Exotic multi-quark states and baryon spectroscopy workshop, Bonn, Germany, 25 – 27 June 2024

N* studies using KY Electroproduction at CLAS12

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e⁻ JLab12

clas

INFN
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di Fisica Nucleare

Outline

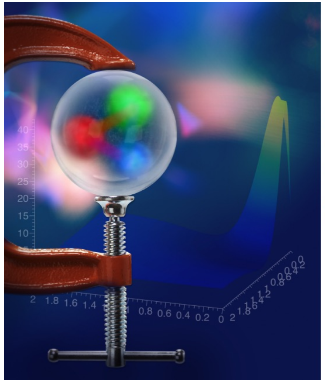
Physics Motivation: Study of the nucleon excitation spectrum to understand the dynamical properties of QCD in the non-perturbative regime.

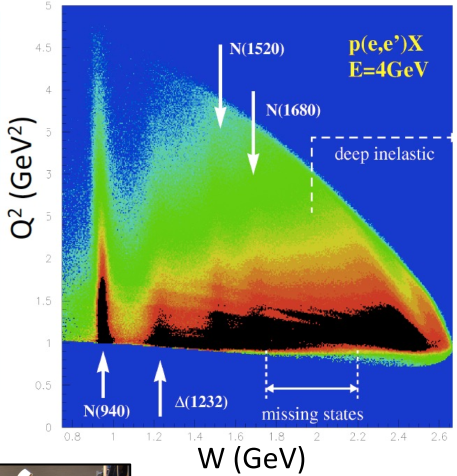
What is the role of glue?

- Search for new Baryon States → Hybrid States

How does the role of the active degrees of freedom in the nucleon spectrum evolve with distance scale?

- Probe underlying degrees of freedom and their emergence from QCD via studies of the Q^2 evolution of electroproduction amplitudes

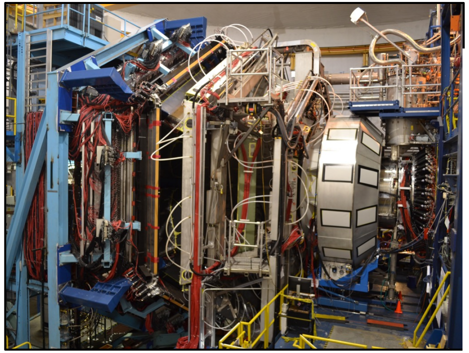




CLAS12 and Forward Tagger (FT) @ JLab: Experimental Setup description.

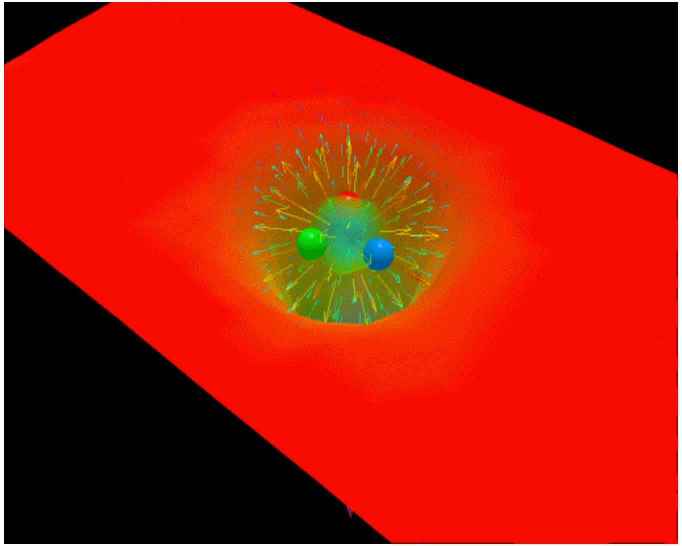
On-going Data Analysis:

- **Results from Physics Runs**: ep -> e'KY channel studied exploiting data from Fall 2018 Physics Runs in Hall B at Jefferson Lab
- **Beam-Recoil Hyperon Transferred Polarization Analysis**



Critical QCD Questions Addressed

- The light N* spectrum: what is the role of glue?



Derek B. Leinweber – University of Adelaide

“Nucleons are the stuff of which our world is made.

*As such they must be **at the center of any discussion of why the world** we actually experience **has the character it does.**”*

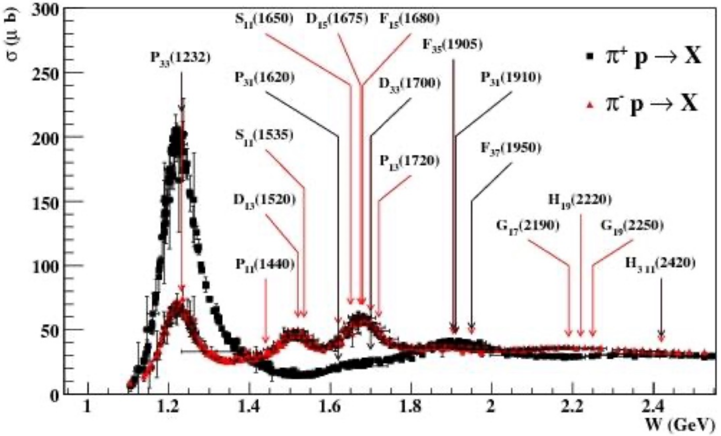
Nathan Isgur, NStar2000, Newport News, Virginia

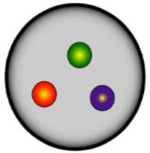
→ **Search for new baryon states**

Why N*? From the N* Spectrum to QCD

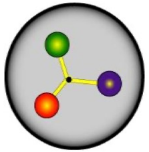
- Understanding the proton's ground state requires understanding its excitation spectrum.

- The N* spectrum reflects the effective degrees of freedom and the forces.

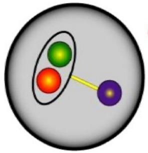




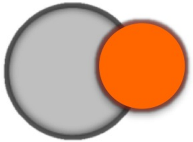
CQM



CQM+flux tubes



Quark–diquark clustering

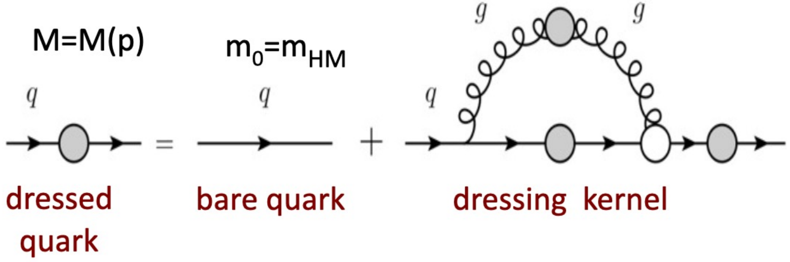


Baryon-meson system

⟶ From the Constituent Quark model to QCD.

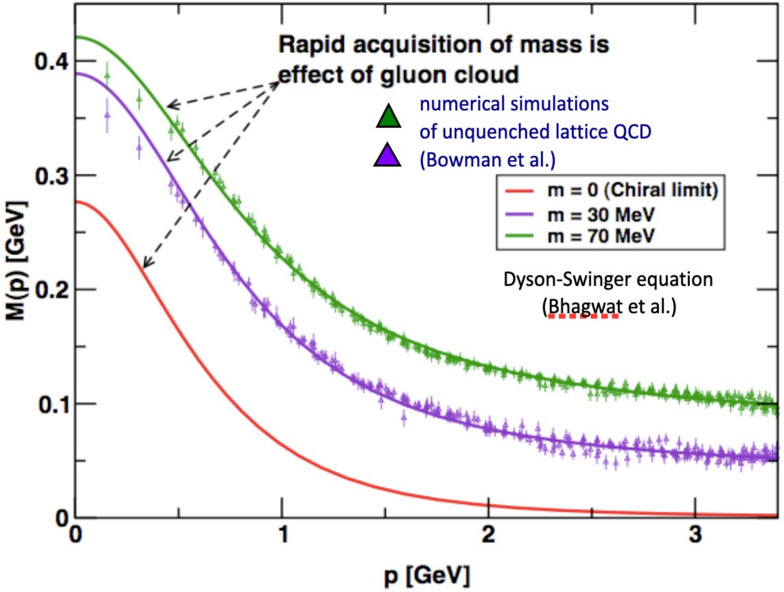
Mass Acquisition

Effective quark mass depends on its momentum



mass composition

<2%	Higgs mechanism
>98%	non-perturbative strong interaction



We need more information about the working of QCD in the non-perturbative regime

Exotic Hadrons

Standard Hadrons come in two varieties: Baryons & Mesons

Exotic Hadrons ⇨ Meson and baryon states whose properties cannot be described in terms of q anti-q or qqq degrees of freedom only

Hybrid mesons/baryons:
qqq or $q\bar{q}$ valence quarks plus a valence gluon

Multiquark states:

- Baryons with more than 3 valence quarks: **pentaquarks or di-baryons**
- Mesons with more than a quark-antiquark pair: **tetraquarks**

Glueballs:
Particles made up of gluonic degrees of freedom only

Molecules…

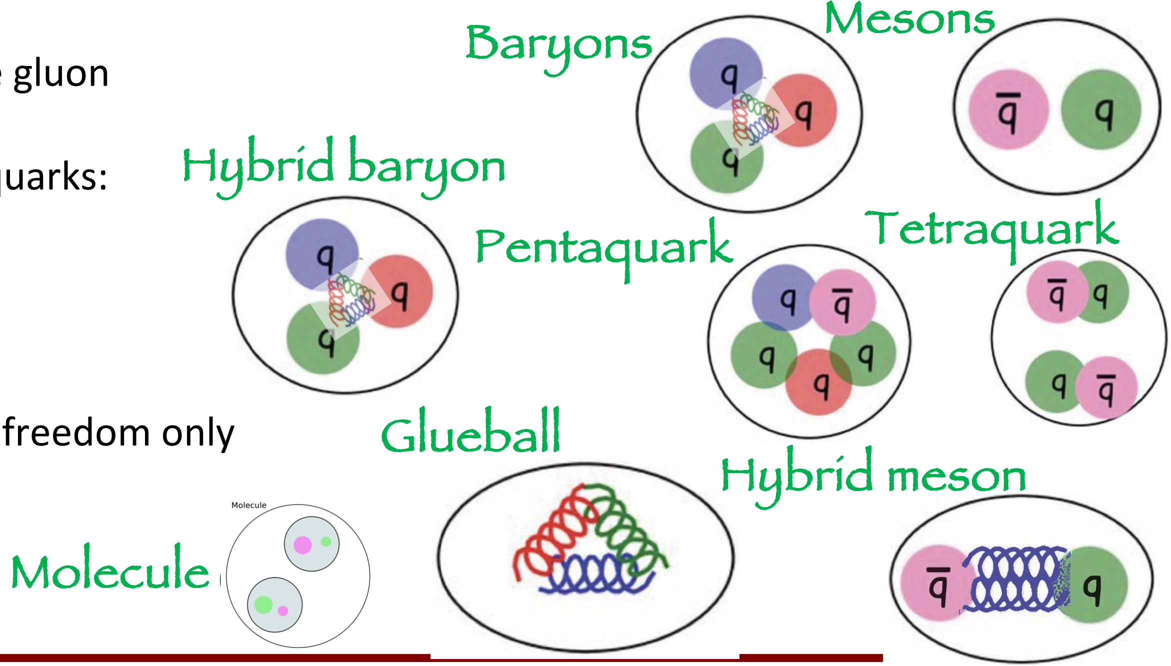


Photo- and Electro- production of mesons on nucleon targets

Meson photo- and electro-production reactions

for

Light quark baryon spectroscopy

Two elements provided a crucial boost in the field:

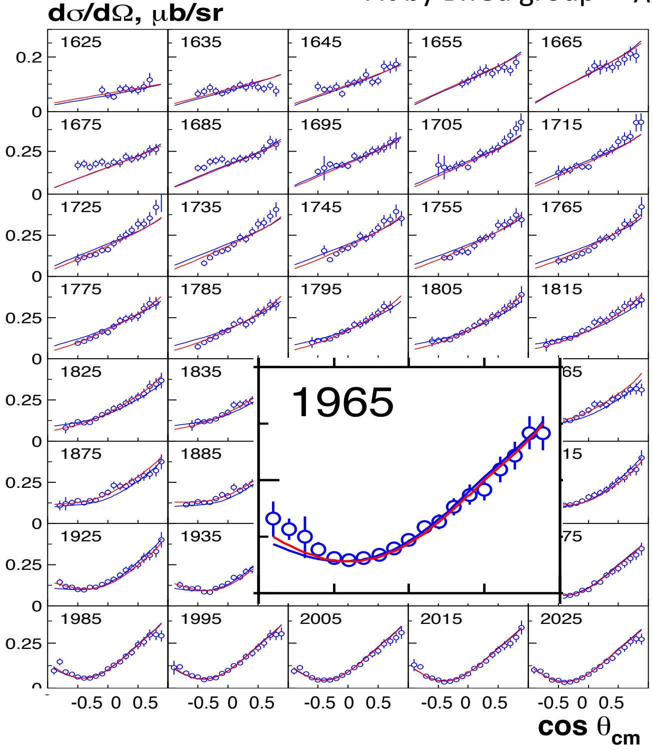
- advent of large solid angle detectors
- polarized beam and targets ⇒ single and double polarization observables

Powerful tool to study the internal structure of the nucleon

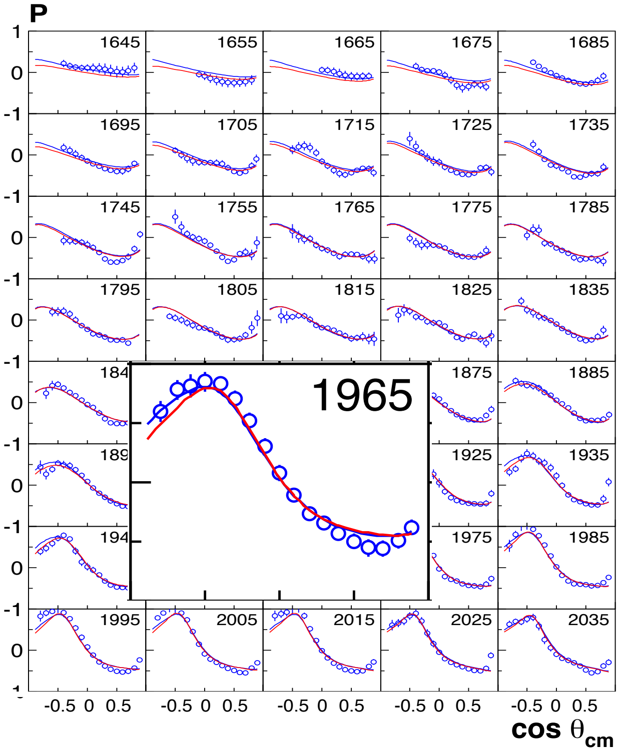
Establishing the N* spectrum – Precision & Polarization are essential

