# DVCS at JLAB

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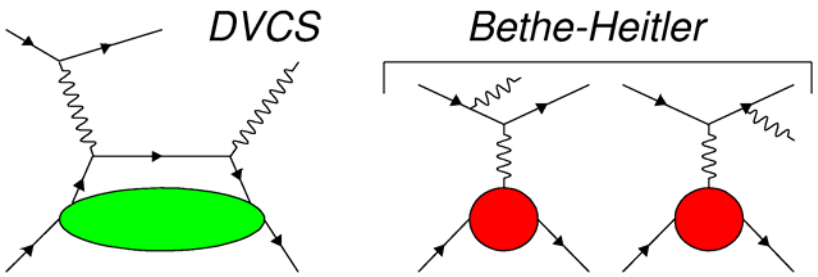
- ✓Theory
- ✓Previous Observations
- ✓New experiments
- ✓Outlook

# DVCS at JLAB

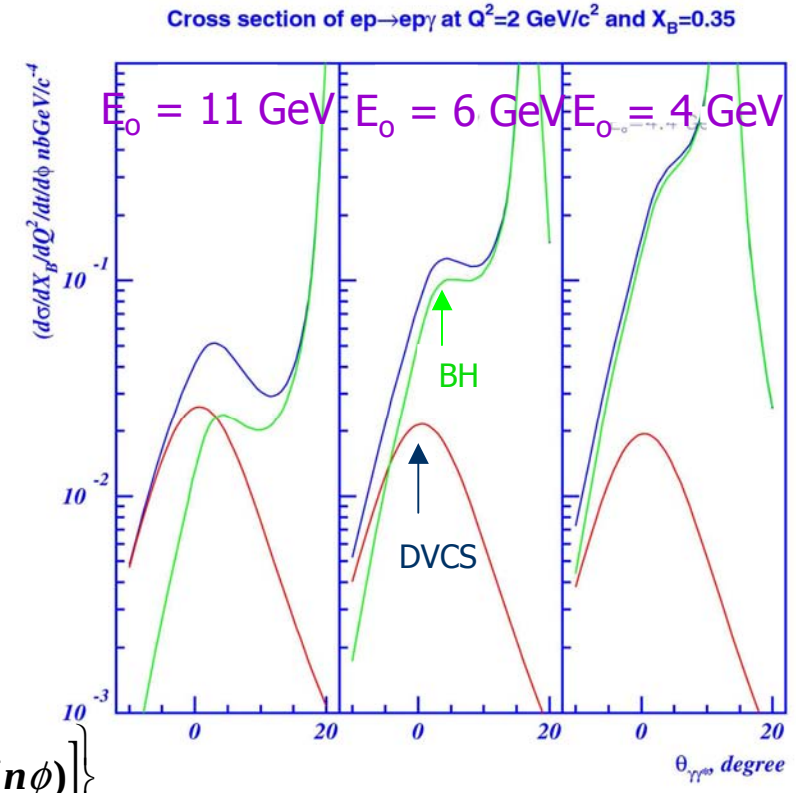
$$\frac{d^4\sigma}{dQ^2 dx_B dt d\phi} \sim |T^{DVCS} + T^{BH}|^2$$




$$T^2 = \left|T^{DVCS}\right|^2 + \left|T^{BH}\right|^2 + I$$

$$I = T_{DVCS} T^*_{BH} + T^*_{DVCS} T_{BH}$$

$$I = \frac{\pm e^6}{x_B^2 y^3 \Delta^2 P_1(\phi) P_2(\phi)} \left\{ c_0^I + \sum_{n=1}^{2} \left[ c_n^I \cos(n\phi) + s_n^I \sin(n\phi) \right] \right\}$$



# Proton Target

$$d^5\sigma^{\rightarrow} - d^5\sigma^{\leftarrow} \propto \mathrm{Im}(BH \bullet DVCS) \sim s_1^I \cdot \sin\phi$$

$$A = F_1(t)\cdot \mathrm{H} + \frac{x_B}{2-x_B}\cdot\left(F_1(t)+F_2(t)\right)\cdot \tilde{\mathrm{H}} - \frac{t}{4M^2}F_2(t)\cdot \mathrm{E}$$

| $-t$ | $F_2^p(t)$ | $F_1^p(t)$ | $\left(F_1^p(t)+F_2^p(t)\right)\cdot x_B/(2-x_B)$ | $(-t/4M^2)\cdot F_2^p(t)$ |
|---|---|---|---|---|
| 0.1 | 1.34 | 0.81 | 0.38 | 0.04 |
| 0.3 | 0.82 | 0.56 | 0.24 | 0.06 |
| 0.5 | 0.54 | 0.42 | 0.17 | 0.07 |
| 0.7 | 0.38 | 0.33 | 0.13 | 0.07 |

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

$x_B = 0.3$

$-t = 0.3$

| **Target** | H | $\tilde{\mathrm{H}}$ | E |
|---|---|---|---|
| **Proton** | 1.13 | 0.70 | 0.98 |

$$A = \underbrace{F_1(t)\cdot \mathrm{H}}_{0.34} + \underbrace{\frac{x_B}{2-x_B}\cdot\left(F_1(t)+F_2(t)\right)\cdot \tilde{\mathrm{H}}}_{0.17} - \underbrace{\frac{t}{4M^2}F_2(t)\cdot \mathrm{E}}_{0.06}$$

$$A = \quad 0.34 \quad + \qquad\qquad 0.17 \qquad\qquad + \quad 0.06$$

# Neutron Target

$$A = F_1(t)\cdot \mathrm{H} + \frac{x_B}{2-x_B}\cdot\left(F_1(t)+F_2(t)\right)\cdot \tilde{\mathrm{H}} - \frac{t}{4M^2}F_2(t)\cdot \mathrm{E}$$

| $-t$ | $F_2^n(t)$ | $F_1^n(t)$ | $\left(F_1^n(t)+F_2^n(t)\right)\cdot x_B/(2-x_B)$ | $(-t/4M^2)\cdot F_2^n(t)$ |
|---|---|---|---|---|
| 0.1 | -1.46 | -0.01 | -0.26 | -0.04 |
| 0.3 | -0.91 | -0.04 | -0.17 | -0.07 |
| 0.5 | -0.60 | -0.05 | -0.12 | -0.08 |
| 0.7 | -0.43 | -0.06 | -0.09 | -0.08 |

$F_1^n(t) << F_2^n(t)$ !!!

