

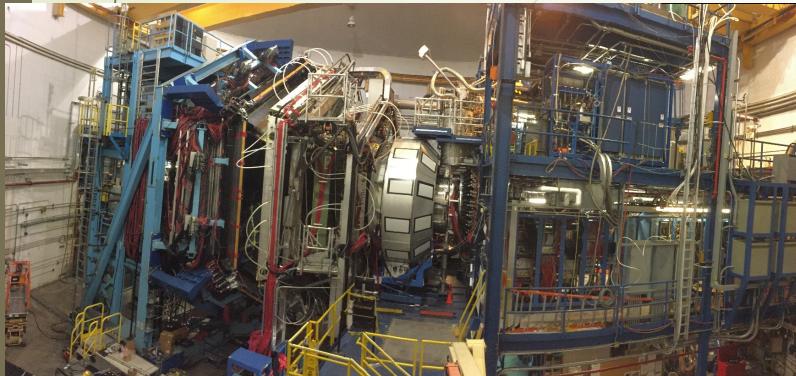


Электророждение мезонов на детекторах CLAS и CLAS12

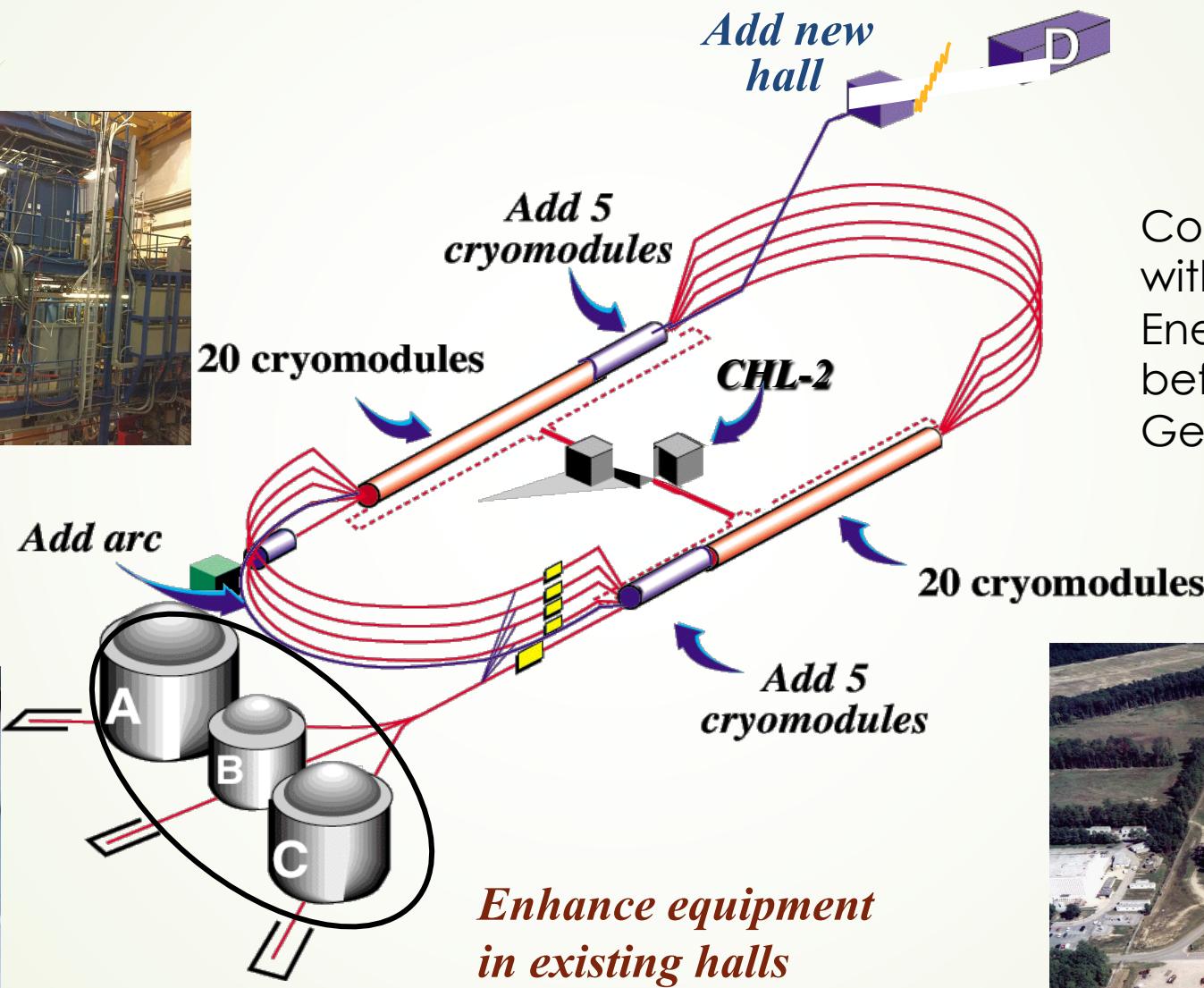
ОЭПВАЯ НИИЯФ МГУ
Е. Исупов

Jefferson Lab (Newport News, VA, USA)

CLAS12 in Hall B



CLAS (1998-2012)



Continuous electron beam
with
Energy = 11 GeV
before upgrade: Energy = 6
GeV



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

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

$$D_a^\mu = \partial^\mu + igA_a^\mu$$

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

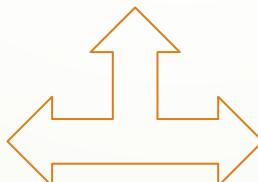
- Color matrices and structure constants

