Studies of e'γX and of e'π0X with clas and clas12

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DeepPWG meeting , JLab, June 15, 2017

- Hard exclusive photon production
    - BH propagators
- Possibilities with e'γX
- Extracting PBPT from double spin asymmetry
- Possibilities with e'π^0X
- Summary & Conclusions

Outline

1) e'X -cross section: electron acceptance is relevant for all other measurements

cons: we need the acceptance and the luminosity as well as contamination
from pions under control.

2) e'π^0X/ e'X ratio (ratio of semi-inclusive pi0 to inclusive electron)
For the ratio we just need the gamma acceptance, which could be defined using the KPP

cons: need efficiency for photon detection and acceptance under good control

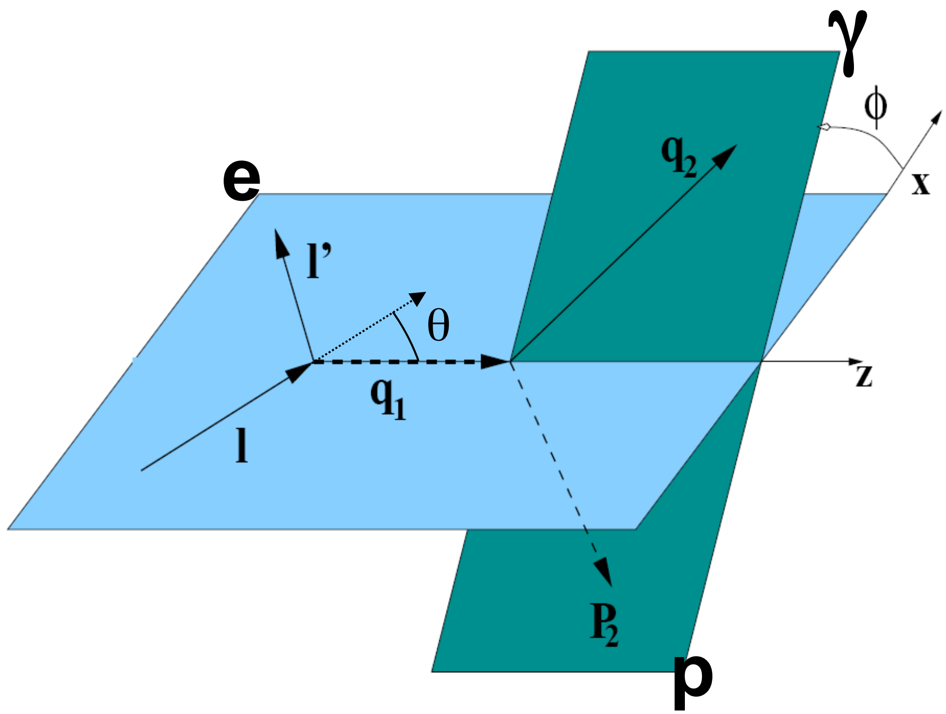
3) e'γX/ e'X ratio for the missing mass below \Delta (exclusive photon production)

a) In the range of phi (phi<60 degree) it is totally dominated by BH and can be used to extract the eX itself from ratio and control the efficiency of our electron reconstruction.

b) It is the same as our DVCS analysis, and can be used as a cross check for extraction with proton detection later on

cons: need efficiency for photon detection and acceptance for photons above 3 GeV (easier than for pi0) and well tuned MC to account for pi0 contamination, which is item 2 and can be extracted simultaneously.

Electroproduction Kinematics



$$Q^2 = -q_1^2 = 4EE' \sin(\theta/2)$$

$$\nu = E - E'$$

$$x_B = -q_1^2 / 2 p_1 q_1 = Q^2 / 2M\nu$$

$$y = \nu / E$$

$$t = (p_2 - p_1)^2 = \Delta^2$$

γ*−>γ require a finite longitudinal momentum transfer defined by the generalized Bjorken variable ξ

$$\xi = -\frac{(q_1 + q_2)^2}{2(p_1 + p_2)(q_1 + q_2)} \approx \frac{x_B}{2 - x_B}$$

$$\Delta_\perp^2 \approx (1 - \xi^2)(t - t_{\min})$$

$$t_{min} \approx \frac{M^2 x^2}{1 - x + xM^2/Q^2}$$

ϕ-dependent amplitude

$$|\mathcal{T}_{\rm BH}|^2 = \frac{e^6}{x_{\rm B}^2 y^2 (1+\epsilon^2)^2 \Delta^2 \mathcal{P}_1(\phi)\mathcal{P}_2(\phi)} \times \left\{ c_0^{\rm BH} + \sum_{n=1}^{2} c_n^{\rm BH} \cos(n\phi) + s_1^{\rm BH} \sin(\phi) \right\}$$

C_{BH}

$$|\mathcal{T}_{\rm DVCS}|^2 = \frac{e^6}{y^2 Q^2} \left\{ c_0^{\rm DVCS} + \sum_{n=1}^{2} \left[c_n^{\rm DVCS} \cos(n\phi) + s_n^{\rm DVCS} \sin(n\phi) \right] \right\}$$

$$\mathcal{P}_1 = -\frac{1}{y(1+\epsilon^2)} \{ J + 2K \cos(\phi) \}$$

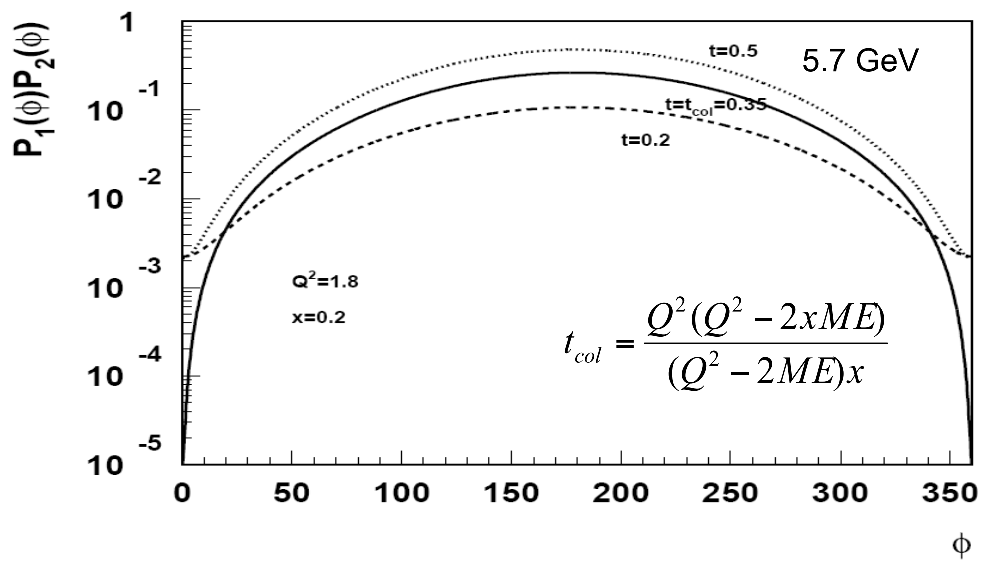
kinematic factors

$$\mathcal{I} = \frac{\pm e^6}{x_{\rm B} y^3 \Delta^2 \mathcal{P}_1(\phi)\mathcal{P}_2(\phi)} \left\{ c_0^{\mathcal{I}} + \sum_{n=1}^{3} \left[c_n^{\mathcal{I}} \cos(n\phi) + s_n^{\mathcal{I}} \sin(n\phi) \right] \right\},$$

$$J = \left(1 - y - \frac{y\epsilon^2}{2}\right)\left(1 + \frac{\Delta^2}{Q^2}\right) - (1-x)(2-y)\frac{\Delta^2}{Q^2}$$

C_{Int}

$$A_{\rm UL}(\phi) \sim \frac{s_{1,\rm LP}^{\mathcal{I}} \sin\phi}{c_{0,\rm unp}^{\rm BH} + (c_{1,\rm unp}^{\rm BH} + c_{1,\rm unp}^{\mathcal{I}} + \ldots)\cos\phi + \ldots}$$

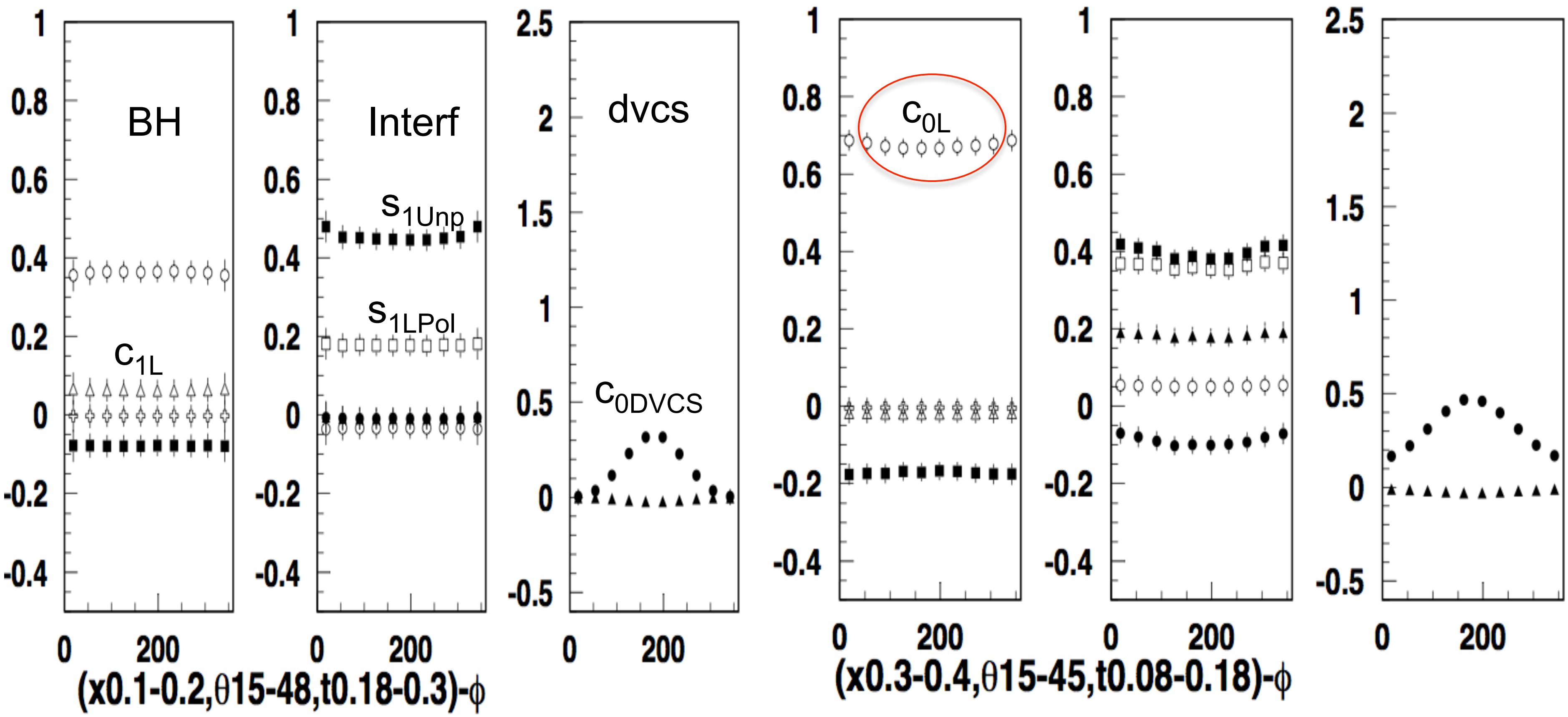


$$\boxed{C_{Int}=C_{BH}{*}x/y{*}(1+\varepsilon^2)^2}$$

- **Strong dependence on kinematics of prefactor ϕ-dependence, at $t\approx t_{col}$, $P_1(\phi)\rightarrow 0$**
- **Do the kinematic factors with propagators in T_{BH} and I cancel in the ratio of**

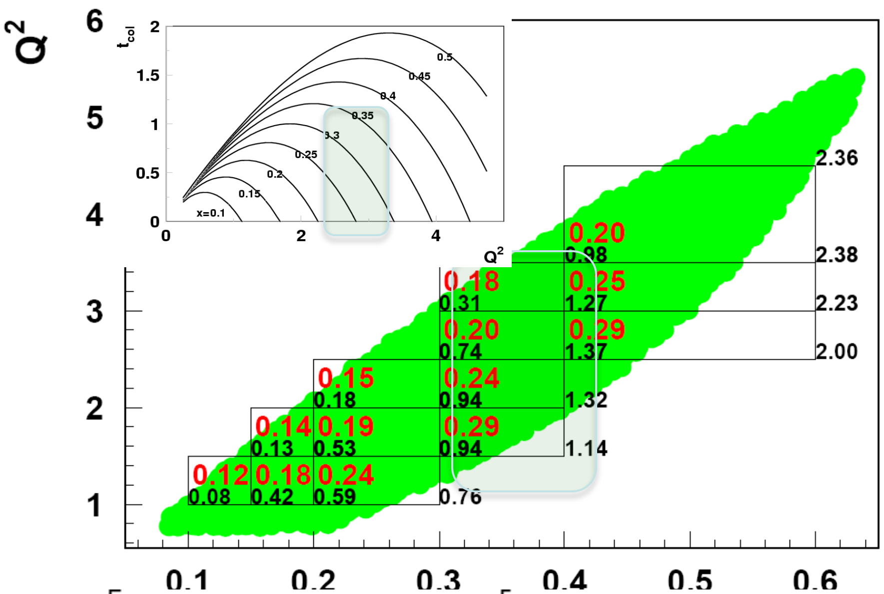
Azimuthal moments in ep->e'p'γ

Ratio of different contributions to c_{0BH}



Different azimuthal moments become relevant in different kinematical regions

ϕ-dependent amplitude



x_B bin	θ_e bin	$\langle x_B \rangle$	$\langle Q^2 \rangle$ ((GeV/c
$0.1 < x_B < 0.2$	$15^o < \theta_e < 48^o$	0.179	1.52
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Bin	$-t$ range $(\mathrm{GeV}/c)^2$	$\langle -t \rangle$ $(\mathrm{GeV}/c)^2$
1	$0.08 < -t < 0.18$	0.137
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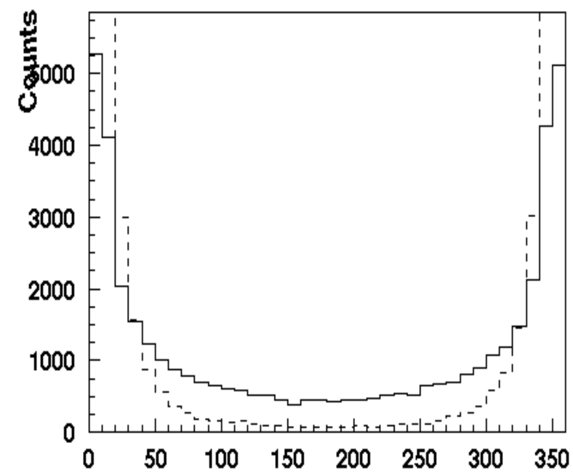
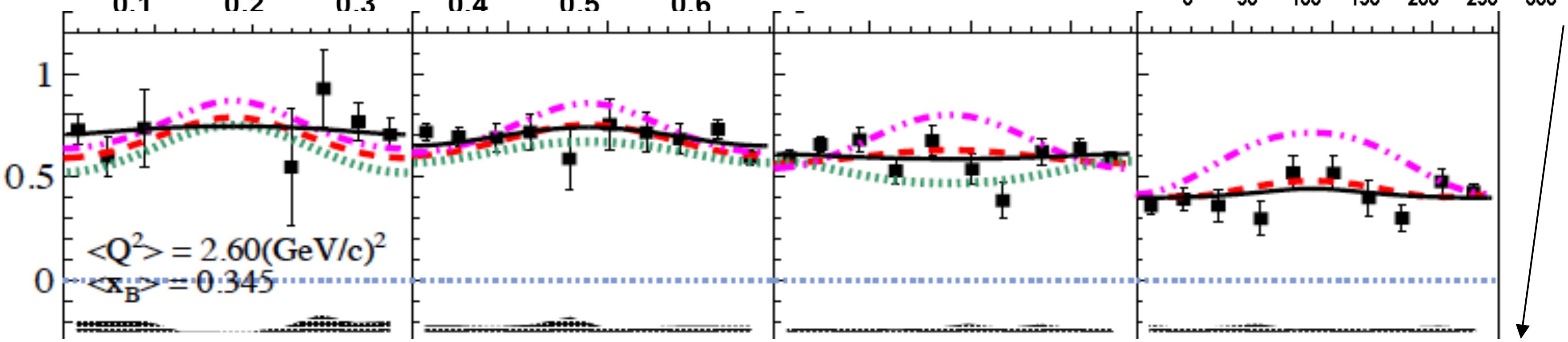
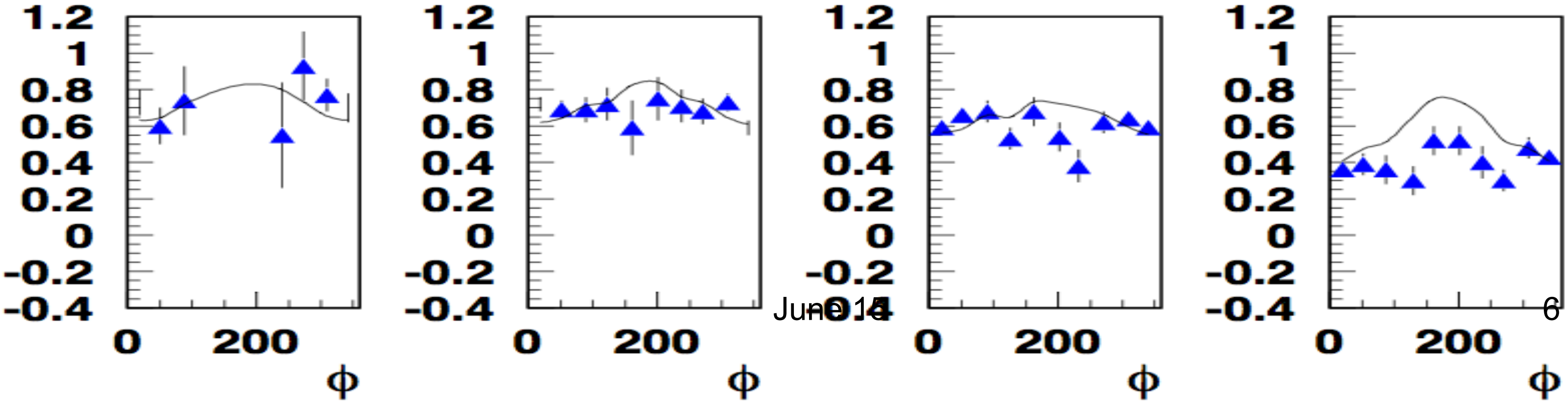
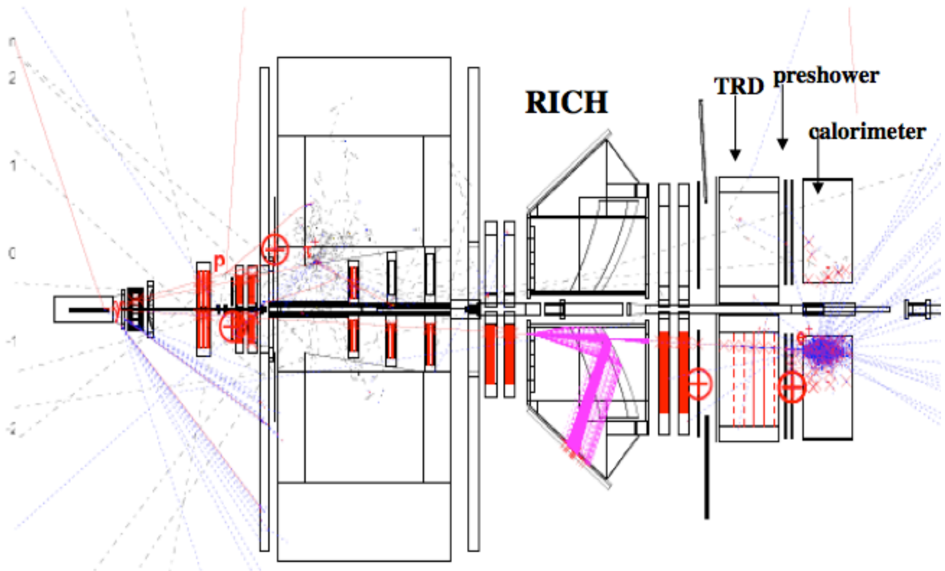


