hadron2011

13-17 June 2011 *Künstlerhaus*
Europe/Berlin timezone

Light Vector Meson Photoproduction on ^{1}H in CLAS and ρ-ω Interference in the e^+e^- Decay Channel

C. Djalali , University of South Carolina

M. Paolone [1], D. Weygand [2], M. Wood [3], R. Nasseripour[4]
and the CLAS Collaboration.

1 University of South Carolina, Columbia, SC.
2 Thomas Jefferson National Accelerator Facility, Newport News, VA.
3 Canisius College, Buffalo, NY.
4 George Washington University, Washington, DC.

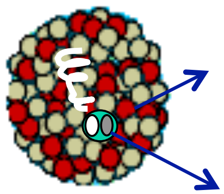
Motivations for γ p $\rightarrow e^+ e^-$ +... at JLab

1. **Strong $\rho-\omega$ interference observed in $\gamma A \rightarrow e^+e^-$ (X) reactions.**

Target	K_{max} (GeV)	Range m_{e+e-} (MeV/c^2)	Phase ϕ (in deg)	Reference
Be	7.0, 5.1	700-870	41 ± 20	PRL25 (1970) 1373 NPB25 (1971) 333
C	4.1	675-850	100^{+38}_{-30}	PRL24 (1970) 1197
C	4.1	590-830	118^{+13}_{-22}	PRL27 (1971) 1157

2. **Theoretical predictions by Lutz and Soyeur (NPA760 2005) for large $\rho-\omega$ interference in the $\gamma N \rightarrow e^+e^-$ N reaction. Constructive on p, destructive on n.**

3. **The elementary reaction $\gamma p \rightarrow e^+e^-$ N needed for comparison to $\gamma A \rightarrow e^+e^-$ (X) reactions measured at Jlab looking at the medium modification of the vector mesons in the medium.**



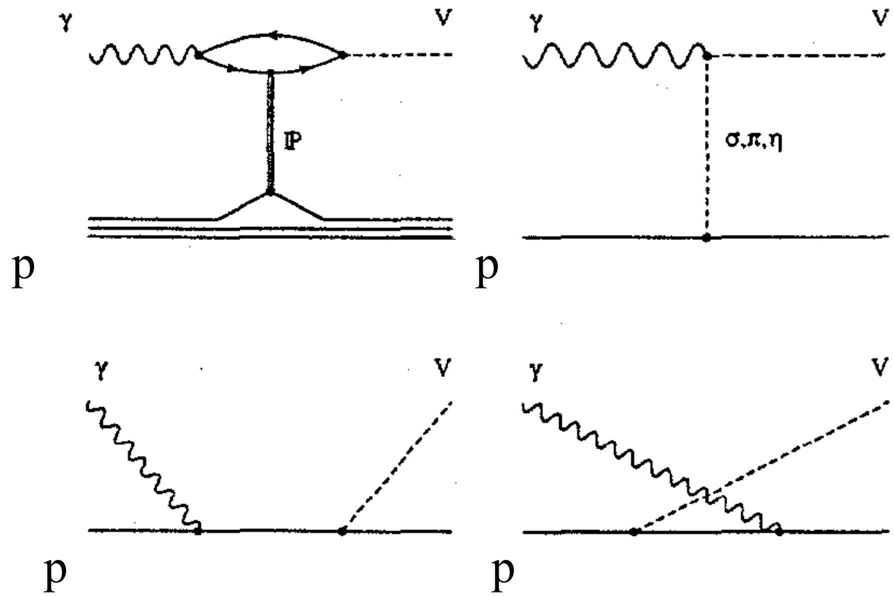
Inside nucleus

Elementary reaction in vacuum

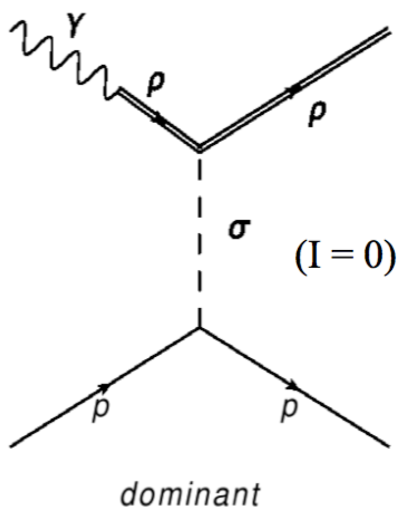
ρ, ω photoproduction on the proton

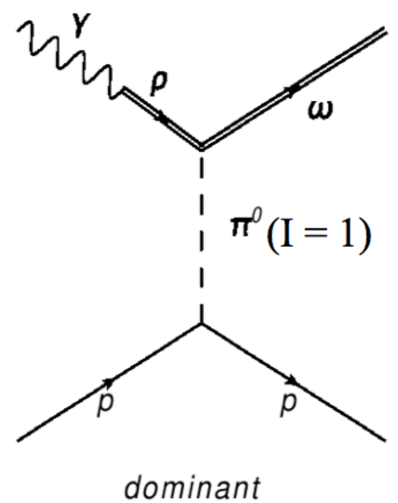
VMD and t-channel VM production:

-At high energies, Pomeron exchange
-Closer to threshold, meson exchange model (π, σ, η)



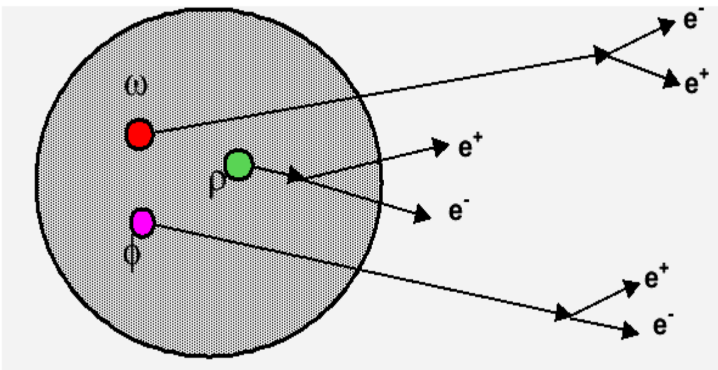
At low energies, Friman and Soyeur model [NPA600, 477(1996)] has the ρ production dominated by the σ exchange and the ω production by the π exchange terms.





Vector mesons in Nuclei (T=0 and $\rho \sim \rho_0$)

Partial restoration of chiral symmetry is predicted to occur at high densities and/or temperatures. The predicted medium modifications at normal nuclear density are large enough to be observed. Different experiments have looked at vector mesons produced in nuclei: (probe) + A --> V X --> e^+e^- X; probe = γ,π,p,A



$$m_{\rho,\omega,\phi}(\vec{p},\rho,T) = \sqrt{(P_{e^+} + P_{e-})^2}$$

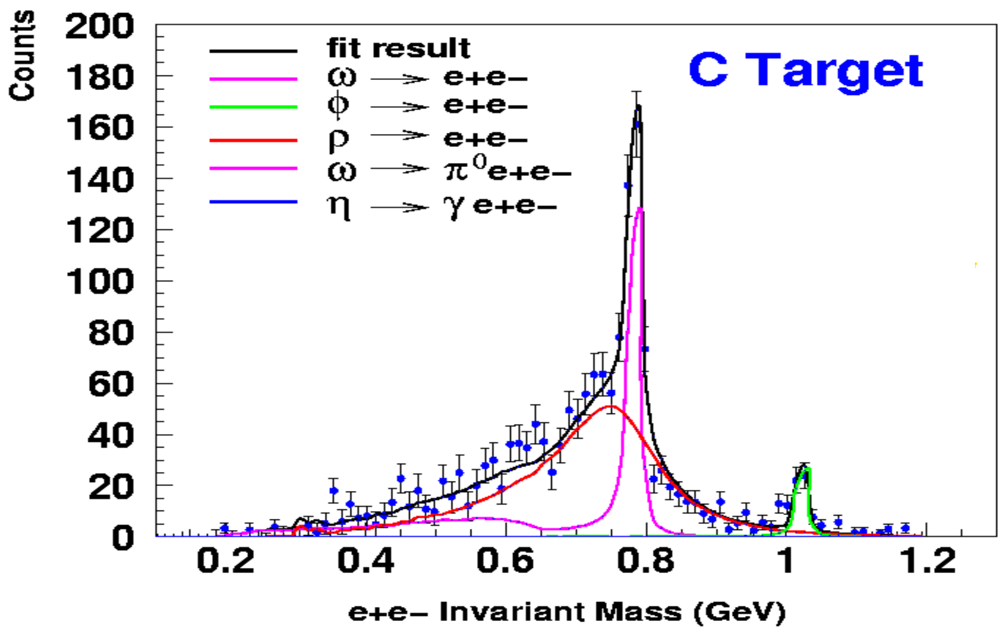
m : invariant mass of meson
P : 4-momentum of lepton
p: 3-momentum of meson/medium

Vector mesons	ρ:	M=775 MeV	Γ= 149 MeV	cτ~1.3 fm
	ω:	M=782 MeV	Γ = 8 MeV	cτ~23 fm
	φ:	M=1019 MeV	Γ = 4 MeV	cτ~46 fm

Most ρ mesons decay inside; ω and φ mesons decay mostly outside, need very low p or indirect widths' information through transparency ratios

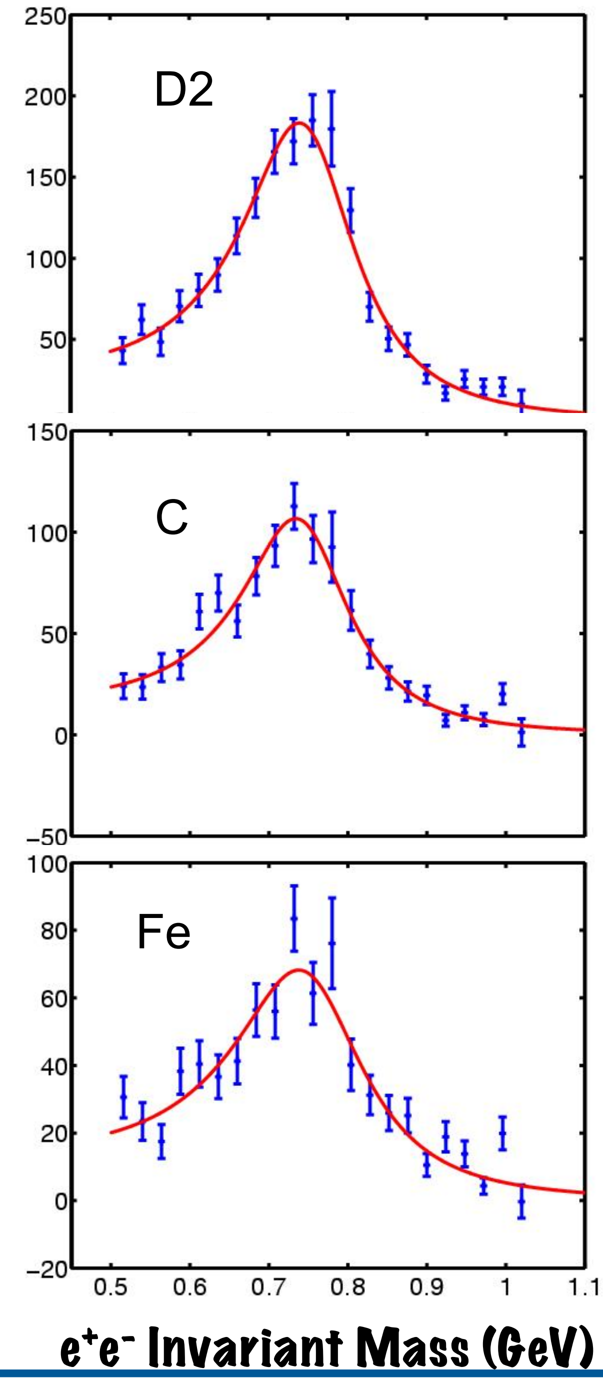
ρ mass spectra at Jlab (g7a)

$\gamma A \rightarrow e^+ e^- (X)$



Target	Mass (MeV/c²) CLAS data	Width(MeV/c²) CLAS data
^{12}C	768.5 +/- 3.7	176.4 +/- 9.5
^{48}Ti-^{56}Fe	779.0 +/- 5.7	217.7 +/- 14.5

The **mass** of the ρ meson consistent with **no shift.**
Broadening of the width ($\Delta\Gamma$~70 MeV) consistent with many-body effects



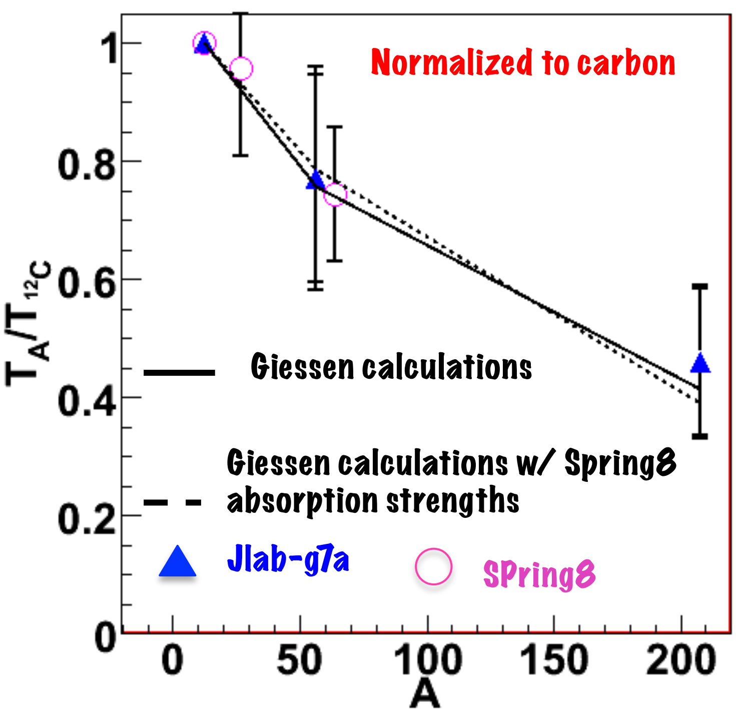
Nasseripour et al., PRL 99 (2007) 262302
Wood et al., PRC 78 (2008) 015201

