An brief overview of Generalised Partons Distributions

Cédric Mezrag

CEA Saclay, Irfu DPhN

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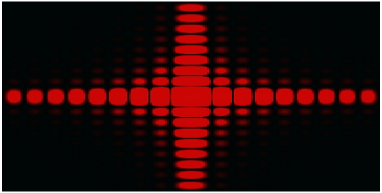
Introduction : probing the internal structure of matter

- Fraunhofer diffraction



Simulation of Fraunhofer diffraction due to a rectangle slit.

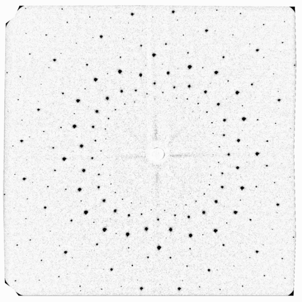
source : Wikimedia Commons

- Far field diffraction
- Diffraction
  $\rightarrow$ Fourier transform of transmission coefficient

Scattering experiments

A key tool to understand the structure of matter

- Fraunhofer diffraction
- X-ray scattering



Silicium crystal diffractive pattern

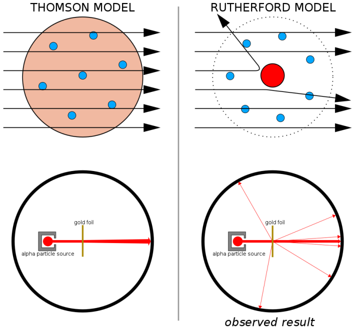
source : UK's national synchrotron

- X-ray wavelength
  $\rightarrow \lambda \simeq$ typical size
- Bragg Law
- Diffraction pattern
  $\rightarrow$ Fourier transform of electronic density
- Provide information on the cristal structure

Scattering experiments

A key tool to understand the structure of matter

- Fraunhofer diffraction
- X-ray scattering
- Rutherford experiment



- α particles scattering on a gold foil
- Some of which are scattered at large angles
- Invalidate the Thomson Model (Plum Pudding)
- Allows to develop the Rutherford planetary model

source : Wikimedia Commons

A pattern a study matter

- Scattering without breaking
- Fourier transform relation between matter structure and diffraction figure
- Repeat itself for different orders of magnitude
- Can we extend that to hadron structure?

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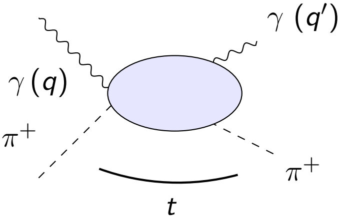

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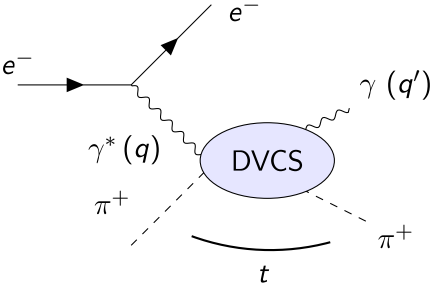
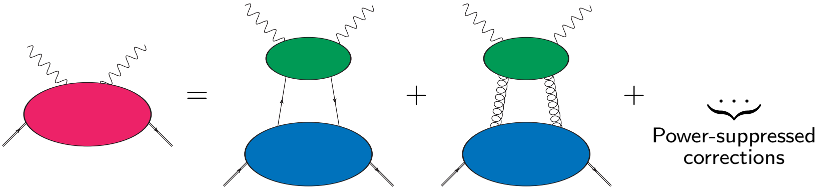


Large virtuality and factorisation

- When the photon is strongly virtual : $Q^2 = -q^2 >> M^2, t$



- Decomposition of DVCS between perturbative (green) and non-perturbative (blue) subparts.
- Perturbative part $\rightarrow$ description of the interaction between the probe and a parton inside hadron
- Non-perturbative part : description of a parton hadron amplitude called Generalised Partons Distributions (GPDs)
- GPDs is where the information on the hadrons structure lies.

Generalised Parton Distributions

References

- General review on GPDs:
  M. Diehl, Phys.Rept., 2003, 388, 41-277
  A. Belitsky and A. Radyushkin, Phys.Rept., 2005, 418, 1-387
- Modern phenomenological applications
  K. Kumericki *et al.*, Eur. Phys. J., 2016, A52, 157
- Future experimental opportunities
  EIC Yellow Report, arXiv:2103.05419

Definitions and some properties

Formal Definition for the pion

$$H_\pi^q(x,\xi,t) = \frac{1}{2}\int \frac{e^{ixP^+z^-}}{2\pi}\langle P+\frac{\Delta}{2}|\bar{\psi}^q(-\frac{z}{2})\gamma^+\psi^q(\frac{z}{2})|P-\frac{\Delta}{2}\rangle \mathrm{d}z^-|_{z^+=0,\mathbf{z}=0}$$

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D. Müller *et al.*, Fortsch. Phy. 42 101 (1994)
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- $t = \Delta^2$: the Mandelstam variable

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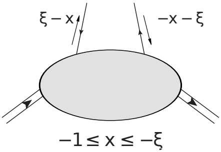
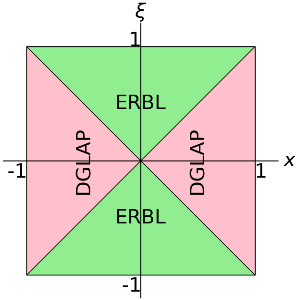
- $t = \Delta^2$: the Mandelstam variable
- Caveat ! In gauges other than the lightcone one, a Wilson line is necessary to make the GPDs gauge invariant

Kinematical Range

Different values of (x, ξ) yields different lightfront interpretations:





- Modifies our understanding of what is probed
- Different type of contributions
- It determines two big regions
- Relevant for evolution equations
- $|\xi| > 1$ region of Generalised Distribution Amplitudes (GDA)

Connection with the PDF

Coming back to the definition:

$$H_\pi^q(x,\xi,t) = \frac{1}{2}\int \frac{e^{ixP^+z^-}}{2\pi}\langle P+\frac{\Delta}{2}|\bar{\psi}^q(-\frac{z}{2})\gamma^+\psi^q(\frac{z}{2})|P-\frac{\Delta}{2}\rangle \mathrm{d}z^-|_{z^+=0,\mathbf{z}=0}$$

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When $\Delta \to 0$, then $(\xi = -2\Delta\cdot n/P\cdot n; t=\Delta^2) \to (0,0)$

$$H_\pi^q(x,0,0) = q(x)\Theta(x) - \bar{q}(-x)\Theta(-x)$$
$$H_\pi^g(x,0,0) = xg(x)\Theta(x) - xg(-x)\Theta(-x)$$

In the limit $(\xi,t)\to(0,0)$, one recover the PDFs.

