Baryon-to-meson Transition Distribution Amplitudes: basic properties, physical interpretation and experimental perspectives

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Outline

1. Introduction: Forward and backward kinematical regimes, DAs, GPDs, TDAs;
2. Baryon-to-meson TDAs: definition and properties;
3. Physical contents of baryon-to-meson TDAs;
4. Current status of experimental analysis at JLab;
5. Summary and Outlook.

In collaboration with:
B. Pire, L. Szymanowski,
and
K. Park, W. Li, G. Huber, S. Diehl, M. Zambrana, B. Ramstein, E. Atomssa.

Factorization regimes for hard meson production I

- J. Collins, L. Frankfurt and M. Strikman'97: the collinear factorization theorem for

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

in the generalized Bjorken limit

$$-q^2 = Q^2,\ W^2 - \text{large};\quad x_B = \frac{Q^2}{2p \cdot q} - \text{fixed};\quad -t = -(p'-p)^2 - \text{small}.$$

- Description in terms of nucleon GPDs and meson DAs.
- A complementary factorization regime:

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Hard exclusive pseudoscalar meson electroproduction and spin structure of the nucleon

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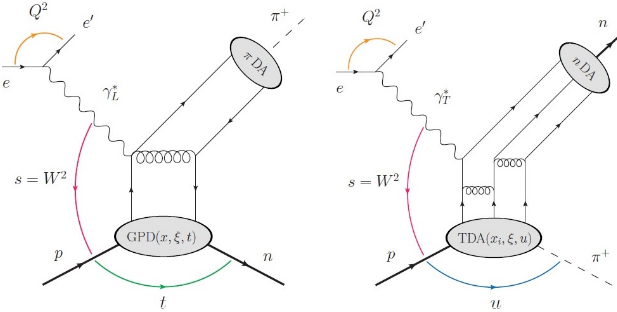
Factorization regimes for hard meson production II

Two complementary regimes in generalized Bjorken limit :

- $t \sim 0$ (near-forward kinematics): GPDs and meson DAs;
- $u \sim 0$ (near-backward kinematics): baryon-to-meson TDAs and nucleon DAs B. Pire, L. Szymanowski'05;



GPDs, DAs and TDAs

- Quark-antiquark bilinear light-cone ($z^2 = 0$) operator:

$$\langle A|\bar{\Psi}(0)[0;z]\Psi(z)|B\rangle$$

$\Rightarrow$ PDFs, meson DAs, GPDs, transition GPDs, etc.

- Three-quark trilinear light-cone ($z_i^2 = 0$) operator:

$$\langle A|\Psi(z_1)[z_1;z_2]\Psi(z_2)[z_2;z_3]\Psi(z_3)[z_3;z_1]|B\rangle$$

- $\langle A| = \langle 0|$; $|B\rangle$ - baryon; $\Rightarrow$ baryon DAs.
- Let $\langle A|$ be a meson state (π, η, ρ, ω, ...) $|B\rangle$ - baryon $\Rightarrow$ baryon-to-meson TDAs.

TDAs have common features with:

- baryon DAs: same operator;
- GPDs: $\langle B|$ and $|A\rangle$ are not of the same momenta $\Rightarrow$ skewness

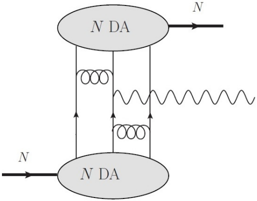
$$\xi = -\frac{(p_A - p_B)\cdot n}{(p_A + p_B)\cdot n}.$$

- TDAs are universal non-perturbative objects with known evolution properties

Nucleon e.m. FF: a well known examples

Nucleon e.m. FF in pQCD at leading order

S. Brodsky & P. Lepage'81 A. Efremov & A. Radyushkin'80

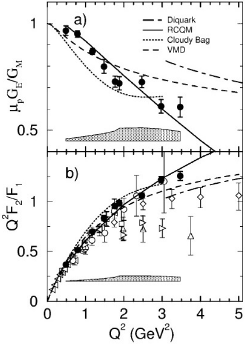


A word of caution:

VOLUME 84, NUMBER 7 PHYSICAL REVIEW LETTERS 14 FEBRUARY 2000

G_{E_p}/G_{M_p} Ratio by Polarization Transfer in $\vec{e}p \to e\vec{p}$

(The Jefferson Lab Hall A Collaboration)



A list of questions:

- What are the properties and physical contents of baryon-to-meson TDAs?
- Can we build models for baryon-to-meson TDAs?
- Can we access backward reactions experimentally?
- What are the marking signs for the onset of the collinear factorization regime?
- What new information can we get about hadrons?

