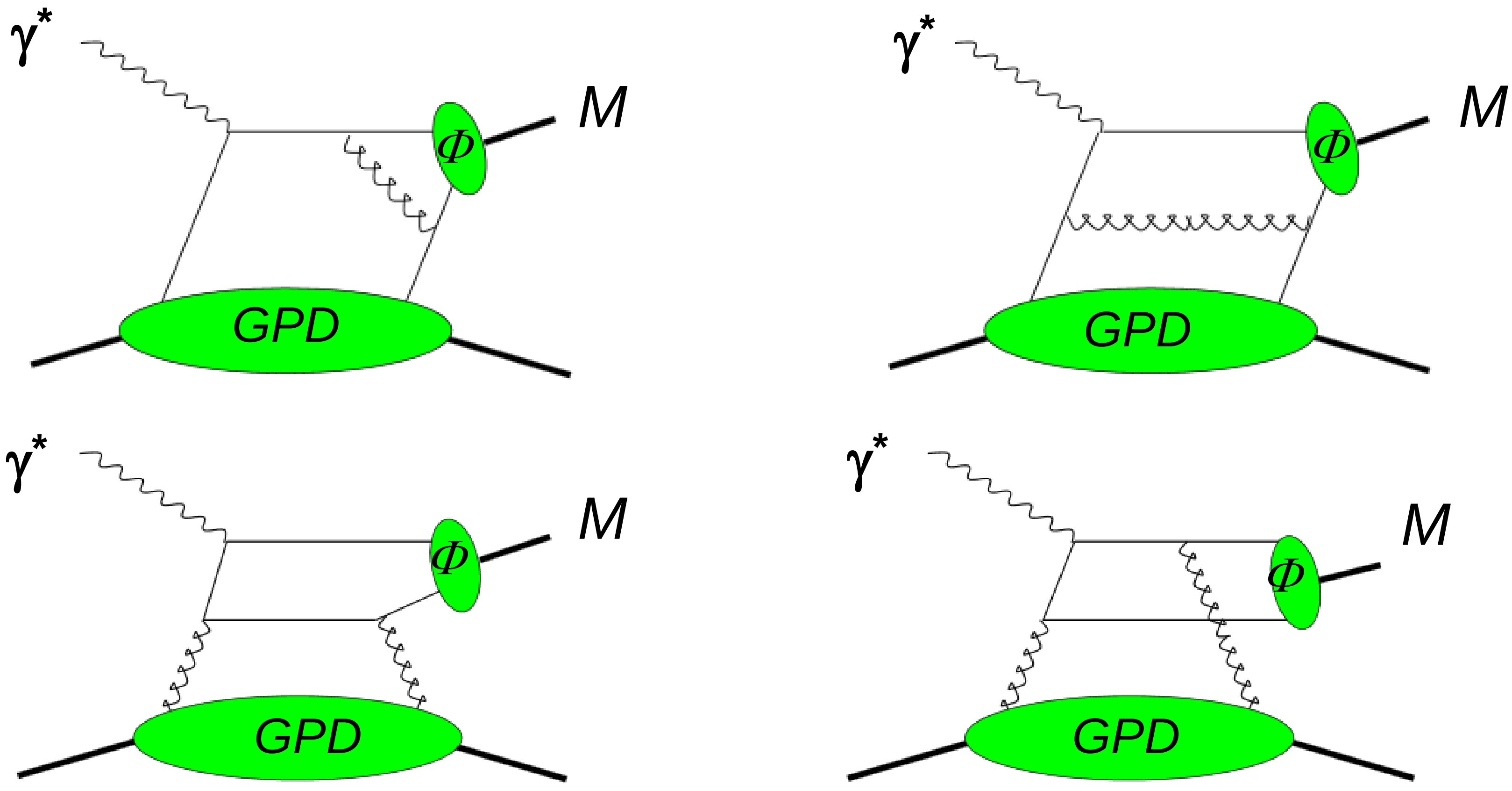
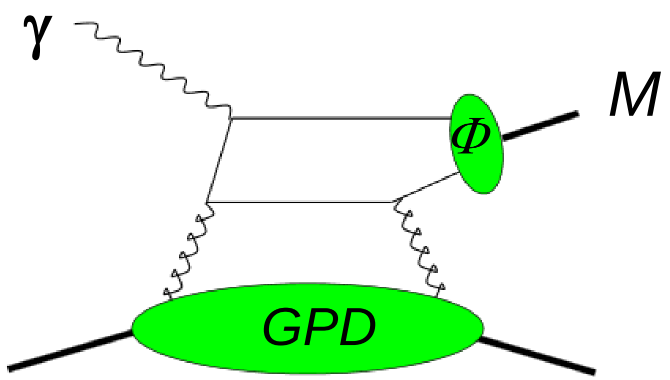
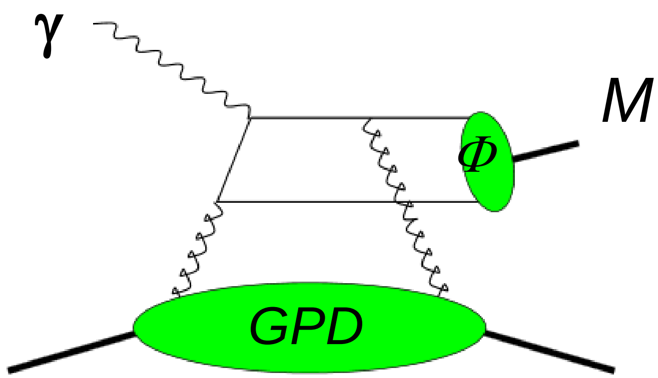
Factorization in hard exclusive meson electro-production



