Diffractive virtual photoproduction of ρ mesons -what can diffraction teach us about meson structure?

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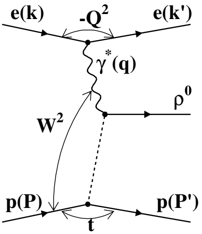
The spectroscopy program at EIC and future accelerators
ECT*, Trento, Italy
18.-21. Dec. 2018

Outline

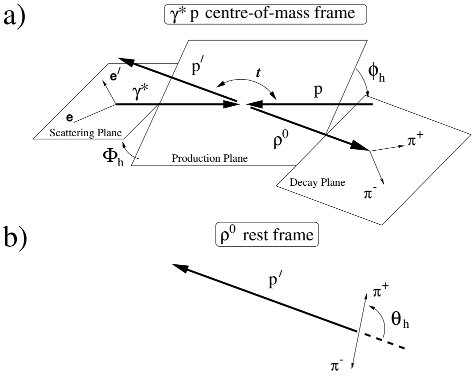
- (Exclusive) diffractive production has few-body final states and presents a rather clean environment to study the produced system.
- "Spectroscopy" and reaction mechanisms should be considered together to get the complete picture of structure & interactions of hadrons
- This discussion contribution is a personal and biased choice of some examples from the literature on how some striking phenomena appear in diffractive electroproduction of ρ mesons. Relevant for EIC & dependent on meson structure.

Diffractive electroproduction



- large $\gamma^* p$-cms energy (or large rapidity gap): Pomeron dominance.
- large Q^2 (or large m_V^2): soft to hard (pQCD) transition ($Q^2 + m_V^2$-scaling !)
- t-dependence: the typical diffractive cone at small t. Helicity flip-terms at larger t.
- very large t: short distance structure of the Pomeron. ("off-forward" BFKL for $|t| \ll W^2$)
- yet another dimension: nuclear target, A-dependence...

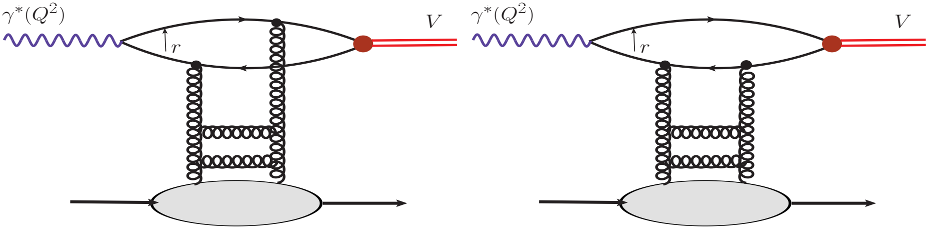
Diffractive electroproduction



$$
\begin{aligned}
& W(\cos\theta_h, \phi_h, \Phi_h) \\
= \; & \frac{3}{4\pi}\Big[\frac{1}{2}(1 - r^{04}_{00}) + \frac{1}{2}(3r^{04}_{00} - 1)\cos^2\theta_h \\
& - \sqrt{2}\,\mathrm{Re}\{r^{04}_{10}\}\sin 2\theta_h \cos\phi_h - r^{04}_{1-1}\sin^2\theta_h \cos 2\phi_h \\
& - \epsilon \cos 2\Phi_h (r^{1}_{11}\sin^2\theta_h + r^{1}_{00}\cos^2\theta_h \\
& - \sqrt{2}\,\mathrm{Re}\{r^{1}_{10}\}\sin 2\theta_h \cos\phi_h - r^{1}_{1-1}\sin^2\theta_h \cos 2\phi_h) + \ldots\Big]
\end{aligned}
$$

- angular distributions allow to study helicity structure of the diffractive production amplitude
- 15 coefficients of spin-density matrix, dependence on W, Q^2, t...

Color dipole/ $k_\perp$-factorization approach



Color dipole representation of forward amplitude:

$$A(\gamma^*(Q^2)p \to Vp; W, t=0) = i \int_0^1 dz \int d^2\boldsymbol{r}\, \Psi_V(z,\boldsymbol{r})\, \Psi_{\gamma^*}(z,\boldsymbol{r},Q^2)\, \sigma(x,\boldsymbol{r})$$

$$\sigma(x,\boldsymbol{r}) = \frac{4\pi}{3}\alpha_S \int \frac{d^2\boldsymbol{\kappa}}{\boldsymbol{\kappa}^4} \frac{\partial G(x,\boldsymbol{\kappa}^2)}{\partial \log(\boldsymbol{\kappa}^2)} \left[1 - e^{i\boldsymbol{\kappa}\boldsymbol{r}}\right], \; x = (M_V^2 + Q^2)/W^2$$

- quark & antiquark share the lightcone-momentum in fractions $z, 1-z$.
- sum over the (conserved) quark & antiquark helicities is implied
- in forward direction, also at the $\gamma \to V$-level s-channel helicity is conserved.