Looking at the quark definition:

$$H^q_\pi(x,\xi,t) = \frac{1}{2}\int \frac{e^{ixP^+z^-}}{2\pi}\langle P+\frac{\Delta}{2}|\bar{\psi}^q(-\frac{z}{2})\gamma^+\psi^q(\frac{z}{2})|P-\frac{\Delta}{2}\rangle \mathrm{d}z^-|_{z^+=0,\mathbf{z}=0}$$

we would recover the Form Factor if we could make the operator "local".

Connection with the form factor

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we would recover the Form Factor if we could make the operator “local”. Simple way to do that → integrate on Fourier conjugate variable:

$$\int \mathrm{d}x\, H_\pi^q(x,\xi,t) = \frac{1}{2}\int \delta(P^+z^-)\langle P+\frac{\Delta}{2}|\bar{\psi}^q(-\frac{z}{2})\gamma^+\psi^q(\frac{z}{2})|P-\frac{\Delta}{2}\rangle \mathrm{d}z^-|_{z^+=0,\mathbf{z}=0}$$
$$= \frac{1}{2P^+}\langle P+\frac{\Delta}{2}|\bar{\psi}^q(0)\gamma^+\psi^q(0)|P-\frac{\Delta}{2}\rangle$$

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We recover the pion electromagnetique Form Factor

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Immediate consequences for GPDs

GPDs encode a kick in the momentum fraction along the lightfront of 2ξ
$\rightarrow$ unless $\xi = 0$ the "centre of mass" is modified between the initial and final Proton

GPD and the hadron 2+1D Structure

Prerequisite

- Hadron description in coordinate space: position of its center of mass in the transverse plane
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GPDs encode a kick in the momentum fraction along the lightfront of 2ξ $\rightarrow$ unless $\xi = 0$ the "centre of mass" is modified between the initial and final Proton

A probabilistic interpretation can be obtained only for $\xi = 0$

$$\rho(x, \tilde{b}_\perp) = \int \frac{\mathrm{d}^2\Delta_\perp}{(2\pi)^2} e^{i\Delta_\perp \tilde{b}_\perp} H(x, 0, -\Delta_\perp^2)$$

M. Burkardt, PRD 62 (2000) 071503, PRD 66 (2002) 119903 (erratum)

Computations

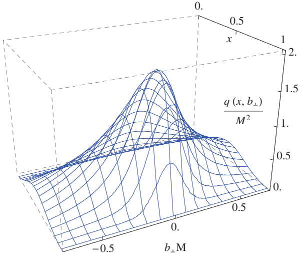


fig. from C. Mezrag *et al.*, PLB 741 (2015) 190-196

Extractions

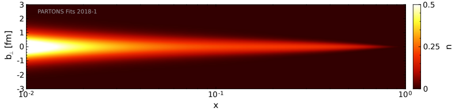


fig. from H. Moutarde *et al.*, EPJ C 78 (2018) 11, 890

Extractions require extrapolations and are model dependent.

Place of GPDs in the Hadron physics context

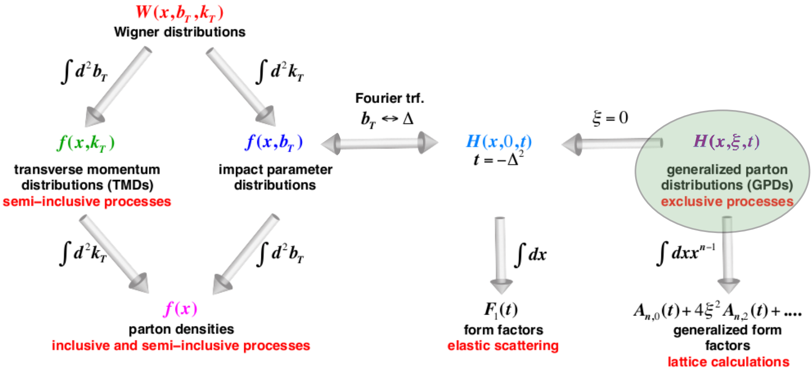
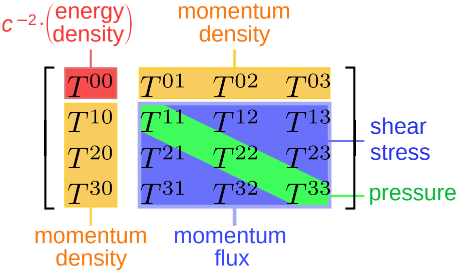


figure from A. Accardi *et al.*, Eur.Phys.J.A 52 (2016) 9, 268

Interpretation of GPDs II

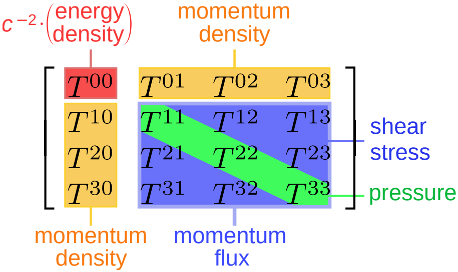
Connection to the Energy-Momentum Tensor



How energy, momentum, pressure are shared between quarks and gluons

Caveat: renormalization scheme and scale dependence

C. Lorcé *et al.*, PLB 776 (2018) 38-47,
M. Polyakov and P. Schweitzer,
IJMPA 33 (2018) 26, 1830025
C. Lorcé *et al.*, Eur.Phys.J.C 79 (2019) 1, 89



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$$\langle p' | T^{\mu\nu}_{q,g} | p \rangle = 2P^\mu P^\nu A_{q,g}(t;\mu) + \frac{1}{2}\left(\Delta^\mu \Delta^\nu - g^{\mu\nu}\Delta^2\right) C_{q,g}(t;\mu) + 2M^2 g^{\mu\nu} \bar{C}_{q,g}(t;\mu)$$

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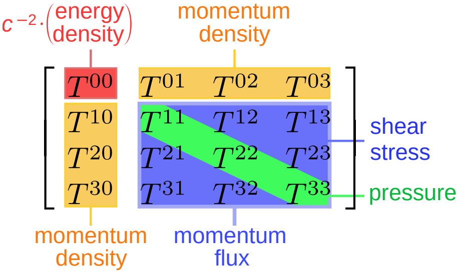

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$$\int_{-1}^{1} \mathrm{d}x \, x \, H_q(x,\xi,t;\mu) = A_q(t;\mu) + \xi^2 C_q(t;\mu)$$

- Ji sum rule (nucleon)
- Fluid mechanics analogy

X. Ji, PRL 78, 610-613 (1997)
M.V. Polyakov PLB 555, 57-62 (2003)

Connection with experimental data

- GPDs are not directly connected to experimental cross sections
- They enter the description of experimental amplitude through Compton Form Factor:

$$\underbrace{\mathcal{H}(\xi, t, Q^2)}_{\text{Exp. Amplitude}} = \int_{-1}^{1} \frac{\mathrm{d}x}{\xi} \underbrace{C\left(\frac{x}{\xi}, \frac{Q^2}{\mu^2}; \alpha_s\right)}_{pQCD} H(x, \xi, t, \mu^2)$$

- The coefficient function C is computed using pertubative QCD up to a given order in α_S.
- This yield a deconvolution problem that we will discuss later

Questions ?

