Stato delle Analisi Dati Run Group K

Riunione Fisica e Analisi JLab12 Italia, 30 aprile 2025

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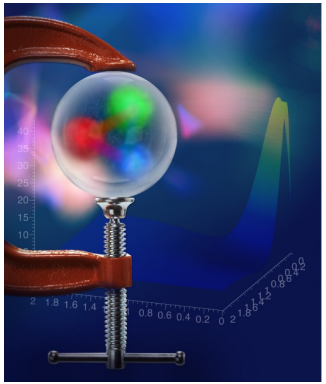
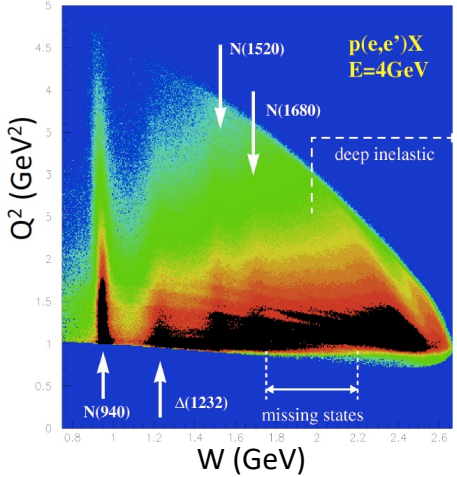
Outline

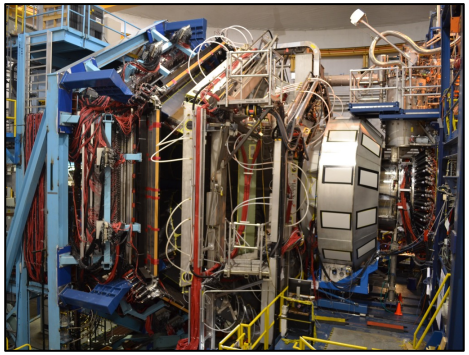
- **RGK**: an experimental program dedicated to **Quark-Gluon Confinement and Strong QCD**

- Latest RGK results overview:
  - **Beam-Recoil Transferred Polarization**
  - **Recoil Hyperon Polarization**
  - **Extraction of KY Differential Cross Sections And Separated Structure Functions**

- Summary and Outlook



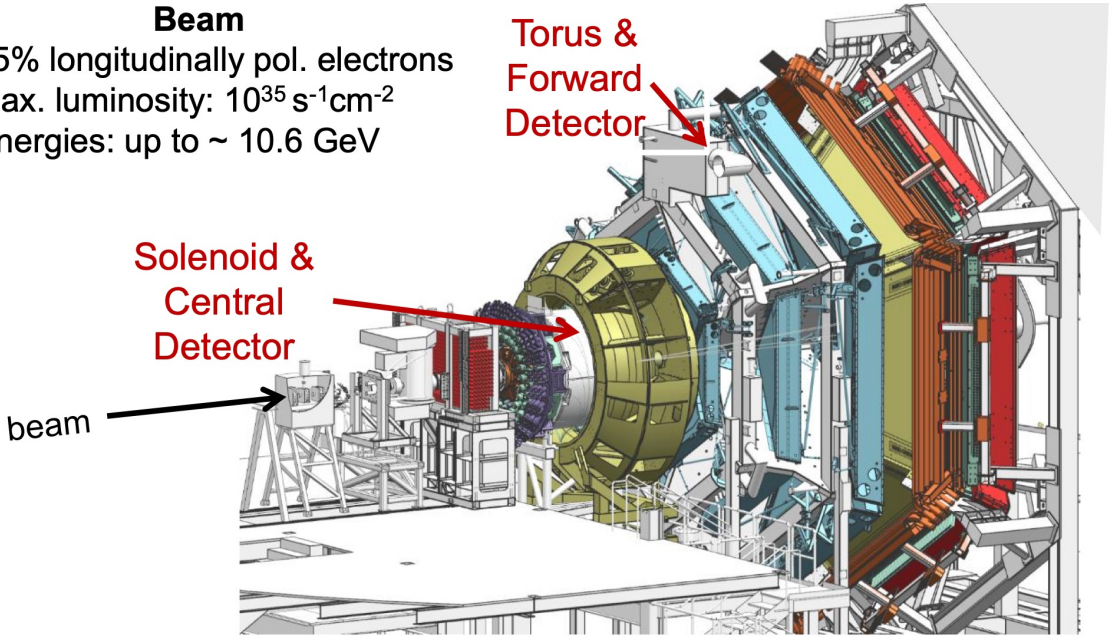




CLAS12

Beam

- 85% longitudinally pol. electrons
- Max. luminosity: $10^{35}\ s^{-1}cm^{-2}$
- Energies: up to ~ 10.6 GeV

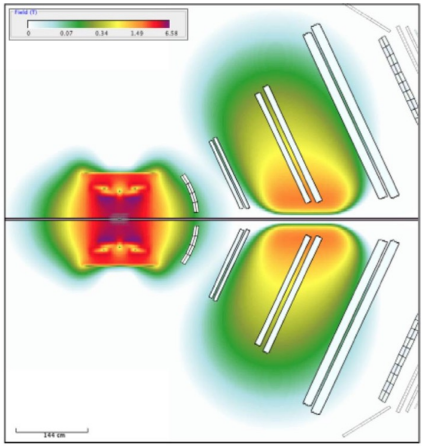


[V.D. Burkert et al., Nucl. Inst. and Meth. A 959, 163419 (2020)]

Targets (org. by Run Groups)

- Proton (RG-A/K)
- Deuteron (RG-B)
- Nuclei (RG-M/D/E)
- Long. pol. NH_3/ND_3 (RG-C)

Magnetic Field



Ideal instrument to study exclusive meson electroproduction in the nucleon resonance region

RGK @ CLAS12

Run Group Proposal (RG K) "Color Confinement and Strong QCD":

Search for Hybrid Baryons (qqqg) **DVCS**

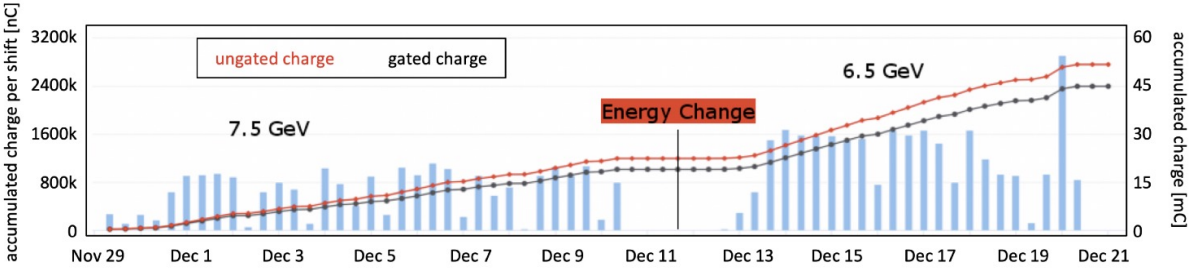
KY Electroproduction for the N* study **SIDIS**

RUN CONDITIONS	
Torus Current	100% (3375 A) - negative out-bending
Solenoid	-100 %
FT	**ON @ 7.5 GeV -> OFF @ 6.5 GeV and 8.5 GeV**
Beam/Target	Polarized electrons, un-polarized LH_2 target
Luminosity	• ~ 5 10^{34} $cm^{-2}s^{-1}$ @ 7.5 GeV ~ 0.87 10^{34} $cm^{-2}s^{-1}$ @ 6.5 GeV 0.87 10^{35} $cm^{-2}s^{-1}$ @ 6.4 GeV 10^{35} $cm^{-2}s^{-1}$@8.5 GeV **FULL LUMINOSITY**

Fall 2018: EVENTS 15.6 G **Spring 2024: EVENTS 60 G (Statistics increased by a factor 4)**

