Deeply Virtual Compton Scattering on the Neutron

Meriem BEN ALI

(PhD student)

Laboratoire LPC Clermont Ferrand

Faculté des sciences de Monastir (FSM)

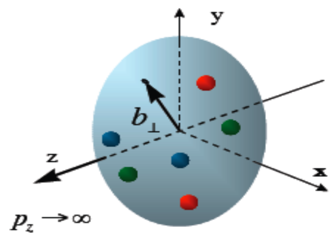
POETIC VI

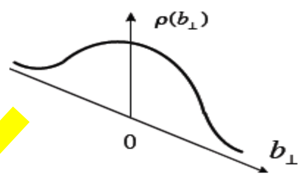
07-09-2015

❖ Elastic Scattering ($W^2=M^2$)

Form Factors

(Transverse position of partons)



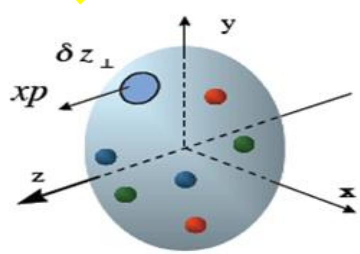


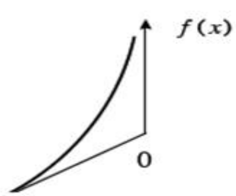
Two independent informations about the nucleon structure

❖ Deeply ($Q^2 \gg M^2$) Inelastic ($W^2 \gg M^2$) Scattering (**DIS**)

Parton Distribution Functions (PDFs)

(Longitudinal momentum distribution of the partons in the nucleon)





❖ Deeply Virtual Compton Scattering (**DVCS**)

New Structure Functions

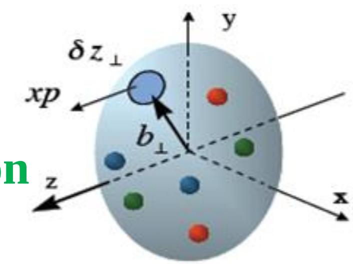
(Generalized Parton Distributions GPDs)

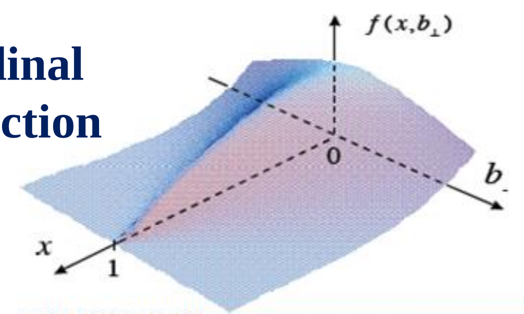
GPDs relate :

Spatial parton distribution in the transverse plane

+

Their longitudinal momentum fraction





Generalized Parton Distribution *GPDs*

❖ **4 GPDs functions of three variables:**

✓ $x \pm \xi$: longitudinal momentum fraction

✓ $\xi = \frac{x_B}{2 - x_B}$ **:** GPDs skewness invariant

✓ t : squared momentum transfer.

➢2 GPDs nucleon spin preserved $\begin{cases} H_q(x,\xi,t) \\ E_q(x,\xi,t) \end{cases}$

➢ 2 GPDs nucleon spin flipped $\begin{cases} \tilde{E}_q(x,\xi,t) \\ \tilde{H}_q(x,\xi,t) \end{cases}$

❖ **Link to Form Factors (□ ξ)**

$$\int_{-1}^{1} dx H_q(x,\xi,t) = F_1(t)$$

$$\int_{-1}^{1} dx E_q(x,\xi,t) = F_2(t)$$

$$\int_{-1}^{1} dx \tilde{H}_q(x,\xi,t) = G_A(t)$$

$$\int_{-1}^{1} dx \tilde{H}_q(x,\xi,t) = G_p(t)$$

❖ **Link to Parton distribution functions (ξ=t=0)**

$$H_q(x,0,0) \begin{cases} = q(x)\ ; \quad x>0 \\ = -\bar{q}(x) \quad x<0 \end{cases}$$

$$\tilde{H}_q(x,0,0) \begin{cases} = \Delta q(x)\ ; \quad x>0 \\ = \Delta\bar{q}(-x)\ ; \quad x<0 \end{cases}$$

❖ Access to **quark angular momentum,**
via Ji sum rule [X. Ji 1997]:

