Can one measure timelike Compton scattering at LHC ?

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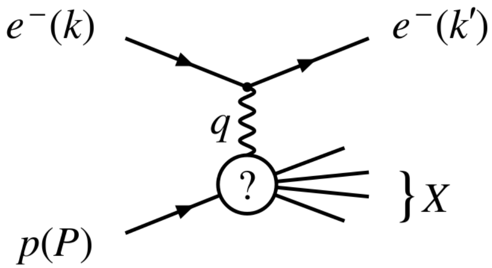
Introduction.

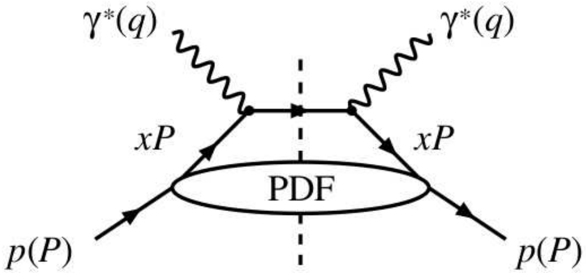
- What is TCS, and why it is important?
- What are Genaralized Parton Distributions and why they are important?
- What does it have to do with LHC?

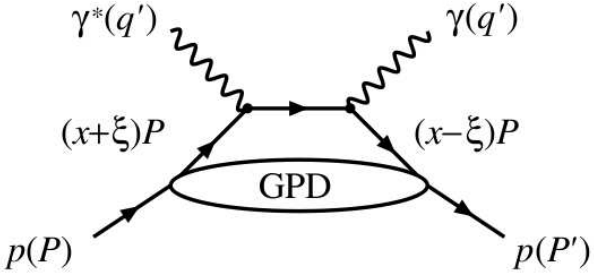
Factorization

- DIS



- DIS vs. DVCS





- factorization:

$$\begin{aligned} \text{DIS} \quad &: \quad \sigma = [\text{PDF}] \otimes [\text{partonic cross section}] \\ \text{DVCS} \quad &: \quad \mathcal{M} = [\text{GPD}] \otimes [\text{partonic amplitude}]. \end{aligned}$$

Generalized Parton Distributions

- GDPs enters factorization theorems for hard exlusive reactions (DVCS, deeply virtual meson production etc.), in a similar manner as PDFs enter factorization theorem for DIS.
- GPDs are functions of **three** kinematical variables: longitudal momentum fraction x, longitudinal momentum transfer ξ and overall momentum transfer t.
- In the forward limit: $t, \xi \to 0$, GPDs reduce to PDFs.
- When integrated over x, GPDs reduce to elastic form factors.
- First moment of GPDs, enter the Ji's sum rule for the angular momentum carried by partons in the nucleon.
- Fourier transform of GPD's to impact parameter space can be interpreted as ,,tomographic" 3D pictures of nucleon, describing charge distribution in the transverse plane, for a given value of x.