Leading twist proton-to-π^0 TDAs

J.P.Lansberg, B.Pire, L.Szymanowski and K.S.'11 $\left(n^2 = p^2 = 0;\; 2p\cdot n = 1;\; \text{LC gauge } \boxed{A\cdot n = 0}\right)$.

- 8 TDAs: $H^{\pi N}(x_1, x_2, x_3, \xi, \Delta^2, \mu^2) \equiv \{V_i^{\pi N}, A_i^{\pi N}, T_i^{\pi N}\}(x_1, x_2, x_3, \xi, \Delta^2, \mu^2)$
- *C.f.* 3 leading twist nucleon DAs: $\{V^p, A^p, T^p\}(y_1, y_2, y_3)$

$$4(P\cdot n)^3 \int \left[\prod_{k=1}^{3} \frac{dz_k}{2\pi} e^{i x_k z_k (P\cdot n)}\right] \langle \pi^0(p_\pi)|\, \varepsilon_{c_1 c_2 c_3} u_\rho^{c_1}(z_1 n) u_\tau^{c_2}(z_2 n) d_\chi^{c_3}(z_3 n)\, |N^p(p_1, s_1)\rangle$$

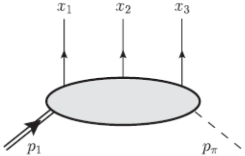
$$= \delta(2\xi - x_1 - x_2 - x_3) i \frac{f_N}{f_\pi M}$$

$$\times \big[V_1^{\pi N}(\hat{P}C)_{\rho\tau}(\hat{P}U)_\chi + A_1^{\pi N}(\hat{P}\gamma^5 C)_{\rho\tau}(\gamma^5 \hat{P}U)_\chi + T_1^{\pi N}(\sigma_{P\mu} C)_{\rho\tau}(\gamma^\mu \hat{P}U)_\chi$$

$$+ V_2^{\pi N}(\hat{P}C)_{\rho\tau}(\hat{\Delta}U)_\chi + A_2^{\pi N}(\hat{P}\gamma^5 C)_{\rho\tau}(\gamma^5 \hat{\Delta}U)_\chi + T_2^{\pi N}(\sigma_{P\mu} C)_{\rho\tau}(\gamma^\mu \hat{\Delta}U)_\chi$$

$$+ \frac{1}{M} T_3^{\pi N}(\sigma_{P\Delta} C)_{\rho\tau}(\hat{P}U)_\chi + \frac{1}{M} T_4^{\pi N}(\sigma_{P\Delta} C)_{\rho\tau}(\hat{\Delta}U)_\chi\big]$$

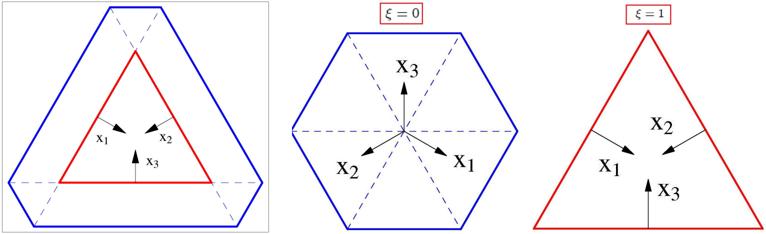
- $P = \frac{p_1 + p_\pi}{2}$; $\Delta = (p_\pi - p_1)$; $\sigma_{P\mu} \equiv P^\nu \sigma_{\nu\mu}$;
  $\xi = -\frac{\Delta\cdot n}{2P\cdot n}$
- C: charge conjugation matrix;
- $f_N = 5.2\cdot 10^{-3}$ GeV^2 (V. Chernyak and A. Zhitnitsky'84);



A list of fundamental properties I:

B. Pire, L.Szymanowski, KS'10,11:

- Restricted support in x_1, x_2, x_3: intersection of three stripes $-1+\xi \leq x_k \leq 1+\xi$ $(\sum_k x_k = 2\xi)$; ERBL-like and DGLAP-like I, II domains.



- Mellin moments in $x_k \Rightarrow \pi N$ matrix elements of local 3-quark operators

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

  Need to be studied on the lattice!

