



Exclusive photoproduction of dileptons at high energy

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Outline

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- Phenomenology for γp process (dipole cross sections)
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Motivation

- Recently, **electromagnetic interactions** in pp and AA collisions extend the physics program of **photon induced** processes beyond energies reached at DESY-HERA.
- LHC detector configurations can explore **small- x hard phenomena** with nuclei and nucleons at photon-nucleon energies **above 1 TeV**.
- Possible to probe **diffractive/inclusive PDFs** in nuclei using several processes: for instance, the interaction of **small dipoles** with protons/nuclei can be investigated in **diffractive meson production** (J/ψ , Υ and high t ρ^0).
- Electromagnetic interactions can also be studied with beams of p or \bar{p} , but there is then no **Z^2 -enhancement** in the photon flux in contrast to AA collisions.

Motivation

- Several analysis on central exclusive production are currently being done at **Tevatron** (see **M. Albrow's talk**):
- For instance, CDF is analyzing the **exclusive production** of **muon pairs** at lower invariant masses.
- The two main contributions to these events are, as with heavy-ion beams, $\gamma\gamma \rightarrow \mu^+ + \mu^-$ and $\gamma + IP \rightarrow J/\Psi$ (or Ψ').
- Here, we use color dipole approach (valid at high energies) to study the exclusive photoproduction of lepton pairs, $\gamma N \rightarrow \gamma^*(\rightarrow \ell^+ \ell^-) N$ (with $N = p, A$). Such a process could be a **contribution** for lepton pair production.
- Use of recent models for elementary **dipole-hadron scattering amplitude** that capture main features of the dependence on A , energy and momentum transfer t .

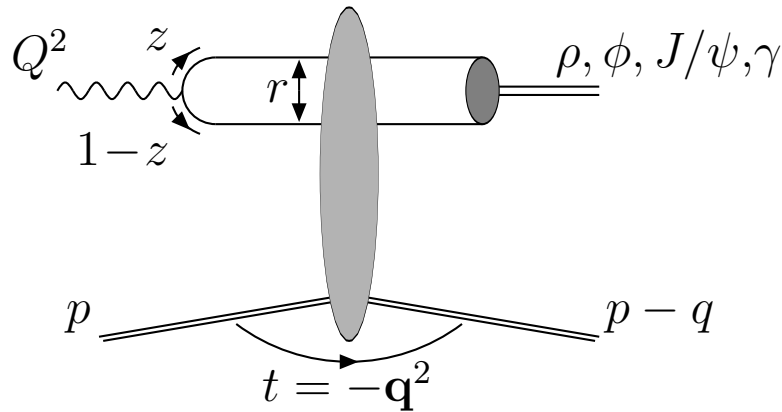
Timelike Compton scattering

- Conventional partonic description of **timelike Compton scattering** (TCS), $\gamma + p \rightarrow \gamma^* + p$, considers the relevant **generalized parton distributions** (GPDs).
- TCS process has been studied at **LO** in the **collinear factorization framework** in terms of the **quark GPDs** and sub-processes initiated by quarks (handbag diagrams).
- E.R. Berger, M. Diehl and B. Pire (2002). B. Pire, L. Szymanowski and J. Wagner, arXiv:0805.1589.
- **TCS** process at small t and large timelike virtuality of the outgoing photon **shares** many features of **DVCS**, $\gamma^* p \rightarrow \gamma p$.
- Here, we use alternative framework . . .

TCS on the dipole approach

- **Color dipole approach** provides good description of data on γp inclusive/diffractive processes at small- x region.
- In particular, **deeply virtual Compton scattering (DVCS)** cross section is nicely reproduced in several implementations of the dipole cross section.
- In **dipole frame** TCS process proceeds in **three stages**:
- **(1)** first the incoming real photon fluctuates into a $q\bar{q}$ pair, **(2)** then this pair scatters elastically on the proton, and finally **(3)** the $q\bar{q}$ pair recombines to form a virtual photon (which subsequently decays into lepton pairs).
- We can use current **rich phenomenology** at small- x region.

TCS on dipole approach



$$\mathcal{A}^{\gamma p \rightarrow \gamma^* p} = \sum_f \sum_{h, \bar{h}} \int d^2 r \int_0^1 dz \Psi_{h\bar{h}}^*(r, z, Q) \mathcal{A}_{q\bar{q}}(x, r, \Delta) \Psi_{h\bar{h}}(r, z, 0)$$

- $\Psi_{h\bar{h}}(r, z, Q)$ denotes the amplitude for a photon to fluctuate into a $q\bar{q}$ dipole with helicities h and \bar{h} and flavor f .
- $\mathcal{A}_{q\bar{q}}(x, r, \Delta)$ is the elementary amplitude for the scattering of a dipole of size r on the proton, Δ is the transverse momentum lost by the outgoing proton (with $t = -\Delta^2$), x is the scaling variable and Q^2 is the photon virtuality.

