HADRON 2013 in Nara

November 4th (Mon) - 8th (Fri), 2013
Nara Prefectural New Public Hall, Nara, Japan

A Study of the ρ-ω Interference in the e^+e^- decay channel from $\gamma p \rightarrow e^+e^-X$

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

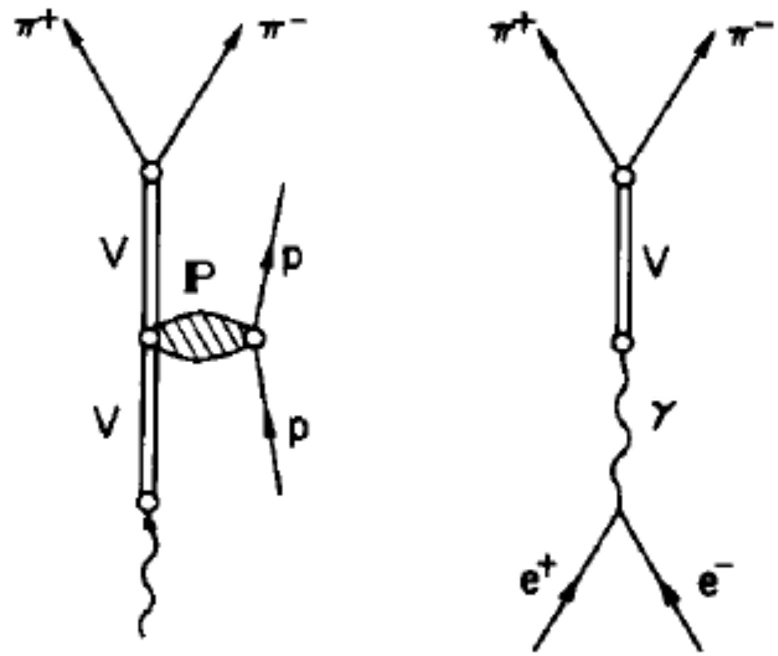
Brief history of ρ−ω interference
Motivation for studying ρ−ω interference on the proton
The g12 experiment in CLAS
Data reduction and analysis
Results and outlook

1 Temple University, Philadelphia, PA.
2 University of Iowa, Iowa City, IA.
3 Canisius College, Buffalo, NY.
4 Thomas Jefferson National Accelerator Facility, Newport News, VA.

A brief history of ρ-ω interference.

- Quantum interference between the ρ and ω mesons was first proposed by S. Glashow (in 61) and became useful interpreting $\rho-\omega$ mass spectra reconstructed from detected pions in particle experiments of the 1960's.

- Results from e^+e^- annihilation required the study of the interference in both $\pi^+\pi^-$ and e^+e^- decay channels.



A brief history of ρ-ω interference.

The interference between identical decay states can be seen in the overlapping mass distributions as a "sharp dip" or a "shoulder".

$\gamma p \to p\pi^+\pi^-$

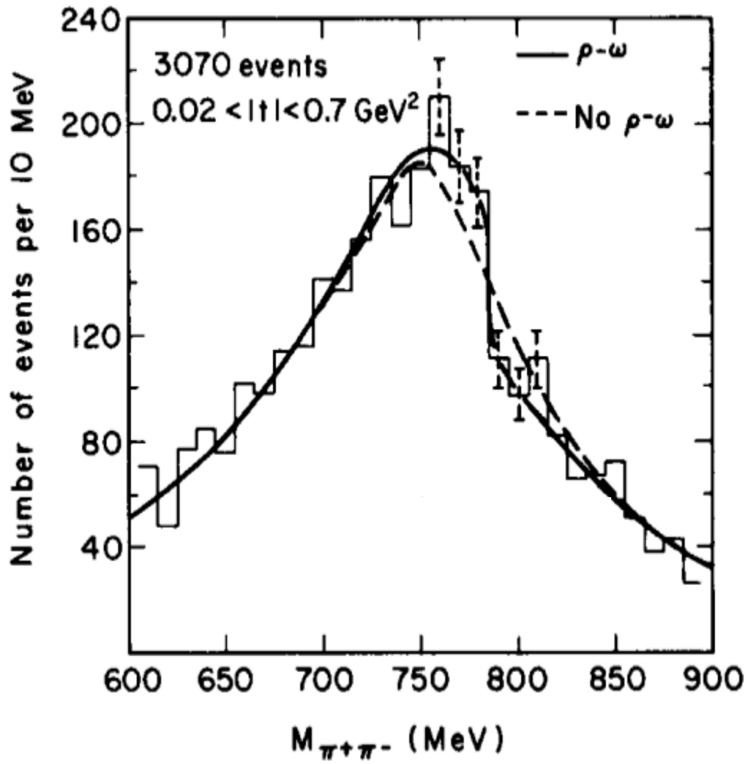
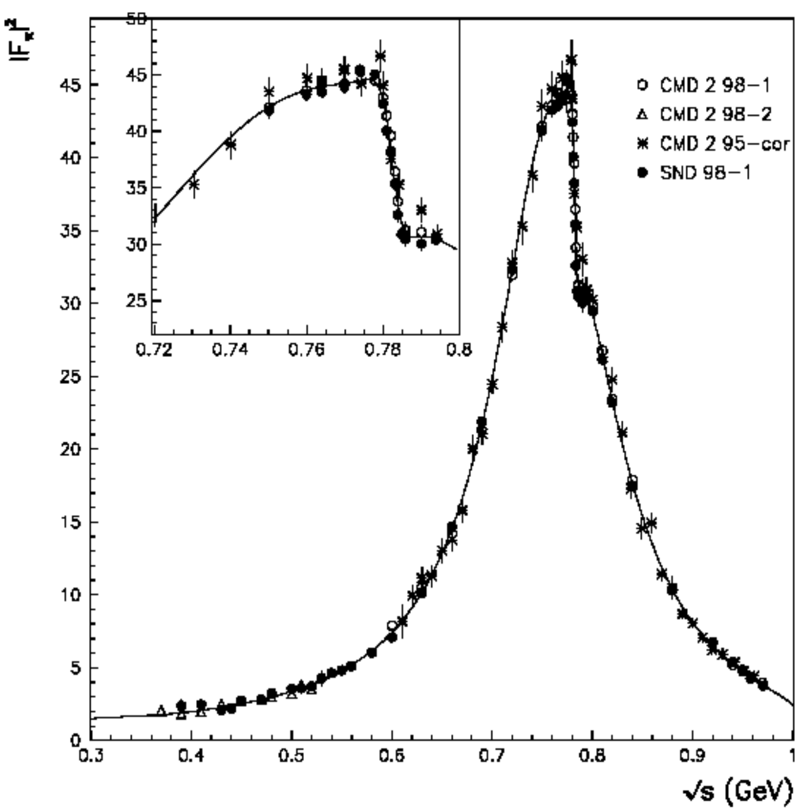


Fig. 2. The $\pi^+\pi^-$ mass distribution for events of the reaction $\gamma p \to \pi^+\pi^- p$. The curves give the results of maximum-likelihood fits with (———) and without (-----) $\rho^0 - \omega$ interference.

K.C. Moffeit *et al*, Nucl.Phys.B29 (1971)

$e^+e^- \to \pi^+\pi^-$



Benayounet et al., Eur.Phys.J.C72, (2012)

Photoproduction and the hadronic decay channel.

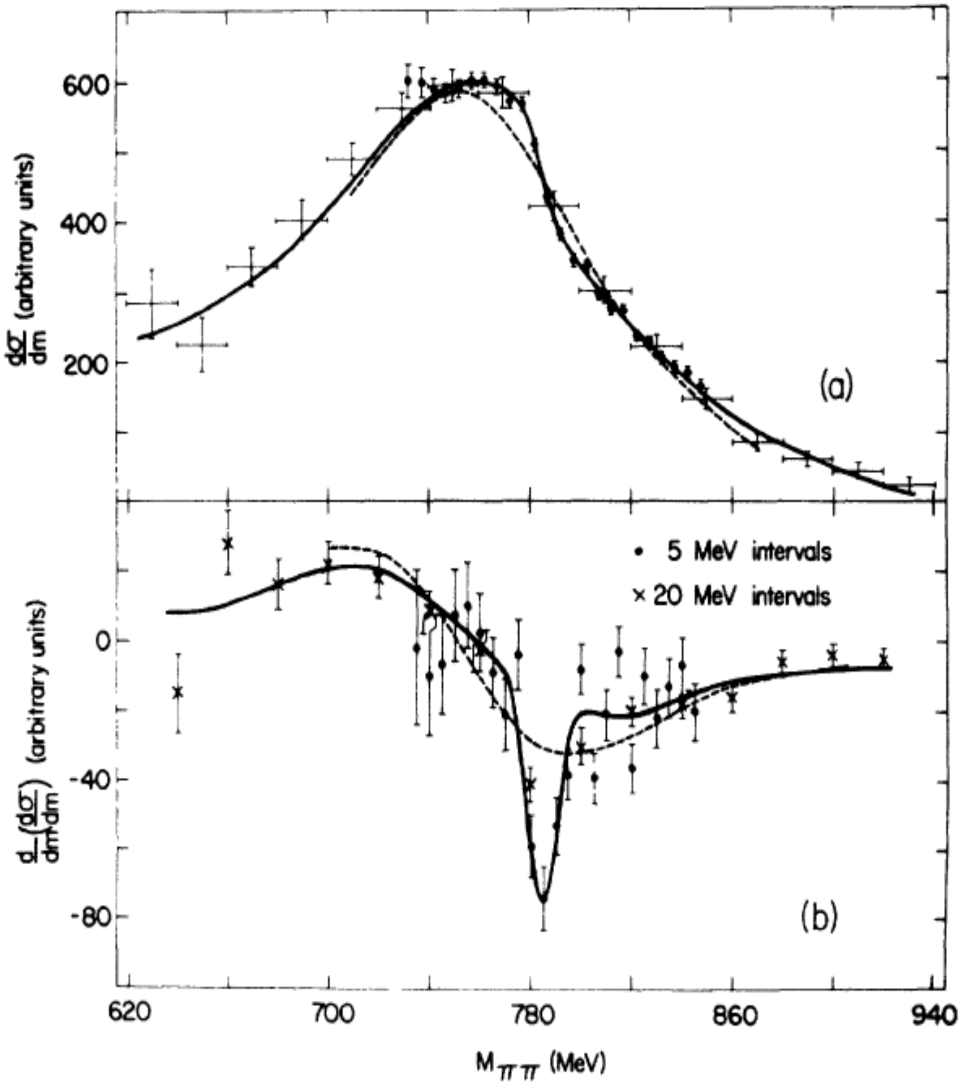


FIG. 2. (a) Mass spectrum and (b) first derivative of the mass spectrum of the π pairs photoproduced from carbon. The solid and dashed curves are fits with and without ρ^0–ω interference.

$\gamma A \rightarrow \pi^+\pi^- A$ A=C, Al, Pb

$$\phi_{\rho\omega} = (63 \pm 16)^\circ$$

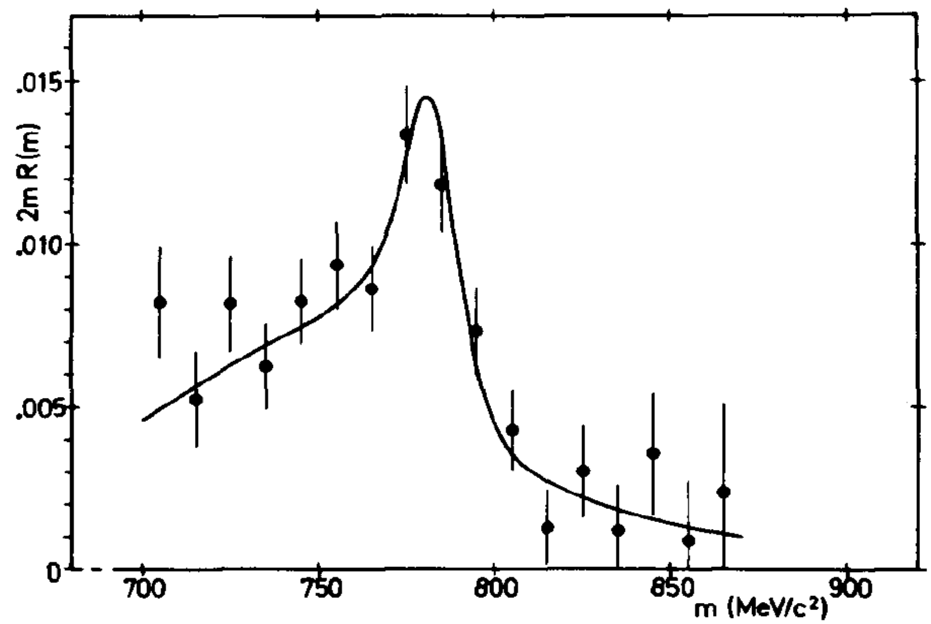
Very little change with A

H. J. Behrend et al, Phys Rev Lett 27 (1971) 61

Photoproduction and the leptonic decay channel.

