Deeply Virtual Compton Scattering on the neutron

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Hall A

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For JLab Hall A & DVCS collaborations

- Physics case
- n-DVCS experimental setup
- Analysis method
- Results and conclusions

Exclusive Reactions at High Momentum Transfer

May 21st 2007

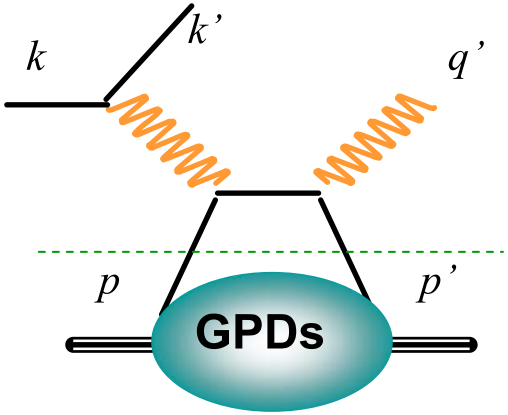
Deeply Virtual Compton Scattering

GPDs give an access to **quark angular momentum** (Ji's sum rule)

$$J_q = \frac{1}{2}\Delta\Sigma_q + L_q = \frac{1}{2}\int_{-1}^{1} x dx \left[H^q(x,\xi,0) + E^q(x,\xi,0) \right]$$

less constrained GPD ← No link to DIS

DVCS is the simplest hard exclusive process involving GPDs

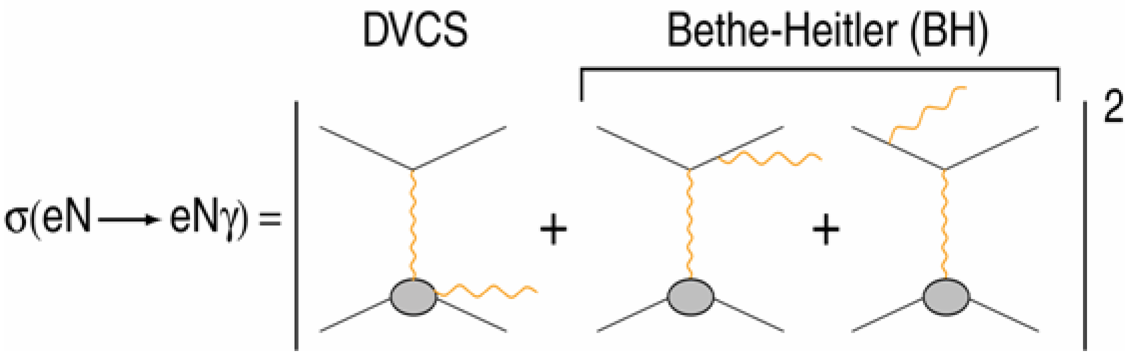


Factorization theorem
in the Bjorken regime

$$Q^2 = -q^2 = -(k-k')^2 >> M^2$$
$$t = (p-p')^2 = \Delta^2 << Q^2$$

Non perturbative
description by GPDs

DVCS and Bethe-Heitler



The **total cross-section** accesses the real part of DVCS and therefore an **integral of GPDs over x**

The **polarized cross-section difference** accesses the Imaginary part of DVCS and therefore **GPDs at x=±ξ**

$$d^5\vec{\sigma} - d^5\overleftarrow{\sigma} = 2\Im\mathrm{m}(T^{BH}.T^{DVCS}) + \left[\left|\vec{T}^{DVCS}\right|^2 - \left|\overleftarrow{T}^{DVCS}\right|^2\right]$$

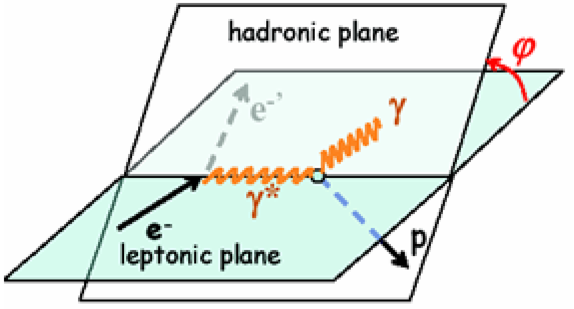
Purely real and **fully calculable**

Small at JLab energies (twist-3 term)

If handbag dominance

$$d^5\vec{\sigma} - d^5\overleftarrow{\sigma} = \Gamma(x_B, Q^2, t, \varphi)\ \Im m\left(C^I\right)\ \sin\varphi$$

$$C^I(F) = F_1(t)\mathcal{H} + \xi\left(F_1(t) + F_2(t)\right)\tilde{\mathcal{H}} - \frac{t}{4M^2}F_2(t)\mathcal{E}$$



Neutron Target

Model:

(Goeke, Polyakov and Vanderhaeghen)

Target	$\mathcal{H}$	$\tilde{\mathcal{H}}$	$\mathcal{E}$
neutron	0.81	-0.07	1.73

$Q^2 = 2\ \mathrm{GeV}^2$

$x_B = 0.3$

$-t = 0.3\ \mathrm{GeV}^2$

$$\Im\mathrm{m}\left(C^I\right) = \underbrace{F_1(t)}\cdot\mathcal{H} + \underbrace{\frac{x_B}{2-x_B}\cdot\left(F_1(t)+F_2(t)\right)}\cdot\tilde{\mathcal{H}} - \underbrace{\frac{t}{4M^2}F_2(t)}\cdot\mathcal{E}$$

$-t$	$F_2^n(t)$	$F_1^n(t)$	$\left(F_1^n(t)+F_2^n(t)\right)\cdot x_B/(2-x_B)$	$(-t/4M^2)\cdot F_2^n(t)$
0.3	-0.91	-0.04	-0.17	-0.07

$$\Im\mathrm{m}\left(C^I\right) = \underbrace{\cancel{F_1(t)\cdot\mathcal{H}}} + \underbrace{\frac{x_B}{2-x_B}\cdot\left(F_1(t)+\cancel{F_2(t)}\right)\cdot\tilde{\mathcal{H}}} - \underbrace{\frac{t}{4M^2}F_2(t)\cdot\mathcal{E}}$$

$$\Im\mathrm{m}\left(C^I\right) = \cancel{-0.03} + \cancel{0.01} - 0.13$$

n-DVCS experiment

An **exploratory** experiment was performed at JLab Hall A on hydrogen target and deuterium target with high luminosity (4.10^{37} cm^{-2} s^{-1}) and exclusivity.

Goal : Measure the n-DVCS polarized cross-section difference which is mostly sensitive to GPD E (less constrained!)

E03-106 (n-DVCS) followed directly E00-110 (p-DVCS) which shows strong indications of handbag dominance at Q^2 about 2 GeV^2.

(C. Muñoz-Camacho et al., PRL 97 (2006) 262002.)

x_{Bj}=0.364	s (GeV²)	Q² (GeV²)	P_e (Gev/c)	Θ_e (deg)	$-\Theta_{\gamma^*}$ (deg)	$\int Ldt$ (fb^{-1})
Hydrogen	4.22	1.91	2.95	19.32	18.25	4365
Deuterium	4.22	1.91	2.95	19.32	18.25	24000