Nikolaev & Zakharov '91, Kopeliovich & Zakharov, '91

off the forward direction: finite transverse momentum transfer $\boldsymbol{\Delta}$:

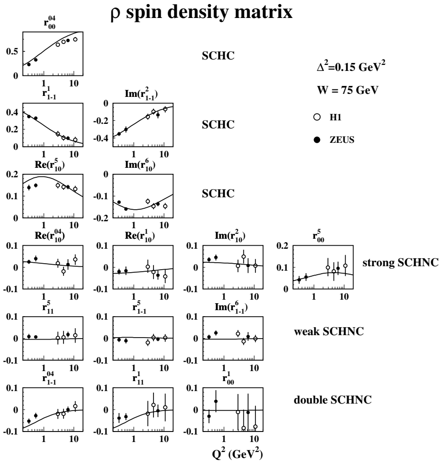
$$\mathcal{A}_{fi}(x,\boldsymbol{\Delta}) = i\int_0^1 dz \int d^2\boldsymbol{r}\sigma(\boldsymbol{r},\boldsymbol{\Delta})\exp[\frac{i}{2}(1-2z)(\boldsymbol{r}\boldsymbol{\Delta})]I_{fi}(z,\boldsymbol{r},Q^2)$$

$$\begin{aligned}
I_{LL} &= 4Qz^2(1-z)^2K_0(\varepsilon r)\psi_L(z,r)\\
I_{TT} &= m_f^2K_0(\varepsilon r)\psi_T(z,r) - [z^2+(1-z)^2]\varepsilon K_1(\varepsilon r)\psi'_T(z,r)\\
I_{LT} &= -i2z(1-z)(1-2z)\psi_L(z,r)\varepsilon K_1(\varepsilon r)\frac{(\boldsymbol{er})}{r}\\
I_{TL} &= -i2Qz(1-z)(1-2z)K_0(\varepsilon r)\psi'_T(z,r)\frac{(\boldsymbol{V}^*\boldsymbol{r})}{r}\\
I_{TT'} &= 4z(1-z)\varepsilon K_1(\varepsilon r)\psi'_T(z,r)\frac{(\boldsymbol{er})^2}{r^2}
\end{aligned}$$

- $I_{fi} = \Psi_{V,f}(z,\boldsymbol{r})\,\Psi_{\gamma^*,i}(z,\boldsymbol{r},Q^2)$, ψ_T,ψ_L appropriate radial WF's. $\boldsymbol{e},\boldsymbol{V}$ transverse pol. of γ, v.
- five independent amplitudes
- after integration over $\boldsymbol{r}$: amplitudes $\propto |\boldsymbol{\Delta}|^{|\lambda_f-\lambda_i|}$.

I. Ivanov, Nikolaev, WS (2004), earlier in mom.-space: Kuraev et al. (1998), D. Ivanov & Kirschner (1998)

ρ-meson density matrix elements: Q^2-dependence



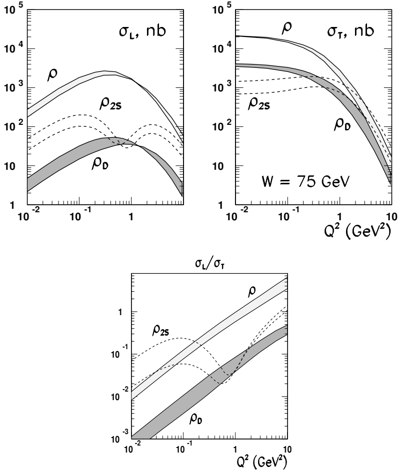
Momentum space (k_T-factorization) calculation by I. Ivanov (2005).

Some common quark model assignments of ρ and ω mesons

$n^{2s+1}L_J$	J^{PC}	I=1, G=+1	I=0, G=-1
1^3S_1	1^{--}	$\rho(770)$	$\omega(782)$
1^3D_1	1^{--}	$\rho(1700)$	$\omega(1650)$
2^3S_1	1^{--}	$\rho(1450)$	$\omega(1420)$
1^3D_3	3^{--}	$\rho(1690)$	$\omega(1670)$

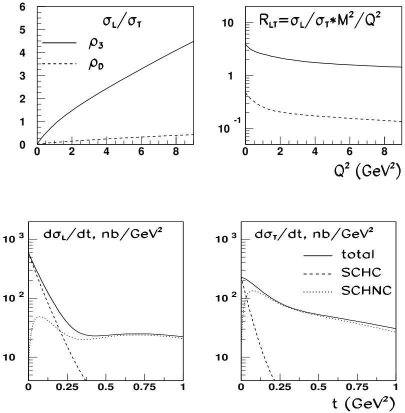
- nb: even for the ground state the substantial S/D mixing is not excluded.
- properties of wave functions that affect the $\psi_{\gamma^*}\psi_V$-overlap: a node in the WF of the radial excitation, vanishing wave function at the origin for the orbital (D-wave) excitation.
- In e^+e^-–annihilation photon doesn't couple to $J = 3$ state, but in diffractive dissociation $J \neq J_\gamma$ is possible!
- diffractive amplitudes for D-wave vectors: I. Ivanov & N.Nikolaev (1999) and $J = 3$ mesons: I. Ivanov & F. Caporale (2005).

σ_L vs. σ_T for ground-state ρ, $\rho(2S)$ and D-wave ρ_D



- Calculation by I. Ivanov & F. Caporale (Phys. Lett. B 662 (2005))
- the simplest "helicity observable".
- $\rho(2S)$ vs. ρ has been discussed by Nemchik et al. ('94,'98), Kulzinger, Dosch, Pirner ('99)
- D-wave excitation suppressed wrt. ρ, but no extra smallness vs. $\rho(2S)$
- uncertainties reflect knowledge of leptonic decay width

The two D wave mesons: ρ_3 vs ρ_D



- I. Ivanov & F. Caporale, Eur. Phys. J C44 (2005).
- spin/angular decomposition predicts strong suppresion of σ_L for D-wave vector, enhancement for $J = 3$ state.
- **Huge** s-channel helicity non-conserving pieces in the $J = 3$ case. Very untypical (for diffraction) t-dependence of the cross section, especially for transverse photons!

Conclusions

- Diffractive electroproduction is a powerful tool to disentangle e.g. hard to soft QCD, helicity properties of diffraction etc.
- Meson internal structure manifests itself through striking phenomena in the helicity structure/t-dependence of diffractive processes.
- unexplored(?): multiquark states, hybrids...