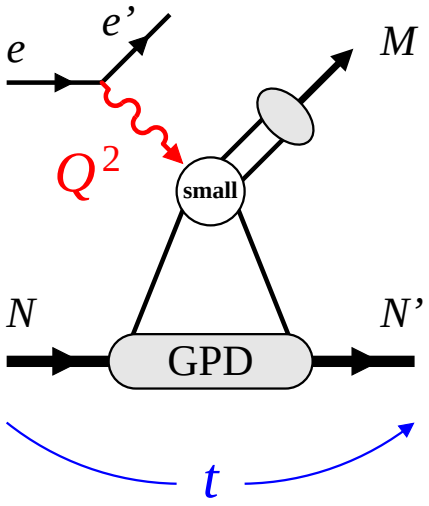
Physics with deeply-virtual meson production

C. Weiss (JLab), CLAS Collaboration Meeting, JLab, 13-Nov-2018



Potential early physics results

This presentation:
— Review context
— Identify physics questions

- High-Q^2 meson production

  Mechanism and structures

  Physics analysis

- CLAS12 experiments

  Pseudoscalar π^0, η: Quark helicity flip, transversity GPDs E12-06-108

  Vector ϕ: Gluonic mechanism, nucleon gluonic radius E12-12-007

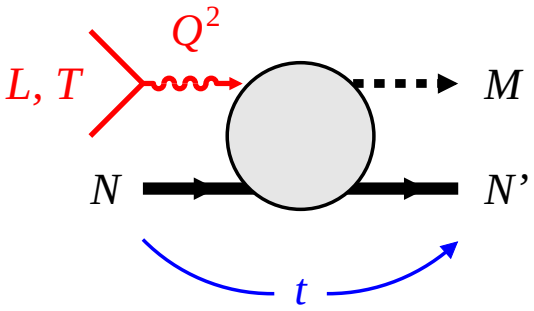
  Heavy J/ψ: Photoproduction near threshold, high-t gluonic form factor E12-12-001

- Connections and extensions

  DVMP in high-energy experiments: COMPASS, LHC ultraperipheral, EIC

  Joint DVCS–DVMP analysis: PARTONS

Exclusive mesons: High Q^2



- Exclusive electroproduction

  Q^2 size of probe, resolution scale

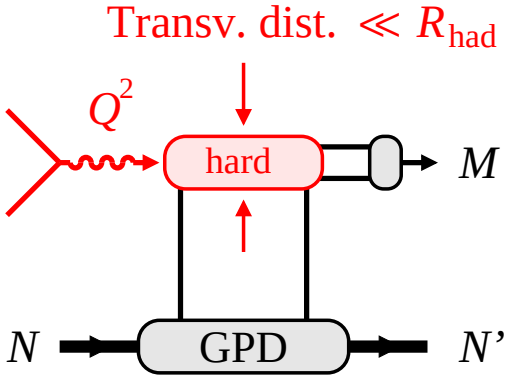
  t size of target configurations

- Transverse distances in interaction $\ll$ hadronic size

  Collinear factorization: GPDs $\times$ hard process $\times$ DA

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

  $Q^2 \sim$ few GeV^2: Finite sizes, $L + T$ responses



- Nucleon structure in GPDs

  Quark/gluon form factors of nucleon

  QCD operator definition $\langle N' | \, \mathcal{O}[\text{QCD}] \, | N \rangle$
  Universal, process–independent $\leftrightarrow$ DVCS, PDFs, FFs
  Non-perturbative methods, Lattice QCD

Exclusive mesons: Physics analysis

I) Explore mechanism and verify approach to small-distance regime

Where does it set in? Quantitative question, not "yes or no!"

Use model-independent criteria: L/T, Q^2-dependence, t-slopes, comparison of channels
Experience with vector mesons at HERA

II) Extract information on GPDs

Mesons select definite structures: Quark $\leftrightarrow$ gluon, spin-flavor

Specific questions can be answered with limited information

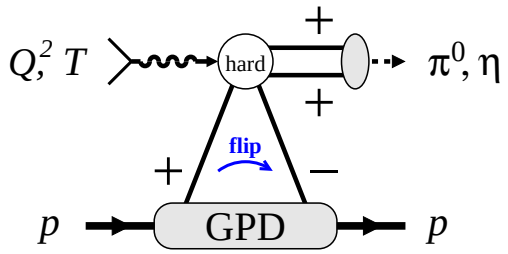
Use QCD-based theoretical description with finite-size effects
Goloskokov, Kroll 08+; Frankfurt, Strikman, Koepf 96

