TDAs for PANDA processes

PANDA 2012 , ORSAY , January 2012

B. Pire

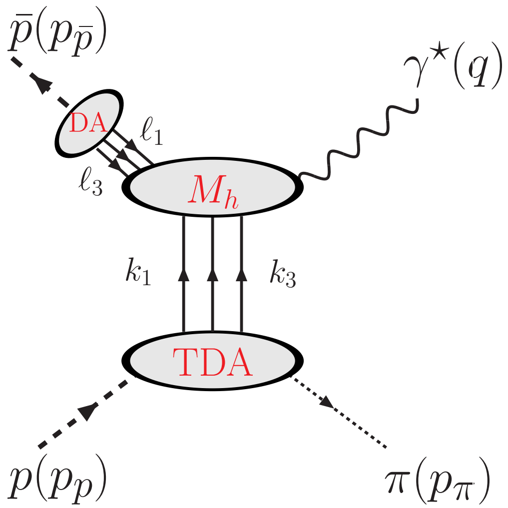
CPhT, École Polytechnique

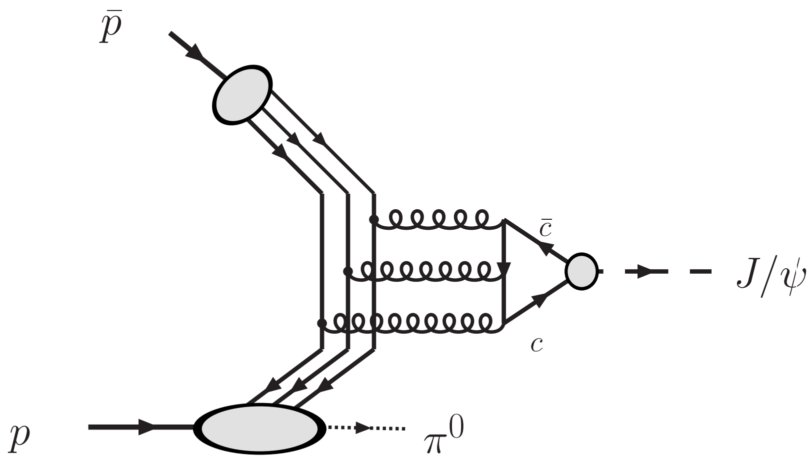
based on work done with

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

Phys Rev D76, 2007 ; Phys Rev D82, 2010 ; Phys Rev D84, 2011 ; arXiv 1112.3570

the PANDA@FAIR processes





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

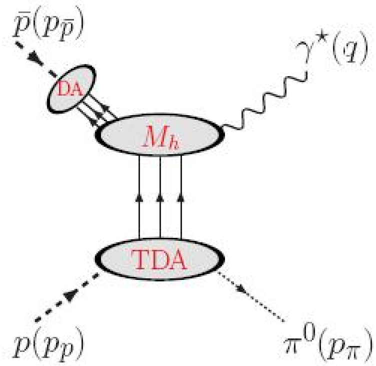
but also

$$\bar{N}N \to \eta\gamma^* \to \eta e^+e^- \quad , \quad \bar{N}N \to \pi\pi\gamma^* \to \pi\pi e^+e^- \quad , \ \ldots$$

Forward and Backward kinematics

- J.P. Lansberg, B. Pire, L. Szymanowski'07: πN TDAs arise in the factorized description of

$$N(p_1) + \bar{N}(p_2) \to \gamma^*(q) + \pi(p_\pi) \to l^+(k_1) + l^-(k_2) + \pi(p_\pi)$$



- $W^2 = (p_1 + p_2)^2$ and $q^2 = Q^2$ - large; $(p_1 - p_\pi)^2$-small ($\theta_\pi \sim 0$ in C.M.S: near forward kinematics)

+ reversed case small u where

π^0 is forward and γ^* backward in CMS (γ^* almost at rest in lab)

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

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

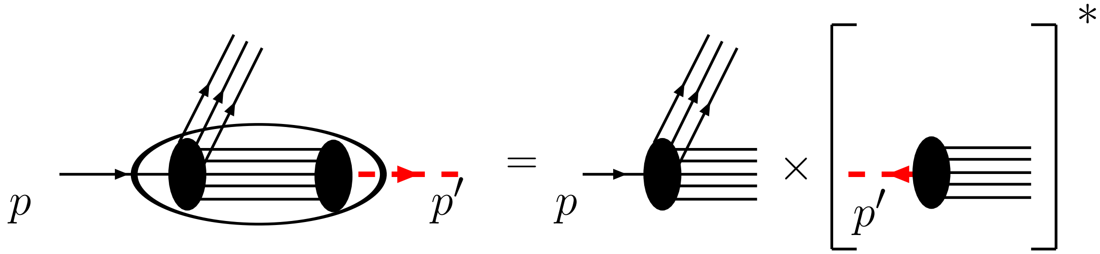
$|qqq>$ **is described by proton DA :** $\langle 0| \, \epsilon^{ijk} u^i_\alpha(z_1) u^j_\beta(z_2) d^k_\gamma(z_3) \, |p(p,s)\rangle \Big|_{z^+=0,\, z_T=0}$

