# UPDATE ON RG-K CASCADE PRODUCTION

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# Motivation to Study Cascades

- There are many missing cascade states that are predicted by flavor $SU(3)_F$ symmetry.
  - *From $SU(3)_F$ flavor symmetry, we expect the total number of $\Xi^*$ states to be the sum of $N^*$ and $\Delta^*$ states.*
  - *Theory calculations and more recently lattice QCD calculations predict many more states that have yet to be found*

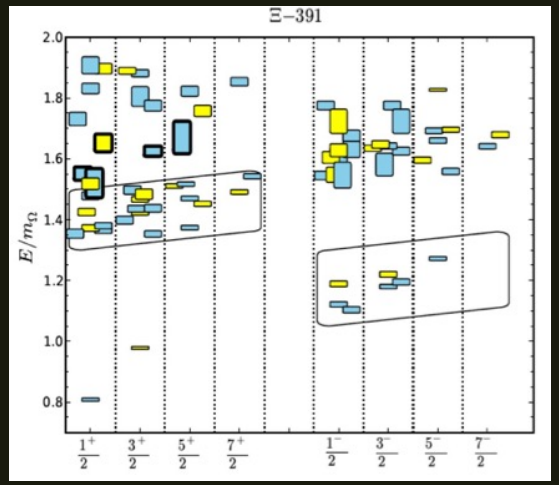
In addition to this…we also don't know their production mechanism!

- **In this analysis we aim to study the octet ground state, $\Xi^-(1320)$ and the decuplet ground state, $\Xi^-(1530)$**

| 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 | | | | | | |

| Particle | $J^P$ | Overall status | Status as seen in — $\Xi\pi$ | $\Lambda K$ | $\Sigma K$ | $\Xi(1530)\pi$ | 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. |

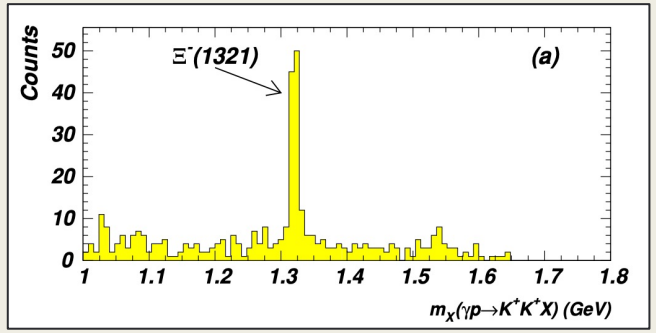


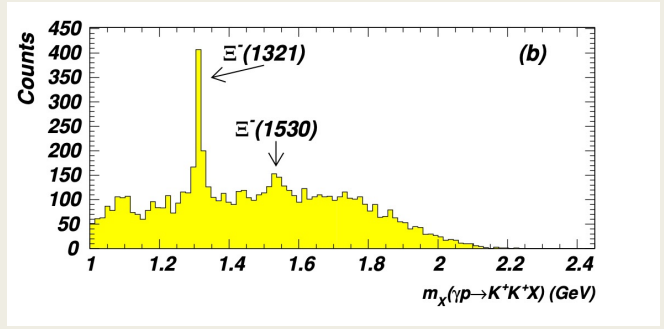

S. Capstick and N. Isgur. Baryons in a relativized quark model with chromo-dynamics. Phys. Rev. D, 34:2809–2835, Nov 1986

Edwards R G, Mathur N, Richards D G and Wallace S J (Hadron Spectrum Collaboration) 2013 Phys. Rev. D 87 05450

# Photoproduction of Cascades

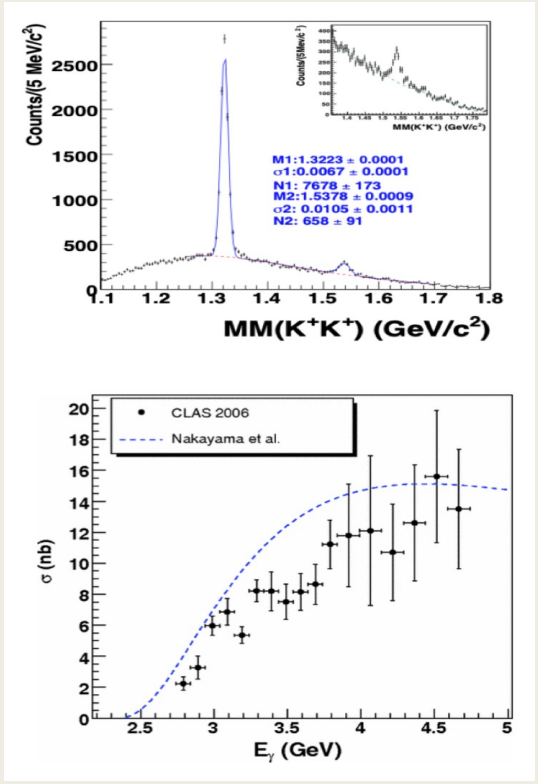
**2005**: CLAS g6 provided the first-ever exclusive measurement of $\Xi^-$ in $\gamma p \rightarrow K^+K^+\Xi^-$



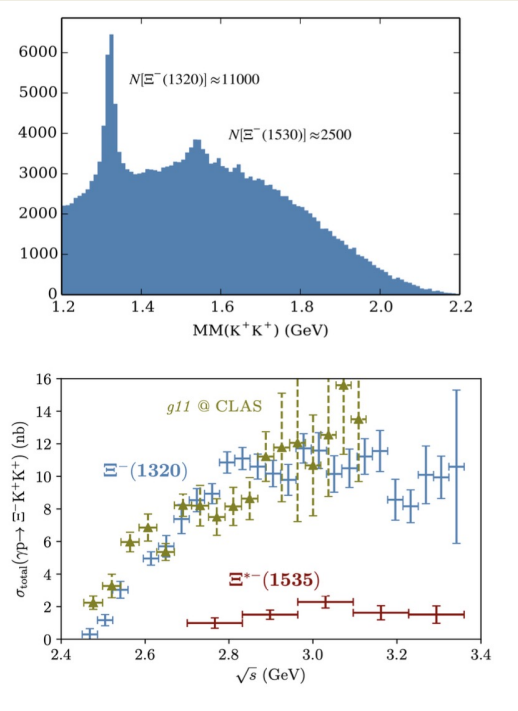

J.W.Price et al. Exclusive photoproduction of the cascade hyperons

**2007**: g11 data, provided cross section results for $\Xi^-$ (1320) and $\Xi^-$(1530)



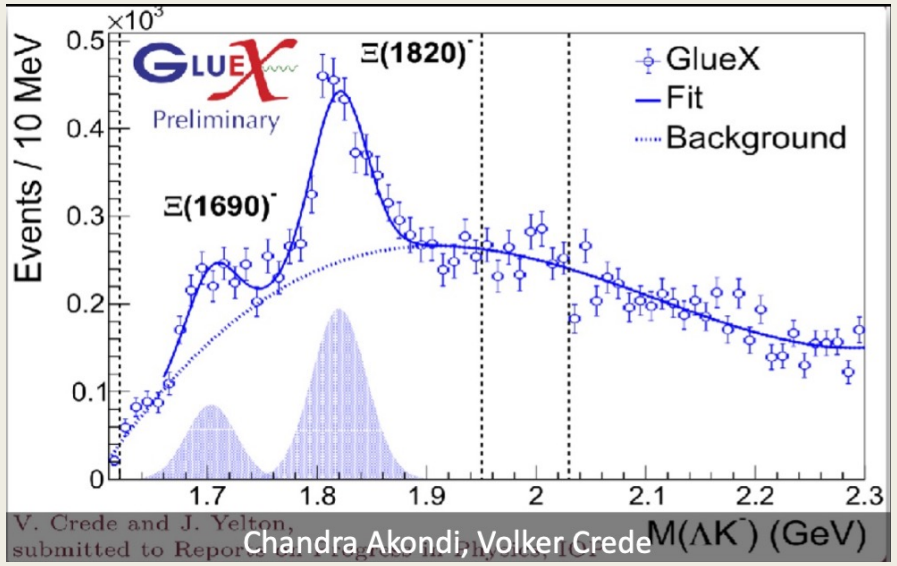

L.Guo et al. Cascade production in the reaction $\gamma p \rightarrow K^+K^+(X)$ and $\gamma p \rightarrow K^+K^+\pi^-(X)$

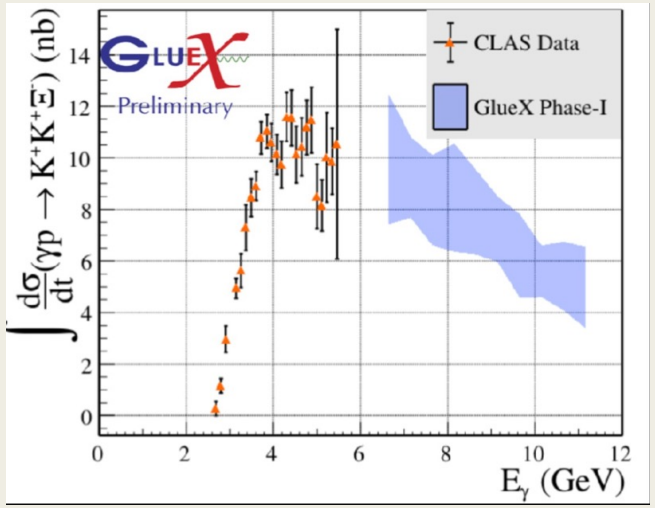
**2018**: g12 expanded the kinematic region of study (W=3.3GeV) as well as increased statistics




