Electroproduction of Ξ Hyperons using CLAS12 at JLab

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11th Workshop of the APS Topical Group on Hadronic Physics

CEBAF Large Acceptance Spectrometer

Outline

Introduction

Previous studies

- Photoproduction
- Electroproduction

Experimentally Studying Cascades at JLab

Preliminary Results

Hyperons in the Hadron Spectrum

- Compared to $N's$ and $\Delta's$ states, hyperons have been less extensively studied

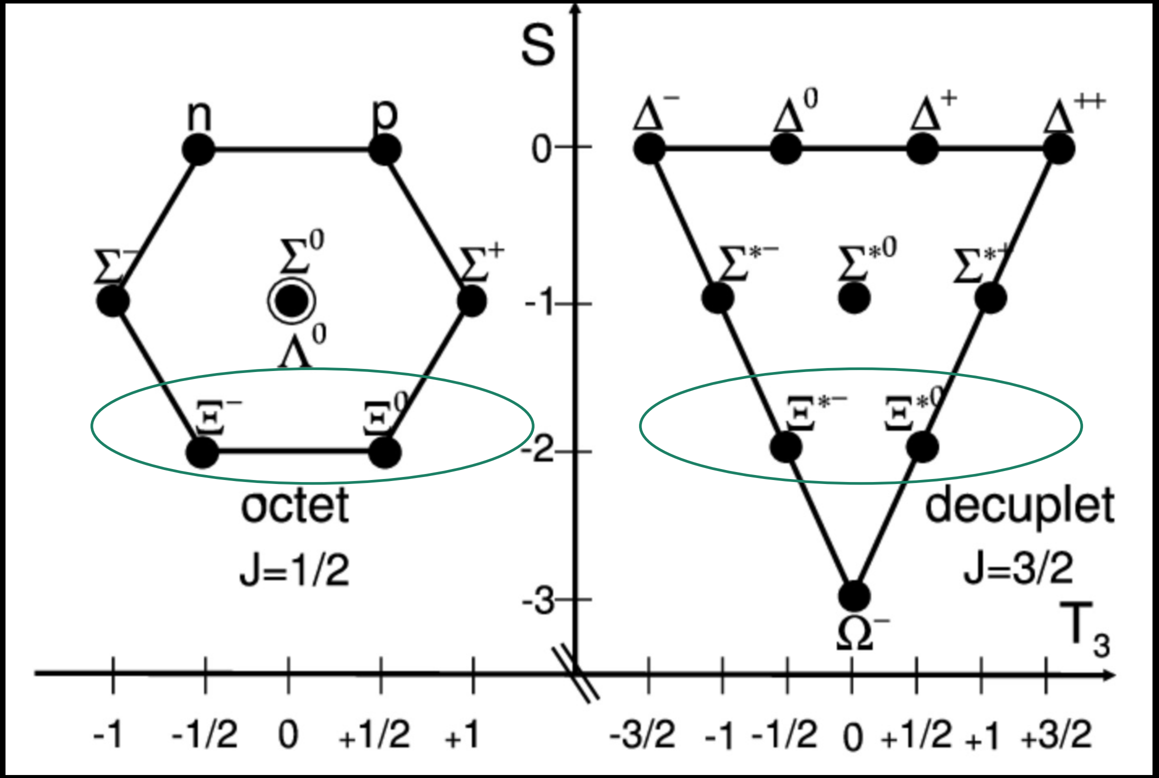
- As strangeness increases, knowledge about hyperon states decreases…

Number of well-established states:

- S = -1 : 14 Λ and 10 Σ
- S = -2 : 6 Ξ
- S = -3 : 2 Ω^{-}

Cascades

- Doubly strange hyperon
  - Ξ^- (ssd)
  - Ξ^0 (ssu)
- $\Xi^-(1320)$ decays weakly
  - $\Xi^- \to \Lambda\pi^-$
  - $\tau = (1.639 \pm 0.015) \times 10^{-10}\ s$
  - Quantum numbers: $I(J^P) = \frac{1}{2}\left(\frac{1}{2}^+\right)$

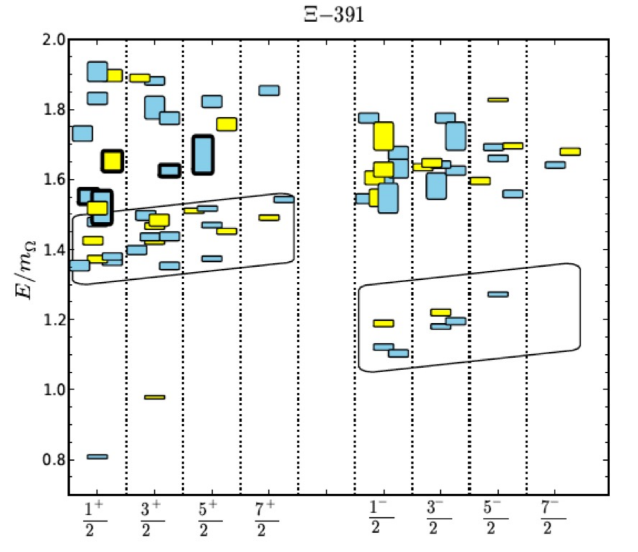


Missing Cascade States

- From SU(3) symmetry, the total number of Ξ^* states should be equal to the number of N^* and Δ^* states combined
- Constituent quark models predict 45 Ξ states
  - Only 11 Ξ states are listed in the PDG
- We should see more Ξ states according to LQCD calculations as well

State, J^P	Predicted masses (MeV)							
$\Xi\frac{1}{2}^+$	1305							
$\Xi\frac{3}{2}^+$	1505							
$\Xi^*\frac{1}{2}^-$	1755	1810	1835	2225	2285	2300	2320	2380
$\Xi^*\frac{3}{2}^-$	1785	1880	1895	2240	2305	2330	2340	2385
$\Xi^*\frac{5}{2}^-$	1900	2345	2350	2385				
$\Xi^*\frac{7}{2}^-$	2355							
$\Xi^*\frac{1}{2}^+$	1840	2040	2100	2130	2150	2230	2345	
$\Xi^*\frac{3}{2}^+$	2045	2065	2115	2165	2170	2210	2230	2275
$\Xi^*\frac{5}{2}^+$	2045	2165	2230	2230	2240			
$\Xi^*\frac{7}{2}^+$	2180	2240						

S. Capstick and N. Isgur. Baryons in a relativized quark model with chromo-
dynamics. Phys. Rev. D, 34:2809–2835, Nov 1986



Particle	J^P	Overall status	Status as seen in — $\Xi\pi$	ΛK	ΣK	$\Xi(1530)\pi$	Other channels
$\Xi(1318)$	1/2+	****					Decays weakly
$\Xi(1530)$	3/2+	****	****				
$\Xi(1620)$		**	**				
$\Xi(1690)$		***	**	***	**		
$\Xi(1820)$	3/2−	***	**	***	**	**	
$\Xi(1950)$		***	**	**		*	
$\Xi(2030)$		***		**	***		
$\Xi(2120)$		*		*			
$\Xi(2250)$		**					3-body decays
$\Xi(2370)$		**					3-body decays
$\Xi(2500)$		*		*	*		3-body decays

**** Existence is certain, and properties are at least fairly well explored.
*** Existence ranges from very likely to certain, but further confirmation is desirable and/or quantum numbers, branching fractions, *etc.* are not well determined.
** Evidence of existence is only fair.
* Evidence of existence is poor.

Edwards R G, Mathur N, Richards D G and Wallace S J (Hadron Spectrum Collaboration) 2013 Phys. Rev. D 87 054506

Why Study Cascades?

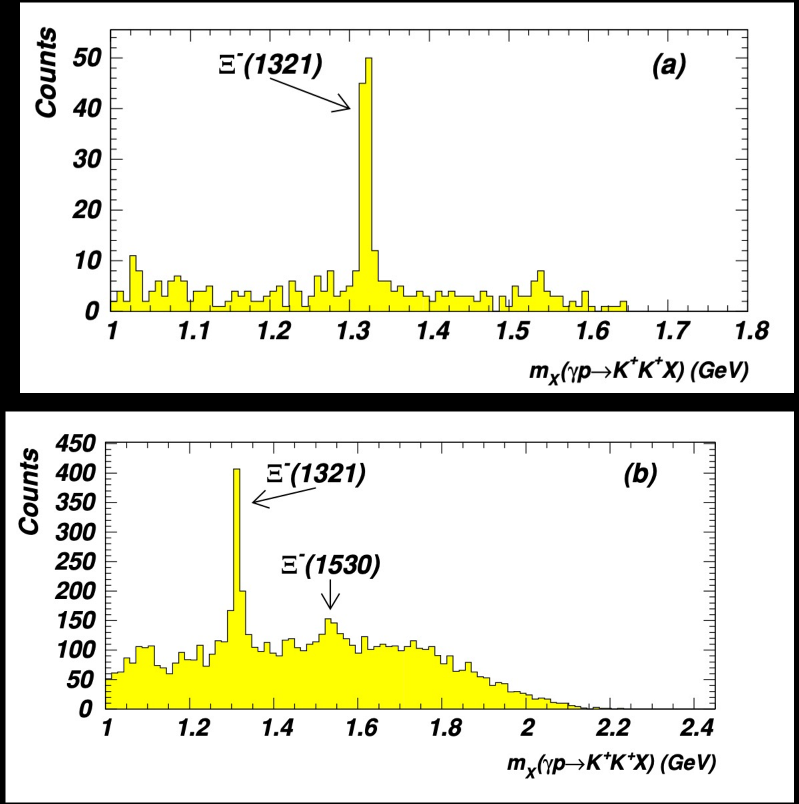
- Most of our knowledge about Ξ's stems from kaon and hyperon beam experiments from the 1960's to 1990's
- Since the 2000's, high luminosity photo– and electro-production experiments have opened new avenues to study cascades
- Relatively narrow widths for well established states
- Production mechanism remains unclear
- Possible production mechanism is a two-step t-channel process through intermediate N^* and Y^* resonance

(K. Nakayama, Y. Oh, and H. Haberzettl. Photoproduction of Ξ off nucleons. Phys. Rev. C, 74:035205, Sep 2006).

