# ``Single pion electroproduction off protons in the second and third resonance regions with CLAS"

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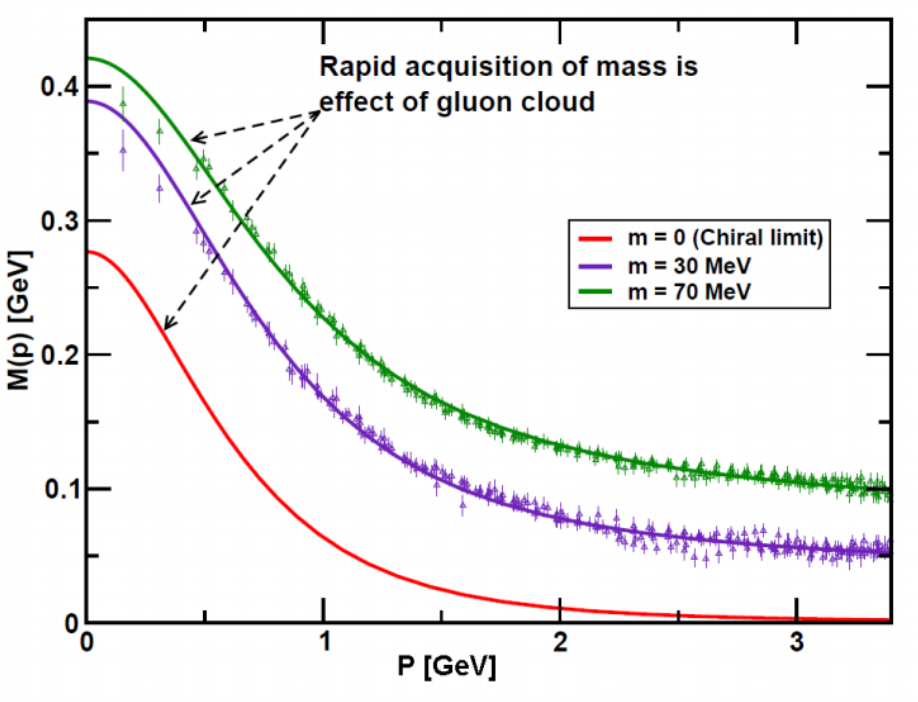
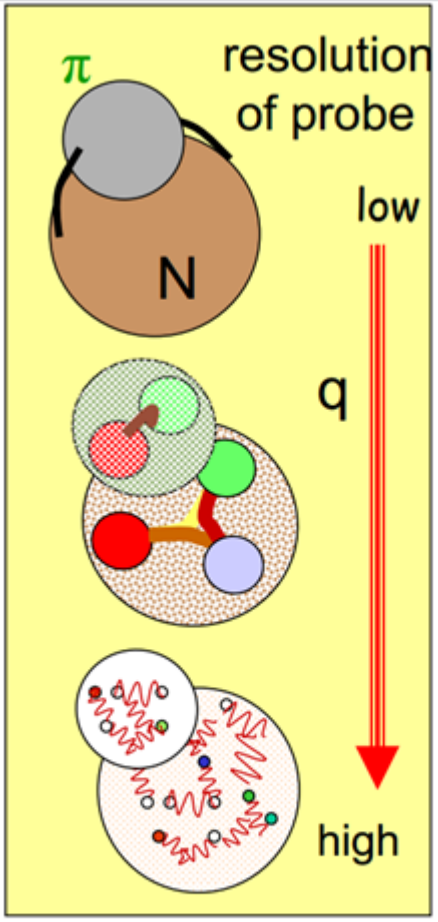
# Motivation to Study N*

- Study of the strong interaction in the non-perturbative regime;
- Particular feature of the strong interaction in non-perturbative regime is generation of effective dressed quarks and gluons with momentum dependent mass;
- More than 98% of dressed quark and hadron masses are generated non-perturbatively through dynamical chiral symmetry breaking (DCSB).
- The Higgs mechanism accounts for less than 2% of the nucleon & N* mass, and is irrelevant for the hadrons of light quarks




- Momentum dependence of the dressed quark mass elucidate the emergence of quark/hadron mass and quark gluon confinement;
- Can be explored from the $Q^2$ evolution of N* electrocouplings.

# Complexity of the Nucleon Resonance Structure




Spatial resolution ~1/q

- Studies of $Q^2$ evolution of $N^*$ electrocouplings allows us to elucidate relevant degrees of freedom in $N^*$ structure offering access to dressed quark mass function;
- We already have extensive data on the low lying resonances with masses below 1.6 GeV. However, states from third resonance region are less explored;
- We still have CLAS experimental data on
  N(1675)5/2$^-$
  N(1680)5/2$^+$
  N(1710)1/2$^+$
  only from $\pi^+$n channel and at high photon virtuality $Q^2 > 2$ GeV$^2$.
- We still have published experimental data on
  $\Delta$(1620)1/2$^-$
  and preliminary
  N(1650)1/2$^+$
  N(1720)3/2$^+$
  $\Delta$(1700)3/2$^-$
  only from double pion channel.

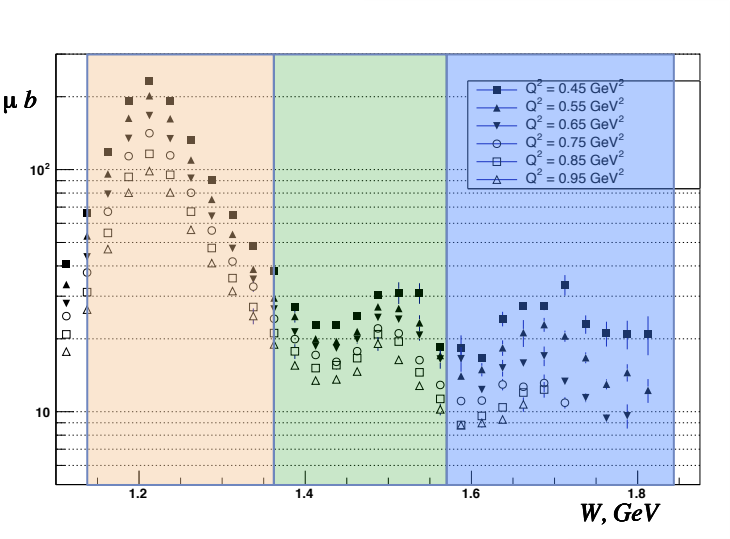
# Coverage of the Resonance region

| |
|---|
| Δ(1232)3/2+ |
| N(1440)1/2+ |
| N(1520)3/2- |
| N(1535)1/2- |
| N(1650)1/2- |
| N(1675)5/2- |
| N(1680)5/2+ |
| N(1710)1/2+ |
| **Δ(1620) 1/2-** |
| **Δ(1700) 3/2-** |

