New results in exclusive hard reactions

GPDs and TDAs

EPS 2011 Grenoble , July 2011

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based on work done with K Semenov-Tian-Shansky, L Szymanowski, J Wagner

Phys Rev D 2005 ; Phys Letters 2005 ; Phys Rev D 2010 ; Phys Rev D 2011

Plan

➫ QCD factorization for exclusive reactions

* Success in DVCS : See previous presentation, J. Bowles

→ GPD properties

➫ On Timelike Compton scattering

→ NLO corrections

→ access in UPC at LHC

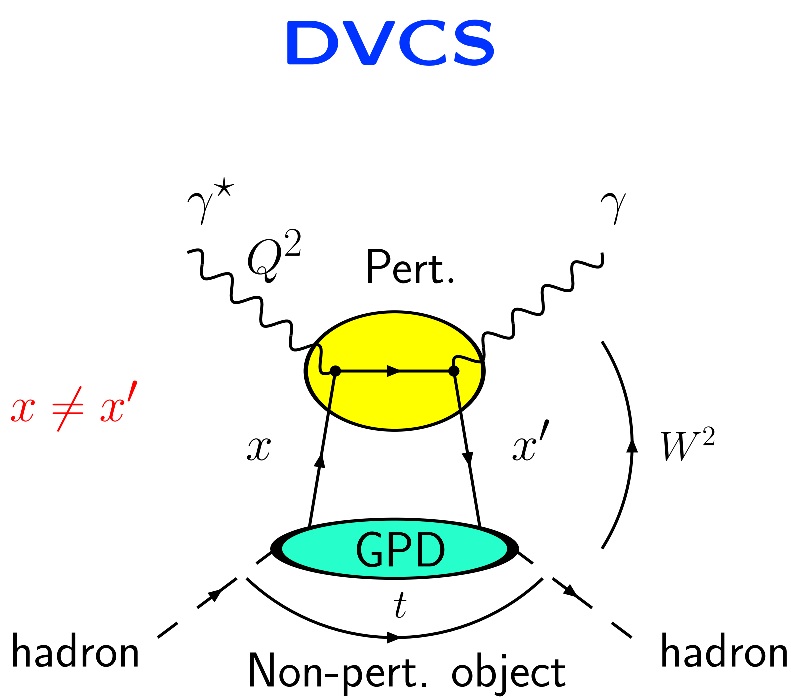
BP, L Szymanowski, J Wagner , Phys Rev D. 2009 and 2011

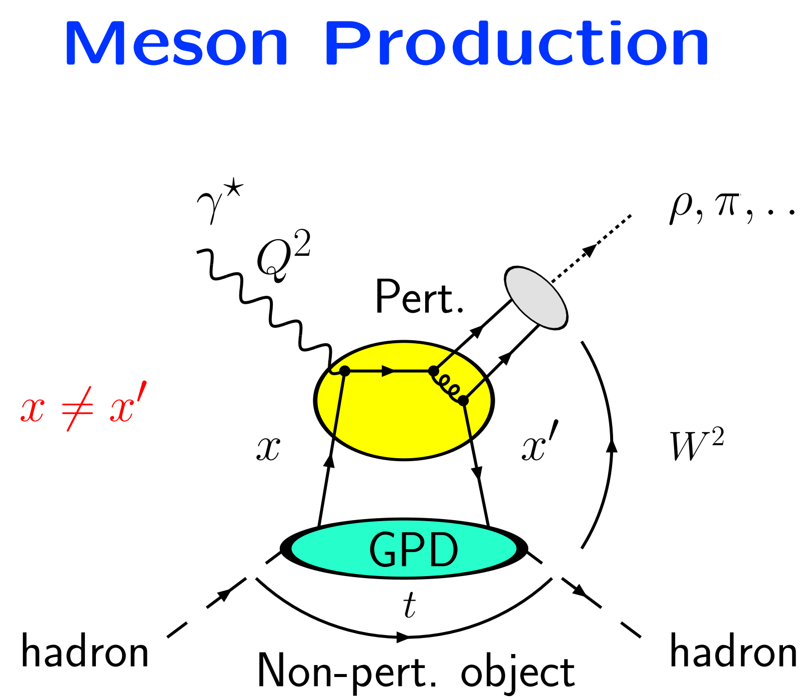
➫ Backward meson electroproduction

→ from GPDs to TDAs

BP, K Semenov-Tian-Shansky, L Szymanowski, Phys Rev D. 2010 and 2011.

QCD factorization in Exclusive processes





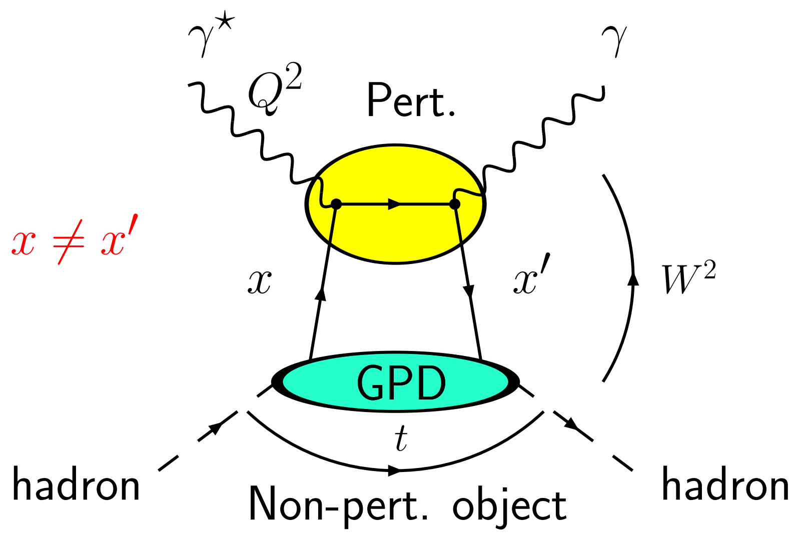
➫ Factorisation between a hard part (perturbatively calculable) and a soft part (non-perturbative) *Generalized Parton Distribution* demonstrated for

