Hard exclusive processes in the backward region

J.P. Lansberg
Ecole Polytechnique - CPHT

Collaborative work with B. Pasquini, B. Pire and L. Szymanowski
Hard limit for backward exclusive processes

Let us analyse Hard Electroproduction of a meson
Let us analyse Hard Electroproduction of a meson but backward!


The kinematics imposes the exchange of 3 quarks in the $u$ channel.

Factorisation in the generalised Bjorken limit: $Q^2 \to \infty$, $u$, $x$ fixed.

The object factorised from the hard part is a Transition Distribution Amplitude (TDA).

Interpretation at the amplitude level in the ERBL region (for $x_i > 0$).

Amplitude of probability to find a meson within the proton!
Hard limit for backward exclusive processes

Let us analyse Hard Electroproduction of a meson

but backward!

- meson nearly at rest in the target rest frame

The kinematics imposes the exchange of 3 quarks in the $u$ channel

Factorisation in the generalised Bjorken limit: $Q^2 \rightarrow \infty$, $u, x$ fixed

Hard limit for backward exclusive processes

Let us analyse Hard Electroproduction of a meson but **backward**!

The meson nearly at rest in the target rest frame

The kinematics imposes the exchange of 3 quarks in the $u$ channel

**Factorisation** in the generalised Bjorken limit: $Q^2 \to \infty$, $u, x$ fixed

The object factorised from the hard part is a **Transition Distribution Amplitude (TDA)**

But $\gamma^* P \rightarrow \gamma^* P$
Hard limit for backward exclusive processes

- Let us analyse Hard Electroproduction of a meson but backward!

\[
\gamma^* \quad \text{Pert.} \quad x \quad \text{meson} \quad \text{GPD}
\]

\[
\gamma^* \quad \text{Pert.} \quad x' \quad \text{proton} \quad \text{TDA}
\]

\[
\text{proton} \quad t \quad \rightarrow \quad u \quad \text{proton}
\]

- The kinematics imposes the exchange of 3 quarks in the \( u \) channel
- Factorisation in the generalised Bjorken limit: \( Q^2 \rightarrow \infty \), \( u, x \) fixed
- The object factorised from the hard part is a transition distribution amplitude (TDA)

\[
\begin{align*}
|p\rangle & = |p'\rangle \\
\end{align*}
\]

- Interpretation at the amplitude level

Amplitude of probability to find a meson within the proton!

Where to look for that?

- Kinematical coverage for $\pi^+$ of the CLAS experiment (for $W \in [1, 2]$ GeV)
  

- We are interested in the region where $\cos \theta_{\pi}^*$ is close to -1, i.e. $u \simeq 0$
Kinematical coverage for $\pi^+$ of the CLAS experiment (for $W \in [1, 2]$ GeV)

We are interested in the region where $\cos \theta^*_\pi$ is close to -1, i.e. $u \simeq 0$

The yield should increase when $u$ gets closer to 0.
$\pi \rightarrow \pi$: parametrisation – similarities with the proton DAs

$p \rightarrow \pi$ (at Leading twist)  
$\Delta_T = 0$: 3 TDAs  
$3 \times p(\uparrow) \rightarrow uud(\uparrow\uparrow\downarrow) + \pi$  
TDA

$
4 \langle \pi^0 | \varepsilon^{ijk} u^i_{\alpha}(z_1 n) u^j_{\beta}(z_2 n) d^k_{\gamma}(z_3 n) | p, s_p \rangle \propto

\left[ V_{1\pi}^{\pi^0}(x_i, \xi, \Delta^2)(\not{p} C)_{\alpha\beta}(N_{sp}^+)_{\gamma} + \\
A_{1\pi}^{\pi^0}(x_i, \xi, \Delta^2)(\not{p} \gamma^5 C)_{\alpha\beta}(\gamma^5 N_{sp}^+)_{\gamma} + \\
T_{1\pi}^{\pi^0}(x_i, \xi, \Delta^2)(\sigma_{\rho\rho} C)_{\alpha\beta}(\gamma^{\rho} N_{sp}^+)_{\gamma} \right]

4 \langle 0 | \varepsilon^{ijk} u^i_{\alpha}(z_1 n) u^j_{\beta}(z_2 n) d^k_{\gamma}(z_3 n) | p \rangle \propto