TCS on dipole approach

- Summed over the quark helicities, for a given quark flavour f one obtains for corresponding **overlap** function,

$$\begin{aligned} (\Psi_{\gamma^*}^* \Psi_{\gamma})_T^f &= \frac{N_c \alpha_{\text{em}} e_f^2}{2\pi^2} \{ [z^2 + \bar{z}^2] \varepsilon_1 K_1(\varepsilon_1 r) \varepsilon_2 K_1(\varepsilon_2 r) \\ &+ m_f^2 K_0(\varepsilon_1 r) K_0(\varepsilon_2 r) \} \end{aligned}$$

- Quantities $\varepsilon_{1,2} = \sqrt{z\bar{z} Q_{1,2}^2 + m_f^2}$ and $\bar{z} = (1 - z)$.
- Accordingly, the photon virtualities are $Q_1^2 = 0$ (incoming real photon) and $Q_2^2 = -Q^2$ (outgoing virtual photon).
- The **elastic diffractive cross section** is then given by,

$$\frac{d\sigma^{\gamma p \rightarrow \gamma^* p}}{dt} = \frac{1}{16\pi} \left| \mathcal{A}^{\gamma p \rightarrow \gamma^* p}(x, Q, \Delta) \right|^2$$

Elementary dipole scattering amplitude

- We consider the **non-forward saturation model** (C. Marquet, R. Peschanski and G. Soyez (2007) - MPS model), which gives directly the t dependence.

$$A_{q\bar{q}}(x, r, \Delta) = 2\pi R_p^2 e^{-B|t|} N(rQ_{\text{sat}}(x, |t|), x)$$

- The t dependence of the **saturation scale** is parametrised as

$$Q_{\text{sat}}^2(x, |t|) = Q_0^2 (1 + c|t|) \left(\frac{1}{x}\right)^\lambda$$

- The scaling function N is:

$$N(x, r) = \begin{cases} \mathcal{N}_0 \left(\frac{r^2 Q_{\text{sat}}^2}{4}\right)^{\gamma_{\text{eff}}(x, r)}, & \text{for } rQ_{\text{sat}} \leq 2, \\ 1 - \exp[-a \ln^2(brQ_{\text{sat}})] , & \text{for } rQ_{\text{sat}} > 2, \end{cases}$$

where $\gamma_{\text{eff}}(x, r) = \gamma_{\text{sat}} + \frac{\ln(2/\tilde{\tau})}{\kappa \lambda Y}$ ($\gamma_{\text{sat}} = 0.63$ or free).

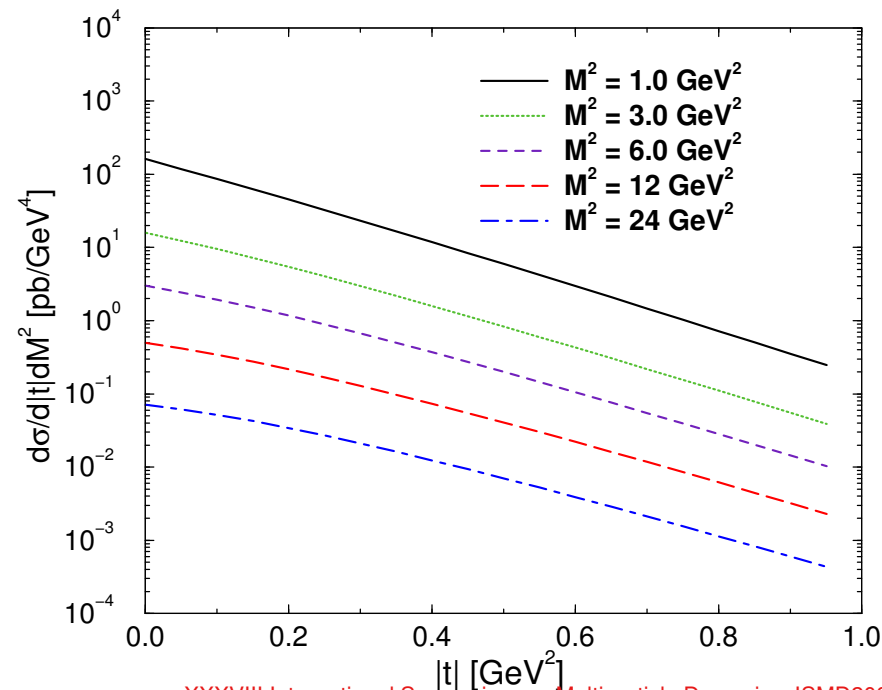
Technicalities and approximations . . .

