Timelike Compton Scattering

Paweł Sznajder
National Centre for Nuclear Research, Poland

NATIONAL CENTRE FOR NUCLEAR RESEARCH
ŚWIERK

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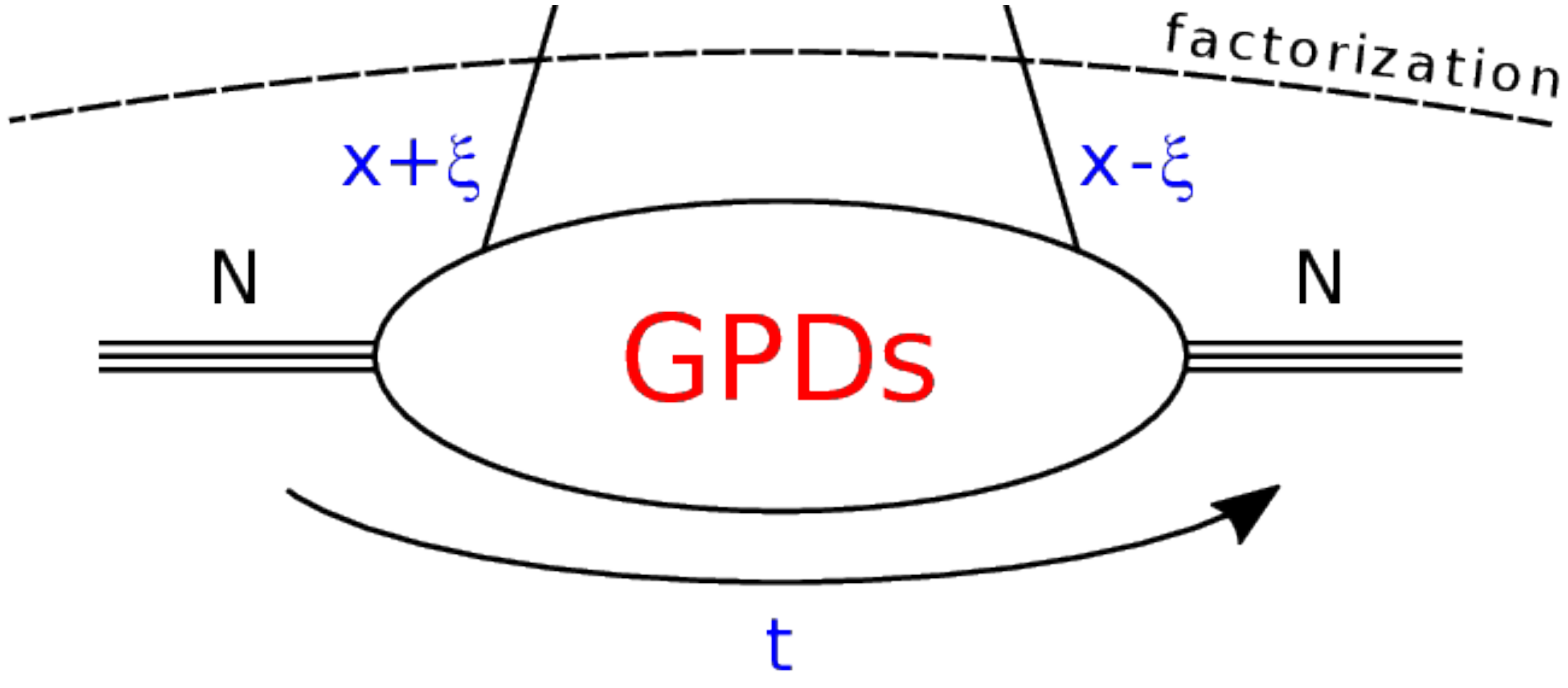
Outline

- Introduction
- Amplitude analysis and predictions from DVCS
- TCS at EIC

Introduction



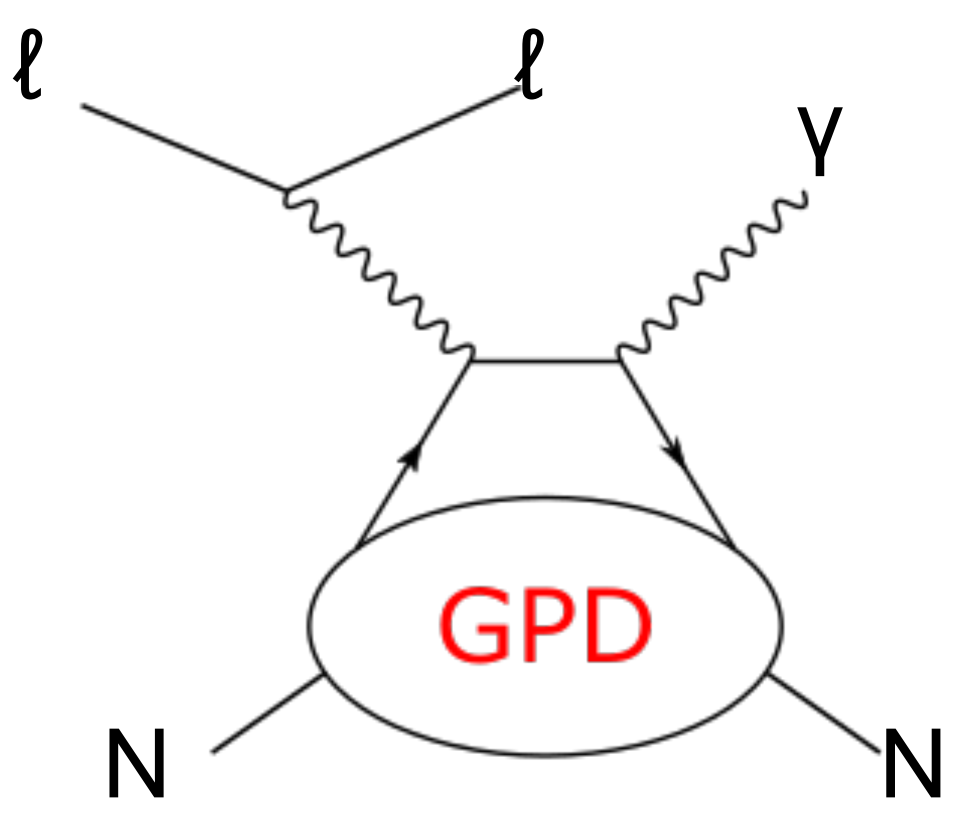
factorisation for |t|/Q² ≪ 1

Chiral-even GPDs:
(helicity of parton conserved)

