Analysis of Single Pion Electroproduction data from CLAS

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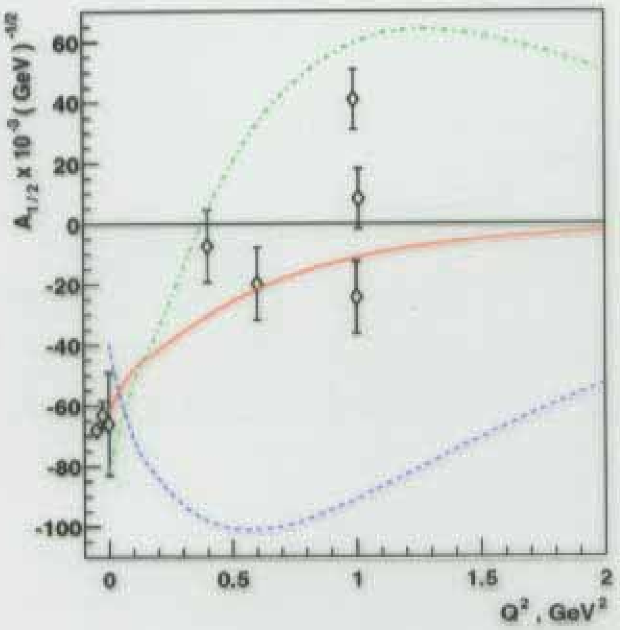
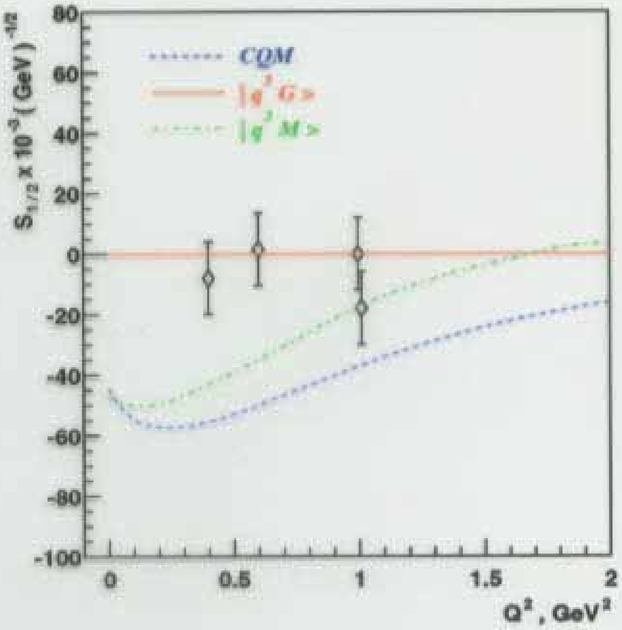
- *Physics Motivation*
- *CLAS data*
- *JANR program*
- *Results of the Analysis*
- *Conclusions and Summary*

Subject of the Talk

- Used CLAS data on cross sections and Single Spin Asymmetry (SSA) for π^+ and π^0 electroproduction at Q^2=0.4 GeV^2, W<1.6 GeV.
- Fit the data with JANR program, based on the Unitary Isobar Model to extract photon-coupling amplitudes for $P_{11}(1440)$, $S_{11}(1535)$ and $D_{13}(1535)$.
- Compare the results with the results from the DASPE program, which is a Dispersion Relation based analysis program.
- Comparison of the two results allows us to have an rough estimate of the model dependencies of the obtained parameters.

$P_{11}(1440)$ Transition Amplitudes





$P_{11}(1440)$ can be either q^3, q^3M or q^3G state (radial, meson cloud around 3-quark core or spin-flavor excitation?).

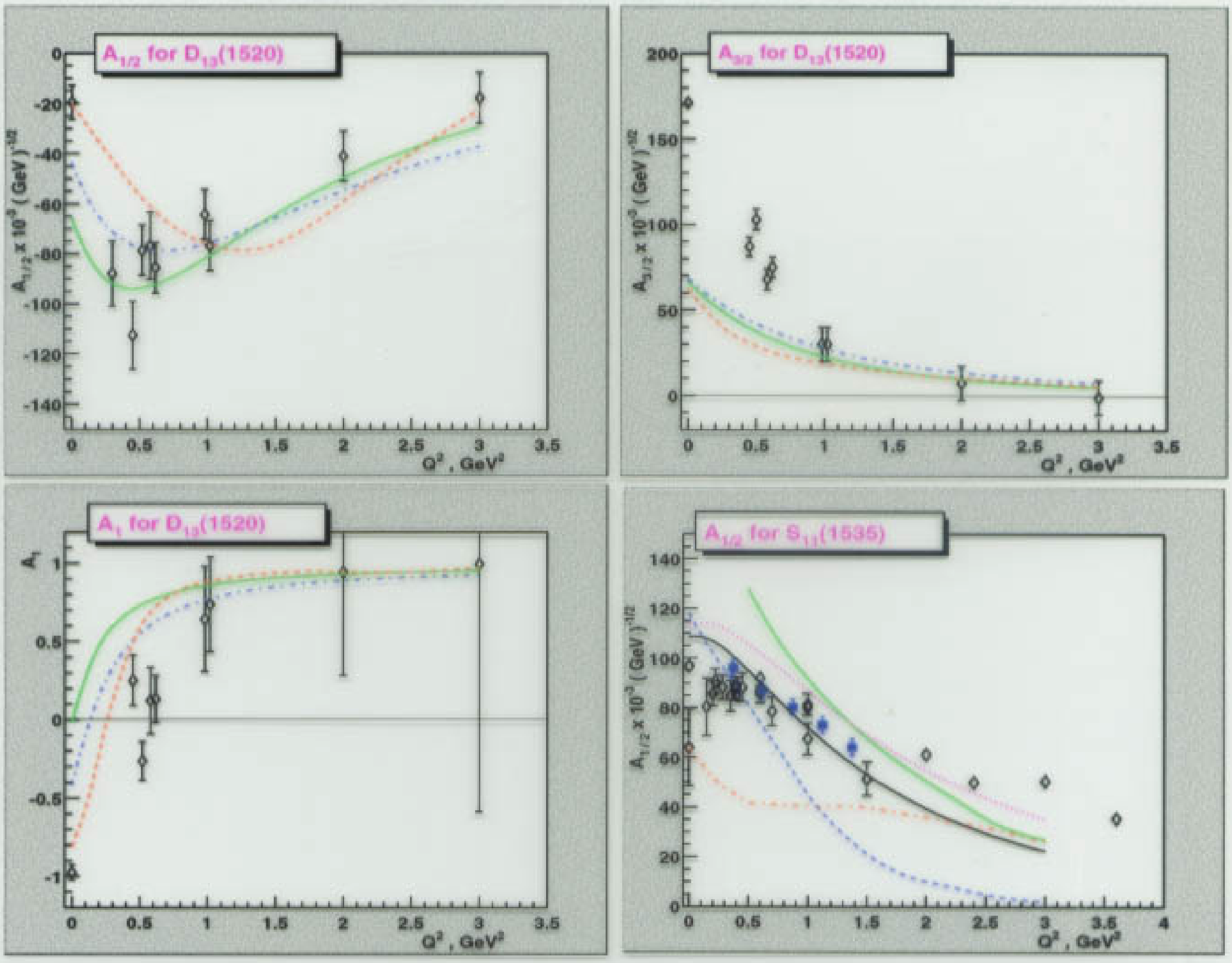
Existing data does not allow to determine the nature of $P_{11}(1440)$ state.

For q^3G state $S_{1/2}$ is predicted to be 0.

