ПЕРСПЕКТИВЫ ИЗУЧЕНИЯ АМПЛИТУД ЭЛЕКТРОВОЗБУЖДЕНИЯ НУКЛОННЫХ РЕЗОНАНСОВ ПРИ БОЛЬШИХ ПЕРЕДАННЫХ ИМПУЛЬСАХ

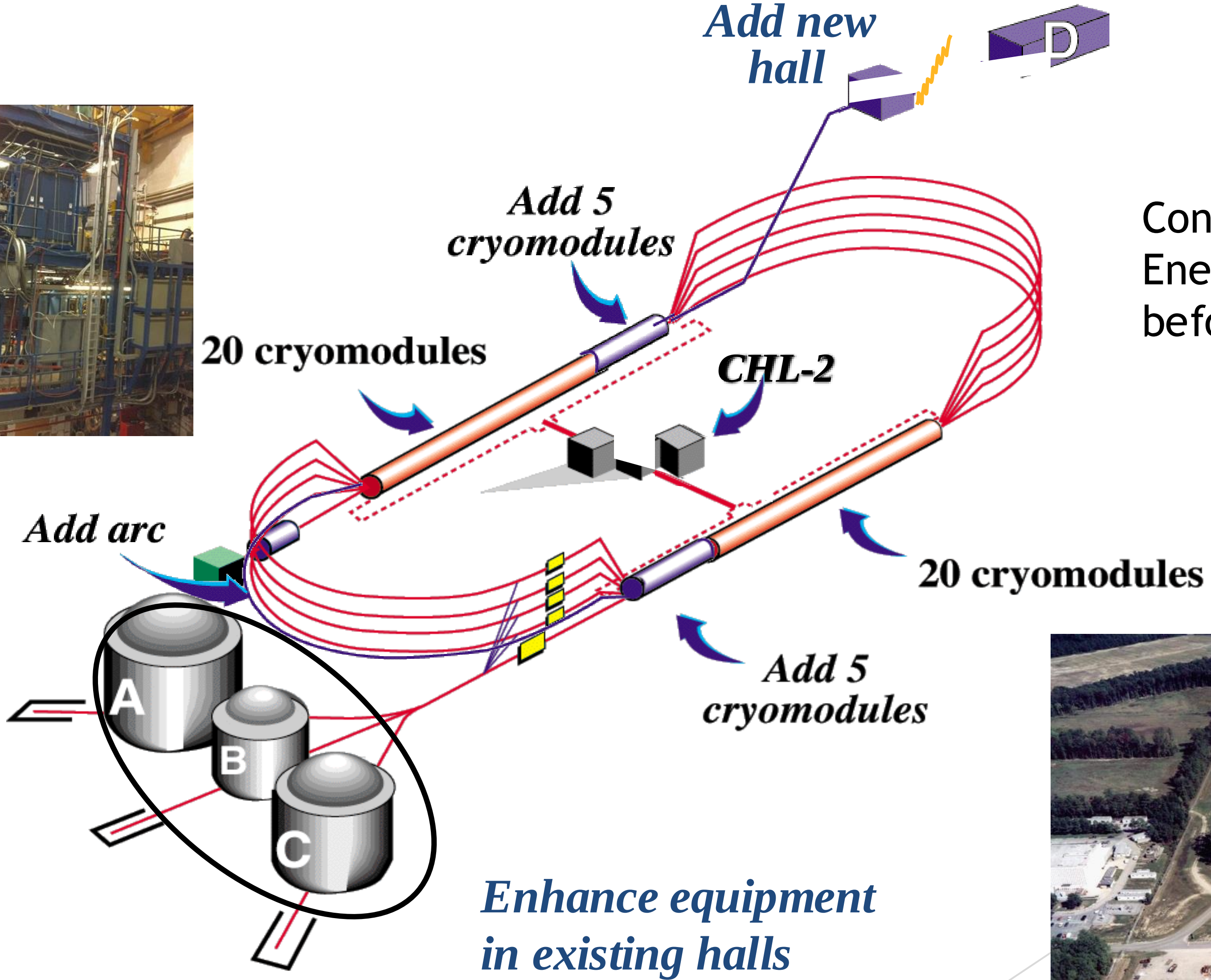
ОЭПВАЯ НИИЯФ МГУ

Е.Л. 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

Summary of Published CLAS Data on Exclusive Meson Electroproduction off Protons in N* Excitation Region

Hadronic final state	Covered W-range, GeV	Covered Q^2-range, GeV^2	Measured observables
$\pi^+ n$	1.1-1.38 1.1-1.55 1.1-1.7 1.6-2.0	0.16-0.36 0.3-0.6 1.7-4.5 1.8-4.5	$d\sigma/d\Omega$ $d\sigma/d\Omega$ $d\sigma/d\Omega$, A_b $d\sigma/d\Omega$
$\pi^0 p$	1.1-1.38 1.1-1.68 1.1-1.39 1.1-1.8	0.16-0.36 0.4-1.8 3.0-6.0 0.4-1.0	$d\sigma/d\Omega$ $d\sigma/d\Omega$, A_b,A_t,A_{bt} $d\sigma/d\Omega$ $d\sigma/d\Omega$, A_b
ηp	1.5-2.3	0.2-3.1	$d\sigma/d\Omega$
$K^+\Lambda$	thresh-2.6	1.40-3.90 0.70-5.40	$d\sigma/d\Omega$ P^0, P'
$K^+\Sigma^0$	thresh-2.6	1.40-3.90 0.70-5.40	$d\sigma/d\Omega$ P'
$\pi^+\pi^- p$	1.3-1.6 1.4-2.1 1.4-2.0	0.2-0.6 0.5-1.5 2.0-5.0	Nine 1-fold differential cross sections

