Beam Spin Asymmetries from ep->epπ^0 in the resonance region

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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:

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

- Covariant derivative, gluon field tensor

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

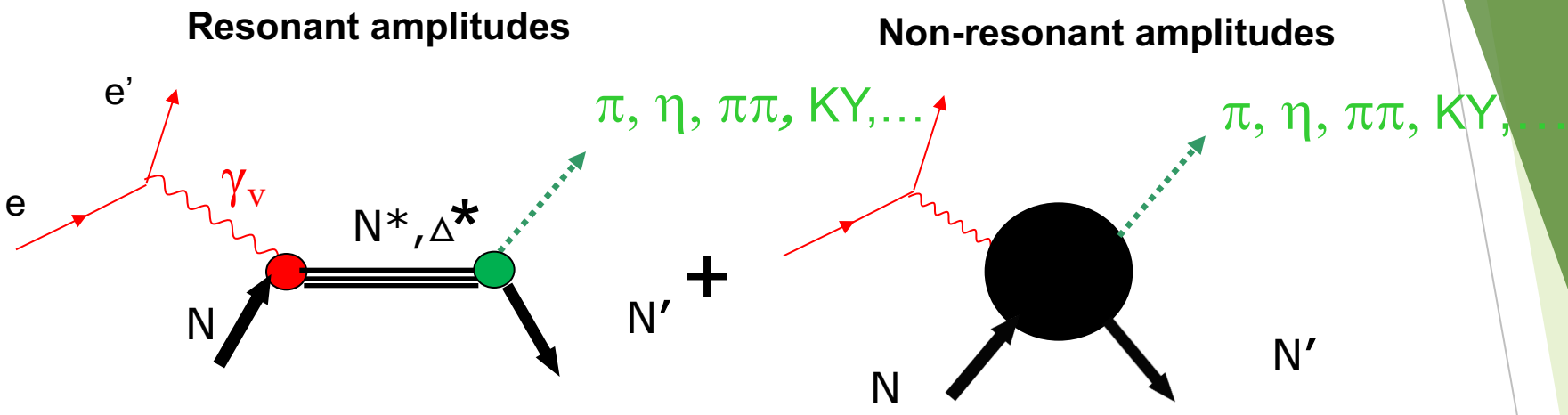
- Color matrices and structure constants

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

- Lattice QCD
- Continuum QCD

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

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.**

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

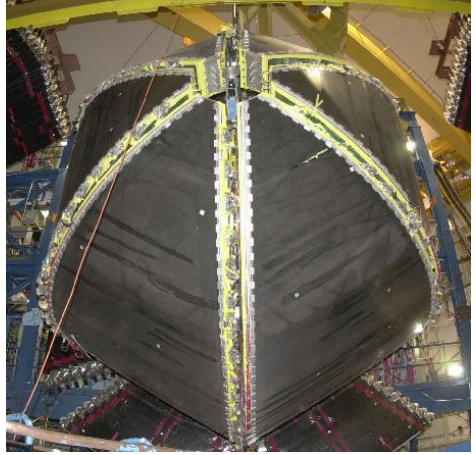
Exclusive $\pi^0 p$ electroproduction off protons in the resonance region at photon virtualities $0.4\ \mathrm{GeV}^2 \leq Q^2 \leq 1\ \mathrm{GeV}^2$

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]

Same data (E1E) 1.1 < W < 1.8 GeV

Access to second and third N^* regions!

