Photoproduction of Cascade Hyperons

PhD Qualifying Oral Exam Presentation

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Outline of Part I: Theory and Motivation

Outline of Part II: Experiment and Analysis

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Outline of Part III: Other Work

Part I

Motivation and Theory

Cascades

There are many exciting reasons to study the Cascade Hyperons

- Direct correlation to the nucleon (proton and neutron) which makes up $> 99\%$ of the mass of the observable universe
- Provides test for flavor independence of strong force (SU(3) flavor symmetry)
- Gives direct measurement of isospin symmetry breaking (interchangeability of u and d quarks)
- Narrower than other hadrons (N's, Δ's, Σ's, etc.)
- There are theories with solvable approximation schemes in the mass range of the Ξ spectrum

The Nucleon

The proton is the only stable particle with *currently* observable structure.

1932 measurement of proton magnetic-dipole moment (Otto Stern).
So the proton has structure, but is it made of quarks and gluons?

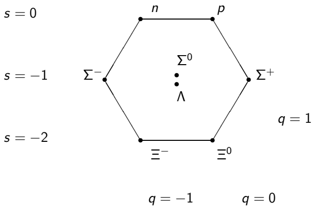


Figure: Baryon ground-state octet organized according to the Eightfold Way.

Ways to investigate the nucleon (these are interrelated)

- precision measurements
- find patterns in excited spectrum
- search for rare processes and exotic particles
- search for predicted resonances

QCD – the leading theory of the strong force

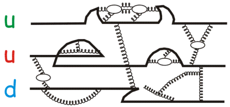
$$\mathcal{L}_{\mathrm{QCD}} = -\sum_q \overline{\psi}_q m_q \psi_q + i\overline{\psi}_q \gamma^\mu d_\mu \psi_q - g(\overline{\psi}_q \gamma^\mu T_a \psi_q) G^a_\mu - \frac{1}{4} G^a_{\mu\nu} G^{\mu\nu}_a$$

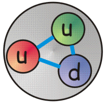
Some problems:

- non-perturbative QCD has not been solved completely
- allows for gluon-gluon interactions which yields divergent slavery (asymptotic freedom allows for some calculations to be made)
- approximations are usually valid only over certain energies

approx. methods for QCD

- quark & gluon model
- $\frac{1}{N_c}$ expansion
- Lattice-Gauge
- χ-perturbation





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Quark-Gluon Model

Quarks spin = 1/2		
Flavor	Approx. Mass GeV/c^2	Electric charge
u up	0.003	2/3
d down	0.006	–1/3
c charm	1.3	2/3
s strange	0.1	–1/3
t top	175	2/3
b bottom	4.3	–1/3

Baryons are made of three quarks in a colorless combination of red, green, and blue.

- They are held together by gluons.
- SU(3) Flavor symmetry means treating the u, d, and s quarks the same.
- This means the only difference in the spectrum of the N*'s and the Ξ*'s will be the mass (assuming a Lagrangian as shown prior)

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First steps for investigating the strong force: Spectroscopy

If the proton is made of three spin-1/2 quarks, then its "atomic" excitation spectrum must contain a certain number of levels with certain quantum numbers. At this time more than half of the low-lying states needed to test this basic picture are missing. [Taken from `jlab.org`]

A more complete catalog of all observable hadrons will facilitate direct tests of QCD calculations.

This will indicate the rough correlations between quarks inside the hyperon.

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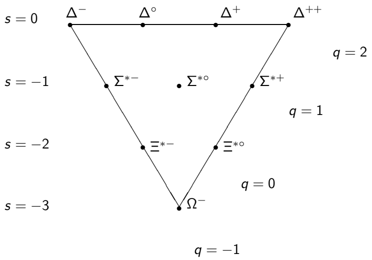
Ξ's are uniquely suited to testing QCD

Advantage of doubly-strange hadrons

- test of flavor independence of the strong force
- narrow excited states when compared with N^*'s
- straight-forward measurement of isospin symmetry breaking
- fall in mass-region accessible to Lattice QCD

Figure: Baryon Decuplet.



