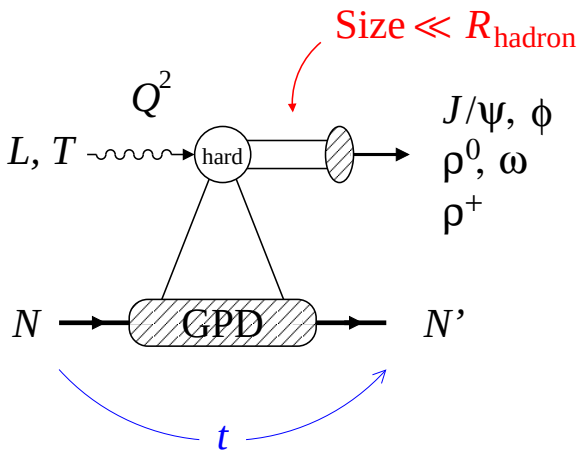
Mechanism of vector meson production at low W

C. Weiss (JLab), INT Workshop "Orbital angular momentum," Seattle, 14–Feb–12



Phenomenological approach based on parton picture

Contains asymptotic pQCD mechanism but more general:

finite–size/higher–twist effects

non–perturbative interactions

Suggests experimental tests of reaction mechanism

- Small–size configurations

  Example: Pion form factor

  Model–independent analysis

  Dynamical origin: pQCD interactions, QCD vacuum structure

- Vector meson production at high W ($\gtrsim 5\,\mathrm{GeV}$)

  Tests of approach to small–size regime: t–slopes, Q^2, W–dependence, ϕ/ρ^0 ratio
  HERA, HERMES, COMPASS, EIC

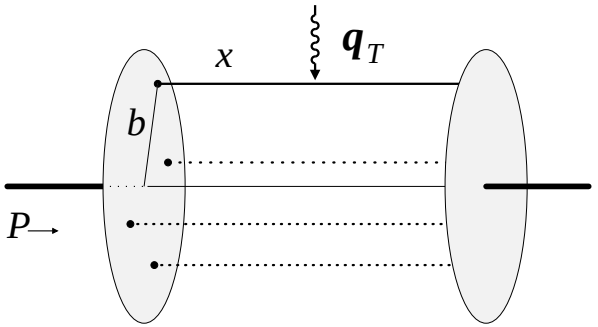
- Vector meson production at low W

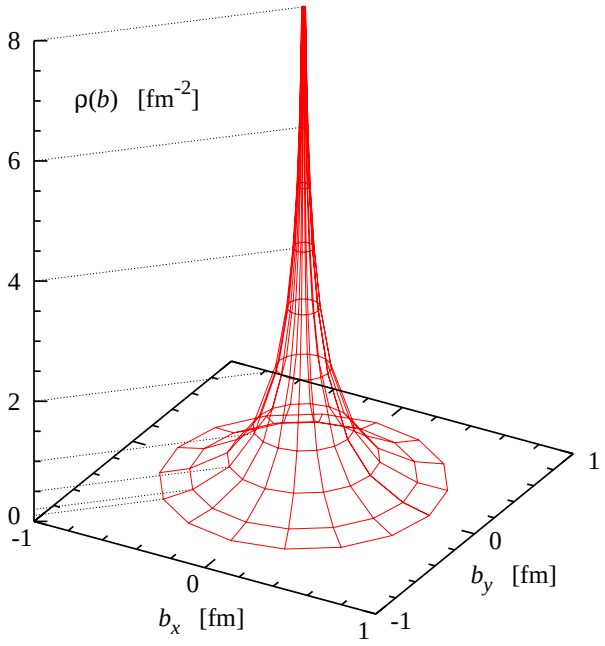
  Existing data: Kinematic dependences, comparison of channels Cornell, JLab 6 GeV

  Speculation: $q\bar{q}$ pair knockout in ρ^0

  Experimental tests JLab 12 GeV

Small–size configurations: Elastic form factors





- Parton picture $P \to \infty$, $\boldsymbol{q}_T$ transverse

  Current cannot produce pairs

  Wave function overlap representation
  $F(q^2) = \sum_{\rm n} \int dx\ d^2k_T\ \psi_n^*(x, k_{T1}, ..)\psi_n(x, k_{T2}, ..)$

  Configurations with different particle number and transverse size

  Expect that large $|\boldsymbol{q}_T|$ "select" small sizes
  How to quantify it?

