Cross Section Measurements of Ground State Cascade Hyperons in RG-K

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CLAS Collaboration Meeting Fall'26

FIU
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clas
CEBAF Large Acceptance Spectrometer

Cascade Hyperons

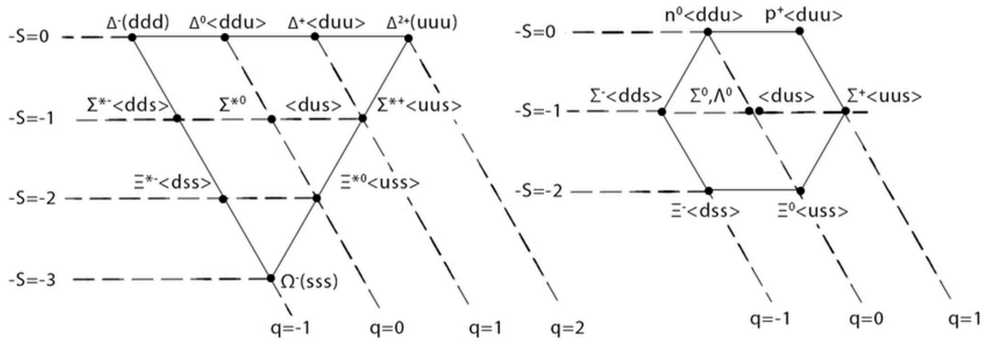
As strangeness increases, our knowledge decreases
We expect the number of Ξ states to be equal to $N^* + \Delta^*$

According to the Particle Data Group in 2026:
27 N^* states; 20 well-established
22 Δ^* states; 12 well-established
11 Ξ^* states; 6 well-established

Most of our current knowledge of multi-strange baryons comes from low-statistics data from 1960-1980 using K^- beams and from hyperon beam experiments used through 1980-1990

While there are many missing Ξ states, we also do not confidently know the production mechanisms of the ground states, Ξ^-_{1320} and Ξ^-_{1530}

The goal of this analysis is to calculate the electroproduction cross section of the ground state cascades, Ξ^-_{1320} and Ξ^-_{1530} with an emphasis on studying the production mechanism

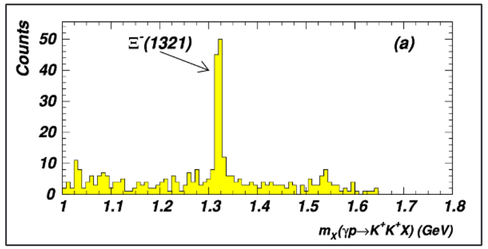


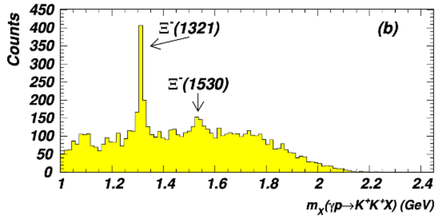
- Properties:
  - Baryon number: B = +1
  - Strangeness: S = -2
  - Isospin: I = 1/2
  - Electric charge: Q = 0,-1
- SU(3) classification:
  - Octet: ground state Ξ(1320)
  - Decuplet: ground state Ξ(1530)

Studying Cascades with Electromagnetic Probes

CLAS6 & GlueX Cascade Studies

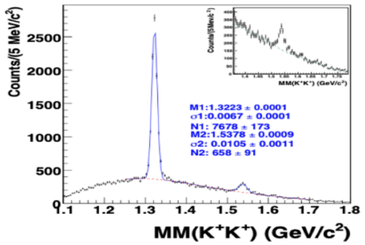
2005: CLAS g6 provided the first-ever exclusive measurement of Ξ^- in $\gamma p \rightarrow K^+K^+\Xi^-$

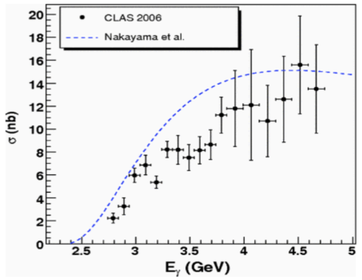




J.W.Price et al. Exclusive photoproduction of the cascade hyperons

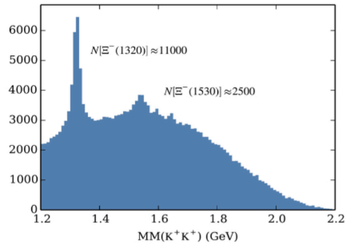
2007: g11 data, provided cross section results for Ξ^- (1320) and Ξ^-(1530)

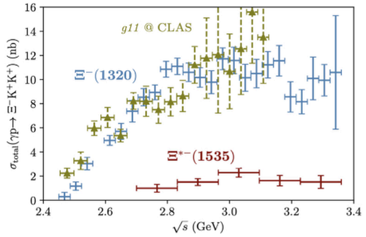




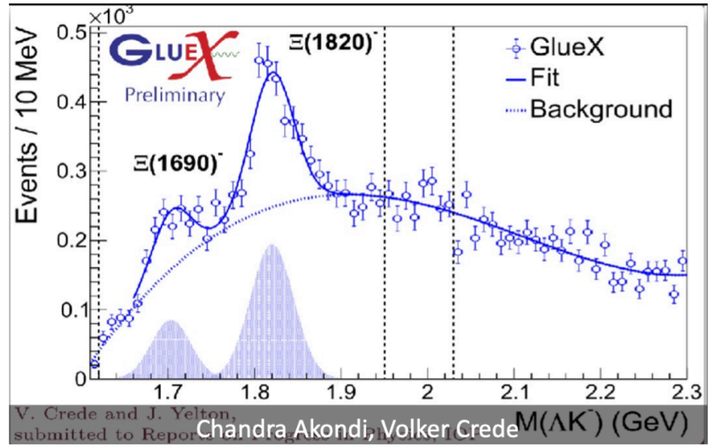
L.Guo et al. Cascade production in the reaction $\gamma p \rightarrow K^+K^+(X)$ and $\gamma p \rightarrow K^+K^+\pi^-(X)$

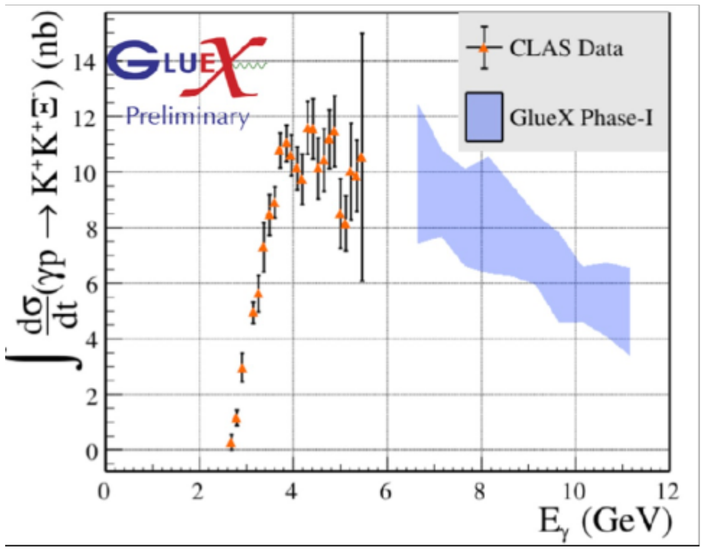
2018: g12 expanded the kinematic region of study (W=3.3GeV) as well as increased statistics





J.T. Goetz et al. Ξ^* Photoproduction from Threshold to W=3.3 GeV





CLAS g6 provided first measurement of cascades using non-strange beams

CLAS g11 provided the first-ever photoproduction cross section of the ground state cascades

With higher photon energy, GlueX can access higher-mass Ξ states

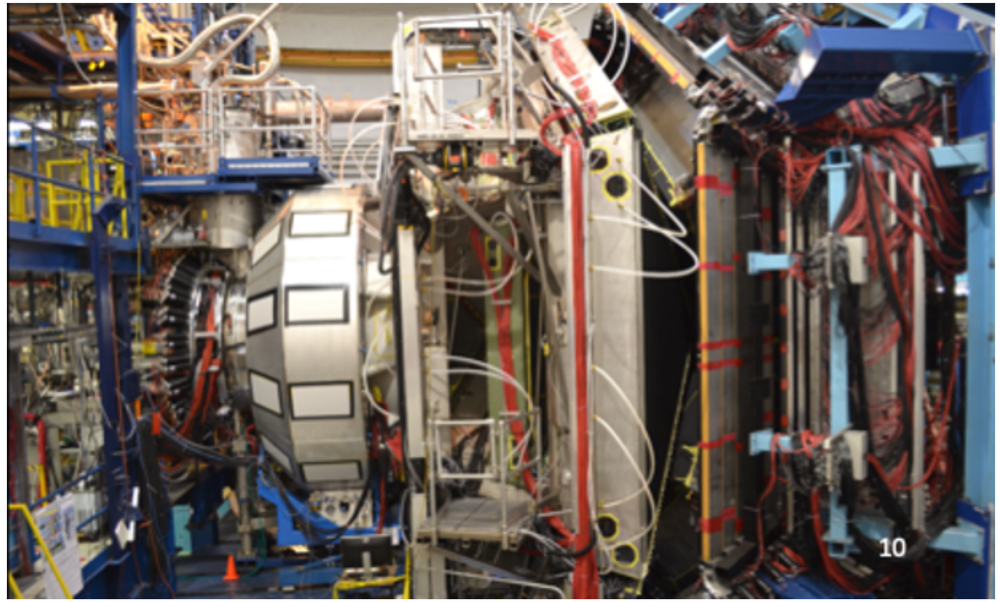
Cascade Electroproduction

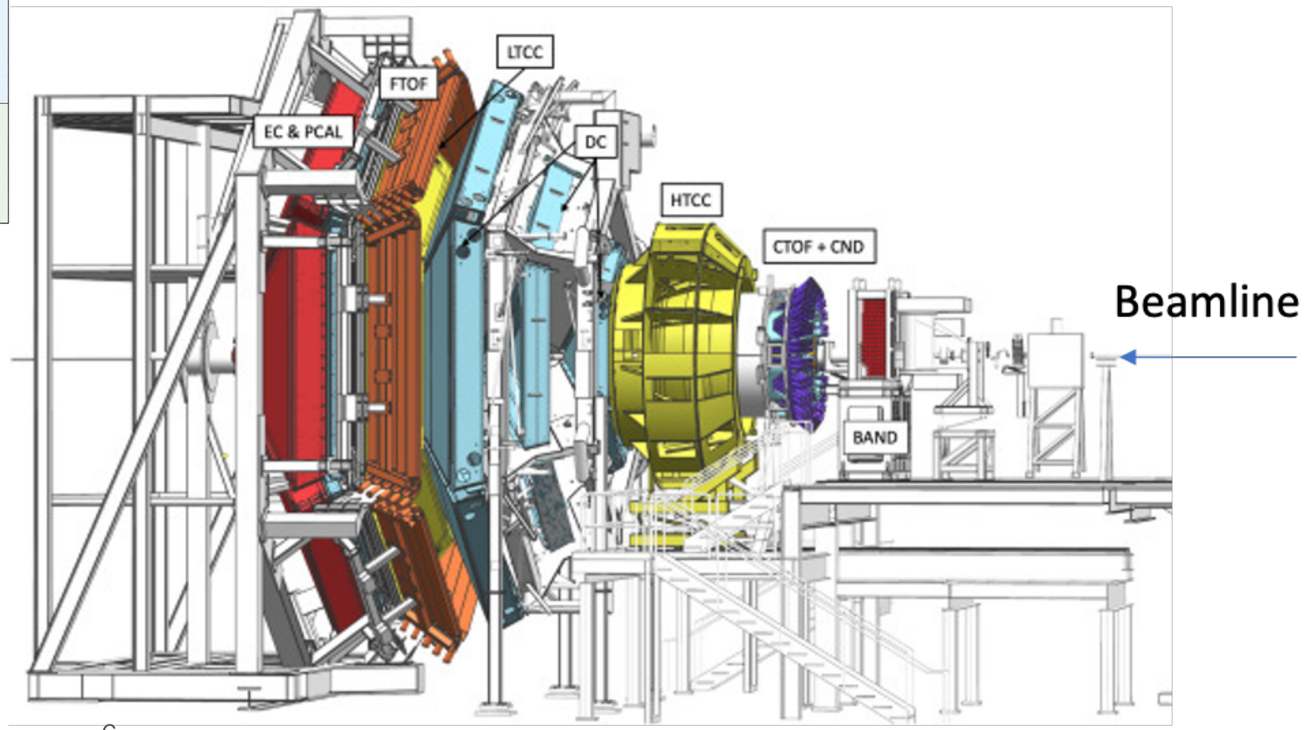
CLAS12

Hall B Jefferson Lab

CEBAF Large Acceptance Spectrometer at 12 GeV

CLAS12 Region	Approx. Angular Coverage	Brief Description
Forward Tagger (FT)	~ 2.5° – 4.5°	Detects electrons scattered at very small angles, giving access to very low Q^2. Uses a calorimeter, tracker, and hodoscope for electron/photon reconstruction.
Forward Detector (FD)	~ 5° – 35°	Main CLAS12 detection region. Uses the toroidal magnetic field, drift chambers, time-of-flight detectors, Cherenkov counters, and calorimeters for tracking and particle identification.
Central Detector (CD)	~ 35° – 125°	Surrounds the target and detects particles produced at larger angles. Uses the solenoidal magnetic field with central tracking and time-of-flight systems.



