Exclusive photoproduction of a lepton pair (TCS) Nucleon and Nuclear Generalized Gluon distributions

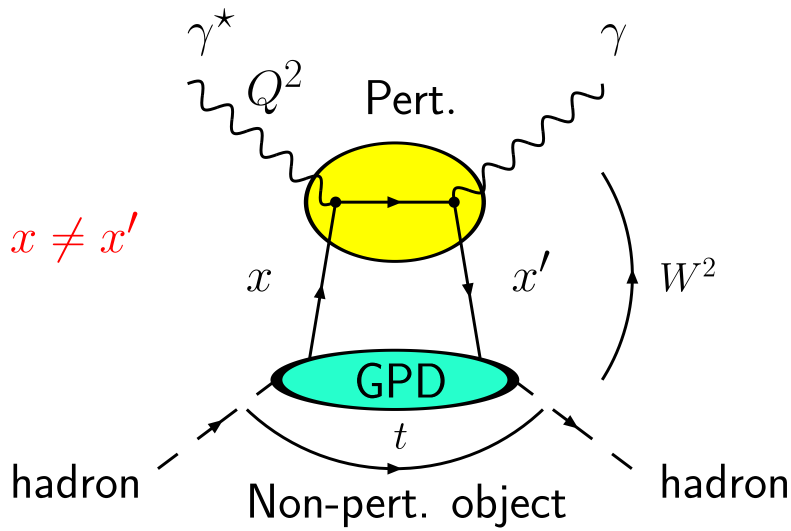
High Energy Photon Collisions at the LHC - CERN - 24 avril 2008

B. Pire
CPhT, École Polytechnique , CNRS , Palaiseau

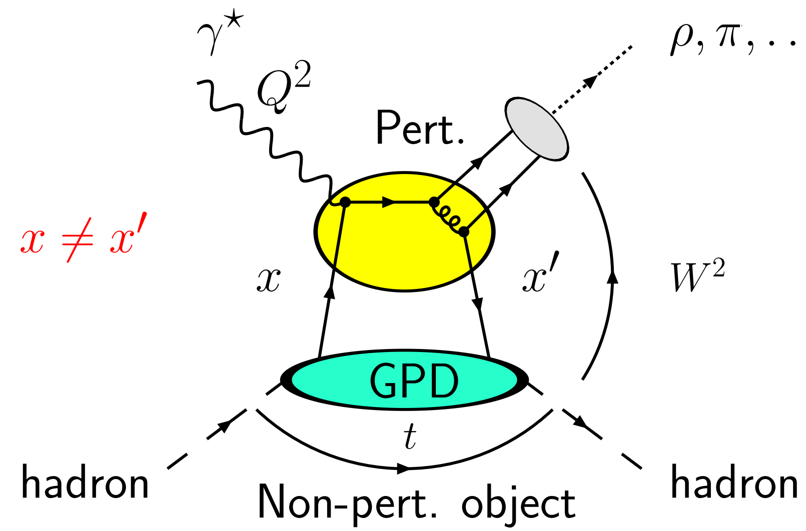
from work with L. Szymanowski, M. Diehl, J. Wagner ...

QCD factorization in Exclusive processes

DVCS



Meson Production



➩ Factorisation between a hard part (perturbatively calculable) and a soft part (non-perturbative) *Generalized Parton Distribution*

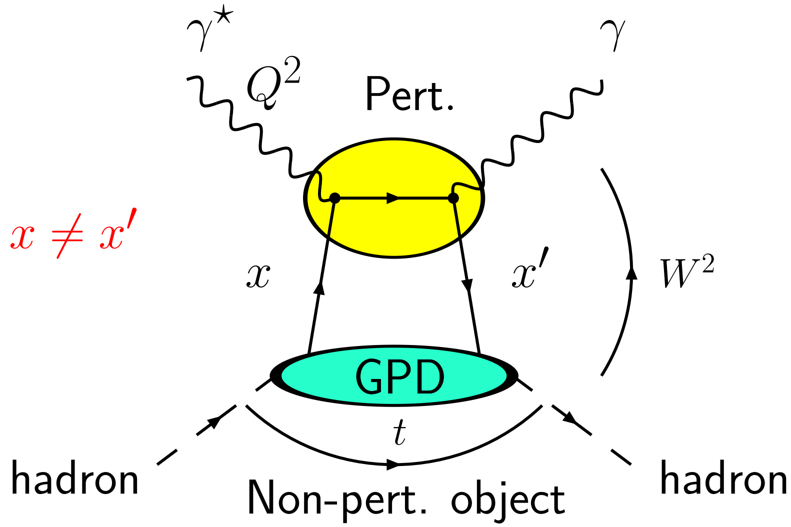
demonstrated for $Q^2 \to \infty$, $x_B = \frac{Q^2}{Q^2+W^2}$ fixed , t small

