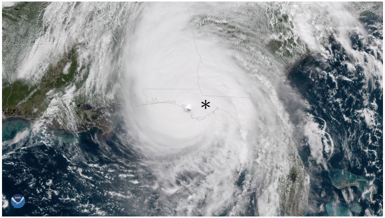
Very Strange Spectroscopy at Jefferson Lab

Volker Credé

Florida State University, Tallahassee, FL *

Electromagnetic Structure of Strange Baryons

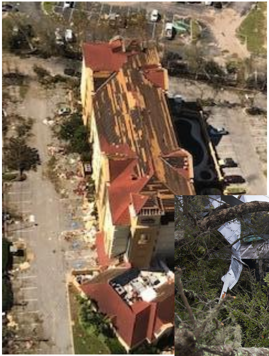


EMMI 2018 RRTF Workshop

GSI

10/25/2018

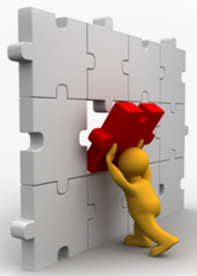
Hurricane Michael: Panama City and Mexico Beach



10 October 2018

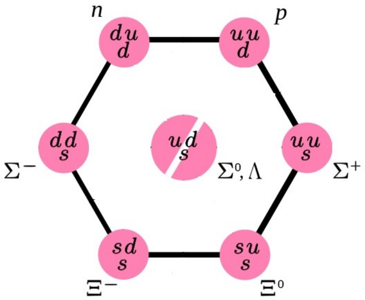
Hurricane Michael: Panama City and Mexico Beach

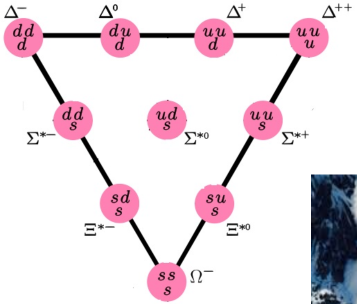
Outline



Outline

Baryon Multiplets and Hyperon Spectroscopy





The decuplets consist of Δ^*, Σ^*, Ξ^*, and Ω^* resonances, but also the octets consist of an Ξ^* state.

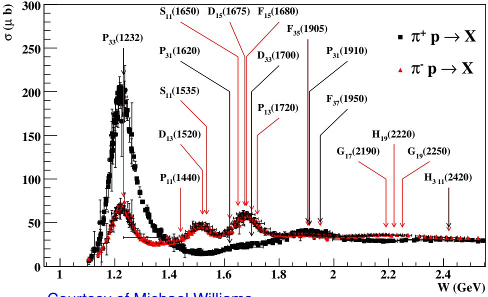
➜ We expect as many Ξ's as N^* & Δ^* states together. Moreover, their properties should be related.

Hadron Spectroscopy: Baryons & Mesons

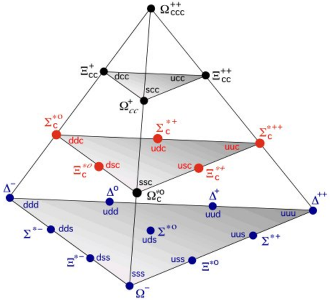
The strong coupling confines quarks and breaks chiral symmetry, and so defines the world of light hadrons.

Baryons are special because

Their structure is most obviously related to the color degree of freedom, e. g. $|\Delta^{++}\rangle = |u^{\uparrow}u^{\uparrow}u^{\uparrow}\rangle$.



Courtesy of Michael Williams



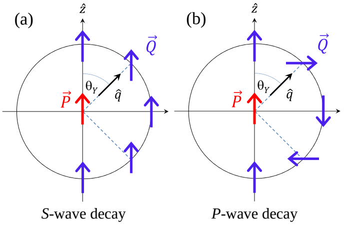
Many Y^* QN not measured:
(Quark model assignments)
➜ many Ξ^* and Ω^*, etc.

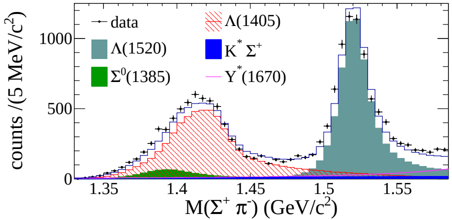
Spin and Parity Measurement of the Λ(1405) Baryon

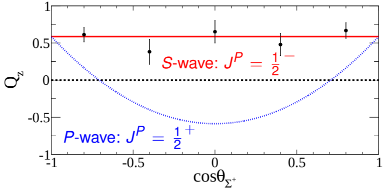
K. Moriya *et al.* [CLAS Collaboration], Phys. Rev. Lett. **112**, 082004 (2014)

Data for $\gamma p \to K^+\Lambda(1405)$ support $J^P = \frac{1}{2}^-$

- Decay distribution of $\Lambda(1405) \to \Sigma^+\pi^-$ consistent with $J = 1/2$.
- Polarization transfer, $\vec{Q}$, in $Y^* \to Y\pi$:
  - S-wave decay: $\vec{Q}$ independent of θ_Y







From the Atomic Spectrum of Hydrogen ...

Development of the theory of atomic structure required

- Hydrogen Atom (ground state)
- Together with the emission (absorption) spectrum.

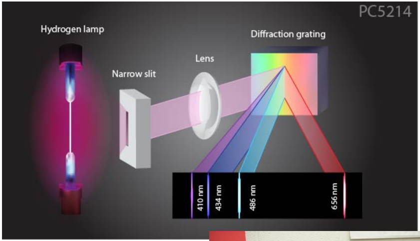
Bohr model ➜ QED

Understanding the nucleon requires

- proton (ground state)
- Together with its excitation spectrum.

Quark model ➜ strong QCD

Atomic Spectrum of Hydrogen



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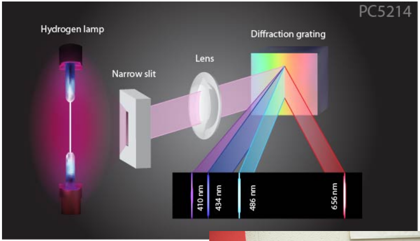
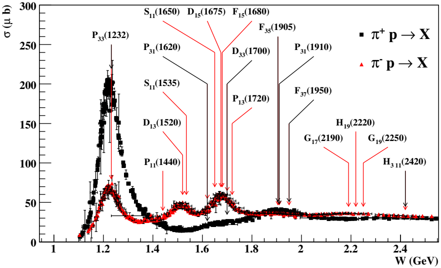


... to Understanding the N^* Spectrum

CLAS (6 GeV) at JLab 1998 - 2012

Photo-/electroproduction experiments in search for N^* states and measurement of the transition amplitudes.



Baryons are broad and overlapping ...

Courtesy of Michael Williams

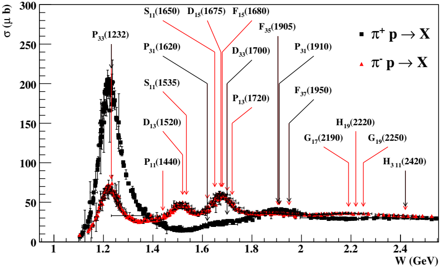
... to Understanding the N^* Spectrum

without polarizer ...

but there is more.

CLAS (6 GeV) at JLab 1998 - 2012

Photo-/electroproduction experiments in search for N^* states and measurement of the transition amplitudes.

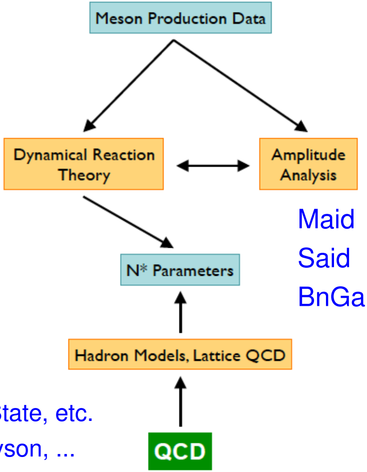


Baryons are broad and overlapping ...