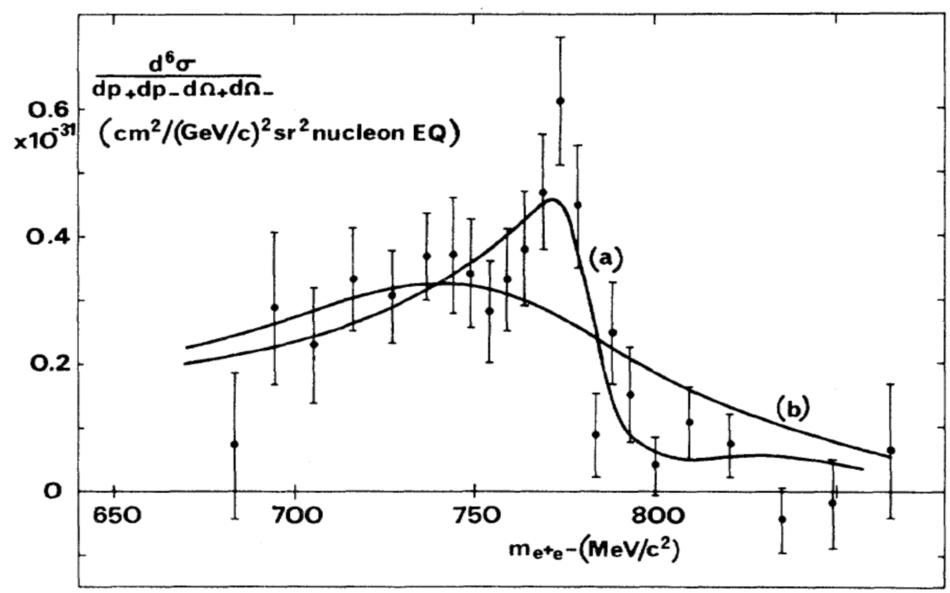
- Two experiments:
  - Alvensleben *et al.*, Nucl. Phys. B25 (1971):
    - $\gamma Be \to e^+e^-(X)$
    - Published interference phase:

$$\boxed{\phi_{\rho\omega} = (41 \pm 20)^\circ}$$



  - Biggs *et al.*, Phys. Rev. Lett. 24 (1970):
    - $\gamma C \to e^+e^-(X)$
    - Published interference phase:

$$\boxed{\phi_{\rho\omega} = (100^{+38}_{-30})^\circ}$$



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Different phase angle

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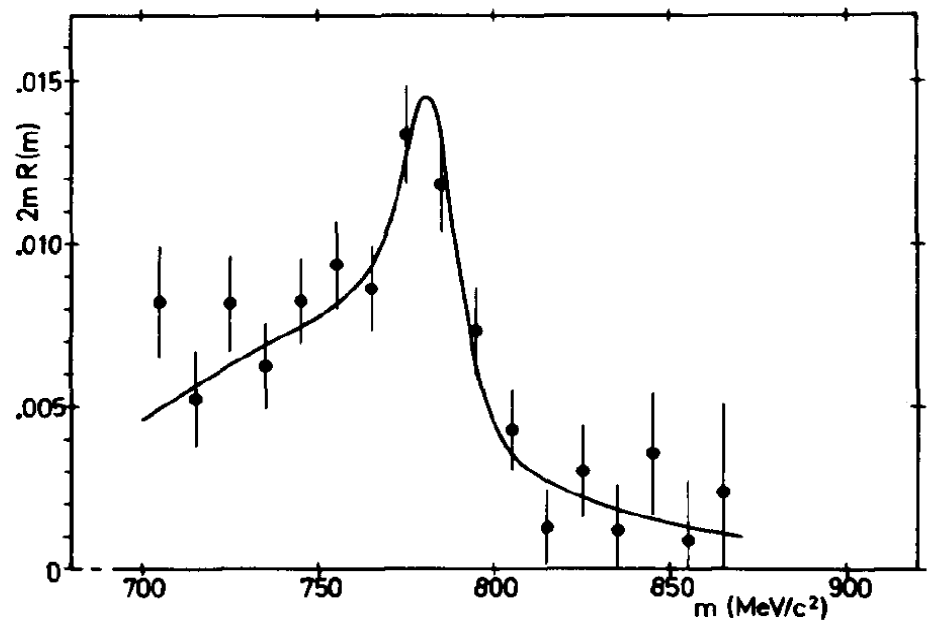

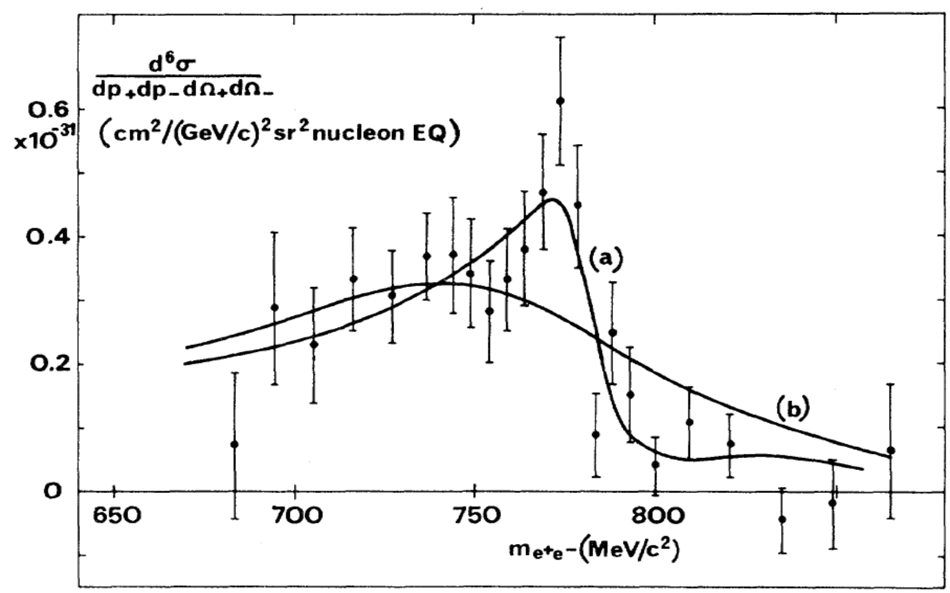

Photoproduction and the leptonic decay channel.

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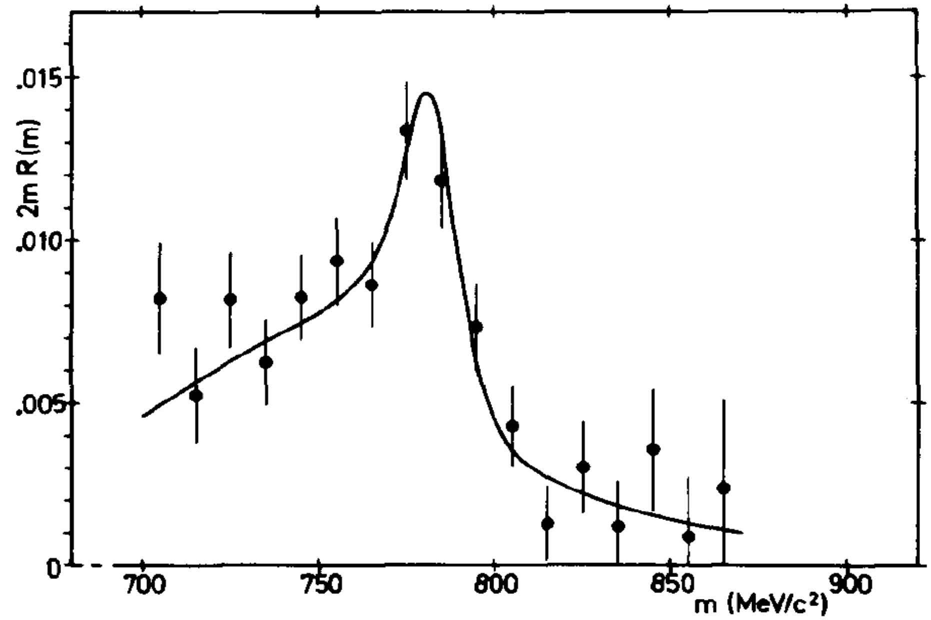
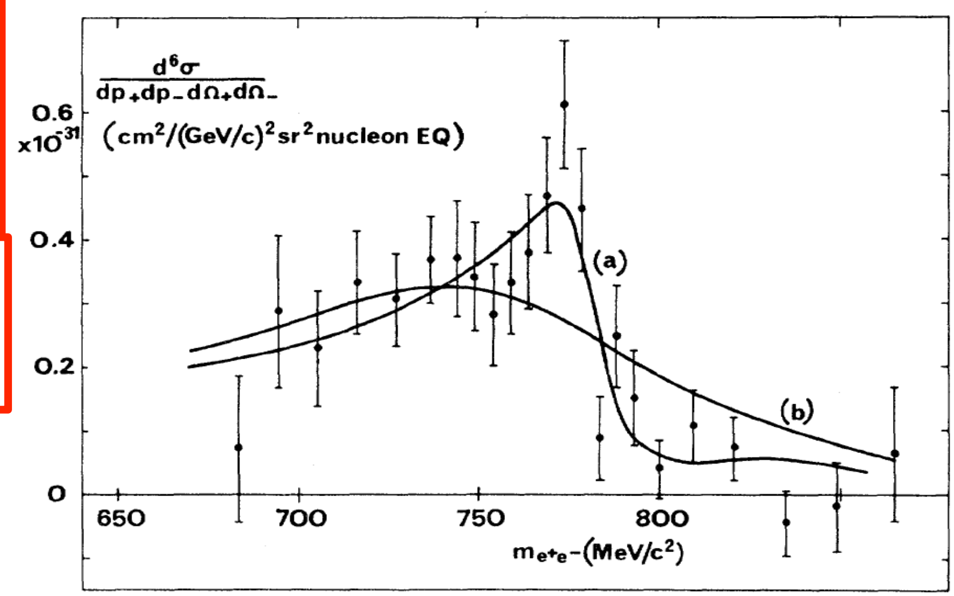
$$\frac{Dm_\rho^4}{m^4}\left|\frac{1}{m_\rho^2-m^2-im_\rho\Gamma_\rho}+\frac{g_\rho^2}{g_\omega^2}\frac{m_\omega^2}{m_\rho^2}\frac{|R|e^{i\phi}}{m_\omega^2-m^2-im_\omega\Gamma_\omega}\right|^2$$

different interference / fit formalism!!

  - Biggs *et al.*, Phys. Rev. Lett. 24 (1970):
    - $\gamma C \rightarrow e^+e^-(X)$

$$\frac{D}{m^2}\left|\frac{1}{m^2-m_\rho^2+im_\rho\Gamma_\rho}+\left(\frac{m_\omega}{m_\rho}\right)^4\frac{\eta}{9}\frac{e^{i\phi}}{m^2-m_\omega^2+im_\omega\Gamma_\omega}\right|^2$$





$\rho-\omega$ interference phase in photoproduction experiments

Group	Data Sample	$\phi_{\rho\omega}$
Daresbury ('70) **C**	$\pi^+\pi^-$	$(104.0 \pm 5.1)^\circ$
Rochester-Cornell ('71) **Al, Fe,Pb**	$\pi^+\pi^-$	$(63 \pm 16)^\circ$
DESY-MIT ('71) **Be**	$\pi^+\pi^-$	$(96 \pm 15)^\circ$
Daresbury ('70) **C**	e^+e^-	$(100^{+38}_{-30})^\circ$
DESY-MIT ('70) **Be**	e^+e^-	$(41 \pm 20)^\circ$

FOCUS –FERMI LAB ('97) Be **$\mu^+\mu^-$** **$(184.5 \pm 3.5 \pm 3.1)^o$**

Results quite inconsistent → photoproduction phase in leptonic decay considered undetermined.

Experimental motivations for our study

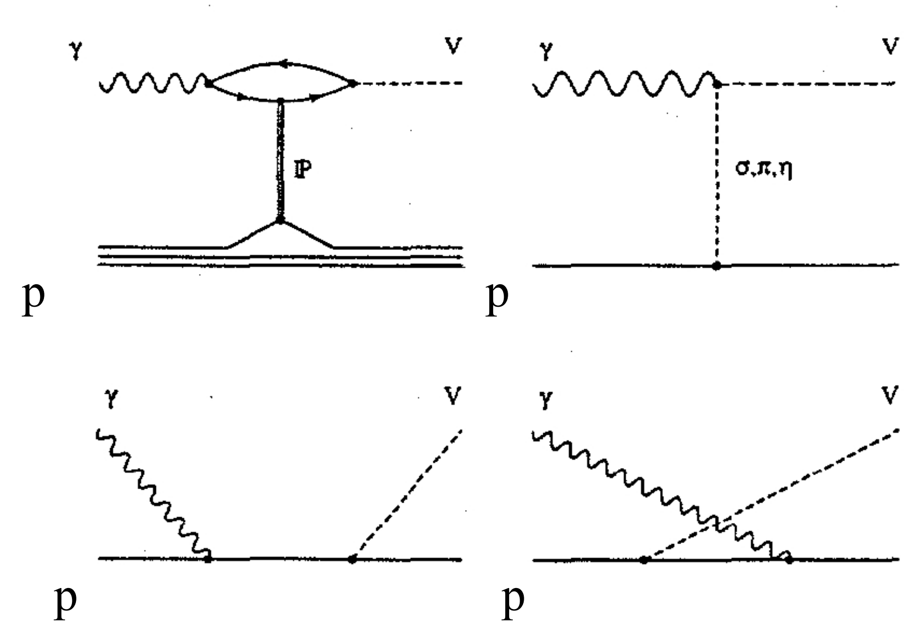
1) Measure a high statistics data set $\gamma p \rightarrow e^+e^-X$ at JLab energies (“baseline” for our studies in nuclei).

2) Extracting the Transparency ratios for the ω (CLAS g7 experiment) → indication for $\rho-\omega$ interference. Not enough statistics.