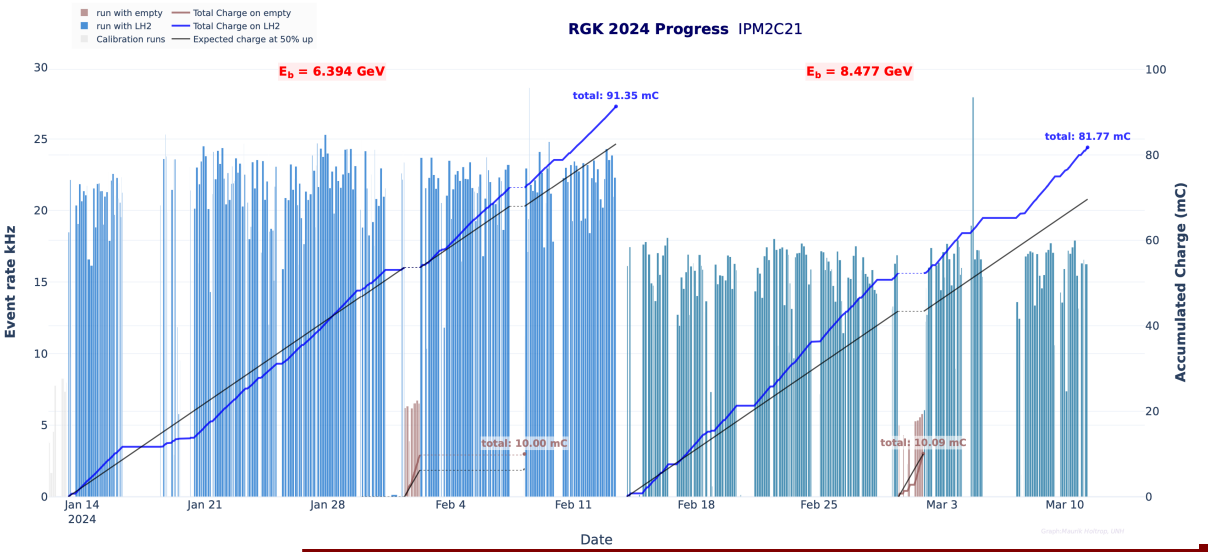
50% of the total

Collected Charge: 2018 vs. 2024



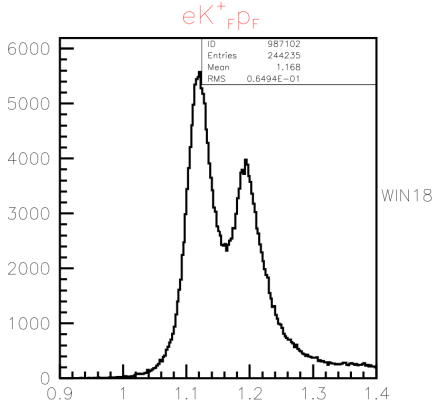
The total collected charge is Q ≈ 45 mC

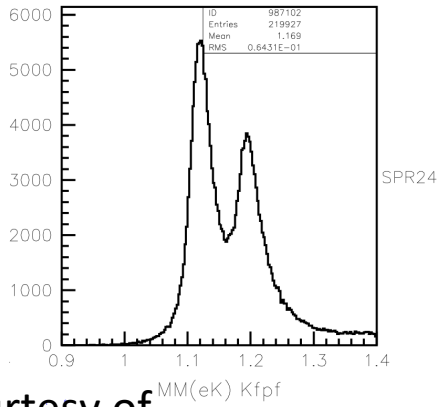
x4

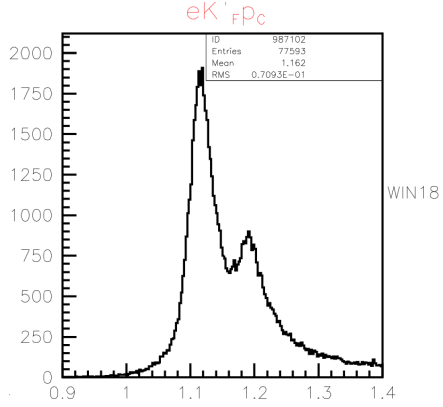


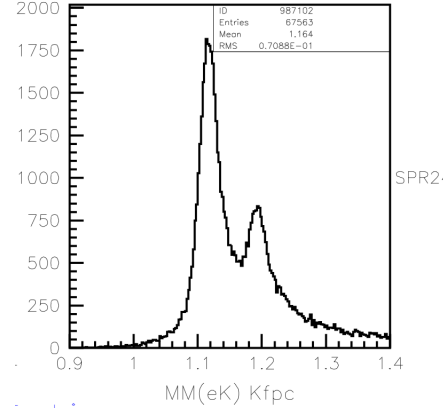
The total collected charge is Q ≈ 91 + 81 mC

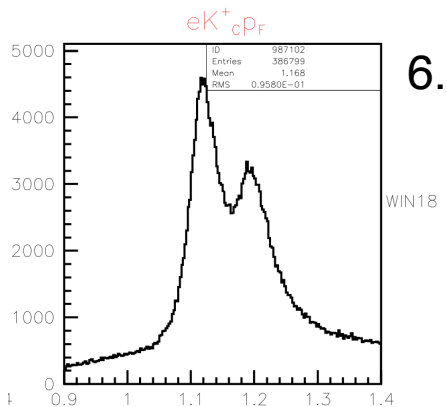
KY Resolution: 2018 vs. 2024



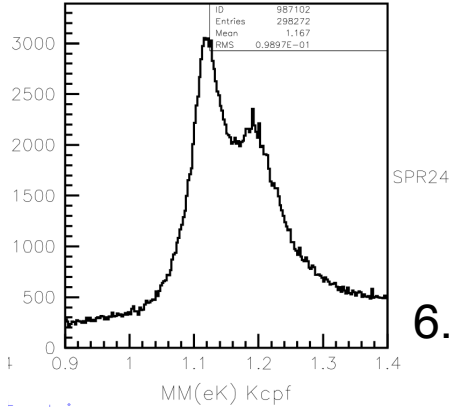








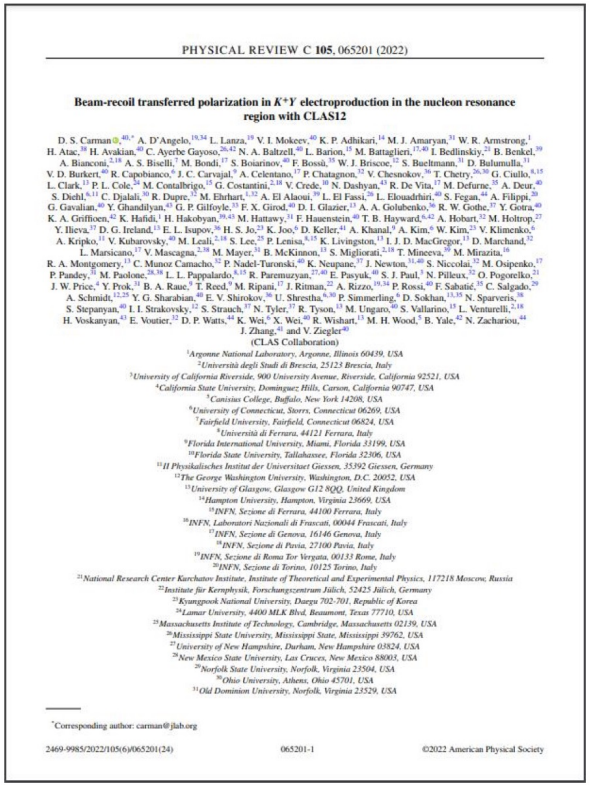
6.5 GeV



6.4 GeV

Courtesy of Dan Carman

Beam-Recoil Transferred Polarization in K^+Y Electroproduction in the Nucleon Resonance Region with CLAS12



PHYSICAL REVIEW C **105**, 065201 (2022)

Beam-recoil transferred polarization in K^+Y electroproduction in the nucleon resonance region with CLAS12

D. S. Carman,[40,*] A. D'Angelo,[19,34] L. Lanza,[19] V. I. Mokeev,[40] K. P. Adhikari,[14] M. J. Amaryan,[31] W. R. Armstrong,[1] H. Atac,[38] H. Avakian,[40] C. Ayerbe Gayoso,[26,42] N. A. Baltzell,[40] L. Barion,[15] M. Battaglieri,[17,40] I. Bedlinskiy,[23] B. Benkel,[39] A. Bianconi,[2,18] A. S. Biselli,[7] M. Bondi,[17] S. Boiarinov,[40] F. Bossù,[35] W. J. Briscoe,[12] S. Bueltmann,[31] D. Bulumulla,[31] V. D. Burkert,[40] R. Capobianco,[6] J. C. Carvajal,[9] A. Celentano,[17] P. Chatagnon,[22] V. Chesnokov,[36] T. Chetry,[26,30] G. Ciullo,[8,15] L. Clark,[13] P. L. Cole,[20] M. Contalbrigo,[15] G. Costantini,[2,18] V. Crede,[10] N. Dashyan,[43] R. De Vita,[17] M. Defurne,[35] A. Deur,[40] S. Diehl,[6,11] C. Djalali,[30] R. Dupre,[22] M. Ehrhart,[1,22] A. El Alaoui,[39] L. El Fassi,[28] L. Elouadrhiri,[40] S. Fegan,[44] A. Filippi,[20] G. Gavalian,[40] Y. Ghandilyan,[43] G. P. Gilfoyle,[37] F. X. Girod,[40] D. I. Glazier,[13] A. A. Golubenko,[36] R. W. Gothe,[37] Y. Gotra,[40] K. A. Griffioen,[42] K. Hafidi,[1] H. Hakobyan,[39,43] M. Hattawy,[31] F. Hauenstein,[40] T. B. Hayward,[6,42] A. Hobart,[32] M. Holtrop,[27] Y. Ilieva,[37] D. G. Ireland,[13] E. L. Isupov,[36] H. S. Jo,[23] K. Joo,[6] D. Keller,[41] A. Khanal,[9] A. Kim,[6] W. Kim,[23] V. Klimenko,[6] A. Kripko,[11] V. Kubarovsky,[40] M. Leali,[2,18] S. Lee,[22] P. Lenisa,[8,15] K. Livingston,[13] I. J. D. MacGregor,[13] D. Marchand,[32] L. Marsicano,[17] V. Mascagna,[2,18] M. Mayer,[31] B. McKinnon,[13] S. Migliorati,[2,18] T. Mineeva,[39] M. Mirazita,[16] R. A. Montgomery,[13] C. Munoz Camacho,[22] P. Nadel-Turonski,[40] K. Neupane,[37] J. Newton,[31,40] S. Niccolai,[22] M. Osipenko,[17] P. Pandey,[31] M. Paolone,[28,38] L. L. Pappalardo,[8,15] R. Paremuzyan,[27,40] E. Pasyuk,[40] S. J. Paul,[5] N. Pilleux,[22] O. Pogorelko,[21] J. W. Price,[4] Y. Prok,[31] B. A. Raue,[9] T. Reed,[9] M. Ripani,[17] J. Ritman,[22] A. Rizzo,[19,34] P. Rossi,[40] F. Sabatié,[35] C. Salgado,[29] A. Schmidt,[12,25] Y. G. Sharabian,[40] E. V. Shirokov,[36] U. Shrestha,[6,30] P. Simmerling,[6] D. Sokhan,[13,35] N. Sparveris,[38] S. Stepanyan,[40] I. I. Strakovsky,[12] S. Strauch,[37] N. Tyler,[37] R. Tyson,[13] M. Ungaro,[40] S. Vallarino,[15] L. Venturelli,[2,18] H. Voskanyan,[43] E. Voutier,[22] D. P. Watts,[44] K. Wei,[9] X. Wei,[40] R. Wishart,[13] M. H. Wood,[3] B. Yale,[42] N. Zachariou,[44] J. Zhang,[41] and V. Ziegler[40]

