Search for Hybrid Baryons with CLAS12 and KY Electroproduction

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Outline

- **Physics motivation**: Study of the nucleon excitation spectrum to understand its ground state.

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**

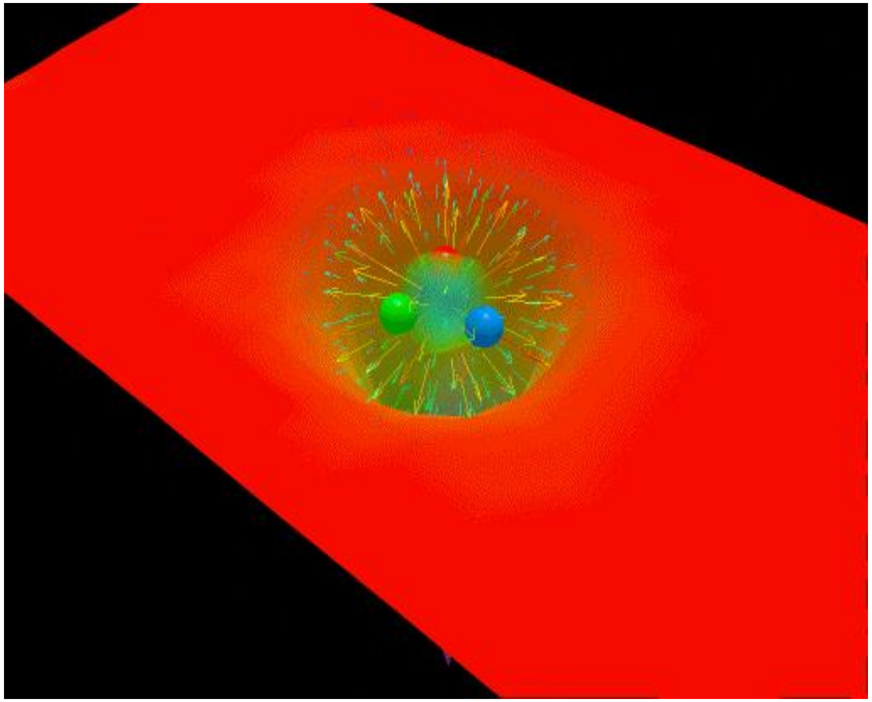
Why N* ?

Baryon Spectroscopy Reveals the Workings of QCD

"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



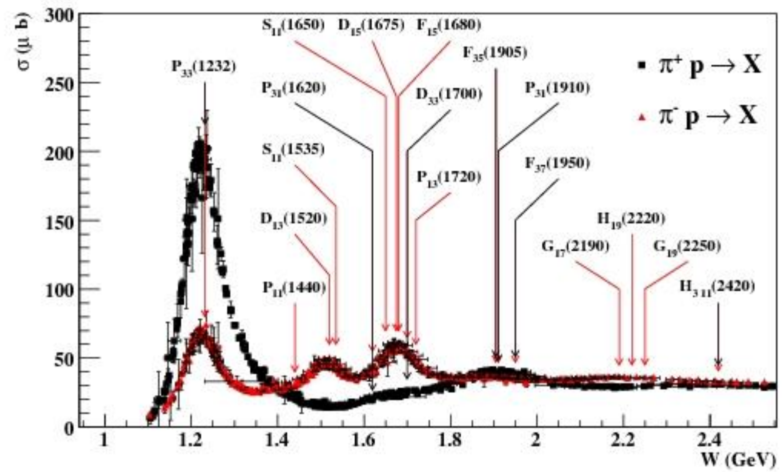
Derek B. Leinweber – University of Adelaide

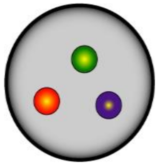
Why N* ?

From the N* Spectrum to QCD

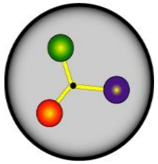
- Understanding the proton’s ground state requires understanding its excitation spectrum.

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

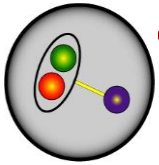




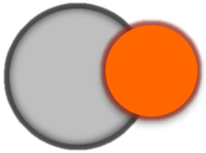
CQM



CQM+flux tubes



Quark–diquark clustering



Baryon-meson system

From the Constituent Quark model to QCD.

Hybrid Baryons in LQCD

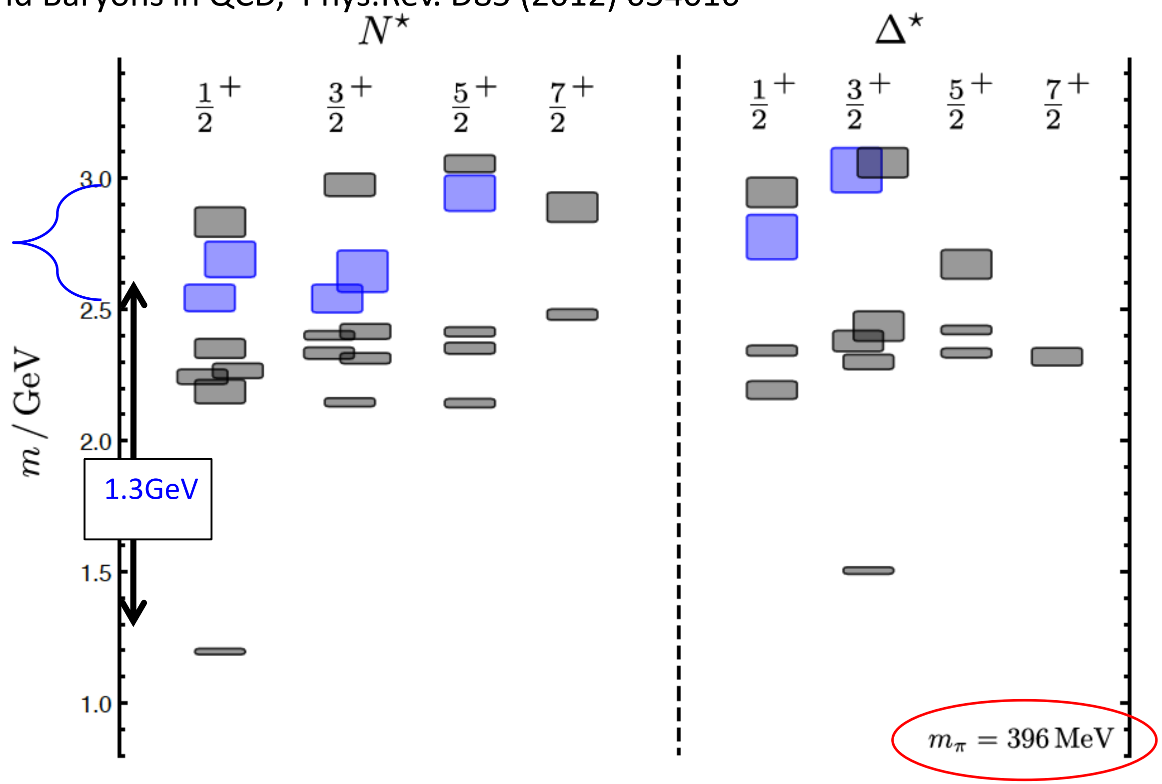
Hybrid baryons emerge as **gluonic excitations of the nucleon** to states where a **constituent gluon** combines with **three quarks**

QCD allows for the existence of Hybrid Baryons.

