Baryon-to-meson transition distribution amplitudes (TDAs): formalism and experimental perspectives

Bernard Pire

L' École Polytechnique, CPhT, Palaiseau

GDR 2019, LPT Orsay, 25 - 27 November, 2019

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 and feasibility studies for $\bar{\text{P}}$ANDA.
5. Summary and Outlook.

Collaboration on theoretical issues with
J.-Ph. Lansberg (IPN, Orsay), K. Semenov Tian-Shansky ((INP, Gatchina)), L. Szymanowski (NCBJ, Warsaw)
and with JLab and PANDA experimentalists:
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:

PHYSICAL REVIEW D, VOLUME 60, 014010

Hard exclusive pseudoscalar meson electroproduction and spin structure of the nucleon

L. L. Frankfurt,[1,2] P. V. Pobylitsa,[2,3] M. V. Polyakov,[2,3] and M. Strikman[2,4,*]

[1]*Physics Department, Tel Aviv University, Tel Aviv, Israel*

[2]*Petersburg Nuclear Physics Institute, Gatchina, Russia*

[3]*Institut für Theoretische Physik II, Ruhr-Universität Bochum, D-44780 Bochum, Germany*

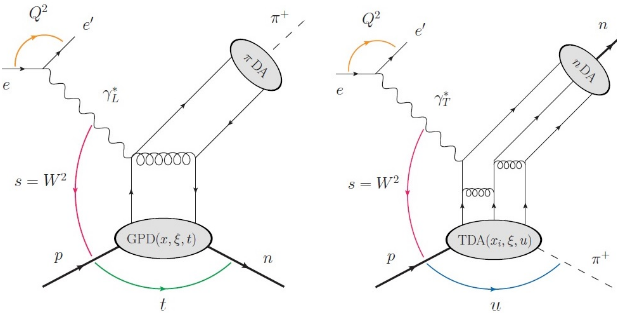
[4]*Department of Physics, Pennsylvania State University, University Park, Pennsylvania 16802 and Deutsches Elektronen Synchrotron DESY, Hamburg, Germany*

(Received 5 February 1999; published 4 June 1999)

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

- Main objects: matrix elements of QCD light-cone ($z^2 = 0$) operators.
- Quark-antiquark bilinear light-cone 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 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.

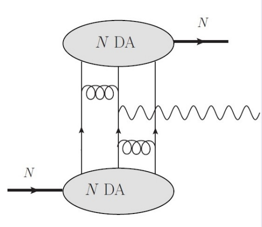
TDAs have common features with:

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

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

Nucleon e.m. FF in pQCD at leading order

Brodsky & Lepage'81 Efremov & Radyushkin'80

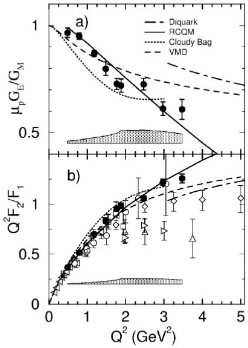


A word of caution:

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 key issues:

- What are the properties and physical contents of baryon-to-meson TDAs?
- Can we access backward reactions experimentally?
- What are the marking signs for the onset of the collinear factorization regime?

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: $\{V^p, A^p, T^p\}(y_1, y_2, y_3)$

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

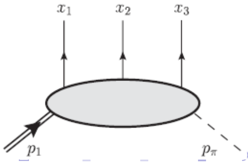
$$= \delta(2\xi - x_1 - x_2 - x_3) i \frac{f_N}{f_\pi M}$$

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

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

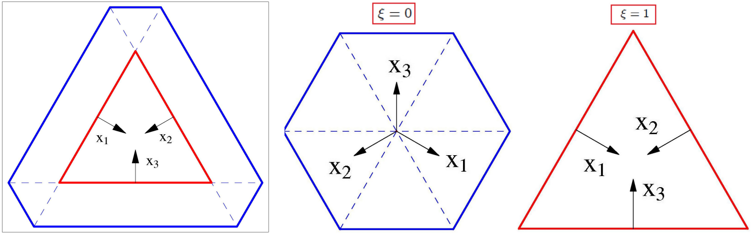
$$\left.+ \frac{1}{M} T_3^{\pi N}(\sigma_{P\Delta} C)_{\rho\tau}(\hat{P}U)_\chi + \frac{1}{M} T_4^{\pi N}(\sigma_{P\Delta} C)_{\rho\tau}(\hat{\Delta}U)_\chi\right]$$

