Baryon Spectroscopy at Jefferson Laboratory

Volker Credé

Florida State University, Tallahassee, Florida

Int. Conf. on Meson-Nucleon Physics and the Structure of the Nucleon

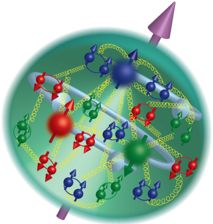
MENU 2023

Mainz, Germany

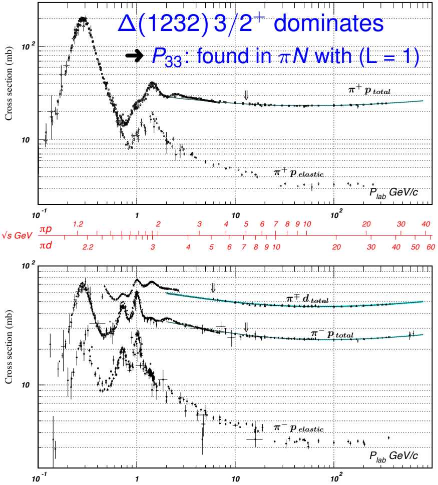
10/16/2023

Outline

Outline



Hadron Beams: Pion- (Kaon-) Nucleon Scattering



First insight into experimental difficulties:

- The elastic cross section drops fast.
  ➜ The resonances decouple from elastic scattering amplitude.
- Gradual disappearance of resonant structures in the πp cross sections
  ➜ For $\sqrt{s} > 1.7$ GeV, more and more inelastic channels open.

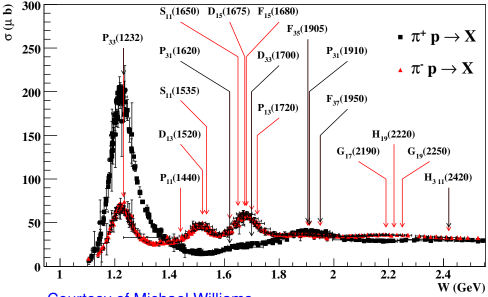
In 1952, first cross-section measurement of $\pi^+ p \to \pi^+ p$
(H. L. Anderson, E. Fermi, E. A. Long, D. E. Nagle, Phys. Rev. 85 (1952) 936)

Baryon Spectroscopy: The Light Flavors

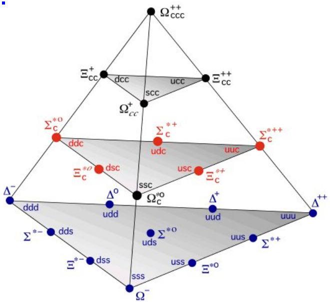
The strong coupling confines quarks and breaks chiral symmetry, and so defines the world of light hadrons.

Baryons are special because

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



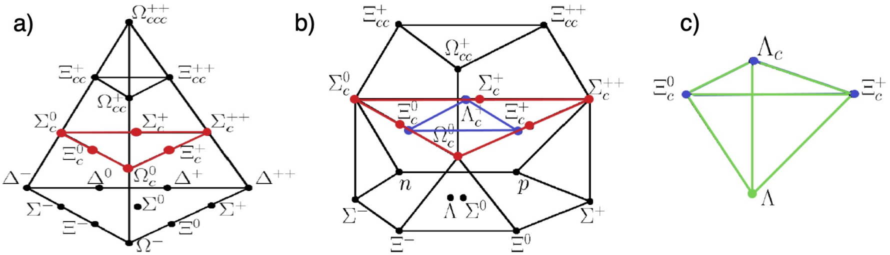
Courtesy of Michael Williams



Many Y^* QN not measured:
(Quark model assignments)

➜ Most Ξ^* and Ω^*, etc.

SU(4) Multiplet Structure of Baryons



Multiplet structure for flavor SU(4):

$$4 \otimes 4 \otimes 4 = 20_S \oplus 20_M \oplus 20_M \oplus 4_A$$

➜ Great progress also for charmed and bottom baryons (Belle, LHCb).
(S. Yang [Belle], next presentation | Zan Ren [LHCb], Tuesday, 10:00 - 10:30)

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

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

   π / K-induced production, e. g. HADES@GSI, (future J-PARC, JLab)

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

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)

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

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

   π / K-induced production, e. g. HADES@GSI, (future J-PARC, JLab)

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

2. Collider Experiments

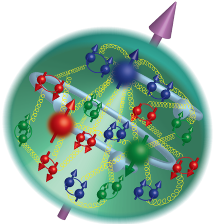
   at e^+e^- machines, e. g. BES III, Belle, BaBar, etc.

