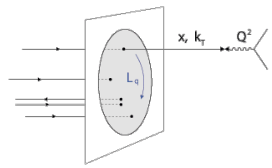
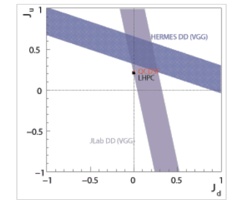
DVCS analysis at CLAS12

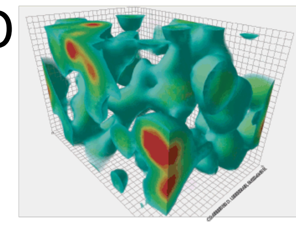
Harut Avakian (JLab)

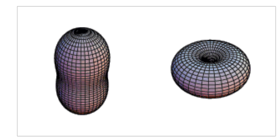




INT Workshop on Orbital Angular Momentum in QCD

February 13 2012

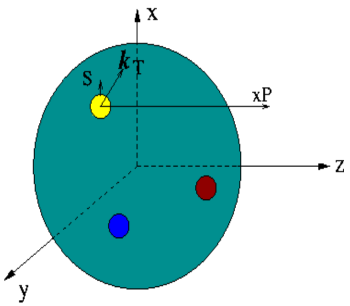


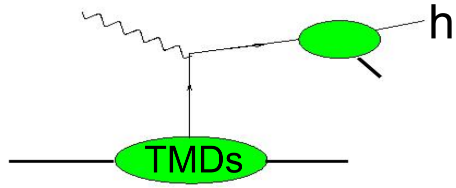


- Introduction
- DVCS measurements
- From clas6 to clas12
- From asymmetries and x-sections to GPDs
- Summary

3D structure of the nucleon

Semi-Inclusive processes and transverse momentum distributions

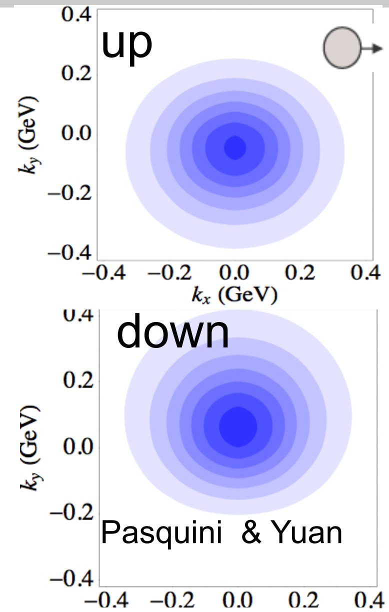




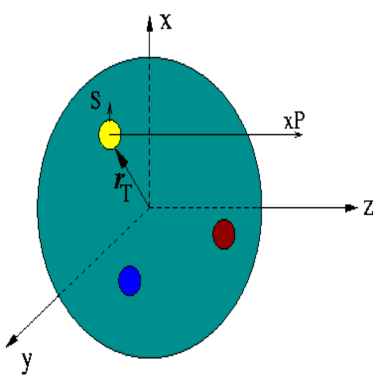
$f_1^q(x,\mathbf{k}_\perp)$ g_1^q $f_{1T}^{\perp q}$ g_{1T}^q

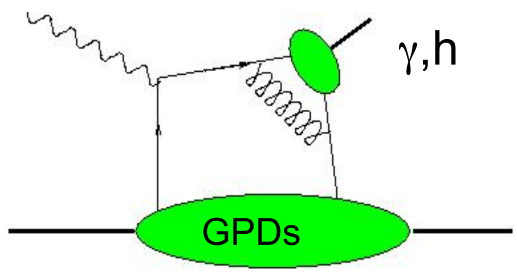
h_1^q $h_{1T}^{\perp q}$ $h_{1L}^{\perp q}$ $h_1^{\perp q}$

	U	L	T
U	f_1		$h_1^\perp$
L		g_{1L}	$h_{1L}^\perp$
T	$f_{1T}^\perp$	g_{1T}	$h_1, h_{1T}^\perp$



Hard exclusive processes and spatial distributions of partons



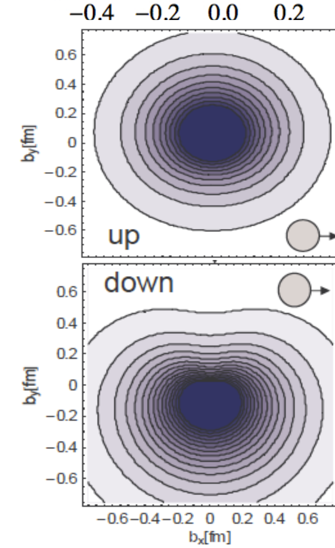


$H^q(x,\xi,t)$ $\tilde{H}^q$ E^q $\tilde{E}^q$

H_T^q $\tilde{H}_T^q$ E_T^q $\tilde{E}_T^q$

Pasquini

	U	L	T
U	$\mathcal{H}$		$\mathcal{E}_T$
L		$\tilde{\mathcal{H}}$	$\tilde{\mathcal{E}}_T$
T	$\mathcal{E}$	$\tilde{\mathcal{E}}$	$\mathcal{H}_T, \tilde{\mathcal{H}}_T$

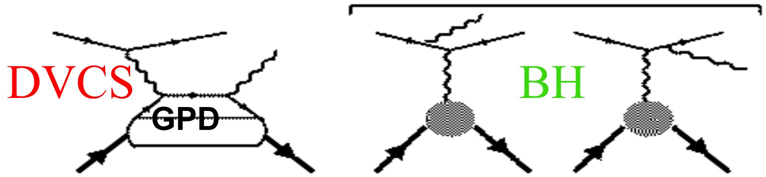


(QCDSF)

$$q(x,\vec{b}_\perp) = \int \frac{d^2\vec{\Delta}_\perp}{(2\pi)^2} e^{i\vec{b}_\perp\cdot\vec{\Delta}_\perp} H(x,\xi=0,-\Delta_\perp^2)$$

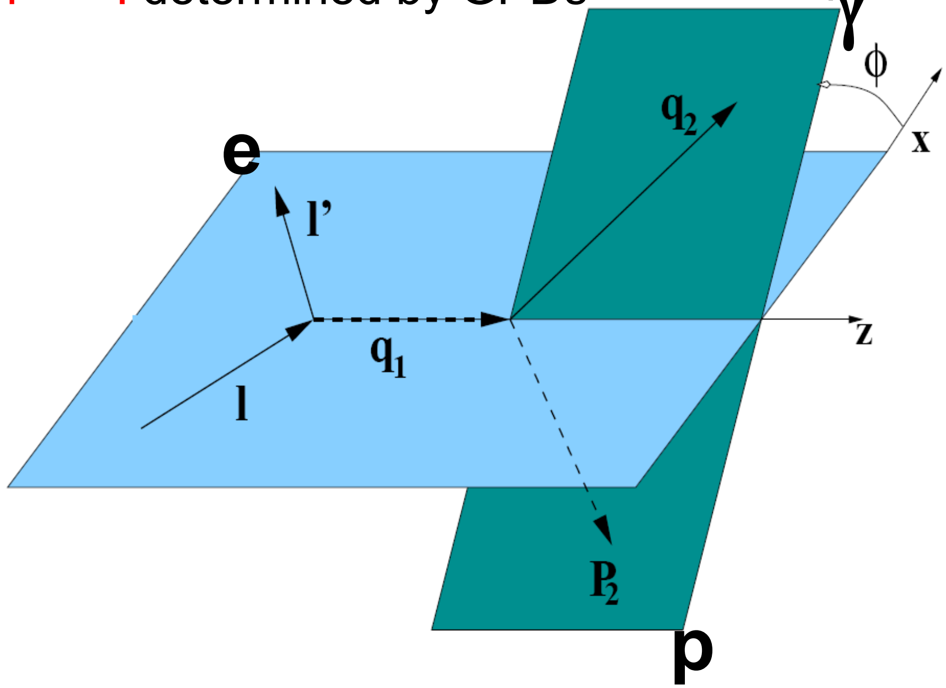
Combination of polarized and unpolarized targets and large acceptance coverage of CLAS12 allows studies of GPDs in a wide kinematic range.

Electroproduction Kinematics



T^{BH}: given by elastic form factors

T^{DVCS}: determined by GPDs



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

$$\nu = E - E'$$

$$x_B = -q_1^2 / 2p_1q_1 = Q^2 / 2M\nu$$

$$y = \nu / E$$

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

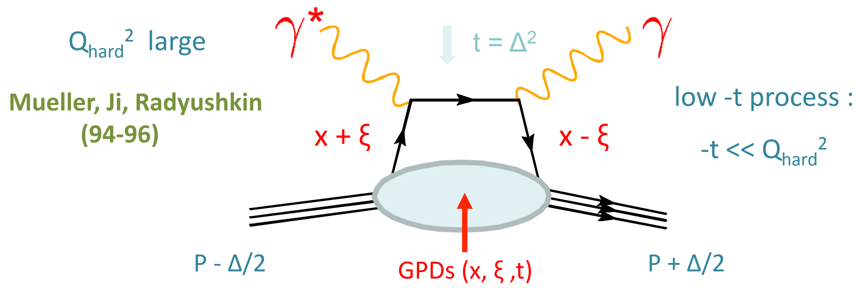
γ*−>γ require a finite longitudinal momentum transfer defined by the generalized Bjorken variable ξ

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

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

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

Deeply Virtual Compton Scattering with CLAS12 – E12-06-119



$\xi = x_B/(2-x_B) \quad k=-t/4M^2$

The DVCS amplitude is expressed in terms of Compton Form Factors (CFF) at LO:

$$\mathcal{H}(\xi,t) = \sum_q e_q^2 \left\{ i\pi \left[H^q(\xi,\xi,t) - H^q(-\xi,\xi,t)\right] + \mathcal{P}\int_{-1}^{+1} dx \left[\frac{1}{\xi - x} - \frac{1}{\xi + x}\right] H^q(x,\xi,t)\right\}$$

(similarly for other GPDs)

Proton

Polarized beam, unpolarized target (BSA) :

$$\Delta\sigma_{LU} \sim \sin\phi \; \mathrm{Im}\{F_1\mathcal{H} + \xi(F_1+F_2)\tilde{\mathcal{H}} - kF_2\mathcal{E}\}d\phi \Longrightarrow Im\{\mathcal{H}_p, \tilde{\mathcal{H}}_p, \mathcal{E}_p\}$$

Unpolarized beam, longitudinal target (lTSA) :

$$\Delta\sigma_{UL} \sim \sin\phi \mathrm{Im}\{F_1\tilde{\mathcal{H}} + \xi(F_1+F_2)(\mathcal{H} + x_B/2\mathcal{E}) - \xi kF_2\,\tilde{\mathcal{E}} + \ldots\}d\phi \Longrightarrow Im\{\mathcal{H}_p, \tilde{\mathcal{H}}_p\}$$

Polarized beam, longitudinal target (BlTSA) :

$$\Delta\sigma_{LL} \sim (A+B\cos\phi)\mathrm{Re}\{F_1\tilde{\mathcal{H}} + \xi(F_1+F_2)(\mathcal{H} + x_B/2\mathcal{E})\ldots\}d\phi \Longrightarrow Re\{\mathcal{H}_p, \tilde{\mathcal{H}}_p\}$$

Unpolarized beam, transverse target (tTSA) :

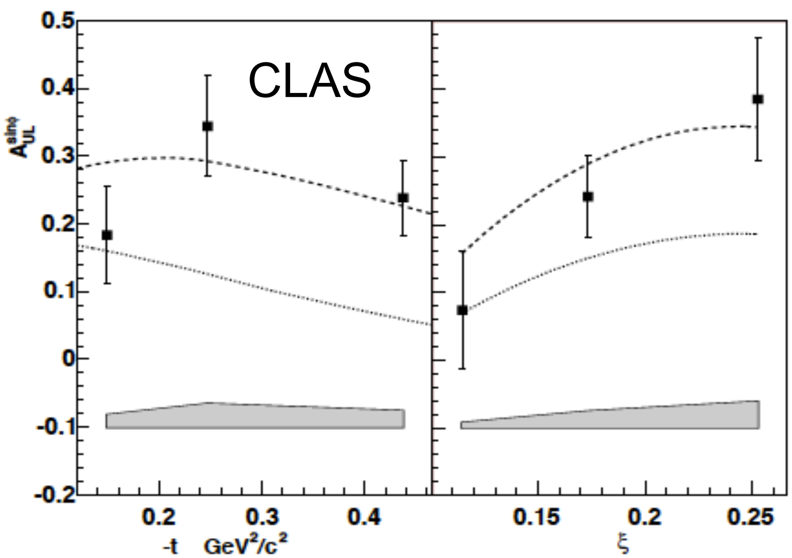
$$\Delta\sigma_{UT} \sim \cos\phi \mathrm{Im}\{k(F_2\mathcal{H} - F_1\mathcal{E}) + \ldots\}d\phi \Longrightarrow Im\{\mathcal{H}_p, \mathcal{E}_p\}$$

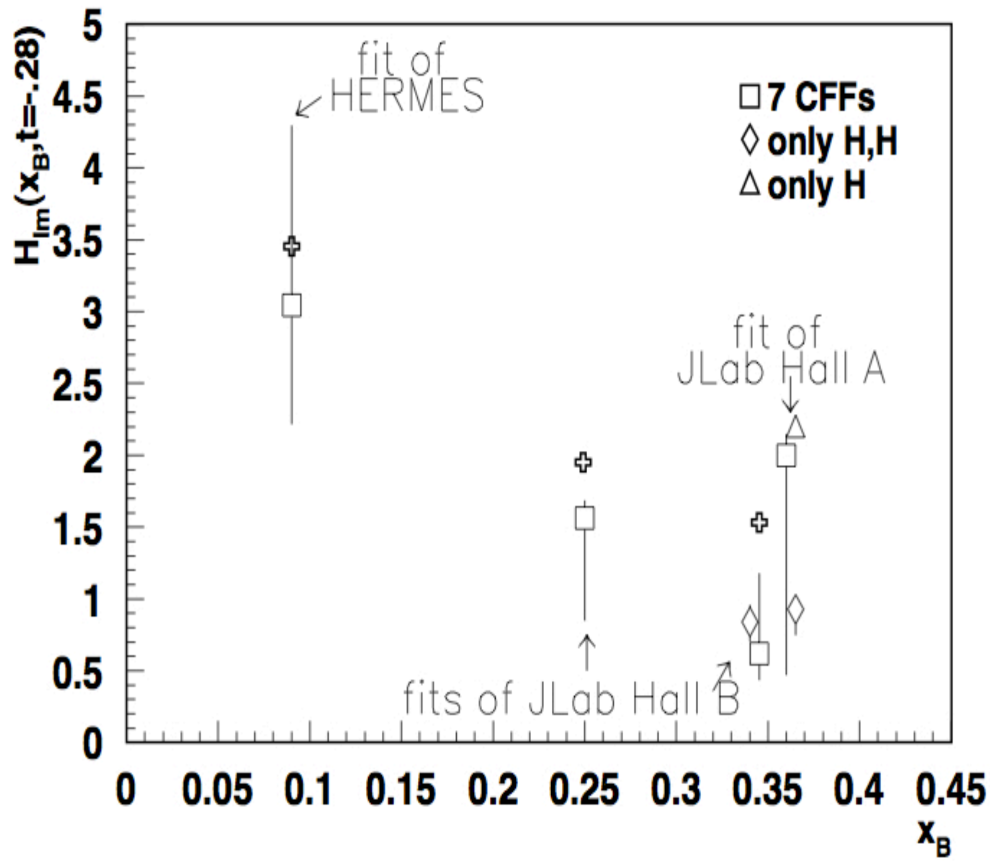
Target Spin Asymmetry: t- Dependence

Unpolarized beam, longitudinal target:

$$\Delta\sigma_{UL} \sim \sin\phi \, \mathrm{Im}\{F_1\tilde{H} + \xi(F_1+F_2)(\tilde{H} + .. \}$$

