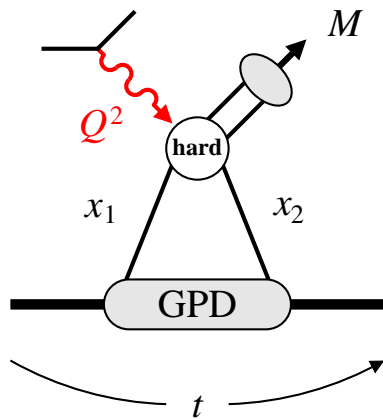


# Hard exclusive meson production and GPDs

C. Weiss (JLab), 3D Nucleon Tomography Workshop, JLab, 15-17 Mar 2017



- Mechanism of high- $Q^2$  meson production

Small-size regime, GPD-based description

- JLab12 meson production experiments

$\phi$ : Nucleon gluonic radius

CLAS12

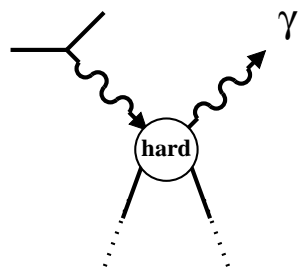
$\pi^0, \eta$ : Helicity-flip GPDs, transversity

CLAS12, Hall A

$J/\psi$  near threshold: High- $t$  gluonic FF

GlueX, CLAS12, SOLID

Hall C  $\pi^+/K^+ \rightarrow$  Talk T. Horn



- EIC meson production program

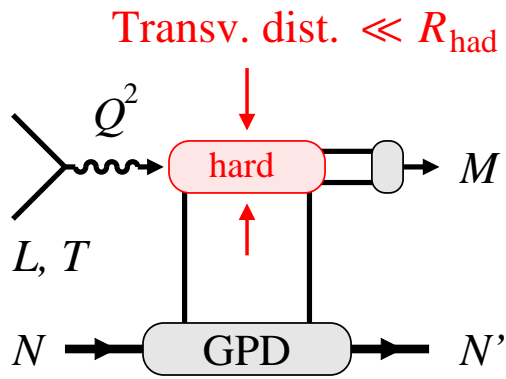
- Discussion

Complementarity and synergies with DVCS

Meson production in nucleon tomography

# Meson production at high $Q^2$

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- Transverse distances in interaction  $\ll$  hadronic size

Collinear factorization: GPDs  $\times$  hard process  $\times$  DA  
[Collins, Frankfurt, Strikman 96](#)

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

$Q^2 \sim \text{few GeV}^2$ : Finite size distribution

- Finite-size effects described theoretically

Space-time picture with finite dipole size

[Frankfurt, Strikman, Koepf 96+](#)

Sudakov suppression of large-size configurations

[Musatov, Radyushkin 97; Goloskokov, Kroll 08+](#)

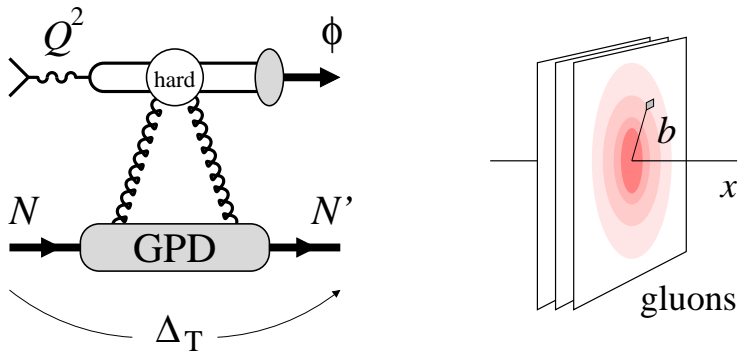
New approaches: SCET, virtuality distributions?

[Radyushkin 15](#)

- Analysis in two stages

I) Verify approach to small-size regime:  $Q^2$ -dependence,  $t$ -slopes, comparison of channels

II) Extract information on nucleon structure: GPD integrals,  $t$ -distribution



- Exclusive  $\phi$  probes gluon GPD

Small-size regime established at HERA  
 $\phi$ - $J/\psi$  comparison, universal  $t$ -slope  $Q^2 \sim 10 \text{ GeV}^2$

GPD calculation describes absolute cross section from HERA to JLab energies [Goloskokov, Kroll 08+](#)