   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)

Outline



Spectrum of N^* Resonances

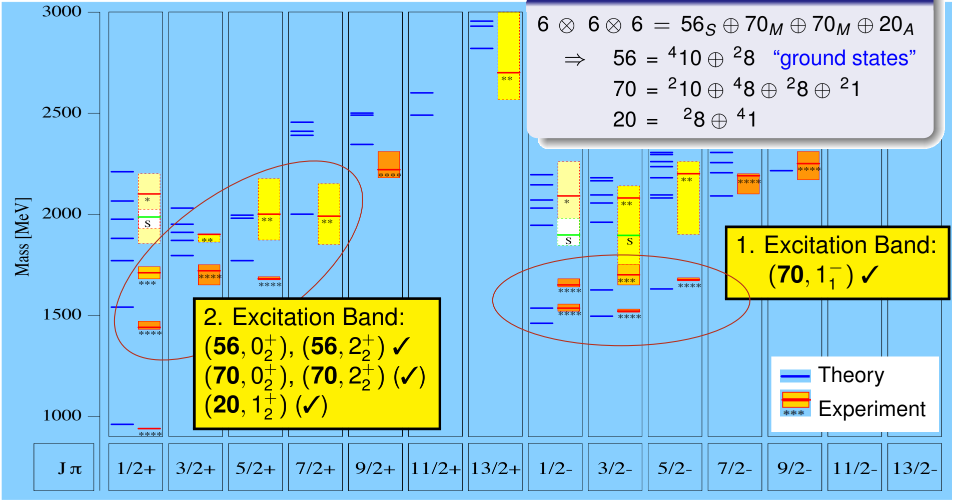
SU(6) ($^{2S+1}$multiplets; u, d, s, spin)

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

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

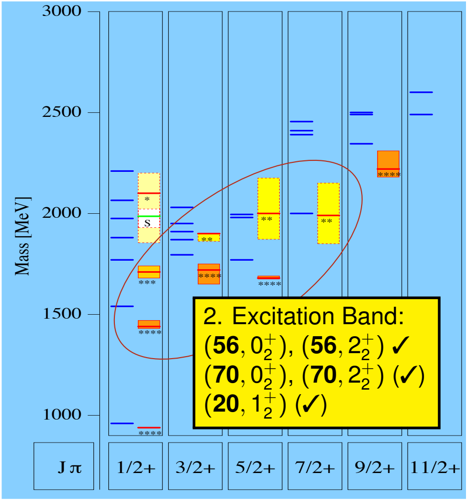
$$70 = {}^2 10 \oplus {}^4 8 \oplus {}^2 8 \oplus {}^2 1$$

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



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	2022
$N(1440)$	$1/2^+$ (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}	* *	

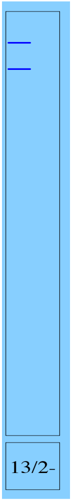


Table representing CLAS@JLab measurements

	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														
$p\,\pi^-$	✔	✓			✔		✓									
$K^+\,\Sigma^-$	✓	✔	✓	✓	✓	✓	✓									
$K^0\,\Lambda$	✔	✓	✓	✓	✔*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
$K^0\,\Sigma^0$	✓	✓	✓	✓	✔*	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

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

Tensor polarization, SDMEs, $I^{\odot}$, I^{s}, I^{c}, etc.

* published

In addition, two-meson reactions are being analyzed:

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

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, $I^{\odot}$, I^{s}, I^{c}, etc.

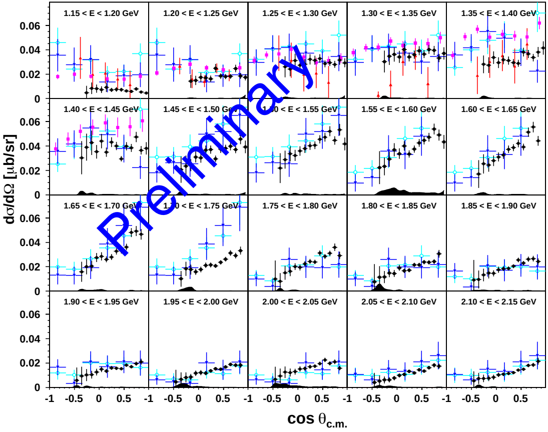
* published

Additional presentations from ELSA:

A. Thiel [CBELSA/TAPS], Monday, 2:00 - 2:30 | T. Jude [BGOOD], Thursday, 4:50 - 5:10.

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

Z. Akbar, T. Hu, V. C. *et al.* [CLAS Collaboration], CLAS approved.

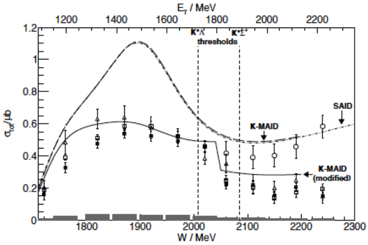


CLAS-g12 ● CB-ELSA ○ CBELSA/TAPS ▼ MAMI ▲ MAMI ■

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

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

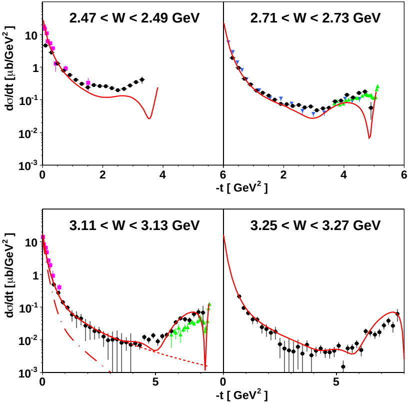
Phys. Lett. B **713**, 180 (2012)



No anomaly observed in CLAS data, i.e. no sudden drop in cross section.

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

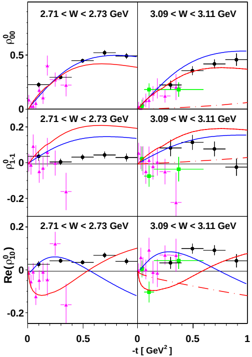
Observables in $\vec{\gamma}\, p \to p\,\omega$ (CLAS-g12)



CLAS-g12 ● SLAC ■ CLAS ▼ NINA ▲

J. M. Laget *et al.* —

Cross Sections $d\sigma/dt$



V. Mathieu *et al.* (JPAC) —

Spin-Density Matrix Elements:

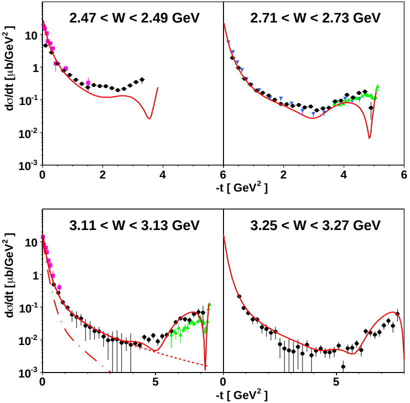
ρ^0_{00}

ρ^0_{1-1}

Re(ρ^0_{10})

T. Hu, Z. Akbar, V. C. *et al.* [CLAS Collaboration], submitted to Physical Review.

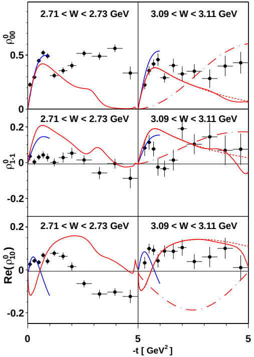
Observables in $\vec{\gamma}\, p \to p\, \omega$ (CLAS-g12)



CLAS-g12 ● SLAC ■ CLAS ▼ NINA ▲

J. M. Laget *et al.* —

Cross Sections $d\sigma/dt$



V. Mathieu *et al.* (JPAC) —

Spin-Density Matrix Elements:

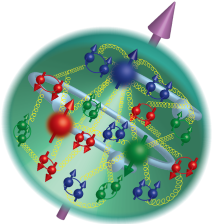
ρ^0_{00}

ρ^0_{1-1}

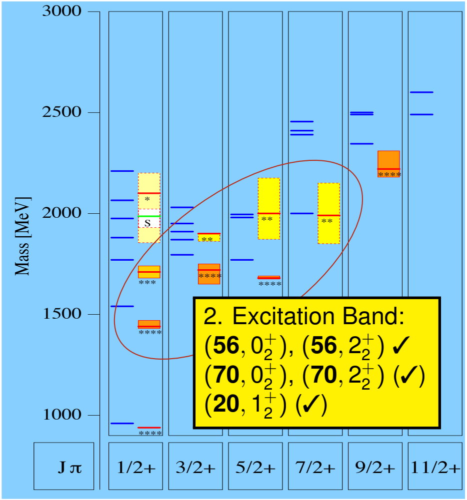
Re(ρ^0_{10})

