Accessing TDAs with PANDA

IPN , October 2012

B. Pire
CPhT, École Polytechnique, Palaiseau

based on work done with K. Semenov - Tian - Shansky,
J.P. Lansberg, L Szymanowski.

New paper

Accessing baryon to meson transition distribution amplitudes in meson production in association with a high invariant mass lepton pair at GSI-FAIR with $\bar{\text{P}}$ANDA

J. P. Lansberg[1], B. Pire[2], K. Semenov-Tian-Shansky[3], L. Szymanowski[4]

submitted to Phys Rev D.

results presented at PANDA meeting - Paris september 2012

Factorization

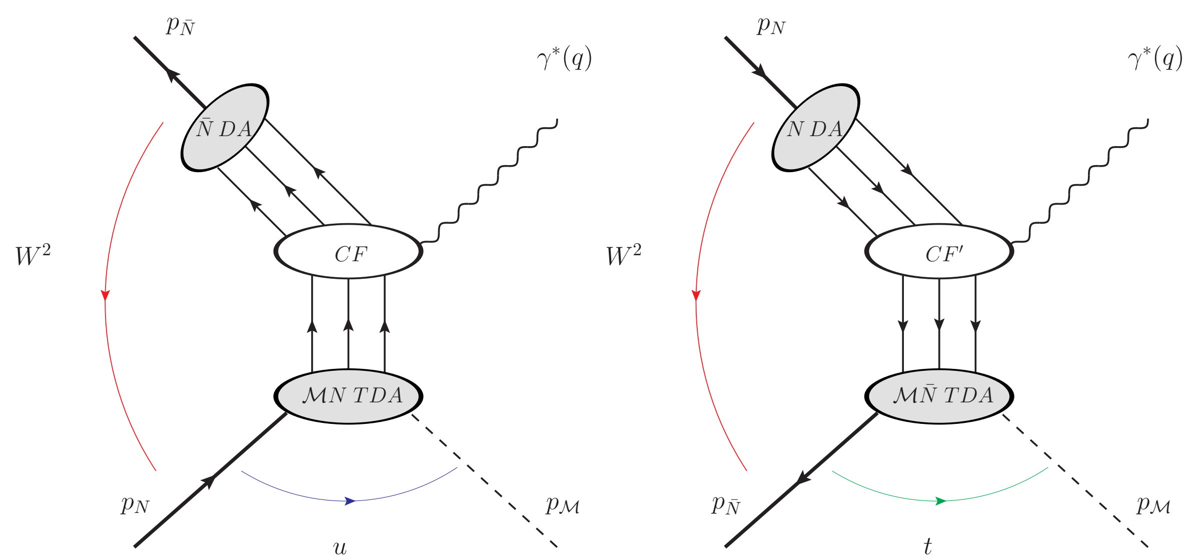


FIG. 1: Two possibilities for collinear factorization of the annihilation process $N\bar{N} \to \gamma^*(q)\mathcal{M}(p_{\mathcal{M}})$. **Left panel:** backward kinematics ($|u| \sim 0$) . **Right panel:** forward kinematics ($|t| \sim 0$). $\bar{N}(N)$ DA stands for the distribution amplitude of antinucleon (nucleon); $\mathcal{M}N(\mathcal{M}\bar{N})$ TDA stands for the transition distribution amplitude from a nucleon (antinucleon) to a meson; CF and CF' denote hard subprocess amplitudes (coefficient functions).

our 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

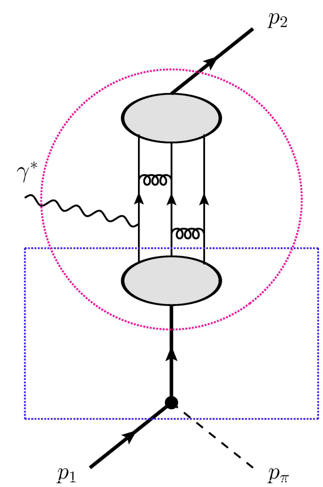
various existing DAs : CZ, COZ, KS, GS, BLW ...

NEW ! (LPS-2007 paper = only soft limit)

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 $0 \le x_i \le 2\xi$.