$L/T$  from  $\phi$  decay + SCHC

- Transverse spatial distribution of gluons

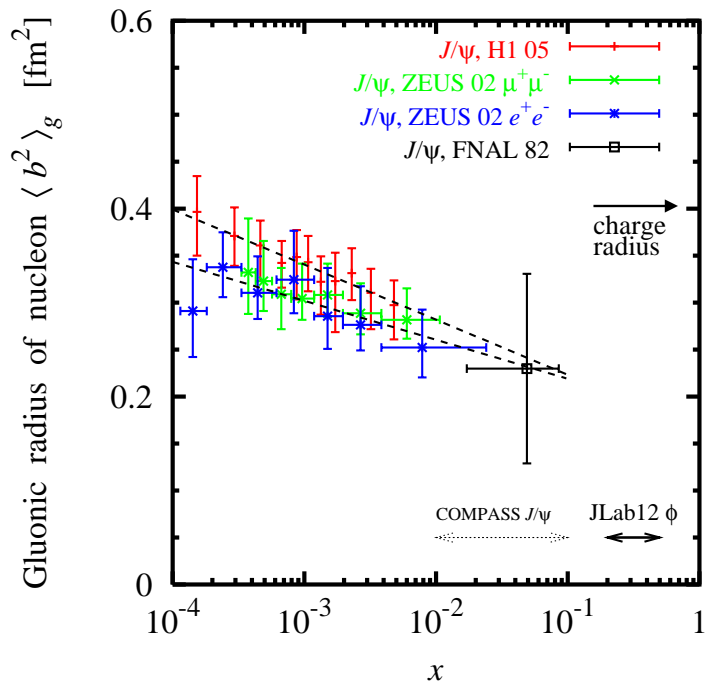
Fundamental gluonic radius, cf. charge radii

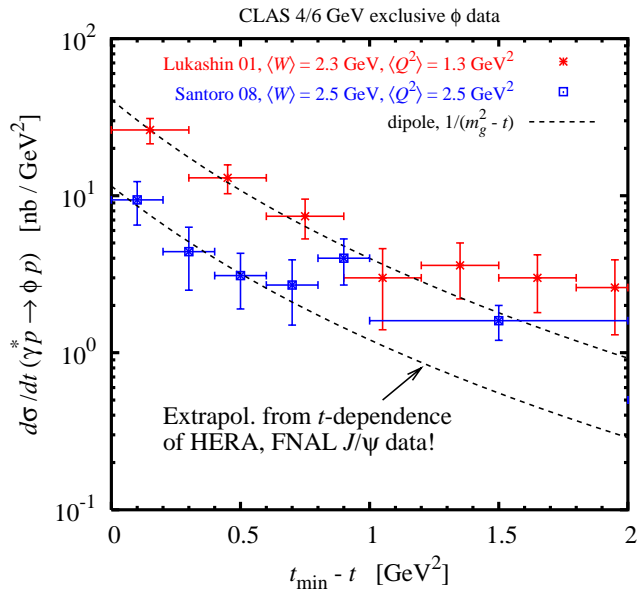
Leading-twist characteristic: LQCD, models

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

Changes with  $x$ : Chiral dynamics, diffusion

DIS: Large gluon density above  $x > 0.1$





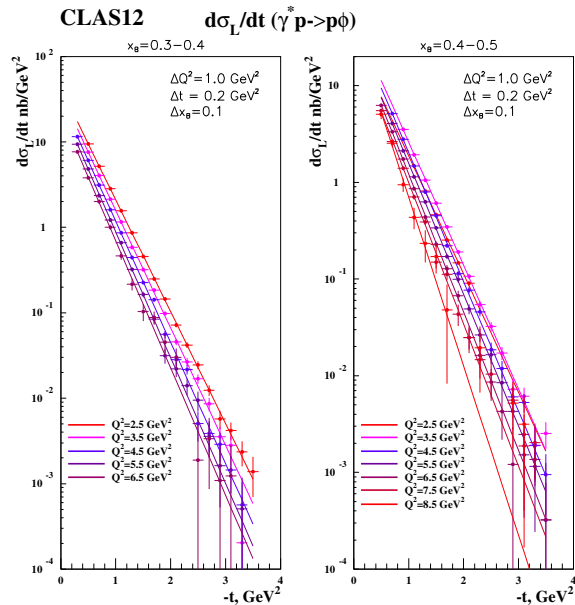
- $t$ -dependence of 6 GeV  $\phi$  data consistent with gluonic radius measured at high energies

Extrapolation of HERA, FNAL  $J/\psi$  results

- JLab12: Test reaction mechanism and GPD-based description CLAS12 E12-12-007

When does  $t$ -slope become independent of  $Q^2$ ?

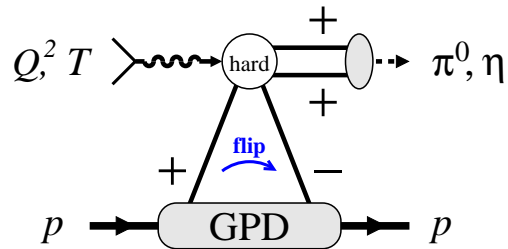
How does  $\xi$ -dependence change with  $Q^2$ ?



