On spacelike vs timelike probe in exclusive reactions

GDR 2011 ORSAY , October 2011

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based on work done with

JP Lansberg, K Semenov-Tian-Shansky, L Szymanowski, J Wagner

Phys Rev D 2007 ; Phys Rev D 2010 ; Phys Rev D 2011

DVCS vs TCS

$$\gamma^*(q)N(p) \to \gamma^*(q')N'(p')$$

spacelike $q^2 < 0$; $q'^2 = 0$ **vs timelike** $q^2 = 0$; $q'^2 > 0$

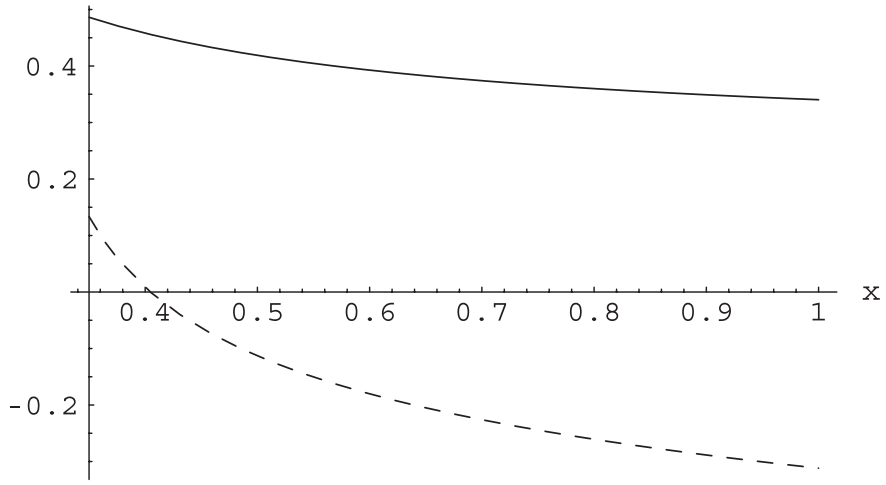
$$\mathcal{A}^{\mu\nu} = g_T^{\mu\nu} \int_{-1}^{1} dx \left[\sum_q^{n_F} T^q(x) F^q(x) + T^g(x) F^g(x) \right]$$

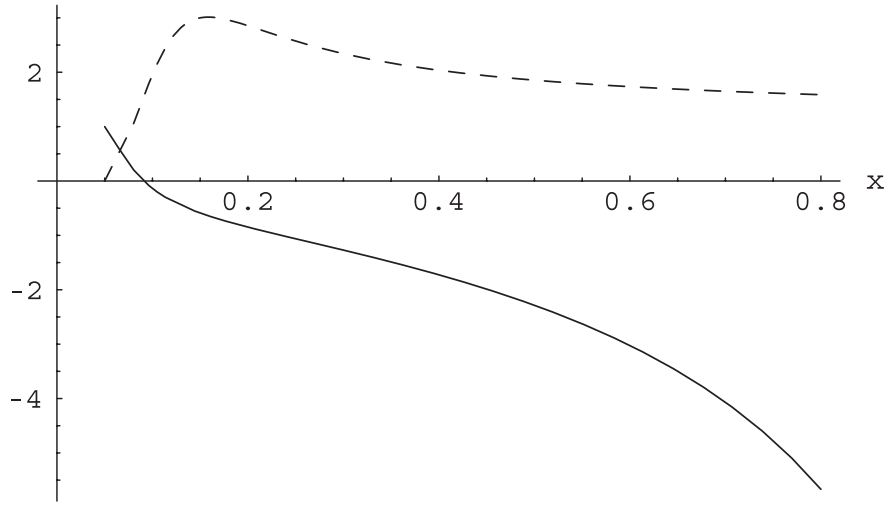
$$\begin{aligned} T^q &= C_0^q + C_1^q + \frac{1}{2} \ln\left(\frac{|Q^2|}{\mu_F^2}\right) \cdot C_{coll}^q \\ T^g &= C_1^g + \frac{1}{2} \ln\left(\frac{|Q^2|}{\mu_F^2}\right) \cdot C_{coll}^g \,. \end{aligned}$$

LO : $\mathcal{A}_{DVCS} = \mathcal{A}^*_{TCS} = C_0^q = e_q^2 \left(\frac{1}{x-\xi+i\epsilon} + \frac{1}{x+\xi-i\epsilon}\right)$

NLO : $\mathcal{A}_{DVCS} \neq \mathcal{A}^*_{TCS}$

$$\frac{{C^q_{1(TCS)}}^* - C^q_{1(DVCS)}}{\frac{e^2\alpha_S C_F}{4\pi}} = \frac{1}{x-\xi+i\varepsilon}\left[\left(3-2\log 2+2\log|1-\frac{x}{\xi}|\right)(i\pi)+\pi^2\left(1+\theta(x-\xi)-\theta(-x+\xi)\right)\right]$$
$$+ \frac{1}{x+\xi-i\varepsilon}\left[\left(3-2\log 2+2\log|1+\frac{x}{\xi}|\right)(i\pi)+\pi^2\left(1+\theta(-x-\xi)-\theta(x+\xi)\right)\right]$$





$$R^q_{T-S} = \frac{C^q_{1(\mathrm{TCS})} - C^{q*}_{1(\mathrm{DVCS})}}{C^q_0}.$$

$\frac{TCS\ \ gluon\ \ correction}{DVCS\ \ gluon\ \ correction}$ $\xi = 0.05$

$\xi = 0.3 \quad \alpha_s = 0.25$

➪ Both timelike and spacelike data useful to check NLO analysis !