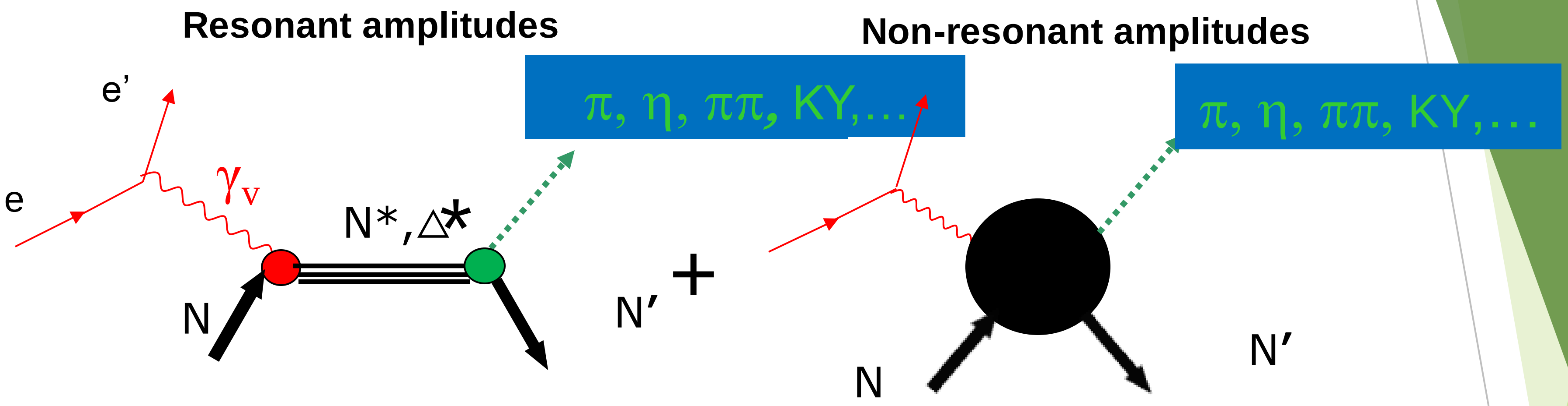
- $d\sigma/d\Omega$–CM angular distributions
- A_b,A_t,A_{bt}-longitudinal beam, target, and beam-target asymmetries
- P^0, P' –recoil and transferred polarization of strange baryon

Over 120,000 data points!

Almost full coverage of the final hadron phase space

The measured observables from CLAS are stored in the [CLAS Physics Data Base http://clas.sinp.msu.ru/cgi-bin/jlab/db.cgi](http://clas.sinp.msu.ru/cgi-bin/jlab/db.cgi)

Extraction of γ_vNN* Electrocouplings from Exclusive Meson Electroproduction off Nucleons



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

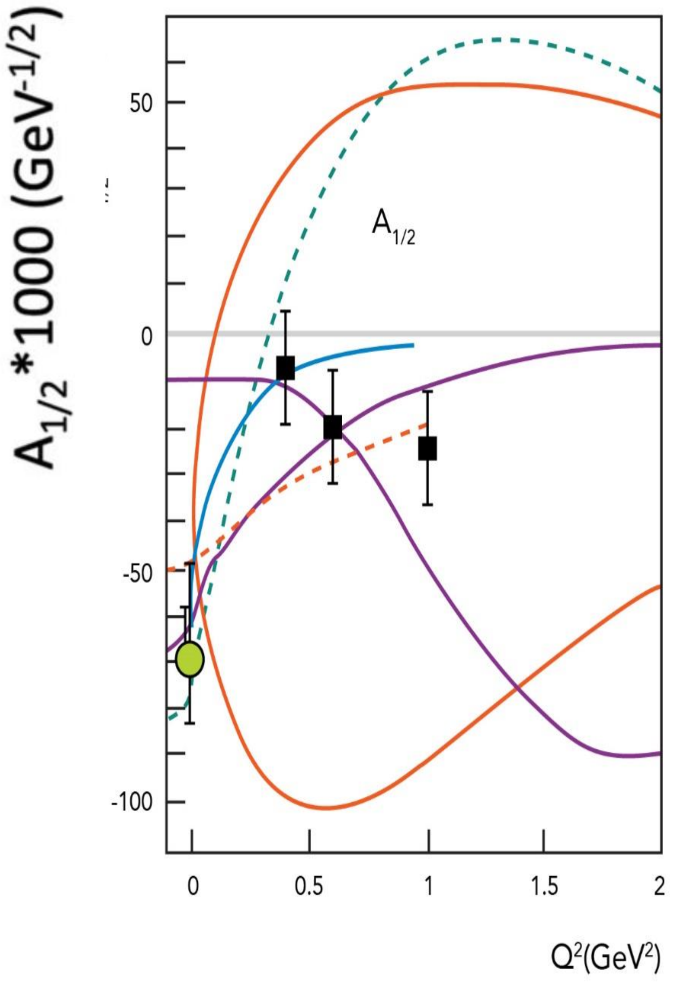
- **Real $A_{1/2}(Q^2)$, $A_{3/2}(Q^2)$, $S_{1/2}(Q^2)$**

