Deeply Virtual Compton Scattering with CLAS

first results from the e1dvcs experiment

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JLab/Hall-B

Exclusive Reactions at High Momentum Transfer
May 21st, 2007

Outline

1. Motivation
   - Describing the nucleon structure
   - Published data
2. Experimental context
   - CLAS/DVCS
   - Performances of the new calorimeter
3. Physics Analysis
   - Particule identification
   - Reaction exclusivity
   - Results for the asymmetries
   - Comparison to models

Wigner distributions and GPDs

What do we wish we knew ? What can we know ?

Wigner distributions $W^q_\Gamma(\vec{r},\vec{k})$

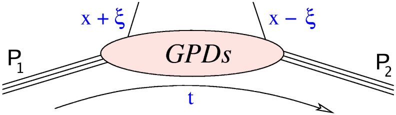
$$\Downarrow \int \mathrm{d}^2\vec{k}_\perp + \mathcal{FT}$$

Generalized Parton Distributions (GPDs)

4 chiral even GPDs

$$F^q_{\gamma^+}(x,\xi,t) = \bar{U}(P_2)\left[H^q(x,\xi,t)\gamma^+ + E^q(x,\xi,t)\frac{\imath\sigma^{+i}q_i}{2M}\right]U(P_1)$$

$$F^q_{\gamma^+\gamma_5}(x,\xi,t) = \bar{U}(P_2)\left[\tilde{H}^q(x,\xi,t)\gamma^+\gamma_5 + \tilde{E}^q(x,\xi,t)\frac{\gamma_5 q^+}{2M}\right]U(P_1)$$



Known quantities from novel ones

What do we wish we knew ? What can we know ? What do we know ?

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$\swarrow$ $\searrow$

Parton distribution functions (PDFs)

$$H^q(x,0,0) = q(x)$$

Form factors (FFs)

$$\int_{-1}^{1}\mathrm{d}x\, H^q(x,\xi,t) = F_1^{\,q}(t)$$

Universal functions constrained by specific processes

Physical content of GPDs : Energy-momentum tensor of q flavored quarks

$$\langle p_2|\hat{T}^q_{\mu\nu}|p_1\rangle = \bar{U}(p_2)\left[M_2^q(t)\,\frac{P_\mu P_\nu}{M} + J^q(t)\,\frac{\imath(P_\mu\sigma_{\nu\rho}+P_\nu\sigma_{\mu\rho})\Delta^\rho}{2M} + d_1^q(t)\,\frac{\Delta_\mu\Delta_\nu - g_{\mu\nu}\Delta^2}{5M}\right]U(p_1)$$

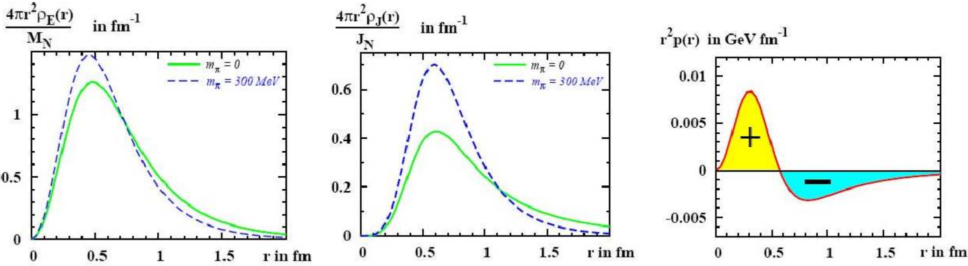
$M_2(t) \longleftrightarrow T_{00}$: mass distributions inside the hadron

$J(t) \longleftrightarrow T_{0i}$: angular momentum distributions

$d_1(t) \longleftrightarrow T_{ij}$: forces and pressure distributions

$$J^q(t) = \frac{1}{2}\int_{-1}^{1} \mathrm{d}x\, x\,[H^q(x,\xi,t) + E^q(x,\xi,t)] \quad , \quad M_2^q(t) + \frac{4}{5}d_1(t)\xi^2 = \frac{1}{2}\int_{-1}^{1}\mathrm{d}x\, x H^q(x,\xi,t)$$

Ji's sum rule



Access to GPDs : the DVCS process

Observables in the Bjorken limit

$$\gamma^* p \to \gamma p'$$

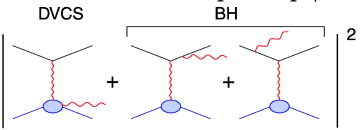
Bjorken regime :

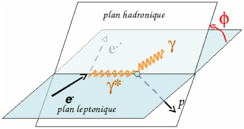
$Q^2 \to \infty$, $\nu \to \infty$ and

$x_B = Q^2/2M\nu$ fixed

$\left(\xi \to \frac{x_B}{2-x_B}\right)$

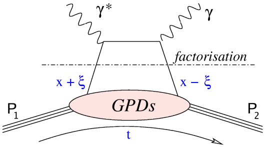
$$\vec{e}p \to ep\gamma$$





Diehl, Gousset, Pire, Ralston (1997)

Belitsky, Müller, Kirchner (2002)



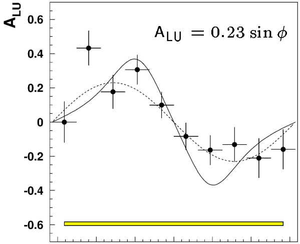
$$A_{LU} = \frac{d^4\sigma^{\rightarrow} - d^4\sigma^{\leftarrow}}{d^4\sigma^{\rightarrow} + d^4\sigma^{\leftarrow}} \overset{\text{twist-2}}{\approx} \frac{\alpha \sin\phi}{1 + \beta\cos\phi}$$