I st resonance region

II nd resonance region

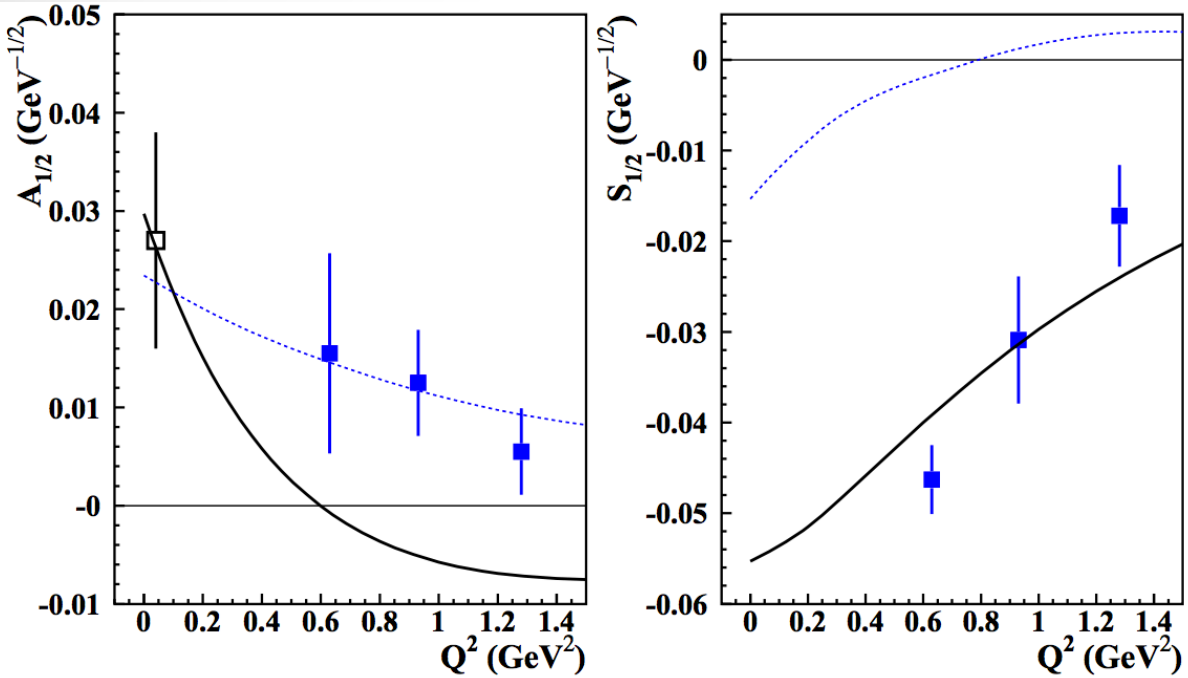
III rd resonance region




Integrated over angles

- For the first time electrocouplings of the resonances in the 3rd resonance region will be available from $\pi^0$ electroproduction;
- For the first time Δ resonances from the third resonance region will be accessible from a single pion channel;
- This study is concentrated on the area of moderate $Q^2$, where MB and quarks degrees of freedom are both important;
- There is an overlap between this data and previous results on low lying resonant states (W < 1.6 GeV), allowing to check procedures of extracting N* parameters.

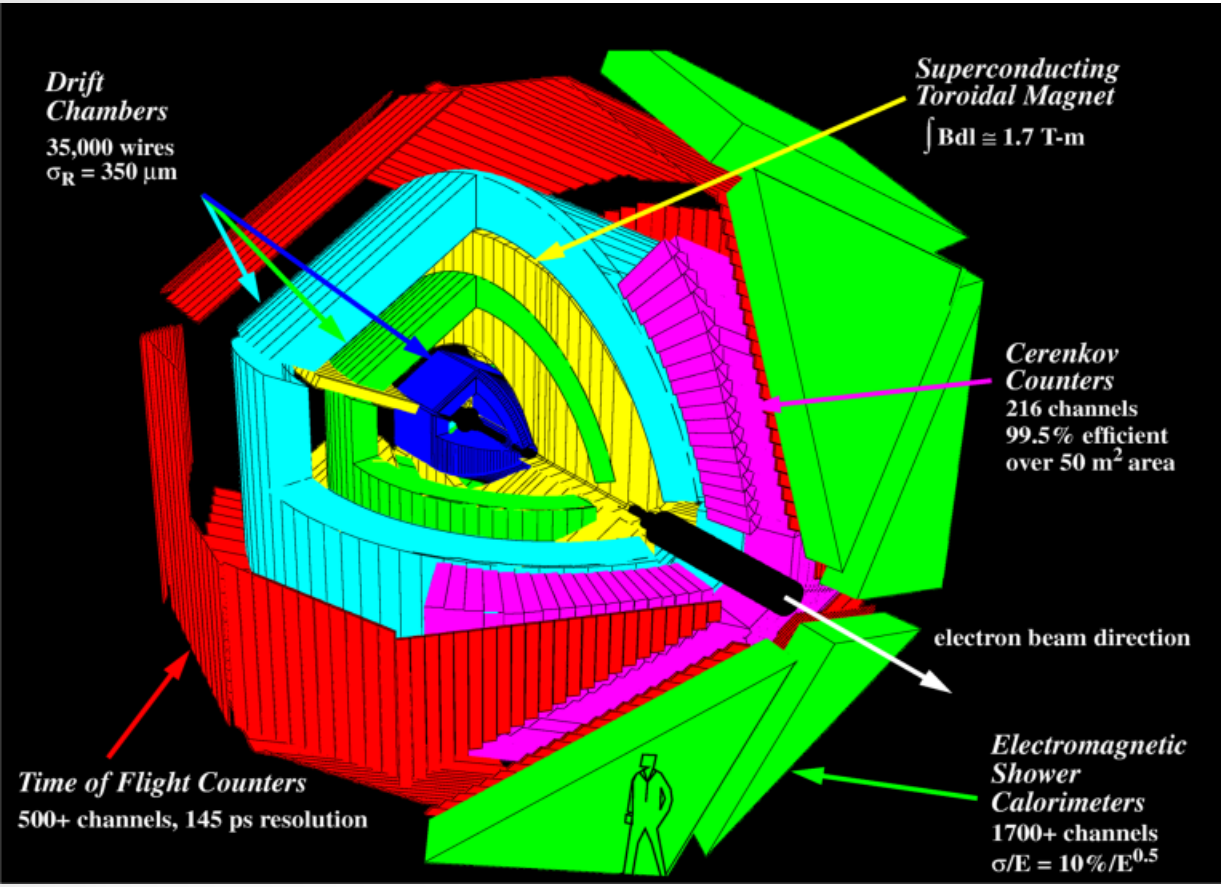
# Peculiarities of the Δ(1620) 1/2⁻




- Obtained from 2 pion channel (BF to Nππ around 80%);
- Only N* that is dominated by the longitudinal $S_{1/2}$ amplitude for 0.5 GeV$^2$ < $Q^2$ < 1.5 GeV$^2$
- hypercentral constituent quark model and Bethe-Salpeter approach describe only one of two amplitudes

Data points: V. Mokeev et al, Phys Rev c93, 025706(2016)
blue line: M. Ronninger and B. Ch. Metsch, Eur. Phys J. A 49, 8(2012).
black line: E. Santopinto and M.M. Giannini, Phys. Rev. C 86,065202 (2012).