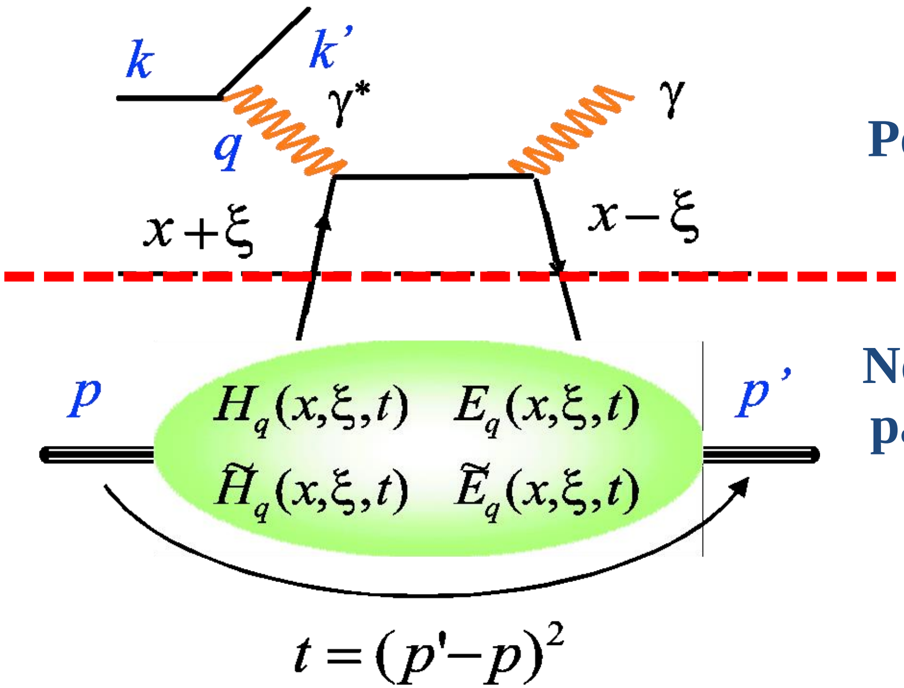
$$J_q = \frac{1}{2}\Delta\Sigma_q + L_q = \int_{-1}^{+1} dx\, x\,[H_q(x,\xi,0) + E_q(x,\xi,0)]$$

How to measure *GPDs* ?

Deeply Virtual Compton Scattering (DVCS) $eN \to eN\gamma$

The simplest process that can be described in terms of GPDs by measuring its cross section

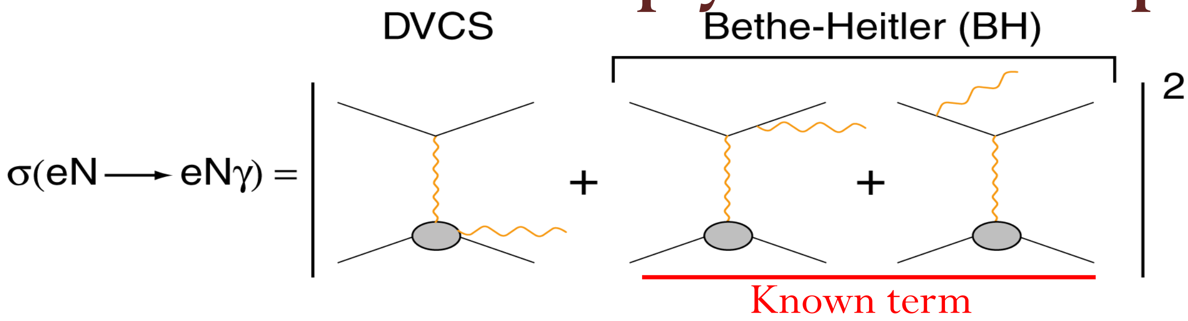
At Bjorken regime ($Q^2 \to \infty$ and $\nu \to \infty$ **)**



Perturbative part
(QCD)

Non perturbative part described by **GPDs**

Deeply Virtual Compton Scattering



$$d^5\sigma = \left|T^{BH}\right|^2 + 2\,T^{BH}\,\mathrm{Re}(T^{DVCS}) + \left|T^{DVCS}\right|^2$$

✓ The **total cross-section** accesses the real part of DVCS and the $|T^{DVCS}|^2$ term which are sensitive to an **integral of GPDs over x**

$$T^{DVCS} \propto P\int_{-1}^{+1}\frac{GPD(x,\xi,t)}{x-\xi}\,dx \pm i\,\Pi\, GPD(x=\pm\xi,\xi,t) + \ldots$$

Real part

Imaginary part

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

Deeply Virtual Compton Scattering

❖ Measure cross section at different kinematics (2 beam energies)

- Separates the Re(T^{DVCS}) of DVCS and the $|T^{DVCS}|^2$

&

- Better constrain theoretical models of GPDs

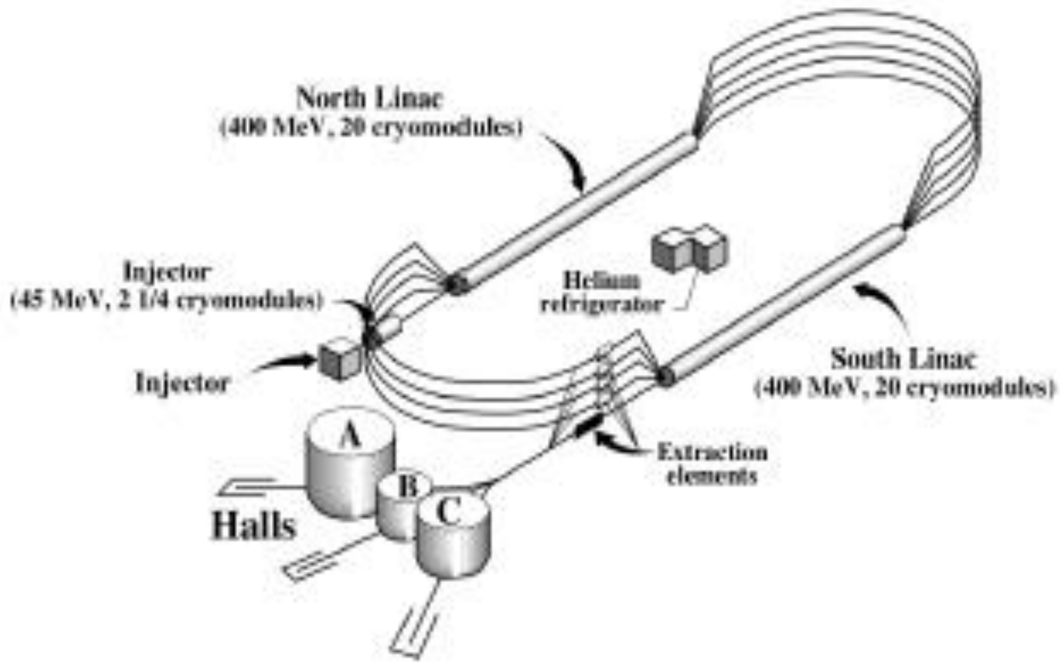
❖ Measure n-DVCS cross section is important