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

# GLUEX CASCADE STUDIES

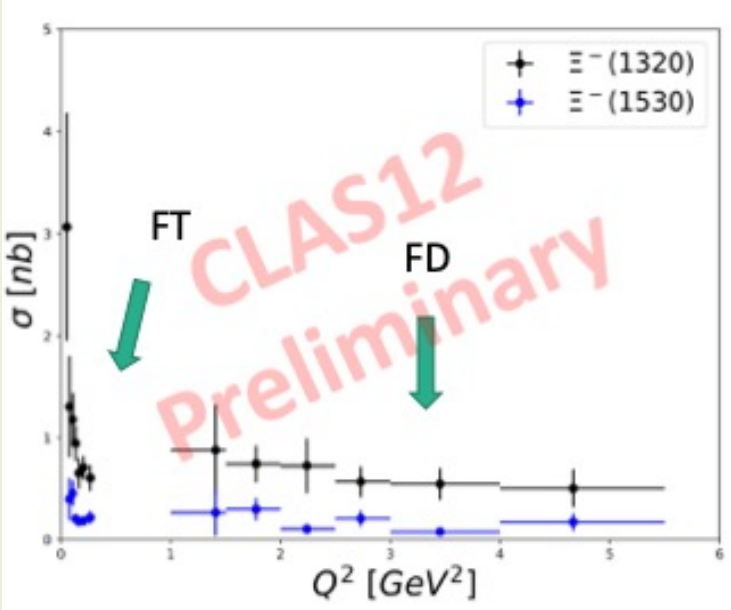


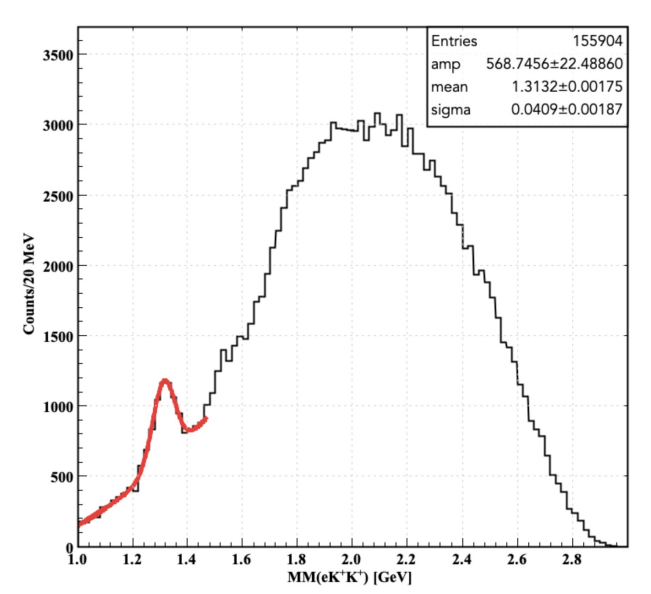



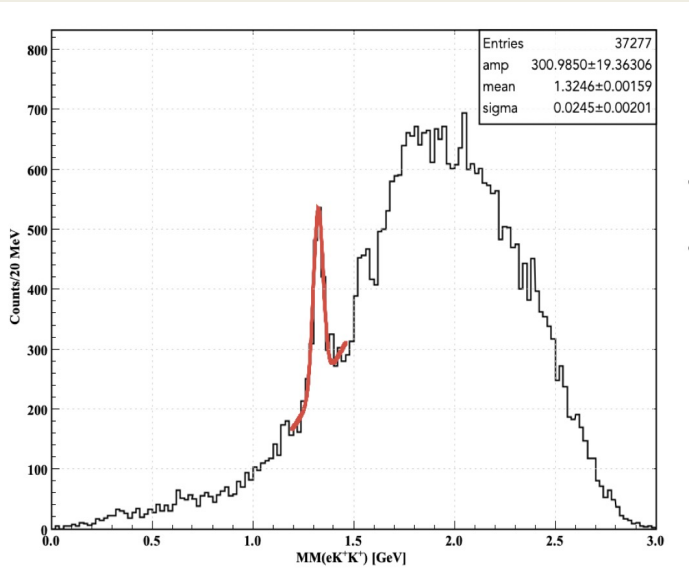

- GlueX presented on Cascade photoproduction (Hao Li, JLUO 2024)
- Extending the energy region of photoproduction data for $\Xi^{-}(1320)$ as well as first photoproduction measurement of $\Xi^{*-}(1690)$ and $\Xi^{*-}(1820)$

# FIRST ELECTROPRODUCTION CASCADE RESULTS

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



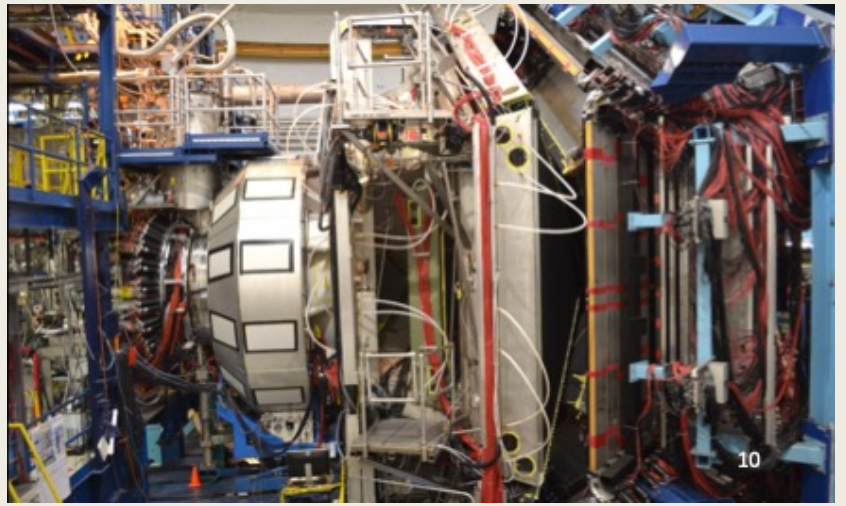



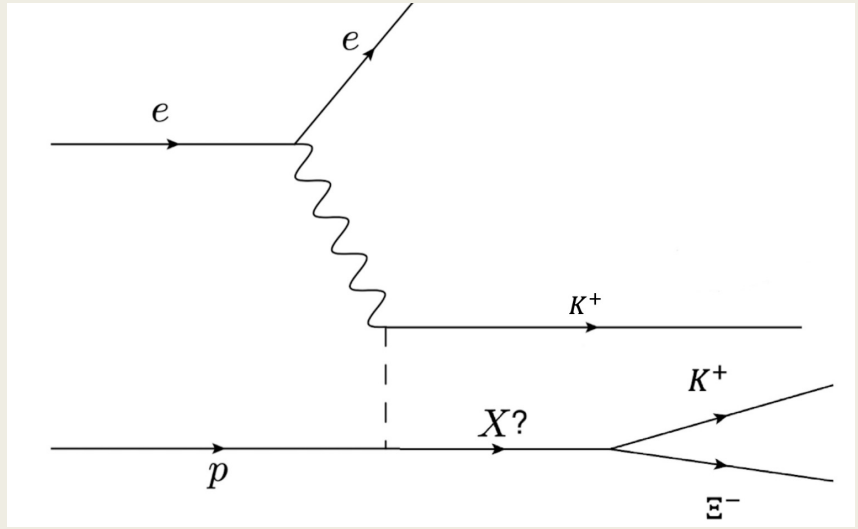
# Current Work

**Cross section measurement for both $\Xi^-(1320)$ and $\Xi^-(1530)$ for lower electron beam energies of 6.5 and 7.5 GeV across a range of $0.04 \leq Q^2 \leq 2.0\ GeV^2$ using CLAS12's forward detector and forward tagger (very low (quasi-real photoproduction) $Q^2$ region)**

- *Binning in $Q^2$ and $cos\theta_{\Xi^-}^{CM}$*
- *Filling in gap in $Q^2$ coverage from previous electroproduction results*
- *Shedding light on unclear production mechanism of $\Xi^-$*
- *Search for potential intermediate hyperon state $Y^*$*