Hyperon photoproduction $\gamma p \to K^+\Lambda \to K^+ p \pi^-$

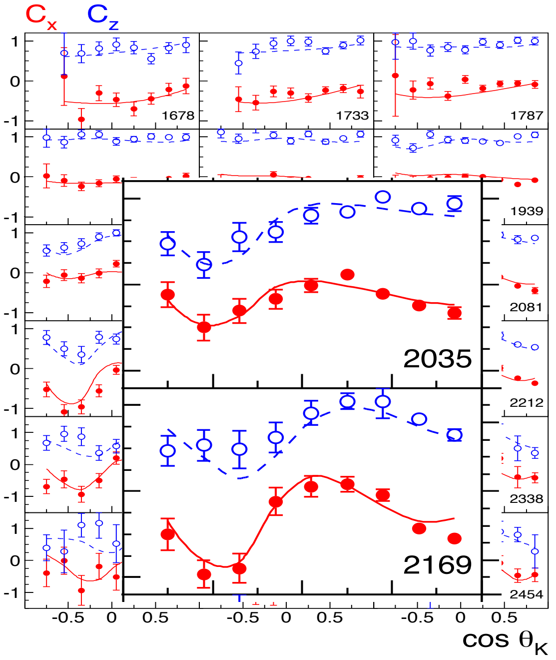
Fit by BnGa group *A.V. Anisovich et al, EPJ A48, 15 (2012)*



M. Mc Cracken et al.(CLAS), Phys.RevC81,025201,2010



γ->Λ **Polarization** transfer

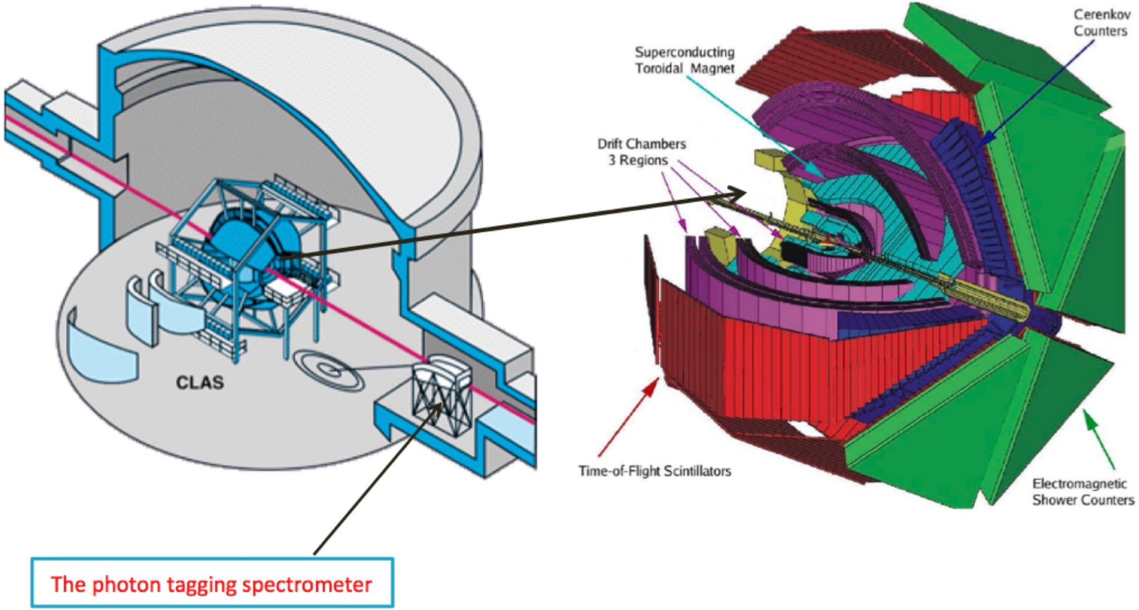


D. Bradford et al. (CLAS), Phys.Rev. C75, 035205, 2007

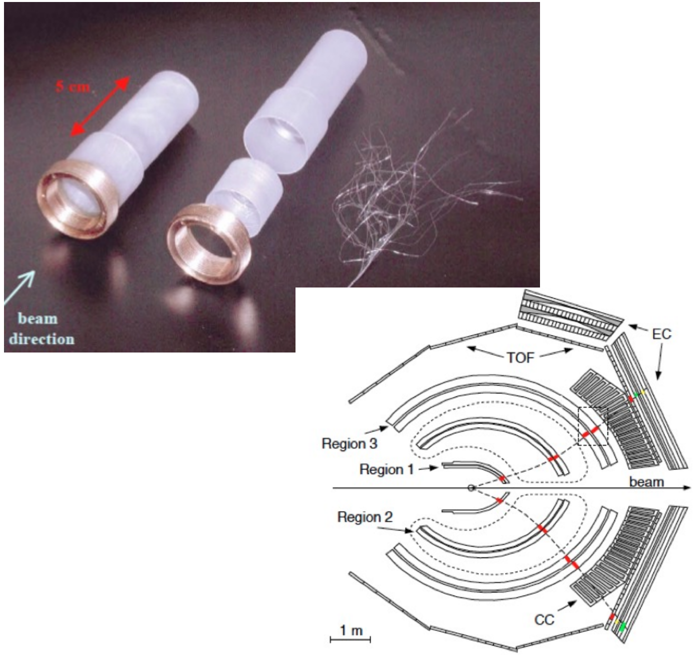
Polarization Observables @ JLab

g14 HD-ICE run period (CLAS):
- circularly polarized photons
- HD frozen spin polarized target

$$\vec{\gamma}\vec{N} \to \pi^+\pi^- N$$



The photon tagging spectrometer



Polarization Observables @ JLab

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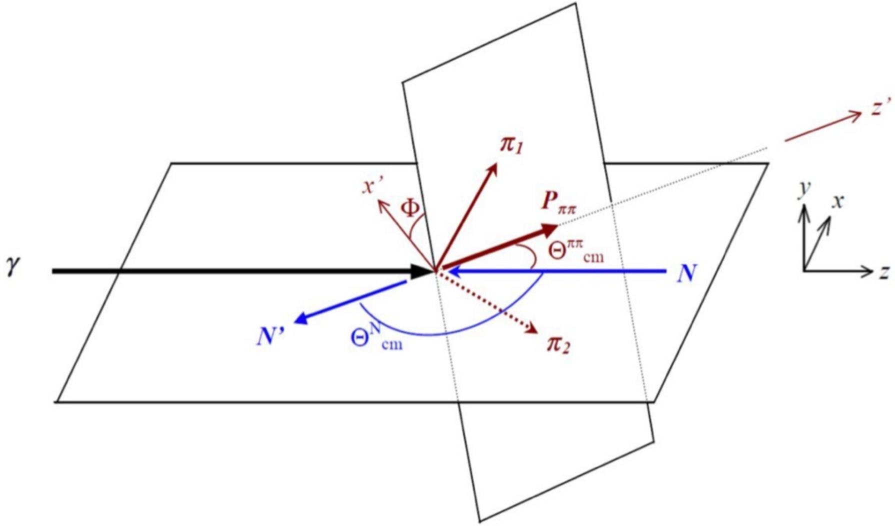


$$P_z = \frac{1}{\Lambda_z}\frac{[N(\rightarrow\Rightarrow)+N(\leftarrow\Rightarrow)]-[N(\rightarrow\Leftarrow)+N(\leftarrow\Leftarrow)]}{[N(\rightarrow\Rightarrow)+N(\leftarrow\Rightarrow)]+[N(\rightarrow\Leftarrow)+N(\leftarrow\Leftarrow)]}$$

$$I^{\odot} = \frac{1}{\delta_{\odot}}\frac{[N(\rightarrow\Rightarrow)+N(\rightarrow\Leftarrow)]-[N(\leftarrow\Rightarrow)+N(\leftarrow\Leftarrow)]}{[N(\rightarrow\Rightarrow)+N(\rightarrow\Leftarrow)]+[N(\leftarrow\Rightarrow)+N(\leftarrow\Leftarrow)]}$$

$$P_z^{\odot} = \frac{1}{\Lambda_z\delta_{\odot}}\frac{[N(\rightarrow\Rightarrow)+N(\leftarrow\Leftarrow)]-[N(\rightarrow\Leftarrow)+N(\leftarrow\Rightarrow)]}{[N(\rightarrow\Rightarrow)+N(\leftarrow\Leftarrow)]+[N(\rightarrow\Leftarrow)+N(\leftarrow\Rightarrow)]}$$

$$\frac{d\sigma}{dx_i} = \sigma_0\{(1+\Lambda_z\cdot\mathbf{P_z})+\delta_{\odot}(\mathbf{I}^{\odot}+\Lambda_z\cdot\mathbf{P}_z^{\odot})\}$$

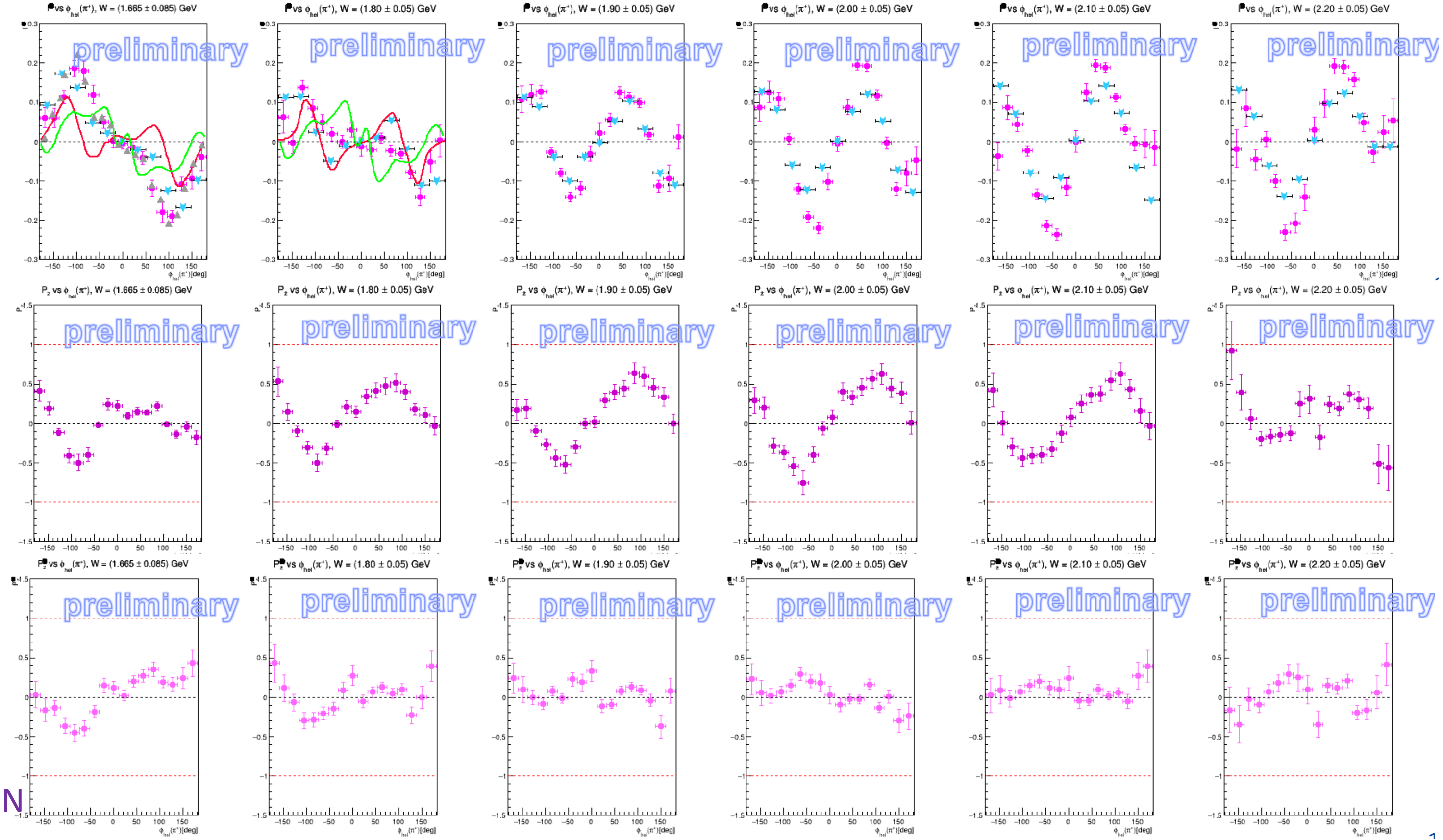
Polarization Observables @ JLab

$I^{\odot}$ Beam asimmetry

Blue points from S. Strauch et al., CLAS Coll., PRL 95 (2005), 162003
W. Roberts and T. Oed, Phys. Rev. C71 (2005), 055201
Fix and H. Arenhovel,, Eur. Phys. J. A25 (2005), 115

