Baryon Spectroscopy: Developing Ideas for Proton Beams at FAIR

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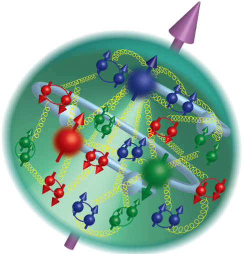
QCD Physics with Proton Beams up to 30 GeV at FAIR

Satellite (MESON 2023) Workshop

Kraków, Poland

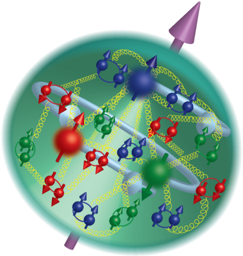
06/21/2023

Outline



Outline

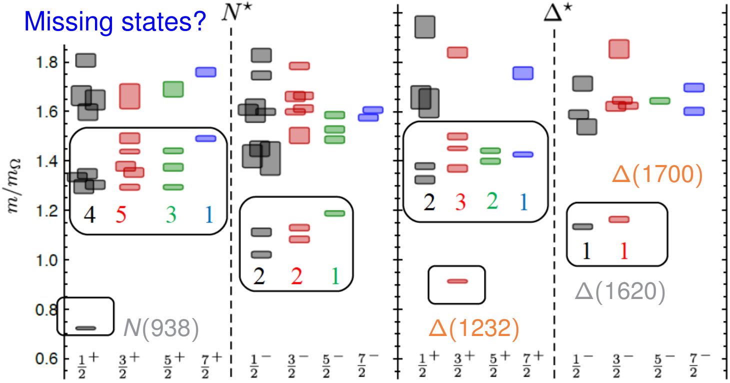
1. Introduction
   - The Nucleon Spectrum
2. Spectroscopy of Baryon Resonances
   - $N^\star$ Spectroscopy: Measurements at GlueX
   - The Study of Strangeness -1 Hyperons
   - Spectroscopy of Ξ Resonances
3. Heavy-Flavor Resonances
4. Summary and Conclusions



The N^* and Δ^* Spectrum from Lattice QCD

R. Edwards *et al.*, Phys. Rev. D **84**, 074508 (2011); Phys. Rev. D **87**, 054506 (2013)

Missing states?

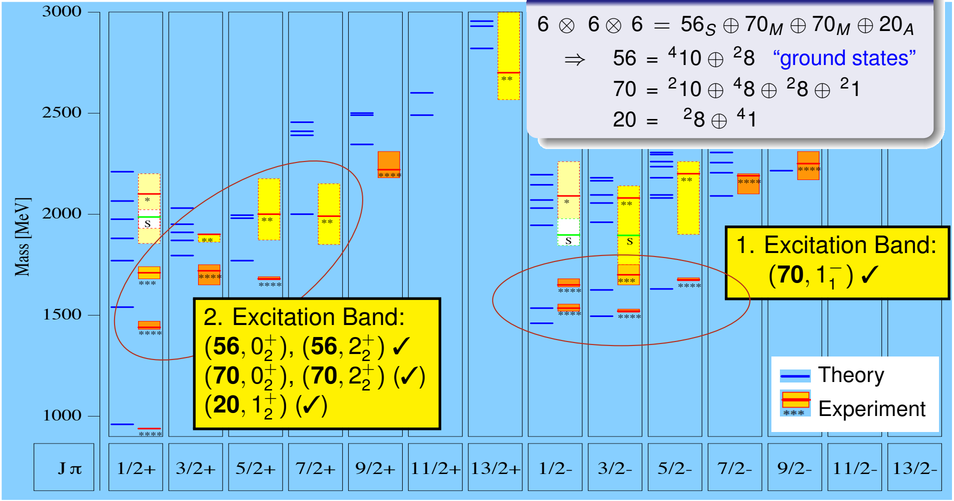


$m_\pi = 396$ MeV

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

➜ Counting of levels consistent with non-rel. quark model, no parity doubling.

Spectrum of N^* Resonances



SU(6) ($^{2S+1}$multiplets; u, d, s, spin)

$$6 \otimes 6 \otimes 6 = 56_S \oplus 70_M \oplus 70_M \oplus 20_A$$

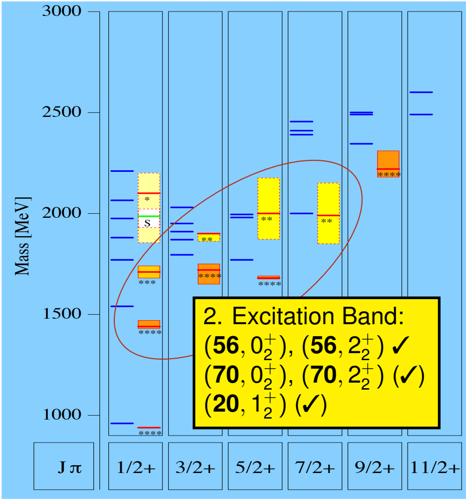
$$\Rightarrow \quad 56 = {}^4 10 \oplus {}^2 8 \quad \text{“ground states”}$$

$$70 = {}^2 10 \oplus {}^4 8 \oplus {}^2 8 \oplus {}^2 1$$

$$20 = {}^2 8 \oplus {}^4 1$$

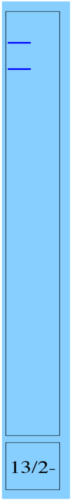
S. Capstick & N. Isgur, Phys. Rev. **D34** (1986) 2809

