Comments on pion-induced hard exclusive processes at J-PARC

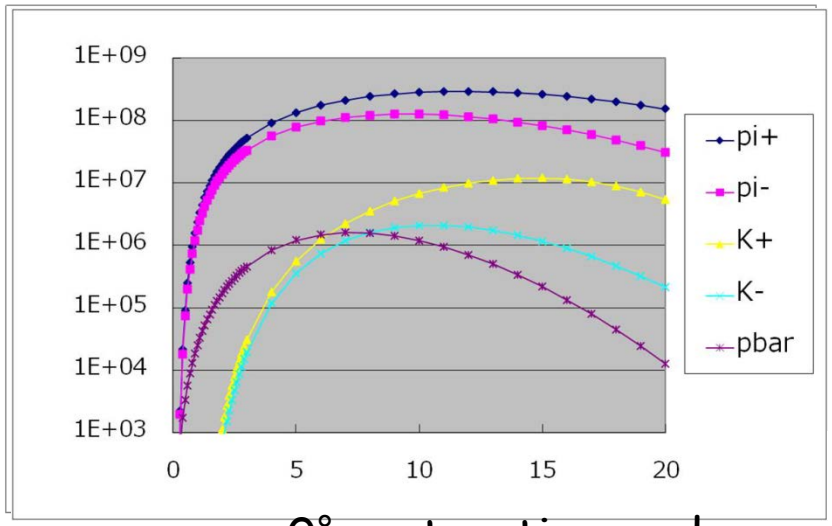
Kazuhiro Tanaka (Juntendo U/KEK)

High-momentum beamline

- 30 GeV proton
- ~15-20 GeV unseparated (mainly pions)

Unseparated Secondary Beam Intensity

beam loss limit @ SM1:15kW
(limited by the thickness of the tunnel wall)



0° extraction angle

high intensity

not too high energy $d\sigma \sim 1/s^a$

best suited to study meson-induced hard exclusive processes

1. exclusive DY $\pi^- p \to \gamma^* n \to \mu^+ \mu^- n$

2. exclusive 2→2 $\pi^{\pm} p \to p \pi^{\pm}$, etc

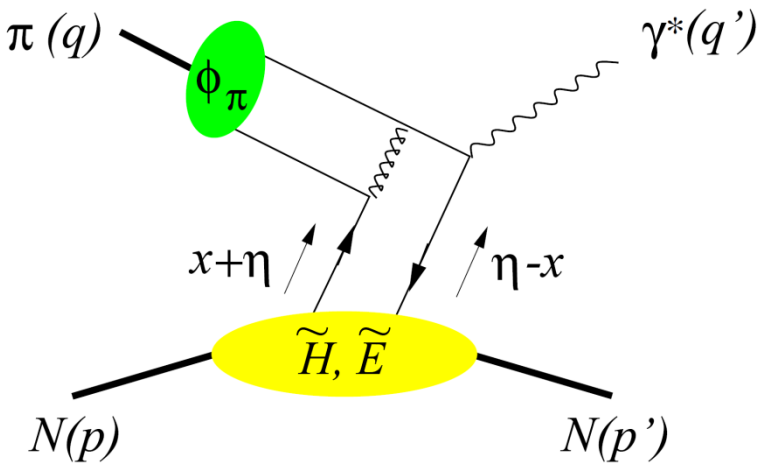
Exclusive lepton pair production in πN scattering

$$\pi^- p \to \gamma^* n \to \mu^+ \mu^- n$$

Berger, Diehl, Pire, PLB523(2001)265

"exclusive limit of DY"

small $t = (q - q')^2$



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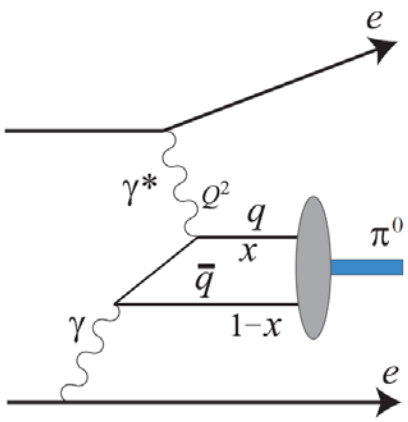

@Belle, Babar

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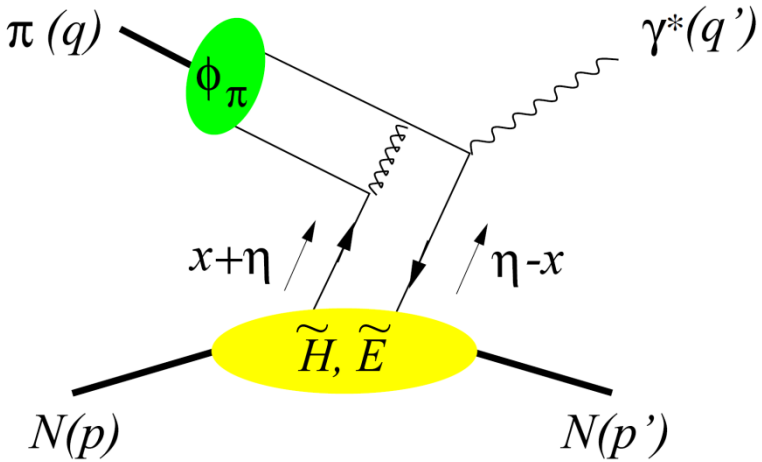

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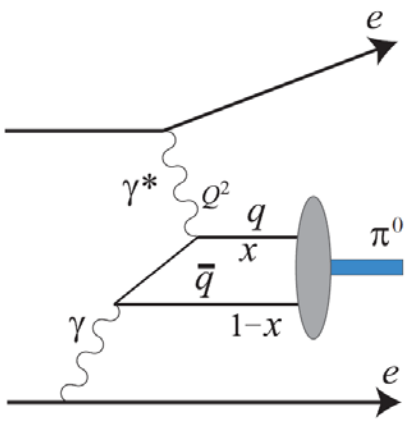

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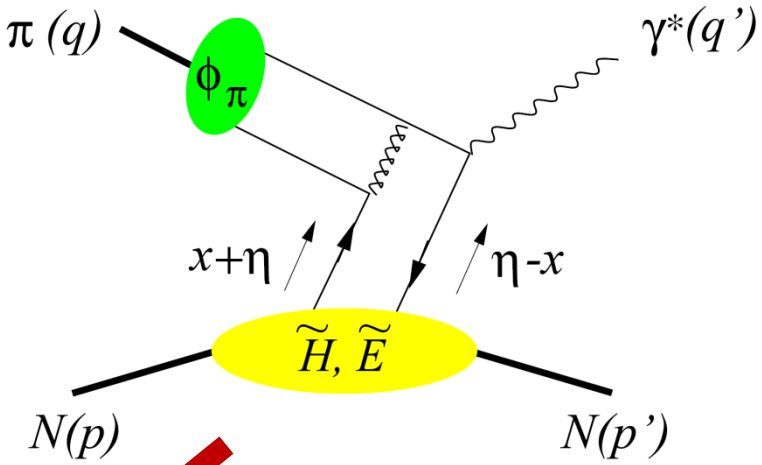

$t \to 0$

$\Delta q_f(x)$

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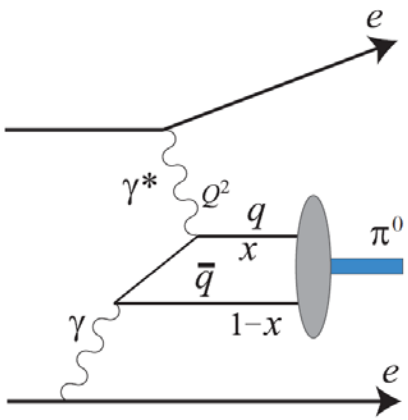
Berger, Diehl, Pire, PLB523(2001)265



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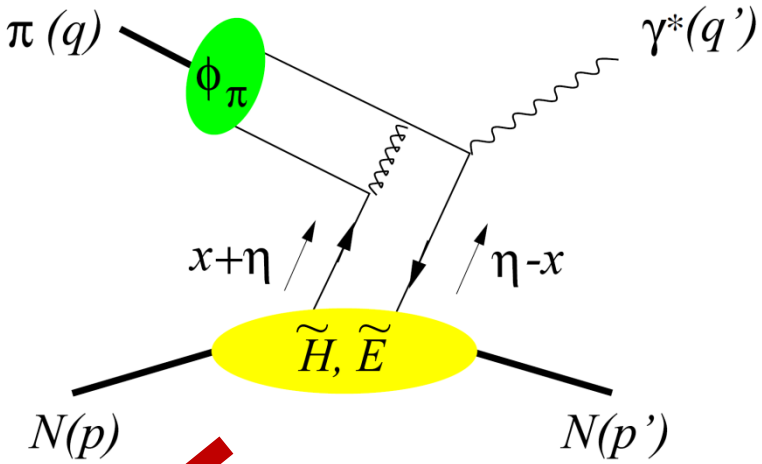

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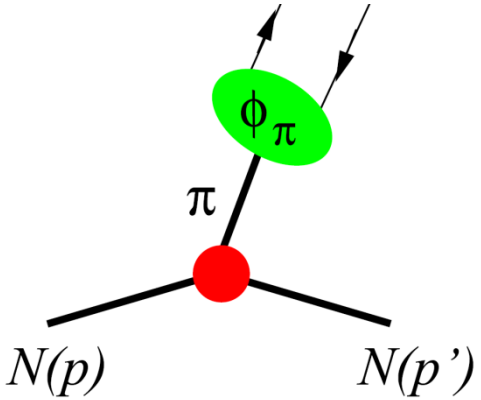
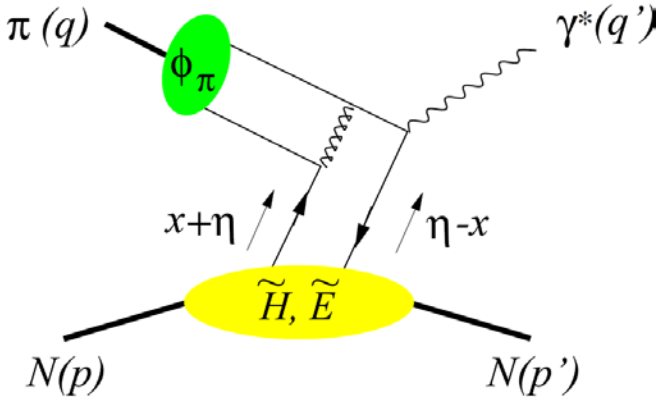