***Focus for this talk will be on the $\Xi^-(1320)$ cross section***



# Analysis Procedure

Skim each data set for the desired final state of $e'K^+K^+$

Reconstruct $\Xi^-$ from MM($e'K^+K^+$) and refine with event selection cuts

Determine bins in $cos\theta_{\Xi^-}^{CM}$ and $Q^2$ and extract yields

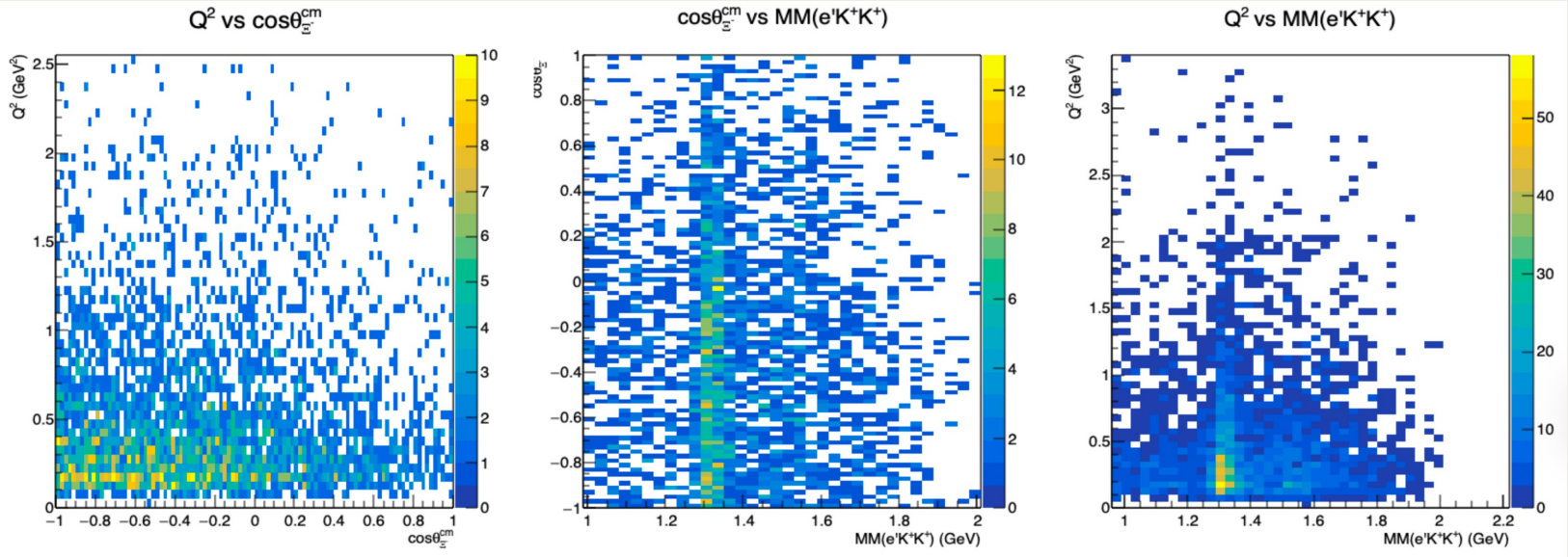
Run simulations for acceptance calculations

Calculate Differential Cross Section

# Forward Detector Kinematic Coverage

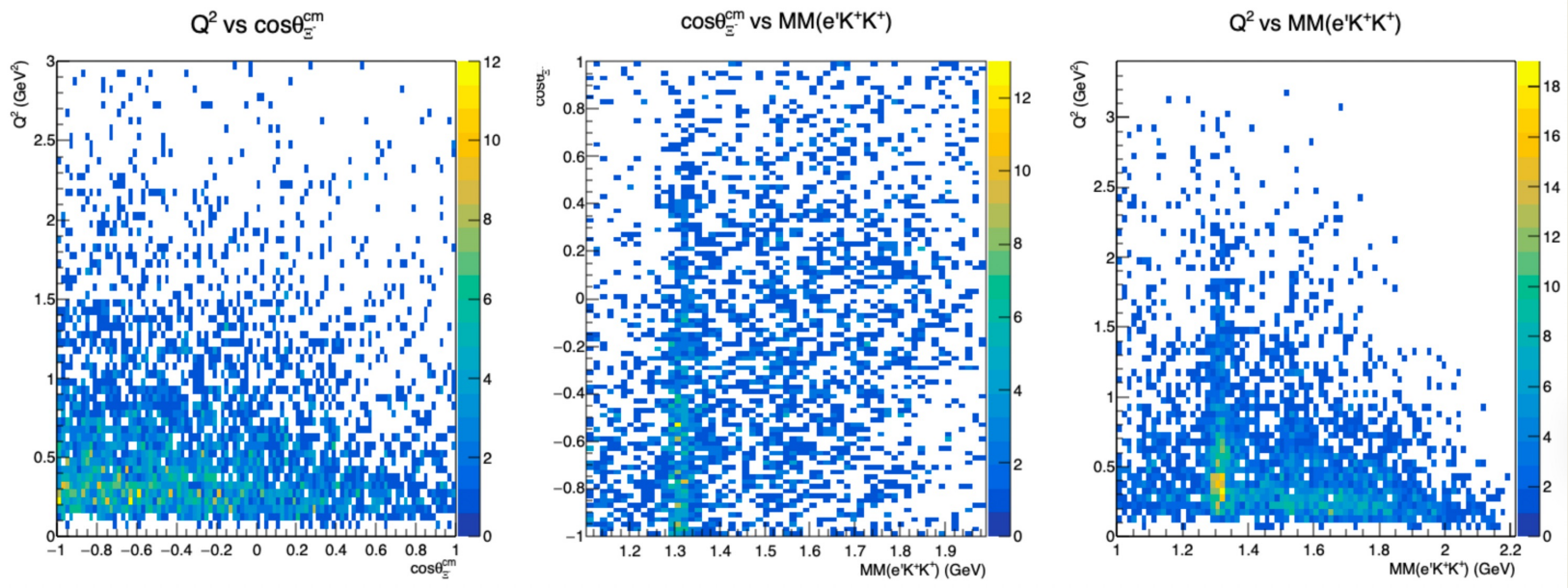
$E_{beam} = 6.5\ GeV$

$0.2 \leq Q^2 \leq 1.2\ GeV^2$

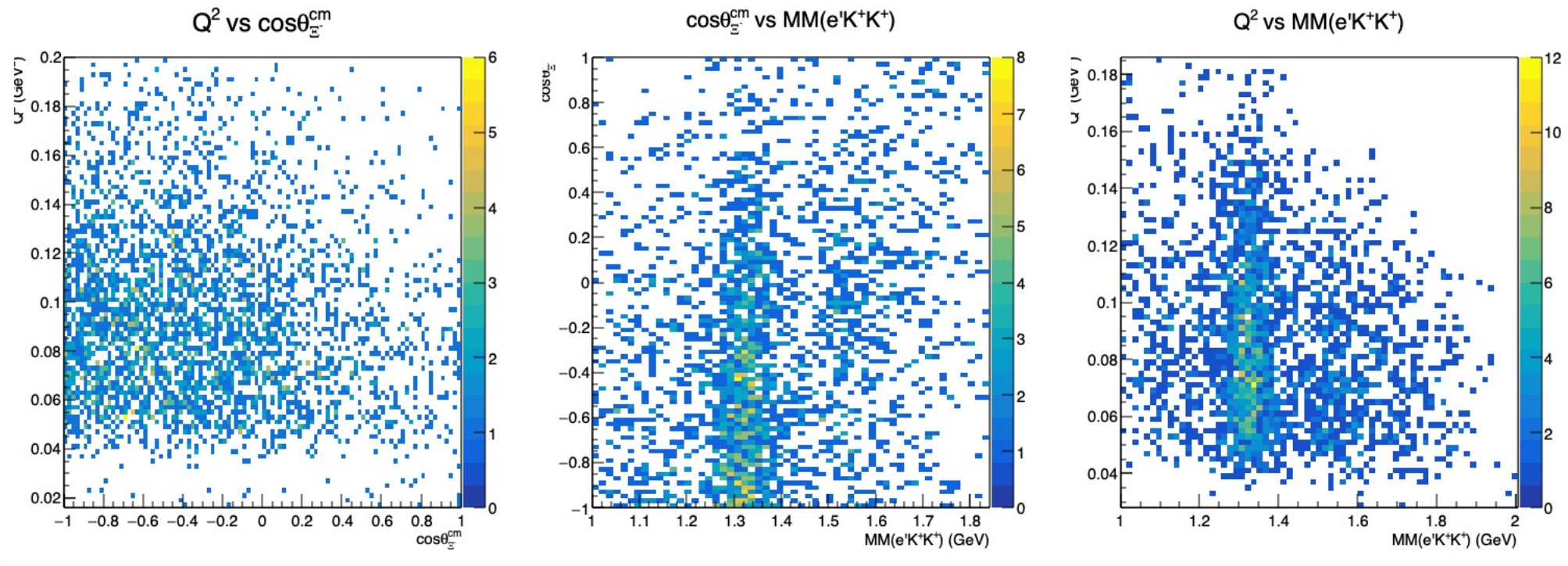



$E_{beam} = 7.5\ GeV$

$0.2 \leq Q^2 \leq 2.0\ GeV^2$



# Forward Tagger Kinematic Coverage




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

$$0.04 \leq Q^2 \leq 0.18\ GeV^2$$

# Event Selection

**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, $\theta_{K^+}$ cuts applied

**Electron Selection Criteria**

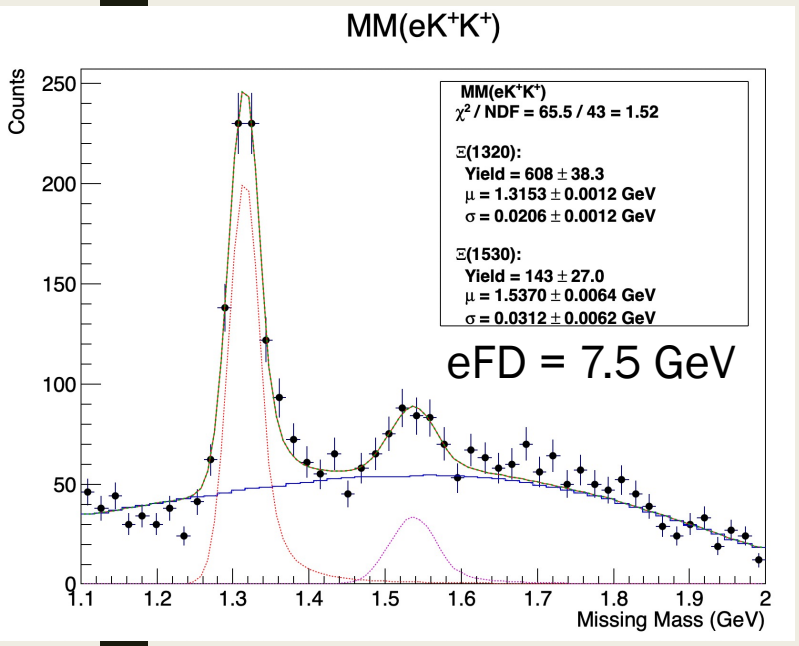
- FT and FD region
- Status, TOF, P, Vz, $\theta_{e'}$ cuts applied