$\tilde{\mathrm{H}}$ small by $u/d$ quark cancellation in neutron

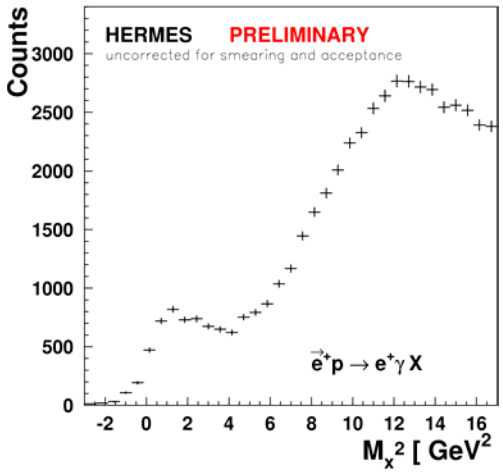
| **Target** | H | $\tilde{\mathrm{H}}$ | E |
|---|---|---|---|
| **Neutron** | 0.81 | -0.07 | 1.73 |

$$A = F_1(t)\cdot \mathrm{H} + \frac{x_B}{2-x_B}\cdot\left(F_1(t)+F_2(t)\right)\cdot \tilde{\mathrm{H}} - \frac{t}{4M^2}F_2(t)\cdot \mathrm{E}$$

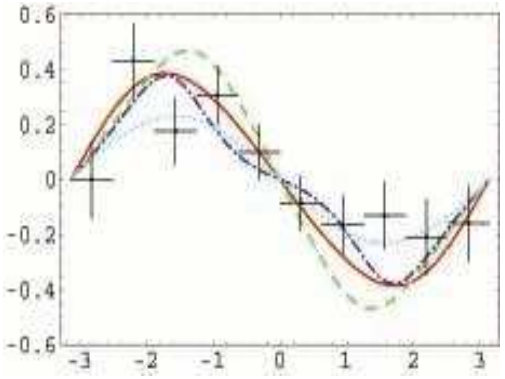
$$A = -0.03 \quad + \quad 0.01 \quad - \quad 0.12$$

# Previous Observations

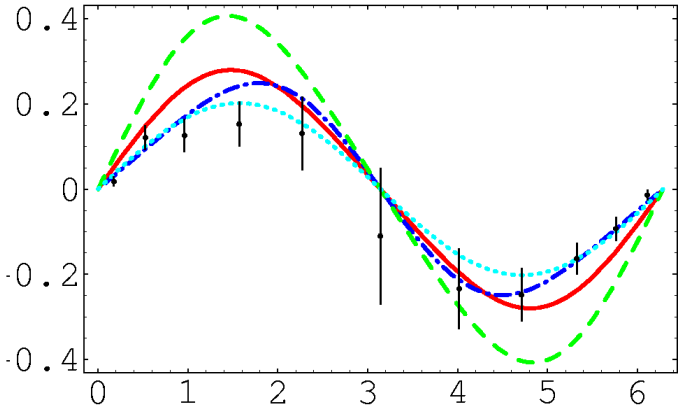
- In 2001 HERMES and CLAS collaborations simultaniously measured DVCS beam spin asymmetry (inclusive measurement).




HERMES BSA
Inclusive ep->eγX.
eγ missing mass cut
-1.7<M<1.7

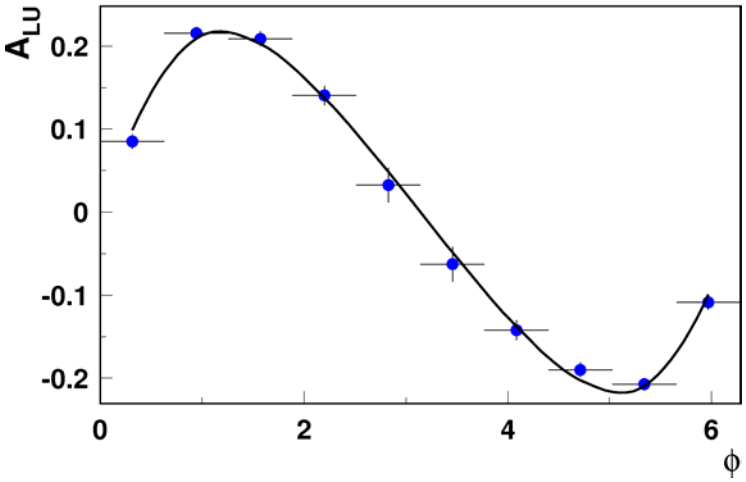


CLAS 4.2 GeV H(ep,epX)
(S.Stepanyanet al, Phys Rev Lett 87 (2001))