- Factorization theorem for hard exclusive meson electro-production (*Collins, Frankfurt, and Strikman, Phys.Rev D56 (1997)*)
  - requires large virtuality for heavy mesons : $Q^2 >> M^2$
  - two soft pices: GPD and Φ (light-cone wave function of the meson)

Factorization in exclusive heavy meson photo-production



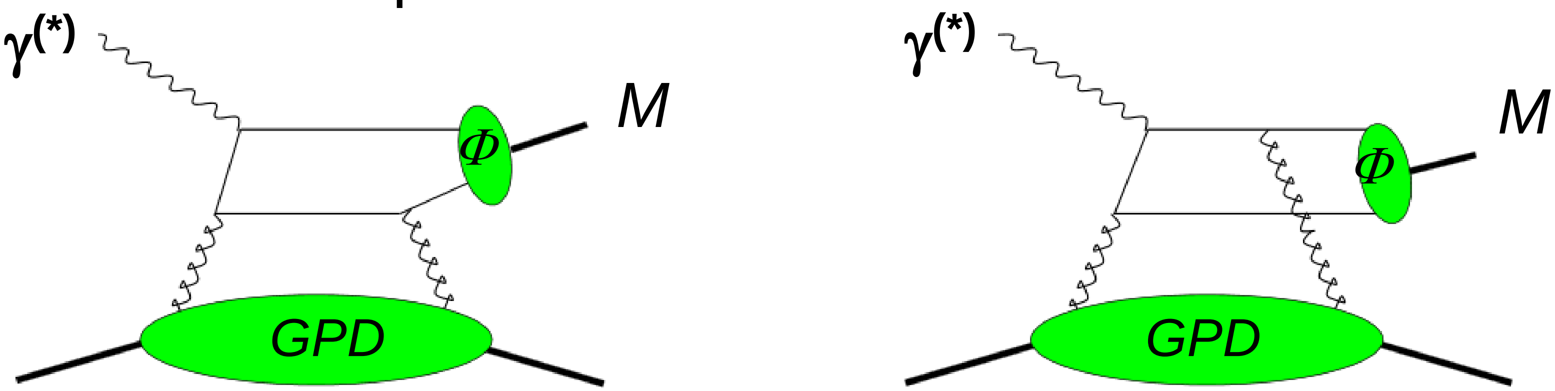


- In contrast in heavy meson photo-production ($Q^2=0$)
  – the heavy quark mass provides the hard scale: $Q^2 << M^2$
  – allows non-relativistic treatment of Φ (studied by *Hoodbhoy, Phys. Rev. D56 (1997)*)
  – factorization demonstrated explicitly in NLO calculations (*Ivanov, Schaefer, Szymanowski, Krasnikov, EPJC 34 (2004)*)