Courtesy of Michael Williams

Extraction of Resonance Parameters in N^* Physics

- Double-polarization measurements
- Measurements off neutron and proton to resolve isospin contributions:
  1. $\mathcal{A}(\gamma N \to \pi,\ \eta,\ K)^{I=3/2} \quad \Longleftrightarrow \quad \Delta^*$
  2. $\mathcal{A}(\gamma N \to \pi,\ \eta,\ K)^{I=1/2} \quad \Longleftrightarrow \quad N^*$
- Re-scattering effects: Large number of measurements (and reaction channels) needed to extract full scattering amplitude.



Maid
Said
BnGa

Coupled Channels

Jülich - GW, Gießen, Kent State, etc.
ANL - Osaka, Schwinger-Dyson, ...

Table representing CLAS@JLab measurements

	σ	Σ	T	P	E	F	G	H	$T_{x'}$	$T_{z'}$	$L_{x'}$	$L_{z'}$	$O_{x'}$	$O_{z'}$	$C_{x'}$	$C_{z'}$
		Proton targets														
$p\,\pi^0$	✓ (red)	✓ (red)	✓ (blue)	(✓) (blue)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)								
$n\,\pi^+$	✓ (red)	✓ (red)	✓ (blue)	(✓) (blue)	✓ (red)	✓ (blue)	✓ (blue)	✓ (blue)								
$p\,\eta$	✓ (red)	✓ (red)	✓ (blue)	(✓) (blue)	✓ (red)	✓ (blue)	✓ (blue)	✓ (blue)								
$p\,\eta'$	✓ (red)	✓ (red)	✓ (blue)	(✓) (blue)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)								
$p\,\omega/\phi$	✓ (red)	✓ (red)	✓ (red)	(✓) (blue)	✓ (red)	✓ (blue)	✓ (blue)	✓ (blue)								
$K^+\,\Lambda$	✓ (red)	✓ (red)	✓ (red)	✓ (red)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (red)	✓ (red)	✓ (red)	✓ (red)
$K^+\,\Sigma^0$	✓ (red)	✓ (red)	✓ (red)	✓ (red)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (red)	✓ (red)	✓ (red)	✓ (red)
$K^0\,\Sigma^+$	✓ (blue)	✓ (blue)	✓ (blue)	✓ (red)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)
		Neutron (deuteron) targets														
$p\,\pi^-$	✓ (red)	✓ (blue)			✓ (red)		✓ (blue)									
$K^-\,\Sigma^+$	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)									
$K^0\,\Lambda$	✓ (red)	✓ (blue)	✓ (blue)	✓ (blue)	✓* (red)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)
$K^0\,\Sigma^0$	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)	✓* (red)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)	✓ (blue)

✓ (red) published
✓ (blue) acquired or under analysis

Tensor polarization, SDMEs

Complete Experiments?

* published

"Uncertainty is an uncomfortable position. But Certainty is an absurd one."

Voltaire

Table representing CLAS@JLab measurements

	σ	Σ	T	P	E	F	G	H	$T_{x'}$	$T_{z'}$	$L_{x'}$	$L_{z'}$	$O_{x'}$	$O_{z'}$	$C_{x'}$	$C_{z'}$
		Proton targets														
$p\,\pi^0$	✔	✔	✓	(✓)	✓	✓	✓	✓								
$n\,\pi^+$	✔	✔	✓	(✓)	✔	✓	✓	✓								
$p\,\eta$	✔	✔	✓	(✓)	✔	✓	✓	✓								
$p\,\eta'$	✔	✔	✓	(✓)	✓	✓	✓	✓								
$p\,\omega/\phi$	✔	✔	✔	(✓)	✔	✓	✓	✓								
$K^+\,\Lambda$	✔	✔	✔	✔	✓	✓	✓	✓	✓	✓	✓	✓	✔	✔	✔	✔
$K^+\,\Sigma^0$	✔	✔	✔	✔	✓	✓	✓	✓	✓	✓	✓	✓	✔	✔	✔	✔
$K^0\,\Sigma^+$	✓	✓	✓	✔	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
		Neutron (deuteron) targets														
$p\,\pi^-$	✔	✓			✔		✓									
$K^-\,\Sigma^+$	✓	✓	✓	✓	✓	✓	✓									
$K^0\,\Lambda$	✔	✓	✓	✓	✔*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
$K^0\,\Sigma^0$	✓	✓	✓	✓	✔*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

✔ published
✓ acquired or under analysis

Tensor polarization, SDMEs

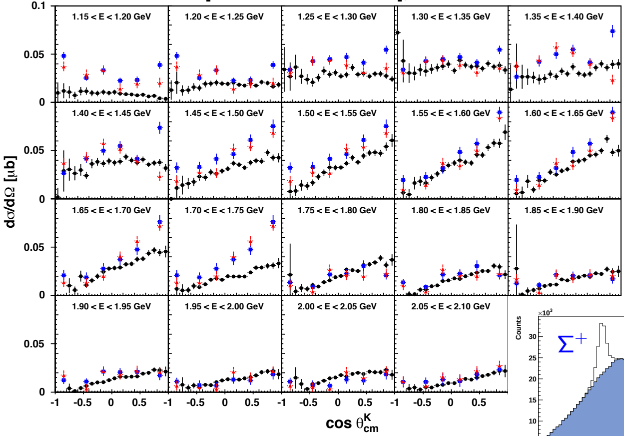
* published

In addition, two-meson reactions are being analyzed:

$$\gamma p \to (p\,\rho) \to p\,\pi^+\pi^- \text{ (CLAS)}, \quad \gamma p \to p\,\pi^0\pi^0, \quad p\,\pi^0\eta, \quad p\,\pi^0\omega \text{ (ELSA, MAMI, etc.)}$$

Cross Sections for $\gamma p \to K^0 \Sigma^+ \to p \pi^+ \pi^- \pi^0$

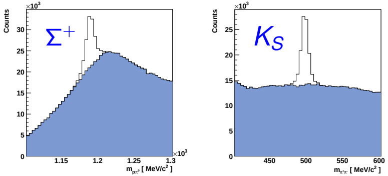
Z. Akbar *et al.* [CLAS Collaboration], under review.



New cross section results in 50-MeV-wide E_γ bins for

$1.15 < E_\gamma < 3.0$ GeV

➜ Need theory support to understand physics!!



CLAS-g12 • CB-ELSA • CBELSA/TAPS •

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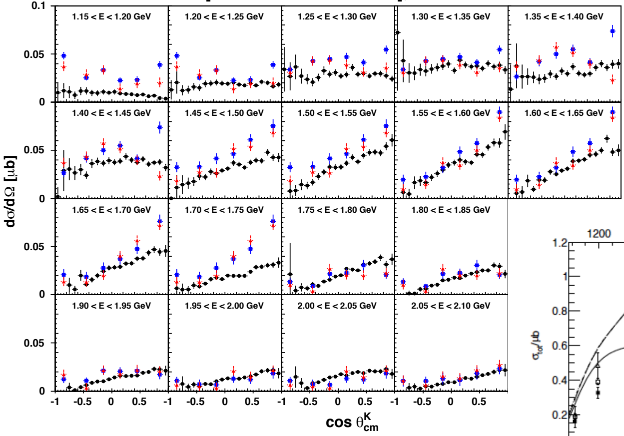

CLAS-g12 ● CB-ELSA ● CBELSA/TAPS ●

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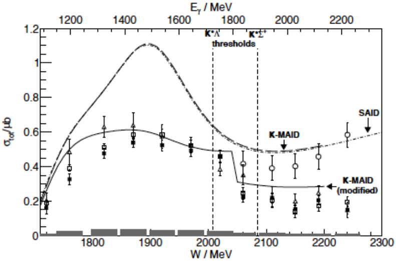
$$1.15 < E_\gamma < 3.0 \text{ GeV}$$