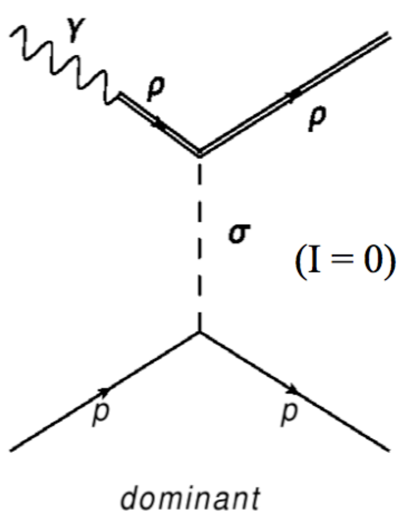
ρ, ω photoproduction on the proton

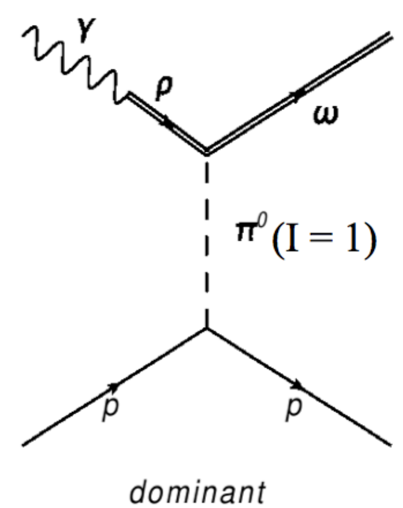
<u>t-channel VM production:</u>

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



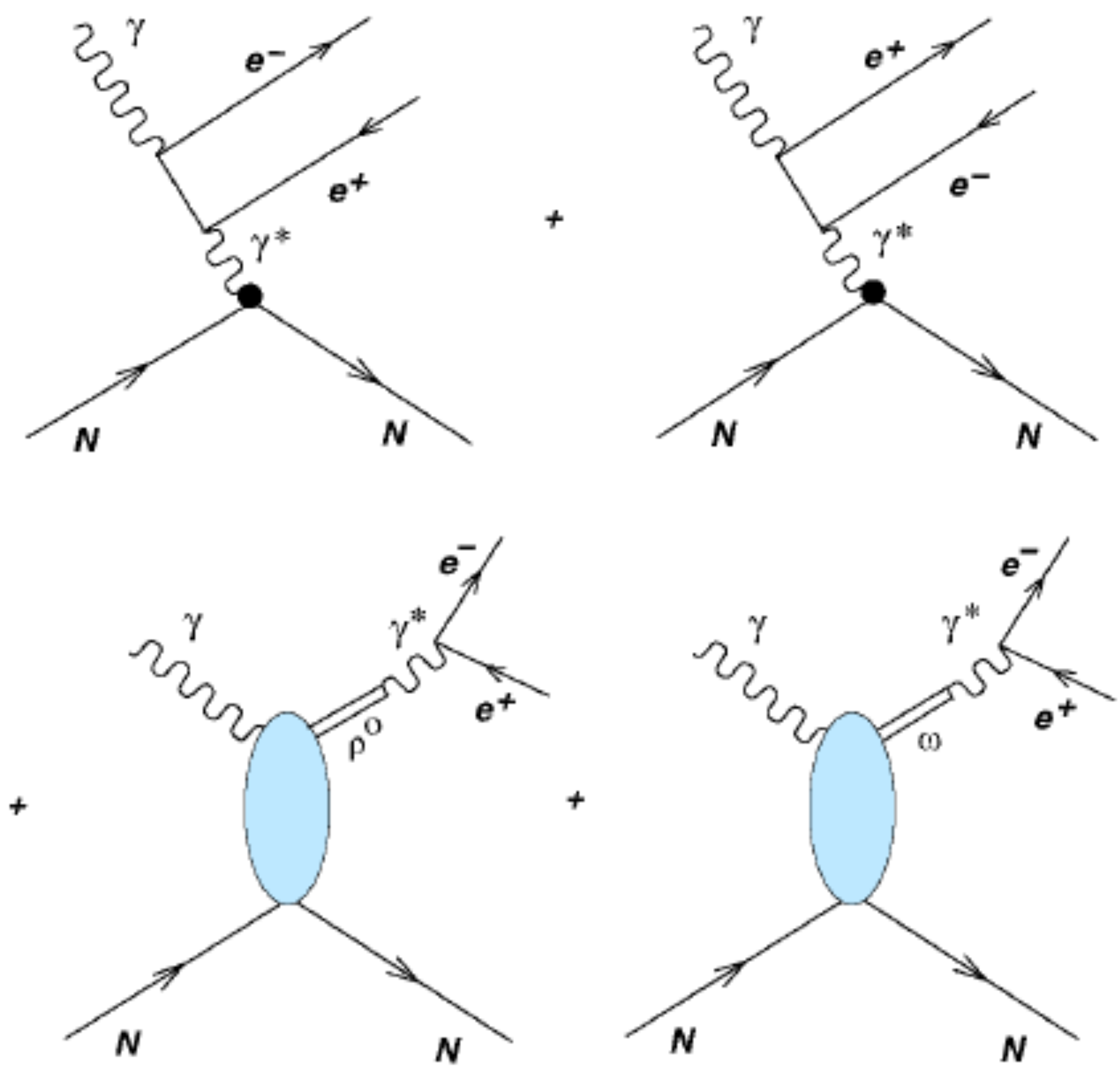
Friman and Soyeur model [NPA600, 477(1996)] at low energies:





The elementary reaction $\gamma p \rightarrow e^+e^-p$

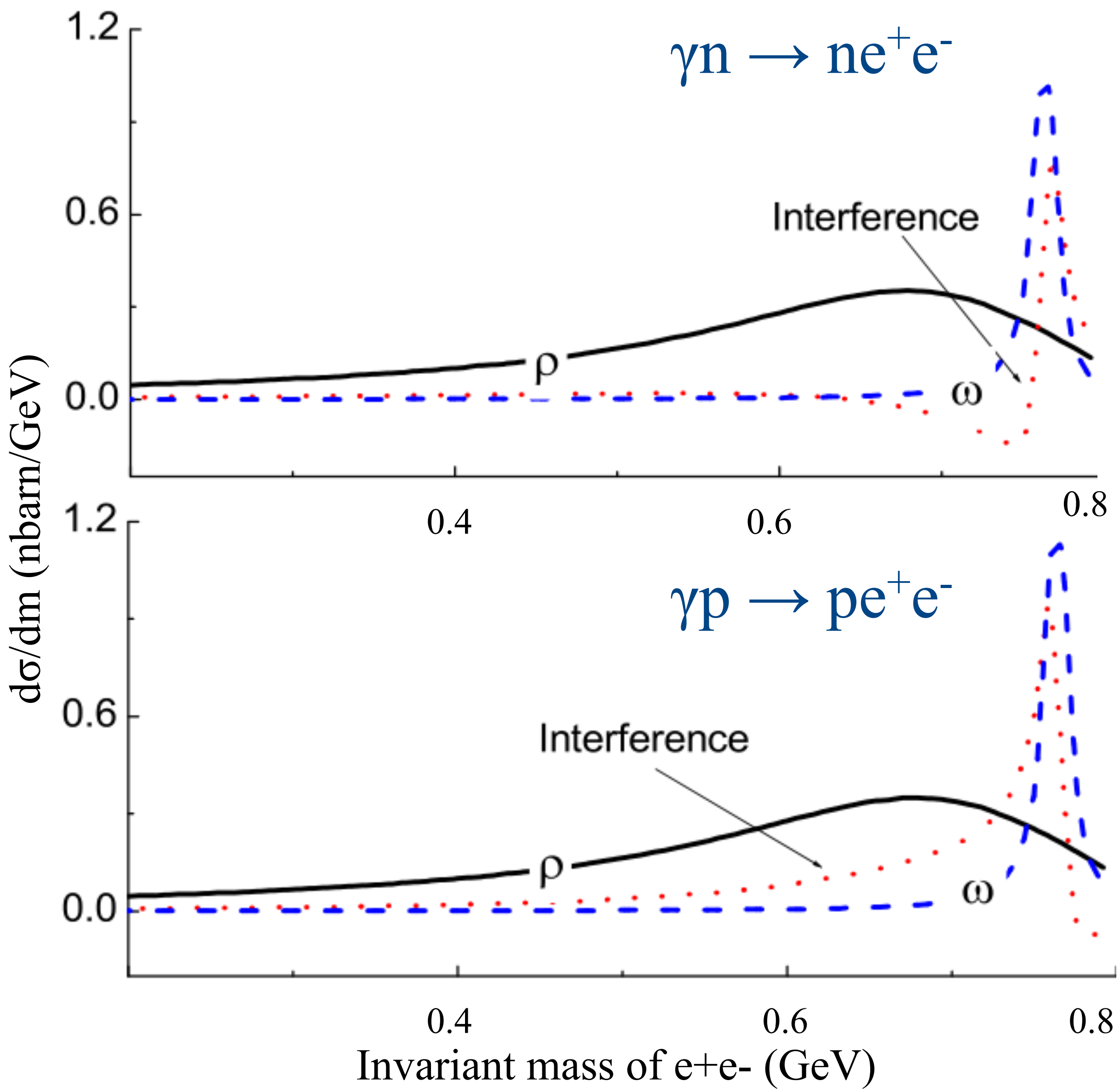
M.F.M Lutz and M.Soyeur, Nucl. Phys. A760 (2005) 85



Bethe–Heitler and vector meson decay contributions to the $\gamma N \rightarrow e^+e^-N$ amplitude.

The elementary reaction $\gamma p \rightarrow e^+e^-p$

M.F.M Lutz and M.Soyeur, Nucl. Phys. A760 (2005) 85



- Calculations predict the interference pattern to change depending on the target nucleon:

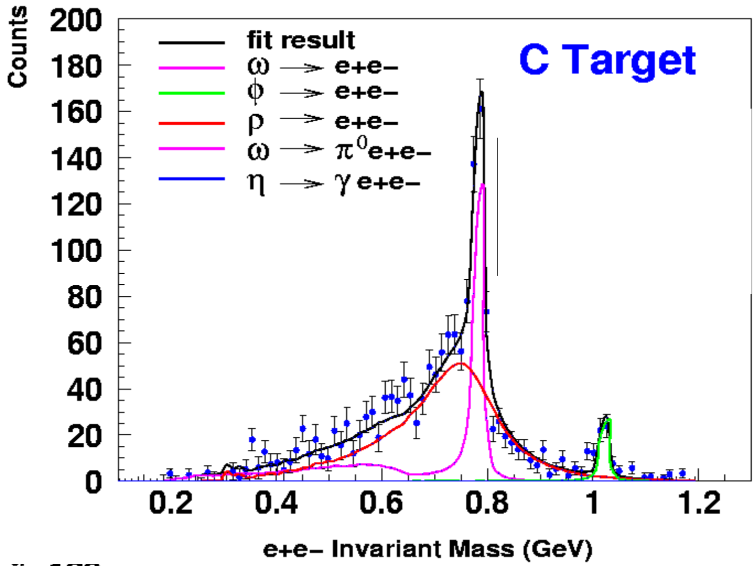
  destructive on n

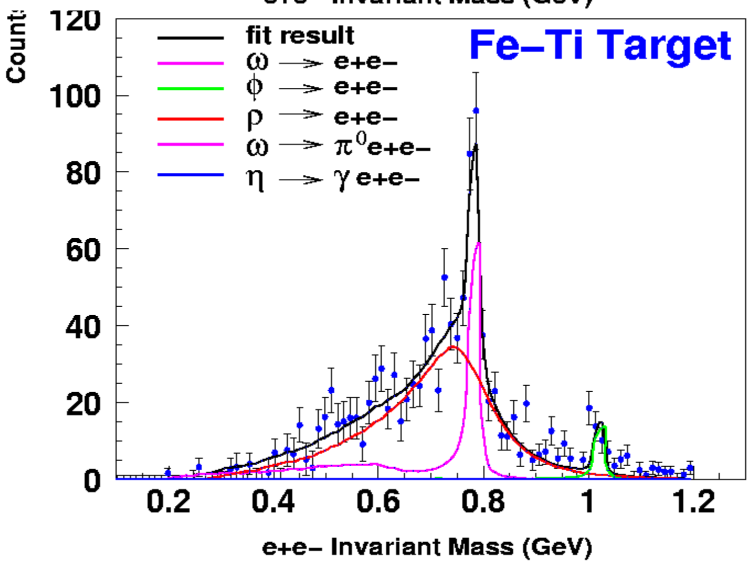
  constructive on p

- The BH-mesons interference is shown to be negligible

JLab g7: Possible $\rho-\omega$ Interference

After Background subtraction, mass spectra mainly ρ , ω and ϕ.





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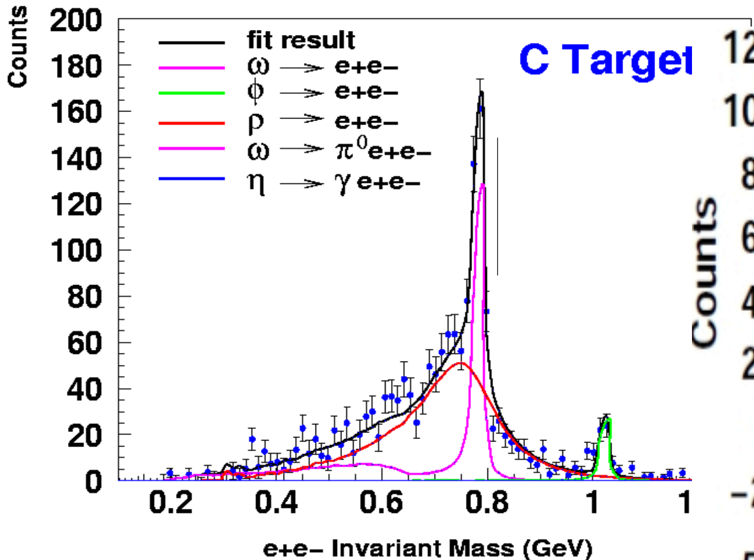

