High Energy Break-Up of Few-Nucleon Systems

Misak Sargsian
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Nuclear QCD

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- obtain parameter free results

Nuclear QCD

- EMC effect

- Formfactors of Few Nucleon Systems
  at high momentum transfer Text
  Energy

- Color Transparency

- DIS at x >1

- High Energy Break up of two hadrons in
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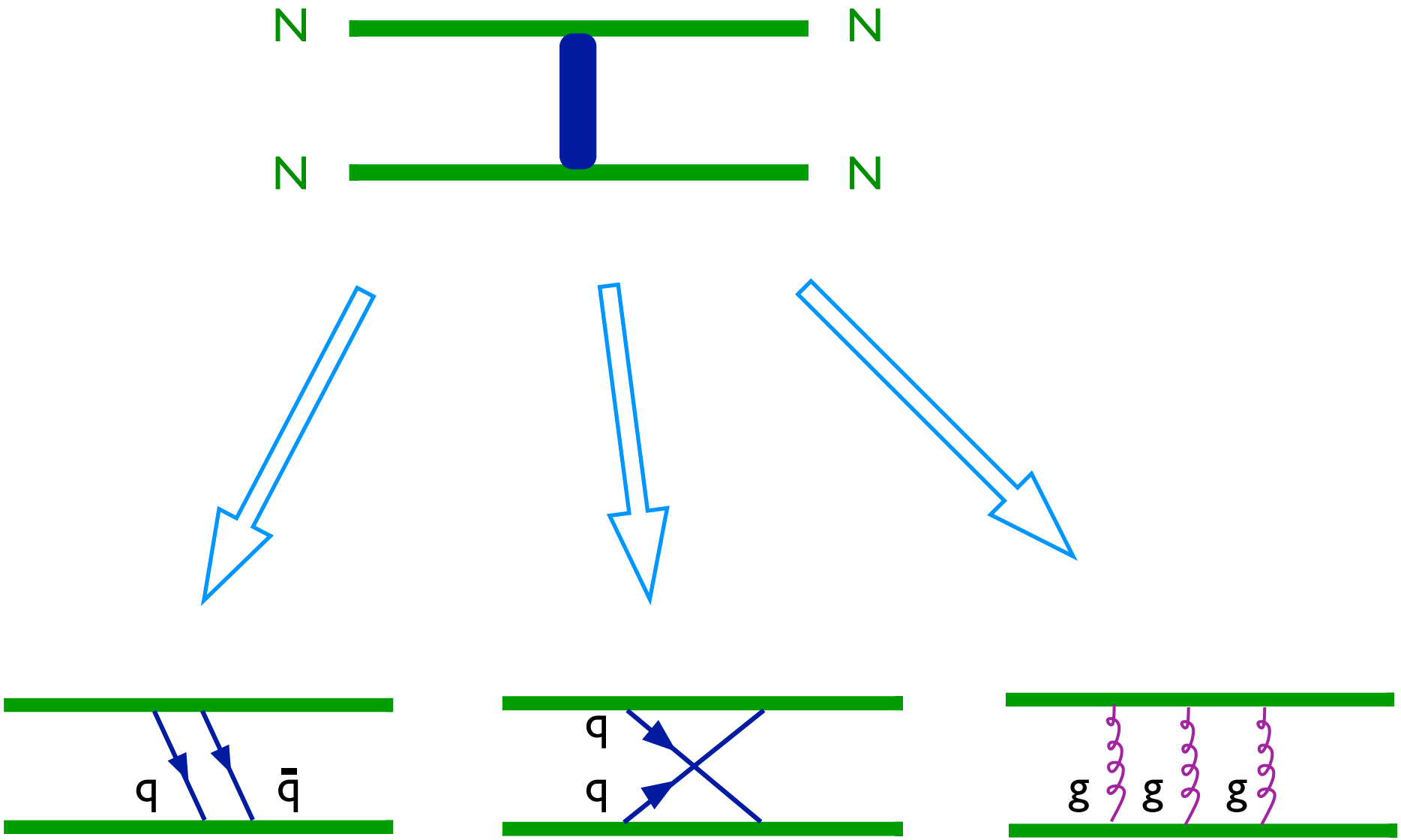
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N
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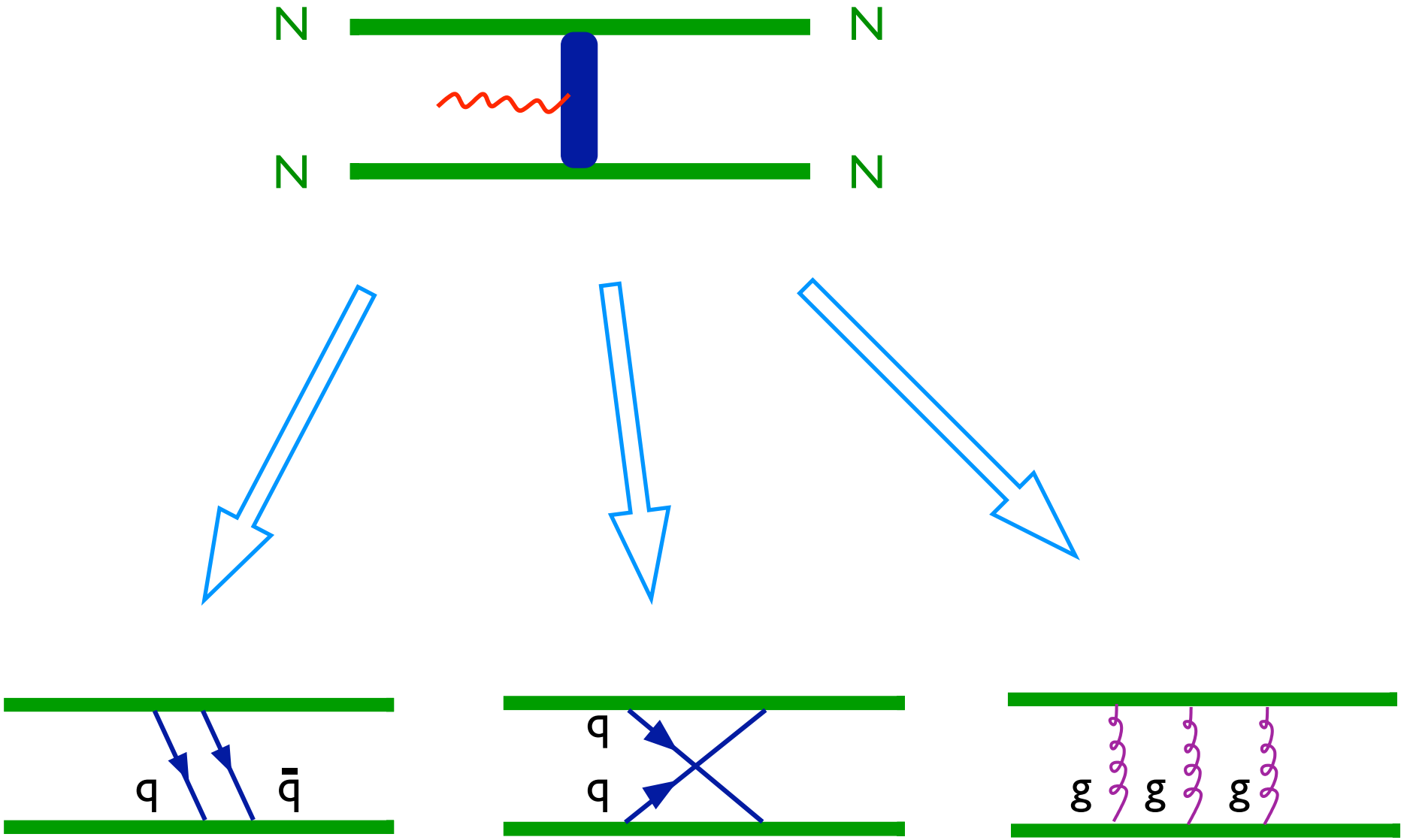
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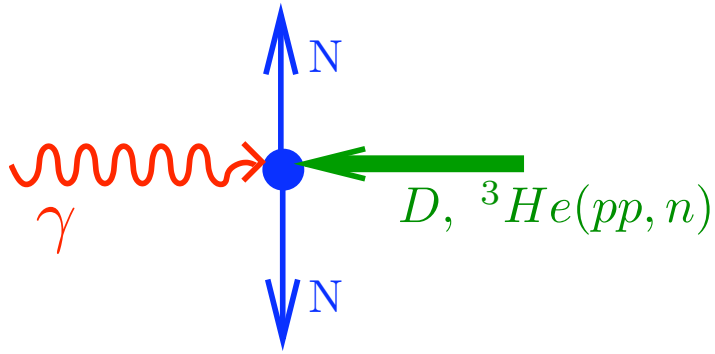
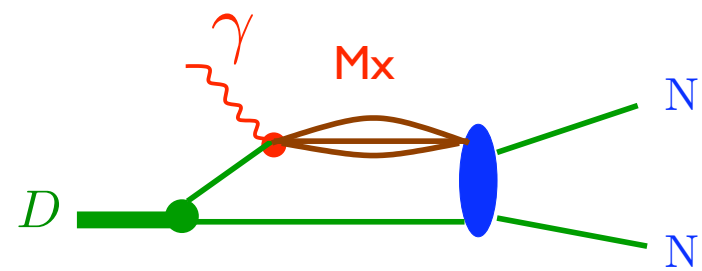
- Large CM angle disintegration of nuclei:





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

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

Brodsky, Chertock, 1976

Holt, 1990

Gilman, Gross, 2002

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

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

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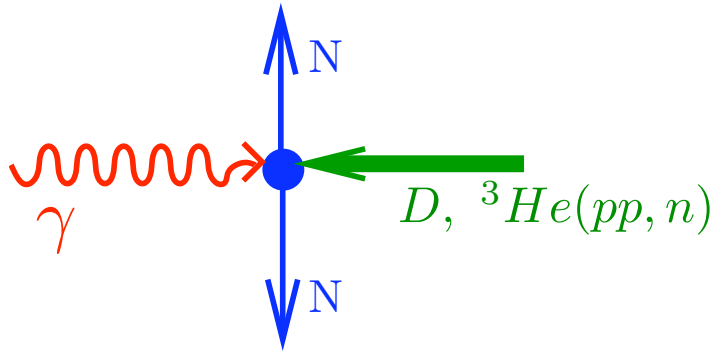

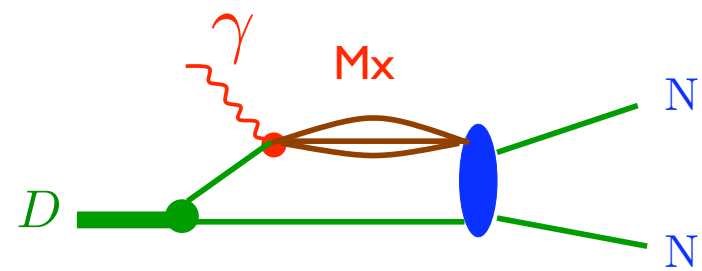

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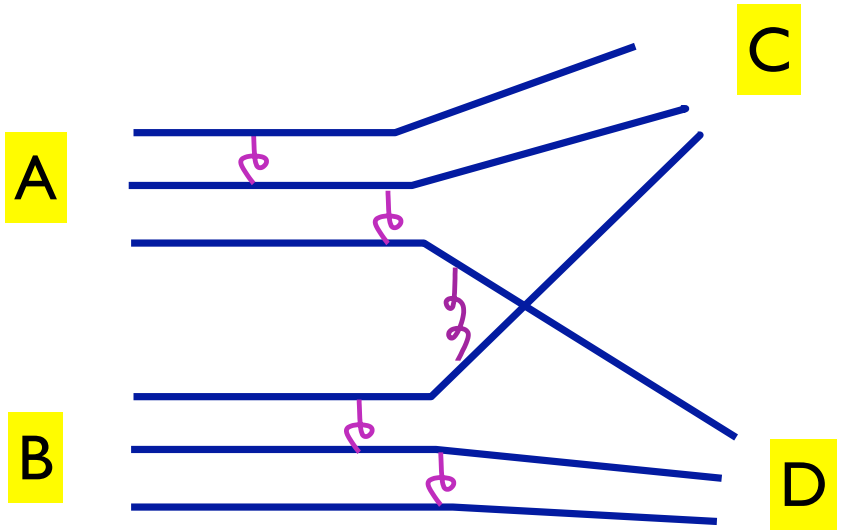
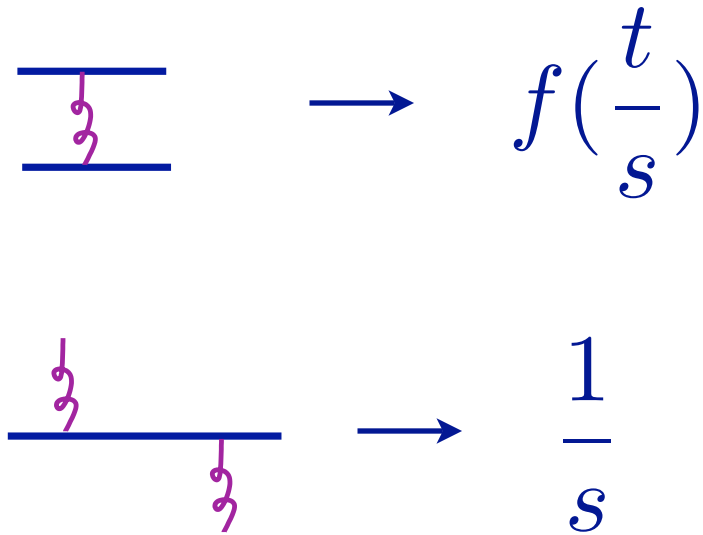
Consider A+B→C + D





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

Brodsky, Farrar 1975
Matveev, Muradyan, Takhvelidze, 1975

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

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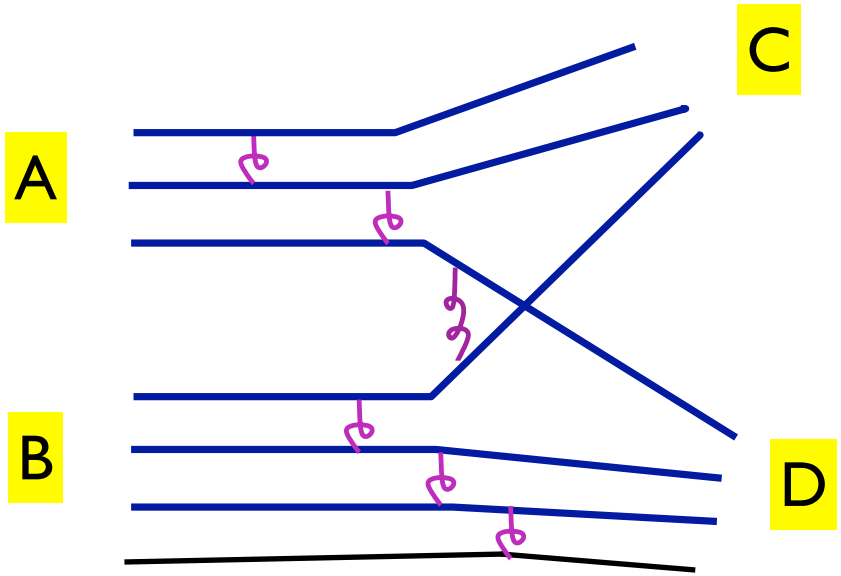
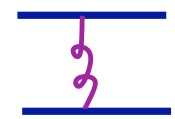
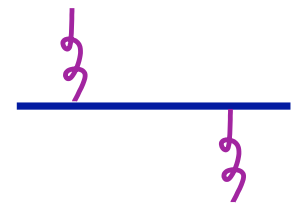