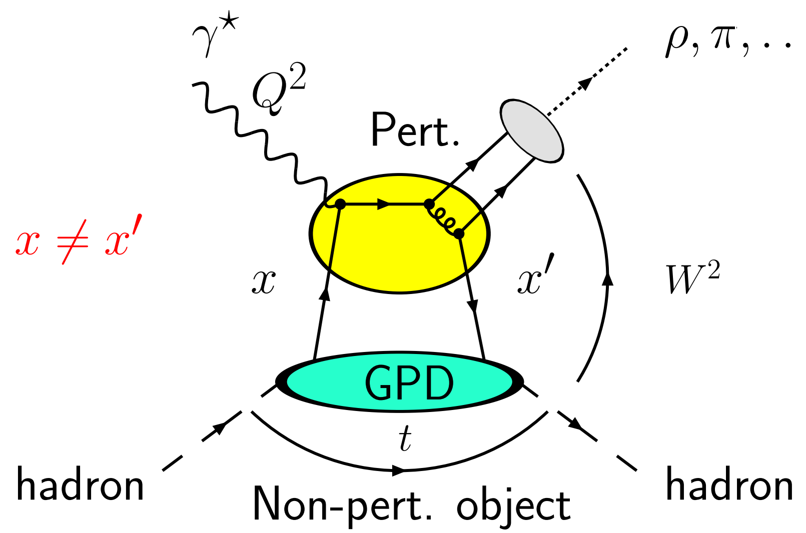
$$Q^2 \to \infty, \; x_B = \frac{Q^2}{Q^2+W^2} \text{ fixed and } t \ll \text{ fixed}$$

D. Muller *et al.* , Ji, Radyushkin, Collins *et al.* , '94, '96,'98

Generalised Parton Distributions

Non-Local operators (as in DIS) and non diagonal matrix elements = soft part of the amplitude for exclusive reactions





GPD = Fourier Transform of matrix elements

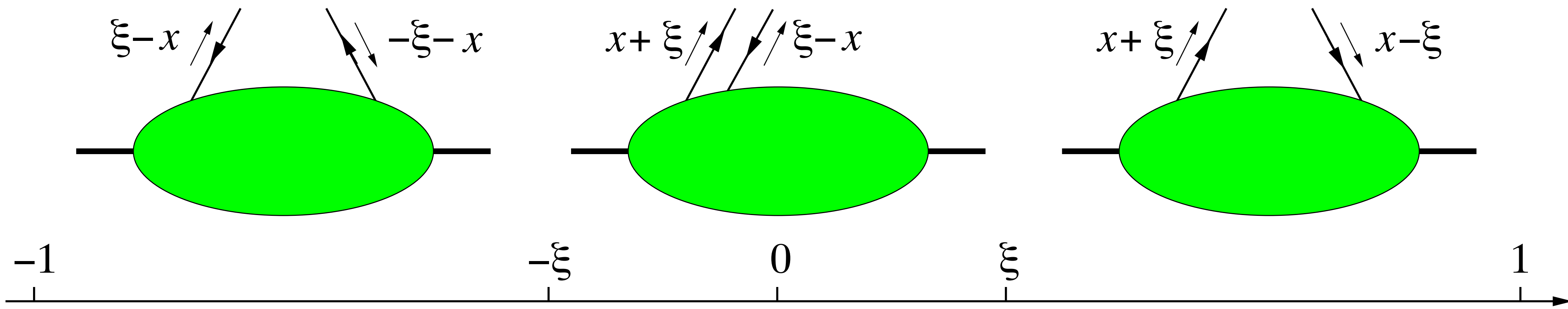
$$\langle N(p',\lambda')|\bar{\psi}(-z/2)_\alpha[-z/2;z/2]\psi(z/2)_\beta|N(p,\lambda)\rangle\Big|_{z^+=0,\, z_T=0}$$

ON THE LIGHT CONE $z^2 = 0$

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

Energy flow in GPDs

Three different regions



antiquark content $\bar{q}q$ **content** **quark content**

Two different evolution equations

as $\bar{q}(-x, Q^2)$ as $\Phi^\pi(z, Q^2)$ as $q(x, Q^2)$

DGLAP **ERBL** **DGLAP**

$\rightarrow \delta(-x)$ $\rightarrow \Phi^\pi_{as}(z, Q^2) = 6z\bar{z}$ $\rightarrow \delta(x)$

Impact picture Representation

t dependence of GPDs maps transverse position b_T of quarks.

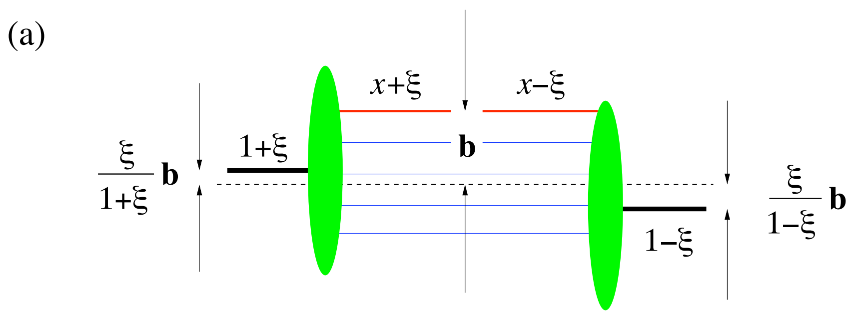
Fourier transform GPD at zero skewedness

$$q(x, b_T) = (2\pi)^{-2} \int d^2\Delta_T e^{i\Delta_T . b_T} H(x, \xi = 0, t)$$ probability

Generalize at $\xi \neq 0 \rightarrow$ Quantum femtophotography.

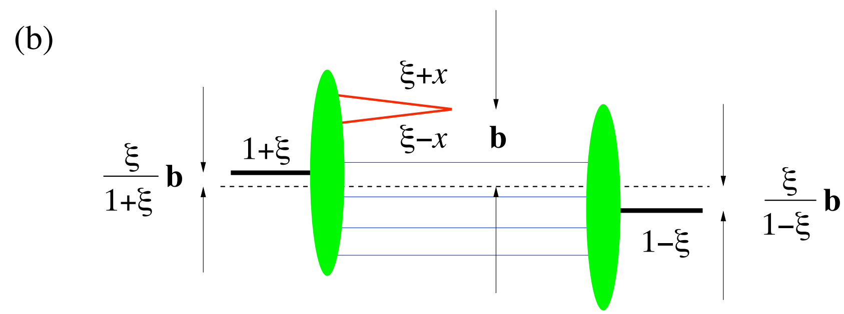
The $t-$dependence of dVCS localizes transversally the q (DGLAP) or the $\bar{q}q$ pairs of size $\frac{1}{Q}$ (ERBL) in the proton

DGLAP region ($x > \xi$)



Femtophotography of quark in the proton

ERBL region ($x < \xi$)



Femtophotography of quark-antiquark pair in the proton

This is the reason I consider GPDs as a breakthrough in QCD physics

➭ Beautiful progress in forward exclusive photon (DVCS) and meson (DVMP) experiments and analysis

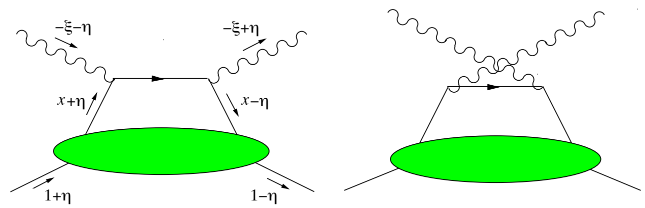
➭ Need to test universality of GPDs : TCS vs DVCS extractions