- Polynomiality in ξ of the Mellin moments in x_k:

$$\int_{-1+\xi}^{1+\xi} dx_1 dx_2 dx_3 \delta(\sum_k x_k - 2\xi) x_1^{n_1} x_2^{n_2} x_3^{n_3} H^{\pi N}(x_1, x_2, x_3, \xi, \Delta^2)$$
$$= [\text{Polynomial of order } n_1 + n_2 + n_3 \{+1\}](\xi).$$

A list of fundamental properties II:

- Spectral representation A. Radyushkin'97 generalized for πN TDAs ensures polynomiality and support:

$$
\begin{aligned}
& H(x_1,\, x_2,\, x_3 = 2\xi - x_1 - x_2,\, \xi) \\
& = \left[\prod_{i=1}^{3} \int_{\Omega_i} d\beta_i d\alpha_i \right] \delta(x_1 - \xi - \beta_1 - \alpha_1 \xi)\, \delta(x_2 - \xi - \beta_2 - \alpha_2 \xi) \\
& \times \delta(\beta_1 + \beta_2 + \beta_3) \delta(\alpha_1 + \alpha_2 + \alpha_3 + 1) F(\beta_1,\, \beta_2,\, \beta_3,\, \alpha_1,\, \alpha_2, \alpha_3)\,;
\end{aligned}
$$

- Ω_i: $\{|\beta_i| \le 1,\ |\alpha_i| \le 1 - |\beta_i|\}$ are copies of the usual DD square support;
- $F(\ldots)$: six variables that are subject to two constraints $\Rightarrow$ quadruple distributions;
- Can be supplemented with a D-term-like contribution (with pure ERBL-like support):

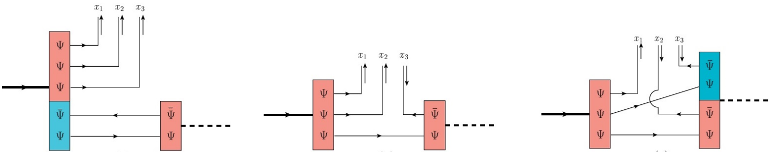
$$
\frac{1}{(2\xi)^2} \delta\left(x_1 + x_2 + x_3 - 2\xi\right) \left[\prod_{k=1}^{3} \theta\left(0 \le x_k \le 2\xi\right) \right] D\left(\frac{x_1}{2\xi}, \frac{x_2}{2\xi}, \frac{x_3}{2\xi} \right).
$$

TDAs and light-cone wave functions

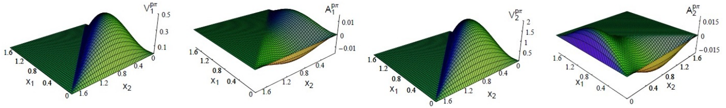
- Light-front quantization approach: πN TDAs provide information on next-to-minimal Fock components of light-cone wave functions of hadrons B. Pasquini et al. 2009:

$$|N\rangle = \underbrace{\psi_{(3q)}|qqq\rangle}_{\text{Described by nucleon DA}} + \psi_{(3q+q\bar{q})}|qqq\, q\bar{q}\rangle + \ldots$$

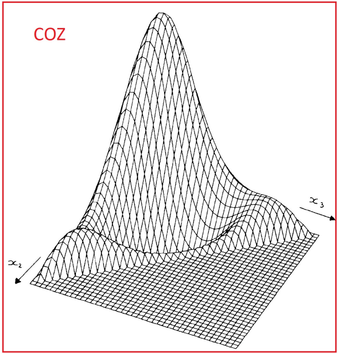
$$|M\rangle = \underbrace{\psi_{(q\bar{q})}|q\bar{q}\rangle}_{\text{Described by meson DA}} + \psi_{(q\bar{q}+q\bar{q})}|q\bar{q}\, q\bar{q}\rangle + \ldots$$



(a) (b) (c)



A connection to the quark-diquark picture I



- $\varphi_{\rm as}(x) = 120 x_1 x_2 x_3$.
- V. Chernyak, Zhitnitsky'84:

$$\varphi_{\rm CZ}(x) = \varphi_{\rm as}(x) \sum_i c_i A_i(x).$$

- Large asymmetry between quarks in nucleon:

$$\varphi^{(1,0,0)} \simeq 0.6; \quad \varphi^{(0,1,0)} \simeq \varphi^{(0,0,1)} \simeq 0.2.$$

- Z. Dziembowski, J. Franklin'90: diquark-like clustering

$$p : \uparrow\downarrow\uparrow \quad \underbrace{ud \uparrow\downarrow} \quad u \uparrow .$$

- No confirmation of asymmetric behavior: e.g. V. Braun, A. Lenz, M. Wittmann'06 .