- Neutron has different flavors from the proton
- **Sensitive to GPD E:**
  (The less constrained GPD and which is important to access quarks orbital momentum via Ji's sum rule**)**

CEBAF

The E08-025 (n-DVCS) experiment was performed at JLab Hall A in 2010.

➢ **Goal : Measure the n-DVCS total cross-sections**



- **Hall A at Jefferson Lab (Newport, Virginia, USA)**
- **Ebeam = 4.45 GeV and Ebeam=5.54 GeV**
- I= 3 μA
- **Beam Polarization** = 72% et 76%
- Beam energy resolution ~10^{-4}

(High precision experiments)

The JLab 12 GeV Upgrade

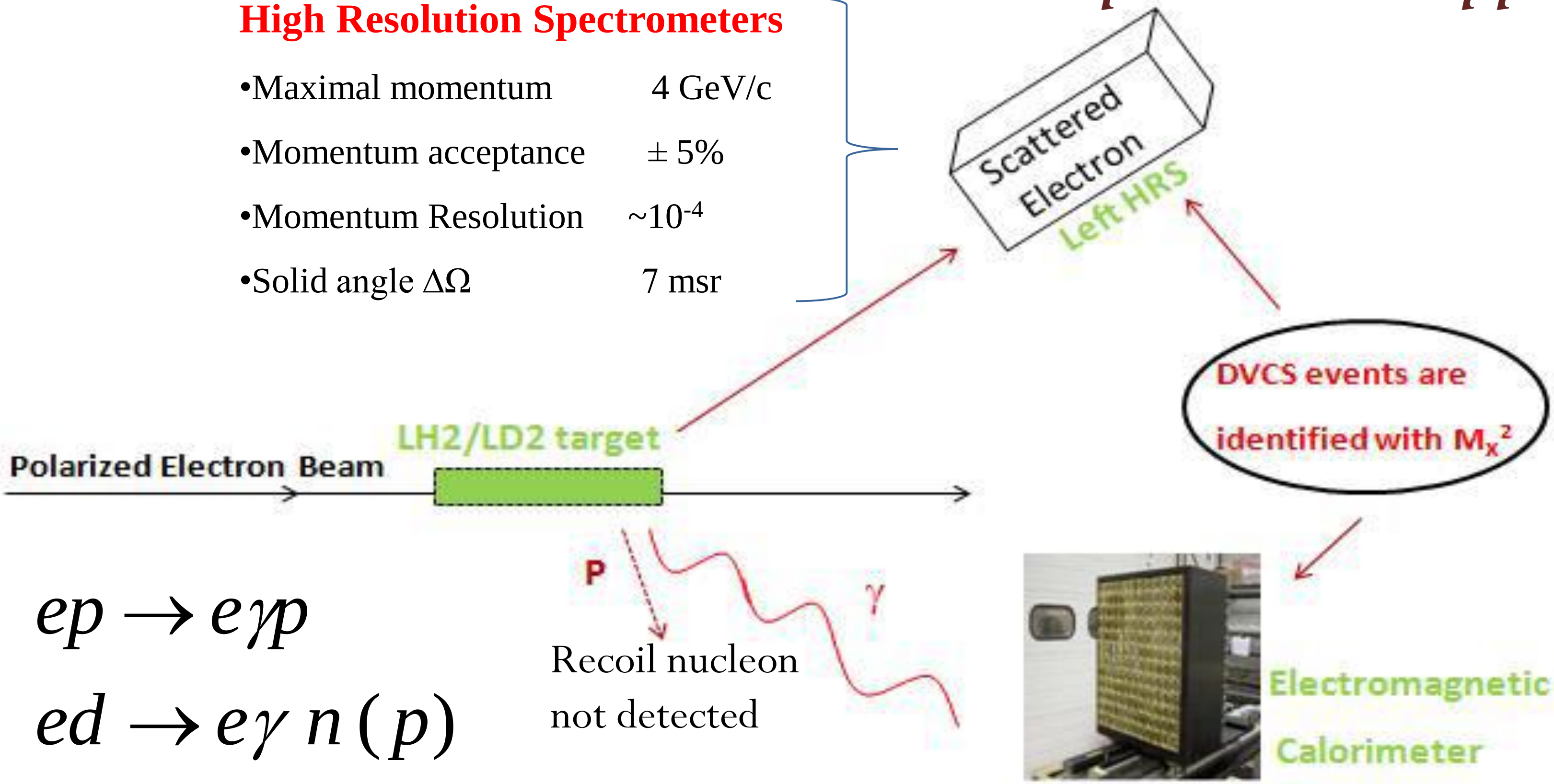
- **increases the energy of CEBAF**
- **Provides very high luminosities**

