RG5 (C12-20-012)

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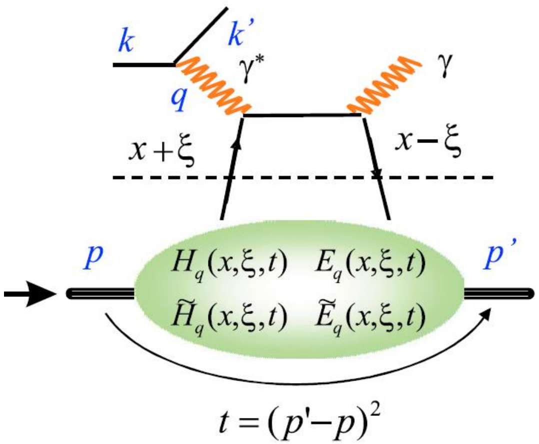
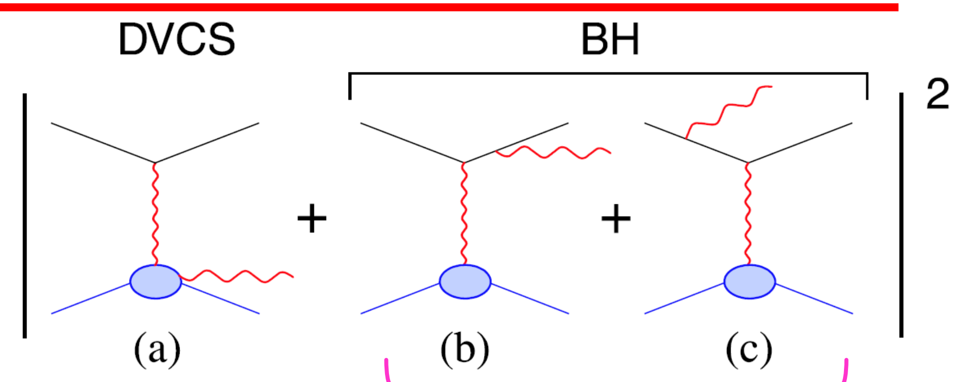
JLab Positron Working Group Proposal
NPS Collaboration Proposal

Motivation



$ep \longrightarrow ep\gamma =$



Calculable in QED with our ~1% knowledge of form factors at low momentum transfer

At leading twist:

$$d^5\overrightarrow{\sigma} - d^5\overleftarrow{\sigma} = \Im m\,(T^{BH}\cdot T^{DVCS})$$

$$d^5\overrightarrow{\sigma} + d^5\overleftarrow{\sigma} = |BH|^2 + \Re e\,(T^{BH}\cdot T^{DVCS}) + |DVCS|^2$$

$$|\mathcal{T}(\pm ep \to \pm ep\gamma)|^2 = |\mathcal{T}^{BH}|^2 + |\mathcal{T}^{DVCS}|^2 \mp \mathcal{I}$$

Opposite sign for e- & e+

$$\mathcal{T}^{DVCS} = \int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi+i\epsilon} + \cdots =$$

$$\underbrace{\mathcal{P}\int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-\xi}} \quad - \quad \underbrace{i\pi\, H(x=\xi,\xi,t)} \quad + \ldots$$

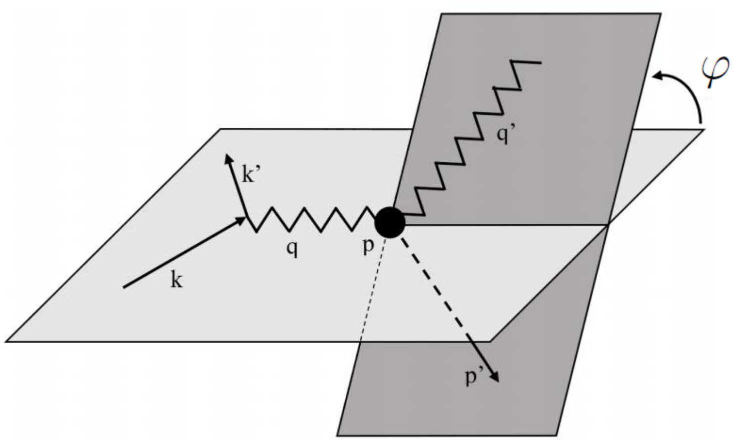
Access in helicity-independent cross section — Access in helicity-dependent cross-section

E07-007: Rosenbluth-like separation of DVCS

$$\sigma(ep \to ep\gamma) = \underbrace{|BH|^2}_{\text{Known to} \sim 1\%} + \underbrace{\mathcal{I}(BH \cdot DVCS)}_{\text{Linear combination of GPDs}} + \underbrace{|DVCS|^2}_{\text{Bilinear combination of GPDs}}$$

$$\mathcal{I} \propto 1/y^3 = (k/\nu)^3,$$

$$|\mathcal{T}^{DVCS}|^2 \propto 1/y^2 = (k/\nu)^2$$



φ-dependence provides 5 independent observables:

$$\sim 1, \sim \cos\varphi, \sim \sin\varphi, \sim \cos(2\varphi), \sim \sin(2\varphi)$$

DVCS with positrons and NPS (proposal to PAC48)

$$|\mathcal{T}(\pm ep \to \pm ep\gamma)|^2 = |\mathcal{T}^{BH}|^2 + |\mathcal{T}^{DVCS}|^2 \mp \mathcal{I}$$