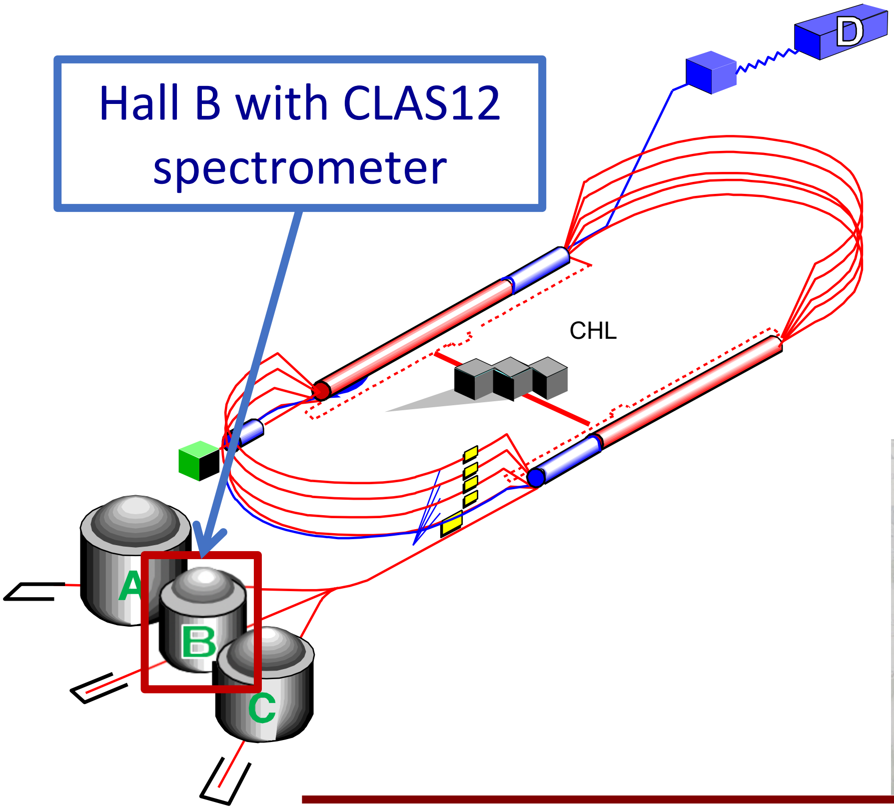
P_z Single Target asimmetry

$P_z^{\odot}$ double target-beam asymmetry



By Alessandra Filippi, INFN Torino

CLAS N* Experimental Program



Hall B with CLAS12 spectrometer

The N* program is one of the Hall B fundamental

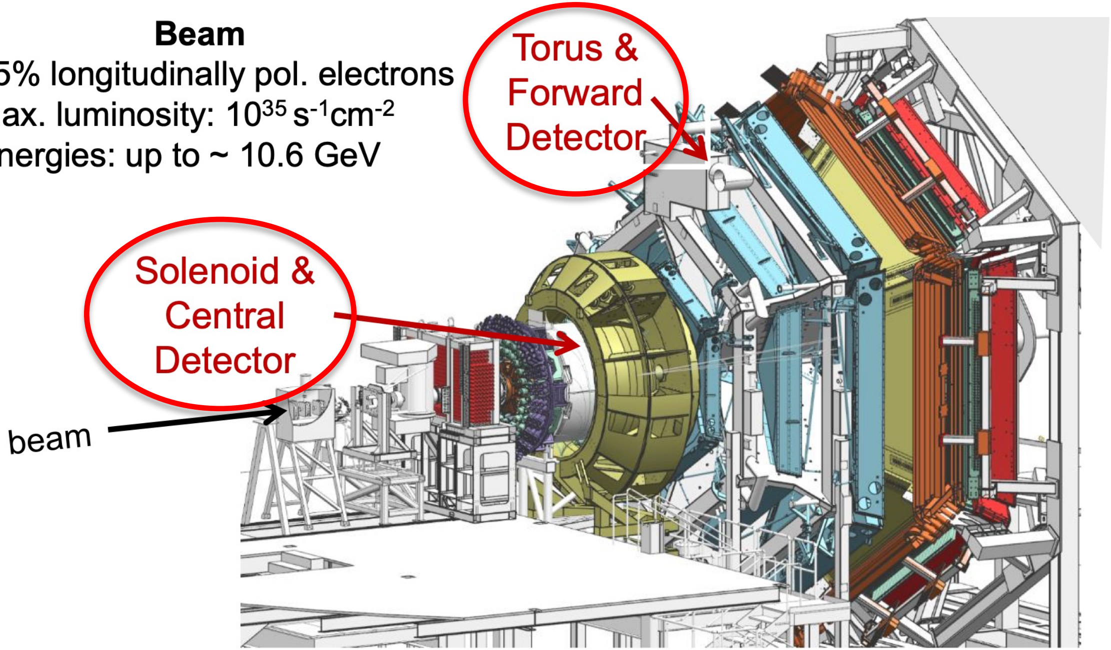
- CLAS & CLAS12 – optimized to study exclusive reaction channels over a broad kinematic range:

πN, ωN, φN, ηN, η'N, $\pi\pi$N, KY, K*Y, KY*

CLAS12

Beam

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

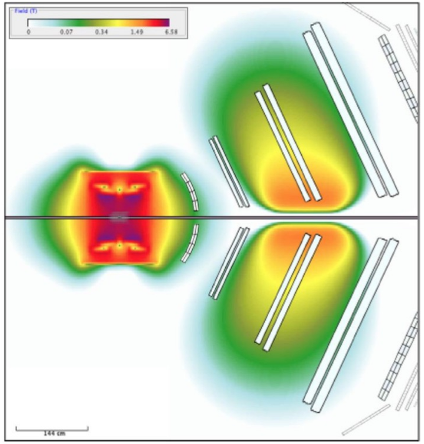


[V.D. Burkert et al., Nucl. Inst. and Meth. A 959, 163419 (2020)]

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)

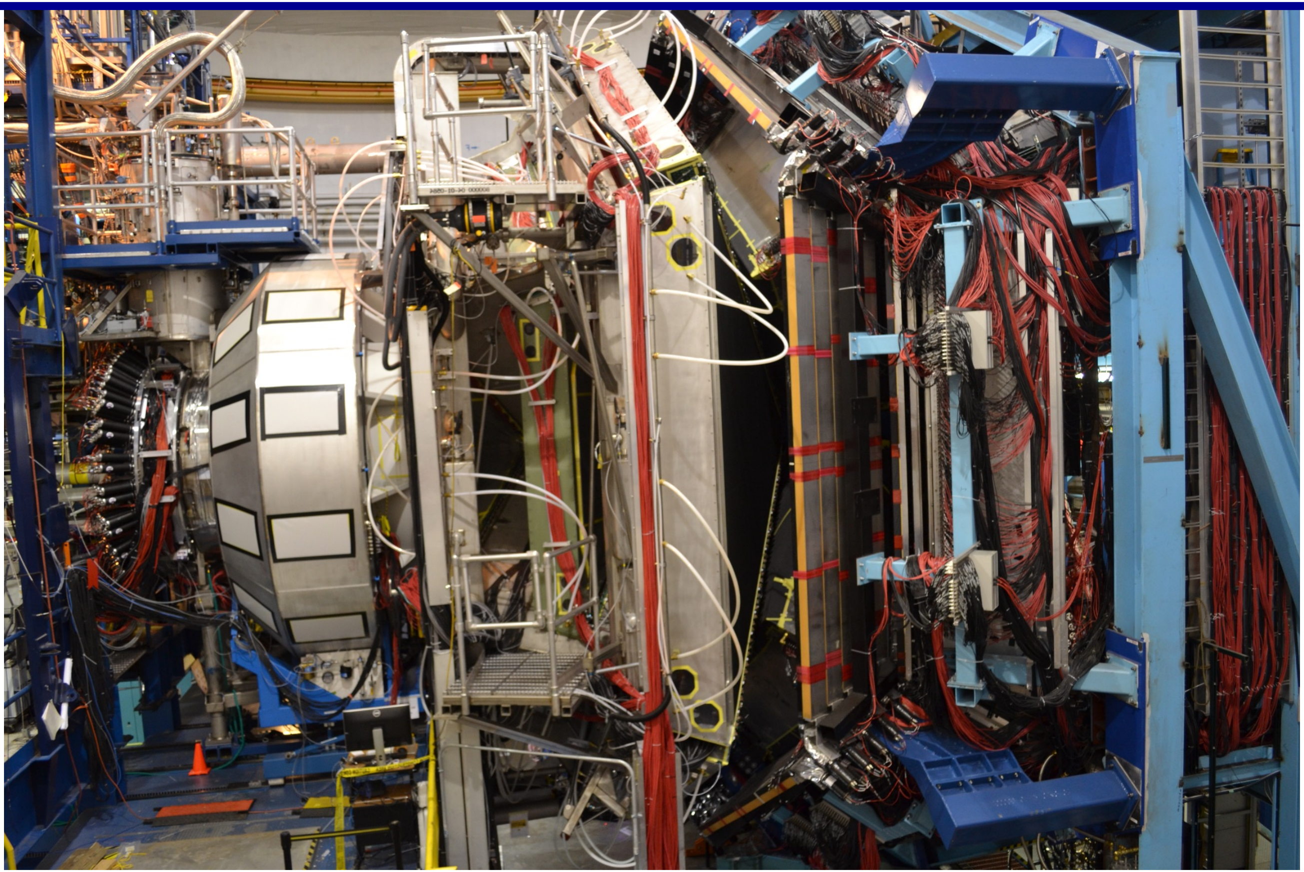
Magnetic Field



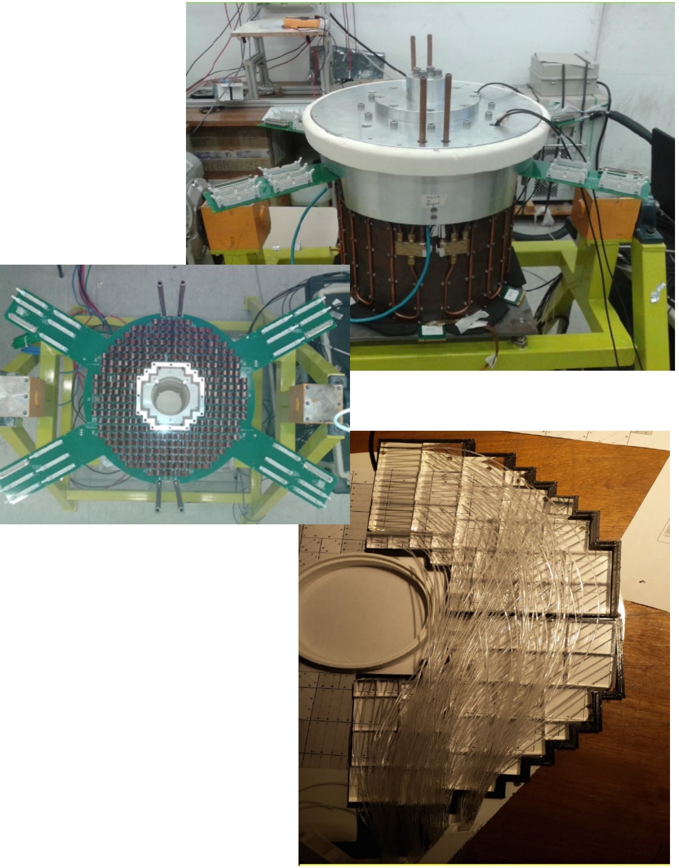
Ideal instrument to study exclusive meson electroproduction in the nucleon resonance region

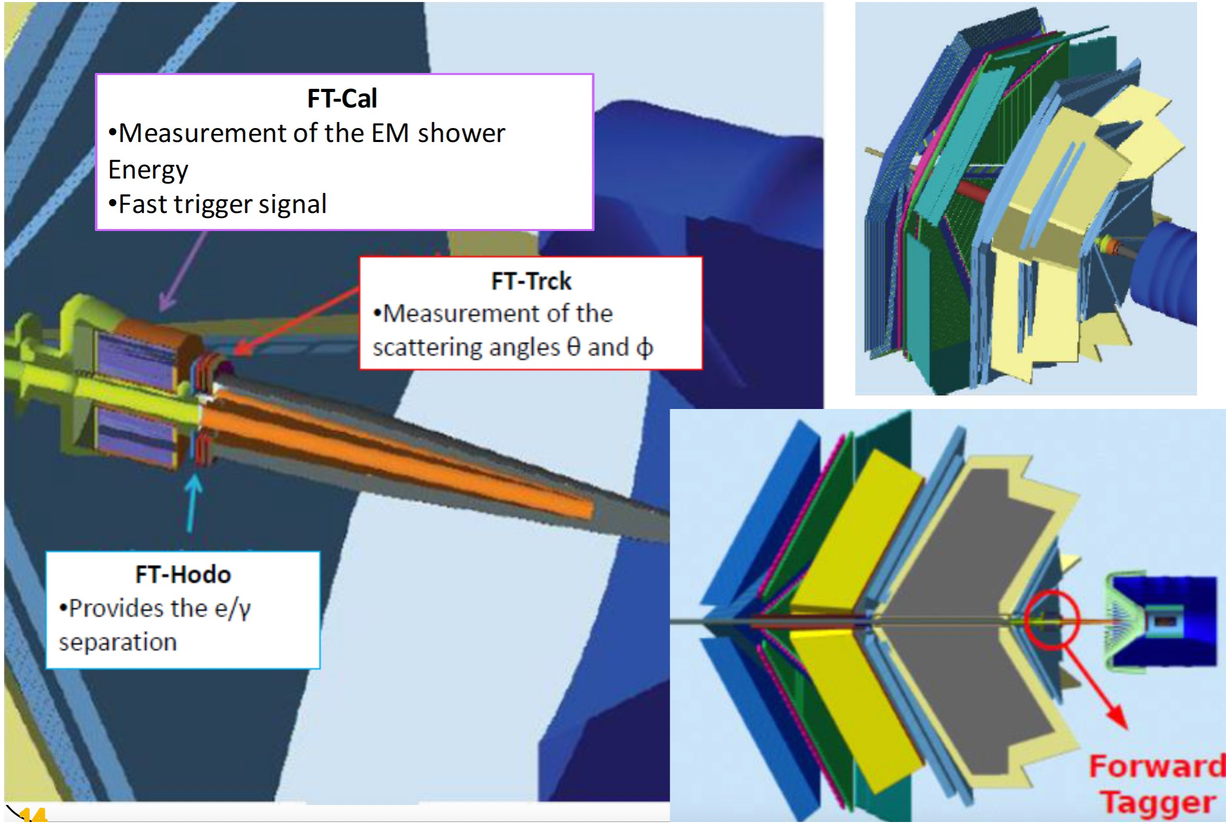
CLAS12 Spectrometer

beam



Experimental Setup: Forward Tagger





FT-Cal
- Measurement of the EM shower Energy
- Fast trigger signal

FT-Trck
- Measurement of the scattering angles θ and ϕ

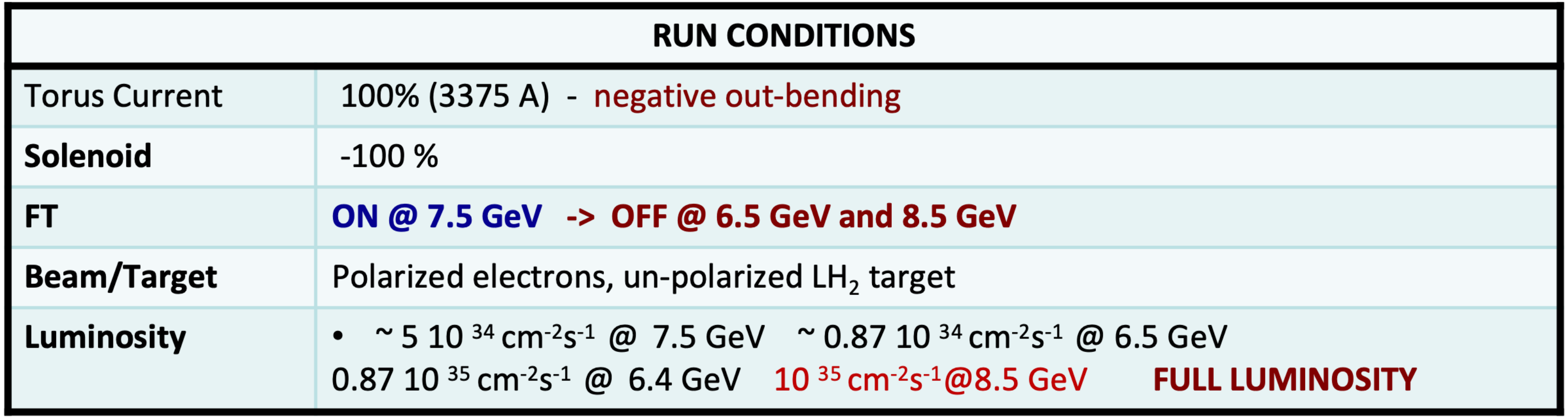
FT-Hodo
- Provides the e/γ separation

RGK @ CLAS12

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

Search for Hybrid Baryons (qqqg)
KY Electroproduction for the N* study

DVCS
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)

