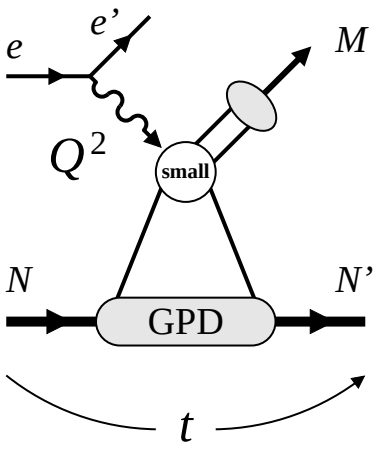
Hard exclusive meson production at JLab12

C. Weiss (JLab), CLAS Collaboration Meeting, JLab, 09-Mar-2018



- High–Q^2 meson production

  Distances $\leftrightarrow$ dynamics $\leftrightarrow$ structures

- Exclusive vector mesons

  Mechanism from small to large x HERA, COMPASS, HERMES

  ϕ at large x: Nucleon gluonic radius CLAS12 E12-12-007

  ρ^0, ρ^+ at large x: Dynamics?

- Exclusive pseudoscalar mesons

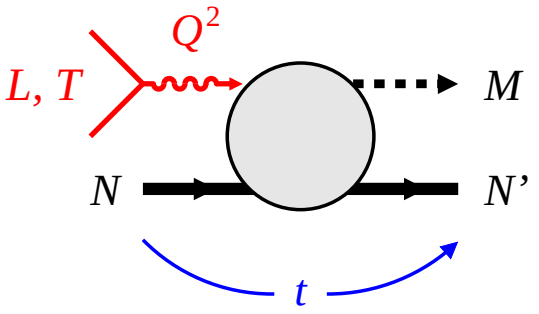
  π^0, η: Helicity-flip mechanism, transversity GPDs
  CLAS12 E12-06-108, Hall A E12-06-114, Hall C E12-13-010

  π^+: Pole vs. non-pole, pion FF Hall C E12-06-101, E12-07-105

- High-t and backward production

  J/ψ near threshold: High-t gluonic FF GlueX, CLAS12, SOLID

Exclusive mesons: High Q^2



- Exclusive electroproduction

  Q^2 size of probe, resolution scale

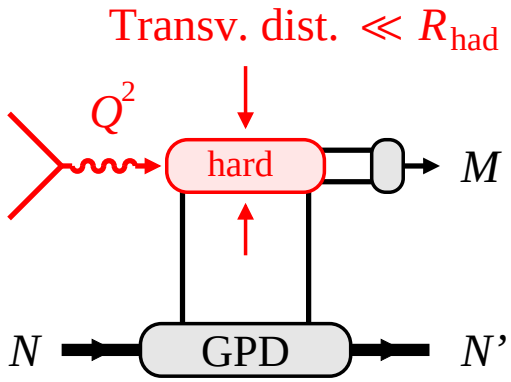
  t size of target configurations

- Transverse distances in interaction $\ll$ hadronic size

  Collinear factorization: GPDs $\times$ hard process $\times$ DA
  Collins, Frankfurt, Strikman 96

  $Q^2 \to \infty$: Pointlike $q\bar{q}$ pair, pQCD interactions, σ_L

  $Q^2 \sim$ few GeV^2: Finite size distribution, non-perturbative interactions, $L + T$ responses



- Nucleon structure in GPDs

  Quark/gluon form factors of nucleon

  QCD operator definition $\langle N'|\text{Twist-2}|N\rangle$
  Universal, process–independent
  Relations to PDFs, FFs, charges
  Non-perturbative methods, LQCD

Exclusive mesons: Physics questions

- Where does approach to small-size regime take place?

  How to observe & quantify it?

  Model-independent criteria!

  Experience with small–x: t slopes, W dependence, ...

- What interactions mediate the production process?

  How to account for finite-size effects?

  pQCD interactions with finite-size corrections

  Frankfurt, Strikman, Koepf 96+;
  Musatov, Radyushkin 97; Goloskokov, Kroll 08+

  Non-perturbative interactions, chiral symmetry breaking?

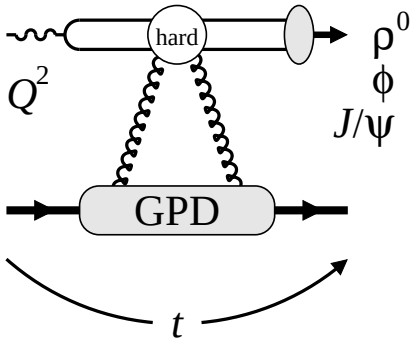
- What structures in nucleon and meson are probed?