(CLAS Collaboration)

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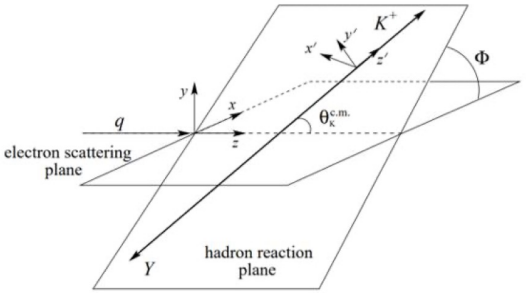
2469-9985/2022/105(6)/065201(24) 065201-1

D.S. Carman, A. D'Angelo, L. Lanza, V. Mokeev (CLAS Collaboration)), "Beam-Recoil Transferred Polarization in K^+Y Electroproduction in the Nucleon Resonance Region with CLAS12", Phys. Rev. C 105, 065201 (2022)



Analysis of CLAS12 RG-K data from Fall 2018

- 6.535 GeV and 7.546 GeV electrons on LH_2 target
- Extract beam-recoil transferred polarization from longitudinally polarized beam electron to final state hyperon vs. Q^2, W, $\cos\theta_K^{c.m.}$

$$A = \frac{N^+ - N^-}{N^+ + N^-} = \nu_Y \alpha_\Lambda P_b \mathcal{P}'_Y \cos\theta_p^{RF}$$

$\mathcal{P}'$ = transferred polarization

(x',y',z')

$\mathcal{P}^0$ = recoil polarization

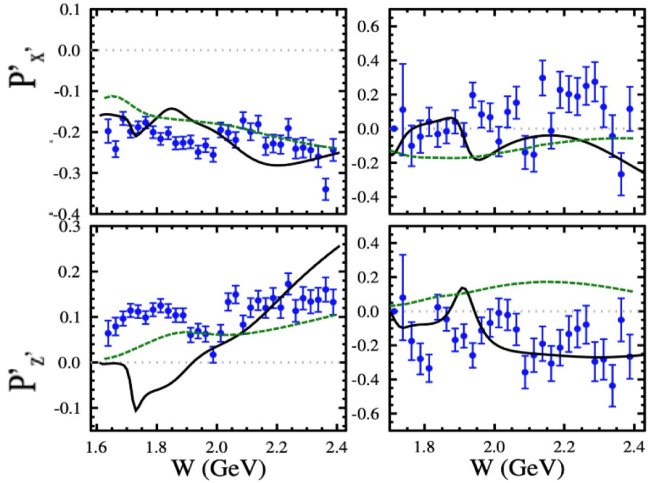
$$\mathcal{P}'_{x'} = K_I\sqrt{1-\epsilon^2}R_{TT'}^{x'0}$$
$$\mathcal{P}'_{y'} = 0$$
$$\mathcal{P}'_{z'} = K_I\sqrt{1-\epsilon^2}R_{TT'}^{z'0}$$

$$\mathcal{P}^0_{x'} \quad 0$$
$$\mathcal{P}^0_{y'} \quad K_I(R_T^{y'0} + \epsilon R_L^{y'0})$$
$$\mathcal{P}^0_{z'} \quad 0$$

K^+Y Transferred Polarization CLAS12 vs. CLAS

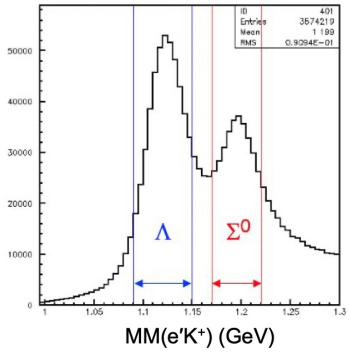
CLAS12 (RG-K)

$ep \rightarrow e'K^+\Lambda$ $ep \rightarrow e'K^+\Sigma^0$



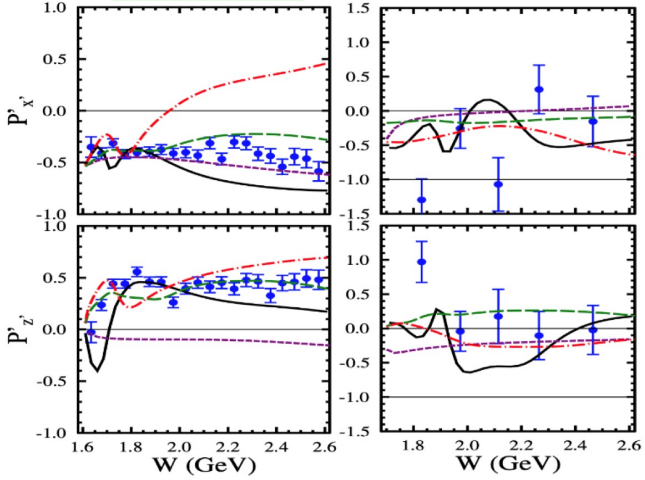
[D.S. Carman et al., Phys. Rev. C 105, 065201 (2022)]

$ep \rightarrow e'K^+Y$



CLAS (e1-6)

$ep \rightarrow e'K^+\Lambda$ $ep \rightarrow e'K^+\Sigma^0$



[D.S. Carman et al., Phys. Rev. C 79, 065205 (2009)]

KAON-MAID
RPR

World data set will get extended by orders of magnitude

Mart/Bennhold
RPR-1
RPR-2
Regge

Recoil Polarization in K^+Y Electroproduction in the Nucleon Resonance Region with CLAS12

- **RG-K Λ and Σ^0 recoil polarization analysis by D. Carman, A. D'Angelo, L. Lanza, V. Mokeev**: WG approval
- **Paper** currently under Collaboration-Wide Review
- **This work aims at extending the available data** from CLAS to provide more complete input to available reaction models to **improve our understanding of strong QCD in the non-perturbative domain**.

KY channels: $e + p \rightarrow e' + K^+ + Y$ where $Y = \Lambda, \Sigma^0$

Yield Integral

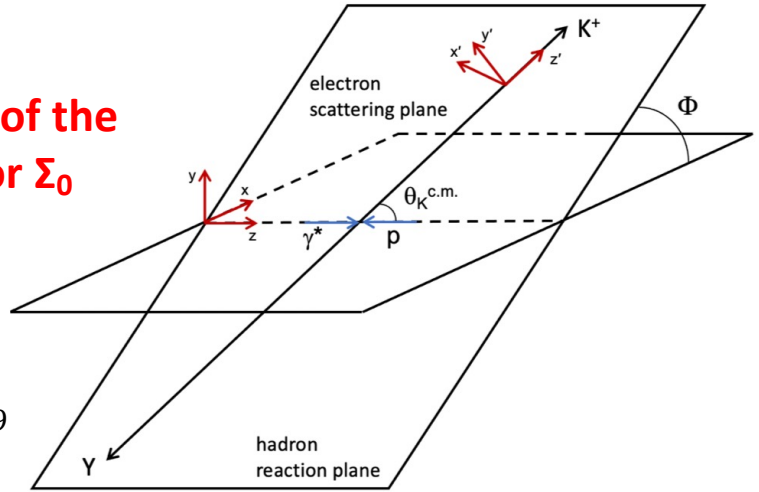
polarization of the parent Λ or Σ_0

$$\frac{dN}{d\cos\theta_p^{RF}} = N_0\left(1 + \nu_Y \alpha P_Y \cos\theta_p^{RF}\right)$$

angular distribution of the decay p in the Y decay frame

$\nu_Y = 1, -0.256\ (\Lambda, \Sigma^0)$
Dilution factor

$\alpha = 0.747 \pm 0.009$
Λ weak decay asymmetry parameter



Recoil Polarization in K^+Y Electroproduction in the Nucleon Resonance Region with CLAS12

$$\frac{dN}{d\cos\theta_p^{RF}} = N_0\left(1 + \nu_Y \alpha P_Y \cos\theta_p^{RF}\right)$$

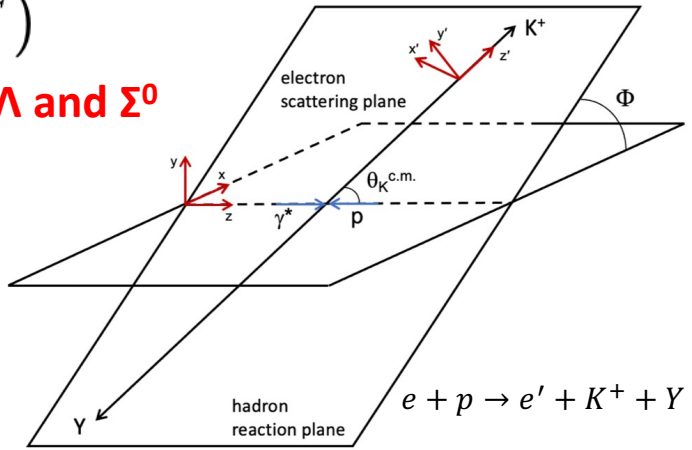
Recoil polarization for Λ and Σ^0

Yield in the forward angle range, i.e. cos θ_{RF}p >0

$$N_F = \int_0^1 N_0\left(1 + \nu_Y \alpha P_Y cos\vartheta_p^{RF}\right) dcos\vartheta_p^{RF} = N_0 + N_0 \cdot \frac{\nu_Y \alpha P_Y}{2}$$