Phys. Lett. B **713**, 180 (2012)



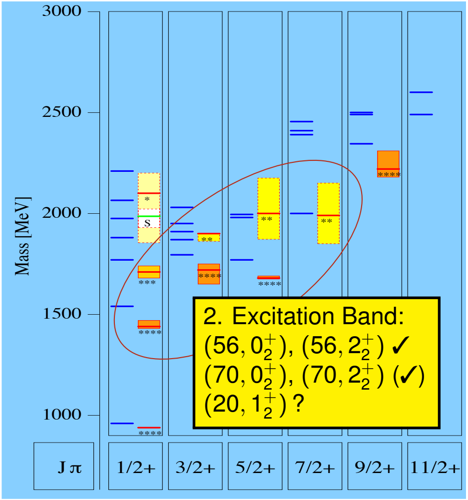
➜ In preparation for $K^0 \Sigma^+$: $E, \Sigma, T, C_x, C_z, O_x, O_z$.

The impact of photoproduction on baryon resonances	Decay modes of nucleon resonances		
	black: PDG 2004	****	Existence is certain.
	red: PDG 2018	***	Existence is very likely.
	blue: BESIII resonances	**	Evidence of existence is fair.
		*	Evidence of existence is poor.

		overall	$N\gamma$	$N\pi$	$\Delta\pi$	$N\sigma$	$N\eta$	ΛK	ΣK	$N\rho$	$N\omega$	$N\eta'$	$N_{1440}\pi$	$N_{1520}\pi$	$N_{1535}\pi$	$N_{1680}\pi$
N	$1/2^+$	****														
$N(1440)$	$1/2^+$	****	****	****	****	***										
$N(1520)$	$3/2^-$	****	****	****	****	**	****									
$N(1535)$	$1/2^-$	****	****	****	***	*	****									
$N(1650)$	$1/2^-$	****	****	****	***	*	****	***					*			
$N(1675)$	$5/2^-$	****	****	****	****	***	*	*	*	**				*		
$N(1680)$	$5/2^+$	****	****	****	****	***	*			****						
$N(1700)$	$3/2^-$	***	**	***	***	*	*	**	*	*						
$N(1710)$	$1/2^+$	****	****	****	**		***	**	*	*	*				*	
$N(1720)$	$3/2^+$	****	****	****	***	*	*	****	*	**	*					
$N(1860)$	$5/2^+$	**	*	**		*	*									
$N(1875)$	$3/2^-$	***	**	**	*	**	*	*	*	*	*	*	*			
$N(1880)$	$1/2^+$	***	**	*	**	*	*	**	**		**				*	
$N(1895)$	$1/2^-$	****	****	*	*	*	****	**	**	*	*	****	*			
$N(1900)$	$3/2^+$	****	****	**	**	*	*	**	**	*	*	**				
$N(1990)$	$7/2^+$	**	**	**	*	*	*	**	**							
$N(2000)$	$5/2^+$	**	**	**	**	*	*	*	*		*					
$N(2040)$	$3/2^+$	*		*												
$N(2060)$	$5/2^-$	***	***	**	*	*	*	*	*	*	*		*	*		*
$N(2100)$	$1/2^+$	***	**	***	**	**	*	*		*	*	**			***	
$N(2120)$	$3/2^-$	***	***	***	**	**		**	*		*	*	*	*	*	
$N(2190)$	$7/2^-$	****	****	****	****	**	*	**	*	*	*					
$N(2220)$	$9/2^+$	****	**	****			*	*	*							
$N(2250)$	$9/2^-$	****	**	****			*	*	*							
$N(2300)$	$1/2^+$	*		*												
$N(2570)$	$5/2^-$	*		*												
$N(2600)$	$11/2^-$	***		***												
$N(2700)$	$13/2^+$	**		**												

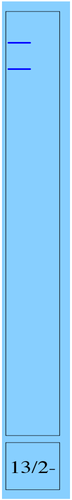
Based on results at Jefferson Lab, ELSA, MAMI, ...

Spectrum of N^* Resonances



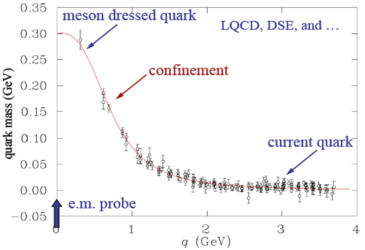
V. C. & W. Roberts, Rep. Prog. Phys. **76** (2013)

N^*	J^P $(L_{2I,2J})$	2010	2018
$N(1440)$	$1/2^+$ (P_{11})	****	****
$N(1520)$	$3/2^-$ (D_{13})	****	****
$N(1535)$	$1/2^-$ (S_{11})	****	****
$N(1650)$	$1/2^-$ (S_{11})	****	****
$N(1675)$	$5/2^-$ (D_{15})	****	****
$N(1680)$	$5/2^+$ (F_{15})	****	****
$N(1685)$			*
$N(1700)$	$3/2^-$ (D_{13})	***	***
$N(1710)$	$1/2^+$ (P_{11})	***	****
$N(1720)$	$3/2^+$ (P_{13})	****	****
$N(1860)$	$5/2^+$		**
$N(1875)$	$3/2^-$		***
$N(1880)$	$1/2^+$		***
$N(1895)$	$1/2^-$		****
$N(1900)$	$3/2^+$ (P_{13})	**	****
$N(1990)$	$7/2^+$ (F_{17})	**	**
$N(2000)$	$5/2^+$ (F_{15})	**	**
~~$N(2080)$~~	D_{13}	**	
~~$N(2090)$~~	S_{11}	*	
$N(2040)$	$3/2^+$		*
$N(2060)$	$5/2^-$		***
$N(2100)$	$1/2^+$ (P_{11})	*	***
$N(2120)$	$3/2^-$		***
$N(2190)$	$7/2^-$ (G_{17})	****	****
~~$N(2200)$~~	D_{15}	**	



Open Issues in (Light) Baryon Spectroscopy

1. What are the relevant degrees of freedom in (excited) baryons?
   ➜ Can the high-mass states be described by the dynamics of three flavored quarks? To what extent are diquark correlations, gluonic modes or hadronic degrees of freedom important in this physics?
2. Can we identify unconventional states in the strangeness sector, e. g. a $\Lambda(1405)$ or $N(1440)$? What is the situation with the $(\mathbf{20}, 1_2^+)$?
3. What is the nature of non-quark contributions, e. g. meson-baryon cloud or dynamically-generated states?
   ➜ Probe the running quark mass and determine the relevant degrees of freedom at different distance scales.
4. How do nearly massless quarks acquire mass? (as predicted in DSE and LQCD)



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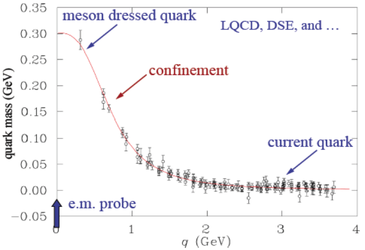

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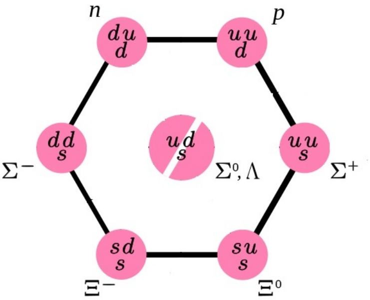
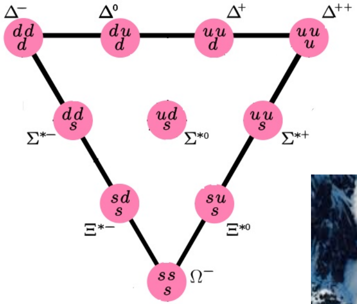
Baryon Multiplets and Hyperon Spectroscopy

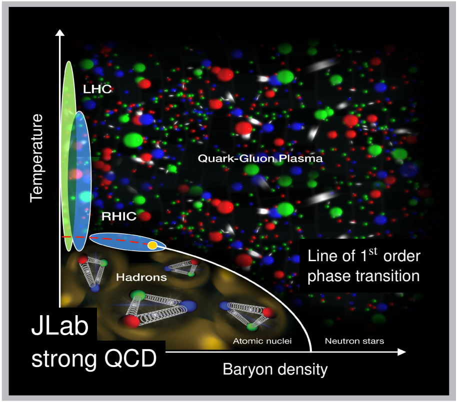




The decuplets consist of Δ^*, Σ^*, Ξ^*, and Ω^* resonances, but also the octets consist of an Ξ^* state.

