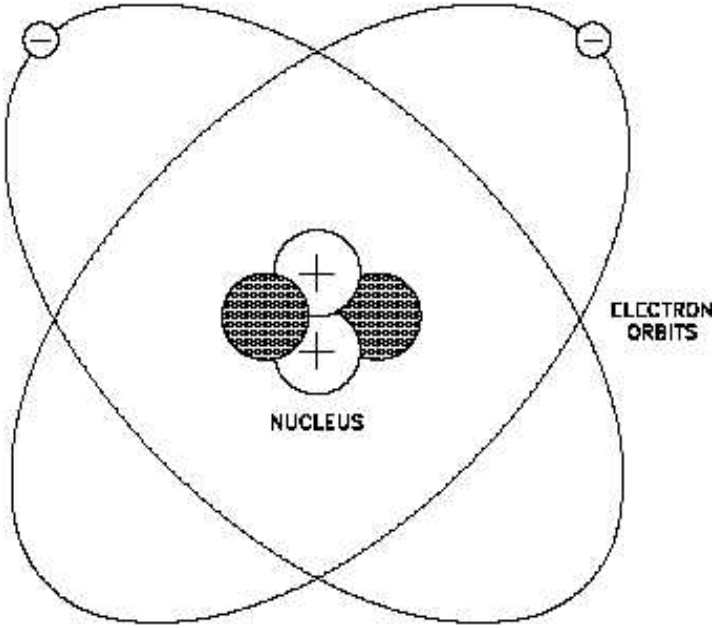
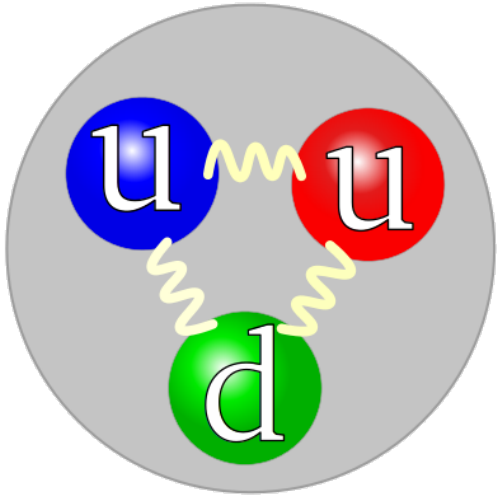
Rosenbluth separation of DVCS cross section

JLab experiment E07-007
Alejandro Marti

HUGS 21 June 2012

The proton structure





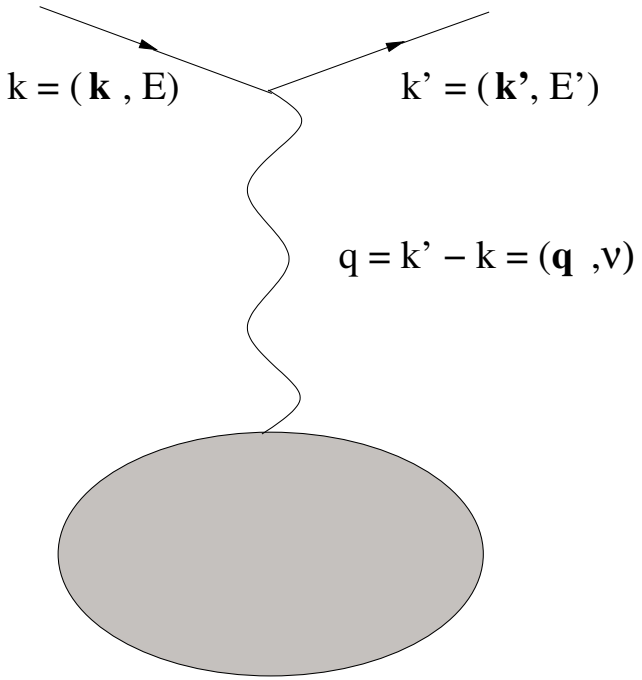
Historically, the atom constituent particles (electrons, protons and neutrons) were all regarded as elementary particles.

But we know now that protons and neutrons are composed of partons, also known as quarks and gluons.

The study of how partons confere the proton its properties can be tackled in several ways...

Elastic and Ineslastic Scattering: Form factors and PDFs

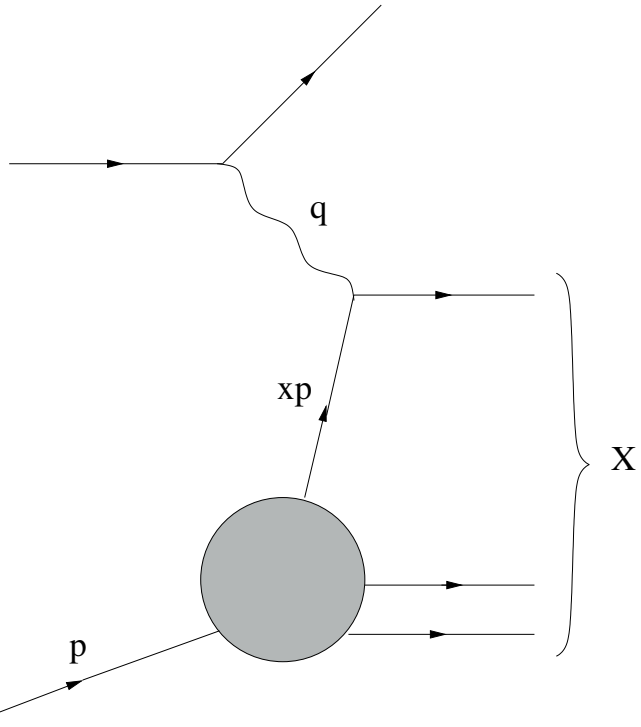
$$e + p \rightarrow e' + p'$$



The form factor can be expressed as the Fourier transform of the charge distribution:

$$F(q) = \int \rho(x) e^{iqx} dx^3$$

$$e + p \rightarrow e' + X$$

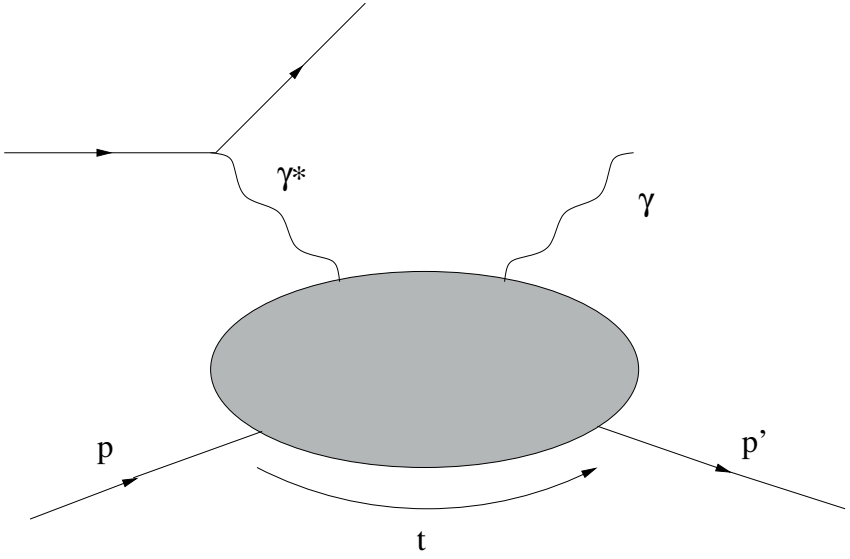


When $\mathcal{Q}^2$ and ν (virtuality and photon energy) are big enough we can access the PDFs:

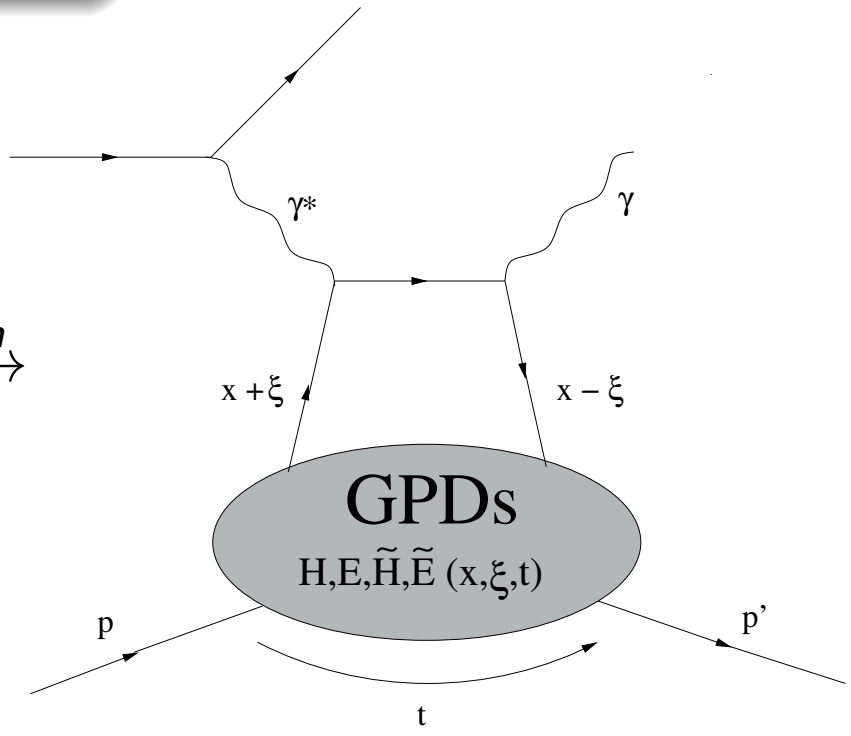
$$\sigma_{DIS}(x, \mathcal{Q}^2) = \sum PDF(x) \sigma_{eq \rightarrow eq}(x, \mathcal{Q}^2)$$

Exclusive Reactions: GPDs in DVCS

$$\gamma^* + p \rightarrow \gamma + p'$$



Factorization $\longrightarrow$

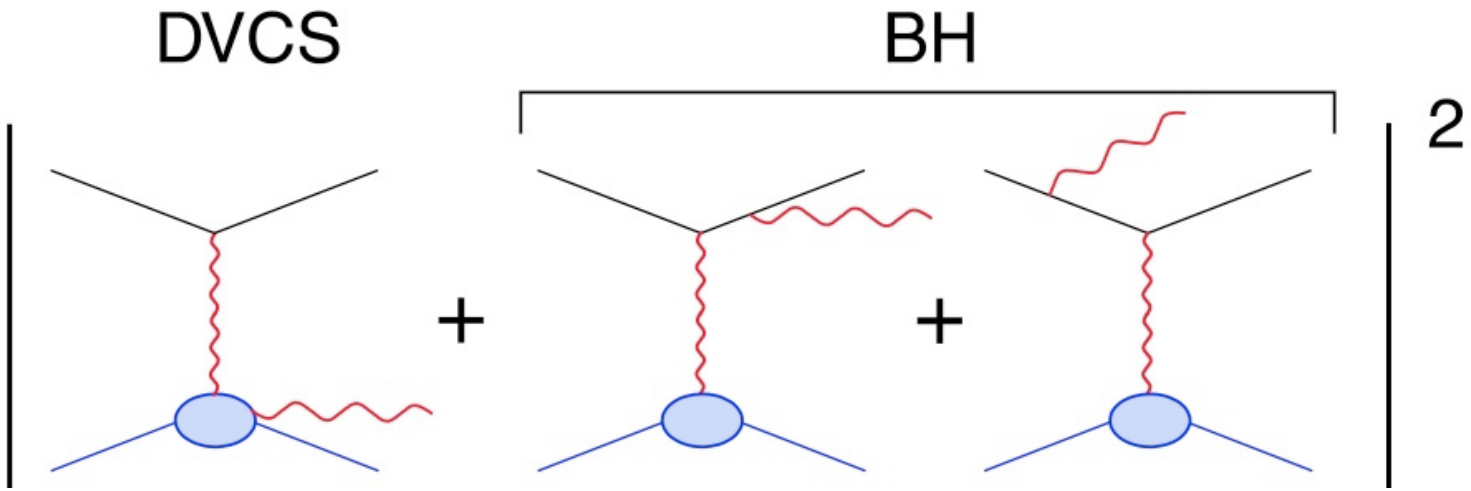


$$\frac{1}{2}\int_{-1}^{1}[H^i(x,\xi;0) + E^i(x,\xi;0)]x\mathrm{d}x = J^i$$

J^i is the quarks total angular momentum.