Different Q^2 dependence for transverse photocoupling for different models of $P_{11}(1440)$:

$$\frac{A_{\frac{1}{2}}(P^G{}_{11})}{A_{\frac{1}{2}}(P_{11})} \sim \frac{1}{\vec{Q}^2}$$

Amplitudes for $S_{11}(1535)$ and $D_{13}(1520)$ Resonances



For $D_{13}(1535)$ a transition from $A_1 = -1$ to $A_1 = 1$ is expected as $Q^2 \to \infty$.

Independent measurements of $A_{1/2}$ for $S_{11}(1535)$ via π^+ channel are needed.

CLAS Experiment

- The present experiment E-89-038 (V. Burkert, R. Minehart) is a part of the **e1** run group, which includes 15 different experiments.

- Data were taken with 1.5 and 1.6 GeV electron beam incident on unpolarized LH_2 target at luminosities $\sim 3 \times 10^{33} cm^{-2} s^{-1}$.

- Measured absolute cross sections and beam single spin asymmetries for both ($p\pi^0$) and ($n\pi^+$) channels.

- Total 500M triggers collected and written to tape, occupying over 2Tbyte space.

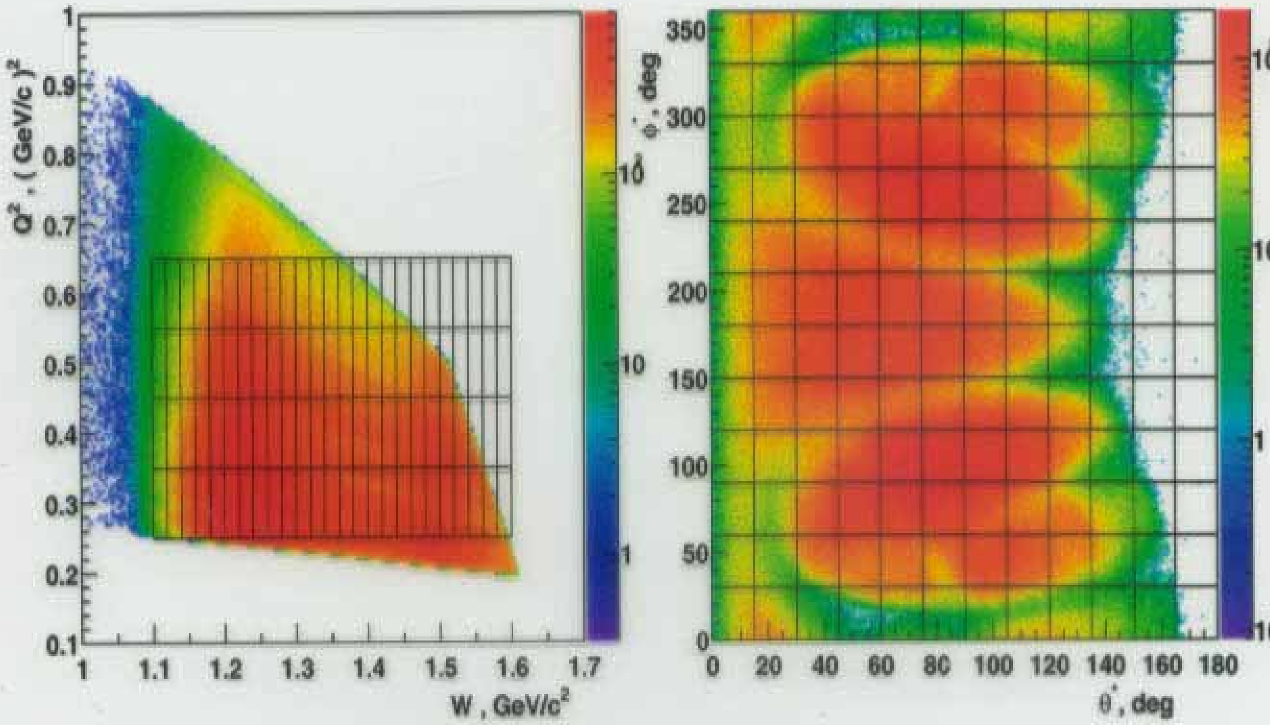
- Raw data were corrected for the geometrical acceptance and efficiency, as well as for the binning effects and the empty target cell contributions.

- Radiative corrections are applied to obtain the radiatively corrected cross sections.

- The combined statistical and systematic errors for dominating π^+ data set was ~10%.

- This combined analysis was done at Q^2=0.4 GeV^2.

Coverage for π^+ Cross Sections



Variable Name	Lowest Value	Highest Value	Number of Bins	Bin Size
Q^2, (GeV/c)^2	0.25	0.65	4	0.1
W, GeV/c^2	1.1	1.6	25	0.02
θ^*, deg	0	180	12	15
ϕ^*, deg	0	360	12	30

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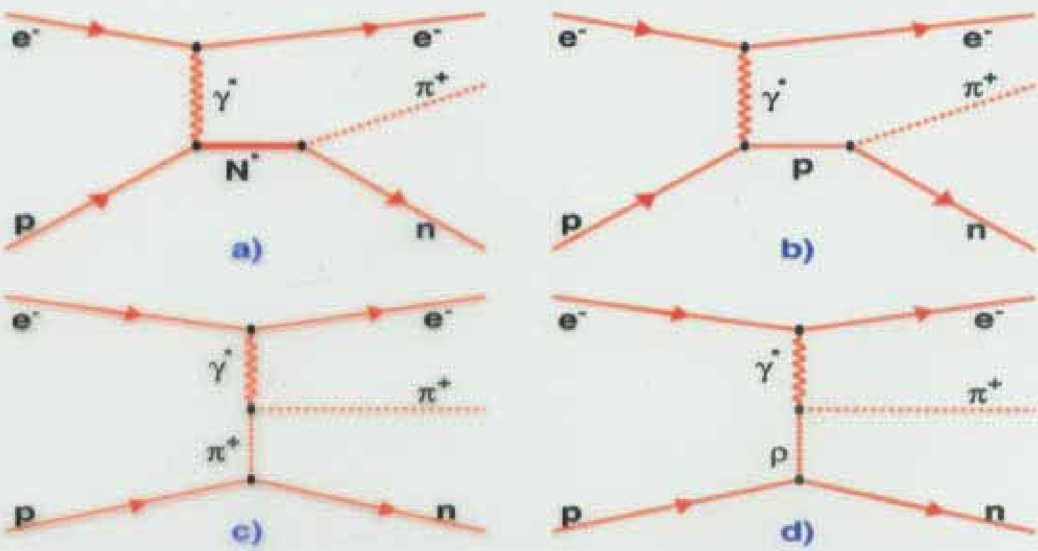
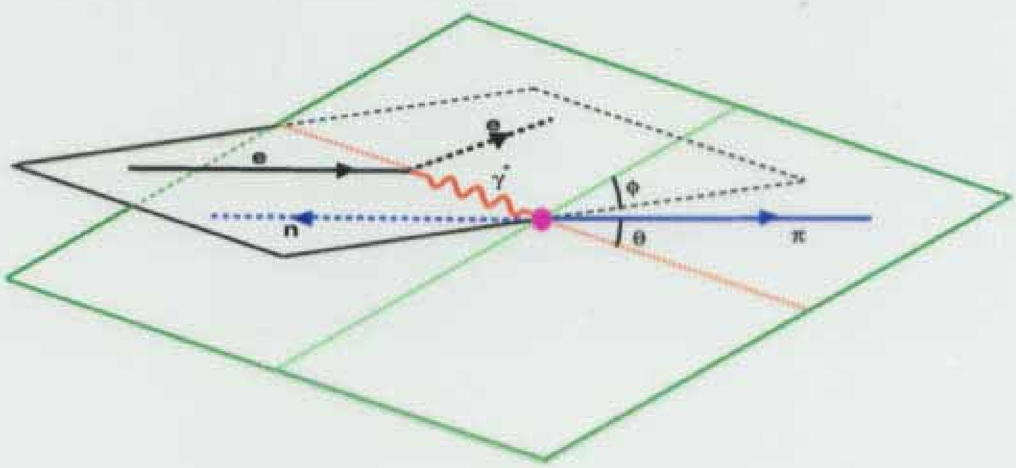
Main Contributing Diagrams