$$\longrightarrow \quad f\left(\frac{t}{s}\right)$$



$$\longrightarrow \quad \frac{1}{s}$$

additional $\frac{1}{s}$

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

Brodsky, Farrar 1975
Matveev, Muradyan, Takhvelidze, 1975

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

$\gamma d \rightarrow pn$

Exclusive large-momentum-transfer scattering

scaling

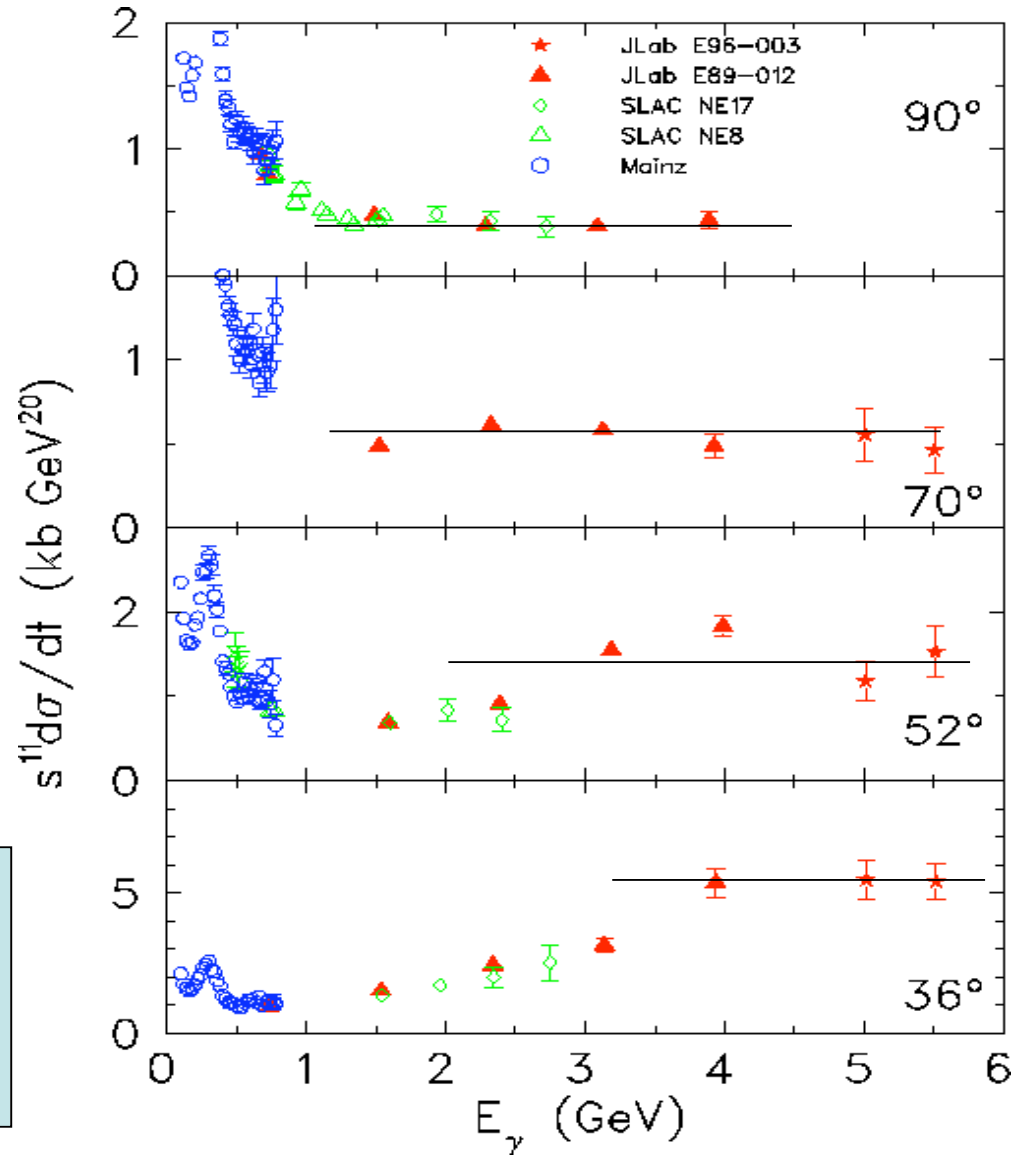
- **Dimensional counting rule:**

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

For

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

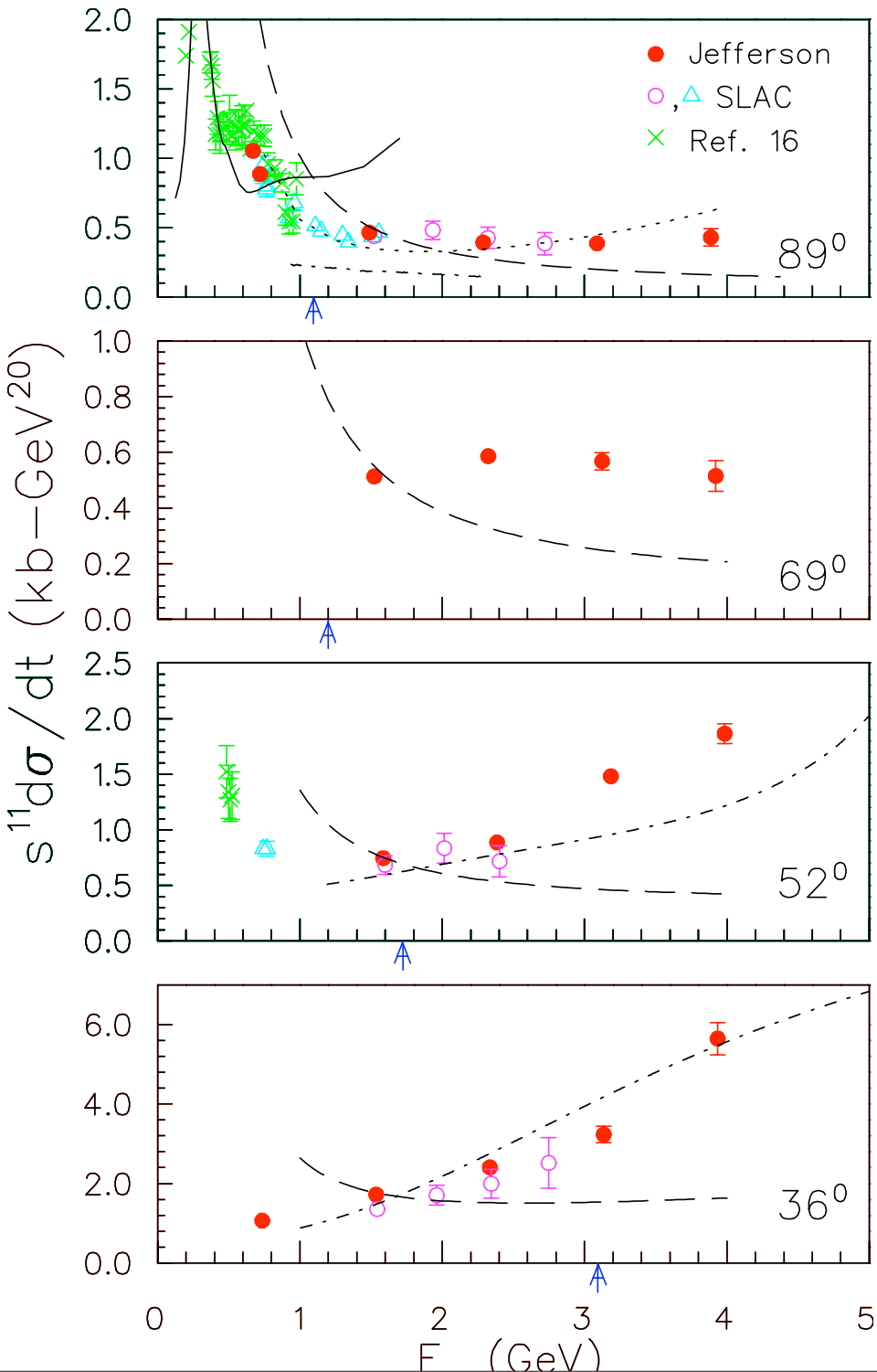
N = 1 + 6 + 3 + 3 – 2 = 11

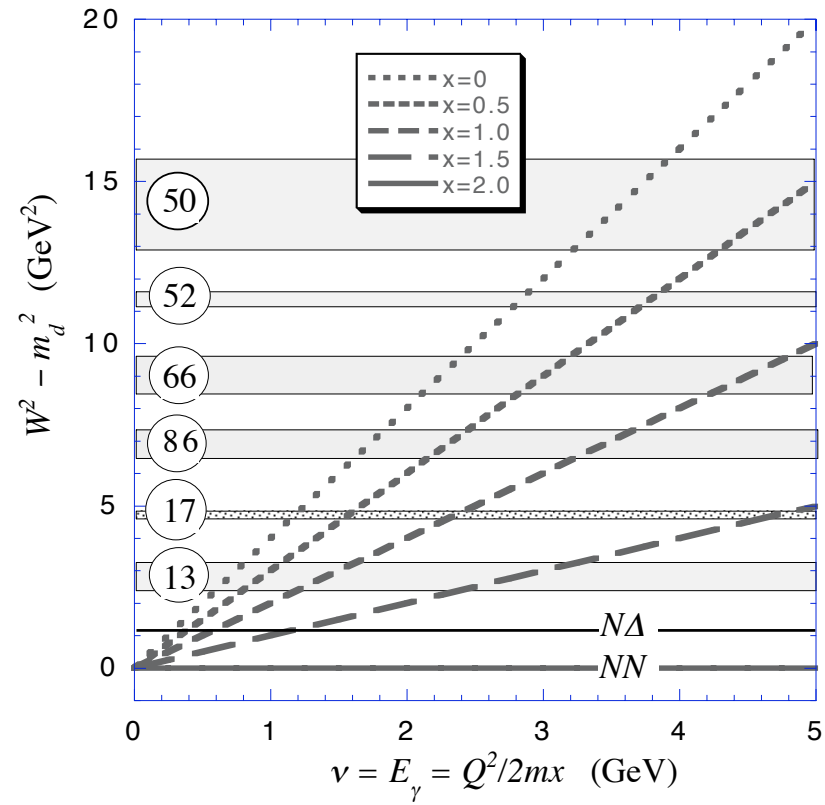


Notice:

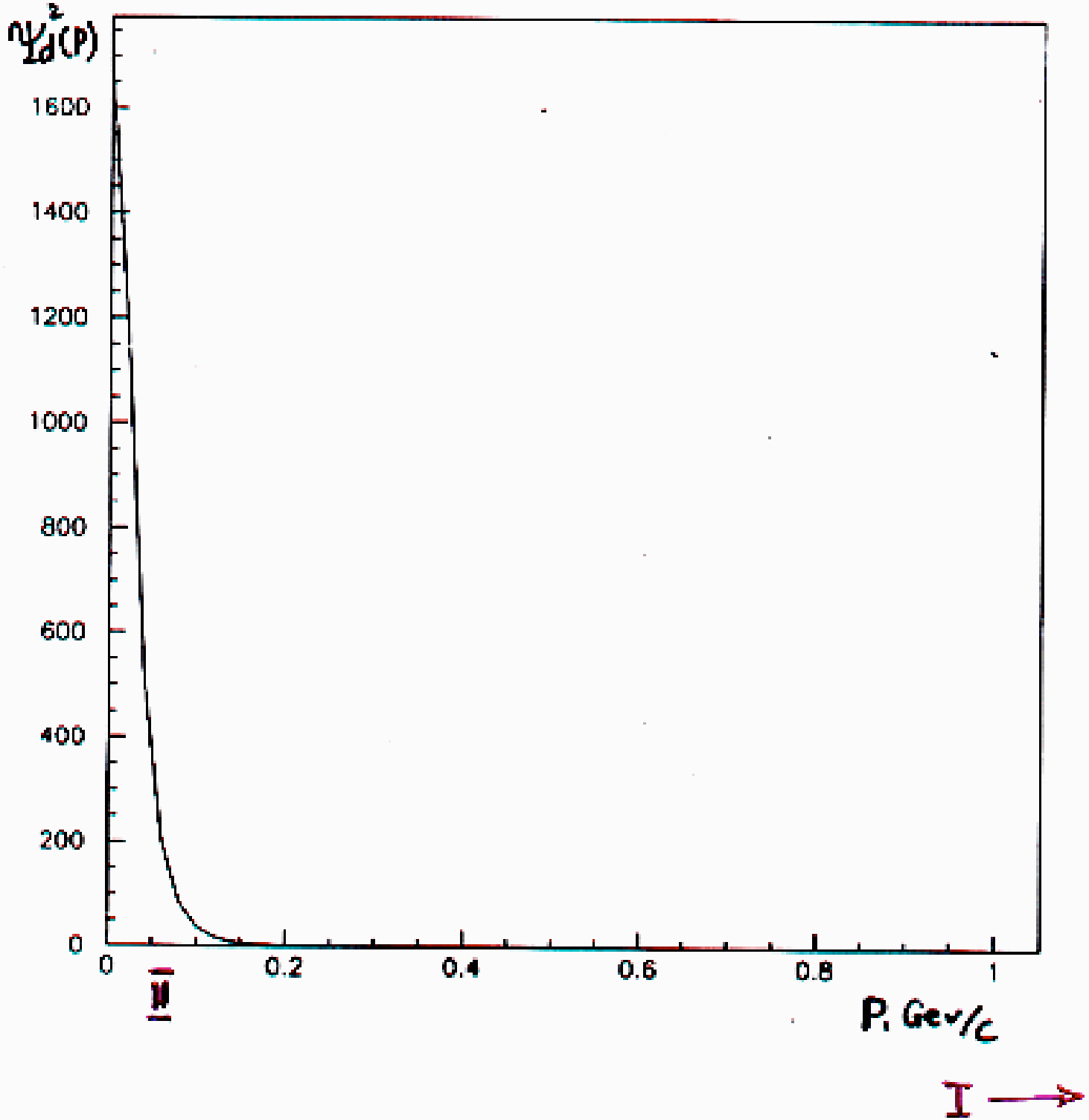
$$\frac{d\sigma}{dt}(E_\gamma = 1\,\text{GeV/c}) / \frac{d\sigma}{dt}(E_\gamma = 4\,\text{GeV/c}) \approx 10^4$$

$\gamma d \rightarrow pn$

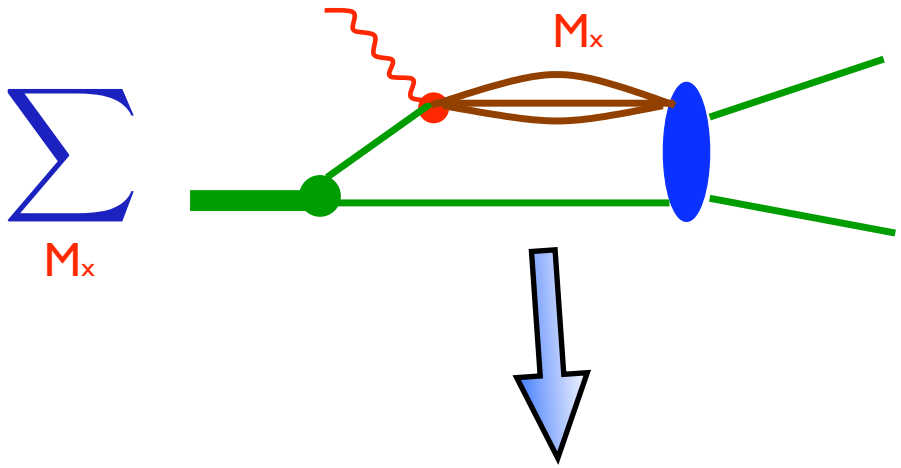




Gilman, Gross, 2002


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

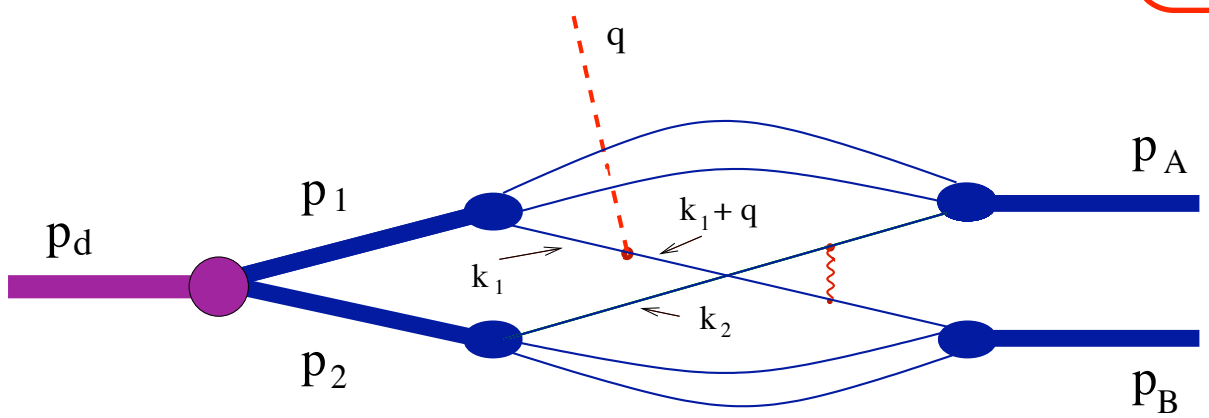
Hard Rescattering



Mmax=w > 2 GeV

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

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



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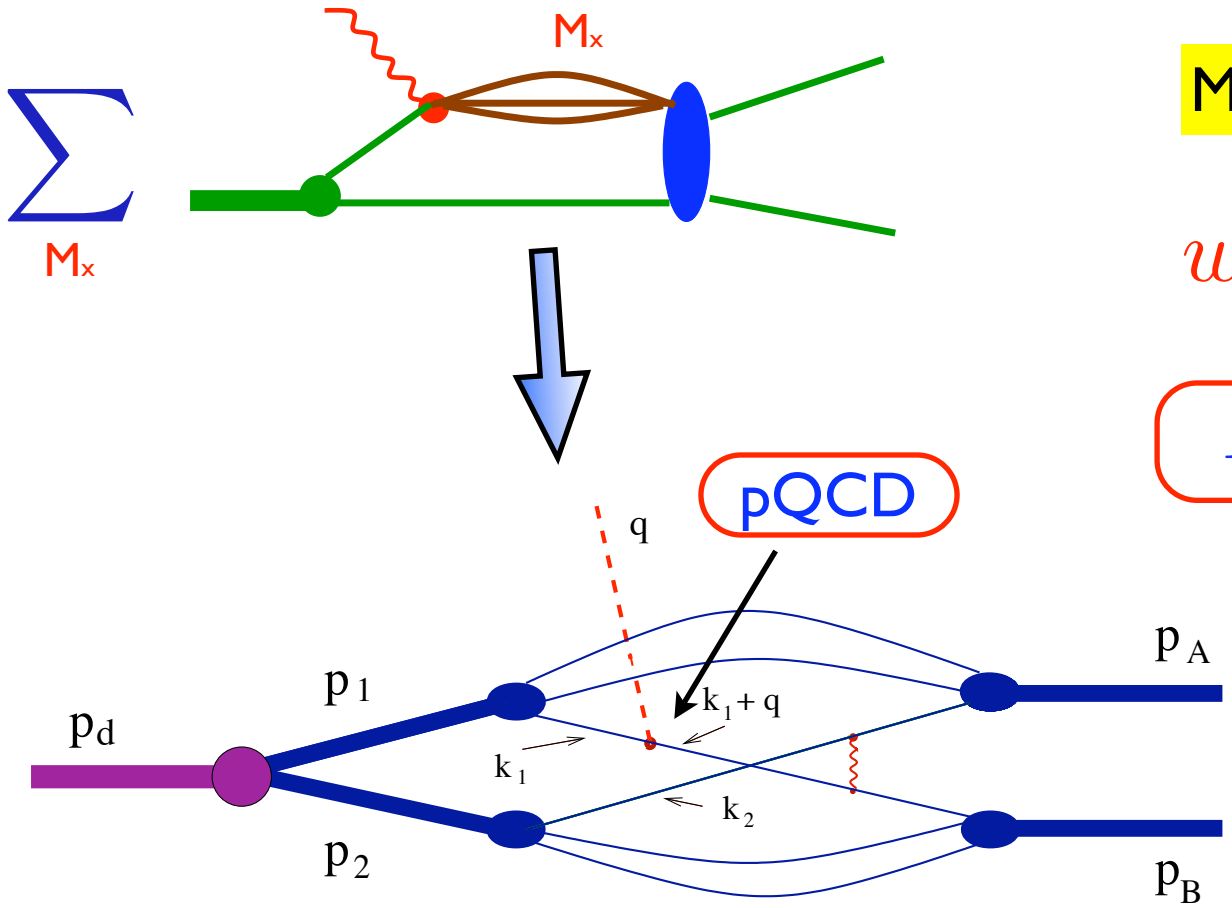

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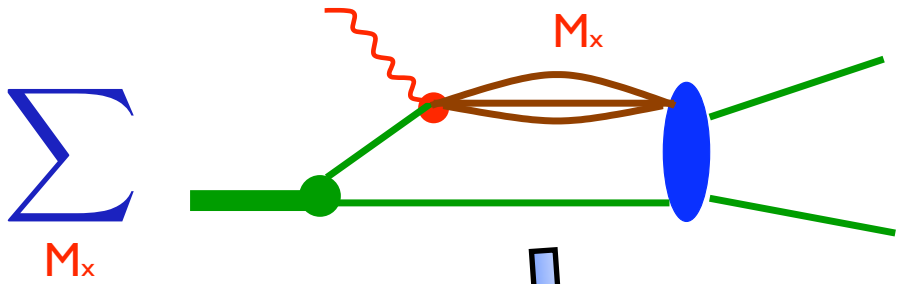