State	PDG rating	Width (MeV)	J^P
$\Xi(1320)$	****		$\frac{1}{2}^+$
$\Xi(1530)$	****	9.5	$\frac{3}{2}^+$
$\Xi(1690)$	***	< 30	$\frac{1}{2}^-?$
$\Xi(1820)$	***	24	$\frac{3}{2}^-$
$\Xi(1950)$	***	60	?
$\Xi(2030)$	***	20	$\frac{5}{2}^?$

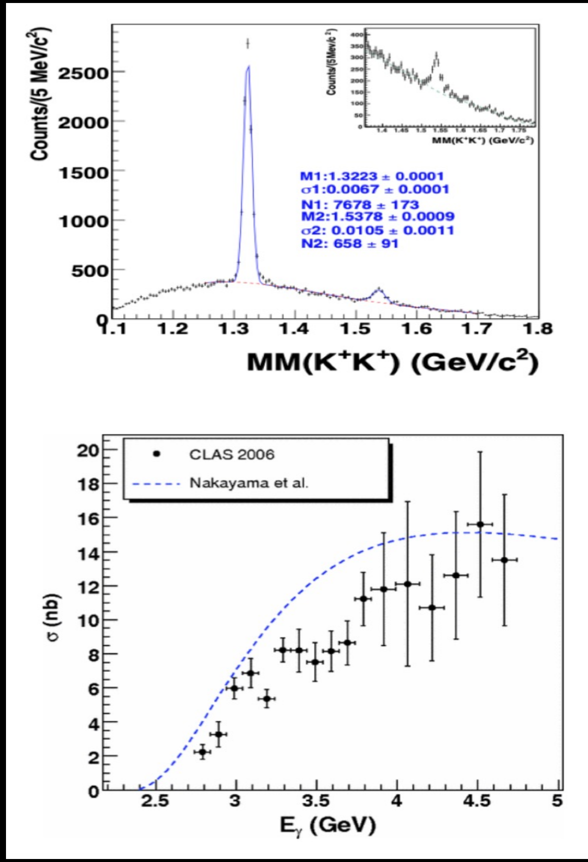
Previous Photoproduction Results

2005: CLAS g6 ($3.2 < E_\gamma < 3.9\ GeV$) provided the first-ever exclusive measurement of Ξ^- in $\gamma p \rightarrow K^+K^+\Xi^-$



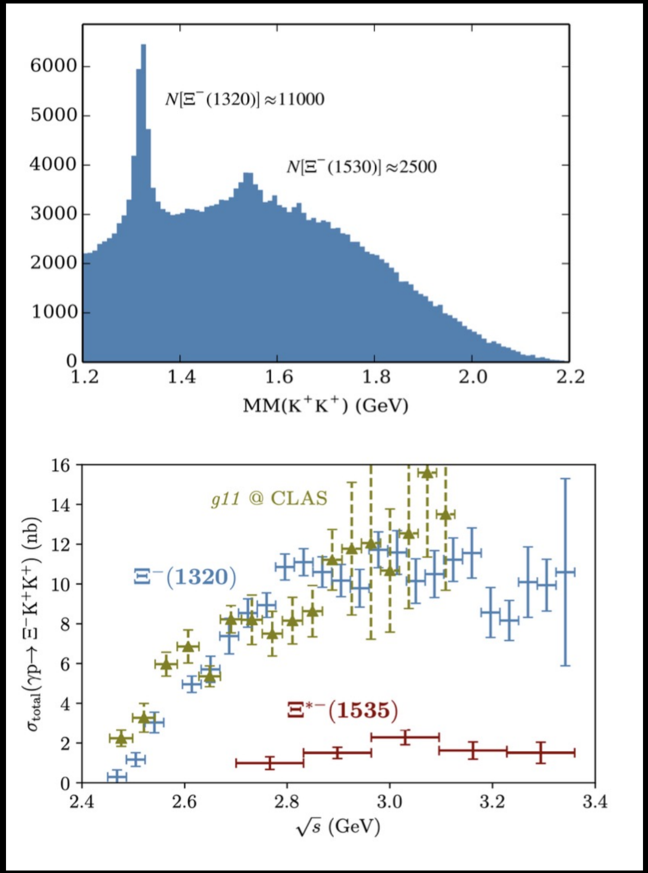
J.W.Price et al. Exclusive photoproduction of the cascade hyperons

2007: CLAS g11 data ($2.75 < E_\gamma < 4.75\ GeV$), 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 $\gamma p \rightarrow K^+K^+\pi^-(X)$

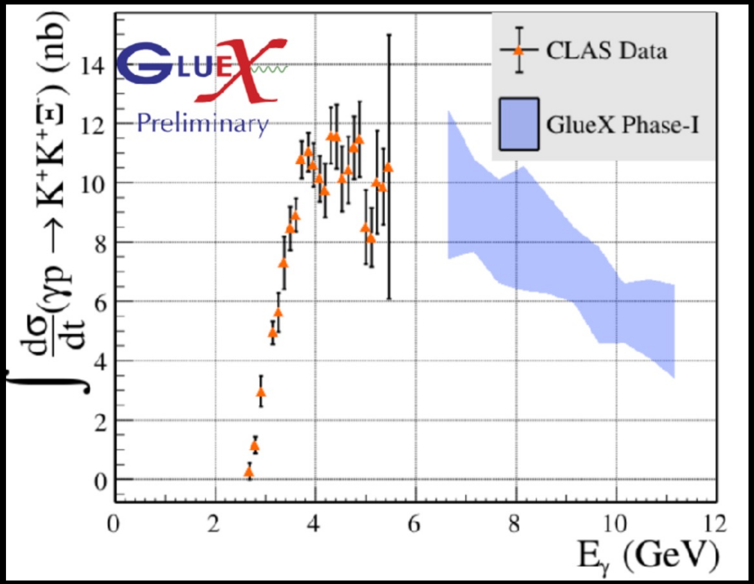
2018: CLAS g12 expanded the kinematic region of study (W=3.3GeV) as well as increased statistics

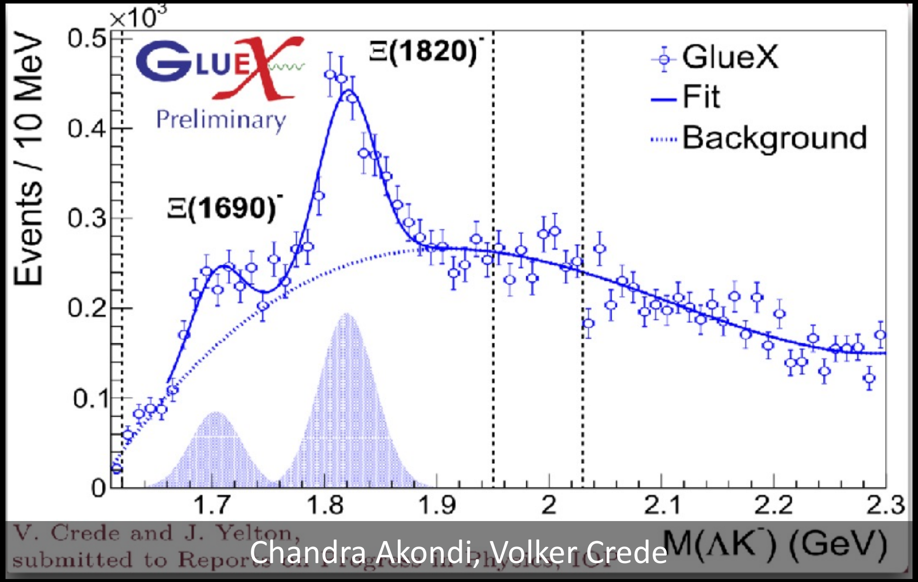


J.T. Goetz et al. Ξ^* Photoproduction from Threshold to W=3.3 GeV

GlueX Cascade Studies

- GlueX has recently presented on Cascade production (Hao Li, JLUO 2024)
- Extending the energy region of photoproduction data for $\Xi^-(1320)$ as well as first photoproduction measurement of $\Xi^{*-}(1690)$ and $\Xi^{*-}(1820)$