A connection to the quark-diquark picture II

- Quark-diquark coordinates (one of 3 possible sets):

$$v_3=\frac{x_1-x_2}{2};\;\; w_3=x_3-\xi;\;\; x_1+x_2=2\xi_3';\;\; \left(\xi_3'\equiv\frac{\xi-w_3}{2}\right).$$

- The TDA support in quark-diquark coordinates:

$$\boxed{-1\leq w_3\leq 1;\quad -1+\left|\xi-\xi_3'\right|\leq v_3\leq 1-\left|\xi-\xi_3'\right|}$$

- v_3-Mellin moment of πN TDAs:

$$\int_{-1+|\xi-\xi_3'|}^{1-|\xi-\xi_3'|} dv_3 H^{\pi N}(w_3,\, v_3,\, \xi,\, \Delta^2)$$

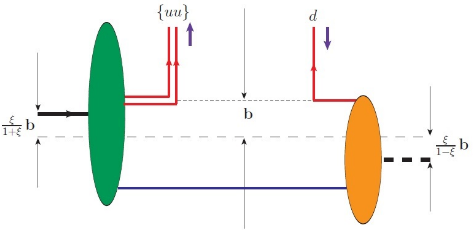
$$\sim h^{-1}_{\rho\tau\chi}\int\frac{d\lambda}{4\pi}e^{i(w_3\lambda)(P\cdot n)}\langle\pi^0(p_\pi)|\underbrace{u_\rho(-\frac{\lambda}{2}n)u_\tau(-\frac{\lambda}{2}n)d_\chi(\frac{\lambda}{2}n)}_{\hat{\mathcal{O}}^{\{uu\}d}_{\rho\tau\chi}(-\frac{\lambda}{2}n,\,\frac{\lambda}{2}n)}|N^p(p_1)\rangle$$

An interpretation in the impact parameter space I

- A generalization of M. Burkardt'00,02; M. Diehl'02 for v_3-integrated TDAs.
- Fourier transform with respect to

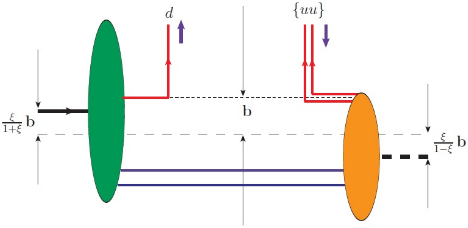
$$\mathbf{D} = \frac{\mathbf{p}_\pi}{1-\xi} - \frac{\mathbf{p}_N}{1+\xi}; \qquad \Delta^2 = -2\xi \left(\frac{m_\pi^2}{1-\xi} - \frac{M_N^2}{1+\xi} \right) - (1-\xi^2)\mathbf{D}^2.$$

- A representation in the DGLAP-like I domain:

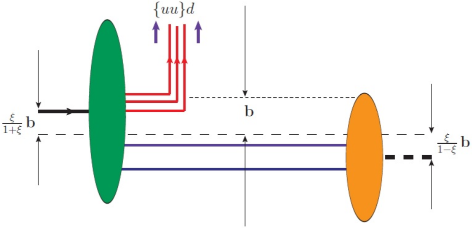


DGLAP I : $x_3 = w_3 - \xi \leq 0; \quad x_1 + x_2 = \xi - w_3 \geq 0;$

An interpretation in the impact parameter space II



DGLAP II : $x_3 = w_3 - \xi \geq 0; \quad x_1 + x_2 = \xi - w_3 \leq 0;$



ERBL : $x_3 = w_3 - \xi \geq 0; \quad x_1 + x_2 = \xi - w_3 \geq 0;$

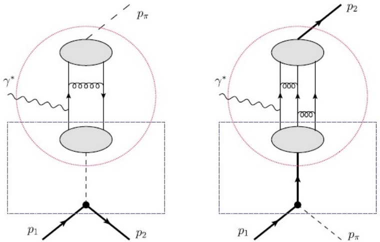
Building up a consistent model for πN TDAs

Key requirements:

1. support properties in x_k and polynomialty;
2. isospin + permutation symmetry;
3. crossing πN TDA $\leftrightarrow$ πN GDA;
4. Soft pion theorem P. Pobylitsa, M. Polyakov and M. Strikman'01; V. Braun, D. Ivanov, A. Lenz, A. Peters'08: πN GDA at the threshold $\xi = 1$, $\Delta^2 = M^2$ in terms of nucleon DAs.

