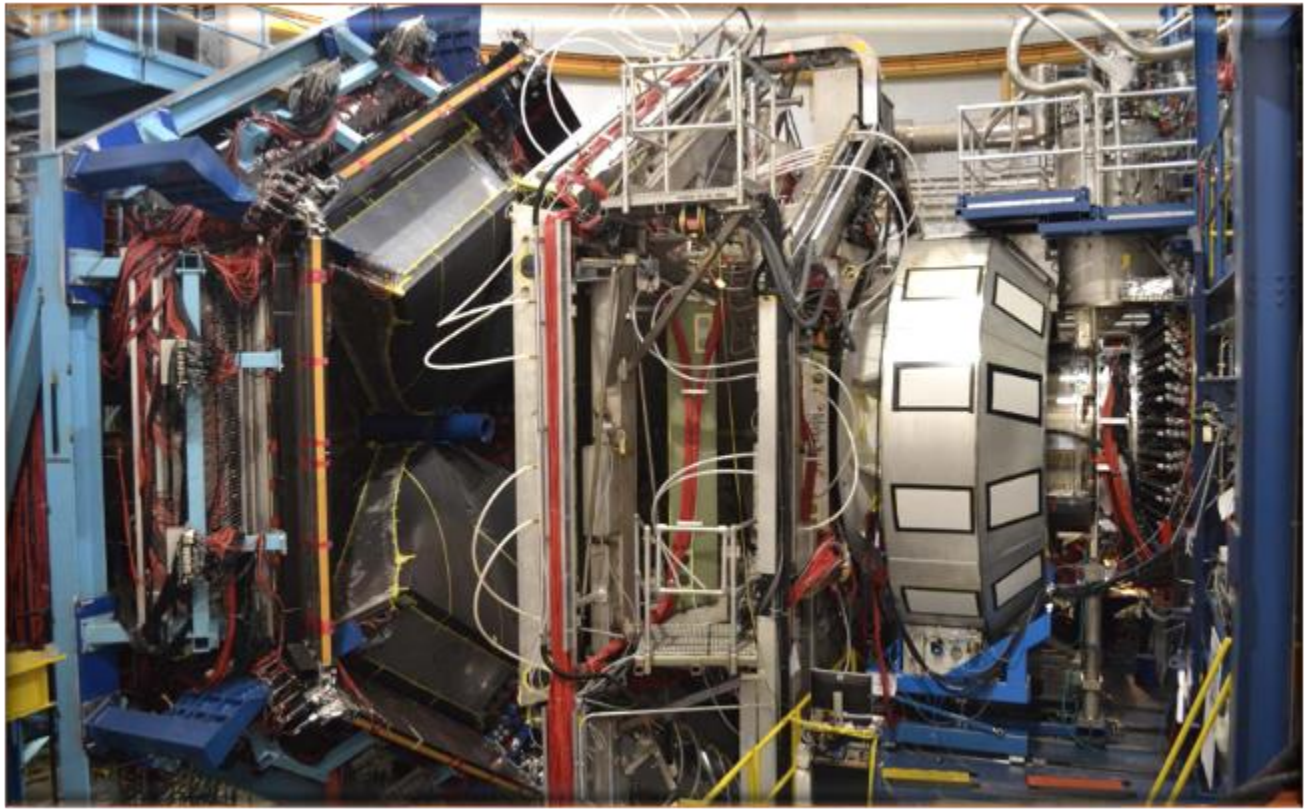
CLAS Collaboration Meeting

July 9, 2025

Jefferson Lab
Thomas Jefferson National Accelerator Facility

Recent Spectroscopy results from CLAS

Veronique Ziegler



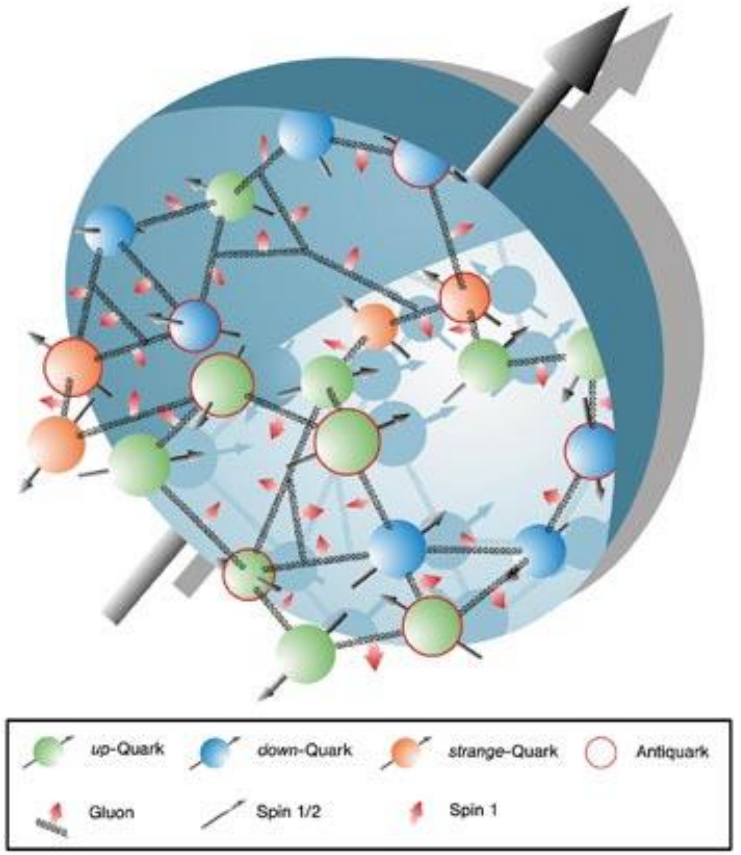
clas

Hadron spectroscopy at CLAS: The Big Picture

Study of hadrons by measuring their mass, widths, quantum numbers, and decay properties.

- To understand how the strong force, described by QCD gives rise to the spectrum and internal structure of hadrons. A key focus is the discovery and characterization of *excited baryonic states* (N*, Δ*, Ξ*) and the search for *exotic hadrons* (e.g., hybrid mesons, glueballs).

- **CLAS instrumented to perform spectroscopy studies with high precision**
  - **Electron Beam:** Provides polarized beams for precise measurements of spin observables.
  - **Targets**: Typically liquid hydrogen or deuterium for spectroscopy analyses.
  - **CLAS12 Detector**: Large-acceptance spectrometer used to detect and reconstruct multi-particle final states.
  - **Photoproduction & Electroproduction Reactions**: Tools to probe hadron resonances and internal structure.



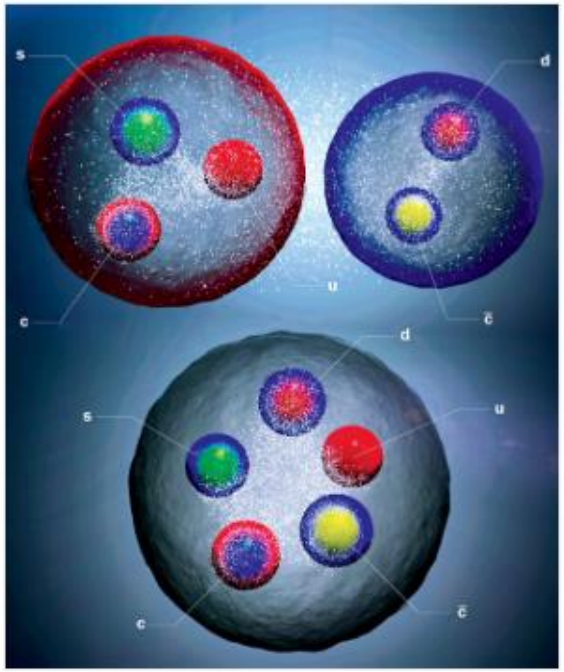
CERN Courier

Gell-Mann and Zweig on Exotic States

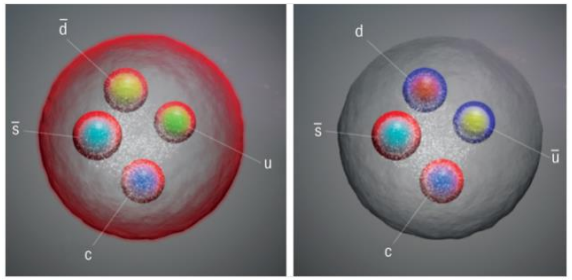
- The discovery of a lot of new particles (*Particle Zoology*) in the sixties led to a need to classify them → “Eightfold Way” - SU(3) flavor symmetry (Gell-Mann and Ne’eman).
- Led to the Quark Model (proposed by Gell-Mann and Zweig independently) → hadrons as bound states of quarks.
- Gell-Mann and Zweig’s theoretical framework allowed for the existence of "qqq̄q̄" states (tetraquarks) and "qqqqq̄" states (pentaquarks), also mentioning possibilities like glueballs and hybrids.

- About 4 decades later new states (*Particle Zoology 2.0*) with unexpected features were observed, prompting renewed interest in the possibility of exotic hadrons which had been only hypothesized until then.

Exotic hadrons

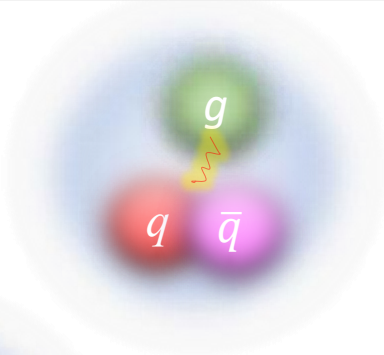


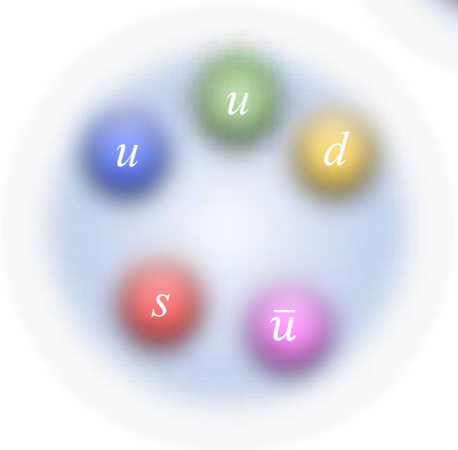
Strange pentaquark Molecular (top) and compact (bottom) interpretations of the $P_{c\bar{c}s}(4338)$ pentaquark discovered by the LHCb collaboration in 2022. Credit: D Dominguez



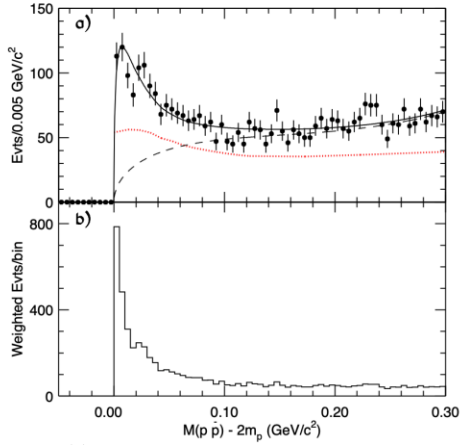
Brand new LHCb's latest tetraquarks, illustrated here as single units of tightly bound quarks, go by the names $T^a_{c\bar{s}0}(2900)^0$ and $T^a_{c\bar{s}0}(2900)^{++}$ in the new naming scheme. Credit: CERN

- Hybrids
  - Contain excited gluonic degree of freedom
  - Exotic quantum numbers (i.e. 0^{+-},1^{-+},2^{+-} not possible for conventional states)
- Molecules
  - Close to the threshold of the two hadrons they are made of
  - Narrow widths above threshold
    - Decay through suppressed channels
- Tetraquark, Pentaquark states
  - Narrow widths above threshold
  - Expected to have charged partners
- Baryonium states
  - E.g. Nucleon-Anti-nucleon bound states
- Non-resonant production
  - Threshold enhancement or cusp effect
  - Cross-channel re-scattering, intermediate mesons





Lattice QCD Evidence that the Λ(1405) Resonance is an Antikaon-Nucleon Molecule
Jonathan M. M. Hall, Waseem Kamleh, Derek B. Leinweber, Benjamin J. Menadue, Benjamin J. Owen[1], Anthony W. Thomas, and Ross D. Young