  GPDs: Quarks vs. gluons, chiral even–odd, spin–flavor

  Meson DAs: chiral even–odd, higher twist

Questions are interrelated
Need to consider all available evidence
Need experimental data and theory

Vector mesons: Mechanism small x



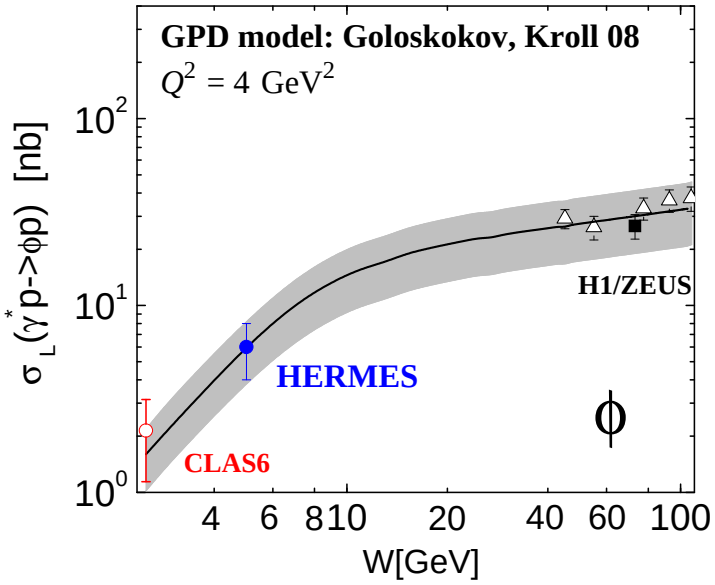
- $\rho^0, \phi, J/\psi$ production at small x

  HERA $x = 10^{-4}$–10^{-2}, $Q^2 = 0$–$30\,\mathrm{GeV}^2$

  Approach to small-size regime tested:
  t-slopes become Q^2-independent above $\sim$10 GeV^2,
  same for $\rho^0, \phi, J/\psi, \gamma$

  Factorized description with finite-size effects
  predicts cross sections & kin dependences
  Frankfurt, Strikman, Koepf 96; Goloskokov, Kroll 08+

  Probes gluon GPD



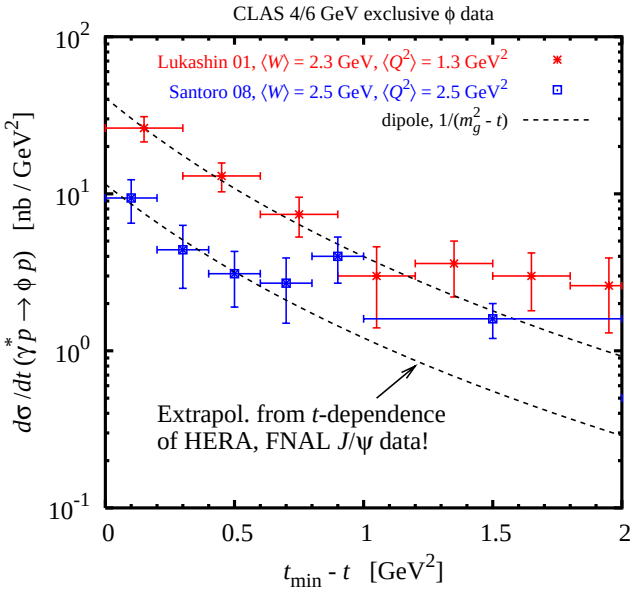
- ϕ production at larger x

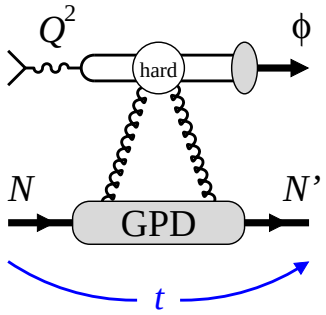
  No change in kin dependences

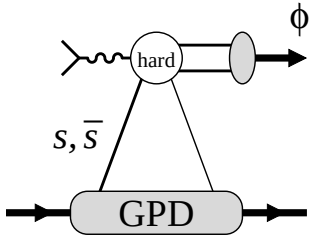
  Appears gluon-dominated even at $x > 0.1$

  GPD model reproduces cross sections
  Goloskokov, Kroll 08+

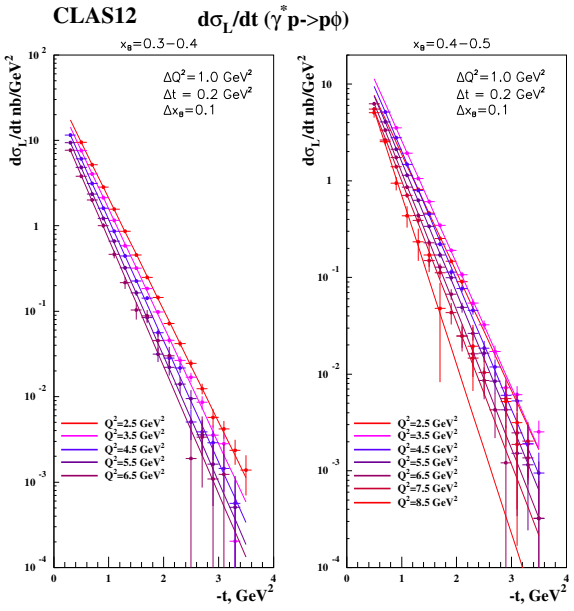
Vector mesons: Mechanism ϕ large x







- t–dependence of 6 GeV ϕ data consistent with gluon GPD measured at high energies
  Extrapolation of HERA, FNAL J/ψ results