Yield in the backward angle range, i.e. cos θ_{RF}p <0

$$N_B = \int_{-1}^0 N_0\left(1 + \nu_Y \alpha P_Y cos\vartheta_p^{RF}\right) dcos\vartheta_p^{RF} = N_0 - N_0 \cdot \frac{\nu_Y \alpha P_Y}{2}$$



Recoil polarization for Λ and Σ^0

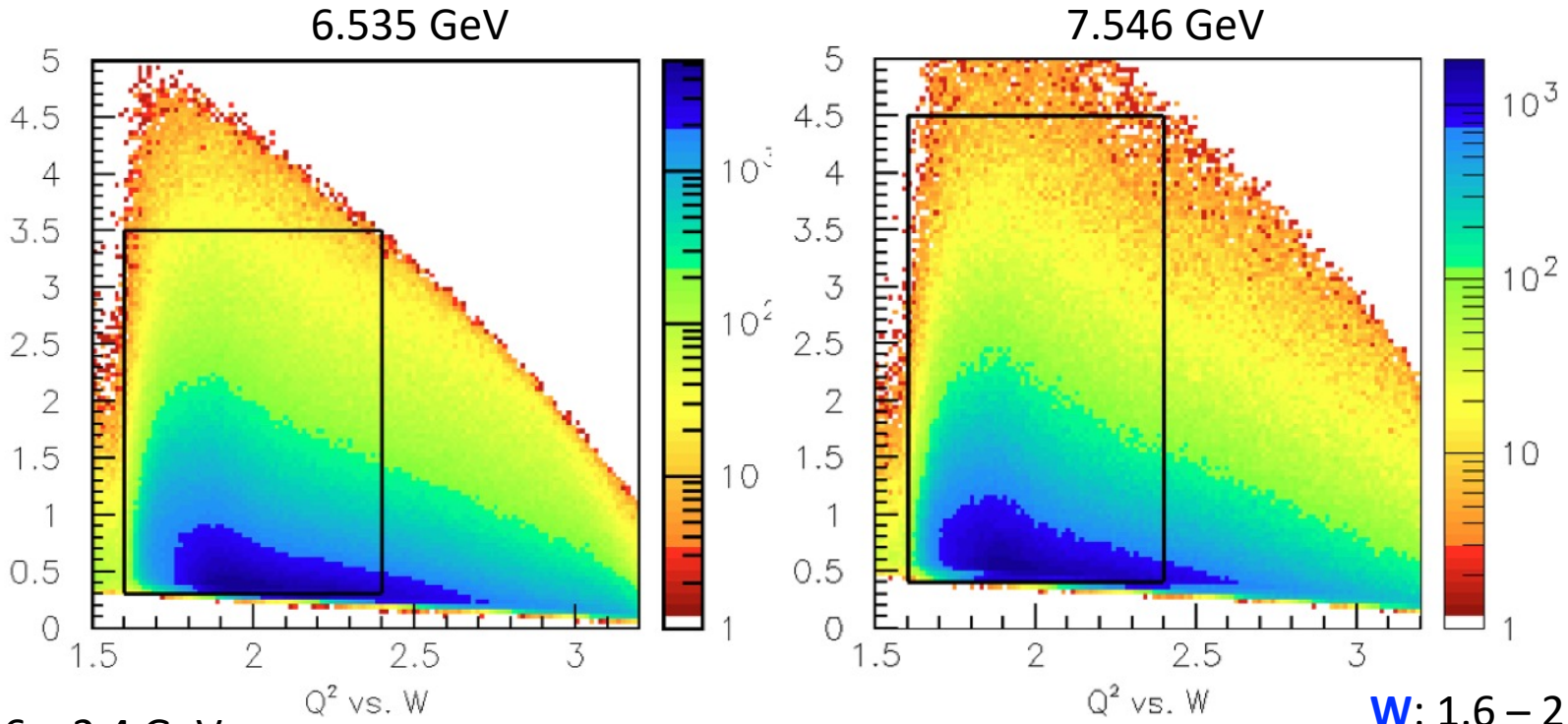
$$A_{FB} = \frac{\frac{N_F}{A_F} - \frac{N_B}{A_B}}{\frac{N_F}{A_F} + \frac{N_B}{A_B}} = \frac{\nu_Y \alpha P_Y}{2}$$

Forward-backward yield asymmetry

Sensitivity to the detector acceptance ⇨ **Acceptance Correction**

$$A_{F,B} = \frac{N_{F,B}^{REC}}{N_{F,B}^{MC}}$$

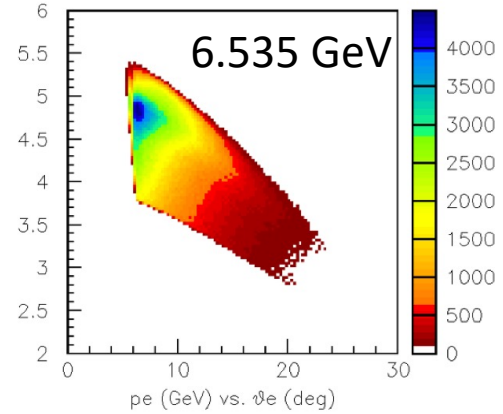
K^+Y Induced Polarization in the Nucleon Resonance Region

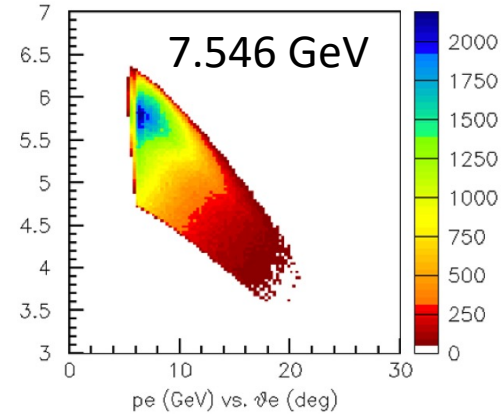


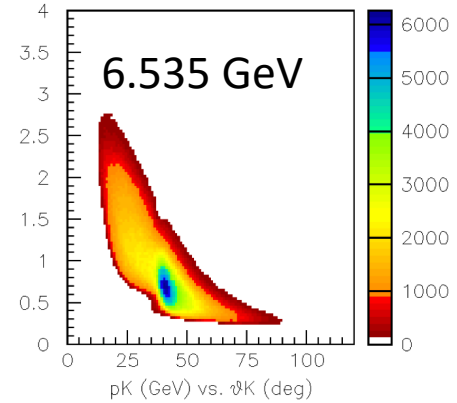
W: 1.6 – 2.4 GeV
Q^2: 0.3 – 3.5 GeV^2

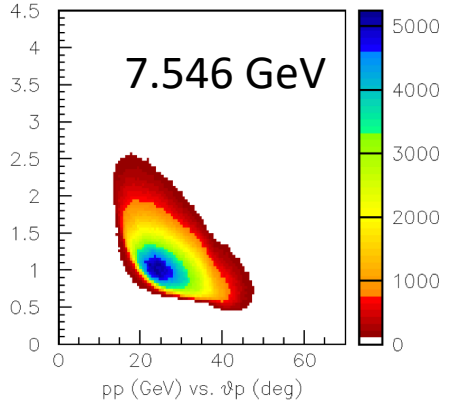
W: 1.6 – 2.4 GeV
Q^2: 0.4 – 4.5 GeV^2

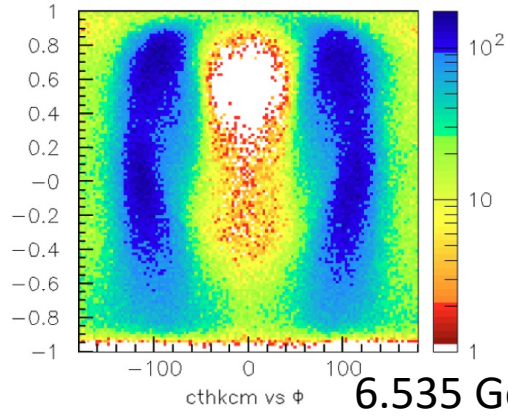
K^+Y Induced Polarization in the Nucleon Resonance Region



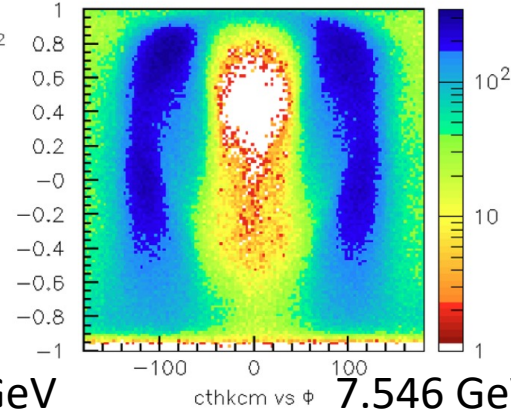








6.535 GeV



7.546 GeV

Analysis Cuts Overview

Electron

Cut	Value
Track Status	$2000 \leq$ abs(STATUS) < 4000
Event Builder PID	11
p_e	[1.0:p_{beam}] GeV
TOF_e	[21:26] ns
v_z	[-10:2] cm
ECAL Sampling Fraction	$\pm 3.5\sigma$
ECAL Fiducial Cut	7 cm edge cut on U, V, W
π^- contamination	$E_{ECin}/p_{e'} < -0.84 * E_{PCAL}/p_{e'} + 0.17$
DC Fiducial Cuts	on