Opposite sign for e- & e+

Physics goals and motivation:

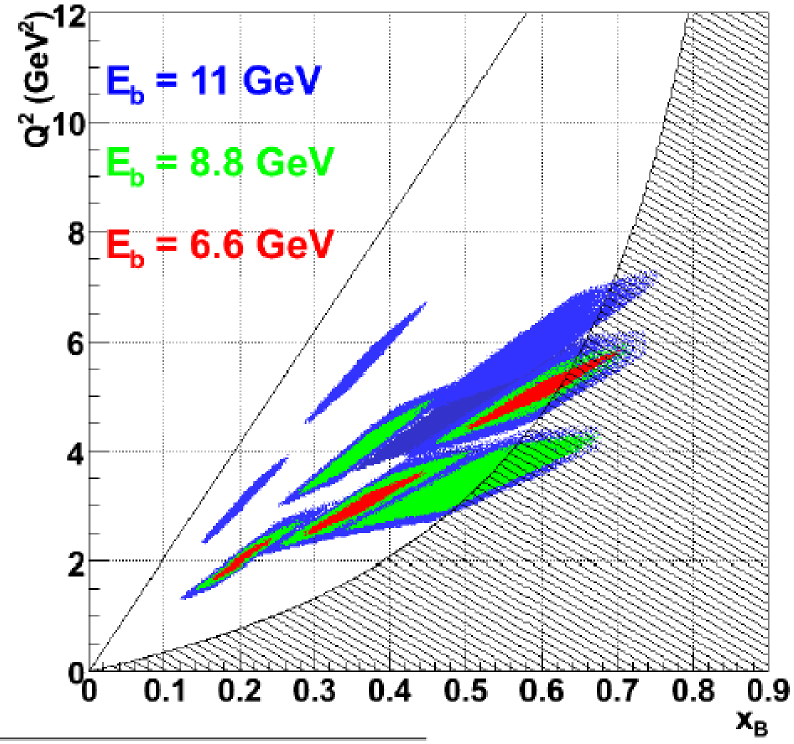
- ✓ Precise determination of the absolute photon electro-production cross section
- ✓ Clean, model-independent separation of $DVCS^2$ and DVCS-BH interference
- ✓ More stringer constraints on CFFs by combining e^- & e^+ data

In a nutshell:

- ➢ Same experimental configuration as approved experiment E12-13-010
- ➢ Expected positron beam momentum spread comparable with current electron beam
- ➢ Positron beam size larger than current electron beam (twice bigger at 11 GeV according to current simulation)
- ➢ No additional systematic uncertainties expected due to the use of positrons

PR12-20-012: Kinematic settings

Same kinematics settings as approved E12—13-010 with electrons



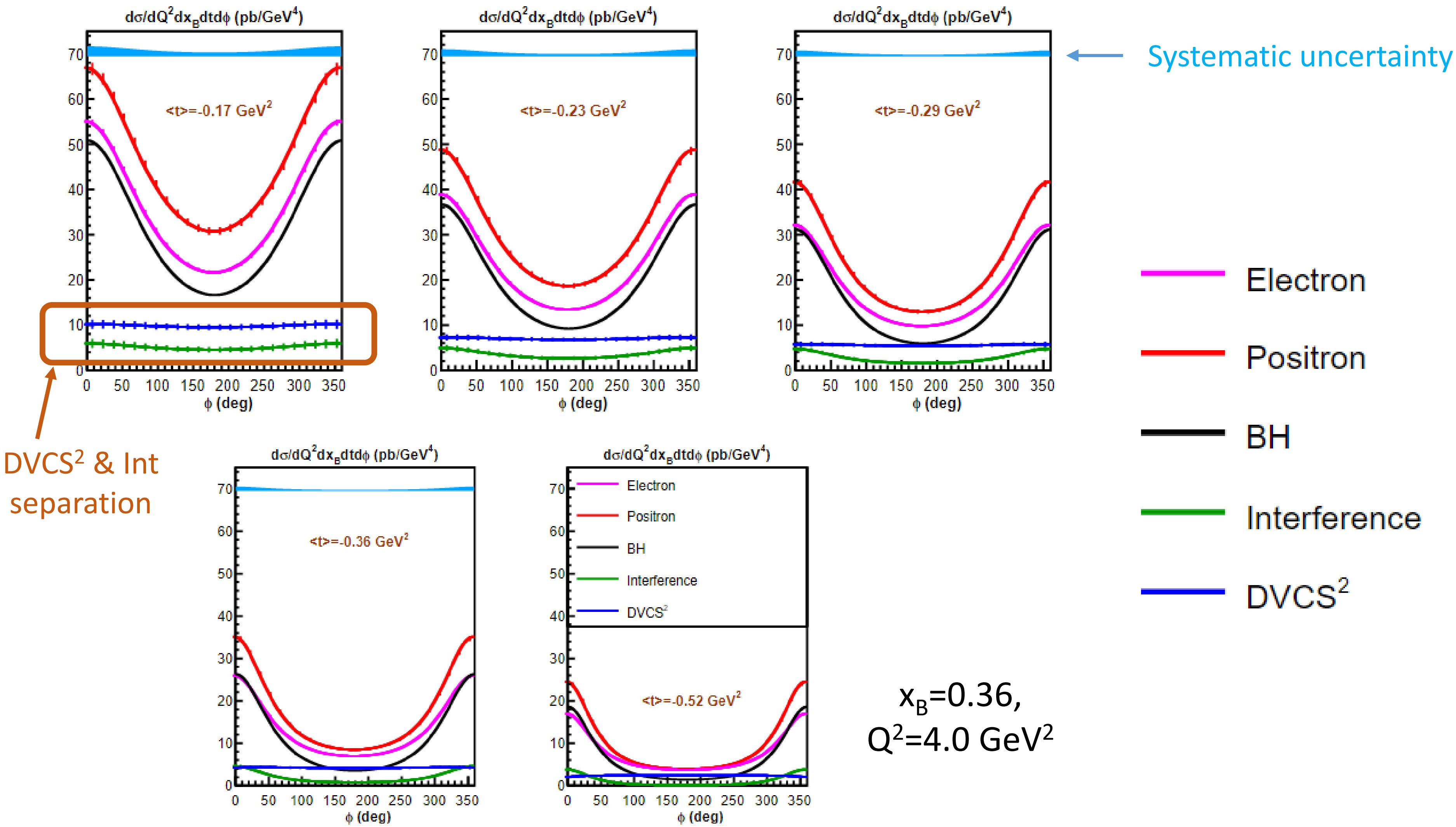
135 days, 1 μA of (unpolarized) positrons assumed

