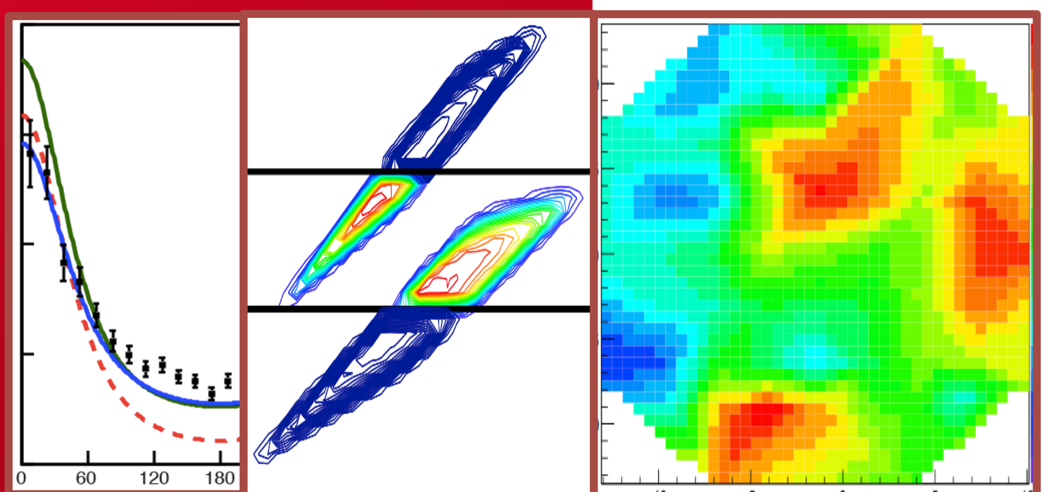
# NEW Deeply Virtual Compton Scattering cross sections from Jefferson Lab

DE LA RECHERCHE À L'INDUSTRIE

F. Sabatié – CEA Saclay, Irfu/SPhN

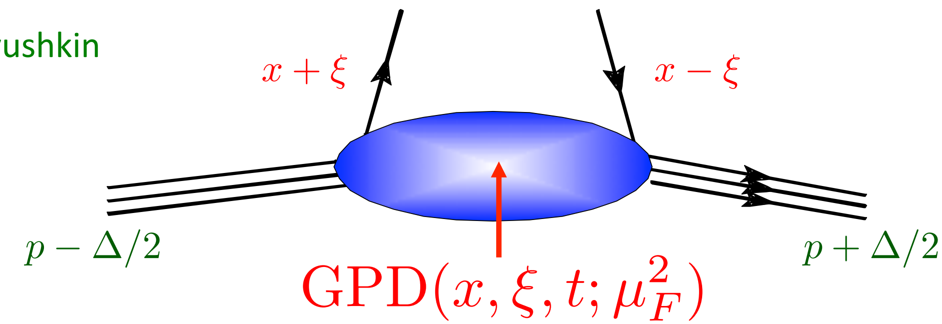


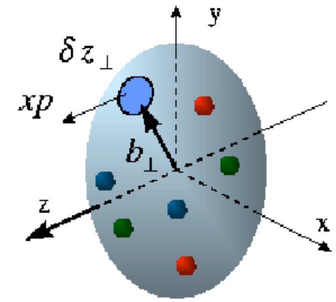

- Introduction
- Hall A DVCS experiments
- Hall B/CLAS experiments
- Summary & Conclusion

Jefferson Lab
EXPLORING THE NATURE OF MATTER

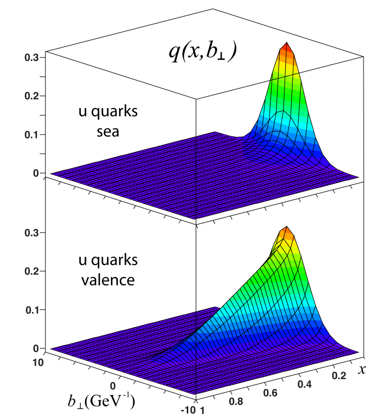
DIS2014

Müller
Ji, Radyushkin




$(x+\xi)$ and $(x-\xi)$ : longitudinal momentum fractions of quarks



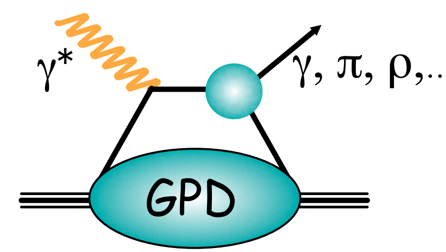

The structure of the nucleon can be described by

4 (chiral-even) **Generalized Parton Distributions** :

$$H, \widetilde{H}, E, \widetilde{E}(x,\xi,t;\mu_F^2)$$

> They enter the $\gamma^* p \to (\gamma \text{ or } M)\ p$ amplitude

as convolution integrals : no direct access




> Forward limit$(t=\xi=0)$ of $H$ and $\widetilde{H}$ : PDFs

> First moment in x : Form Factors

> Second moment of $(H+E)$ when $t \to 0$ : total angular momentum

> First “few” moments *calculable on the lattice*

Deep Exclusive Processes
**Parton distributions** in both coordinate and momentum space

## Deeply Virtual Compton Scattering

- Theory is under control : up to $\alpha_S^2$ , twist-3, target mass corrections, etc.
- Sensitive to the quark combination : $\frac{4}{9}u + \frac{1}{9}d + \frac{1}{9}s$

Müller et al,
Braun et al, ...

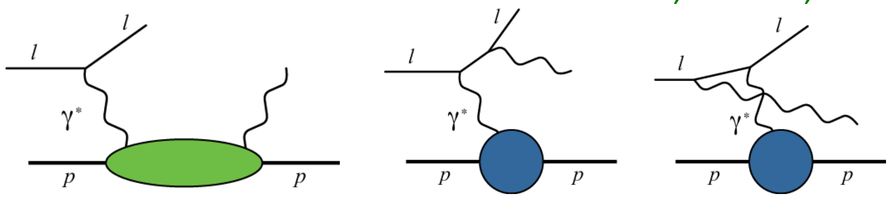
- At Jefferson Lab energies, *mostly* sensitive to valence quarks
- Actually sensitive to *gluon* GPDs at NLO or beyond (even at somewhat large x)

Moutarde, Pire,
F.S. , Wagner, ...

Direct access to the Re and Im part of Compton Form Factors $\mathcal{H}$, ...

through interference with known Bethe-Heitler process

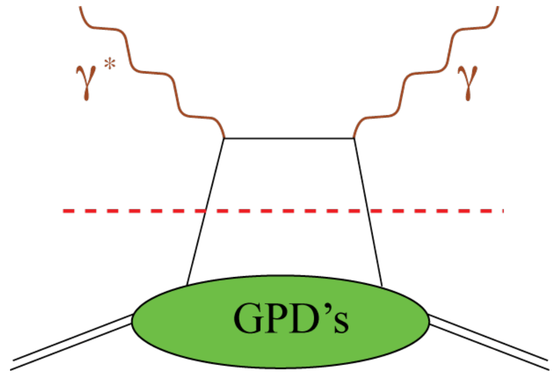
Diehl, Gousset,
Pire, Ralston, ...




## Hard Meson Electroproduction

- Many channels available for flavor separation ($\rho^0$, $\rho^+$, $\pi^0$, $\pi^+$, $\phi$, ...)
- J/$\Psi$ and $\phi$ are especially interesting to access gluon GPDs (H and even E)
- Theory less under control : convolution with (unknown) meson WF,

  very slow scaling, large power and NLO corrections




GPD's

$$\mathcal{F}(\xi,t,Q^2) = \int_{-1}^{+1} dx\, C\left(x,\xi,\alpha_S(\mu_R),\frac{Q}{\mu_F}\right) F(x,\xi,t,\mu_F)$$

Compton Form Factor (CFF)
CFF are *complex* functions !

