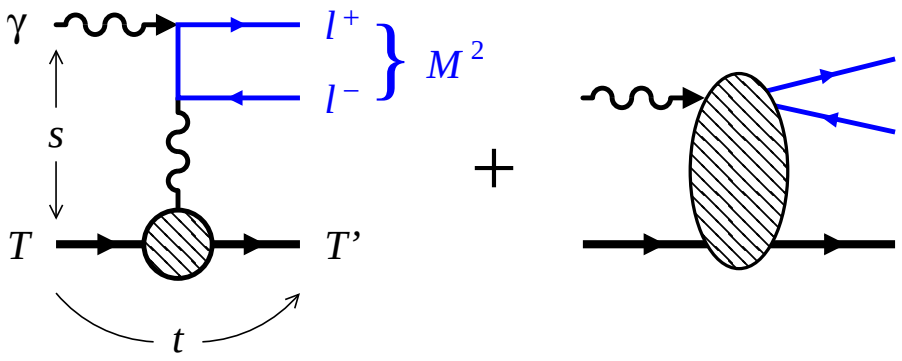
Physics with exclusive dilepton photoproduction

C. Weiss (JLab), Nucleon and nuclear structure through dilepton production,
ECT* Trento, 24–28 Oct 2016



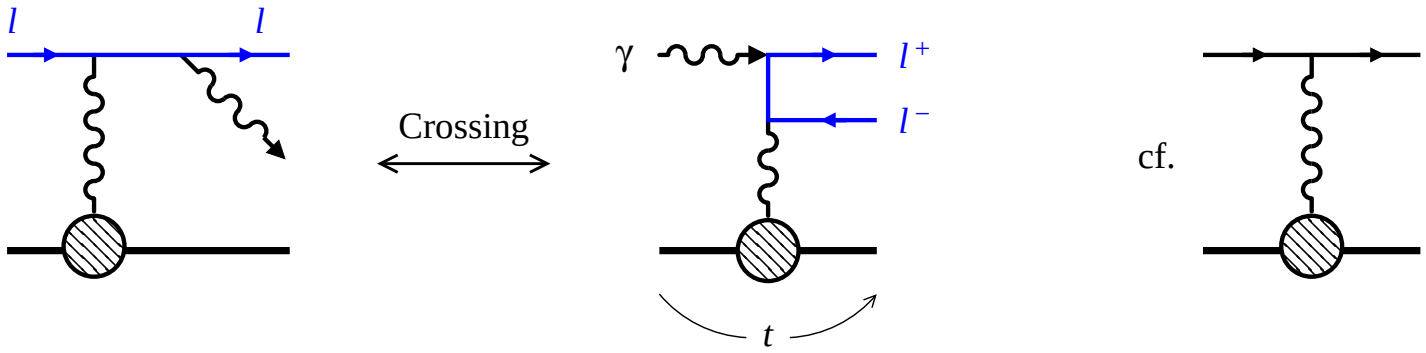
$\gamma + T \to (l^+ l^-) + T'$

quasi two-body

$T = N, A, \quad l = e, \mu$

- Crossing, BH-TCS interference, kinematic regions
- Vector meson region $M_{l^+l^-} \sim M_V$: Re/Im amplitude
- High-mass region $M_{l^+l^-} \gg 1$ GeV: QCD description, GPDs
- J/ψ region $M_{l^+l^-} \sim M_{c\bar{c}}$: Gluon GPDs, J/ψ–N bound states
- Related processes: Electro- and hadroproduction of dileptons

Dileptons: Crossing



Bethe−Heitler radiation

Pair production

- Crossing: Relativity & analyticity
- Measure form factors $F(t < 0)$ with photon beam

  QED pair production process as "radiator/source"