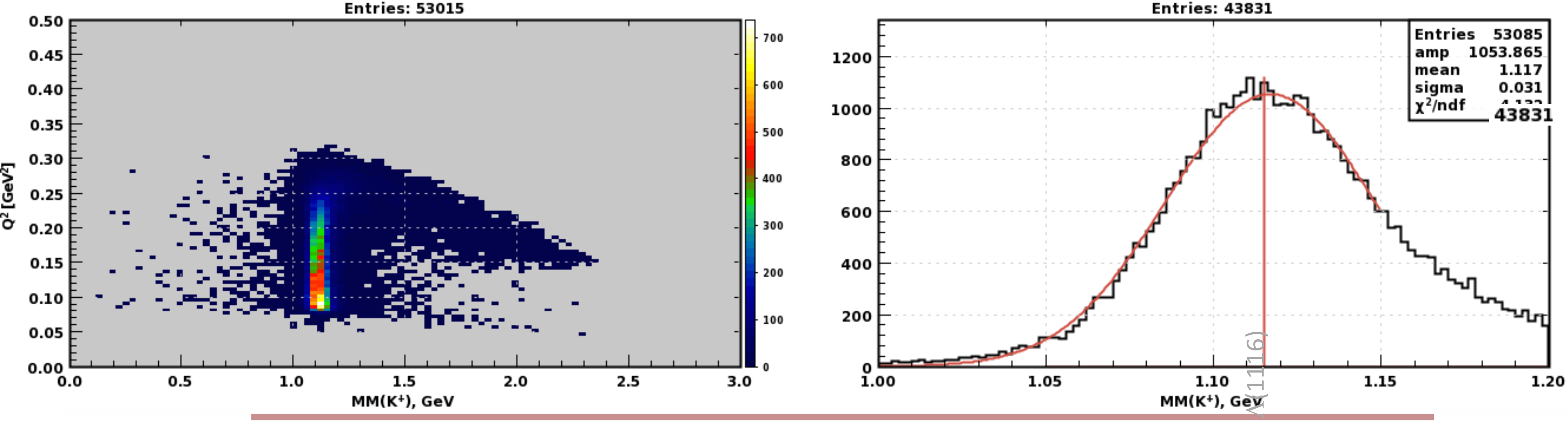
50% of the total

Upgraded Simulation and Reconstruction of $K^+\Lambda$ Electroproduction Events in CLAS12 using the RPR-2011 Model, GEMC and CLARA

Simulations have been performed using:

- Event Generator based on the Ghent RPR-2011 Model to produce electroproduction events
- GEMC to simulate CLAS12 acceptance effects.
- CLARA Framework to reconstruct events

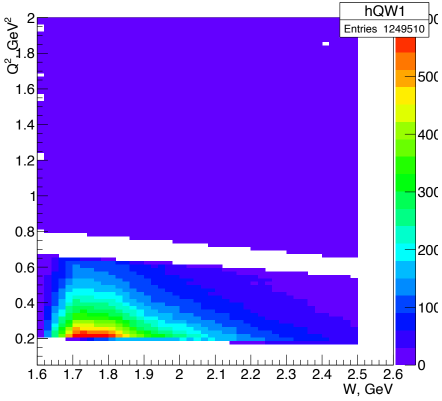
- $1.6\ \mathrm{GeV} < W < 3\ \mathrm{GeV}$
- $E_{beam} = 7.5$ GeV
- Torus/Solenoid current: 100%/ -100%
- 529948 KΛ Events analized

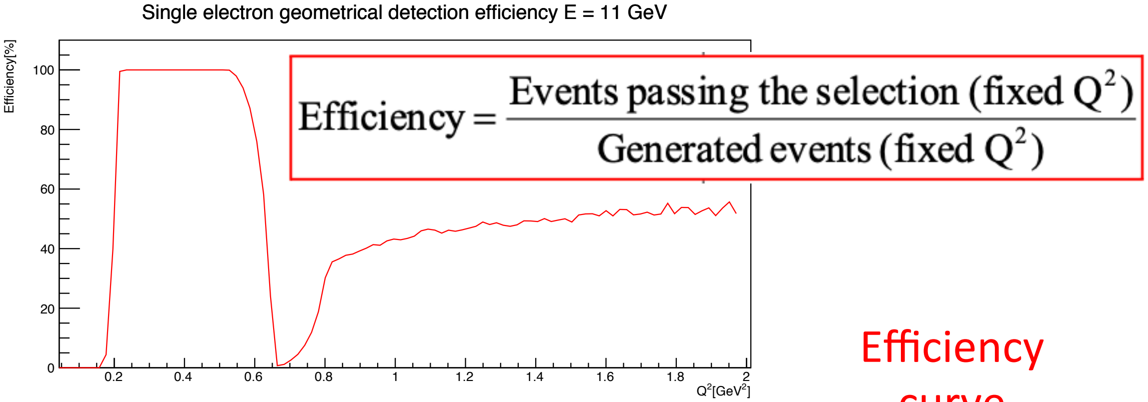


Magnetic Field

Q^2 vs W

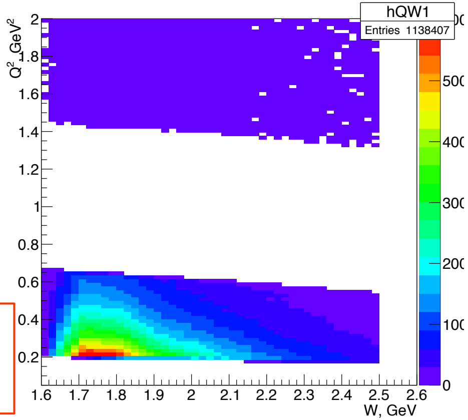
Outbending
TorCur= -3775 A

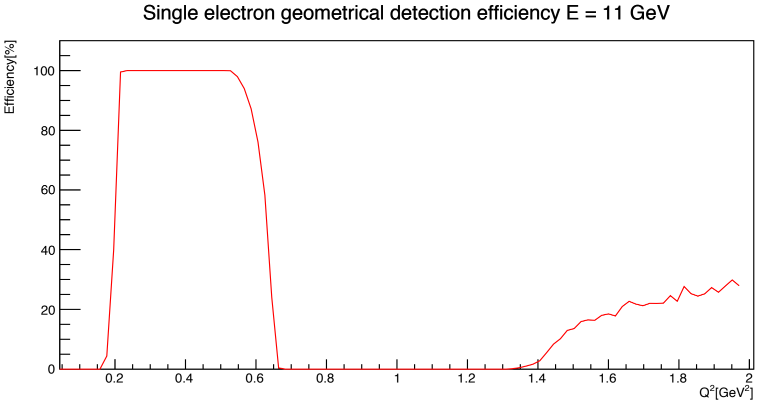




$$\text{Efficiency} = \frac{\text{Events passing the selection (fixed } Q^2\text{)}}{\text{Generated events (fixed } Q^2\text{)}}$$

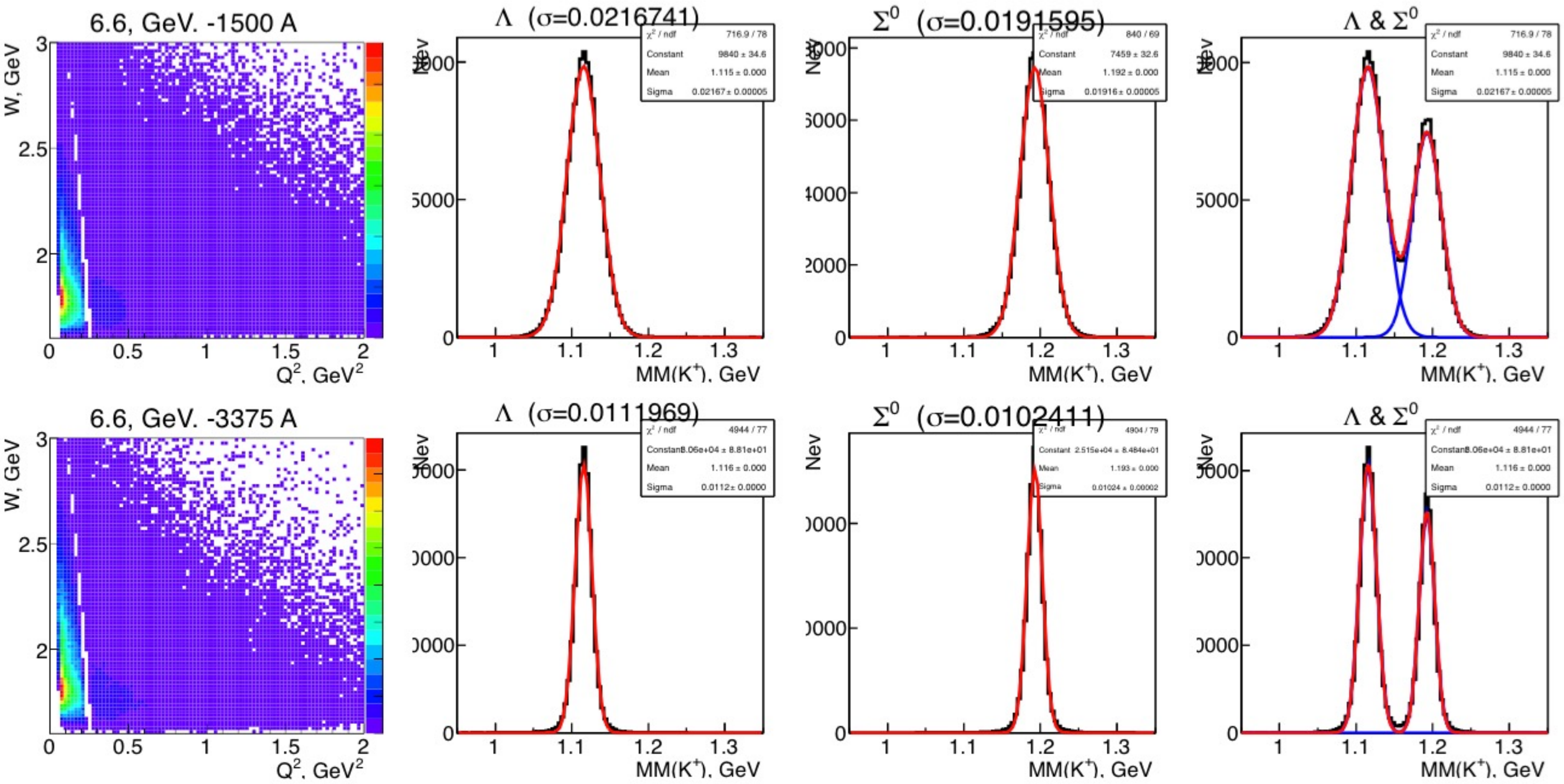
Inbending
TorCur= +3775 A





Efficiency curve

Strength of Torus Current



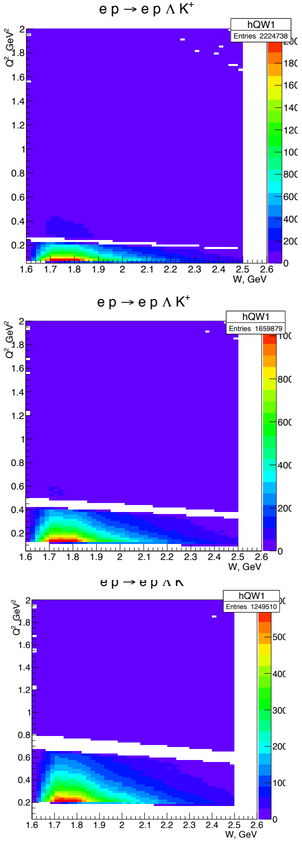
Advantage of high CLAS12 torus currents

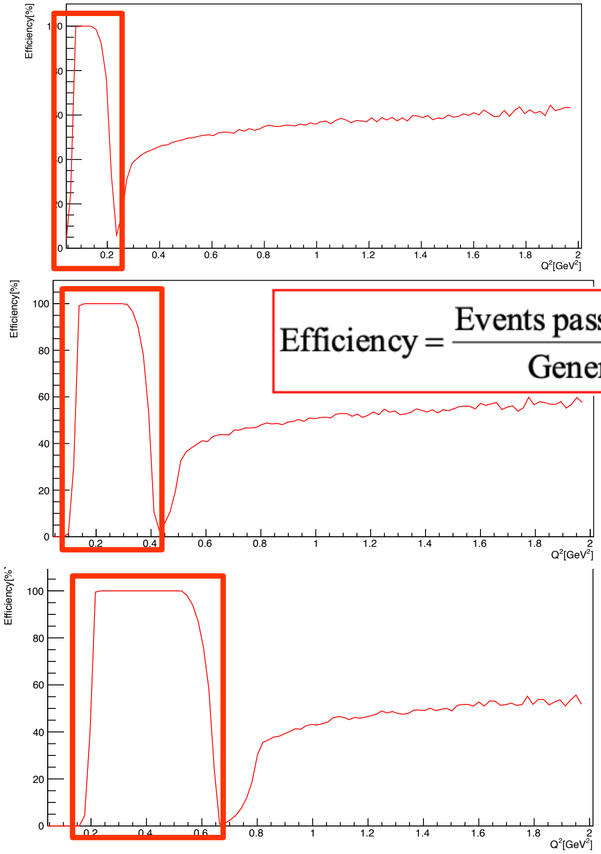
Magnetic Field

E = 6.6 GeV
TorCur= -3775 A

E = 8.8 GeV
TorCur= -3775 A

E = 11 GeV
TorCur= -3775 A





Efficiency curve

$$\text{Efficiency} = \frac{\text{Events passing the selection (fixed } Q^2)}{\text{Generated events (fixed } Q^2)}$$

Complementary ranges

Hybrid Hadrons

Hybrid hadrons with dominant gluonic contributions are predicted to exist by QCD.

Experimentally:

- **Hybrid mesons** $|q\bar{q}g>$ states may have exotic quantum numbers J^{PC} not available to pure $|\ q\bar{q}\ >$ states
  GlueX, MesonEx, COMPASS, PANDA ….