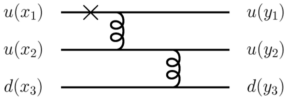
How to model quadruple distributions?

- No enlightening $\xi = 0$ limit as for GPDs (*cf.* RDDA A. Radyushkin'97
- Instead, $\xi \to 1$ fixed from the soft pion theorem;
- A factorized Ansatz with input at $\xi = 1$ designed in J.P. Lansberg, B. Pire, K.S., L. Szymanowski'12
- Cross-channel exchange as a source of the D-term-like contribution: $\tilde{E}$ GPD v.s. TDA



Calculation of the amplitude

- LO amplitude for $\gamma^* + N^p \to \pi^0 + N^p$ computed as in J.P. Lansberg, B. Pire and L. Szymanowski'07;
- 21 diagrams contribute;



$$\mathcal{I} \sim \int_{-1+\xi}^{1+\xi} d^3x\delta(x_1 + x_2 + x_3 - 2\xi) \int_0^1 d^3y\delta(1 - y_1 - y_2 - y_3) \left(\sum_{\alpha=1}^{21} R_\alpha \right)$$

Each R_α, has the structure:

$$R_\alpha \sim K_\alpha(x_1, x_2, x_3) \times Q_\alpha(y_1, y_2, y_3) \times$$
$$[\text{combination of } \pi N \text{ TDAs}] \times [\text{combination of nucleon DAs}]$$

$$R_1 = \frac{q^u(2\xi)^2[(V_1^{p\pi^0} - A_1^{p\pi^0})(V^p - A^p) + 4T_1^{p\pi^0} T^p + 2\frac{\Delta_T^2}{M^2} T_4^{p\pi^0} T^p]}{(2\xi - x_1 + i\epsilon)^2(x_3 + i\epsilon)(1 - y_1)^2 y_3}$$

$$\text{c.f.} \quad \int_{-1}^{1} dx \frac{H(x,\xi)}{x \pm \xi \mp i\epsilon} \int_0^1 dy \frac{\phi_M(y)}{y} \quad \text{for HMP}$$

$N\gamma^* \to \pi N$ amplitude and the cross section

- $N\gamma^* \to \pi N$ helicity amplitudes:

$$\mathcal{M}^{\lambda}_{s_1 s_2} = -i \frac{(4\pi\alpha_s)^2 \sqrt{4\pi\alpha_{em}} f_N^2}{54 f_\pi} \frac{1}{Q^4} \left[\mathcal{S}^{\lambda}_{s_1 s_2} \mathcal{I}(\xi, \Delta^2) - \mathcal{S'}^{\lambda}_{s_1 s_2} \mathcal{I}'(\xi, \Delta^2) \right],$$

where $\mathcal{S}^{\lambda}_{s_1 s_2} \equiv \bar{U}(p_2, s_2) \hat{\epsilon}^*(\lambda) \gamma_5 U(p_1, s_1)$; $\mathcal{S'}^{\lambda}_{s_1 s_2} \equiv \frac{1}{M} \bar{U}(p_2, s_2) \hat{\epsilon}^*(\lambda) \hat{\Delta}_T \gamma_5 U(p_1, s_1)$,

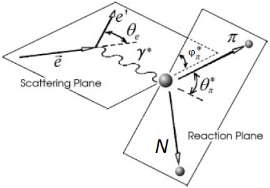
- Unpolarized cross section for hard leptoproduction of a pion off nucleon:

$$\frac{d^5\sigma}{dE' d\Omega_{e'} d\Omega_\pi} = \Gamma \times \frac{\Lambda\left(s, m^2, M^2\right)}{128\pi^2 s \left(s - M^2\right)} \times \sum_{s_1, s_2} \left\{ \frac{1}{2} \left(\left| \mathcal{M}^{1}_{s_1 s_2} \right|^2 + \left| \mathcal{M}^{-1}_{s_1 s_2} \right|^2 \right) + \ldots \right\} = \Gamma \times \left(\frac{d^2 \sigma_T}{d\Omega_\pi} + \ldots \right).$$