Exclusive photoproduction of dileptons, $\gamma N \to \ell^+\ell^- N$

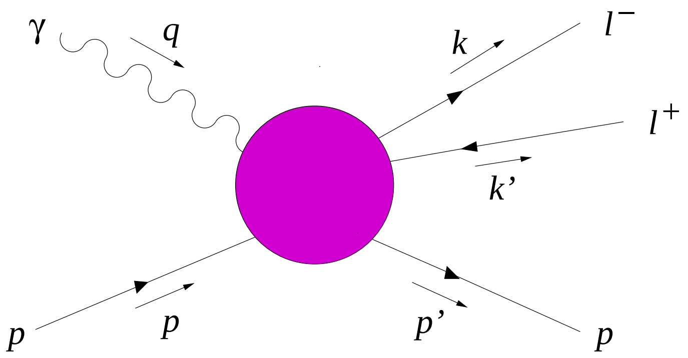
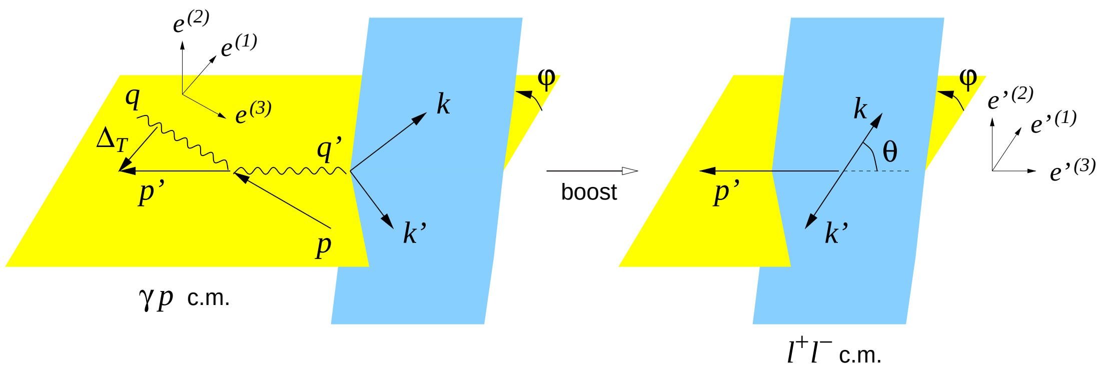


Figure 1: Real photon-proton scattering into a lepton pair and a proton.



Timelike Compton Scattering

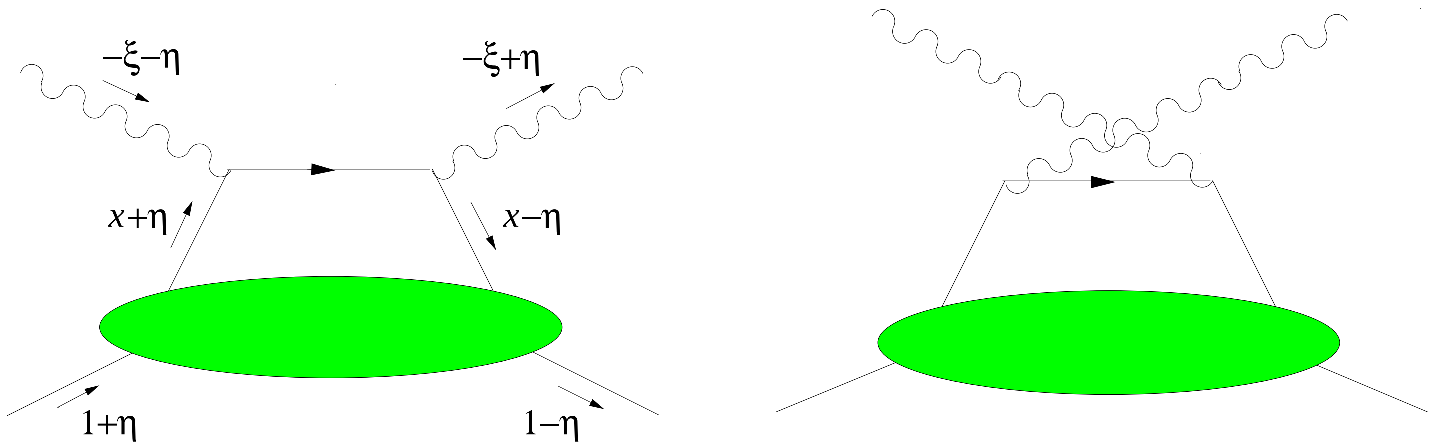


Figure 2: Handbag diagrams for the Compton process in the scaling limit. The plus-momentum fractions x, ξ, η refer to the average proton momentum $\frac{1}{2}(p+p')$.