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 billions

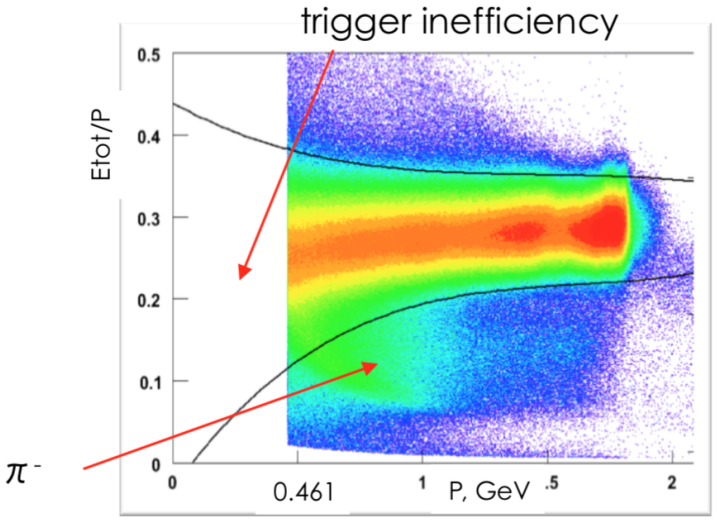
$0.4 < Q^2 < 1\ GeV^2$

$1.1 < W < 1.8\ GeV$

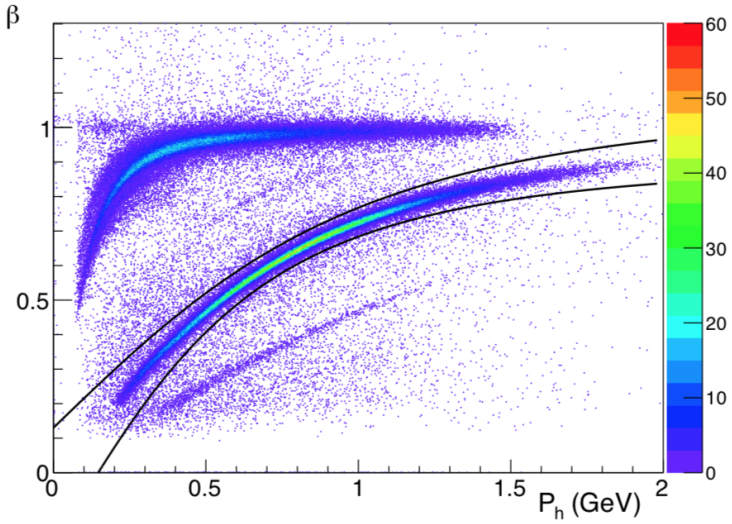
Summary of particle ID

from N.Markov talk at CLAS Coll. – 16 November 2018

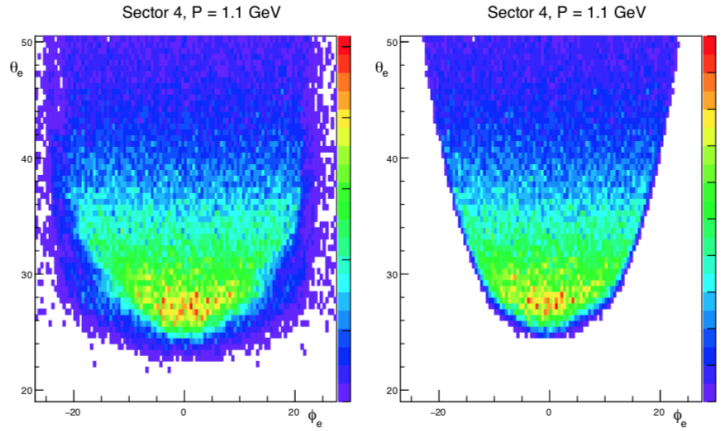
e π^- separation



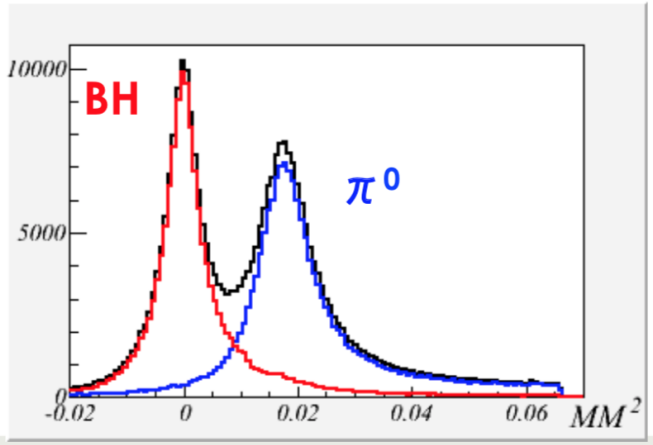
Proton identification



Fiducial cuts



Final event selection



Polarized Structure Function $\sigma_{LT'}$

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

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

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

We have unpolarized cross sections from the same data.

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

Polarized Structure Function $\sigma_{LT'}$

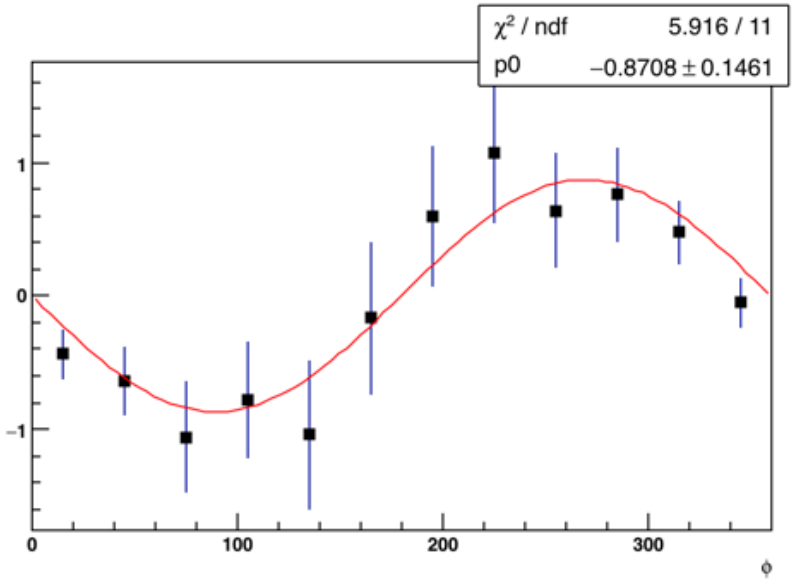
Binning:

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°

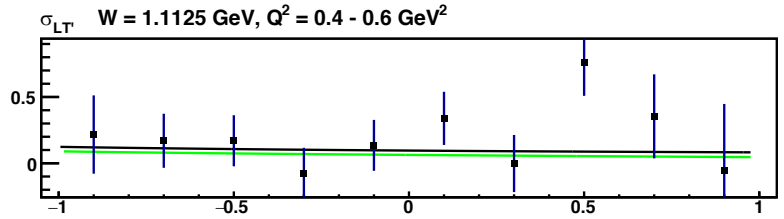
W = 1.66 GeV

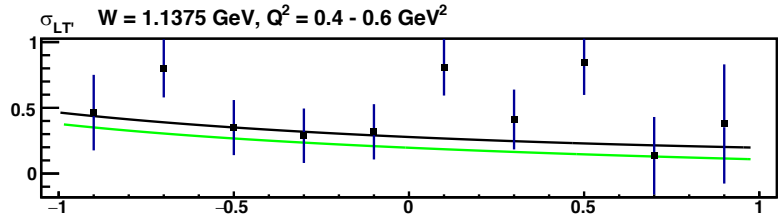
$0.4<Q^2<0.6$ GeV^2

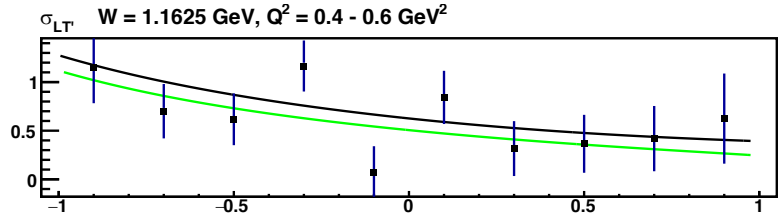
Cos(θ)=-0.9

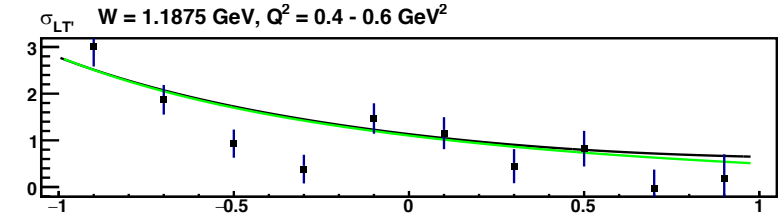


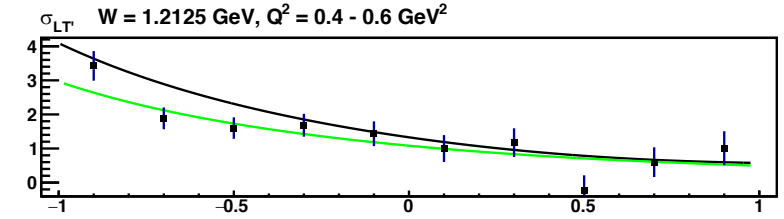
$\sigma_{LT'}$ $0.4<Q^2<0.6$ GeV^2 green-MAID2007, black-UIM

