JLAB12 Collaboration Meeting
Rome, October 18-19

Photoproduction of $\pi\pi$ meson pairs

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Analysis of $\pi^+\pi^-$ production from g11 data set

First measurement of direct $f_0(980)$ photoproduction on the proton

$\gamma\ p \to p\ \pi\ \pi$ reaction

Kinematic:

The highest γ energy (E_γ ~3 – 4 GeV)

Low momentum transfer (-t < 1 GeV^2)

$\pi^+\pi^-$ spectrum below 1.5 GeV

- P wave: ρ meson
- S wave: σ, $f_0(980)$ and $f_0(1320)$
- D wave: $f_2(1270)$

Production mechanisms are related to the the resonance nature e.g. short range (QCD) vs long range (hadron) dynamics

Data analysis strategy:

0) Extract ρ cross section and compare to existing data (correcting for the CLAS acceptance)

- weakly model dependence
- check for the data quality and exp corrections

1) Extract moments of the angular distribution (correcting for the CLAS acceptance) by log-likelihood fit

$$\langle Y_{\lambda\mu}\rangle \equiv \frac{1}{\sqrt{4\pi}} \int d^2\Omega Y_{\lambda\mu}(\Omega)\Delta N_{th}(\Omega)$$

$$\Delta N_{th}(\Omega) = \sqrt{4\pi} \sum_{\lambda=0}^{\lambda_{\max}} \sum_{\mu=-\lambda}^{\mu=\lambda} \frac{\langle Y_{\lambda\mu}\rangle}{\epsilon_\mu} \mathrm{Re} Y_{\lambda\mu}(\Omega)$$

$$-2\ln\mathcal{L} = -2\sum_{i=0}^{\Delta N_{data}} \ln \Delta N_{th}(\Omega_i)$$

2) Describe moments in terms of partial waves

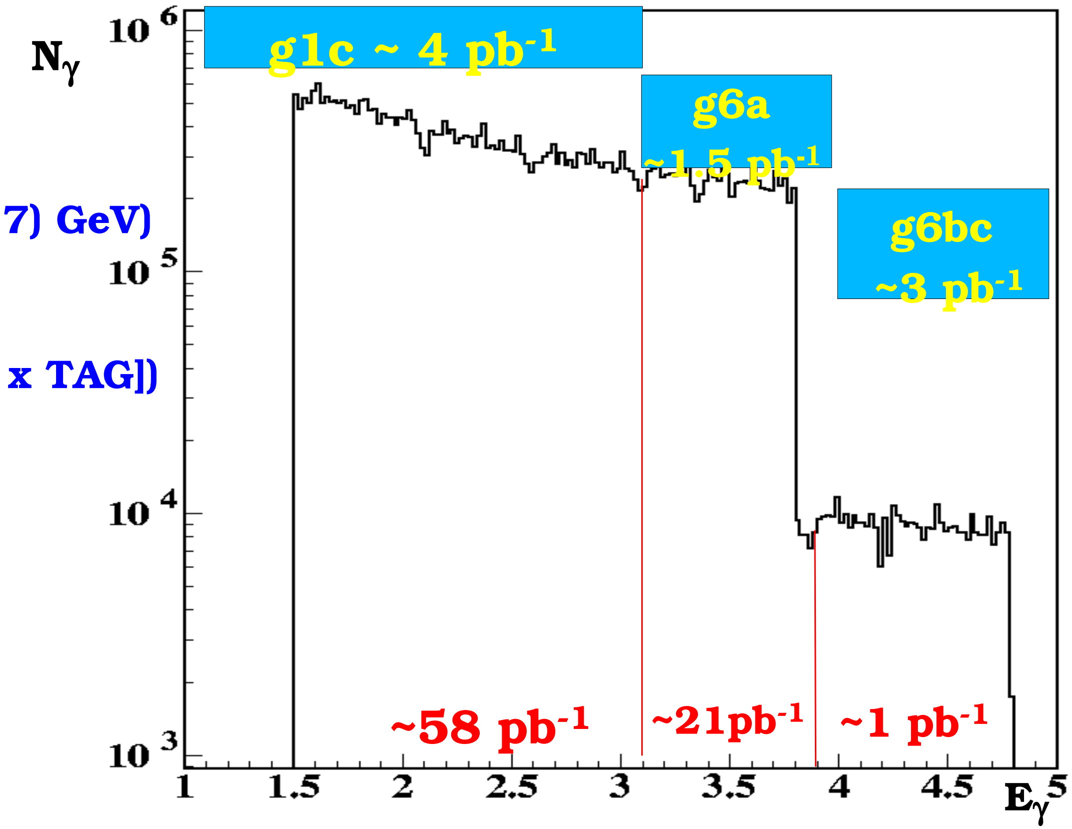
$$\langle Y_{00}\rangle = N\left[|S|^2 + |P_-|^2 + |P_0|^2 + |P_+|^2 + |D_-|^2 + |D_0|^2 + |D_+|^2 + |F_-|^2 + |F_0|^2 + |F_+|^2\right]$$

3) Parametrize partial waves in term of known pp phase shift and unknown coefficients

4) Derive partial wave cross sections to compare with models

g11 experiment at JLAB

- Hall B photon tagger: 0.4 - 0.95% (1.6-3.8 (4.7) GeV)
- In bending torus field (0.5 B_{max})
- Trigger: 2 ch in 2 CLAS sectors (2x[(STxTOF) x TAG])
- ~7G triggers (~400M at 5GeV)
- Luminosity ($1.8 < E_\gamma < 3.8$ GeV) ~ 80 pb^{-1}
  - Allocated 600 hours (~25x2 days)
  - Data taking: 55 5/22- 7/26 2004
  - Calibration completed in October 2004
  - Cooking completed on February 2005



Data quality

Basic corrections

- Energy/Tagger
- Energy loss
- Momentum corrections

All known masses are within 1.5 MeV from the nominal value!