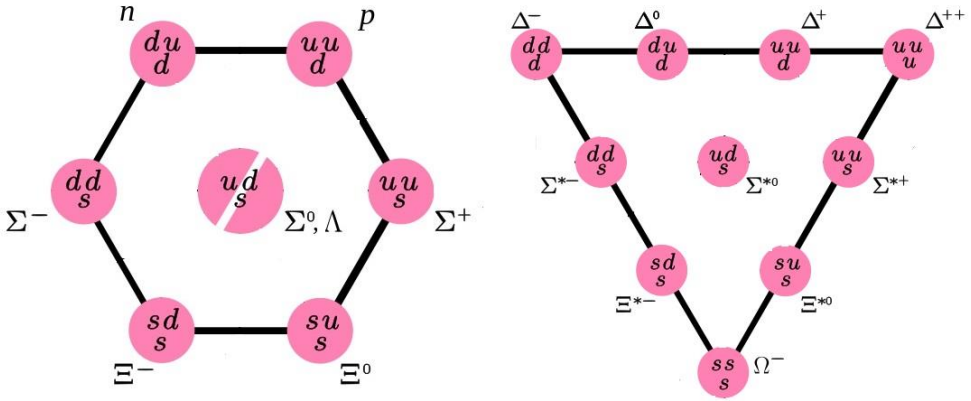
BES-II: a) $M(p\bar{p}) - 2m_p$

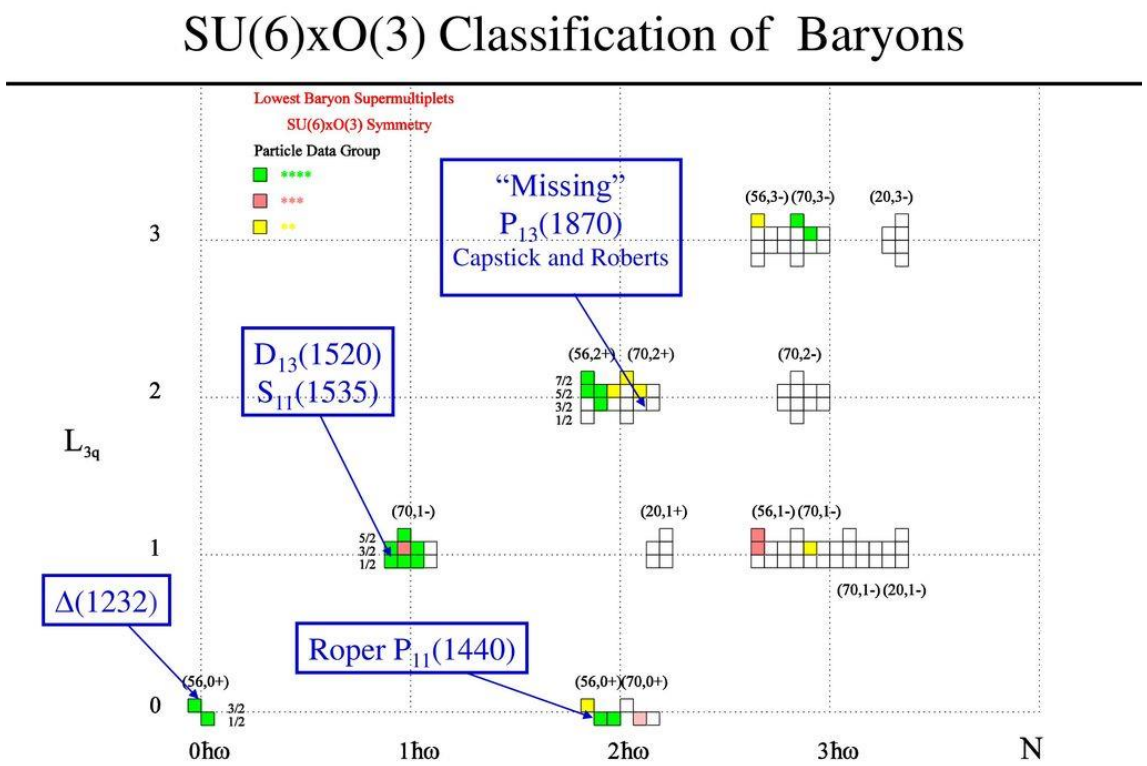
[1]Bai, J. Z., et al. "Observation of a Near-Threshold Enhancement in Th P Pbar Mass Spectrum from Radiative J/Psi-->gamma P Pbar Decays." *arXiv.Org*, 7 Mar. 2003, arxiv.org/abs/hep-ex/0303006v1.

[2] Ablikim, M, et al. "Spin-Parity Analysis of Ppbar Mass Threshold Structure in J/PSI and Psi' Radiative Decays." *arXiv.Org*, 5 Dec. 2011, arxiv.org/abs/1112.0942.

Searches for missing (excited) hyperon states

- Excited Ξ's
  - Improve knowledge of excited baryons with strangeness
  - Parity and polarization measurements
  - Searches for missing excited hyperon states
- Nucleon resonance studies
  - Study the baryon spectrum to map the Q^2 evolution of excited states
- Ω- in photo- and electro-production
  - Not seen in this production mechanism
  - First cross section measurement





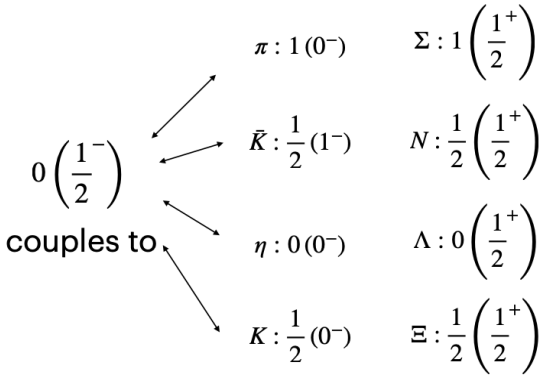
Motivation for the analysis of the $\Lambda(1405)$ with CLAS12

- $\Lambda(1405)$ [I=0, $J^P=1/2^-$, S=-1] located slightly below the $\bar{K}N$ threshold decays into the $\pi\Sigma$ channel through the strong interaction.
- Existence theoretically predicted in 1959 by Dalitz and Tuan, based on the analysis of the experimental data of $\bar{K}N$ scattering.

  R.H. Dalitz and S.F. Tuan,
  "The phenomenological description of-K–Nucleon reaction processes,"
  Annals of Physics 8 (1959) 100–118.

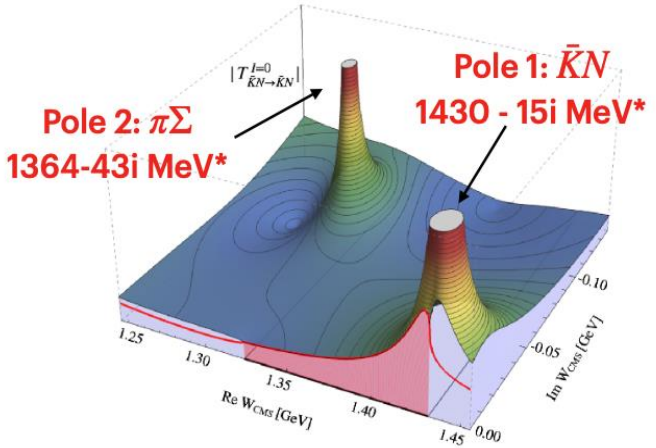
- **Description of the Λ(1405) as hadron molecular state**

$$|\Lambda(1405)\rangle = |\text{meson}\rangle \otimes |\text{baryon}\rangle \otimes |s\ wave\rangle$$



Previous CLAS results

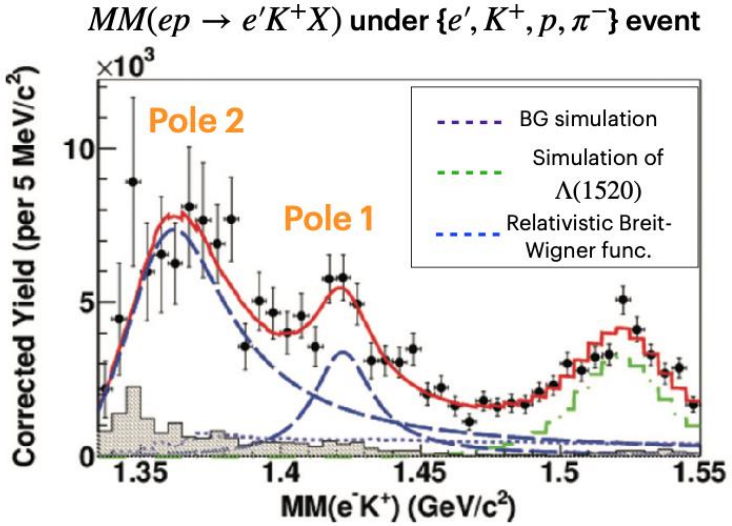
- Position of poles measurement
- Study of Q^2 dependence not possible due to limited statistic
  - Possible with high statistics obtained with CLAS12



M. Mai, Eur. Phys. J. Spec. Top. (2021) 230:1593-1607

* S. Navas et al. (Particle Data Group), "83. Pole Structure of the Λ(1405) Region", Phys. Rev. D 110, 030001 (2024)

Expect two states in one resonance!



* H. Lu et al., Phys. Rev. C 88, 045202 (2013)

Courtesy of Tatsuhiro Ishige – Tohoku U.

Analysis of the $\Lambda(1405)$ with CLAS12

Search for the $\Lambda(1405)$ in the reaction: $ep \rightarrow e'K^+(X)$ by missing mass technique

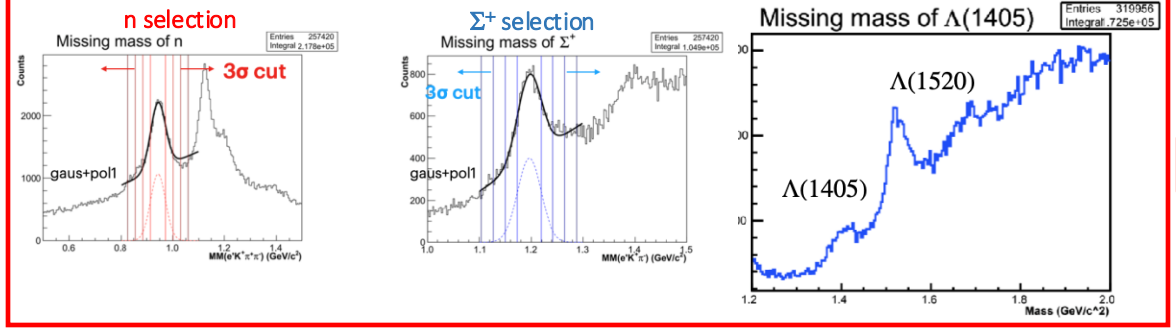
- RG-K data (E_{beam} = 7.5 GeV, 6.5 GeV)

$ep \rightarrow e'K^+$ ($\Lambda(1405)$)

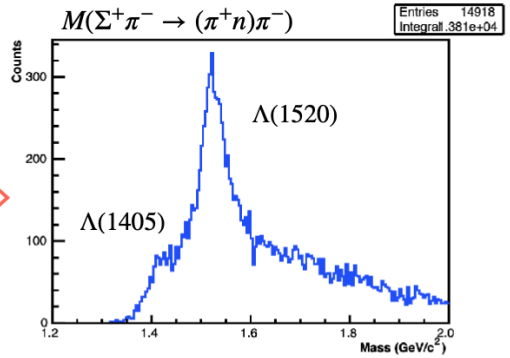
- $\Lambda(1405) \rightarrow \Sigma^+(\rightarrow \pi^+ n, \pi^0 p)\ \pi^-$
  - $ep \rightarrow e'K^+\ \pi^+\ \pi^-$ (n) ,
    $ep \rightarrow e'K^+$ p π^- (π^0) channels
- $\Lambda(1405) \rightarrow \Sigma^-(\rightarrow \pi^-$ n) π^+
  - $ep \rightarrow e'K^+\ \pi^-\ \pi^+$ (n) channel
- Reconstructing final state hadrons in FD
- Accidental background estimate

- **By missing mass technique**

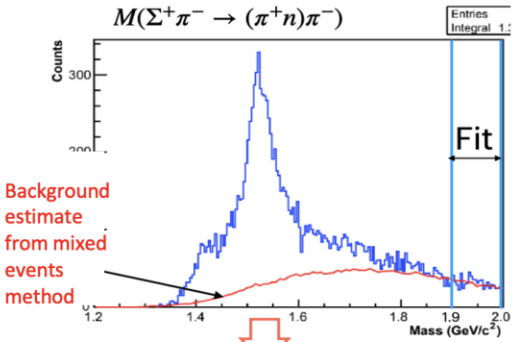
Preliminary

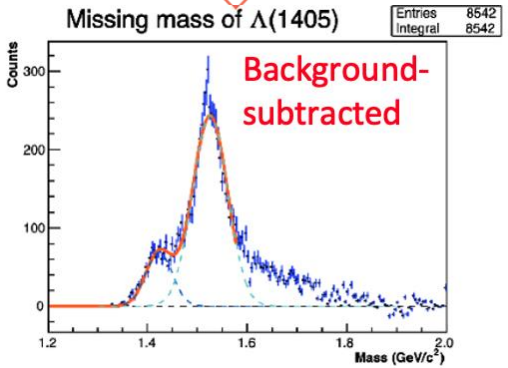


- **By invariant mass reconstruction**



Preliminary





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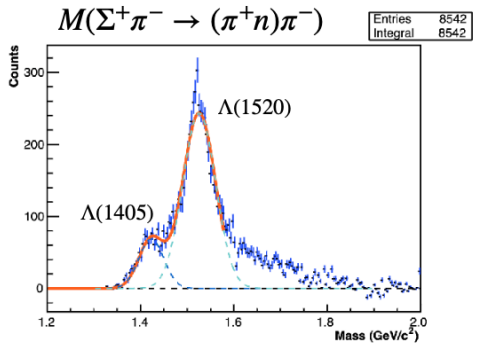
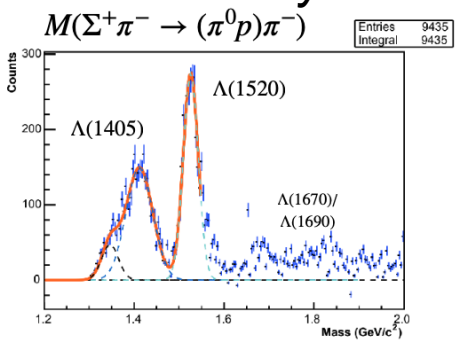
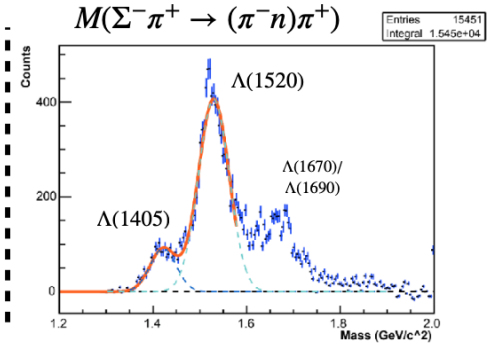






Fitting results

	Λ(1405) yield [Counts]	Λ(1405) sigma [MeV]
$M(\Sigma^+\pi^- \rightarrow (\pi^+ n)\pi^-)$	1100	33
$M(\Sigma^+\pi^- \rightarrow (\pi^0 p)\pi^-)$	3300	30
$M(\Sigma^-\pi^+ \rightarrow (\pi^- n)\pi^+)$	1500	27

- Consistent with the rough estimation at the order-of-magnitude level
  - ✦ Result: ~6000 , Rough estimation: ~2800
- Two-pole structure in $M(\Sigma^+\pi^- \rightarrow (\pi^0 p)\pi^-)$

- Analysis of poles coupling to $\Lambda(1405)$ a function of Q^2
- High statistics using Spring24 RG-K statistics ~ 5x statistics shown in this preliminary study.

Courtesy of Tatsuhiro Ishige – Tohoku U.

