SINGLE PION ELECTROPRODUCTION IN THE RESONANCE REGION

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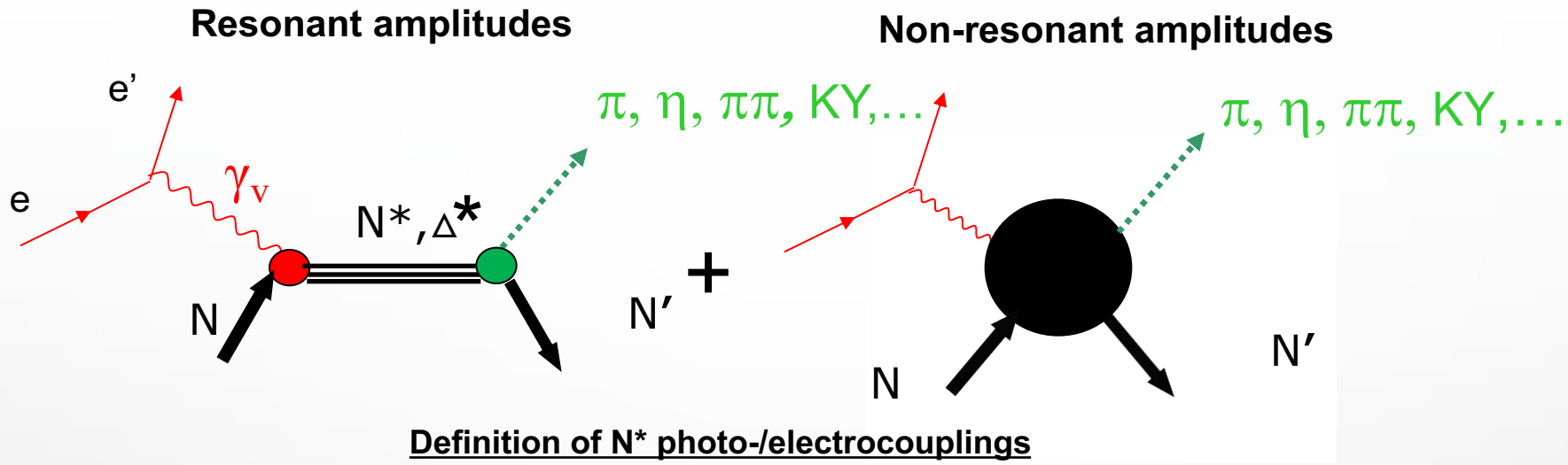
TALK OUTLINE

- MOTIVATION
- POLARIZED STRUCTURE FUNCTION $\sigma_{LT'}$ FROM ep->epπ^0 (E1E CLAS)
- preliminary BSA from ep->epπ^0 and ep->enπ^+ (RG-A FALL 2018 CLAS12)
- CONCLUSIONS

Extraction of γ_vNN* Electrocouplings from Exclusive Meson Electroproduction off Nucleons



Definition of N* photo-/electrocouplings employed in the CLAS data analyses:

- Real $A_{1/2}(Q^2)$, $A_{3/2}(Q^2)$, $S_{1/2}(Q^2)$

I.G. Aznauryan and V.D. Burkert, Prog. Part. Nucl. Phys. 67, 1 (2012)

$$\Gamma_\gamma = \frac{k^2_{\gamma_{N^*}}}{\pi}\frac{2M_N}{(2J_r+1)M_{N^*}}\left[|A_{1/2}|^2+|A_{3/2}|^2\right]$$

- **Consistent results on γ_vpN* electrocouplings from different meson electroproduction channels are critical in order to validate reliable extraction of these quantities.**

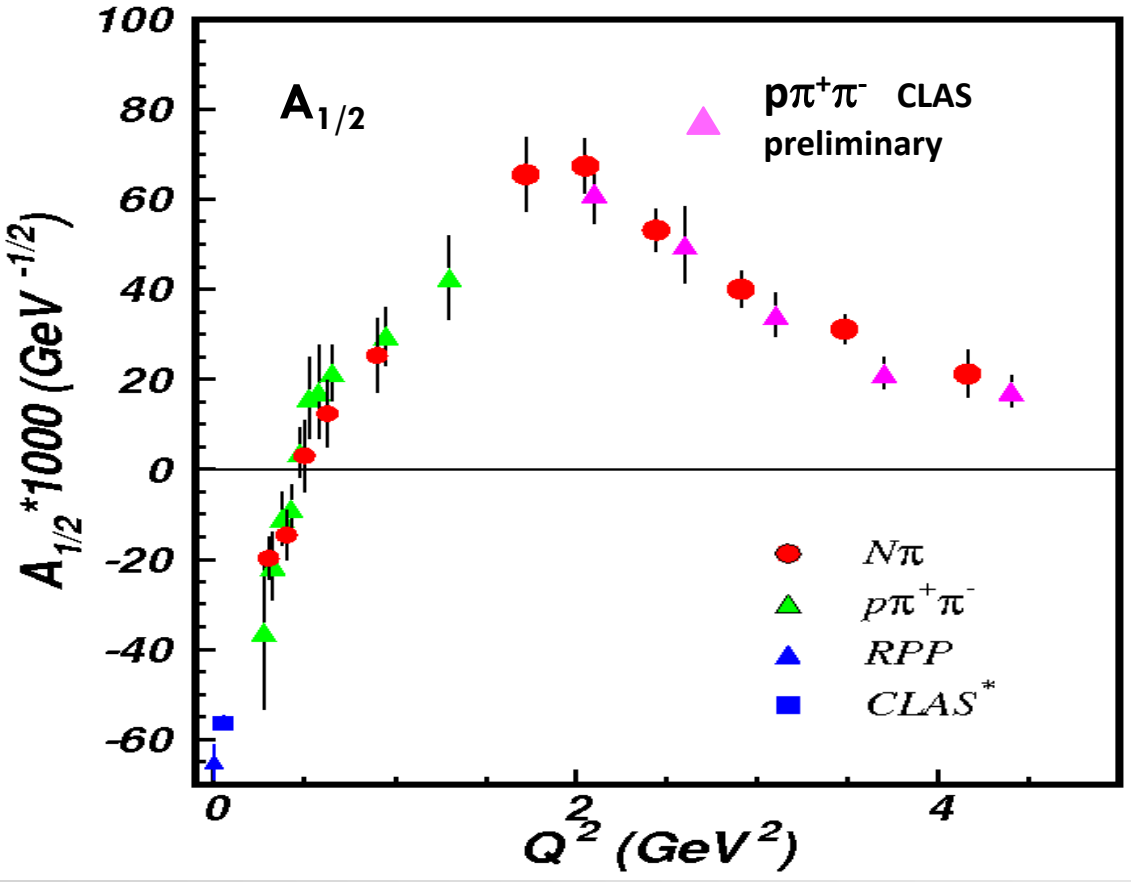
Nπ ELECTROPRODUCTION IN EXPLORATION OF THE NUCLEON RESONANCE ELECTROEXCITATION

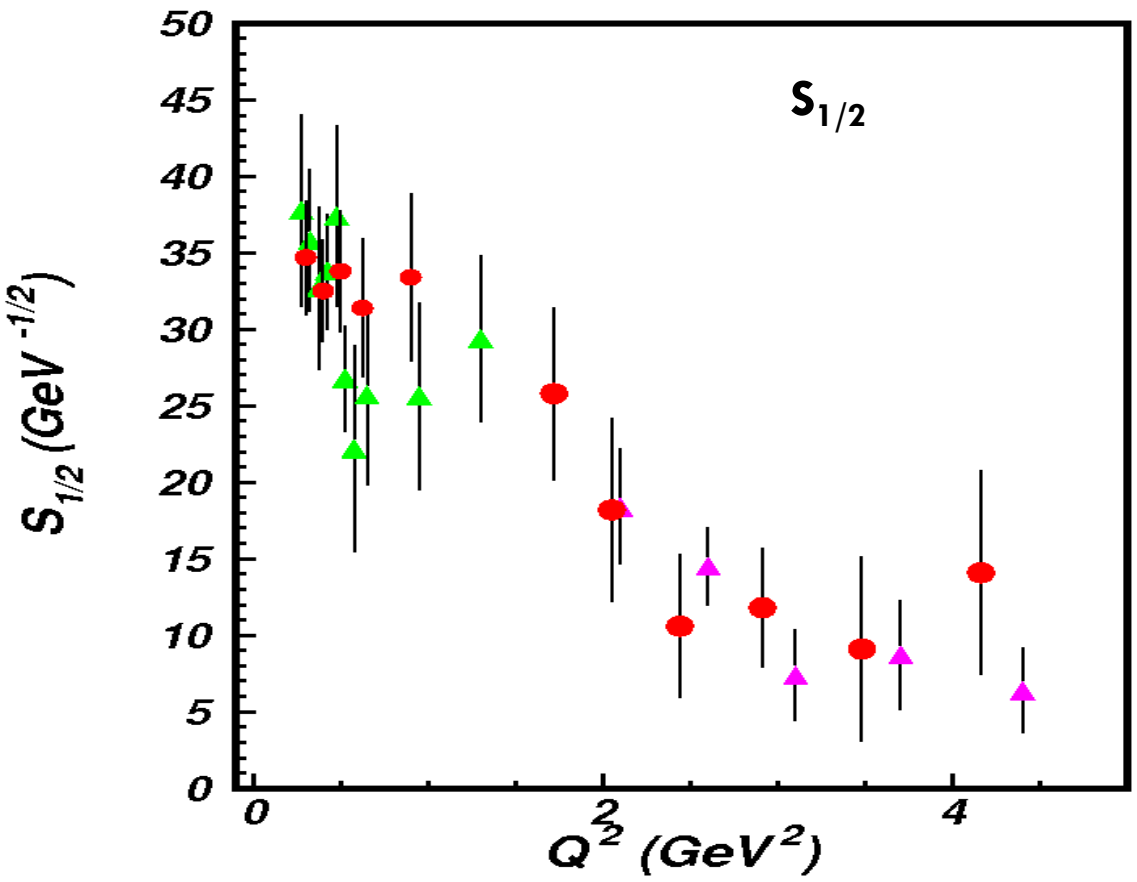
Exclusive $\pi^0 p$ and $\pi^+ n$ channels represent the major source of the information on $\gamma_v pN^*$ electrocouplings of the nucleon resonances in the mass range of $W<1.6$ GeV and for several high-lying N* with the preferential decays to the Nπ final states.