Yield correction

- 1) Time window cut
- 2) TAG Multiple hits correction
- 3) Flux correction
- 4) Trigger efficiency

- Fiducial cuts

Channel Id

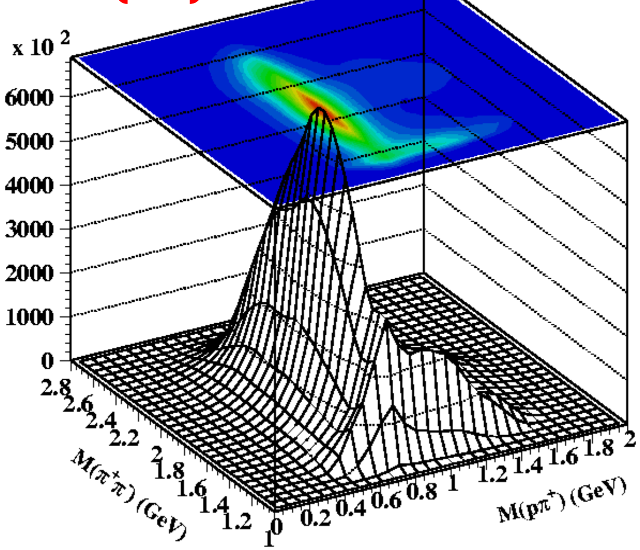
$\gamma\, p \rightarrow p\, \pi^+\, \pi^-$

- Missing mass technique
- Multi pions rejection
- Fiducial cuts applied
- E_γ = 3.0 – 3.8 GeV

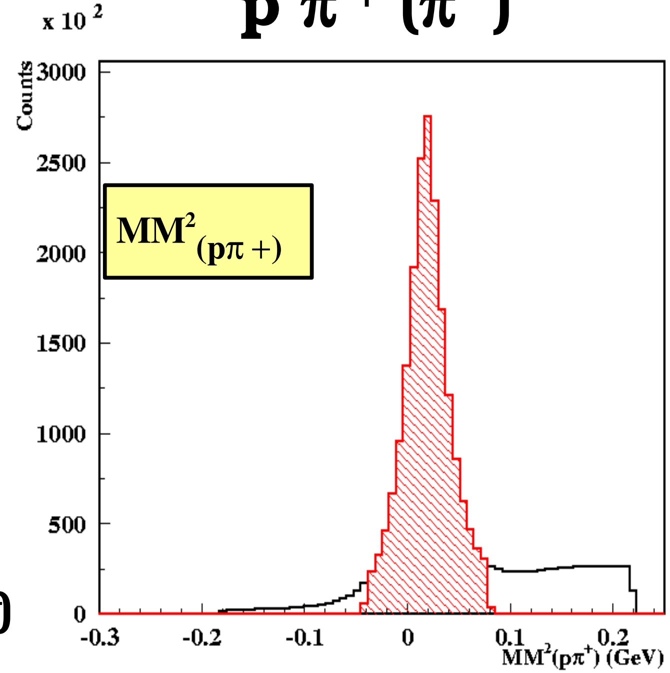
After all cuts:

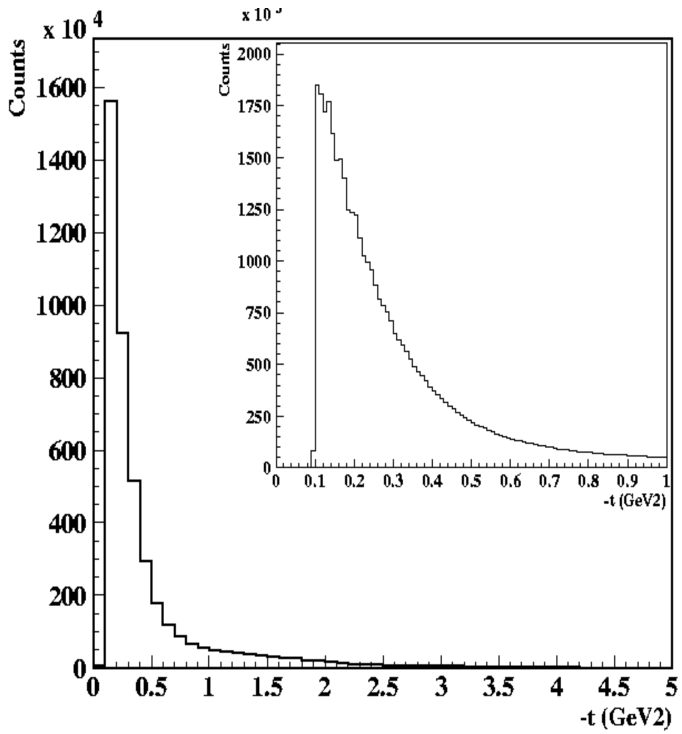
- 41M events in $p\, \pi^+\, (\pi^-)$
- 7 M events in $p\, \pi^+\, (\pi^-)$