Evidence for Narrow Widths

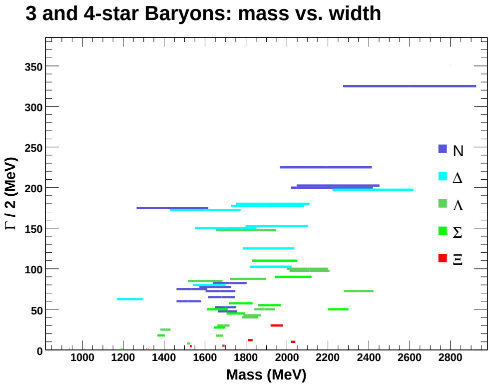


Figure: N^* and Δ states overlap in many places due to their large widths. Λ's and Σ's do little better. Ξ's are the most narrow and thus can be separated more easily.

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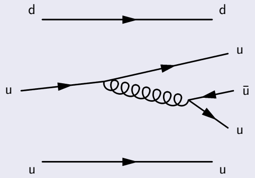
Explanation for Narrow Widths

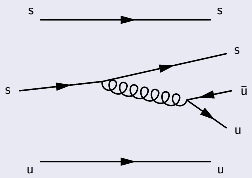
Ξ's have a narrower width than Σ's and N*'s due to a simple combinatorial argument

consider the following (strong) decays:

Δ* decay



Ξ* decay



When These decay to a pion, the ū has the option of coupling with any of the Δ's three quarks whereas for the Ξ, there is only one option. The alternative is to have the baryon decay to the much heavier kaon.

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Part II

The Experiment

Photoproduction of Ξ's

Photoproduction provides a very clean signal which allows a straight-forward analysis due to small number of tracks.

By exciting the proton via an electromagnetic interaction we avoid introducing any kind of strong interaction outside of the intermediate and decay processes.

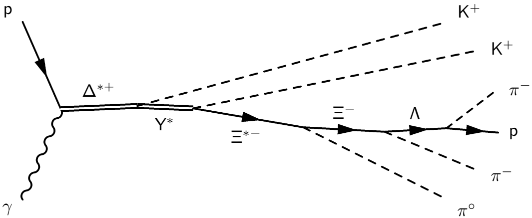
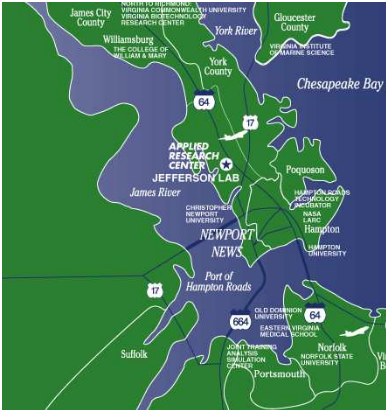
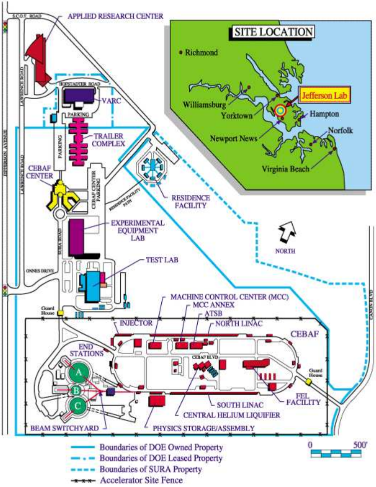


Figure: Example of Ξ^{*-} photoproduction via intermediate Y^* decay. Notice the relatively few number of tracks that need to be observed for identification of the cascade baryons.

JLab, Newport News, Virginia





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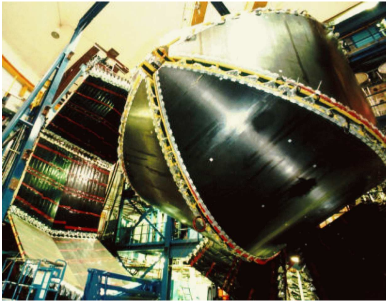
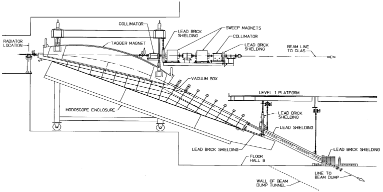
The CLAS Detector

