Timelike Compton Scattering and related processes

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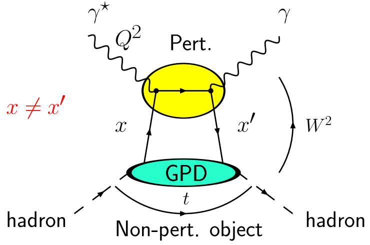
Processes



- Universality of GPDs,
- Meson production - additional difficulties,

So, in addition to spacelike DVCS ...

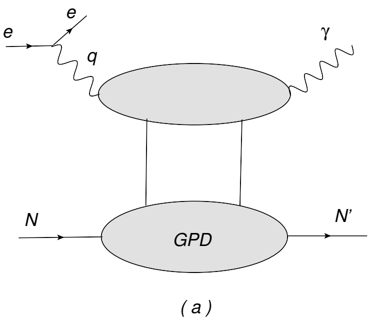


Figure: Deeply Virtual Compton Scattering (DVCS) : $lN \to l'N'\gamma$

we can also study timelike DVCS

Berger, Diehl, Pire, 2002

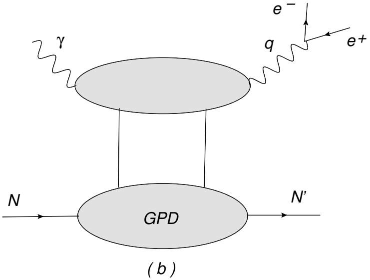


Figure: Timelike Compton Scattering (TCS): $\gamma N \to l^+ l^- N'$

Why TCS:

- universality of the GPDs
- another source for GPDs (special sensitivity on real part of GPD H),
- spacelike-timelike crossing (different analytic structure - additional cut in Q^2)

General Compton Scattering:

$$\gamma^*(q_{in})N(p) \to \gamma^*(q_{out})N'(p')$$

variables, describing the processes of interest in this generalized Bjorken limit, are the scaling variable ξ and skewness $\eta > 0$:

$$\xi = -\frac{q_{out}^2 + q_{in}^2}{q_{out}^2 - q_{in}^2}\eta\,, \quad \eta = \frac{q_{out}^2 - q_{in}^2}{(p+p')\cdot(q_{in}+q_{out})}\,.$$

- DDVCS: $q_{in}^2 < 0\,, \quad q_{out}^2 > 0\,, \quad \eta \neq \xi$
- DVCS: $q_{in}^2 < 0\,, \quad q_{out}^2 = 0\,, \quad \eta = \xi > 0$
- TCS: $q_{in}^2 = 0\,, \quad q_{out}^2 > 0\,, \quad \eta = -\xi > 0$

Coefficient functions and Compton Form Factors

CFFs are the GPD dependent quantities which enter the amplitudes. They are defined through relations:

$$\mathcal{A}^{\mu\nu}(\xi,\eta,t) = -e^2 \frac{1}{(P+P')^+}\,\bar{u}(P')\Big[g_T^{\mu\nu}\left(\mathcal{H}(\xi,\eta,t)\,\gamma^+ + \mathcal{E}(\xi,\eta,t)\,\frac{i\sigma^{+\rho}\Delta_\rho}{2M}\right) + i\epsilon_T^{\mu\nu}\left(\widetilde{\mathcal{H}}(\xi,\eta,t)\,\gamma^+\gamma_5 + \widetilde{\mathcal{E}}(\xi,\eta,t)\,\frac{\Delta^+\gamma_5}{2M}\right)\Big] u(P)\,,$$

,where:

$$\begin{aligned}
\mathcal{H}(\xi,\eta,t) &= +\int_{-1}^{1} dx \left(\sum_q T^q(x,\xi,\eta)H^q(x,\eta,t) + T^g(x,\xi,\eta)H^g(x,\eta,t)\right) \\
\widetilde{\mathcal{H}}(\xi,\eta,t) &= -\int_{-1}^{1} dx \left(\sum_q \widetilde{T}^q(x,\xi,\eta)\widetilde{H}^q(x,\eta,t) + \widetilde{T}^g(x,\xi,\eta)\widetilde{H}^g(x,\eta,t)\right).
\end{aligned}$$

LO

- DVCS vs TCS

$$
\begin{aligned}
{}^{DVCS}T^q &= -e_q^2 \tfrac{1}{x+\eta-i\varepsilon} - (x \to -x) = \quad ({}^{TCS}T^q)^* \\
{}^{DVCS}\tilde{T}^q &= -e_q^2 \tfrac{1}{x+\eta-i\varepsilon} + (x \to -x) = \quad -({}^{TCS}\tilde{T}^q)^*
\end{aligned}
$$

$$
{}^{DVCS}Re(\mathcal{H}) \sim P\int \frac{1}{x \pm \eta} H^q(x,\eta,t)\,, \qquad {}^{DVCS}Im(\mathcal{H}) \sim i\pi H^q(\pm\eta,\eta,t)
$$

- DDVCS

$$
{}^{DDVCS}T^q = -e_q^2 \frac{1}{x+\xi-i\varepsilon} - (x \to -x)
$$

$$
{}^{DDVCS}Re(\mathcal{H}) \sim P\int \frac{1}{x \pm \xi} H^q(x,\eta,t)\,, \qquad {}^{DVCS}Im(\mathcal{H}) \sim i\pi H^q(\pm\xi,\eta,t)
$$

But this is only true at LO. At NLO all GPDs hidden in the convolutions.
Digression: $\log(\frac{Q^2-Q'^2}{\mu_F^2})$ in DDVCS?

