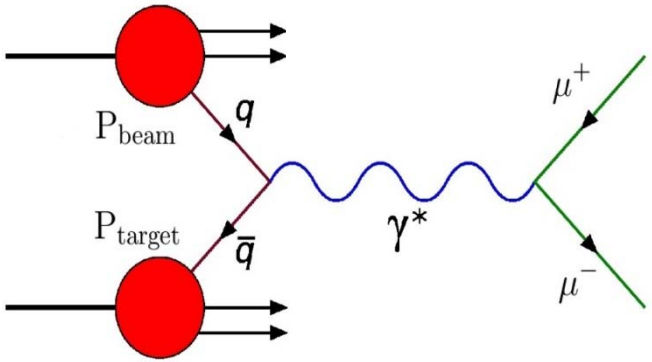
Exclusive pion-induced Drell-Yan process at J-PARC for accessing the nucleon GPDs and soft nonfactorizable mechanism

Kazuhiro Tanaka (Juntendo U/KEK)

Pion-induced Drell-Yan process

$\pi N \to \mu^+ \mu^- X$



inclusive

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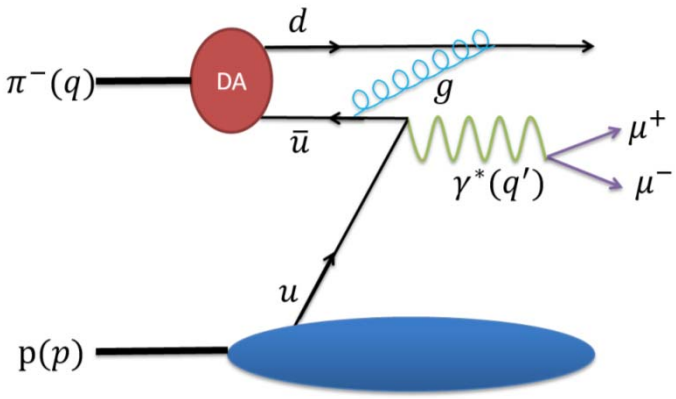

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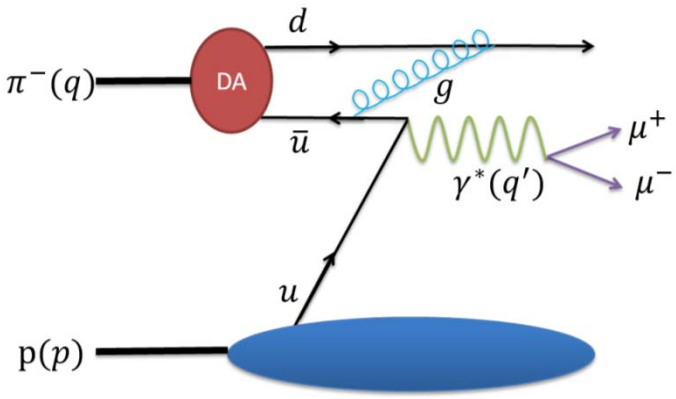

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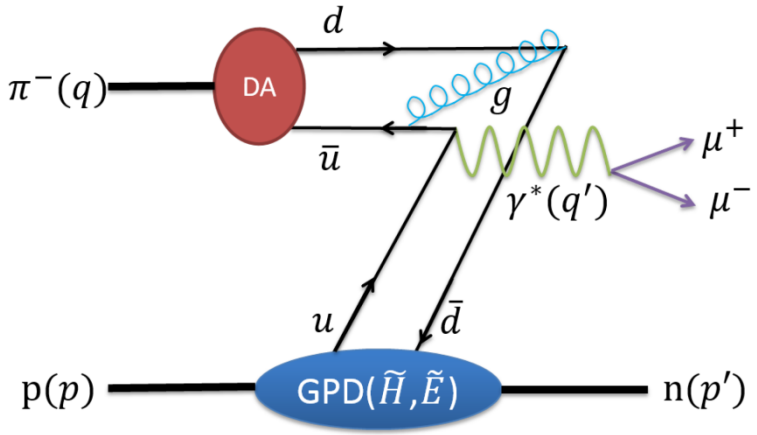


exclusive

high intensity

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

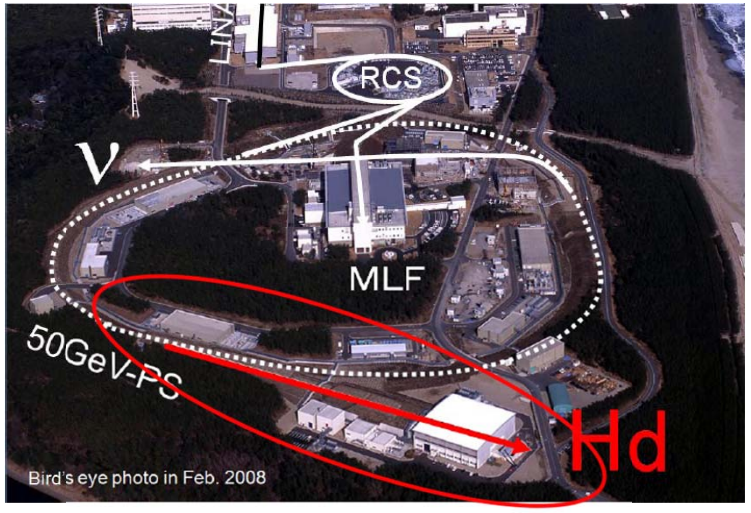
High momentum beam line at J-PARC

- Primary beam (proton)

$E = 30\text{GeV}\ (\rightarrow 50\text{GeV?})$

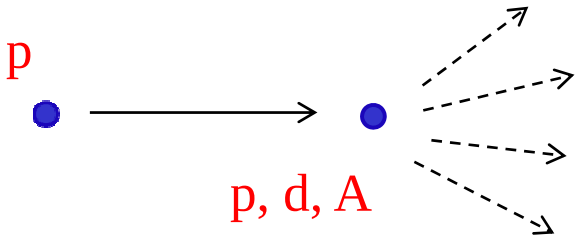
$L = 10^{35}\text{cm}^{-2}\text{s}^{-1}$

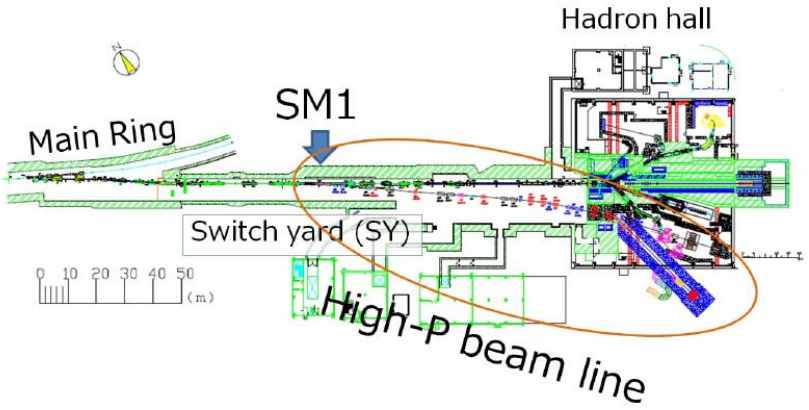
Hadron Facility at J-PARC



- Secondary beam (pion)

E = 15-20GeV



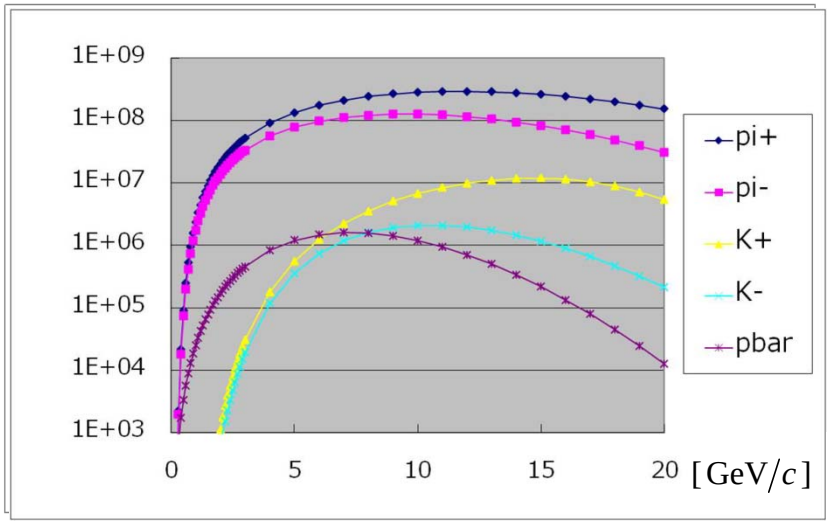


High-momentum beamline

- 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

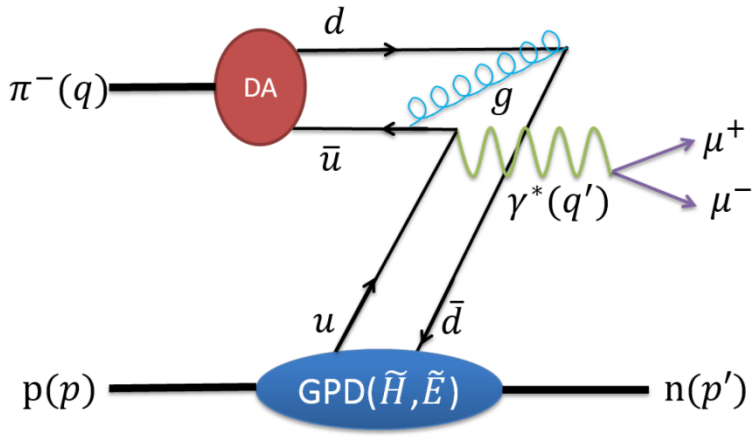
high intensity

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

best suited to study meson-induced hard exclusive processes

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

$\pi N \to \mu^+ \mu^- N$



exclusive

1. QCD factorization

- cross-section estimate
- feasibility study at J-PARC

T. Sawada, W.C. Chang, S. Kumano, J.C. Peng, S. Sawada, KT,
PRD93 (2016) 114034

2. Non-factorizable mechanism

- estimate of soft QCD effect

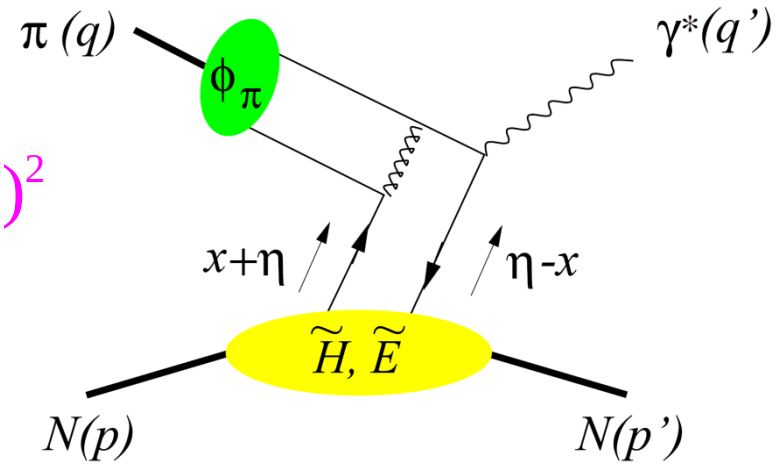
KT, arXiv:1703.02190 and in preparation

Exclusive lepton pair production in πN scattering

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

"exclusive limit of DY"

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



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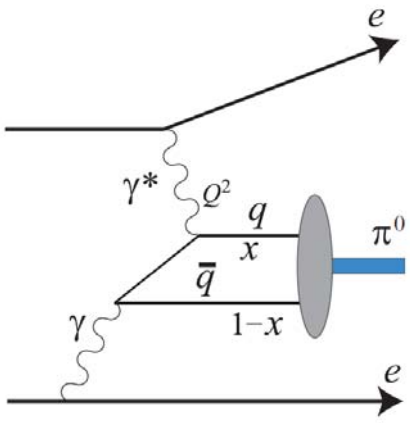

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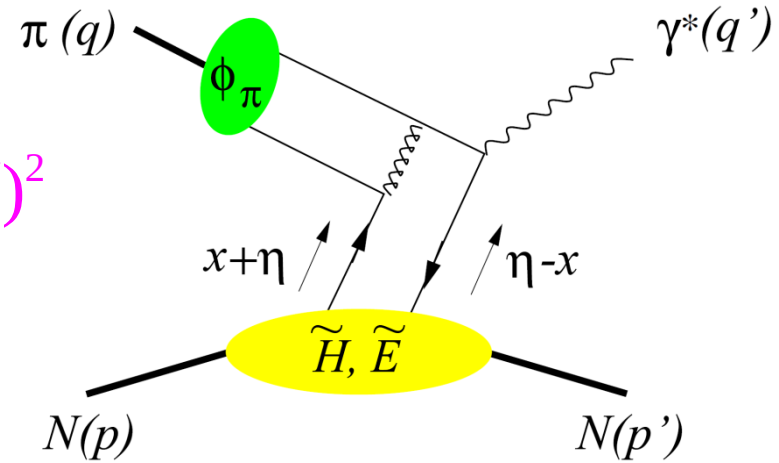
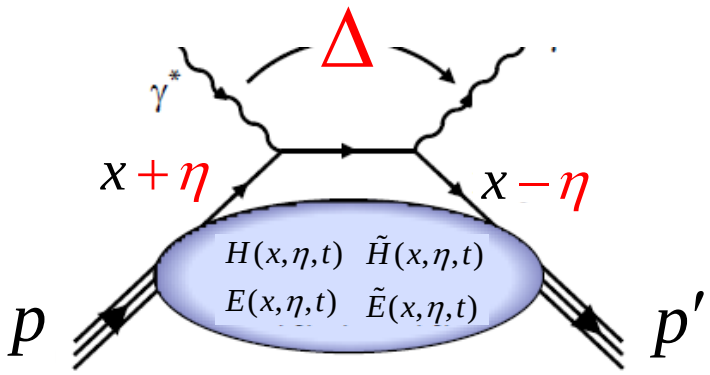


GPD



$$t = \Delta^2$$

$$-2\eta \bar{P} = \Delta$$

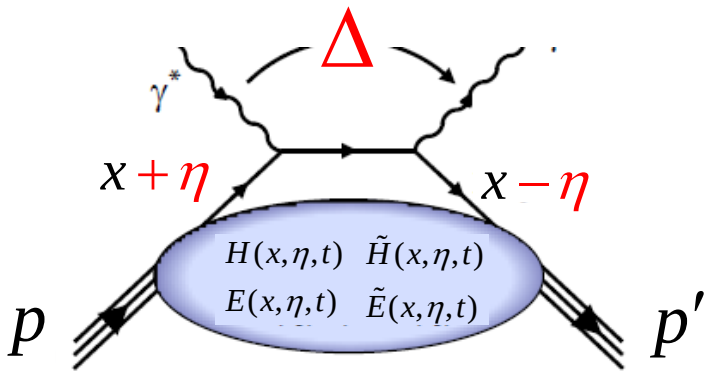
$$\int dz^- e^{i(x+\eta)pz} \left\langle N(p') \left| \psi^\dagger(0)\psi(z^-) \right| N(p) \right\rangle$$

$$\bar{P} = \frac{p + p'}{2}$$

$$\int \frac{dz^-}{2\pi} e^{i(x+\eta)\bar{P}z} \langle p' | \bar{\psi}(0)\gamma^+ \psi(z^-) | p \rangle = \frac{1}{\bar{P}^+} \left[H(x,\eta,t)\bar{u}(p')\gamma^+ u(p) + E(x,\eta,t)\bar{u}(p') \frac{i\sigma^{+\alpha}(p'-p)_\alpha}{2M} u(p) \right]$$

$$J_q = \frac{1}{2}\int_{-1}^{1} dx x \left(H(x,\eta,0) + E(x,\eta,0) \right)$$

GPD



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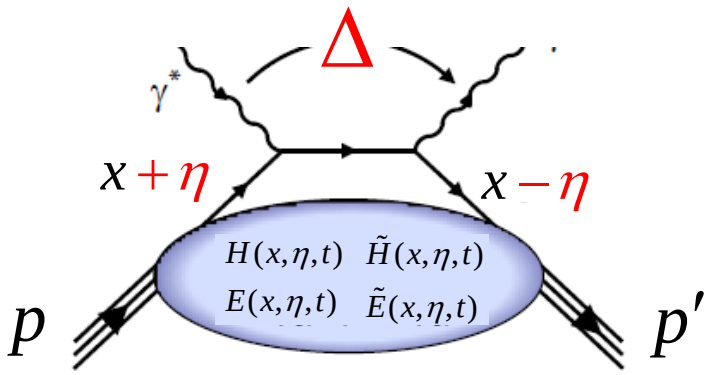

