New results on $\pi^0 p$ beam asymmetry in the resonance region with CLAS

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Insight into the Strong QCD from the Synergy between Experiment, Phenomenology, and Theory

Experiment

Observables from the Experiments with the EM Probes:

- Differential cross sections
- Beam asymmetry
- Target asymmetries
- Recoil asymmetries
- Combinations of 2-fold and 3-fold asymmetries

Phenomenology:

- Amplitude analyses
- Reaction models

Elastic/Transition form factors
PDFs, PDA,TMD-functions
Compton form factors
Projection of GPD to observables

Strong QCD underlying the hadron generation
$\alpha_s \sim 1$

Theory

QCD Lagrangian:

$$\mathcal{L}_{QCD} = \bar{\psi}(i \not{D}_a T_a - m)\psi - \frac{1}{4} F_a^{\mu\nu} F_{\mu\nu,a}$$

- Covariant derivative, gluon field tensor

$$D_a^\mu = \partial^\mu + igA_a^\mu$$
$$F_a^{\mu\nu} = \partial^\mu A_a^\nu - \partial^\nu A_a^\mu - g f_{abc} A_b^\mu A_c^\nu$$

- Color matrices and structure constants

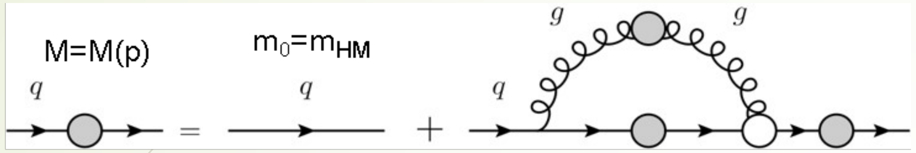
$$[T_a^{(F)}, T_b^{(F)}] = i f_{abc} T_c^{(F)}, \quad (T_a^{(A)})_{bc} = -i f_{abc}$$

- Lattice QCD
- Continuum QCD

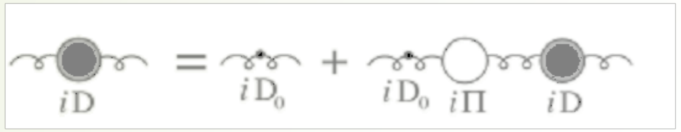
Light front quark models
AdS/CFT approaches
χ Quark-Soliton models
Hypercentral quark model
Covariant quark models
………………………………..

Basics for Insight into EHM from Data on N* Electrocouplings

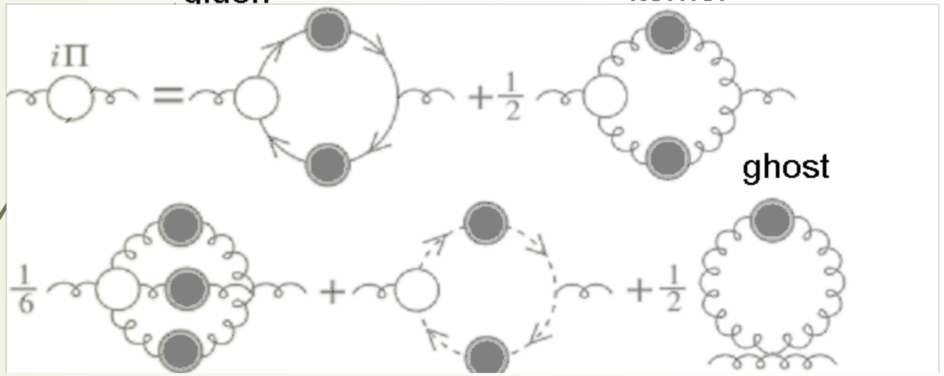
Emergence of Dressed Quarks and Gluons
D. Binosi et al, Phys. Rev. D 95, 031501 (2017)