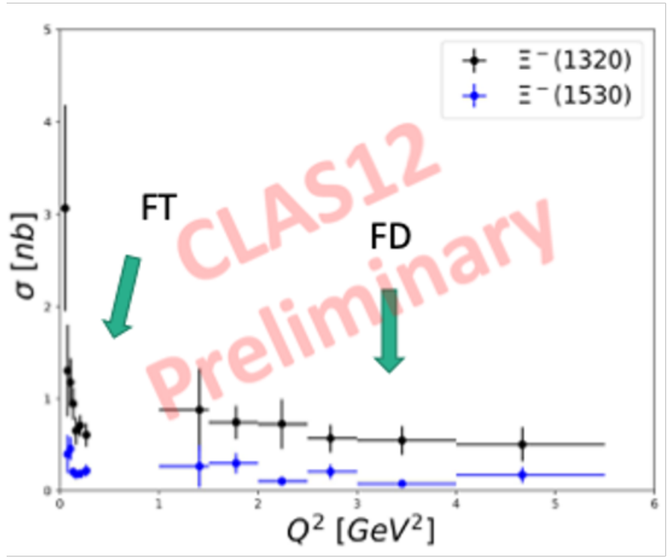


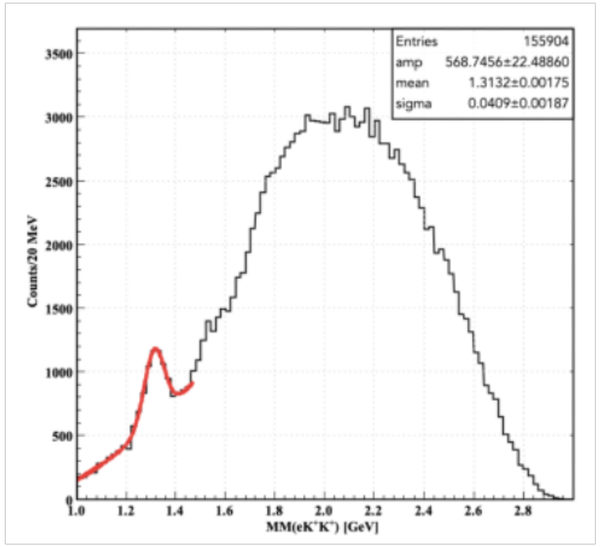
Experimental Conditions

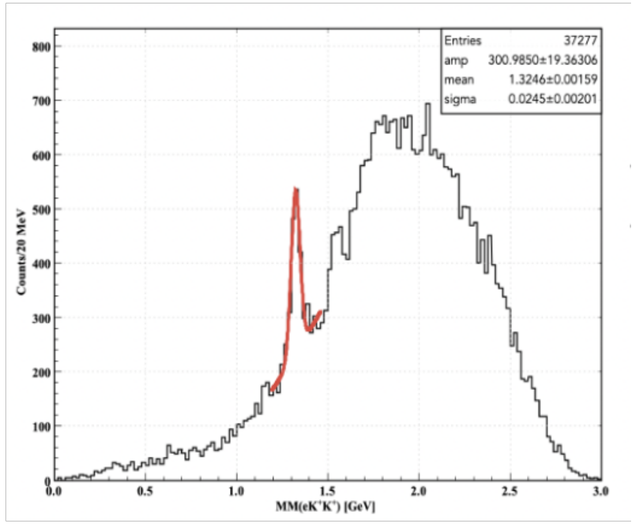
Data set: CLAS12 Run Group K (Fall 2018)
Beam: 6.5 and 7.5 GeV longitudinally polarized electron beam
Target: Unpolarized 5 cm LH_2
Total Charge:
- 6.5 GeV: 18.32 mC
- 7.5 GeV: 10.77 mC

Luminosity: $10^{35}\ cm^{-2}s^{-1}$

Prior CLAS12 Ξ^- Cross Sections







- Jose Carvajal, FIU Ph.D thesis, "First Time Measurement of Ground State Ξ^- Hyperon Cross Section in Electroproduction"
- Data taken at 10.2 GeV (RG-A) in the very forward, low Q^2 region as well as in the "high" Q^2 region
- Cross sections on the scale of nano-barns

Motivation for Studying Cascades in Electroproduction

Physics Goals:

Q^2 Evolution

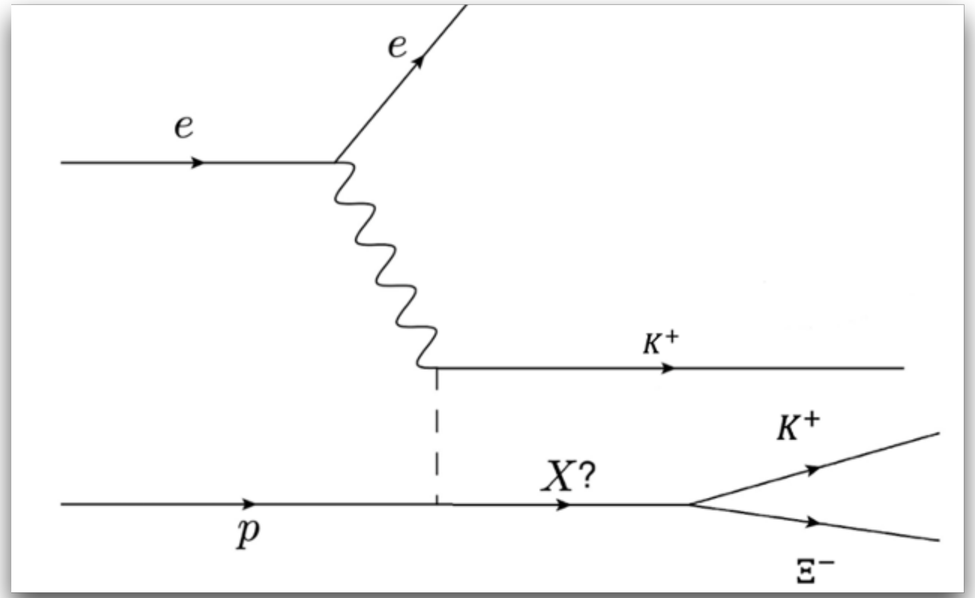
Study how the ground state cascade cross sections evolve with increasing photon virtuality

Production Mechanism

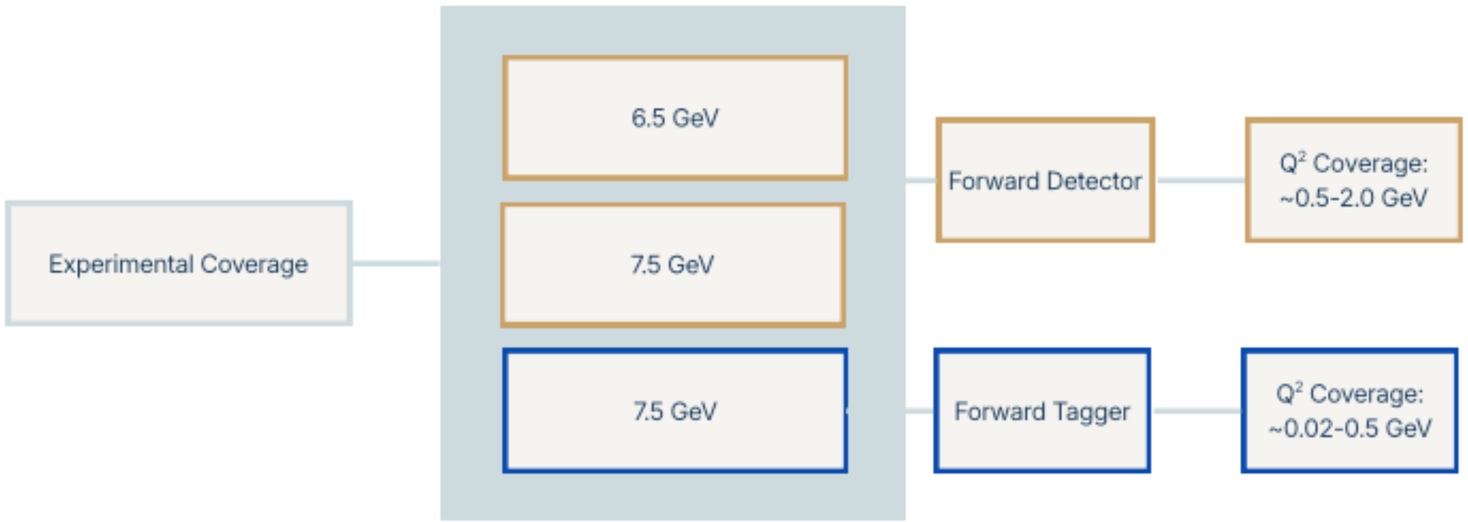
Since the discovery of Ξ hyperons over 70 years ago, we still don't understand their production mechanism. This study aims to give insight into the production mechanism of the two ground states Ξ^-_{1320} and Ξ^-_{1530}

Reaction Channel:

$ep \rightarrow e'K^+K^+(\Xi^-)$

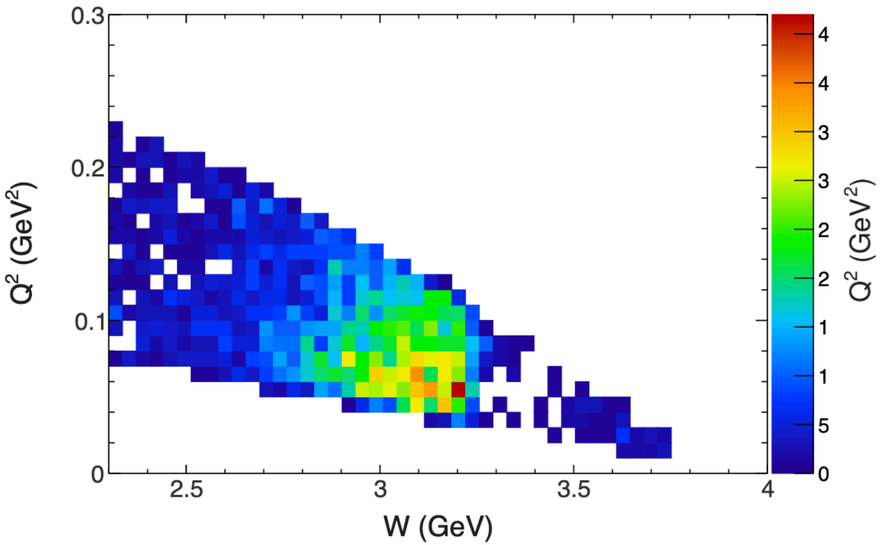


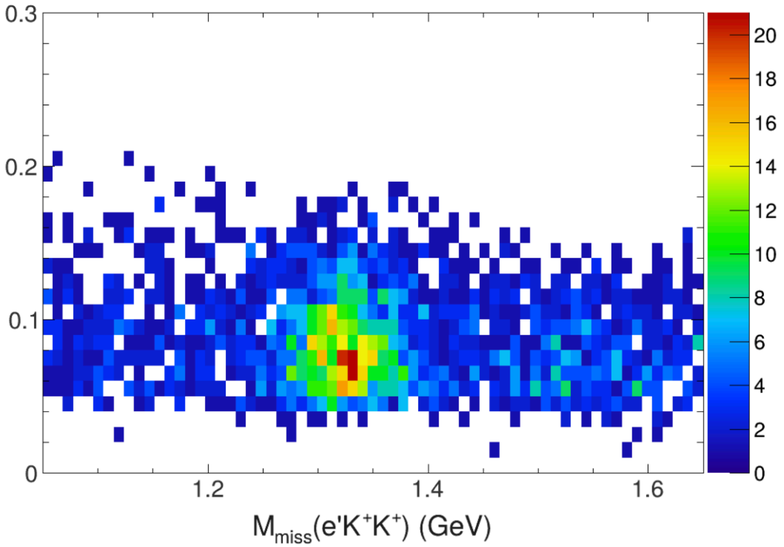
RG-K

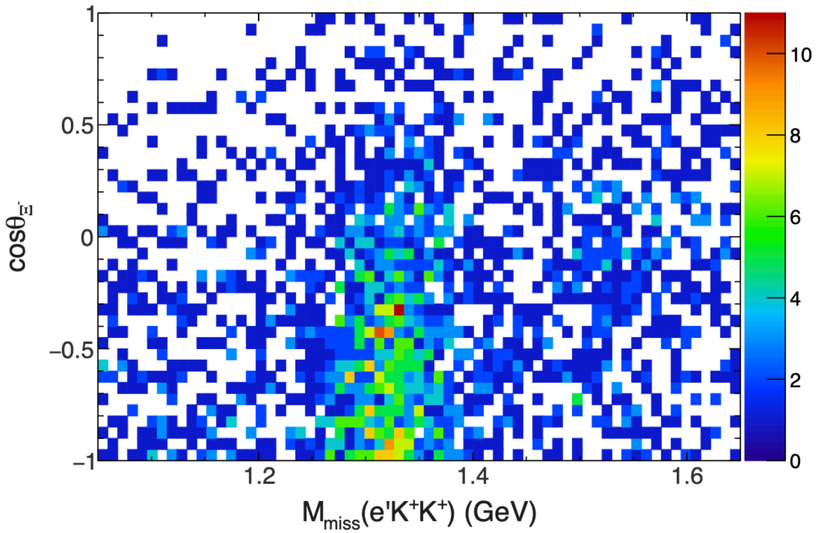


Forward Tagger Kinematic Coverage

$$E_{beam} = 7.5\ GeV$$





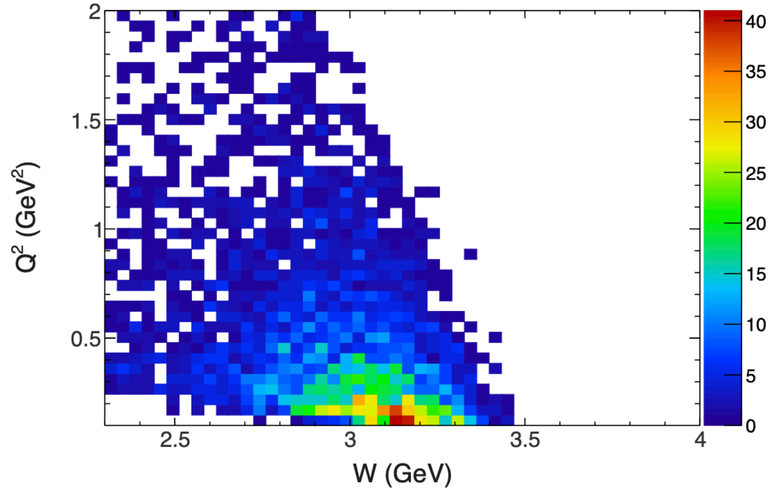


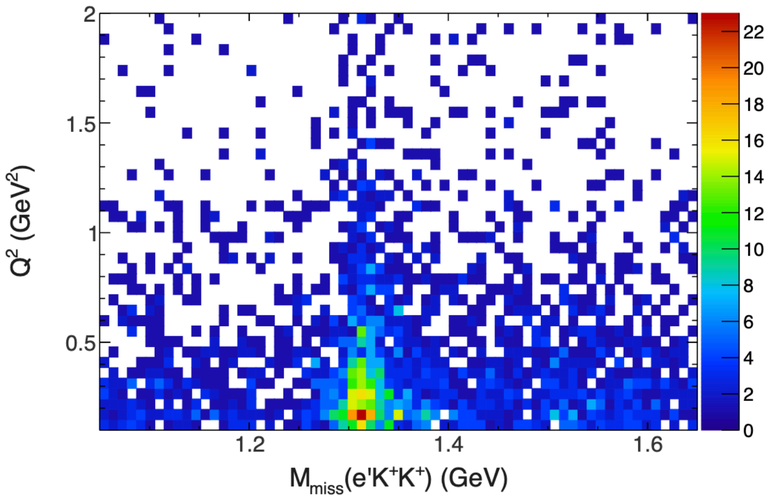
Data are binned in Q^2 and $\cos\theta^{CM}_{\Xi^-_{1320}}$

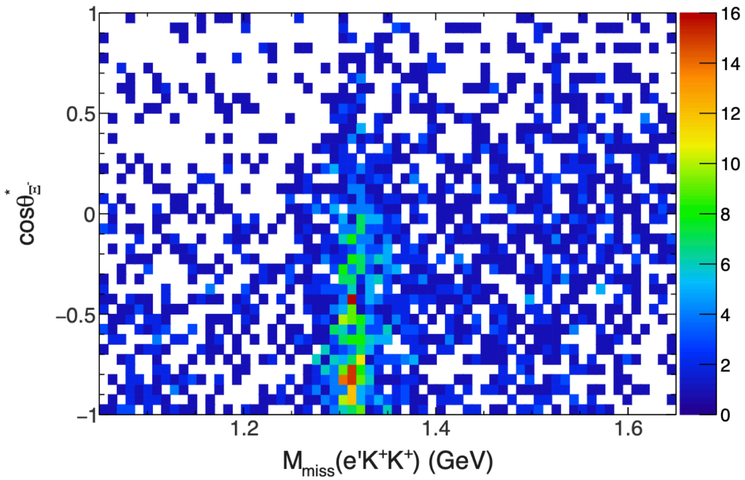
Q^2 range: ~ $0.04 \leq Q^2 \leq 0.18\ GeV^2$

Forward Detector Kinematic Coverage

$E_{beam} = 6.5\ GeV$



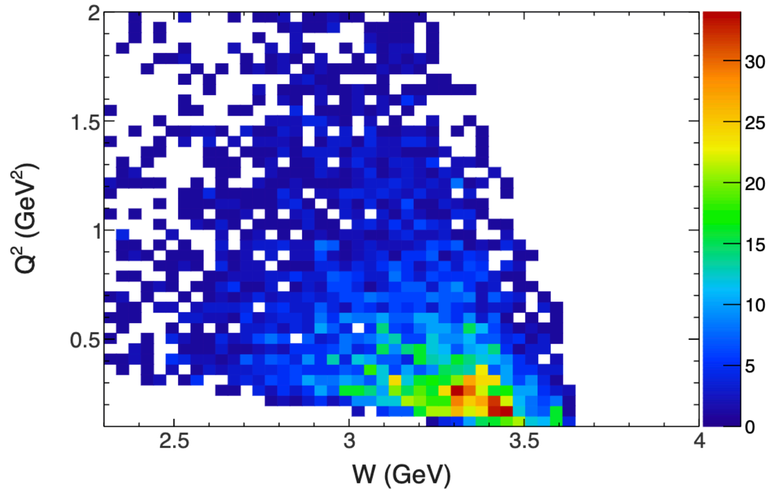


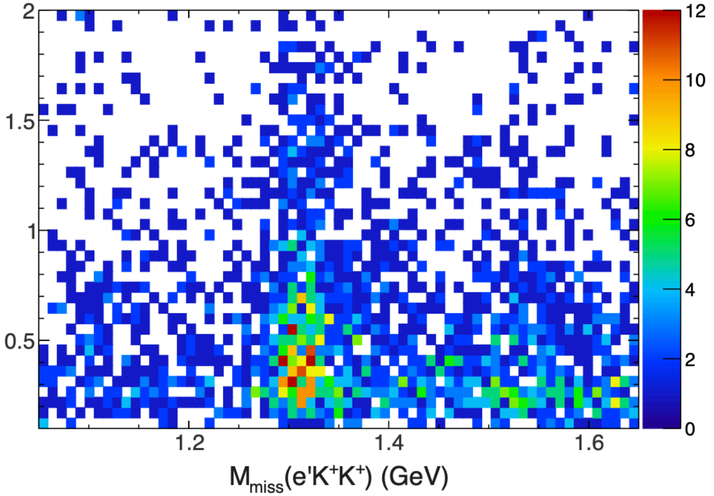


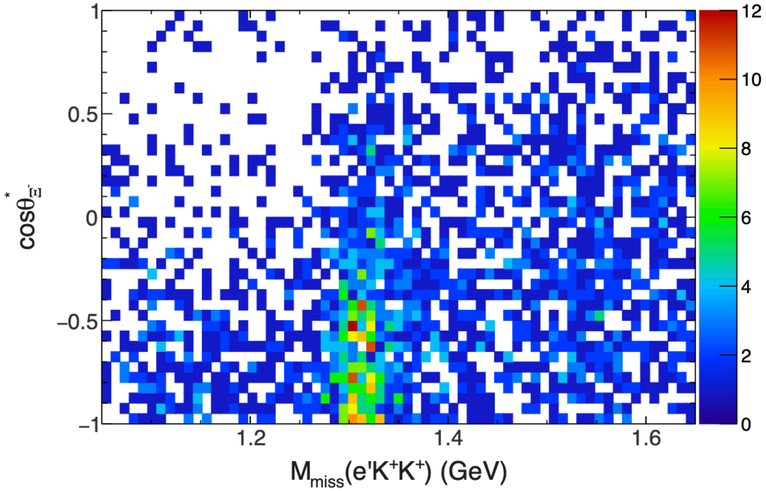
Data are binned in Q^2 and $\cos\theta^{CM}_{\Xi^-_{1320}}$

Q^2 range: ~ $0.2 \leq Q^2 \leq 2.0\ GeV^2$

$E_{beam} = 7.5\ GeV$







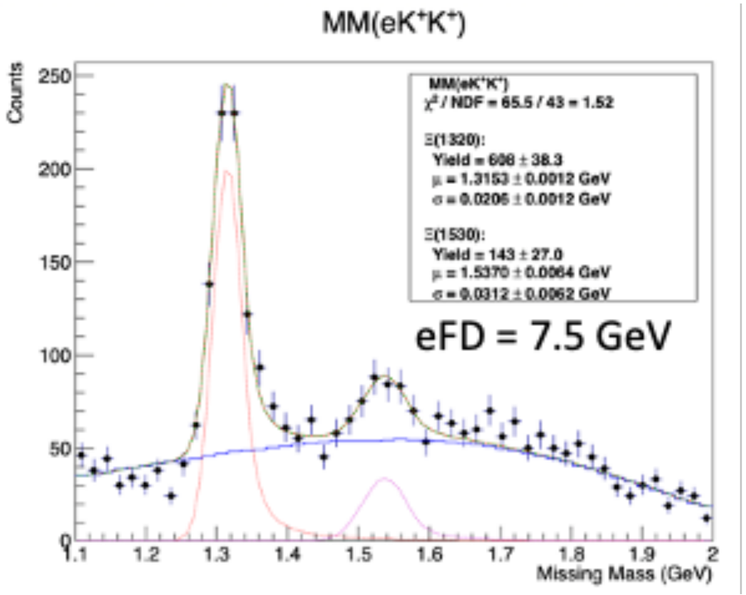
Reconstructing Cascade

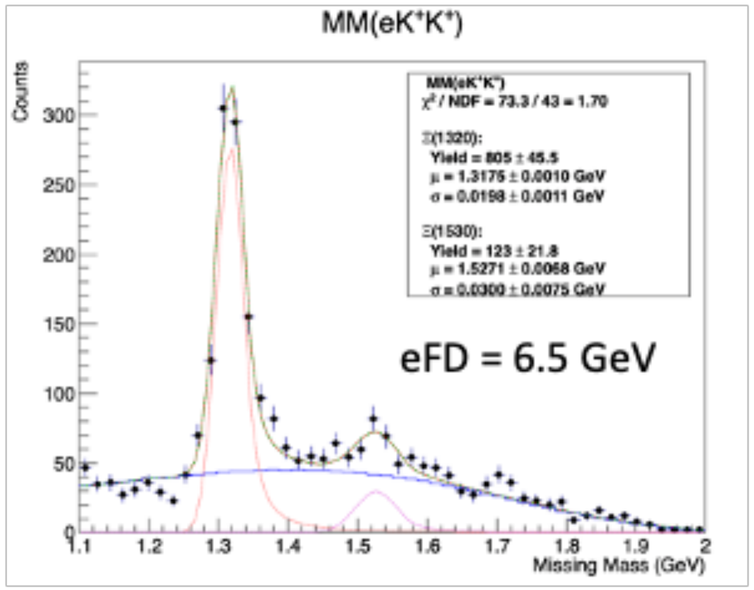
- After the data passes various selection cuts (backup slides), the missing mass of $e'p \rightarrow e'K^+K^+(\Xi^-)$ is computed to reconstruct the cascade spectrum
- Each signal is fitted to a Crystal Ball function
- The background is modeled using mixed events:
  - Recompute the missing mass and randomize one kaon from a different event. This breaks the correlation between the kaons that come from cascade production

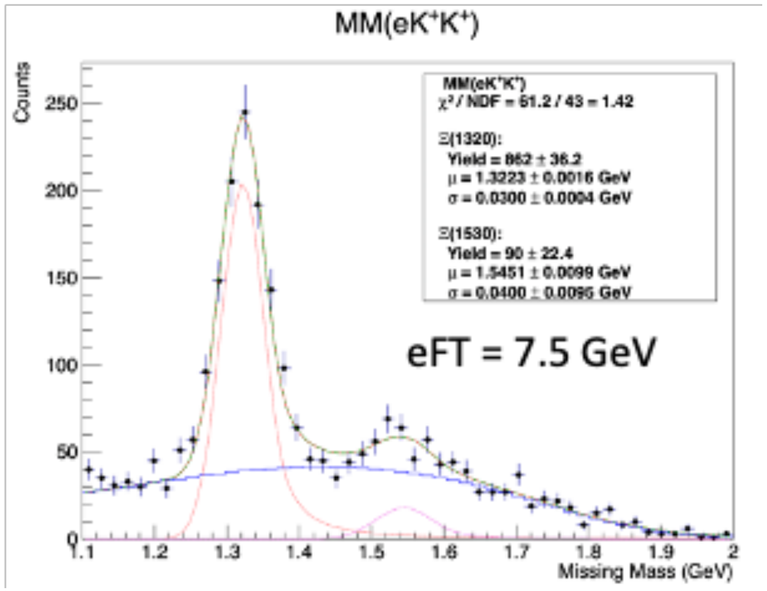
Crystal Ball Function

$$f(x) = N \begin{cases} \exp\left(-\frac{t^2}{2}\right), & t > -\alpha, \\ A(B-t)^{-n}, & t \leq -\alpha, \end{cases}$$

$$t = \frac{x-\mu}{\sigma}, \quad A = \left(\frac{n}{|\alpha|}\right)^n \exp\left(-\frac{\alpha^2}{2}\right), \quad B = \frac{n}{|\alpha|} - |\alpha|.$$







Hyperon Event Generator

Input parameters:

Ξ^- mass distribution

Intermediate hyperon distribution $M(\Xi^- K^+_{decay})$

Angular coverage

Q^2 weighting

W weighting

$t - slope$ weighting

Weighting Procedure

FIU's Hyperon Event Generator

The initial event generator samples the kinematically allowed phase space for $ep \rightarrow e'K^+K^+\Xi^-$

First iteration – Q^2 weighting:

An exponential weight, $e^{-1.847Q^2}$ (based on data), was introduced using the slope extracted from an exponential fit to the experimental Q^2 distribution.