Kinematics of the reaction



$$\frac{d^5\sigma}{dE' d\Omega_e d\Omega^*_\pi} = \Gamma_t \frac{d\sigma}{d\Omega^*_\pi}(\theta, \phi, \varepsilon, W, Q^2)$$

$$\frac{d\sigma}{d\Omega^*_\pi} = \sigma_T + \varepsilon\sigma_L + \varepsilon\sigma_{TT}\cos 2\phi + \sqrt{\frac{\varepsilon(1+\varepsilon)}{2}}\sigma_{TL}\cos\phi + h\sqrt{\frac{\varepsilon(1-\varepsilon)}{2}}\sigma_{TL}'\sin\phi$$

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JLab Analysis of Nucleon Resonances (JANR) Program

- *Program developed at JLab to analyze pion electroproduction data (I. Aznauryan).*
- *Based on the* ***Unitary Isobar Model***
- *Includes all resonances which have been seen in photoproduction PWA.*
- *Breit-Wigner for resonant amplitudes:*

$A_{l\pm}(W) = a_{l\pm}\left(\frac{q_r}{q}\frac{k_r}{k}\frac{\Gamma_\pi\Gamma_\gamma}{\Gamma}\right)^{\frac{1}{2}}\frac{M\Gamma}{M^2-W^2-iM\Gamma_{tot}}$, *where* $a_{l\pm}$ *are the fit parameters for fixed* Q^2.

- *Fixed background from nucleon pole diagrams, t-channel pion,* ρ*- and* ω*-meson exchange graphs.*
- *Regge behavior for* $W^2 > 2$ *GeV*^{2} *region for nonresonant background with a smooth transition from UIM to Regge background:*

$$B_{Tot} = B_{UIM}\frac{1}{1+(W-W_0)^2} + B_{Reg}\frac{(W-W_0)^2}{1+(W-W_0)^2}$$

- *Unitarized nonresonant background using K-matrix formalism:* $B_{unit} = (1+ih_{l\pm})B_{nonunit}$.

Method of Dispersion Relations

- From causality principle one can express real part of amplitudes in terms of imaginary part:

$$ReB_i^{(\pm,0)}(s,t,Q^2) = Born + \frac{P}{\pi}\int_{thr}^{\infty} ImB_i^{(\pm,0)}(s',t,Q^2)\left(\frac{1}{s'-s} \pm \frac{1}{s'-u}\right)ds'$$

- The Born term is nucleon pole contributions in s- and u-channels and π-exchange in t-channel.
- Dispersion integrals are represented as a sum of integrals over 3 energy regions:

$$\int_{thr}^{\infty} ds' = \int_{thr}^{2.2GeV} ds' + \int_{2.2GeV}^{3GeV} ds' + \int_{3GeV}^{\infty} ds'$$

- Integrals over resonance region saturated by known resonances using Breit-Wigner form. P33(1232) amplitudes were found by solving the integral equations.
- In the integrals over intermediate energy region small contributions, ± 0.1 mFm, were introduced and were varied to obtain better description of the data.
- The integrals over the high energy region were calculated through π,ρ,ω,b_1,a_2 Regge poles. These contributions turn out to be negligible in the I and II resonance regions.

- *Masses, widths and amplitudes for $P_{33}(1232)$, $P_{11}(1440)$, $D_{13}(1520)$ and $S_{11}(1535)$ states were allowed to vary.*
- *The PV-PS mixing parameter was also fitted: the obtained result $\Lambda_m = 469 \pm 7$ MeV, compared to $\Lambda_m = 450$ MeV in the MAINZ model.*

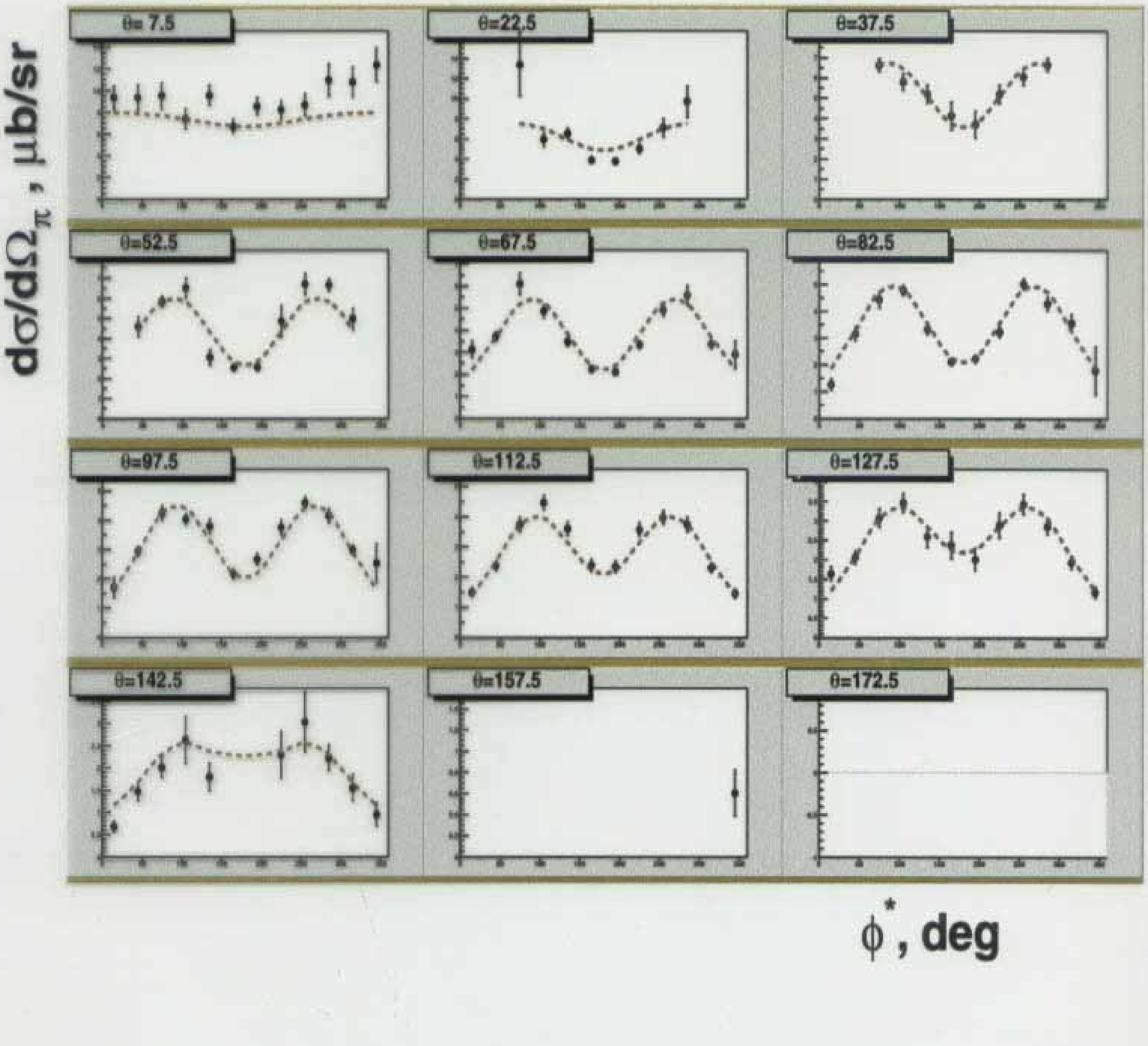
Type of Observable	Number of points	χ^2 / N_{pt} JANR	χ^2 / N_{pt} DR
π^0 cross section	3064	2.06	1.86
π^+ cross section	2424	1.81	2.43
π^0 asymmetry	832	1.48	3.56
π^+ asymmetry	828	1.06	3.66