dressed quark   bare quark   dressing kernel



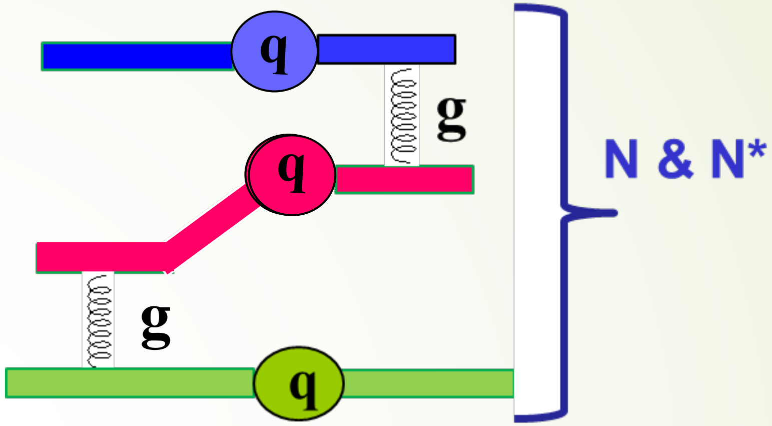
dressed gluon   bare gluon   dressing kernel



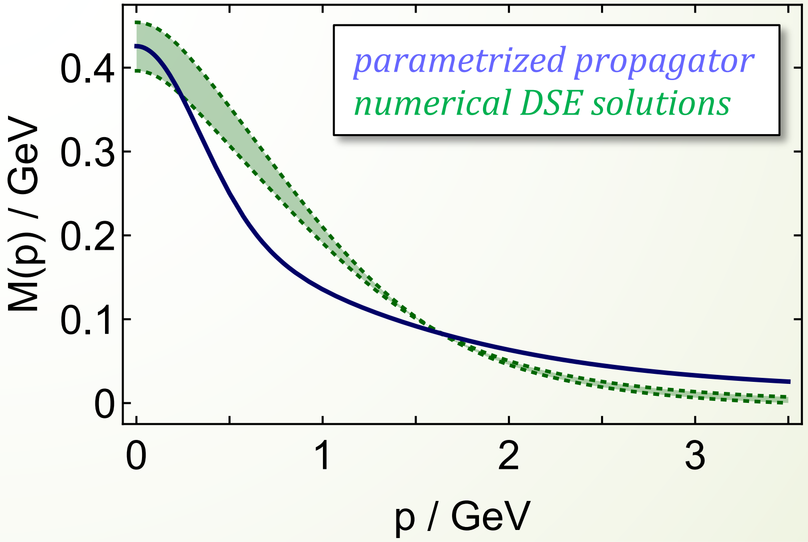
Data on N* electrocoupling are sensitive to the quark propagators and allow us to:

- Map out quark mass function
- Constrain the ground nucleon and meson form factors, PDA, & PDF

Dressed Quark Borromeo Binding in N/N*
J. Segovia et al., arXiv:1908:0572 [nucl-th]



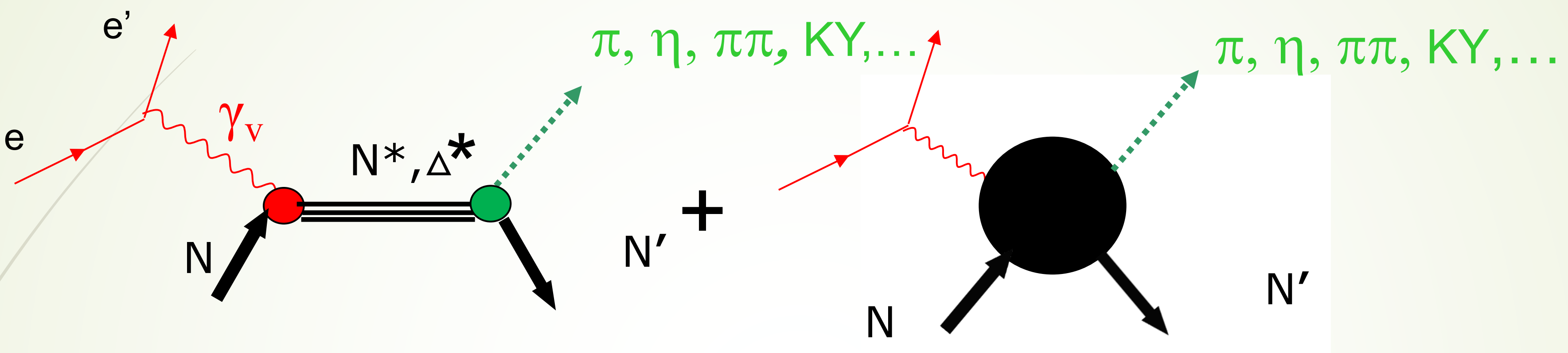
Dressed Quark Mass Function
C.D. Roberts, Few Body Syst. 58, 5 (2017)