T. Hu, Z. Akbar, V. C. *et al.* [CLAS Collaboration], submitted to Physical Review.

Outline



Spectrum of N^* Resonances

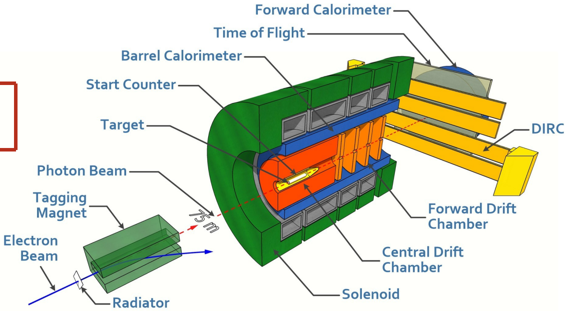


V. C. & W. Roberts, Rep. Prog. Phys. **76** (2013)

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	$(56,\, 0_2^+)$	$\frac{1}{2}$	$\frac{1}{2}^+$	$N(1440)$	$\Lambda(1600)$	$\Sigma(1660)$		–
	$(70,\, 0_2^+)$	$\frac{1}{2}$	$\frac{1}{2}^+$	$N(1710)$	$\Lambda(1810)^\dagger$	$\Sigma(1770)^\dagger$		
		$\frac{3}{2}$	$\frac{3}{2}^+$					–
	$(56,\, 2_2^+)$	$\frac{1}{2}$	$\frac{3}{2}^+$	$N(1720)^\dagger$	$\Lambda(1890)^\dagger$	$\Sigma(1840)^\dagger$		–
			$\frac{5}{2}^+$	$N(1680)$	$\Lambda(1820)^\dagger$	$\Sigma(1915)^\dagger$		–
	$(70,\, 2_2^+)$	$\frac{1}{2}$	$\frac{3}{2}^+$					
			$\frac{5}{2}^+$	$N(1860)$				
		$\frac{3}{2}$	$\frac{1}{2}^+$	$N(1880)$				–
			$\frac{3}{2}^+$	$N(1900)^\dagger$		$\Sigma(2080)^\dagger$		–
			$\frac{5}{2}^+$	$N(2000)$	$\Lambda(2110)^\dagger$	$\Sigma(2070)^\dagger$		–
			$\frac{7}{2}^+$	$N(1990)$	$\Lambda(2020)$	$\Sigma(2030)^\dagger$		–
	$(20,\, 1_2^+)$	$\frac{1}{2}$	$\frac{1}{2}^+$	$N(2100)^\dagger$				
			$\frac{3}{2}^+$	$N(2040)^\dagger$				
			$\frac{5}{2}^+$	–	–	–	–	

Hadron Spectroscopy

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

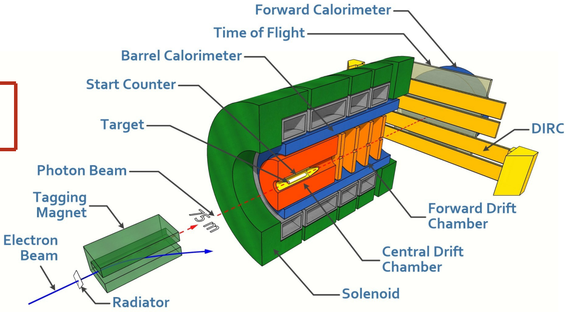


The GlueX Collaboration

- $\sim$135 members, 29 institutions
  (Armenia, Canada, Chile, China, Germany, Greece, Russia, UK, USA)
- GlueX phase-I complete (120 PAC days)
- First physics published in 2017

Hadron Spectroscopy

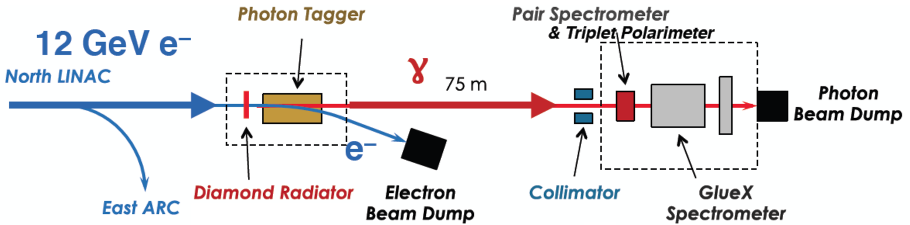
- π + Nucleus
- $\gamma\, p$ *Photoproduction*
- $e^+\, e^-$
- $\bar{p}\, p$