- Transverse density Soper 76, Miller 07

  $F(q^2) \ = \ \int d^2b\ e^{i\boldsymbol{q}_T\boldsymbol{b}}\ \rho(b)$ 2D Fourier

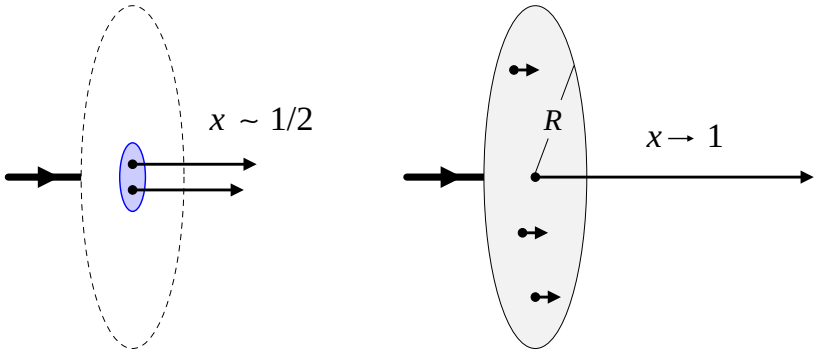
  Cumulative charge/current of constituents at transverse position b

- Empirical charge density in pion

  Dispersion integral over timelike FF e^+e^- data

  High density at $b \to 0$: Small–size configurations?

Small–size configurations: Pion



small–size end–point

- Two sources of small–b density

$x \sim 1/2$	size $\ll R$	small–size	mostly $q\bar{q}$
$x \to 1$	size $\sim R$	end–point	multiparticle, soft gluons

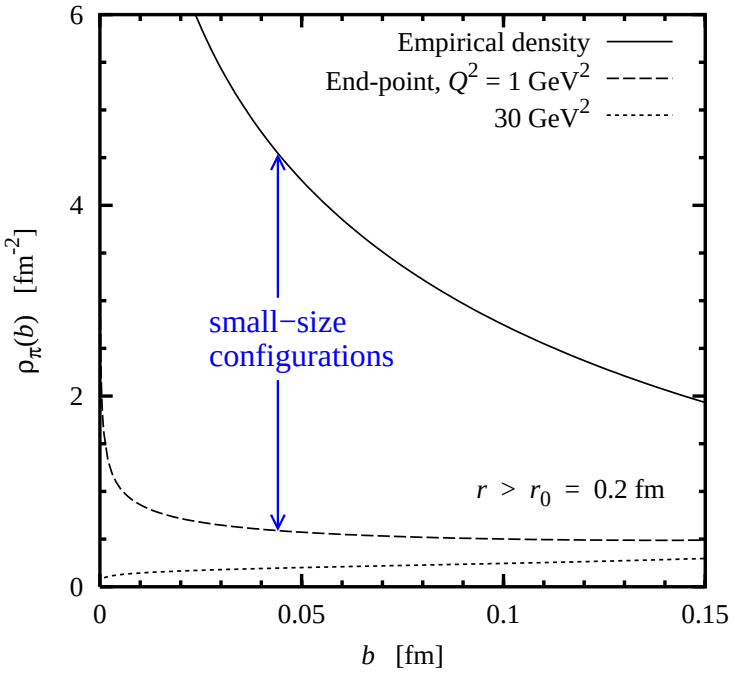
  Dynamical question!

- Density in center of pion mostly from small–size configurations

  End–point contribution constrained by quark density in pion at $x \to 1$

  Miller, Strikman, CW 10. πA Drell–Yan data.