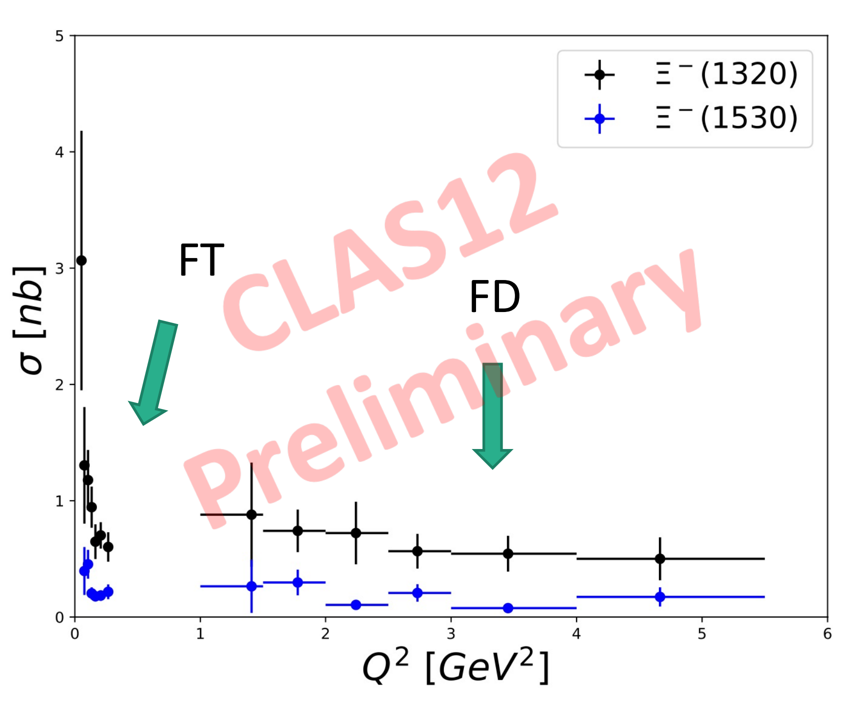


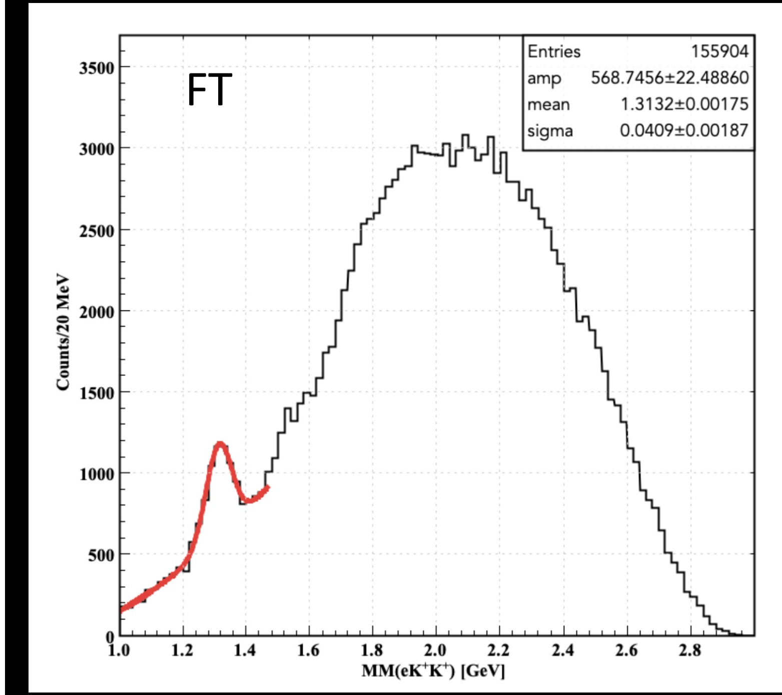


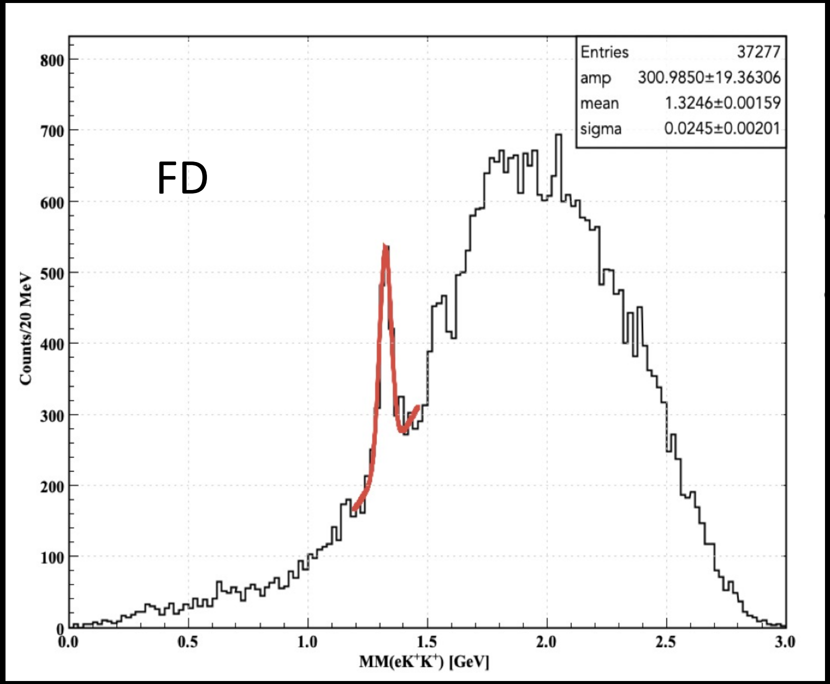
Chandra Akondi, Volker Crede

First time C.S. for $\Xi^-(1320)$ in Electroproduction (2024)

- Jose Carvajal, Ph.D. thesis "First Time Measurement of Ground State Ξ^- Hyperon Cross Section in Electroproudction"
- RG-A data ($E_{beam} = 10.2\ GeV$, Inbending)