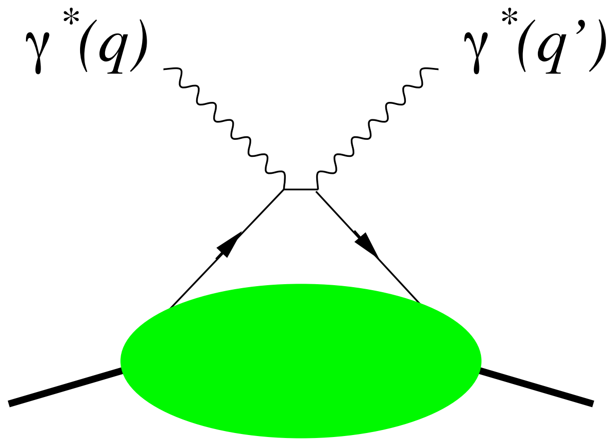
experimentally shown for $Q^2 > 2GeV^2$, at HERA and JLab

Generalised Parton Distributions

Same operators as in DIS but non diagonal matrix elements
= soft part of the amplitude for exclusive reactions

$x \neq x'$





$H(x, \xi, t) =$ **Fourier Transform of matrix elements**

$$\langle N(p', \lambda')|\bar{\psi}(-z/2)_\alpha[-z/2; z/2]\psi(z/2)_\beta|N(p, \lambda)\rangle\Big|_{z^+=0,\, z_T=0}$$

$p' - p = \Delta$ $\quad \Delta^2 = t$ $\quad \Delta^+ = -\xi(p + p')^+$ $\quad x - x' = 2\xi$

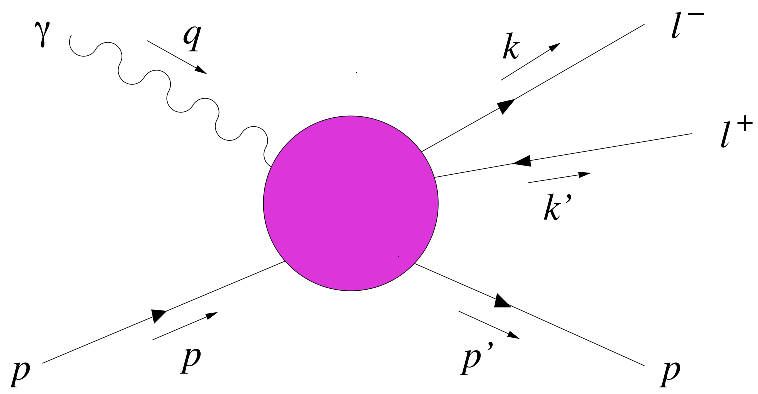
From spacelike to Timelike

Initial Photon Beam allows to study crossed reaction.

At lowest order, same amplitude $\rightarrow$ critical check of the universality of GPDs.