  Soft–gluon resummation → Talk Vogelsang

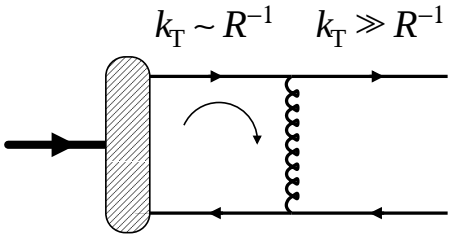


- Alt. picture: Rest frame

  Photon reverses quark in pair with momenta back–to–back along reaction axis

Model–independent statement on small–size configurations!

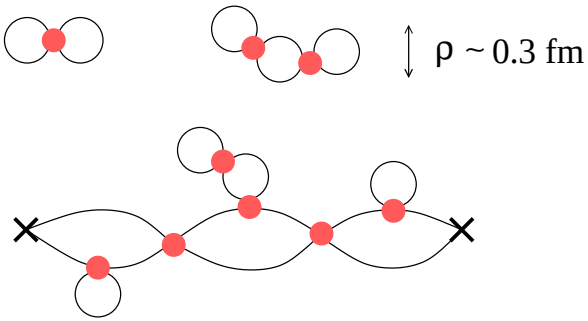
Small–size configurations: Dynamical origin



- Perturbative interactions

  High–momentum component of wave function
  $k_T \sim R^{-1}$ wave function as source, $\int d^2k_T$

  Responsible for leading $Q^2 \to \infty$ asymptotics of pion FF Efremov, Radyushkin 77+; Brodsky Lepage 80



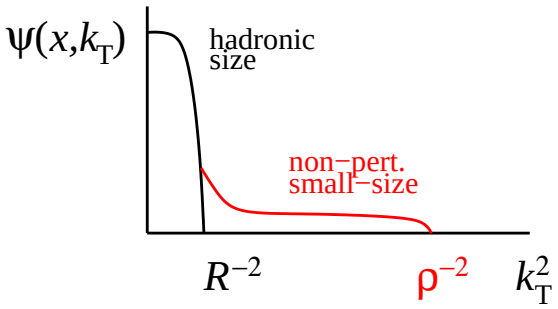
- QCD vacuum structure

  Strong non–perturbative gluon fields
  of size $\rho \sim 0.2$–0.3 fm

  Objective measure: Average quark virtuality
  $\langle\bar\psi\nabla^2\psi\rangle/\langle\bar\psi\psi\rangle > (0.7\,\text{GeV})^2$
  Lattice: Teper 87, Doi 02, Chiu 03

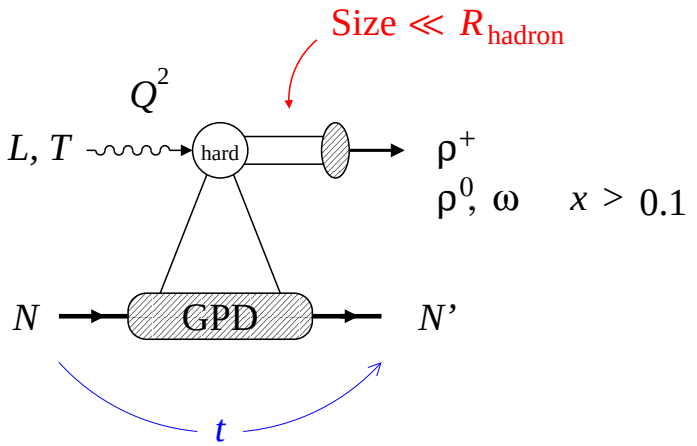
  Non–perturbative semi–hard component of WF
  Cf. short–range correlations in nuclei

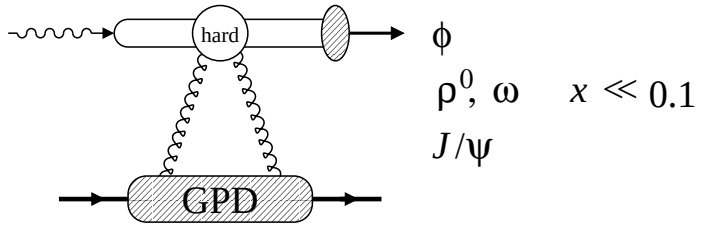
  Chiral anomaly? $\gamma^*\gamma \to \pi^0$ puzzle



Evidence for non-perturbative small–size configurations!