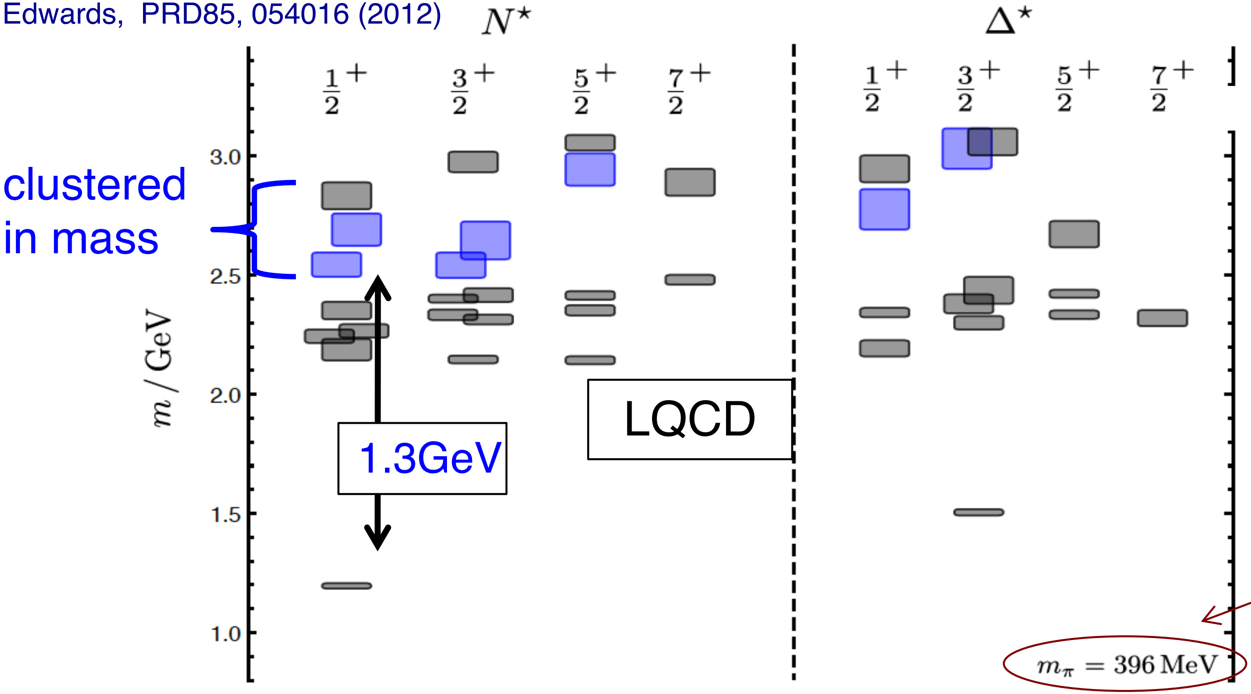
- **Hybrid baryons** |qqqg> have the same quantum numbers J^{P} as |qqq> electroproduction with CLAS12 (Hall B).

Theoretical predictions:

- ✧ MIT bag model - T. Barnes and F. Close, Phys. Lett. 123B, 89 (1983).
- ✧ QCD Sum Rule - L. Kisslinger and Z. Li, Phys. Rev. D 51, R5986 (1995).
- ✧ Flux Tube model - S. Capstick and P. R. Page, Phys. Rev. C 66, 065204 (2002).
- ✧ LQCD - J.J. Dudek and R.G. Edwards, PRD85, 054016 (2012).

Hybrid Baryons in LQCD

J.J. Dudek and R.G. Edwards, PRD85, 054016 (2012)



regular states

hybrid states

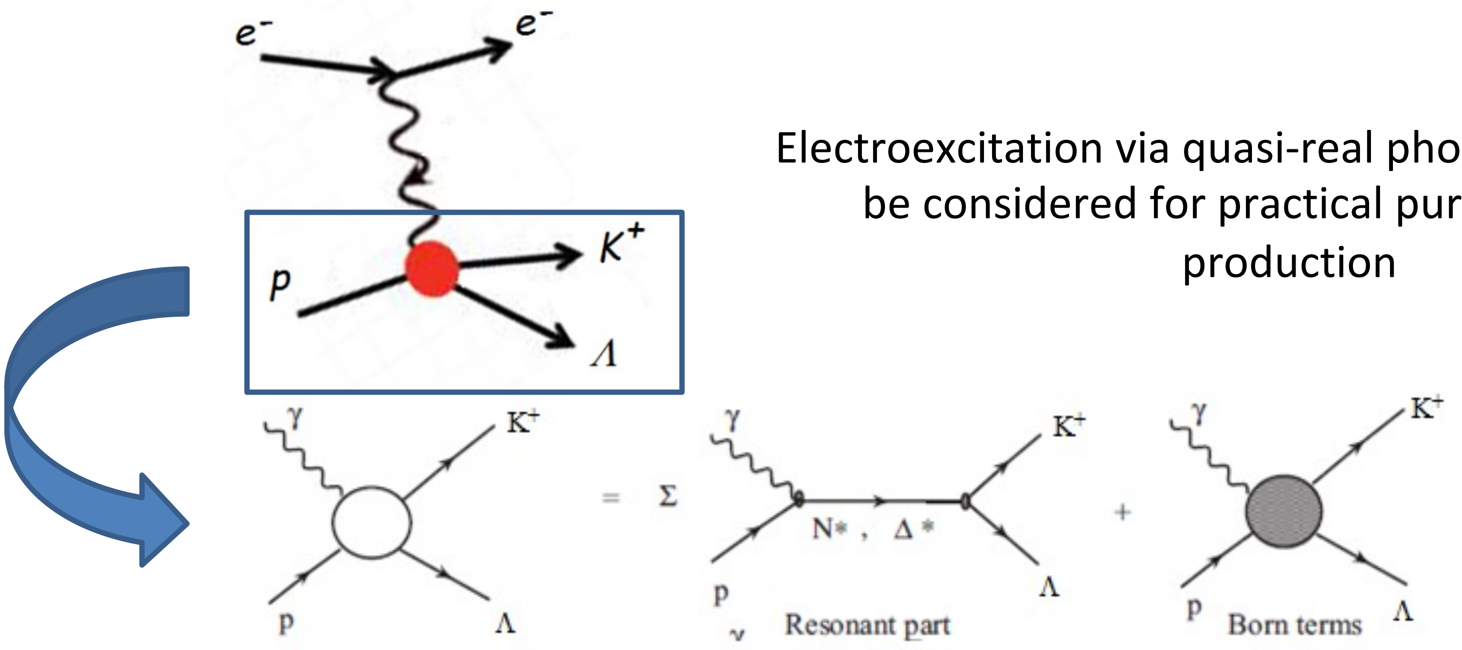
The nucleon mass is shifted ~300 MeV to higher masses

Hybrid states have same J^P values as qqq baryons. How to identify them?

- Overpopulation of N $1/2^+$ and N $3/2^+$ states compared to QM projections.
- **$A_{1/2}$ ($A_{3/2}$) and $S_{1/2}$ show different Q^2 evolution.**

Separating q^3g from q^3 states?

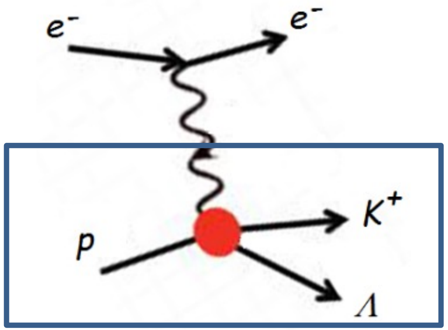
Transverse helicity amplitudes $A_{1/2}(Q^2)$, $A_{3/2}(Q^2)$ and longitudinal helicity amplitude $S_{1/2}(Q^2)$ allow to distinguish Q^3G from Q^3 states



Electroexcitation via quasi-real photon exchange can be considered for practical purposes photo-production

V. I. Mokeev, CLAS Collaboration, PHYSICAL REVIEW C 86, 035203 (2012)

Separating q^3g from q^3 states?



Hybrid resonance contribution in the helicity representation

Helicities of final state hadrons

Helicities of γ and p

N* helicity = λ_γ - λ_p

$$\langle \lambda_f | T_r | \lambda_\gamma \lambda_p \rangle = \sum_{N*} \frac{\boxed{\langle \lambda_f | T_{dec} | \lambda_R \rangle} \boxed{\langle \lambda_R | T_{em} | \lambda_\gamma \lambda_p \rangle}}{M_r^2 - W^2 - i\Gamma_r(W) M_r}$$

where

Resonance mass

Invariant mass

Energy dependent total width

The **resonance electroexcitation amplitudes** can be related to the $\gamma_v NN^*$ electrocouplings **$A_{1/2}$, $A_{3/2}$**, and **$S_{1/2}$** for nucleons

$$\langle \lambda_R | T_{em} | \lambda_\gamma \lambda_p \rangle = \frac{W}{M_r} \sqrt{\frac{8 M_N M_r q_{\gamma_r}}{4\pi\alpha}} \sqrt{\frac{q_{\gamma_r}}{q_\gamma}} \boxed{A_{1/2,3/2}(Q^2)} \text{ with } |\lambda_\gamma - \lambda_p| = \frac{1}{2}, \frac{3}{2} \text{ for transverse photons,}$$

$$\langle \lambda_R | T_{em} | \lambda_\gamma \lambda_p \rangle = \frac{W}{M_r} \sqrt{\frac{16 M_N M_r q_{\gamma_r}}{4\pi\alpha}} \sqrt{\frac{q_{\gamma_r}}{q_\gamma}} \boxed{S_{1/2}(Q^2)} \text{ for longitudinal photons}$$

The ***N**** **hadronic decay amplitudes** can be expanded in **partial waves** of total momentum *J*

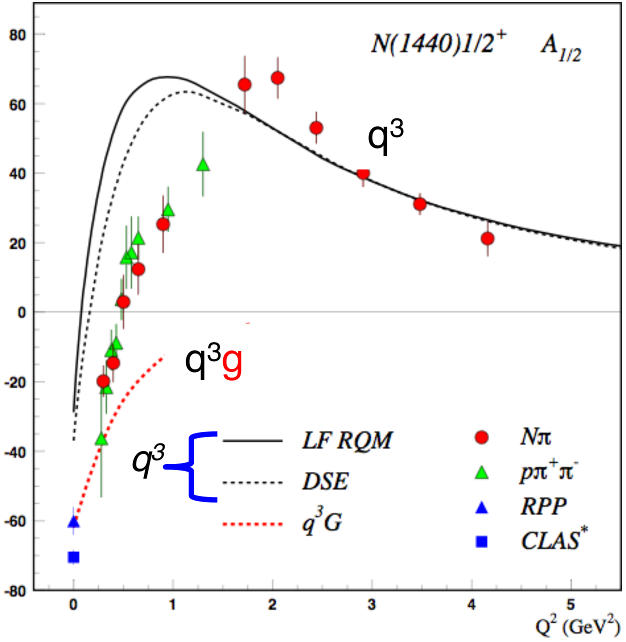
$$\langle \lambda_f | T_{dec} | \lambda_R \rangle = \langle \lambda_f | T_{dec}^{J_r} | \lambda_R \rangle d_{\mu\nu}^{J_r}(\cos\theta^*) e^{i\mu\phi^*}$$ where $$\langle \lambda_f | T_{dec}^{J_r} | \lambda_R \rangle = \frac{2\sqrt{2\pi}\sqrt{2J_r+1} M_r \sqrt{\Gamma_{\lambda_f}}}{\sqrt{\langle p_i^r \rangle}} \sqrt{\frac{\langle p_i^r \rangle}{\langle p_i \rangle}}$$

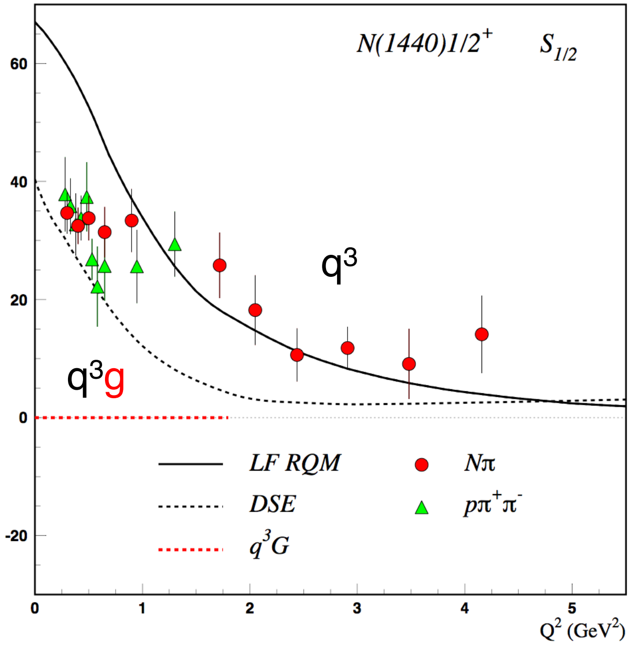
V. I. Mokeev, CLAS Collaboration, PHYSICAL REVIEW C 86, 035203 (2012)

Separating q^3g from q^3 states?

CLAS results on electrocouplings clarified nature of the Roper.

Will CLAS12 data be able to identify gluonic contributions ?





For hybrid "Roper", $A_{1/2}(Q^2)$ drops off faster with Q^2 and $S_{1/2}(Q^2)$ ~ 0.

Separating q^3g from q^3 states?

Based on available knowledge, the ***signature*** for hybrid baryons may consist of ***:***

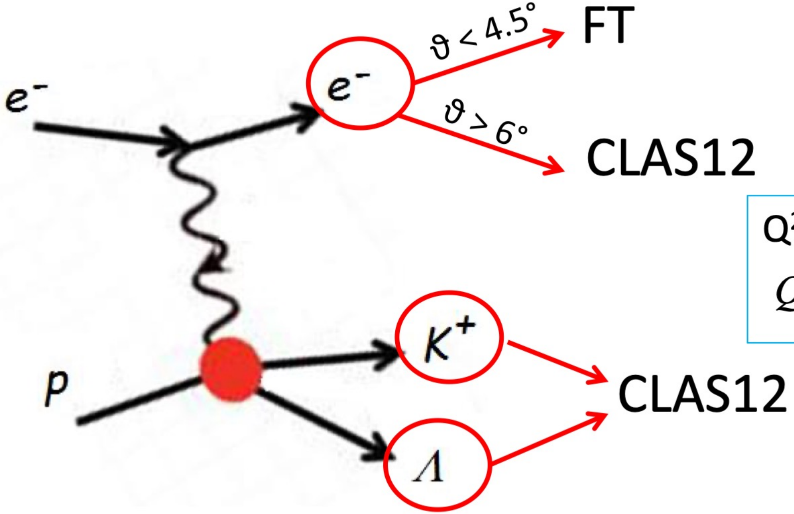
- Extra resonances with $J^p=1/2^+$ and $J^p=3/2^+$, with masses from 1.8 GeV to 2.5 GeV and decays to Nππ or KY final states
- A drop of the transverse helicity amplitudes $A_{1/2}(Q^2)$ and $A_{3/2}(Q^2)$ faster than for ordinary three quark states, because of extra glue-component in valence structure
- A suppressed longitudinal amplitude $S_{1/2}(Q^2)$ in comparison with transverse electro-excitation amplitude

KY channel, low Q^2 region

Data from KY are critical to provide the extraction of the electrocoupling amplitudes:

$$e\,p \rightarrow e'\,K^+\,\Lambda\,,\ \Lambda \rightarrow p\pi^-$$

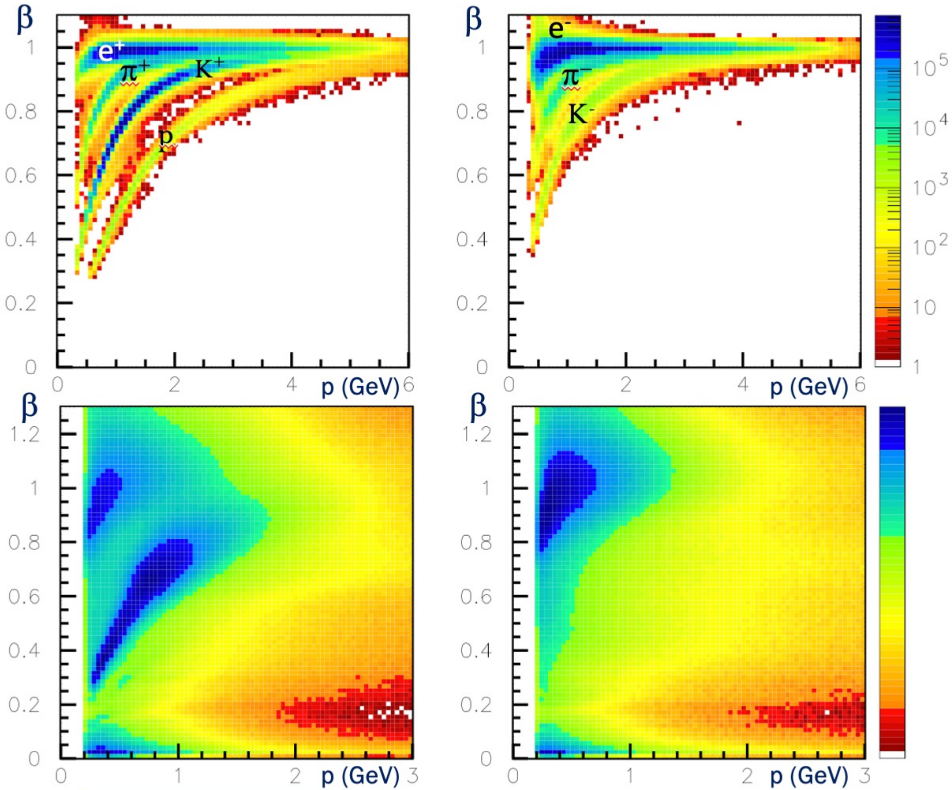
FT allows to probe the **crucial Q^2 range** where hybrid baryons may be identified due to their fast dropping $A_{1/2}(Q^2)$ amplitude and the suppression of the scalar $S_{1/2}(Q^2)$ amplitude.