- The quark-antiquark **light-cone wavefunctions** of **timelike photons** has been derived recently by **L. Motyka and G. Watt (2008)**.
- It was shown that is needed to deal with **imaginary arguments** for the modified Bessel functions and this fact leads to **wildly oscillatory r -integrand**.
- In the following calculations, (incorrect) **space-like kinematics** is used and we expect that the numeric impact of this procedure to be reasonably small.

Phenomenology for TCS at high energies

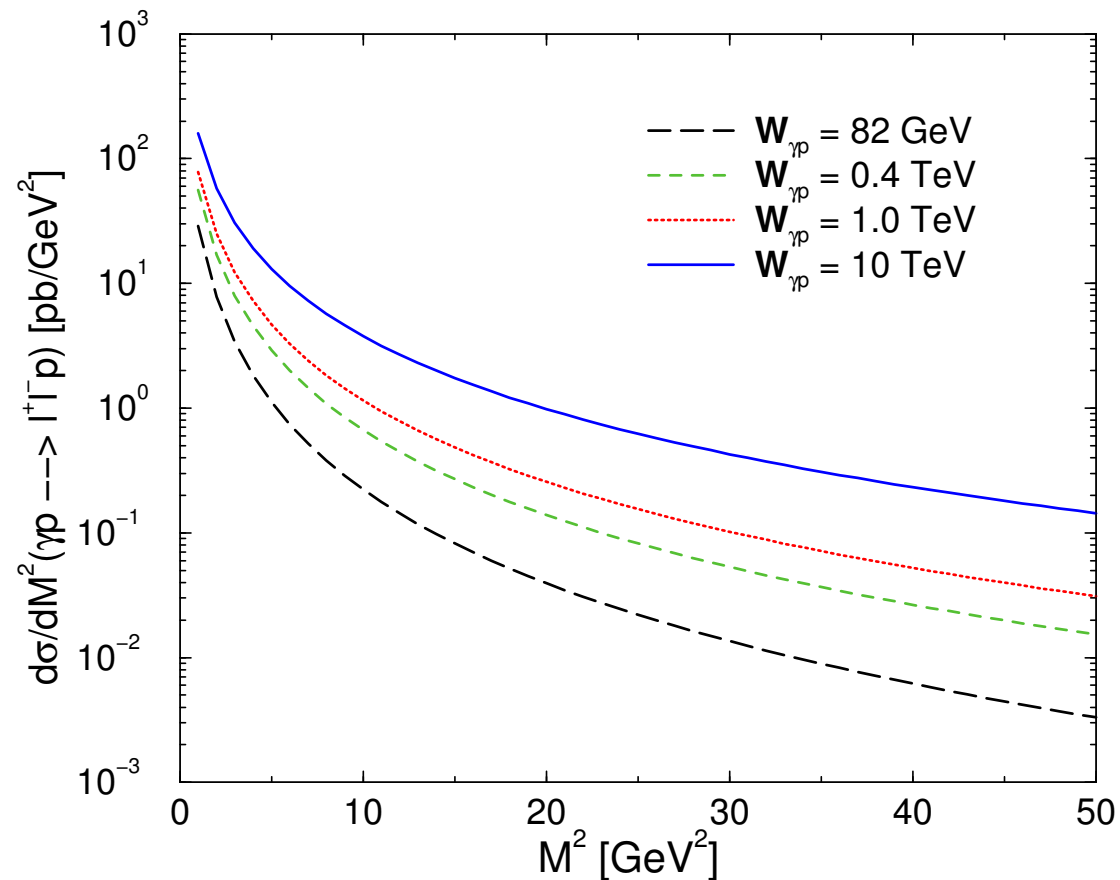
- We investigate the exclusive photoproduction of a heavy timelike photon which decays into a lepton pair, $\gamma p \rightarrow \ell^+ \ell^- p$.
- Therefore, for the $\ell^+ \ell^-$ invariant mass distribution from the virtual γ^* decay we have (with $Q^2 = M_{\ell^+ \ell^-}^2$),

$$\frac{d\sigma}{dM_{\ell^+ \ell^-}^2} (\gamma p \rightarrow \ell^+ \ell^- p) = \frac{\alpha_{em}}{3\pi M_{\ell^+ \ell^-}^2} \sigma (\gamma p \rightarrow \gamma^* p)$$