ϕ Absorption at JLab (g7a)

$\phi \rightarrow e^+ e^-$

$\gamma A \rightarrow e^+ e^- (X)$

$\Gamma=\Gamma_0+\Gamma_{coll}$; $\Gamma_{coll} = \gamma\rho v\sigma^*_{VN}$

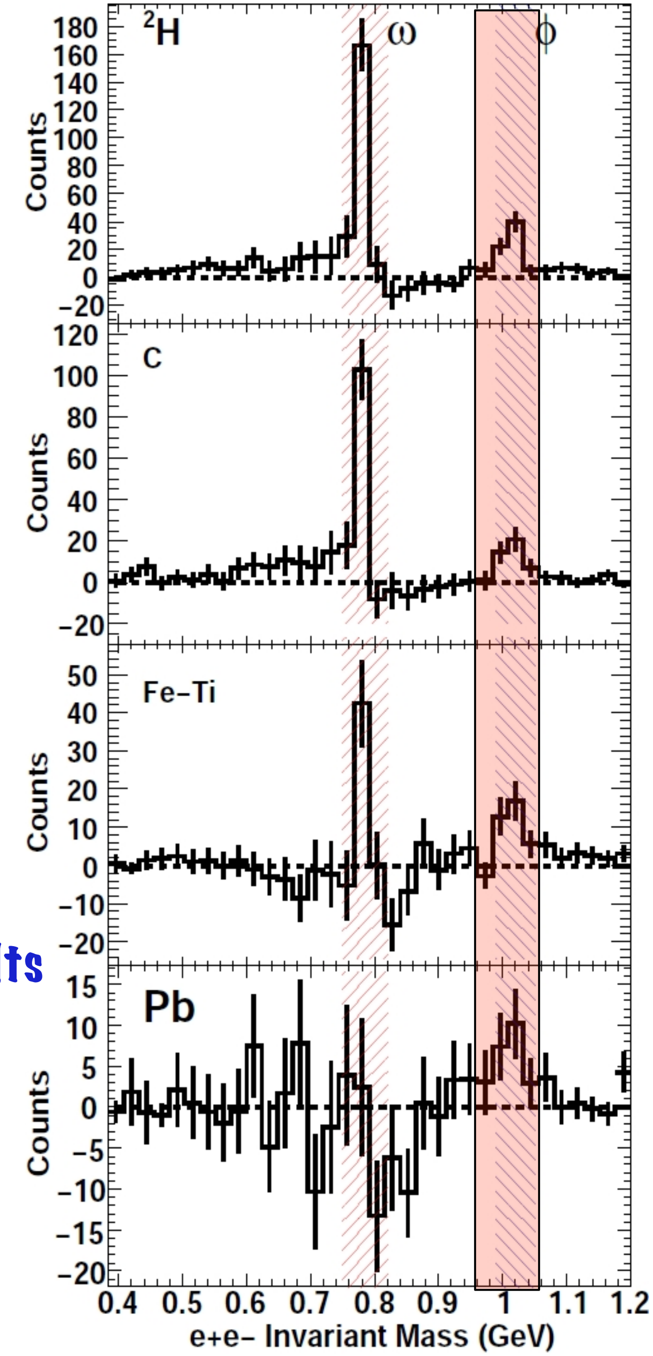


$$T_A = \frac{\sigma_{\gamma A \rightarrow \omega X}}{A \cdot \sigma_{\gamma N \rightarrow \omega X}}$$

$$T_{norm} = \frac{12 \cdot \sigma_{\gamma A \rightarrow \omega X}}{A \cdot \sigma_{\gamma ^{12}C \rightarrow \omega X}}$$

$\sigma_{\phi N} \sim$ 25–55 mb

Γ_ϕ(~ 70 MeV) compatible with Spring8 and recent ANKE results

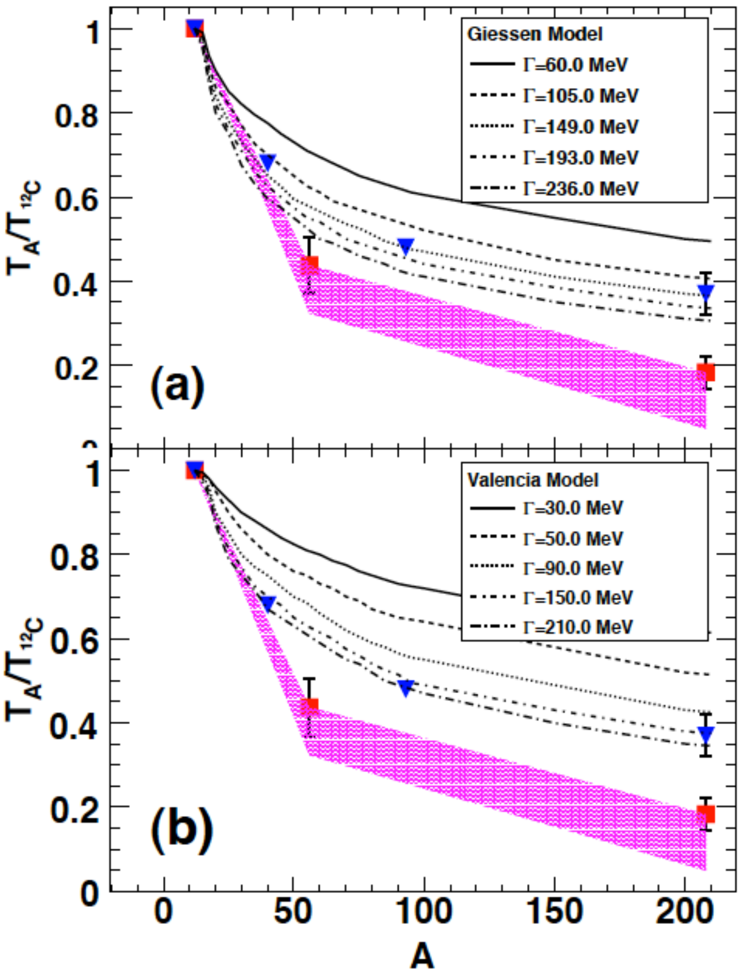


Jlab: Wood *et al,* Phys. Rev. Lett. 105 2010

Spring 8: T. Ishikawa et al. Phys. Lett. B 608, 215 (2005)

ω Absorption at JLab (g7a)

$\gamma A \rightarrow e^+ e^- (X)$

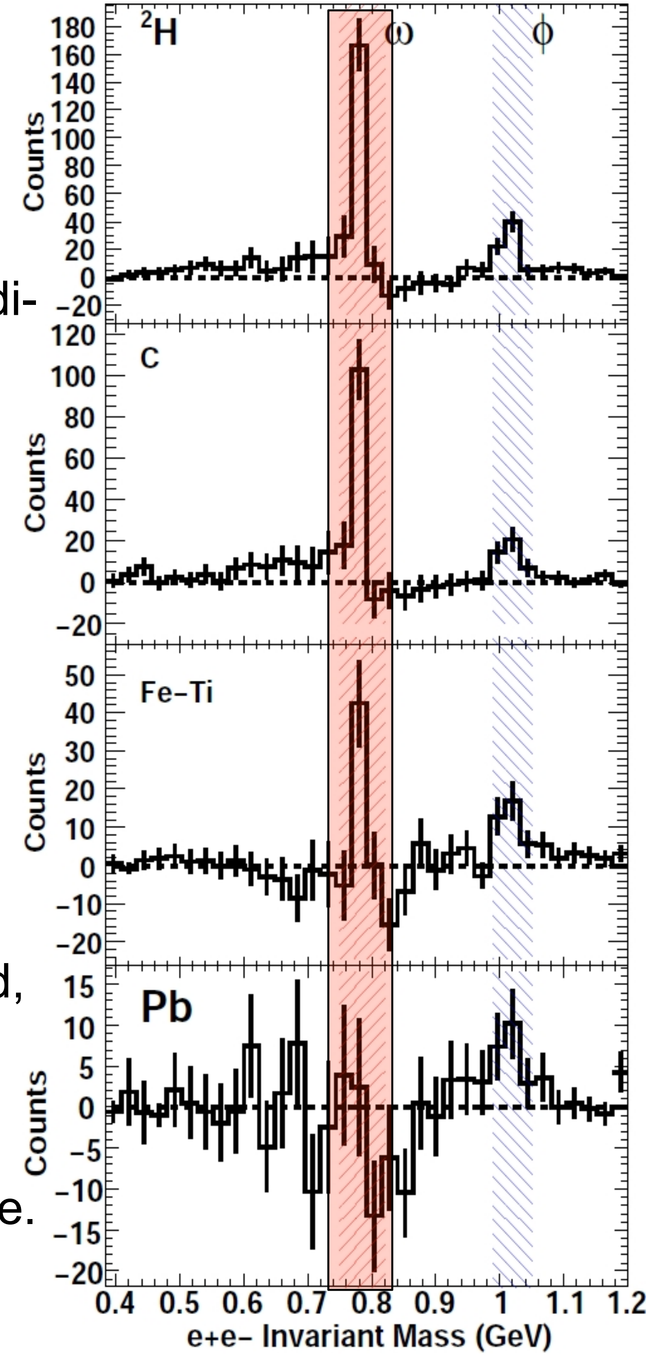


$\omega \rightarrow e^+ e^-$

- Transparency ratios in the di-lepton decay channel indicate a very large in-medium width for the ω

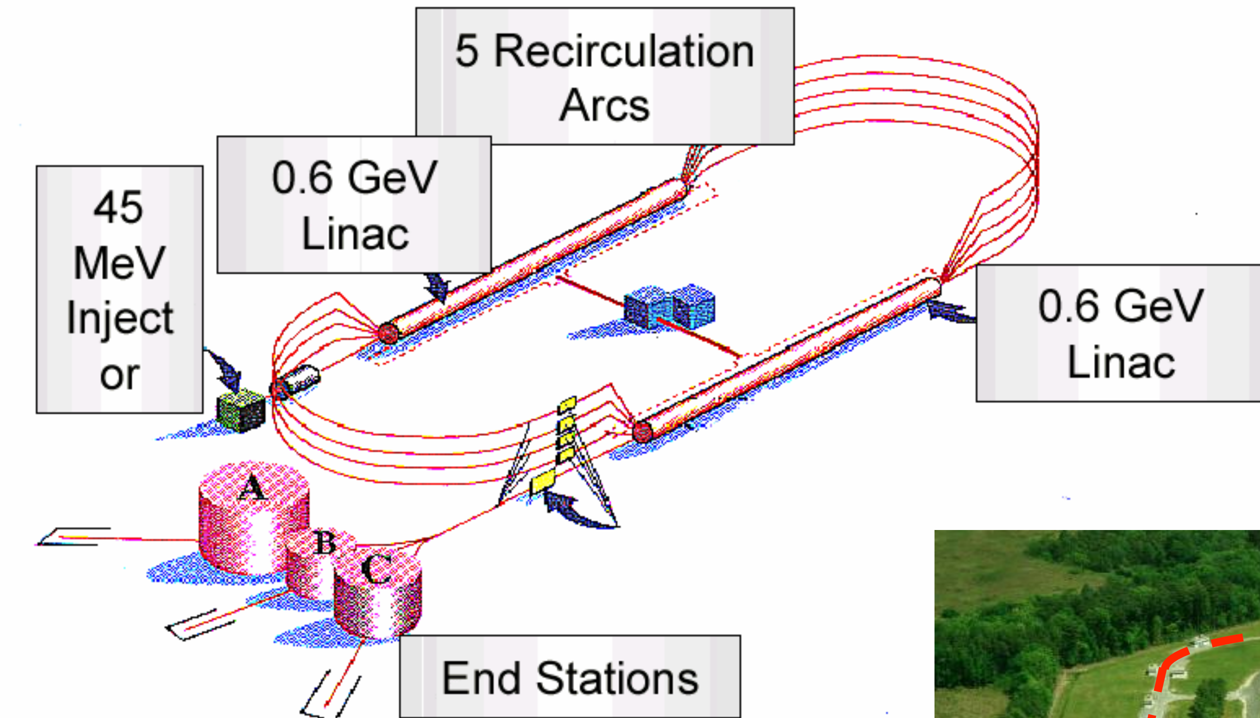
(Γ_ω >200 MeV)

- Recent calculations by Rodrigues et al, try to reconcile the in-medium widths found in different experiments.
- Once ρ meson is subtracted, the "negative yield" on the high invariant mass side of the ω-peak could be indicative of ρ-ω interference.