Positron data: 25% of statistics of electron data

$x_{\rm Bj}$	0.2				0.36						0.5			0.6			
Q^2 (GeV)^2	2.0			3.0	3.0			4.0		5.5	3.4		4.8	5.1			6.0
E_b (GeV)	6.6	8.8	11		6.6	8.8	11	8.8	11		8.8	11		6.6	8.8	11	
k' (GeV)	1.3	3.5	5.7	3.0	2.2	4.4	6.6	2.9	5.1	2.9	5.2	7.4	5.9	2.1	4.3	6.5	5.7
$\theta_{\rm Calo}$ (deg)	6.3	9.2	10.6	6.3	11.7	14.7	16.2	10.3	12.4	7.9	20.2	21.7	16.6	13.8	17.8	19.8	17.2
$D_{\rm Calo}$ (m)	6	4		6	3			4	3	4	3						
$\sigma_{M_X^2}$ (GeV^2)	0.17			0.22	0.13		0.12	0.15		0.19	0.09		0.11	0.09			
$I_{\rm beam}$ (μA)	5				1						5						
Days	1	1	3	1	10	15	10	15	20	65	4	3	7	7	2	7	14
					This Proposal: 135 days												

Separation of DVCS^2 and BH-DVCS interference

Projections based on the KM15 model (Kumericki and Mueller, 2015)



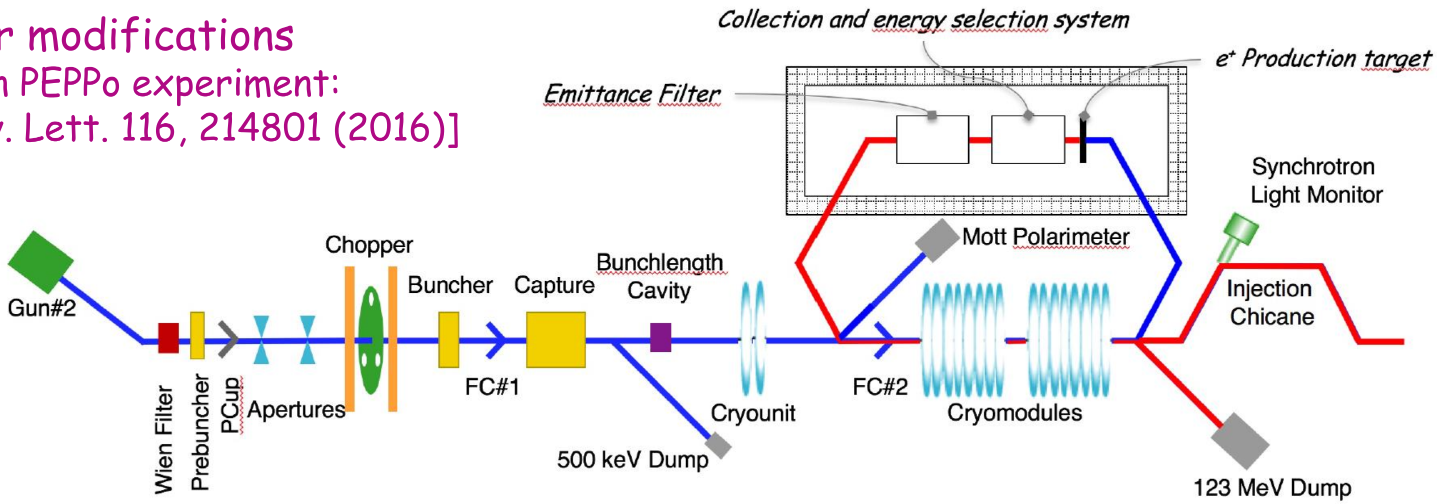
Summary and conclusion

- Positrons are the unique way to unambiguously separate the $DVCS^2$ and the BH-DVCS interference
- They will have a strong impact on GPD CFFs fits and extraction, and the 3D-imaging program of the nucleon
- We request **135 (+2) PAC days** of (unpolarized) positrons at $I \geq 1\ \mu A$
- Same setup (HMS+NPS) and kinematics of approved experiment E12-13-010