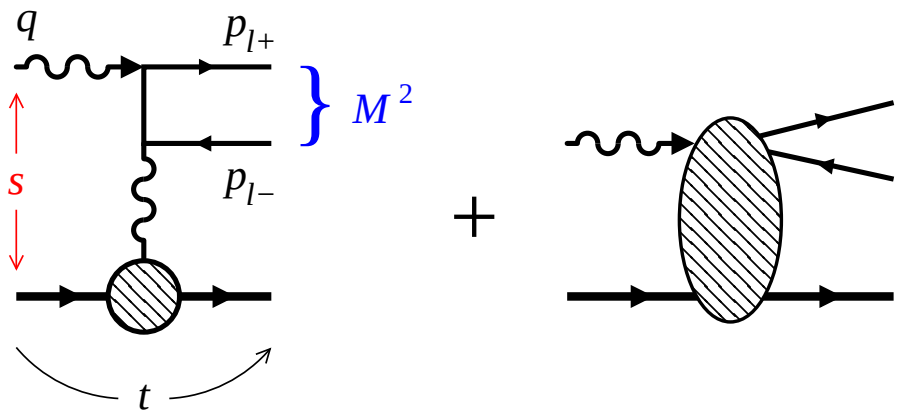
- Advantages of pair production channel

  Lepton charge asymmetry $l^+ \leftrightarrow l^-$

  Different lepton species $l = e, \mu$

  Lepton universality in elastic scattering: Pauk, Vanderhaeghen 15

Dileptons: BH and TCS amplitudes



- Exclusive dilepton production

  $\gamma + T \to (l^+ l^-) + T'$

  Quasi two–body

  Kinematic variables M^2, s, t

- BH amplitude

  Strong kinematic variation because lepton virtuality becomes small in collinear configurations $\boldsymbol{p}_{l+} \,||\, \boldsymbol{q}$ or $\boldsymbol{p}_{l-} \,||\, \boldsymbol{q}$

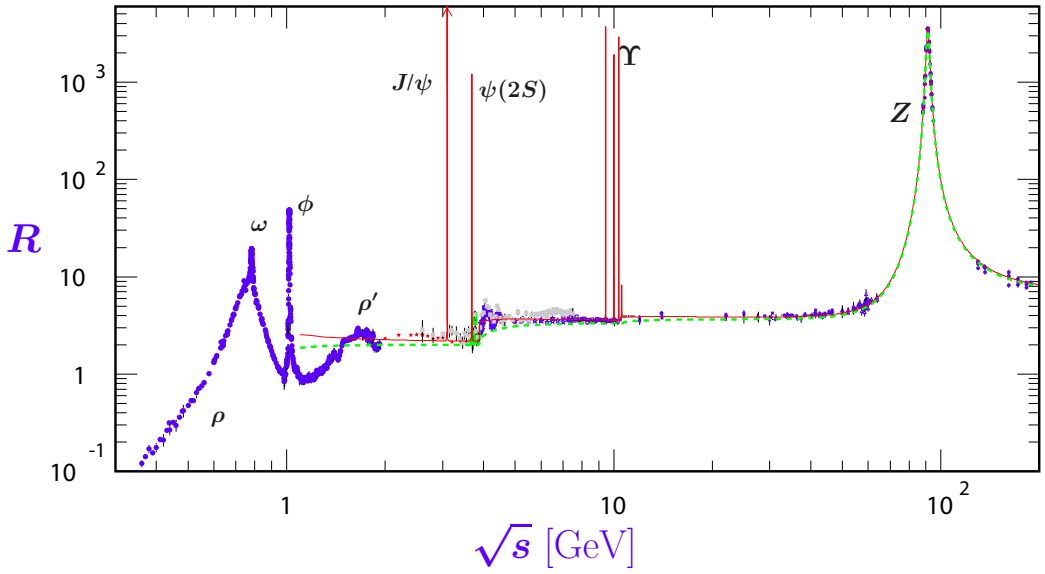
  Leading-order amplitude real, higher-order corrections give Im(BH) $\neq 0$

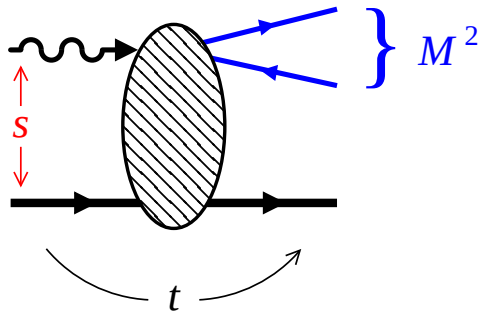
- BH and TCS amplitudes interfere

  Interference effect depends on relative size of amplitudes, width of M^2 window, polarization states

  Use as tool for nucleonic and nuclear structure!

Dileptons: TCS kinematic regions





- Pair mass $M_{l^+l^-}$

  $M_{l^+l^-} \sim M_V$ hadronic

  $M_{l^+l^-} \gg 1$ GeV QCD, quarks/gluons

  $M_{l^+l^-} \approx M_{c\bar{c}}$ QCD, gluons

- CM energy squared s

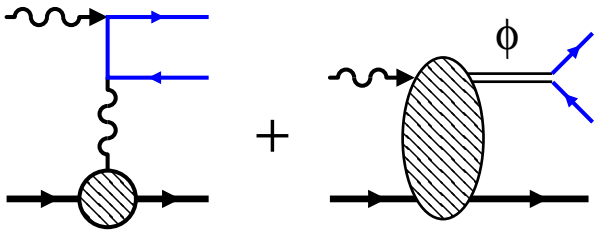
  Reggeon $\leftrightarrow$ pomeron exchange (hadronic)