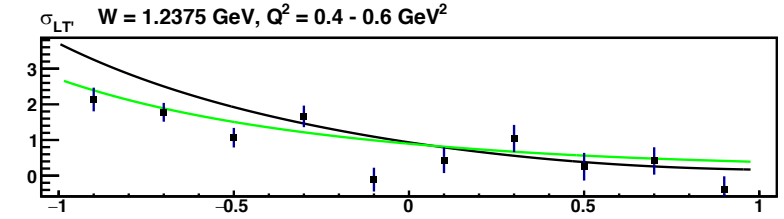


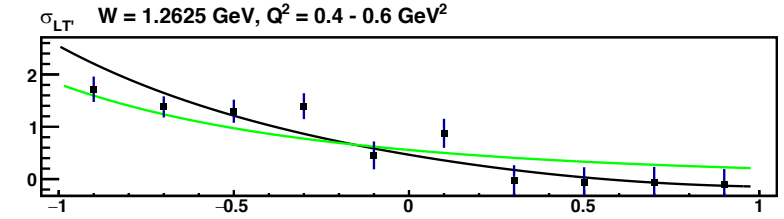


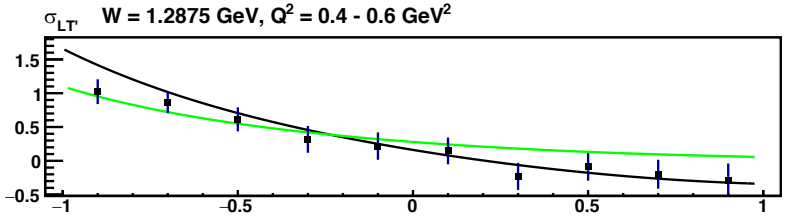


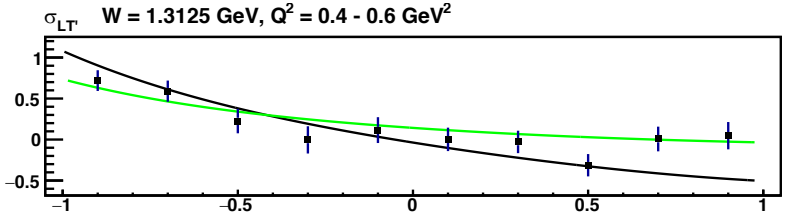


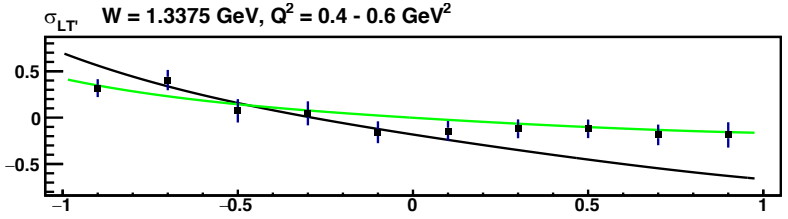




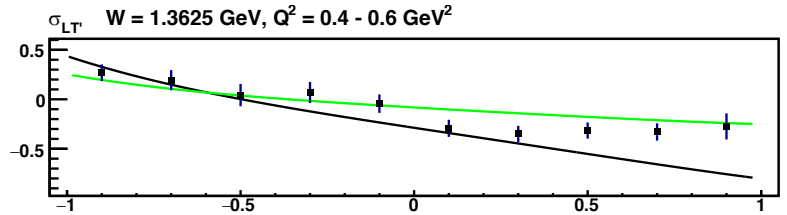


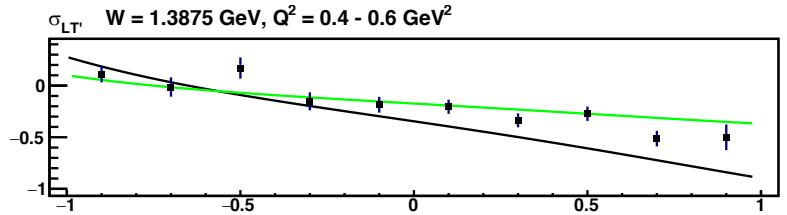


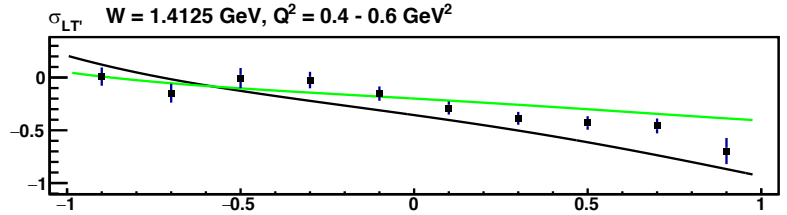


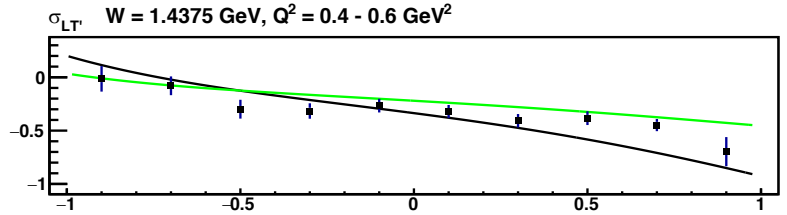


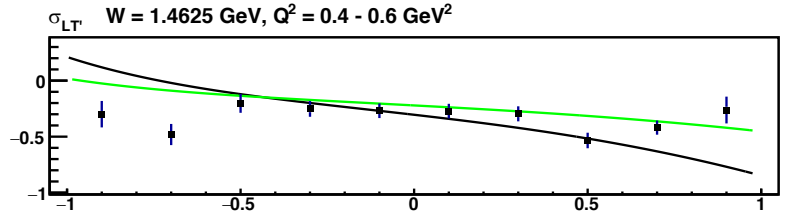
$\sigma_{LT'}$ $0.4<Q^2<0.6$ GeV^2 green-MAID2007, black-UIM