- CLAS12: Test ϕ production mechanism and GPD description

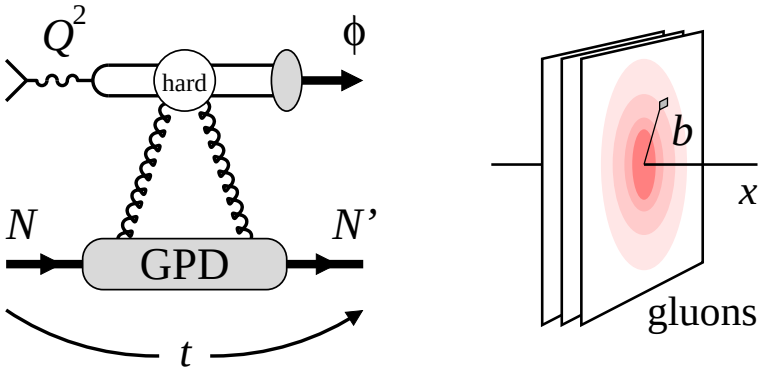
  When does t–slope become independent of Q^2?

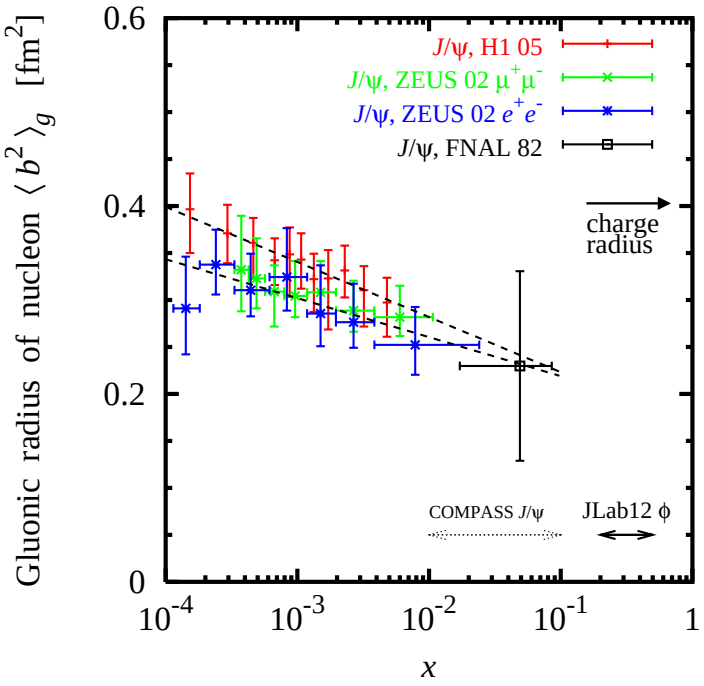
  How does ξ–dependence change with Q^2?

- Strange quark contributions?

  Indications of $s\bar{s}$ at $x > 0.1$
  Requires theoretical estimate

Vector mesons: Gluon imaging ϕ large x





- Transverse spatial distribution of gluons

  2D Fourier of t-dependence of gluon GPD

  Fundamental gluonic radius, cf. charge radii

  Leading-twist characteristic: LQCD, models

  $x < 0.01$ measured at HERA, FNAL,
  $x > 0.1$ practically unknown

  Changes with x: Chiral dynamics, diffusion

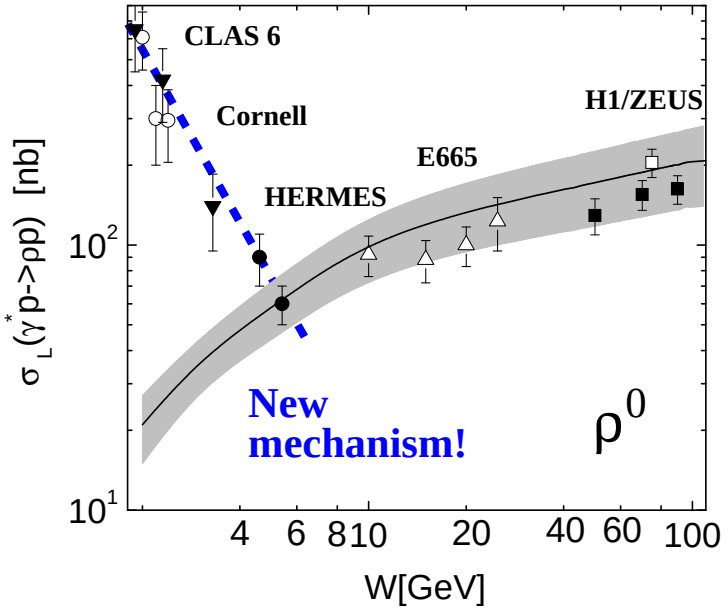
  DIS: Large gluon density above $x > 0.1$