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- We looked for a way to performed internal tomography of hadrons (similarly to X-ray cristallography for instance)
- We introduced Deeply Virtual Compton Scattering (DVCS) as an exclusive process
- We introduced GPDs as a way to parametrise DVCS
- We realised that GPDs contained the 3D information we are after and are connected to the energy momentum tensor
- We saw that GPDs are connected to data through a convolution

Evolution properties of GPDs

UV singularities of operators

- Coming back to the operator definition of GPDs:

$$\langle \pi, P + \frac{\Delta}{2} | \bar{\psi}\left(-\frac{z}{2}\right) \gamma^{+} \psi\left(\frac{z}{2}\right) | \pi, P - \frac{\Delta}{2} \rangle$$

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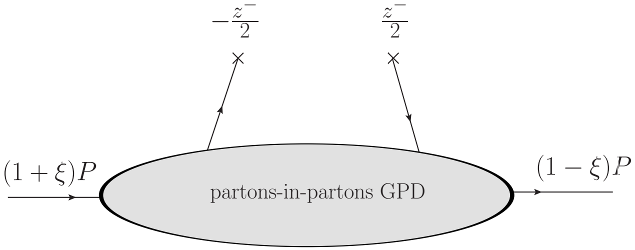
Two approaches (among others)

- Renormalisation of local operators
- Renormalisation using "in partons" matrix elements

Partons in partons GPDs

- Instead of moments, one can consider partons-in-partons GPDs



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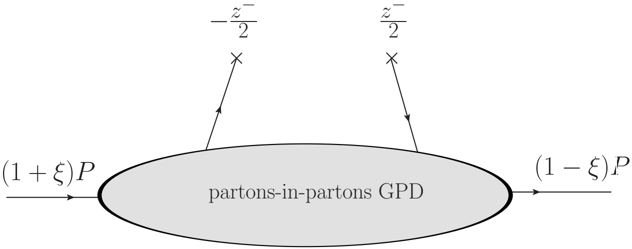

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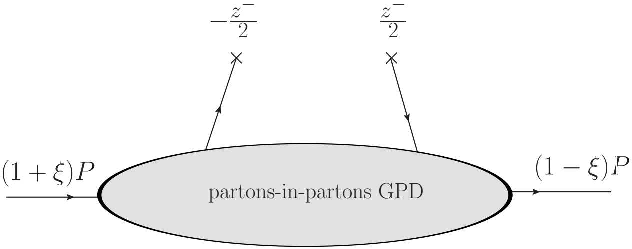

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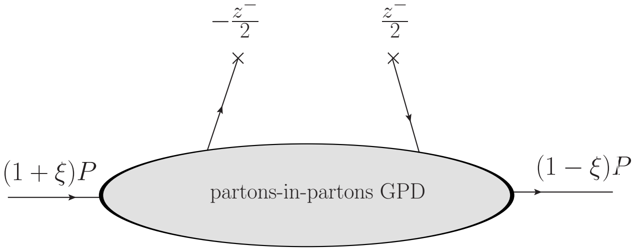

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For that purpose, $\overline{\mathrm{MS}}$ is well suited
GPDs (3D structure, pressure) become *scheme dependent* !

First order computation

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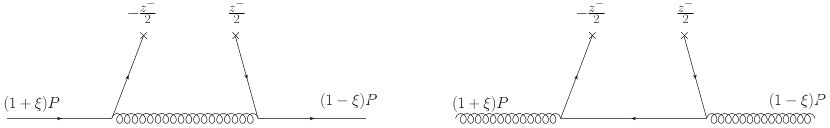
- Consequence: it complicates the gluon propagator, but reduce the Wilson line to unity !
- We are left in the quark sector with:



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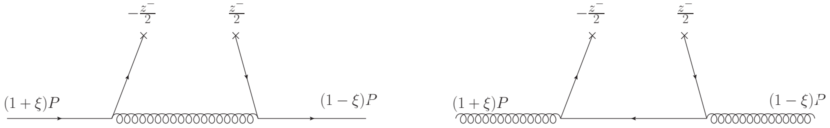

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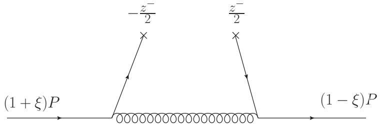

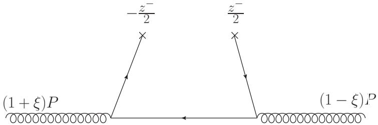

- Applying dimensional regularisation, and $\overline{MS}$ renormalisation.

Final result

$$H^i(x,\xi,t,\mu) = \int_{-1}^{1} \frac{\mathrm{d}y}{|y|} Z_{i,j}\left(\frac{x}{y}, \frac{\xi}{x}, \alpha_s(\mu), \epsilon\right) H^j_{reg}(y,\xi,t,\epsilon)$$

Renormalisation group

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Renormalisation Group

- Knowing the GPD at a scale μ we want to know how it behaves at $\mu + \mathrm{d}\mu$
- we describe perturbatively the impact of this $\mathrm{d}\mu$ leap

$$H(x, \xi, t, \mu + \mathrm{d}\mu) - H(x, \xi, t, \mu)$$

- we obtain like this a first-order integro-differential equation
- α_S becomes "exponentiated"

Evolution equations for GPDs

Non-Singlet Case

$$\frac{\mathrm{d}H^q_{NS}(x,\xi,t,\mu)}{\mathrm{d}\ln(\mu)} = \frac{\alpha_s(\mu)}{4\pi}\int_0^1 \frac{\mathrm{d}y}{y}\mathcal{P}^0_{q\leftarrow q}\left(\frac{x}{y},\frac{\xi}{x}\right)H^q_{NS}(y,\xi,t,\mu)$$