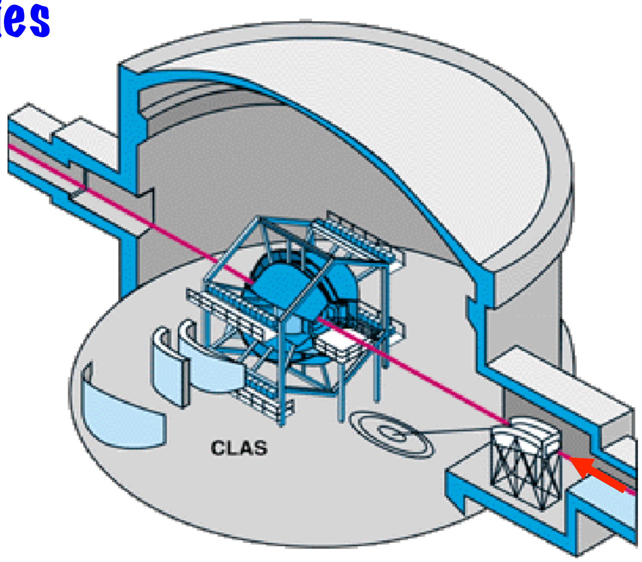
Wood *et al*, Phys. Rev. Lett. 105 2010

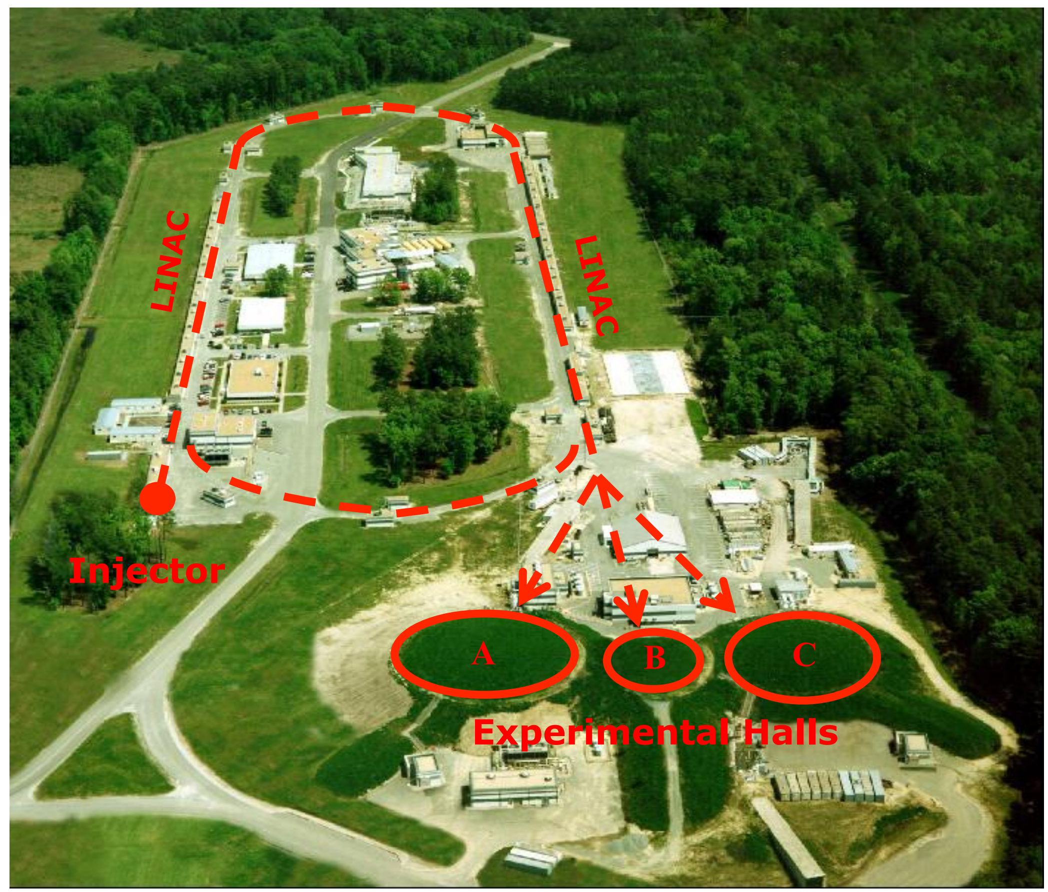
Jlab-CEBAF: The 6 GeV CW Electron Accelerator



E_{max}	~ 6 GeV
I_{max}	~ 200 μA
Duty Factor	~ 100%
σ_E/E	~ 2.5 10^{-5}
Beam P	~ 80%
E_g(tagged)	~ 0.8- 5.5 GeV

HALL B:
>200 Physicists
~ 15 countries



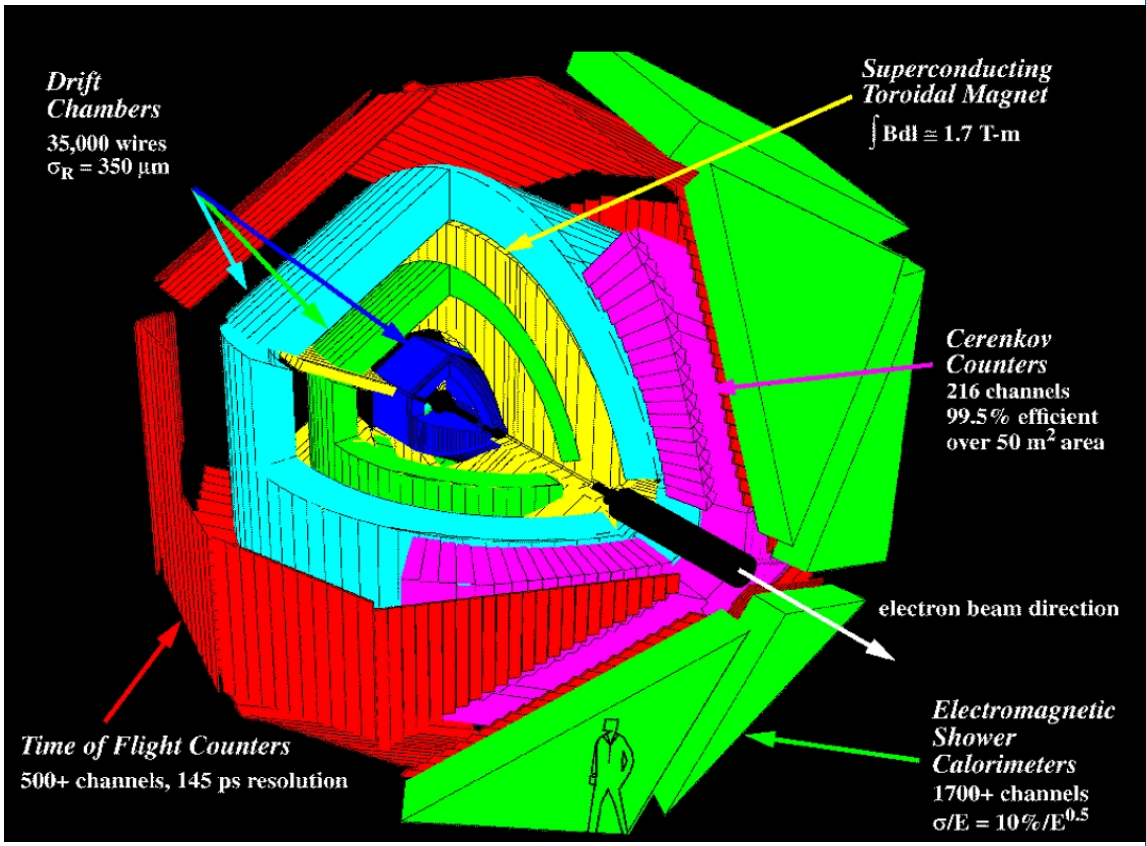


Jefferson Lab Experiment g12

$\gamma\, p \rightarrow e^+ e^- X$ channel

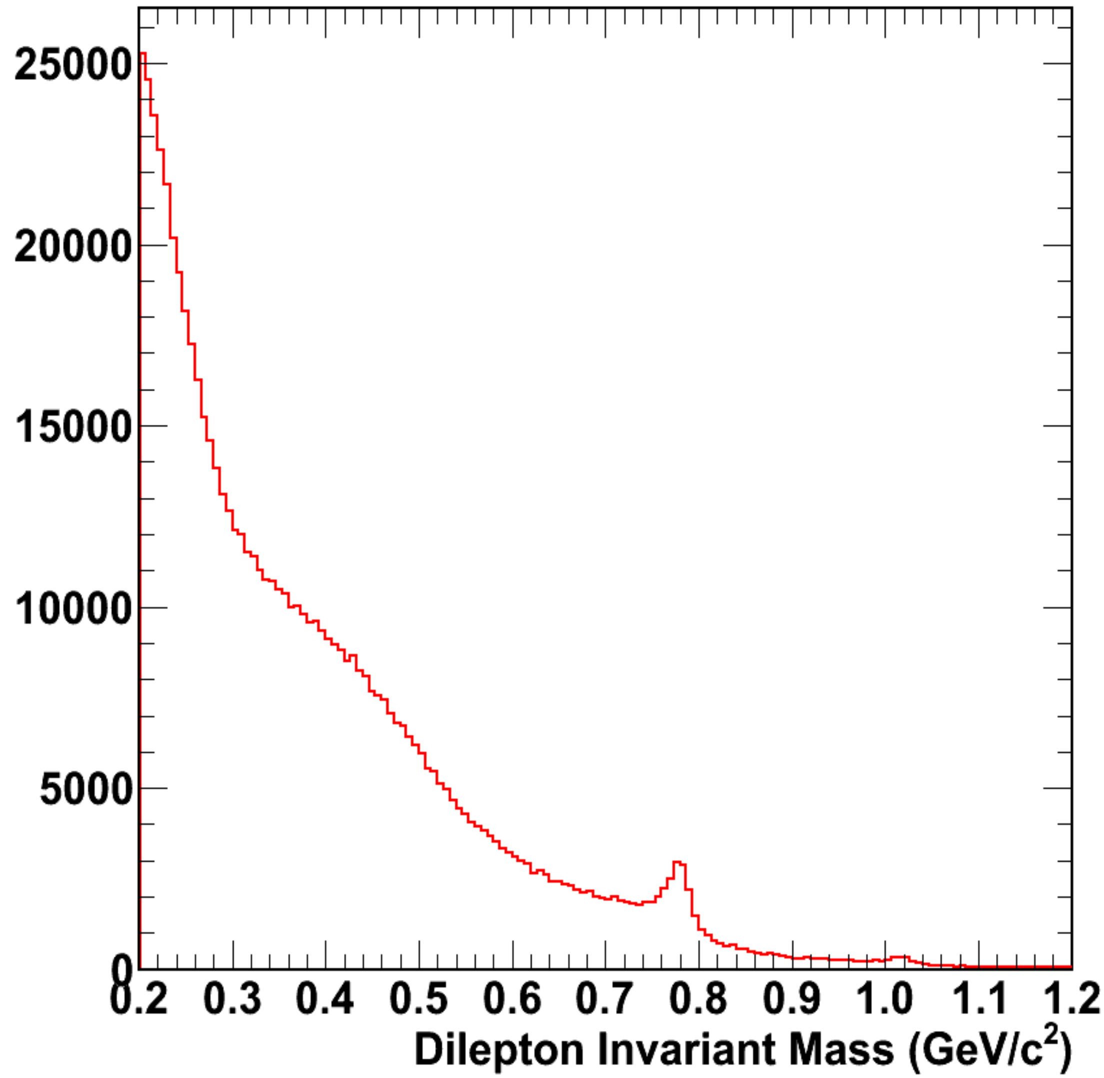
- Hall-B houses the CLAS detector, ideal for photoproduction and lepton identification.
- g12 in CLAS
  - ✓ 44 days of beam
  - ✓ Tagged Photons Eγ [1.1 to 5.5 GeV] incident on a LH_2 target
  - ✓ 26.2 x10^9 production triggers

    (3 x 10^6 di-lepton triggers)
  - ✓ EC and CC combine to provide an e/π rejection factor better than 10^{-6} for di-lepton pairs.
  - ✓ LH_2 target placed 90 cm upstream