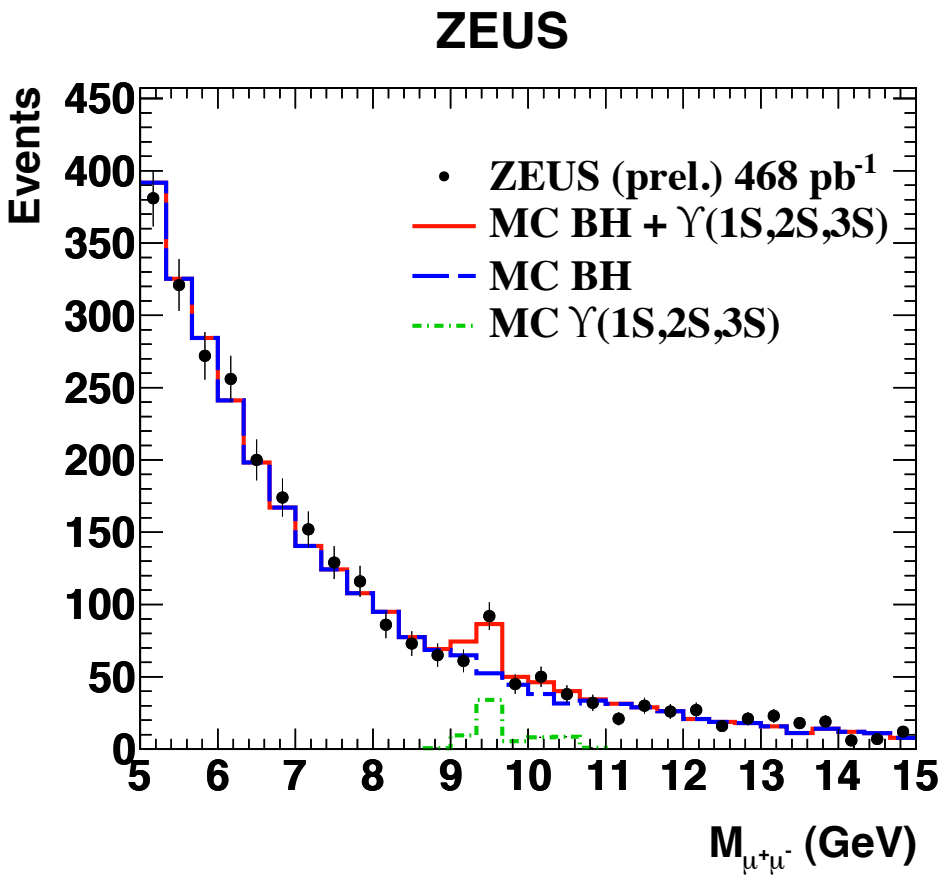
work in progress : Hervé Moutarde, Franck Sabatié and Jakub Wagner

provisionnal conclusion : numerics are subtle, mistakes are easy ...

➪ NLO corrections are sizeable but not huge

➪ π^2 terms cry for resummation : in progress with Tolga Altinoluk

New data on timelike dvcs (?)



from G. Grzelak, DIS 2011.

Exclusive di-muon candidates

⇨ more to come from JLab, Hermes, Compass

⇨ next electron - ion collider

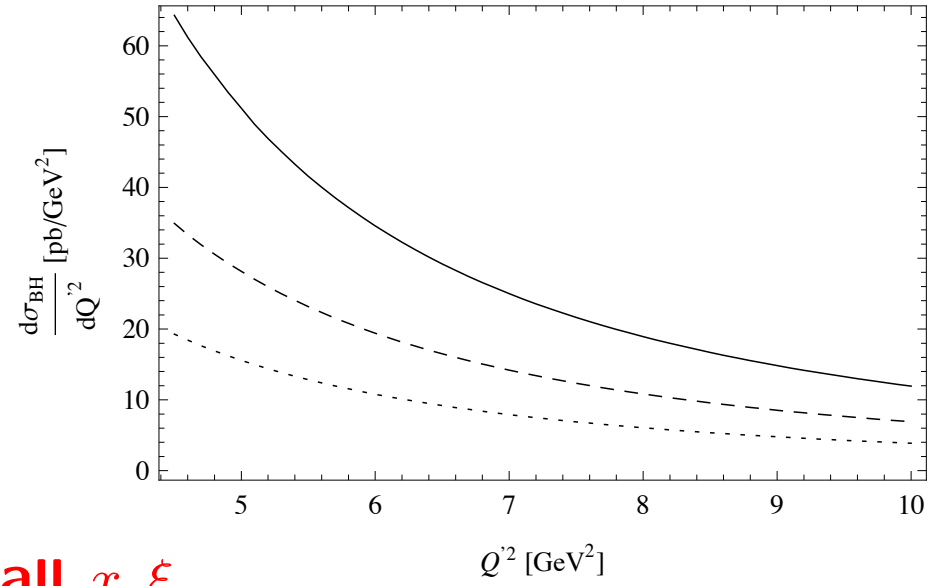
GPDs at LHC (and RHIC)

➪ **Ultraperipheral Collisions : quasi real photons from proton beam**

Bethe Heitler process

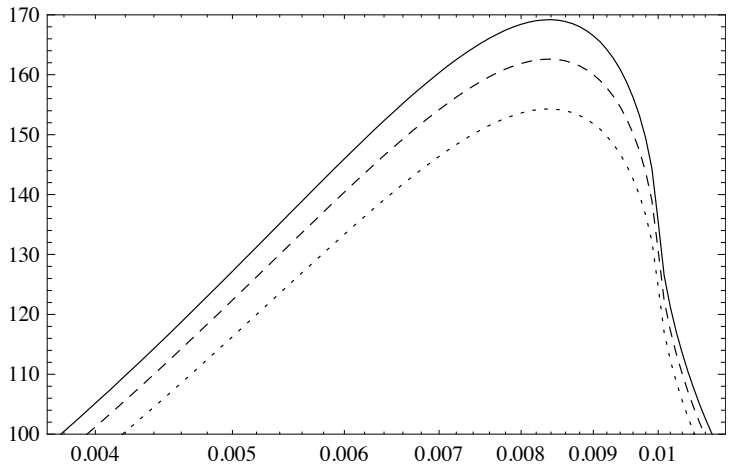
= large background

$s_{\gamma p} = 10^5\ GeV^2$



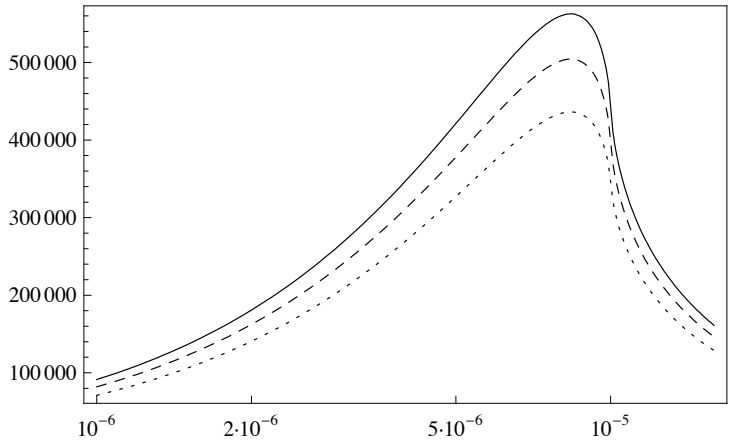
but GPDs are large at small x, ξ

(a)