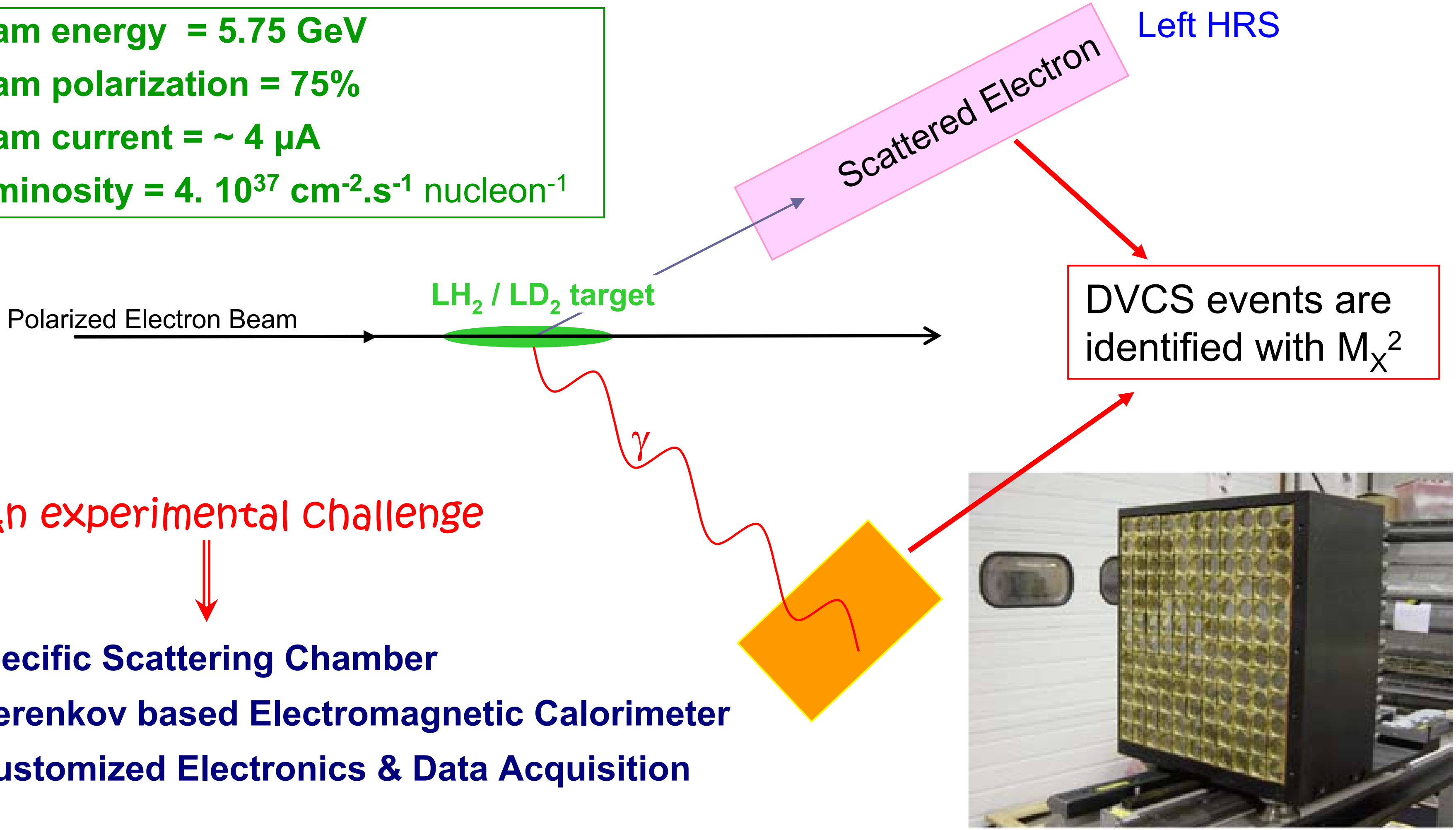
Experimental apparatus

Beam energy = 5.75 GeV

Beam polarization = 75%

Beam current = ~ 4 μA

Luminosity = 4. 10^{37} $cm^{-2}.s^{-1}$ nucleon^{-1}



DVCS events are identified with M_X^2

Electromagnetic Calorimeter

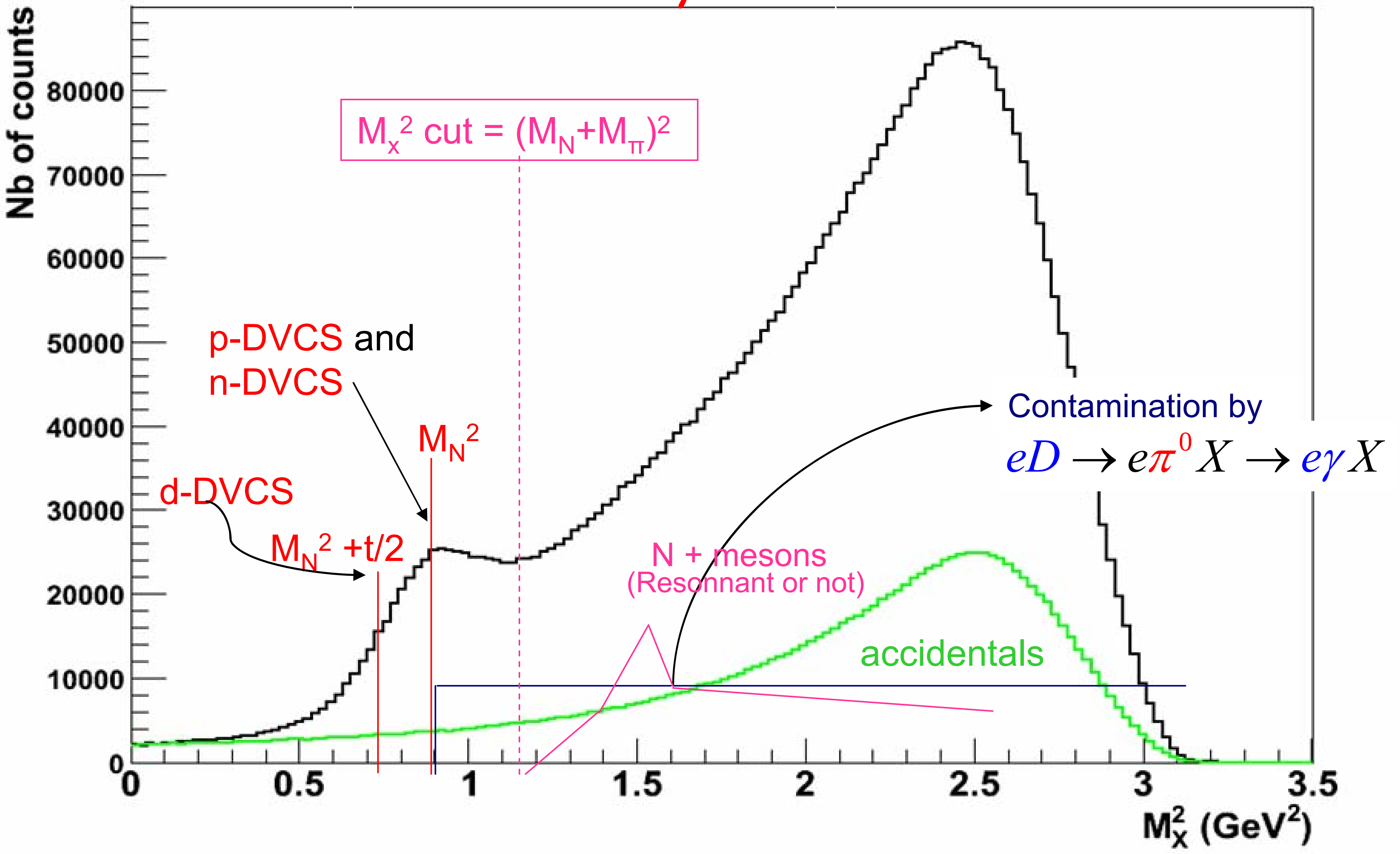
An experimental challenge

$\Downarrow$

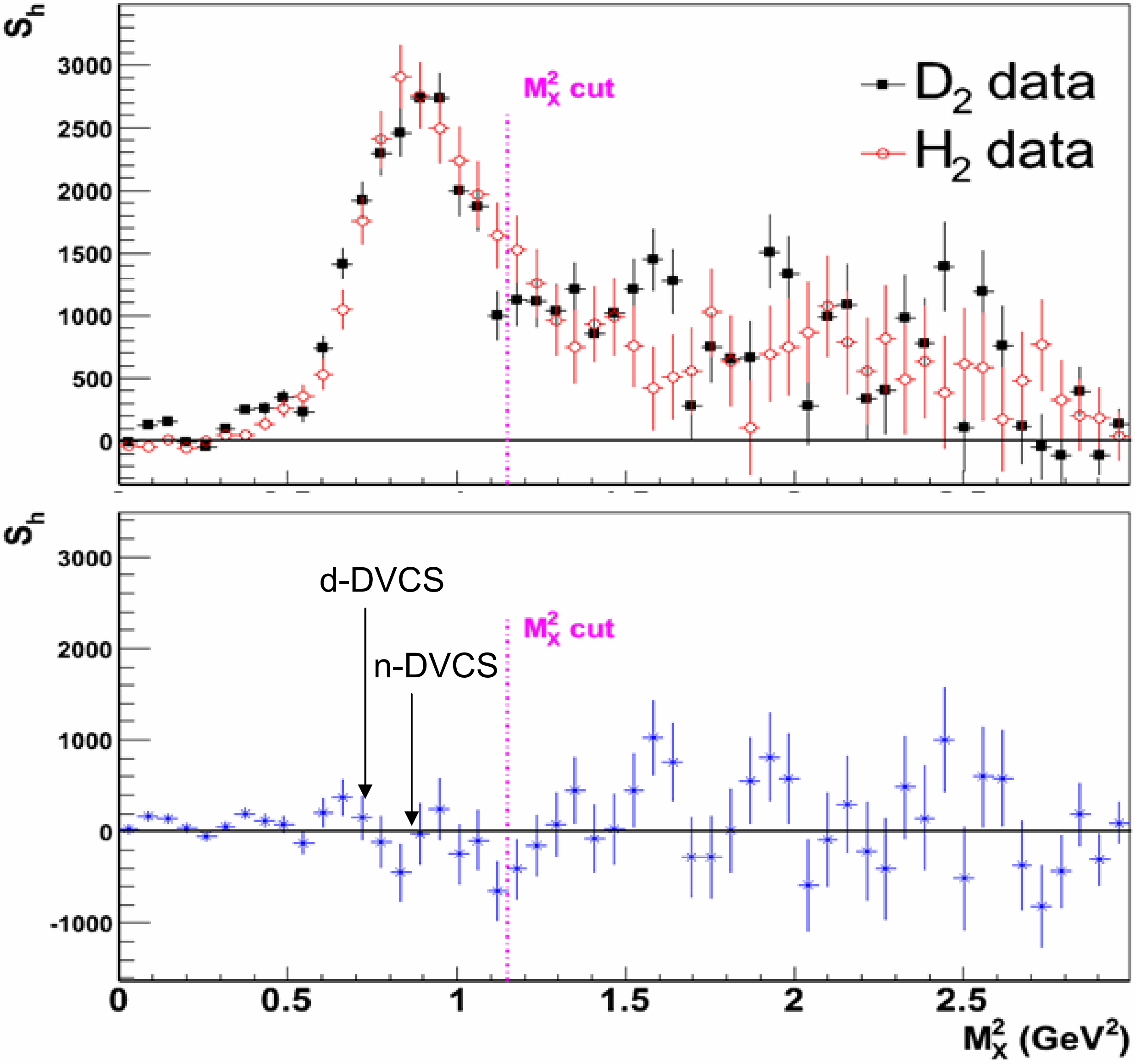
- **-Specific Scattering Chamber**
- **- Čerenkov based Electromagnetic Calorimeter**
- **- Customized Electronics & Data Acquisition**

Analysis method

$e\,D \rightarrow e\,\gamma\,X$ (target mass = M_N^2)



Helicity signal and exclusivity



After :

-Normalizing H_2 and D_2 data to the same luminosity

-Adding Fermi momentum to H_2 data

2 principle sources of systematic errors :

-The contamination of π^0 electroproduction on the neutron (and deuteron).

- The uncertainty on the relative calibration between H_2 and D_2 data

Extraction of observables

$$\frac{1}{2}\left[\frac{d\vec{\sigma}}{dQ^2dx_Bd\Delta^2d\varphi_ed\varphi_{\gamma\gamma}}-\frac{d\overleftarrow{\sigma}}{dQ^2dx_Bd\Delta^2d\varphi_ed\varphi_{\gamma\gamma}}\right]=$$

$$\Gamma_n(x_B,\varphi_e,\Delta^2,\varphi)\cdot\mathfrak{I}\mathrm{m}\left(C_n^{I-\exp}\right)\sin\varphi+\Gamma_d(x_B,\varphi_e,\Delta^2,\varphi)\cdot\mathfrak{I}\mathrm{m}\left(C_d^{I-\exp}\right)\sin\varphi$$

A. V. Belitsky, D. Muller, A. Kirchner, Nucl. Phys. B629, 323 (2002).

$\Delta N^{Exp}(i_e)=N^+_{i_e}-N^-_{i_e}$ with $i_e = 20\otimes 12\otimes 7$ bins in $\left(M_X^2,\varphi,t\right)$

$$\Delta N^{MC}(i_e)=\underset{\substack{\nearrow\\ \text{Luminosity}}}{L}\left[\mathfrak{I}\mathrm{m}\left(C_n^{I-\exp}\right)\underbrace{\int_{x\in i_e}\Gamma_n.\sin\varphi\otimes Acc}_{\text{MC sampling}}+\mathfrak{I}\mathrm{m}\left(C_d^{I-\exp}\right)\underbrace{\int_{x\in i_e}\Gamma_d.\sin\varphi\otimes Acc}_{\text{MC sampling}}\right]$$

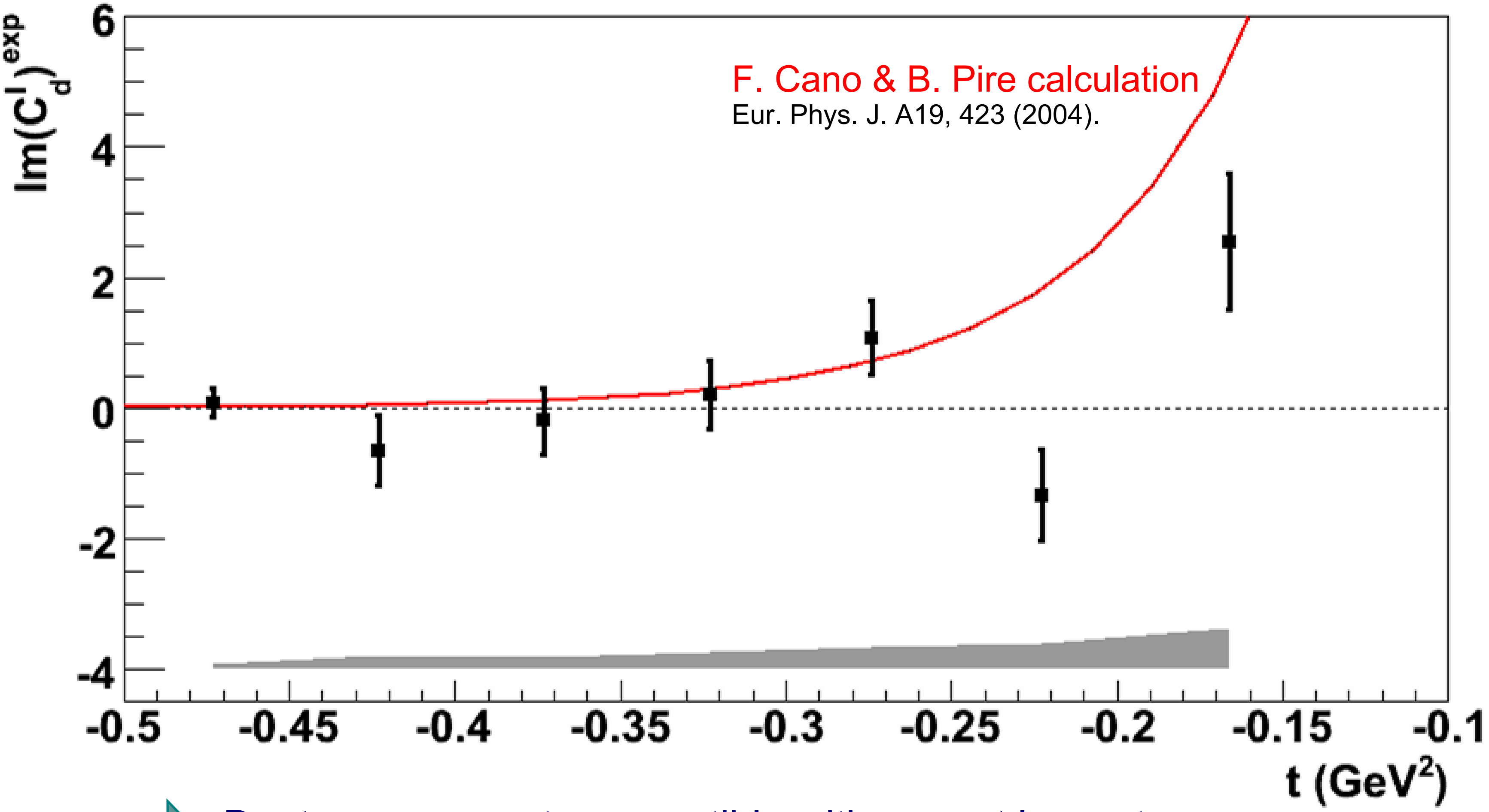
MC includes real radiative corrections (external+internal)

$$\chi^2=\sum_{i_e}\frac{\left[\Delta N^{Exp}(i_e)-\Delta N^{MC}(i_e)\right]^2}{\left[\sigma^{Exp}(i_e)\right]^2}\quad\Longrightarrow\quad\left\{\begin{array}{l}\mathfrak{I}\mathrm{m}\left(C_n^{I-\exp}\right)\\ \mathfrak{I}\mathrm{m}\left(C_d^{I-\exp}\right)\end{array}\right.$$