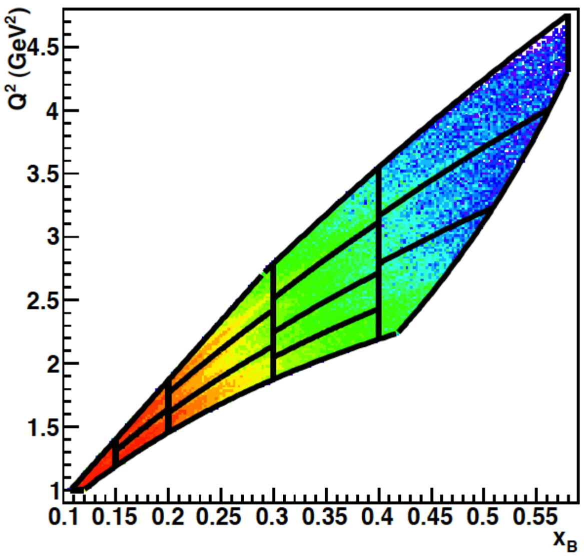
Kinematically suppressed



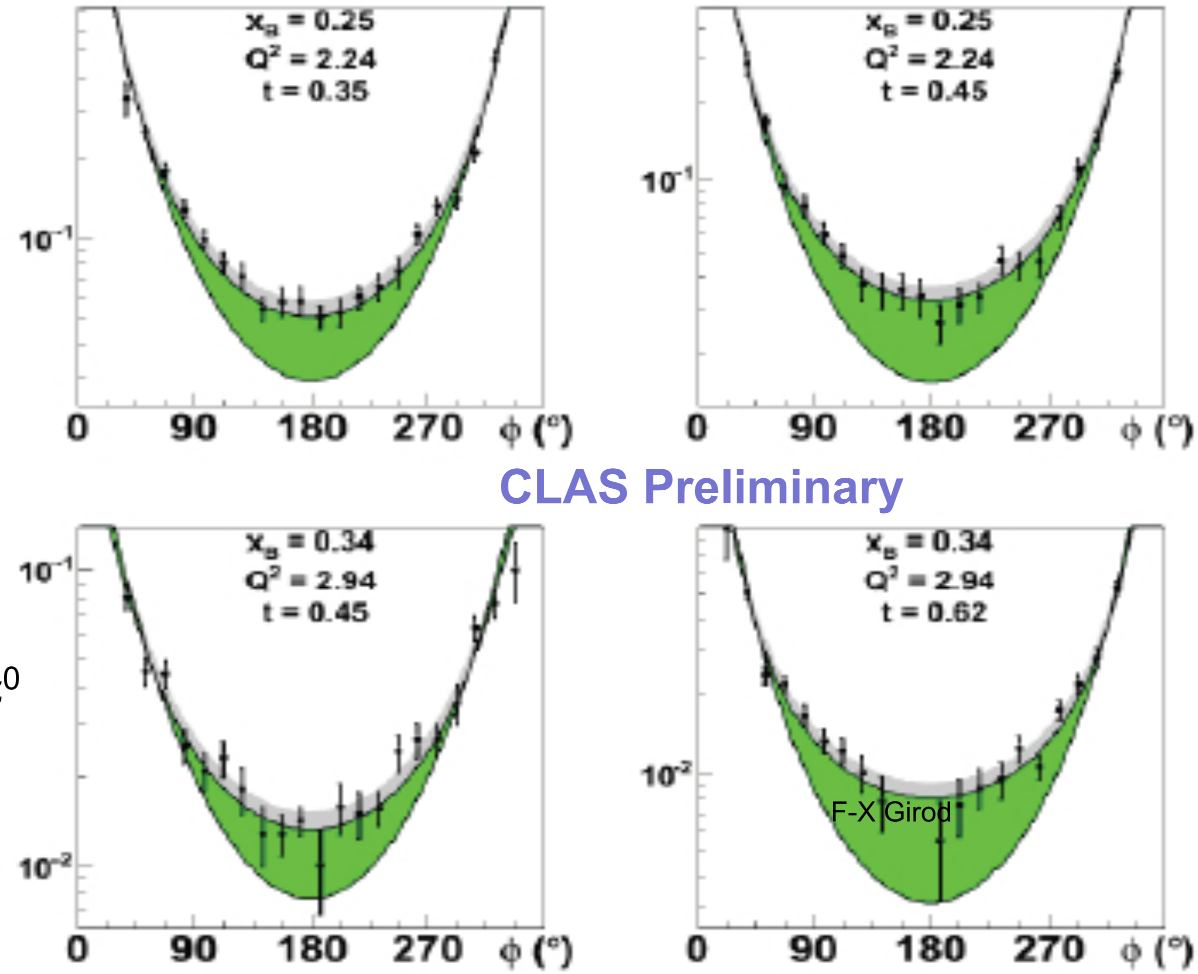


Measurements with polarized target will constrain the polarized GPDs and combined with beam SSA measurements would allow precision measurement of unpolarized GPDs.

DVCS x-sections from CLAS



CLAS DVCS data sample at 6 GeV



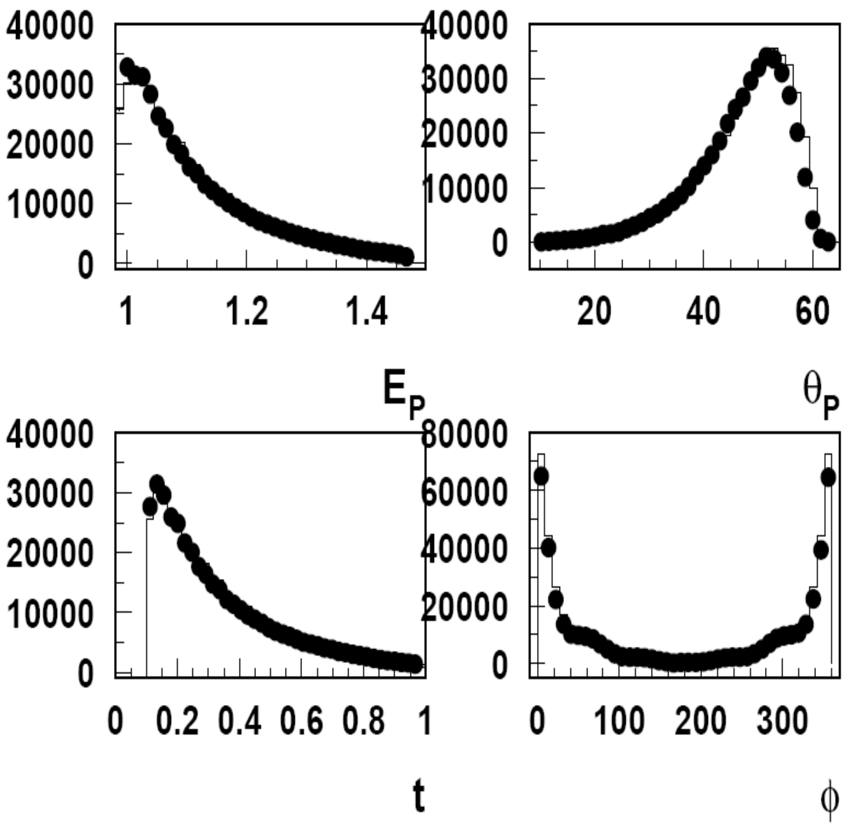
$ep_0 \rightarrow e'p_f\gamma$ $t=(p_0-p_f)^2$

Radiative corrections and π^0 contamination accounted

qualitatively agrees with Hall-A

- In certain region of azimuthal angles the x-section is higher than BH calculations indicating data may be sensitive to DVCS already in JLab kinematics.

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

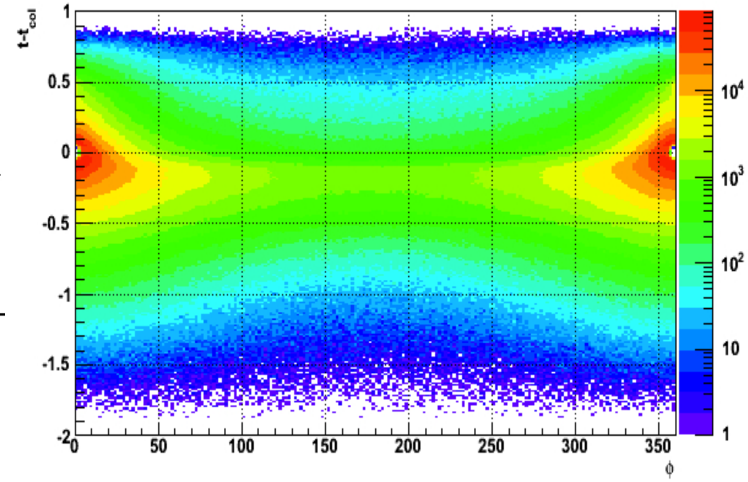
- Uniform coverage in angle ϕ, photon measurement less challenging
- DVCS x-section non negligible introduce some model dependence)
- π^0 dominates the single photon sample (in particular at low Q^2)

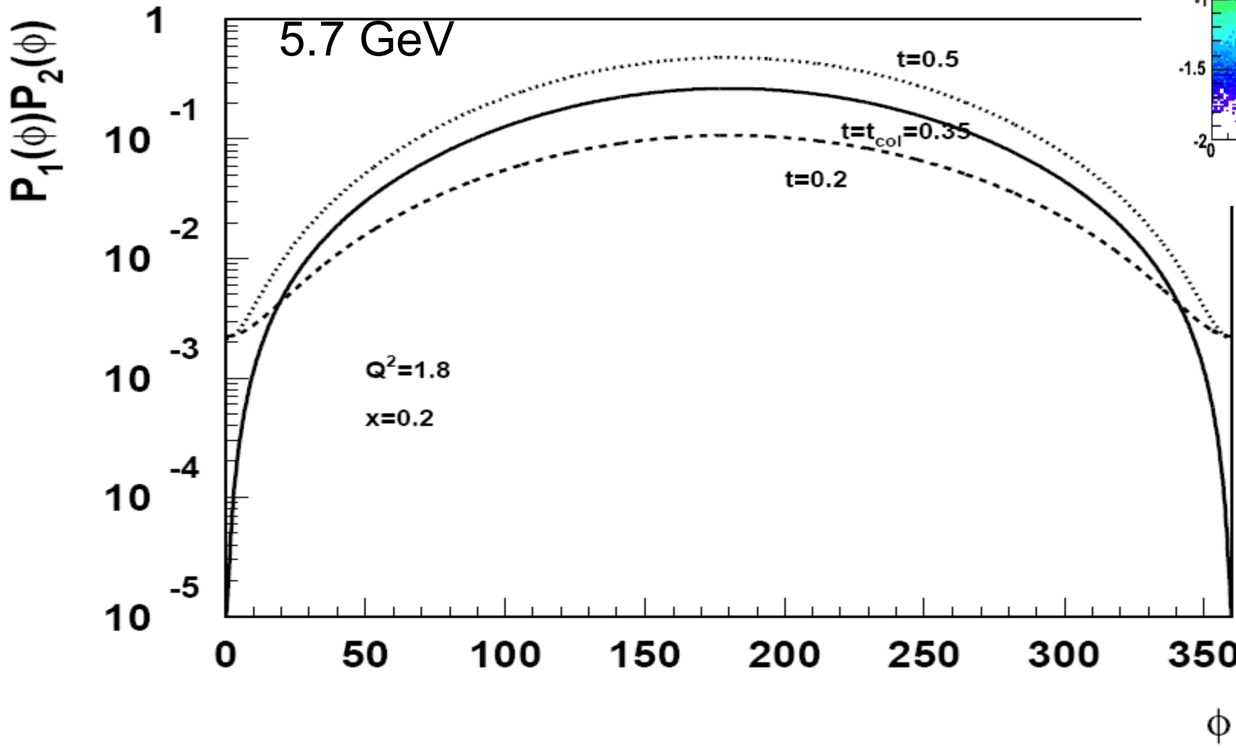
- Kinematic distributions in x,Q^2,t consistent with the CLAS data

ϕ-dependent amplitude

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

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





$$t_{col} = \frac{Q^2(Q^2 - 2xME)}{(Q^2 - 2ME)x}$$

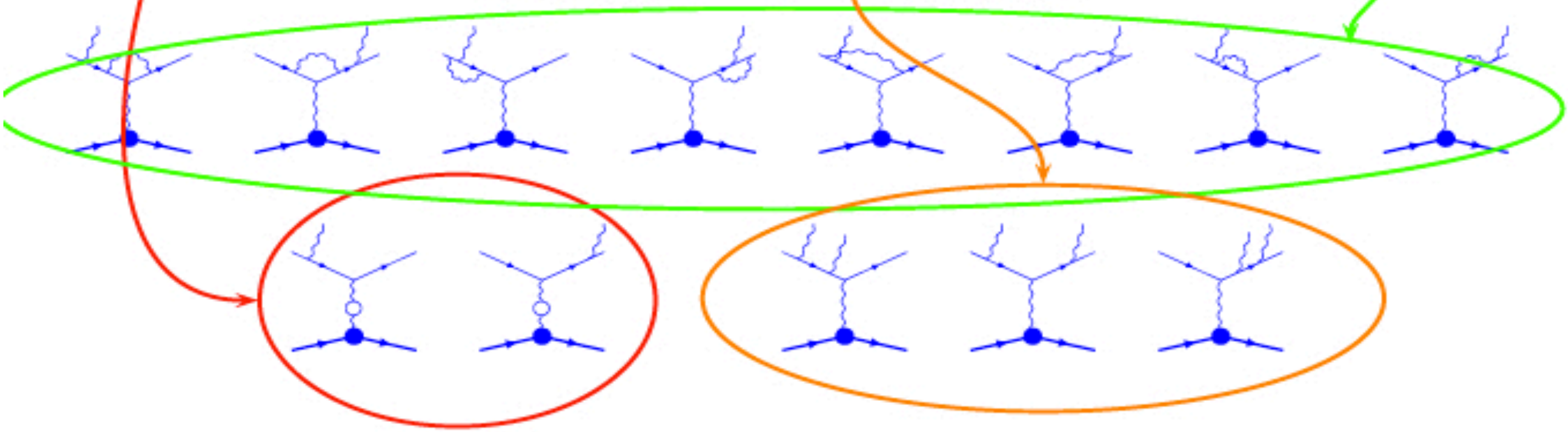
- **Strong dependence on kinematics of prefactor ϕ-dependence, at $t \approx t_{col}$, $P_1(\phi) \rightarrow 0$**
- **Radiative corrections may be significant**

Radiative corrections

I. Akushevich

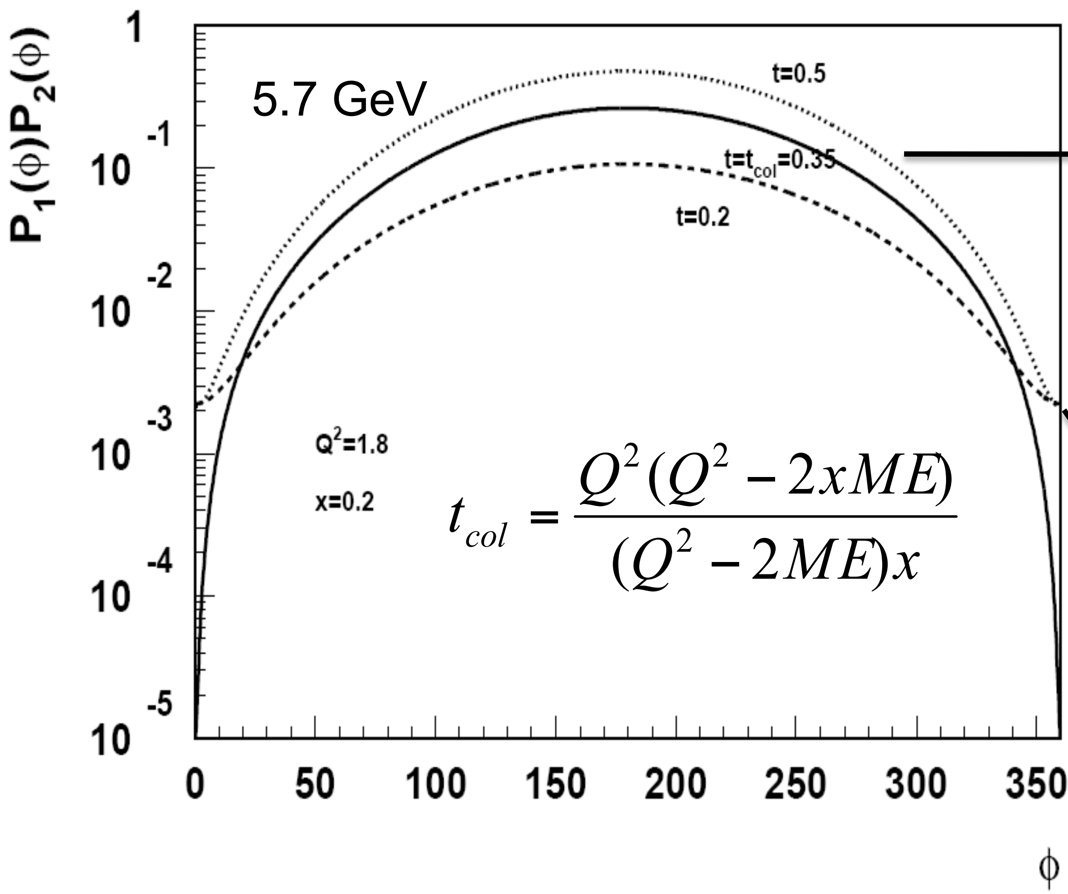
true x

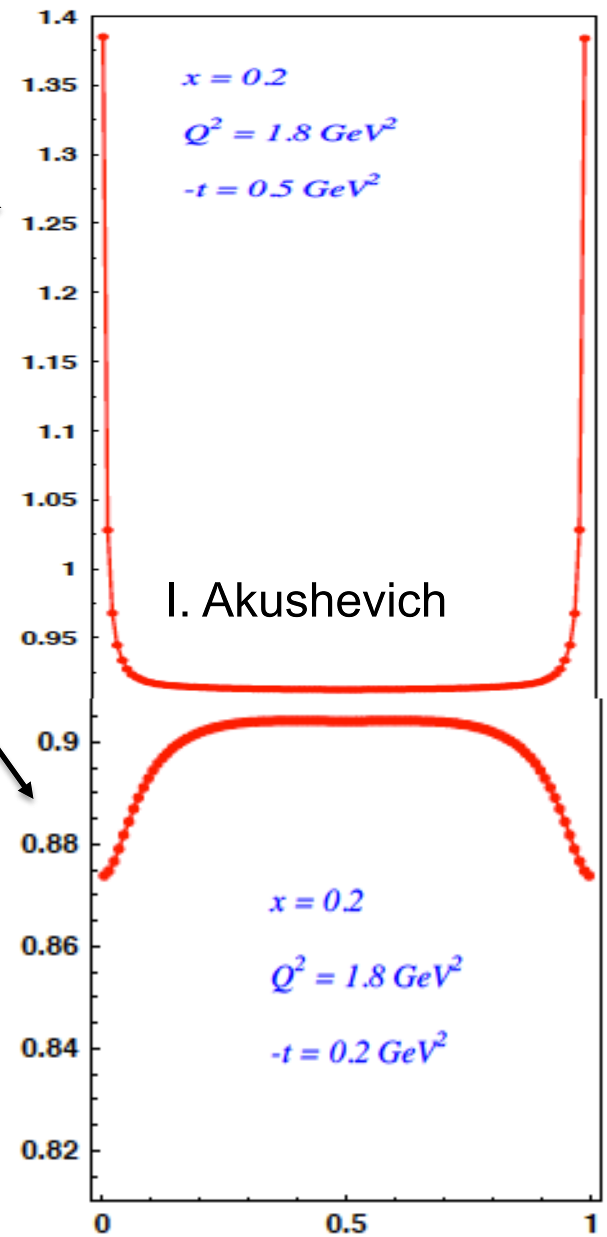
$$\sigma_{obs}(s,x,Q^2,t,\phi) = (1+2\Pi(t))\sigma_0(s,x,Q^2,t,\phi) + \frac{\alpha}{2\pi}(L-1)\Bigg[\int_0^1 dz_1 \left(\frac{1+z_1^2}{1-z_1}\right)\left(A(z_1)\theta(z-z_1^m)\frac{x_1}{x}\sigma_0(z_1 s, x_1, z_1 Q^2, t,\phi) - \sigma_0(s,x,Q^2,t,\phi)\right)$$
$$+ \int_0^1 dz_2 \left(\frac{1+z_2^2}{1-z_2}\right)\left(A(z_2)\theta(z-z_2^m)\frac{x_2}{z_2 x}\sigma_0(s, x_2, Q^2/z_2, t,\phi) - \sigma_0(s,x,Q^2,t,\phi)\right)\Bigg]$$