Spectrum of N^* Resonances

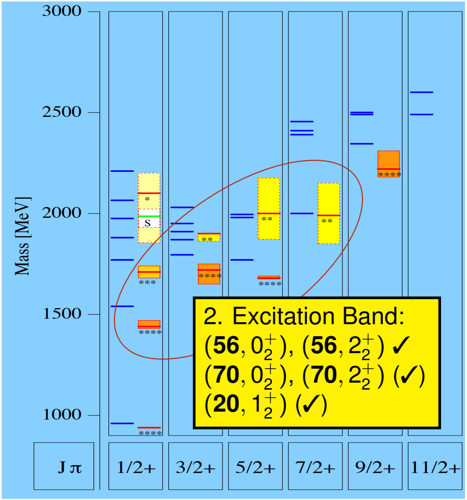


V. C. & W. Roberts, Rep. Prog. Phys. **76** (2013)

N^*	J^P $(L_{2I,2J})$	2010	2020
$N(1440)$	$1/2^+$ (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}	∗ ∗	



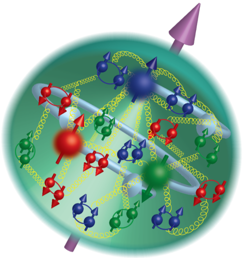
Spectrum of N^* Resonances



N	(D, L_N^P)	S	J^P	Octet Members				Singlets
0	$(56, 0_0^+)$	$\frac{1}{2}$	$\frac{1}{2}^+$	$N(939)$	$\Lambda(1116)$	$\Sigma(1193)$	$\Xi(1318)$	–
1	$(70, 1_1^-)$	$\frac{1}{2}$	$\frac{1}{2}^-$	$N(1535)$	$\Lambda(1670)$	$\Sigma(1620)$	$\Xi(1690)$	$\Lambda(1405)$
			$\frac{3}{2}^-$	$N(1520)$	$\Lambda(1690)$	$\Sigma(1670)$	$\Xi(1820)$	$\Lambda(1520)$
		$\frac{3}{2}$	$\frac{1}{2}^-$	$N(1650)$	$\Lambda(1800)$	$\Sigma(1750)$		–
			$\frac{3}{2}^-$	$N(1700)$				–
			$\frac{5}{2}^-$	$N(1675)$	$\Lambda(1830)$	$\Sigma(1775)$		–
2	$(56, 0_2^+)$	$\frac{1}{2}$	$\frac{1}{2}^+$	$N(1440)$	$\Lambda(1600)$	$\Sigma(1660)$		–
	$(70, 0_2^+)$	$\frac{1}{2}$	$\frac{1}{2}^+$	$N(1710)$	$\Lambda(1810)^\dagger$	$\Sigma(1770)^\dagger$		
		$\frac{3}{2}$	$\frac{3}{2}^+$					–
	$(56, 2_2^+)$	$\frac{1}{2}$	$\frac{3}{2}^+$	$N(1720)^\dagger$	$\Lambda(1890)^\dagger$	$\Sigma(1840)^\dagger$		–
			$\frac{5}{2}^+$	$N(1680)$	$\Lambda(1820)^\dagger$	$\Sigma(1915)^\dagger$		–
	$(70, 2_2^+)$	$\frac{1}{2}$	$\frac{3}{2}^+$					
			$\frac{5}{2}^+$	$N(1860)$				
		$\frac{3}{2}$	$\frac{1}{2}^+$	$N(1880)$				–
			$\frac{3}{2}^+$	$N(1900)^\dagger$		$\Sigma(2080)^\dagger$		–
			$\frac{5}{2}^+$	$N(2000)$	$\Lambda(2110)^\dagger$	$\Sigma(2070)^\dagger$		–
			$\frac{7}{2}^+$	$N(1990)$	$\Lambda(2020)$	$\Sigma(2030)^\dagger$		–
	$(20, 1_2^+)$	$\frac{1}{2}$	$\frac{1}{2}^+$	$N(2100)^\dagger$				
			$\frac{3}{2}^+$	$N(2040)^\dagger$				
			$\frac{5}{2}^+$	–	–	–	–	

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

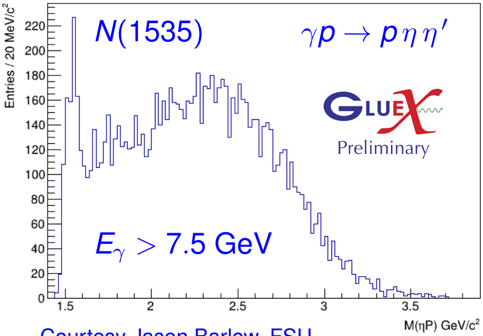
Outline



N^* Spectroscopy at GlueX

GlueX is not the ideal experiment for N^* spectroscopy without a polarized target. However,

- N^* resonances are abundantly produced at $E_\gamma > 7$ GeV.
- Interesting program on N^* physics is possible.