\left[ V(x_i)(\not{p} C)_{\alpha\beta}(\gamma^5 N_{sp}^+)_{\gamma} + \\
A(x_i)(\not{p} \gamma^5 C)_{\alpha\beta}(N_{sp}^+)_{\gamma} + \\
T(x_i)(i\sigma_{\rho\rho} C)_{\alpha\beta}(\gamma^{\rho} \gamma^5 N_{sp}^+)_{\gamma} \right]$
\[ p \rightarrow \pi: \text{ parametrisation \textendash\ similarities with the proton DAs} \]

\( \rightarrow p \rightarrow \pi \) (at Leading twist)
\[ \Delta_T = 0: 3 \text{ TDAs} \ (3 \times p(\uparrow) \rightarrow uud(\uparrow\uparrow\downarrow) + \pi) \]

TDA (Chernyak-Zhitnitsky)

\[ 4 \langle \pi^0 | \epsilon^{ijk} u_\alpha^i (z_1 n) u_\beta^j (z_2 n) d_\gamma^k (z_3 n) | p, s_p \rangle \propto \]

\[ \left[ V_{1}^{\pi^0}(x_i, \xi, \Delta^2)(\not p C)_{\alpha\beta}(N_{sp}^+)_{\gamma} + A_{1}^{\pi^0}(x_i, \xi, \Delta^2)(\not p \gamma^5 C)_{\alpha\beta}(N_{sp}^+s)_{\gamma} + T_{1}^{\pi^0}(x_i, \xi, \Delta^2)(\sigma_{\rho\rho} C)_{\alpha\beta}(\gamma^\rho N_{sp}^+)_{\gamma} \right] \]

\[ V_{1}^{\pi^0} \rightarrow D_{\uparrow\downarrow,\uparrow} + D_{\downarrow\uparrow,\uparrow} \]

\[ A_{1}^{\pi^0} \rightarrow D_{\uparrow\downarrow,\uparrow} - D_{\downarrow\uparrow,\uparrow} \]

\[ T_{1}^{\pi^0} \rightarrow D_{\uparrow\uparrow,\downarrow} \]

\[ p \rightarrow \pi: \text{parametrisation} - \text{similarities with the proton DAs} \]

\[ p \rightarrow \pi \text{ (at Leading twist)} \]
\[ \Delta_T = 0: 3 \text{ TDAs} (3 \times p(\uparrow) \rightarrow uud(\uparrow\uparrow\downarrow) + \pi) \]

\[ \text{TDA (Chernyak-Zhitnitsky)} \]

\[ 4 \langle \pi^0 | \epsilon^{ijk} u^i_\alpha(z_1 n) u^j_\beta(z_2 n) d^k_\gamma(z_3 n) | p, s_p \rangle \propto \]
\[ 4 \langle 0 | \epsilon^{ijk} u^i_\alpha(z_1 n) u^j_\beta(z_2 n) d^k_\gamma(z_3 n) | p \rangle \propto \]

\[ \left[ V_{1}^{\pi^0}(x_i, \xi, \Delta^2)(\not{p} C)_{\alpha\beta}(N_{sp}^+)_\gamma + \right] \]
\[ A_{1}^{\pi^0}(x_i, \xi, \Delta^2)(\not{p} \gamma^5 C)_{\alpha\beta}(\gamma^5 N_{sp}^+)_\gamma + \]
\[ T_{1}^{\pi^0}(x_i, \xi, \Delta^2)(\sigma_{\rho\rho} C)_{\alpha\beta}(\gamma^\rho N_{sp}^+)_\gamma \]

\[ V_{1}^{\pi^0} \rightarrow D^{\uparrow\downarrow,\uparrow} + D^{\downarrow\uparrow,\uparrow} \]
\[ A_{1}^{\pi^0} \rightarrow D^{\uparrow\downarrow,\uparrow} - D^{\downarrow\uparrow,\uparrow} \]
\[ T_{1}^{\pi^0} \rightarrow D^{\uparrow\uparrow,\downarrow} \]

When \( \Delta_T \neq 0, D^{\uparrow\downarrow,\downarrow} \neq 0, \ldots, D^{\downarrow\downarrow,\downarrow} \neq 0 \rightarrow 8 \text{ TDAs} \]

(\( \Delta_T \) is source of angular momentum)