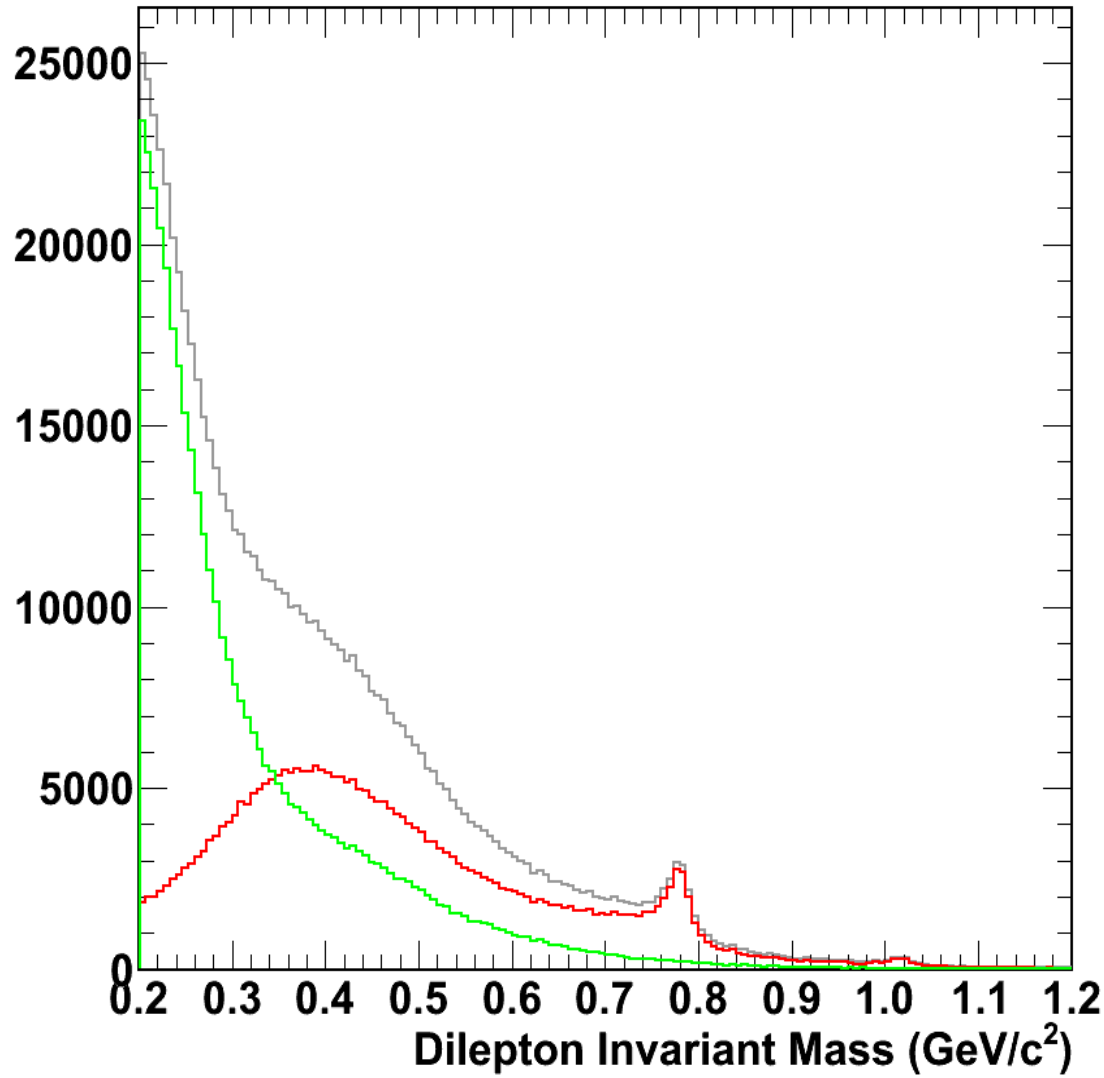
Background and Cuts

- Cut 1: Two leptons are skimmed from the total g12 data set.
- Cut 2: Both leptons must be in different sectors of CLAS.
- Cut 3: Vertex cut on event to be inside target walls.
- Cut 4: Opening angle cut between leptons.



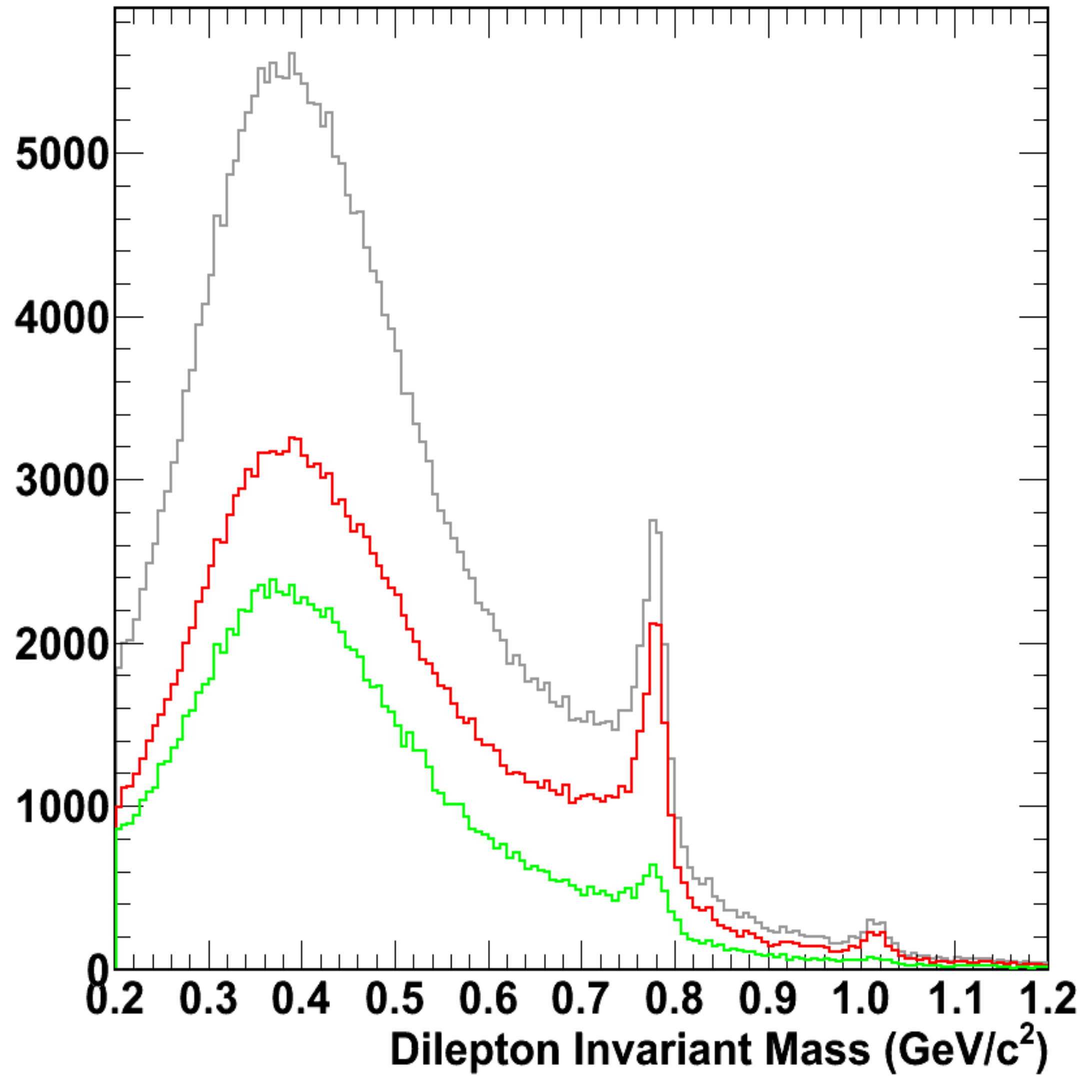
Background and Cuts

- Cut 1: Two leptons are skimmed from the total g12 data set.
- Cut 2: Both leptons must be in different sectors of CLAS.
- Cut 3: Vertex cut on event to be inside target walls.
- Cut 4: Opening angle cut between leptons.



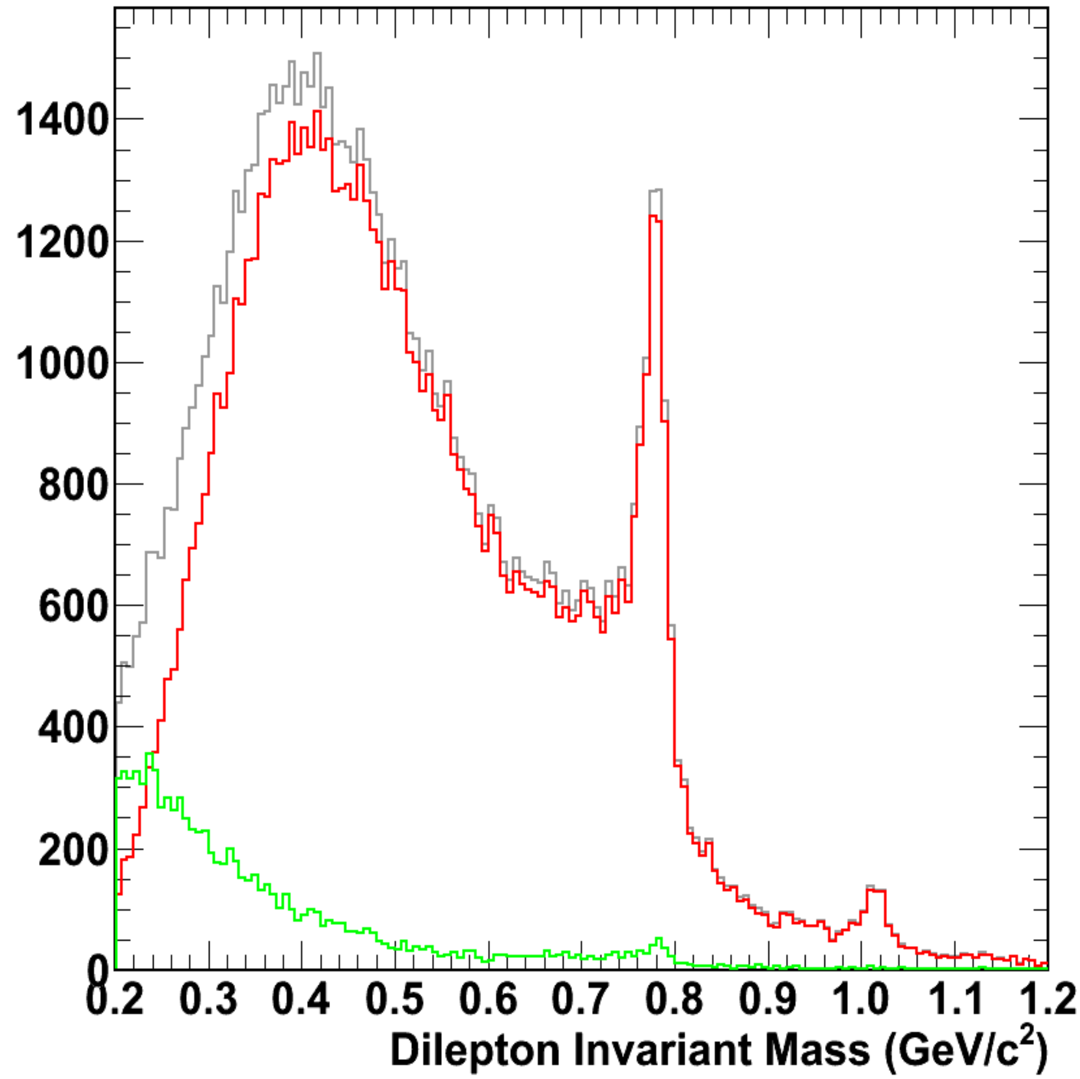
Background and Cuts

- Cut 1: Two leptons are skimmed from the total g12 data set.
- Cut 2: Both leptons must be in different sectors of CLAS.
- Cut 3: Vertex cut on event to be inside target walls.
- Cut 4: Opening angle cut between leptons.



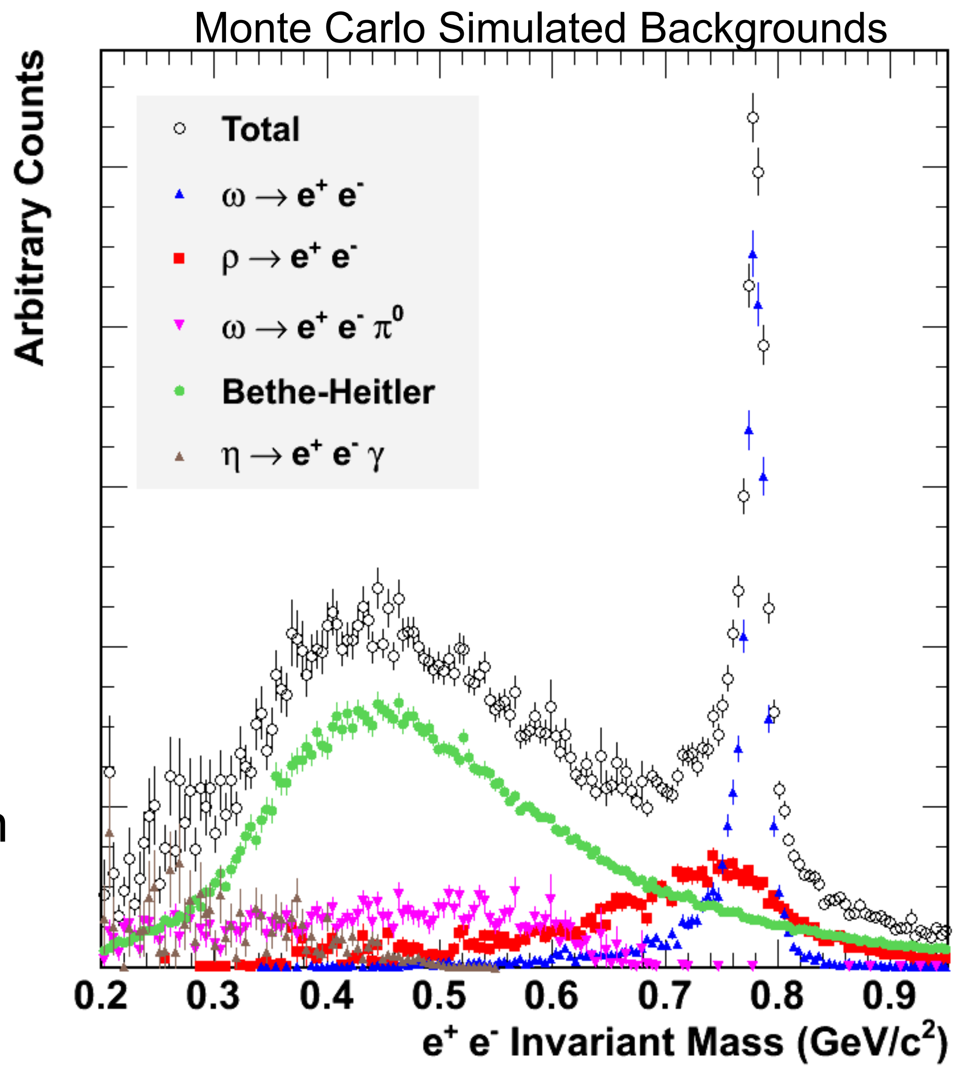
Background and Cuts

- Cut 1: Two leptons are skimmed from the total g12 data set.
- Cut 2: Both leptons must be in different sectors of CLAS.
- Cut 3: Vertex cut on event to be inside target walls.
- Cut 4: Opening angle cut between leptons.