Exclusive meson electroproduction channels	Excited proton states	Q^2-ranges for extracted $\gamma_v pN^*$ electrocouplings, GeV^2
$\pi^0 p$, $\pi^+ n$	$\Delta(1232)3/2^+$	0.16-6.0
	$N(1440)1/2^+$, $N(1520)3/2^-$, $N(1535)1/2^-$	0.30-4.16
$\pi^+ n$	$N(1675)5/2^-$, $N(1680)5/2^+$ $N(1710)1/2^+$	1.6-4.5
ηp	$N(1535)1/2^-$	0.2-2.9
$\pi^+\pi^- p$	$N(1440)1/2^+$, $N(1520)3/2^-$	0.25-1.50 2.0-5.0 (preliminary)
	$\Delta(1620)1/2^-$, $N(1650)1/2^-$, $N(1680)5/2^+$, $\Delta(1700)3/2^-$, $N(1720)3/2^+$, $N'(1720)3/2^+$	0.5-1.5

The website with numerical results and references:
https://userweb.jlab.org/~mokeev/resonance_electrocouplings/

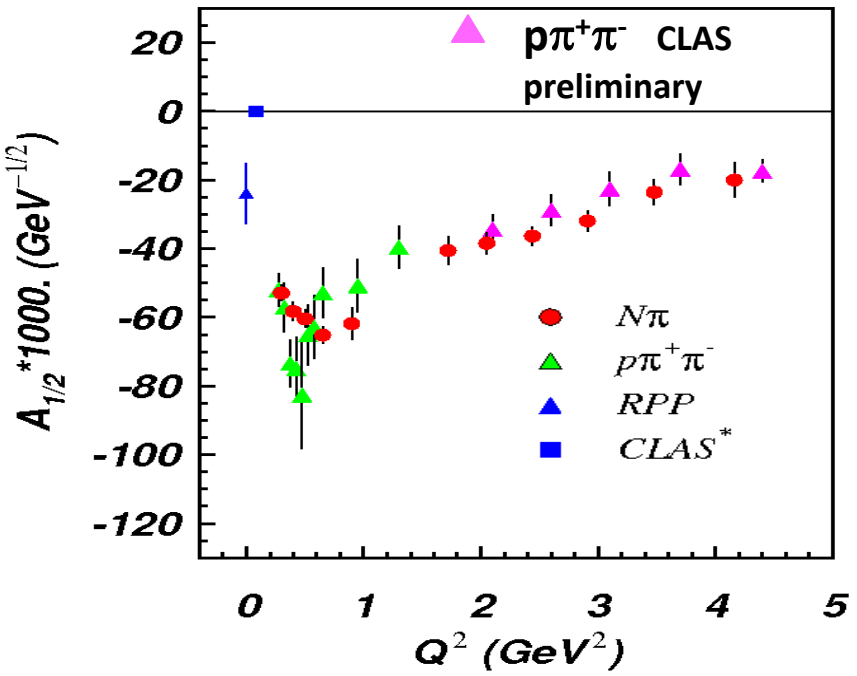
Electrocouplings of N(1440)1/2$^+$ from Nπ and $\pi^+\pi^-$p Electroproduction off Proton Data

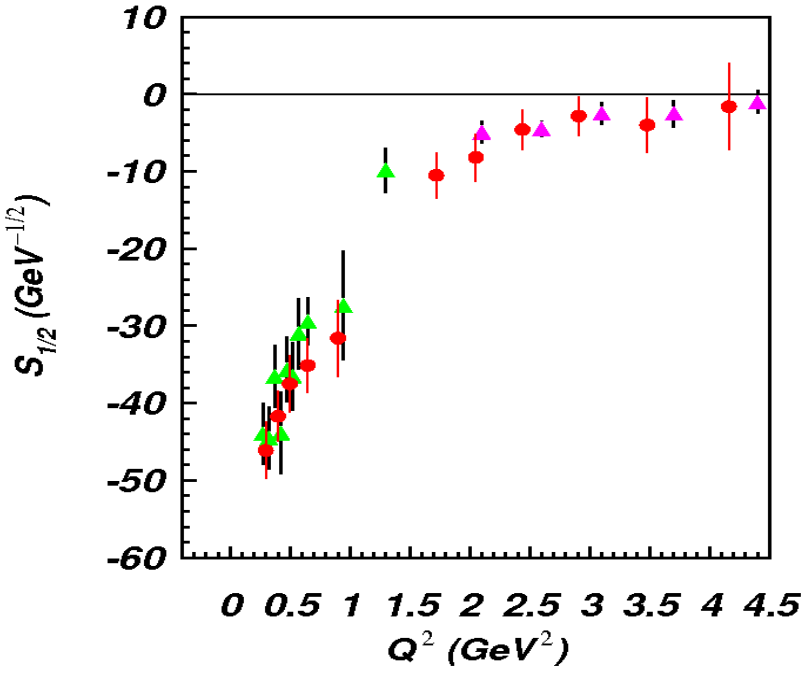


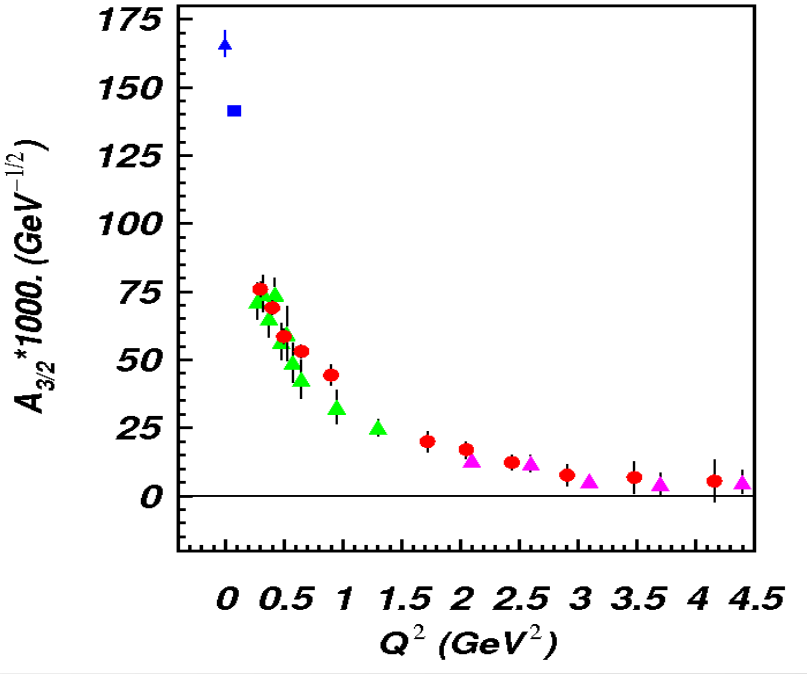


Consistent results on N(1440)1/2$^+$ electrocouplings from the independent studies of two major Nπ and $\pi^+\pi^-$p electroproduction off proton channels with different non-resonant contributions allows us to determine the systematic uncertainties of the results in a nearly model-independent way.

Electrocouplings of N(1520)3/2$^-$ from Nπ and $\pi^+\pi^-$p Electroproduction off Proton Data

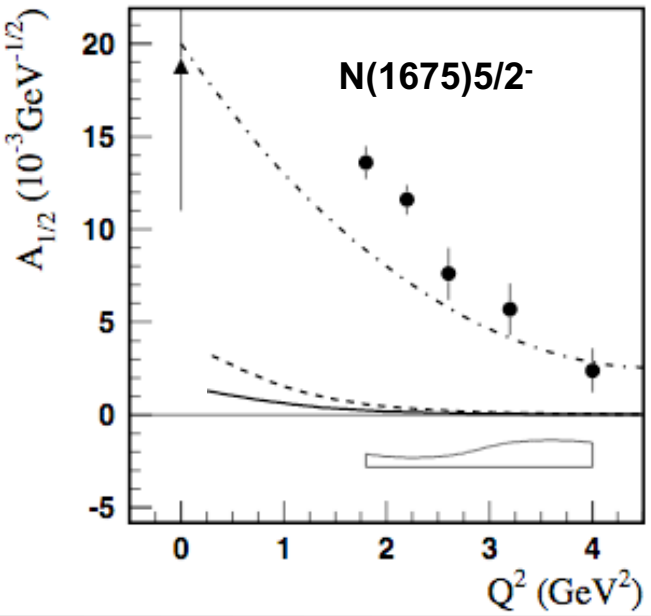


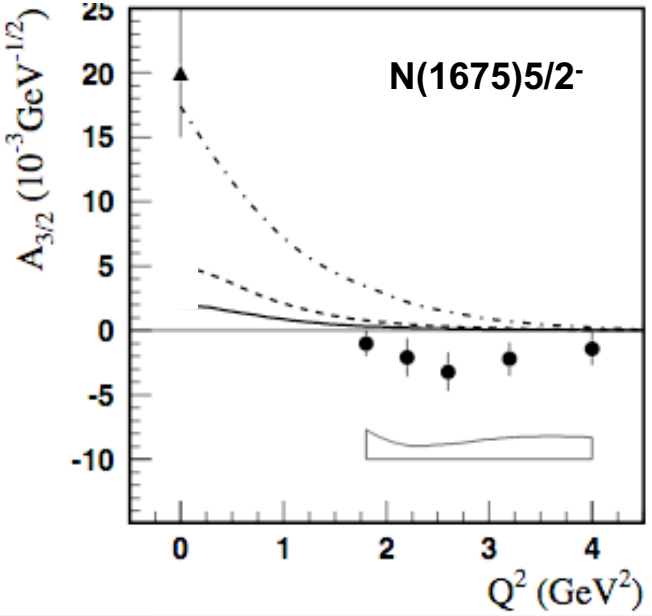




Consistent results from Nπ and $\pi^+\pi^-$p electroproduction off proton data on electrocouplings of N(1440)1/2$^+$ and N(1520)3/2$^-$ resonances support the capabilities of the developed reaction models for credible extraction of resonance electrocouplings from independent analyses of both Nπ and $\pi^+\pi^-$p electroproduction.