Exclusive meson production: High Q^2





Pseudoscalars π, η: Quark helicity/transversity structure
→ Talks Kroll, Liuti

- Meson produced in small–size configuration

  $Q^2 \to \infty$: $q\bar{q}$ pointlike, pQCD interactions
  QCD factorization for σ_L: Collins, Frankfurt, Strikman 96

  $Q^2 \sim$ few GeV^2: $q\bar{q}$ has small size,
  but non-perturbative interactions possible
  Recent progress: Sudakov suppression. Goloskokov, Kroll 08/10

  Nucleon structure in GPDs: Quark/gluon form factors, universal, process–independent
  ↔ DVCS, other processes, lattice QCD

- Meson selects flavor/spin component

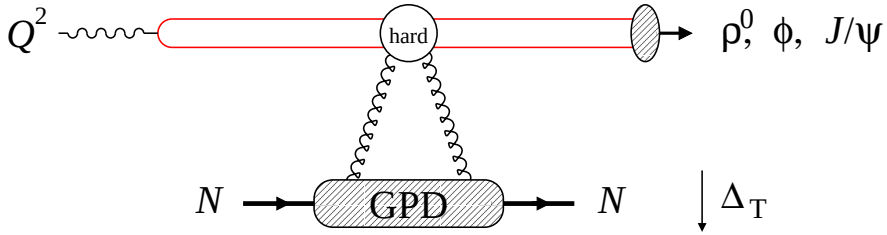
$\phi, J/\psi$	gluons
ρ^+	quarks $u - d$
ρ^0, ω	quarks $2u \pm d$ + gluons

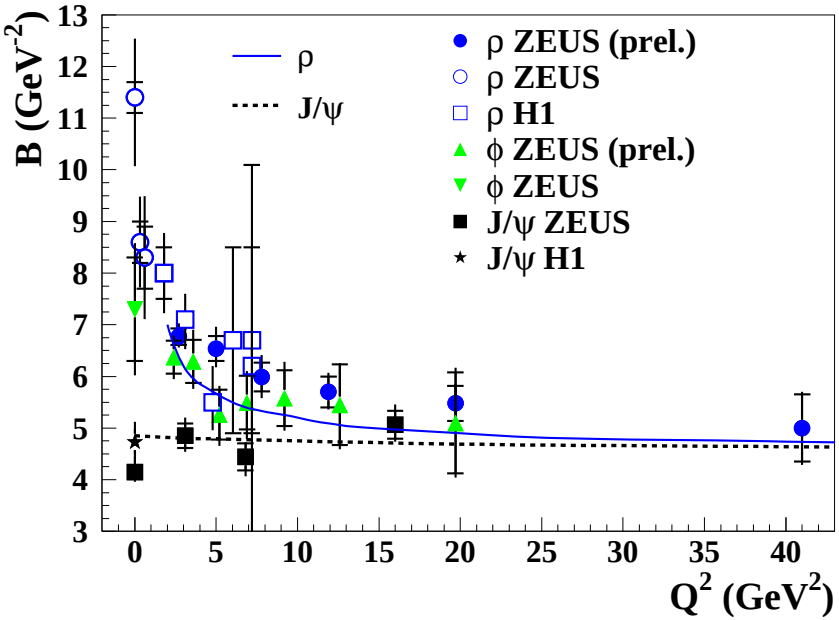
- Two–stage analysis

  Verify approach to small–size regime:
  Kinematic dependences, comparison of channels
  Quantitative questions: Effective sizes? Dominant amplitudes?

  Extract nucleon structure information:
  Transverse parton distributions, $q\bar{q}$ correlations, . . .

High W: Approach to small–size regime I





- Simplifications at high W

  Gluon exchange dominant in ρ^0, similar to ϕ, J/ψ

  Coherence length $\gg 1$ fm:
  Dipole picture in nucleon rest frame

  Im A $\gg$ Re A: DGLAP region of GPD

  Test approach to small–size regime!