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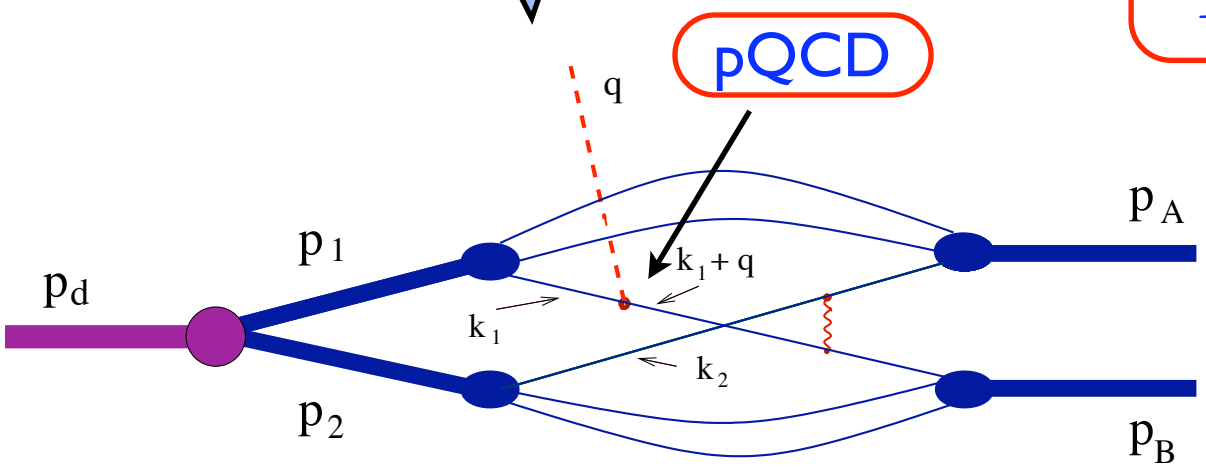
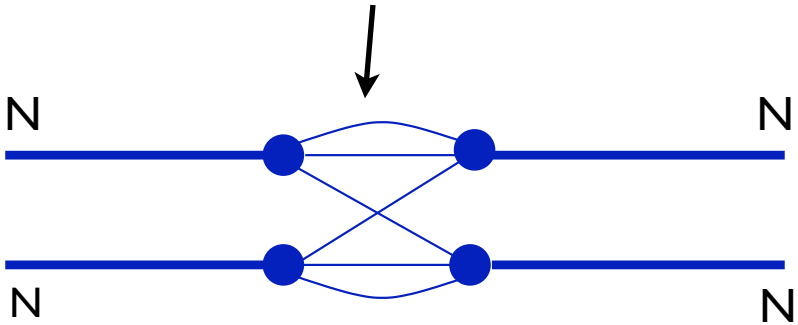
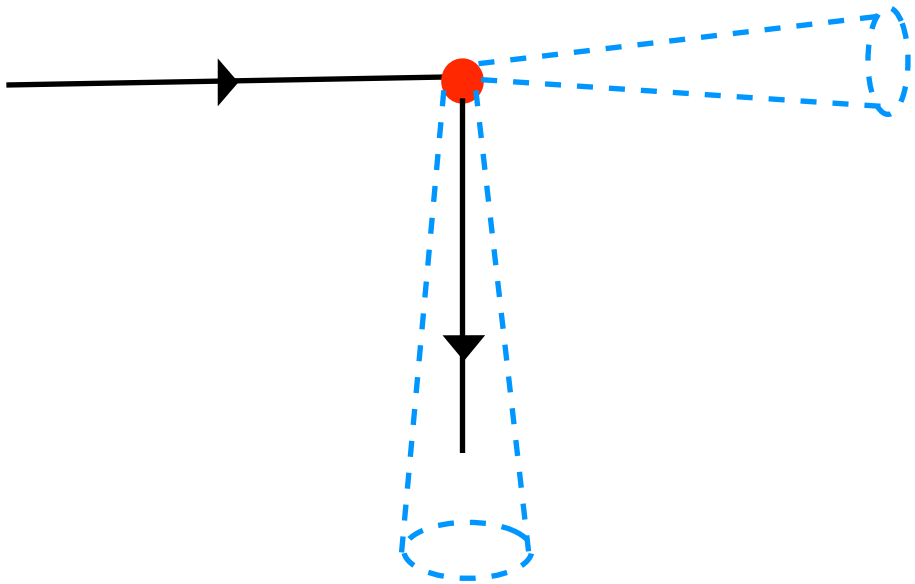
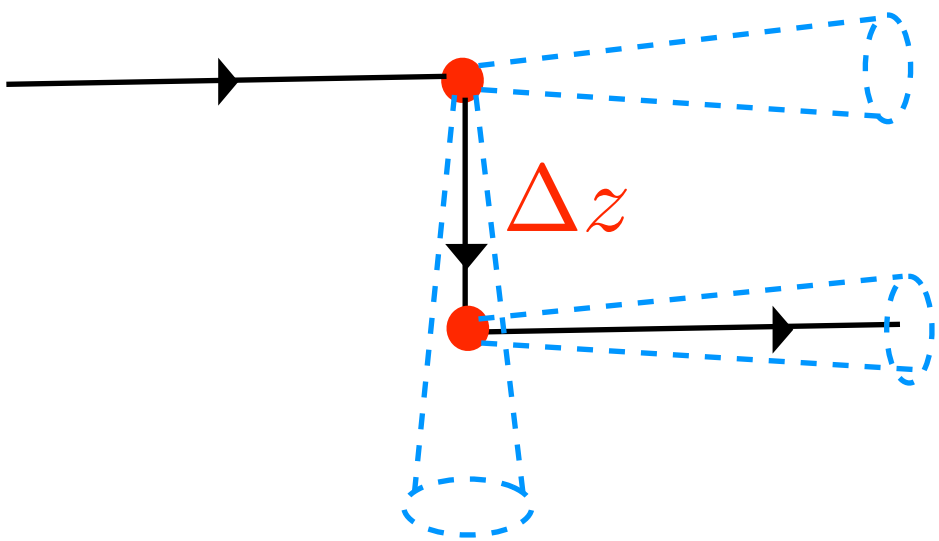




NN -amplitude

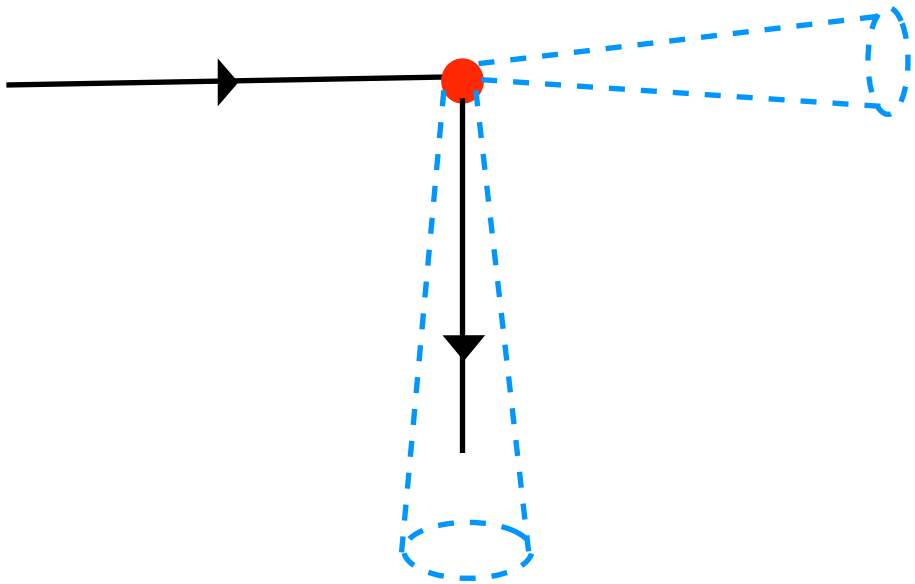


$$l_{regen} \sim \frac{k_{||}}{k_{\perp}^2}$$



$$l_{regen}$$

Landau, Pameranchuk, Migdal



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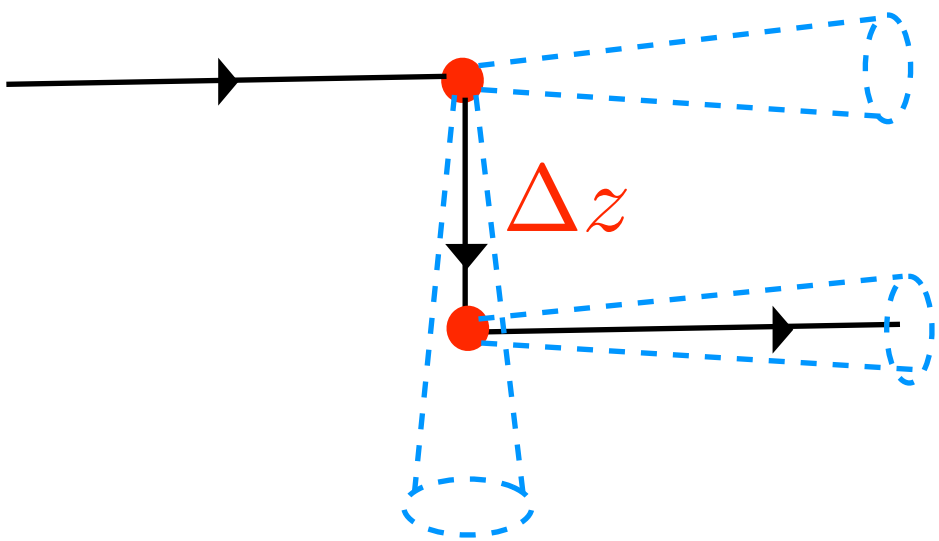
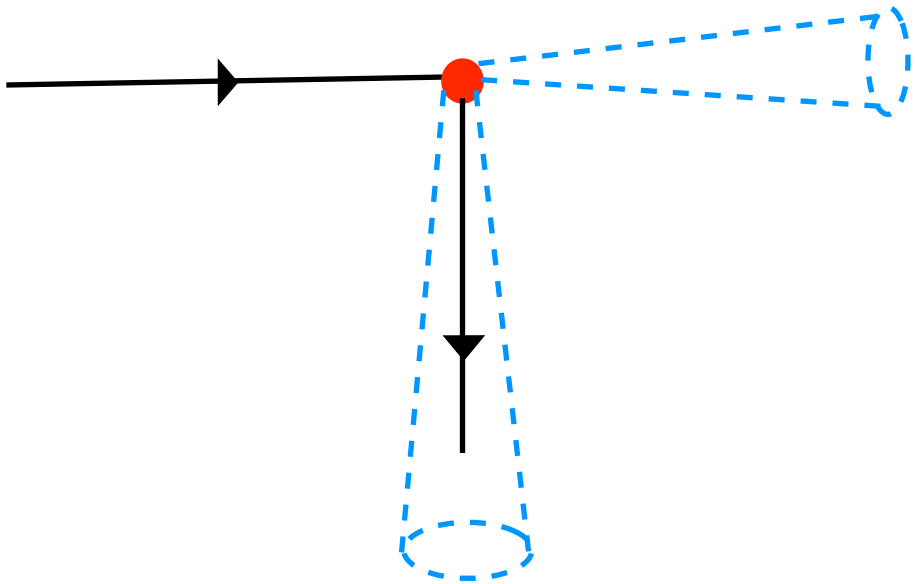


$$l_{regen} > \Delta Z$$

Landau, Pameranchuk, Migdal



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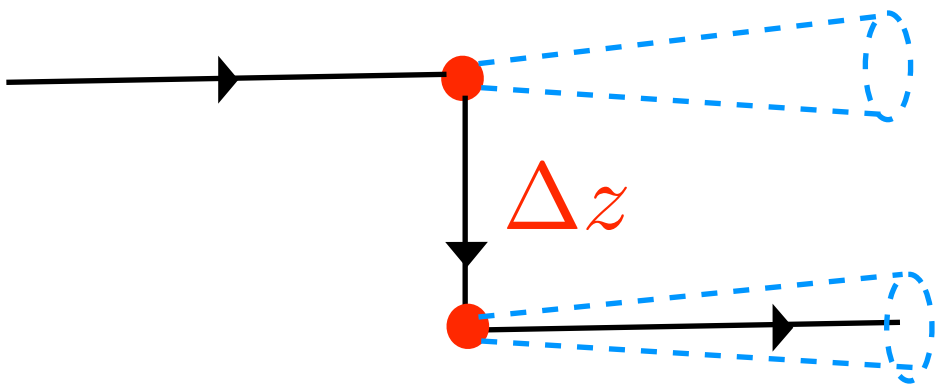

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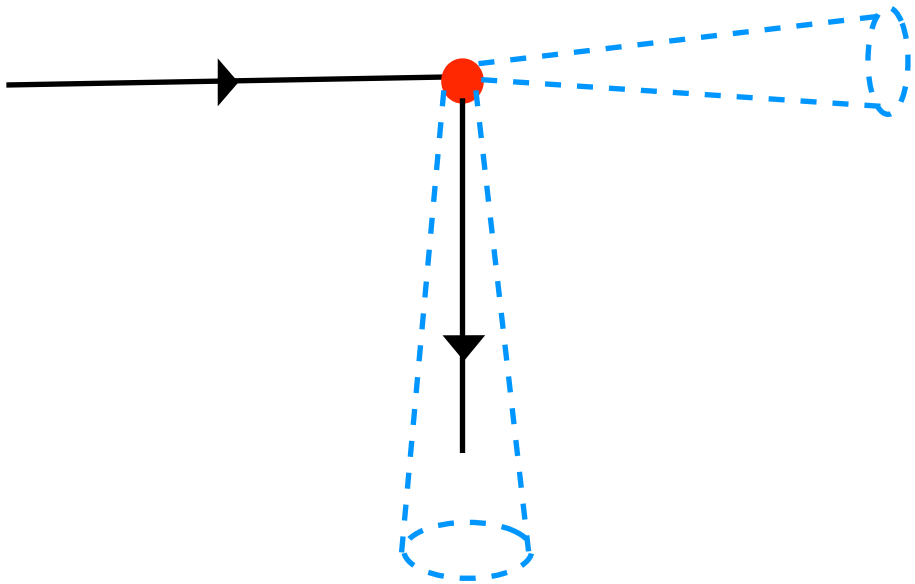

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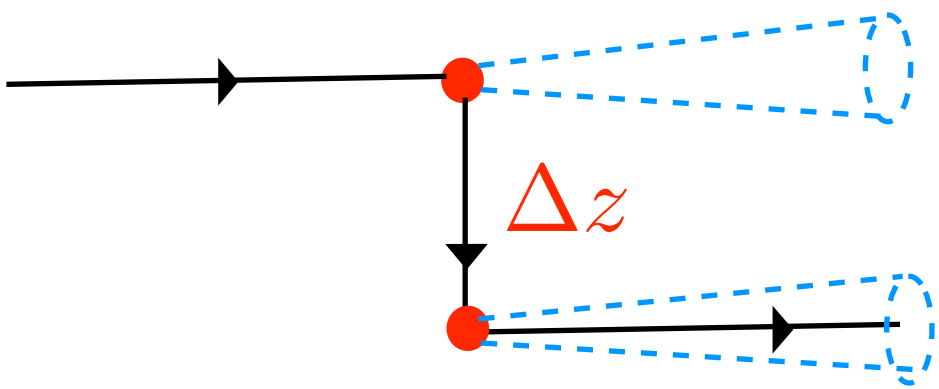

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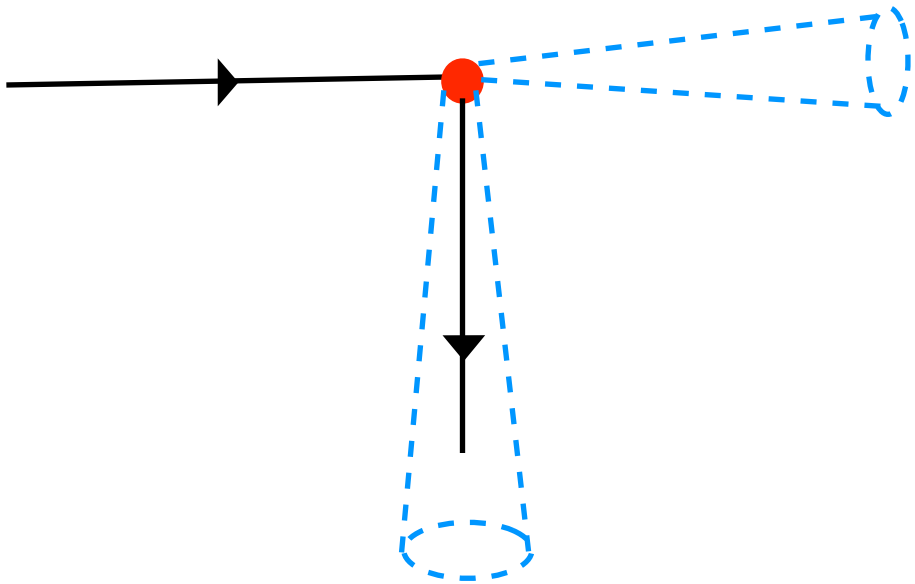
Landau, Pameranchuk, Migdal



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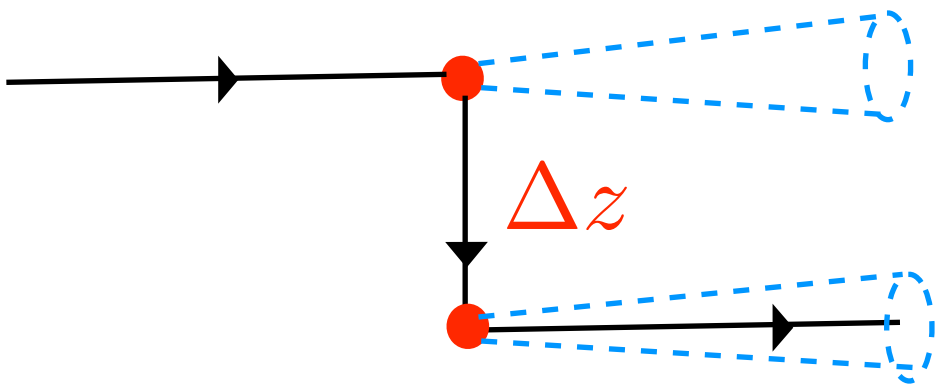

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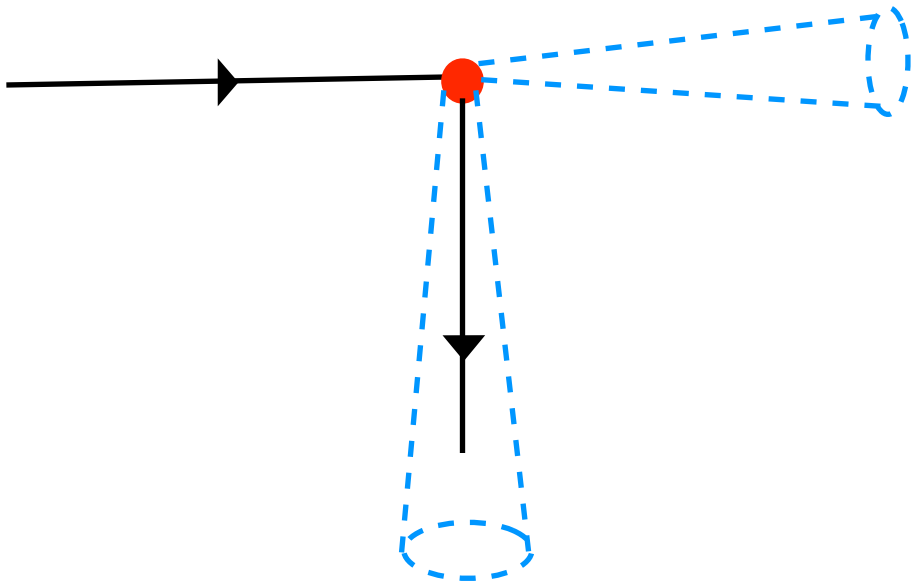
Landau, Pameranchuk, Migdal