Inferred from QCD Lagrangian with only the Λ_{QCD} parameter

Extraction of $\gamma_v NN^*$ Electrocouplings from Exclusive Meson Electroproduction off Nucleons

Resonant amplitudes **Non-resonant amplitudes**



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 $\gamma_v pN^*$ electrocouplings from different meson electroproduction channels are critical in order to validate reliable extraction of these quantities.**

Single meson electroproduction in the resonance region from Hall-B

		Q^2	W	
JLab/Hall B	$\frac{d\sigma}{d\Omega}(\pi^0 p, \pi^+ n)$	0.16–0.36	1.1–1.38	[8]
	$\frac{d\sigma}{d\Omega}(\pi^0 p)$	0.4–1.8	1.1–1.68	[9]
	$\frac{d\sigma}{d\Omega}(\pi^0 p)$	3.0–6.0	1.1–1.39	[10]
	$A_{LT'}(\pi^0 p)$	0.4, 0.65	1.1–1.66	[11]
	$A_t, A_{et}(\pi^0 p)$	0.252, 0.385, 0.611	1.12–1.55	[12]
	$\frac{d\sigma}{d\Omega}(\pi^+ n)$	0.3–0.6	1.1–1.55	[13]
	$\frac{d\sigma}{d\Omega}, A_{LT'}(\pi^+ n)$	1.7–4.5	1.11–1.69	[14]
	$A_{LT'}(\pi^+ n)$	0.4, 0.65	1.1–1.66	[15]
	$\frac{d\sigma}{d\Omega}(\eta p)$	0.375–1.385	1.5–1.86	[16]
	$\frac{d\sigma}{d\Omega}(\eta p)$	0.17–3.1	1.5–2.3	[17]

Progress in Particle and Nuclear Physics 67 (2012) 1
I.G. Aznauryan, V.D. Burkert

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

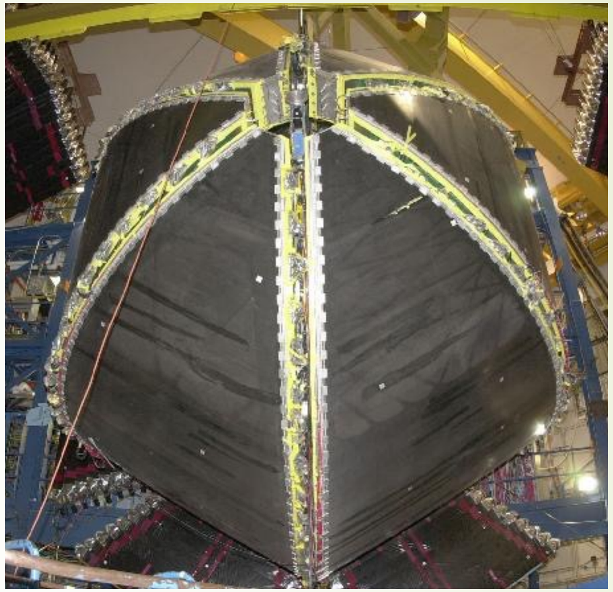
N. Markov,[8,36,*] K. Joo,[8] V.D. Burkert,[36] V.I. Mokeev,[36] L. C. Smith,[41] M. Ungaro,[36] S. Adhikari,[11]

2020

Same data run (E1E) 1.1 < W < 1.8 GeV

Access to second and third N^* regions!