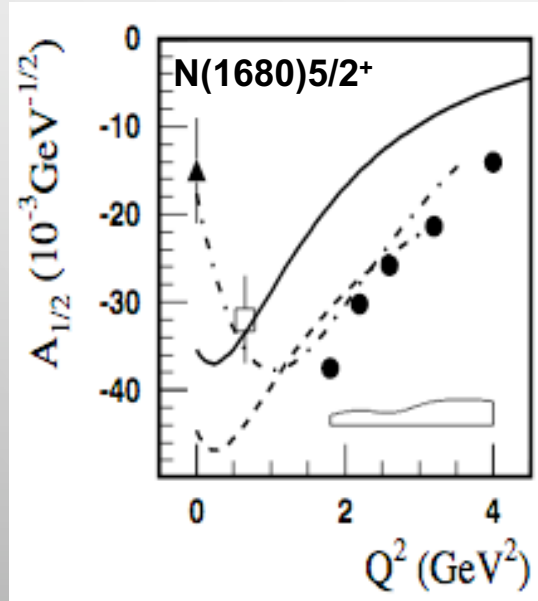
Electrocouplings of High-Lying Resonances from π^+n Electroproduction off Proton Data

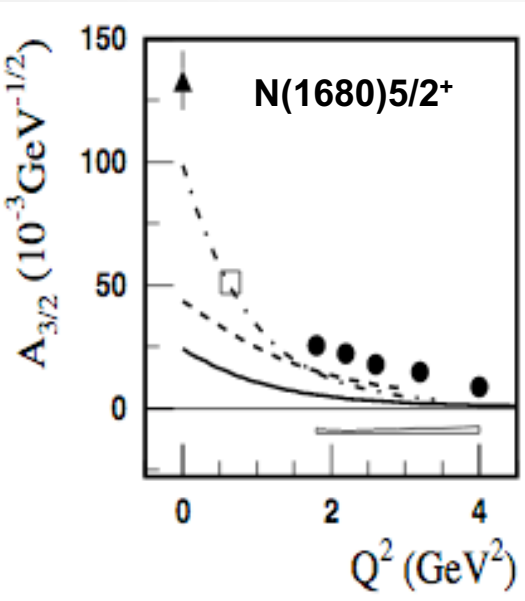


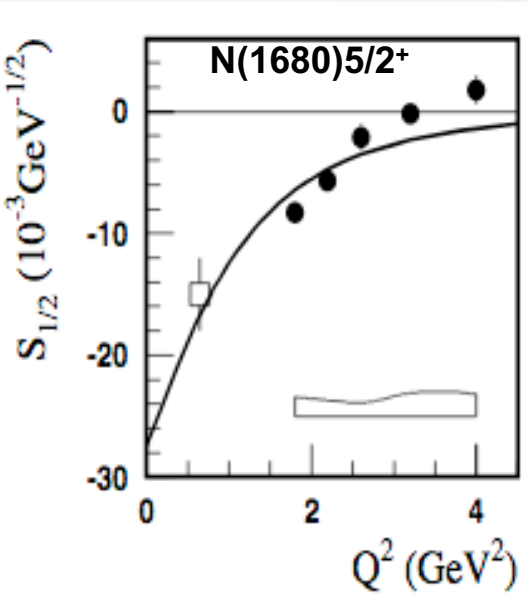


K.Park et al., CLAS Collab.,
Phys. Rev. C91, 045203 (2015).

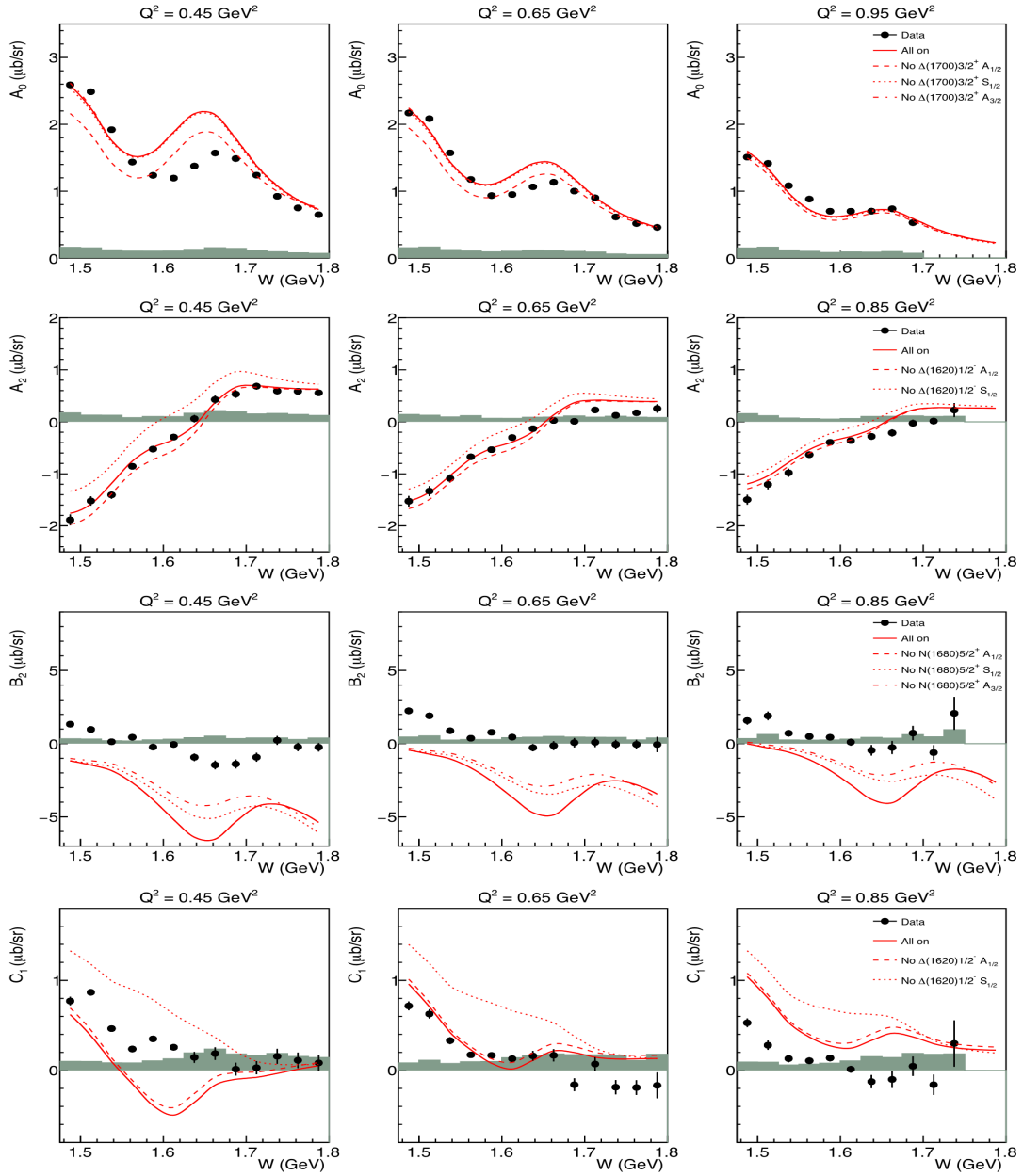
The first results on electrocouplings of N(1675)5/2$^-$, N(1680)5/2$^+$, and N(1710)1/2$^+$ resonances have Become available at 2.0<Q2<5.0 GeV^2 from the CLAS $n\pi^+$ electroproduction data







First Results on $\pi^0 p$ Electroproduction in the Third Resonance Region



Legendre moments

$\Delta(1700)3/2^-$ electrocouplings are turned on/off

$\Delta(1620)1/2^-$ electrocouplings are turned on/off

$N(1680)5/2^+$ electrocouplings are turned on/off

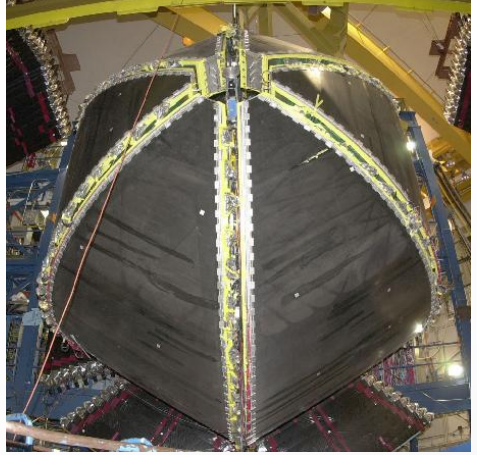
$\Delta(1620)1/2^-$ electrocouplings are turned on/off

N.Markov et al., CLAS Collab., Phys. Rev. C101, 015208 (2020).

Legendre moments demonstrate the sensitivity to electrocouplings of excited nucleon states in the third resonance region.

Combined studies of $p\pi^0$ and $n\pi^+$ electroproduction channels are needed to determine electrocouplings of the resonances in the third resonant region.

E1E RUN



- CLAS detector data 12/2002 – 1/2003
- Beam energy: 2.036 GeV
- Beam polarization: ~ 80%
- Target: Liquid Hydrogen, thickness 2 cm
- Number of triggers: ~ 1.5 billion

$0.4 < Q^2 < 1\ GeV^2$

$1.1 < W < 1.8\ GeV$

PHYSICAL REVIEW C **101**, 015208 (2020)

Exclusive $\pi^0 p$ electroproduction off protons in the resonance region at photon virtualities $0.4\ GeV^2 \leqslant Q^2 \leqslant 1\ GeV^2$

N. Markov,[8,36,*] K. Joo,[8] V. D. Burkert,[36] V. I. Mokeev,[36] L. C. Smith,[41] M. Ungaro,[36] S. Adhikari,[11] M. J. Amaryan,[30]

PHYSICAL REVIEW C **98**, 025203 (2018)

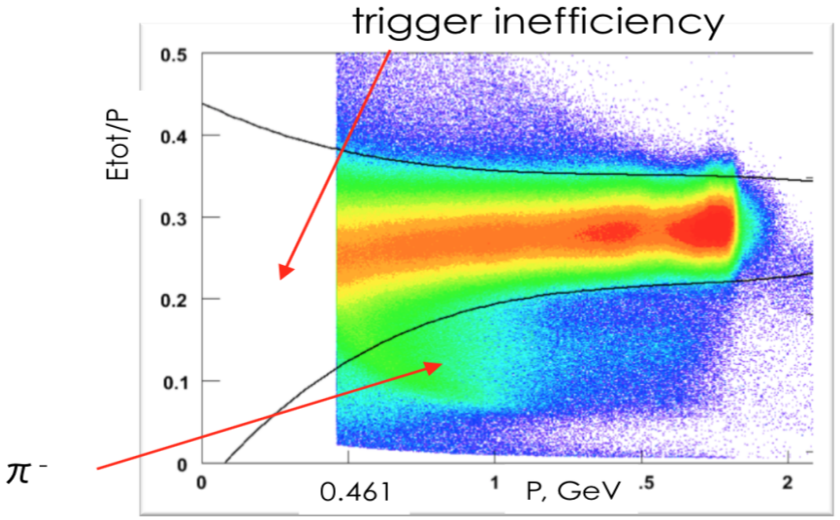
Measurements of the $\gamma_v p \to p'\pi^+\pi^-$ cross section with the CLAS detector for $0.4\,GeV^2 < Q^2 < 1.0\ GeV^2$ and $1.3\ GeV < W < 1.825\ GeV$