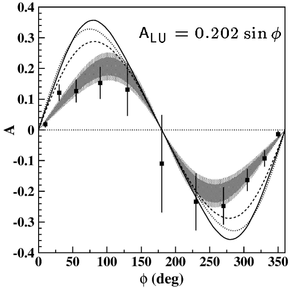
$$\alpha \propto \left(F_1 \mathcal{H} + \xi G_M \tilde{\mathcal{H}} - \frac{t}{4M^2} F_2 \mathcal{E}\right)$$

$$\mathcal{H}(\xi, t) = \pi \sum_q Q_q^2 \left[H^q(\xi,\xi,t) - H^q(-\xi,\xi,t)\right]$$

Non-dedicated DVCS observations

Experiment	Observable
H1	σ
ZEUS	σ
HERMES	BSA/A_{LU} BCA TSA/A_{UL} & A_{UT}
CLAS	BSA/A_{LU} TSA/A_{UL}



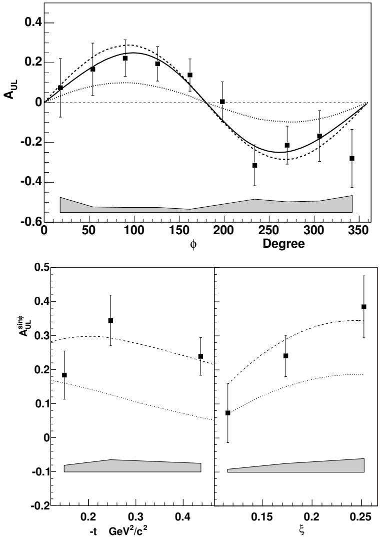


HERMES and CLAS : first observations $A_{LU} \sim \sin\phi$

Non-dedicated DVCS observations

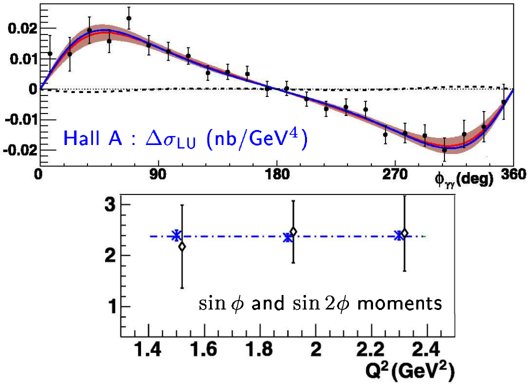
Experiment	Observable
H1	σ
ZEUS	σ
HERMES	BSA/A_{LU} BCA TSA/A_{UL} & A_{UT}
CLAS	BSA/A_{LU} TSA/A_{UL}

First publication of exclusive $A_{UL} \sim \sin\phi$ for DVCS



DVCS dedicated experiments

Expérience	Observable
HERMES	BSA/A_{LU} BCA
CLAS	BSA/A_{LU}
Hall A	σ & $\Delta\sigma_{LU}$ on the neutron

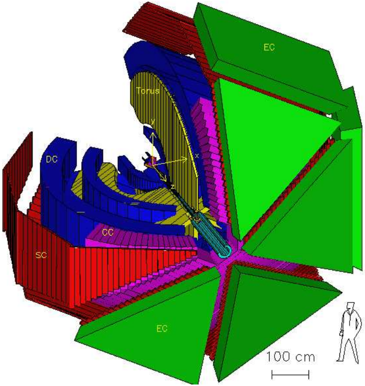


The Q^2 dependancy shows perturbative QCD scaling.

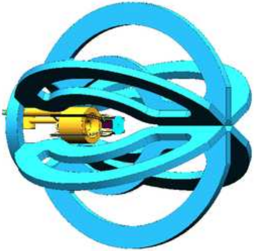
First solid evidence of twist-2 dominance.

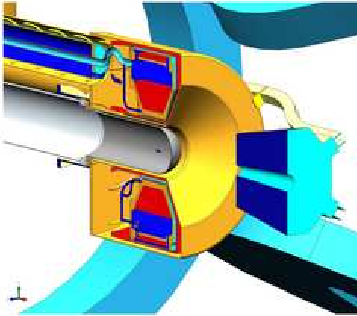
The e1dvcs experiment with CLAS

- Began 02/01/2005
- 6 weeks of installation
- 1 week of commissioning
- 10 weeks of data taking
- $E = 5.8$ GeV
- Average beam polarisation 80%
- Average current 25 nA
- Target : lH_2 2.5 cm
- $\mathcal{L}_{H_2} = 1.7 \times 10^{34}$ cm^{-2}s^{-1}
- $L_{H_2} = 45$ fb^{-1}
- ≈ 7 TBytes raw data