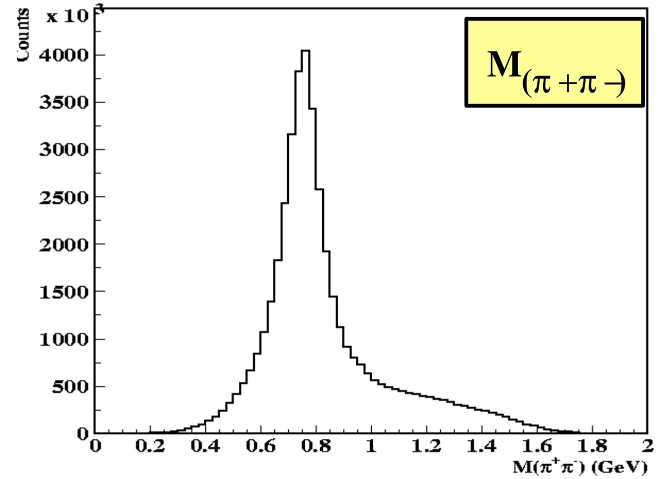
$p\, \pi^+\, (\pi^-)$

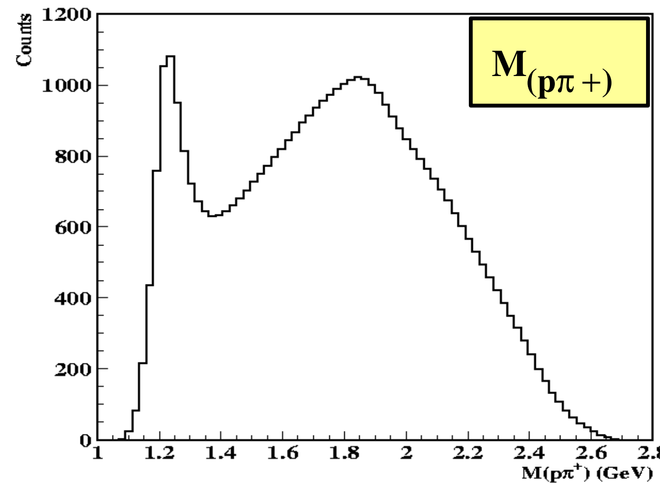


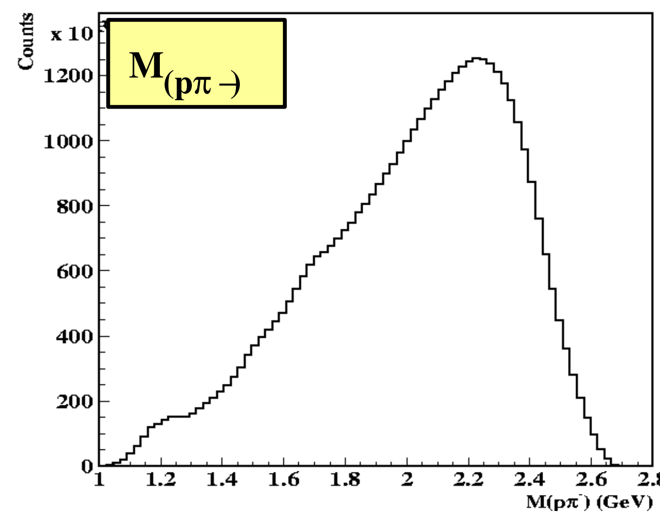
$p\, \pi^+\, (\pi^-)$











CLAS efficiency

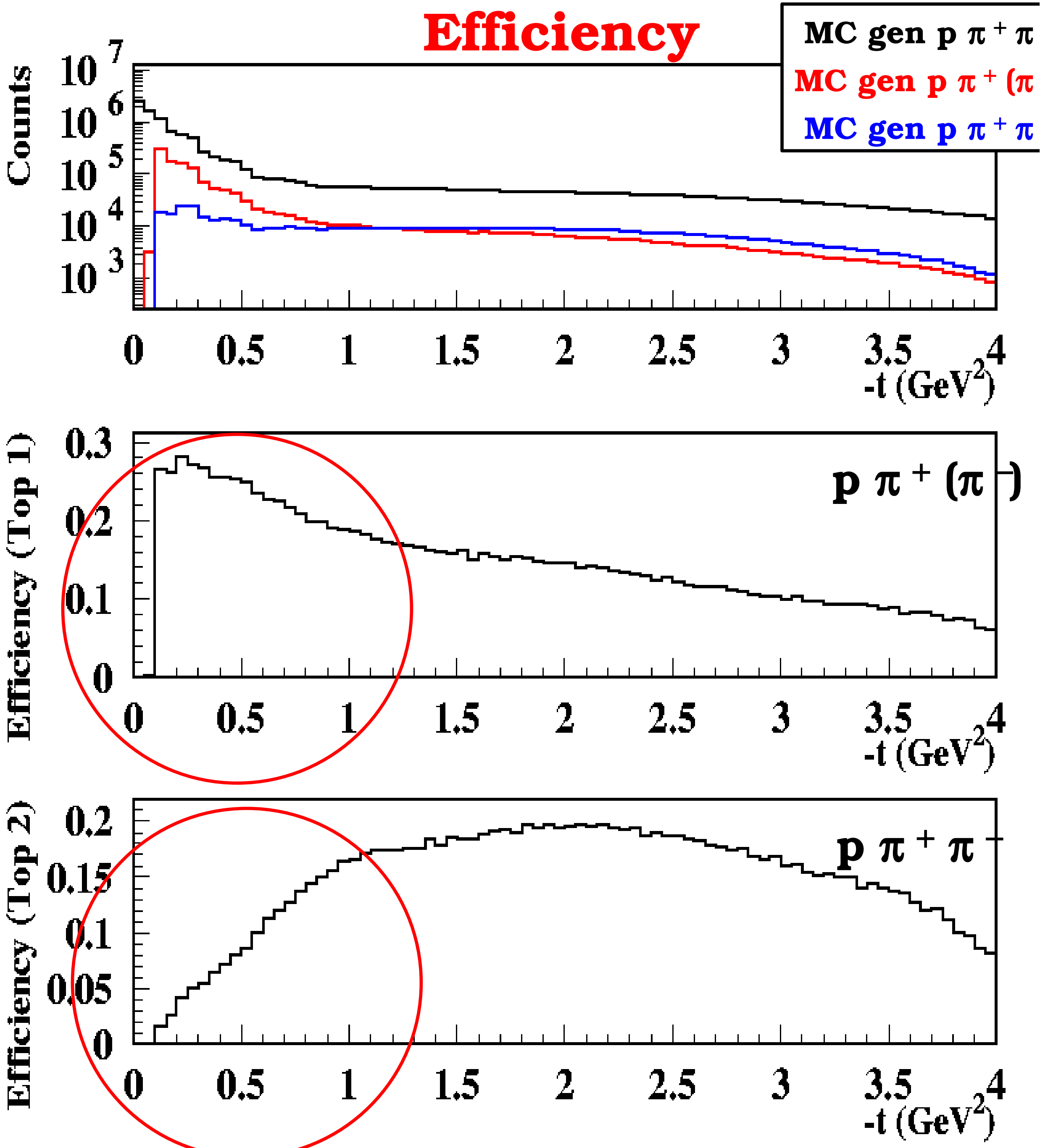
- MC 2π ch

60% ρ 20% PS 10% Δ^{++} 10% $f_2(1270)$

- realistic angular distributions: production and decay
- GSIM+GPP processing
  ~ 40M events generated

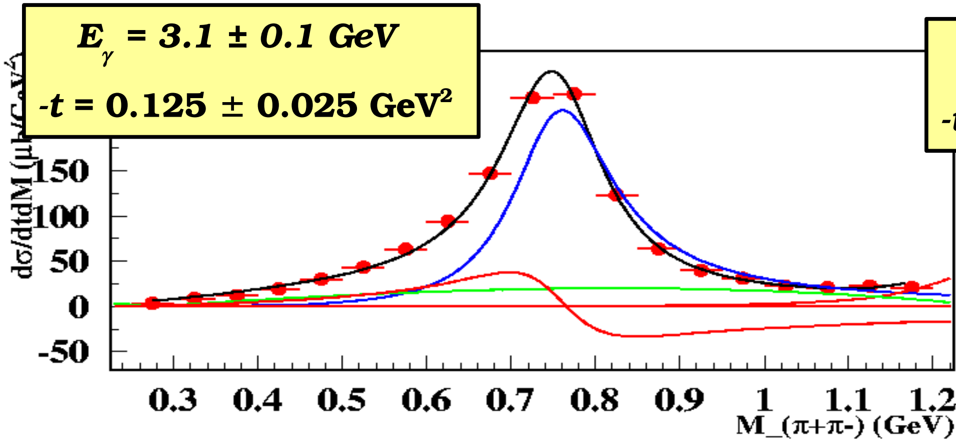
- Kinematic region of interest:
0.0 < *-t* < 1.0 GeV²