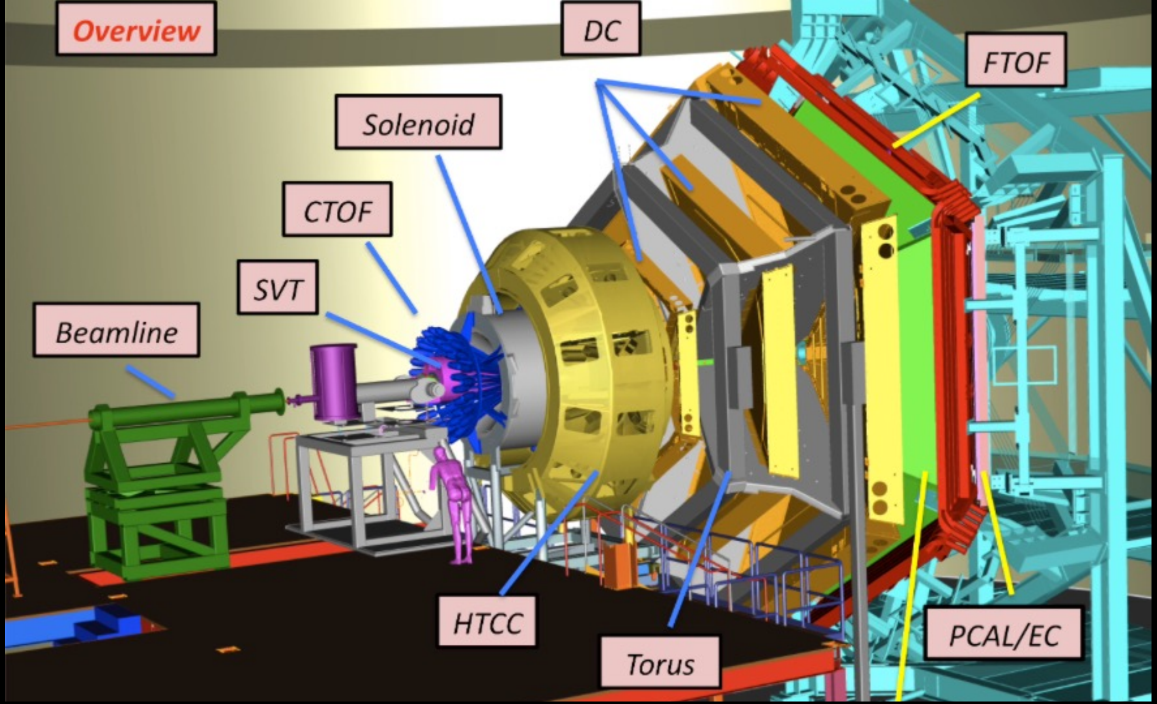


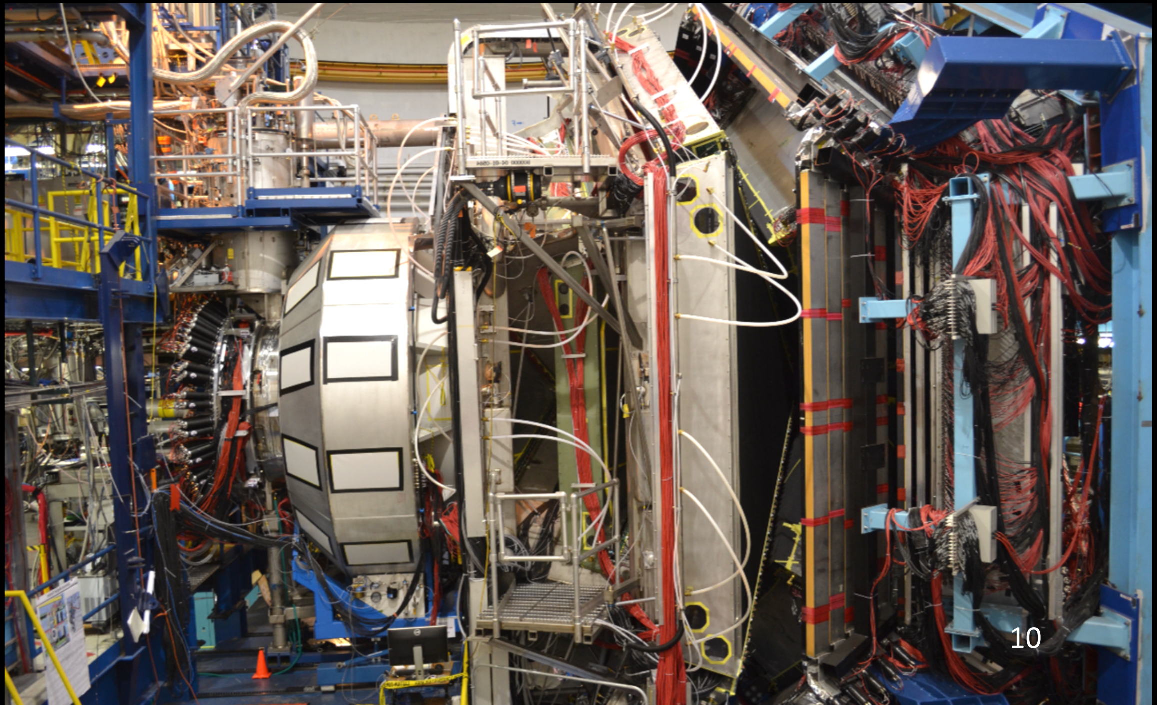




CLAS12 at Jefferson Lab

- **C**EBAF **L**arge **A**cceptance **S**pectrometer at 12 GeV (CLAS12)
- Nearly 4π solid angle coverage
- 3 polar angle regions:
  - Very Forward (Forward Tagger)
    - $2.5° \leq \theta \leq 4.5°$
  - Forward (Forward Detector)
    - $5.0° \leq \theta \leq 35°$
  - Central
    - $35° < \theta \leq 125°$





Experimental Conditions

- **Data**: CLAS12 Run Group K (Fall 2018)
- **Beam**: 6.5 and 7.5 GeV
- **Target**: 5 cm unpolarized LH_2
- **Total charge**:

  $6.5\ GeV: 18.32\ mC$

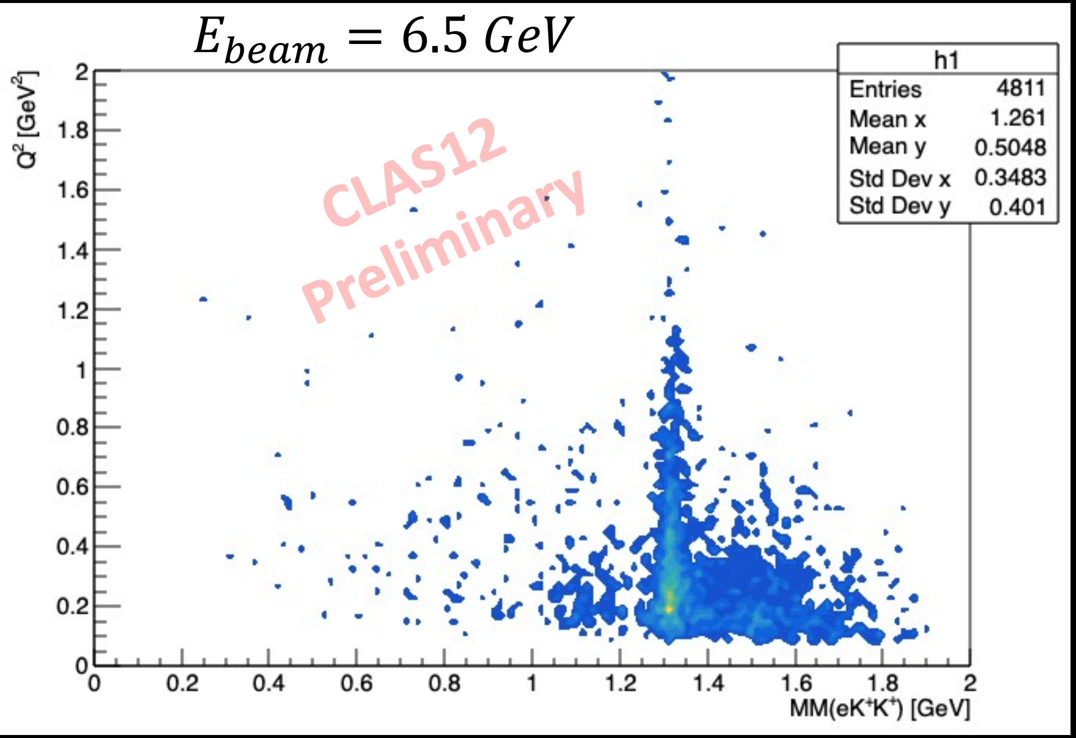
  $7.5\ GeV: 10.77\ mC$
- **Luminosity**: $10^{35} cm^{-2} s^{-1}$

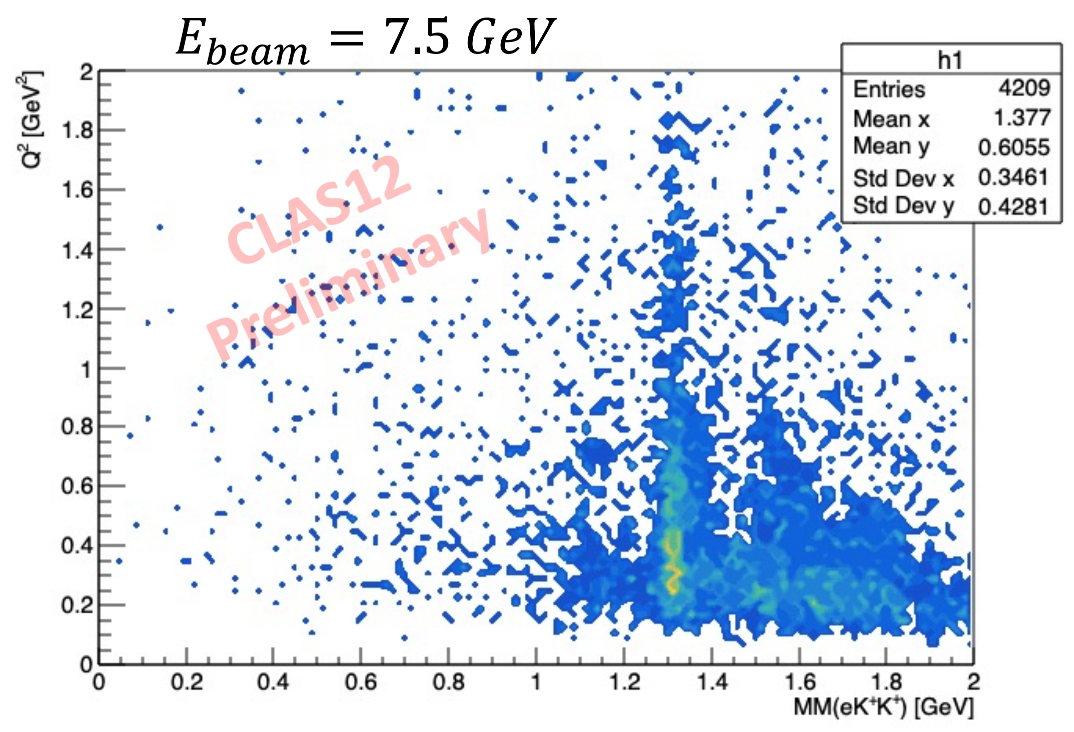
Event Reconstruction

- Studying the exclusive reaction: $ep \rightarrow e'K^{+}K^{+}(\Xi^{-})$
  - Reconstructing Ξ^{-} signal via missing mass technique
- All $K^{+'}s$ required to be in Forward Detector
  - For optimal tracking efficiency
- Electron in both the FD and FT are being analyzed
  - Forward Tagger ($E_{beam} = 7.5\ GeV$):
    - $0.1 \leq Q^2 \leq 0.4\ GeV^2$
  - Forward Detector region ($E_{beam} = 6.5\ and\ 7.5\ GeV$)
    - $0.5 \leq Q^2 \leq 2\ GeV^2$
- Various selection cuts on timing, $P, \theta, ToF, \chi^2_{pid}$ are applied