Singlet Case

$$\begin{pmatrix} \frac{\mathrm{d}H^q_S(x,\xi,t,\mu)}{\mathrm{d}\ln(\mu)} \\ \frac{\mathrm{d}H^g(x,\xi,t,\mu)}{\mathrm{d}\ln(\mu)} \end{pmatrix} = \frac{\alpha_s(\mu)}{4\pi}\int_0^1 \frac{\mathrm{d}y}{y}\begin{pmatrix} \mathcal{P}^0_{q\leftarrow q}\left(\frac{x}{y},\frac{\xi}{x}\right) & \mathcal{P}^0_{q\leftarrow g}\left(\frac{x}{y},\frac{\xi}{x}\right) \\ \mathcal{P}^0_{g\leftarrow q}\left(\frac{x}{y},\frac{\xi}{x}\right) & \mathcal{P}^0_{g\leftarrow g}\left(\frac{x}{y},\frac{\xi}{x}\right) \end{pmatrix}\begin{pmatrix} H^q_S(y,\xi,t,\mu) \\ H^g(y,\xi,t,\mu) \end{pmatrix}$$

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The $\mathcal{P}$ distributions can in principle be computed in pQCD

- Splitting function have been computed at:
  - LO (α_s)

    D. Mueller *et al.*, Fortsch.Phys. 42 101–141, 1994
    X. Ji PRD55, 7114–7125, 1997
    A. Radyushkin, PRD56, 5524–5557, 1997
  - NLO (α_S^2)

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    V.M. Braun *et al.*, JHEP, vol. 02, p. 191, 2019
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$$\lim_{\xi \to 0} \mathcal{P}\left(\frac{x}{y}, \frac{\xi}{x}\right) = P_{DGLAP}\left(\frac{x}{y}\right)$$

Other properties

- Charge conservation: the electromagnetic for factor is independent of μ (observable)
- Energy-Momentum Conservation: $\int \mathrm{d}x x(q(x) + g(x))$ is independent of μ
- Continuity at the crossover lines $|x| = |\xi|$

Questions ?

Questions ?

- We needed to take care of singularities, typical of QFT
- We introduced renormalisation constants, a renormalisation scheme and a scale
- Quantities related to GPDs become scale and scheme dependent
- We introduced an integro-differential equation to describe the scale dependence
- Experimental data do not depend on the scale and scheme (in principle)

The Nucleon

Nucleon vs. Pion

Main difference: spin-1/2 $\rightarrow$ more tensorial structures!

$$\frac{1}{2}\int \frac{e^{ixP^+z^-}}{2\pi}\langle P+\frac{\Delta}{2}|\bar{\psi}^q(-\frac{z}{2})\gamma^+\psi^q(\frac{z}{2})|P-\frac{\Delta}{2}\rangle \mathrm{d}z^-|_{z^+=0,\mathbf{z}=0}$$
$$=\frac{1}{2P^+}\left[H^q(x,\xi,t)\bar{u}\gamma^+u+E^q(x,\xi,t)\bar{u}\frac{i\sigma^{+\alpha}\Delta_\alpha}{2M}u\right].$$

$$\frac{1}{2}\int \frac{e^{ixP^+z^-}}{2\pi}\langle P+\frac{\Delta}{2}|\bar{\psi}^q(-\frac{z}{2})\gamma^+\gamma_5\psi^q(\frac{z}{2})|P-\frac{\Delta}{2}\rangle \mathrm{d}z^-|_{z^+=0,\mathbf{z}=0}$$
$$=\frac{1}{2P^+}\left[\tilde{H}^q(x,\xi,t)\bar{u}\gamma^+\gamma_5 u+\tilde{E}^q(x,\xi,t)\bar{u}\frac{\gamma_5\Delta^+}{2M}u\right].$$

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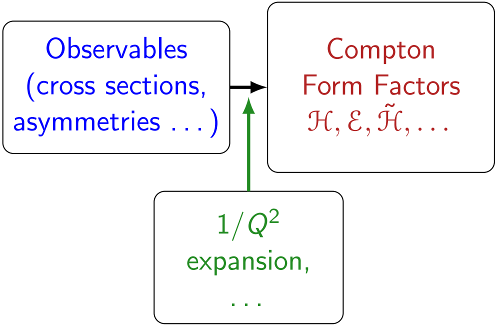
$$

The nucleon has 4 chiral-even and 4 chiral-odd quark GPDs.
All previous properties apply

Probing GPDs through exclusive processes

Observables
(cross sections,
asymmetries . . .)

Experimental connection to GPDs



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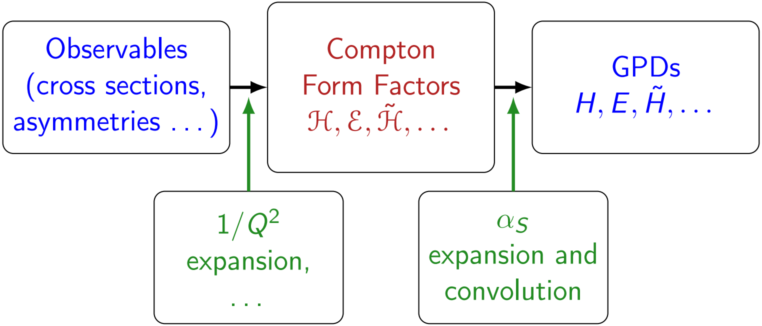

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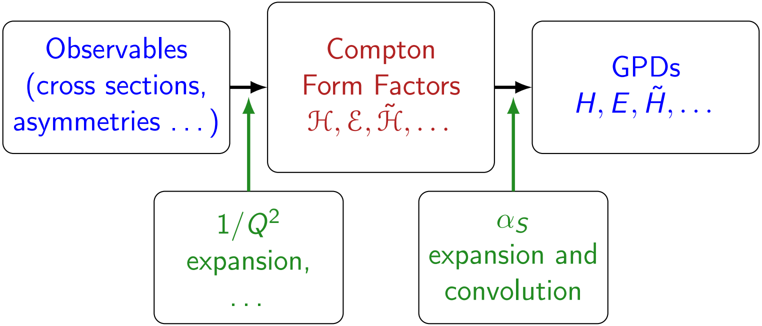
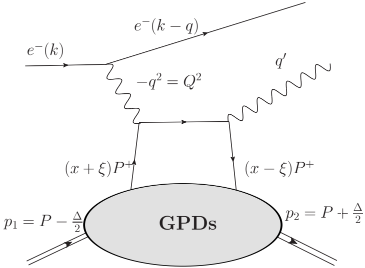