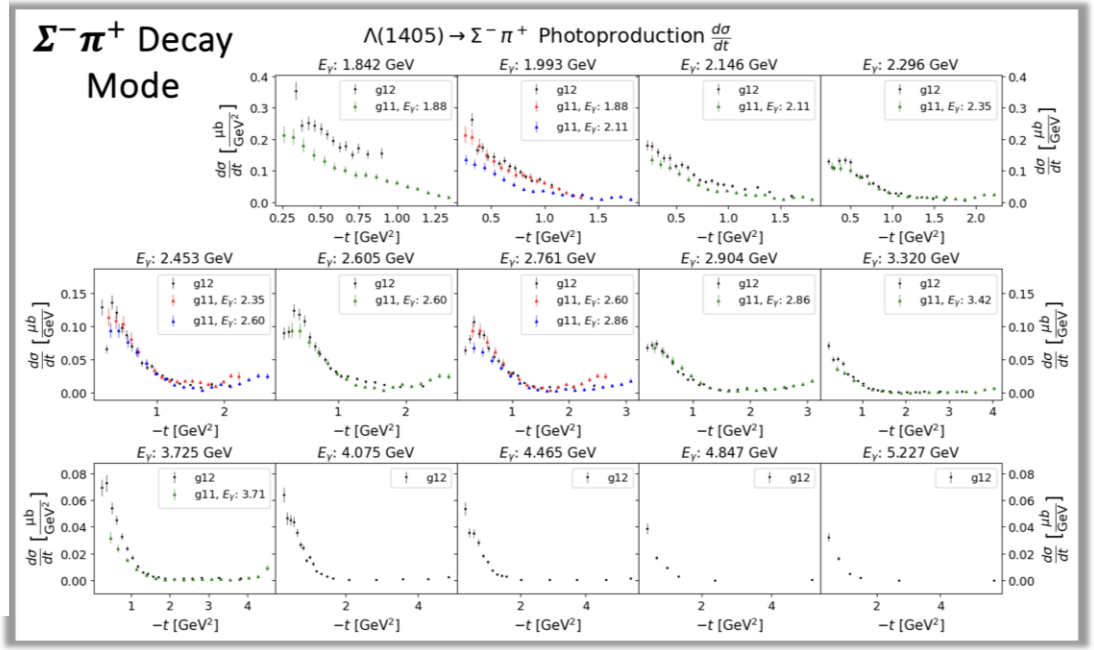
Analysis of the $\Lambda(1405)$ with CLAS6

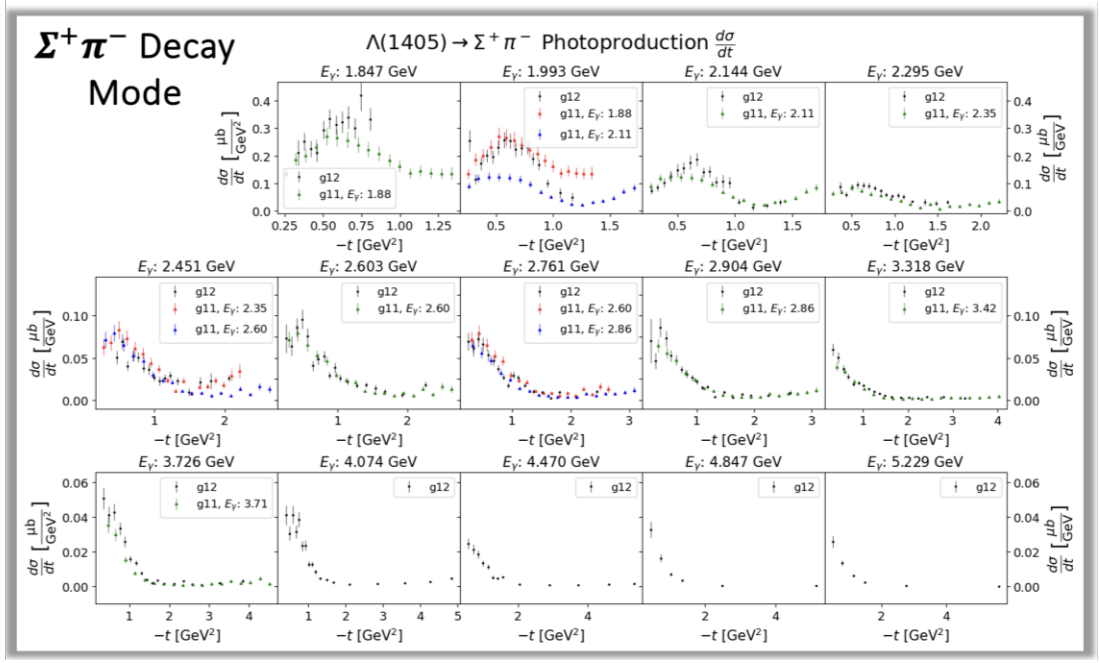
Analysis of the $\Lambda(1405)$ Cross Section as a function of -t

- g-12 data ($E_{\text{beam}} = 5.7\ GeV$)

Preliminary – under analysis review

- **CLAS Results**: Black
- **Published Results from Another (CLAS) Experiment:**
  Green, Red, Blue

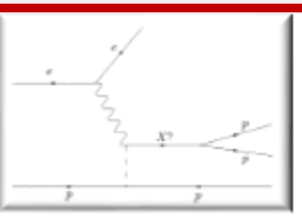




- Trevor Reed thesis (2024) – differential cross-section measurements for $\Lambda(1405)$ photoproduction
- Results in good agreement with prior photoproduction measurements (CLAS g11) with extended energy range over g-11 data.

Plots courtesy of Trevor Reed – FIU

Motivation for $Baryon - Antibaryon$ analyses with CLAS12

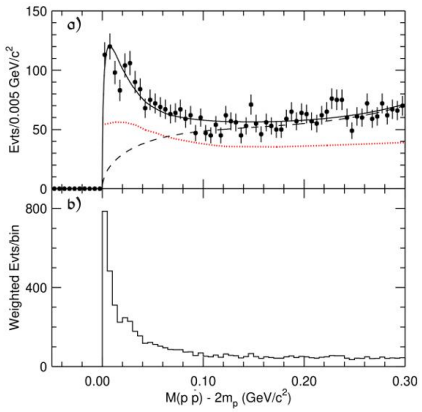


Threshold enhancement observations

- BES-II:
  - $J/\psi \to \gamma p\bar{p}$
  - Near mass threshold enhancement
  - Peak Mass: $M = 1859^{+3}_{-10}\ MeV/c^2$
  - Width: $\Gamma = 0 \pm 21\ MeV/c^2$

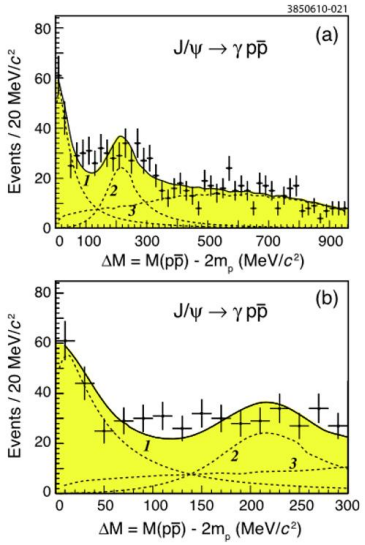
- CLEO
  - $J/\psi \to \gamma p\bar{p}$
  - Corroborated near mass threshold enhancement
  - Looked into extended mass range
  - Peak Mass: $M = 1861^{+16}_{-6} MeV/c^2$
  - Width: $\Gamma = 0^{+32}_{-0} MeV/c^2$

BES



J Z Bai *et al.* 2003 *Phys. Rev. Lett.* **91** 022001

CLEO



J. P. Alexander *et al.* Phys. Rev. D **82**, 092002

No evidence of narrow resonance

Photoproduction of $p\bar{p}$

- CLAS [a]
  - Measured differential cross sections
    - Angular distribution
    - Invariant Mass
  - Combinatorial background from two final state protons
- GlueX [b]
  - Measured differential cross sections
    - Invariant Mass
    - Mandelstam-t
  - Broader threshold enhancement observed
  - Phenomenological model for enhancement

$$\frac{d\sigma}{dm} \approx \exp\left[-\frac{m_{12}-m_{threshold}}{c_m}\right]$$

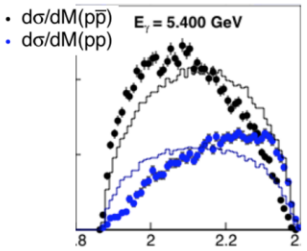


Figure 3: Differential cross sections of $p\bar{p}$ and pp showing the mass distributions.
Phelps W. "Antibaryon Photoproduction using CLAS at Jefferson Lab"

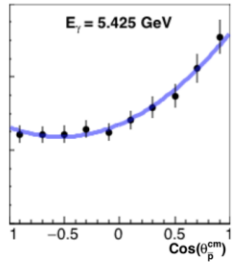


Figure 4: Differential cross sections for $\gamma p \to pp\bar{p}$ showing the angular distribution of the antiproton in the CM frame.
Phelps W. "Antibaryon Photoproduction using CLAS at Jefferson Lab"

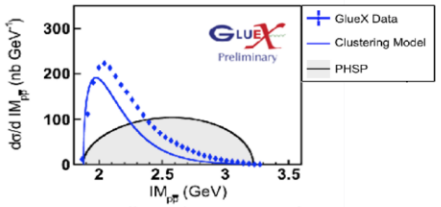


Figure 5: Differential cross sections of $p\bar{p}$ invariant mass measurements.
Li, Hao. "Baryon Anti-Baryon Photoproduction off the Proton"

[a] Phelps, Will. "Antibaryon Photoproduction Using CLAS at Jefferson Lab." *FIU*, 2017

[b] Li, Hao. "Baryon–Antibaryon Photoproduction Off the Proton." *Carnegie Mellon U*, 2023.

- Search for Baryon-Antibaryon structures in electroproduction off proton target with **CLAS12 RGA data**
  - High statistics (significantly higher statistics than CLAS photoproduction sample)
    - Results shown based on CLAS12 RGA Spring-19 data (~ 15% of RGA-2018/19 dataset → > factor 10 increase in signal yields obtained in electroproduction compared to CLAS6 photoproduction data sample)
  - Investigate multiple channels with Baryon-Antibaryon particles in the final state
  - High statistics allow for amplitude analysis

$Baryon - Antibaryon$ electroproduction off the proton at CLAS12

- Reactions
  - $ep \rightarrow epp\bar{p}$
  - $ep \rightarrow epp\pi^{-}\bar{n}$
  - $ep \rightarrow ep\bar{p}\pi^{+}n$

- $ep \rightarrow epp(\bar{p})$

- $ep \rightarrow epp\pi^{-}(\bar{n})$

	ep	γp
$\frac{Y_{\bar{n}}}{Y_{\bar{p}}}$	10%	0.52%

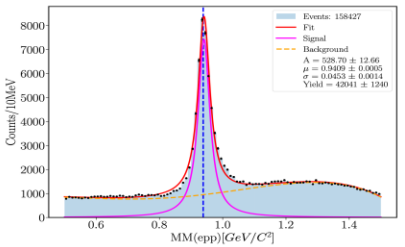
- $ep \rightarrow ep\bar{p}\pi^{+}(n)$

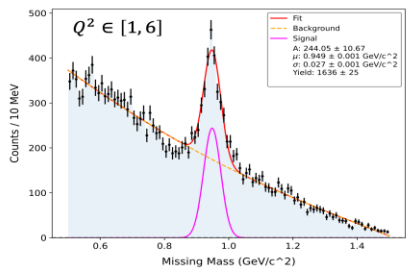
	ep	γp
$\frac{Y_{n}}{Y_{\bar{p}}}$	4%	0.52%

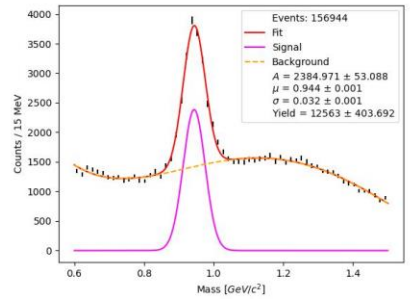
- Beam energy = 10.2 GeV
- Missing mass technique used
- Electron in EC or Forward Detector

Preliminary

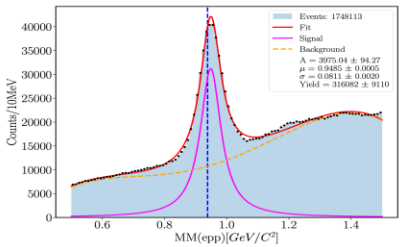
recoil electron detected in the FD

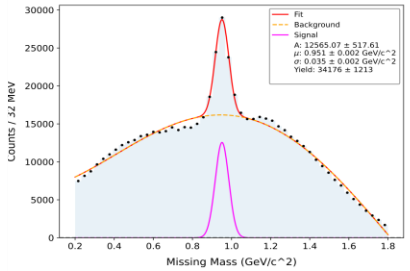


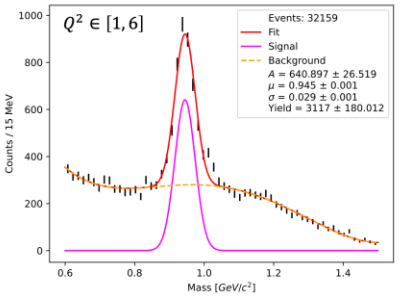




recoil electron detected in the FT



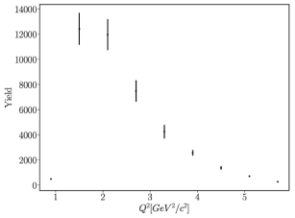


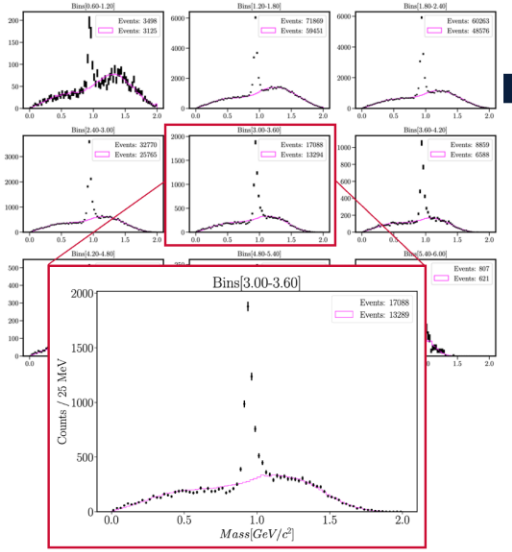


Q^2 Bins

Preliminary

- Binning Missing Mass distribution by Q^2
- $Q^2 \in [0.6,6]$ with 9 equally spaced bins
- Can extract yield by subtracting background and fitting signal peak





Analysis Goals:

- First time high statistics cross section extractions of Baryon-Antibaryon in electroproduction
- Amplitude analyses