LQCD predicts several hybrid baryons states.

J. Dudek et al, Hybrid Baryons in QCD, Phys.Rev. D85 (2012) 054016

clustered in masses



Regular states

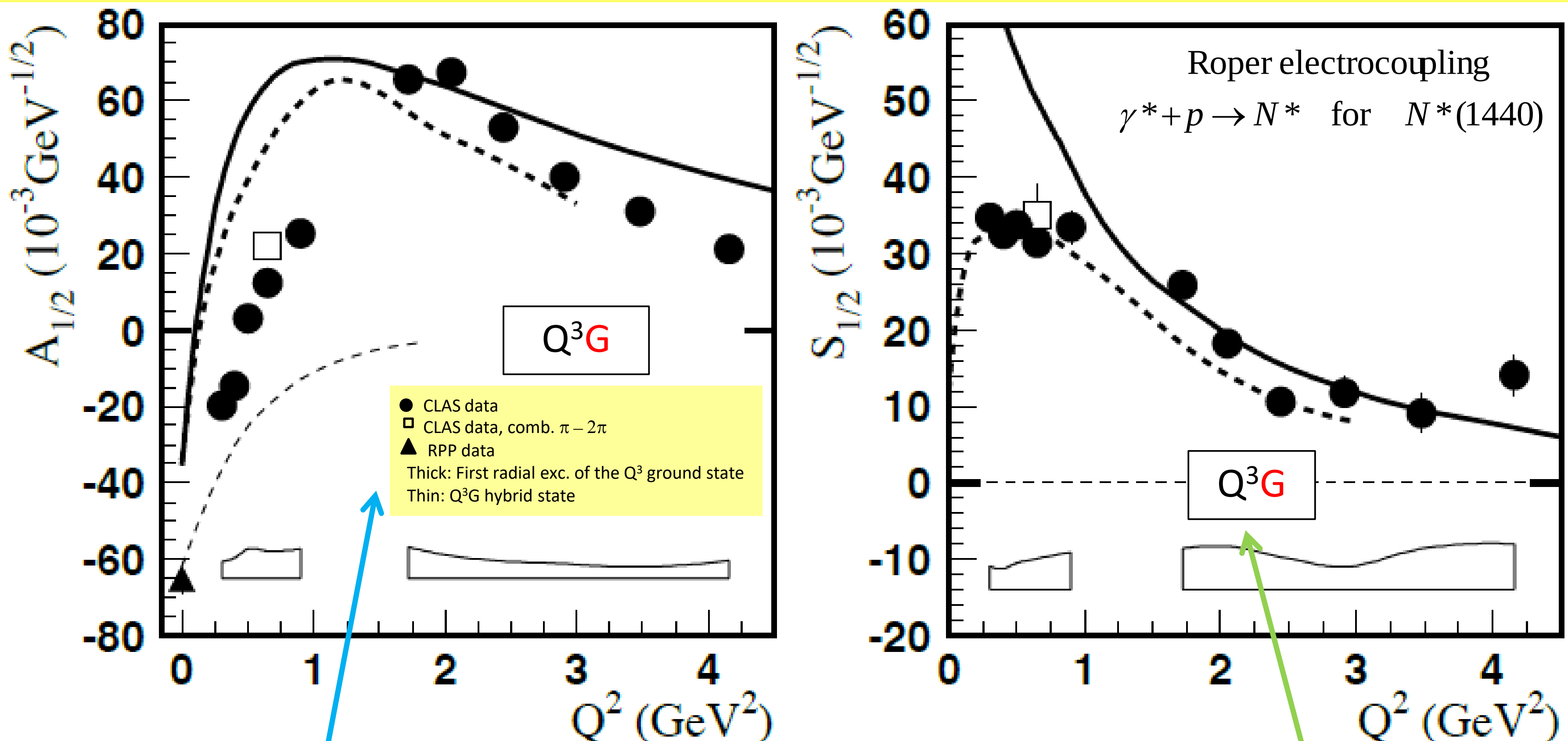
Hybrid states

The nucleon mass is shifted ~300 MeV to higher masses

Differently from the case of hybrid mesons, hybrid baryons are predicted to have **same quantum numbers** of N* resonances

Separating Q^3G from Q^3 states

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



A drop of the transverse helicity amplitudes $A_{1/2}(Q^2)$ 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

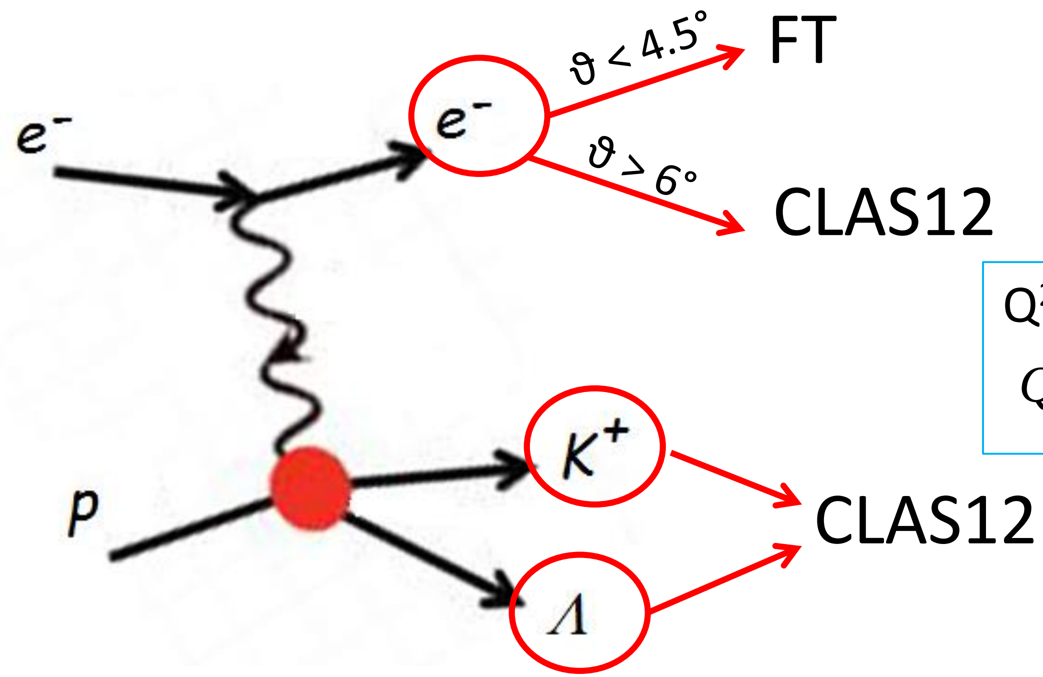
I. G. Aznauryan et al., CLAS Collaboration, PHYSICAL REVIEW C 80, 055203 (2009)

The Experiment

Data from KY and $\pi^+\pi^-$ channels are critical to provide an independent extraction of the electrocoupling amplitudes:

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

FT allows to probe the **crucial Q² 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.