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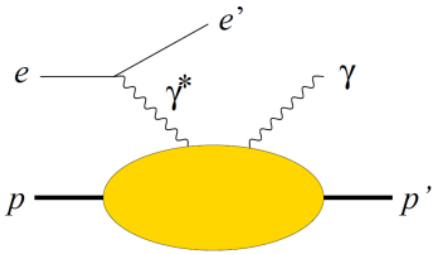

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JLab, HERMES, COMPASS,…

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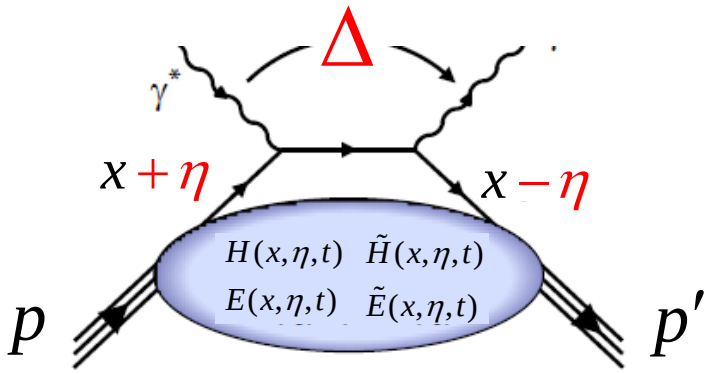

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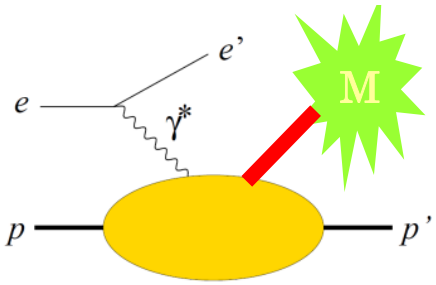

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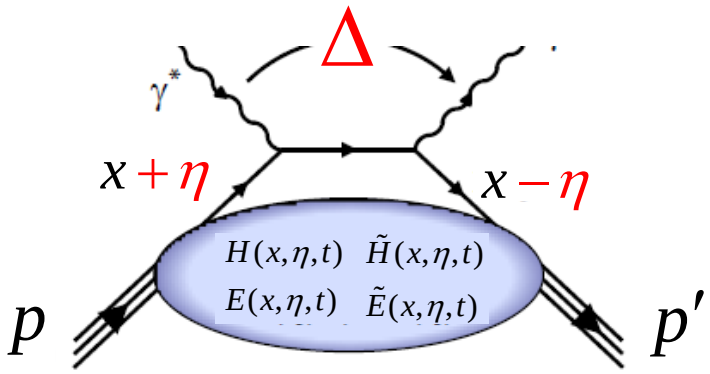

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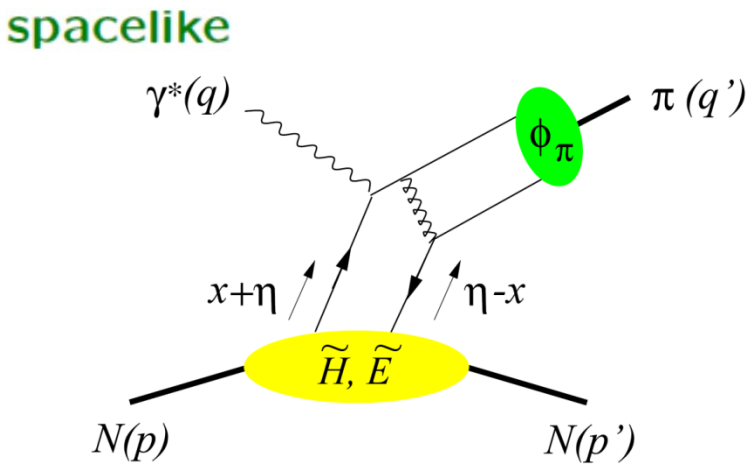
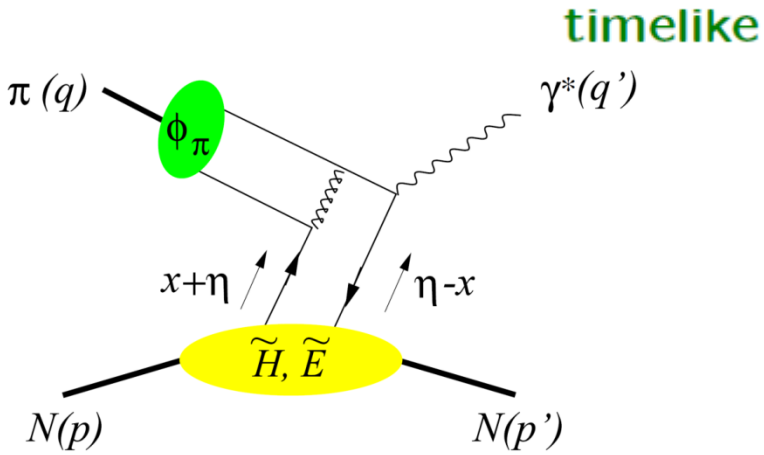
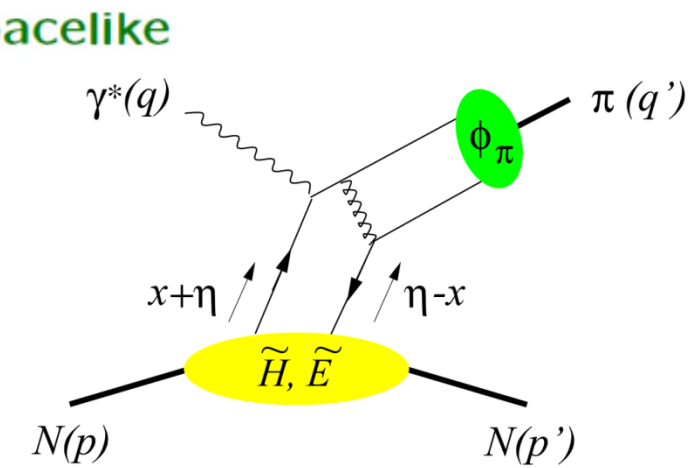


DVMP



exDY



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Exclusive lepton pair production in πN scattering

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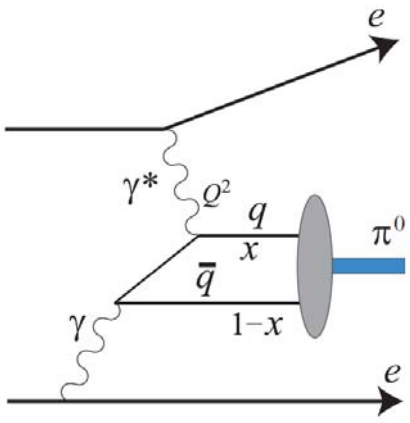

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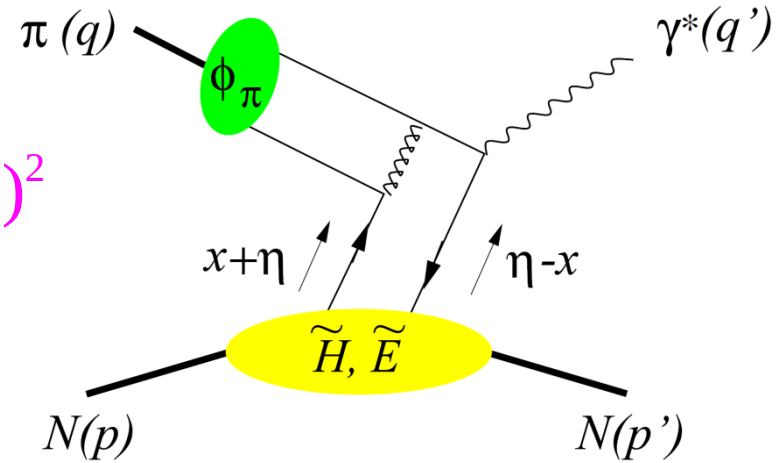
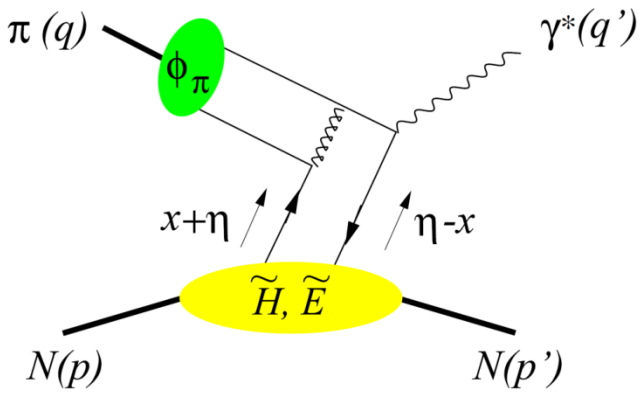


Pion beams reveal $\tilde{H}, \tilde{E}$ Generalized Parton distributions

timelike



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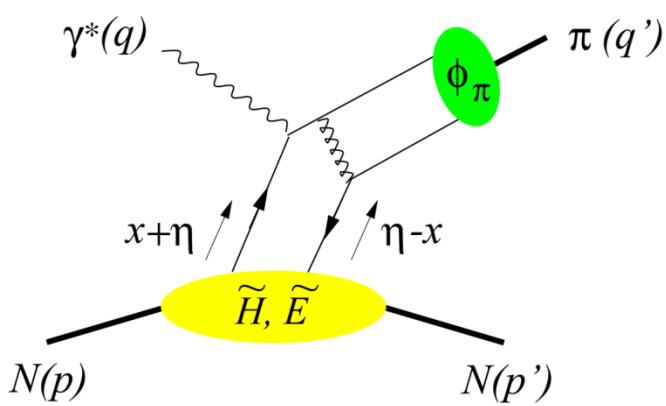
spacelike



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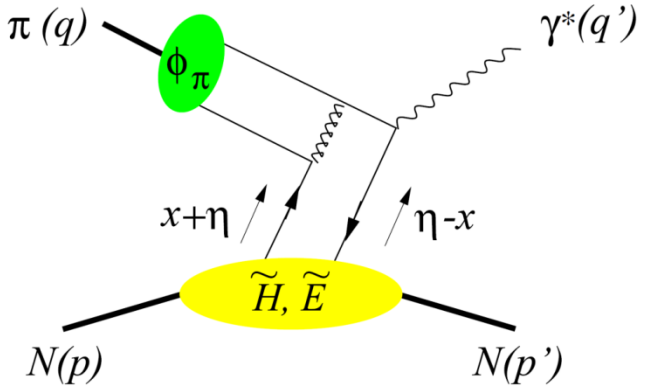

exDY@J-PARC

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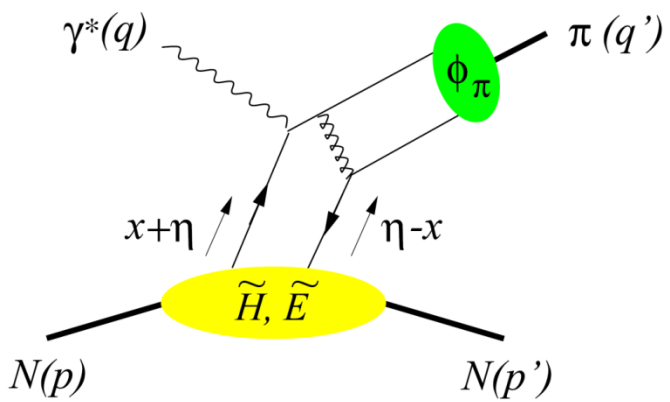

DVMP@JLab

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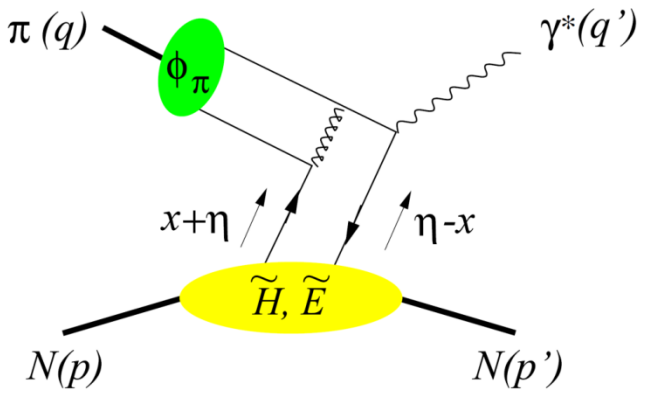

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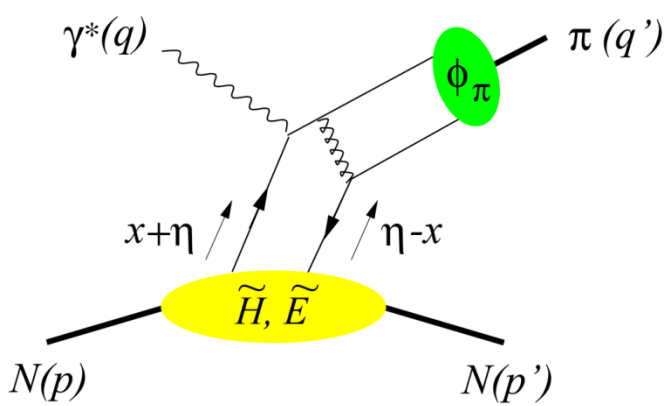

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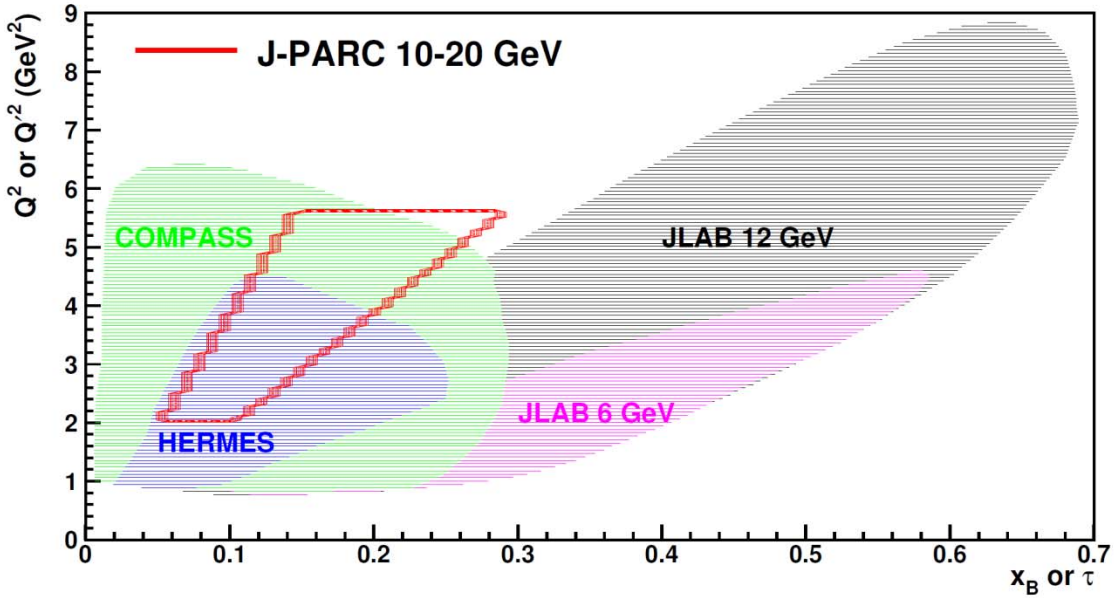