Courtesy of Leonel Martinez – FIU, with contributions from FIU students Alexander Lohr and Edward Morell

Motivation for *Cascade Baryons* analyses with CLAS12

Missing Cascade States

- Number of excited Ξ's predicted from SU(3) symmetry greater than the number of states seen experimentally
- Incomplete knowledge of quantum numbers
- Production mechanism still unclear

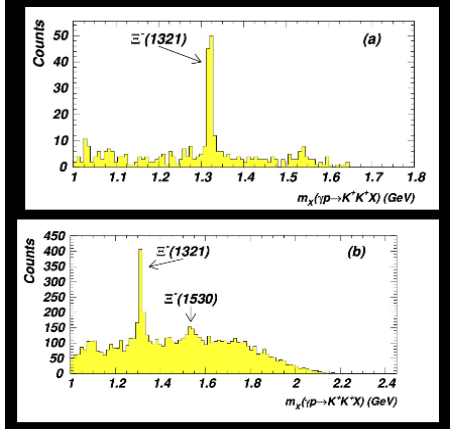
Particle	J^P	Overall status	Status as seen in — $\Xi\pi$	ΛK	ΣK	$\Xi(1530)\pi$	Other channels
Ξ(1318)	1/2+	****					Decays weakly
Ξ(1530)	3/2+	****	****				
Ξ(1620)		**	**				
Ξ(1690)		***	**	***	**		
Ξ(1820)	3/2−	***	**	***	**	**	
Ξ(1950)		***	**	**		*	
Ξ(2030)		***		**	***		
Ξ(2120)		*		*			
Ξ(2250)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

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

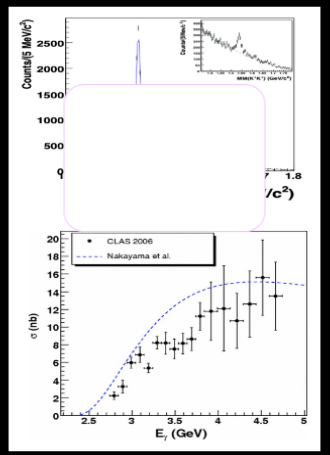
Previous Photoproduction Results

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



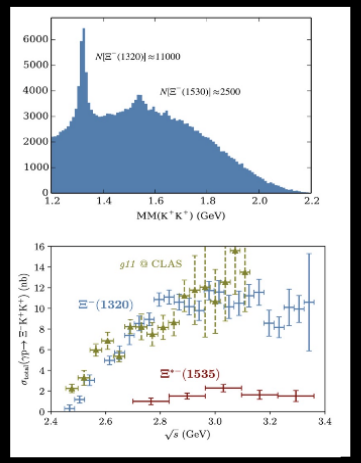
J.W.Price et al. Exclusive photoproduction of the cascade hyperons

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



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

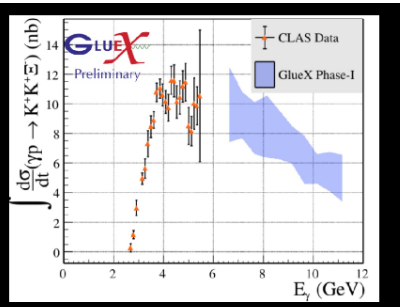
2018: g12 expanded the kinematic region of study (W=3.3GeV) as well as increased statistics

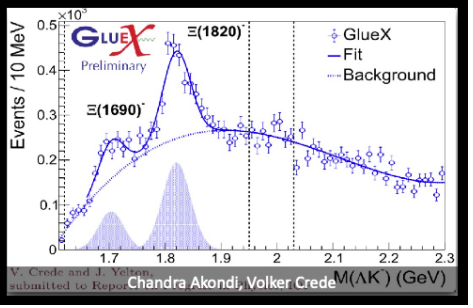


J.T. Goetz et al. Ξ* Photoproduction from Threshold to W=3.3 GeV

GlueX Cascade Studies

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





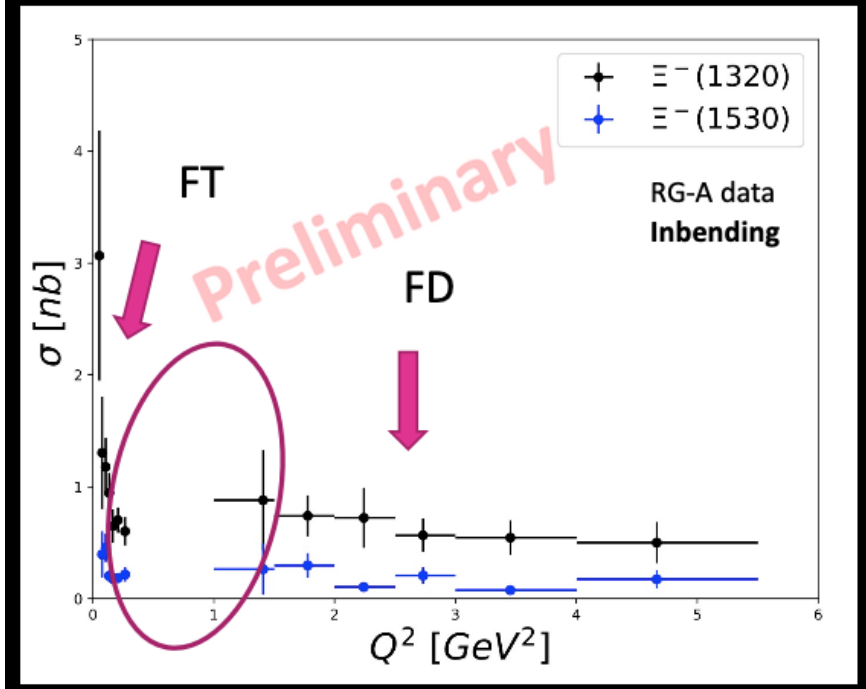
Chandra Akondi, Volker Crede

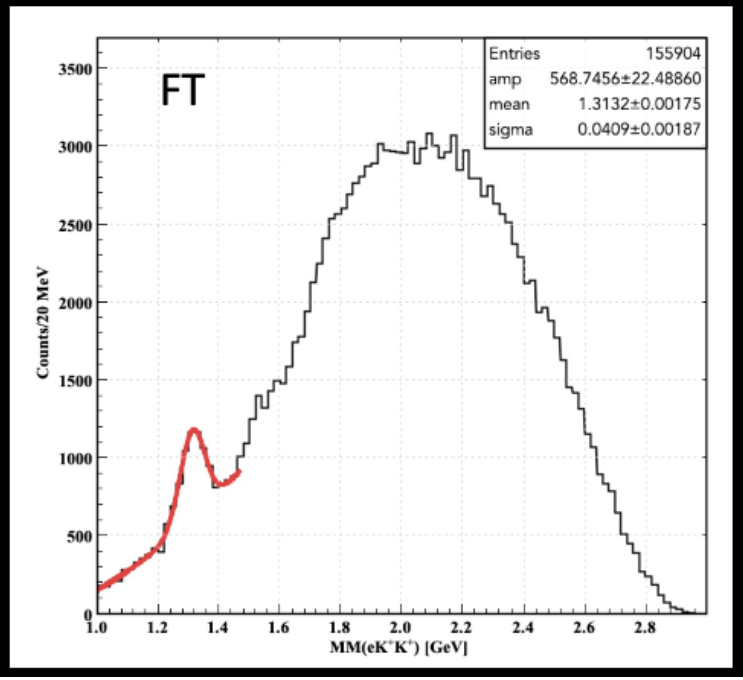
- Search for excited Cascades in the exclusive reaction: $ep \to e'K^+K^-(\Xi^-)$ [missing mass technique]

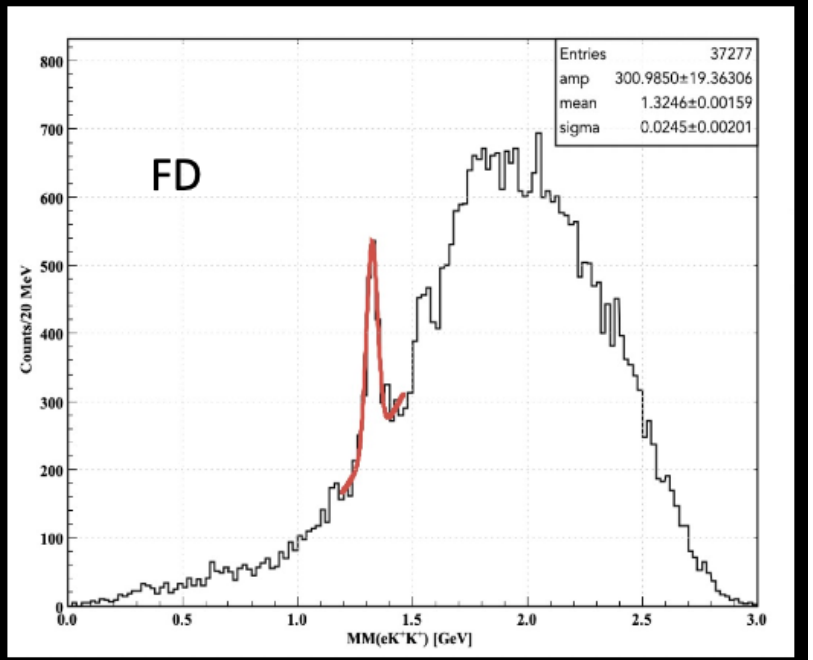
Courtesy of Bianca Gualtieri - FIU

Jose Carvajal, Ph.D. thesis "First Time Measurement of Ground State Ξ^- Hyperon Cross Section in Electroproduction" (2024)

- First cross section measurement for the ground state Cascade in electroproduction
- RG-A data (E_{beam} = 10.2 GeV)



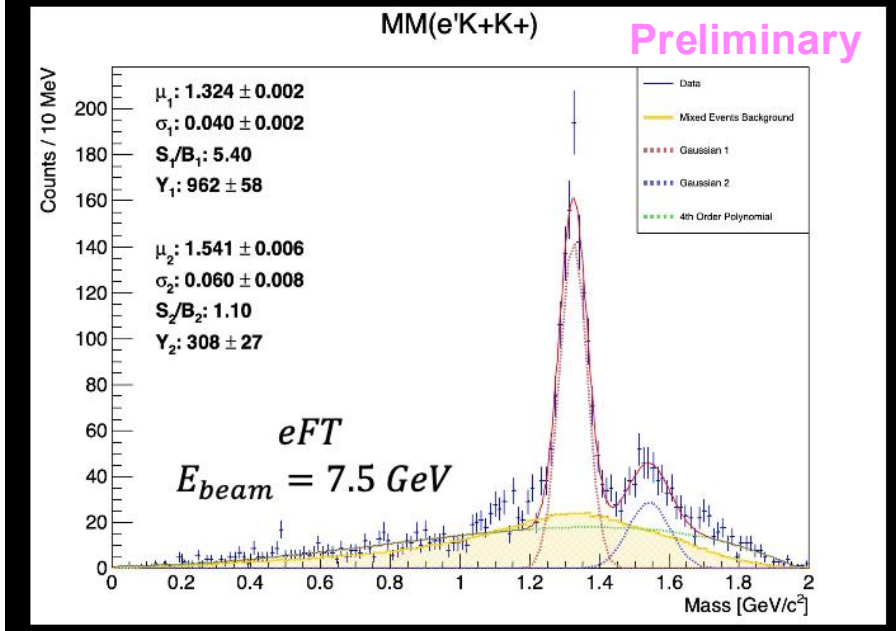


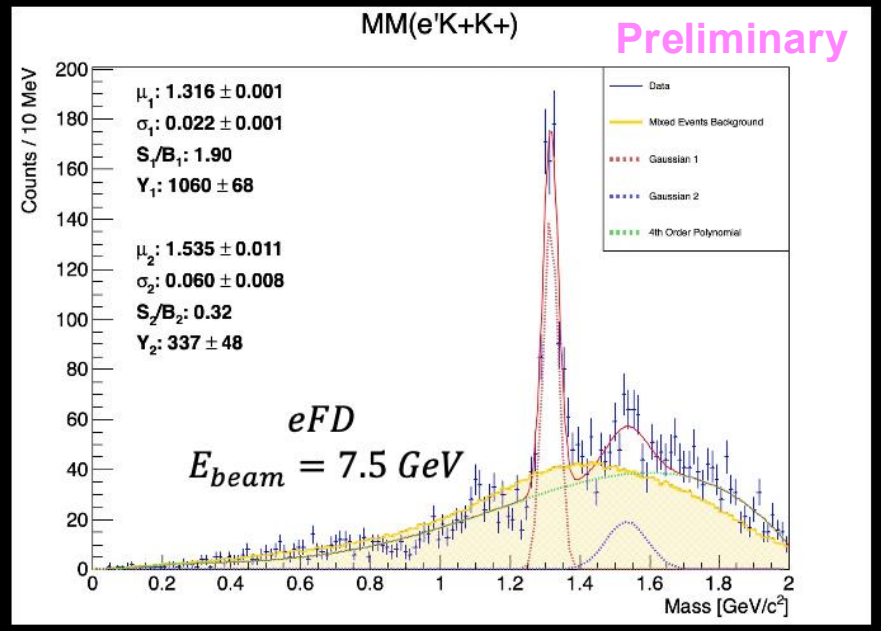


Cascade Baryons analyses with CLAS12

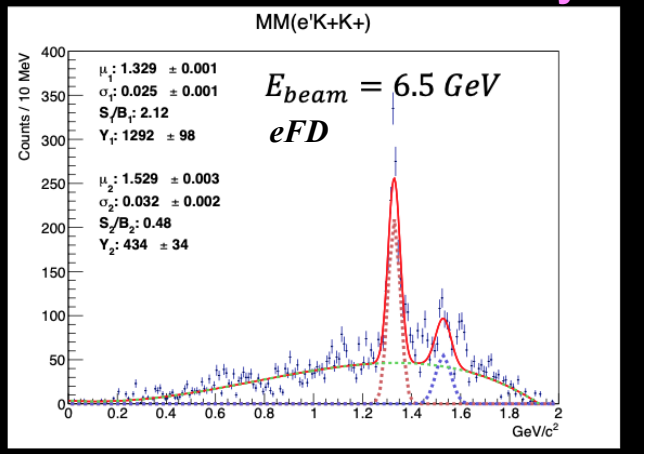
Search for excited Cascades in the reaction: $ep \rightarrow e'K^+K^-(\Xi^-)$ by missing mass technique

