

# $\Delta$ VCS

## Beam Spin Asymmetries with CLAS: Update

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$$e + p \rightarrow e' + \Delta^+ + \gamma$$



# $\Delta$ VCS

## Beam Spin Asymmetries

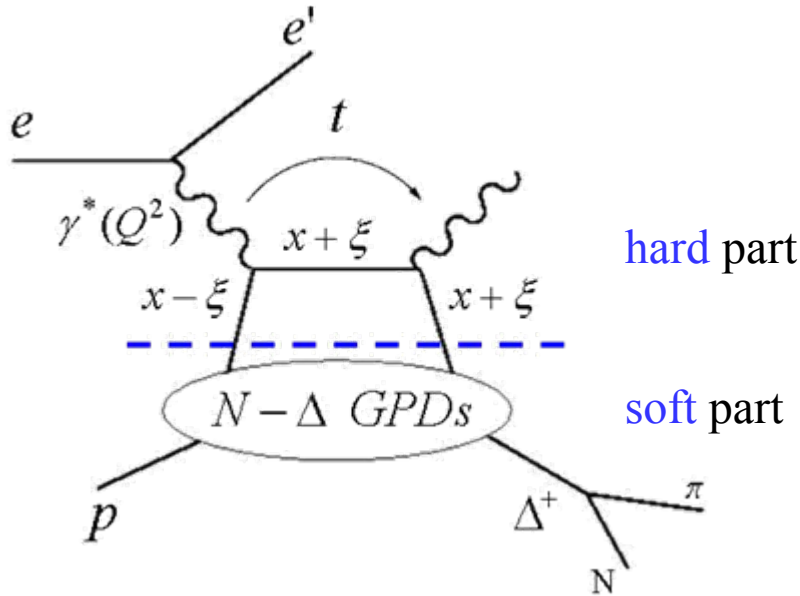
### with CLAS: Update

- $\Delta$ VCS analyses reminder
- Double  $\pi^0$  background study
- $\pi^+ \pi^0$  background study
- $\Delta$ VCS: results
- Conclusions and outlook

# $\Delta$ VCS and GPDs

$$ep \rightarrow e'\Delta^+\gamma$$

In the **Bjorken limit**:



Handbag diagram

$N-\Delta$  GPDs : same information as nucleon GPDs

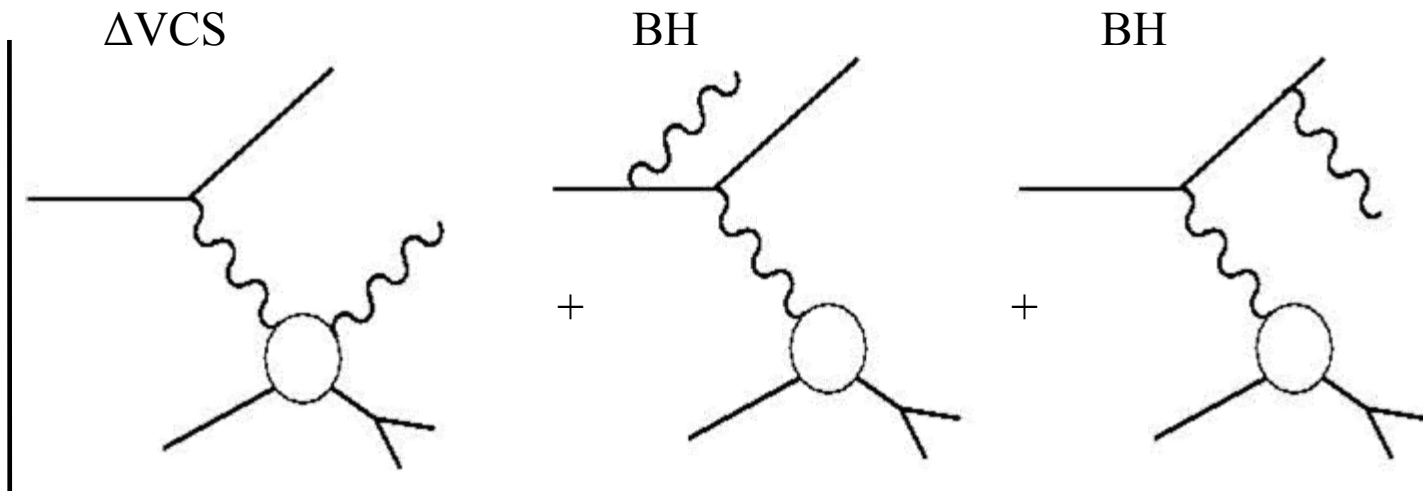
- $N-\Delta$  transitions at a partonic level
- large  $N_c$  approximation:  $\Delta$ VCS can be described in terms of quark GPDs

*L.L. Frankfurt, M. V. Polyakov, M. Strikman, M.Vanderhaeghen*  
*Phys. Rev. Lett. 84: 2589-2592 (2000)*

*P.A.M Guichon, L.Mossé, M.Vanderhaeghen*  
*Phys. Rev. D68 034018 (2003)*

$$\left. \begin{matrix} H_M, H_E, H_C \\ C_1, C_2, C_3, C_4 \end{matrix} \right\} \mathbf{N-\Delta GPDs}$$

$$\sigma(ep \rightarrow e\Delta^+\gamma) \propto$$

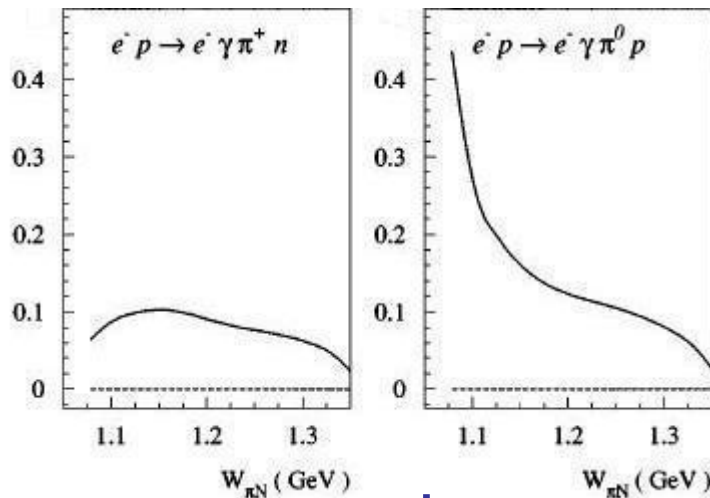


Interference between  $\Delta$ VCS and Bethe-Heitler

$$\Delta^+ \rightarrow n\pi^+$$

$$\Delta^+ \rightarrow p\pi^0$$

BSA



*P.A.M Guichon, L.Mossé, M.Vanderhaeghen*

*Phys. Rev. D68 034018 (2003)*

$$\Delta\text{VCS } (\pi^+): \quad ep \rightarrow e\Delta^+\gamma \rightarrow en\pi^+\gamma$$

$$\Delta\text{VCS } (\pi^0): \quad ep \rightarrow e\Delta^+\gamma \rightarrow ep\pi^0\gamma$$

Experimental data is integrated  
over this whole range

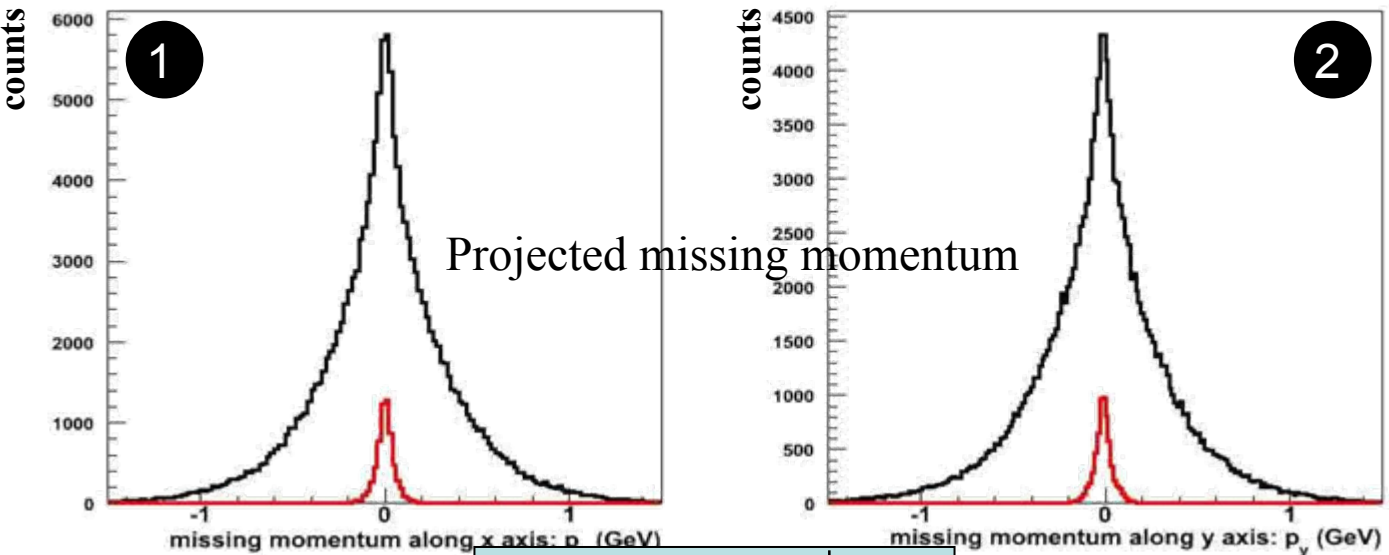
**Calculated Beam Spin Asymmetry**

# $\Delta VCS (\pi^+)$ : event selection

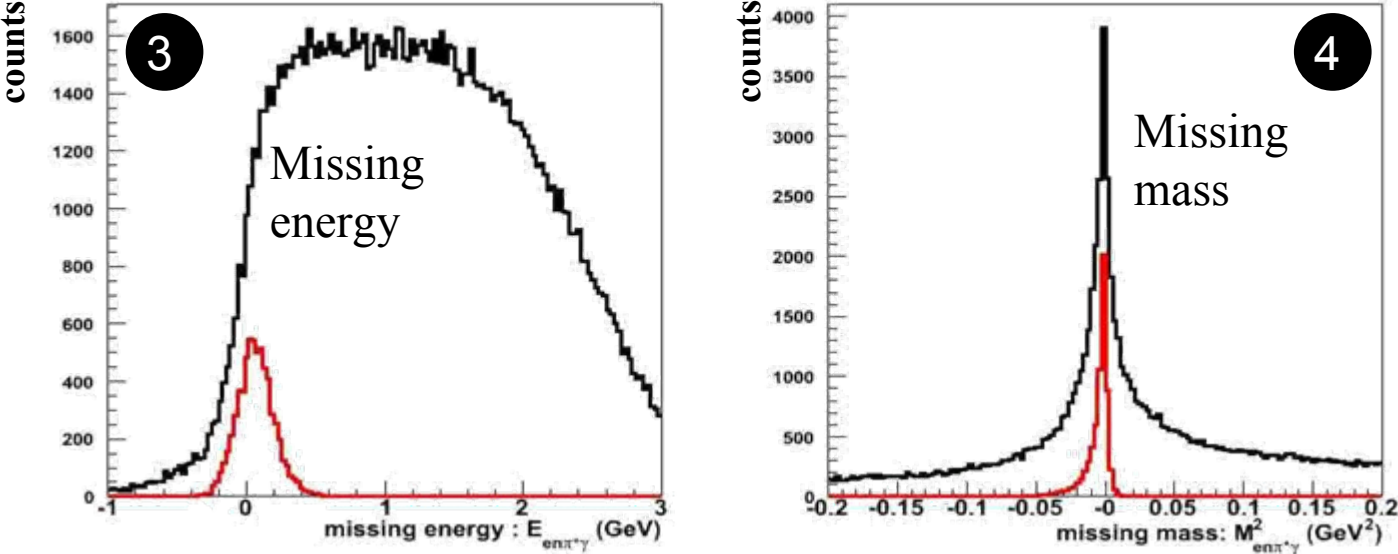
$$ep \rightarrow e\Delta^+ \gamma \rightarrow en \pi^+ \gamma$$

ALL final state particles detected

— data before cuts  
— data after cuts



$$ep \rightarrow en \pi^+ \gamma X$$



$P_{en\pi^+\gamma}^x$	1
$P_{en\pi^+\gamma}^y$	2
$E_{en\pi^+\gamma}^X$	3
$M_{en\pi^+\gamma}^2$	4
$M_{en\pi^+}^2$	
$M_{en\gamma}^2$	
$M_{e\pi^+\gamma}^2$	
$\Delta\Phi$	