# Experiment




- $4\pi$ acceptance
- Possibility to detect multiple neutral and charged particles in the final state
- High energy and timing resolution

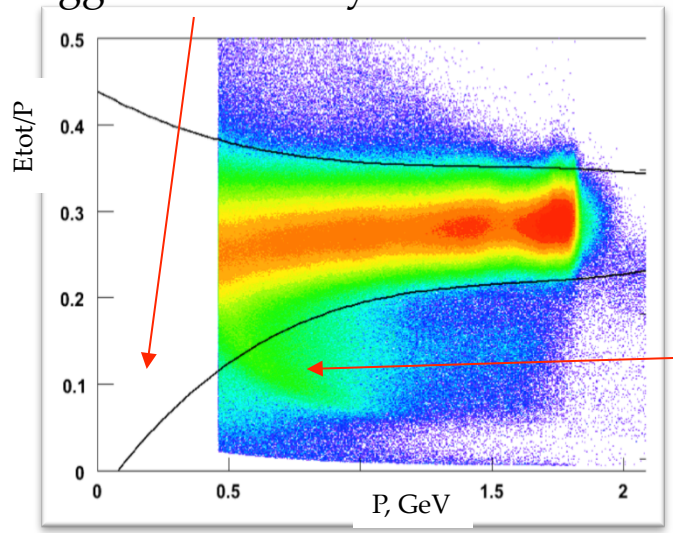
- Beam energy: 2.036 GeV
- Beam polarization: ~ 70%
- Target: Liquid Hydrogen
- Number of triggers: $1.5*10^9$
- Number of $ep\pi^0$ events: 10M

# Data Analysis

- Electron ID
- Proton ID
- Final state selection
- Acceptance correction
- Radiative corrections
- Bin centering corrections