Rosenbluth separation of DVCS cross section

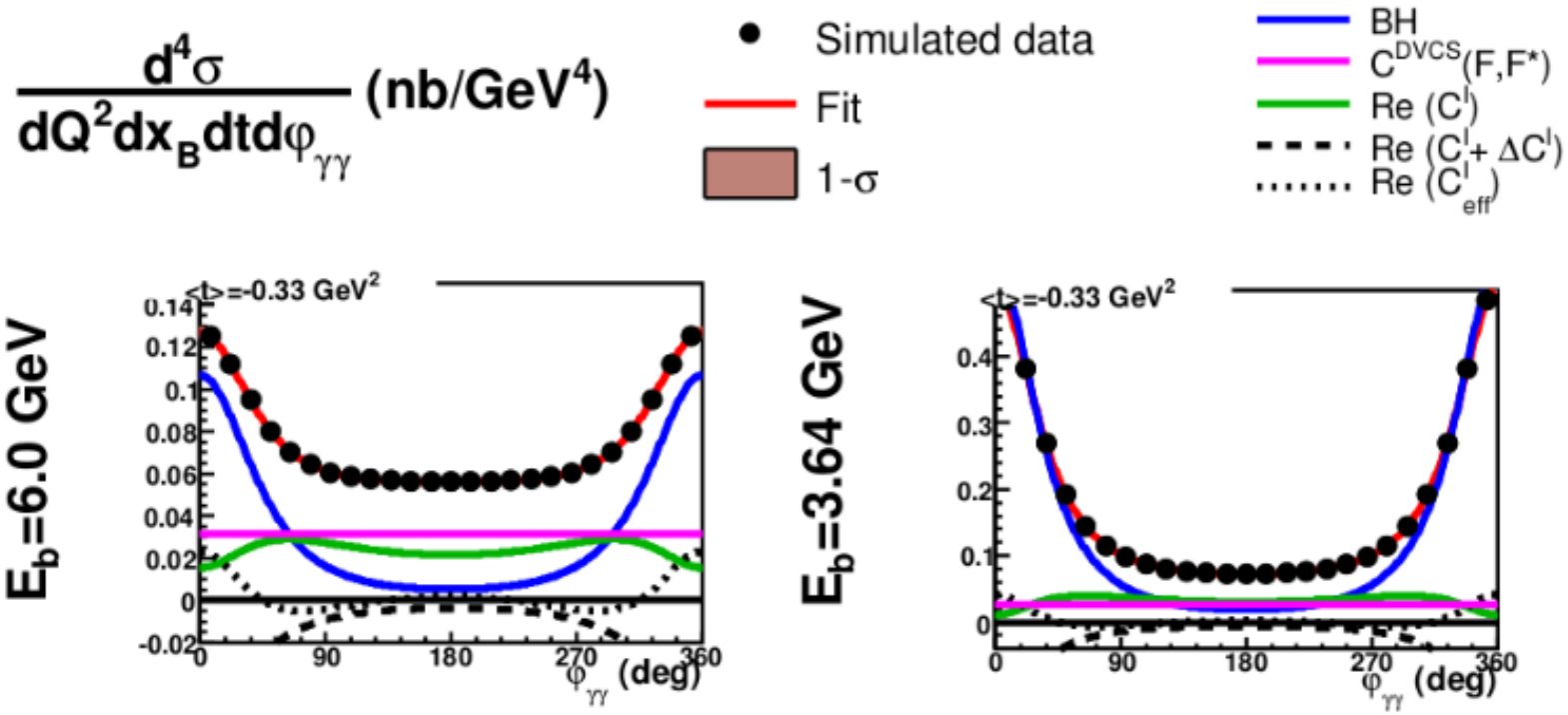
• The experiment was conducted in Jefferson Lab's Hall A, where the beam energy may reach up to 6GeV (while the experience).
• Its goal is to isolate the interference and $DVCS^2$ terms, both related to GPDs.



$$\sigma_{DVCS} = \Gamma_1 \times |\mathcal{T}_{BH}|^2 + \Gamma_2 \times |\mathcal{T}_{DVCS}|^2 + \Gamma_3 \times \mathcal{I}$$

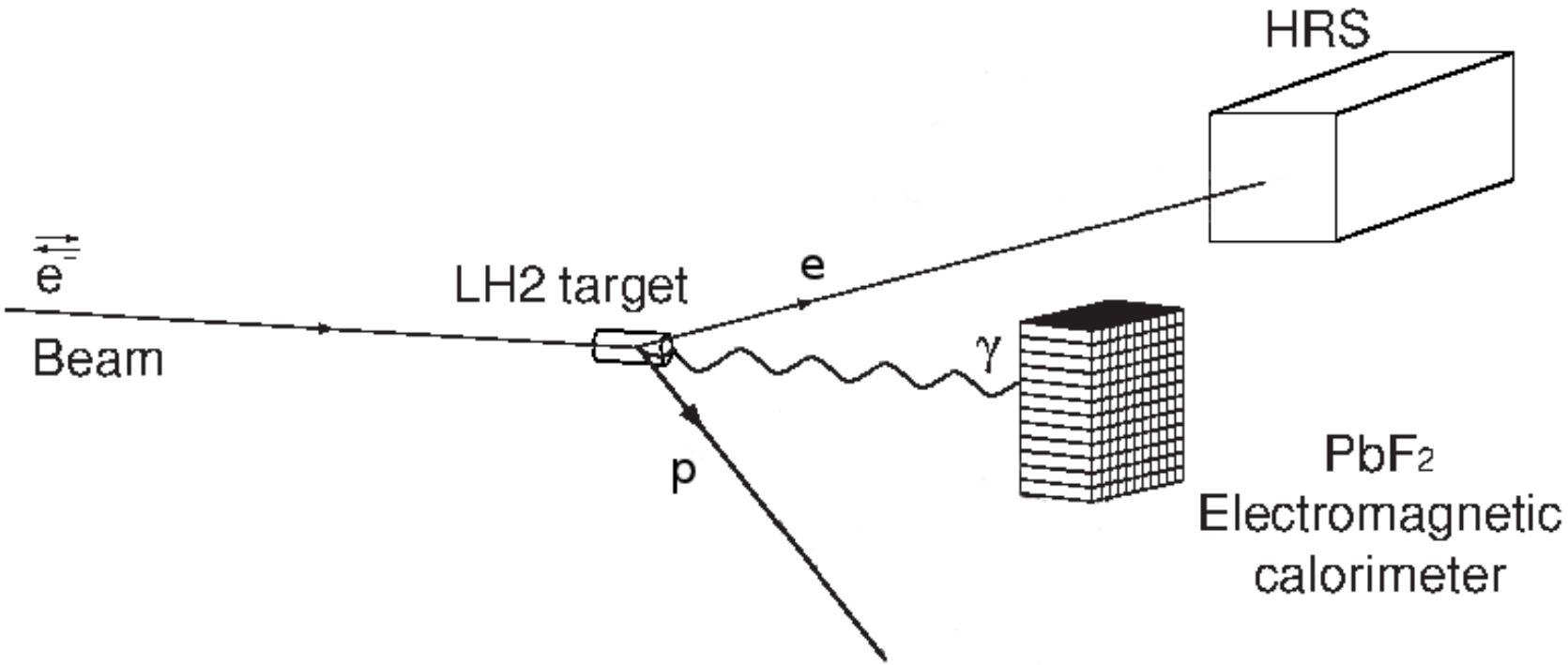
- Γ_i are kinematic factors which depend on the beam energy.
- The three amplitudes depend on x_B, $\mathcal{Q}^2$ and t.
- $|\mathcal{T}_{BH}|^2$ is calculable.