➭ Need to better understand NLO and twist 3 contributions ($\rightarrow \rho_T$)
see A. Besse POSTER session

➭ Extend forward case (= GPDs : $\bar{\psi}\psi$ operators) to backward kinematics $\rightarrow$ TDAs : $\psi\psi\psi$ operators

On spacelike vs timelike probe

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

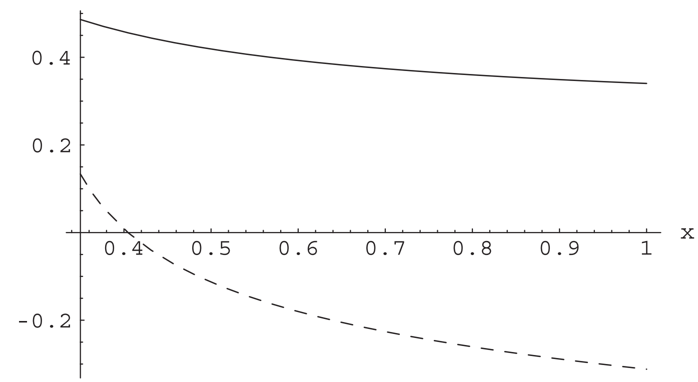


spacelike $q^2 < 0$; $q'^2 = 0$ **vs** **timelike** $q^2 = 0$; $q'^2 > 0$

$e\ N \to\ e'\ N\ \gamma$ **vs** $\gamma\ N \to\ N\ \mu^+\ \mu^-$

LO : $\mathcal{A}_{DVCS} = \mathcal{A}^*_{TCS}$

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



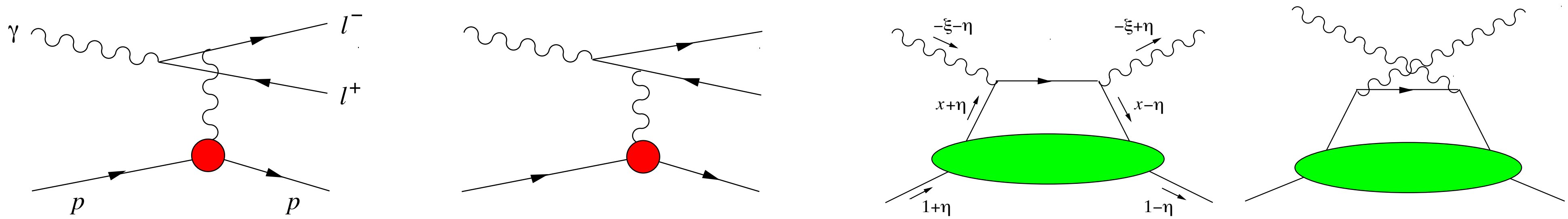
NLO : $\mathcal{A}_{DVCS} \neq \mathcal{A}^*_{TCS}$

➩ **Both timelike and spacelike data useful to check NLO analysis !**

GPDs at LHC (and RHIC)

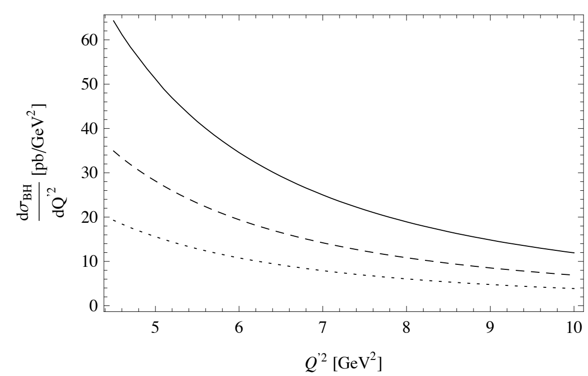
➯ Ultraperipheral Collisions : quasi real photons from proton beam

$\mu^+\mu^-$ pair production



QED dominates over TCS but in specific kinematics

→ cutting out QED with angular cuts :