Second iteration – $Q^2 + W$ weighting:

Additional W-dependent weights were introduced to reproduce the measured differential cross-section shape within each Q^2 bin. At the generator level, the initial shape-matching requirement was:

$$\frac{dN_{\mathrm{GEN}}}{dW} \propto \frac{d\sigma}{dW}$$

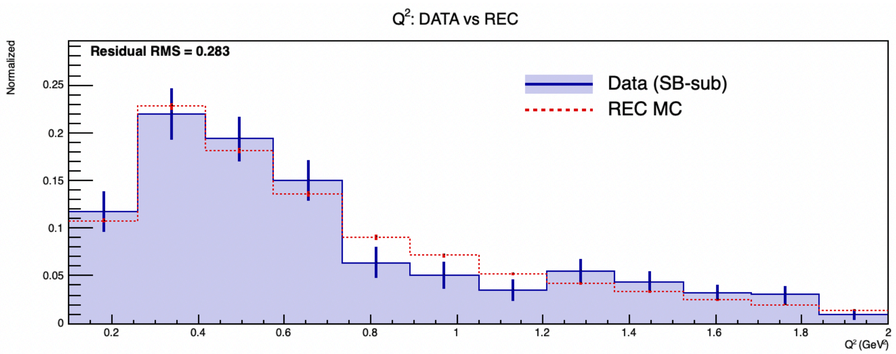
Subsequent iterations – Iterative acceptance correction:

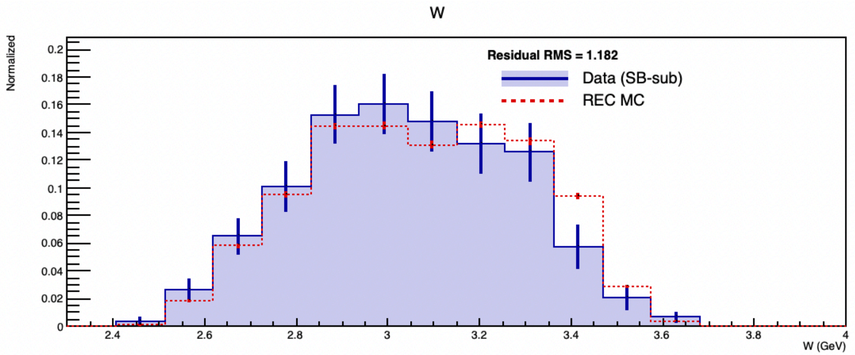
The acceptance was recalculated using the most recently weighted GEN and REC samples. We then used the updated acceptance to extract new differential cross sections and construct the weights for the next iteration.

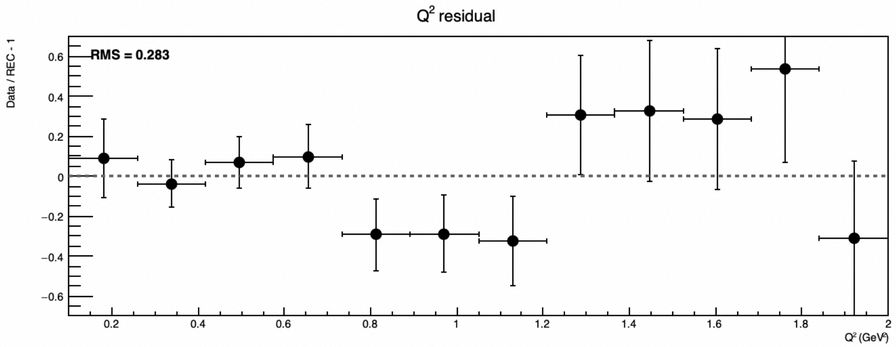
Data to Simulation Matching

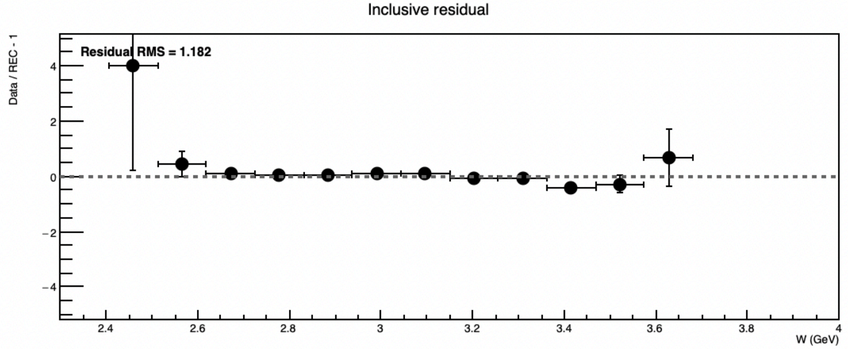
eFD 7.5 GeV

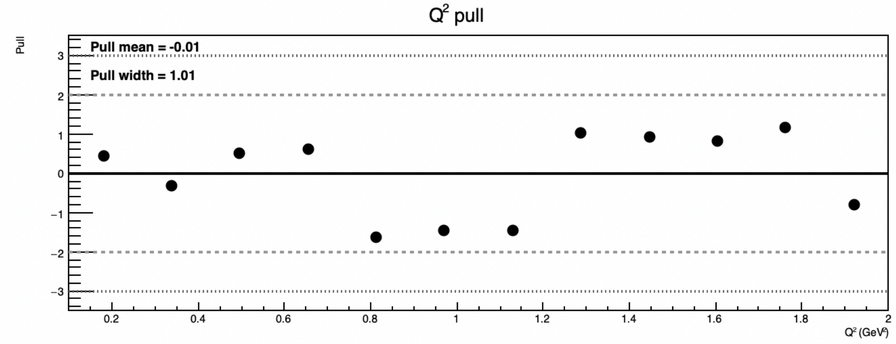
Q^2 and W distributions in $\Xi^-(1320)$ signal region after 3 iterations

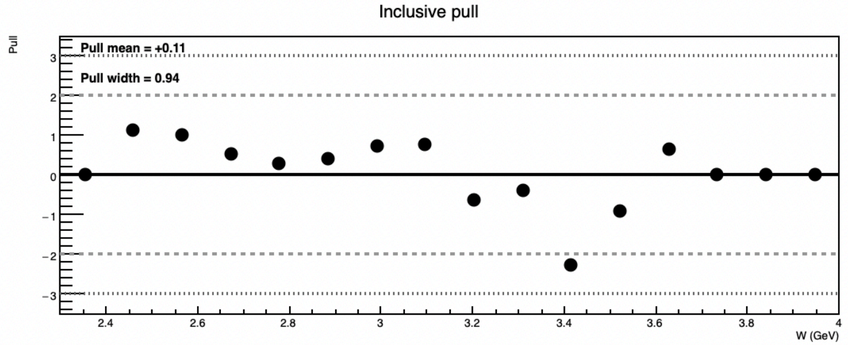






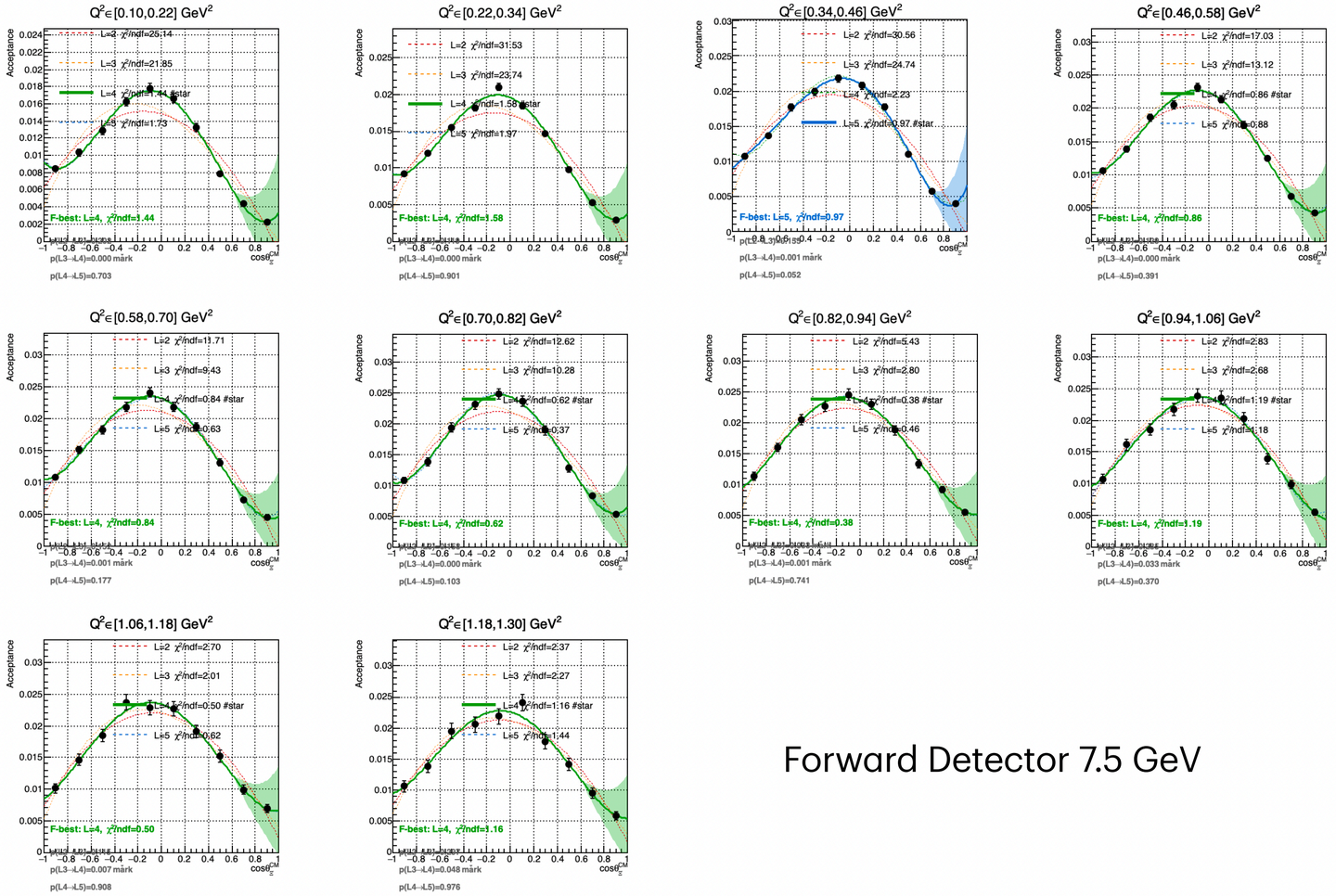






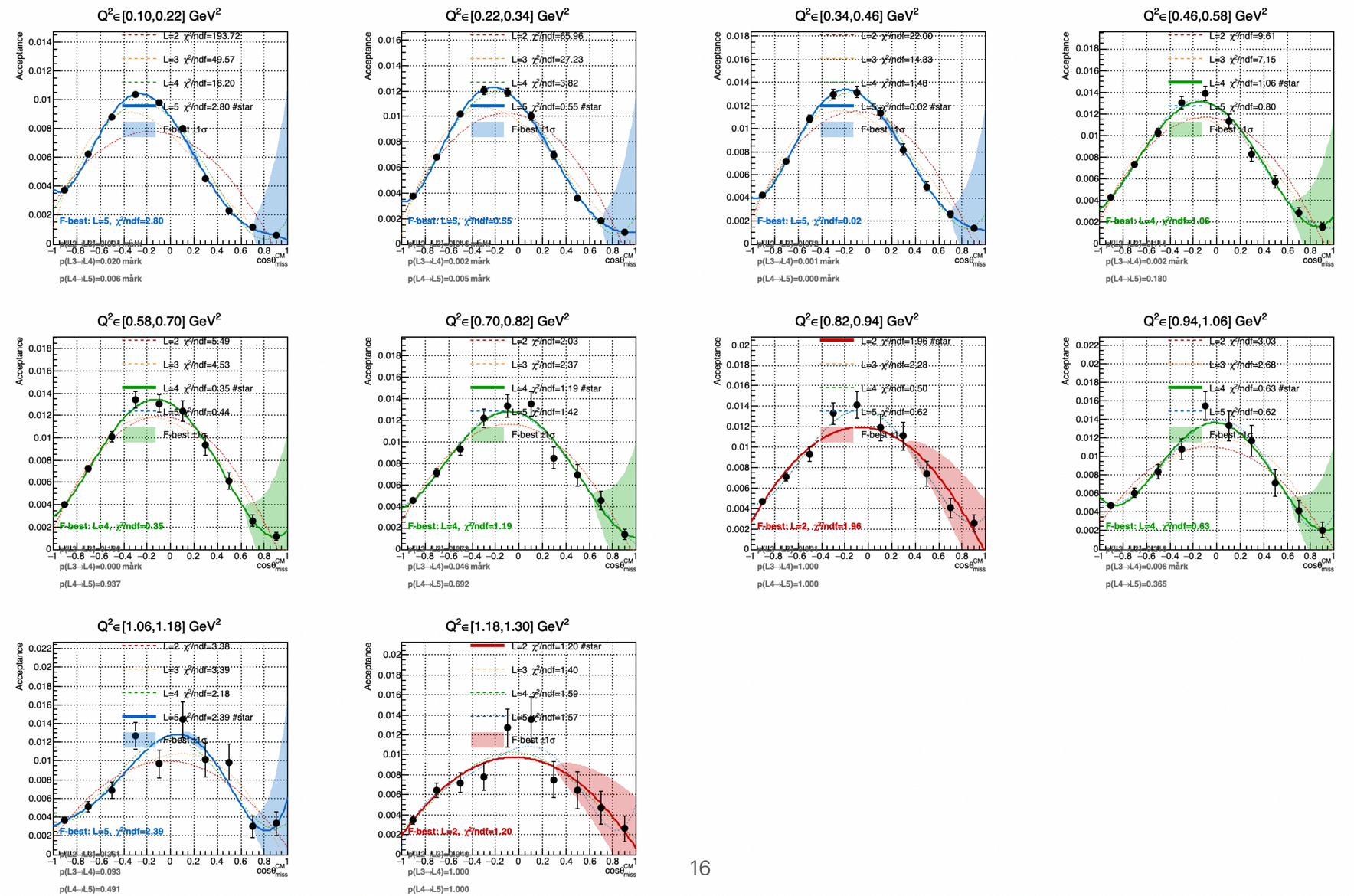
Acceptance Calculation

- Acceptance is calculated in two ways:
  - Bin-by-bin: $\eta_i = \dfrac{N_i^{REC}}{N_i^{GEN}}$
    - The bin-by-bin method assumes acceptance is flat throughout each bin
    - Legendre Polynomial Parameterization:
      - Models acceptance throughout the entire bin
      - Legendre polynomials are ideal for parameterization:
        - Orthogonal
        - Independent coefficients
    - Degree of the polynomial is determined by an F-test computed for each Q^2 bin