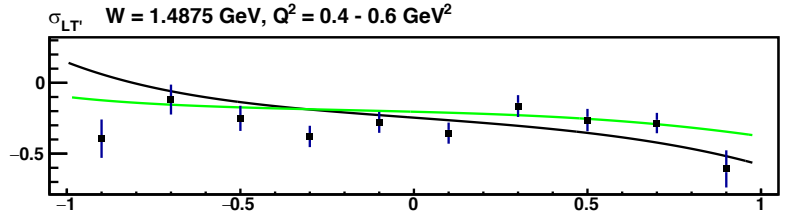


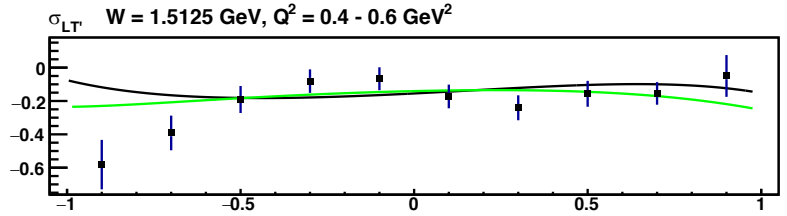


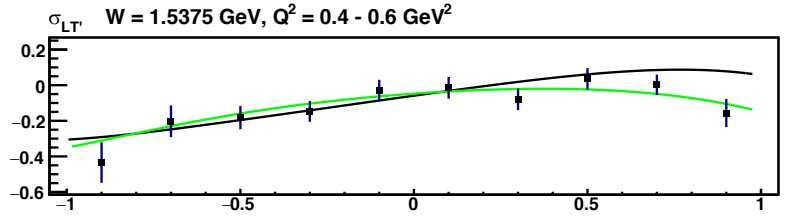


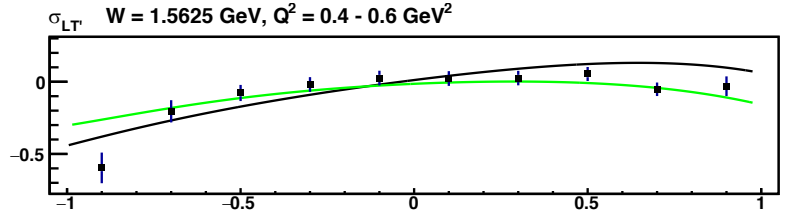


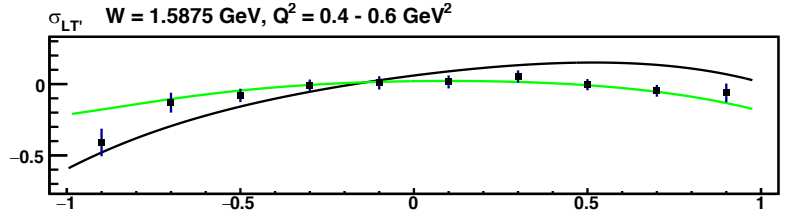












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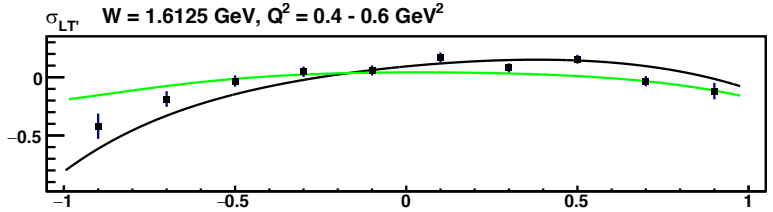
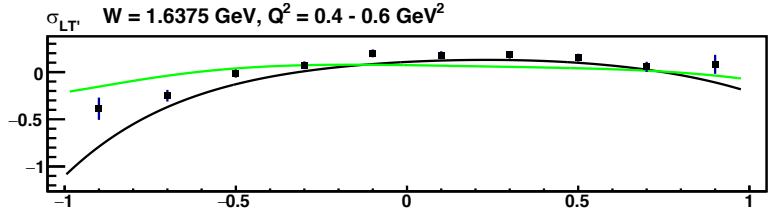
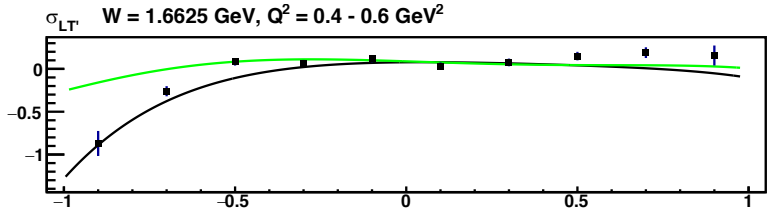
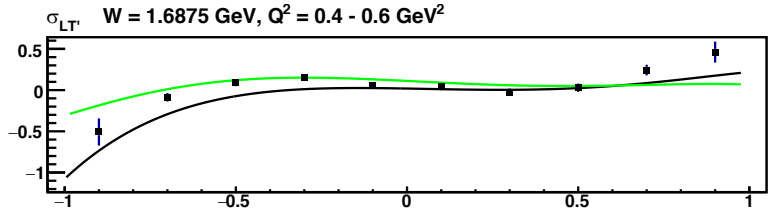
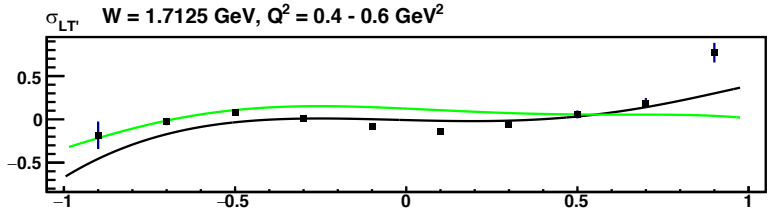
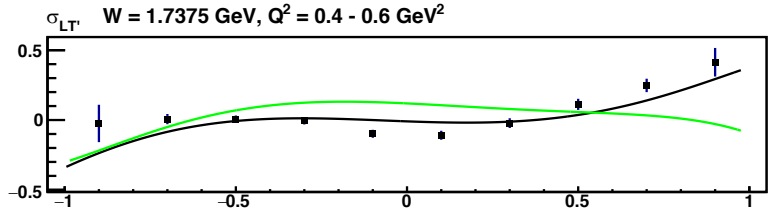