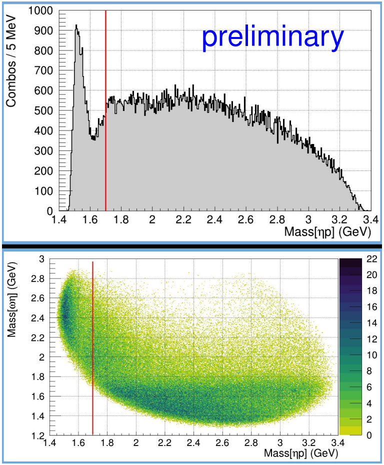
Courtesy Jason Barlow, FSU

Data selection:

- General cuts to improve overall event kinematics (CL, missing mass, etc.).
- No cuts (yet) to enhance $\gamma p \to \eta'\, N(1535)$ production.

Possibly, direct access to $N(1535)\,\frac{1}{2}^-$ due to t-channel production.

N^* Spectroscopy at GlueX



Courtesy Edmundo Barriga, FSU

Reaction: $\gamma p \to p\,\eta\,\omega$

Data selection:

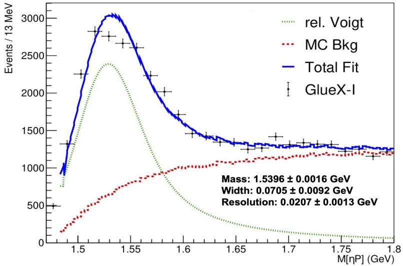
- General cuts to improve overall event kinematics (CL, missing mass, etc.).
- $8.2\ \mathrm{GeV} < E_\gamma < 8.8\ \mathrm{GeV}$
- $-t < 0.6\ \mathrm{GeV}^2$
- No cuts (yet) to enhance $\gamma p \to \omega\, N(1535)$ production.

Possibly, direct access to $N(1535)\,\frac{1}{2}$ due to t-channel production.

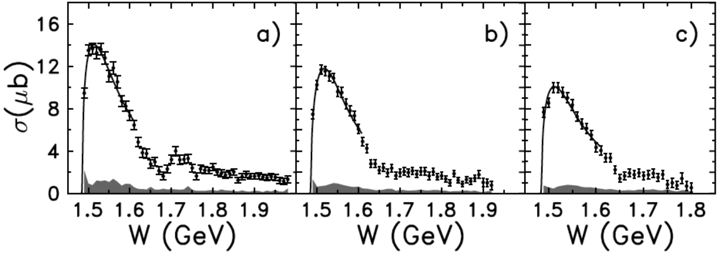
N(1535) BREIT-WIGNER WIDTH

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
125 to 175 (≈ 150) OUR ESTIMATE				
147 ± 5	[6] HUNT	19	DPWA	Multichannel
163 ±25	KASHEVAROV	17	DPWA	$\gamma p \to \eta p, \eta' p$
120 ±10	SOKHOYAN	15A	DPWA	Multichannel
131 ±12	[6] SHKLYAR	13	DPWA	Multichannel
188.4± 3.8	[6] ARNDT	06	DPWA	$\pi N \to \pi N, \eta N$
240 ±80	CUTKOSKY	80	IPWA	$\pi N \to \pi N$
120 ±20	HOEHLER	79	IPWA	$\pi N \to \pi N$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
128 ±14	ANISOVICH	12A	DPWA	Multichannel
141 ± 4	[6] SHRESTHA	12A	DPWA	Multichannel
182 ±25	BATINIC	10	DPWA	$\pi N \to N\pi, N\eta$
129 ± 8	PENNER	02C	DPWA	Multichannel
95 ±25	BAI	01B	BES	$J/\psi \to p\bar{p}\eta$
143 ±18	THOMPSON	01	CLAS	$\gamma^* p \to p\eta$

t-channel production: $\gamma p \to \omega\,(p\,\eta)$



s-channel production: $\gamma^* p \to p\,\eta$ (CLAS)



How do we study baryons experimentally?

Light-flavor baryons are typically studied in fixed-target experiments (nuclear physics), heavy-flavor baryons are studied at colliders (high-energy physics).

1. Fixed-Target Experiments

   Photo-/electroproduction, e. g. Jefferson Lab, ELSA, MAMI, etc.

   e. g. $\gamma N\,(\mathrm{e}^-\,N) \to (\mathrm{e}^-)\,N^*/\Delta^*$

   $\gamma N\,(\mathrm{e}^-\,N) \to (\mathrm{e}^-)\,K\,Y^*\;(Y^{ast} = \Lambda^*, \Sigma^*)$

   $\pi\,/\,K$-induced production, e. g. HADES@GSI, J-PARC

   e. g. $\pi N \to N^*/\Delta^*$

   ➜ pp reactions at FAIR (new idea) ?

2. Collider Experiments

   at e^+e^- machines, e. g. BES III, Belle, BaBar, etc.

   e. g. $\Xi_c^+\,(\Lambda_c^+) \to [\Xi^-\pi^+]_{\Xi^*}\,\pi^+\,(K^+)$ or $e^+e^- \to J/\psi \to N^*\bar{N}$

   at pp machines, e. g. LHC

   e. g. $\Xi_b^{*\,-} \to \Xi_b^-\,\pi^+\pi^-$ (LHCb, CMS)

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   at pp machines, e. g. LHC

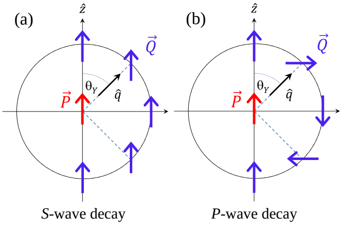
   e. g. $\Xi_b^{*\,-} \to \Xi_b^-\,\pi^+\pi^-$ (LHCb, CMS)