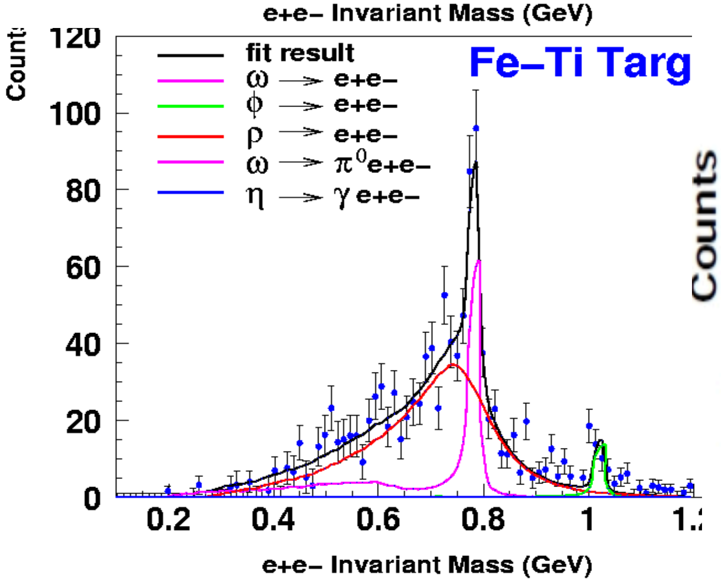

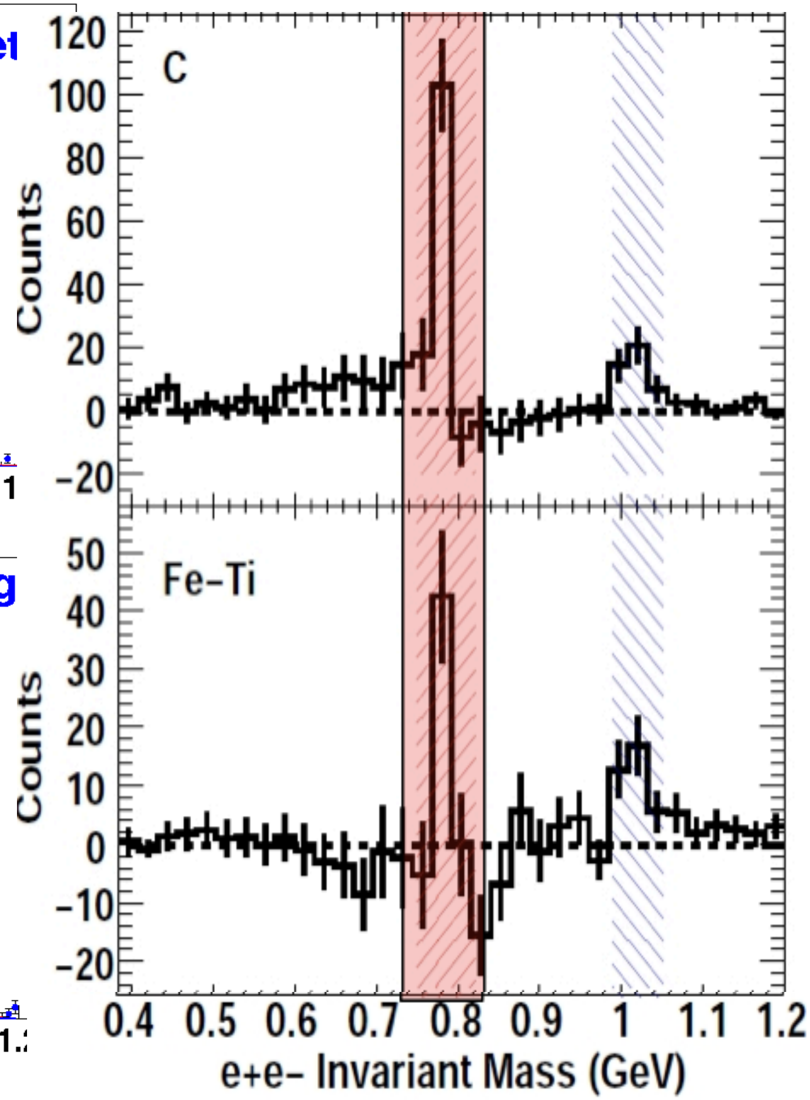

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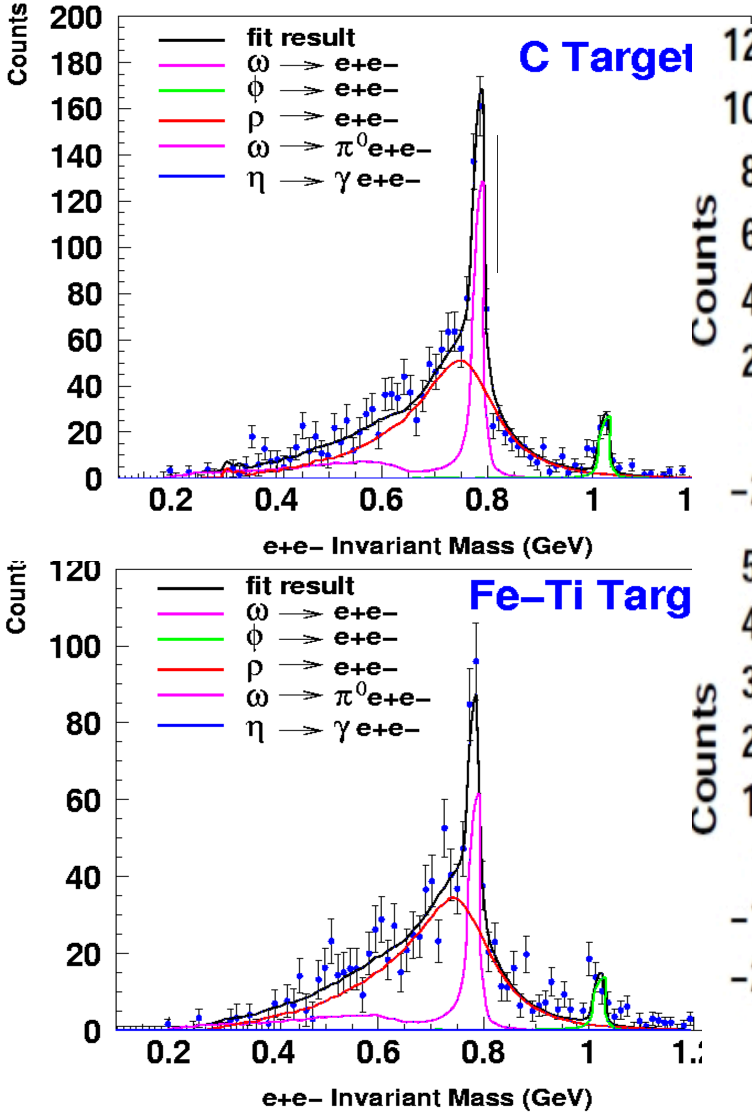

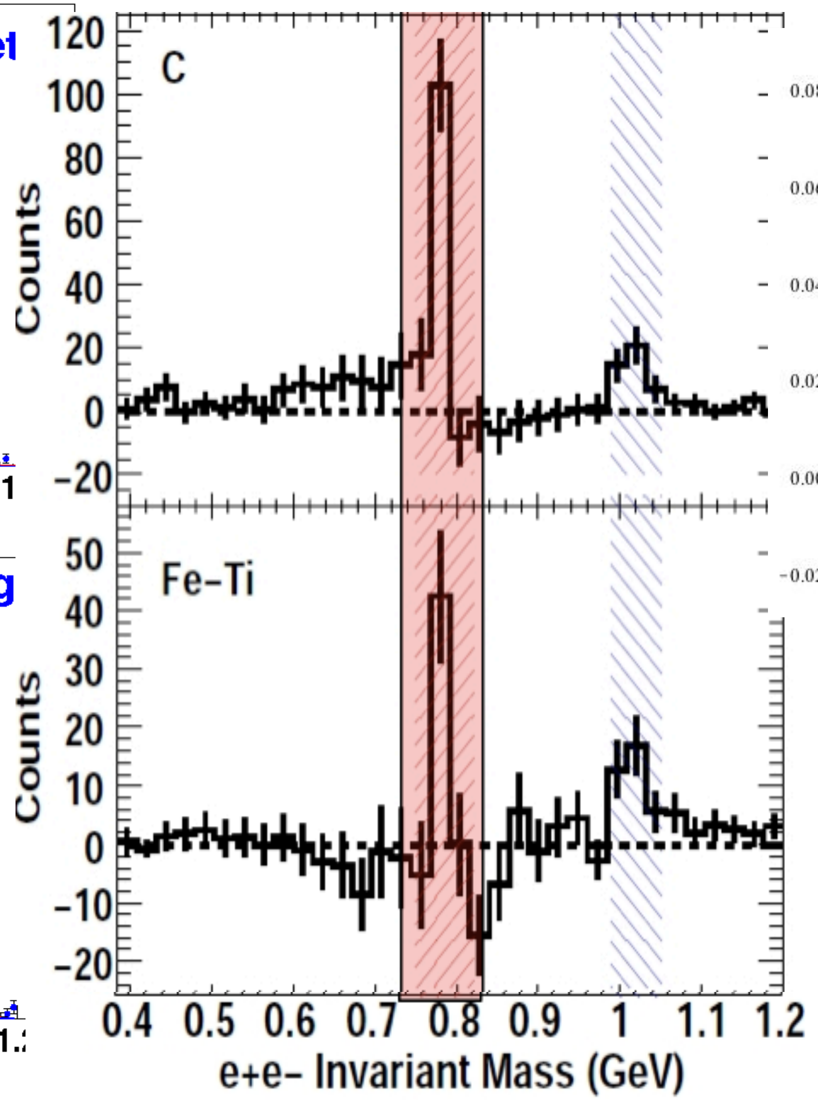

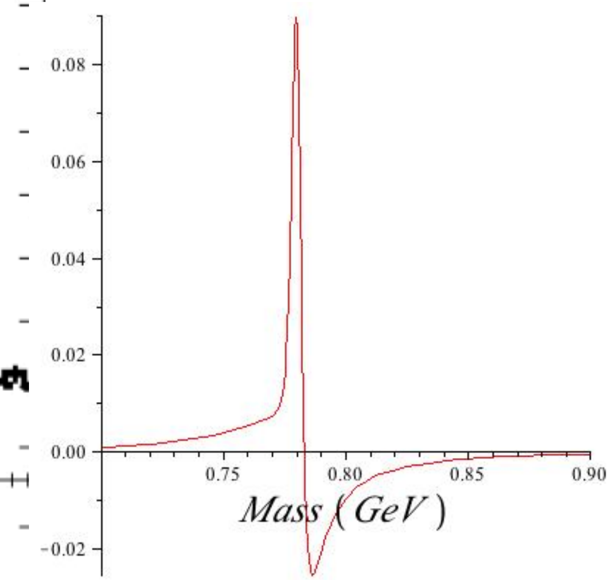

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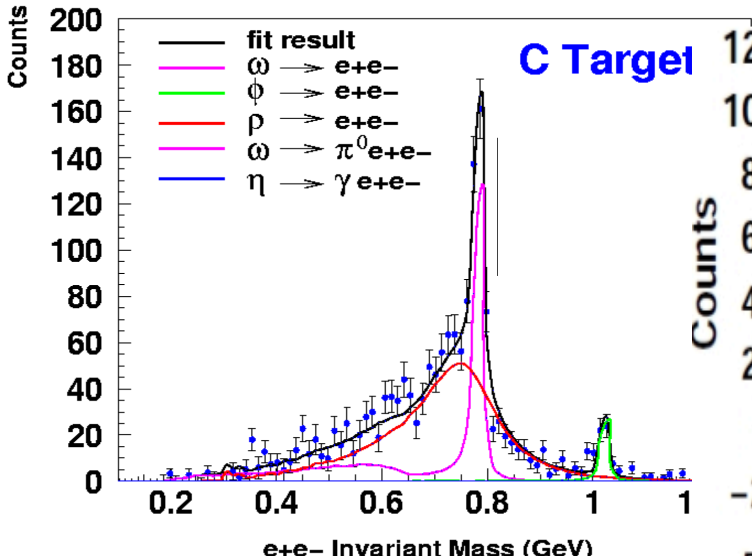
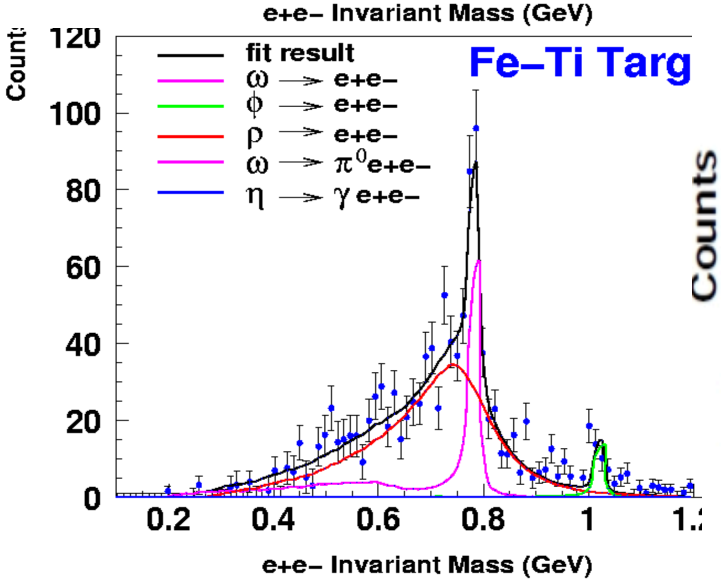
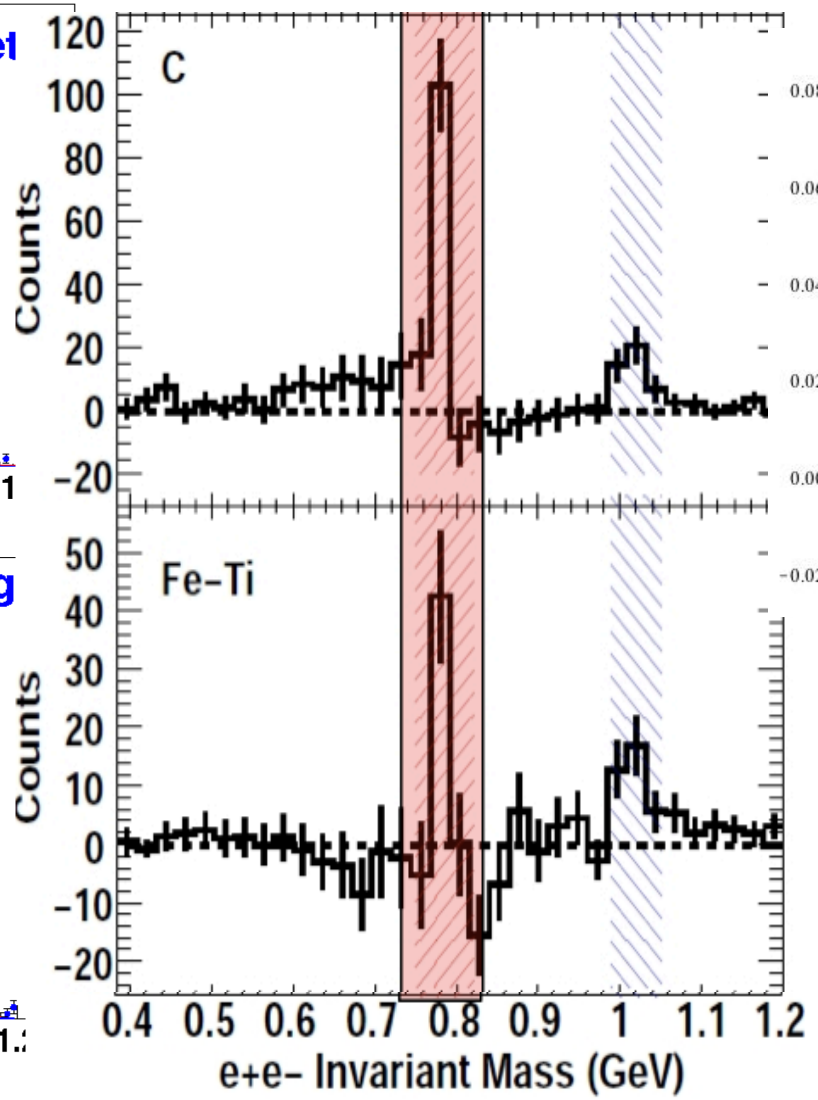
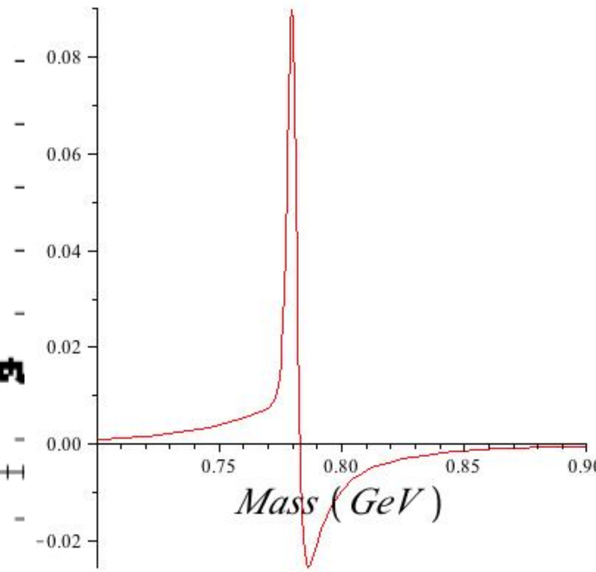