- CFFs play today a central role in our understanding of GPDs
- Extraction generally focused on CFFs

Deep Virtual Compton Scattering



- Best studied experimental process connected to GPDs

  $\rightarrow$ Data taken at Hermes, Compass, JLab 6, JLab 12

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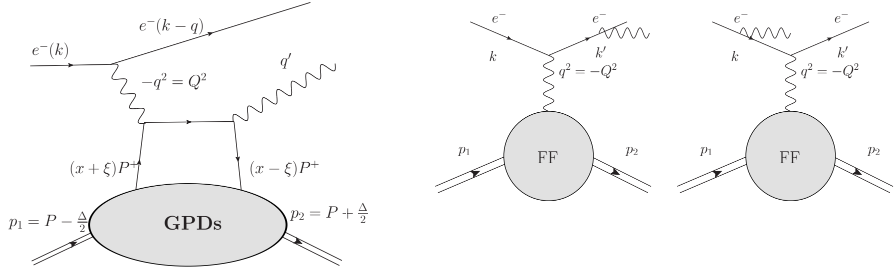
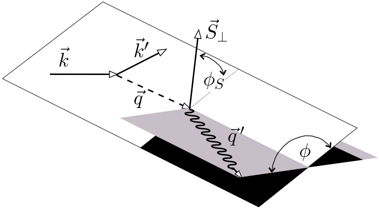


- Best studied experimental process connected to GPDs
  → Data taken at Hermes, Compass, JLab 6, JLab 12
- Interferes with the Bethe-Heitler (BH) process
  - Blessing: Interference term boosted w.r.t. pure DVCS one
  - Curse: access to the angular modulation of the pure DVCS part difficult

M. Defurne *et al.*, Nature Commun. 8 (2017) 1, 1408



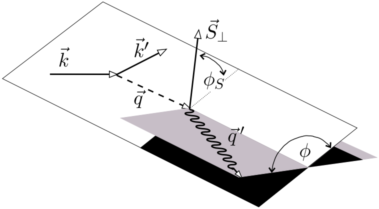
The differential $ep \to ep\gamma$ cross section is given by

$$\frac{d^5\sigma}{dx_B dQ^2 d|t| d\phi d\phi_S} = \frac{\alpha^3 x_B}{16\pi^2 4\sqrt{1+\epsilon^2}} |\mathcal{T}|^2 ,$$

e.g. K. Kumericki *et al.*, EPJ A 52 (2016) 6, 157

where

$$|\mathcal{T}|^2 = |\mathcal{T}_{\mathrm{BH}} + \mathcal{T}_{\mathrm{DVCS}}|^2 = |\mathcal{T}_{\mathrm{BH}}|^2 + |\mathcal{T}_{\mathrm{DVCS}}|^2 + \mathcal{I} .$$



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The different contributions are then analysed in terms of harmonics of ϕ:

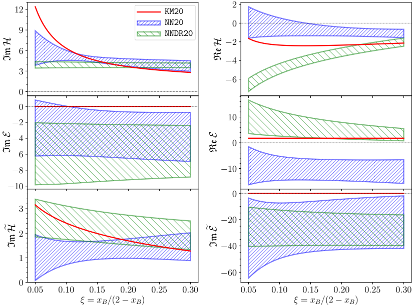
$$\mathcal{I} \propto c_0^{\mathcal{I}} + \sum_{n=1}^{3} \left[c_n^{\mathcal{I}} \cos(n\phi) + s_n^{\mathcal{I}} \sin(n\phi) \right]$$

$$|\mathcal{T}_{\mathrm{DVCS}}|^2 \propto c_0 + \sum_{n=1}^{2} \left[c_n \cos(n\phi) + s_n \sin(n\phi) \right]$$

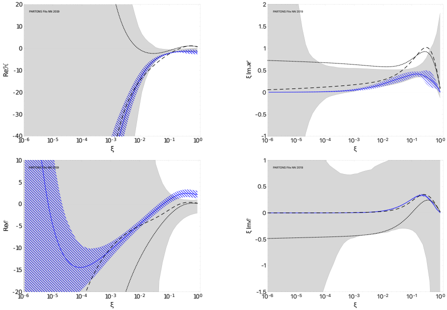
Strategy

- The coefficients are extracted from data
- GPDs enter the description of the coefficients through Compton Form Factors

Recent CFF extractions



M. Cuič *et al.*, PRL 125, (2020), 232005



H. Moutarde *et al.*, EPJC 79, (2019), 614

- Recent effort on bias reduction in CFF extraction (ANN)

  additional ongoing studies, J. Grigsby *et al.*, PRD 104 (2021) 016001

- Studies of ANN architecture to fulfil GPDs properties (dispersion relation,polynomiality,. . .)
- Recent efforts on propagation of uncertainties (allowing impact studies for JLAB12, EIC and EicC)

  see *e.g.* H. Dutrieux *et al.*, EPJA 57 8 250 (2021)

QCD corrections to DVCS

- At LO, the DVCS coefficient function is a QED one

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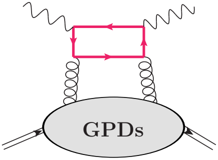
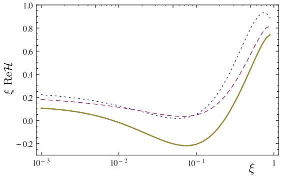
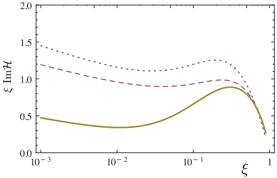
- At NLO, gluon GPDs play a significant role in DVCS







H. Moutarde *et al.*, PRD 87 (2013) 5, 054029

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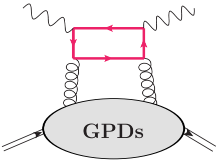
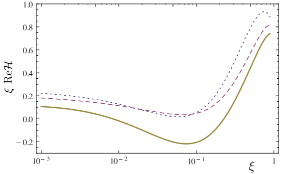
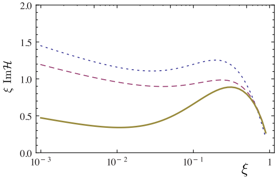






H. Moutarde *et al.*, PRD 87 (2013) 5, 054029

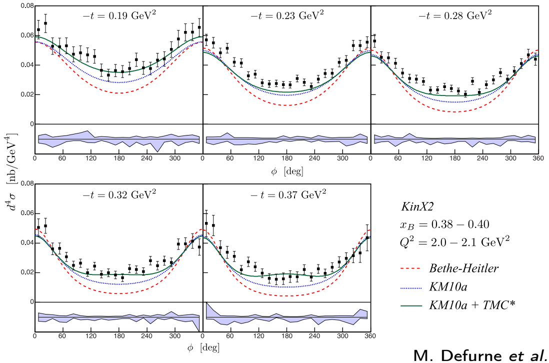
- Recent N2LO studies, impact needs to be assessed

V. Braun *et al.*, JHEP 09 (2020) 117

Finite t corrections

Kinematical corrections in t/Q^2 and M^2/Q^2

V. Braun *et al.*, PRL 109 (2012), 242001



M. Defurne *et al.* PRC 92 (2015) 55202

- Sizeable even for $t/Q^2 \sim 0.1$
- Not currently included in global fits.
- Difficulty for probabilistic interpretation (Hankle transform)

Dispersion relation and the D-term

- At all orders in α_S, dispersion relations relate the real and imaginary parts of the CFF.