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

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

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

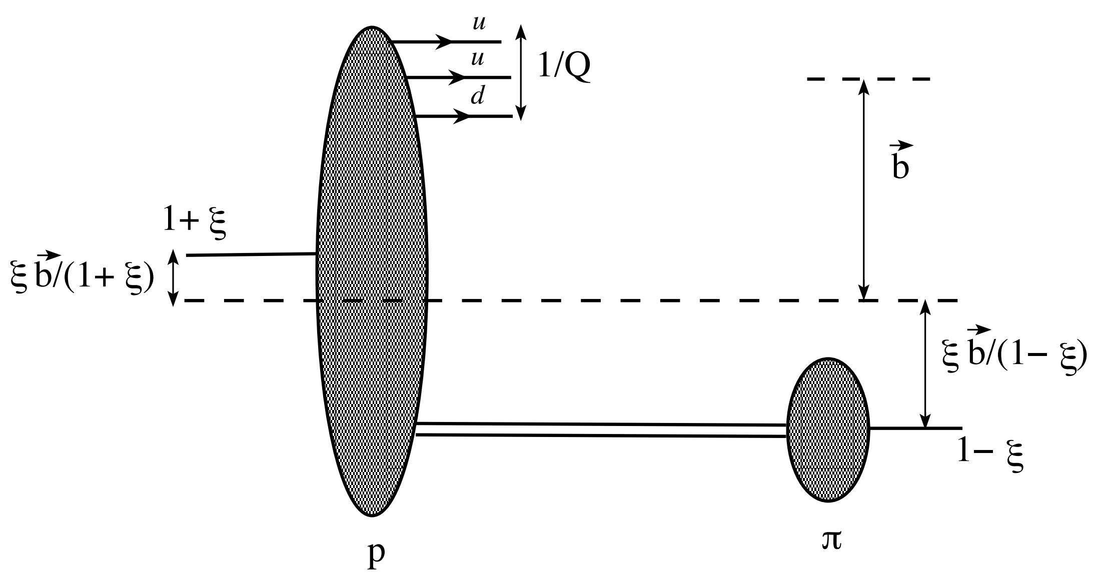
or *how one can find a meson in a proton*

Impact parameter interpretation

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

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

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

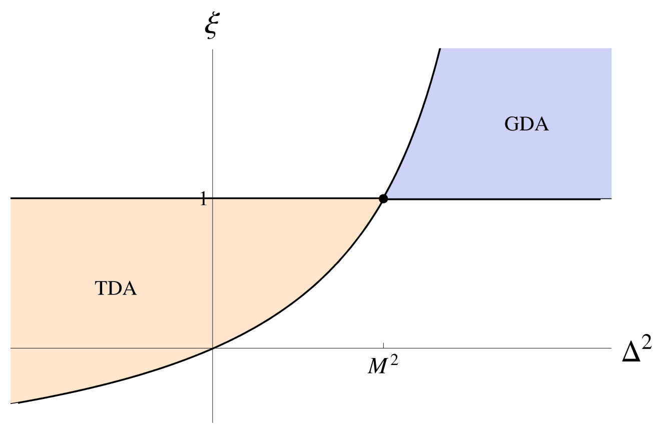


if factorization works

Crossing to πN final state

Crossing πN TDA $\leftrightarrow$ πN GDA and soft pion theorem

- Crossing relates πN TDA in $\gamma^* N \to \pi N'$ and πN GDAs (light-cone wave function)
- Physical domain in (Δ^2, ξ)-plane (defined by $\Delta_T^2 \leq 0$) in the chiral limit $(m = 0)$:



- Soft pion theorem Pobylitsa, Polyakov and Strikman'01 $(Q^2 \gg \Lambda^3_{\rm QCD}/m)$ constrains πN GDA at the threshold $\xi = 1$, $\Delta^2 = M^2$.