GlueX Presentations at MENU 2023

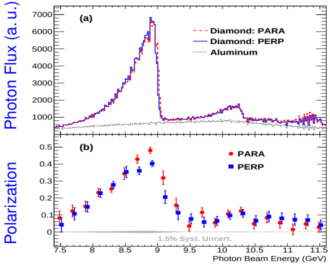
- Justin Stevens, this session
- William Imoehl, Thursday, 3:10 - 3:30
- Farah Afzal, Thursday, 5:30 - 5:50
- R. Schumacher, Thursday, 5:30 - 5:50

The GlueX Experiment: Photon Beamline



Polarized photon beam produced via coherent bremsstrahlung off thin diamond radiator:

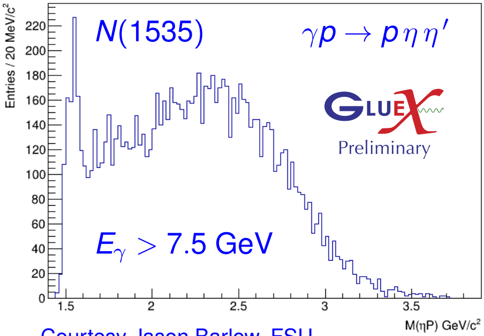
- Tagging system with $\Delta E < 25$ MeV.
- Linear photon polarization of $P_\gamma \approx 40\,\%$ in the coherent peak.
- Phase-I intensity of 5×10^7 γ/s in peak.



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.



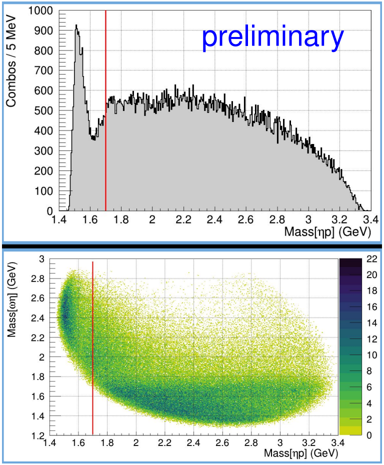
Courtesy Jason Barlow, FSU

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

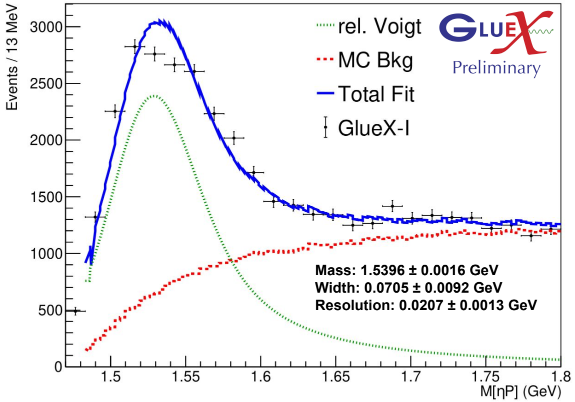
Data selection:

- 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^* Spectroscopy at GlueX

V.C. *et al.* [GlueX], Few Body Syst. **64** (2023) 2, 32



Courtesy Edmundo Barriga, FSU

$N(1535)$ 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	$\gamma^* p \to p\eta$

Description with rel. Voigtian

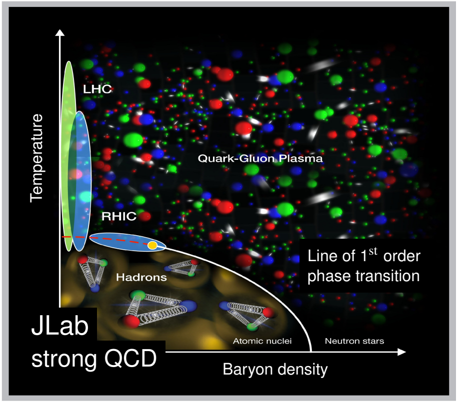
Barrier factor of $L = 1$

$\eta\omega$ MC background

$M_{\eta\omega} < 2$ GeV/c^2

➜ $\Gamma = 70.5 \pm 9.2$ MeV

QCD Phases and the Study of Baryon Resonances

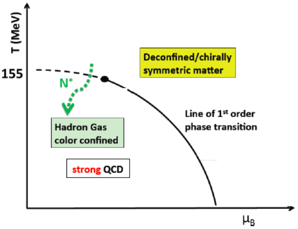


QGP

↓

hadron phase

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



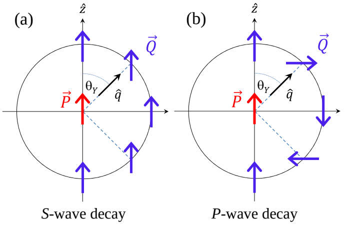
RPP (u, d, s, c) baryons not sufficient to describe freeze-out behavior.
(e. g. A. Bazavov *et al.*, PRL **113** (2014) 7, 072001)