No Deuterium target is used to study the n-DVCS in Hall A

Experimental apparatus

High Resolution Spectrometers

- Maximal momentum 4 GeV/c
- Momentum acceptance ± 5%
- Momentum Resolution ~10^{-4}
- Solid angle ΔΩ 7 msr



$$ep \rightarrow e\gamma p$$

$$ed \rightarrow e\gamma\, n\,(p)$$

❖The data were taken at two kinematics:

- ✓ **Beam energy = 4.45 GeV & 5.54 GeV**
- ✓ **Q^2 = 1.75 GeV^2**
- ✓ **x_{Bj} = 0.36**
- ✓ **t ~ [-0.5 , -0.1] GeV^2**
- ✓ **Maximal luminosity = 3. $10^{37} cm^{-2} s^{-1}$**

Electromagnetic Calorimeter

- 13x16 PbF_2 blocks (Čerenkov light detection)
- Block size: 3x3 cm^2 x 20 X_0
- Each block is connected to (PMT + base + ARS)
- The energy deposit determination is based on a wave form analysis of the ARS signals.

Calorimeter energy calibration

❖ The calibration method is based on the comparison between the measured energy of a detected π^0 from $H(e,e'\pi^0)p$ events and its expected energy calculated with its scattering angle.

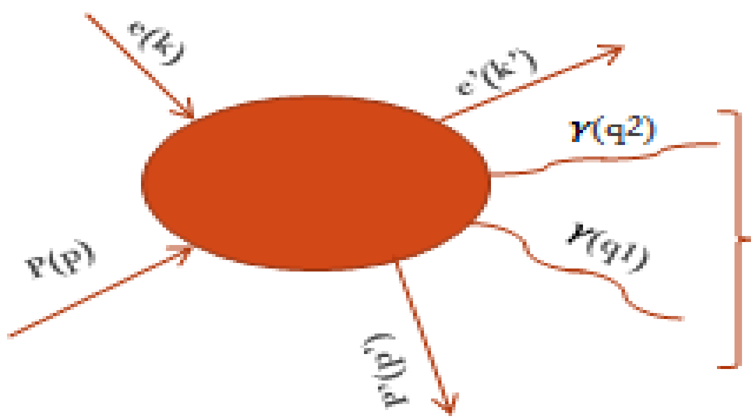
$$e\,N \rightarrow e'\,\pi^0\,N, \quad \pi^0 \rightarrow \gamma\,\gamma$$

$$\chi^2 = \sum_j \left(E_\pi^j - \sum_i C_i E_i^j\right)^2$$

- $\sum_j$: Sum over all events
- E_π^j: Pion energy
- $\sum_i$: Sum over all blocks
- C_i: Calibration coefficients
- E_i^j: measured energy in one block

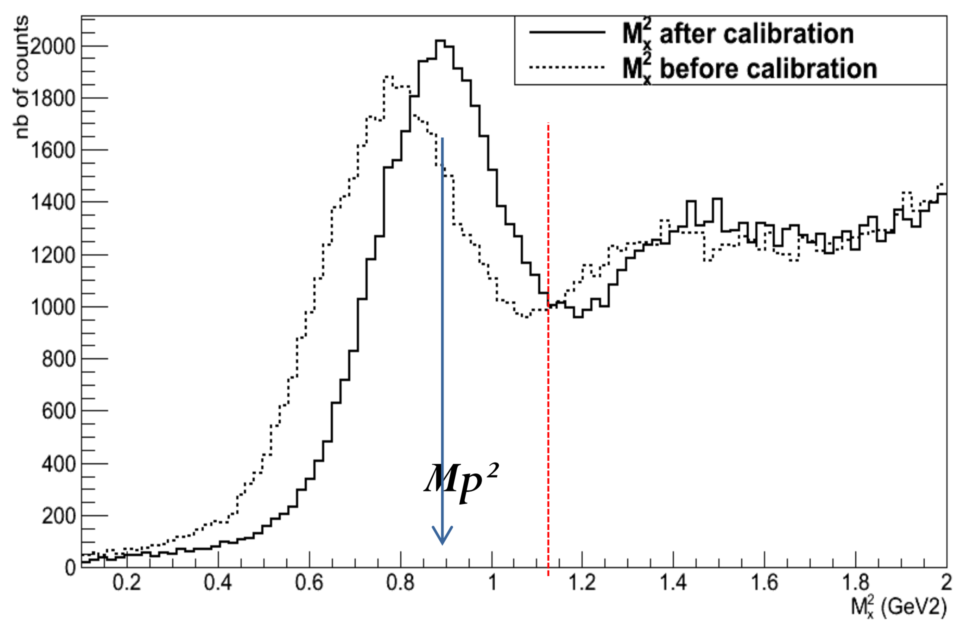
After the minimization we get the coefficients for each block i

$$\Rightarrow \frac{\partial \chi^2}{\partial C_i} = 0 \Rightarrow [C_i] = [M]^{-1}[B]$$



