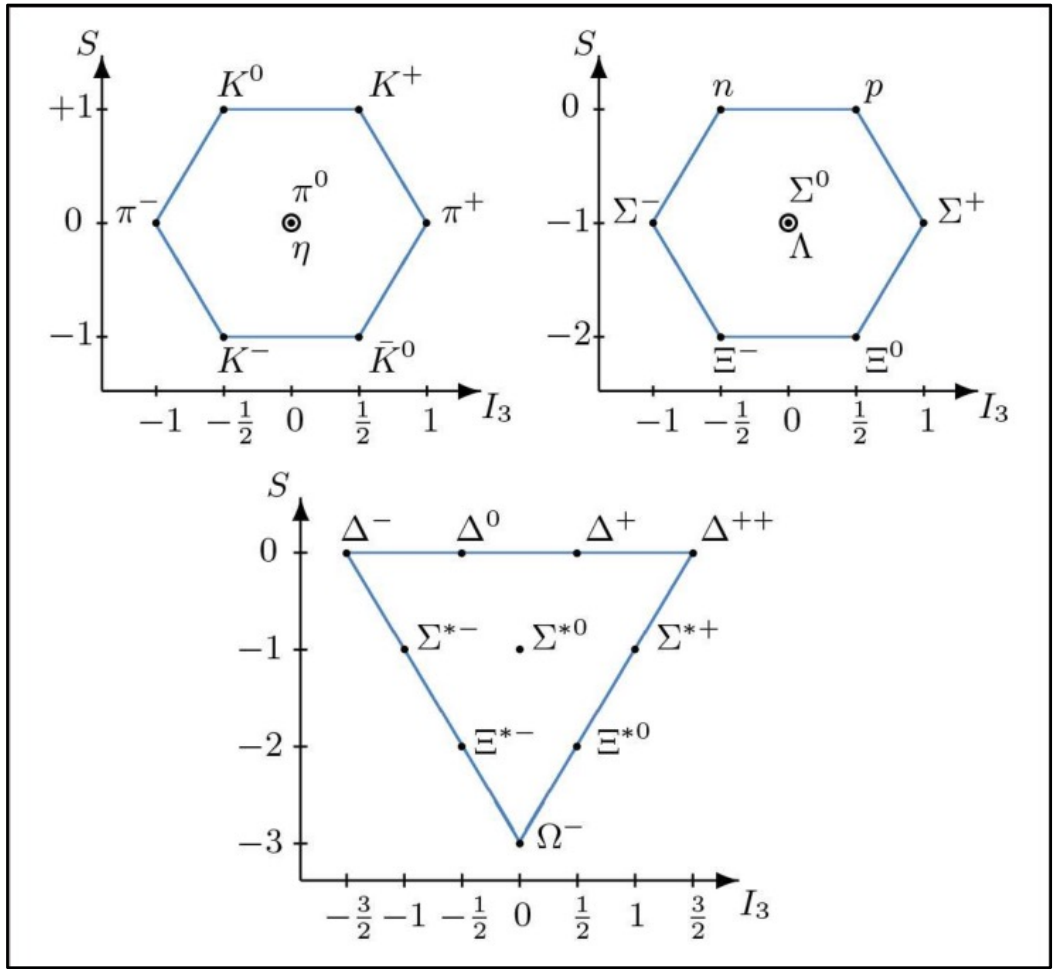
From Strange to Very, Very Strange

Trevor Reed

On behalf of the Very Strange Group



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Overview

- **PR12-12-008: Photoproduction of the Very Strangest Baryons on a Proton Target in CLAS12**
  - "We propose to study the production mechanisms of the S = −2, −3 baryons in exclusive photonuclear reactions with the CLAS12 detector."

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

$$ep \longrightarrow e'K^+K^+K^0\Omega^-$$

Challenges

- Cross sections are small, and the background is high
  - Displaced vertices
  - Kinematic fit
- Multiparticle final state. Efficiency is important!
  - Central detector tracking improvement validation
- Started with some exploratory studies and development of necessary tools

Exploratory Studies

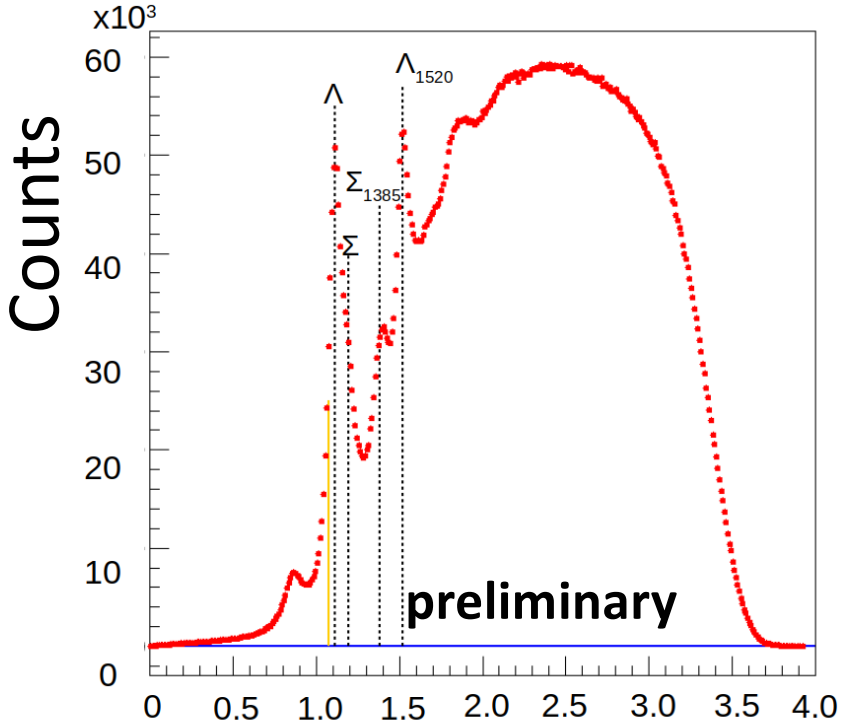
- Matthew Nicol
  - Exploratory studies of single, double, and triple strangeness production (both RGA and RGB)
  - Scaling behaviour of multi-strangeness production x-section

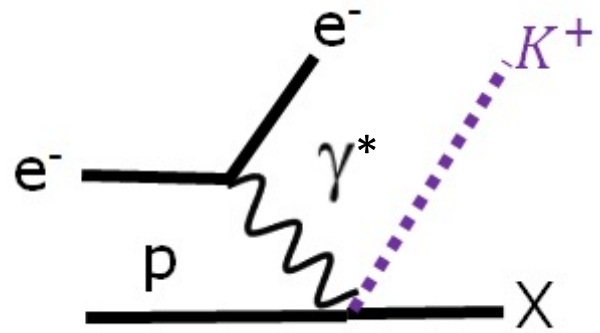
- Veronique Ziegler
  - $\Lambda \rightarrow p\ \pi^-$ and $\overline{\Lambda} \rightarrow \bar{p}\ \pi^+$
  - Ω^-

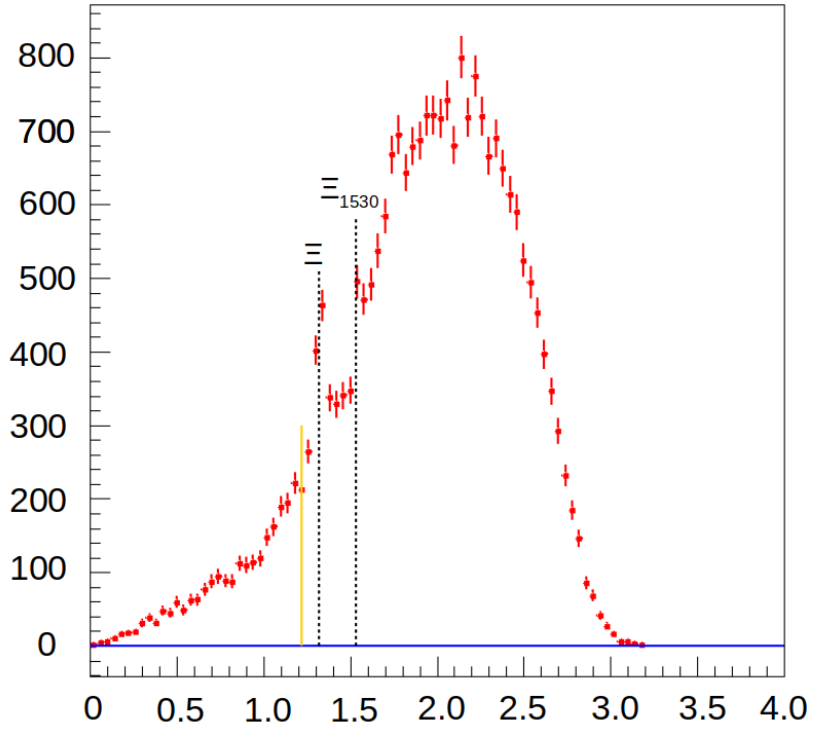
Identified issues:

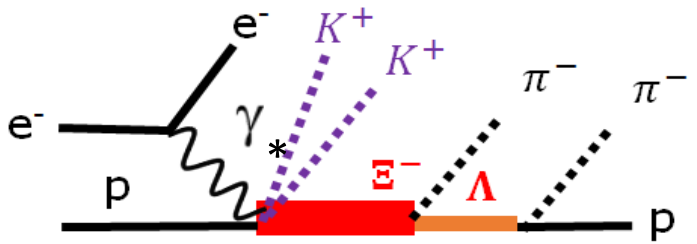
- Statistics
- Resolution

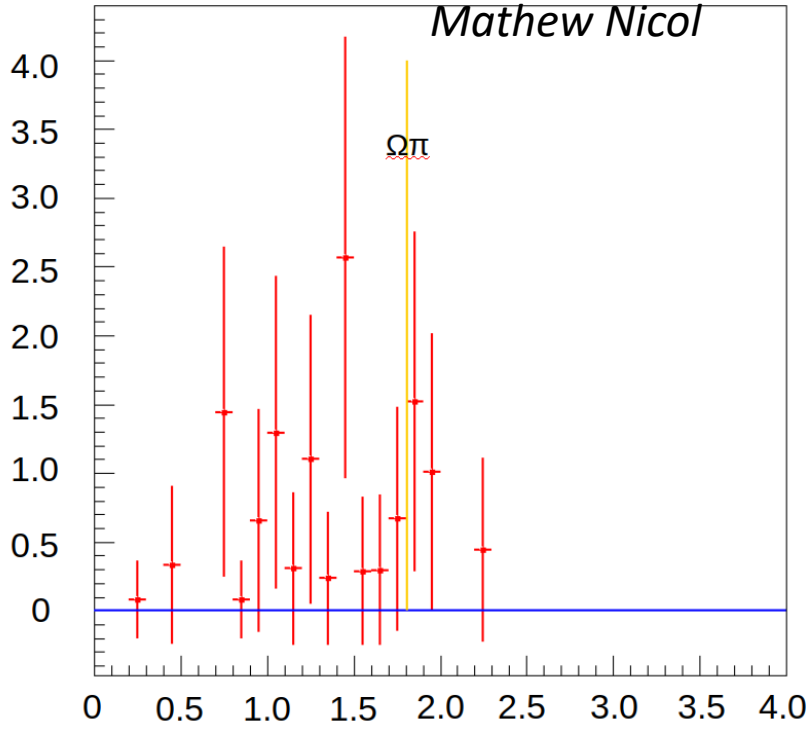
Exploratory studies of strangeness production

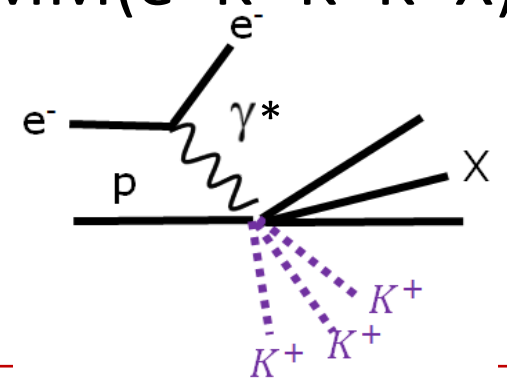








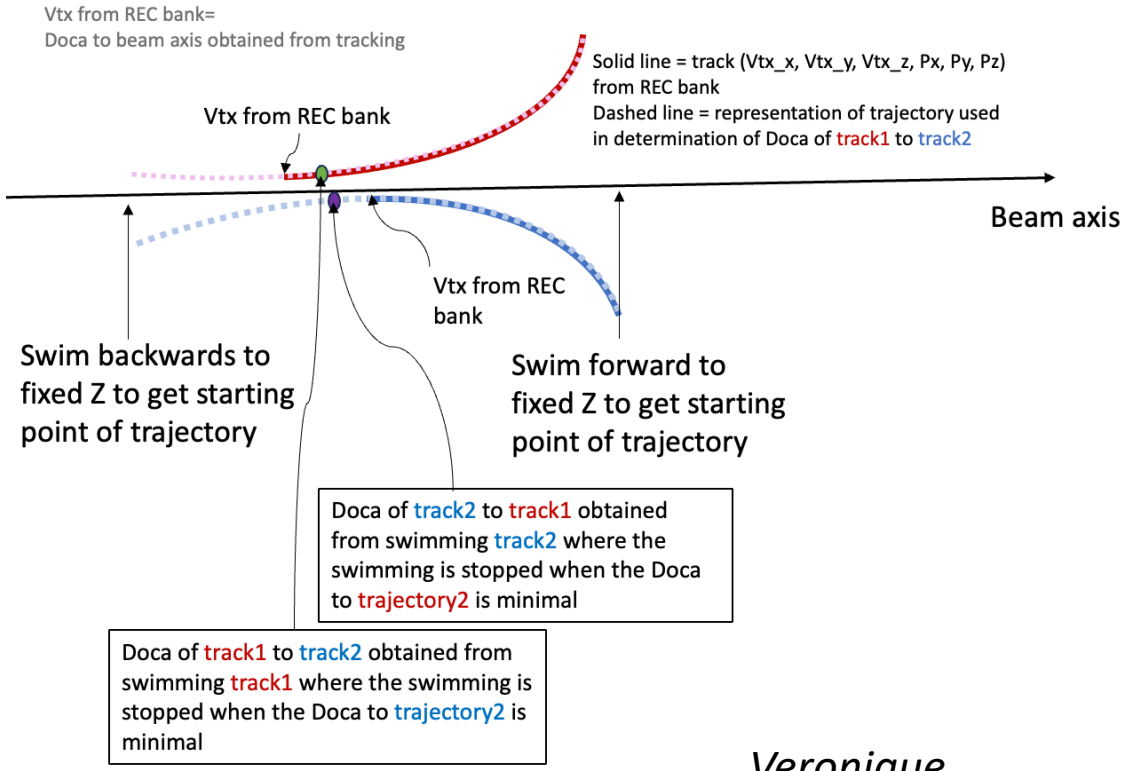




Study of Lambda production off the proton and off the deuteron using displaced vertex reconstruction

