Baryon-to-meson Transition Distribution Amplitudes

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

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

Factorization regimes for hard meson production

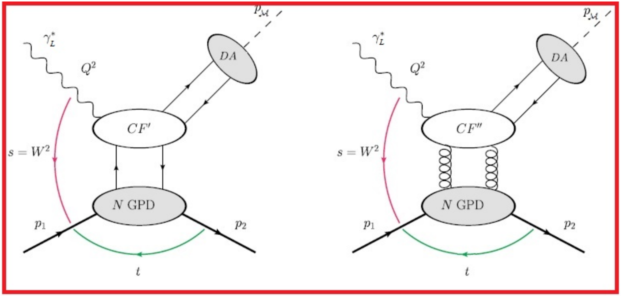
- J. Collins, L. Frankfurt and M. Strikman'97: the collinear factorization theorem for

$$\gamma^*(q) + N(p_1) \to N(p_2) + \mathcal{M}(p_{\mathcal{M}}).$$

Generalized Bjorken limit $t \sim 0$ (near-forward kinematics):

$$\boxed{-q^2 = Q^2,\ W^2 - \text{large};\quad x_B = \frac{Q^2}{2p_1 \cdot q} - \text{fixed};\quad -t = -(p_2 - p_2)^2 - \text{small.}}$$

- Description in terms of nucleon GPDs and meson DAs.



A complementary regime in the generalized Bjorken limit:

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,*]

(Received 5 February 1999; published 4 June 1999)

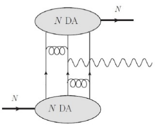
"..... Therefore the factorization theorem is valid also for the production of leading baryons

$$\gamma^*(q)+p \to B(q+\Delta)+M(p-\Delta)$$

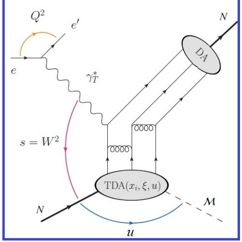
and even leading antibaryons $\gamma^*(q)+p \to \overline{B}(q+\Delta)+B_2(p-\Delta)$...."

- $u \sim 0$ (near-backward kinematics): nucleon-to-meson TDAs B. Pire, L. Szymanowski'05, 07 and nucleon DAs. No rigorous proof of the factorization theorem so far!

LO pQCD description of the nucleon e.m. FF:



Brodsky & Lepage'81
Efremov & Radyushkin'80



GPDs, DAs, GDAs and TDAs

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

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

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

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

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

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

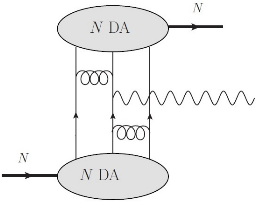
$\mathcal{M}N$ and γN TDAs have common features with:

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

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

Nucleon e.m. FF in QCD: a well known example

LO pQCD description of the nucleon e.m. FF:



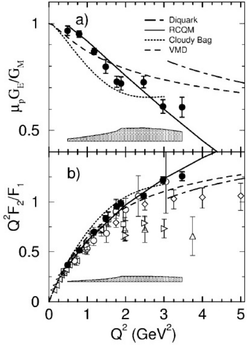
Brodsky & Lepage'81
Efremov & Radyushkin'80

A word of caution:

VOLUME 84, NUMBER 7 PHYSICAL REVIEW LETTERS 14 FEBRUARY 2000

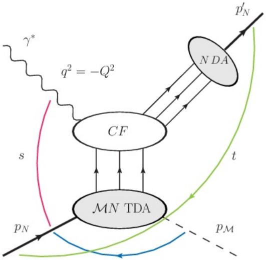
G_{E_p}/G_{M_p} **Ratio by Polarization Transfer in** $\vec{e}p \to e\vec{p}$

(The Jefferson Lab Hall A Collaboration)



- Delayed scaling regime. Importance of higher twist corrections!