Kinematic Coverage
Forward Detector

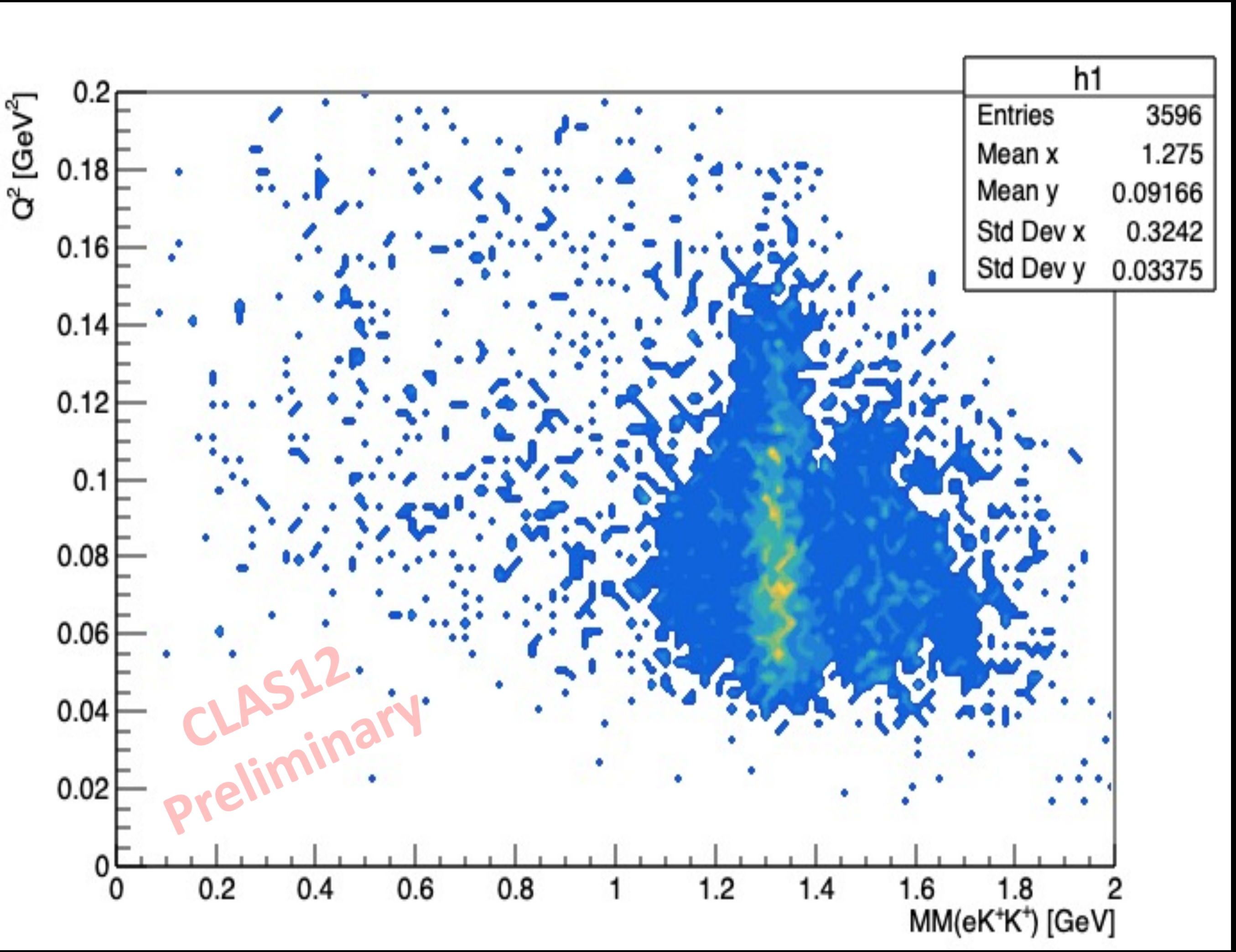
- Data are binned in Q^2
- Q^2 coverage ranges from $\sim 0.15 - 2.0\ GeV^2$
- Clear $\Xi^-(1320)$ signal
- $\Xi^-(1530)$ signal as well





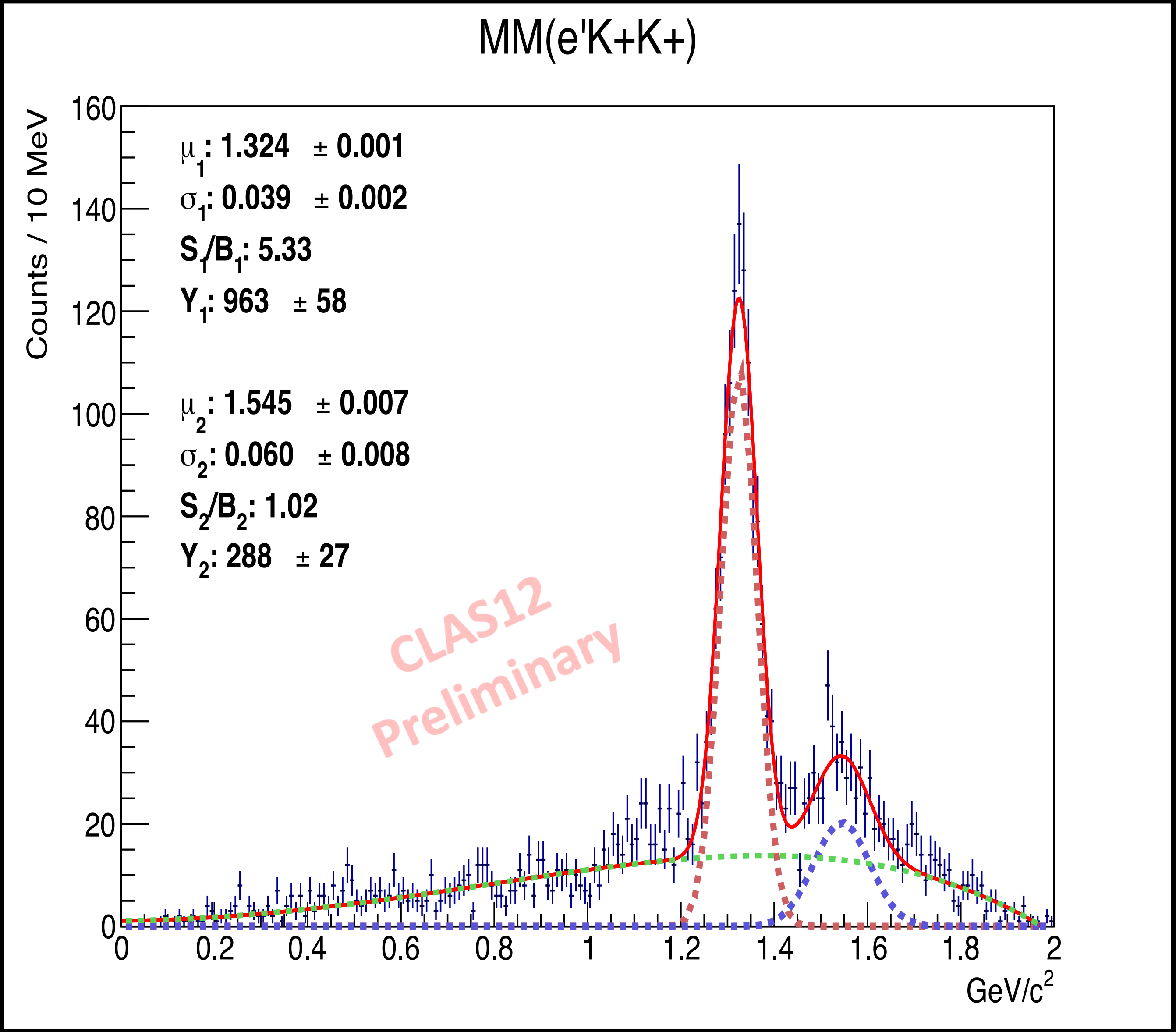
Kinematic Coverage Forward Tagger

- Quasi-real photoproduction regime
- Very Forward
  - $(2.5° \leq \theta \leq 4.5°)$
- Q^2 coverage from $\sim 0.04\ - 0.18\ GeV^2$



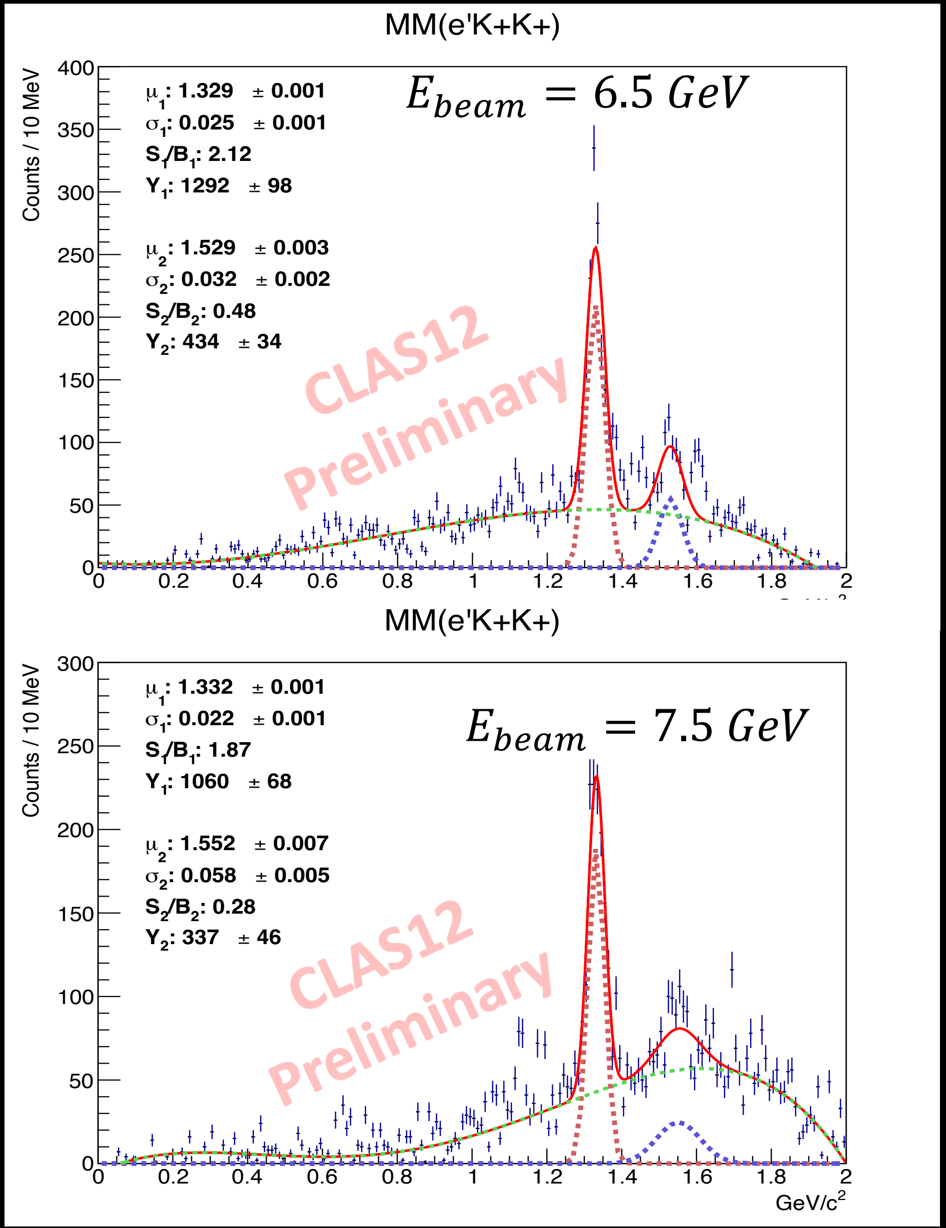
Missing Mass Distribution (FT)

