Deeply Virtual Compton Scattering with CLAS6

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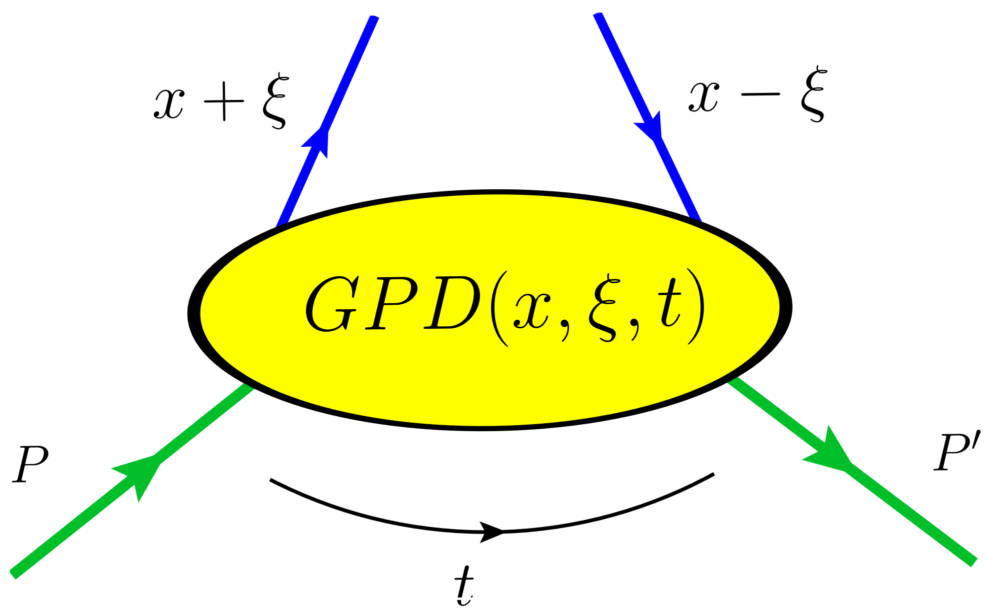
Introduction

GPDs describe the nucleon structure in terms of quark and gluon degrees of freedom

Correlation between transverse position and longitudinal momentum fraction of quark in the nucleon



Form Factors:
Transverse distribution of quarks in space coordinate.
F(t)=∫dx*GPD(x, ξ, t)

PDFs:
Quark longitudinal momentum fraction in the nucleon.
q(x)=GPD(x, ξ=0, t=0)

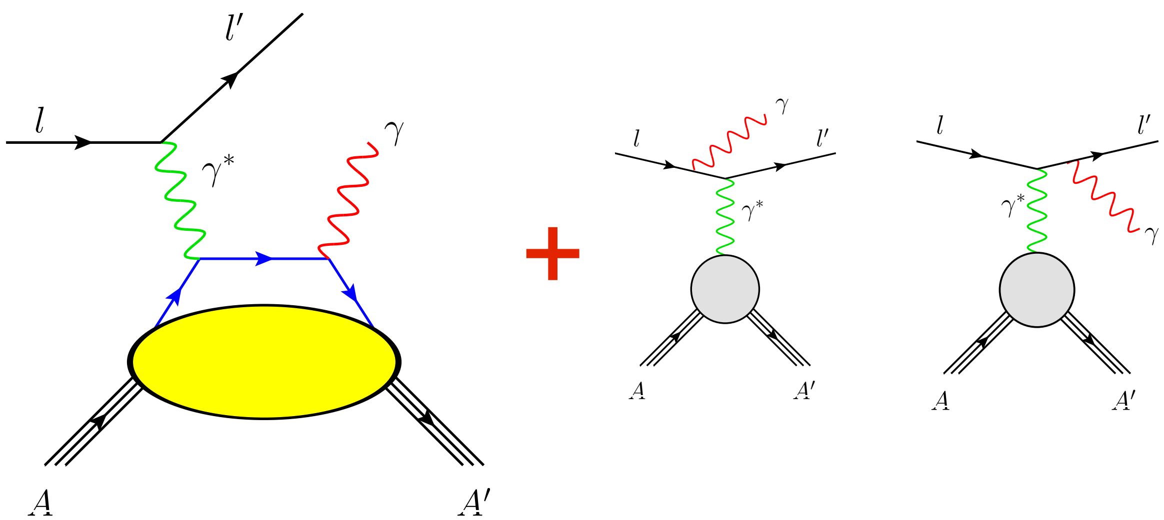
Relation to total angular momentum (Ji relation):

$$J_q = \frac{1}{2}\lim_{t\to 0}\int_{-1}^{1} dx\, x\,(H_q(x,\xi,t) + E_q(x,\xi,t))$$

leading-twist, quark chirality conserving		
spin-1/2	unpolarized	polarized
no nucleon hel. flip	H	$\widetilde{H}$
nucleon hel. flip	E	$\widetilde{E}$

Experimental Access to GPDs

Experimental probe of GPDs ⟶ Hard exclusive Processes



Deeply Virtual Compton Scattering

- Theoretically the cleanest probe of GPDs
- Theoretical accuracy at NNLO
- GPDs are accessed through convolution integrals with hard scattering amplitude
- Experimental observables: Azimuthal asymmetries, cross sections, cross section differences.
- Amplitudes depend on all GPDs $H, E, \widetilde{H}, \widetilde{E}$

DVCS and Bethe-Heitler $\Rightarrow$ Same final state $\Rightarrow$ Interference

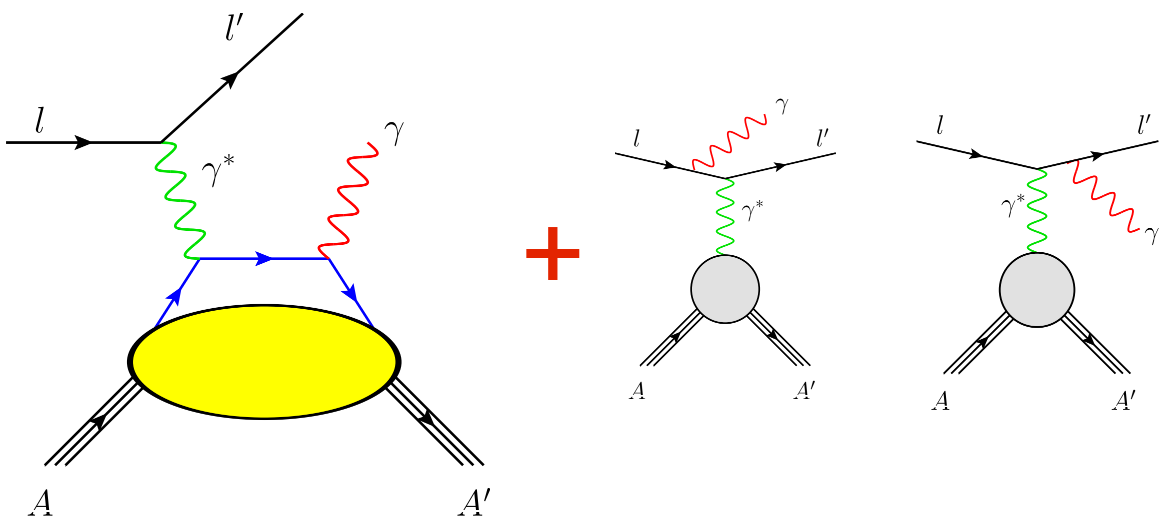
$$\frac{d\sigma}{dx_B dQ^2 d|t| d\phi} \propto |\mathcal{T}_{BH}|^2 + |\mathcal{T}_{DVCS}|^2 + \underbrace{\mathcal{T}_{DVCS}\mathcal{T}^*_{BH} + \mathcal{T}_{BH}\mathcal{T}^*_{DVCS}}_{I}$$

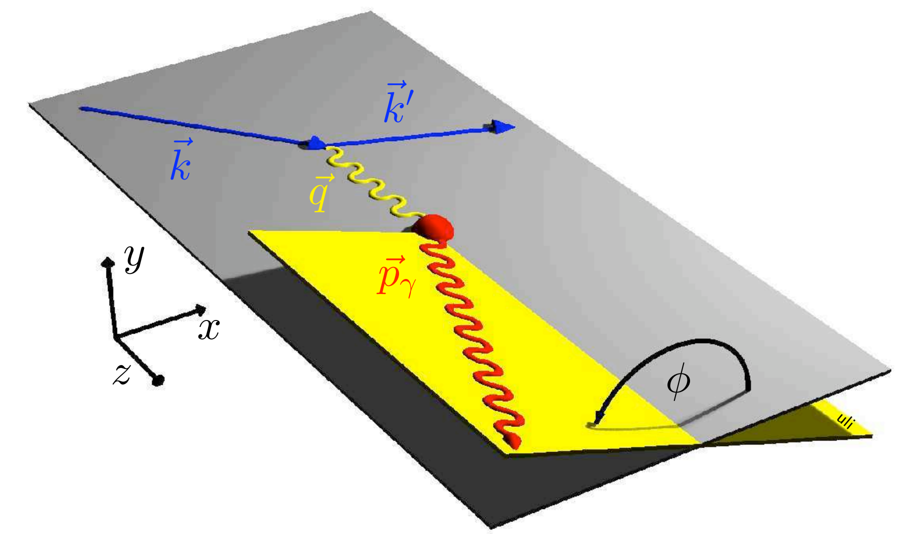
At CLAS kinematics $\quad |\mathcal{T}_{DVCS}|^2 << |\mathcal{T}_{BH}|^2$

DVCS amplitudes can be accessed trough Interference

Interference $\Rightarrow$ non-zero azimuthal asymmetries

Deeply Virtual Compton Scattering





DVCS and Bethe-Heitler $\Rightarrow$ Same final state $\Rightarrow$ Interference

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Bethe-Heitler is parametrized in terms of electromagnetic Form-Factors $F_1, \; F_2$

DVCS is parametrized in terms of Compton Form-Factors $\mathcal{H}, \mathcal{E}, \widetilde{\mathcal{H}}, \widetilde{\mathcal{E}}$