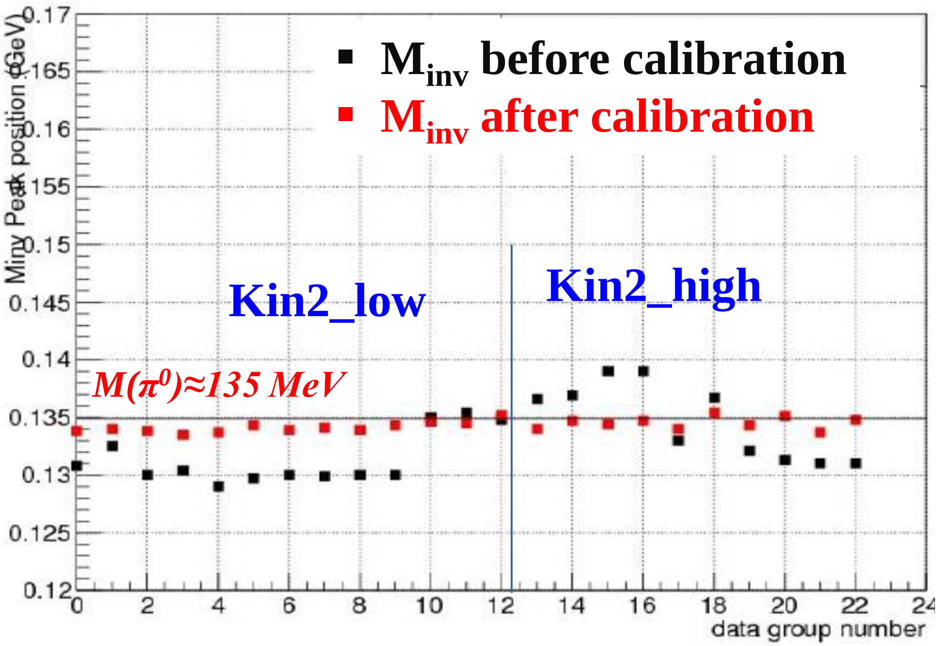
(Missing mass)² =(k + p - k' - q1 - q2)²

(i

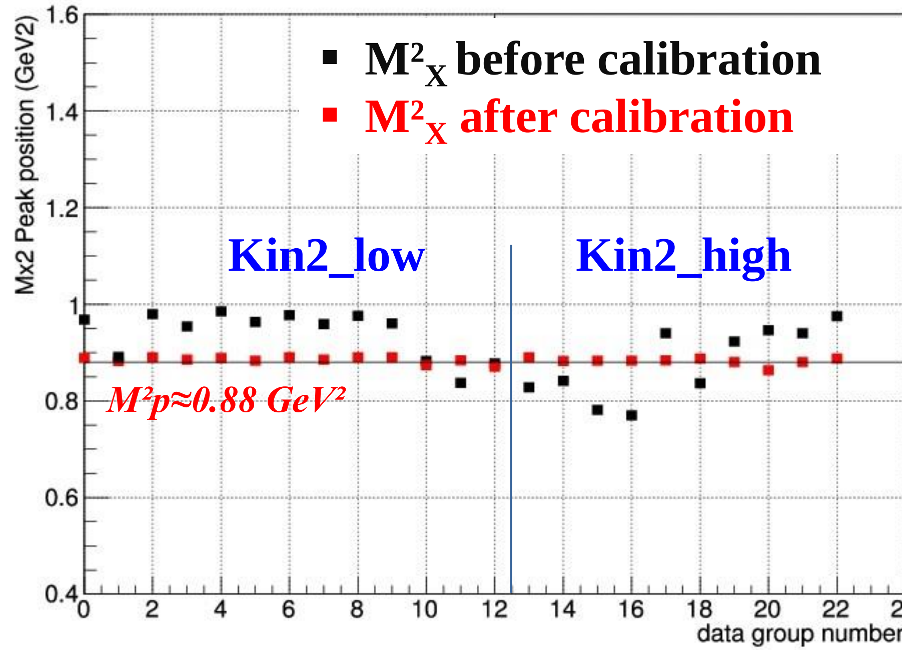


Calorimeter energy calibration: Results

Invariant mass peak position



(Missing mass)² peak position



After the π^0 calibration we reproduce: the π^0 mass & the proton mass

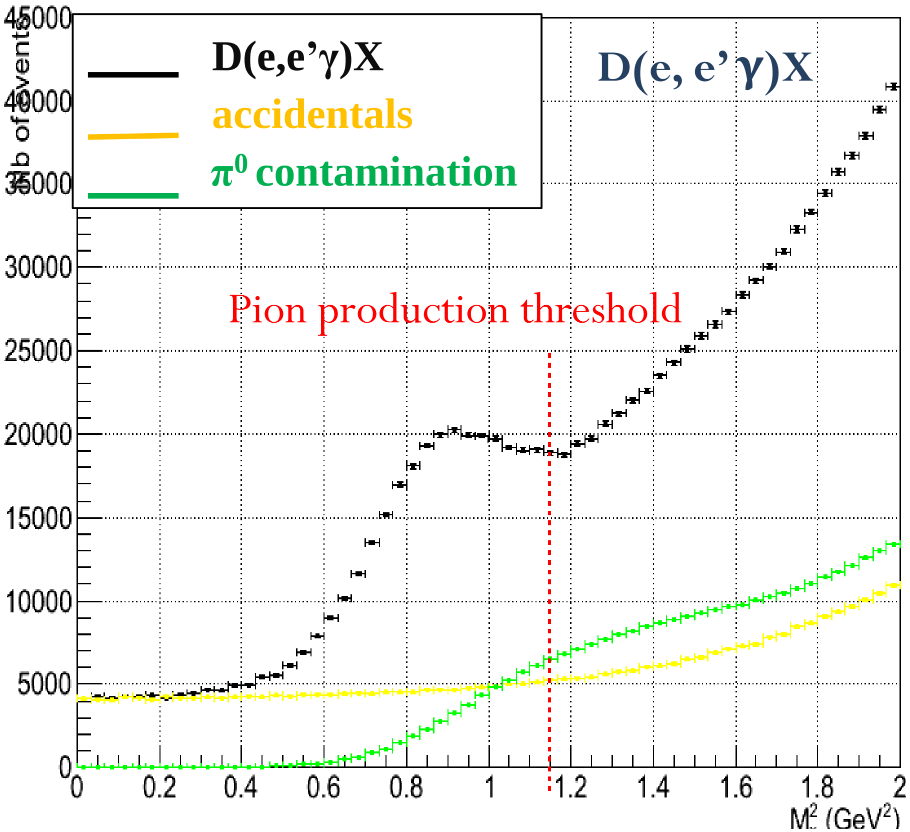
Each group number correspond to 1 or 2 days of data taking