**e $\pi^-$ separation**

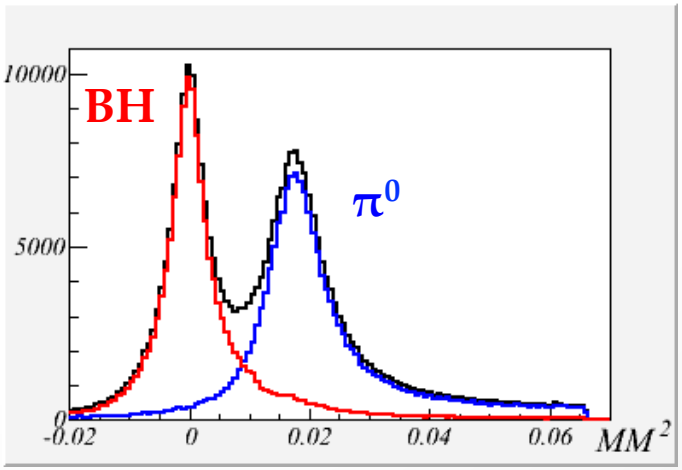
trigger inefficiency



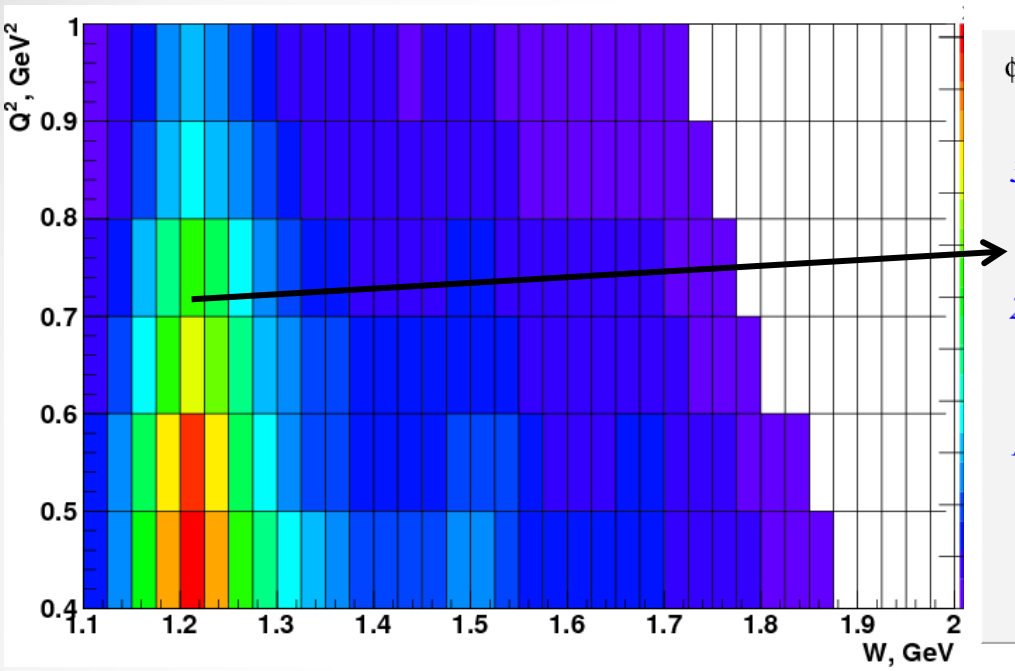

$\pi^-$ contamination

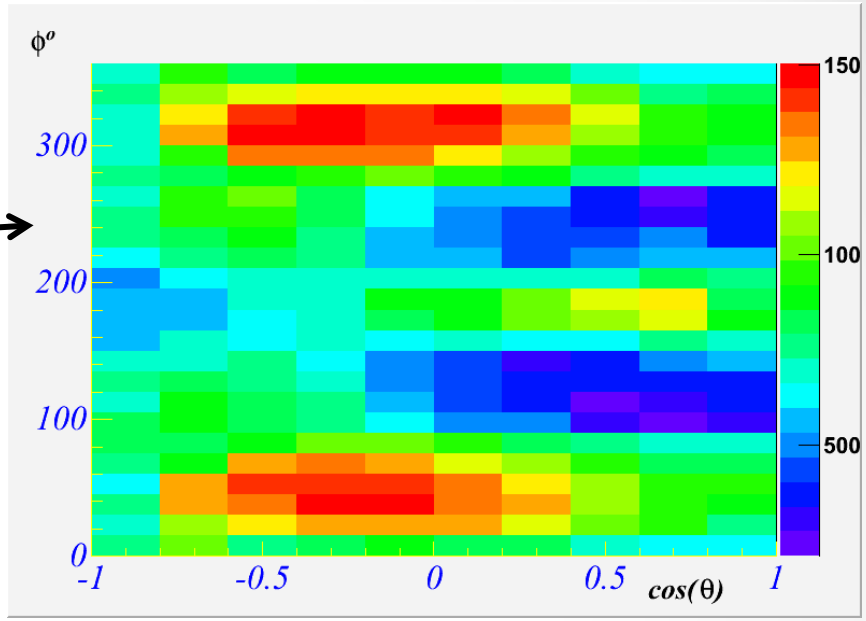
0.461

**Event selection**



# Binning ep->ep$\pi^0$



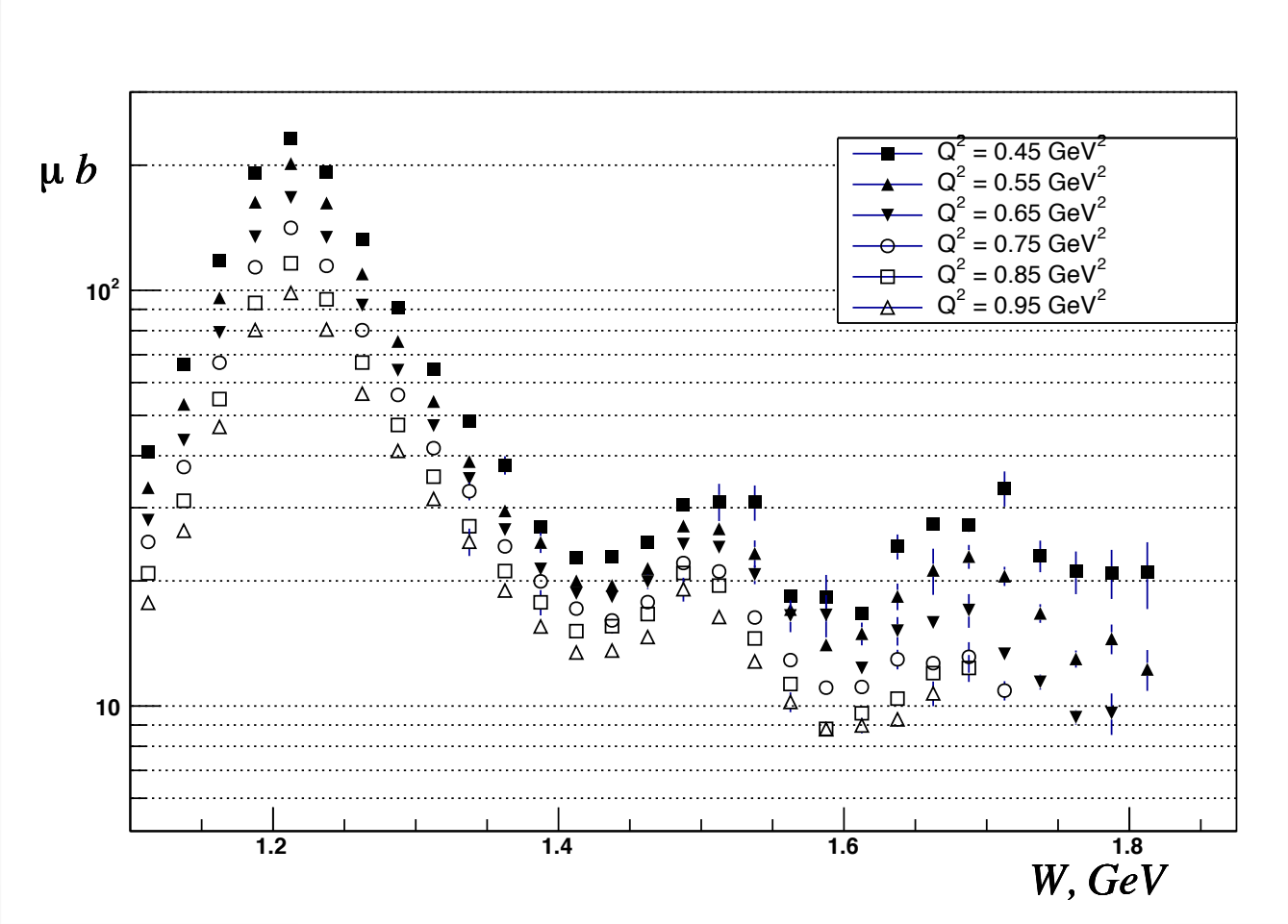

Wide kinematical coverage

Nearly full angular coverage

| | Bin size | Number of bins | Low edge | High edge |
|---|---|---|---|---|
| W | 25 MeV | 28 | 1.1 | 1.8 |
| $Q^2$ | 0.1 $GeV^2$ | 6 | 0.4 | 1.0 |
| $Cos\theta^*_{\pi^0}$ | 0.2 | 10 | -1 | 1 |
| $\phi^*_{\pi^0}$ | 15° | 24 | 0 | 360 |

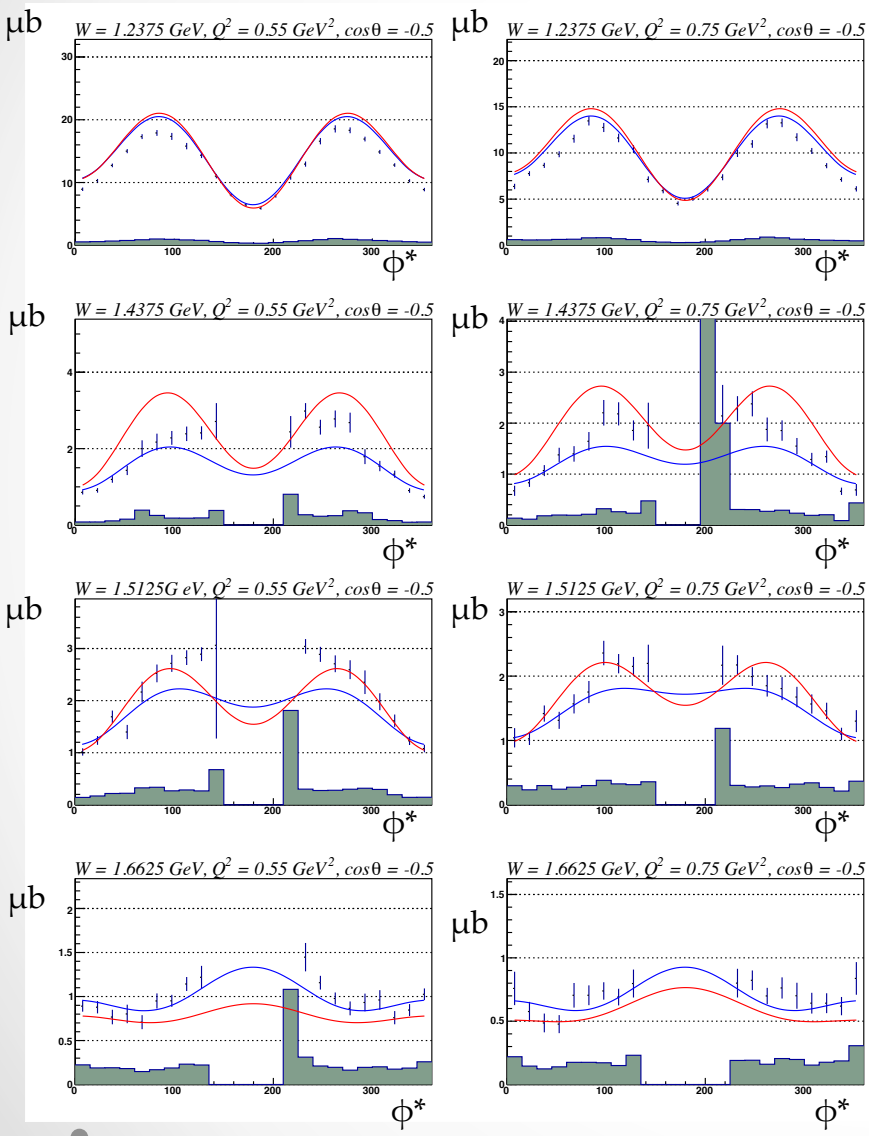
Number of bins = 40320

# Fully Integrated Cross Sections




Covering first, second and third resonance region
Three resonance regions are prominent in all 6 $Q^2$ bins