BACK-UP

Positron production and transport

Injector modifications
[based on PEPPo experiment:
Phys. Rev. Lett. 116, 214801 (2016)]



Electrons

Dominated by damping in the LINACS

Dominated by synchrotron rad. in Arcs

Area	δp/p [x10-3]	ε_x [nm]	ε_y [nm]
Chicane	0.5	4.00	4.00
Arc 1	0.05	0.41	0.41
Arc 2	0.03	0.26	0.23
Arc 3	0.035	0.22	0.21
Arc 4	0.044	0.21	0.24
Arc 5	0.060	0.33	0.25
Arc 6	0.090	0.58	0.31
Arc 7	0.104	0.79	0.44
Arc 8	0.133	1.21	0.57
Arc 9	0.167	2.09	0.64
Arc 10	0.194	2.97	0.95
Hall D	0.18	2.70	1.03

Positrons

Area	δp/p [x10-3]	ε_x [nm]	ε_y [nm]
Chicane	10	500	500
Arc 1	1	50	50
Arc 2	0.53	26.8	26.6
Arc 3	0.36	19	18.6
Arc 4	0.27	14.5	13.8
Arc 5	0.22	12	11.2
Arc 6	0.19	10	9.5
Arc 7	0.17	8.9	8.35
Arc 8	0.16	8.36	7.38
Arc 9	0.16	8.4	6.8
MYAAT01	0.18	9.13	6.19

At 11 GeV, after Arc9, e+ beam size ~twice bigger than e- beam

Averaging εx and ε_y:

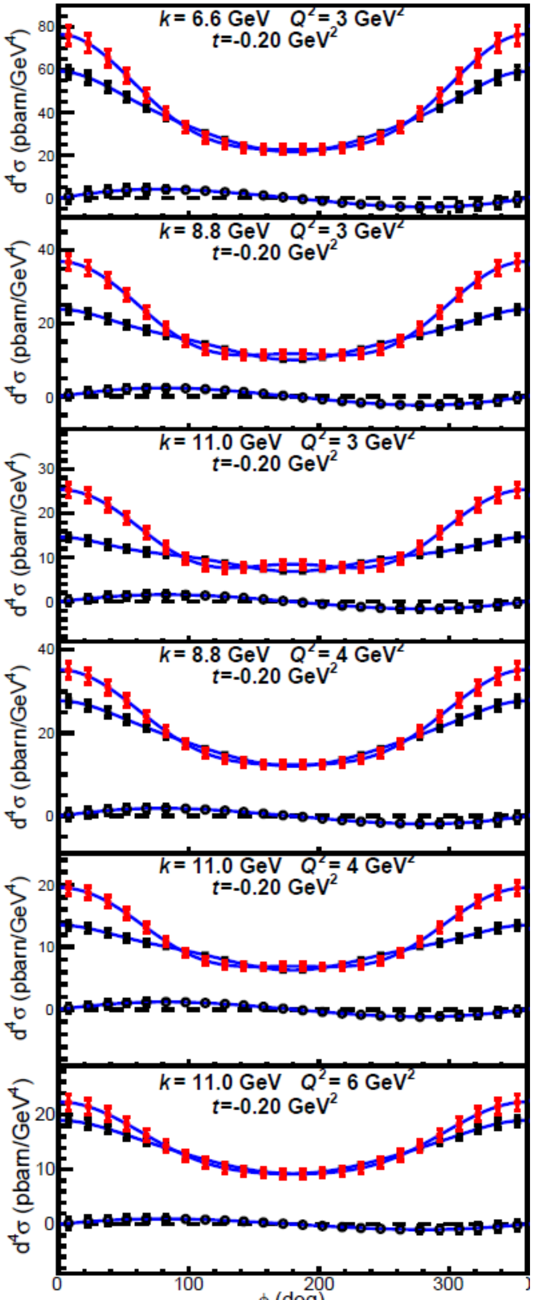
$$\sqrt{7.6/1.4} \sim 2.3$$

Systematic uncertainties

Source	pt-to-pt (%)	scale (%)
Acceptance	0.4	1.0
Electron PID	<0.1	<0.1
Efficiency	0.5	1.0
Electron tracking	0.1	0.5
Charge	0.5	1.0
Target thickness	0.2	0.5
Kinematics	0.4	<0.1
Exclusivity	1.0	2.0
π^0 subtraction	0.5	1.0
Radiative corrections	1.2	2.0
Total	**1.8-1.9**	**3.4-3.5**

The π^0 electroproduction cross section would be measured concurrently with DVCS with both electrons and positrons, and would allow to monitor the systematics of the e- and e+ runs

Impact on Compton Form Factors (CFFs) extraction



- ✓ Combined fit of all electron data from approved experiment E12-13-010

(helicity-dependent AND helicity-independent cross sections)