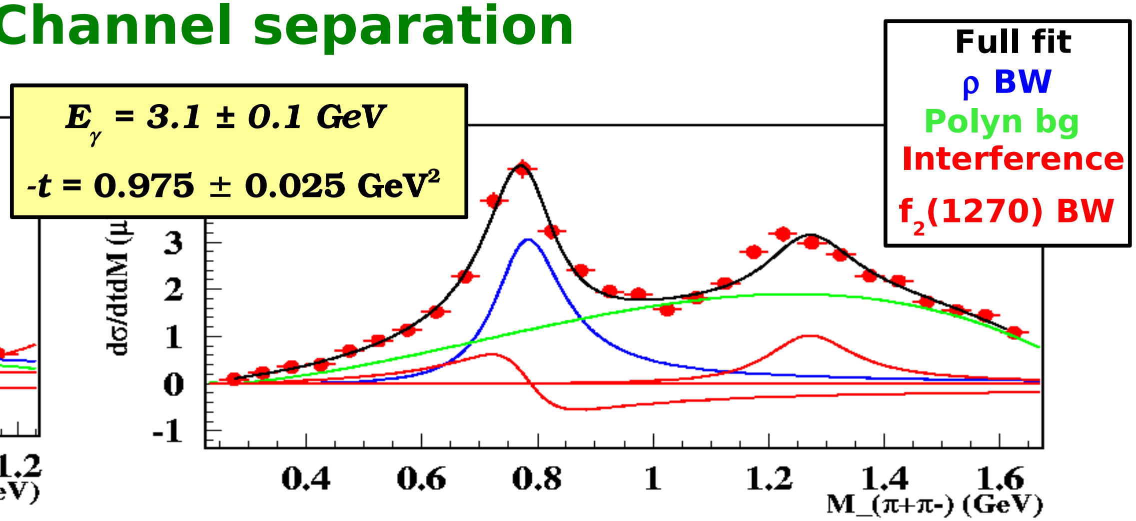
- CLAS Efficiency for p $\pi^+\pi^-$ showa steep dependence up to *-t* < 1.0 GeV²

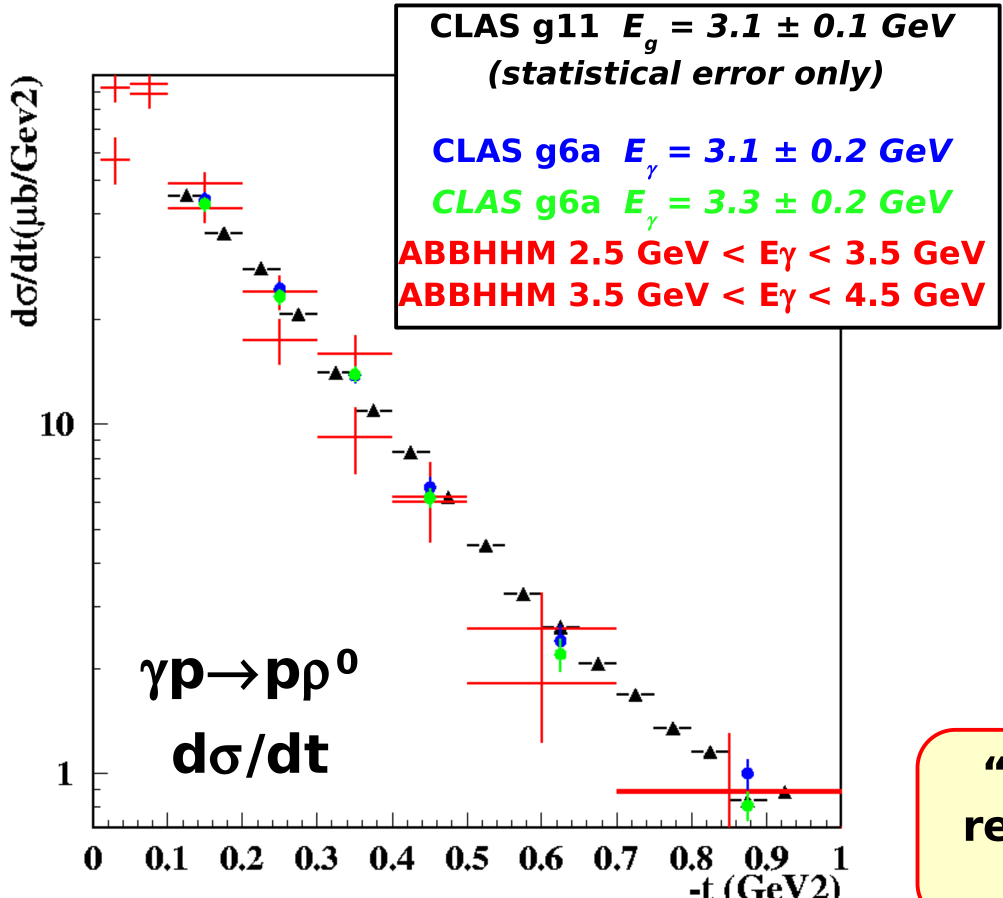


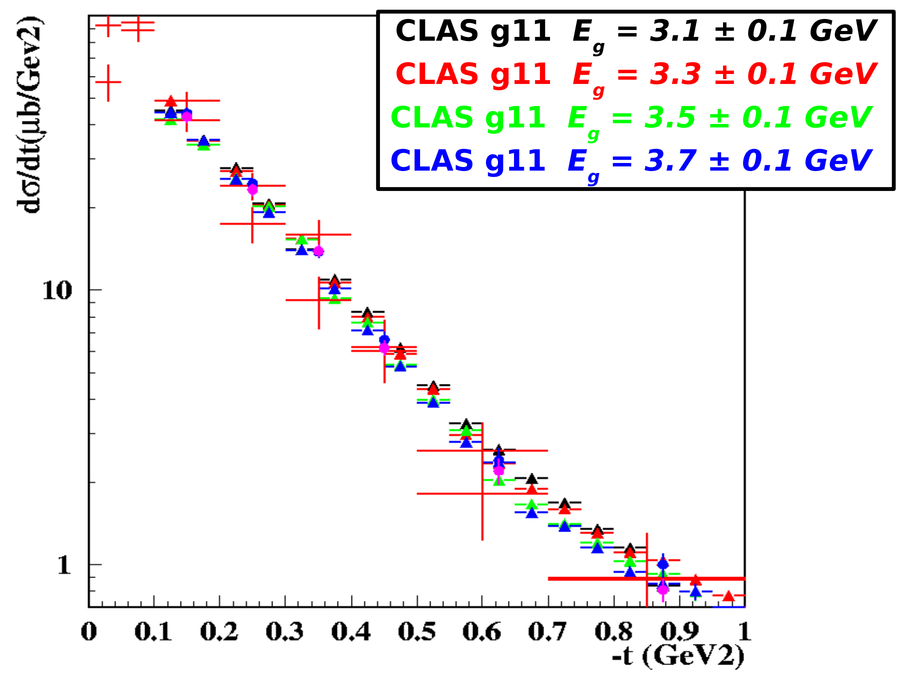
Only the topology p $\pi^+(\pi^-)$ is used in this analysis