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



- Lattice QCD
- Continuum QCD

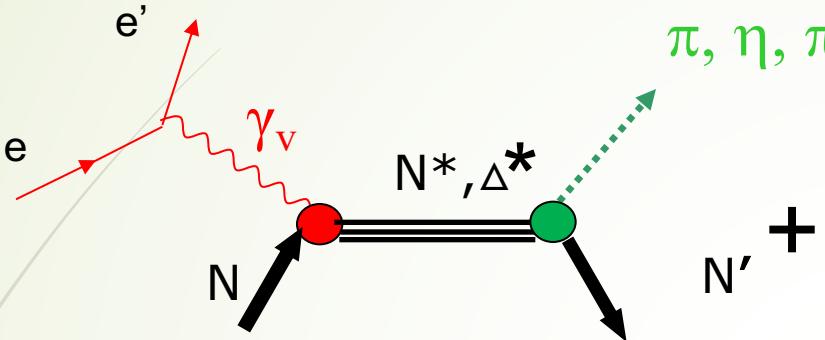
Light front quark models
AdS/CFT approaches
χ Quark-Soliton models
Hypercentral quark model
Covariant quark models
.....



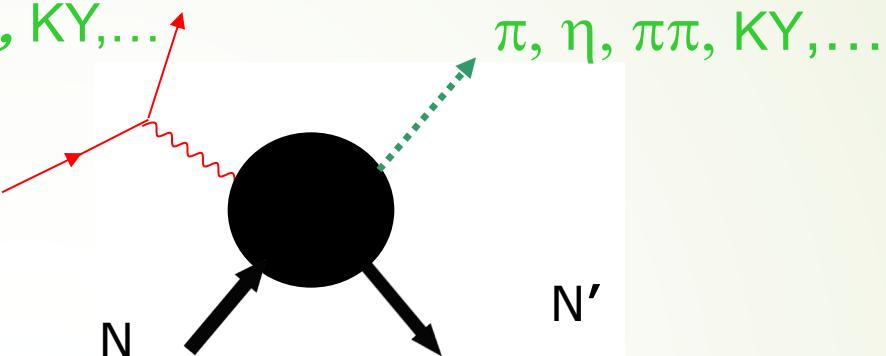
Extraction of $\gamma_v NN^*$ Electrocouplings from Exclusive Meson Electroproduction off Nucleons

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Resonant amplitudes



Non-resonant amplitudes



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

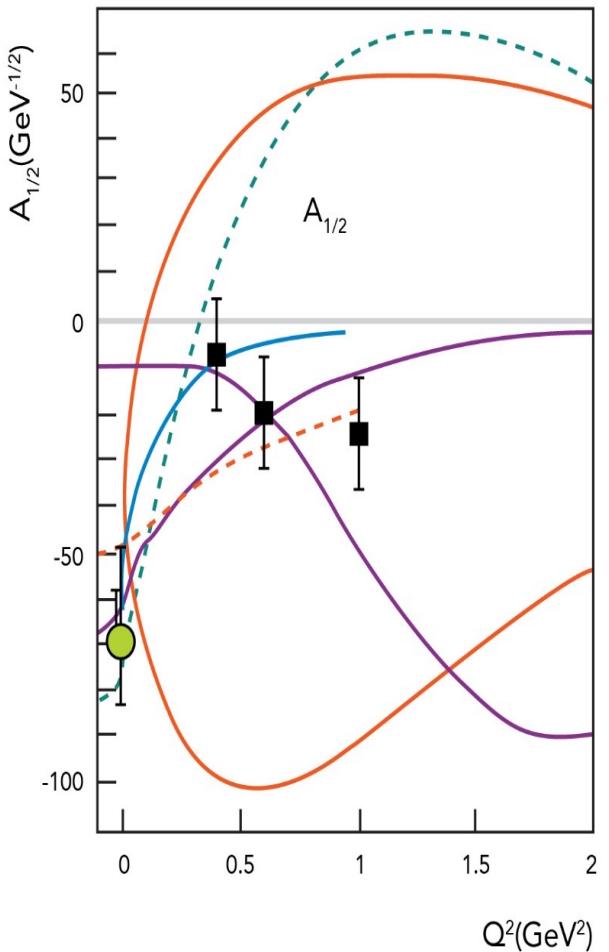
- $A_{1/2}(Q^2), A_{3/2}(Q^2), S_{1/2}(Q^2)$

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

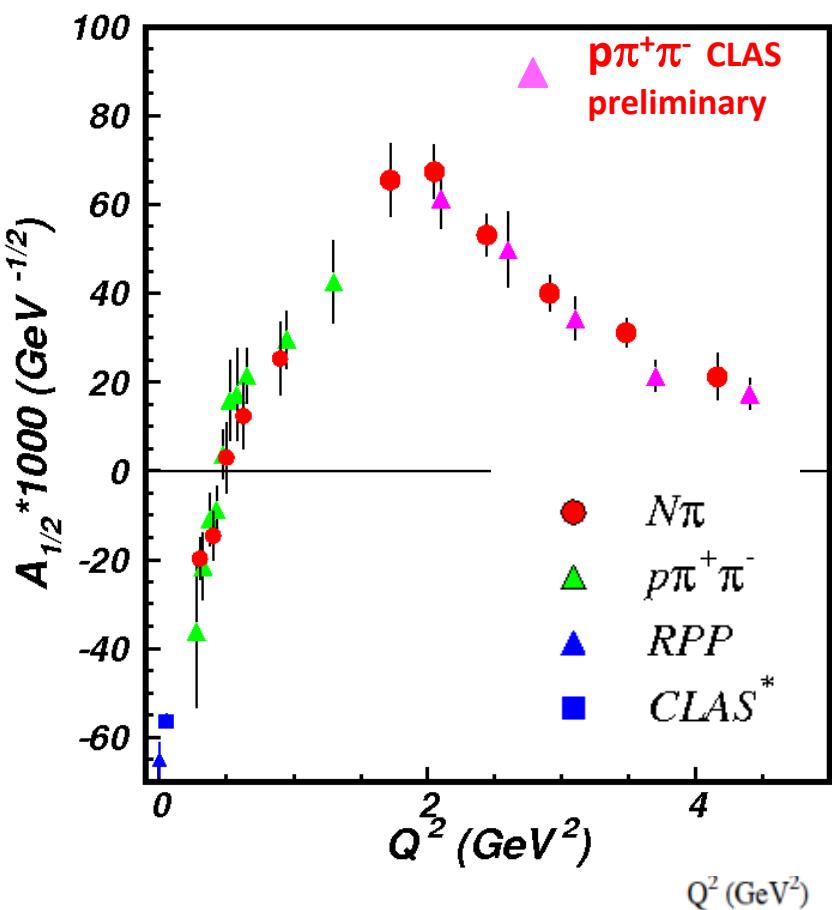
- Consistent results on $\gamma_v p N^*$ electrocouplings from different meson electroproduction channels are critical in order to validate reliable extraction of these quantities.