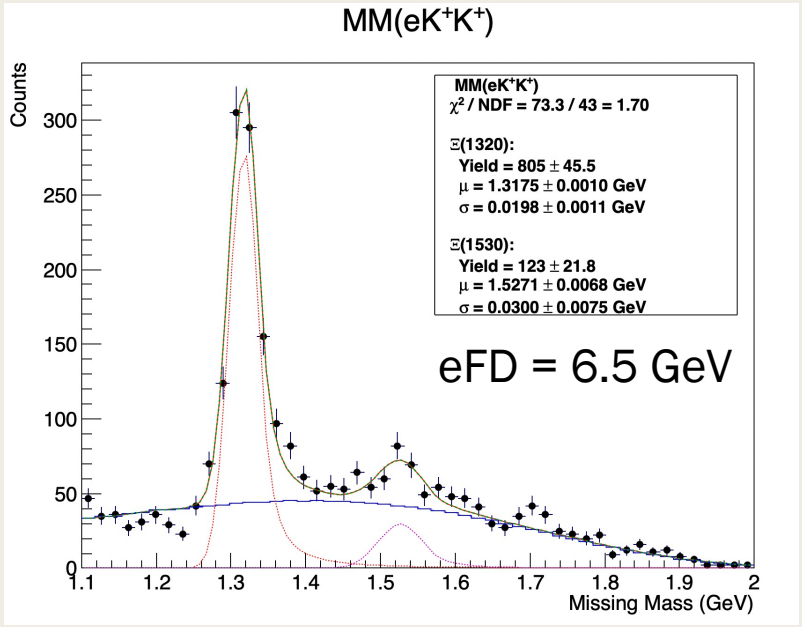
| Cuts (Forward Detector) | K+ | e' |
|---|---|---|
| Track status | $2000 \leq status < 4000$ | $2000 \leq \lvert status \rvert < 4000$ |
| $V_z[cm]$ | $-10 \leq V_z \leq 2$ | $-10 \leq V_z \leq 2$ |
| $\theta[^\circ]$ | $5 \leq \theta_{K^+} \leq 35$ | $5 \leq \theta_{e'} \leq 35$ |
| P [GeV] | $0.4 \leq P \leq 7.5$ | $P > 1.0$ |
| ToF [ns] | $20 \leq ToF \leq 35$ | $21 \leq ToF \leq 26$ |
| $\chi^2 PID$ | $-6 \leq \chi^2 \leq 6$ | N/A |
| $\beta$ | $0.4 \leq \beta < 1.1$ | N/A |

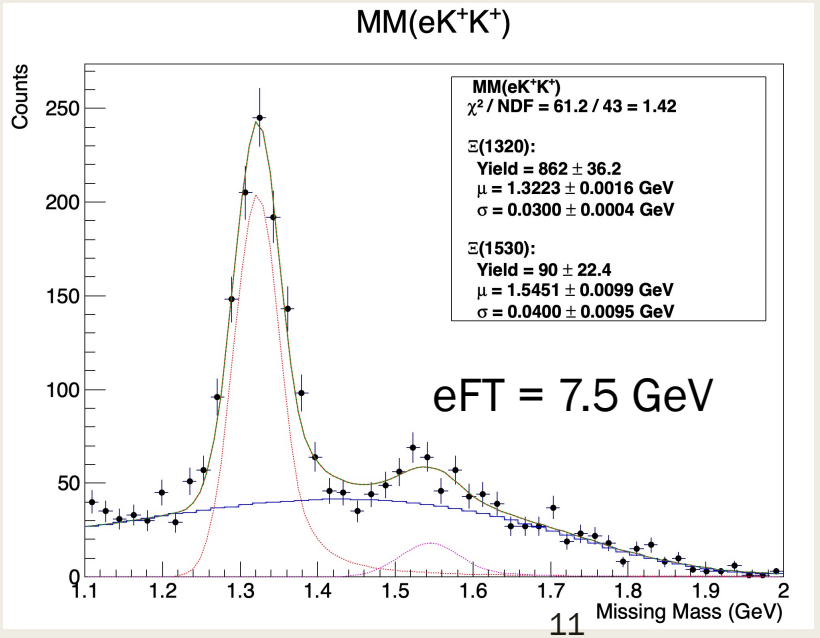
# Missing Mass

- Signals are fitted to a Crystal Ball function; a Gaussian core with a power law tail to account for radiative effects

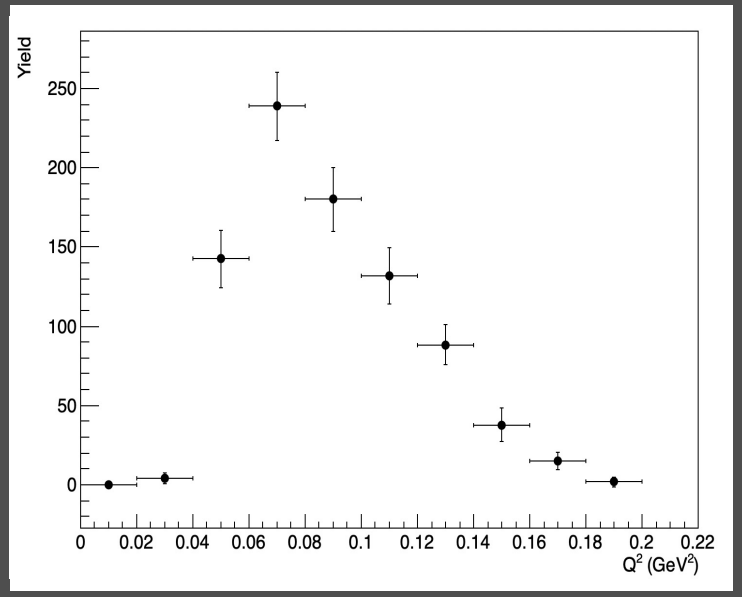
- Due to the combinatorial nature of the final state, $e'K^+K^+$, event mixing is used for the background template
    - Recalculating missing mass while randomizing one or both kaons
    - This is represented in blue on the plots