$\xi = 10^{-2}$

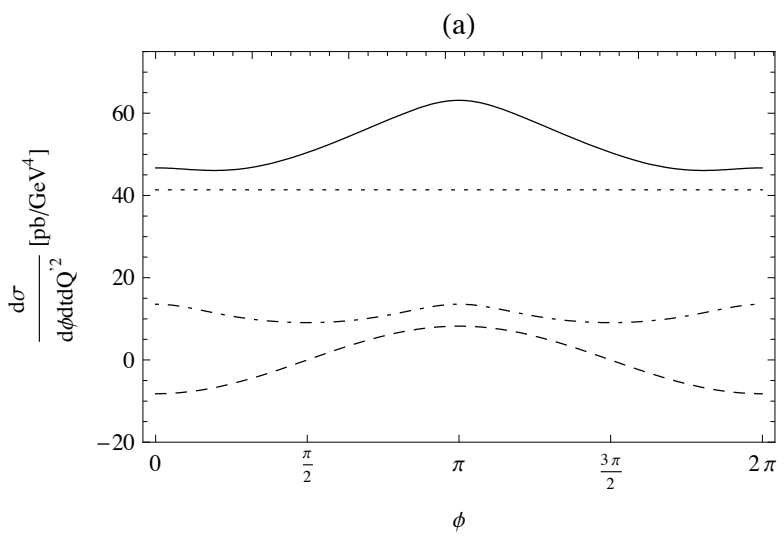
(b)

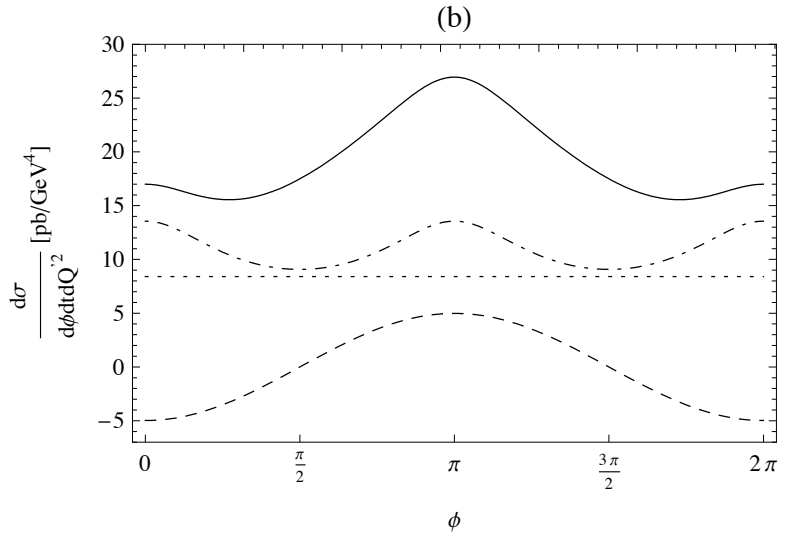


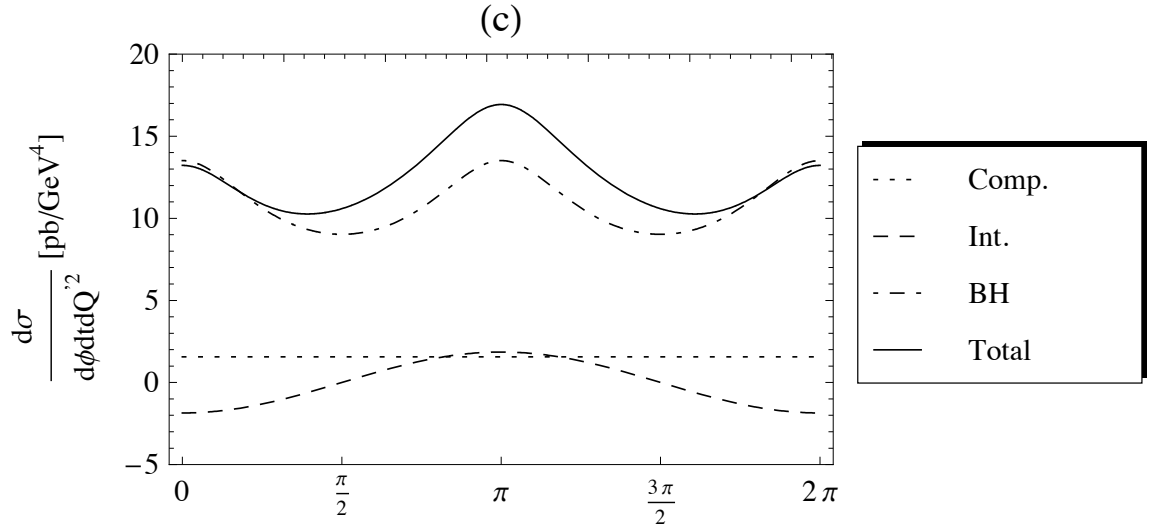
$\xi = 10^{-5}$

Observing TCS at LHC

⇨ Characteristic signal from interference (charge conj. odd)