$z_{1/2}^m$ defined from minimum photon energy cut, $x_{1/2}$-defined shifted kinematics

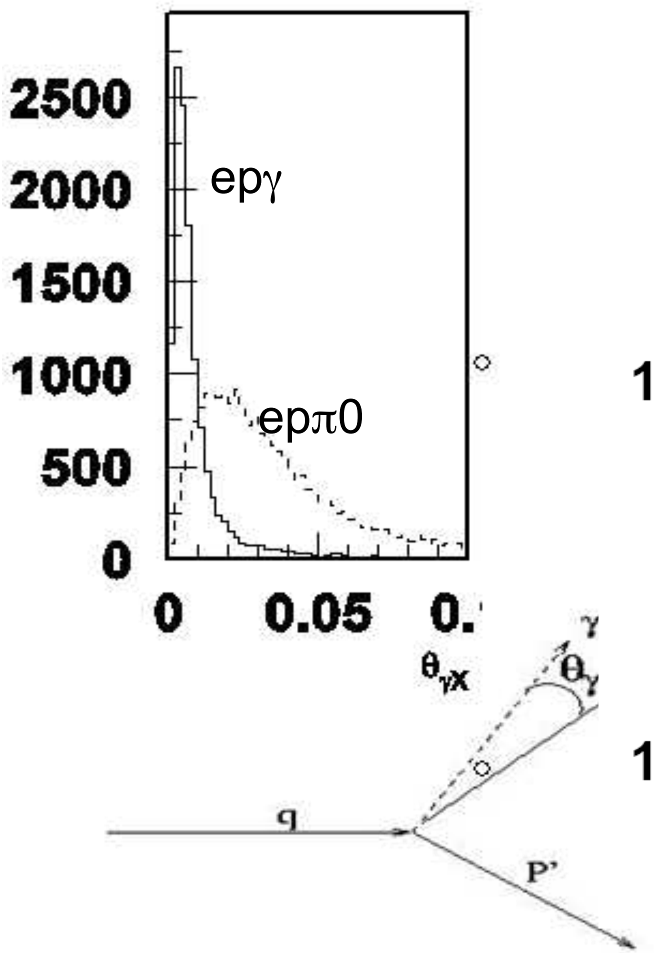
ϕ-dependent amplitude

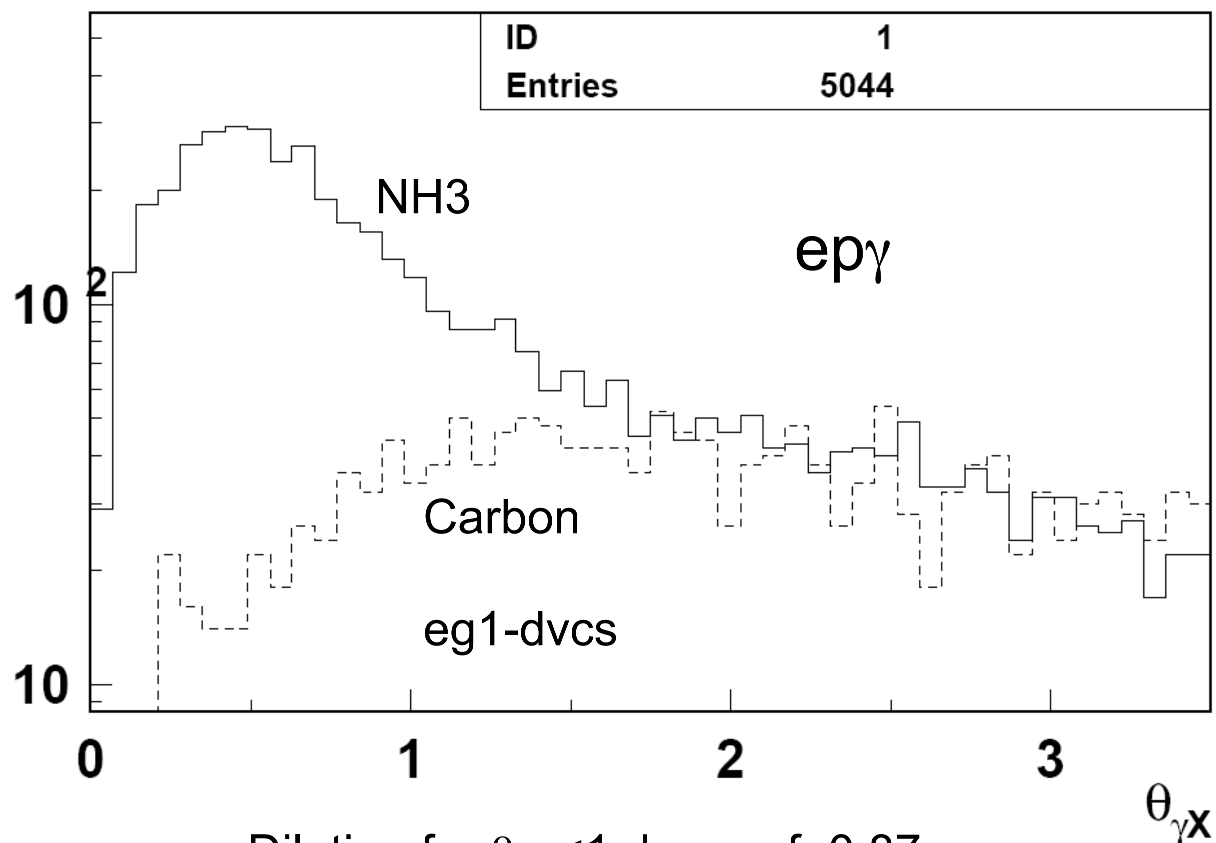




• **Depending on the t the correction (**the leading term of double bremsstrahlung x-section expanded over the electron mass **) can change the shape.**

Nuclear background





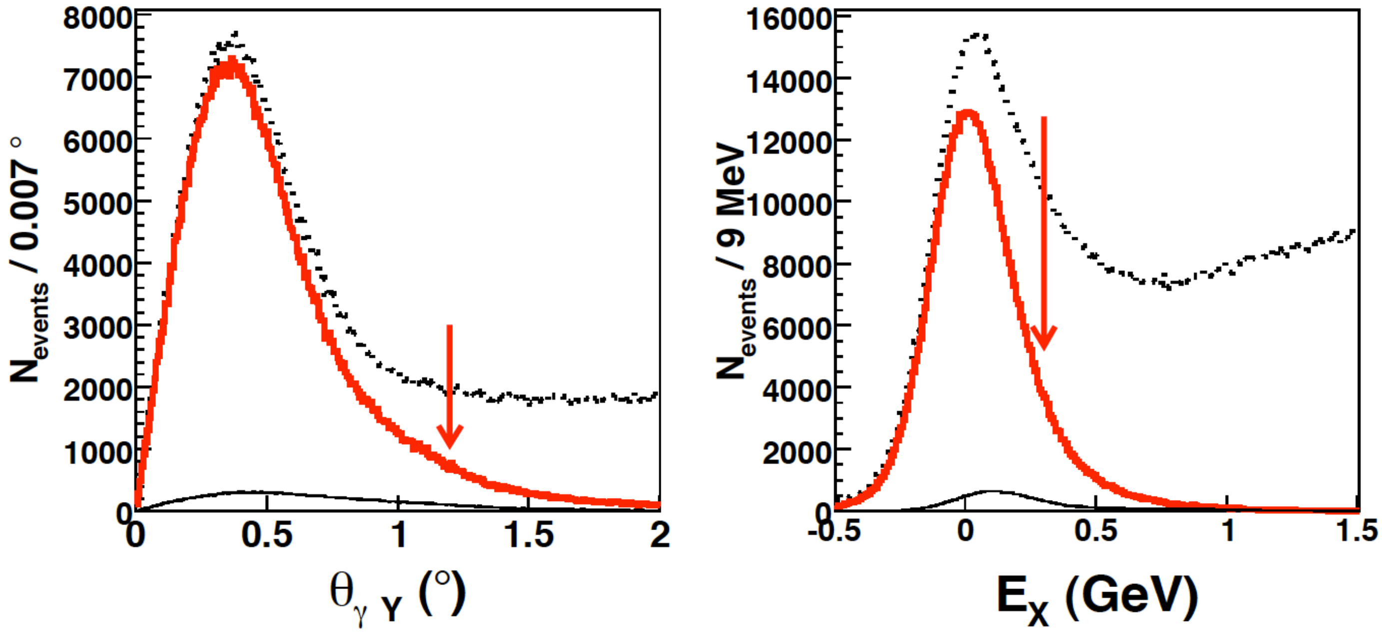
Dilution for $\theta\gamma_X$<1 degree f=0.87

Angular cut cleans up also the nuclear background

DVCS: π^0 –background

ep → epγ/π^0

- Use **epγγ(π^0)** to estimate the contribution of **π^0** in the **epX, epγ** sample.



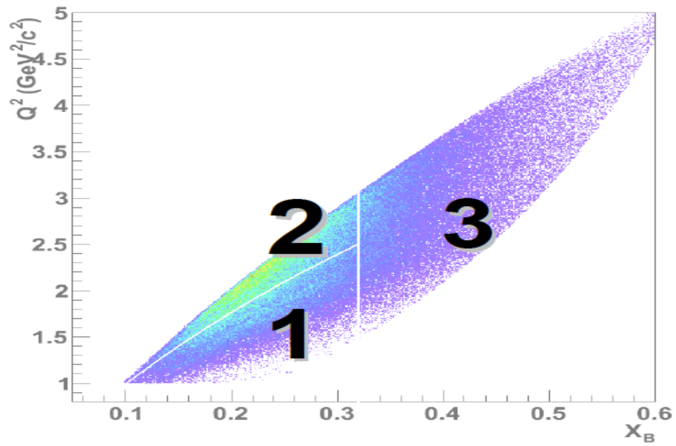
$$N_{0,1\gamma}^{Data}(\pi^0) = N_{\pi^0}^{Data} \frac{N_{0,1\gamma(\pi^0)}^{MC}}{N_{\pi^0}^{MC}},$$

- contamination by π^0 photons
- π^0 *SSA.*

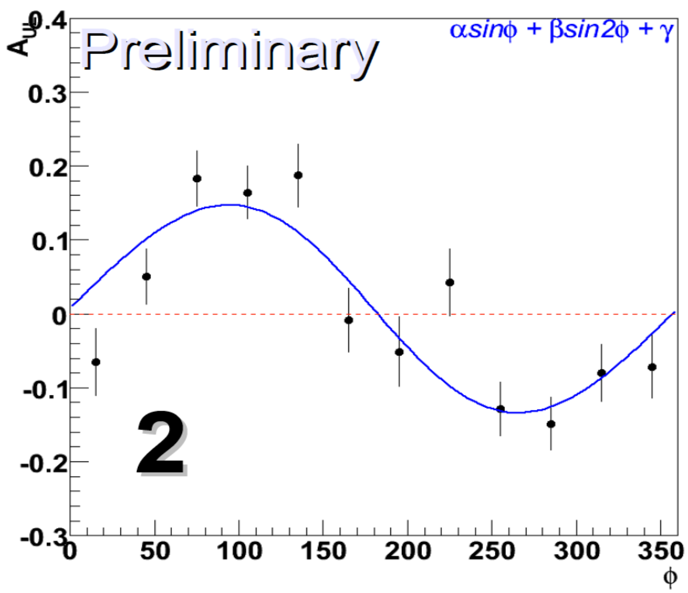
~300000 exclusive π^0s

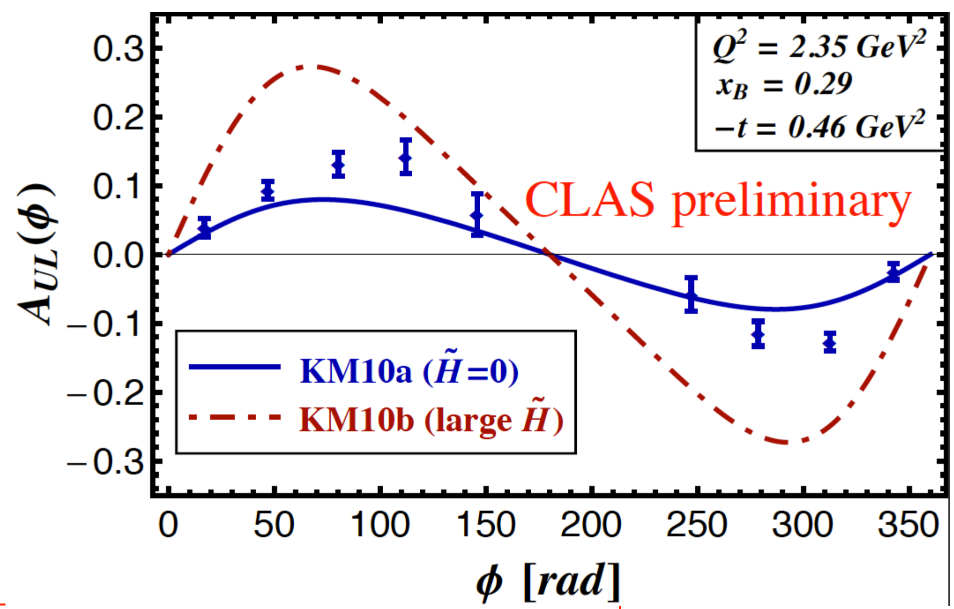
Polarized DVCS kinematics

E. Seder



$$A_{UL} = \frac{N^{\Uparrow}(\phi) - N^{\Downarrow}(\phi)}{f\,[P^{\Downarrow}_t N^{\Uparrow}(\phi) + P^{\Uparrow}_t N^{\Downarrow}(\phi)]}$$





Longitudinal target SSA will be extracted in bins in x and t

CLAS12 DVCS Experiments

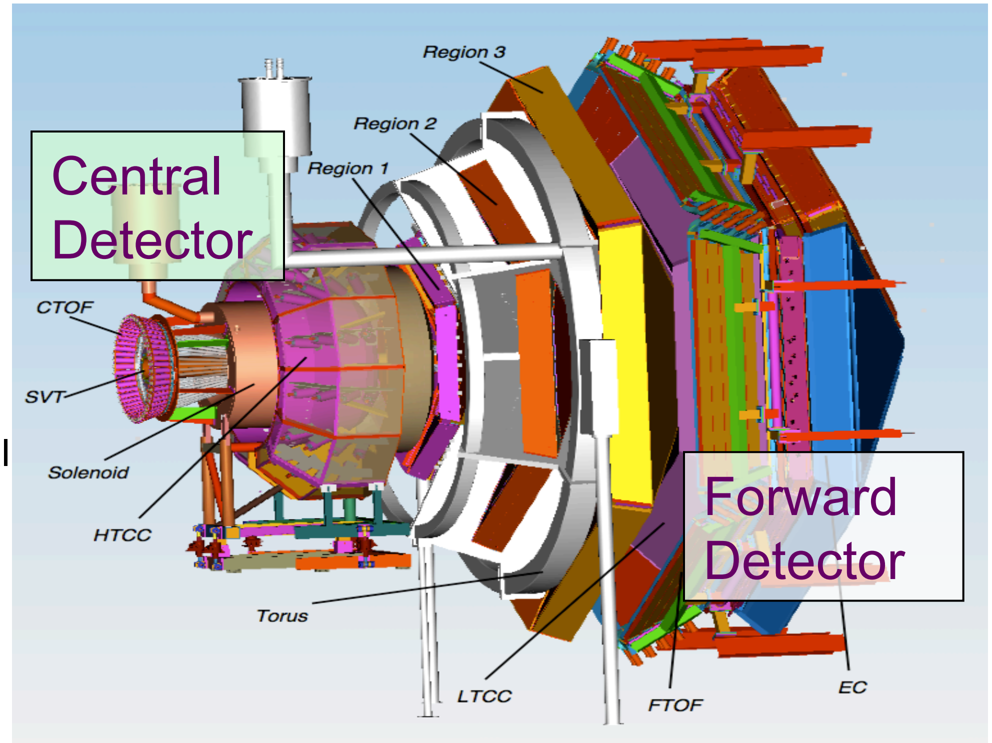
Large angle coverage:
5°- 135°

Broad kinematic range coverage:
current to target fragmentation

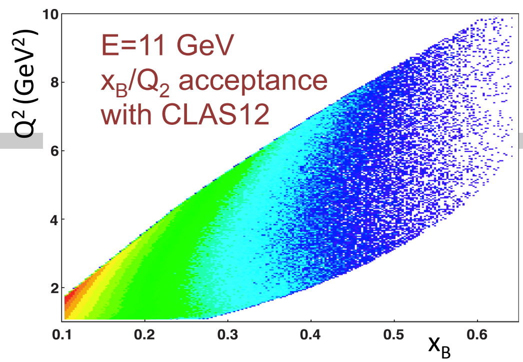
High luminosity:
10^{35} cm^{-2}s^{-1}

Concurrent measurement of deeply virtual
- exclusive,
- semi-inclusive,

inclusive processes, for same target,
polarized/ unpolarized.