More quantitatively: the pionic content of the proton

Let us start with a limiting case: soft pion

\[ \langle \pi^a(k)|\mathcal{O}|p(p, s)\rangle = -\frac{i}{f_\pi} \langle 0| [Q^a_5, \mathcal{O}] |p(p, s)\rangle \]

\[ + \frac{ig_A}{4f_\pi p \cdot k} \sum_{s'} \langle 0|\mathcal{O}|p(p, s')\rangle \bar{u}(p, s') k\gamma_5 \tau^a u(p, s) \]
More quantitatively: the pionic content of the proton

\[ \langle \pi^a(k) | \mathcal{O} | p(p, s) \rangle = \frac{i}{f_{\pi}} \langle 0 | [Q_5^a, \mathcal{O}] | p(p, s) \rangle + \frac{ig_\pi}{4f_{\pi} p \cdot k} \sum_{s'} \langle 0 | \mathcal{O} | p(p, s') \rangle \bar{u}(p, s') k_5 \gamma^a \tau^a u(p, s) \]

Let us start with a limiting case: soft pion

Direct relation between the TDAs, \( \langle \pi^a(k) | \mathcal{O} | p(p, s) \rangle \), and the proton wavefunction (DAs), \( \langle 0 | \mathcal{O} | p(p, s) \rangle \)
Let us start with a limiting case: soft pion

\[
\langle \pi^a(k)|\mathcal{O}|p(p, s)\rangle = -\frac{i}{f_\pi} \langle 0|[Q_5^a, \mathcal{O}]|p(p, s)\rangle
\]

\[
+ \frac{ig_A}{4f_\pi p \cdot k} \sum_{s'} \langle 0|\mathcal{O}|p(p, s')\rangle \bar{u}(p, s') \gamma_5 \tau^a u(p, s)
\]

Direct relation between the TDAs, \(\langle \pi^a(k)|\mathcal{O}|p(p, s)\rangle\), and the proton wavefunction (DAs), \(\langle 0|\mathcal{O}|p(p, s)\rangle\)

\[
V_1^\pi\big(x_1, x_2, x_3, \xi, \Delta^2\big) \xrightarrow{p_\pi \rightarrow 0} \frac{1}{4\xi} \mathcal{V}\left(\begin{array}{c} x_1 \\ 2\xi \\ 2\xi \\ 2\xi \end{array}\right)
\]

\[
A_1^\pi\big(x_1, x_2, x_3, \xi, \Delta^2\big) \xrightarrow{p_\pi \rightarrow 0} \frac{1}{4\xi} \mathcal{A}\left(\begin{array}{c} x_1 \\ 2\xi \\ 2\xi \\ 2\xi \end{array}\right)
\]

\[
T_1\big(x_1, x_2, x_3, \xi, \Delta^2\big) \xrightarrow{p_\pi \rightarrow 0} \frac{3}{4\xi} \mathcal{T}\left(\begin{array}{c} x_1 \\ 2\xi \\ 2\xi \\ 2\xi \end{array}\right)
\]

Similar relations obtained for the proton-pion DAs \(\langle 0|\pi(k)p(p, s)\rangle\)

V.M Braun et al. PRD75:014021,2007
Sufficient to evaluate the backward electroproduction of a pion for $p_\pi^z \rightarrow 0$

The amplitude at the Leading-twist accuracy:

$$\mathcal{M}_{s_1 s_2}^\lambda = -i \frac{(4\pi \alpha_s)^2 \sqrt{4\pi \alpha_{em} f_N^2}}{54 f_\pi Q^4} \bar{u}(p_2, s_2) \bar{\psi}(\lambda) \gamma^5 u(p_1, s_1)$$

$$\times \int_{-1+\xi}^{1+\xi} d^3 x \int_0^1 d^3 y \left( 2 \sum_{\alpha=1}^{7} T_\alpha + \sum_{\alpha=8}^{14} T_\alpha \right)$$

Example:

$$T_7 = \frac{Q_d (2\xi)^2 [(V_1^{p,0} - A_1^{p,0}) (V^p - A^p)]}{(x_1 - i\epsilon) (2\xi - x_1 - i\epsilon) (x_2 - i\epsilon) y_1 y_2 (1 - y_3)}$$
Backward Electroproduction of a pion: III