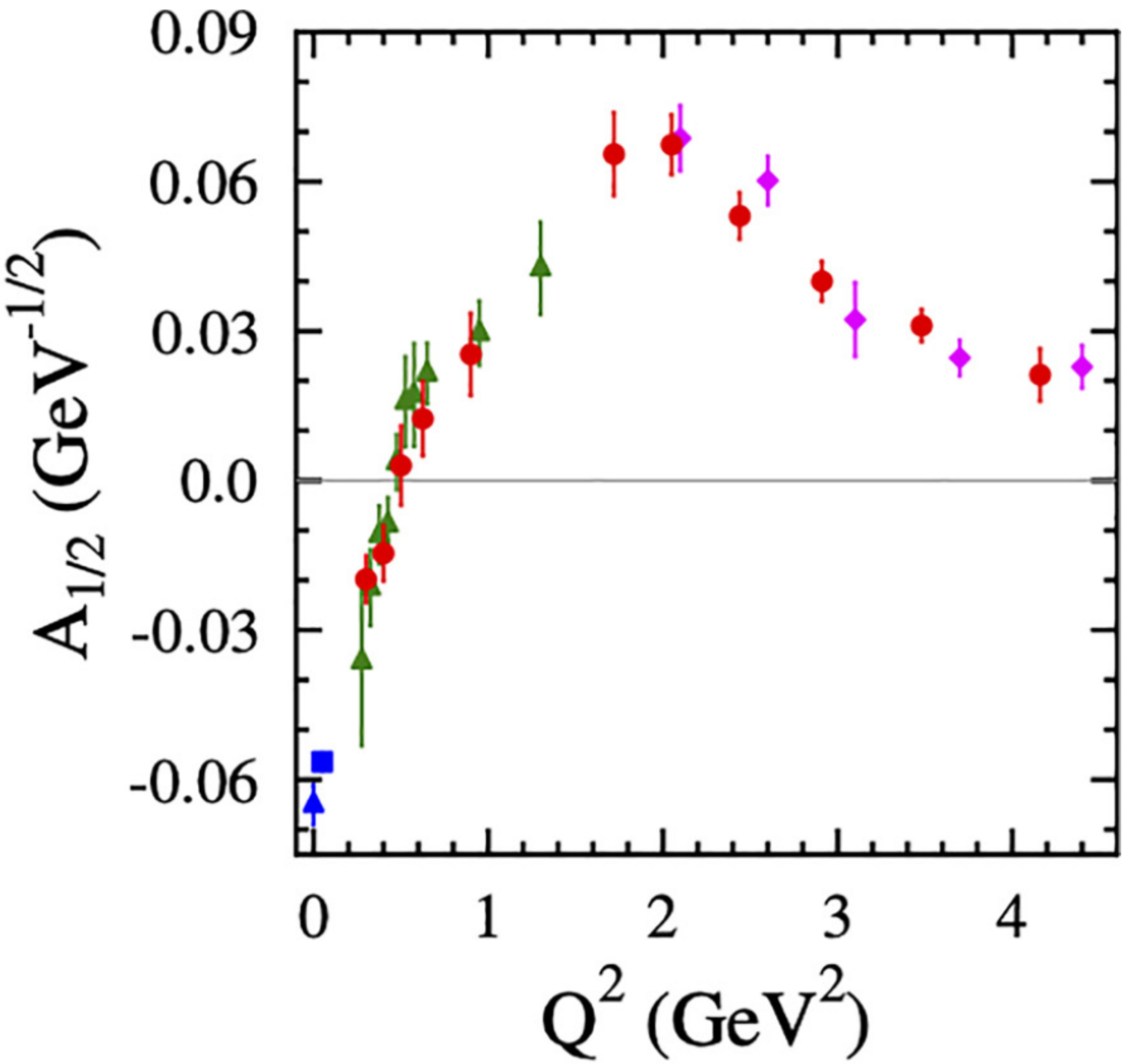
I.G. Aznauryan and V.D. Burkert, Prog. Part. Nucl. Phys. 67, 1 (2012)

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

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

Roper resonance before and after CLAS





Eur. Phys. J. A (2024) 60:173
https://doi.org/10.1140/epja/s10050-024-01282-x

THE EUROPEAN PHYSICAL JOURNAL A

Review

Strong interaction physics at the luminosity frontier with 22 GeV electrons at Jefferson Lab

A. Accardi[1], P. Achenbach[2], D. Adhikari[3], A. Afanasev[4], C. S. Akondi[5], N. Akopov[6], M. Albaladejo[7], H. Albataineh[8], M. Albrecht[2], B. Almeida-Zamora[9], M. Amaryan[10], D. Androić[11], W. Armstrong[12], D. S. Armstrong[13], M. Arratia[14], J. Arrington[15], A. Asaturyan[16], A. Austregesilo[2], H. Avakian[2], T. Averett[13], C. Ayerbe Gayoso[13], A. Bacchetta[17], A. B. Balantekin[18], N. Baltzell[2], L. Barion[19], P. C. Barry[2], A. Bashir[2,20], M. Battaglieri[21], V. Bellini[22], I. Belov[21], O. Benhar[23], B. Benkel[24], F. Benmokhtar[25], W. Bentz[26], V. Bertone[27], H. Bhatt[28], A. Bianconi[29], L. Bibrzycki[30], R. Bijker[31], D. Binosi[32], D. Biswas[3], M. Boër[3], W. Boeglin[33], S. A. Bogacz[2], M. Boglione[34], M. Bondí[22], E. E. Boos[35], P. Bosted[13], G. Bozzi[36], E. J. Brash[37], R. A. Briceño[38], P. D. Brindza[10], W. J. Briscoe[4], S. J. Brodsky[39], W. K. Brooks[24,40,41], V. D. Burkert[2], A. Camsonne[2], T. Cao[2], L. S. Cardman[2], D. S. Carman[2], M. Carpinelli[42], G. D. Cates[43], J. Caylor[2], A. Celentano[21], F. G. Celiberto[44], M. Cerutti[17], L. Chang[45], P. Chatagnon[2], C. Chen[46,47], J.-P. Chen[2], T. Chetry[33], A. Christopher[1], E. Christy[2], E. Chudakov[2], E. Cisbani[23], I. C. Cloët[12], J. J. Cobos-Martinez[48], E. O. Cohen[49,50], P. Colangelo[51], P. L. Cole[52], M. Constantinou[53], M. Contalbrigo[19], G. Costantini[17,29], W. Cosyn[33], C. Cotton[43], A. Courtoy[168], S. Covrig Dusa[2], V. Crede[5], Z.-F. Cui[54], A. D'Angelo[55], M. Döring[4], M. M. Dalton[2], I. Danilkin[56], M. Davydov[35], D. Day[43],