Roper resonance in 2002 & 2016

(updated 2019)



V. Burkert, Baryons 2002



V. D. Burkert, Baryons 2016 and the recent update from the CLAS $\pi^+\pi^-p$ electroproduction off protons data

Single meson electroproduction in the resonance region from CLAS

	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]

Polarized structure function $\sigma_{LT'}$ from $\pi^0 p$ electroproduction data in the resonance region at $0.4 \text{ GeV}^2 < Q^2 < 1.0 \text{ GeV}^2$

E. L. Isupov *et al.* (CLAS Collaboration)

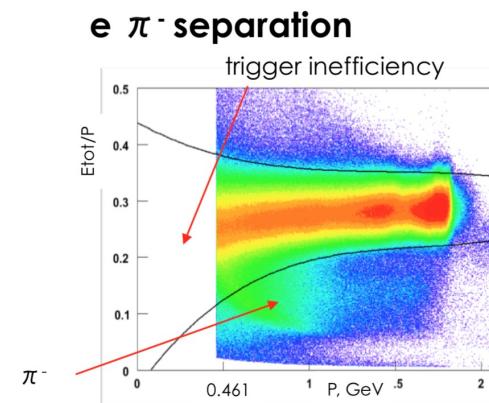
Phys. Rev. C **105**, L022201 – Published 18 February 2022

Data

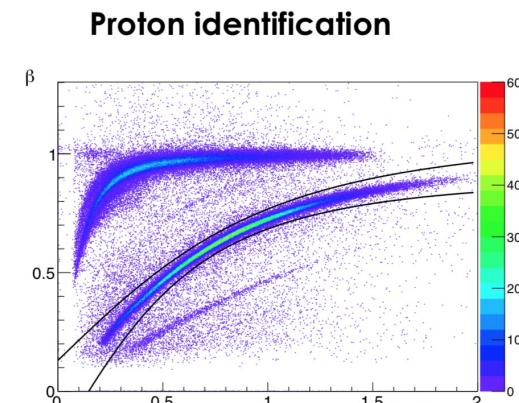
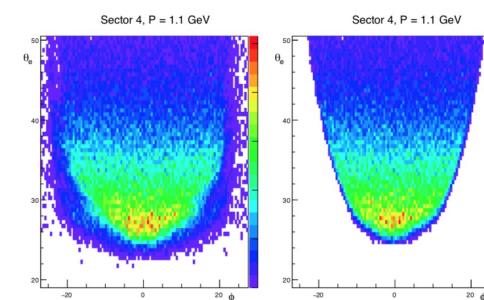
- CLAS detector data 12/2002 – 1/2003
- Beam energy: 2.036 GeV
- Beam polarization: $\sim 80\%$
- Target: Liquid Hydrogen, thickness 2 cm
- Number of triggers: ~ 1.5 billion