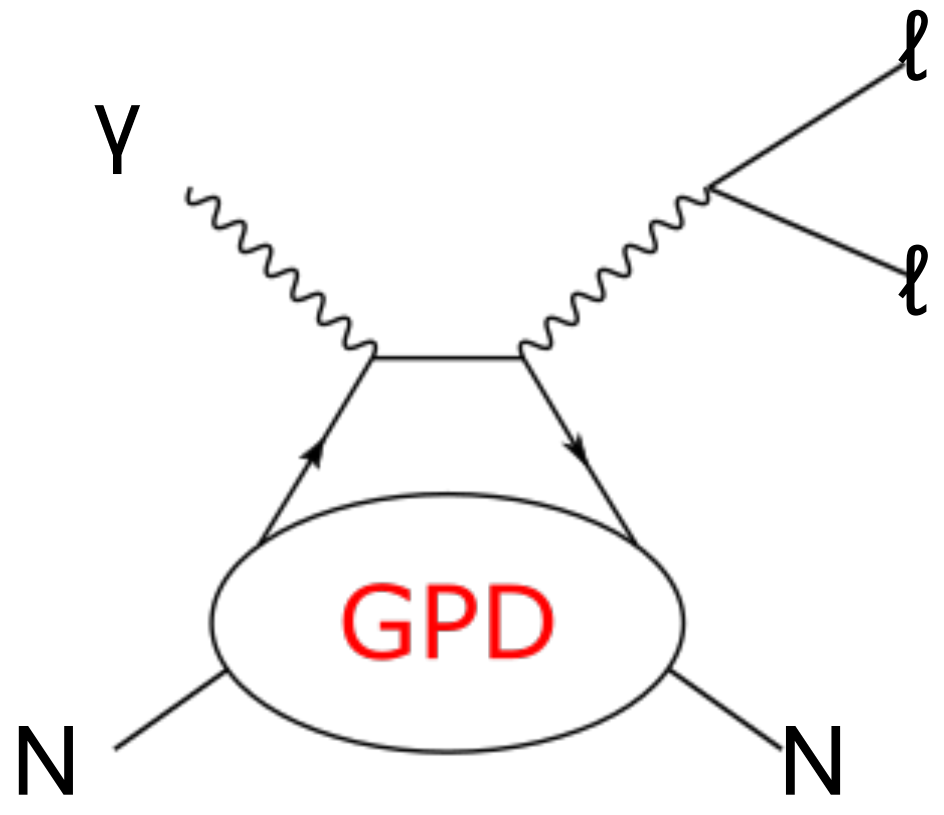
$H^{q,g}(x,\xi,t)$	$E^{q,g}(x,\xi,t)$	*for sum over parton helicities*
$\widetilde{H}^{q,g}(x,\xi,t)$	$\widetilde{E}^{q,g}(x,\xi,t)$	*for difference over parton helicities*
nucleon helicity conserved	*nucleon helicity changed*	

Introduction

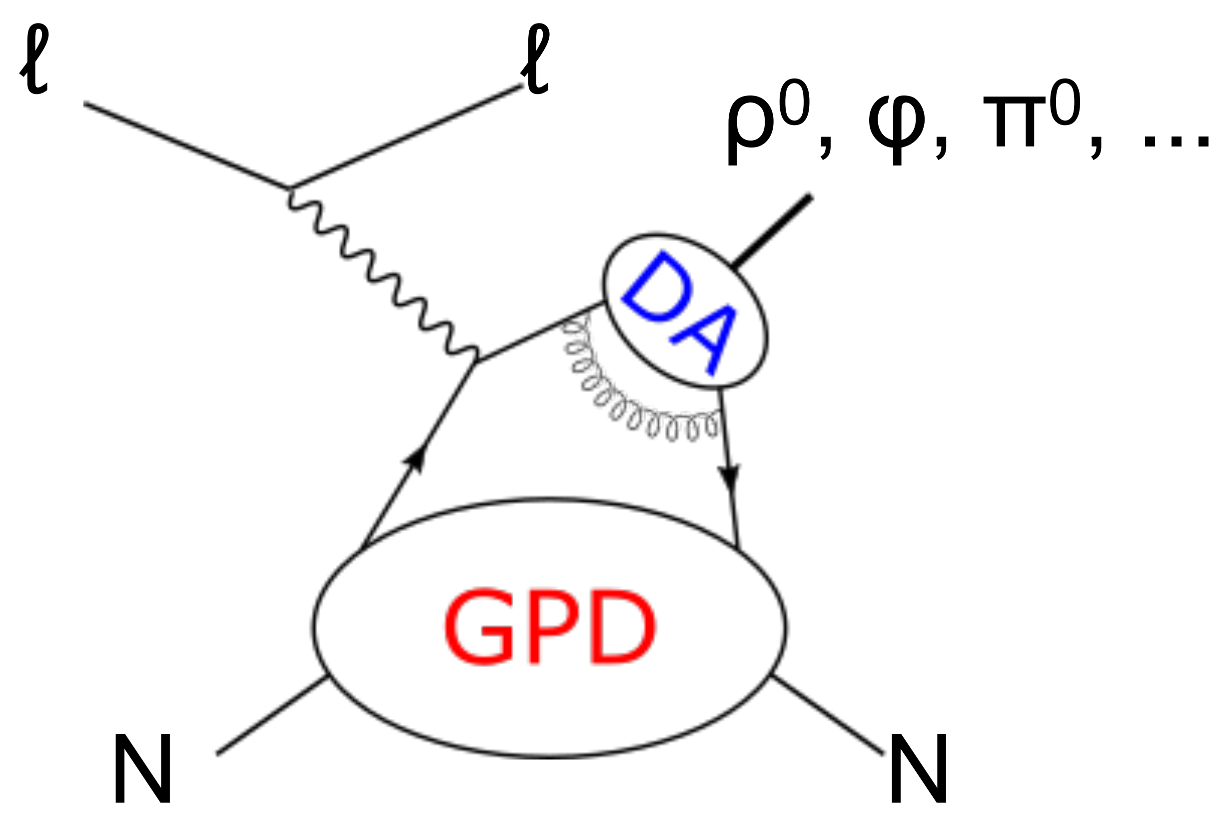
GPDs accessible in various production channels and observables
→ experimental filters



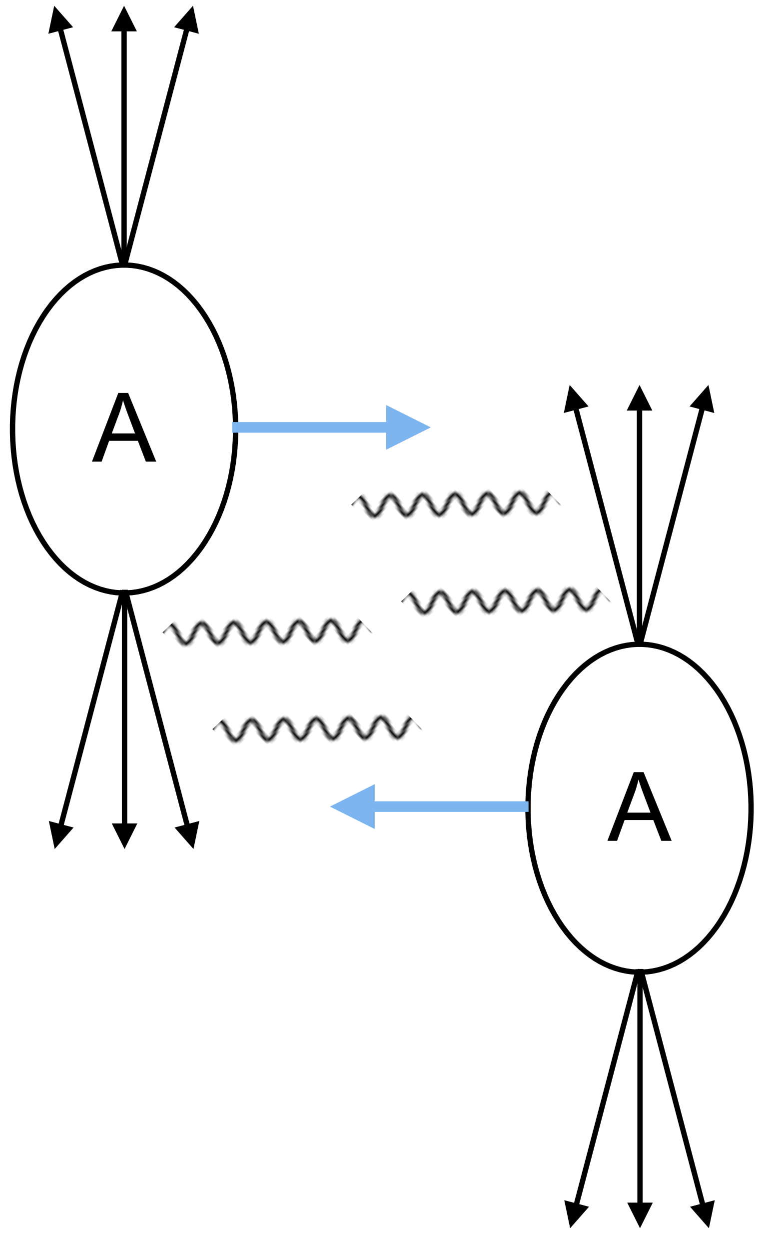
DVCS
Deeply Virtual Compton Scattering



TCS
Timelike Compton Scattering



HEMP
Hard Exclusive Meson Production



UPC
Ultra Peripheral Collisions

more production channels sensitive to GPDs exist!