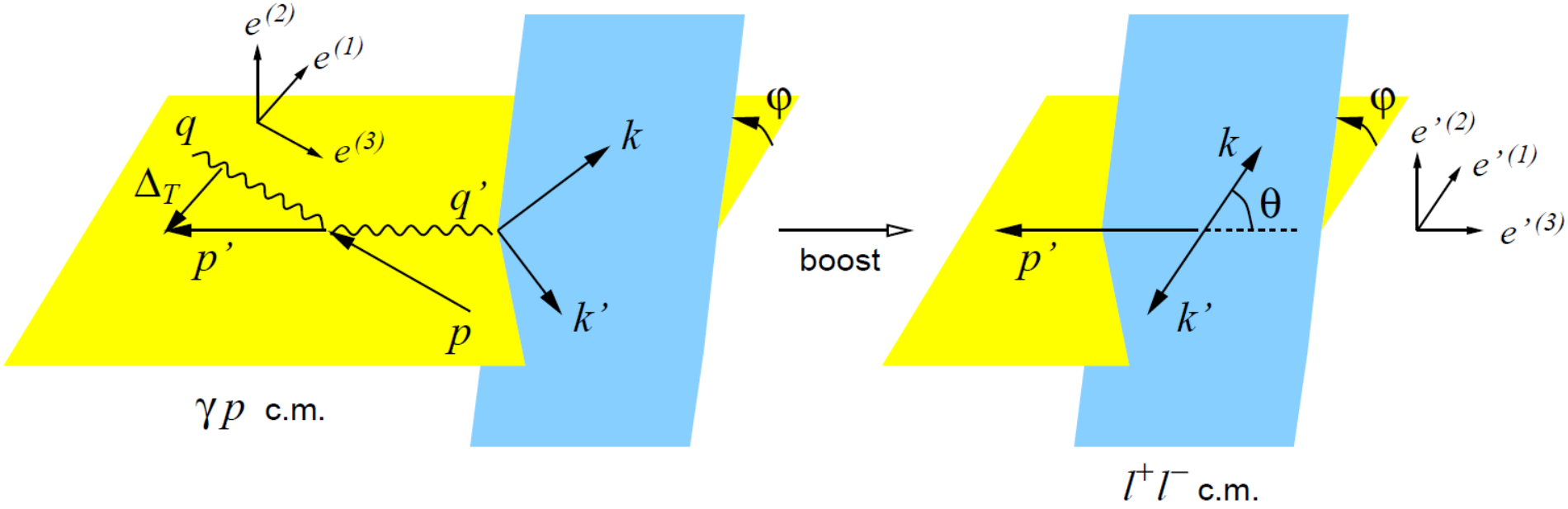


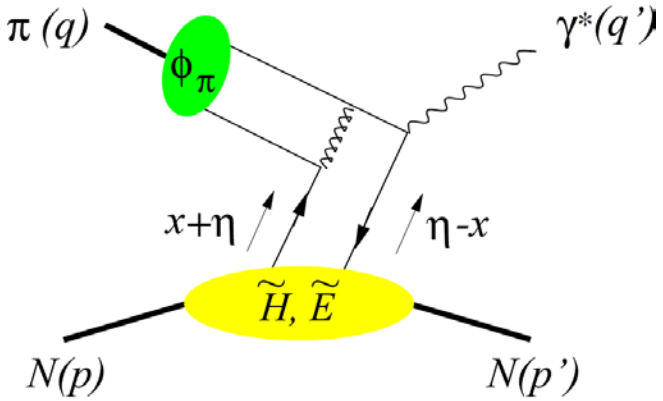
Bjorken variable: $\tau = \dfrac{Q'^2}{2\,p\cdot q}$

Skewness: $\eta = \dfrac{p^+ - p'^+}{p^+ + p'^+}$

long. photon

$$\frac{d\sigma}{dQ'^2\,dt\,d(\cos\theta)\,d\varphi} = \frac{\alpha_{em}}{256\,\pi^3}\,\frac{\tau^2}{Q'^6}\,\sum_{\lambda',\lambda}|M^{0\lambda',\lambda}|^2\sin^2\theta$$





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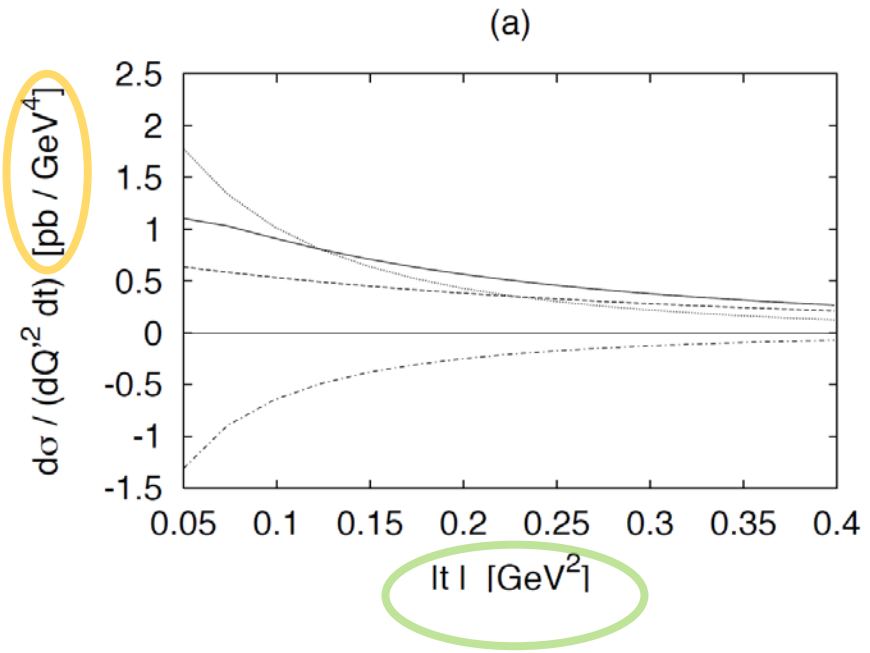
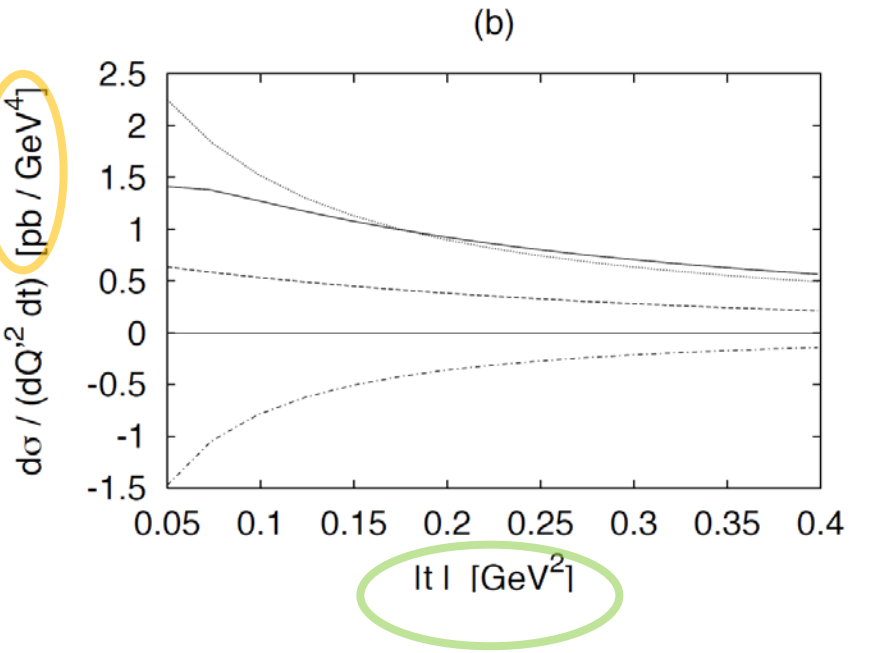
LO Estimates

Bjorken variable $\tau = \frac{Q'^2}{s-M^2}$

Berger, Diehl, Pire, PLB523(2001)265

$$Q'^2 = 5GeV^2 \qquad \tau = 0.2$$





(dashed) $= |\tilde{\mathcal{H}}|^2$; **(dash-dotted)** $= \mathrm{Re}(\tilde{\mathcal{H}}^* \tilde{\mathcal{E}})$; **(dotted)** $= |\tilde{\mathcal{E}}|^2$

$$\frac{d\sigma}{dQ'^2\,dt}(\pi^- p \to \gamma^* n) = \frac{4\pi\alpha_{\mathrm{em}}^2}{27}\frac{\tau^2}{Q'^8} f_\pi^2 \left[(1-\eta^2)\,|\,\widetilde{H}^{du}\,|^2 - 2\eta^2\,\mathrm{Re}\left(\widetilde{H}^{du*}\,\widetilde{E}^{du}\right) - \eta^2 \frac{t}{4M^2}|\,\widetilde{E}^{du}\,|^2 \right]$$

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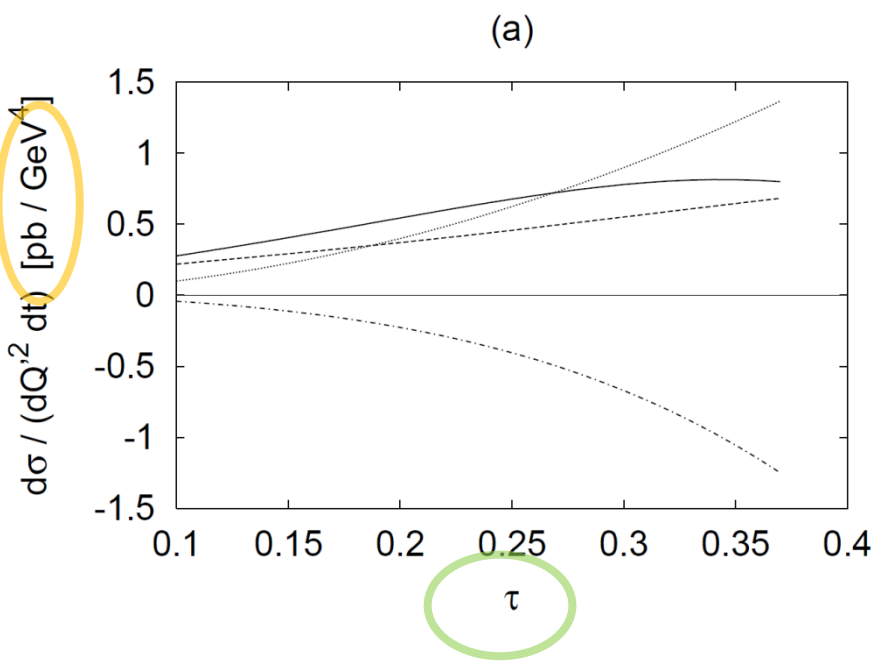