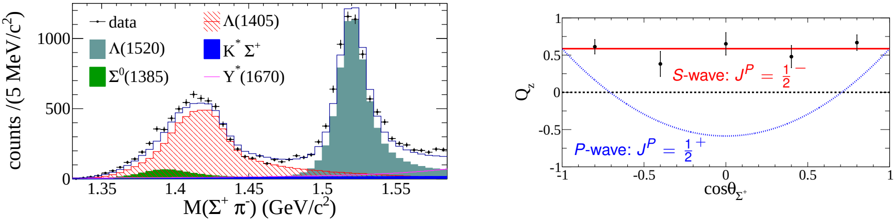
Spin and Parity Measurement of the $\Lambda(1405)$ Baryon

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

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

- 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

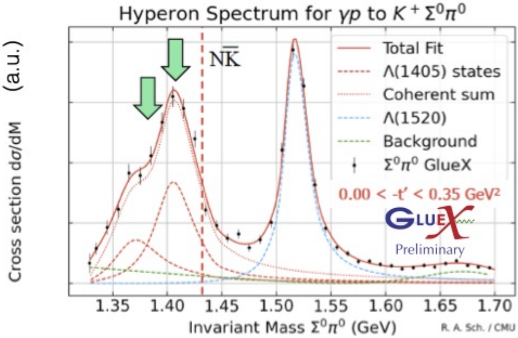




The $\Lambda(1405)$ Baryons at GlueX

1. Measurement of the $\Sigma\pi$ photoproduction line shapes near the $\Lambda(1405)$
K. Moriya *et al.* [CLAS Collaboration], Phys. Rev. C **87**, no. 3, 035206 (2013)

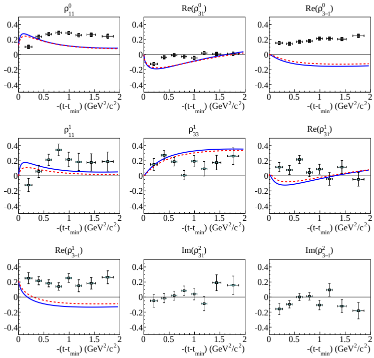
More coming from GlueX on $\Lambda(1405) \to \Sigma^0\pi^0$

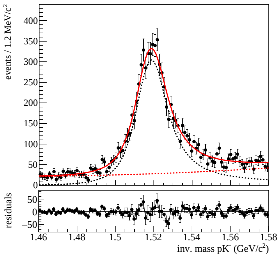


- Fit of (1) two coherent Flatté amplitudes plus (2) incoherent $\Lambda(1520)$, and (3) backgrounds.
- Preliminary fit results support the two-pole structure.

The $\Lambda(1405)/\Lambda(1520)$ Baryons at GlueX

- Measurement of the $\Sigma\pi$ photoproduction line shapes near the $\Lambda(1405)$
  K. Moriya *et al.* [CLAS Collaboration], Phys. Rev. C **87**, no. 3, 035206 (2013)
- Measurement of SDMEs in $\Lambda(1520)$ photoproduction at 8.2 – 8.8 GeV
  S. Adhikari *et al.* [GlueX Collaboration], Phys. Rev. C **105**, no. 3, 035201 (2022)





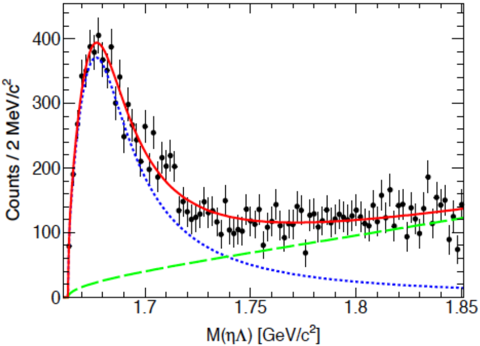
$-(t - t_0) \in [\,0.3, 0.5\,]$ GeV^2

Spectroscopy of Excited Λ^* Baryons

First direct mass and width determination for the $\Lambda(1670)$

[Belle Collaboration], Phys. Rev. D **103**, no. 5, 052005 (2021)

$\Lambda_c^+ \to \Lambda(1670)\pi^+$



Λ(1670) WIDTH

VALUE (MeV)	DOCUMENT ID		TECN	COMMENT
25 to 35 (≈ 30) OUR ESTIMATE				
$36.1 \pm 2.4 \pm 4.8$	LEE	21A	BELL	$\Lambda_c^+ \to \Lambda(1670)\pi^+$
33 ± 4	SARANTSEV	19	DPWA	$\overline{K}N$ multichannel
29 ± 5	ZHANG	13A	DPWA	$\overline{K}N$ multichannel
34.1 ± 3.7	KOISO	85	DPWA	$K^- p \to \Sigma\pi$
29 ± 5	GOPAL	80	DPWA	$\overline{K}N \to \overline{K}N$
29 ± 5	ALSTON-...	78	DPWA	$\overline{K}N \to \overline{K}N$
46 ± 5	HEPP	76B	DPWA	$K^- N \to \Sigma\pi$
40 ± 3	KANE	74	DPWA	$K^- p \to \Sigma\pi$
19 ± 5	PREVOST	74	DPWA	$K^- N \to \Sigma(1385)\pi$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
23 ± 6	MANLEY	02	DPWA	$\overline{K}N$ multichannel
21.1 ± 3.6	ABAEV	96	DPWA	$K^- p \to \Lambda\eta$
45 ± 10	GOPAL	77	DPWA	$\overline{K}N$ multichannel
12	[1] MARTIN	77	DPWA	$\overline{K}N$ multichannel