G. V. Fedotov,[34,29] Iu. A. Skorodumina,[35] V. D. Burkert,[37] R. W. Gothe,[35] K. Hicks,[29] V. I. Mokeev,[37,34] S. Adhikari,[13]

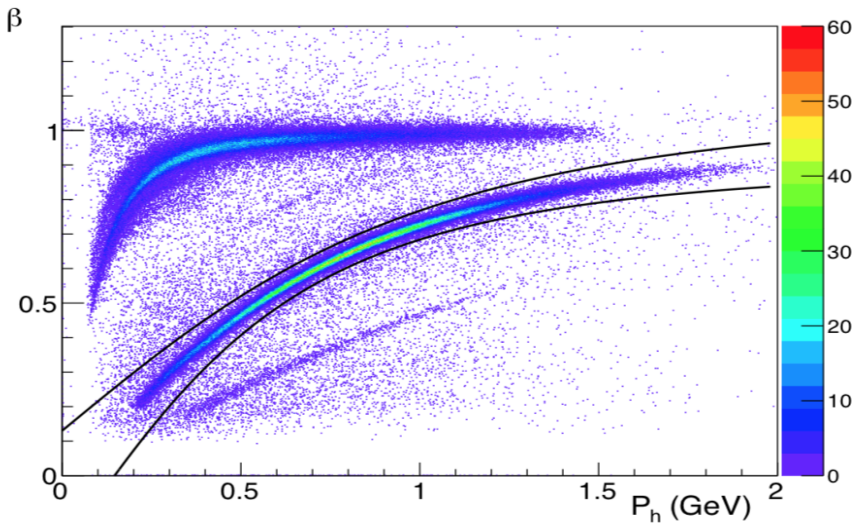
SUMMARY OF PARTICLE ID

Cuts and corrections by N. Markov

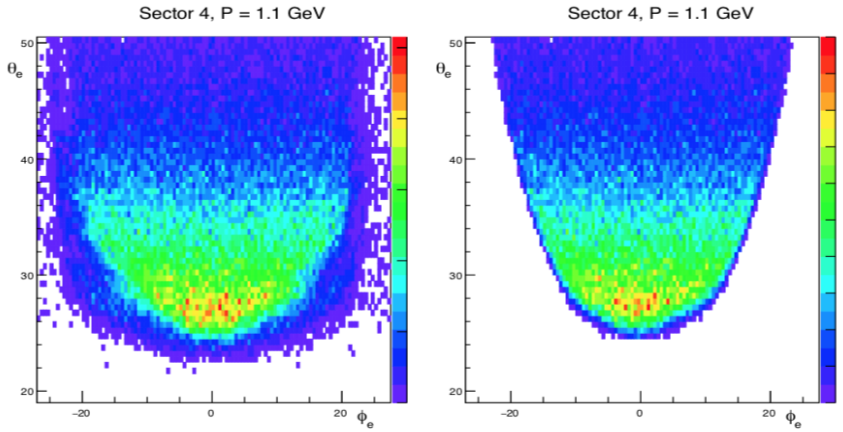
e π^- separation



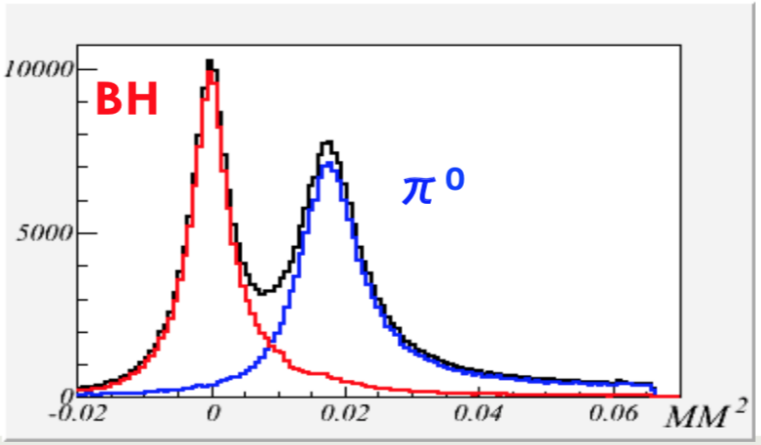
Proton identification



Fiducial cuts



Final event selection



POLARIZED STRUCTURE FUNCTION $\sigma_{LT'}$

$$\frac{d^2\sigma^h}{d\Omega_\pi^*} = \frac{p_\pi^*}{k_\gamma^*}[\sigma_0 + h\sqrt{2\epsilon_L(1-\epsilon)}\ \sigma_{LT'}\ \sin\ \theta_\pi^*\ \sin\ \phi_\pi^*]$$

$$A_{LT'} = \ = \frac{\sqrt{2\epsilon_L(1-\epsilon)}\ \sigma_{LT'}\ \sin\ \theta_\pi^*\ \sin\ \phi_\pi^*}{\sigma_0}$$

$$A_{LT'} = \frac{A_m}{P_e},$$

$$A_m = \frac{N_\pi^+ - N_\pi^-}{N_\pi^+ + N_\pi^-}$$

We have unpolarized cross sections from the same data.

ep->epπ^0 POLARIZED STRUCTURE FUNCTION $\sigma_{LT'}$

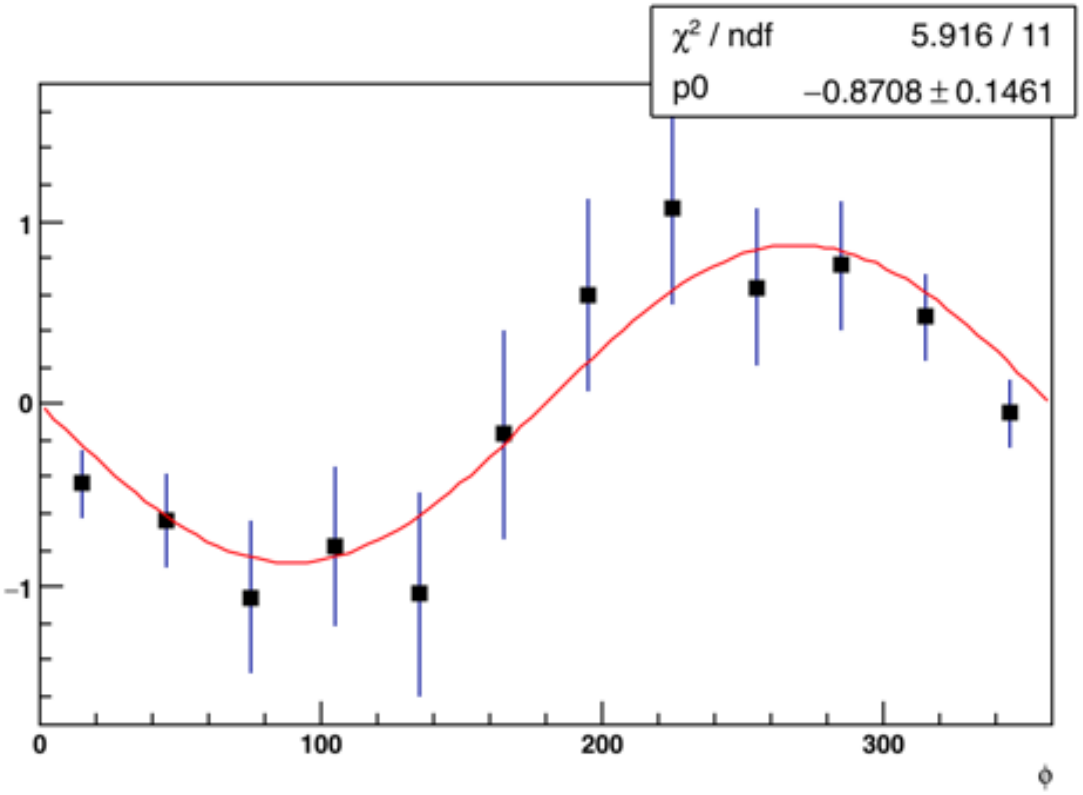
Binning:

28 W-bins from 1.1 to 1.8 GeV, width = 25 MeV
2 Q^2-bins [0.4-0.6] and [0.6-1.0] GeV^2
10 Cos(θ)-bins [-1,1] width = 0.2
12 Φ-bins [0,360] width = 30°

W = 1.66 GeV

$0.4<Q^2<0.6$ GeV^2

Cos(θ)=-0.9



$\sigma_{LT'}$ =D0+D1*X+D2*0.5*(3*X^2 -1)+D3*0.5*(5*X^3 -3*X), X = COS(θ)

FOR l=0,1,2 WE HAVE THESE MULTIPOLE DECOMPOSITION OF D'S

D0 = -IM (3*S0P*CONJUGATE(E1P) + S0P*CONJUGATE(M1M) - S0P*CONJUGATE(M1P) + S1M*CONJUGATE(E0P) - 2*S1M*CONJUGATE(E2M) + 3*S1M*CONJUGATE(E2P) - S1M*CONJUGATE(M2P) - 2*S1P*CONJUGATE(E0P) - 2*S1P*CONJUGATE(E2M) + 18*S1P*CONJUGATE(E2P) + 6*S1P*CONJUGATE(M2M) - 4*S1P*CONJUGATE(M2P) + 6*S2M*CONJUGATE(E1P) - 2*S2M*CONJUGATE(M1M) + 2*S2M*CONJUGATE(M1P) - 9*S2P*CONJUGATE(E1P) + 3*S2P*CONJUGATE(M1M) - 3*S2P*CONJUGATE(M1P))

D1 = -IM (-3*S0P*CONJUGATE(E2M) + 12*S0P*CONJUGATE(E2P) + 3*S0P*CONJUGATE(M2M) - 3*S0P*CONJUGATE(M2P) + 6*S1M*CONJUGATE(E1P) + 6*S1P*CONJUGATE(E1P) + 6*S1P*CONJUGATE(M1M) - 6*S1P*CONJUGATE(M1P) + 6*S2M*CONJUGATE(E0P) - 6*S2M*CONJUGATE(E2M) + 30*S2M*CONJUGATE(E2P) - 6*S2M*CONJUGATE(M2M) - 12*S2M*CONJUGATE(M2P) - 9*S2P*CONJUGATE(E0P) - 9*S2P*CONJUGATE(E2M) + 27*S2P*CONJUGATE(E2P) + 27*S2P*CONJUGATE(M2M))