CFFs = convolutions of hard scattering amplitudes and GPD's

$$\mathcal{F}(\xi, t) = \sum_q \int_{-1}^{1} dx C_q(\xi, x) F^q(x, \xi, t)$$

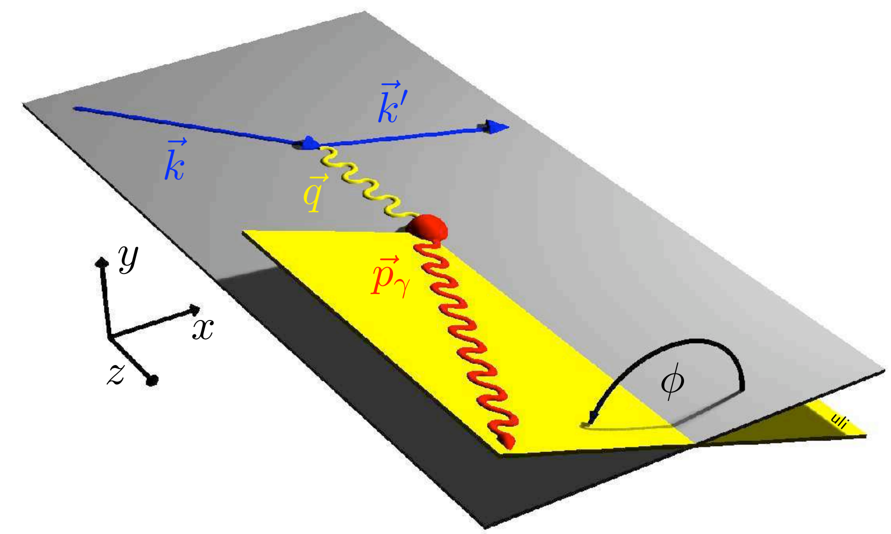
Azimuthal Dependence

4-fold differential cross-sections & cross-section difference

$$|\mathcal{T}_{\rm BH}|^2 = \frac{K_{\rm BH}}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)}\left\{\sum_{n=0}^{2} c_n^{\rm BH}\cos(n\phi)\right\}$$

$$|\mathcal{T}_{\rm DVCS}|^2 = K_{\rm DVCS}\left\{\sum_{n=0}^{2} c_n^{\rm DVCS}\cos(n\phi) + \sum_{n=1}^{2} s_n^{\rm DVCS}\sin(n\phi)\right\}$$

$$\mathcal{I} = -\frac{K_{\rm I}e_\ell}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)}\left\{\sum_{n=0}^{3} c_n^{\rm I}\cos(n\phi) + \sum_{n=1}^{3} s_n^{\rm I}\sin(n\phi)\right\}$$



$$d\sigma = d\sigma_{UU} + P_{Beam}\, d\sigma_{LU}$$

Polarized target

$$c_n^T = c_{n,unp}^T + \lambda\Lambda c_{n,LP}^T$$
$$s_n^T = \lambda s_{n,unp}^T + \Lambda s_{n,LP}^T$$

λ - Beam polarization

Λ - Target spin projection

- Beam-Spin Asymmetry
  $\sigma(\overrightarrow{e},\phi) - \sigma(\overleftarrow{e},\phi) \propto Im[F_1\mathcal{H}]$
- Longitudinal Target-Spin Asymmetry
  $\sigma(\overset{\Rightarrow}{P},\phi) - \sigma(\overset{\Leftarrow}{P},\phi) \propto Im[F_1\widetilde{\mathcal{H}}]$
- Longitudinal Double-Spin Asymmetry
  $\sigma(\overset{\Rightarrow}{P},\overrightarrow{e},\phi) - \sigma(\overset{\Rightarrow}{P},\overleftarrow{e},\phi) \propto Re[F_1\widetilde{\mathcal{H}}]$

DVCS at CLAS

DVCS with Longitudinally Polarized Target :

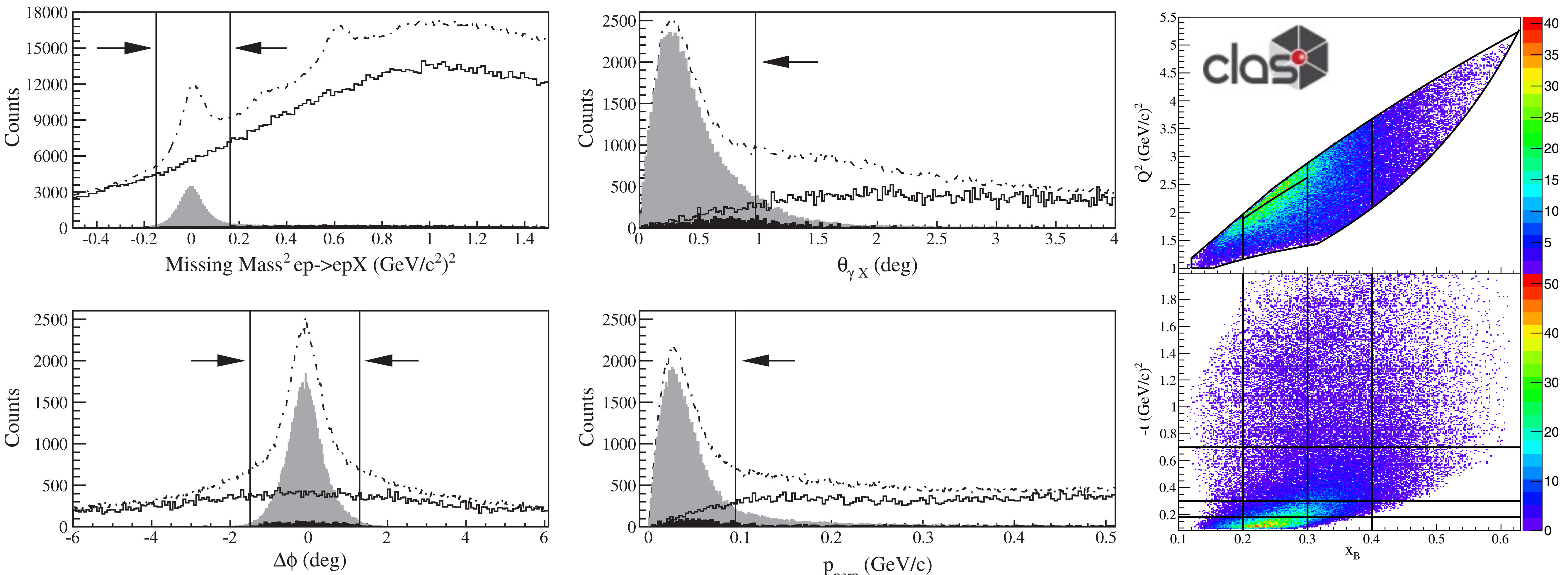
Analysis based on eg1-dvcs experiment

Extraction of beam-spin, target-spin and double-spin asymmetries

$$d\sigma = d\sigma_{UU} + P_{Beam} d\sigma_{LU} + P_{Target} d\sigma_{UL} + P_{Beam} P_{Target} d\sigma_{LL}$$

DVCS channel selection

Detection of complete final state of the process $ep \to ep\gamma$



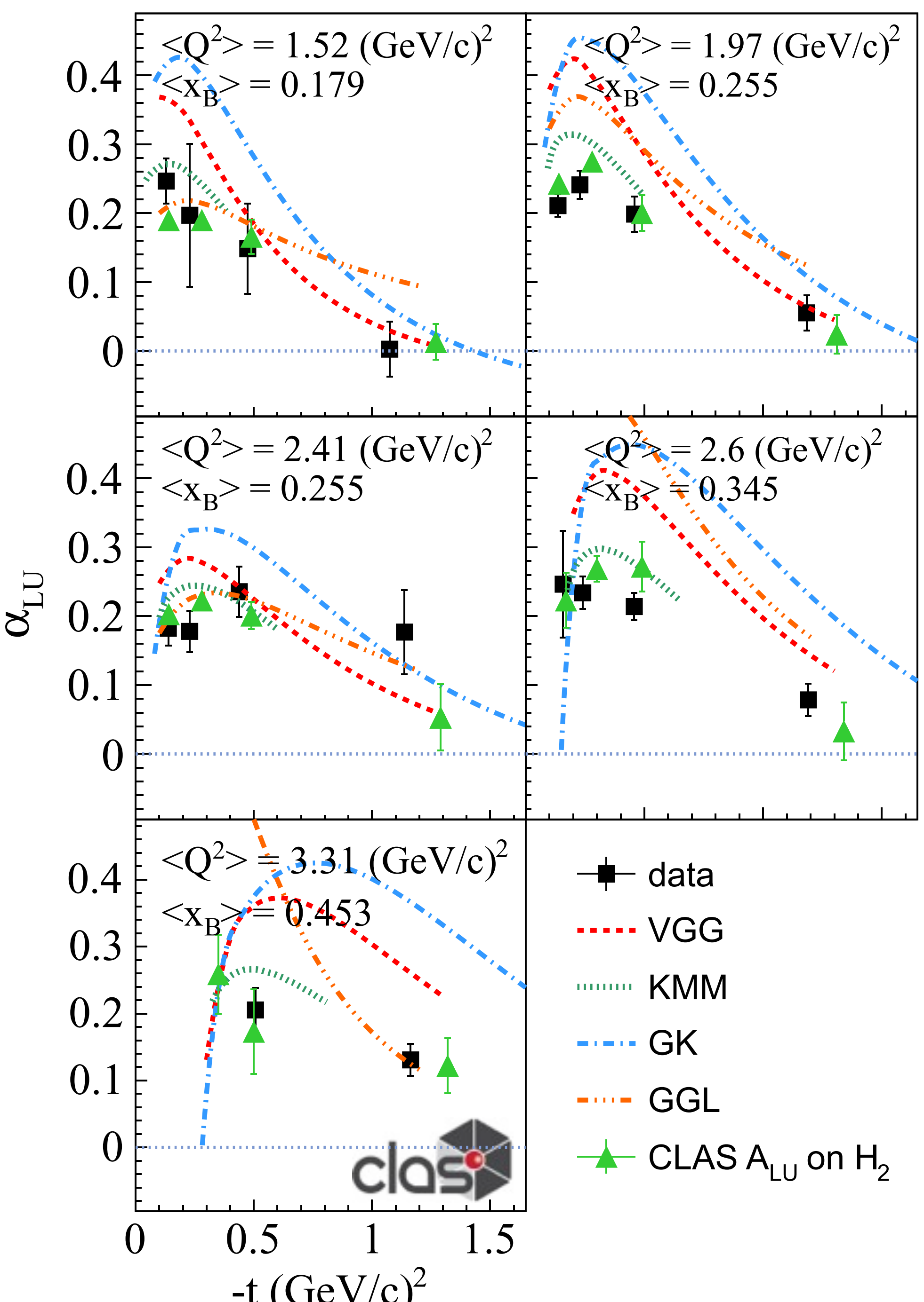
Results are published in 2015 S.Pisano et al. Phys.Rev.D91:052014 (2015)

