

Exclusive meson production and short-range hadron structure

Topical Workshop, Jefferson Lab, 22-24 Jan 2015 

F.X. Girod, T. Horn, Ch. Hyde, V. Kubarovsky, P. Stoler, C. Weiss

- Welcome

JLab 12 GeV operations just starting . . .

- Physics perspective

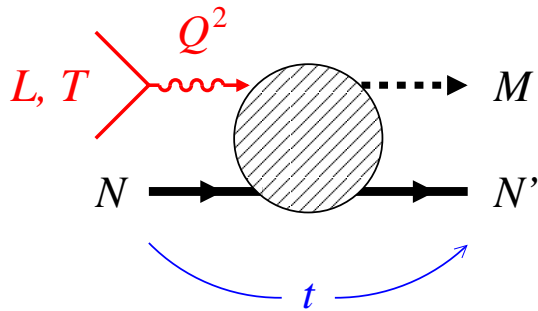
Unifying framework: Small-size configurations, GPDs

Specific structures: Transversity, gluons, . . .

- Plan of meeting

Exclusive mesons: High Q^2

2



- Exclusive electroproduction

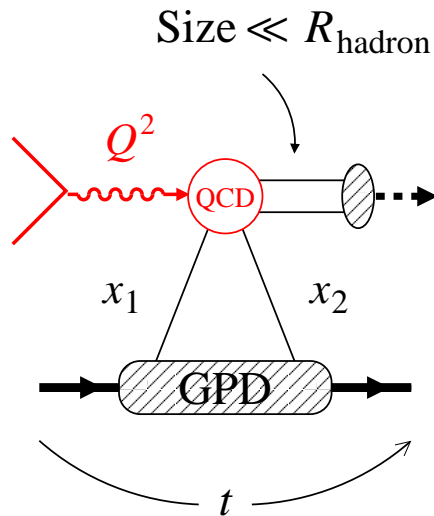
Q^2 size of probe, resolution scale

t size of target configurations

- $Q^2 \gg R_{\text{had}}^{-2}$ Meson produced in small-size configuration

$Q^2 \rightarrow \infty$: $q\bar{q}$ pointlike, pQCD interactions
QCD factorization theorem σ_L

Collins, Frankfurt, Strikman 96



$Q^2 \sim \text{few GeV}^2$: $q\bar{q}$ has small size, non-perturbative interactions possible

Recent progress \rightarrow Talk Kroll

Nucleon structure in GPDs:

Quark/gluon form factors

universal, process-independent

\rightarrow DVCS, other processes

\rightarrow Sum rules, charges

\rightarrow Non-perturbative methods, Lattice QCD

- How to observe/quantify approach to small-size regime?

Model-independent criteria!

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

- What interactions mediate transition?

How to account for finite-size effects?

Non-perturbative forces, chiral symmetry breaking?

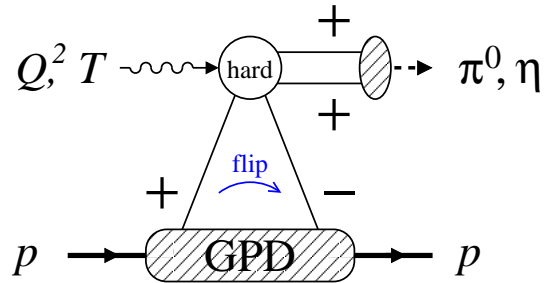
- What structures are probed?