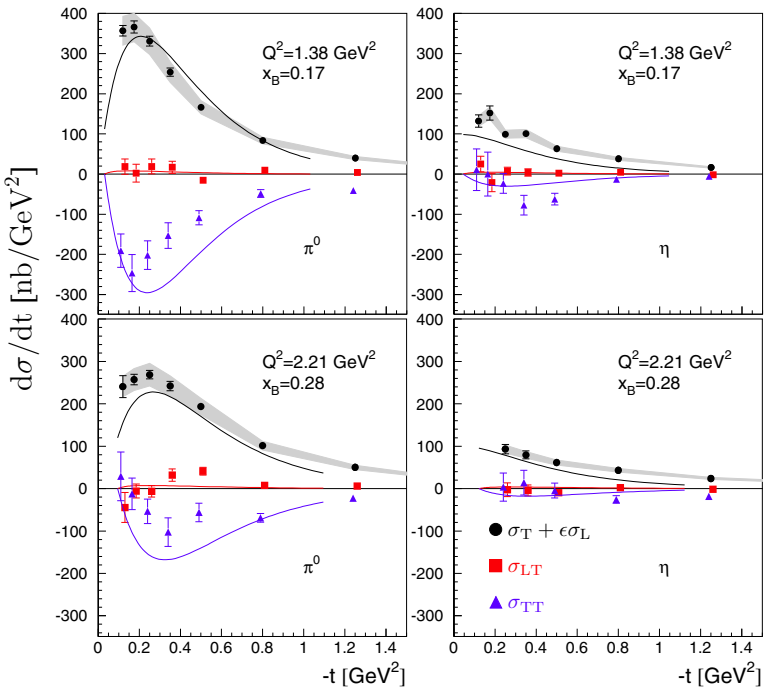
Comments

Interplay of theory and experiment

Theory development needs broad-based studies of reaction mechanism

Pseudoscalars π^0, η: Mechanism





CLAS6 2017 Bedlinskiy et al.

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

  Large helicity-flip pion DA induced by dyn chiral symmetry breaking in QCD

  Helicity-flip GPD $\leftrightarrow$ transversity

  Twist-3 mechanism, formally subleading

- Practical implementation

  Finite size of $q\bar{q}$ through Sudakov FF

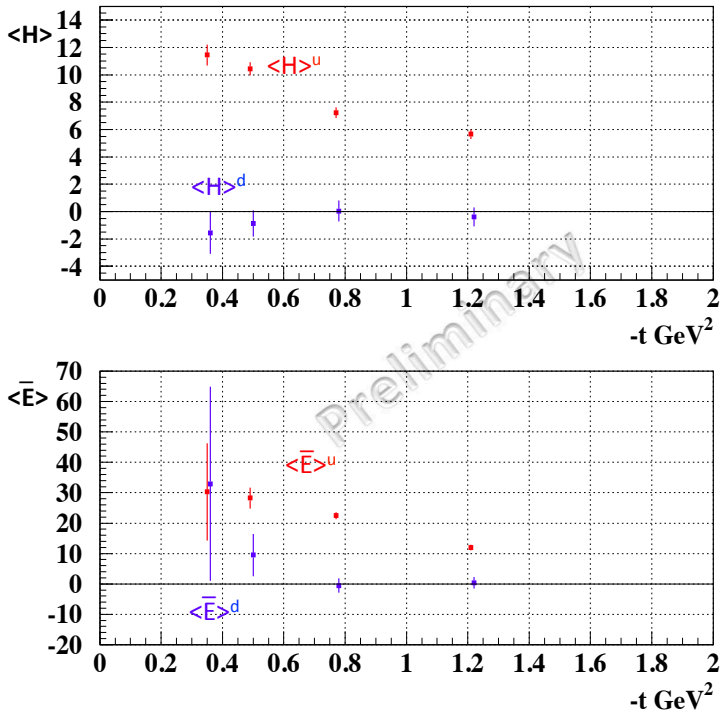
  Transversity GPD models

- Describes JLab 6 GeV data

  L vs. T from response functions

  Absolute cross sections

Pseudoscalars π^0, η: Quark transversity GPDs



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, Weiss 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

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

Invariant amplitude, cf. Compton form factors

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

Pseudoscalars π^0, η: 12 GeV physics analysis

Reaction mechanism

- L/T ratio order-of-magnitude and Q^2-dependence
  Pattern of L and T responses from ϕ-harmonics
  Expect $L \ll T$. Can we demonstrate $|L| > 0$ at high Q^2?
  No Rosenbluth separation needed

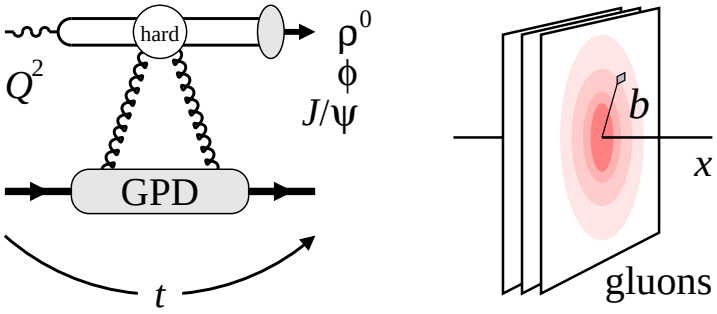
- t–dependence and change with Q^2
  Direct evidence of transverse distances in production process
  t-distribution at fixed ξ should become independent of Q^2 in small-distance regime
  Not just "t-slope". Need to include $t - t_{\min}$ factors from helicity flip
  No absolute cross secn measurements required!