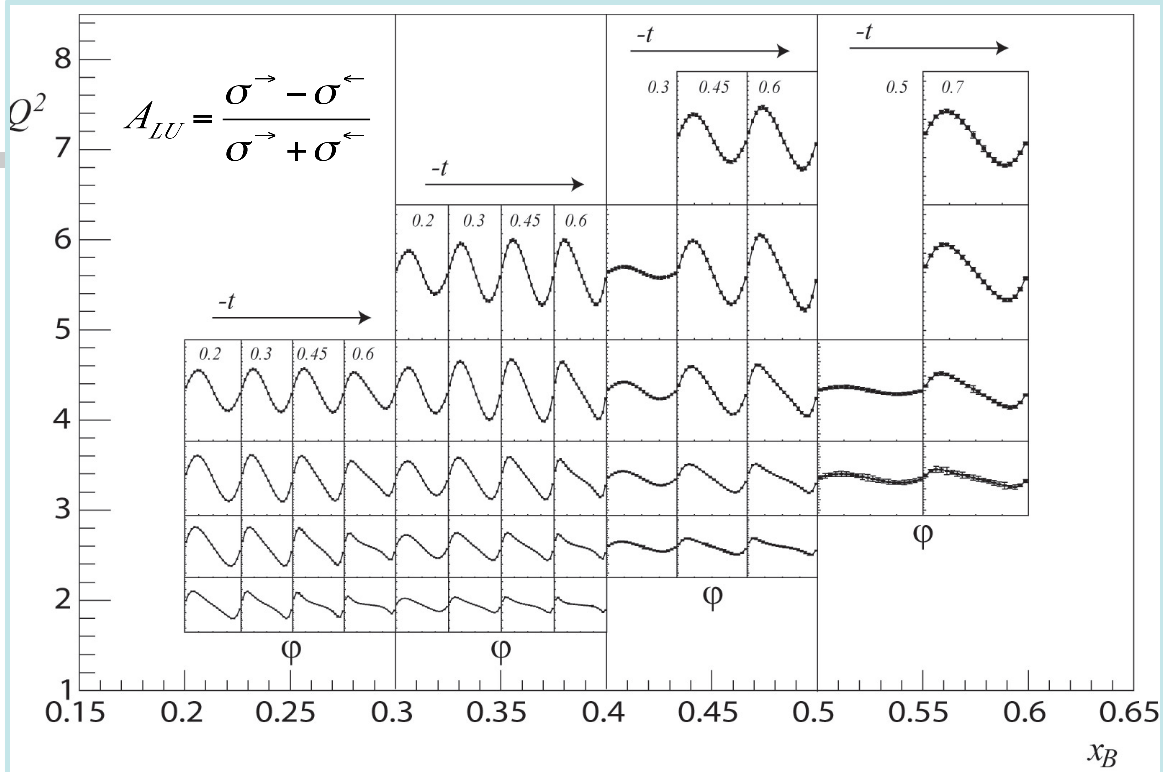


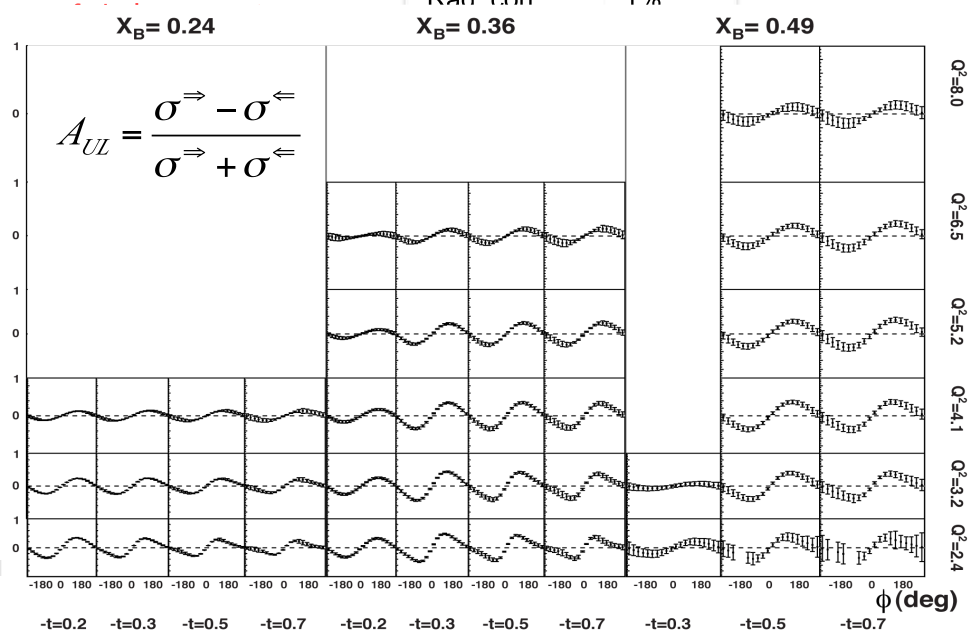
Nucleon polarization	Sensitivity to GPDs	
UP	$H, \tilde{H}, E$	E12-06-114 : γ, π^0 (A) proton E12-06-119 : γ, π^0 (B) proton E12-11-003: γ, π^0 (B) neutron
LP	$\tilde{H}, H, E$	E12-06-119 : γ, π^0 (NH_3) (B) proton
TP	E, H	LOI12-11-105 : γ, π^0 (HD) (B) proton



120 days of beam time
P_{beam} = 85%, P_{target} = 80%
2.10^{35} cm^{-2}s^{-1} luminosity
$1 < Q^2 < 10$ GeV^2
$0.1 < x_B < 0.65$
$-t_{min} < -t < 2.5$ GeV^2
Statistical error : 2% to 15%

Nucl. material	4%
Target Polar.	3%
π^0 contam.	1-5%
Acceptance	3%
Accidentals	1%
Rad. corr	1%



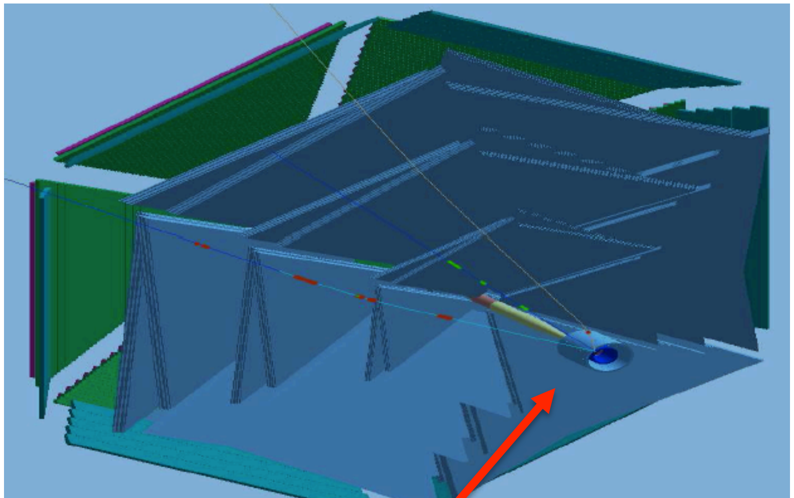


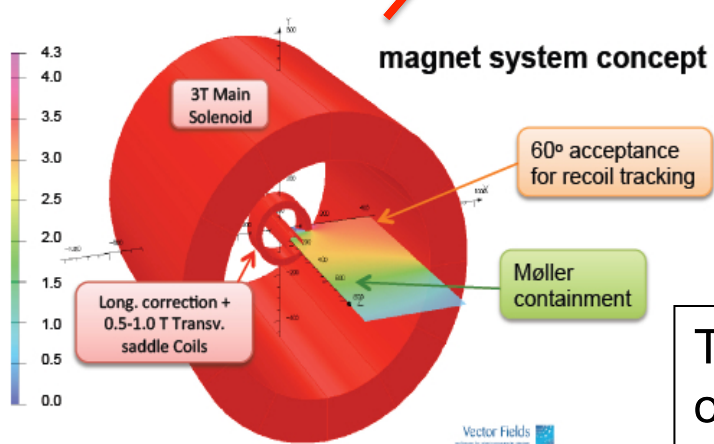
Source	A_{LU} (90°)	Δσ	σ
Beam Polar.	2%	2%	-
π^0 contam.	1-5%	1-5%	3-8%
Acceptance	3%	5-8%	5-8%
Radi. corr.	1%	3%	3%
Luminosity	-	2%	2%
Total	**4-7%**	**8-10 %**	**8-12%**

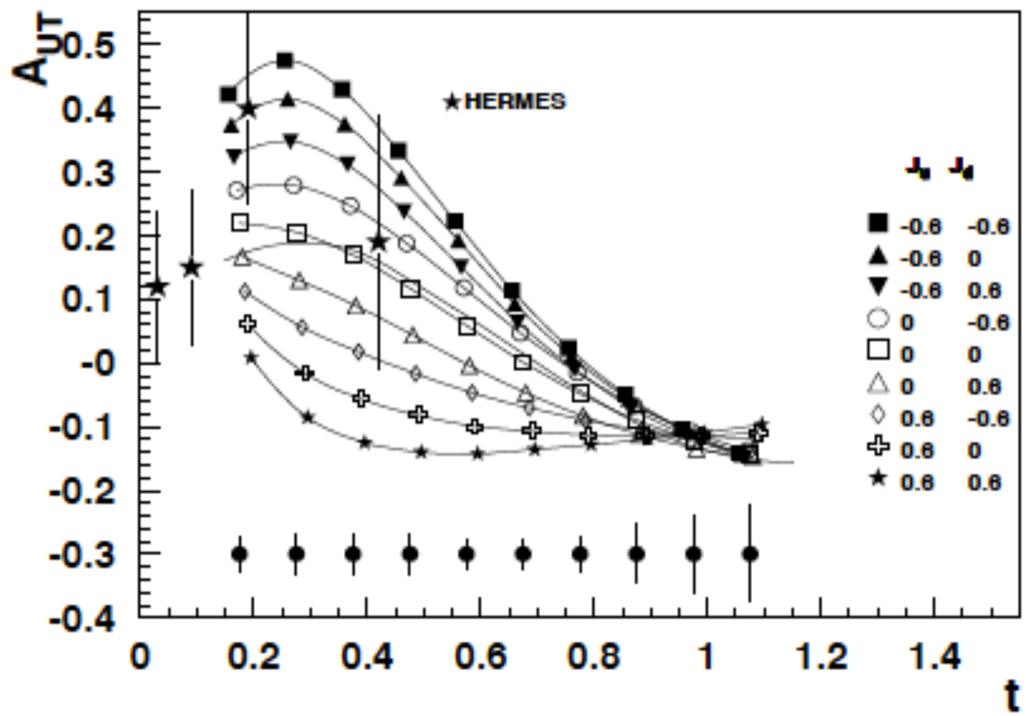
80 days of beam time
85% beam pol.
10^{35} cm^{-2}s^{-1} luminosity
$1 < Q^2 < 10$ GeV^2
$0.1 < x_B < 0.65$
$-t_{min} < -t < 2.5$ GeV^2
Statistical error : 1 to 10%
of sinΦ moment

F. Sabatie PAC39

DVCS with CLAS12 transverse target

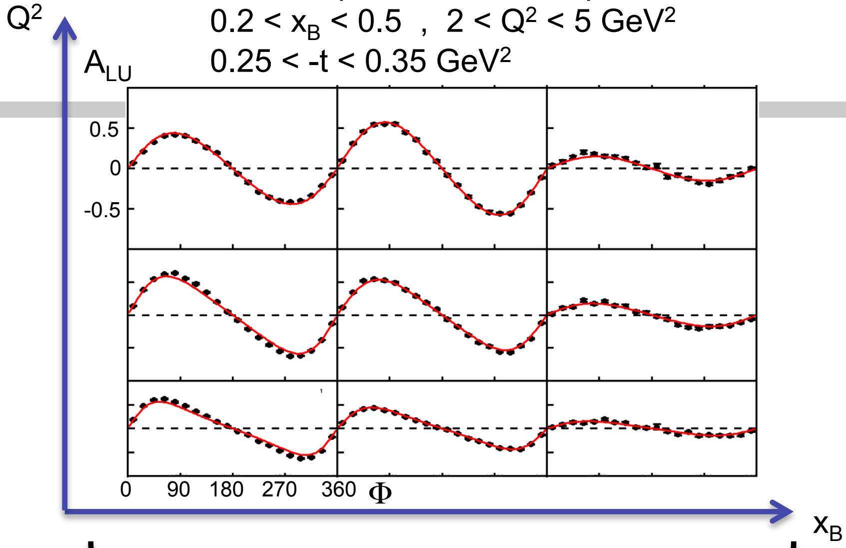




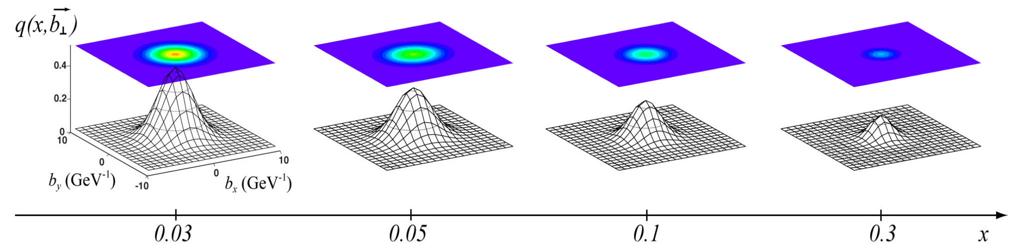


The Q^2, xB, and t dependences
of the DVCS single and double asymmetries will be studied in a wide range of kinematics.
Demonstrate capabilities to reconstruct protons

CLAS12 pseudo-data sample in :
$0.2 < x_B < 0.5$, $2 < Q^2 < 5$ GeV^2
$0.25 < -t < 0.35$ GeV^2



$$q(x,\vec{b}_\perp) = \int \frac{d^2\vec{\Delta}_\perp}{(2\pi)^2} e^{i\vec{b}_\perp\cdot\vec{\Delta}_\perp} H(x,\xi=0,-\Delta_\perp^2)$$