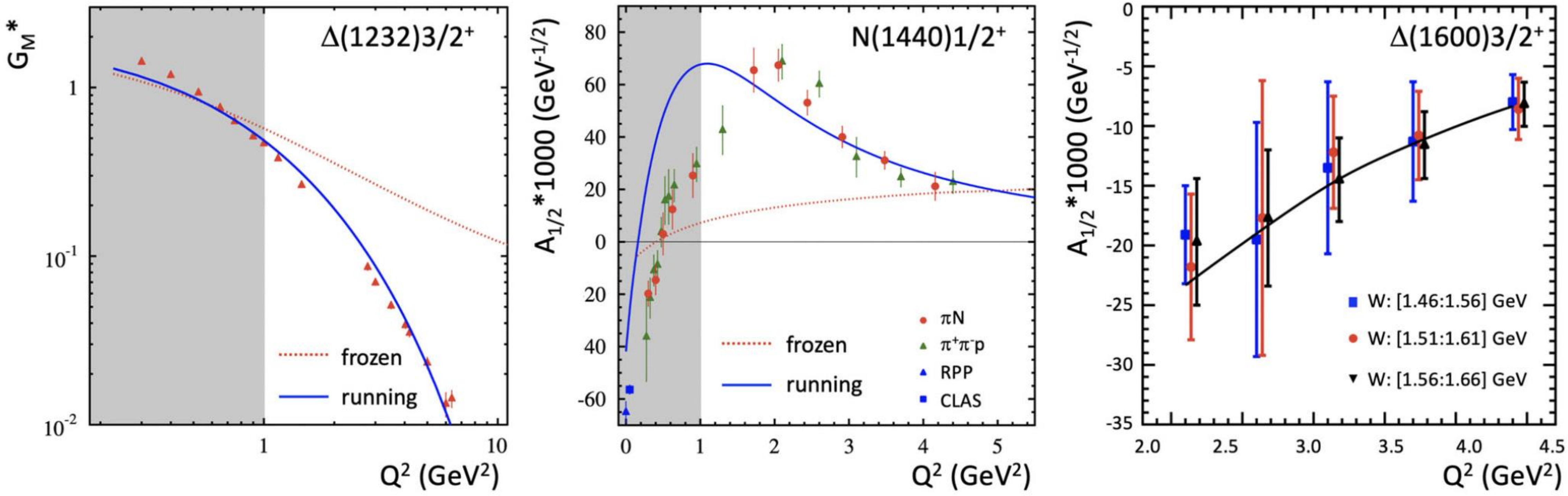
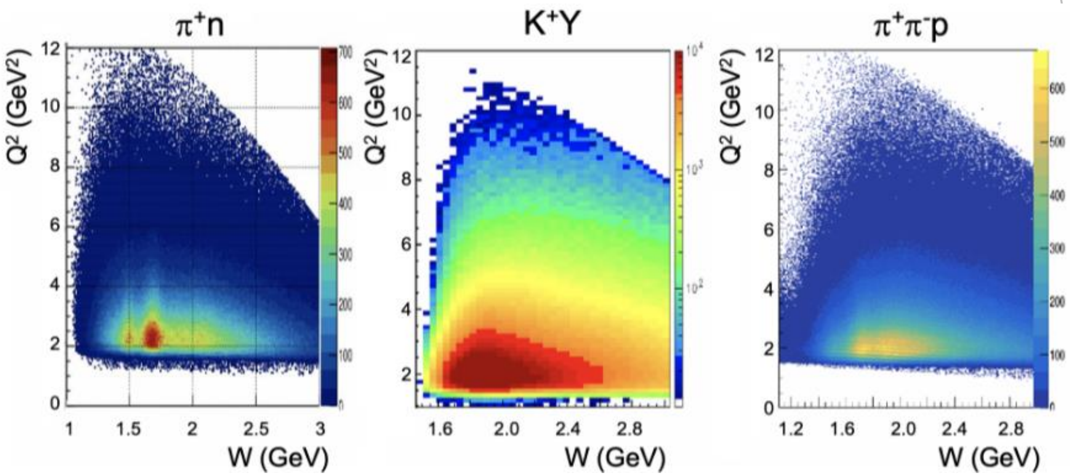