Questions to address with $\mathcal{M}N$ (and γN) TDAs



Why this is interesting?

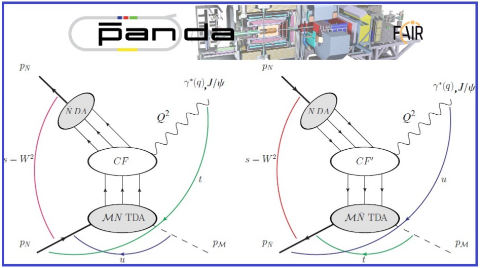
- Direct access to the 5-quark components of the nucleon LC WF.
- Different mesons (π^0, $\pi^{\pm}$, η, η', ρ^0, $\rho^{\pm}$, ω, ϕ, $\ldots$) probe different components.
- A view of the meson cloud (and electromagnetic cloud) inside a nucleon.
- Impact parameter picture: baryon charge distribution in the transverse plane.
- πN & ηN TDAs: chiral dynamics and threshold soft pion theorems.

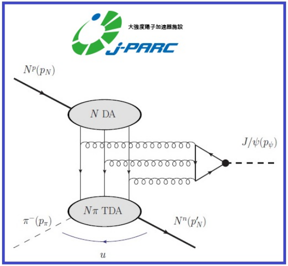
Learn more about QCD technique

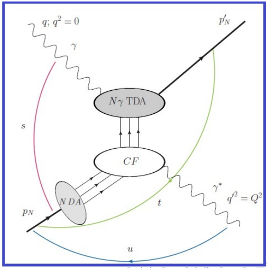
- A testbed for the QCD collinear factorization approach.
- A challenge for the lattice QCD & functional approaches based on DS/BS equations.

Cross channel counterpart reactions: $\bar{\text{P}}$ANDA, JPARC and photoproduction at JLab

- Complementary experimental options\universality of TDAs. See talks by S. Diehl, B. Pire.







A list of key issues:

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

Leading twist-3 πN TDAs

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

- $\frac{2^3 \cdot 2}{2} = 8$ TDAs: $\left\{ V_{1,2}^{\pi N},\ A_{1,2}^{\pi N},\ T_{1,2,3,4}^{\pi N} \right\} (x_1,\ x_2,\ x_3,\ \xi,\ \Delta^2, \mu^2)$

Proton-to-π^0 TDAs:

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

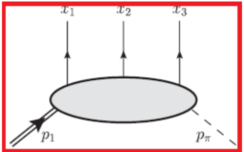
$$= \delta(2\xi - x_1 - x_2 - x_3) i \frac{f_N}{f_\pi m_N}$$

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

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

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

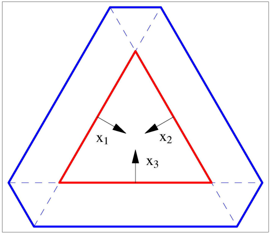
- $P = \frac{p_1 + p_\pi}{2}$; $\Delta = (p_\pi - p_1)$; $\sigma_{P\mu} \equiv P^\nu \sigma_{\nu\mu}$;
  $\xi = -\frac{\Delta \cdot n}{2P \cdot n}$
- C: charge conjugation matrix;
- $f_N = 5.2 \cdot 10^{-3}$ GeV^2 (V. Chernyak and A. Zhitnitsky'84);
- *C.f.* 3 leading twist-3 nucleon DAs: $\{ V^p,\ A^p,\ T^p \}$

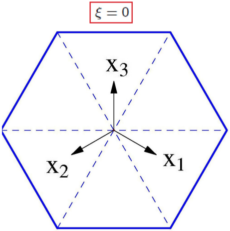


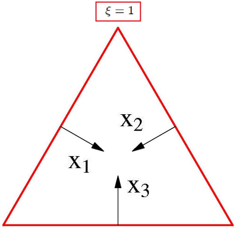
Fundamental properties I: support & polynomiality

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

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

  Can be studied on the lattice!