[1] MARTIN 77 obtains identical resonance parameters from a T-matrix pole and from a Breit-Wigner fit.

all PDG listings based on PWA

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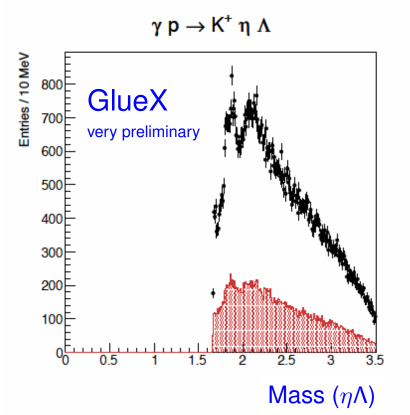
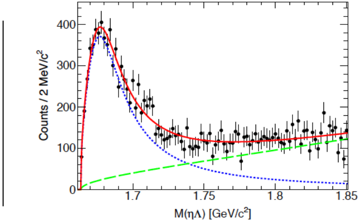
[Belle Collaboration], Phys. Rev. D **103**, no. 5, 052005 (2021)

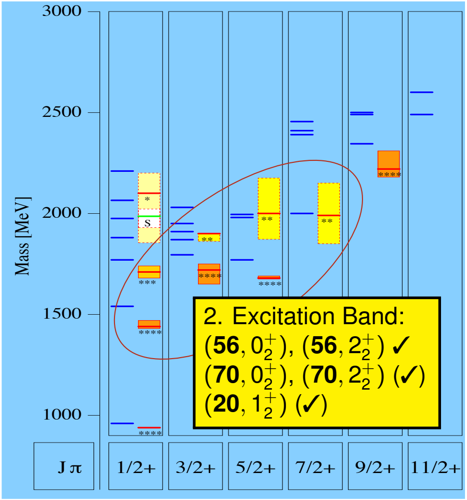




Resonances	Mass [MeV$/c^2$]	Width [MeV]
$\Lambda(1670)$	$1674.3 \pm 0.8 \pm 4.9$	$36.1 \pm 2.4 \pm 4.8$
$\Sigma(1385)^+$	$1384.8 \pm 0.3 \pm 1.4$	$38.1 \pm 1.5 \pm 2.1$

all PDG listings based on PWA

Spectrum of N^* Resonances

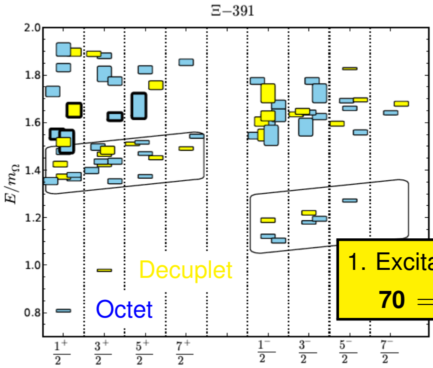


V. C. & W. Roberts, Rep. Prog. Phys. **76** (2013)

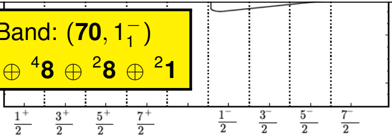
N	$(D,\, L_N^P)$	S	J^P	Octet Members				Singlets
0	$(56,\, 0_0^+)$	$\frac{1}{2}$	$\frac{1}{2}^+$	$N(939)$	$\Lambda(1116)$	$\Sigma(1193)$	$\Xi(1318)$	–
1	$(70,\, 1_1^-)$	$\frac{1}{2}$	$\frac{1}{2}^-$	$N(1535)$	$\Lambda(1670)$	$\Sigma(1620)$	$\Xi(1690)$	$\Lambda(1405)$
			$\frac{3}{2}^-$	$N(1520)$	$\Lambda(1690)$	$\Sigma(1670)$	$\Xi(1820)$	$\Lambda(1520)$
		$\frac{3}{2}$	$\frac{1}{2}^-$	$N(1650)$	$\Lambda(1800)$	$\Sigma(1750)$		–
			$\frac{3}{2}^-$	$N(1700)$				–
			$\frac{5}{2}^-$	$N(1675)$	$\Lambda(1830)$	$\Sigma(1775)$		–
2	$(56,\, 0_2^+)$	$\frac{1}{2}$	$\frac{1}{2}^+$	$N(1440)$	$\Lambda(1600)$	$\Sigma(1660)$		–
	$(70,\, 0_2^+)$	$\frac{1}{2}$	$\frac{1}{2}^+$	$N(1710)$	$\Lambda(1810)^\dagger$	$\Sigma(1770)^\dagger$		
		$\frac{3}{2}$	$\frac{3}{2}^+$					–
	$(56,\, 2_2^+)$	$\frac{1}{2}$	$\frac{3}{2}^+$	$N(1720)^\dagger$	$\Lambda(1890)^\dagger$	$\Sigma(1840)^\dagger$		–
			$\frac{5}{2}^+$	$N(1680)$	$\Lambda(1820)^\dagger$	$\Sigma(1915)^\dagger$		–
	$(70,\, 2_2^+)$	$\frac{1}{2}$	$\frac{3}{2}^+$					
			$\frac{5}{2}^+$	$N(1860)$				
		$\frac{3}{2}$	$\frac{1}{2}^+$	$N(1880)$				–
			$\frac{3}{2}^+$	$N(1900)^\dagger$		$\Sigma(2080)^\dagger$		–
			$\frac{5}{2}^+$	$N(2000)$	$\Lambda(2110)^\dagger$	$\Sigma(2070)^\dagger$		–
			$\frac{7}{2}^+$	$N(1990)$	$\Lambda(2020)$	$\Sigma(2030)^\dagger$		–
	$(20,\, 1_2^+)$	$\frac{1}{2}$	$\frac{1}{2}^+$	$N(2100)^\dagger$				
			$\frac{3}{2}^+$	$N(2040)^\dagger$				
			$\frac{5}{2}^+$	–	–	–	–	