Rho analysis Channel separation







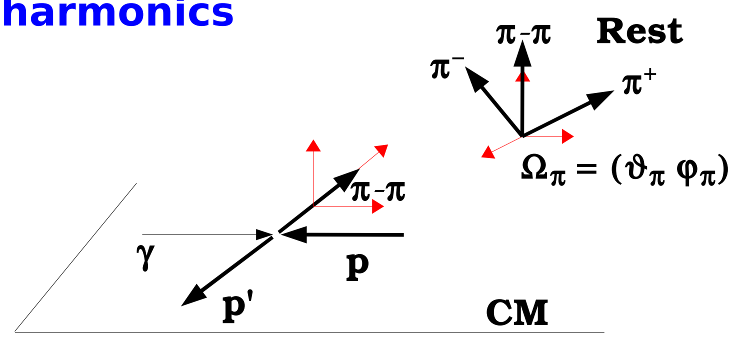


"Standard" CLAS analysis of the $\gamma\, p \rightarrow p\, \rho^0$ results in a good agreement with world data down to $-t \sim 0.1$ GeV^2

PWA analysis of γ p $\rightarrow$ p$\pi^+\pi^-$ reaction
extraction of experimental moments

Moments = Integral of the cross section over spherical harmonics

$$\langle Y_{\lambda\mu}\rangle(E_\gamma, t, M) = \frac{1}{\sqrt{4\pi}}\int d\Omega_\pi \frac{d\sigma}{dt dM d\Omega_\pi} Y_{\lambda\mu}(\Omega_\pi)$$



Why Moments?

- Specific sensitivity to particular Partial Waves amplifying their contribution via interference with dominant waves (e.g. Y_{10}~S-P Interference)
- Unambiguous definition
- Derived directly from data
- Avoid mathematical ambiguities of direct PW fit
- Expressed in term of bilinear of PW

How to extract moments

- Measured angular distributions need to be corrected by CLAS efficiency
- Monte Carlo simulations: flat distribution in p$\pi^+\pi^-$ phase space (~4G Gen, ~0.7G rec)
- Three different procedures:
  1) Binned data, corrected for acceptance and then extract moments
  2a) Theor. moments parametr. in term of *amplitudes*, corrected for acceptance and fit to the data
  2b) Theor. moments directly corrected for acceptance and fit to the data

... just an example:

2a) Theor. moments parametrized in term of *amplitudes*, corrected for acceptance and fit to the data

2b) Theor. moments directly corrected for acceptance and fit to the data

- **Efficiency Corrected Theory compared to data**
- **Moments expanded in a model independent way on a set of basis functions**
- **No binning necessary**
- **Comparison of the two methods allows us to evaluate systematic error**

Moments are extracted minimizing a LOG-likelihood in each (E_g,-*t*,M_{pp}) bin independently

2a)

$$-2\ln\mathcal{L} = -2\sum_{a=1}^{\Delta N_{data}(i,j,k)} \ln\eta(\tau_a)I(\tau_a) + 2\Delta N_{data}(i,j,k)\ln\sum_{\lambda'\mu';\lambda\mu}\tilde{a}^*_{\lambda'\mu'}(i,j,k)\tilde{a}_{\lambda\mu}(i,j,k)\Psi_{\lambda'\mu';\lambda,\mu}(i,j,k)$$

Moments expanded in simplified Amplitudes (no gamma and nucleon spin dependence)

CLAS Efficiency

2b)

$$-2\ln\mathcal{L} = -2\sum_{a=1}^{\Delta N_{data}(i,j,k)} \ln\sqrt{4\pi}\frac{\Delta N_{data}(i,j,k)}{\eta_{00}}Y_{00}(\Omega_\pi) + \sqrt{4\pi}\sum_{\lambda>0,\mu}\left[\mathrm{Re}Y_{\lambda\mu}(\Omega_\pi) - \frac{\eta_{\lambda\mu}}{\eta_{00}}\epsilon_0 Y_{00}(\Omega_\pi)\right]\langle\tilde{Y}_{\lambda\mu}\rangle$$