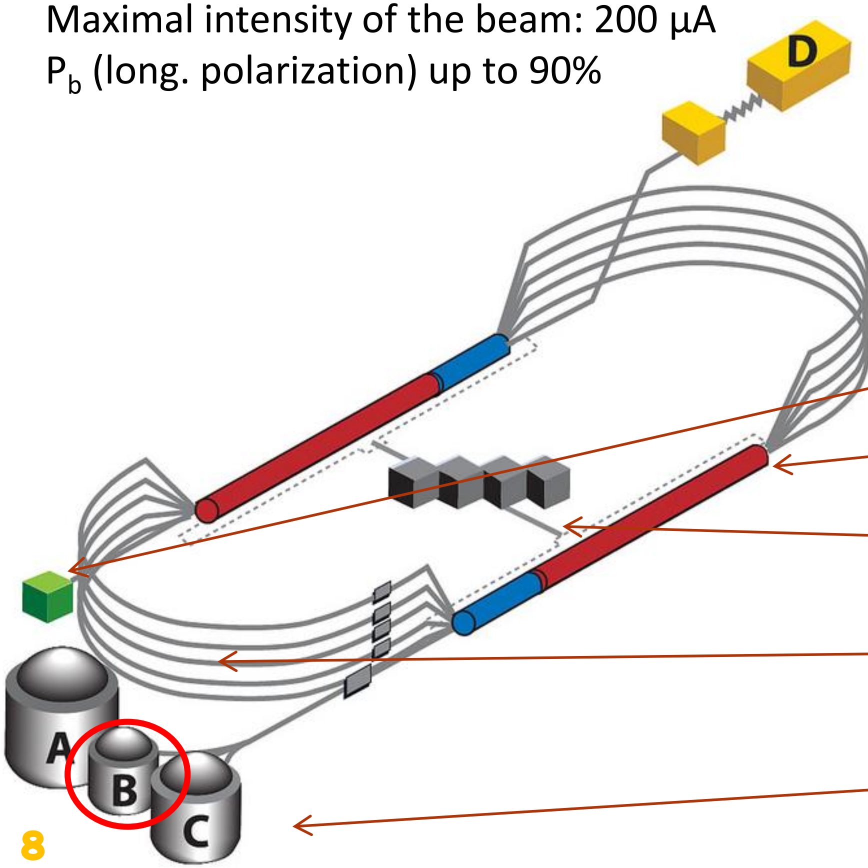
Q² range of interest: 0.05 - 2 GeV²

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

Experimental Setup: CEBAF

Important parameters:

- Injector energy: 45 MeV
- Temporal separation of the bunches 0,7 ns
- 1200 MeV each loop
- Halls A, B, C receive a 11 GeV electron beam, Hall D a 12 GeV electron with a 2 ns time interval
- High work frequency: almost continuum beam
- Maximal intensity of the beam: 200 µA
- P_b (long. polarization) up to 90%



Components:

Injector

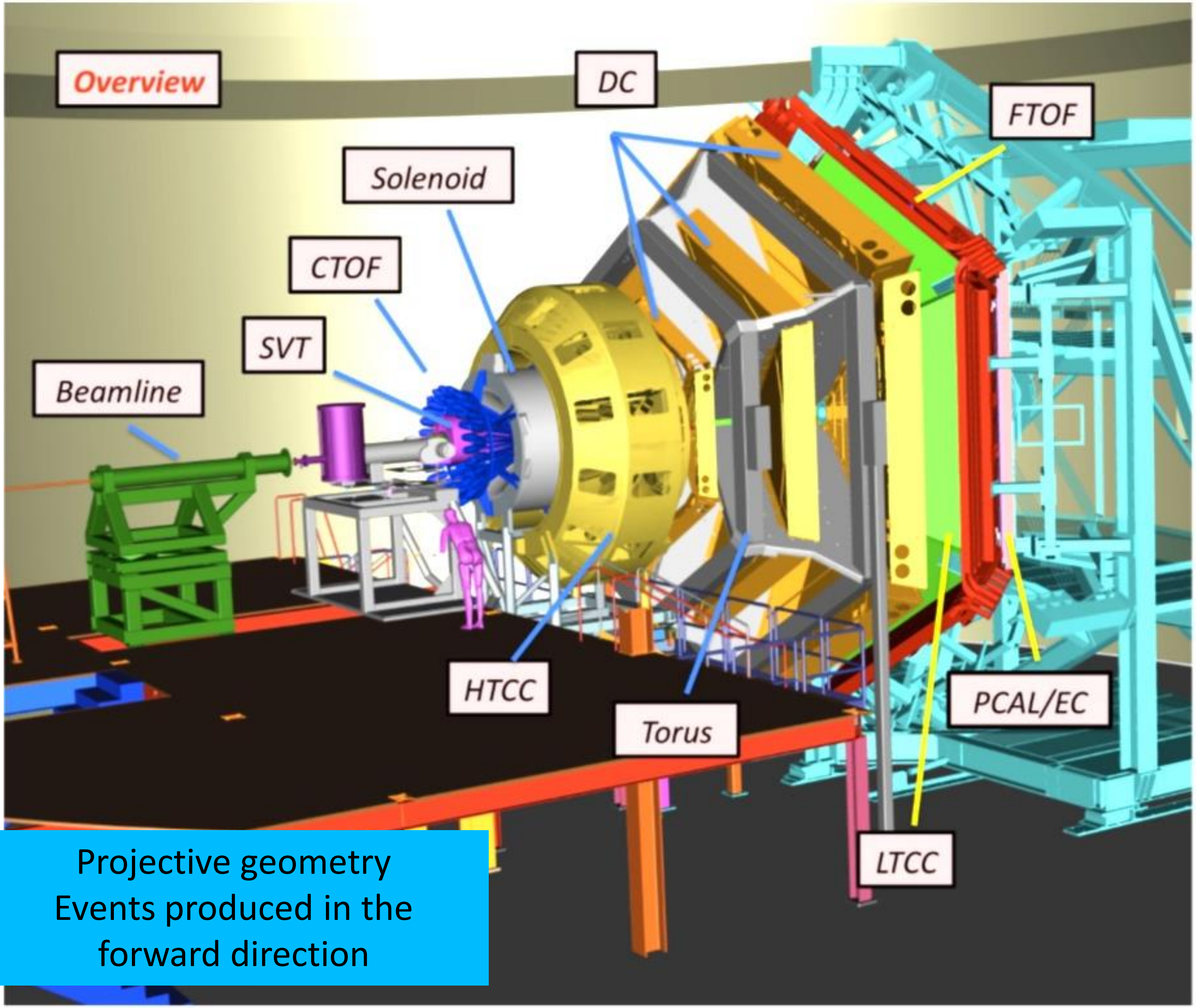
LINAC

Refrigeration plant

Magnets

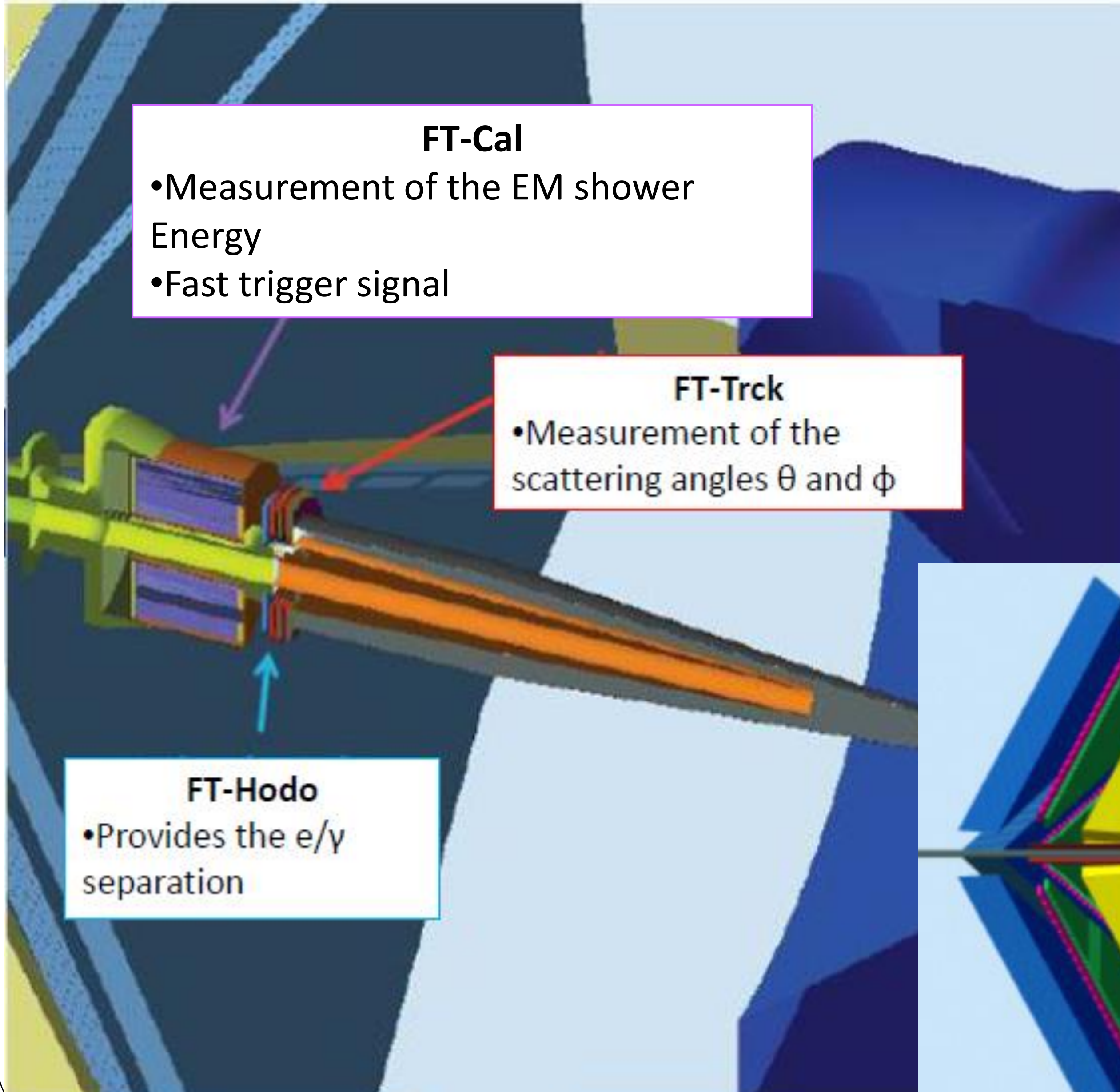
Experimental Halls

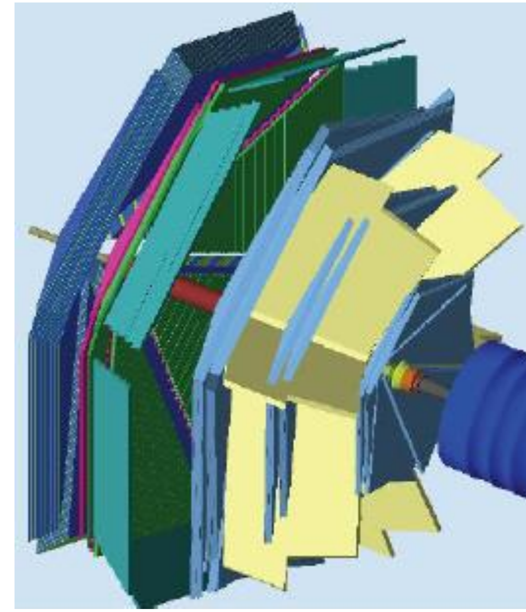
Experimental Setup: CLAS12

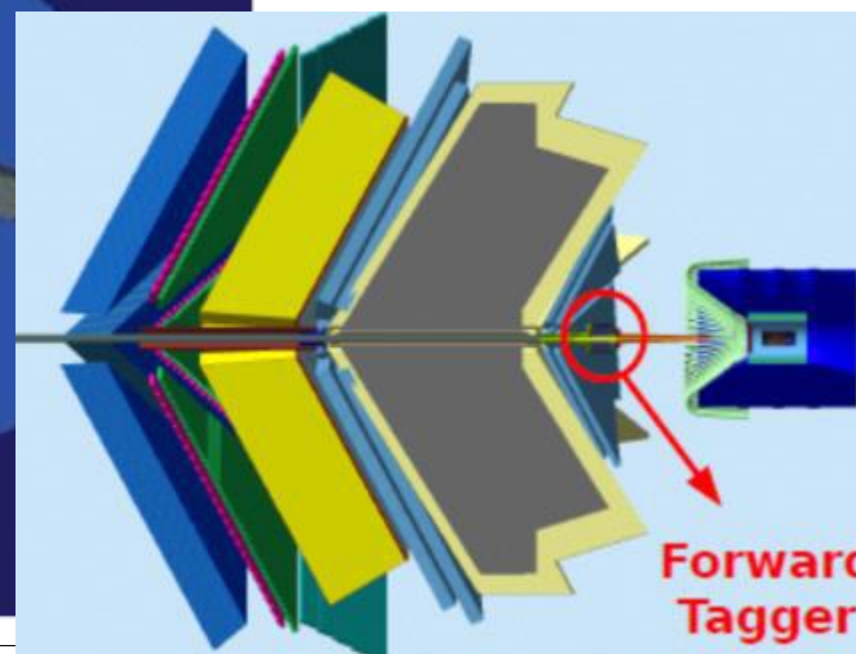


Projective geometry
Events produced in the forward direction

Experimental Setup: Forward Tagger (FT)