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



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

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



- Mellin moments in x_k $\Rightarrow$ πN 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:

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

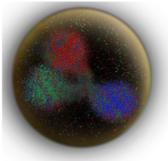
- Ω_i: $\{|\beta_i| \leq 1,\ |\alpha_i| \leq 1 - |\beta_i|\}$ are copies of the usual DD square support;
- $F(...)$: six variables that are subject to two constraints $\Rightarrow$ quadruple distributions;
- Can be supplemented with a D-term-like contribution (with pure ERBL-like support):

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

A connection to the quark-diquark picture

- 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:

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

- v_3-Mellin moment of πN TDAs:

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

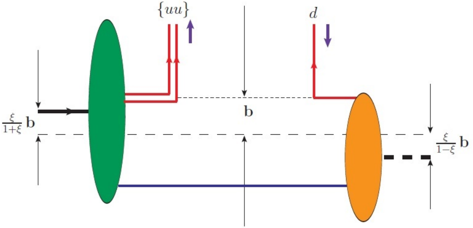
$$\sim h^{-1}_{\rho\tau\chi}\int\frac{d\lambda}{4\pi}e^{i(w_3\lambda)(P\cdot n)}\langle\pi^0(p_\pi)|\underbrace{u_\rho(-\frac{\lambda}{2}n)u_\tau(-\frac{\lambda}{2}n)d_\chi(\frac{\lambda}{2}n)}_{\hat{\mathcal{O}}^{\{uu\}d}_{\rho\tau\chi}(-\frac{\lambda}{2}n,\,\frac{\lambda}{2}n)}|N^p(p_1)\rangle$$

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

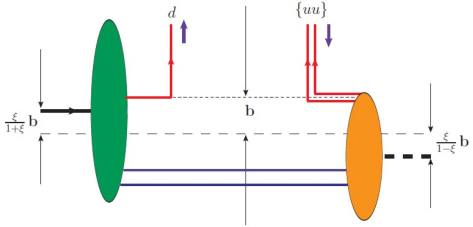
$$\mathbf{D} = \frac{\mathbf{p}_\pi}{1-\xi} - \frac{\mathbf{p}_N}{1+\xi}; \quad \Delta^2 = -2\xi \left(\frac{m_\pi^2}{1-\xi} - \frac{M_N^2}{1+\xi} \right) - (1-\xi^2)\mathbf{D}^2.$$

- A representation in the DGLAP-like I domain:

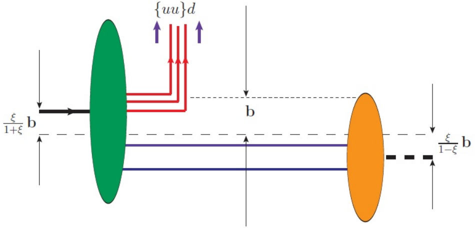


$$\text{DGLAP I}: \quad x_3 = w_3 - \xi \le 0; \quad x_1 + x_2 = \xi - w_3 \ge 0;$$

An interpretation in the impact parameter space II



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

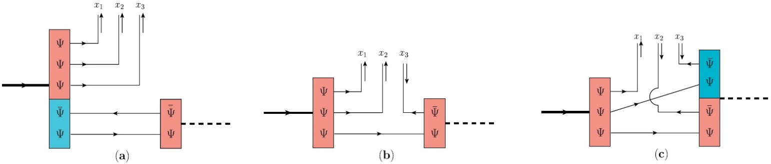


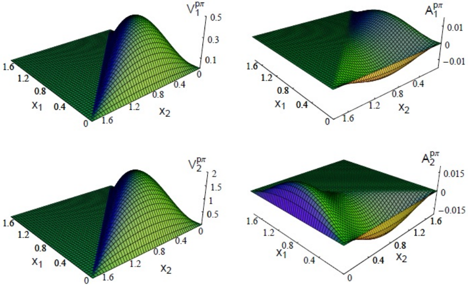
ERBL : $x_3 = w_3 - \xi \geq 0; \quad x_1 + x_2 = \xi - w_3 \geq 0;$

Light-cone quark model interpretation

- πN TDAs provides information on the next to minimal Fock states B. Pasquini et al. 2009:

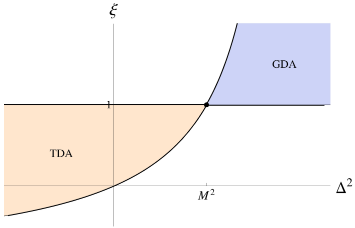
$$\underbrace{|qqq\rangle}_{\text{Described by nucleon DA}} \qquad +|qqq\,\pi\rangle + \ldots$$