Integration Kernel has been worked out up to NLO

Müller et al
Pire et al
…

Factorization scale dependence through evolution equations

$$\xi \simeq \frac{x_B}{2-x_B}$$

# DVCS observables

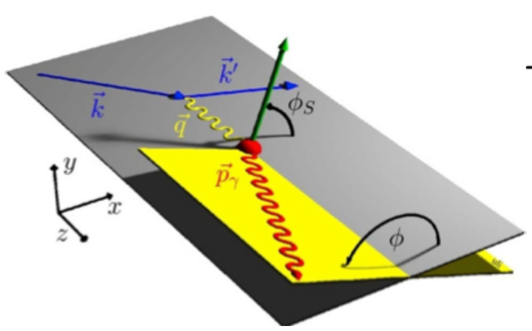
In the one-photon exchange approximation of QED,
the BH, DVCS and interference parts of the ***ep*** $\rightarrow$ ***ep***$\gamma$ cross section read :

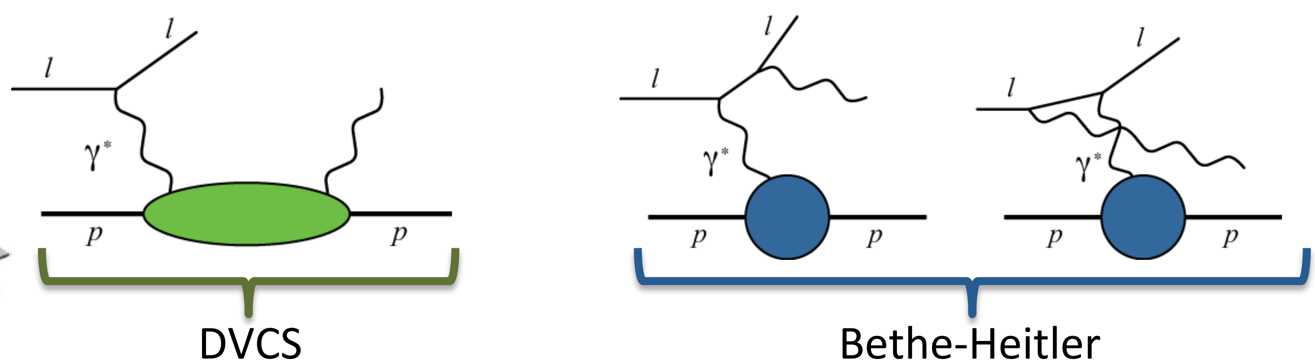
Diehl et al

$$|\mathcal{M}_{\mathrm{BH}}|^2 \quad \propto \quad \frac{1}{|t|}\frac{1}{P(\cos\phi)}\sum_{n=0}^{3}\left[c_n^{\mathrm{BH}}\cos(n\phi)+s_n^{\mathrm{BH}}\sin(n\phi)\right]$$

$$|\mathcal{M}_{\mathrm{DVCS}}|^2 \quad \propto \quad \sum_{n=0}^{3}\left[c_n^{\mathrm{DVCS}}\cos(n\phi)+s_n^{\mathrm{DVCS}}\sin(n\phi)\right]$$

$$\mathcal{M}_{\mathrm{I}} \quad \propto \quad \frac{1}{|t|}\frac{1}{P(\cos\phi)}\sum_{n=0}^{3}\left[c_n^{\mathrm{I}}\cos(n\phi)+s_n^{\mathrm{I}}\sin(n\phi)\right]$$





# Cross sections at JLab mostly sensitive to CFF $\mathcal{H}$

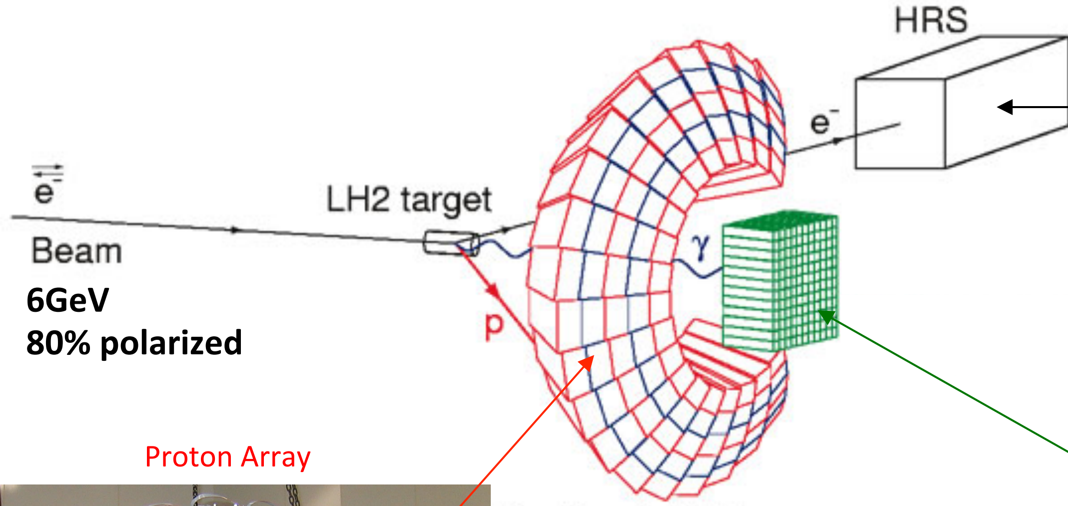
| Experiment | Observable | Normalized CFF dependence |
|---|---|---|
| CLAS | $A_{LU}^{-,\sin\phi}$ | $\mathrm{Im}\mathcal{H} + 0.06\mathrm{Im}\mathcal{E} + 0.21\mathrm{Im}\widetilde{\mathcal{H}}$ |
| | $A_{UL}^{-,\sin\phi}$ | $\mathrm{Im}\widetilde{\mathcal{H}} + 0.12\mathrm{Im}\mathcal{H} + 0.04\mathrm{Im}\mathcal{E}$ |
| | $A_{UL}^{-,\sin 2\phi}$ | $\mathrm{Im}\widetilde{\mathcal{H}} - 0.79\mathrm{Im}\mathcal{H} + 0.30\mathrm{Im}\mathcal{E} - 0.05\mathrm{Im}\widetilde{\mathcal{E}}$ |
| HALL A | $\Delta\sigma^{\sin\phi}$ | $\mathrm{Im}\mathcal{H} + 0.07\mathrm{Im}\mathcal{E} + 0.47\mathrm{Im}\widetilde{\mathcal{H}}$ |
| | $\sigma^{\cos 0\phi}$ | $1 + 0.05\mathrm{Re}\mathcal{H} + 0.007\mathcal{H}\mathcal{H}^*$ |
| | $\sigma^{\cos\phi}$ | $1 + 0.12\mathrm{Re}\mathcal{H} + 0.05\mathrm{Re}\widetilde{\mathcal{H}}$ |

Kroll, Moutarde, F.S., EPJC73 2278 (2013)

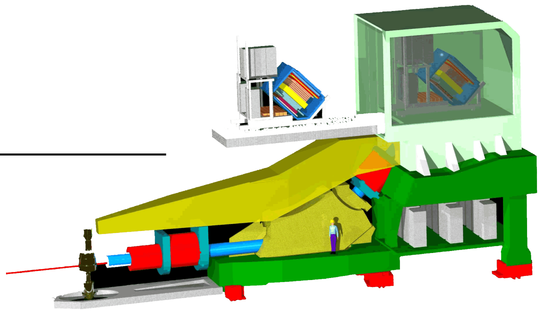
E00-110 and E03-106

Two high precision experiments (p and n)