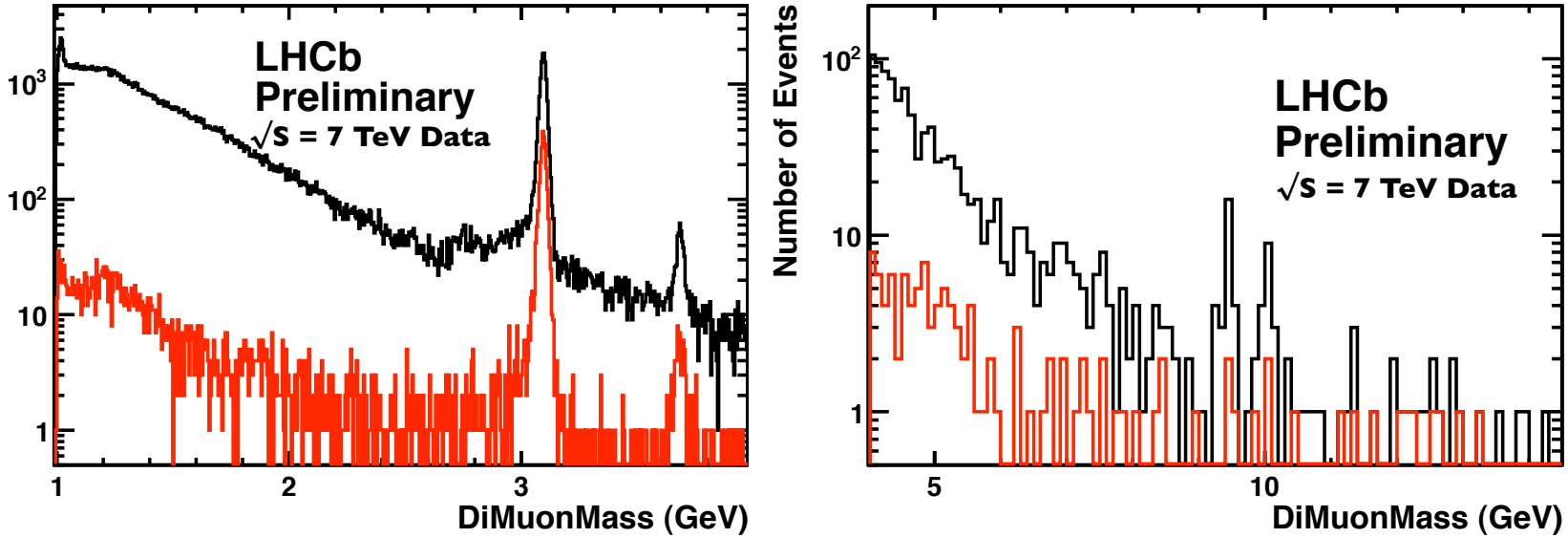






$s_{\gamma p} = 10^7\ GeV^2$ $s_{\gamma p} = 10^5\ GeV^2$ $s_{\gamma p} = 10^3\ GeV^2$ $Q'^2 = 5\ GeV^2$

First data

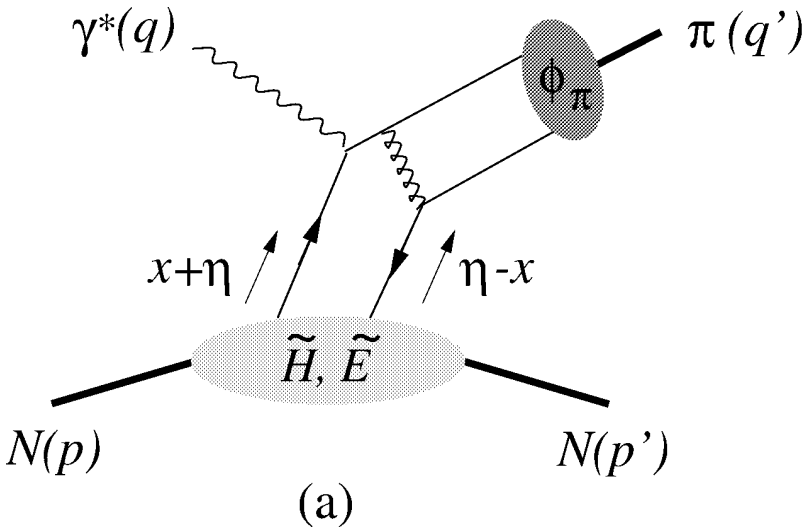


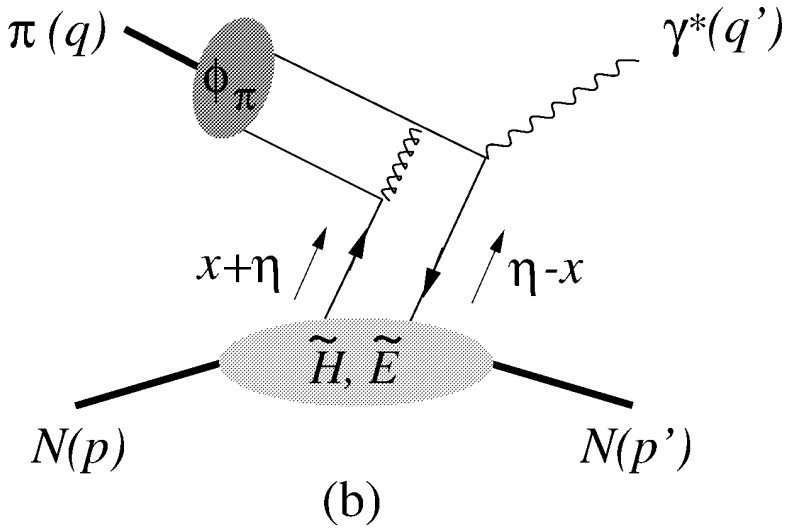
D. Moran, DIS 2011

$\gamma^* N \to \pi N'$ and $\pi N \to \gamma^* N'$

E.Berger,M.Diehl,BP,Phys Lett.B523

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





spacelike

timelike

(= Exclusive Limit of Drell Yan process)