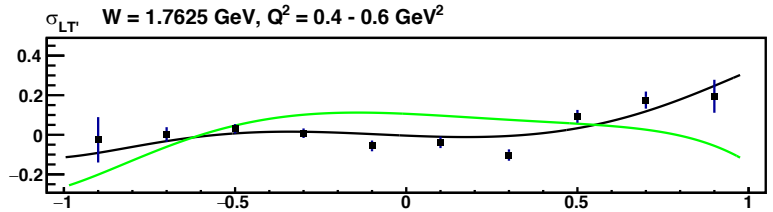


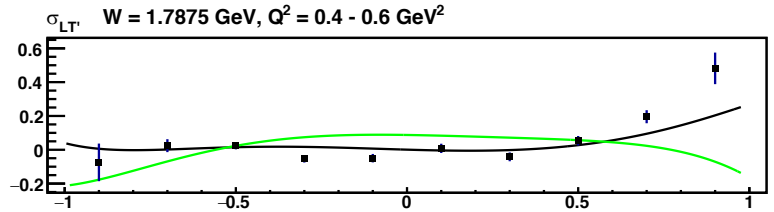




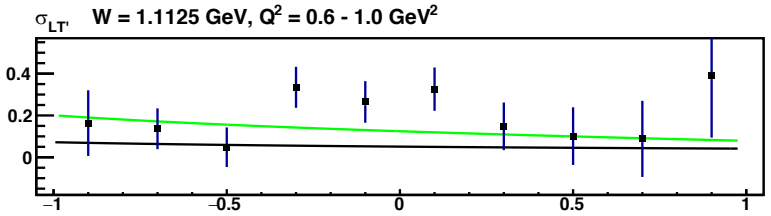


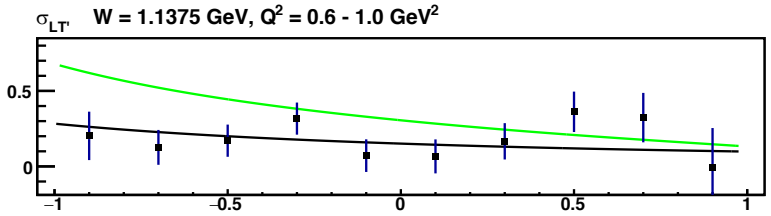


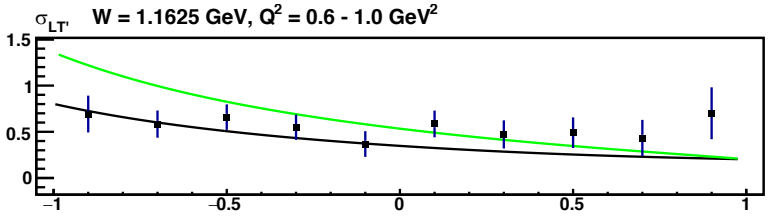


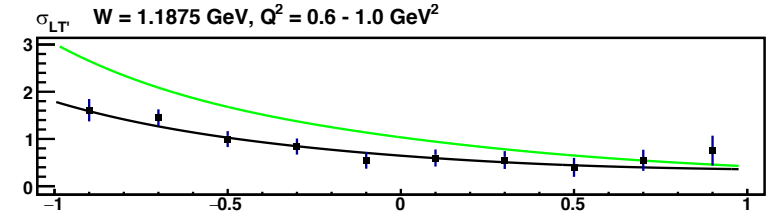


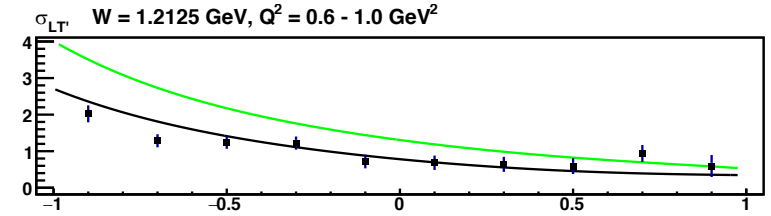
$\sigma_{LT'}$ $0.6<Q^2<1.0$ GeV^2 green-MAID2007, black-UIM