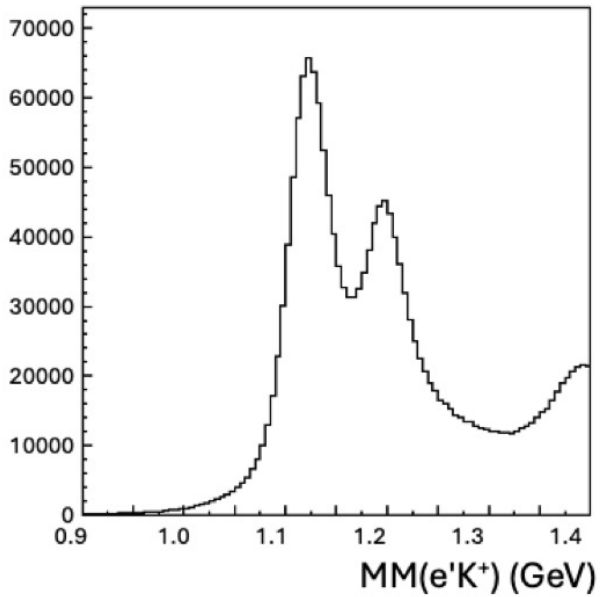
Hadron FD

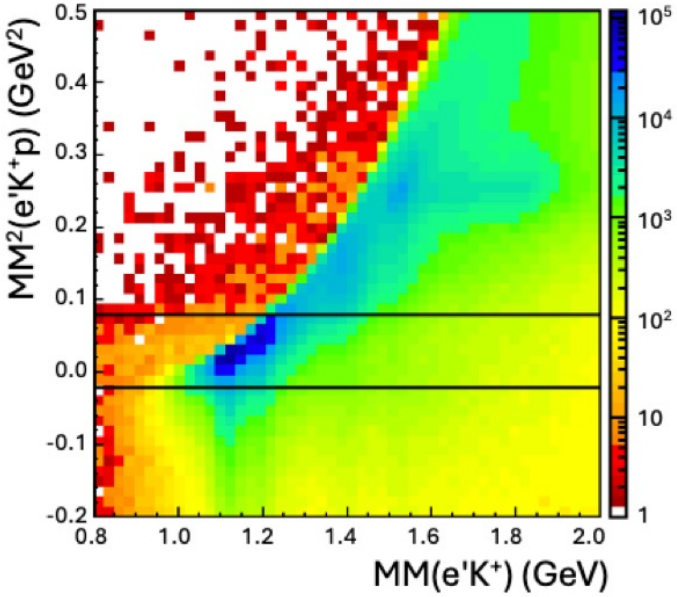
Cut	Value
Track status	$2000 \leq \lvert\text{STATUS}\rvert < 4000$
q	$\neq 0$
p_h	[0.4:5.0] GeV
β_h	[0.4:1.1]
Event Builder PID	± 211, ± 321, or ± 2212
TOF_h	[20:55] ns ($q > 0$)
v_z	[-10:2] cm (K^+ candidates)
DC Fiducial Cuts	on
$\theta_{K^+}^{max}$ Cut	40°

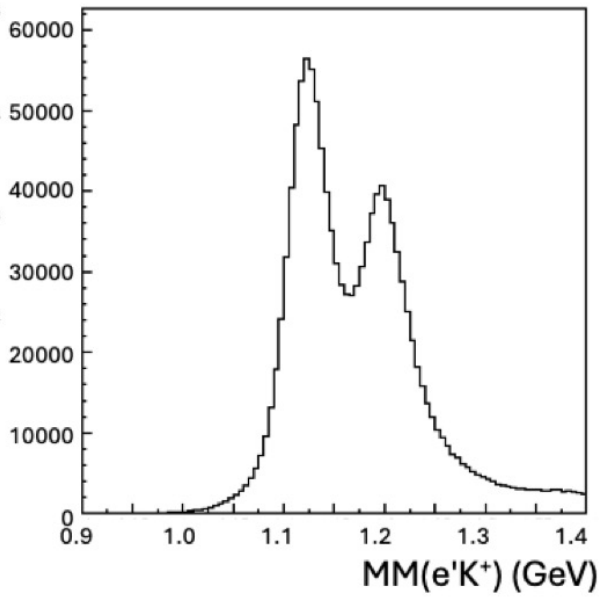
Hadron CD

Cut	Value
Track status	$\lvert\text{STATUS}\rvert \geq 4000$
q	$\neq 0$
p_h	[0.2:1.5] GeV
β_h	[0.2:1.1]
Event Builder PID	± 211, ± 321, or ± 2212
TOF_h	[0.5:4.0] ns
v_z	[-10:2] cm (K^+ candidates)
$\theta_{K^+}^{min}/\theta_{K^+}^{max}$ Cuts	35°/95°

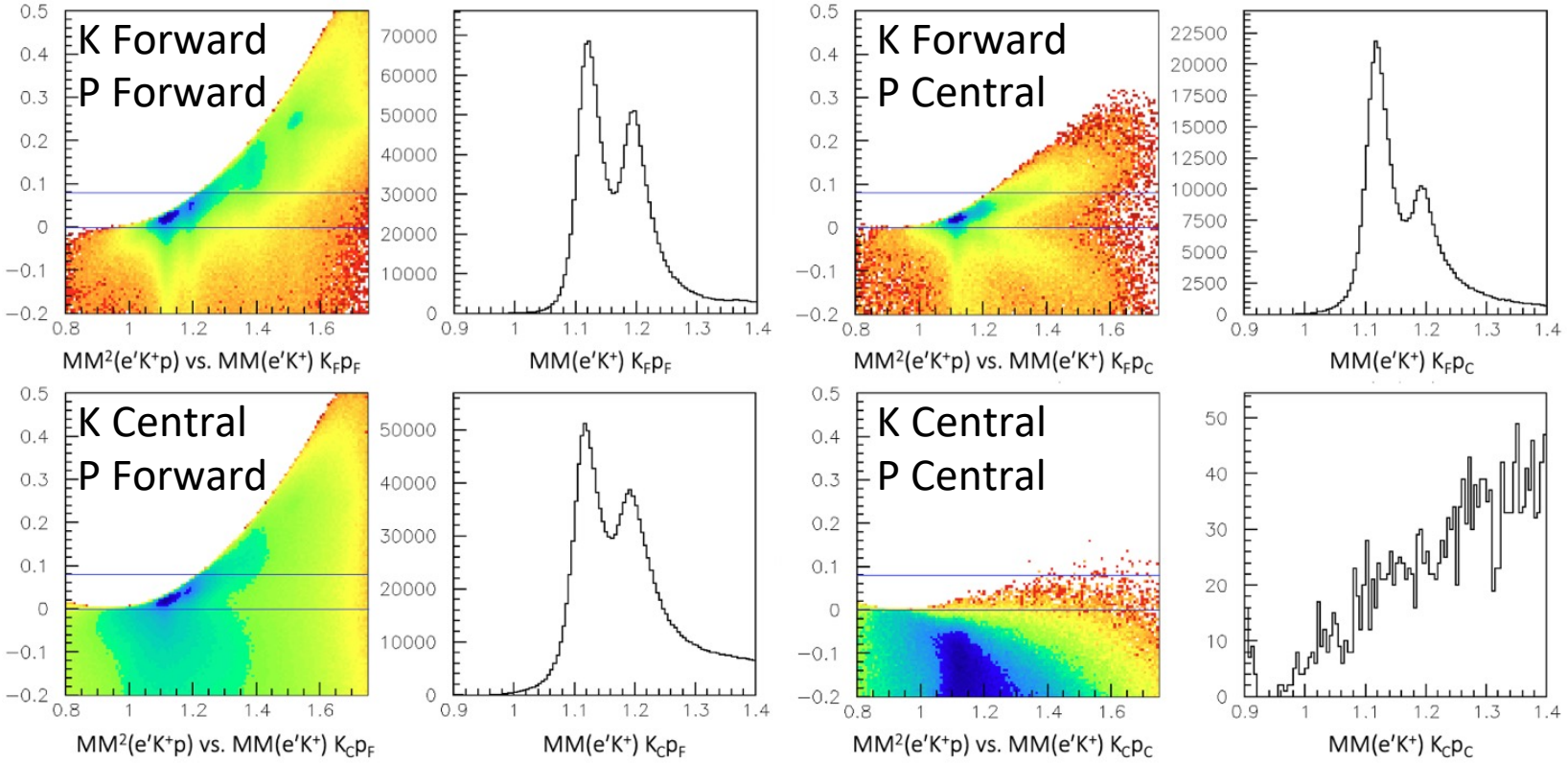
K^+Y Induced Polarization: $MM^2(e'K^+p)$ vs. $MM(e'K^+)$ Cut







$MM^2(e'K^+p)$ vs. $MM(e'K^+)$ Cut, Topologies



Yields Extraction: Kinematic Bins

Once the exclusive final state e'K⁺p events were selected, the events were divided in **kinematic bins** of

- **Q^2** , photon virtuality
- **W** , invariant mass of $K^+\Lambda$
- $\boldsymbol{cos\vartheta^K_{c.m.}}$
- $\boldsymbol{cos\vartheta^p_{RF}}$ >0 and $\boldsymbol{cos\vartheta^p_{RF}}$<0

and the **number of Λ events was extracted in each bin from a fit of the MM(e'K⁺) spectrum**.

