Hard exclusive J/Ψ (and Φ) photoproduction off a proton

A.T. Goritschnig[1], B. Melic[2], K. Passek-Kumerički[2], W. Schweiger[1]

[1]University of Graz, Graz, Austria

[2]Rudjer-Boškovic-Institute, Zagreb, Croatia

DIS 2014 - Warsaw at the 1^{st} of May 2014

Motivation

We investigate the photoproduction

$$\gamma(p_\gamma)\ p(p_i) \quad \rightarrow \quad J/\Psi(p_\psi)\ p(p_f)$$

at large four-momentum transfer $\mid t \mid = \mid (p_f - p_i)^2 \mid$.

- heavy charm-quark mass sets a hard energy scale
  $\Rightarrow$ perturbative QCD can become applicable
- studying quark-mass influences on production mechansim
- comparison to other mechanisms (pomeron, regge, etc...)

Perturbative Methods in QCD

Perturbative methods in QCD are based on factorization, i.e., separation of the overall process into hard and soft subprocesses.

Hard subprocess

- dominated by large energy effects
- takes place at short space-time distances
- perturbatively manageable
- calculation of several Feynman graphs

Soft subprocess

- dominated by low energy effects
- takes place at long space-time distances
- non-perturbative
- parametrized by a priori unknown functions

Basic idea: Scale separation $\Rightarrow$ quantum-mechanical incoherence.
This means the two scales are uncorrelated and will not interfere.

Hard Scattering Approach (HSA)

[Efremov and Radyushkin, Phys. Lett. B 94, 245 (1980)]

[Lepage and Brodsky, Phys. Rev. D 22, 2157 (1980)]

The HSA should be the dominant mechnism for exclusive reactions at very large (infinitely large) four-momentum transfer $| t |$.

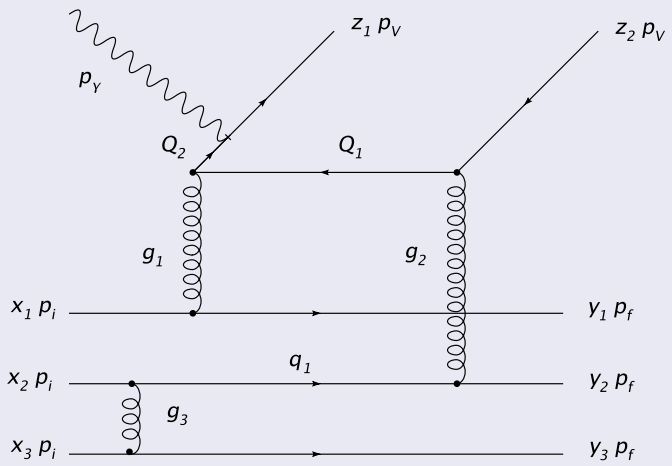
Problem statement: large $| t |$ AND specific final state requested.

- In the hard scattering subprocess hadrons replaced by on-shell valence quarks (since redistribution of momentum easier when only a few partons involved)
- and minimal number of hard gluons is introduced to connect all quark lines (to redistribute large $| t |$ and to allow formation of requested final state).
- The soft subprocess, i.e., the transitions from quarks to hadronic bound-states, described by distribution amplitudes.

HSA: hard subprocess & its generic graphs

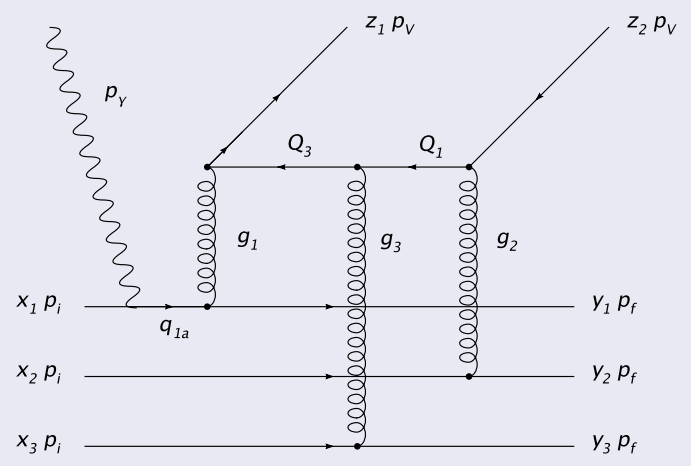
When applying the HSA to $\gamma\, p \to J/\Psi\, p$ photoproduction, for the hard subprocess one has to consider a coherent sum of altogether 108 tree graphs with (in principle) different topology. They can be grouped into two generic classes according to where γ couples:

Class I "VMD type"



72 diagrams

Class II "CS type"

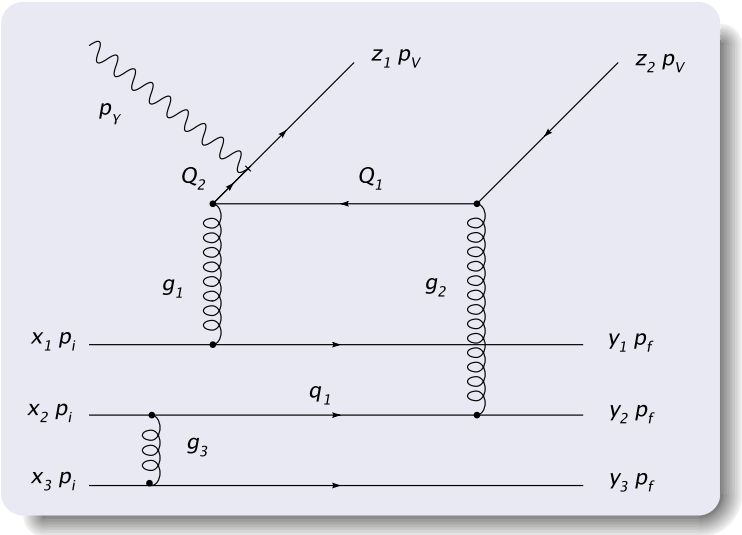


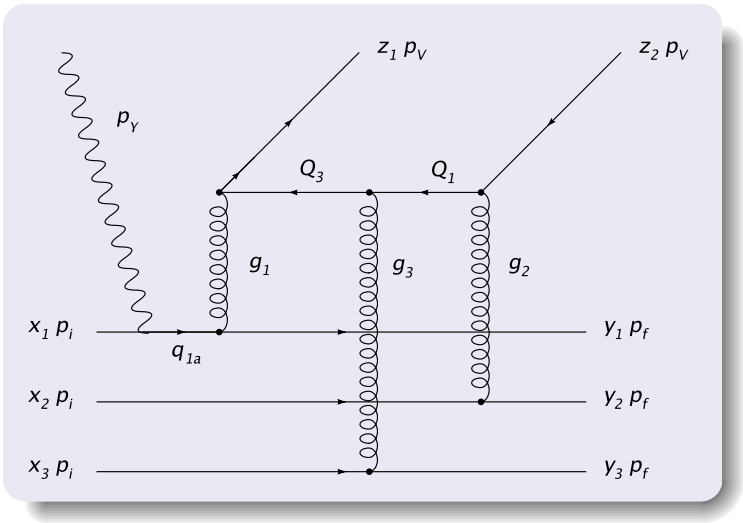
36 diagrams

HSA: hard subprocess & collinear approximation

We furthermore work within a collinear approximation where...

- ...four-momenta of valence quarks assumed to be collinear to the four-momenta of their parent hadrons.
- ...for each quark momentum fractions are introduced, which then parametrize their relative momenta.