  Quark $\leftrightarrow$ gluon GPDs (QCD)

- Momentum transfer t

  $t < t_{\min}(s, M^2)$ kinematic limit

VM region: Re/Im of ϕ amplitude ^{0}

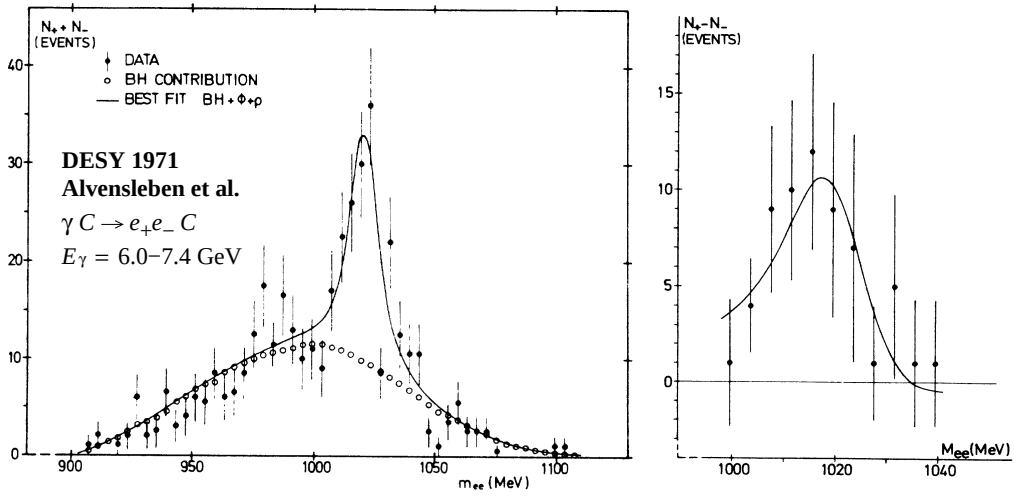


$$\frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} = \frac{4\mathcal{M}_{\rm BH}{\rm Re}\mathcal{M}_\phi}{|\mathcal{M}_{\rm BH} + \mathcal{M}_\phi|^2}$$

- Charge asymmetry $l^+ \leftrightarrow l^-$ gives direct access to ${\rm Re}\mathcal{M}_\phi/{\rm Im}\mathcal{M}_\phi \equiv \beta$
- Method demonstrated

  DESY71: ^{12}C nucleus, $\beta = -0.48^{+0.33}_{-0.45}$

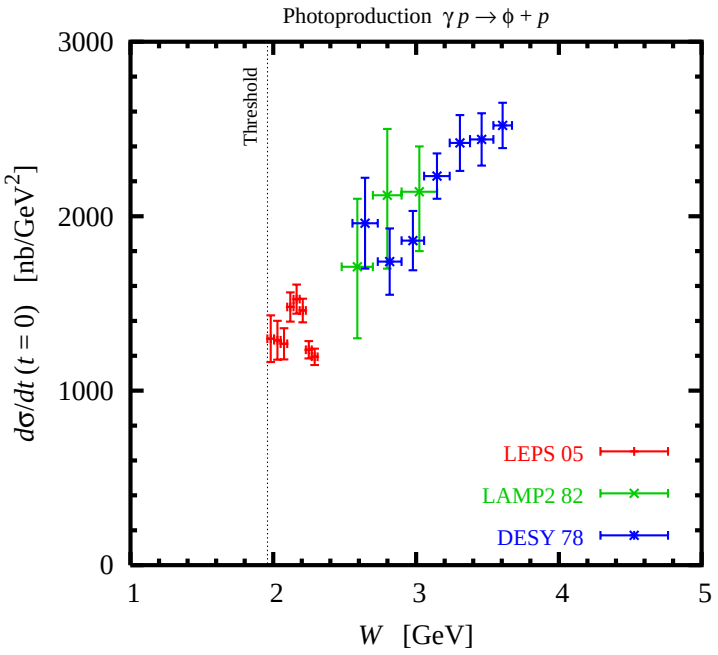
  Precise measurements possible with JLab12
  CLAS12, GlueX?

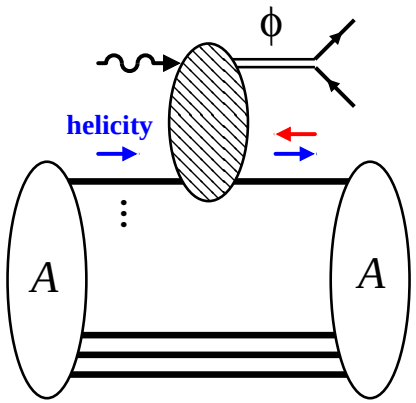


- Re/Im important information on production mechanism

  Exchange mechanisms?