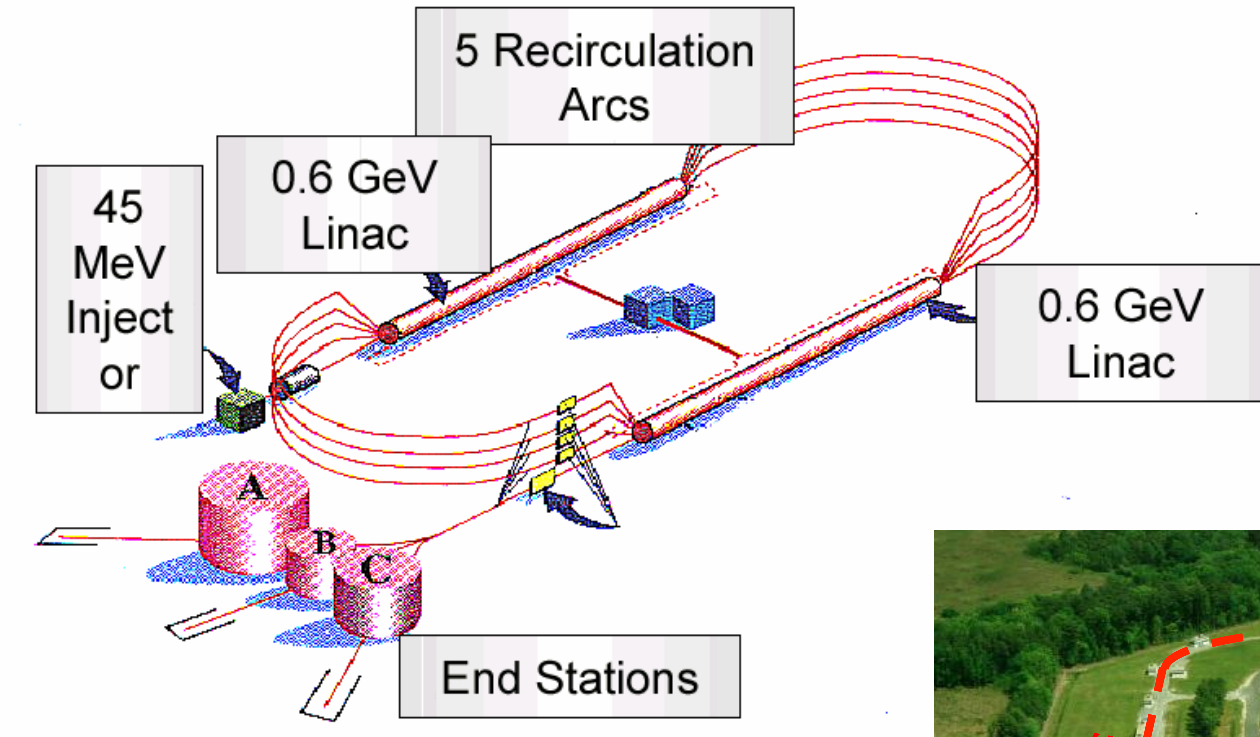




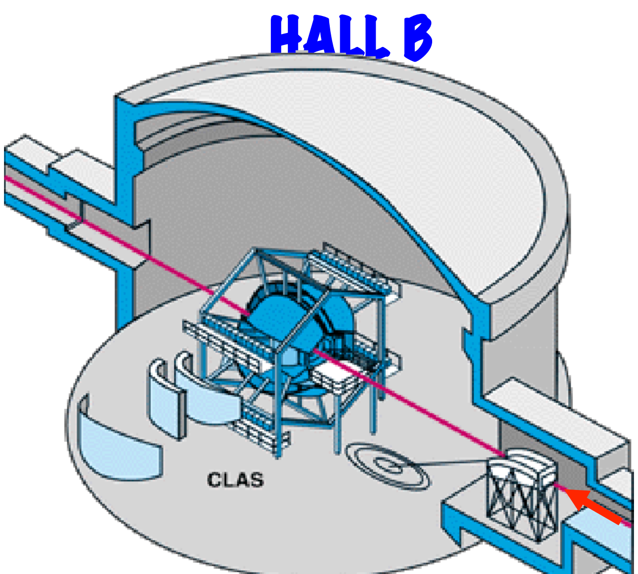


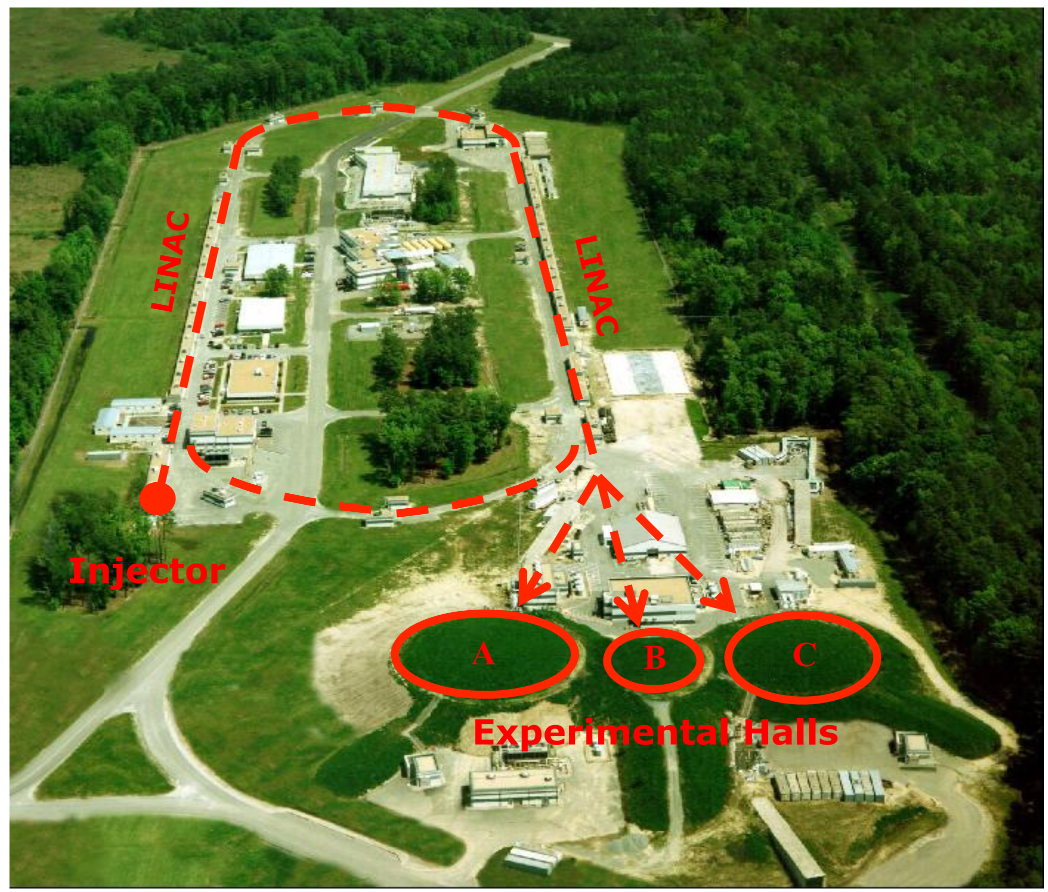
Studying ρ−ω Interference

Jlab"6GeV": The "old" 6 GeV 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

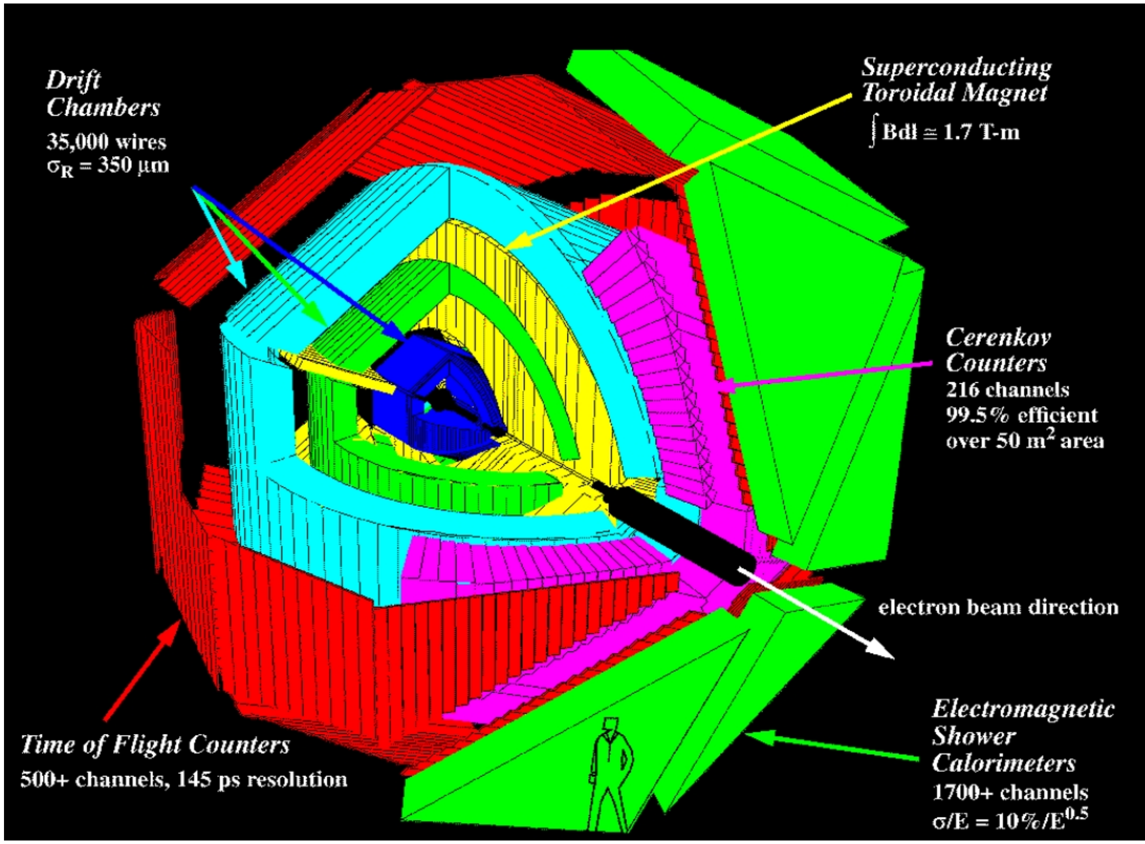




CLAS Experiment g12

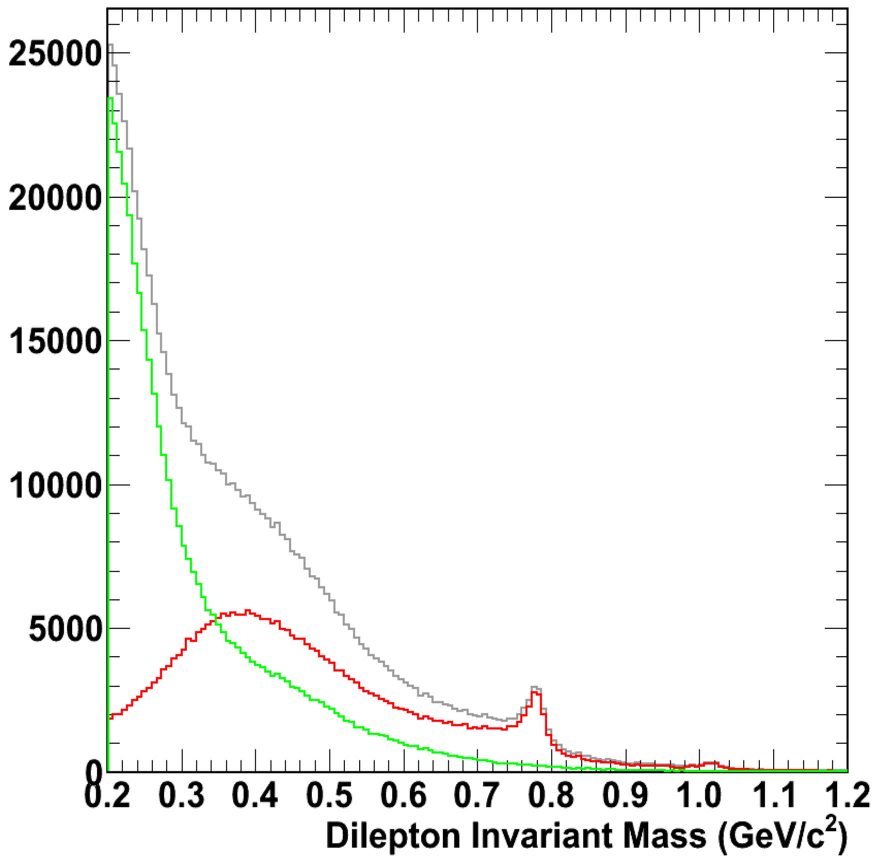
$\gamma\, p \rightarrow e^{+} e^{-} X$ channel, parallel trigger

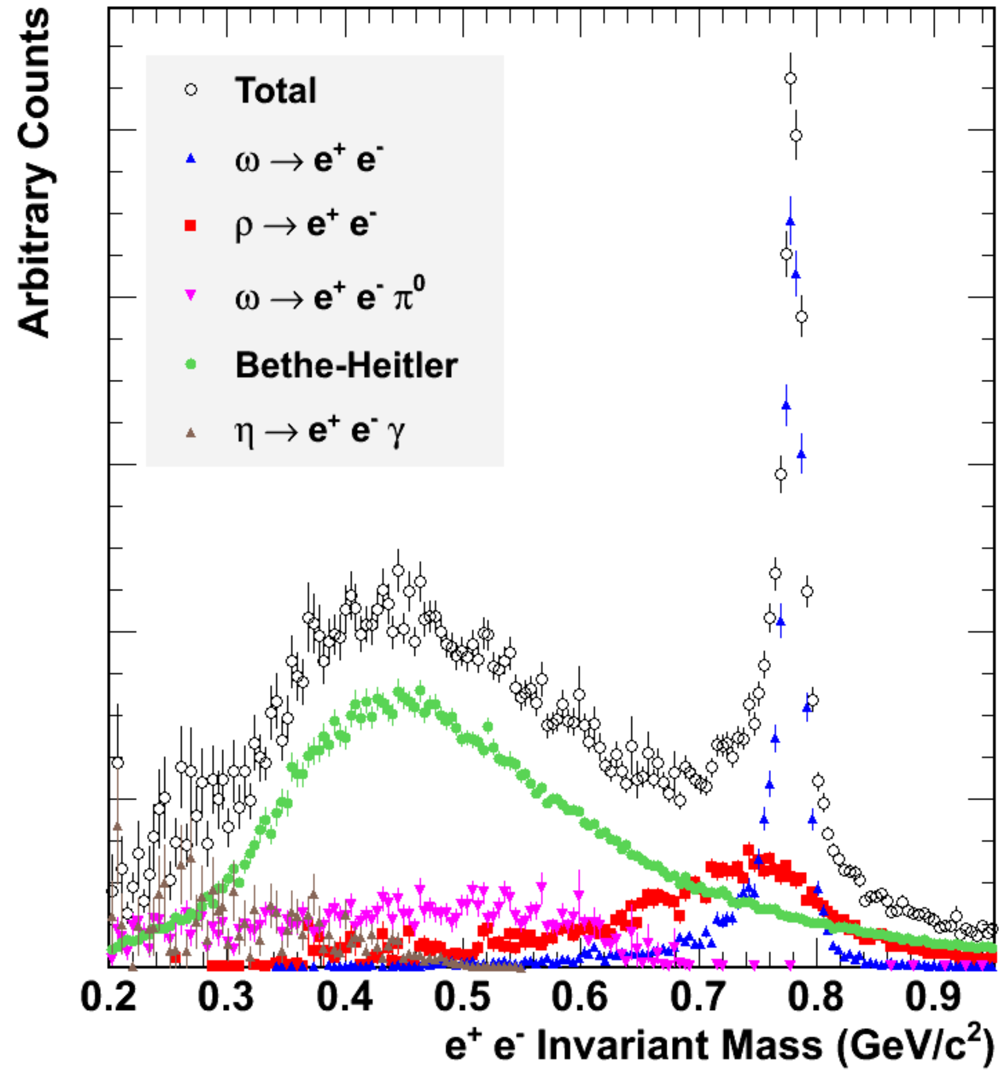
- Hall-B houses the CLAS detector, ideal for photoproduction and lepton identification.
- g12 in CLAS
  - ✓ 44 days of beam
  - ✓ Tagged Photons E_γ [1.1 to 5.5 GeV] incident on a LH_2 target
  - ✓ 26.2 $\times 10^9$ production triggers
    (3 x 10^6 di-lepton triggers)
  - ✓ EC and CC combine to provide an e/π rejection factor better than 10^{-6} for di-lepton pairs.
  - ✓ <u>LH_2 target placed 90 cm upstream</u>