CLAS upgrade



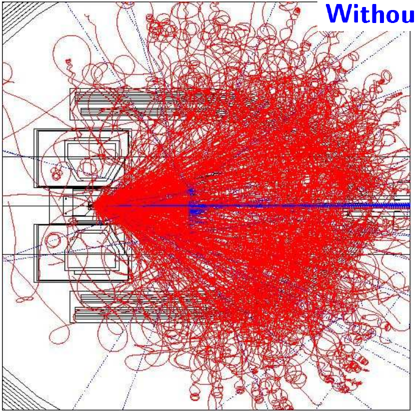


- Inner Calorimeter (IC) :
  424 $PbWO_4$ crystals
  (16 cm length, 1.3 cm^2 to 1.6 cm^2)
  $X_0 = 0.9$ cm, $R_M = 2.0$ cm
  Truncated pyramidal stacking
  Light collection : APDs
  $-2\%/^\circ \Rightarrow$ temperature stabilisation
  laser monitoring system
- Move target upstream w.r.t. nominal CLAS center
- Superconductor solenoidal magnet :
  Cu+Nb/Ti alloy at 4.3 K
  Original cryogenic system
  Additional coil compensate fringe field

  Average field at the level of the target 4.5 T at 534 A

Illustrations

The solenoidal field acts as a magnetic shield

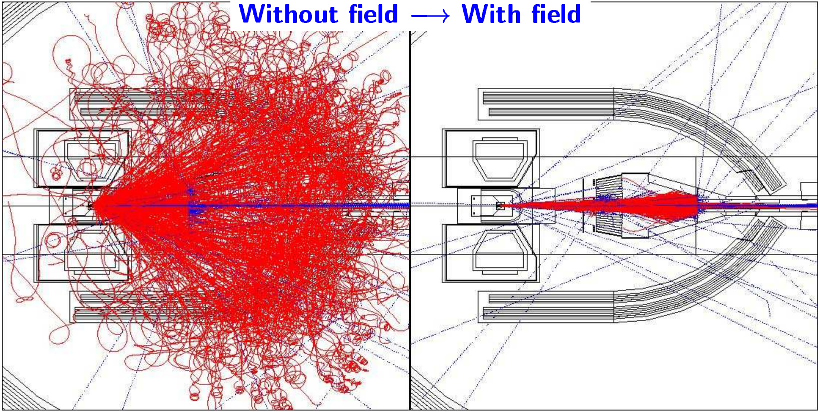


Without field

Møller electrons energy of the order 1-10 MeV

Illustrations

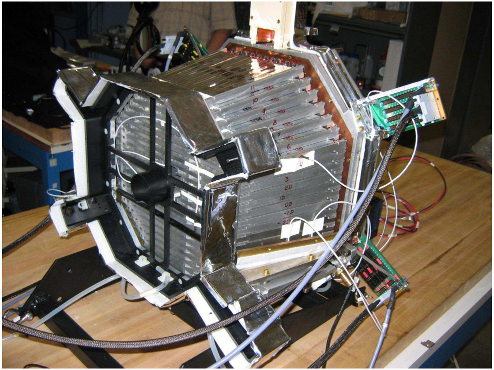
The solenoidal field acts as a magnetic shield

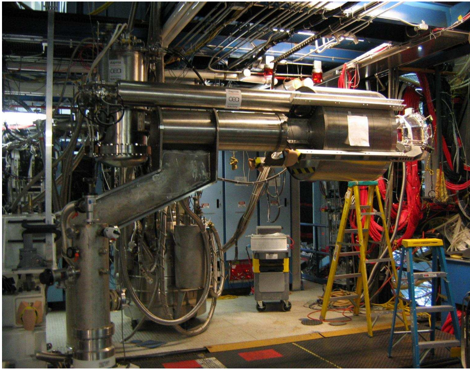


Møller electrons energy of the order 1-10 MeV

Illustrations

IC cabling and insertion in CLAS

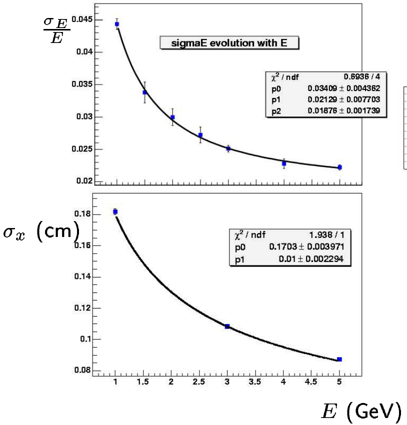


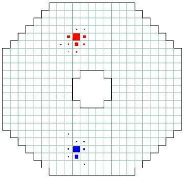


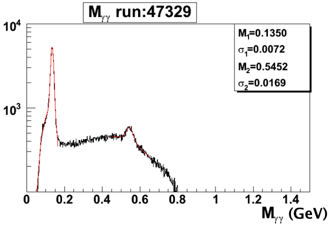
Instrumentation from international collaboration CEA/IN2P3/ITEP(Moscow)/JLab

IC resolutions : Energy and Position

Simulations and Data







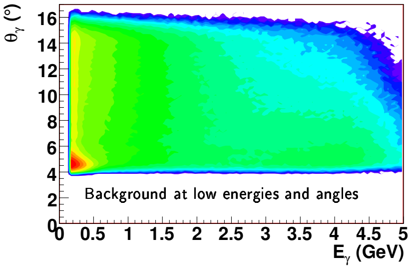
$$\frac{\sigma_E}{E} = \frac{0.02}{E} \oplus \frac{0.03}{\sqrt{E}} \oplus 0.024 \quad (E \text{ in GeV})$$