$\int_{-1}^{1}$

  – NLO corrections significant

Factorization in hard exclusive heavy meson electro-production at small x



- Heavy meson electro-production at small x (*Flett, Jones, Martin, Ryskin, Teubner, arXiv:1908.08398 (Aug 2019*))
  - GPD *F(x,ξ)* related to *PDF(x+ξ)* at small x (Shuvaev transform)
  - avoid scale dependence of NLO

J/ψ-nucleon cross-section – perturbative calculations

Kharzeev et al. EPJ C (1999):

- As the heavy charmonium sets the hard scale:

$$r_Q << \Lambda_{\rm QCD}^{-1}, \quad t_Q << \Lambda_{\rm QCD}^{-1}; \qquad r_{J/\psi} \simeq 0.2 \text{ fm} = (1 \text{ GeV})^{-1}; \quad E_{J/\psi} = 2M_D - M_{\psi'} \simeq 0.64 \text{ GeV}$$

calculations of Φh -> Φh very similar to those for DIS, using Operator Product Expansion (OPE):

$$F_{\Phi h} = \sum_n c_n(Q, m_Q)\langle O_n \rangle$$

where the Willson coefficients **C**$_n$ are process independent (calculated for DIS)

- Using dispersive relations (same as in DIS) one can relate the cross-section to the partonic structure of the proton:

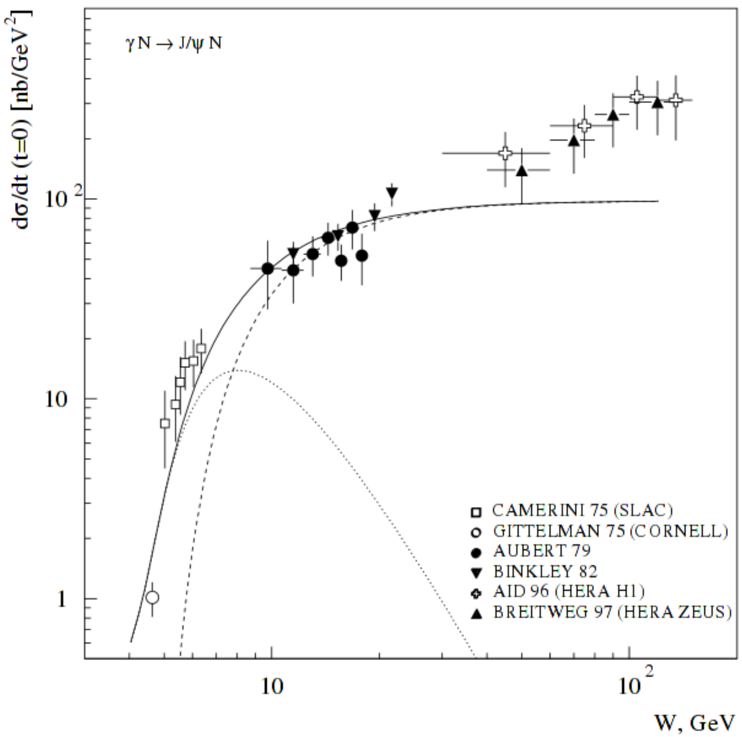
$$\int_0^1 dy \; y^{n-2} \sigma_{\Phi h}(\lambda_0/y) = I(n) \int_0^1 dx \; x^{n-2} g(x, Q^2 = \epsilon_0^2)$$

