Experimental landscape: vector-meson DVMP data

Exp.	years	V	Q^2 [GeV^2]	ξ	W [GeV]
ZEUS	96–00	$\rho^0, \phi, J/\psi$	2–160	10^{-5}–0.08	32–180
H1	96–00	$\rho^0, \phi, J/\psi$	2.5–60	10^{-5}–0.02	35–180
HERMES	96–07	ρ^0, ω, ϕ	0.5–7	10^{-2}–0.3	3–7
COMPASS	12/16–17	ρ^0, ω, ϕ	1–10	10^{-3}–0.2	5–17
JLab CLAS	01–08	ρ^0, ω, ϕ	1–6	0.06–0.5	2–3
JLab CLAS12	18–	$\phi, \omega, J/\psi$	1–12	0.03–0.7	thr.–4.5

Theory description: vector-meson DVMP

subprocess	accuracy	scheme	reference	comment
$\gamma_L^* \to V_L$	tw-2, LO/NLO	collinear	[Lautenschläger, Müller, KPK, Schäfer '14 (unpublished)], [Čuić, Duplančić, Kumerički, KPK '23], [Guo et al. '24 '25]	GPD and DA evolution important; small-x pheno (conf. rep.)
	tw-2, LO	MPA	[Goloskokov, Kroll '05]	meson-side $k_\perp$ + Sudakov; hard to extend consistently to NLO
$\gamma_T^* \to V_L$	partial tw-3	MPA	[Goloskokov, Kroll '13]	transversity GPDs
$\gamma_L^* \to V_T$	partial tw-3	MPA	[Goloskokov, Kroll '07]	usually small
$\gamma_T^* \to V_T$	partial tw-3	MPA	[Goloskokov, Kroll '07]	(gluon transversity GPDs for double flip)
	twist-3	collinear	[Anikin, Teryaev '02]	endpoint singularities; no pheno

DVMP kinematics

$$\boxed{\gamma^*(q) + N(p) \to V(q_V) + N'(p')}$$

$$Q^2 = -q^2 \qquad t = (p' - p)^2 = (q - q_V)^2 \qquad W^2 = (p+q)^2$$

$$x_B = \frac{Q^2}{2p\cdot q} = \frac{Q^2}{W^2 + Q^2 - M_N^2} \qquad \xi_{m_V=0} = \frac{x_B}{2 - x_B} = \frac{Q^2}{2(W^2 - M_N^2) + Q^2}$$

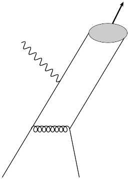
$$p_T^2 = (1-\xi^2)(t_{\min} - t) \qquad t_{\min} = -\frac{4\xi^2 M_N^2}{1-\xi^2}$$

$$\sigma_U = \sigma_T + \epsilon\sigma_L \qquad R = \frac{\sigma_L}{\sigma_T}$$

We need $\sigma_L(Q^2, \xi, t)$ i.e. $\sigma_L(Q^2, W, p_T^2)$

Appendix

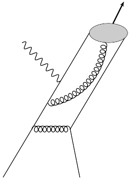
Subprocess amplitudes $\mathcal{H}$: projectors



$q\bar{q} \to \pi$ projector [Beneke, Feldmann '00]

$$(\tau q' + k_\perp) + (\bar{\tau} q' - k_\perp) = q'$$

$$\begin{aligned}\mathcal{P}_2^\pi \quad \sim \quad & f_\pi \Big\{ \gamma_5 \, \not{q}' \phi_\pi(\tau, \mu_F) \\ & + \mu_\pi(\mu_F) \Big[\gamma_5 \, \phi_{\pi p}(\tau, \mu_F) \\ & - \frac{i}{6} \gamma_5 \, \sigma_{\mu\nu} \, \frac{q'^\mu n^\nu}{q' \cdot n} \, \phi'_{\pi\sigma}(\tau, \mu_F) \\ & + \frac{i}{6} \gamma_5 \, \sigma_{\mu\nu} \, q'^\mu \phi_{\pi\sigma}(\tau, \mu_F) \frac{\partial}{\partial k_{\perp\nu}} \Big] \Big\}_{k_\perp \to 0}\end{aligned}$$



$q\bar{q}g \to \pi$ projector [Kroll, P-K '18]

$$\tau_a q' + \tau_b q' + \tau_g q' = q'$$

$$\mathcal{P}_3^\pi \sim f_{3\pi}(\mu_F) \, \frac{i}{g} \, \gamma_5 \, \sigma_{\mu\nu} q'^\mu g_\perp^{\nu\rho} \, \frac{\phi_{3\pi}(\tau_a, \tau_b, \tau_g, \mu_F)}{\tau_g} \, , \quad f_{3\pi} \sim \mu_\pi$$

$\mu_\pi = m_\pi^2/(m_u + m_d) \cong 2$ GeV

DAs and EOMs

$$\tau\phi_{\pi p}(\tau) + \frac{\tau}{6}\,\phi'_{\pi\sigma}(\tau) - \frac{1}{3}\,\phi_{\pi\sigma}(\tau) \quad = \quad \phi_\pi^{EOM}(\bar\tau)$$

$$\bar\tau\phi_{\pi p}(\tau) - \frac{\bar\tau}{6}\phi'_{\pi\sigma}(\tau) - \frac{1}{3}\phi_{\pi\sigma}(\tau) \quad = \quad \phi_\pi^{EOM}(\tau)$$

$$\phi_\pi^{EOM}(\tau) = 2\frac{f_{3\pi}}{f_\pi \mu_\pi}\int_0^{\bar\tau}\frac{d\tau_g}{\tau_g}\,\phi_{3\pi}(\tau, \bar\tau - \tau_g, \tau_g)$$

- EOMs and symmetry properties
  $\Rightarrow$ the subprocess amplitudes in terms of two twist-3 DAs
  and 2- and 3-body contributions combined

- combined EOMs $\rightarrow$ first order differential equation $\Rightarrow$ from known form of $\phi_{3\pi}$ [Braun, Filyanov '90] one determines $\phi_{\pi p}$ (and $\phi_{\pi\sigma}$)

Note: $q\bar{q}g$ projector and EOMs were derived using light-cone gauge for constituent gluon