T. Sawada et al., PRD93, 114034

Exclusive lepton pair production in πN scattering

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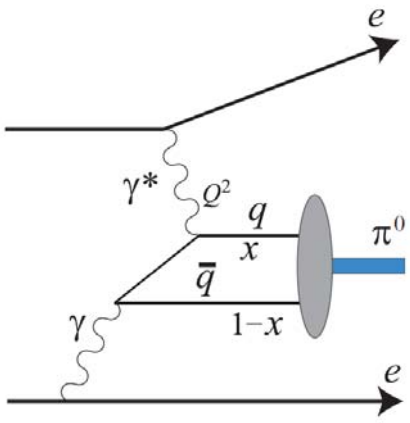
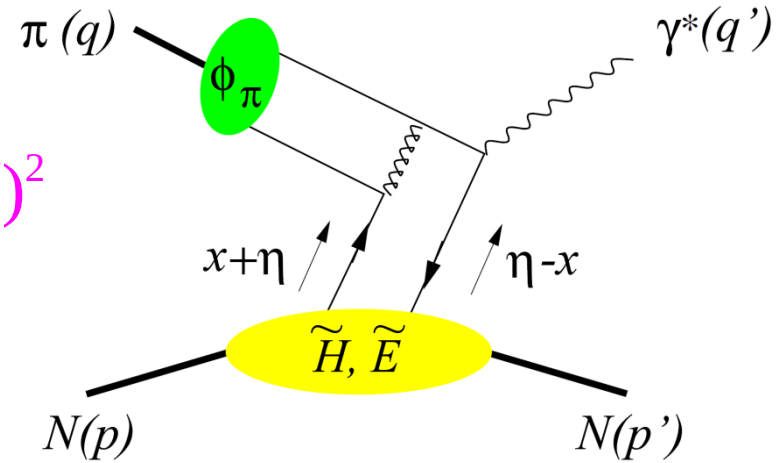


@Belle, Babar

"exclusive DY"



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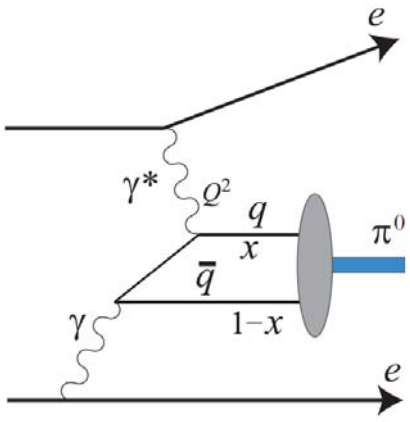

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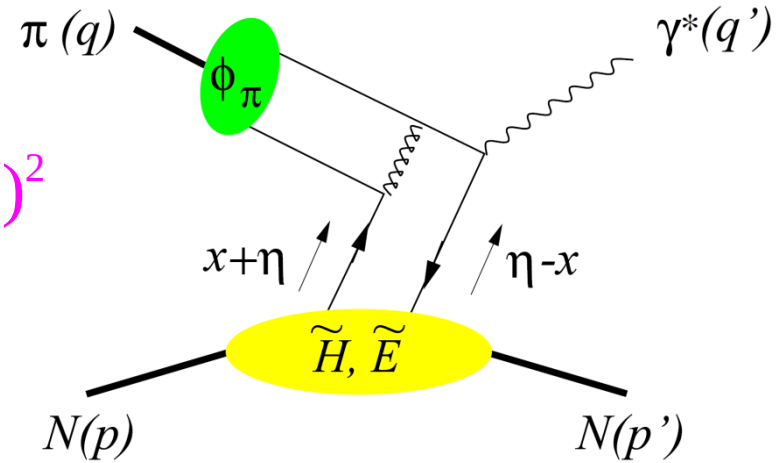

LO in QCD factorization

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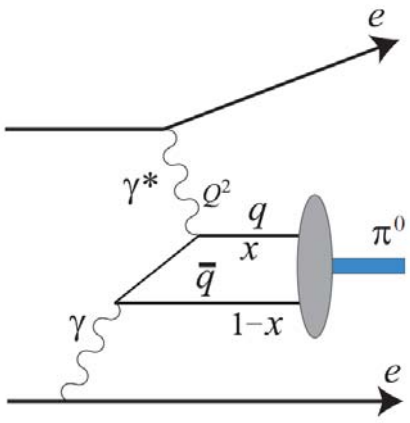
Berger, Diehl, Pire, PLB523(2001)265



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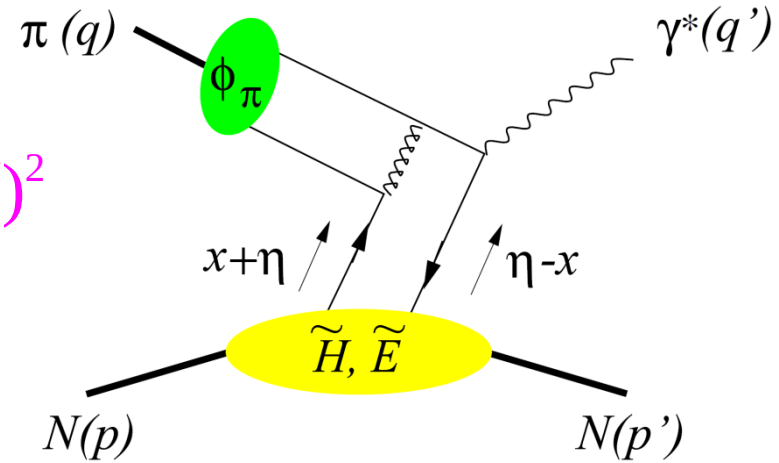

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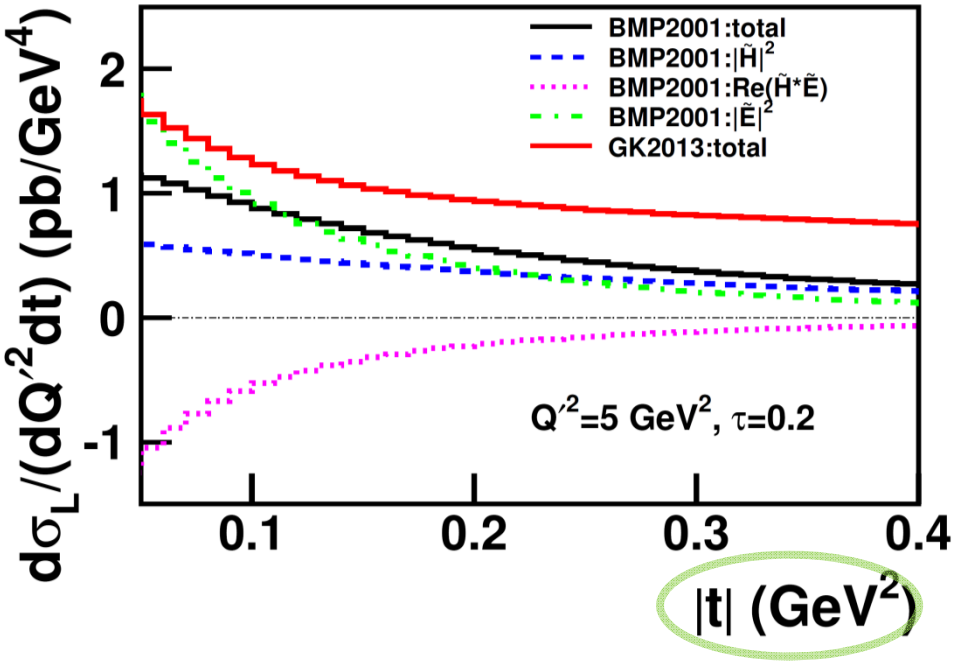
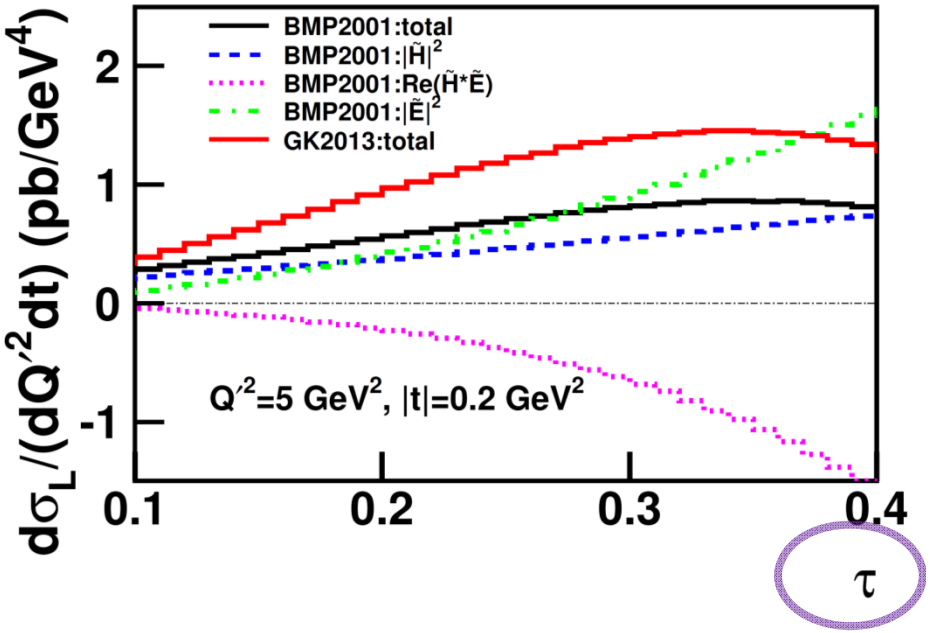
Bjorken variable $\tau = \frac{Q'^2}{s - M^2}$

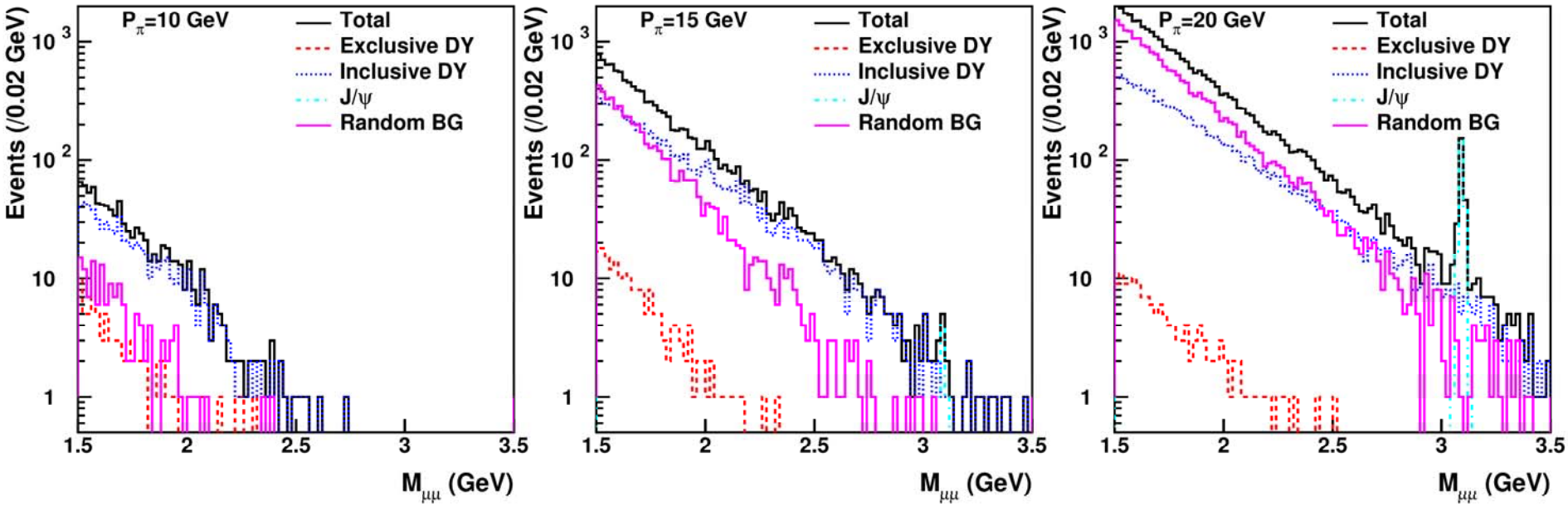
$$Q'^2 = 5\ \mathrm{GeV}^2$$





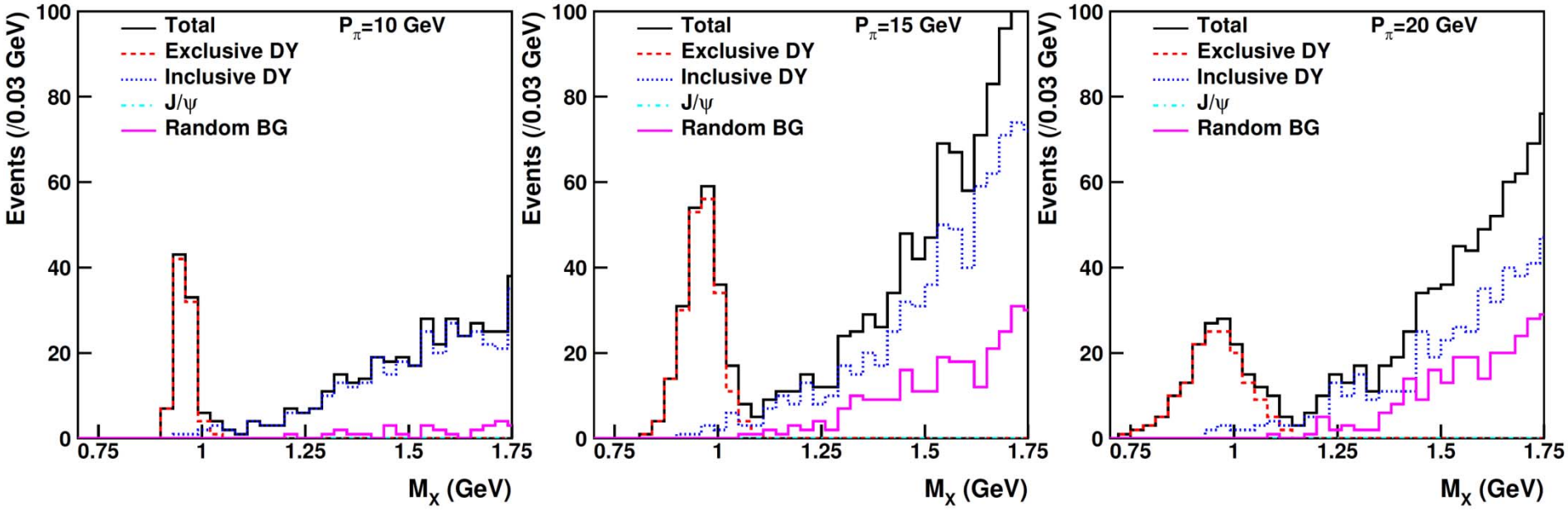
$$\frac{d\sigma}{dQ'^2\,dt}(\pi^- p \to \gamma^* n) = \frac{4\pi\alpha_{\mathrm{em}}^2}{27}\frac{\tau^2}{Q'^8} f_\pi^2 \left[(1-\eta^2)\,|\widetilde{\mathcal{H}}^{du}|^2 - 2\eta^2\,\mathrm{Re}\left(\widetilde{\mathcal{H}}^{du*}\widetilde{\mathcal{E}}^{du}\right) - \eta^2 \frac{t}{4M^2}|\widetilde{\mathcal{E}}^{du}|^2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