- *Overall, the π^+ cross section data dominate the fit. As a result, the JANR fit describes the π^+ cross sections data better than the other observables.*

Quantity	$P_{11}(1440)$	$S_{11}(1535)$	$D_{13}(1520)$
M, MeV	1426 ± 4	1525 ± 1	1515 ± 0.5
Γ, MeV	340 ± 27	118 ± 2	109 ± 2

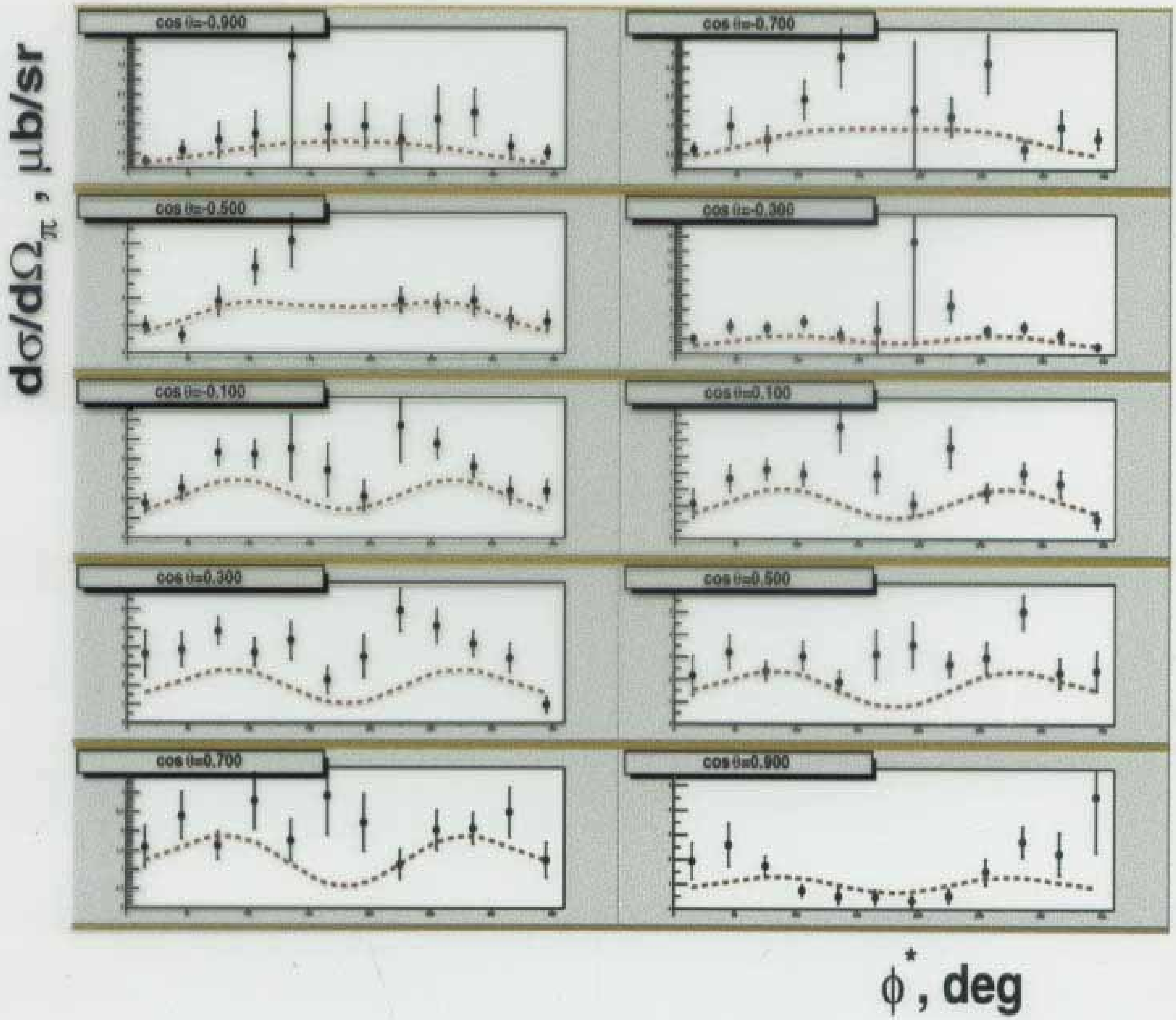
Cross sections for $n\pi^+$

$Q^2 = 0.40\ (GeV/c)^2$, $W = 1.510\ GeV/c^2$ $\Delta Q^2 = 0.100\ (GeV/c)^2$, $\Delta W = 0.020\ GeV/c^2$



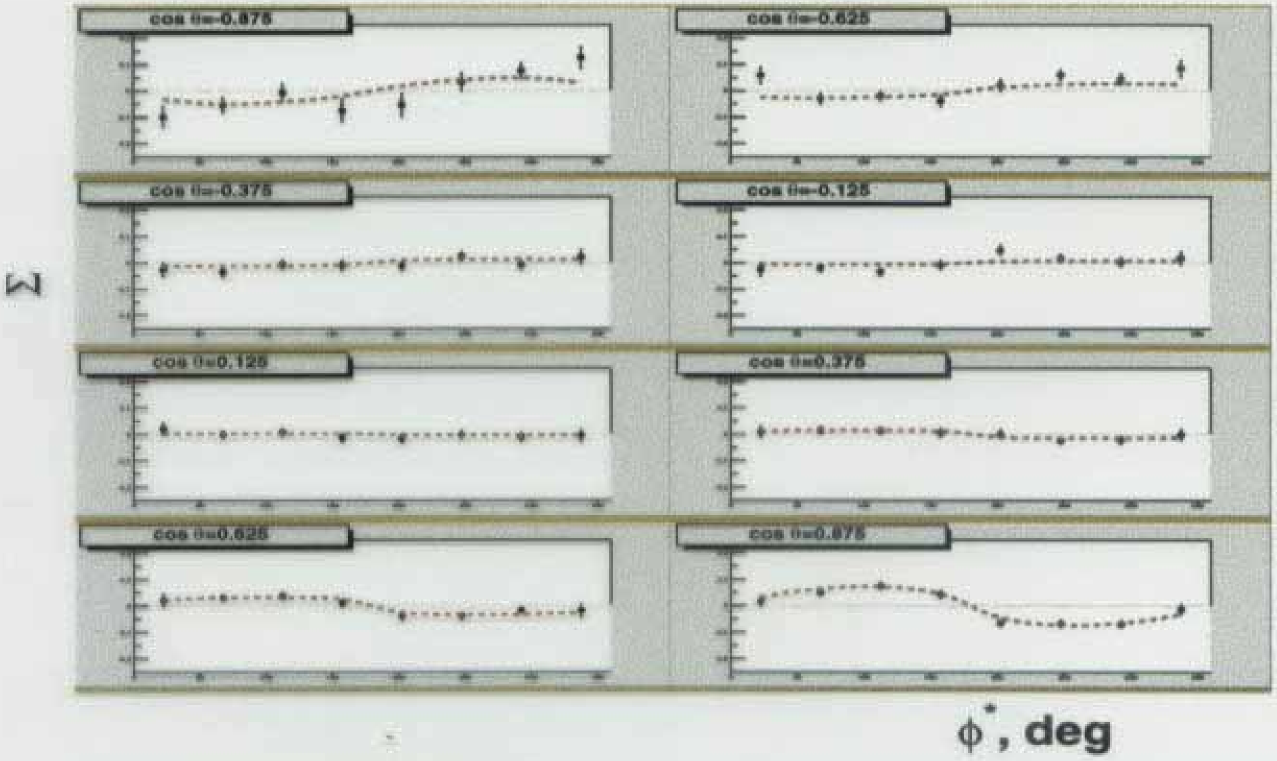
Cross sections for $p\pi^0$

$Q^2 = 0.40\ (GeV/c)^2$, $W = 1.520\ GeV/c^2$ $\Delta Q^2 = 0.100\ (GeV/c)^2$, $\Delta W = 0.020\ GeV/c^2$