VM region: ϕ photoproduction mechanism





- Energy dependence puzzle

  Non-uniform energy dependence of $d\sigma/dt(t=0)$ observed near threshold
  LEPS05, CLAS 6 GeV

  Important to correct for $t_{\min}$ effect!

  Exchange mechanisms: η vs. Pomeron?

- Nuclear targets

  Helicity–flip suppressed in coherent production $\gamma + A \to \phi + A$:
  Nucleus has to stay intact! Strikman

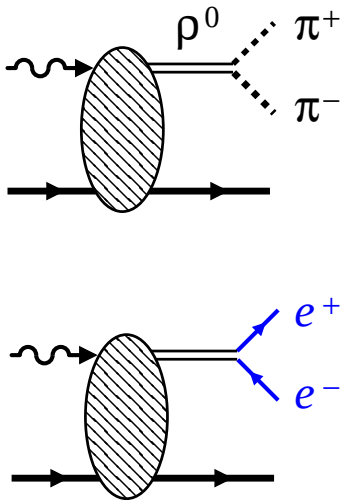
  Nuclear FSI: Glauber approximation

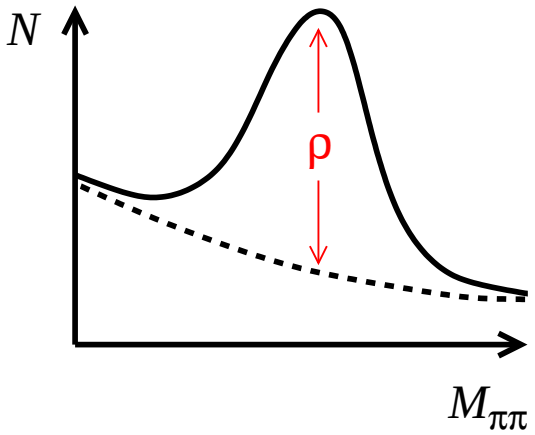
- ϕ electroproduction at $Q^2 \gg 1$ GeV^2
  $\to$ Talk Kroll

  Strange quark vs. gluon GPD?

  Intrinsic strangeness?

VM region: ρ^0 photoproduction





- ρ^0 reconstruction using e^+e^- mode

  Complement/test reconstruction in $\pi^+\pi^-$ mode

  Wide resonance, pedestal subtraction specific to decay mode

- Re/Im from BH–ρ^0 interference

  DESY 70 measurement, $\beta = 0.2 \pm 0.1$

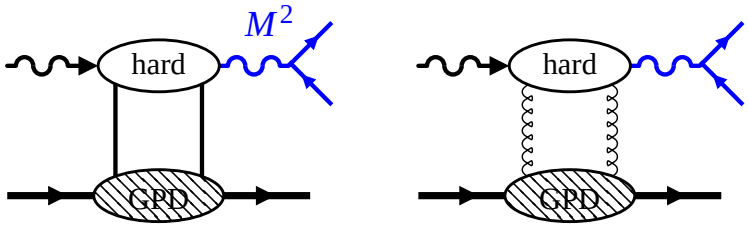
  Precise measurements possible with JLab12
  CLAS12, GlueX?

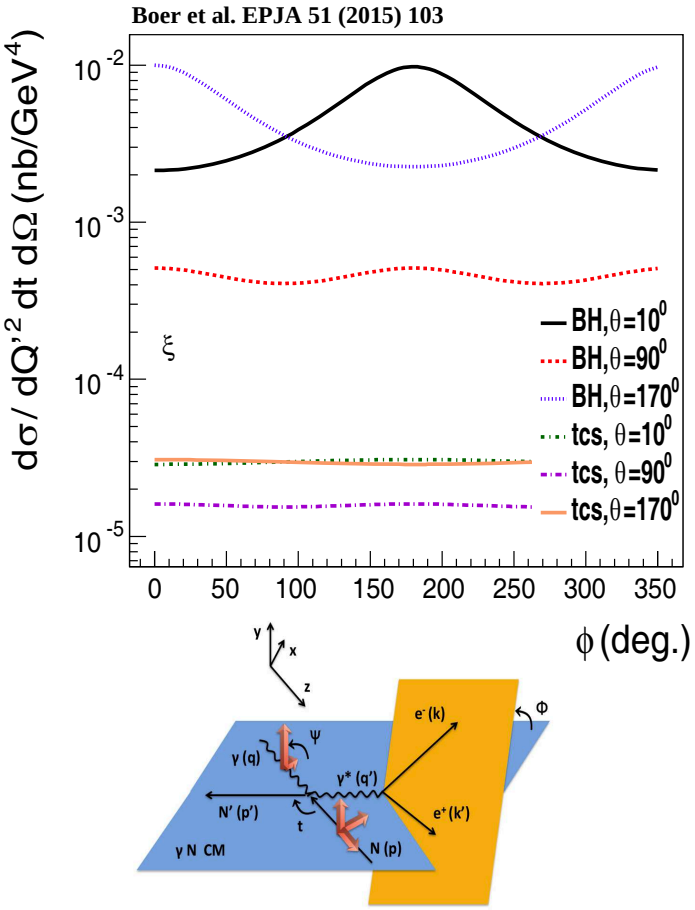
- ρ^0 electroproduction puzzle → Talk Kroll