➜ We expect as many Ξ's as N^* & Δ^* states together. Moreover, their properties should be related.

QCD Phases and the Study of Baryon Resonances

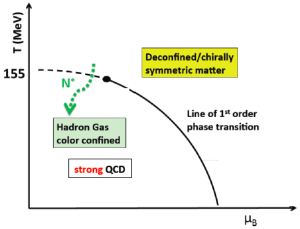


QGP

↓

hadron phase

- Chiral symmetry is broken
- Quarks acquire mass
- Baryon resonances occur
- Color confinement emerges

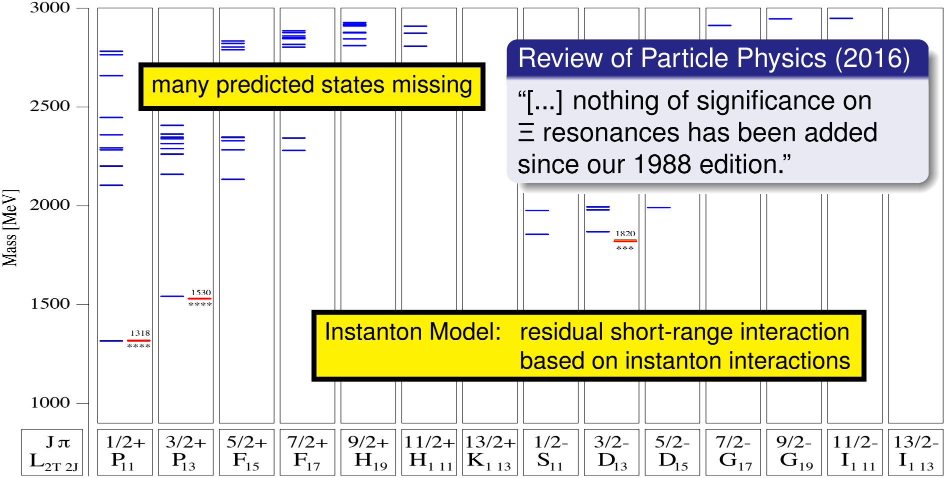


RPP (u, d, s, c) baryons not sufficient to describe freeze-out behavior.

(e. g. A. Bazavov *et al.*, PRL **113** (2014) 7, 072001)

Cascade Resonances: Status as of 2018

—— U. Loering, B. Ch. Metsch, H. R. Petry, Eur. Phys. J. **A10** (2001) 447-486



many predicted states missing

Review of Particle Physics (2016)

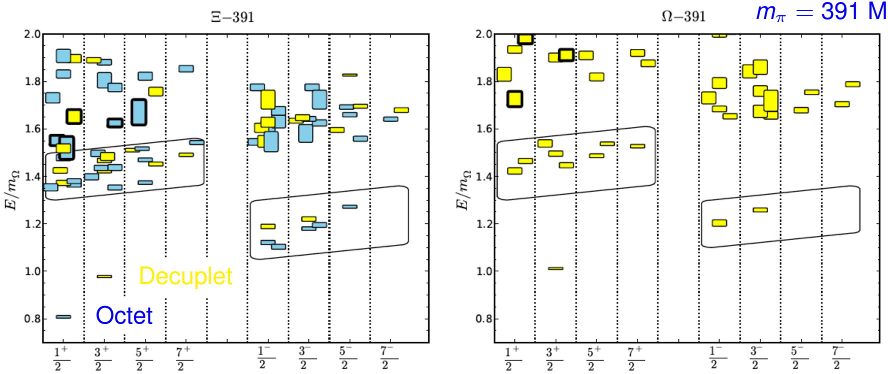
"[...] nothing of significance on Ξ resonances has been added since our 1988 edition."

Instanton Model: residual short-range interaction based on instanton interactions

The Ξ^* and Ω^* Spectrum from Lattice QCD

R. Edwards *et al.*, Phys. Rev. D **87**, no. 5, 054506 (2013)

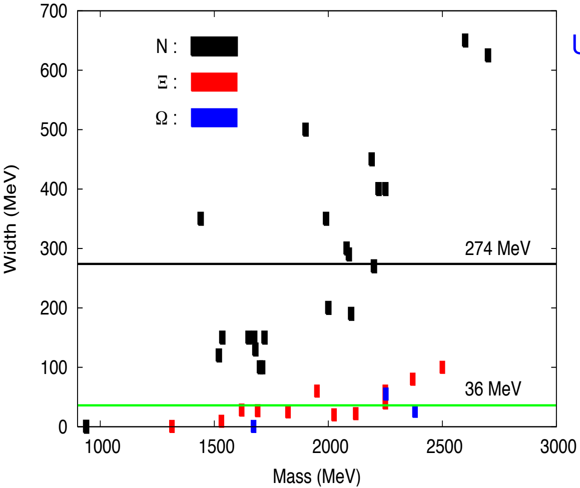
$m_\pi = 391$ MeV



Exhibits broad features expected of $SU(6) \otimes O(3)$ symmetry

➜ Counting of states of each flavor and spin consistent with QM for the lowest negative- and positive-parity bands.

Baryon Widths: The Experimental Point of View



Unique features of Ξ^* and Ω^*:

- Strangeness $S > 1$
- Narrow widths: $\Gamma_{\Xi^*} \approx 10-20$ MeV?

↓

N^* PWA machinery needed?

Why are Cascade Resonances Narrow?

Possible explanations:

1. Narrowness related to the number of light quarks
   ➜ Specifically, resonance width proportional to square of the number of light quarks: $\Gamma_{N^*,\Delta^*} : \Gamma_{\Lambda^*,\Sigma^*} : \Gamma_{\Xi^*} \approx 9 : 4 : 1$
   (D. O. Riska, Eur. Phys. J. **A17**, 297 (2003))
2. Alternative explanation based on Cascade structure and decay modes
   (S. Capstick *et al.*)
   - Decays $\Xi^* \to \Xi\pi$ are suppressed relative to $N^*, \Delta^* \to N\pi$.
     Non-rel. one-gluon exchange model: Chao, Isgur, Karl, PR **D23**, 155 (1981)
   - Flavor symmetry requires *s*-quarks at ends of ρ oscillator; excitation energy is given by the square root of K/M where K will be equal for all quark pairs if the confinement potential is flavor independent.

     ➜ Excitation of ρ costs less energy than the excitation of λ.
     (Argument only valid for lowest states.)