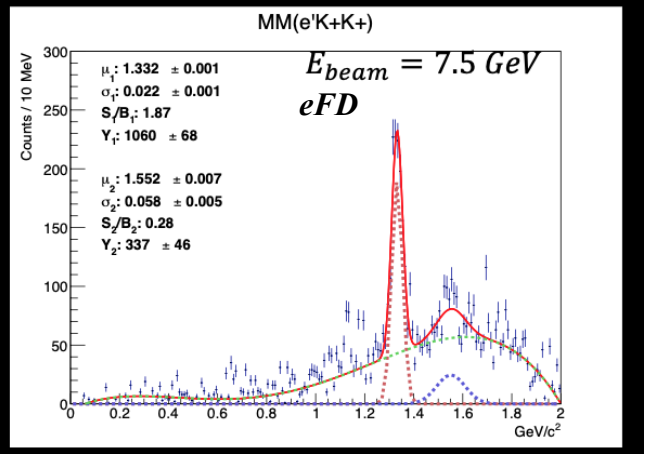
- RG-K data ($E_{\text{beam}} = 7.5\ GeV$, $6.5\ GeV$)

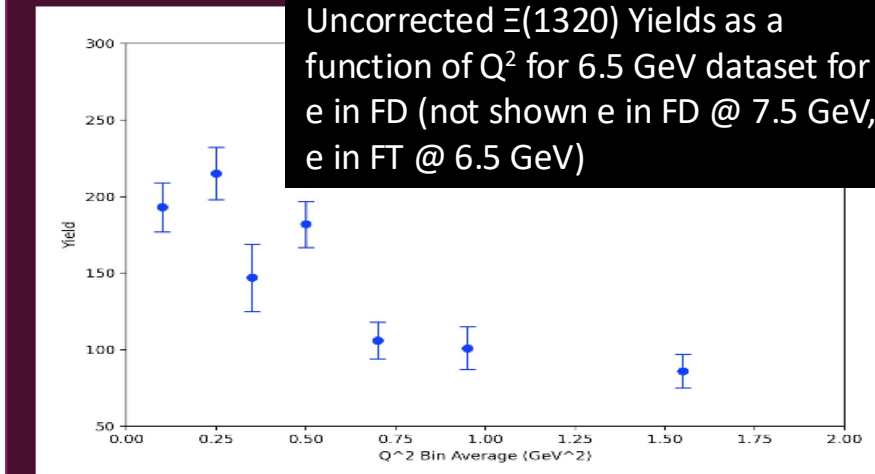




Preliminary







Uncorrected Ξ(1320) Yields as a function of Q^2 for 6.5 GeV dataset for e in FD (not shown e in FD @ 7.5 GeV, e in FT @ 6.5 GeV)

- Clear evidence for Ξ(1530)
- Lower background than RG-A
- Cross section measurements in progress

Courtesy of Bianca Gualtieri - FIU

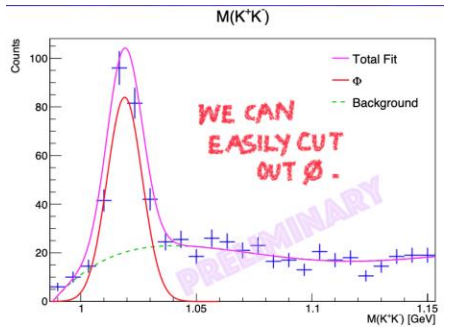
Cascade Baryons analyses with CLAS12

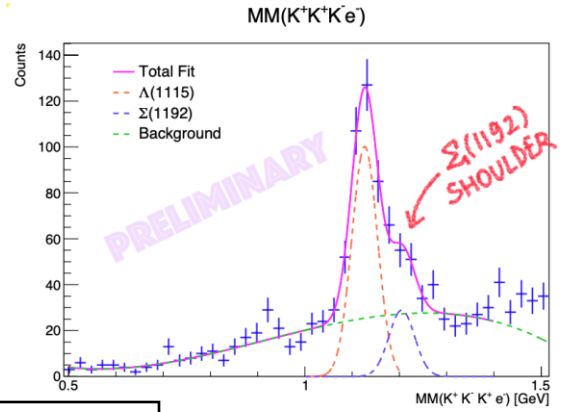
Search for the Ξ(1690) in the reactions: $ep \rightarrow e'K^+ K^+ K^-(\Lambda)$ and $ep \rightarrow e'K^+ K^+ \pi^-(\Xi^0)$ (missing mass technique)

- RG-A data (E_{beam} = 10.2 GeV)

$ep \rightarrow e'K^+ K^+ K^-(\Lambda)$ channel: $\Xi(1690)^- \rightarrow K^-\Lambda$

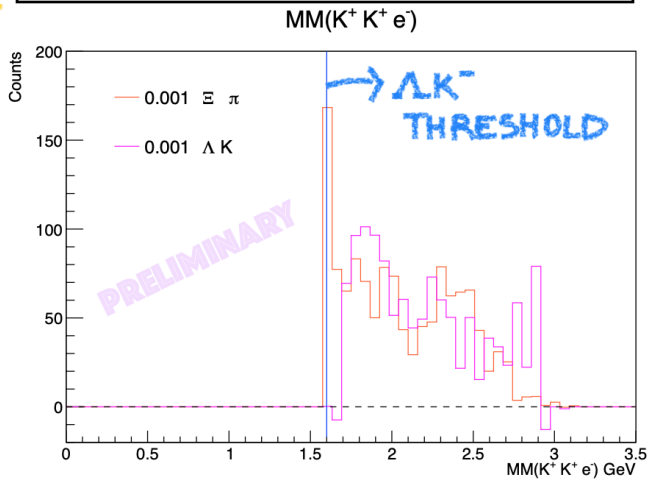
- Reconstructing 3 kaons
- Contamination from $ep \rightarrow e'\ \phi(\rightarrow K^+ K^-)\ \ N*(\rightarrow \Lambda\ K^+)$

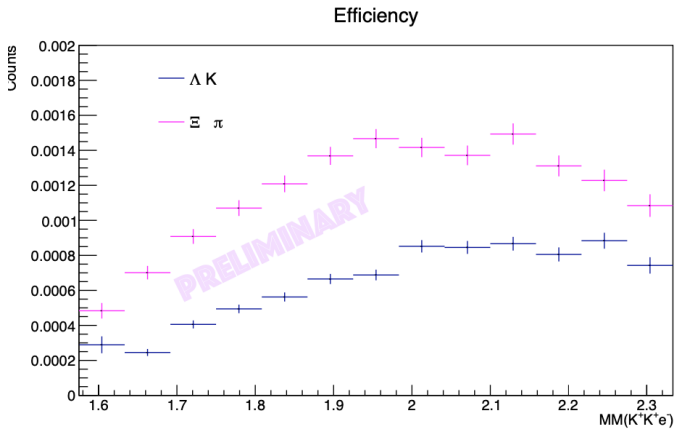




Background-subtracted yields

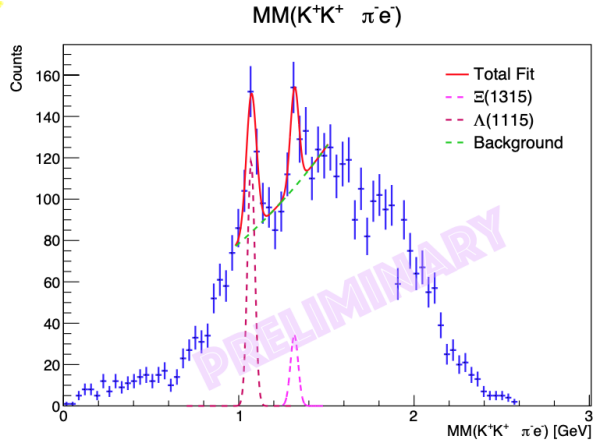
- Efficiency corrected





$ep \rightarrow e'K^+ K^+ \pi^-(\Xi^0)$ channel: $\Xi(1690)^- \rightarrow \pi^-\Xi^0$

- Reconstructing 2 kaons and a pion
- Contribution from $ep \rightarrow e'\ K^+\ Y*(\rightarrow K^+\ \Xi^-(\rightarrow \Lambda\ \pi^-))$



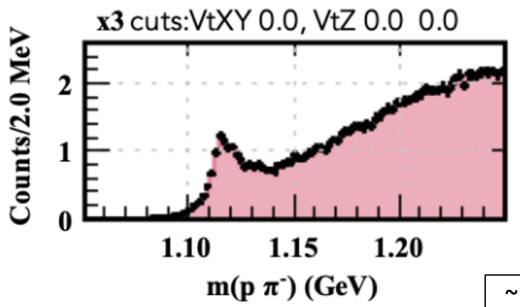
- First analysis to search for the $\Xi(1690)$ in electroproduction
- Analysis to be done 6x more statistics
- Goal is to extract J^P and branching ratios

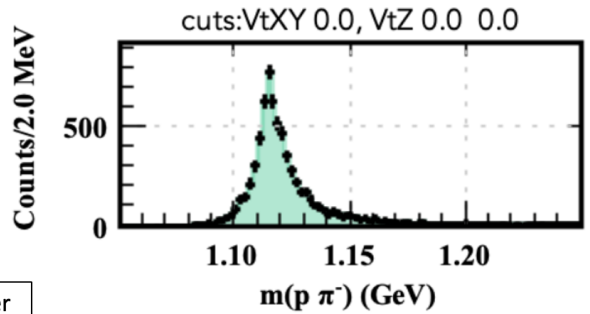
Courtesy of Asli Acar – University of York

Strangeness Production Studies with Λ's

Λ Skim

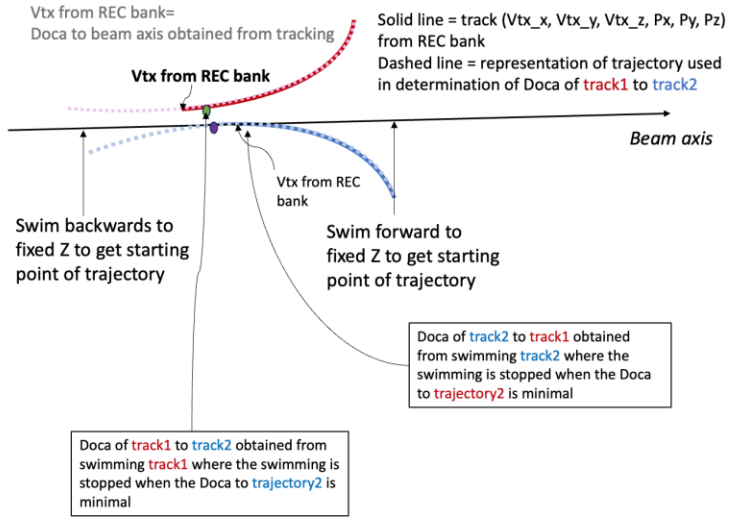
- Using displaced vertex reconstruction

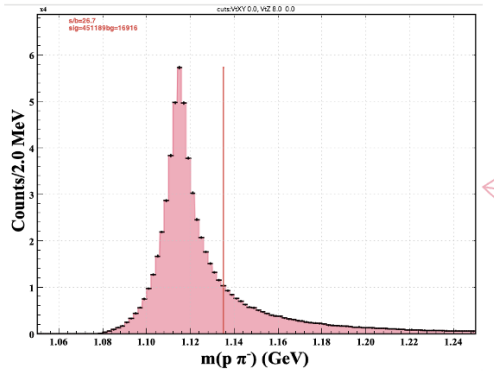




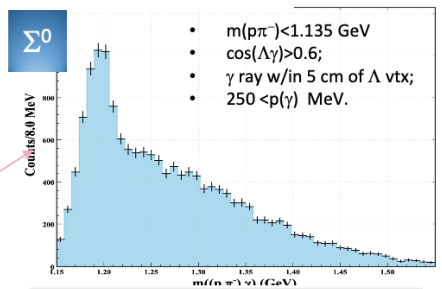
~ no loss in number of signal events

1. For each track
   1. Swim backwards to fixed Z to get starting point of trajectory
   2. Swim forward to fixed Z to get starting point of trajectory
2. Compute Doca of track2(1) to track1(2) obtained from swimming track2(1) where the swimming is stopped when the Doca to trajectory2(1) is minimal
3. Compute r as the distance between the so-obtained doca points of each track