Extraction results

d-DVCS extraction results

PRELIMINARY

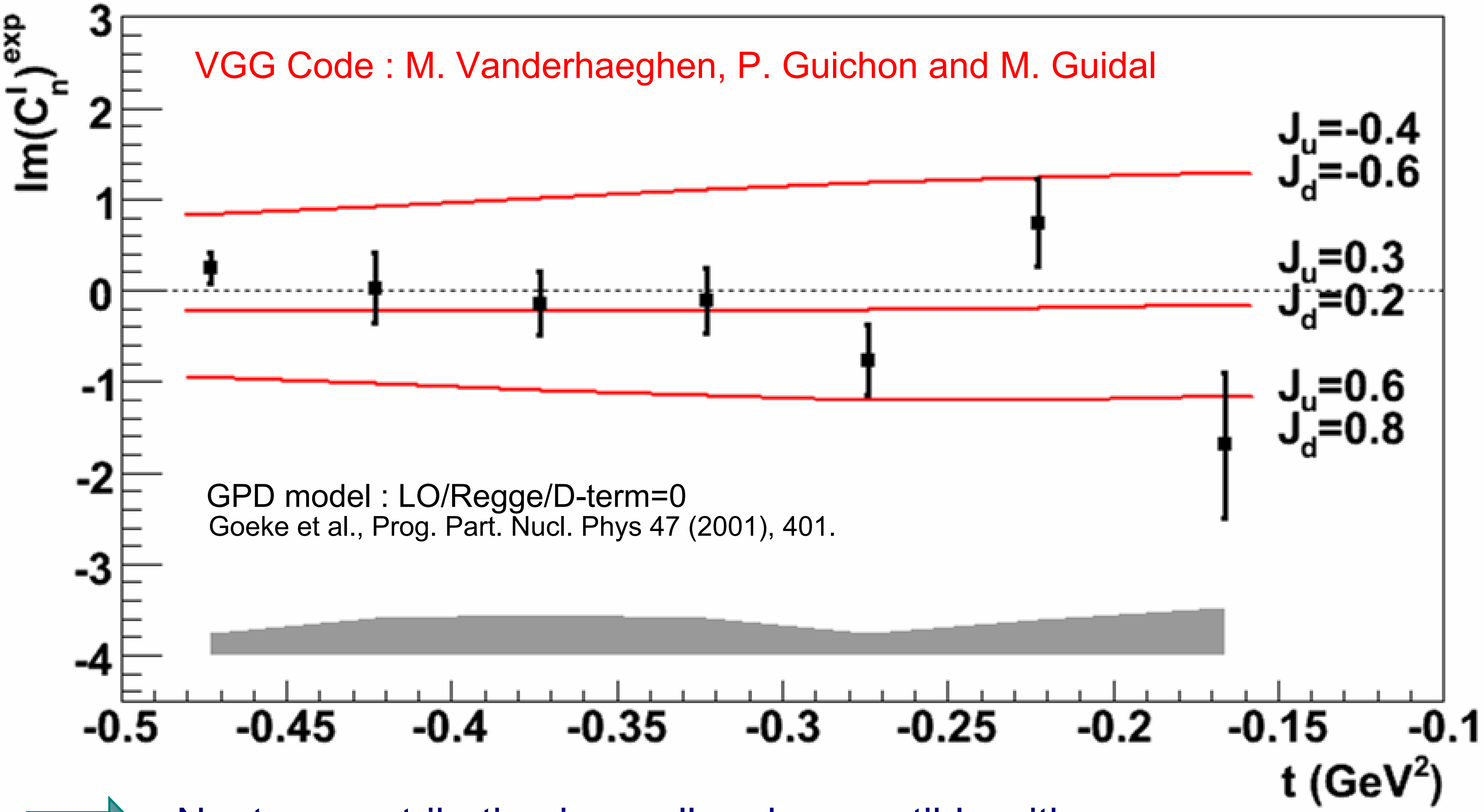


- Deuteron moments compatible with zero at large -t
- Exploration of small –t regions in future experiments is interesting

Extraction results

n-DVCS extraction results

PRELIMINARY



- Neutron contribution is small and compatible with zero
- Results can constrain GPD models (and therefore GPD E)

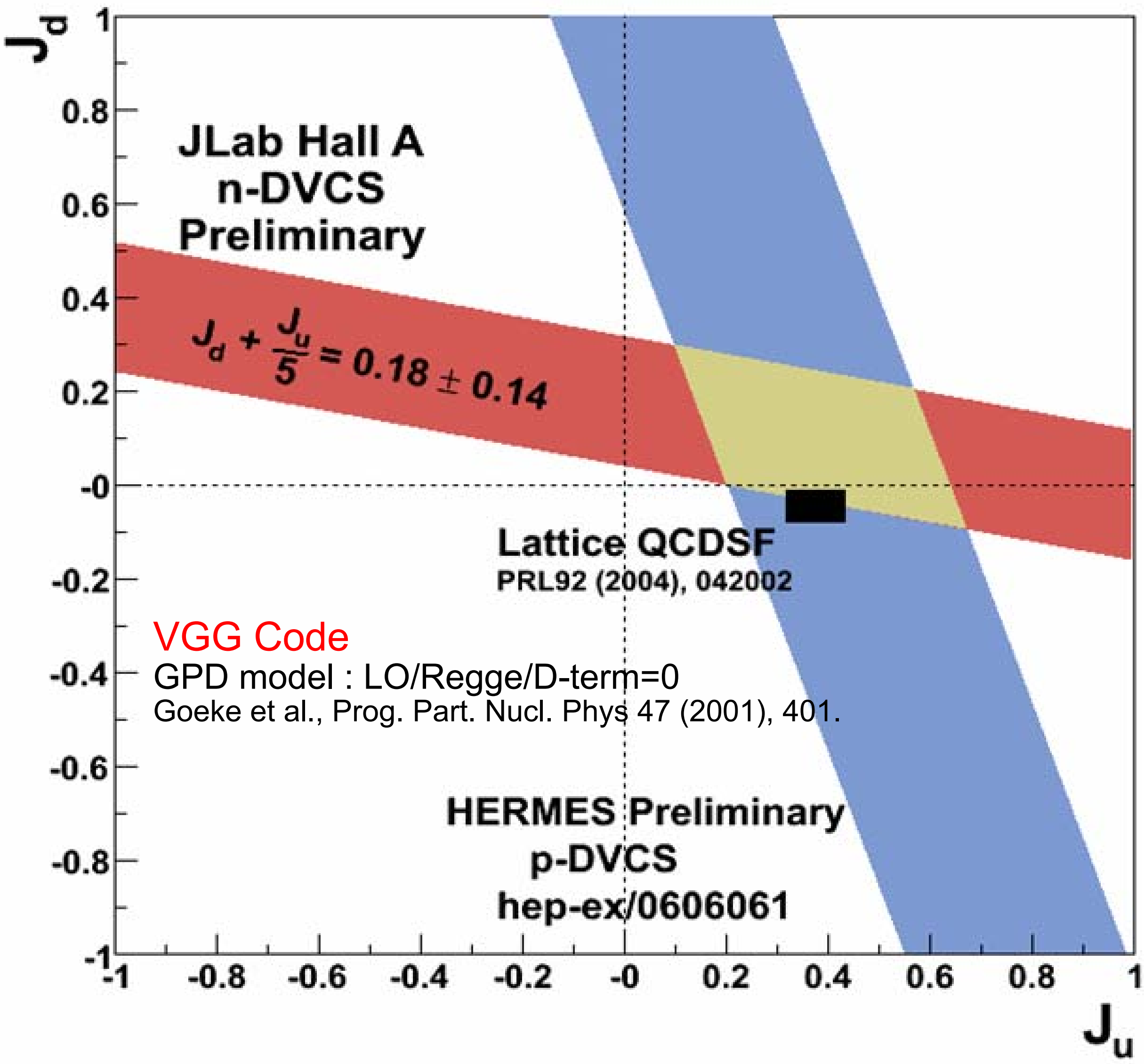
n-DVCS experiment results

Systematic errors of models are not shown

n-DVCS is sensitive to **Jd**

p-DVCS is sensitive to **Ju**

Complementarity between **neutron** and **transversally polarized proton** measurements



VGG Code

GPD model : LO/Regge/D-term=0

Goeke et al., Prog. Part. Nucl. Phys 47 (2001), 401.

Summary and conclusion

- Our experiment is exploratory and is dedicated to n-DVCS.

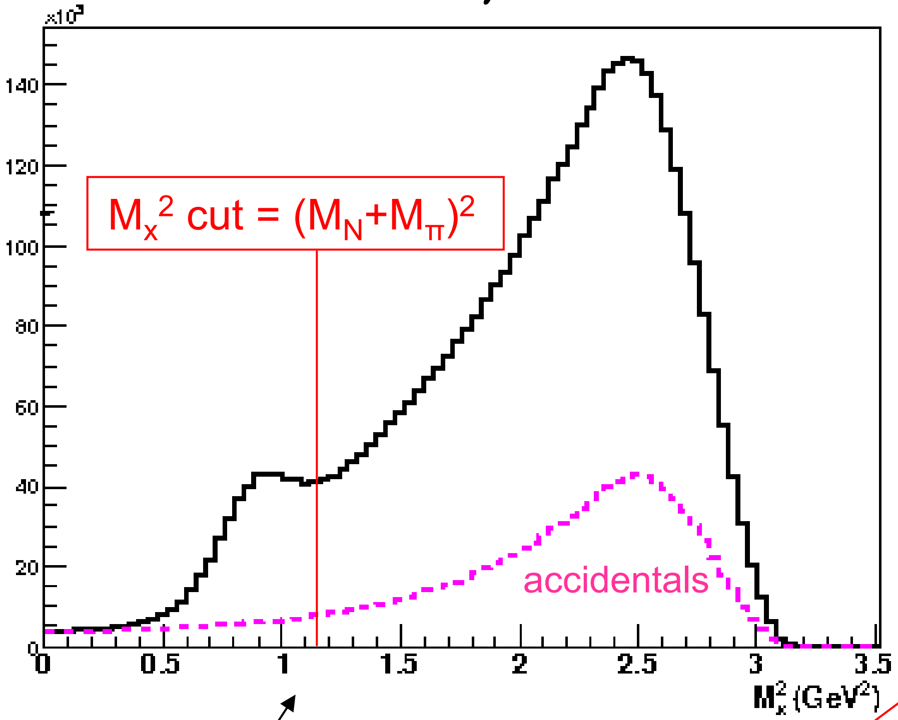
  n-DVCS and d-DVCS contributions are obtained after a subtraction of Hydrogen data from Deuterium data (no recoil detectors needed).