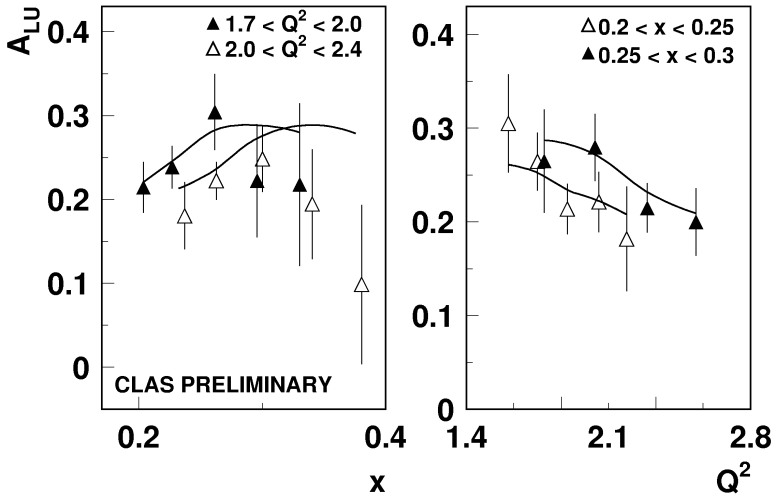


# Previous Observations

- Beam Spin Asymmetry in CLAS with 5.7 GeV initial electron energy

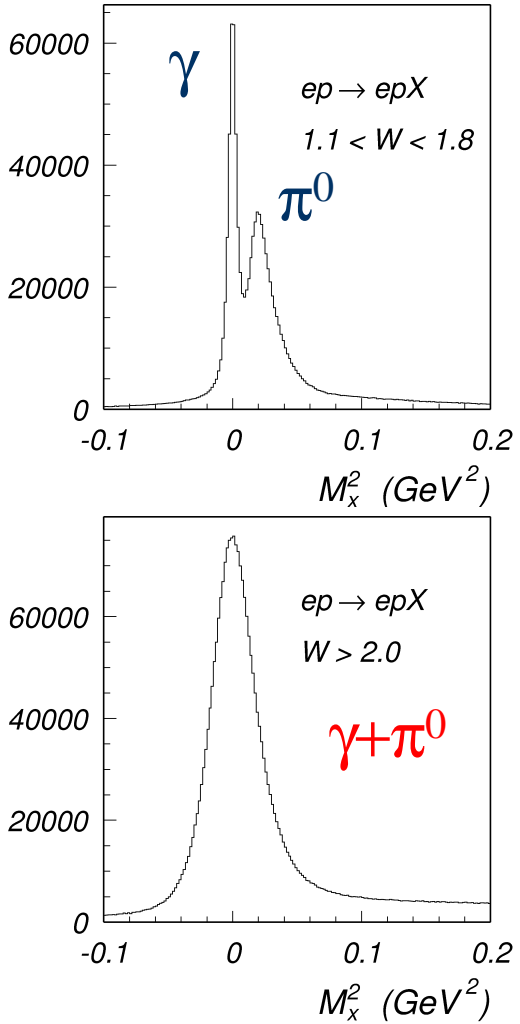



- $x_B$ and $Q^2$ dependences for beam spin asymmetry at 5.7 GeV. The theoretical curves from calculations by M.Vanderhagen.



# Previous Observations

- CLAS Collaboration 2003 obtained beam spin asymmetries for 3 different Q2 bins.
- CLAS detector resolution is not sufficient for separating pion and photon production events on event-by-event basis.
- A fit to line shape of ep missing mass was used to extract the number of photo-production events under the ep missing mass peak.

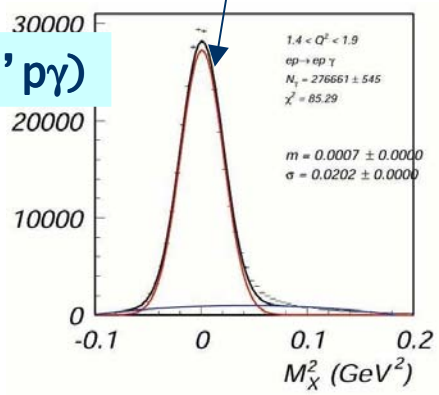


# DVCS in CLAS

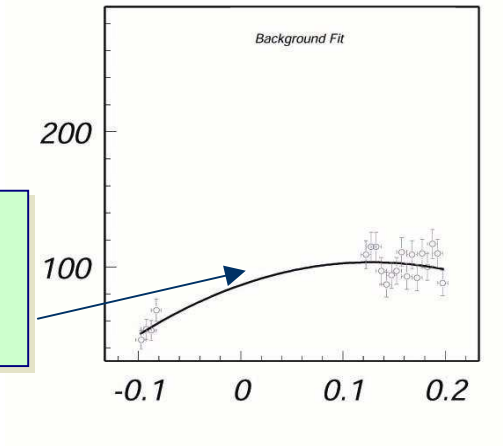
$$F = N_\gamma \cdot G_\gamma + N_\pi \cdot G_\pi + Pol3$$

Fixing photon and pion missing mass
Properties Gγ and Gπ

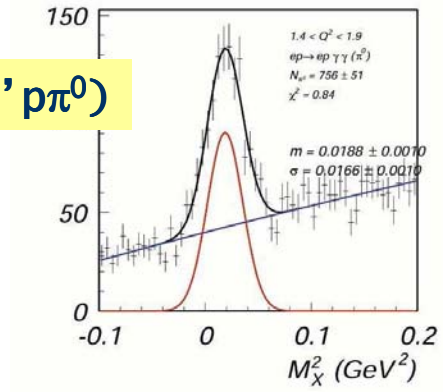
H(e,e'pγ)



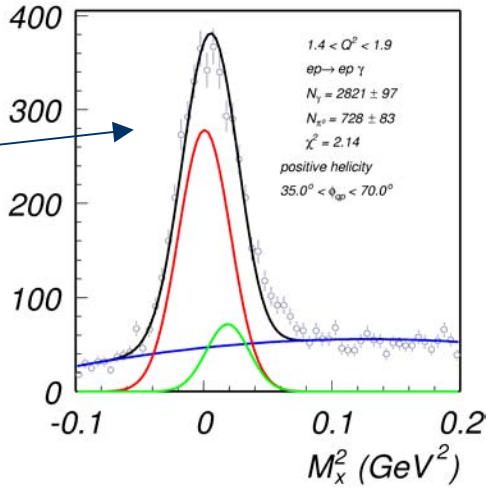

Fit to the end points
Of missing mass to fix
background




H(e,e'pπ$^0$)