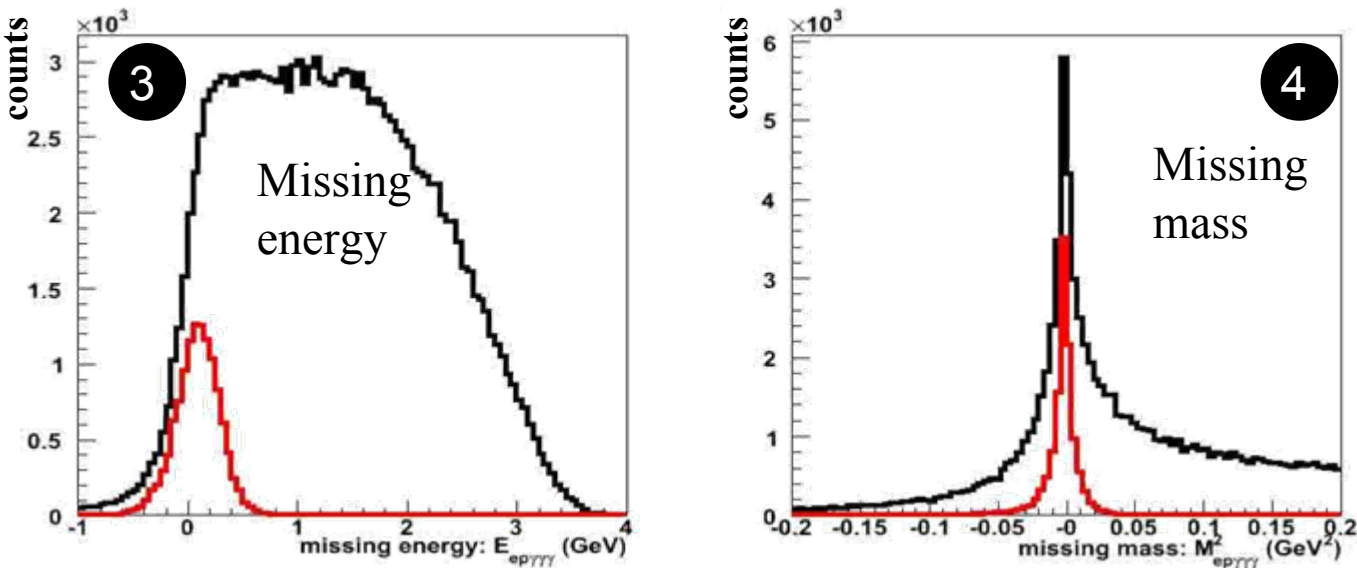
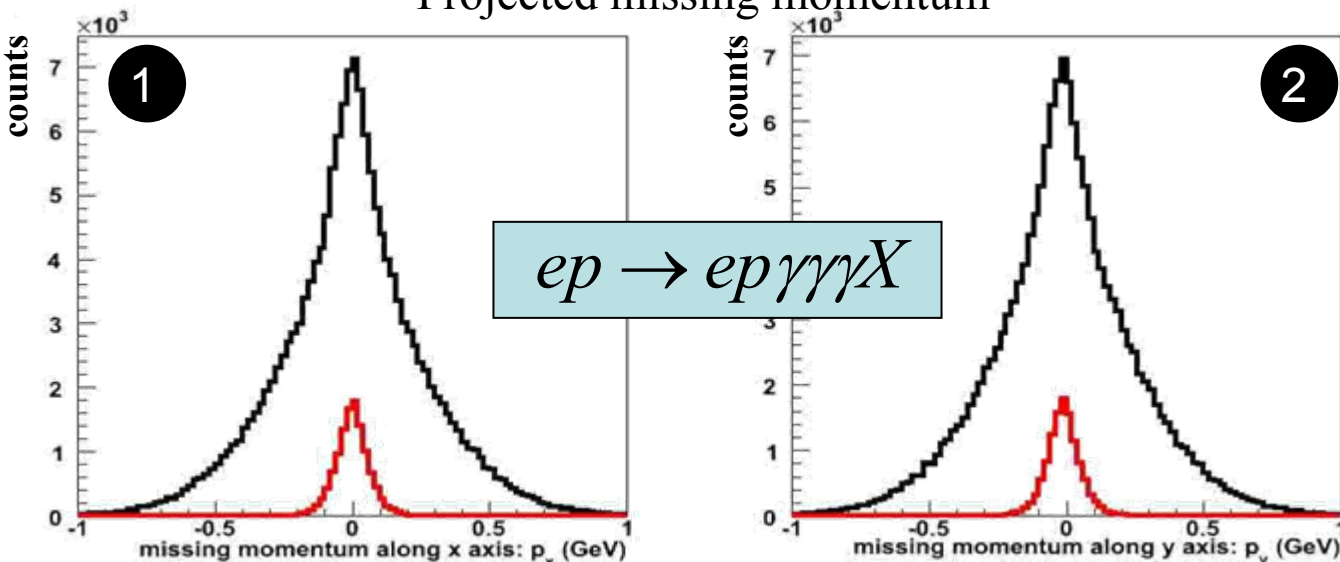
ALL final state particles detected

# $\Delta VCS (\pi^0)$ : event selection

$$ep \rightarrow e\Delta^+ \gamma \rightarrow ep \pi^0 \gamma$$

— data before cuts  
 — data after cuts

Projected missing momentum



$P_{ep3\gamma}^x$	1
$P_{ep3\gamma}^y$	2
$E_{ep3\gamma}^X$	3
$M_{ep3\gamma}^2$	4
$M_{ep\pi^0}^2$	
$M_{ep\gamma}^2$	
$M_{e\pi^0\gamma}^2$	
$\Delta\Phi$	

Sideband method used to subtract combinatorial background under  $\pi^0$  mass peak

# $\Delta$ VCS : background subtraction

	FINAL State (S)	BACKGROUND (B)
$\Delta$ VCS ( $\pi^0$ )	$ep \rightarrow ep\pi^0\gamma$	$ep \rightarrow ep\pi^0\pi^0 \rightarrow ep\pi^0\gamma(\gamma)$
$\Delta$ VCS ( $\pi^+$ )	$ep \rightarrow en\pi^+\gamma$	$ep \rightarrow en\pi^+\pi^0 \rightarrow en\pi^+\gamma(\gamma)$

## background

*calculated* and then  
*subtracted* using MC  
simulations and  
exclusive double pion  
production  
DATA

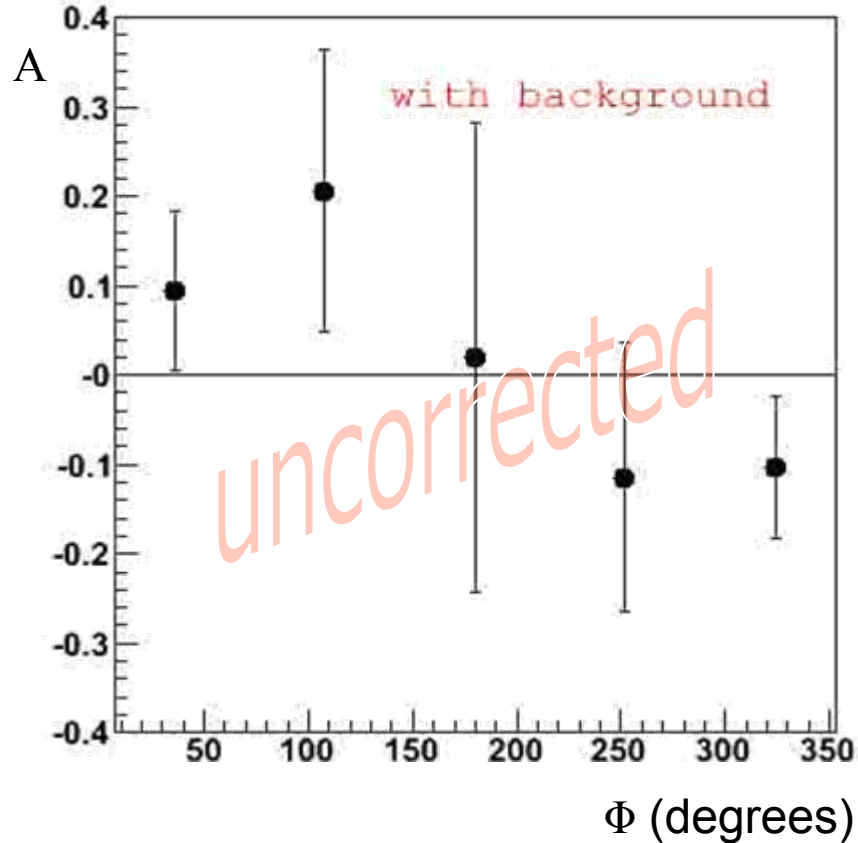
*New!!!*



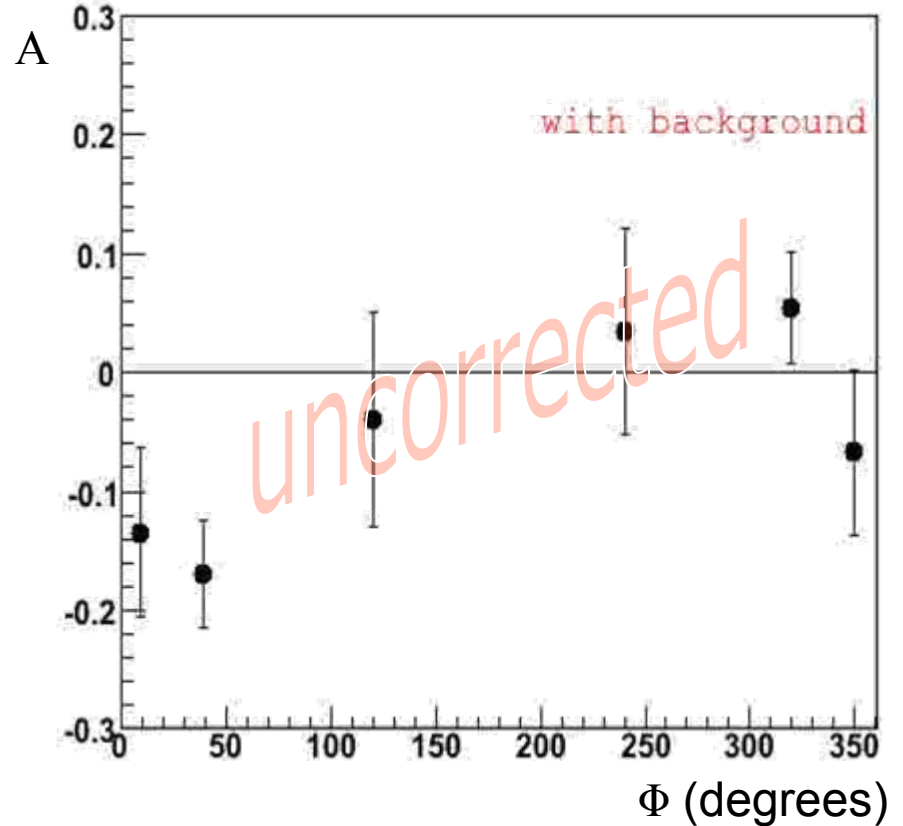
same procedure used for both  
 $\Delta$ VCS channel

# $\Delta$ VCS raw asymmetries

$$ep \rightarrow ep\pi^0\gamma X$$



$$ep \rightarrow en\pi^+\gamma X$$



In the  $\Delta^+$  region

error bars: statistical only



# Double $\pi^0$ production analysis

$$ep \rightarrow ep\pi^0\pi^0$$

$\Delta$ VCS ( $\pi^0$ ) background

# $\pi^0$ pair reconstruction

Events with exactly 1 electron, 1 proton, and 4 photons

Exclusive events

Photons ordered in decreasing energy

$$E_{\gamma_1} \geq E_{\gamma_2} \geq E_{\gamma_3} \geq E_{\gamma_4}$$

	first photon pair: $\pi^0_1$	second photon pair: $\pi^0_2$
combination 1	$\gamma_1\gamma_2$	$\gamma_3\gamma_4$
combination 2	$\gamma_1\gamma_3$	$\gamma_2\gamma_4$
combination 3	$\gamma_1\gamma_4$	$\gamma_2\gamma_3$