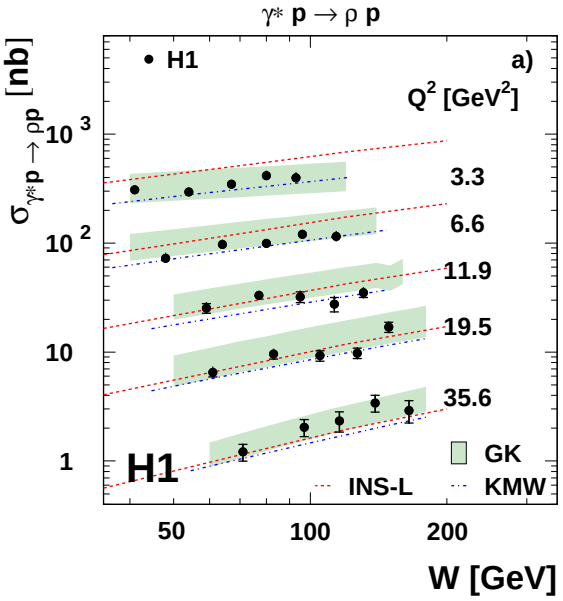
- Universality of t–slopes at high Q^2

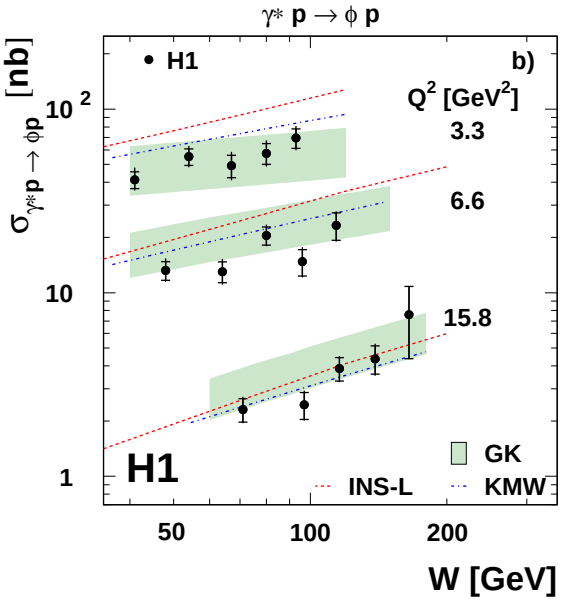
  Δ_T^2 slope measures transverse size of interaction region = size of target and meson configurations

  Decreases at large Q^2, becomes universal:
  Approach to small–size regime
  Contradicts Regge factorization!

  Seen in HERA data!