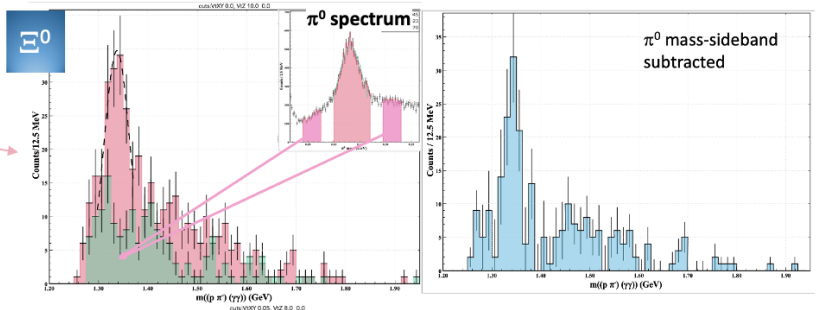




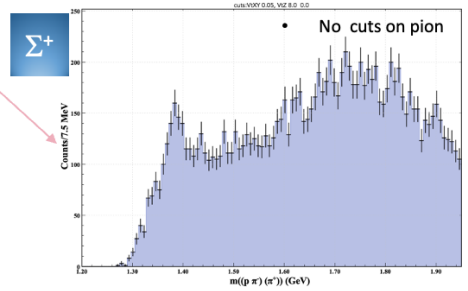
+ γ



+ π^0



+ π^+

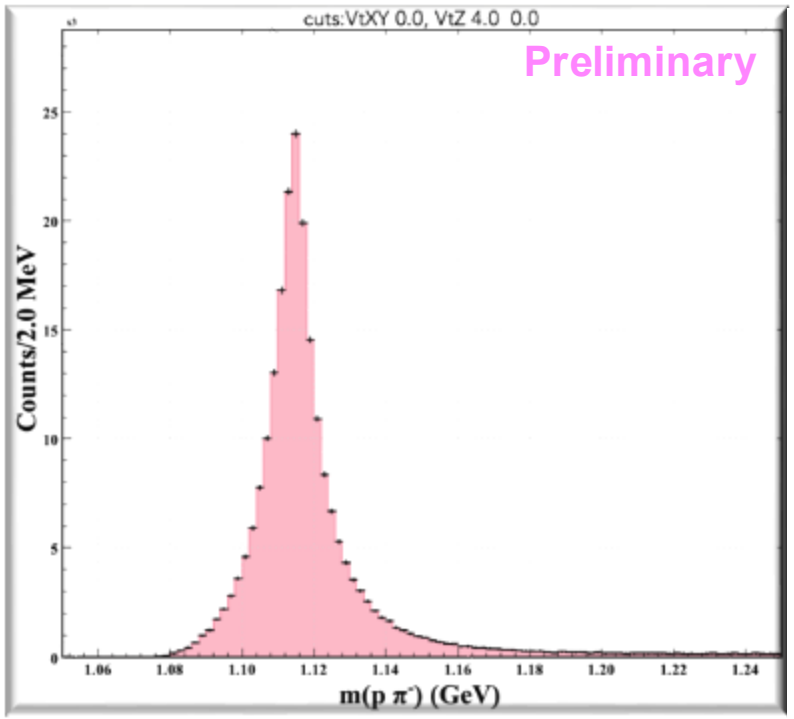


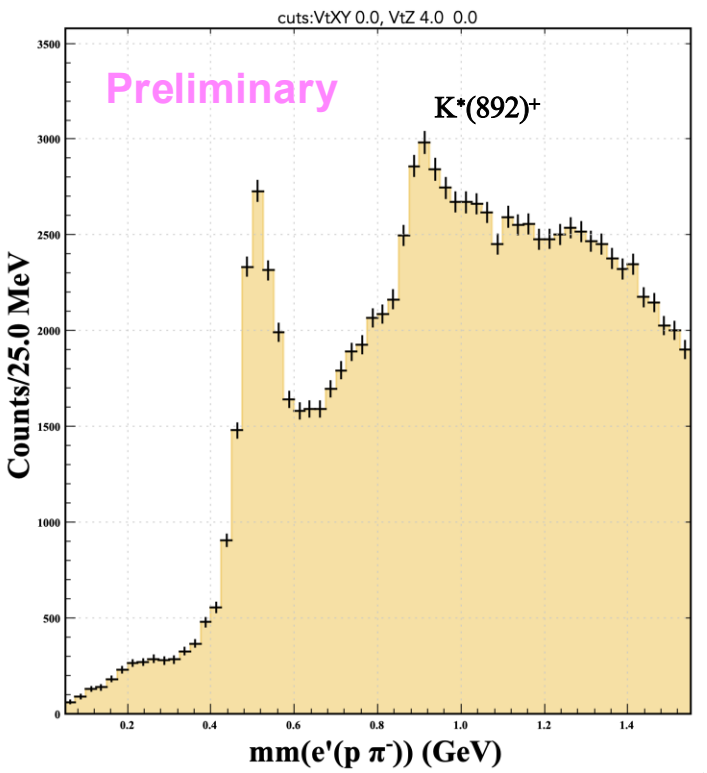
- Study hyperons properties with higher precision
  → decay products track parameters at decay vertex

Polarization Observables for Λ's

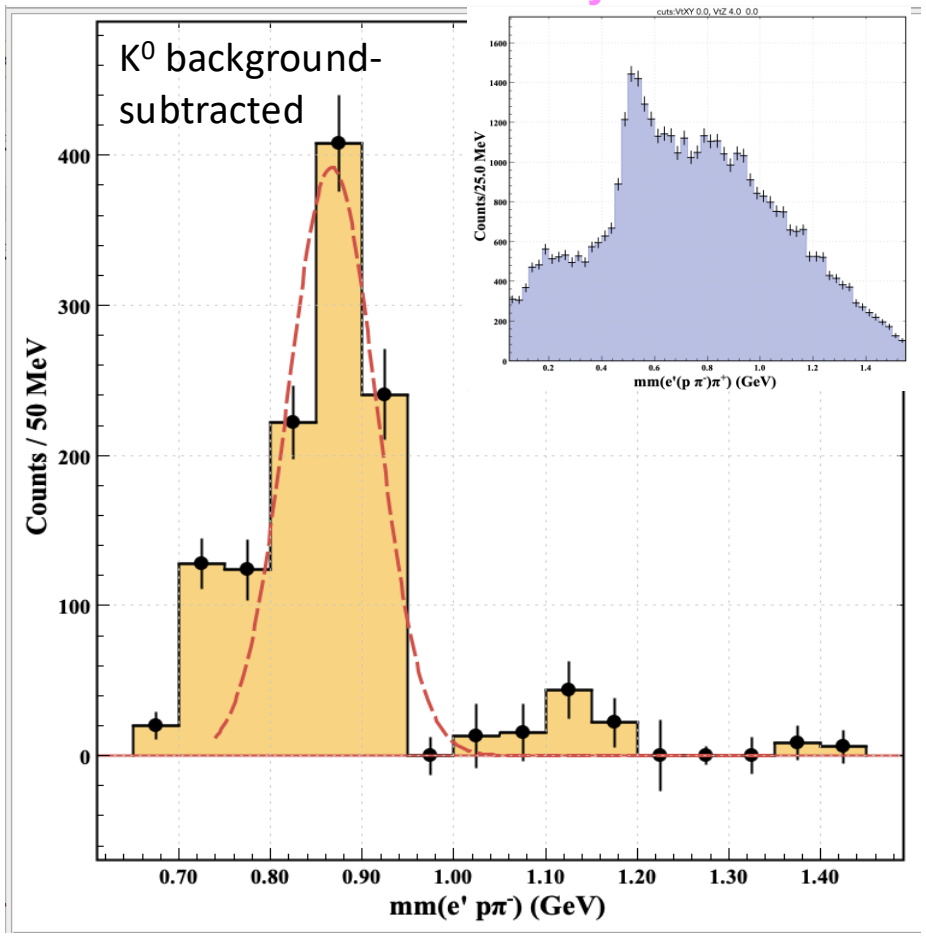
First observation of the reaction ep→e'$\Lambda K^*(892)^+$ in electroproduction using RGK Pass-2 data (6.5, 7.5 GeV)

- Clean Λ spectrum ➔ reduces background in extraction of physics observables from mis-reconstructed Λ candidates
- Studies of beam-recoil spin transfer in electro-produced $K^+\Lambda$ final states from unpolarized proton target have shown that the Λ polarization is predominantly in the direction of the spin of the virtual photon.
- For the **electro-produced $K^{*+}\Lambda$** final state, the spin of the u-quark is the same as for $K^+\Lambda$
  → test hypothesis that the **Λ spin direction should flip**.





Preliminary



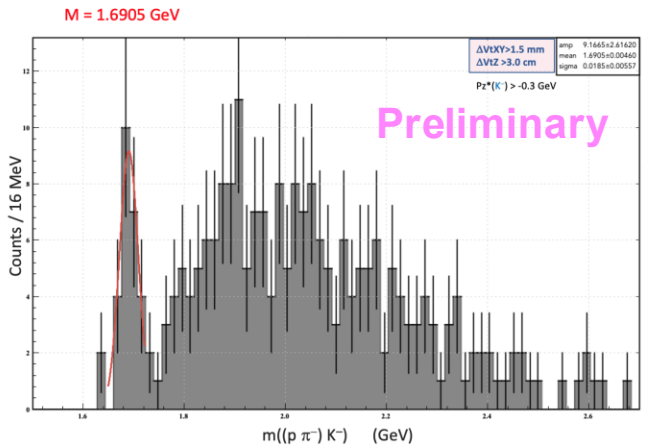
A Search for the Ω^- *Baryon* in RGA Data

- Not observed in electro- (photo-) production
- Part of Very Strange program

- Possible ***evidence*** for a peak in m((p π^-) K^-) distribution consistent with the Ω^-

RGA Fall-18 Data

REMARKS:
- W/o momentum correction
  - Λ mass peak shifted by about +5 MeV wrt PDG
  - m((p π^-) K^-) peak shifted by + 17 +/- 5 MeV wrt PDG Ω^- mass
    - no K^- vertex vertex correction
    - Effect of binning on peak position (next slide)
    - m((p π^-) K^-) spectrum has large bins (limited stats)



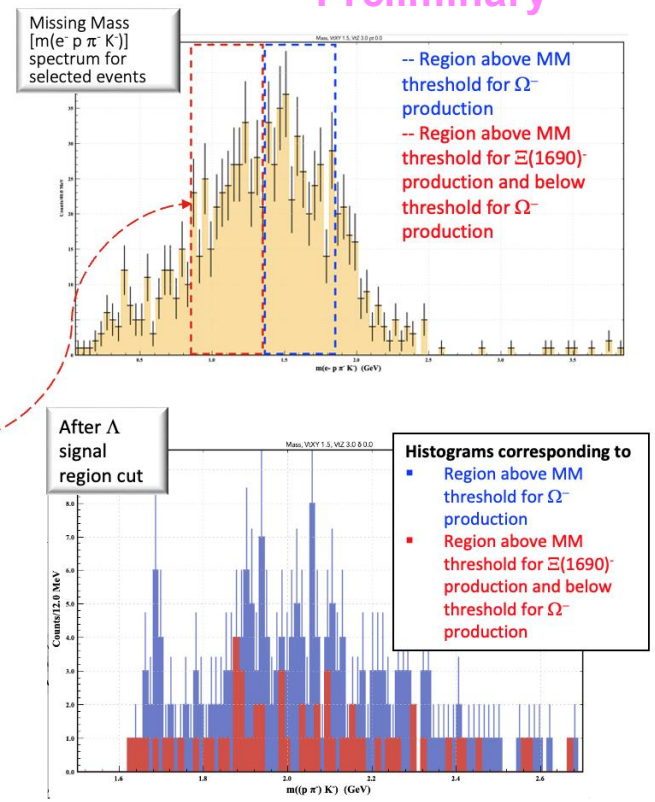
Looking for evidence for $\Xi(1690)^- \rightarrow \Lambda\, K^-$ production

Potential Overlap with the $\Xi(1690)^- \rightarrow \Lambda\, K^-$

By Missing Mass [MM(e^- p π^- K^-)] Analysis

- The Missing Mass (MM) threshold for $\Xi(1690)^-$ *[dss]* production correspond to the sum of the masses of 2 kaons. Taking into account resolution effect, the threshold is estimated to be 0.85 GeV
- We would expect some $\Xi(1690)^-$ production to occur for MM(e^- p π^- K^-)] in the region above MM threshold for $\Xi(1690)^-$ production and below threshold for Ω^- production
- No peak is observed in the red distribution corresponding to this MM range

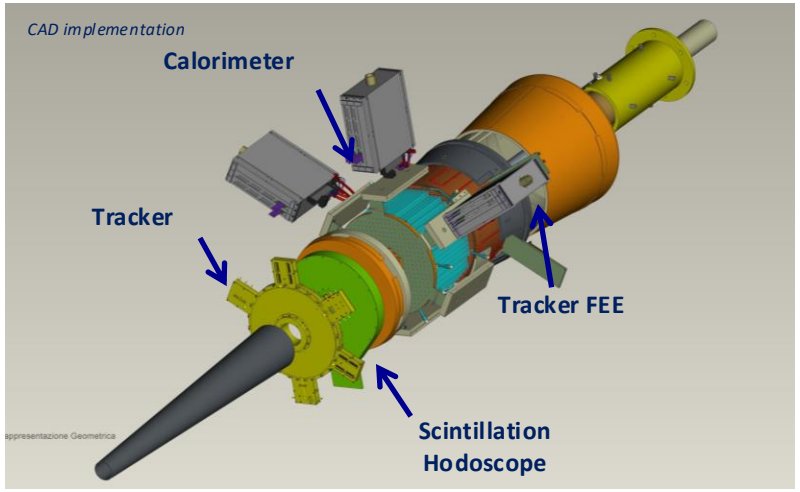
Preliminary

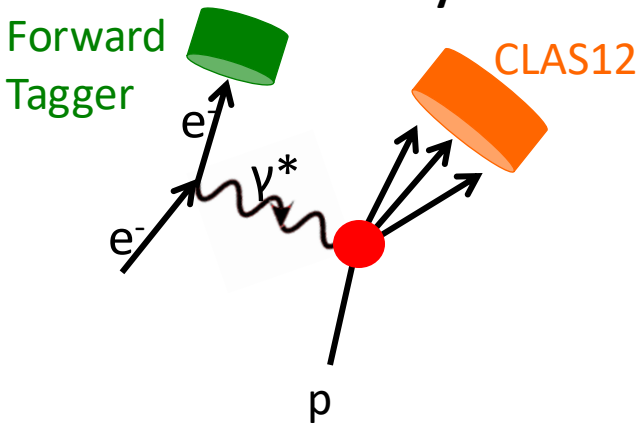


- Not seen in RGB (deuteron target)
- Analysis to be redone with dataset processed with improved tracking and latest Lambda skim
- Spring-18 RG-A dataset to be included

Meson Spectroscopy with photons at CLAS12

- **Quasi-real photoproduction with CLAS12 (Low Q^2 electron scattering) using a Forward Tagger detector to investigate the light quark meson spectrum and search for hybrid meson states**





- Detection of multiparticle final state from meson decay in the large acceptance spectrometer CLAS12
- Detection of the scattered electron for tagging the quasi-real photon in the CLAS12 Forward Tagger (low angle detection 2.5 to 4.5°)
- High-intensity and high-polarization tagged "photon" beam; degree of polarization can be determined event-by-event from the electron kinematics

The MesonEx Program:

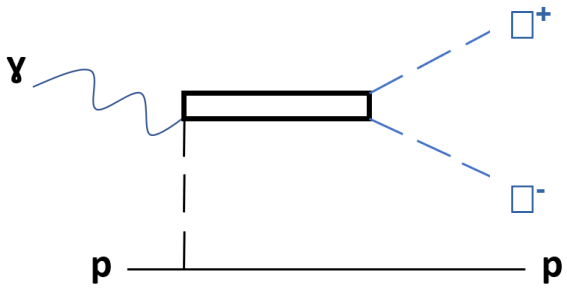
- Detailed mapping of the meson spectrum up to 2.5 GeV mass.
- Search for rare or poorly known states (strangeness-rich, scalars, …).
- Search states with unconventional quark-gluon configurations.
- Ongoing di-meson photoproduction analyses:
  - Current analyses of final states with charged mesons (π, K) →better resolution (acceptance correction, background modeling).
  - Model-independent moment analyses, Partial Wave Analyses (PWA) ➔ structures in the moments can suggest the presence of resonances.
  - Analysis techniques to be extended to vector-pseudoscalar final states.