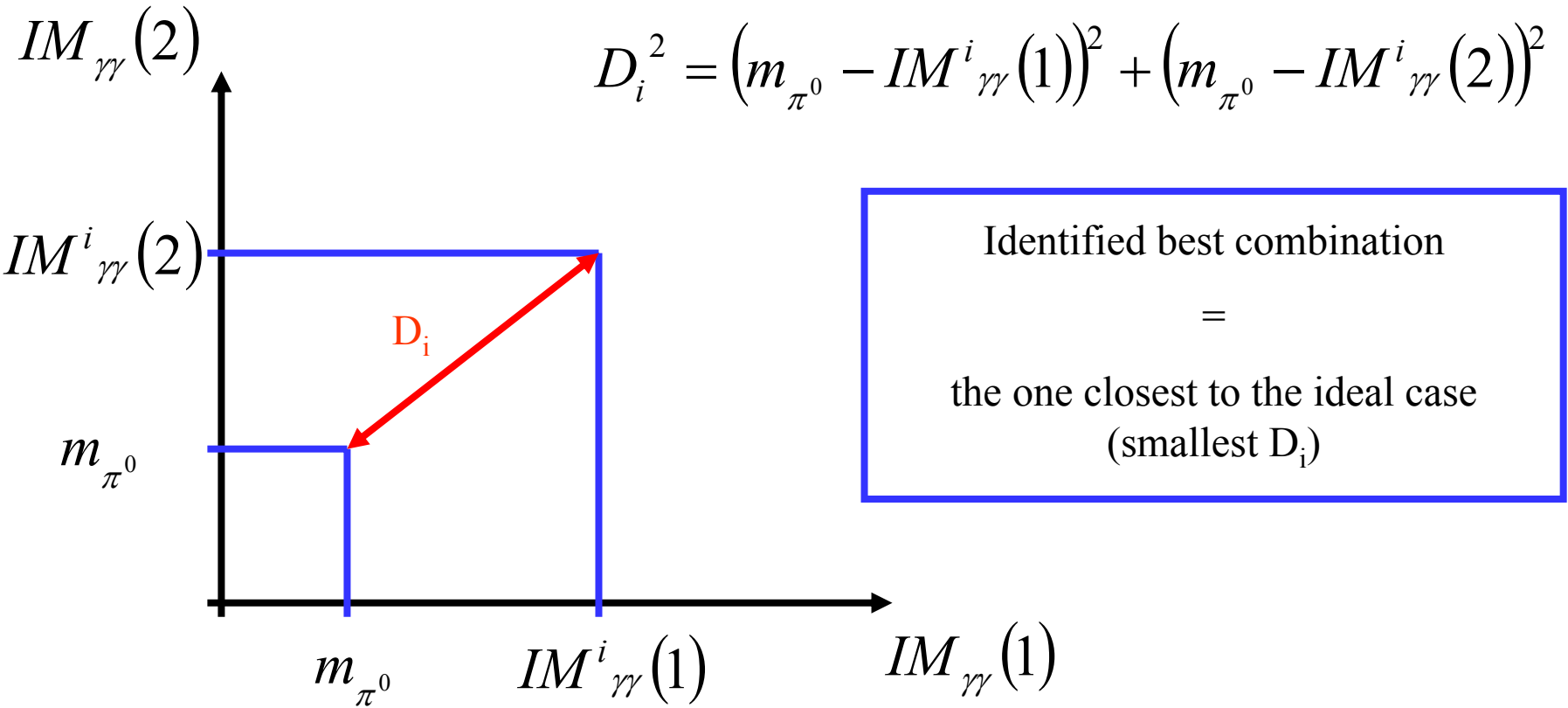
$$IM^i_{\gamma\gamma}(1)$$

Invariant mass of the first photon pair for combination i

$$IM^i_{\gamma\gamma}(2)$$

Invariant mass of the second photon pair for combination i

Ideal combination:  $IM_{\gamma\gamma}^i(1) = IM_{\gamma\gamma}^i(2) = m_{\pi^0}$



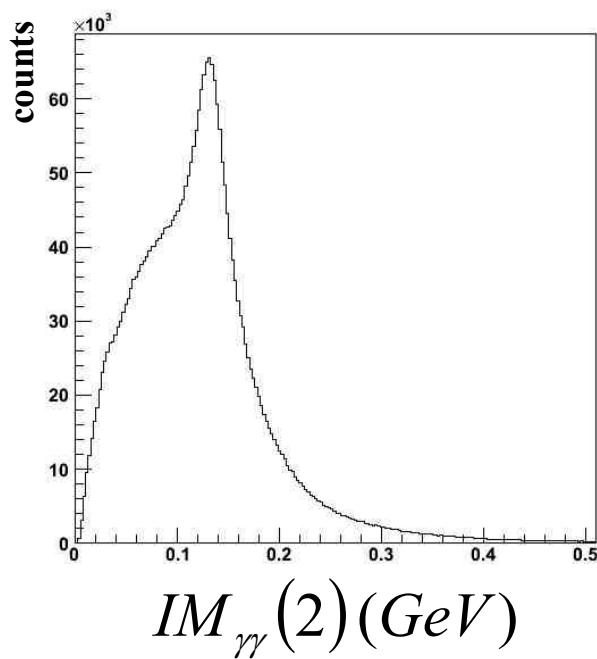
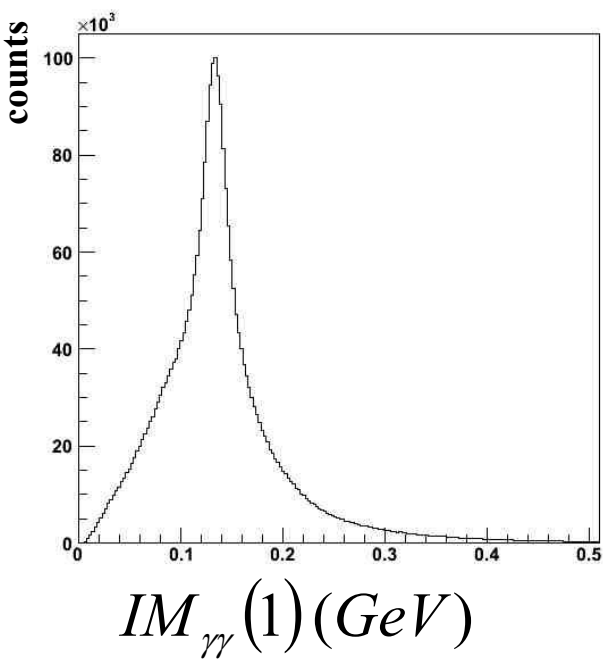
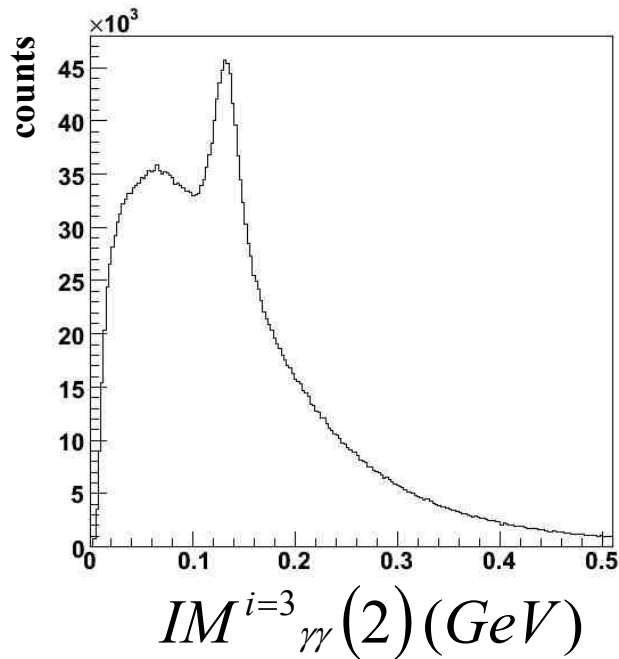
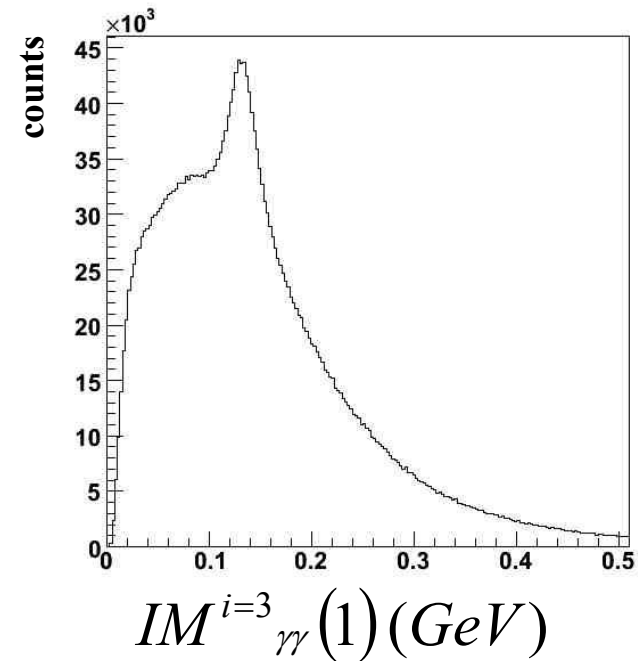
$$\chi^2 = \frac{\left(m_{\pi^0} - IM_{\gamma\gamma}^i(1)\right)^2}{\sigma_{IM_{\gamma\gamma}^i(1)}^2} + \frac{\left(m_{\pi^0} - IM_{\gamma\gamma}^i(2)\right)^2}{\sigma_{IM_{\gamma\gamma}^i(2)}^2}$$

$\chi^2$  minimized to select the best combination

Takes into account resolution

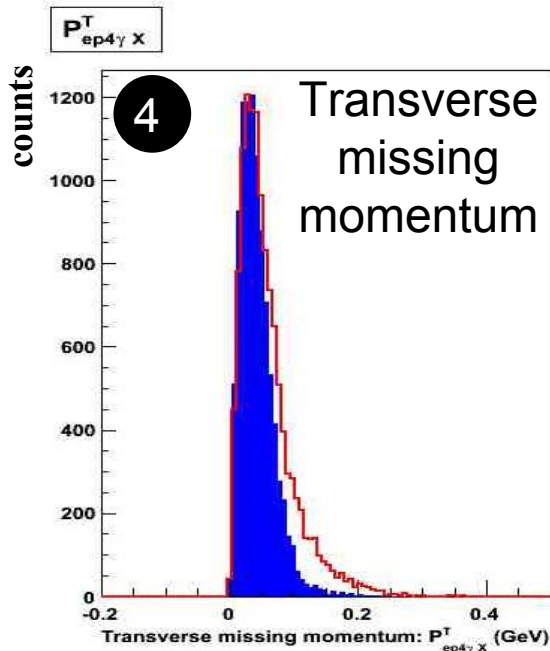
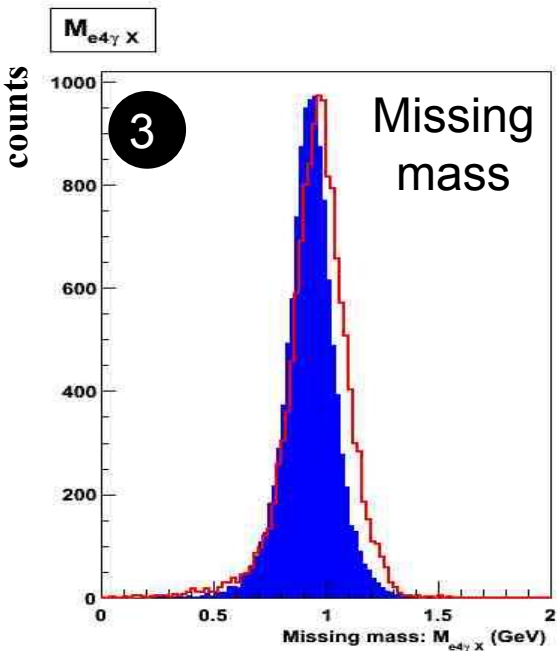
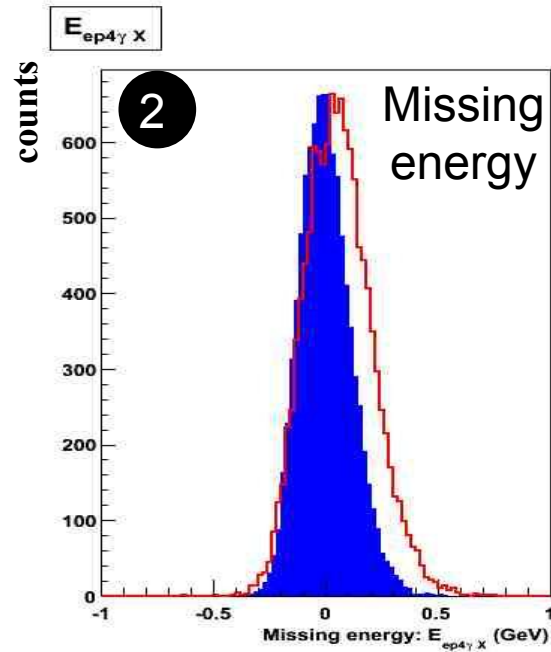
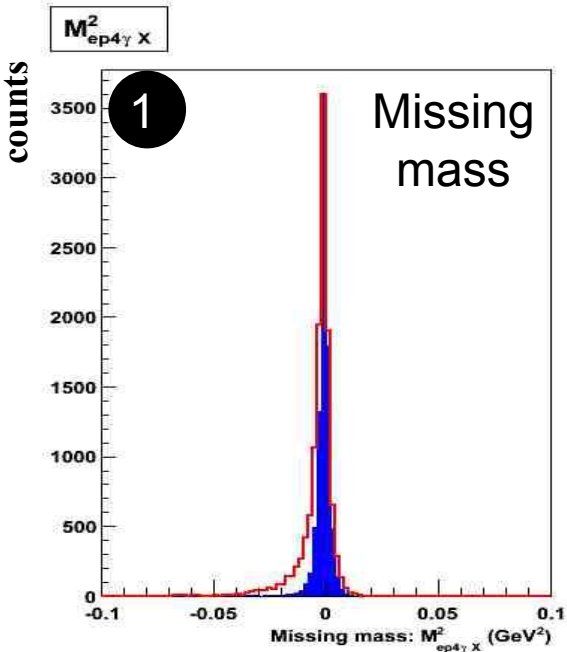
Example