- 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:

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

Remarks

Nucleon pole dominant almost everywhere

Confidential : seems to give right order of magnitude for TDAs at JLab

$$e \quad N \longrightarrow e' \quad N' \quad \pi^0$$

Forward and Backward Peaks

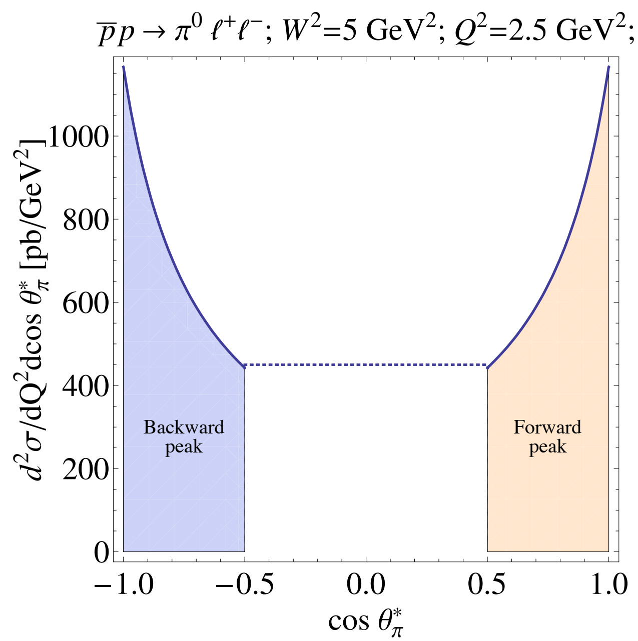


FIG. 6: Differential cross section $d\sigma/dQ^2 d\cos\theta^*_\pi$ for $\bar{p}p \longrightarrow \ell^+\ell^-\pi^0$ as a function of $\cos\theta^*_\pi$ for $W^2 = 5\text{GeV}^2$ and $Q^2 = 2.5\text{GeV}^2$. Forward and backward peaks are clearly visible. COZ solution for the nucleon DAs is used as the numerical input. Dotted region denotes scattering over large angles in which the present factorization description does not apply.

in Center of Mass frame !

From Center of Mass to Lab frame

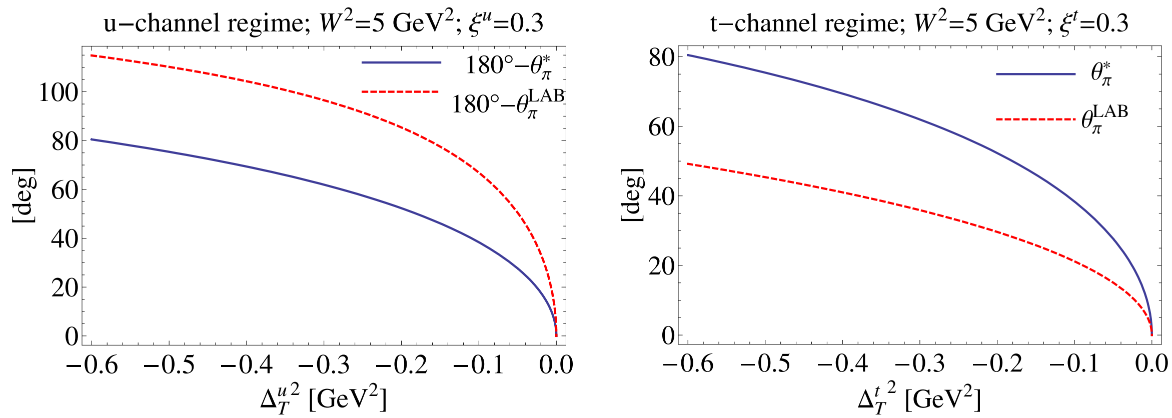


FIG. 3: The solid lines illustrate the dependence of the CMS scattering angles θ_π^* for the u-channel (left panel) and the t-channel (right panel) factorization regimes for the reaction (7) as functions of $\Delta_{T\,\rm min}^{u\,2}$ and $\Delta_{T\,\rm min}^{t\,2}$ respectively. The dashed lines illustrate the dependence of the LAB frame scattering angles $\theta_\pi^{\rm LAB}$ for the two factorization regimes as the function of $\Delta_{T\,\rm min}^{u\,2}$ and $\Delta_{T\,\rm min}^{t\,2}$ respectively. Note that the forward peak is narrowed and the backward peak is broadened due to the effect of the boost from the CMS to the LAB frame which corresponds to the nucleon N at rest in the $\bar{\rm P}$ANDA set up.