- JLab12: Extract  $t$ -dependence of gluon GPD and transverse profile at  $x = 0.2 - 0.5$

Obtained from relative  $t$ -dependence of  $d\sigma_L/dt$

- Theory: Dynamical models of large- $x$  gluons  
 Constituent quarks  $\leftrightarrow$  chiral symmetry breaking?



- Exclusive  $\pi^0, \eta$  probe helicity-flip GPD  
Goldstein Liuti 08, Goloskokov, Kroll 11

Large helicity-flip pion DA induced by dynamical  $\chi$ SB in QCD

Twist-3 mechanism

- Describes JLab 6 GeV data

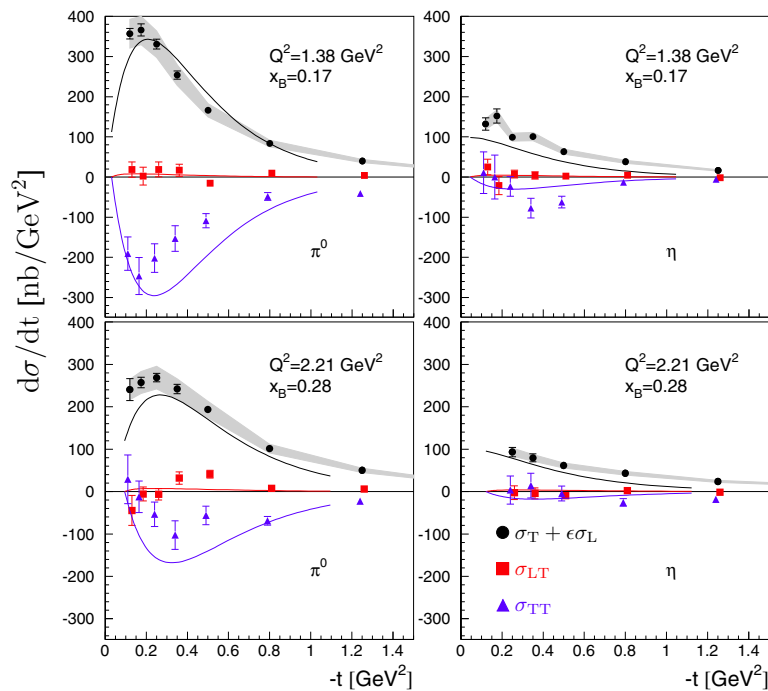
Absolute cross sections

$L$  vs.  $T$  from response functions

- Access to quark transversity

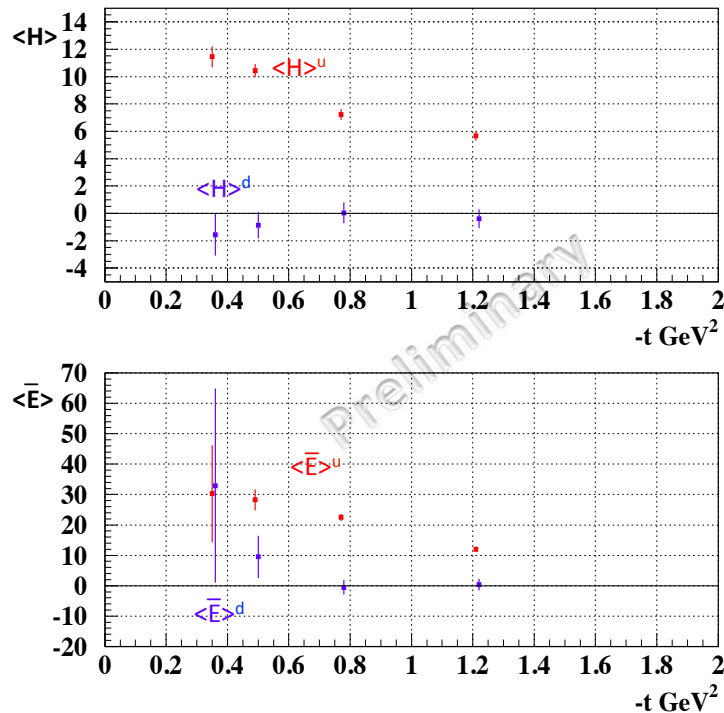
Complements SIDIS,  $pp$  Drell-Yan

Leading-twist structure: LQCD, models



- JLab12 experiment

E12-06-108. No Rosenbluth separation required



- 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](#)