Coefficient functions

Renormalized coefficient functions for DVCS are given by

$$
\begin{aligned}
T^q(x) &= \left[C_0^q(x) + C_1^q(x) + \ln\left(\frac{Q^2}{\mu_F^2}\right) \cdot C_{coll}^q(x)\right] - (x \to -x)\,, \\
T^g(x) &= \left[C_1^g(x) + \ln\left(\frac{Q^2}{\mu_F^2}\right) \cdot C_{coll}^g(x)\right] + (x \to -x)\,, \\
\widetilde{T}^q(x) &= \left[\widetilde{C}_0^q(x) + \widetilde{C}_1^q(x) + \ln\left(\frac{Q^2}{\mu_F^2}\right) \cdot \widetilde{C}_{coll}^q(x)\right] + (x \to -x)\,, \\
\widetilde{T}^g(x) &= \left[\widetilde{C}_1^g(x) + \ln\left(\frac{Q^2}{\mu_F^2}\right) \cdot \widetilde{C}_{coll}^g(x)\right] - (x \to -x)\,.
\end{aligned}
$$

The results for DVCS and TCS cases are simply related:

$$
{}^{TCS}T(x,\eta) = \pm\left({}^{DVCS}T(x,\xi=\eta) + i\pi \cdot C_{coll}(x,\xi=\eta)\right)^{*}\,,
$$

D.Mueller, B.Pire, L.Szymanowski, J.Wagner, Phys.Rev.D86, 2012.

where $+$ $(-)$ sign corresponds to vector (axial) case.

Exclusive Drell-Yann

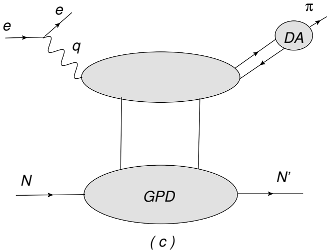


Figure: DVMP

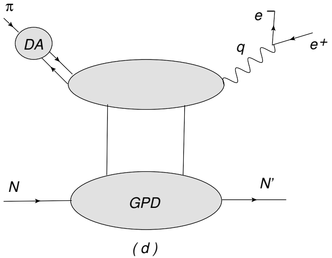


Figure: Exclusive Drell-Yan

Compton Form Factors - DVCS - $Im(\mathcal{H})$

H. Moutarde, B. Pire, F. Sabatié, L. Szymanowski and JW - Phys. Rev. D87 (2013),

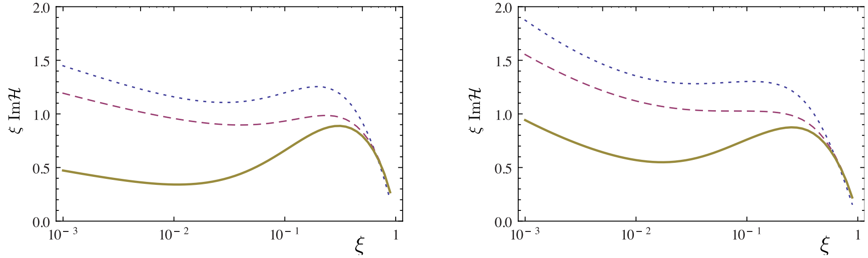


Figure: The imaginary part of the *spacelike* Compton Form Factor $\mathcal{H}(\xi)$ multiplied by ξ, as a function of ξ in the double distribution model based on Kroll-Goloskokov (upper left) and MSTW08 (upper right) parametrizations, for $\mu_F^2 = Q^2 = 4\,\mathrm{GeV}^2$ and $t = -0.1\,\mathrm{GeV}^2$, at the Born order (dotted line), including the NLO quark corrections (dashed line) and including both quark and gluon NLO corrections (solid line).

Compton Form Factors - TCS - $Re(\mathcal{H})$

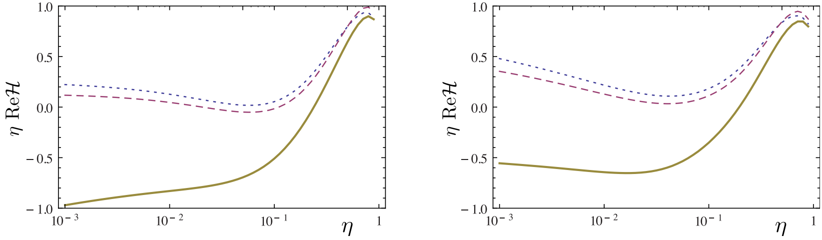


Figure: The real part of the *timelike* Compton Form Factor $\mathcal{H}$ multiplied by η, as a function of η in the double distribution model based on Kroll-Goloskokov (upper left) and MSTW08 (upper right) parametrizations, for $\mu_F^2 = Q^2 = 4$ GeV^2 and $t = -0.1$ GeV^2. Below the ratios of the NLO correction to LO result of the corresponding models.

Few words about factorization scale.

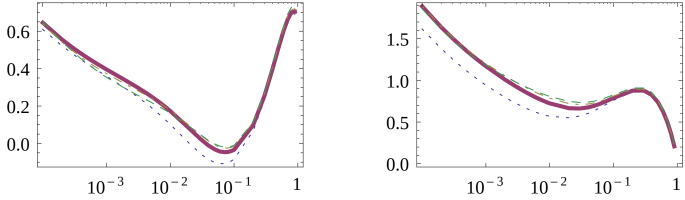


Figure: Full NLO result for DVCS. Left column - $\xi \cdot Re(\mathcal{H}(\xi))$, right column - $\xi \cdot Im(\mathcal{H}(\xi))$, $Q^2 = 4\,\mathrm{GeV}^2$, $\mu_F^2 = Q^2, Q^2/2, Q^2/3$