Combination 3



Identified  $\pi^0 \pi^0$  candidates

# Double $\pi^0$ event selection



Exclusive events

— exp data after cuts  
 — mc data after cuts  
 (phase space)

$$M_{ep4\gamma X}^2$$

1

$$E_{ep4\gamma X}$$

2

$$M_{e4\gamma X}$$

3

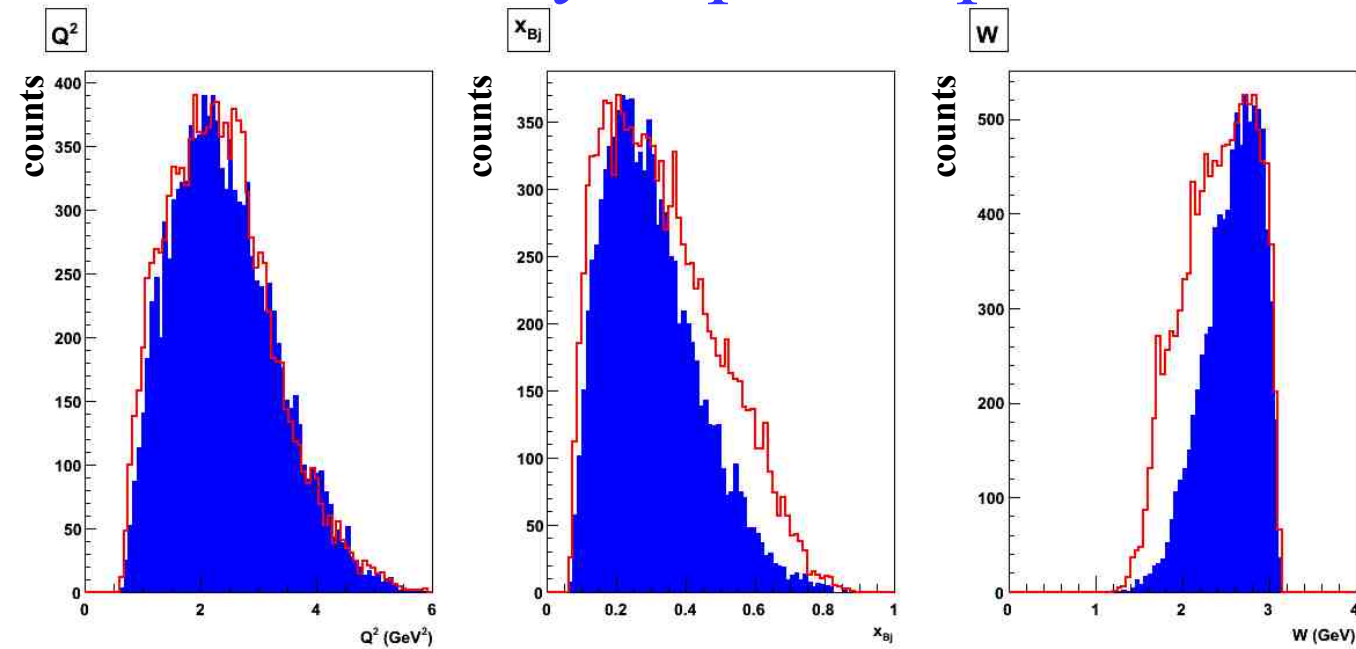
$$P_{ep4\gamma X}^T$$

4

$$M_{ep\pi_1^0 X}^2$$

$$M_{ep\pi_2^0 X}^2$$

# Validity of phase space MC model

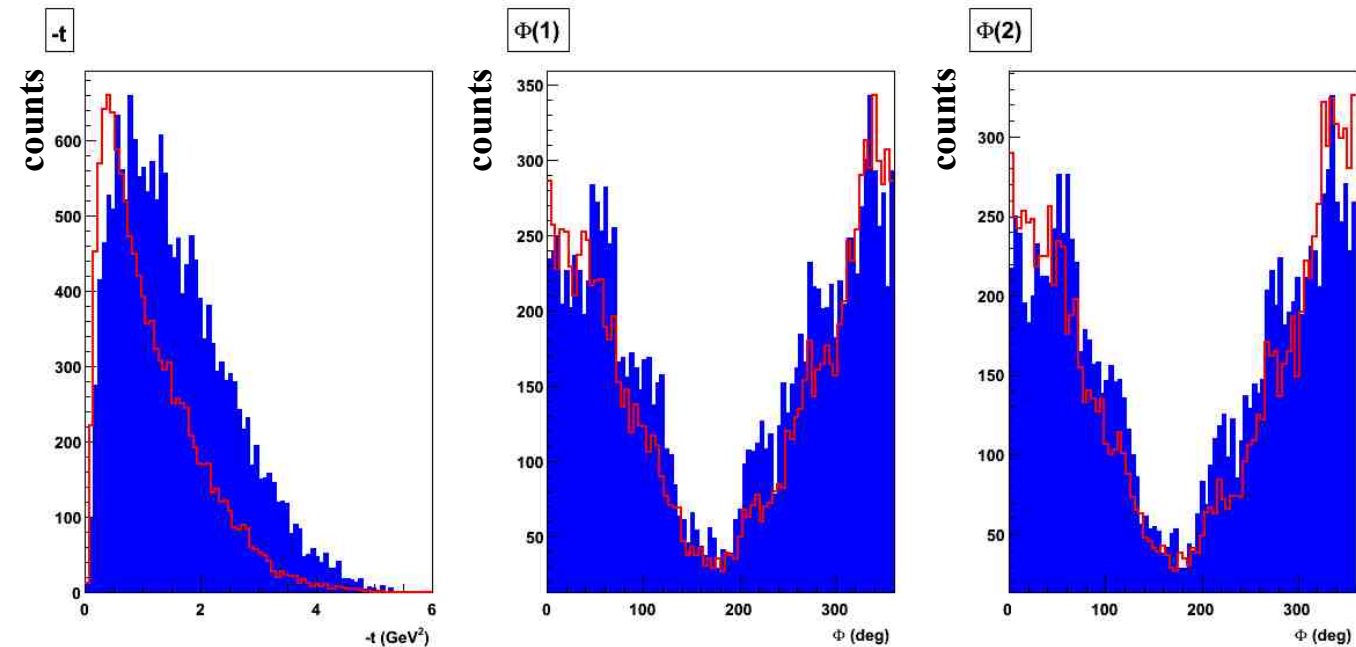


— exp data after cuts  
— mc data after cuts

Good agreement  
between Data/MC



Validate the MC  
model for double  $\pi^0$   
production

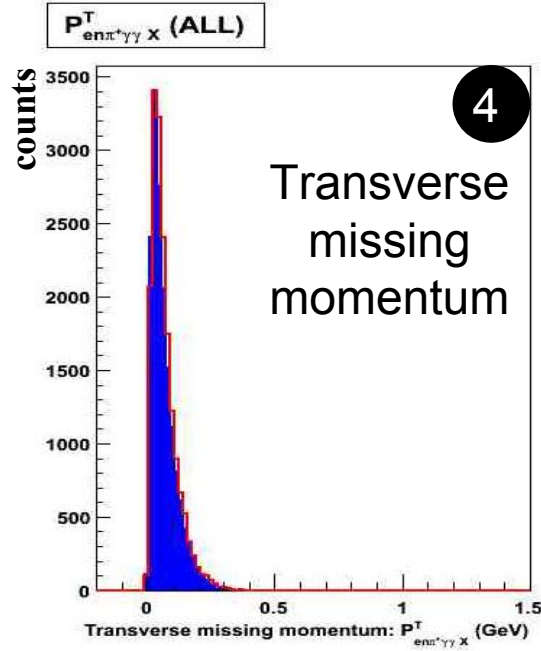
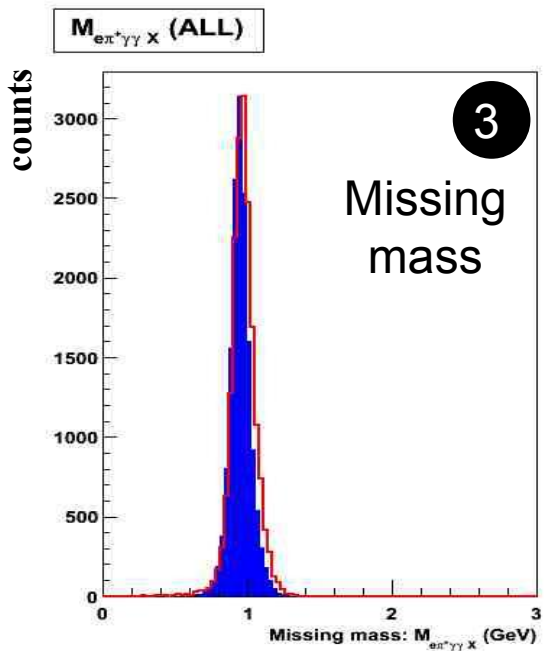
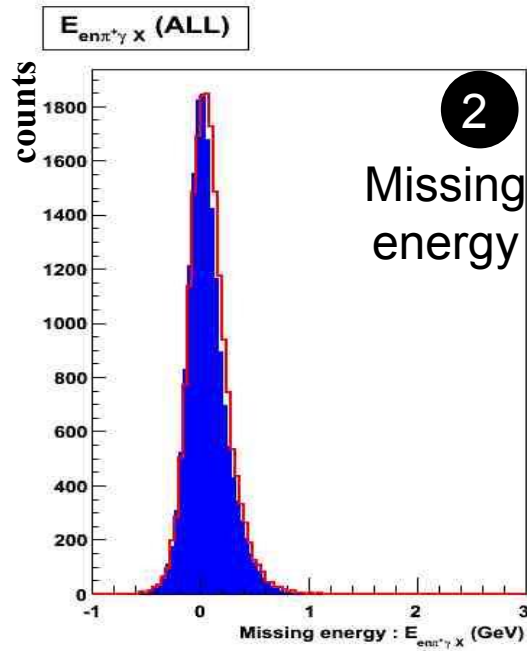
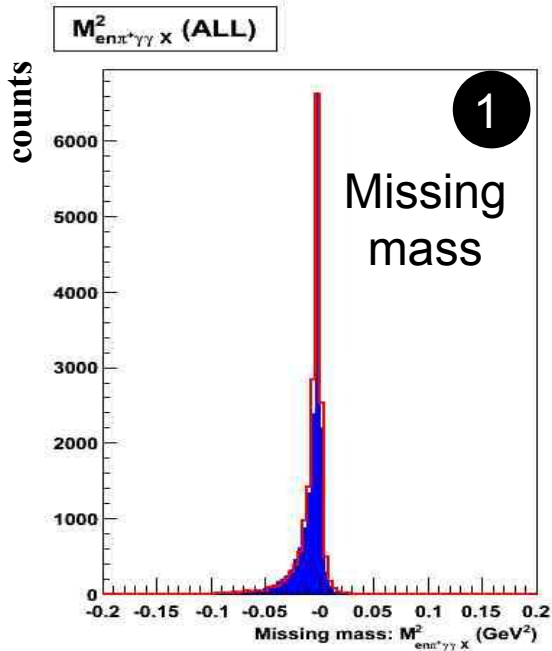


# $\pi^+ \pi^0$ production analysis

$$ep \rightarrow en\pi^+\pi^0$$
$$ep \rightarrow en\rho^+ \rightarrow en\pi^+\pi^0$$

$\Delta$ VCS ( $\pi^+$ ) background

# $\pi^+ \pi^0$ event selection



Exclusive events

- exp data after cuts
- mc data after cuts  
(phase space +  $\rho^+$ )