Analyses of the reactions
- ed → e' K+ Λ(→ pπ−) (X) 70% of RGB Pass-2 Spring 2019 dataset
- ep → e' K+ Λ(→ pπ−) (X) 25% of RGA Pass-2 Spring 2019 dataset
- ep → e' K+ Λ(→ pπ−) (X) 95% of RGK Pass-2 Fall 2018 7.5 GeV dataset

- Analysis based on the following reconstruction
  - Exclusive reconstruction of Λ candidate into pπ− decay mode
  - Pass-2 datasets
  - Using vertexing package to select Λ candidates
  - Set of cuts include
    - chi2PID
    - Vertex DOCA between the p π− tracks
    - Vertex displacement cuts to e- vertex (Vtxy: transverse; Vtz:longitudinal)
    - Requirement of tracks (p, π, K) to be in CD or FD

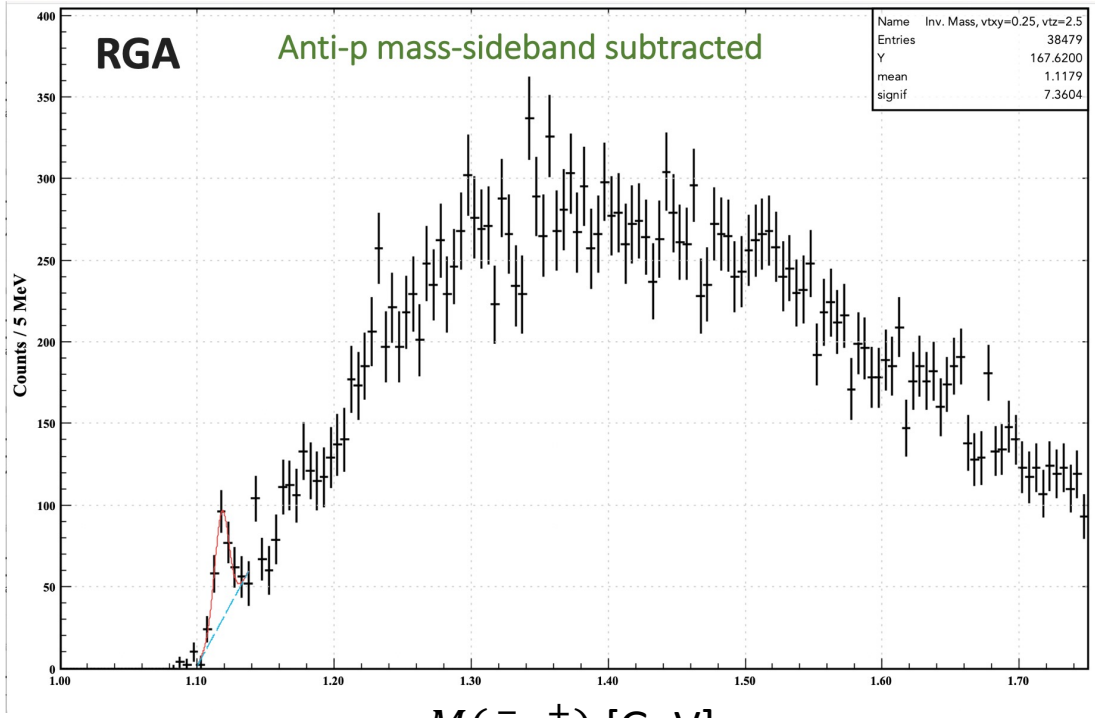


Veronique

Study of exclusive $\Lambda \rightarrow p\pi^-$ and $\bar{\Lambda} \rightarrow \bar{p}\,\pi^+$ production in RGA & RGB data

Veronique

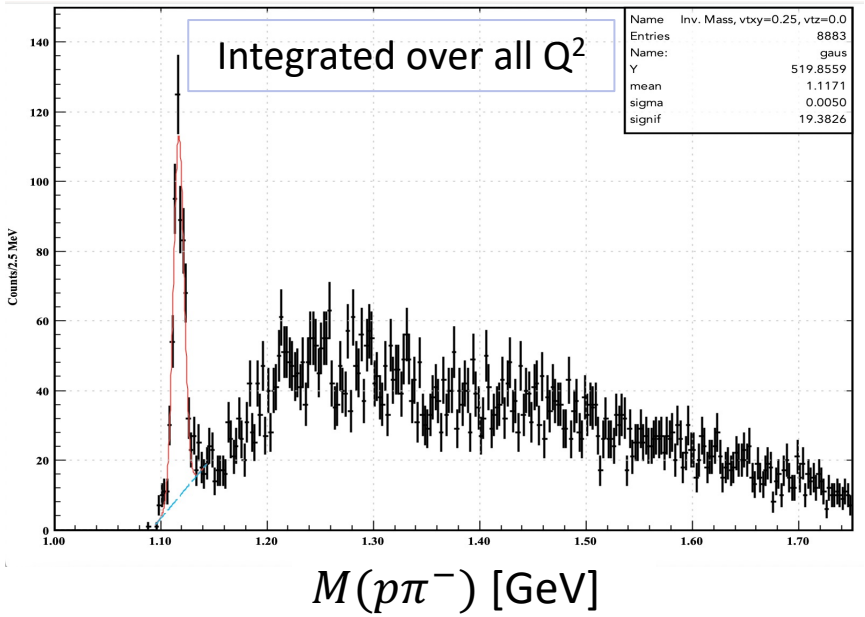
85% of Spring 2019 Dataset



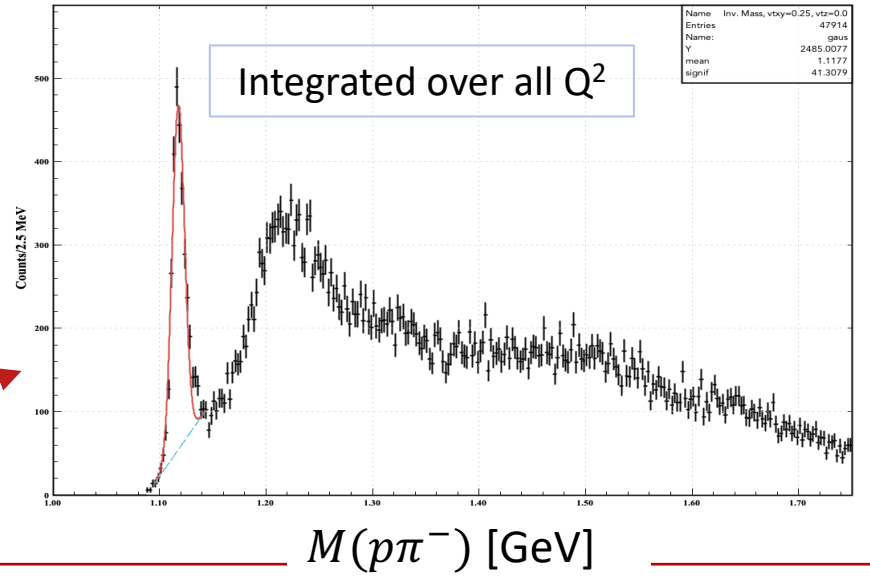
Outlook

These preliminary analyses show the feasibility of the proposed analyses and their potential to contribute to essential topics of QCD within the reach of RGB and RGA experimental configurations.

RGA



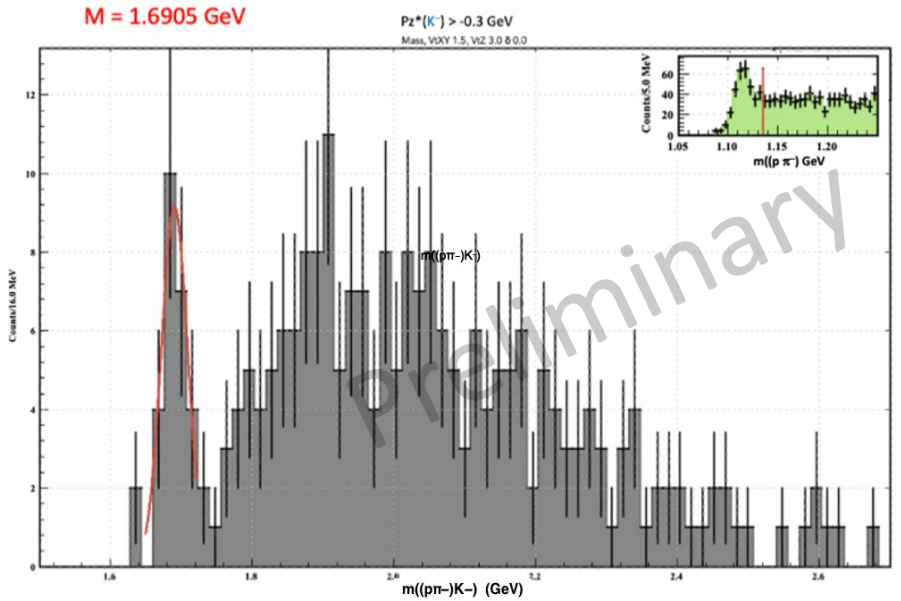
RGB

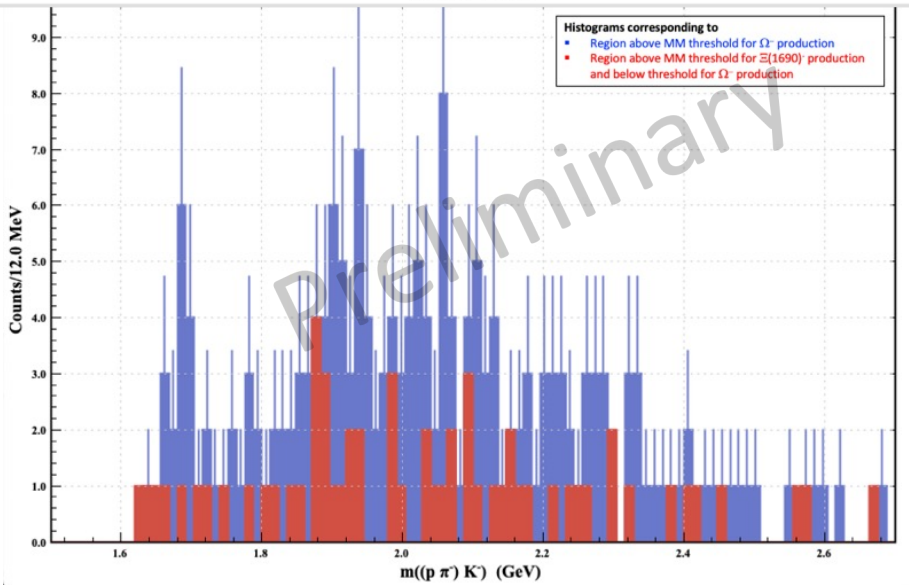


Cut on **MM**(e-K+p $\pi-$) to select the neutron

Search for Ω^-

- Search for the Ω^- in the reaction ep → e'ΛK^-(X), Λ → pπ^- using the RG-A fall 2018 and spring 2019 datasets.
  - Select events containing at least one proton, one negative pion, and one negative kaon.
  - Algorithm estimating the position of the Λ hyperon detached vertex used to improve the signal-to-background ratio.
- An excess of events in the expected Ω^- region is observed with a statistical significance close to 3σ.
- Possible ambiguity for an observed signal in the expected Ω region: The $\Xi^-(1690)$ resonance also decays to ΛK^-.
- MM threshold (0.85 GeV) for doubly strange $\Xi^-(1690)$ is lower than that for Ω^-. We compare m(($p\pi^-$)K^-) spectra corresponding to $\Xi^-(1690)$ and Ω^- production thresholds to study possible contamination from $\Xi^-(1690)$ to the peak Ω^-.
- Need for more statistics to resolve ambiguity.





Within the remaining approved RG-A beam time, we expect to collect several times more statistics for this reaction.

If the signal is confirmed, it will constitute the first observation of the Ω^- in electroproduction.