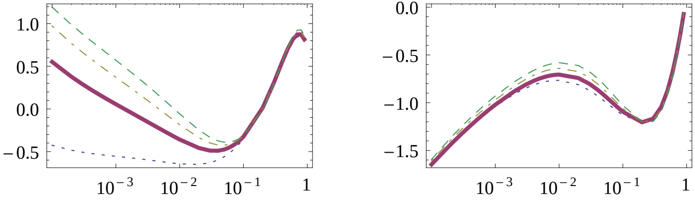


Figure: Full NLO result for TCS. Left column - $\xi \cdot Re(\mathcal{H}(\xi))$, right column - $\xi \cdot Im(\mathcal{H}(\xi))$, $Q^2 = 4\,\mathrm{GeV}^2$, $\mu_F^2 = Q^2, Q^2/2, Q^2/3$

Digression: J/ψ photoproduction cross section

Ivanov, Pire, Szymanowski, Wagner, EPJ Web Conf. 112 (2016) 01020, arXiv:1601.07338

NLO/LO for large W:

$$\sim \frac{\alpha_S(\mu_R)N_c}{\pi} \ln\left(\frac{1}{\xi}\right) \ln\left(\frac{\frac{1}{4}M_V^2}{\mu_F^2}\right)$$

What to do ??? (PMS??, BLM??, resummation?,...?)

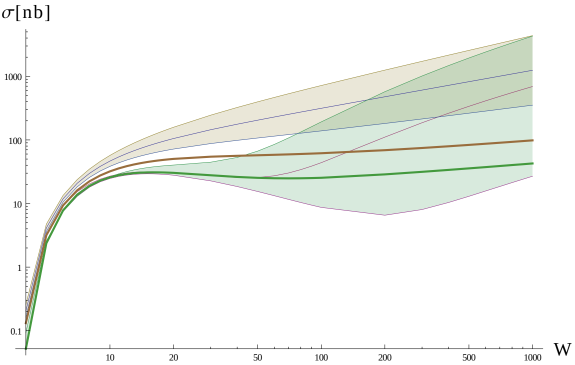
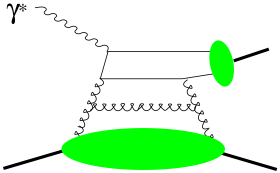


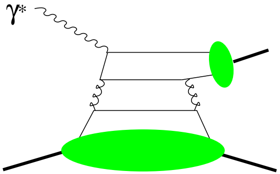
Figure: Photoproduction cross section as a function of $W = \sqrt{s_{\gamma p}}$ for $\mu_F^2 = M_{J/\psi}^2 \times \{0.5, 1, 2\}$- LO and NLO. Thick lines for LO and NLO for $\mu_F^2 = 1/4 M_{J/\psi}^2$.

- Jones & Martin & Ryskin & Teubner, choice of the factorization scale.
- Why NLO corrections are large at small x_B?
  large contribution comes from

$$ImA^g \sim H^g(\xi,\xi) + \frac{3\alpha_s}{\pi}\left[\log\frac{M_V^2}{\mu_F^2} - \log 4\right]\int\limits_{\xi}^{1}\frac{dx}{x}H^g(x,\xi)$$

$H^g(x,\xi) \sim xg(x) \sim const$, therefore $\int dx/xH^g(x,\xi) \sim \log(1/\xi)H^g(\xi,\xi)$





D.Yu. Ivanov, Blois 2007 Conference arXiv:0712.3193
Braun, Ivanov, Manashov, Shafer *in preparation*

At higher orders powers of energy log are generated

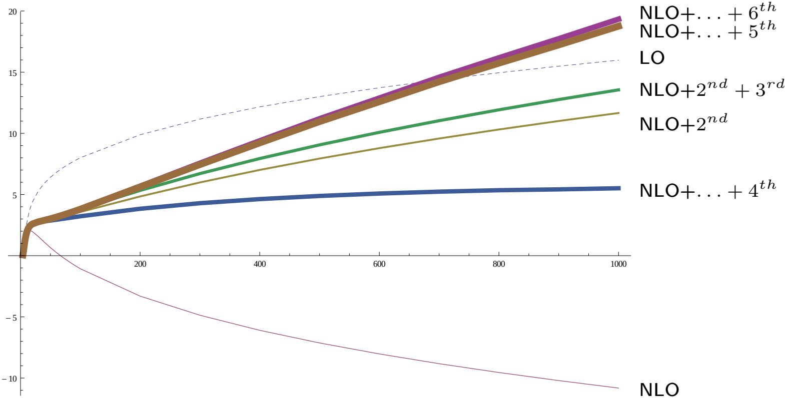
$$\mathcal{I}mA^g \sim H^g(\xi,\xi) + \int_\xi^1 \frac{dx}{x} H^g(x,\xi) \sum_{n=1} C_n(L) \frac{\bar{\alpha}_s^n}{(n-1)!} \log^{n-1}\frac{x}{\xi}$$

$C_n(L)$ - polynomials of $L = \log\frac{Q^2}{\mu_F^2}$, maximum power is L^n

- for DIS a technique suggested by Catani, Ciafaloni and Hautmann; [Catani, Hautmann '94]
- One can calculate $C_n(L)$ in $D = 4 + 2\epsilon$ dimensions.
- Consistently with collinear factorization, in terms of corrections to coeff. functions and anomalous dimensions, in $\overline{MS}$ scheme
- The method used in DIS can be generalized to exclusive, nonforward processes.