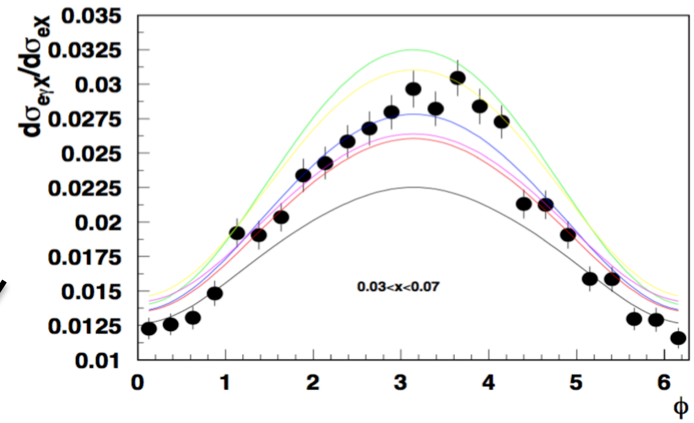




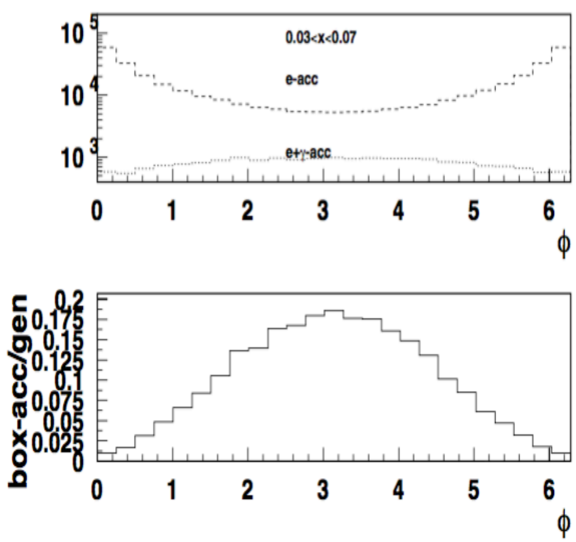
HERMES @ 27.6 GeV

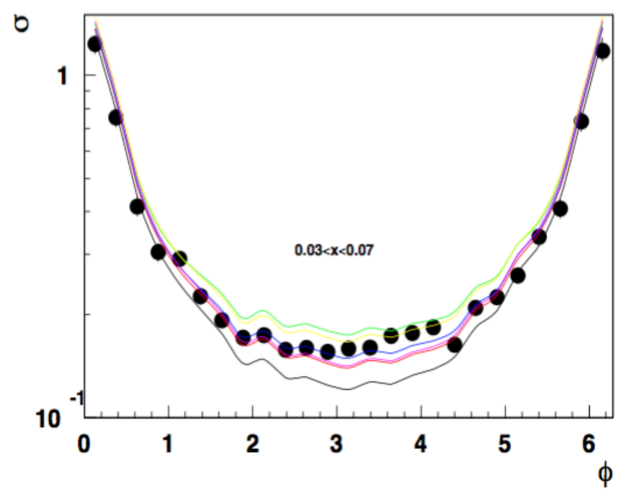


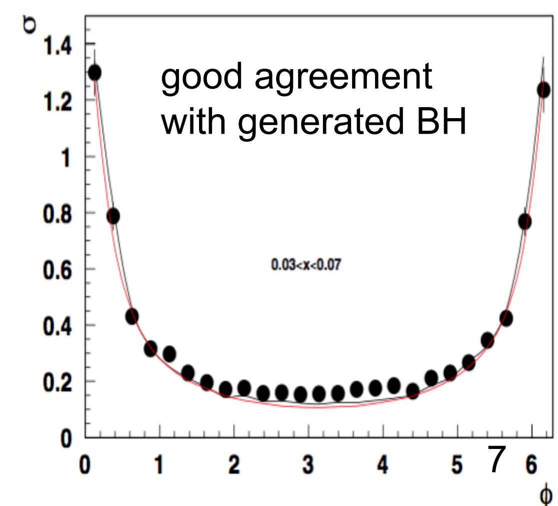
- resolution: $\delta p/p \sim 2\%$, $\delta\theta < 1$ mrad
- "simple box" acceptance for photons
- measure ratios to DIS



dvcsgen

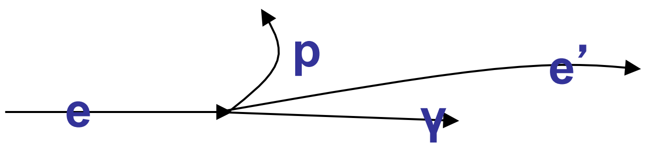






good agreement
with generated BH

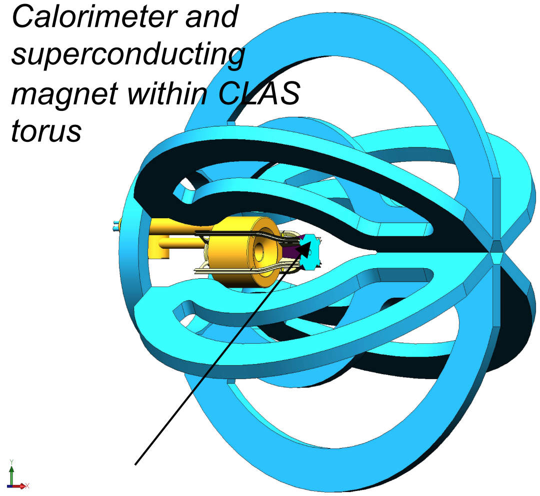
CLAS e1DVCS2 experiment

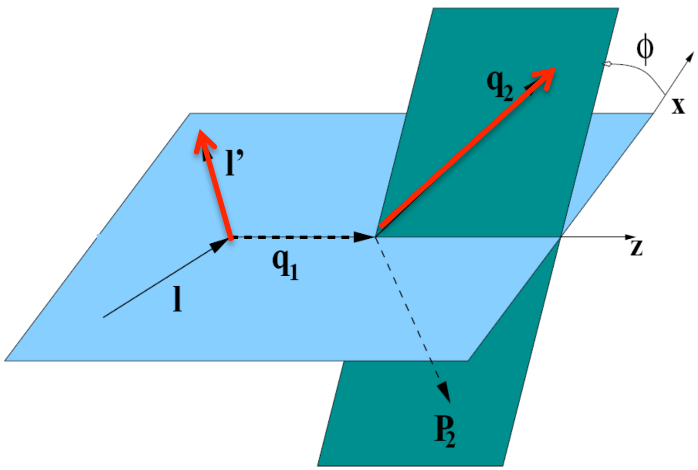


→ Less background than in e1dvcs
→ Large kinematical coverage in x_B and t (higher E_b)

CLAS@5.9 GeV

Calorimeter and superconducting magnet within CLAS torus

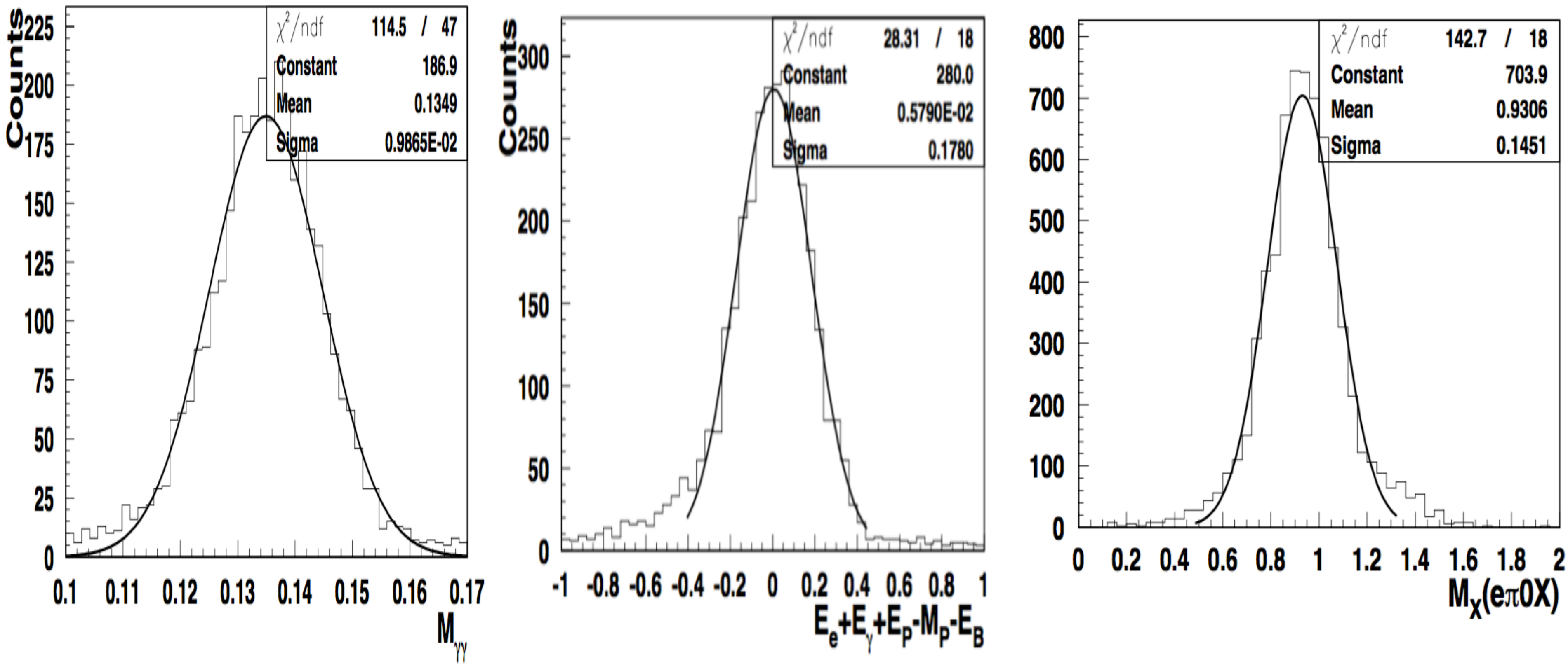




dedicated calorimeter (424 PbWO4 crystals) detect photons from 5°-15°

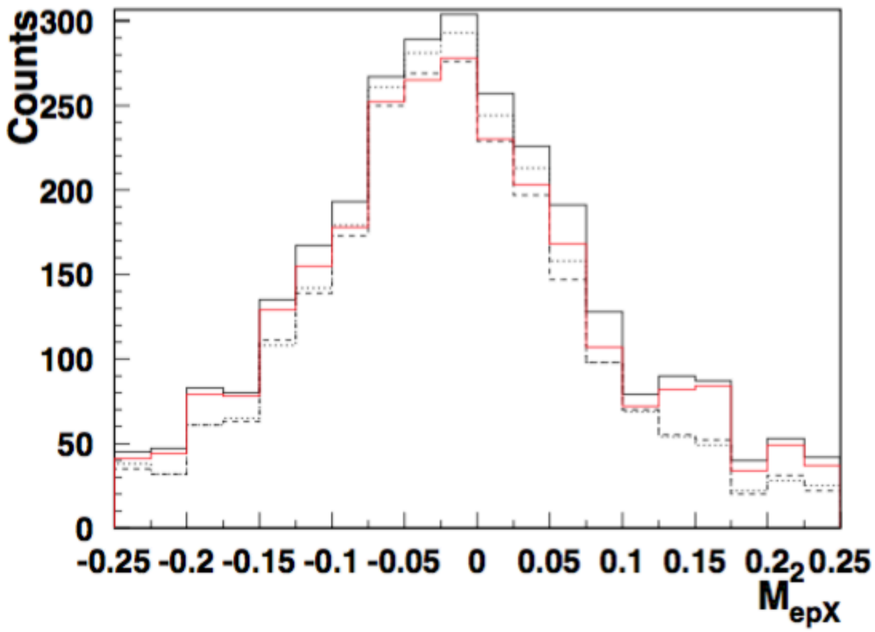
Use e1dvcs2 data to study feasibility of DVCS/BH studies with only electron and photon detection!

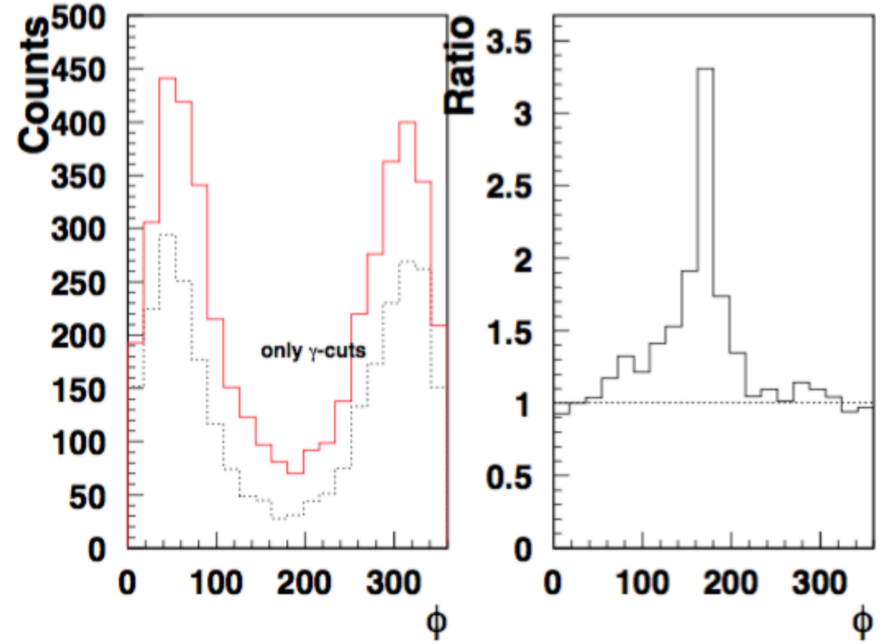
e1dvcs2 distributions



Resolution consistent with expectations for CLAS12

e1dvcs2 distributions

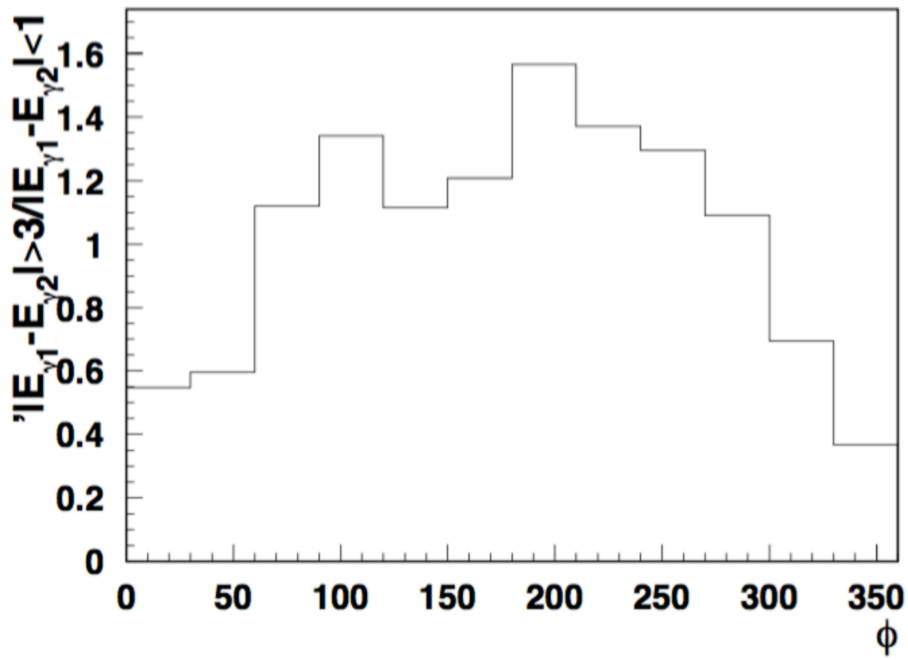




Cuts on photon missing mass, minimum energy and the angle between γγ*, may be sufficient, but will require good MC simulation to understand better the background around 180 degrees, where p0 contribution may be significant.