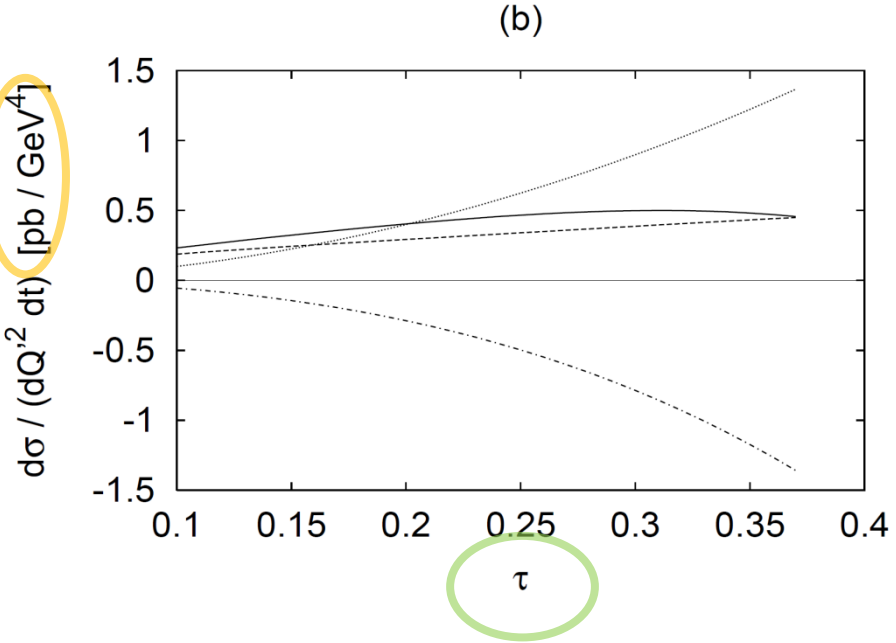

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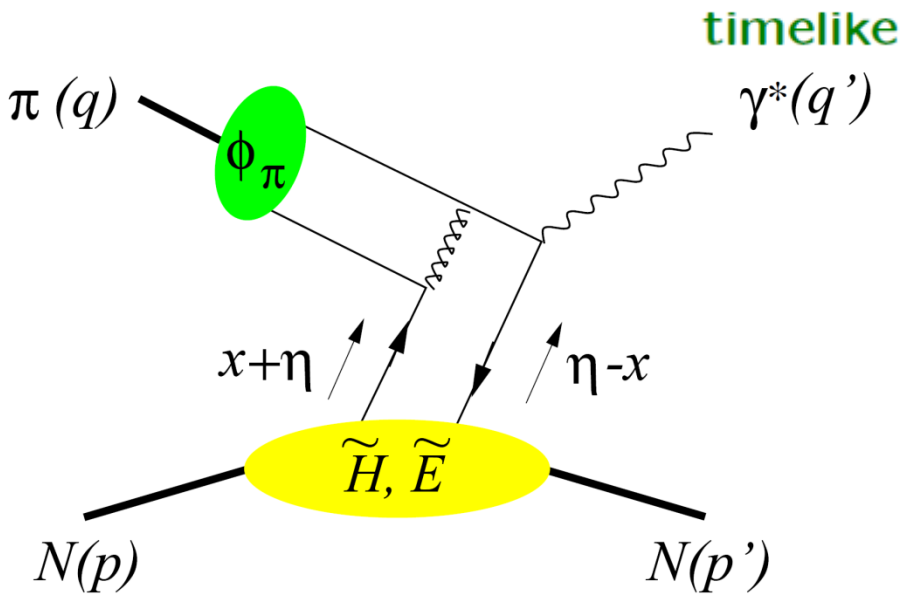
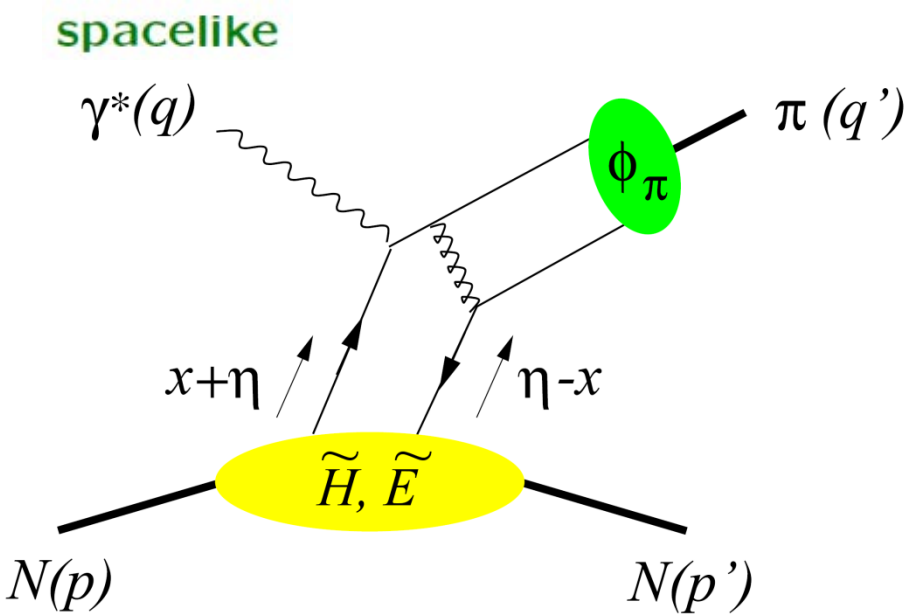
Pion beams reveal $\tilde{H}, \tilde{E}$ Generalized Parton distributions



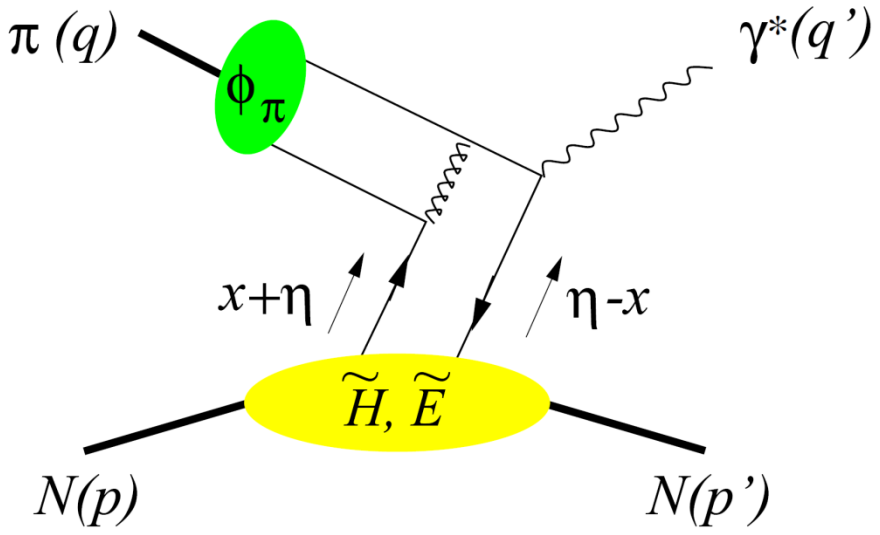


exDY@J-PARC

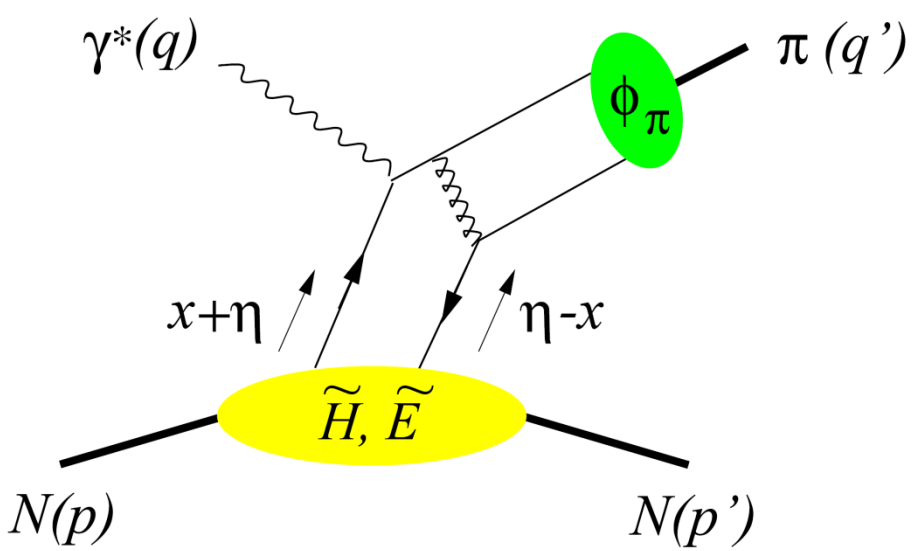
DVMP@JLab

Pion beams reveal $\tilde{H}, \tilde{E}$ Generalized Parton distributions

timelike



spacelike



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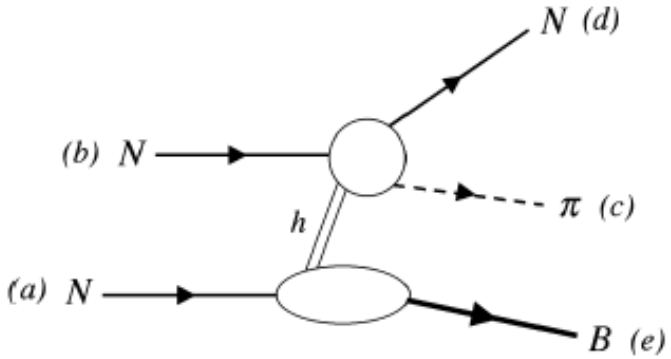
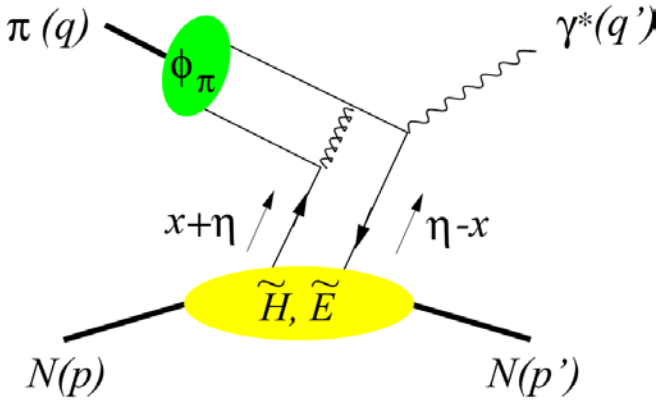


Kumano,Sudoh,Strikman, PRD80(2000)074003.