- Lowest yield out of all data sets
- Both signals are fitted to a gaussian
- Background fitted to 4th order polynomial



Missing Mass Distributions (FD)

- Highest yield out of all data sets is the eFD for $E_{beam} = 6.5\ GeV$
- Both signals are fitted to a gaussian
- Background fitted to 4th order polynomial
  - Need a better understanding of background shape!



Understanding the Background

Mixed events background

- Randomizing the lower momentum kaon and computing the missing mass

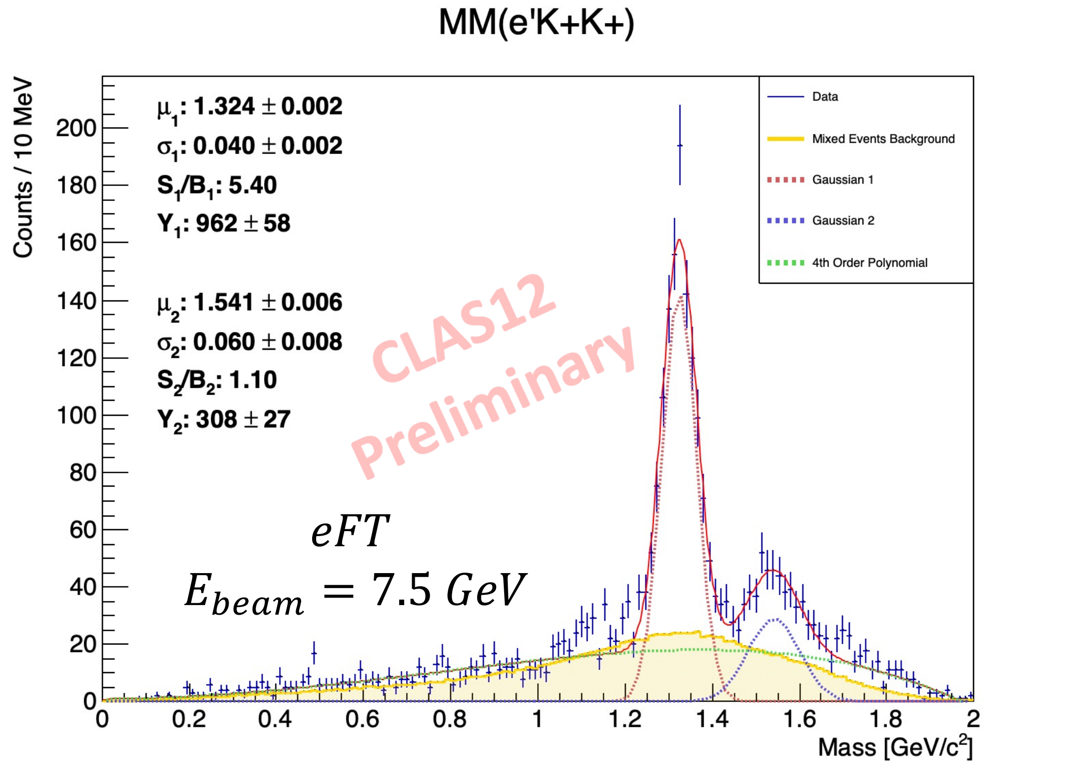
$$\mathrm{P}^{\mu}_{miss} = \mathrm{P}^{\mu}_{beam} + P^{\mu}_{target} - \left(P^{\mu}_{e} + P^{\mu}_{K_1^+} + P^{\mu}_{K_i^+}\right)$$

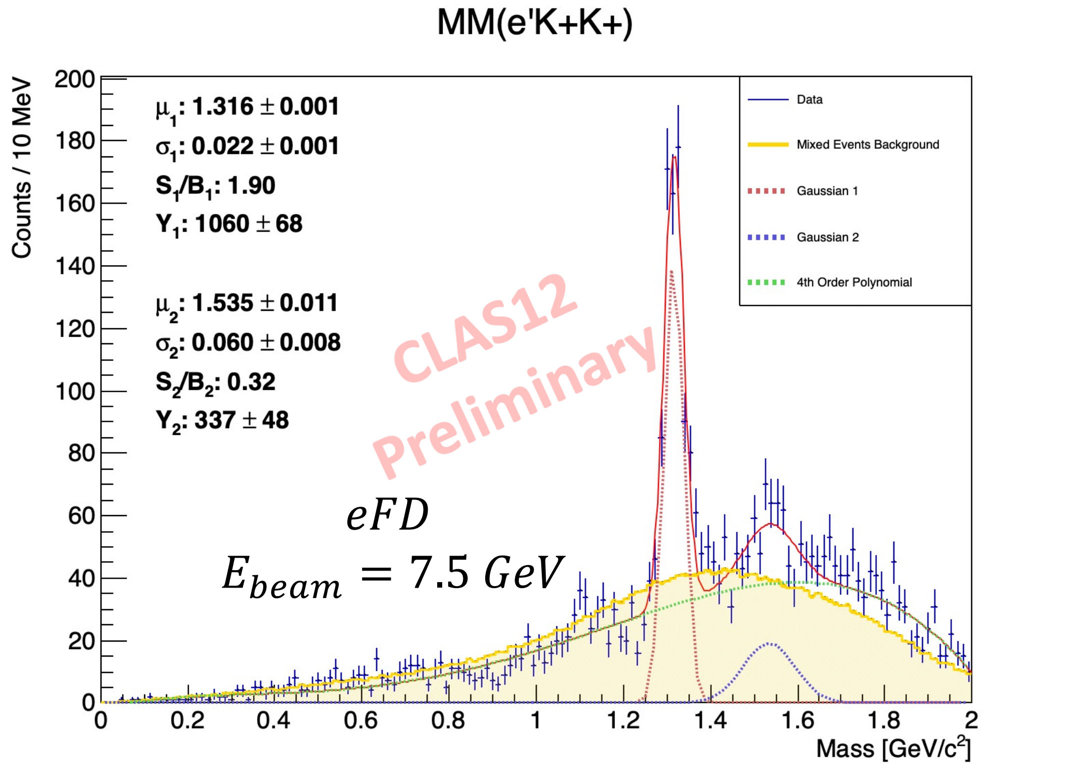
where $P^{\mu}_{K_i^+}$ is randomly selected