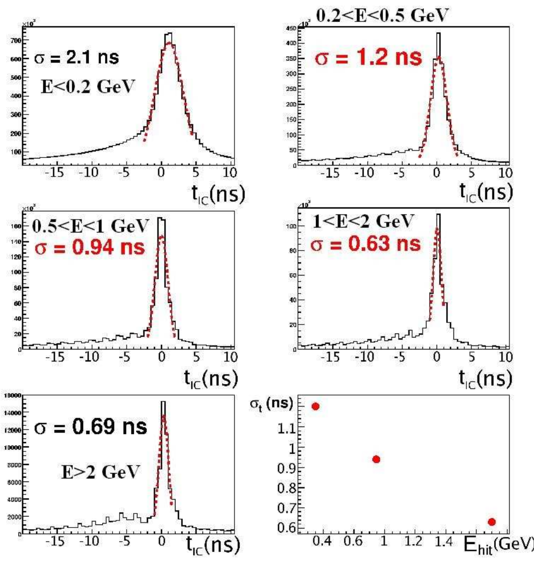
$$\sigma_x = \frac{0.2}{\sqrt{E}} \text{ (cm)}$$

IC resolutions : Timing

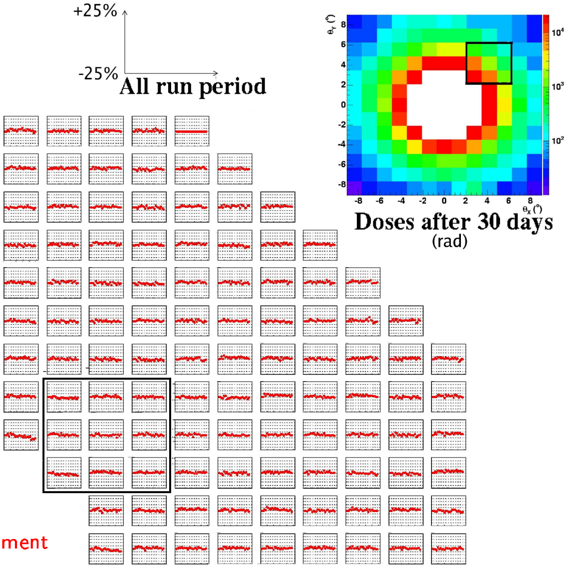
Data

- Correction for time-walk
- Time spectra for several energies (all channels)
- CEBAF beam packet structure visible
- Very few accidentals with good electron trigger





Laser and doses in IC



Doses after 30 days
(rad)

Relative gains measured with LASER

Doses evaluated with pedestals taken with beam on

Agreement with Møller electrons simulations

Transparency losses :
compatible with expectations.

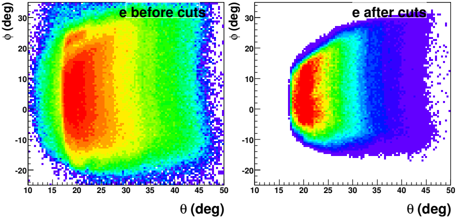
Succesful operation of the new equipment

Electron trigger, Proton, Photon

- Electron :
  - Reconstruction in DC
  - $P > 800$ MeV/c
  - π^- rejection : EC and CC
  - Fiducial cuts in DC and EC
- Proton :
  - Reconstruction in DC
  - Fiducial cuts DC
  - $\Delta\beta = \frac{l}{ct} - \frac{p}{\sqrt{p^2+M^2}}$
- Photon :
  - EC : fiducial cuts, $\beta_\gamma > 0.92$ (neutrons rejection)
  - IC : fiducial cuts

Fiducial cuts (θ, ϕ) for the electron

before after



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- Photon :
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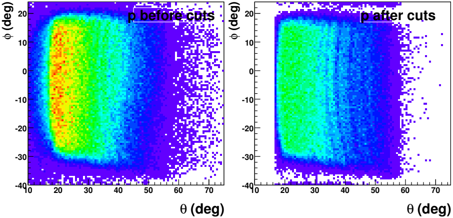
  - IC : fiducial cuts

Fiducial cuts (θ, ϕ) for the proton

before after



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- Photon :
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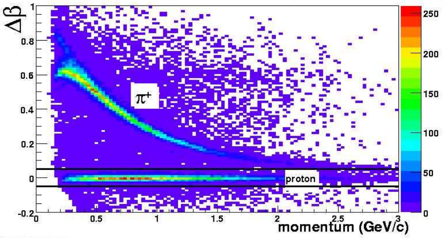
  - IC : fiducial cuts

Proton : $\Delta\beta$ cut



Electron trigger, Proton, Photon

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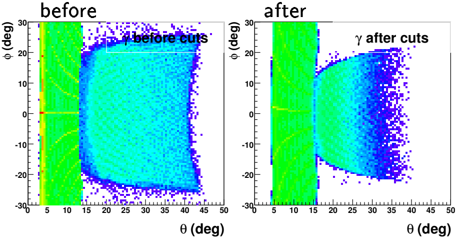
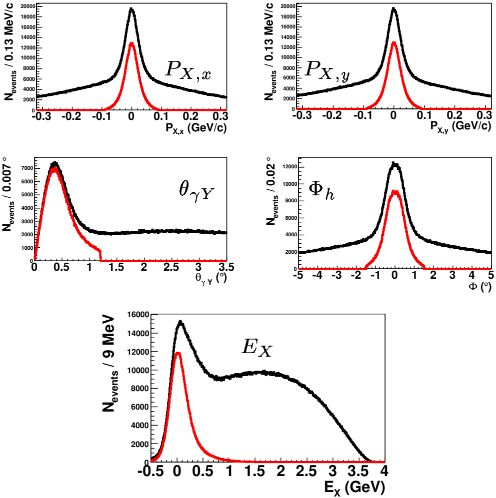
  - IC : fiducial cuts