At $\xi = 0.8$ and using CZ Distribution Amplitudes, one gets:

\[
TDA_{\ell_1 \ell_3 k_1 k_3}^{M_h} P(p_1) P'(p_2) \gamma^{\ast} (q) \pi(p_\pi)
\]
At $\xi = 0.8$ and using CZ Distribution Amplitudes, one gets:

$$
\begin{align*}
TDA_{\ell_1 \ell_3} & \quad k_1 k_3 \\
M_h & \quad \gamma^*(q) \\
\ell_1 & \quad P'(p_2) \\
\ell_3 & \quad \gamma^* \pi(p_{\pi}) \\
P(p_1) & \quad \pi(p_{\pi})
\end{align*}
$$

\[d\sigma/d\Omega^{*\pi}|_{\theta^{*\pi}=\pi} (\text{nb/sr})\]

\[Q^2 \quad (\text{GeV}^2)\]
Much more than the soft limit

The factorised framework is not restricted at all to the soft limit
Much more than the soft limit

- The factorised framework is not restricted at all to the soft limit
- To go away from $p_{\pi}^z = 0$, one needs input from models, such as the pion cloud model, ...

Much more than the soft limit

- The factorised framework is not restricted at all to the soft limit
- To go away from $p^Z_\pi = 0$, one needs input from models, such as the pion cloud model, ...

Model-independent predictions

Scaling law for the amplitude:

\[ M(Q^2) \propto \alpha^2 s(Q^2) Q^4 \]

Approximate \( Q^2 \)-independence of the ratios

\[
\frac{M(\gamma^* p \rightarrow p\pi)}{M(\gamma^* p \rightarrow p\gamma)} , \frac{M(\gamma^* p \rightarrow p\pi)}{M(\gamma^* p \rightarrow p\rho)} \]

and

\[
\frac{d\sigma(p\bar{p} \rightarrow \ell^+ \ell^- \pi^0)}{dQ^2} \quad \text{(see later)}
\]

Dominance of \( \gamma^* T p \rightarrow p\pi \), . . .
Model-independent predictions

Scaling law for the amplitude:

\[ \mathcal{M}(Q^2) \propto \frac{\alpha_s^2(Q^2)}{Q^4} \]
Model-independent predictions

Scaling law for the amplitude:

\[ \mathcal{M}(Q^2) \propto \frac{\alpha_s^2(Q^2)}{Q^4} \]

Approximate \( Q^2 \)-independence of the ratios

\[ \frac{\mathcal{M}(\gamma^* p \rightarrow p\pi)}{\mathcal{M}(\gamma^* p \rightarrow p\gamma)}, \frac{\mathcal{M}(\gamma^* p \rightarrow p\pi)}{\mathcal{M}(\gamma^* p \rightarrow p\rho)} \text{ and } \frac{d\sigma(p\bar{p} \rightarrow \ell^+ \ell^- \pi^0)}{dQ^2}, \frac{d\sigma(p\bar{p} \rightarrow \ell^+ \ell^-)}{dQ^2} \text{ (see later)} \]
Model-independent predictions

Scaling law for the amplitude:
\[ M(Q^2) \propto \frac{\alpha_s^2(Q^2)}{Q^4} \]

Approximate $Q^2$-independence of the ratios

\[ \frac{M(\gamma^* p \to p\pi)}{M(\gamma^* p \to p\gamma)}, \frac{M(\gamma^* p \to p\pi)}{M(\gamma^* p \to p\rho)} \]

and

\[ \frac{d\sigma(p\bar{p} \to \ell^+ \ell^- \pi^0)}{dQ^2}, \frac{d\sigma(p\bar{p} \to \ell^+ \ell^-)}{dQ^2} \]

Dominance of $\gamma_T^* p \to p\pi, \ldots$
Single Transverse Spin Asymmetry

Single Spin Asymmetry and the DGLAP contribution

- Single Transverse Spin Asymmetry:
  \[ \sigma^{\uparrow} - \sigma^{\downarrow} \text{ is non zero for complex } \mathcal{T} \text{ and } \mathcal{T}' \]
Single Transverse Spin Asymmetry: 
\[ \sigma^\uparrow - \sigma^\downarrow \] is non zero for complex \( T \) and \( T' \)