Moments used as a basis for the expansion

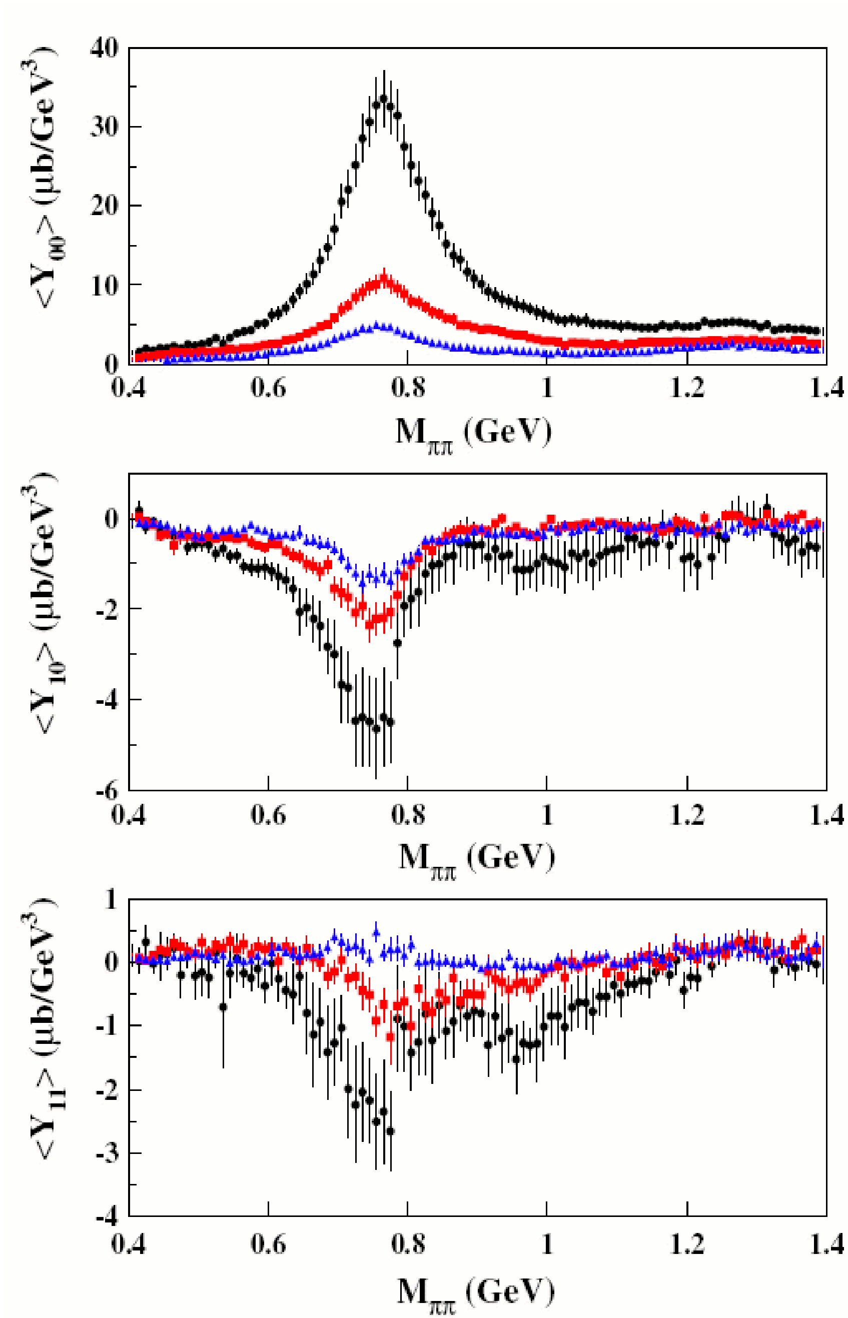
Final results

- **Combination of fit with moments with λ_{max}=4 (3 initialization) +fit with amplitudes (λ_{max}=2)**

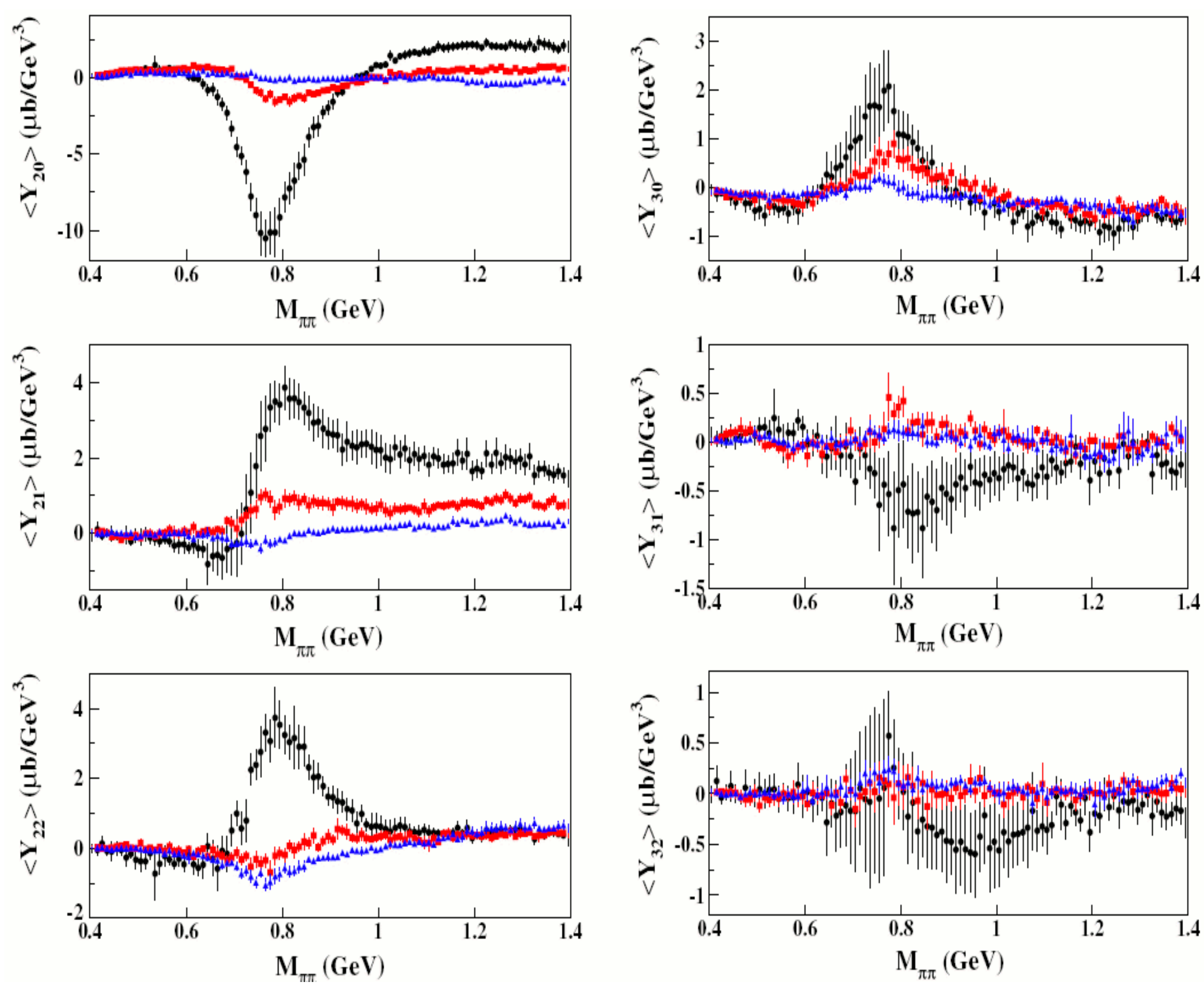
- **Extracted all moments $\langle Y_{\lambda\mu}\rangle$ up to λ=4 (all μ) for 10 -*t* bin and 4 E_γ bin**
- **Starting point for the PWA**

Moments

e.g. 3.2 GeV< E_g < 3.4 GeV



0.4 GeV^2 < $-t$ < 0.5 GeV^2
0.6 GeV^2 < $-t$ < 0.7 GeV^2
0.9 GeV^2 < $-t$ < 1.0 GeV^2



PWA: fitting the moments

- **Moments as bilinear combination of amplitudes $a_{lm}(\lambda, \lambda', \lambda_\nu, E_\nu, t, M_{\pi\pi})$**