Fig. 48 Results for the $p \to \Delta(1232)3/2^+$ magnetic transition form factor (left) and the $N(1440)1/2^+$ $A_{1/2}(Q^2)$ electrocoupling (middle) [331–333] from studies of πN and $\pi^+\pi^- p$ electroproduction in measurements of the JLab 6-GeV era. CSM predictions with the running dressed quark mass deduced from the QCD Lagrangian, see Fig. 47 left, are shown as blue solid lines [309,334] and by employing a simplified contact qq-interaction resulting in a momentum-independent (frozen) quark mass of $\approx$ 0.36 GeV as red dotted lines [335]. Comparisons between the CSM prediction (solid line) on the $A_{1/2}(Q^2)$ $\Delta(1600)3/2^+$ electrocoupling [326] and preliminary results from the studies of $\pi^+\pi^- p$ electroproduction with CLAS are shown on the right. The data points with error bars have become available from independent analyses of the cross sections in overlapping W-intervals with substantial contributions from the $\Delta(1600)3/2^+$ as labeled for Q^2 from 2 to 5 GeV^2

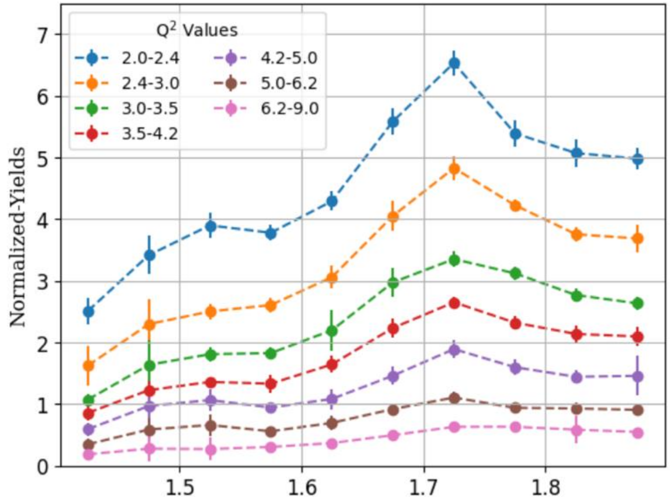
Measurements with CLAS12 and “CLAS22”

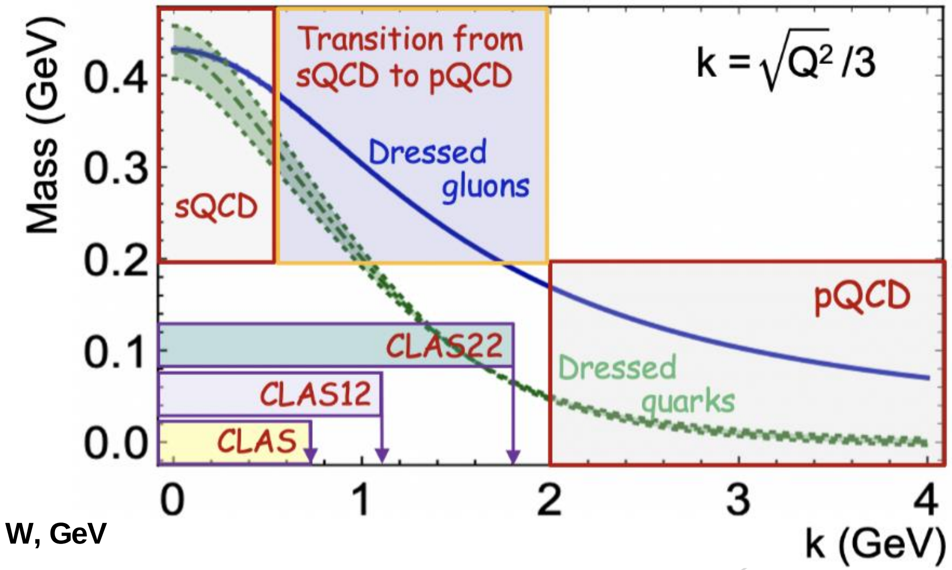
CLAS12: Extension of the results on N* electrocouplings for W < 2.5 GeV and Q^2 to 10 GeV^2 from exclusive channels, πN, $\pi\pi N$, KY, K*Y, KY*, allows us to map out the range of quark momenta where ~50% of dressed quark mass is generated