# $d\sigma/d\Omega_{\pi^0 CM}$ Differential Cross Section




Data
MAID07 (Eur.Phys.J. A34 (2007) 69-97)
JANR (Phys. Rev. C 78, 045209 (2008) )

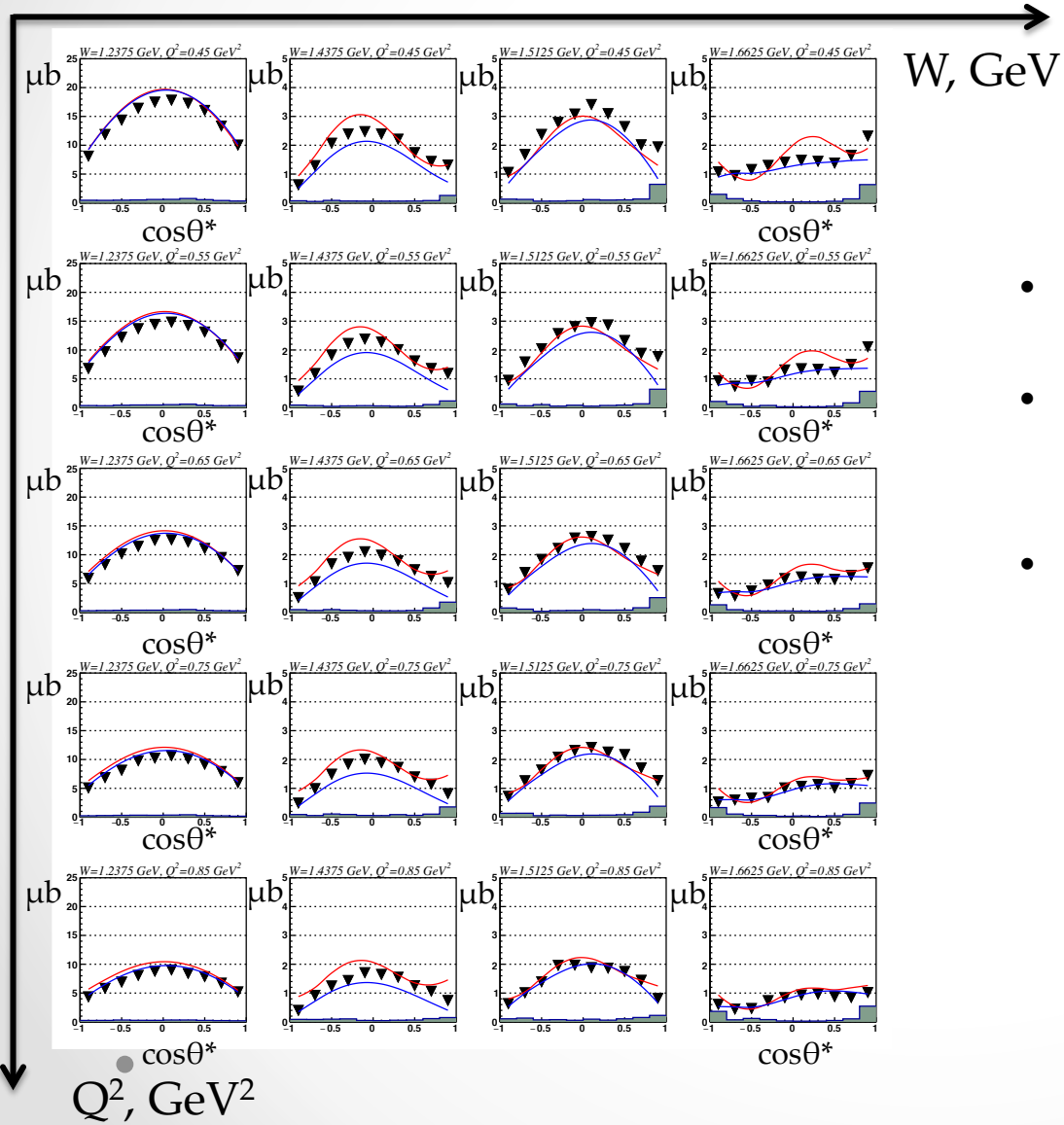
MAID07: default parameters

JANR: code by I. Aznauryan with resonance electrocouplings from the empiric fit to data on resonance electrocouplings by E. Isupov (userweb.jlab.org/~isupov/couplings/).

- Models capture the major features throughout the full kinematical range, good agreement in well known Δ region
- High statistics even at high W values