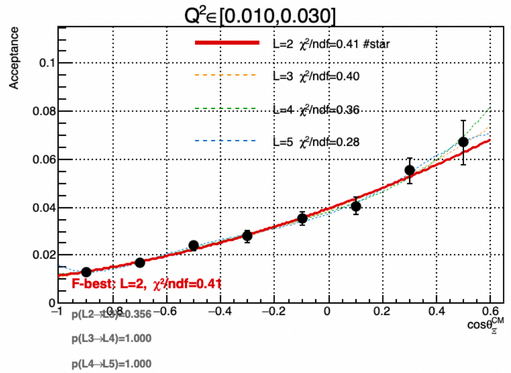


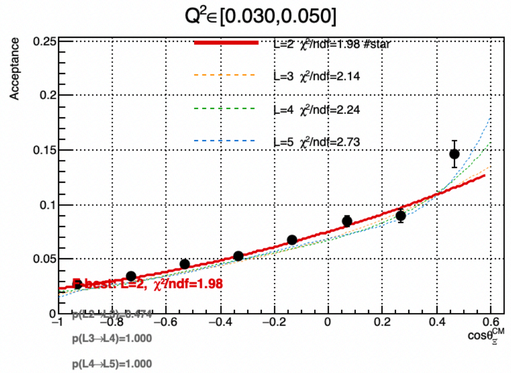
Forward Detector 7.5 GeV

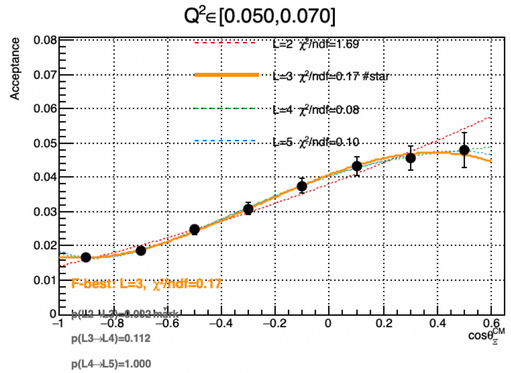
6.5 GeV FD Acceptance

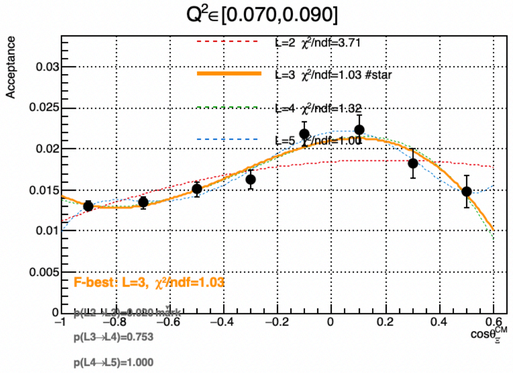


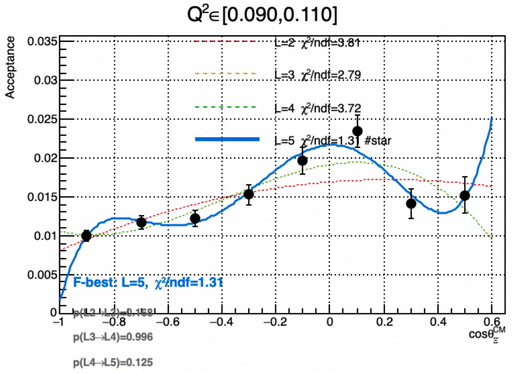
eFT 7.5 GeV Acceptance

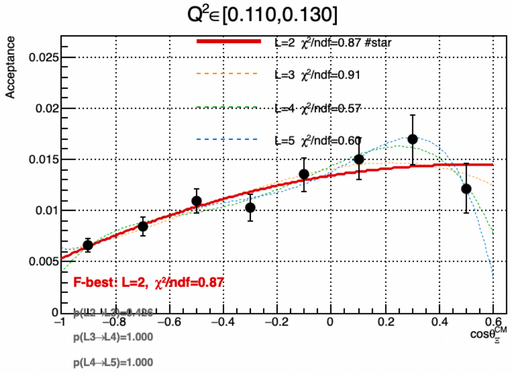


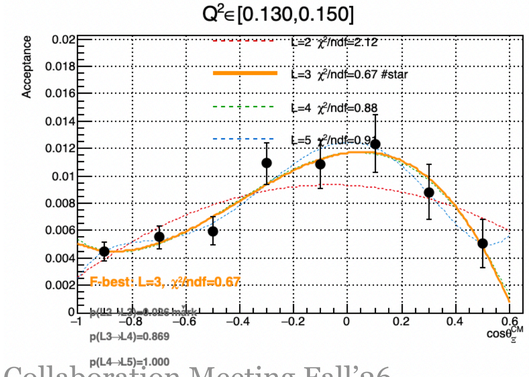


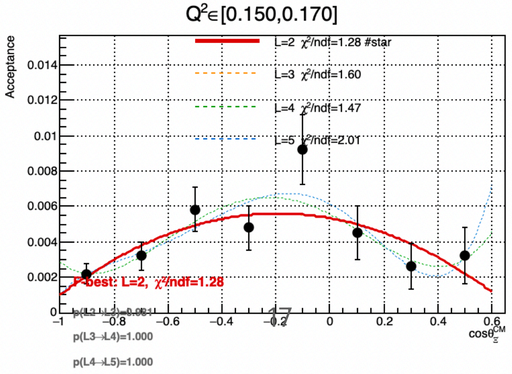


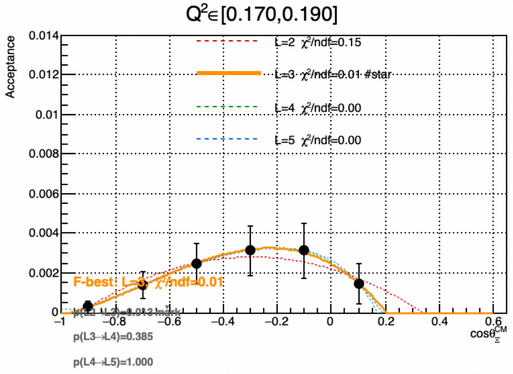












Preliminary

Ξ^-_{1320} Cross Sections

Ξ^-_{1320} Cross Section

The cross section is calculated bin by bin as follows:

$$\frac{d\sigma}{dQ^2 d\cos\theta^{CM}_{\Xi^-}} = \frac{Y}{\eta} * \frac{1}{N_0(N_A \rho t_l / A_W)} * \frac{1}{\Gamma_\nu} * \frac{1}{\Delta Q^2 \Delta\cos\theta^{CM}_{\Xi^-}}$$

$\frac{Y}{\eta}$: Acceptance corrected yield

N_0: Number of incident beam electrons

$\frac{N_A \rho t_l}{A_W}$: Target number density

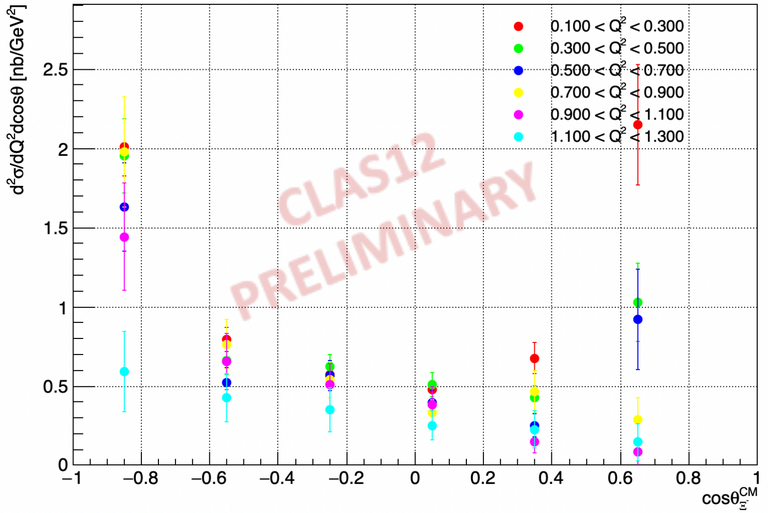
Γ_ν : Virtual photon flux

$$\Gamma_\nu = \frac{\alpha}{4\pi} * \frac{W}{M_p E_b^2} * \frac{W^2 - M_p^2}{M_p Q^2} * \frac{1}{1-\epsilon}$$

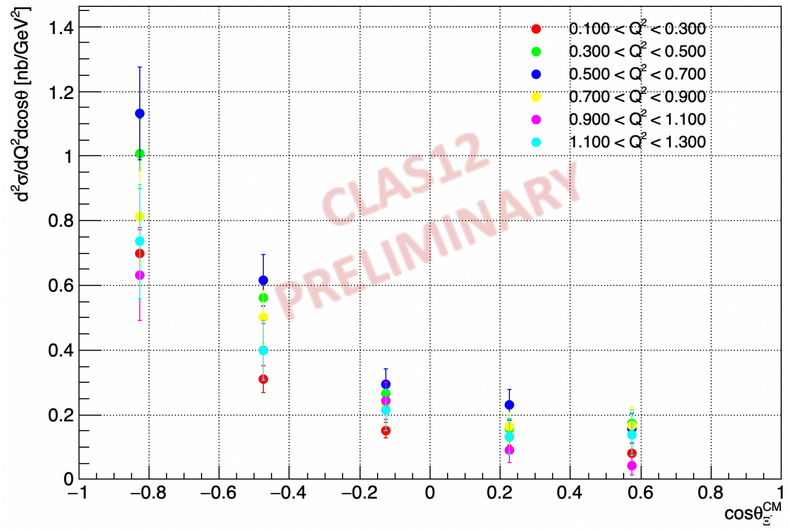
α: fine structure constant
E_b: beam energy
M_p: proton mass
ϵ : Virtual photon polarization parameter

- $\epsilon = 1/(1 + 2\left(1 + \frac{\nu^2}{Q^2}\right)\tan^2\left(\frac{\theta_e}{2}\right))$