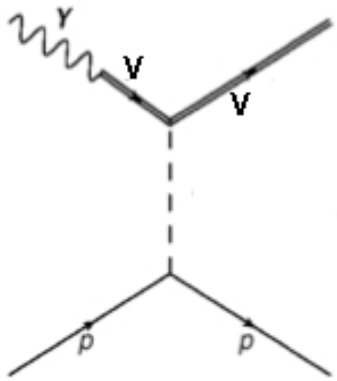


Different e^+e^- channels

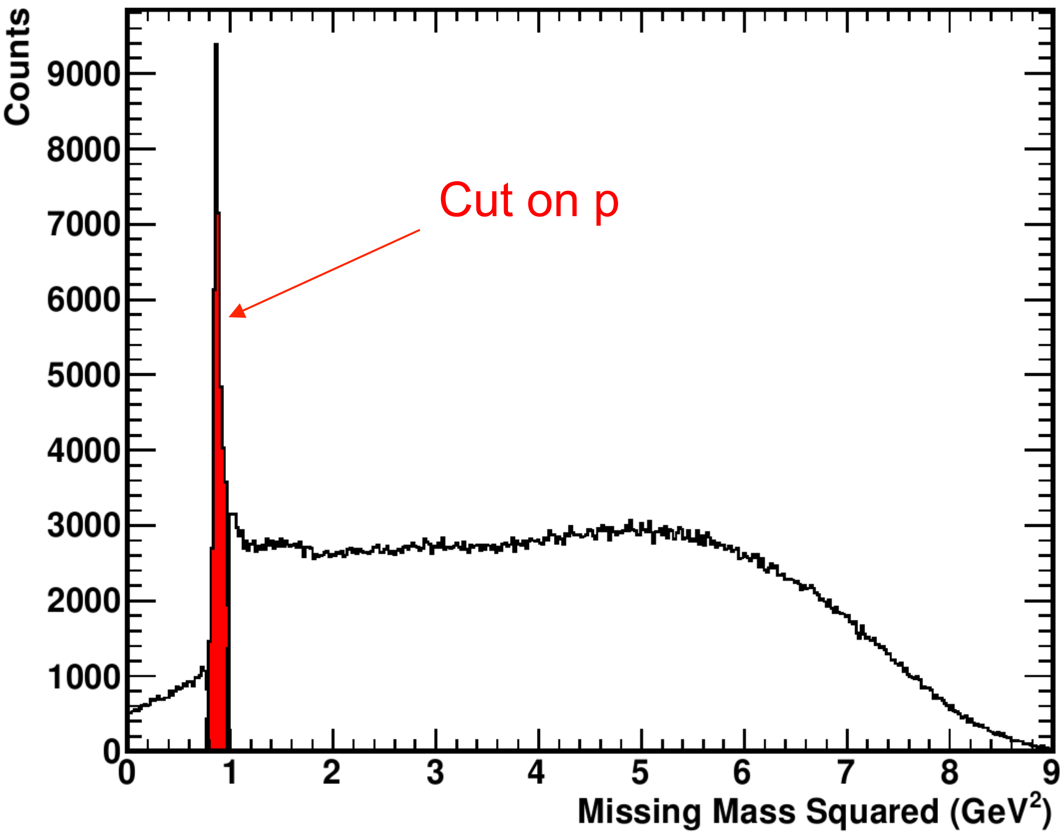
- Channels of interest: $\rho \rightarrow e^+ e^-$; $\omega \rightarrow e^+ e^-$
- Other channels:
  - ✓ $\omega \rightarrow e^+e^-\pi^0$ “background” reduced with tight missing mass cut on the proton.
  - ✓ Bethe-Heitler is significant and must be accounted for. The upstream location of the target increases the small angle acceptance. (angle cut)
  - ✓ Uncorrelated lepton pairs are also eliminated by tight missing mass cuts on the proton.

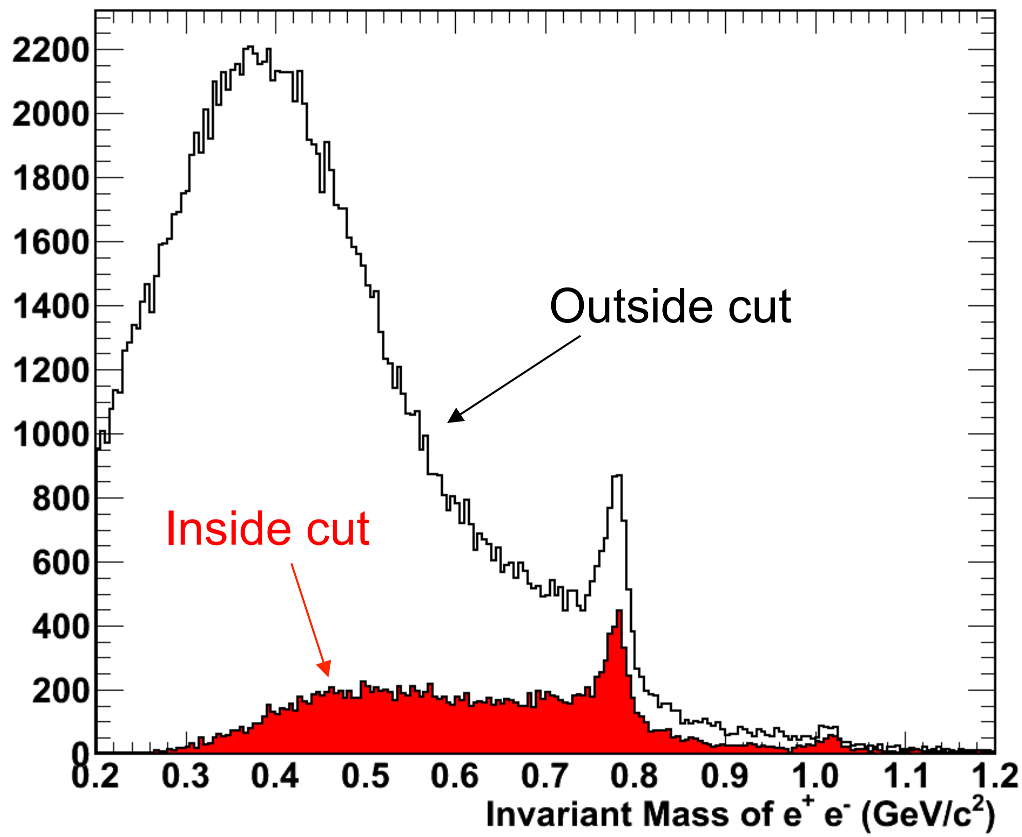


Selecting an Outgoing Proton



- Initial cuts must be made on the missing mass to isolate a proton in the final state.

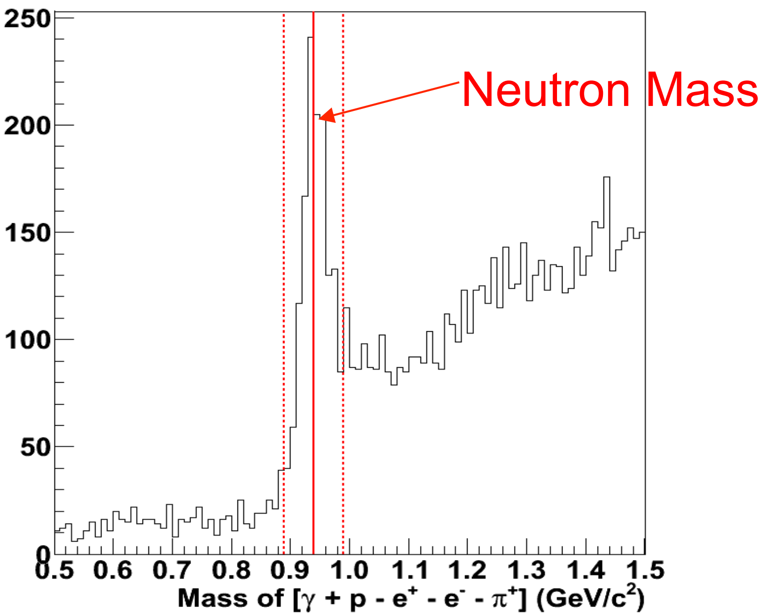


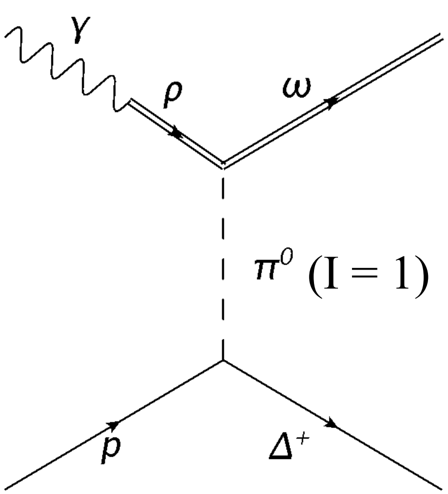


Selecting the Delta

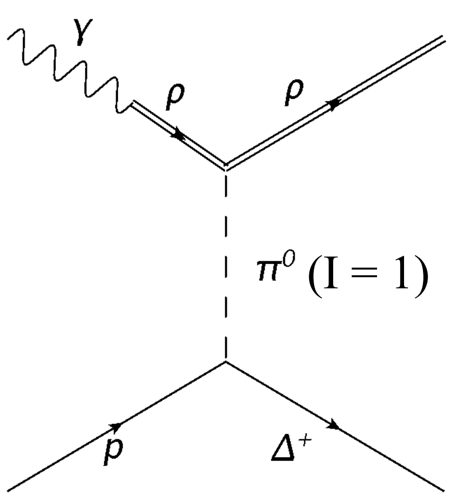
$$\gamma p \rightarrow e^{+}e^{-}\pi^{+}(n)$$

- If a secondary cut is made on a (n π^+) mass to be (1232 +/- 100 MeV), the Δ^+ baryon resonance can be selected.
- This channel prefers ω production:

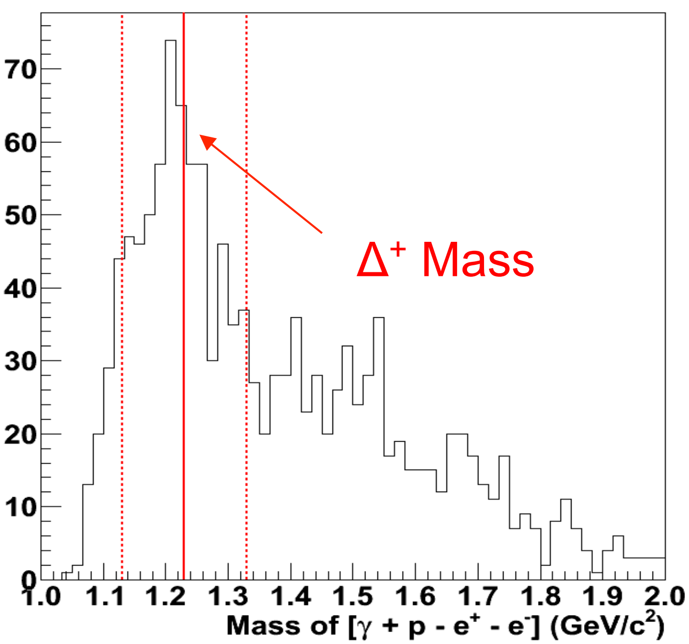




Allowed



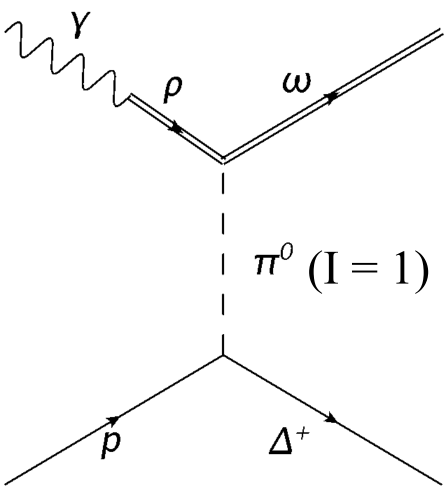
Isospin Restricted



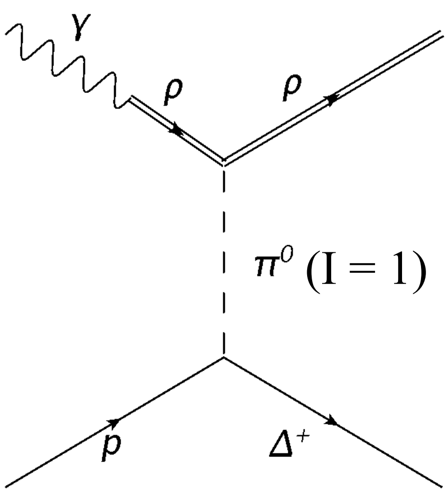
Selecting the Delta

$$\gamma p \rightarrow e^+ e^- \pi^+ (n)$$

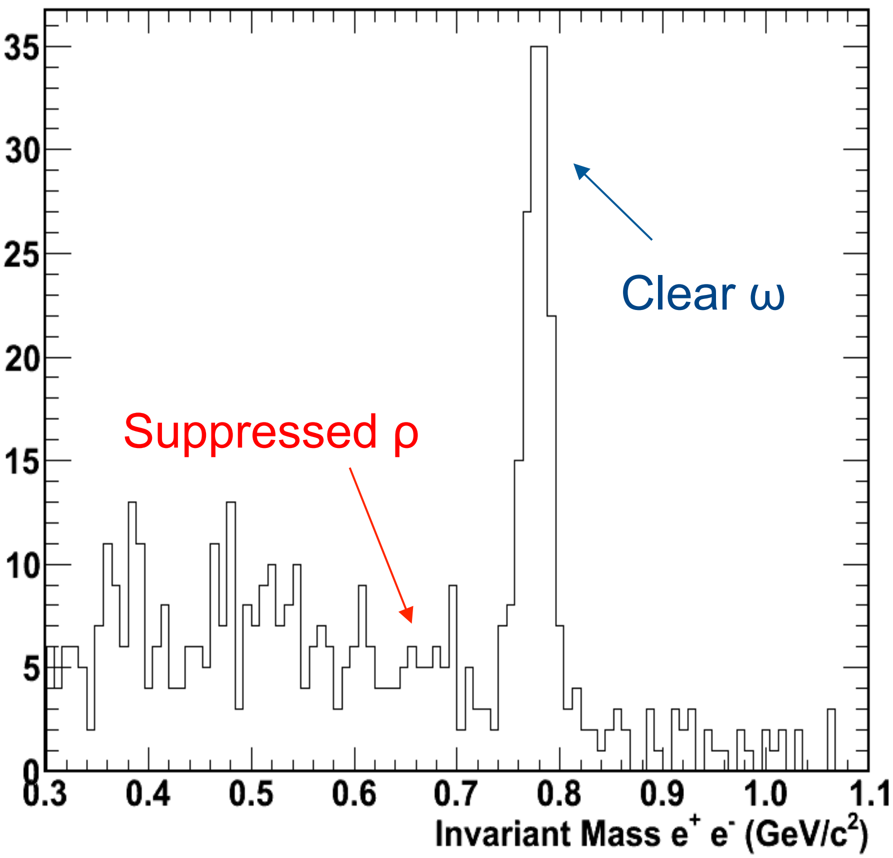
- If a secondary cut is made on a ($n\ \pi^+$) mass to be (1232 +/- 100 MeV), the Δ^+ baryon resonance can be selected.
- This channel prefers ω production:



Allowed



Isospin Restricted



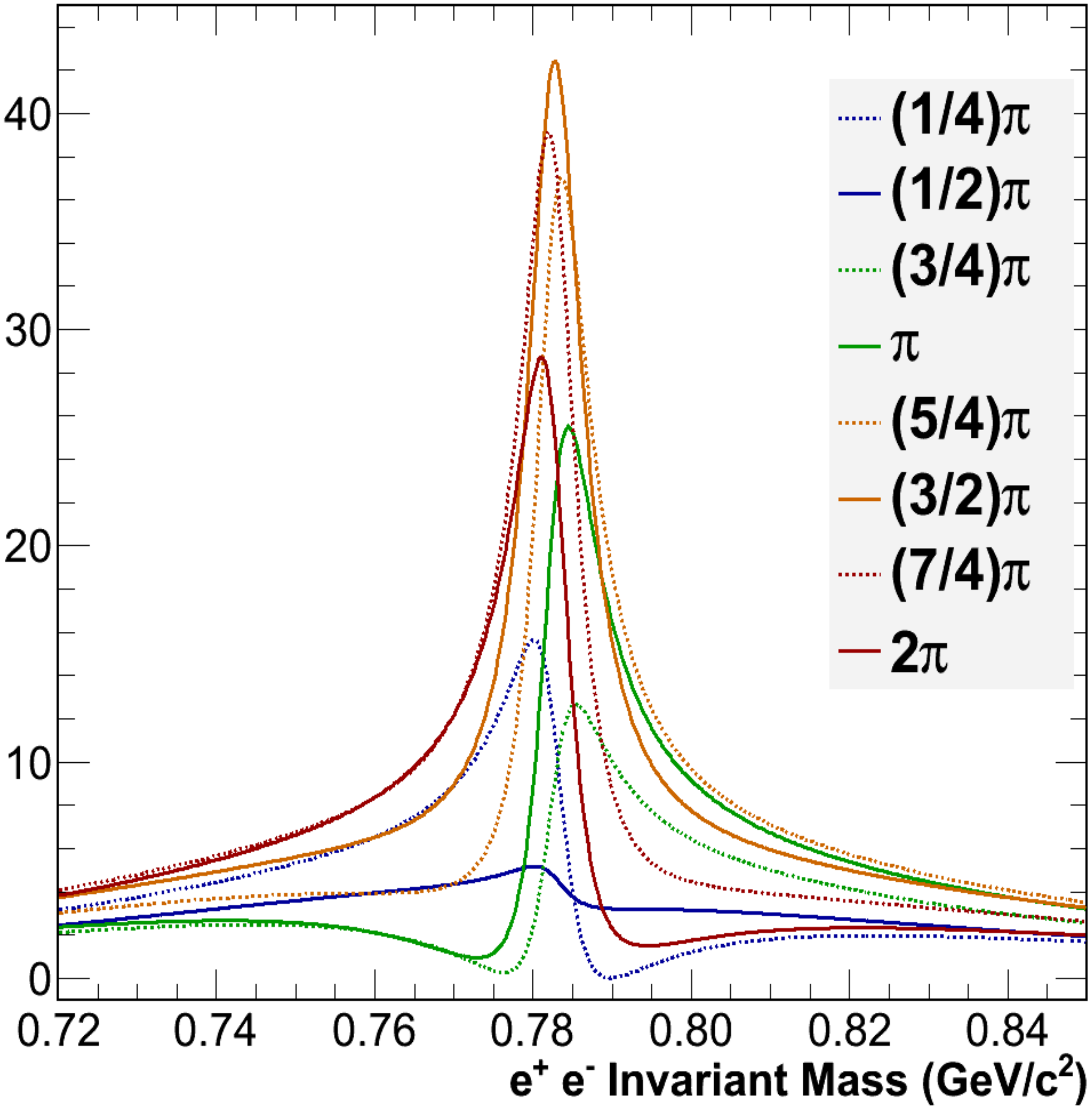
ρ, ω Interference

- The total amplitude is written as a combination of the ρ and ω meson amplitudes with a complex phase term:

$$F = f_\rho + ie^{i\phi_\rho} f_\omega$$

where f_ρ, f_ω are relativistic BW and

ϕ_ρ is the ρ-ω relative phase



Fitting Procedure

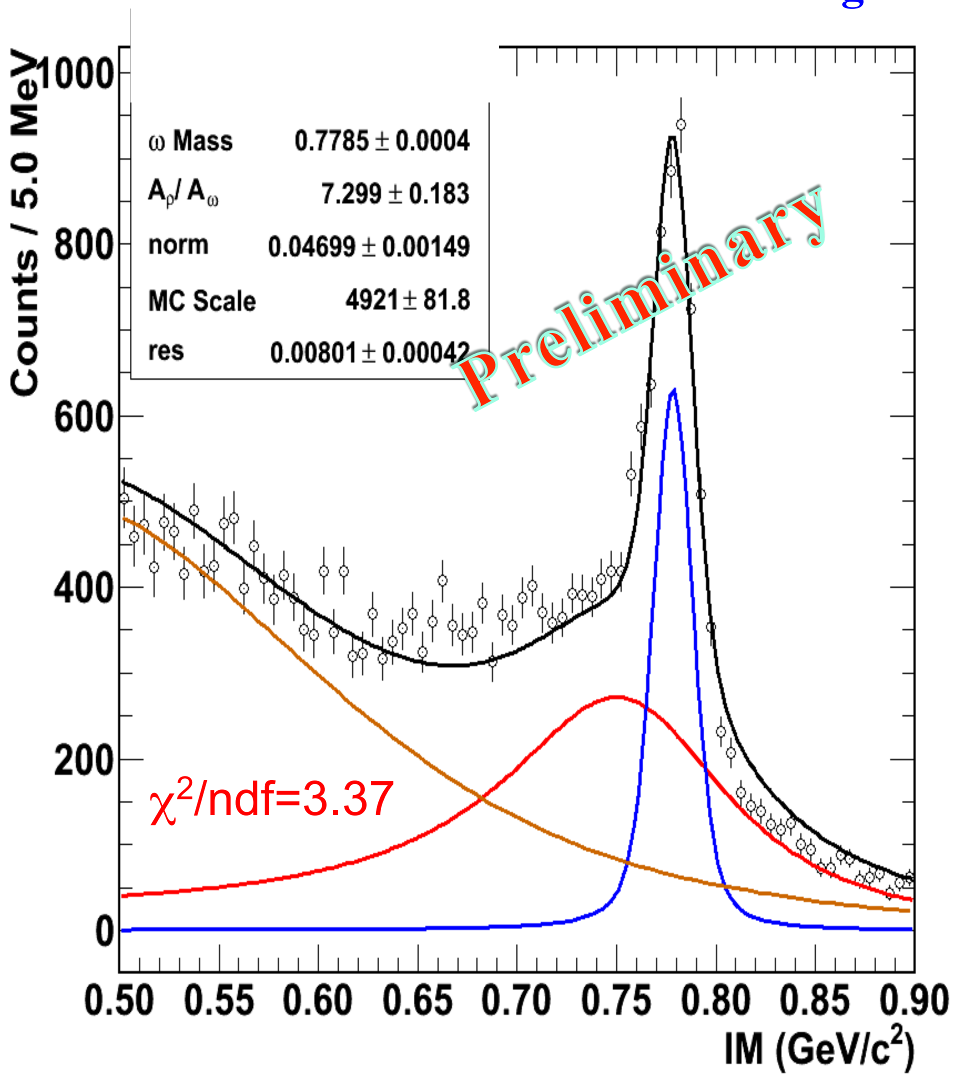
- The ρ-ω invariant mass spectrum is fit with:
  - Two Briet-Wigner functions
    - Relativistic
    - Mass dependent widths
    - Interference term
    - Gaussian convolution (width ← Fit)
  - Background Shape for Bethe-Heitler:

    1: Monte Carlo GiBUU form (norm← Fit)

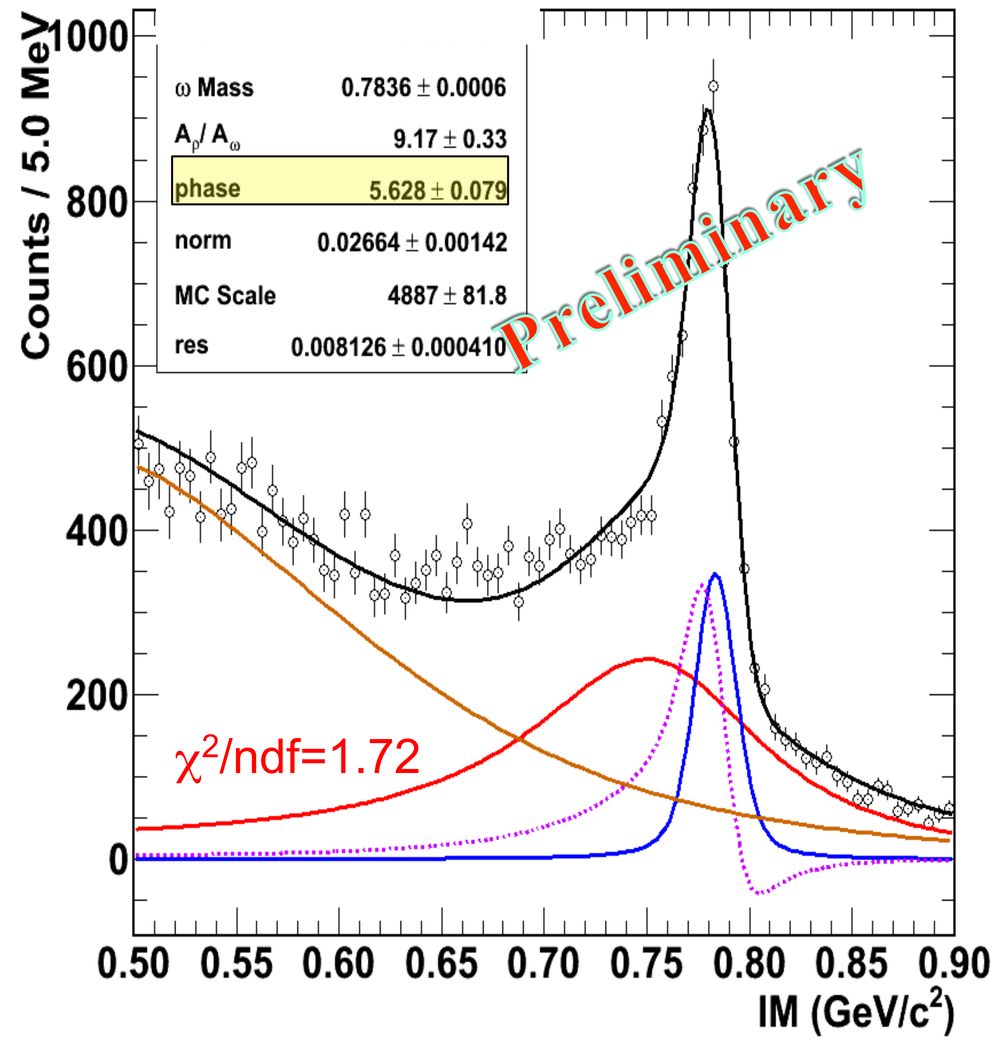
    2: Third-order Polynomial (norm← Fit)