Crossing, chiral properties and soft pion theorem for πN GDA/TDA

- Crossing relates and πN GDAs (light-cone wave functions of $|\pi N\rangle$ states).
- Physical domain in (Δ^2, ξ)-plane (defined by $\Delta_T^2 \leq 0$) in the chiral limit ($m_\pi = 0$):



- Soft pion theorem P. Pobylitsa, M. Polyakov and M. Strikman'01; V. Braun, D. Ivanov, A. Lenz, A. Peters'08 ($Q^2 \gg \Lambda^3_{\rm QCD}/m_\pi$): πN GDA at the threshold $\xi = 1$, $\Delta^2 = M^2$ in terms of nucleon DAs V^p, A^p, T^p.

Building up a consistent model for πN TDAs

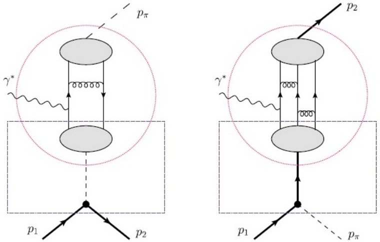
Key requirements:

1. support properties in x_k and polynomialty;
2. isospin + permutation symmetry;
3. crossing πN TDA $\leftrightarrow$ πN GDA and chiral properties: soft pion theorem;

How to model quadruple distributions?

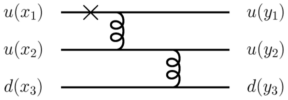
- No enlightening $\xi = 0$ limit as for GPDs. RDDA A. Radyushkin'97
- Instead, the soft pion theorems fixes the $\xi \to 1$ limit in terms of nucleon DAs and thus provides the overall magnitude of TDAs.
- A factorized Ansatz with input at $\xi = 1$ designed in J.P. Lansberg, B. Pire, K.S. and L. Szymanowski'12

- 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:

$$R_\alpha \sim K_\alpha(x_1,x_2,x_3) \times Q_\alpha(y_1,y_2,y_3) \times$$
[combination of πN TDAs] $\times$ [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:

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

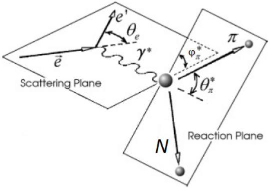
where $\mathcal{S}^{\lambda}_{s_1 s_2} \equiv \bar{U}(p_2, s_2) \hat{\epsilon}^*(\lambda) \gamma_5 U(p_1, s_1)$; $\mathcal{S'}^{\lambda}_{s_1 s_2} \equiv \frac{1}{M} \bar{U}(p_2, s_2) \hat{\epsilon}^*(\lambda) \hat{\Delta}_T \gamma_5 U(p_1, s_1)$,

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

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

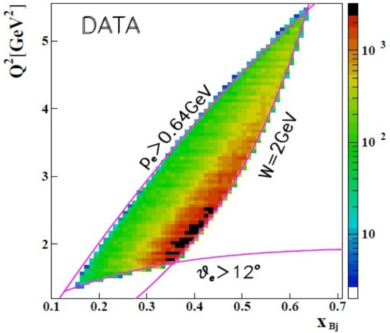
Distinguishing features of the TDA-based mechanism

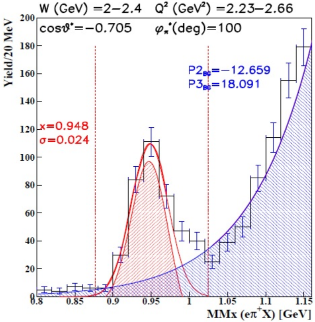
- Dominance of the transverse cross section $\frac{d^2\sigma_T}{d\Omega_\pi}$.
- $1/Q^8$ scaling behavior of the cross section.
- Non-zero imaginary part of the amplitude. Transverse Target Single Spin Asymmetry $\sim$ Im part of the amplitude



- 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. Semenov Tian-Shansky., PLB 780 (2018)





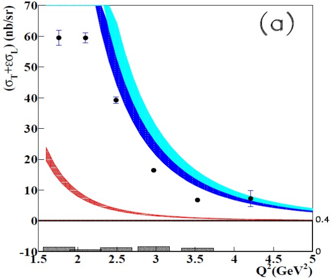
Backward pion electroproduction @ CLAS II