Measurements at BNL in $K^- p \to K^+_{\rm slow} + X^-$

"Existence of Ξ Resonances above 2 GeV"
(C.M. Jenkins *et al.*, Phys. Rev. Lett. **51**, 951 (1983))

Observed Ξ States:

$\Xi(1320)$ **** $I(J^P) = \frac{1}{2}(\frac{1}{2}^+)$

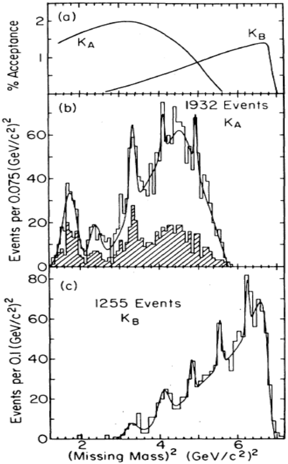
$\Xi(1530)$ **** $I(J^P) = \frac{1}{2}(\frac{3}{2}^+)$

$\Xi(1820)$ *** $I(J^P) = \frac{1}{2}(\frac{3}{2}^-)$

$\Xi(2030)$ *** $I(J^P) = \frac{1}{2}(\geq \frac{5}{2}^?)$

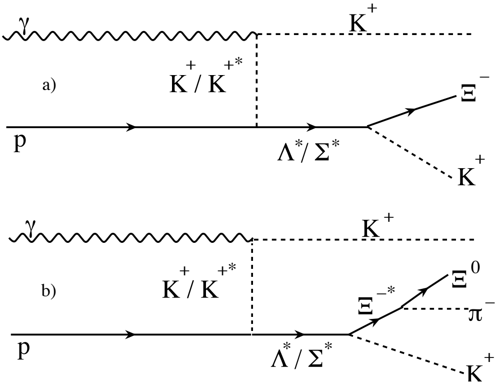
$\Xi(2370)$ *** $I(J^P) = \frac{1}{2}(?^?)$

$\Xi(2500)$ *** $I(J^P) = \frac{1}{2}(?^?)$



Outline

Possible Production Mechanisms



$K^+(\Xi^- K^+)$, $K^+(\Xi^0 K^0)$, $K^0(\Xi^0 K^+)$

➜ Cross sections, beam asymmetries (similar to $p\pi\pi$ & pKK^*)

Production of excited states via a

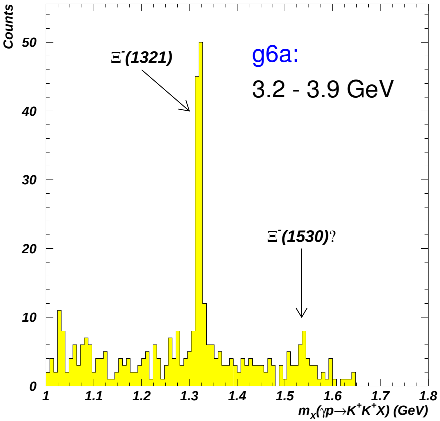
1. forward-going K^0 meson
   ➜ $K^0\,(\,\Xi^-\,\pi^+\,)\,K^+$, etc.
2. forward-going K^+ meson
   ➜ $K^+\,(\,\Xi^-\,\pi^+\,)\,K^0$,
   $K^+\,(\,\Xi^0\,\pi^-\,)\,K^+$, etc.

* W. Roberts *et al.*, Phys. Rev. C **71**, 055201 (2005)

CLAS g6 Runs

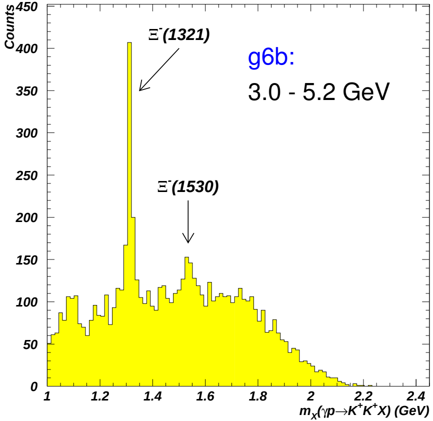
First exclusive photoproduction of Ξ^-

J. Price *et al.*, PRC **71**, 058201 (2005)



Look for $\gamma p \to K^+ K^+ (X)$

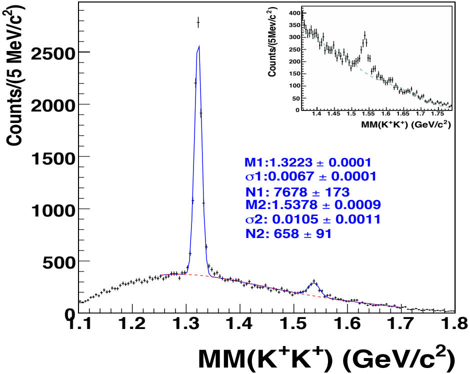
with $B = +1,\ Q = -1,\ S = -2$



CLAS g11a Run

More data mining based on much higher statistics

Guo *et al.*, PRC **76**, 025208 (2007)

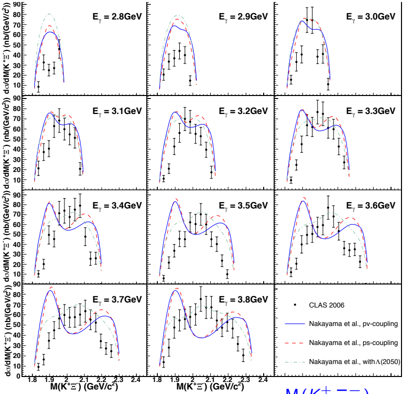


Reaction $\gamma p \to K^+ K^+ (X)$

- Very strong Ξ(1320) signal
- Clear signal for Ξ(1530)
- Ratio $N_\Xi \,/\, N_{\Xi(1530)} \approx 10 : 1$
  - ➜ About the same as for the CLAS-g6 data.

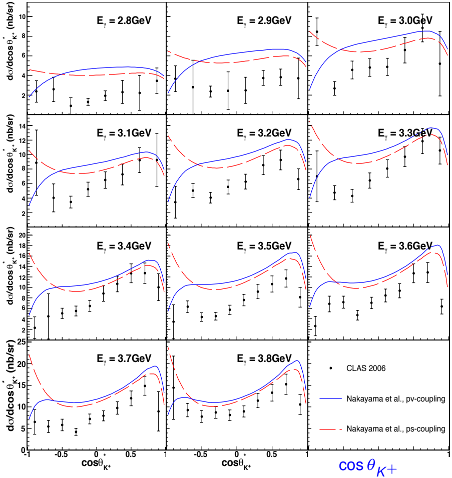
CLAS g11a Run: Differential Cross Sections

E_γ range of 2.75 – 3.85 GeV



M $(K^+ \Xi^-)$

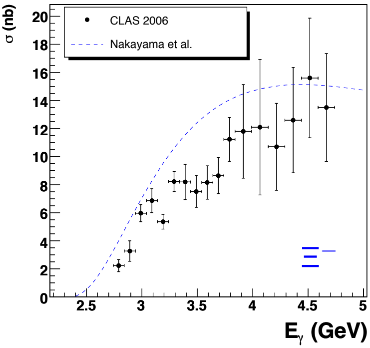
cos $d\sigma/d\cos\theta_{K^+}$ [nb/sr]

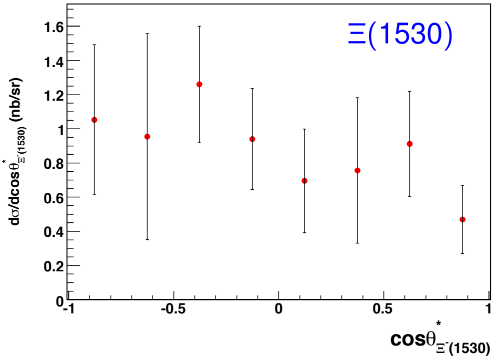


cos θ_{K^+}

CLAS g11a: Cross Sections of Ξ^- and $\Xi(1530)$

E_γ range of 2.75 – 4.75 GeV

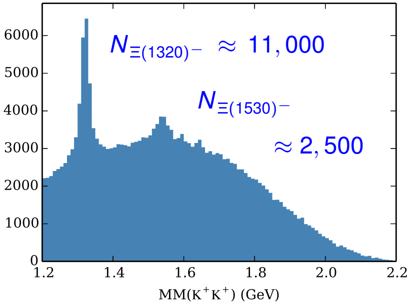




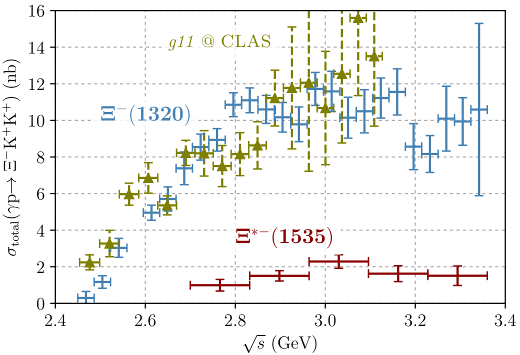
K. Nakayama, Y. Oh, and H. Haberzettl, Phys. Rev. **C74**, 035205 (2006)