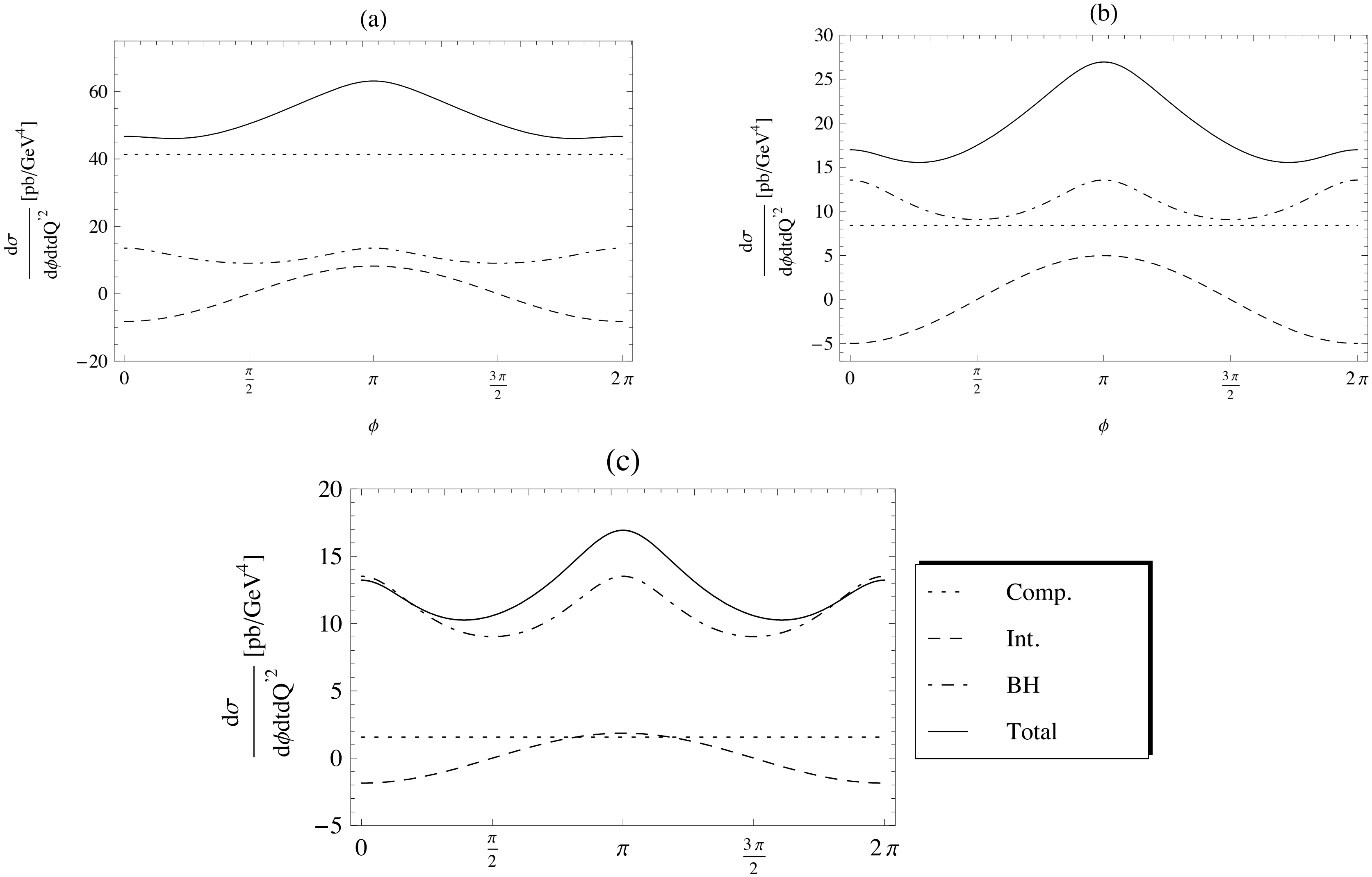


GPDs are expected to be large at small $x \approx \xi$ $\xi \approx Q^2/s_{\gamma p}$

➯ Probe of sea and gluon GPDs in small x regime

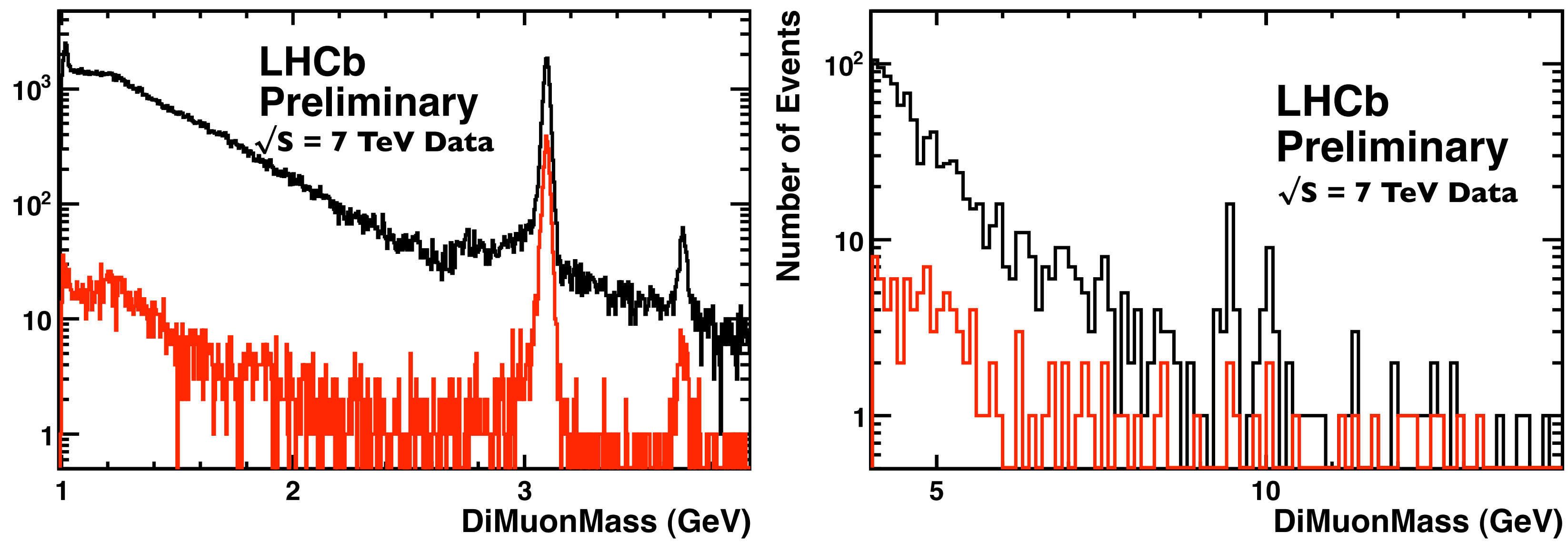
Observing TCS at LHC

➩ **Characteristic signal from interference** (charge conj. odd)



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

First data



D. Moran, DIS 2011

CAUTION : TCS not in Monte Carlo !

From Forward to Backward electroproduction

From GPDs to TDAs

Meson (or γ) deep electroproduction : 3 kinematics

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

define $t = (q-k)^2 = (p'-p)^2 \qquad u = (q-p')^2 = (p-k)^2$

- Forward region : $-t$ small $\to$ GPD domain
- Fixed angle region $-t \approx -u$ $\to$ very small cross sections
- Backward region : $-u$ small $\to$ TDA domain

Backward region may be analyzed similarly as Forward region with GPDs replaced by TDAs and many common features

$$Q^2 = -q^2 \text{ large}$$

from GPDs to TDAs

➩ GPDs are not the adequate tool for describing backward hard electroproduction

➩ Basic difference forward vs backward is the exchange of $\bar{q}q$ vs qqq

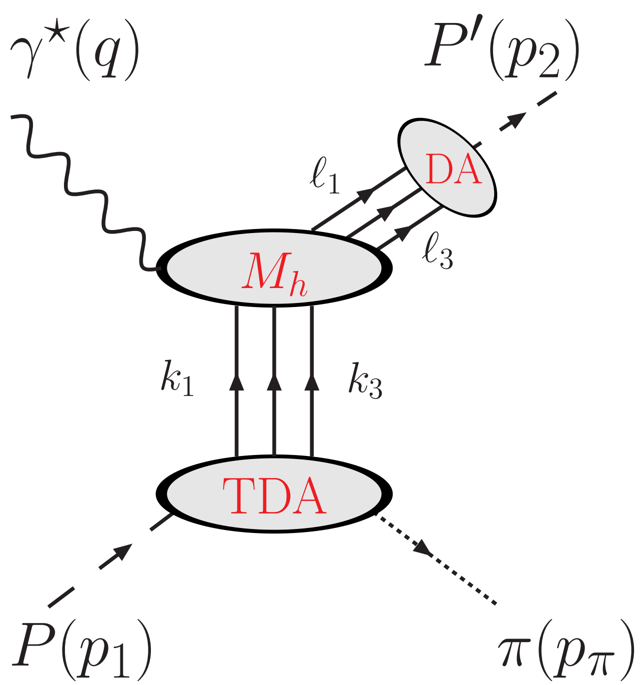
➩ From $\bar{\psi}(z_1)\psi(z_2)$ to $\psi(z_1)\psi(z_2)\psi(z_3)$ operators

TDAs : transition distribution amplitudes

In backward DVCS and backward meson electroproduction, one may factorize a non-perturbative part describing a baryon to photon or baryon to meson transition.