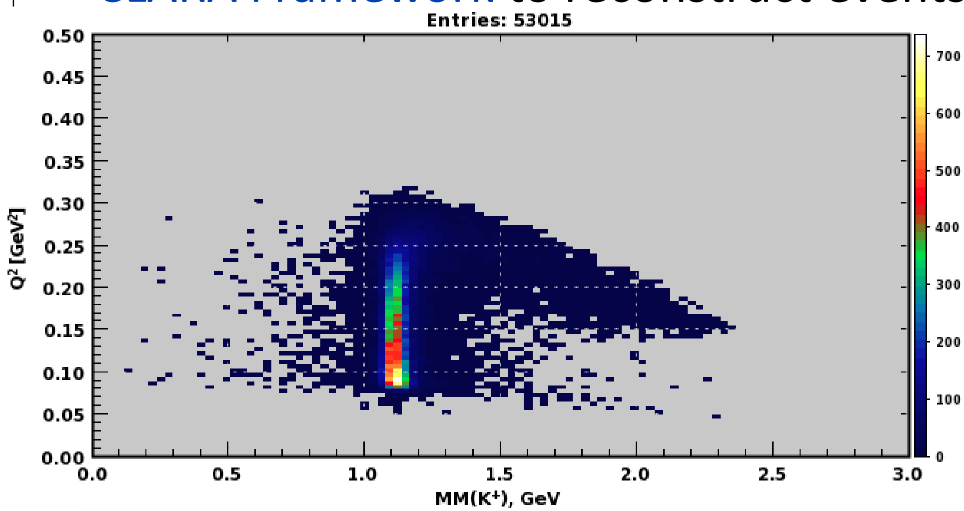


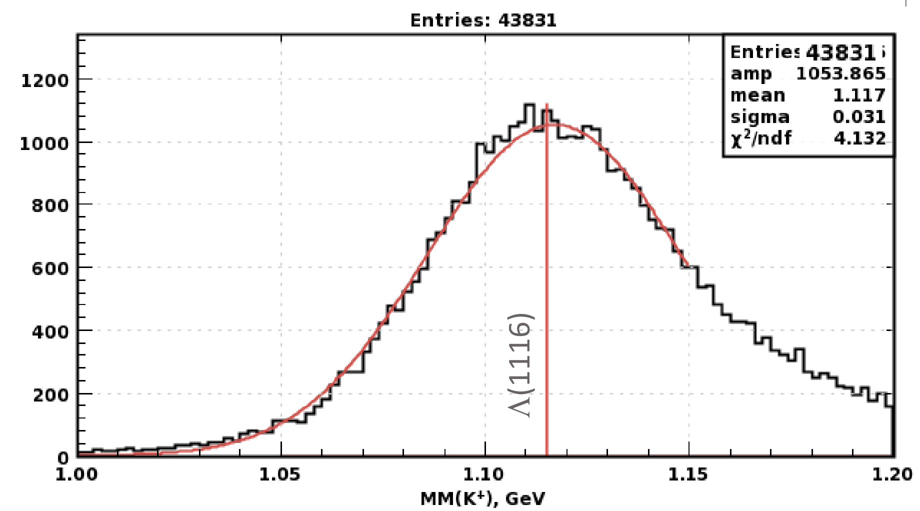


Upgraded Simulation and Reconstruction of $K^{+}\Lambda$ Electroproduction Events in CLAS12 using the RPR-2011 Model, GEMC and CLARA

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

12 GeV electron with CLAS12

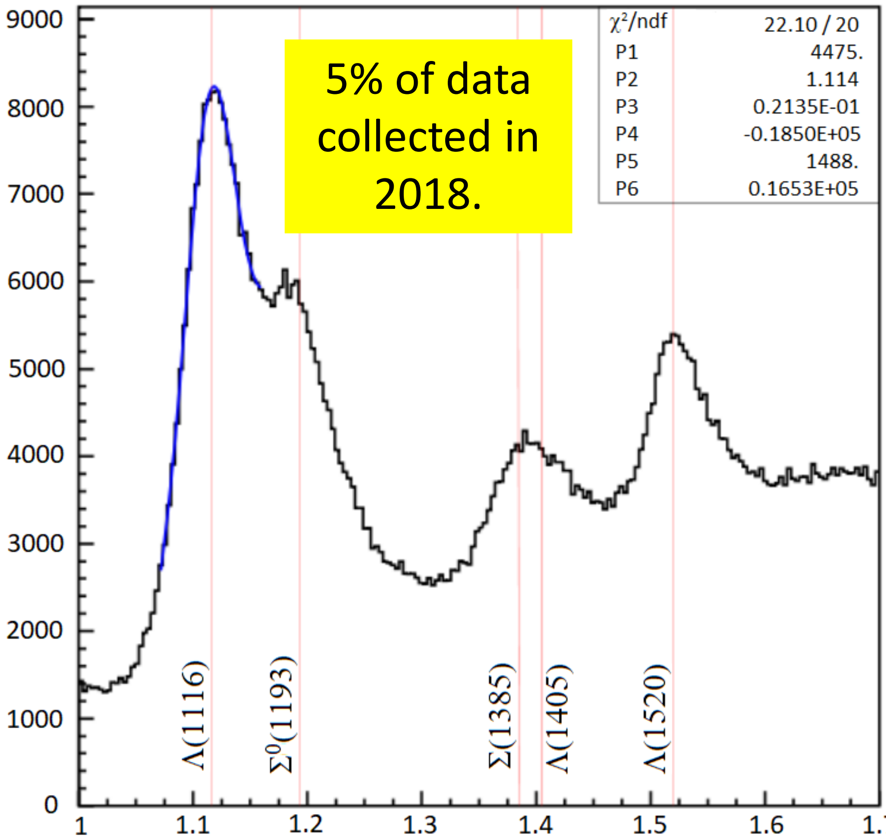
Physics Run started in February 2018.

RGK dedicated Run took data during Fall 2018.