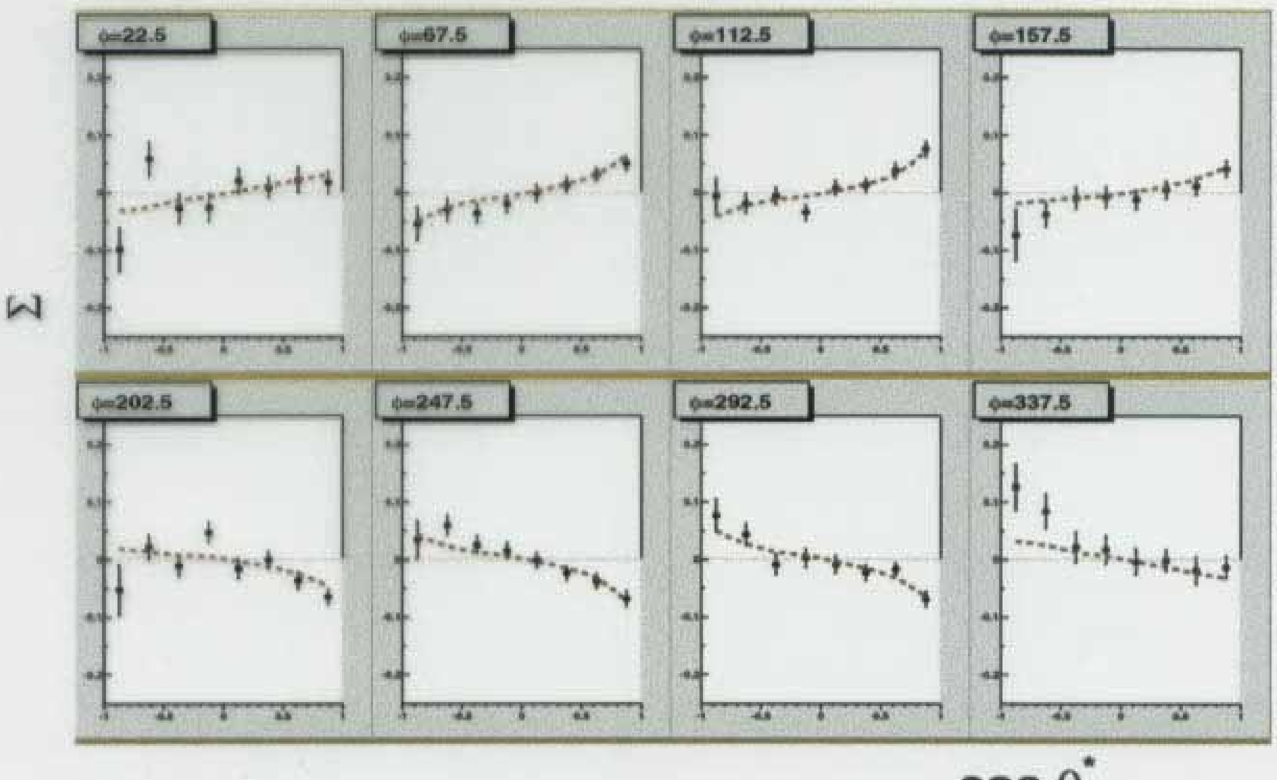


Single Spin Asymmetry for $n\pi^+$

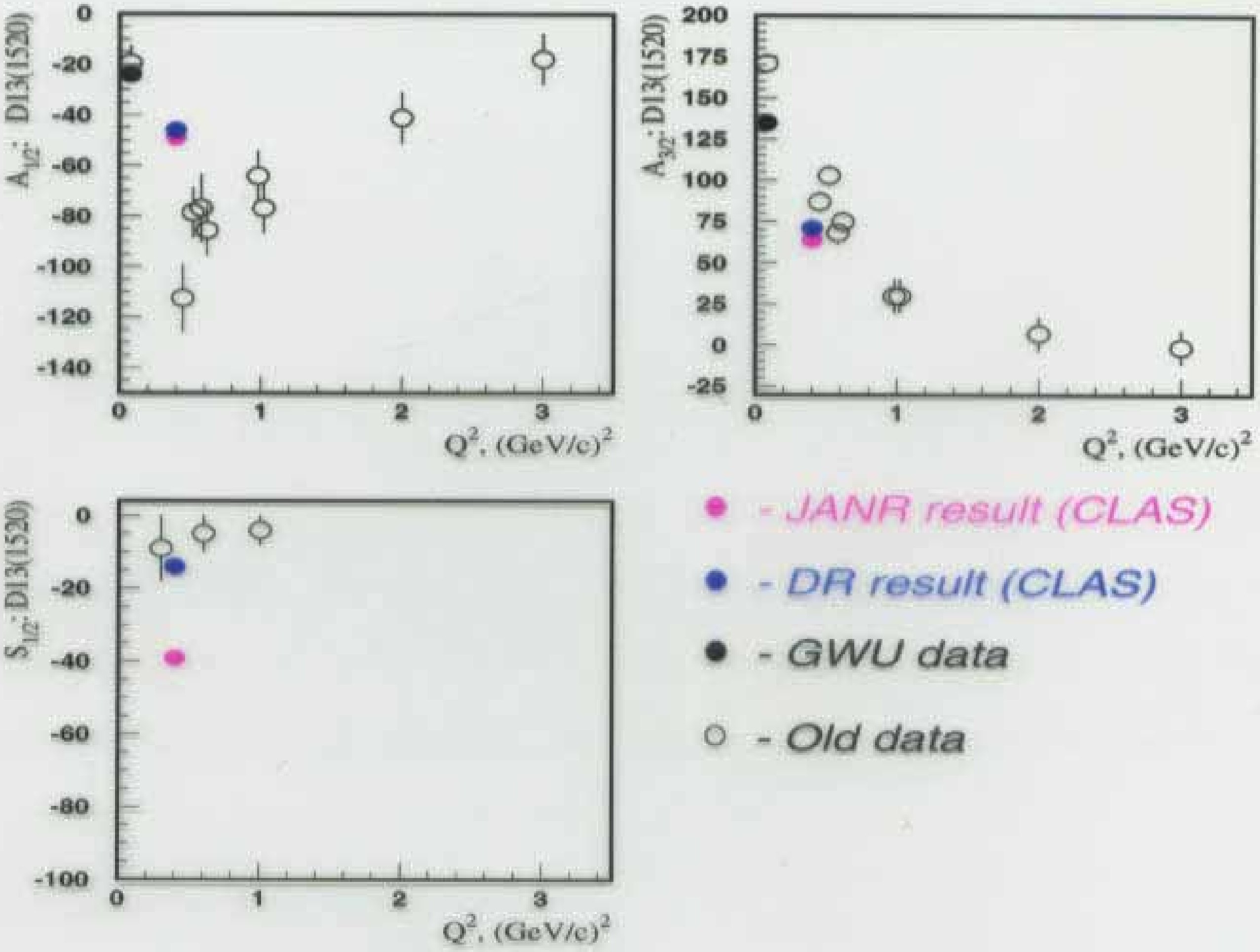
$Q^2 = 0.40\ (GeV/c)^2,\ W = 1.500\ GeV/c^2\ \ \Delta Q^2 = 0.100\ (GeV/c)^2,\ \Delta W = 0.040\ GeV/c^2$