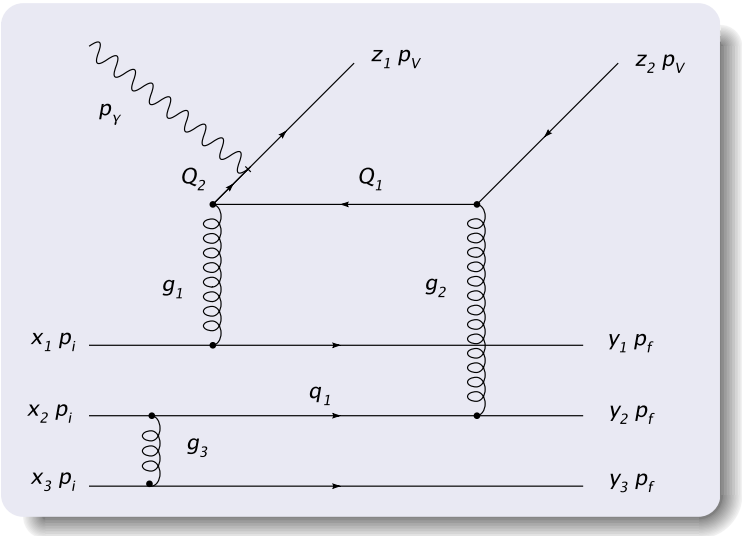


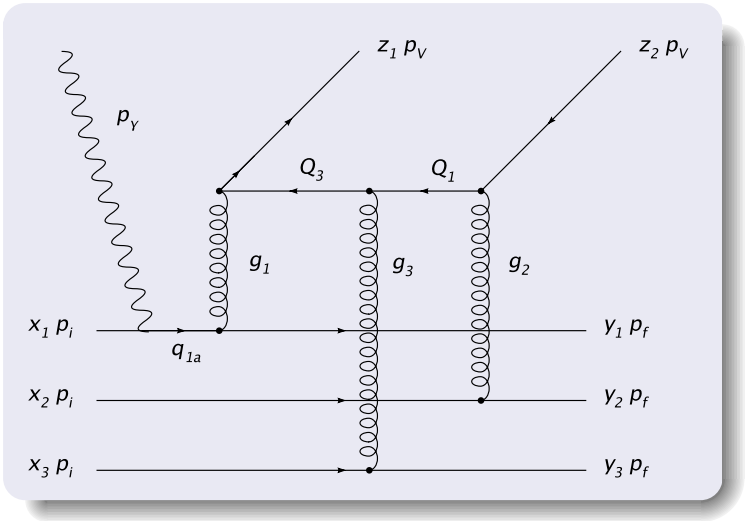


HSA: hard subprocess & quark masses

Within our approach we treat the quark masses as follows...

- ...we neglect the light quark-masses of the valence-quarks inside the proton (as it is foreseen in the "pure" HSA).
- ...we approximate the heavy quark-mass of the (anti)charm inside the J/Ψ by $m_c = z_1 M_{J/\psi}$ or $m_c = z_2 M_{J/\psi}$.





HSA: soft subprocess & distribution amplitudes

- Distribution amplitudes defined via matrix elements $\langle 0 \mid u(r_3)\, u(r_2)\, d(r_1) \mid p \rangle$ and $\langle 0 \mid \bar{c}(r)\, c(0) \mid J/\Psi \rangle$ for the proton and the J/Ψ, respectively.
- They incorporate the soft, non-perturbative transitions from the quarks to the hadronic bound-states.
- They are probability amplitudes for a certain configuration of momentum-fractions of quarks inside parent hadron.

For the distribution amplitudes of the proton and the J/Ψ we take

$$\phi_p\left(x_1, x_2, x_3\right) = 120\, x_1\, x_2\, x_3 \text{ and } \phi_{J/\Psi}\left(z_1\right) = \delta\left(z_1 - 1/2\right),$$

respectively. (ϕ_p is the so-called "asymptotic" nucleon amplitude. $\phi_{J/\Psi}$ is helicity independent and essentially non-relativistic.)

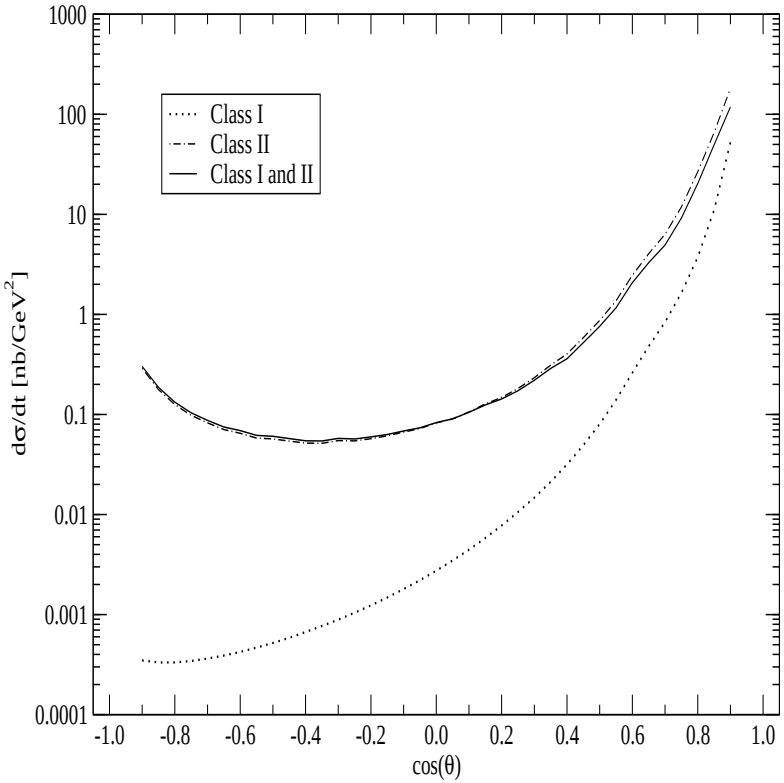
The $\gamma\, p \to J/\Psi\, p$ Amplitude