Fiducial cuts (θ, ϕ) for the photon



Exclusivity cuts : IC

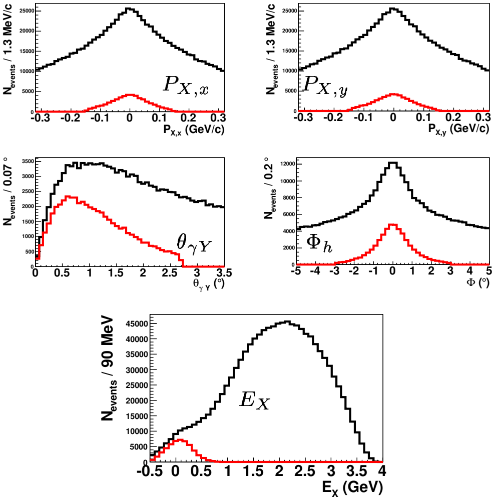


e, p and γ detected + exclusivity cuts

$ep \to ep\gamma X$
$ep \to epY$

- Missing transverse momentum : $|P_{X\perp}| < 90$ MeV/c
- Angle between photon and predicted photon $\theta_{\gamma Y} < 1.2°$
- Hadron coplanarity : $|\Phi_h| < 1.5°$
- Missing energy : $E_X < 300$ MeV

Exclusivity cuts : EC

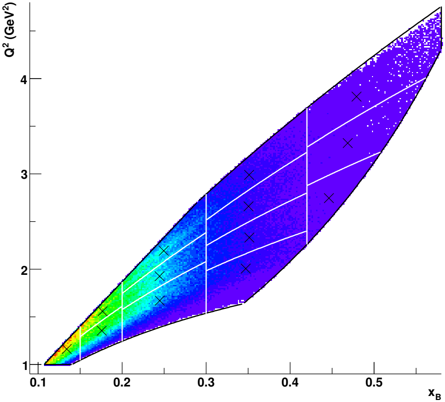


e, p and γ detected + exclusivity cuts

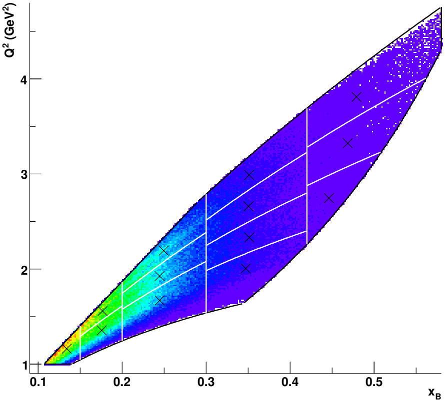
$ep \to ep\gamma X$
$ep \to epY$

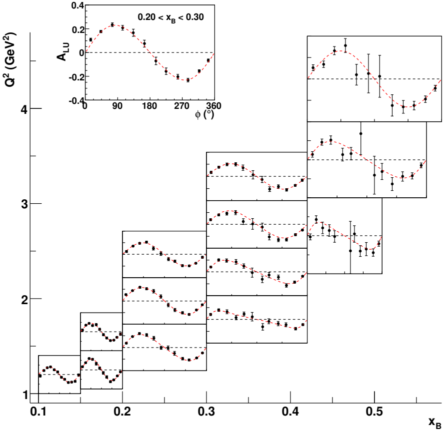
- Missing transverse momentum : $|P_{X\perp}| < 150$ MeV/c
- Angle between photon and predicted photon $\theta_{\gamma Y} < 2.7°$
- Hadron coplanarity : $|\Phi_h| < 3°$
- Missing energy : $E_X < 500$ MeV

Kinematical coverage and binning



Raw asymmetries as a function of ϕ





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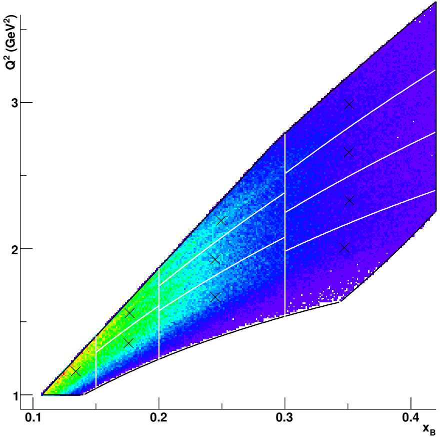