DVCS at CLAS

Single Beam-Spin & Target-Spin Asymmetries

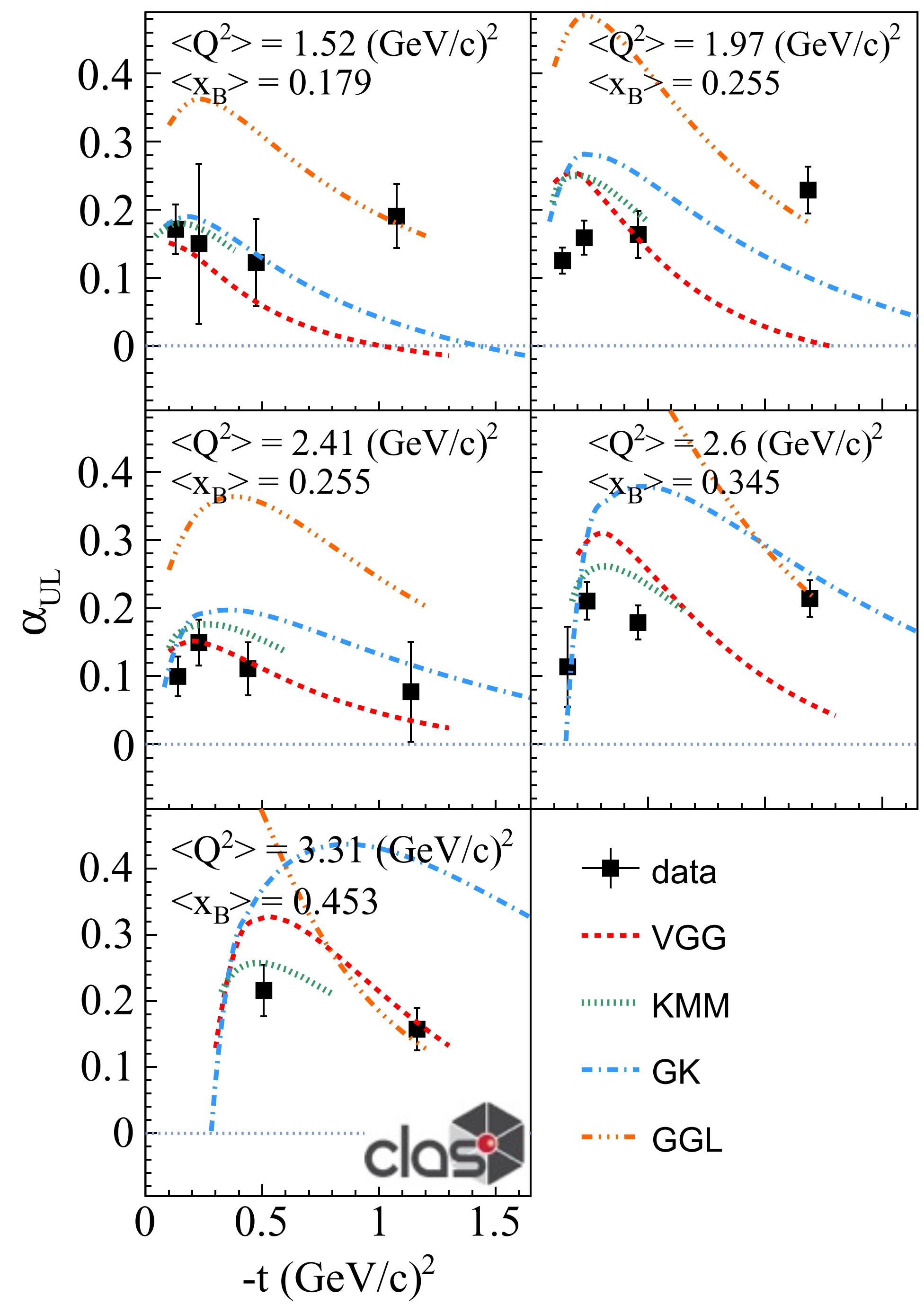
S.Pisano et al. [Phys.Rev.D91:052014 (2015)](https://doi.org/10.1103/PhysRevD.91.052014)