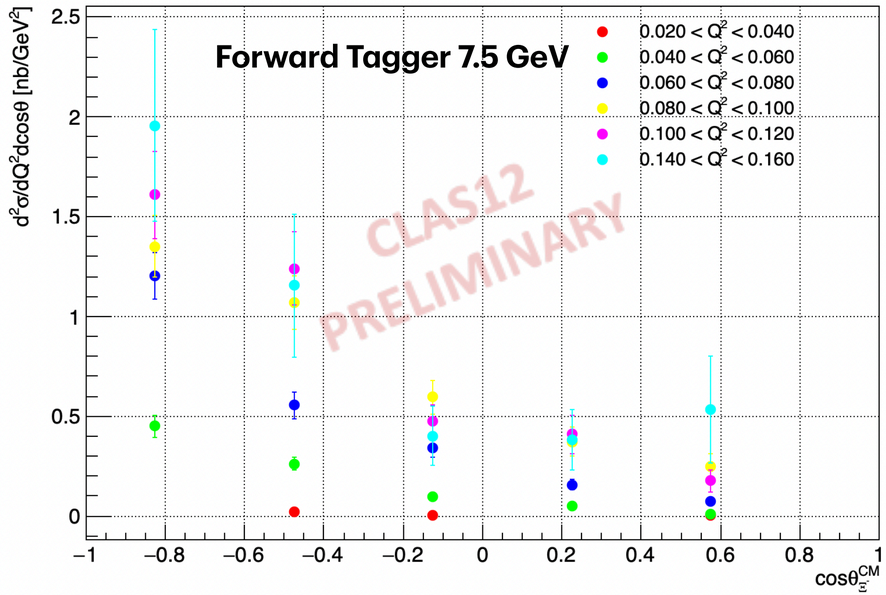
Forward Detector 6.5 GeV



Forward Detector 7.5 GeV



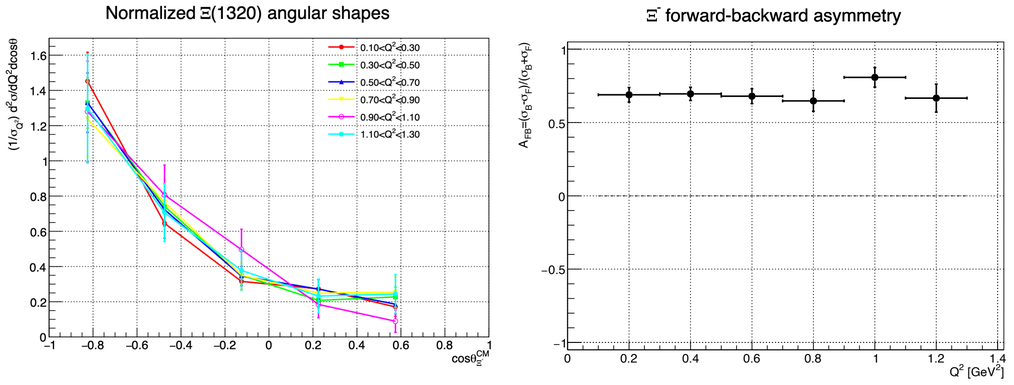
Forward Tagger 7.5 GeV



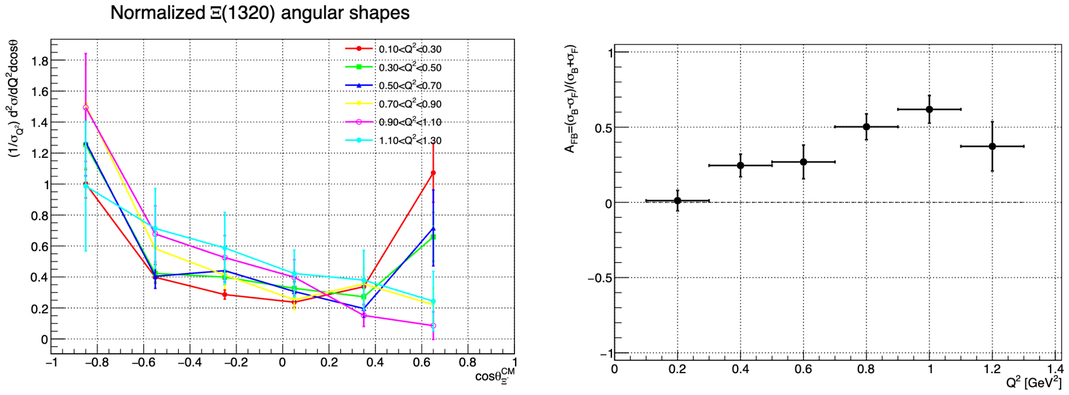
Production Mechanism Interpretation

- Cross section is predominantly enhanced at backwards Ξ^- angles, $\cos\theta^*_{\Xi} < 0$
  - This is consistent with a t-channel-dominated production mechanism
  - In t-channel exchange, production preferentially produces K^+ in the forward direction. From momentum conservation, we expect the Y^* and consequently the Ξ^- to be produced at backward angles
  - This behavior is consistent with CLAS6 photoproduction results that also implied t-channel production (L Guo. Et al Cascade production in the reactions of $\gamma p \to K^+K^+(X)$ and $\gamma p \to K^+K^+\pi^-(X)$ PRC)
- However, the 6.5 GeV data show a rise in both the forward and backwards directions.
  - This additional forward enhancement can indicate that additional production amplitudes contribute at lower beam energies

Forward Detector 7.5 GeV



Forward Detector 6.5 GeV

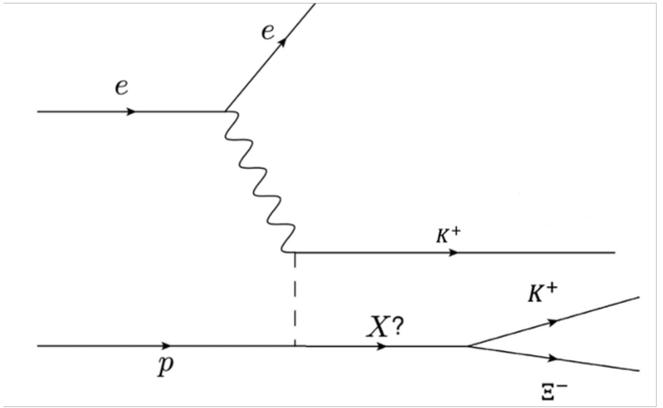


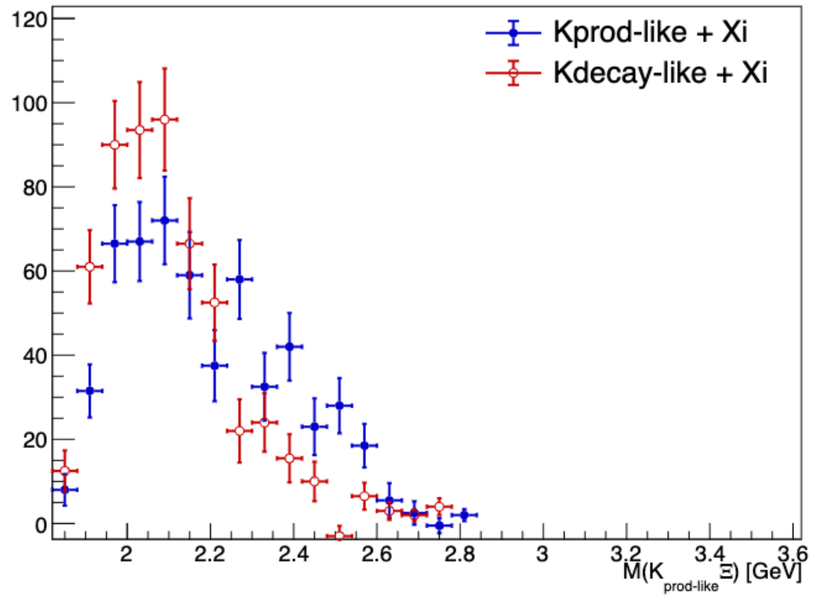
Potential Intermediate *Y** State?

Kaon Assignment for Potential Intermediate State

$Y^* \rightarrow K^+\Xi^-$

- Two identical K^+ mesons give two possible $K^+\Xi^-$ combinations. There is no direct experimental label discriminating between the production and decay kaons.
- The kaons are assigned using the hadronic CM angle:
  - Assumption: For forward t-channel production
    - smaller θ_K^*; (larger $\cos\theta_K^*$) $\rightarrow$ K^+prod-like
    - Larger θ_K^*; (smaller $\cos\theta_K^*$) $\rightarrow$ K^+decay-like





The decay-like pairing preferentially populates lower $K^+\Xi^-$ masses, although no isolated intermediate state is clearly resolved

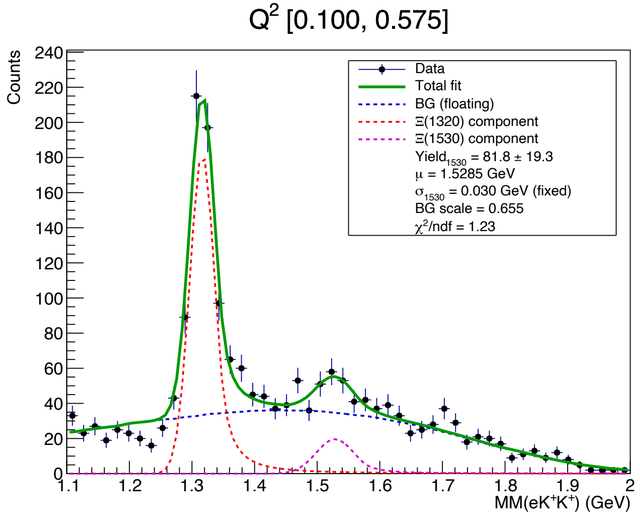
*** Mainly used as another input to the event generator ***

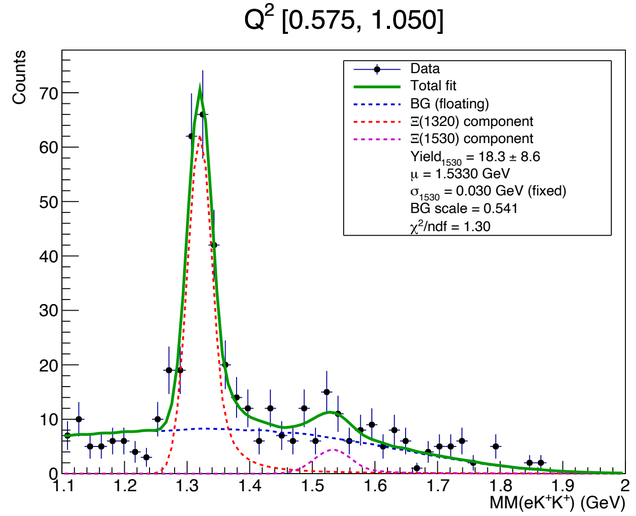
Preliminary Ξ^-_{1530} Forward Detector Cross Sections

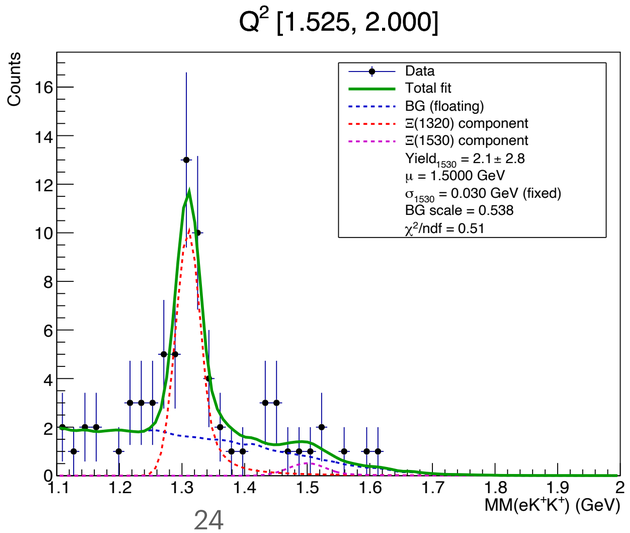
1530 Signal

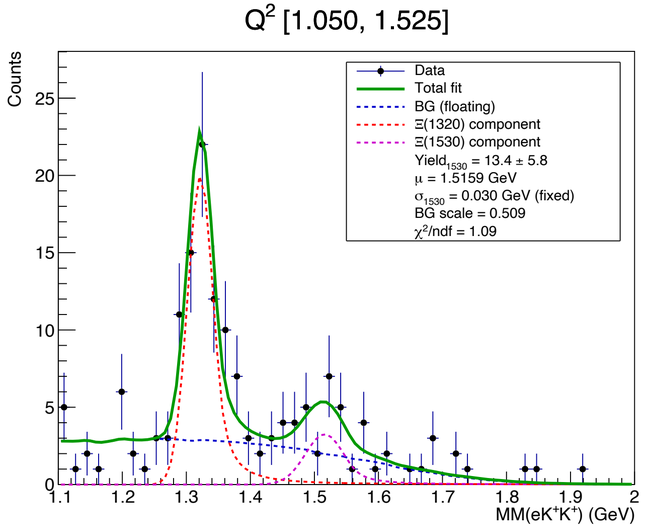
FD 6.5 GeV

- Similar to the Ξ^-_{1320} signal extraction, the MM($e'K^+K^+$) is fitted to a Crystal Ball function with a mixed event background
- Due to limited statistics, cross section for the Ξ^-_{1530} are measured in 4 bins of Q^2





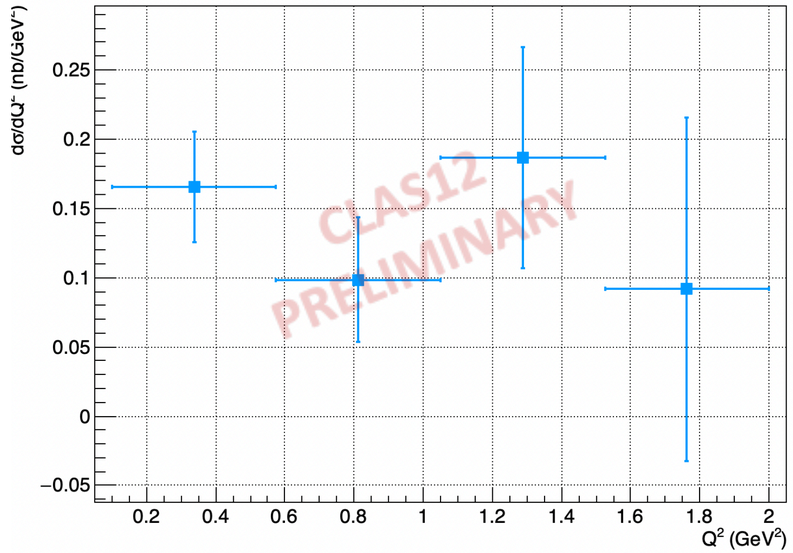


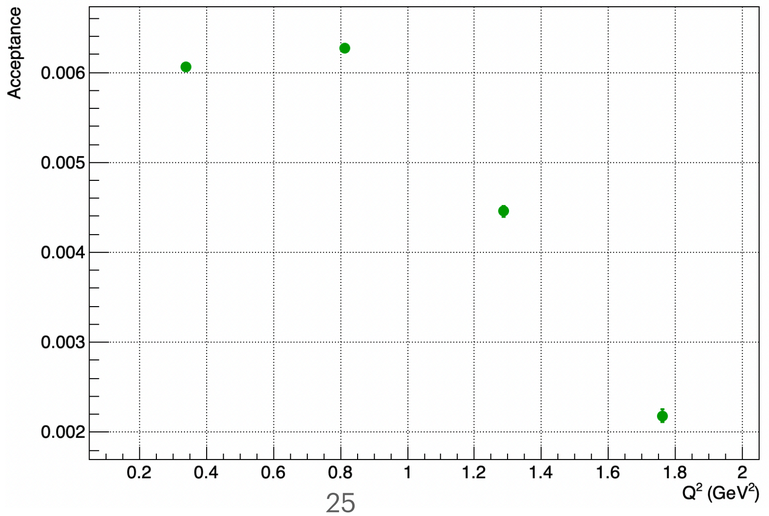


Ξ^-_{1530} Acceptance and Cross Section

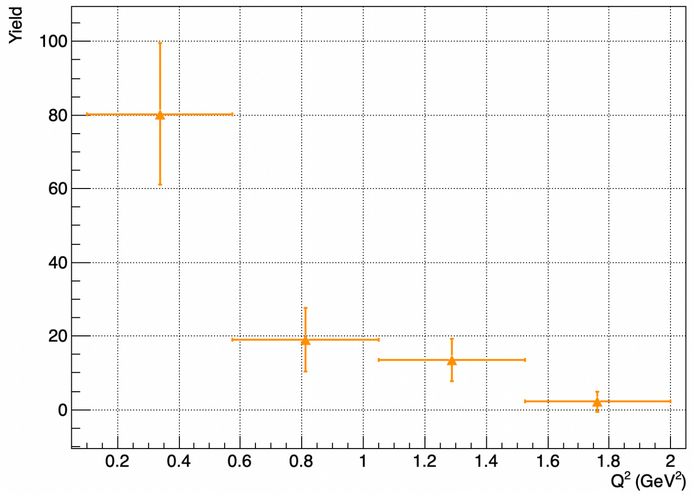
eFD 6.5 GeV

- It should be noted that simulation for Ξ^-_{1530} is not as well established as for the 1320. Only Q^2 weighting is taken into account here.