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Polarized target:

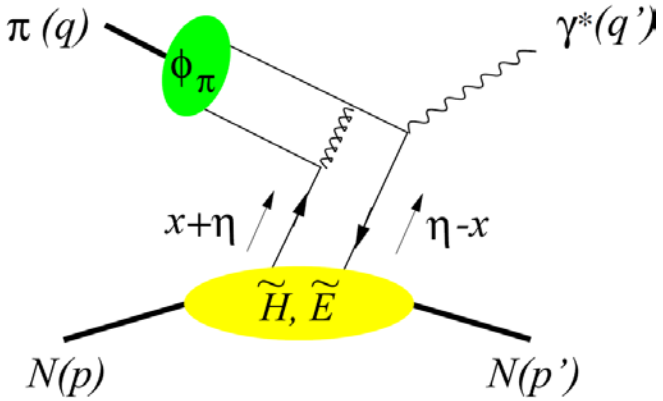
Target Transverse Spin asymmetry

At the twist 2 level : $\dfrac{d^{\uparrow}\sigma - d^{\downarrow}\sigma}{d^{\uparrow}\sigma + d^{\downarrow}\sigma} = A_{\rm UT}^{\sin(\phi-\phi_S)} \sin(\phi-\phi_S) + \text{other harmonics}$

$$A_{UT} = \frac{-2\sqrt{\frac{t-t_{min}}{t_{min}}}\,\eta^2\,\mathcal{I}m\,(\,\tilde{\mathcal{H}}\,\tilde{\mathcal{E}}^*\,)}{(1-\eta^2)|\tilde{\mathcal{H}}|^2-\frac{t}{4M^2}|\eta\tilde{\mathcal{E}}|^2-2\eta^2\mathcal{R}e(\tilde{\mathcal{H}}\tilde{\mathcal{E}}^*)}$$

➪ New information on GPDs.

e.g. if $\tilde{E}$ is well modelized by pion pole, $\tilde{\mathcal{E}}$ is real $\rightarrow A_{UT} \sim \tilde{H}(x, \xi = x, t)$



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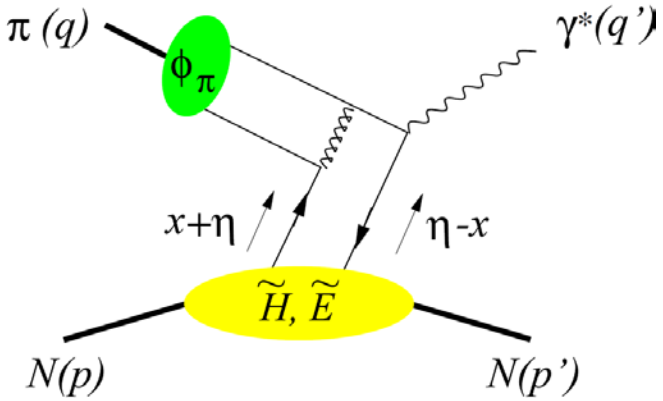

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$$M^{\perp,\lambda;\lambda'}(\pi^- p\to\gamma^* n)\sim\frac{1}{Q'^2}$$

$\dfrac{1}{Q'}$ **correction to** $\dfrac{d\sigma}{dQ'^2\,dt\,d(\cos\theta)\,d\varphi}$

different angular distribution

need estimate!

Exclusive processes at J-PARC

- **Physics proposal by Wen-Chen et al.**

Physics to be investigated in the high momentum beam line of hadron hall at J-PARC

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Hiroyuki Kawamura and Shunzo Kumano

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Jen-Chieh Peng

Department of Physics, University of Illinois at Urbana-Champaign, Urbana, Illinois 61801, USA

Shin'ya Sawada

Institute of Particle and Nuclear Studies, High Energy Accelerator Research Organization (KEK)

(Dated: January 2, 2013)

Abstract

In this report we summarize the important subjects of hadron physics possibly to be explored in the high-momentum beam line of hadron hall at J-PARC in the near future

$$\pi^- + p \to l^+ l^- (q') + n$$

$$q'^2 \gg Q^2_{had}$$

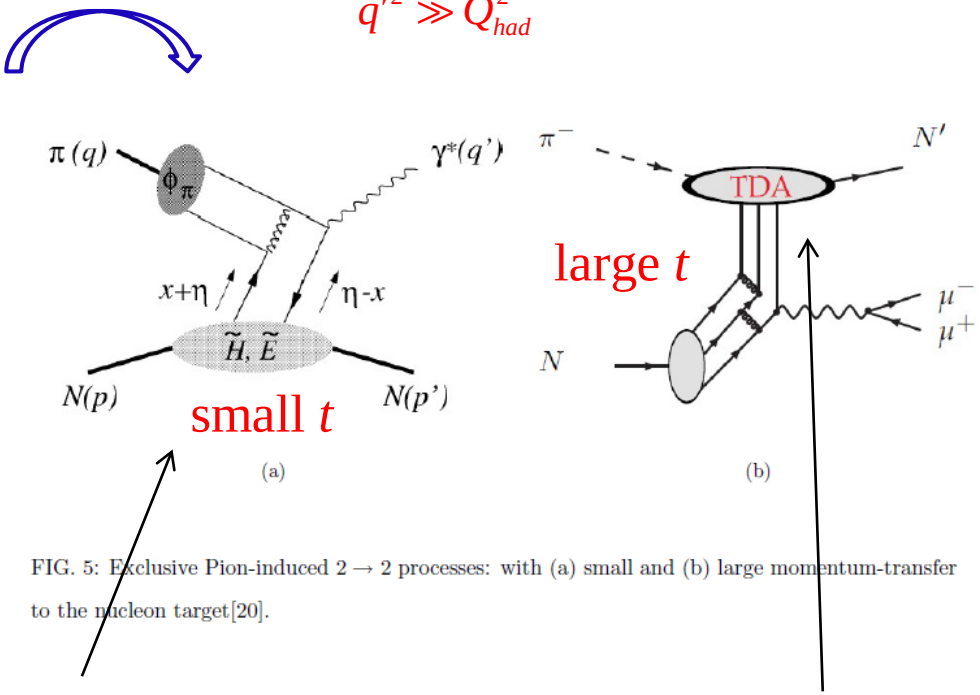


FIG. 5: Exclusive Pion-induced $2 \to 2$ processes: with (a) small and (b) large momentum-transfer to the nucleon target[20].

GPDs $\tilde{H}^{ud}(x,\eta,t),\ \tilde{E}^{ud}(x,\eta,t)$

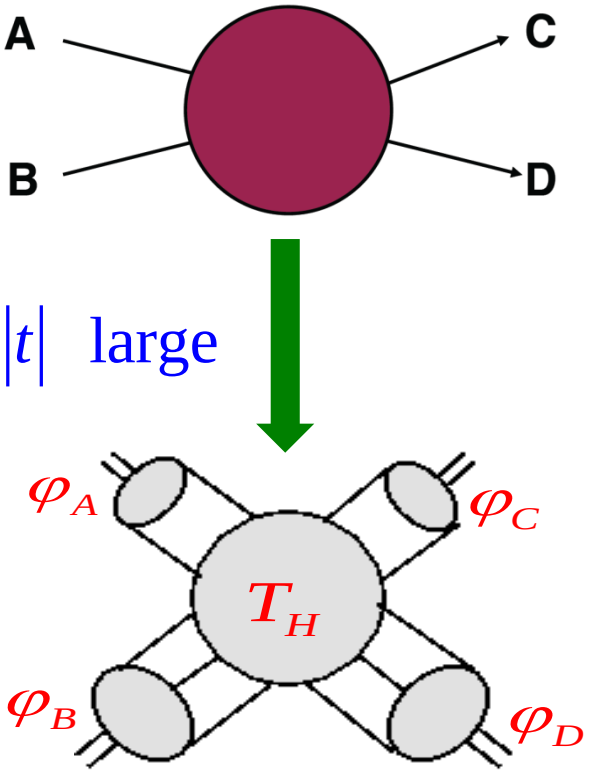
"Transition distribution amplitude"

1. exclusive DY $\pi^- p \to \gamma^* n \to \mu^+ \mu^- n$

2. exclusive 2→2 $\pi^{\pm} p \to p \pi^{\pm}$, etc

Systematic study of hard exclusive meson-nucleon reactions

$$\pi^{\pm} p \to p\pi^{\pm},$$
$$K^{\pm} p \to pK^{\pm},$$
$$\pi^{\pm} p \to p\rho^{\pm},$$
$$\pi^{\pm} p \to \pi^{+}\Delta^{\pm},$$
$$\pi^{\pm} p \to K^{+}\Sigma^{\pm},$$
$$\pi^{-} p \to \Lambda^{0}K^{0}, \Sigma^{0}K^{0},$$
$$p^{\pm} p \to pp^{\pm}.$$

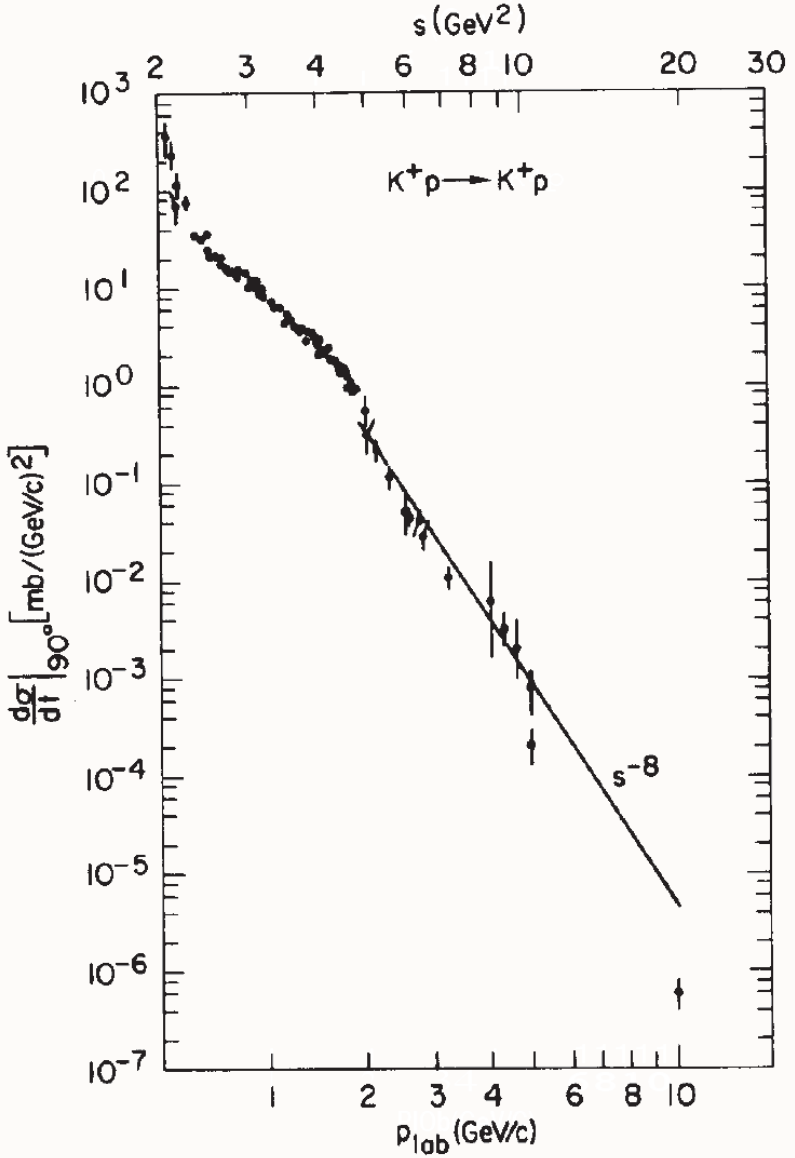


$$= \int dx_a dx_b dx_c dx_d$$
$$\times \varphi_D^*(x_d)\varphi_C^*(x_c)T_H(x_i, s, \theta_{\mathrm{CM}})\varphi_B(x_b)\varphi_A(x_a)$$

$$\frac{d\sigma}{dt} \sim \frac{1}{s^{n-2}}$$

$$n = n_A + n_B + n_C + n_D$$

Quark-Counting



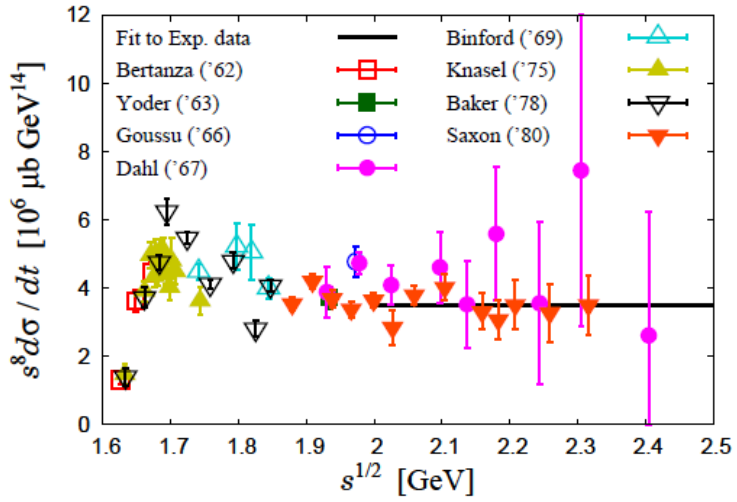
$$\frac{d\sigma}{dt}(K^+p \to K^+p) = \frac{F(\theta_{CM})}{s^8}$$

$$n-2 = 2\times 3 + 2\times 2 - 2 = 8$$

Lambda & Lambda(1405)