Spikes in systematical error correspond to bins with low statistics

# Unpolarized Structure Functions

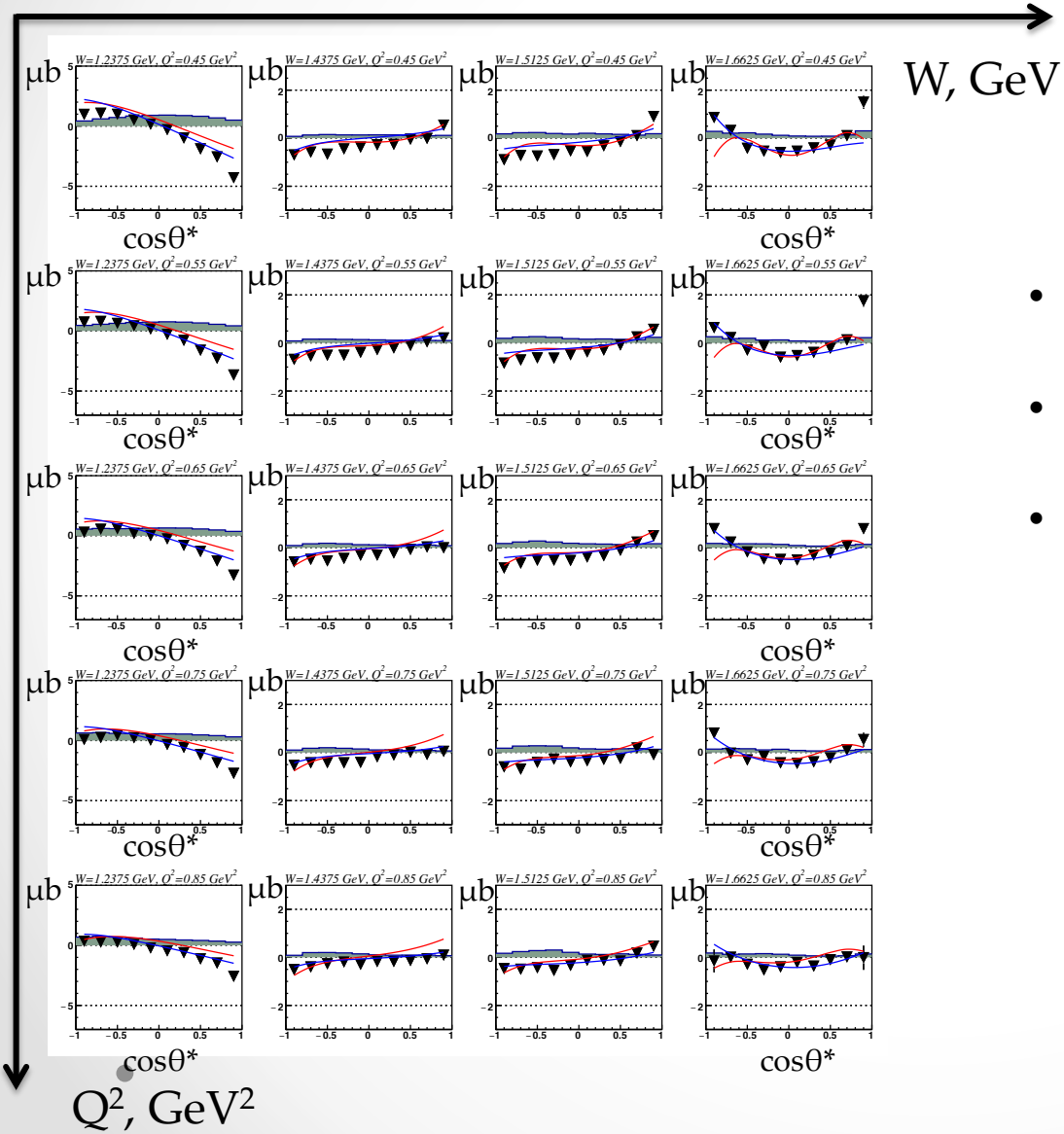



$$\frac{d\sigma_U}{d\cos\theta^*_{\pi^0\,CM}}$$

Data
MAID07
JANR

- Good agreement in the Δ region for both models;
- In the second resonance region JANR seems to have a minor advantage, especially at higher $Q^2$;
- In the third resonance regions models should be further adjusted to the experimental data.

# Unpolarized Structure Functions

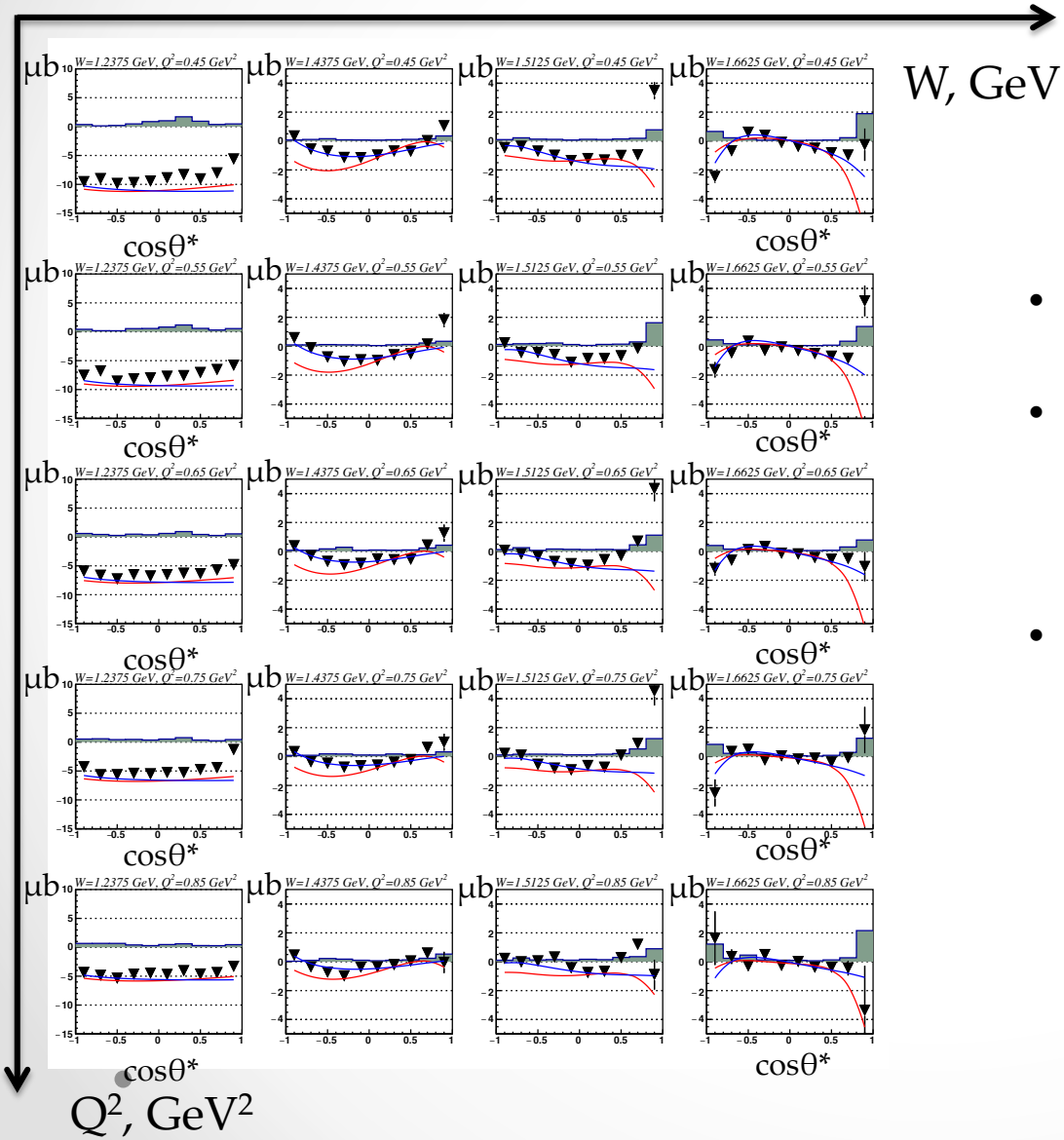



$$\frac{d\sigma_{LT}}{d\cos\theta^*_{\pi^0\,CM}}$$

Data
MAID07
JANR

- Good agreement in the Δ region for both models;
- Good agreement in the second resonance region;
- Decent agreement in the third resonance region with discrepancy at extreme values of cosθ.