This method allows a daily calibration of the calorimeter

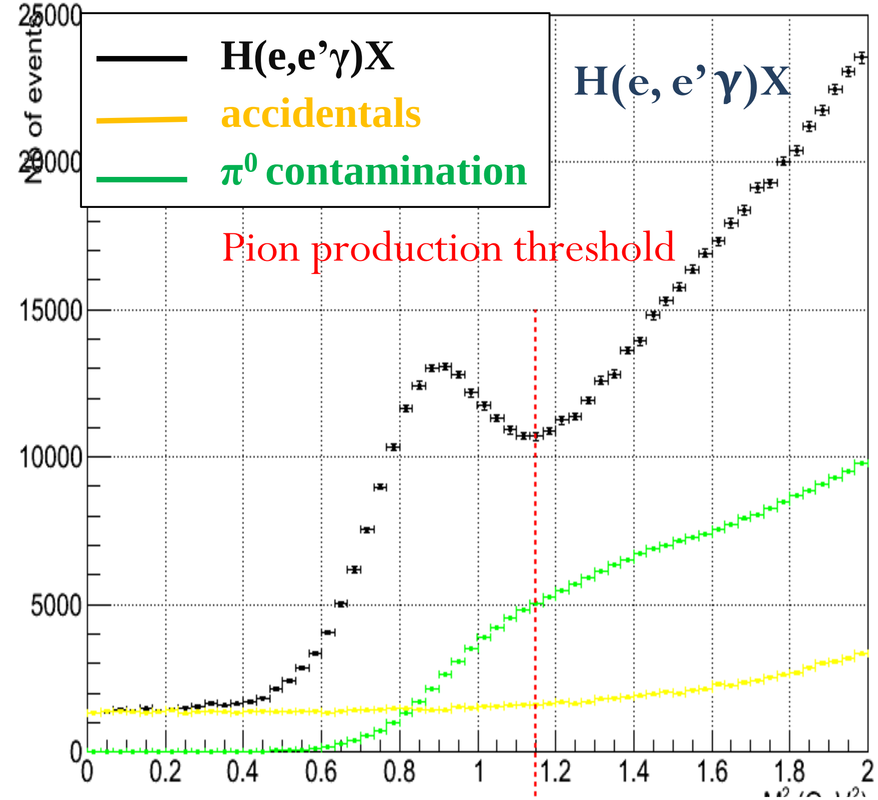
Selection of the n-DVCS events

❖ **In order to select the DVCS events in both targets:**

(Missing mass)^2= (e + N - e' - γ)^2



Mx² GeV²



Mx² GeV²

Selection of the n-DVCS events

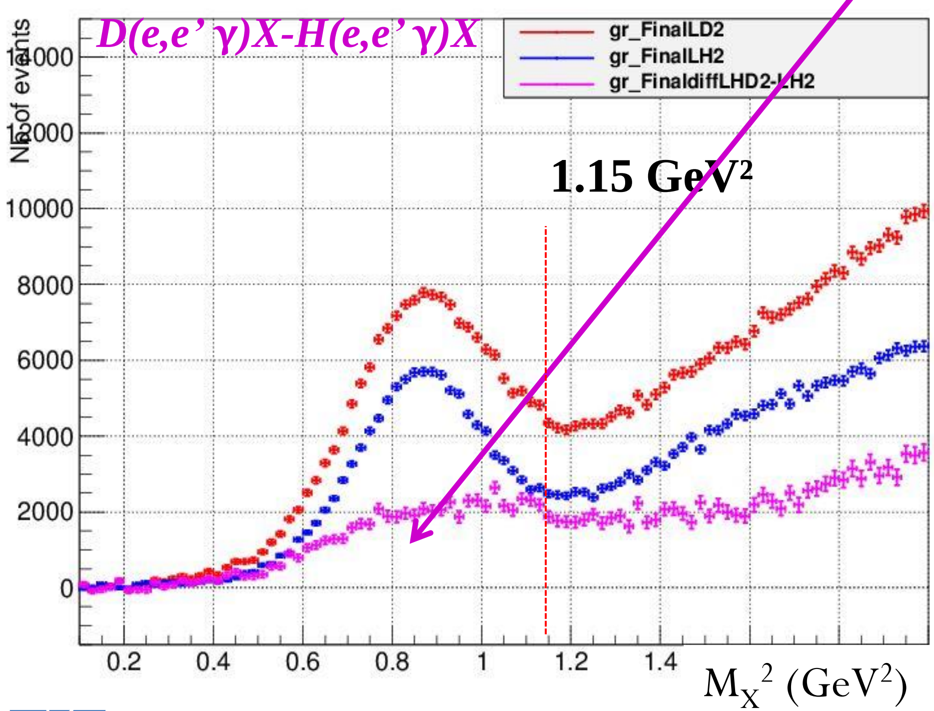
After
- subtracting the accidentals,
- subtracting single photons coming from π^0 decay (π^0 contamination),
- adding Fermi momentum to H2 data,
- normalizing H2 and D2 data to the same luminosity,