Within the HSA the $\gamma\, p \to J/\Psi\, p$ photoproduction amplitude is a convolution integral between the hard scattering amplitude and the soft distribution amplitudes w.r.t. the momentum fractions:

$$\mathcal{M} = \int_0^1 [dx] \int_0^1 [dy] \int_0^1 [dz]\, \phi^{\dagger}_{J/\Psi}(z_i)\, \phi^{\dagger}_{P}(y_i)\, T_H(x_i, y_i, z_i)\, \phi_P(x_i)\ .$$

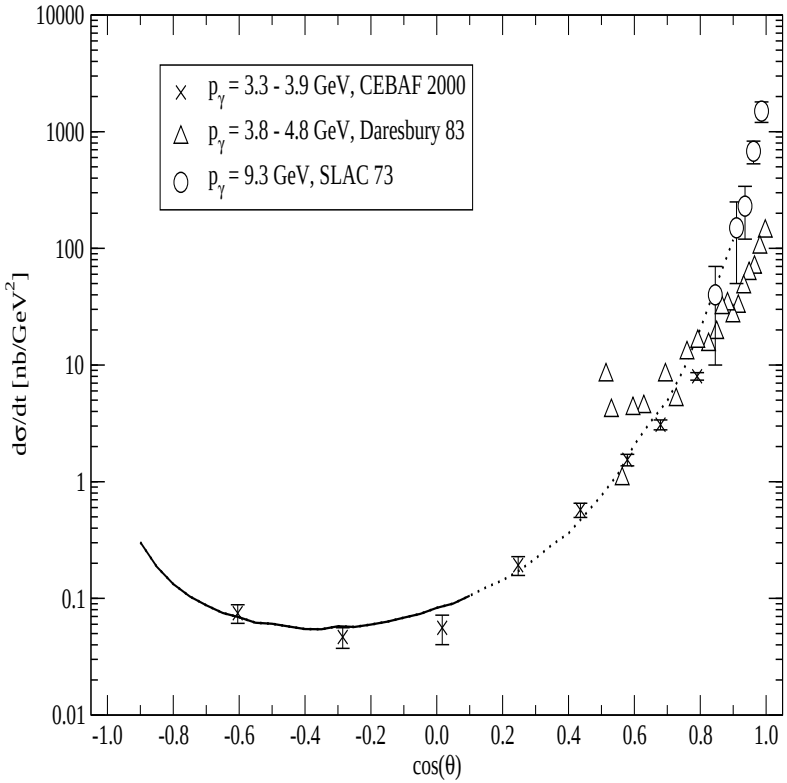
This means that the hard scattering amplitude is weighted with corresponding probability distribution amplitudes of each hadron participating in the scattering process

Φ Production



Contribution of class I (dotted) and class II (dashed-dotted) graphs to our predictions for $d\sigma_{\gamma p \to \Phi p}/dt$ at $p_\gamma^{(lab)} = 9.3 GeV$. For comparison the complete calculation (class I and II) is also shown (solid line).