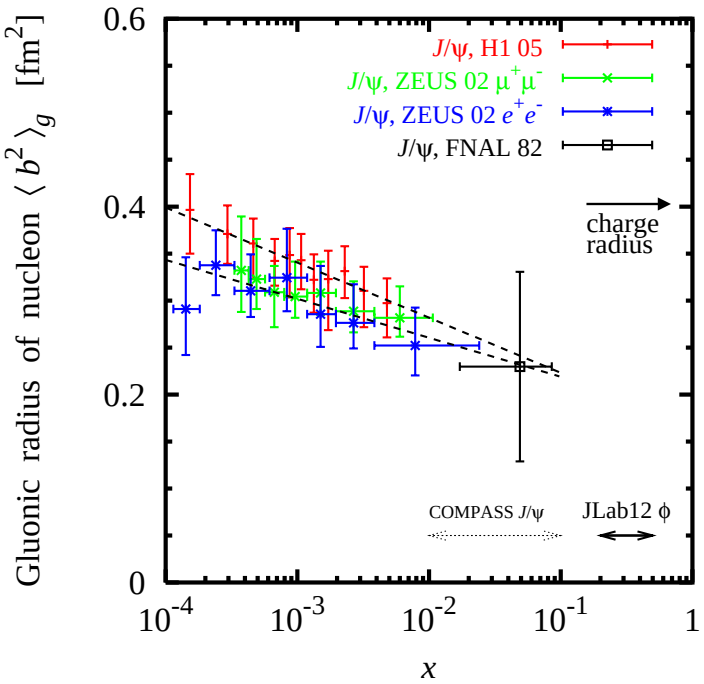
Transversity GPDs

- Transverse images of transversely polarized quarks at $\langle x \rangle \sim$ 0.2-0.5
  Use GK model to relate $\xi \neq 0$ to $\xi = 0$

- Flavor separation using π^0 and η
  Same method as in 6 GeV analysis

Vector mesons: 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 $\rho^0, \phi, J/\psi, \gamma$

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

- Transverse spatial distribution of gluons

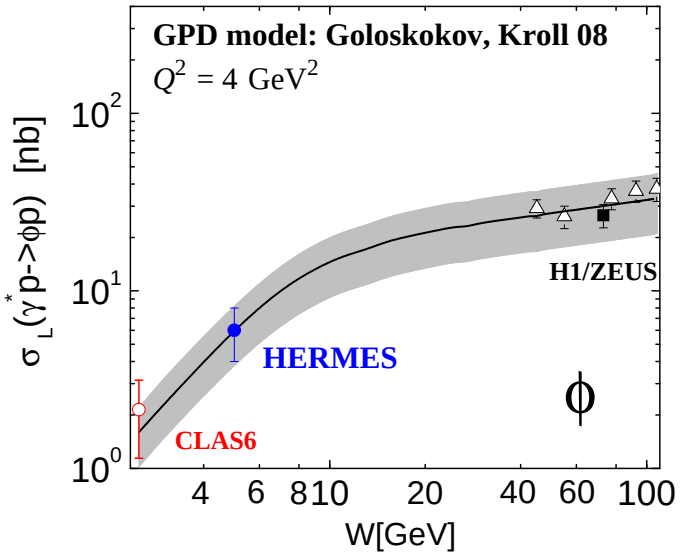
  2D Fourier of t-dependence of gluon GPD

  Fundamental gluonic radius, cf. charge radii
  Leading-twist characteristic: LQCD, models

  Changes with x: Chiral dynamics, diffusion

  $x < 0.01$ from HERA, FNAL; $x > 0.1$ unknown

Vector mesons: ϕ at large x

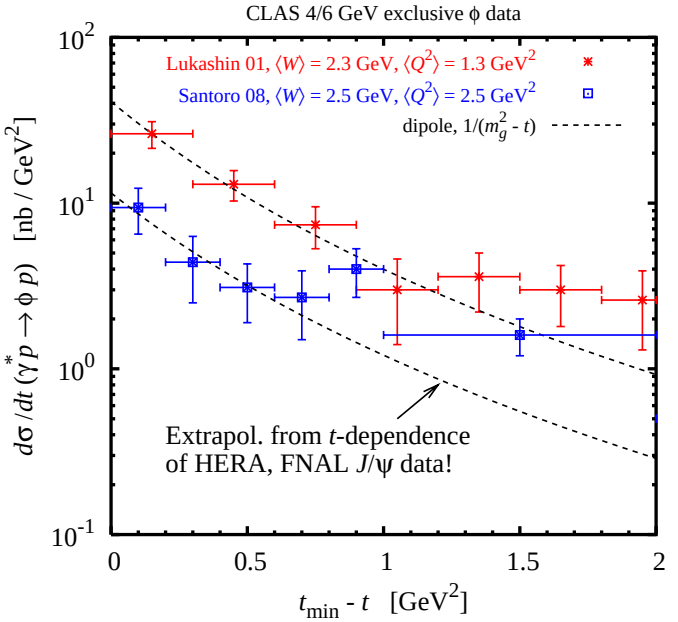


- ϕ appears gluon-dominated at $x > 0.1$

  No change in W-dependence ($\leftrightarrow \rho^0$)