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

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

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

- Model calculations of transversity GPDs

→ [Talk K. Tezgin](#)

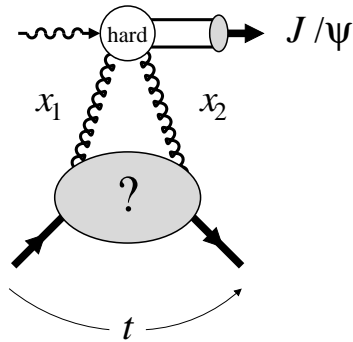
CLAS6 preliminary Kubarovsky 14

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

Invariant amplitude, cf. Compton form factors

# JLab12: Exclusive $J/\psi$ near threshold

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- Near-threshold kinematics

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

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

Probes high- $t$  gluon GPD/FF

- Theoretical questions

Factorization in near-threshold regime?

[Strikman, CW, in progress](#)

Behavior of gluonic form factor?

Correlations in nucleon LC wave function?

[Cf. model of Brodsky, Chudakov, Hoyer, Laget 01](#)

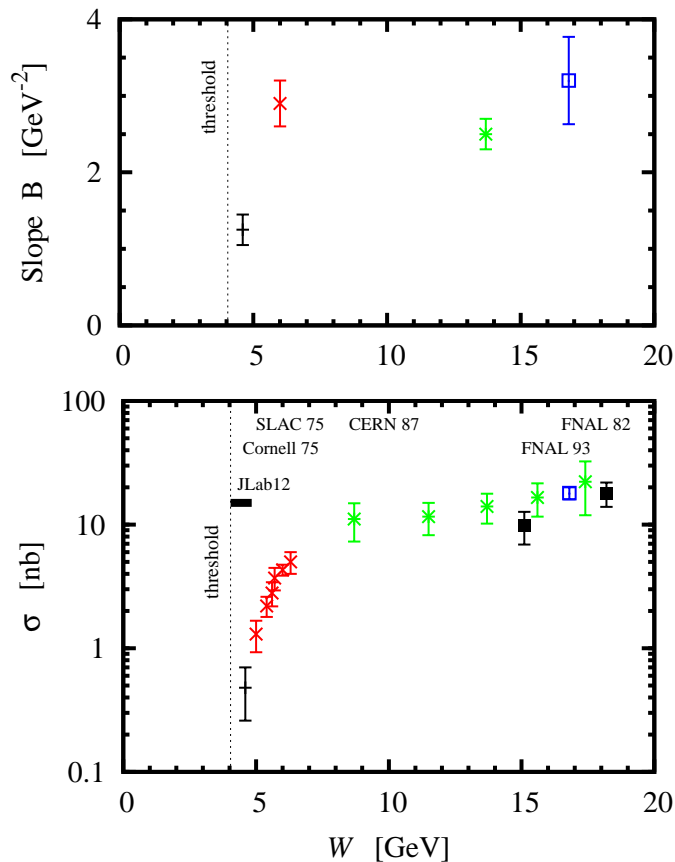
$J/\psi - p$  bound states

[LHCb Pentaquark](#)

- JLab12  $J/\psi$  experiments

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

First  $J/\psi$ 's seen at GlueX!



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

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

- Probe structures selectively

gluons	$\phi, J/\psi, \Upsilon$
gluons + singlet quarks	$\rho^0, \omega, \gamma$
non-singlet quarks	$\rho^+, K^*$
polarized quarks	$\pi^+, \pi^0, \eta, K^+, K_L$

- Explore novel dynamics

Non-singlets and polarization at small  $x$

$N \rightarrow N^*$  transitions through hard processes

Quantum fluctuations of gluons and diffractive dissociation

- JLEIC detectors designed for exclusive reactions

→ Talk R. Yoshida



## DVCS

- Early  $Q^2$ -scaling expected from single-quark Compton process (“handbag graph”)
- BH-DVCS interference gives access to Im/Re amplitudes, dispersion relations
- Structures separated through spin observables,  $p$  and  $n$  targets

## Meson production

- Finite-size effects substantial, but can be included: theory + experiment, also  $\sigma_T$
- Meson selects definite quantum numbers:  $I = 0$  or  $1$ ,  $C = \text{odd or even}$
- Possible to access gluons and transversity
- Simple structure of cross section and observables

Disclaimer: Very schematic. Points for discussion only.

- Hard exclusive meson production essential tool in “tomography” program
- Select/probe structures not directly accessible otherwise: gluons, transversity
- Theoretical progress in modeling finite-size effects and GPDs
- Expect interesting “early results” from 12 GeV running:  $\phi, \pi^0, J/\psi$
- Analysis and interpretation to be discussed jointly with DVCS [→ This meeting](#)