Ultra-peripheral collisions to constrain Generalised Parton Distributions

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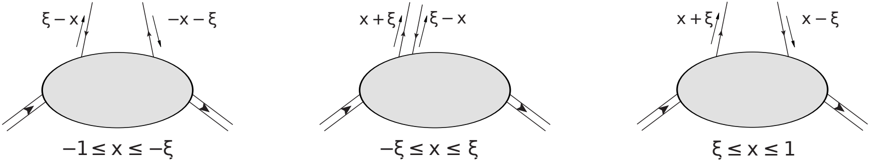
GPDs definitions

Fourier transform of non-local matrix elements:

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

D. Müller *et al.*, Fortsch. Phy. 42 101 (1994)
X. Ji, Phys. Rev. Lett. **78**, 610 (1997)
A. Radyushkin, Phys. Lett. **B380**, 417 (1996)



Nucleon GPDs Zoologies

Leading-Twist GPDs				
Chiral Even	Quarks (u,d,s ...)	unpolarised	H^q	E^q
		polarised	$\tilde{H}^q$	$\tilde{E}^q$
	Gluons	unpolarised	H^g	E^g
		polarised	$\tilde{H}^g$	$\tilde{E}^g$
Chiral Odd	Quarks (u,d,s ...)	unpolarised	H_T^q	E_T^q
		polarised	$\tilde{H}_T^q$	$\tilde{E}_T^q$
	Gluons	unpolarised	H_T^g	E_T^g
		polarised	$\tilde{H}_T^g$	$\tilde{E}_T^g$

Counting GPDs

- 4 Chiral even and 4 chiral odd GPDs per quark flavour
- 4 Chiral even and 4 chiral odd gluon GPDs

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Counting GPDs

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Fortunately not all of them take place together in all experimental processes

Theoretical Constraints on GPDs

- Polynomiality Property:

$$\int_{-1}^{1} \mathrm{d}x \; x^m H^q(x,\xi,t) = \sum_{j=0}^{\left[\frac{m}{2}\right]} \xi^{2j} C_{2j}^q(t) + mod(m,2)\xi^{m+1} C_{m+1}^q(t)$$

Lorentz Covariance

Theoretical Constraints on GPDs

- Polynomiality Property:

Lorentz Covariance

- Positivity property:

$$\left| H^q(x,\xi,t) - \frac{\xi^2}{1-\xi^2} E^q(x,\xi,t) \right| \leq \sqrt{\frac{q\left(\frac{x+\xi}{1+\xi}\right) q\left(\frac{x-\xi}{1-\xi}\right)}{1-\xi^2}}$$

A. Radysuhkin, Phys. Rev. **D59**, 014030 (1999)
B. Pire *et al.*, Eur. Phys. J. **C8**, 103 (1999)
M. Diehl *et al.*, Nucl. Phys. **B596**, 33 (2001)
P.V. Pobilitsa, Phys. Rev. **D65**, 114015 (2002)

Positivity of Hilbert space norm

Theoretical Constraints on GPDs

- Polynomiality Property:

Lorentz Covariance

- Positivity property:

Positivity of Hilbert space norm

- Support property:

$$x \in [-1; 1]$$

M. Diehl and T. Gousset, Phys. Lett. **B428**, 359 (1998)

Relativistic quantum mechanics

Theoretical Constraints on GPDs

- Polynomiality Property:

  Lorentz Covariance

- Positivity property:

  Positivity of Hilbert space norm

- Support property:

  Relativistic quantum mechanics

- Soft pion theorem (pion GPDs only)

  M.V. Polyakov, Nucl. Phys. **B555**, 231 (1999)
  CM *et al.*, Phys. Lett. **B741**, 190 (2015)

  Axial-Vector WTI

Theoretical Constraints on GPDs

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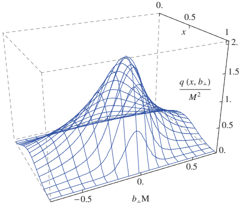
Problem

There is no model (until now) fulfilling a priori all these constraints.

- 2+1D picture of the nucleon



1D in momentum space (x),
2D in coordinate space $\vec{b}_\perp$

M. Burkardt, Phys. Rev. **D62**, 071503 (2000)

Interpretation of GPDs

- 2+1D picture of the nucleon
- Connection with the Energy-momentum tensor

$$\langle p', s' | T^{\mu\nu}_{q,g} | p, s \rangle = \bar{u} \left[P^{\{\mu}\gamma^{\nu\}} A_{q,g}(t, \zeta^2) + \frac{\Delta^\mu \Delta^\nu - \eta^{\mu\nu}\Delta^2}{M} C_{q,g}(t, \zeta^2) + M\eta^{\mu\nu} \bar{C}_{q,g}(t, \zeta^2) + \frac{P^{\{\mu} i\sigma^{\nu\}\Delta}}{2M} B_{q,g}(t, \zeta^2) + \frac{P^{[\mu} i\sigma^{\nu]\Delta}}{4M} D_{q,g}(t, \zeta^2) \right]$$

with $A_{q,g}$, $B_{q,g}$ and $C_{q,g}$ being given by moments of the GPDs H and E.