GPDs: Spin/flavor structure, quarks vs. gluons, dynamical scales

Meson distribution amplitudes: Chirality, higher twist

... **Great progress in last 5 years!**

Exclusive π^0, η : Transversity



- Quark helicity flip in pion WF

Chiral symmetry breaking in QCD

Dominates σ_T at $W \sim$ few GeV

→ Liuti, Goldstein, Kroll

- Quark transversity GPDs

Cf. SIDIS, Drell–Yan

Tensor charge: LQCD → Richards

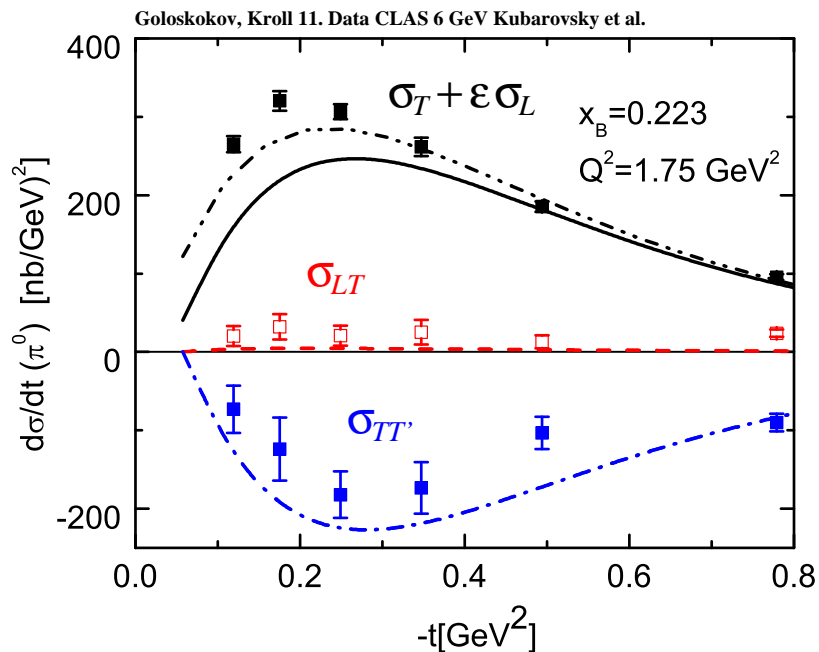
Dynamical models → Schweitzer, Lorce

- Exclusive π^0, η experiments

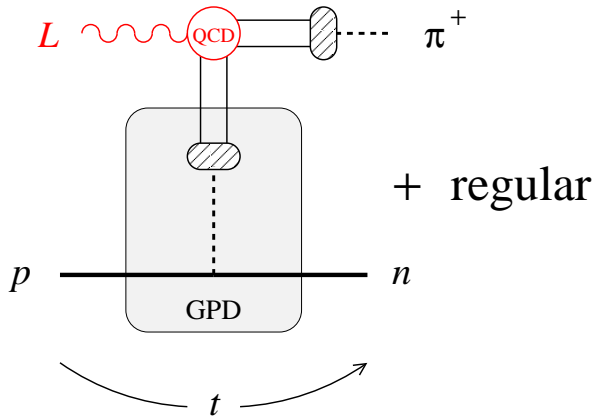
JLab 6 GeV data: CLAS, Hall A

JLab12 experiments → Kubarovsky, Kim

Higher energies: HERMES, COMPASS? → D'Hose



Exclusive π^+ : Pion form factor



- Pion pole in pseudoscalar GPD

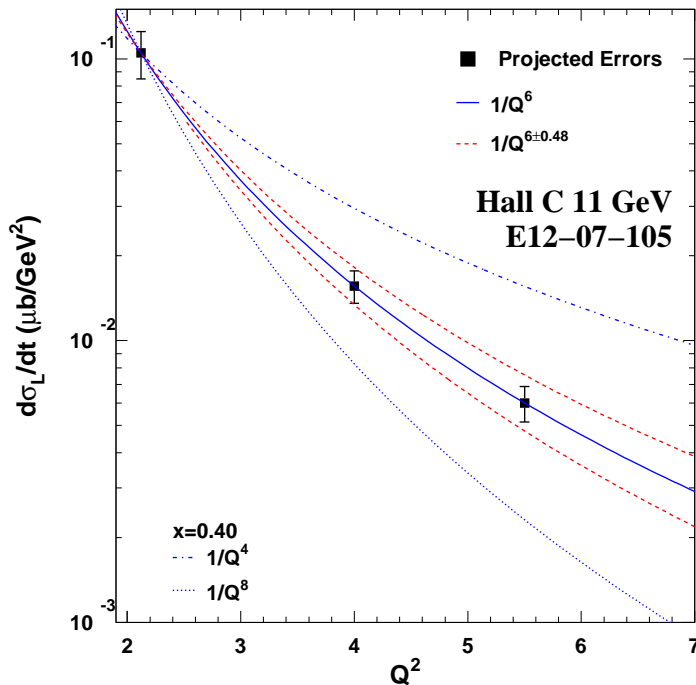
Interplay hadronic exchange mechanism \leftrightarrow GPD

Mostly L amplitude

Separate pole and non-pole?

Models: Vanderhaeghen et al. 97+, Gallmeister et al. 08+

Model-independent approach?