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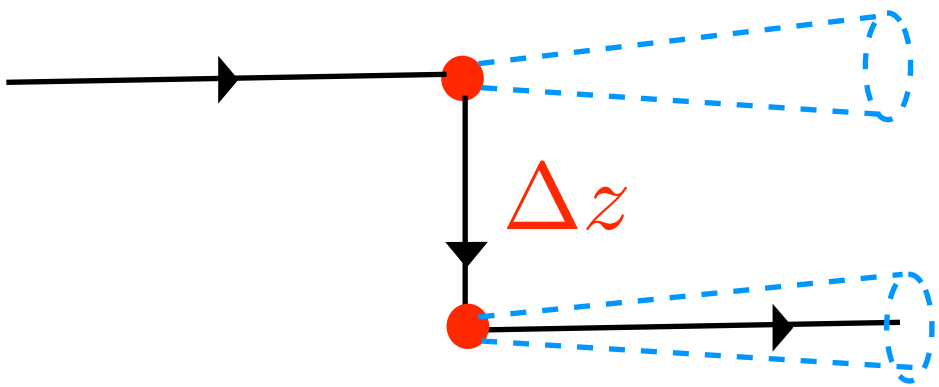

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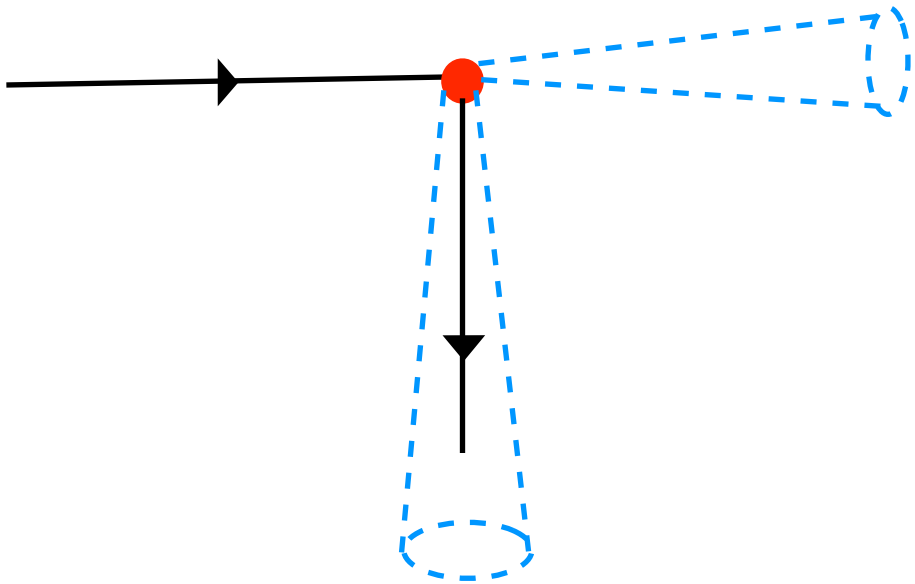
Landau, Pameranchuk, Migdal



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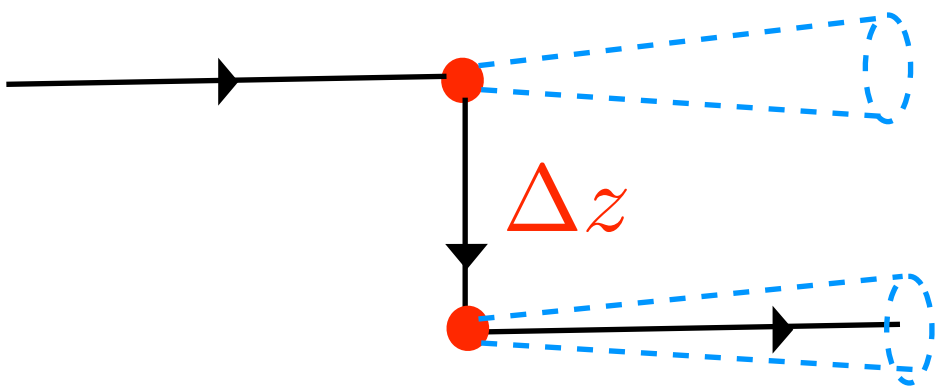

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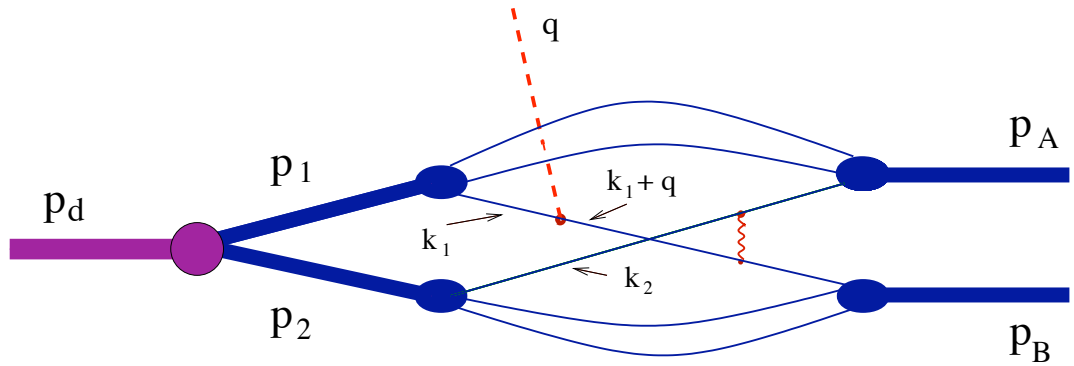
Δz > 1fm

Landau, Pameranchuk, Migdal

Frankfurt, Miller, MS, Strikman
PRL 2000



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

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

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

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

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.

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

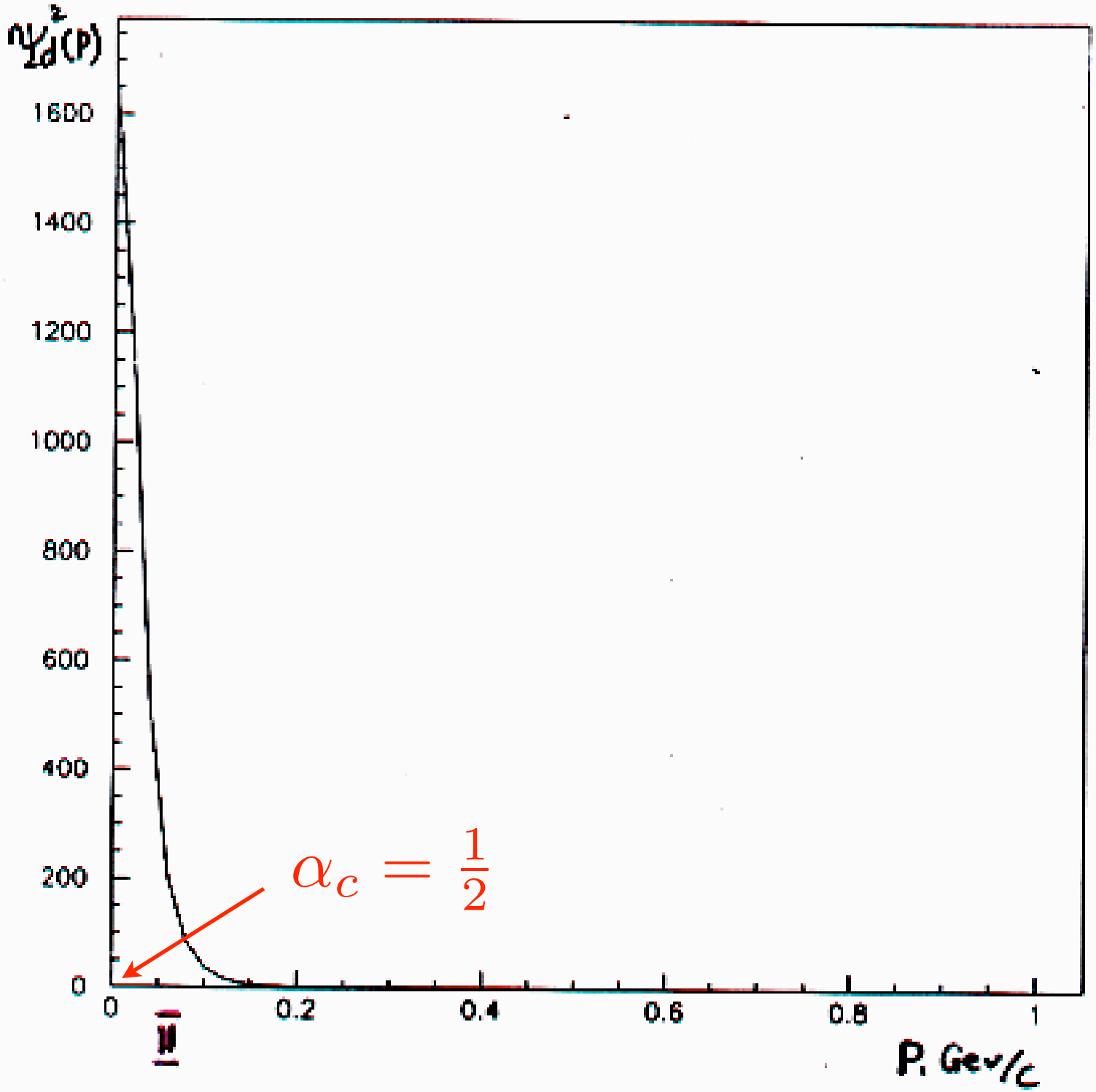
-We are concerned with momenta such that $p_\perp^2 \ll m_N^2 \ll s'$ and $\alpha \sim \frac{1}{2}$ so we neglect terms of order $p_\perp^2, m_N^2/s' \ll 1$ to obtain:

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

$$\alpha_c \equiv \frac{x_1 m_R^2 + k_{1\perp}^2}{(1-x_1)x_1 \tilde{s}}. \quad \text{looking for } \alpha_c \sim \tfrac{1}{2} \text{ contribution} \quad (2)$$

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 $\alpha_c = \frac{1}{2}$.

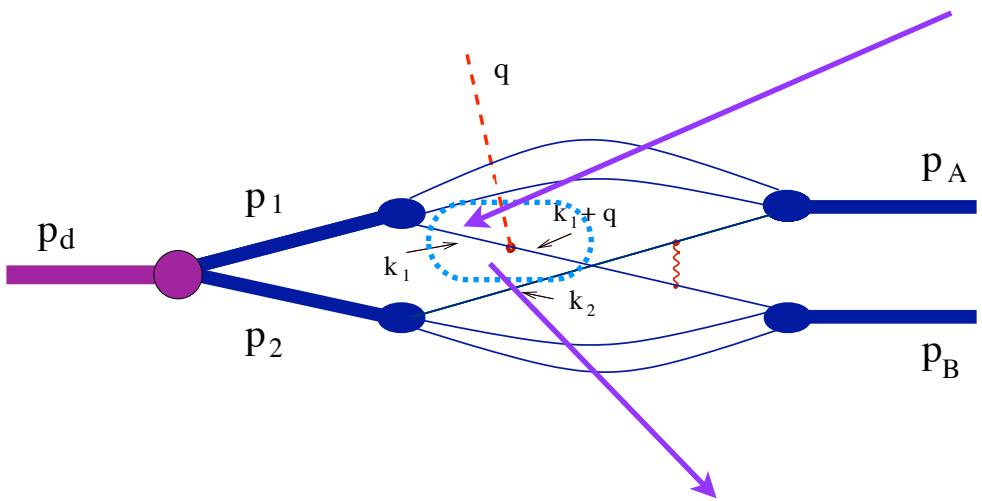

$\Psi_d^2(P)$
1600
1400
1200
1000
800
600
400
200
0
0
0.2
0.4
0.6
0.8
1
P, Gev/c
$\alpha_c = \frac{1}{2}$

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

- 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: $(\alpha - \alpha_c + \epsilon)^{-1} \equiv \mathcal{P}(\alpha - \alpha_c)^{-1} - i\pi\delta(\alpha - \alpha_c)$:



$$\bar{u}^\beta(k_1+q)\left[-ie\epsilon^\mu(\lambda_\gamma)\gamma_\mu\right]u^\alpha(k_1) = ie_q 2\sqrt{2E_2E1}(-\lambda_\gamma)\delta^{\beta,\alpha}\delta^{\lambda_\gamma,\alpha}$$

$$\langle \lambda_A, \lambda_B \mid A \mid \lambda_\gamma, \lambda_D \rangle = \sum_{(\eta_1,\eta_2),(\xi_2),(\lambda_1,\lambda_2)} \int \frac{e_q\sqrt{2}}{x_1\sqrt{s'}} \sqrt{[1-(1-\alpha_c)x_1](1-\alpha_c)x_1}$$

$$\left\{ \frac{\psi_N^{\dagger\lambda_B,\eta_2}(p_B, x_2', k_{2\perp})}{x_2'} \bar{u}_{\eta_2}(p_B - k_2)[-igT_c^F\gamma^\nu]\cdot u_{\lambda_\gamma}(p_1 - k_1 + q) \frac{\psi_N^{\lambda_1,\lambda_\gamma}(p_1, x_1, k_{1\perp})}{x_1} \times \right.$$

$$\left. \frac{\psi_N^{\dagger\lambda_A,\eta_1}(p_B, x_1', k_{1\perp})}{x_1'} \bar{u}_{\eta_1}(p_A - k_1)[-igT_c^F\gamma^\mu] u_{\xi_2}(p_2 - k_2) \frac{\psi_N^{\lambda_2,\xi_2}(p_2, x_2, k_2)}{x_2} G^{\mu,\nu}(r) \frac{dx_1}{1-x_1} \frac{d^2k_{1\perp}}{2(2\pi)^3} \frac{dx_2}{1-x_2} \frac{d^2k_{2\perp}}{2(2\pi)^3} \right\}$$

$$\frac{\Psi^{\lambda_D,\lambda_1,\lambda_2}(\alpha, p_\perp)}{(1-\alpha)\alpha} \frac{d^2p_\perp}{4(2\pi)^2}. \tag{1}$$

$$A_{pn}^{QIM} = \int \frac{\psi_N^\dagger(x_2', p_{B\perp}, k_{2\perp})}{x_2'} \bar{u}(p_B - p_2 + k_2) \left[-igT_c^F\gamma^\nu\right] u(k_1 + q) \frac{\psi_N(x_1, p_{1\perp}, k_{1\perp})}{x_1}$$

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

$$\times \frac{dx_1}{1-x_1} \frac{d^2k_{1\perp}}{2(2\pi)^3} \frac{dx_2}{1-x_2} \frac{d^2k_{2\perp}}{2(2\pi)^3} \tag{1}$$

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

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

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

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

Assuming $\lambda_1 = \lambda_\gamma$

Brodsky,Carlson,Lipkin Phys.Rev.D 1979

NN ⇨ NN

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

γnp ⇨ np

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

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

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

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

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

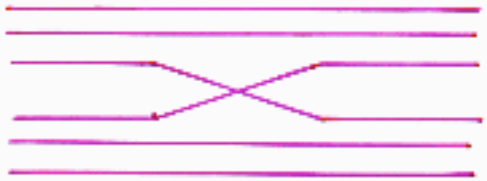
$$\int \Psi^{\lambda_D, \lambda_\gamma, \lambda_2}(\alpha_c, p_\perp) \frac{d^2 p_\perp}{(2\pi)^2} \tag{1}$$

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

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

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

QIM



GLUON EXCHANGE

ANIHILLATION

≡ COMPARE $PP \to PP$ AND $P\bar{P} \to P\bar{P}$ CROSS SECTIONS

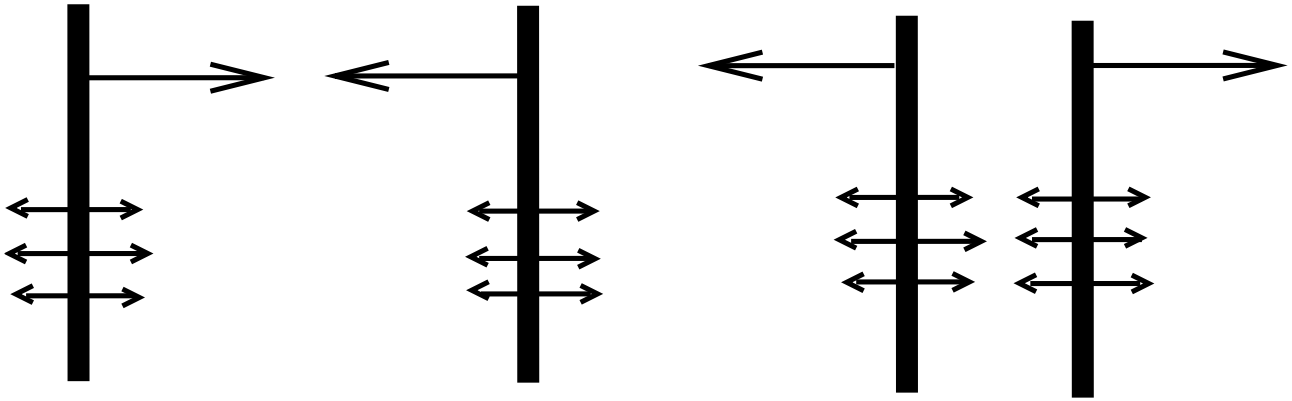
$$\frac{d\sigma/dt^{\bar{P}P}}{d\sigma/dt^{PP}} \sim 1.7 \text{ AT } \theta_{CM} \approx 0^\circ$$