- Polynomiality in ξ of the Mellin moments in x_k:

$$\int_{-1+\xi}^{1+\xi} dx_1 dx_2 dx_3 \delta(\sum_k x_k - 2\xi) x_1^{n_1} x_2^{n_2} x_3^{n_3} H^{\pi N}(x_1, x_2, x_3, \xi, \Delta^2)$$

$$= [\text{Polynomial of order } n_1 + n_2 + n_3 \{+1\}] (\xi).$$

Fundamental properties II: spectral representation

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

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

- Ω_i: $\{|\beta_i| \le 1,\ |\alpha_i| \le 1 - |\beta_i|\}$ 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):

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

Fundamental properties III: evolution

- Evolution properties of 3-quark light-cone operator: V. M. Braun, S. E. Derkachov, G. P. Korchemsky, A. N. Manashov'99.
- Evolution equations for πN TDAs: B. Pire, L. Szymanowski'07.
- Conformal basis (Jacobi and Gegenbauer polynomials):

$$\Psi_{N,n}^{(12)3}(y_1, y_2, y_3) = (N+n+4)(y_1+y_2)^n P_{N-n}^{(2n+3,1)}(y_3-y_1-y_2) C_n^{\frac{3}{2}}\left(\frac{y_1-y_2}{y_1+y_2}\right).$$

- The conformal PWs:

$$p_{N,n}^{(12)3}(w,v,\xi) = \theta(|w| \le \xi)\, \theta(|v| \le \xi')\, \xi^{-N-2} \frac{1}{g_{N,n}} \times \left(1-\frac{v^2}{\xi'^2}\right) C_n^{\frac{3}{2}}\left(-\frac{v}{\xi'}\right)\left(1-\frac{w}{\xi}\right)^{n+2}\left(1+\frac{w}{\xi}\right) P_{N-n}^{2n+3,1}\left(\frac{w}{\xi}\right).$$

- Conformal PW expansion for πN TDAs:

$$H(w,v,\xi,\Delta^2) = \sum_{N=0}^{\infty}\sum_{n=0}^{N} p_{N,n}^{(12)3}(w,v,\xi) h_{n,N}^{(12)3}(\xi,\Delta^2).$$

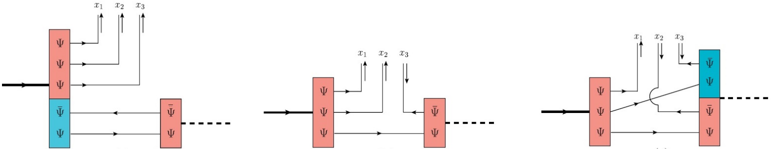
- SO(3) PW expansion of the conformal moments $h_{n,N}^{(12)3}$ $\Rightarrow$ cross-channel picture of baryon exchanges. Dual parametrization, see D. Müller, M.Polyakov, K.S.'15.

TDAs and light-front wave functions

- Light-front quantization approach: πN TDAs provide information on next-to-minimal Fock components of light-cone wave functions of hadrons:

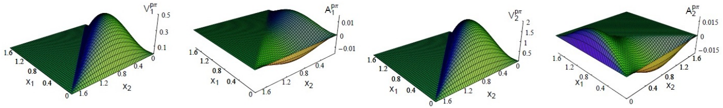
$$|N\rangle = \underbrace{\psi_{(3q)}|qqq\rangle}_{\text{Described by nucleon DA}} + {\color{red}\psi_{(3q+q\bar{q})}|qqq\,q\bar{q}\rangle} + \ldots$$

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



(a) (b) (c)

- B. Pasquini et al. 2009: LFWF model calculations



A connection to the quark-diquark picture

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

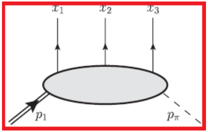
$$v_3 = \frac{x_1 - x_2}{2}; \quad w_3 = x_3 - \xi; \quad x_1 + x_2 = 2\xi_3'; \quad \left(\xi_3' \equiv \frac{\xi - w_3}{2}\right).$$