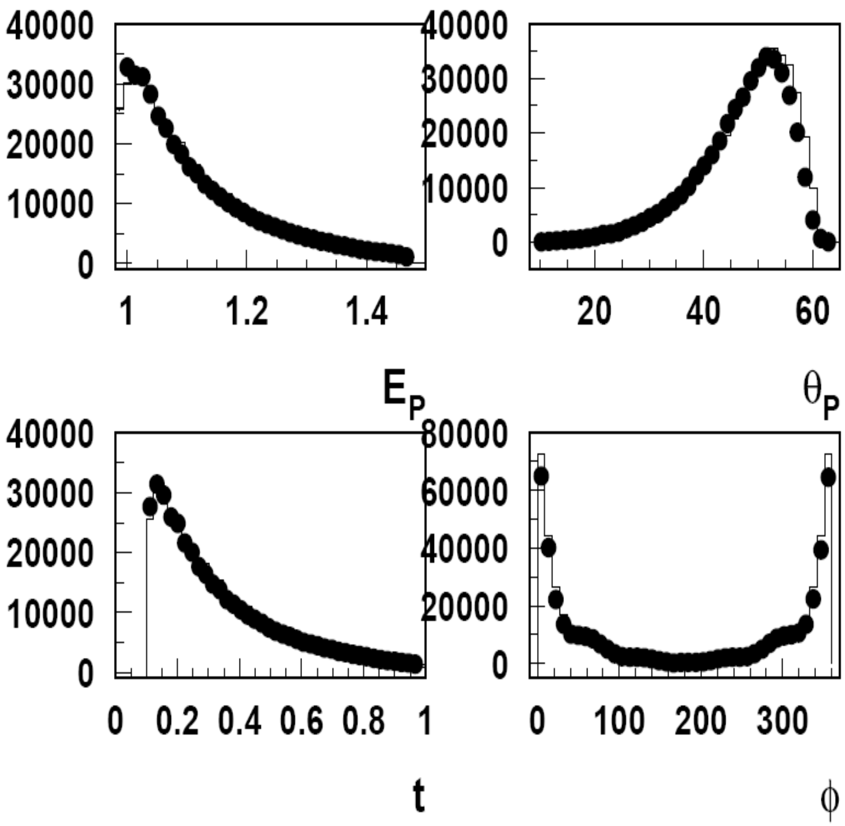
DVCS studies with just e' and γ are feasible and require only detailed understanding of the photon acceptance (+MC)

ϕ-distributions from π^0s



With full exclusivity cut the photons from asymmetric decays may have very different azimuthal distributions compared to symmetric decays, which are used to get the contamination.

γ MC vs Data



Region where BH totally dominates (small t, small photon θ_{LAB})

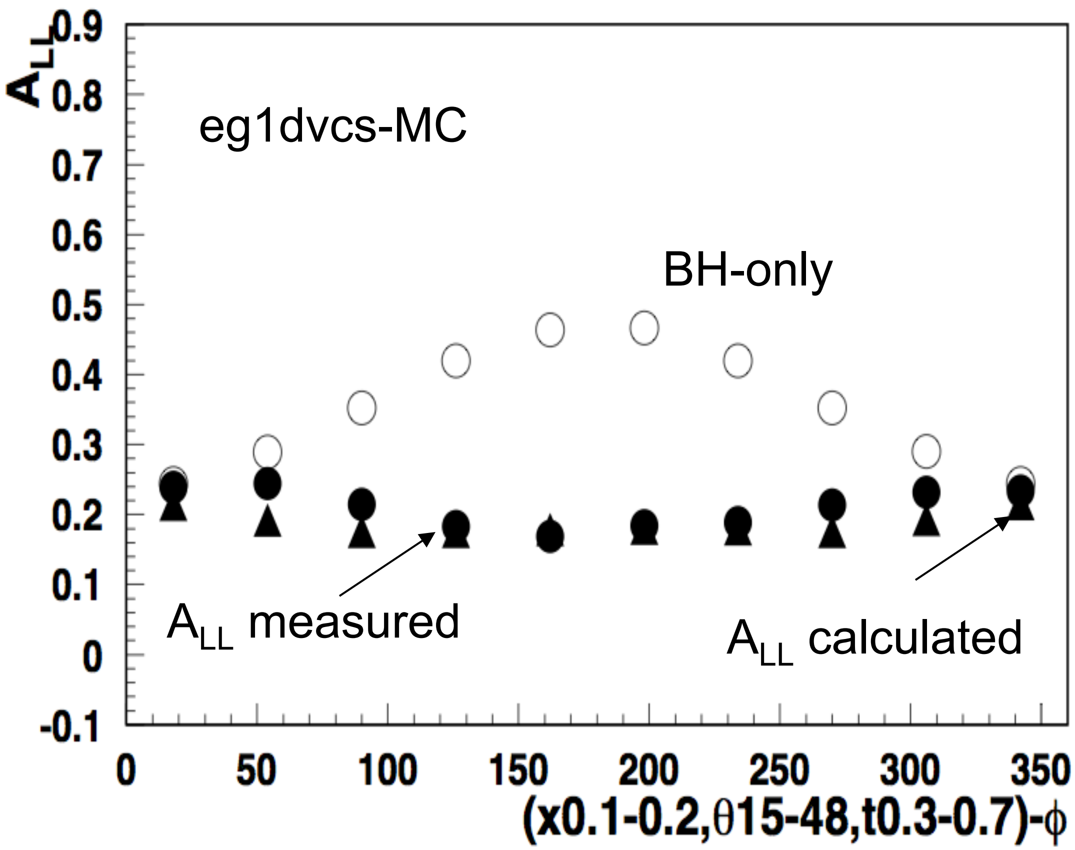
- Negligible DVCS x-section, small π^0 contamination
- Rapidly changing prefactors, mainly small ϕ, hard to detect photons

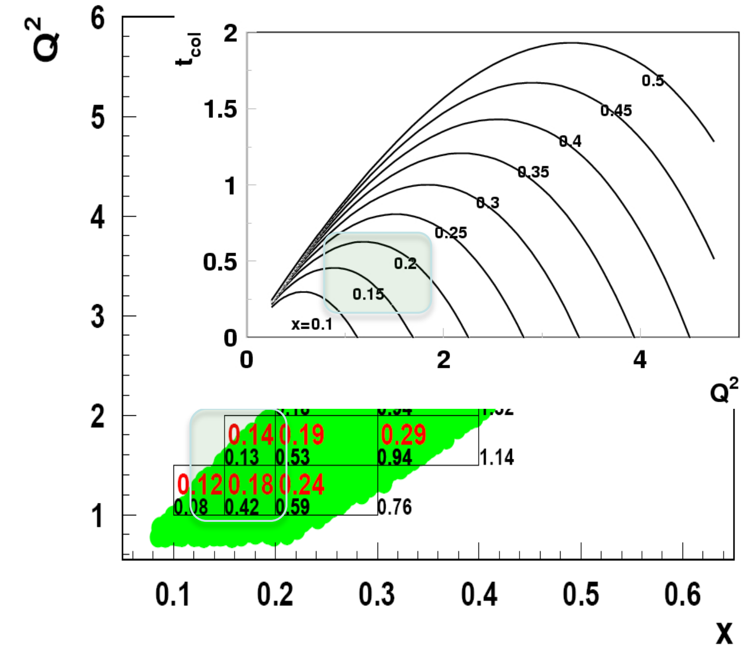
Large angles

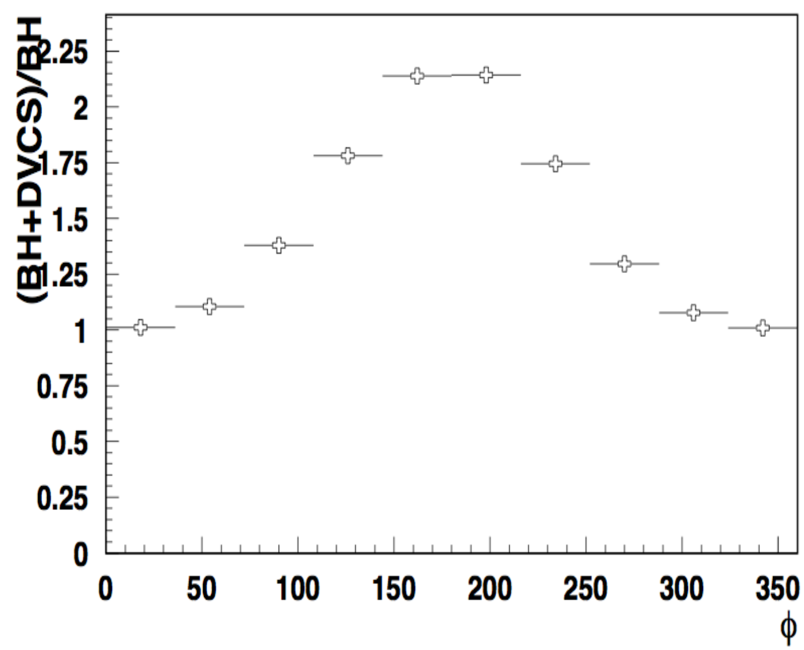
- Uniform coverage in angle ϕ, photon measurement less challenging
- DVCS x-section non negligible introduce some model dependence)
- π^0 dominates the single photon sample (in particular at low Q^2 and large t)

- MC Kinematic distributions in x,Q^2,t consistent with the CLAS data

MC studies: BH in A_{LL}







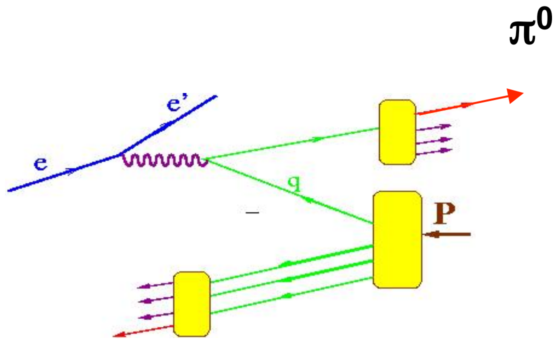
The A_{LL} ϕ-dependence dominated by BH only at relatively small ϕ

Semi-Inclusive electrons (ep->e' π^0X)

$$\sigma_p^{eX} \propto 4u + d + \ldots$$

$$\sigma_p^{\pi^0} \propto 4uD^{u\to\pi^0} + dD^{d\to\pi^0} + \ldots$$

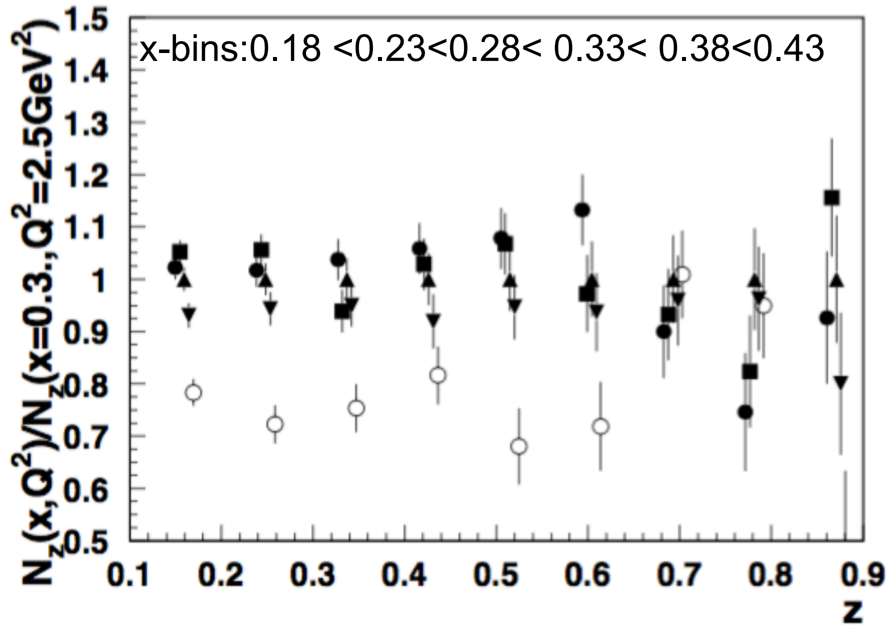
$$D^{u\to\pi^0} \approx D^{d\to\pi^0}$$



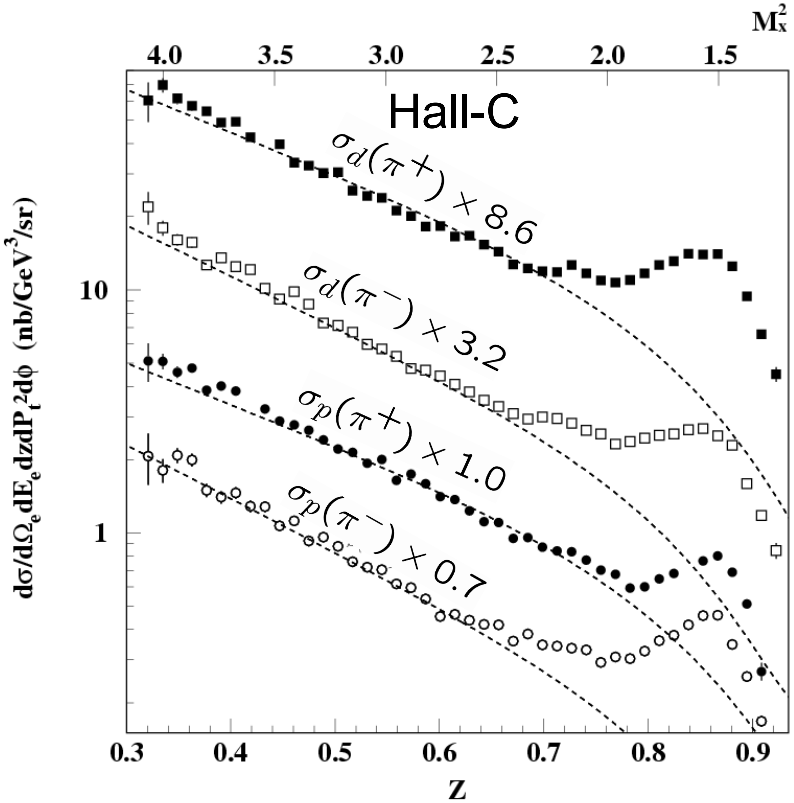
The ratio of e'π^0X/e'X provides cleanest info on fragmentation function

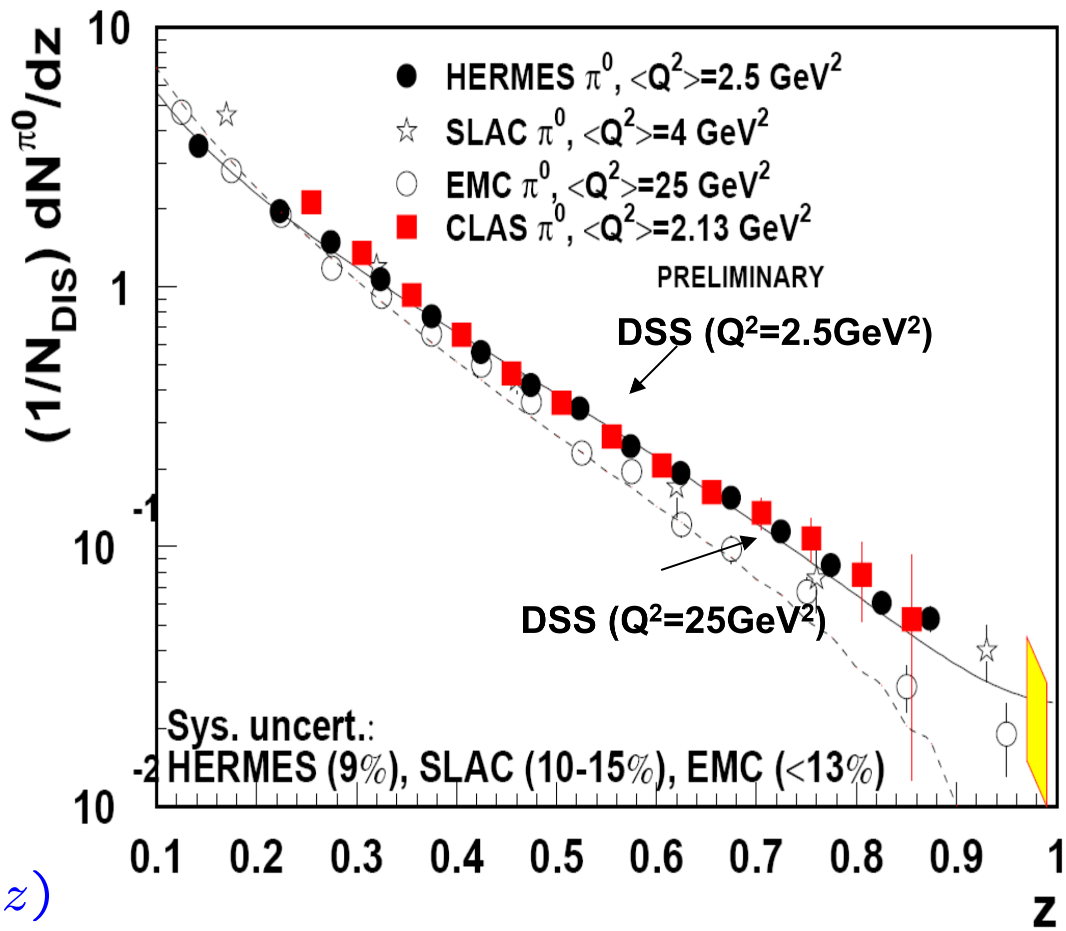
Ratios studied using the clasDIS LUND generator

1) ratio should have weak dependence on x
2) Ratio should follow z-dependence of the fragmentation function.