1

$$M_{en\pi^+\gamma\gamma X}^2$$

2

$$E_{en\pi^+\gamma\gamma X}$$

3

$$M_{e\pi^+\gamma\gamma X}$$

4

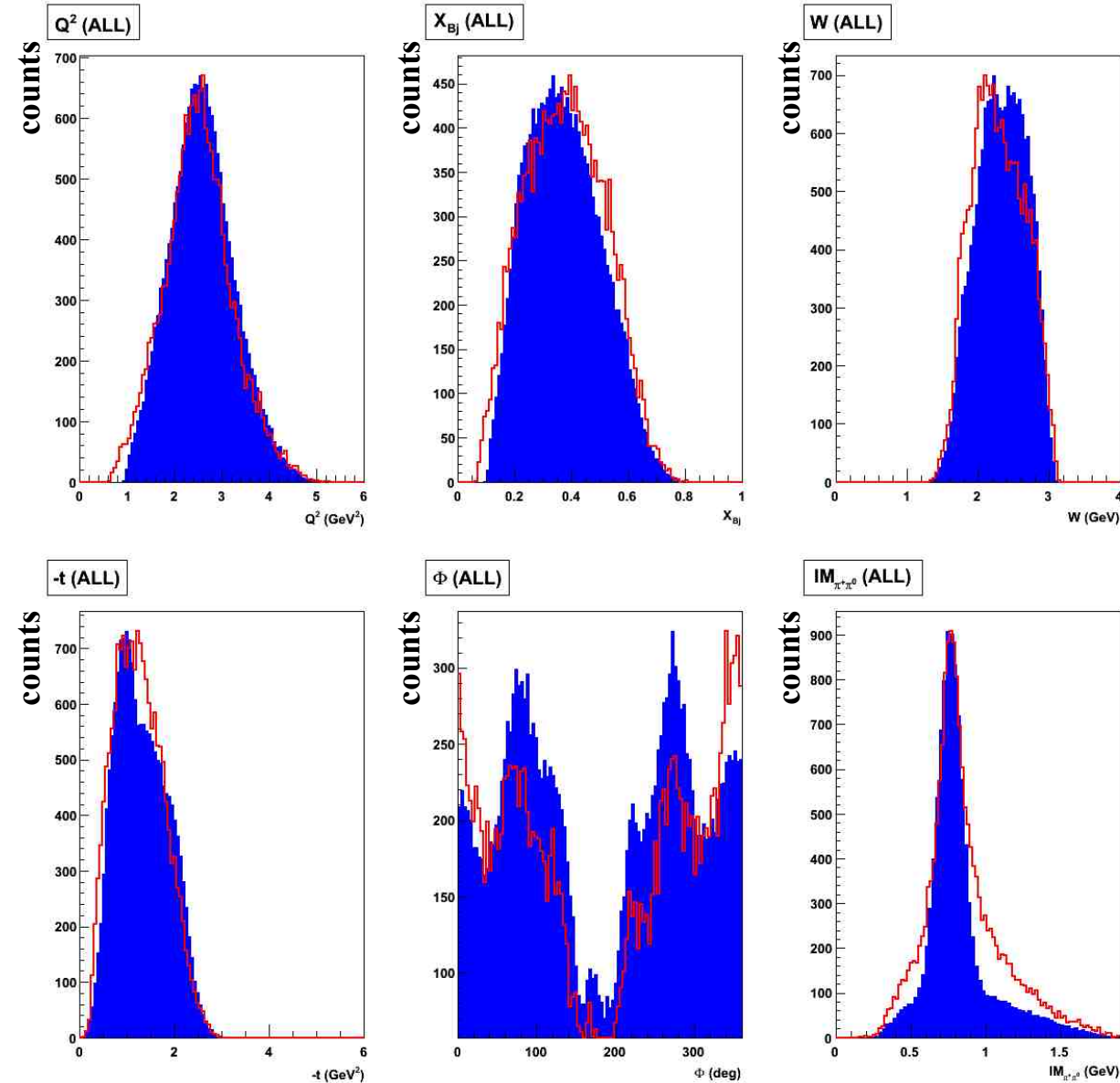
$$P_{en\pi^+\gamma\gamma X}^T$$

$$M_{en\gamma\gamma X}^2$$

$$M_{en\pi^+ X}^2$$



# Validity of $\pi^+ \pi^0$ MC model



— exp data after cuts

— mc data after cuts

MC = phase space +  $\rho^+$

Good agreement  
between Data/MC



Validate the MC  
model for  $\pi^+ \pi^0$   
production

# $\Delta$ VCS results

$$\Delta\text{VCS } (\pi^0): \quad ep \rightarrow ep\pi^0\gamma$$

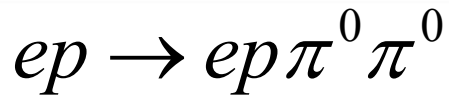
$$\Delta\text{VCS } (\pi^+): \quad ep \rightarrow en\pi^+\gamma$$

in the  $\Delta^+$  region

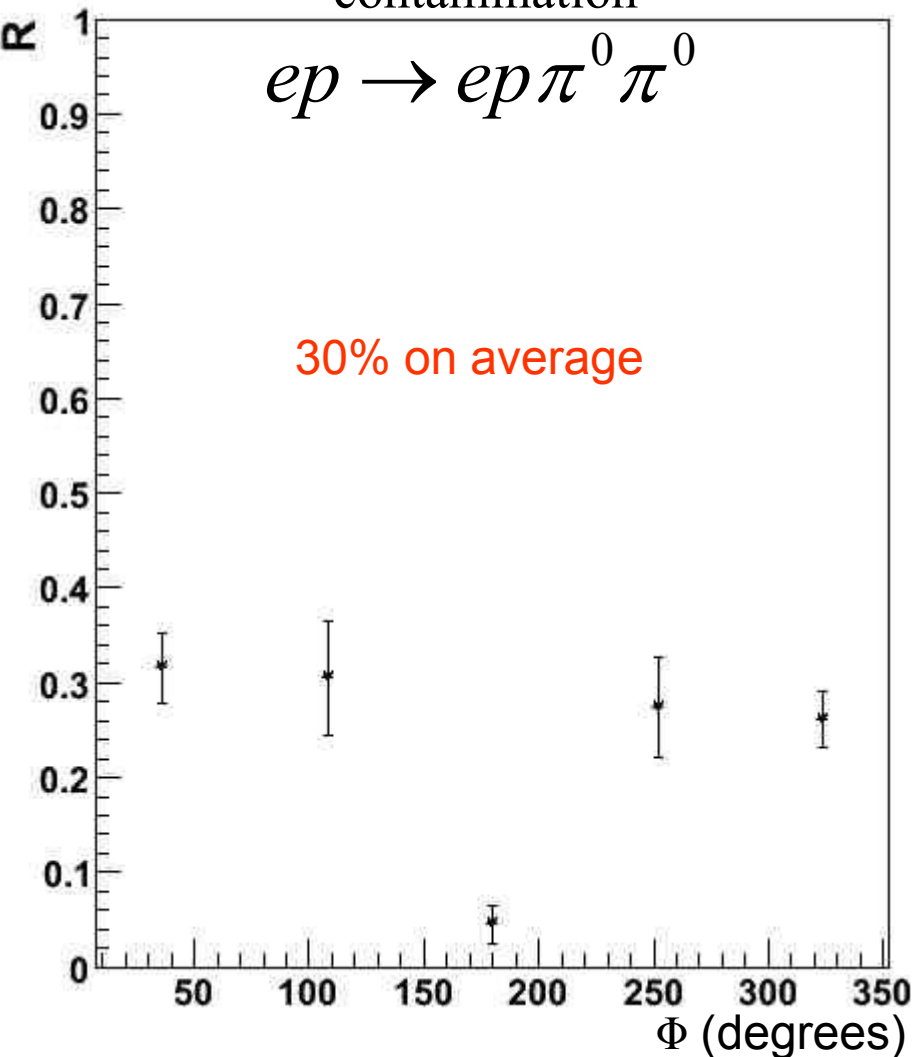
# Contamination

R= percentage of  $\Delta$ VCS data samples estimated to be background

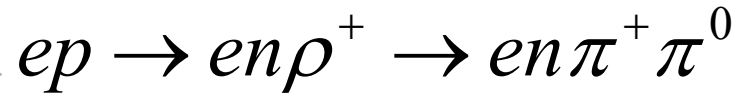
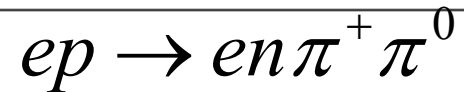
$\Delta$ VCS ( $\pi^0$ )  
contamination