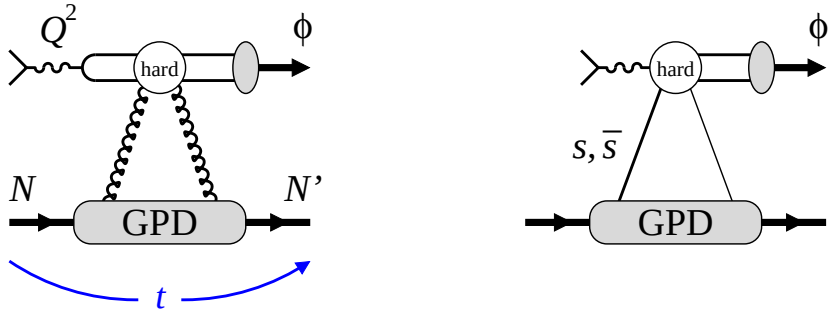
  Gluon GPD model reproduces cross sections
  Goloskokov, Kroll 08+

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

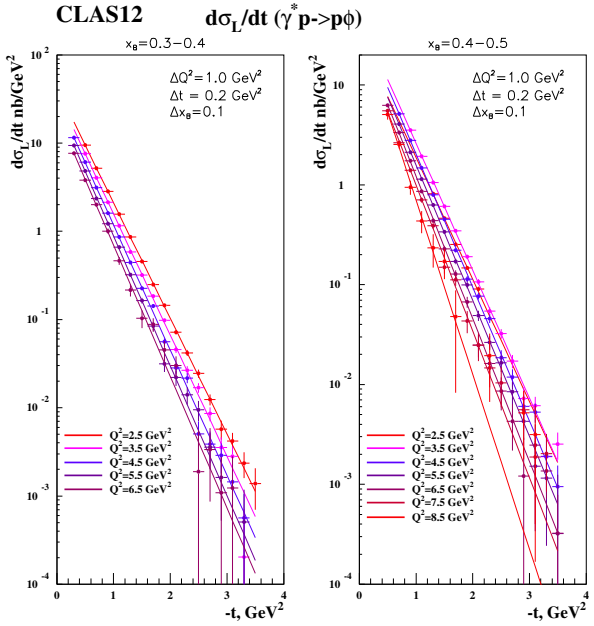


- Strange quark contributions?

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



Vector mesons: ϕ 12 GeV physics analysis



Reaction mechanism

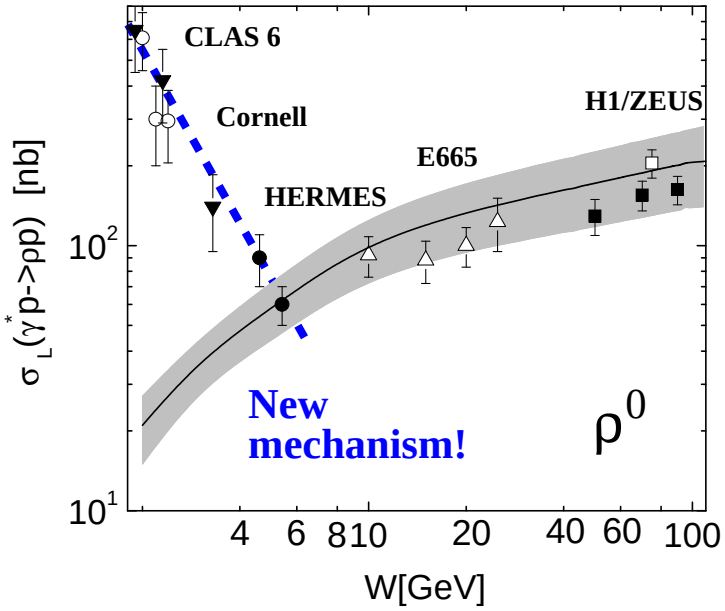
- When does t-slope become independent of Q^2?
- How does ξ-dependence change with Q^2?
- L/T ratio from SCHC, Q^2 dependence

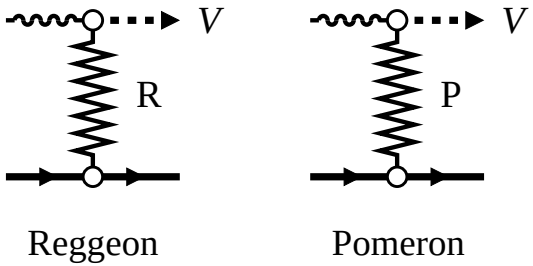
Gluon GPD and nucleon radius

- t-dependence of gluon GPD at $x = 0.2 - 0.5$
  From relative t-dependence of $d\sigma_L/dt$
  Use L/T from SCHC. No absolute cross secn required!