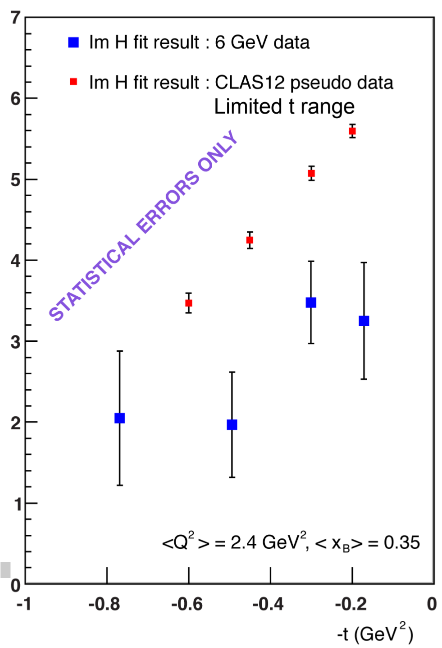
$\xi = 0$

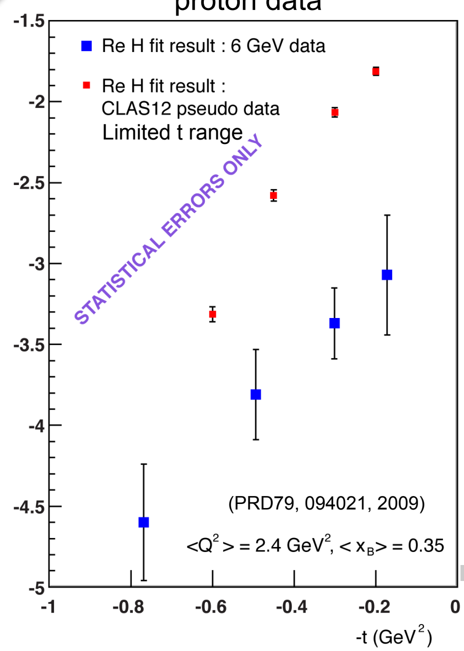
GPD parametrization needed for ξ=0 or t=0 extrapolations

Fit to CLAS6 or **CLAS12** A_{LU}

x10 accuracy improvement from CLAS6 to CLAS12

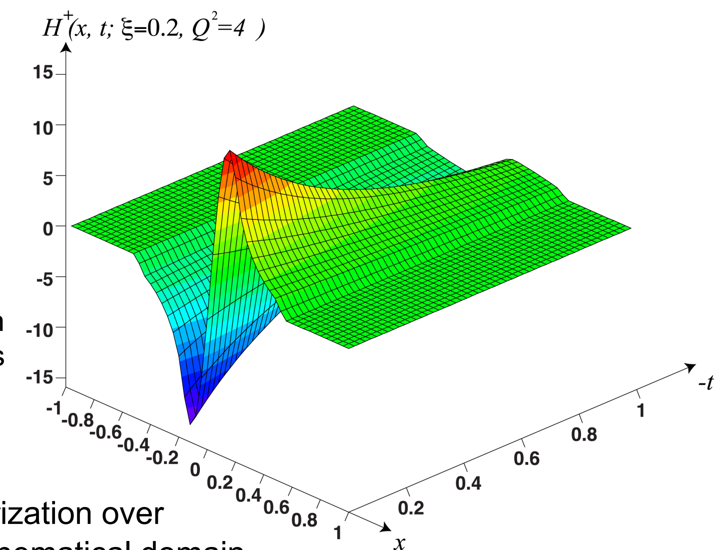
H and $\tilde{H}$ separation needs unpolarized and polarized proton data





Parametrized GPDs

Lots of new developments in the next 5 years



Global fits:

- Parametrization over the full kinematical domain
- Use all kinds of data from several experiments
- Include Q^2 evolution

In general, 8 GPD quantities accessible
(Compton Form Factors)

DVCS : Anticipated Leading Twist dominance already at low Q^2

$$H_{Re} = P\int_0^1 dx\,[H(x,\xi,t) - H(-x,\xi,t)]\,C^+(x,\xi) \quad (1)$$

$$E_{Re} = P\int_0^1 dx\,[E(x,\xi,t) - E(-x,\xi,t)]\,C^+(x,\xi) \quad (2)$$

$$\tilde{H}_{Re} = P\int_0^1 dx\left[\tilde{H}(x,\xi,t) + \tilde{H}(-x,\xi,t)\right]C^-(x,\xi) \quad (3)$$

$$\tilde{E}_{Re} = P\int_0^1 dx\left[\tilde{E}(x,\xi,t) + \tilde{E}(-x,\xi,t)\right]C^-(x,\xi) \quad (4)$$

$$H_{Im} = H(\xi,\xi,t) - H(-\xi,\xi,t), \quad (5)$$

$$E_{Im} = E(\xi,\xi,t) - E(-\xi,\xi,t), \quad (6)$$

$$\tilde{H}_{Im} = \tilde{H}(\xi,\xi,t) + \tilde{H}(-\xi,\xi,t) \quad \text{and} \quad (7)$$

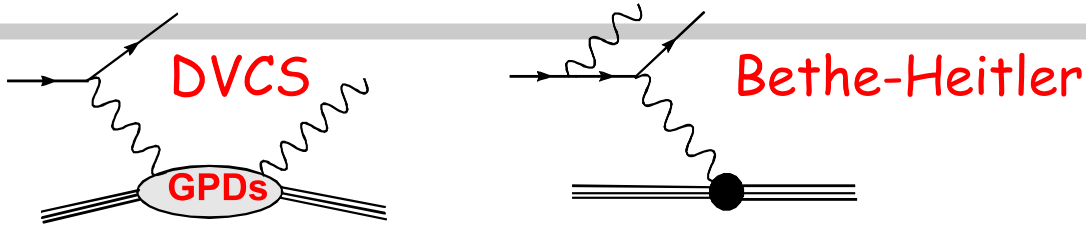
$$\tilde{E}_{Im} = \tilde{E}(\xi,\xi,t) + \tilde{E}(-\xi,\xi,t) \quad (8)$$

with

$$C^\pm(x,\xi) = \frac{1}{x-\xi} \pm \frac{1}{x+\xi}. \quad (9)$$

Given the well-established LT-LO DVCS+BH amplitude

M. Guidal



Can one recover the CFFs from data ?

Obs=Amp(DVCS+BH) $\otimes$ CFFs

**Model-independent fit, at fixed x_B, t and Q^2,
of DVCS observables with
MINUIT + MINOS**

8 unknowns (the CFFs), non-linear problem, strong correlations

⇨ **Bounding the domain of variation of the CFFs (5xVGG)**

Simulations for CLAS12: Using count rate files

1/ #DVCS events generated (according to some (DVCS+BH) and GPD model)

$<x_B>$ $<-t>$ $<Q^2>$ #events$<\phi_1>$ ++ #events$<\phi_2>$

1 1 0 0 0.11 0.07 1.25 0.56 1131960 59696 53818 40284 28929 21388 16118
12611 10893 10666 13186 22512 42872 43281 22374 13192 10792 10875 12795 16127
21077 29207 40631 54065 60012 32532 19436 12097 9049 8386 8847
10570 13270 17866 25040 34681 40668 40452 34621 24906 17994 13333
10414 8975 8430 9230 11875 19560 32327
2 1 0 1 0.11 0.22 1.24 0.56 542532 47816 25070 12910 8080 5594 4351
3773 3553 3319 3697 7063 29738 29832 7050 3617 3359 3519 3898 4358
5507 8013 13116 25130 47289 23897 7807 4359 3400 3166 3302 3618 4107
5626 8775 16253 32564 32415 16360 8534 5506 4139 3559 3224 3094 3334
4239 7782 23820

#events$<\phi_{12}>$ --

#events$<\phi_{11}>$ --

2/ #DVCS events accepted (some FASTMC)

1 1 0 0 0.11 0.11 1.32 0.60 68044 7205 3232 584 888 1126 809 379
58 0 104 1224 4805 5047 1321 187 335 640 670 481 107 0 326
3195 7013 3788 1105 164 315 562 521 358 77 0 217 2074 4719 4818
2162 388 593 779 579 323 38 0 90 1028 3610
2 1 0 1 0.11 0.22 1.30 0.58 108933 13281 4660 192 440 1249 1138 642
51 9 93 1525 8386 8464 1565 68 192 765 1007 690 86 27 374 4758
13301 6643 1488 53 196 694 803 574 66 12 244 2971 9116 9102 2995
130 244 921 890 499 67 10 95 1411 6746

1/ Take some GPD model (VGG)

2/Calculate observables (σ, A_{LU}, A_{UL}, A_{LL}, A_{Ux}, A_{Lx},…)

3/ Introduce errors: $\Delta\sigma$: sqrt(N) ΔA: 1/P sqrt((1-P.A)^2)/sqrt(N)
(according to rate tables)

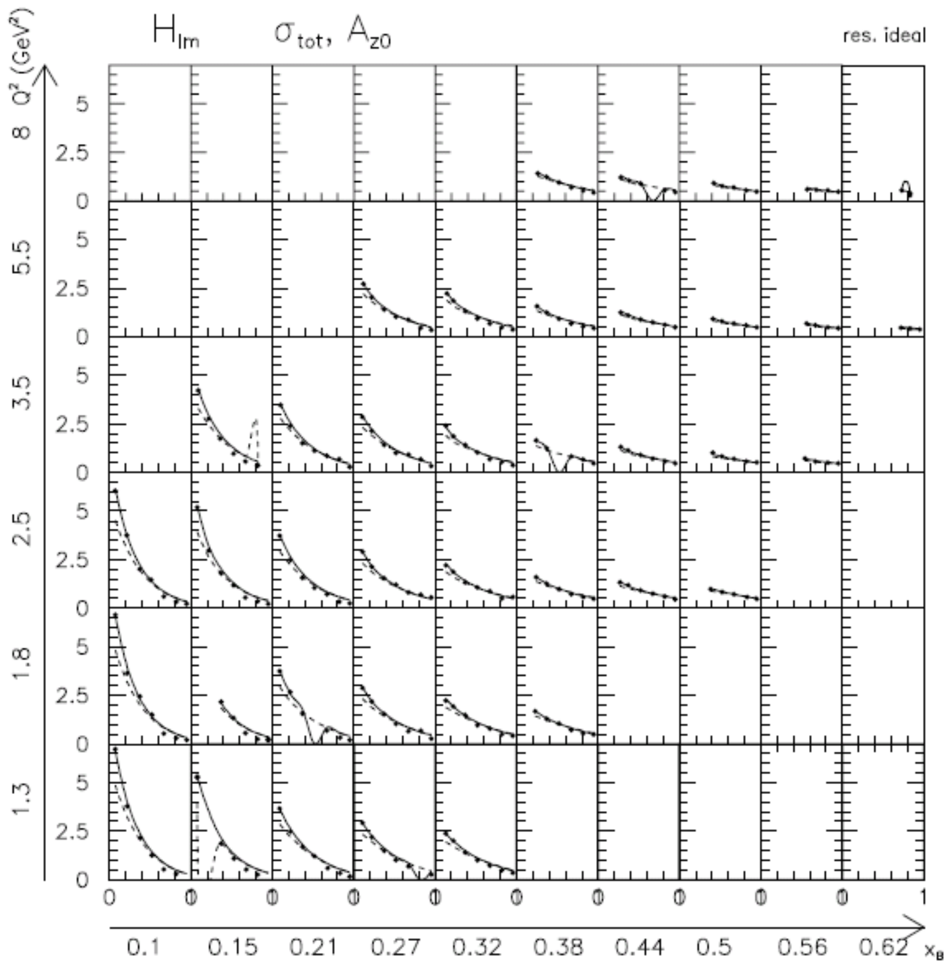
4/ Smear the data accordingly

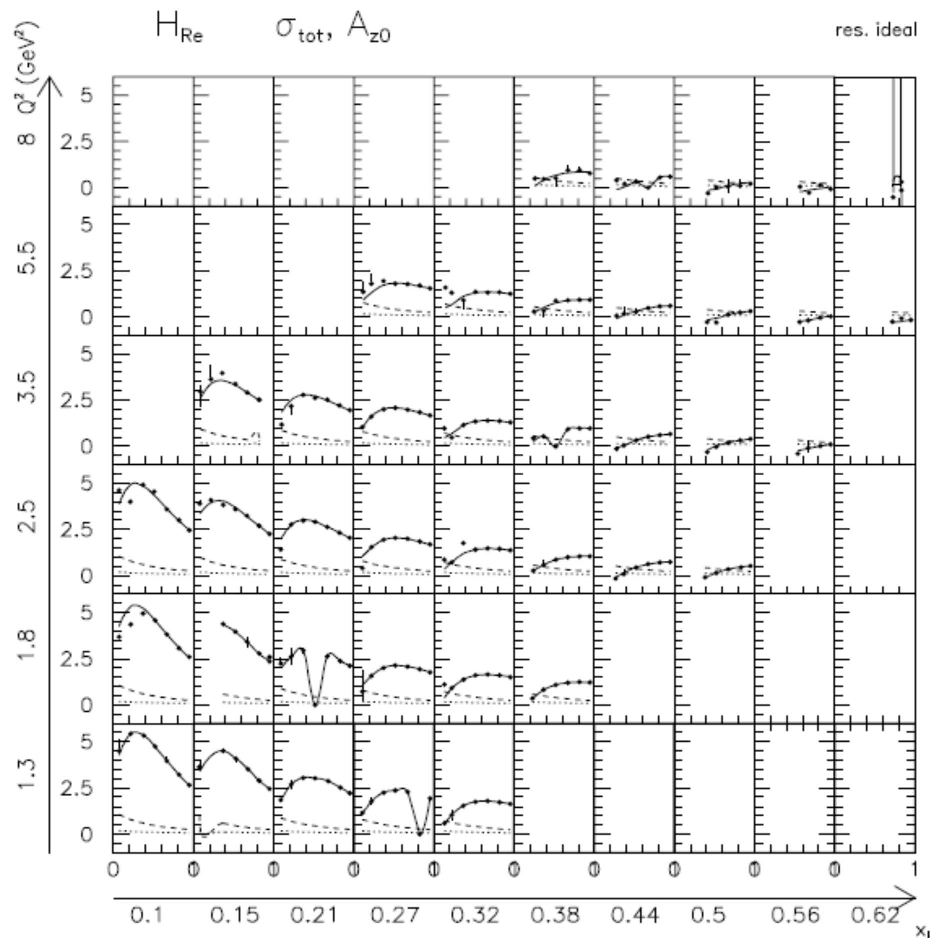
5/ Fit the CFFs from these pseudo-data

6/Compare generated CFF and resulting CFFs from fit

Extraction of GPDS from CLAS12 data

Fit including unpolarized x-section and the BSA (A_z0), with IDEAL (i.e. infinite precision) uncertainties for each ϕ point