$$T^{\alpha\beta} = -\frac{1}{(p+p')^+}\bar{u}(p')\left[g_T^{\alpha\beta}\left(\mathcal{H}\gamma^+ + \mathcal{E}\frac{i\sigma^{+\rho}\Delta_\rho}{2M}\right) + i\epsilon_T^{\alpha\beta}\left(\tilde{\mathcal{H}}\gamma^+\gamma_5 + \tilde{\mathcal{E}}\frac{\Delta^+\gamma_5}{2M}\right)\right]u(p)$$

Factorization

$$\mathcal{H}(\xi,\eta,t) = \sum_q e_q^2 \int_{-1}^{1} \mathrm{d}x \left(\frac{1}{\xi - x - i\epsilon} - \frac{1}{\xi + x - i\epsilon}\right) H^q(x,\eta,t)$$

$$\mathcal{E}(\xi,\eta,t) = \sum_q e_q^2 \int_{-1}^{1} \mathrm{d}x \left(\frac{1}{\xi - x - i\epsilon} - \frac{1}{\xi + x - i\epsilon}\right) E^q(x,\eta,t)$$

$$\tilde{\mathcal{H}}(\xi,\eta,t) = \sum_q e_q^2 \int_{-1}^{1} \mathrm{d}x \left(\frac{1}{\xi - x - i\epsilon} + \frac{1}{\xi + x - i\epsilon}\right) \tilde{H}^q(x,\eta,t)$$

$$\tilde{\mathcal{E}}(\xi,\eta,t) = \sum_q e_q^2 \int_{-1}^{1} \mathrm{d}x \left(\frac{1}{\xi - x - i\epsilon} + \frac{1}{\xi + x - i\epsilon}\right) \tilde{H}^q(x,\eta,t)$$

$$\frac{\mathrm{d}\sigma_{TCS}}{\mathrm{d}Q'^2\mathrm{d}\Omega\mathrm{d}t} \approx \frac{\alpha^3}{8\pi}\frac{1}{s^2}\frac{1}{Q'^2}\left(\frac{1+\cos^2\theta}{4}\right) 2(1-\eta^2)\left(|\mathcal{H}|^2 + |\tilde{\mathcal{H}}|^2\right)$$

Bethe-Heitler process

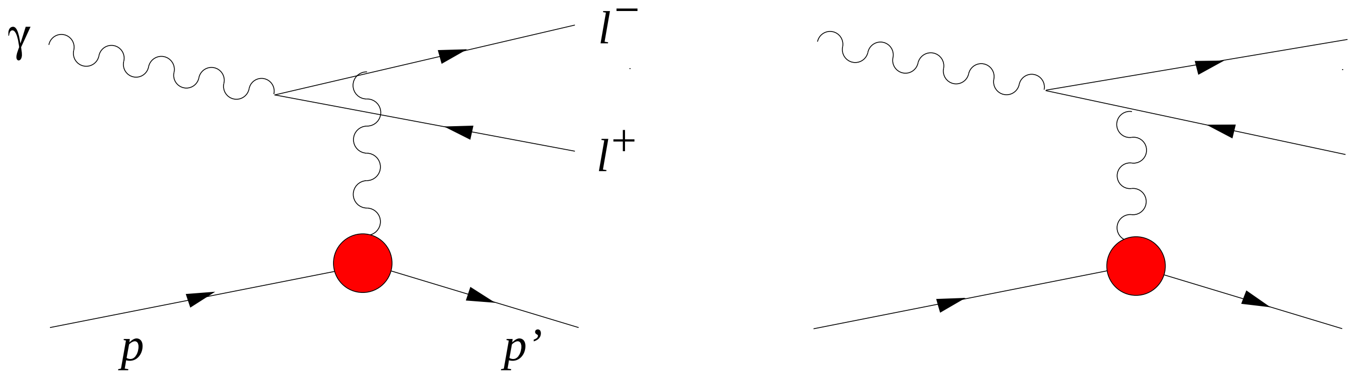


Figure 3: The Feynman diagrams for the Bethe-Heitler amplitude.