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

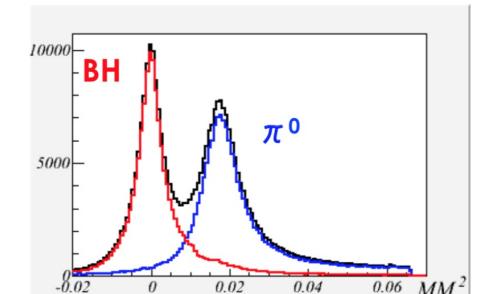
$$1.1 < W < 1.8 \text{ GeV}$$



Fiducial cuts



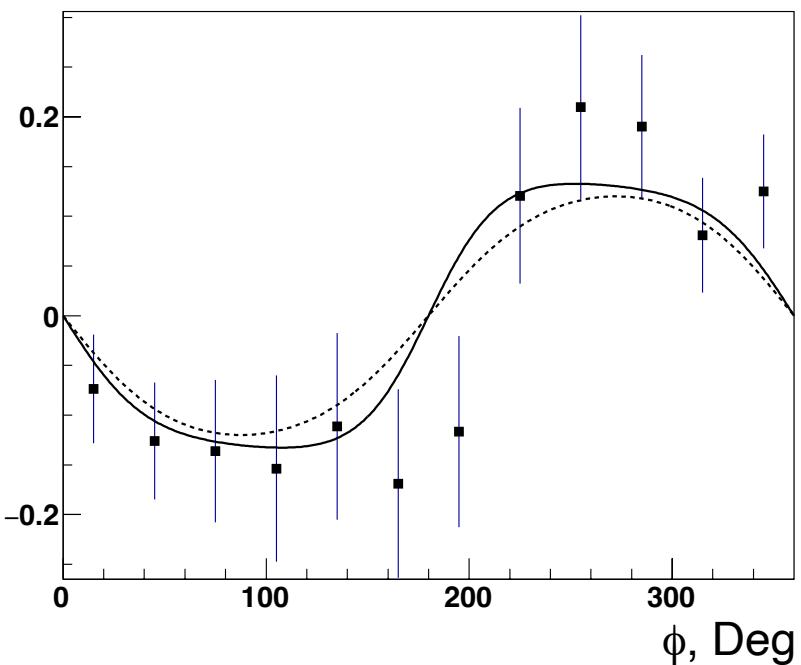
Final event selection



Beam spin asymmetries

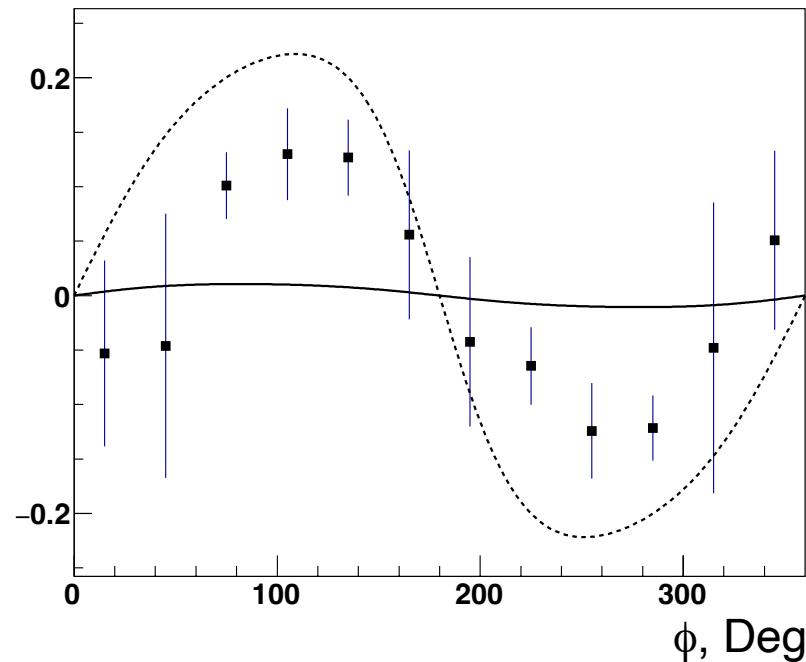
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BSA $W = 1.56 \text{ GeV}$, $Q^2 = 0.5 \text{ GeV}^2$, $\cos(\theta) = -0.9$



MAID 2007 (solid line)

BSA $W = 1.71 \text{ GeV}$, $Q^2 = 0.5 \text{ GeV}^2$, $\cos(\theta) = 0.9$



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

EC fits <https://userweb.jlab.org/~isupov/couplings/>

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

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

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 σ_{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

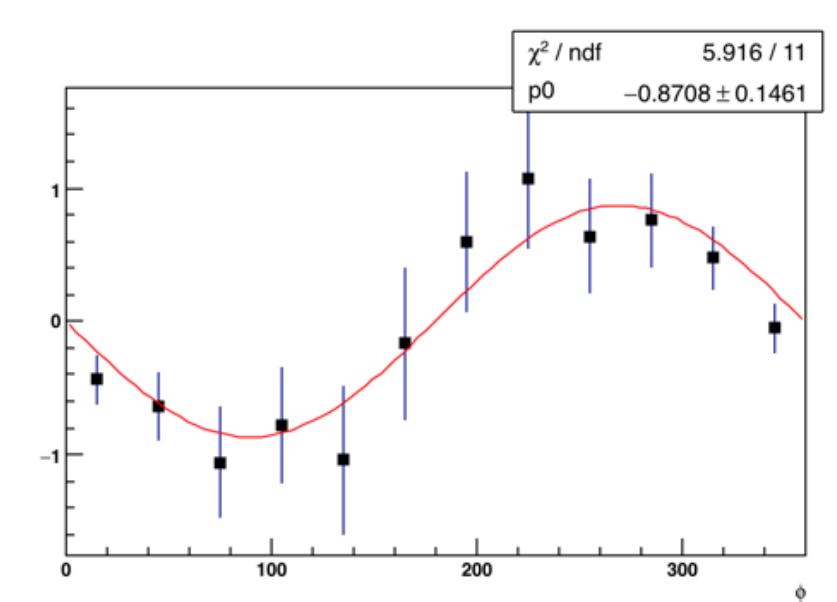
10 $\text{Cos}(\theta)$ -bins [-1,1] width = 0.2