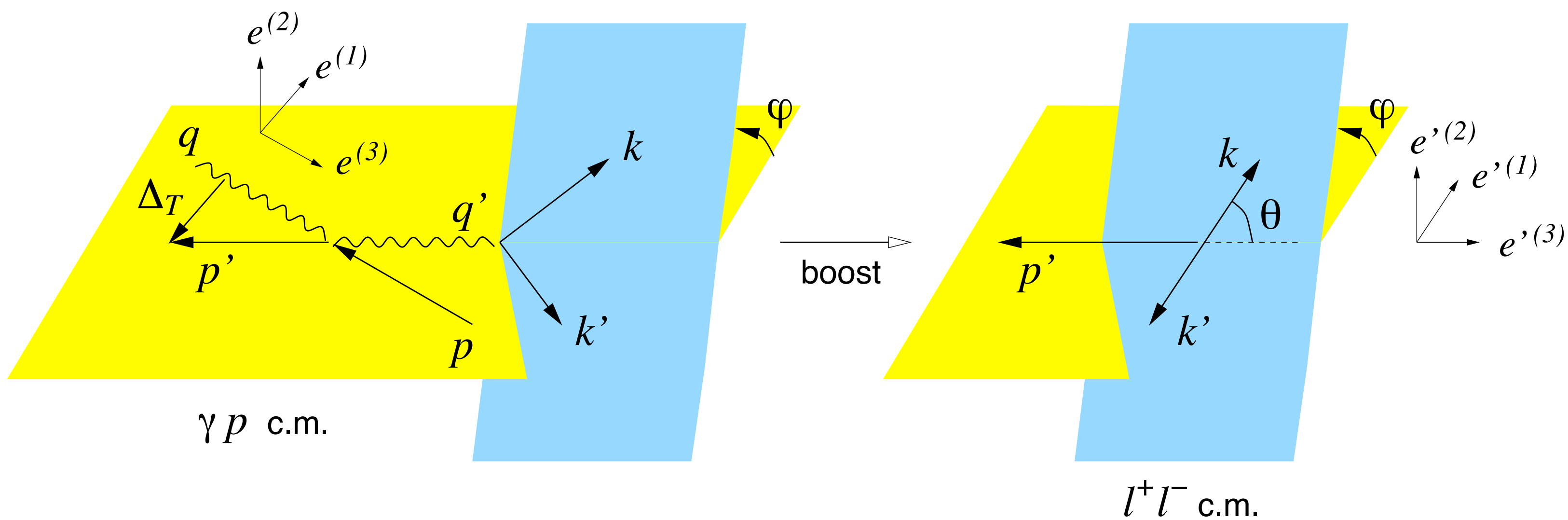
At higher orders, significant differences under control thanks to analitycity properties.