Resummed amplitude for J/ψ

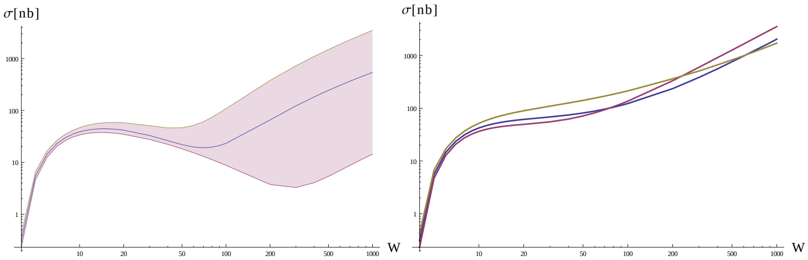
Ivanov, Pire, Szymanowski, Wagner, EPJ Web Conf. 112 (2016) 01020, arXiv:1601.07338



Imaginary part of the amplitude for photoproduction of heavy mesons as a function of $W = \sqrt{s_{\gamma p}}$ for $\mu_F^2 = M_{J/\psi}^2$

Resummed cross section for J/ψ

Ivanov, Pire, Szymanowski, Wagner, EPJ Web Conf. 112 (2016) 01020, arXiv:1601.07338



NLO Resumed

Photoproduction cross section as a function of $W = \sqrt{s_{\gamma p}}$ for $\mu_F^2 = M_{J/\psi}^2 \times \{0.5, 1, 2\}$

Remarks: only forward evolution, $\mu_R = Q$.

TCS and Bethe-Heitler contribution to exlusive lepton pair photoproduction.

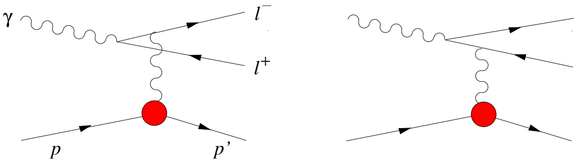


Figure: The Feynman diagrams for the Bethe-Heitler amplitude.

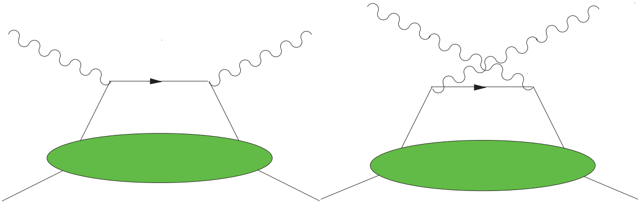


Figure: Handbag diagrams for the Compton process in the scaling limit.

TCS

Berger, Diehl, Pire, 2002

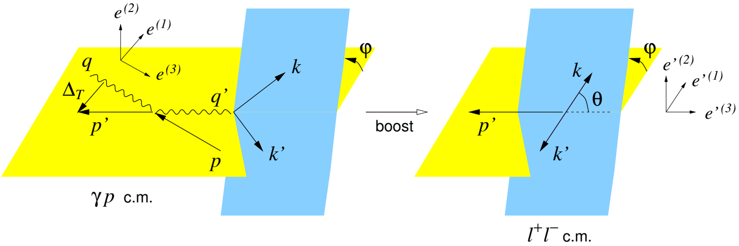
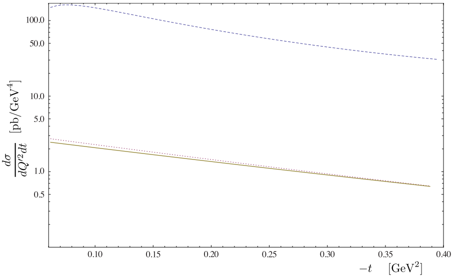


Figure: Kinematical variables and coordinate axes in the γp and $\ell^+\ell^-$ c.m. frames.

Interference

B-H dominant for not very high energies:



The interference part of the cross-section for $\gamma p \to \ell^+ \ell^- \, p$ with unpolarized protons and photons is given by:

$$\frac{d\sigma_{INT}}{dQ'^2 \, dt \, d\cos\theta \, d\varphi} \sim \cos\varphi \cdot \; \mathrm{Re}\, \mathcal{H}(\eta, t)$$

Linear in GPD's, odd under exchange of the l^+ and l^- momenta $\Rightarrow$ angular distribution of lepton pairs is a good tool to study interference term.

TCS

The photon beam circular polarization asymmetry:

$$A = \frac{\sigma^+ - \sigma^-}{\sigma^+ + \sigma^-} \sim Im(H)$$

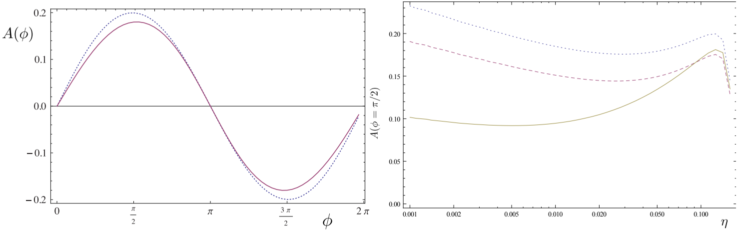


Figure: (Left) Photon beam circular polarization asymmetry as a function of ϕ, for $t = -0.1$ GeV^2, $Q^2 = \mu^2 = 4$ GeV^2, integrated over $\theta \in (\pi/4, 3\pi/4)$ and for $E_\gamma = 10$ GeV ($\eta \approx 0.11$). (Right) The η dependence of the photon beam circular polarization asymmetry for $Q^2 = \mu^2 = 4$ GeV^2, and $t = -0.2$ GeV^2 integrated over $\theta \in (\pi/4, 3\pi/4)$. The LO result is shown as the dotted line, the full NLO result by the solid line.

JLAB 6 GeV data

Rafayel Paremuzyan PhD thesis

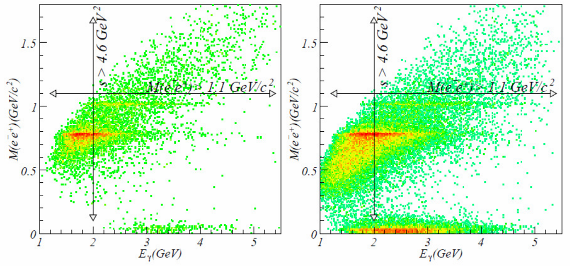


Figure: e^+e^- invariant mass distribution vs quasi-real photon energy. For TCS analysis $M(e^+e^-) > 1.1\,\mathrm{GeV}$ and $s_{\gamma p} > 4.6\,\mathrm{GeV}^2$ regions are chosen. Left graph represents e1-6 data set, right one is from e1f data set.