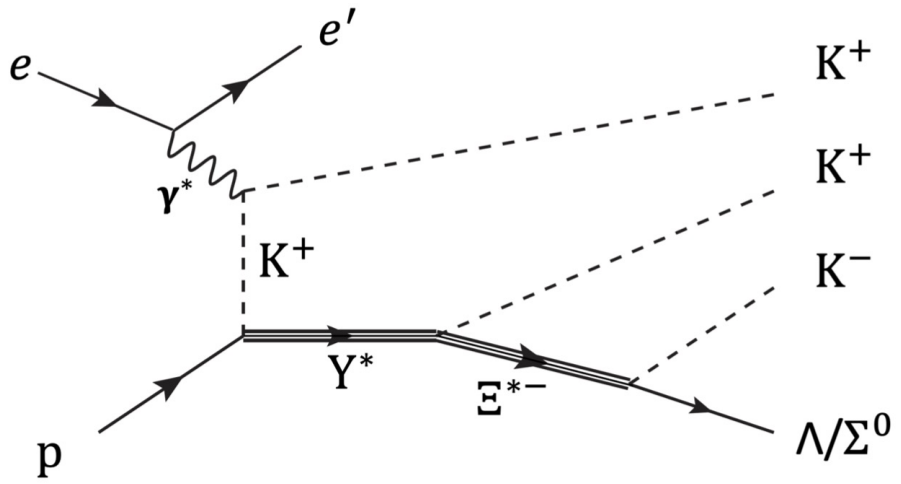
Recent Work

- Ξ^* Cross-section upper limit from Rg-A (pass 1)
  - **Achyut Khanal** (FIU)
- $\Xi^{-(*)}$ Cross sections from Rg-A (pass 2)
  - **Jose Carvajal** (FIU)
- Scaling behaviour of multi-strangeness production x-section
  - **Matthew Nicol** (York)
- $\Lambda(1405)$ photoproduction cross sections from g12 (CLAS6)
  - **Trevor Reed** (FIU)

Ξ^* Cross-Section Upper Limit

Results for RGA pass1

$$ep \rightarrow eK^+K^+K^-(\Lambda, \Sigma^0)$$

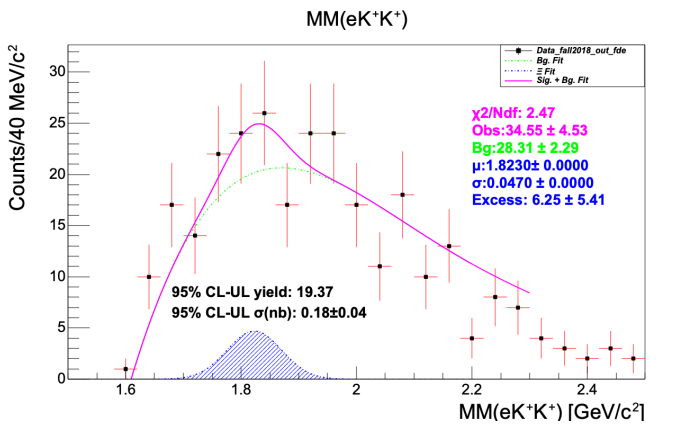


Achyut Khanal (FIU)

Upper Limit for Excited Cascades Yields

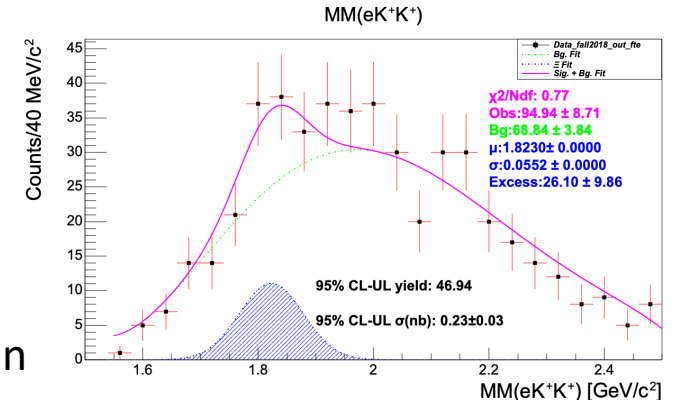
Fall 18 Outbending

Electron in FD



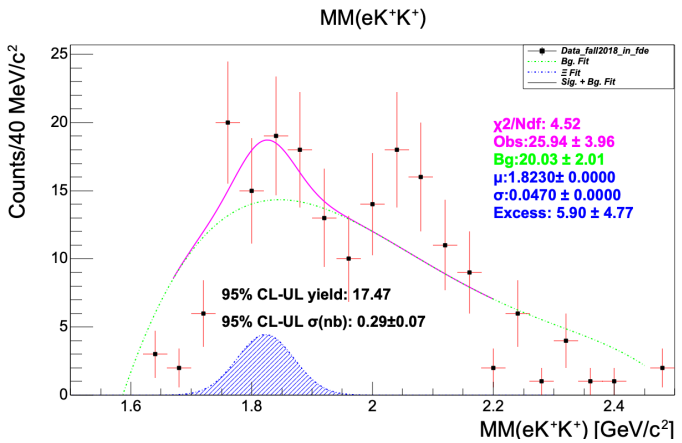
(a) Scattered electron detected in the FD.

Electron in FT



(b) Scattered electron detected in the FT.

Fall 18 Inbending



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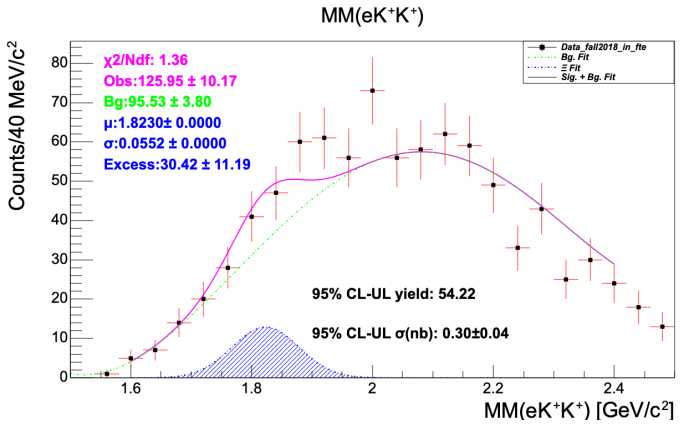
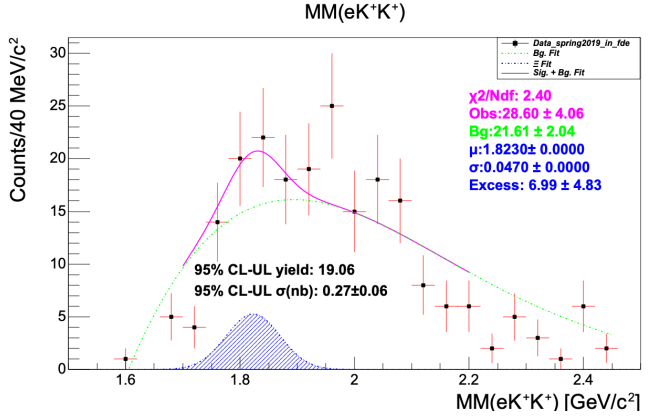


(b) Scattered electron detected in the FT.

Spring 19 Inbending



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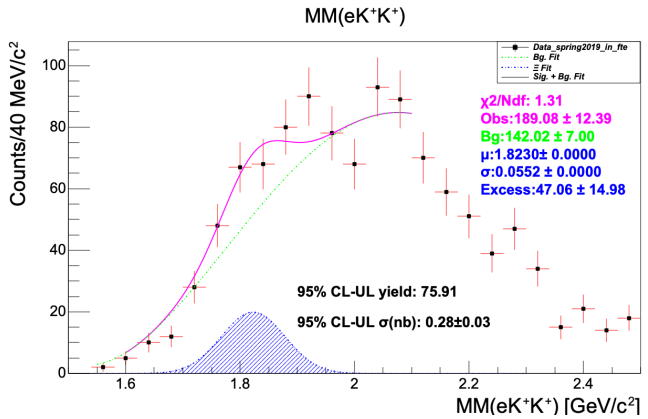


(b) Scattered electron detected in the FT.

Background shape defined by mixed-events

Achyut Khanal

Excited Cascades Cross-Section Upper Limit from RGA

Achyut Khanal

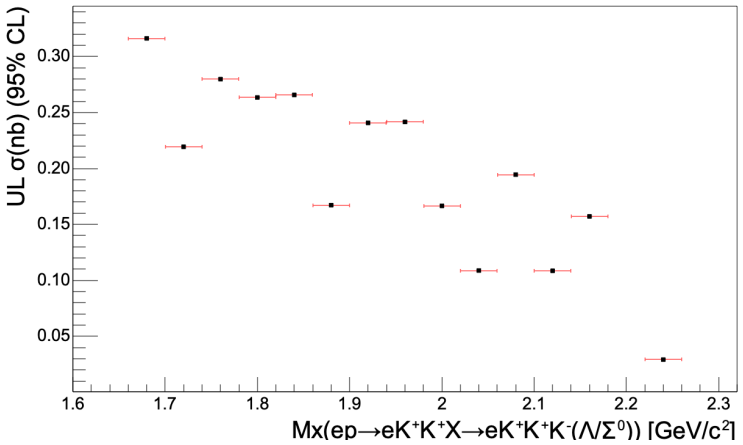
Fall 18 outbending

Fall 18 Inbending

Spring 19 Inbending

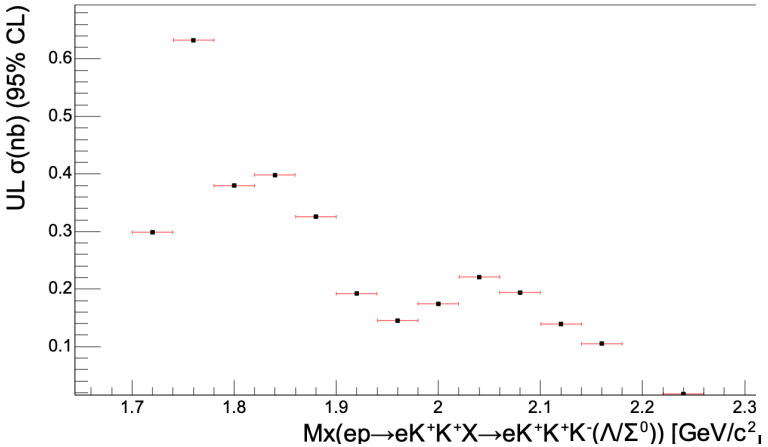
Electron in FD

95% Confidence Level Upper Limit Cross Section



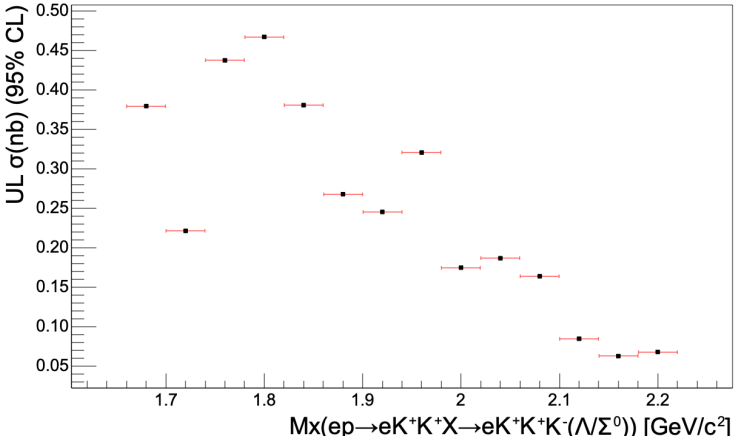
(a) Fall 2018 out FD-e Q^2 : $[0.16, 1.28]$ GeV^2.

95% Confidence Level Upper Limit Cross Section



(a) Fall 2018 in FD-e Q^2 : $[1.28, 1.88]$ GeV^2.

95% Confidence Level Upper Limit Cross Section



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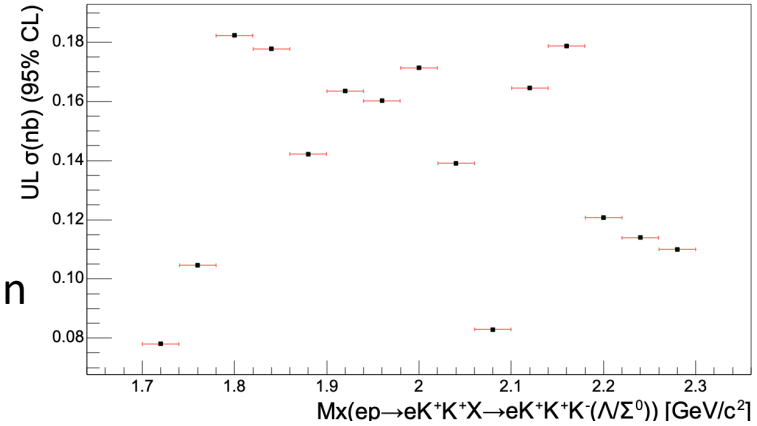
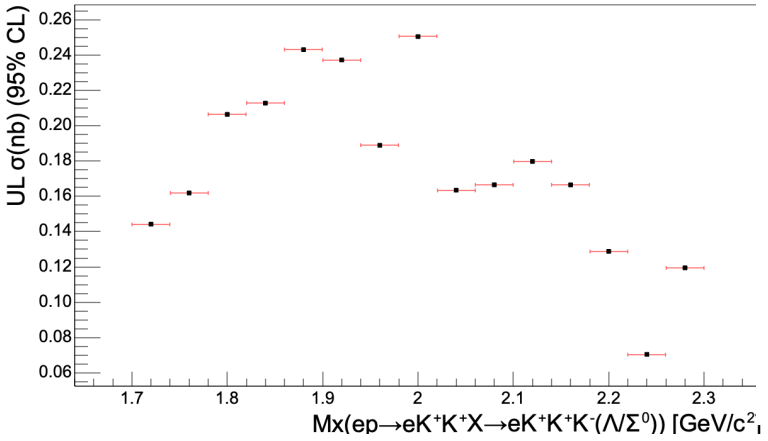
Electron in FT



(b) Fall 2018 out FT-e Q^2 : $[0.03, 0.13]$ GeV^2.