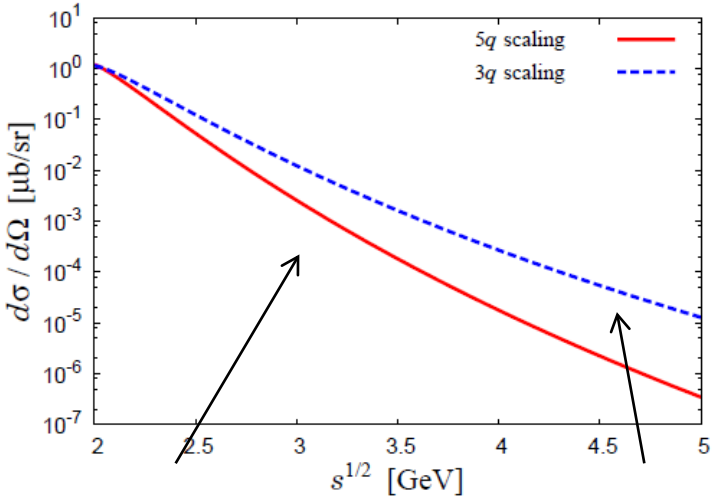
Kumano, Sekihara, Kawamura (2013)

$\pi^- + p \to K + \Lambda$



$n = 10$

$\pi^- + p \to K + \Lambda,\ K + \Lambda(1405)$



5-quark **3-quark**

$n = 10$ or 12?

Systematic study of hard exclusive meson-nucleon reactions

$$\pi^{\pm} p \to p\pi^{\pm},$$
$$K^{\pm} p \to pK^{\pm},$$
$$\pi^{\pm} p \to p\rho^{\pm},$$
$$\pi^{\pm} p \to \pi^{+}\Delta^{\pm},$$
$$\pi^{\pm} p \to K^{+}\Sigma^{\pm},$$
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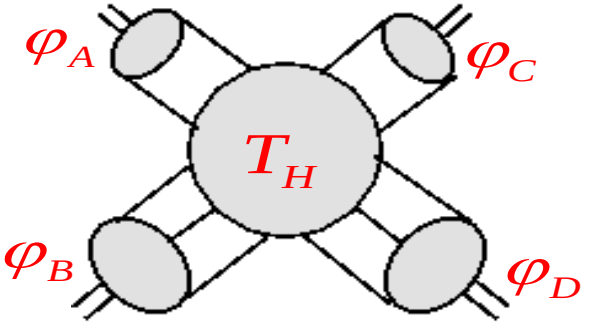

$$= \int dx_a dx_b dx_c dx_d$$
$$\times \varphi_D^*(x_d)\varphi_C^*(x_c)T_H(x_i, s, \theta_{\mathrm{CM}})\varphi_B(x_b)\varphi_A(x_a)$$

$$\frac{d\sigma}{dt} \sim \frac{1}{s^{n-2}}$$

$$n = n_A + n_B + n_C + n_D$$

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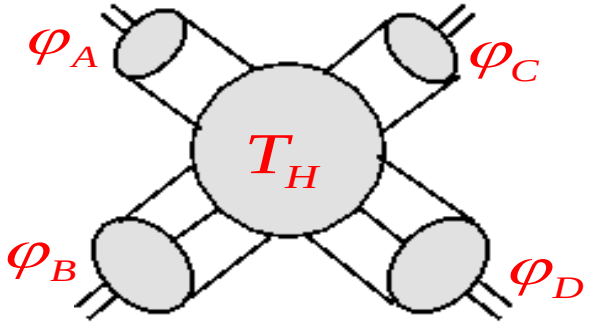
E838('94) 5.9 GeV



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$\pi^{\pm} p \to$

$\pi^{\pm} p \to$

$\pi^{-} p \to$

$p^{\pm} p \to$

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E838('94) 5.9 GeV

TABLE V. The scaling between E755 and E838 has been measured for eight meson-baryon and 2 baryon-baryon interactions at $\theta_{\text{c.m.}} = 90°$. The nominal beam momentum was 5.9 GeV/c and 9.9 GeV/c for E838 and E755, respectively. There is also an overall systematic error of $\Delta n_{\text{syst}} = \pm 0.3$ from systematic errors of $\pm 13\%$ for E838 and $\pm 9\%$ for E755.

		Cross section		n-2
No.	Interaction	E838	E755	$(\frac{d\sigma}{dt} \sim 1/s^{n-2})$
1	$\pi^+ p \to p\pi^+$	132 ± 10	4.6 ± 0.3	6.7 ± 0.2
2	$\pi^- p \to p\pi^-$	73 ± 5	1.7 ± 0.2	7.5 ± 0.3
3	$K^+ p \to pK^+$	219 ± 30	3.4 ± 1.4	$8.3^{+0.6}_{-1.0}$
4	$K^- p \to pK^-$	18 ± 6	0.9 ± 0.9	≥ 3.9
5	$\pi^+ p \to p\rho^+$	214 ± 30	3.4 ± 0.7	8.3 ± 0.5
6	$\pi^- p \to p\rho^-$	99 ± 13	1.3 ± 0.6	8.7 ± 1.0
13	$\pi^+ p \to \pi^+ \Delta^+$	45 ± 10	2.0 ± 0.6	6.2 ± 0.8
15	$\pi^- p \to \pi^+ \Delta^-$	24 ± 5	≤ 0.12	≥ 10.1
17	$pp \to pp$	3300 ± 40	48 ± 5	9.1 ± 0.2
18	$\bar{p}p \to p\bar{p}$	75 ± 8	≤ 2.1	≥ 7.5

$$\frac{d\sigma}{dt} \sim \frac{1}{s^{n-2}} \times \varphi_D^*(x_d)\varphi_C^*(x_c)T_H(x_i, s, \theta_{\text{CM}})\varphi_B(x_b)\varphi_A(x_a)$$

$$n = n_A + n_B + n_C + n_D$$

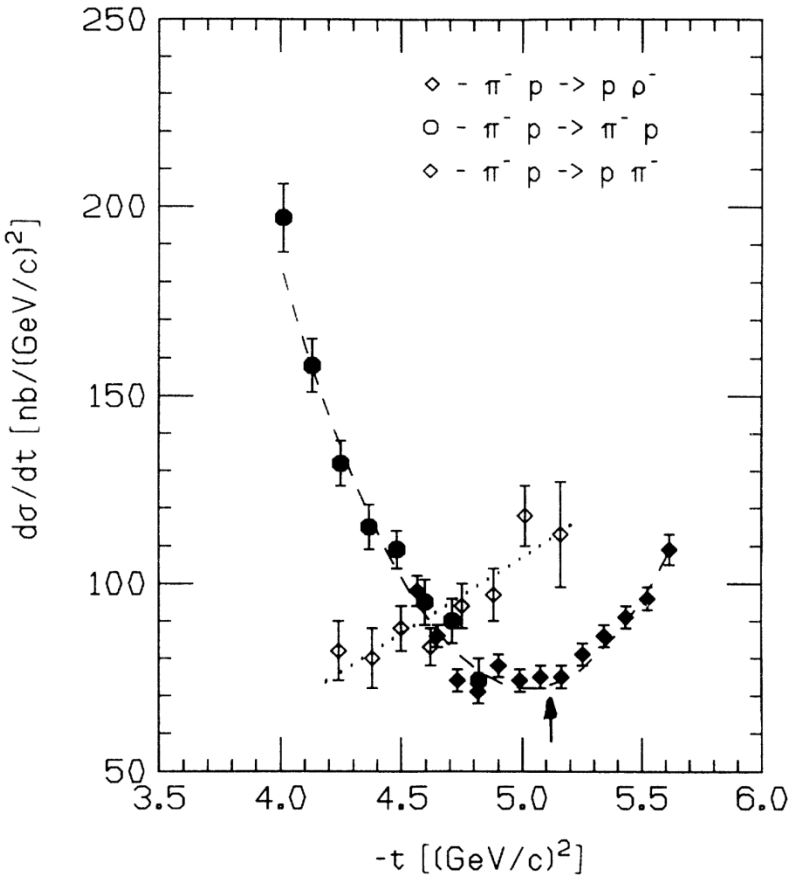

FIG. 23. The differential cross sections are plotted for the reactions $\pi^- p$ elastic and $\pi^- p \to p\rho^-$. The arrow shows the 90° point for $\pi^- p$ elastic scattering. The corresponding point for ρ production is 4.81 $(\mathrm{GeV}/c)^2$.