Signal and Background

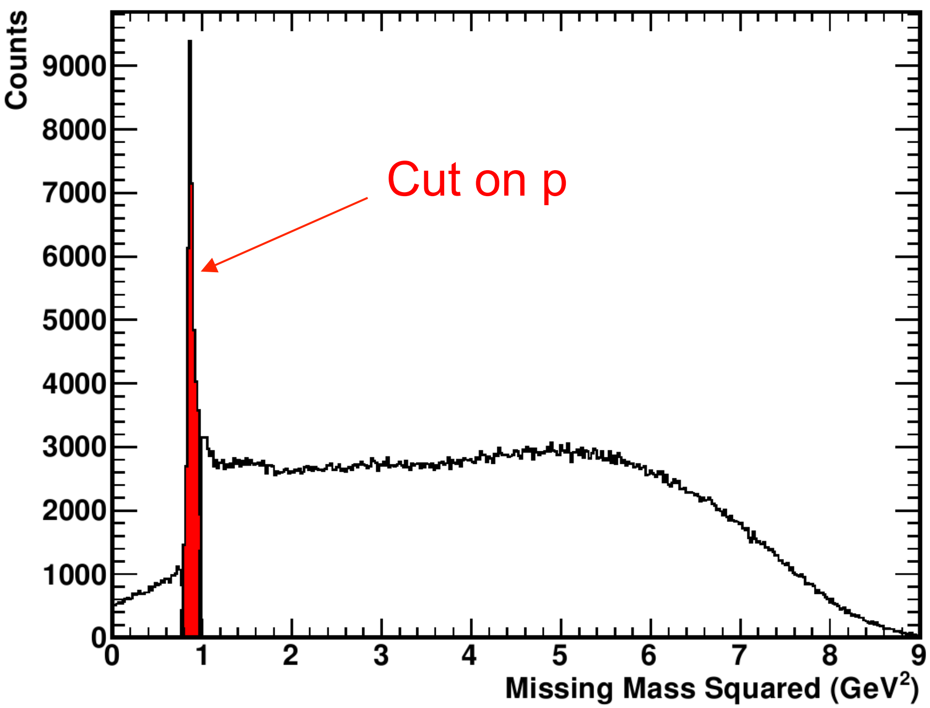
- Looking for $\rho \rightarrow e^+ e^-$ and $\omega \rightarrow e^+ e^-$
  - ✓ Bethe-Heitler is significant and must be accounted for. The upstream location of the target increases the small angle acceptance. (angle cut)



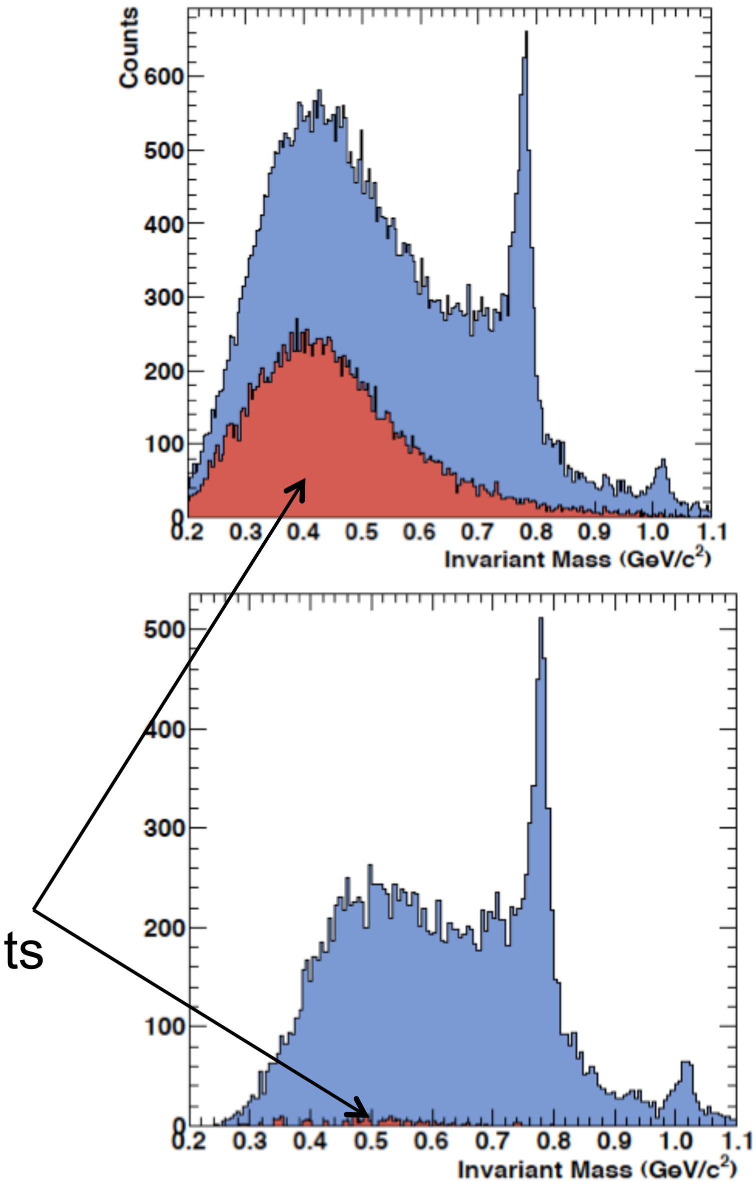


Selecting an Outgoing Proton

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

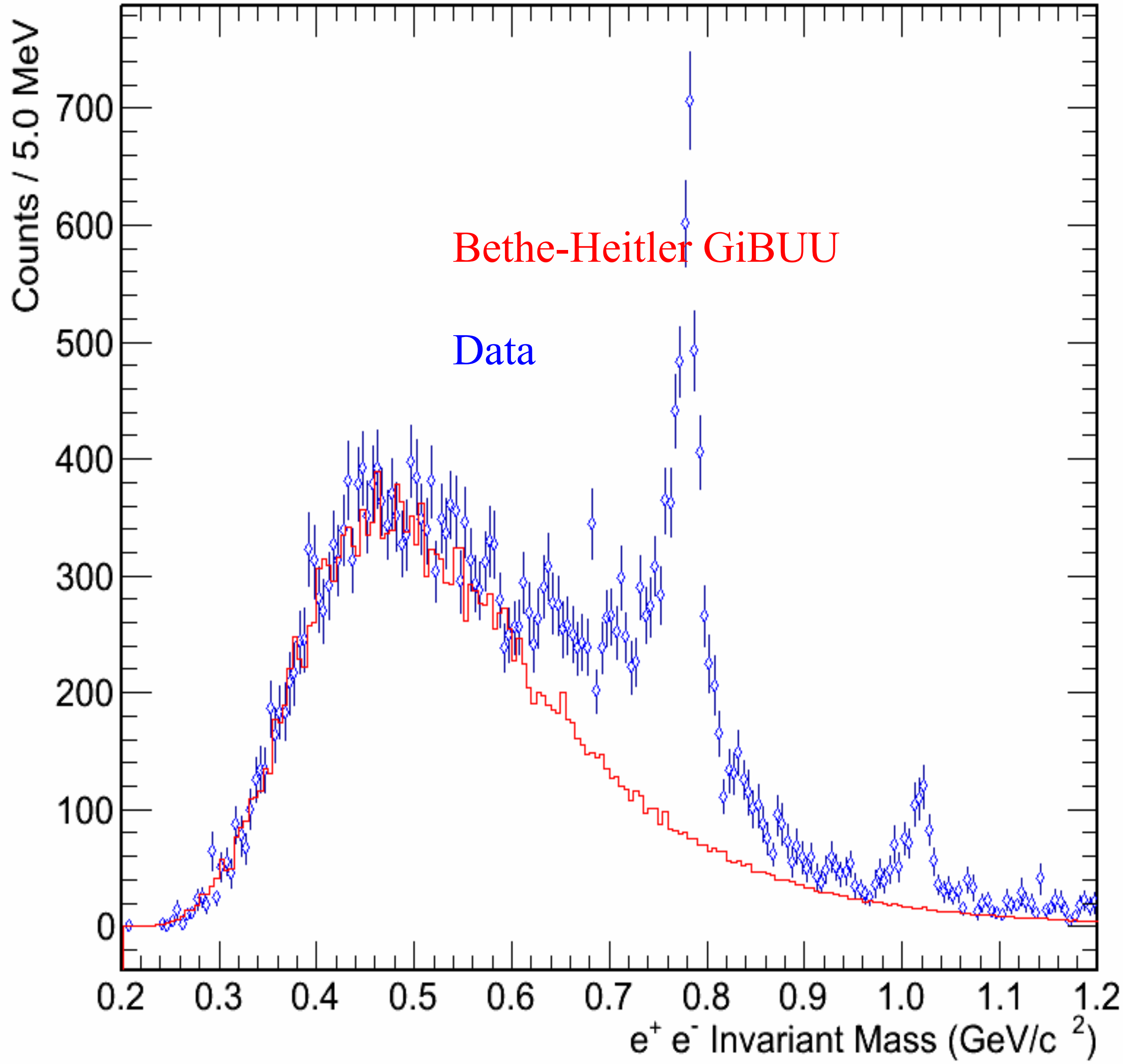


✓ Uncorrelated lepton pairs are also eliminated by tight missing mass cuts on the proton.



BH subtraction

After lepton acceptance correction, missing proton selection, timing, and vertex cuts, the Bethe-Heitler is calculated by GiBUU and subtracted



The ρ-ω invariant mass spectrum is now ready for the fit

Interference Formalism, cont.

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

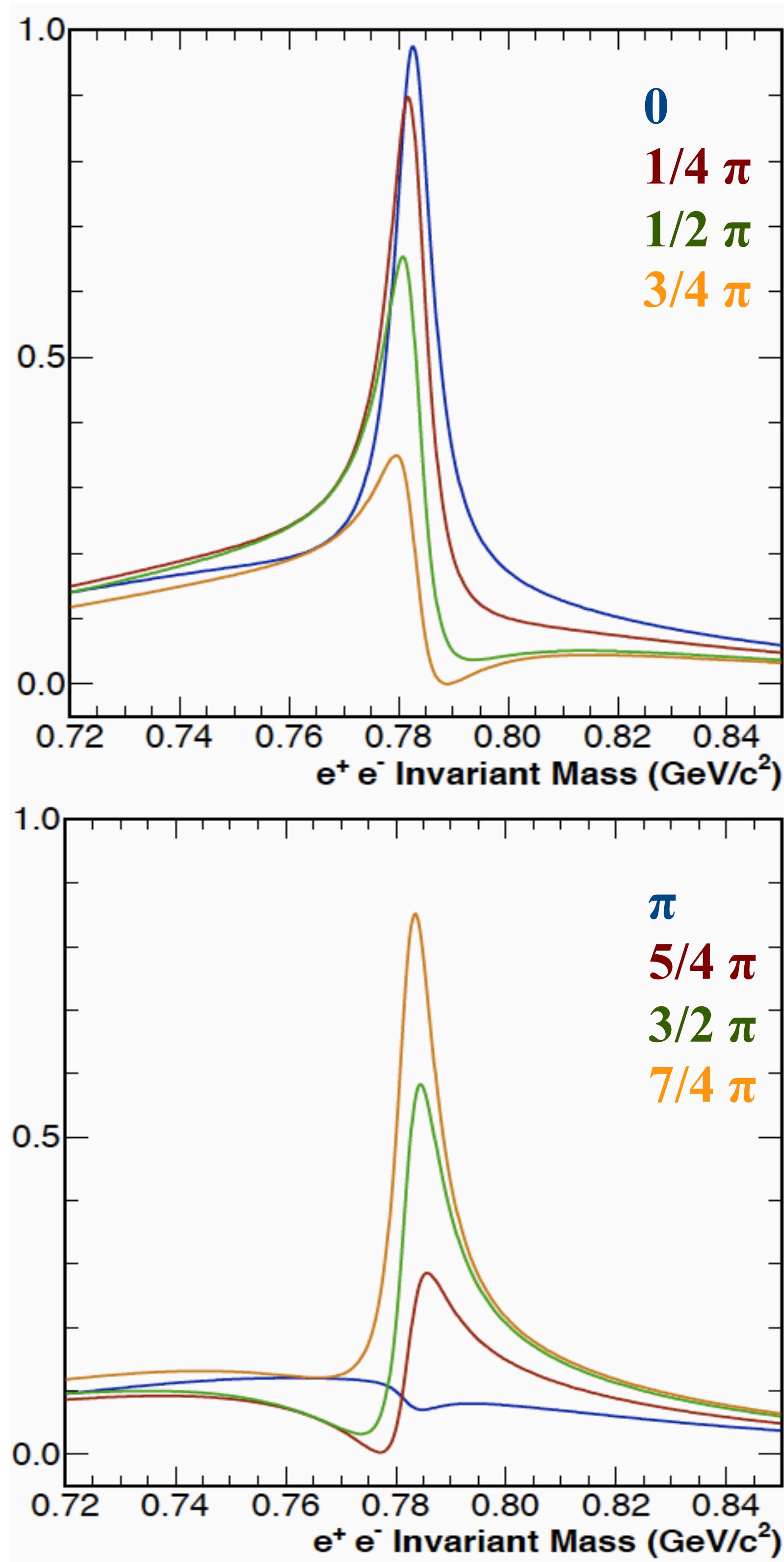
$$1 - ie^{i\phi_\rho} = -\frac{\delta}{M_\rho}\left(\frac{T_\rho A_\omega + T_\omega A_\rho}{T_\omega A_\omega}\right)$$

- 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:

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



Preliminary Results

-Two Relativistic Breit-Wigner functions

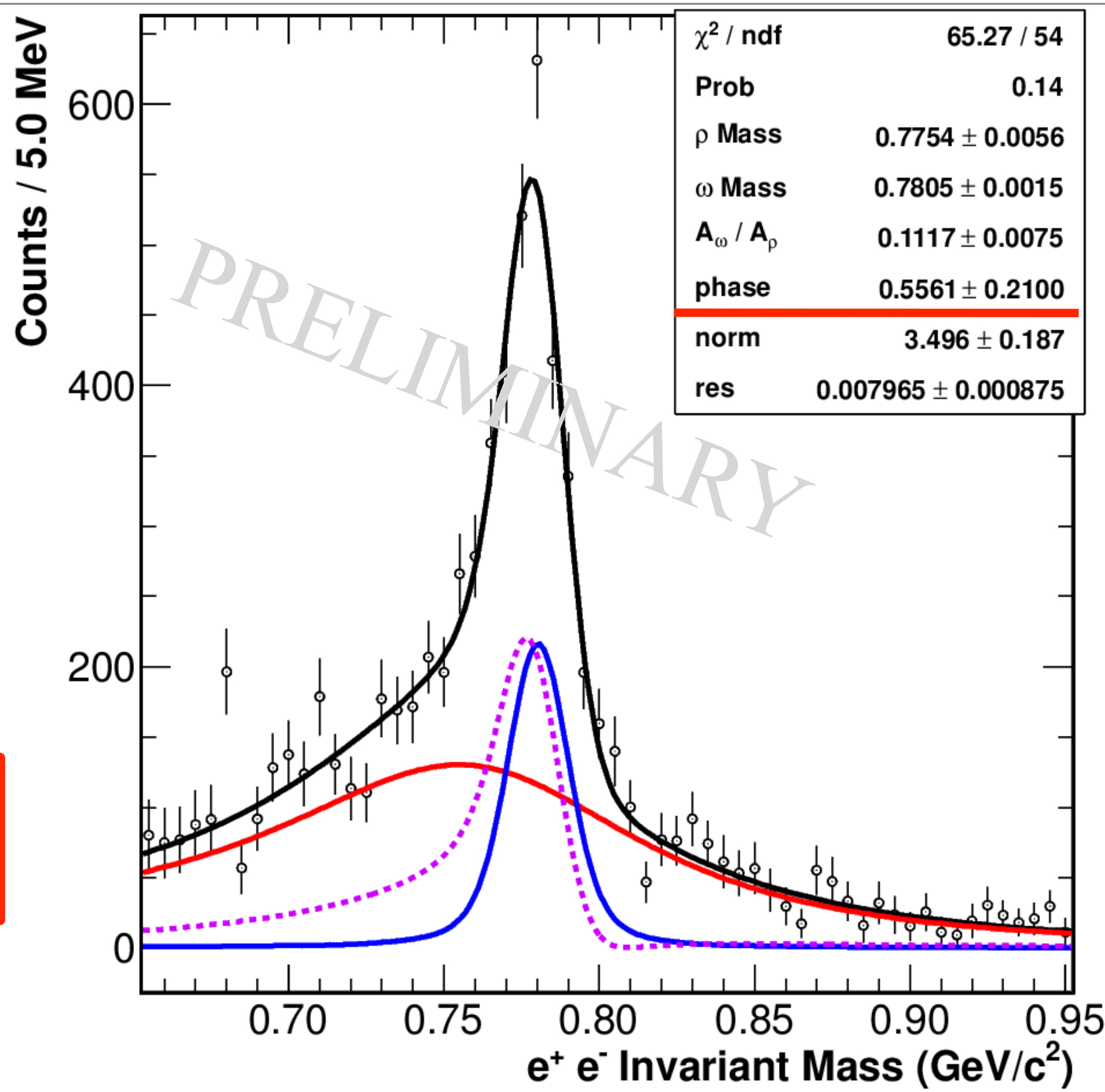
-Interference term

-Gaussian convolution

- The ρ and ω widths are set to the PDG value.
- χ^2/ndf = 1.21
- Interference phase of:

$$\boxed{\phi_{\rho\omega} \;=\; (32 \pm 12)^\circ}$$

Stat uncertainties only



Fits of g12 data using Biggs' function

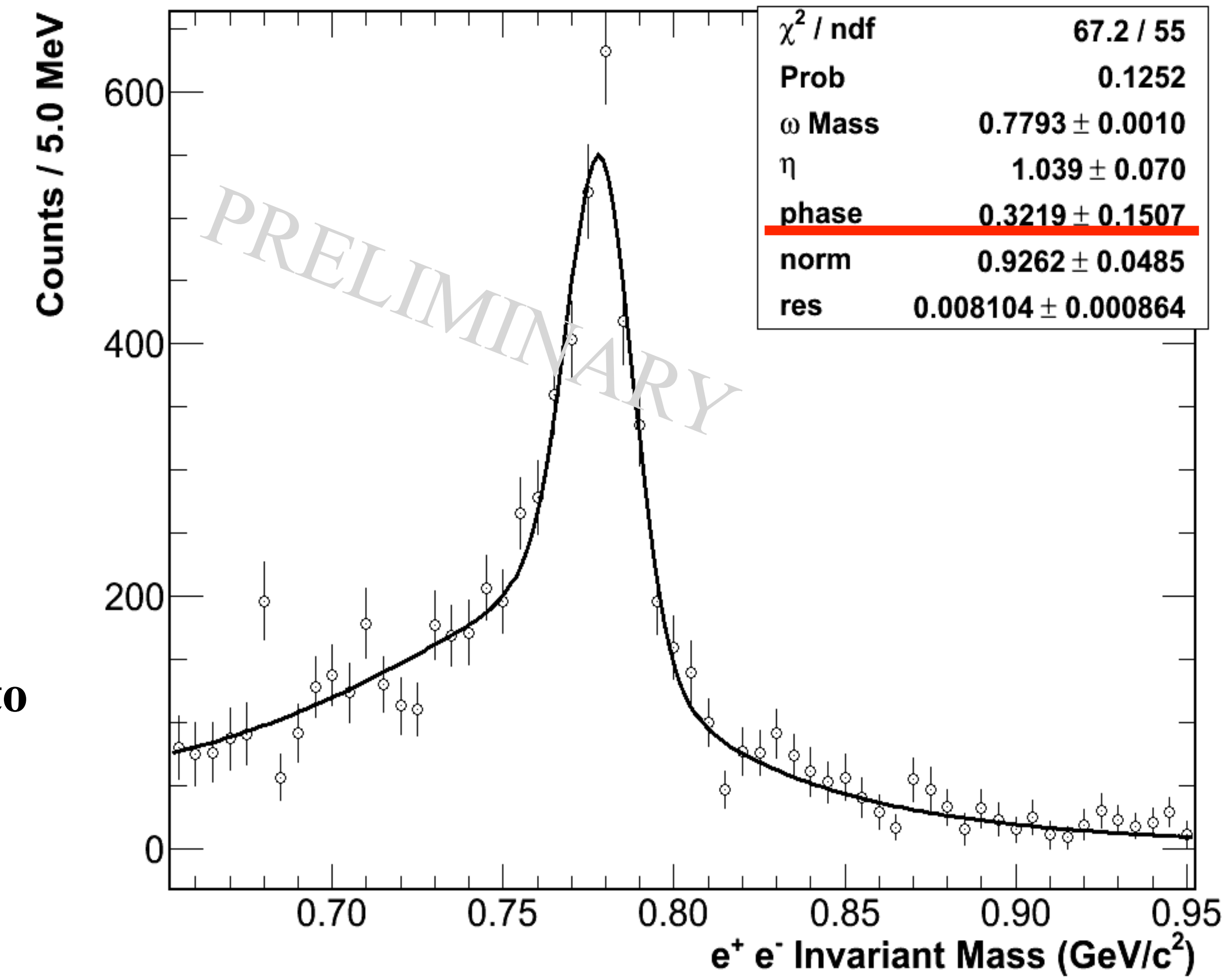
- The ρ and ω widths are set to the PDG value.
- $\chi^2/ndf = 1.22$
- Interference phase of:

$$\boxed{\phi^{H}_{\rho\omega} = (18.5 \pm 8.6)^\circ}$$

This phase on H can be compared to the one measured on C:

$$\phi^{C}_{\rho\omega} = (100^{+38}_{-30})^\circ$$

Biggs Function



Phases are very different. Target dependence?

Summary and outlook

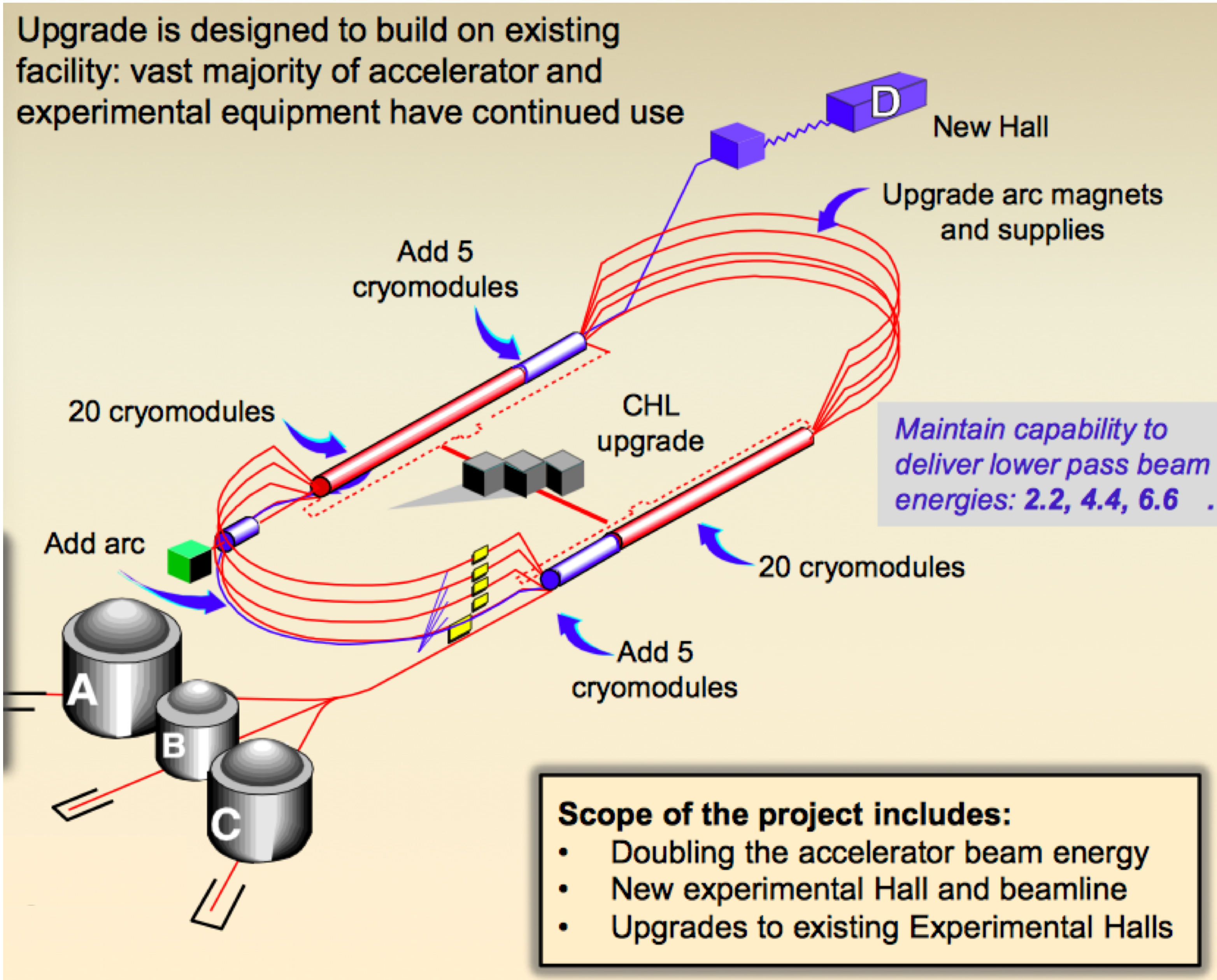
- The CLAS g12 experiment at JLab has generated large statistics data in the $\gamma p \rightarrow e^+e^-X$ channel.
- Vector mesons clearly seen. After subtracting the Bethe-Heitler "background", the fit to the ρ-ω mass region clearly shows an interference in the di-lepton channel.

preliminary result : $\phi_{\rho\omega} = (32. \pm 12.)^\circ$ **(stat)**

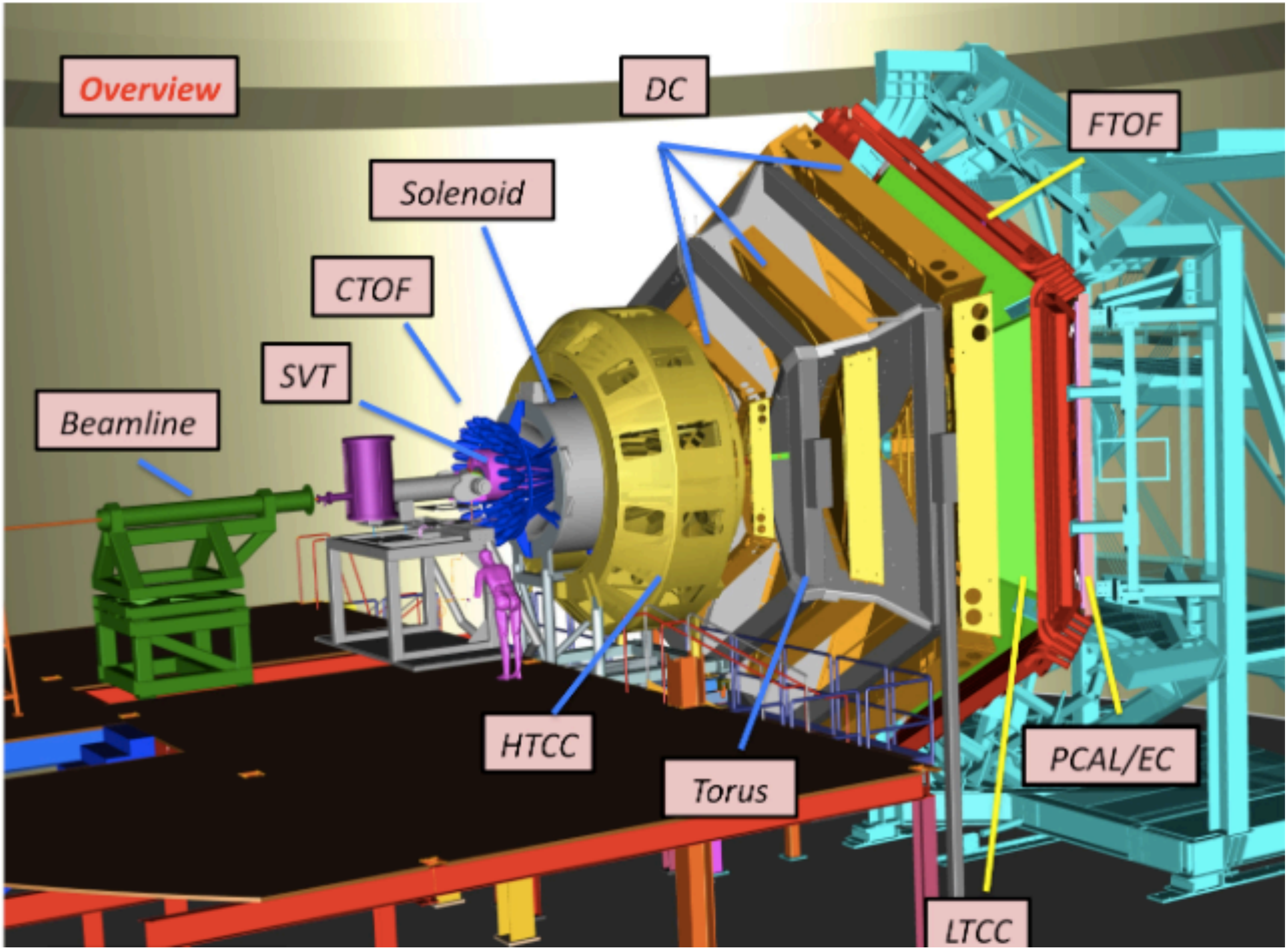
- Careful when comparing with other published results
- Systematic uncertainties being determined, PRL draft ready.
- Target/Medium dependence of interference phase?
- Extension of studies with CLAS12?