Spokespersons : Bertin, Hyde, Ransome, F.S.*, Voutier

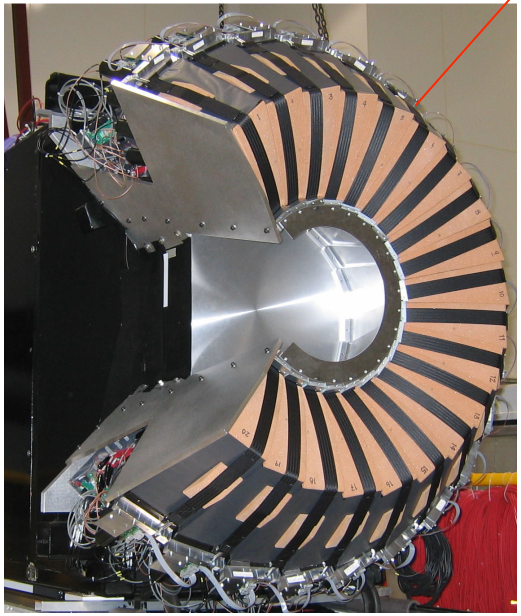



**6GeV**
**80% polarized**



HRS spectrometer in Hall A

Proton Array



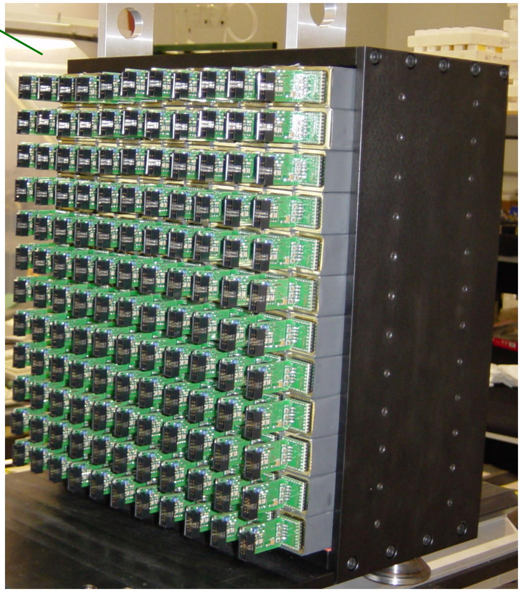
50 days of beam time in the fall of 2004, at 2.5μA

L=13300 $fb^{-1}$

3 kinematic settings :

| Kin | $Q^2$ ($GeV^2$) | $x_B$ | $\theta_{\gamma^*}$ (deg.) | $W$ (GeV) |
|---|---|---|---|---|
| 1 | **1.5** | 0.36 | **22.3** | 1.9 |
| 2 | **1.9** | 0.36 | **18.3** | 2.0 |
| 3 | **2.3** | 0.36 | **14.8** | 2.2 |

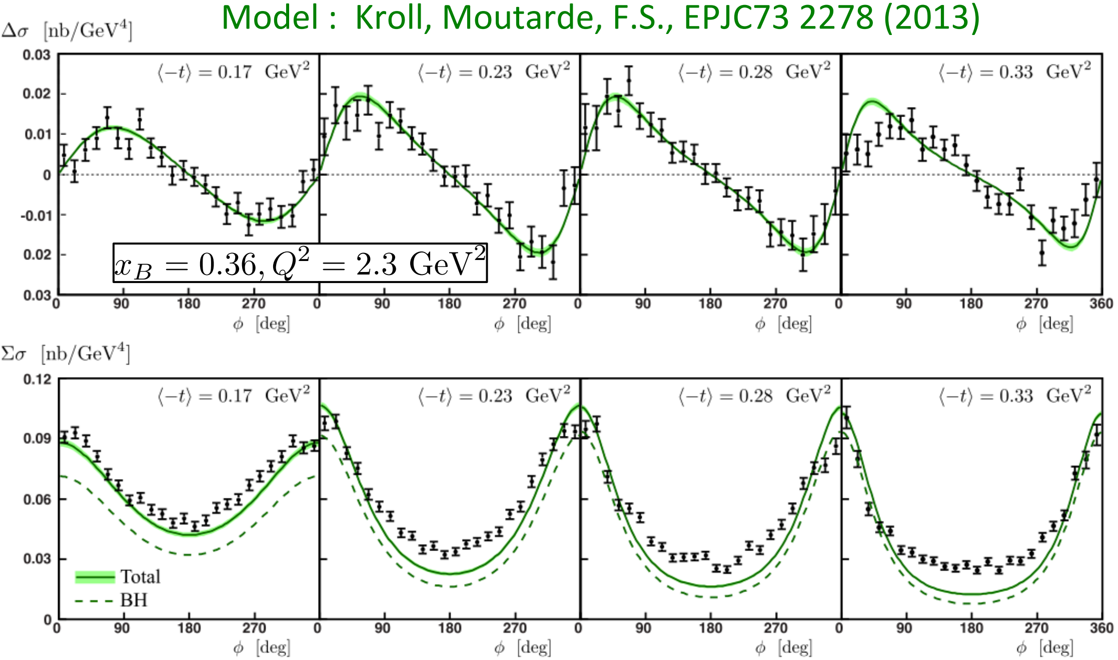
Electromagnetic Calorimeter



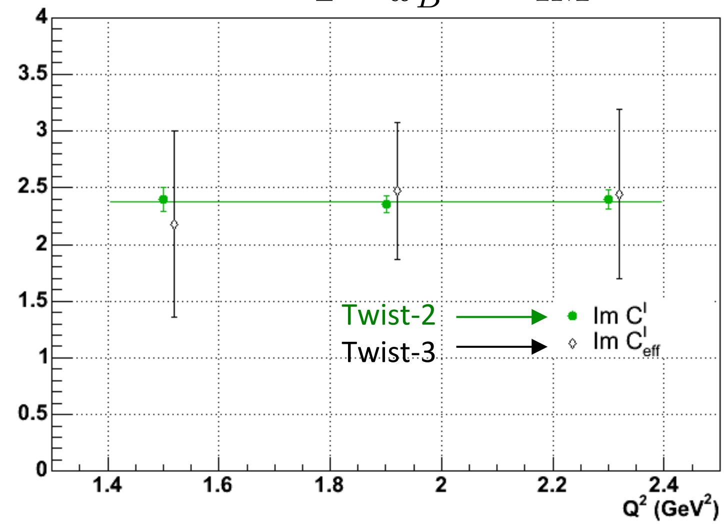
# Hall A pioneering results (proton target)

Data : Munoz et al, PRL97, 262002 (2006)

Model : Kroll, Moutarde, F.S., EPJC73 2278 (2013)




$$C^I = F_1\mathcal{H} + \frac{x_B}{2-x_B}\widetilde{\mathcal{H}} - \frac{t}{4M^2}F_2\mathcal{E}$$




<u>What happened since then ?</u>

New DVCS experiment in 2010 induced :

- Improved experimental setup
- Improved Monte Carlo simulation
- Improved treatment of Radiative Corrections
- Improved understanding of normalization (inclusive trigger)

**JLab Hall A DVCS experiment run 2 (2010)**

*Full separation of DVCS$^2$ with 3 beam energies*

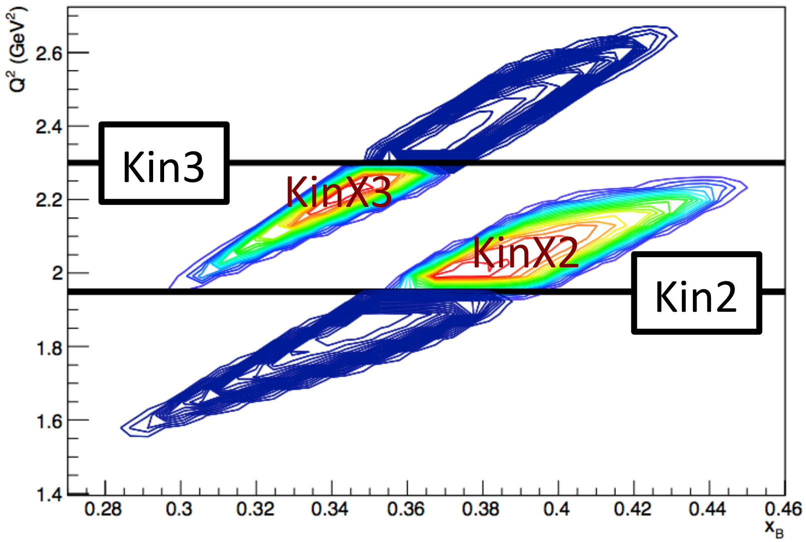
Beam: 5.5 - 4.5 - 3.4 GeV, 80% polarized
Luminosity: 20,000 fb$^{-1}$
Targets: LH2, LD2