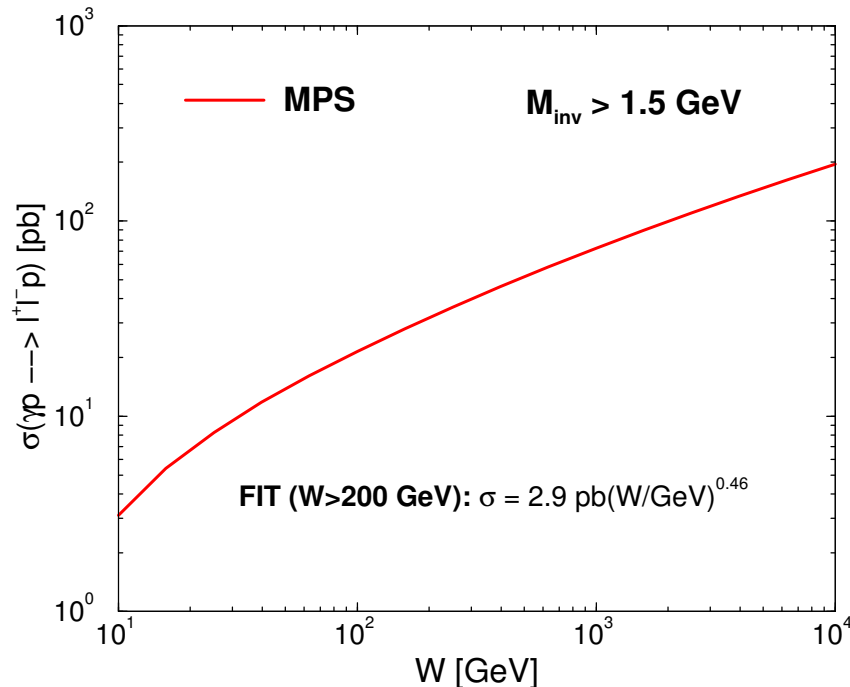
More results . . .

- Differential cross section, $d\sigma/dM^2$, as a function of dilepton invariant mass for fixed values of energy (integrated over $|t| < 1 \text{ GeV}^2$).



More results . . .

- Integrated cross section ($M_{e+e-} \geq 1.5 \text{ GeV}$ and $|t| \leq 1 \text{ GeV}^2$) as a function of photon-nucleon energy.



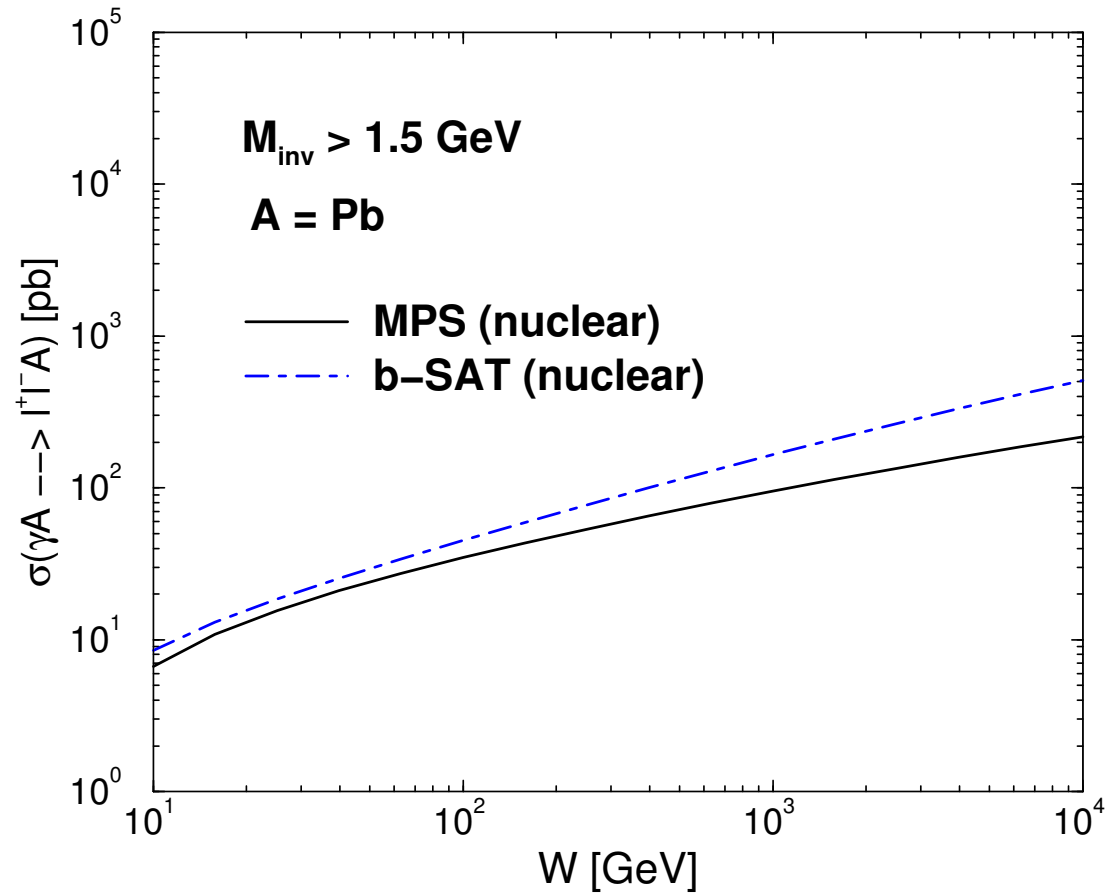
- Calculations using other saturation models are distinct mostly at low energy (different threshold behavior) and extrapolation to very high energy (different saturation scales/QCD evolutions).