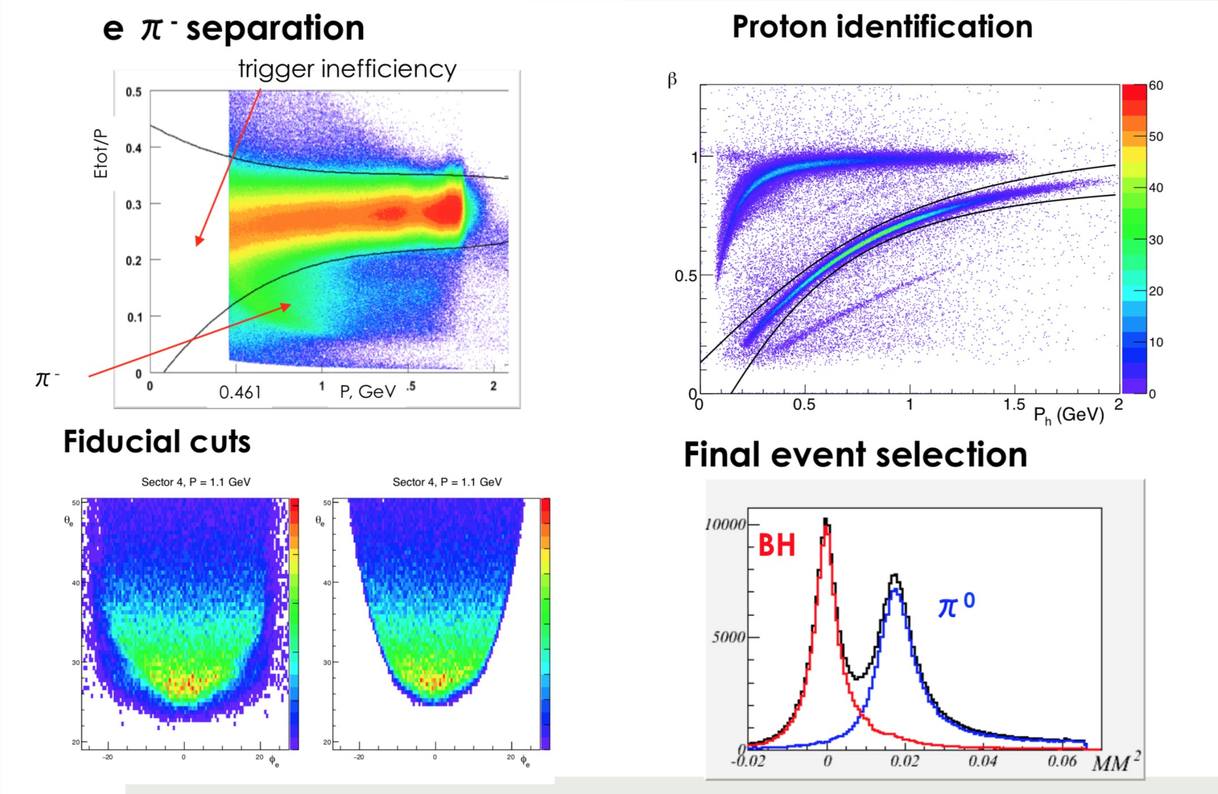
Data



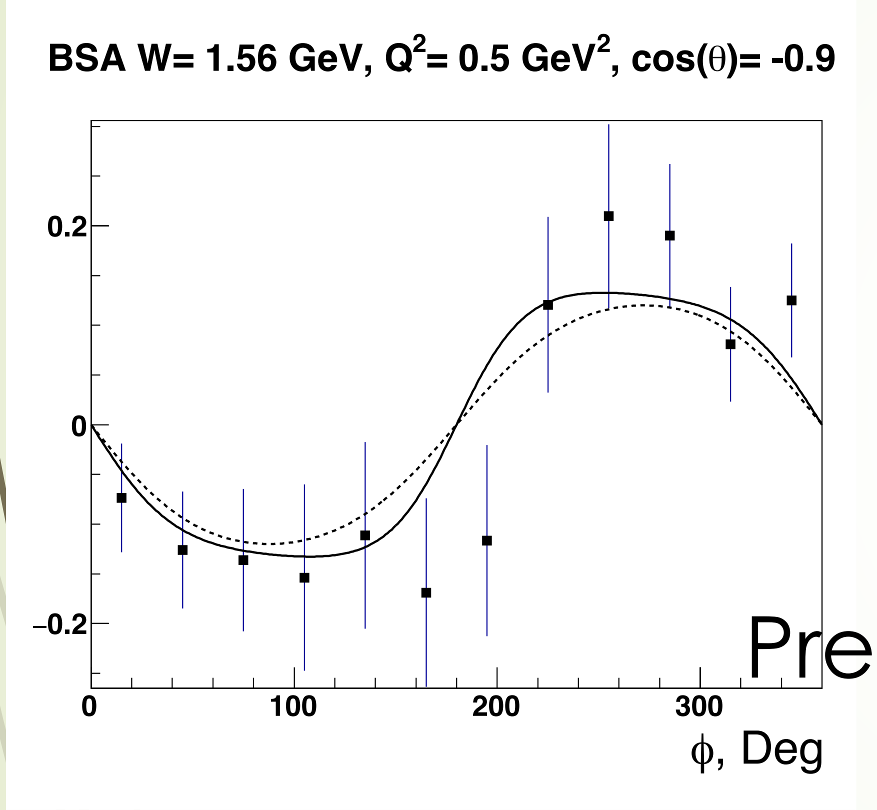
- CLAS detector data 12/2002 – 1/2003
- Beam energy: 2.036 GeV
- Beam polarization: ~ 80%
- Target: Liquid Hydrogen, thickness 2 cm
- Number of triggers: ~ 1.5 billion