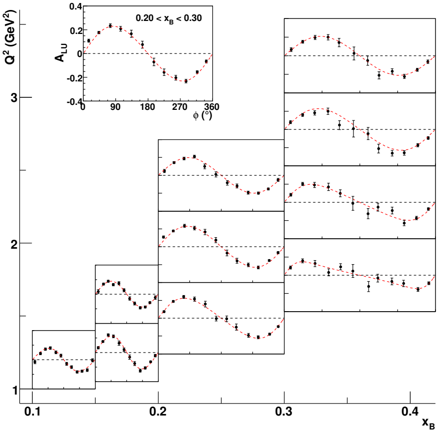

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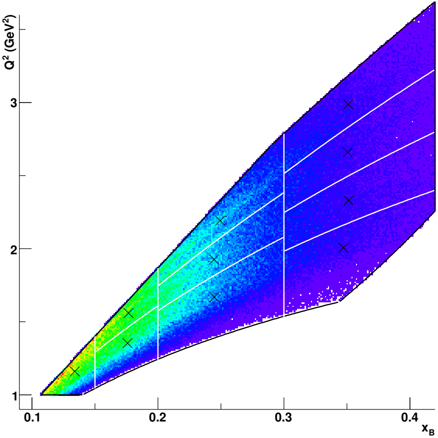
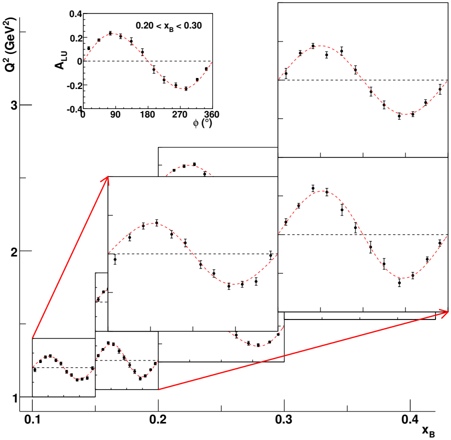




π^0 subtraction

Simulations : GSIM and Fast Monte-Carlo

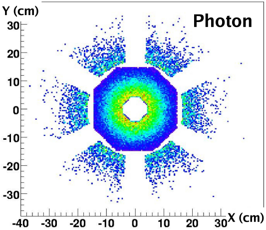
Principles :
Evaluate contamination in :

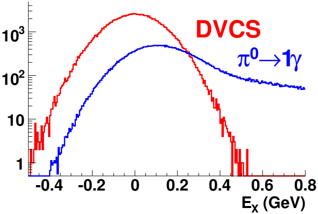
$$N_{ep \to ep\gamma X} = N_{ep\gamma} + N^{1\gamma}_{\pi^0}$$

in each elementary bin

$$\sigma_{ep \to ep\pi^0} \propto \frac{N^{2\gamma}_{\pi^0}}{\text{Acc}^{2\gamma}_{\pi^0}} = \frac{N^{1\gamma}_{\pi^0}}{\text{Acc}^{1\gamma}_{\pi^0}}$$

$$N^{1\gamma}_{\pi^0} = N^{2\gamma}_{\pi^0} \frac{N^{1\gamma}_{\pi^0\,\text{simu}}}{N^{2\gamma}_{\pi^0\,\text{simu}}}$$

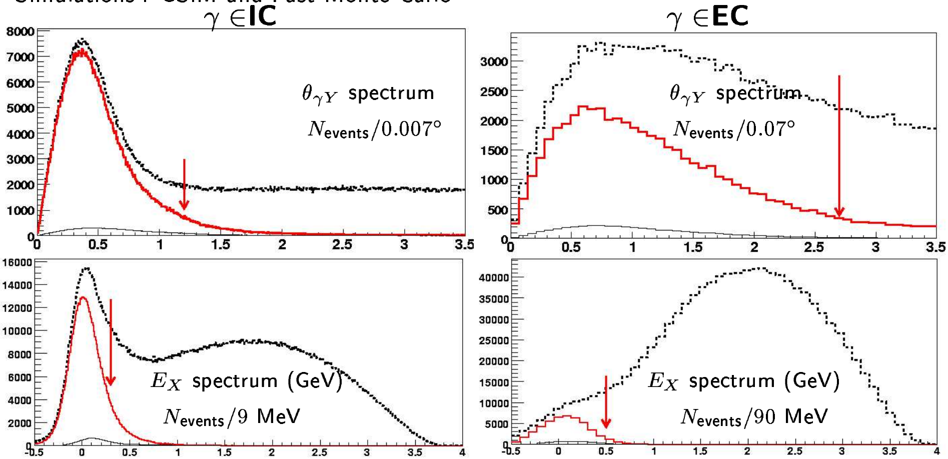




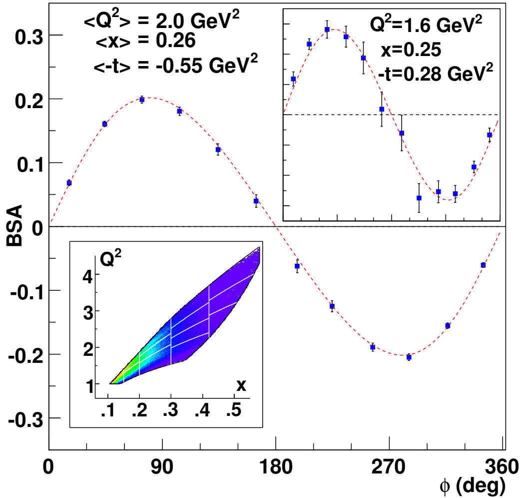
Result :
$\frac{N^{1\gamma}_{\pi^0}}{N_{ep \to ep\gamma X}}$ rises slightly with t, between 5 and 15%

π^0 subtraction

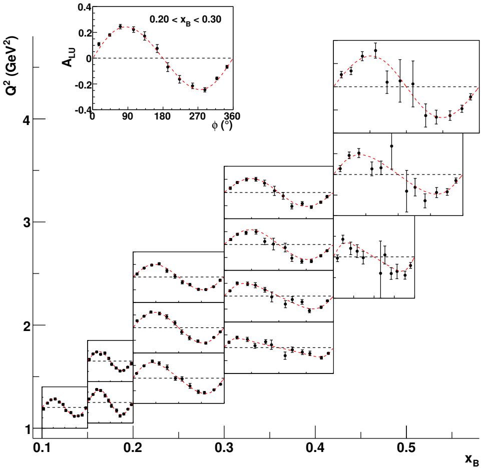
Simulations : GSIM and Fast Monte-Carlo



Asymmetries as a function of ϕ integrated over (x_B, Q^2, t)