Meson electroproduction yields measured with the CLAS12

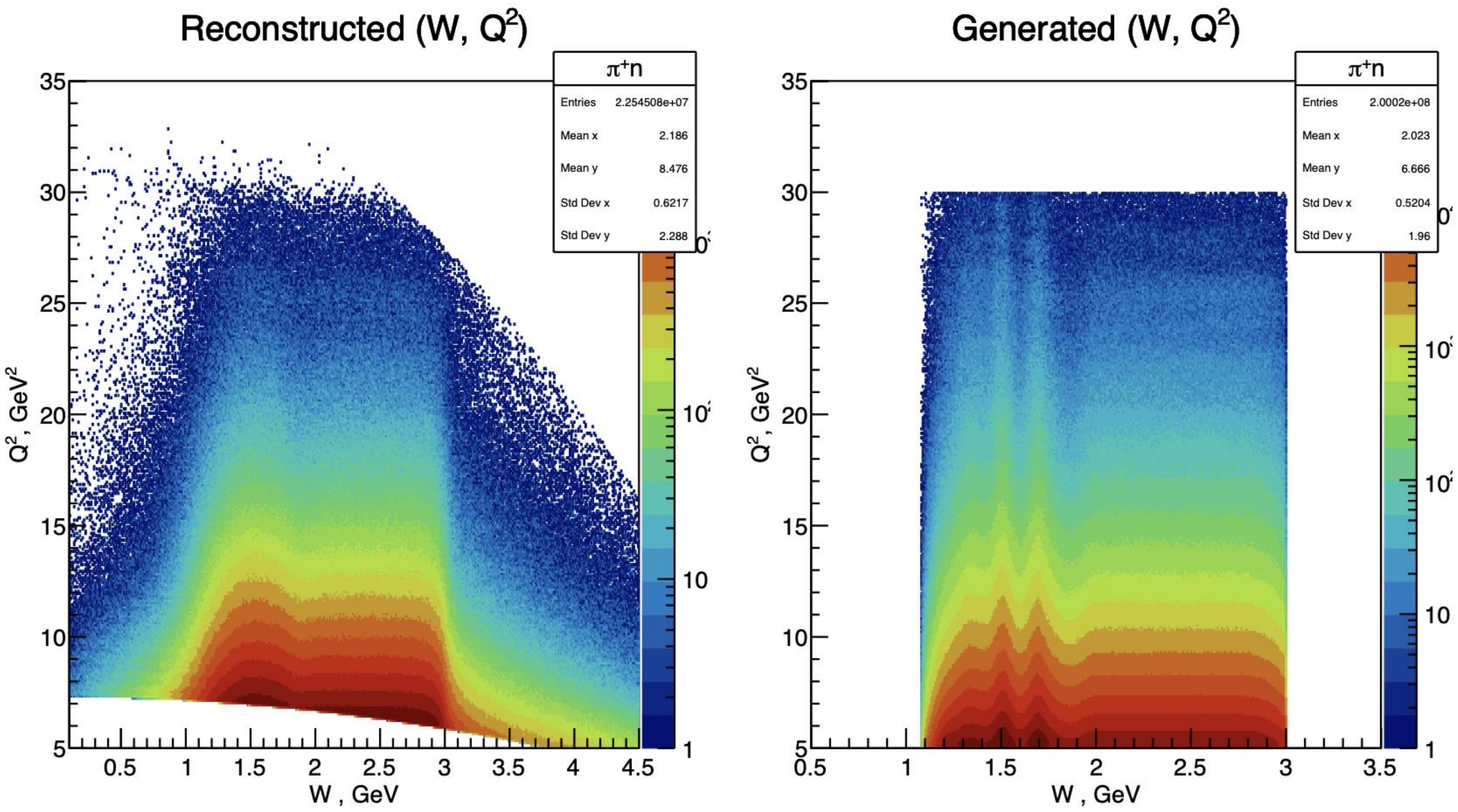


Efficiency corrected $\pi^+\pi^-p$ yields binned over W/Q^2 from RG-A data





$\pi^+ n : E_{beam} = 24$ GeV

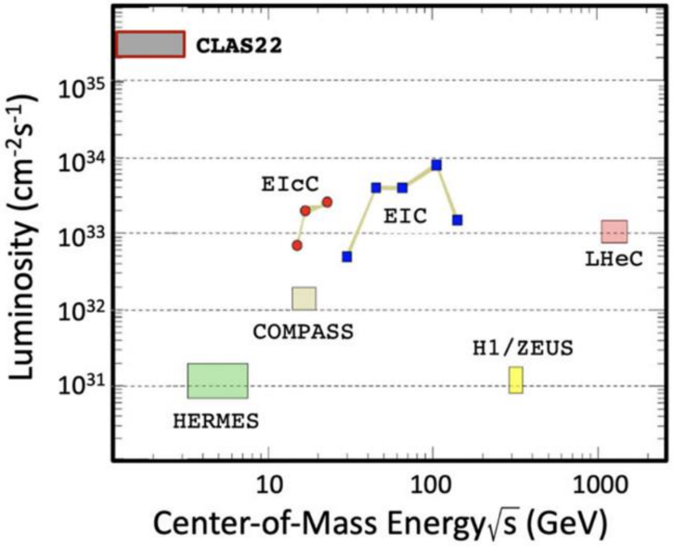


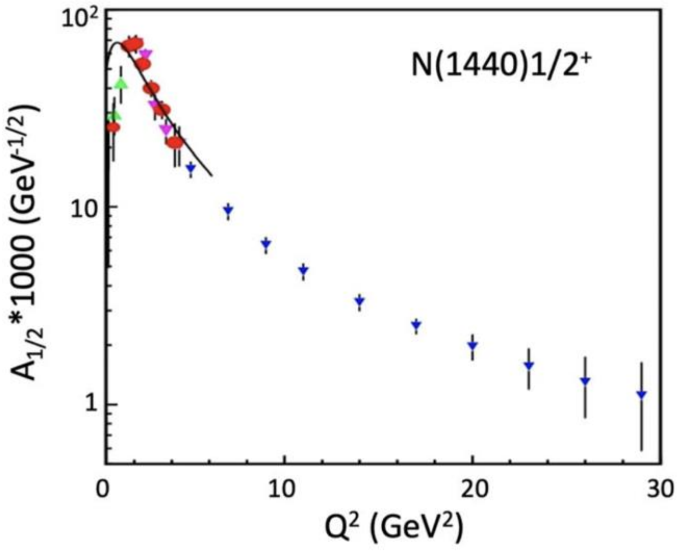
$$W = \sqrt{(P_e - P_{e'} + P_{p_{init.}})^2} \qquad Q^2 = -(P_e - P_{e'})^2$$

Оценка возможностей извлечения электромагнитных амплитуд возбуждения резонансных состояний нуклона при переданных импульсах до 30 ГэВ^2

- Моделирование реакций электророждения πN, KY и $\pi^+\pi^- p$ при энергии 22 ГэВ демонстрирует:

Амплитуды электровозбуждения нуклонных резонансов могут быть извлечены вплоть до значений переданного импульса $Q^2 \sim 30$ ГэВ^2 при $\mathcal{L} \sim 2 - 5 \times 10^{35}$ см$^{-2}$ с$^{-1}$





- Энергия непрерывного пучка электронов 22 ГэВ
- Детектор большого аксептанса CLAS12
- Рекордная светимость
- Возможность изучения эксклюзивных реакций

- Расширение результатов по амплитудам электровозбуждения возбужденных состояний нуклона до значений переданного импульса $Q^2 = 10 - 30$ GeV^2 после увеличения максимальной энергии ускорителя CEBAF до 22 ГэВ и при светимостях $2\text{-}5 \times 10^{35}$ см$^{-2}$ с$^{-1}$ позволит исследовать как доминирующая часть массы адронов и структура возбужденных состояний нуклона может возникнуть в рамках фундаментальной Квантовой Хромодинамики

Физический факультет
Московского
государственного университета
имени М.В.Ломоносова

НИИЯФ МГУ

Jefferson Lab
Thomas Jefferson National Accelerator Facility

Методы машинного обучения в задаче предсказания дифференциальных сечений и структурных функций электророждения пиона на протоне в резонансной области.

аспирант Голда А.В.
кафедра общей ядерной физики

π^+ distribution over azimuthal angle φ

- Rotational properties of the production amplitudes
- Single photon exchange for $ep \to e'\pi^+n$ reaction

$$\frac{d\sigma_{\gamma_v}}{d\Omega_\pi} = \frac{d\sigma_u}{d\Omega_\pi} + \varepsilon \frac{d\sigma_{tt}}{d\Omega_\pi} \cdot cos2\varphi + \sqrt{2\varepsilon(1+\varepsilon)} \frac{d\sigma_{lt}}{d\Omega_\pi} \cdot cos\varphi \equiv A + Bcos2\varphi + Ccos\varphi$$

- Is AI/ML capable of reconstructing the φ–dependence from the studies of the measured two-fold differential cross sections?
- Can the use of AI/ML improve knowledge of exclusive structure functions beyond the limitations imposed by restricted data coverage over azimuthal/polar angles?

E = 5.754 GeV; Q^2 = 2.915 GeV^2 - 1st resonance maximum

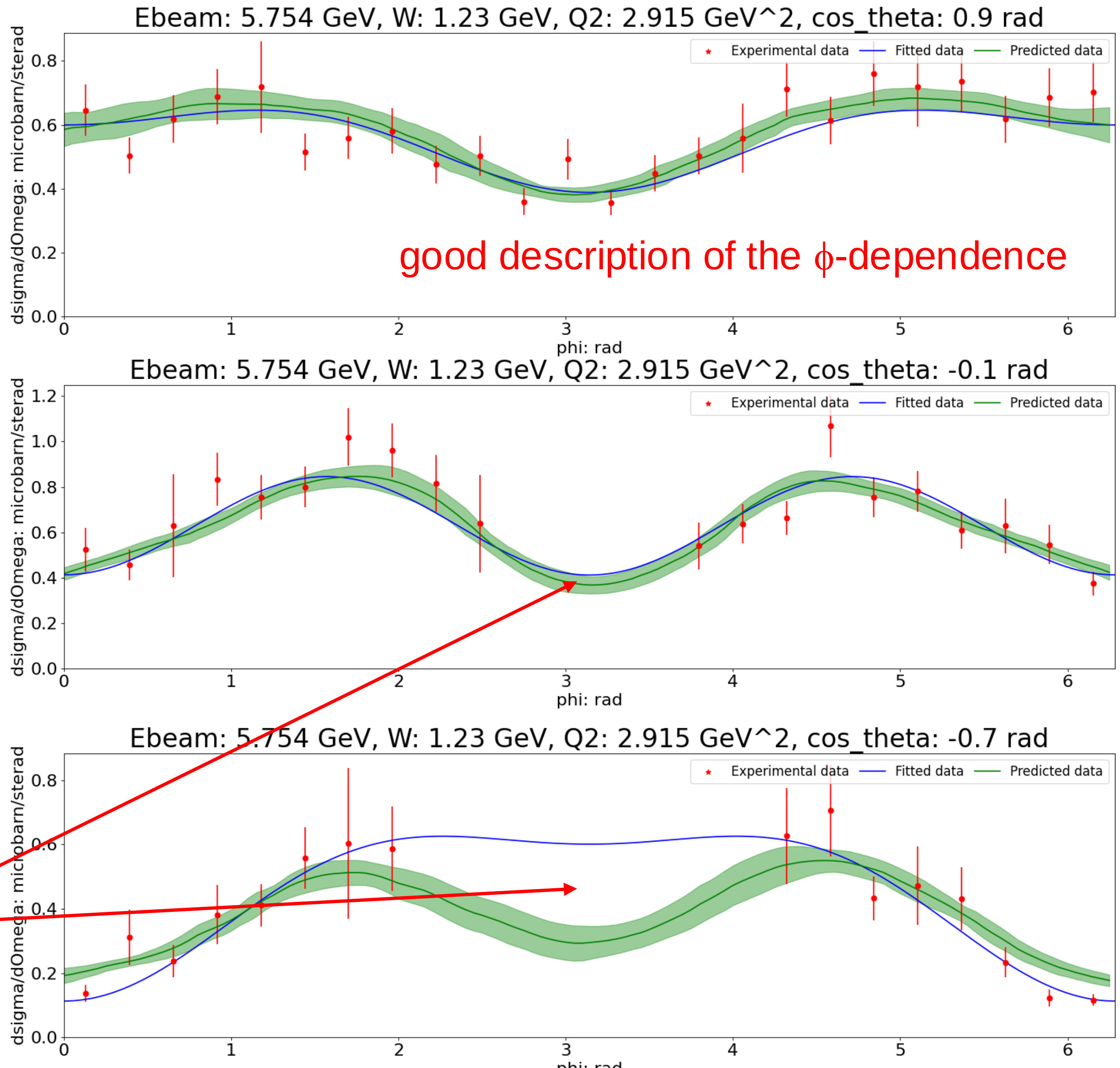
Red dots with error bars – experimental data