# Unpolarized Structure Functions

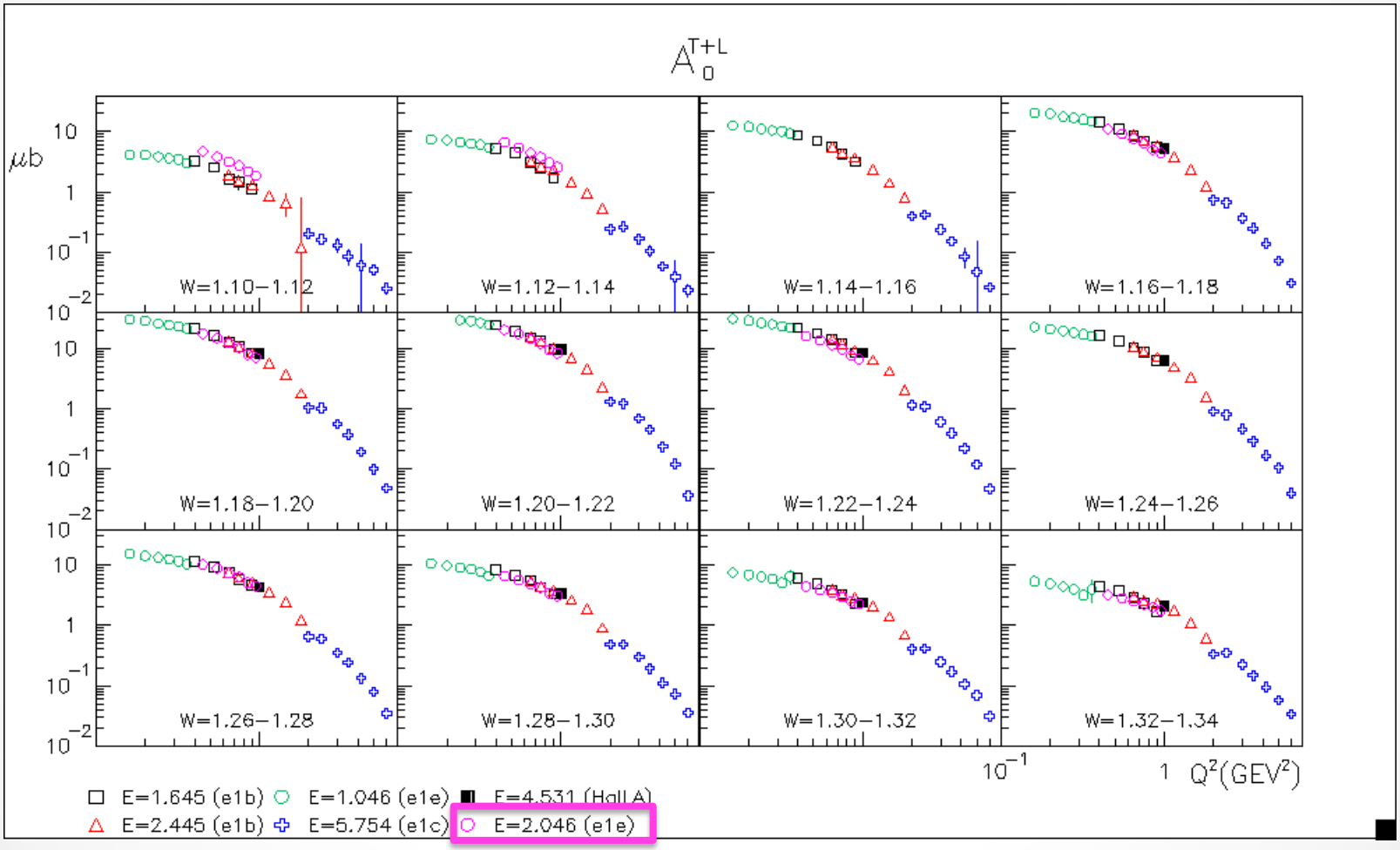



$$\frac{d\sigma_{TT}}{d\cos\theta^*_{\pi^0\,CM}}$$

Data
MAID07
JANR

- Decent agreement in the Δ region for both models
- In the second resonance region MAID 07 seems to have some advantage, both models need to be further adjusted;
- In the third resonance regions MAID 07 seems to have some advantage, both models need to be adjusted.

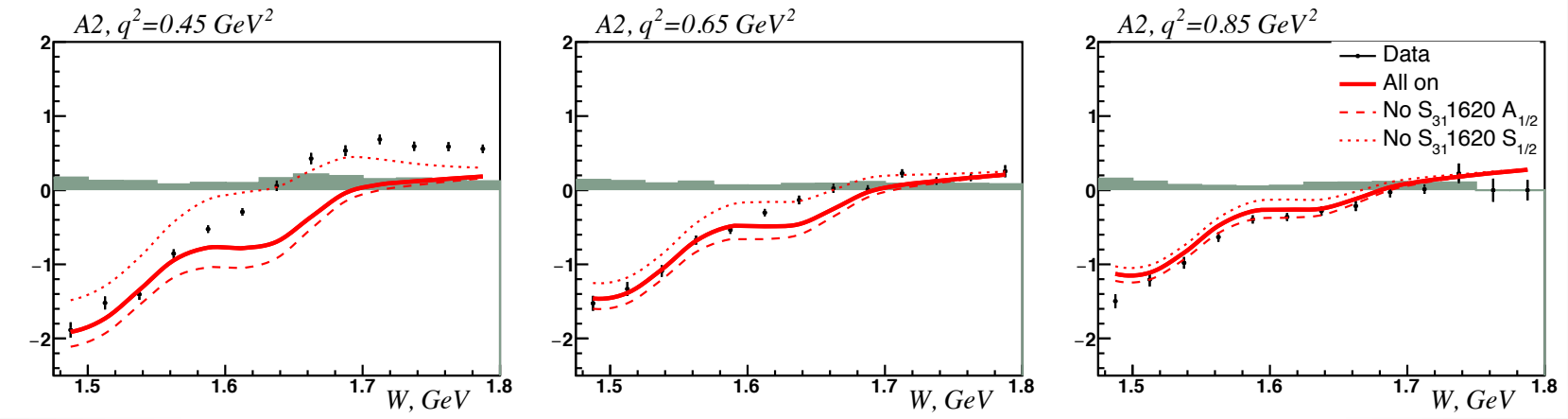
# Comparison to Available Data




- Results are consistent with previously available data in the Δ region and beyond