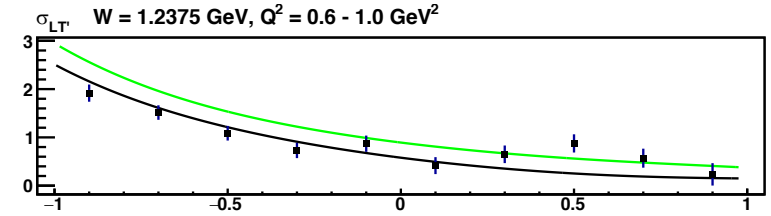


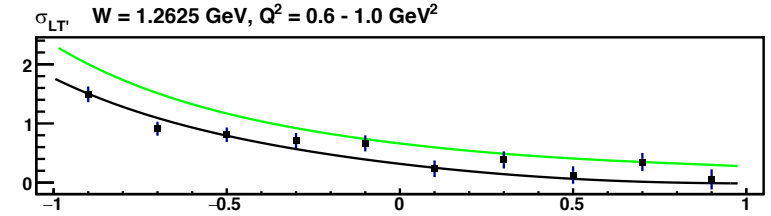


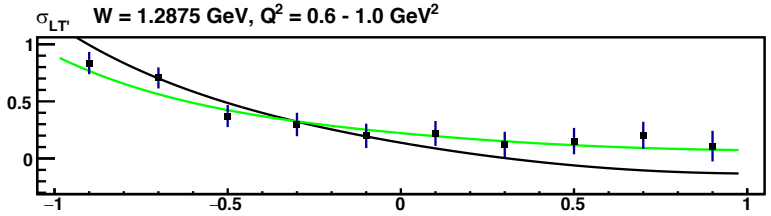


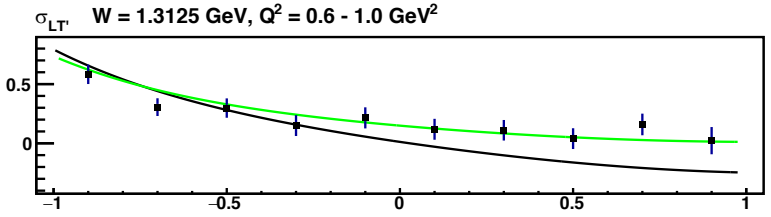


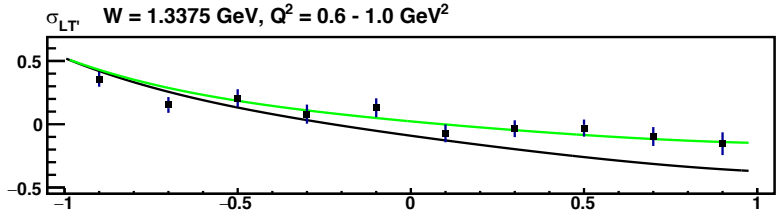












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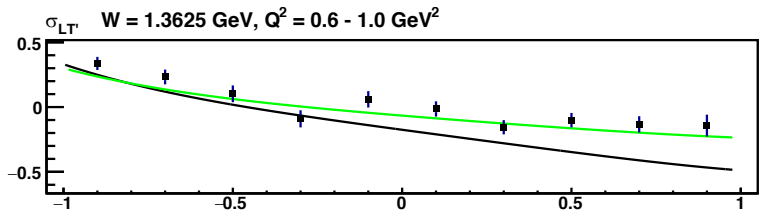
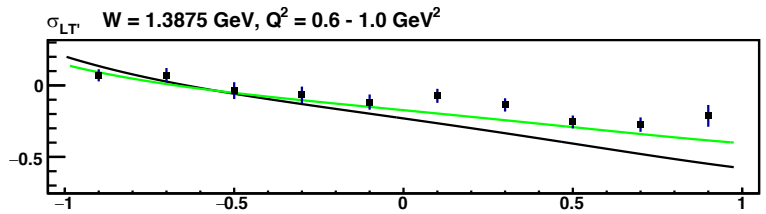
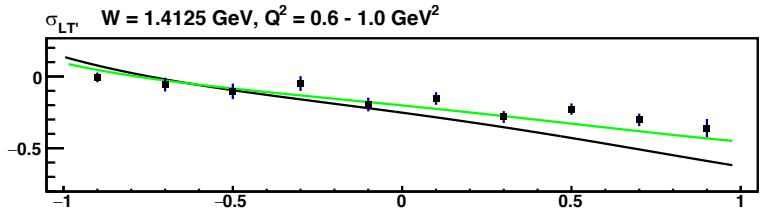
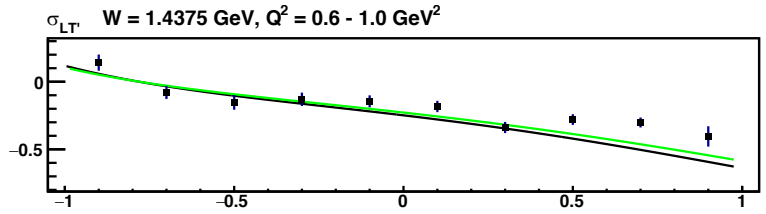
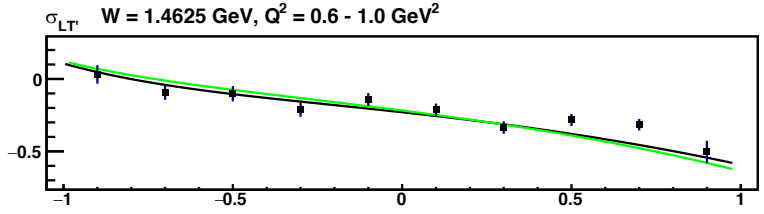
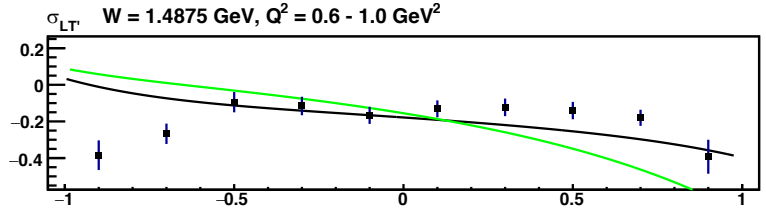