Blue line – fit of the experimental data by Eq. in slide #4

Green line - Neural network predictions with uncertainties shown by green areas obtained from bootstrap

AI/ML is capable of determining ϕ-dependence of π^+n differential cross sections from the multi-dimensional data analysis

AI/ML provides predictions for π^+n differential cross sections within ϕ-ranges where the data are not available



E = 5.754 GeV; Q^2 = 2.915 GeV^2 Structrure function - A

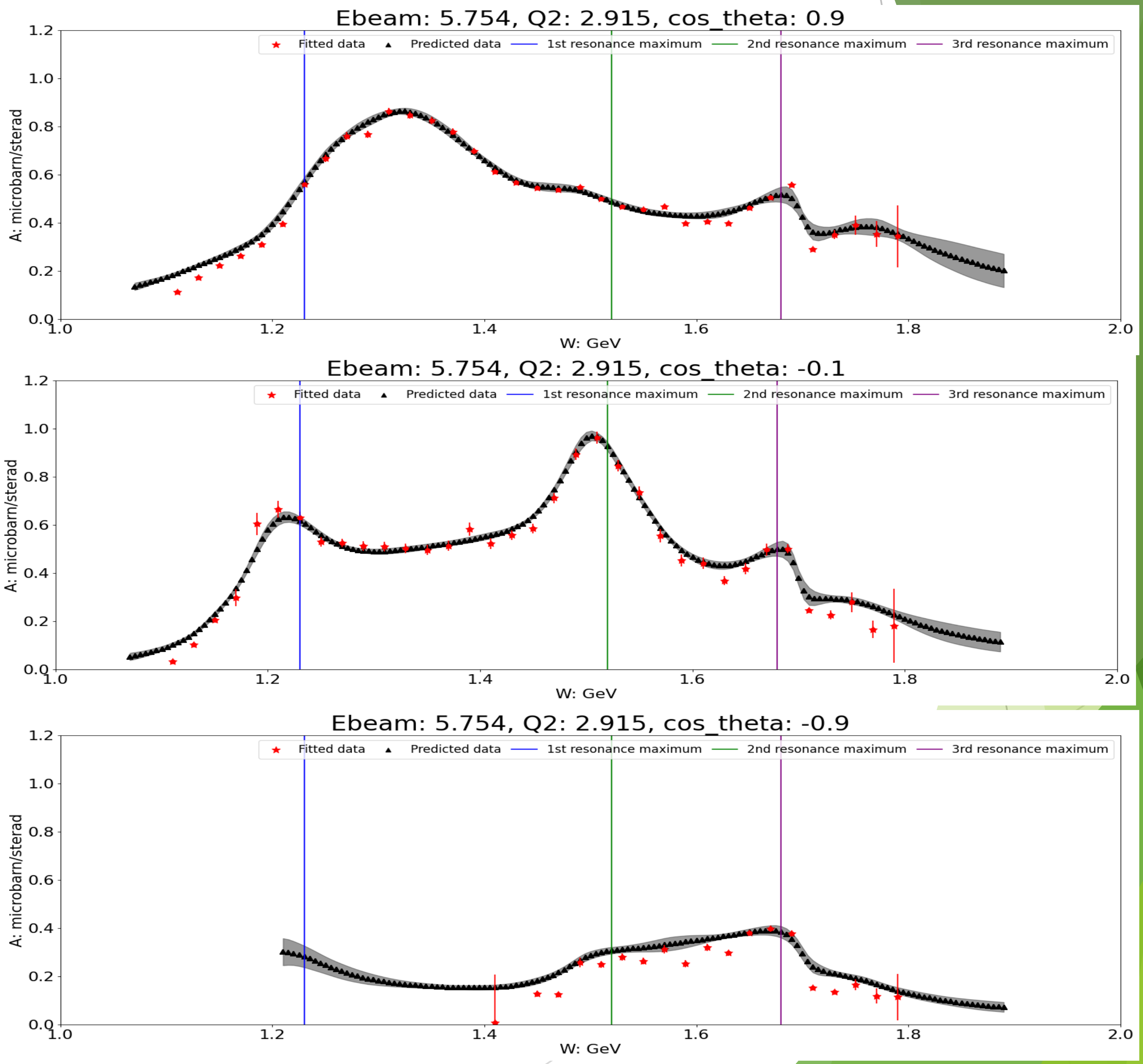
Red dots with error bars – structure functions from the experimental data fit by Eq in slide #4

Black line – predicted structure function obtained from the moments of the predicted within AI/ML cross sections with uncertainties from bootstrap

Blue line – the center of the 1st resonance region (W=1.23 GeV)

Green line – the center of the 2nd resonance region (W=1.52 GeV)

Purple line – the center of 3rd resonance region for π^+n (W=1.68 GeV)



Спасибо за внимание!