**Preliminary results expected later this year !**

**>>> Re-analysis of 2004 data <<<**

# New analysis of 2004 data

PhD Student : Maxime Defurne (CEA Saclay)




2004 analysis kinematics

| Kin | $Q^2$ (GeV$^2$) | $x_B$ |
|---|---|---|
| 1 | **1.5** | 0.36 |
| 2 | **1.9** | 0.36 |
| 3 | **2.3** | 0.36 |

Additional kinematics

| Name | $Q^2$ (GeV$^2$) | $x_B$ |
|---|---|---|
| KinX2 | 2.1 | 0.4 |
| KinX3 | 2.1 | 0.34 |

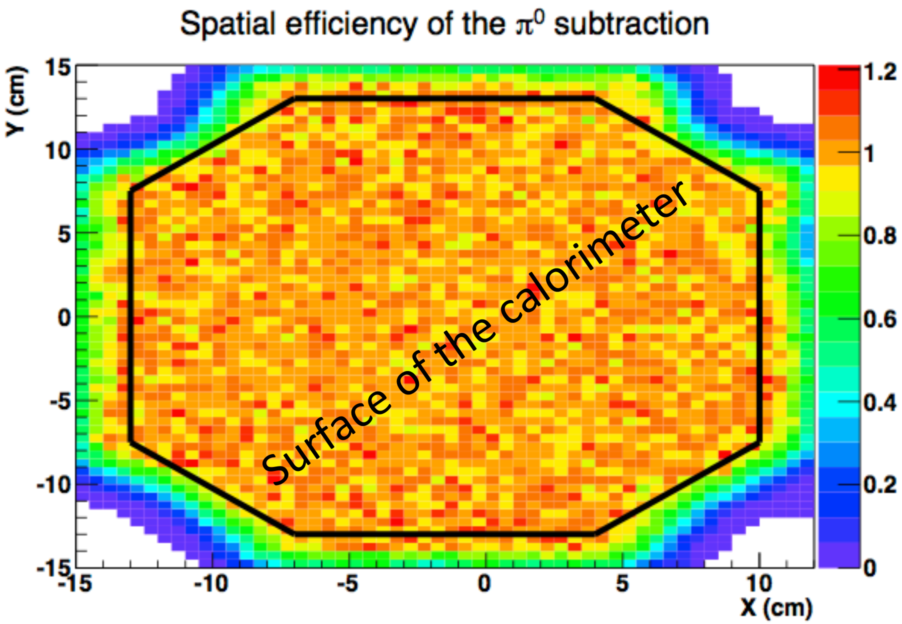
<u>What's new :</u>

- Improved Monte Carlo simulation
- Improved treatment of Radiative Corrections
- Improved understanding of normalization (inclusive trigger)
- Improved understanding of $\pi^0$ data for subtraction
- Improved systematic studies

<u>Re-analysis of *full* data set, but in addition :</u>

- Analysis of $Q^2$=1.9 GeV$^2$ unpolarized cross section (only 2.3 GeV$^2$ in 2004)
- Analysis of $x_B$-dependence of cross section (only $Q^2$ dependence in 2004)

# Analysis of unpolarized $Q^2$=1.9GeV$^2$ cross section

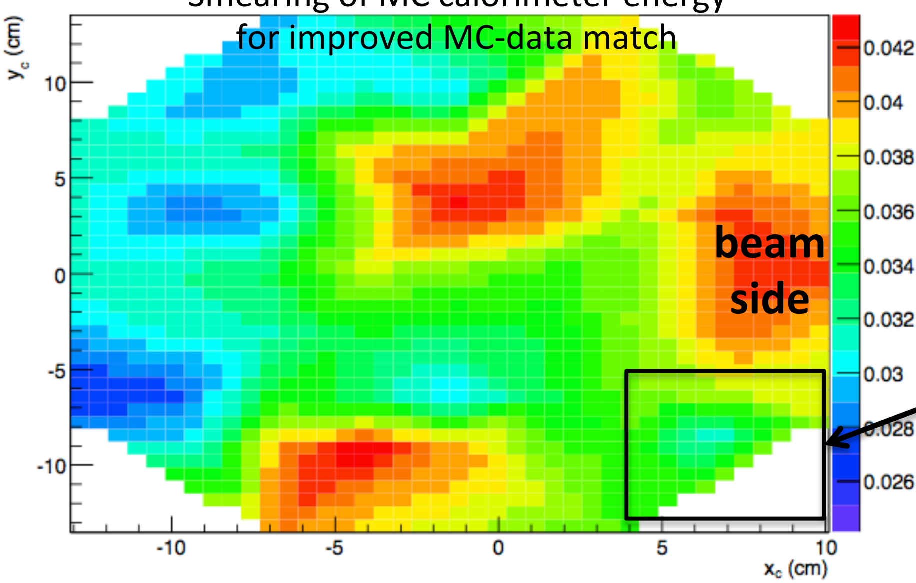



Building on $\pi^0$ analysis published in
Fuchey et al., Phys.Rev. C83 025201 (2011)

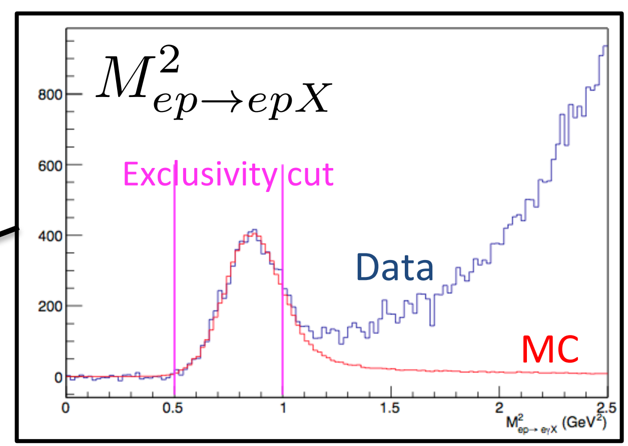
Efficient $\pi^0$ subtraction zone defined by *fiducial cut* at the surface of the calorimeter

Correction of Kin2 cross section is now possible !

Smearing of MC calorimeter energy
for improved MC-data match




Upgraded Monte-Carlo techniques :
*Improved agreement* in the fiducial area between data and MC