12 Φ -bins [0,360] width = 30°

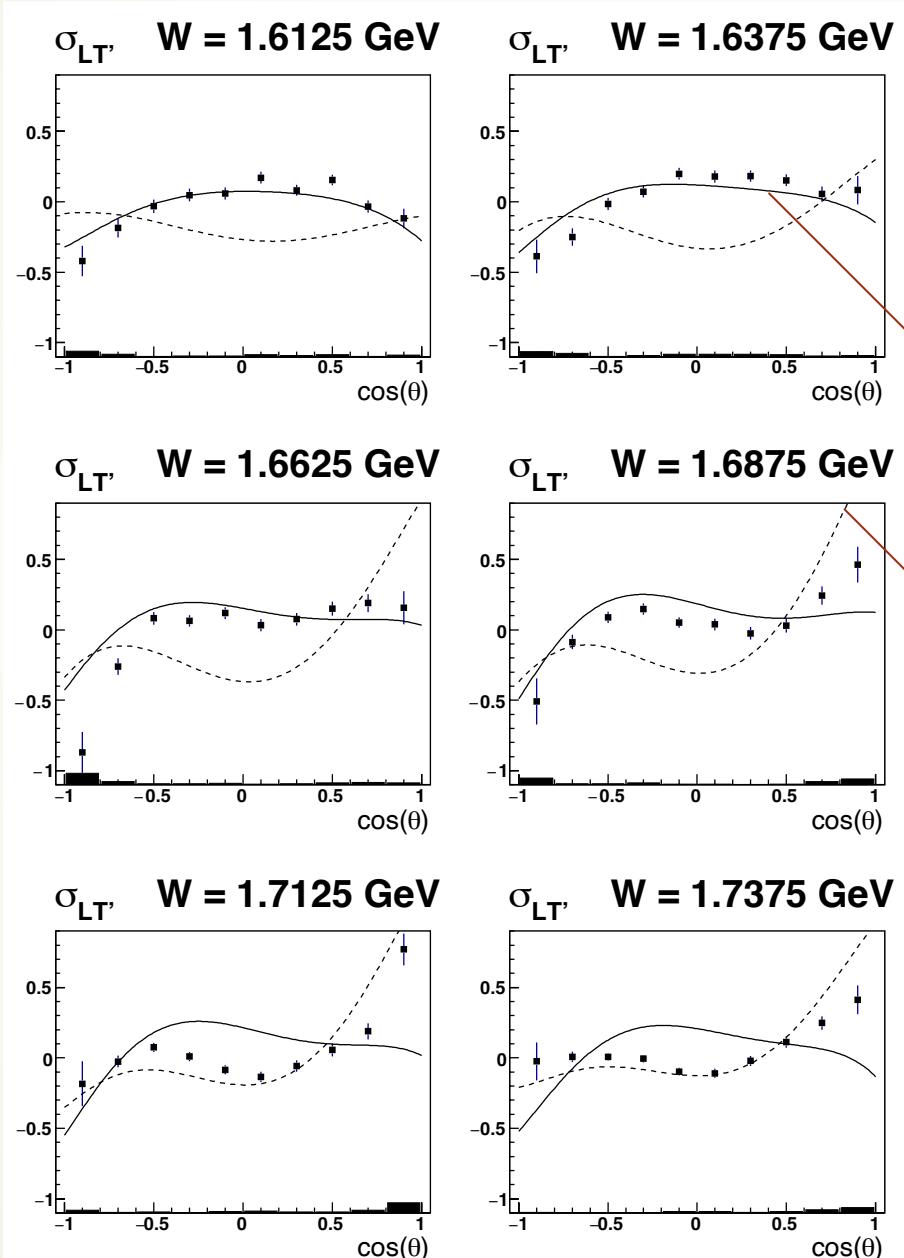
$W = 1.66 \text{ GeV}$

$0.4 < Q^2 < 0.6 \text{ GeV}^2$

$\text{Cos}(\theta) = -0.9$



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



MAID 2007 (solid line)

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

Legendre Polynomials of $\sigma_{LT'}$

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$$l=0,1,2,3 \quad \sigma_{LT'} = D_0 + D_1 x + D_2 * 0.5 * (3 * x^2 - 1) + D_3 * 0.5 * (5 * x^3 - 3 * x)$$

sensitivity to P13(1720)

$$D_1 \sim -\text{Im}(\dots 6 * S1p * \text{conj}(E1p) - 6 * S1p * \text{conj}(M1p) \dots)$$

sensitivity to D33(1700)