- 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: "diquark-quark" light-cone operator

$$\int_{-1+|\xi-\xi_3'|}^{1-|\xi-\xi_3'|} dv_3 H^{\pi N}(w_3,\, v_3,\, \xi,\, \Delta^2)$$
$$\sim h^{-1}_{\rho\tau\chi} \int \frac{d\lambda}{4\pi} e^{i(w_3\lambda)(P\cdot n)} \langle \pi^0(p_\pi)| \underbrace{u_\rho(-\frac{\lambda}{2}n) u_\tau(-\frac{\lambda}{2}n) d_\chi(\frac{\lambda}{2}n)}_{\hat{\mathcal{O}}^{\{uu\}d}_{\rho\tau\chi}(-\frac{\lambda}{2}n,\, \frac{\lambda}{2}n)} |N^p(p_1)\rangle.$$

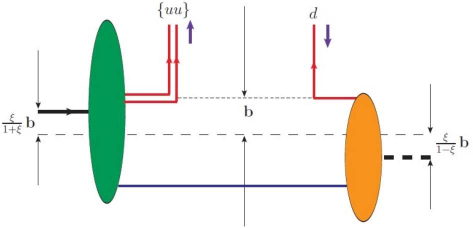


An interpretation in the impact parameter space I

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

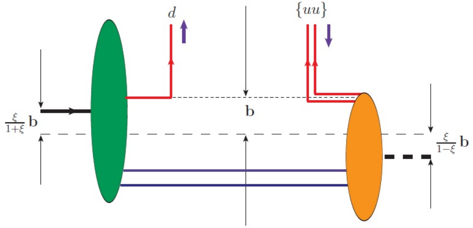
$$\mathbf{D} = \frac{\mathbf{p}_\pi}{1-\xi} - \frac{\mathbf{p}_N}{1+\xi}; \qquad \Delta^2 = -2\xi \left(\frac{m_\pi^2}{1-\xi} - \frac{m_N^2}{1+\xi} \right) - (1-\xi^2)\mathbf{D}^2.$$

- A representation in the DGLAP-like I domain:

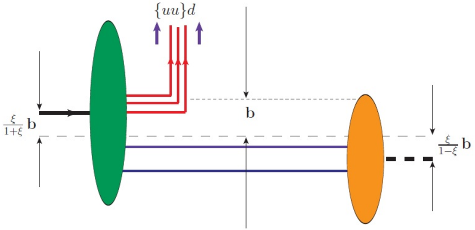


$$\text{DGLAP I}: \ x_3 = w_3 - \xi \leq 0; \quad x_1 + x_2 = \xi - w_3 \geq 0;$$

An interpretation in the impact parameter space II



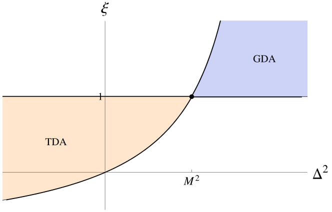
$$\text{DGLAP II}: \ x_3 = w_3 - \xi \geq 0; \quad x_1 + x_2 = \xi - w_3 \leq 0;$$



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

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

- Crossing relates πN TDAs 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

$$Q^2 \gg \Lambda^3_{\rm QCD}/m_\pi \gg \Lambda^2_{\rm QCD}$$

πN GDA at the threshold $\xi = 1$, $\Delta^2 = m_N^2$ fixed in terms of nucleon DAs V^p, A^p, T^p.

Building up a consistent model for πN TDAs

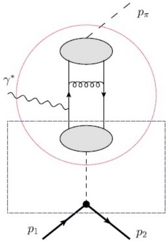
Key requirements:

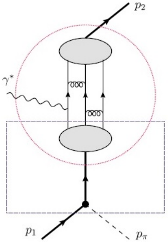
1. support in x_ks and polynomialty;
2. isospin + permutation symmetry;
3. crossing πN TDA $\leftrightarrow$ πN GDA and chiral properties: soft pion theorem;

How to model quadruple distributions?