- n-DVCS and d-DVCS polarized cross-sections difference are compatible with zero.
- Neutron results can constrain GPD models (GPD E parametrization)

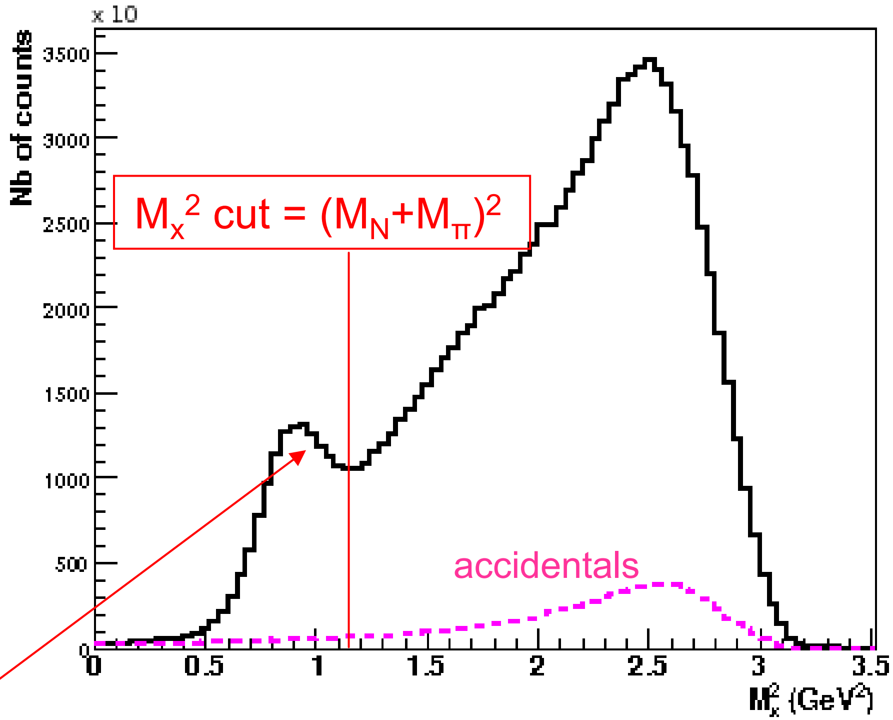
- Neutron has a different flavor sensitivity to GPD E than transversally polarized proton.
- Neutron experiments are mandatory complements to proton ones.
- Re(DVCS) from unpolarized cross-section should be measured.

Analysis method

$eD \rightarrow e\gamma X$



$eH \rightarrow e\gamma X$



$$D(e,e'\gamma)X = p(e,e'\gamma)p + n(e,e'\gamma)n + d(e,e'\gamma)d + \ldots$$

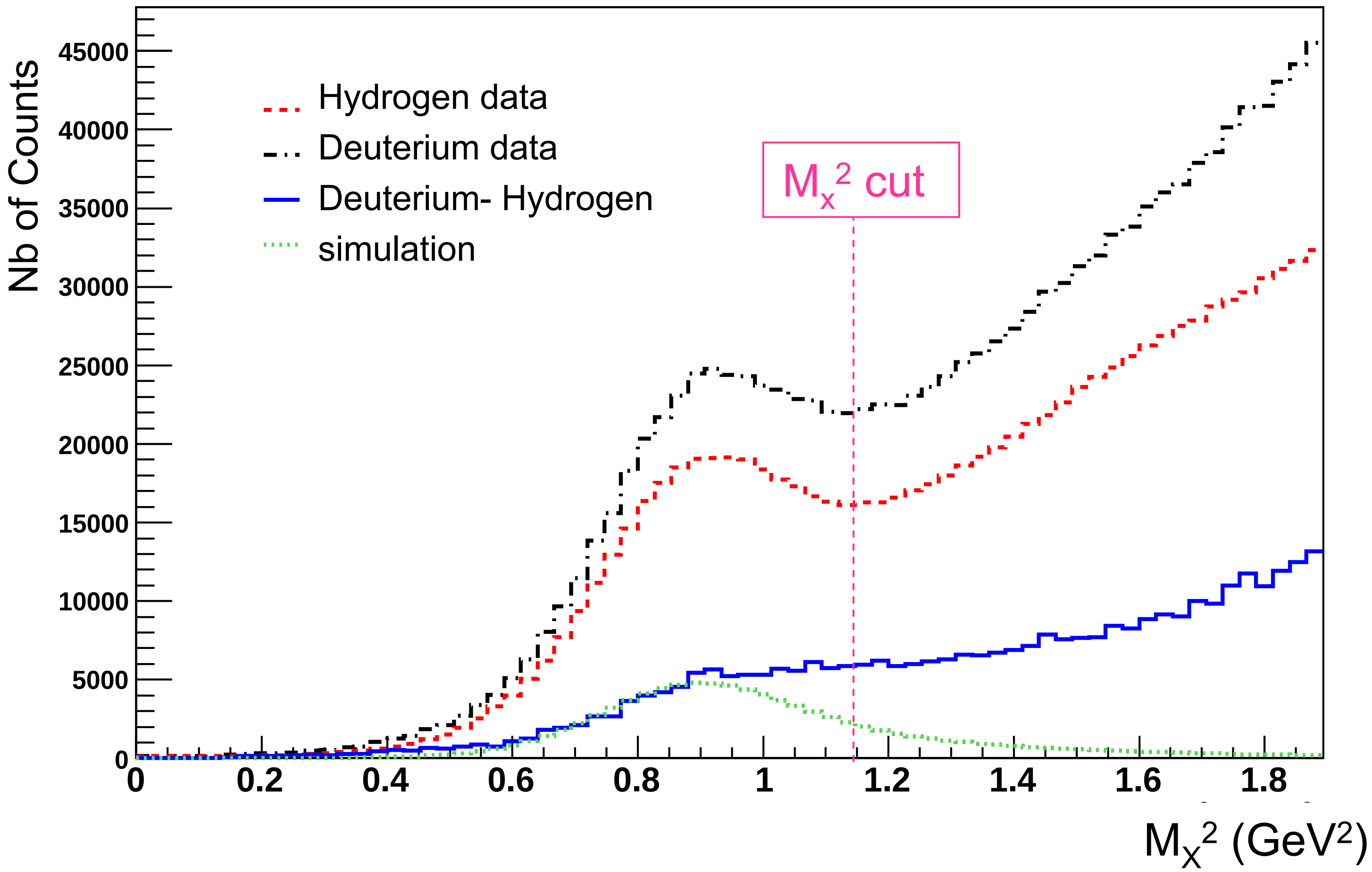
p-DVCS events

n-DVCS events

d-DVCS events

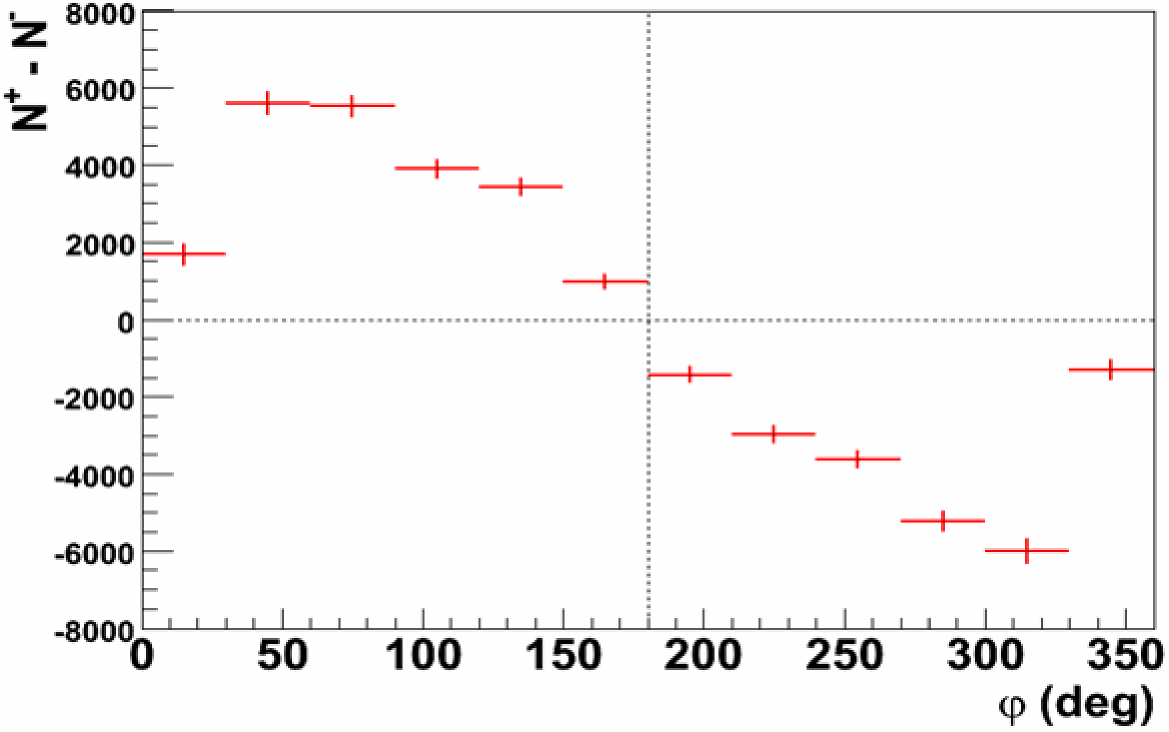
Mesons production

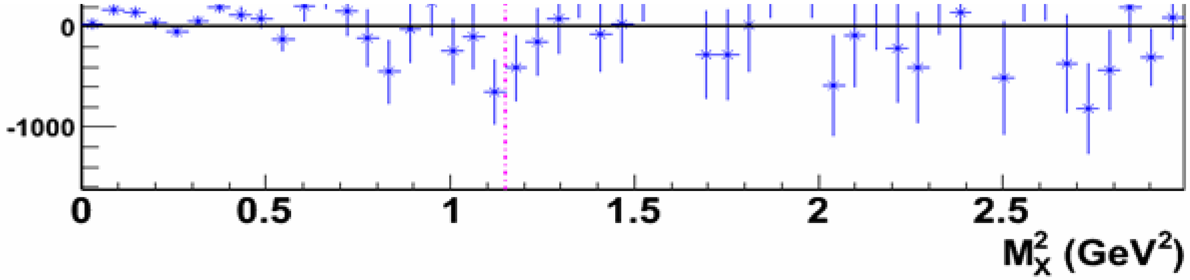
Double coincidence analysis



Helicity signal and exclusivity

$$S_h = \int_0^{\pi} (N^+ - N^-) d\varphi - \int_{\pi}^{2\pi} (N^+ - N^-) d\varphi$$





After :

-Normalizing H_2 and D_2 data to the same luminosity

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2 principle sources of systematic errors :