L.L.Frankfurt et al, PRD60(1999)

BP, L. Szymanowski, PRD 71 ; PLB 622 (2005)



Kinematics (light-cone vectors p, n)

$$p_1 = (1+\xi)p + \frac{M^2}{1+\xi}n$$

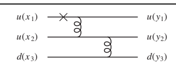
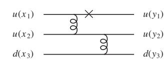
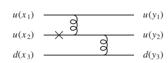
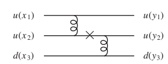
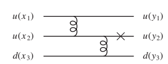
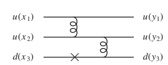
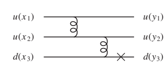
$$p_\pi = (1-\xi)p + \frac{m^2-\Delta_T^2}{1-\xi}n + \Delta_T$$

$$u = (p_1 - p_\pi)^2 \ll Q^2 \sim O(W^2)$$

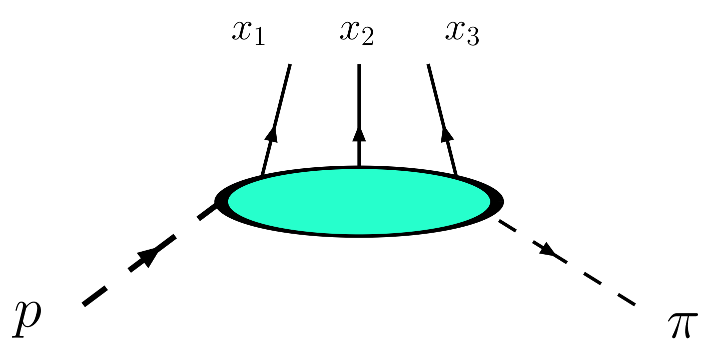
skewness parameter : $\xi = \frac{Q^2}{2W^2-Q^2}$

Factorization

The perturbative part describes the $\gamma^* qqq \to qqq$ transition.

α		T_α	T'_α
1		$\frac{-Q_u(2\xi)^2[(V_1^{p\pi^0}-A_1^{p\pi^0})(V^p-A^p)+4T_1^{p\pi^0}T^p+2\frac{\Delta_T^2}{M^2}T_4^{p\pi^0}T^p]}{(2\xi-x_1-i\epsilon)^2(x_3-i\epsilon)(1-y_1)^2y_3}$	$\frac{-Q_u(2\xi)^2[(V_2^{p\pi^0}-A_2^{p\pi^0})(V^p-A^p)+2(T_2^{p\pi^0}+T_3^{p\pi^0})T^p]}{(2\xi-x_1-i\epsilon)^2(x_3-i\epsilon)(1-y_1)^2y_3}$
2		0	0
3		$\frac{Q_u(2\xi)^2[4T_1^{p\pi^0}T^p+2\frac{\Delta_T^2}{M^2}T_4^{p\pi^0}T^p]}{(x_1-i\epsilon)(2\xi-x_2-i\epsilon)(x_3-i\epsilon)y_1(1-y_1)y_3}$	$\frac{Q_u(2\xi)^2[2(T_2^{p\pi^0}+T_3^{p\pi^0})T^p]}{(x_1-i\epsilon)(2\xi-x_2-i\epsilon)(x_3-i\epsilon)y_1(1-y_1)y_3}$
4		$\frac{-Q_u(2\xi)^2[(V_1^{p\pi^0}-A_1^{p\pi^0})(V^p-A^p)]}{(x_1-i\epsilon)(2\xi-x_3-i\epsilon)(x_3-i\epsilon)y_1(1-y_1)y_3}$	$\frac{-Q_u(2\xi)^2[(V_2^{p\pi^0}-A_2^{p\pi^0})(V^p-A^p)]}{(x_1-i\epsilon)(2\xi-x_3-i\epsilon)(x_3-i\epsilon)y_1(1-y_1)y_3}$
5		$\frac{Q_u(2\xi)^2[(V_1^{p\pi^0}+A_1^{p\pi^0})(V^p+A^p)]}{(x_1-i\epsilon)(2\xi-x_3-i\epsilon)(x_3-i\epsilon)y_1(1-y_2)y_3}$	$\frac{Q_u(2\xi)^2[(V_2^{p\pi^0}+A_2^{p\pi^0})(V^p+A^p)]}{(x_1-i\epsilon)(2\xi-x_3-i\epsilon)(x_3-i\epsilon)y_1(1-y_2)y_3}$
6		0	0
7		$\frac{-Q_d(2\xi)^2[2(V_1^{p\pi^0}V^p+A_1^{p\pi^0}A^p)]}{(x_1-i\epsilon)(2\xi-x_3-i\epsilon)^2y_1(1-y_3)^2}$	$\frac{-Q_d(2\xi)^2[2(V_2^{p\pi^0}V^p+A_2^{p\pi^0}A^p)]}{(x_1-i\epsilon)(2\xi-x_3-i\epsilon)^2y_1(1-y_3)^2}$

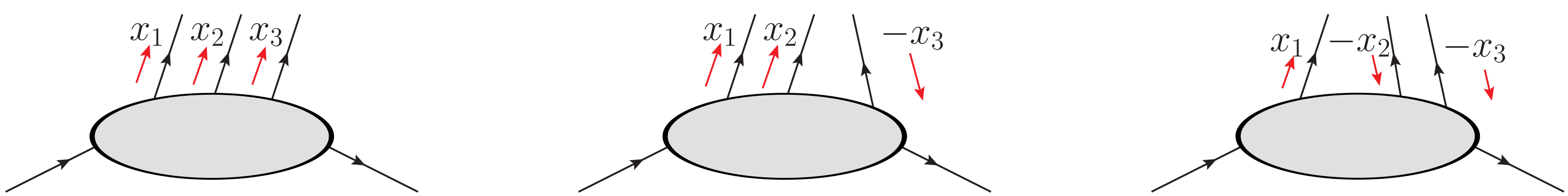
The non-perturbative part describes the proton-meson transition.