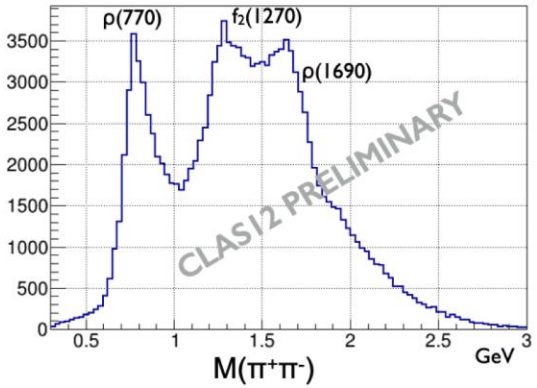
MesonEx analyses with CLAS12

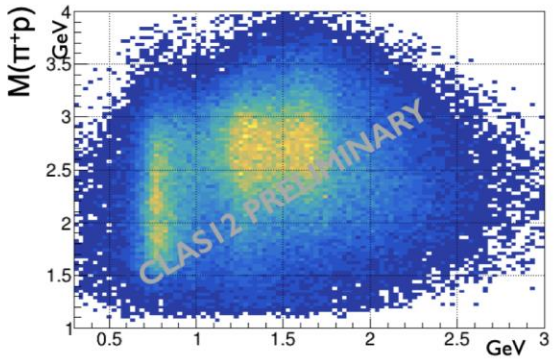
Moment analysis for the reaction: $\gamma p \rightarrow p\,\pi^+\pi^-$ using RG-A data (E_{beam} = 10.6 GeV on LH2 target)

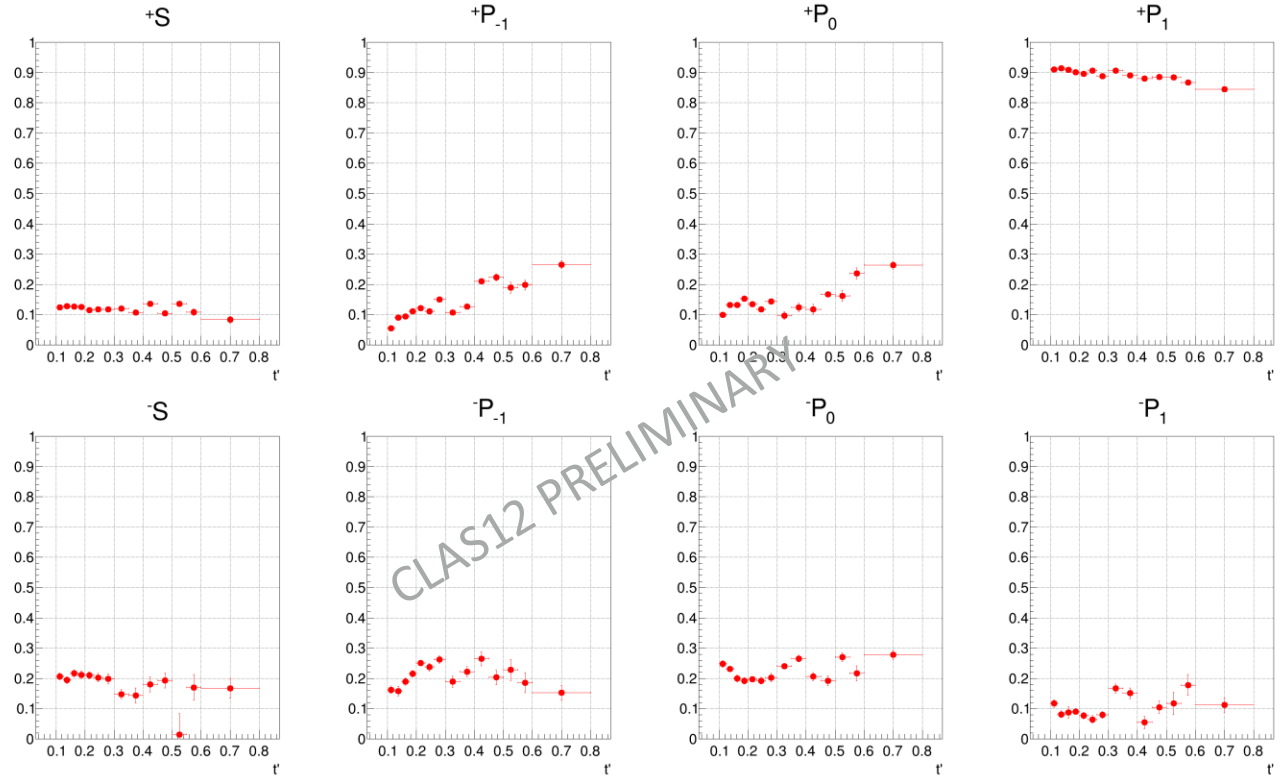
$\gamma p \rightarrow p\,\pi^+\pi^-$ channel:

- Detection of all particles in the final state
- Clear observation of the $\rho(770)$, $f_2(1270)$, $\rho(1690)$
  - Moment, PWA analysis taking baryon into account ongoing
  - Preliminary results in good agreement with expectations from S-channel helicity conservation and pomeron exchange
- Similar ongoing analysis of the $\gamma p \rightarrow \gamma p\,K^+K^-$ channel (Charlie Velasquez, U. of York)







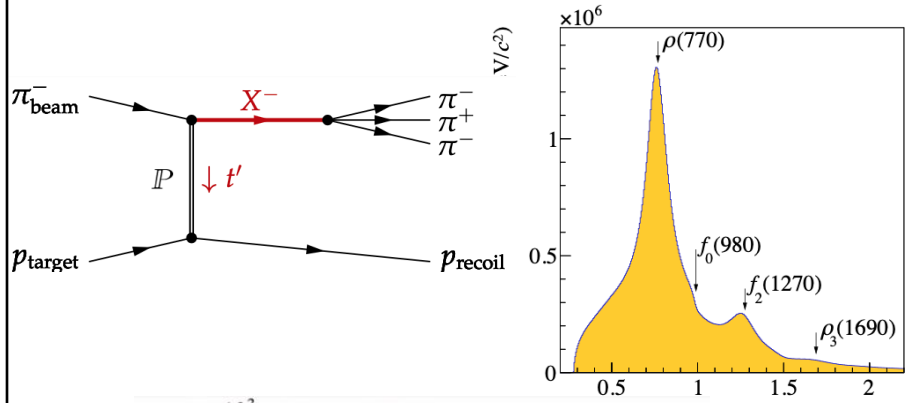


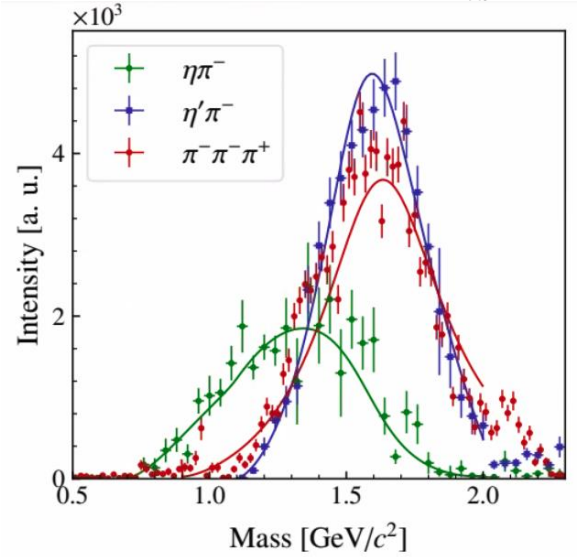
Courtesy of Derek Glazier– University of Glasgow

Motivation for the search for the exotic $\pi_1(1600)$ with CLAS12

Evidence from COMPASS in pion diffraction data:

- 3-pion final state analysis to search for the exotic spin-1 isovector meson $\pi_1(1600)$ [I=1, $J^{PC} = 1^{-+}$]
- Seen in $\eta\pi$, $\eta'\rho$, $\rho(770)(\rightarrow\pi^+\pi^-)\pi$ channels



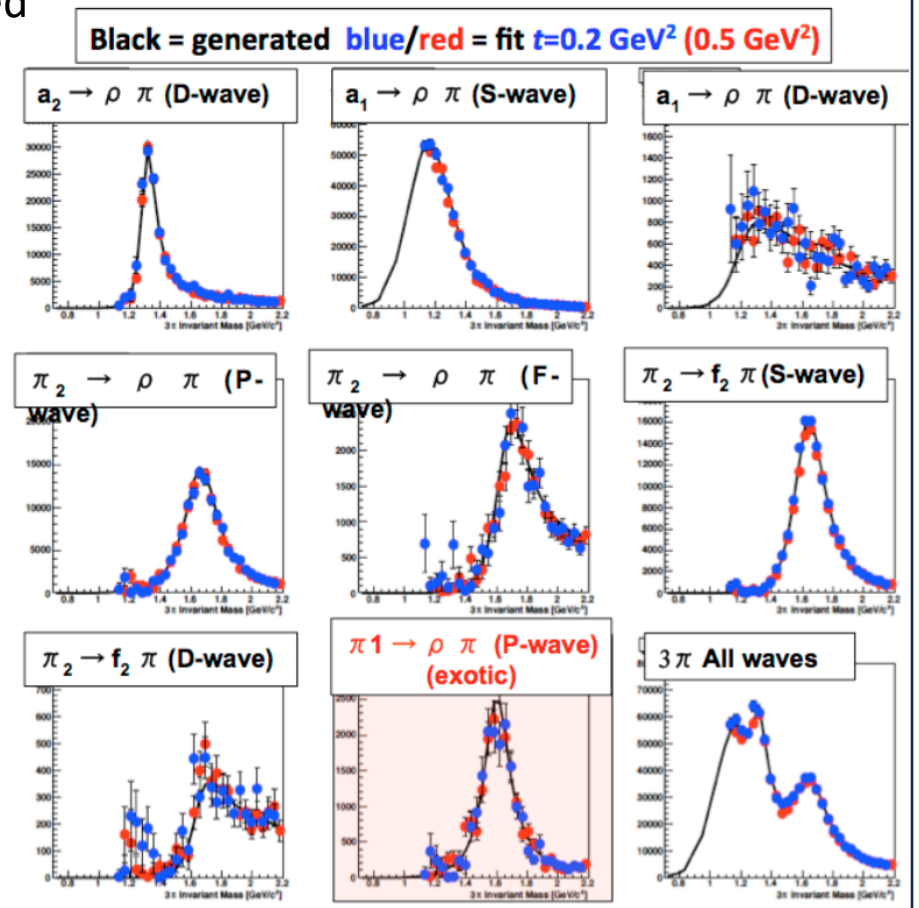


Phys.Lett.B 740 (2015) 303; PRD 105 (2022) 1012005; PRD 98 (2018) 092003; PRL 104 (2010) 2418

Feasibility of PWA with CLAS12

- $\gamma p \rightarrow n\pi^+\pi^+\pi^-$ process is described as sum of 8 isobar channels:

  $a_2 \rightarrow \rho\,\pi$ (D-wave)
  $a_1 \rightarrow \rho\,\pi$ (S-wave)
  $a_1 \rightarrow \rho\,\pi$ (D-wave)
  $\pi_2 \rightarrow \rho\,\pi$ (P-wave)
  $\pi_2 \rightarrow \rho\,\pi$ (F-wave)
  $\pi_2 \rightarrow f_2\,\pi$ (S-wave)
  $\pi_2 \rightarrow f_2\,\pi$ (D-wave)
  $\pi_1 \rightarrow \rho\,\pi$ (P-wave) (exotic)



- Amplitudes calculated by A. Szczepaniak and P. Guo
  - CLAS12 acceptance projected and fitted
  - PWA is stable against CLAS12 acceptance / resolution distortion

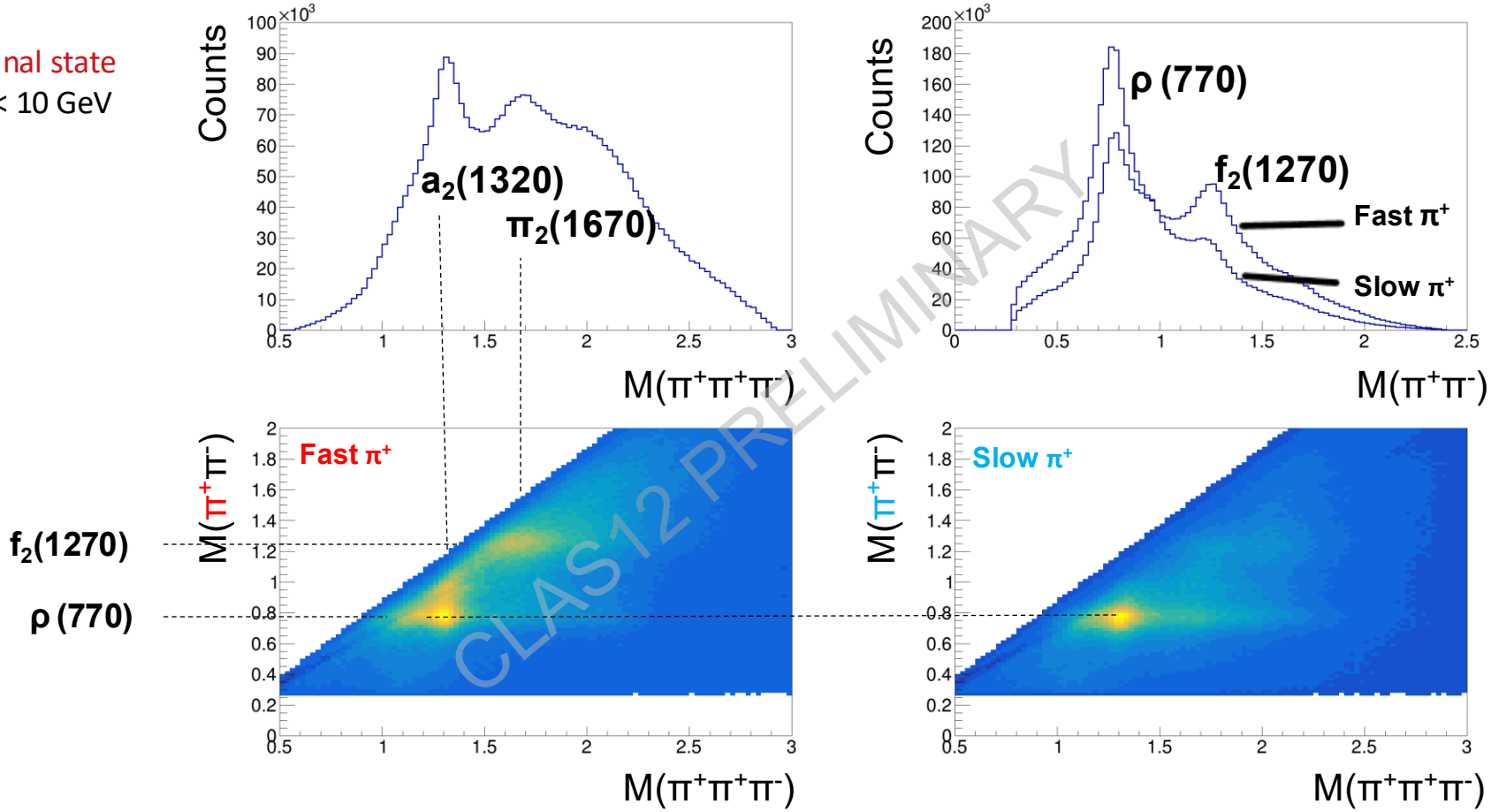
MesonEx analysis: a search for the exotic $\pi_1(1600)$ with CLAS12

Search for the $\pi_1(1600)$ in the reaction: $\gamma p \rightarrow n\,\pi^+\pi^+\pi^-$ using RG-A data (E_{beam} = 10.6 GeV on LH2 target)

$\gamma p \rightarrow \pi^+\pi^+\pi^-(n)$ channel:

- Preliminary results on subsample of dataset shows feasibility to carry out the analysis with complex PWA involving multiple isobars

Missing neutron final state
$|t| < 2$ and $6 < E_\gamma < 10$ GeV



Courtesy of Derek Glazier– University of Glasgow

Summary

- High precision and large data sample provided with CLAS12 allows for a rich spectroscopy program.
  - Various targets, beam energy to probe production mechanism and allow for an extended physics reach over CLAS6.