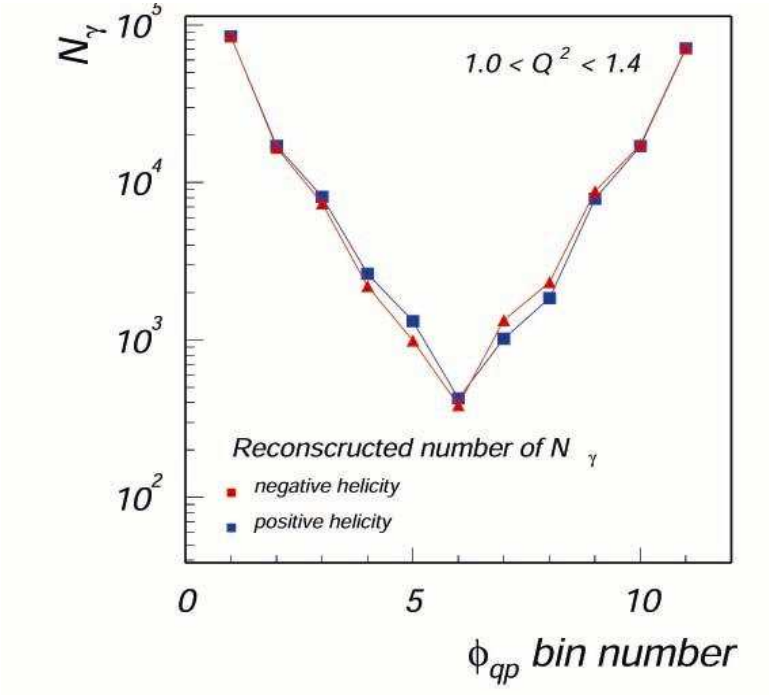



Fit of missing mass
with double gaussian
function H(ep,epX)

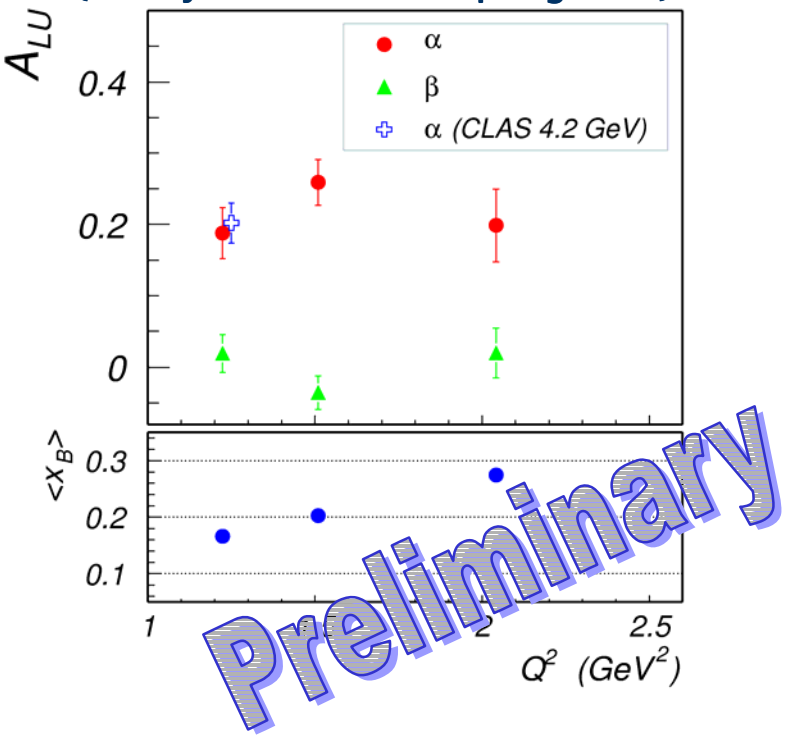


# DVCS in CLAS

Number of extracted photon final states as a function of azimuthal angle bin




G.Gavalian (CLAS 4.8 GeV)
(analysis note in progress)