$$\widetilde{\mathcal{H}}^{du} = \frac{8\alpha_s}{3}\int_0^1 du \frac{\phi_\pi(u)}{4u(1-u)} \int_{-1}^1 dx \left(\frac{e_d}{-\eta - x - i\epsilon} - \frac{e_u}{-\eta + x - i\epsilon} \right) \left(\tilde{H}^d(x,\eta,t) - \tilde{H}^u(x,\eta,t) \right)$$



feasibility with E50 spectrometer at J-PARC

T. Sawada, W.C. Chang, S. Kumano, J.C. Peng, S. Sawada, KT,
PRD93, 114034



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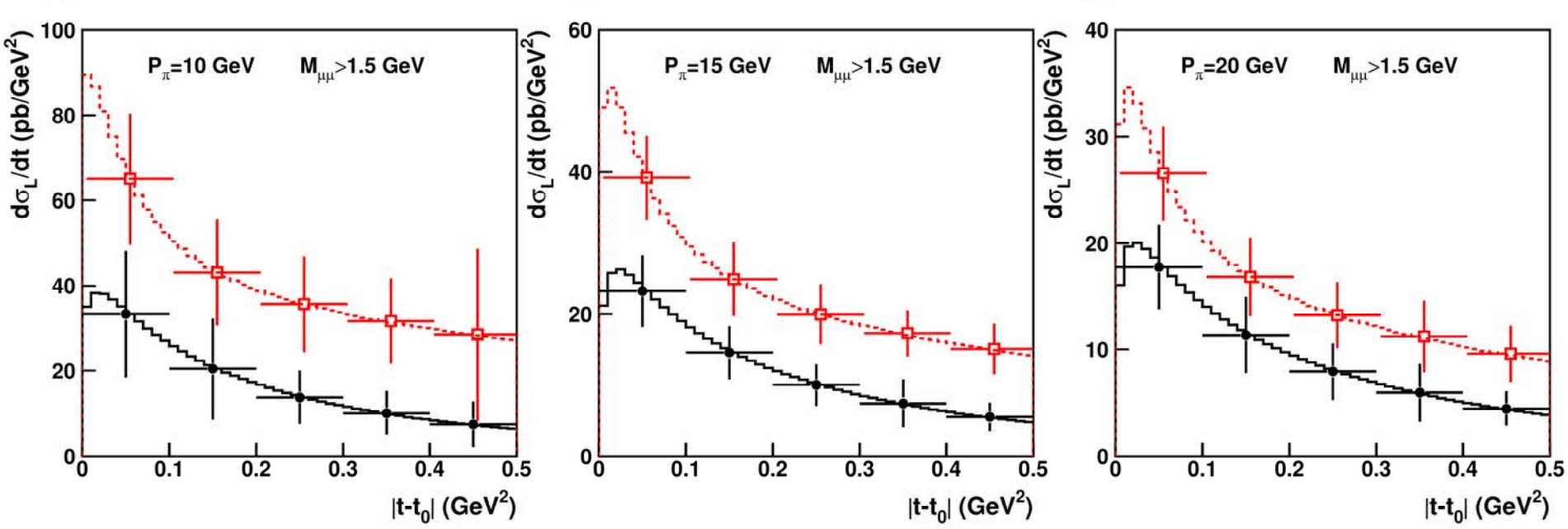


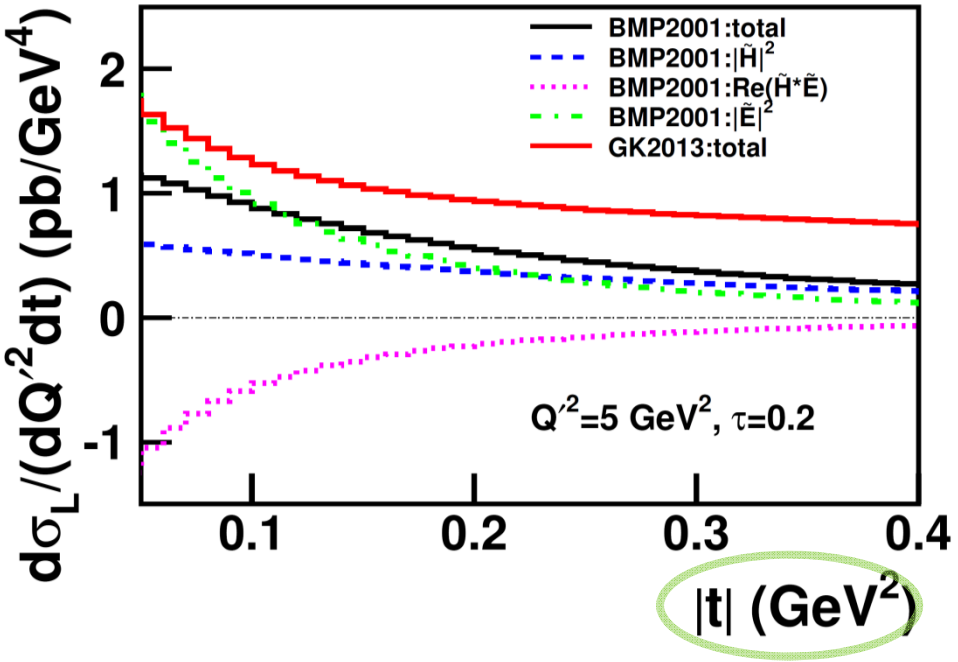
feasibility with E50 spectrometer at J-PARC

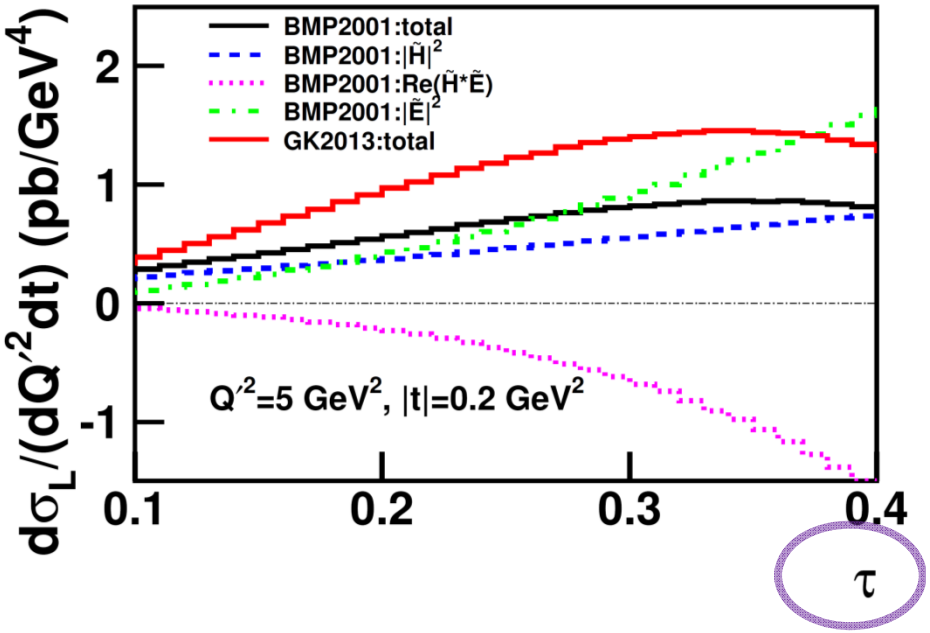
T. Sawada, W.C. Chang, S. Kumano, J.C. Peng, S. Sawada, KT,
PRD93, 114034

T. Sawada, W.C. Chang, S. Kumano, J.C. Peng, S. Sawada, KT, PRD93, 114034

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

$$Q'^2 = 5\ \mathrm{GeV}^2$$

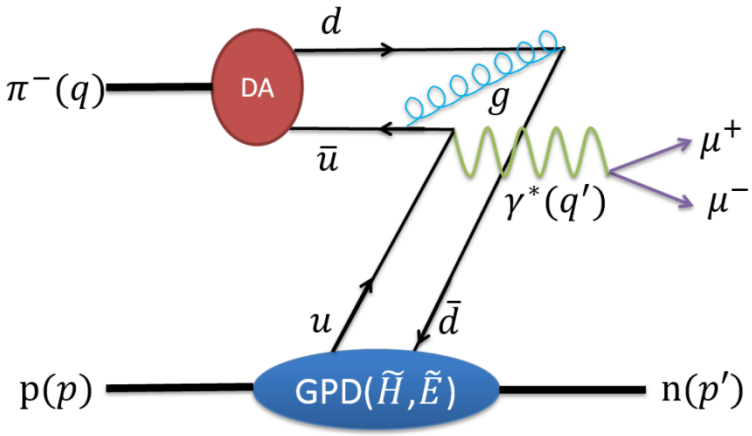




$$\frac{d\sigma}{dQ'^2\,dt}(\pi^- p \to \gamma^* n) = \frac{4\pi\alpha_{\mathrm{em}}^2}{27}\frac{\tau^2}{Q'^8} f_\pi^2 \left[(1-\eta^2)\,|\widetilde{\mathcal{H}}^{du}|^2 - 2\eta^2\,\mathrm{Re}\left(\widetilde{\mathcal{H}}^{du*}\widetilde{\mathcal{E}}^{du}\right) - \eta^2 \frac{t}{4M^2}|\widetilde{\mathcal{E}}^{du}|^2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

$$\widetilde{\mathcal{H}}^{du} = \frac{8\alpha_s}{3}\int_0^1 du \frac{\phi_\pi(u)}{4u(1-u)} \int_{-1}^1 dx \left(\frac{e_d}{-\eta - x - i\epsilon} - \frac{e_u}{-\eta + x - i\epsilon} \right) \left(\tilde{H}^d(x,\eta,t) - \tilde{H}^u(x,\eta,t) \right)$$

$\pi N \to \mu^+ \mu^- N$



exclusive

1. QCD factorization
   - cross-section estimate
   - feasibility study at J-PARC

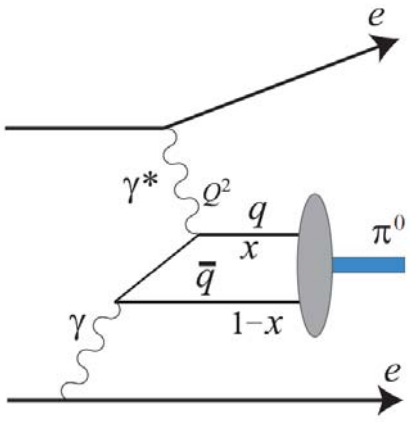
   T. Sawada, W.C. Chang, S. Kumano, J.C. Peng, S. Sawada, KT, PRD93 (2016) 114034

2. Non-factorizable mechanism
   - estimate of soft QCD effect

   KT, arXiv:1703.02190 and in preparation

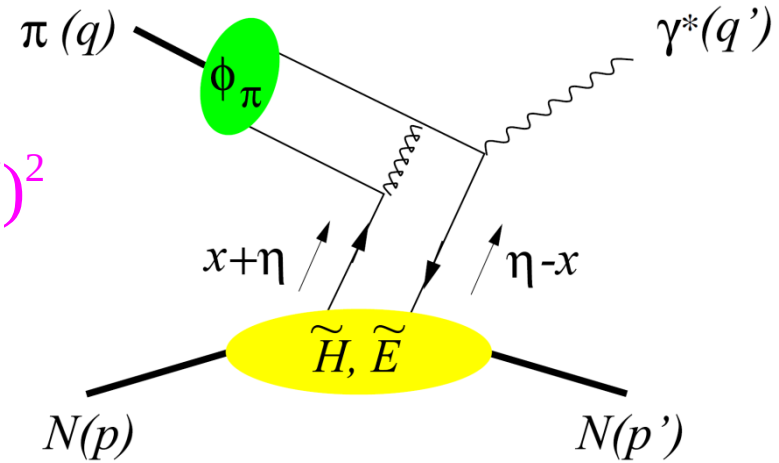
Exclusive lepton pair production in πN scattering

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



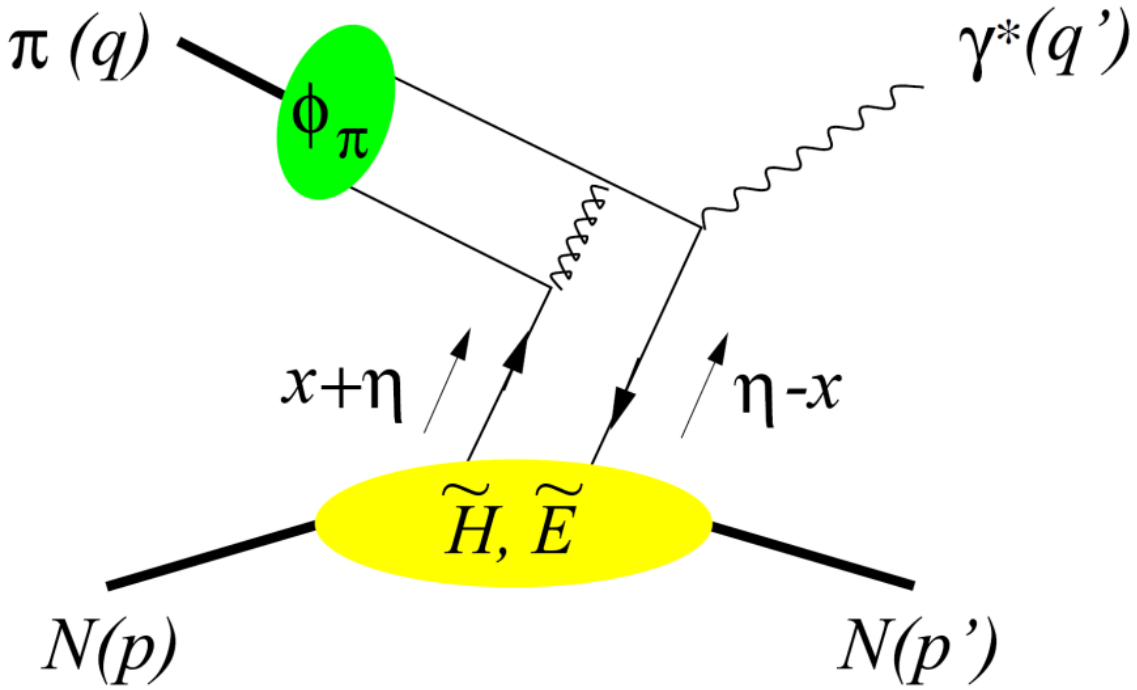
@Belle, Babar

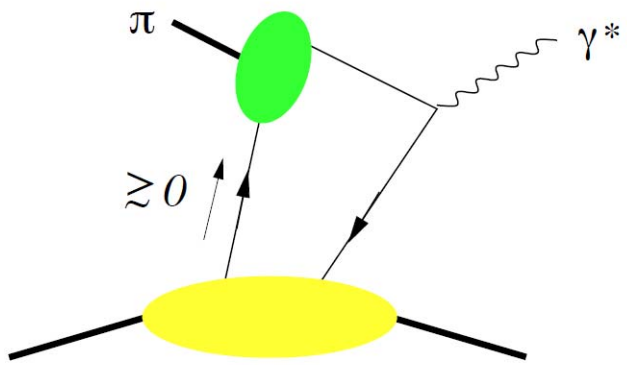
"exclusive DY"