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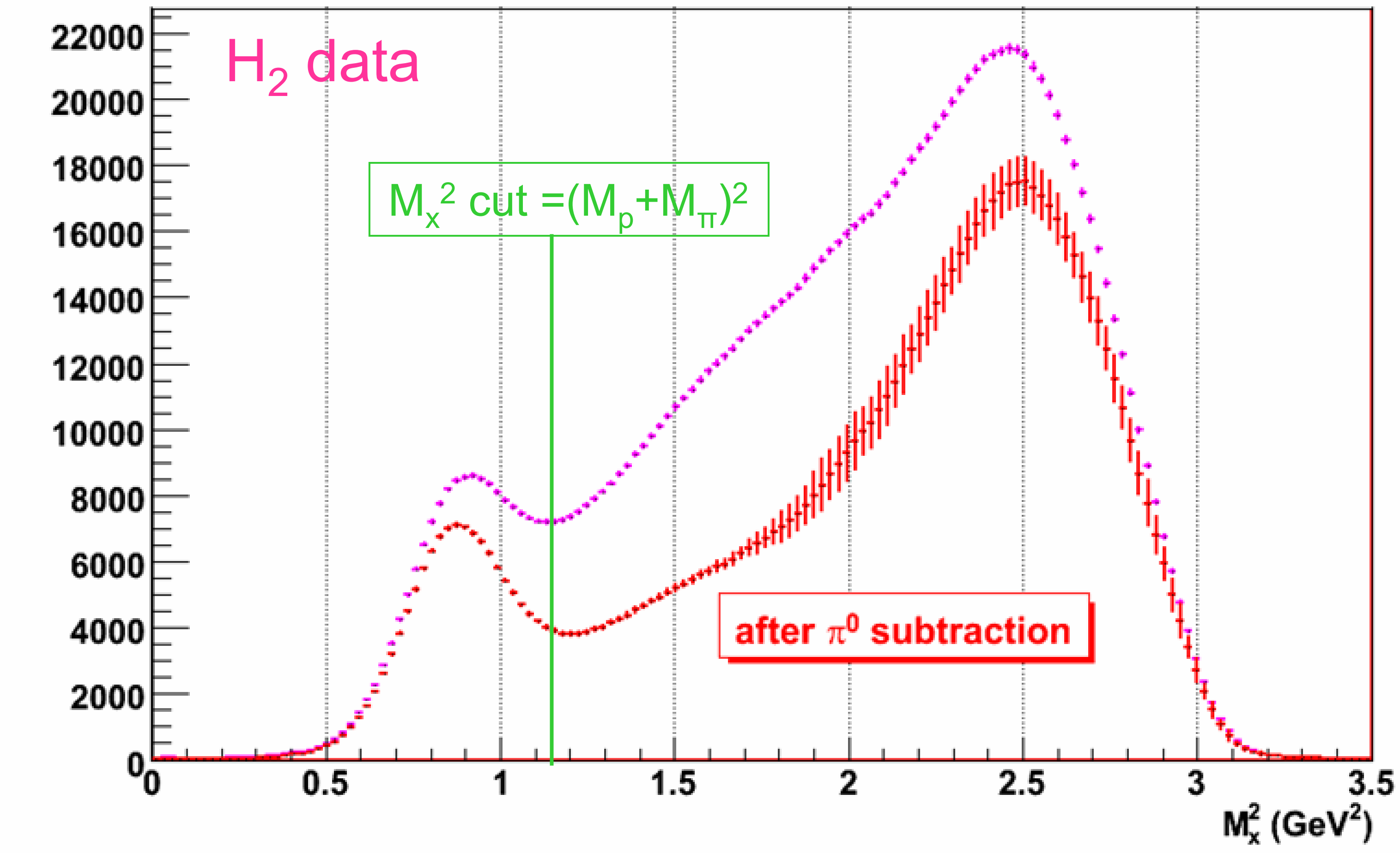
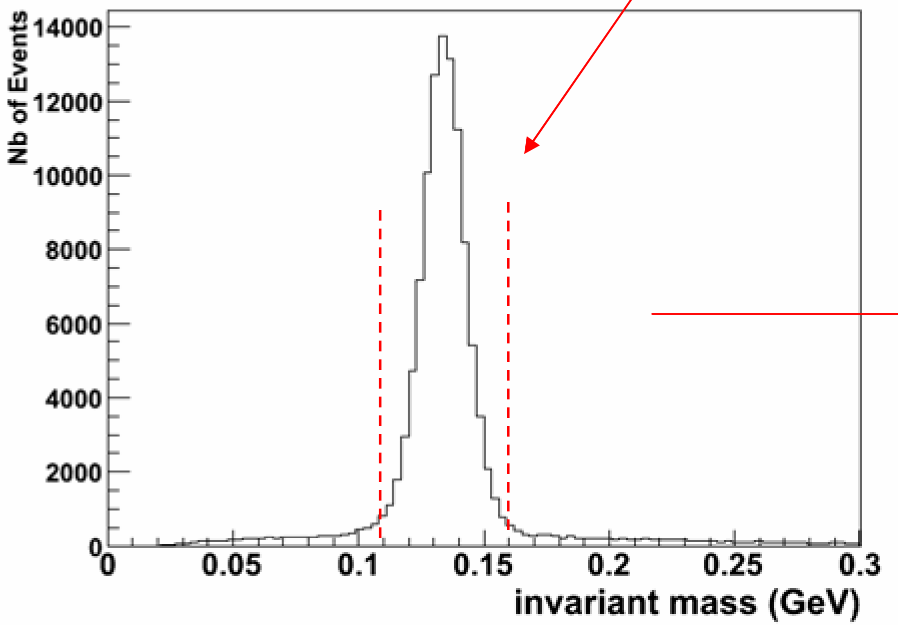
π^0 contamination subtraction

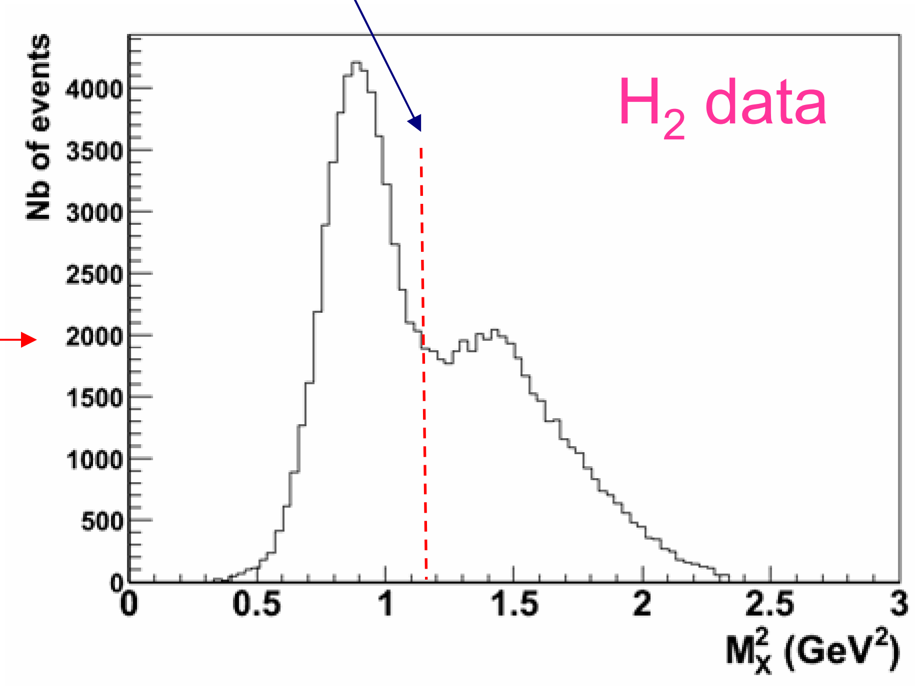


Subtraction of π^0 contamination (**1**γ in the calorimeter) is obtained from a phase space simulation which weight is adjusted to the experimental π^0 cross section (**2**γ in the calorimeter).

π^0 contamination subtraction

Unfortunately, the high trigger threshold during **Deuterium** runs did not allow to record **all** exclusive π^0 events ($M_X^2<1.15$ GeV^2)





But : according to the procedure of π^0 contamination subtraction, **we must have** :

Actually, we find :

$$0.5 < \frac{\sigma(ed \to en\pi^0 X)}{\sigma(ep \to ep\pi^0 X)} < 1.5$$

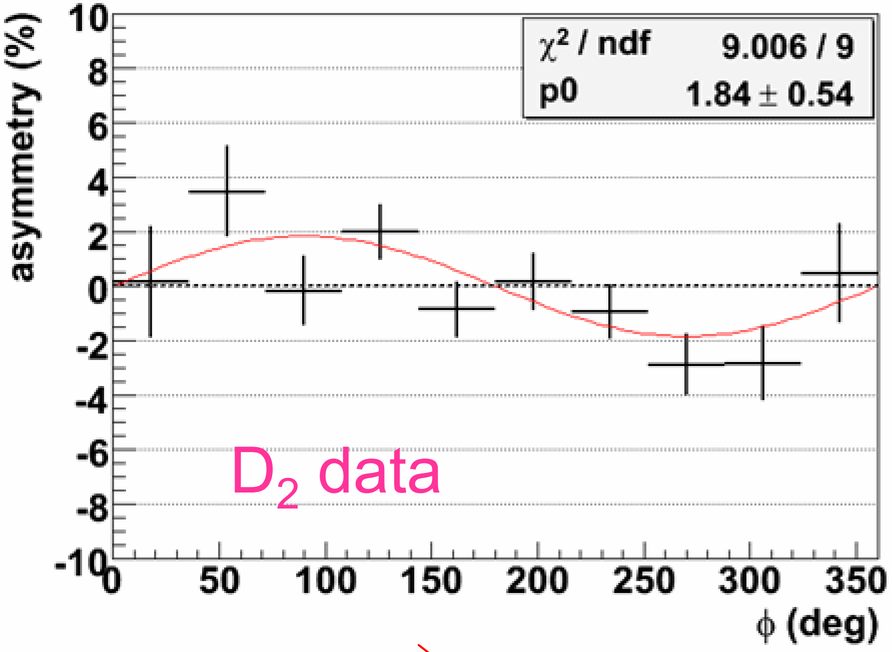
$$\frac{\sigma(ed \to en\pi^0 n)}{\sigma(ep \to ep\pi^0 p)} = 0.95 \pm 0.06 + sys$$

with $M_X^2<1.15$ GeV^2

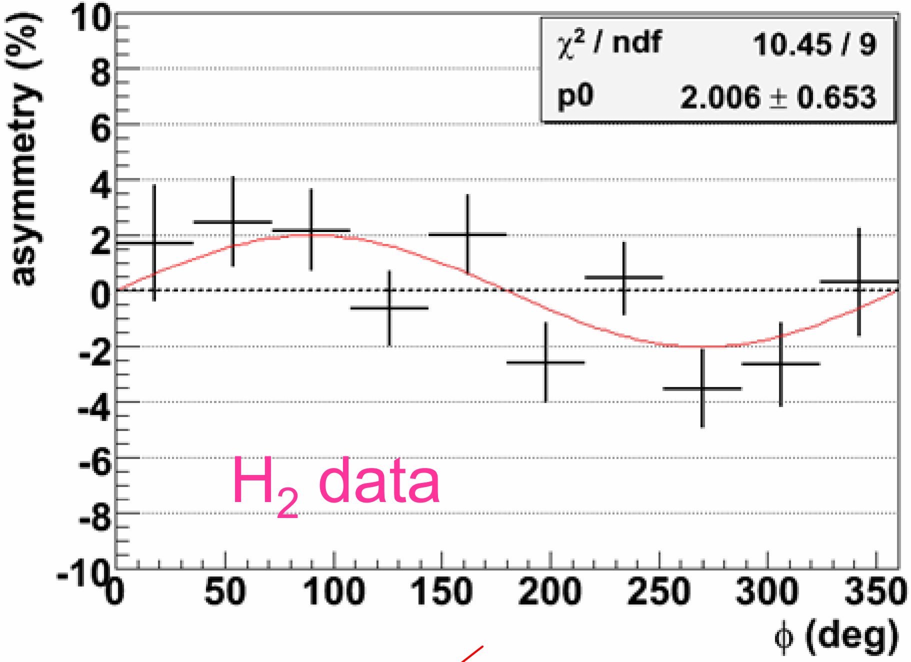
by comparing two samples of high energy π^0 in each case