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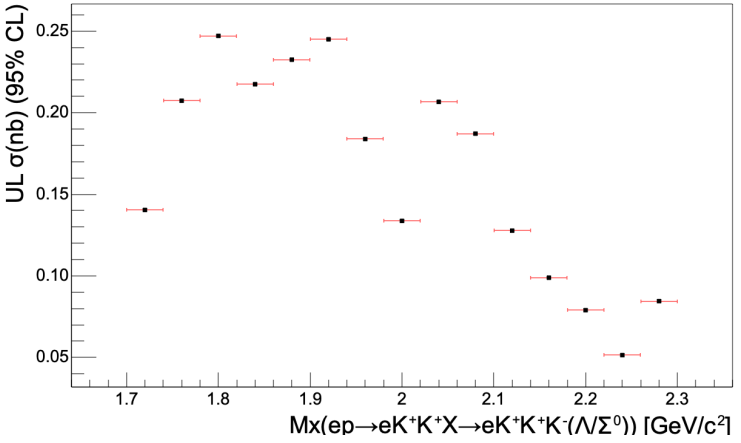


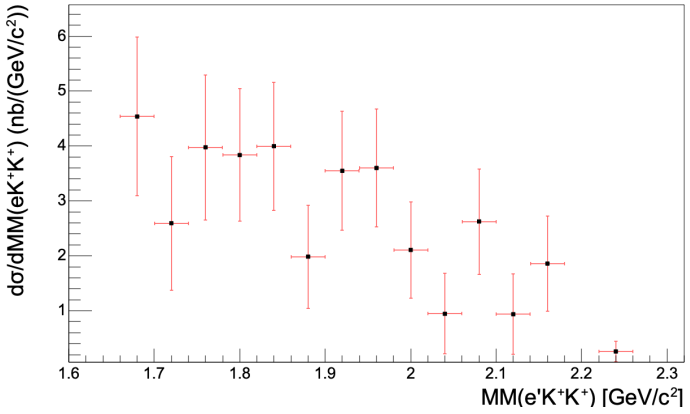
(b) Spring 2019 in FT-e Q^2 : $[0.03, 0.13]$ GeV^2.

$ep \rightarrow eK^+K^+K^-(\Lambda, \Sigma^0)$ Reaction Differential Cross Section

Achyut Khanal

Fall 18 outbending

Differential Cross Section as a Function of Missing Mass



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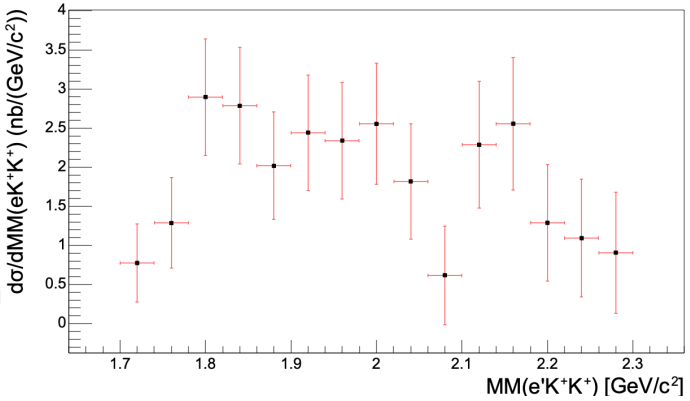
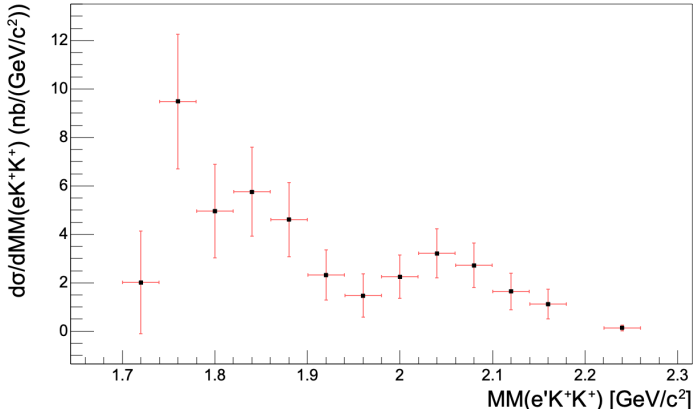


(b) Fall 2018 out FT-e Q^2 : $[0.03, 0.13]$ GeV^2.

Fall 18 Inbending

Differential Cross Section as a Function of Missing Mass



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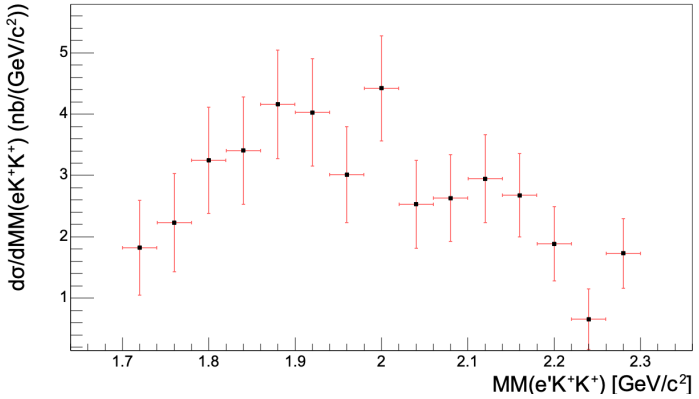
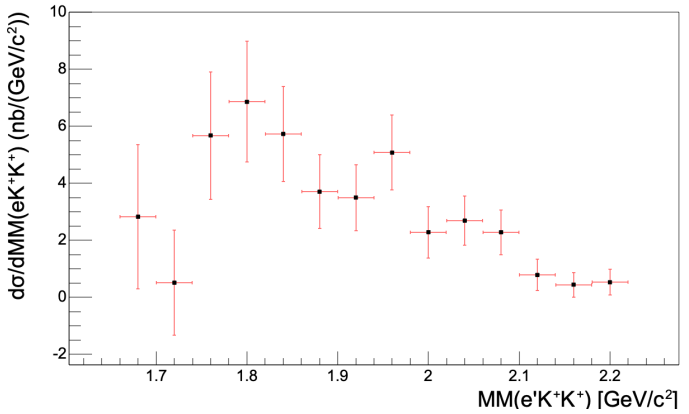


(b) Fall 2018 in FT-e Q^2 : $[0.03, 0.13]$ GeV^2.

Spring 19 Inbending

Differential Cross Section as a Function of Missing Mass



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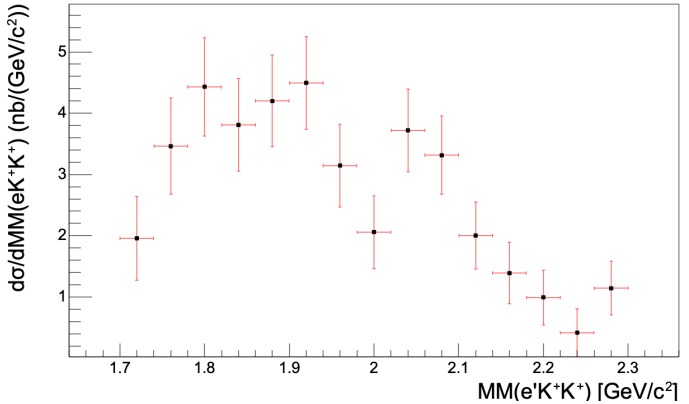


(b) Spring 2019 in FT-e Q^2 : $[0.03, 0.13]$ GeV^2.

Electron in FD

Electron in FT

Ξ^-'s Analysis: RGA Pass2

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

Jose Carvajal, FIU

Reaction Channel and Event Selection

Jose Carvajal

- $ep \rightarrow e'K^+K^+(\Xi^{-(*)})$
  - Ground state and 1530

GOAL:

- Cross section as a function of Q^2

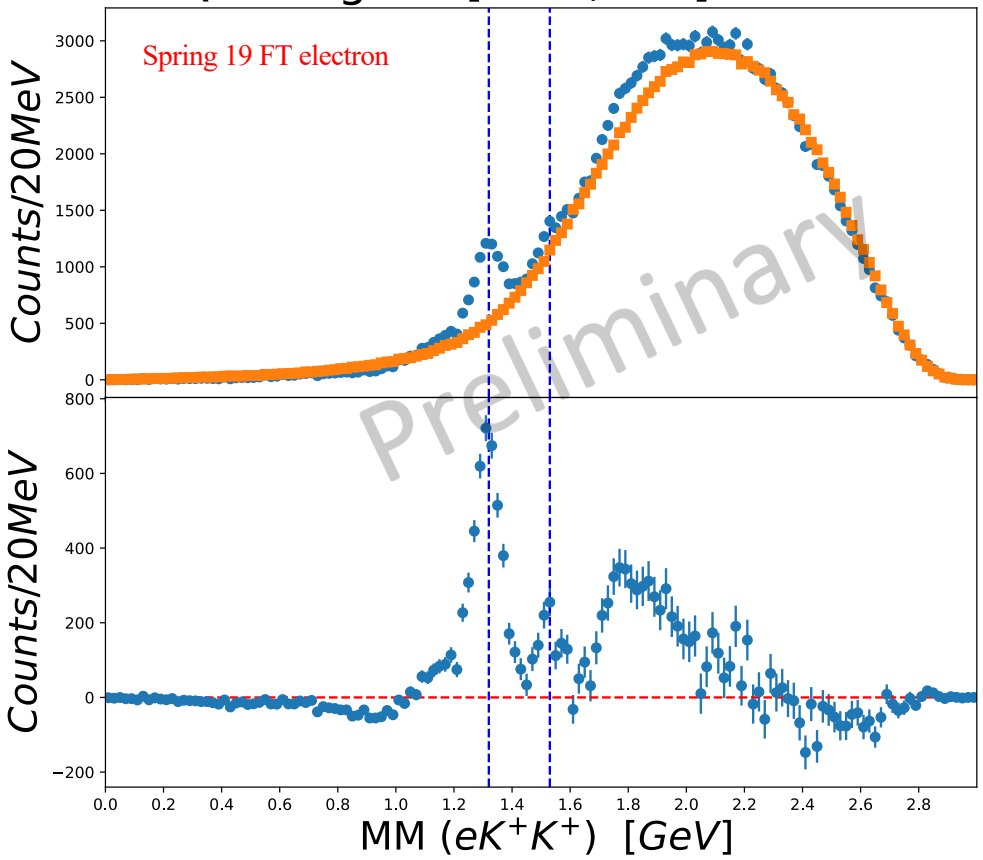
- Scattered electron e' can be detected in two regions
  - Low-Q^2 $(0.03 - 0.30GeV^2)$: e' detected in the FT
  - High-Q^2 $(> 0.30GeV^2)$: e' detected in the FD

- Data Skim:
  - "ElecFTKaon" skim with an additional K^+ required
  - "eK+" skim with an additional K^+ required