Let's look at the third graph contribution:
\[
Q_u(2\xi)^2 \left[ 4T_1^{\rho\pi^0} T^\rho + 2\frac{\Delta^2 T}{M^2} T_4^{\rho\pi^0} T^\rho \right]
\]
\[
\frac{1}{(x_1 - i\epsilon)(2\xi - x_2 - i\epsilon)(x_3 - i\epsilon)y_1(1 - y_1)y_3}
\]
Single Spin Asymmetry and the DGLAP contribution

- Single Transverse Spin Asymmetry: 
  \[ \sigma^\uparrow - \sigma^\downarrow \] is non zero for complex \( T \) and \( T' \)

- Let's look at the third graph contribution:
  \[
  Q_u(2\xi)^2 \left[ 4 T_1^{p\pi^0} T^p + 2 \frac{\Delta^2}{M^2} T_4^{p\pi^0} T^p \right] \frac{(x_1 - i\epsilon)(2\xi - x_2 - i\epsilon)(x_3 - i\epsilon)y_1(1-y_1)y_3}{(x_1 - i\epsilon)(2\xi - x_2 - i\epsilon)(x_3 - i\epsilon)y_1(1-y_1)y_3}
  \]

  → The TDAs \( T_1^{p\pi^0}, \ldots \) and the DAs \( T^p, \ldots \) are real valued functions;
  → The \( y \)-integration does not generate any imaginary part;
  → The \( x \)-integration may do so, but only if \( x_i \) change sign;
Single Spin Asymmetry and the DGLAP contribution

- Single Transverse Spin Asymmetry:
  \[ \sigma^{\uparrow} - \sigma^{\downarrow} \] is non zero for complex \( T \) and \( T' \)

- Let's look at the third graph contribution:
  \[
  Q_u(2\xi)^2 [4 T_1^{p\pi^0} T^p + 2 \frac{\Delta^2}{M^2} T_4^{p\pi^0} T^p] \\
  \frac{1}{(x_1-i\epsilon)(2\xi-x_2-i\epsilon)(x_3-i\epsilon)y_1(1-y_1)y_3}
  \]

  \( \to \) The TDAs \( T_1^{p\pi^0},... \) and the DAs \( T^p, ... \) are real valued functions;

  \( \to \) The \( y \)-integration does not generate any imaginary part;

  \( \to \) The \( x \)-integration may do so, but only if \( x_i \) change sign;

- Non vanishing SSA: signal of a non zero DGLAP contribution
Single Transverse Spin Asymmetry and the DGLAP contribution

- Single Transverse Spin Asymmetry:
  \[ \sigma^\uparrow - \sigma^\downarrow \text{ is non zero for complex } T \text{ and } T' \]

- Let's look at the third graph contribution:
  \[
  Q_u(2\xi)^2 \left[ 4 T_1^{p\pi^0} T^p + 2 \frac{\Delta^2}{M^2} T_4^{p\pi^0} T^p \right] \\
  \frac{1}{(x_1-i\epsilon)(2\xi-x_2-i\epsilon)(x_3-i\epsilon)y_1(1-y_1)y_3}
  \]

  \[ \rightarrow \] The TDAs (\(T_1^{p\pi^0}, \ldots\)) and the DAs (\(T^p, \ldots\)) are real valued functions;

  \[ \rightarrow \] The \(y\)-integration does not generate any imaginary part;

  \[ \rightarrow \] The \(x\)-integration may do so, but only if \(x_i\) change sign;

- Non vanishing SSA: signal of a non zero DGLAP contribution

- One expects a vanishing SSA for (simple) baryon-exchange approaches (including the soft pion limit)
Existing data

Backward Electroproduction of a meson: existing data

→ Data from JLab exist for the $\pi^+$

Analysis on-going (K. Park)

→ “Visible signal in the yield of $\omega$ at $180^\circ$”

(G. Huber, Sept. 09)

→ Electroduction of $\eta$ and $\pi^0$

(CLAS DVMP: V. Kubarovsky, P. Stoler)

$\eta$ to be modelled
TDAs in exclusive processes at GSI/FAIR

- $\bar{p}p \rightarrow \gamma^* \pi^0$ can be studied by PANDA
- Involves the same TDAs as for backward electroproduction

*In the GPD case, after crossing, we have to deal with GDAs*
TDAs in exclusive processes at GSI/FAIR

- $\bar{p}p \rightarrow \gamma^* \pi^0$ can be studied by PANDA
- Involves the same TDAs as for backward electroproduction