Q^2 range of interest: 0.05 - 2 GeV^2

$$Q^2 = 4E_{Beam}E_{e'}\sin^2\frac{\vartheta}{2} \quad \Rightarrow \quad \vartheta < 5°$$

Particle ID, electron in CLAS



Forward Detector

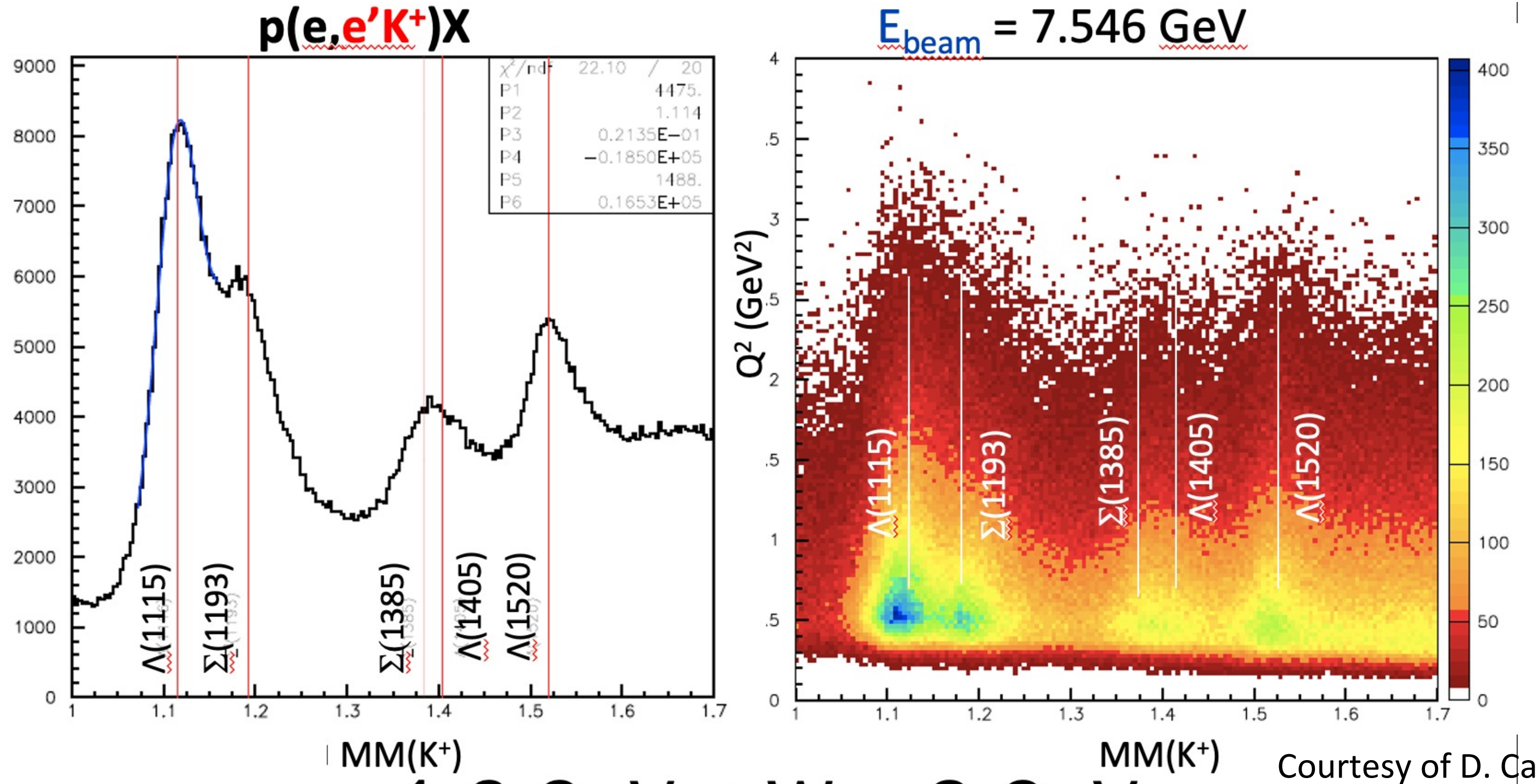
Central Detector

Positive particles

Negative particles

Courtesy of D. Carman

Preliminary Results: electron in the FD(CLAS)

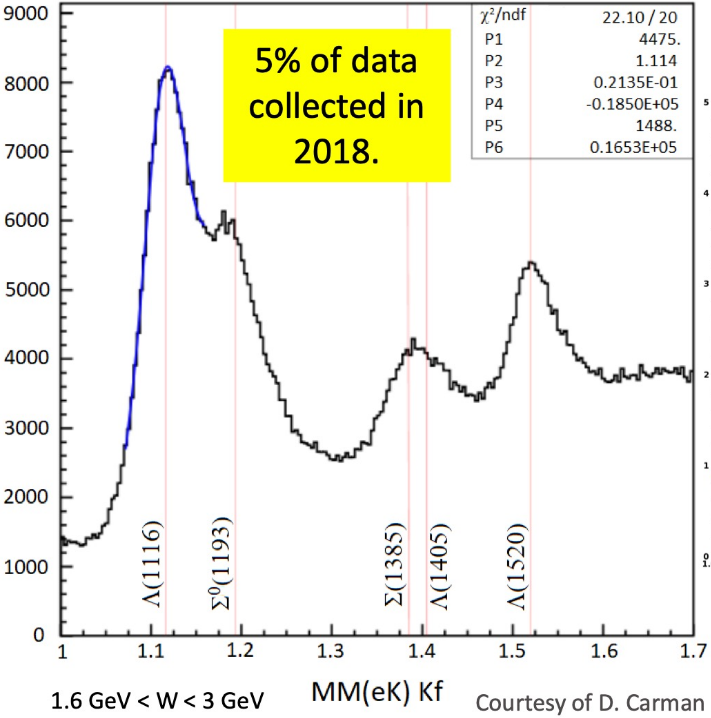

p(e,e'K$^+$)X

E_{beam} = 7.546 GeV

Courtesy of D. Carman

1.6 GeV < W < 3 GeV

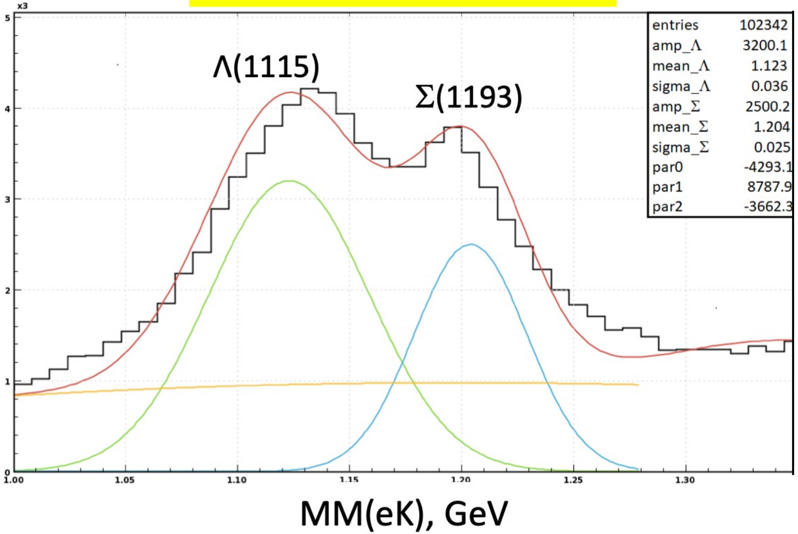
Preliminary Results: electron in the FD(CLAS)/FT



5% of data collected in 2018.

Courtesy of D. Carman

Exclusive Kinematics

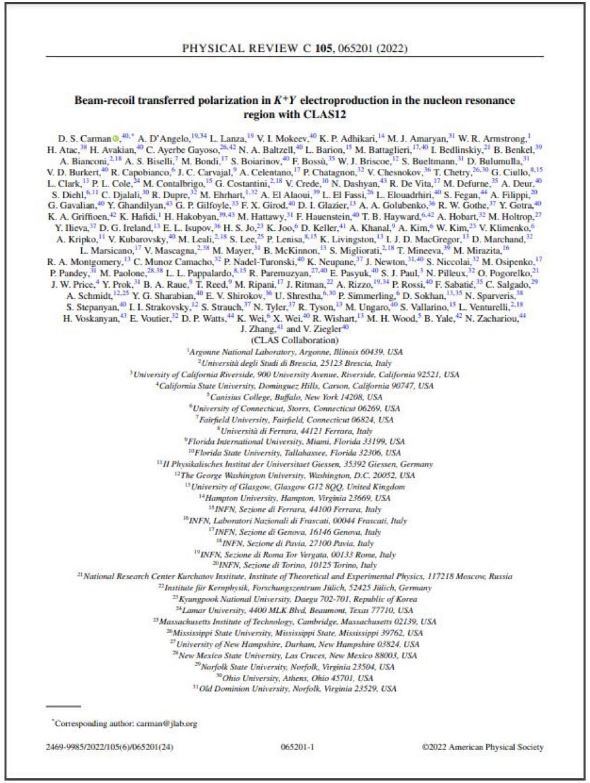


Preliminary results obtained with data collected in 2018

p(e,e’K⁺)X

E_{beam} = 7.546 GeV

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,[21] 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,[32] V. Chesnokov,[36] T. Chetry,[26,30] G. Ciullo,[8,15] L. Clark,[13] P. L. Cole,[24] 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,[32] M. Ehrhart,[1,32] A. El Alaoui,[39] L. El Fassi,[26] L. Elouadrhiri,[40] S. Fegan,[44] A. Filippi,[20] G. Gavalian,[40] Y. Ghandilyan,[43] G. P. Gilfoyle,[33] 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,[25] P. Lenisa,[8,15] K. Livingston,[13] I. J. D. MacGregor,[13] D. Marchand,[32] L. Marsicano,[17] V. Mascagna,[2,38] M. Mayer,[31] B. McKinnon,[13] S. Migliorati,[2,18] T. Mineeva,[39] M. Mirazita,[16] R. A. Montgomery,[13] C. Munoz Camacho,[32] P. Nadel-Turonski,[40] K. Neupane,[37] J. Newton,[31,40] S. Niccolai,[32] 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,[3] N. Pilleux,[32] 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,[32] D. P. Watts,[44] K. Wei,[6] X. Wei,[40] R. Wishart,[13] M. H. Wood,[5] B. Yale,[42] N. Zachariou,[44] J. Zhang,[41] and V. Ziegler[40]

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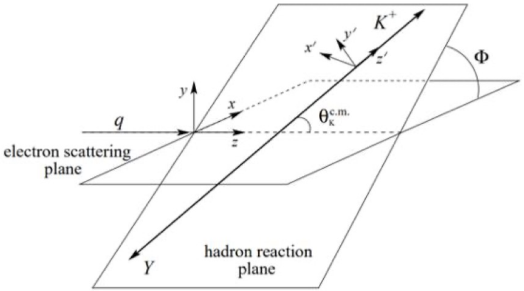
D.S. Carman, A. D'Angelo, L. Lanza, V. Mokeev (CLAS Collaboration)), "Beam-Recoil Transferred Polarization in K⁺Y Electroproduction in the Nucleon Resonance Region with CLAS12", Phys. Rev. C 105, 065201 (2022)



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

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

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

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

Theoretical expectation:

$\mathcal{P}'_x$	$\frac{1}{2}\sqrt{\epsilon(1-\epsilon)}K_I(R^{x'0}_{TL'}\cos\theta^*_K - R^{y'0}_{TL'} + R^{z'0}_{TL'}\sin\theta^*_K)$
$\mathcal{P}'_y$	0
$\mathcal{P}'_z$	$\sqrt{1-\epsilon^2}K_I(-R^{x'0}_{TT'}\sin\theta^*_K + R^{z'0}_{TT'}\cos\theta^*_K)$

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

How to extract the polarization from data (approach 1):

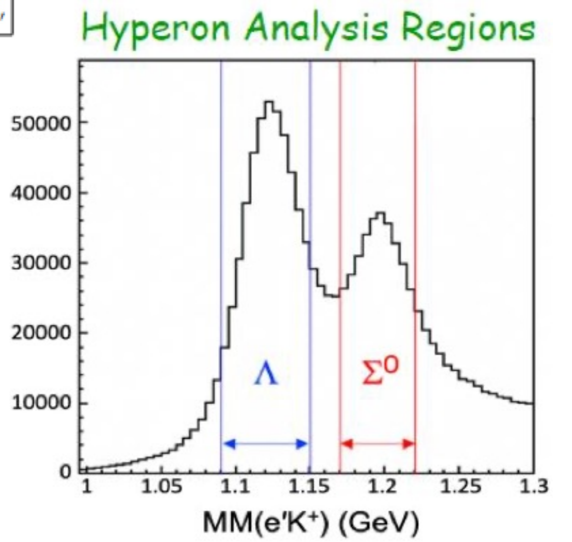
$$\frac{dN}{d\cos\theta_P^{RF}} = N_0\left(1 + \nu_Y \alpha P_Y \cos\theta_p^{RF}\right)$$