# NEW Results : unpolarized cross section, $Q^2$ dependence

Systematics under study

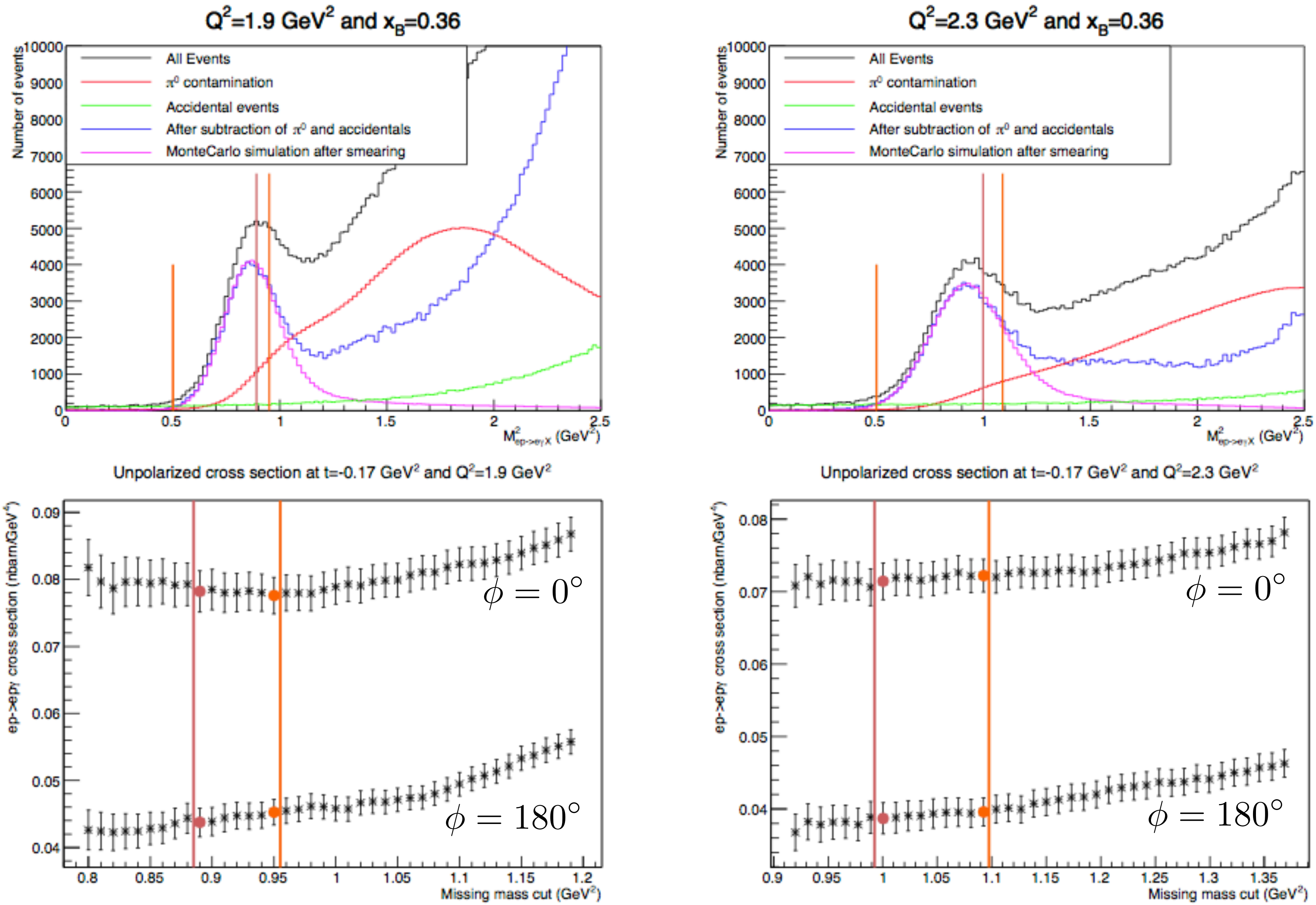
PRELIMINARY

Old data set

the other bins are new !

KM10a (fit) : Kumericki, Müller, Nucl.Phys. B841 1 (2010)
KMS12 : Kroll, Moutarde, F.S., EPJC73 2278 (2013)

# Systematic studies : $M^2_{ep\to e\gamma X}$ exclusivity cut



# NEW Results : unpolarized cross section, $x_B$ dependence

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PRELIMINARY

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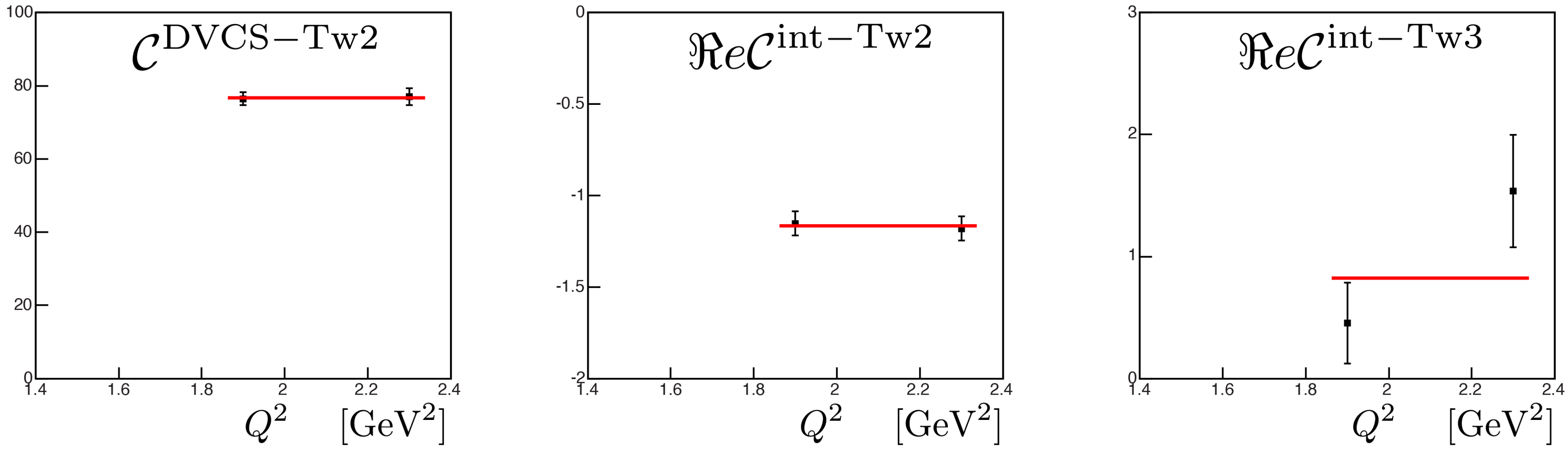
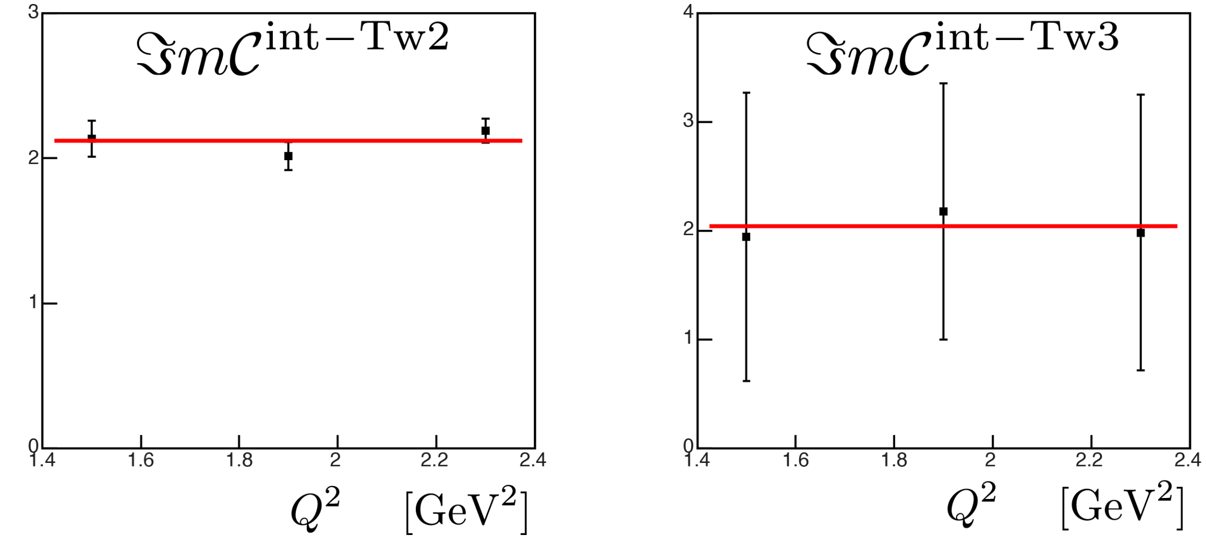
Systematics under study

# UPDATED $Q^2$ scaling check (pol.) + NEW check (unpol.)




Scaling verified overall

Hint of significant DVCS$^2$

Will be checked with larger $Q^2$ level arm (12 GeV data)