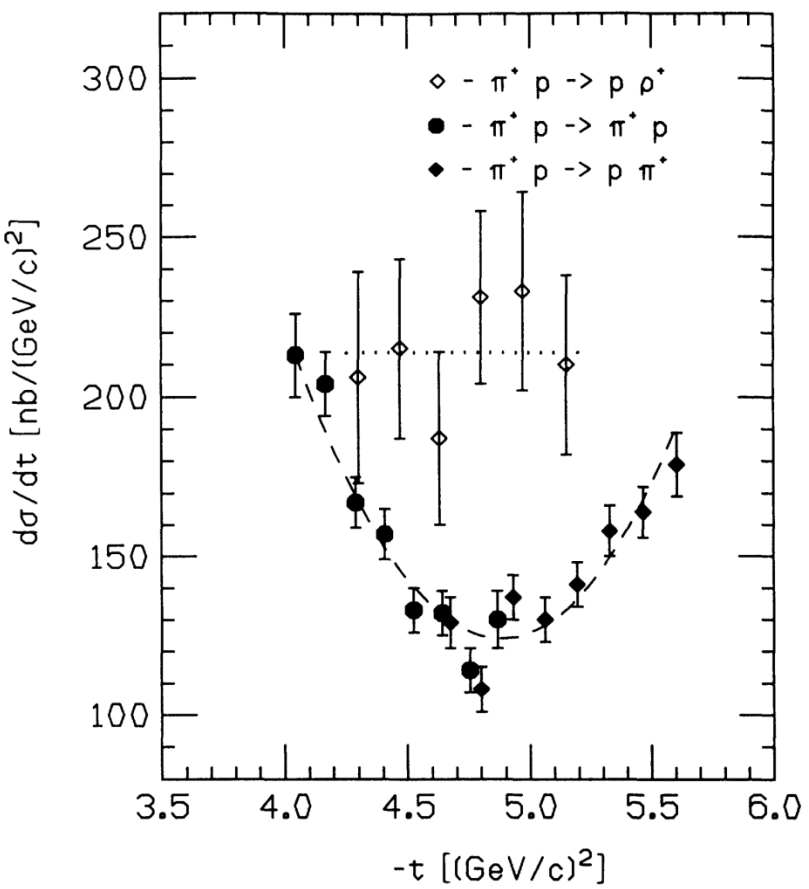

FIG. 25. The differential cross sections for $\pi^+ p$ elastic scattering and the reaction $\pi^+ p \to p\rho^+$ are plotted. The fitted curves are discussed in the text.

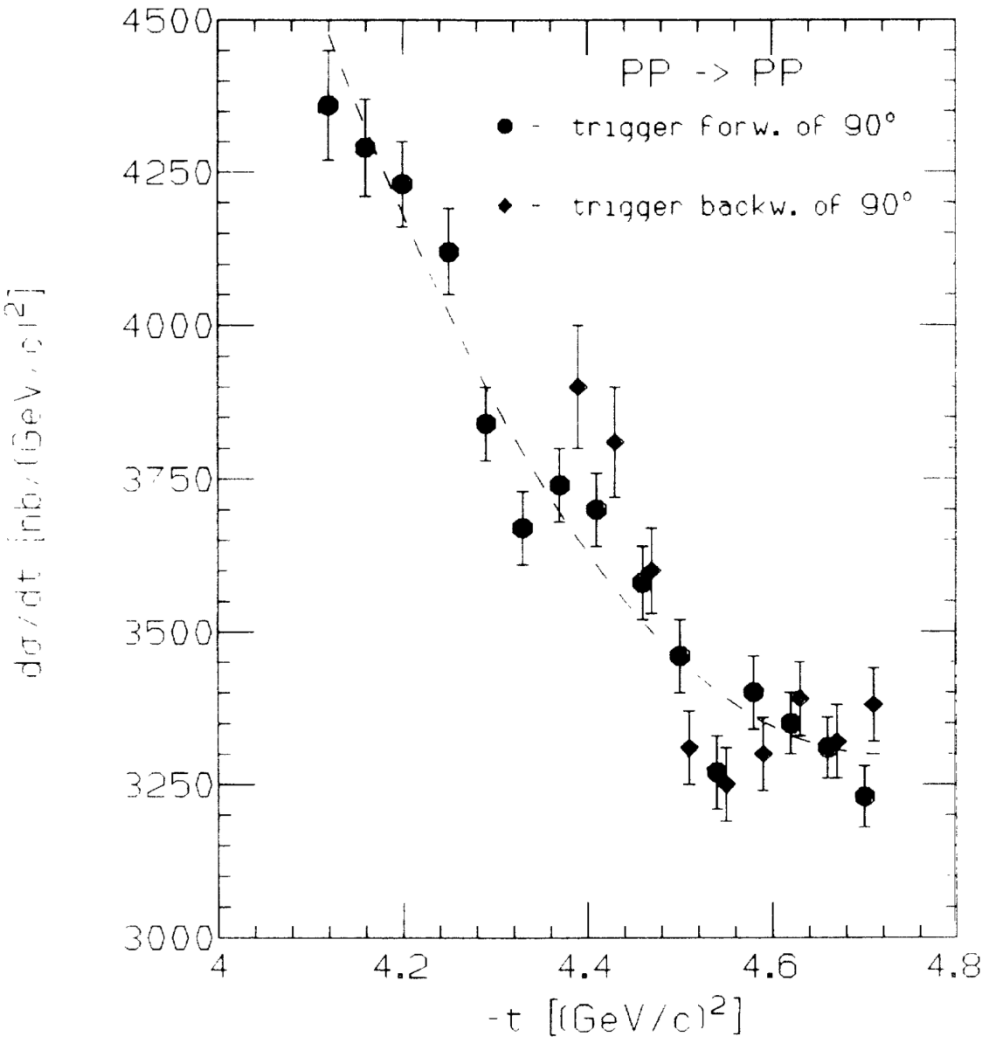

FIG. 21. The differential cross section for *pp* elastic scattering. Data points are included for events with the spectrometer particle forward or backward of the symmetric 90° point. The fitted curve is described in the text.

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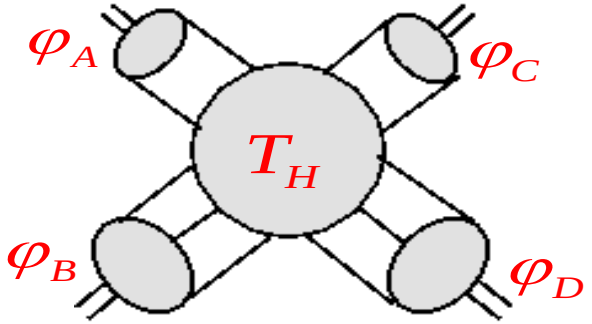

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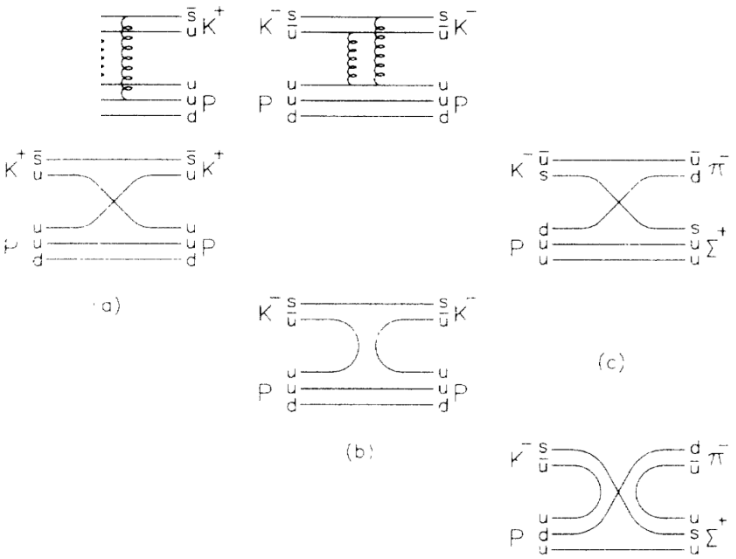

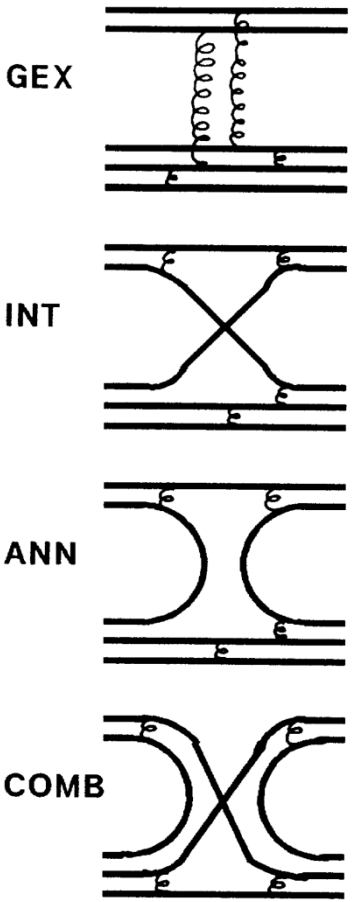

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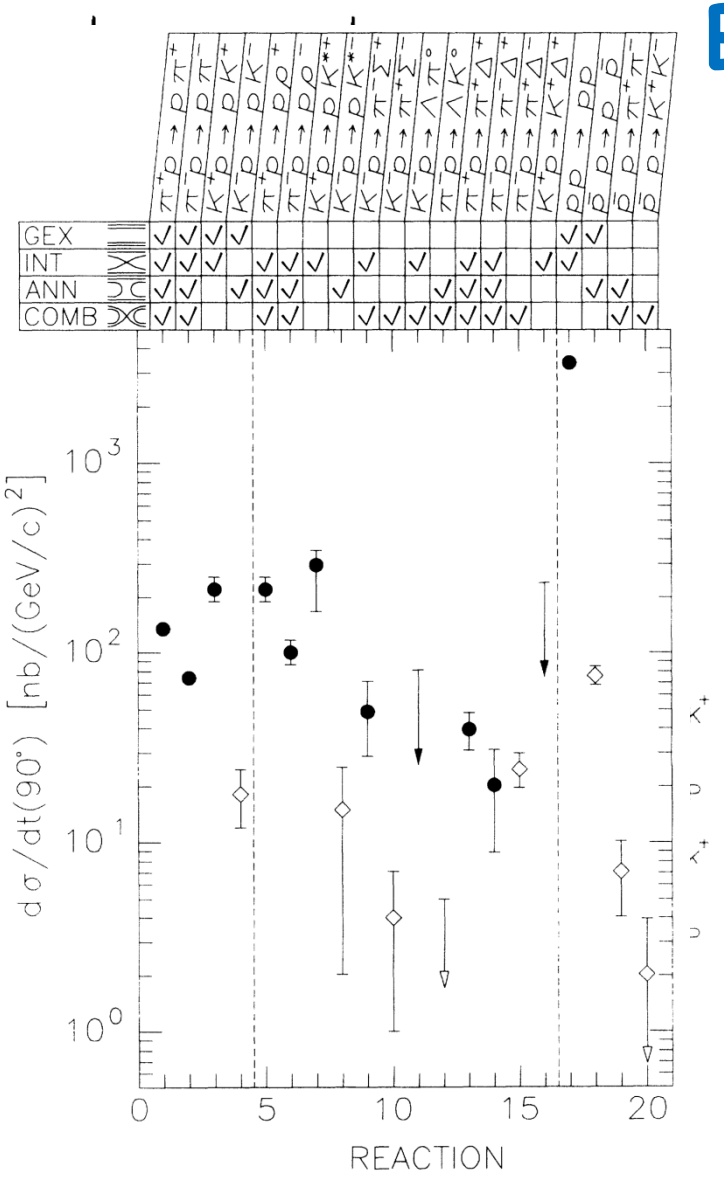