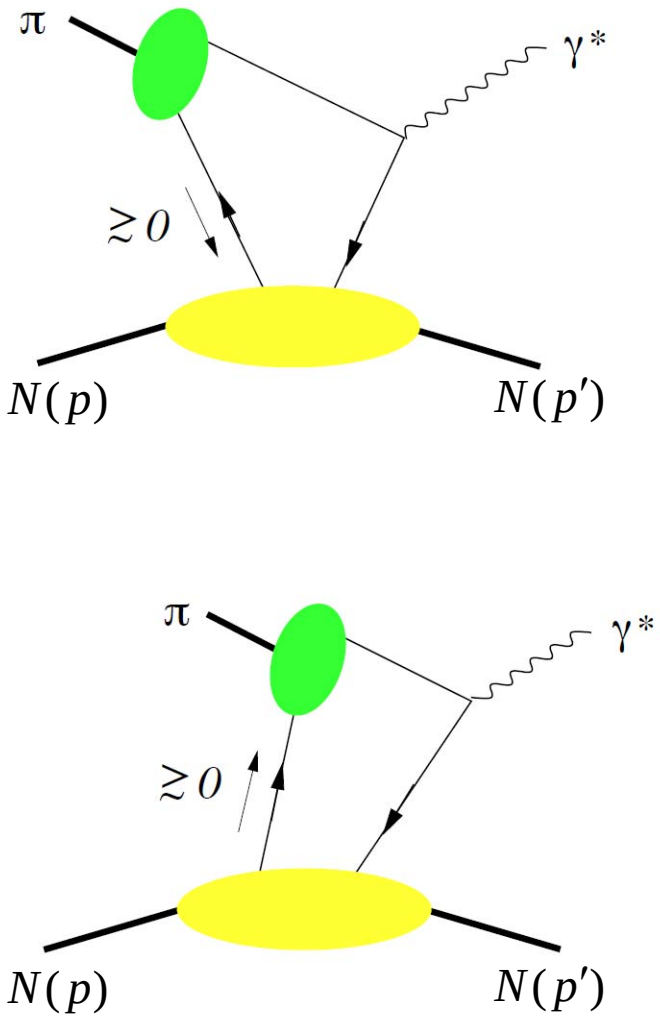


LO in QCD factorization

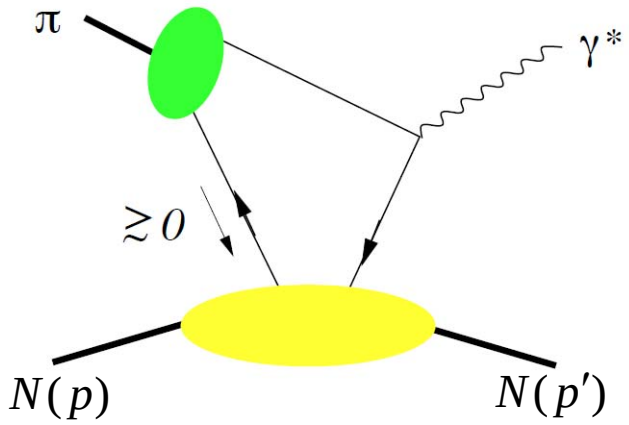
small $t = \Delta^2 = (q - q')^2$


π (q)
γ*(q')
ϕ_π
x+η
η-x
$\widetilde{H}, \widetilde{E}$
N(p)
N(p')

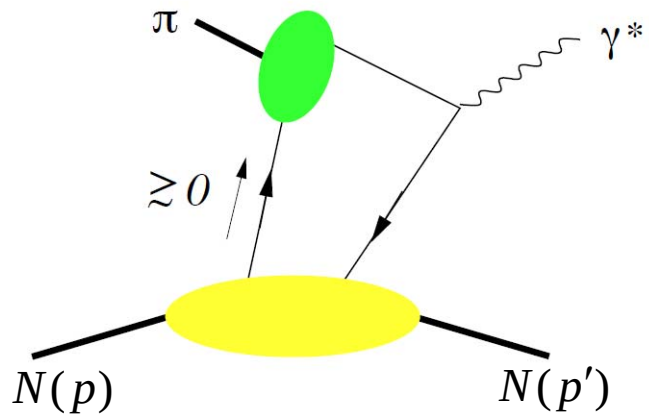

π
γ*
≳ 0


π
γ*
≳0
N(p)
N(p′)
π
γ*
≳0
N(p)
N(p′)

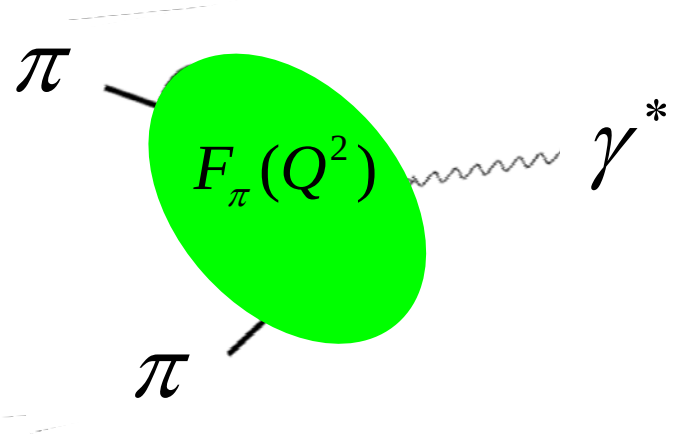
"nonfactorizable" mechanism

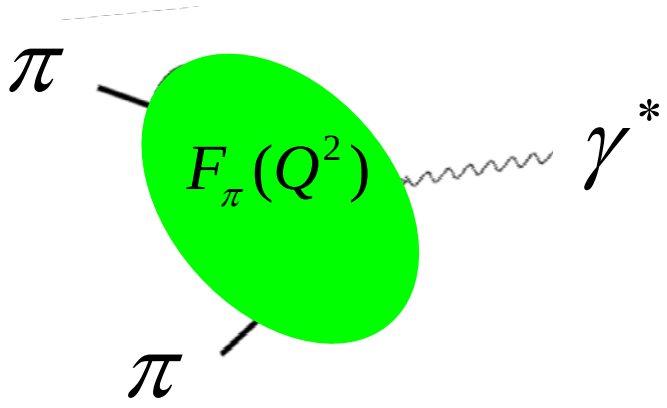


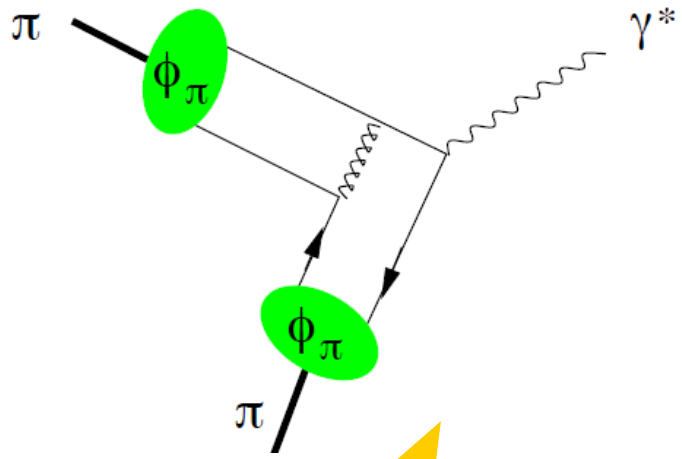
lower order in α_s



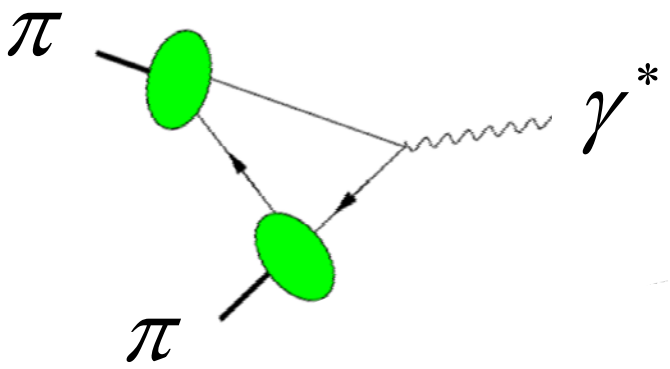
"Feynman mechanism"