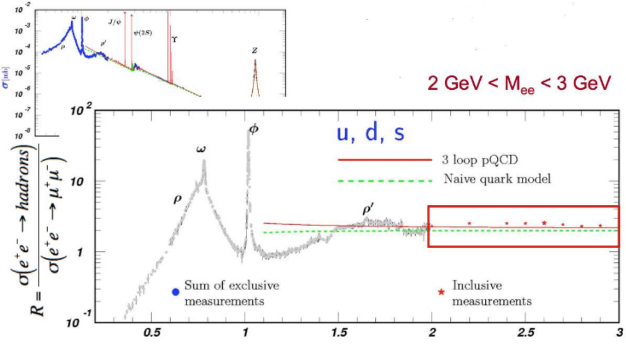


FIG. 4: Measurements of e^+e^- annihilation into hadrons show a resonance-free window between the ρ' and the J/ψ, which is ideal for TCS studies at 12 GeV.

Experimental status

→ Marie Boër talk

- Hall B - taking fist data in E12-12-001 : "*Timelike Compton Scattering and J/psi photoproduction on the proton in e+e- pair production with CLAS12 at 11 GeV.*"
- Hall A proposal approved in 2015, also parallel to J/psi, higher luminosity, smaller acceptance
- TCS proposal submitted for Hall C with transversely polarized target
- UPC's ?

Studies of the impact on GPDs

Marie Boër, M.Guidal and M. Vanderhaeghen, Eur.Phys.J. A51 (2015) no.8, 103

- Numerical studies of some higher twist effects
- Evaluation of beam and target asymmetries in VGG model
- Studies of the GPDs dependence of observables in VGG model

Marie Boër, M.Guidal and M. Vanderhaeghen, *Timelike Compton scattering off the neutron*, Eur.Phys.J. A52 (2016) 33

Fits of VGG GPDs with TCS $\rightarrow$ M.Boer talk

Summary

- TCS is complementary measurement to DVCS, cleanest way to test universality of GPDs.
- Inclusion of NLO corrections to the coefficient function is an important issue, understood in JLAB kinematics, more work needed for small ξ's.
- TCS measured at JLAB 6 GeV, but much richer and more interesting kinematical region available after upgrade to 12 GeV,
- Linear polarization in TCS may give some information on $\tilde{H}$.
- Approved experiment for Hall B and for Hall A.
- Linear polarization possible after upgrade of GlueX at higher photon intensity
- Numerical studies of asymmetries by Boer,Guidal and Vanderhaeghen
- Possible also in UPC in LHC ...

Hard photoproduction of a diphoton with a large invariant mass

A. Pedrak, B. Pire, L. Szymanowski, JW, arXiv:1708.01043

$$\gamma(q,\epsilon) + N(p_1,s_1) \to \gamma(k_1,\epsilon_1) + \gamma(k_2,\epsilon_2) + N'(p_2,s_2)$$

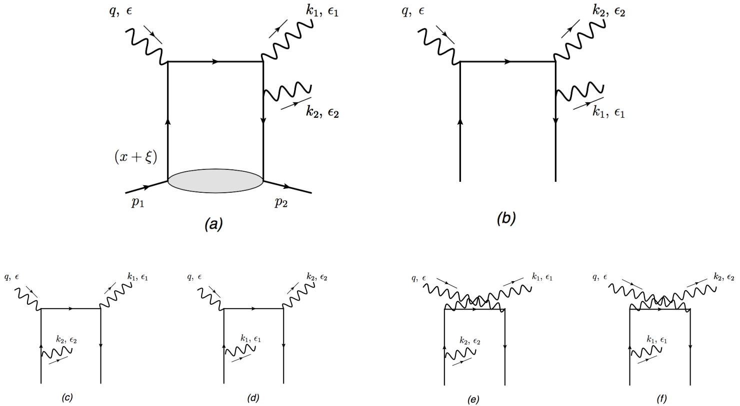


Figure: Feynman diagrams contributing to the coefficient function of the process $\gamma N \to \gamma\gamma N'$

Hard photoproduction of a diphoton with a large invariant mass

- Purely electromagnetic process at Born order - as are deep inelastic scattering (DIS), deeply virtual Compton scattering (DVCS) and timelike Compton scattering (TCS).
- Insensitive to gluon GPDs.
- No contribution from the badly known chiral-odd quark distributions.
- This study enlarges the range of $2 \to 3$ reactions analyzed in the framework of collinear QCD factorization. Simplest - great tool to study factorization.