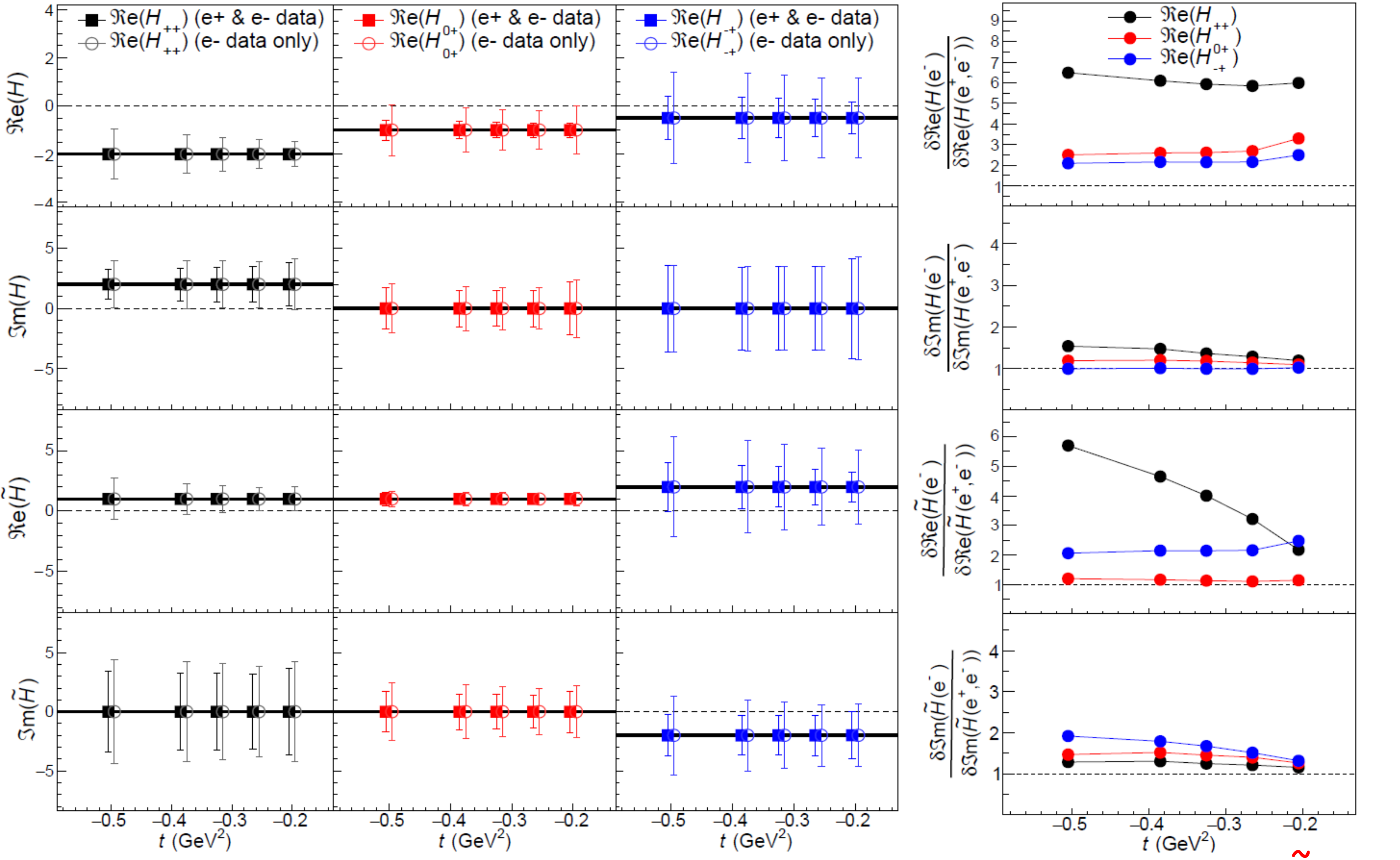
- ✓ Fits with and without the proposed positron data
- ✓ Fits include helicity-conserving CFFs, but also +1 helicity-flip CFFs ("HT") and +2 helicity-flip CFFs ("NLO")
- ✓ Cross sections generated with CFFs values fitted to 6 GeV data

In order to extract the CFFs we exploit the combined

- Azimuthal dependence (ϕ)
- Beam-energy dependence
- Q^2-dependence
- Helicity dependence (for E12-13-010 data)
- **Beam-charge dependence**

of the DVCS cross section

Impact on Compton Form Factors (CFFs) extraction



A factor or 4-6 improvement in the extraction of LO/LT CFFs Re(H) and Re($\tilde{H}$)

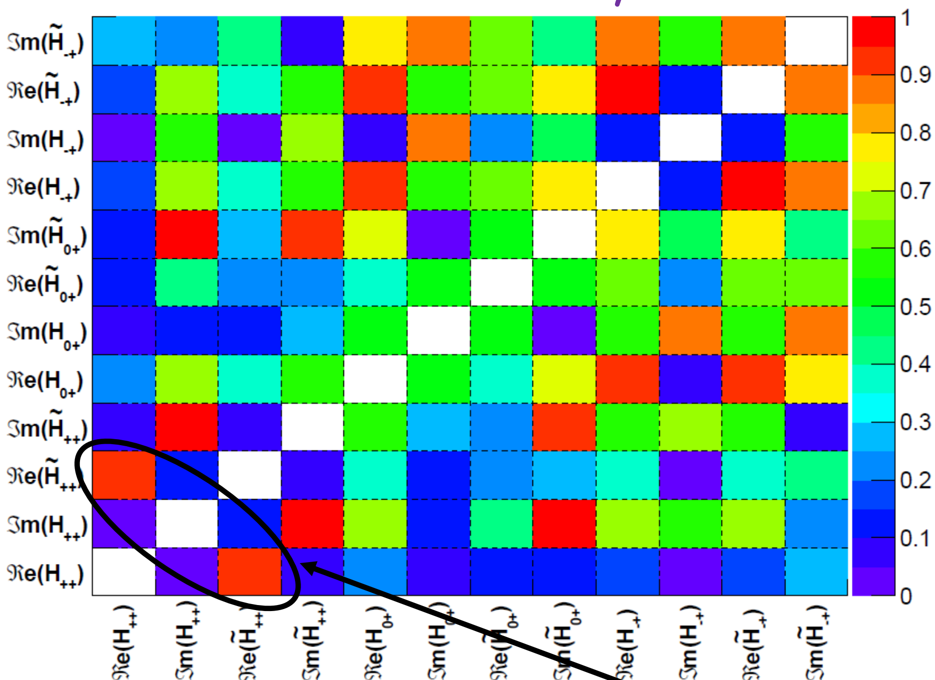
(factor of ~2 for HT and NLO)