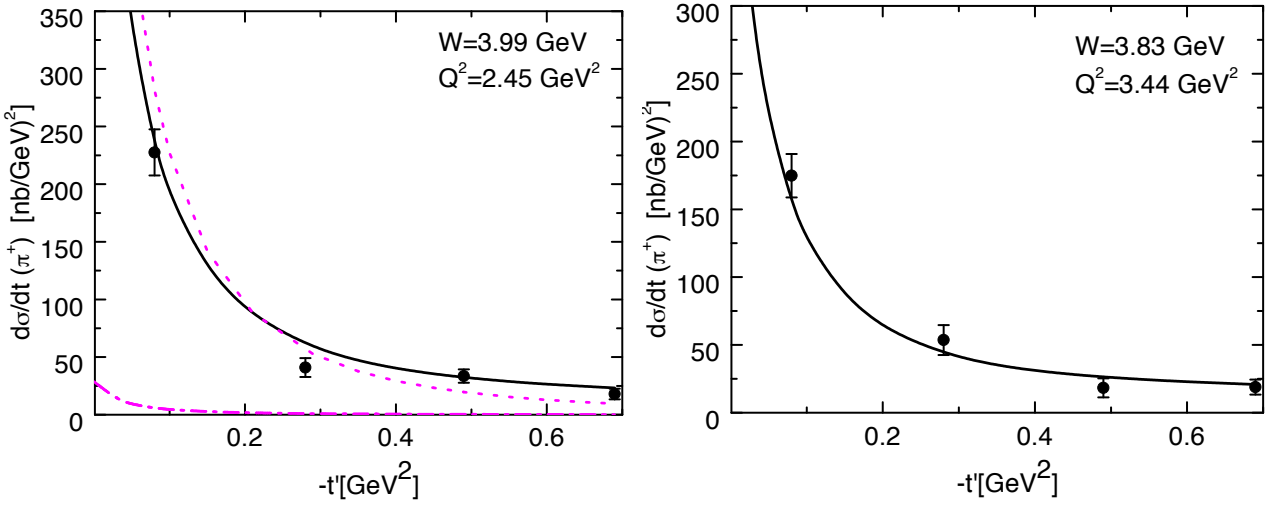
COMPASS with μ beams $\Longleftrightarrow$ **COMPASS with π beams**

JLab with e beams

Status of spacelike $\gamma^*(Q)p \to \pi N$

Data from HERMES :

$\sigma_T + \epsilon\sigma_L$ σ_T **vs** σ_L **?**



(also data from JLab)

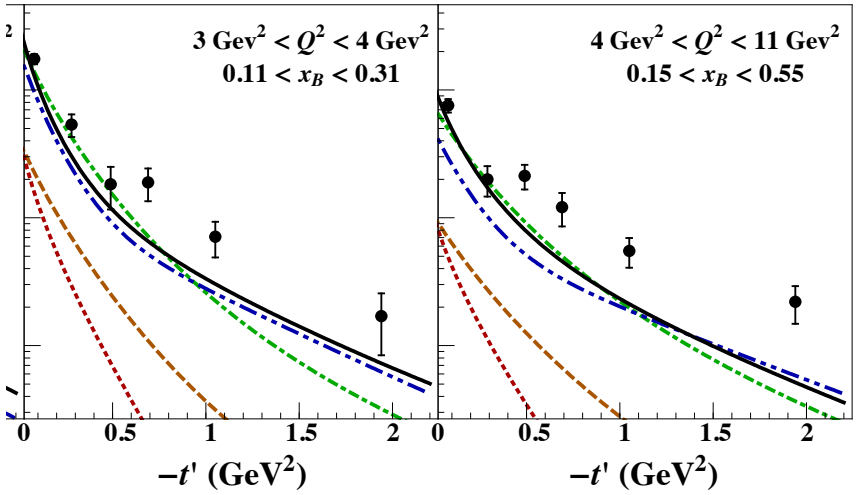
2 contradictory phenom. analysis

π-exchange with exp FF ;