Coefficient functions and generalized Form Factors

$$
\begin{aligned}
iCF_q^V &= Tr[i\mathcal{M}\ \not{p}] = \\
&- ie_q^3\Big[\ A^V\left(\frac{1}{D_1(x)D_2(x)}+\frac{1}{D_1(-x)D_2(-x)}\right) \\
&\qquad + B^V\left(\frac{1}{D_1(x)D_3(x)}+\frac{1}{D_1(-x)D_3(-x)}\right) \\
&\qquad + C^V\left(\frac{1}{D_2(x)D_3(-x)}+\frac{1}{D_2(-x)D_3(x)}\right)\Big], \\
iCF_q^A &= Tr[i\mathcal{M}\gamma^5\ \not{p}] = \\
&-ie_q^3\Big[\ A^A\left(\frac{1}{D_1(x)D_2(x)}-\frac{1}{D_1(-x)D_2(-x)}\right) \\
&\qquad +B^A\left(\frac{1}{D_1(x)D_3(x)}-\frac{1}{D_1(-x)D_3(-x)}\right)\Big]
\end{aligned}
$$

where $A^V, \ldots, A^A, \ldots$ depend on photons polarizations and final photons p_T.
Denominators read:

$$
D_1(x) = s(x+\xi+i\varepsilon), \quad D_2(x) = s\alpha_2(x-\xi+i\varepsilon), \quad D_3(x) = s\alpha_1(x-\xi+i\varepsilon)
$$

Generalized form factors

The scattering amplitude is written in terms of generalized Compton form factors $\mathcal{H}^q(\xi)$, $\mathcal{E}^q(\xi)$, $\tilde{\mathcal{H}}^q(\xi)$ and $\tilde{\mathcal{E}}^q(\xi)$ as

$$\mathcal{T} = \frac{1}{2s}\left[\left(\mathcal{H}(\xi)\bar{U}(p_2)\not{n}U(p_1) + \mathcal{E}(\xi)\bar{U}(p_2)\frac{i\sigma^{\mu\nu}\Delta_\nu n_\mu}{2M}U(p_1)\right) + \left(\tilde{\mathcal{H}}(\xi)\bar{U}(p_2)\not{n}\gamma^5 U(p_1) + \tilde{\mathcal{E}}(\xi)\bar{U}(p_2)\frac{i\gamma_5(\Delta\cdot n)}{2M}U(p_1)\right)\right]$$

$$\mathcal{H}(\xi) = \sum_q \int_{-1}^{1} dx\, CF_q^V(x,\xi)H^q(x,\xi), \quad \tilde{\mathcal{H}}(\xi) = \sum_q \int_{-1}^{1} dx\, CF_q^A(x,\xi)\tilde{H}^q(x,\xi)\,,$$

$$\mathrm{Re}\,\mathcal{H}(\xi) \sim \sum_q e_q^3 P.V. \int_{-1}^{1} dx \frac{H^q(x,\xi) + H^q(-x,\xi)}{x-\xi}$$

$$\mathrm{Im}\,\mathcal{H}(\xi) \sim \sum_q e_q^3 \left[H^q(\xi,\xi) + H^q(-\xi,\xi)\right]$$

$$\mathrm{Re}\,\tilde{\mathcal{H}}(\xi) \sim 0$$

$$\mathrm{Im}\,\tilde{\mathcal{H}}(\xi) \sim \sum_q e_q^3 \left[\tilde{H}^q(\xi,\xi) - \tilde{H}^q(-\xi,\xi)\right]$$

Differential cross section

Choosing as independent kinematical variables $\{t, u', M^2_{\gamma\gamma}\}$, the fully unpolarized differential cross section reads

$$\frac{d\sigma}{dM^2_{\gamma\gamma}dtd(-u')} = \frac{1}{2}\frac{1}{(2\pi)^3 32 S^2_{\gamma N} M^2_{\gamma\gamma}} \sum_{\lambda,\lambda_1\lambda_2,s_1,s_2} \frac{|\mathcal{T}|^2}{4}$$

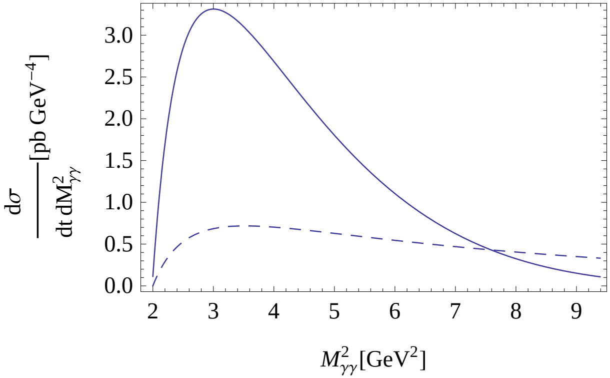


Figure: the $M^2_{\gamma\gamma}$ dependence of the unpolarized differential cross section on a proton at $t = t_{min}$ and $S_{\gamma N} = 20 GeV^2$ (full curves) and $S_{\gamma N} = 100 GeV^2$ (dashed curve). The bounds in u' are chosen so that both $-u'$ and $-t'$ are larger than 1 GeV^2.

Polarization asymmetries

- **Circular** initial photon polarization cross-section difference reads:

$$\mathcal{T}_+\mathcal{T}_+^* - \mathcal{T}_-\mathcal{T}_-^* \sim |\Delta_t||p_t|\,,$$

so circular polarization asymmetry is of $O(\frac{\Delta_T}{Q})$.

- **Linear** initial photon polarization defines the x axis:

