = \tfrac{1}{3}\langle a'b' \mid A_{QIM}^{pn\to pn} \mid ab\rangle$$

$$\langle a'b' \mid A_{QIM}^{\gamma pp\to pp} \mid ab\rangle = \tfrac{5}{6}\langle a'b' \mid A_{QIM}^{pp\to pp} \mid ab\rangle$$

Preliminary

Conclusion and Outlook

- Hard Rescattering may be the valid mechanism from photoproduction of two nucleons at 90 cm

- pp disintegration data are crucial for verifying the validity of the HR mechanism

- High Energy Photodisintegration of two Nucleons eventually my provide a new framework of probing the QCD structure of NN force

New Venues

- Hard disintegration into Delta pairs $\frac{\sigma(\gamma D \to \Delta^{++}\Delta^{-})}{\sigma(\gamma D \to pn)} \approx \left| \frac{A(NN \to \Delta^{++}\Delta^{-})}{A(NN \to NN)} \right|^2$

- Hard Disintegraion into Strange Baryons