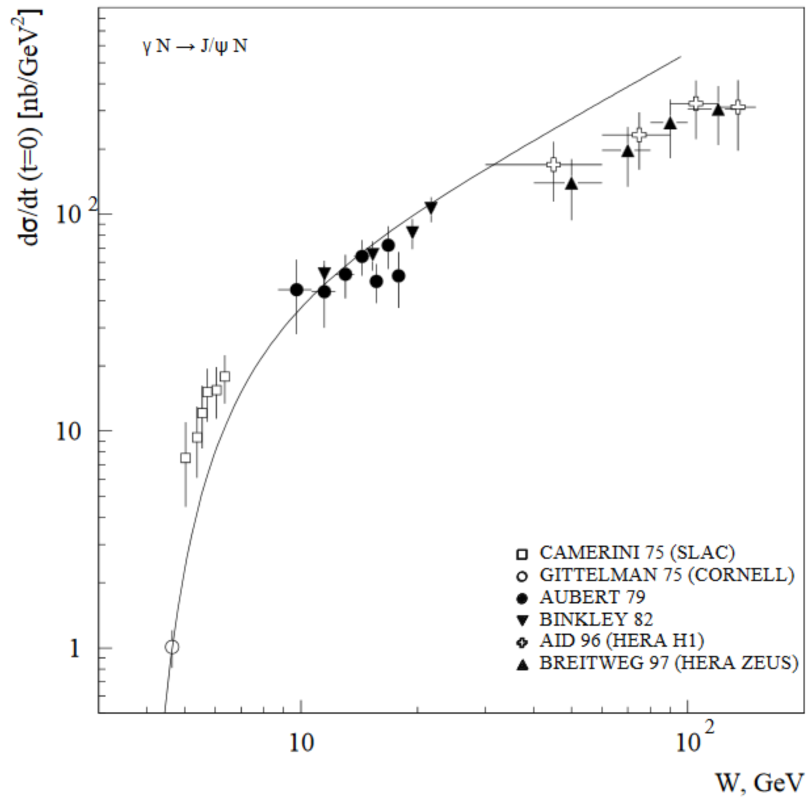
in first approximation total cross-section:: $\sigma_{\Phi h}(\lambda_0/x) \sim g(x, Q^2 = \epsilon_0^2)$

(λ – nucleon energy in J/ψ rest frame) and then *Im* and *Re* parts:

$$\sigma_{\psi N}^{tot} = \frac{Im \, \mathcal{M}_{\psi N}}{2m_\psi \sqrt{\lambda^2 - m_N^2}}, \quad Re \, \mathcal{M}_{\psi N}(\lambda) = \mathcal{M}_{\psi N}(0) + \frac{2\lambda^2}{\pi} \int_{\lambda_0}^{\infty} \frac{d\lambda'}{\lambda'} \frac{Im \, \mathcal{M}_{\psi N}(\lambda')}{\lambda'^2 - \lambda^2}$$

J/ψ differential cross-section – using VMD





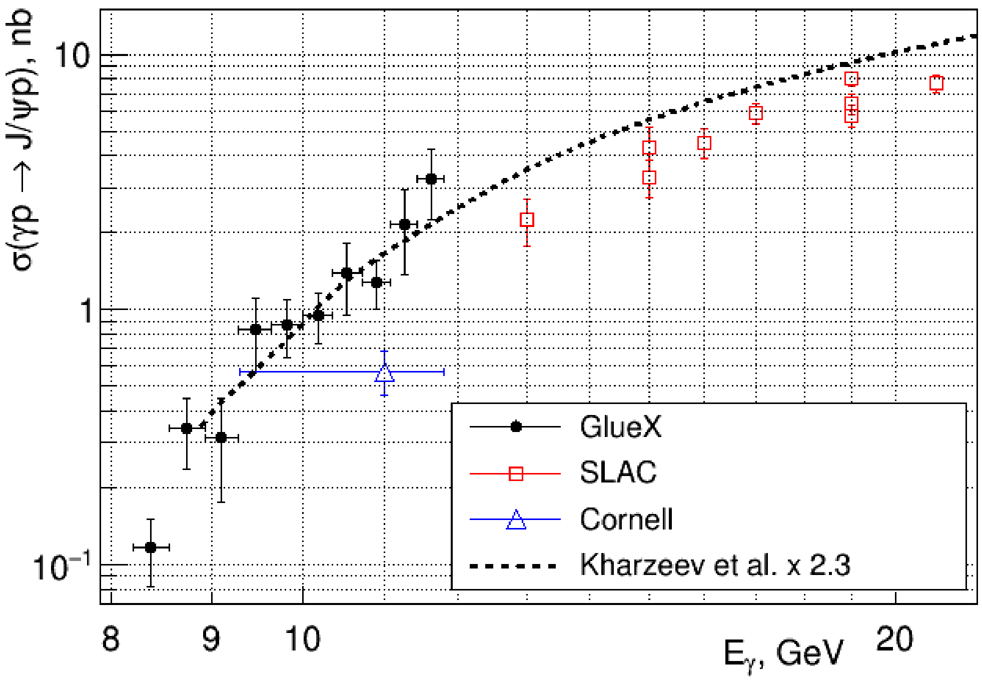
Kharzeev et al. EPJ C (1999):