100 PAC days assigned -> 12 PAC days in 2018

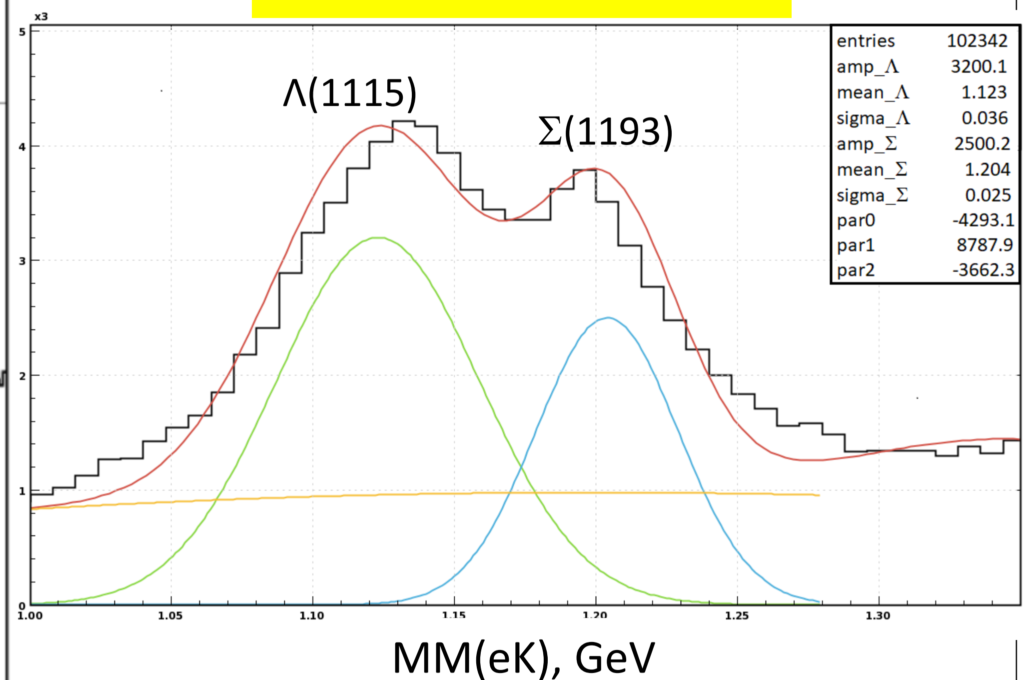
RUN CONDITIONS – FALL 2018	
Torus Current	+100% (3375 A) – negatives outbending
Solenoid	-100%
FT	ON @ 7.5 GeV & OFF @ 6.5 GeV
Beam/Target	Polarized electrons, unpolarized LH_2 target
Luminosity	~ 5 x 10^{34} cm^{-2} s^{-1} @ 7.5 GeV 1x10^{35} cm^{-2} s^{-1} @ 6.5 GeV FULL LUMINOSITY

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



1.6 GeV < W < 3 GeV   MM(eK) Kf   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

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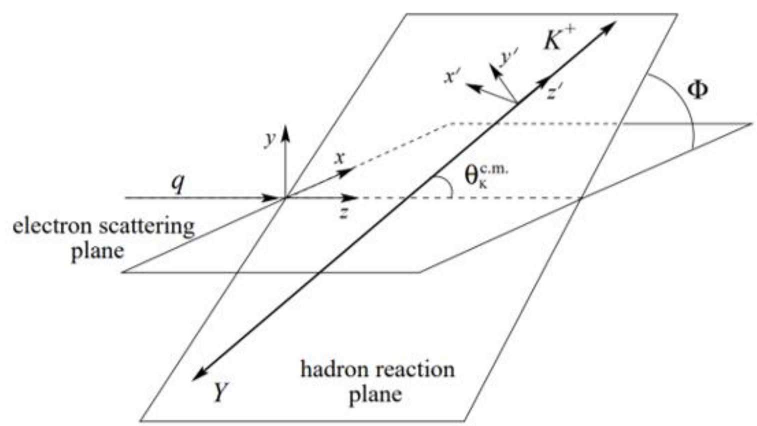
D.S. Carman, A. D'Angelo, L. Lanza, V. Mokeev (CLAS Collaboration)), "Beam-Recoil Transferred Polarization in K^+Y Electroproduction in the Nucleon Resonance Region with CLAS12", Phys. Rev. C 105, 065201 (2022)

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 θ_K $^{c.m.}$

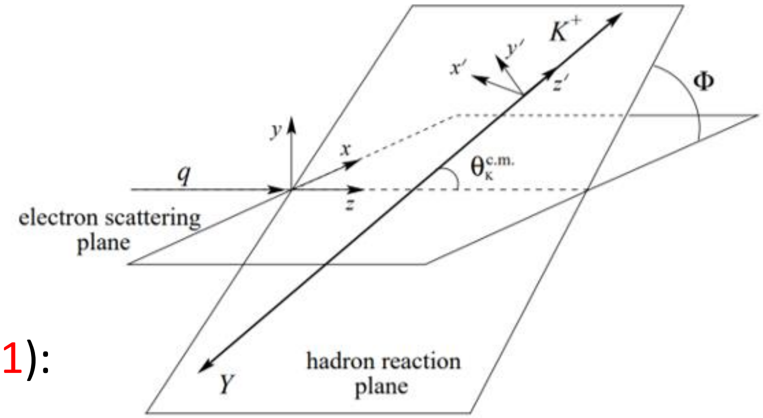


Hyperon Polarization Analysis

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):

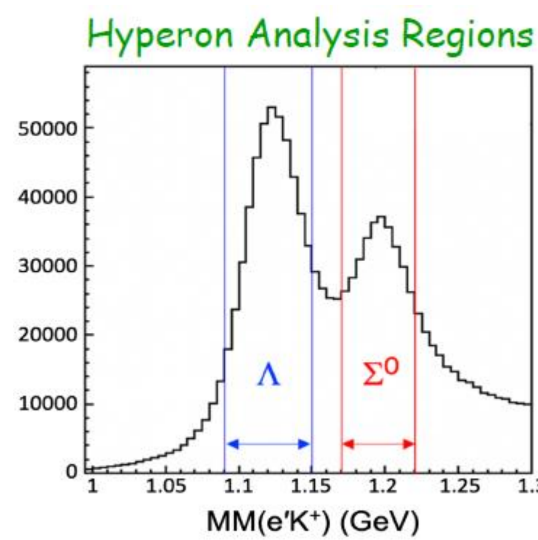
$$\frac{dN}{d\cos\theta_P^{RF}} = N_0\left(1 + \nu_Y \alpha P_Y \cos\theta_p^{RF}\right)$$

Where α_Λ = 0.732, P_b = 0.8567 and $\theta^{RF}{}_p$ is the angle between the spin quantization axis and the Λ decay proton in the Yperon rest frame