Phenomenology for nuclear targets

- We consider now the process $\gamma A \rightarrow \gamma^* (\rightarrow \ell^+ \ell^-) A$ which is the **coherent contribution** to nuclear TCS, where the nucleus remains intact.
- Following **geometric scaling** arguments, for MPS model we take $R_p \rightarrow R_A$ and $Q_{\text{sat},p}^2(x, t = 0) \rightarrow (AR_p^2/R_A^2)^\Delta Q_{\text{sat},p}^2$.
- When $\Delta = 1$ such a replacement becomes the usual assumption for nuclear saturation scale, $Q_{\text{sat},A}^2 = A^{1/3} Q_{\text{sat},p}^2$.
- For simplicity, we replace the form factor $F(t) = \exp(-B|t|)$ by corresponding nuclear form factor $F_A(t) = \exp(-\frac{R_A^2}{6}|t|)$.
- In order to check procedure, we compare it with nuclear version of impact parameter saturation model (H. Kowalski, L. Motyka and G. Watt (2006) - b-SAT).

Numerical results . . .

- The photonuclear cross section per nucleon as a function of energy for a lead nucleus.



Dilepton photoproduction on pp collision

- Photoproduction of dileptons can be computed for pp collisions using equivalent-photon approximation.
- Such processes are characterized by the photon-hadron interaction, with the photon stemming from the electromagnetic field of one of the two colliding hadrons.
- Cross section for the $hh \rightarrow h \otimes \ell^+ \ell^- \otimes h$ process is:

$$\frac{d^2\sigma}{d\omega dM_{\ell^+\ell^-}^2}(hh \rightarrow \ell^+\ell^- hh) = 2 \frac{dN_\gamma}{d\omega} \frac{d\sigma}{dM_{\ell^+\ell^-}^2}(\gamma h \rightarrow \ell^+\ell^- h),$$

- ω is the photon energy and $\frac{dN_\gamma}{d\omega}$ is the equivalent flux of photons from a charged hadron.
- Moreover, γ_L is the Lorentz boost of a single beam, $W_{\gamma h}^2 = 2\omega\sqrt{S_{NN}}$ and $\sqrt{S_{NN}}$ is the c.m.s energy of the hadron-hadron system.

Numerical results

Collider	$(M_{\ell^+\ell^-} > 1.2 \text{ GeV})$	$(3 < M_{\ell^+\ell^-} < 4 \text{ GeV})$
Tevatron	7 pb	400 fb
LHC	25 pb	—

- Rough estimation of cross section.
- Very small cross sections compared to contribution from two-photon process and vector meson decays.
- For instance, $\sigma(p\bar{p} \rightarrow p\bar{p} + \mu^+\mu^- [M_{inv} > 1.5 \text{ GeV}]) = 2.4 \text{ nb}$ [J. Nystrand (2007)].

Summary

- Using the color dipole formalism, dilepton photoproduction was investigated. Such an approach is robust in describing a wide class of exclusive processes at small- x .
- Using current phenomenology for the elementary dipole-hadron scattering, we estimate the order of magnitude of the exclusive photoproduction of lepton pairs.
- We also investigate the photonuclear cross section, focusing on the nuclear coherent scattering.
- These calculations can be used to compute dilepton photoproduction in pp (small cross section) and AA .