Rosenbluth separation of DVCS cross section



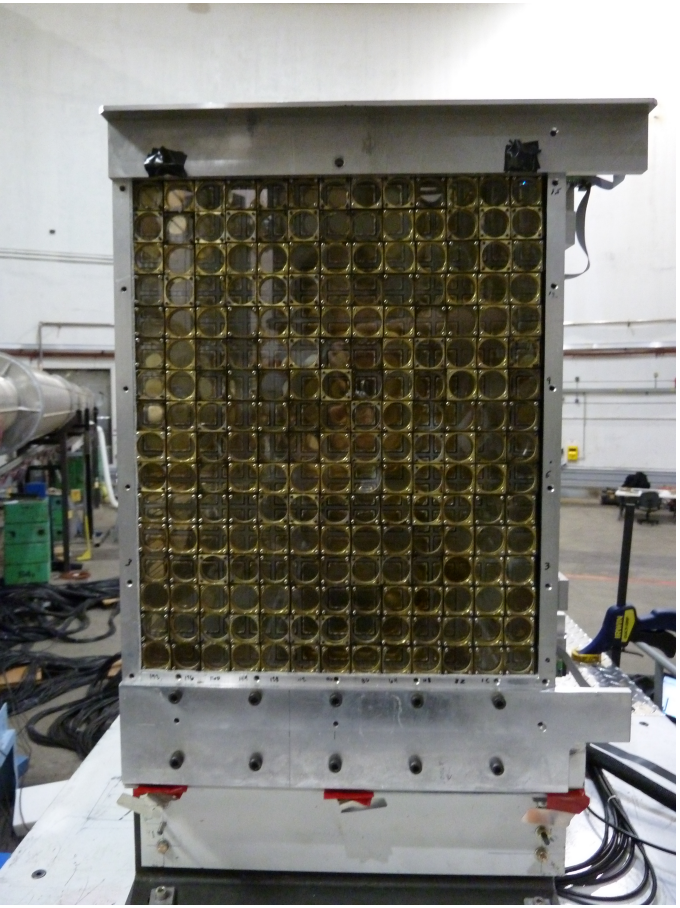
	*Kinematics*1		*Kinematics*2		*Kinematics*3	
$\mathcal{Q}^2$ (GeV^2)	1.5		1.9		2.3	
x_B	0.36		0.36		0.36	
W^2 (GeV^2)	3.78		4.26		4 .96	
q' (GeV)	2.14		2.73		3.32	
E_b (GeV)	6.00	3.64	6.00	3.64	6.00	4.82

Experimental setup



The electron beam interacts with the LH_2 or LD_2 target, producing an electron, a proton and a photon.

Electromagnetic calorimeter



- Composed of 208 PbF_2 blocks.
- Each one with dimensions 3 x 3 x 18.6 cm^3.
- Based on Čerenkov photons emission.
- PbF_2 Radiation length: 0.95cm.
- Molière radius: 2.2cm.
- More than 99.9% of the incident energy is absorbed.

Signal analysis: Fitting algorithm

The purpose of the waveform analysis is to obtain the amplitude a and time of arrival t_1 of our pulse $\{x_i\}$ by fitting the signal to a reference shape $\{h_i\}$:

$$\chi^2 = \sum_{i=0}^{i=127} (x_i - ah_i)^2$$

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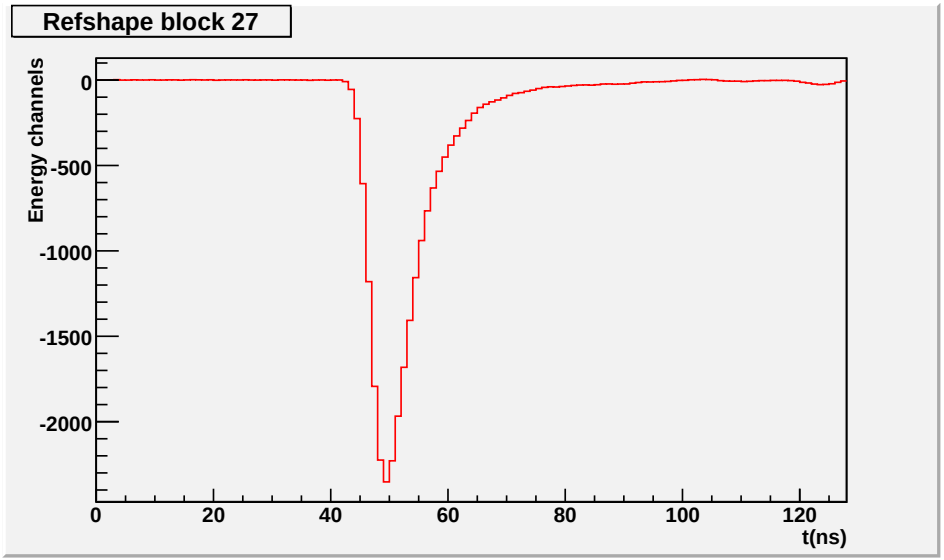
$$\chi^2 = \sum_{i=0}^{i=127} (x_i - ah_i)^2 \longrightarrow \chi^2(t) = \sum_{i=0}^{i=127} (x_i - a(t)h_{i-t})^2$$



- t is defined by the minimum $\chi^2(t)$ and so by the best fit.