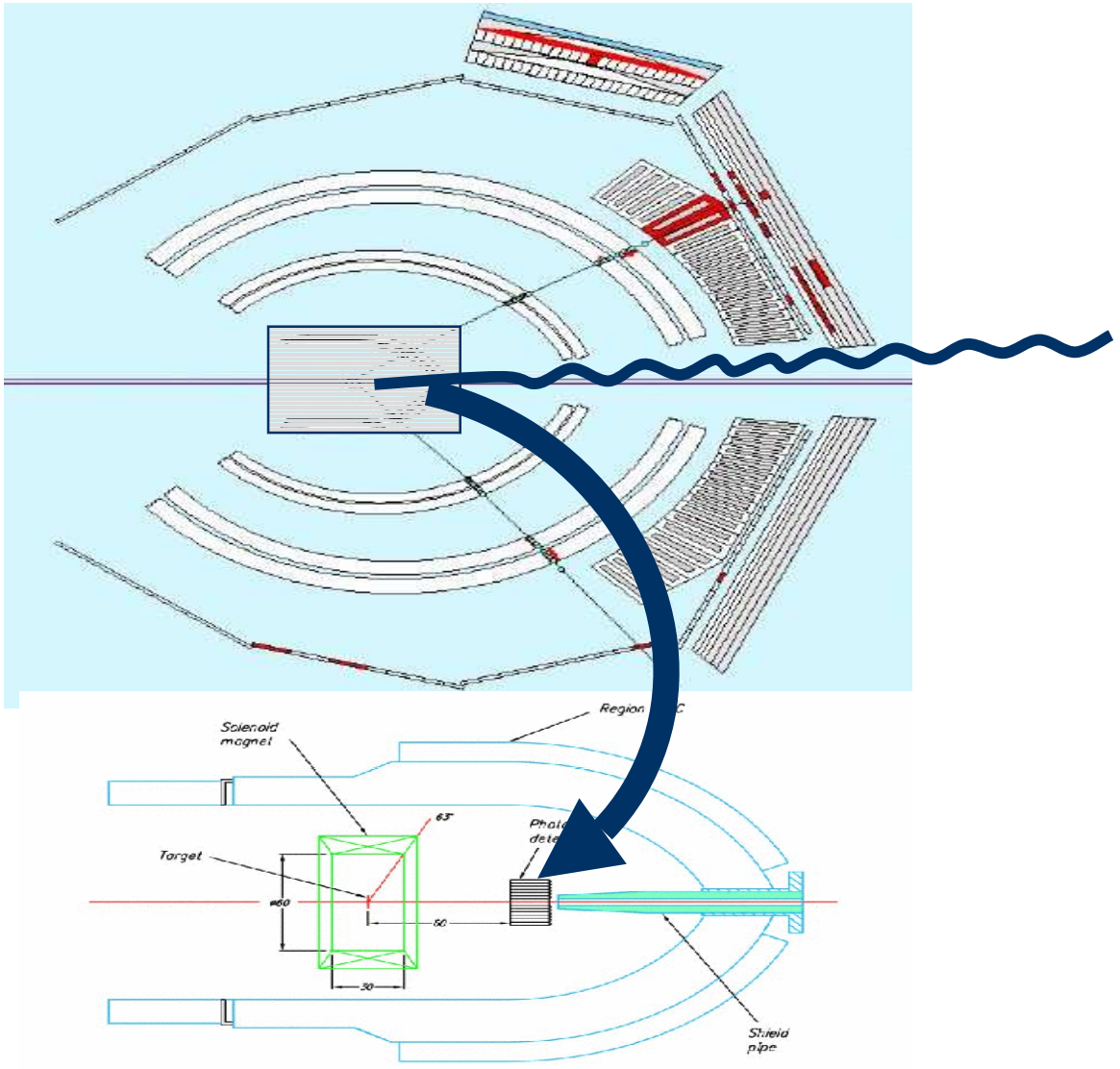

$$A_{LU} = \frac{1}{P} \cdot \frac{N_\gamma^+ - N_\gamma^-}{N_\gamma^+ + N_\gamma^-}$$

# Dedicated CLAS DVCS measurements

2001-2003 :
A typical
ep->epγ event
in CLAS

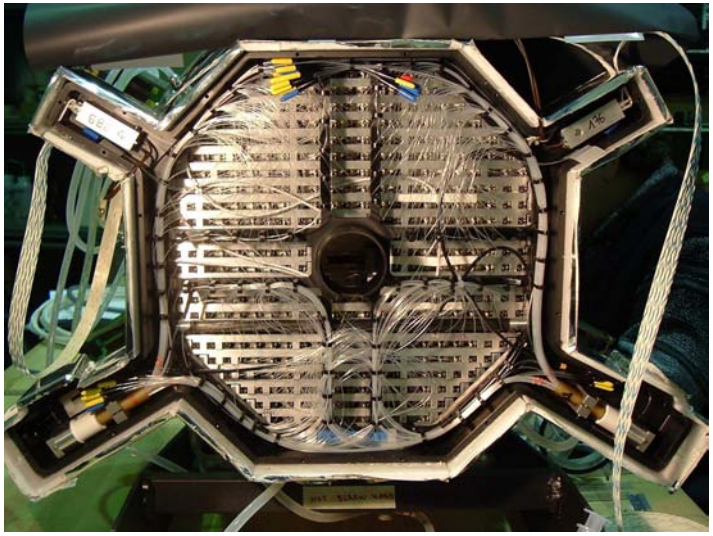
2005:
A calorimeter is
added at
$3^o<\theta_\gamma<14^o$

A solenoid
Møller shield
Is added around
The target

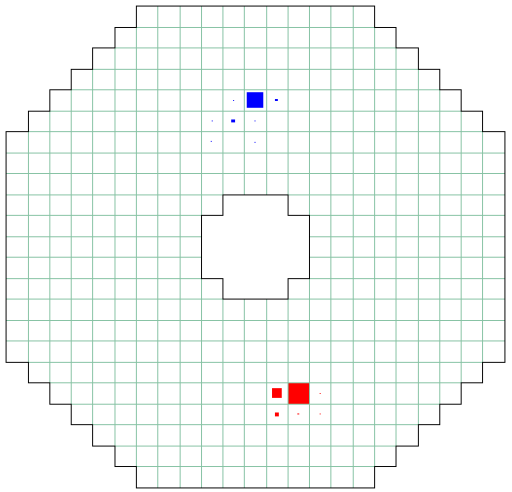


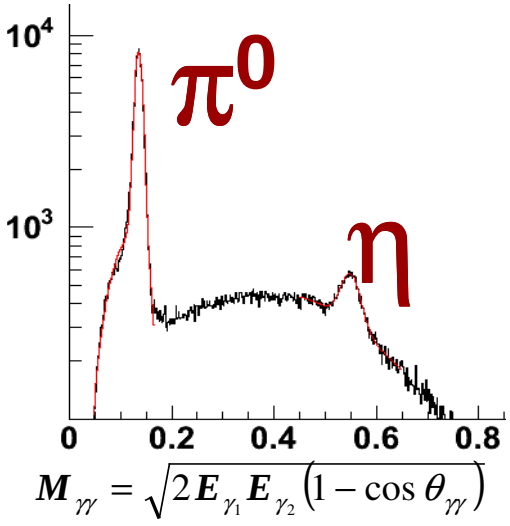
# Dedicated CLAS DVCS measurements

- The new Calorimeter consists of 424 $PbWO_4$ crystals 13x13x100mm$^3$
- Light read out via avalanche photo-diodes
- Temperature stabilization for high precision energy measurements.



$$\pi^0(\eta) \rightarrow \gamma\gamma$$






$$M_{\gamma\gamma} = \sqrt{2E_{\gamma_1}E_{\gamma_2}(1-\cos\theta_{\gamma\gamma})}$$