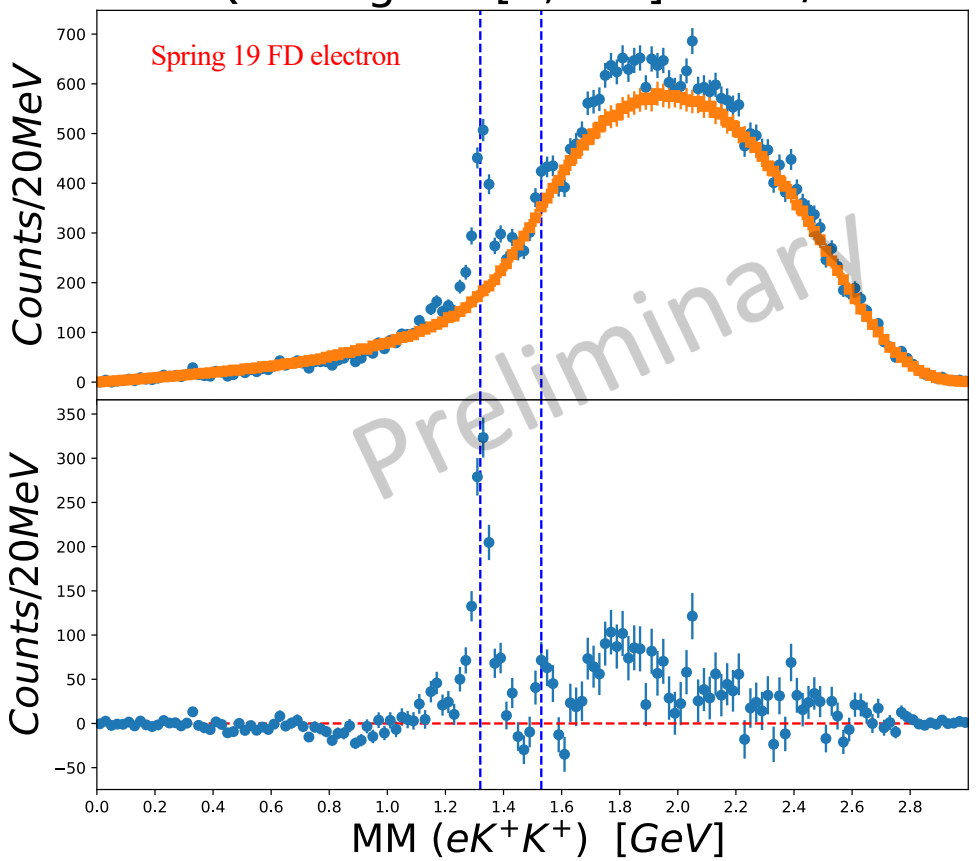
$ep \rightarrow e'K^+K^+(\Xi^{-(*)})$

Jose Carvajal

Q^2 range = [0.03, 0.3] GeV^2/c^2



Q^2 range = [1, 5.5] GeV^2/c^2

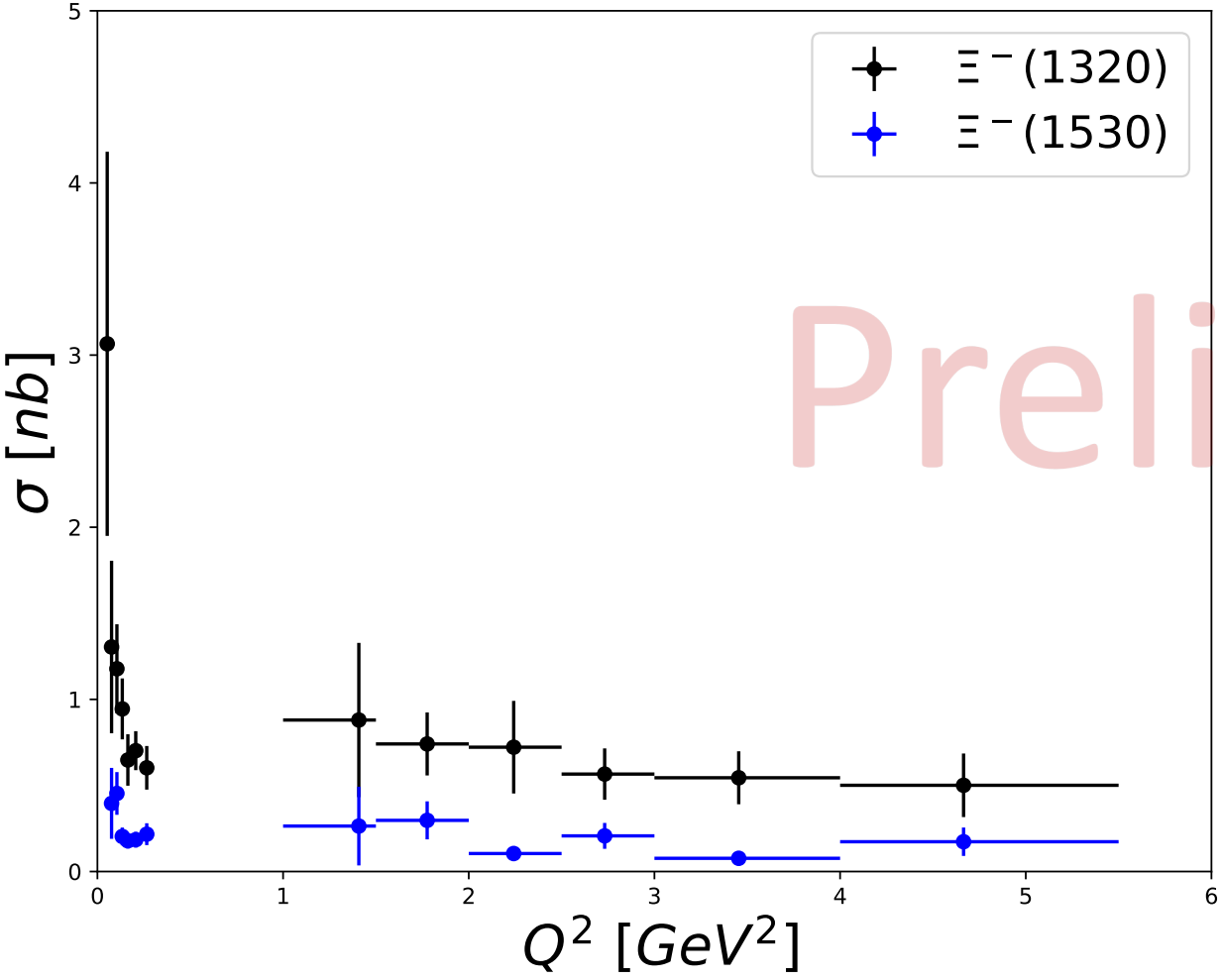


- First time $\Xi^-(1320)$ and $\Xi^*(1530)^-$ seen in electroproduction
- Background determined using mixed events techniques.

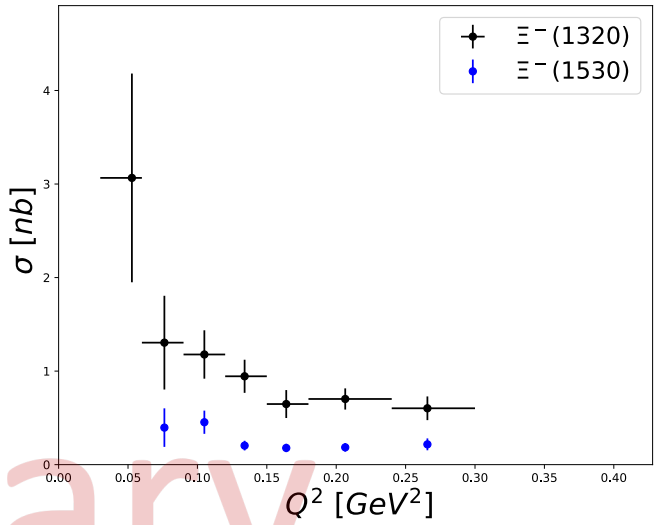
We expect to collect several times more statistics within the remaining approved RG-A beam time. This is critical for higher mass cascades. It will also allow us to measure decay branching and decay angular distributions necessary for determining the quantum numbers.

Cross Sections: Ξ^- and $\Xi^-(1530)$

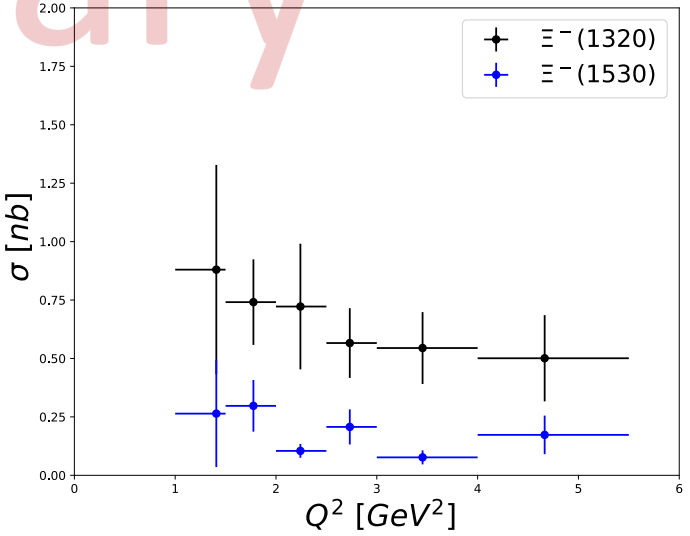
Jose Carvajal



FT



FD



CLAS g12 Experiment (photoproduction)

- Reaction: $\gamma p \rightarrow K^{+}\Lambda(1405)$
- Goal: Differential Cross Sections, $\frac{d\sigma}{dt}$, for two decay channels:
  - $\Lambda(1405) \rightarrow \Sigma^{-}\pi^{+}$
  - $\Lambda(1405) \rightarrow \Sigma^{+}\pi^{-}$
- Currently available $\frac{d\sigma}{dt}$ data for $\Lambda(1405)$ photoproduction (from CLAS g11 experiment) go up to $E_{\gamma} = 3.7$ GeV
- This analysis extends $\Lambda(1405)$ photoproduction cross section data to $E_{\gamma} = 5.25$ GeV