Dependence	Range	Bin Size
Q^2	Q^2_{min} - 1.5 GeV^2	0.1 GeV^2
	1.5 - 2.5 GeV^2	0.2 GeV^2
	2.5 - 3.1 GeV^2	0.3 GeV^2
	3.1 - 3.5 GeV^2	0.4 GeV^2
	3.5 - 4.5 GeV^2	1.0 GeV^2
W	W_{min} - 2.4 GeV	25 MeV
$\cos\theta^{c.m.}_K$	-1 $\rightarrow$ 1	0.08

Yields Extraction: Acceptance Correction

Acceptance-corrected yields were calculated for each kinematic bin and P_0 was extracted by employing

$$A_{FB} = \frac{\frac{N_F}{A_F} - \frac{N_B}{A_B}}{\frac{N_F}{A_F} + \frac{N_B}{A_B}} = \frac{\nu_Y \alpha P_Y}{2}$$

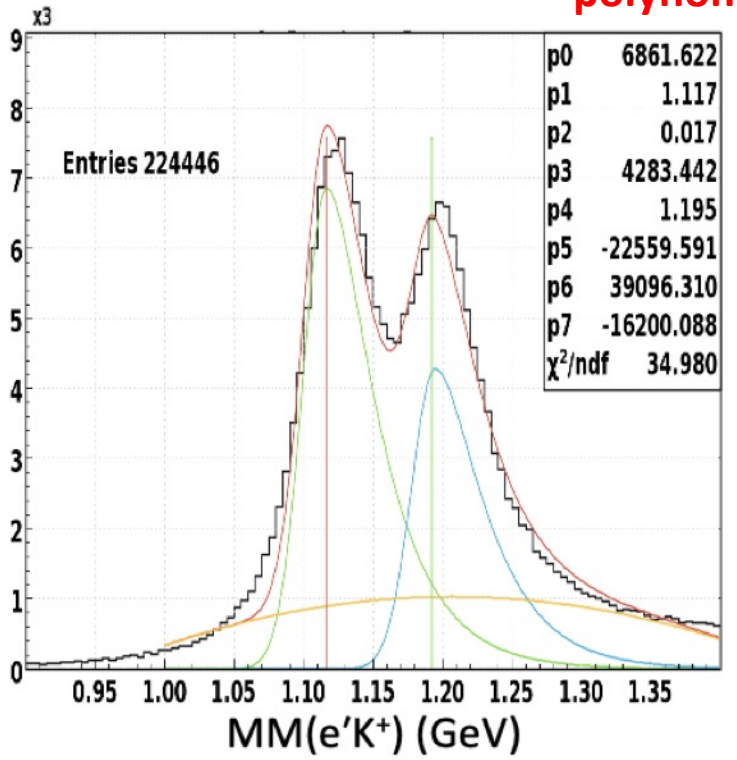
Dependence	Range	Bin Size
Q^2	Q^2_{min} - 1.5 GeV^2	0.1 GeV^2
	1.5 - 2.5 GeV^2	0.2 GeV^2
	2.5 - 3.1 GeV^2	0.3 GeV^2
	3.1 - 3.5 GeV^2	0.4 GeV^2
	3.5 - 4.5 GeV^2	1.0 GeV^2
W	W_{min} - 2.4 GeV	25 MeV
$\cos\theta_K^{c.m.}$	-1 $\rightarrow$ 1	0.08

genKYandOnePion event generator was employed for $K^+\Lambda$ and $K^+\Sigma^0$ generated events

$$A_F = \frac{N_F^{REC}}{N_F^{MC}} \qquad A_B = \frac{N_B^{REC}}{N_B^{MC}}$$

Yields Extraction: Fitting Procedure

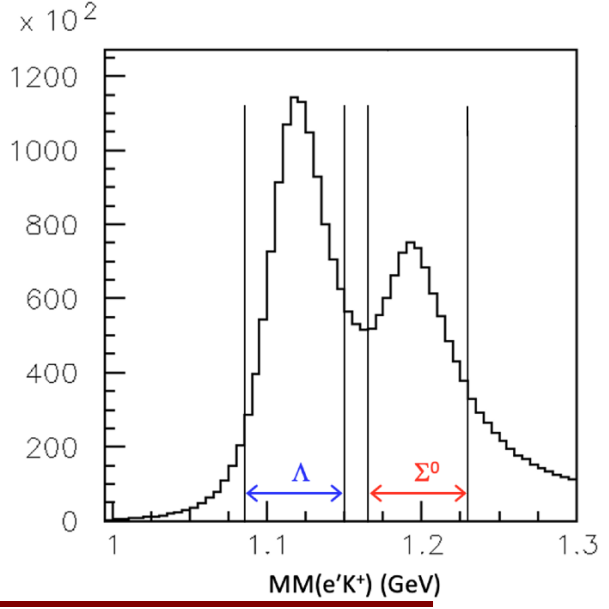
Two **half-Gaussian/half-Landau** functions for the Λ and Σ^0 hyperons and **a second-order polynomial** to model the background.



Gaussian : Low mass side of the hyperon peaks is dominated by the detector resolution

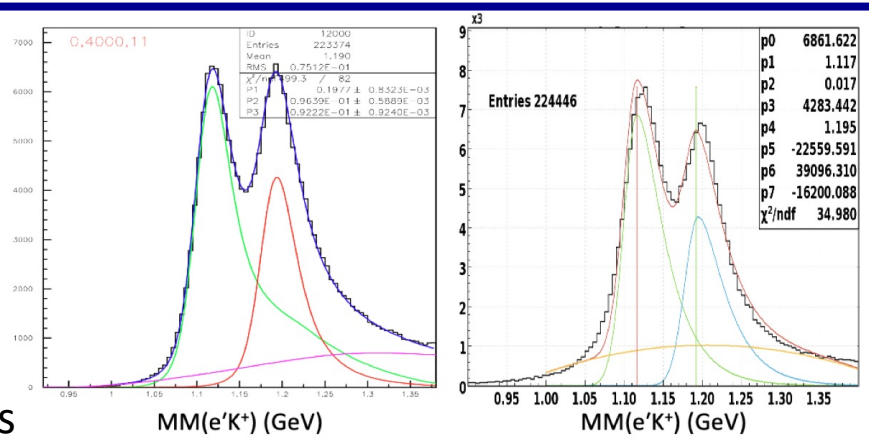
Landau: High mass side of the peaks includes a radiative tail

Background: multi-pion events dominated by $ep \rightarrow e'p\pi^+\pi^-$, where the π^+ is misidentified by CLAS12 as a K^+