π
$F_\pi(Q^2)$
γ^*
π



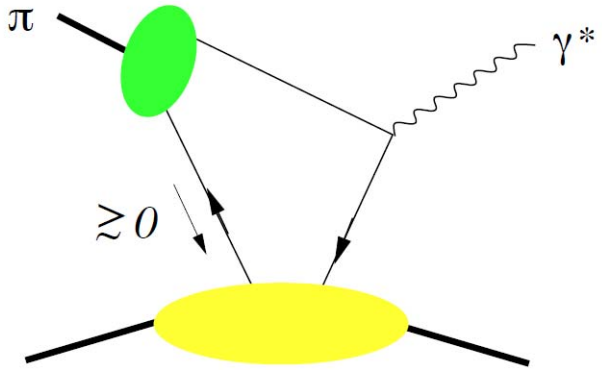


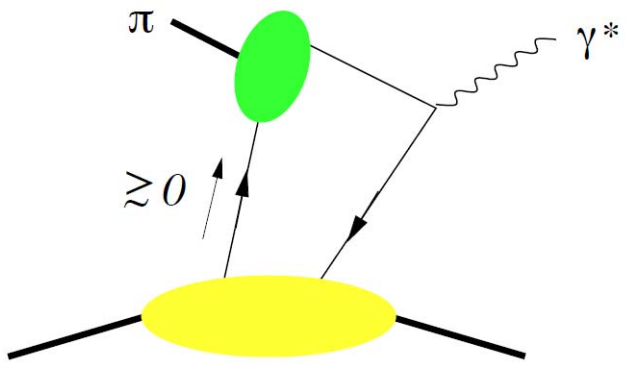
LO in QCD factorization



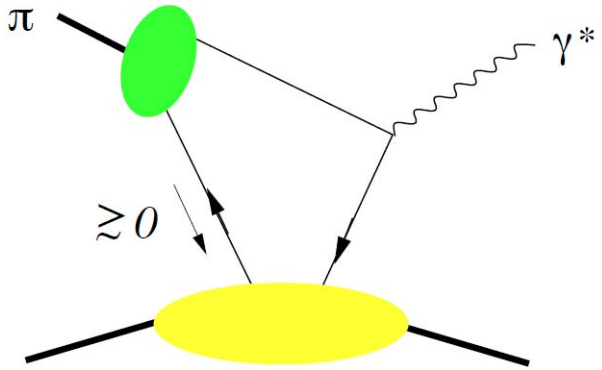
"nonfactorizable" Feynman mechanism

"nonfactorizable" mechanism

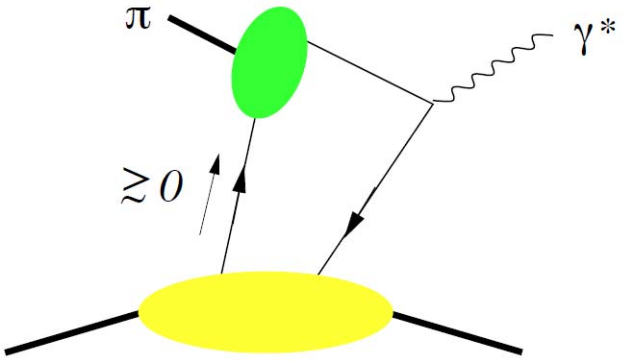




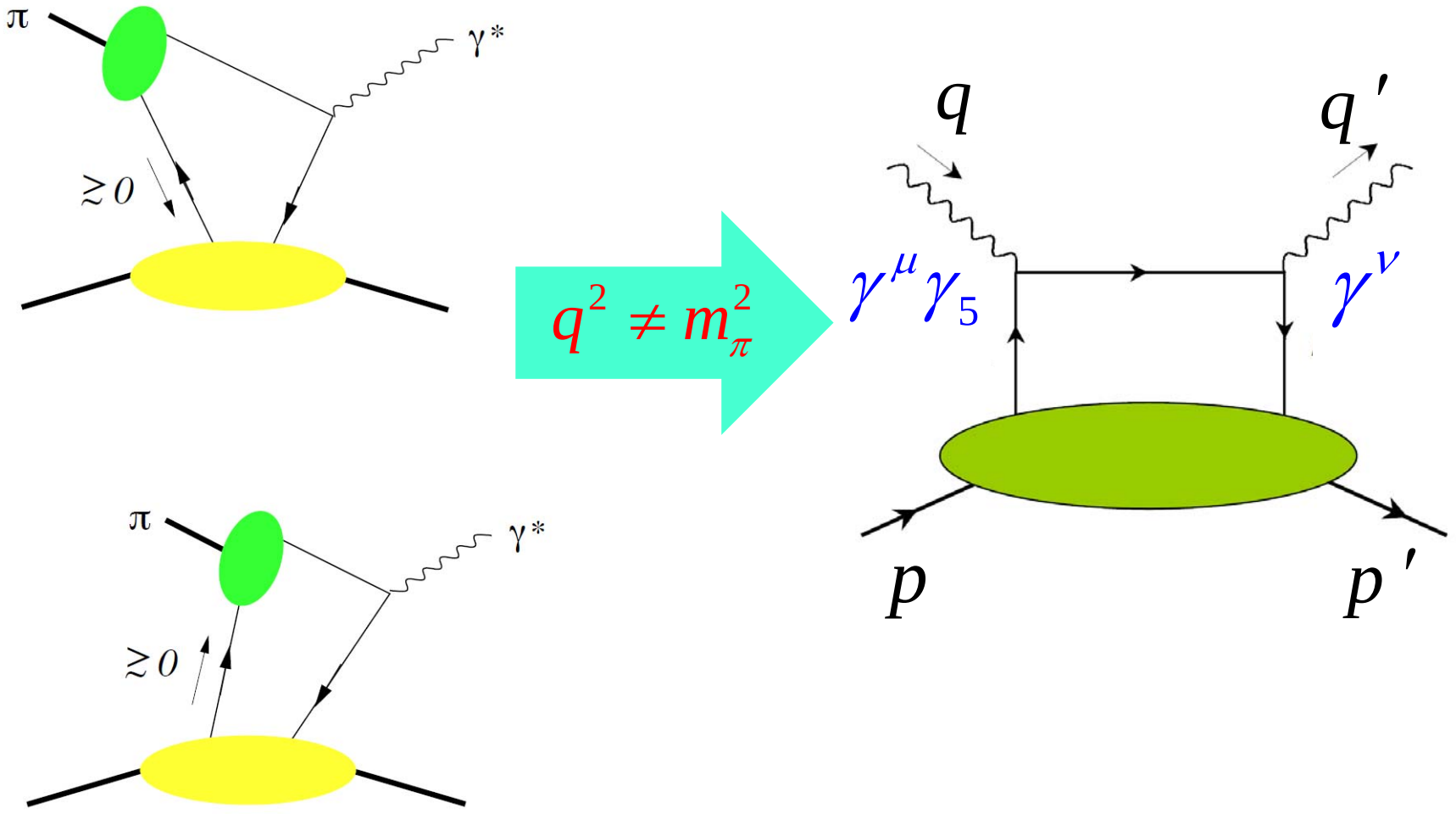
"nonfactorizable" mechanism



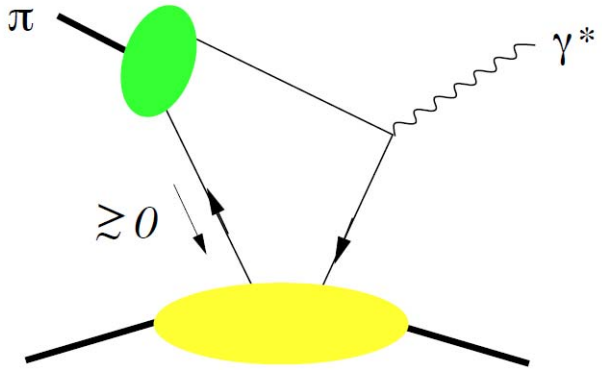
$$q^2 \neq m_\pi^2$$

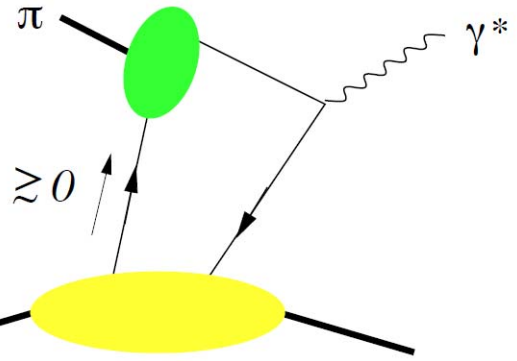


"nonfactorizable" mechanism



"nonfactorizable" mechanism





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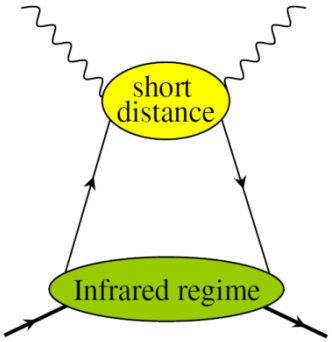
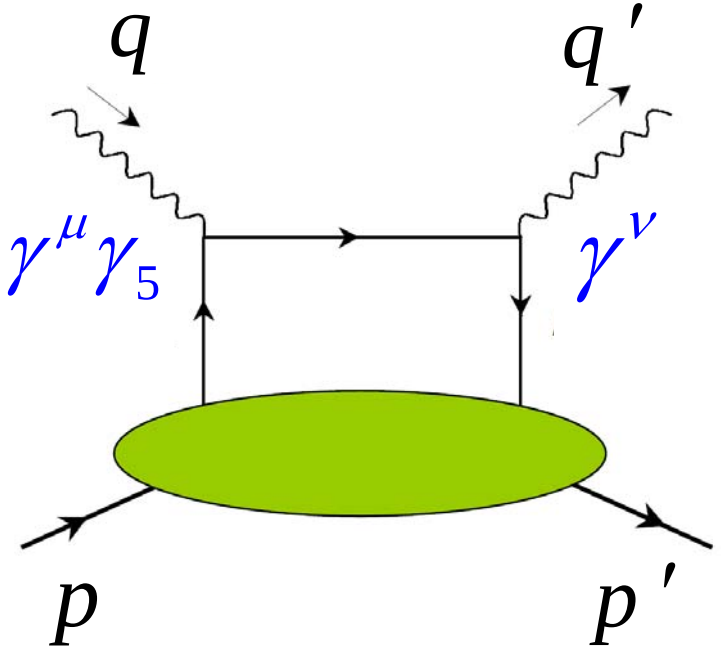
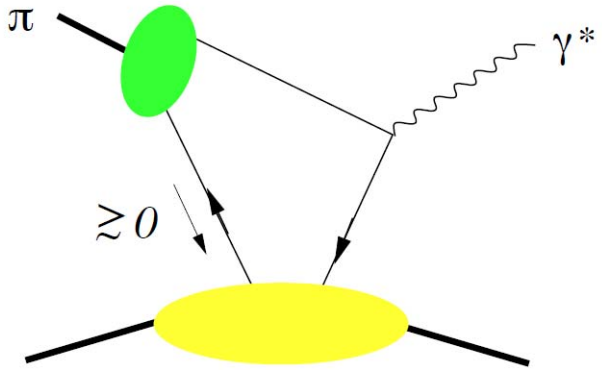
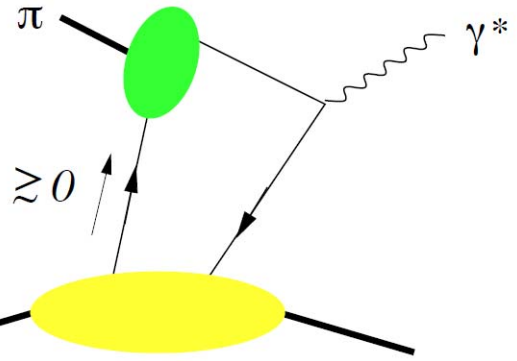




"nonfactorizable" mechanism





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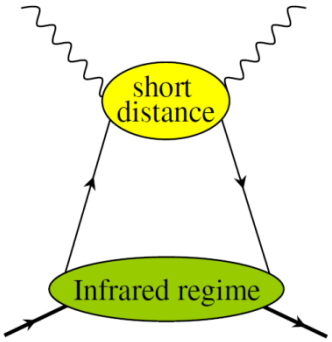
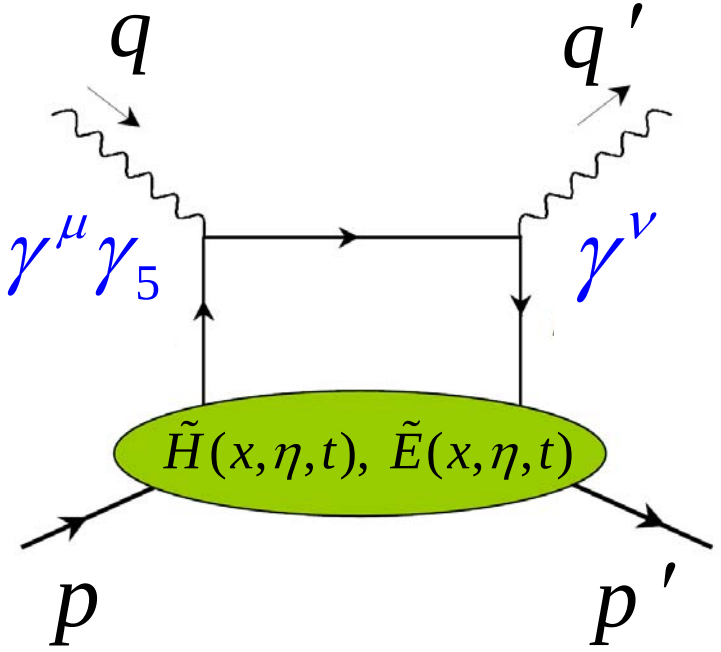
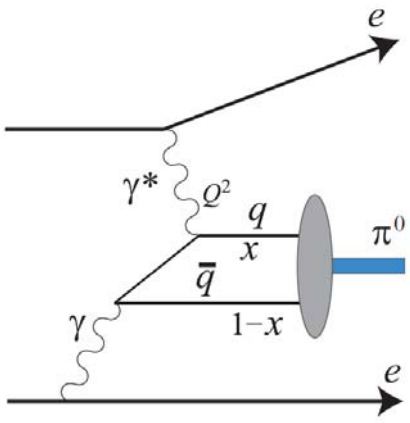




Exclusive lepton pair production in πN scattering

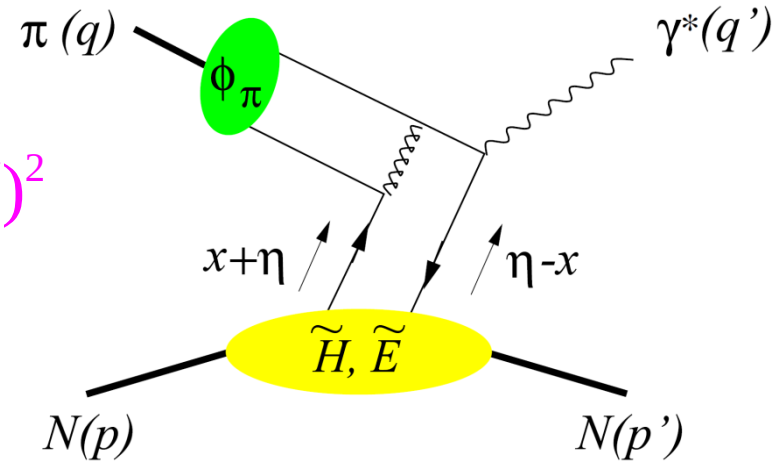
$\pi^- p \to \gamma^* n \to \mu^+ \mu^- n$

Berger, Diehl, Pire, PLB523(2001)265



@Belle, Babar

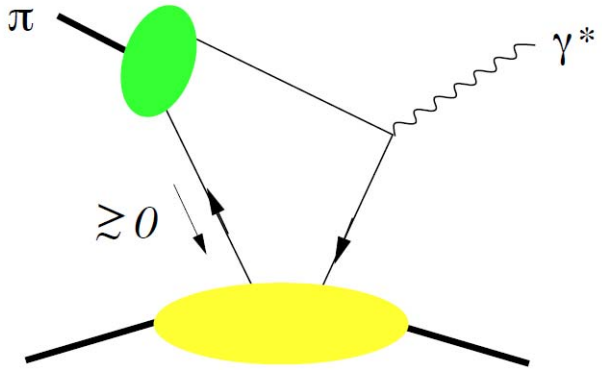
"exclusive DY"

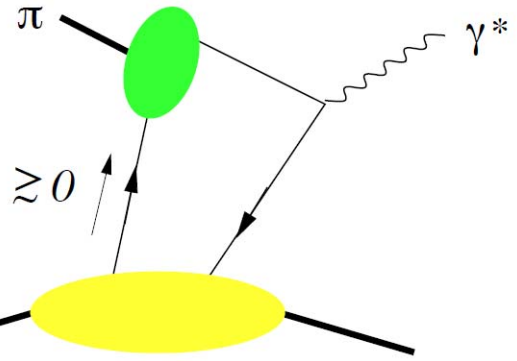


LO in QCD factorization

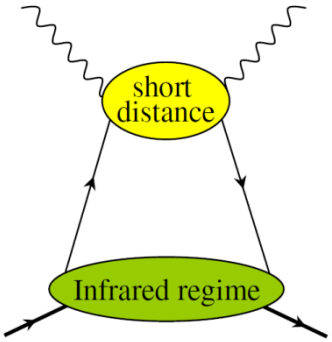
small $t = \Delta^2 = (q - q')^2$

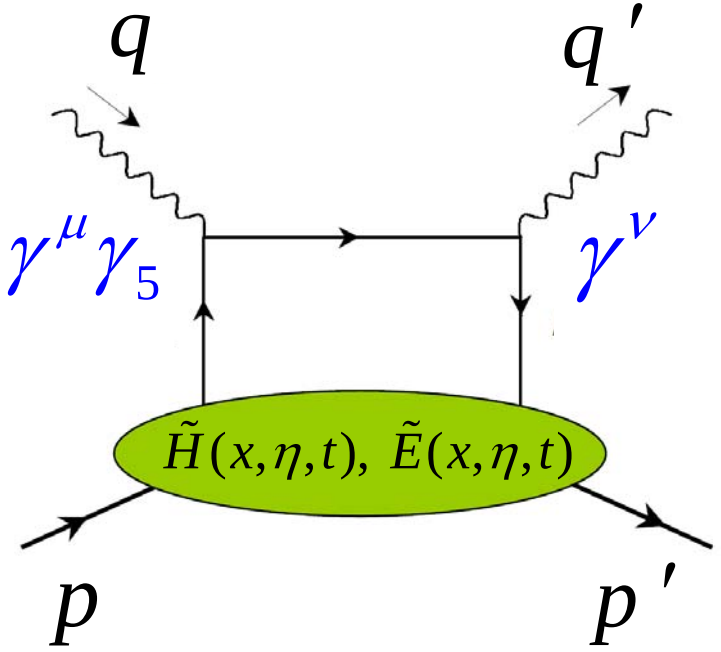
"nonfactorizable" mechanism



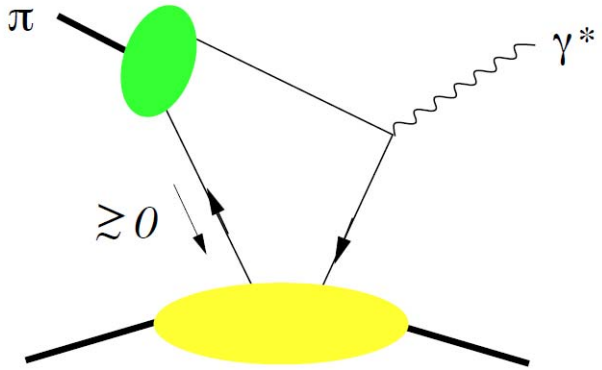


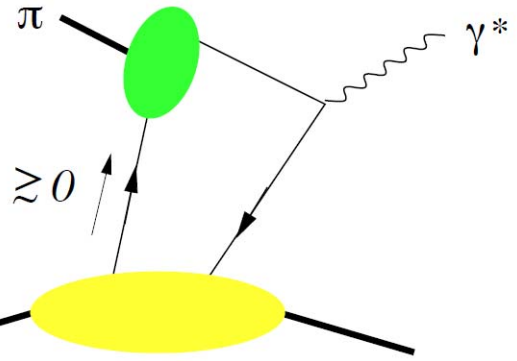
$q^2 \neq m_\pi^2$





"nonfactorizable" mechanism





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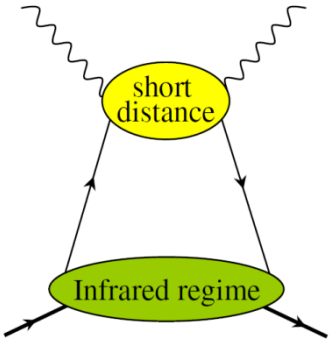
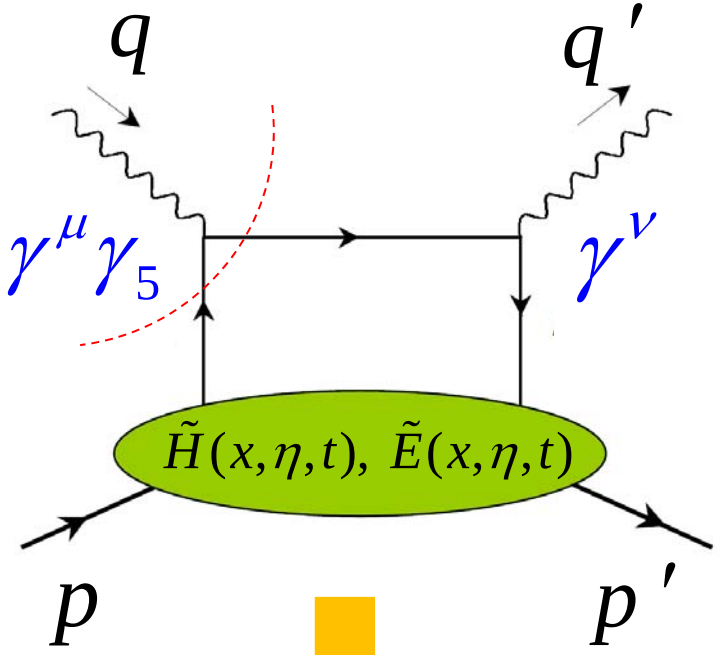
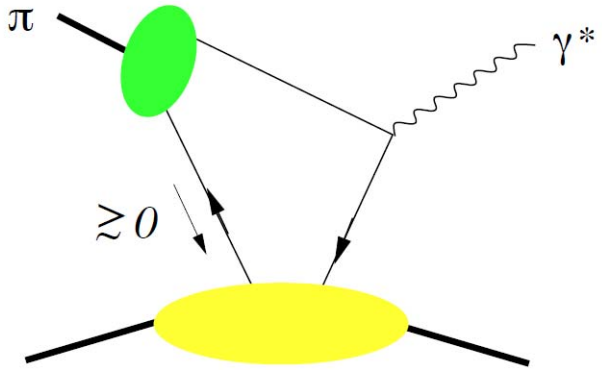
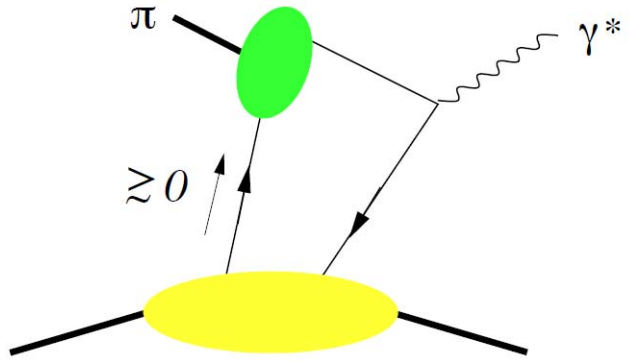