- Pion form factor

- JLab 6/12 GeV experiments

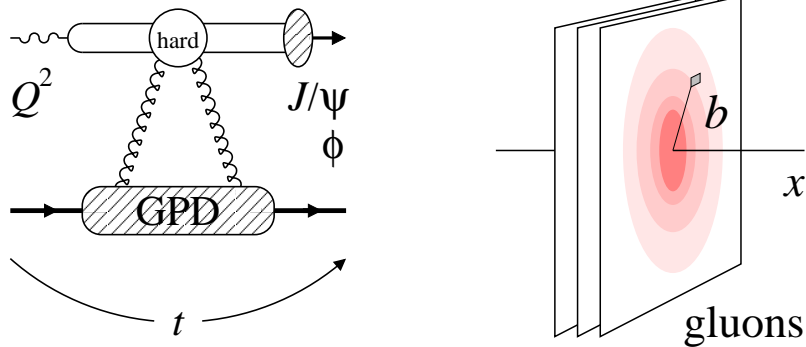
Production mechanism:

L/T from response functions

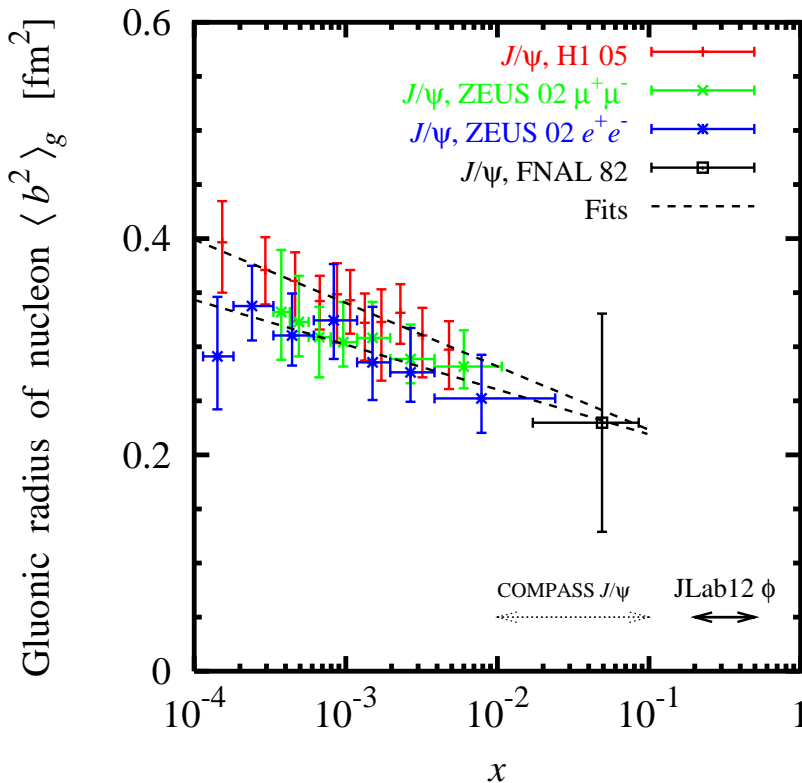
Rosenbluth separation? \rightarrow Gaskell

Pion form factor \rightarrow Horn

Exclusive ϕ , J/ψ : Gluonic size of nucleon



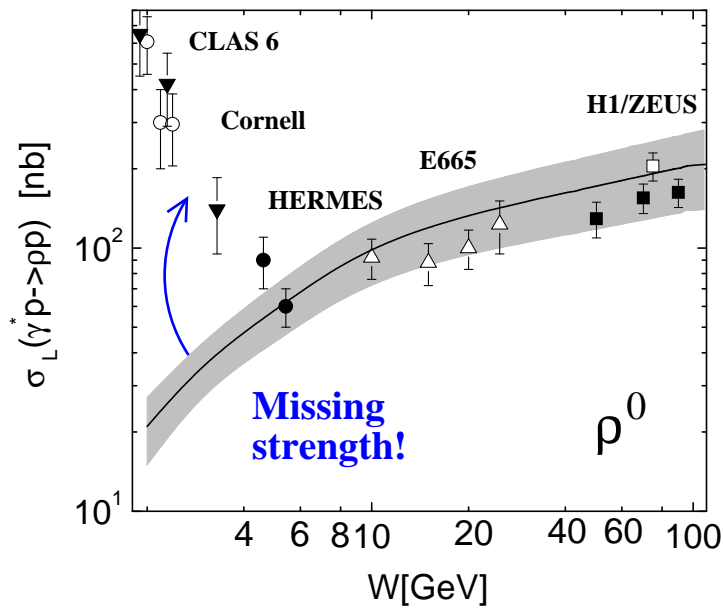
- J/ψ , ϕ probe gluon GPD
 - $x < 10^{-1}$ HERA, COMPASS, EIC
 - $x > 0.2$ JLab12 $\phi \rightarrow$ Girod