Energy flow in TDAs

Different regions

➫ Both for Baryon → Meson and Baryon → photon,
3 quarks are exchanged in the t-channel ; $x_1 + x_2 + x_3 = 2\xi$



ERBL DGLAP1 DGLAP2

➫ ERBL region : $x_i > 0$; (as for proton DA)

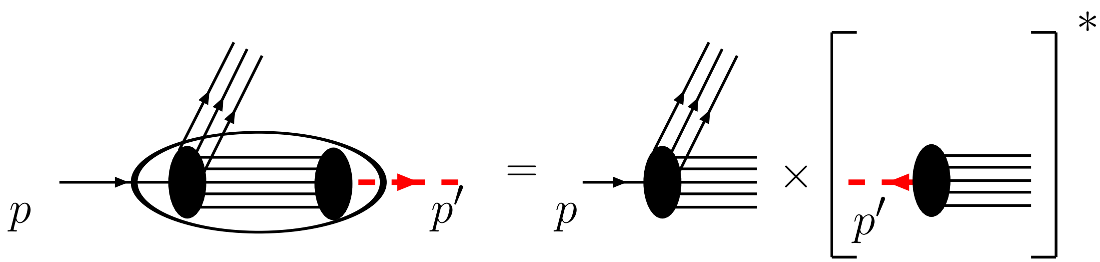
➫ DGLAP1 regions : $x_1 > 0; x_2 > 0; x_3 < 0$ + permutations

➫ DGLAP2 regions : $x_1 > 0; x_2 < 0; x_3 < 0$ + permutations

→ Different physical picture and evolution equations

Physical picture of TDAs

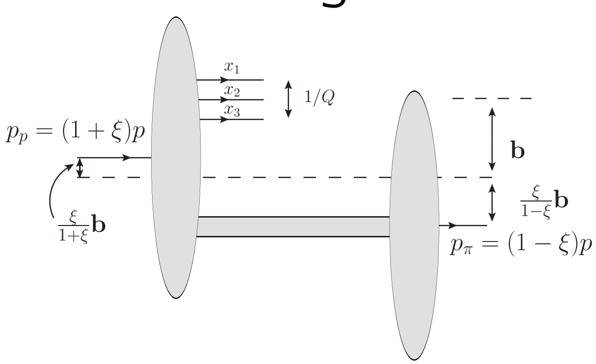
➪ The TDAs provides information on the next to minimal Fock state in P



$P = |u\ u\ d\ \pi^0 >$ or $|u\ d\ d\ \pi^+ >$ *how one can find a meson in a proton*

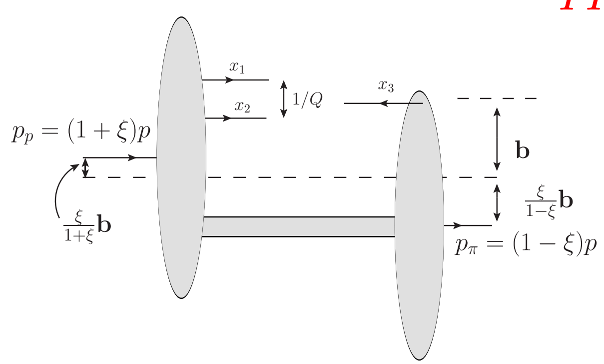
➪ Impact picture Representation Fourier transform $\vec{\Delta}_T \to \vec{b}_T$

As for GPDs, the t dependence of TDAs maps the transverse quark position
In the ERBL region : Transverse localization of qqq core of size $\frac{1}{Q}$



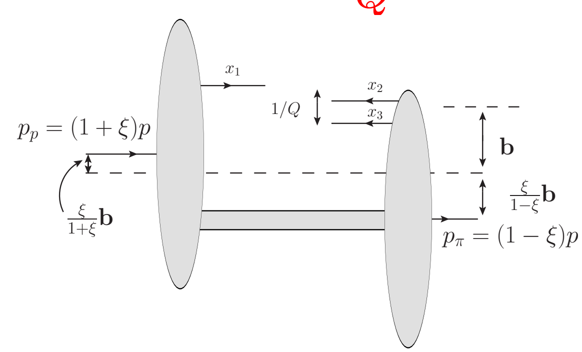
Femtophoto of 3 quark core in the proton

ERBL



Femtophoto of 2 quark in the proton

DGLAP1



Femtophoto of 2 antiquark in the meson

DGLAP2

Evolution equations

➯ **Same operator as in DAs → Same renormalization group equations**

$$Q\frac{d}{dQ}\,F^{\uparrow\downarrow\uparrow}(x_i) = -\frac{\alpha_s}{2\pi}\left[\frac{3}{2}\,C_F\,F^{\uparrow\downarrow\uparrow}(x_i) - \left(1+\frac{1}{N_c}\right)\mathcal{A}\right]$$

$$\begin{aligned}
\mathcal{A} = \Bigg[&\left(\int_{-1+\xi}^{1+\xi} dx'_1 \left[\frac{x_1\rho(x'_1,x_1)}{x'_1(x'_1-x_1)}\right]_+ + \int_{-1+\xi}^{1+\xi} dx'_2 \left[\frac{x_2\rho(x'_2,x_2)}{x'_2(x'_2-x_2)}\right]_+\right) F^{\uparrow\downarrow\uparrow}(x'_1,x'_2,x_3) \\
&+ \left(\int_{-1+\xi}^{1+\xi} dx'_1 \left[\frac{x_1\rho(x'_1,x_1)}{x'_1(x'_1-x_1)}\right]_+ + \int_{-1+\xi}^{1+\xi} dx'_3 \left[\frac{x_3\rho(x'_3,x_3)}{x'_3(x'_3-x_3)}\right]_+\right) F^{\uparrow\downarrow\uparrow}(x'_1,x_2,x'_3) \\
&+ \left(\int_{-1+\xi}^{1+\xi} dx'_2 \left[\frac{x_2\rho(x'_2,x_2)}{x'_2(x'_2-x_2)}\right]_+ + \int_{-1+\xi}^{1+\xi} dx'_3 \left[\frac{x_3\rho(x'_3,x_3)}{x'_3(x'_3-x_3)}\right]_+\right) F^{\uparrow\downarrow\uparrow}(x_1,x'_2,x'_3) \\
&+ \frac{1}{2\xi-x_3}\left(\int_{-1+\xi}^{1+\xi} dx'_1 \frac{x_1}{x'_1}\rho(x'_1,x_1) + \int_{-1+\xi}^{1+\xi} dx'_2 \frac{x_2}{x'_2}\rho(x'_2,x_2)\right) F^{\uparrow\downarrow\uparrow}(x'_1,x'_2,x_3) \\
&+ \frac{1}{2\xi-x_1}\left(\int_{-1+\xi}^{1+\xi} dx'_2 \frac{x_2}{x'_2}\rho(x'_2,x_2) + \int_{-1+\xi}^{1+\xi} dx'_3 \frac{x_3}{x'_3}\rho(x'_3,x_3)\right) F^{\uparrow\downarrow\uparrow}(x_1,x'_2,x'_3) \Bigg] \Bigg\}
\end{aligned}$$

with integration region restricted by : $\rho(x,y) = \theta(x \geq y \geq 0) - \theta(x \leq y \leq 0)$**, and** $x'_i \in [-1+\xi, 1+\xi]$

No detailed study yet

Dirac decomposition

decompose $\langle \pi(p_\pi)|\, \epsilon^{ijk} u^i_\alpha(z_1\, n) u^j_\beta(z_2\, n) d^k_\gamma(z_3\, n)\, |p(p,s)\rangle\Big|_{n^2=0}$

on independent Dirac structures ($\Delta = p_\pi - p$, $2P = p_\pi + p$)