S. Goloskokov and P.Kroll, EPJ, C65

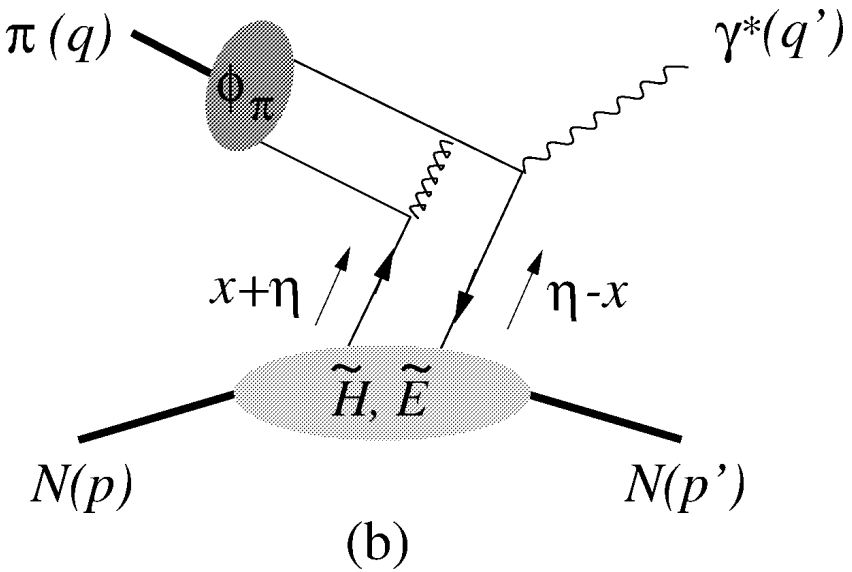
QCD with $\alpha_S = .8$

C. Bechler, D. Muller, ArXiv 0906.2571



Exclusive lepton pair production in πN scattering

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



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

skewness $\eta = \frac{(p - p')^+}{(p + p')^+} = \frac{\tau}{2 - \tau}$

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

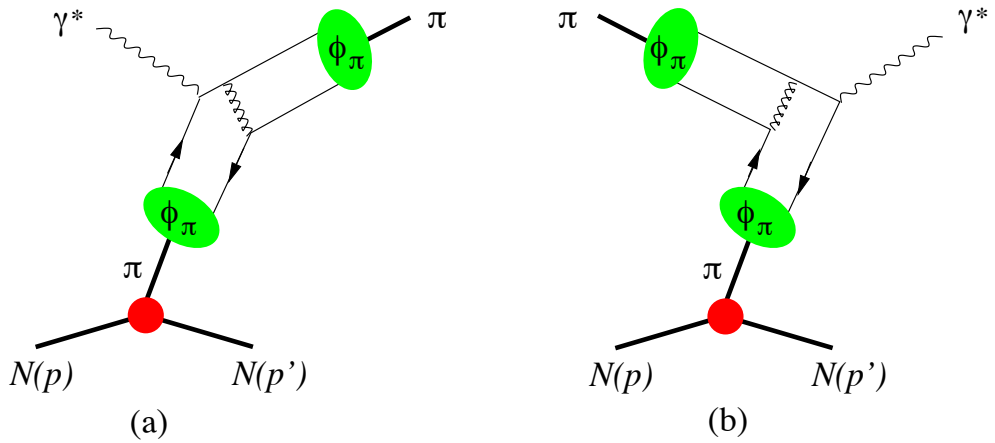
$$M^{0\lambda',\lambda}(\pi^- p \to \gamma^* n) = -ie\,\tfrac{4\pi}{3}\,\tfrac{f_\pi}{Q'}\,\tfrac{1}{(p+p')^+}\,\bar{u}(p',\lambda')\left[\gamma^+\gamma_5\,\tilde{\mathcal{H}}^{du}(\eta,t) + \gamma_5\tfrac{(p'-p)^+}{2M}\,\tilde{\mathcal{E}}^{du}(\eta,t)\right] u(p,\lambda)$$

$$\tilde{\mathcal{H}}^{du}(\eta,t) = \frac{8\alpha_S}{3}\int_{-1}^{1} dz\,\frac{\phi_\pi(z)}{1-z^2}\int_{-1}^{1} dx\,\left[\frac{e_d}{-\eta - x - i\epsilon} - \frac{e_u}{-\eta + x - i\epsilon}\right]\left[\tilde{H}^d(x,\eta,t) - \tilde{H}^u(x,\eta,t)\right]$$