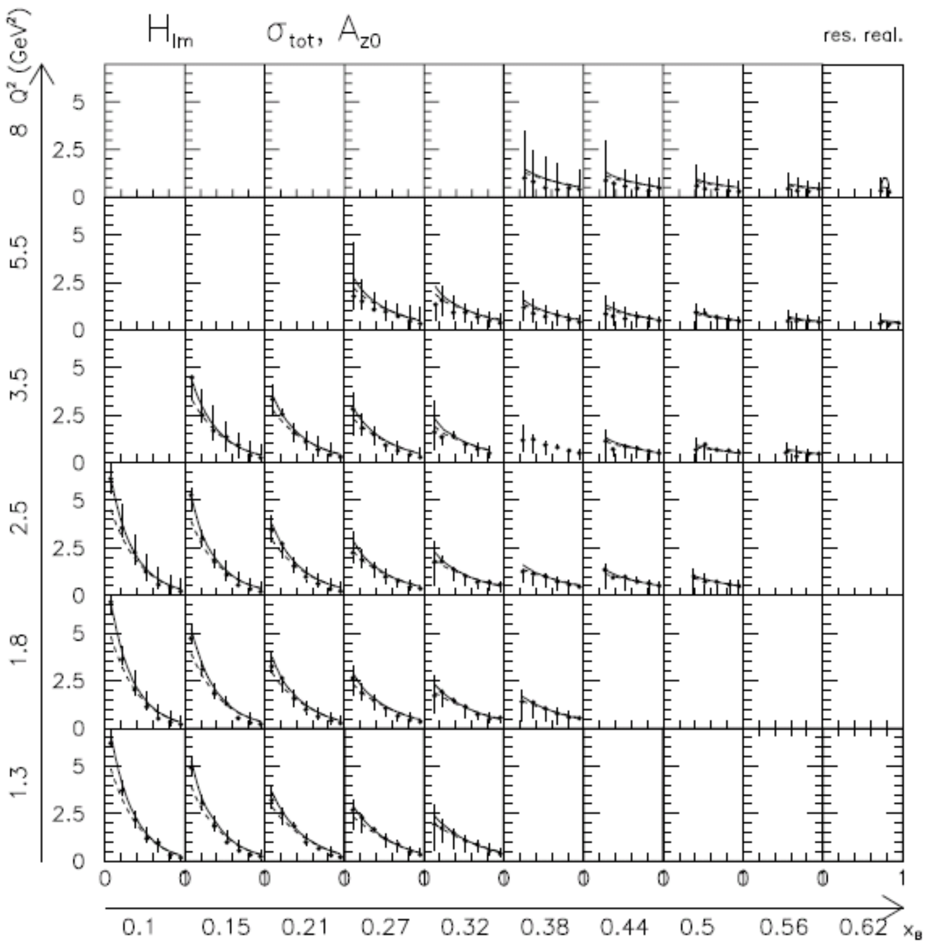


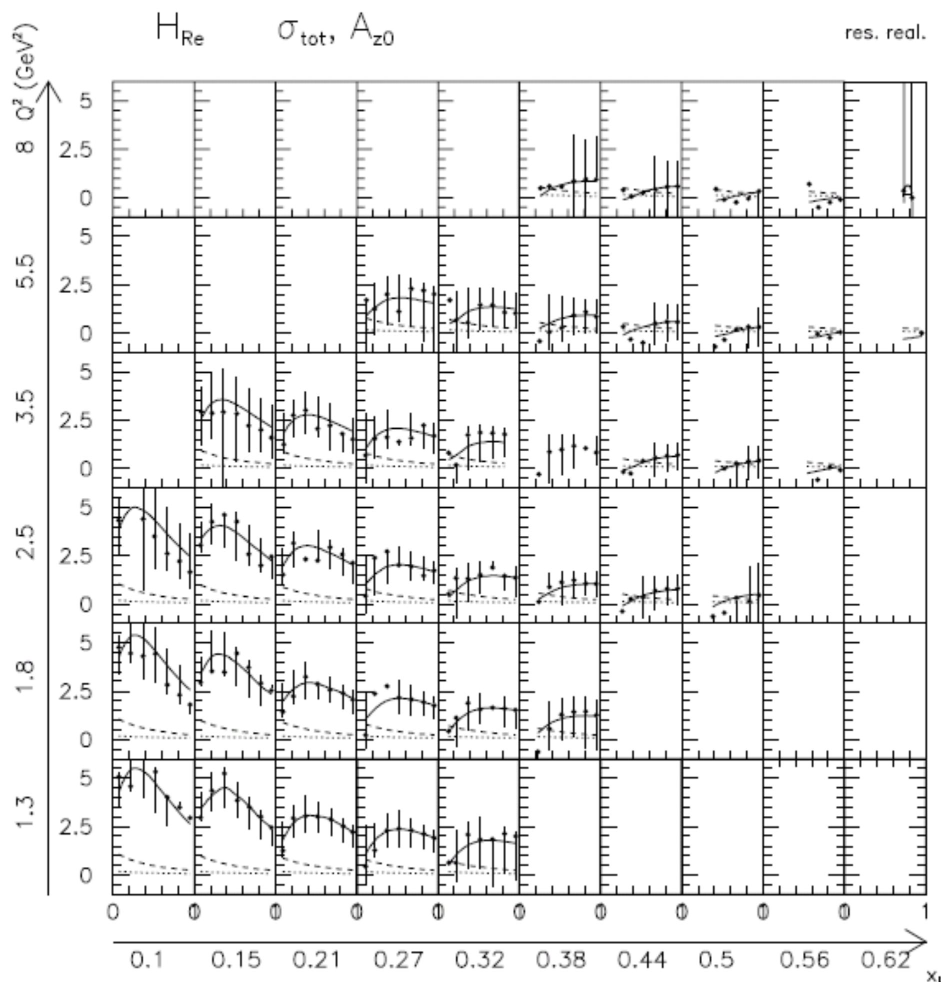
Recover well H_{IM} and H_{RE}

(and sometimes some other “RE” but badly)

Extraction of GPDS from CLAS12 data

Fit including unpolarized x-section and the BSA (A_z0), with "REALISTIC" (i.e. statistical) CLAS12 uncertainties for each ϕ point

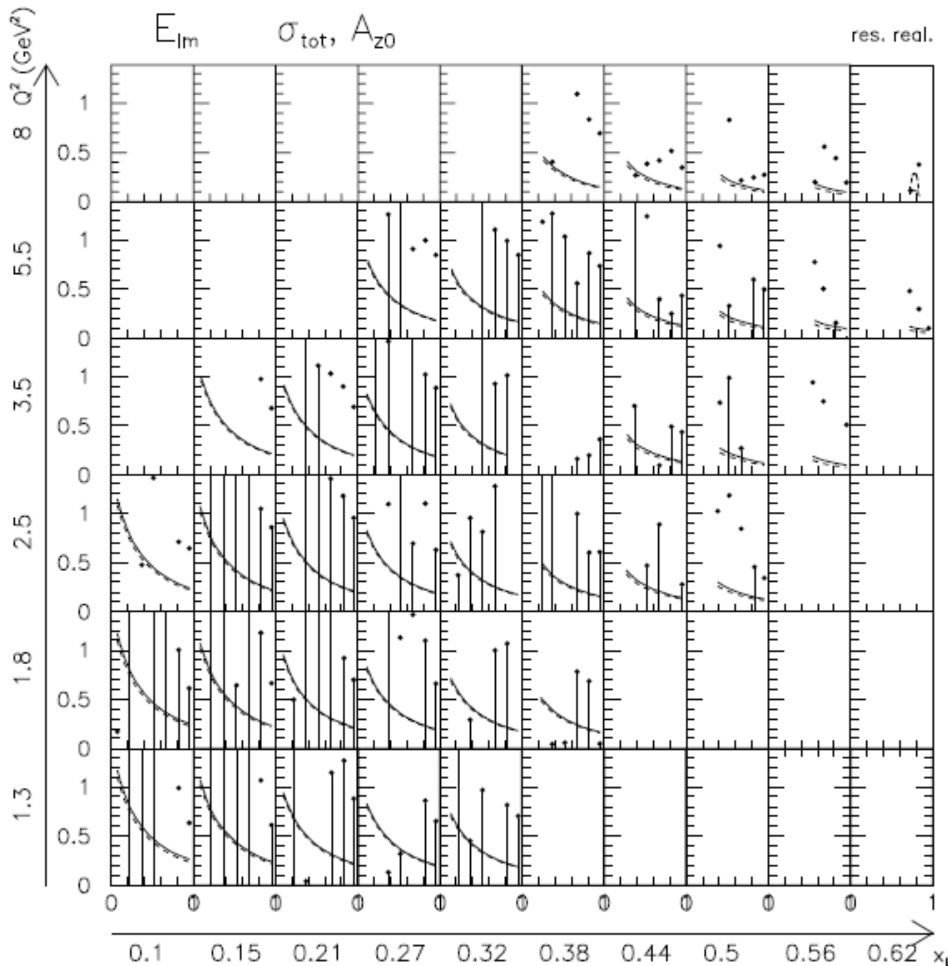




Recover relatively well H_{IM} and H_{RE} (and none of the other CFFs)

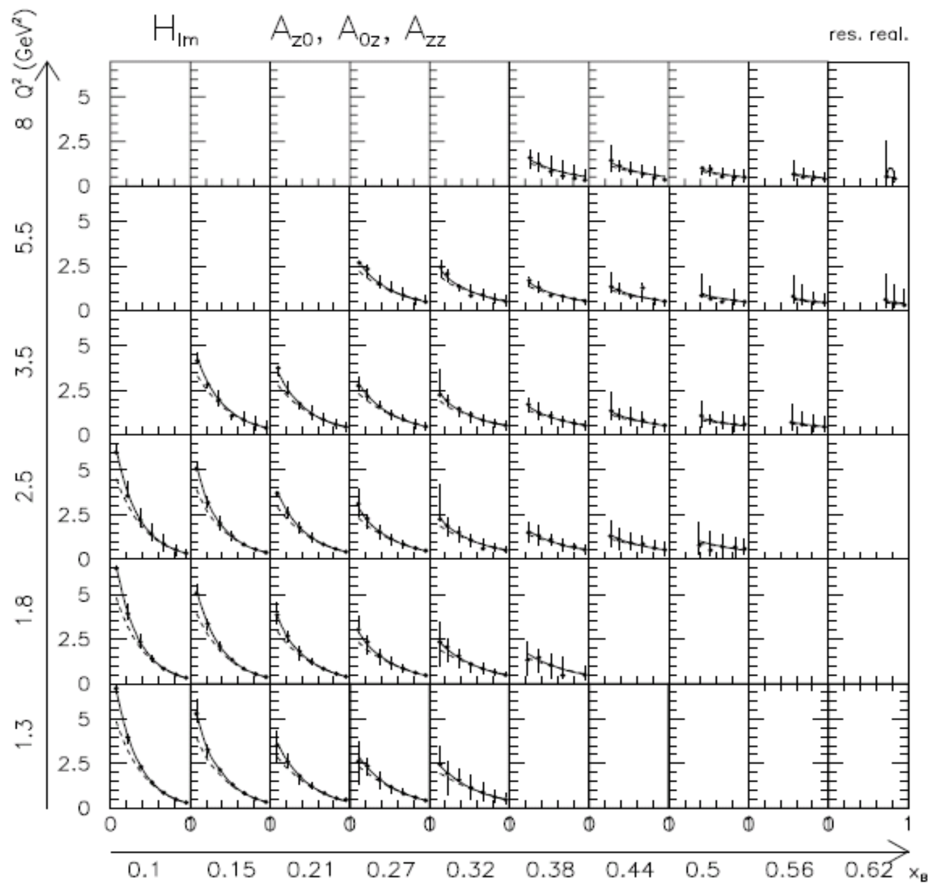
Extraction of GPDS from CLAS12 data

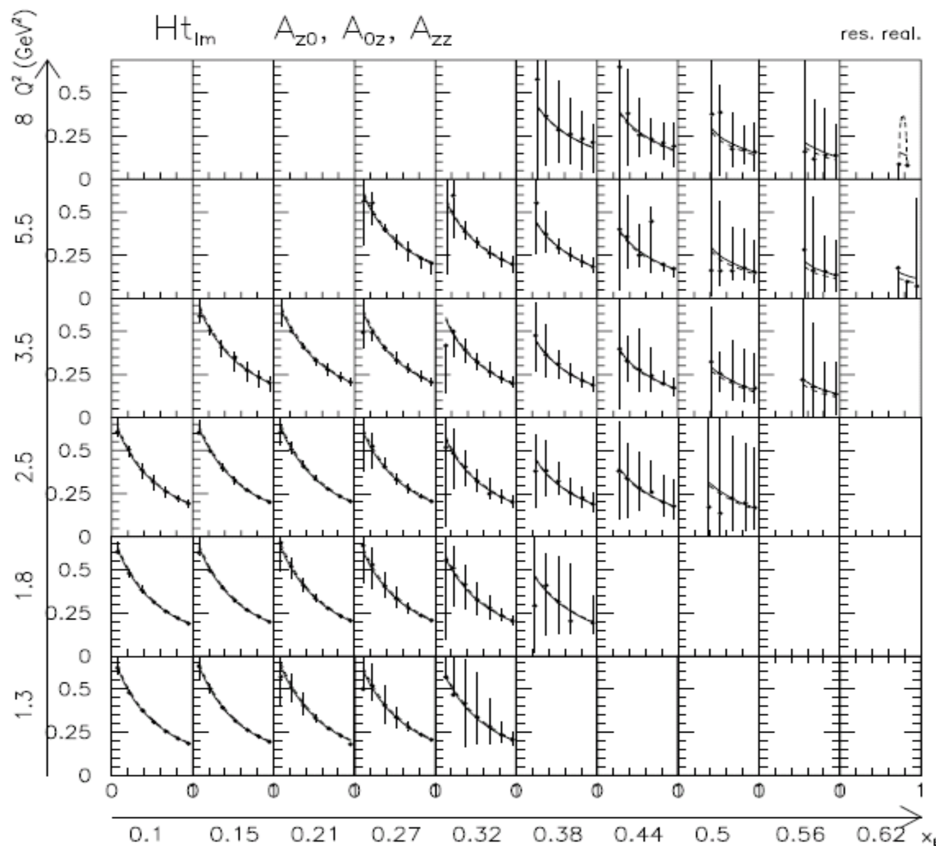
x-sections and beam SSA have little sensitivity to E_{IM}



Extraction of GPDS from CLAS12 data

Now fit only asymmetries (no x-section): BSA (A_z0) + ITSA (A_0z)
+ double asymmetry (A_zz) with “REALISTIC” resolution

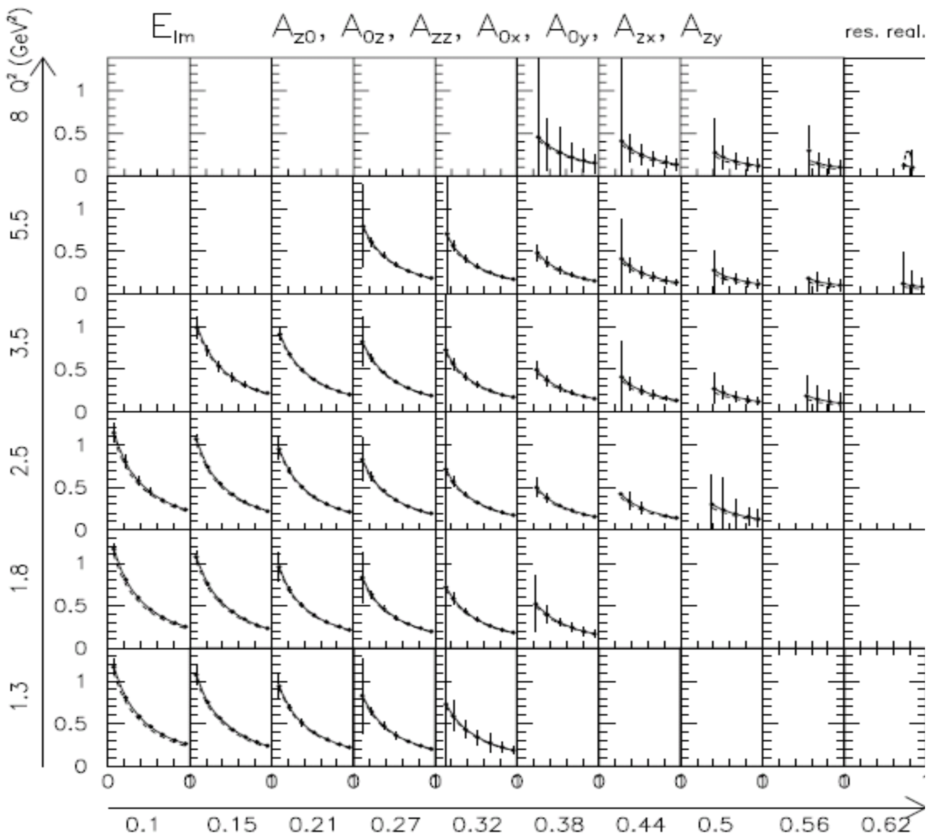


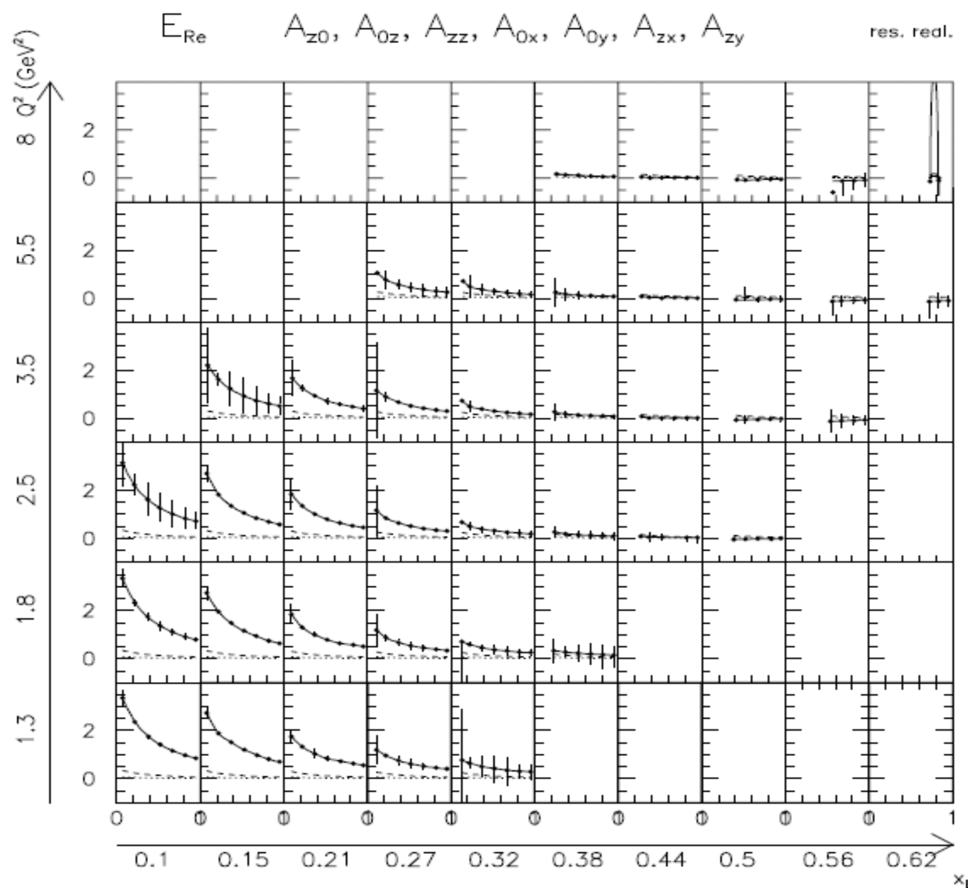


With beam and target single and double spin asymmetries
one can recover H_{Im} and $\tilde{H}_{Im}$

Extraction of GPDS from CLAS12 data

fit the BSA (A_z0) + lTSA (A_0z) + tTSA (A_0x+A_0y) + double asymmetries (A_zz+A_zx+A_zy) with "REALISTIC" resolutions