Correlation coefficients

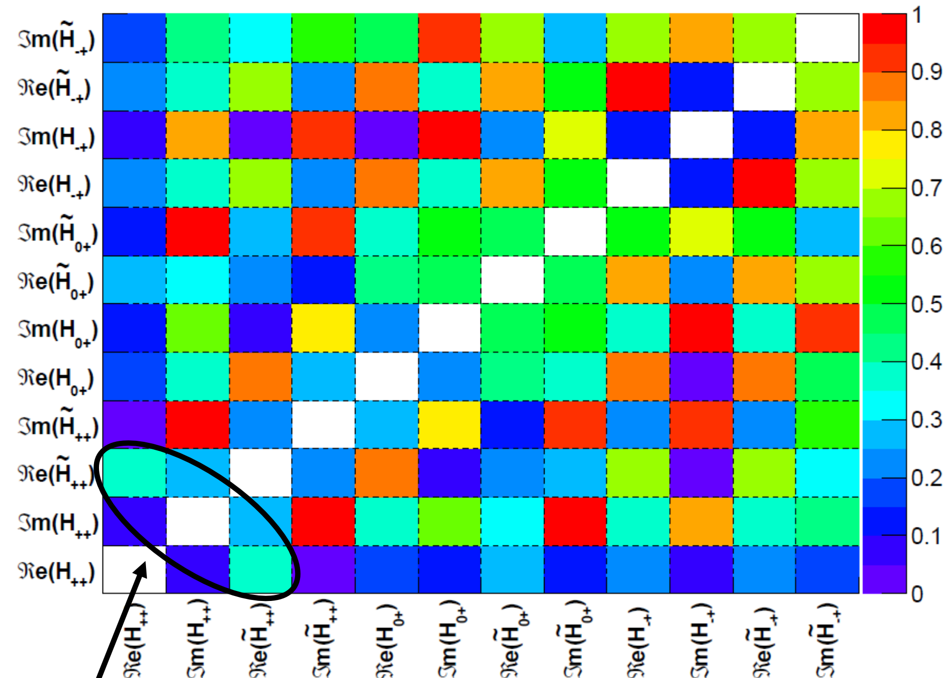
Correlations between different CFFs are significantly improved by a combined fit with positrons

$$|\rho_{i,j}| = \left|\mathrm{cov}[\mathbb{F}_i, \mathbb{F}_j]/(\sigma_i \sigma_j)\right|$$

Electrons only



Electrons & Positrons



LT/LO HT NLO

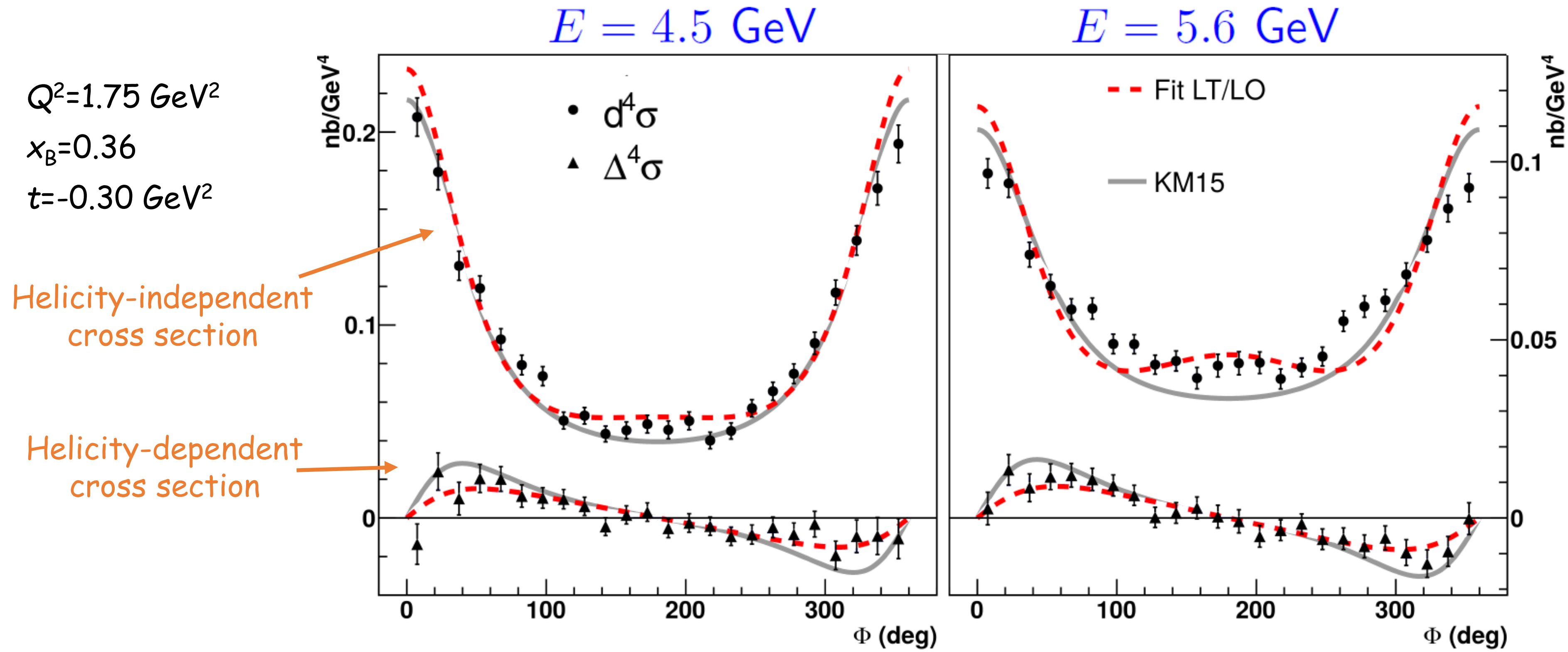
(t = -0.26 GeV^2)