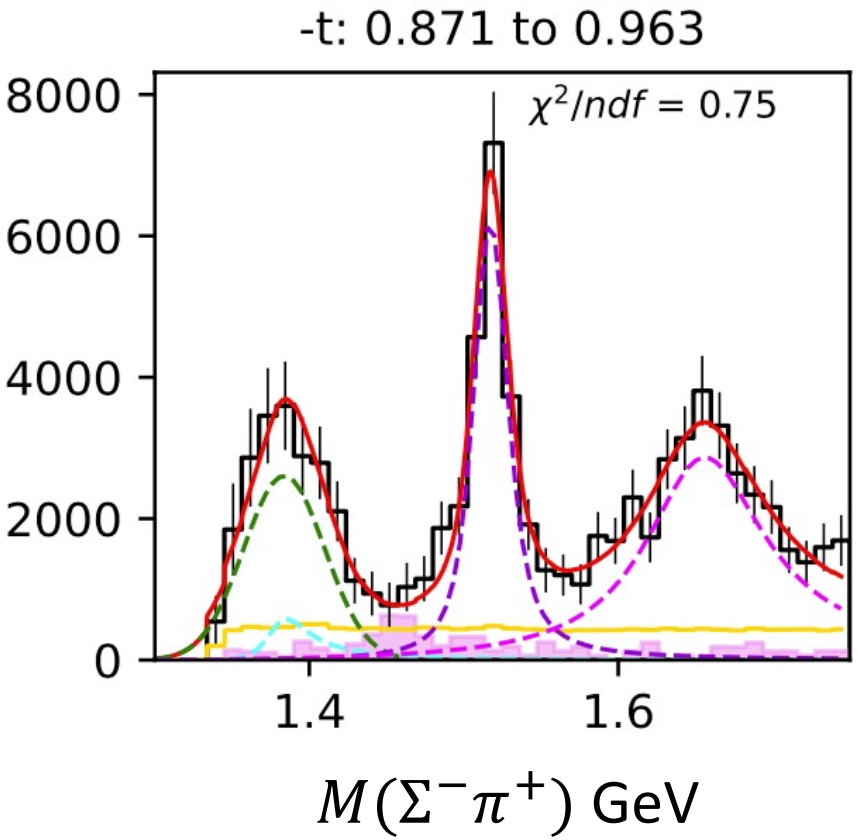
Trevor Reed, FIU

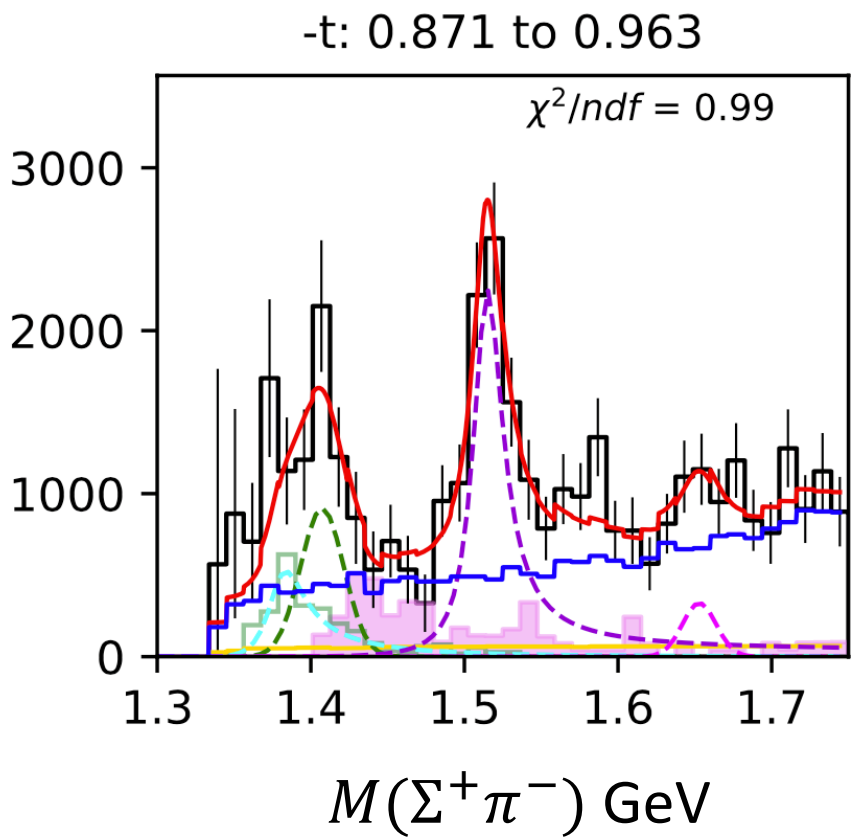
Invariant Mass $(\Sigma^-\pi^+)$

Trevor Reed

E_γ: 2.84 to 2.98 GeV

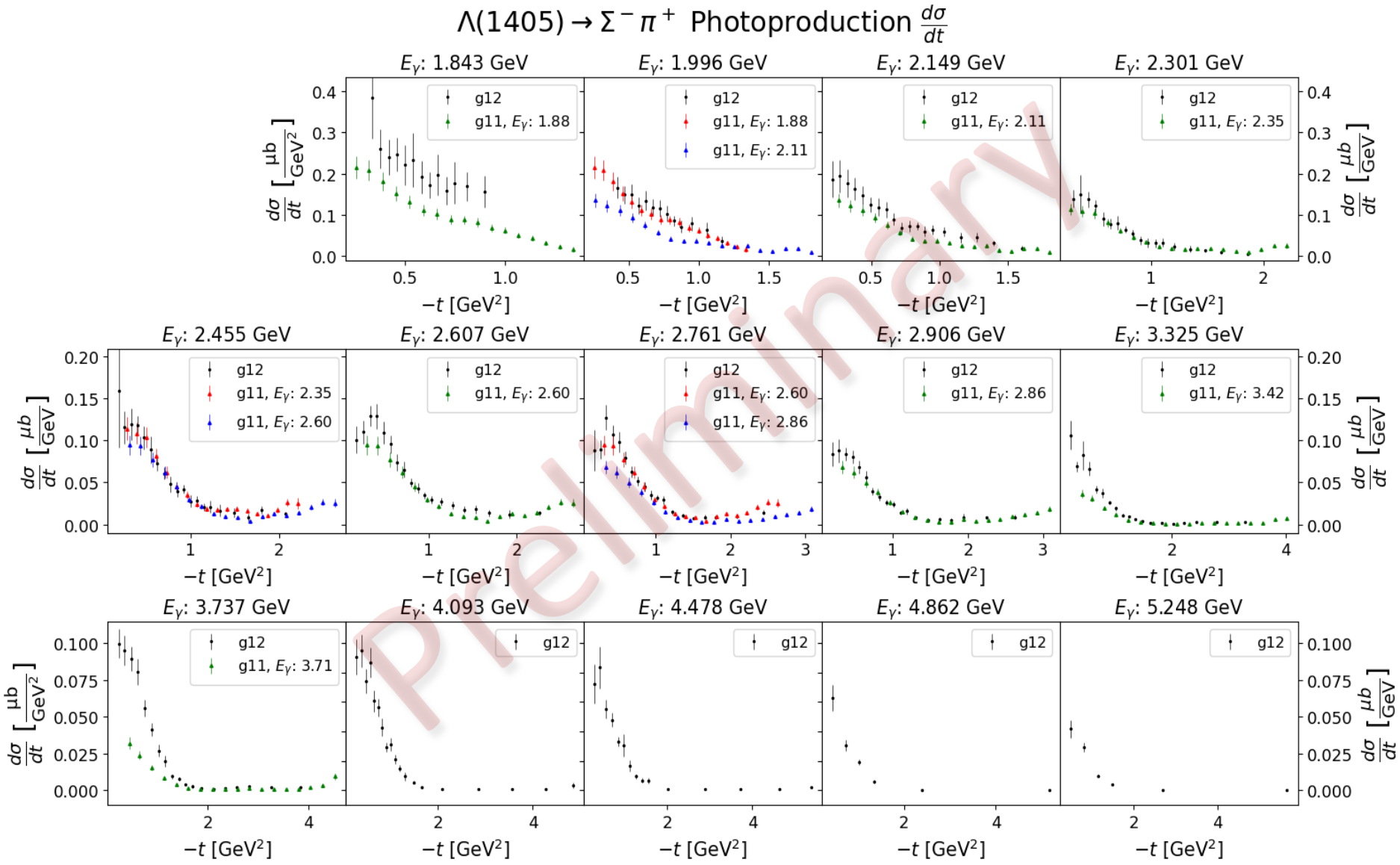
- Total fit
- $\Lambda(1405)$
- $\Lambda(1520)$
- $Y^{*0}(1660/1670)$
- $\Sigma(1385)$
- Mixed event background (histogram)
- Sideband background (histogram)
- K^* simulation





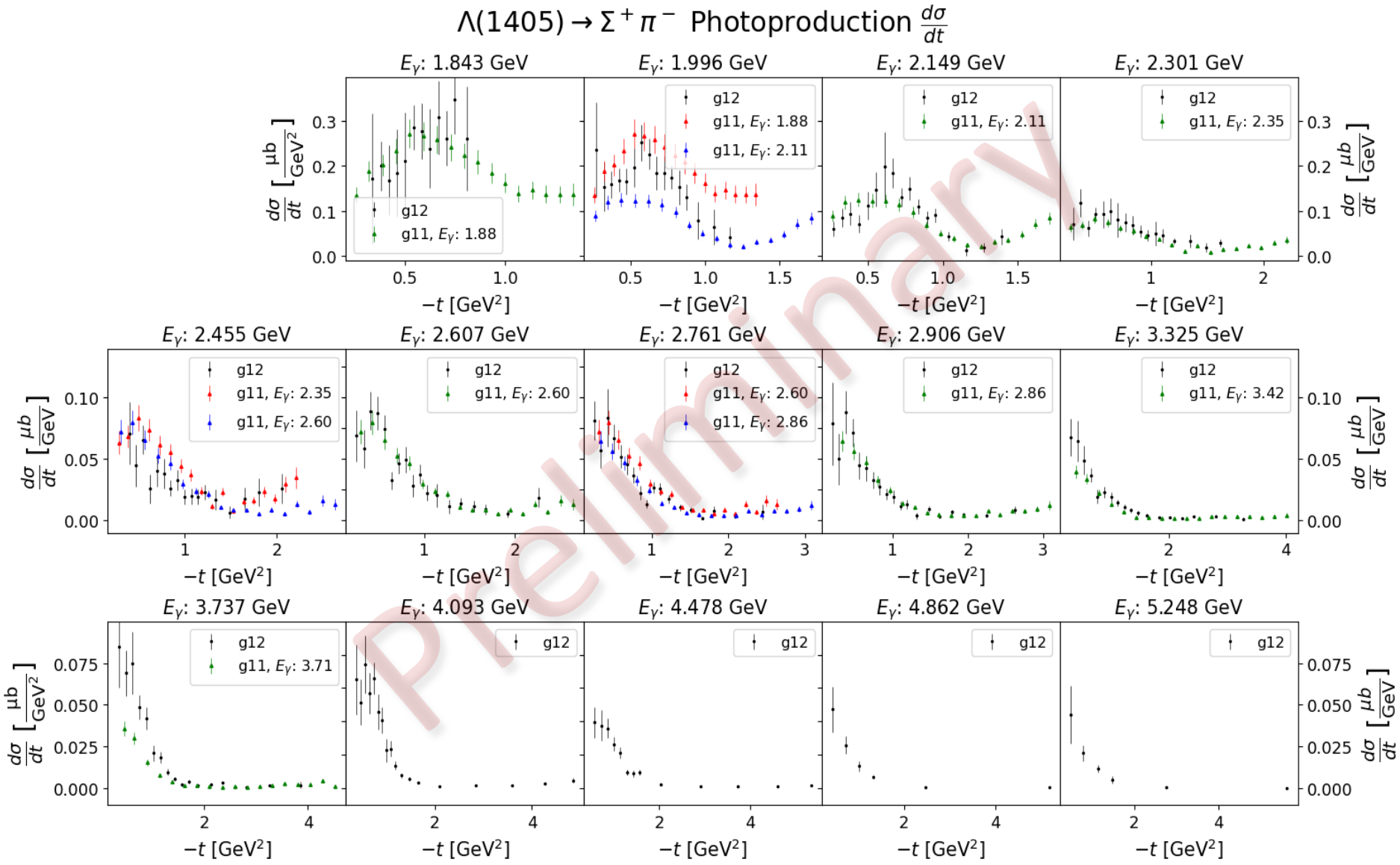
Cross Sections: $\Sigma^-\pi^+$ Decay Mode

Trevor Reed



Cross Sections: $\Sigma^+\pi^-$ Decay Mode

Trevor Reed



Recently Graduated with “Very Strange” Analyses

- Achyut Khanal, 2022 (FIU)
  - Ξ^* cross-section upper limit from Rg-A (pass 1)
  - Differential cross sections of $ep \rightarrow eK^+K^+K^-(\Lambda, \Sigma^0)$
- Mathew Nicol, 2022 (York)
  - Scaling behaviour of multi-strangeness production cross section
- Jose Carvajal, Spring 2024 (FIU)
  - Ξ^- cross sections from Rg-A (pass 2)
- Trevor Reed, Spring 2024 (FIU)
  - $\Lambda(1405)$ photoproduction cross sections from g12 (CLAS6)

Ongoing/Upcoming Work

- Ξ^* branching ratios ($\Xi^* \to \Xi\pi$/ $\Xi^* \to \Lambda K$/ $\Xi^* \to \Lambda K^*$) and quantum numbers
  - New PhD student Asli Acar (started Oct. 23, 2023)
- Ξ^* cross sections from Rg-K
  - Bianca Gualtieri (grad student, FIU)
- $p\bar{p}$ in RG-A (extending Will Phelps' analysis using real photons)
  - Will be first electroproduction cross sections for $ep \to epp\bar{p}$
  - Leonel Martinez (grad student, FIU)

All three will be presenting their work after the coffee break

2024 and Beyond

- FIU:
  - **Jose**: CLAS Analysis Note
  - **Trevor**: CLAS Analysis Note and publish g12 $\Lambda(1405)$ results
  - **Bianca**: $\Xi^{-(*)}$ in RGK
    - Expected graduation date: Spring 2027
  - **Leonel**: RGA data for $eppp\bar{p}$
    - CAA needed
    - Expected graduation date: Spring 2029
- Veronique Ziegler:
  - Exclusive Lambda from RGA/RGB/RGK
- John Price:
  - ΛN scattering CLAS12 (CAA needed)
- York:
  - **Asli Acar**
    - Ξ^* branching ratios and quantum numbers
- Open Analyses:
  - Excited Lambda's and Sigma's
    - $\Lambda(1405)$ electroproduction (RGA/RGK)?
  - $\Lambda\bar{\Lambda}$
  - Ω^-

Thank You

This research was funded in part by the U.S. Department of Energy, Office of Nuclear Physics under contract No. DE-SC0013620

Backup Slides

ed → e'K^+ (Λ → p π^-) n in RGB data

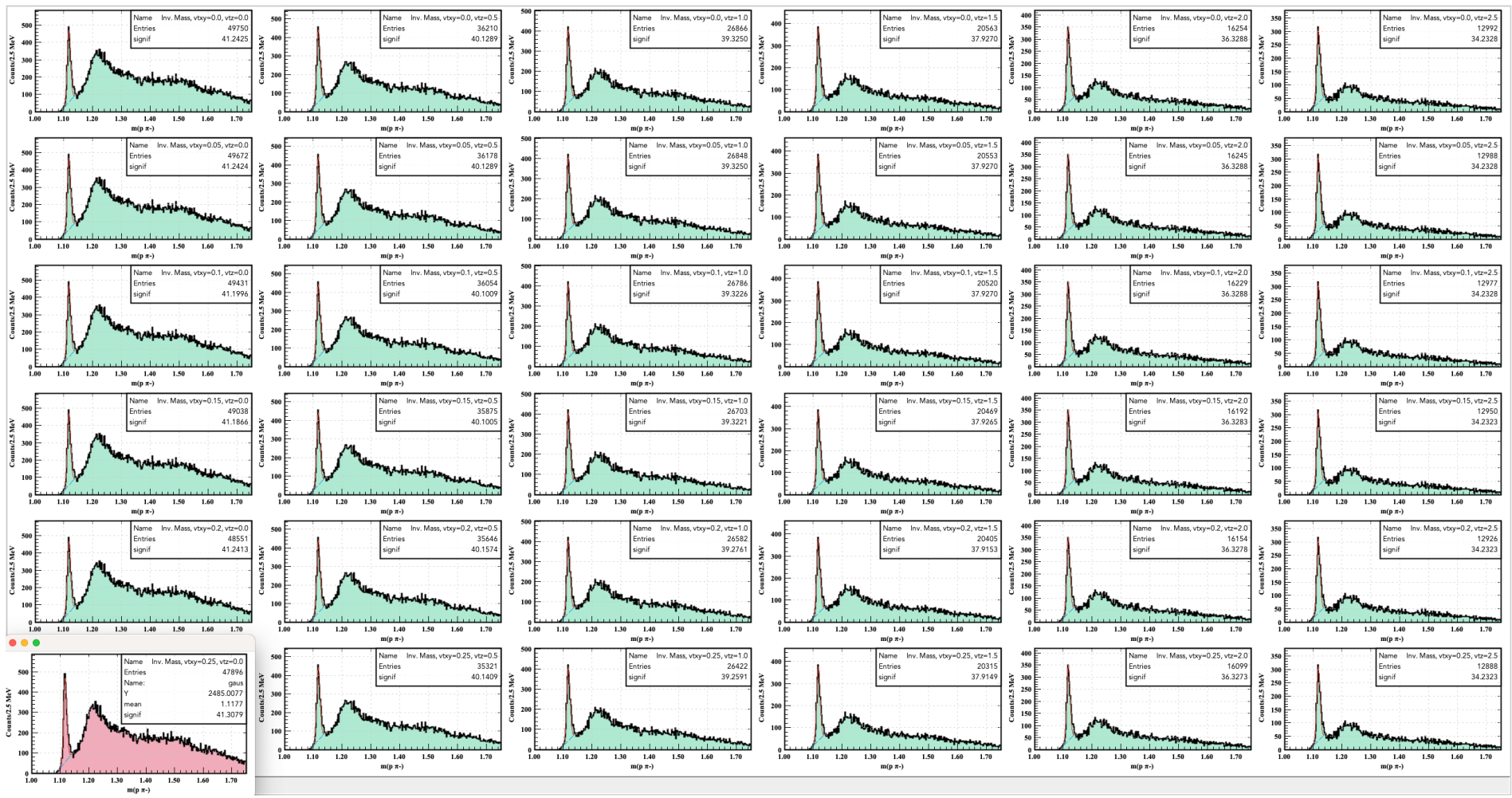
Vertex displacement cut optimization

Veronique

m(p π^-) for the reaction ed → e'K^+ (Λ → p π^-) n in RGB data, for varying vertex displacement cuts (vtxy: transverse wrt e-vertex; vtz: longitudinal wrt vtz). The neutron is selected by a missing mass cut of 200 MeV about the neutron peak (green box). The Λ signal significance ($S/\sqrt{S+B}$) is computed for each set of vertex cuts; the distribution with the higher significance is the pink histogram.