- Gluonic size of nucleon
 - Increases with $x \rightarrow 0$
 - Large- x gluons more central than valence quarks
 - Input for pp@LHC, saturation
- Intrinsic strangeness in ϕ ?
 - Hints from SIDIS HERMES

Exclusive ρ^0, ρ^+, ω at low W : Quark GPDs

7



- Exclusive VM at $W = 2-4$ GeV must come from quark GPDs

$\rho^+ > \rho^0$ cf. u -quark dominance
 CLAS 6 Morrow et al. 08, Fradi et al. 10. → Talk Guidal

- Missing strength in present GPD models

Goloskokov, Kroll 08; Vanderhaegen, Guichon, Guidal 99

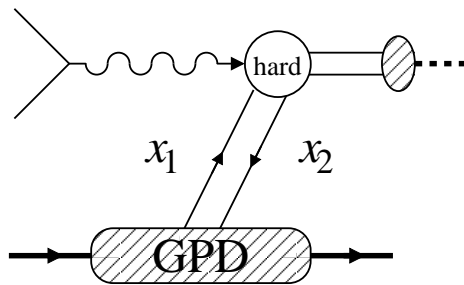
- Correlated $q\bar{q}$ pairs in nucleon?

Guidal, Morrow 08

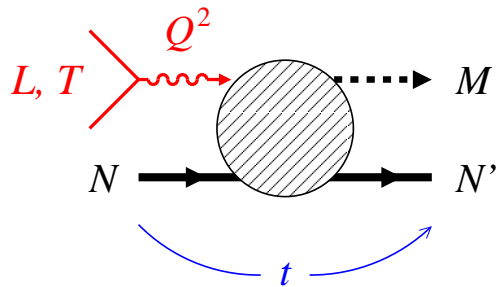
Small-size $q\bar{q}$ pairs from dynamical chiral symmetry breaking in QCD

Schweitzer, Strikman, CW 13

Chirally odd: Quark helicity-flip



- Great potential for JLab12!



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

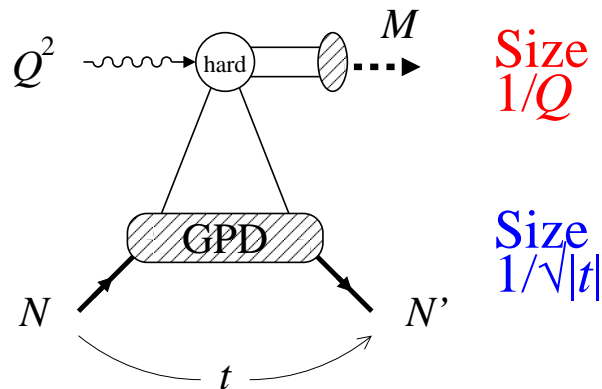
Cf. high- t elastic nucleon form factors

- QCD-based description

Likely single-quark dominance,
handbag graph [Kroll et al.](#)

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

Hadron-induced processes \rightarrow [Talk Strikman](#)
SCET approach [Kivel, Vanderhaeghen](#)