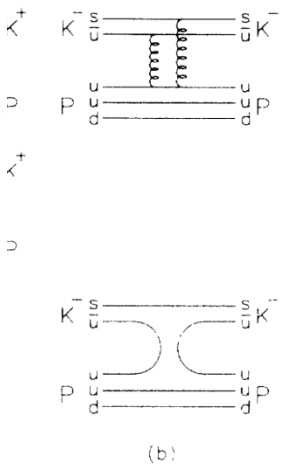

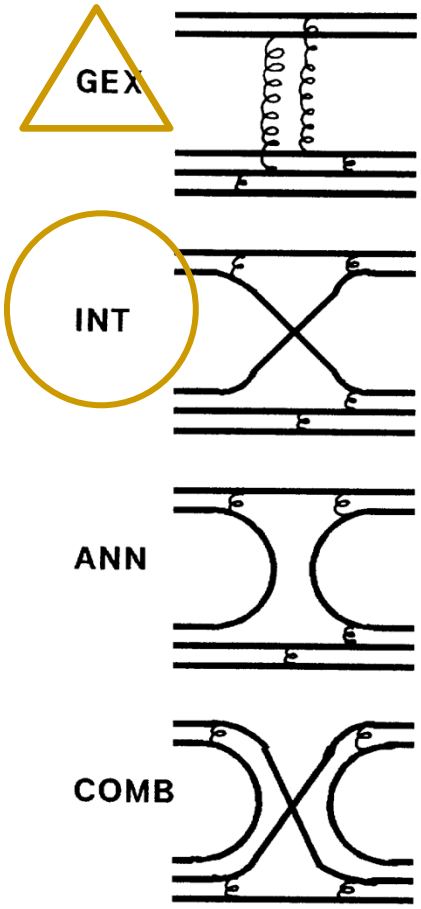

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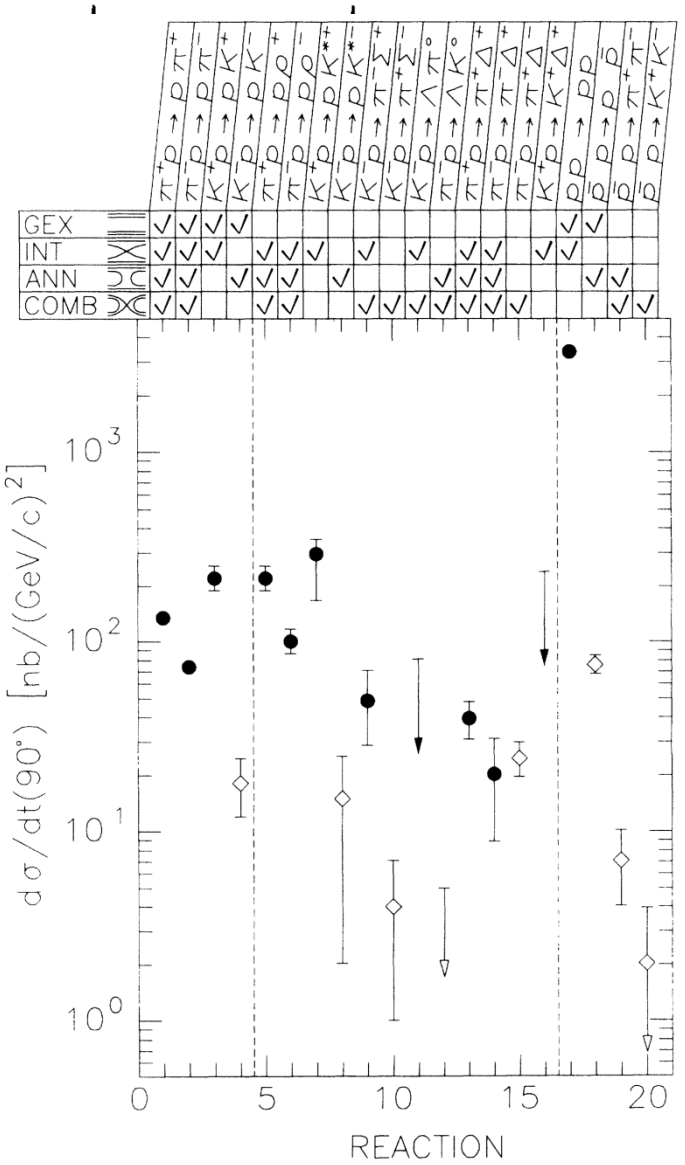
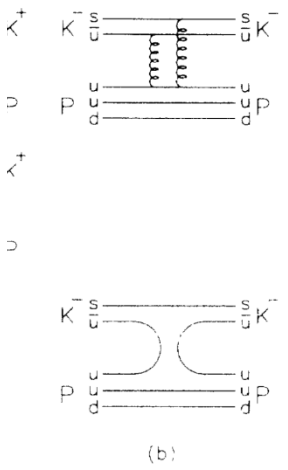
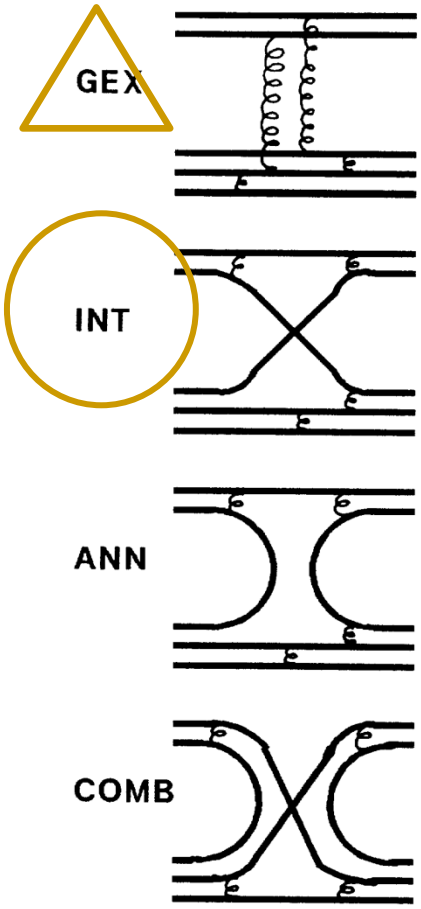
J-PARC 15-20 GeV







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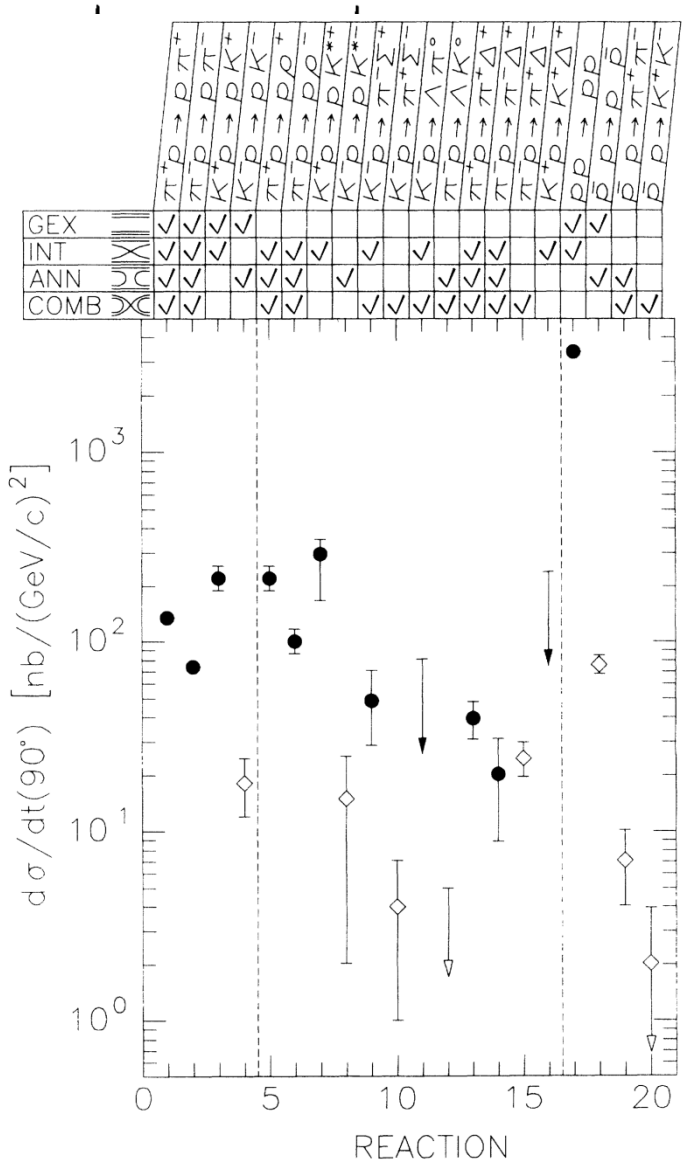

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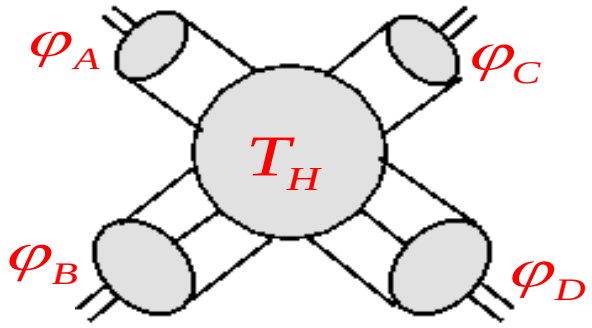

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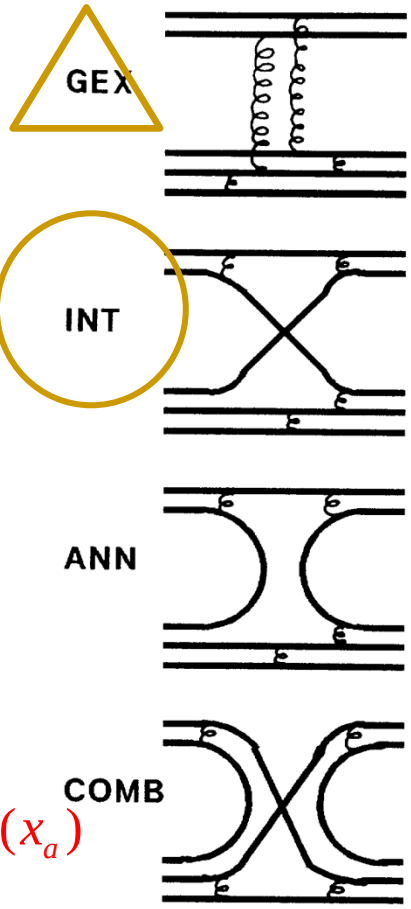