- Nucleon gluonic radius in valence region
  Extend HERA/FNAL results to large x
  Large density of valence-like gluons at $x > 0.2$

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?

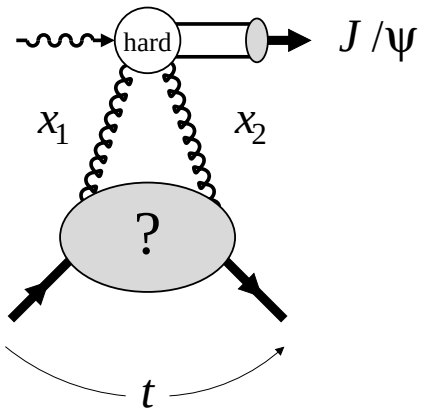
  Soft regime: Reggeon vs. Pomeron

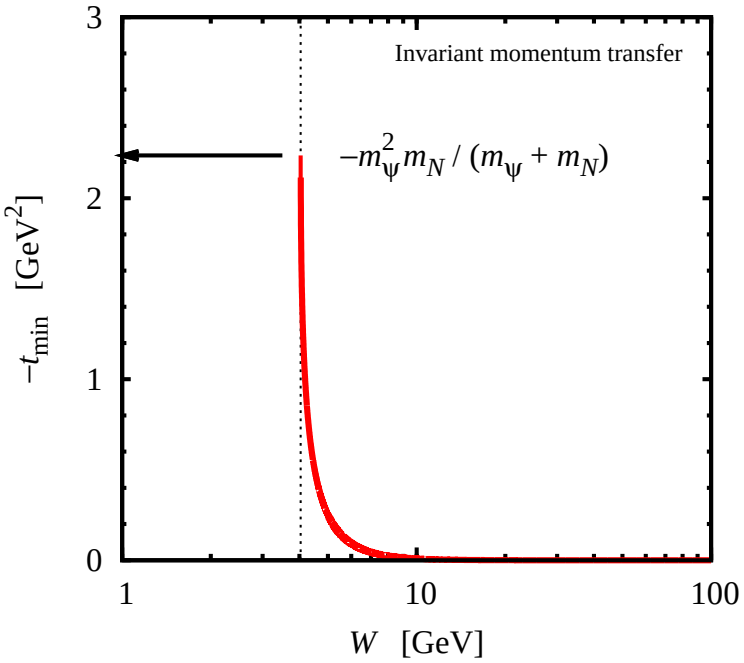
  Hard regime: GPD description?

  Guidal, Morrow 07: Rescaled D-term not realistic.
  Kroll, Goloskokov 14: Transversity GPDs in ρ spin density.
  To be tested with COMPASS data.

  CLAS12 data could have major impact!

Heavy J/ψ: Near-threshold production





- Near-threshold kinematics

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

  Large longitud. mom. transfer $\zeta \sim 0.75$

- Near-threshold production mechanism

  pQCD hard scattering mechanism
  Brodsky, Chudakov, Hoyer, Laget 01

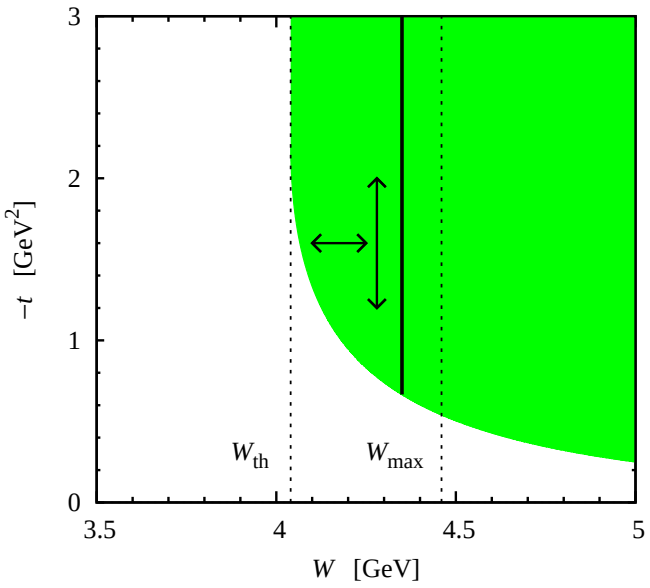
  GPD-like production mechanism
  with large skewness $\zeta = x_2 - x_1$
  Frankfurt, Strikman 02

  Pointlike production mechanism,
  operator related to QCD EM tensor
  Kharzeev et al. 99; Hatta, Yang 18

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

- JLab12: GlueX, CLAS12 e^+e^-, SOLID
  First J/ψ's seen at GlueX!