Cross-section

(S)pace-like or (T)ime-like

Helicity amplitudes: $^{X}M_{\lambda'\mu',\lambda\mu}$

Helicities (p'ɣ',pɣ), where ɣp→ɣ'p'

Cross-section: $d\sigma \propto |\mathcal{T}_{\mathrm{BH}} + \mathcal{T}(M_{\lambda'\mu',\lambda\mu})|^2$

Compton Form Factors: $\mathcal{H}, \mathcal{E}, \widetilde{\mathcal{H}}, \widetilde{\mathcal{E}}$

DVCS:

$$^{S}M_{++++} = \sqrt{1-\xi^2}\left[{}^{S}\mathcal{H} + {}^{S}\widetilde{\mathcal{H}} - \frac{\xi^2}{1-\xi^2}({}^{S}\mathcal{E} + {}^{S}\widetilde{\mathcal{E}})\right]$$

$$^{S}M_{-+-+} = \sqrt{1-\xi^2}\left[{}^{S}\mathcal{H} - {}^{S}\widetilde{\mathcal{H}} - \frac{\xi^2}{1-\xi^2}({}^{S}\mathcal{E} - {}^{S}\widetilde{\mathcal{E}})\right]$$

$$^{S}M_{++-+} = \frac{\sqrt{t_0 - t}}{2M}\left[{}^{S}\mathcal{E} - \xi\, {}^{S}\widetilde{\mathcal{E}}\right]$$

$$^{S}M_{-+++} = -\frac{\sqrt{t_0 - t}}{2M}\left[{}^{S}\mathcal{E} + \xi\, {}^{S}\widetilde{\mathcal{E}}\right]$$

TCS:

$$^{T}M_{+-+-} = \sqrt{1-\xi^2}\left[{}^{T}\mathcal{H} + {}^{T}\widetilde{\mathcal{H}} - \frac{\xi^2}{1-\xi^2}({}^{T}\mathcal{E} + {}^{T}\widetilde{\mathcal{E}})\right]$$

$$^{T}M_{----} = \sqrt{1-\xi^2}\left[{}^{T}\mathcal{H} - {}^{T}\widetilde{\mathcal{H}} - \frac{\xi^2}{1-\xi^2}({}^{T}\mathcal{E} - {}^{T}\widetilde{\mathcal{E}})\right]$$

$$^{T}M_{+---} = \frac{\sqrt{t_0 - t}}{2M}\left[{}^{T}\mathcal{E} - \xi\, {}^{T}\widetilde{\mathcal{E}}\right]$$

$$^{T}M_{--+-} = -\frac{\sqrt{t_0 - t}}{2M}\left[{}^{T}\mathcal{E} + \xi\, {}^{T}\widetilde{\mathcal{E}}\right]$$

for more details see:
Berger, Diehl, Pire Eur. Phys. J. C23 675, 2002
Diehl Phys. Rept. 388 41,2003

Cross-section

Compton Form Factors in terms of GPDs:

$$\mathscr{F}(\xi,t,\mathscr{Q}^2) = \int_{-1}^{1} dx \sum_{i=u,d,\ldots,g} T^i(x,\xi,\mathscr{Q}^2) F^i(x,\xi,t)$$

Coefficient functions:

DVCS:

$${}^{S}T^i \overset{\text{LO}}{=} {}^{S}C_0^i$$

$${}^{S}T^i \overset{\text{NLO}}{=} {}^{S}C_0^i + \frac{\alpha_s(\mu_R^2)}{2\pi}\left[{}^{S}C_1^i + {}^{S}C_{\text{coll}}^i \ln\frac{\mathscr{Q}^2}{\mu_F^2}\right]$$

TCS:

$${}^{T}T^i \overset{\text{LO}}{=} \pm{}^{S}T^{i*}$$

$${}^{T}T^i \overset{\text{NLO}}{=} \pm{}^{S}T^{i*} \mp i\pi\frac{\alpha_s(\mu_R^2)}{2\pi}{}^{S}C_{\text{coll}}^{i*}$$

Relation between DVCS and TCS CFFs:

$${}^{T}\mathscr{H} \overset{\text{LO}}{=} {}^{S}\mathscr{H}^*$$

$${}^{T}\widetilde{\mathscr{H}} \overset{\text{LO}}{=} -{}^{S}\widetilde{\mathscr{H}}^*$$

$${}^{T}\mathscr{H} \overset{\text{NLO}}{=} {}^{S}\mathscr{H}^* - i\pi\,\mathscr{Q}^2\frac{\partial}{\partial\mathscr{Q}^2}{}^{S}\mathscr{H}^*$$

$${}^{T}\widetilde{\mathscr{H}} \overset{\text{NLO}}{=} -{}^{S}\widetilde{\mathscr{H}}^* + i\pi\,\mathscr{Q}^2\frac{\partial}{\partial\mathscr{Q}^2}{}^{S}\widetilde{\mathscr{H}}^*\,.$$

for more details see:
Mueller, Pire, Szymanowski, Wagner
Phys. Rev. D86, 031502 (2012)

Cross-section

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$$^{T}\mathscr{H} \stackrel{\text{NLO}}{=} {}^{S}\mathscr{H}^{*} - i\pi\,\mathscr{Q}^2 \frac{\partial}{\partial \mathscr{Q}^2} {}^{S}\mathscr{H}^{*}$$

$$^{T}\widetilde{\mathscr{H}} \stackrel{\text{NLO}}{=} -{}^{S}\widetilde{\mathscr{H}}^{*} + i\pi\,\mathscr{Q}^2 \frac{\partial}{\partial \mathscr{Q}^2} {}^{S}\widetilde{\mathscr{H}}^{*}.$$

Combined study of DVCS and TCS:

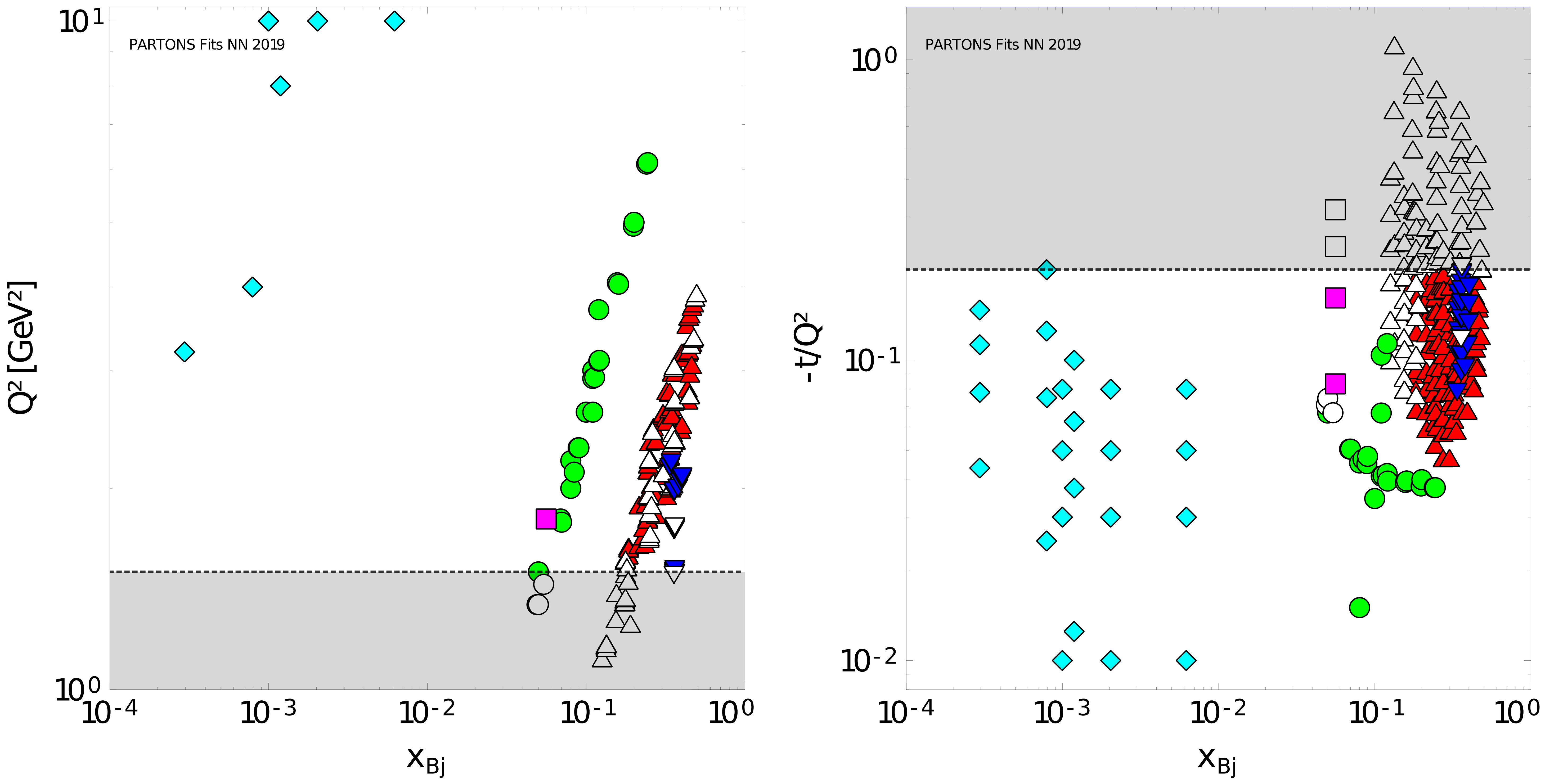
- source of GPD information
- useful to prove universality of GPDs
- impact of NLO corrections
- constrain Q2-dep. of CFF*

for more details see:
Mueller, Pire, Szymanowski, Wagner Phys. Rev. D86, 031502 (2012)

Amplitude analysis

Extraction of DVCS CFFs from world proton data

No.	Collab.	Year	Observable		Kinematic dependence	No. of points used / all
1	HERMES	2001	A_{LU}^{+}		ϕ	10 / 10
2		2006	$A_{C}^{\cos i\phi}$	$i=1$	t	4 / 4
3		2008	$A_{C}^{\cos i\phi}$	$i=0,1$	x_{Bj}	18 / 24
			$A_{UT,\mathrm{DVCS}}^{\sin(\phi-\phi_S)\cos i\phi}$	$i=0$		
			$A_{UT,\mathrm{I}}^{\sin(\phi-\phi_S)\cos i\phi}$	$i=0,1$		
			$A_{UT,\mathrm{I}}^{\cos(\phi-\phi_S)\sin i\phi}$	$i=1$		
4		2009	$A_{LU,\mathrm{I}}^{\sin i\phi}$	$i=1,2$	x_{Bj}	35 / 42
			$A_{LU,\mathrm{DVCS}}^{\sin i\phi}$	$i=1$		
			$A_{C}^{\cos i\phi}$	$i=0,1,2,3$		
5		2010	$A_{UL}^{+,\sin i\phi}$	$i=1,2,3$	x_{Bj}	18 / 24
			$A_{LL}^{+,\cos i\phi}$	$i=0,1,2$		
6		2011	$A_{LT,\mathrm{DVCS}}^{\cos(\phi-\phi_S)\cos i\phi}$	$i=0,1$	x_{Bj}	24 / 32
			$A_{LT,\mathrm{DVCS}}^{\sin(\phi-\phi_S)\sin i\phi}$	$i=1$		
			$A_{LT,\mathrm{I}}^{\cos(\phi-\phi_S)\cos i\phi}$	$i=0,1,2$		
			$A_{LT,\mathrm{I}}^{\sin(\phi-\phi_S)\sin i\phi}$	$i=1,2$		
7		2012	$A_{LU,\mathrm{I}}^{\sin i\phi}$	$i=1,2$	x_{Bj}	35 / 42
			$A_{LU,\mathrm{DVCS}}^{\sin i\phi}$	$i=1$		
			$A_{C}^{\cos i\phi}$	$i=0,1,2,3$		
8	CLAS	2001	$A_{LU}^{-,\sin i\phi}$	$i=1,2$	—	0 / 2
9		2006	$A_{UL}^{-,\sin i\phi}$	$i=1,2$	—	2 / 2
10		2008	A_{LU}^{-}		ϕ	283 / 737
11		2009	A_{LU}^{-}		ϕ	22 / 33
12		2015	A_{LU}^{-}, A_{UL}^{-}, A_{LL}^{-}		ϕ	311 / 497
13		2015	$d^4\sigma_{UU}^{-}$		ϕ	1333 / 1933
14	Hall A	2015	$\Delta d^4\sigma_{LU}^{-}$		ϕ	228 / 228
15		2017	$\Delta d^4\sigma_{LU}^{-}$		ϕ	276 / 358
16	COMPASS	2018	$d^3\sigma_{UU}^{\pm}$		t	2 / 4
17	ZEUS	2009	$d^3\sigma_{UU}^{+}$		t	4 / 4
18	H1	2005	$d^3\sigma_{UU}^{+}$		t	7 / 8
19		2009	$d^3\sigma_{UU}^{\pm}$		t	12 / 12
					SUM:	2624 / 3996



for more details see:

Moutarde, PS, Wagner

Eur. Phys. J. C79 (2019) 7, 614

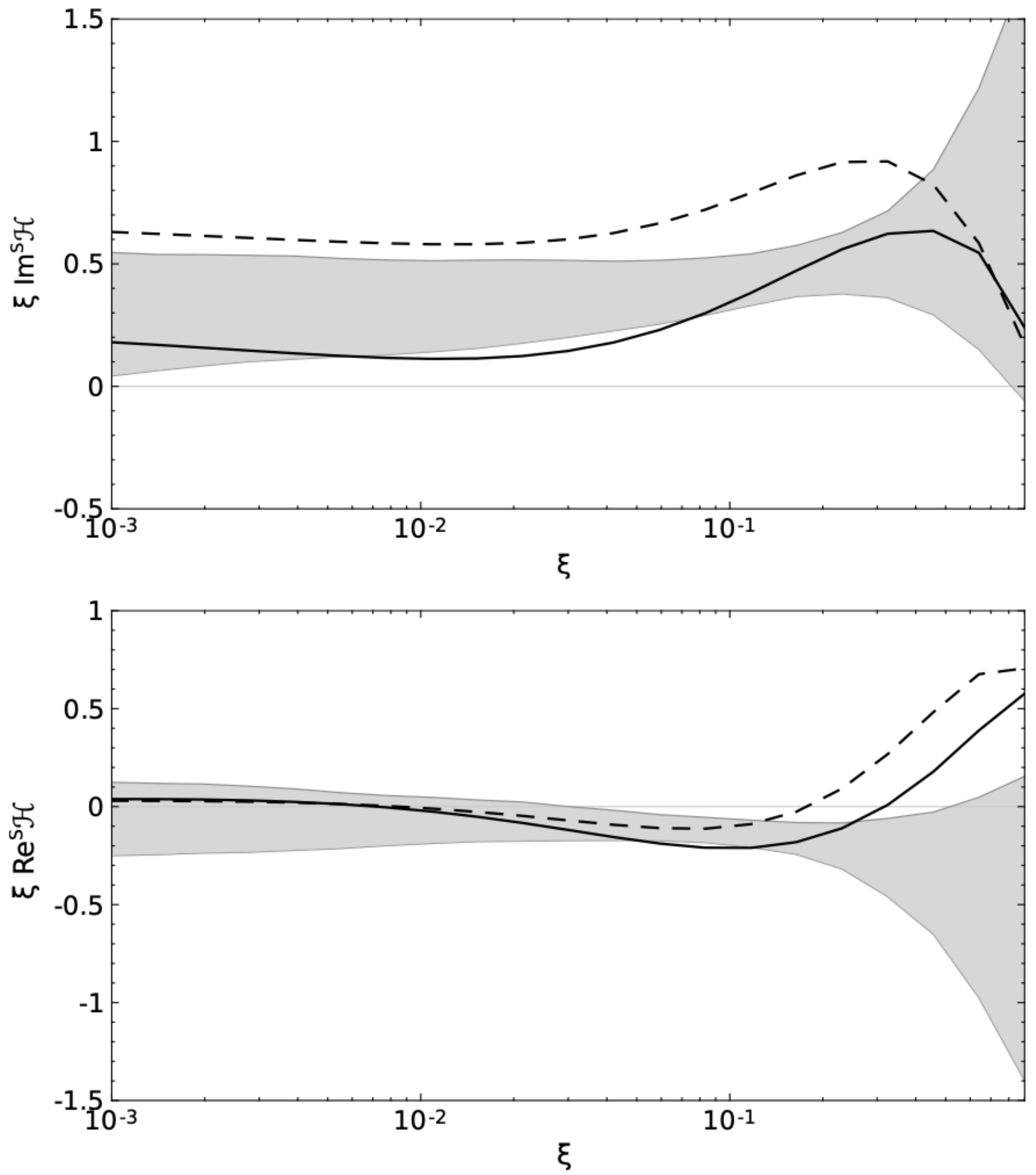
Eur. Phys. J. C78 (2018) 11, 890

Analysis of DVCS subtraction constant: arXiv:2101.03855

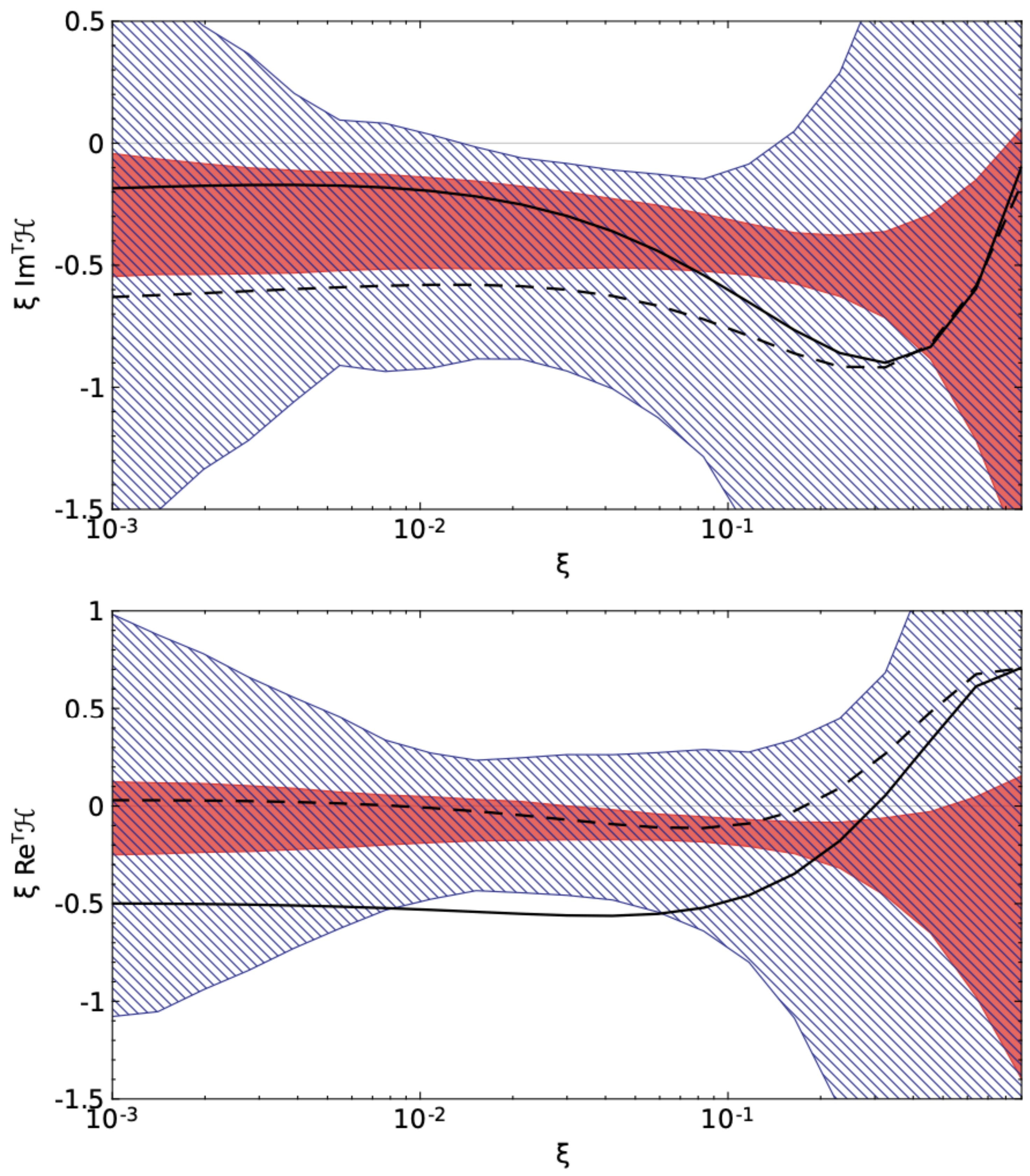
Amplitude analysis

TCS amplitudes and observables from DVCS amplitudes

DVCS:



TCS:



DVCS

TCS from DVCS (LO)

TCS from DVCS (NLO)

GK model (LO)