Fit / no p cut in MM /BH: MC shape

non-interfering



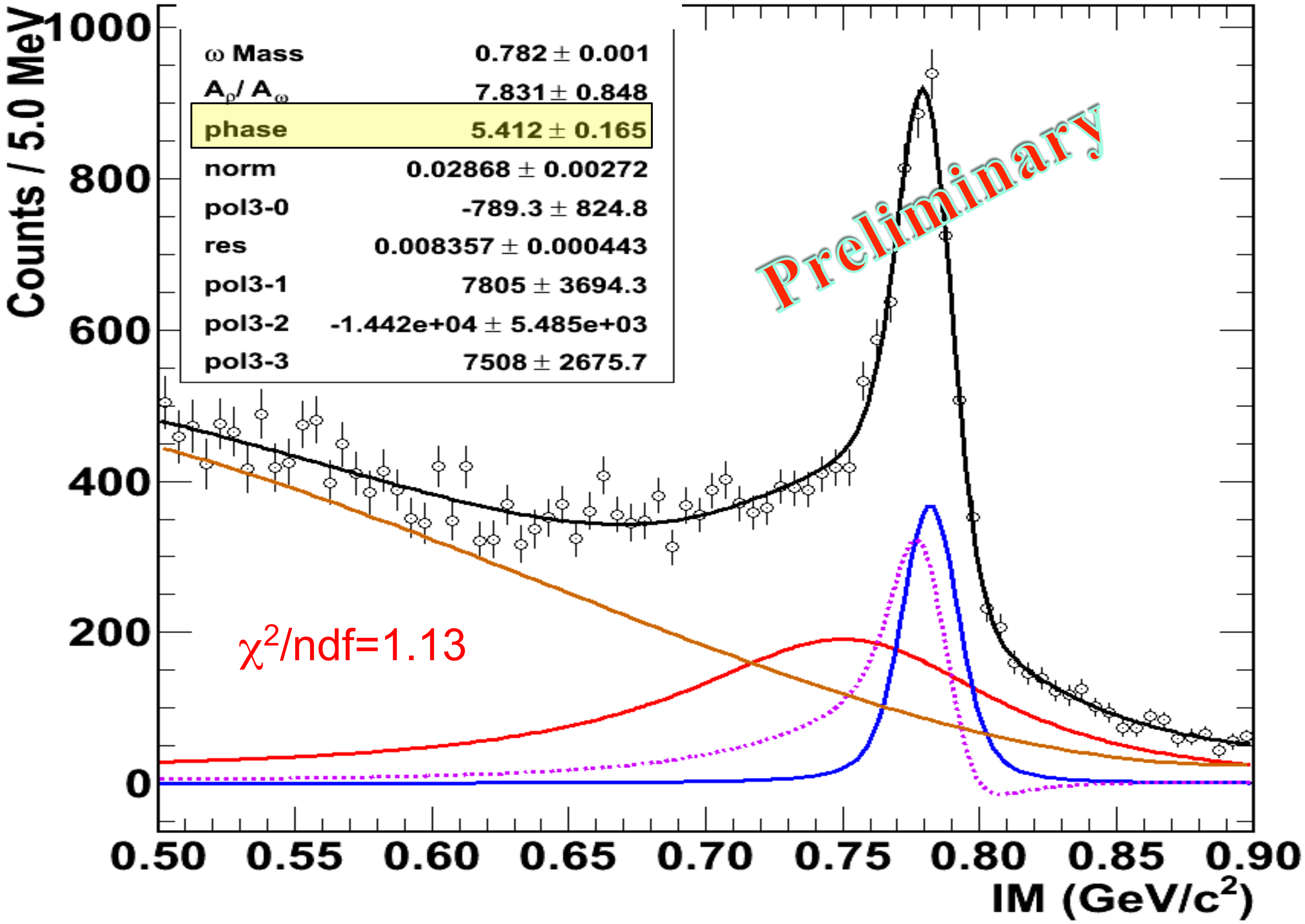
interfering



Total ω ρ Bethe-Heitler Interference Term

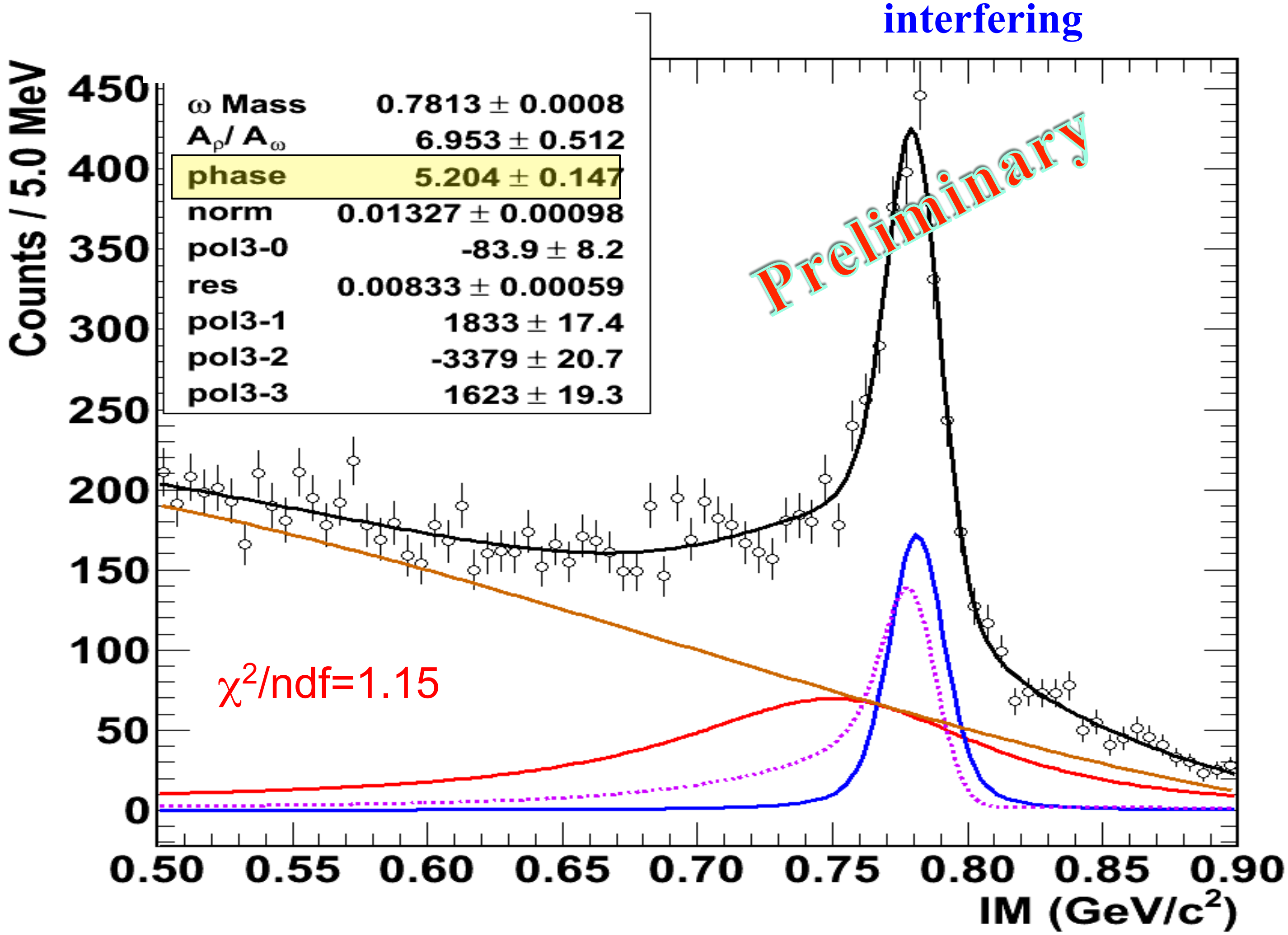
Fit / no p cut in MM / BH shape polynomial

interfering



Total ω ρ Bethe-Heitler Interference Term

Fit /p cut in MM / BH shape polynomial



Total ω ρ Bethe-Heitler Interference Term

Interference Phase **Preliminary** Results

Fit Type	Interference Phase (in radians)	X^2/ndf
MM cut / MC background	5.14 +/- 0.11	1.77
MM cut / 3^{rd} order pol.	5.20 +/- 0.15	1.15
No MM cut / MC background	5.63 +/- 0.08	1.72
No MM cut / 3^{rd} order pol.	5.41 +/- 0.17	1.13

Many other fits with slightly different ranges in IM, BH shape, etc. lead to phase angles in the same range

Summary, Conclusions and Outlook

- The g12 experiment at JLab has generated large statistics data in the $\gamma p \rightarrow e^+e^-X$ channels. The light vector mesons are clearly observed.

- Preliminary analysis show a ρ-ω interference in the di-lepton channel. The interference phase from fits with different background shapes agree within statistical error:

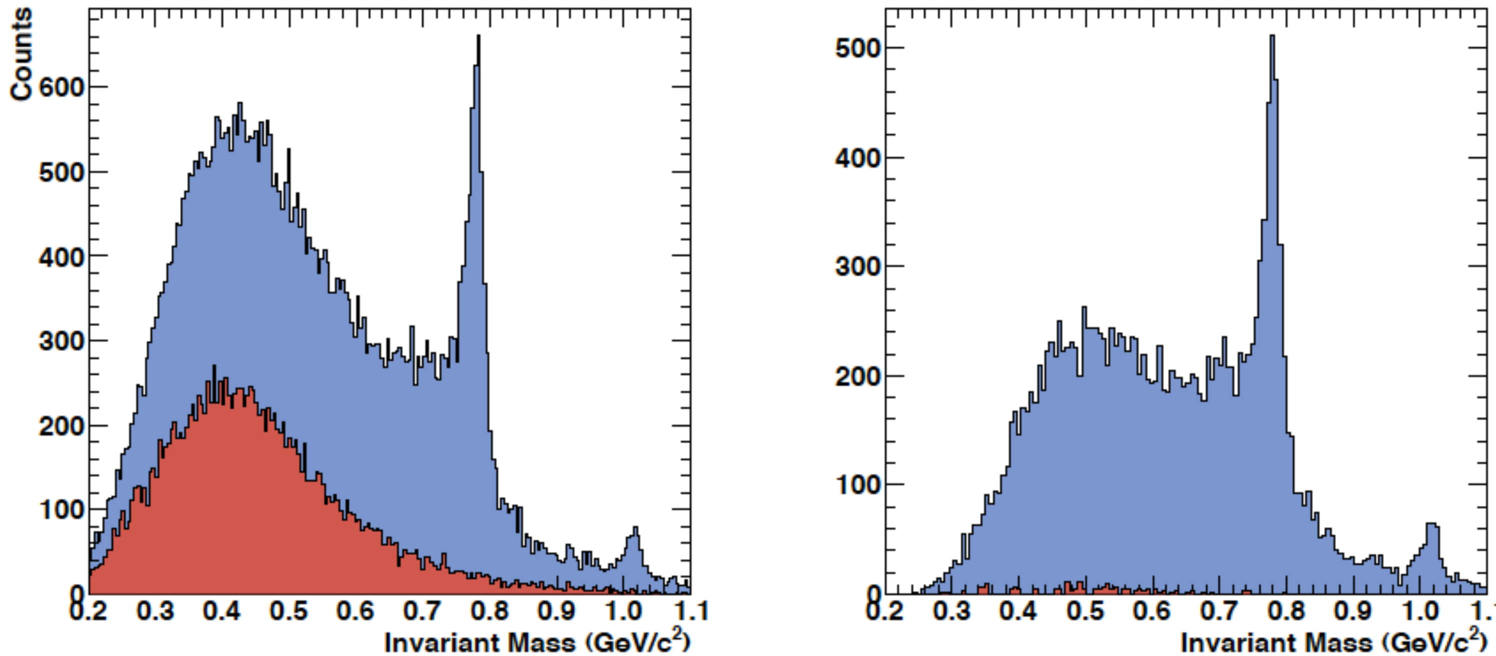
  preliminary result : φ in the range 5.35 +/- 0.25 rad

- Further analysis is underway to calculate the shape and magnitude of the Bethe-Heitler “background”, before extracting the final ρ-ω interference phases (≠ E_γ range). Cross sections will be compared to Lutz and Soyeur predictions.

- Extend study to nuclei.