π multiplicities in SIDIS ep→e'πX





$$d\sigma^h \propto \sum f^{H\to q}(x)\mathrm{d}\sigma_q(y)D^{q\to h}(z)$$

π^0 multiplicities less affected by higher twists
0.4<z<0.7 kinematical range, where higher twists are expected to be small

Suggestions for first publication

- First measurements could be performed using only identified electrons and photons (e’X, e’π^0X, e’γX)
- KPP data can be used to define the efficiency and acceptance for photons in the PCAL+EC

Need:

Precision calculations of the e’X x-sections

Precision MC description of the CLAS12

summary & plans

- The eγX with missing mass cuts can be used to study the BH observables (for PbPT,lumi monitoring,…)
  - theoretically under control with high precision
  - dominates all other processes at small ϕ
  - need dilution factor for gammas (nuclear contributions)
- Extraction of eγX/eX ratios using first CLAS12 data→ minimum effect from charge particle acceptance
- Extraction of eπ^0X/eX ratios using first CLAS12 data→ provide access to fragmentation functions

Plans:

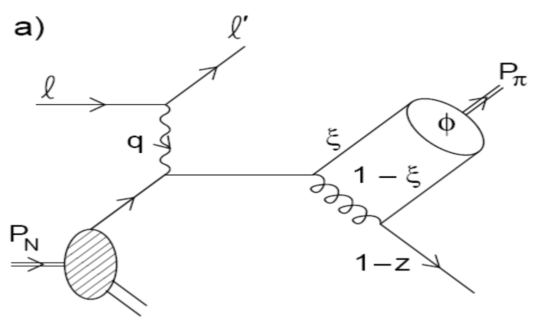
Use clas12 software to study eg1dvcs/clas6 e'γX/e'X

Check calculations of the e'X x-sections using eγX for BH

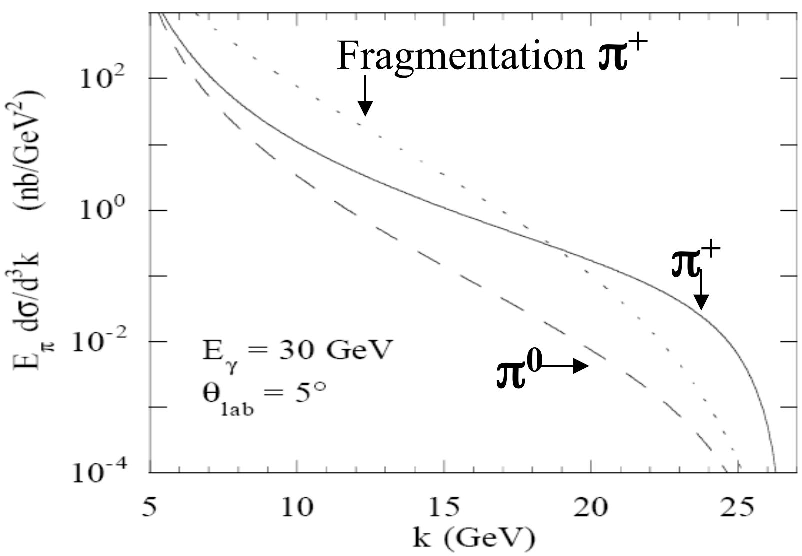
Compare the A_{LL} with calculations (eg1dvcs data) and develop procedure for extraction of the P_BP_T from eγX/eX

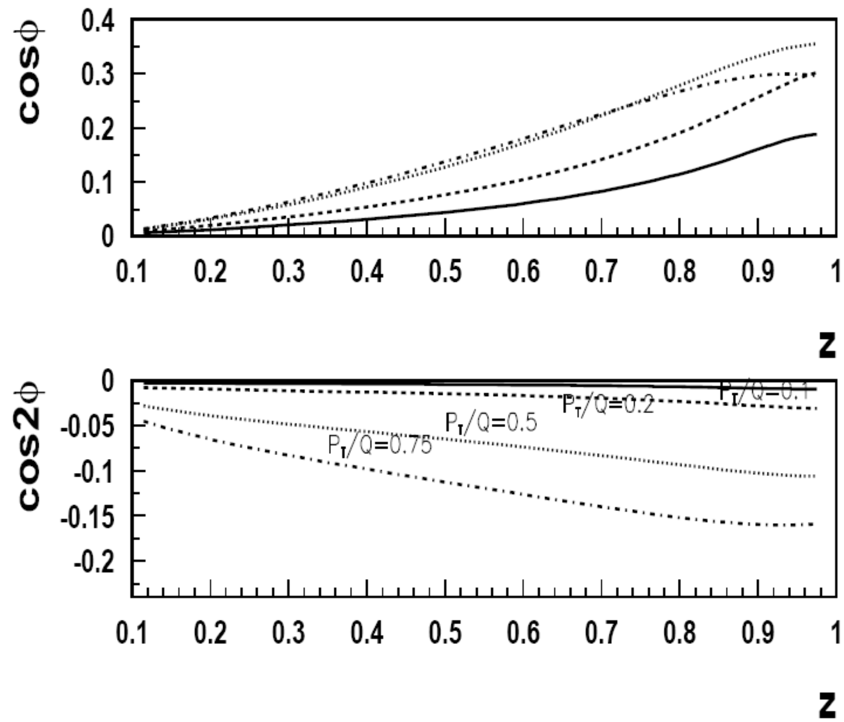
Precision MC description of the CLAS12 comparing with KPP support slides…

HT and Semi-Exclusive Pion Production



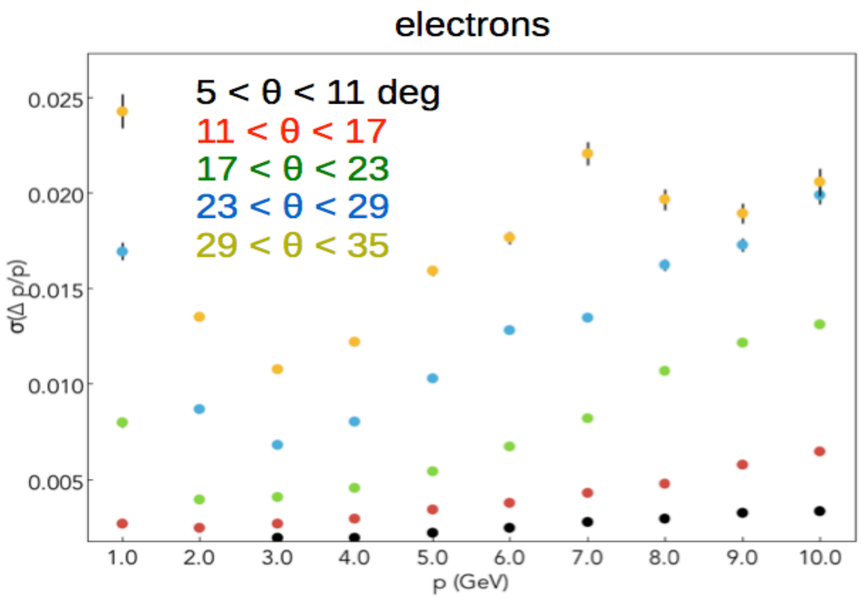
E. Berger, S. Brodsky 1979 (DY), E.Berger 1980,
A.Brandenburg, V. Khoze, D. Muller 1995

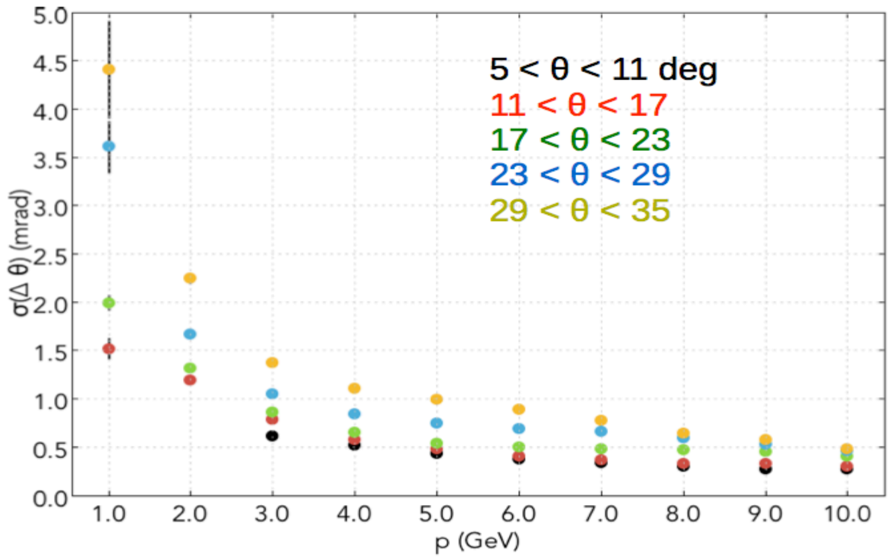




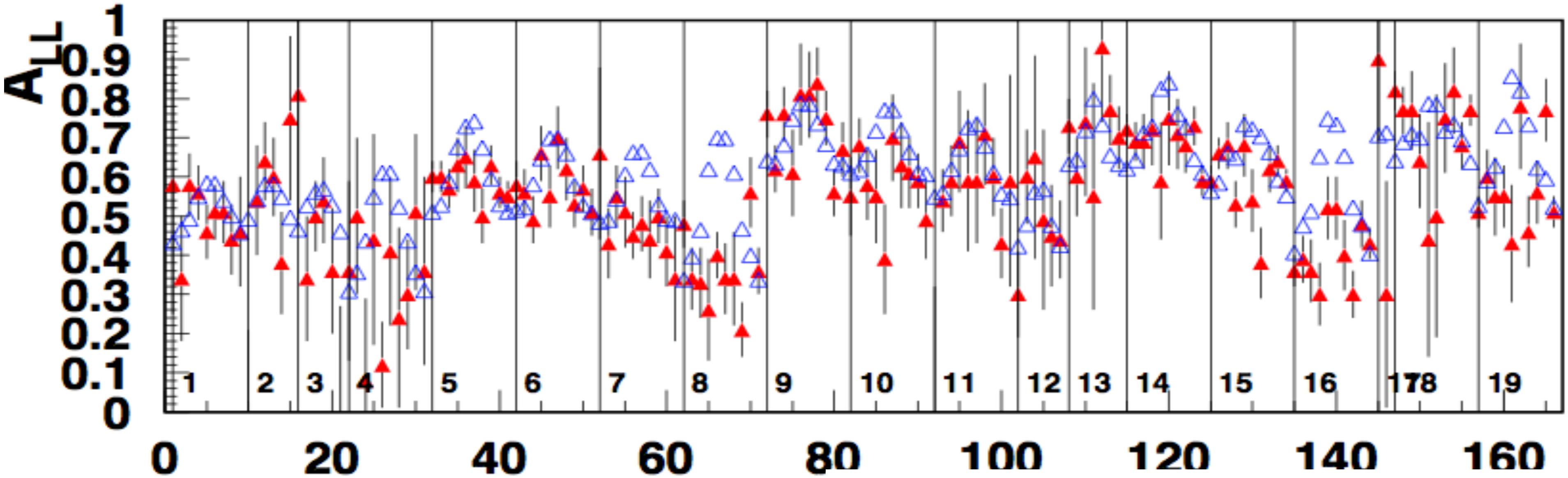
- Azimuthal asymmetries with opposite sign from HT effects
- Effect may be suppressed for semi-exclusive π^0 compared to $\pi^{+/-}$

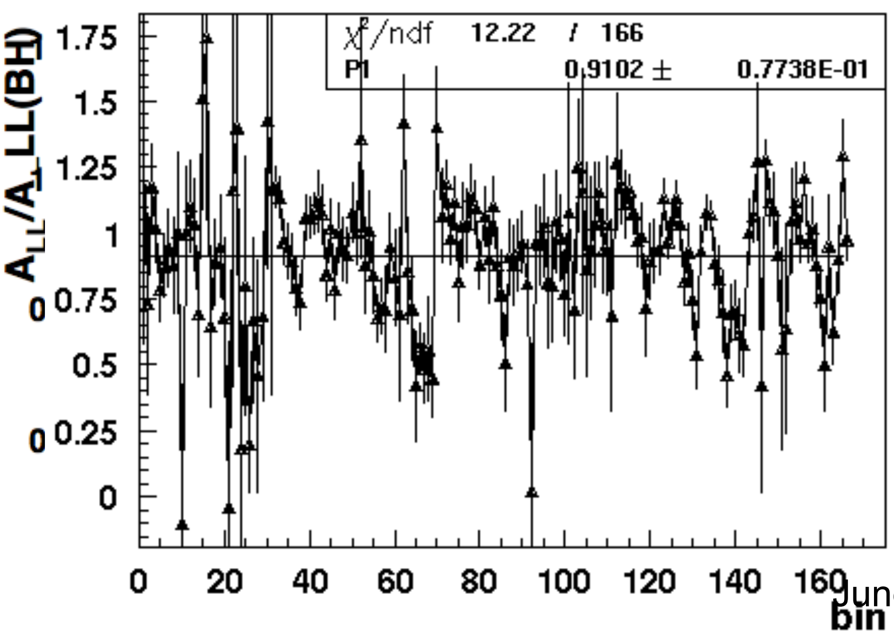
CLAS12 resolutions

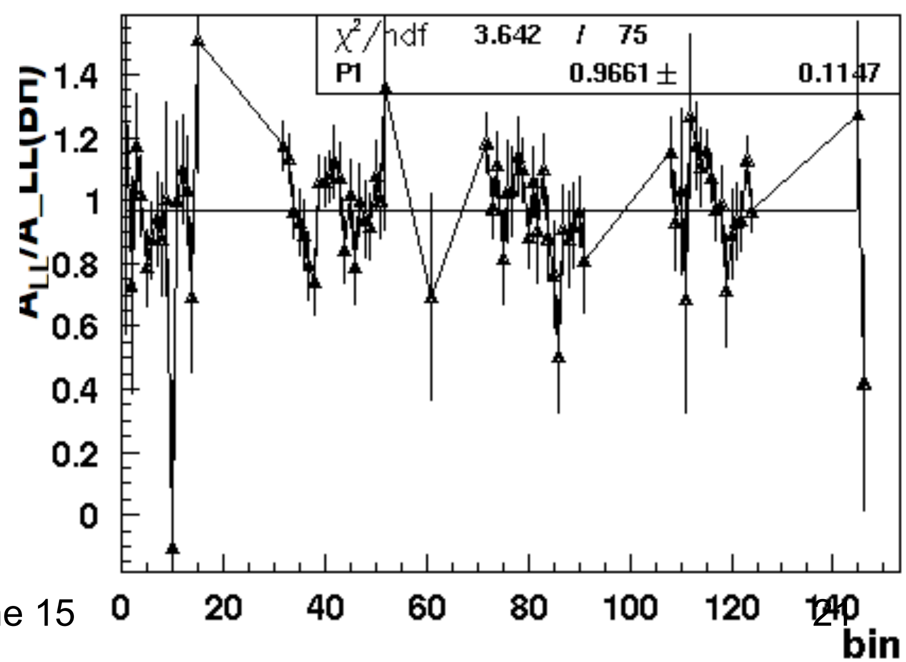




A_{LL}-data vs BH







ϕ-dependent ratios (eg1dvcs paper)

Bin	x_B bin	θ_e bin	$\langle x_B \rangle$	$\langle Q^2 \rangle$ ((GeV/c)^2)
1	$0.1 < x_B < 0.2$	$15^o < \theta_e < 48^o$	0.179	1.52
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Bin	$-t$ range (GeV/c)^2	$\langle -t \rangle$ (GeV/c)^2
1	$0.08 < -t < 0.18$	0.137
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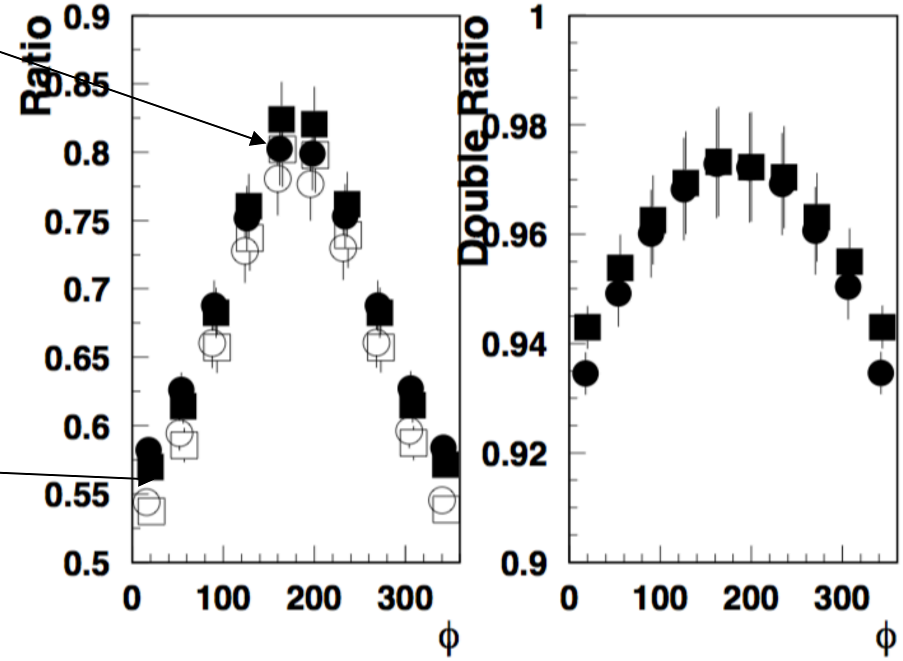
GPD model independent

$$\frac{C^{BH}_{0LP} + C^{BH}_{1LP} cos\phi}{C^{BH}_{0Unp} + C^{BH}_{1Unp} cos\phi + C^{BH}_{2Unp} cos2\phi}$$