Asymmetries as a function of ϕ integrated over t



$$A_{LU} = \frac{\sigma^{\rightarrow} - \sigma^{\leftarrow}}{\sigma^{\rightarrow} + \sigma^{\leftarrow}}$$

Results integrated on all range
$0.09 < -t < 1.8$ GeV^2

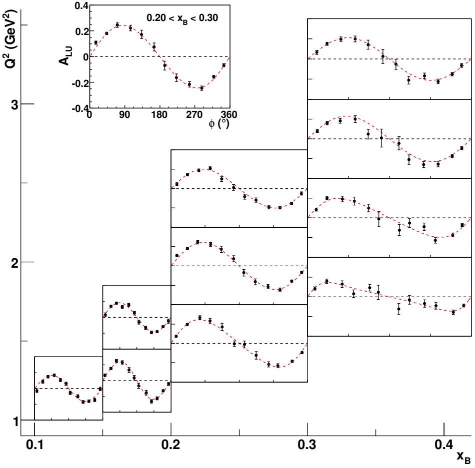
Fitted with parameterization :

$$A_{LU} = \frac{\alpha \sin\phi}{1 + \beta\cos\phi}$$

describing well the observed shapes

Errors dominated by statistics

Asymmetries as a function of ϕ integrated over t



$$A_{\mathrm{LU}} = \frac{\sigma^{\rightarrow} - \sigma^{\leftarrow}}{\sigma^{\rightarrow} + \sigma^{\leftarrow}}$$

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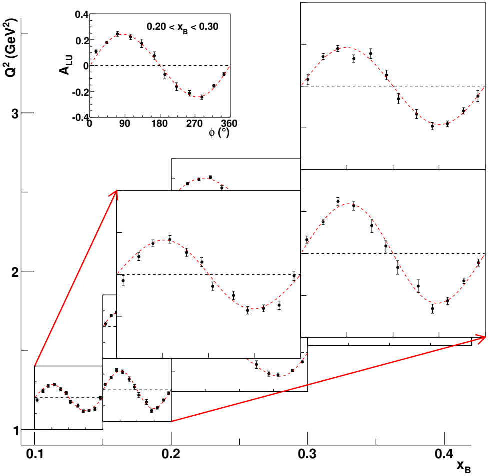


$$A_{LU} = \frac{\sigma^{\rightarrow} - \sigma^{\leftarrow}}{\sigma^{\rightarrow} + \sigma^{\leftarrow}}$$

Results integrated on all range
$0.09 < -t < 1.8$ GeV^2

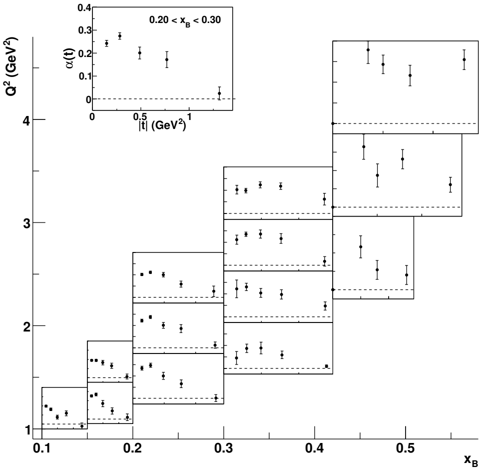
Fitted with parameterization :

$$A_{LU} = \frac{\alpha \sin\phi}{1 + \beta \cos\phi}$$

describing well the observed shapes

Errors dominated by statistics

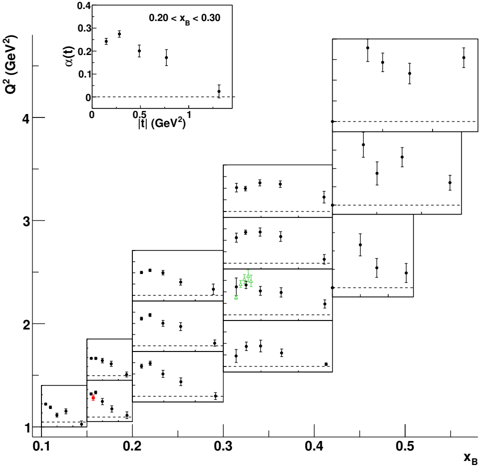
Asymmetries at 90° as function of $t \Leftrightarrow \alpha(t)$



Slope $d\alpha/d|t|$ decreases with x_B/Q^2

First constraints
for a global fit of GPDs
on a wide kinematical domain

Asymmetries at 90° as function of $t \Leftrightarrow \alpha(t)$



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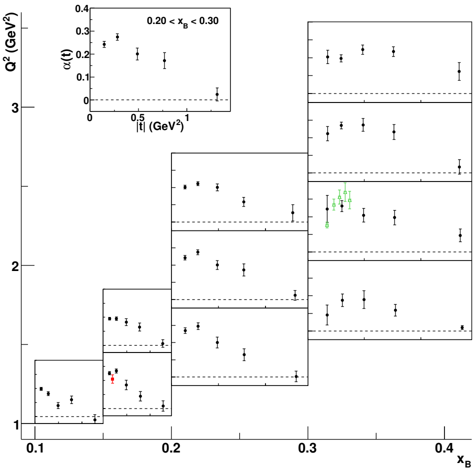