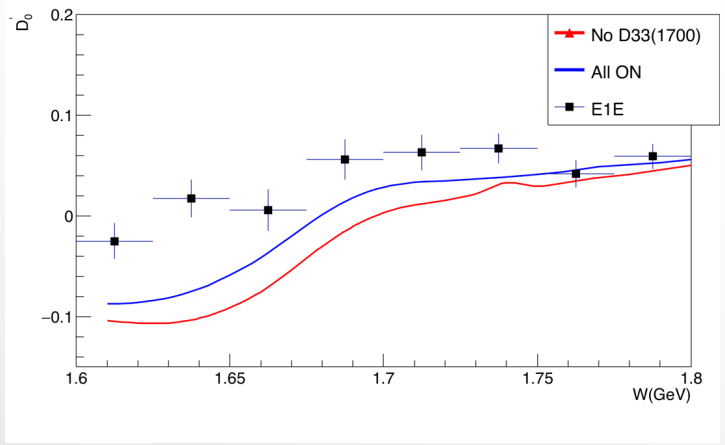
D2 = -IM (15*S1M*CONJUGATE(E2P) - 5*S1M*CONJUGATE(M2P) - 12*S1P*CONJUGATE(E2M) + 18*S1P*CONJUGATE(E2P) + 12*S1P*CONJUGATE(M2M) - 2*S1P*CONJUGATE(M2P) + 24*S2M*CONJUGATE(E1P) + 9*S2P*CONJUGATE(E1P) + 15*S2P*CONJUGATE(M1M) - 15*S2P*CONJUGATE(M1P))

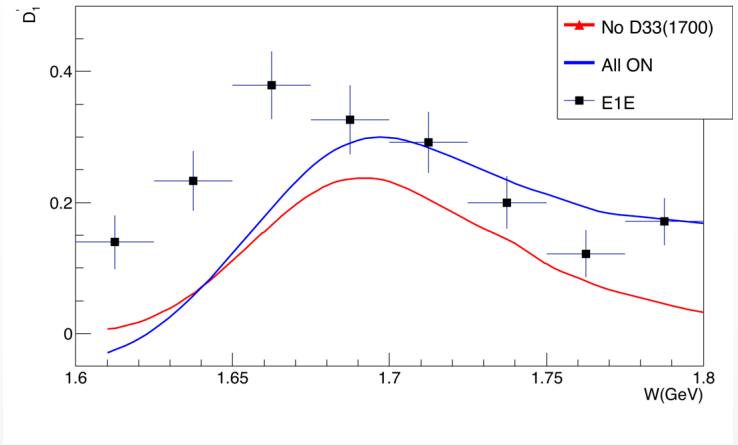
D3 = -IM (54*S2M*CONJUGATE(E2P) - 18*S2M*CONJUGATE(M2P) - 27*S2P*CONJUGATE(E2M) + 27*S2P*CONJUGATE(E2P) + 27*S2P*CONJUGATE(M2M))

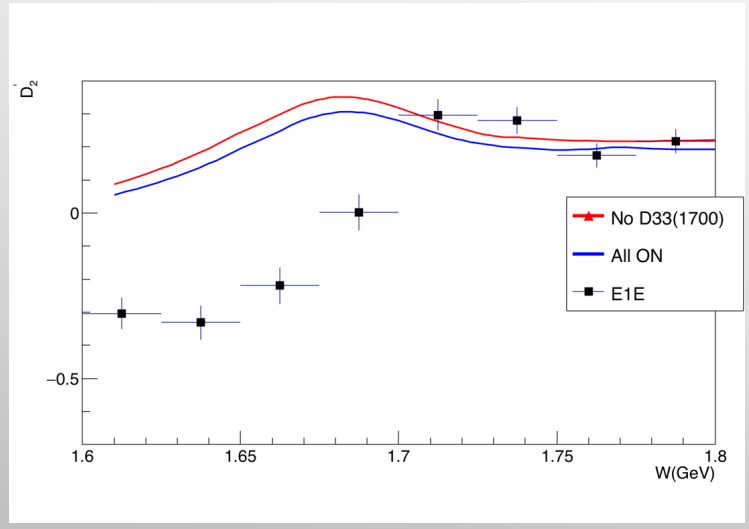
- SENSITIVITY TO D33(1700)

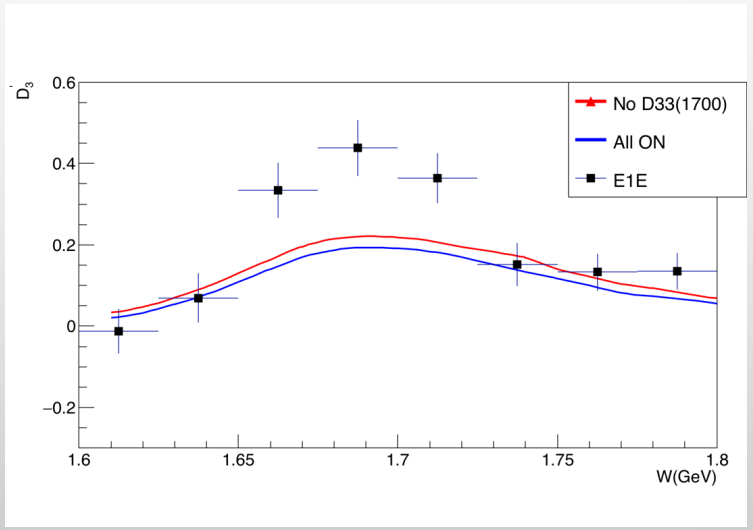
D1 ~ -IM(… - 6*S2M*CONJ(E2M) - 6*S2M*CONJ(M2M)…)

$0.4<Q^2<0.6$ GeV^2









MAID 2007 with modified couplings

P11(1440)		D13(1520)		
$A_{1/2}$	$S_{1/2}$	$A_{3/2}$	$A_{1/2}$	$S_{1/2}$
1.0	1.0	1.0	1.0	1.0

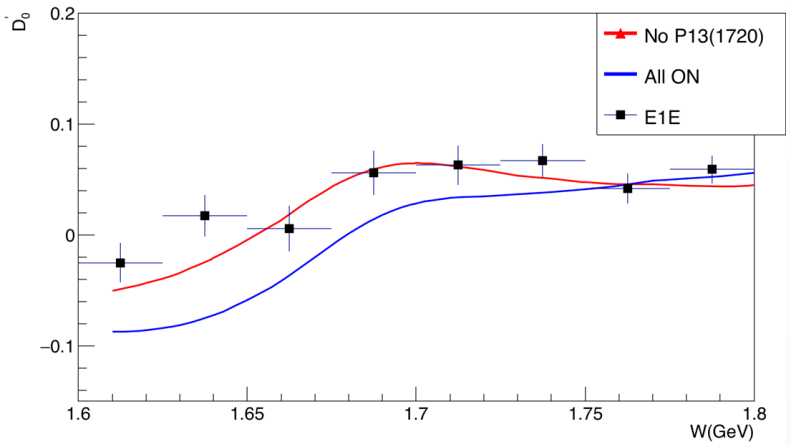
D15(1675)			F15(1680)	
$A_{3/2}$	$A_{1/2}$	$S_{1/2}$	$A_{3/2}$	$A_{1/2}$
1.0	1.0	1.0	1.0	1.0

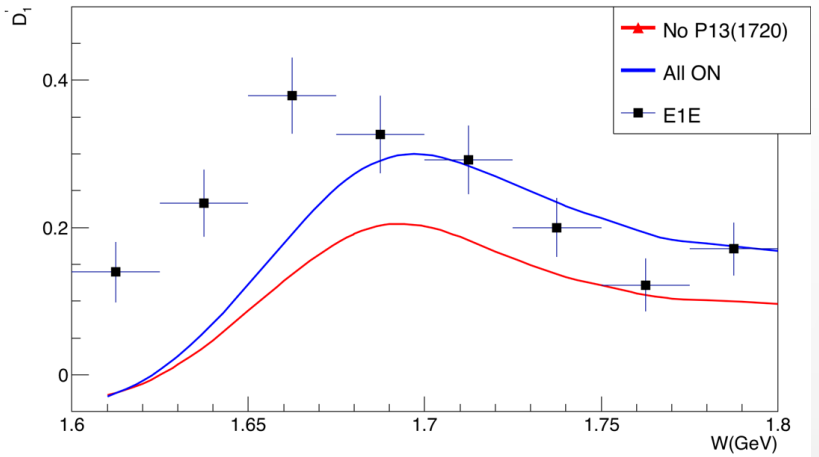
P_{11}	P_{31}	$\frac{1}{2}^+$	1^+	L_{1-}
S_{11}	S_{31}	$\frac{1}{2}^+$	0^-	L_{0+}, E_{0+}
D_{13}	D_{33}	$\frac{1}{2}^+$	2^-	L_{2-}, E_{2-}
P_{11}	P_{31}	$\frac{1}{2}^+$	1^+	M_{1-}
P_{13}	P_{33}	$\frac{1}{2}^+$	1^+	M_{1+}
P_{13}	P_{33}	$\frac{1}{2}^+$	1^+	L_{1+}, E_{1+}
F_{15}	F_{35}	$\frac{1}{2}^+$	3^+	L_{3-}, E_{3-}
D_{13}	D_{33}	$\frac{1}{2}^+$	2^-	M_{2-}
D_{15}	D_{35}	$\frac{1}{2}^+$	2^-	M_{2+}

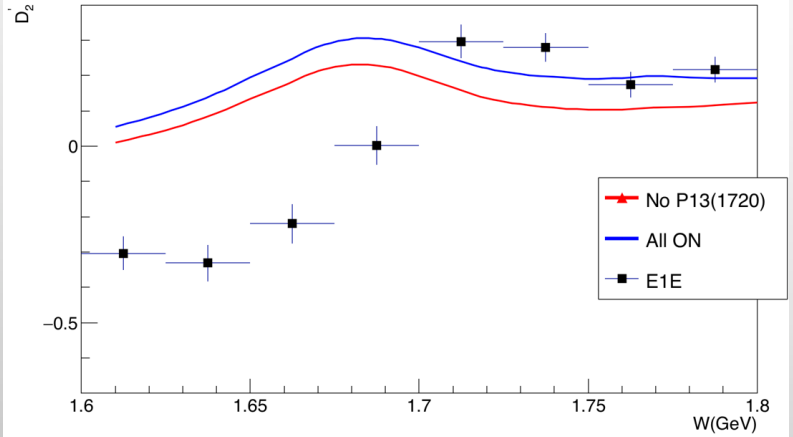
- SENSITIVITY TO P13(1720)