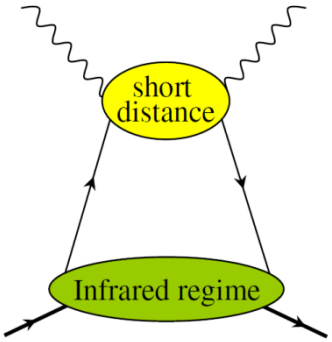
dispersion relation

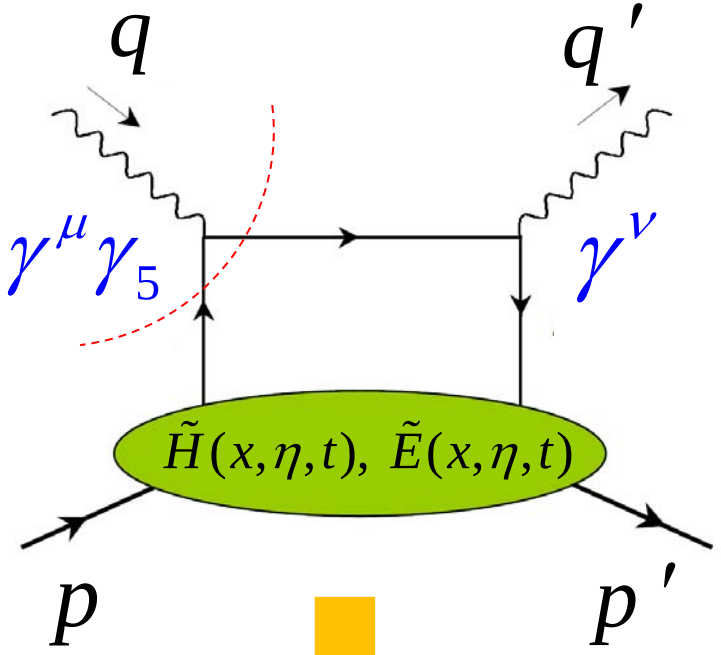
"nonfactorizable" mechanism





$q^2 \neq m_\pi^2$

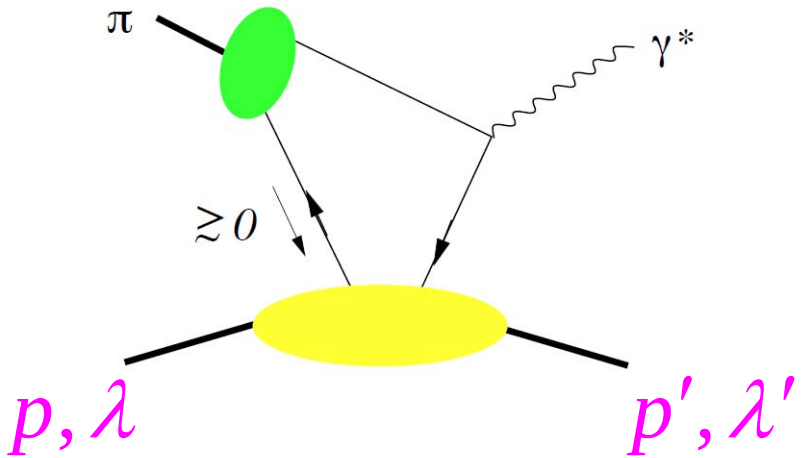


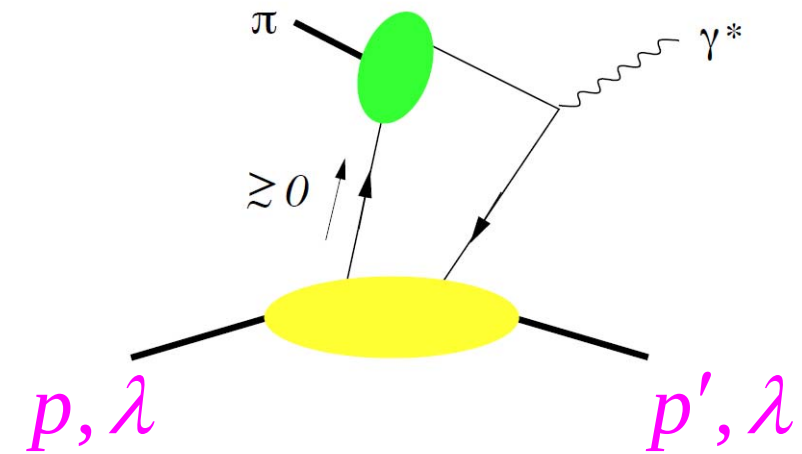


dispersion relation

quark-hadron duality

"nonfactorizable" mechanism





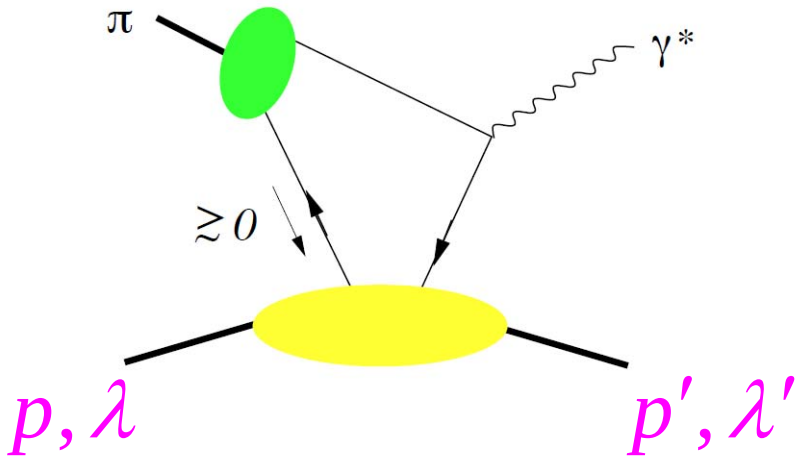
$$= g_v^- \int_\eta^{x_0} dx\, e^{-\frac{x-\eta}{x+\eta}\frac{Q'^2}{M_B^2}} \tilde{C}_H(x,\eta,Q'^2)$$

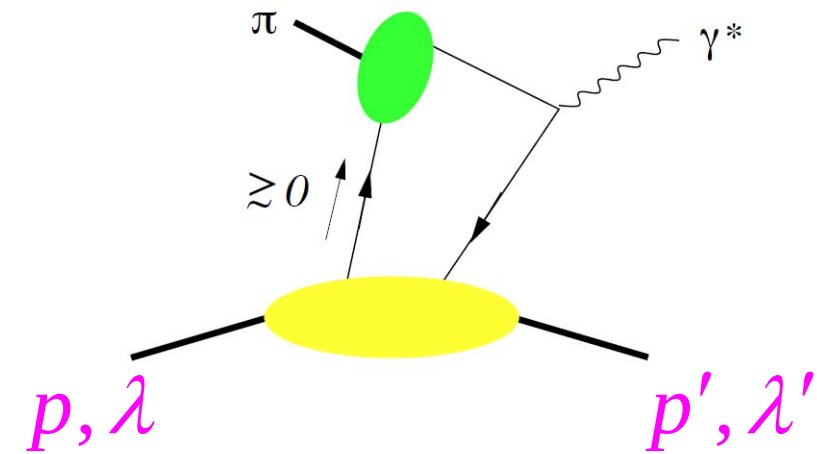
$$\times \left[e_u \tilde{H}^{du}(x,\eta,t) - e_d \tilde{H}^{du}(-x,\eta,t) \right]$$

$$\times \bar{u}(p'\lambda')\gamma^+\gamma_5 u(p\lambda) + \cdots$$

$$\tilde{H}^{du}(x,\eta,t) = \tilde{H}^u(x,\eta,t) - \tilde{H}^d(x,\eta,t)$$

"nonfactorizable" mechanism





"Light-cone QCD SR (LCSR)"

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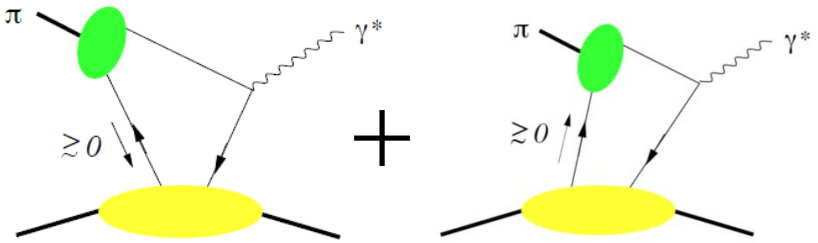
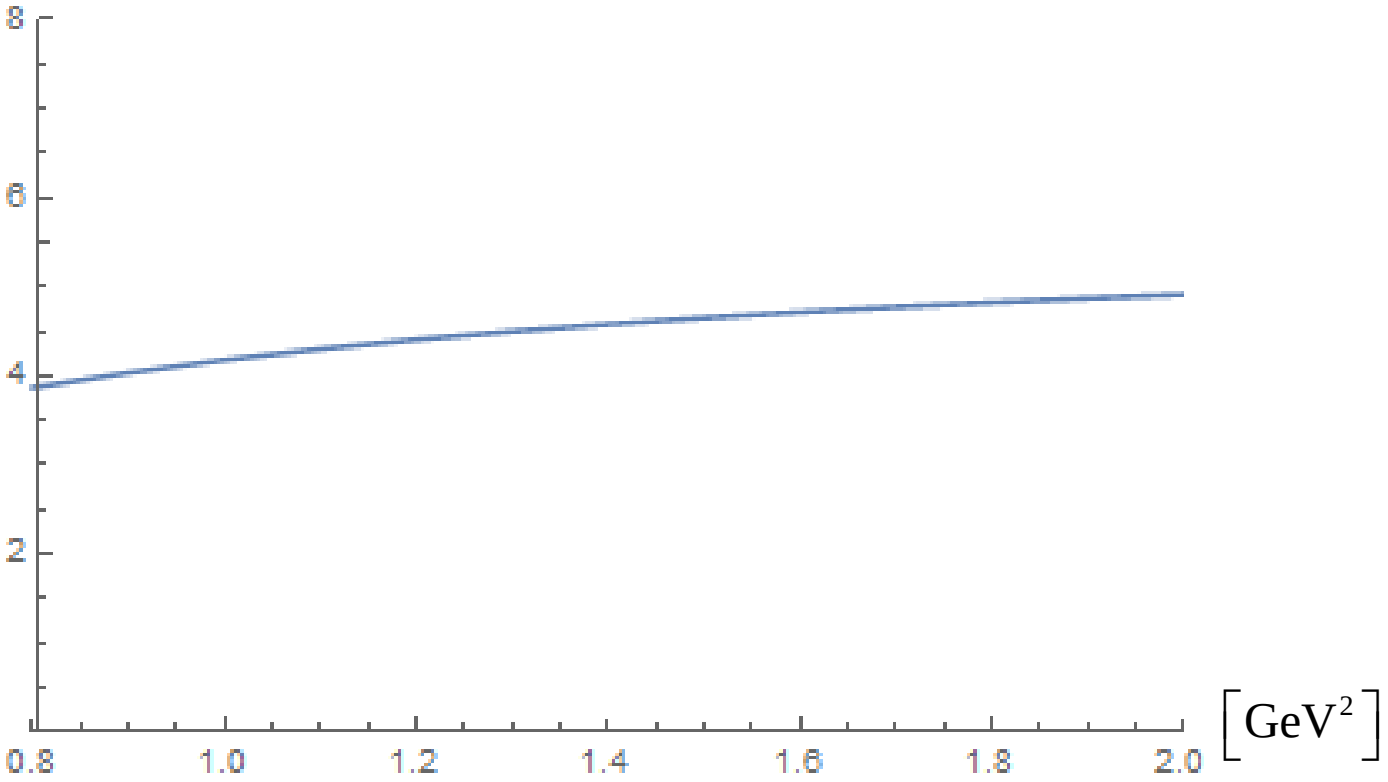


from LCSR

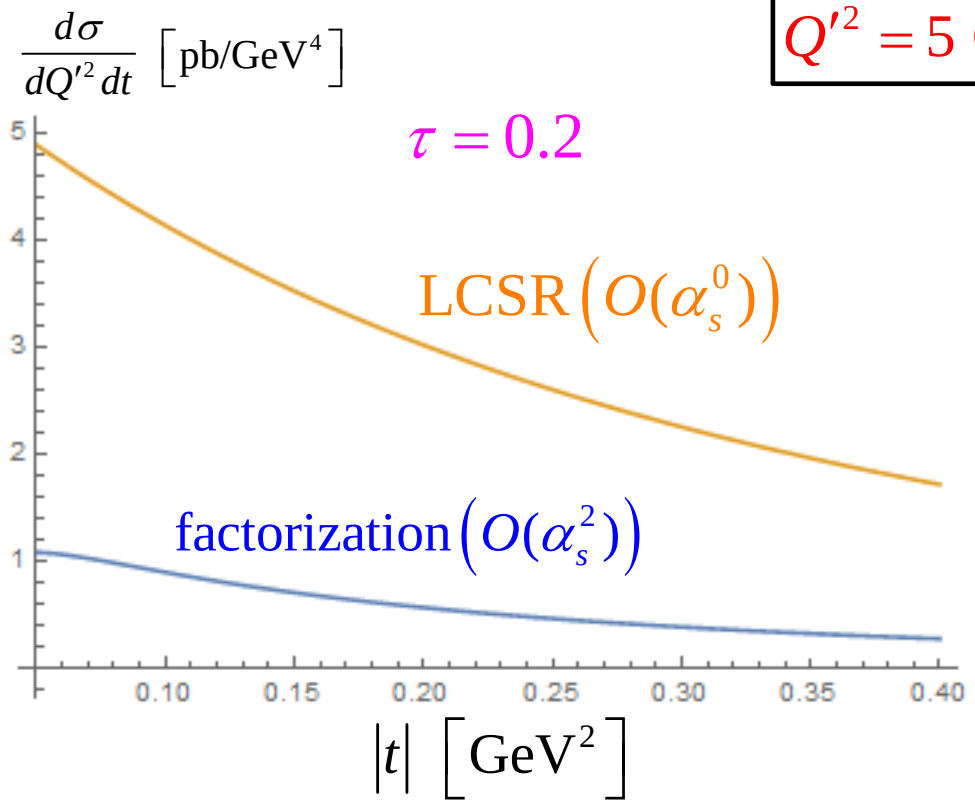


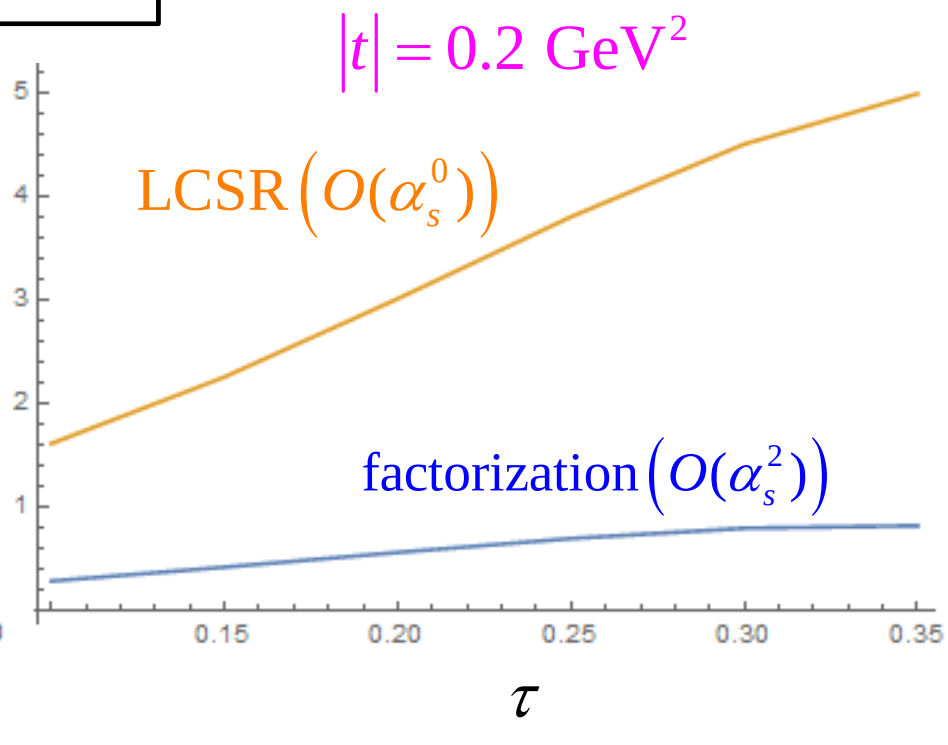
M_B^2 (Borel parameter)