$$\frac{d\sigma_{BH}}{dQ'^2 d\Omega dt} \longrightarrow \frac{\alpha^3}{4\pi} \frac{1}{-tL} (1+\cos^2\theta) \left(F_1^2 - \frac{t}{4M_p^2} F_2^2 \right)$$

Interference

$$\frac{d\sigma_{INT}}{dQ'^2\,dt\,d\cos\theta\,d\varphi} = -\frac{\alpha_{em}^3}{4\pi s^2}\,\frac{1}{-t}\,\frac{M}{Q'}\,\frac{1}{\tau\sqrt{1-\tau}}\,\cos\varphi\frac{1+\cos^2\theta}{\sin\theta}\mathrm{Re}\,\tilde{M}^{--}$$

with

$$\tilde{M}^{--} = \frac{2\sqrt{t_0-t}}{M}\,\frac{1-\eta}{1+\eta}\left[F_1\mathcal{H}_1 - \eta(F_1+F_2)\,\tilde{\mathcal{H}}_1 - \frac{t}{4M^2}\,F_2\,\mathcal{E}_1\right]$$

Since the amplitudes for the Compton and Bethe-Heitler processes transform with opposite signs under reversal of the lepton charge, the interference term between TCS and BH is odd under exchange of the ℓ^+ and ℓ^- momenta. It is thus possible to project out the interference term through a clever use of the angular distribution of the lepton pair.