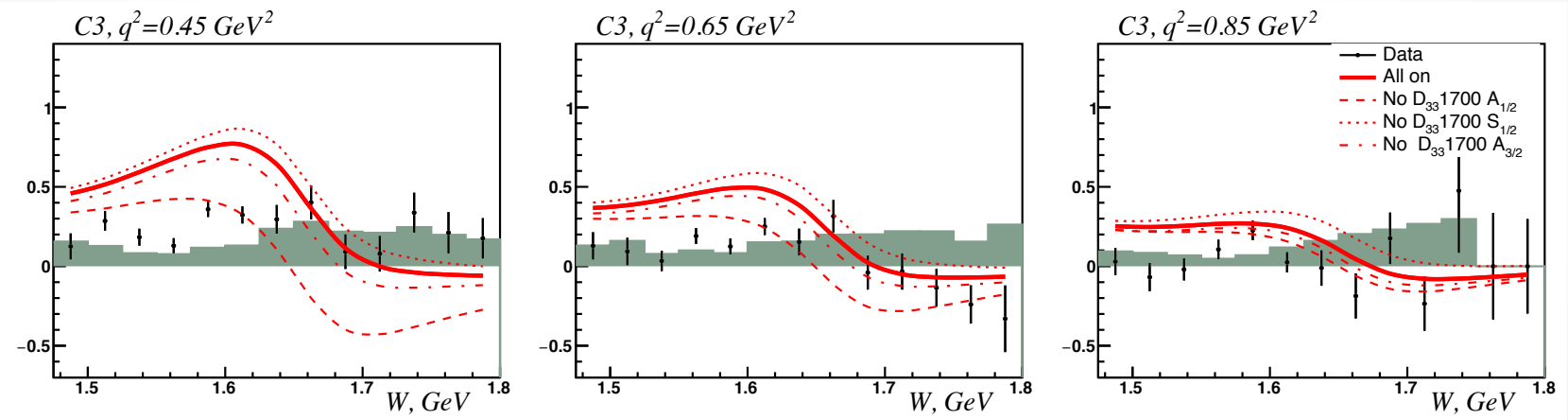
# Sensitivity to Resonances

## $S_{31}(1620)$



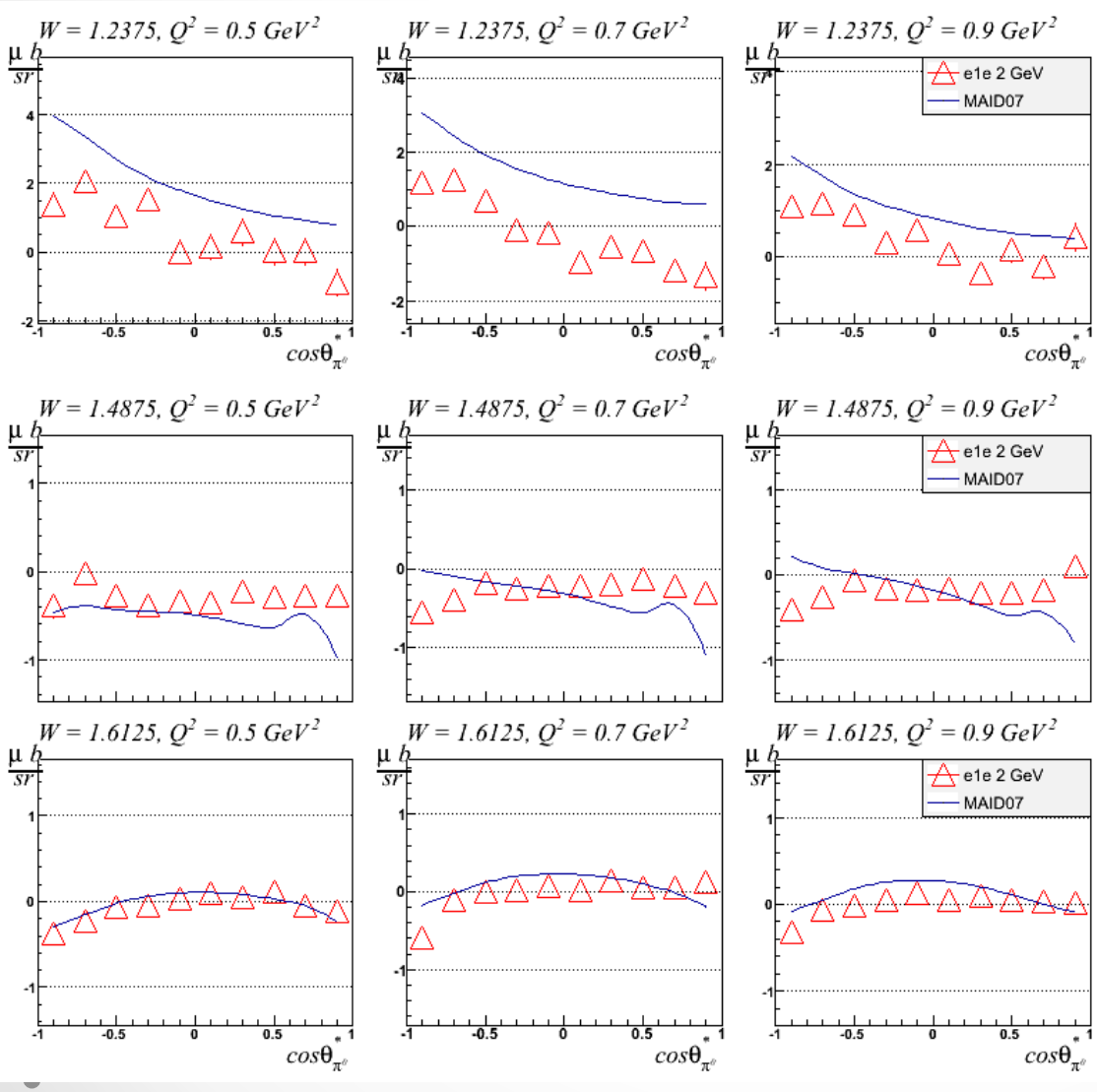

Very sensitive to $S_{1/2}$ at low $Q^2$
Hint to overestimation at low $Q^2$

## $D_{33}(1700)$




Very sensitive to the $A_{1/2}$

# Polarization Observables




$$\frac{d\sigma_{LT'}}{d\cos\theta^*_{\pi^0 CM}}$$

- This observable is sensitive to interference between different resonances, resonances and background and between different background terms;
- Relatively coarse $Q^2$ binning is important to pick up a small signal.

# Conclusion

- For the first time, differential $\pi^0$ electroproduction cross section and beam spin asymmetry are measured in wide $Q^2$ (0.4 – 1.0 $GeV^2$) and W (1.1 – 1.8 GeV) range;
- Exclusive electroproduction structure functions $d\sigma_U/d\Omega_{\pi^0 CM}$, $\sigma_{TT}/d\Omega_{\pi^0 CM}$, $\sigma_{LT}/d\Omega_{\pi^0 CM}$ and $\sigma_{LT'}/d\Omega_{\pi^0 CM}$ have been extracted;
- Comparison with models (MAID07, JANR) and multipole decomposition demonstrated data sensitivity to the contribution of individual resonances for both N* and Δ* resonances in the third resonance region for states with mass > 1.6 GeV;
- Presented data is ready for the extraction of N* couplings within a framework of JANR for the first time;
- Combined studies of $p\pi^0$ and $\pi^+n$ exclusive electroproduction will allow us to determine electrocouplings of N* and Δ* in the third resonance region for all states with substantial single pion decays.