$Q^2 = 0.40\ (GeV/c)^2,\ W = 1.500\ GeV/c^2\ \ \Delta Q^2 = 0.100\ (GeV/c)^2,\ \Delta W = 0.040\ GeV/c^2$



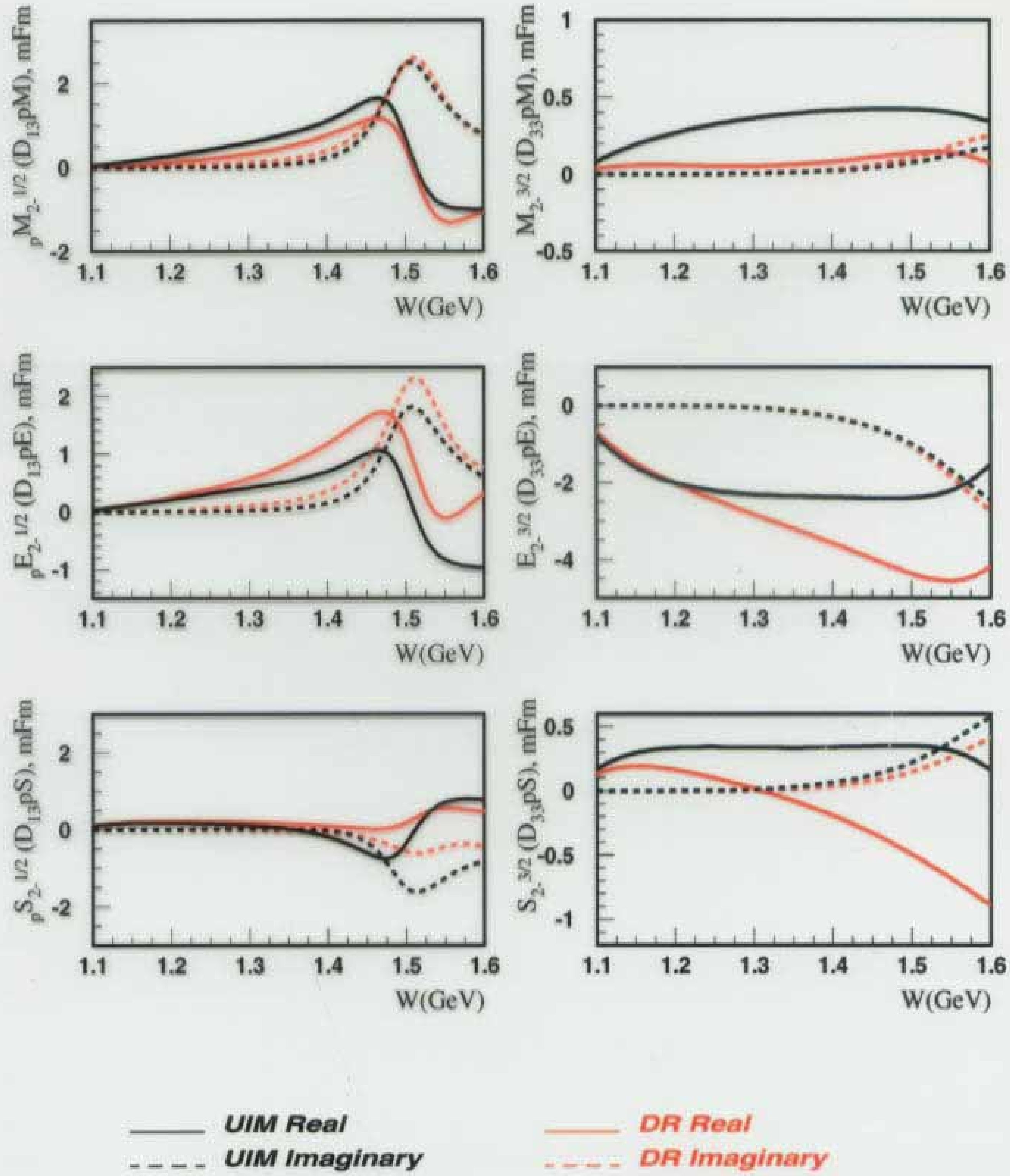
Preliminary Results for $D_{13}(1520)$



- *JANR and DR analysis results for $A_{1/2}$ and $A_{3/2}$ agree. $S_{1/2}$ is model dependent.*
- *The difference between two methods reflects the model dependence.*
- *Reasonable agreement with the existing data.*
- *Helicity amplitudes are obtained using:*

$$\Gamma_{tot} = 110\,MeV, \frac{\Gamma_\pi}{\Gamma_{tot}} = 0.6.$$

Multipoles for $D_{13}(1520)$



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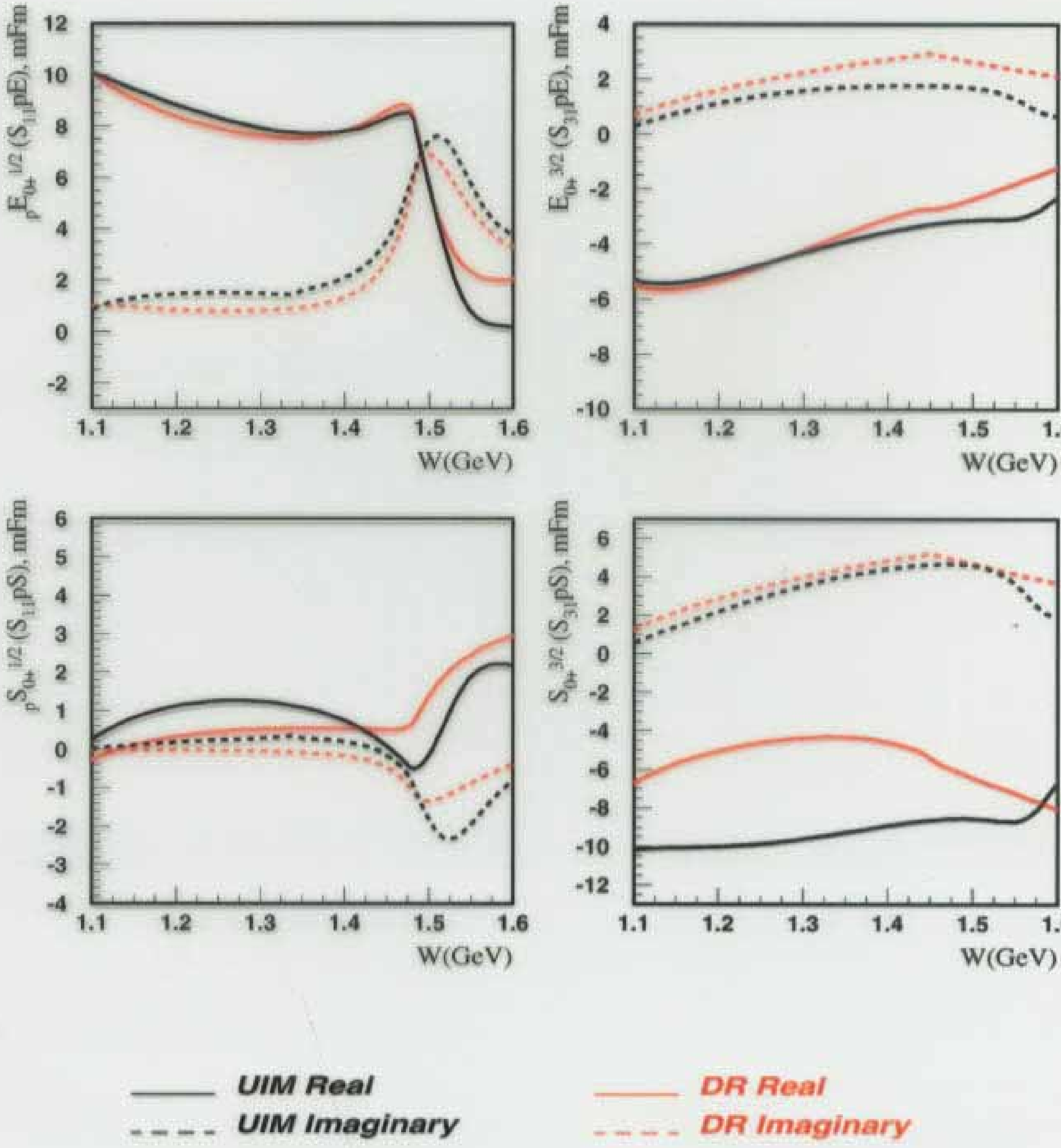
Multipoles for $S_{11}(1535)$