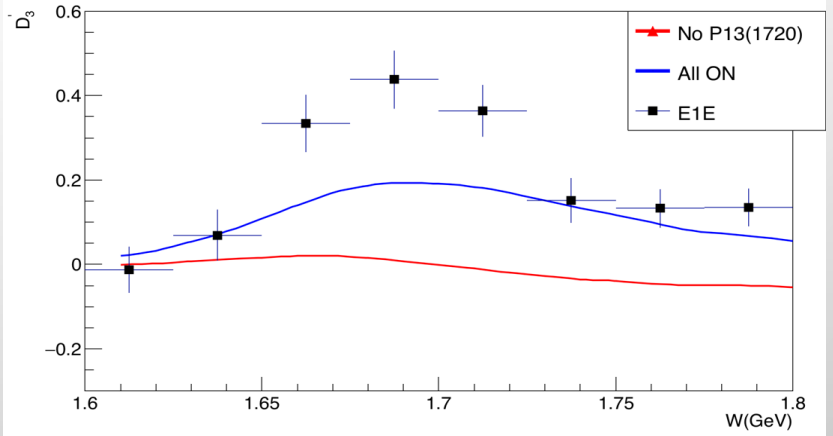
D1 ~ -IM(… 6*S1P*CONJ(E1P) - 6*S1P*CONJ(M1P) …)

$0.4<Q^2<0.6$ GeV^2









Emergence of Hadron Mass and Quark-Gluon Confinement

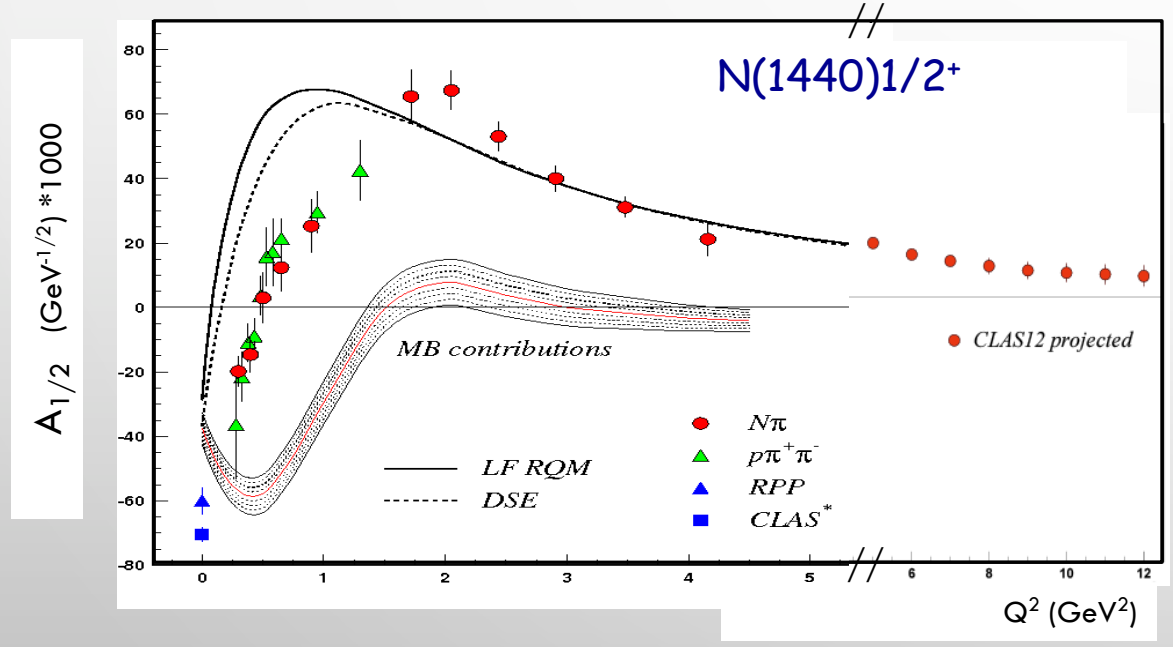
N* electroexcitation studies at JLab will address the critical open questions:

How is >98% of visible mass generated?

How does confinement emerge from QCD and how is it related to Dynamical Chiral Symmetry Breaking?

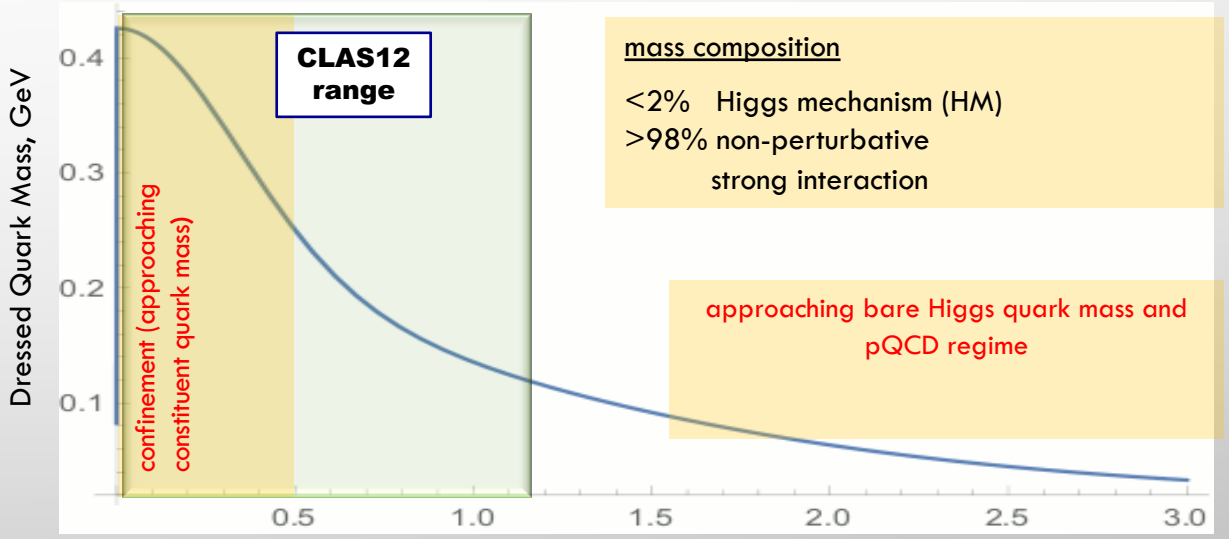
What is the behavior of QCD's running coupling at infrared momenta?

Mapping-out quark mass function from the CLAS12 results on $\gamma_v pN^*$ electrocouplings of spin-isospin flip, radial, and orbital excited nucleon resonances at $5<Q^2<12$ GeV^2 will allow us to explore the transition from strong QCD to pQCD regimes.



CLAS results versus theory expectations with running quark mass

Access to the dressed quark/hadron mass generation



Beam spin asymmetry in the resonance region for ep->eπ^+n

1. Cook: pass1 skim4 (inclusive)
2. Data runs: about 75% of RG-A Fall 2018 inbending
3. Beam energy is 10.6 GeV
4. Torus/Solenoid = -100%/-100%
5. Reaction: ep->eπ^+n and ep->eπ^0p

V. Klimenko, UConn

Objective: determine beam asymmetry in the resonance region in exclusive π^+n and π^0p electroproduction off protons at W<2.0 GeV and Q^2<12.0 GeV^2

Event selection for ep->eπ^+n

Cuts on electrons:

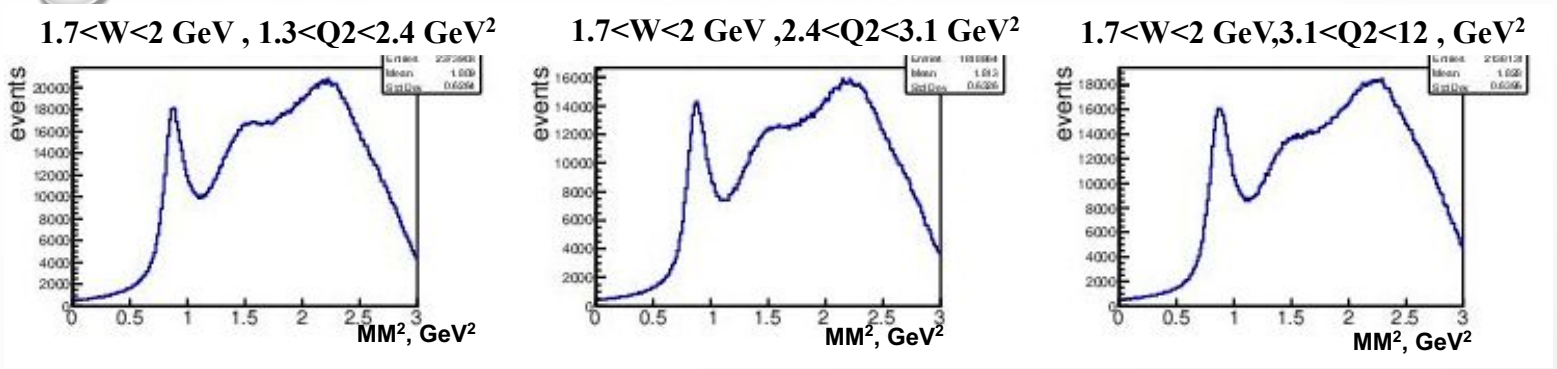
1. Exactly one electron (Event Builder)
2. Electron momentum > 1 GeV
3. A cut on the minimal energy deposition in the PCAL
4. DC and PCAL fiducial cuts
5. cut on the z-vertex position ($-9 < v_z < 6$)
6. 3 sigma on SF
7. W < 2.3 GeV

Cuts on positive pions:

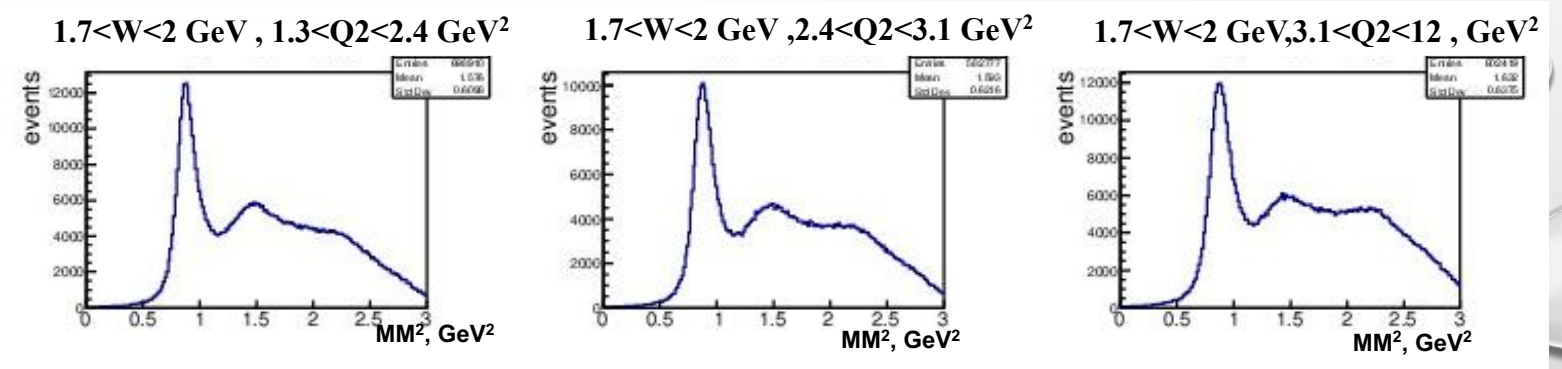
1. Exactly one π^+ (Event Builder) in FD (1999<status<3999)
2. No other charged particles
3. DC fiducial cuts
4. A cut on the vertex difference ($|v_z(el) - v_z(hadr)| < 20$ cm)
5. A cut on chi2PID from the event builder
6. MM2 is fitted with gaussian + pol. degree 2.