Much better separation of H & Ht CFFs at LT/LO

(from -94% without positrons to -39% when electron and positrons are combined, in this t-bin)

E07-007: Rosenbluth-like separation of DVCS

- Cross section measured at 2 beam energies and constant Q^2, x_B, t

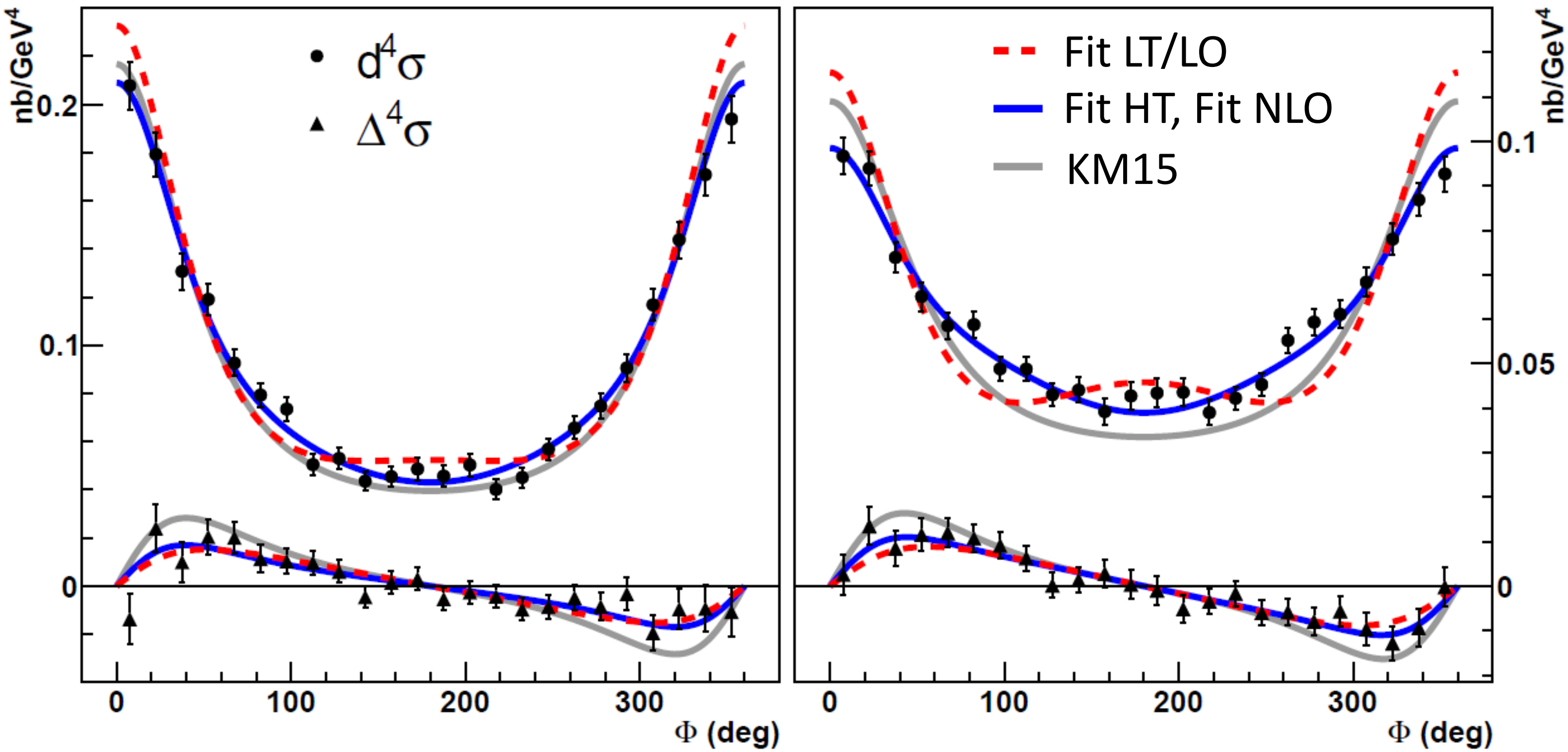


- Leading-twist and LO simultaneous fit of both beam energies (dashed line) does not reproduce the data