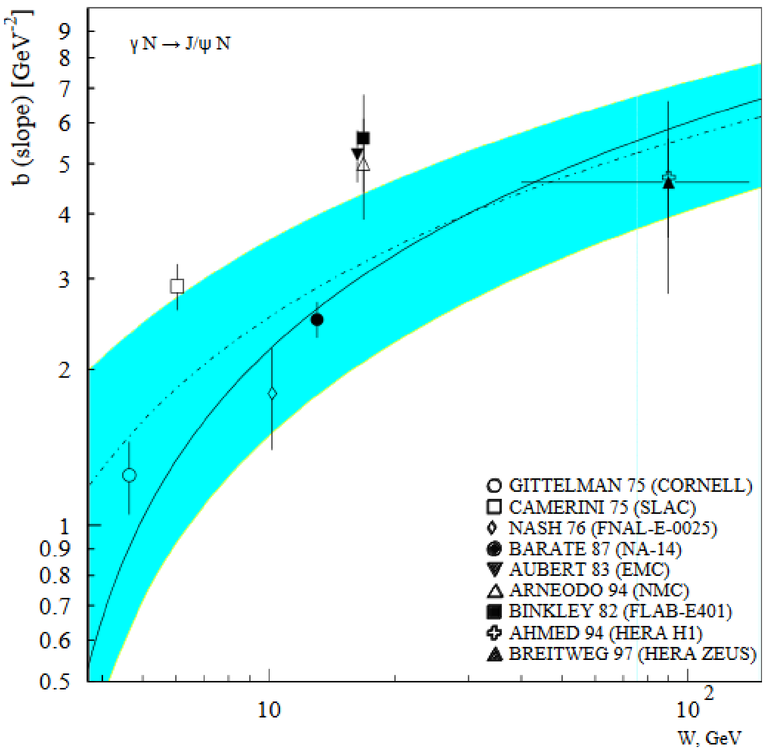
- Assuming VMD:

$$\frac{d\,\sigma_{\gamma\,N\to\psi\,N}}{d\,t}(s,t=0)=\frac{3\Gamma(\psi\to e^+e^-)[s-(m_N+m_\psi)^2][s-(m_N-m_\psi)^2](1+\rho^2)}{16\pi\alpha\;m_\psi(s-m_N{}^2)^2}\left(\sigma^{tot}_{\psi\,N}\right)^2, \tag{4}$$

where ρ is the ratio of real and imaginary parts of forward $J/\psi - N$ scattering amplitude.