JLab from the air

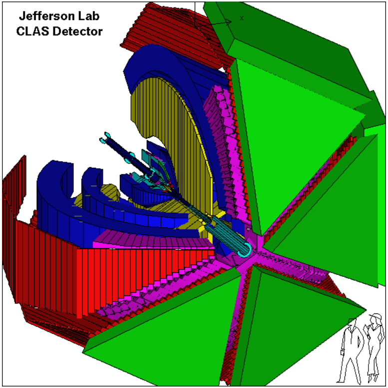
The CLAS Detector (upstream)



The CLAS Detector Components



- six sectors — three 'planes'
- radiator & electron tagger
- ℓH_2 or ℓD_2 target (others are possible)
- start counter (scintillator)
- magnets (toroidal)
- drift chambers (3x per sector)
- Čerenkov Detectors
- Time of Flight Detectors
- Electromagnetic Calorimeter



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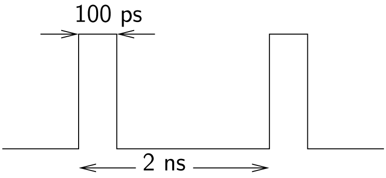
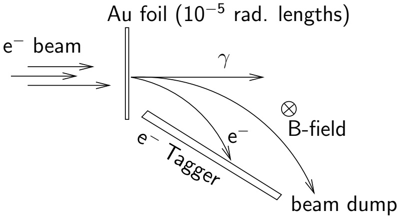
Beam and Electron Tagger System

the profile of the CLAS e^- beam is pulsed as depicted below. The total current is about 10 nA. This comes out to be about 120 electrons in each 'bucket.'



With a radiator of 10^{-5} rad. len., we expect an e^- to interact with a Au nucleus once every 1000 buckets (every 2 μs).

Using the timing of the beam, we can get about 300 ps resolution in the start and time-of-flight counters.



DAQ and Event Reconstruction

The data acquisition system is capable of storing $\sim$ 8k events/sec. Typical raw data storage is 1 TB/day, and our experiment (g12) is scheduled for 64 days.

The tracks can be reconstructed and shown individually as seen at right.

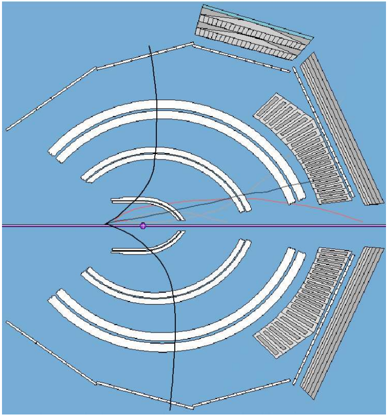


Figure: A reconstructed event in the CLAS detector showing six tracks in one of the three planes. This event is of the form: $\gamma p \rightarrow K^+K^+\Xi^- \rightarrow \pi^-\Lambda \rightarrow p\pi^-$. The four darker tracks are K^+, K^+, p, and π^-.

Master Trigger for Events

The master trigger for g12 will require two charged tracks. (though, the actual master trigger is not set in stone yet)

For analysis of the reactions $\gamma p \rightarrow \mathrm{K}^{+}\mathrm{K}^{+}\Xi^{-*}$ we will make a loose cut on the kaon masses and require two of them.

Each kaon brings the data set down to about 10% of the original size.

Further initial cuts include:

- limits on coincidence of the photon time to the electron at the tagger
- minimum photon energy
- vertex cuts along the beam axis

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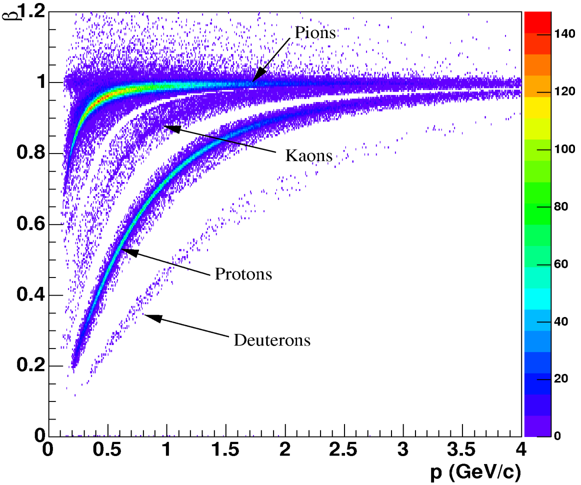
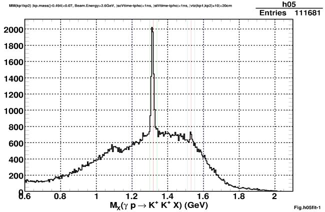
Particle Identification