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

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

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



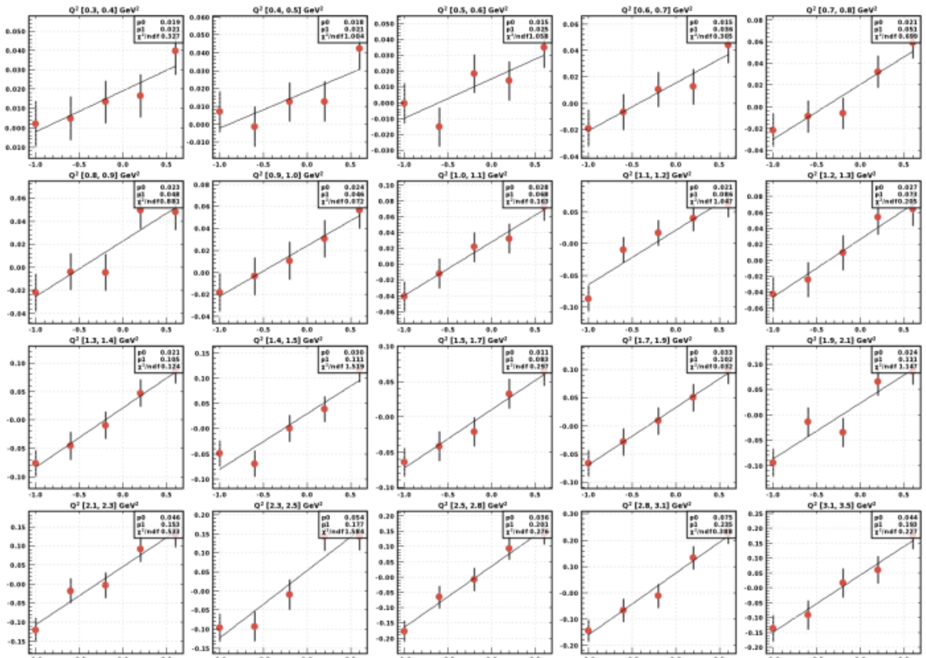
Binning is performed over the three kinematic variables Q^2, W, cos $\theta_K{}^{c.m.}$.

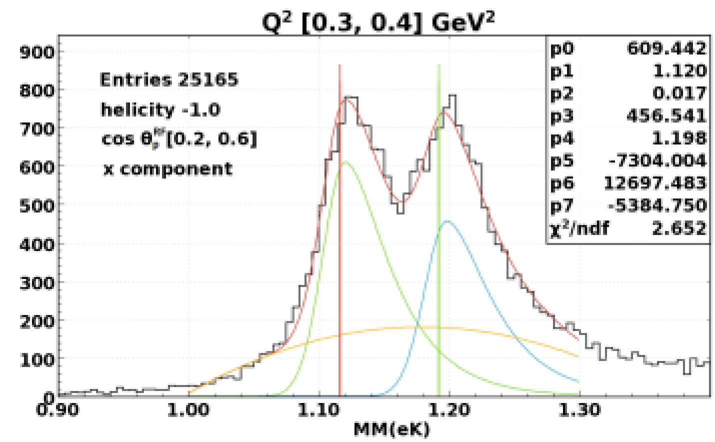
Hyperon Polarization Analysis

An independent analysis (approach 2) consists of the direct exploitation of equation:

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

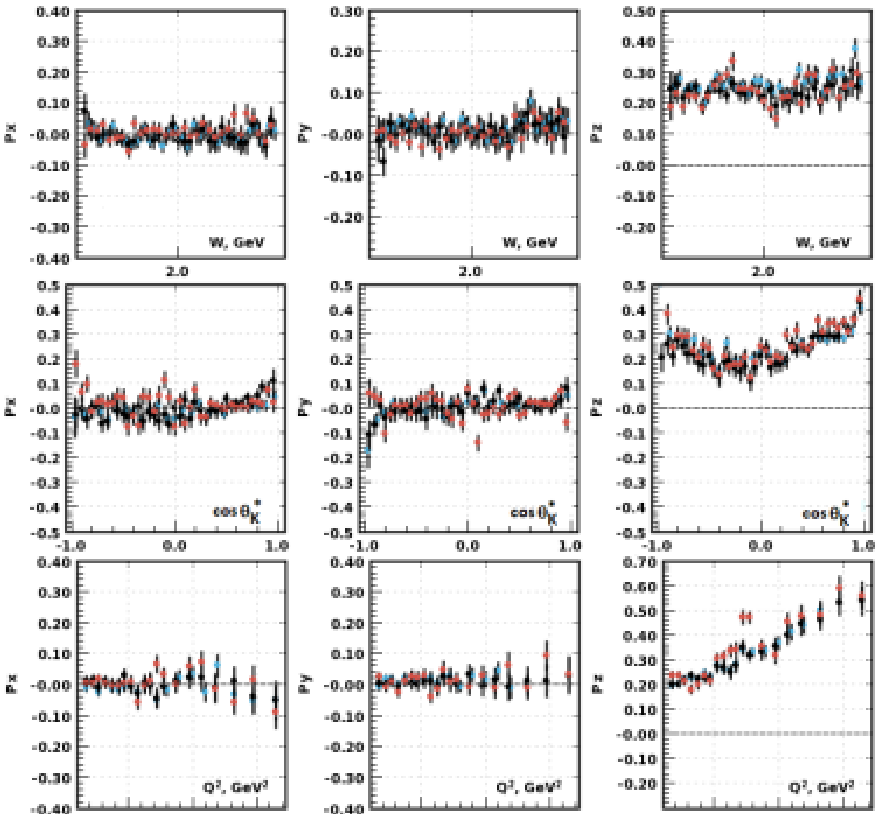
The events in each kinematic bin of Q^2, W, and $\cos\theta^*_K$ were divided into 5 $\cos\theta^{RF}_p$ bins for each beam helicity…