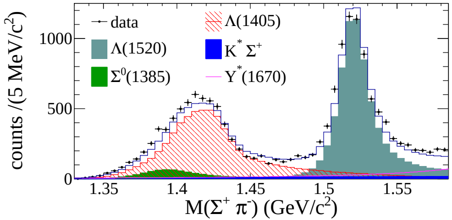
Spin and Parity Measurement of the Λ(1405) Baryon

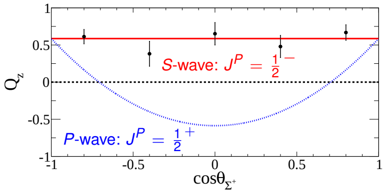
K. Moriya *et al.* [CLAS Collaboration], Phys. Rev. Lett. **112**, 082004 (2014)

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





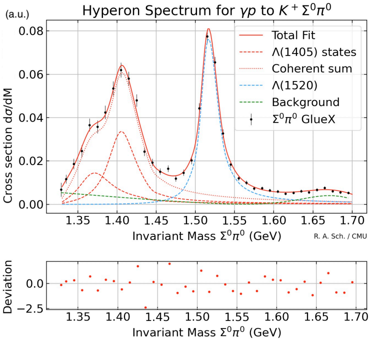


The $\Lambda(1405)/\Lambda(1520)$ Baryons at CLAS / GlueX

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 $\Lambda(1405) \to \Sigma^0\pi^0$



- Description based on

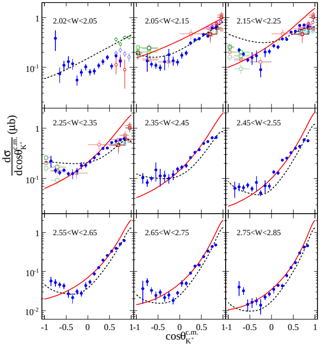
  (1) interfering rel. Breit-Wigners with Flatté amplitudes plus

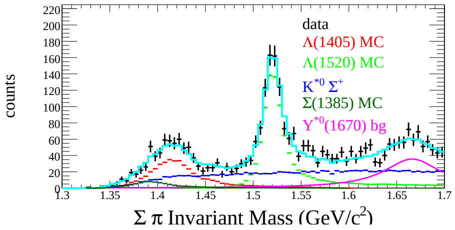
  (2) incoherent $\Lambda(1520)$, and

  (3) further backgrounds.
- Preliminary fit results support the two-pole structure.

The Λ(1405)/Λ(1520) Baryons at CLAS / GlueX

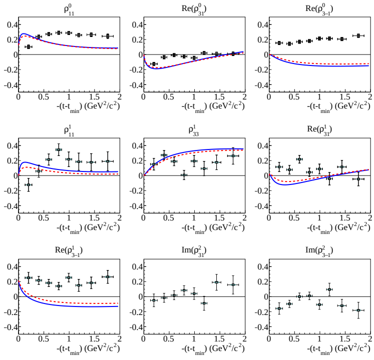
1. Measurement of the $\Sigma\pi$ photoproduction line shapes near the Λ(1405)
   K. Moriya *et al.* [CLAS Collaboration], Phys. Rev. C **87**, no. 3, 035206 (2013)
2. Differential Cross Sections for $\gamma p \to \Sigma^0(1385)$, Λ(1405), and Λ(1520)
   K. Moriya *et al.* [CLAS Collaboration], Phys. Rev. C **88**, 045201 (2013)