Exclusive π^0 asymmetry

$ed \rightarrow ep(n)\pi^0 + ed \rightarrow en(p)\pi^0 + ed \rightarrow ed\pi^0$



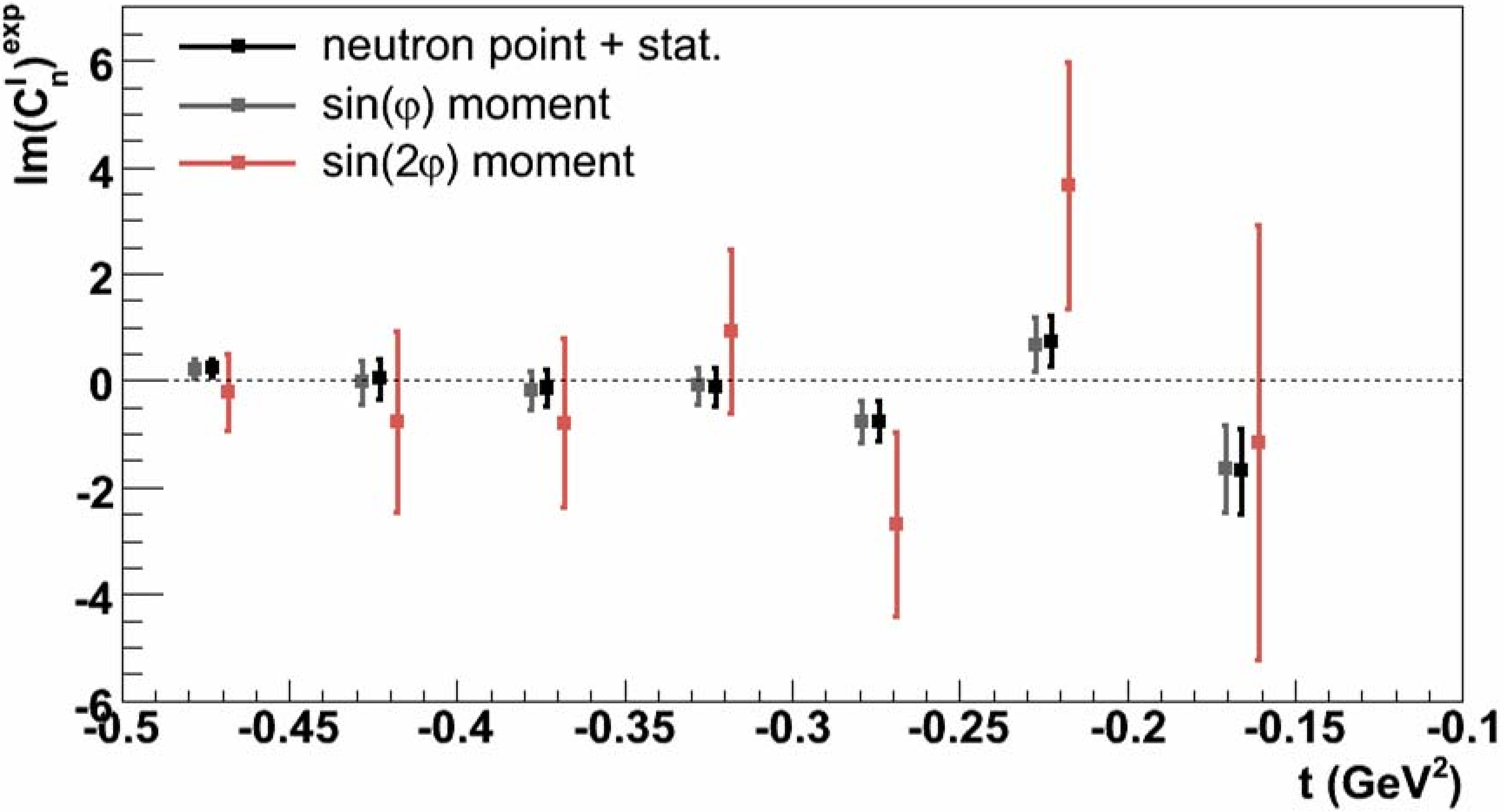
$ep \rightarrow ep\pi^0$



$$-0.5 < \frac{S_h\left(en \rightarrow en\pi^0 + ed \rightarrow ed\pi^0\right)}{S_h\left(ep \rightarrow ep\pi^0\right)} < 1$$

Well known from H_2 data

sin(φ) and sin(2φ) moments

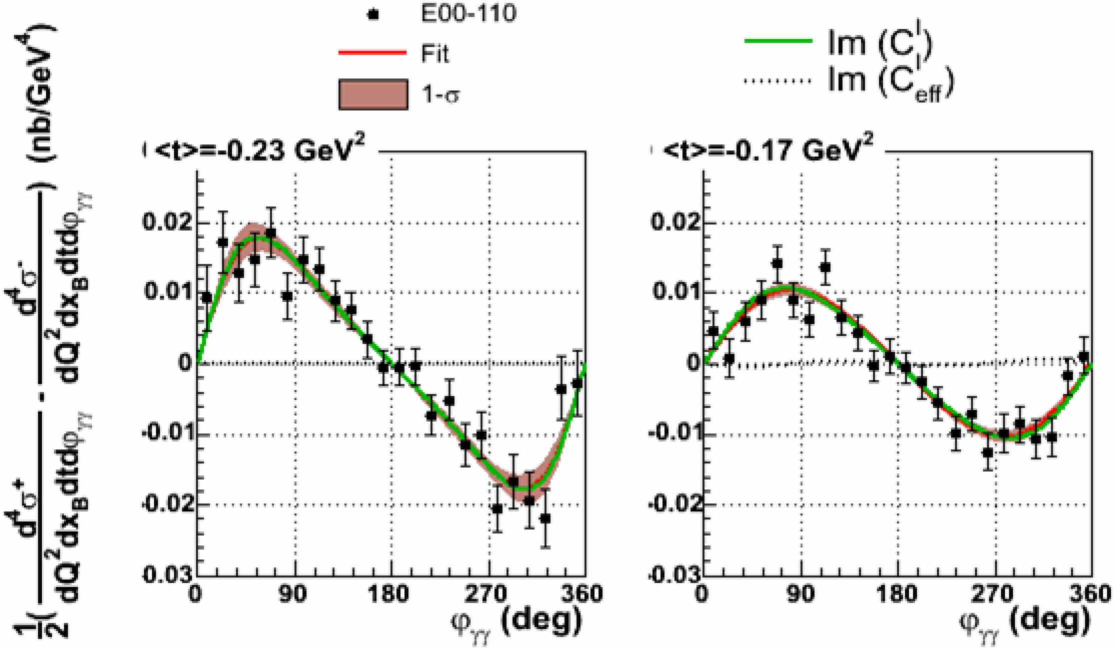


Results are coherent with the fit of a single sin(φ) contribution

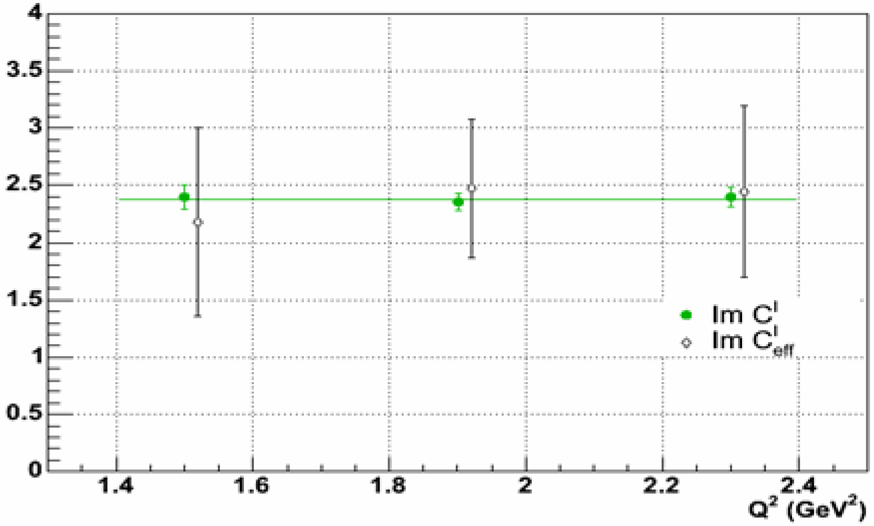
Test of the handbag dominance : E00-110

p-DVCS experiment results

C. Muňoz-Camacho *et al.*,
to appear in PRL (2007)



Twist-2 contribution dominates the total cross-section and the cross-section difference.



No Q^2 dependence of twist-2 and twist-3 terms

Strong indications for handbag dominance

VGG parametrisation of GPDs

Vanderhaeghen, Guichon, Guidal,
Goeke, Polyakov, Radyushkin, Weiss …

Non-factorized *t* dependence

$$H^q(x,\xi,t)=\int_{-1}^{1}d\beta\int_{-1+|\beta|}^{1-|\beta|}d\alpha\;\delta(x-\beta-\alpha\xi)\,F^q(\beta,\alpha,t)\;+\;\theta(\xi-|x|)\,D^q\underbrace{\left(\frac{x}{\xi}\right)}_{\text{D-term}}$$

Double distribution :

$\alpha' = 0.8\ \mathrm{GeV}^{-2}$ for quarks

$$F^q(\beta,\alpha,t)=\frac{1}{|\beta|^{\alpha' t}}\,h(\beta,\alpha)\,q(\beta)$$

Parton distribution

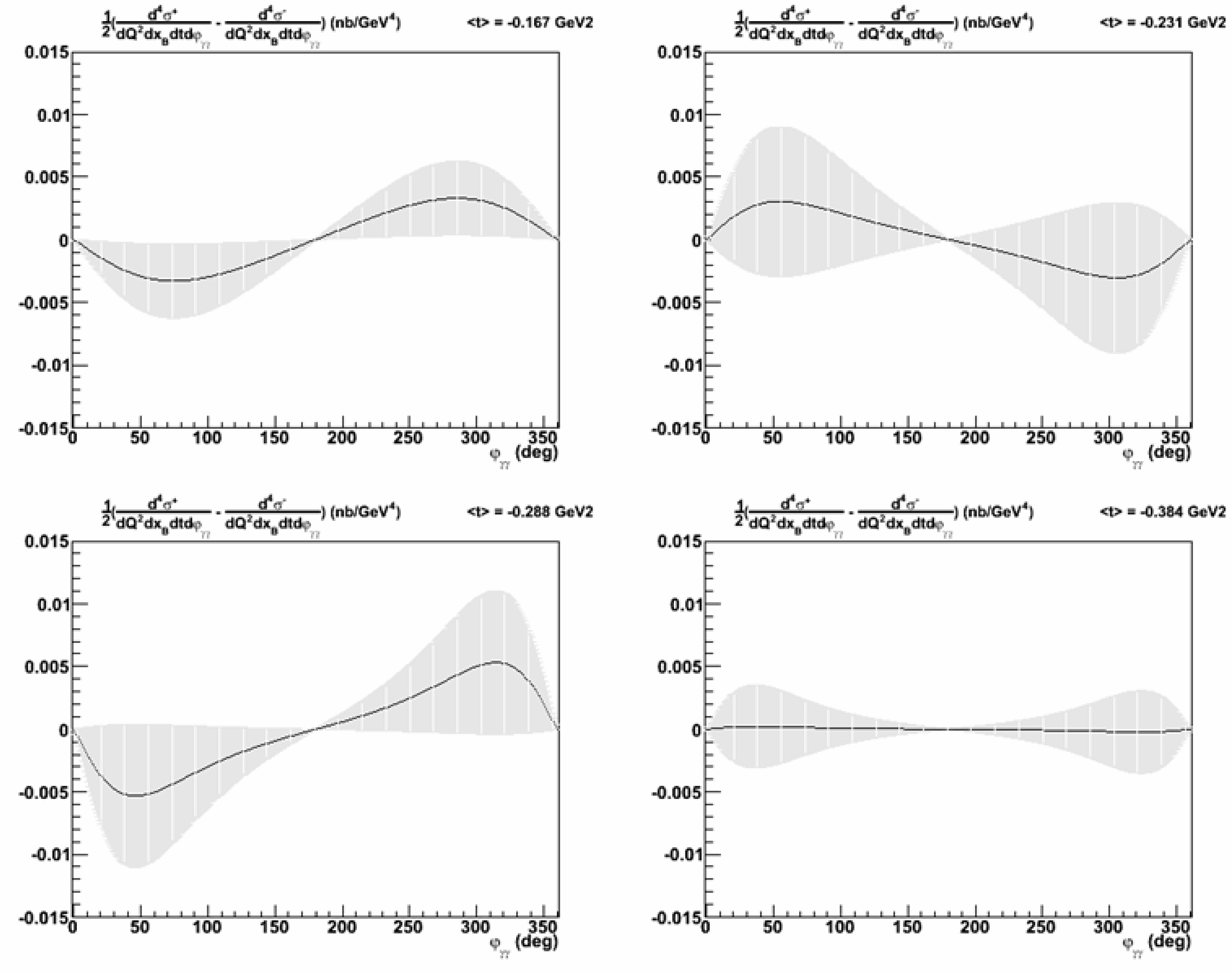
Profile function :