  What causes rise of cross section at $W < 4$ GeV?
  CLAS 6 GeV data. Guidal, Morrow 08

  Re/Im can give new insight

High-mass region: Factorization, GPDs





- Factorization (cf. DVCS)
  Berger, Diehl, Pire 02

  M^2 as large scale, collinear approximation

  Quark-gluon process $\times$ GPD

  Crossing of quark-gluon process

- Observables

  Differential cross section (BH dominant)

  Photon SSA linear pol A_{LU},
  circular pol $A_{\circ U}$ (BH $= 0$)
  Goritschnig, Pire, Wagner 14

  Target SSA linear pol $A_{Ux,y,z}$ (BH $= 0$)

  Double spin asymmetries

- Use for GPD analysis → Talk Boer

  Sensitive to Re(TCS), D–term
  Boer, Guidal, Vanderhaeghen 15+

High-mass region: Questions

- NLO QCD corrections

  Apparently large in Re(TCS): Effective scale? Quark $\leftrightarrow$ gluon GPDs?
  Pire, Szymanowski, Wagner 11; Moutarde, Sabatie, Szymanowski, Pire 13

  Crossing of partonic amplitudes
  Müller, Pire, Szymanowski, Wagner 12

- Dispersion relations for TCS amplitude

  s–channel dispersion relation (cf. DVCS)?

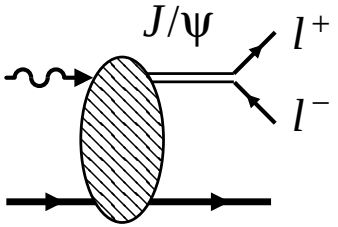
  Analyticity in M^2: Rich structure, Landau singularities

- Higher-order QED corrections

  Two-photon exchange makes Im(BH) $\neq 0$

  Soft-photon emission from BH and TCS amplitudes can generate asymmetries

J/ψ region: Probing gluonic structure



- Charmonium production using l^+l^- mode
- Charmonium size small on hadronic scale

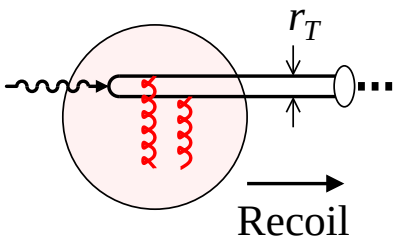
  LQCD, potential models: $\langle r^2 \rangle^{1/2} \sim$ 0.2–0.3 fm

  EFT approach: Non–relativistic QCD, $v \ll 1$
  Lepage et al 92; Manohar 97; Brambilla 2000; Kniehl et al. 2002

$$m \quad \gg \quad mv \quad \gg \quad mv^2$$

mass — momentum, inverse size — binding energy

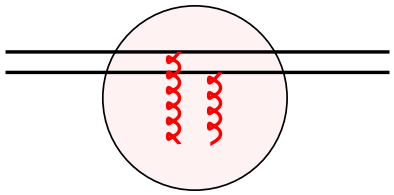
"intermediate"



- $\bar{Q}Q$ couples to gluon field in nucleon/nucleus

  Multipole expansion: Dipole + ...