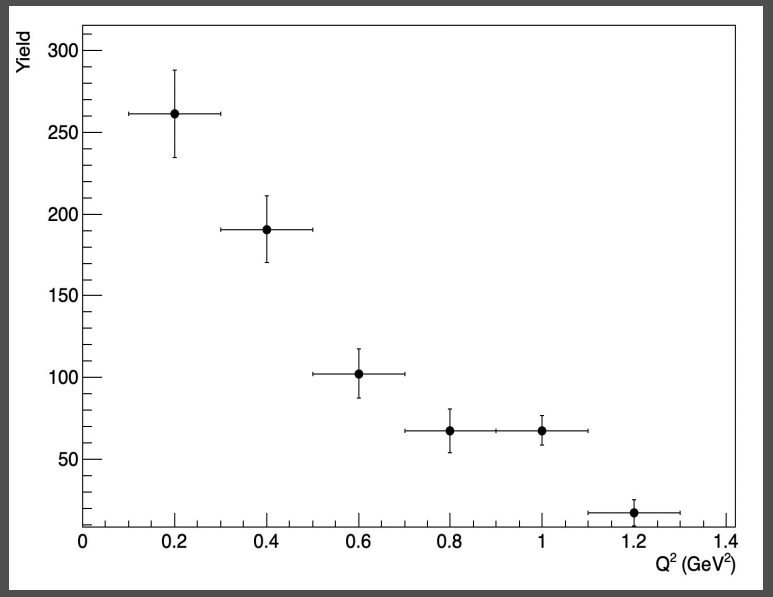


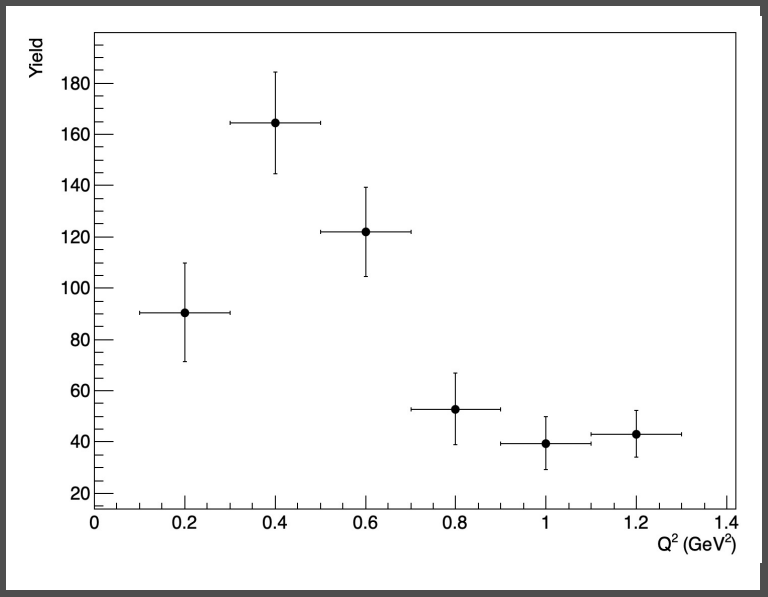



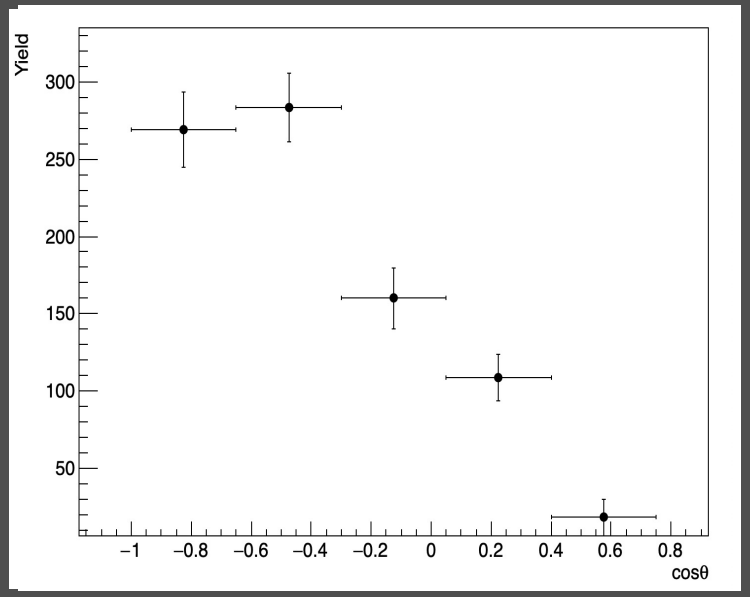
# $\Xi^-(1320)$ Yield




eFT 7.5 GeV

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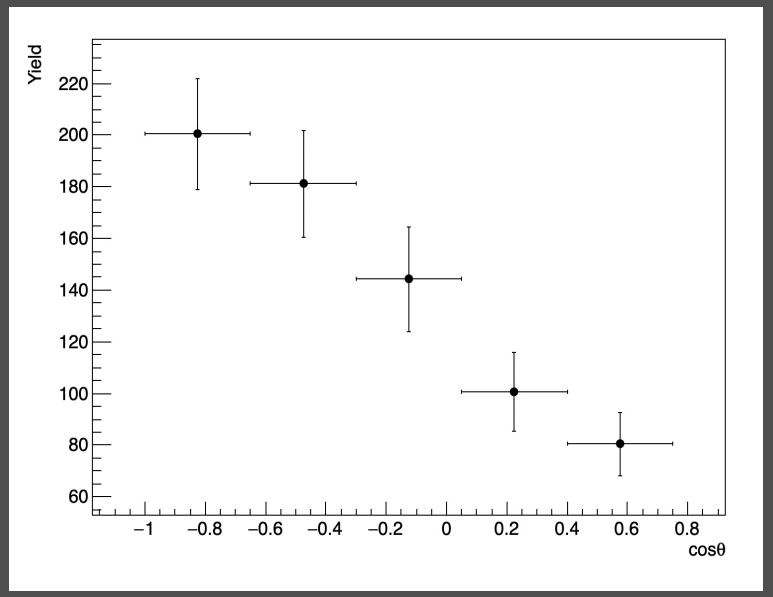


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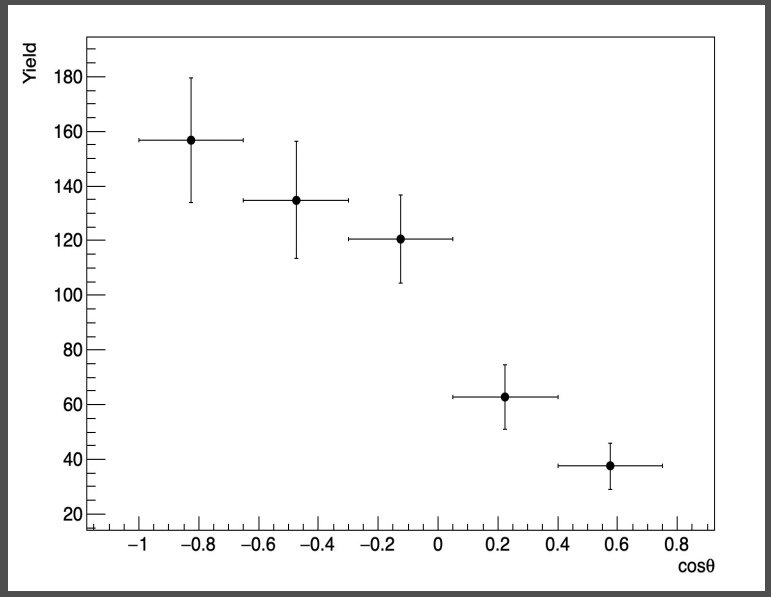


# Simulations

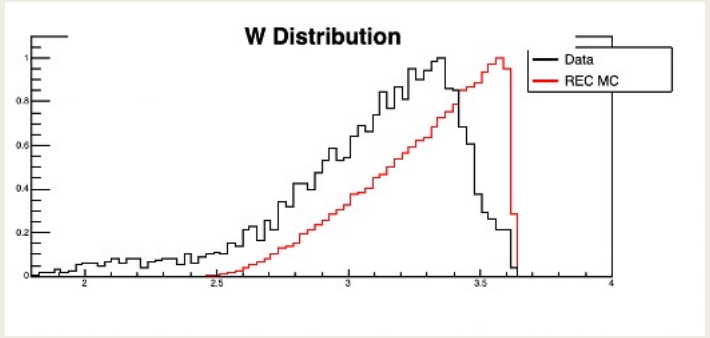
**Input parameters for event generator:**

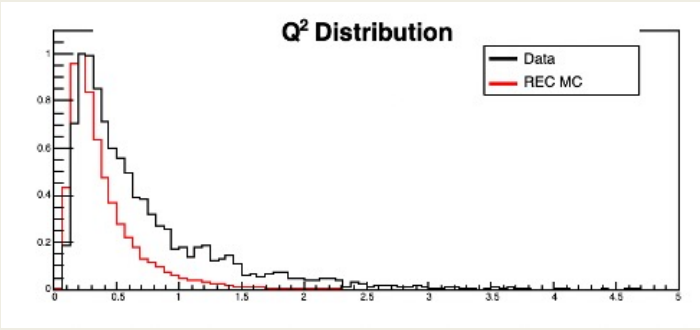
- Intermediate resonance mass distribution, i.e. $X^0 \rightarrow \Xi^- K^+_{slow}$
- $\Xi^-$ Mass distribution (delta functionat 1.322 GeV)
- Polar angle coverage
- t-slope weighting
- $Q^2$ weighting
- $W$ weighting

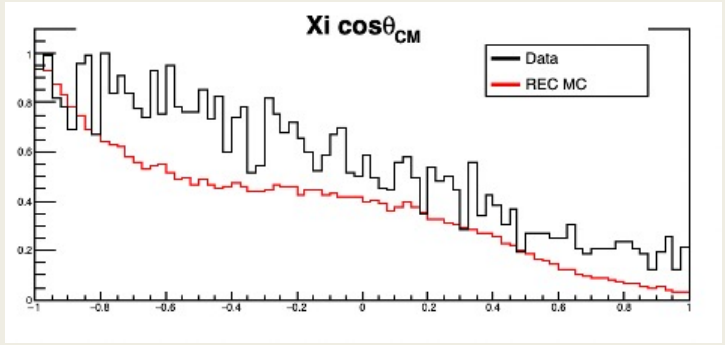
- Background merging tool is used as well

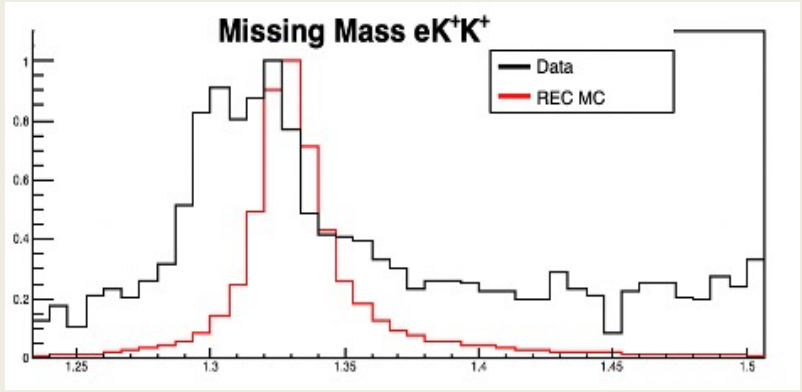
# Data vs simulation (REC)

- Weighting the event generator is still a work in progress for better data matching!
  - Currently a W-weighting procedure is employed