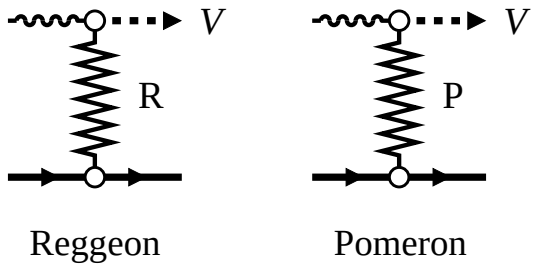
- CLAS12: Extract t-dep of gluon GPD and transverse profile at $x = 0.2 - 0.5$

  Relative t–dependence of $d\sigma_L/dt$

  L/T from SCHC

Vector mesons: ρ mechanism





- Change of mechanism

  Gluons at high W / small x

  New mechanism at low W / large x

- CLAS6 data: $\rho^+ > \rho^0$ at large x Fradi et al.

  New mechanism must involve quarks

- Theoretical description?

  Soft regime: Reggeon vs. Pomeron

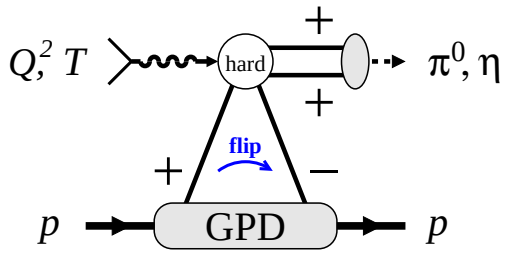
  Hard regime: GPD description?

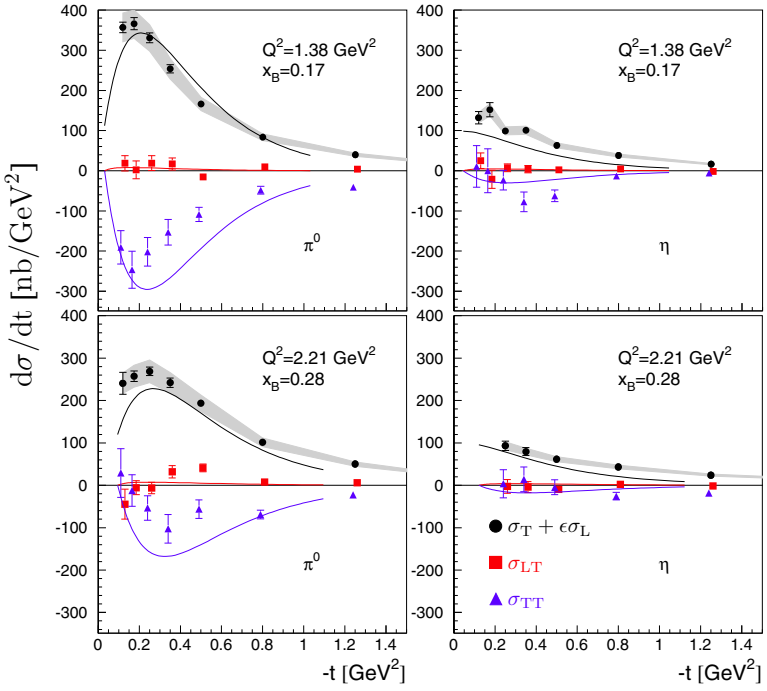
  Guidal, Morrow 07: Rescaled D-term. Conflicts DVCS.

  Kroll, Goloskokov 14: Transversity GPDs in ρ spin density.
  To be tested with COMPASS data.

- CLAS12 could have major impact!

Pseudoscalars: π^0, η mechanism





CLAS6 2017 Bedlinskiy et al.

- Dominance of helicity-flip structures
  Goldstein Liuti et al. 08+, Goloskokov, Kroll 11+