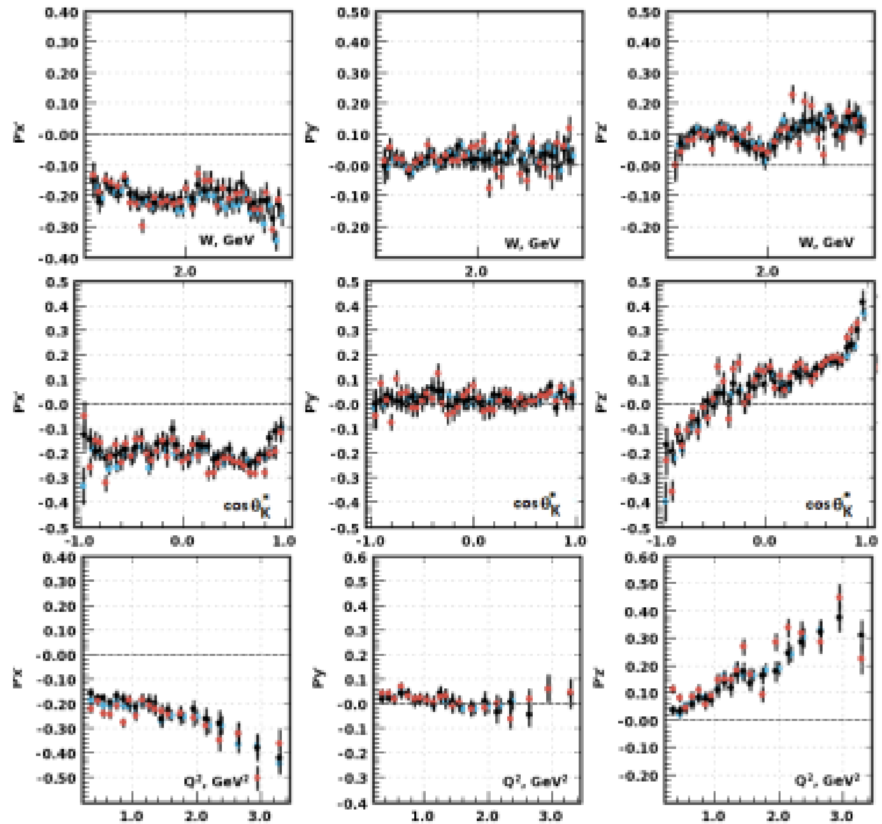


…and the number of Λ events was extracted using a fit of the MM(e K⁺) spectrum

Comparison between Independent Analyses Results



6.535 GeV



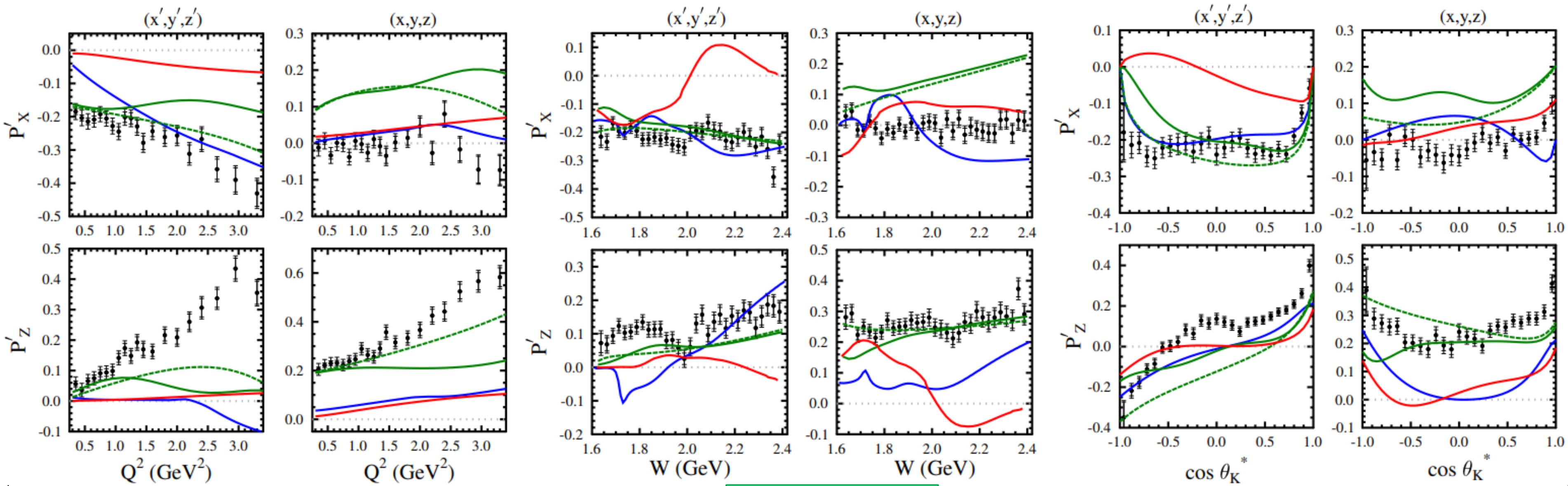
7.546 GeV

Blue dots : Approach 1

Red dots : Approach 2

Black dots : Approach 1 (different fitting procedure)

Beam-Recoil Λ Transferred Polarization



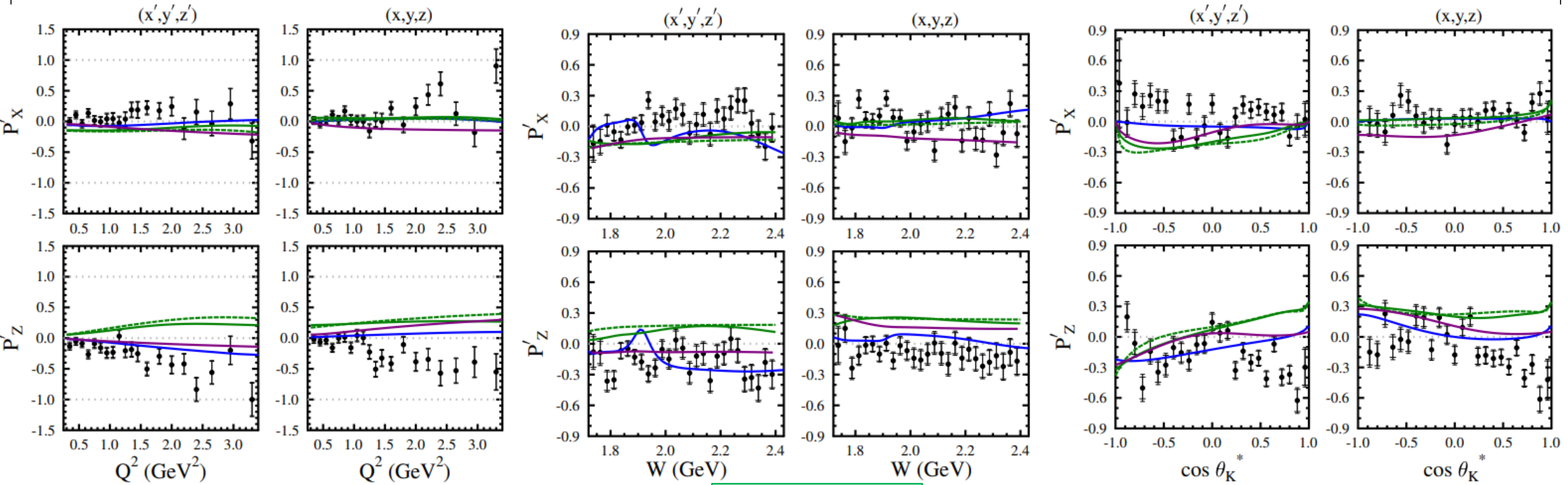
6.535 GeV

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.

Conclusions and Outlook

- The study of N* states is one of the crucial topics of the CLAS and CLAS12 physics programs:
  - CLAS has provided a huge amount of data up to $Q^2 \sim 5$ 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 RG-K Fall 2018 run
  - The RG-K dataset is ~5x larger than the available KY world data in the resonance region
  - Only 10% of expected statistics analized
- 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 and advancing well
  - MORE data are expected in 2023-2024
- Future work with these data is expected to face up the most challenging problems of the Standard Model on the nature of hadron mass, confinement, and the emergence of N* states from quarks and gluons

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Thank you

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