$$h(\beta,\alpha)=\frac{\Gamma(2b+2)}{2^{2b+1}\Gamma^2(b+1)}\,\frac{\left[(1-|\beta|)^2-\alpha^2\right]^b}{(1-|\beta|)^{2b+1}}$$

for GPD *E*, the spin-flip parton densities is used : $e_q(\beta)$

Modelled using J_u and J_d as free parameters

n-DVCS polarized cross-section difference

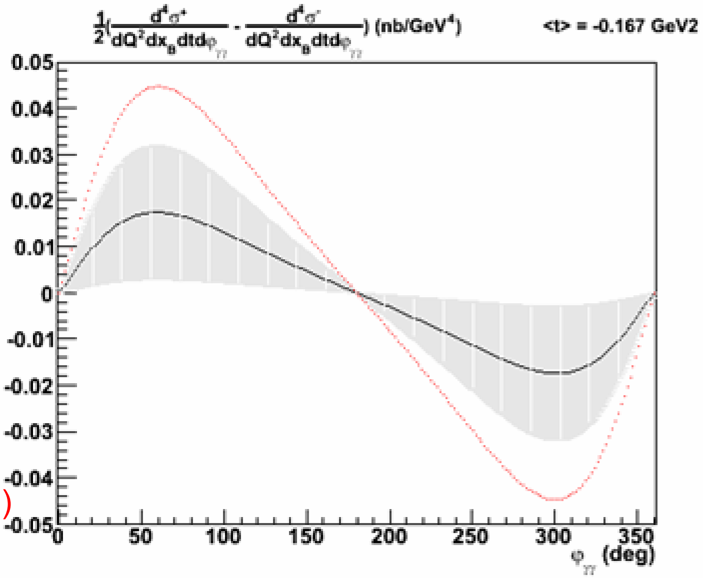


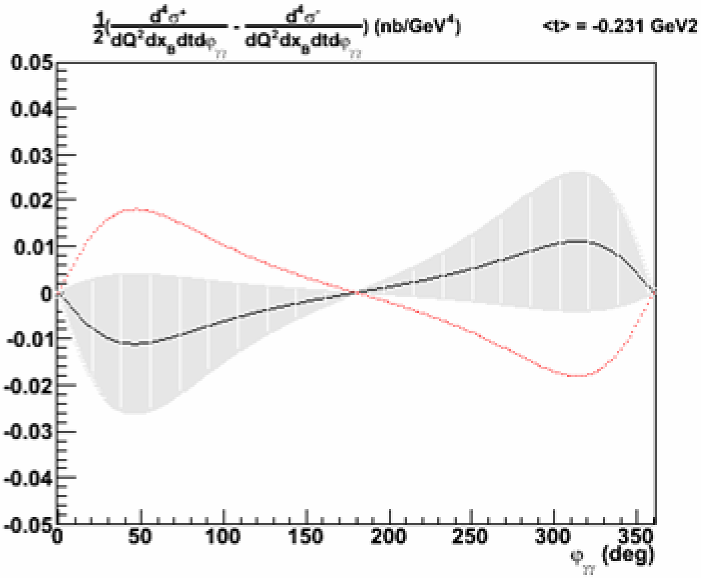
d-DVCS polarized cross-section difference

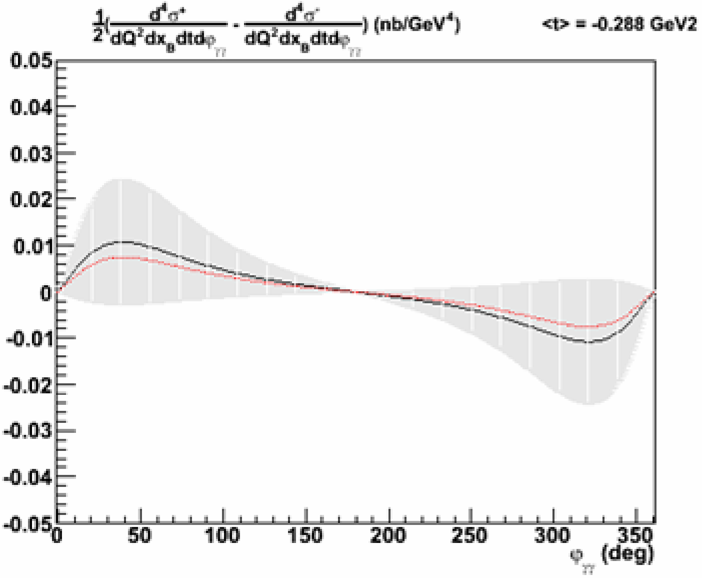
Experimental
results

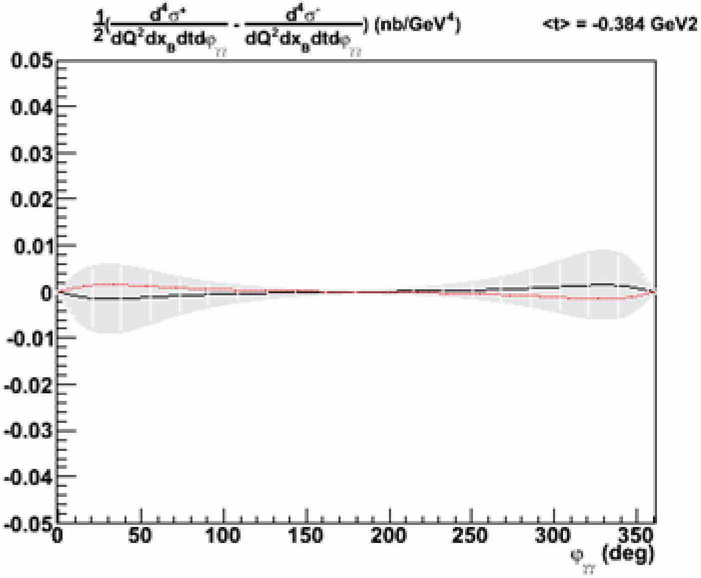
+

Prediction from F.
Cano and B. Pire.
Eur. Phys. J. A19, 423 (2004)









π^0 electroproduction on the neutron

Pierre Guichon, private communication (2006)

Amplitude of pion electroproduction :

$$T(N,\alpha) = \delta(\alpha,3)T^+ + \tau_N^\alpha T^0 + i\varepsilon_{3\alpha\beta}\tau^\beta T^-$$

α is the pion isospin

nucleon isospin matrix

⇨ π^0 electroproduction amplitude (α=3) is given by :

$$\left.\begin{aligned} T(p,3) &= T^+ + T^0 \propto \frac{2}{3}\Delta u + \frac{1}{3}\Delta d \\ T(n,3) &= T^+ - T^0 \propto \frac{1}{3}\Delta u + \frac{2}{3}\Delta d \end{aligned}\right\} \quad \boxed{\frac{T(p,3)+T(n,3)}{T(p,3)} \approx \frac{3+3\Delta d/\Delta u}{2+\Delta d/\Delta u} \approx 1.15}$$

Polarized parton distributions in the proton

Triple coincidence analysis

Proton Array and Tagger (hardware) work properly during the experiment, but :

Identification of n-DVCS events with the recoil detectors is impossible because of the high background rate.

➡ Many Proton Array blocks contain signals on time for each event .

➡ Accidental subtraction is made for p-DVCS events and gives stable beam spin asymmetry results. The same subtraction method gives incoherent results for neutrons.

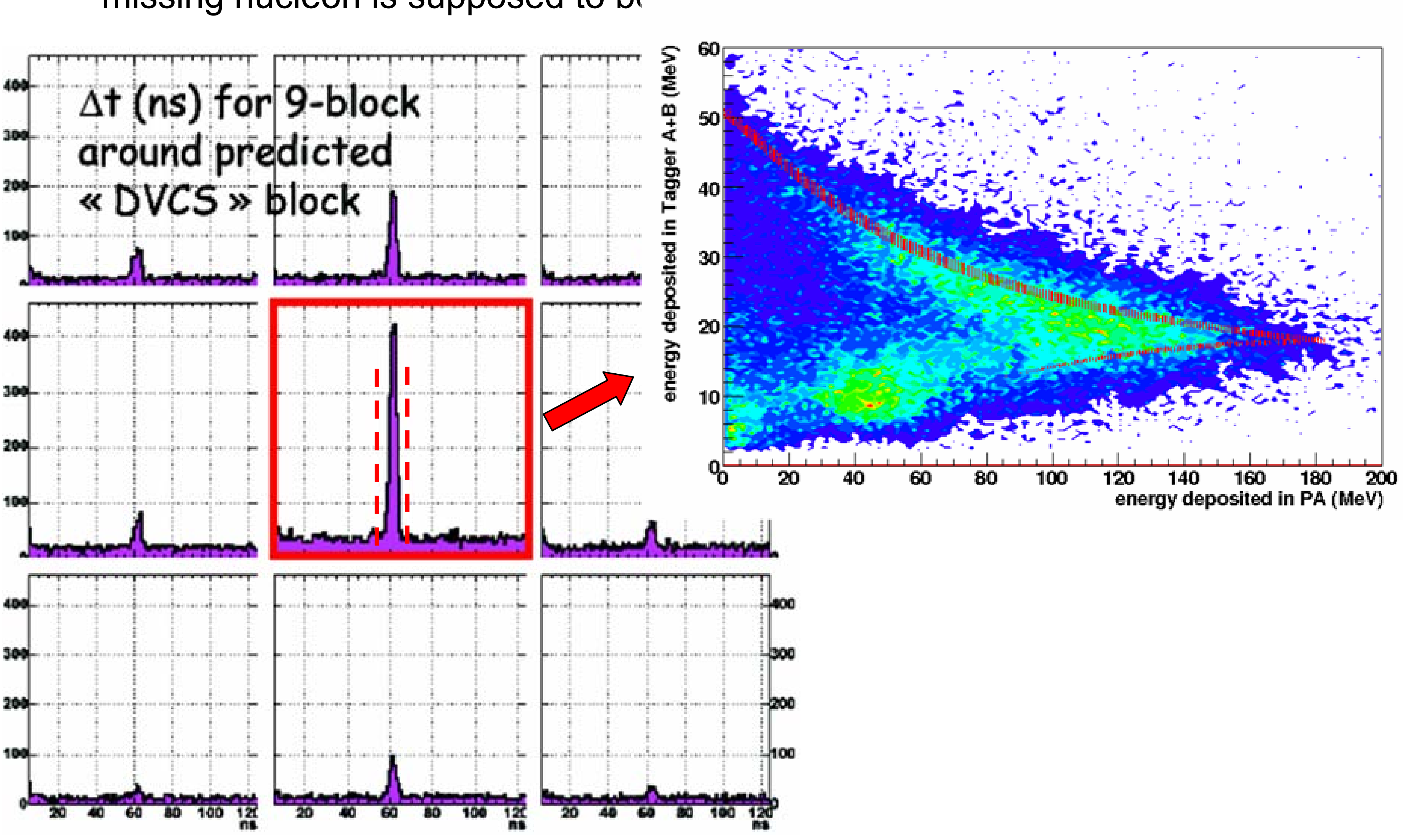
Other major difficulties of this analysis:

➡ proton-neutron conversion in the tagger shielding.
Not enough statistics to subtract this contamination correctly

➡ The triple coincidence statistics of n-DVCS is at least a factor 20 lower than the available statistics in the double coincidence analysis.