  Large helicity-flip pion DA induced by dynamical χSB in QCD

  Helicity-flip GPD $\leftrightarrow$ transversity

  Twist-3 mechanism, formally subleading

- Describes JLab 6 GeV data

  Absolute cross sections

  L vs. T from response functions

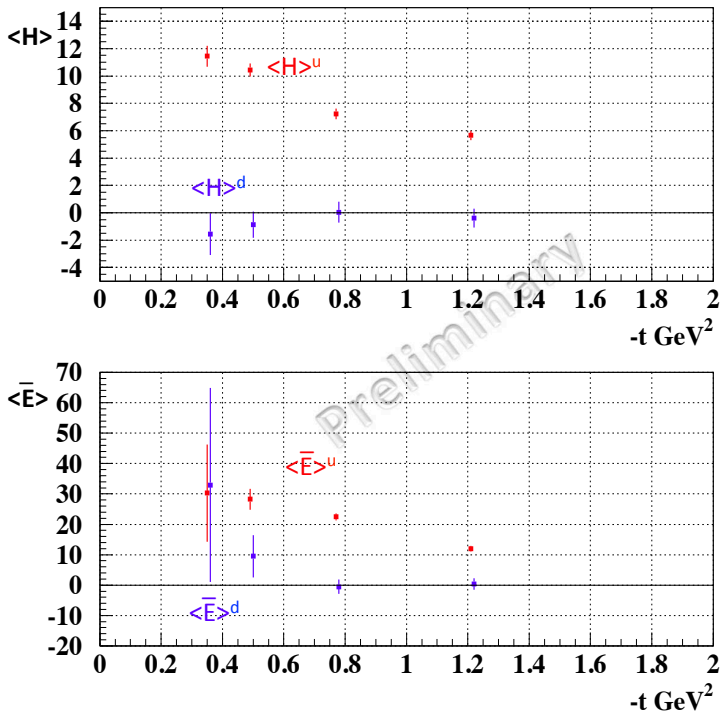
- JLab12: Test mechanism

  Expect $T \gg L$

  Avoid Rosenbluth separation $\rightarrow$ Discussion

CLAS12 E12-06-108, Hall A E12-06-114, Hall C E12-13-010

Pseudoscalars: π^0, η and quark transversity



CLAS6 preliminary Kubarovsky 14

- Potential access to quark transversity

  Complements SIDIS, pp Drell-Yan
  Leading-twist structure: LQCD, models

- Flavor separation with $\pi^0 + \eta$

  Different isospin components of amplitude

  Simplifying assumptions about phase

- Theoretical insight from large-N_c QCD
  Schweitzer, CW PRC94 (2016) 045202

  $\langle H_T \rangle : \quad |u - d| \gg |u + d|$ nonsinglet leading

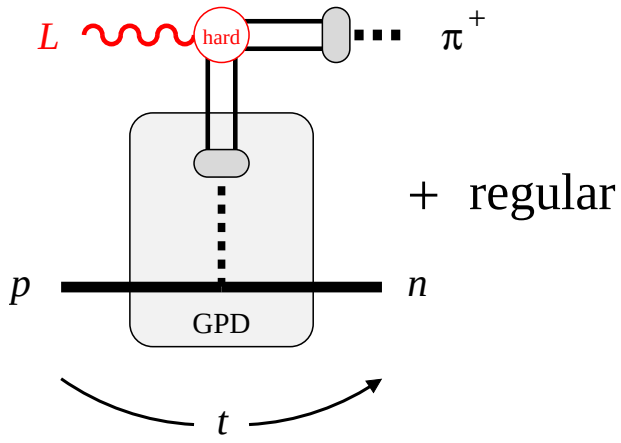
  $\langle \bar{E}_T \rangle : \quad |u + d| \gg |u - d|$ singlet leading

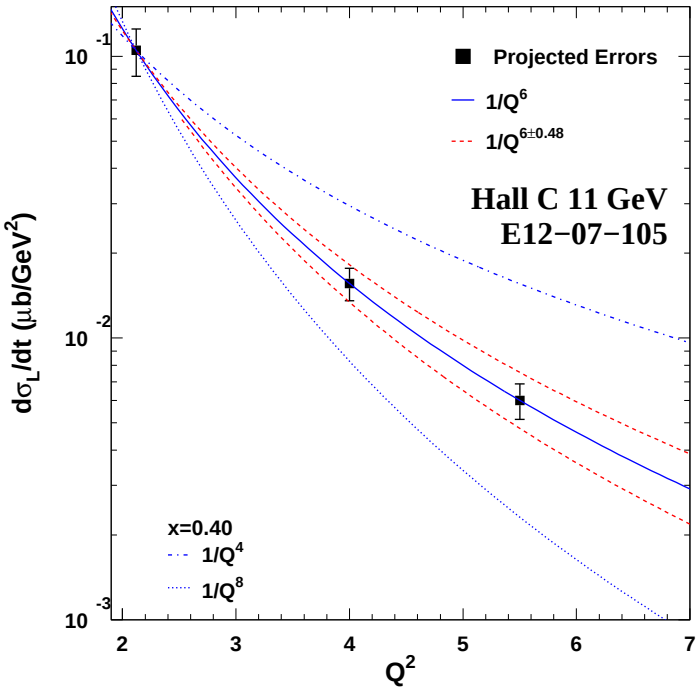
$$\langle H \rangle = \int dx\, H(x,\xi,t) \int d^2k_T\, A_{\rm hard}(x,\xi,k_T)\, S(k_T)$$