Kinematics of exclusive lepton pair production

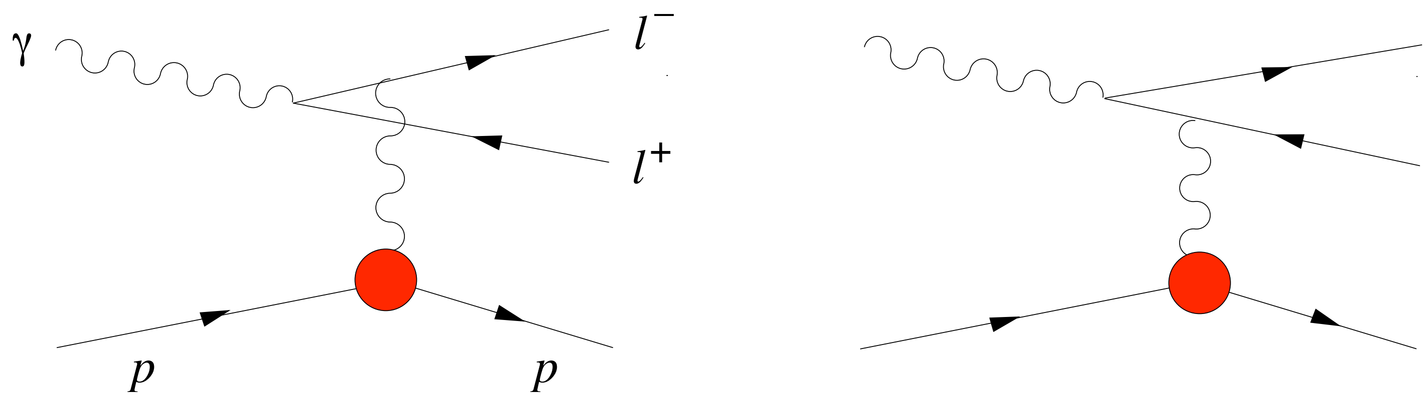


$$\tau = \frac{(k+k')^2}{s-M^2}$$

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



Bethe-Heitler process



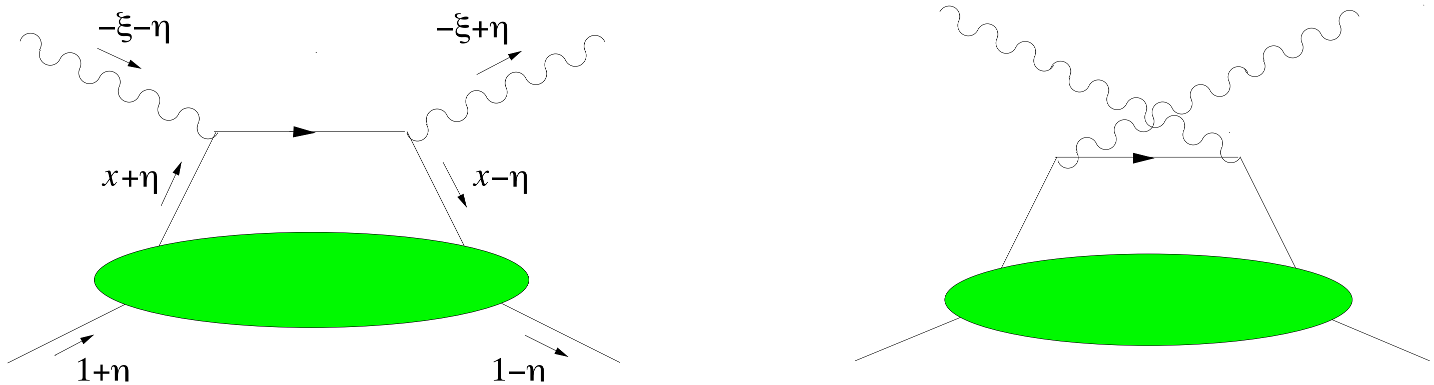
$$\frac{d\sigma_{BH}}{dQ'^2\, dt\, d(\cos\theta)\, d\varphi} \approx \frac{\alpha_{em}^3}{2\pi s^2} \frac{1}{-t} \frac{1+\cos^2\theta}{\sin^2\theta} \left[\left(F_1^2 - \frac{t}{4M^2} F_2^2 \right) \frac{2}{\tau^2} \frac{\Delta_T^2}{-t} + (F_1 + F_2)^2 \right].$$

restrict to $\sin^2\theta > 1/2$ **to keep B-H far from** $\frac{1}{sin^2\theta}$ **singularity**

$\frac{\Delta_T^2}{-t} \approx 1$ $\rightarrow$ **first term dominant at small** τ

$\rightarrow$ **B-H Cross section almost constant in** s **at fixed** Q^2

The TCS amplitude at lowest order



The hadronic tensor is $T^{\alpha\beta} = i\int d^4x\, e^{-iq\cdot x}\langle p(p')|\, T J^\alpha_{em}(x) J^\beta_{em}(0)\, |p(p)\rangle =$

$$-\frac{1}{(p+p')^+}\,\bar{u}(p')\left[g_T^{\alpha\beta}\left(\mathcal{H}_1\,\gamma^+ + \mathcal{E}_1\,\frac{i\sigma^{+\rho}\Delta_\rho}{2M}\right) + i\epsilon_T^{\alpha\beta}\left(\tilde{\mathcal{H}}_1\,\gamma^+\gamma_5 + \tilde{\mathcal{E}}_1\,\frac{\Delta^+\gamma_5}{2M}\right)\right] u(p)$$

with

$$\mathcal{H}_1(\xi,\eta,t) = \sum_q e_q^2 \int_{-1}^{1} dx \left(\frac{1}{\xi - x - i\epsilon} - \frac{1}{\xi + x - i\epsilon}\right) H^q(x,\eta,t)...$$

$H^q(x,\eta,t)$ **is the quark GPD in the target**

TCS : $-\xi = \eta = \frac{\tau}{2-\tau}$

Resulting cross-section at LO

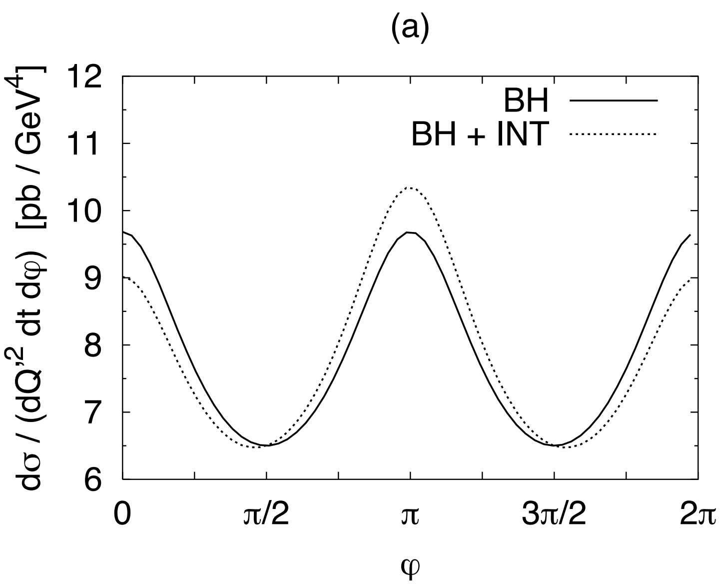
$$\frac{d\sigma_{TCS}}{dQ'^2\,dt\,d(\cos\theta)\,d\varphi} \approx \frac{\alpha_{em}^3}{8\pi s^2}\,\frac{1}{Q'^2}\,\frac{1+\cos^2\theta}{4}\sum_{\lambda,\lambda'}|M^{\lambda'-,\lambda-}|^2.$$