J/ψ total cross-section – using t-dependence



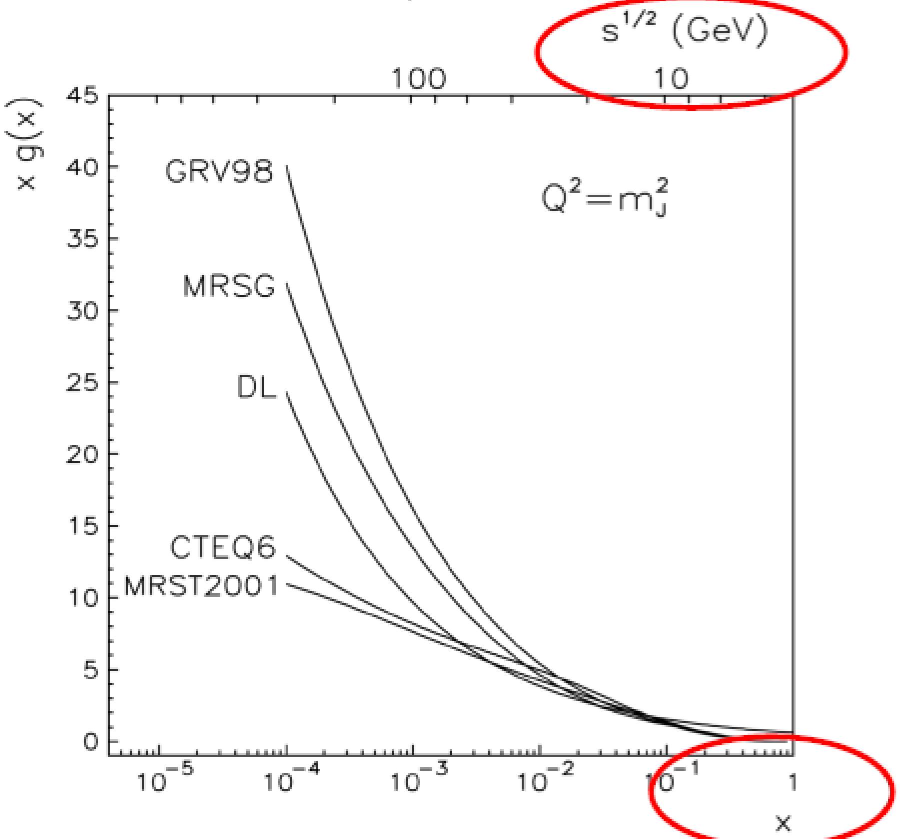


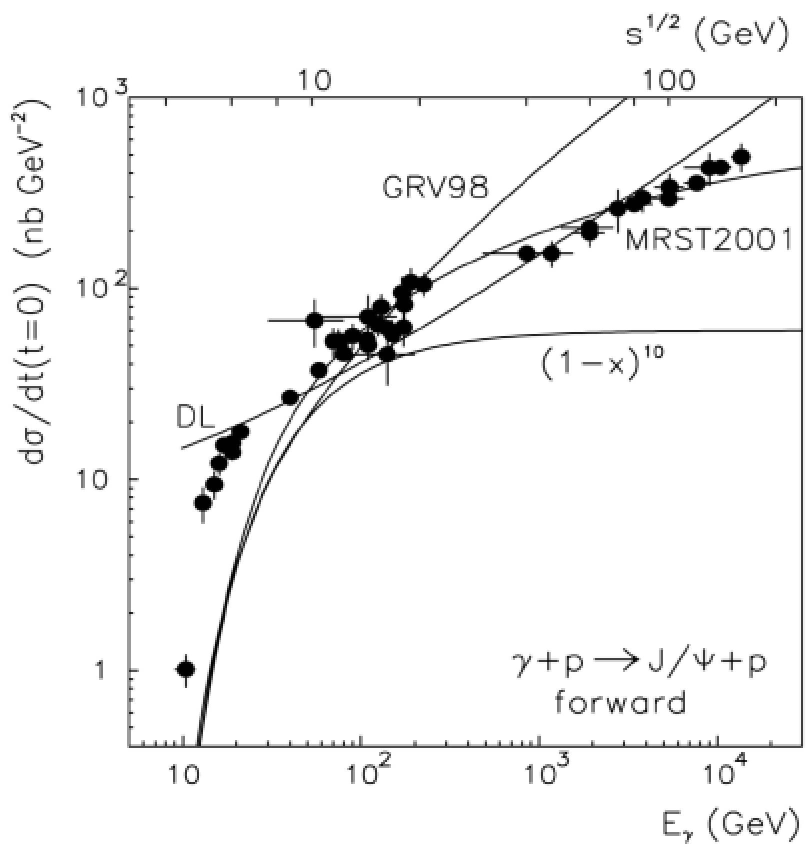
Kharzeev et al. EPJ C (1999):

- Total cross-section calculated using exponential t-dependence parametrization:

$$b = a_0 + a_1 \ln W^2$$

J/ψ differential cross-section – using VMD





Sibirtsev et al. JP G 30 (2004):

- Cross-section is very sensitive to gPDF at high x
- In case of two gluon exchange:

$$d\sigma/dt(t=0) \sim x^2 g^2(x) \text{ where } x = m^2_{J/\psi}/s$$

- The near-threshold energy dependence is defined by the gPDF as x → 1
- t-dependence not defined by the pQCD calculations (discussed later)
- Comparison to the old data only