$$\epsilon(q) = (0, 1, 0, 0)$$

and hence the azimuthal angle ϕ through

$$p_T^\mu = (0,\ p_T\ cos\phi,\ p_T\ sin\phi, 0).$$

Azimuthal dependence

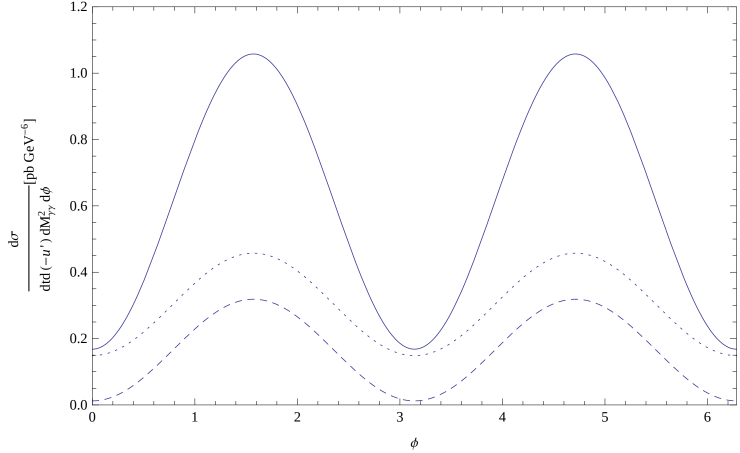


Figure: the azimuthal dependence of the differential cross section $\frac{d\sigma}{dM^2_{\gamma\gamma}dtdu'd\phi}$ at $t = t_{min}$ and $S_{\gamma N} = 20$ GeV^2. $(M^2_{\gamma\gamma}, u') = (3, -2)$ GeV^2 (solid line), $(M^2_{\gamma\gamma}, u') = (4, -1)$ GeV^2 (dotted line) and $(M^2_{\gamma\gamma}, u') = (4, -2)$ GeV^2 (dashed line). ϕ is the angle between the initial photon polarization and one of the final photon momentum in the transverse plane.

Summary - diphoton photoproduction

- Purely electromagnetic process at Born order
- Insensitive to gluon GPDs
- Cross section of the order of TCS which is measurable at JLAB
- Strong azimuthal dependence for linearly polarized photon beam

To be done:

- The $O(\alpha_s)$ corrections to the amplitude need to be calculated.They are particularly interesting since they open the way to a perturbative proof of factorization.
- Importance of the timelike vs spacelike nature of the probe with respect to the size of the NLO corrections; since the hard scales at work in our process are both the timelike one $M^2_{\gamma\gamma}$ and the spacelike one u', we are facing an intermediate case between timelike Compton scattering (TCS) and spacelike DVCS.
- Leptoproduction needs to be complemented by the analysis of the Bethe Heitler processes where one or two photons are emitted from the lepton line. Probably dominating and leading to interesting interference effects.

→ arXiv:1512.06174, EPJC ← new version from EPJC soon on arXiv!

- New precise experiments
- Various models, schemes, processes, observables
- Extraction of GPDs is complicated - various channels needed
- Various approaches: local and global CFF fitting, GPDs fitting...,
- Extrapolation for tomography (uncerteinties propagation),
- Various groups doing usually one chain

based on the talks and material from
H. Moutarde, P. Sznajder, L. Colaneri, N.Chouika, C.Mezrag

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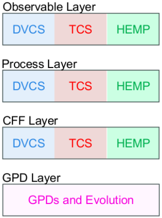
Layers



Layered structure:

- Layer - collection of objects designed for common purpose
- One module - one physical developenement
- Operation on modules provided by services
- Automation
- Features improving calculation speed (some layer services store previously calculated values)

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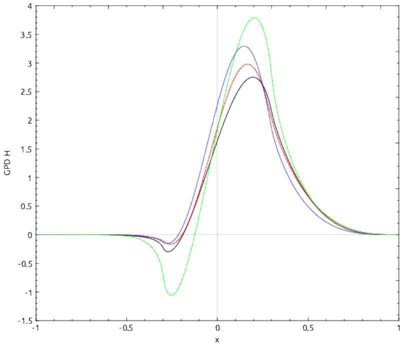
Existing modules

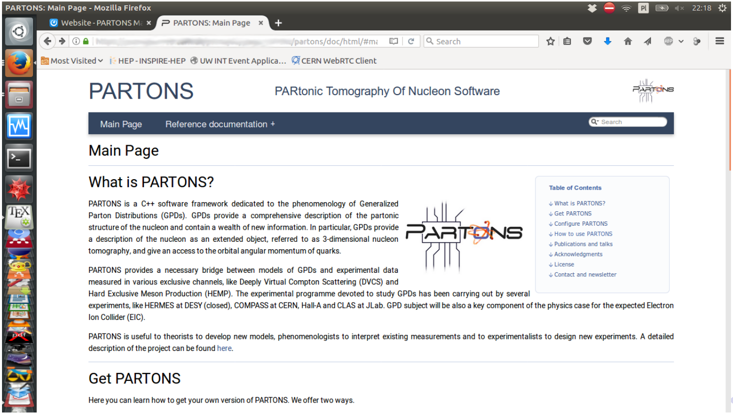
- GPD models: Goloskokov-Kroll, VGG, Vinnikov, MPSSW13, MMS13,
- Evolution: Vinnikov,
- Compton Form Factors (generally: convolution of GPDs or DA with coefficient functions): LO, NLO, NLO + heavy quarks (Noritsch)
- Cross section (DVCS + BH): VGG, BMJ, GV
- Observables: A_{LU}, A_{UL}, A_{LL}, A_C, fourier moments, . . .
- Running coupling: 4-loop PDG expression, constant value



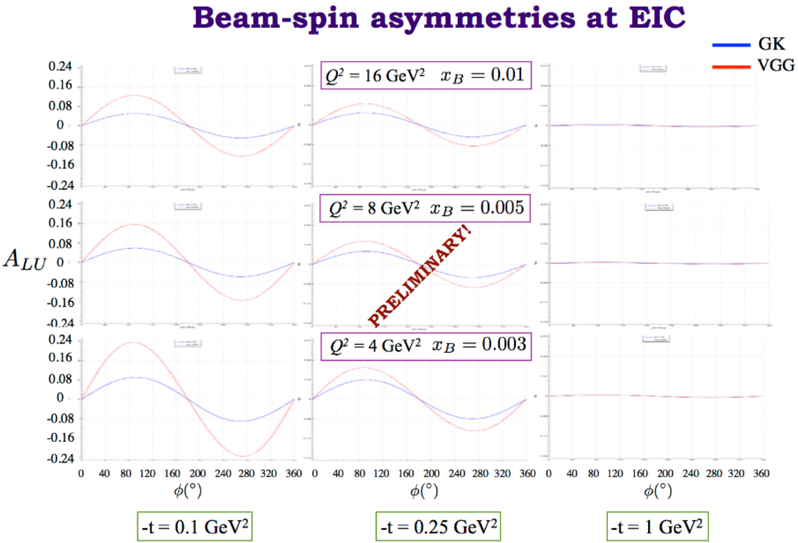
PARTONS

Release

- Released in spring 2018
- Open source
- Virtual Machine with out-of-the-box running PARTONS (also possible to install on your own Linux or Mac)
- Examples: xml, c++ codes
- preprint arXiv:1512.06174v1 (new description to appear soon !)
- Website with documentation and manuals: http://partons.cea.fr