CLAS g12: Total Cross Sections of $(\Xi^-)^*$

$2.31 < \sqrt{s} < 3.4$ GeV



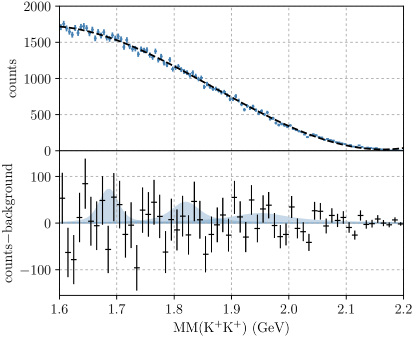
J. T. Goetz *et al.* [CLAS Collaboration], arXiv:1809.00074 [nucl-ex].

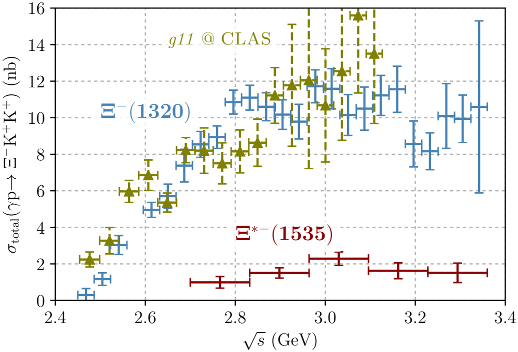


No statistically significant structures beyond the 1530 MeV peak: different reaction (production) mechanism for Ξ^* states?

CLAS g12: Total Cross Sections of $(\Xi^-)^*$

arXiv:1809.00074 [nucl-ex]



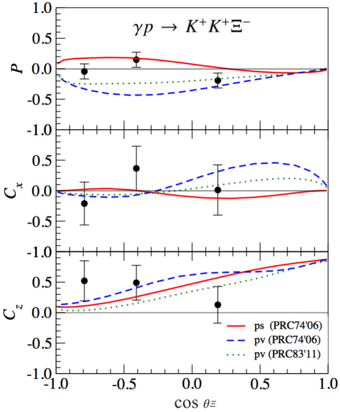


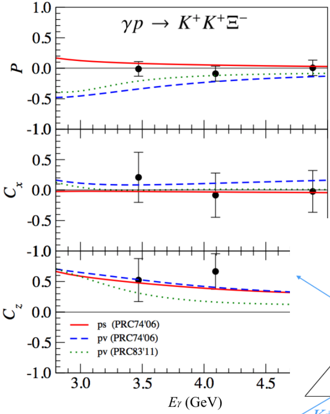
Upper Limits (integrated over all energies):

(1) Ξ(1690): 0.75 nb (2) Ξ(1820): 1.01 nb (3) Ξ(1950): 1.58 nb

CLAS g12: First Measurement of Ξ^- Polarization

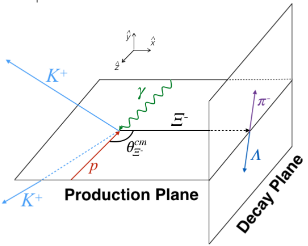
arXiv:1804.04564 [nucl-ex]





induced polarization

transferred polarization



K. Nakayama *et al.*, Phys. Rev. C **74**, 035205 (2006)

J. K. S. Man *et al.*, Phys. Rev. C **83**, 055201 (2011)

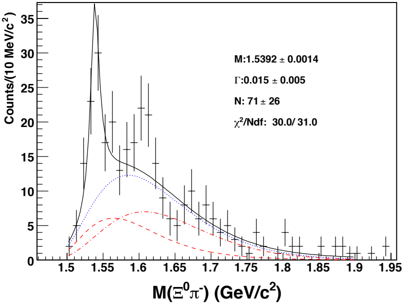
CLAS g11a: Excited States in $\gamma p \to K^+ K^+ \pi^- (X)$

From the paper: *Although a small enhancement is observed in the $\Xi^0\pi^-$ invariant mass spectrum near the controversial 1-star $\Xi^-(1620)$ resonance, it is not possible to determine its exact nature without a full partial wave analysis.*

Need high-statistics, high-energy data from an experiment designed to see Ξ states:

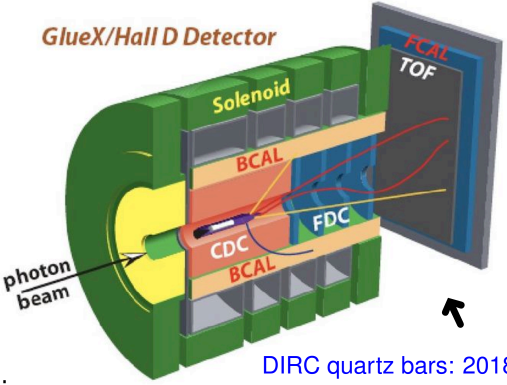
- 3- or 4-track trigger
- Reconstruction of full decay chain
- Higher photon energy
- Improved detectors

→ CLAS 12 and GlueX at Jefferson Lab



Hadron Spectroscopy

- π + Nucleus
- $\gamma\, p$ *Photoproduction*
- $e^+\, e^-$
- $\bar{p}\, p$



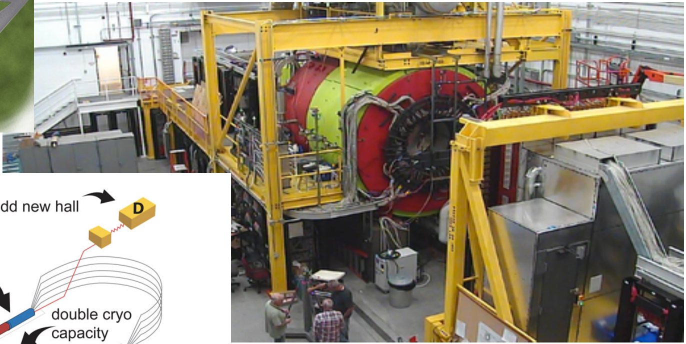
DIRC quartz bars: 2018+

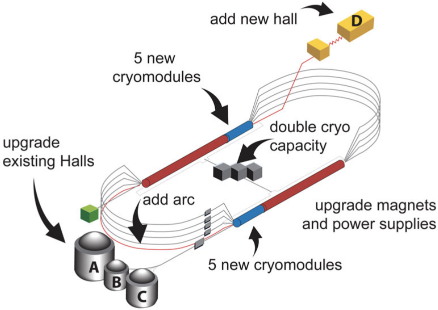
The GlueX Collaboration

- $\sim$130 members, 28 institutions
  (USA, Chile, China, Armenia, Greece, Russia, UK)
- Production data-taking in full swing
- First physics published in 2017