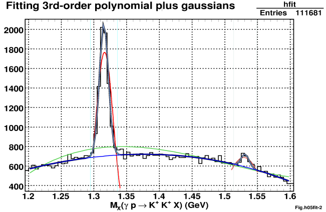
Figure: Particle identification is done by looking at charge first, then assigning each particle as a possible candidate for one of: pion, kaon, proton, or deuteron depending on the calculated mass (found from momentum and speed as depicted to the right. Shown is the g6 data.)

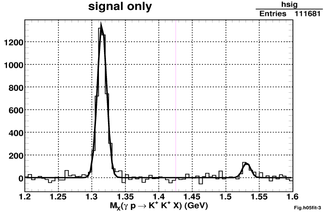


previous results – g11

This is the g11 data with only the cuts described on the previous slide. Missing mass (M_X) of the reaction: $\gamma p \rightarrow \mathrm{K}^+\mathrm{K}^+\mathrm{X}$.







1st Peak: 4700 +/- 130 events
sigma = 0.007 +/- 0.0002
2nd Peak: 390 +/- 90 events
sigma = 0.006 +/- 0.001

X^2/Ndf = 0.983

Fri, 21 Oct 2005 Fig.h05fit-4

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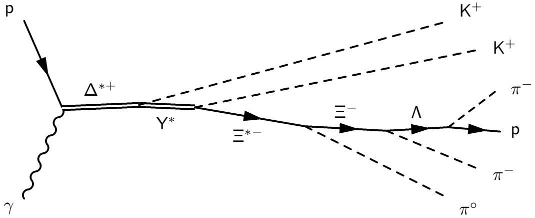
Detached Vertexes

Figure: Again: Ξ^{*-} photoproduction via intermediate Y^* decay. This time, consider where the vertexes around the Ξ's will be. The Ξ^- and Λ have lifetimes of a couple of cm. This will make it possible to get strangeness without requiring the kaons and will help to suppress the random background.



Part III

Other Work

Nefkens Computer Cluster at UCLA

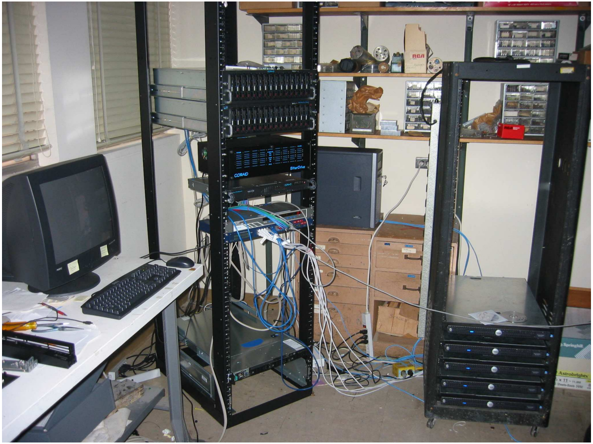


Figure: Computing cluster in Knudsen Hall, UCLA.

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Nefkens Computer Cluster at UCLA

There are five major parts to the entire Computing Cluster.

1. Queue-based computing farm
2. Hard drive array
3. Tape library system
4. User workstations
5. back-up system

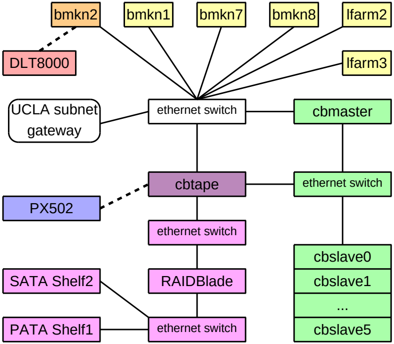

Figure: The layout of these systems.