- No enlightening $\xi = 0$ limit as for GPDs.
- $\xi \to 1$ limit fixed from chiral dynamics.
- A factorized Ansatz with input at $\xi = 1$ designed in J.P. Lansberg, B. Pire, K.S. and L. Szymanowski'12

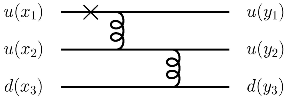
- N and $\Delta(1232)$ cross-channel exchanges $\Rightarrow$ D-term-like contribution: $\tilde{E}$ GPD v.s. TDA





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;



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

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

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

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

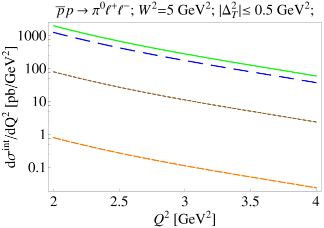
How to check that the TDA-based reaction mechanism is relevant?

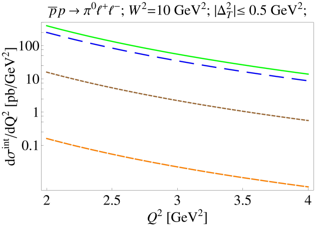
Distinguishing features

- Characteristic backward peak of the cross section. Special behavior in the near-backward region.
- Scaling behavior of the cross section in Q^2 and specific counting rules (see the next talk by S. Diehl).
- Dominance of the transverse cross section σ_T (see the talk by G. Huber today).
- For time-like reactions: specific angular distribution of the lepton pair $\sim (1+\cos^2\theta_\ell)$.
- Non vanishing and Q^2-independent Transverse Target Single Spin Asymmetry ($10-15\%$ TSA for $\gamma^* N \to \pi N$ with the two component TDA model).

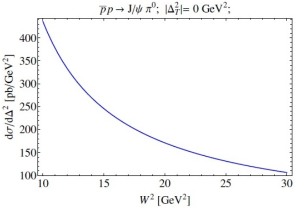
Model predictions and feasibility studies for $\bar{\text{P}}$ANDA

- J.P.Lansberg, B. Pire, L. Szymanowski and K.S.'12: $\bar{p}p \to \pi^0 \gamma^* \to \pi^0 \ell^+ \ell^-$
- Numerical input: COZ, KS, BLW NLO/NNLO solutions for nucleon DAs.





- Feasibility studies: M. C. Mora Espi, M. Zambrana, F. Maas, K.S.'15, see also S.Diehl's talk Tuesday.
- B. Pire, L. Szymanowski and K.S.'13 $\bar{p}p \to \pi^0 J/\psi$



- Feasibility studies: B. Ramstein, E. Atomssa and $\bar{\text{P}}$ANDA collaboration and K.S. PRD 95'17

Backward meson electroproduction @ JLab Hall B

- Pioneering analysis of backward $\gamma^* p \to \pi^0 p$. A. Kubarovsky, CIPANP 2012.
- 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) , see K. Park's talk today.

$$\boxed{\frac{d\sigma}{d\Omega_\pi^*} = A + B\cos\varphi_\pi^* + C\cos 2\varphi_\pi^*,} \quad \text{where} \quad \begin{array}{c} A = \sigma_T + \epsilon\sigma_L; \quad B = \sqrt{2\epsilon(1+\epsilon)}\sigma_{LT} \\ C = \epsilon\sigma_{TT} \end{array}$$

- S. Diehl et al. (CLAS collaboration) to appear at PRL see S. Diehl's talk today
- The cross section of $\gamma^* p \to \pi^+ n$ can be expressed as