Soft pion limit

Soft pion theorem for πN GDA

- Soft pion theorem Pobylitsa, Polyakov and Strikman'01 ($Q^2 \gg \Lambda^3_{\mathrm{QCD}}/m$):

$$\langle 0|\widehat{O}^{\alpha\beta\gamma}_{\rho\tau\chi}(z_1,\, z_2,\, z_3)|\pi_a N_\iota\rangle = -\frac{i}{f_\pi}\langle 0|\left[\widehat{Q}^a_5,\, \widehat{O}^{\alpha\beta\gamma}_{\rho\tau\chi}(z_1,\, z_2,\, z_3)\right]|N_\iota\rangle\,,$$

with $\left[\widehat{Q}^a_5,\ \Psi^\alpha_\eta\right] = -\frac{1}{2}(\sigma_a)^\alpha_\delta \gamma^5_{\eta\tau}\Psi^\delta_\tau\,;$

- At the pion threshold ($\xi = 1$, $\Delta^2 = M^2$ in the chiral limit) soft pion theorem fixes πN TDAs/GDAs in terms of nucleon DAs V^p, A^p, T^p (see V. Braun, D. Ivanov, A.Lenz, A.Peters'08).
- E.g. soft pion theorem for uud proton to π^0 TDAs:

$$\{V_1^{p\pi^0},\, A_1^{p\pi^0}\}(x_1, x_2, x_3, \xi = 1, \Delta^2 = M^2) = -\frac{1}{8}\{V^p,\, A^p\}(\frac{x_1}{2}, \frac{x_2}{2}, \frac{x_3}{2})\,;$$

$$T_1^{p\pi^0}(x_1, x_2, x_3, \xi = 1, \Delta^2 = M^2) = \frac{3}{8}T^p(\frac{x_1}{2}, \frac{x_2}{2}, \frac{x_3}{2})$$

$$\{V_2^{p\pi^0},\, A_2^{p\pi^0},\, T_2^{p\pi^0}\} = -\frac{1}{2}\{V_1^{p\pi^0},\, A_1^{p\pi^0},\, T_1^{p\pi^0}\} \quad T_{3,4}^{p\pi^0} = 0\,;$$

A skewing ansatz

"Skewing" $\xi = 1$ limit for πN TDAs

After suitable change of spectral variables ($\kappa = \alpha_3 + \beta_3$, $\theta = \frac{\alpha_1+\beta_1-\alpha_2-\beta_2}{2}$, $\mu = \alpha_3 - \beta_3$, $\lambda = \frac{\alpha_1-\beta_1-\alpha_2+\beta_2}{2}$) and introduction of "quark-diquark" coordinates $w = x_3 - \xi$; $v = \frac{x_1-x_2}{2}$:

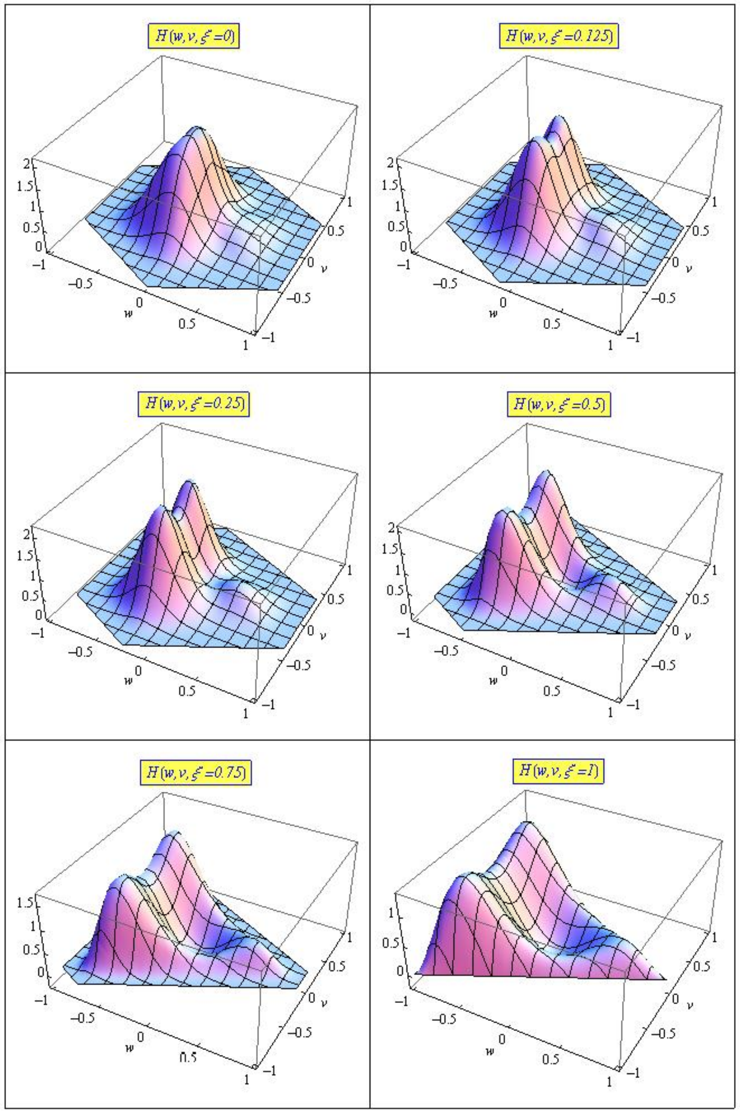
$$H(w,\, v,\, \xi) = \int_{-1}^{1} d\kappa \int_{-\frac{1-\kappa}{2}}^{\frac{1-\kappa}{2}} d\theta \int_{-1}^{1} d\mu_i \int_{-\frac{1-\mu}{2}}^{\frac{1-\mu}{2}} d\lambda\, \delta(w - \frac{\kappa-\mu}{2}(1-\xi) - \kappa\xi)$$
$$\times \delta\left(v - \frac{\theta-\lambda}{2}(1-\xi) - \theta\xi\right) F(\kappa,\, \theta,\, \mu,\, \lambda)$$