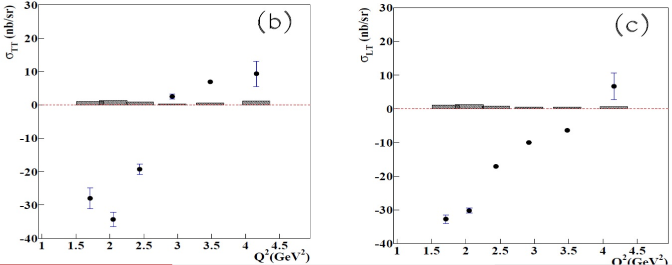
$$\frac{d\sigma}{d\Omega_\pi^*} = A + B\cos\varphi_\pi^* + C\cos 2\varphi_\pi^*,$$ where

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

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.

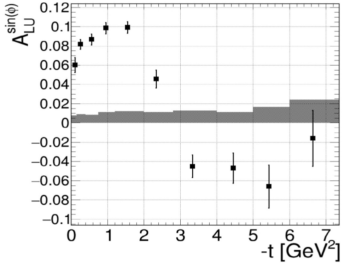
- The cross section can be expressed as

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

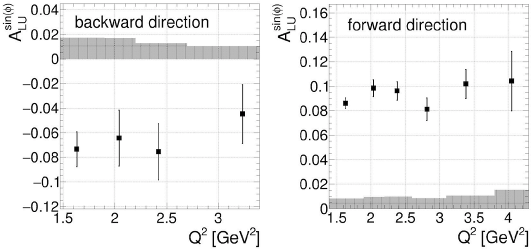
- Beam Spin Asymmetry

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

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



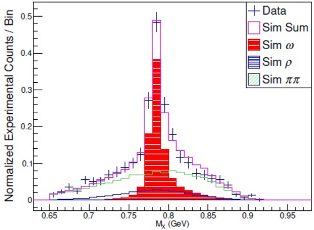
- Beam Spin Asymmetry is a subleading twist effect both in the forward and backward regimes.



Remark: it looks that in JLab, in the backward region and for higher Q^2 the higher twist contributions are not so important as in the forward kinematics

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. Semenov Tian-Shansky '15.
- The analysis W. Li, G. Huber et al. (The JLab F_π Collaboration) and B. Pire, L. Szymanowski, J.-M. Laget and K. Semenov Tian-Shansky., PRL 123 (2019) .
- Clear signal from backward regime of $ep \to e' p\omega$.



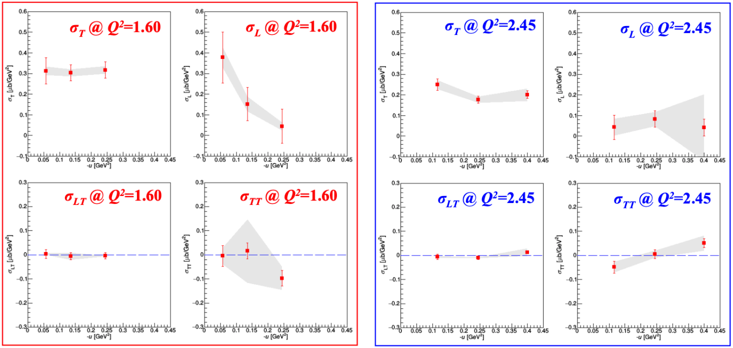
- Full Rosenbluth separation: $\sigma_{\rm T}$ and $\sigma_{\rm L}$ extracted.

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

Separated Cross Sections $\frac{d\sigma}{dt}$ vs $-u$

University of Regina

Garth Huber, huberg@uregina.ca



Observations:

- σ_T falls slowly with $-u$; σ_L falls faster.
- σ_{LT} is very small; σ_{TT} may sign flip for different Q^2 values.

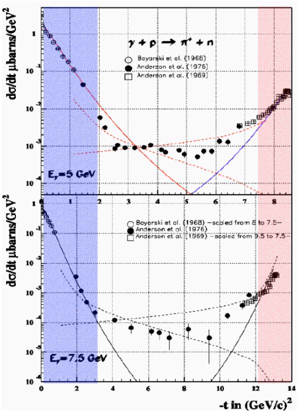
Error bars = statistical and uncorrelated syst. unc; Error bands = correlated syst. unc.