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with $A_{q,g}$, $B_{q,g}$ and $C_{q,g}$ being given by moments of the GPDs H and E.

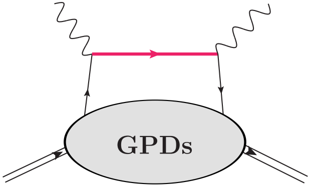
$$\int_{-1}^{1}\mathrm{d}x\, x\, H_q(x,\xi,t,\zeta^2) = A_q(t,\zeta^2) + (2\xi)^2 C_q(t,\zeta^2)$$

$$\int_{-1}^{1}\mathrm{d}x\, x\, E_q(x,\xi,t,\zeta^2) = B_q(t,\zeta^2) - (2\xi)^2 C_q(t,\zeta^2)$$

→ Ji sum rule and analogy with fluid mechanics (pressure, shear forces)

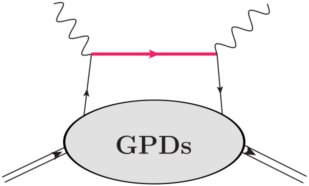
X. Ji, PRL 78, 610-613 (1997)
M.V. Polyakov PLB 555, 57-62 (2003)

GPDs and exclusive processes



- Exclusive processes with intact nucleon
- DVCS and TCS interfere with BH process

GPDs and exclusive processes



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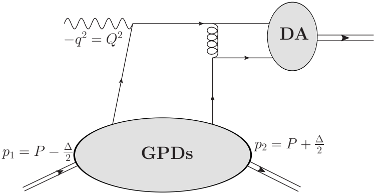

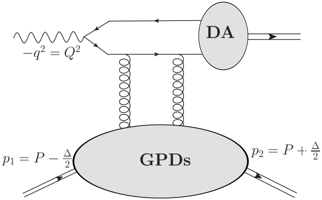

DVCS, a golden channel?

$$\mathcal{H}(\xi, t, Q^2) = \int_{-1}^{1} \mathrm{d}x \underbrace{C(x, \xi, t, Q^2, \zeta^2)}_{\text{pQCD}} H(x, \xi, t, \zeta^2)$$

DVCS, a golden channel?

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- Parity of $C(x, \dots)$ select only the odd part of the GPDs
  $\rightarrow$ DVCS will not tell us anything about the even part of the GPDs

DVCS, a golden channel?

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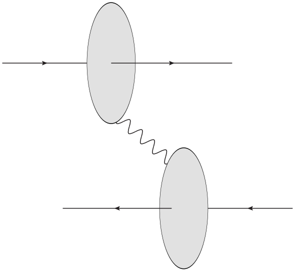
- Parity of $C(x, \dots)$ select only the odd part of the GPDs
  $\rightarrow$ DVCS will not tell us anything about the even part of the GPDs
- Question about the invertibility even restricted to the odd part of GPDs
  - At LO, C is non-invertible (known from long-time) and we have characterised the kernel
  - At NLO, we believe that C remains non invertible, but the proof is not yet complete

H. Dutrieux, CM and H. Moutarde, in preparation

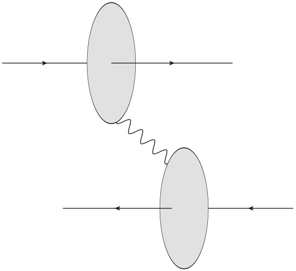
DVCS alone is not enough to fully characterised GPDs

UPCs and GPDs



- Ultra peripheral collisions $b > R_1 + R_2$
- EM interaction between the two hadrons
- Quasi-real photon exchanged $Q_1^2 \leq 1/R^2$
  $\rightarrow$ Hard scale does come from exchanged photon $\rightarrow$ **No DVCS in UPC**
- TCS and Heavy-Meson photoproduction can be envisaged