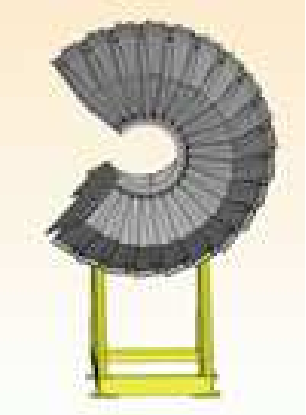
# DVCS in Hall-A

- Hall-A set up an experiment in Sep. 2004 with a goal to measure the absolute cross section of DVCS on proton and neutron for 3 $Q^2$ values

  ($Q^2$ = 1.4,1.9,2.3 $GeV^2$)
- Standard High Resolution Spectrometer (HRS) was used to detect electrons.
- Electromagnetic Calorimeter was used to detect photons
- An array of scintillating counters (Proton Array) was used to tag protons.
- A neutron veto scintillating paddles where used to tag veto protons on electron-deuterium scattering

# Hall-A Equipment

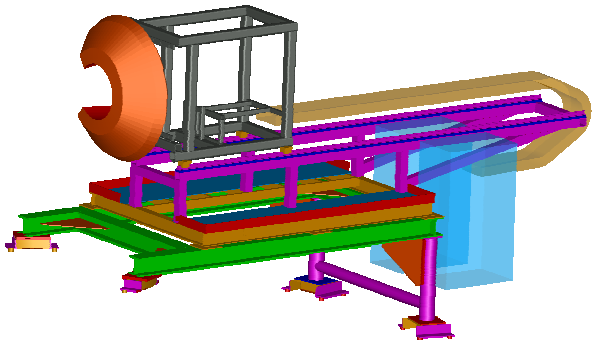
Proton Array with
100 elements
(5x20 matrix)



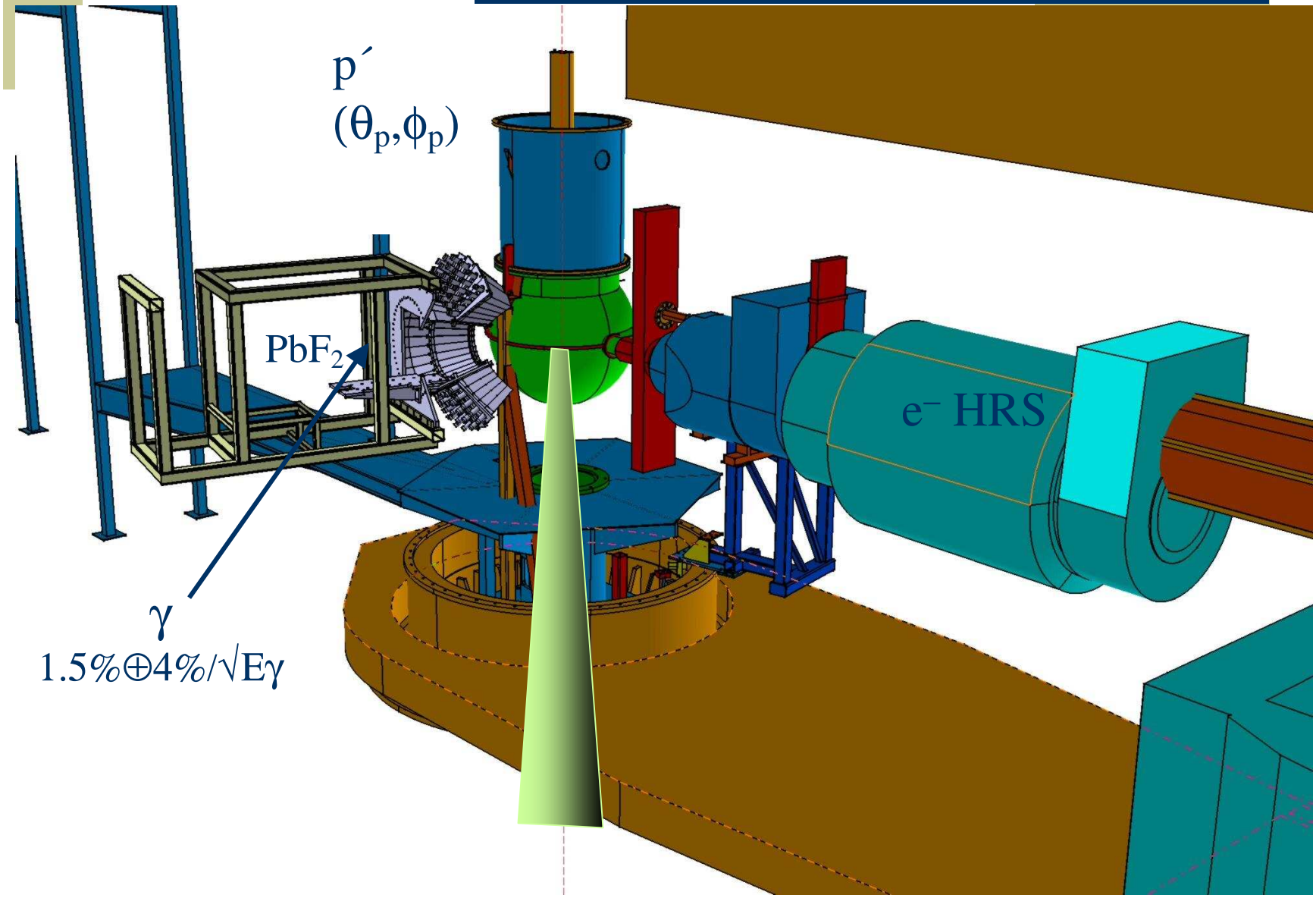
Scattering Chamber

Calorimeter
with 132 $PbF_2$ elements
(11x12 matrix)

Support structure

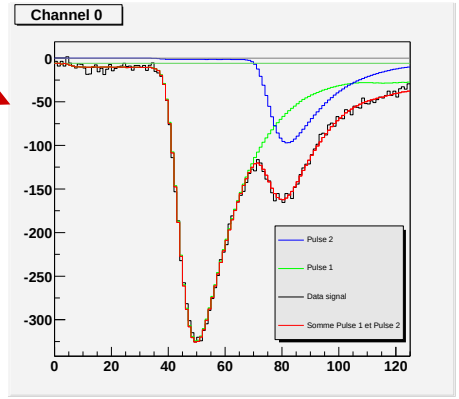


# Hall-A equipment



# Electronics


• 1Ghz Analog Ring Sampling (ARS)
x 128 samples → 1MHz FADC.