GPD model dependent (systematics from models)

$$\frac{C^{BH}_{0LP} + C^{BH}_{1LP} cos\phi + C^{Int}_{0LP} + C^{Int}_{1LP} cos\phi}{C^{BH}_{0Unp} + C^{BH}_{1Unp} cos\phi + C^{BH}_{2Unp} cos2\phi + C^{Int}_{0Unp} + C^{Int}_{1Unp} cos\phi}$$



Empty symbols correspond to separate nominator and denominator calculations and filled symbols to calculation of the ratio (right plot is for ratio)

•Difference ~5% from calculating as ratio of structure functions

ϕ-dependent amplitude

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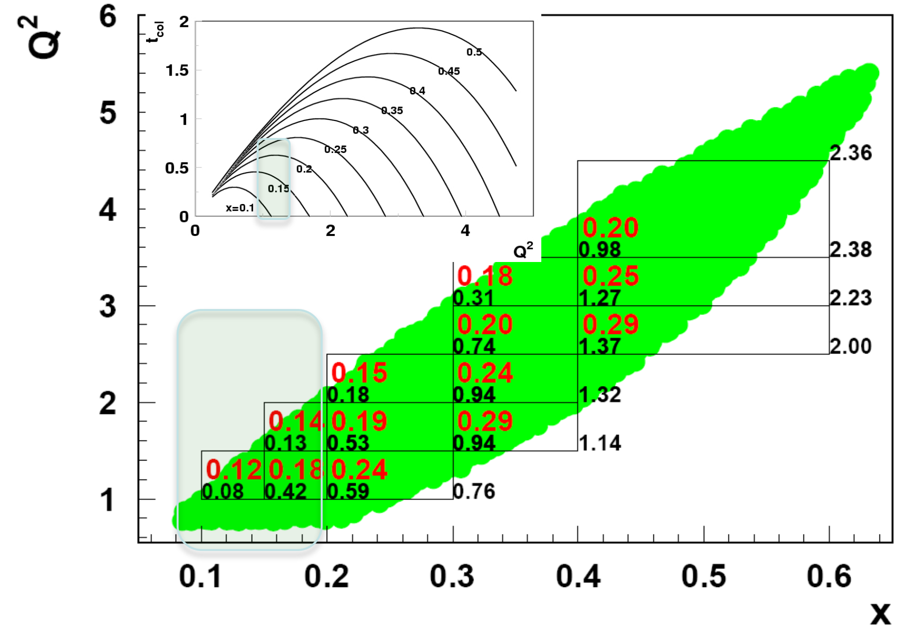

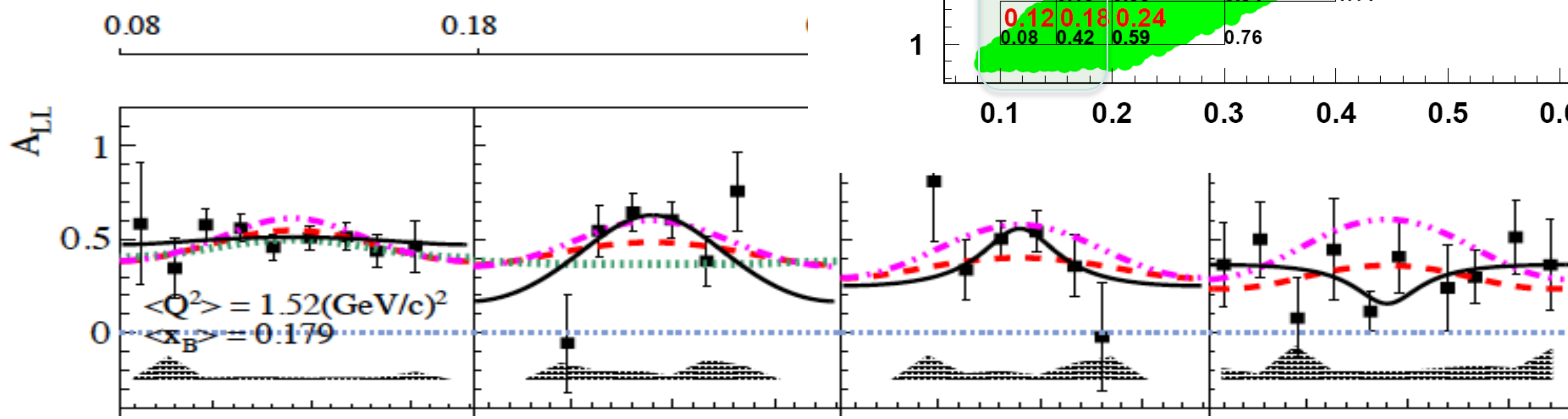

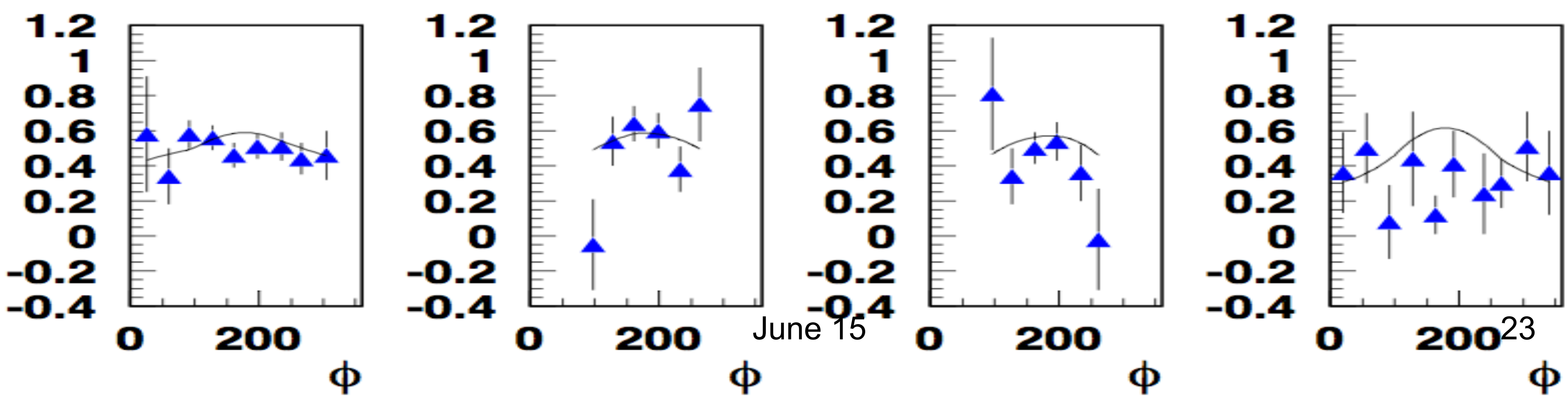

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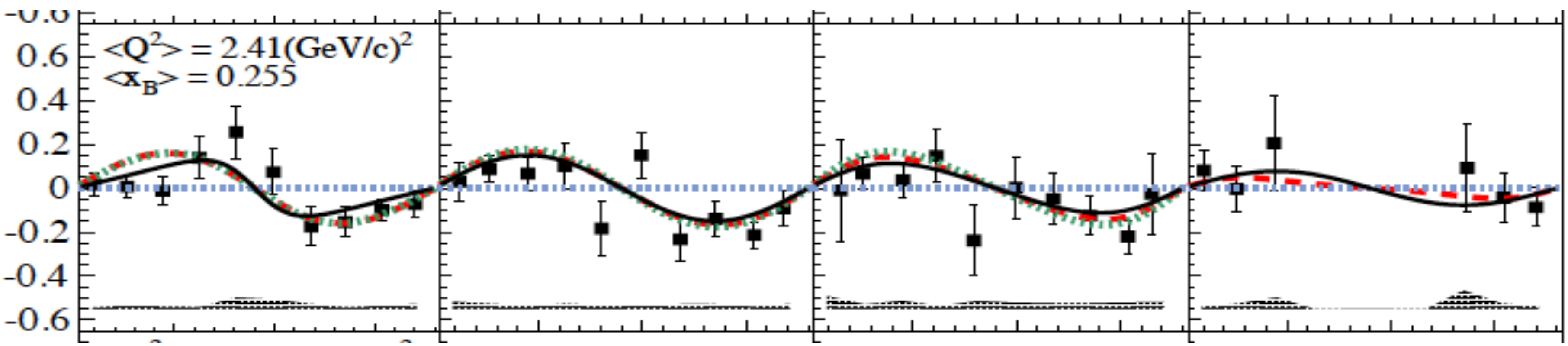
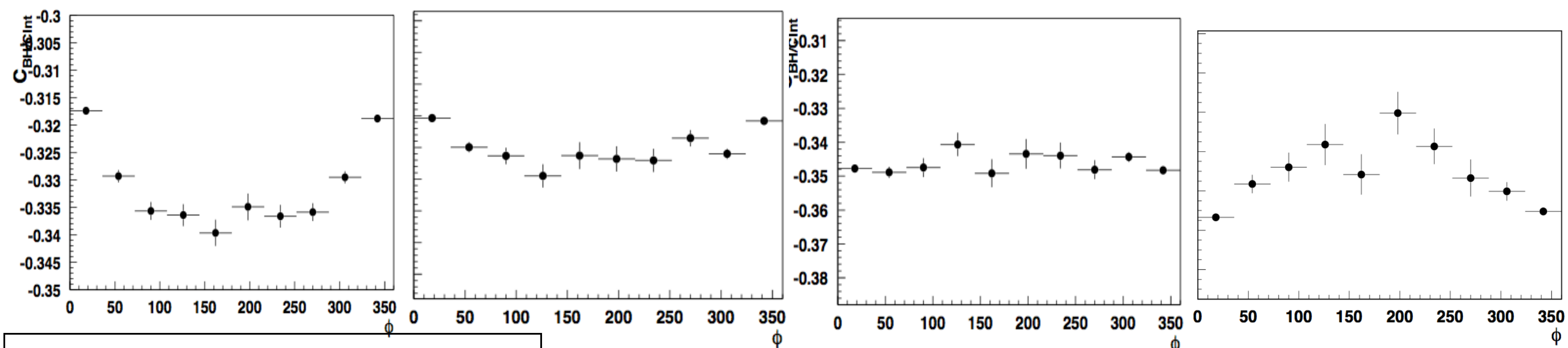
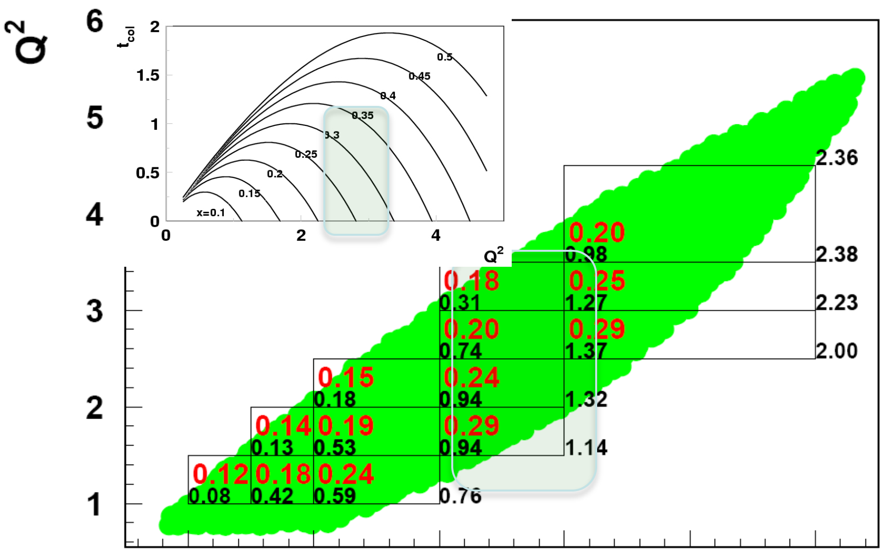




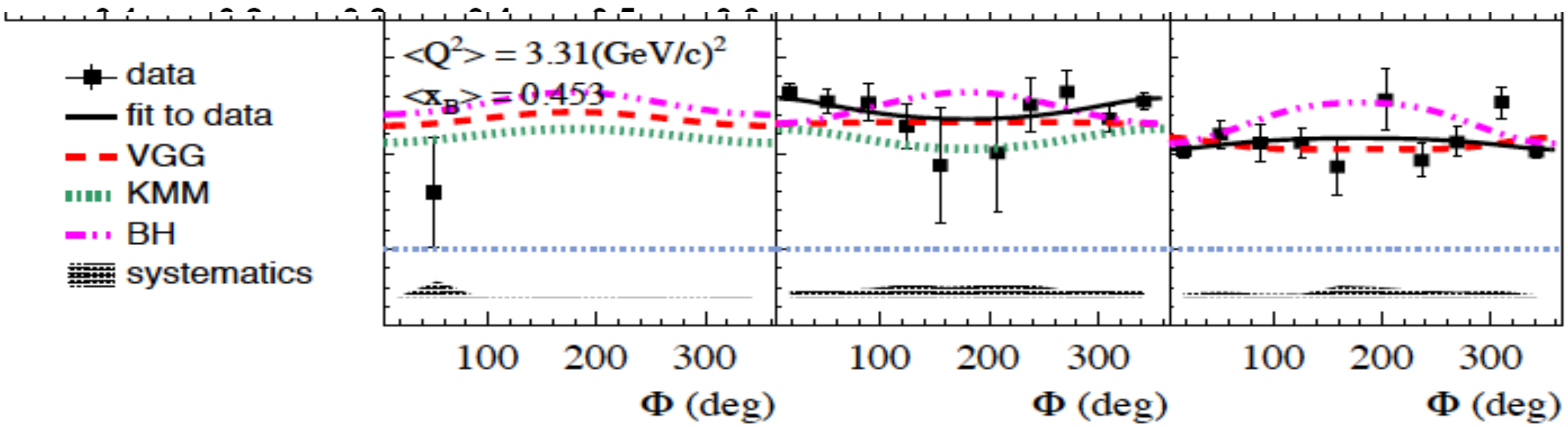
C_{int}/C_{BH}=-x/y*$(1+\varepsilon^2)^2$

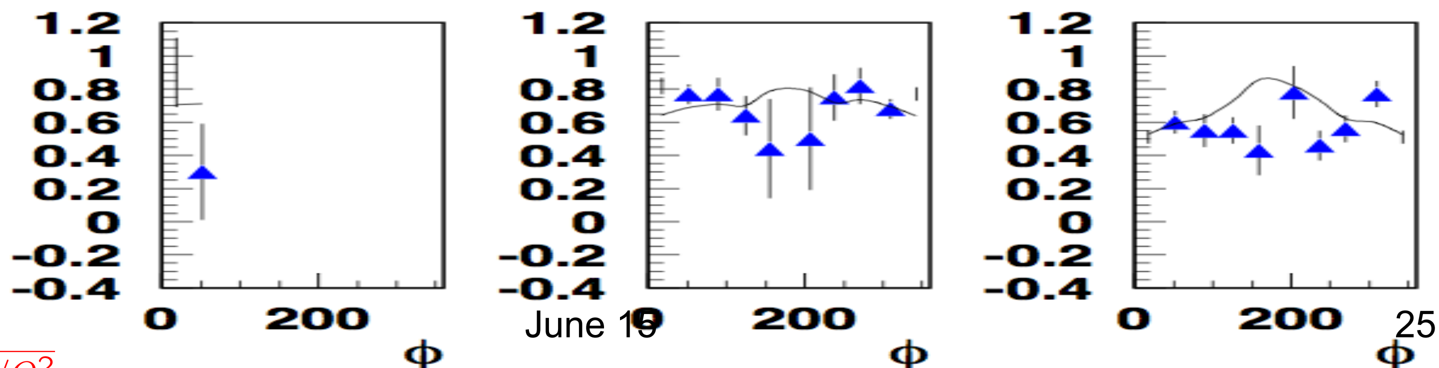
•**The ϕ-dependence of prefactor doesn't cancel: should be accounted in calculations**

ϕ-dependent amplitude



x_B bin	θ_e bin	$\langle x_B \rangle$	$\langle Q^2 \rangle$ ((GeV/c)^2)
$0.1 < x_B < 0.2$	$15^o < \theta_e < 48^o$	0.179	1.52
$0.2 < x_B < 0.3$	$15^o < \theta_e < 34^o$	0.255	1.97
$0.2 < x_B < 0.3$	$34^o < \theta_e < 48^o$	0.255	2.41
$0.3 < x_B < 0.4$	$15^o < \theta_e < 45^o$	0.345	2.60
$x_B > 0.4$	$15^o < \theta_e < 45^o$	0.453	3.31





$$t_{min} \approx \frac{M^2 X^2}{1 - x + xM^2/Q^2}$$

azimuthal moments in DVCS (example)

$$\mathcal{I} = \frac{\pm e^6}{x_B y^3 \mathcal{P}_1(\phi)\mathcal{P}_2(\phi)\Delta^2}\left\{c_0^{\mathcal{I}} + \sum_{n=1}^{3}\left[c_n^{\mathcal{I}}\cos(n\phi) + s_n^{\mathcal{I}}\sin(n\phi)\right]\right\}$$

$$\left\{\begin{array}{c} c^{\mathcal{I}}_{1,\mathrm{unp}} \\ s^{\mathcal{I}}_{1,\mathrm{unp}} \end{array}\right\} = 8K\left\{\begin{array}{c} -(2-2y+y^2) \\ \lambda y(2-y) \end{array}\right\}\left\{\begin{array}{c} \Re\mathrm{e} \\ \Im\mathrm{m} \end{array}\right\}\mathcal{C}^{\mathcal{I}}_{\mathrm{unp}}(\mathcal{F})$$