# NEW Results : polarized cross section, $x_B$ dependence

Systematics under study

PRELIMINARY

KM10a (fit) : Kumericki, Müller, Nucl.Phys. B841 1 (2010)

KMS12 : Kroll, Moutarde, F.S., EPJC73 2278 (2013)

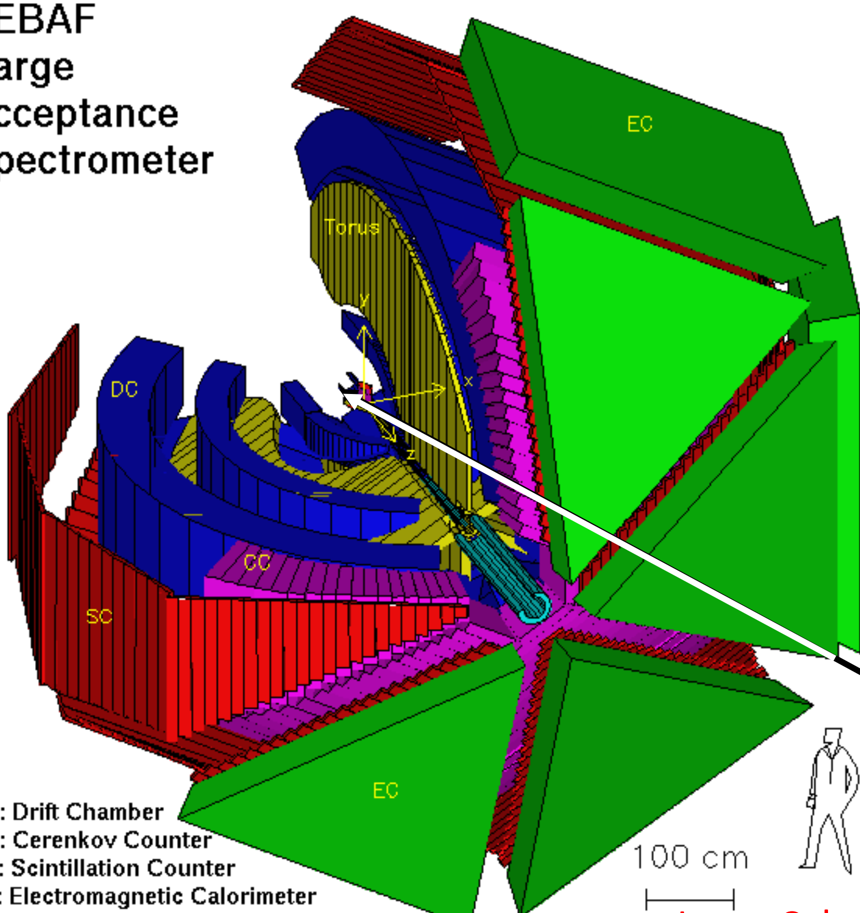
Beam energy: 5.8 GeV

Beam Polarization: 75-85%

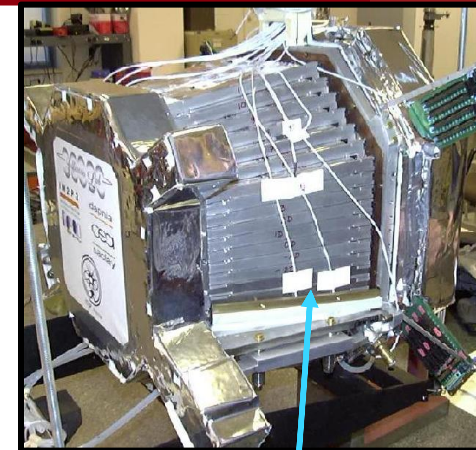
Integ. Luminosity: 45 $fb^{-1}$

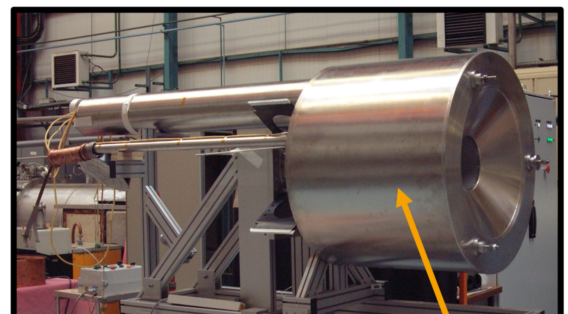
2nd half of data under analysis

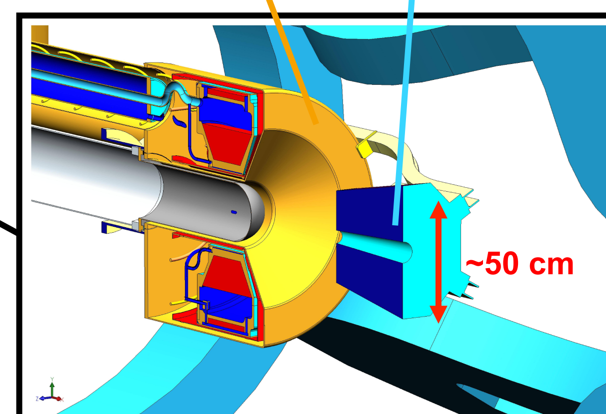
CEBAF
Large
Acceptance
Spectrometer




DC: Drift Chamber
CC: Cerenkov Counter
SC: Scintillation Counter
EC: Electromagnetic Calorimeter