In the GPD case, after crossing, we have to deal with GDAs

$\bar{p}p \rightarrow J/\psi + \pi^0$

The same TDAs appear also in $p\bar{p} \rightarrow J/\psi + \pi^0$

Same channel as for $h_c$ studies
$\bar{p}p \rightarrow \gamma^* \pi^0$ at GSI/FAIR

GSI-FAIR: $E_p \leq 15$ GeV $\Rightarrow W^2 \leq 30$ GeV$^2$
\( \bar{p}p \rightarrow \gamma^{*}\pi^{0} \) at GSI/FAIR

**GSI-FAIR:** \( E_p \leq 15 \text{ GeV} \Rightarrow W^2 \leq 30 \text{ GeV}^2 \)

![Graph](image)

- **Graph (a):** 
  - \( d\sigma/dt\big|_{\Delta t=0} \) (nb/GeV^2)
  - \( W^2 \) (GeV^2)
  - \( |p_{\pi}^Z|=0 \)
  - \( |p_{\pi}^Z|=155 \text{ MeV} \)

- **Graph (b):** 
  - \( d\sigma/d\Omega^2\big|_{\Delta t=0} \) (pb/GeV^4)
  - \( Q^2 \) (GeV^2)
  - \( W^2=5 \text{ GeV}^2 \)
  - \( W^2=10 \text{ GeV}^2 \)
  - \( W^2=20 \text{ GeV}^2 \)
\( \bar{p}p \rightarrow \gamma^* \pi^0 \) at GSI/FAIR

**GSI-FAIR:** \( E_\bar{p} \leq 15 \text{ GeV} \Rightarrow W^2 \leq 30 \text{ GeV}^2 \)

\[
\begin{align*}
\frac{d\sigma}{dW^2}(\Delta T=0) &= \text{nb/GeV}^2 \\
\frac{d\sigma}{dQ^2}(\Delta T=0) &= \text{pb/GeV}^4
\end{align*}
\]

\( |p_\pi^-|=0 \)

\( |p_\pi^-|=155 \text{ MeV} \)

\( W^2 = 5 \text{ GeV}^2 \)

\( W^2 = 10 \text{ GeV}^2 \)

\( W^2 = 20 \text{ GeV}^2 \)

\( \sigma_{\ell^+ \ell^- \pi^0}(7 < Q^2 < 8 \text{GeV}^2, W^2 = 10 \text{GeV}^2, \Delta T < 0.5 \text{GeV}) \sim 100 \text{fb} \)

- Expected \( \int dt \mathcal{L} \) of about 2 \( \text{fb}^{-1} \) for a 100-day experiment
- Other channels are also of much interest, such as
  \( \bar{p}p \rightarrow \ell^+ \ell^- \eta \) or \( \bar{p}p \rightarrow \ell^+ \ell^- \rho^0 \)
Summary

→ Further quantitative predictions require models
  → Soft pion limit: OK
  → Pion Cloud Model: on-going
  → 4-ple distribution (spectral representation: double distr. for GPD):

→ TDA moments can be computed on the lattice
→ etc.

K. Semenov et al., to appear.
Summary

- Further quantitative predictions require models
  - Soft pion limit: OK
  - Pion Cloud Model: on-going
  - 4-ple distribution (spectral representation: double distr. for GPD):
    
    ![Diagram](image)
    
    K. Semenov et al., to appear.

- TDA moments can be computed on the lattice
- etc.

- Experimental data are necessary to test the picture and then to extract physics
Summary

→ Further quantitative predictions require models
  → Soft pion limit: OK
  → Pion Cloud Model: on-going
  → 4-ple distribution (spectral representation: double distr. for GPD):

→ TDA moments can be computed on the lattice
→ etc.

→ Experimental data are necessary to test the picture and then to extract physics
→ ...expected from
  → JLab-6 GeV: Backward electroproduction of $\pi$, $\eta$, $\omega$. Backward DVCS ?
  → GSI: $p\bar{p} \rightarrow \gamma^*\pi^0$, $p\bar{p} \rightarrow J/\psi\pi^0$, $p\bar{p} \rightarrow \gamma^*\gamma$, ...
  → Of course JLab-12 GeV
  → COMPASS: $\gamma^*p \rightarrow pJ/\psi$

K. Semenov et al., to appear.