KT, arXiv:1703.02190 and in preparation

KT, arXiv:1703.02190 and in preparation

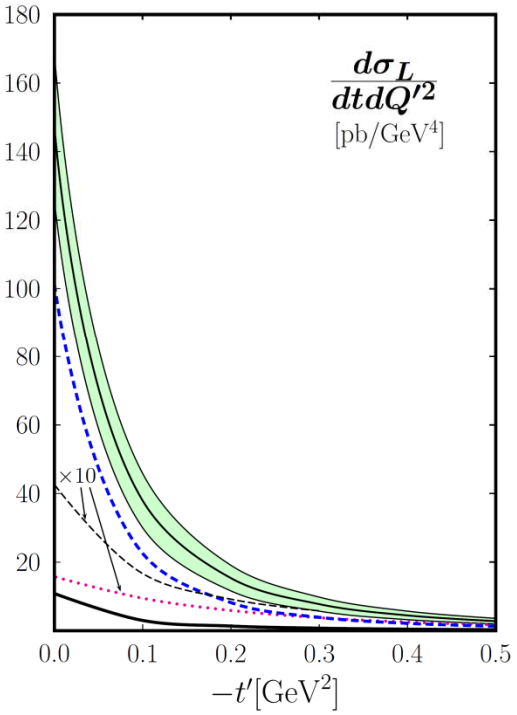
$Q'^2 = 5\ \mathrm{GeV}^2$

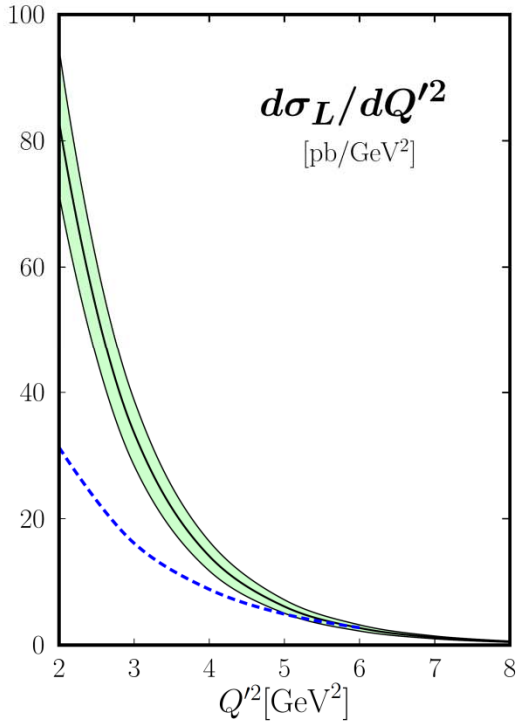


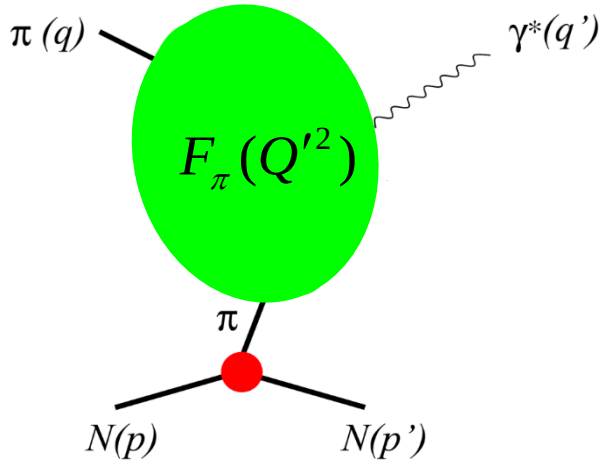


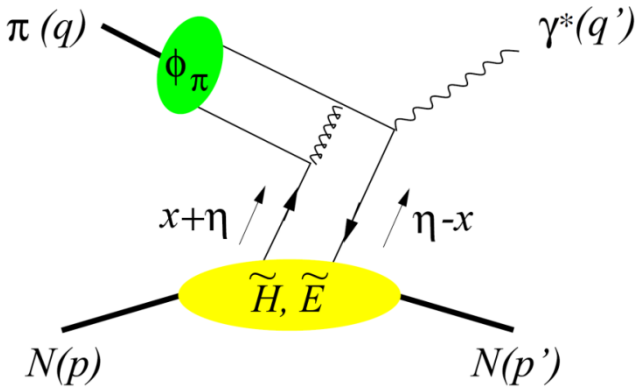
$$\frac{d\sigma}{dQ'^2\,dt}(\pi^- p \to \gamma^* n)$$
$$= \frac{4\pi\alpha_{\mathrm{em}}^2}{27}\frac{\tau^2}{Q'^8} f_\pi^2 \left[(1-\eta^2)\,|\,\widetilde{\mathscr{H}}^{du}\,|^2 - 2\eta^2\,\mathrm{Re}\left(\widetilde{\mathscr{H}}^{du*}\,\widetilde{\mathscr{E}}^{du}\right) - \eta^2\,\frac{t}{4M^2}\,|\,\widetilde{\mathscr{E}}^{du}\,|^2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

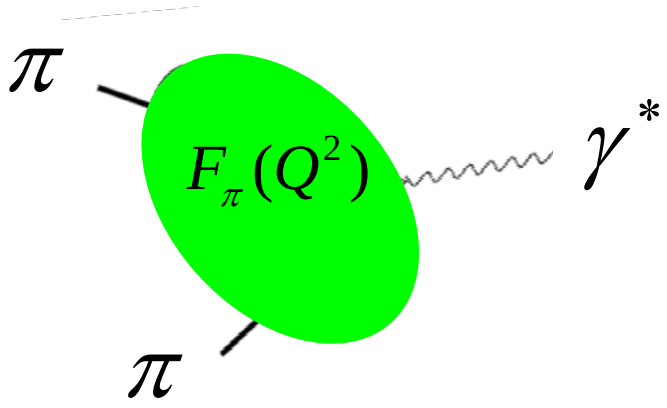
Goloskokov, Kroll ('15)

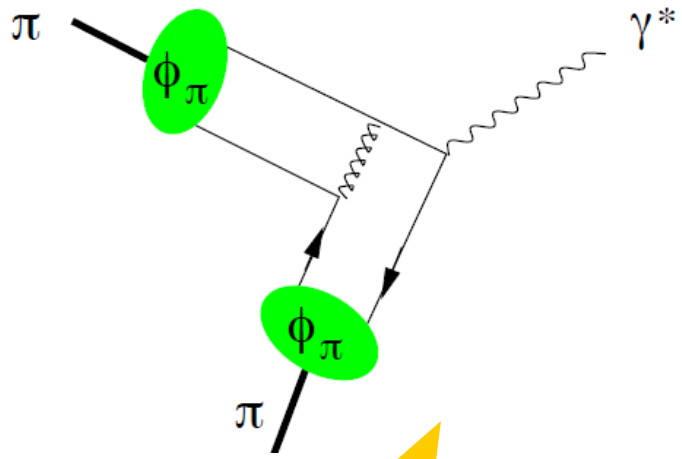




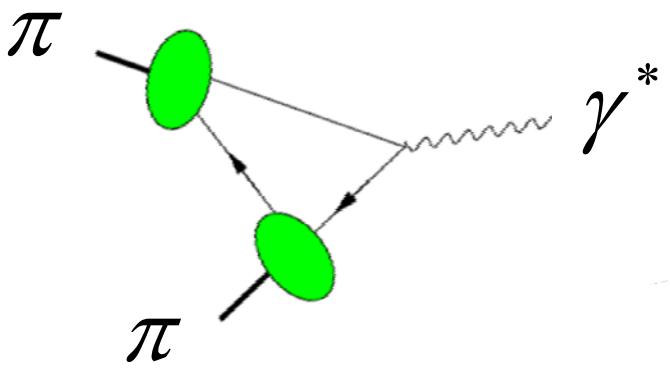






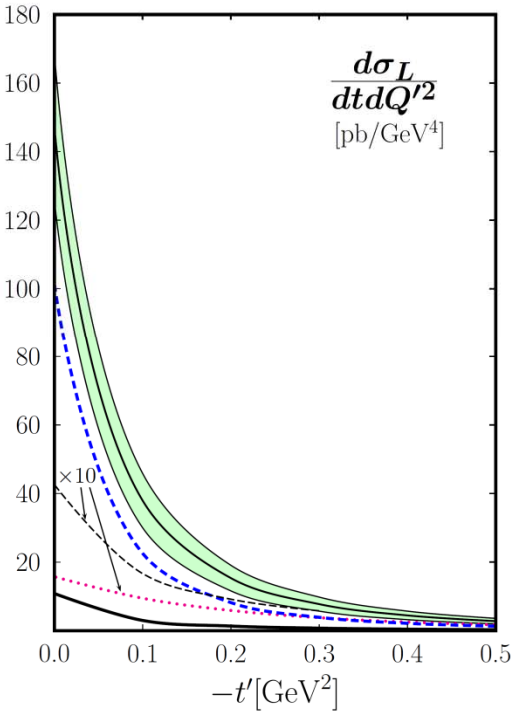


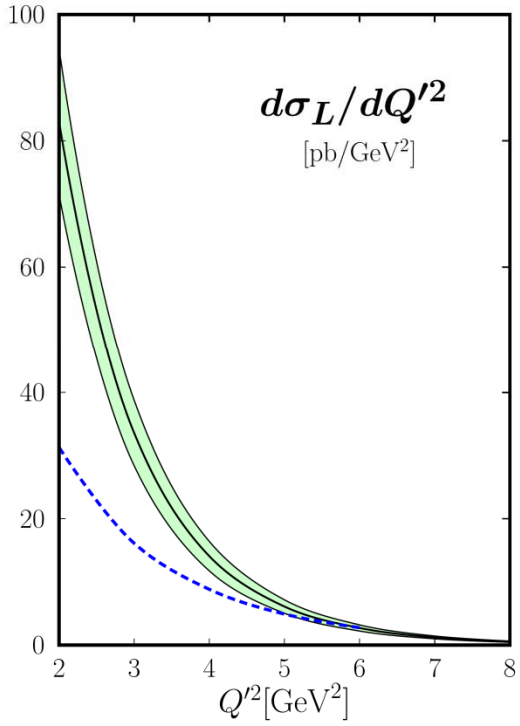
LO in QCD factorization

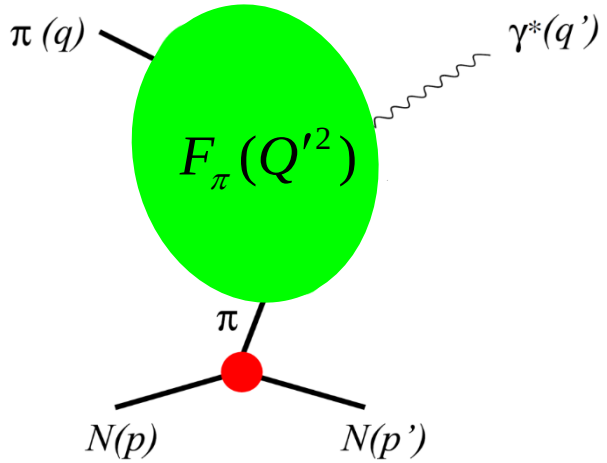


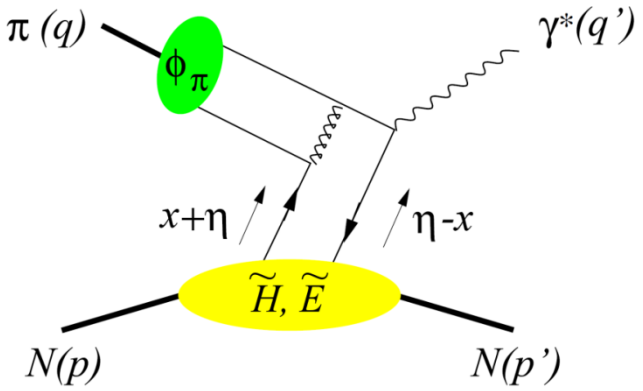
"nonfactorizable" Feynman mechanism

Goloskokov, Kroll ('15)

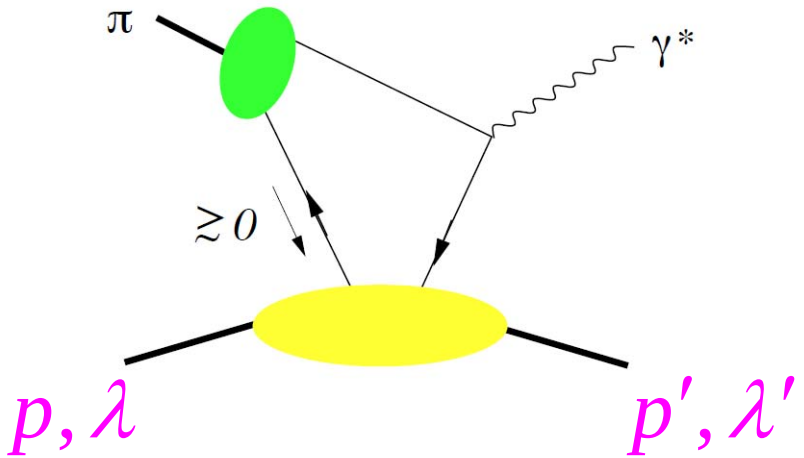


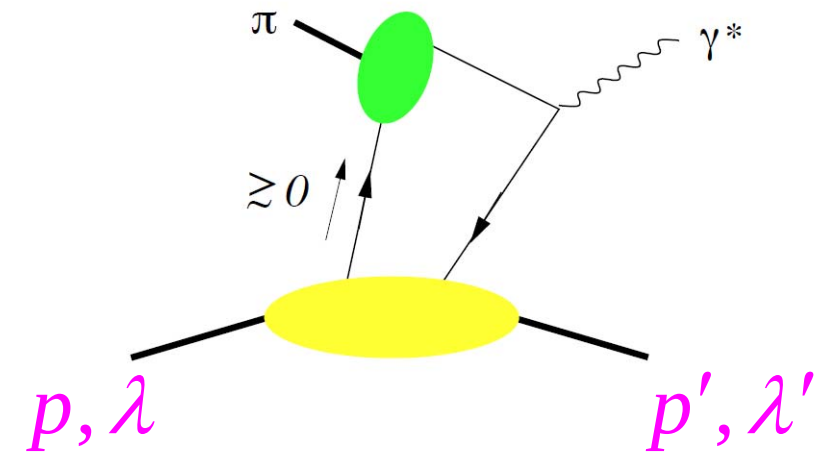






"nonfactorizable" mechanism





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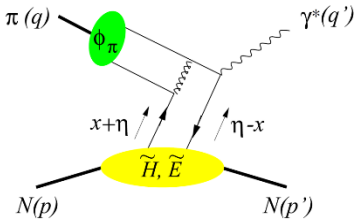
Summary

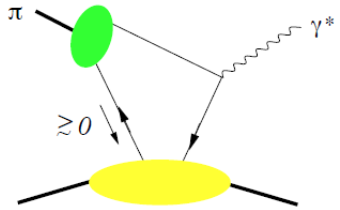
exDY ($\pi^- p \to \gamma^* n \to \mu^+ \mu^- n$) @J-PARC

GPDs



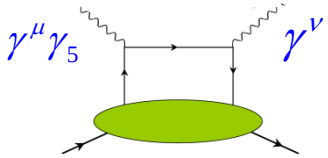
estimate with QCD factorization & feasibility study

T. Sawada, W.C. Chang, S. Kumano, J.C. Peng, S. Sawada, KT
PRD93, 114034



soft nonfactorizable mechanism (SNM)

LCSR



$\tilde{H}$, $\tilde{E}$, x_0

SNM α_s^0 > QCD factorization α_s^2

interplay of soft/hard QCD mechanism