256 channels: Sample the PMT signal from PbF2 and proton array.

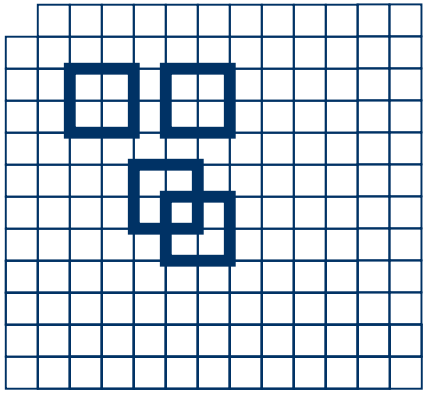
•Digital Trigger for Calorimeter

Following HRS trigger, stop ARS. 30MHz trigger FADC digitizes all calorimeter signals in 30ns window.

Compute all 4-block sums.

Look for at least one block of four over threshold

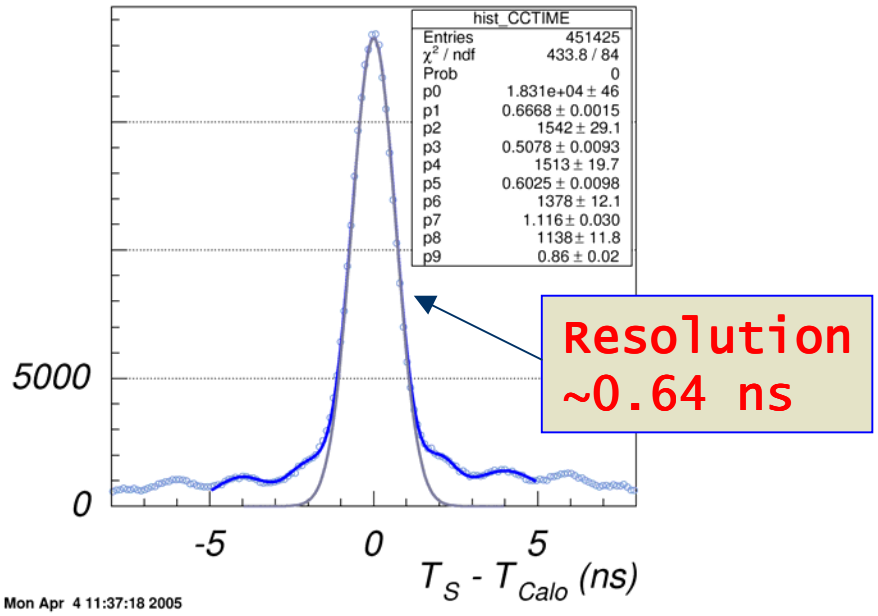
Validate or reject HRS trigger within 340 ns: Readout or fast clear of ARS.



# DVCS in Hall-A

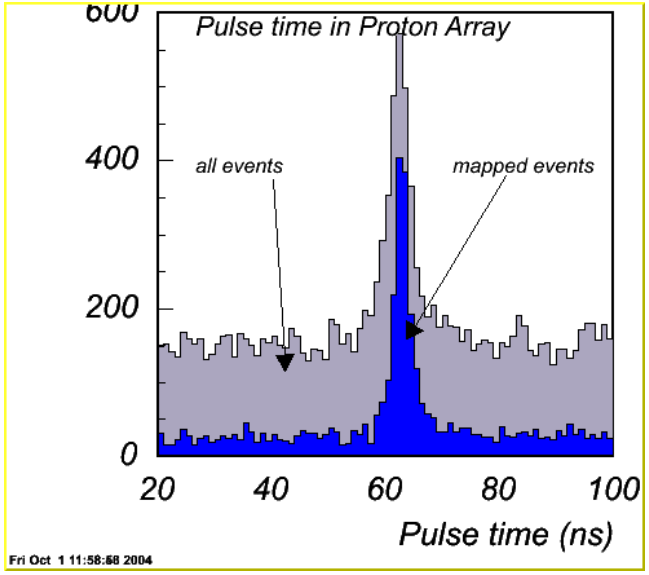
- The DVCS events are selected via triple coincidence between HRS Calorimeter and the proton array.

Time difference between the electron arm and the detected photon (2 ns beam structure can be seen)