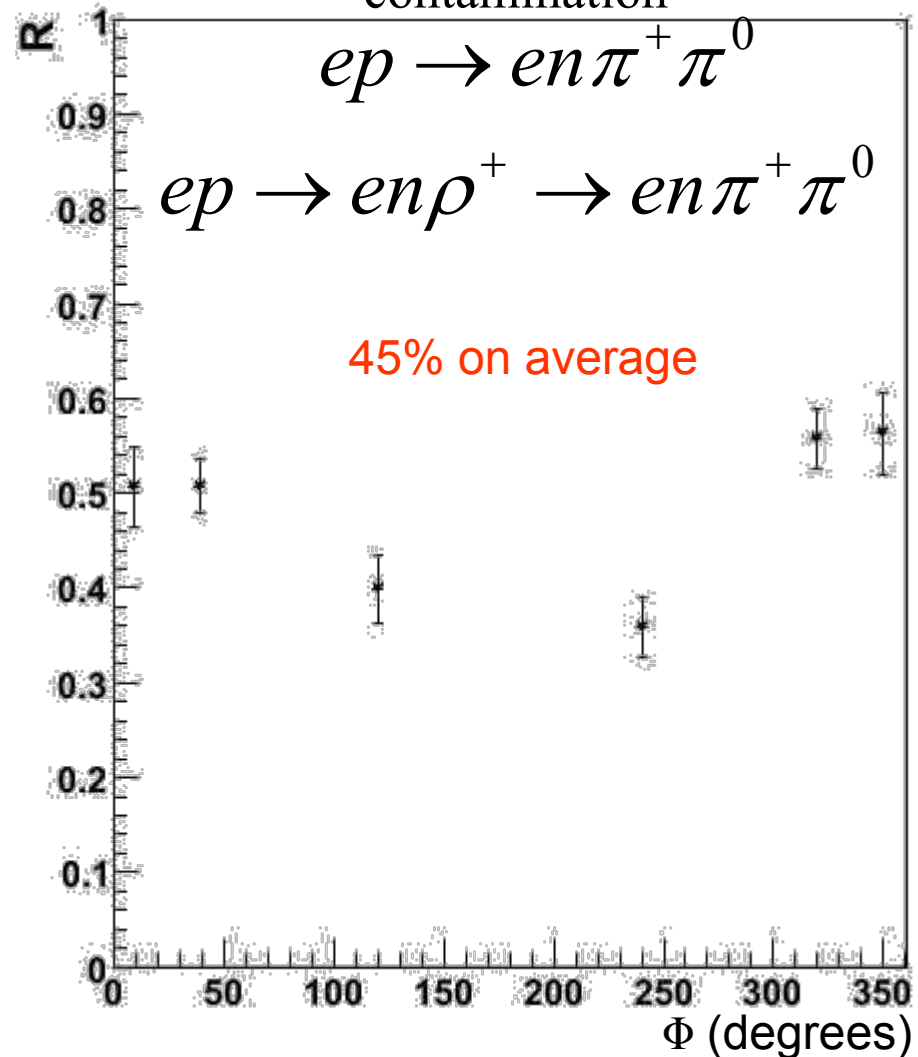
30% on average



$\Delta$ VCS ( $\pi^+$ )  
contamination

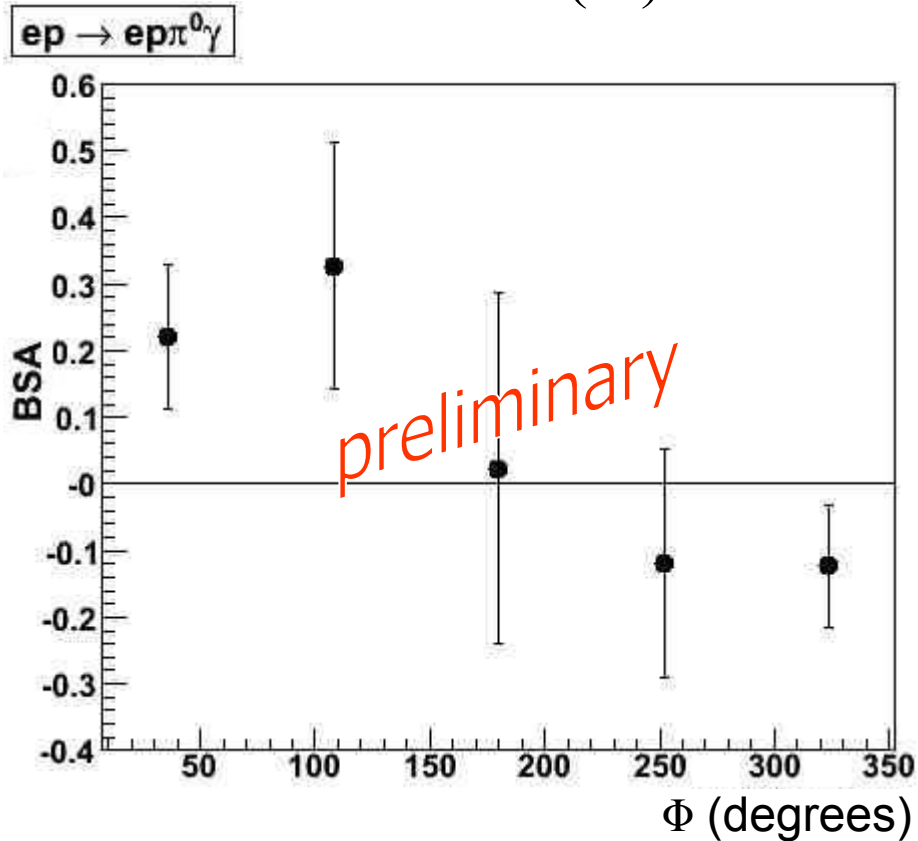


45% on average

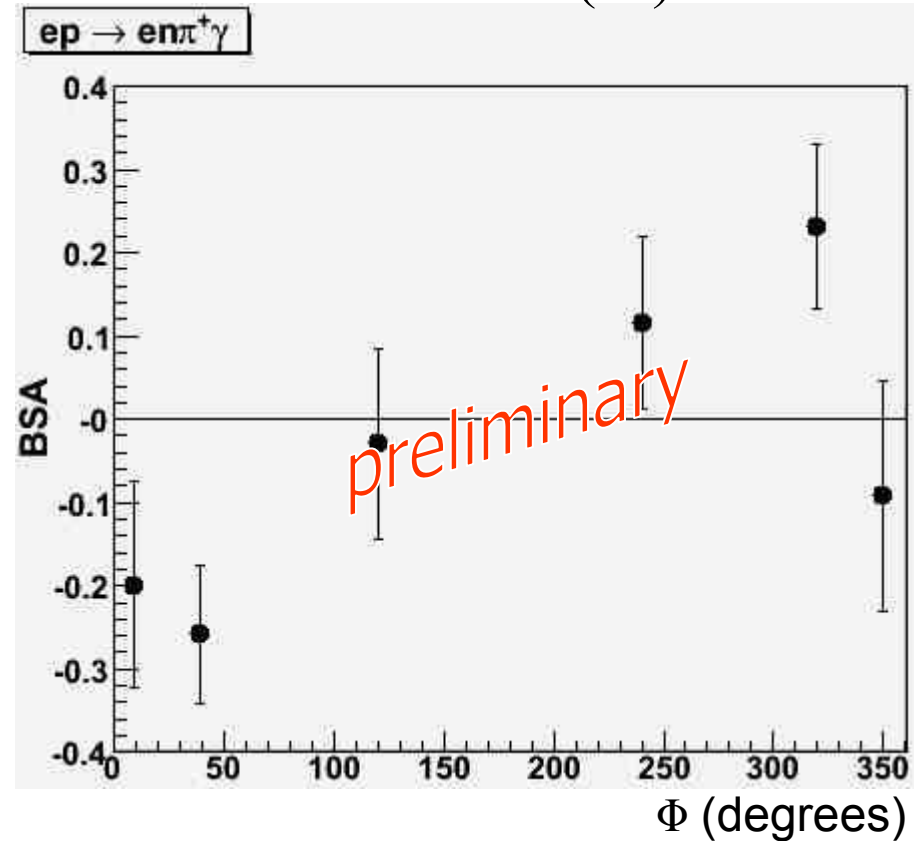


# $\Delta$ VCS Beam Spin Asymmetries

## $\Delta$ VCS ( $\pi^0$ )



## $\Delta$ VCS ( $\pi^+$ )



error bars: statistical only

# Conclusions

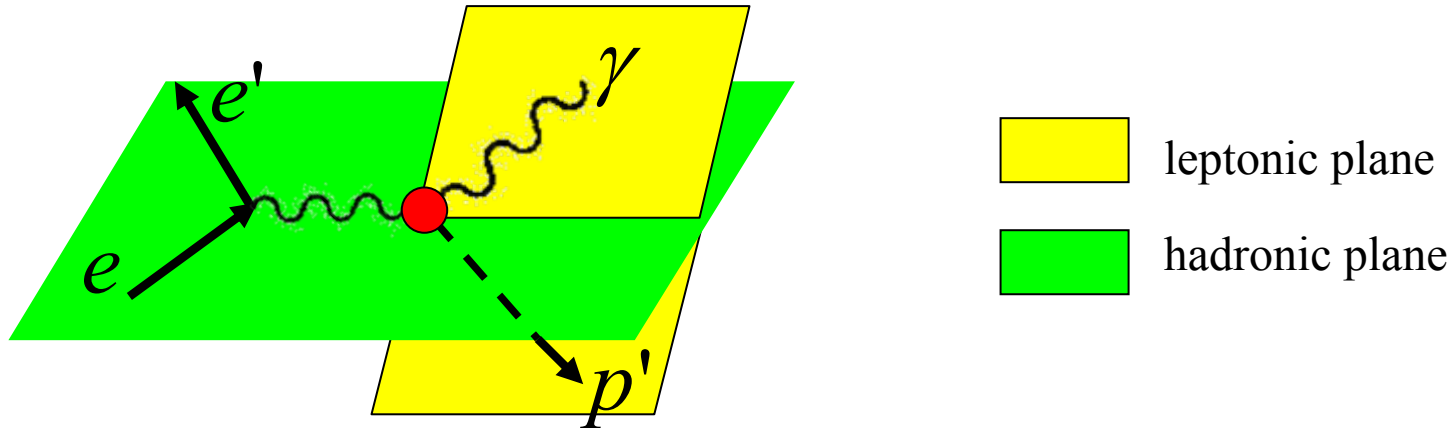
- Pioneering investigation for  $\Delta VCS$  asymmetries
- First asymmetry results obtained for both  $\Delta VCS$  channel
- BSA show a clear  $\Phi$  dependency which may indicate that interference between  $\Delta VCS$  and Bethe-Heitler was observed
- Limited statistics : more data needed for an extensive  $\Delta VCS$  study

## Outlook

- Systematic uncertainties currently being evaluated
- PhD expected to be defended in June 2009
- Analysis note to be written

Complementary slides

# DVCS asymmetry and GPDs



Polarized beam, unpolarized target:

$$\boxed{H}, \tilde{H}, E$$

Unpolarized beam, longitudinally polarized target:

$$H, \boxed{\tilde{H}}$$

Unpolarized beam, transversally polarized target:

$$\boxed{H}, \boxed{E}$$

Beam charge asymmetry:

$$\boxed{H}, \tilde{H}, E$$

# N-Δ GPDs

## • Sum rules :

$$\int_{-1}^1 dx H_{M,E,C}(x, \xi, \Delta^2) = 2G_{M,E,C}^*(\Delta^2)$$

$$\int_{-1}^1 dx C_1(x, \xi, \Delta^2) = 2C_5^A(\Delta^2)$$

$$\int_{-1}^1 dx C_2(x, \xi, \Delta^2) = 2C_6^A(\Delta^2)$$

$$\int_{-1}^1 dx C_3(x, \xi, \Delta^2) = 2C_3^A(\Delta^2)$$

$$\int_{-1}^1 dx C_4(x, \xi, \Delta^2) = 2C_4^A(\Delta^2)$$

• Relevant **N-Δ GPDs** for **ΔVCS** process:  $H_M, H_E, H_C$

In the **large Nc** limit

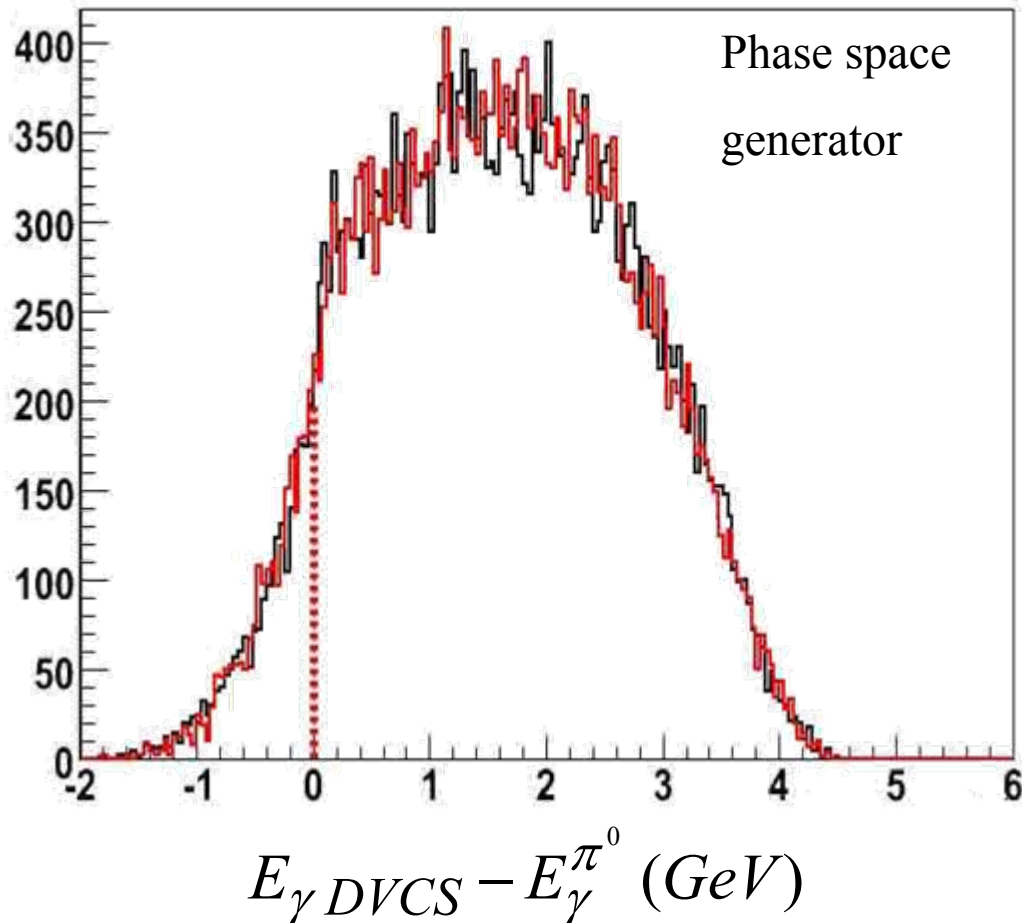
$$\left\{ \begin{array}{l} H_M(x, \xi, t) \Rightarrow H_M = \frac{2}{\sqrt{3}} [E^u(x, \xi, t) - E^d(x, \xi, t)] \\ C_1(x, \xi, t) \Rightarrow C_1(x, \xi, t) = \sqrt{3} [\tilde{H}^u(x, \xi, t) - \tilde{H}^d(x, \xi, t)] \\ C_2(x, \xi, t) \Rightarrow C_2(x, \xi, t) = \frac{\sqrt{3}}{4} [\tilde{E}^u(x, \xi, t) - \tilde{E}^d(x, \xi, t)] \end{array} \right.$$



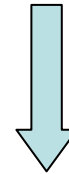
# $\Delta\text{VCS} (\pi^0)$ : $\pi^0$ reconstruction

$$\Delta\text{VCS} (\pi^0): ep \rightarrow ep\pi^0\gamma \rightarrow ep\boxed{3\gamma}$$

Which photons are likely to come from  $\pi^0$  decay?



8% events under 0 GeV



DVCS photon = most energetic one

# Cuts optimization method

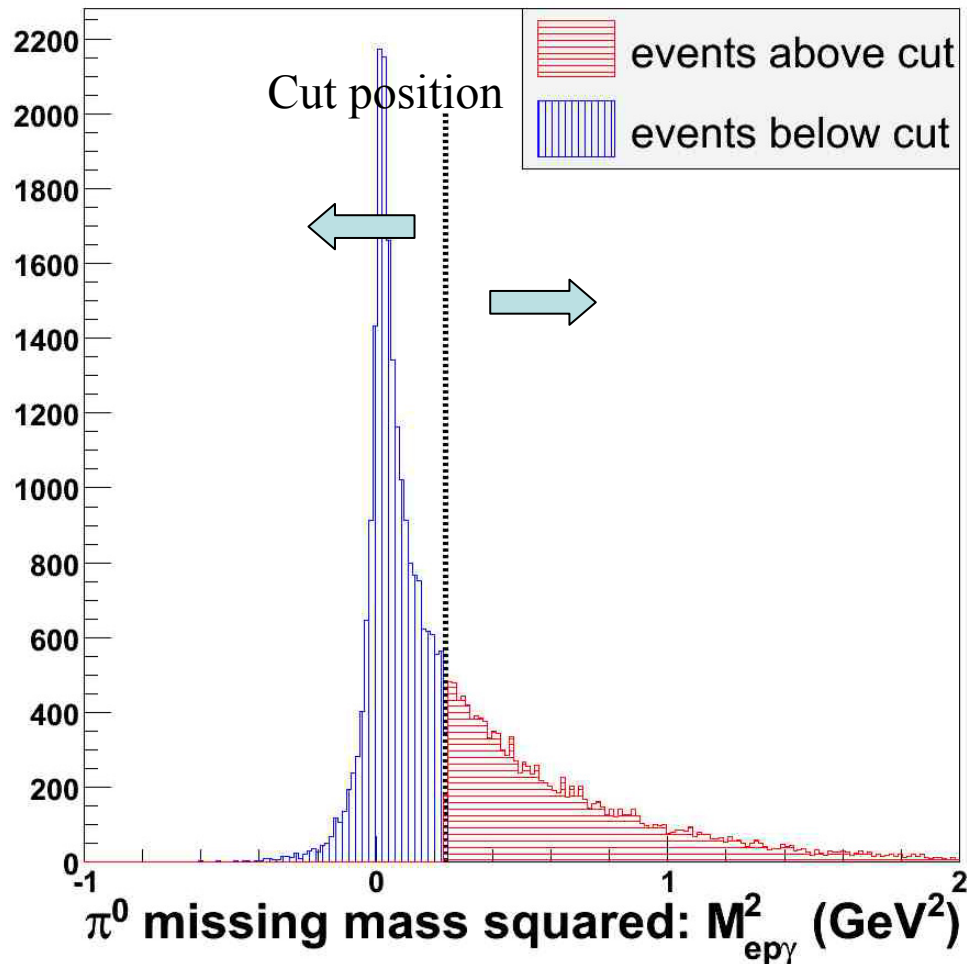
Study statistical effect of evolving cuts on each event selection variables:

- $\Delta$ VCS MC

-Double  $\pi^0$  MC



Establish the optimal values



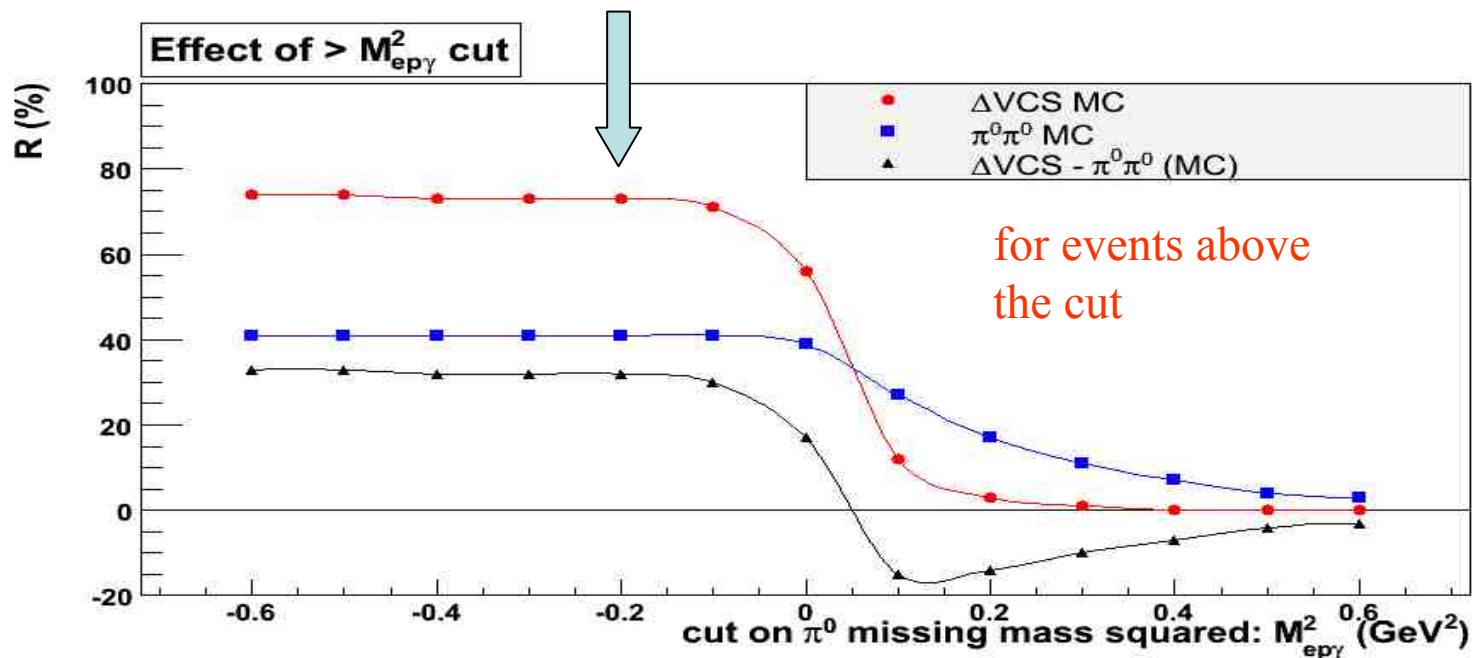
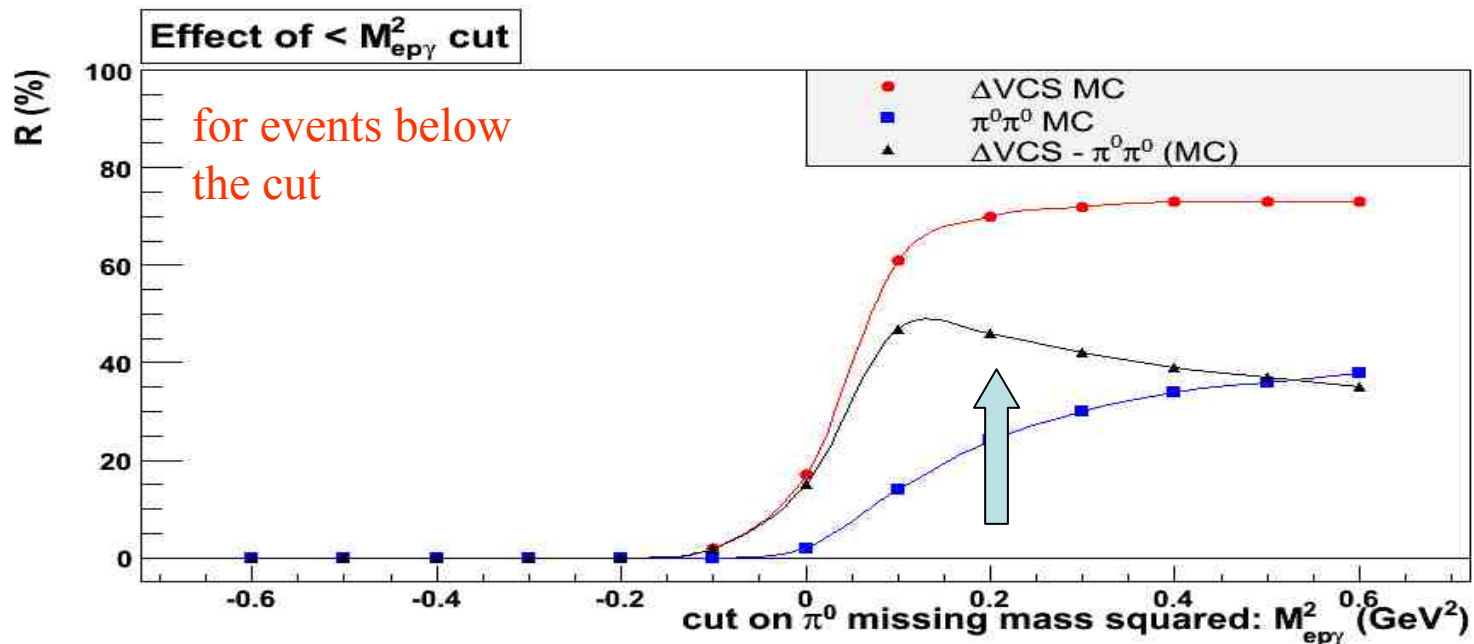
$$R = \frac{N_{after\ cut}}{N_{before\ cut}}$$

Varying cut  
position



$R(\text{cut value})$

# Example



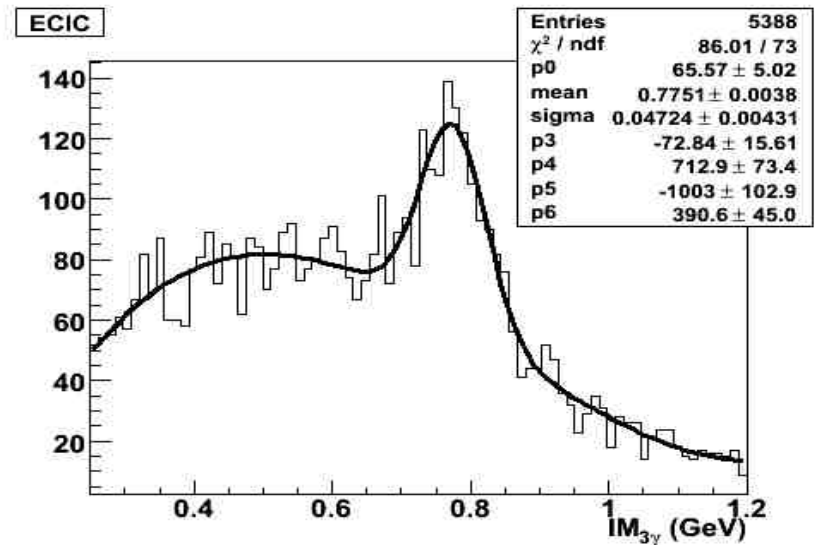
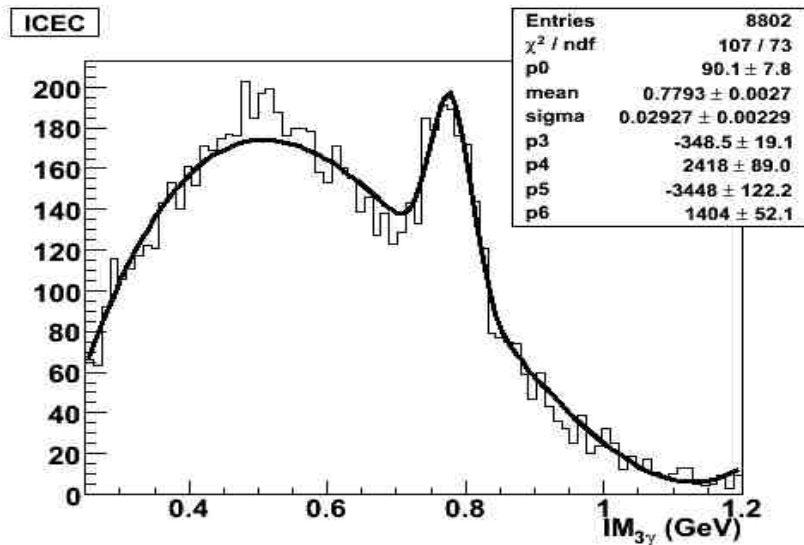
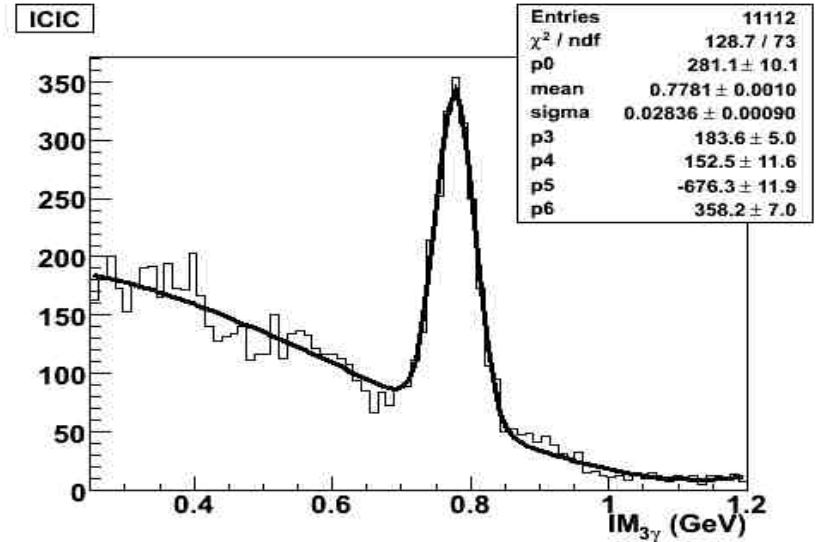
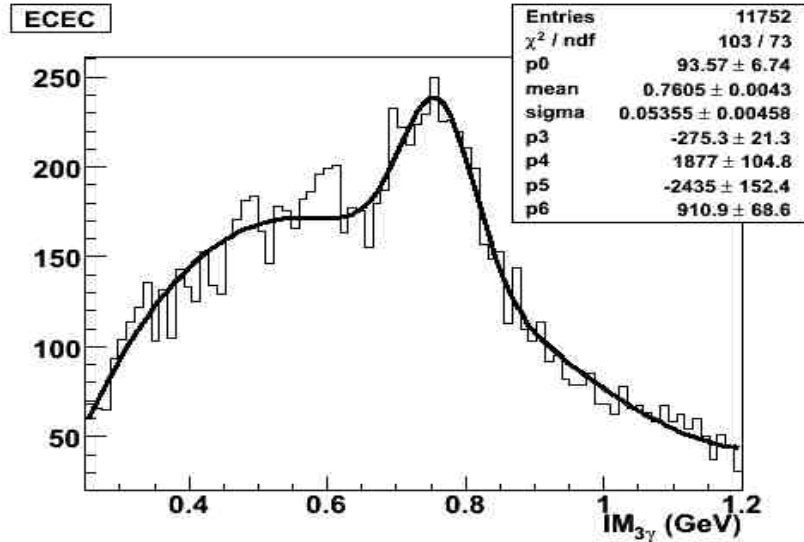
# Omega contamination