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

NN $\longrightarrow$ NN

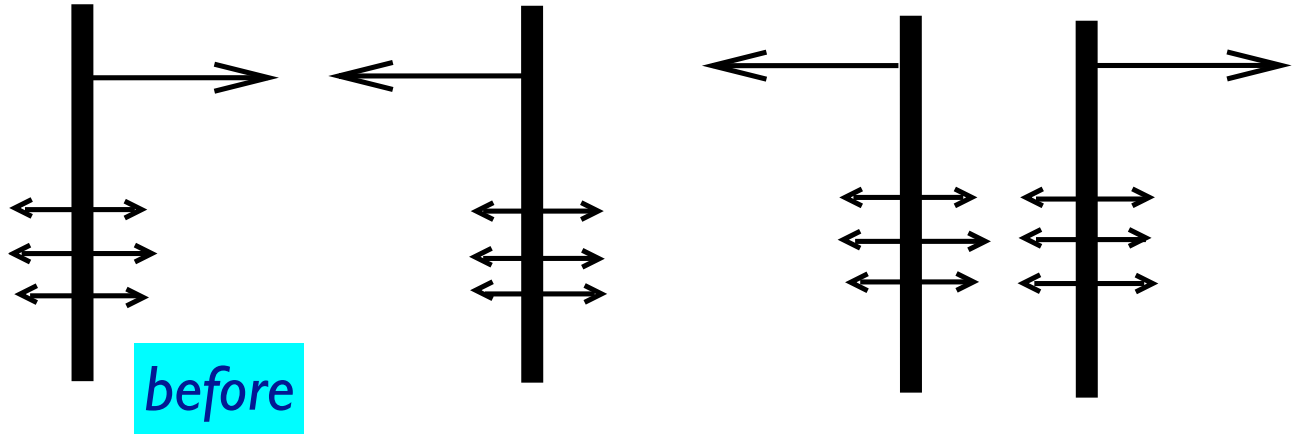
R.Feynman
Photon Hadron Interactions

NN ⟶ NN



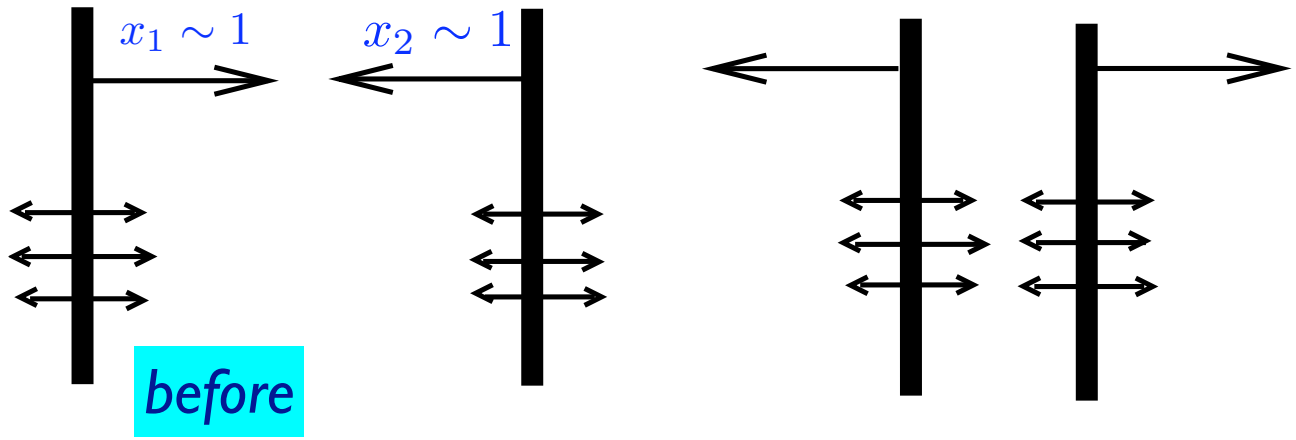
R.Feynman
Photon Hadron Interactions

NN ⟶ NN



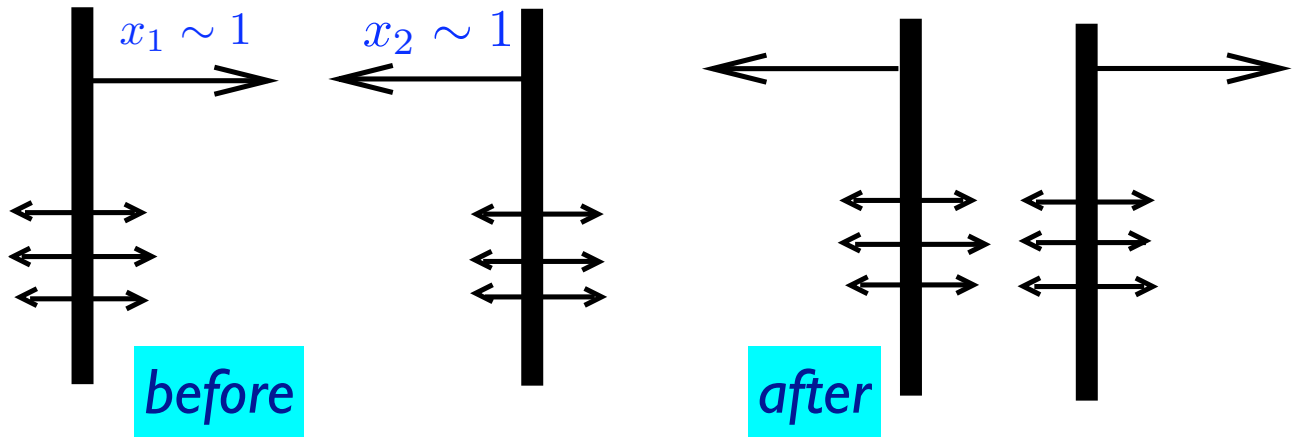
R.Feynman
Photon Hadron Interactions

NN ⟶ NN

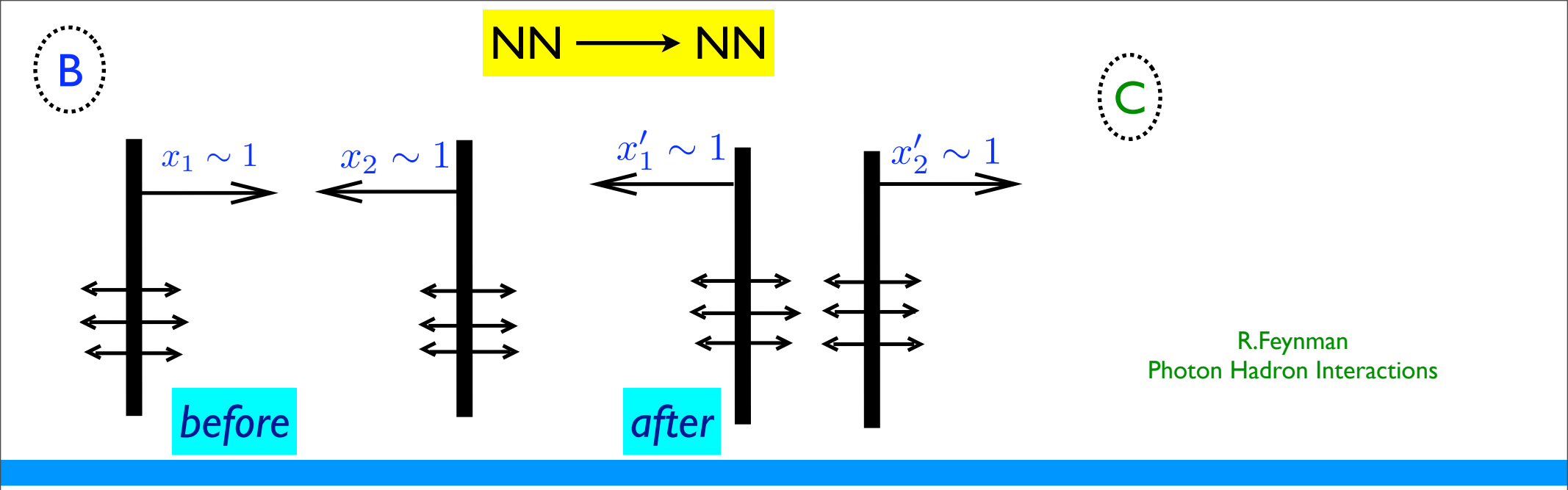


R.Feynman
Photon Hadron Interactions

NN ⟶ NN



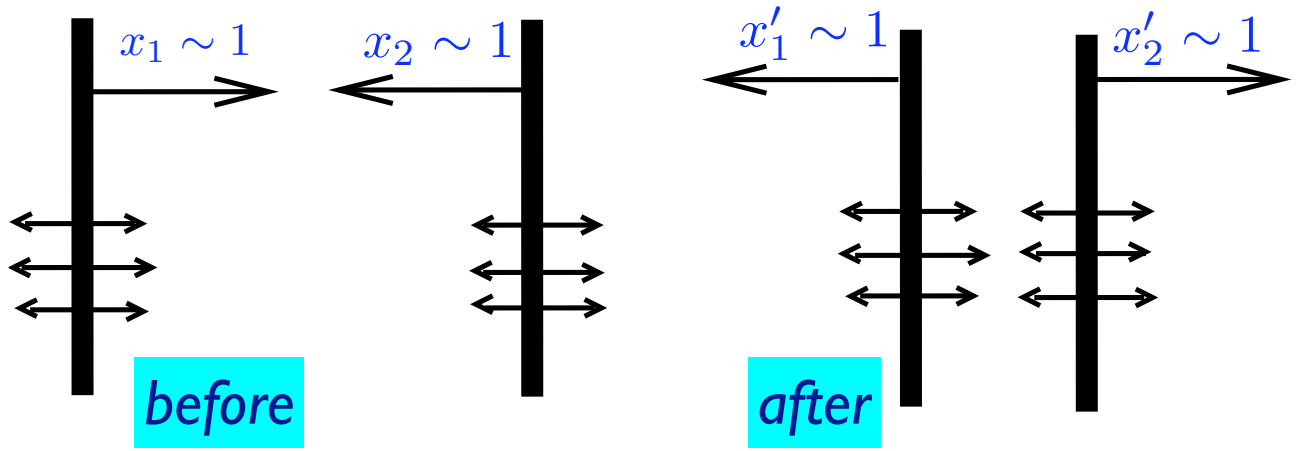
R.Feynman
Photon Hadron Interactions


B
NN ⟶ NN
C
$x_1 \sim 1$
$x_2 \sim 1$
$x_1' \sim 1$
$x_2' \sim 1$
before
after
R.Feynman
Photon Hadron Interactions