I. Anikin and O. Teryaev, PRD 76 056007
M. Diehl and D. Ivanov, EPJC 52 (2007) 919-932

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- For instance at LO:

$$Re(\mathcal{H}(\xi,t)) = \frac{1}{\pi}\int_{-1}^{1} \mathrm{d}x \; Im(\mathcal{H}(x,t))\left[\frac{1}{\xi - x} - \frac{1}{\xi + x}\right] + \underbrace{2\int_{-1}^{1} \mathrm{d}\alpha \frac{D(\alpha,t)}{1-\alpha}}_{\text{Independent of } \xi}$$

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$$\underbrace{Re(\mathcal{H}(\xi,t))}_{\text{Extracted from data}} = \frac{1}{\pi}\int_{-1}^{1}\mathrm{d}x \underbrace{Im(\mathcal{H}(x,t))}_{\text{Extracted from data}} \left[\frac{1}{\xi-x}-\frac{1}{\xi+x}\right]+2\int_{-1}^{1}\mathrm{d}\alpha\frac{D(\alpha,t)}{1-\alpha}$$

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M.V. Polyakov PLB 555, 57-62 (2003)

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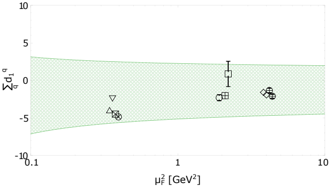


figure from H. Dutrieux *et al.*, Eur.Phys.J.C 81 (2021) 4

- First attempt from JLab 6 *GeV* data

Burkert *et al.*, Nature 557 (2018) 7705, 396-399

- Tensions with other studies
  $\rightarrow$ uncontroled model-dependence

K. Kumericki, Nature 570 (2019) 7759, E1-E2
H. Moutarde *et al.*, Eur.Phys.J.C 79 (2019) 7, 614
H. Dutrieux *et al.*, Eur.Phys.J.C 81 (2021) 4

- Scheme/scale dependence

The DVCS deconvolution problem I

From CFF to GPDs

Observables
(cross sections,
asymmetries . . .)

Compton
Form Factors
$\mathcal{H}, \mathcal{E}, \tilde{\mathcal{H}}, \ldots$

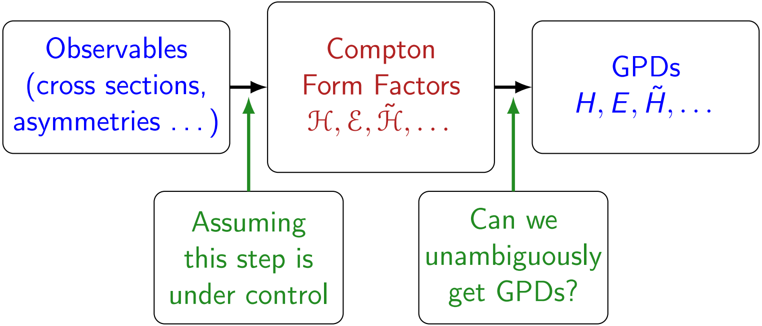
GPDs
$H, E, \tilde{H}, \ldots$

Assuming
this step is
under control

Can we
unambiguously
get GPDs?

The DVCS deconvolution problem I

From CFF to GPDs



- It has been known for a long time that this is not the case at LO
  Due to dispersion relations, any GPD vanishing on $x = \pm\xi$ would not contribute to DVCS at LO (neglecting D-term contributions).

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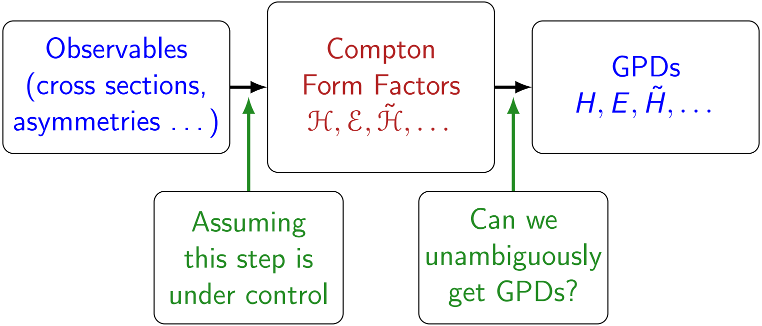

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  Due to dispersion relations, any GPD vanishing on $x = \pm\xi$ would not contribute to DVCS at LO (neglecting D-term contributions).
- Are QCD corrections improving the situation?

Shadow GPDs

CFF Definition

$$\underbrace{\mathcal{H}(\xi, t, Q^2)}_{\text{Observable}} = \int_{-1}^{1} \frac{\mathrm{d}x}{\xi} \underbrace{T\left(\frac{x}{\xi}, \frac{Q^2}{\mu^2}, \alpha_s(\mu^2)\right)}_{\text{Perturbative DVCS kernel}} H(x, \xi, t, \mu^2)$$

Shadow GPDs

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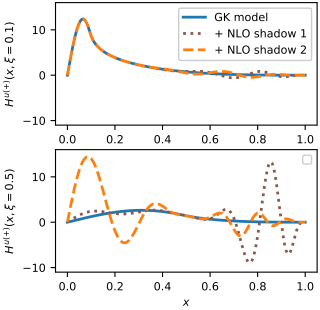
Shadow GPD definition