- A factorized Ansatz for quadruple distribution F_i:

$$F(\kappa,\, \theta,\, \mu,\, \lambda) = V(\kappa,\, \theta)\, h(\mu,\, \lambda)$$

  with the profile $h(\mu,\, \lambda)$ normalized as $\int d\mu \int d\lambda\, h(\mu,\, \lambda) = 1$.
- Since $H(w,\, v,\, \xi = 1) = V(w, v)$ for V one may use input from the soft pion theorem
- A possible choice for the profile: $h(\mu,\, \lambda) = \frac{15}{16}\,(1+\mu)((1-\mu)^2 - 4\lambda^2)$; vanishes at the borders of the definition domain.

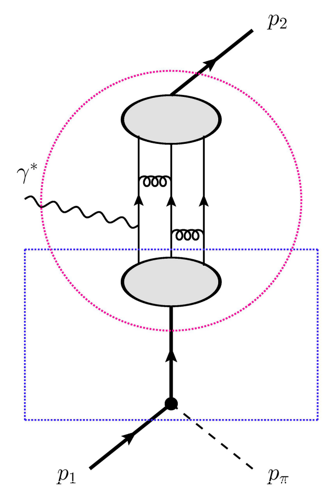
From $\xi = 0$ to $\xi = 1$



Nucleon exchange through a TDA

Nucleon pole contribution

- u-channel nucleon exchange is complementary to the spectral representation (D-term like contributions) non-zero in the ERBL-like region $0 \leq x_i \leq 2\xi$.



- The effective Hamiltonian for $\pi \bar{N} N$:

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

$$\langle \pi_a(p_\pi) | \widehat{O}^{\alpha\,\beta\,\gamma}_{\rho\tau\chi}(\lambda_1 n,\, \lambda_2 n,\, \lambda_3 n) | N_\iota(p_1, s_1) \rangle$$
$$= \sum_{s_p} \langle 0 | \widehat{O}^{\alpha\beta\gamma}_{\rho\tau\chi}(\lambda_1 n,\, \lambda_2 n,\, \lambda_3 n) | N_\kappa(-\Delta, s_p) \rangle (\sigma_a)^\kappa_{\ \iota} \frac{i g_{\pi NN} \bar{U}_\varrho(-\Delta, s_p)}{\Delta^2 - M^2} \left(\gamma^5 U(p_1, s_1) \right)_\varrho .$$

- After decomposition over the Dirac structures:

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

a 2 - component model for TDA

➩ **A spectral representation with input fixed at $\xi = 1$ through soft pion theorem**

and deskewing (i.e. $\xi \rightarrow\neq 1$) through an ansatz

➩ **A nucleon pole exchange in the $u-$channel**

These two components are additive and there is no double counting

(one may also add a $\Delta-$pole exchange but small contribution)

➩ A model driven by a nucleon DA parametrization

various existing DAs : CZ, COZ, KS, GS, BLW ...

input dependence

Cross section (for electroproduction now) calculated from the modeled TDA depends much on the DA model