MM^2 distributions at 1.7<W<2.0 GeV, in Q^2 bins for ep->eπ^+n

1. Electron cuts and one pion(EB) in event only:

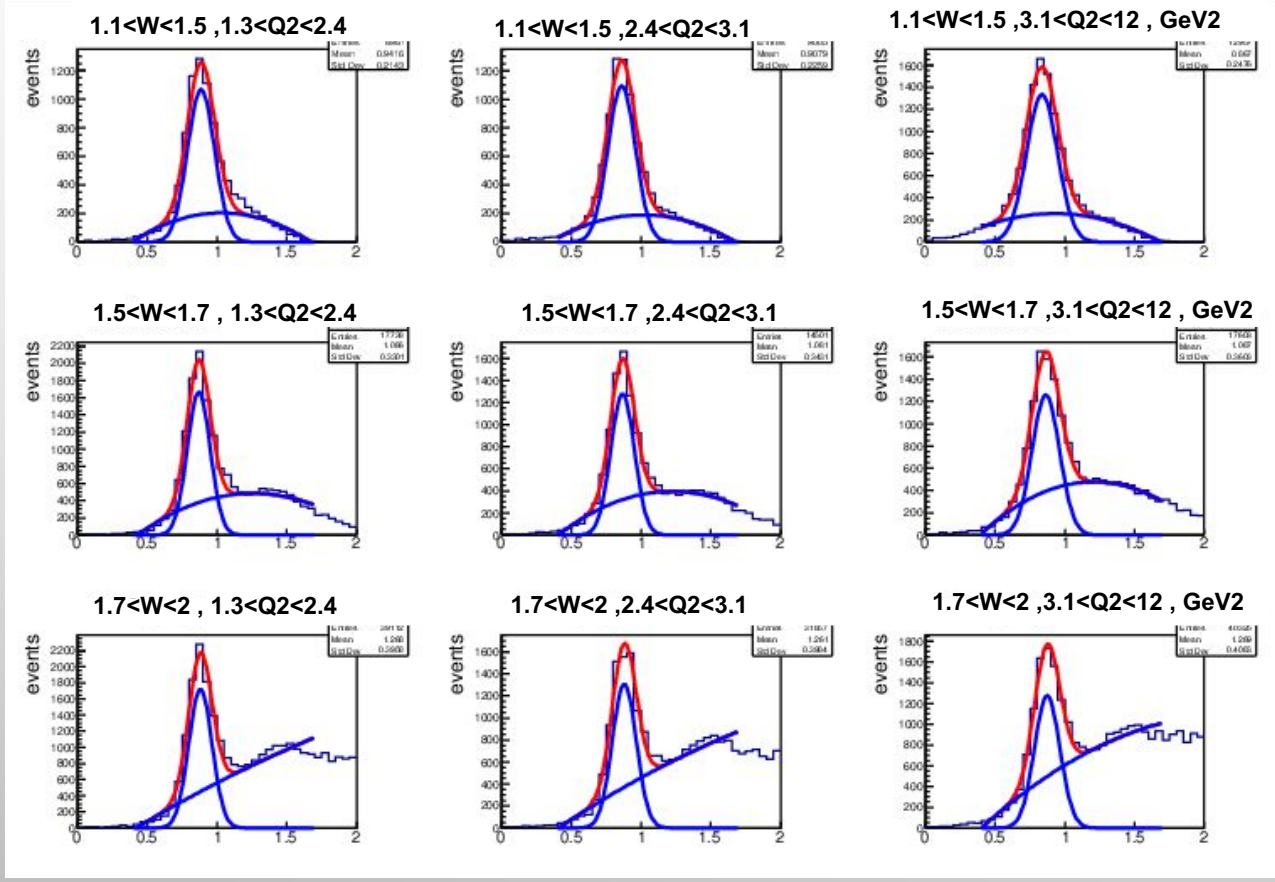


2. + additional cuts on pions:

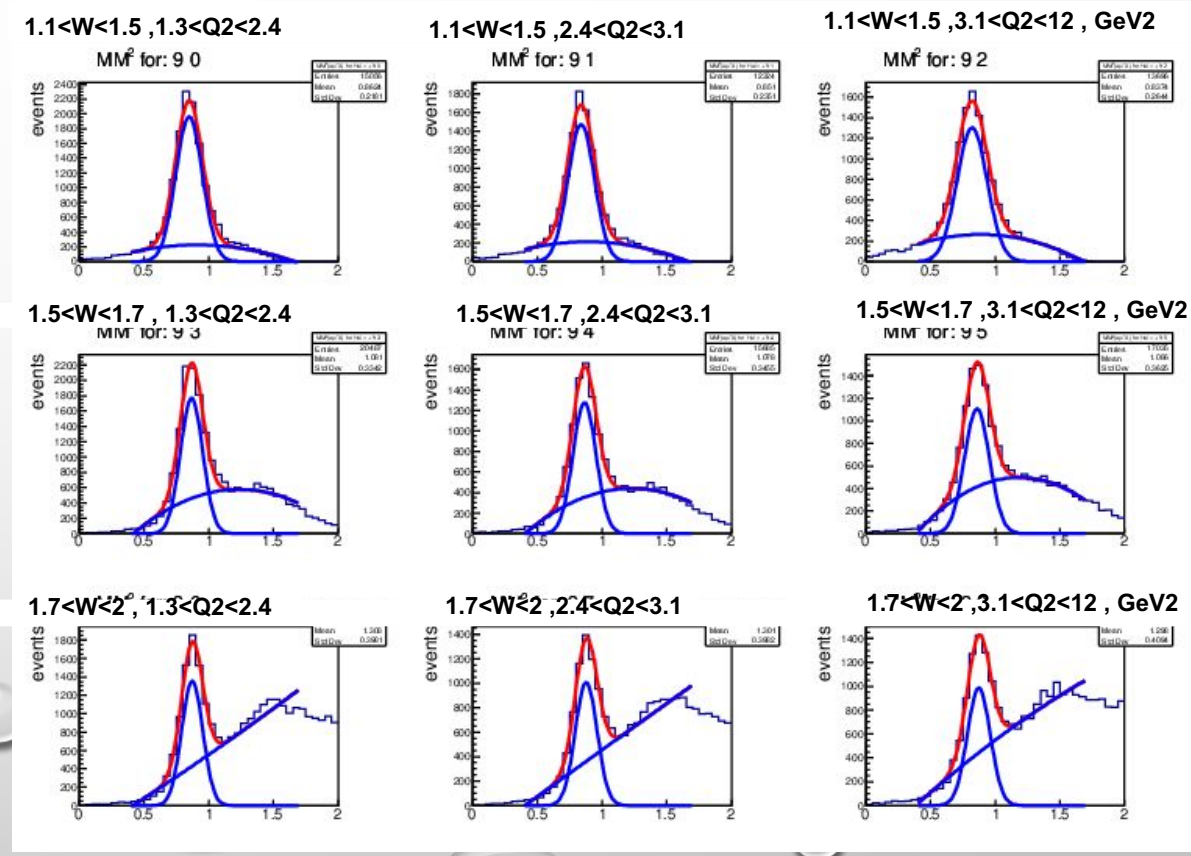


$MM^2(e\pi^+X)$ distributions for the positive electron helicity

Phi : 270-300 deg.
Cos(theta) bin: from -1 to 1 (integrated)



Phi : 300-330 deg.
Cos(theta) bin: from -1 to 1 (integrated)



Event selection for $ep \to e\pi^0 p$

Cuts on protons:

1. Exactly one proton (pid =2212) in FD (status<3999)
2. No other charged particles
3. DC fiducial cuts
4. The vertex difference to the electron (|vz(elec) – vz(had)| < 20 cm)
5. A cut on chi2PID from the event builder

Cut on angle between Z axis and P_x should be more then 5 deg,

$P_x = P_e + P_p - P_{e'} - P_{p'}$

Cuts on photons:

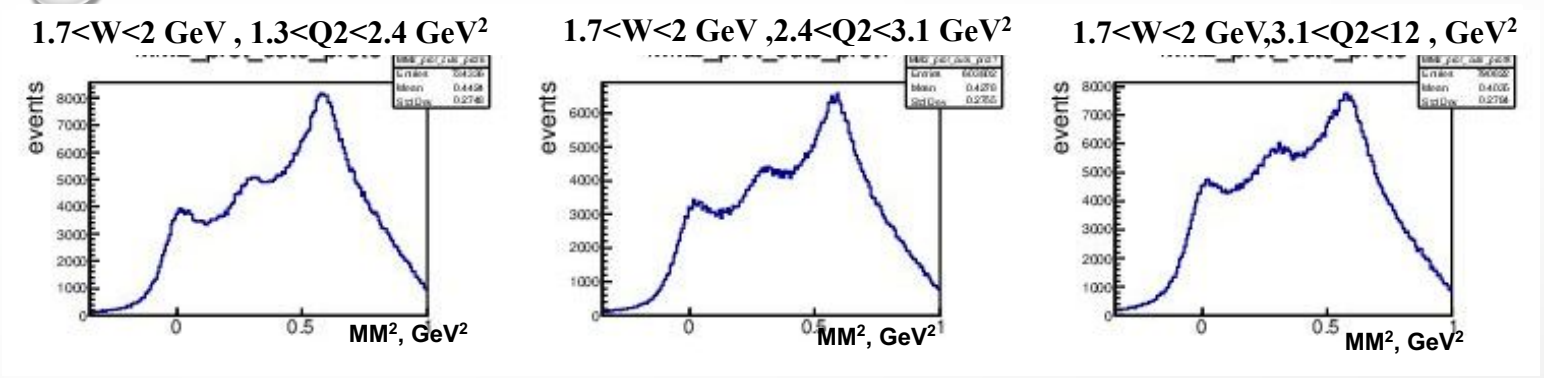
1. Event builder PID (pid =22)
2. PCAL fiducial cut
3. A cut on beta value (0.9 < bet a<1.1)
4. Angle between the photon and scattered electron > 5 deg
5. I compare MM^2(eggX) with m_p^2 for all photon pairs and select the closest pair.
6. a) Calculate the pion energy from the two photons
   b) Calculate the pion energy from energy conservation.