High W: Approach to small–size regime II



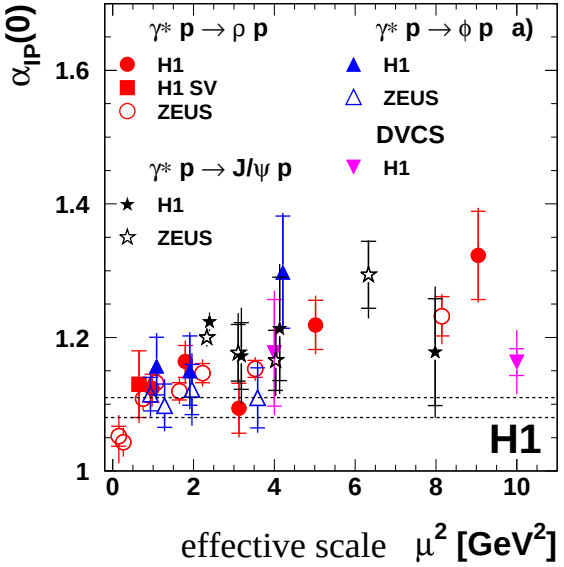


- Hardening of W–dependence with Q^2

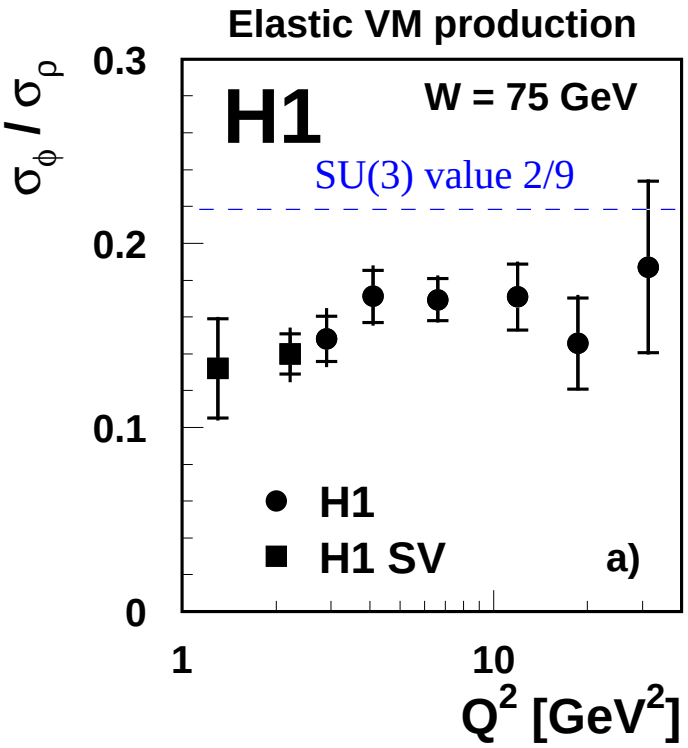
  W–dependence becomes steeper with increasing Q^2

  Rate of growth reveals effective scale in gluon GPD $Q^2_{\rm eff} \approx \pi^2/\langle r^2_{\rm q\bar{q}}\rangle \ll Q^2$

  Contradicts Regge factorization
  "Effective" trajectory



High W: Approach to small–size regime III

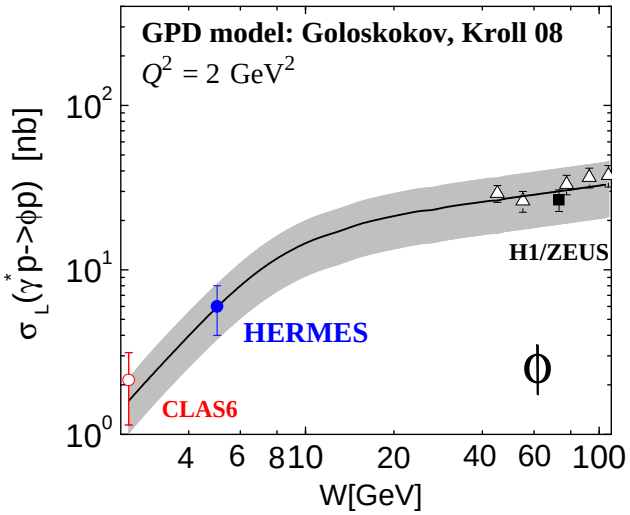


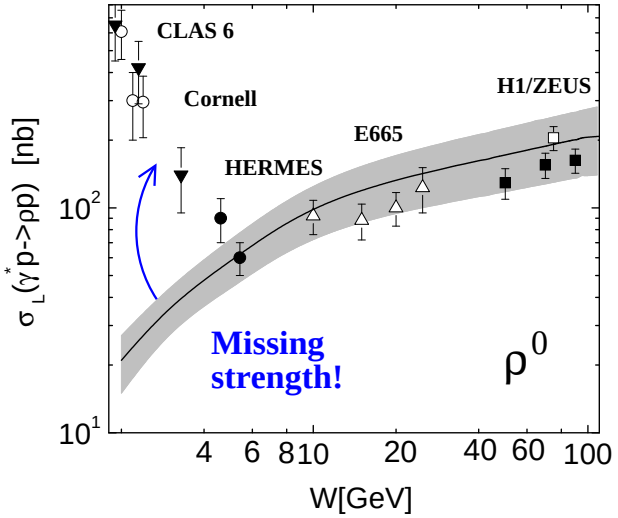
- Ratio ϕ/ρ^0 constant at high Q^2

  Same spatial size of configurations, only difference in quark charges

  Consistent with $SU(3)$ value $2/9$

Low W: Reaction mechanism





- Mechanism of hard exclusive vector meson production more complex at low W

  Quark exchange important in ρ^0, ω; cf. ρ^+, K^*

  Re/Im could be large: ERBL region of GPDs?