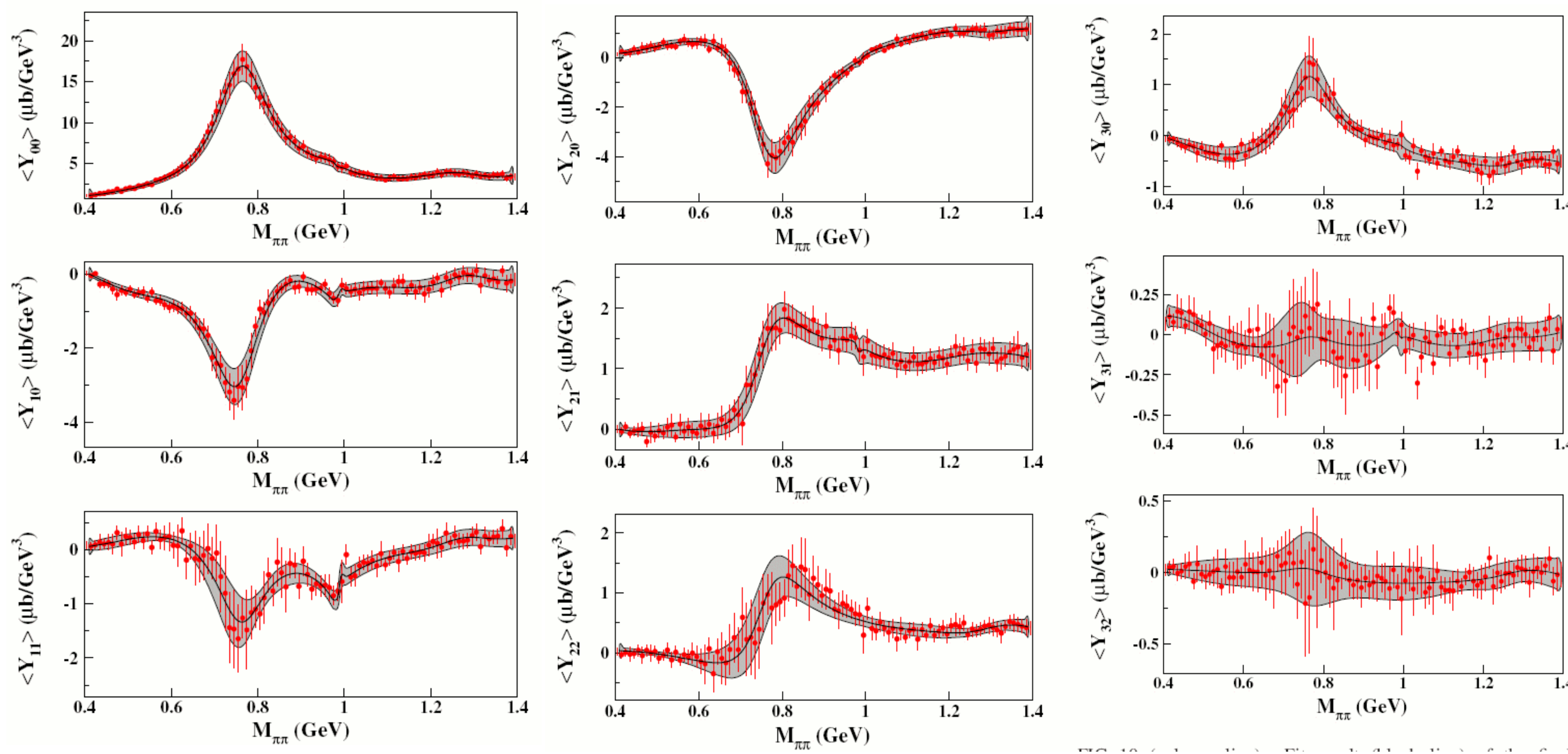
$$\langle Y_{LM}\rangle = \sum_{l'm', lm, \lambda, \lambda'} C(l'm', lm, LM) \times a_{lm} a^*_{l'm'},$$

$$\langle Y_{00}\rangle = |S|^2 + |P_-|^2 + |P_0|^2 + |P_+|^2 + |D_-|^2 + |D_0|^2 + |D_+|^2 + |F_-|^2 + |F_0|^2 + |F_+|^2$$

$$\langle Y_{10}\rangle = SP_0^* + P_0 S^* + \sqrt{\frac{3}{5}}(P_- D_-^* + P_-^* D_- + P_+ D_+^* + D_+ P_+^*) + \sqrt{\frac{4}{5}}(P_0 D_0^* + D_0 P_0^*) + \sqrt{\frac{24}{35}}(D_- F_-^* + F_- D_-^* + D_+ F_+^* + F_+ D_+^*) + \sqrt{\frac{216}{280}}(D_0 F_0^* + F_0 D_0^*)$$

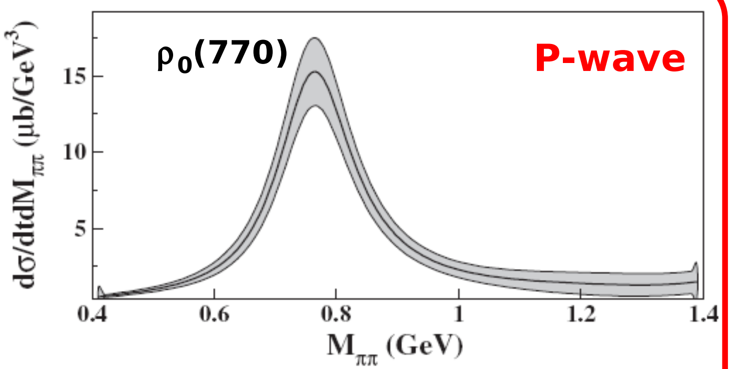
- **a_{lm} parametrized using a dispersion relation to incorporate $\pi\pi$ scattering info**

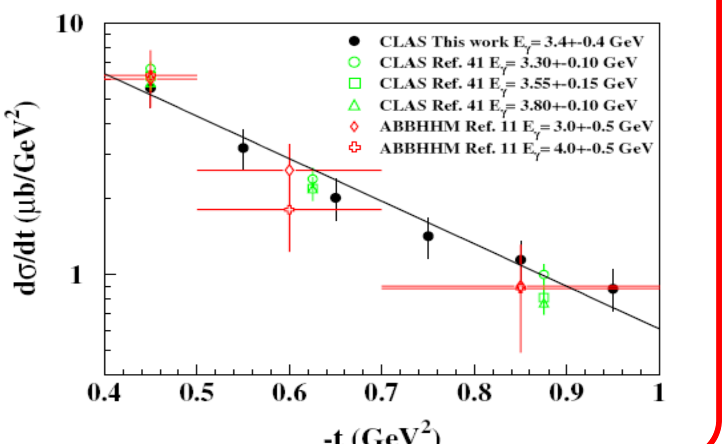
- **Moments were then fitted to extract a_{lm}**