B

NN ⟶ NN

C



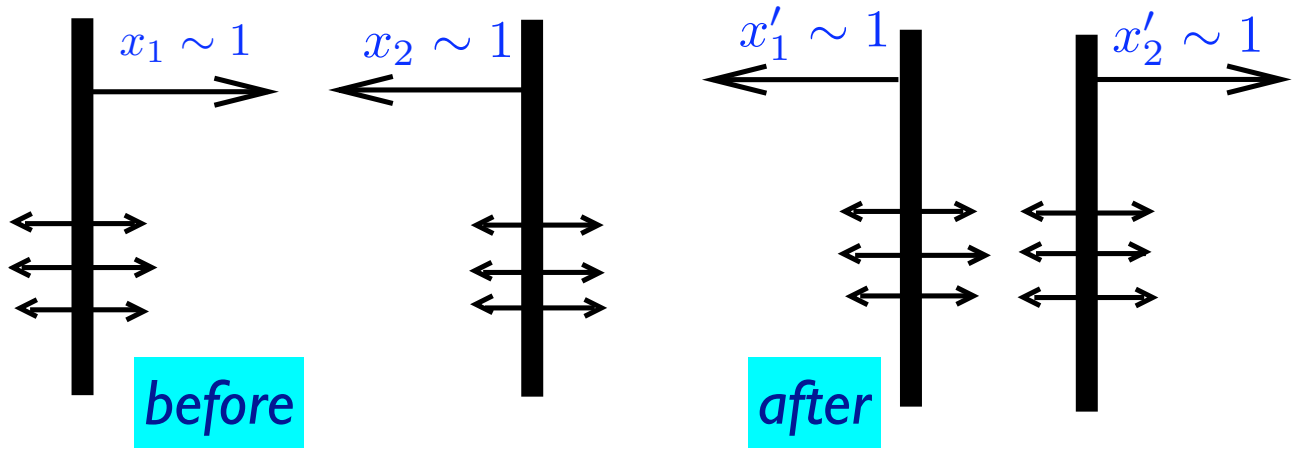
R.Feynman
Photon Hadron Interactions

$$\gamma d \to pn$$

B

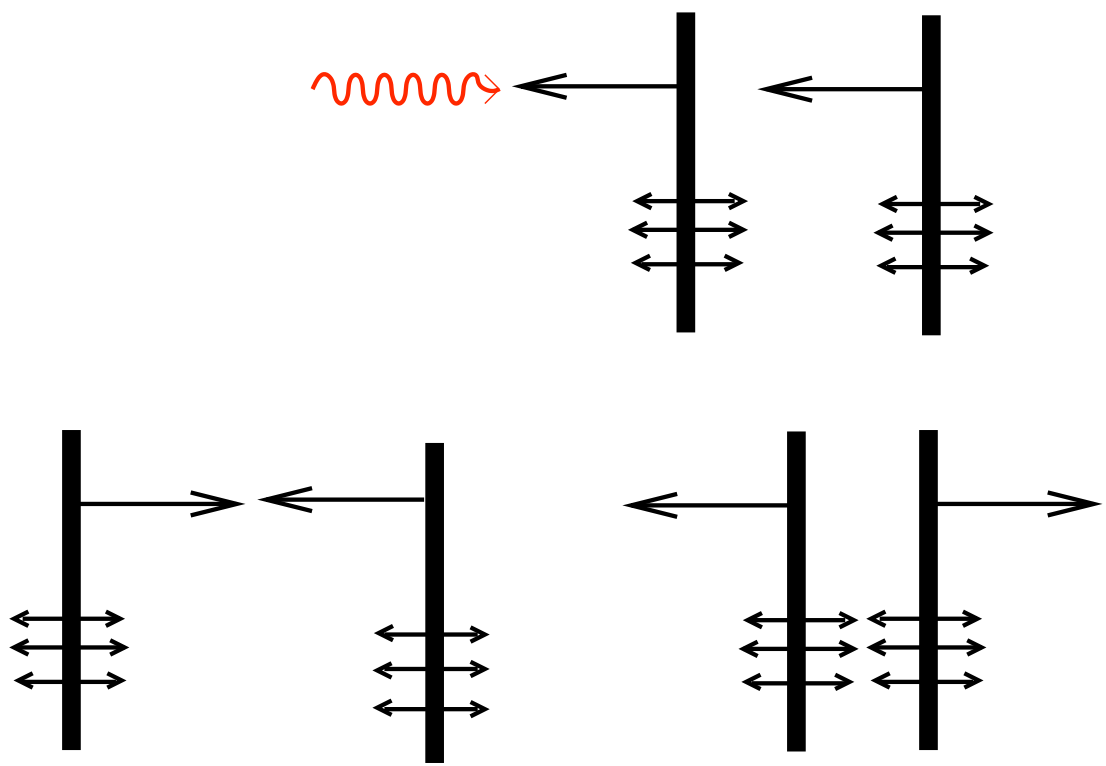
NN ⟶ NN

C

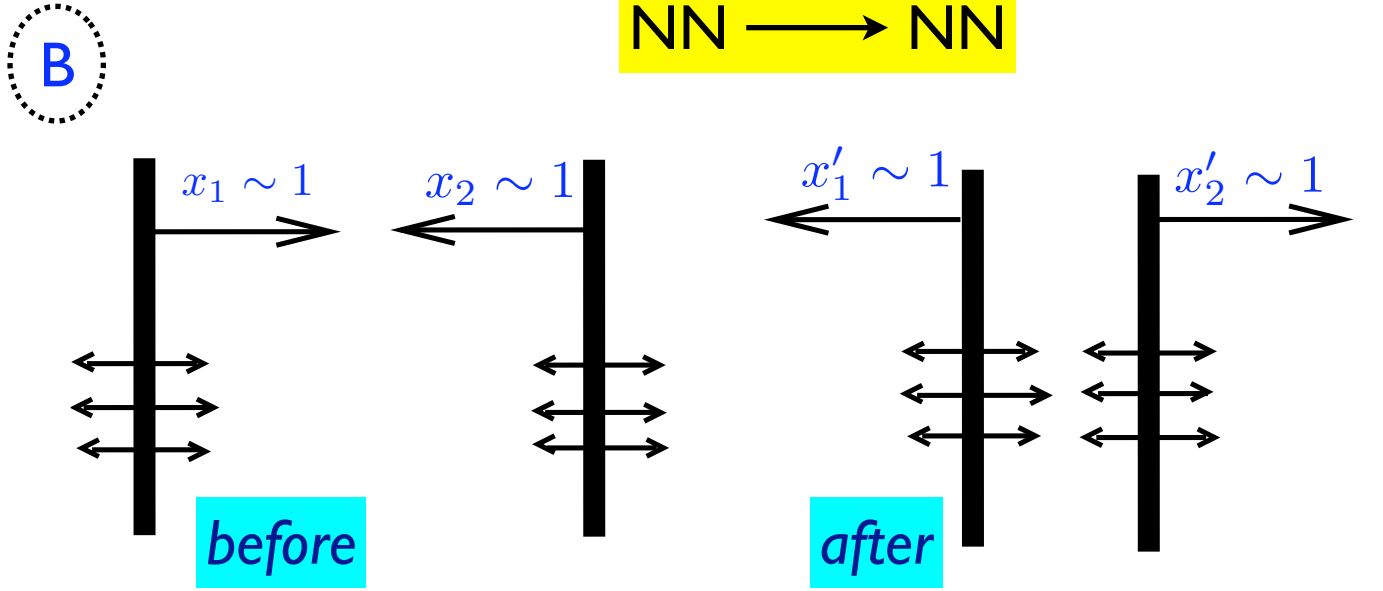


R.Feynman
Photon Hadron Interactions

$\gamma d \to pn$

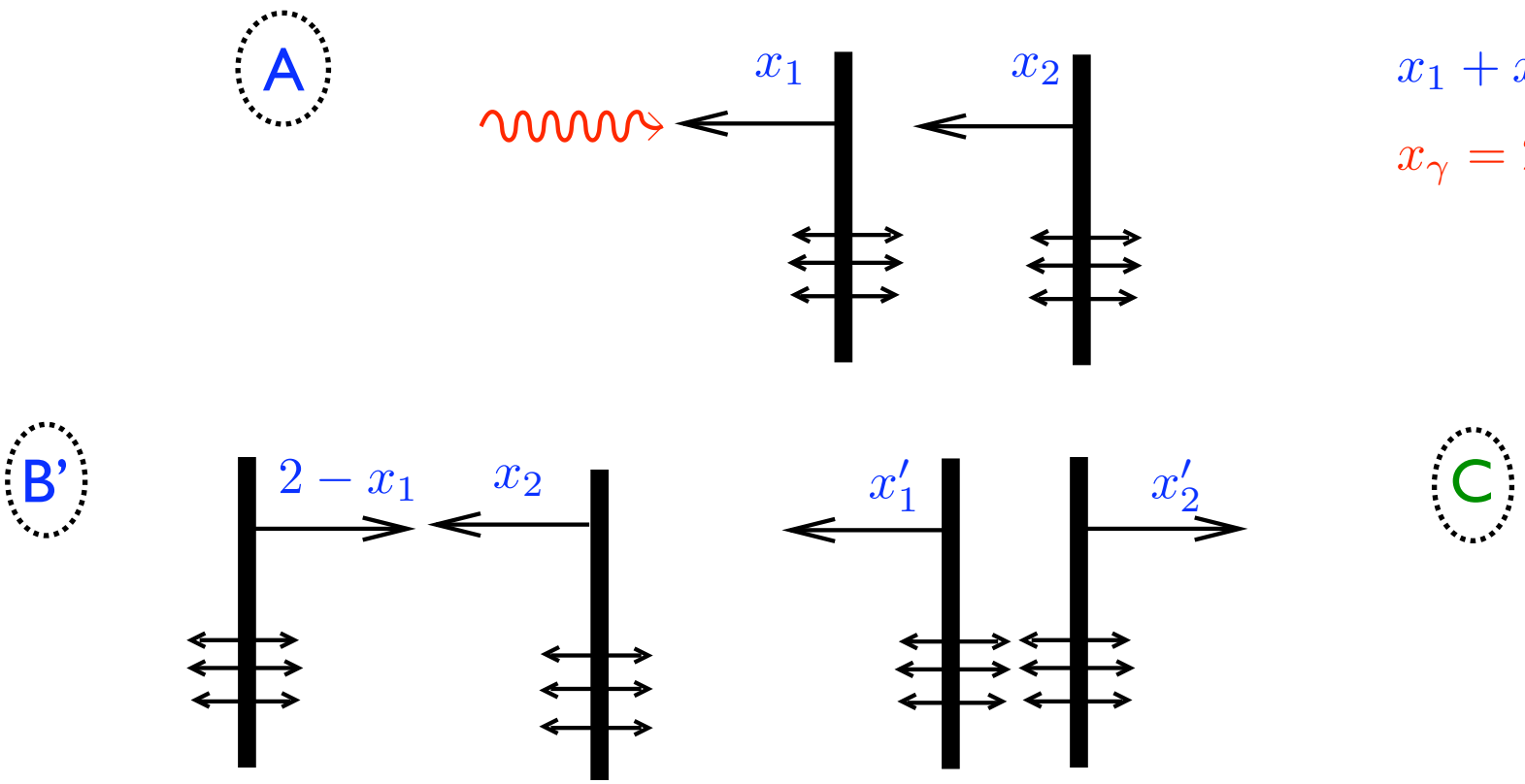


NN ⟶ NN



R.Feynman
Photon Hadron Interactions

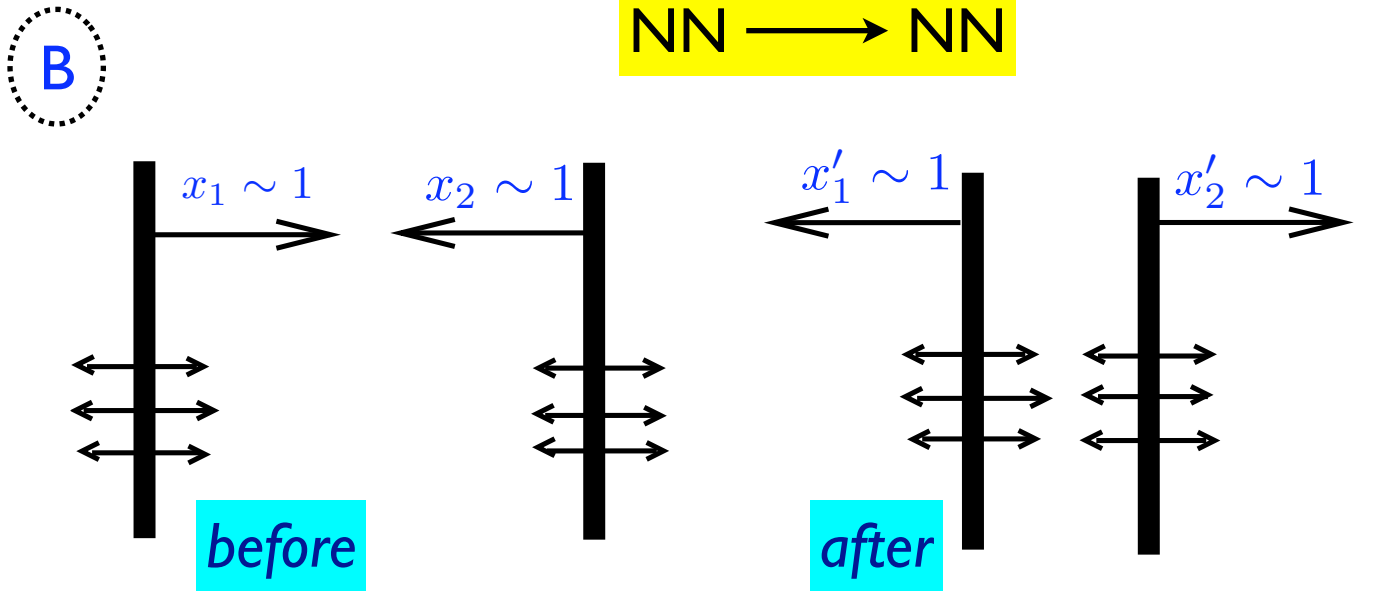
$\gamma d \to pn$



$x_1 + x_2 = 1$

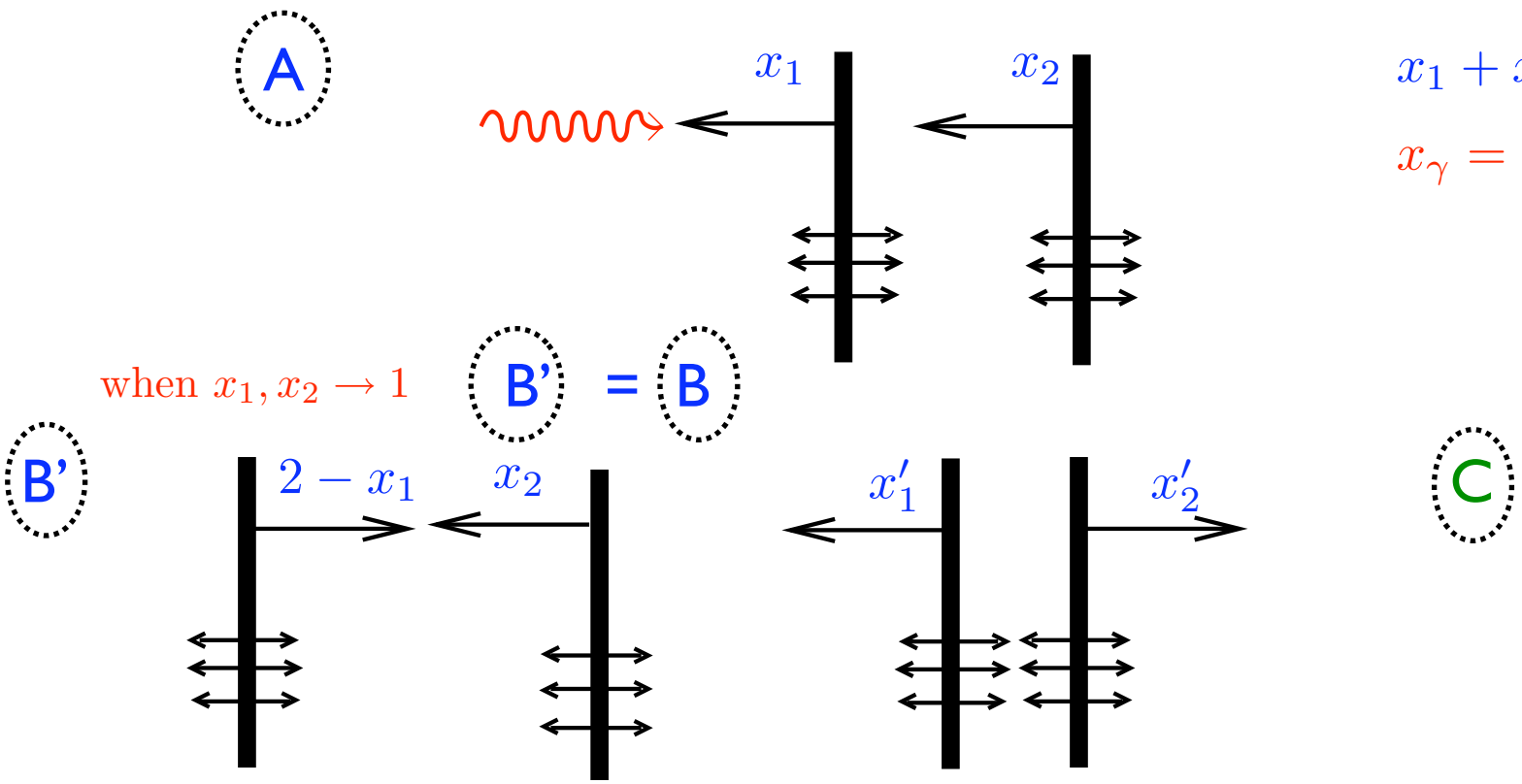
$x_\gamma = 2$

NN ⟶ NN



R.Feynman
Photon Hadron Interactions

$$\gamma d \to pn$$

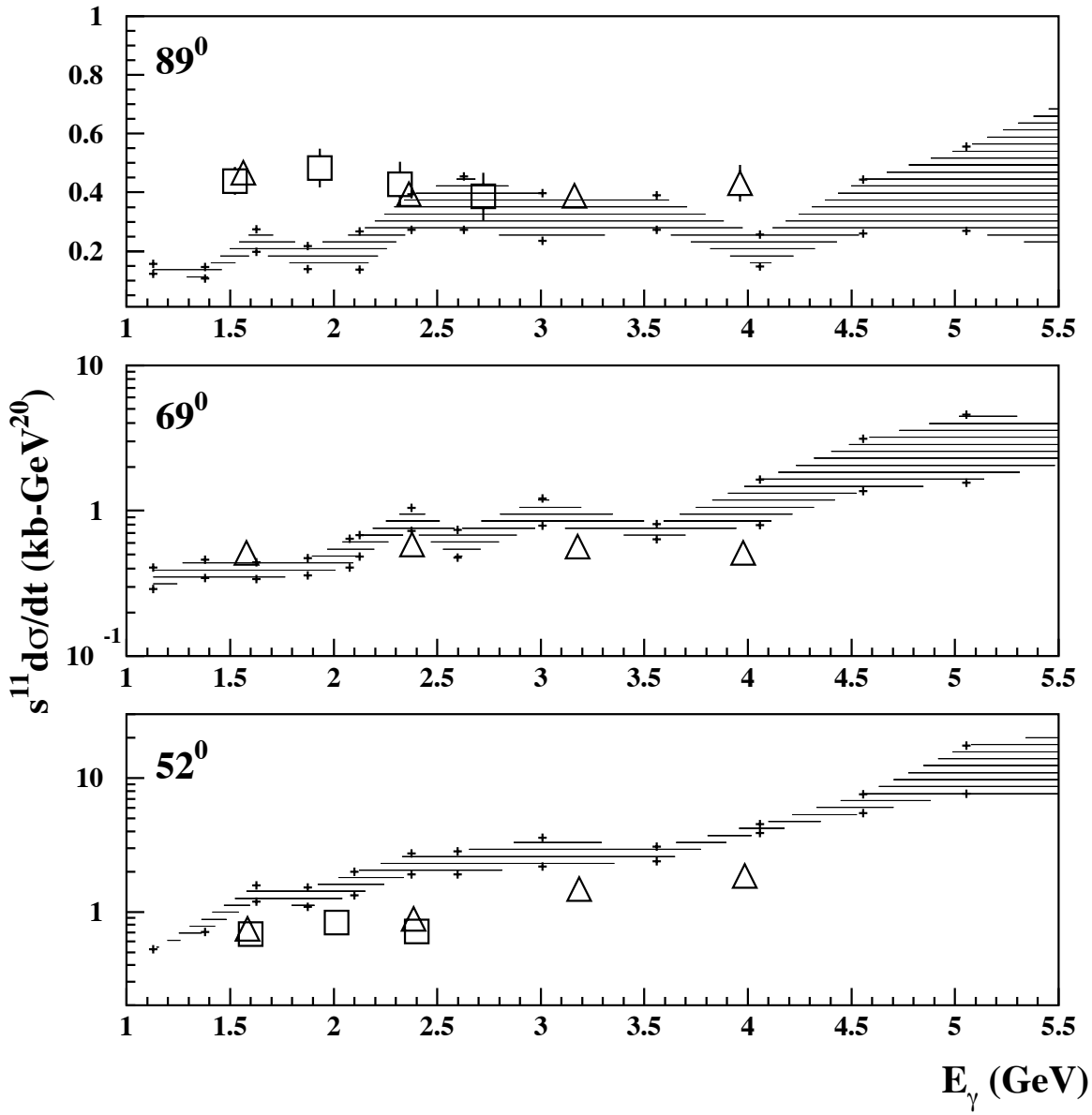


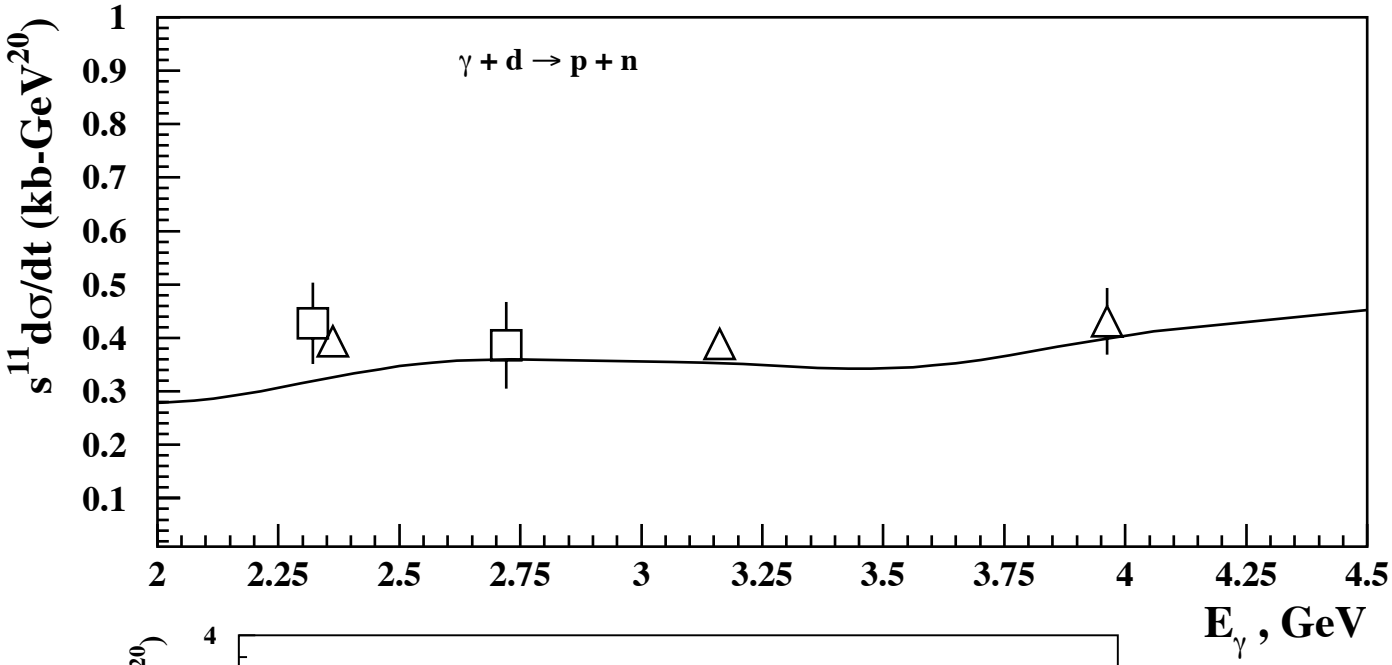
$x_1 + x_2 = 1$

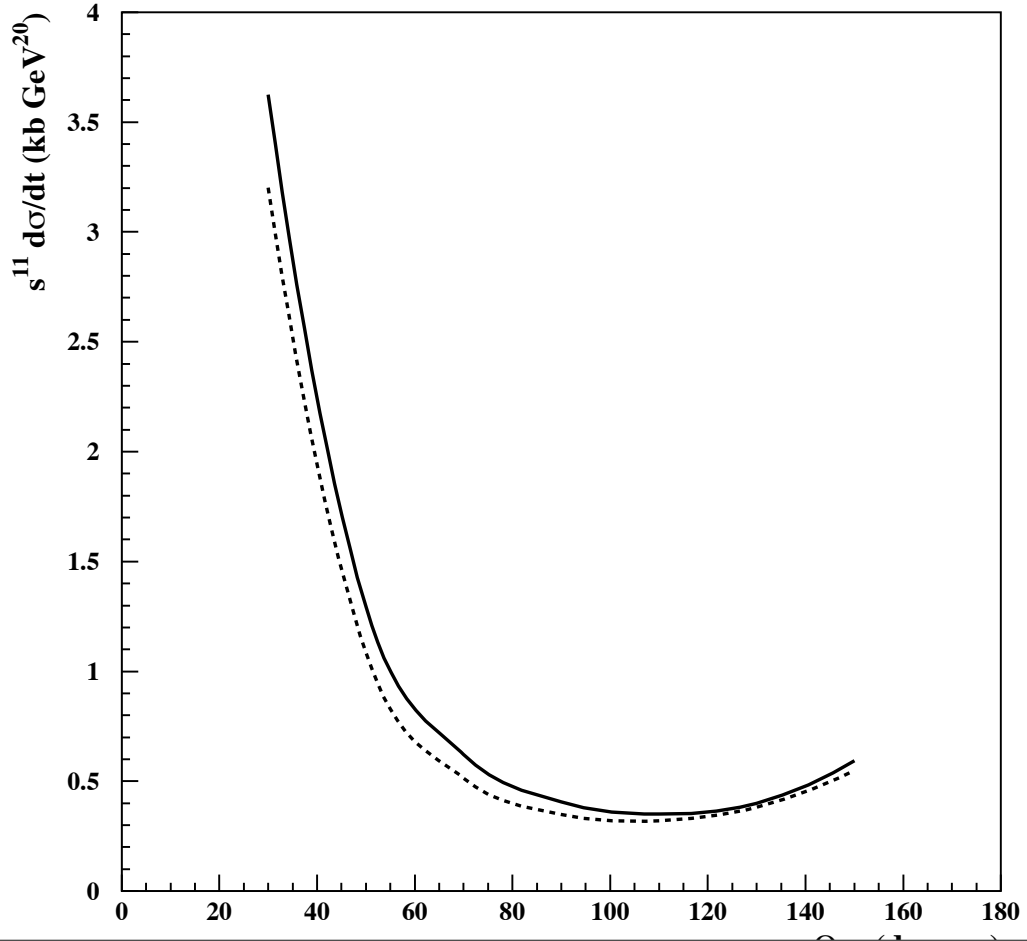
$x_\gamma = 2$

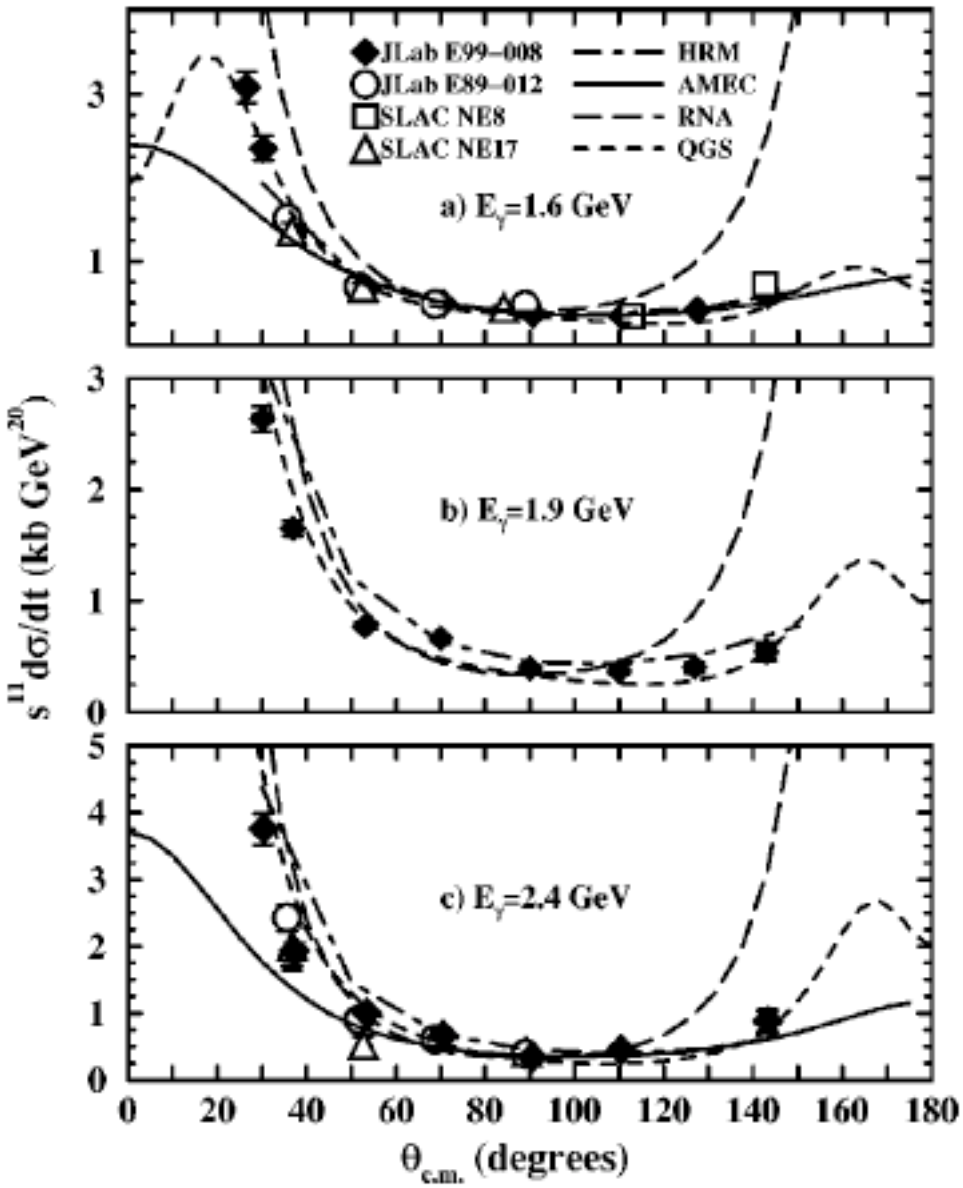
Frankfurt, Miller, M.S. Sargsian
PRL 2000