$$0.4 < Q^2 < 1\ \text{GeV}^2$$

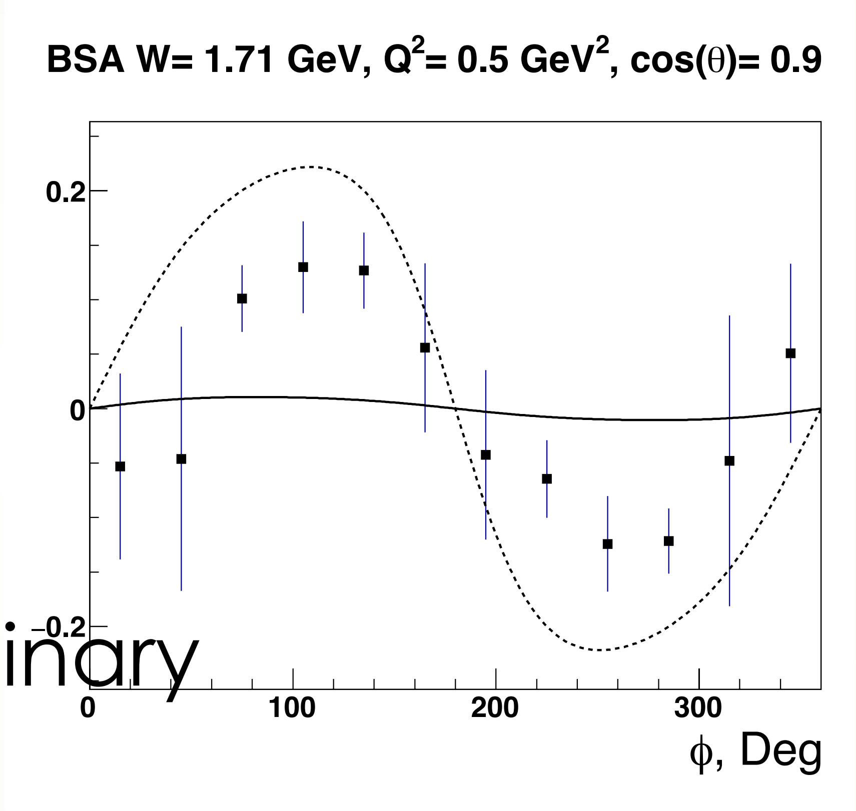
$$1.1 < W < 1.8\ \text{GeV}$$



Beam spin asymmetries



Preliminary



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

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

MAID 2007 (solid line)