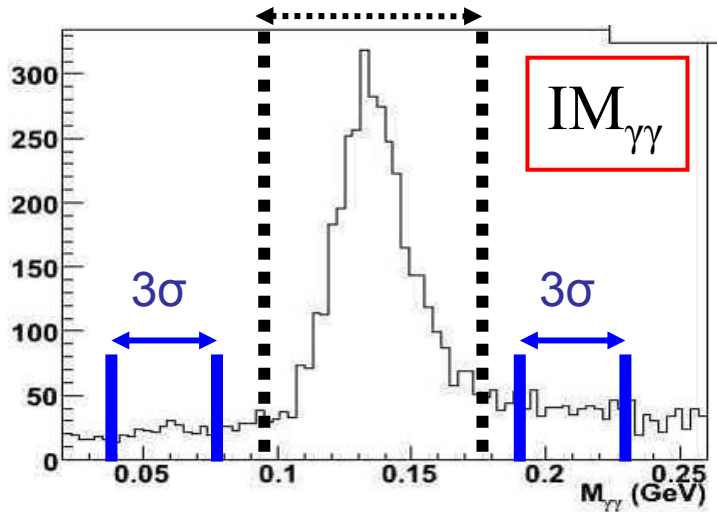
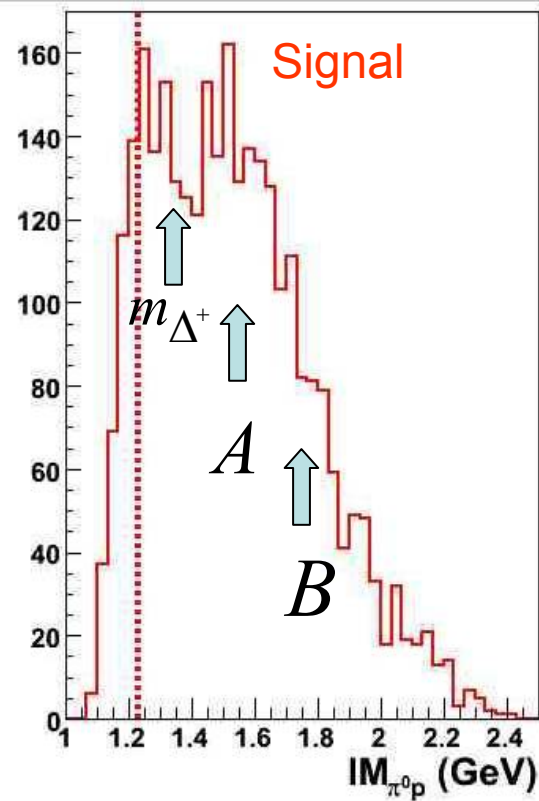
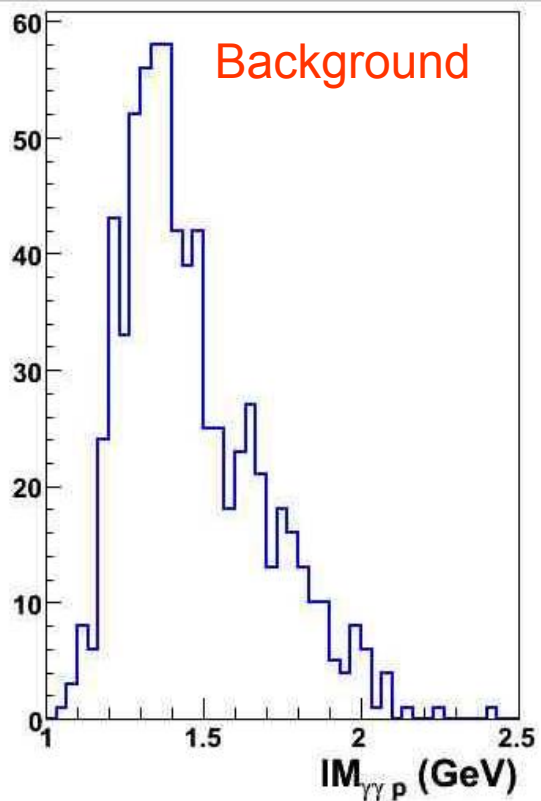
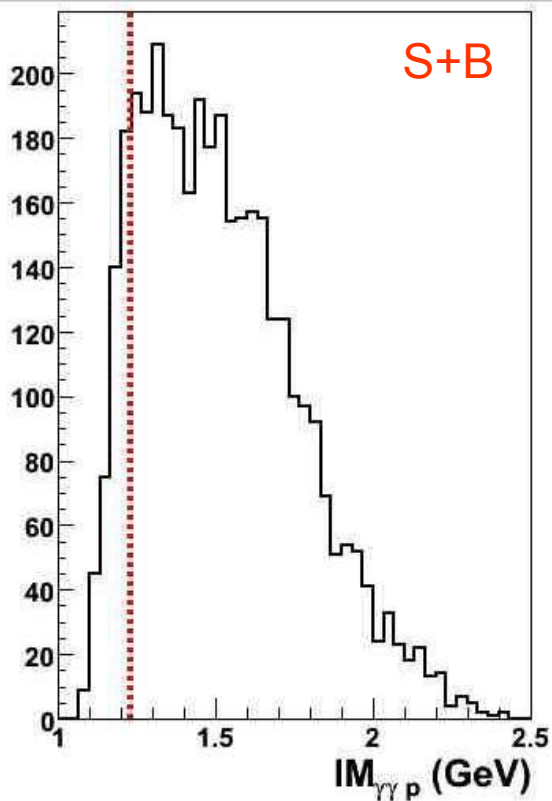
$$ep \rightarrow e\Delta^+ \gamma \rightarrow ep\pi^0 \gamma$$

$$ep \rightarrow ep\omega \rightarrow ep\pi^0 \gamma$$



Invariant mass  $\pi^0 \gamma$



$6\sigma$  $\Delta VCS (\pi^0)$ : combinatorial background**Sideband method**

# $\Delta$ VCS : background subtraction

	FINAL State (S)	BACKGROUND (B)
$\Delta$ VCS ( $\pi^0$ )	$ep \rightarrow ep\pi^0\gamma$	$ep \rightarrow ep\pi^0\pi^0 \rightarrow ep\pi^0\gamma(\gamma)$
$\Delta$ VCS ( $\pi^+$ )	$ep \rightarrow en\pi^+\gamma$	$ep \rightarrow en\pi^+\pi^0 \rightarrow en\pi^+\gamma(\gamma)$

$$\overbrace{N_{en\pi^+\gamma X}}^{S+B} = \overbrace{N_{en\pi^+\gamma}}^S + \overbrace{N_{en\pi^+\pi^0}^{1\gamma}}^B$$

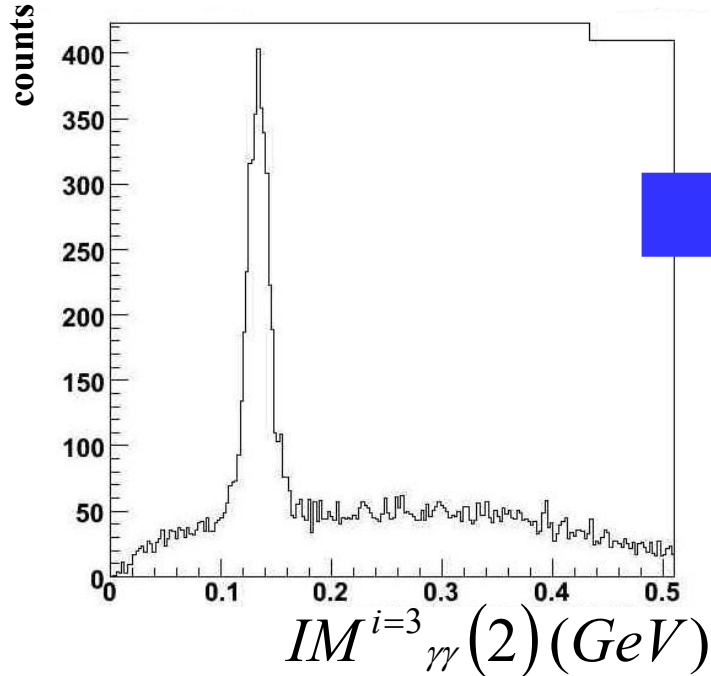
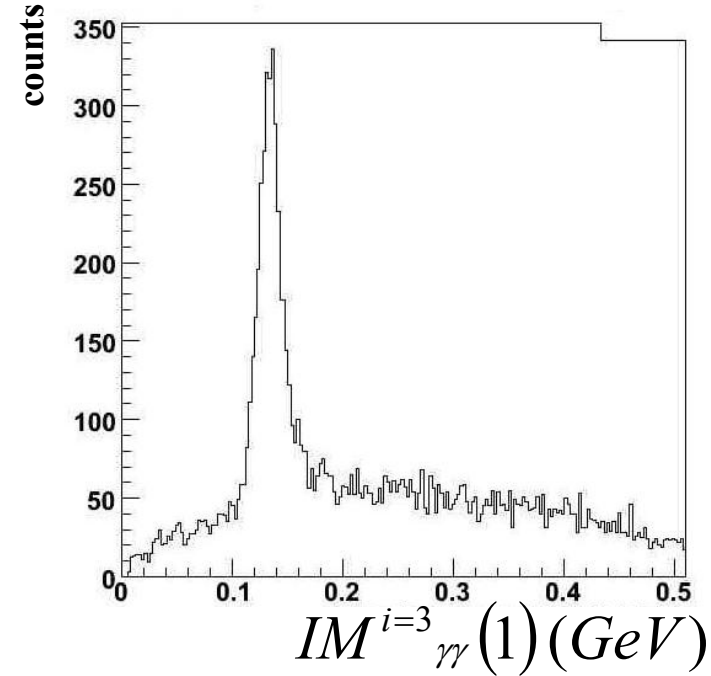
$$\sigma_{ep \rightarrow en\pi^+\pi^0} \propto \frac{N_{\pi^+\pi^0}^{1\gamma}}{Acc_{\pi^+\pi^0}^{1\gamma}} \quad \text{single photon detected}$$

$$\sigma_{ep \rightarrow en\pi^+\pi^0} \propto \frac{N_{\pi^+\pi^0}^{2\gamma}}{Acc_{\pi^+\pi^0}^{2\gamma}} \quad \text{all photons detected}$$

*Ongoing work*

$$\underbrace{N_{en\pi^+\gamma}}_S = \underbrace{N_{en\pi^+\gamma X}}_{S+B} - \underbrace{N_{en\pi^+\pi^0}^{2\gamma} \frac{Acc_{\pi^+\pi^0}^{1\gamma}}{Acc_{\pi^+\pi^0}^{2\gamma}}}_B$$

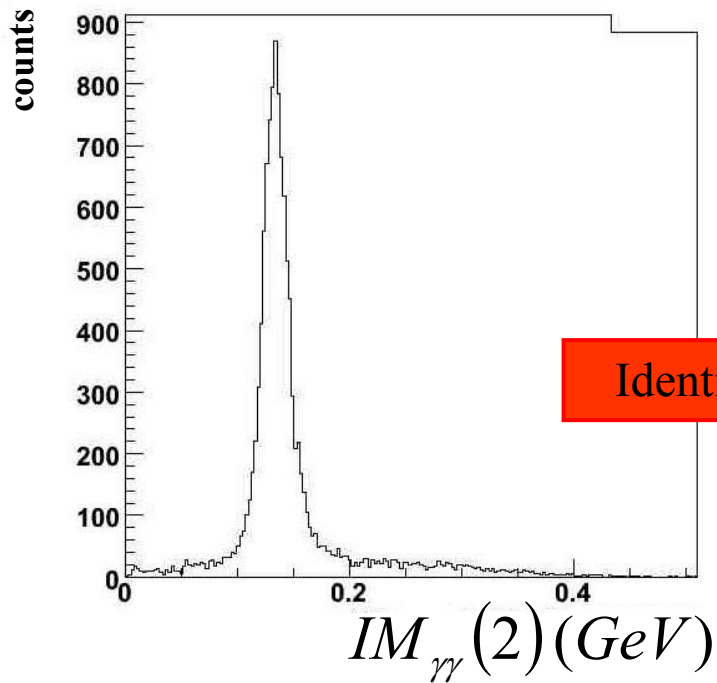
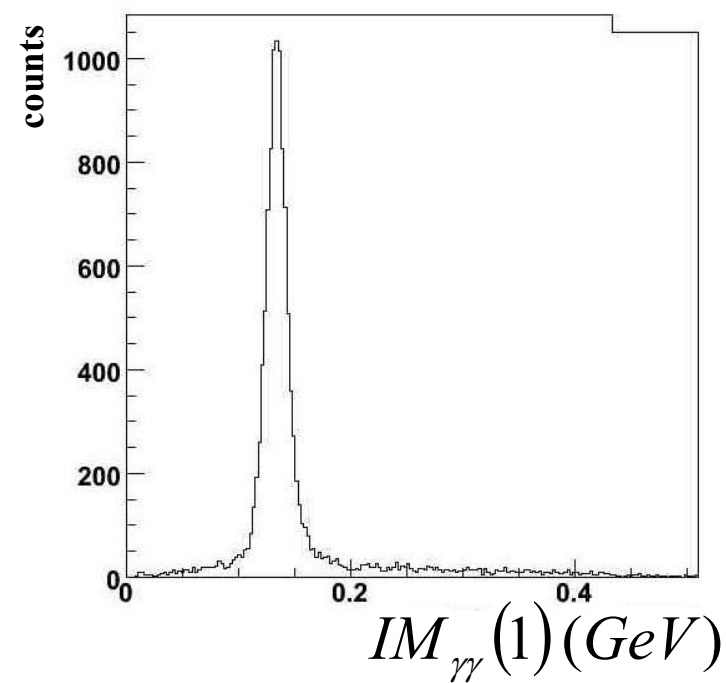
→ same procedure used for both  $\Delta$ VCS channel



Example

Combination 3

Selection cuts  
applied



Identified  $\pi^0 \pi^0$  candidates