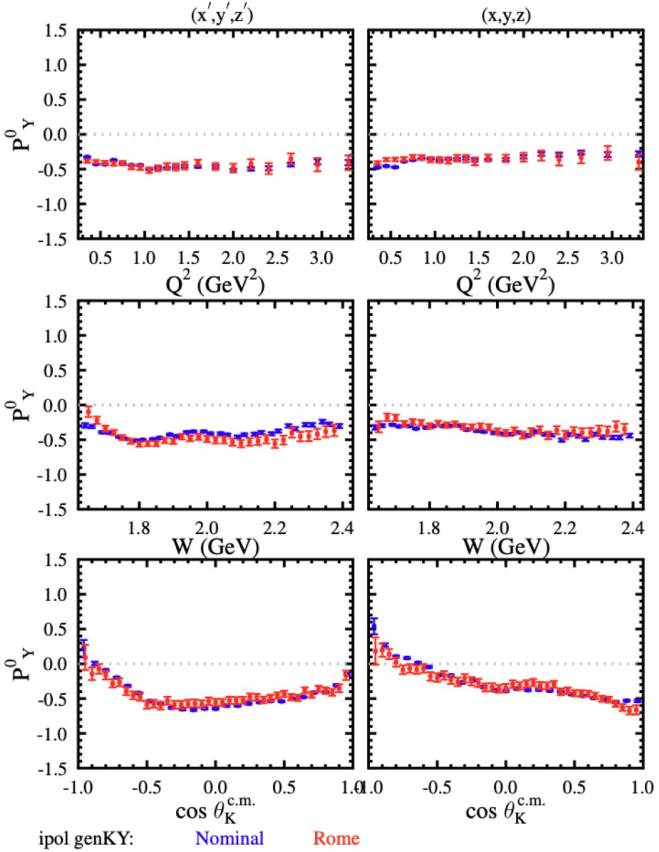
Fitting Procedure: Comparison

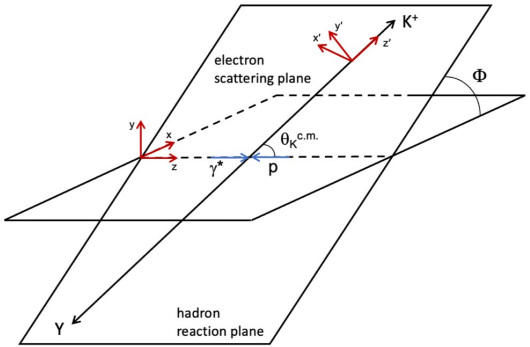
Λ and Σ^0 MC templates



Fitting Function

K^+Y Induced Polarization CLAS12: Independent Analyses Match

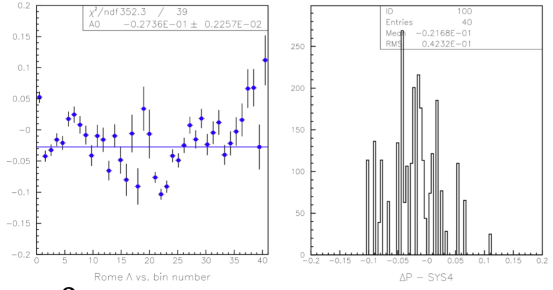




(x′,y′,z′)
$\mathcal{P}^U$ = recoil polarization

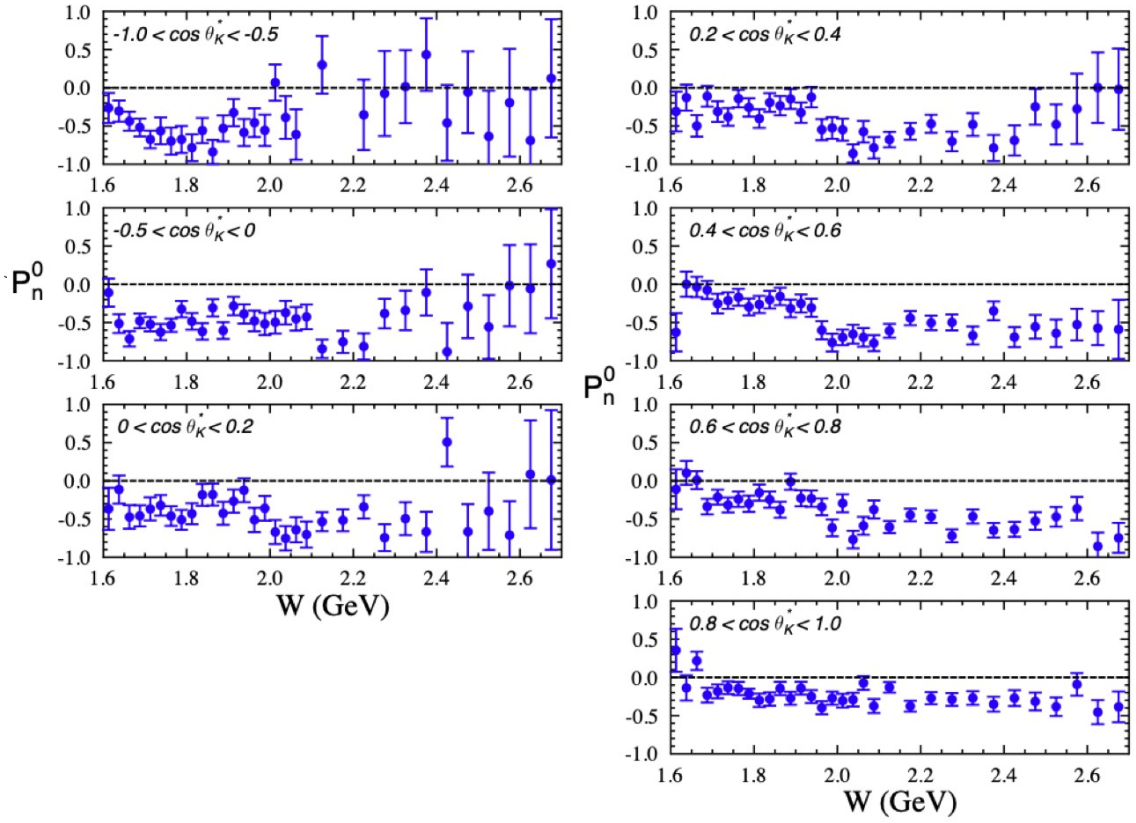
$\mathcal{P}^0_{x'}$	0
$\mathcal{P}^0_{y'}$	$K_I(R_T^{y'0} + \epsilon R_L^{y'0})$
$\mathcal{P}^0_{z'}$	0

Agreement between **independent** approaches support final results



$\Delta P^0 = -0.027$, RMS = 0.042

K^+Y Induced Polarization: Previous Results from CLAS e1f



Λ recoil polarization in the ep reaction was **first measured from the CLAS e1f** experiment using a 5.479 GeV electron beam

Kinematic range:

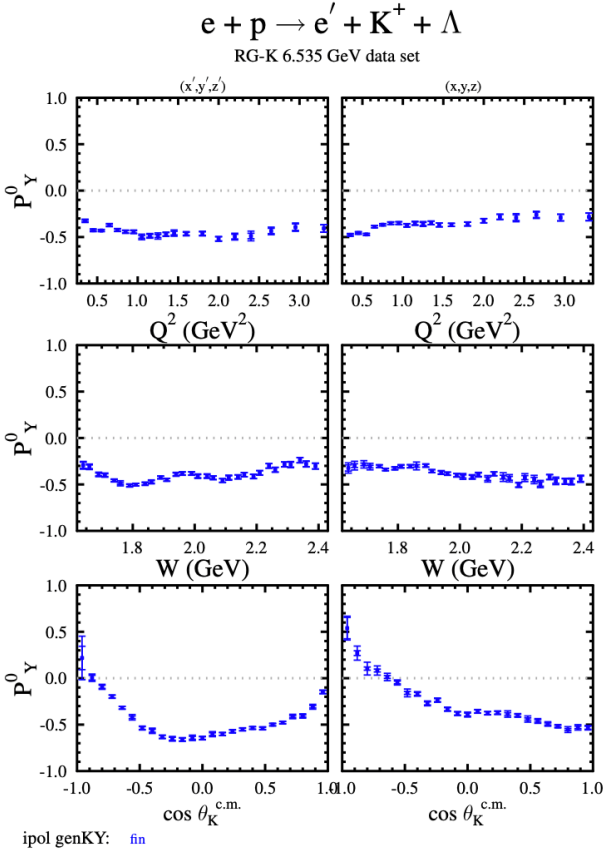
Q^2: 0.8–3.5 GeV^2

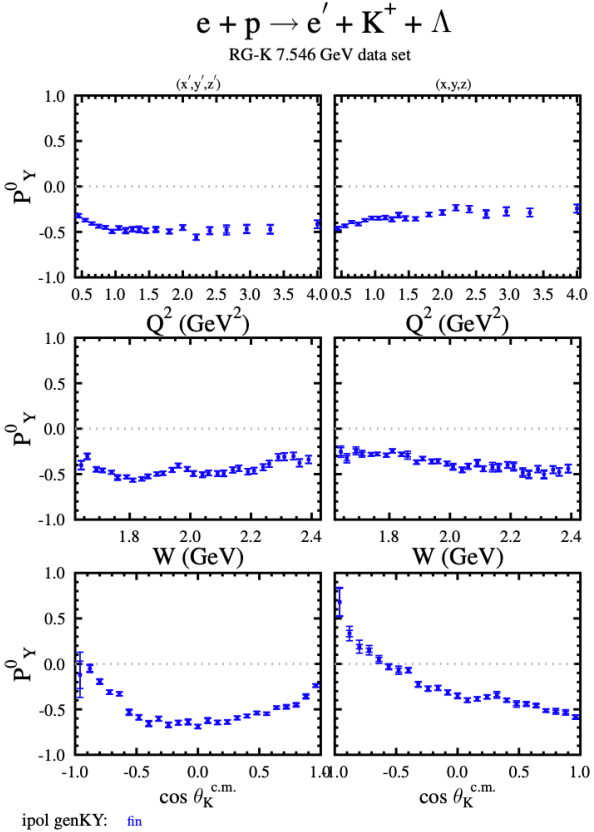
W: 1.6–2.7 GeV.

Due to limited statistics the polarization was provided in **coarse bins** in W and $cos\vartheta^K_{c.m.}$ integrated over Q^2

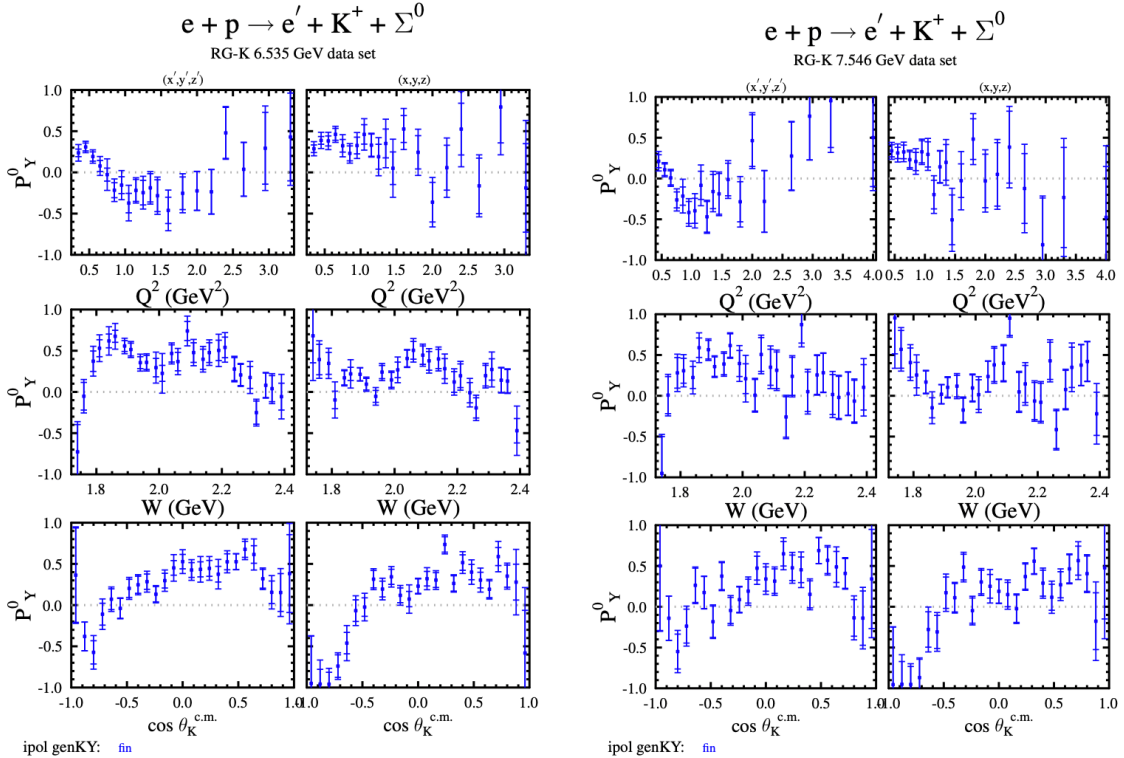
RGK data have ~5 times the statistics compared to e1f