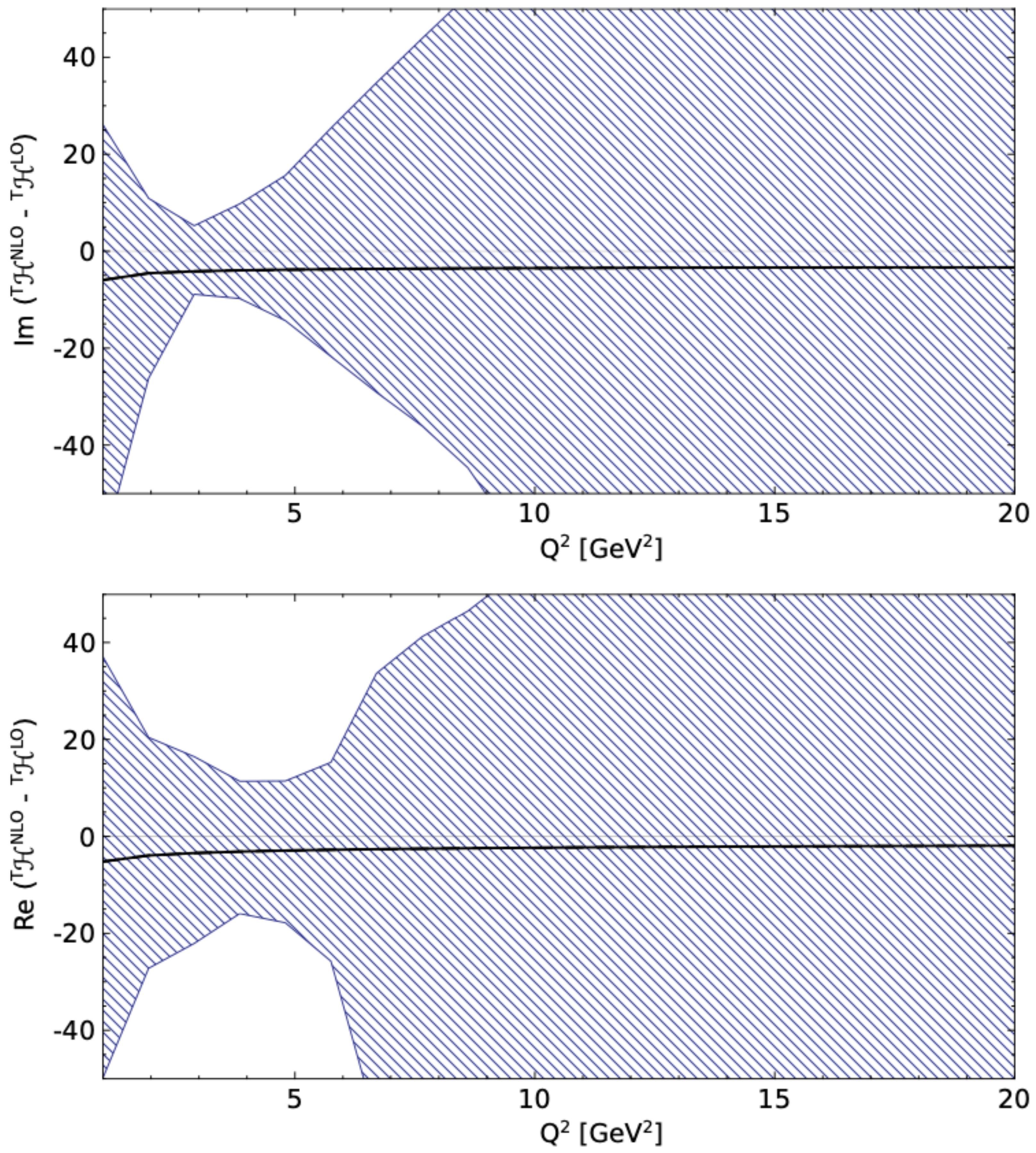
GK model (NLO)

@ $Q^2 = 2\ \mathrm{GeV}^2$, $t = -0.3\ \mathrm{GeV}^2$

for more details see:
Grocholski, Moutarde, Pire, Sznajder, Wagner
Eur. Phys. J. C 80 (2020) 2, 171

Amplitude analysis

TCS amplitudes and observables from DVCS amplitudes



TCS from DVCS (NLO)

GK model (NLO)