(**u = nucleon spinor,** $\hat{a} = a^\mu \gamma^\mu, \sigma_{ab} = [\hat{a}, \hat{b}]/2$)

$$(v_1)_{\alpha\beta\gamma} = (\hat{P}C)_{\alpha\beta}(\hat{P}u)_\gamma \qquad (a_1)_{\alpha\beta\gamma} = (\hat{P}\gamma^5 C)_{\alpha\beta}(\gamma^5 \hat{P}u)_\gamma$$

$$(v_2)_{\alpha\beta\gamma} = (\hat{P}C)_{\alpha\beta}(\hat{\Delta}u)_\gamma \qquad (a_2)_{\alpha\beta\gamma} = (\hat{P}\gamma^5 C)_{\alpha\beta}(\gamma^5 \hat{\Delta}u)_\gamma$$

$$(t_1)_{\alpha\beta\gamma} = (\sigma_{P\mu}C)_{\alpha\beta}(\gamma^\mu \hat{P}u)_\gamma \qquad (t_2)_{\alpha\beta\gamma} = (\sigma_{P\mu}C)_{\alpha\beta}(\gamma^\mu \hat{\Delta}u)_\gamma$$

$$(t_3)_{\alpha\beta\gamma} = \frac{1}{M}(\sigma_{P\Delta}C)_{\alpha\beta}(\hat{P}u)_\gamma \qquad (t_4)_{\alpha\beta\gamma} = \frac{1}{M}(\sigma_{P\Delta}C)_{\alpha\beta}(\hat{\Delta}u)_\gamma$$

equivalent to helicity decomposition of $p \to \pi qqq$

$v_1 - 2\xi v_2$, $a_1 - 2\xi a_2$, $t_1 - 2\xi t_2$ **survive at** $\Delta_T = 0$

and define scalar functions $V_1, A_1, T_1, V_2, A_2, T_2, T_3, T_4$

Polynomiality property

As for GPDs Lorentz invariance constrains skewness dependence :

➩ **Define x_i Mellin moments**

$$\langle x_1^{n_1} x_2^{n_2} x_3^{n_3} H_s^{\pi N}\rangle = \int dx_1 \int dx_2 \int dx_3 \delta(x_1+x_2+x_3-2\xi) x_1^{n_1} x_2^{n_2} x_3^{n_3} H_s^{\pi N}(x_1,x_2,x_3,\xi,\Delta)\,.$$

➩ **They are expressed through Form Factors of local operators**

$$\widehat{O}_{\rho\tau\chi}^{\mu_1\ldots\mu_{n_1},\,\nu_1\ldots\nu_{n_2},\,\lambda_1\ldots\lambda_{n_3}}(0) = \left[i\vec{D}^{\mu_1}\ldots i\vec{D}^{\mu_{n_1}}\Psi_\rho\right]\left[i\vec{D}^{\nu_1}\ldots i\vec{D}^{\nu_{n_2}}\Psi_\tau\right]\left[i\vec{D}^{\lambda_1}\ldots i\vec{D}^{\lambda_{n_3}}\Psi_\chi\right],$$

➩ **Get polynomials in ξ up to $\xi^{n_1+n_2+n_3+1}$**

$$\langle x_1^{n_1} x_2^{n_2} x_3^{n_3}\{V_i,\, A_i,\, T_{1,2}\}\rangle = \sum_{n=1}^{N}(-1)^{N-n}(2\xi)^n \sum_{i=0}^{n_1}\sum_{j=0}^{n_2}\sum_{k=0}^{n_3}\delta_{i+j+k,\,n}\, A_{ijk}^{\{V_i,\,A_i,\,T_{1,2}\}\;(n_i)}(\Delta^2)$$

$$-(2\xi)^{N+1} C_{N+1}^{\{V_i,\,A_i,\,T_{1,2}\}\;(n_1,n_2,n_3)}(\Delta^2) \qquad (\xi^{N+1}\to \text{D-term})$$

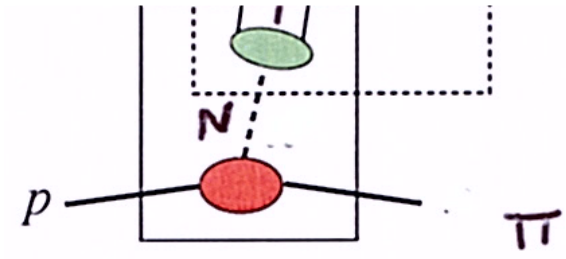
$$\langle x_1^{n_1} x_2^{n_2} x_3^{n_3}\{T_{3,4}\}\rangle = \sum_{n=1}^{N}(-1)^{N-n}(2\xi)^n \sum_{i=0}^{n_1}\sum_{j=0}^{n_2}\sum_{k=0}^{n_3}\delta_{i+j+k,\,n}\, A_{ijk}^{\{T_{3,4}\}\;(n_1,n_2,n_3)}(\Delta^2)\,.$$

TO BE SATISFIED BY ALL CONSISTENT MODELS

Nucleon exchange in TDA framework

➾ **Write effective Lagrangian for $\pi \bar{N} N$ interaction :**

$$\mathcal{H}_{\text{eff}} = -i g_{\pi NN} \bar{N}_\alpha (\sigma_a)^\alpha_\beta \gamma_5 N^\beta \pi_a$$



➾ **Get πN matrix element**

$$\langle \pi_a(p_\pi) | \widehat{O}^{\alpha\beta\gamma}_{\rho\tau\chi}(\lambda_i n) | N_\iota(p_1) \rangle = \sum_{s_p} \langle 0 | \widehat{O}^{\alpha\beta\gamma}_{\rho\tau\chi}(\lambda_i n) | N_\kappa(-\Delta, s_p) \rangle (\sigma_a)^\kappa_\iota \frac{i g_{\pi NN} \bar{U}_\varrho(-\Delta, s_p)}{\Delta^2 - M^2} \left(\gamma^5 U(p_1, s_1) \right)_\varrho .$$

➾ **Decompose on Dirac struct. and get contrib. to $I = \frac{1}{2}$ πN TDAs**

$$\{V_1,\, A_1,\, T_1\}^{(\pi N)_{1/2}}(x_1, x_2, x_3) = \Theta_{\text{ERBL}}(x_1, x_2, x_3) \times (g_{\pi NN}) \frac{M f_\pi}{\Delta^2 - M^2} 2\xi \frac{1}{(2\xi)^2} \{V^p,\, A^p,\, T^p\} \left(\frac{x_1}{2\xi}, \frac{x_2}{2\xi}, \frac{x_3}{2\xi} \right) ;$$

$$\{V_2,\, A_2,\, T_2\}^{(\pi N)_{1/2}}(x_1, x_2, x_3) = \frac{1}{2} \{V_1,\, A_1,\, T_1\}^{(\pi N)_{1/2}}(x_1, x_2, x_3) \quad ; \quad T_3^{(\pi N)} = T_4^{(\pi N)} = 0$$

with $\Theta_{\text{ERBL}}(x_1, x_2, x_3) \equiv \prod_{k=1}^3 \theta(0 \leq x_k \leq 2\xi)$.