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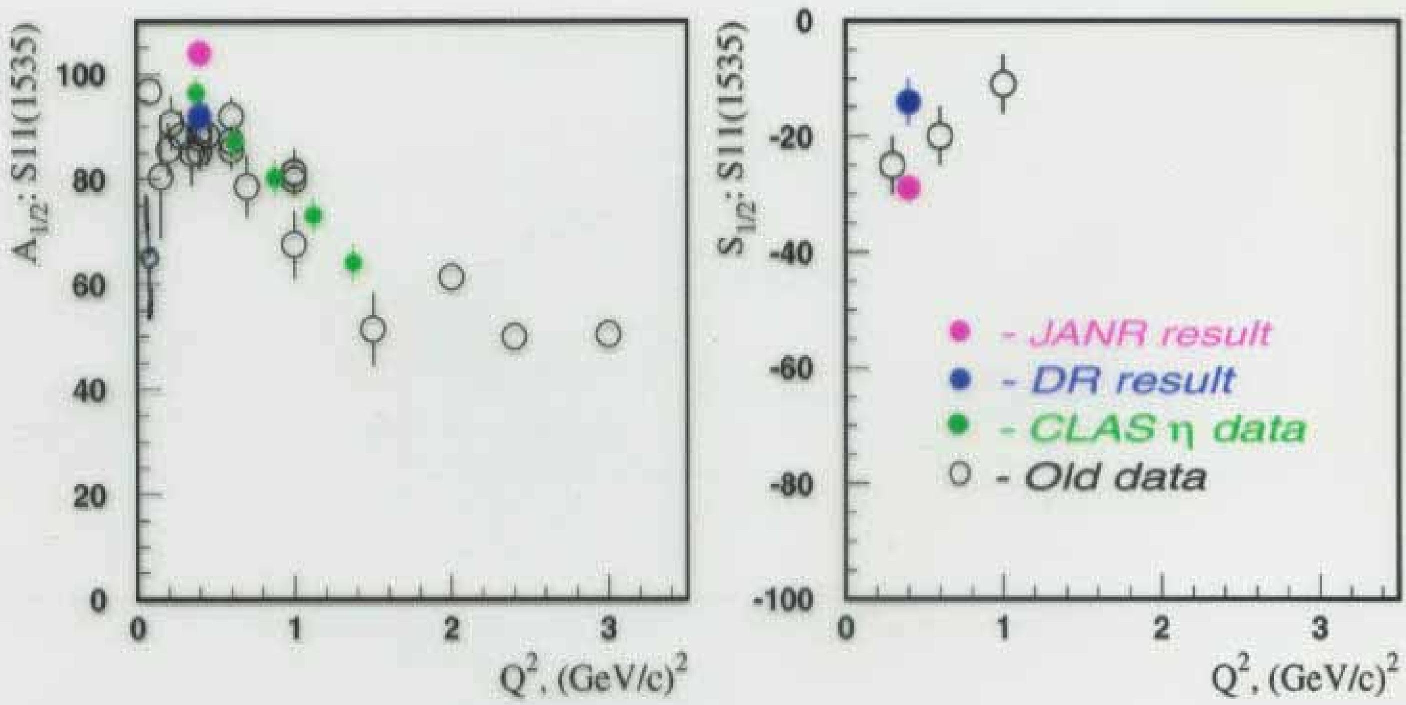
Preliminary Results for $S_{11}(1535)$

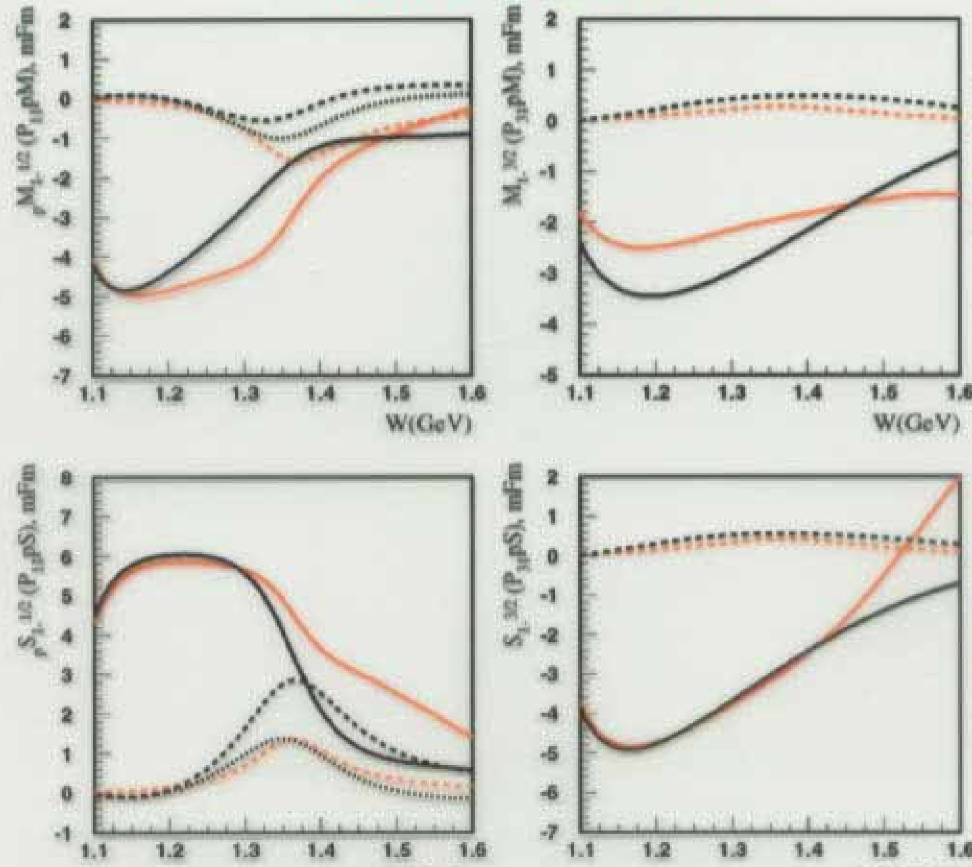


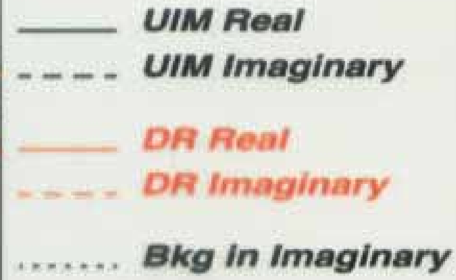
- *JANR and DR analysis results for $A_{1/2}$ agree, while $S_{1/2}$ is model dependent.*
- *The difference between two methods reflects the model dependence.*
- *Reasonable agreement with existing data from η-production channel.*
- *Helicity amplitudes are obtained using:*