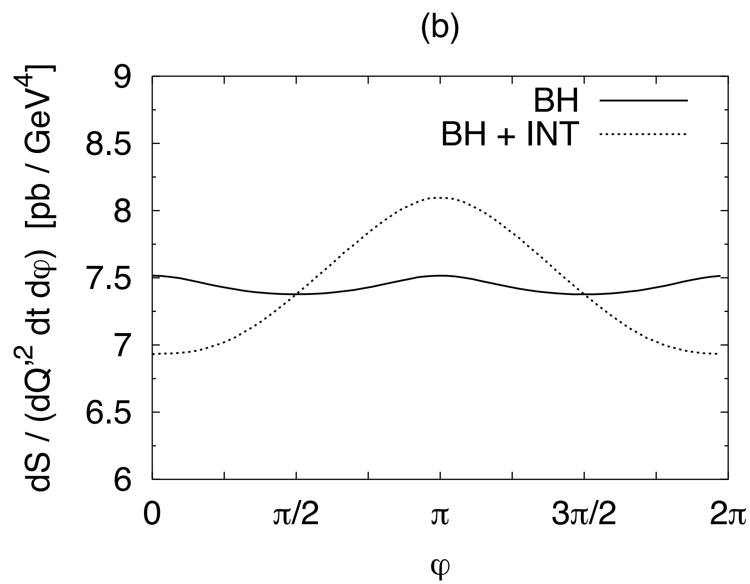
$$\frac{1}{2}\sum_{\lambda,\lambda'}|M^{\lambda'-,\lambda-}|^2 \;=\; (1-\eta^2)\Big(|\mathcal{H}_1|^2+|\tilde{\mathcal{H}}_1|^2\Big)-2\eta^2\,\mathbf{Re}\Big(\mathcal{H}_1^*\,\mathcal{E}_1+\tilde{\mathcal{H}}_1^*\,\tilde{\mathcal{E}}_1\Big) - \left(\eta^2+\frac{t}{4M^2}\right)|\mathcal{E}_1|^2-\eta^2\frac{t}{4M^2}\,|\tilde{\mathcal{E}}_1|^2,$$

where $\mathcal{H}_1$, $\tilde{\mathcal{H}}_1$, $\mathcal{E}_1$, $\tilde{\mathcal{E}}_1$ are to be evaluated at $-\xi=\eta$.

Results at low energy

cf. E. Berger, M. Diehl, B.P., Eur. Phys. J. C 23, 675 (2002)





B-H dominant ; TCS dominated by quark GPDs

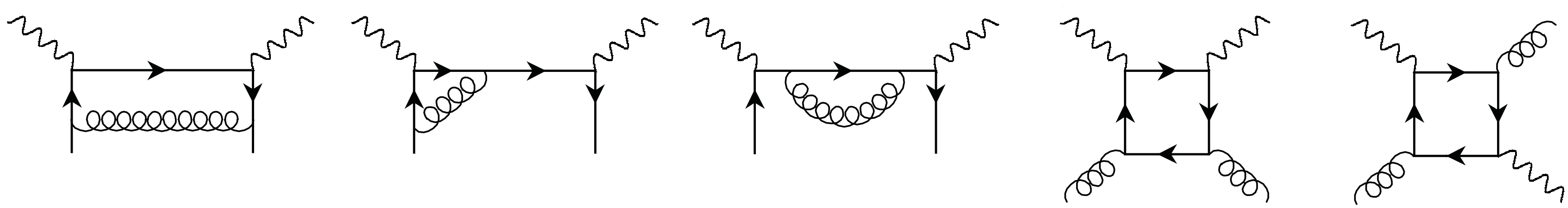
Charge asymmetry $\sim$ interference of B-H and TCS contributions