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

R. Edwards *et al.*, PRD **87**, 054506 (2013)



$\Xi(1320)$ ****	$\to \Lambda\pi$	$I\left(J^P\right) = \frac{1}{2}\left(\frac{1}{2}^+\right)$	
$\Xi(1530)$ ****	$\to \Xi\pi$	$I\left(J^P\right) = \frac{1}{2}\left(\frac{3}{2}^+\right)$	
$\Xi(1620)$ *	$\to \Xi\pi$?	$I\left(J^P\right) = \frac{1}{2}\left(\frac{1}{2}^- \text{ or } \frac{1}{2}^+\right)$	
$\Xi(1690)$ ***	$\to Y\overline{K}$	$I\left(J^P\right) = \frac{1}{2}\left(\frac{1}{2}^- ?\right)$	
$\Xi(1820)$ ***	$\to \Lambda\overline{K}$!	$I\left(J^P\right) = \frac{1}{2}\left(\frac{3}{2}^-\right)$	
$\Xi(1950)$ ***	$\to \Xi\pi,\ Y\overline{K}$	$I\left(J^P\right) = \frac{1}{2}\left(\frac{3}{2}^- ?\right)$,	"broad"
$\Xi(2030)$ ***	$\to Y\overline{K}$	$I\left(J^P\right) = \frac{1}{2}\left(\geq \frac{5}{2}^?\right)$	



1. Excitation Band: $(\mathbf{70}, 1_1^-)$

$$\mathbf{70} = {}^2\mathbf{10} \oplus {}^4\mathbf{8} \oplus {}^2\mathbf{8} \oplus {}^2\mathbf{1}$$

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.

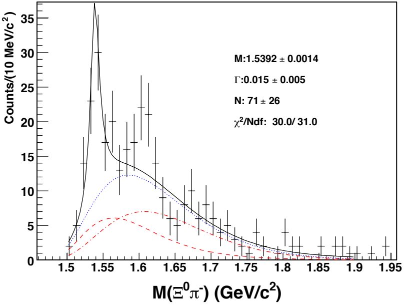
CLAS g11a: Excited States in $\gamma p \to K^+K^+\pi^-\ (X)$

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.*
Phys. Rev. C **76**, 025208 (2007)

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



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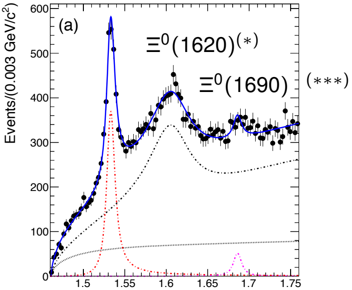
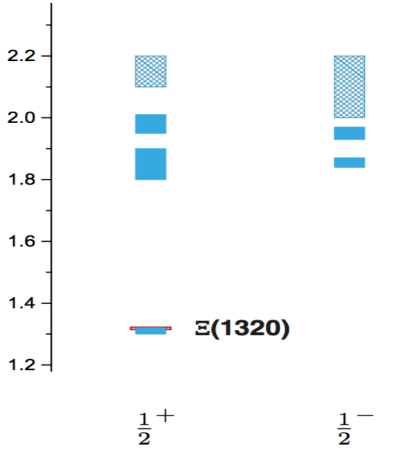
Belle: PRL **122**, 072501 (2019)



$\Xi_c^+ \to (\Xi^-\pi^+)_{\Xi^*}\pi^+$ ➜ $M_{\Xi^-\pi^+_{(L)}}$ [GeV]