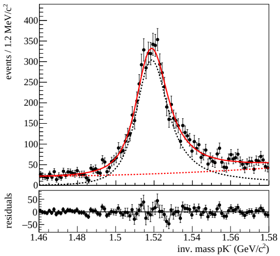




The Λ(1405)/Λ(1520) Baryons at CLAS / GlueX

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

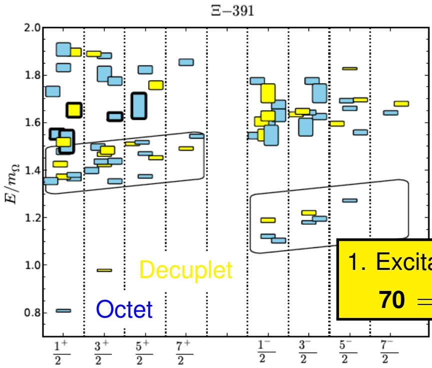




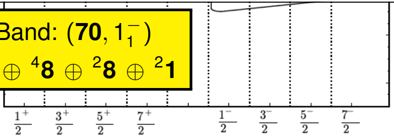
$-(t - t_0) \in [\,0.3, 0.5\,]$ GeV^2

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

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



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



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

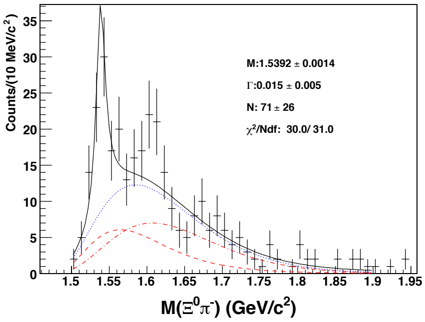
$$\mathbf{70} = {}^2\mathbf{10} \oplus {}^4\mathbf{8} \oplus {}^2\mathbf{8} \oplus {}^2\mathbf{1}$$

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

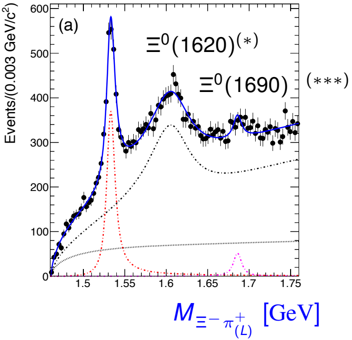
➜ Counting of states of each flavor and spin consistent with QM for the lowest negative- and positive-parity bands.

Excited Ξ^* States: 1500 - 1750 Mass Region

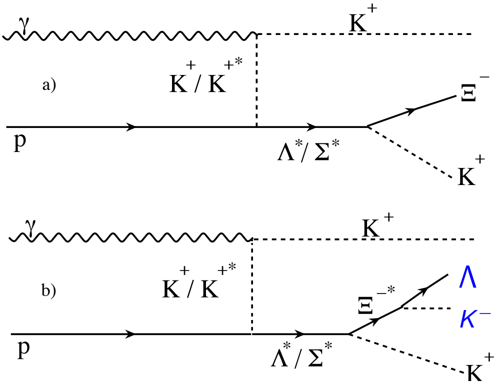
From the paper: *Although a small enhancement is observed in the $\Xi^0\pi^-$ invariant mass spectrum near the controversial 1-star $\Xi^-(1620)$ resonance, it is not possible to determine its exact nature without a full partial wave analysis.*
[CLAS], Phys. Rev. C **76**, 025208 (2007)



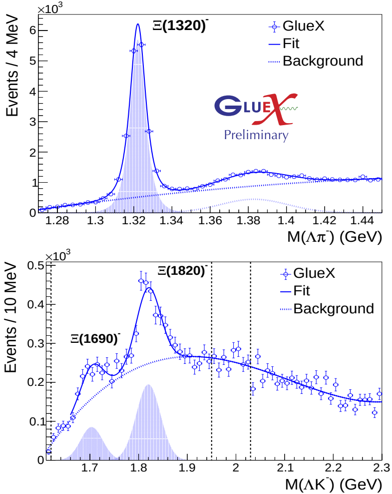
Belle: PRL **122**, 072501 (2019)



Possible Production Mechanisms

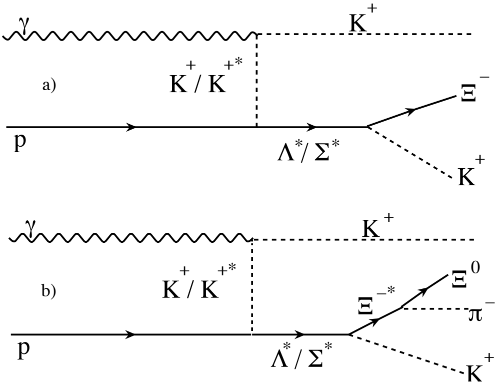


$$\gamma p \to K^+ (K^+ \Xi^{-*}) \to K^+ (p \pi^- K^-) K^+$$



Courtesy of Jesse Hernandez, Chandra Akondi (FSU)