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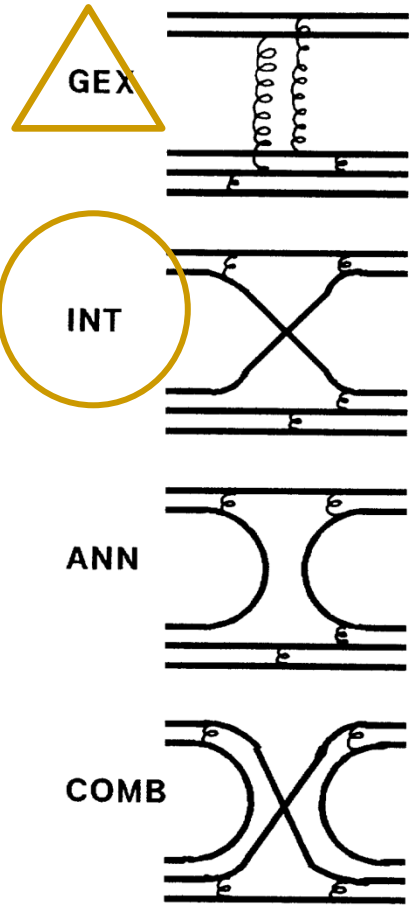
J-PARC 15-20 GeV

$$\frac{d\sigma}{dt} \sim \frac{1}{s^{8}}$$



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$$\frac{d\sigma}{dt} \sim \frac{1}{s^{a}} \quad (a < 8)$$

"Landshoff mechanism"

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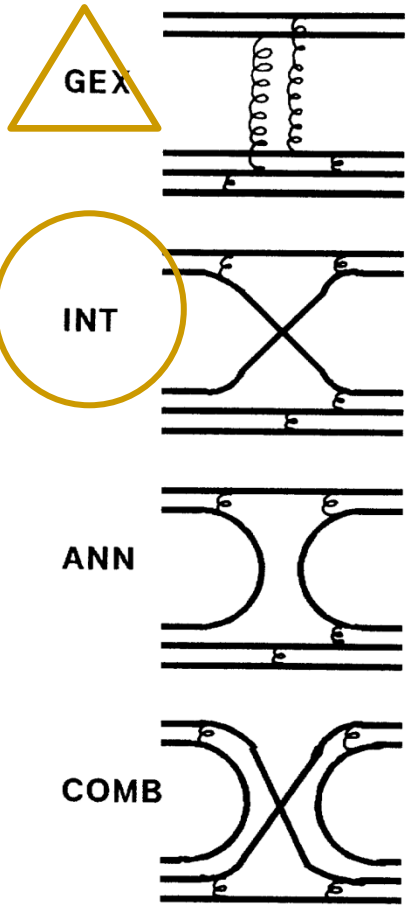


"Landshoff mechanism"

Landshoff (1974)

Donnachie, Landshoff (1979)

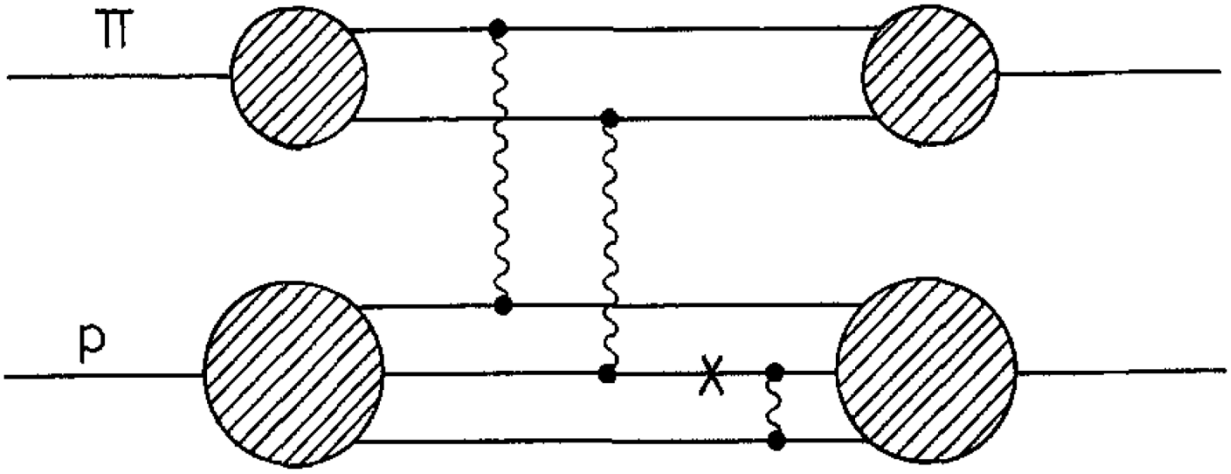
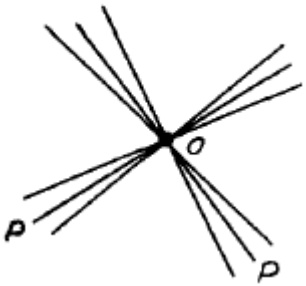
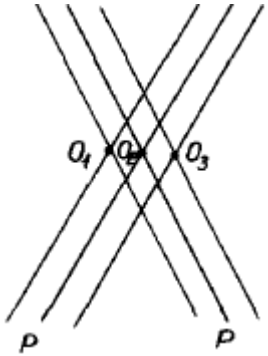


Fig. 4. Leading mechanism for πp elastic scattering. The quark marked with a cross is far off shell

$$\frac{d\sigma}{dt} \sim \frac{1}{t^7} \quad !?$$

$$s \gg -t \gg \Lambda^2_{\mathrm{QCD}}$$





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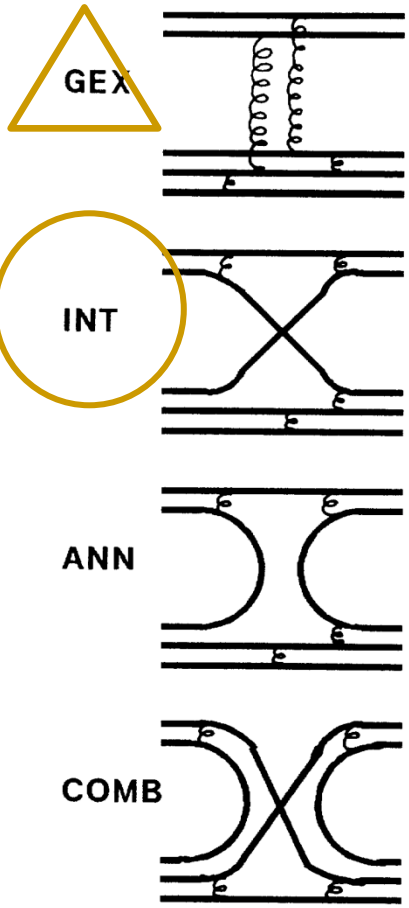

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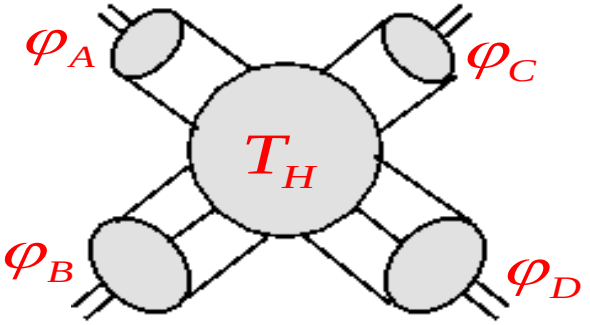

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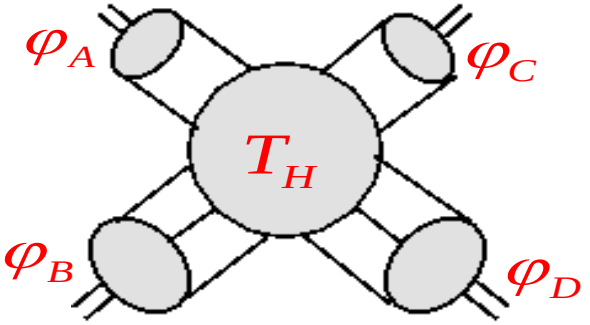

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$$(4\pi/3)\, W(\theta,\phi) = r_{0,0}\cos^2(\theta) + r_{1,1}\sin^2(\theta) - r_{1,-1}\sin^2(\theta)\cos(2\phi) - \sqrt{2}\,\mathrm{Re}(r_{1,0})\sin(2\theta)\cos(\phi),$$

$$r_{i,i'} = \sum_{m,n} A^{i}_{m,n} A^{i'*}_{m,n}.$$

$$m = i + n = i' + n$$

$$r_{0,0} = 0.12 \pm 0.30, \quad r_{1,1} = 0.44 \pm 0.15,$$

$$r_{1,-1} = 0.32 \pm 0.10, \quad \mathrm{Re}(r_{1,0}) = -0.01 \pm 0.05.$$

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Polarization Effects in Exclusive Hadron Scattering

Glennys R. Farrar

Department of Physics, Rutgers University, Piscataway, New Jersey 08854

(Received 5 March 1986)

Measured helicity nonconservation in $\pi^- p \to \rho^- p$ and in pp elastic scattering indicates that higher-twist contributions are $\frac{1}{10}$–$\frac{1}{3}$ the size of the leading-twist amplitudes, and that the relative phase between certain pp amplitudes is at least 16°. The reported levels of helicity nonconservation are therefore consistent with leading-twist perturbative QCD.

PACS numbers: 13.85.Dz, 13.38.Be, 13.38.Qk, 13.85.Fb

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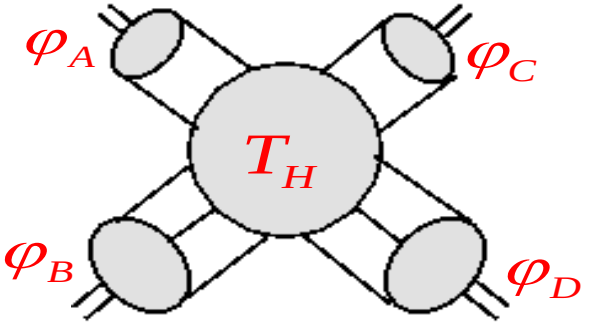

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violated!

Higher twist effect?

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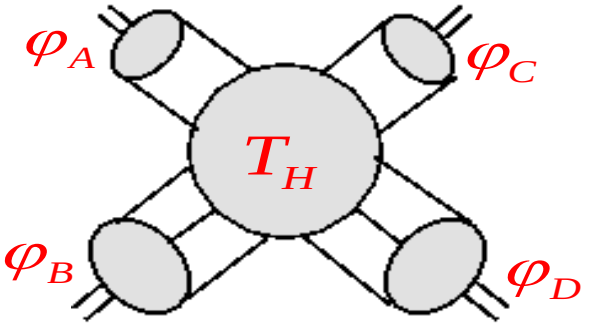

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violated!

Higher twist effect?

persist at J-PARC?

Summary

unpol. beam $\pi^{\pm}, K^{\pm}, \cdots$

exclusive DY GPDs

need to estimate 1/Q' power correction

exclusive 2→2 $\left(\pi^{\pm} p \to p\pi^{\pm},\ \pi^{-} p \to \rho^{-} p, \text{etc}\right)$

interplay of soft/hard QCD mechanism from pQCD side

~~counting rule~~ Landshoff mechanism

~~helicity conserv.~~ higher twist effect