we obtain the difference **(D(e,e' γ)X- H(e,e' γ)X)**

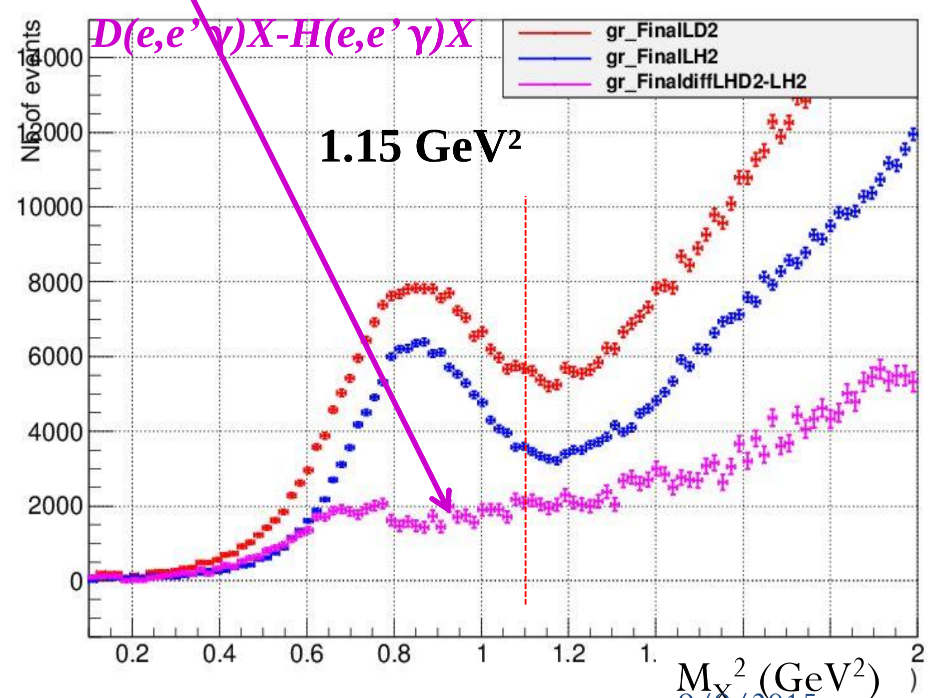
__.__ **D(e,e'γ)X - acc -** ***π⁰ cont***
__.__ **H(e,e'γ)X – acc -** ***π⁰ cont***
__.__ **D(e,e'γ)X-H(e,e'γ)X**

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

Ebeam=4.45 GeV



Ebeam=5.54 GeV



❖ The total unpolarized cross section of H(e,e'γ)p:

$$\frac{d^4\sigma}{dQ^2 dx_B dt d\varphi} = |T\,BH|^2 + |T\,DVCS|^2 + I$$

The interference term

❖The data D(e,e'γ)X- H(e,e'γ)X (with $Mx^2<1.15GeV$) are fitted by a GEANT4 simulation assuming a cross section of the form [A.V. Belitsky, D. Muller Phys. Rev., D82:074010, 2010]

$$\frac{d^4\sigma}{dQ^2 dx_B dt d\varphi} = BH_n + BH_d + \sum_i \Gamma_{in}(Q^2, x_B, t, \varphi)\, X_{in} + \sum_i \Gamma_{id}(Q^2, x_B, t, \varphi)\, X_{id}$$

BH _neutron contribution

BH_coherent deuteron contribu

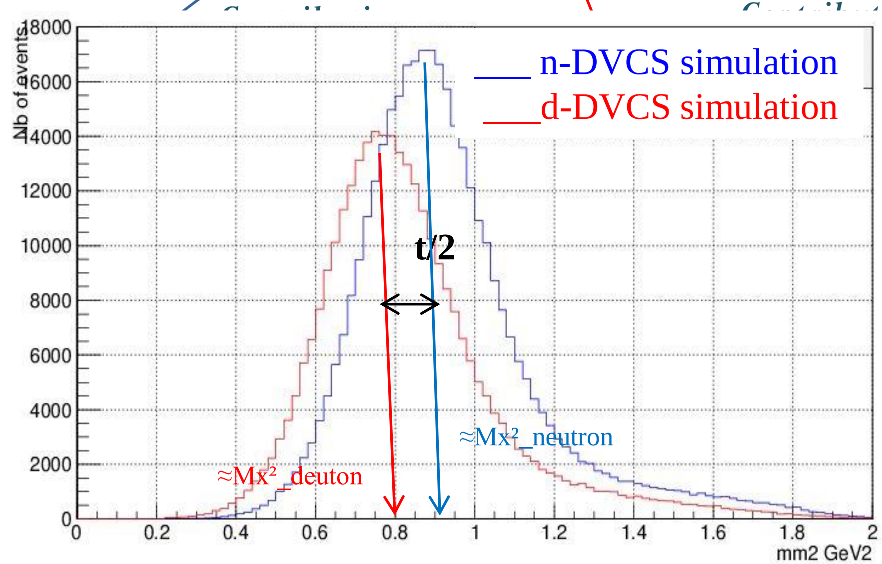
(DVCS²+I) neutron

Coherent deuteron (DVCS²+I)