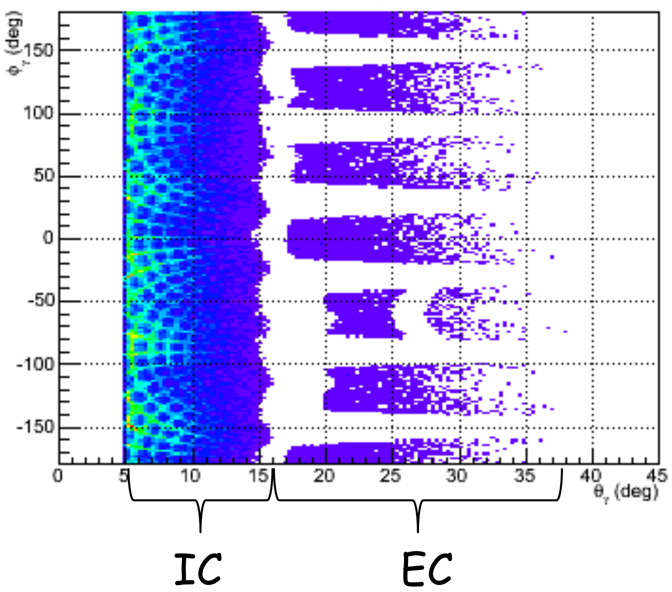


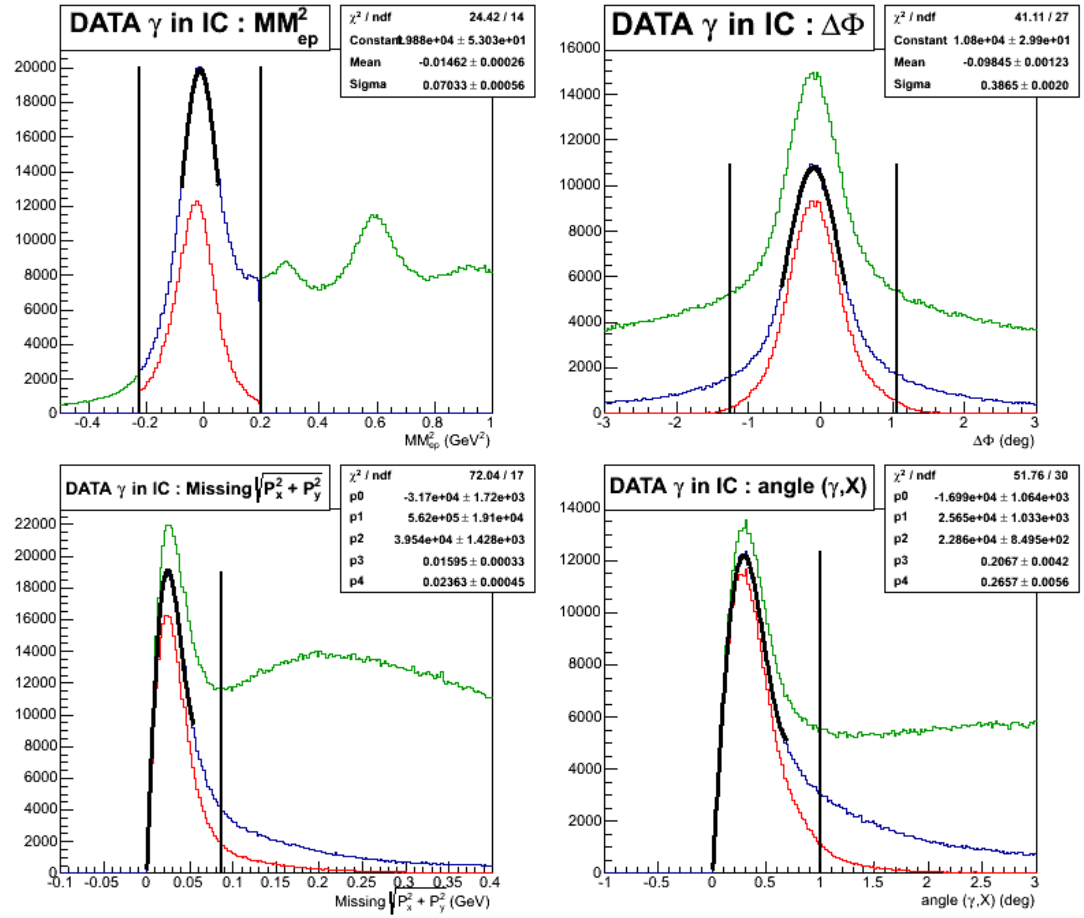



Inner Calorimeter
+ Moller shielding solenoid

$ep \to ep\gamma$ exclusivity cuts in the case where the photon is detected in the IC