Heavy J/ψ: 12 GeV physics analysis



- "Locality" of production mechanism implies that W-dependence is generated by $t_{\rm min}$
  Frankfurt, Strikman 02

$$\frac{d\sigma}{dt}(W,t) \;=\; [\text{kin}] \;\times\; |F(t)|^2 \qquad \text{gluonic form fct}$$

$$\frac{d\sigma}{dt}(W,t_{\rm min}) \;\propto\; |F(t_{\rm min}(W))|^2 \qquad W\text{-dependence generated by } t_{\rm min}$$

- Test "locality" with JLab12 data

1) Measure $F(t)$ at highest available W, by varying t via Δ_T^2

2) Verify that measured $F(t_{\rm min}(W))$ describes W dependence near threshold

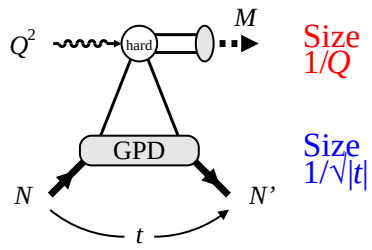
Model-independent. Can be done with limited statistics.
No absloute cross section measurements required, only t- and W-dependence

Exclusive mesons: Other kinematics, channels

- Wide-angle meson production — large t, u

  Nucleon in small-size configuration

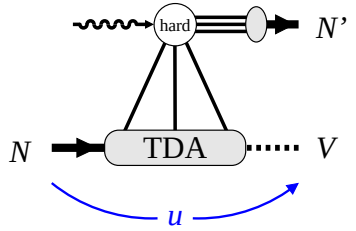
  QCD descriptions: hard pQCD, soft handbag, unified SCET
  Brodsky, Lepage 80's. Kroll et al. Kivel, Vanderhaeghen



- Backward meson production — large t, small u

  Knockout of small-size qqq configuration

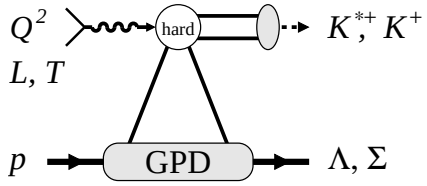
  QCD description: Transition DAs $\langle M|qqq|N\rangle$
  Frankfurt et al. 02; Pire, Szymanowski et al. 10+



- Strange meson production — large Q^2

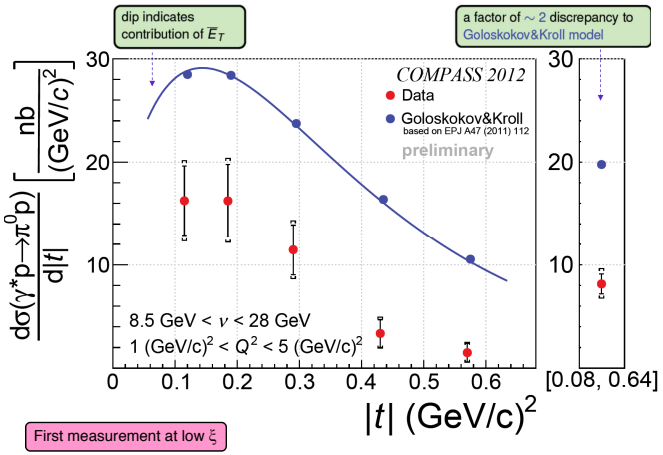
  Pseudoscalar $\gamma^* N \to K^+\Lambda,\ K^+\Sigma$:
  Helicity-flip mechanism? SU(3) transversity GPDs

  Vector $\gamma^* N \to K^{*+}\Lambda,\ K^*\Sigma$:
  Production mechanism? Spin structure $N \to \Lambda$?

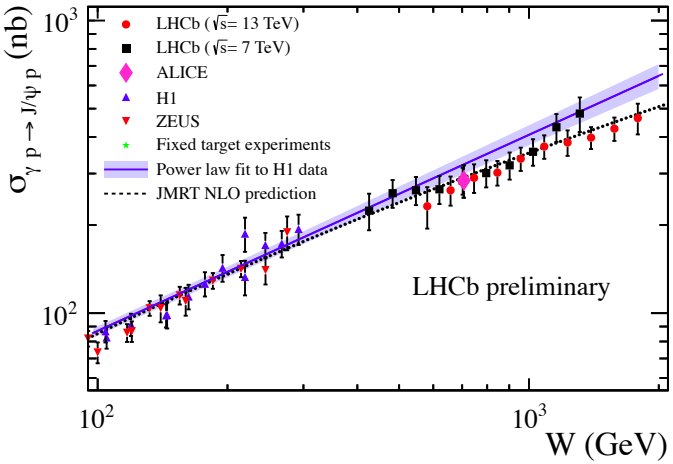


All accessible with CLAS12 — potential impact!