Factorization at NLO

$$\mathscr{F}_i(\xi, \eta, \Delta^2; Q^2) = \sum_{a=q,g} \int_{-1}^{1} \mathrm{d}x\, C_i^{a[-]}(x, \xi, \eta; Q^2/\mu^2) F^a(x, \eta, \Delta^2; \mu^2) + \mathscr{O}(Q^{-2}) \; ,$$

$F^q, F^g =$ **Quark and Gluon GPDs** $(\xi = -\eta)$

$$C_i^{a[\pm]}(x, \xi, \eta; Q^2/\mu^2) = C_{i\,(0)}^{a[\pm]}(x, \xi) + \frac{\alpha_s}{2\pi} C_{i\,(1)}^{a[\pm]}(x, \xi, \eta; Q^2/\mu^2) + \mathscr{O}(\alpha_s^2) \; .$$



Coefficient Functions

cf. Belitsky-Radyushkin, Phys. Rep. 418 (2005)

$$C^{q[\pm]}_{i(1)}(x,\xi,\eta;Q^2/\mu^2) \equiv C_F\, Q_q^2 \left[c^{q[\pm]}_{i(1)}(x,\xi,\eta) + \kappa^{q[\pm]}_{i(1)}(x,\xi,\eta)\ln(Q^2/\mu^2) \right] ,$$

$$C^{g[\pm]}_{i(1)}(x,\xi,\eta;Q^2/\mu^2) \equiv 2T_F \sum_q Q_q^2 \left[c^{g[\pm]}_{i(1)}(x,\xi,\eta) + \kappa^{g[\pm]}_{i(1)}(x,\xi,\eta)\ln(Q^2/\mu^2) \right] .$$

$$\begin{aligned} c^{g[-]}_{1(1)}(x,\eta,\xi) = {} & \frac{4\xi^2 - 4x\xi + x^2 - \eta^2}{2(x^2-\eta^2)^2} \ln\left(1 - \frac{x}{\xi}\right) - \frac{2\xi^2 - 2x\xi + x^2 - \eta^2}{4(x^2-\eta^2)^2} \ln^2\left(1 - \frac{x}{\xi}\right) \\ & + \frac{(\xi-\eta)(x^2 - 4\eta\xi - \eta^2)}{2\eta(x^2-\eta^2)^2} \ln\left(1 - \frac{\eta}{\xi}\right) - \frac{(\xi-\eta)(x^2 - 2\eta\xi - \eta^2)}{4\eta(x^2-\eta^2)^2} \ln^2\left(1 - \frac{\eta}{\xi}\right) \\ & + (\xi \leftrightarrow -\xi) \ . \end{aligned}$$

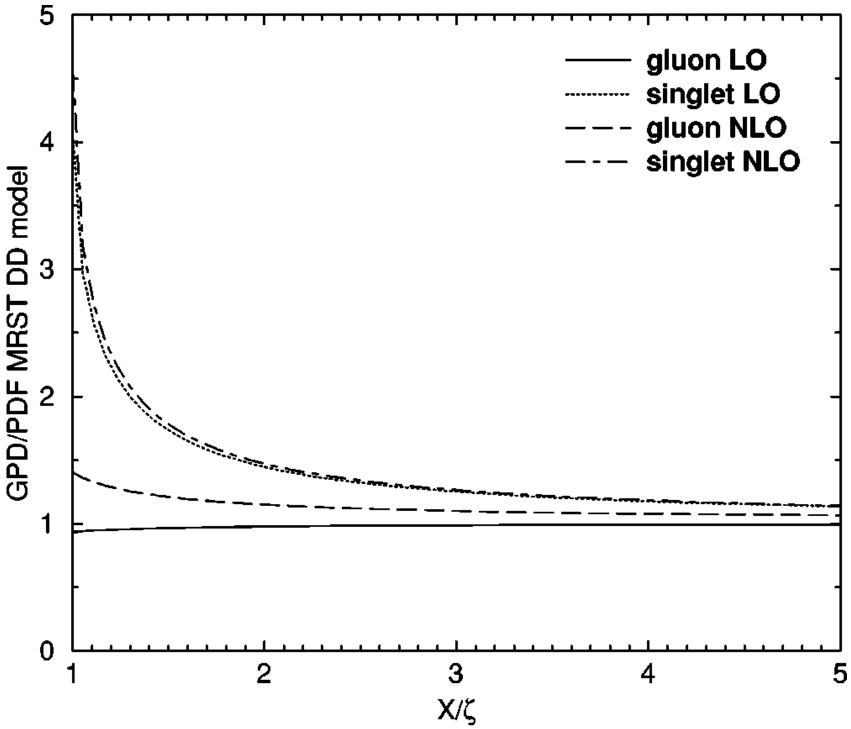
$$\begin{aligned} \kappa^{g[-]}_{1(1)}(x,\xi,\eta) = {} & - \frac{2\xi^2 - 2x\,\xi + x^2 - \eta^2}{2(x^2-\eta^2)^2} \ln\left(1 - \frac{x}{\xi}\right) \\ & - \frac{(\xi-\eta)(x^2 - 2\eta\xi - \eta^2)}{2\eta(x^2-\eta^2)^2} \ln\left(1 - \frac{\eta}{\xi}\right) + (\xi \leftrightarrow -\xi) \ , \end{aligned}$$