Where α_Λ =0.732, P=0.8567 and ϑ_p^{RF} is the angle between the spin quantization axis and the Λ decay proton in the yperon rest frame

$$A_{meas} = \frac{(N_\Lambda^+ + N_\Sigma^+ + N_B^+) - (N_\Lambda^- + N_\Sigma^- + N_B^-)}{N_\Lambda + N_\Sigma + N_B} = \alpha P_b[P'_{meas}]\cos\theta_P^{RF}$$

$$P'_\Lambda = P'_{meas}(1 + F_\Sigma + F_B) - \nu_\Sigma P'_\Sigma F_\Sigma$$

$$F_\Sigma = \frac{N_\Sigma}{N_\Lambda}, \qquad F_B = \frac{N_B}{N_\Lambda}$$



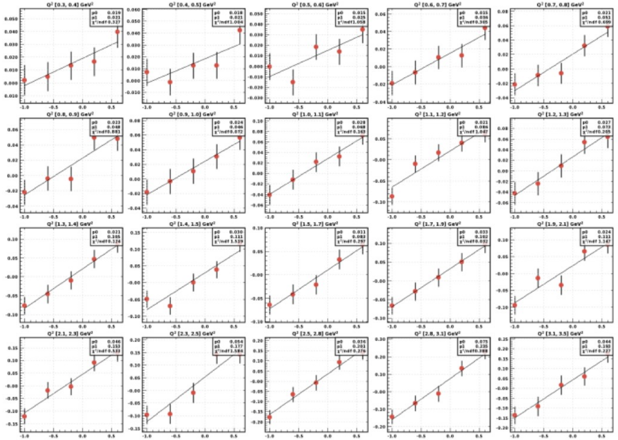
Binning is performed over the three kinematic variables Q^2, W and cos ϑ_K^*

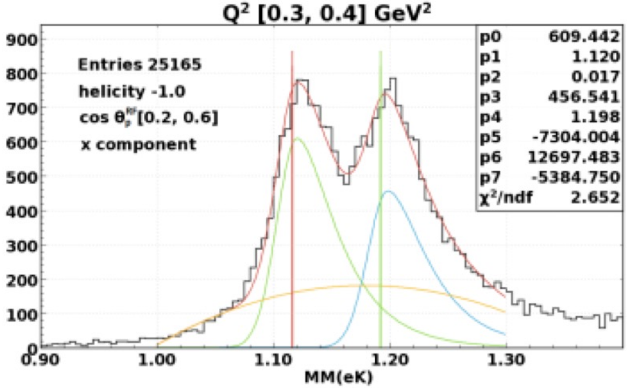
Beam-Recoil Transferred Polarization in K$^+$Y Electroproduction in the Nucleon Resonance Region with CLAS12

The **independent analysis** consists of the direct exploitation of equation

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

The events in each kinematic bin of **Q^2, W and cos ϑ_K^*** were divided into 5 cos ϑ_p^{RF} bins for each beam helicity…

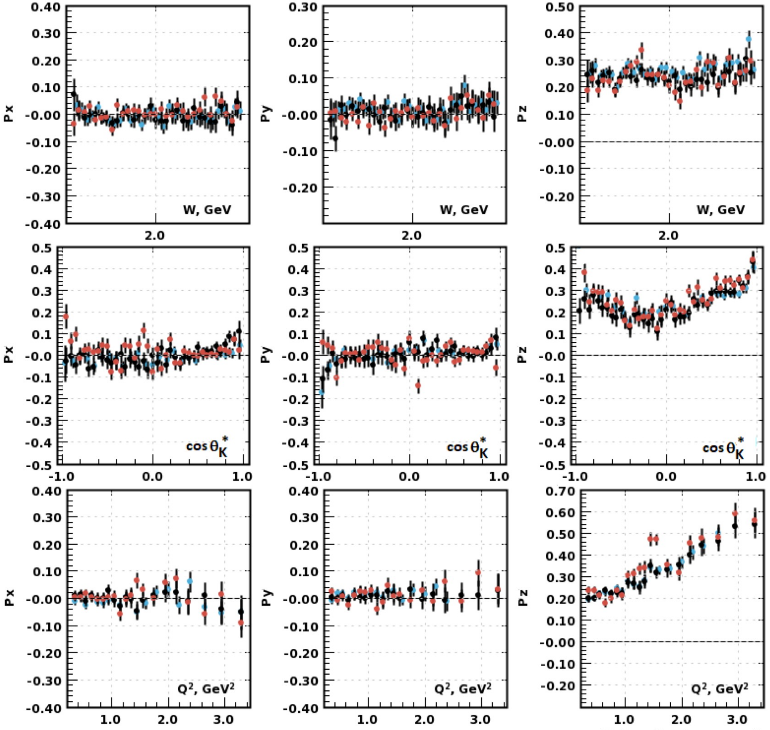




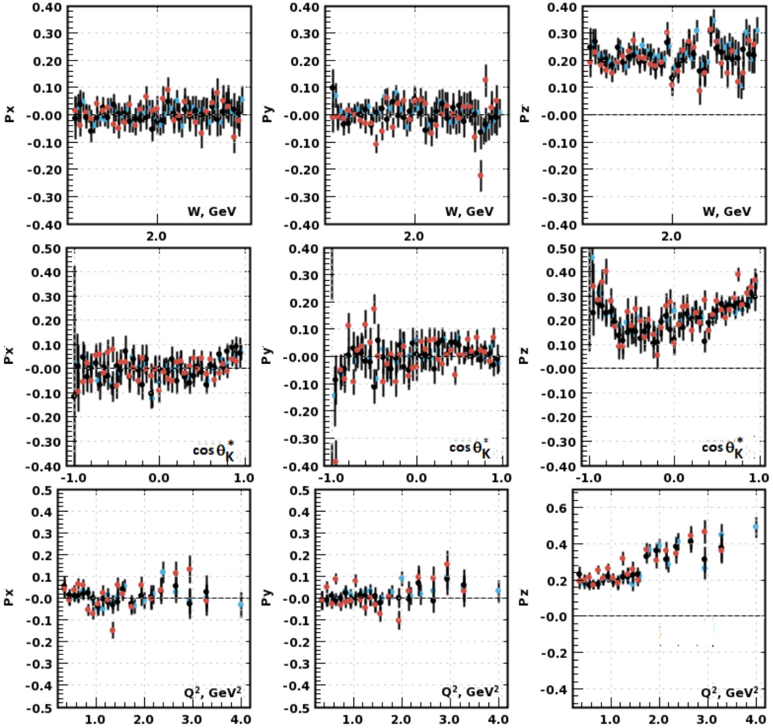
… and the number of Λ events was extracted using a fit of the MM(eK$^+$) spectrum

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

$\mathcal{P}'$



6.5 GeV



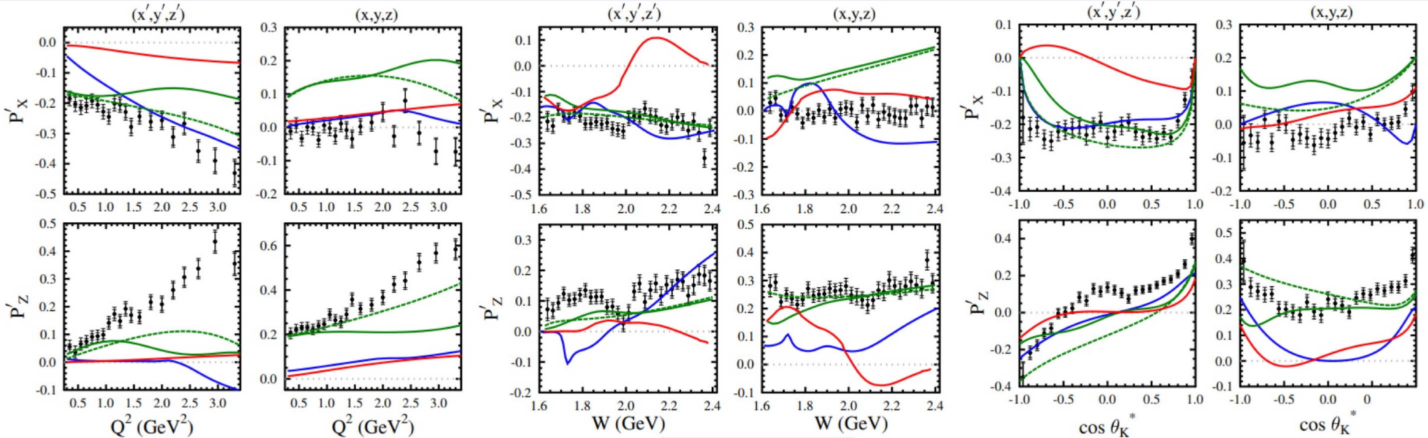
7.5 GeV

Blue dots : Approach 1

Red dots : Approach 2

Black dots : Approach 1 (different fitting procedure)

Beam-Recoil Λ Transferred Polarization



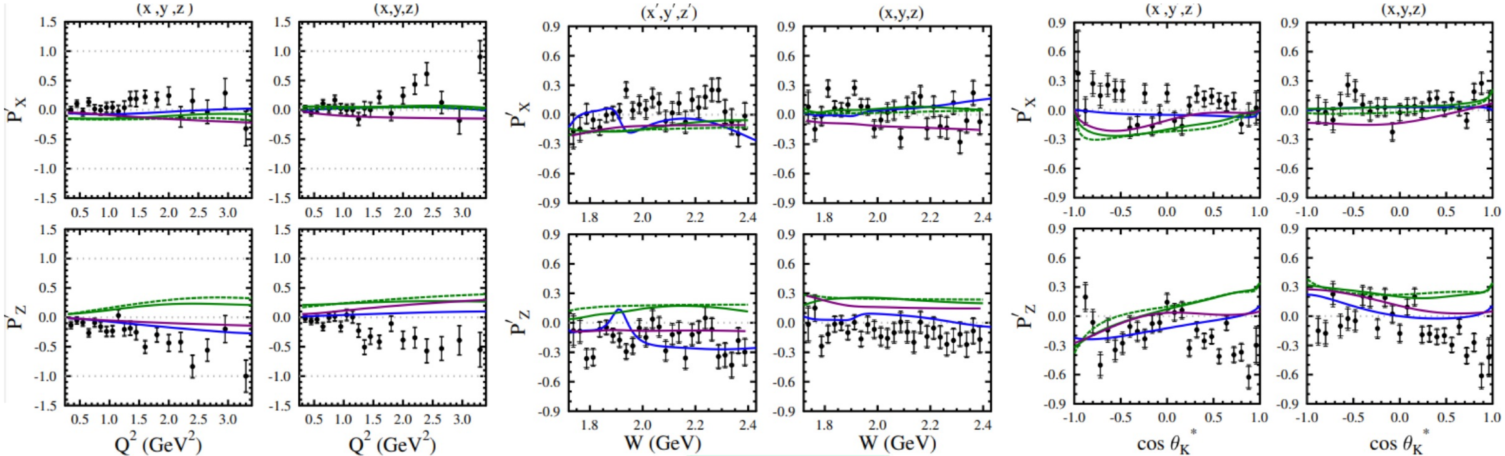
6.535 GeV

Model	Year	Type	Fit Data	N* States
Kaon-MAID	2000	Isobar	None	1/2, 3/2
RPR	2011	Isobar+Regge	CLAS γp	1/2, 3/2, 5/2
BS3	2018	Isobar	CLAS γp & ep	1/2, 3/2, 5/2

D.S. Carman *et al. (CLAS Collaboration)*, "Beam-Recoil Transferred Polarization in K^+Y Electroproduction in the Nucleon Resonance Region with CLAS12", Phys. Rev. C 105, 065201 (2022)

Λ polarization results extend available data from previous experiments (e.g. CLAS e1-6 @ 5.754 GeV)

Beam-Recoil Σ^0 Transferred Polarization



6.535 GeV

Model	Year	Type	Fit Data	N* States
SL	1996	Isobar	none	1/2, 3/2
Kaon-MAID	2000	Isobar	none	1/2, 3/2
RPR	2007	Isobar+Regge	CLAS γp	1/2, 3/2, 5/2

D.S. Carman *et al. (CLAS Collaboration)*, "Beam-Recoil Transferred Polarization in K^+Y Electroproduction in the Nucleon Resonance Region with CLAS12", Phys. Rev. C 105, 065201 (2022)

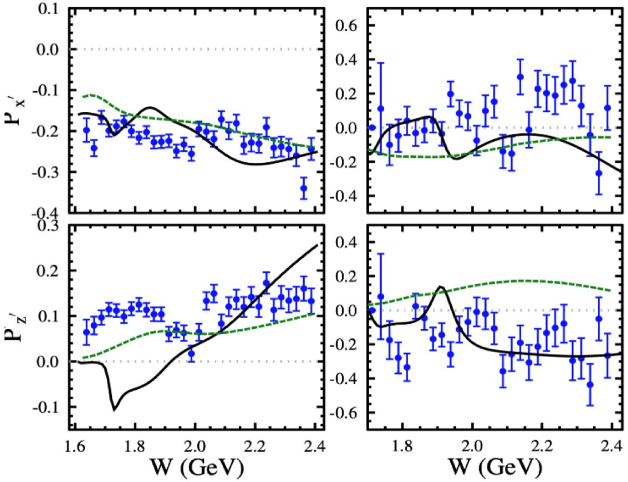
Σ^0 are the first statistically meaningful datasets that can be compared with model predictions.