$\tilde{H}$ and $\tilde{E}$ GPDs

⇨ $\tilde{H}(x, \xi = 0, t = 0) = \Delta q(x)$

⇨ $\tilde{E}$ **unknown : Pion pole dominance often assumed**



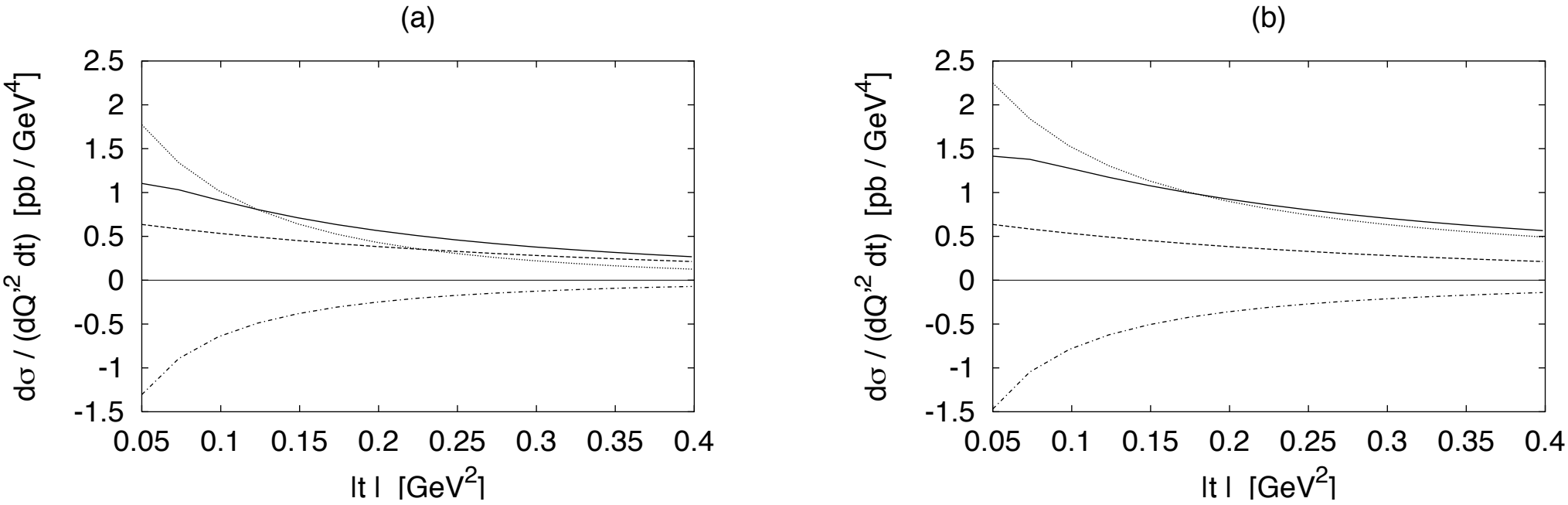
to be tested

⇨ $t-$**dependence** $\rightarrow$ **proton femtophotography**

LO Estimates

E.Berger,M.Diehl,BP,Phys Lett.B523

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



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

NLO analysis not done

At LO, space - and timelike amplitudes are related

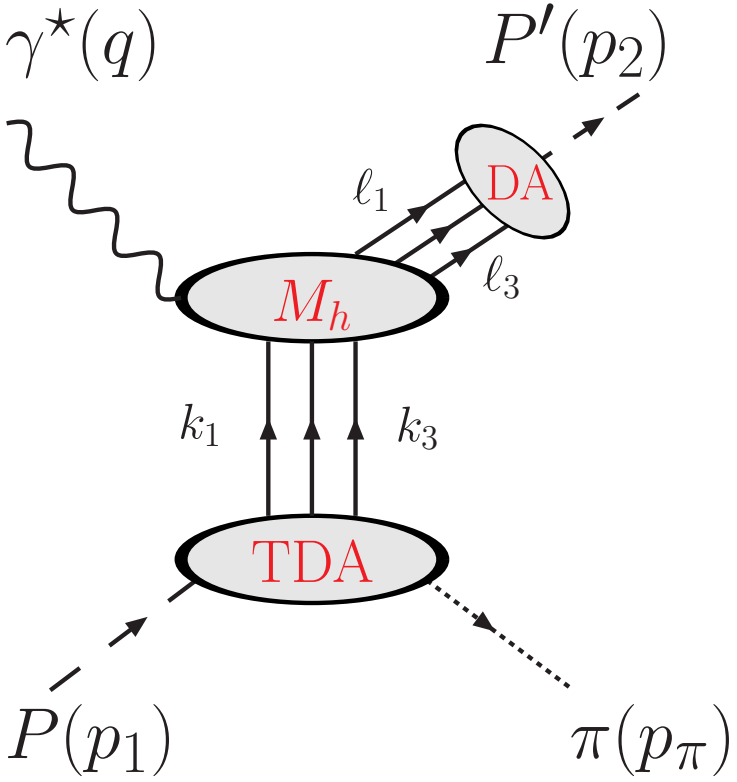
$$M^{0\lambda',\lambda}(\pi^- p \to \gamma^* n) = \left[M^{\lambda',0\lambda}(\gamma^* p \to \pi^+ n)\right]^*$$

At higher orders, significant differences expected

$\to$ critical check of the universality of GPDs and of factorization.

How to factorize backward leptoproduction $\gamma^* N \to N'\pi$

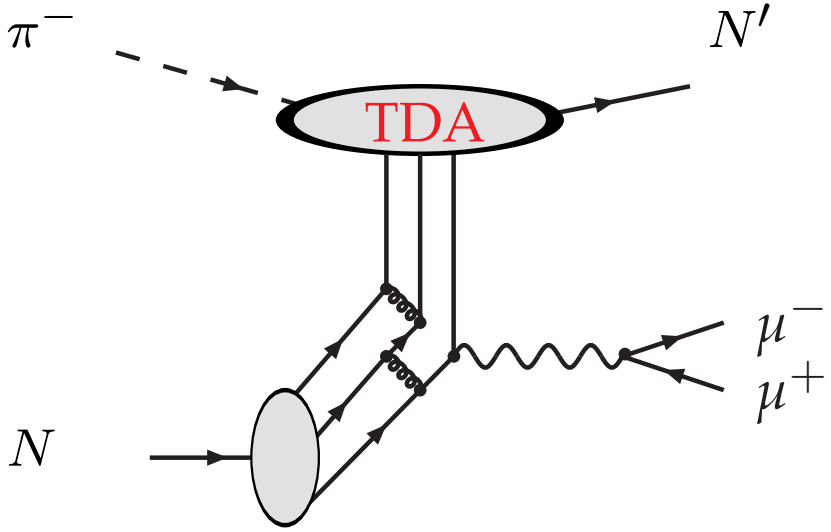
remember Kirill's presentation a few minutes ago



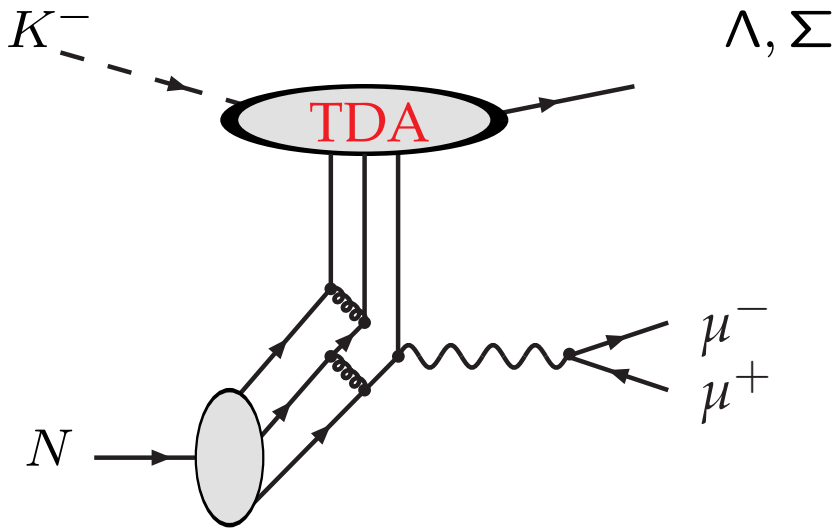
at large q^2, *small* $u = (p_1 - p_\pi)^2$, *fixed* $\xi = \frac{p^+_{N'} - p^+_\pi}{p^+_{N'} + p^+_\pi}$