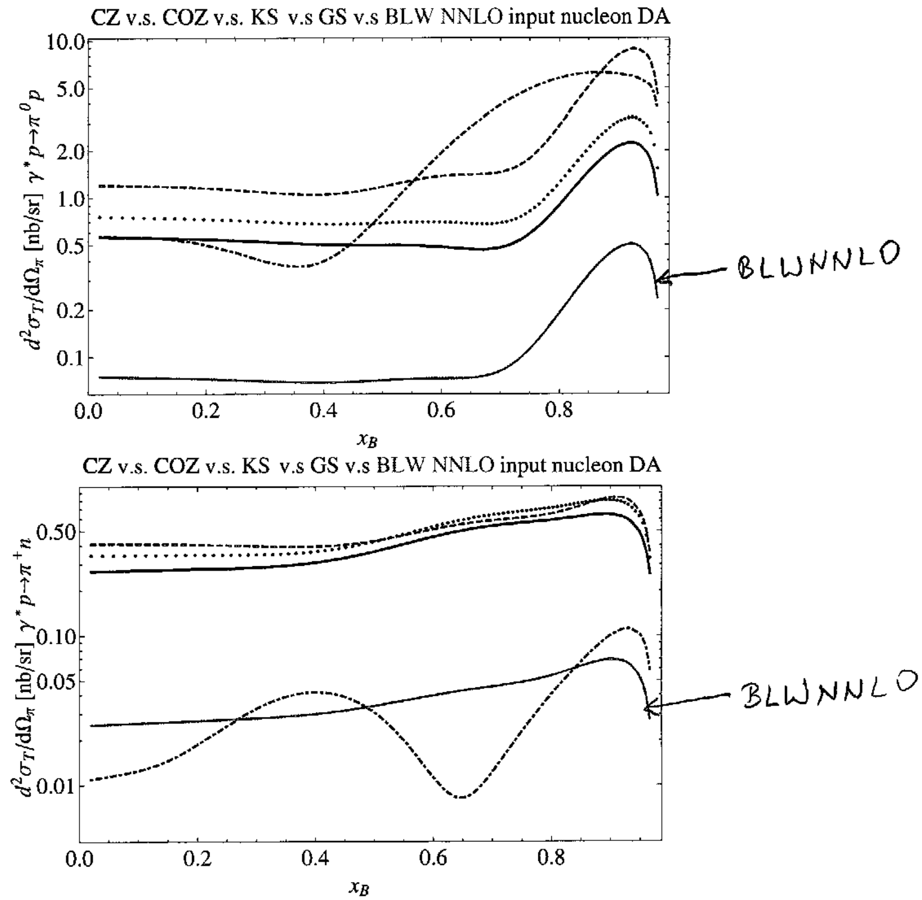


Figure 1: Unpolarized cross section $\frac{d^2\sigma_T}{d\Omega_\pi}$ (in nb/sr) for backward $\gamma^* p \to p\pi^0$ **(upper panel)** and for backward $\gamma^* p \to n\pi^+$ **(lower panel)** as the function of x_B computed in the two component model for πN TDAs for $Q^2 = 10\,\text{GeV}^2$, $u = -0.5\,\text{GeV}^2$ as a function of x_B. CZ [7] (red solid lines), COZ [8] (dotted lines), KS [9] (dashed lines), GS [10] (dash-dotted lines) nucleon DAs and BLWNNLO [4] (orange solid lines) were used as inputs for our model.

Conclusions

TDAs explore confinement dynamics of quarks in hadrons .

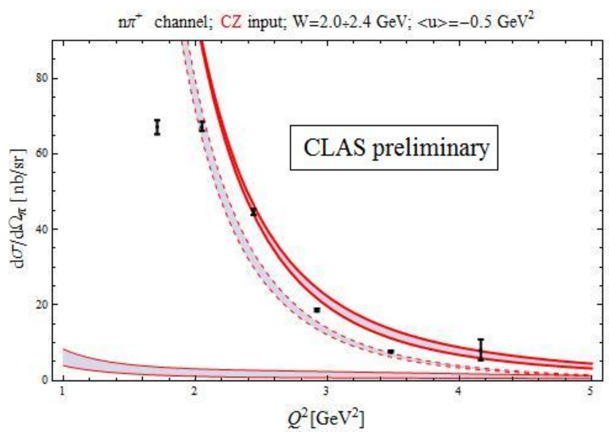
TDA extraction is crucial to probe meson content of baryons

➩ **First signals at JLab at 6 GeV + CLAS12 : spacelike channels**

CLAS $\gamma^* p \to \pi^+ n$ very preliminary analysis by Kijun Park I

Table: Determination of kinematic bin

variable	unit	num. bin	range	bin size
W	GeV	1	> 2.0	0.4
Q^2	GeV^2	5	$1.6 \sim 4.5$	various
$\lvert\Delta_T^2\rvert$	GeV^2	1	< 0.5	0.5



➩ **PANDA @FAIR : timelike channels**