UPCs and GPDs



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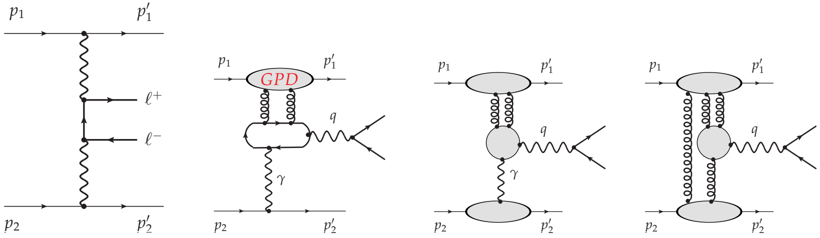
LHCspin

- Gazeous fixed target in front of LHCb
- Polarised target
- Successor of SMOG (Run 2) and SMOG2 (Run 3) targets

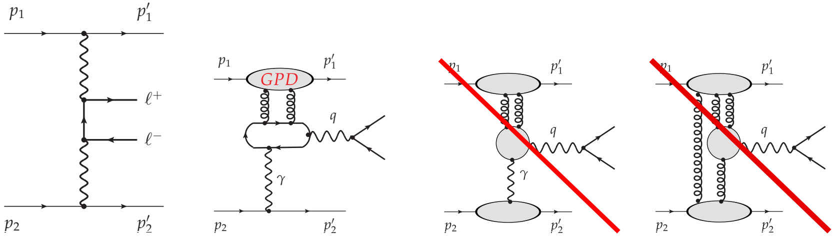
C. A. Aidala arXiv 1901.08002

TCS



figures from J.-P. Landsberg *et al.*,JHEP 1509 (2015) 087

TCS



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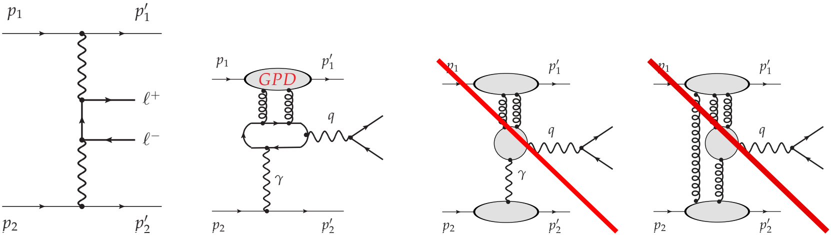
TCS

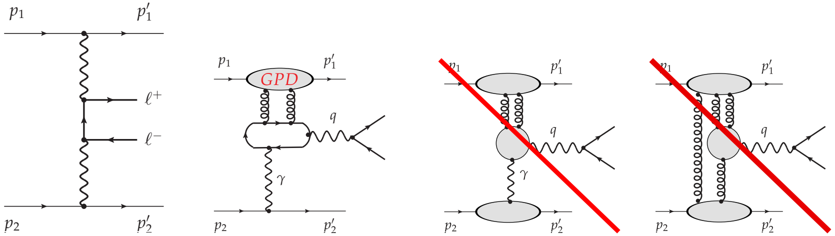


figures from J.-P. Landsberg *et al.*,JHEP 1509 (2015) 087

- Pomeron contributions are neglected (large Z)
- 2 EM processes remain: Bethe-Heitler and TCS
  - Pure TCS contribution is expected to be very small
  - Interference between BH and TCS may be measurable $\sim 15\%$ of the pure BH contribution
  - Pure BH and interference terms can be separated thanks to their angular dependencies

J.-P. Landsberg *et al.*,JHEP 1509 (2015) 087

TCS



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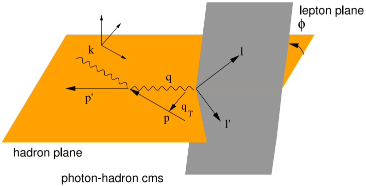
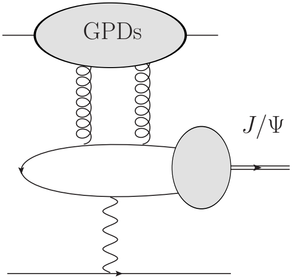


$$\frac{d\sigma_{BH}}{d\phi} \sim 1$$

$$\frac{d\sigma_{Int}}{d\phi} \sim \cos\phi$$

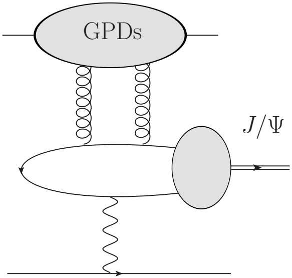
J.-P. Landsberg *et al.*,JHEP 1509 (2015) 087

J/Ψ photoproduction in UPC



- Access (mostly) to gluon distributions (H^c and E^c neglected)
- Large scale given by $M^2_{J/\Psi}$ not Q^2 (FYI, at JLab $Q^2 \sim 2\mathrm{GeV}^2$)
- NR-QCD description of J/Ψ matrix element (instead of Lightcone DA)