Cross sections

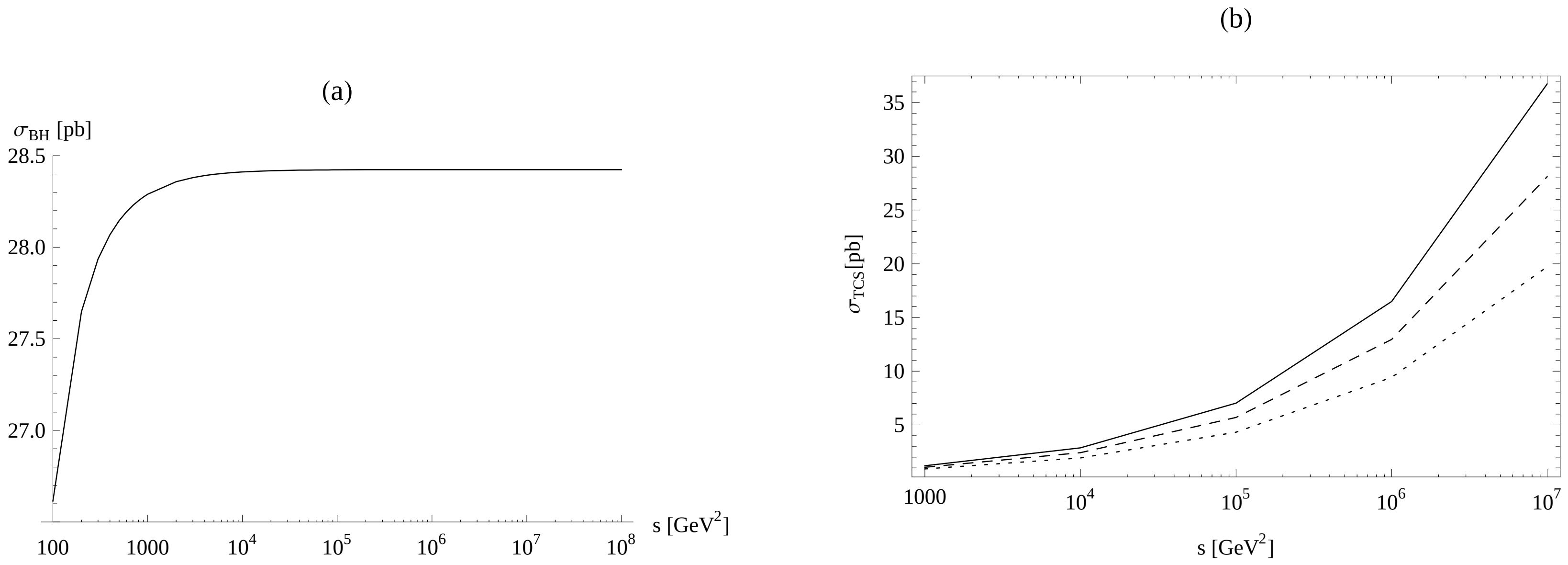
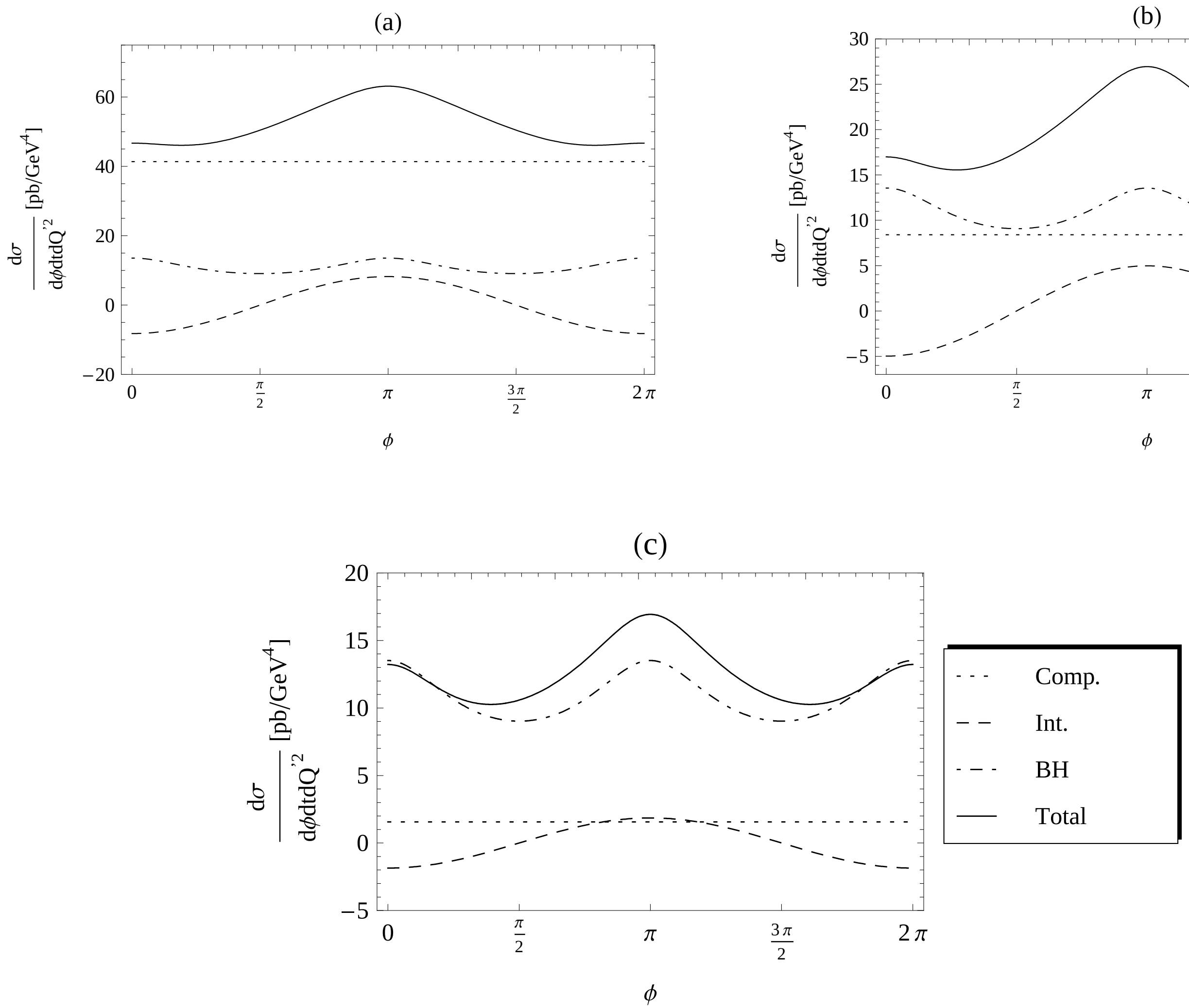