Invariant amplitude, cf. Compton form factors

Model-independent parametric predictions
for hierarchy of spin-flavor components

Pseudoscalars: π^+ mechanism





- Same helicity-flip mechanism in π^+
- Pion pole in electroproduction

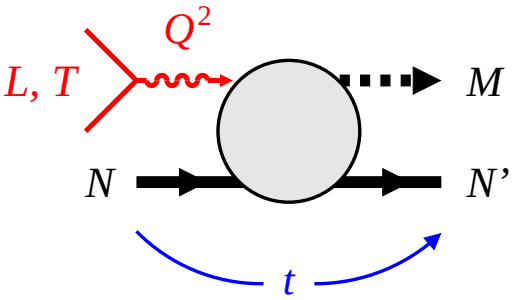
  Mostly L amplitude

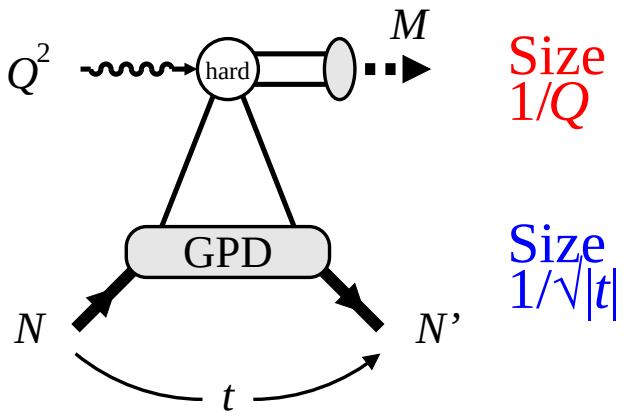
  Residue = pion form factor

  Separate pole $\leftrightarrow$ non-pole
  Should be revisited in view of helicity-flip mechanism

- JLab12 experiments — Hall C E12-07-105
- Joint physics analysis $\pi^0, \eta \leftrightarrow \pi^+$

Exclusive mesons: High t





Size $1/Q$

Size $1/\sqrt{|t|}$

- Meson production at $|t| \gg 1\,\mathrm{GeV}^2$: Nucleon in small–size configuration

  Cf. high–t elastic nucleon form factors

- QCD–based description

  pQCD mechanism — Brodsky, Lepage 80's

  Single–quark dominance, handbag graph — Kroll et al.

  Conventional GPD based on $|t| \ll \mu^2$, new concept if $|t| \sim \mu^2$,

  Hadron-induced processes — Kumano, Strikman, Sudoh 09
  SCET approach — Kivel, Vanderhaeghen

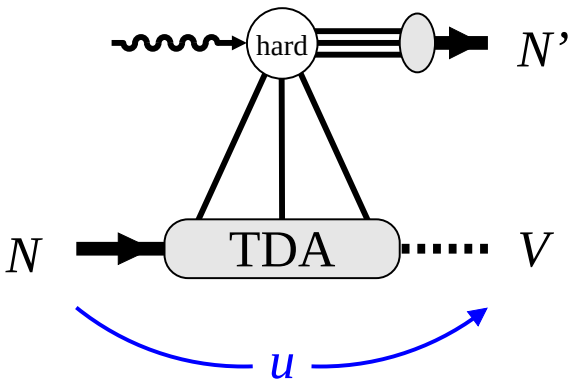
- JLab12: Explore mechanism

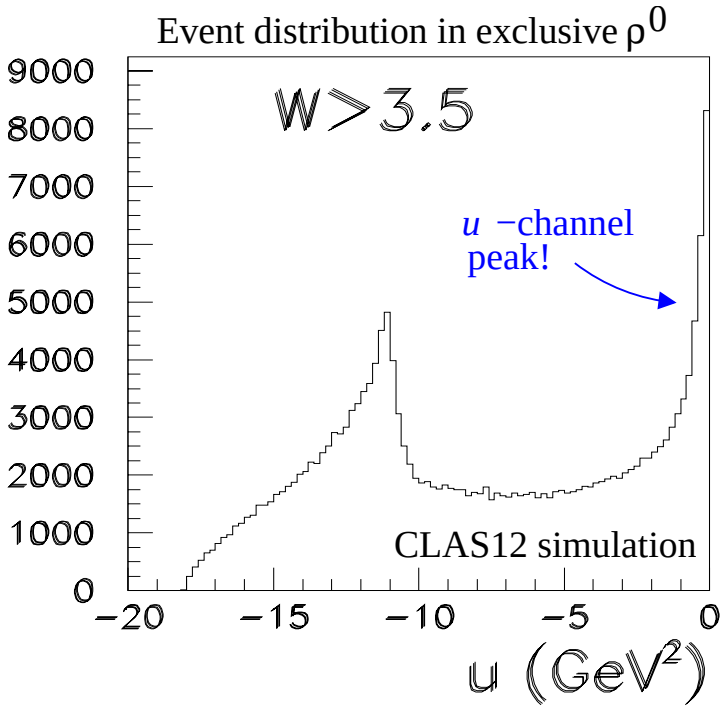
  Extend t-range

  Realize high $|t|$ and high Q^2 – new regime

  CLAS12 E12-06-108, Hall C E12-14-005

Exclusive mesons: Backward angles





- Large $|t|$, small $|u| < 1\,\mathrm{GeV}^2$
- Knockout of small–size nucleon configuration, mesonic system left