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




γ + d → p + n
s^11 dσ/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 dσ/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


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)

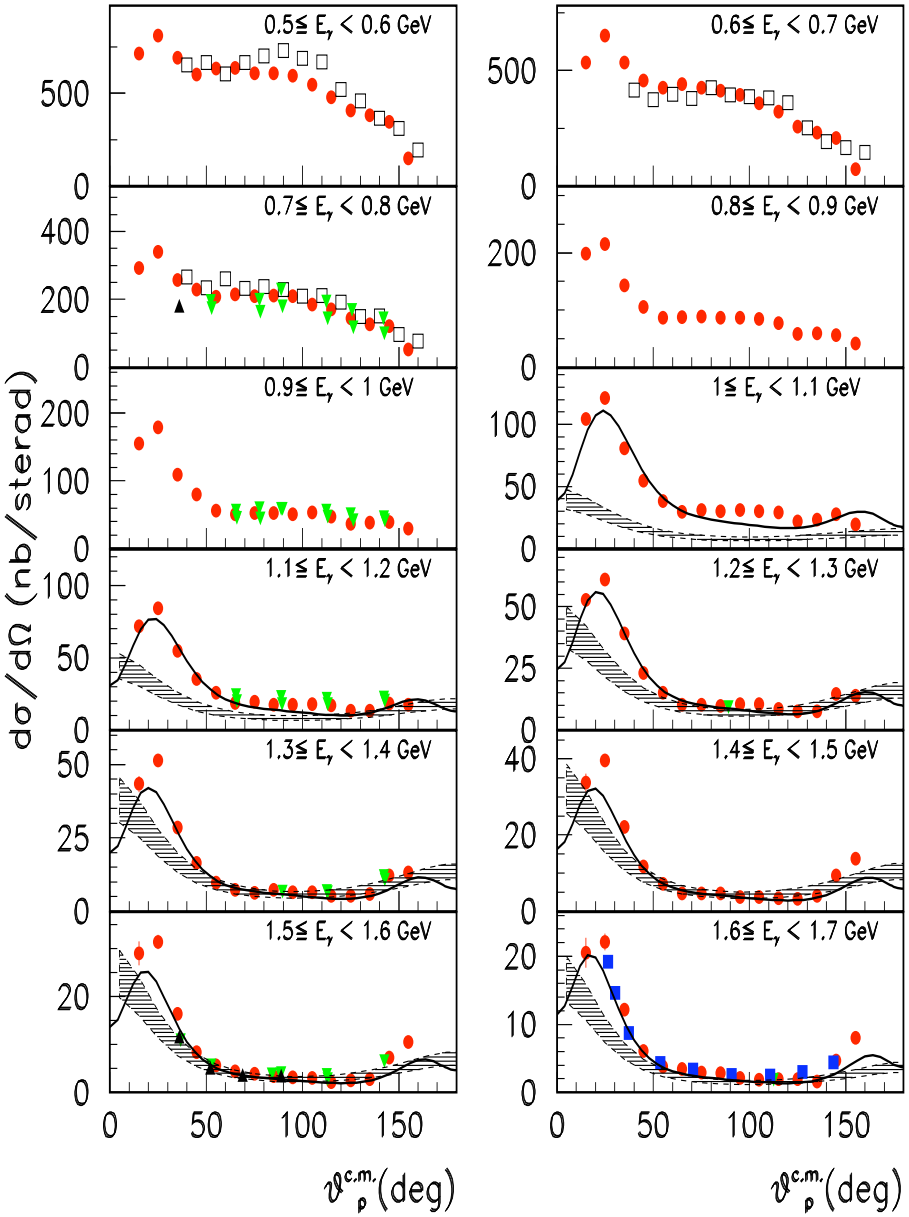


FIG. 7: (Color) Angular distributions of the deuteron photodisintegration cross section measured by the CLAS (full/red circles) in the incident photon energy range 0.50 − 1.70 GeV. Results from Mainz [26] (open squares, average of the measured values in the given photon energy intervals), SLAC [5, 6, 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.

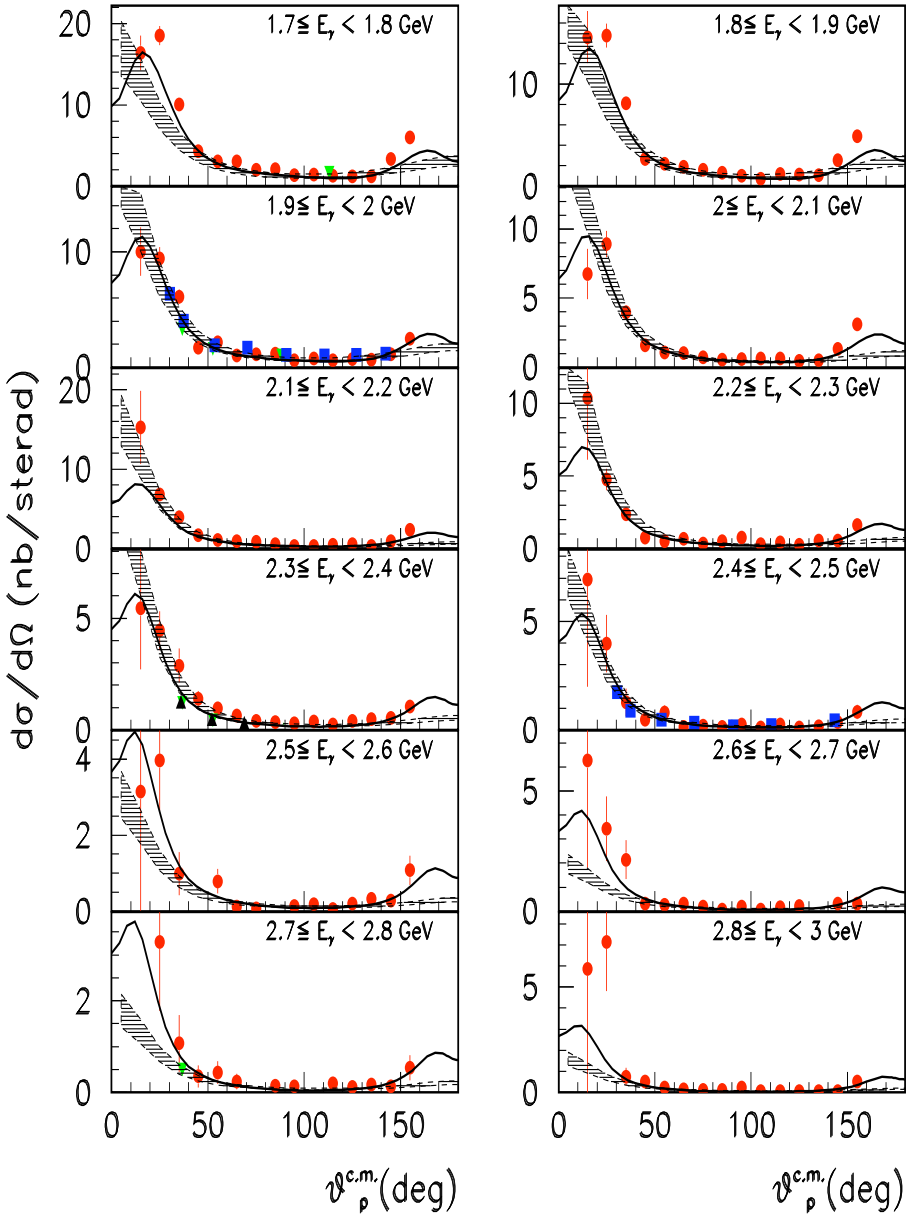
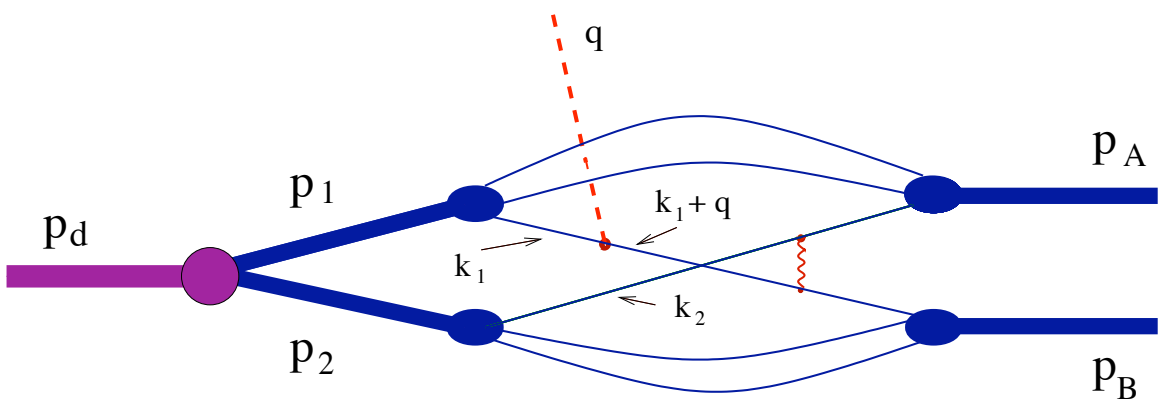


FIG. 8: (Color) Same as Fig. 7 for photon energies 1.7 − 3.0 GeV.

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.

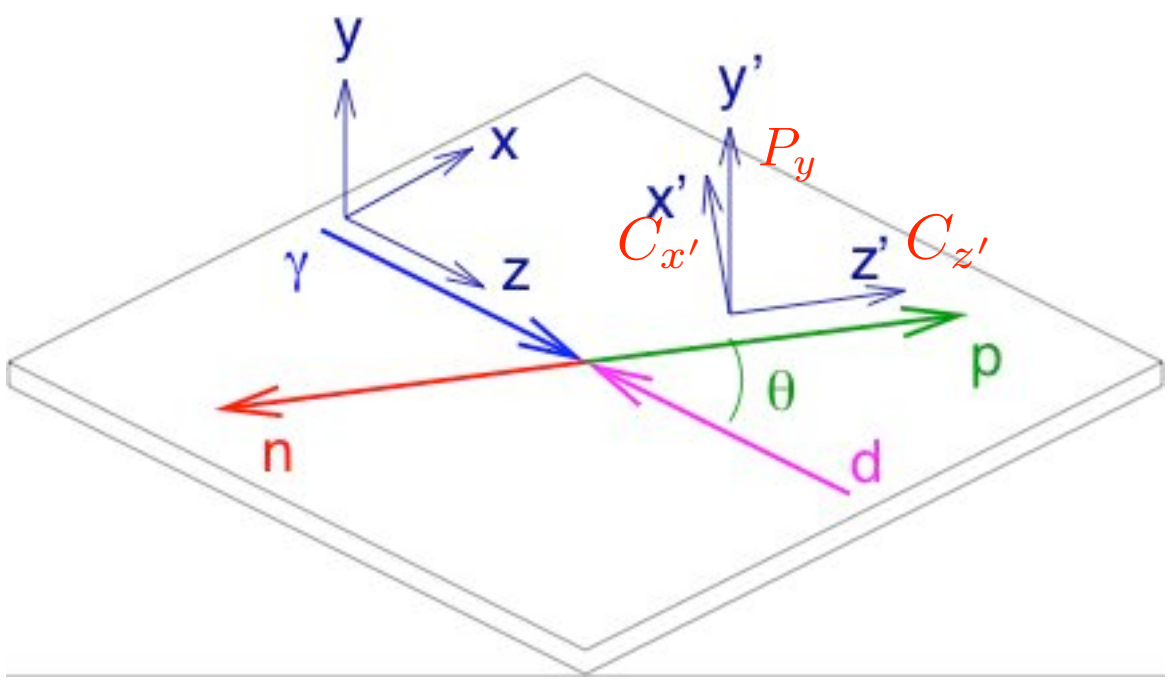


Polarization Observables

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

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

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



Gilman, Gross, 2002

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

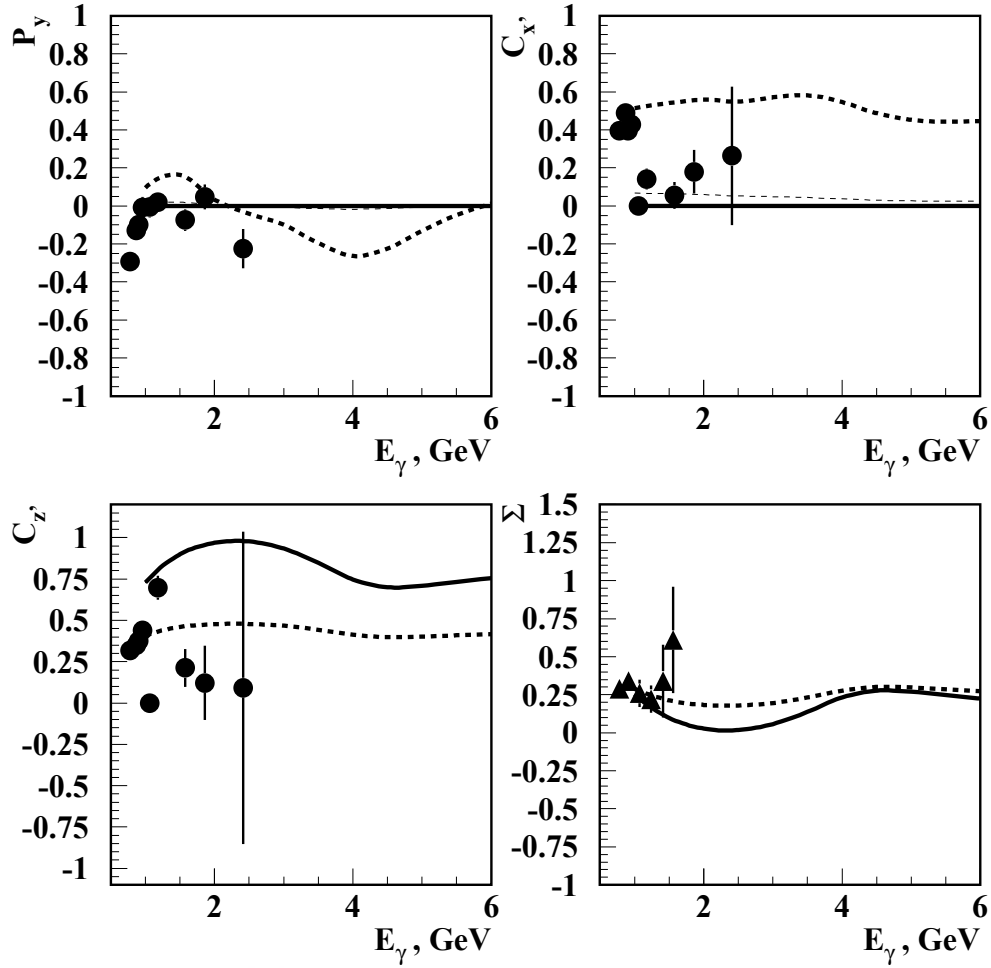
$$C_{x'} = \frac{2Re\left\{\phi_5^\dagger[2(\phi_1-\phi_2)+\phi_3+\phi_4]\right\}}{2|\phi_1|^2+2|\phi_2|^2+|\phi_3|^2+|\phi_4|^2+6|\phi_5|^2}$$

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

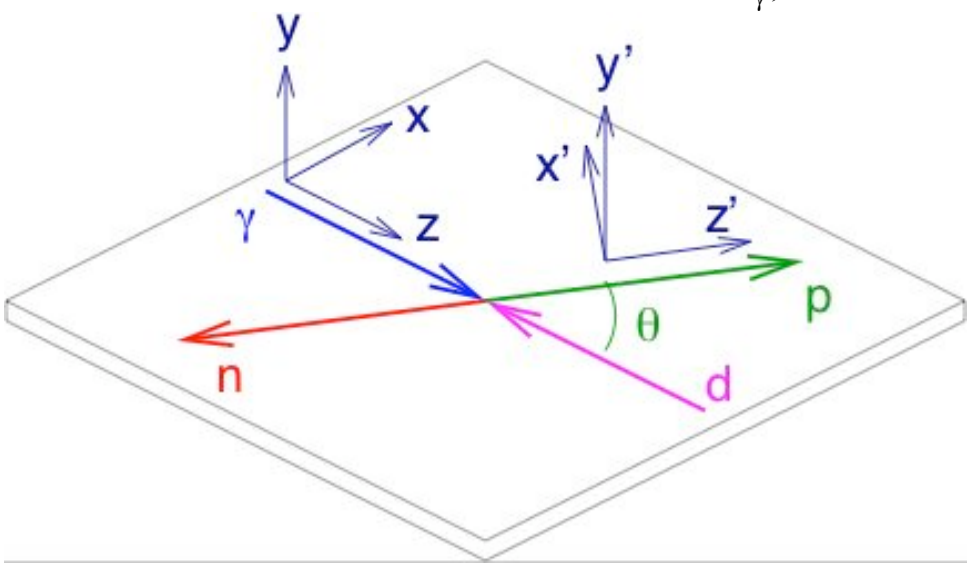
$$\Sigma = \frac{2Re\left[|\phi_5|^2-\phi_3^\dagger\phi_4\right]}{2|\phi_1|^2+2|\phi_2|^2+|\phi_3|^2+|\phi_4|^2+6|\phi_5|^2},$$