$$\Gamma_{tot} = 150\,MeV,\ \frac{\Gamma_\pi}{\Gamma_{tot}} = 0.45.$$

Multipoles for $P_{11}(1440)$

CLAS Electroproduction

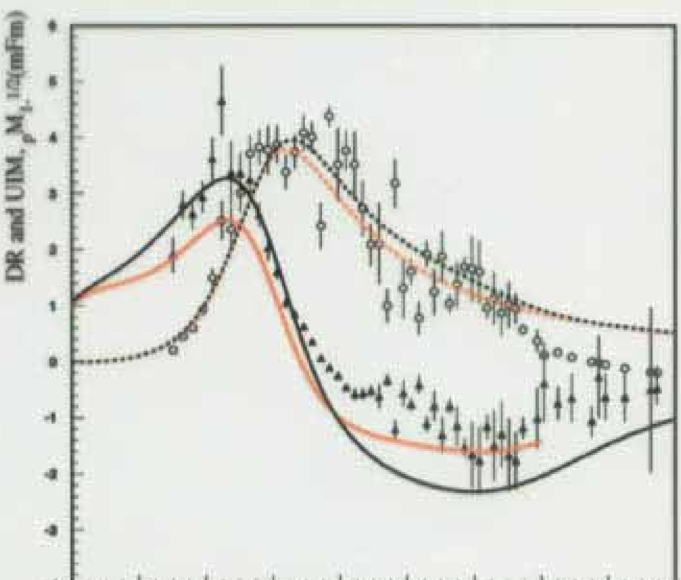




The background is very large compared to resonance part. Discrepancy in JANR and DR is due to the difference in the non-resonant background

Photoproduction

In case of photoproduction the real parts are not so big, meaning that nonresonant part in imaginary part is also significantly smaller than in case at Q^2=0.4 GeV^2.



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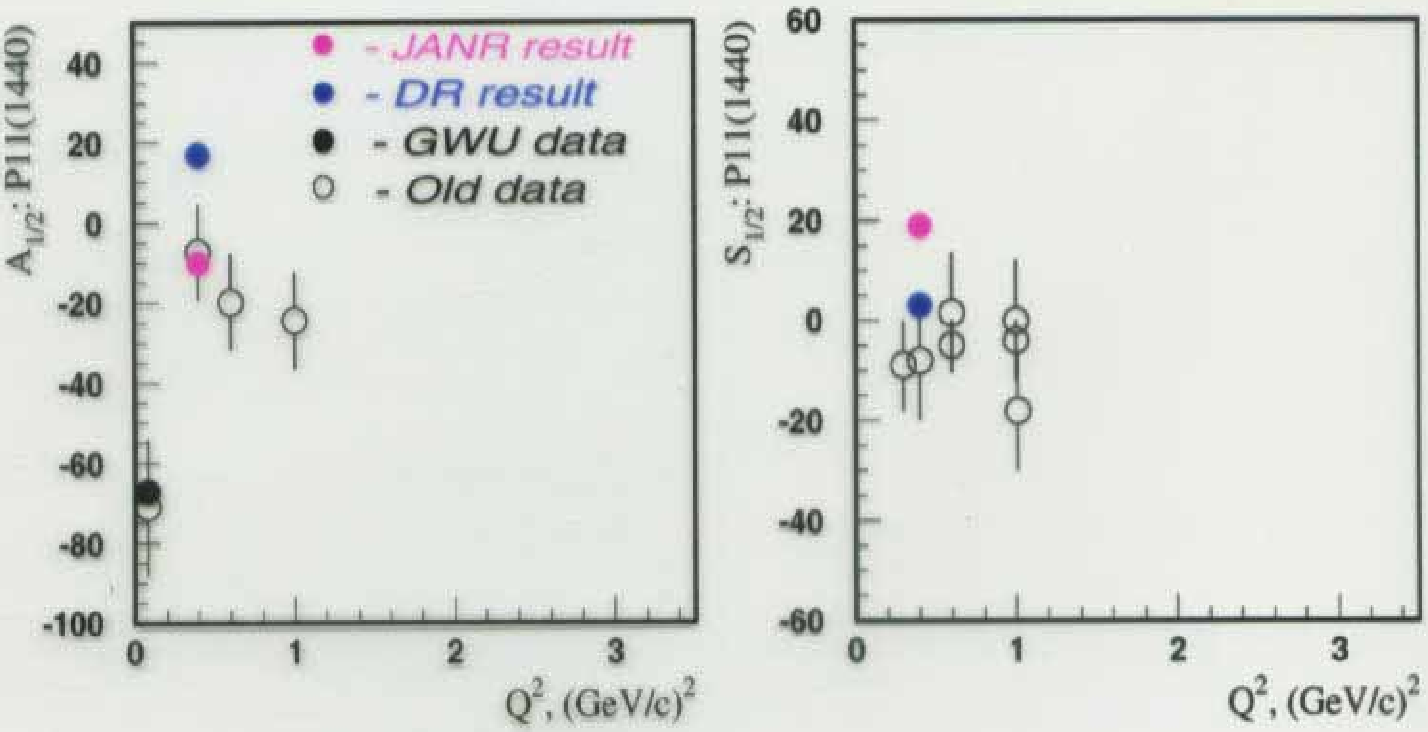
Preliminary Results for $P_{11}(1440)$



- *Both $A_{1/2}$ and $S_{1/2}$ amplitudes are small at Q^2=0.4 GeV^2.*
- *JANR and DR analysis results for $A_{1/2}$ and $S_{1/2}$ disagree, indicating strong model dependence for extraction of both amplitudes.*
- *Helicity amplitudes are obtained using:*

$\Gamma_{tot} = 350$ *MeV*, $\frac{\Gamma_\pi}{\Gamma_{tot}} = 0.7$.

Summary

- *The π^+ and π^0 cross section and beam SSA data from CLAS were fit to obtain the resonant amplitudes for $P_{11}(1440)$, $D_{13}(1520)$ and $S_{11}(1535)$.*
- *Results from the two approaches for the $S_{11}(1535)$ $A_{1/2}$ amplitude are close, and are in good agreement with the results of η–meson electroproduction. The $S_{1/2}$ amplitude is found to be small and extraction model dependent.*
- *Results from two approaches for $A_{1/2}$ and $A_{3/2}$ for $D_{13}(1520)$ state agree, and are in reasonable agreement with the existing data. The $S_{1/2}$ amplitude is model dependent.*
- *The $P_{11}(1440)$ $A_{1/2}$ helicity amplitude at Q^2=0.4GeV^2 appears to be much smaller than for photoproduction. $S_{1/2}$ amplitude is found to be small. The values for the resonant multipoles are difficult to extract due to large nonresonant background.*
- *Comparison with the dispersion relations analysis provides an estimate for model dependencies for the amplitudes.*