Nucleon exchange contrib. is a pure D- term contribution.

Models for TDAs

➩ **Closest object : Baryon Distribution Amplitude ϕ^N :**

known from RG analysis, Conf. Inv. , Lattice , QCD sum rules

➩ **CHIRAL LIMIT of $p \to \pi$ TDA ($\xi \to 1$)**

$$< \pi^a(k)|O|P(p,s) >= \frac{-i}{f_\pi} < 0|[Q_5^a, O]|P(p,s) >$$

$$\phi_1^{(\pi N)_{1/2}}(x_1,x_2,x_3,\xi=1,\Delta^2=M^2)\Big|_{\substack{\text{soft}\\ \text{pion}}} = \frac{1}{24}\phi^N(x_1,x_2,x_3) + \frac{1}{6}\phi^N(x_3,x_2,x_1)\,;$$

$$\phi_2^{(\pi N)_{1/2}}(x_1,x_2,x_3,\xi=1,\Delta^2=M^2)\Big|_{\substack{\text{soft}\\ \text{pion}}} = -\frac{1}{2}\phi_1^{(\pi N)_{1/2}}(x_1,x_2,x_3,\xi=1,\Delta^2=M^2)\Big|_{\substack{\text{soft}\\ \text{pion}}}\;;$$

$$\phi_1^{(\pi N)_{3/2}}(x_1,x_2,x_3,\xi=1,\Delta^2=M^2)\Big|_{\substack{\text{soft}\\ \text{pion}}} = \frac{1}{4}\left(\phi^N(x_1,x_2,x_3) + \phi^N(x_3,x_2,x_1)\right)\;;$$

$$\phi_2^{(\pi N)_{3/2}}(x_1,x_2,x_3,\xi=1,\Delta^2=M^2)\Big|_{\substack{\text{soft}\\ \text{pion}}} = -\frac{1}{2}\phi_1^{(\pi N)_{3/2}}(x_1,x_2,x_3,\xi=1,\Delta^2=M^2)\Big|_{\substack{\text{soft}\\ \text{pion}}}\;.$$

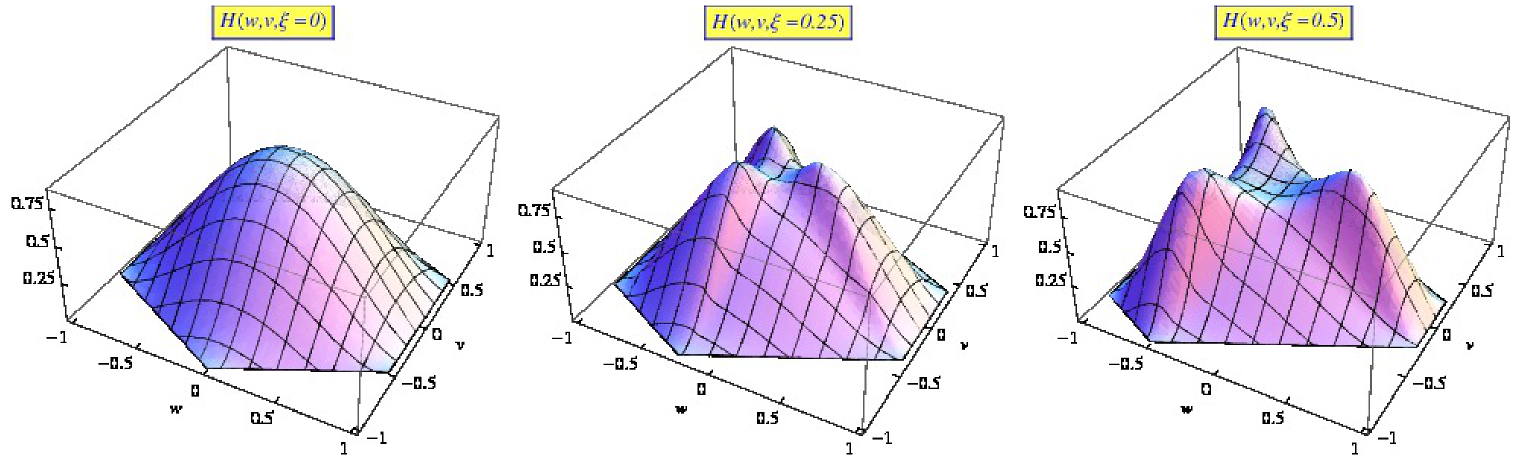
➩ **Skew the chiral limit away from $\xi = 1$ limit**

through quadruple distributions (cf Radyushkin's double dist. for GPDs)

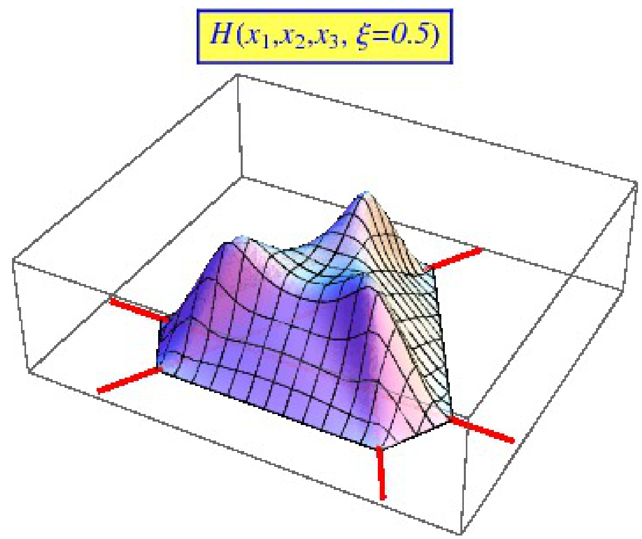
which populate the DGLAP regions.

TDA modeling

from BP,LS + Kirill Semenov-Tian-Shansky, Phys Rev D82 (2010) 094030



"quark-diquark" (ω, v) coordinates



(x_1, x_2, x_3) barycentric coordinates

Conclusions

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

They are matrix elements of different non local light cone operators

GPDs extraction needs more understanding of NLO corrections

➩ Timelike Compton Scattering = a useful complement to dVCS

➩ TCS data from ZEUS and LHC ... and from JLab12 ?

TDAs extraction is crucial to probe meson content of baryons

➩ First signals at JLab at 6 GeV

➩ CLAS12 proposals on pseudoscalar and vector meson production : backward φ (strangeness in the nucleon)

➩ PANDA at GSI-FAIR and COMPASS with π beam : timelike channels for TDA extraction

Please note

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