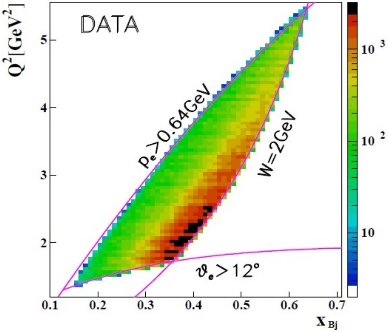
Distinguishing features of the TDA-based mechanism

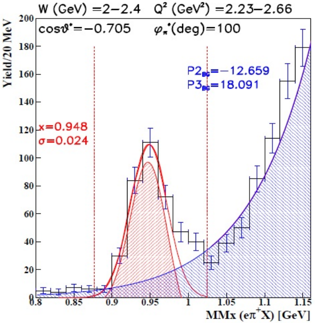
- Dominance of the transverse cross section $\frac{d^2\sigma_T}{d\Omega_\pi}$.
- $1/Q^8$ scaling behavior of the cross section.
- Non-zero imaginary part of the amplitude. Transverse Target Single Spin Asymmetry $\sim$ Im part of the amplitude

Backward pion electroproduction @ CLAS I



- Analysis of JLab @ 6 GeV data (Oct.2001-Jan.2002 run) for the backward $\gamma^* p \to \pi^+ n$
  K. Park et al. (CLAS Collaboration) and B. Pire and K.S., PLB 780 (2018)





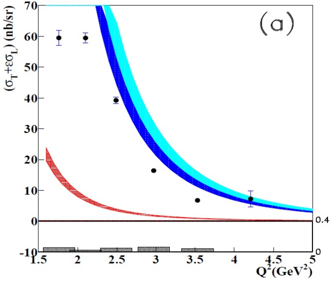
Backward pion electroproduction @ CLAS II

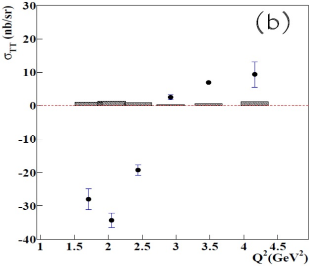
$$\frac{d\sigma}{d\Omega_\pi^*} = A + B\cos\varphi_\pi^* + C\cos 2\varphi_\pi^*,$$ where

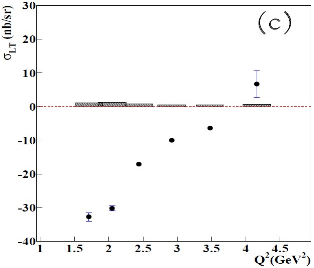
$A = \sigma_T + \epsilon\sigma_L$; $B = \sqrt{2\epsilon(1+\epsilon)}\sigma_{LT}$;
$C = \epsilon\sigma_{TT}$

Table ; Determination of kinematic bin.

Variable	Number of bins	Range	Bin size
W	1	2.0 – 2.4 GeV	400 MeV
Q^2	5	1.6 – 4.5 GeV^2	various
Δ_T^2	1	0 – 0.5 GeV^2	0.5 GeV^2
φ_π^*	9	0^o – 360^o	40^o







Backward pion electroproduction @ CLAS III

S. Diehl et al. (CLAS collaboration), analysis approved by the collaboration.

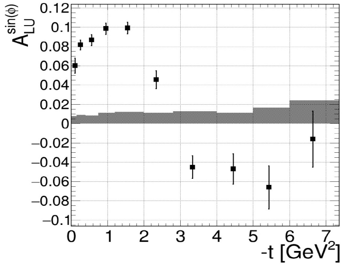
- The cross section can be expressed as

$$\frac{d^4\sigma}{dQ^2\,dx_B\,d\varphi\,dt} = \sigma_0 \cdot \left(1 + A_{UU}^{\cos(2\varphi)} \cdot \cos(2\varphi) + A_{UU}^{\cos(\varphi)} \cdot \cos(\varphi) + A_{LU}^{\sin(\varphi)} \cdot \sin(\varphi)\right).$$