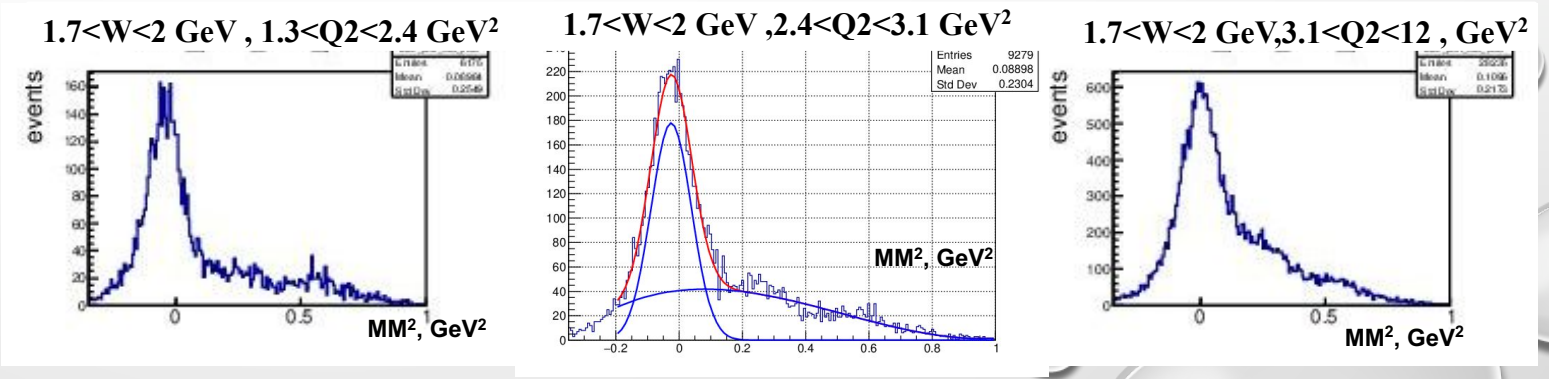
Cut: |Ea-Eb| < 0.25 GeV and polar angle(Pa,Pb) < 15 deg

MM^2 distributions At 1.7<W<2.0 GeV, in Q^2 bins for ep->eπ^0p

1. Electron and proton cuts:

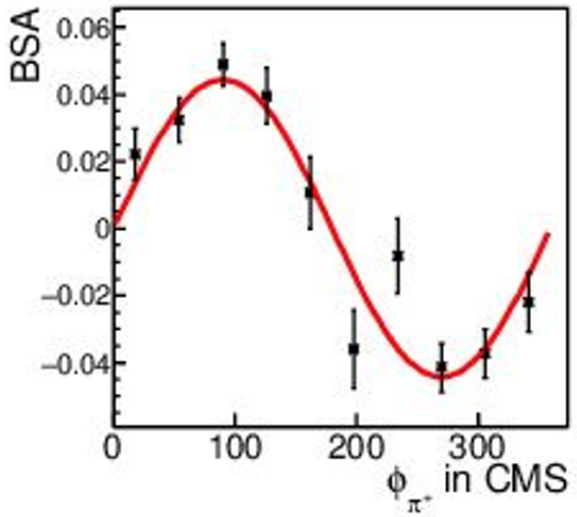
2. + cuts on photons:



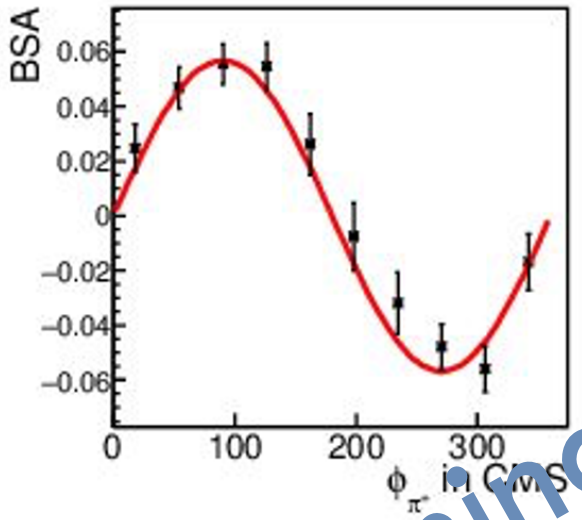


very preliminary BSA ep->eπ⁺n ep->eπ⁰p

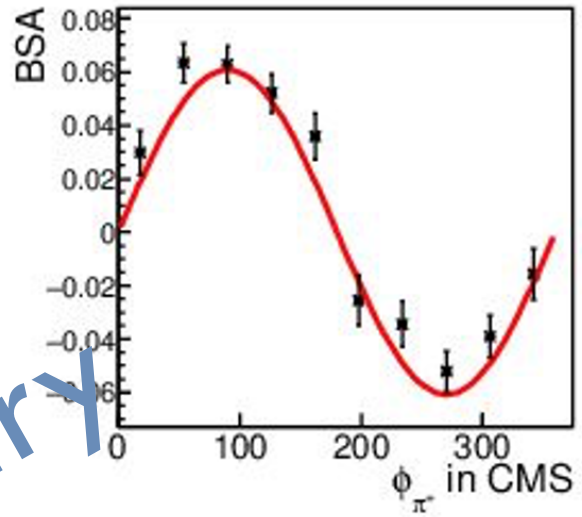
1.7<W<2 , 1.3<Q2<2.4



1.7<W<2 ,2.4<Q2<3.1

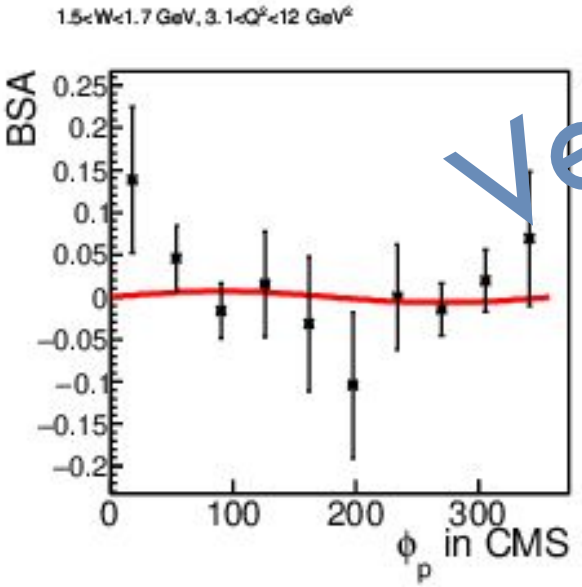


1.7<W<2 ,3.1<Q2<12 , GeV2

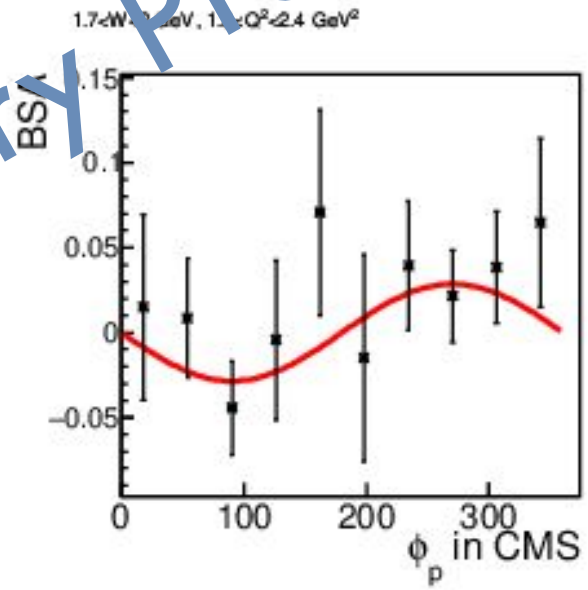


ep->eπ⁺n:

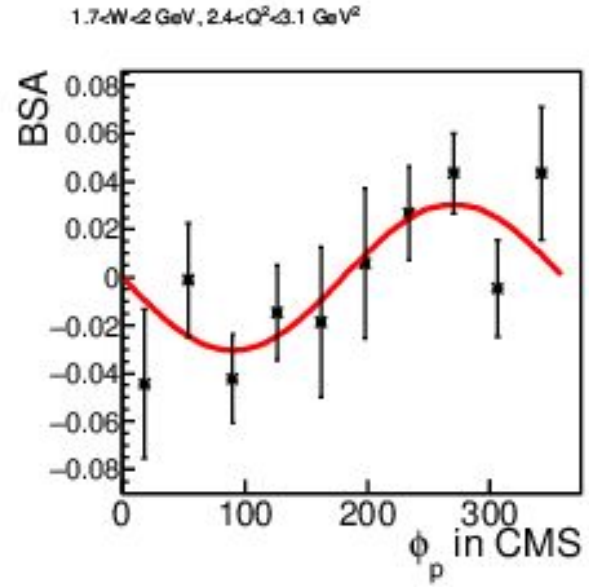
1.7 < W < 2 GeV , 1.3 < Q² < 2.4 GeV²



1.7 < W < 2 GeV , 2.4 < Q² < 3.1 GeV²



1.7 < W < 2 GeV , 3.1 < Q² < 12 GeV²



ep->eπ⁰p:

Very Preliminary

75% of RG-A Fall 2018 statistics

CONCLUSIONS

- ep->epπ^0 polarized structure function $\sigma_{LT'}$ is extracted from E1E CLAS data
- Legendre moments analysis of $\sigma_{LT'}$ is underway
- Preliminary BSA for ep->epπ^0 for ep->enπ$^+$ are measured from RG-A FALL-2018 CLAS12 DATA