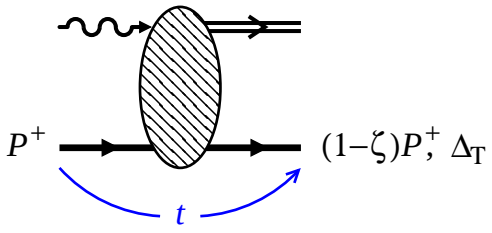
  Fields change with energy s, momentum transfer t

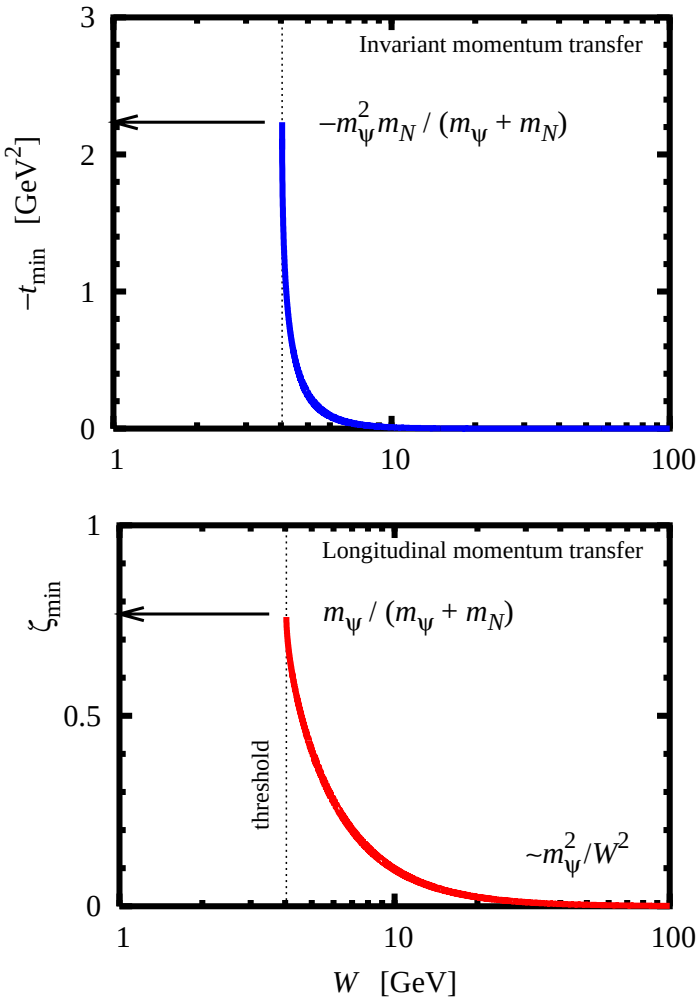


- Related process: Charmonium–nucleon scattering

  Theoretically simpler, difficult to realize in exp

J/ψ region: Photoproduction kinematics





- Light–cone variables

  ζ "Plus" momentum transfer, cf. x_B
  large near threshold, but not $\zeta \to 1$!

  Δ_T Transverse momentum transfer

  $$t = -(\zeta^2 m_N^2 + \Delta_T^2)/(1-\zeta)$$

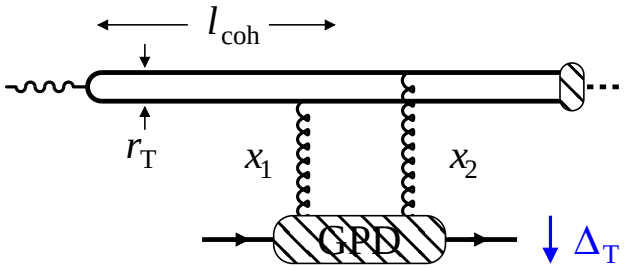
- Invariant momentum transfer grows near threshold: $|t_{\rm min,th}| = 2.2\,{\rm GeV}^2$

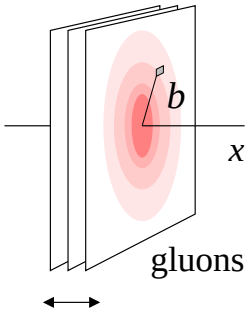
- Two regimes

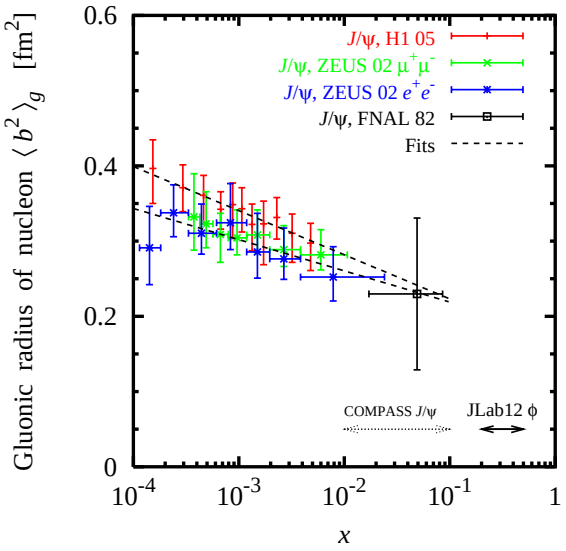
  $W \approx W_{\rm th}$ $t_{\rm min} = 1$–$2\ {\rm GeV}^2$, ζ large
  cf. nucleon elastic form factors
  Cornell, SLAC, JLab 12 GeV