$$\frac{\alpha_{LU} \sin\phi}{(1+\beta\cos\phi)}$$



$\propto \mathcal{I}m\left[F_1\mathcal{H}\right]$

$$\frac{\alpha_{UL} \sin\phi}{1+\beta\cos\phi}$$

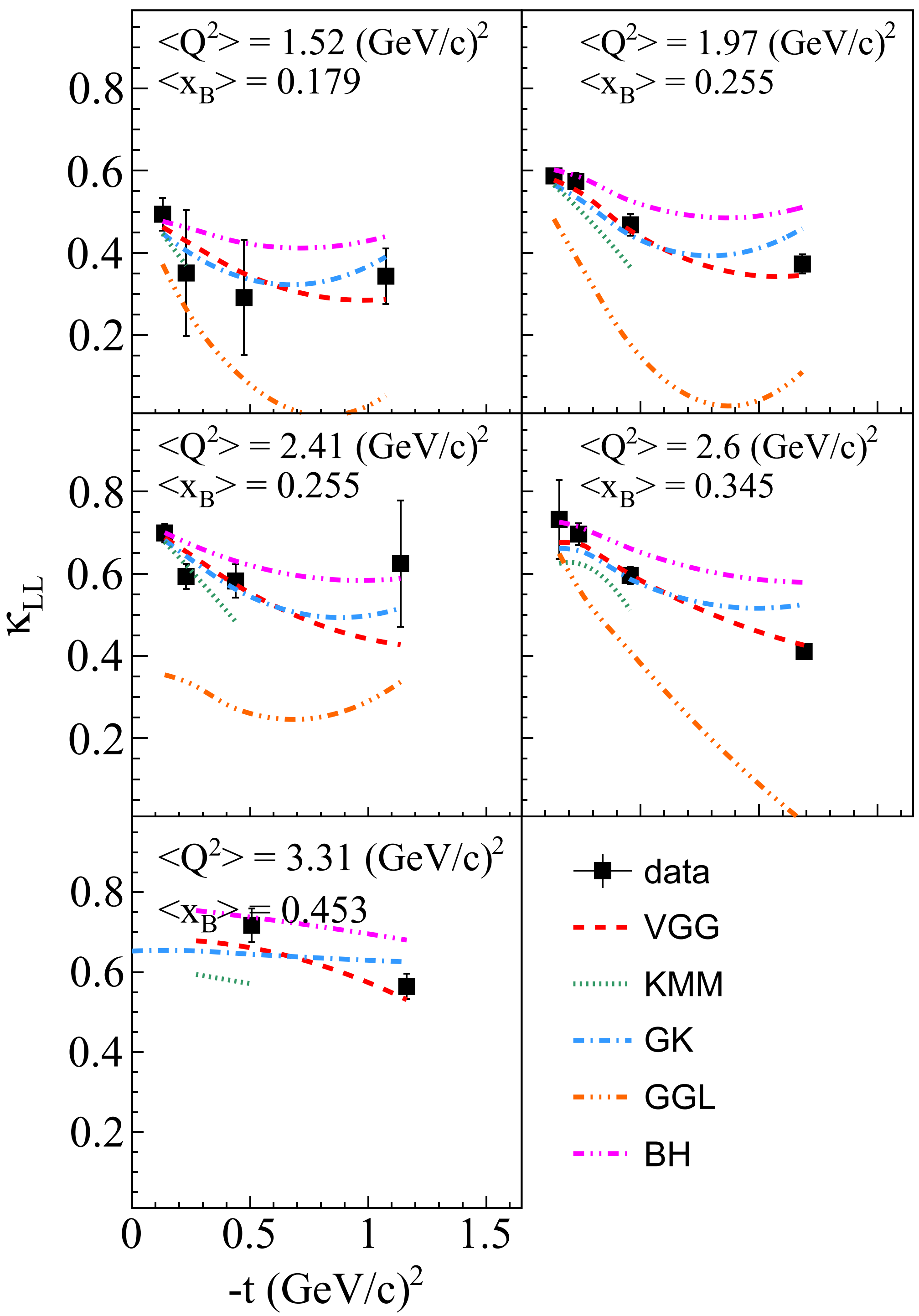


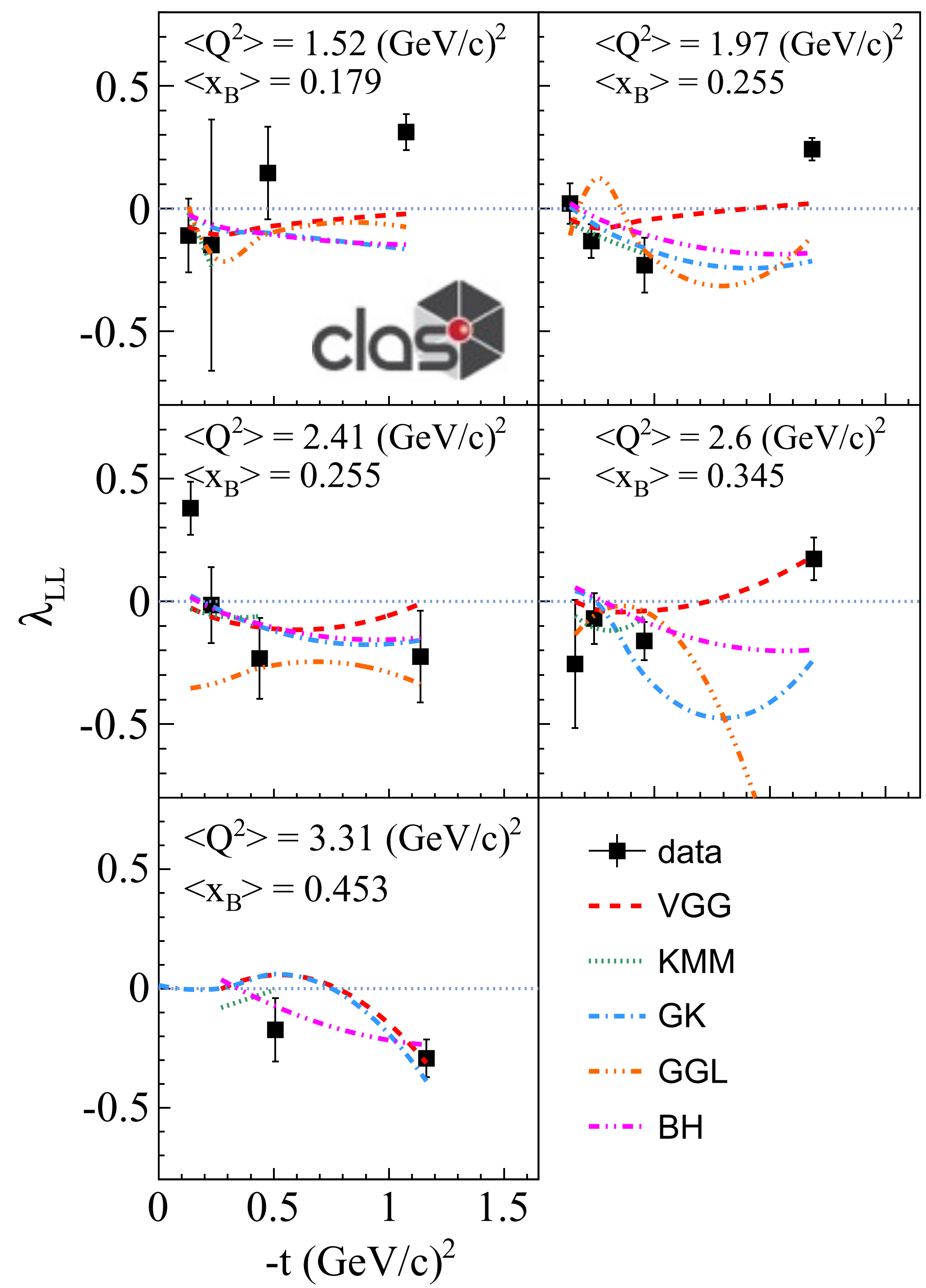
$\propto \mathcal{I}m\left[F_1\widetilde{\mathcal{H}}\right]$

Longitudinal Double-Spin Asymmetry

S.Pisano et al. Phys.Rev.D91:052014 (2015)

$$\frac{\kappa_{LL} + \lambda_{LL}\cos\phi}{1 + \beta\cos\phi}$$





$\propto \mathcal{R}e[F_1 \widetilde{\mathcal{H}}]$

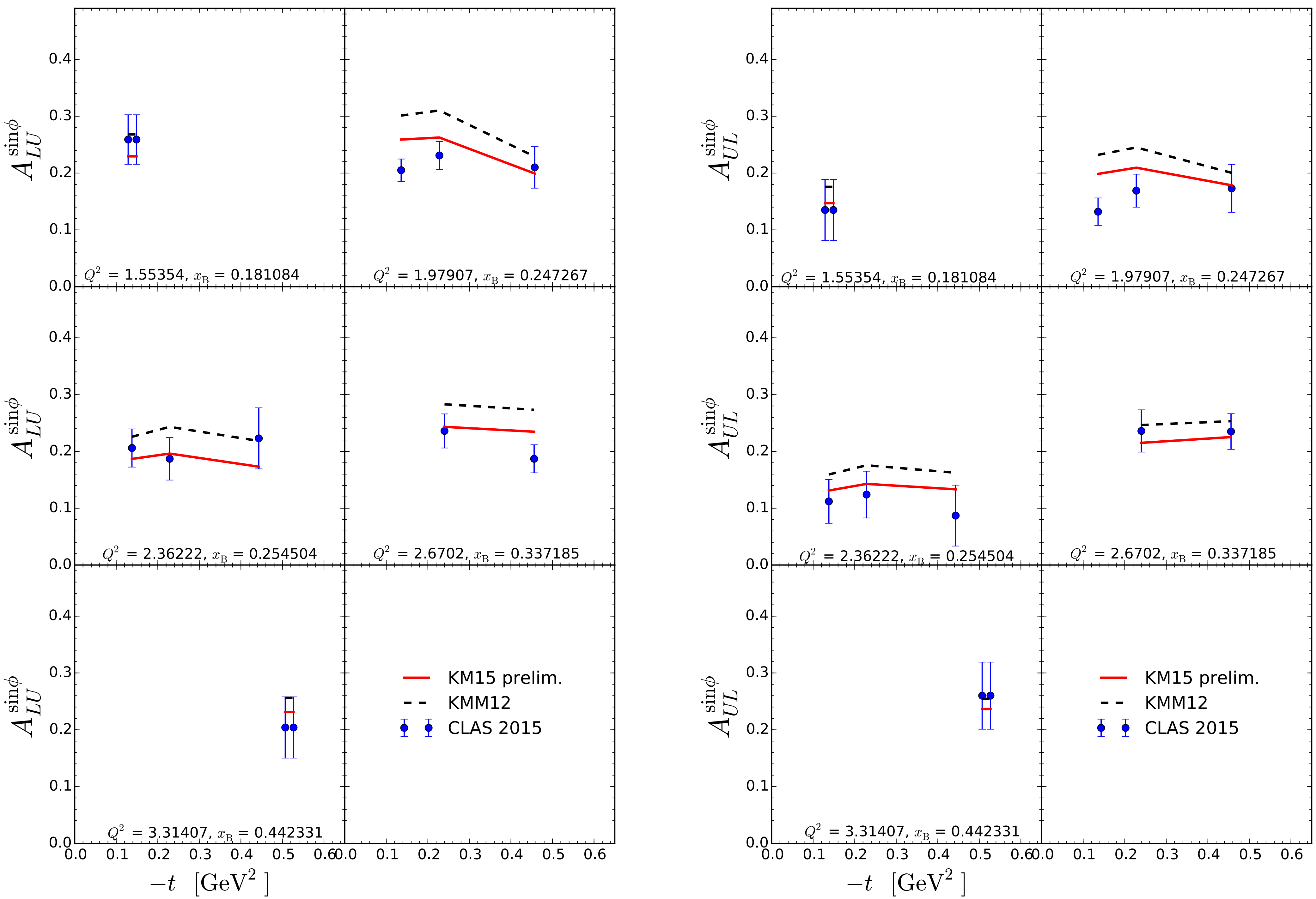
Comparison with recent global fits

Single Beam-Spin & Target-Spin Asymmetries

☞ Kresimir Kumericki: <u>Status of GPD phenomenology - fits to DVCS data</u> (IWHSS 2015, Suzdal, Russia)

Data included in the fit 2012.
- H1 & ZEUS
- HERMES BSA, BCA
- CLAS BSA.
- Hall-A (2006)

Data included in the fit 2015.
- H1 & ZEUS
- HERMES BSA, BCA+ Tpol.
- CLAS BSA + (2015)
- Hall-A (2015)