N.Chouika, L.Colaneri



→ Paweł Sznajder DIS2017, IPNO2017
→ Moutarde, Sznajder, JW in preparation

Asumptions:

- Leading order, Leading twist, with dispersion relations:

$$Im\mathcal{G}(\xi,t) = \pi G^{(+)}(\xi,\xi,t)$$

$$Re\mathcal{G}(\xi,t) = C_G(t) + \mathrm{P.V.}\int_0^1 G^{(+)}(x,x,t)\left(\frac{1}{\xi-x} \mp \frac{1}{\xi+x}\right)\mathrm{d}x\ .$$

- Border and skewness functions:

$$G^q(x,0,t) = \mathrm{pdf}^q_G(x)\ \exp(f^q_G(x)t)\ .$$

$$G^q(x,x,t) = G^q(x,0,t)\ g^q_G(x,x,t)\ ,$$

$$g^q_G(x,x,t) = \frac{a^q_G}{(1-x^2)^2}\left(1+t(1-x)(b^q_G+c^q_G\log(1+x))\right)\ ,$$

- Subtraction constant (with some assumption about analyticity of GPDs):

$$C^q_G(t) = 2\int_{(0)}^1 \frac{G^{q(+)}(x,x,t) - G^{q(+)}(x,0,t)}{x}dx\ . \qquad (1)$$

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Examples: FITS

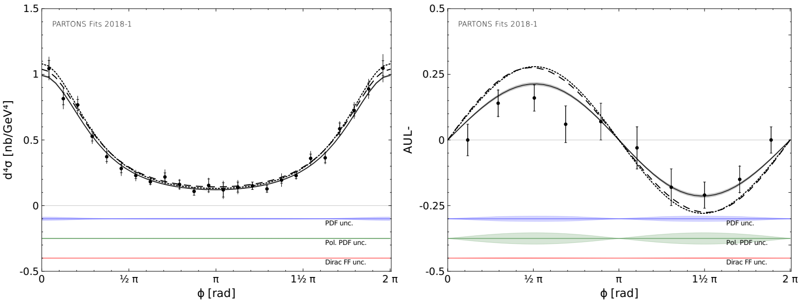

Figure: Comparison between our fit, selected GPD models and experimental data by CLAS for $d^4\sigma^{-}_{UU}$ at $x_{\mathrm{Bj}} = 0.244$, $t = -0.15\ \mathrm{GeV}^2$ and $Q^2 = 1.79\ \mathrm{GeV}^2$ (left), and for A^{-}_{UL} at $x_{\mathrm{Bj}} = 0.2569$, $t = -0.23\ \mathrm{GeV}^2$, $Q^2 = 2.019\ \mathrm{GeV}^2$ (right). The grey band indicate 68% confidence level for uncertainties coming from DVCS data. The corresponding bands for (un-)polarized PDF and elastic form factors are indicated by labels. The inner bars for data points are for statistical uncertainties, while those outer ones represent statistical and systematic uncertainties added geometrically. The dotted curve is for GK , while the dashed one is for VGG. The curves are evaluated at the kinematics of experimental data.

C++:

```
// Retrieve GPD service
GPDService* pGPDService =
                Partons::getInstance()->getServiceObjectRegistry()->getGPDService();
// Load GPD module with the BaseModuleFactory
GPDModule* pGPDModel =
        Partons::getInstance()->getModuleObjectFactory()->newGPDModule(GK11Model::classId);
// Create a GPDKinematic(x, xi, t, MuF, MuR) to compute
GPDKinematic gpdKinematic(0.1, 0.00050025, -0.3, 8., 8.);
// Compute data and store results
GPDResult gpdResult = pGPDService->computeGPDModel(gpdKinematic, pGPDModel, List<GPDType>());
// Print results
std::cout << gpdResult.toString() << std::endl;
```

XML:

```xml
<?xml version="1.0" encoding="UTF-8" standalone="yes" ?>
<scenario date="2016-03-25" description="Example : computation of one GPD model (GK11) without evolution">
  <task service="GPDService" method="computeGPDModel" storeInDB="0">
      <kinematics type="GPDKinematic">
         <param name="x" value="0.1" />
         <param name="xi" value="0.00050025" />
         <param name="t" value="-0.3" />
         <param name="MuF2" value="8" />
         <param name="MuR2" value="8" />
      </kinematics>
      <computation_configuration>
         <module type="GPDModule">
            <param name="className" value="GK11Model" />
         </module>
      </computation_configuration>
   </task></scenario>
```

- Modern platform devoted to study GPDs
- Design to support the effort of GPD community
- Can be used by both theoreticians and experimentalists
- Come with number of available physics developments implemented
- Modular - addition of new developments as easy as possible
- Open source code, but also out-of-the-box running PARTONS with examples and documentation
- Coming soon: Study of DVCS Observables at EIC kinematics (NLO effects, heavy flavours à la Noritzsch)
- Coming soon: global fits of CFFs, neural networks, ...
- We are looking forward to your input and feedback