The Ξ^* Spectrum in a Dyson-Schwinger Approach

C. Fischer *et al.*, PoS Hadron 2017 (2018) 007



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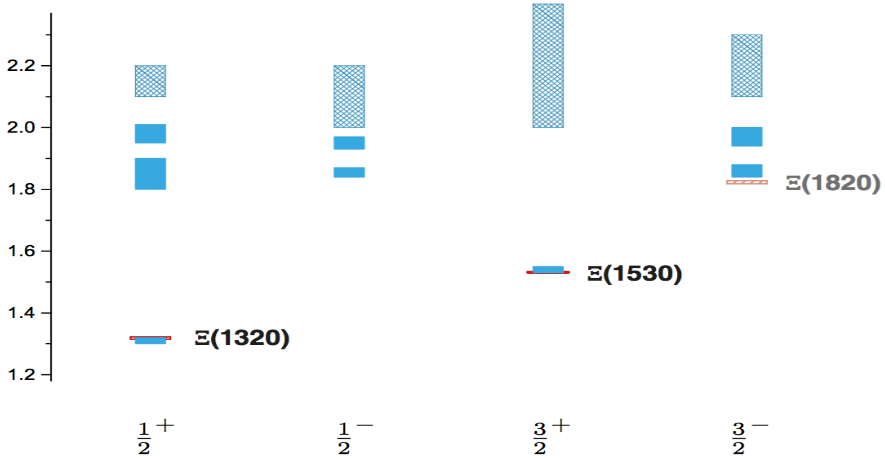
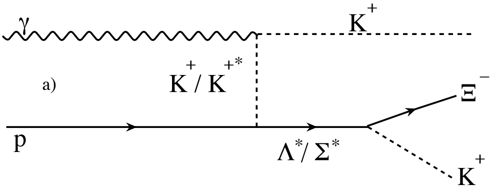
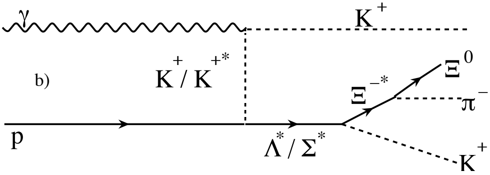


Possible Production Mechanisms





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

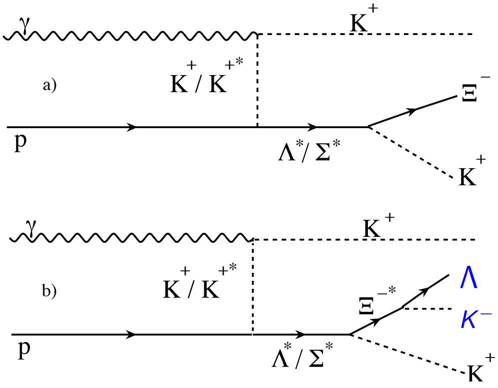
➜ Cross sections, beam asymmetries (similar to $p\pi\pi$ & pKK^*)

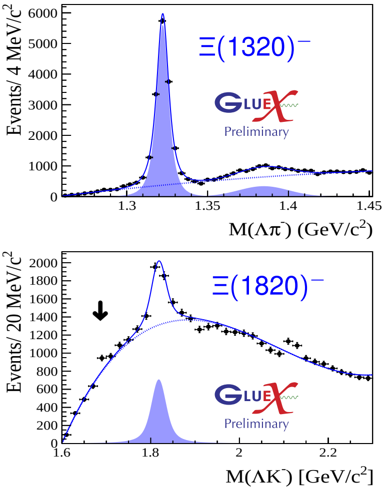
At other facilities (for comparison):

$K^- p \to K^+ \Xi^{*-}$	J-PARC (2029?)
$K_L p \to K^+ \Xi^{*0}$	Hall D (2026/30?)
$p p \to \Xi^* X$	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



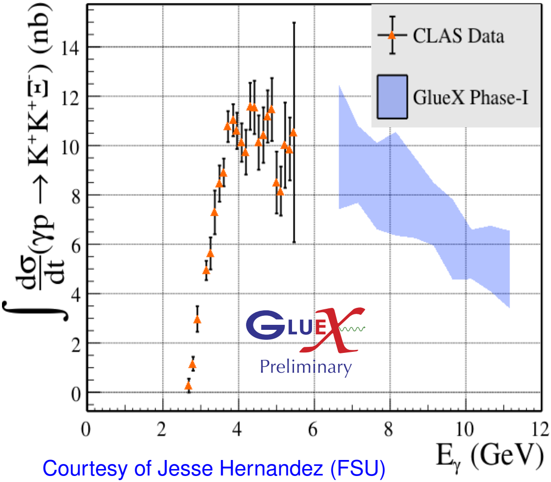


$$\gamma p \to K^+ (K^+ \Xi^{-*}) \to K^+ (p \pi^- K^-) K^+$$

Courtesy of Jesse Hernandez, Chandra Akondi (FSU)

GlueX: Cross Sections in $\gamma p \to K^+K^+\,\Xi(1320)^-$

[CLAS Collaboration], Phys. Rev. C **98** (2018) 6, 062201



Courtesy of Jesse Hernandez (FSU)

Measurements of

- Differential cross sections
- Polarization observables
- Mass, width, spin

➜ Band denotes current systematic uncertainties, not final.

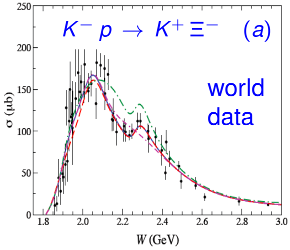
Opportunities with Secondary K_L^0 Beams in Hall D

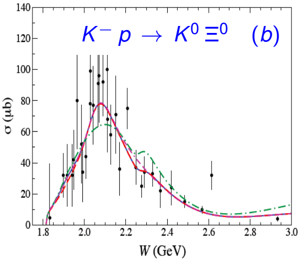
Possible reactions to be studied (elastic and charge-exchange reactions):

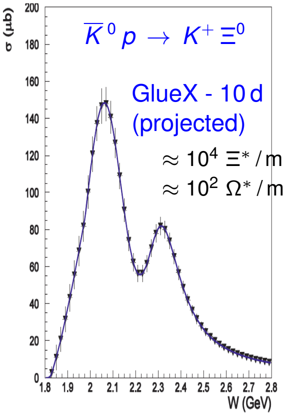
- 2- & 3-body reactions producing $S = -1$ hyperons
- 2-body reactions producing $S = -2$ hyperons