Krešimir Kumerički : GPD phenomenology

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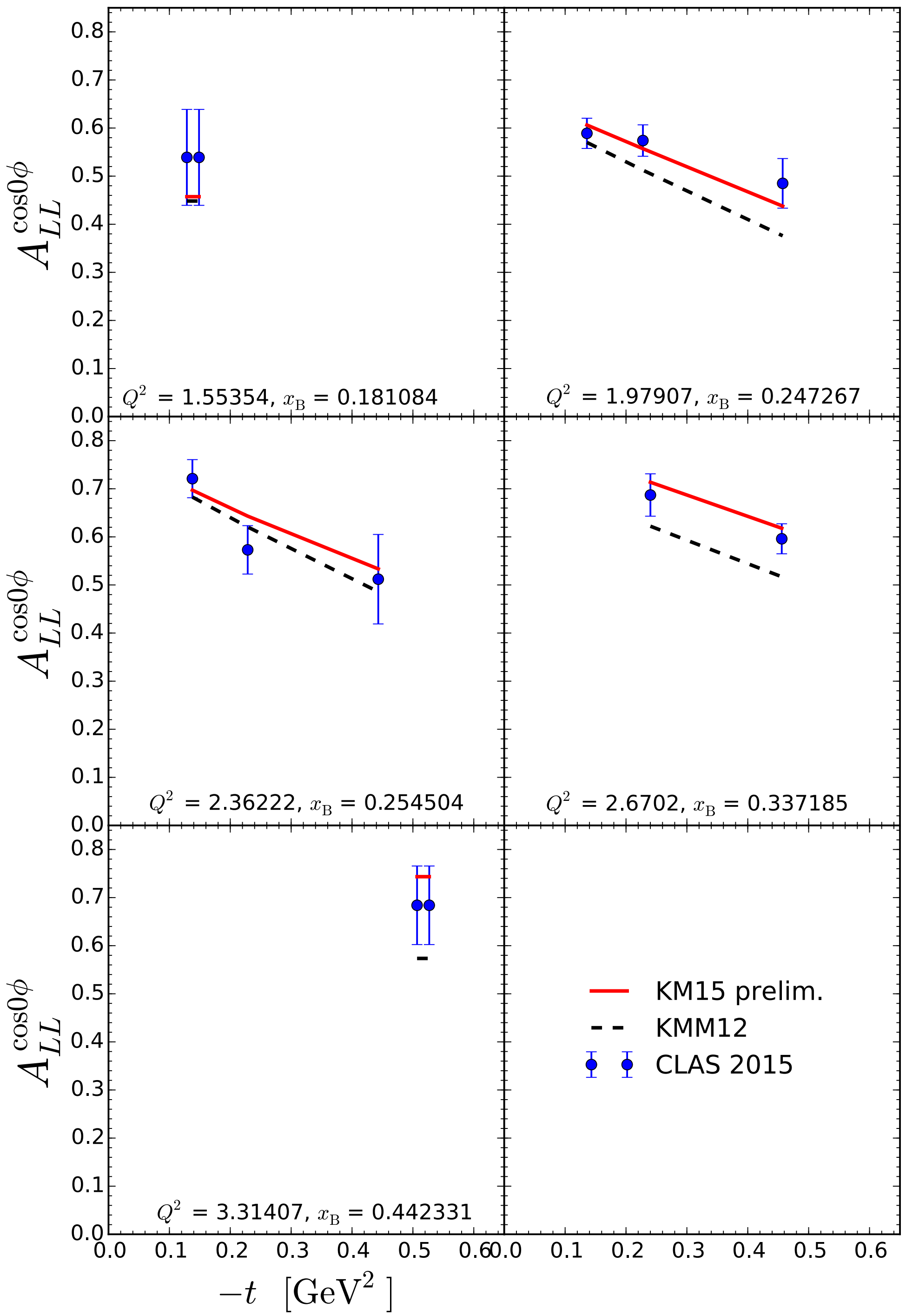
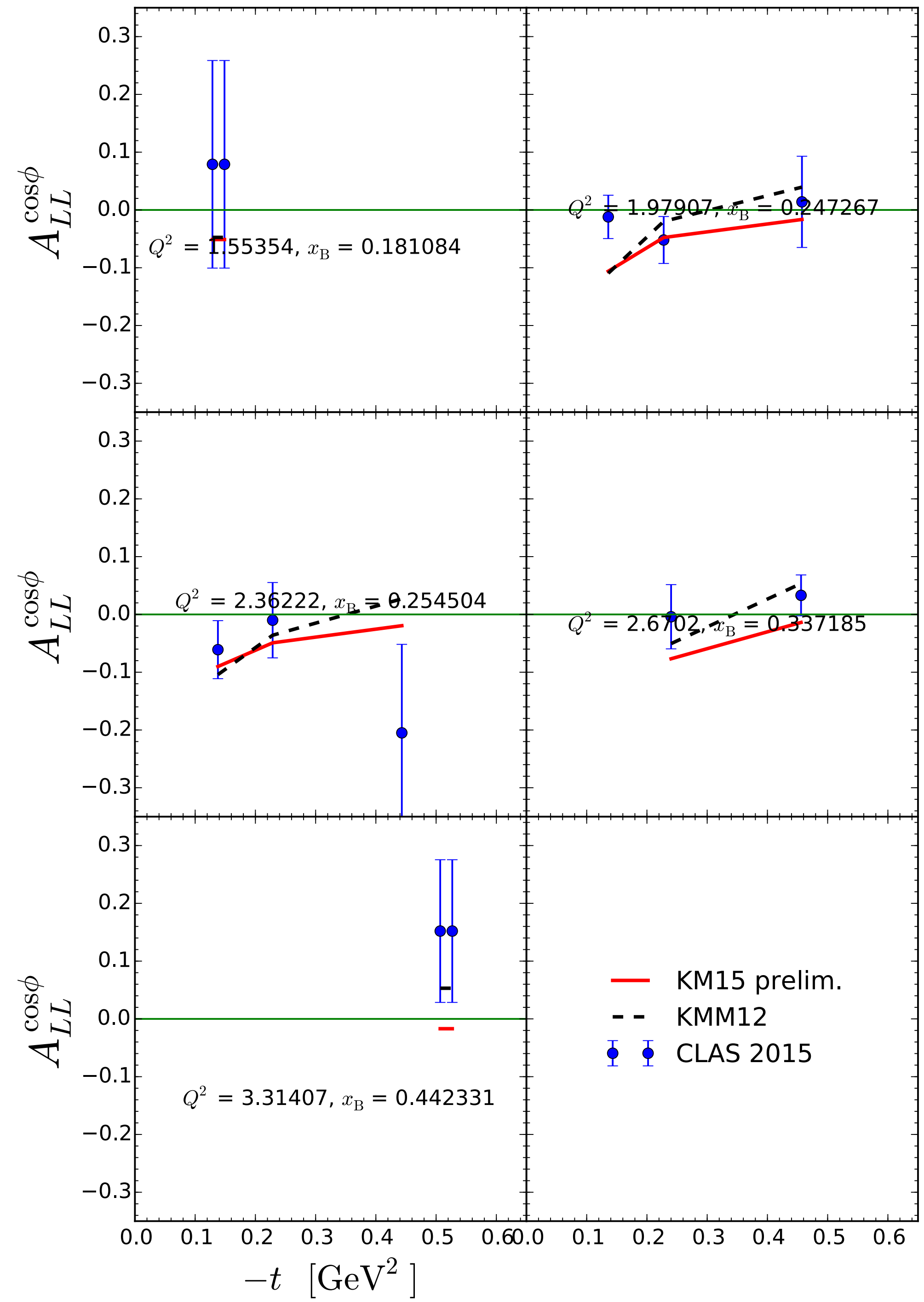
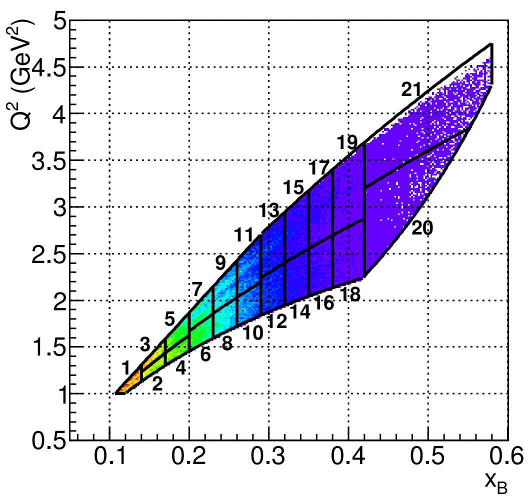


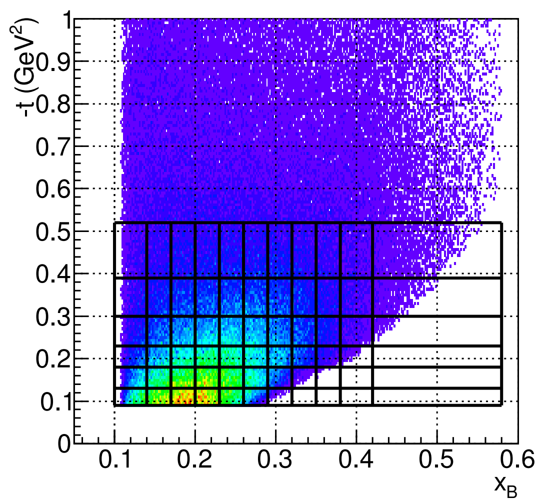


Krešimir Kumerički : GPD phenomenology

Cross Section Results

4-fold differential cross-sections & cross-section difference



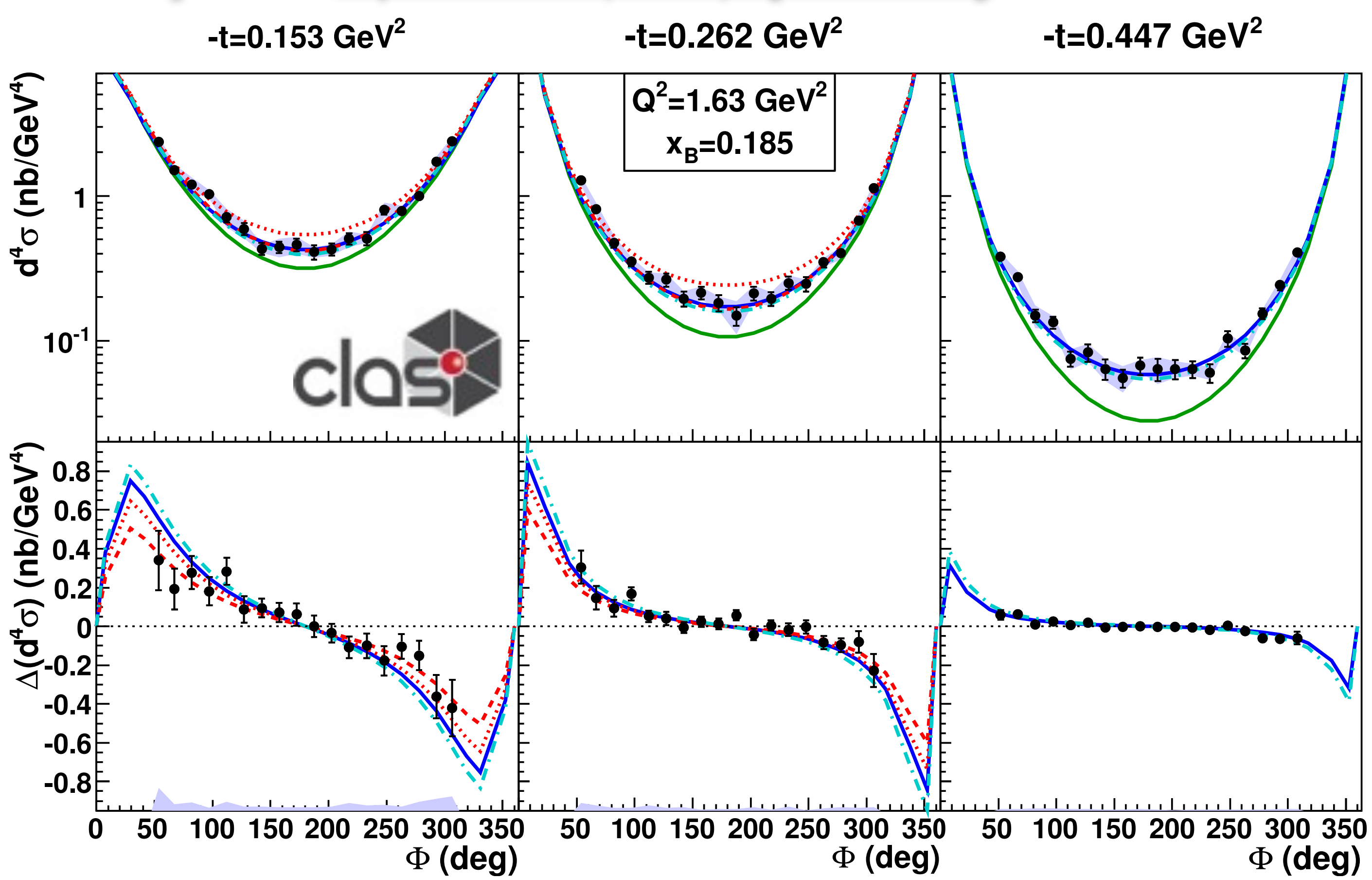


$$|\mathcal{T}_{\rm BH}|^2 = \frac{K_{\rm BH}}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)} \left\{ \sum_{n=0}^{2} c_n^{\rm BH} \cos(n\phi) \right\}$$

$$|\mathcal{T}_{\rm DVCS}|^2 = K_{\rm DVCS} \left\{ \sum_{n=0}^{2} c_n^{\rm DVCS} \cos(n\phi) + \sum_{n=1}^{2} s_n^{\rm DVCS} \sin(n\phi) \right\}$$

$$\mathcal{I} = -\frac{K_{\rm I} e_\ell}{\mathcal{P}_1(\phi)\mathcal{P}_2(\phi)} \left\{ \sum_{n=0}^{3} c_n^{\rm I} \cos(n\phi) + \sum_{n=1}^{3} s_n^{\rm I} \sin(n\phi) \right\}$$