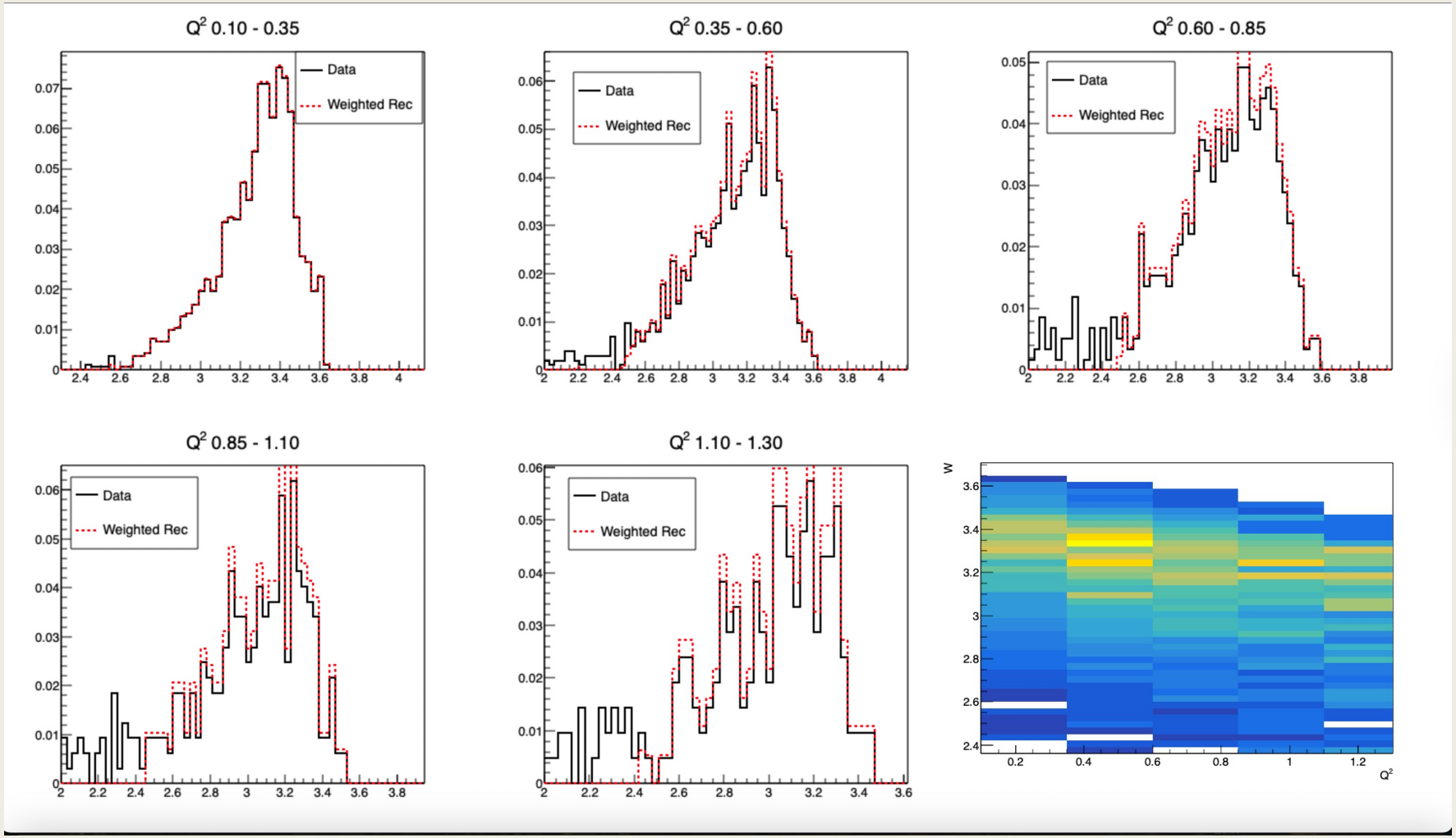



# W-Weighting Procedure

Due to the discrepancy between the generated reconstructed data and real data, a W weighting procedure is employed where in each bin of $Q^2$, W is plotted and the REC data is weighted to the real data and a weight map is created and used in event generation

W for each bin of $Q^2$



# Acceptance Determination

Acceptance is calculated bin by bin using

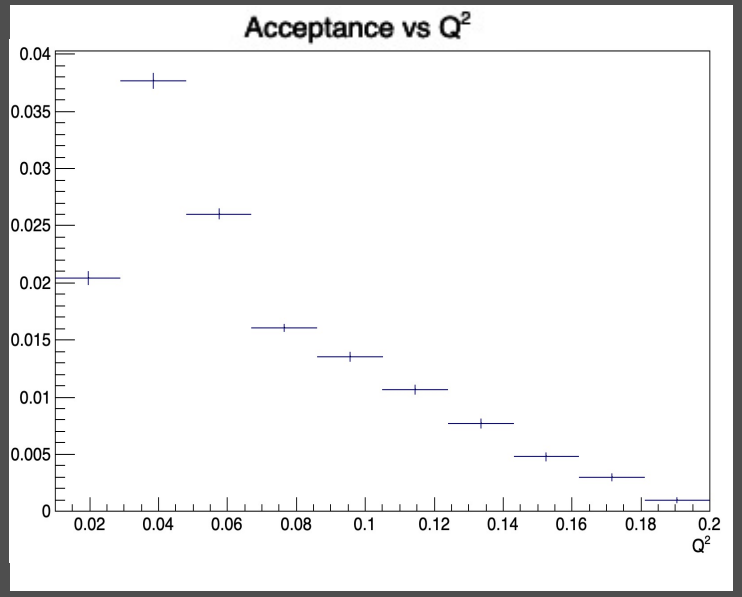
$$\eta_{i,j} = \frac{N_{i,j}^{REC}}{N_{i,j}^{GEN}}$$

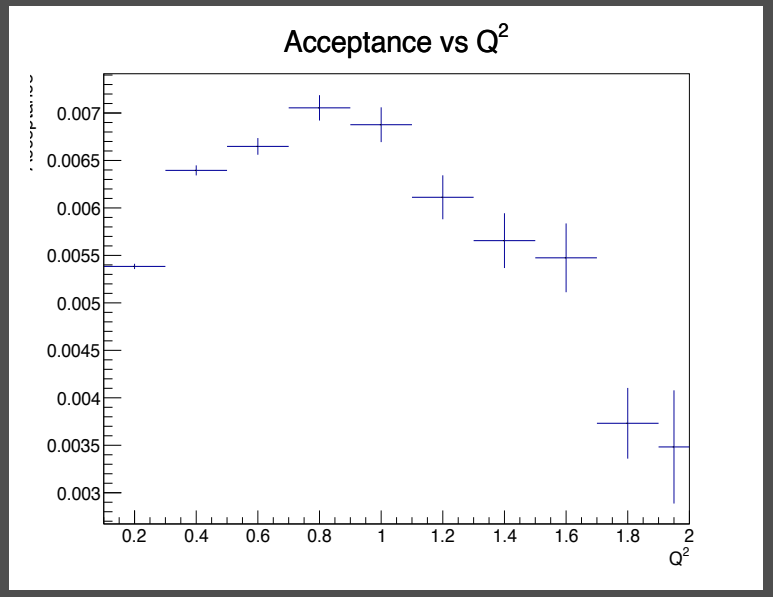
Where $N_{i,j}^{REC}$ is yield determined by fitting the signal of the **missing mass of** $\boldsymbol{e'K^+K^+}$. For $N_{i,j}^{GEN}$, since MM($\boldsymbol{e'K^+K^+}$) is a delta function at 1.322 GeV with no background, we just count the events in the delta function

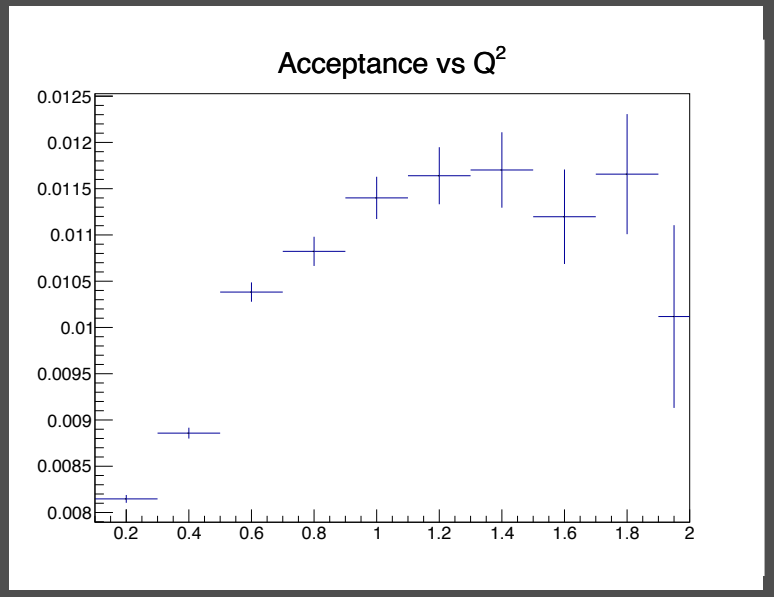
Later, for the cross section calculation, corrected detector acceptance is calculated by

$$\eta_{corr} = R_{eff}^{K^+} * R_{eff}^{K^+} * R_{eff}^{e} * \eta_{i,j}$$

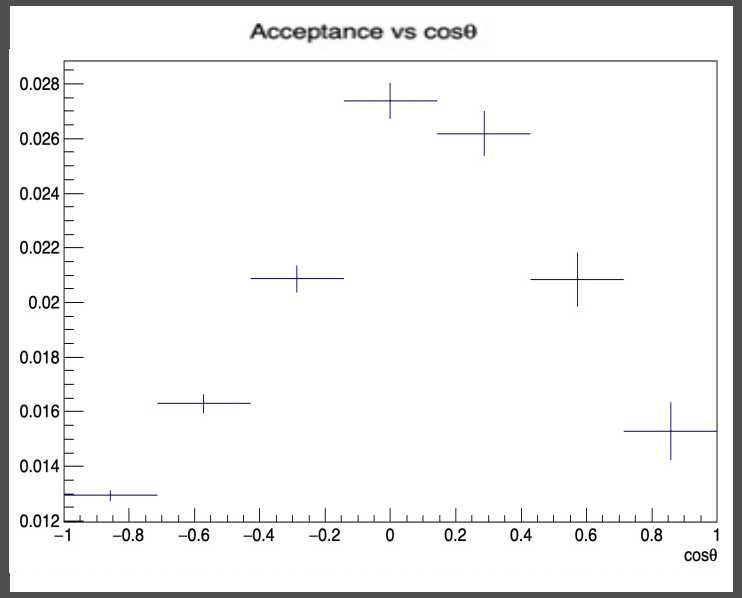
Where $R_{eff}^{particle}$ is the tracking efficiency for each particle in the final state