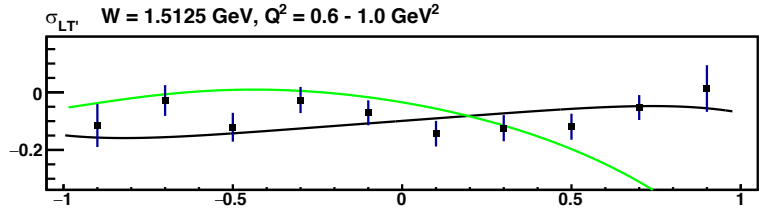


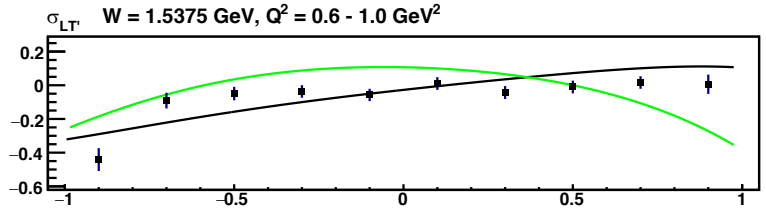


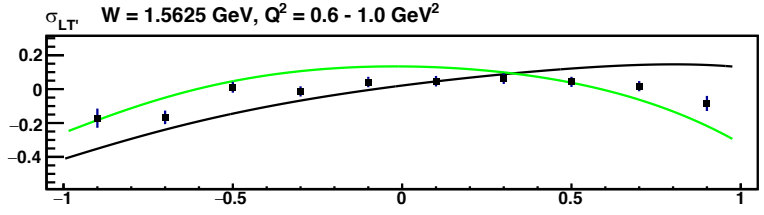


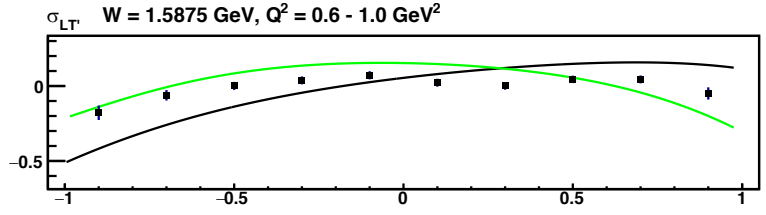




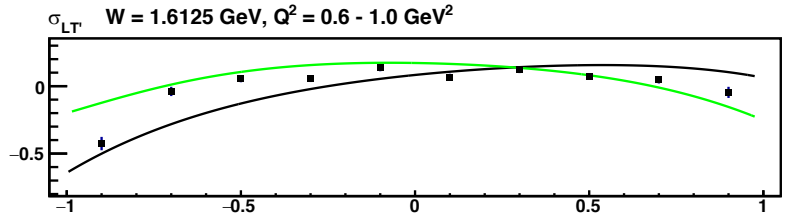


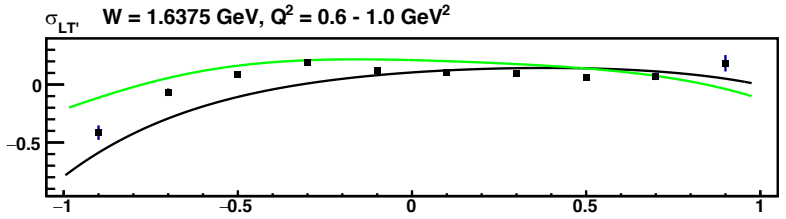


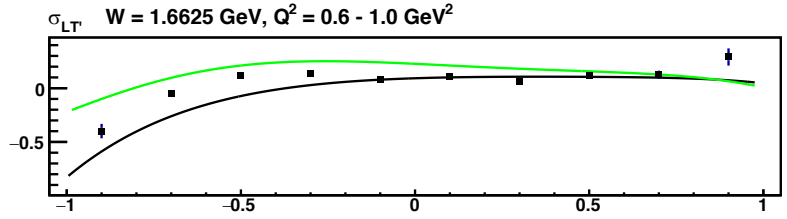


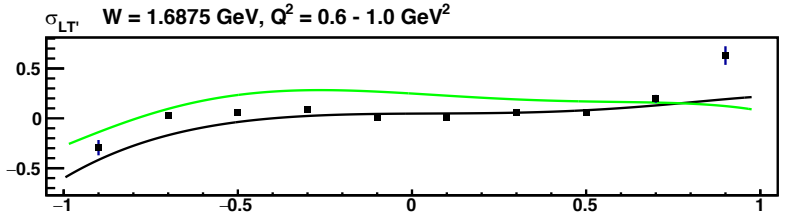


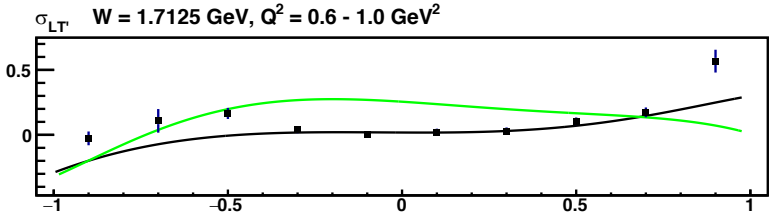
$\sigma_{LT'}$ $0.6<Q^2<1.0$ GeV^2 green-MAID2007, black-UIM

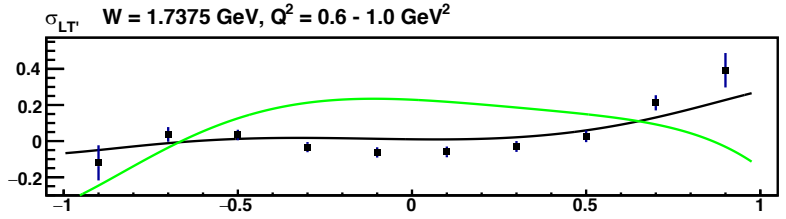


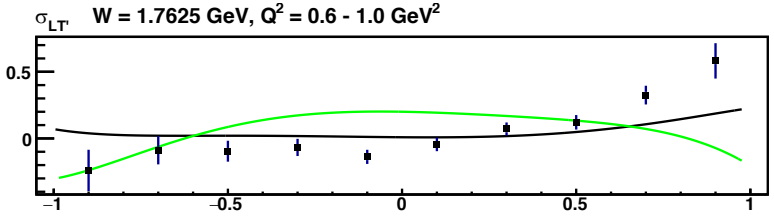


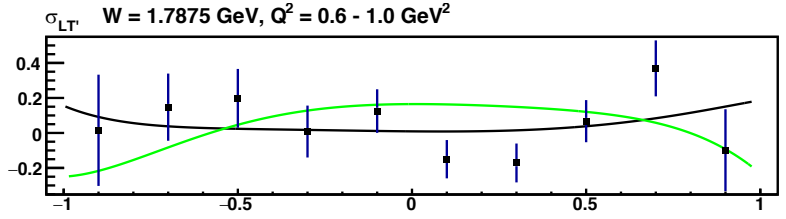












Next Steps and Conclusions

- LP analysis and overall check on the data
- The polarized structure function $\sigma_{LT'}$ was extracted from the CLAS E1E data in the kinematical region

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

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

- The combined analysis of polarized and unpolarized data will give us information on electroexcitation amplitudes with focus on the second and third resonance regions.