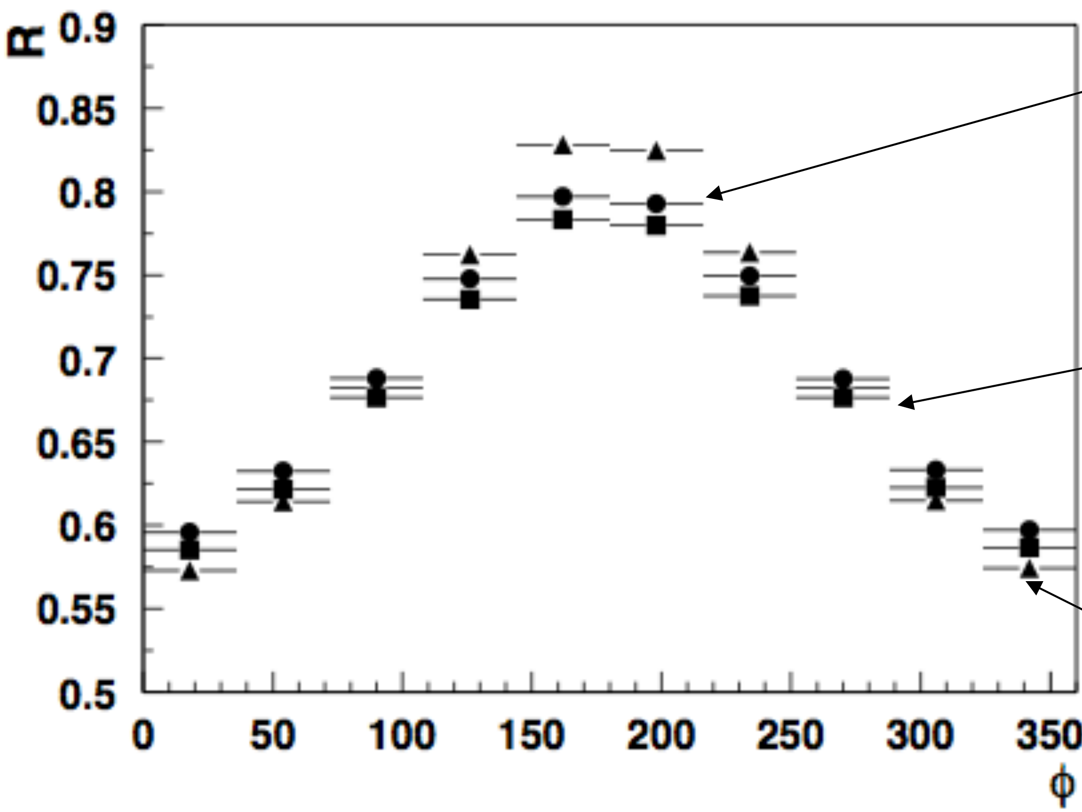
$$\mathcal{C}^{\mathcal{I}}_{\mathrm{LP}} = \frac{x_B}{2-x_B}(F_1+F_2)\left(\mathcal{H} + \frac{x_B}{2}\mathcal{E}\right) + F_1\widetilde{\mathcal{H}} - \frac{x_B}{2-x_B}\left(\frac{x_B}{2}F_1 + \frac{\Delta^2}{4M^2}F_2\right)\widetilde{\mathcal{E}},$$

All moments involve several contributions with different Form Factors and GPDs multiplied by a kinematic term involving propagators

ϕ-dependent ratios (eg1dvcs paper)

Bin	x_B bin	θ_e bin	$\langle x_B \rangle$	$\langle Q^2 \rangle$ ((GeV/c)^2)
1	$0.1 < x_B < 0.2$	$15^o < \theta_e < 48^o$	0.179	1.52
2	$0.2 < x_B < 0.3$	$15^o < \theta_e < 34^o$	0.255	1.97
3	$0.2 < x_B < 0.3$	$34^o < \theta_e < 48^o$	0.255	2.41
4	$0.3 < x_B < 0.4$	$15^o < \theta_e < 45^o$	0.345	2.60
5	$x_B > 0.4$	$15^o < \theta_e < 45^o$	0.453	3.31

Bin	$-t$ range (GeV/c)^2	$\langle -t \rangle$ (GeV/c)^2
1	$0.08 < -t < 0.18$	0.137
2	$0.18 < -t < 0.3$	0.234
3	$0.3 < -t < 0.7$	0.467
4	$0.7 < -t < 2.0$	1.175



$$\frac{C^{BH}_{0LP} + C^{BH}_{1LP}cos\phi}{C^{BH}_{0Unp} + C^{BH}_{1Unp}cos\phi + C^{BH}_{2Unp}cos2\phi}$$

GPD model independent

$$\frac{C^{BH}_{0LP} + C^{BH}_{1LP}cos\phi + C^{Int}_{0LP} + C^{Int}_{1LP}cos\phi}{C^{BH}_{0Unp} + C^{BH}_{1Unp}cos\phi + C^{BH}_{2Unp}cos2\phi}$$

GPD model dependent (systematics from models)

$$\frac{C^{BH}_{0LP} + C^{BH}_{1LP}cos\phi + C^{Int}_{0LP} + C^{Int}_{1LP}cos\phi}{C^{BH}_{0Unp} + C^{BH}_{1Unp}cos\phi + C^{BH}_{2Unp}cos2\phi + C^{Int}_{0Unp} + C^{Int}_{1Unp}cos\phi}$$

•The ϕ-dependence of prefactor doesn't cancel: should be accounted in calculations

Target Polarization Measurement from BH Double Spin Asymmetry

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Jefferson Lab, Newport News, VA 23606

Abstract

We present studies of the double spin asymmetry in the hard exclusive photon production. The double spin asymmetry which is dominated by the BH, is discussed as an alternative source of information on the product of beam and target polarizations for CLAS12 polarized target runs.

$$A_{LL} = \frac{\left(\frac{N^{\downarrow\uparrow}}{Q^{\downarrow\uparrow}} - \frac{N^{\uparrow\uparrow}}{Q^{\uparrow\uparrow}}\right) + \left(\frac{N^{\uparrow\downarrow}}{Q^{\uparrow\downarrow}} - \frac{N^{\downarrow\downarrow}}{Q^{\downarrow\downarrow}}\right)}{f\left(\frac{N^{\uparrow\uparrow}}{Q^{\uparrow\uparrow}} + \frac{N^{\downarrow\uparrow}}{Q^{\downarrow\uparrow}} + \frac{N^{\uparrow\downarrow}}{Q^{\uparrow\downarrow}} + \frac{N^{\downarrow\downarrow}}{Q^{\downarrow\downarrow}}\right)}$$

$$A_{LL} \sim \frac{c^{\mathrm{BH}}_{0,\mathrm{LP}}}{c^{\mathrm{BH}}_{0,\mathrm{unp}}}$$

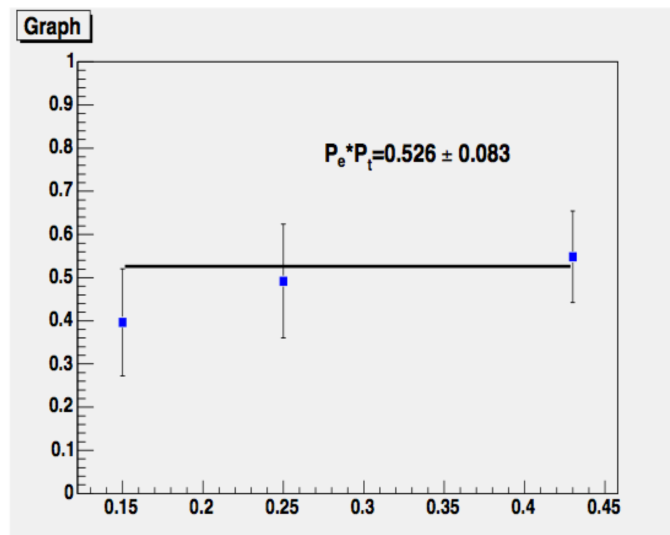
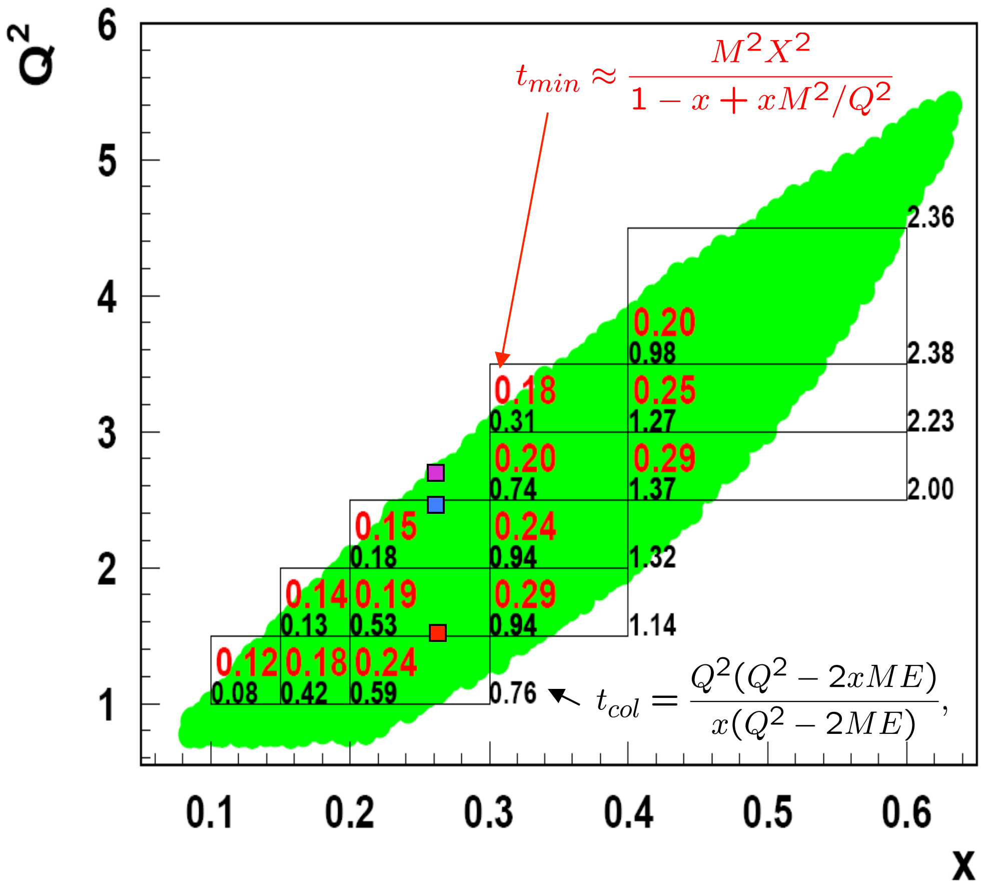
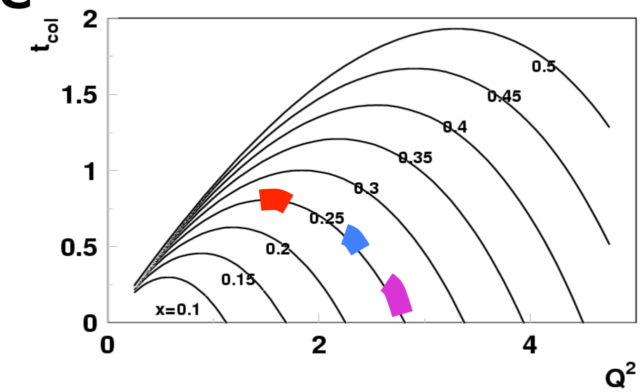


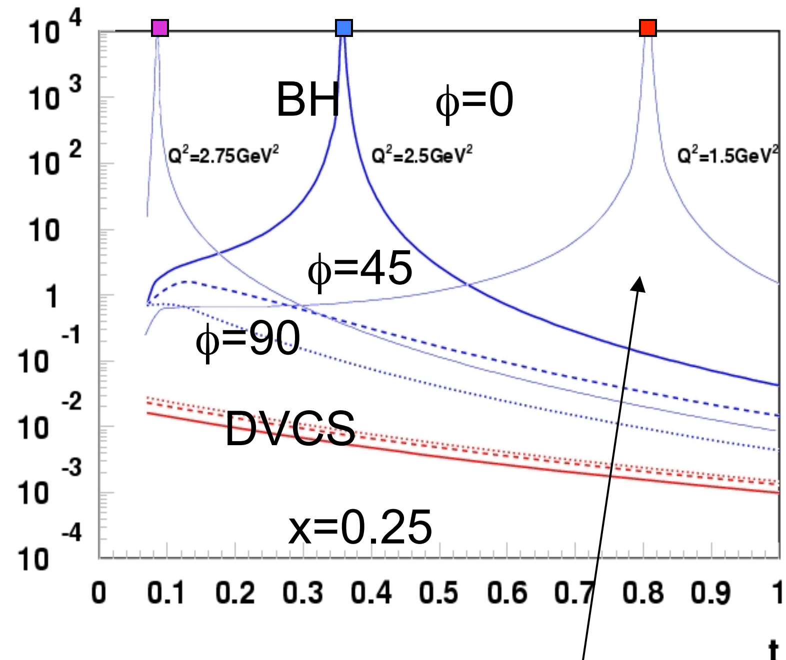
Figure 2: $P_B * P_T$ extracted using the A_{LL} as a function of t from EG1 data.

DVCS: BH propagators

$$\mathcal{I} = \frac{\pm e^6}{x_{\rm B} y^3 \Delta^2 \mathcal{P}_1(\phi)\mathcal{P}_2(\phi)} \left\{ c_0^{\mathcal{I}} + \sum_{n=1}^{3} \left[c_n^{\mathcal{I}} \cos(n\phi) + s_n^{\mathcal{I}} \sin(n\phi) \right] \right\} ,$$

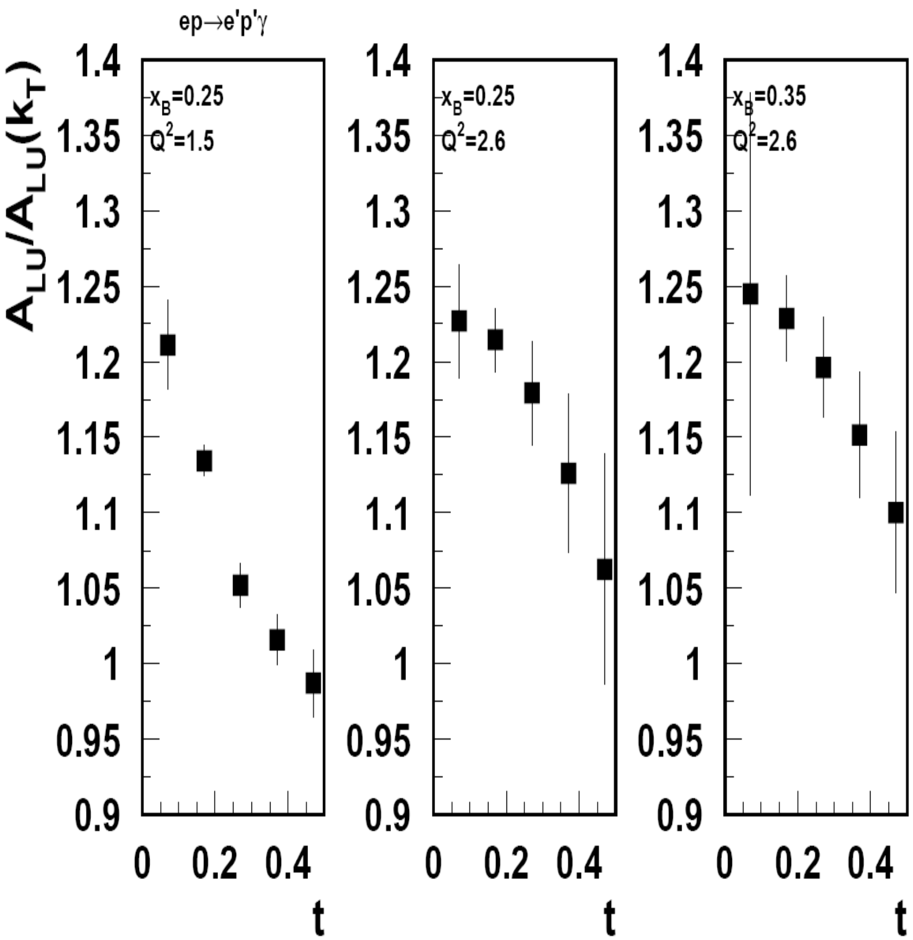


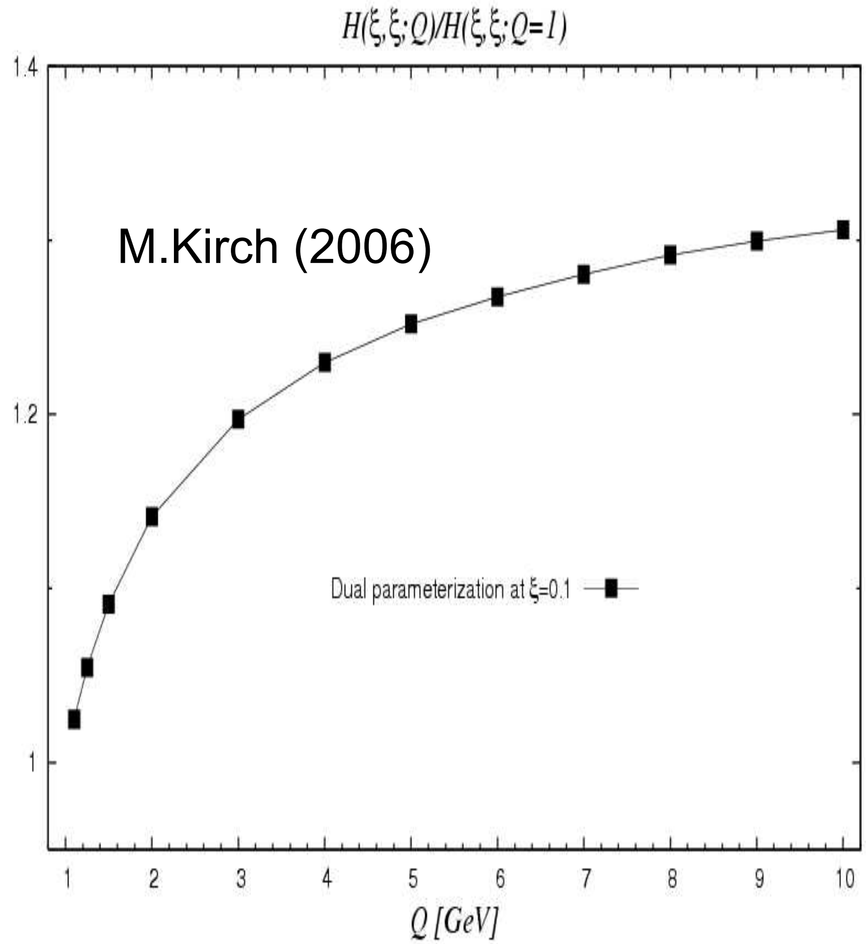




- Strong dependence on kinematics of prefactor ϕ-dependence, at $t=t_{col}$ $P_1(\phi)=0$ require special attention in interpretation of beam averaged beam SSA and in particular x-section differences
- Fraction of pure DVCS increases with **t** and **ϕ**