Signal analysis: Baseline fit

Due to the high luminosity beam in Hall A it is necessary to deal with pile up events and many noise. We analyze the digitalized signals to find 3 different cases:

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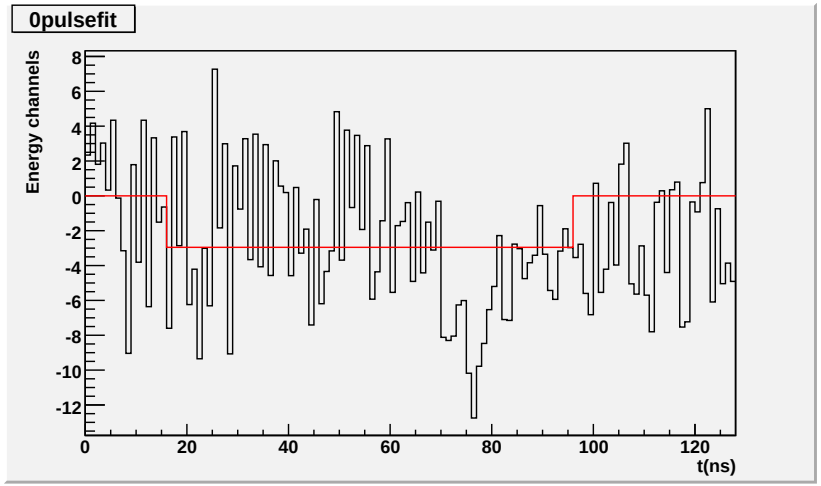
- No pulse → Baseline fit:

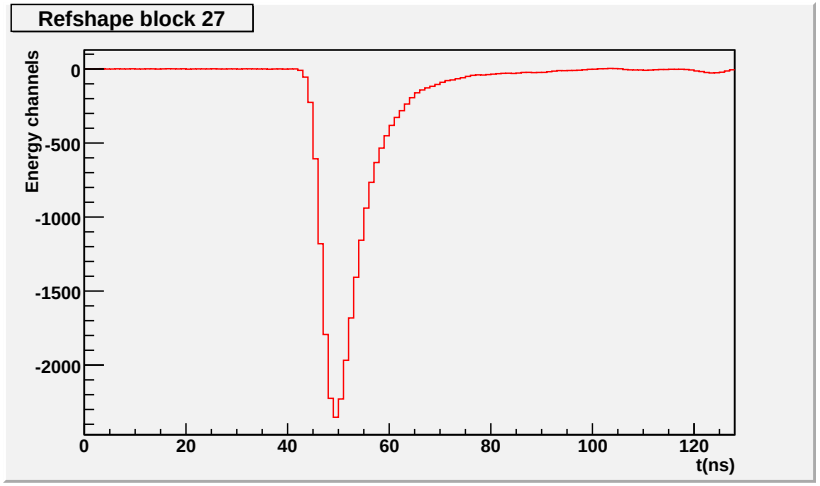
$$\chi^2 = \sum_{i=min}^{i=max} (x_i - b)^2 \qquad where \qquad b = \frac{1}{(i_{max} - i_{min})} \sum_{i=min}^{i=max} x_i$$



Signal analysis: 1 pulse fit

- 1 pulse fit: $$\chi^2(t_1) = \sum_{i=imin}^{imax} (x_i - a_1(t_1)h_{i-t_1} - b(t_1))^2$$

We use reference pulses for each of the blocks of the calorimeter in order to analyze the signals collected.



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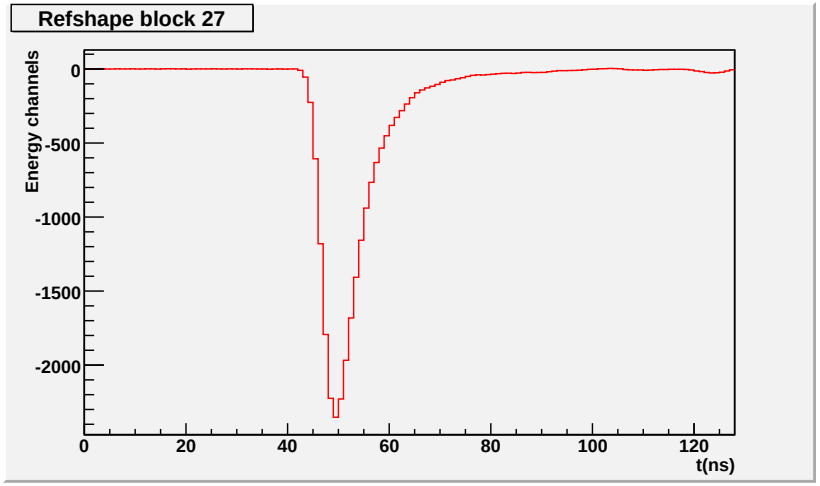
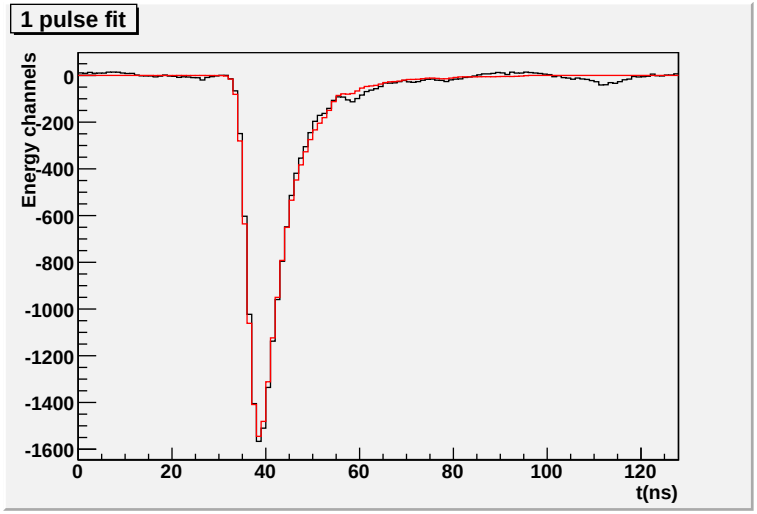