  New probe of valence quark core

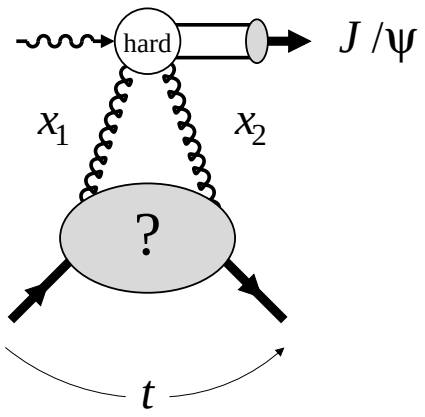
  pQCD–based description through transition DA $\langle M|qqq|N\rangle$
  Frankfurt et al. 02; Pire, Szymanowski et al. 10+
- JLab6 results

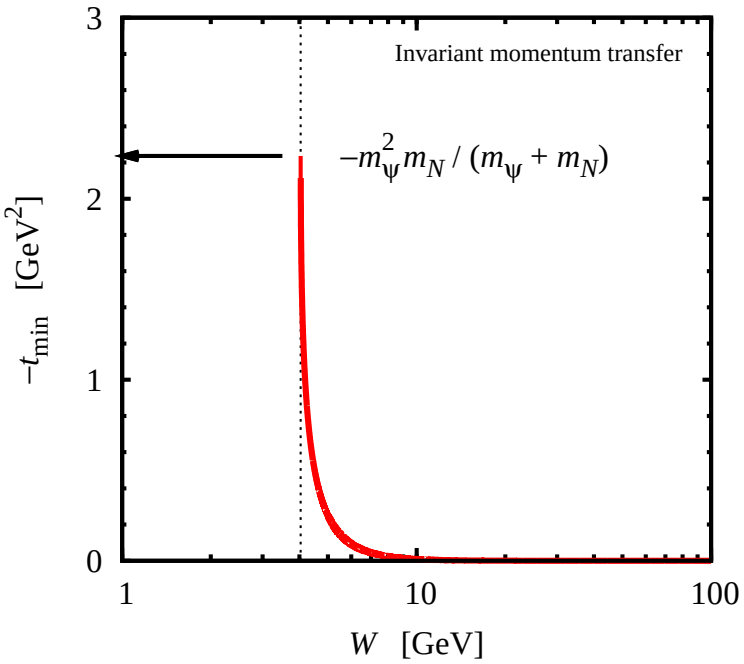
  Hall C backward ω, σ Huber et al.

  CLAS6 backward π^+, π^0 Kubarovsky, Park et al.
- CLAS12 data expected

  New physics — explore mechanism!

Exclusive mesons: J/ψ near threshold





- Near-threshold kinematics

  Large $|t_{\min}| \sim 2.2, \mathrm{GeV}^2$

  Large skewness $\zeta = x_1 - x_2 \sim 0.75$

  Probes high-t gluon GPD/FF

- Theoretical questions

  Factorization in near-threshold regime?

  Behavior of gluonic form factor?
  Correlations in nucleon LC wave function?
  Cf. model of Brodsky, Chudakov, Hoyer, Laget 01

  $J/\psi - p$ bound states
  LHCb Pentaquark

- JLab12 J/ψ experiments

  GlueX, CLAS12 e^+e^-, SOLID electroproduction

  First J/ψ's seen at GlueX!

Exclusive mesons: Strangeness

- Strange vector mesons $\gamma^* N \to K^{*+}\Lambda,\ K^*\Sigma$

  Contribute to understanding of quark-based production mechanism at large x, cf. ρ

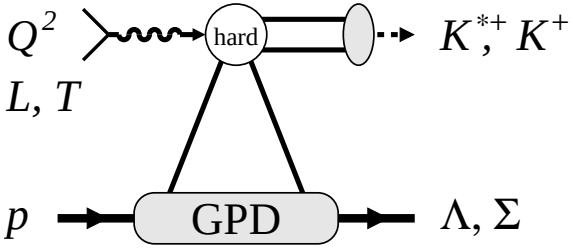
  Spin structure of nucleon transition through N(pol) and Λ(self-analyzing)

- Strange pseudoscalar mesons $\gamma^* N \to K^+\Lambda,\ K^+\Sigma$

  Helicity-flip vs. non-flip mechanism?