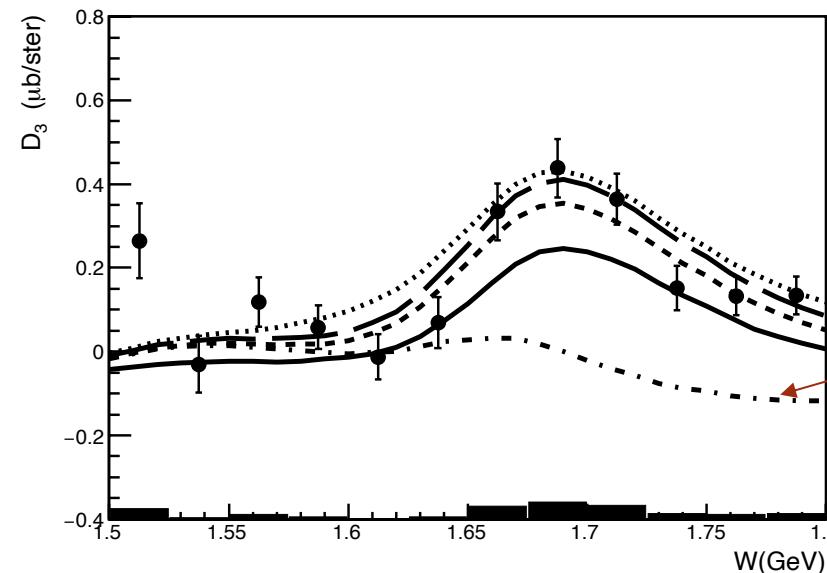
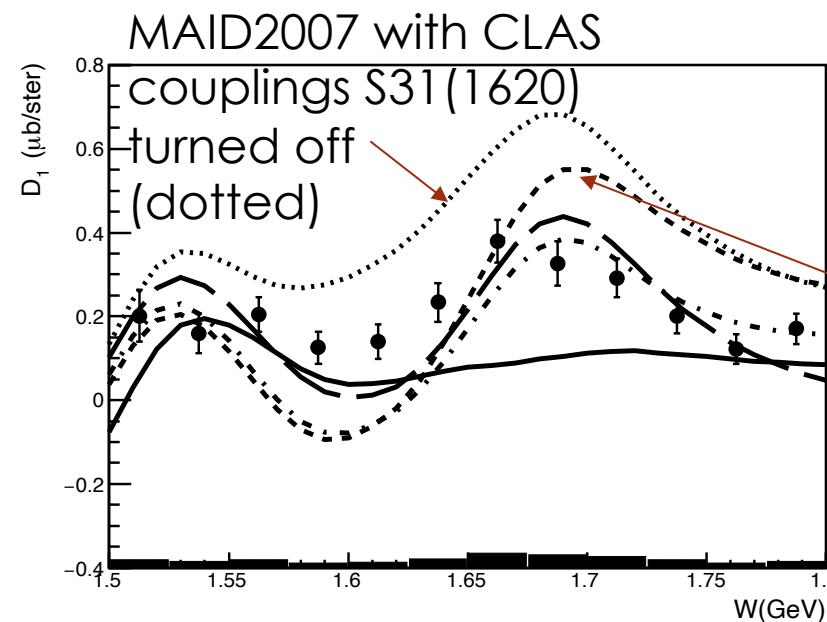
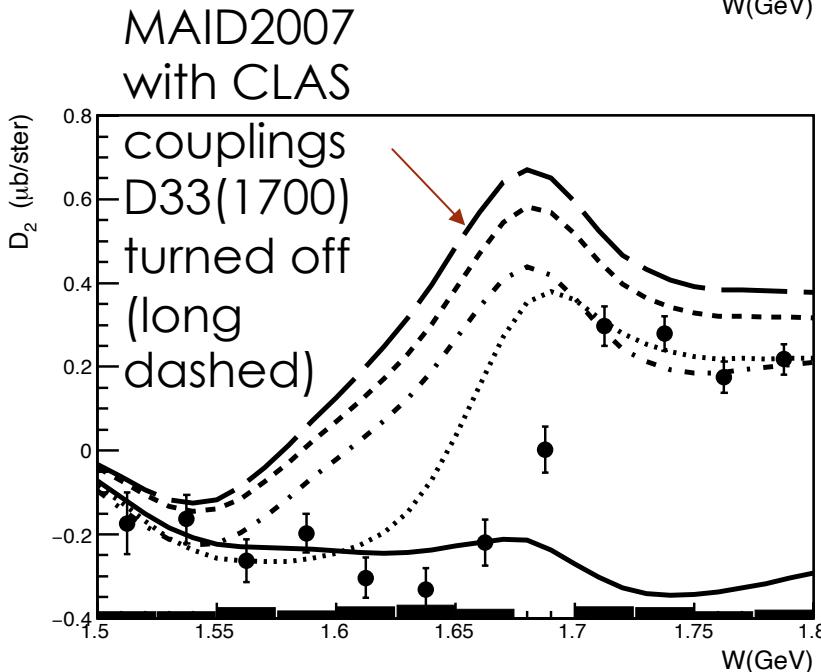
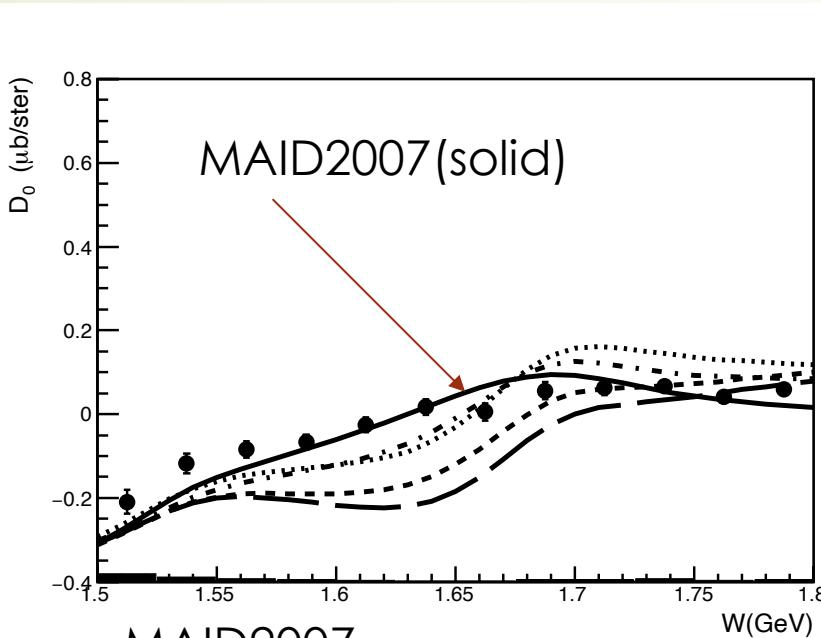
$$D_1 \sim -\text{Im}(\dots - 6 * S2m * \text{conj}(E2m) - 6 * S2m * \text{conj}(M2m) \dots)$$