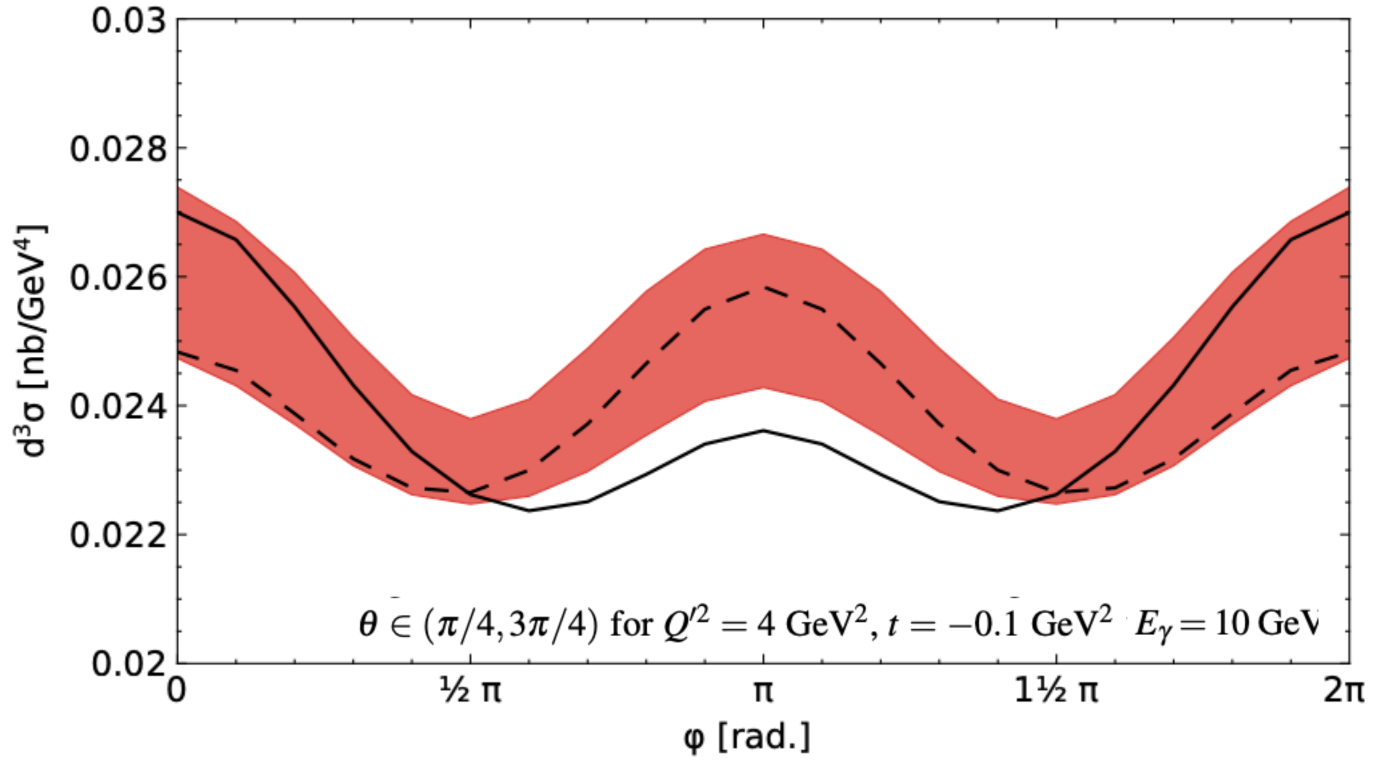
@ xi = 0.1, t = -0.1 GeV^2

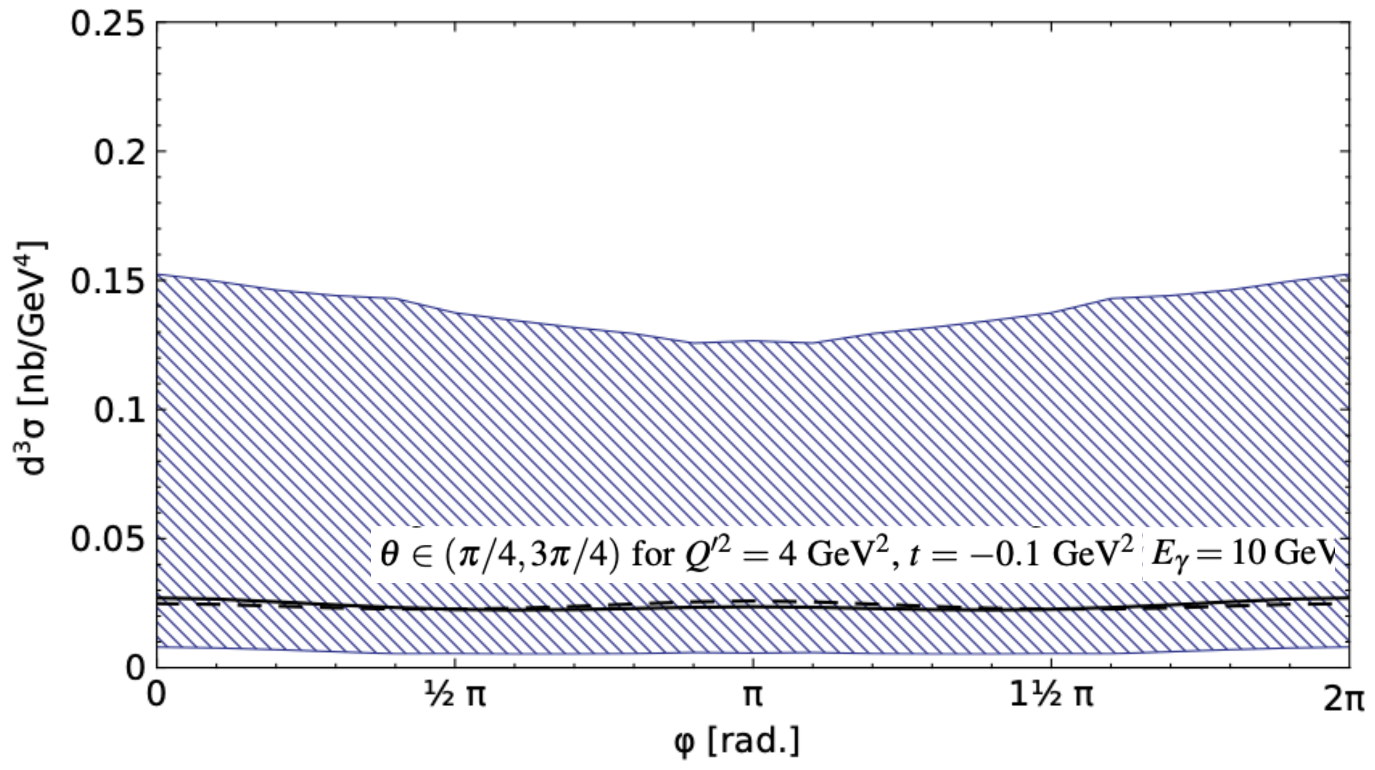
for more details see:
Grocholski, Moutarde, Pire, Sznajder, Wagner
Eur. Phys. J. C 80 (2020) 2, 171

Amplitude analysis

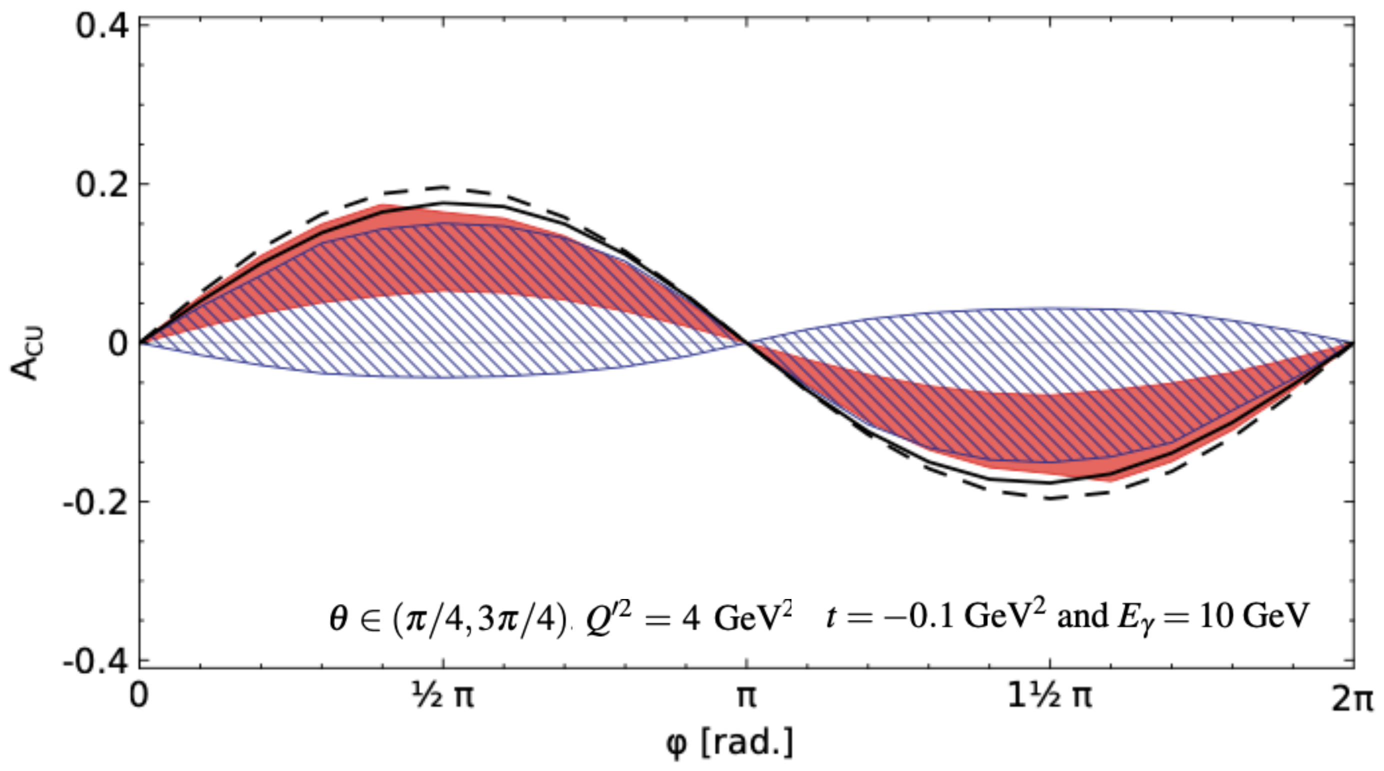
TCS amplitudes and observables from DVCS amplitudes