- Study of asymmetric pairs on p and A (2^{nd} order Born corrections)

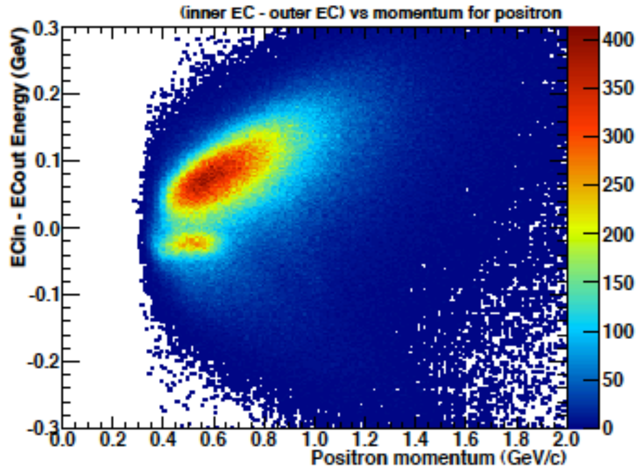
EXTRA SLIDES



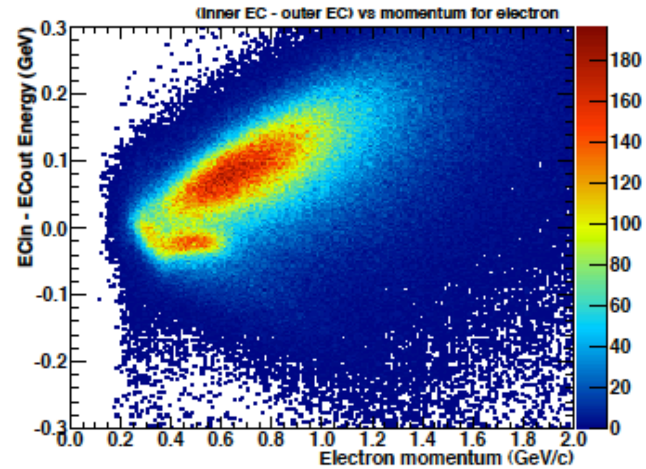
(a) Without missing mass cut. (b) With missing mass cut.

Invariant Mass of two opposite charged leptons (blue)

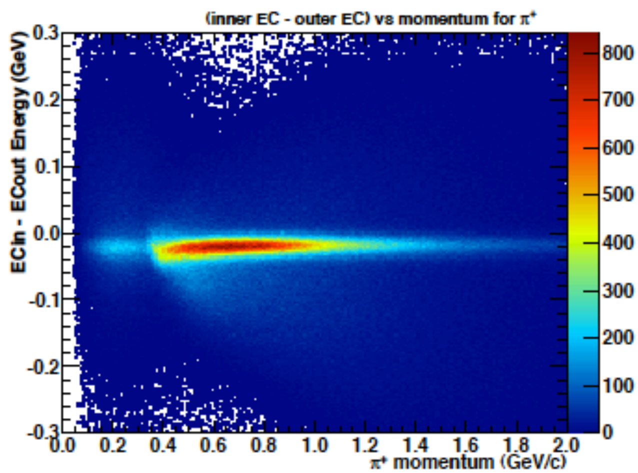
uncorrelated lepton pairs (red).



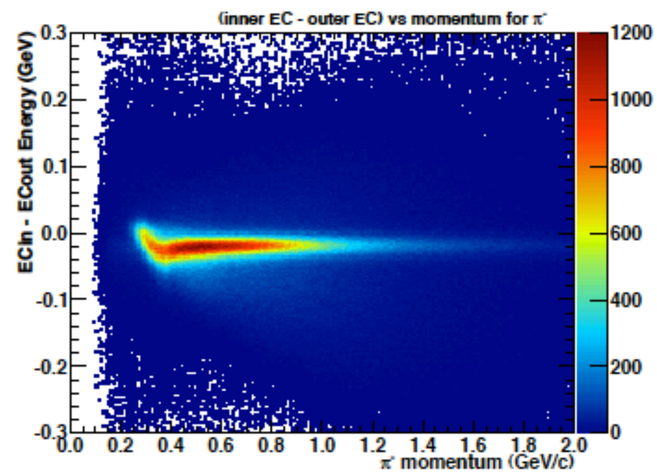
(a) Positrons after the g7 lepton identification cut.



(b) Electrons after the g7 lepton identification cut.



(c) π^+ using standard particle identification.



(d) π^- using standard particle identification.

Inner EC - Outer EC vs momentum for leptons and pions.

Interference Formalism

- The ρ-ω interference can be described by constructing a complex and symmetric mass matrix:

$$M = \begin{bmatrix} M_\rho & -\delta \\ -\delta & M_\omega \end{bmatrix} \qquad M_a = (m^2 - m_a^2 + im\Gamma_a)/m\Gamma_a$$

- The propagator can then be constructed as:

$$P = |M|^{-1} = \frac{1}{M_\rho M_\omega - \delta^2} \begin{bmatrix} M_\omega & +\delta \\ +\delta & M_\rho \end{bmatrix} \approx \begin{bmatrix} 1/M_\rho & \delta/M_\rho M_\omega \\ \delta/M_\rho M_\omega & 1/M_\omega \end{bmatrix}$$

- And the amplitude then takes the form:

$$F(e^+e^-) = [T(\rho \to e^+e^-) \quad T(\omega \to e^+e^-)]P \begin{bmatrix} A(\gamma p \to \rho) \\ A(\gamma p \to \omega) \end{bmatrix}$$

- Combining to make:

$$F(e^+e^-) = \frac{T_\rho A_\rho}{M_\rho} + \frac{T_\omega A_\omega}{M_\omega} + \frac{\delta(T_\rho A_\omega + T_\omega A_\rho)}{M_\omega M_\rho}$$

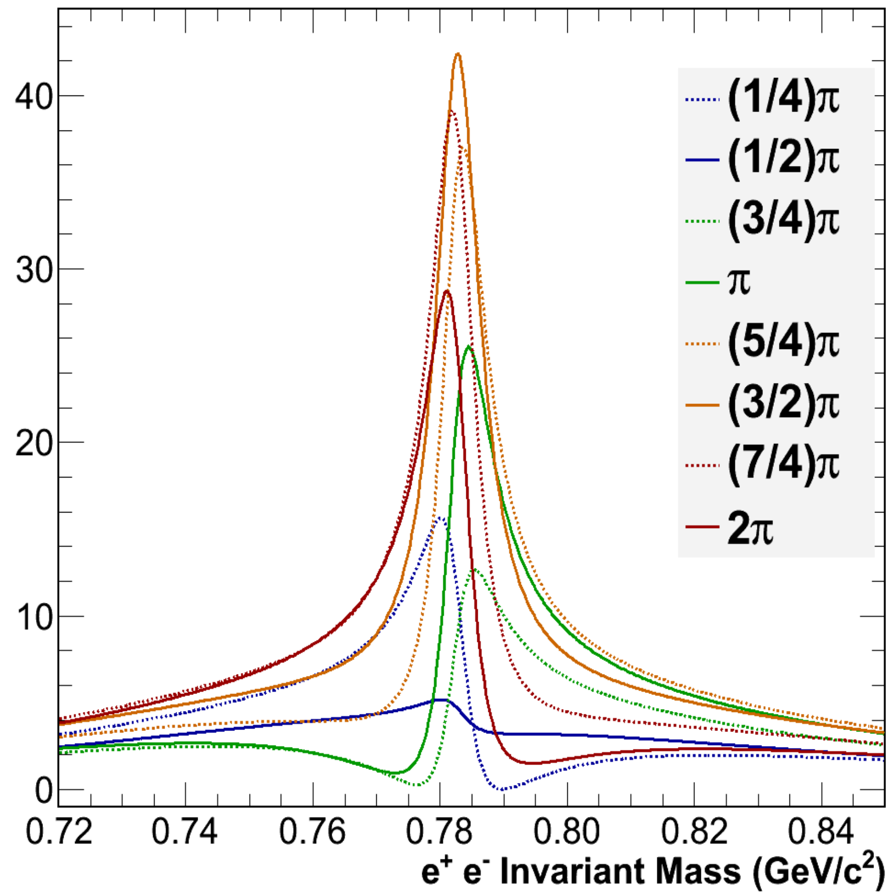
Interference Formalism

- A phase is then introduced, accounting for the cross amplitudes and mass term:

$$1 - ie^{i\phi_\rho} = -\frac{\delta}{M_\rho}\left(\frac{T_\rho A_\omega + T_\omega A_\rho}{T_\omega A_\omega}\right)$$

- The amplitude is then rewritten as a combination of the meson amplitudes with a complex phase term:

$$F = f_\rho + ie^{i\phi_\rho} f_\omega$$



- When squared, the amplitude takes the form:

$$F^2 = f_\rho^2 + f_\omega^2 - \frac{2a}{b^2 + c^2}(b \sin\phi_\rho + c \cos\phi_\rho)$$

Kinematic Variables

$$a = m^2 A'_\rho \Gamma_\rho A'_\omega \Gamma_\omega$$

$$b = (m^2 - m_\rho^2)(m^2 - m_\omega^2) + m^2 \Gamma_\rho \Gamma_\omega$$

$$c = m[\Gamma_\rho (m^2 - m_\omega^2) - \Gamma_\omega (m^2 - m_\rho^2)]$$

Fitting Procedure

- The ρ-ω invariant mass spectrum is fit with:
  - Two Briet-Wigner functions
    - Relativistic: $$\frac{m^2}{(m^2 - m_a^2)^2 + \Gamma_a^2 m^2}$$
    - Mass dependent ρ width: $$\Gamma_\rho(m, m_{\rho 0}, \Gamma_{\rho 0}) = \Gamma_{\rho 0} \left(\frac{m_{\rho 0}}{m}\right) \left(\frac{m^2 - 4m_\pi^2}{m_{\rho 0}^2 - 4m_\pi^2}\right)^{3/2}$$
    - Interference term
    - Gaussian convolution
  - Background function for Bethe-Hietler:

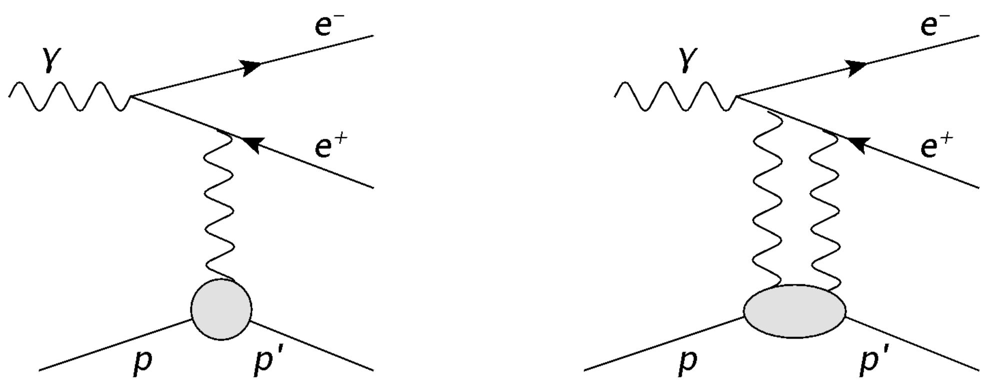
    1: Monte Carlo GiBUU form

    2: Third-order Polynomial

2^{nd} Order Born Corrections

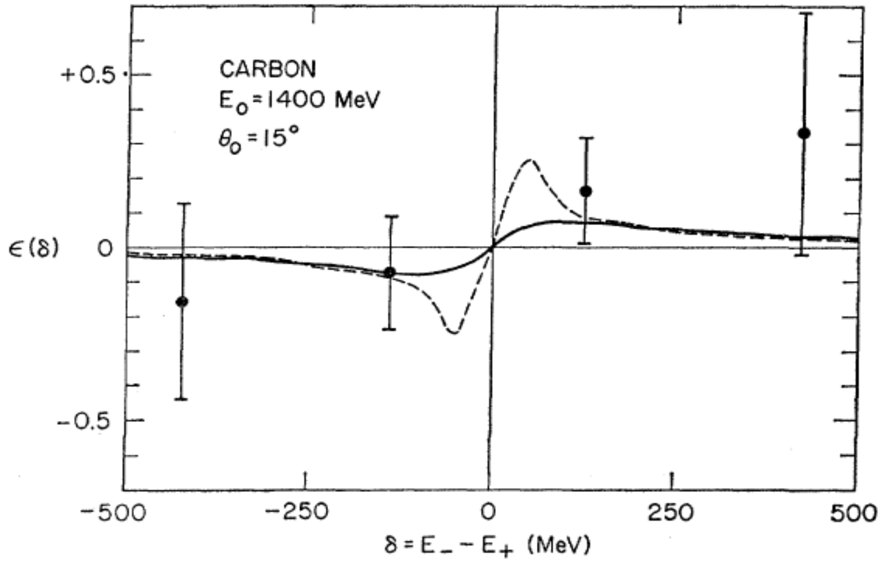
- In leptonic pair photoproduction, the 2^{nd} order Born contributions can be accessed through asymmetric detector acceptance between electrons and positrons.
- $N_+(\delta)$ {or $N_-(\delta)$ } is the rate of positrons {or electrons} with identical and opposite angle of the electron pair, but have an excess momentum of δ.

$$\epsilon(\delta) = \frac{N_+(\delta) - N_-(\delta)}{N_+(\delta) + N_-(\delta)}$$



First Order

Second Order



Brodsky, and Gillespie, Phys. Rev. V173 N4 **1968**