Ξ(1530) yield



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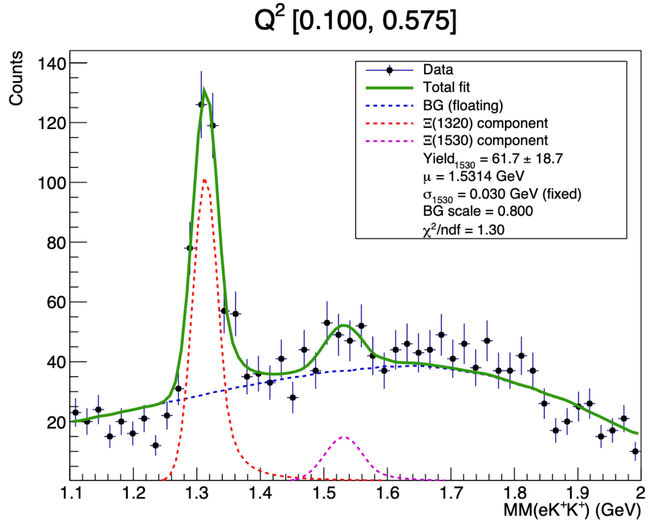

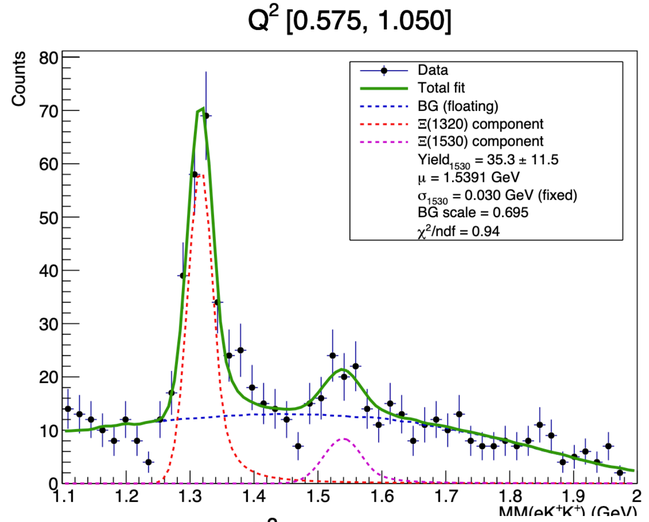

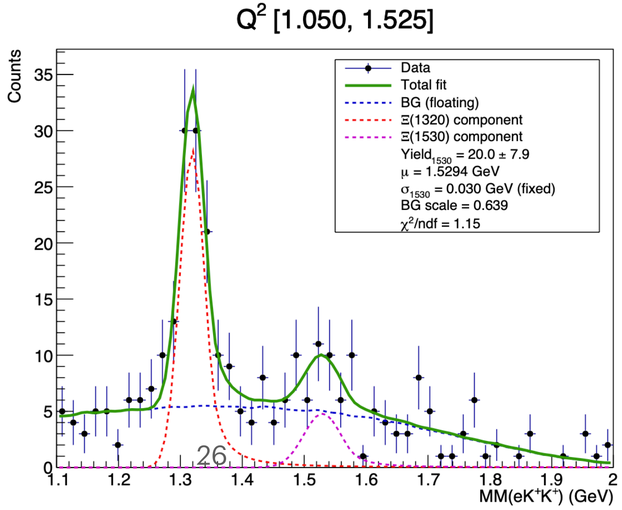

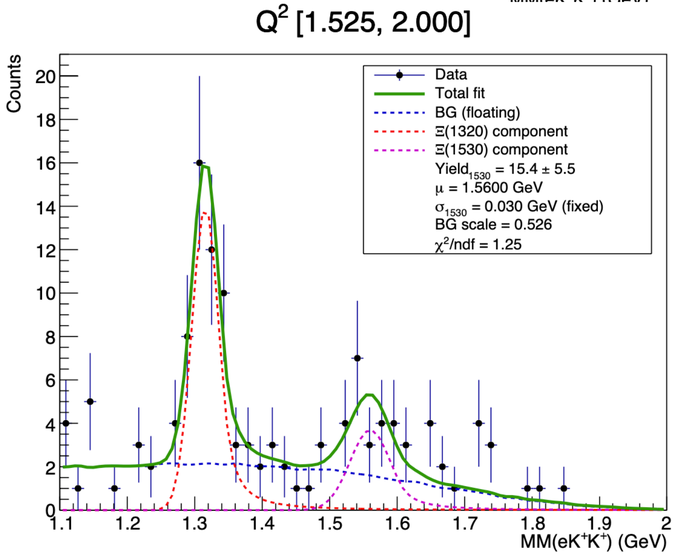

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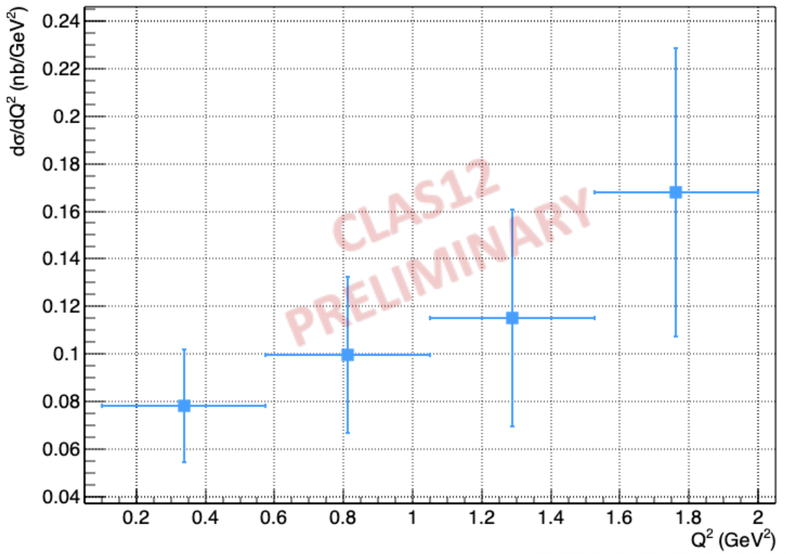
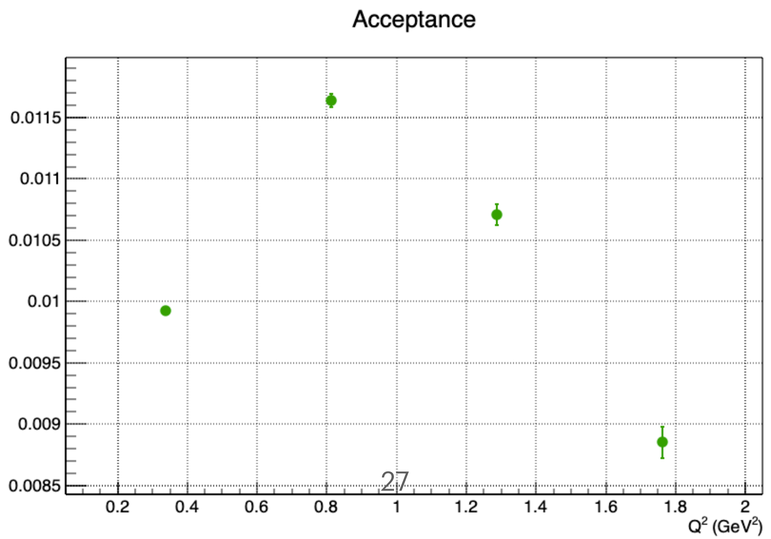
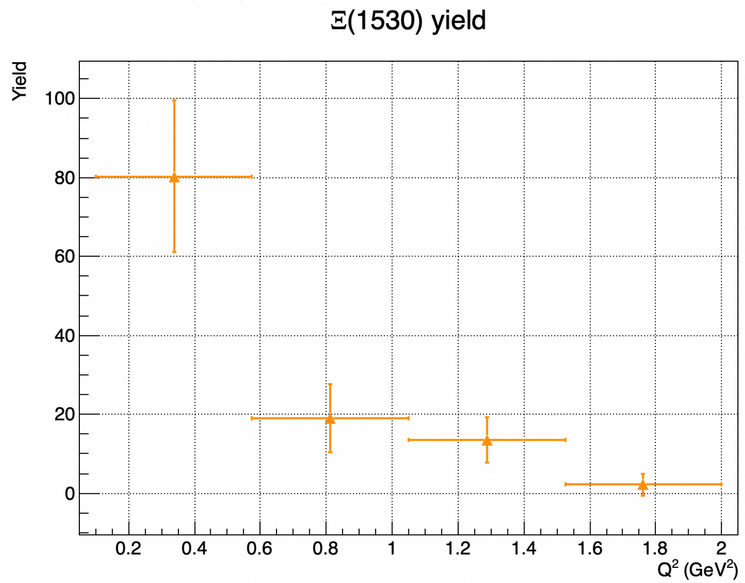






Summary and Outlook

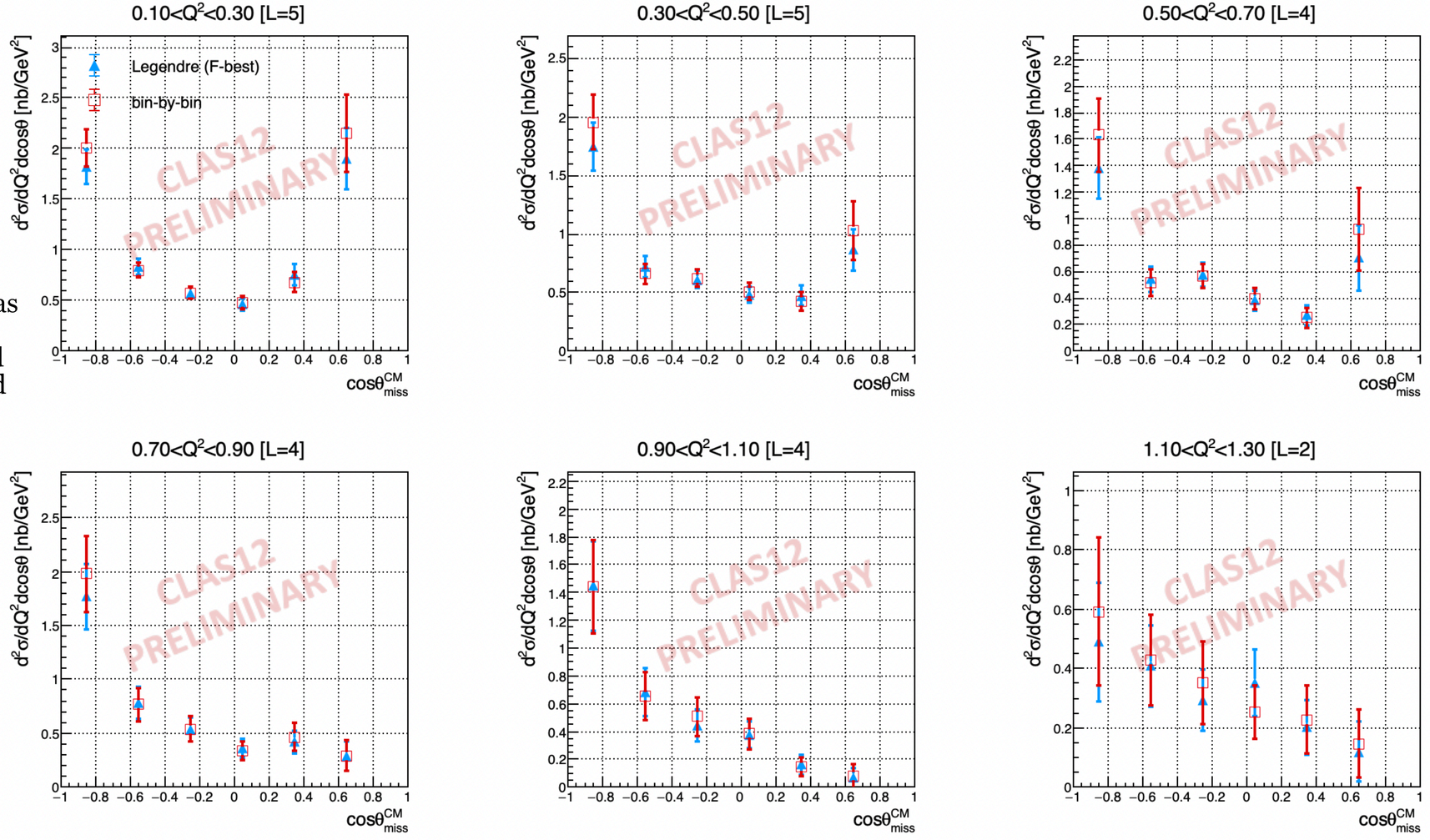
- Predominantly backward enhancement in most bins of Ξ^-_{1320} the cross section results, which is indicative of a t-channel production mechanism
  - Data from CLAS6 also showed similar behavior for photoproduction
  - Although for the 6.5 GeV data, there are potentially multiple contributing production amplitudes
- Newer, higher-statistics data from RG-K is available
  - With higher statistics, there is potential to better expand this analysis to more indepth study of production mechanisms using BSA, PWA, etc.
- Error analysis is underway