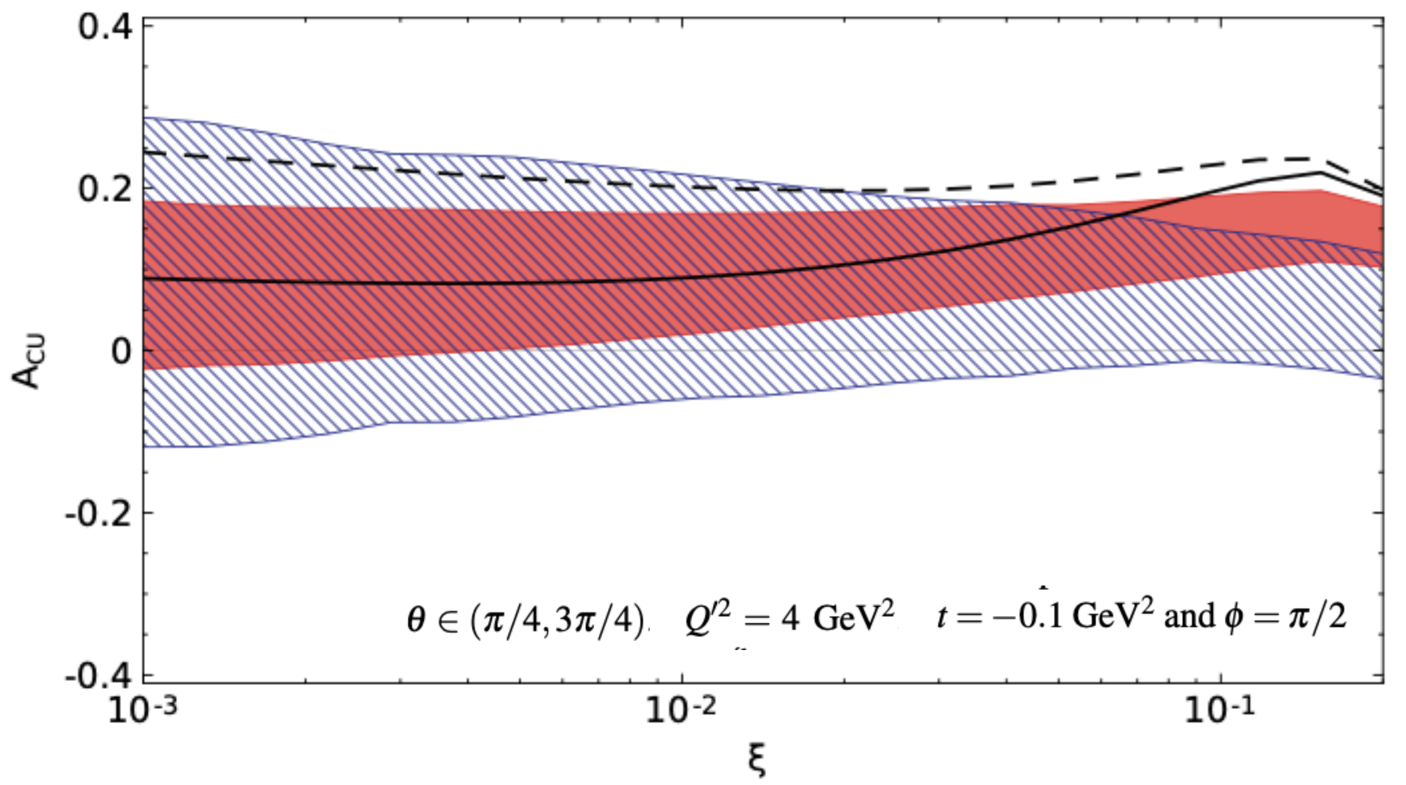
cross-section:





circular beam asymmetry:





TCS from DVCS (LO)

TCS from DVCS (NLO)

GK model (LO)

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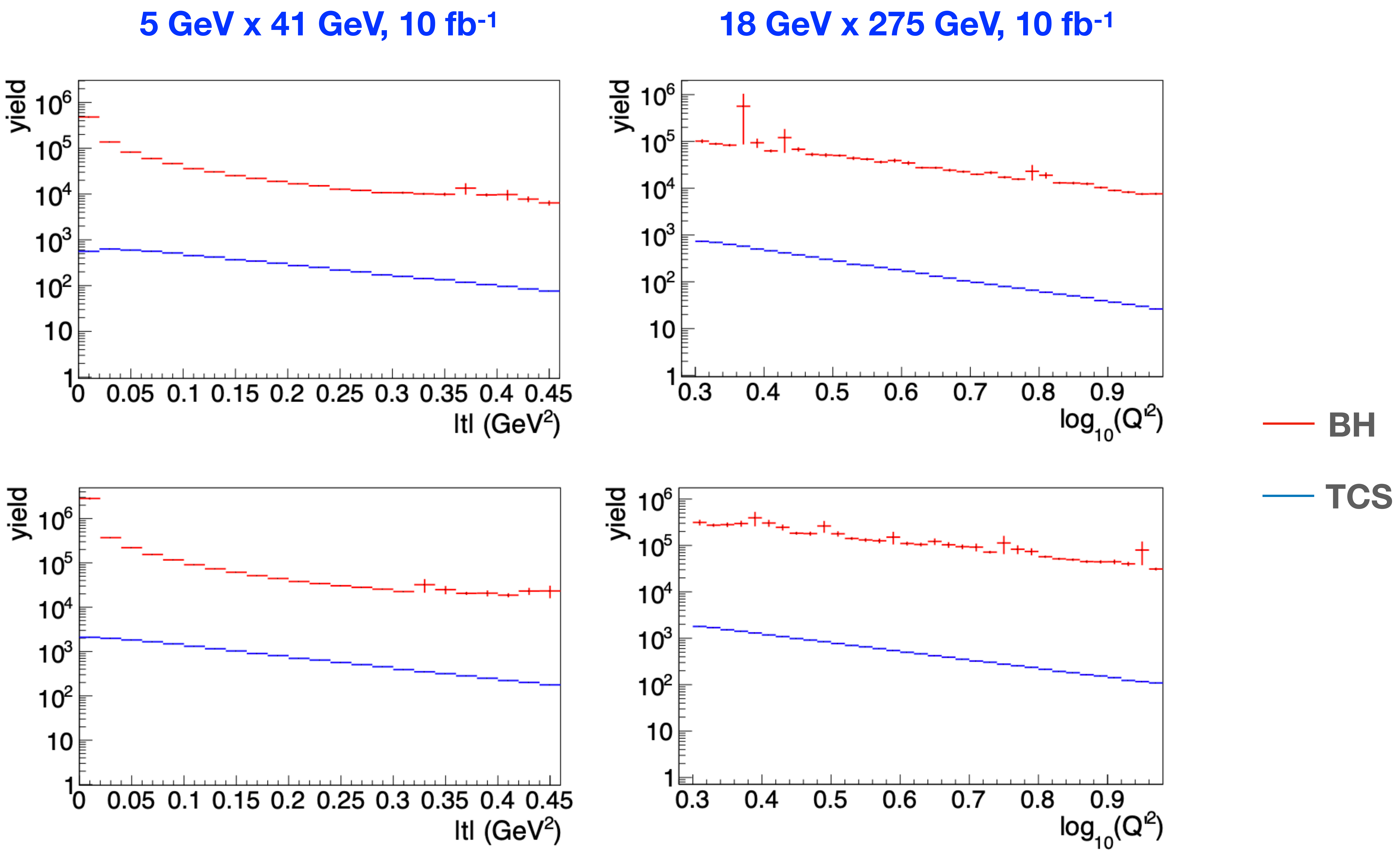
Eur. Phys. J. C 80 (2020) 2, 171

EIC predictions

Part of EIC YR activities



credit:
D. Sokhan, K. Gates

Conclusions

- TCS - source of GPD information
- Combined analysis with DVCS may prove universality of GPDs
- TCS available in PARTONS

  (http://partons.cea.fr, B. Berthou *et al.*, Eur. Phys. J. C78 (2018), 478)
- Impact studies for future colliders in progress
- Development of new MC generator (EpIC) in progress