  Spin-flavor structure of transversity GPDs

  $SU(3)$ and large-N_c relations



Exclusive mesons: EIC

- Kinematic coverage $Q^2 \sim$ few 10 GeV^2 should allow to reach small-size regime in most meson channels; luminosity $\sim 10^{34}$ cm^{-2} s^{-1} required

- Definitive tests of reaction mechanism: t–slopes, Q^2–scaling

- Probe structures selectively

gluons	$\phi, J/\psi, \Upsilon$
gluons + singlet quarks	ρ^0, ω, γ
non-singlet quarks	ρ^+, K^*
polarized quarks	$\pi^+, \pi^0, \eta, K^+, K_L$

- Explore novel dynamics

  Non-singlets and polarization at small x
  $N \to N^*$ transitions through hard processes
  Quantum fluctuations of gluons and diffractive dissociation

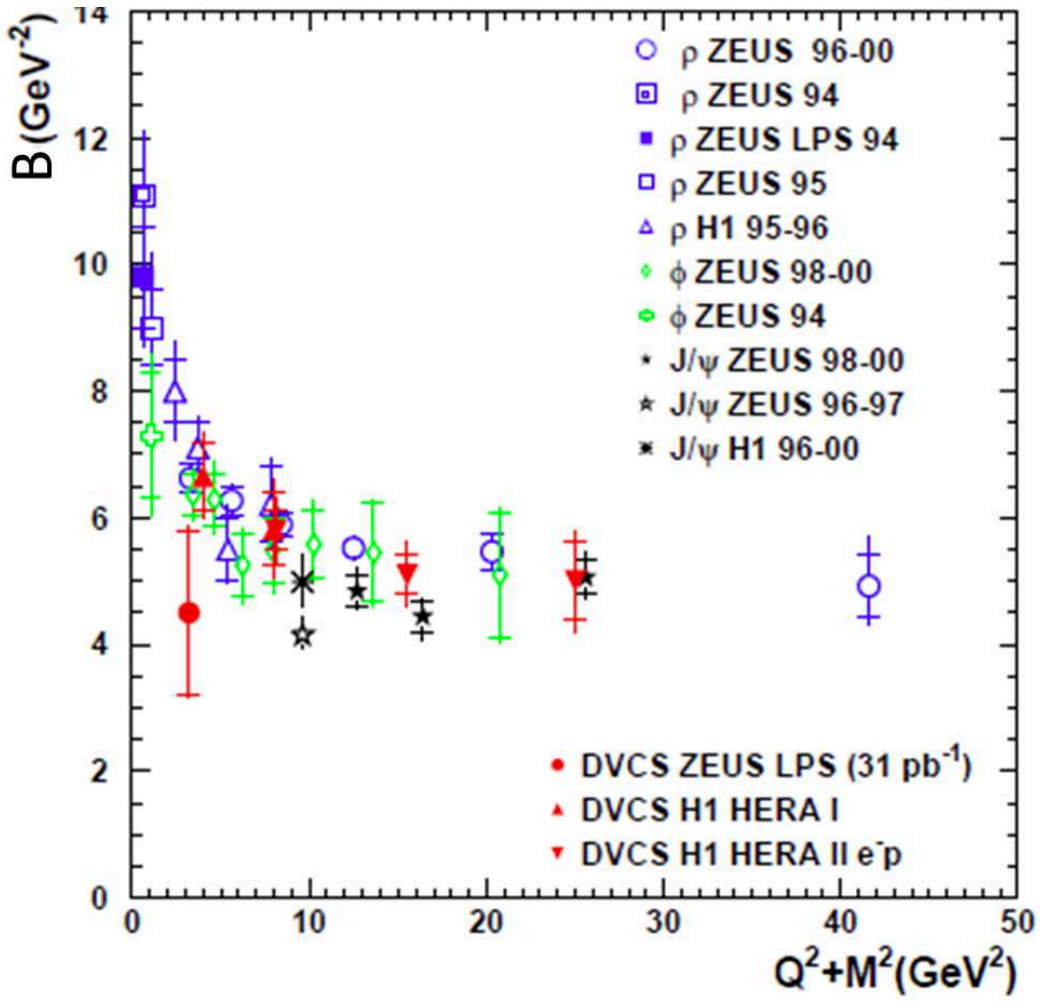
- JLEIC detectors designed for exclusive reactions

Exclusive mesons: Summary

- Unifying framework: Small transverse distances, GPDs
- Access specific structures: Gluonic radius, transversity, ...
- Analysis in two stages: Understand mechanism, extract structures
- Theory work needed: Non-perturbative interactions
- Many open questions: Mechanism of ρ production at large x?
  Potential for real discoveries!
- Looking forward to JLab12 data

Supplementary material

Vector mesons: t-slopes



Summary t-slopes of exclusive vector mesons and DVCS measured at HERA, as function of Q^2