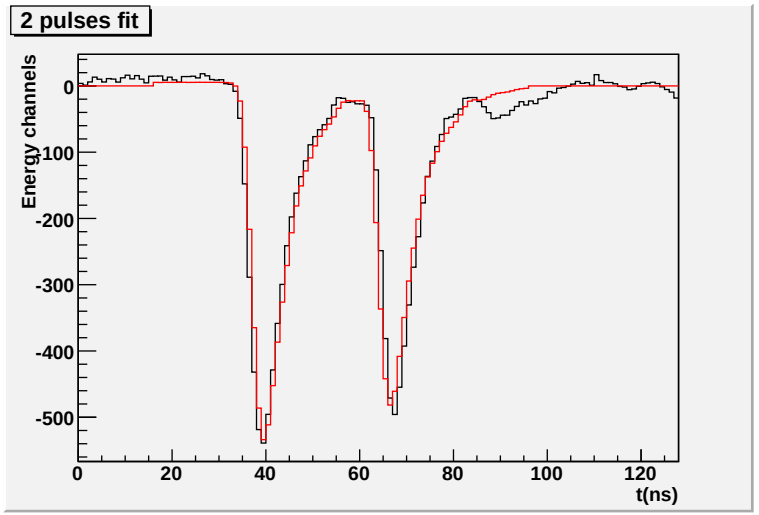


a_1 and b that minimize χ^2 are calculated analytically, then we calculate χ^2 for each t_1 in order to find the minimum.

Signal analysis: 2 pulses fit

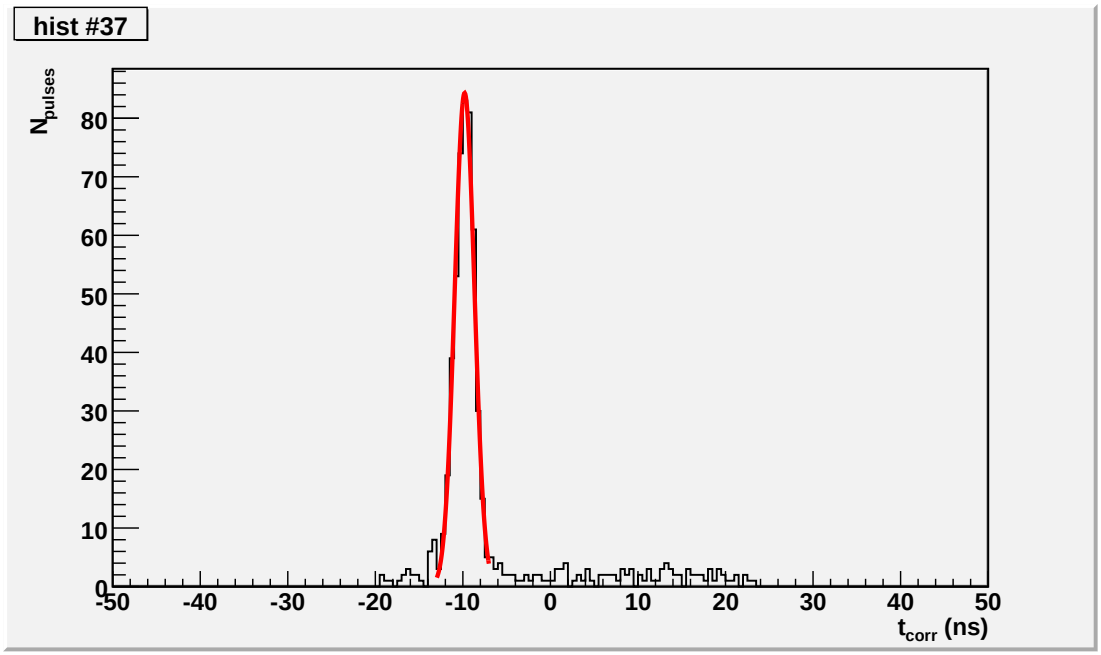
- 2 pulses fit:

$$\chi^2(t_1, t_2) = \sum_{i=imin}^{imax} (x_i - a_1(t_1, t_2)h_{i-t_1} - a_2(t_1, t_2)h_{i-t_2} - b(t_1, t_2))^2$$