- CLAS12 well positioned to contribute to exotic hadrons searches and observations of excited baryons as part of its hadron spectroscopy program.
  - Ability to reconstruct final states with multiple particles.

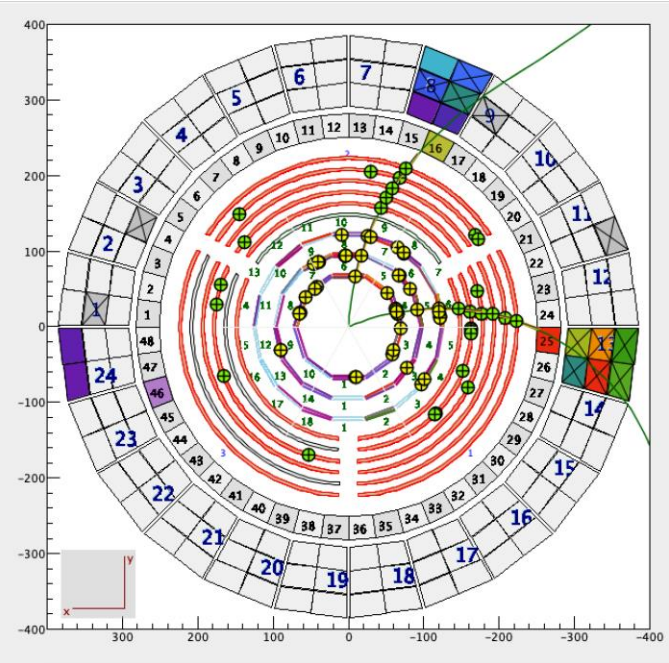
- Tools for PWA analyses in place to study spin-parity assignments of identified states.

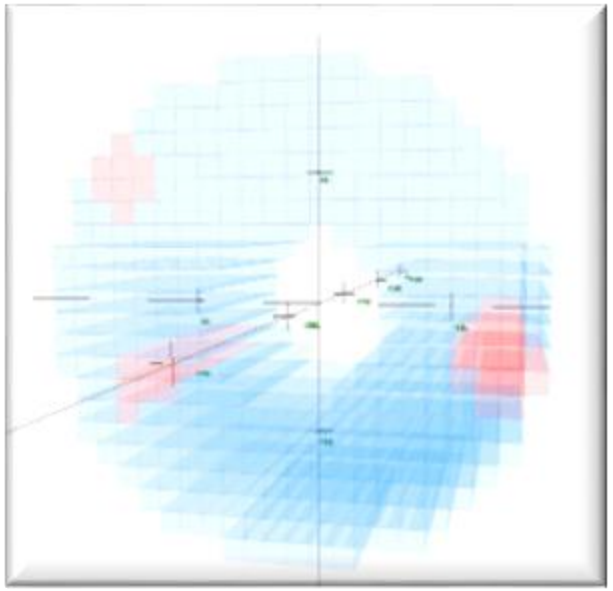
- Future directions: continued analyses on newly collected and processed large data samples to further studies of resonance decays and multi-hadron final states.

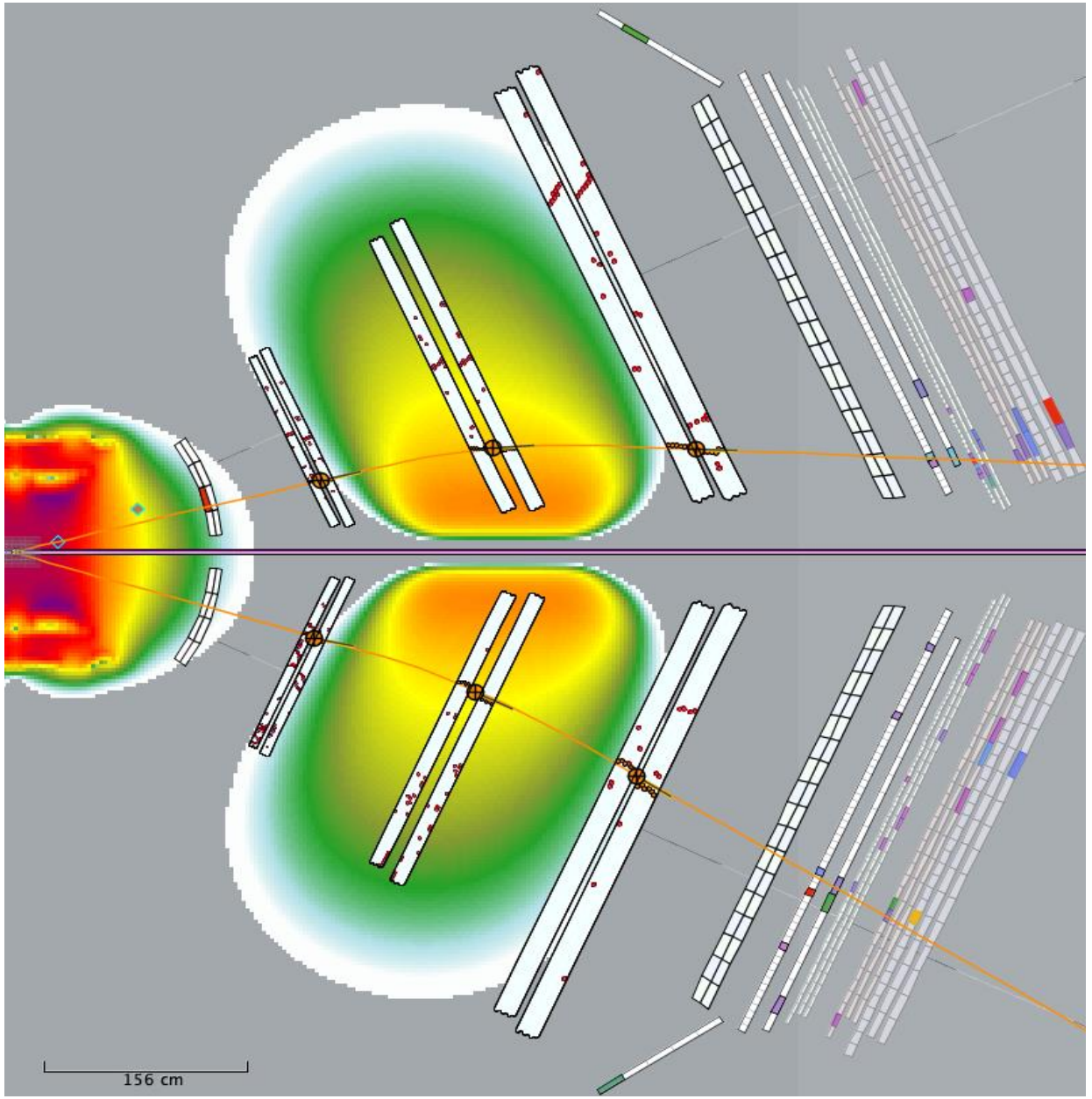
- Collaborative efforts among experimentalists and the involvement of theorists greatly impacts the success of this program.

BACK-UP SLIDES

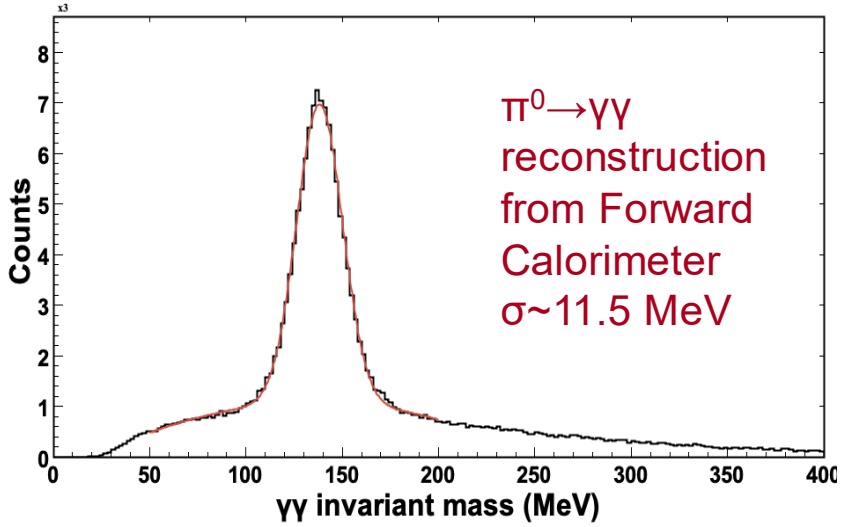
CLAS12 Event Display



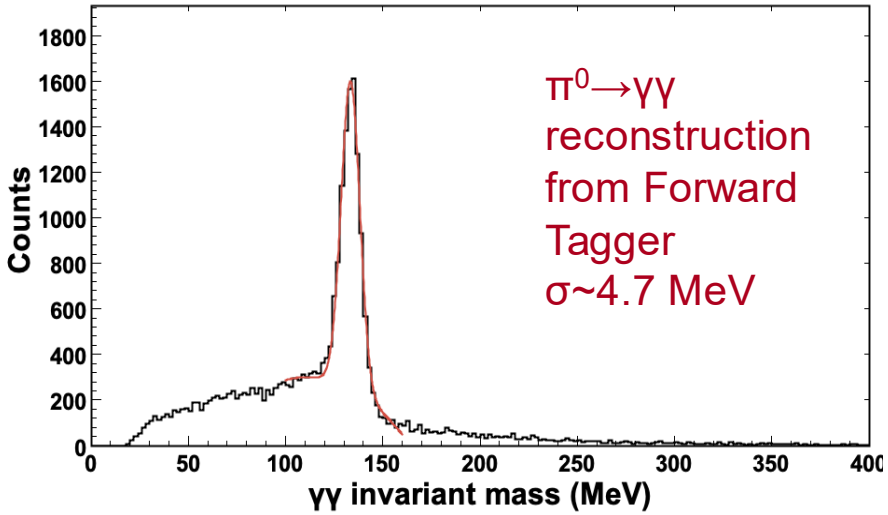




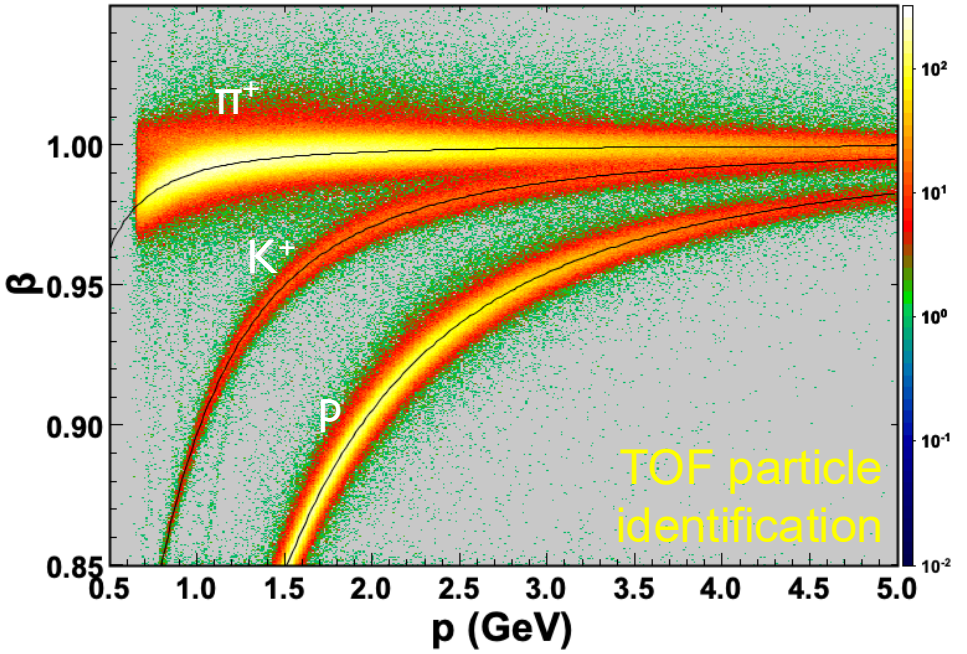
CLAS12 PID



$\pi^0 \rightarrow \gamma\gamma$ reconstruction from Forward Calorimeter
σ~11.5 MeV



$\pi^0 \rightarrow \gamma\gamma$ reconstruction from Forward Tagger
σ~4.7 MeV



Forward Calorimeter sampling fraction for electrons