Sensitivity on theory input



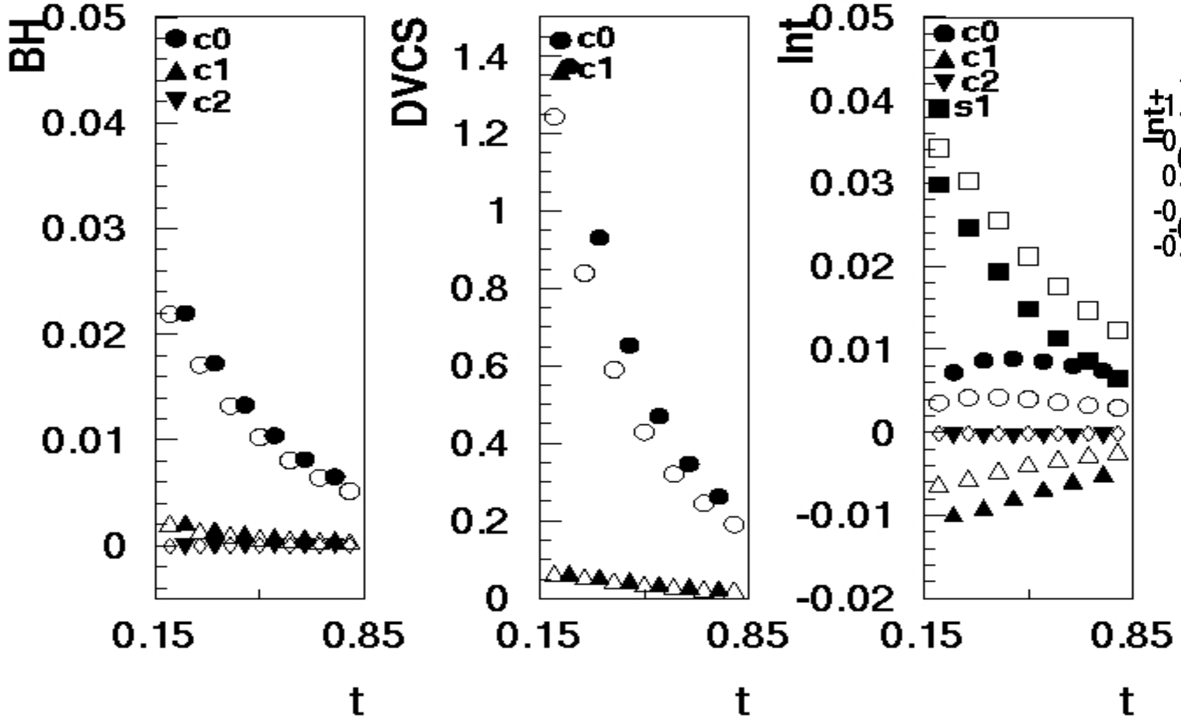


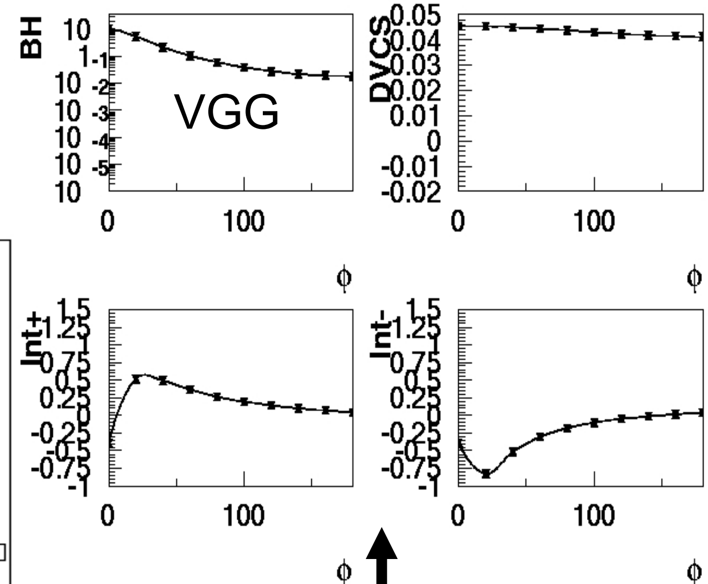
Dynamical HT may decrease the beam SSA at small **t**

Evolution effects significant at small **Q2**

Contributions to the DVCS cross section

	VGG	BMK
BH	exact	exact
Int	BH_e*DVCS_a	$(BH*DVCS)_a$



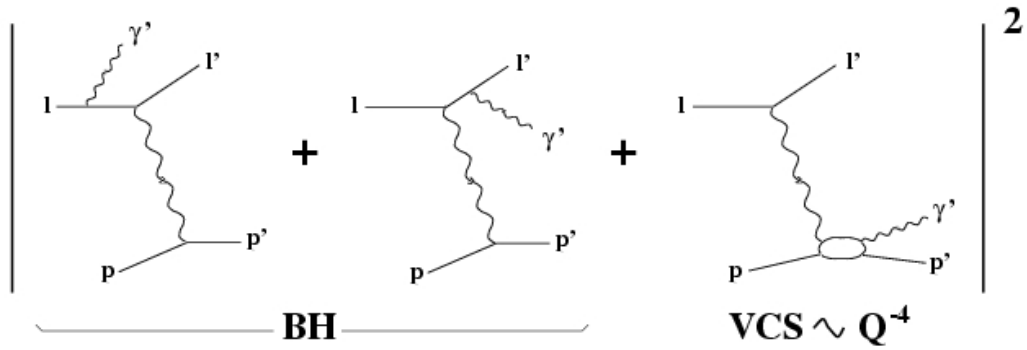


VGG x-section described as a sum of moments

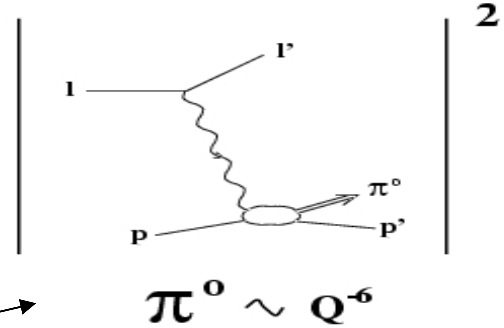
Azimuthal moments in the DVCS MC (BMK-open symbols) and Vanderhaeghen et al (filled symbols).

Reason for difference under studies (2002)

GPDs from ep->e’p’γ



Requirements for precision (<15%) measurements of GPDs from DVCS SSA:



- Define the procedure to extract GPDs from A_{LU}
  - effect of finite bins (prefactor variations) ~10%
  - other moments
- Define background corrections (>1γ)
  - pion contamination ~10%
  - radiative background
  - ADVCS

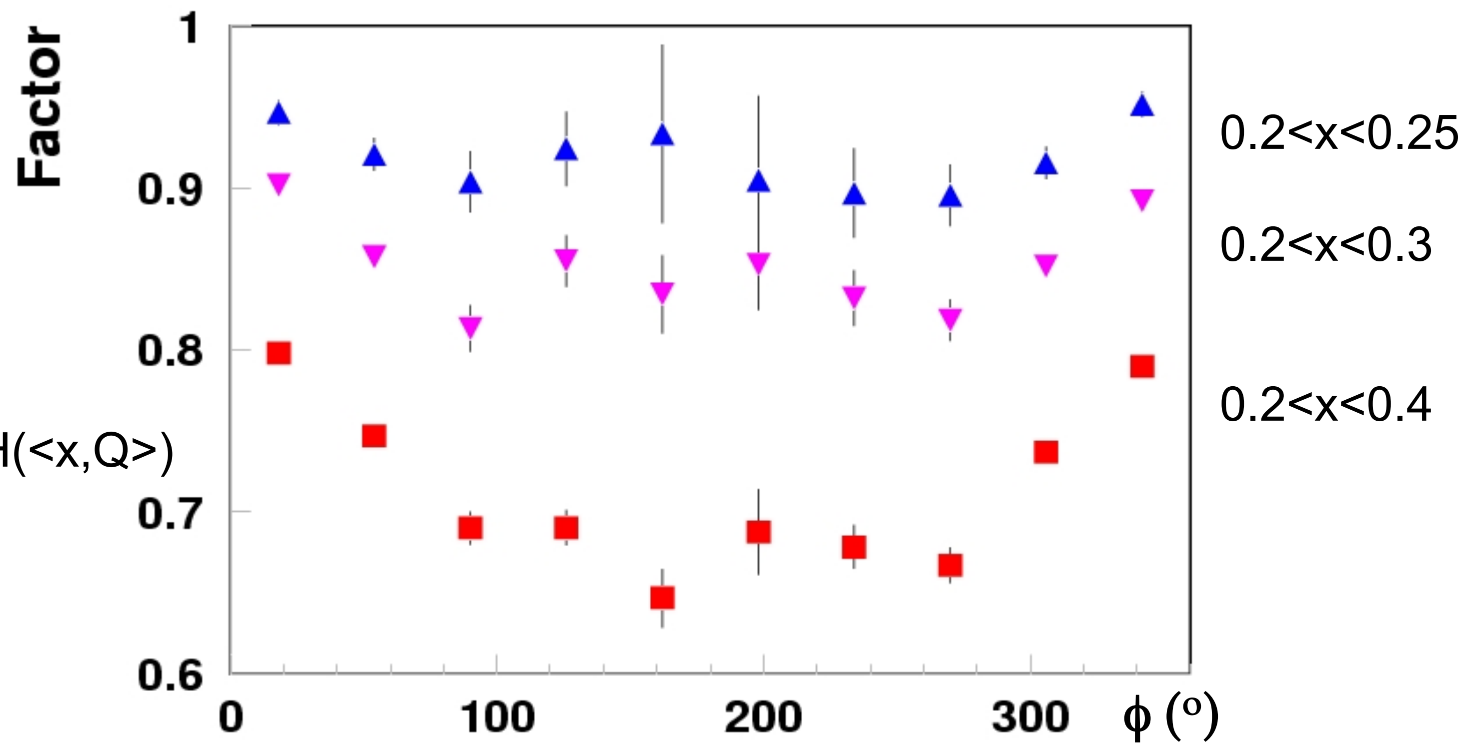
A complete simulation of the whole chain from particle detection to GPD extraction, including the DVCS and background (counts, asymmetries) as well as extraction procedure (averaging over kinematic factors) required to ensure the reliability of measured GPDs.

Correction factor as a function of bin size

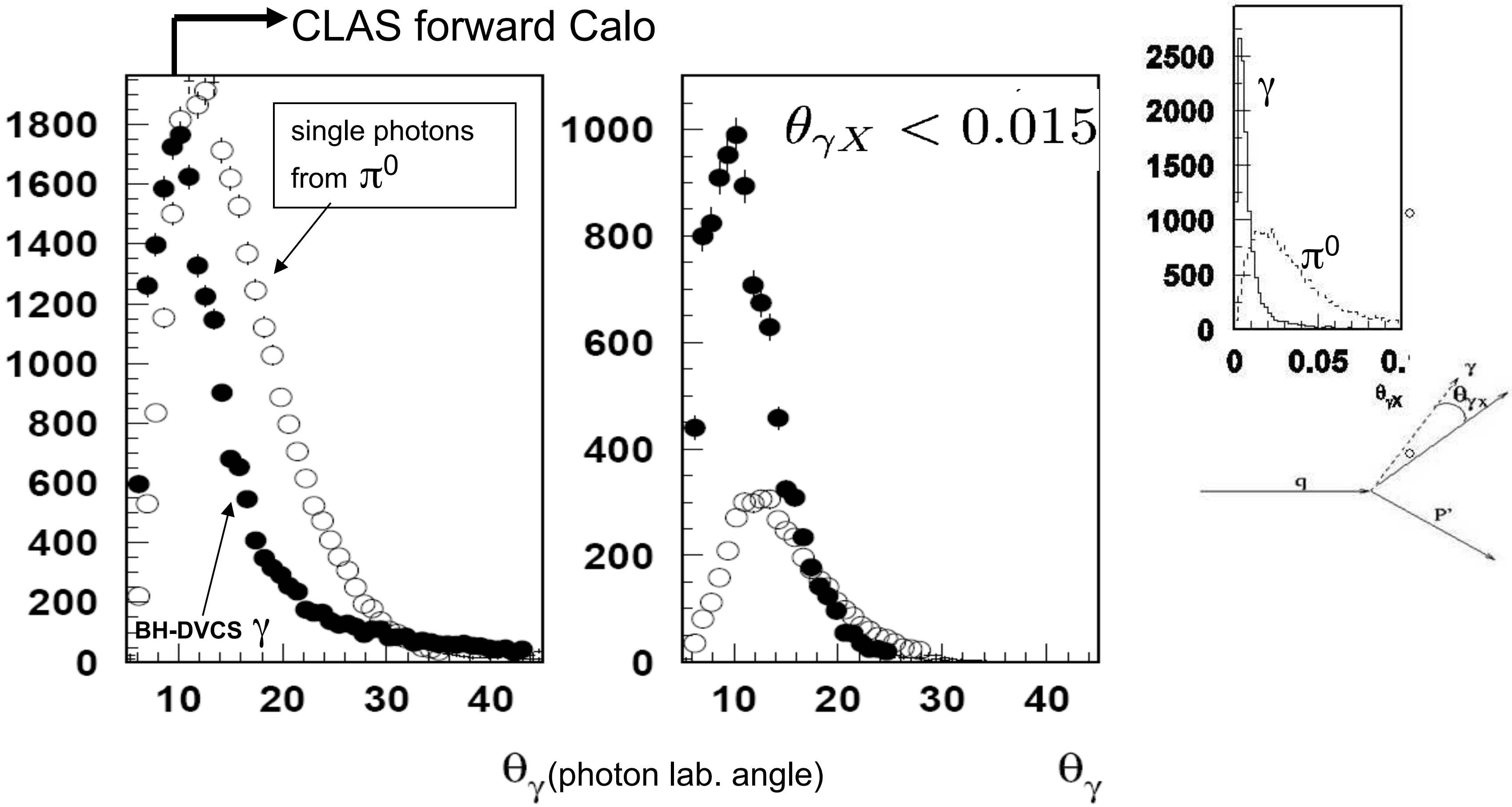
ϕ – dependence of $\mathcal{P}_1 = -\frac{1}{y(1+\epsilon^2)}\{J + 2K\cos(\phi)\}$

in BH and INT terms doesn't cancel for finite bins

$$\frac{\langle Int\rangle / \langle BH\rangle}{Int(\langle x,Q\rangle)/BH(\langle x,Q\rangle)}$$



π^0 contamination in epγ-sample



•At large angles detected photon can be used as veto (epX-sample).
•Cut on the direction of the measured photon (require detection of proton) significantly reduce the contamination (epγ-sample).