- Differs bin-by-bin in Q^2
- Worked well for previous electroproduction results

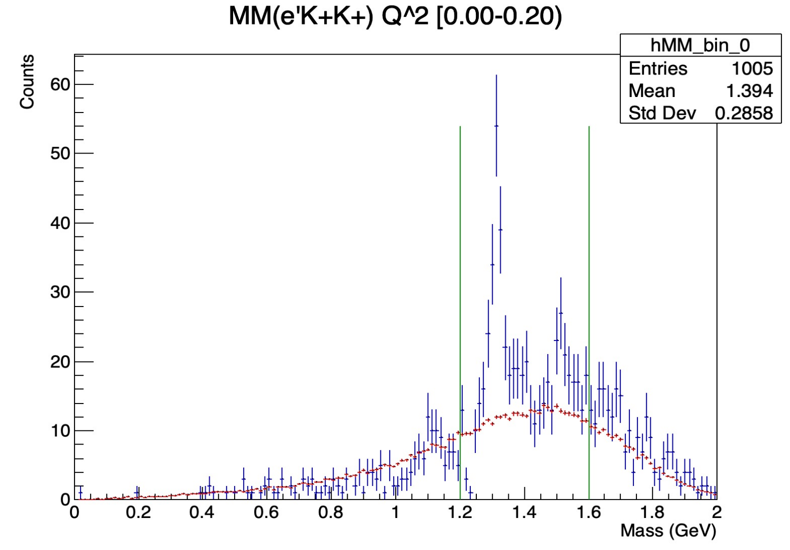
Mixed Events overall Q^2 range

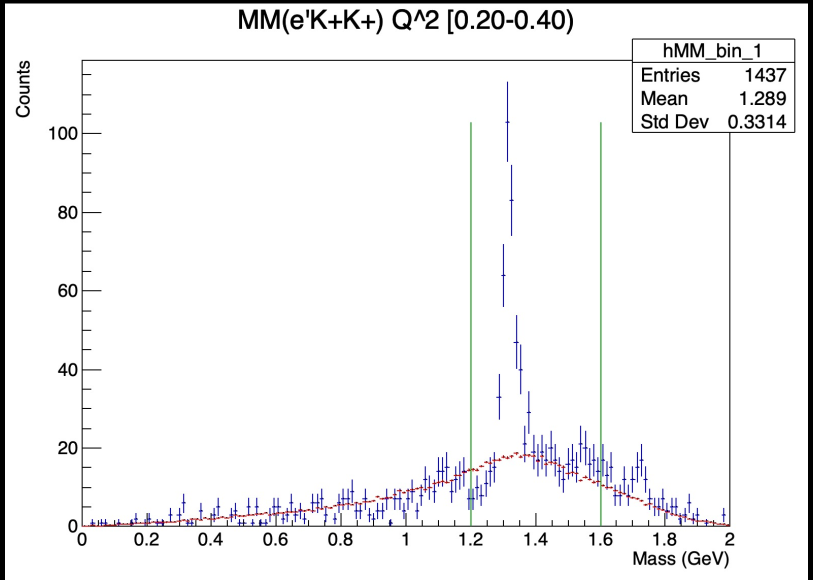
- Shaded yellow represents the mixed events background
- Summary of Forward Tagger and Forward Detector at 7.5 GeV over full Q^2 range

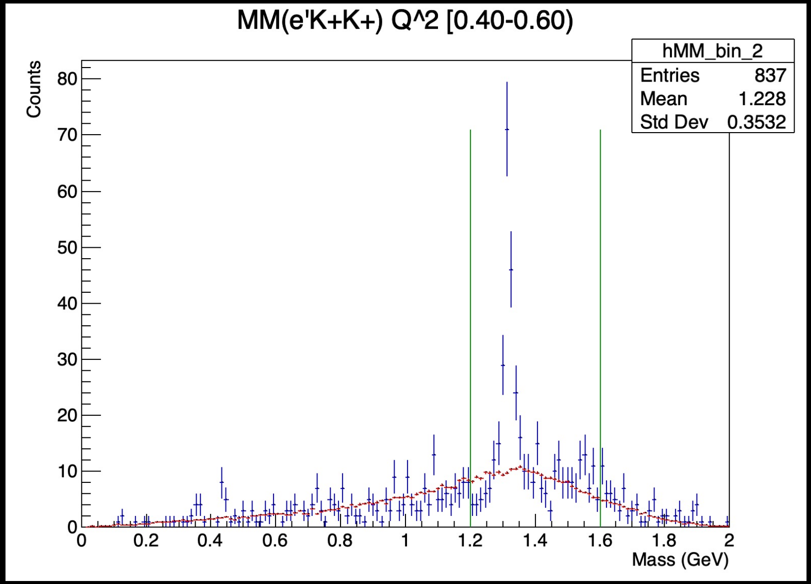


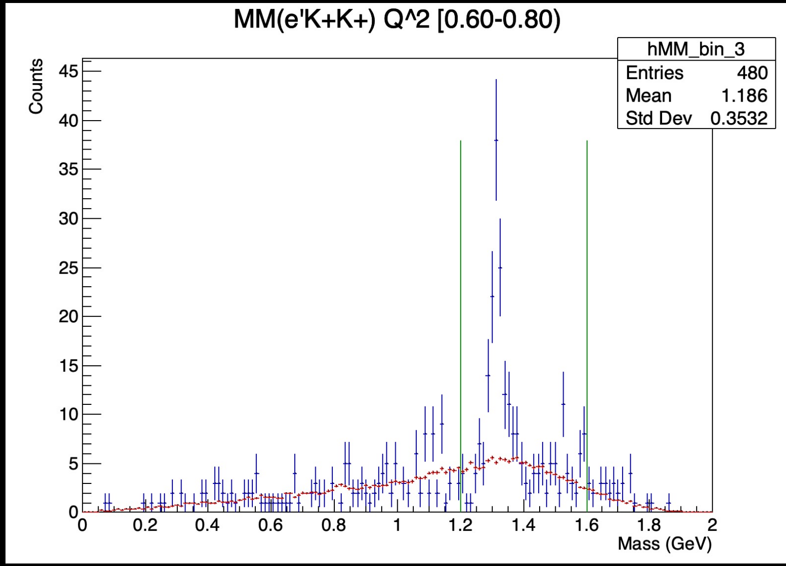


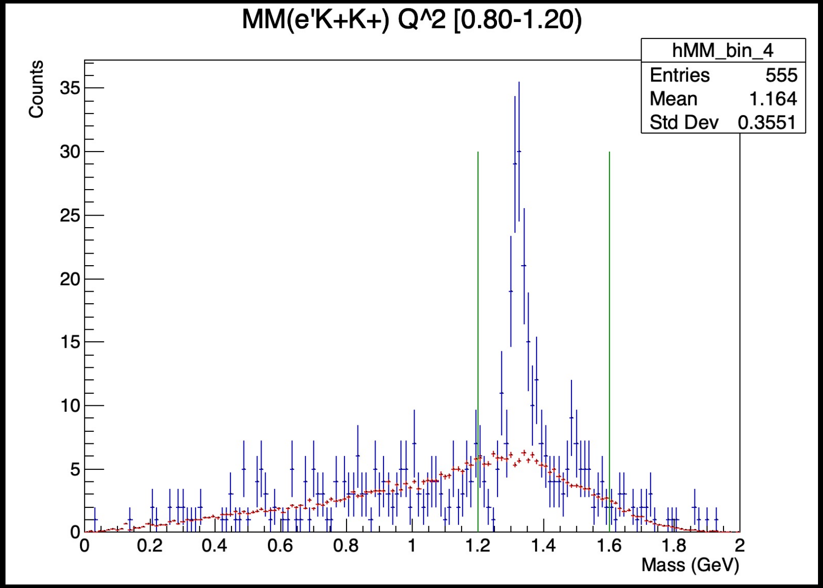
Mixed Events bin-by-bin in Q^2 eFD $E_{beam} = 6.5$ GeV

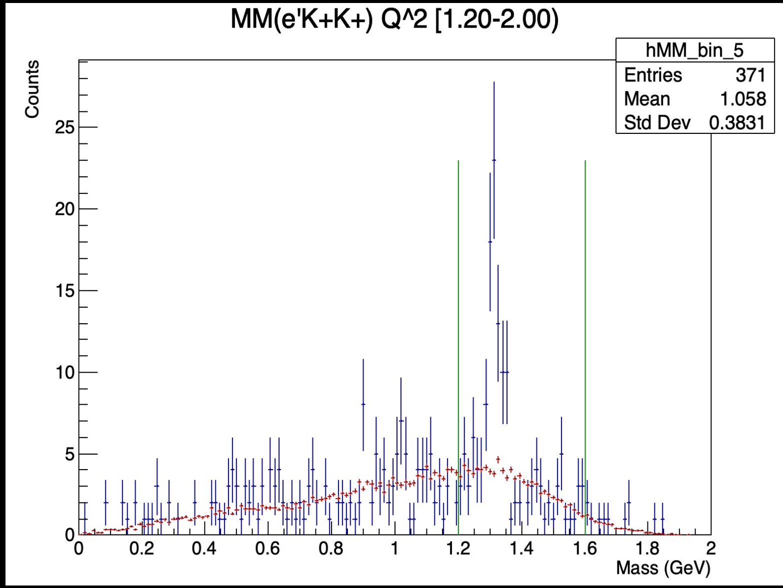

MM(e'K+K+) Q^2 [0.00-0.20)
hMM_bin_0
Entries 1005
Mean 1.394
Std Dev 0.2858
Counts
Mass (GeV)


MM(e'K+K+) Q^2 [0.20-0.40)
hMM_bin_1
Entries 1437
Mean 1.289
Std Dev 0.3314
Counts
Mass (GeV)


MM(e'K+K+) Q^2 [0.40-0.60)
hMM_bin_2
Entries 837
Mean 1.228
Std Dev 0.3532
Counts
Mass (GeV)

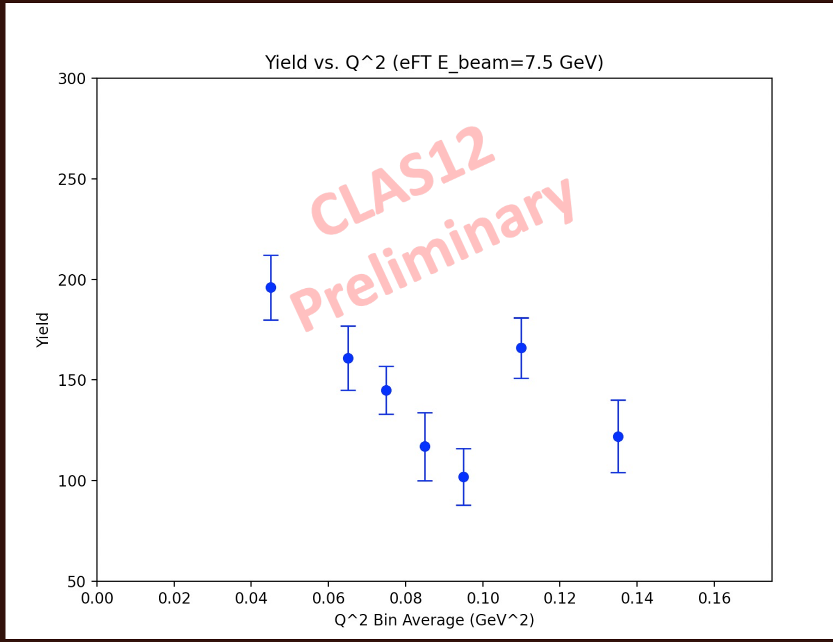

MM(e'K+K+) Q^2 [0.60-0.80)
hMM_bin_3
Entries 480
Mean 1.186
Std Dev 0.3532
Counts
Mass (GeV)