Exclusive mesons: Higher energies



COMPASS preliminary: A. Sandacz, CFNS Workshop "Next-generation GPD studies," June 2018



- DVMP program at COMPASS

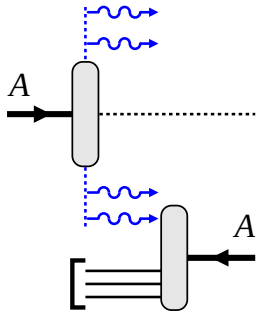
  ρ^0, ω on transversely polarized proton,
  ω spin density matrix elements

  π^0 on unpolarized proton:
  First high-energy measurement ←**NEW**

- Heavy quarkonium photoproduction at LHC

  Ultraperipheral AA/pA collisions:
  Weizsäcker-Williams photons

  Highest-ever energies in EM processes:
  $W \sim 10^3$ GeV $= 10\times$ HERA



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

- Establish reaction mechanism definitively: t-slopes, Q^2-scaling, universality

- Probe structures selectively

gluons	ϕ, J/ψ, Υ
gluons + singlet quarks	ρ^0, ω, γ
non-singlet quarks	ρ^+, K^*
polarized quarks	π^+, π^0, η, 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

- Detector design & simulations ongoing

- Topical workshops, great interest

  Next-gen GPD studies with exclusive meson production at EIC, CFNS Stony Brook, 4-6 June 2018 [Webpage]
  INT-18-3 Week 1 Generalized Parton Distributions, 1-5 Oct 2018 [Webpage]
  Meson production simulations & impact studies, NCBJ Warsaw, 22-25 Jan 2019

Exclusive mesons: Summary

- Unifying framework for DVMP processes: Small transverse distances, GPDs

- Potential early physics from approved DVMP experiments

π^0, η	helicity-flip mechanism, transversity GPDs
ϕ	gluon dominance, nucleon's gluonic radius
$J\psi$	test of locality of near-threshold production

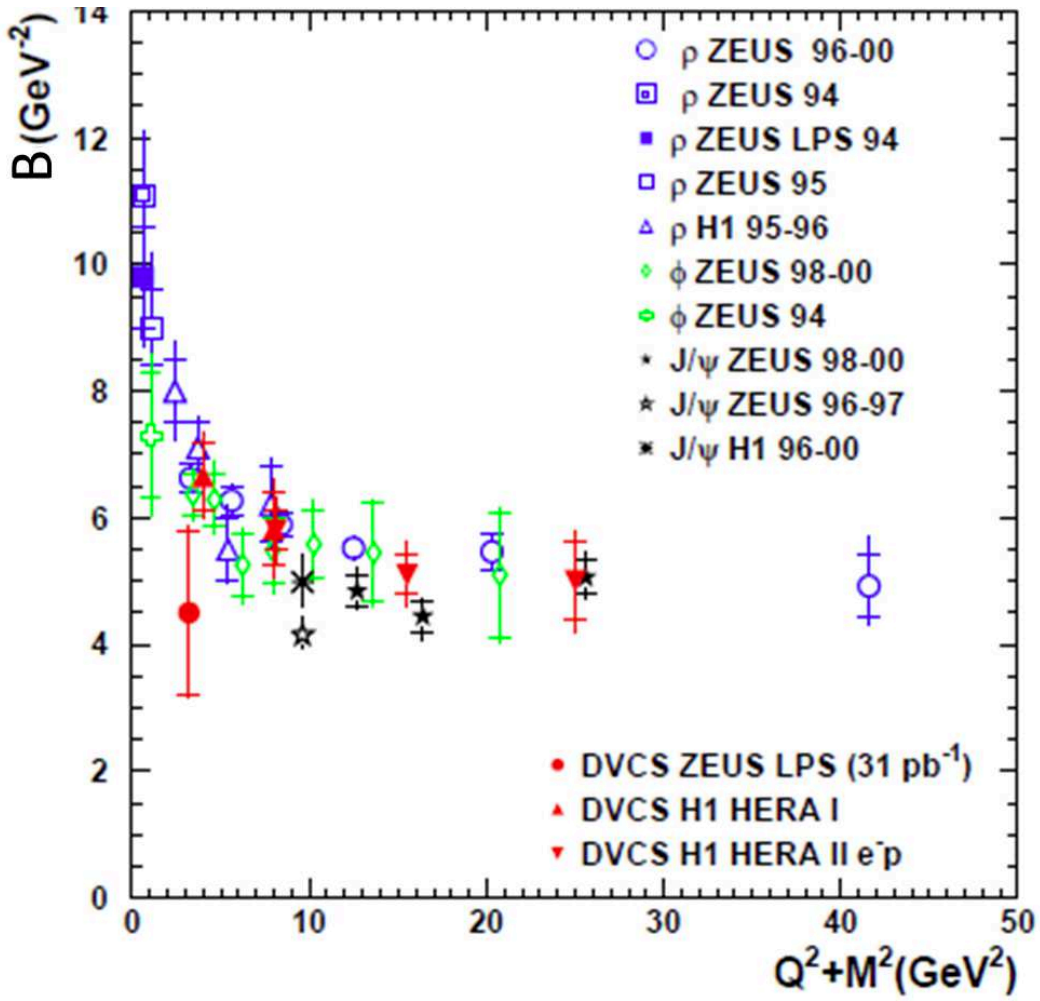
- Experimental tests of reaction mechanism essential for theory development, should be considered important objectives in their own right