Increasing longitudinal vertex cut

Increasing transverse vertex cut



Outline

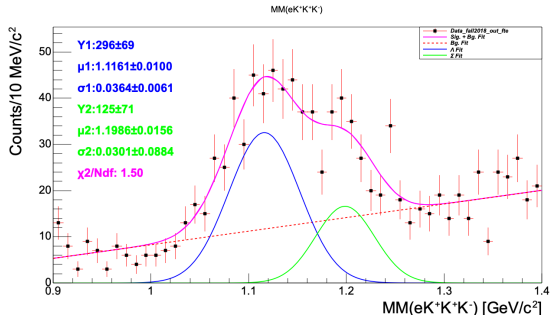
- **Description**
  - Analysis of differential cross sections and induced polarizations of Λ hyperons produced off the deuteron using RGB data. Comparisons with production off the proton using RGA and RGK data will also be carried out. The Λ will be exclusively reconstructed in the $\Lambda \rightarrow p\,\pi^-$ decay mode.
- **This is a proposed CAA (not yet approved)**
- **Outlook**
  - Preliminary analyses of $\Lambda \rightarrow p\,\pi^-$ and $\overline{\Lambda} \rightarrow \bar{p}\,\pi^+$ with CLAS12 electroproduction data show the feasibility of the proposed analyses and their potential to contribute to essential topics of QCD within the reach of RGB and RGA experimental configurations.

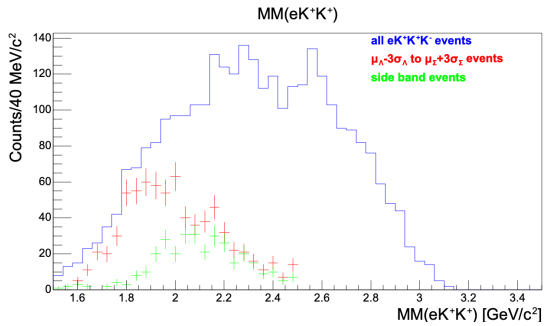
Veronique

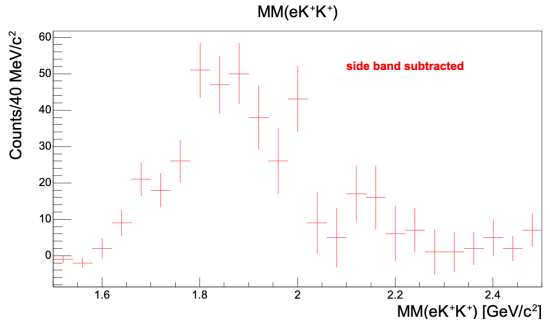
Missing mass distributions (electron in FT):

Identifying missing hyperon

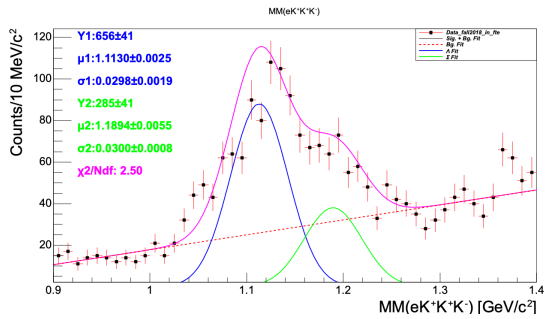
Fall 18 outbending

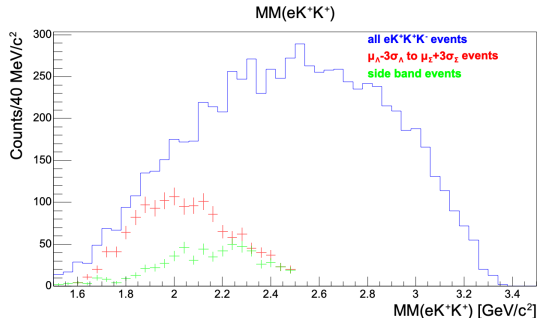


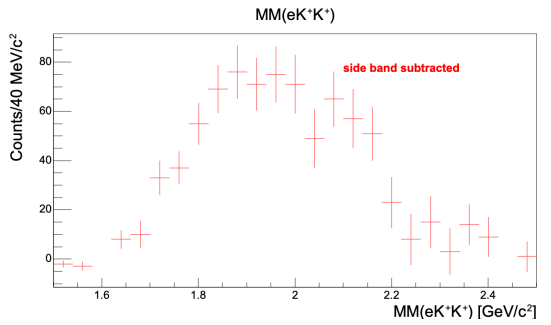




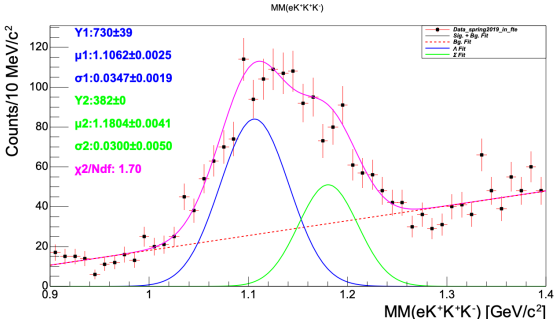
Fall 18 Inbending

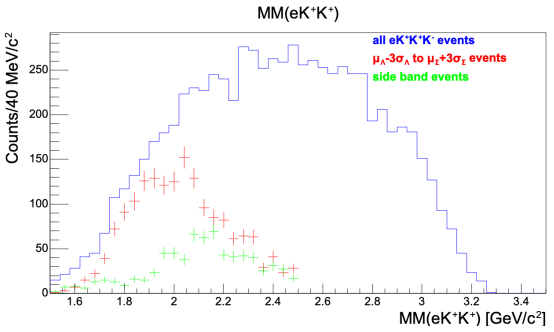


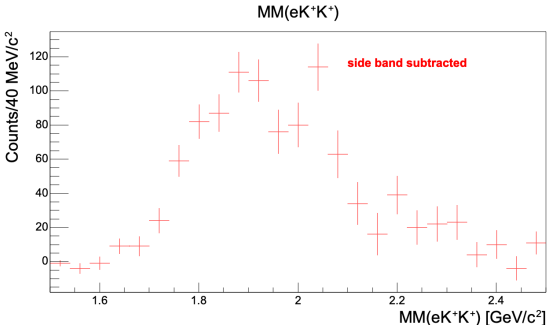




Spring 19 Inbending

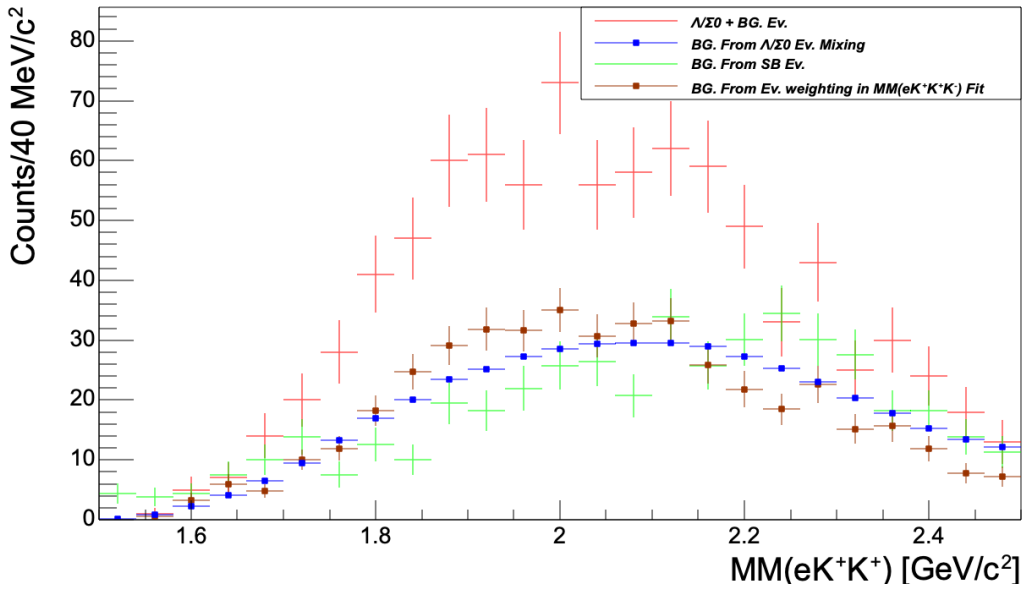






Background shape comparison example

Fall 18 Inbending



(b) Scattered electron detected in the FT.

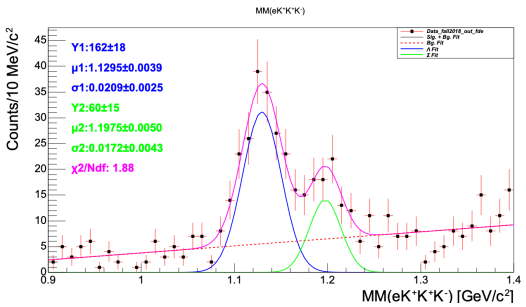
Different backgrounds were tried;
Event mixing proved to mostly be consistent with other methods ---- used for upper limit yield extraction;
Other methods (side band events) suffer From low statistics

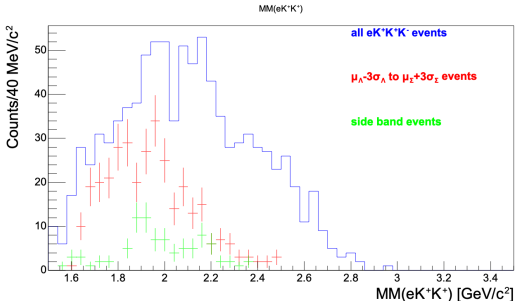
Missing mass distributions (electron in FD):