MAID 2007 with modified electrocouplings, taken from CLAS analyses (dotted line)

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.

Extraction Of Polarized Structure Function $\sigma_{LT'}$

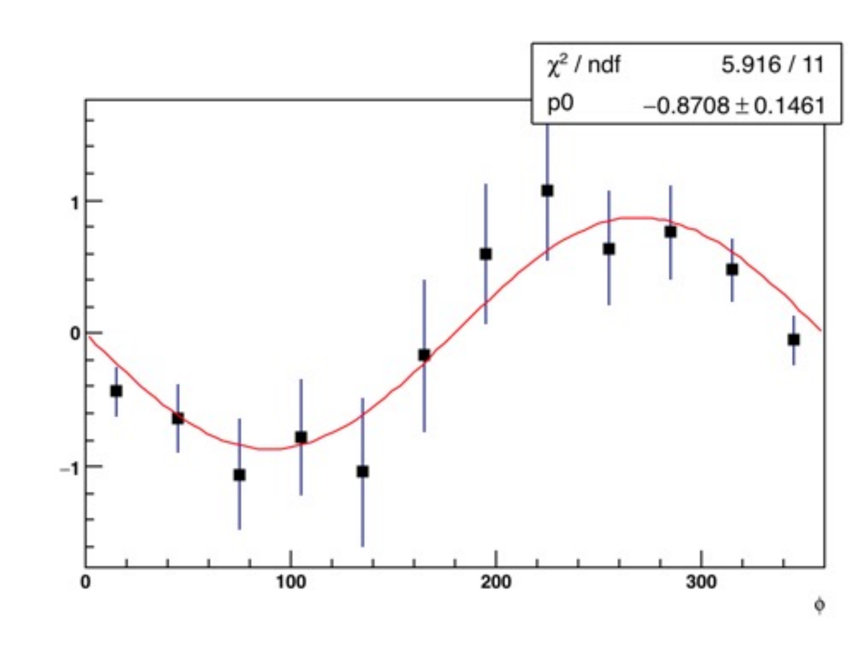
Binning:

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°

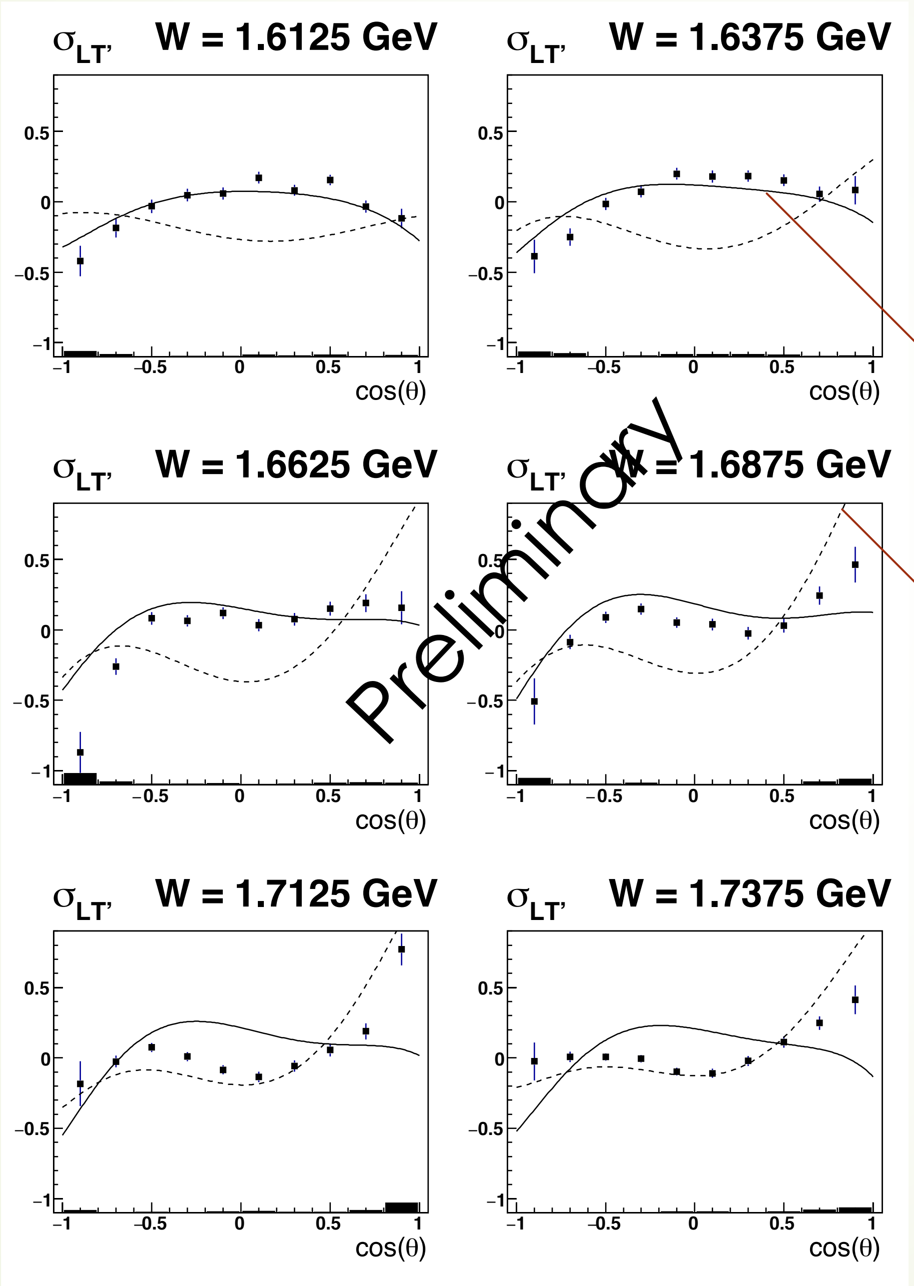
W = 1.66 GeV

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

Cos(θ)=-0.9



Polarized Structure Function $\sigma_{LT'}$, $0.4 < Q^2 < 0.6$ GeV^2



MAID 2007 (solid line)

MAID 2007 with modified electrocouplings, taken from CLAS analyses (dashed line)

Legendre Polynomials of $\sigma_{LT'}$

l=0,1,2,3 $\sigma_{LT'}$=D0+D1*x+D2*0.5*(3*x^2 -1)+D3*0.5*(5*x^3 -3*x)

sensitivity to P13(1720)
D1 ~ -Im(… 6*S1p*conj(E1p) - 6*S1p*conj(M1p) …)