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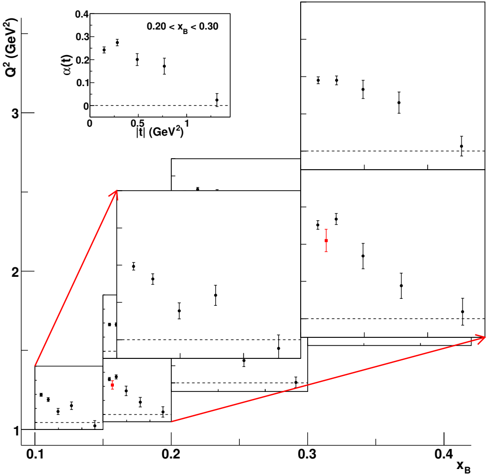

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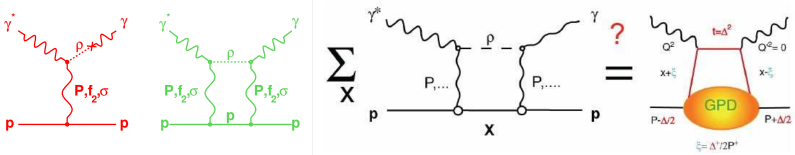
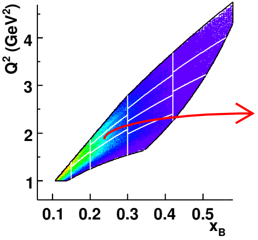
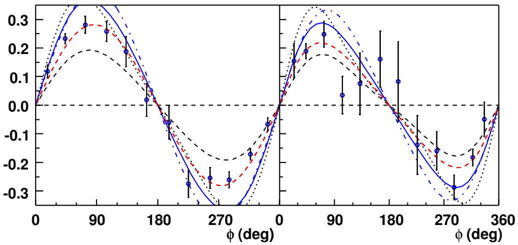
VGG model (GPD-based) and JML model

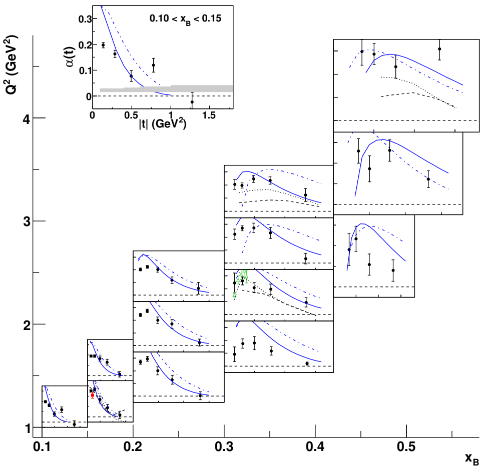
VGG model : Double distributions with Regge anzätse + D-term (χQSM)







VGG model (GPD-based) and JML model : t dependancy



Model with D-tern without GPD E

Excellent qualitative agreement

Good quantitative agreement

Overshoot at moderate $|t|$

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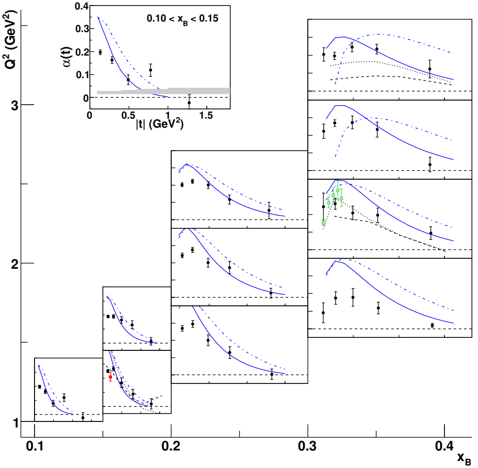

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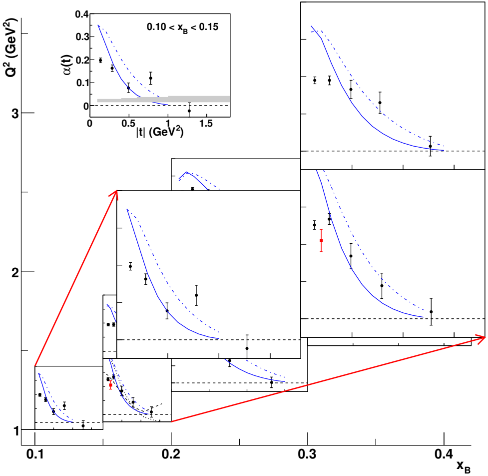

Model with D-tern without GPD E

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Conclusion

The e1dvcs experiment with CLAS :

- has benefited from excellent performances of the new equipment.
- achieved full exclusivity of the reaction.
- provides first constraints on a vast kinematical domain for a global fit of GPDs.

What is next ?

Perspectives :

- Experiments :
  - CLAS/DVCS : A_{LU} and A_{UL}
  - Hall A : $\Delta\sigma$ and σ for DVCS, $d\sigma_L$ and $d\sigma_T$ for π^0
  - DESY : H1/ZEUS σ for DVCS
  - DESY : HERMES A_C, A_{LU}
  - COMPASS σ, A_C
  - JLab 12 GeV
- Phenomenology :
  - Encouraging results towards GPDs extraction.
  - Hadronic femtophotography