Triple coincidence analysis

One can **predict** for each (e,γ) event the Proton Array block where the missing nucleon is supposed to be (assuming DVCS event)

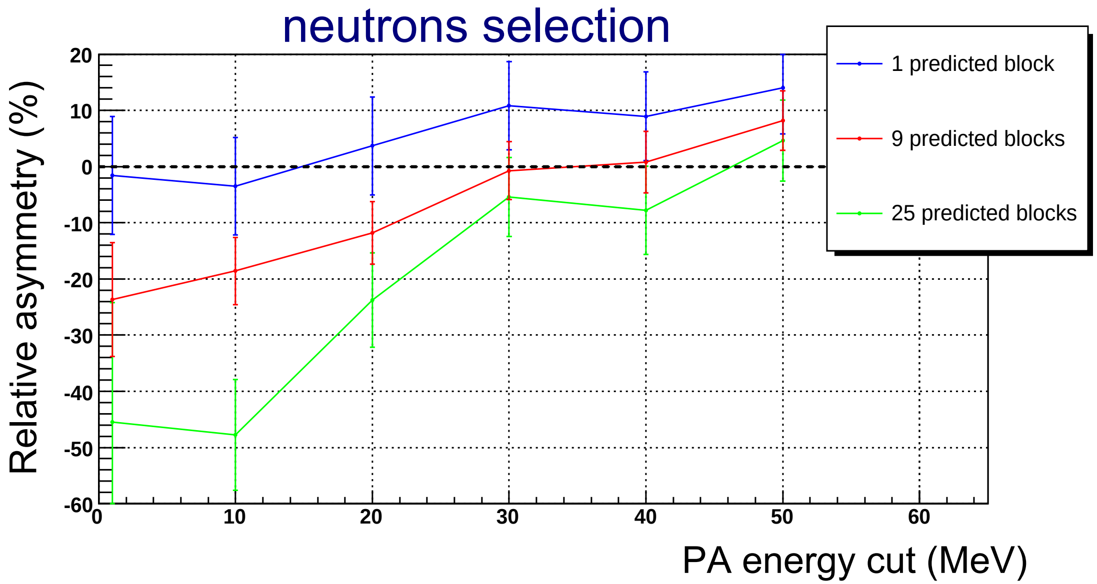


Triple coincidence analysis

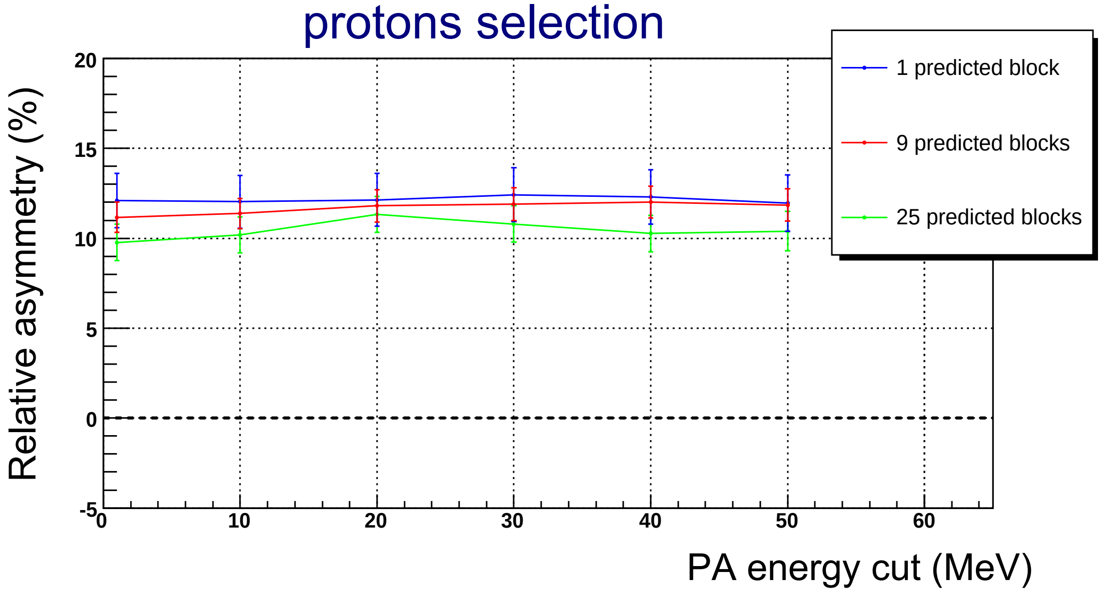
After accidentals subtraction

-proton-neutron conversion in the tagger shielding

- accidentals subtraction problem for neutrons



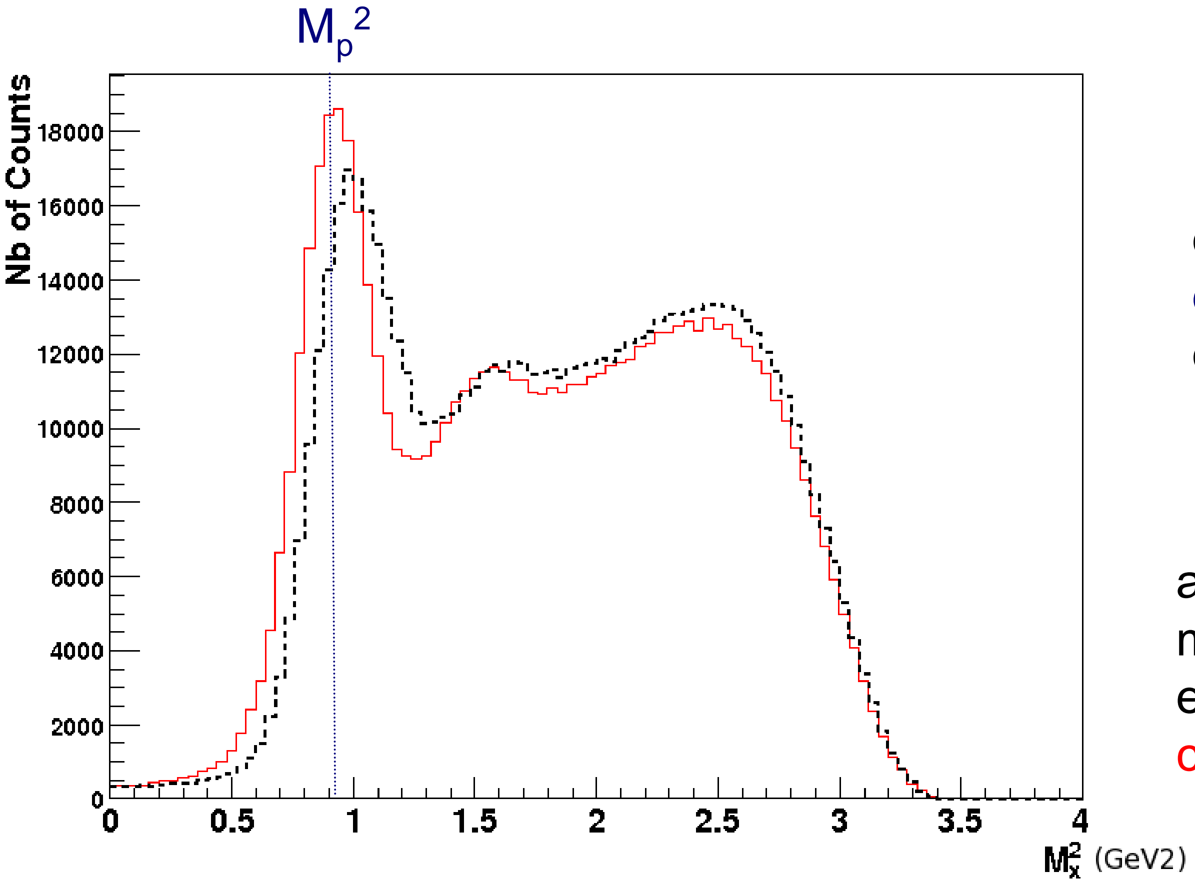
p-DVCS events (from LD2 target) asymmetry is stable



Calorimeter energy calibration

We have 2 independent methods to check and correct the calorimeter calibration

1^{st} method : missing mass of $D(e,e'\pi^-)X$ reaction

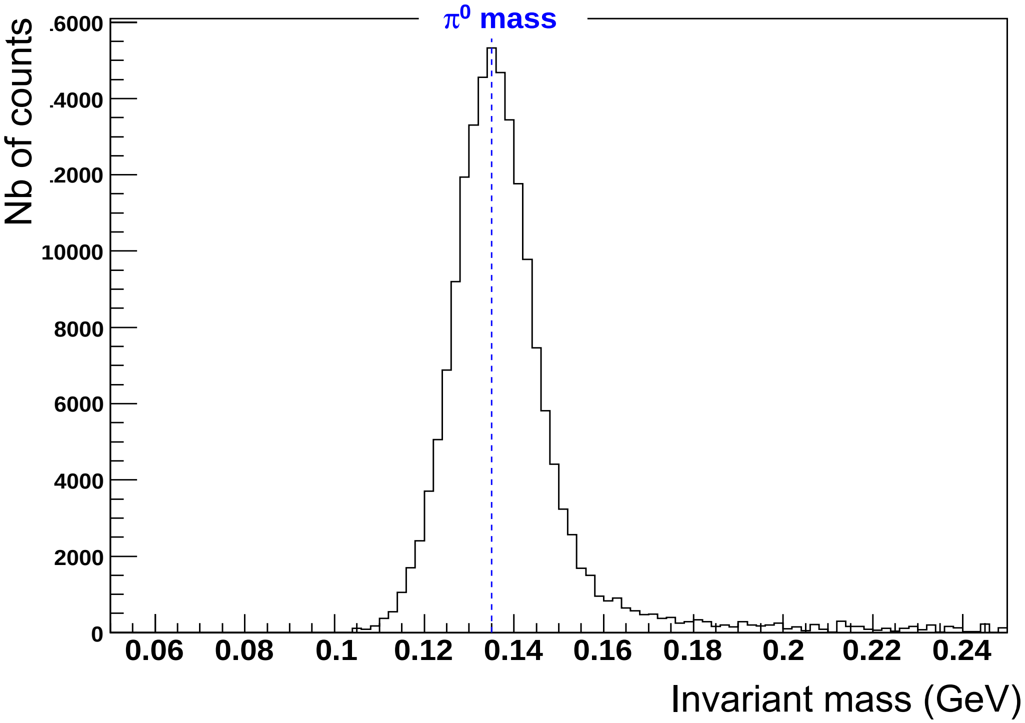


By selecting $n(e,e'\pi-)p$ events, one can predict the energy deposit in the calorimeter using only the cluster position.

a χ^2 minimisation between the measured and the predicted energy gives a better calibration.

Calorimeter energy calibration

2nd method : Invariant mass of 2 detected photons in the calorimeter (π^0)



π^0 invariant mass position check the quality of the previous calibration for each calorimeter region.

Corrections of the previous calibration are possible.

Differences between the results of the 2 methods introduce a systematic error of **1%** on the calorimeter calibration.