Related development

- DVMP processes to be included in PARTONS software for future joint DVMP-DVCS analysis and GPD extraction
  Moutarde, Sznajder, Wagner; in collaboration with JLab

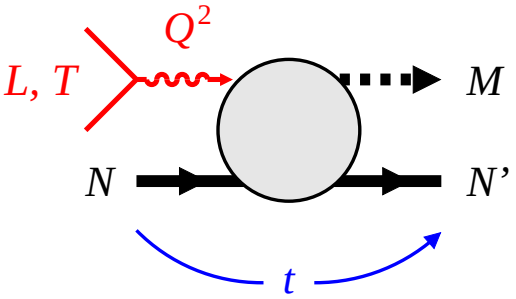
Supplementary material

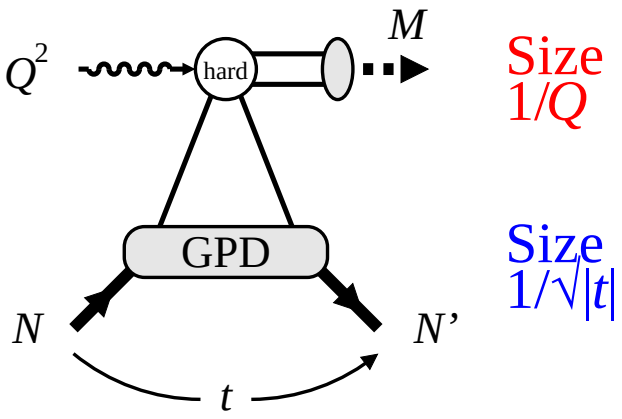
Vector mesons: t-slopes



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

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

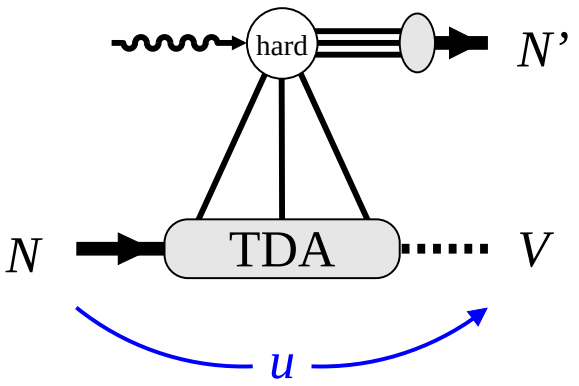
- JLab12: Explore mechanism

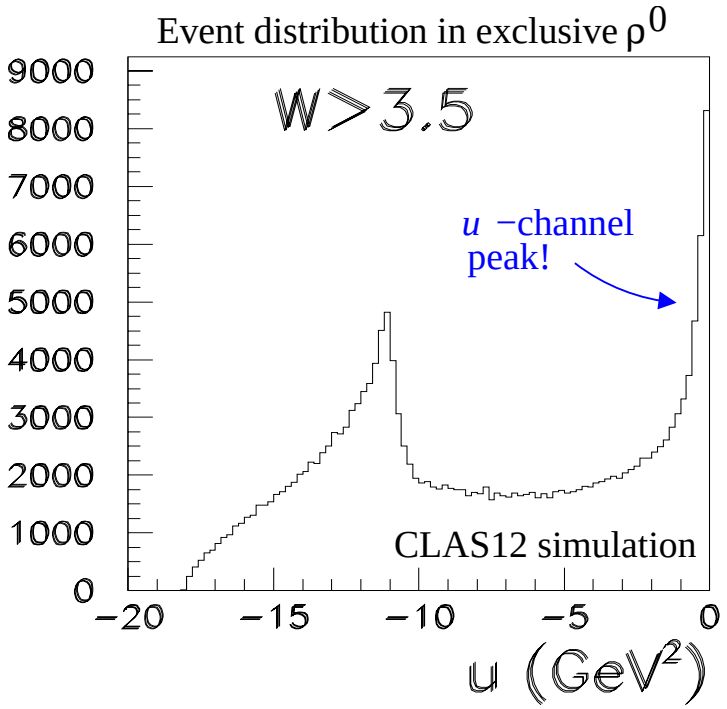
  Extend t-range

  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: 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