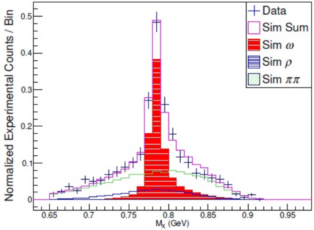
$$\frac{d^4\sigma}{dQ^2 dx_B d\varphi dt} = \sigma_0 \cdot \left(1 + A_{UU}^{\cos(2\varphi)} \cdot \cos(2\varphi) + A_{UU}^{\cos(\varphi)} \cdot \cos(\varphi) + A_{LU}^{\sin(\varphi)} \cdot \sin(\varphi)\right).$$

- Beam Spin Asymmetry:

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

Backward ω-production at JLab Hall C

- TDA formalism for the case of light vector mesons (ρ, ω, ϕ) B. Pire, L. Szymanowski and K.S'15. 24 *VN* TDAs at the leading twist.
- 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'19 . G. Huber's talk today
- Clear signal from backward regime of $ep \to e'p\omega$.



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

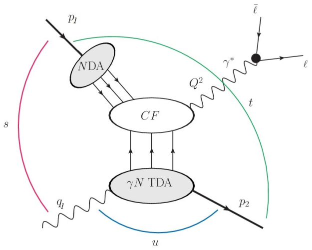
$$2\pi \frac{d^2\sigma}{dt d\phi} = \frac{d\sigma_{\rm T}}{dt} + \epsilon \frac{d\sigma_{\rm L}}{dt} + \sqrt{2\epsilon(1+\epsilon)} \frac{d\sigma_{\rm LT}}{dt} \cos\phi + \epsilon \frac{d\sigma_{\rm TT}}{dt} \cos 2\phi$$

Backward timelike Compton scattering

(see the talk by B. Pire on Wednesday)

$$\boxed{\gamma(q_1) + N(p_1) \to \gamma^*(q_2) + N(p_2) \to \ell\bar{\ell} + N(p_2)}$$

large s and $q_2^2 \equiv Q^2$; fixed x_B; small $|u| = |(p_2 - q_1)^2|$.

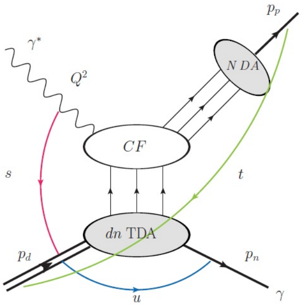


- Crude cross section estimates: VMD + $\gamma^* N \to VN$;
- γ_T^* dominance: $(1 + \cos^2 \theta^*_{\ell\bar{\ell}})$ angular dependence;
- large $-t$: small BH background.
- Possible access to the D-term FF for large $-t$ (small $|u|$).

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?

Conclusions & Outlook

1. Nucleon-to-meson TDAs provide new information about correlation of partons inside hadrons. A consistent picture for the integrated TDAs emerges in the impact parameter representation.
2. We strongly encourage to detect near forward and backward signals for various mesons (π, η, ω, ρ) and backward DVCS: there is interesting physics around!
3. PAC 48 decision is a challenge both for the experiment and for theory. An effort is required. Factorization theorem, physical interpretation, models.
4. 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).
5. First evidences for the onset of the factorization regime in backward $\gamma^* N \to N'\omega$ from JLab Hall C analysis and BSA measurements in $\gamma^* p \to \pi^+ n$ from CLAS.
6. $\bar{p}N \to \pi \ell^+ \ell^-$ (q^2 - timelike) and $\bar{p}N \to \pi J/\psi$ $\bar{\text{P}}$ANDA would allow to check universality of TDAs.
7. Backward timelike Compton scattering and backward DVCS may provide access to nucleon-to-photon TDAs. Ultimate goal D-term FF for large $-t$.
8. May be an addition to the ultraperipheral physics program at hadron colliders.
9. TDAs as a tool for nuclear physics: deuteron-to-nucleon TDAs.

Thank you for your attention!