Backup

Preliminary Cross Section Results

Forward Detector 6.5 GeV

Blue indicates cross section was computed with Legendre polynomail acceptance vs red the acceptance was calculated bin-by-bin



Preliminary Cross Section Results

Forward Detector 7.5 GeV

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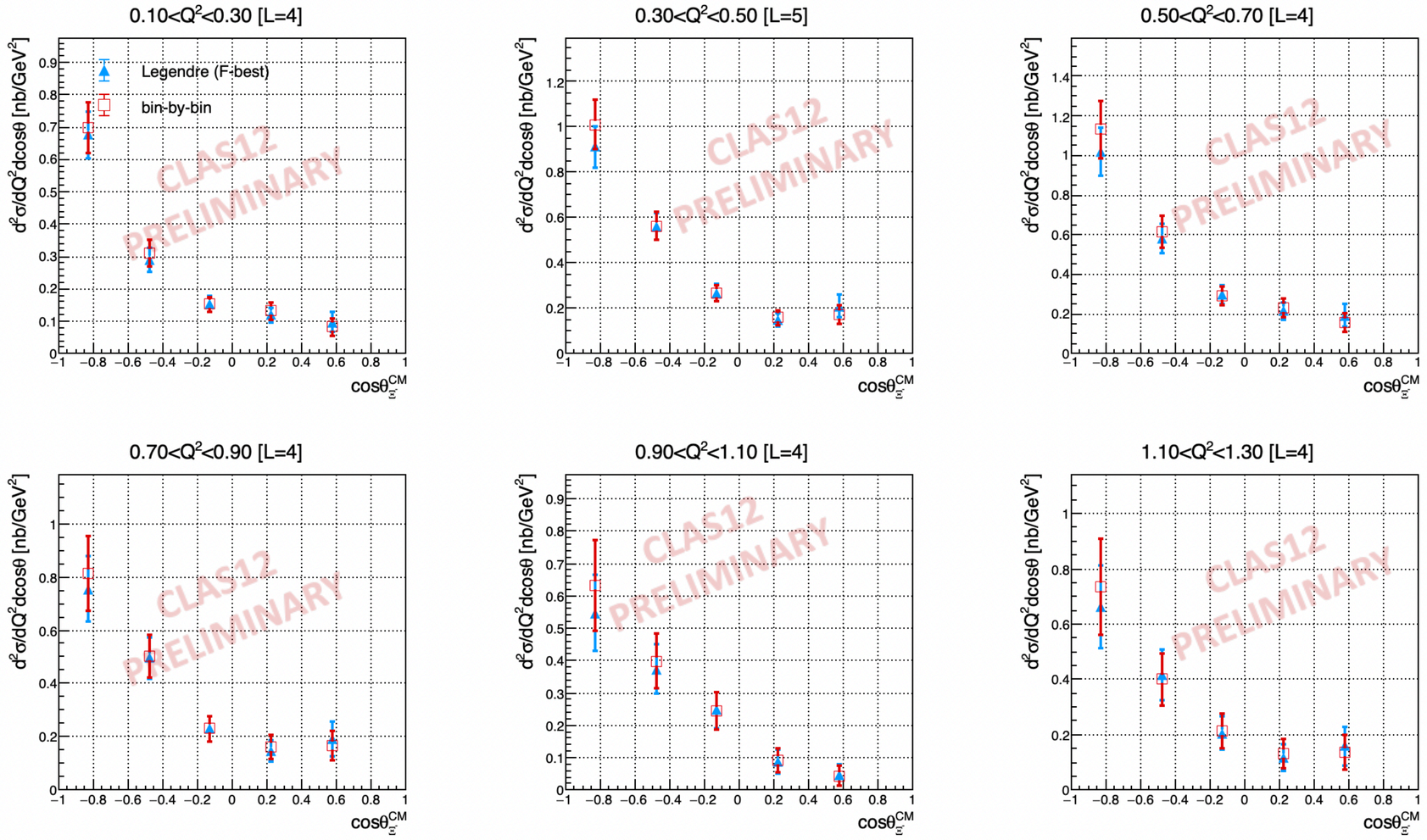
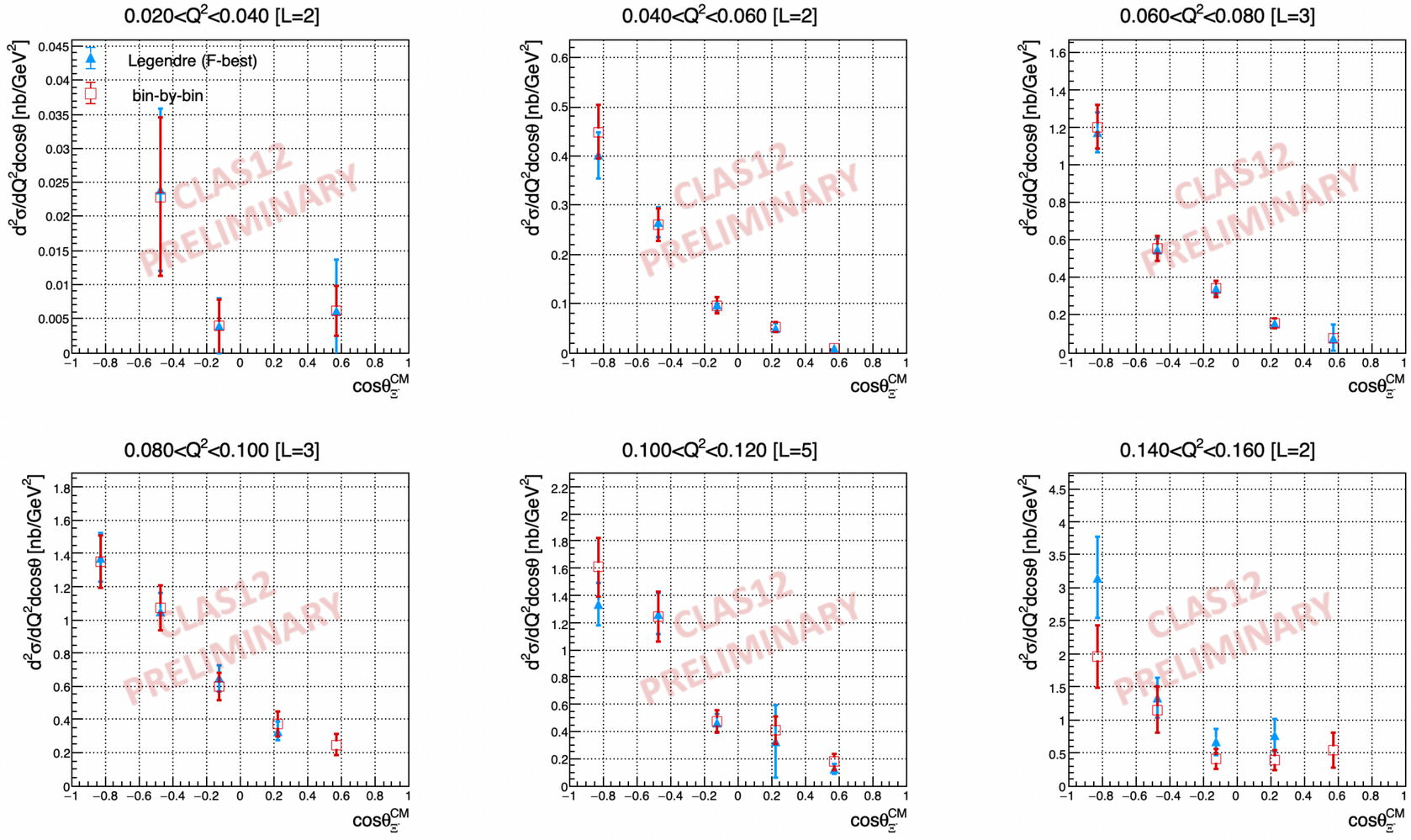


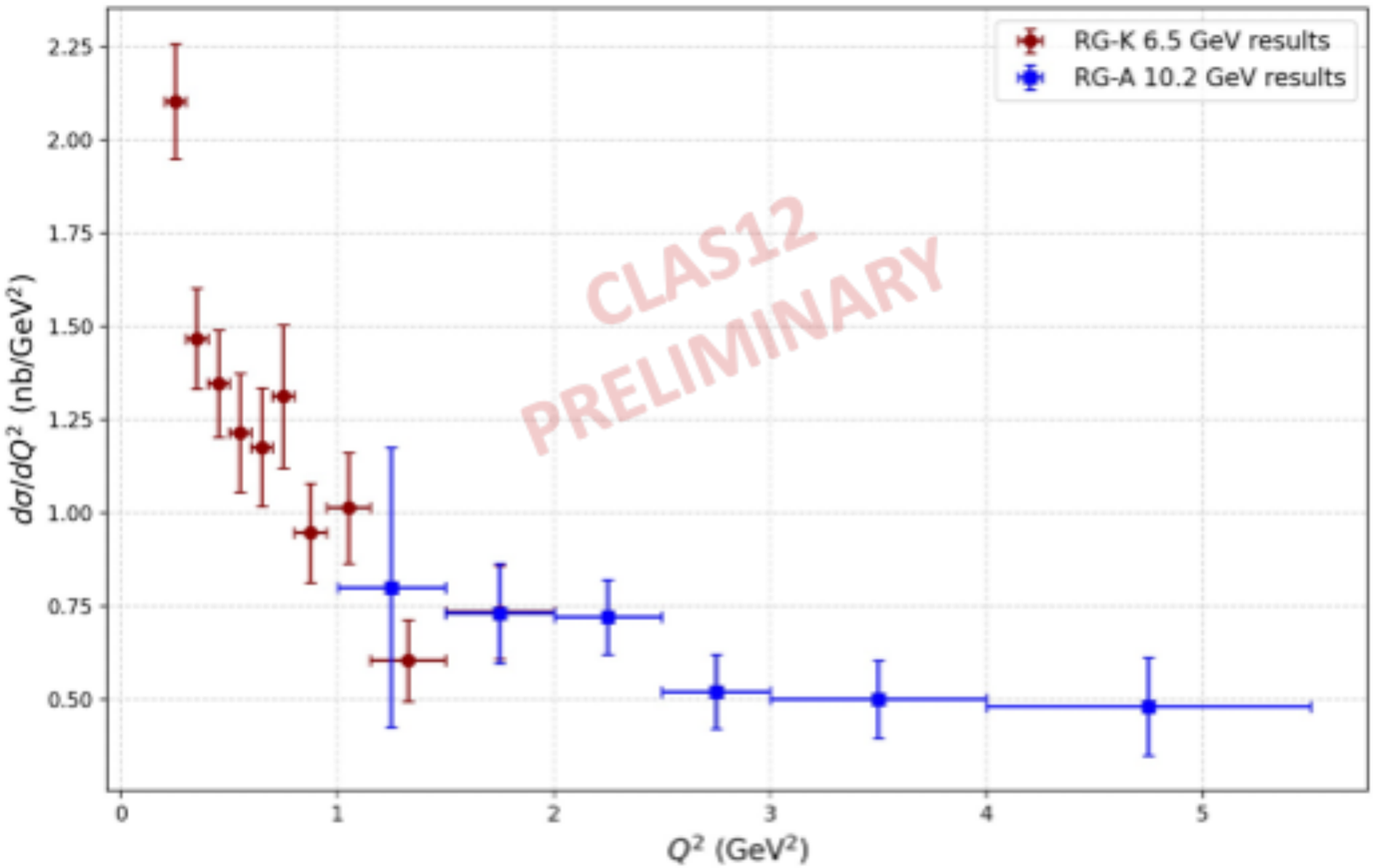
Preliminary Cross Section Results

Forward Tagger 7.5 GeV

Blue indicates cross section was computed with Legendre polynomail acceptance vs red the acceptance was calculated bin-by-bin



Comparison of 6.5 GeV to 10.2 GeV Cross Section



Event Selection Cuts

Dataset	• RG-K Fall 2018 • $E_{beam} = 6.5\ (eFD)$ & $7.5\ GeV\ (eFT, eFD)$ • Unpolarized LH_2 target
Reconstruction	• $ep \rightarrow e'K^+K^+(\Xi^-)_{miss}$
Kaon Selection Criteria	• FD region only • Status, TOF, P, Vz, θ_{K^+} cuts applied
Electron Selection Criteria	• FT and FD region • Status, TOF, P, Vz, $\theta_{e'}$ cuts applied

Cuts (Forward Detector)	K+	e'
$V_z[cm]$	$-10 \leq V_z \leq 2$	$-10 \leq V_z \leq 2$
$\theta[^\circ]$	$5 \leq \theta_{K^+} \leq 35$	$5 \leq \theta_{e'} \leq 35$
P [GeV]	$0.4 \leq P \leq 7.5$	$P > 1.0$
ToF [ns]	$20 \leq ToF \leq 35$	$21 \leq ToF \leq 26$
$\chi^2 PID$	$-6 \leq \chi^2 \leq 6$	N/A
β	$0.4 \leq \beta < 1.1$	N/A

Cuts (Forward Tagger)	K+	e'
$V_z[cm]$	$-10 \leq V_z \leq 2$	$-10 \leq V_z \leq 2$
$\theta[^\circ]$	$5 \leq \theta_{K^+} \leq 35$	$2.5 \leq \theta_{e'} \leq 4.5$
P [GeV]	$0.4 \leq P \leq 7.5$	$P > 1.0$
ToF [ns]	$20 \leq ToF \leq 35$	N/A
$\chi^2 PID$	$-4 \leq \chi^2 \leq 3$	N/A
β	$0.4 \leq \beta < 1.1$	N/A