H.S.Jo et al. Phys.Rev.Lett. (2015) [submitted]



$$d\sigma = d\sigma_{UU} + P_{Beam} d\sigma_{LU}$$

$\propto \mathcal{R}e[F_1\mathcal{H}]$

$\propto \mathcal{I}m[F_1\mathcal{H}]$

BH only
VGG (H only)
Goloskokov, Kroll
KM10 (Kumericki, Muller)
KM10a

Comparison with recent global fits

Cross Sections & cross section differences

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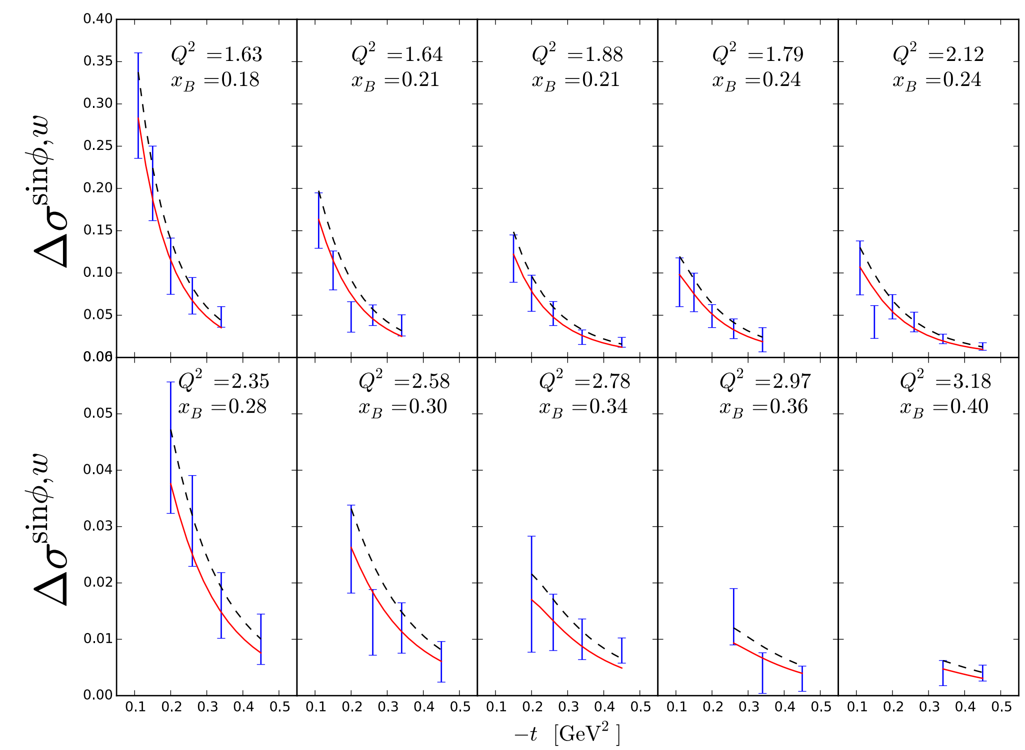
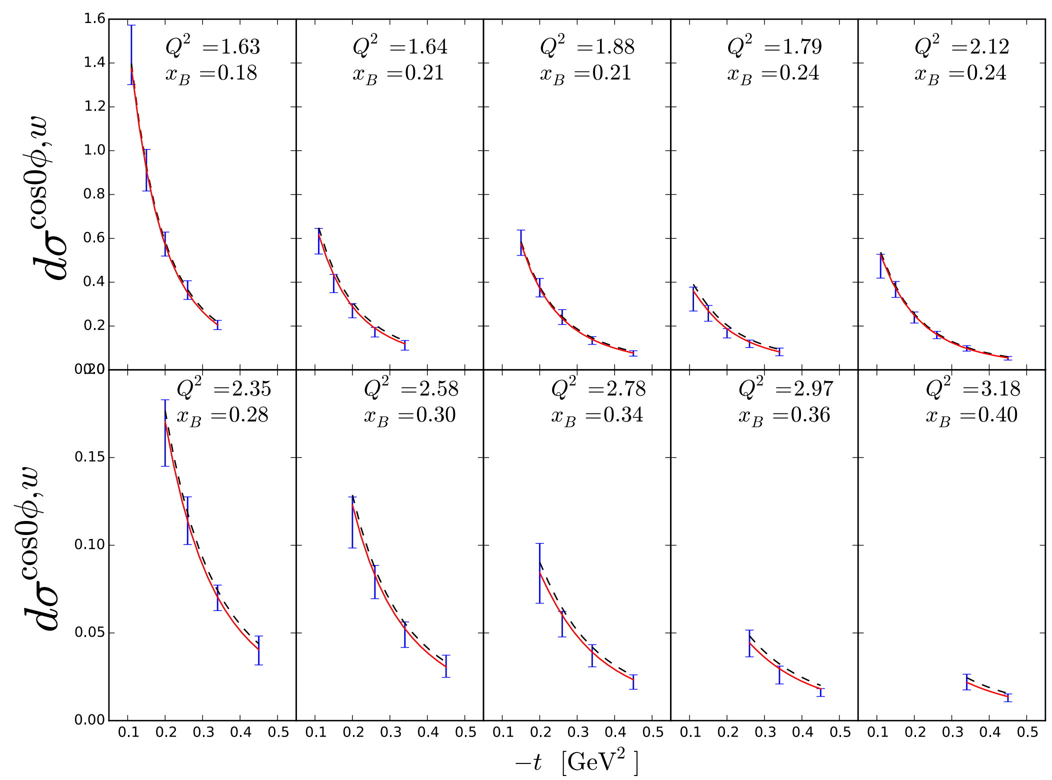
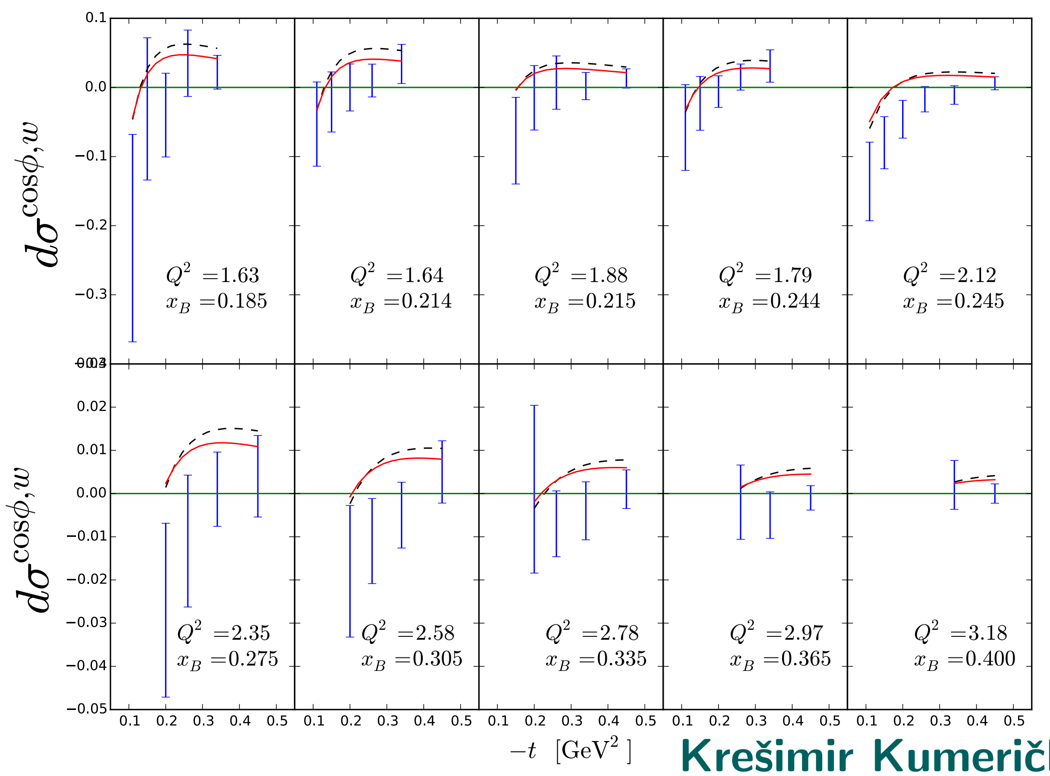
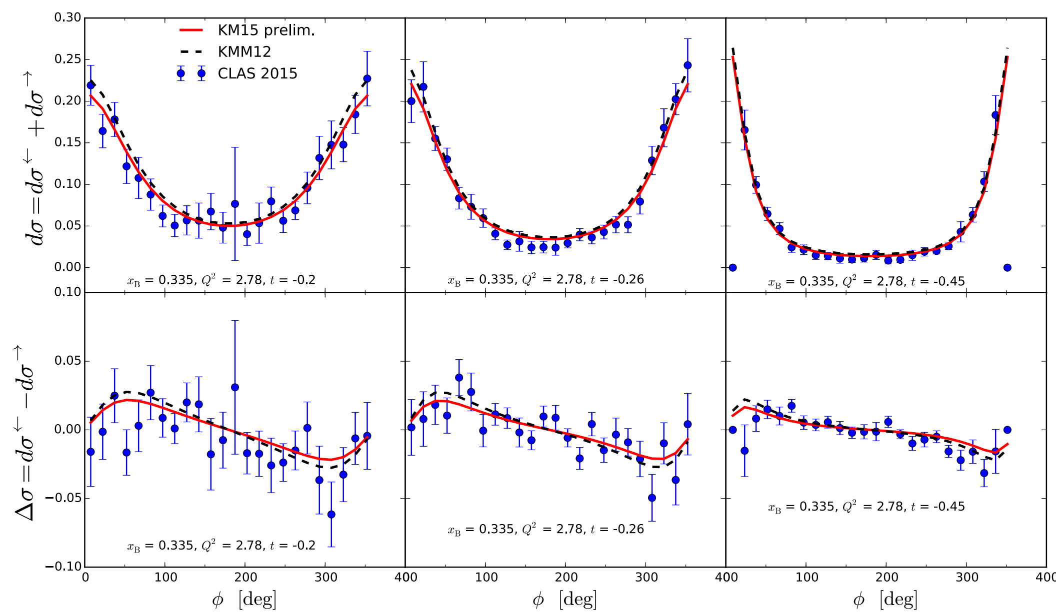