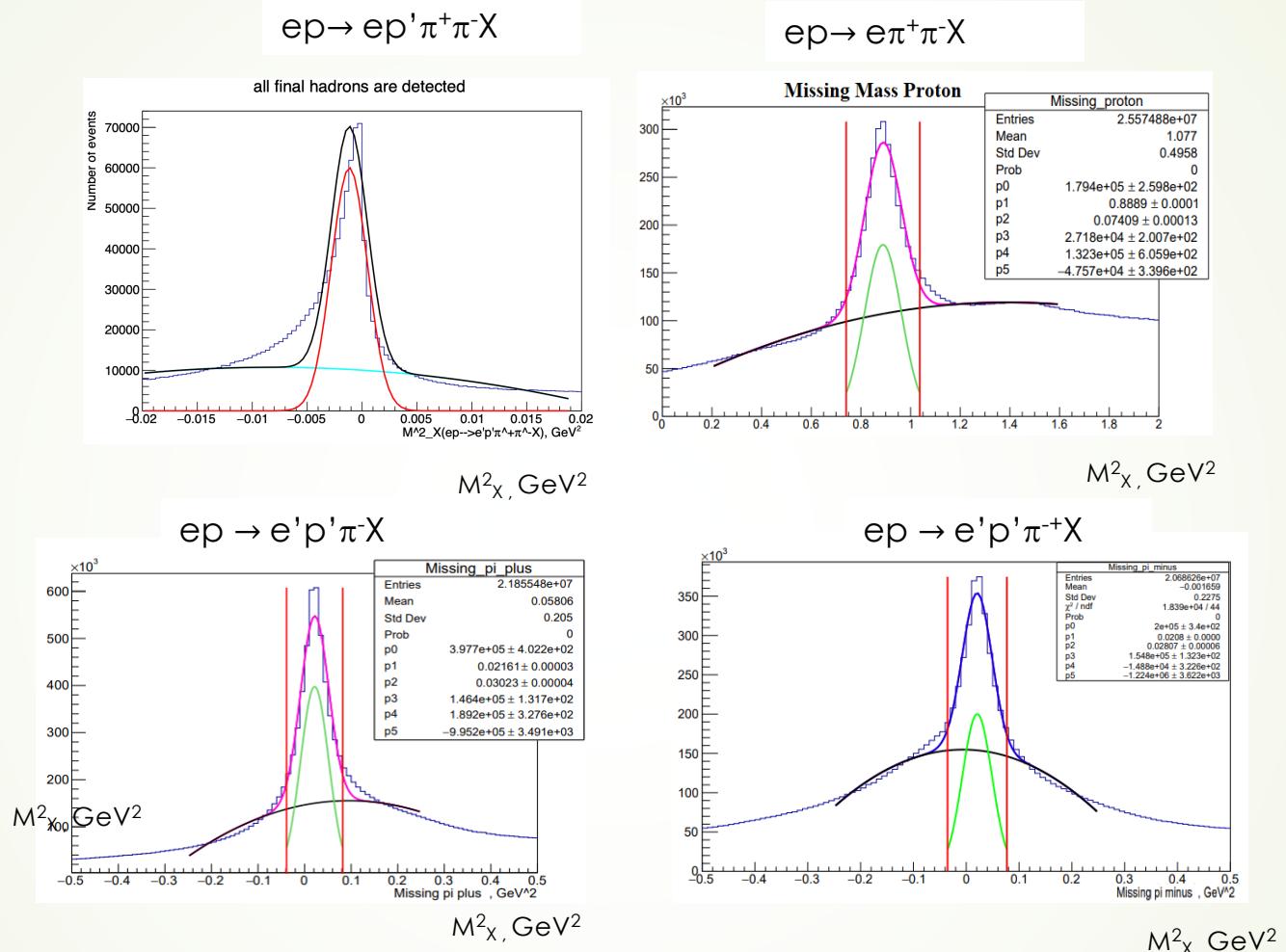
LP – effective way to present our data
and to demonstrate sensitivity to
different excited states of the nucleon

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 σ_{LT} , $0.4 < Q^2 < 0.6 \text{ GeV}^2$

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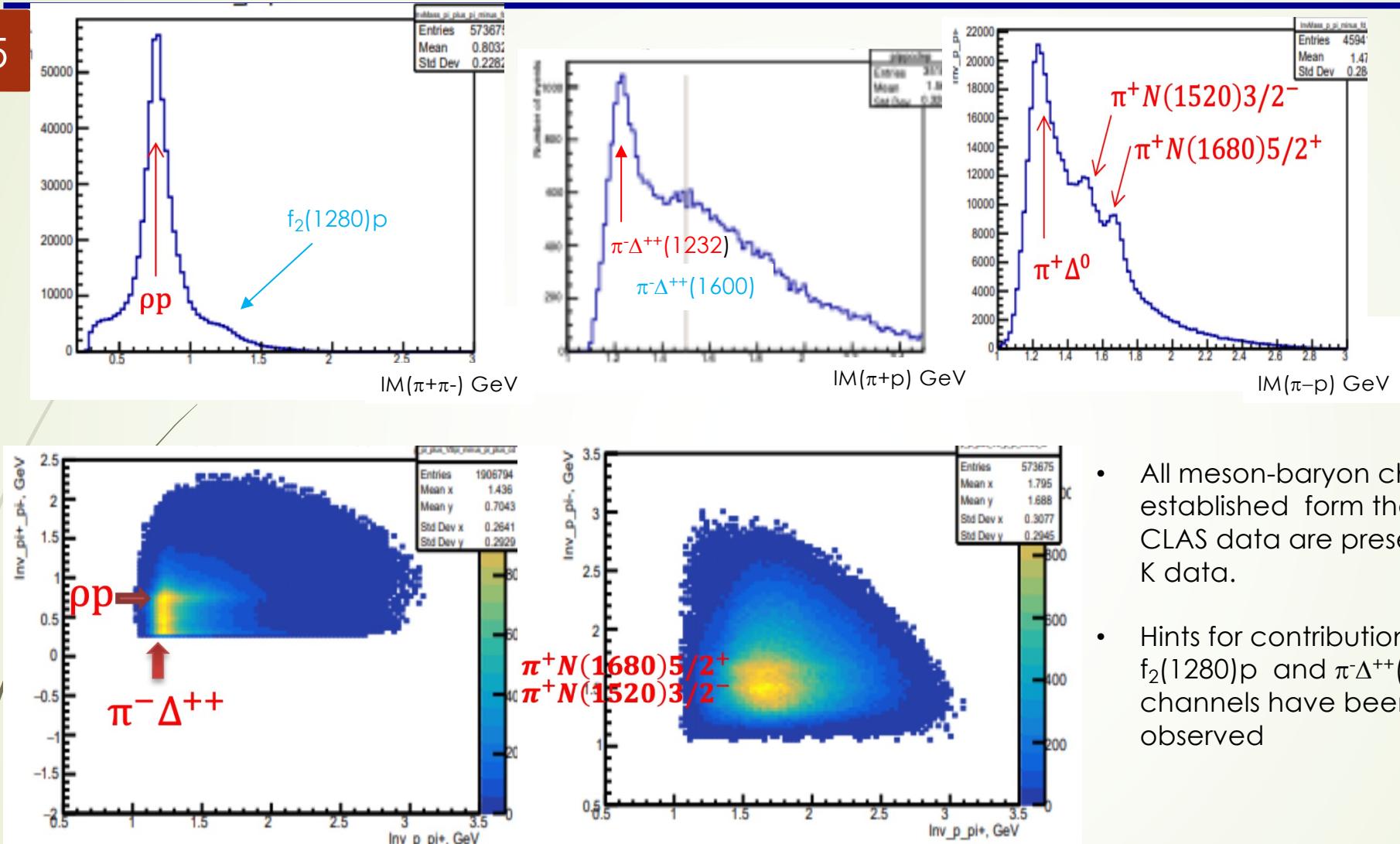
Available data-set: Data on nine independent one-fold differential cross sections \rightarrow nucleon resonance electroexcitation