J/Ψ photoproduction in UPC



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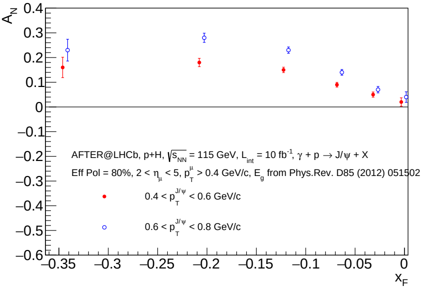
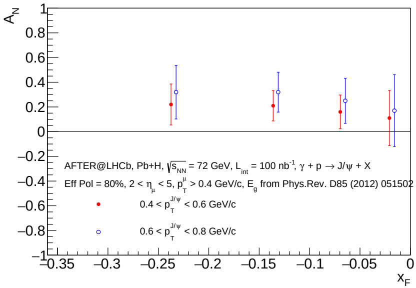
Single Transverse Spin Asymmetries (STSA)

- STSA measurement would give access to the GPD E^g **for the first time!**
- Possible with LHCb fixed target experiment on polarised H target
- Measurable with storage cells, else density is too small

J.-P. Landsberg *et al.*, Phys.Lett. B793 (2019) 33-40

STSA





Plots from J.-P. Landsberg *et al.*, Phys.Lett. B793 (2019) 33-40

Impact on gluon EMT

$$\langle p', s' | T^{\mu\nu}_{q,g} | p, s \rangle = \bar{u} \left[P^{\{\mu}\gamma^{\nu\}} A_{q,g}(t, \zeta^2) + \frac{\Delta^\mu \Delta^\nu - \eta^{\mu\nu}\Delta^2}{M} C_{q,g}(t, \zeta^2) + M\eta^{\mu\nu}\bar{C}_{q,g}(t, \zeta^2) + \frac{P^{\{\mu} i\sigma^{\nu\}\Delta}}{2M} B_{q,g}(t, \zeta^2) + \frac{P^{[\mu} i\sigma^{\nu]\Delta}}{4M} D_{q,g}(t, \zeta^2) \right] u$$

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$B_g \to$ Ji sum rules, gluon contribution to the nucleon spin
$C_g \to$ "pressure" distribution due to gluon in the nucleon

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$B_g \rightarrow$ Ji sum rules, gluon contribution to the nucleon spin
$C_g \rightarrow$ "pressure" distribution due to gluon in the nucleon

Current situation in the quark sector:

- E_q and therefore B_q remains unknown
- Despite JLab DVCS measurements constraining H_q, C_q remains compatible with 0

K. Kumericki, Nature 570 (2019) no.7759, E1-E2

Possible complications?

- Mass corrections: $m_c^2/M_{J/\Psi}^2 \sim 17\%$, yet m_c corrections neglected in previous calculations shown

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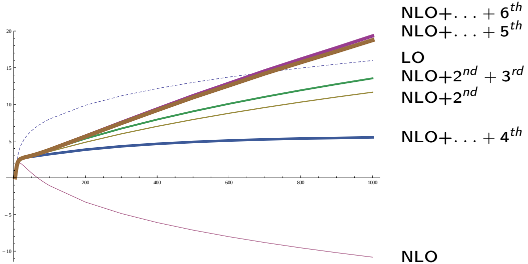
  $\rightarrow$ resummation techniques for $\ln^n(1/\xi)$ terms needed



D. Ivanov *et al.*,EPJ Web Conf. 112 (2016) 01020

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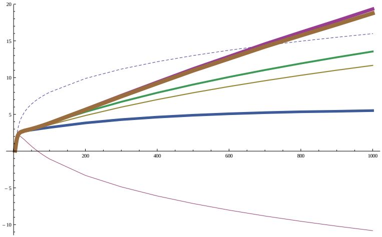

D. Ivanov *et al.*,EPJ Web Conf. 112 (2016) 01020

- Higher twist ? (Hard scale is fixed by $M_{J/\Psi}^2$)

Summary and Conclusion

Summary

- GPDs offers a way to access the 3D structure of hadrons and part of their EMT.
- GPDs remains poorly constrained experimentally
- UPCs offer a welcome possibility to evaluate TCS together with lepton-hadron facilities (consistency check)
- UPC may help us to probe gluon GPDs through J/Ψ production

Conclusion

Despite expected difficulties, UPC may bright (heavily) desirable experimental knowledge on GPDs

Thank you for your attention

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