Forward peak narrowed ; Backward peak broadened

input dependence

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

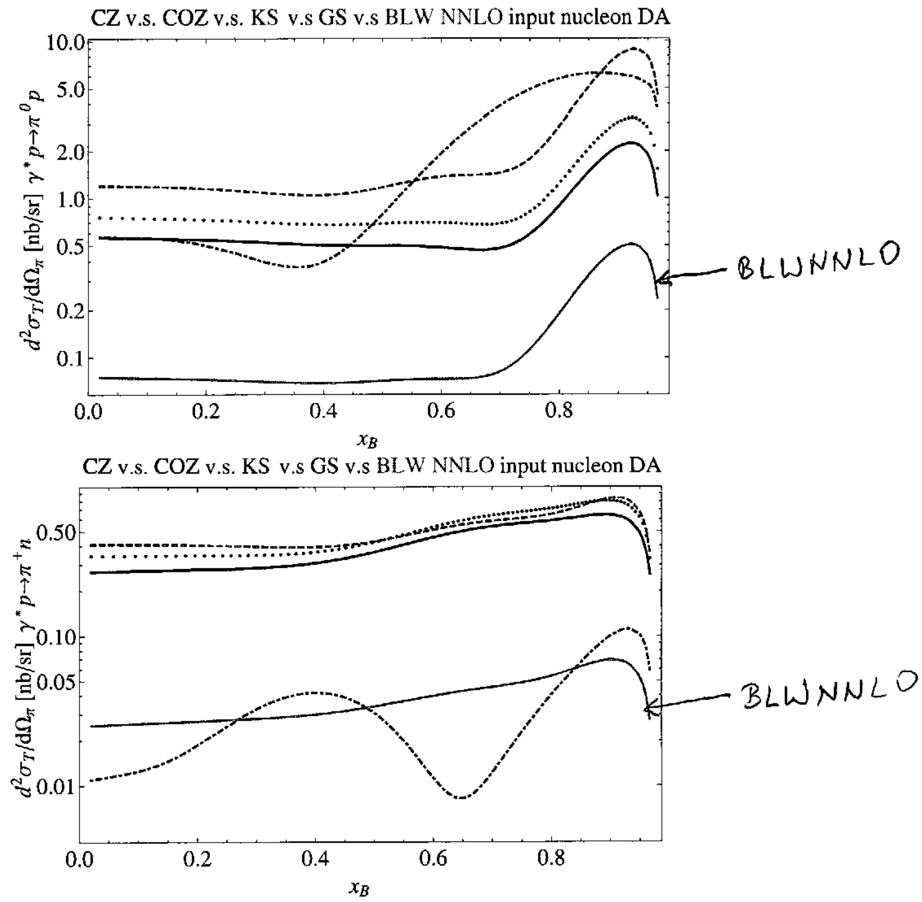
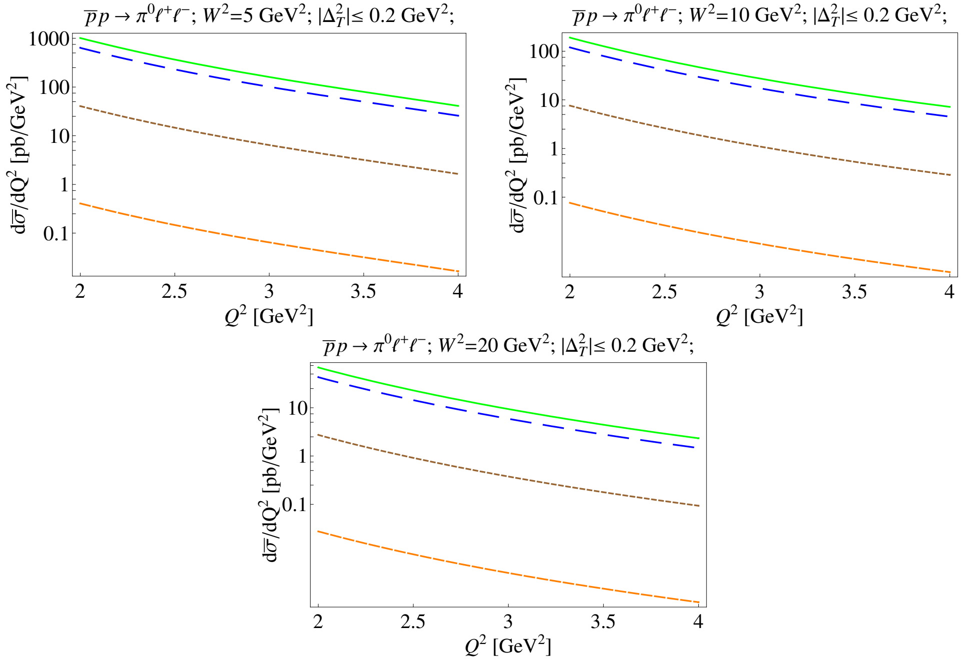