- Beam Spin Asymmetry

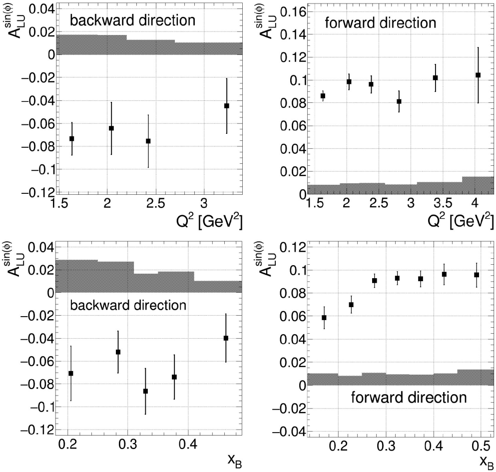
$$\mathrm{BSA}\,(Q^2, x_B, -t, \varphi) = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} = \frac{A_{LU}^{\sin(\varphi)} \cdot \sin(\varphi)}{1 + A_{UU}^{\cos(\varphi)} \cdot \cos(\varphi) + A_{UU}^{\cos(2\varphi)} \cdot \cos(2\varphi)};$$

- $\sigma^{\pm}$ is the cross-section with the beam helicity states $(\pm)$.



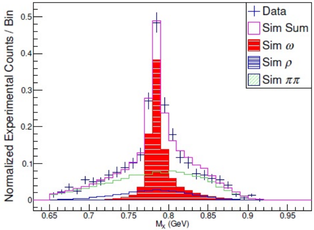
Backward pion electroproduction @ CLAS IV

- Beam Spin Asymmetry is a subleading twist effect both in the forward and backward regimes.



Backward ω-production at JLab Hall C I

- A generalization of the TDA formalism for the case of light vector mesons (ρ, ω, ϕ) B. Pire, L. Szymanowski and K.S'15.
- The analysis W. Li, G. Huber et al. (The JLab F_π Collaboration) and B. Pire, L. Szymanowski, J.-M. Laget and K.S., PRL 123 (2019) .
- Clear signal from backward regime of $ep \to e' p\omega$.

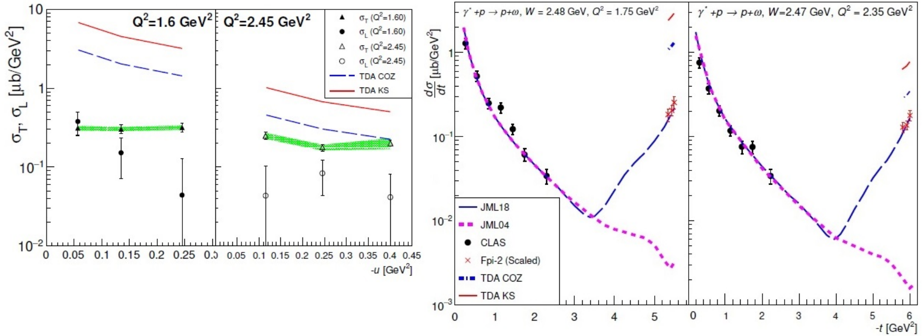


- Full Rosenbluth separation: $\sigma_{\rm T}$ and $\sigma_{\rm L}$ extracted.

$$2\pi \frac{d^2\sigma}{dtd\phi} = \frac{d\sigma_{\rm T}}{dt} + \epsilon \frac{d\sigma_{\rm L}}{dt} + \sqrt{2\epsilon(1+\epsilon)} \frac{d\sigma_{\rm LT}}{dt} \cos\phi + \epsilon \frac{d\sigma_{\rm TT}}{dt} \cos 2\phi$$

Backward ω-production at JLab Hall C II

- For $Q^2 = 2.45$ GeV^2: $\sigma_L/\sigma_T < \mu^2/Q^2$ and $\sigma_T \gg \sigma_L$;



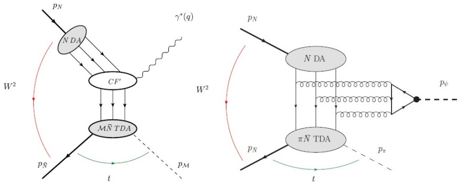
- Experiment v.s. the predictions of the cross-channel nucleon exchange model for $p \to \omega$ TDAs.
- Combined (CLAS and F_π-2 data for $\gamma^* p \to \omega p$).
- TDA-based predictions v.s. the Regge-based J.M. Laget's JML'18 model.