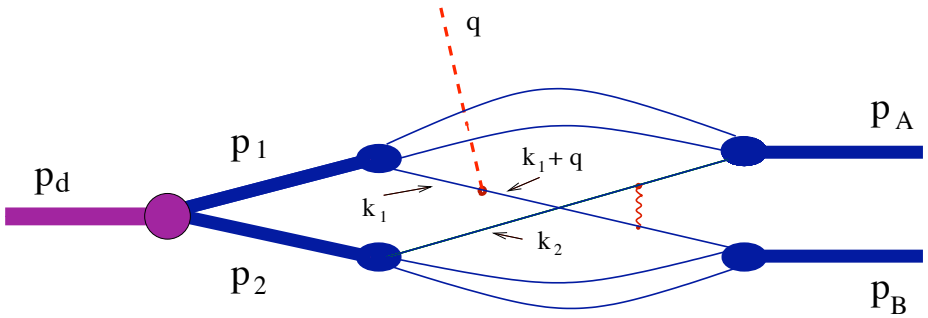
$$\begin{aligned}
\phi_1(s,t_n,u_n) &= \langle +,+\mid A_{pn}\mid +,+\rangle \\
\phi_2(s,t_n,u_n) &= \langle +,+\mid A_{pn}\mid -,-\rangle \\
\phi_3(s,t_n,u_n) &= \langle +,-\mid A_{pn}\mid +,-\rangle \\
\phi_4(s,t_n,u_n) &= \langle +,-\mid A_{pn}\mid -,+\rangle \\
\phi_5(s,t_n,u_n) &= \langle +,+\mid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

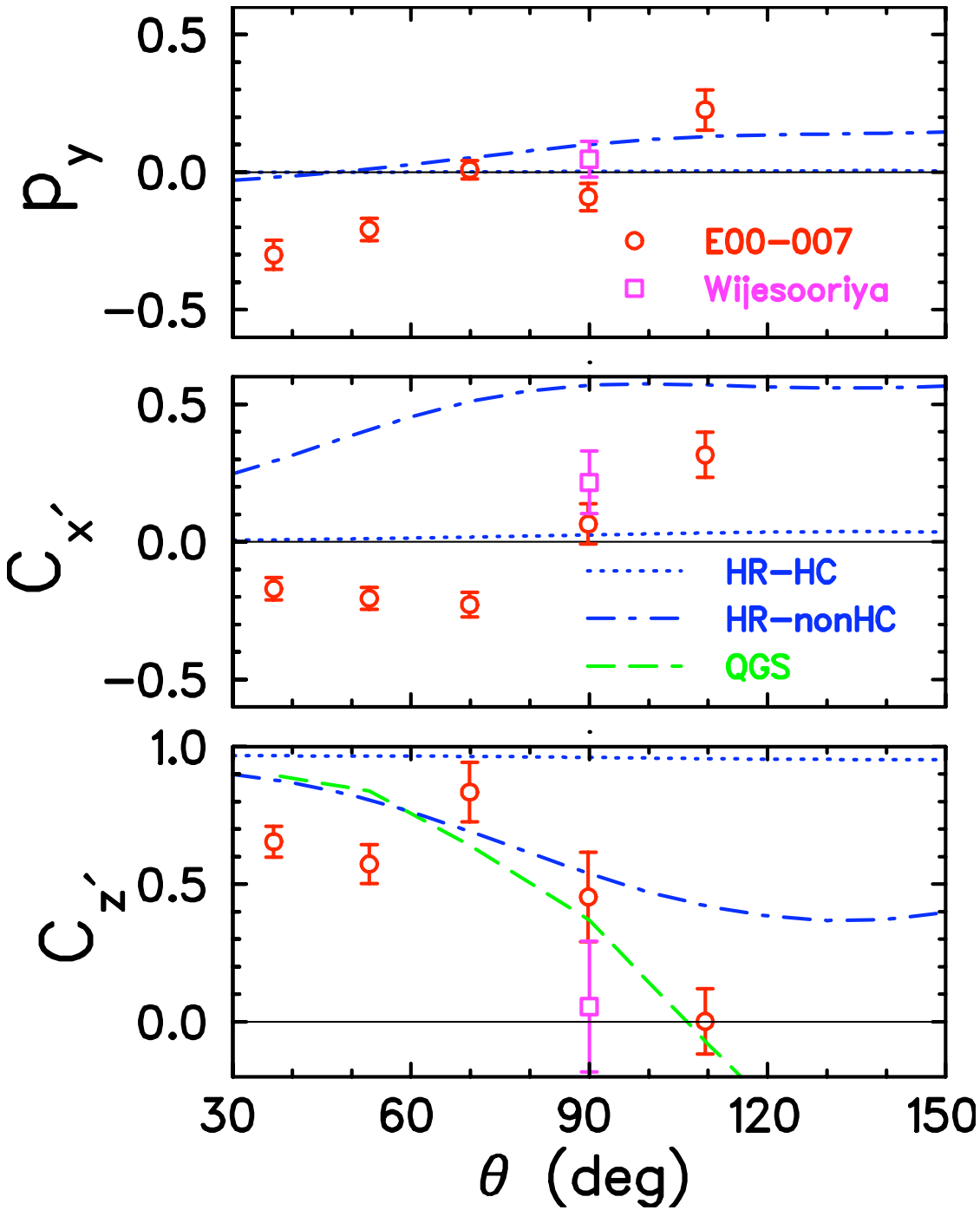
$$|\phi_1| \geq |\phi_3|, |\phi_4| > |\phi_5| > |\phi_2|.$$



Sargsian, Phys. Lett. B 2004







Jiang, PRL2007

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

Magnitude of pp vs. pn hard photodisintegration

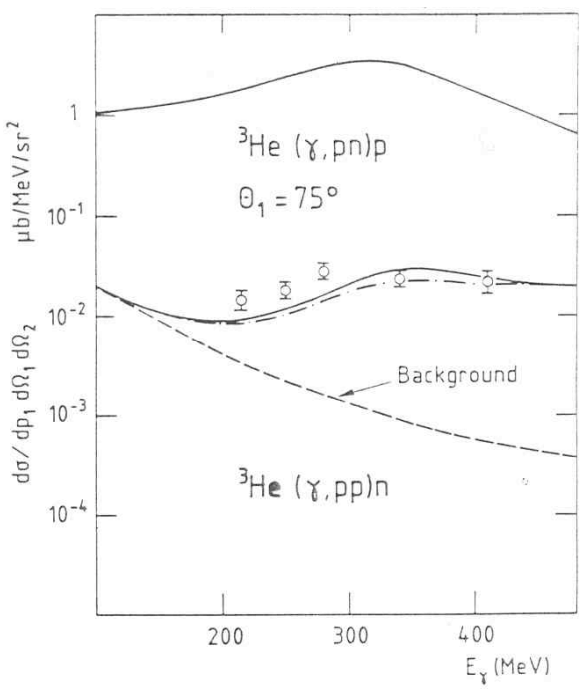
At low photon energy

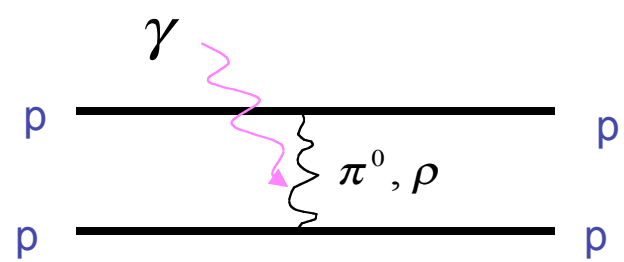
For $E_\gamma \leq 0.5\,\mathrm{GeV/c}$

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

$$\sigma_{\gamma pp} << \sigma_{\gamma \mathrm{pn}}$$

$$\sigma_{\gamma pp} \approx 0$$





MEC is the dominant process

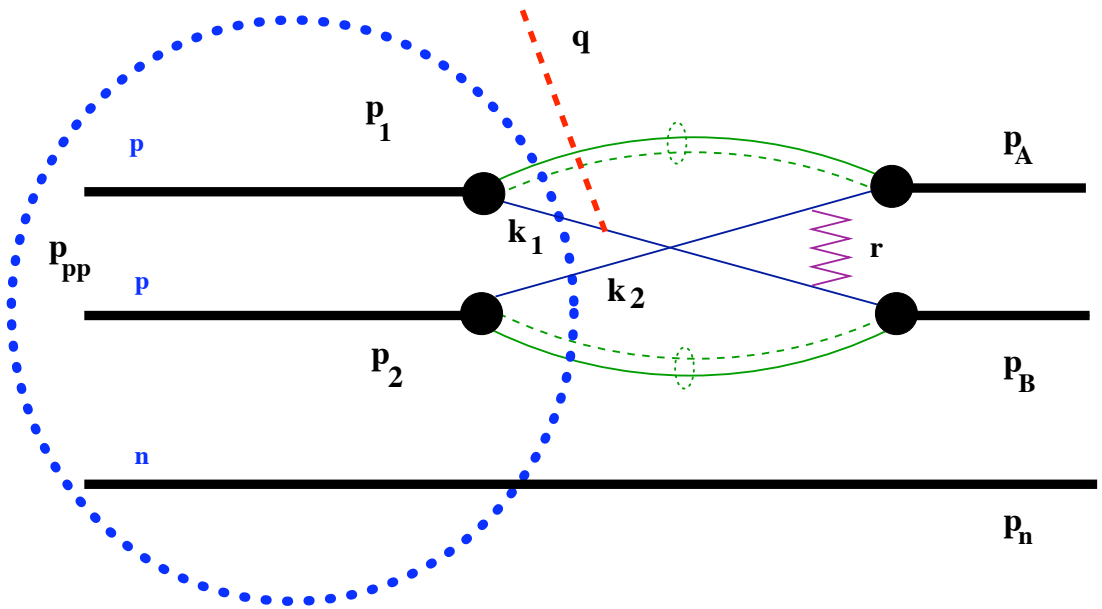
pp pair : only a neutral pion can be exchanged , its coupling to the photon is weak.

Laget NP A497 (89) 391, (Saclay data).

- Three Body Processes are Dominant

Hard Disintegration of pp from 3He

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



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

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

- Hard Photodisintegration of pp pair:

MS, Carlos Granados,2007

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

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

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

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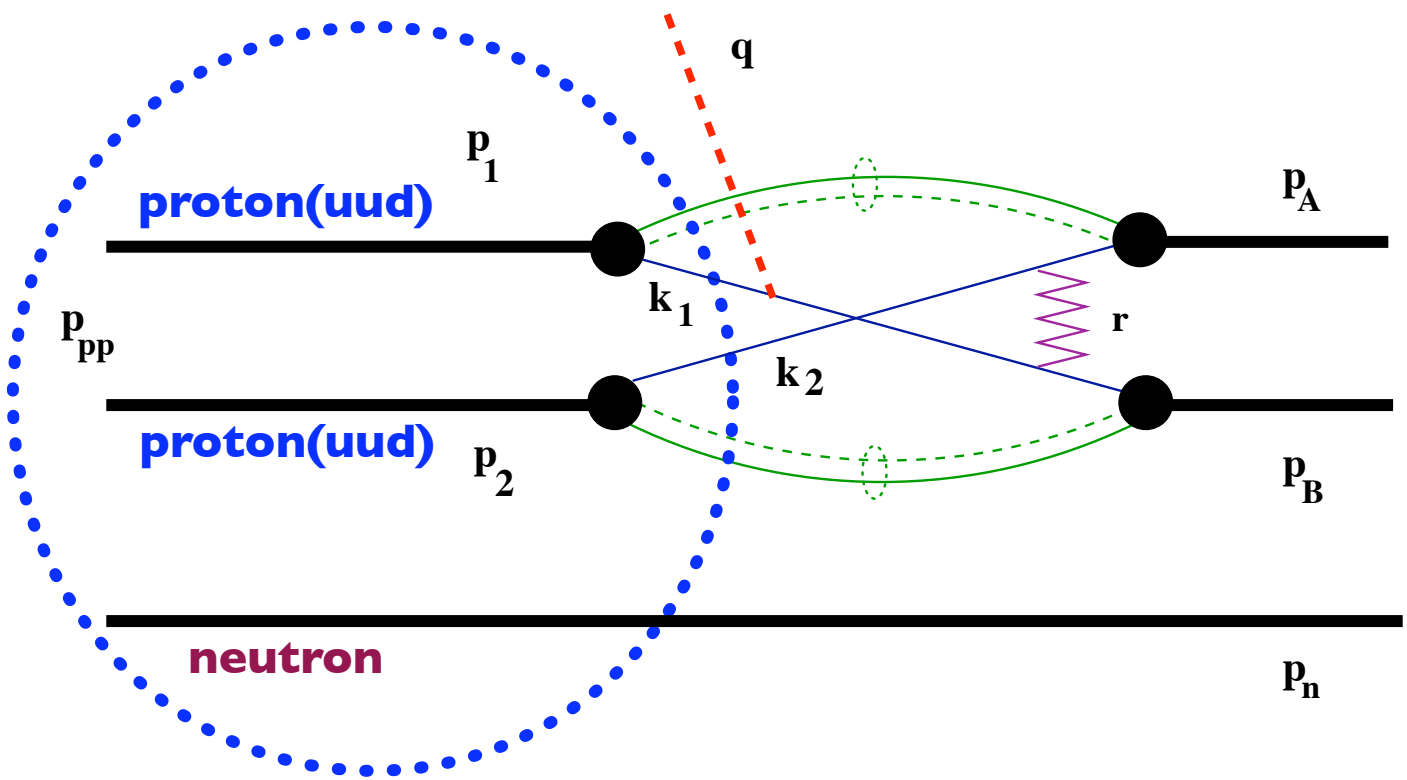
He3



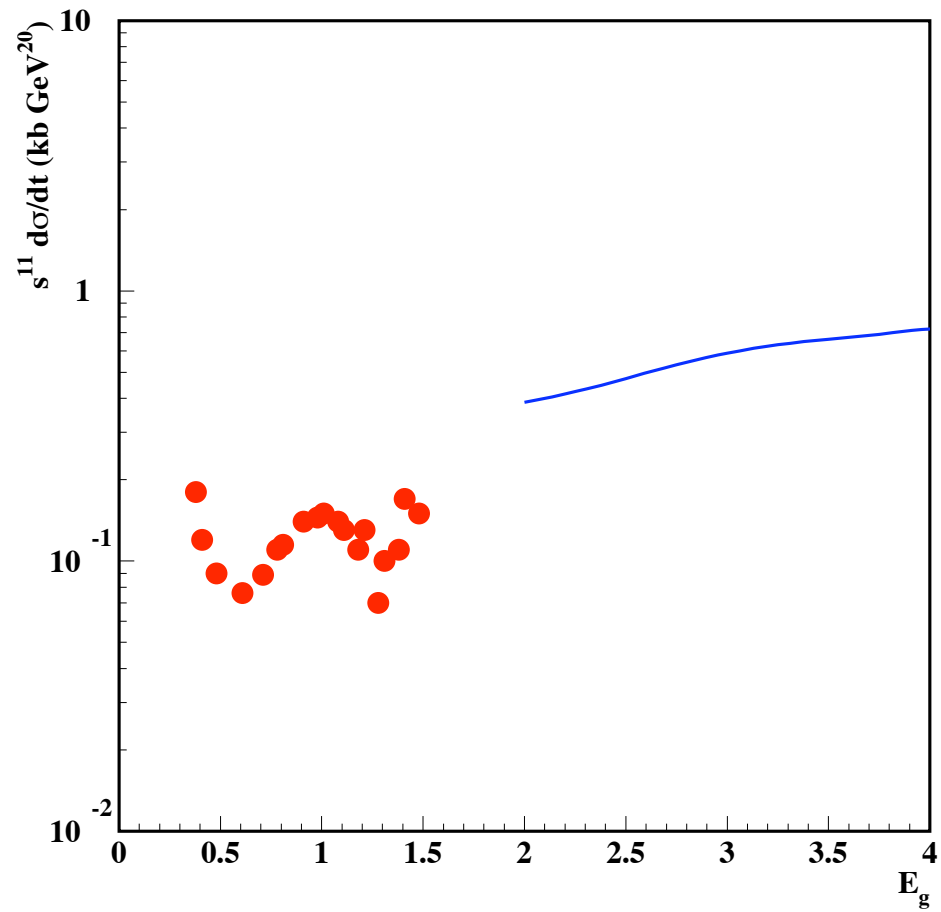
$$|\bar{A}|^2 = const \cdot \frac{1}{2}\left[\phi_1^2 S_1 + (\phi_3^2 + \phi_4) S_{34}\right]$$

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

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

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

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



Polarization Observables

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

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

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

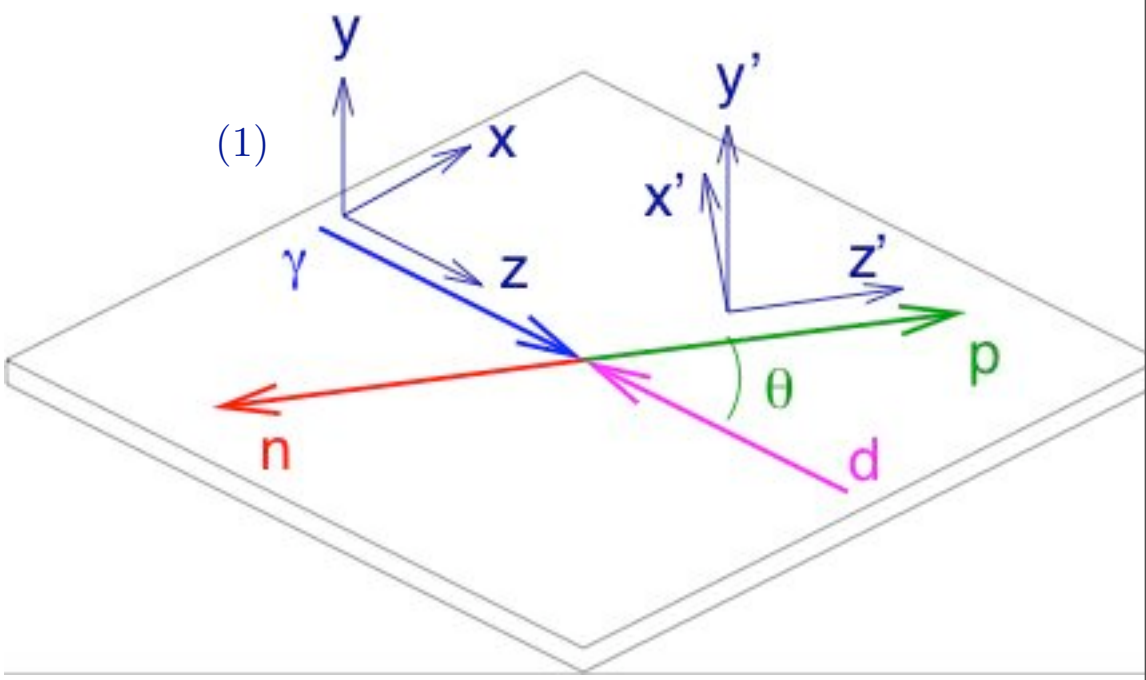
$$C_{z'} = \frac{2|\phi_1|^2-2|\phi_2|^2+|\phi_3|^2-|\phi_4|^2}{2|\phi_1|^2+2|\phi_2|^2+|\phi_3|^2+|\phi_4|^2+6|\phi_5|^2}$$

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

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

Helicity Selection Rule

(1)



Conclusion and Outlook

- High Energy Photodisintegration of Few Nucleon System may eventually provide a framework of probing the QCD structure of NN force

- Hard Rescattering Mechanism represents one such example

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

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