Signal analysis: Time correction

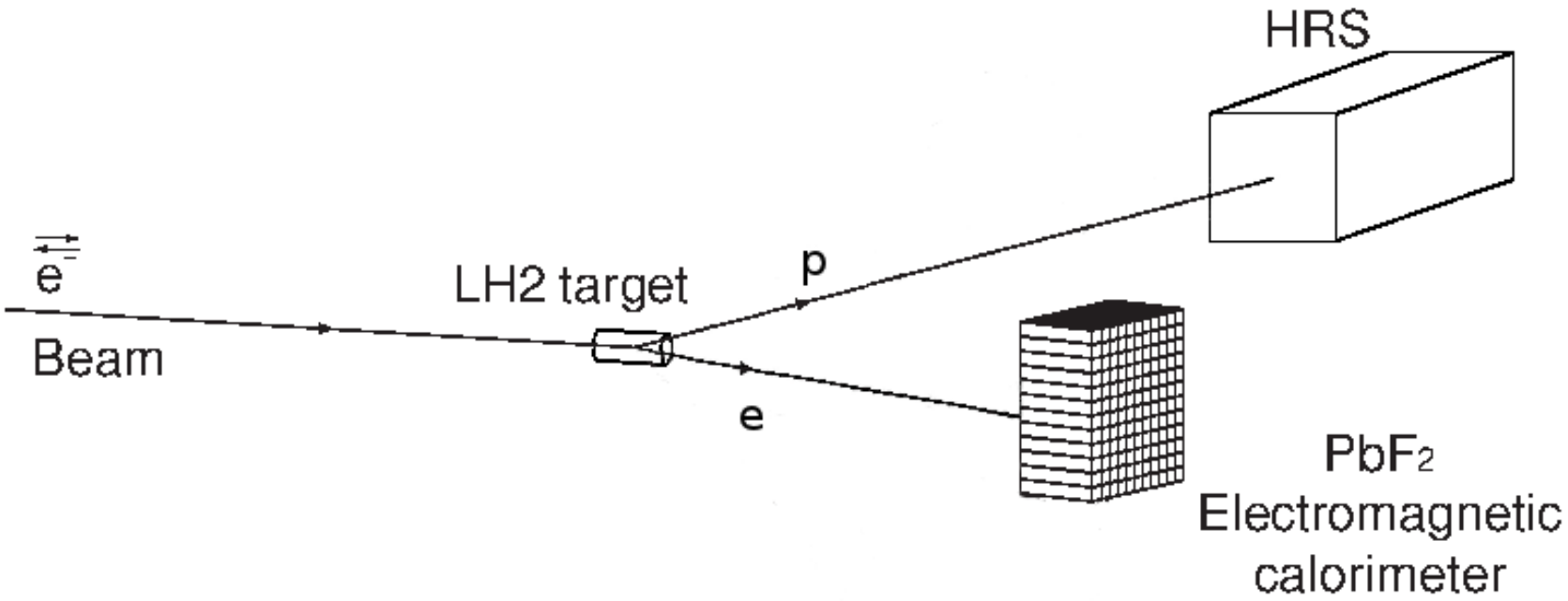
In a preliminary analysis we search for the time of arrival for the majority of signals.



This corrections are necessary mainly due to:

- Different position of the calorimeter in the setup.
- Different cable length for data acquisition.
- Relative position of blocks.

Experimental setup: Calorimeter calibration



The electron beam interacts with the LH_2 target, producing an electron and a proton in an elastic process.

Elastic calibration: obtaining the calibration coefficients

We define our χ^2 and minimize it to yield a series of 208 (amount of blocks in the calorimeter) linear equations:

$$\chi^2 = \sum_{j=1}^{N} \left(\frac{E_j}{\sigma} - \sum_{i=0}^{207} \frac{C_i A_j^i}{\sigma} \right)^2$$

- C_i: Coefficients
- A^i: Pulse amplitudes
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$$\sum_{i=0}^{207} \left[\sum_{j=1}^{N} \frac{A_j^k A_j^i}{\sigma^2} \right] C_i = \sum_{j=1}^{N} \frac{E_j A_j^k}{\sigma^2} \qquad \forall k = 0, 1, ..., 207$$

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$$\downarrow \qquad\qquad \downarrow$$

$$M_{ik} = \sum_{j=1}^{N} \frac{A_j^k A_j^i}{\sigma^2} \qquad V_k = \sum_{j=1}^{N} \frac{E_j A_j^k}{\sigma^2}$$

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We invert the matrix M_{ik} to obtain the coefficients and their errors:

$$C_i = M_{ik}^{-1} V_k \quad \forall k \qquad \delta(C_i) = \sqrt{(M_{ii}^{-1})}$$

Calibration Results

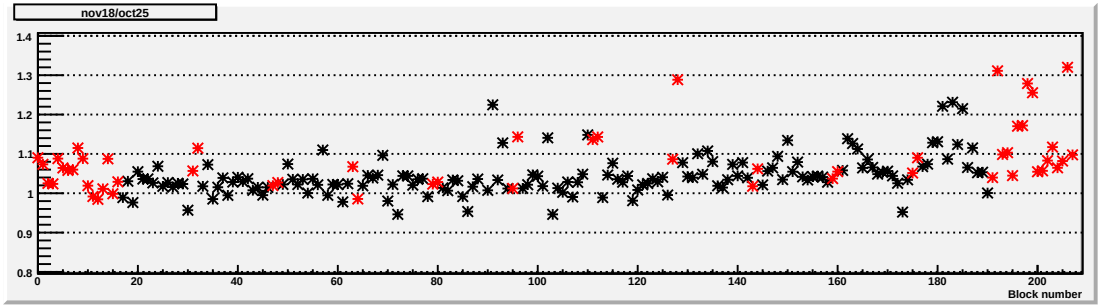
There were several calibration sessions during the experiment. The coefficients were calculated for each one, so we can keep track of the calorimeter status.

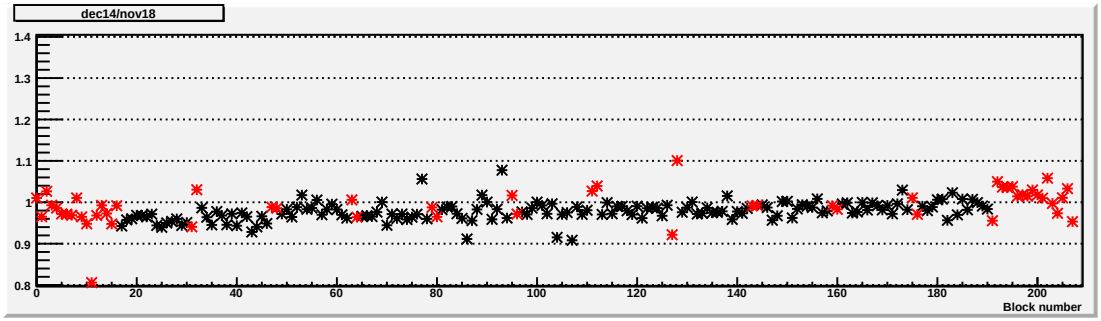
Date	$E_r(M)(GeV)$	E *Resolution*	$\Delta x(cm)$	$\Delta y(cm)$
17 oct	3.76	4.12 %	0.85	1.05
19 oct	3.75	3.25 %	0.81	1.09
25 oct1	3.15	3.18 %	0.94	1.21
25 oct2	3.13	3.16 %	0.93	1.21
17 nov1	3.13	3.16 %	0.97	1.18
17 nov2	3.13	3.15 %	0.96	1.18
14 dec	3.85	2.81 %	0.80	1.07

Energy and Angular resolution. $E_r(M)$ in GeV (Mean value of E_r).