  $W \gg W_{\rm th}$ $t_{\rm min}$ negligible, $\zeta \ll 1$
  cf. diffractive processes
  FNAL, COMPASS, HERA, EIC

J/ψ region: Photoproduction at high W







- Collinear factorization Collins, Frankfurt, Strikman 96

  Space-time picture in rest frame: $l_{\rm coh} \gg 1\,{\rm fm}$
  Brodsky et al. 94

  GPD as gluonic dipole moment of target

- HERA exp: Kinematic dependences, absolute cross secns, comparison of diffractive channels $J/\psi \leftrightarrow \rho^0, \phi(Q^2)$
  More data: Ultraperipheral pA at LHC $\rightarrow$ Talk Guzey

- Transverse spatial distribution of gluons

  Fourier $\boldsymbol{\Delta}_{\rm T} \rightarrow \boldsymbol{b}$ impact parameter

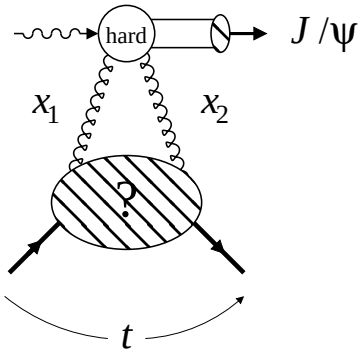
  Distribution changes with x and scale μ^2:
  Parton diffusion, DGLAP evolution

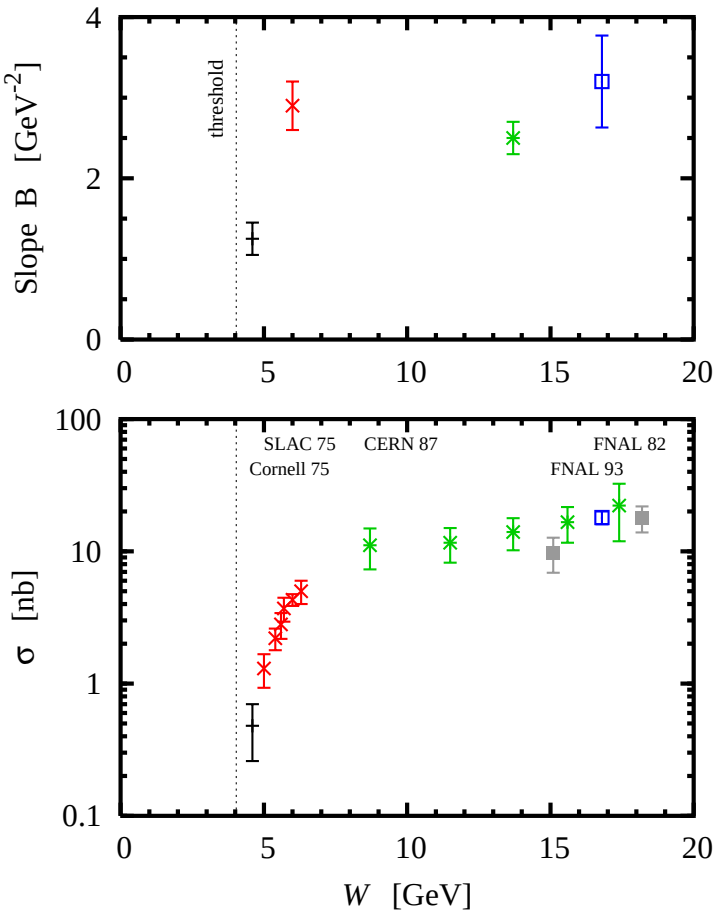
  Fundamental gluonic size of nucleon in QCD:
  Gluon vs. quark radii, non–pert. dynamics

  Needed for small–x physics, pp@LHC underlying event, multiparton processes, diffraction
  Frankfurt, Strikman, CW 04/11; Frankfurt, Hyde, Strikman, CW 07

  EIC: Gluon imaging"

J/ψ region: Photoproduction near threshold





- Kinematics near threshold → Talk Meziani

  Large $|t_{\min}|$, up to 2.2 GeV^2

  Large longit. momentum transfer $x_1 - x_2 = \zeta$

- Reaction mechanism near threshold

  GPD-based description at $t \sim$ 1–2 GeV^2 and large skewness: Two-gluon form factor
  Frankfurt, Strikman 02

  Hard scattering mechanism, cf. high–t FFs
  Brodsky, Chudakov, Hoyer, Laget 01

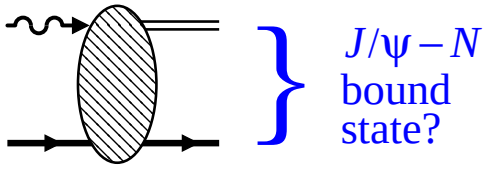
  Can be tested with JLab 12 GeV!