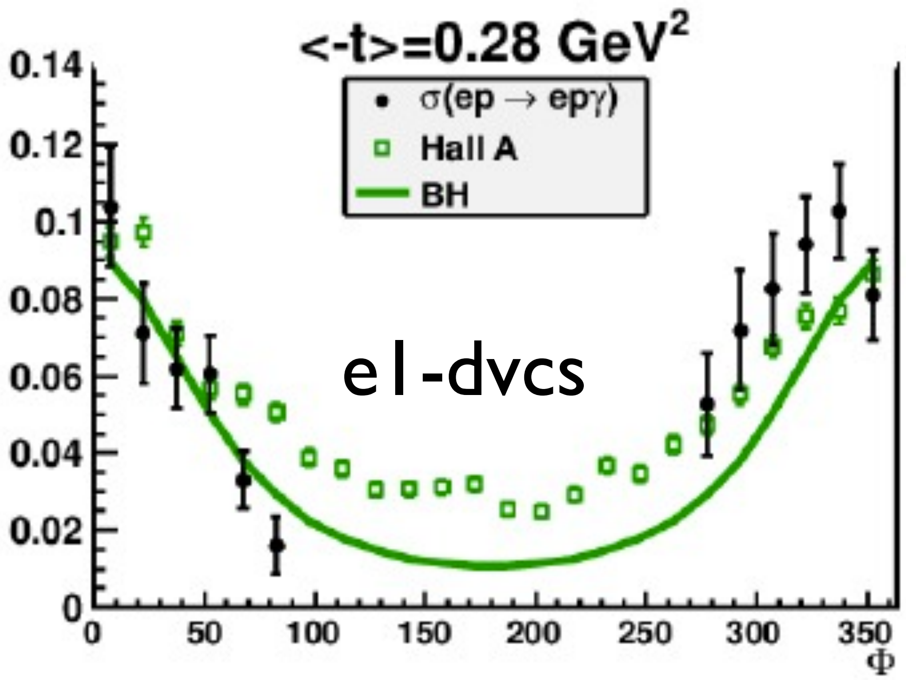


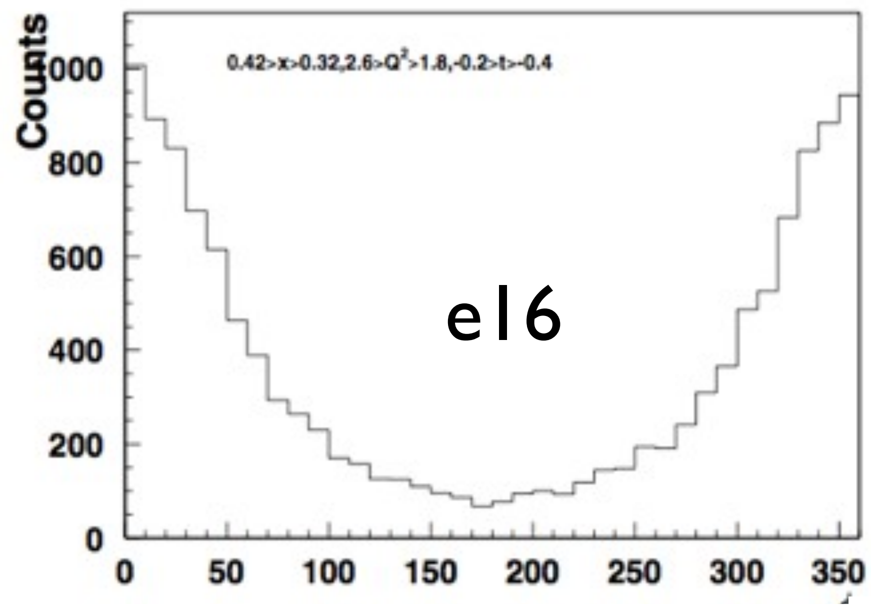
Krešimir Kumerički : GPD phenomenology

Ongoing DVCS analysis

DVCS measurement via $ep \to epX$

Analysis based on e16 data data (possibility to combine with e1f)



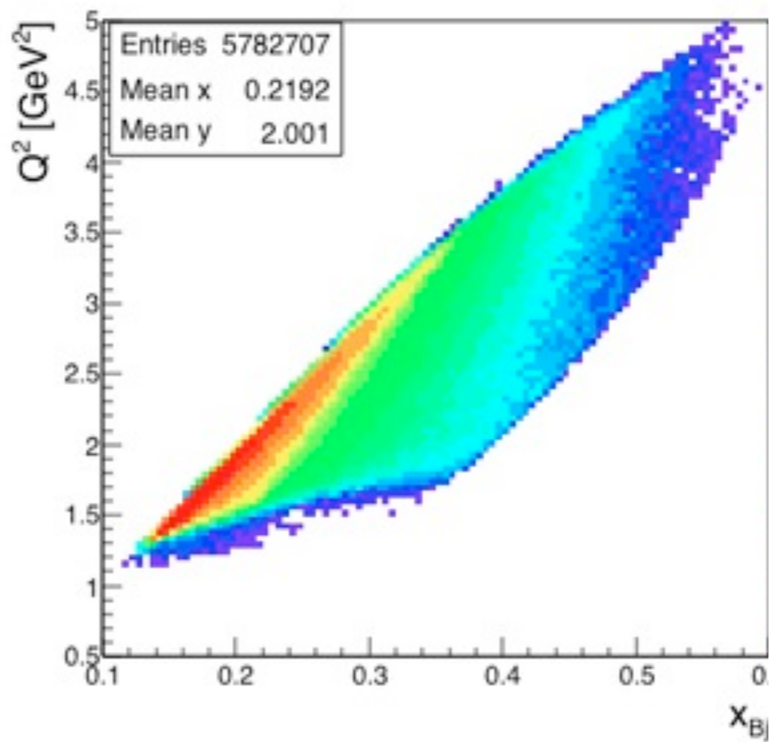


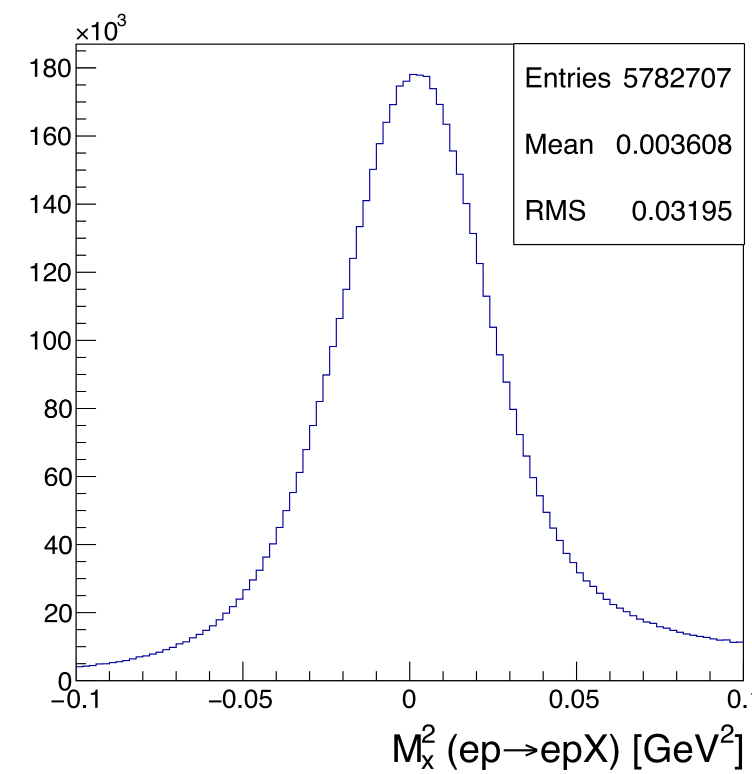
Simultaneous analysis of 3 sub-samples.

ep - broad kinematic coverage.

epγ - clean channel for systematic studies.