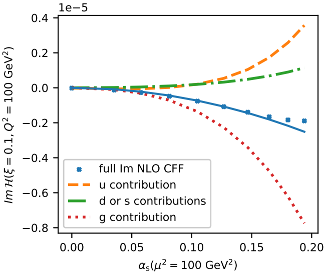
We define shadow GPD $H^{(n)}$ of order n such that when C is expanded in powers of α_s up to n one has:

$$0 = \int_{-1}^{1} \frac{\mathrm{d}x}{\xi} C^{(n)}\left(\frac{x}{\xi}, \frac{Q^2}{\mu_0^2}, \alpha_s(\mu_0^2)\right) H^{(n)}(x, \xi, t, \mu_0^2) \quad \text{invisible in DVCS}$$

$$0 = H^{(n)}(x, 0, 0) \quad \text{invisible in DIS}$$

A part of the GPD functional space is invisible to DVCS and DIS combined





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  - Cancelling the line $x=\xi$ is necessary but **no longer** sufficient
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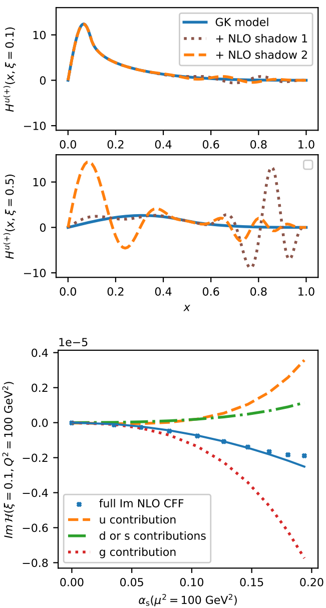
H. Dutrieux *et al.*, PRD 103 114019 (2021)

The DVCS deconvolution problem II



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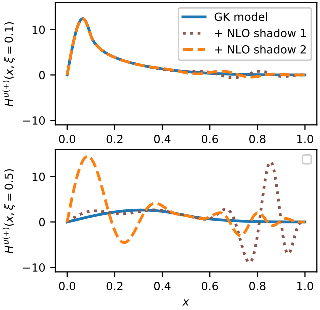

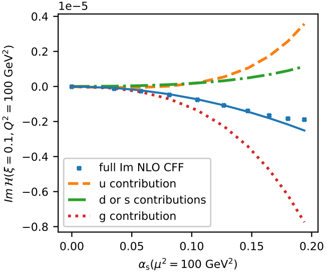

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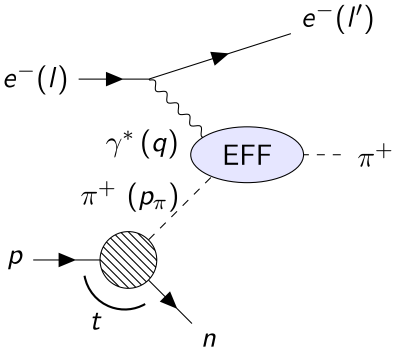
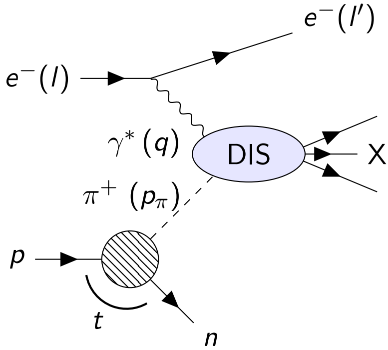
Multichannel Analysis required to fully determine GPDs

Sullivan processes





- Tested at JLab 6
  Huber *et al.*,PRC78, 045203
- Planned for JLab 12
  Aguilar *et al.*, EPJA 55 10, 190
- Envisioned at EIC and EicC
  see EIC Yellow Report and EicC white paper

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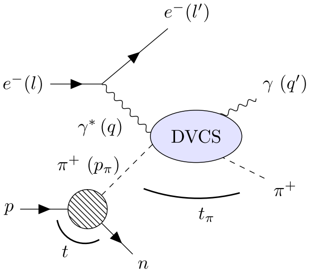
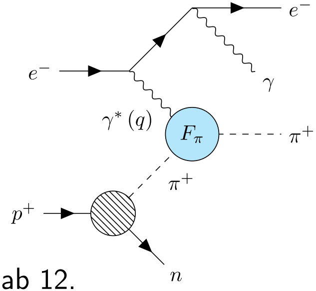
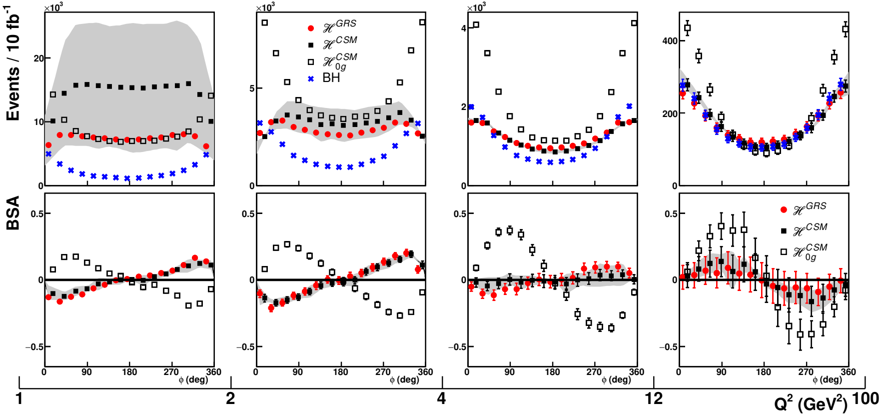
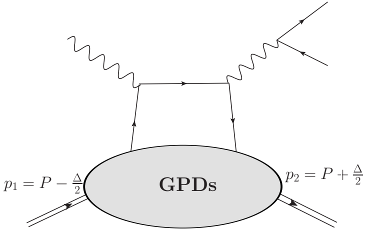




- Question already raised in 2008 for JLab 12.
  Amrath *et al.*, EPJC 58, 179-192
- Would such processes be measurable at the future EIC and EicC? Answering the question of measurability of DVCS requires:
  - A pion GPD model
  - An evolution code
  - A phenomenological code able to compute amplitudes from GPDs
  - An event generator simulating how many events could be detected

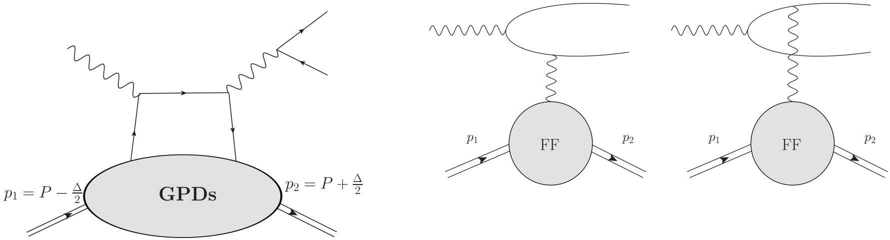


- Sullivan DVCS seems measurable at the EIC
- Our model predicts a sign flip of the Beam Spin Asymmetry due to gluons