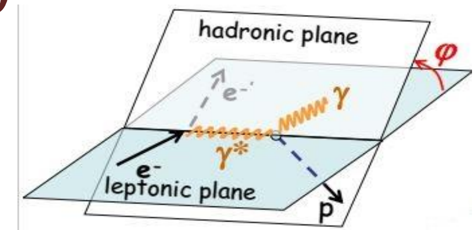
Calculated with n and d elastic form factors

Dependence in φ

Separate the different neutron contributions X_{in}(and separate th coherent deuteron contributions X



Extraction of the cross section



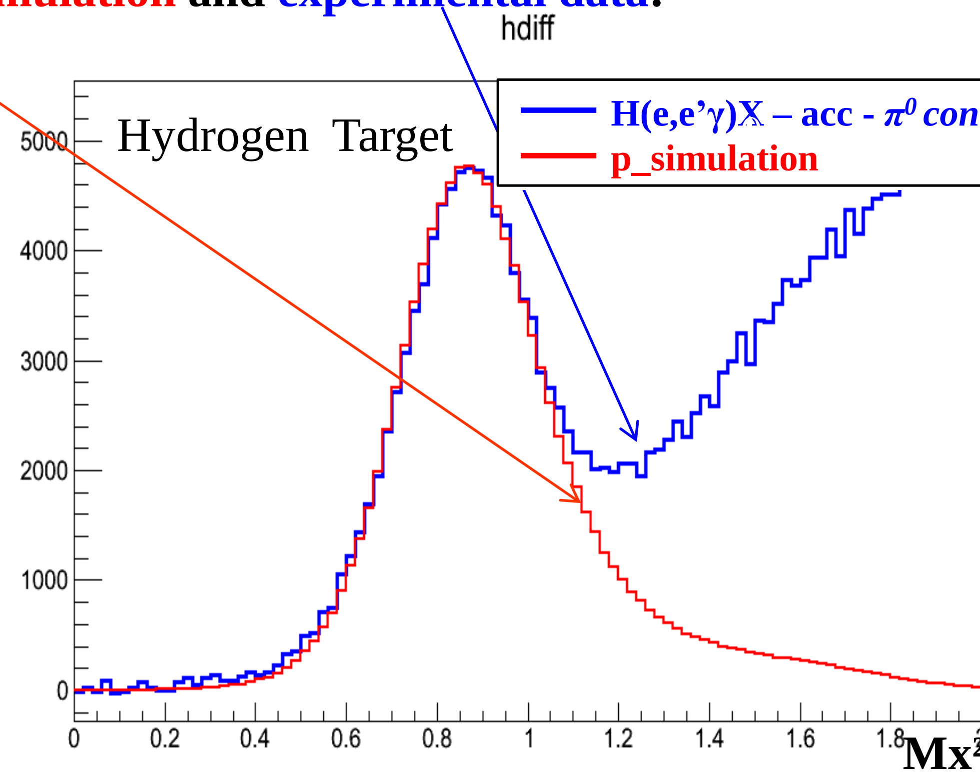
Binning : **4 bins on t** (squared momentum transfer)× **20 bins on φ**

A χ^2 minimization between the smeared simulation and experimental data:

$$\chi^2 = \sum_{k=0}^{Nbin} \left(\frac{N_k^{sim} - N_k^{data}}{\sigma_k^{\exp}} \right)^2$$

The statistical errors in the bin k

Number of experimental events in the bin k



$$N_k^{sim} = \sum_{v\lambda...} L\, \Gamma_\lambda(Q^2, x_B, t, \varphi) P(k,v)\, X_{\lambda v}$$

luminosity

Bin migration probability

$$\frac{d\chi^2}{dX_{\lambda_0 v_0}} = 0$$

Values of the $X_{\lambda v}$

The cross section :

$$d^4\sigma^{\exp}(k) = d^4\sigma^{Fit}(k)\frac{N^{\exp}(k)}{N^{MC}(k)}$$

conclusion

✓ These results show for the first time the existence of a positive contribution of n-DVCS (+ d-DVCS)

Expérimental cross section > (n-BH+d-BH)

✓ These results are relatively stable as a function of M_X^2 cut and the experimental cross section is almost independent of the experimental binning.

✓ The errors bars in the previous plots are purely statistical errors, systematic errors are under estimation.

❖ Stability and correlation studies to estimate separately the contributions of n-DVCS and d-DVCS still to be done.

❖ A global fit will be performed using both energies (high and low) data to extract CFFs.

❖ Other Phd works on the same subject and data (C. Desnault, IPN-Orsay)

Thank you for your attention

Extraction of the cross section

A.V. Belitsky, D. Muller Phys. Rev., D82:074010, 2010

In the new BKM Formalism we have:
- 9 CFFs for the neutron
- 9 CFFs for the coherent deuton

18 Contributions !!
(we can't fit everything)

We chose to fit only 6 CFFs:

$$3\ X_{in} = Re(C^{I})_{n}\,,\ \ Re(C^{I}{}_{Feff})_{n}\,,\ \ C_{n}{}^{DVCS}$$

AND

$$3\ X_{id} = Re(C^{I})_{d}\,,\ \ Re(C^{I}{}_{Feff})_{d}\,,\ \ C_{d}{}^{DVCS}$$

BUT:

These coefficients X_{in} and X_{id} are effective coefficients

AND

These coefficients are not stable (event if the χ^2 of the fit is good) as a function of:

- ❖Cut on Mx^2
- ❖the binning on Mx^2
- ❖The number of contributions to fit

Only the BH_contributions and the total experimental cross section will be shown