Baryon to meson TDAs at P̄ANDA

- $E_{\bar{p}} \leq 15\,\mathrm{GeV}$; $W^2 \leq 30\,\mathrm{GeV}^2$
- J.P. Lansberg et al.'12; B. Pire, L. Szymanowski, KS,'13: πN TDAs occur in factorized description of

$$\bar{N} + N \to \gamma^*(q) + \pi \to \ell^+ + \ell^- + \pi;$$
$$\bar{N} + N \to J/\psi + \pi \to \ell^+ + \ell^- + \pi;$$

- Two regimes (forward and backward). C invariance $\Rightarrow$ perfect symmetry;
- Test of universality of TDAs;
- $(1+\cos^2\theta_\ell)$ distribution marks the reaction mechanism: transverse polarization dominance (leading twist accuracy).

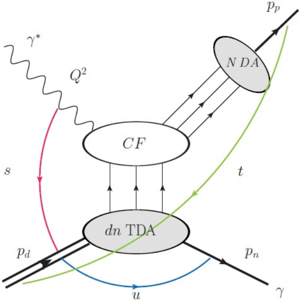


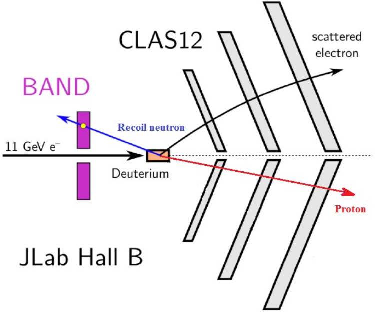
- M. C. Mora Espi, M. Zambrana, F. Maas, K.S.'15: feasibility of $\bar{p}p \to e^+e^-\pi^0$.
- B. Ramstein, E. Atomssa and P̄ANDA collaboration and K.S., PRD 95'17 feasibility of $\bar{p}p \to J/\psi\,\pi^0$.

Deep deuteron electrodissociation with a $B = 1$ exchange in the cross channel

- More use for $3q$ light-cone operator: TDAs for $B \to B-1$ baryons as a tool for nuclear physics.
- Deep deuteron electrodissociation with a baryon number exchange in the cross channel:

$$\gamma^*(q) + d(p_d) \to p(p_p) + n(p_n); \quad |u| = |(p_d - p_n)^2| \ll Q^2,\ W^2 = (q + p_d)^2.$$

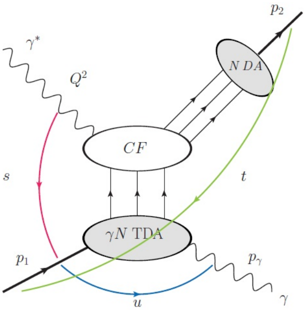




- BAND coverage in θ: $155 - 176^\circ$.
- Can CLAS measure this reaction?

Backward DVCS and nucleon-to-photon TDAs

- Nucleon-to-photon TDAs J.P. Lansberg, B. Pire, and L. Szymanowski'07 : 16 $N \to \gamma$ TDAs at the leading twist-3 .



- Cross channel processes $N\bar{N} \to \gamma^* \gamma$ can be studied with $\bar{\text{P}}$ANDA.
- New information on the subtraction constant in the dispersion relation for the DVCS amplitude (D-term FF).
- May be important in connection with the $J = 0$ fixed pole universality conjecture S. Brodsky, F. Llanes-Estrada, and A. Szczepaniak'09, D. Müller and K.S.'15.

Conclusions & Outlook

1. Nucleon-to-meson TDAs provide new information about correlation of partons inside hadrons. A consistent picture for integrated TDAs emerges in the impact parameter representation.
2. We strongly encourage to try to detect near forward and backward signals for various mesons (π, η, ω, ρ) and photons: there is an interesting physics around!
3. The experimental success achieved for backward $\gamma^* N \to N'\pi$ and $\gamma^* N \to N'\omega$ already with the old 6 GeV data set (more is expected at 12 GeV).
4. First evidences for the onset of the factorization regime in backward $\gamma^* N \to N'\omega$ from JLab Hall C analysis.
5. $\bar{p}N \to \pi \ell^+ \ell^-$ (q^2 - timelike) and $\bar{p}N \to \pi J/\psi$ at P̄ANDA would allow to check universality of TDAs.
6. TDAs as a tool for nuclear physics: deuteron-to-nucleon TDAs.