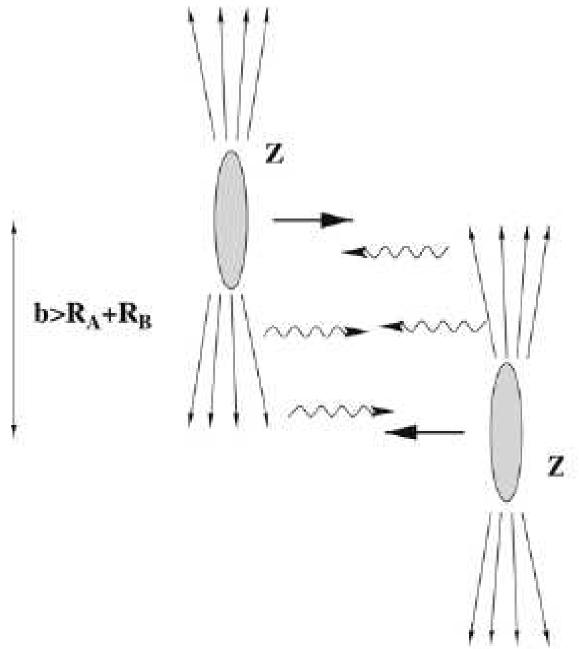
Figure 4: (a) The BH cross section integrated over $\theta \in [\pi/4, 3\pi/4]$, $\varphi \in [0, 2\pi]$, $Q'^2 \in [4.5, 5.5]\,\mathrm{GeV}^2$, $|t| \in [0.05, 0.25]\,\mathrm{GeV}^2$, as a function of γp c.m. energy squared s. (b) σ_{TCS} as a function of γp c.m. energy squared s, for GRVGJR2008 NLO parametrizations, for different factorization scales $\mu_F^2 = 4$ (dotted), 5 (dashed), 6 (solid) GeV^2.

Angular distributions



Hadron colliders as photon colliders.

Ultraperipherical collisions:



Effective photon approximation

$$\sigma_{pp} = 2 \int \frac{dn(k)}{dk} \sigma_{\gamma p}(k) dk$$

$$s \approx 2\sqrt{s_{pp}} k$$

The pure Bethe - Heitler contribution to σ_{pp}, integrated over $\theta = [\pi/4, 3\pi/4]$, $\phi = [0, 2\pi]$, $t = [-0.05\,\mathrm{GeV}^2, -0.25\,\mathrm{GeV}^2]$, ${Q'}^2 = [4.5\,\mathrm{GeV}^2, 5.5\,\mathrm{GeV}^2]$, and photon energies $k = [20, 900]\,\mathrm{GeV}$ gives:

$$\sigma_{pp}^{BH} = 2.9\,\mathrm{pb}\ . \tag{1}$$

The Compton contribution (calculated with NLO GRVGJR2008 PDFs, and $\mu_F^2 = 5\,\mathrm{GeV}^2$) gives:

$$\sigma_{pp}^{TCS} = 1.9\,\mathrm{pb}\ . \tag{2}$$

- The range of photon energies - expected capabilities to tag photon energies at the LHC.
- 10^5 events/year at the LHC with its nominal luminosity ($10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$).

Summary

- Compton scattering in ultraperipheral collisions at hadron colliders opens a new way to measure generalized parton distributions.
- Sizeble rates even for the lower luminosity which can be achieved in the first months of run.
- Our work has to be supplemented by studies of higher order contributions which will involve the gluon GPDs; they will hopefully lead to a weaker factorization scale dependence of the amplitudes.