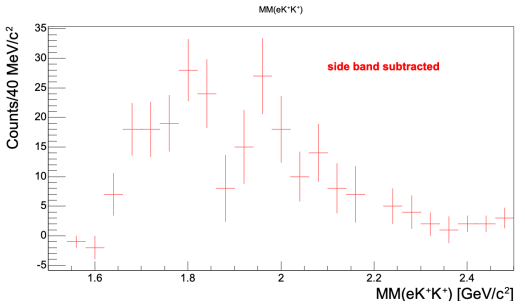
Identifying missing hyperon

Fall 18 outbending

Missing Mass Distribution Using RG-A Fall 2018 Outbending FD-e

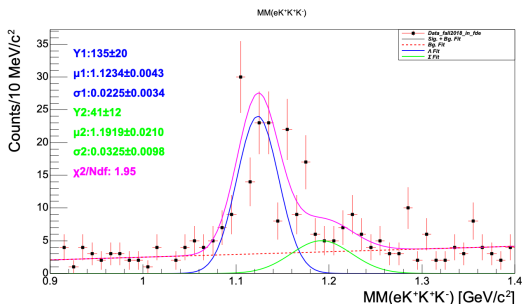


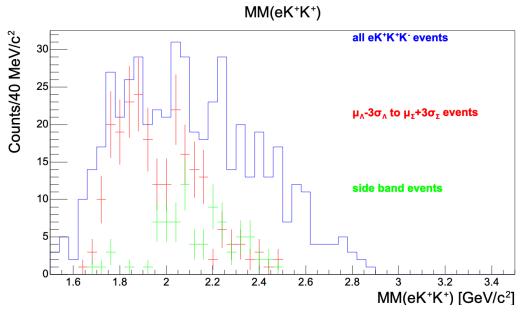


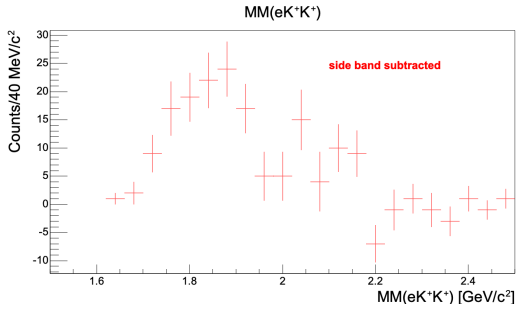


Fall 18 Inbending

Missing m Mass Distribution Using RG-A Fall 2018 Inbending FD-e

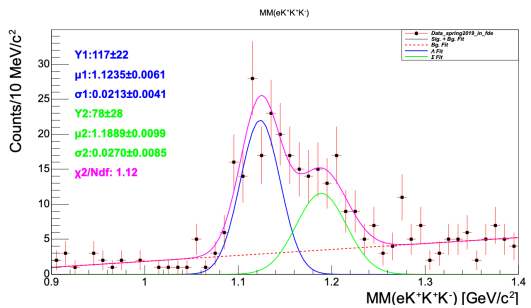


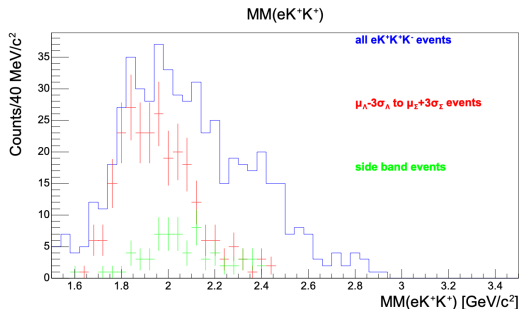


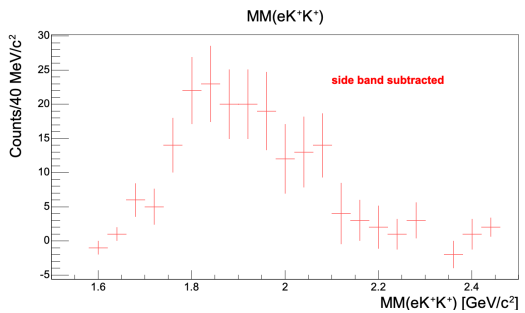


Spring 19 Inbending

Missing Mass Distribution Using RG-A Spring 2019 Inbending FD-e

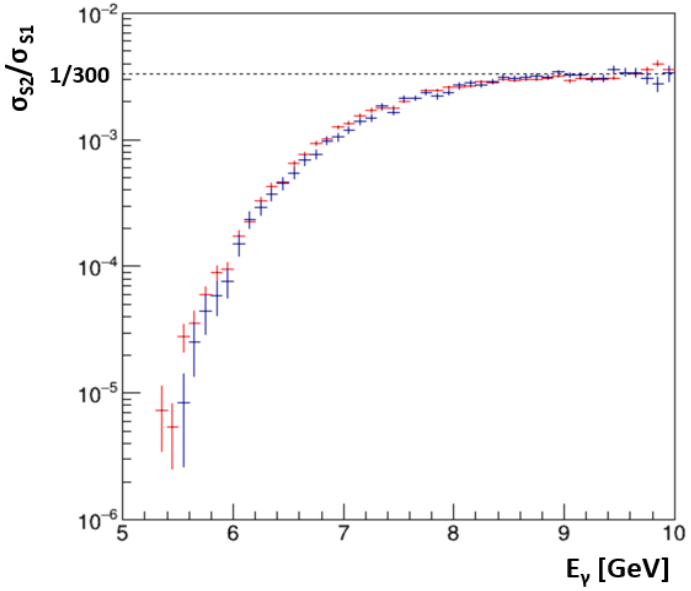


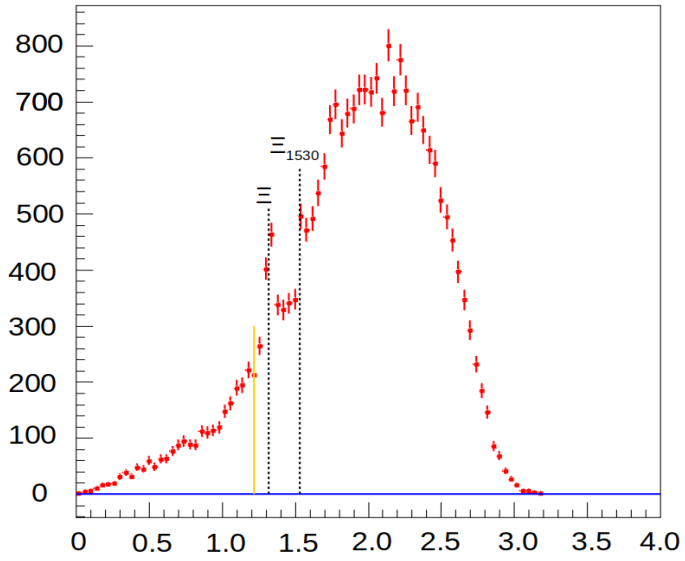




To do with Pass2

- Finalising scaling behaviour of multi-strangeness production x-section
  - Matt. Nicol (defended PhD, currently a postdoc, in SC)
- Ξ^* branching ratios ($\Xi^* \rightarrow \Xi\pi$/ $\Xi^* \rightarrow \Lambda K$/ $\Xi^* \rightarrow \Lambda K^*$)
  - New PhD student Asli Askar (started Oct 23)





$p\bar{p}$ Electroproduction off Protons in CLAS12

Leonel Martinez

Current Work

- $ep \rightarrow epp\bar{p}$
- RGA Spring 2019 In-Bending
- Missing mass to reconstruct missing particle

Goals

- Find Q^2 dependence for electroproduced $p\bar{p}$
- First time $p\bar{p}$ electroproduction cross-section measurement off proton target

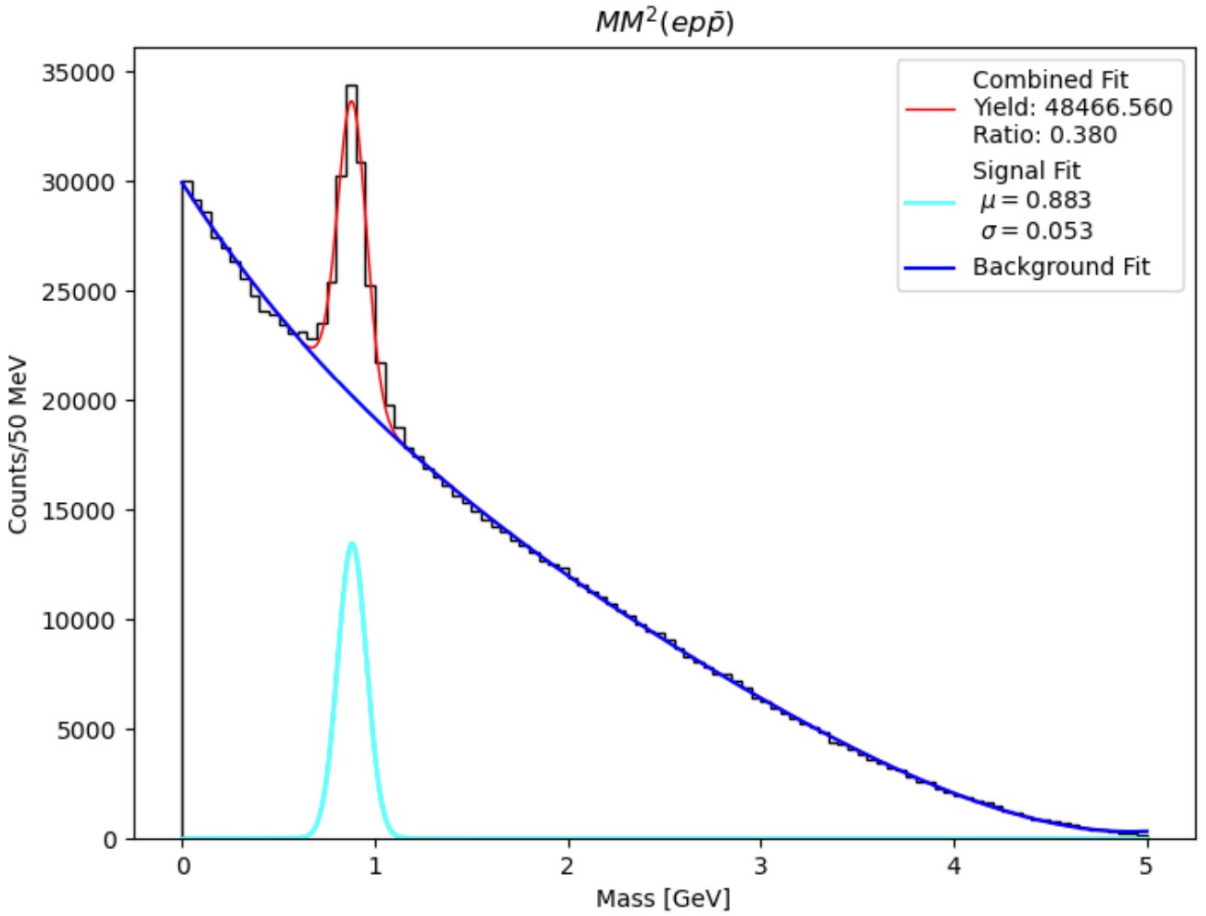
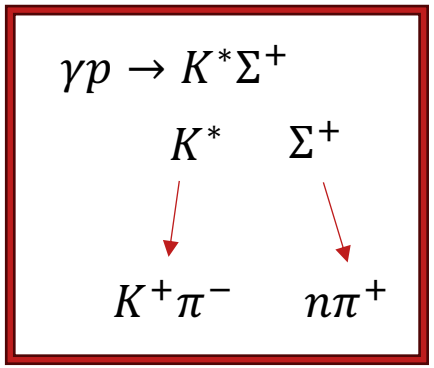
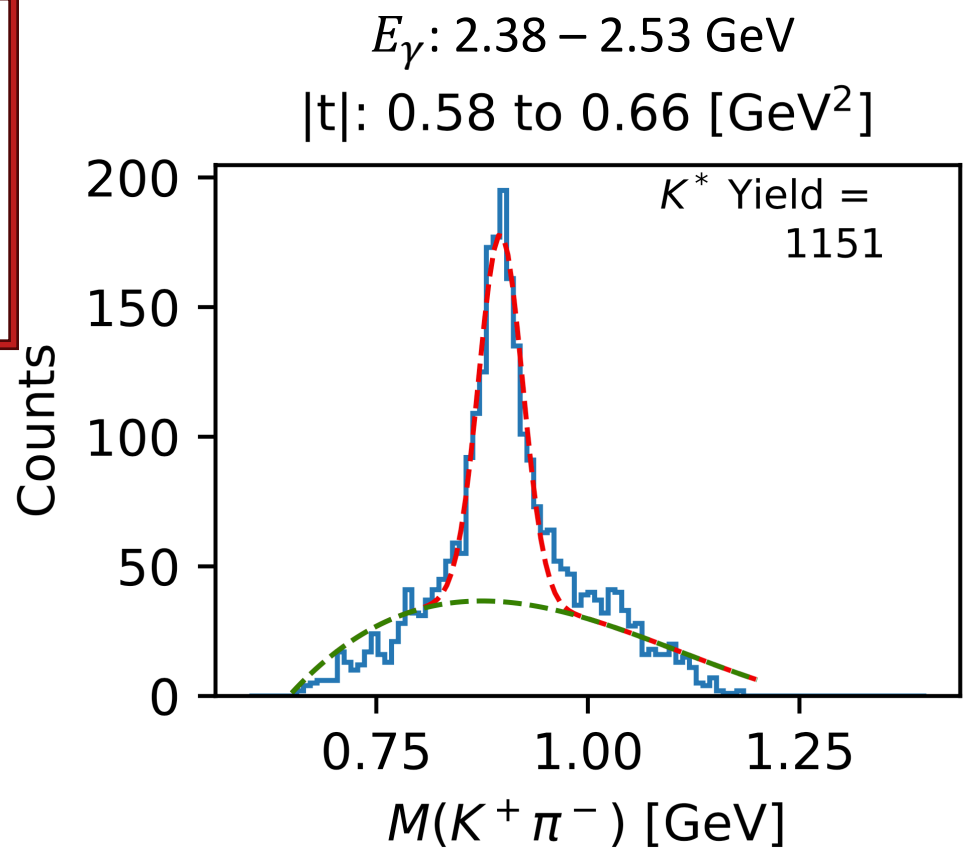


Figure: Missing mass squared off of $ep\bar{p}$. The dataset being used is RG-A Spring 2019 in-bending with ~50% of total files being used.

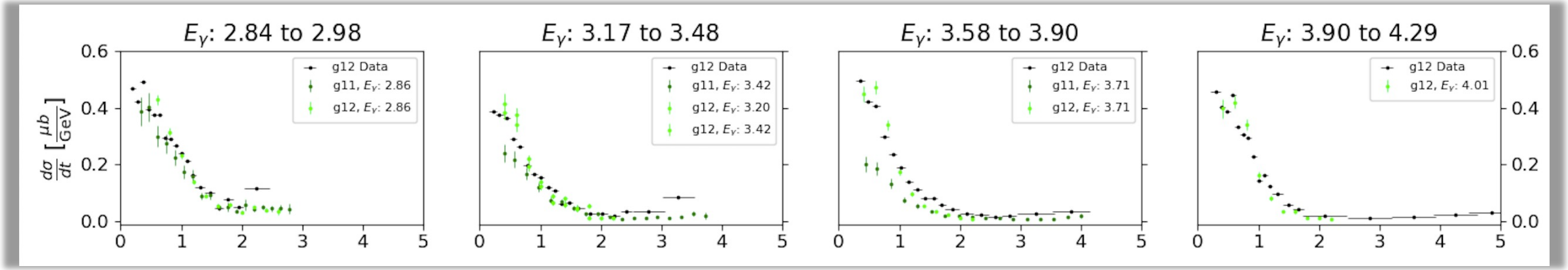
Accounting for $K^*(892)^0$ Contamination in $\Sigma^+\pi^-$ Decay Mode

- $K^*(892)^0$ only present in $\Sigma^+\pi^-$ mode
- Simulate $\gamma p \to K^*(892)^0\Sigma^+$ events
  - Provides template for background shape
- Total Fit: Scaling factor initialized by estimated K^* yield in the data





$\Lambda(1520)$ **Cross Sections**



$-t$ (GeV^2)