May 2014

Hall D

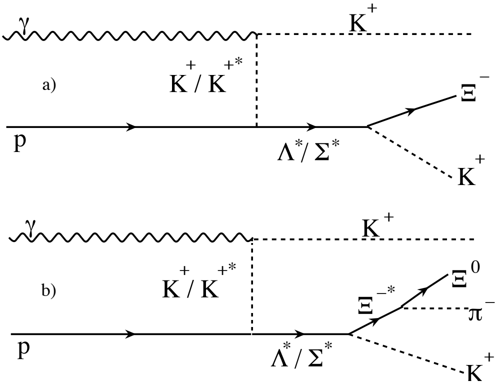




Jefferson Lab Upgrade to 12 GeV

- 10.1 GeV achieved, Fall 2014
- Hall D project complete

Possible Production Mechanisms



$K^+(\Xi^- K^+)$, $K^+(\Xi^0 K^0)$, $K^0(\Xi^0 K^+)$

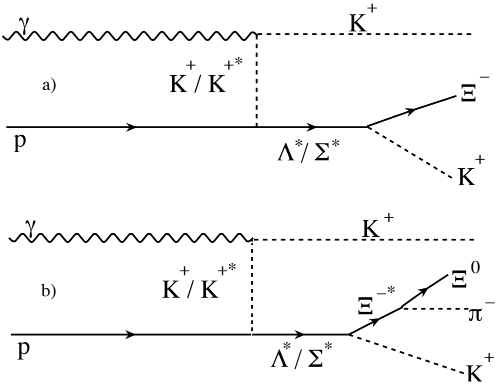
➜ Cross sections, beam asymmetries (similar to $p\pi\pi$ & pKK^*)

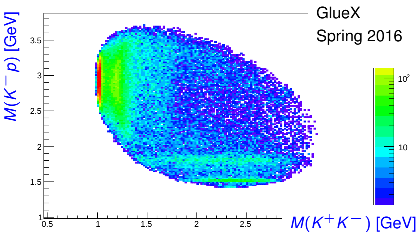
At other facilities (for comparison):

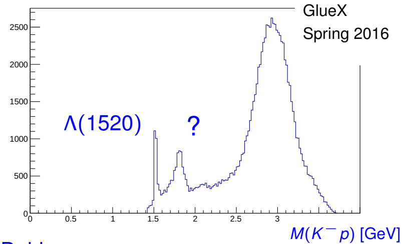
$K^- p \to K^+ \Xi^{*-}$	J-PARC
$K_L p \to K^+ \Xi^{*0}$	Hall D ?
$p p \to \Xi^* X$	LHCb
$\bar{p} p \to \Xi^* \bar{\Xi}$	$\overline{\text{P}}$ANDA
$e^+ e^- \to \Xi^* X$	Belle II, BES III

* W. Roberts *et al.*, Phys. Rev. C **71**, 055201 (2005)

Possible Production Mechanisms

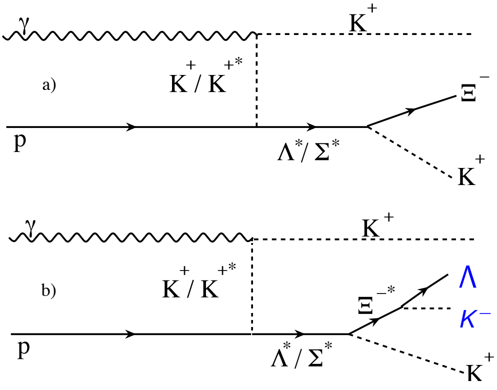




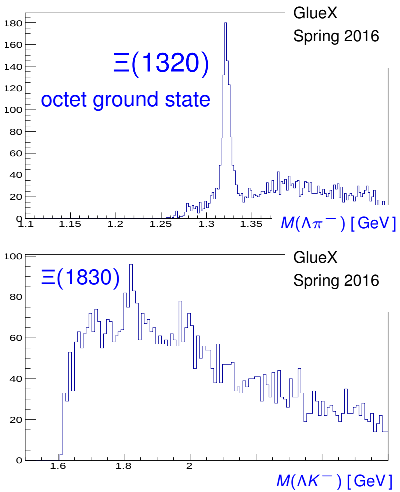


Courtesy of Sean Dobbs

Possible Production Mechanisms

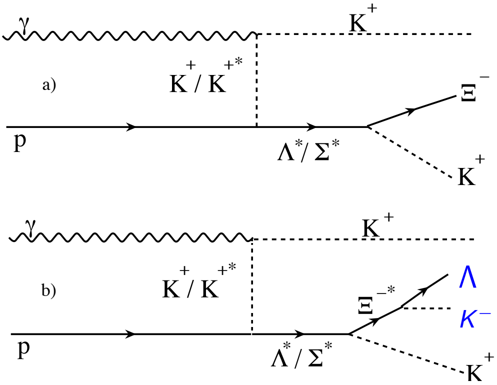


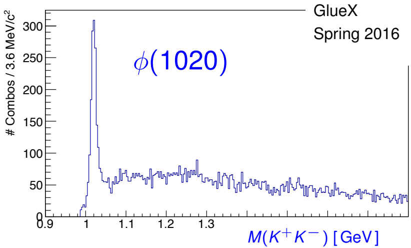
$$\gamma p \to K^+ (K^+ \Xi^{-*}) \to K^+ (p \pi^- K^-) K^+$$

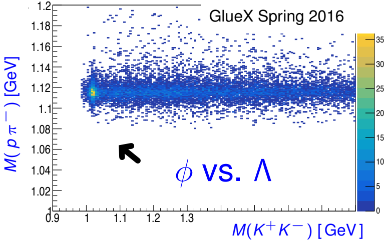


Courtesy of Ashley Ernst (FSU)

Possible Production Mechanisms







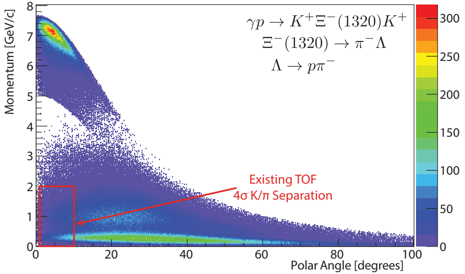
$\gamma p \to K^+ (\Lambda K^+ K^-)$

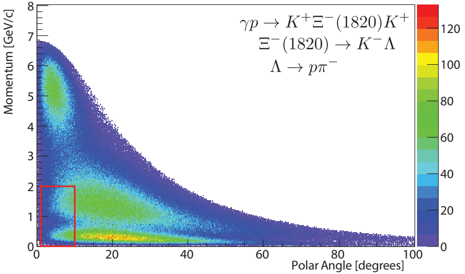
1) $K^+ (\Xi^{-*} K^+)$, 2) $K^+ (\Lambda \phi)$

Courtesy of Ashley Ernst (FSU)

Ξ Spectroscopy with the GlueX Detector

GlueX Proposal on "Decays to Strange Final States" (JLab PAC 39, 40 & 42)





Efficiency should be adequate for conducting a study of excited Ξ states with the baseline detector:

- Detailed studies of the production, especially of the ground state Ξ's, and a parity measurement * will likely require enhanced kaon identification in the forward direction ➜ Components of the BaBar DIRC for GlueX.

* e.g. Nakayama *et al.*, Phys. Rev. C **85**, 042201 (2012)

Ξ Spectroscopy with the GlueX Detector

The Ξ octet ground states (Ξ^0, Ξ^-) will be challenging to study via exclusive t-channel (meson exchange) production. The typical final states have kinematics for which the baseline GlueX detector has very low acceptance due to:

- the high-momentum forward-going kaon and
- the relatively low-momentum pions produced in the Ξ decay.

The production of the Ξ decuplet ground state, Ξ(1530), and other excited Ξ's decaying to $\Xi\pi$ results in a lower momentum kaon at the upper vertex, and these heavier Ξ states produce higher momentum pions in their decays.