Full statistics for RG-K will allow:

- to obtain $\pi^+\pi^-p$ electroproduction cross section within Q^2 -bins of 0.1 GeV^2 size

$\pi^+\pi^-p$ CLAS12 data analysis

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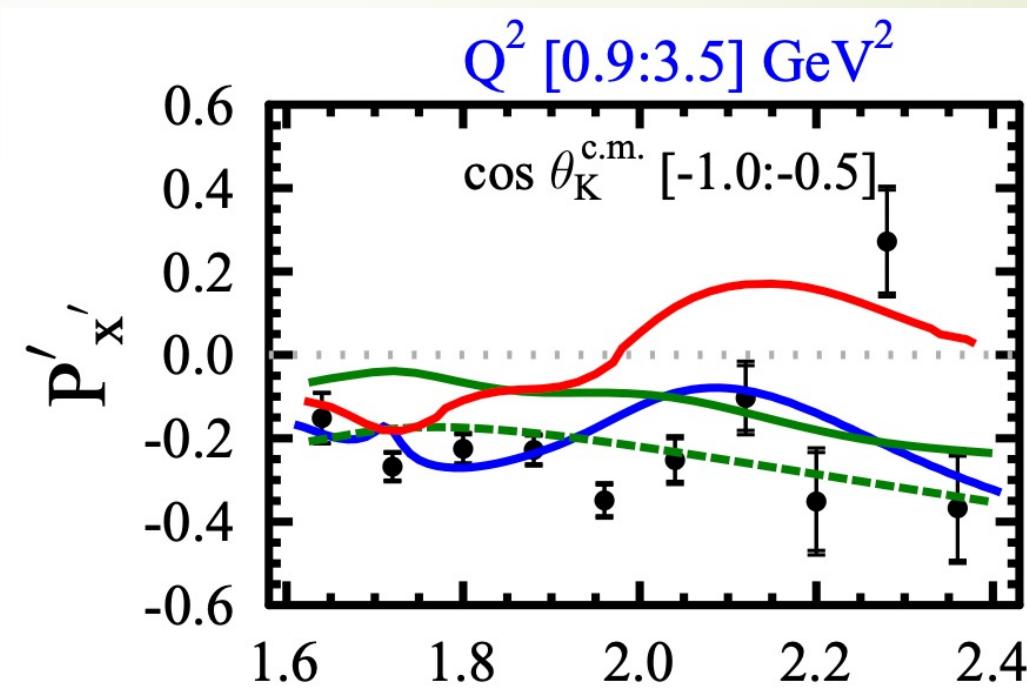


- All meson-baryon channels established from the $\pi^+\pi^-p$ CLAS data are present in RG-K data.
- Hints for contributions from $f_2(1280)p$ and $\pi^-\Delta^{++}(1600)3/2^+$ channels have been observed

$\pi^+\pi^-p$ is the ideal ground for resonance electrocoupling extraction as proved by the discovery of the $N'(1720)3/2^+$ from the CLAS data analysis (V.I. Mokeev et al., Phys. Lett. B 805, 135457 (2020)).

Первые данные детектора CLAS12 по реакциям электророждения $K^+\Lambda$ и $K^+\Sigma^0$ на протоне

- Получены первые результаты экспериментов по исследованию структуры и спектра нуклонных резонансов (N^*) на детекторе CLAS12. Из данных реакций электророждения $K^+\Lambda$ и $K^+\Sigma^0$ определены поляризации конечных гиперонов в области инвариантных масс конечных адронов W , отвечающей полному перекрытию резонансной области. Впервые получены детальные результаты по зависимостям поляризации гиперонов от W при $1.6 < W < 2.4$ ГэВ, где могут быть обнаружены гибридные барионы состоящие из 3 одетых кварков и глюона
- Будущий совместный анализ дифференциальных сечений и поляризационных наблюдаемых позволит извлечь амплитуды электровозбуждения большинства N^* . Детектор CLAS12 является единственной в мире установкой позволяющей исследовать эволюцию амплитуд электровозбуждения N^* в области квадратов 4-импульсов виртуальных фотонов до 8-10 ГэВ²
- Анализ этих результатов в рамках решений уравнений движения полей кварков и глюонов определяемых Лагранжианом КХД в методе уравнений Дайсона-Швингера открывает перспективу доступа к механизмам формирования доминирующей части массы адронов и структуры N^* при переходе от непертурбативного к пертурбативному режимам сильного взаимодействия



P'_x компонента поляризации Λ гиперона как функция инвариантной массы конечных адронов $W(\text{ГэВ})$, при виртуальности фотона $0.9 < Q^2 < 3.5 \text{ ГэВ}^2$ и значении косинуса угла эмиссии каона в системе центра масс фотон-протон $[-1.0;-0.5]$. Зеленая сплошная линия – модель RPR-2011, зеленая штриховая линия – модель RPR-2011 без резонансного вклада, красная линия – модель BS3, голубая линия – модель Kaon-MAID



Спасибо за внимание!