- Amplitude related to the DVCS one ($Q^2 \to -Q^2, \dots$)
  $\to$ theoretical development for DVCS can be extended to TCS
  E. Berger *et al.*, EPJC 23 (2002) 675
- Excellent test of GPD universality but not the best option to solve the deconvolution problem

Timelike Compton Scattering



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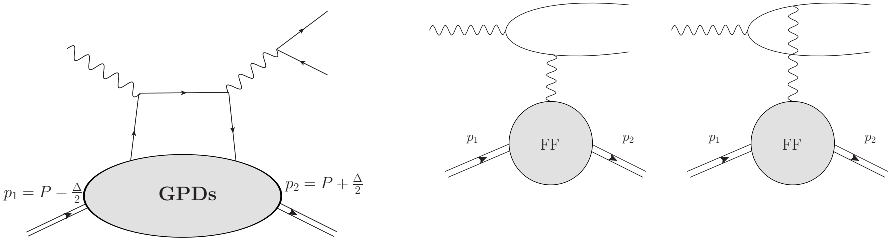

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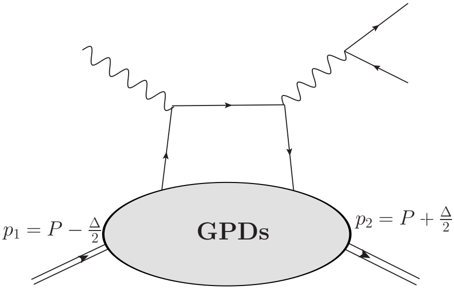
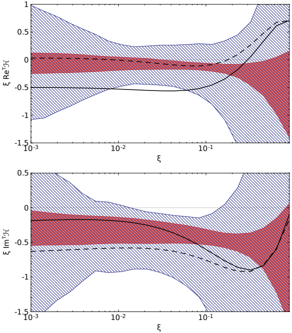
TCS: Recent results





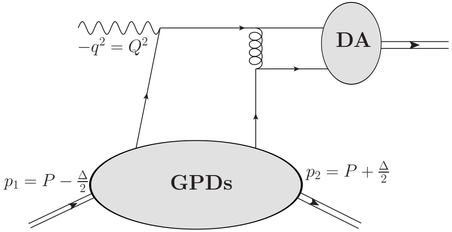
O. Grocholski *et al.*, EPJC 80, (2020) 61

- DVCS Data-driven prediction for TCS at LO and NLO
- First experimental measurement at JLab through forward-backward asymmetry (interference term)

P. Chatagnon *et al.*,arXiv:2108.11746

- Measurable at the LHC in UPC ?

Deep Virtual Meson Production



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- Formalism available at NLO

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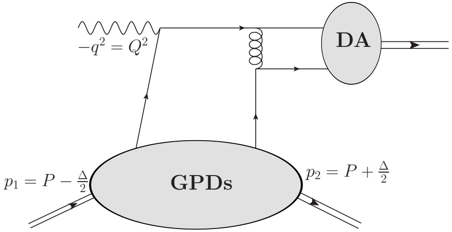

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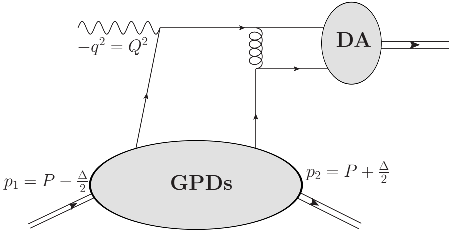

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- Factorisation proven $\neq$ factorisation visible at achievable Q^2
  - Leading-twist dominance at a given Q^2 is process-dependent
    $\rightarrow$ for DVMP it can change between mesons.
  - At JLab kinematics, higher-twist contributions are very strong
    $\rightarrow$ hide factorisation of σ_L

Status of DVMP

- π^0 electroproduction
  - $\sigma_T > \sigma_L$ at JLab 6 and likely at JLab 12 kinematics ($Q^2 = 8.3 GeV^2$)
    M. Dlamini *et al.*, Phys.Rev.Lett. 127 (2021) 15, 152301
  - No extraction of σ_L at JLab 12 yet
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    see *e.g.* L. Favart, EPJA 52 (2016) 6, 158
  - $\sigma_T \neq 0$ though $\rho_{0;T}$ production vanishes at leading twist
    $\rightarrow$ No LT access to chiral-odd GPDs.

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  - Sizeable higher-twist effects need to be understood

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DVMP is as interesting as challenging
Additional data would be more than welcome

PARTONS and Gepard

PARTONS

partons.cea.fr

B. Berthou *et al.*, EPJC 78 (2018) 478

Gepard

calculon.phy.hr/gpd/server/index.html

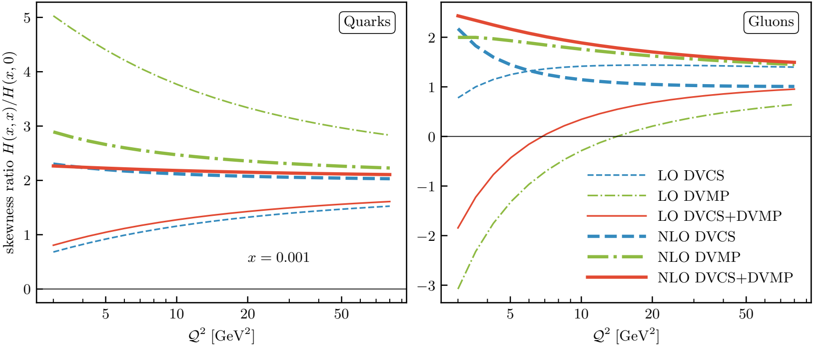
K. Kumericki, EPJ Web Conf. 112 (2016) 01012

- Similarities : NLO computations, BM formalism, ANN, ...
- Differences : models, evolution, ...

Physics impact

These integrated softwares are the mandatory path toward reliable multichannel analyses.

First NLO DVCS-DVMP multichannel analysis



M. Cuic *et al.*, JHEP 12 (2023) 192

First NLO-multichannel analysis regarding in the GPDs community

Conclusion

Summary

- Introduction to GPDs and their place in hadron structure studies
- Evolution of GPD
- Connection to experimental processes

Conclusion

- GPD field is as complicated as interesting
- Many theoretical and phenomenological works remain required
- Forthcoming facilities will likely shed new light on them
- Progresses in ab-initio computations (continuum and lattice) expected to be significant in the forthcoming years

Thank you for your attention !

Some final questions ?