eFT 7.5 GeV

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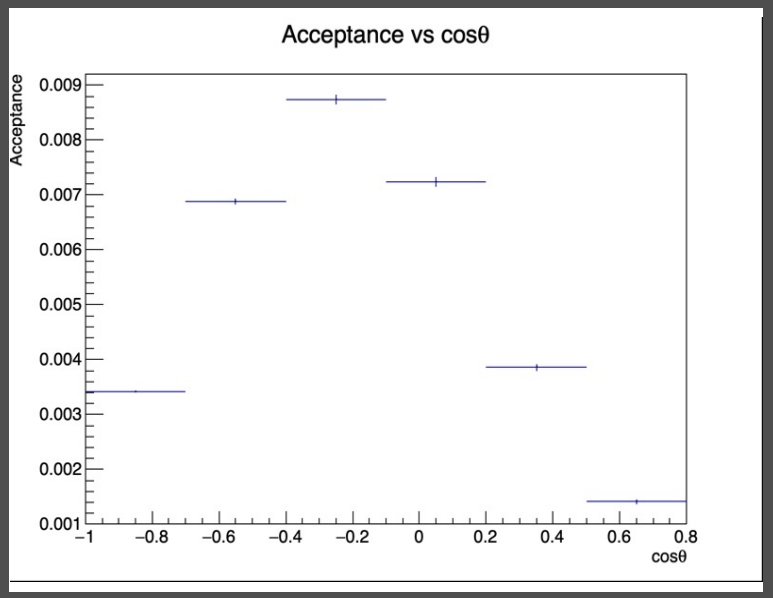


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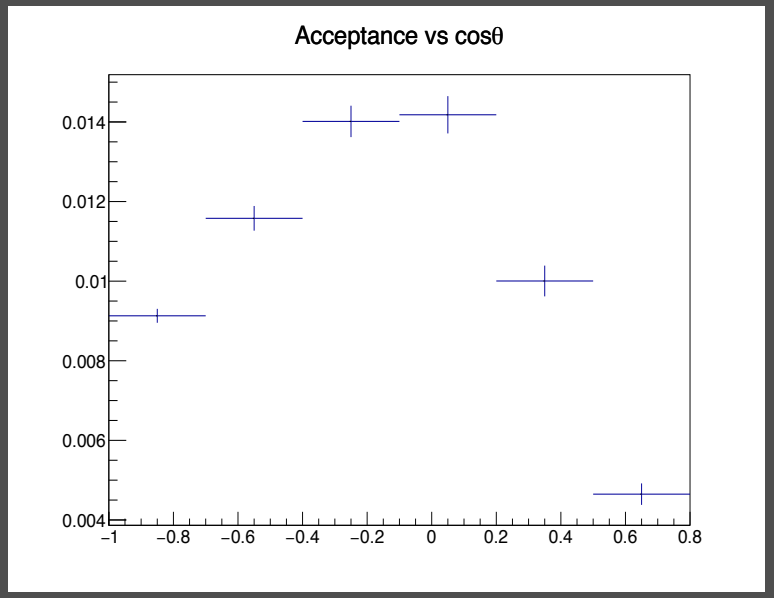
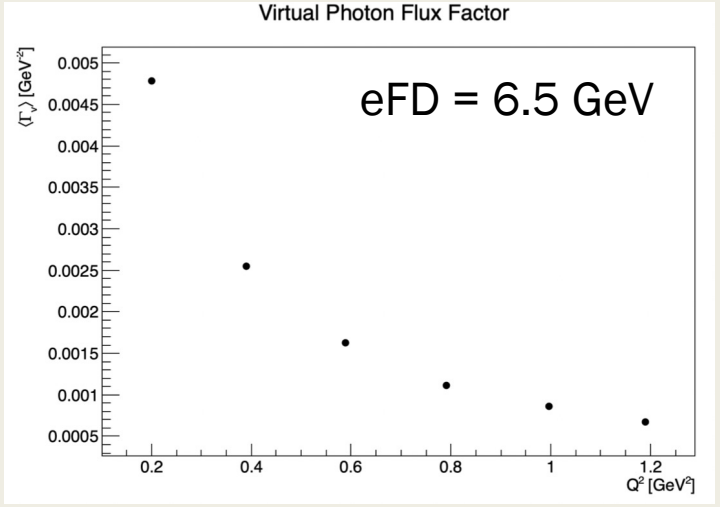


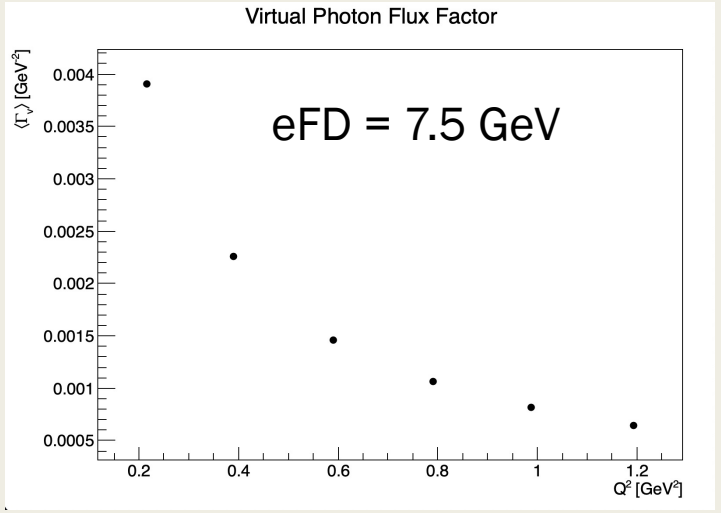
# Virtual Photon Flux Factor

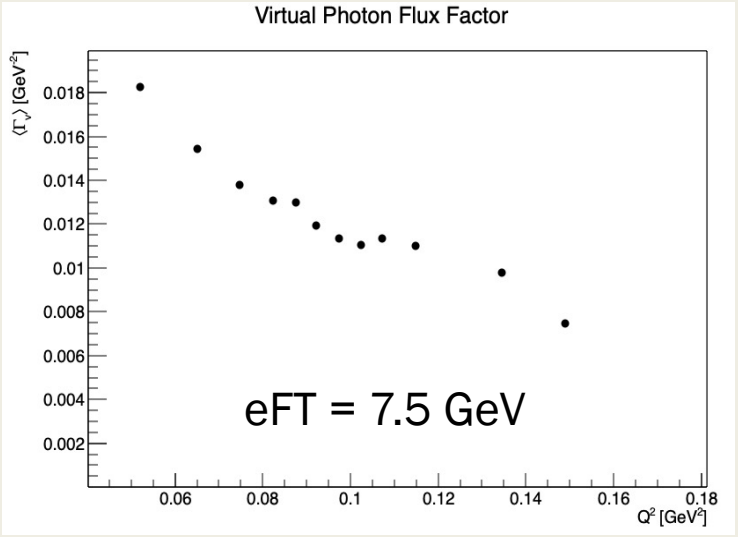
$$\Gamma_\nu = \frac{\alpha}{4\pi} * \frac{W}{ME_b^2} * \frac{W^2 - M_p^2}{M_p Q^2} * \frac{1}{1-\epsilon}$$

Where,

- $\alpha$: fine structure constant
- $E_b$: beam energy
- $M_p$: proton mass
- $\epsilon$ : Virtual photon polarization parameter
  - $\epsilon = 1/(1 + 2\left(1 + \frac{\nu^2}{Q^2}\right)\tan^2\ (\frac{\theta_e}{2}))$



# Forward Detector Preliminary Differential Cross Section

This cross section is calculated from the following equation:

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

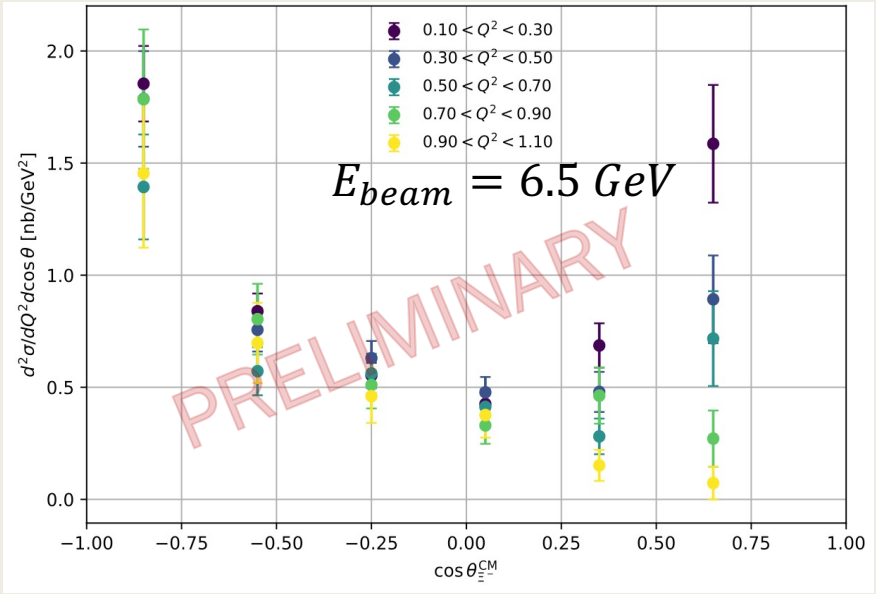
Where:

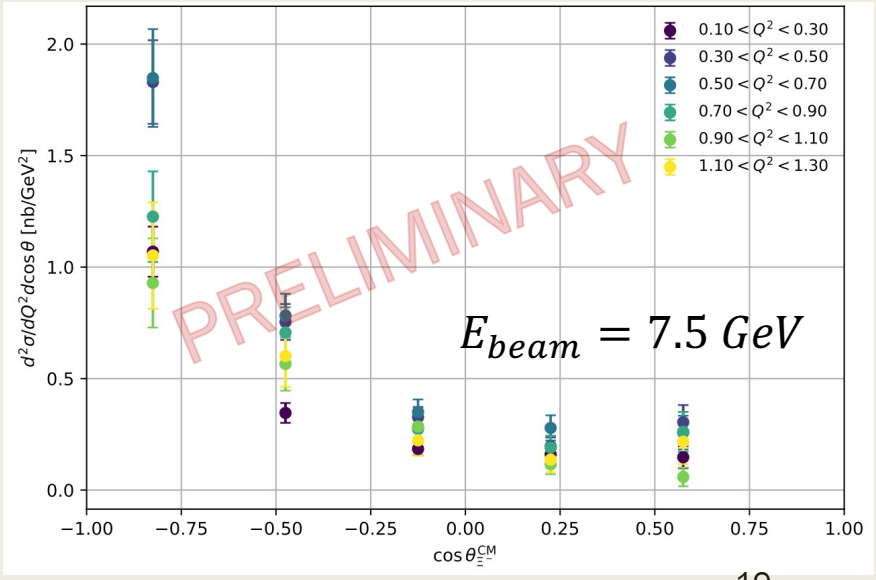
$\frac{Y}{\eta}$ : Acceptance corrected yield

$N_0$: Number of incident beam electrons

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

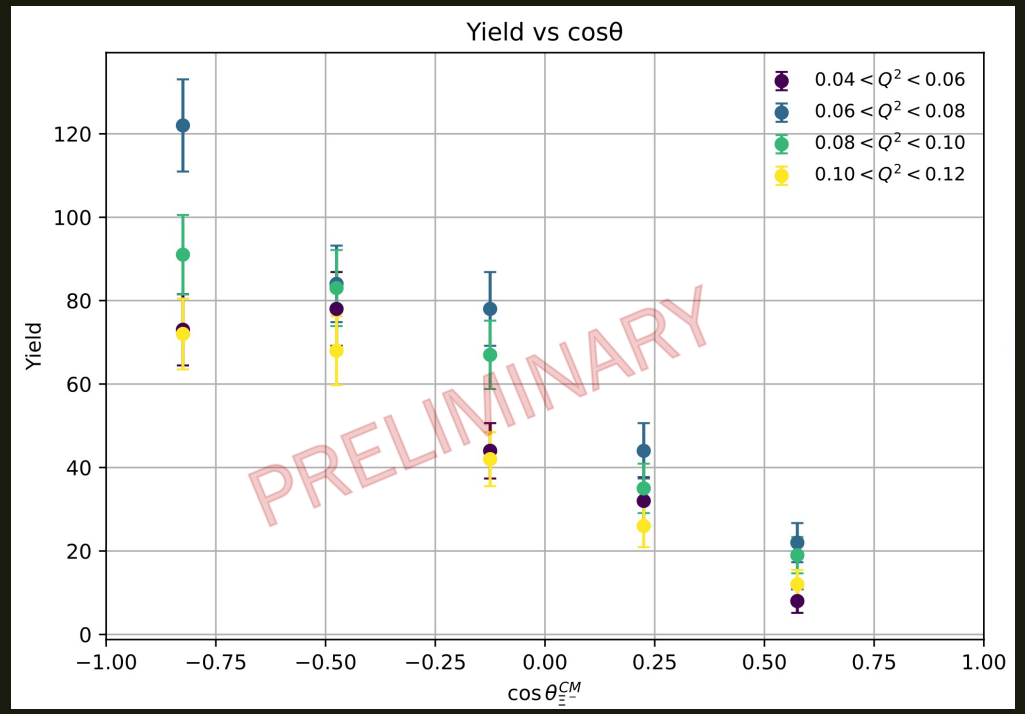
$\Gamma_\nu$ : Virtual photon flux



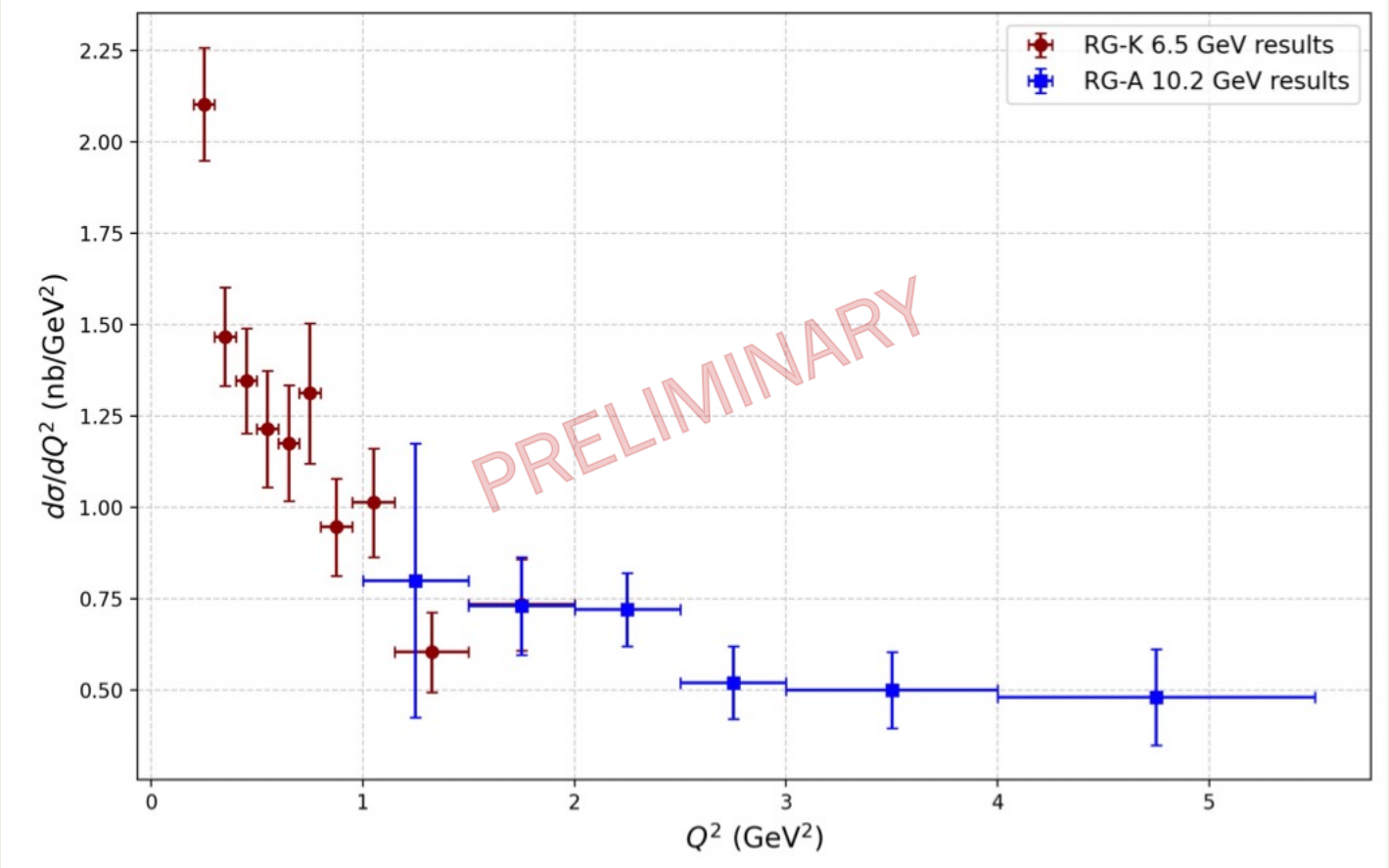
# Forward Tagger Results

- Cross section for the $\Xi^{-}(1320)$ for the electron in the FT are still being worked on
- Forward tagger results have higher acceptance than FD region
- We still see backward peaking behavior with no forward peaks



# Comparison to RG-A

- **Not a direct comparison** as RG-K data shown here is at 6.5 GeV and RG-A data shown is at 10.2 GeV both in forward detector
- Comparing only bins of $Q^2$ since this is the only other electroproduction cross section for cascade available at the current time



# Outlook

- Finish FT cross section results

- Next is to expand cross section to $\Xi^{-}(1530)$ for all data sets
- Expand binning to W to look at $d\sigma/(dcos\theta_{\Xi^{-}}^{CM} dW)$ overall $Q^2$

- Vary parameters in simulation such as, t-slope to better understand the kinematic dependance

- Better data matching from simulation

- Interpolate acceptance and compare to bin-by-bin acceptance

# Thank you!

Any Questions?

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