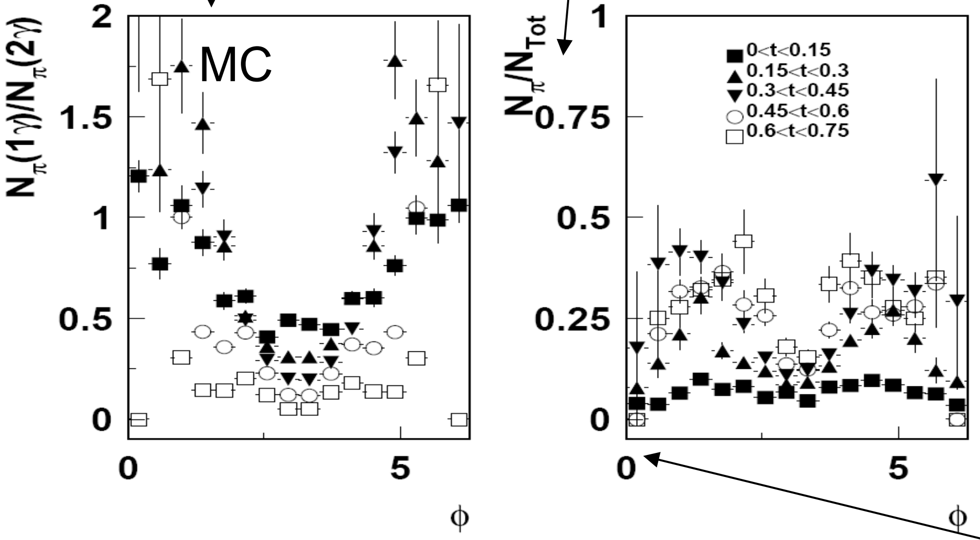
π^0 contamination

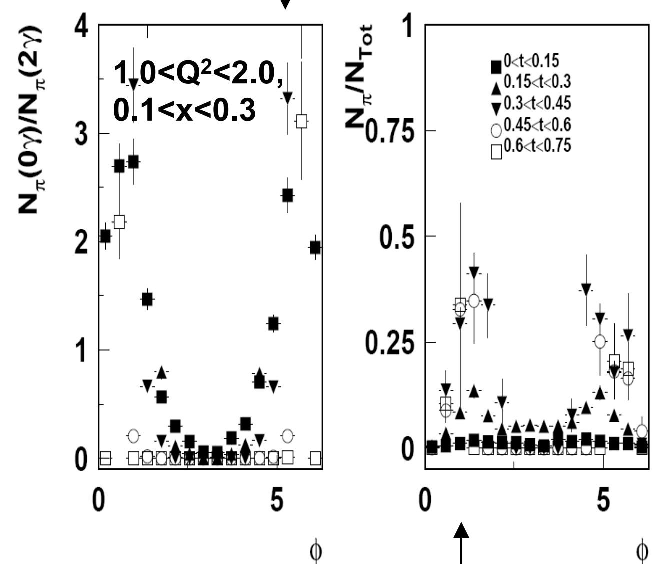
Main unknown in corrections of photon SSA are the π^0 contamination and its beam SSA.

Extract from epπ^0 MC the ratio of single to double photon detection probability

$$N_\gamma^{Data}(\pi^0) = N_{\pi^0}^{Data} \frac{N_\gamma^{MC}(\pi^0)}{N_{\pi^0}^{MC}},$$

MC the ratio for 0 γ

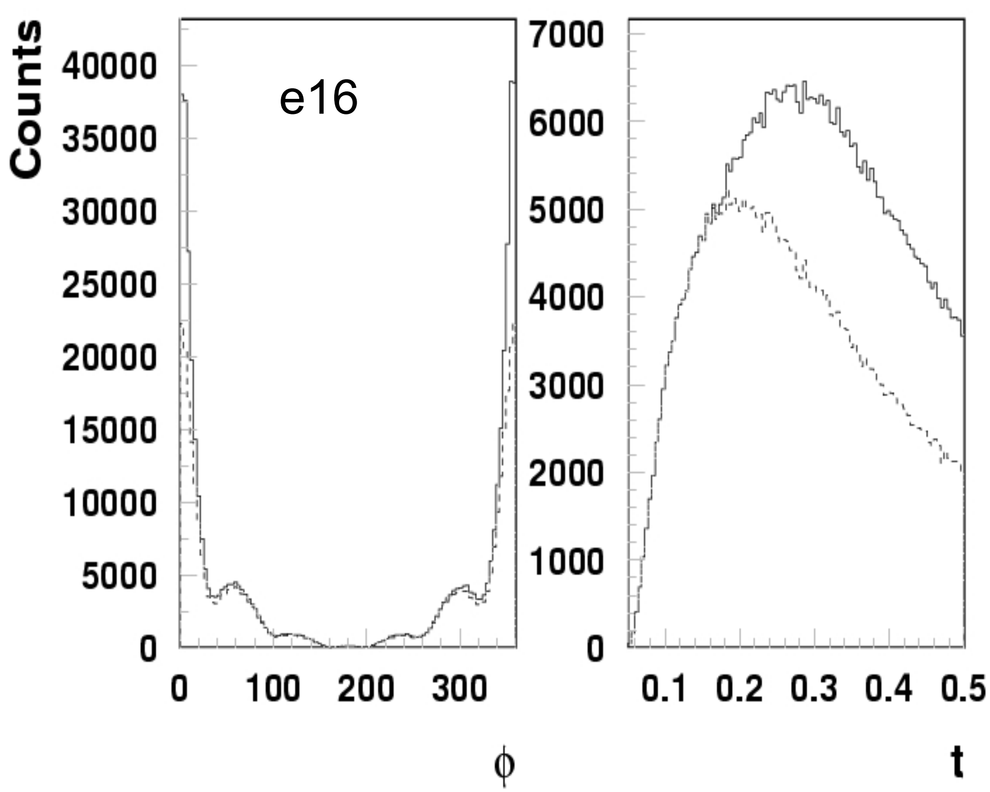


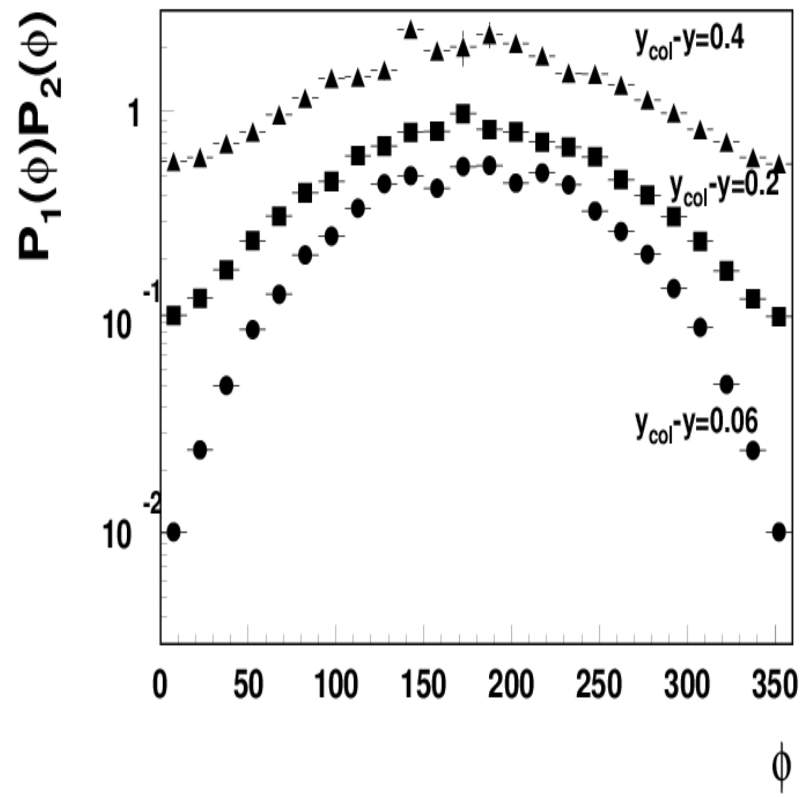


Use epπ^0 MC and data to estimate the contribution of π^0 in the epγ and epX samples

Contamination from π^0 photons increasing at large t and x .

ϕ-dependence and collinearity cut



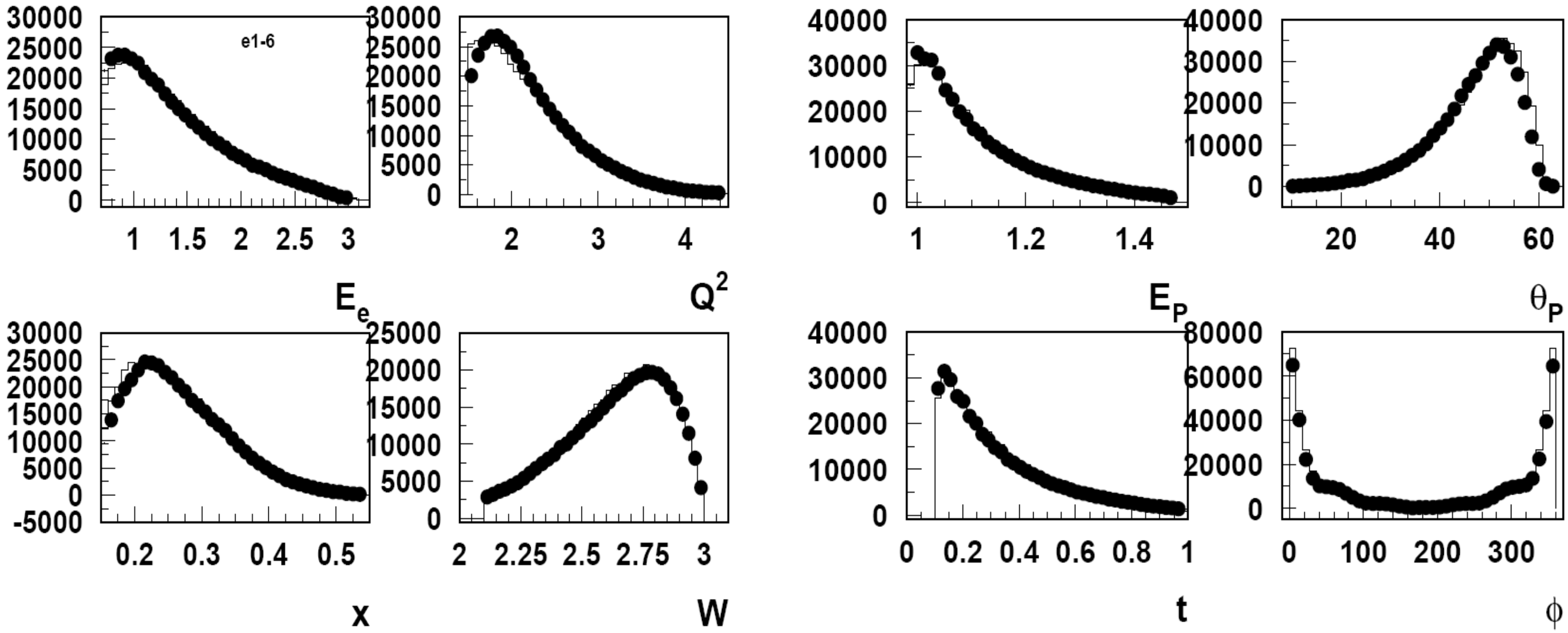


Collinearity cut y_{col}-y>0.025 eliminates low ϕ and large **t** (the beam direction)

$$y = y_{\rm col} \equiv \frac{Q^2 + \Delta^2}{Q^2 + x\Delta^2}$$

γ MC vs Data

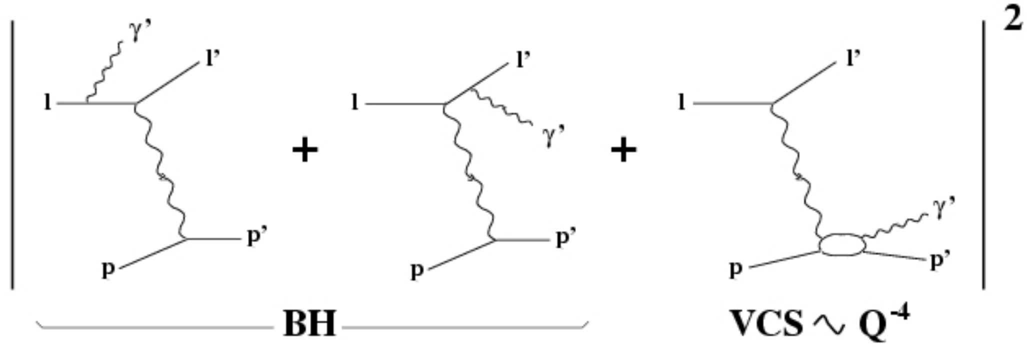
•Exclusive photon production simulated using a realistic MC(based on S.Korotkov’s code)



•Exclusive photon production simulated using a realistic MC(based on S.Korotkov’s code)

•Kinematic distributions in x,Q^2,t consistent with the CLAS data

GPDs from ep->e’p’γ



Requirements for precision (<10%) measurements of GPDs from DVCS SSA

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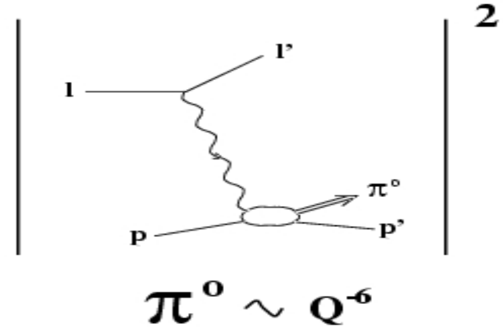
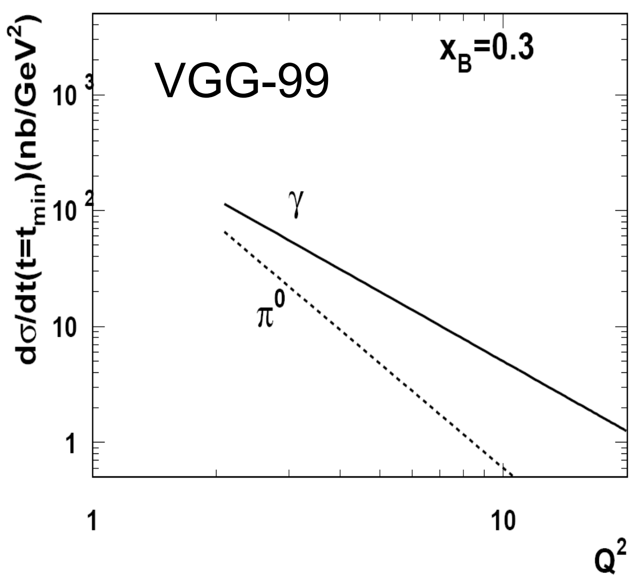
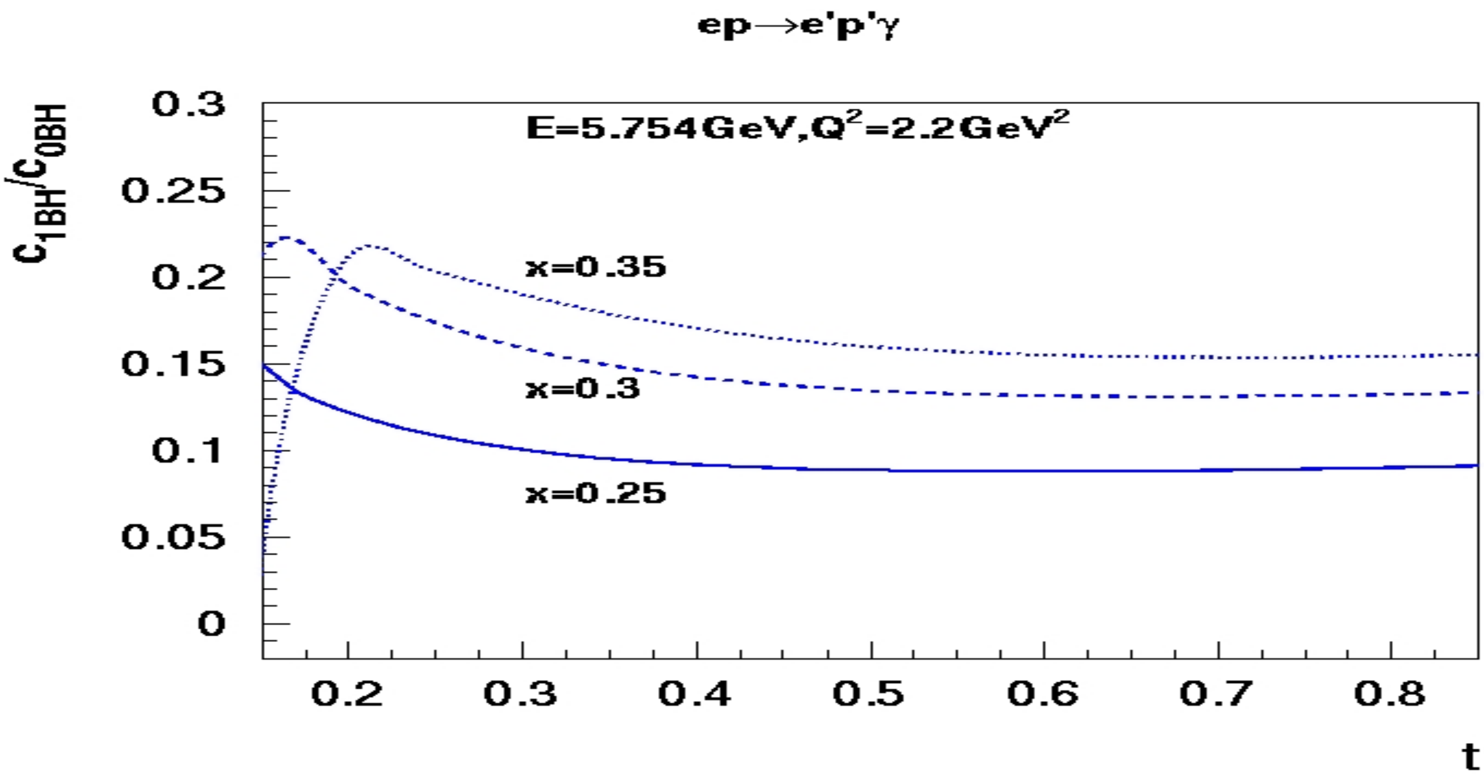




π^0 dominates the single photon sample at low Q^2 in the kinematics where BH is small

BH cosϕ moment



$$A_{LU} \propto \frac{\lambda s_2^I \sin\phi}{c_0^{BH}(1+c_1^{BH}/c_0^{BH}\cos\phi)} \approx \frac{\lambda s_2^I \sin\phi - \lambda s_2^I (c_1^{BH}/2c_0^{BH})\sin 2\phi}{c_0^{BH}}$$

BH cosϕ moment can generate ~3% sin2ϕ in the A_{LU}