Light-cone axis in the (q,q') plane (Braun et al.): $\mathbb{H}_{++}$, $\widetilde{\mathbb{H}}_{++}$, $\mathbb{E}_{++}$, $\widetilde{\mathbb{E}}_{++}$

E07-007: Rosenbluth-like separation of DVCS

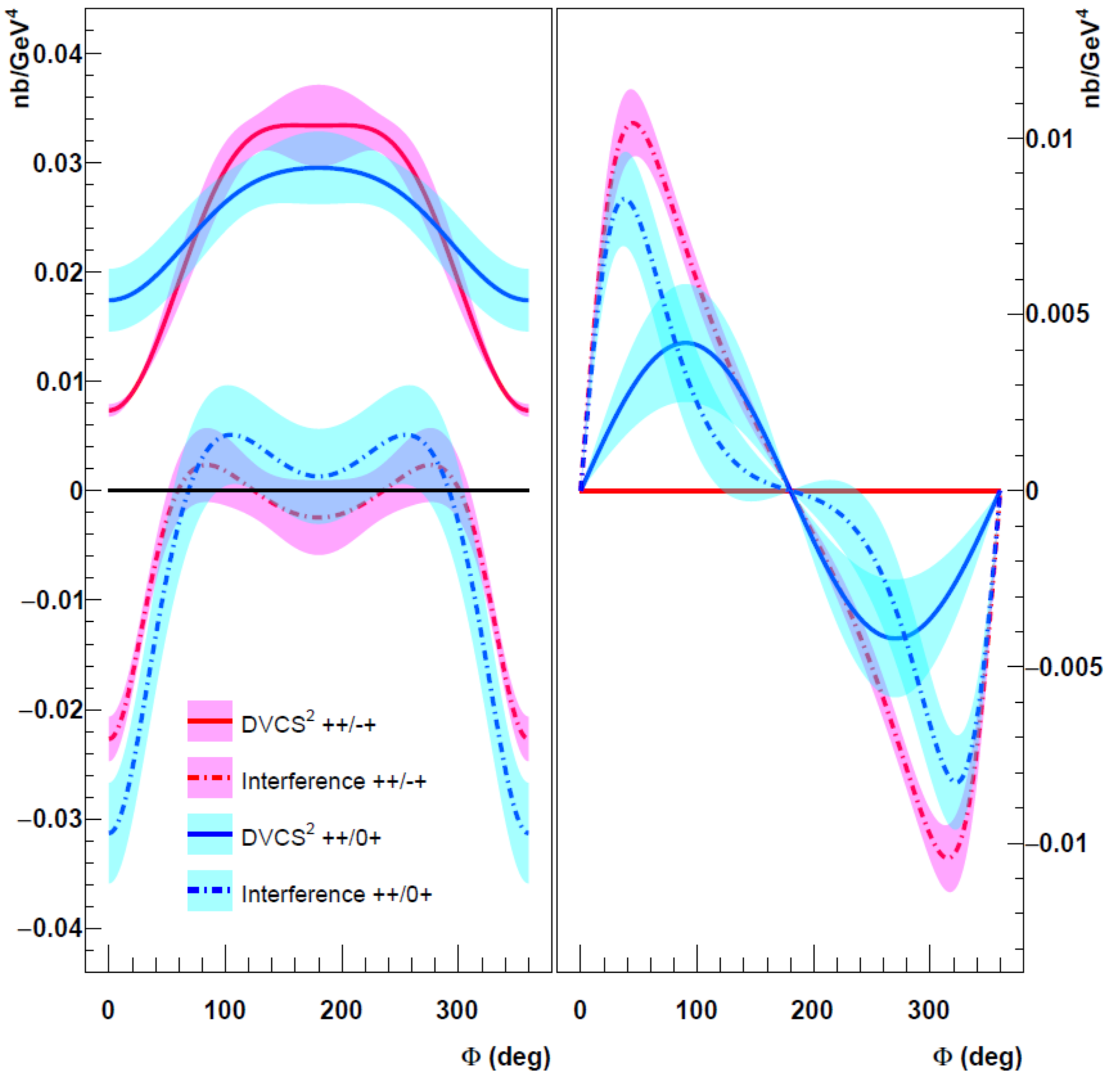
- Cross section measured at 2 beam energies and constant Q^2, x_B, t



- Using only helicity-conserving CFFs ("LT/LO") the fit of both beam energies (dashed line) does not reproduce the data
- Including helicity-flip CFFs, either single-helicity flip ("HT") or double-helicity flip ("NLO") satisfactorily reproduce the angular dependence (blue solid line)

E07-007: Rosenbluth-like separation of DVCS

DVCS^2 and $\mathcal{I}$(DVCS·BH) separated in NLO and higher-twist scenarios



Helicity-independent cross section

Helicity-dependent cross section

- DVCS^2 & $\mathcal{I}$ significantly different in each scenario
- Sizeable DVCS^2 contribution in the higher-twist scenario in the helicity-dependent cross section

Nature Commun. 8, 1408 (2017)