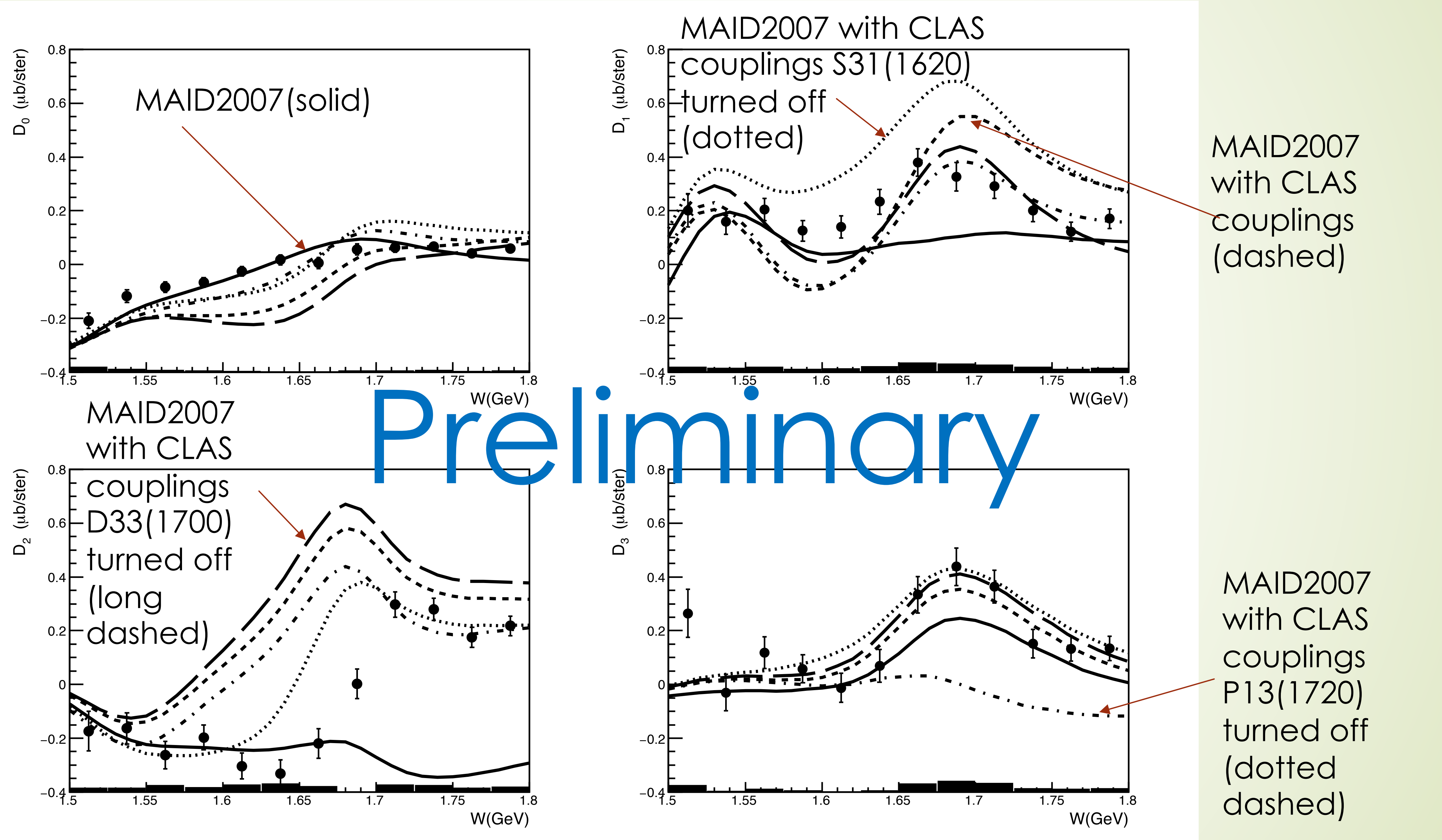
sensitivity to D33(1700)

D1 ~ -Im(… - 6*S2m*conj(E2m) - 6*S2m*conj(M2m)…)

LP – effective way to present our data and to demonstrate sensitivity to different excited states of the nucleon

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+}

Legendre Moments of Polarized Structure Function $\sigma_{LT'}$ $0.4 < Q^2 < 0.6$ GeV^2



Conclusions

- The polarized structure function $\sigma_{LT'}$ was extracted from the CLAS data in the kinematical region

$$0.4 < Q^2 < 1 \text{ GeV}^2$$
$$1.1 < W < 1.8 \text{ GeV}$$

- Legendre Polynomials of $\sigma_{LT'}$ were analyzed with different resonances turned on/off
- The combined analysis of polarized and unpolarized data will give us information on electroexcitation amplitudes with focus on the second and third resonance regions
- PRC paper under review in CLAS collaboration