The lightest excited Ξ states are expected to decouple from $\Xi\pi$ and can be searched for and studied also in their decays to $\Lambda\overline{K}$ and $\Sigma\overline{K}$:

$$\gamma p \to K\,Y^* \quad \to \quad K^+\,(\overline{K}\Lambda)_{\Xi^{-*}}\,K^+, \quad K^+\,(\overline{K}\Lambda)_{\Xi^{0*}}\,K^0, \quad K^0\,(\overline{K}\Lambda)_{\Xi^{0*}}\,K^+,$$

$$\gamma p \to K\,Y^* \quad \to \quad K^+\,(\overline{K}\Sigma)_{\Xi^{-*}}\,K^+, \quad K^+\,(\overline{K}\Sigma)_{\Xi^{0*}}\,K^0, \quad K^0\,(\overline{K}\Sigma)_{\Xi^{0*}}\,K^+.$$

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$$\gamma p \to K\,Y^* \quad \to \quad K^+\,(\overline{K}\Sigma)_{\Xi^{-*}}\,K^+, \quad K^+\,(\overline{K}\Sigma)_{\Xi^{0*}}\,K^0, \quad K^0\,(\overline{K}\Sigma)_{\Xi^{0*}}\,K^+.$$

Ξ Spectroscopy with the GlueX Detector

Expected yields of Ξ states using (PAC 40 proposal):

$$N = \epsilon\, \sigma\, n_\gamma\, n_t\, T \quad \text{where}$$

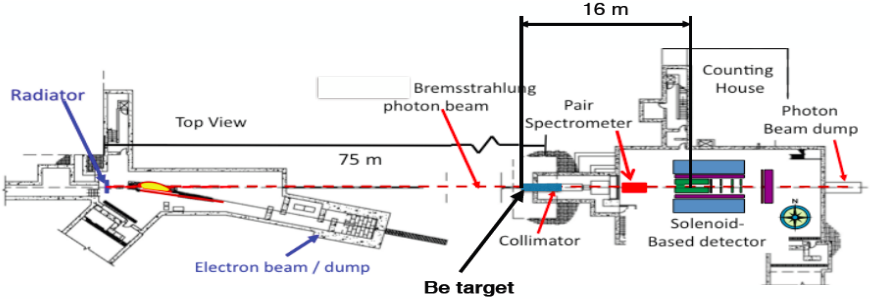
$\sigma_{\Xi(1320)} = 15$ nb and $\sigma_{\Xi(1530)} = 2$ nb at $E_\gamma = 5$ GeV

$\epsilon_{\Xi(1820)} \approx 30\,\%$ (BDT: signal purity 0.9)

➜ $800,000$ $\Xi^-(1320)$ events
$100,000$ $\Xi^-(1530)$ events
$90,000$ $K^+K^+K^-\Lambda$ events (based on PYTHIA)

➜ At least x10 more statistics than previous CLAS result.

Opportunities with Secondary K_L^0 Beams in Hall D



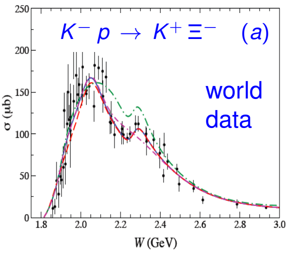
K_L^0 mesons from collimated photon beam on a Be target ($R = 2$ cm, $L = 40$ cm)

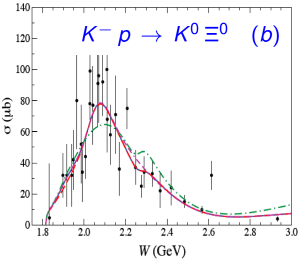
- $\Delta L \approx 16$ m (between Be & LH_2 targets); thick lead absorber to stop photons.
- ≈ 2000 K_L^0 / sec (x10 higher than in LASS experiment at SLAC).
- Resolution of $\Delta p/p \approx 0.3\,\%$ for K_L^0 momenta based on TOF.
- Reduced n rate compared to LASS.

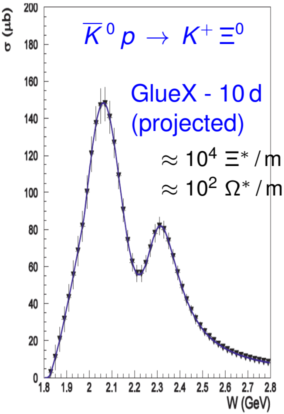
Opportunities with Secondary K_L^0 Beams in Hall D

Possible reactions to be studied (elastic and charge-exchange reactions):

- 2- & 3-body reactions producing $S = -1$ hyperons
- 2-body reactions producing $S = -2$ hyperons
  ➜ $K_L^0\, p \to K^+\, \Xi^0;\ \pi^+ K^+\, \Xi^-;\ K^+\, \Xi^{0*};\ \pi^+ K^+\, \Xi^{-*}$
- 3-body reactions producing $S = -3$ hyperons
  ➜ $K_L^0\, p \to K^+ K^+\, \Omega^-;\ K^+ K^+\, \Omega^{-*}$







Outline

Summary and Outlook

Baryon Spectroscopy: Are we there, yet? Certainly not ...

New era in the spectroscopy of strange baryons (GlueX, LHCb, PANDA, ...)

- Mapping out the spectrum of Ξ baryons is the primary motivation (including parity measurements); some hope for peak hunting.
- Ground-state Ξ in $\gamma p \to KK\,\Xi$ will allow the spectroscopy of Σ^* / Λ^* states.

The multi-strange baryons provide a missing link between the light-flavor and the heavy-flavor baryons. Also:

1. Do the lightest excited Ξ states in certain partial waves decouple from the $\Xi\pi$ channel, confirming the flavor independence of confinement?
2. Ξ baryons as a probe of excited hadron structure?
   ➜ Measurements of the isospin splittings in spatially excited Ξ states appear possible for the first time (similar to $n - p$ or $\Delta^0 - \Delta^{++}$).

Acknowledgement

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Backup Slides

SU(3) Flavor Symmetry

$SU(3)_F$ symmetry is broken by the strange-light quark mass difference
➜ Corrections in quark models are substantial

However:

- Some static properties, such as the masses of the baryons, are found to obey $SU(3)_F$ symmetry:

$$\Delta m\,[N(1440)\frac{1}{2}^{+} - N(939)\frac{1}{2}^{+}] \approx \Delta m\,[\Lambda(1600)\frac{1}{2}^{+} - \Lambda(1115)\frac{1}{2}^{+}]$$

- Also some dynamic properties exhibit $SU(3)_F$ symmetry:
  1. Similarity of near-threshold cross sections of the reactions $\pi^- p \to \eta n$ and $K^- p \to \eta\Lambda$ (S. Prakhov *et al.*, Phys. Rev. **C72**, 015203 (2005))
  2. Similarity in the Dalitz plots for the processes $\pi^- p \to \pi^0\pi^0 n$ and $K^- p \to \pi^0\pi^0\Lambda$ (S. Prakhov *et al.*, Phys. Rev. **C69**, 042202 (2004))

SU(3) Flavor Symmetry: Implications

Conclusion:

Parallel members of different multiplets should exhibit a similar mass difference Δm.

➜ Unfortunately, we cannot compare with any Ξ states because the 2^{nd} $\Xi(?)P_{11}(J^P = \frac{1}{2}^+)$ has not been found, yet.

However, the SU(3)_F symmetric basis may not be ideal:
(Everything is strongly mixed.)

- Better choice (S. Capstick): *"uds" basis where you (anti-)symmetrize only in u, d quark degrees of freedom.*

  ➜ Isospin much better symmetry than SU(3)_F.
- E.g.: $\phi_\Lambda = (ud - du)s/\sqrt{2}$ $\phi_\Sigma = uus,\ (ud + du)s/\sqrt{2},\ dds$

  In Ξ states, symmetrize only in ss pair: $\phi_\Xi = ssu,\ ssd$