$\rightarrow$ factorize timelike versions of backward $\gamma^* N \to N'\pi$

$\pi N \to N'\gamma^*(Q')$

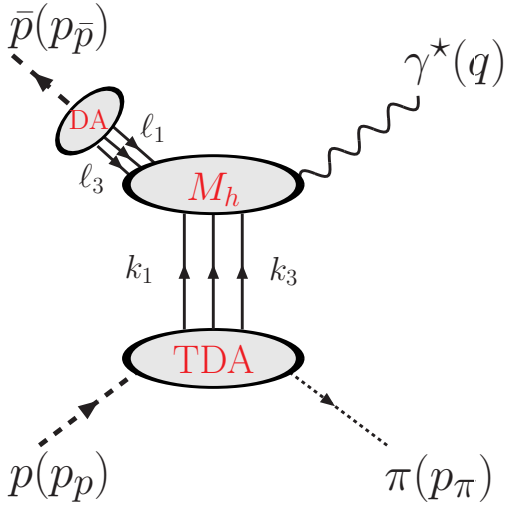


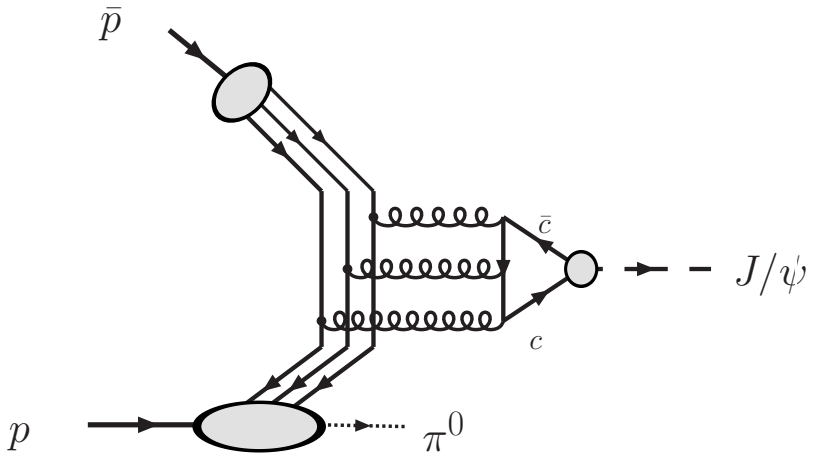
$K^- N \to \Lambda\gamma^*(Q')$



at large Q'^2, small $u = (p_{N'} - p_\pi)^2$, fixed ξ

and the PANDA@FAIR processes





$\bar{N}N \to \pi\gamma^* \to \pi e^+ e^-$

$\bar{N}N \to \pi\psi \to \pi e^+ e^-$

Interpretation of the $(\pi \to N) or (N \to \pi)$ TDAs

Develop proton wave function as (schematically) $|qqq> + \quad |qqq\pi> + ...$

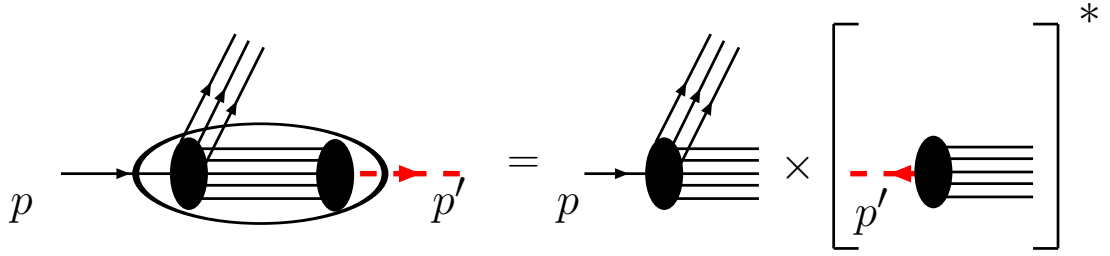
$|qqq>$ **is described by proton DA :** $\langle 0|\, \epsilon^{ijk} u^i_\alpha(z_1\, n) u^j_\beta(z_2\, n) d^k_\gamma(z_3\, n)\, |p(p,s)\rangle \Big|_{z^+=0,\, z_T=0}$

Define matrix elements sensitive to $|qqq\ \pi>$ **part : the TDAs**

$$\langle \pi(p')|\, \epsilon^{ijk} u^i_\alpha(z_1\, n) u^j_\beta(z_2\, n) d^k_\gamma(z_3\, n)\, |p(p,s)\rangle \Big|_{z^+=0,\, z_T=0}$$

light cone matrix elements of operators obeying usual RG evolution equations

⇨ The $\pi \to N$ TDAs provides information on the next to minimal Fock state in the baryon



$Proton = |u\ d\ d\ \pi^+>$ with small transverse separation for the quark triplet

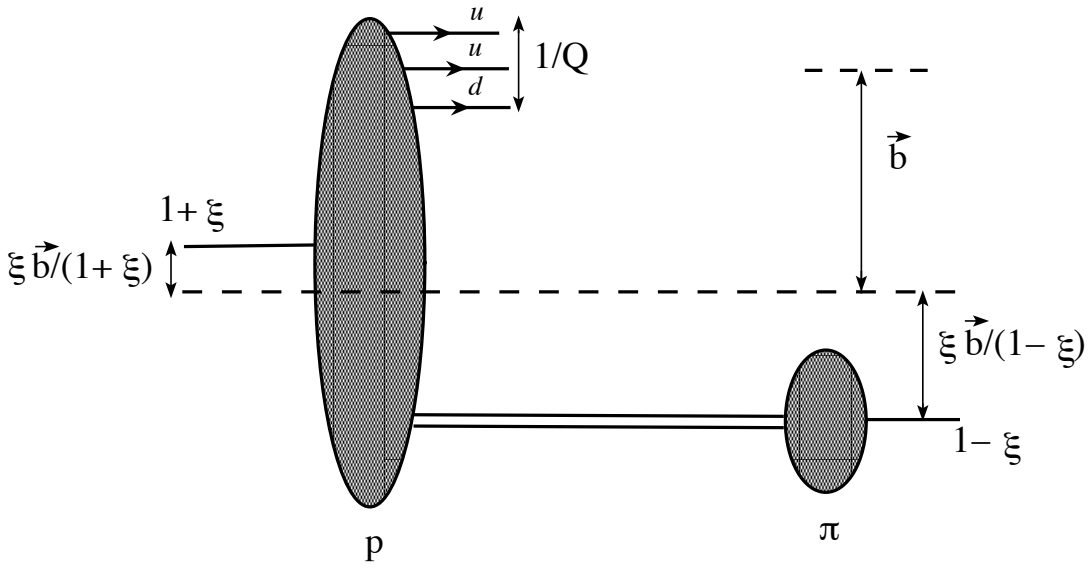
or *how one can find a meson in a proton*

Impact parameter interpretation

- **As for GPDs Fourier transform** $\Delta_T \to b_T$

$$F(x_i, \xi, u = \Delta^2) \to \tilde{F}(x_i, \xi, b_T)$$

$\to$ **Transverse picture of pion cloud in the proton**



if factorization works

Conclusions

GPDs and TDAs explore confinement dynamics of quarks in hadrons in a complementary way.

GPDs extraction needs more understanding of NLO corrections

- ⇨ **Timelike Compton Scattering = a useful complement to dVCS**
- ⇨ **Exclusive Drell-Yan with π and K beams complements DEMP**

TDAs extraction is crucial to probe meson content of baryons

- ⇨ **First signals at JLab at 6 GeV + CLAS12 : spacelike channels**
- ⇨ **PANDA @FAIR and π beam : timelike channels**