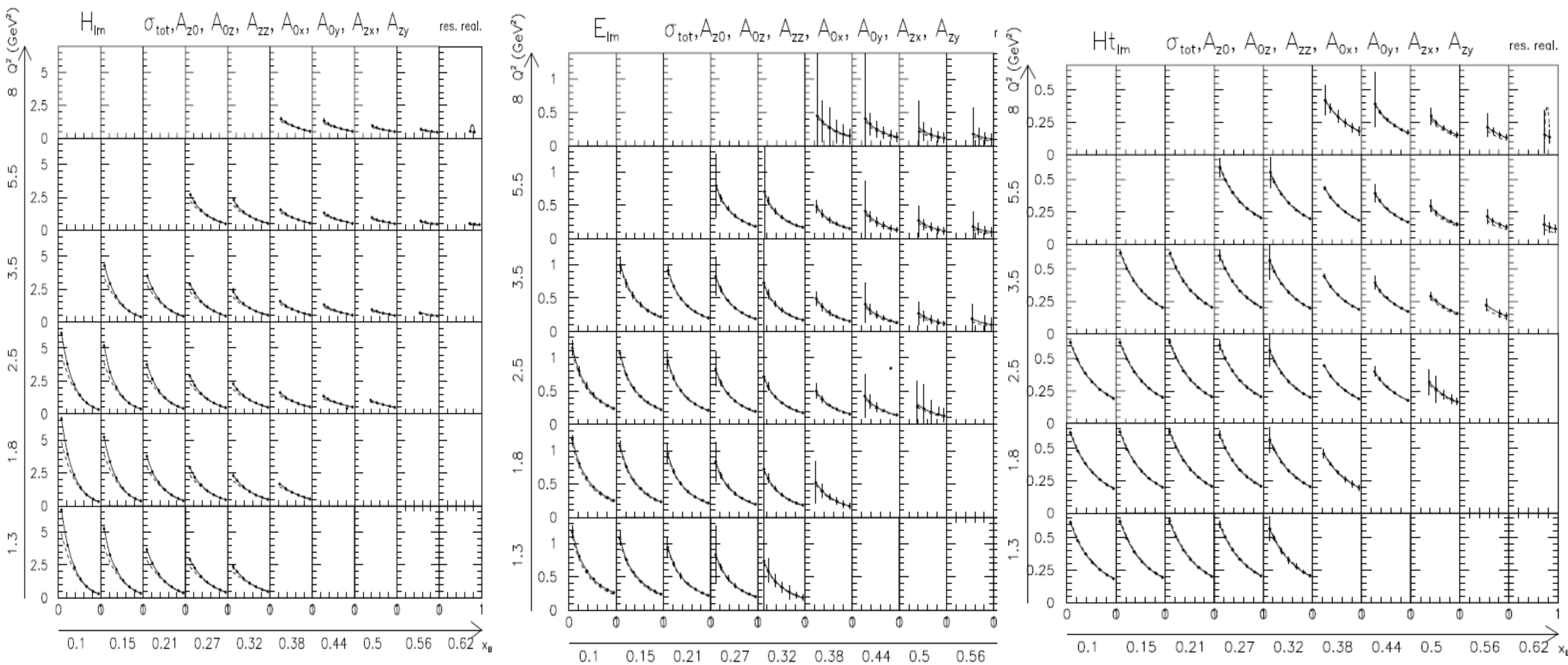




The full set of CFFs can be reconstructed, using the full set of single and double spin asymmetries

Extraction of CFFs from CLAS12 data (IM parts)

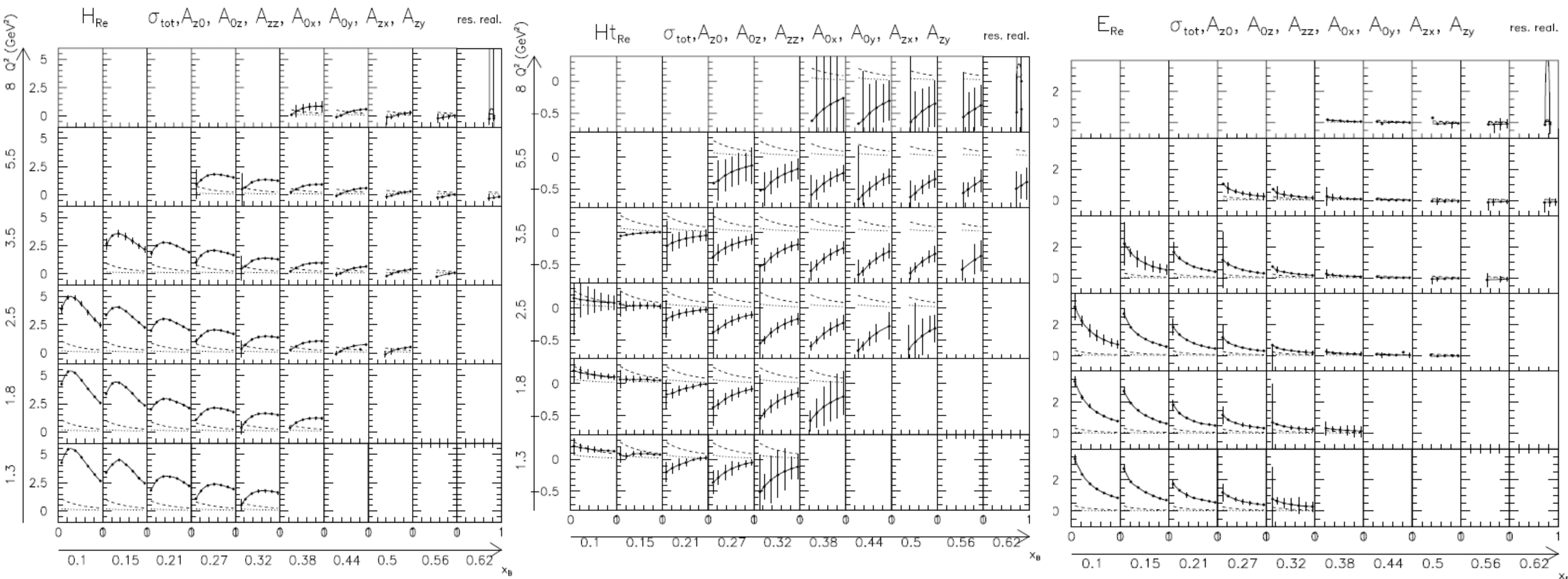
fit the unpol. x-sec + BSA (A_z0) + lTSA (A_0z) + tTSA (A_0x+A_0y) + double asymmetries (A_zz+A_zx+A_zy) with realistic resolution/statistics, i.e. the "quasi-complete" experiment (except for "charge" asymmetry)



H_{IM}, $H\sim_{IM}$ & E_{IM}

Extraction of CFFs from CLAS12 data (RE parts)

fit the unpol. x-sec + BSA (A_z0) + ITSA (A_0z) + tTSA (A_0x+A_0y) + double asymmetries (A_zz+A_zx+A_zy) with realistic resolution/statistics, i.e. the "quasi-complete" experiment (except for "charge" asymmetry)



Real and imaginary parts of CFFs with high precision could be extracted from full set of measurements, including spin asymmetries and x-sections

Summary

CLAS experiment with unpolarized and longitudinally polarized NH3 and ND3 targets provide superior sample of events allowing for detailed studies of single and double spin asymmetries using multidimensional bins.

Radiative corrections are important for precision measurement of CFFs from final observables

Combination of DVCS measurements from CLAS12 with unpolarized, longitudinally and transversely polarized targets would allow precision measurement of GPDs H, H~ and E

Support slides….

Extraction of CFFs from BKM

$$\mathcal{H} = \frac{2-x_B}{(1-x_B)D}\left\{\left[\left(2-x_B+\frac{4x_B^2M^2}{(2-x_B)\Delta^2}\right)F_1+\frac{x_B^2}{2-x_B}F_2\right]\mathcal{C}^{\mathcal{I}}_{\mathrm{unp}} - (F_1+F_2)\left[x_B\mathcal{C}^{\mathcal{I}}_{\mathrm{LP}}+\frac{2x_B^2M^2}{(2-x_B)\Delta^2}\left(x_B\mathcal{C}^{\mathcal{I}}_{\mathrm{LP}}-\mathcal{C}^{\mathcal{I}}_{\mathrm{TP}+}\right)\right]+F_2\mathcal{C}^{\mathcal{I}}_{\mathrm{TP}-}\right\} \qquad (90)$$

$$\mathcal{E} = \frac{2-x_B}{(1-x_B)D}\left\{\left[4\frac{1-x_B}{2-x_B}F_2-\frac{4M^2x_B^2}{(2-x_B)\Delta^2}F_1\right]\mathcal{C}^{\mathcal{I}}_{\mathrm{unp}} + \frac{4x_BM^2}{(2-x_B)\Delta^2}(F_1+F_2)\left(x_B\mathcal{C}^{\mathcal{I}}_{\mathrm{LP}}-\mathcal{C}^{\mathcal{I}}_{\mathrm{TP}+}\right)+\frac{4M^2}{\Delta^2}F_1\mathcal{C}^{\mathcal{I}}_{\mathrm{TP}-}\right\}, \qquad (91)$$

$$\widetilde{\mathcal{H}} = \frac{2-x_B}{(1-x_B)D}\left\{(2-x_B)F_1\mathcal{C}^{\mathcal{I}}_{\mathrm{LP}}-x_B(F_1+F_2)\mathcal{C}^{\mathcal{I}}_{\mathrm{unp}} + \left[\frac{2x_BM^2}{\Delta^2}F_1+F_2\right]\left(x_B\mathcal{C}^{\mathcal{I}}_{\mathrm{LP}}-\mathcal{C}^{\mathcal{I}}_{\mathrm{TP}+}\right)\right\}, \qquad (92)$$

$$\widetilde{\mathcal{E}} = \frac{2-x_B}{(1-x_B)D} \times\left\{\frac{4M^2}{\Delta^2}(F_1+F_2)\left(x_B\mathcal{C}^{\mathcal{I}}_{\mathrm{unp}}+\mathcal{C}^{\mathcal{I}}_{\mathrm{TP}-}\right)+\left[4\frac{1-x_B}{x_B}F_2-\frac{4x_BM^2}{\Delta^2}F_1\right]\mathcal{C}^{\mathcal{I}}_{\mathrm{LP}} - \frac{4(2-x_B)M^2}{x_B\Delta^2}F_1\mathcal{C}^{\mathcal{I}}_{\mathrm{TP}+}\right\}, \qquad (93)$$

$$\begin{Bmatrix} c^{\mathcal{I}}_{2,\mathrm{LP}} \\ s^{\mathcal{I}}_{2,\mathrm{LP}} \end{Bmatrix} = \frac{16\Lambda K^2}{2-x_{\mathrm{B}}} \begin{Bmatrix} -\lambda y \\ 2-y \end{Bmatrix} \begin{Bmatrix} \Re\mathrm{e} \\ \Im\mathrm{m} \end{Bmatrix} \mathcal{C}^{\mathcal{I}}_{\mathrm{LP}}(\mathcal{F}^{\mathrm{eff}}),$$

$$\mathcal{C}^{\mathcal{I}}_{\mathrm{LP}} = \frac{x_{\mathrm{B}}}{2-x_{\mathrm{B}}}(F_1+F_2)\left(\mathcal{H}+\frac{x_{\mathrm{B}}}{2}\mathcal{E}\right) + F_1\widetilde{\mathcal{H}} - \frac{x_{\mathrm{B}}}{2-x_{\mathrm{B}}}\left(\frac{x_{\mathrm{B}}}{2}F_1 + \frac{\Delta^2}{4M^2}F_2\right)\widetilde{\mathcal{E}}, \quad (70)$$

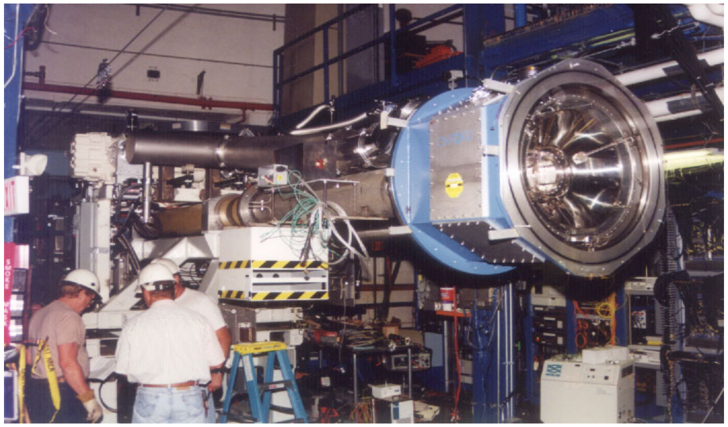
$$\{\mathcal{H}, \mathcal{E}, \mathcal{H}^3_+, \mathcal{E}^3_+, \widetilde{\mathcal{H}}^3_-, \widetilde{\mathcal{E}}^3_-\}(\xi) = \int_{-1}^{1} dx\, C^{(-)}(\xi,x)\{H, E, H^3_+, E^3_+, \widetilde{H}^3_-, \widetilde{E}^3_-\}(x,\eta)|_{\eta=-\xi},$$

$$\{\widetilde{\mathcal{H}}, \widetilde{\mathcal{E}}, \widetilde{\mathcal{H}}^3_+, \widetilde{\mathcal{E}}^3_+, \mathcal{H}^3_-, \mathcal{E}^3_-\}(\xi) = \int_{-1}^{1} dx\, C^{(+)}(\xi,x)\{\widetilde{H}, \widetilde{E}, \widetilde{H}^3_+, \widetilde{E}^3_+, H^3_-, E^3_-\}(x,\eta)|_{\eta=-\xi},$$

$$\mathcal{F}^{\mathrm{eff}}(\xi) = \frac{2}{1+\xi}\mathcal{F}(\xi) + 2\xi\frac{\partial}{\partial\xi}\int_{-1}^{1} dx\, C^{3(\mp)}(\xi,x)F(x,\xi) + \frac{8M^2\xi}{(1-\xi^2)(\Delta^2-\Delta^2_{\mathrm{min}})}\mathcal{F}^{\perp}(\xi) - 2\xi\int_{-1}^{1} du \int_{-1}^{1} dx\, C^{qGq}(\xi,x,u)\big(S^+_F(-x,-u,-\xi) - S^-_F(x,u,-\xi)\big), \quad (84)$$

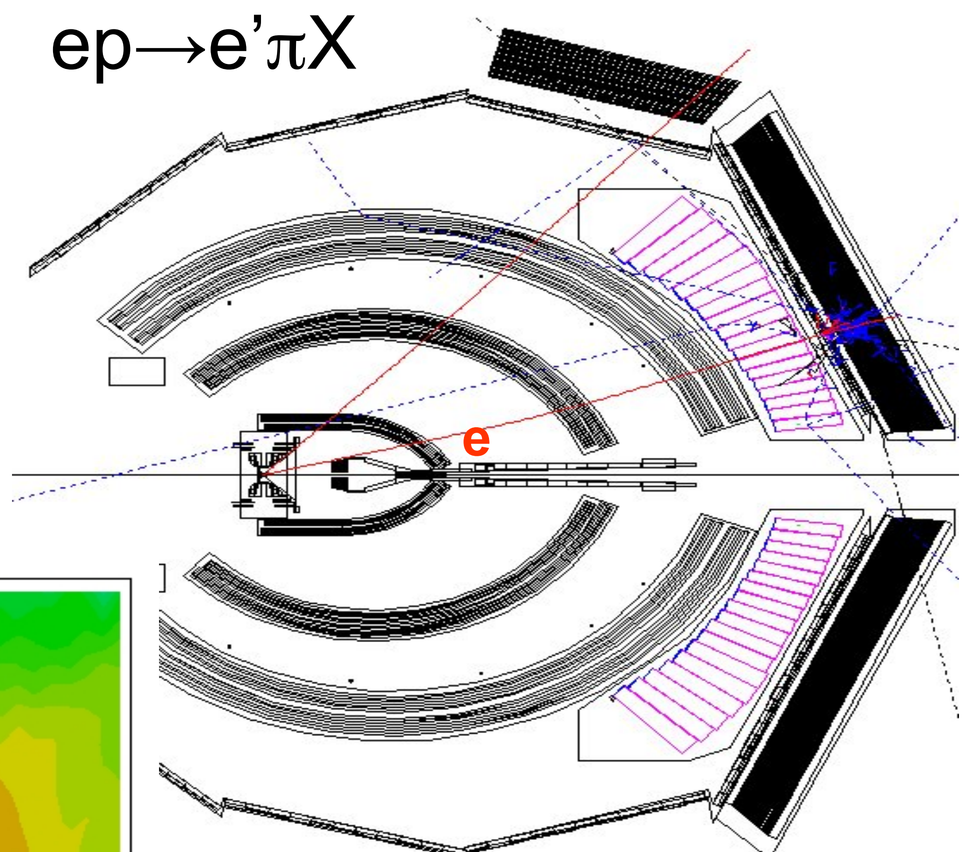
$$K^2 = -\frac{\Delta^2}{Q^2}(1-x_{\mathrm{B}})\left(1-y-\frac{y^2\epsilon^2}{4}\right)\left(1-\frac{\Delta^2_{\mathrm{min}}}{\Delta^2}\right) \times \left\{\sqrt{1+\epsilon^2} + \frac{4x_{\mathrm{B}}(1-x_{\mathrm{B}})+\epsilon^2}{4(1-x_{\mathrm{B}})}\frac{\Delta^2-\Delta^2_{\mathrm{min}}}{Q^2}\right\}$$

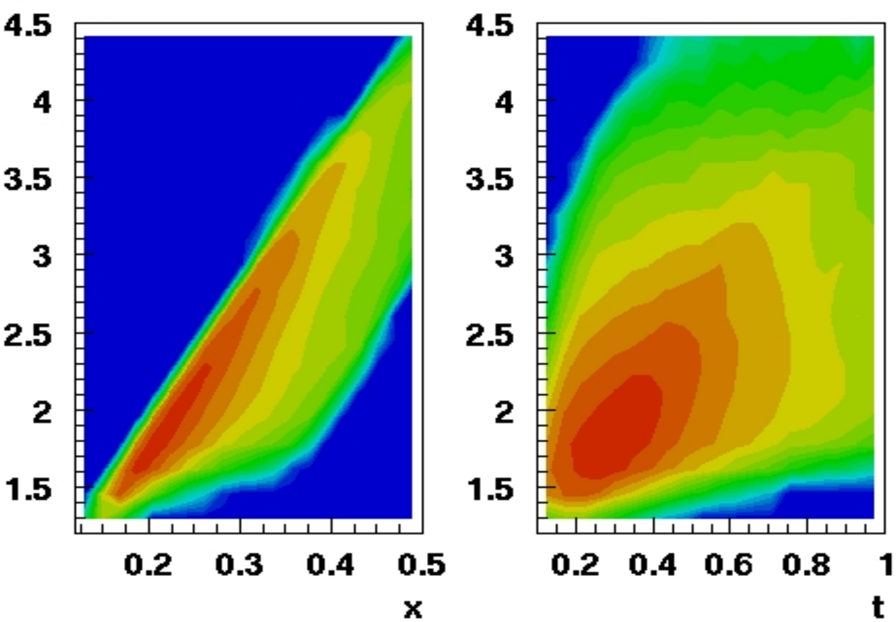
CLAS configuration with longitudinally pol. target



Longitudinally polarized target

$ep \rightarrow e'\pi X$





- Polarizations:
  - Beam: ~70%
  - NH3 proton ~70%
- Target position -55cm
- Torus +/-2250
- Beam energy ~5.7 GeV

Radiative corrections

RC of the lowest order to the BH cross section is calculated using

- the method of the Electron Structure Functions (Butev, Kuraev, Tomasi-Gustafsson, PR C77, 055206 2008)
- the direct calculations, i.e., performing leading log approaximation in matrix element squared of double bremmstrahlung.