Backward Angle Omega Electroproduction Peak

University of Regina

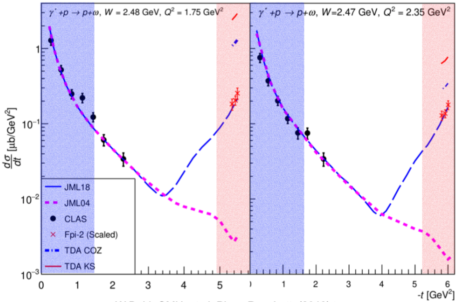
Garth Huber, huberg@uregina.ca

Photoproduction



M. Guidal, J.–M. Laget, M. Vanderhaeghen, PLB **400**(1997)6

First observation of backward angle peak in electroproduction!



W.B. Li, GMH, et al, Phys. Rev. Lett. (2019) to appear

Hall C data are scaled to match kinematics of Hall B data

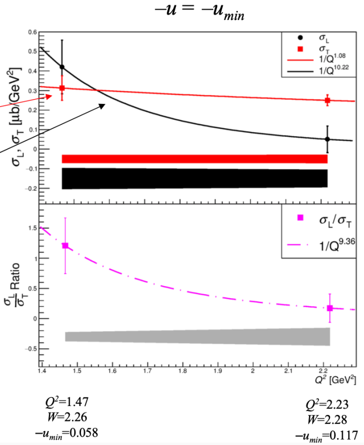
	W (GeV)	x_B	Q^2 (GeV^2)	$-t$ (GeV^2)	$-u$ (GeV^2)
Hall B	1.8 – 2.8	0.16 – 0.64	1.6 –5.1	< 2.7	> 1.68
Fπ–2	2.21	0.29	1.6	4.014	0.08 – 0.13
		0.38	2.45	4.724	0.17 – 0.24

27

$p(e,e'p)\omega$ Q^2–Dependence

University of Regina

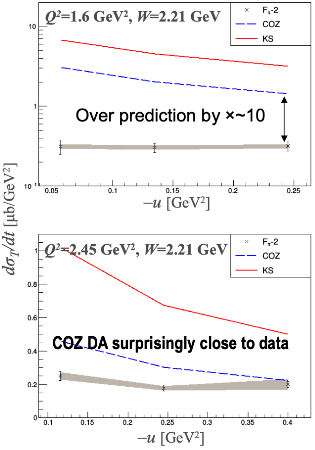
- To investigate Q^2–dependence, fit lowest $-u$ bin values of σ_T and σ_L to Q^{-n} function
  - σ_T appears to have a flat Q^2–dependence within measured range
  - σ_L shows much stronger decrease
- **Decreasing L/T ratio indicates the gradual dominance of σ_T as Q^2 increases.**
- Trend qualitatively consistent with prediction of TDA Collinear Factorization.



Garth Huber, huberg@uregina.ca

TDA model Comparison to Data

Garth Huber, huberg@uregina.ca

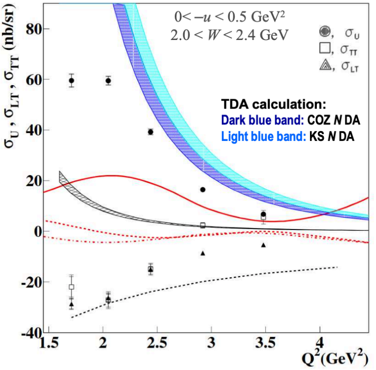


Hall C ω electroproduction

TDA calculation by B. Pire, K. Semenov, L. Szymanowski
Private Communication (2015)

30

Both data sets suggestive of early TDA scaling $Q^2 \approx 2.5$ GeV² !?



Hall B π^+ Electroproduction

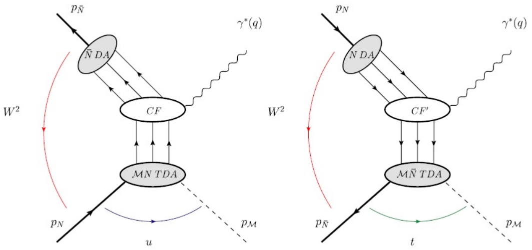
K. Park et al., PLB **780** (2017) 340

Baryon to meson TDAs at P̄ANDA I

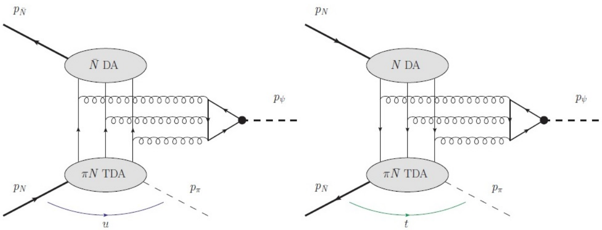
- $E_{\bar{p}} \leq 15$ GeV;
  $W^2 \leq 30$ GeV^2
- J.P. Lansberg et al.'12; B. Pire, L. Szymanowski, KS,'13: πN TDAs occur in factorized description of

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

- To be done with the proton FF studies in the timelike region and heavy charmonium studies.
- Two regimes (forward and backward). C invariance $\Rightarrow$ perfect symmetry.
- Test of universality of TDAs.