Calibration Results

It is possible to observe the evolution of the coefficients as the experience went by (blocks located in the borders are in red):

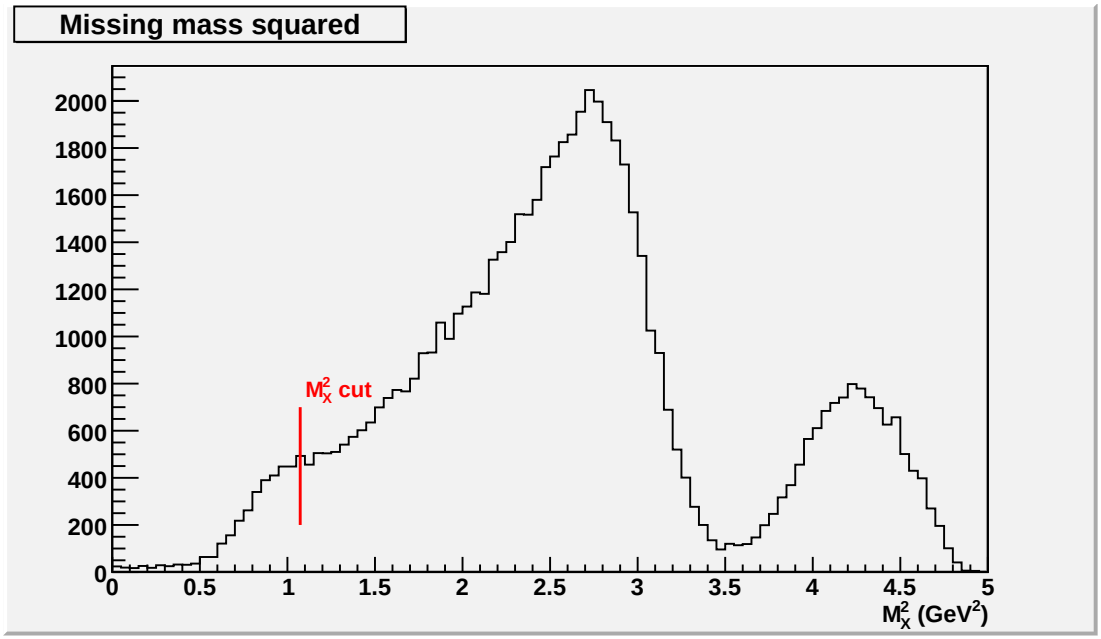




We observe that the blocks nearer to the beam (right) lose transparency at a faster pace.

Data analysis

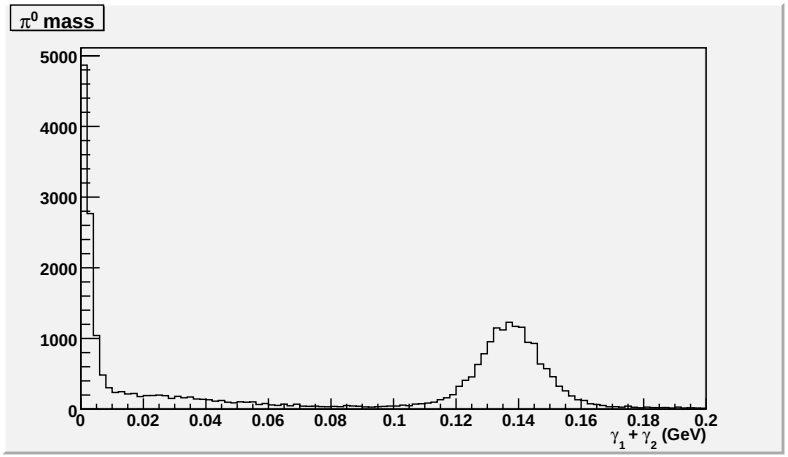
Since the scattered proton is not detected we introduce a cut in the missing mass variable $M_X^2 = (e' + \gamma - e - p)^2$ to select DVCS events:

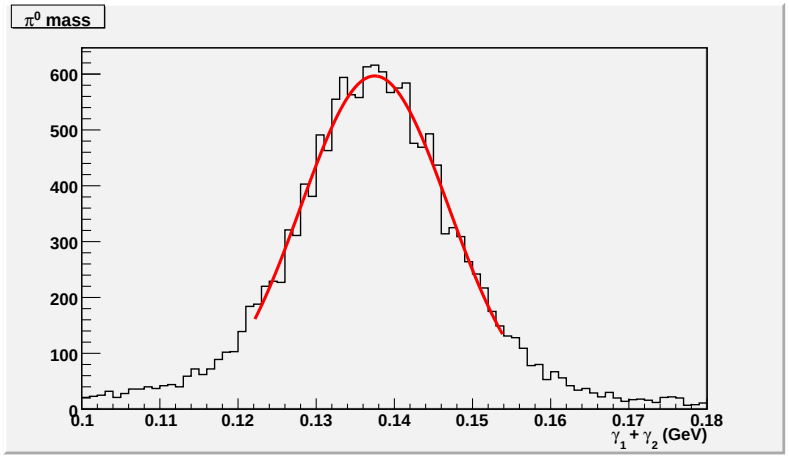


$$M_X^2 < (M_p + M_{\pi^0})^2$$

Data analysis

We can carry on a test to verify that the calibration of the calorimeter is correct by selecting events where $\pi^0 \rightarrow \gamma + \gamma$ (2 cluster events).





π^0 mass: 137.5 ± 9.5 MeV.
Theoretical value: 134.9766(6) MeV

Conclusions

- Calibration coefficients are reliable, as shown in M_{π^0} calculation.
- Half of the data from calorimeter already analysed.
- I haven't talked about clustering method (how we select the blocks to reconstruct the energy of the particles)
- Once the rest of the data has been analysed we will be in position to calculate cross sections.

Thank you for your attention.