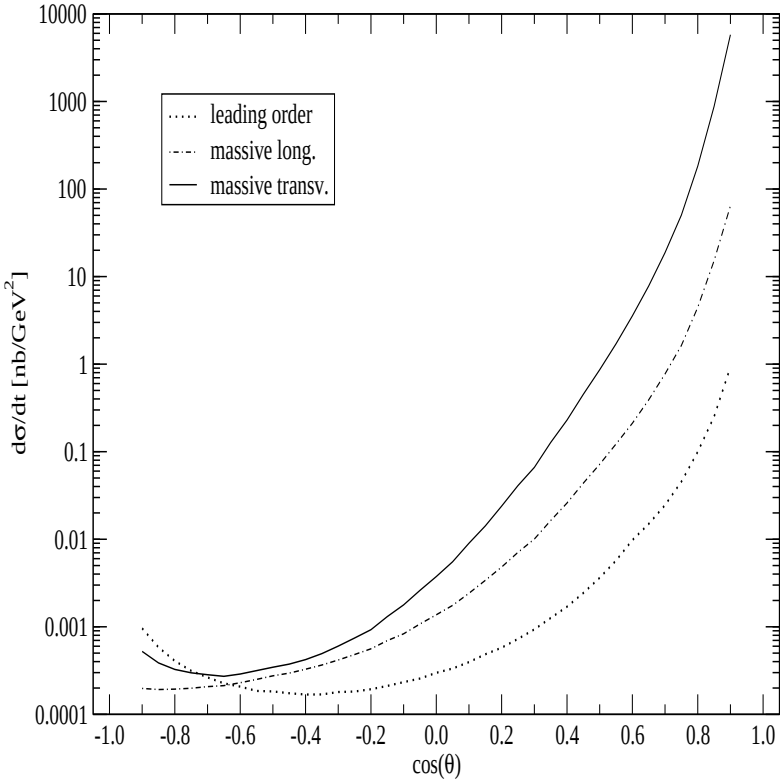
Φ Production



Our predictions for $d\sigma_{\gamma p \to \Phi p}/dt$ at $p_\gamma^{(lab)} = 9.3 GeV$ in comparison with SLAC, Daresbury and CEBAF data. (Daresbury and CEBAF scaled to $p_\gamma^{(lab)} = 9.3 GeV$.)

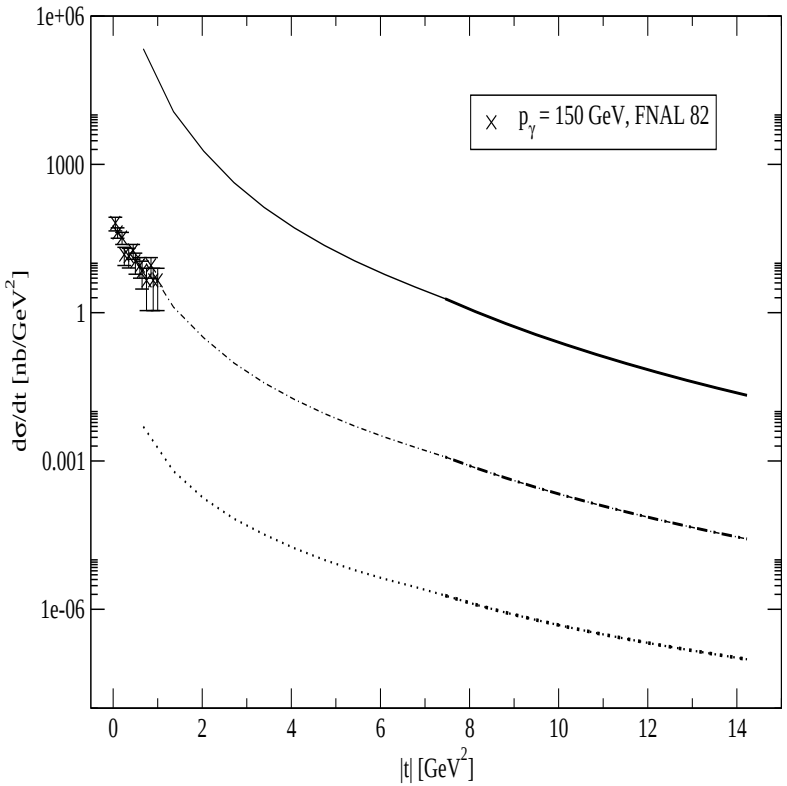
Solid part of the curve corresponds to $\alpha_S \leq 0.5$, for the rest $0.5 \leq \alpha_S \leq 0.7$.

J/Ψ Production



The influence of mass effects over the whole angular range. Calculations performed at $p_\gamma^{(lab)} = 20GeV$. Cross section for $\lambda_{J/\Psi} = 0$ without (dotted) and with (dashed-dotted) J/Ψ mass is compared to cross section for $\lambda_{J/\Psi} = \pm 1$ (solid line).

J/Ψ Production



Our predictions for $d\sigma_{\gamma p \to J/\Psi p}/dt$ at $p_\gamma^{(lab)} = 150 GeV$ in comparison with FNAL data. Cross section for $\lambda_{J/\Psi} = 0$ without (dotted) and with (dashed-dotted) J/Ψ mass is compared to full cross section (solid line).

Conclusions

- Good (indirect) reproduction of Φ photoproduction data by our perturbative results.
- Photoproduction at large $|t|$ dominated by class II graphs.
- For J/Ψ the c-quark has been taken into account in the constituents' kinematics.
- Mass effects are crucial and raise the cross section nearly over the whole angular range.
- Finite c-mass $\rightarrow$ longitudinally and transversely polarized J/Ψs can be produced.
- $\lambda_{J/\Psi} = \pm 1$ amplitudes (which come as mass effects) even dominate.

Thank You!