Backup Slides

Jlab"12GeV": The "new" 12 GeV Accelerator Coming very soon!



CLAS 12 Detector



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:

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

Fitting Procedure

- The ρ-ω invariant mass spectrum is fitted with:
  - Two Relativistic Breit-Wigner functions

$$\frac{m^2}{(m^2 - m_a^2)^2 + \Gamma_a^2 m^2}$$

    - With a mass dependent ρ width:

$$\Gamma_\rho(m, m_{\rho 0}, \Gamma_{\rho 0}) = \Gamma_{\rho 0}\left(\frac{m_{\rho 0}}{m}\right)\left(\frac{m^2 - 4m_\pi^2}{m_{\rho 0}^2 - 4m_\pi^2}\right)^{3/2}$$

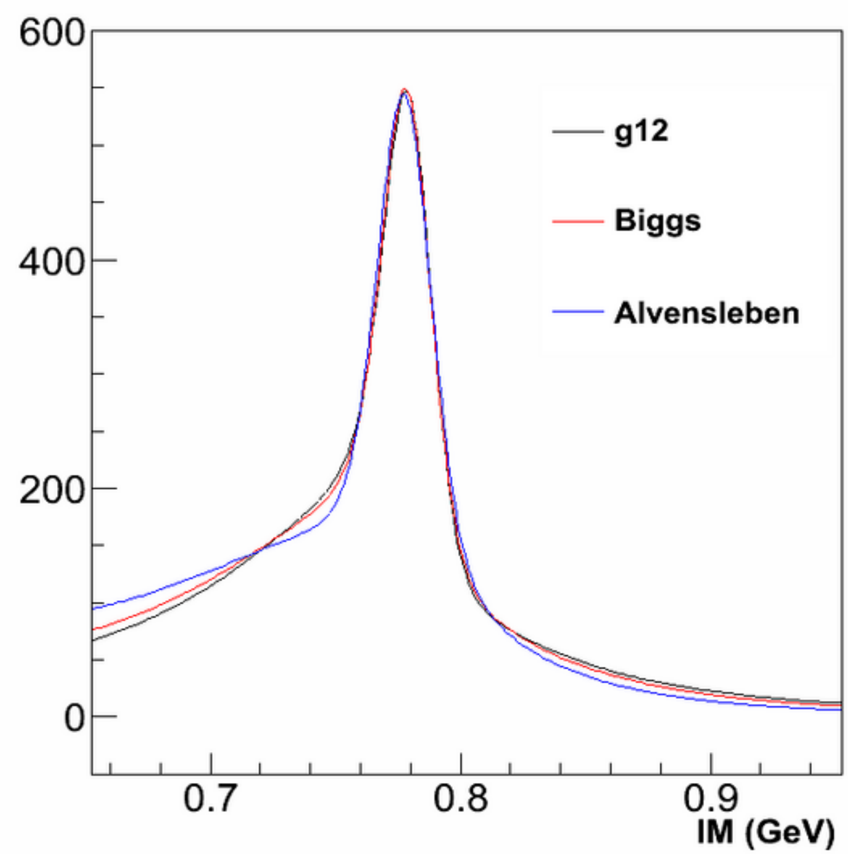
    - Interference term
    - Gaussian convolution

Different functional forms for ρ, ω and interference

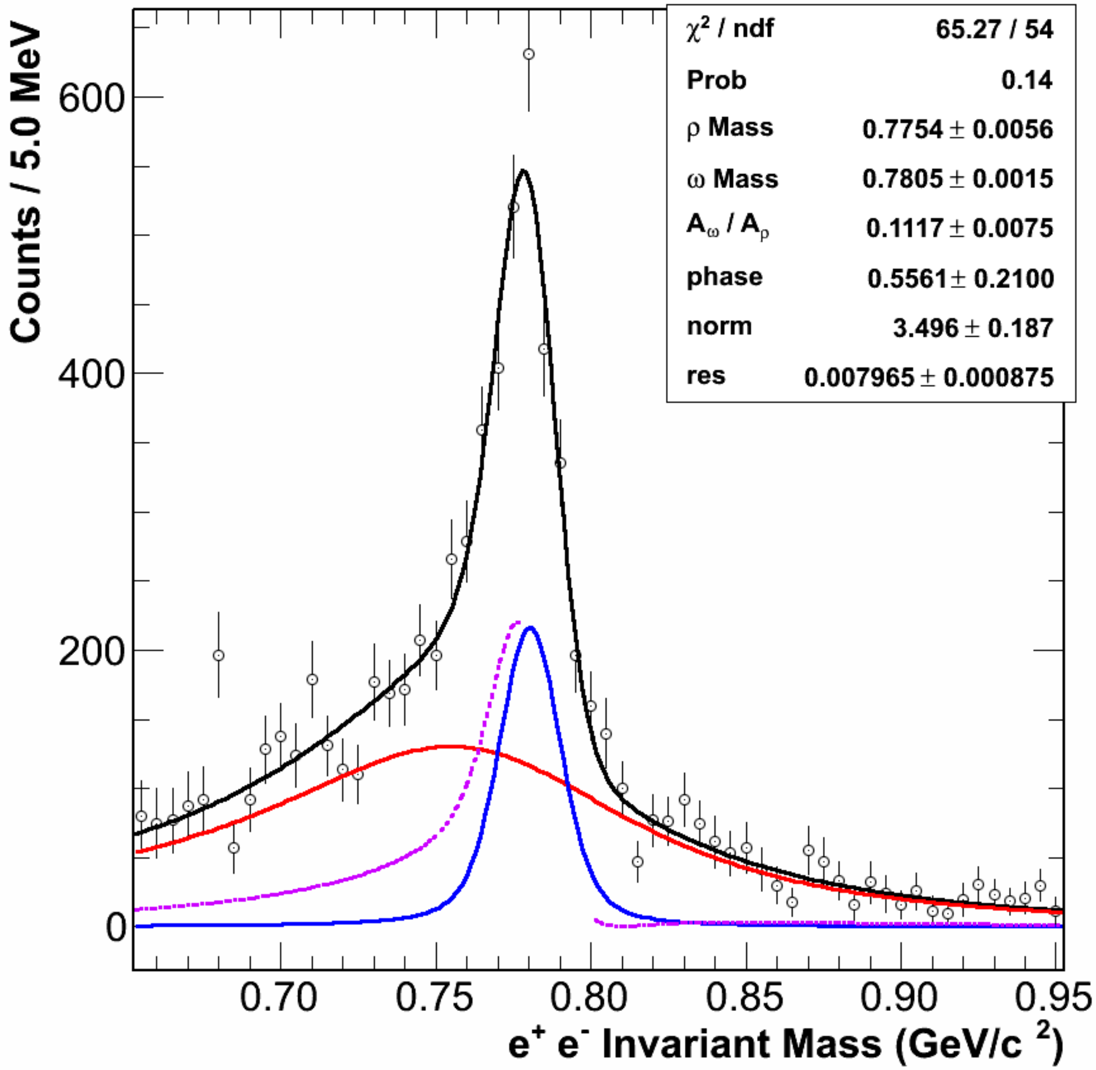
$$F^2_{g12} = \frac{D\,A^2_\rho\,m^4_\rho}{m}\left|\frac{1}{(m^2_\rho - m^2) + im_\rho\Gamma_\rho} + \frac{A_\omega}{A_\rho}\frac{m^2_\omega}{m^2_\rho}\frac{e^{i\phi}}{(m^2_\omega - m^2) + im_\omega\Gamma_\omega}\right|^2$$

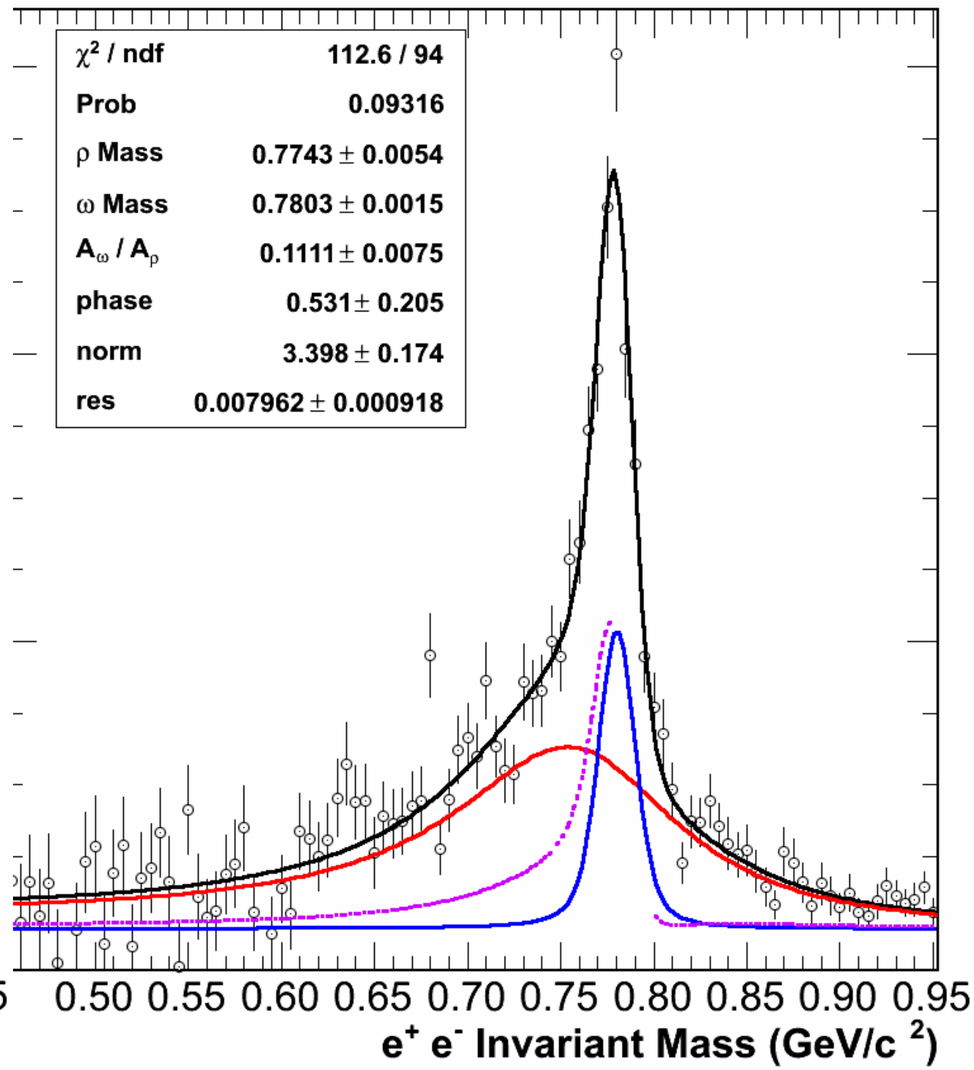
$$F^2_{Biggs} = \frac{D}{m^2}\left|\frac{1}{m^2 - m^2_\rho + im_\rho\Gamma_\rho} + \left(\frac{m_\omega}{m_\rho}\right)^4\frac{\eta}{9}\frac{e^{i\phi}}{m^2 - m^2_\omega + im_\omega\Gamma_\omega}\right|^2$$

$$F^2_{Alvensleben} = \frac{Dm^4_\rho}{m^4}\left|\frac{1}{m^2_\rho - m^2 - im_\rho\Gamma_\rho} + \frac{g^2_\rho}{g^2_\omega}\frac{m^2_\omega}{m^2_\rho}\frac{|R|e^{i\phi}}{m^2_\omega - m^2 - im_\omega\Gamma_\omega}\right|^2$$



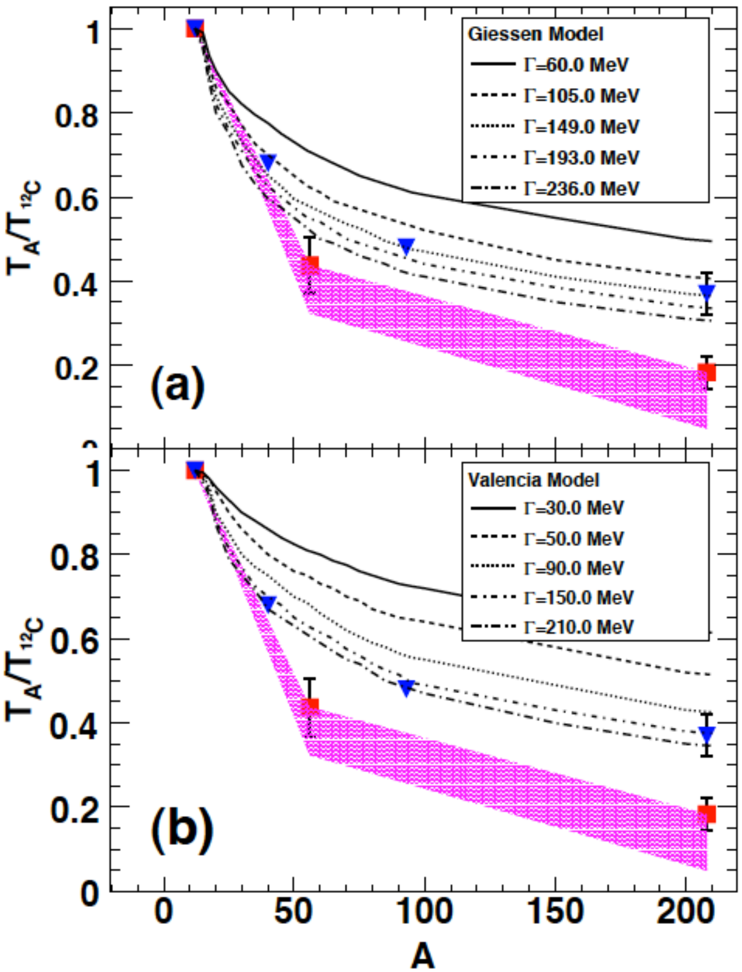
Systematic uncertainties (effect of range of MM)





Jlab Transparency ratios for ω

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



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

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

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

(Γ_ω **>200 MeV**)

- Once ρ meson is subtracted, the "negative yield" on the high invariant mass side of the ω-peak is indicative of ρ-ω interference.