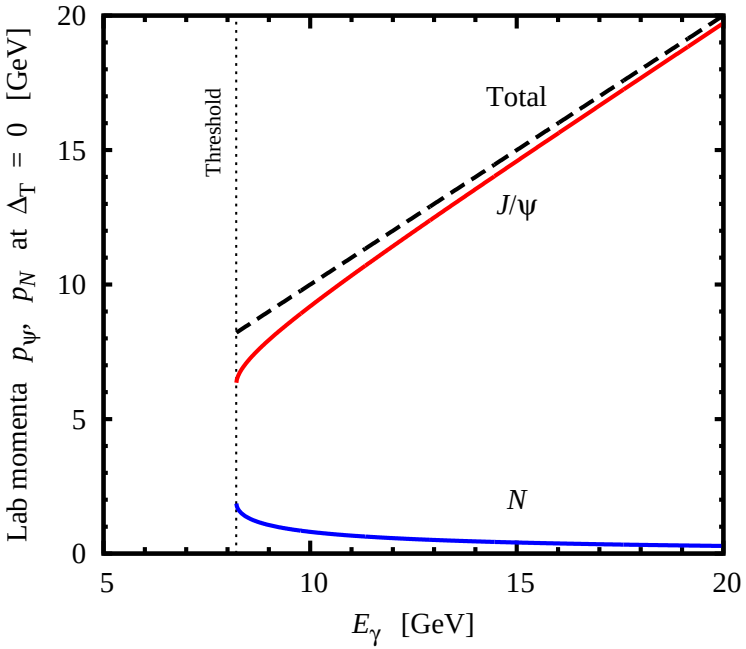
- Theoretical questions

  Behavior of two–gluon form factor?

  Correlations in nucleon LCWF?

J/ψ region: Bound states and nuclei





- J/ψ nucleon bound states

  Hints seen in LHCb experiments, great interest

  Can be studied in dilepton photoproduction

  J/ψ and N fast in lab frame

- J/ψ photoproduction on nuclei

  J/ψ fast in nucleus rest frame

  Study J/ψ–N interaction at $p_\psi \sim$ few GeV

- Low-energy J/ψ–N interaction

  Theoretical interest: Operator expansion,
  QCD Van–der–Waals force, nuclear bound states
  Fuji, Kharzeev 99; Brodsky, Miller 97;
  Brodsky, de Teramond 90; Luke, Manohar, Savage 92

  How to study it experimentally?

Dileptons: Related processes

- Exclusive dilepton electroproduction $e + T \to e' + (l^+ l^-) + T'$

  L/T amplitudes, Q^2 dependence

  Antisymmetrization if $l = e$; effect minor if kinematically separated; absent if $l = \mu$

  Vector meson region: Re/Im in ρ^0, ϕ electroproduction

  High-mass region: DDVCS for GPD analysis, very challenging
  JLab12 → Talks Guidal, Baltzel, Camsonne

  J/ψ region: Electroproduction near threshold
  JLab12 SOLID → Talk Meziani

- Inclusive dilepton photoproduction on nuclei $\gamma + A \to (l^+ l^-) + X$

  Vector mesons "in medium:" Mass shift, broadening, optical potential
  CBELSA/TAPS, CLAS. Overview see V. Metag, Workshop Nuclear photoproduction with GlueX, JLab, April 28-29, 2016.

- Exclusive hadronproduction $\pi + T \to (l^+ l^-) + T'$ → Talk Chang

  Timelike meson photoproduction, exclusive version of Drell-Yan
  JPARC, COMPASS?

Dileptons: Summary

- Interesting physics in exclusive dilepton photo/electroproduction

  Vector meson region: Re/Im in ρ^0, ϕ, test of universality

  High-mass region: Re/Im in GPD analysis, D–term

  Gluonic structure, J/ψ–N bound states

- Much can be covered by approved JLab12 experiments or extensions

  Discuss need for $\mu^+\mu^-$ vs. e^+e^-

- Accurate treatment of QED radiative corrections essential

  Im(BH) $\neq 0$ in higher orders; real emissions change charge parity

- Photoproduction capabilities at EIC $\rightarrow$ Talk Hyde

  Small-angle electron tagger for photoproduction in JLEIC design

  What dilepton capabilities will be needed in central detector?