Figure 1: Unpolarized cross section $\frac{d^2\sigma_T}{d\Omega_\pi}$ (in nb/sr) for backward $\gamma^* p \to p\pi^0$ **(upper panel)** and for backward $\gamma^* p \to n\pi^+$ **(lower panel)** as the function of x_B computed in the two component model for πN TDAs for $Q^2 = 10\,\text{GeV}^2$, $u = -0.5\,\text{GeV}^2$ 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.

$$\bar{p}p \longrightarrow e^+e^-\pi^0$$



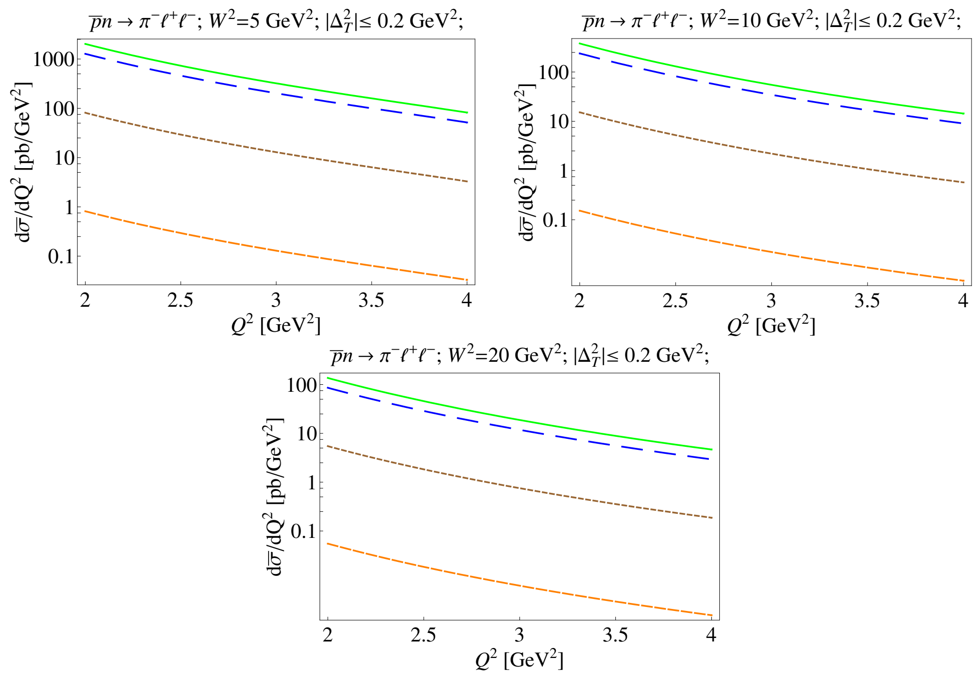
$$W^2 = 5, 10 GeV^2$$

$$W^2 = 20 GeV^2$$

FIG. 4: Integrated cross section $d\bar{\sigma}/dQ^2$ for $\bar{p}p \longrightarrow \ell^+\ell^-\pi^0$ as a function of Q^2 for different values of $W^2 = 5,\ 10$ and 20 GeV^2 for various phenomenological nucleon DA solutions: COZ (long dashes); KS (solid line); BLW NLO (medium dashes) and NNLO modification [25] of BLW (short dashes).

depends much on DA input in TDA model

$$\bar{p}n \longrightarrow e^+ e^- \pi^-$$



$W^2 = 5, 10 GeV^2$

$W^2 = 20 GeV^2$

FIG. 5: Integrated cross section $d\bar{\sigma}/dQ^2$ for $\bar{p}n \to \ell^+\ell^-\pi^-$ as a function of Q^2, for different values of $W^2 = 5,\ 10$ and 20 GeV^2 for various phenomenological nucleon DA solutions: COZ (long dashes); KS (solid line); BLW NLO (medium dashes) and NNLO modification [25] of BLW (short dashes).