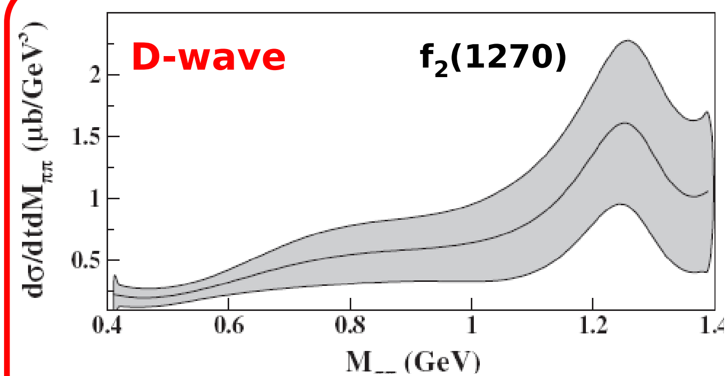


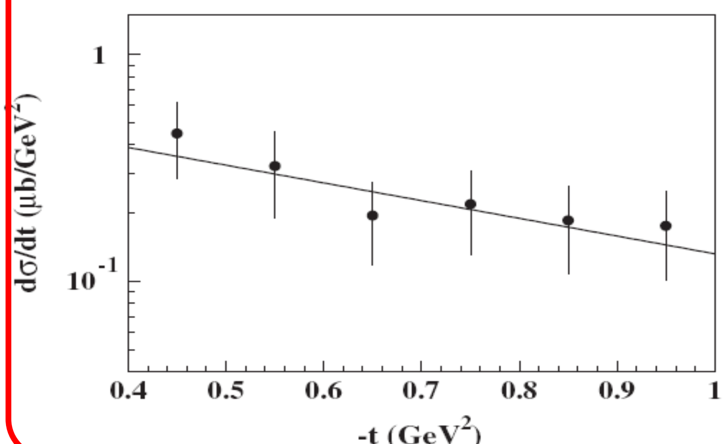
PWA: extracting individual waves

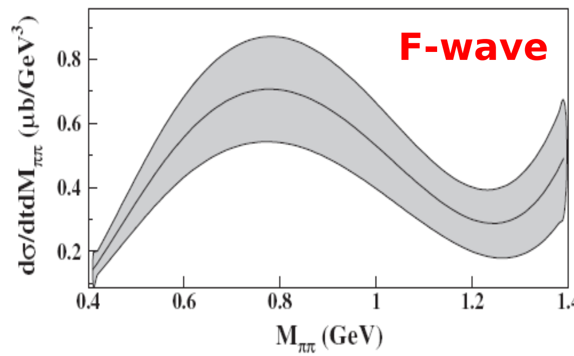
$$I_l = \sum_m \sum_{i=1,2} |a_{lm,i}(E_\gamma, t, M_{\pi\pi})|^2,$$

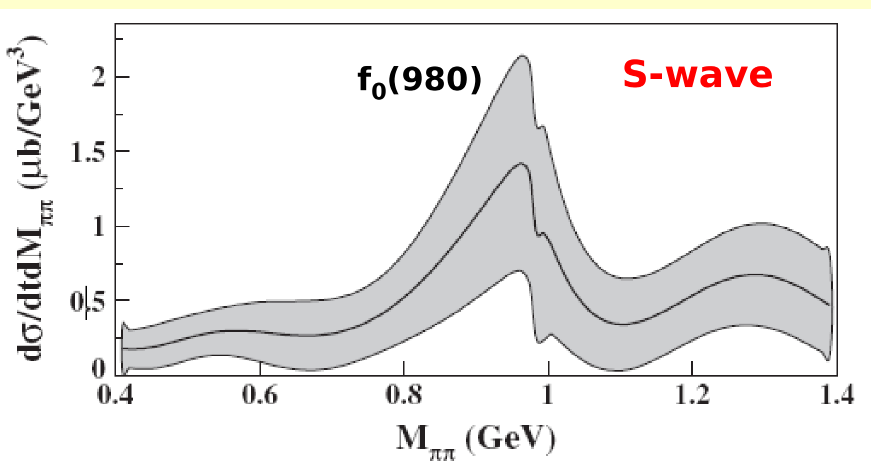




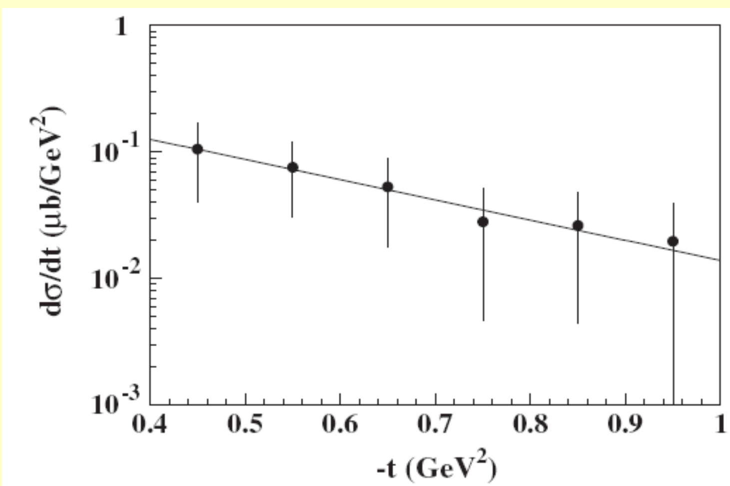








First observation of the $f_0(980)$ in a photoproduction experiment



Conclusions

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Measurement of Direct $f_0(980)$ Photoproduction on the Proton

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Photoproduction of $\pi^+\pi^-$ meson pairs on the proton

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(The CLAS Collaboration)

PRD accepted

- **Physics interpretation in term of long/short distance interaction in progress**
- **Repeating the same analysis on kk channel**
- **PWA dedicated workshop at *Institute for Nuclear Physics (INT, Seattle) in November* with involvement of many labs interested in hadron spectroscopy**
- **Extension of this analysis to JLAB12 kinematic**