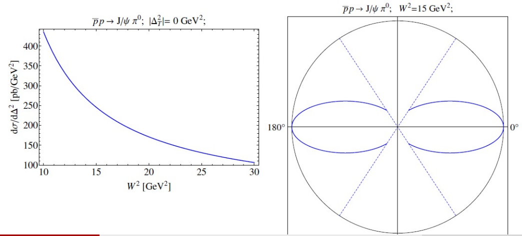


$N\,\bar{N} \to J/\psi\,\pi$ at $\bar{\text{P}}$ANDA



- Amplitude calculation and cross section estimates
  B. Pire, L. Szymanowski, K Semenov Tian-Shansky,'13.

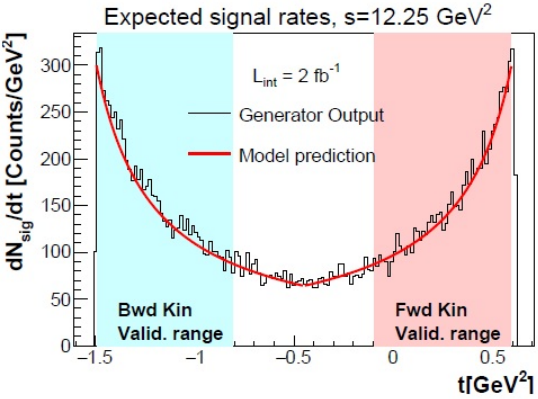
Unpolarized cross section and angular distribution



Feasibility study of $\bar{p}p \to J/\psi\pi^0$ at $\bar{\text{P}}$ANDA I

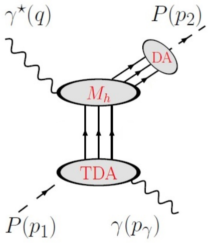
B. Ramstein, E. Atomssa and $\bar{\text{P}}$ANDA collaboration and K.Semenov Tian-Shansky PRD 95'17

- Event generator based on TDA model prediction Pire et al.'13.
- Simulations performed for $s = 12.2$ GeV^2, $s = 16.9$ GeV^2 and $s = 24.3$ GeV^2.
- Study of $p\bar{p} \to J/\psi\pi^0$ (signal) with background from $p\bar{p} \to \pi^+\pi^-\pi^0$ and $p\bar{p} \to J/\psi\pi^0\pi^0$ and other sources.



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. Semenov Tian-Shansky '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.

u–channel Workshop @ JLab/W&M

t-channel (Forward Angle) physics

u-channel (Backward Angle) physics

The First Backward Angle Physics Workshop at Jefferson Lab

- **Exclusive to the u–channel or backward angle physics**

Topics:

- **Explore Backward Photoproduction experiments**
  - **Programs at JLab D**
- **Explore Backward Electroproduction experiments**
  - **Programs at JLab A, B and C**
  - **PANDA TDA program will be invited**
- **TDA and Regge Approaches**

Tentative date: May 24th to May 26th, 2020

Merci pour votre attention !

Transverse Target Single Spin Asymmetry $\gamma^* N \to \pi N$

More distinguishing features with a polarized target

- TSA$= \sigma^{\uparrow} - \sigma^{\downarrow} \sim \mathrm{Im}$ part of the amplitude.
- Sensitive to the contribution of the DGLAP-like regions.
- Non vanishing and Q^2-independent TSA within TDA approach.
- $10 - 15\%$ TSA for $\gamma^* N \to \pi N$ with two component TDA model.

$$\mathcal{A} = \frac{1}{|\vec{s}_1|}\left(\int_0^{\pi} d\tilde{\phi}|\mathcal{M}_T^{s_1}|^2 - \int_{\pi}^{2\pi} d\tilde{\phi}|\mathcal{M}_T^{s_1}|^2\right)\left(\int_0^{2\pi} d\tilde{\phi}|\mathcal{M}_T^{s_1}|^2\right)^{-1}; \quad \tilde{\phi} \equiv \phi - \phi_s$$