Possible Production Mechanisms



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

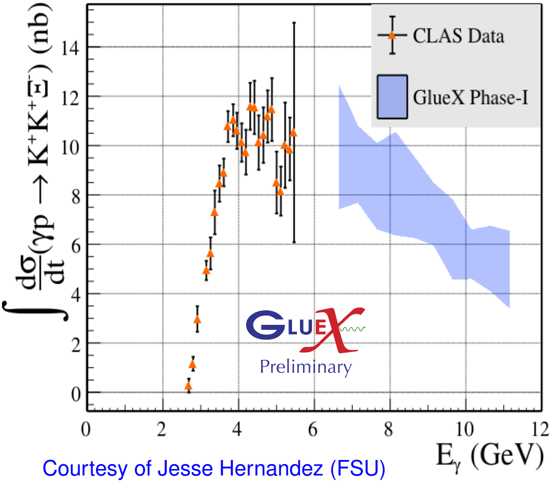
➜ Cross sections, beam asymmetries (similar to $p\pi\pi$ & pKK^*)

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
$\bar{p} p \to \Xi^* \bar{\Xi}$	$\overline{\rm P}$ANDA ?
$e^+ e^- \to \Xi^* X$	Belle II, BES III

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

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



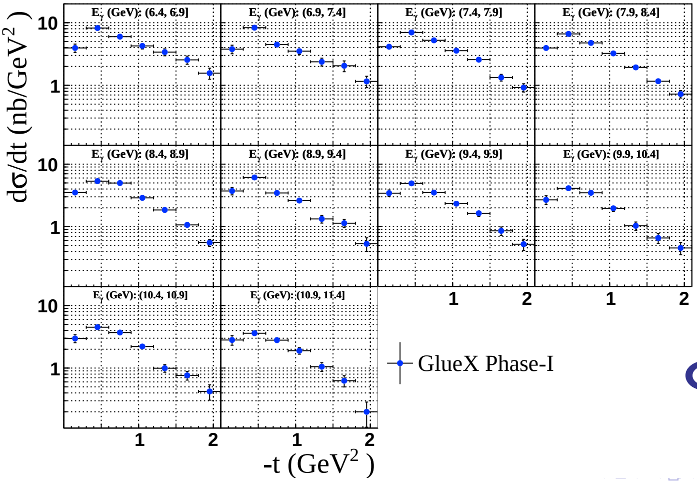
Courtesy of Jesse Hernandez (FSU)

Measurements of

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

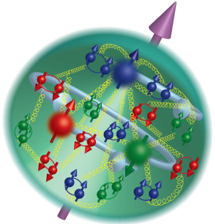
GlueX: Cross Sections in $\gamma p \to K^+ K^+ \Xi(1320)^-$

Courtesy of Jesse Hernandez (FSU)



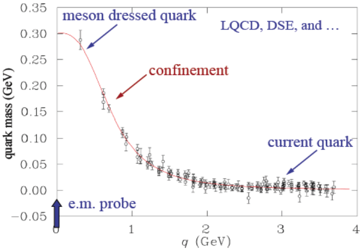
GlueX Preliminary

Outline



Open Issues in (Light) Baryon Spectroscopy

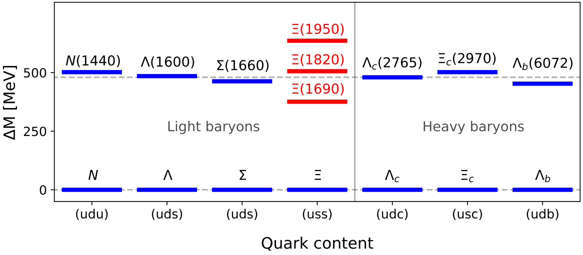
1. What are the relevant degrees of freedom in (excited) baryons?
   ➜ Can the high-mass states be described by the dynamics of three flavored quarks? To what extent are diquark correlations, gluonic modes or hadronic degrees of freedom important in this physics?
2. Can we identify unconventional states 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)



Summary and Conclusions

Spectroscopy of (low-mass) Ξ resonances very important to understand the systematics of the baryon spectrum:

- What about the properties of the Ξ(1620) / Ξ(1690) states?
- Is the Ξ(1620) more than one state? Is the Ξ(1620) the doubly strange partner of the Λ(1405)?
- Where is the radial excitation of the Ξ(1320)?



Radial Excitations (Roper-like states)

for the octet members with $J^P = \frac{1}{2}^+$

Arifi *et al.*, PRD **105**, 094006

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