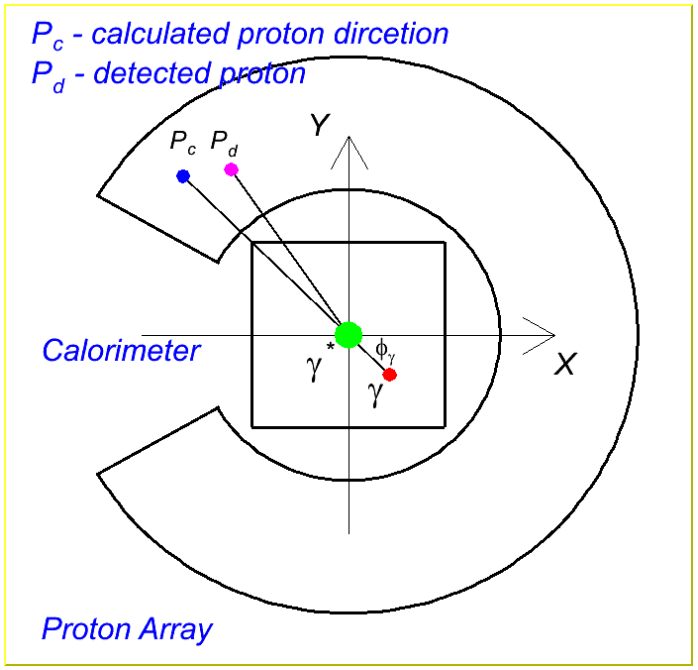

Resolution ~0.64 ns

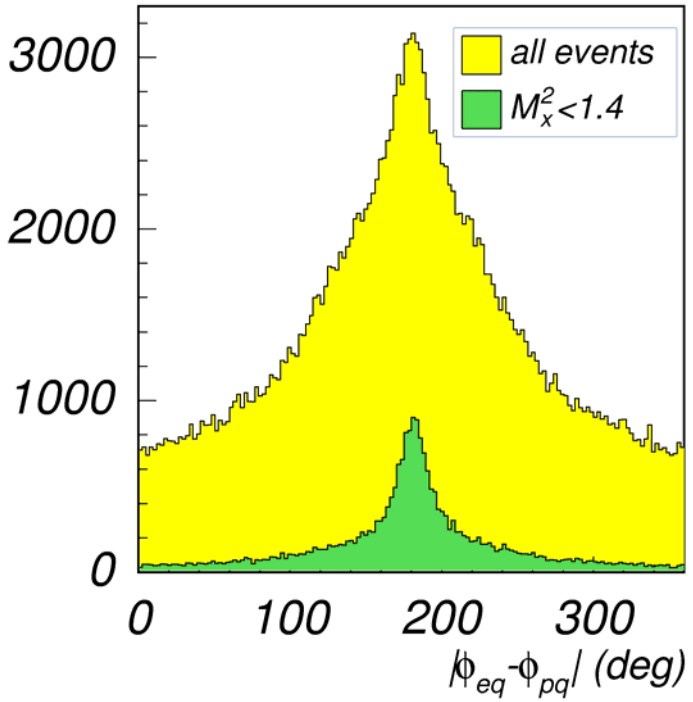
Arrival time of the pulses in Proton Array



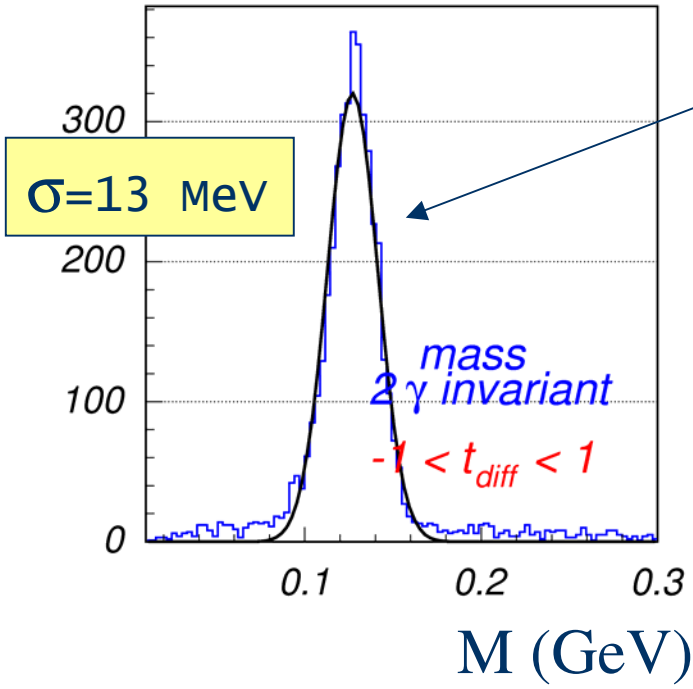
# DVCS in Hall-A

- After timing cuts the geometrical matching of the events is done (assuming it's an exclusive DVCS event)



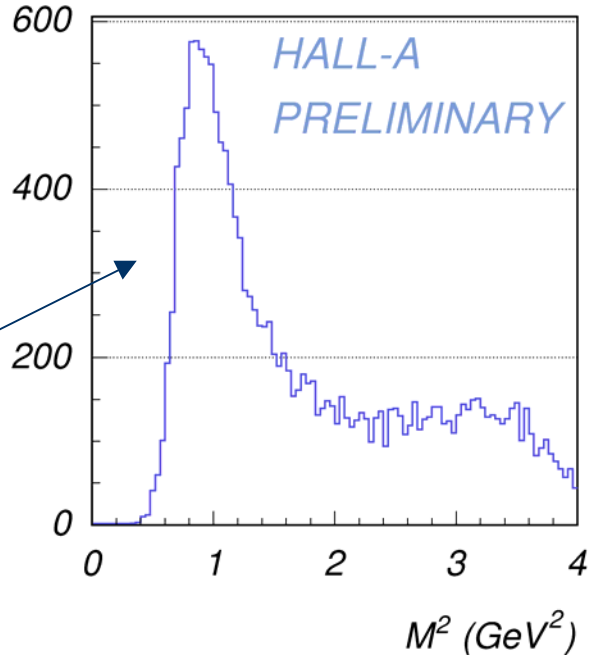



# Preliminary Results




Invariant mass of events with two clusters in the calorimeter (calorimeter calibration check)

Missing mass$^2$ of H(e,e'γ)X for events with coplanar hit in the Proton Array



# Outlook

- After first observations of DVCS beam spin asymmetry an interest for new experiments rose.
- CLAS collaboration experiment is still running.
- Hall-A experiment has finished in December 2004.
- The Hall-A collaboration is in process of calibrating data.
- Simulations are ran to address acceptance and efficiency issues
- Results are expected soon….
- There are plans (hopes) to measure DVCS cross sections with upgraded JLAB

( 12 GeV), where one can reach $Q^2 \sim 9$ GeV$^2$ and $x_B \sim 0.2\text{-}0.6$