  Large skewness ξ: GPDs not simply related to forward limit

  Potentially quark helicity–flip amplitudes, SCHC violation

- Present GPD models challenged

  ϕ overall well described with gluon GPD
  Hints of non–uniform W dependence near threshold.
  Other exchange mechanism? s–channel hyperon resonances?

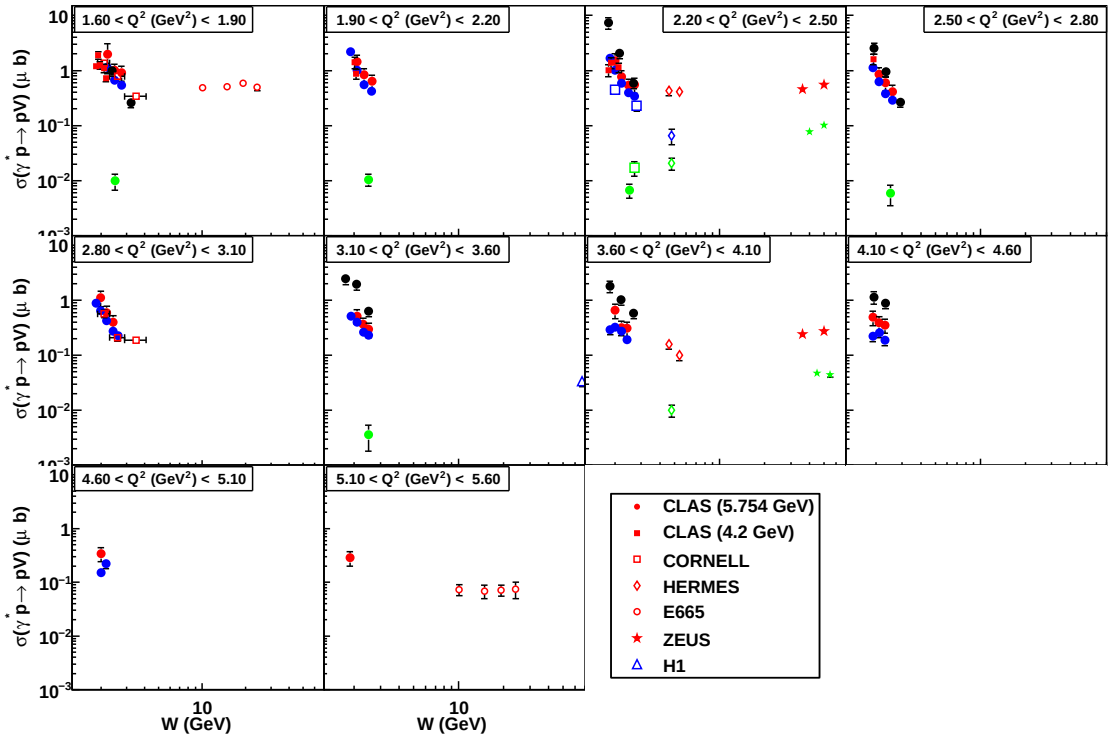
  Missing strength in ρ^0 — origin?

- Need experimental information
  JLab 6 and 12 GeV

  Approach to small–size regime?

  Type of exchanges/GPDs?
  Essential to reduce complexity!

Low W: Quark vs. gluon exchange



CLAS 09 Fradi et al. **Black** ρ^+, **Red** ρ^0 **Blue** ω **Green** ϕ

- Comparison $\rho^+ \leftrightarrow \rho^0 \leftrightarrow \phi$

  ρ^0 comparable to ρ^+:
  Quark exchange!

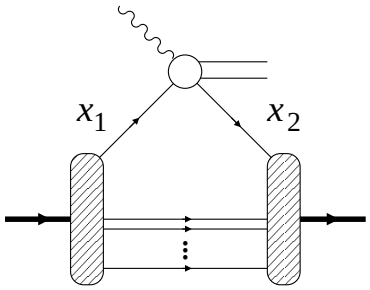
  Ratios consistent with u–quark dominance $\rho^0 : \omega : \rho^+ \sim 1 : 1 : 2$

- Scattering from valence quark or knockout of $q\bar{q}$ pair?