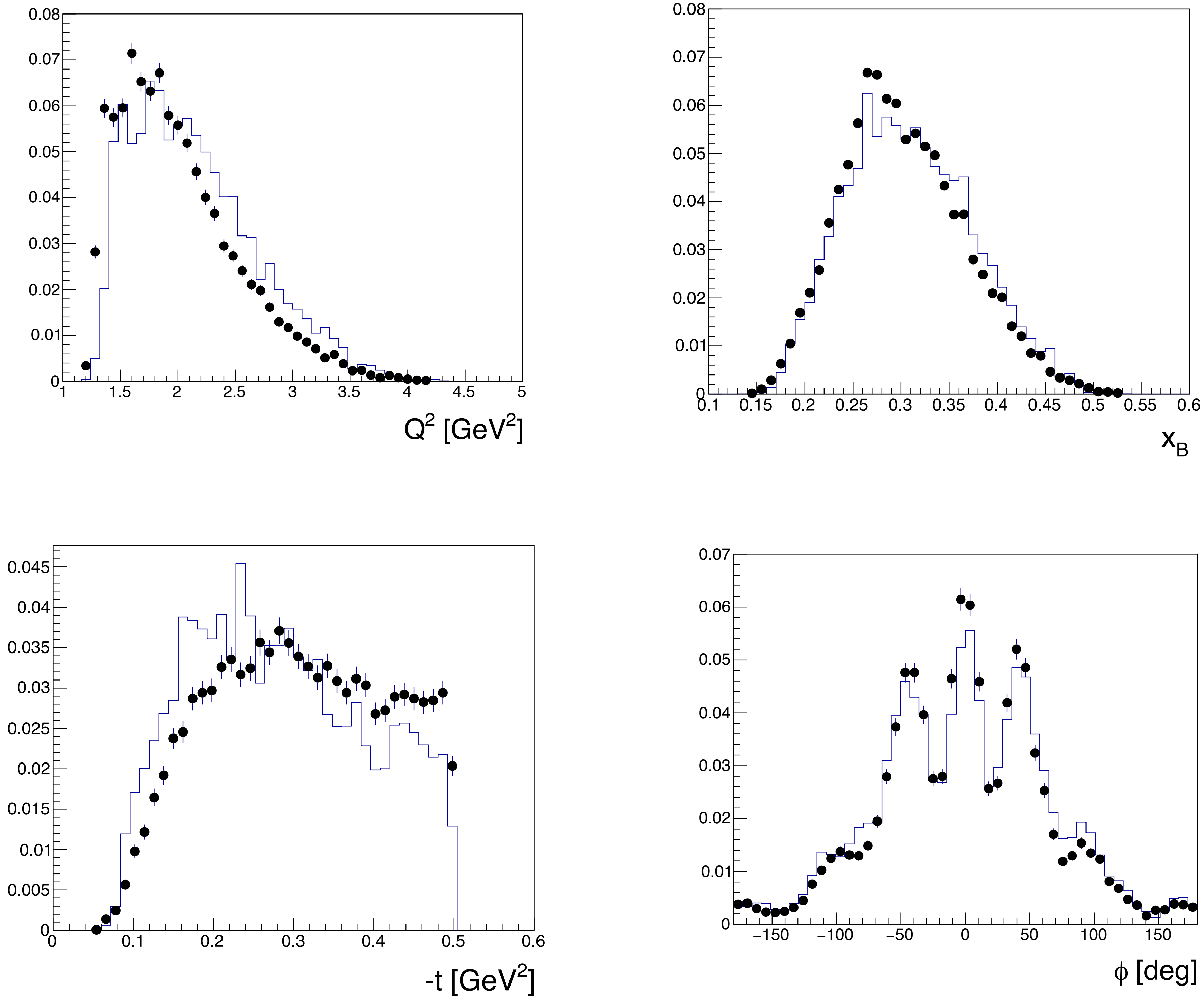
epγγ - used to study exclusive pion production: main background in ep & epγ





Exclusive pion production $ep \rightarrow ep\gamma\gamma$

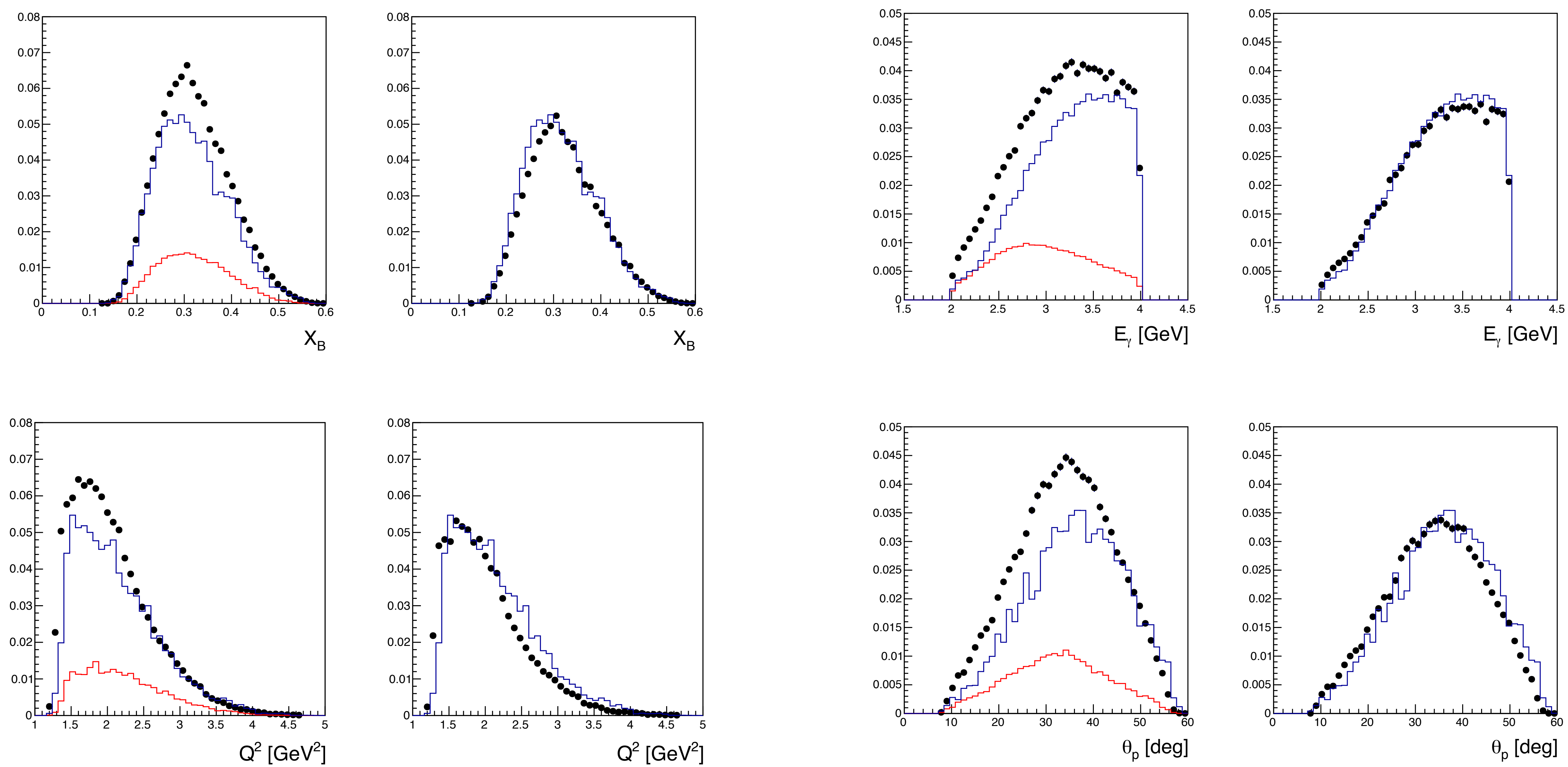
Data -MC comparison



Ongoing DVCS analysis

DVCS with photon detection $ep \rightarrow ep\gamma$

Data -MC comparison



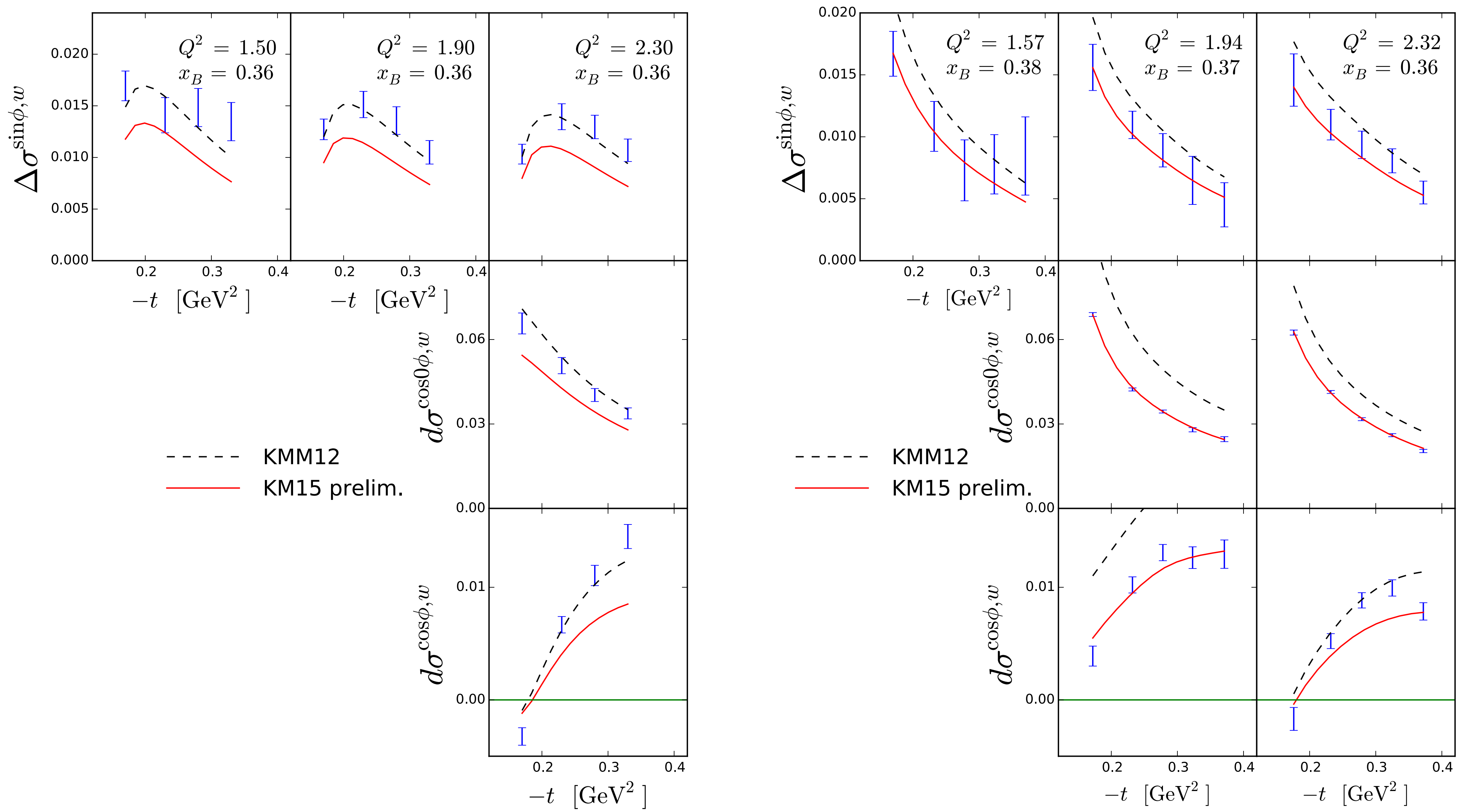
Thank you.

Comparison with recent global fits

Longitudinal Double-Spin Asymmetry

☞ Kresimir Kumericki: Status of GPD phenomenology - fits to DVCS data

2006 2015



Krešimir Kumerički : GPD phenomenology