K^+Y Transferred Polarization CLAS12 vs. CLAS

CLAS12 (RG-K)

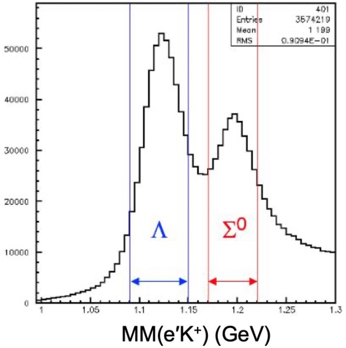
ep → e'$K^+\Lambda$

ep → e'$K^+\Sigma^0$



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

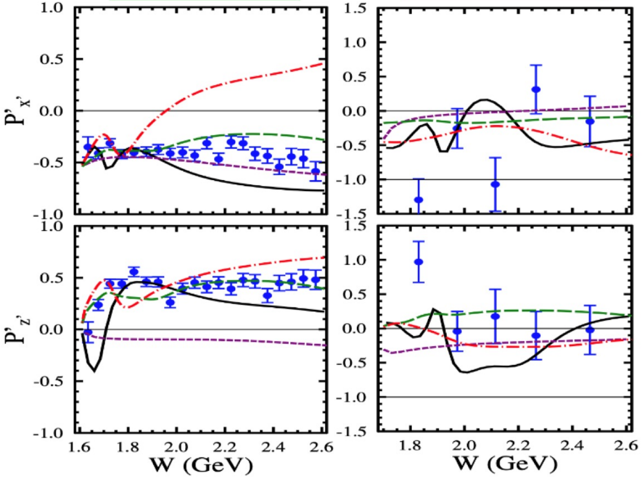
ep → e'K^+Y



CLAS (e1-6)

ep → e'$K^+\Lambda$

ep → e'$K^+\Sigma^0$



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

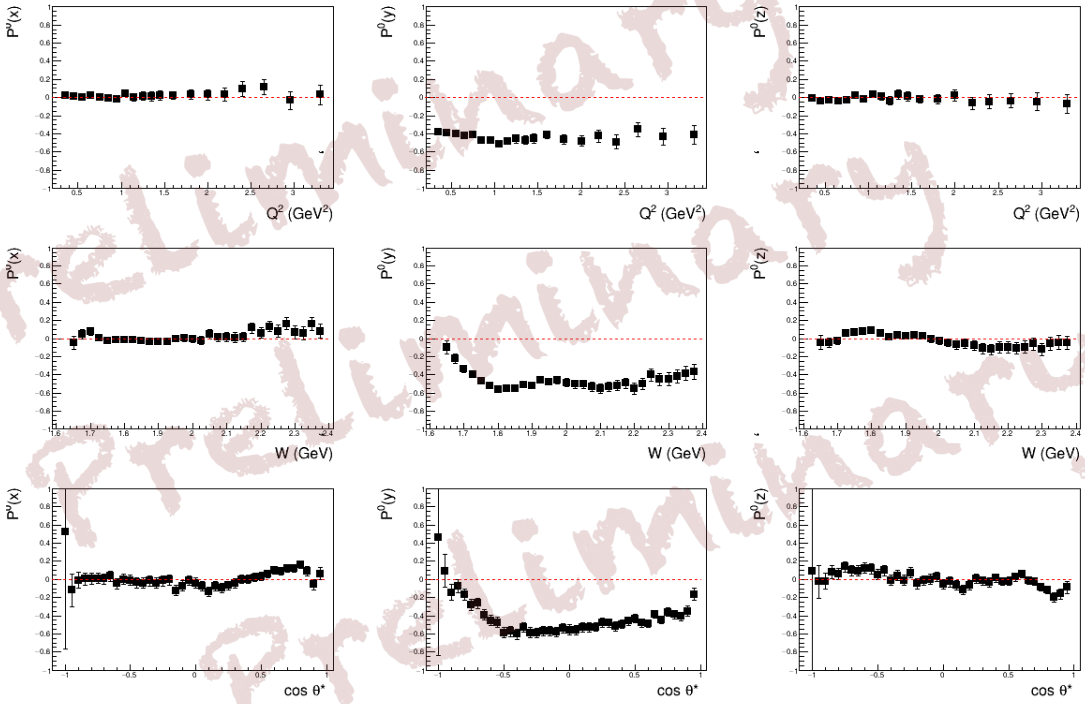
KAON-MAID
RPR

World data set will get extended
by orders of magnitude

Mart/Bennhold
RPR-2
RPR-1
Regge

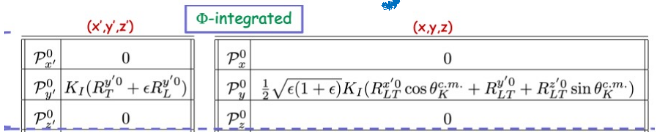
K^+Y Induced Polarization CLAS12

$$\frac{N^+ - N^-}{N^+ + N^-} = \frac{\nu_Y \alpha P_Y}{2}, \nu_Y = 1 \; or \; \nu_Y = -0.256, \alpha = 0.732$$



x and z components still not fully compatible with 0

as expected from theory



Φ-integrated

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

(x,y,z)	
$\mathcal{P}^0_{x}$	0
$\mathcal{P}^0_{y}$	$\frac{1}{2}\sqrt{\epsilon(1+\epsilon)}K_I(R_{LT}^{x'0}\cos\theta_K^{c.m.} + R_{LT}^{y'0} + R_{LT}^{z'0}\sin\theta_K^{c.m.})$
$\mathcal{P}^0_{z}$	0

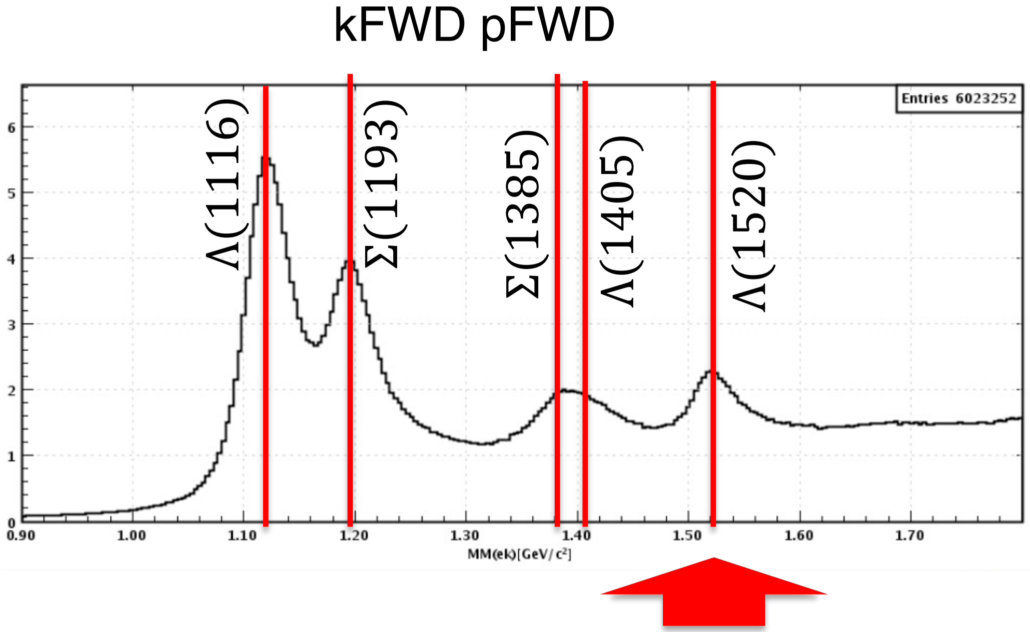
The analysis will be improved once the **Spring 2024** data will be available for analysis

Λ(1520)

Other channels could be exploited as final states for possible new resonances..

$$ep \rightarrow eK^{+}\Lambda(1520) \rightarrow eK^{+}\ K^{-}p$$

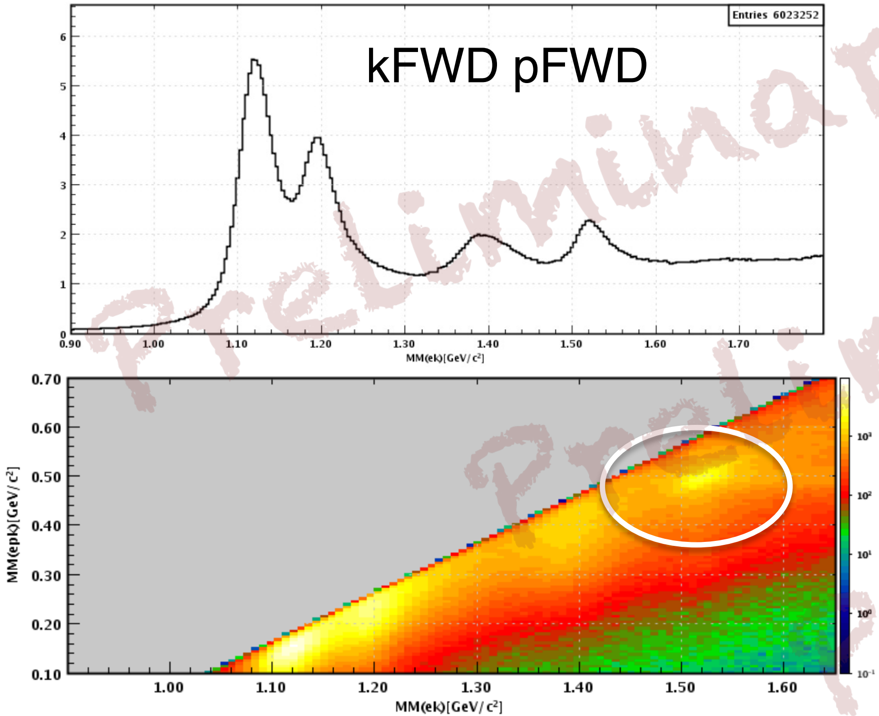
The existence of several nonstrange N* resonances with significant (~5%) branching ratios into the decay channel $K^{+}\Lambda(1520)$ has been predicted

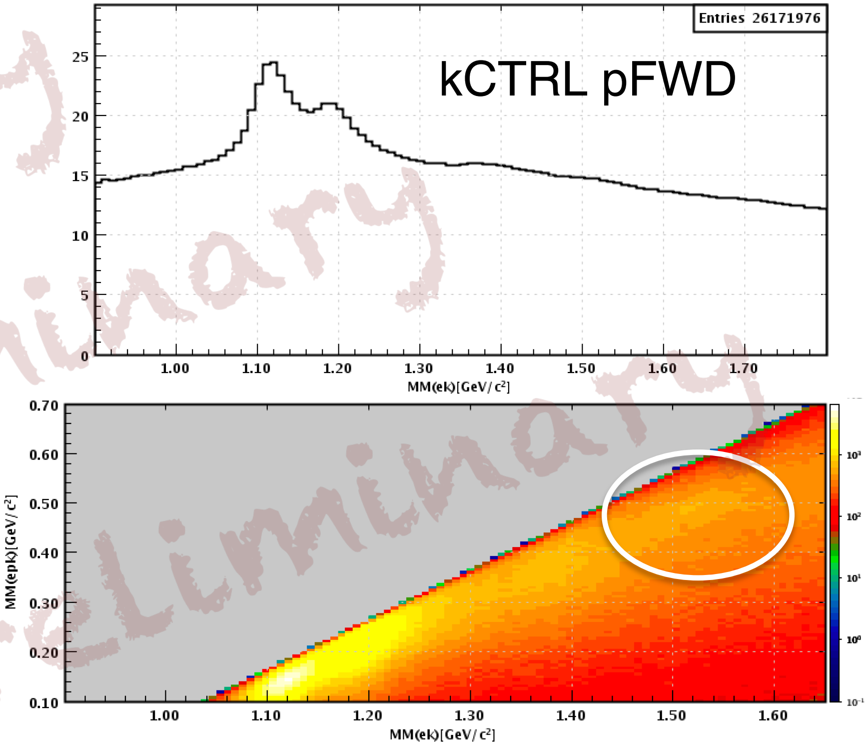


Λ(1520) arises as a separate structure

→ S. Barrow et al., CLAS Coll., Phys.Rev.C64:044601,2001
→ Simon Chapstick and W. Roberts, Phys. Rev. D **58** 074011

Λ(1520)



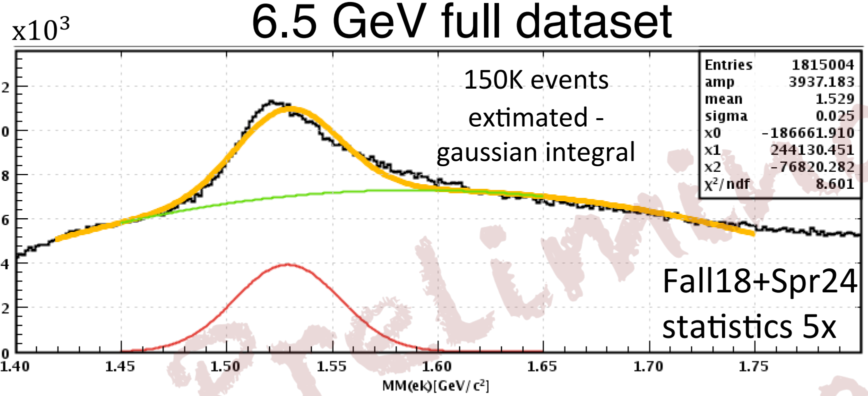


Five structures: Λ(1116), Σ^0(1193), Σ(1385), Λ(1405), Λ(1520)

$$ep \rightarrow eK^+\Lambda(1520) \rightarrow eK^+\,K^-p$$

Λ(1520)

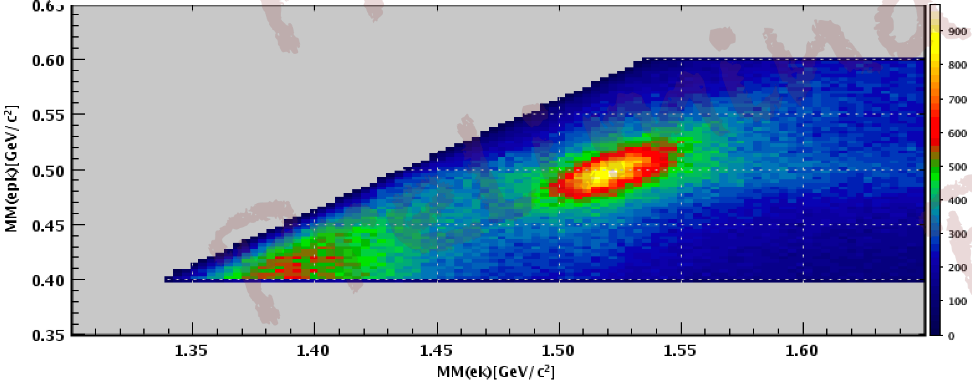
6.5 GeV full dataset



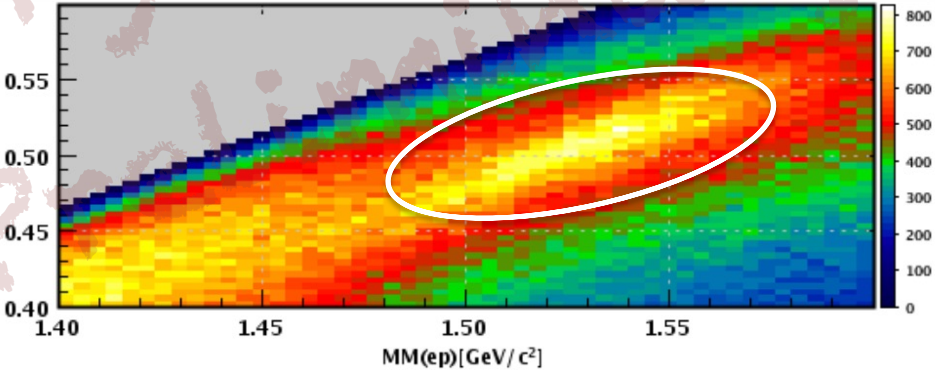
150K events extimated - gaussian integral

Fall18+Spr24 statistics 5x

It is possible to isolate Λ(1520) also in events with an electron detected in the FT



7.5 GeV dataset



$$ep \to eK^+\Lambda(1520) \to eK^+\ K^-p$$

Summary and Outlook

Summarizing:

- 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
  - -More data have been collected in Spring 2024

And in the future…

- Future work with these data is expected to face up he most challenging problems of the Standard Model on the nature of hadron mass, confinement, and the emergence of N* states from quarks and gluons

Stay tuned for further updates…

Summary and Outlook

Summarizing:

- The study of N* states is one of the crucial topics of the CLAS and CLAS12 ams:
  - -CLAS has produced a huge amount of data up to Q2 5 GeV2
  - -CLAS12 was designed to extend these studies for 0.05 Q2 12 Ge
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  - -Only 10% of expected statisti
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  - -Other an cing well
  - -More data

And in the future

- Future work w ce up he most challenging problems of the Standard Model on the nature ement, and the emergence of N* states from quarks and gluons

Stay tuned for further updates…

Thank you for the attention!