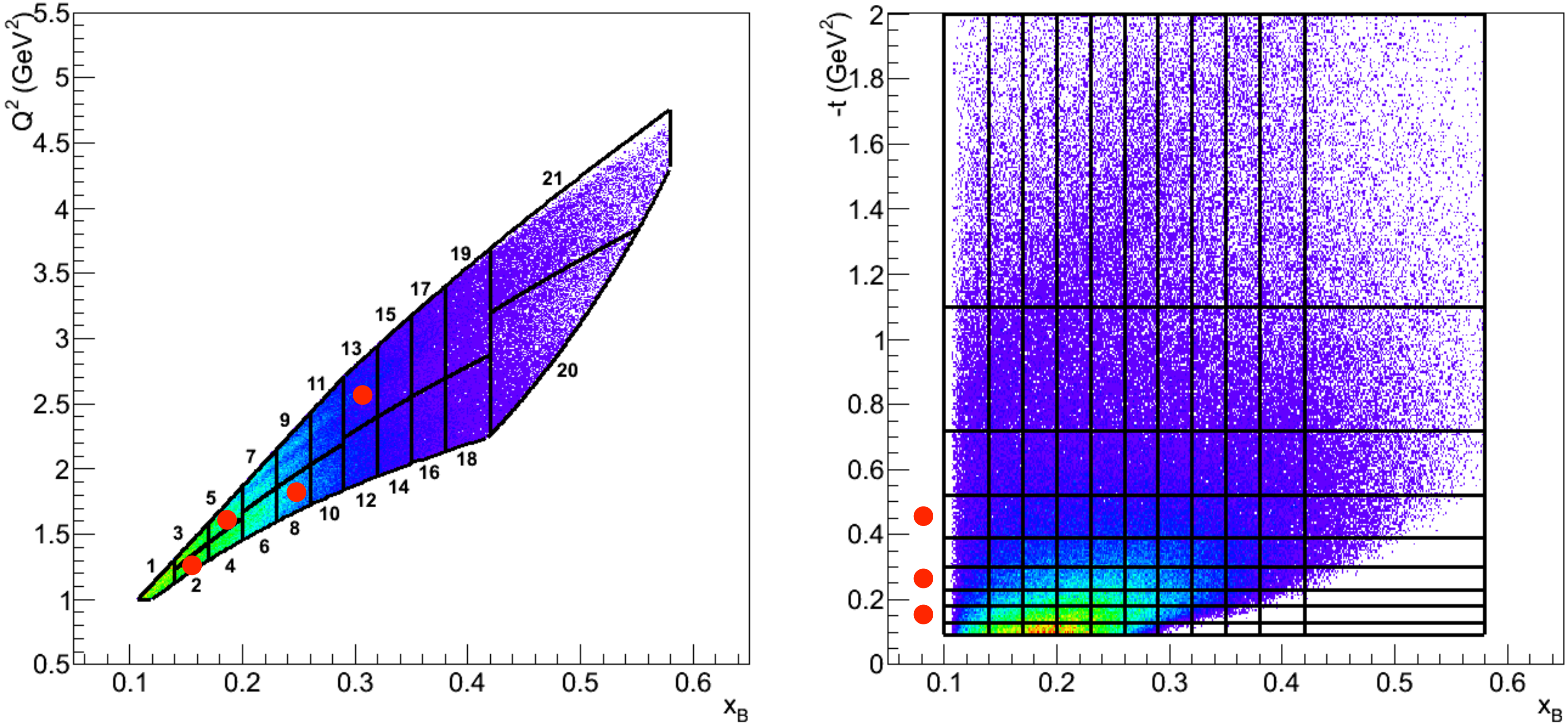
Photon : $\theta$ vs $\phi$



# Kinematics, binning

$$Q^2 > 1,\ 0.1 < x_B < 0.58,\ 21 < \theta_e < 45,\ p_e > 0.8,\ W > 2$$



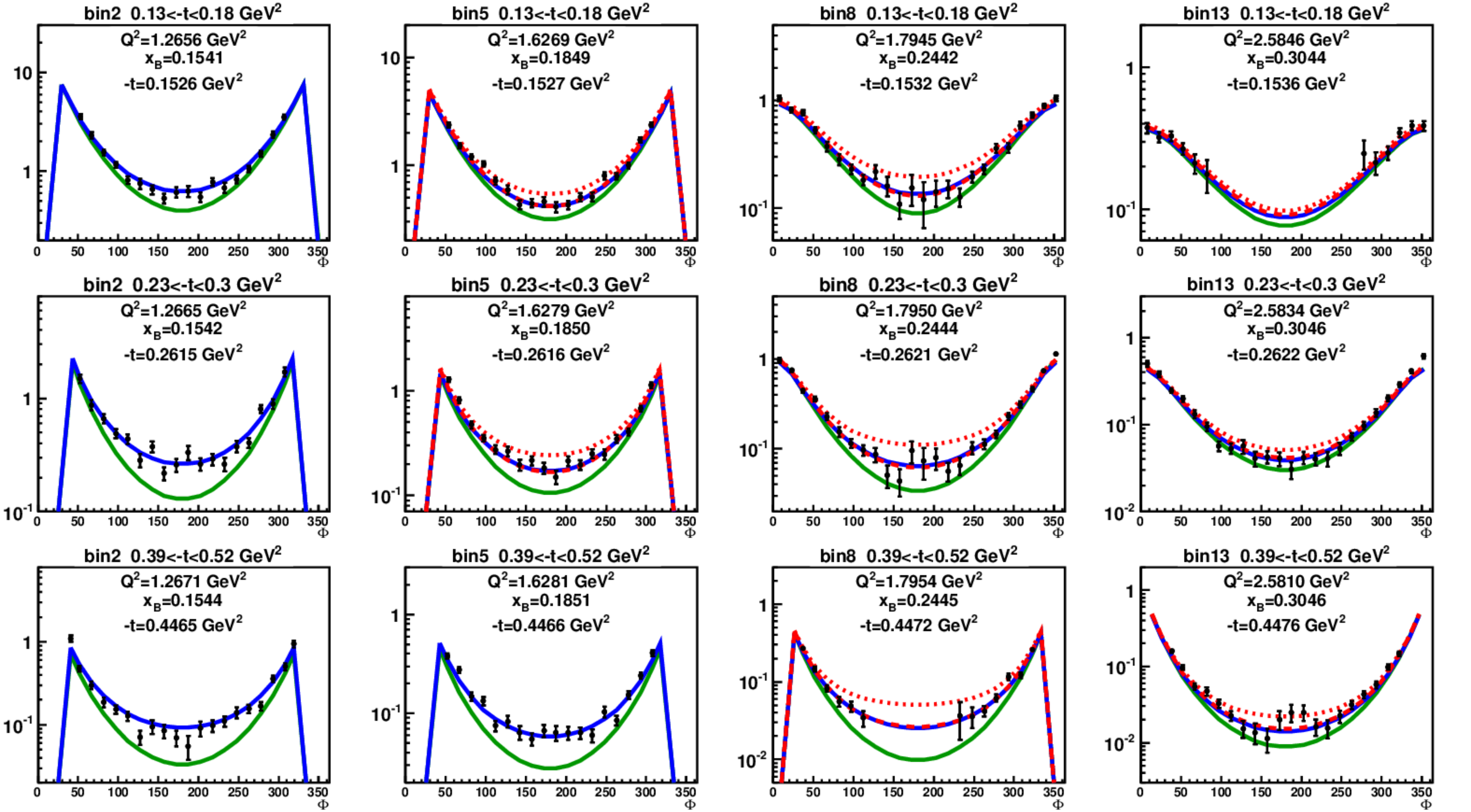

21 bins in ($x_B$,$Q^2$), 9 bins in t, 24 bins in $\phi$

# Cross sections

Data from: H.S. Jo

VGG
KM10a
KM10b
BH

PRELIMINARY




KM10ab (fit) : Kumericki, Müller, Nucl.Phys. B841 1 (2010)

VGG (only H) : Goeke, Polyakov, Vanderhaeghen , Prog.Part.Nucl.Phys. 47 401 (2001)

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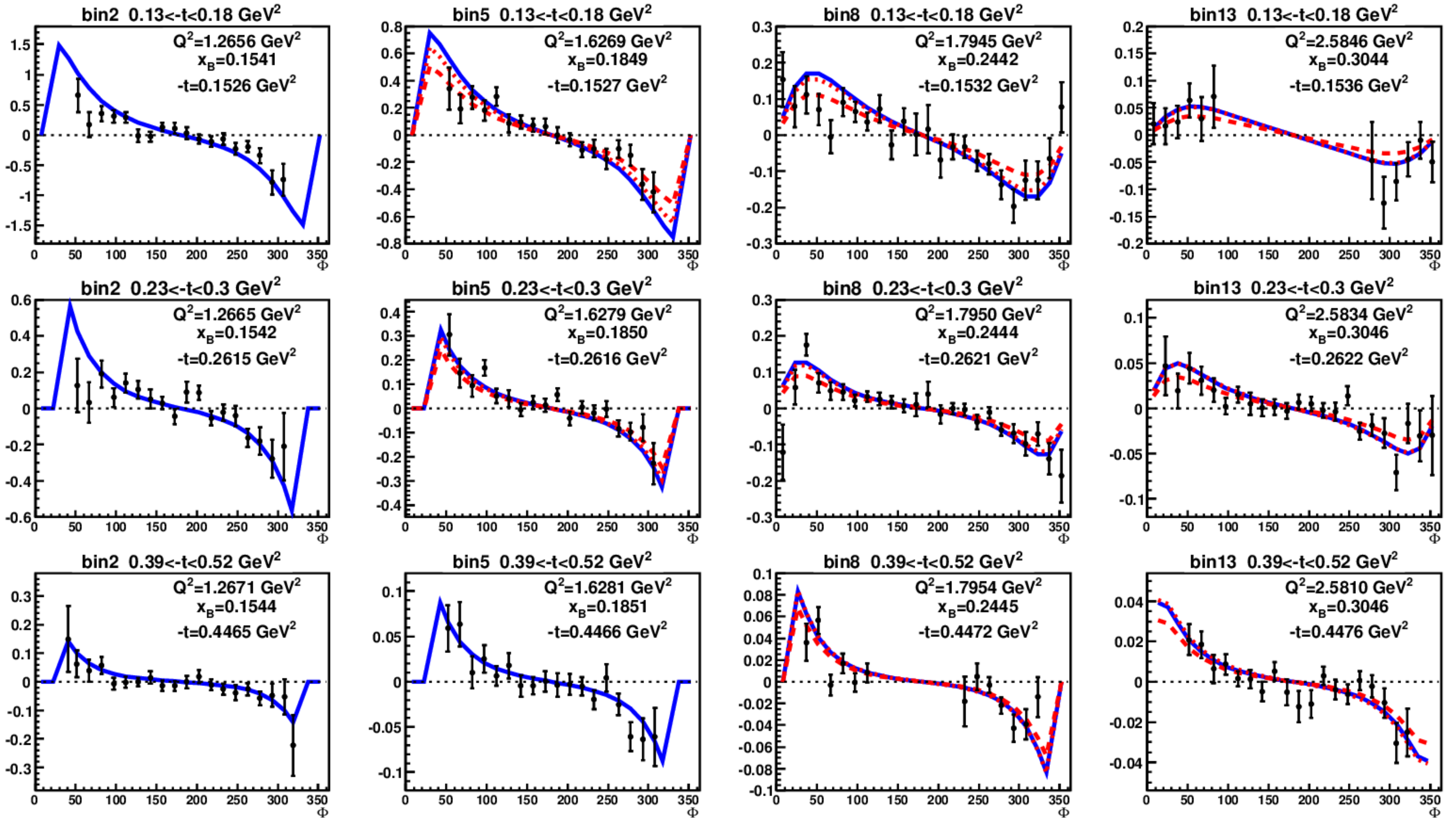
Data from: H.S. Jo

VGG
KM10a
KM10b

PRELIMINARY

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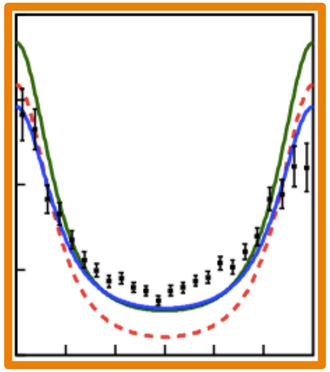
# Summary and Conclusion

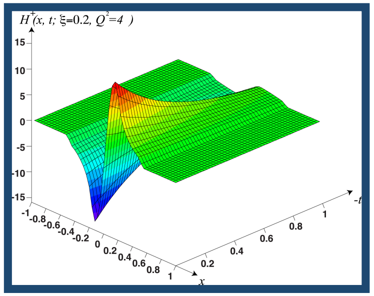


- Exciting times for DVCS in the valence region :

  New analysis and/or New data from Hall A and CLAS

  Fair agreement with previous fits of world-wide data (KM10)

- These data will be used in global fits when released (summer 2014)

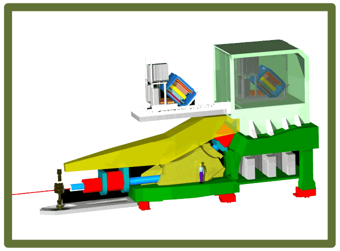



- GPD H is pinned down using data from low-x (HERA) to high-x (JLab)

- More data expected from JLab in 2014 :

  Hall A : Rosenbluth study to pin down DVCS² contribution to cross section

  Hall B : longitudinally polarized target data (already preliminary)



- The future :

  "12" GeV experiments at JLab A/B/C (Hall A experiment already started)

  DVCS @ COMPASS in 2016, and then an exciting program at EIC !