Hard exclusive vector meson production: Mechanism and GPD description

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- Mechanism of high–$Q^2$ meson production
  Small–size configurations ↔ color transparency
  Challenges in quantitative implementation
  Tests of reaction mechanism

- Gluon–dominated region $W > 10$ GeV
  HERA, COMPASS, EIC
  Reaction mechanism: $t$–slopes, universality, $\alpha'$
  GPD–based description

- Quark exchange region $W \sim$ few GeV
  JLab 6/12 GeV, EIC
  Comparison $\rho^+ \leftrightarrow \rho^0$, $\omega \leftrightarrow \phi$
  CLAS data: Fradi
  Missing strength from scalar $q\bar{q}$ exchange:
  Chiral symmetry breaking

→ Transverse quark/gluon imaging of nucleon

→ Spin/flavor structure of GPDs

→ Meson structure
Mechanism of high–$Q^2$ meson production

- Partonic mechanism at high $Q^2$
  \[ Q^2 \gg \text{hadronic scale}: \text{Meson produced predominantly in } q\bar{q} \text{ configuration of transverse size } r \sim 1/Q \]

  \[ Q^2 \to \infty: \text{pQCD interaction, factorization theorem} \]
  Brodsky et al. 94; Collins, Frankfurt, Strikman 96

  Target structure in GPDs: Universal, process–independent

- Quantitative questions
  Distribution of sizes/configurations for given $Q^2$?
  Effective QCD scale, finite–size corrections
  Role of different partons/exchanges?
  Quark vs. gluon GPDs in $\rho^0$
  Partonic kinematics $x_{1,2}$: Scattering from quarks vs. $q\bar{q}$ pair knockout? Re/Im of amplitude

  ... should be addressed before detailed modeling!
Gluon–dominated region: Mechanism I

- Simplifications at $W > 10$ GeV
  - Gluon exchange dominant in $\rho^0 \leftrightarrow \phi, J/\psi$
  - Coherence length $\gg 1$ fm:
    - Dipole picture in nucleon rest frame
  - Im $A \gg$ Re $A$: DGLAP region of gluon GPD

- Test approach to small–size regime
  - $\Delta_T^2$ slope measures transverse size of interaction region: Decreases at large $Q^2$, becomes universal
  - Seen in HERA data!

- Further tests
  - $Q^2$ dependence, $\sigma_L$ dominance
  - $\phi : \rho^0 = 2 : 9$ from SU(3)
Gluon-dominated region: Mechanism II

- Test reaction mechanism through $W$–dependence: Changes with $t$ through effective Regge slope $\alpha'$
  - Soft process: Pomeron trajectory
  - Hard processes: $\alpha'(Q^2) \ll \alpha'_{\text{soft}}$, drops with $Q^2$, Seen in HERA data!

$\sigma \sim W^{4\alpha'_{\text{soft}}} t$

$\alpha'(Q^2) \ll \alpha'_{\text{soft}}$

$\frac{Q^2 + M_Y^2}{4} [\text{GeV}^2]$
Gluon–dominated region: GPD description

- Successful GPD–based phenomenology including finite–size effects
  - Dipole picture with size distribution \textit{Frankfurt, Strikman, Koepf 95}
  - Hard scattering with intrinsic $k_T$ \textit{VGG 98; Kroll, Goloskokov 05+}

- Lower energies
  - $\phi$ still gluon–dominated at JLab energies
  - Nucleon gluonic consistent with HERA \textit{Frankfurt, Strikman 02}
  - $\rho^0$: Quark exchange – new challenges!

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure.png}
\caption{Graphs showing the behavior of $\phi$ and $\rho$ with $W$ [GeV].}
\end{figure}
Quark exchange region: Mechanism

- Comparison $\rho^+ \leftrightarrow \rho^0 \leftrightarrow \phi$: Quark exchange!

  Approximate $u$–quark dominance
  $\rho^0 : \omega : \rho^+ \sim 1 : 1 : 2$

- Valence quarks or $q\bar{q}$ pair?

  $W$ dependence at $W < 4$ GeV
  suggest spin–0 exchange
  Guidal, Morrow: Modified D–term in GPD?

Chiral symmetry breaking:
Correlated spin–0 pairs in nucleon

Most likely $q\bar{q}$ exchange
with non-perturb. interactions
(“soft mechanism”)

CLAS 09 Fradi et al.  **Black** $\rho^+$, **Red** $\rho^0$ **Blue** $\omega$ **Green** $\phi$

Scattering from quark

Knockout of $q\bar{q}$ pair
Quark exchange region: Mechanism

- $t$-slopes and their $Q^2$ dependence
  
  Interpretation more difficult: exponential fits dominated by large $|t| \sim 1 - 2 \text{ GeV}^2$
  
  Possibly factors $\sqrt{-t}$ from nucleon helicity flip
  
  Approach to small-size regime at large $Q^2$? . . . Need also low-$Q^2$ data!
Summary

- Experimental input essential for understanding reaction mechanism of exclusive meson production
  - Not “GPDs or not GPDs,” but quantitative questions
  - Kinematic dependences more important than pushing for highest $Q^2$

- Successful GPD–based phenomenology in gluon–dominated region
  - Substantial finite–size effects at $Q^2 \sim$ few GeV$^2$, physically motivated
  - No reason why it should not work at lower energies!

- New insights into reaction mechanism from CLAS $\rho^+/\rho^0/\omega/\phi$ data
  - Likely $q\bar{q}$ exchange with non-perturbative interactions
  - Toward a partonic description of meson production at JLab 6 and 12 GeV!