Isospin factor doubles the cross section

η production

$$N(p_p) + \bar{N}(p_{\bar{p}}) \to \gamma^*(q) + \eta(p_\eta) \to \ell^+(p_{\ell^+}) + \ell^-(p_{\ell^-}) + \eta(p_\eta).$$

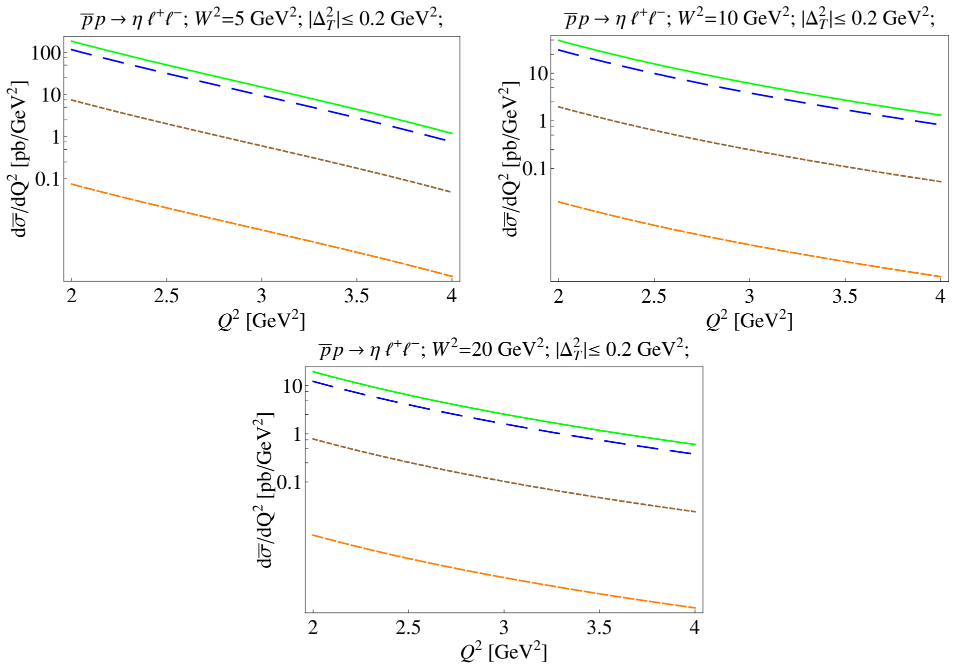
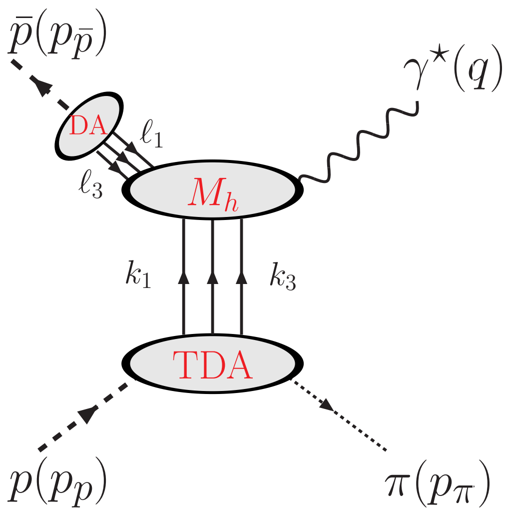
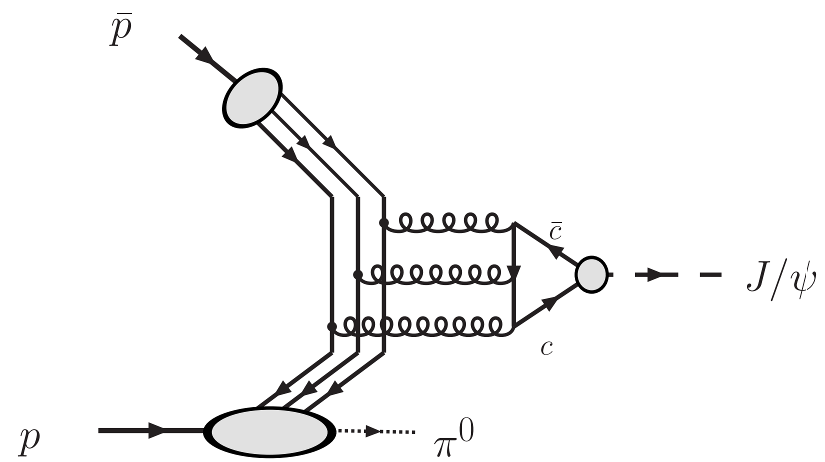


FIG. 7: Integrated cross section $d\bar{\sigma}/dQ^2$ for $\bar{p}p \to \ell^+\ell^-\eta$ as a function of Q^2 for different values of $W^2 = 5,\ 10$ and 20 GeV^2 for various phenomenological nucleon DA solutions: COZ (long dashes); KS (solid line); BLW NLO (medium dashes) and NNLO modification [25] of BLW (short dashes).

Smaller cross section ; less background ?

the PANDA@FAIR processes





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

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

but also

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

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 $\xi = 1$