K^+Y Induced Polarization CLAS12: Λ





K^+Y Induced Polarization CLAS12: Σ^0

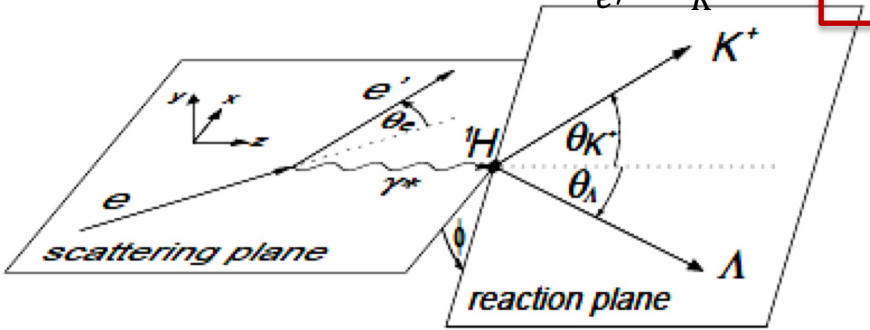


The data included here for the recoil polarization of the Σ^0 in the exclusive $e'K^+\Sigma^0$ final state represent the **first time this observable has become available in electroproduction**.

Separation of Cross Sections Into Structure Functions

Five-fold differential cross section separates in **virtual photon flux** and **virtual photoproduction**

$$\frac{d\sigma}{dE'd\Omega_{e'}d\Omega_K^*} = \Gamma \frac{d\sigma}{d\Omega_K^*}$$



$$\Gamma = \frac{\alpha}{4\pi} \cdot \frac{W}{ME_b^2} \cdot \frac{W^2 - M^2}{MQ^2} \cdot \frac{1}{1-\varepsilon}$$

$$\frac{d\sigma}{d\Omega_K^*} = \sigma_T + \varepsilon\sigma_L + \varepsilon\sigma_{TT}cos2\varphi + \sqrt{2\varepsilon(1-\varepsilon)}\sigma_{LT}cos\varphi + h\sqrt{2\varepsilon(1-\varepsilon)}\sigma_{LT'}sin\varphi$$

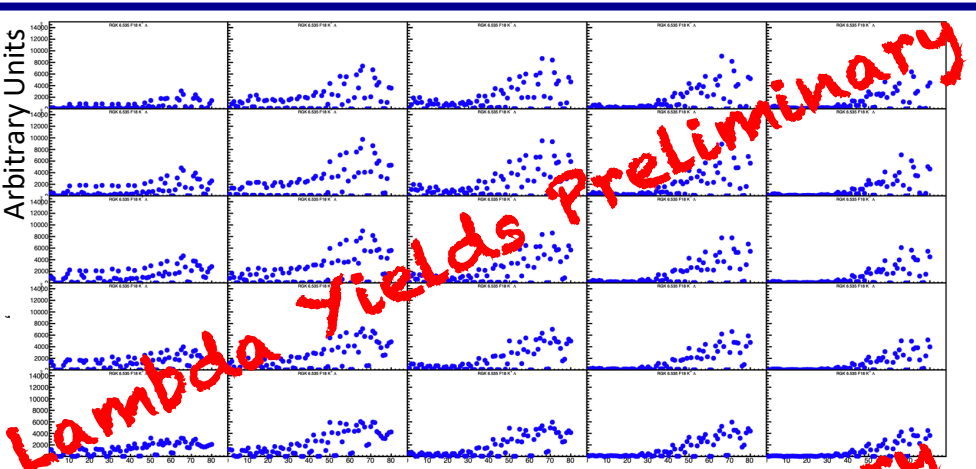
Photon degree-of-polarization: $\varepsilon = (1 + 2\frac{|\vec{q}|^2}{Q^2} tan^2 {}^{\vartheta}/_2)^{-1}$

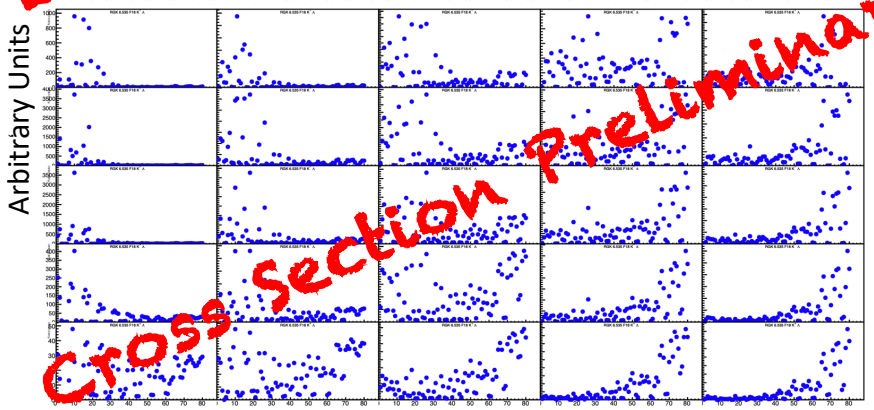
Helicity of incoming electron: h

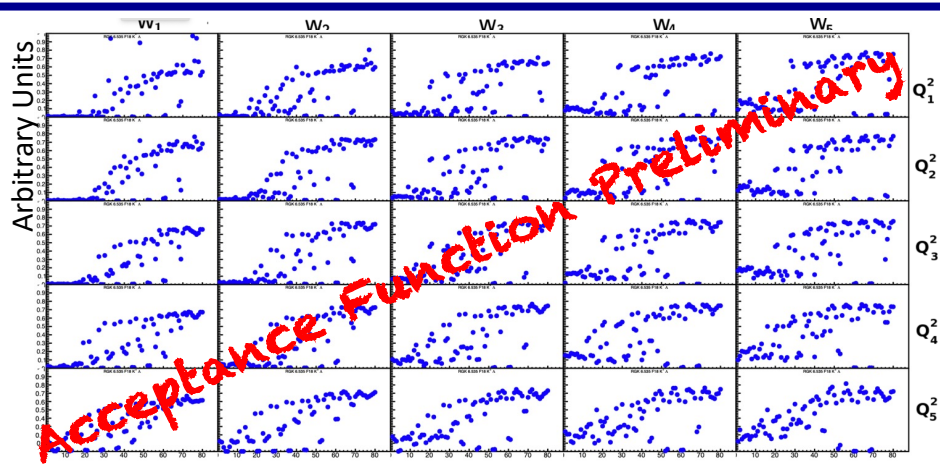
[E. Amaldi, S. Fubini, and G. Furlan, Pion-Electroproduction (1979)]

[A. Donnachie & G. Shaw, Electromagnetic Interactions of Hadrons (1978)]

Separation of Cross Sections Into Structure Functions







Λ yields binned in kinematic variables:

Q^2, W, $cos\vartheta^K_{c.m.}$, Φ, h

$$\frac{d\sigma}{d\Omega^*_K} = \sigma_T + \varepsilon\sigma_L + \varepsilon\sigma_{TT}cos2\varphi + \sqrt{2\varepsilon(1-\varepsilon)}\sigma_{LT}cos\varphi$$ **helicity integrated**

$$\frac{d\sigma}{d\Omega^*_K} = A + Bcos\varphi + Ccos2\varphi$$ **Structure Functions obtained via a fit**

$$A_{LT'} = \frac{\sqrt{\varepsilon(1-\varepsilon)}\sigma_{LT'}sin\Phi}{\sigma_0}$$ $\sigma_{LT'}$ **- helicity sensitive, extracted via a fit**

Summary and Outlook

- The study of N* states is one of the **crucial topics** of the CLAS and CLAS12 physics programs:
  - -CLAS has produced a huge amount of data up to $Q^2 < 5$ GeV^2
  - -CLAS12 was designed to extend these studies for $0.05 < Q^2 < 12$ GeV^2
- The first results of the CLAS12 N* program have been obtained with the analysis of KY polarization transfer data from the RGK Fall 2018 Run
  - -The RGK dataset is 5x larger than the available KY world data in the resonance region
  - -Only 10% of expected statistics has been analyzed.
- On going analyses:
  - -First paper on KY electroproduction has been published on PRC
  - -Other analyses based on the existing RG-K data are in progress:

    i) The paper "Recoil Polarization in K^+Y Electroproduction in the Nucleon Resonance Region with CLAS12" is now undergoing Collaboration-wide review (target journal PRC)

    ii) A new analysis concerning the Extraction of KY Differential Cross Sections And Separated Structure Functions is ongoing- JLab (D. Carman, V. Mokeev)/Roma Tor Vergata (A. D'Angelo, L. Lanza + new Ph.D student C. Ammendola) group
  - -More data have been collected in Spring 2024

Stay tuned for further updates...