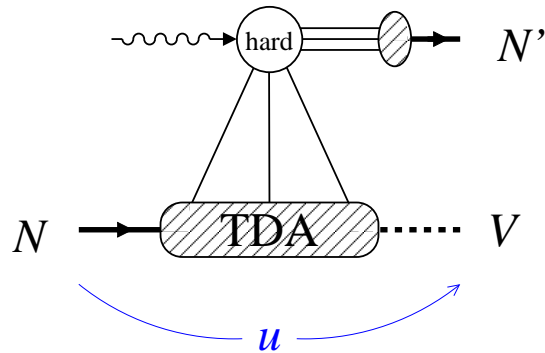
- JLab experiments

6 GeV π^+, π^0 data \rightarrow [Talk Amaryan](#)

12 GeV can reach high $|t|$ and high Q^2 ,
test reaction mechanism

Exclusive mesons: Backward angles

9

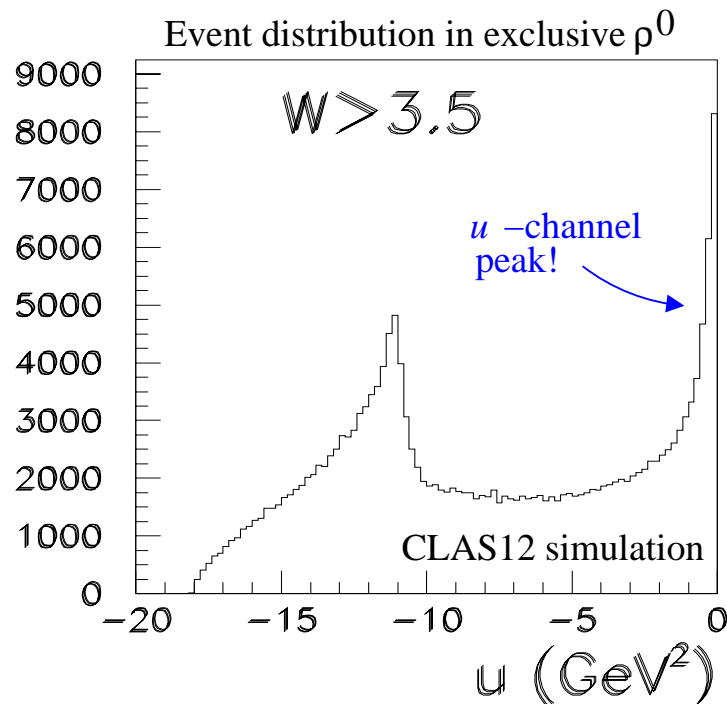


- Large $|t|$, small $|u| < 1 \text{ GeV}^2$
- Knockout of small-size nucleon configuration, mesonic system left

New probe of valence quark core

pQCD-based description through transition DA $\langle M|qqq|N\rangle$

Frankfurt et al. 02; Pire et al. 10+ → Semenov-Tian-Shansky



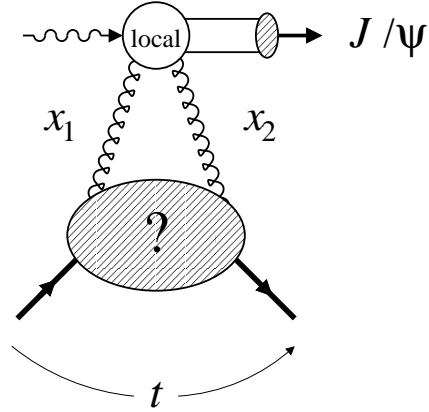
- JLab experiments

Hall C backward $\omega, \sigma \rightarrow$ Huber

CLAS 6 backward $\pi^+, \pi^0 \rightarrow$ Kubarovsky, Park

Should be extended to 12 GeV!

Exclusive J/ψ near threshold: High- t gluon FF



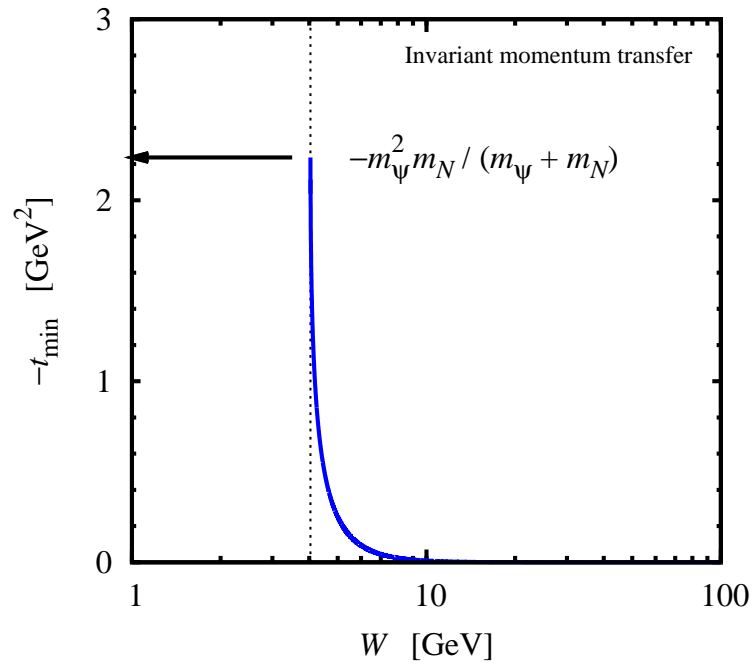
- Near-threshold kinematics
 - Large $|t_{\min}|$, up to 2.2 GeV^2
 - Large skewness $x_1 - x_2 \sim 0.7$

- J/ψ near threshold probes high- t gluon form factor

Strikman, CW, in preparation \rightarrow Talk Weiss

pQCD hard scattering calculation

Brodsky et al. 01



- JLab12 experiments

CLAS12 photoproduction e^+e^-

SOLID electroproduction

Summary

- Unifying framework: Small-size configurations, GPDs
- Specific nucleon structures: Transversity, gluonic size, ...
- Theory progress: Finite-size effects, chirally-odd structures
- Many open questions: Mechanism of light VM production?
Potential for real discoveries!
- Future experiments: JLab 12 GeV, COMPASS, EIC