$$\kappa^{g[+]}_{1(1)}(x,\xi,\eta) = -\frac{2x\xi - x^2 - \eta^2}{2(x^2-\eta^2)^2} \ln\left(1 - \frac{x}{\xi}\right) + \frac{x(\xi-\eta)}{(x^2-\eta^2)^2} \ln\left(1 - \frac{\eta}{\xi}\right) - (\xi \leftrightarrow -\xi)$$

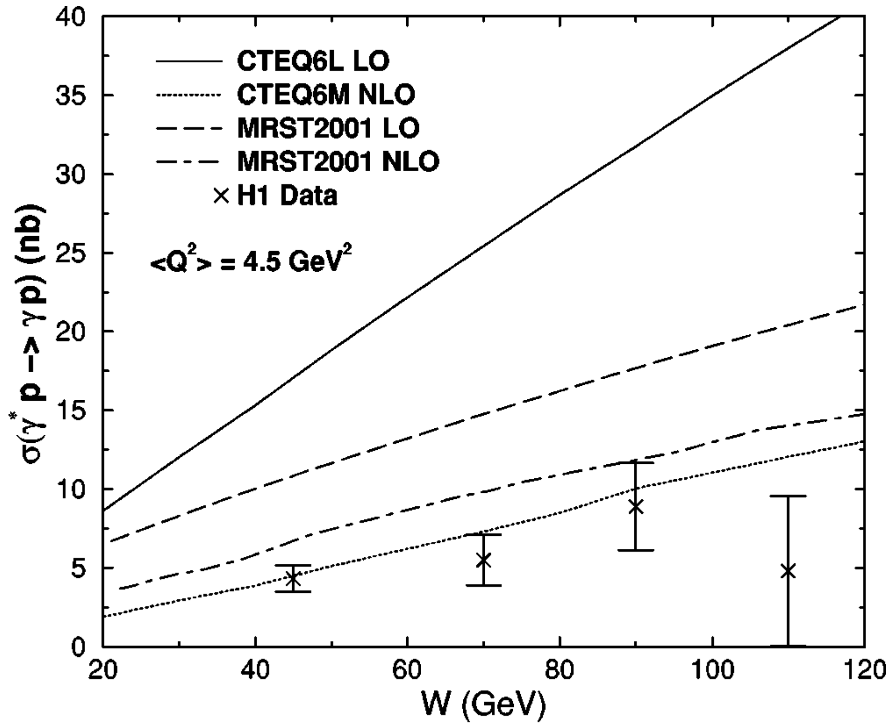
Lessons from HERA

cf. A.Freund, M.McDermott, M. Strikman

GPD/PDF at $\xi = 10^{-4}$



DVCS cross-section
($10^{-4} < \xi < 10^{-3}$)



gluon dominant ; flat $s = W^2$ -dependence

Prospects for LHC

→ **Timelike Compton scattering may be measurable ;**

$$Q^2 \sim \textbf{2-10 GeV}^2 \text{ , } \tau \sim 10^{-2} - 10^{-4}$$

→ **Possibility to probe GPDs in the small x regime**

→ **Order of magnitude to estimate**

→ **Nuclear effects : Nuclear gluon GPDs** cf. V.Guzey, M. Strikman

→ **"differential" EMC effect**