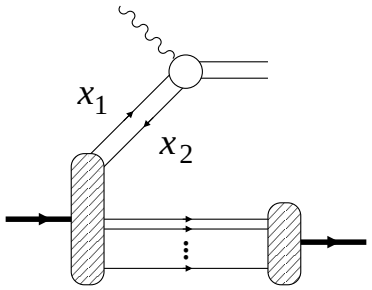
  GPDs contain both
  DGLAP and ERBL regions

  $\sigma \sim W^{-4}$ at $W < 4\,\text{GeV}$
  Cf. spin–0 meson exchange in soft regime

  Hard regime: Knockout of spin–0 $q\bar{q}$ pair?
  Guidal, Morrow: Modified D–term in GPD

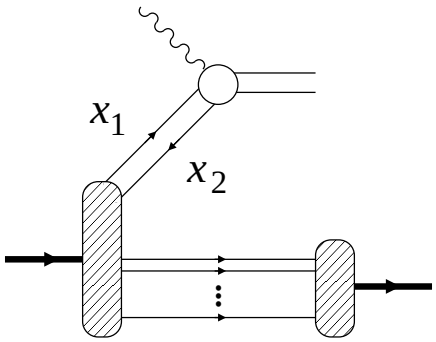


Scattering from quark



Knockout of $q\bar{q}$ pair

Low W: $q\bar{q}$ knockout in ρ



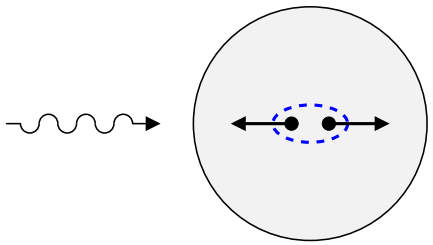
- Speculation: ρ^0 and ρ^+ at $W < 4\,\mathrm{GeV}$ dominated by $q\bar{q}$ knockout

  Chiral symmetry breaking prodces correlated small–size spin–0 $q\bar{q}$ pairs in nucleon
  Light–cone formulation: Schweitzer, Strikman, CW; in progress

  Measured ρ^+/ρ^0 ratio consistent with exchange of $q\bar{q}$ with pion quantum numbers
  Isospin symmetry and $\rho \to \gamma\pi$ decay widths

  ρ production may involve chirally odd GPDs and distribution amplitudes
  Cf. pseudoscalar production → Talks Kroll, Liuti

  Challenge to implement quantitative model



- Rest frame picture: Reversal of quark in pair aligned along reaction axis

  Analogy with short–range NN correlations in nuclei

  Allows for modeling of non–perturbative interactions

Low W: Approach to small–size regime

- Q^2–dependence of t–slopes

  $t_{\rm min}$ large, varies with Q^2

  If actual t–dependence of amplitude is non–exponential,
  changing $t_{\rm min}$ will change effective slope in $t - t_{\rm min}$

  Need to separate kinematic decrease of slope from actual
  "squeezing" of $q\bar{q}$ configurations

- Extensive tests with JLab 12 GeV

  L/T ratio from SCHC, ϕ–dependent response functions

  Change of W–dependence with t: Higher $|t|$ enhances scattering
  from valence quarks, suppresses $q\bar{q}$ knockout

Summary

- Small–size configurations key concept in phenomenology of hard exclusive processes

  More primary than specific interaction models

  Encompasses non–perturbative interactions,
  e.g. chiral symmetry–breaking forces in QCD vacuum

  Substantial probability of SSC's in pion from model–independent analysis

  Can be probed in other experiments: Nuclear transparency, $\pi + A \to 2\,\mathrm{jets}$

- Mechanism of exclusive vector meson production well understood at high W

  Model–independent tests of approach to small–size regime

  Successful phenomenology based on gluon GPDs

- Challenge to understand reaction mechanism at low W

  ϕ mostly from gluons — needs closer look near threshold

  ρ^0, ρ^+ possibly dominated by $q\bar{q}$ knockout — needs to be quantified

  Experimental data essential for deciding between possible scenarios