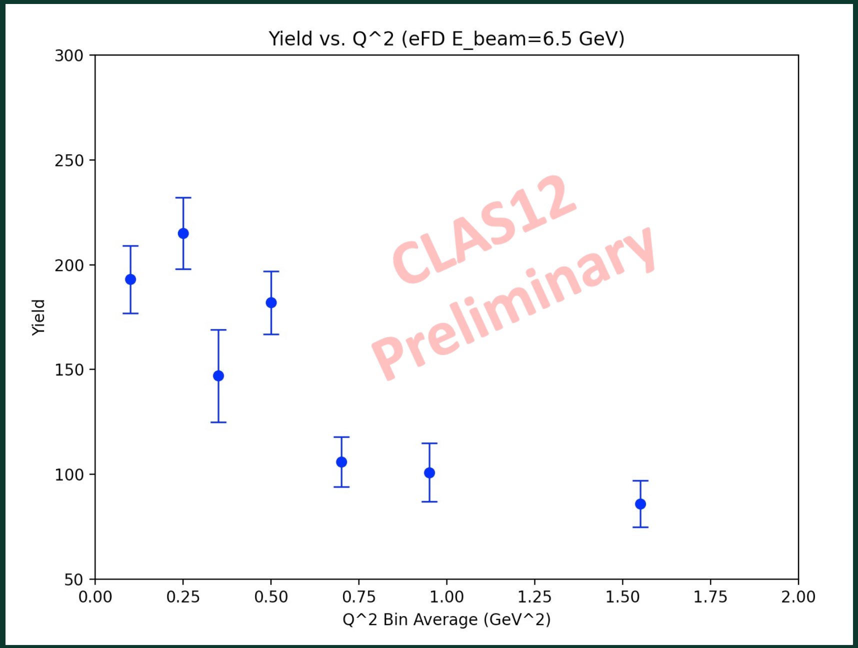

MM(e'K+K+) Q^2 [0.80-1.20)
hMM_bin_4
Entries 555
Mean 1.164
Std Dev 0.3551
Counts
Mass (GeV)

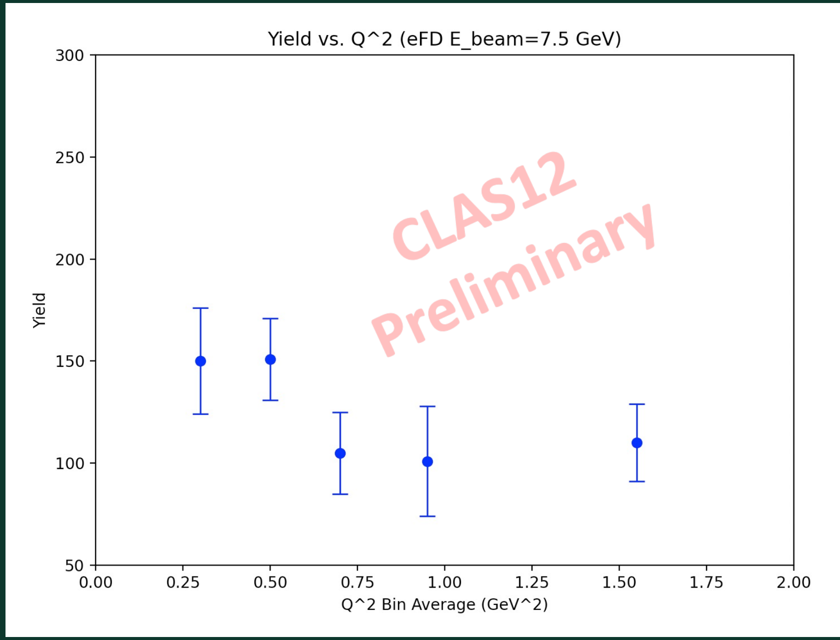

MM(e'K+K+) Q^2 [1.20-2.00)
hMM_bin_5
Entries 371
Mean 1.058
Std Dev 0.3831
Counts
Mass (GeV)

$\Xi^-(1320)$ Yield

- All current available data from pass 2 RG-K is presented
- Reported at the bin-average
- Not acceptance corrected

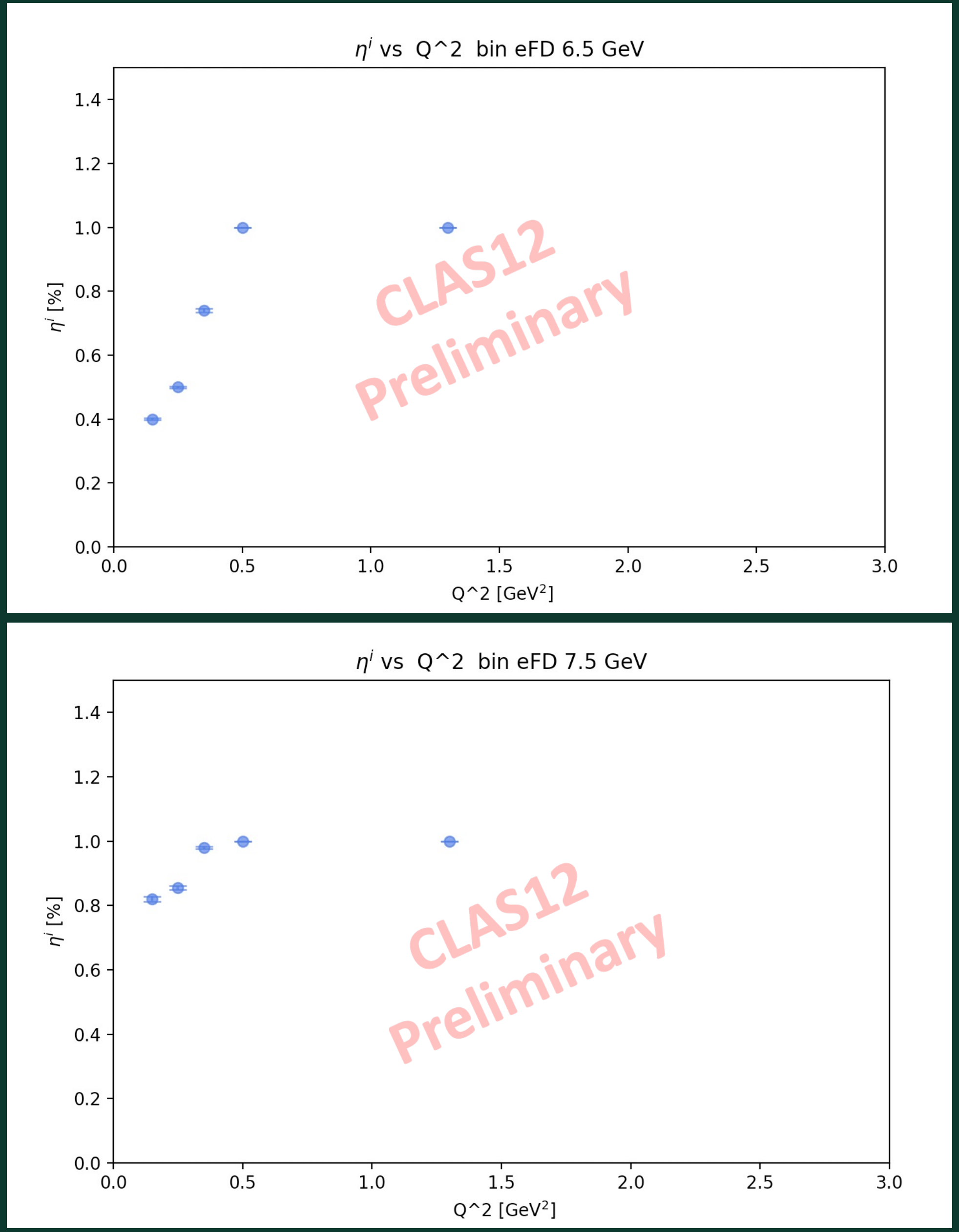






Forward Detector Acceptance

- Acceptance: $\eta^i = \frac{N_{rec}}{N_{gen}}$
- Does not account for uncertainties from the model
- Current acceptance is shown for equal weighing for s and t-channel production
- Forward Tagger acceptance is underway



Summary and Outlook

- Yield for ground state shows promising results
  - Potential to explore $\Xi(1530)$ as well
- Data compliments previous electroproduction results
  - Gap in FD Q^2 coverage is filled
- New run data is coming very soon with increased statistics!
  - Approximately 30% more statistics
- Cross section results coming soon!

Thank You!

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