Coincidence of analytical results calculated by both approaches was proved, and the code for numerical calculations was developed and applied to Hall-B kinematics

Note, we calculated only the leading term of double bremsstrahlung cross section in the expansion over the electron mass:

$$\sigma_{rad} = A \log(Q^2/m^2) + B + O(m^2/Q^2)$$

where A and B are independent on the electron mass.

Deeply Virtual Compton Scattering ep->e'p'γ

$$\frac{d^4\sigma}{dQ^2 dx_B dt d\phi} \sim |T^{DVCS} + T^{BH}|^2$$

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

Polarized beam, unpolarized target:

$\Delta\sigma_{LU} \sim \sin\phi \, \mathrm{Im}\{F_1 H + \xi(F_1+F_2)\tilde{H} + kF_2 E\}$

Kinematically suppressed

Unpolarized beam, longitudinal target:

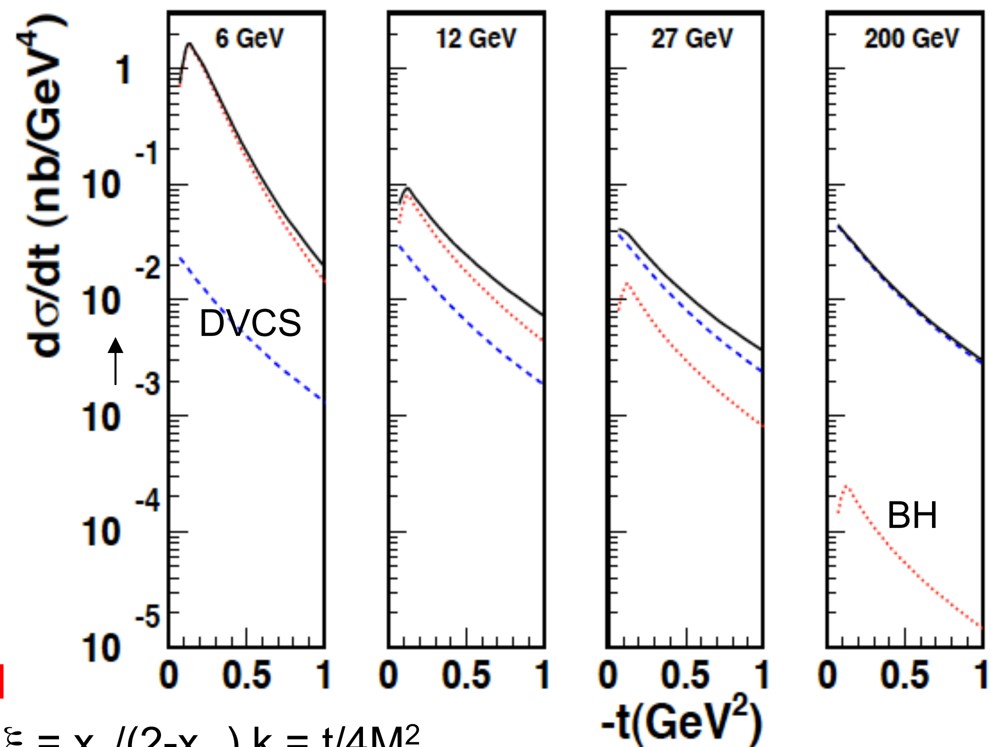
$\Delta\sigma_{UL} \sim \sin\phi \, \mathrm{Im}\{F_1\tilde{H} + \xi(F_1+F_2)(H + .. \}$

Kinematically suppressed

Unpolarized beam, transverse target:

$\Delta\sigma_{UT} \sim \cos\phi \, \mathrm{Im}\{k_1(F_2 H - F_1 E) + .. \}$

Kinematically suppressed



$\xi = x_B/(2-x_B), k = t/4M^2$

•Different GPD combinations accessible as **azimuthal moments** of the total cross section.

1/ Take some GPD model (VGG)

2/Calculate observables (σ, A_{LU}, A_{UL}, A_{LL}, A_{Ux}, A_{Lx},…)

3/ Introduce errors: $\Delta\sigma$: sqrt(N) ΔA: 1/P sqrt((1-P.A)^2)/sqrt(N)
(according to rate tables)

4/ Smear the data accordingly

5/ Fit the CFFs from these pseudo-data

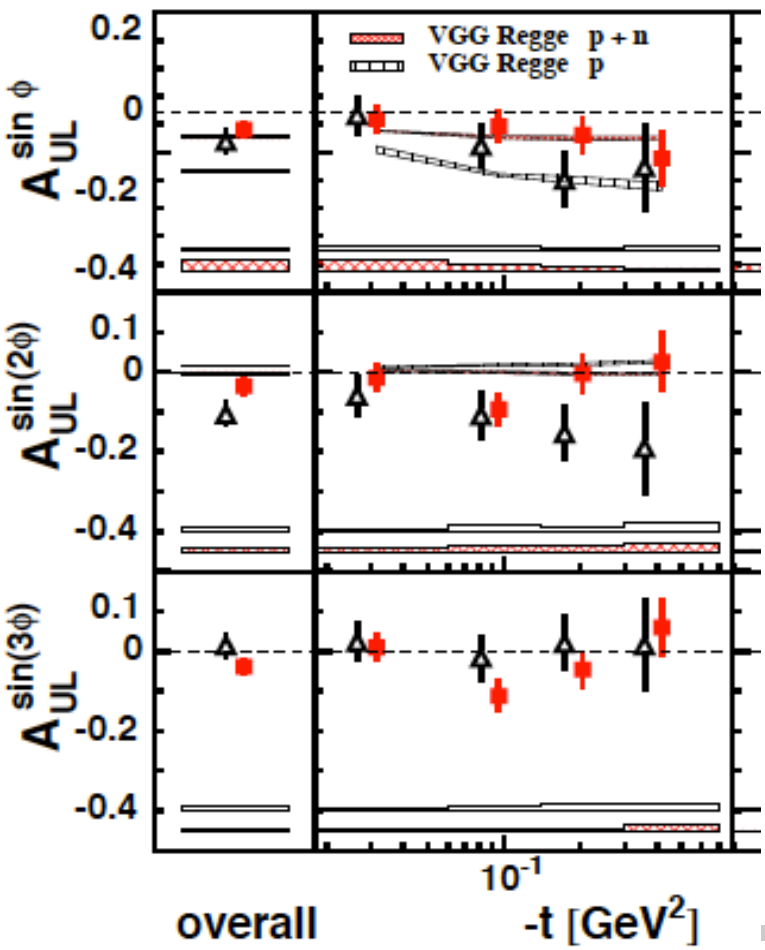
6/Compare generated CFF and resulting CFFs from fit

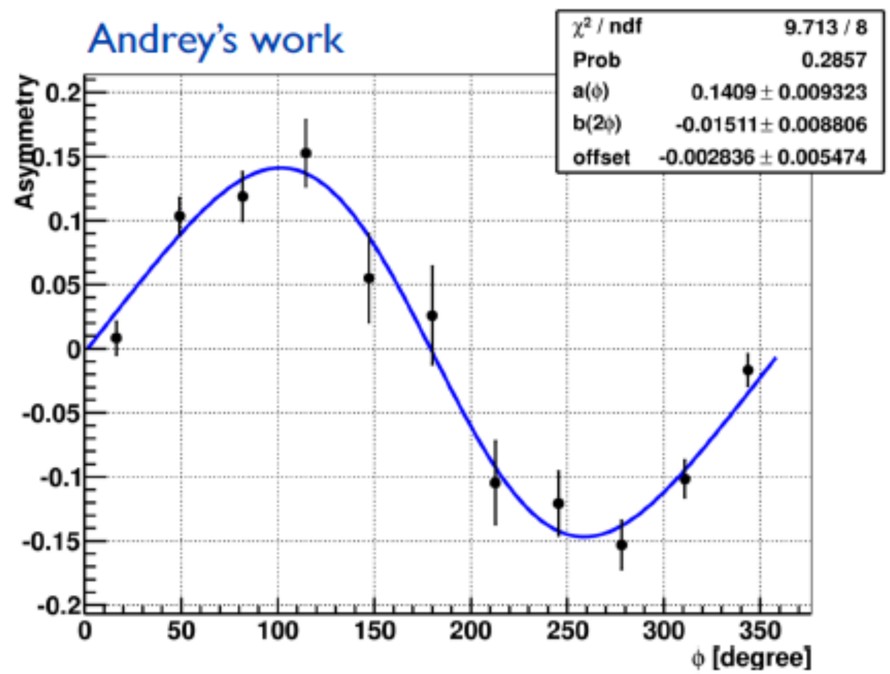
Several approximations:

* To what beam time the tables precisely correspond to ?
* The count rates don't correspond exactly to the generated CFFs
* Acceptance & #counts for L target=Acceptance & #counts for T target,…

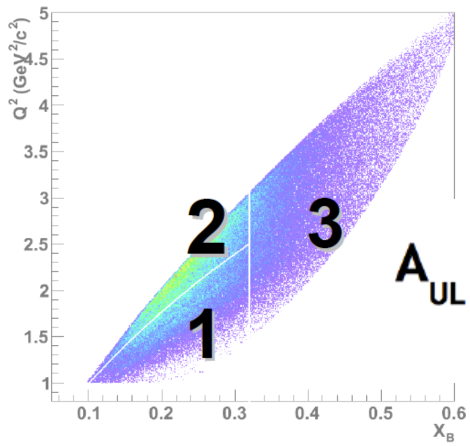
$$\begin{Bmatrix} c^{\mathcal{I}}_{2,\mathrm{LP}} \\ s^{\mathcal{I}}_{2,\mathrm{LP}} \end{Bmatrix} = \frac{16\Lambda K^2}{2-x_B} \begin{Bmatrix} -\lambda y \\ 2-y \end{Bmatrix} \begin{Bmatrix} \Re\mathrm{e} \\ \Im\mathrm{m} \end{Bmatrix} \mathcal{C}^{\mathcal{I}}_{\mathrm{LP}}(\mathcal{F}^{\mathrm{eff}}),$$

$$\mathcal{C}^{\mathcal{I}}_{\mathrm{LP}} = \frac{x_B}{2-x_B}(F_1+F_2)\left(\mathcal{H} + \frac{x_B}{2}\mathcal{E}\right) + F_1\widetilde{\mathcal{H}} - \frac{x_B}{2-x_B}\left(\frac{x_B}{2}F_1 + \frac{\Delta^2}{4M^2}F_2\right)\widetilde{\mathcal{E}}, \quad (70)$$



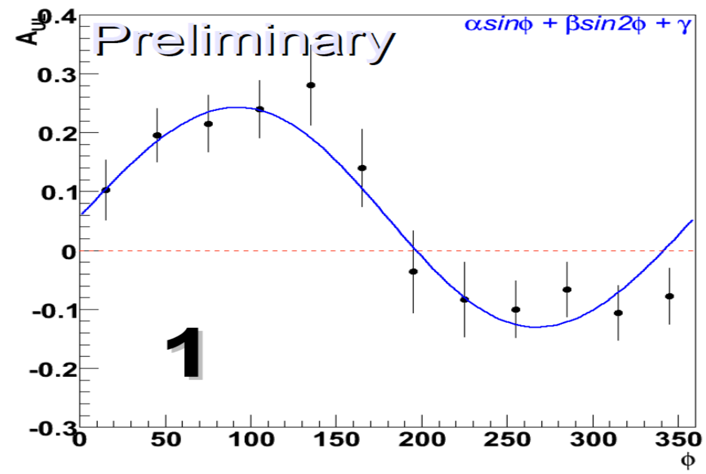


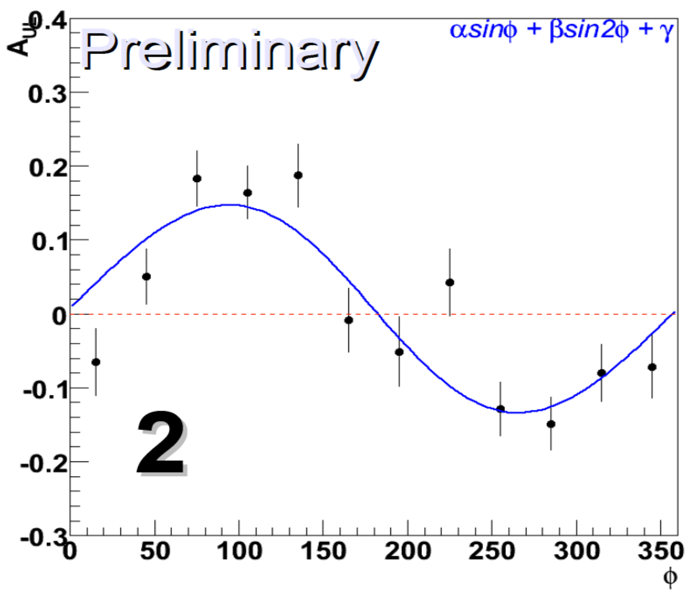
Polarized DVCS kinematics

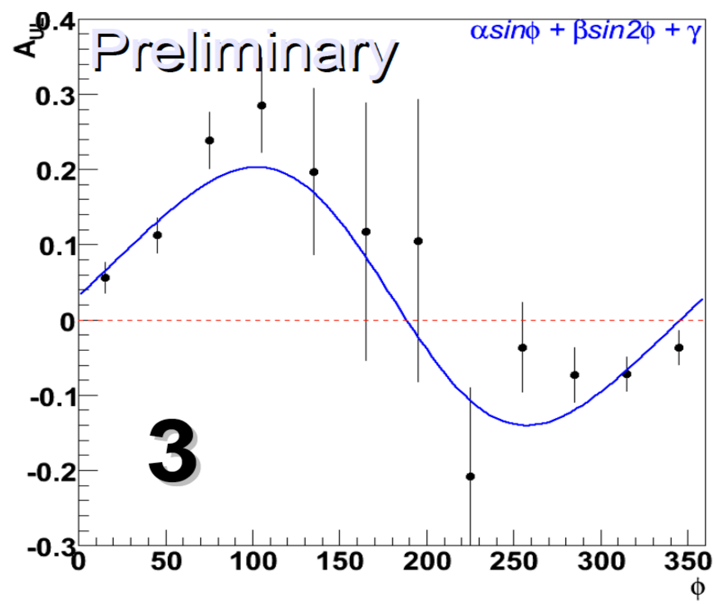


E. Seder

$$A_{UL} = \frac{N^{\Uparrow}(\phi) \; - \; N^{\Downarrow}(\phi)}{f\,[P_t^{\Downarrow} N^{\Uparrow}(\phi) \; + \; P_t^{\Uparrow} N^{\Downarrow}(\phi)]}$$







Longitudinal target SSA will be extracted in bins in x and t