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

  ➜ $K_L^0\, p \to K^+ K^+\,\Omega^-;\ K^+ K^+\,\Omega^{-*}$

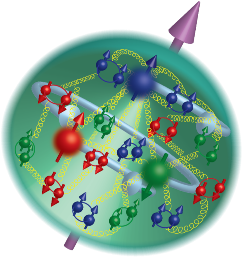




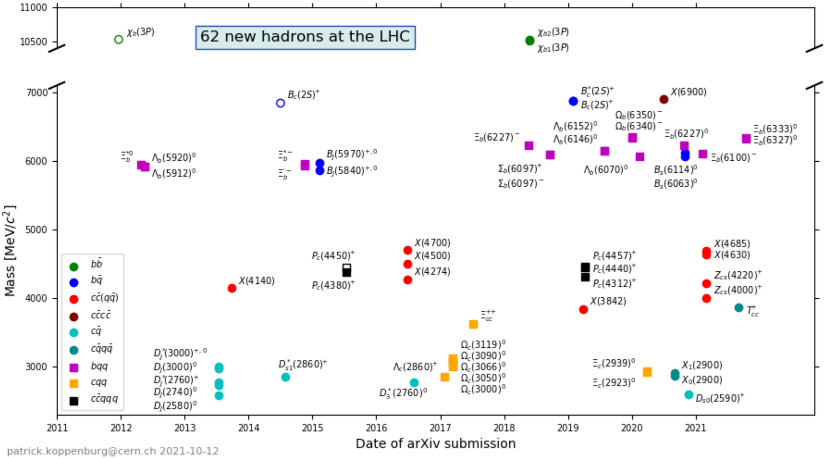


Outline

1. Introduction
   - The Nucleon Spectrum
2. Spectroscopy of Baryon Resonances
   - N^* Spectroscopy: Measurements at GlueX
   - The Study of Strangeness -1 Hyperons
   - Spectroscopy of Ξ Resonances
3. Heavy-Flavor Resonances
4. Summary and Conclusions



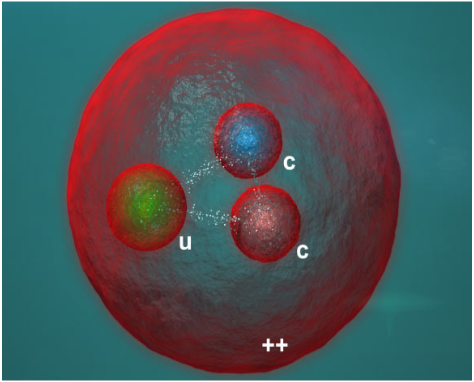
Peak Hunting for Heavy-Flavor States

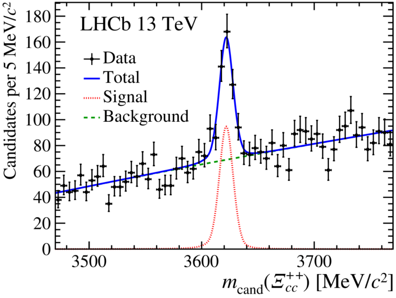


https://www.nikhef.nl/ pkoppenb/particles.html

Doubly-Heavy (Charmed) Resonances

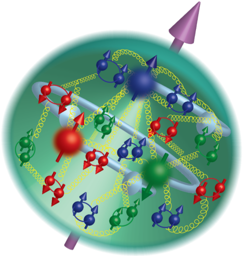
2017: The LHCb (Large Hadron Collider beauty) collaboration at CERN's Large Hadron Collider in Switzerland has reported the observation of a doubly charmed particle, $\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$.





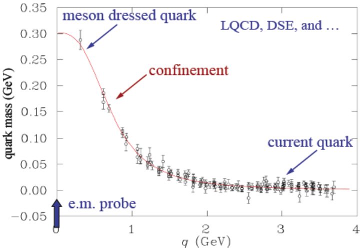
R. Aaij *et al.*, PRL **119** (2017) 112001

Outline



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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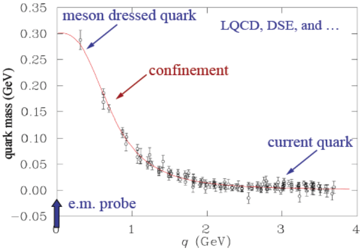

Summary and Conclusions

A “low”-energy p beam on a fixed target would be a novel spectroscopy tool:

- Photoproduction at 8 – 9 GeV seems to be able to produce isolated N^* peaks in t-channel prroduction. Would this be possible in pp reactions? (certainly not a selling point for a new facility).
- Spectroscopy of Λ^* and Σ^* resonances ideal for K_L - and K^- - beam facilities. Jefferson Lab, J-PARC, and FAIR appear to have a similar timeline, i.e. first physics runs around 2027 / 2028.

  J-PARC also plans to study Ω and charmed baryons.
- Spectroscopy of (low-mass) Ξ resonances important to understand the systematics of the baryon spectrum.
  1. What about the $\Xi(1620)$ / $\Xi(1690)$ states?
  2. Is $\Xi(1620)$ the doubly strange partner of the $\Lambda(1405)$?

➜ Selling point for hadron spectroscopy with proton beams is charmonium production & study of hyperons in decay of excited charmed hadrons, e.g. in the reaction $pp \to \Lambda_c^+ p \bar{D}^0$.