Photoproduction of the doubly-strange Ξ Hyperons

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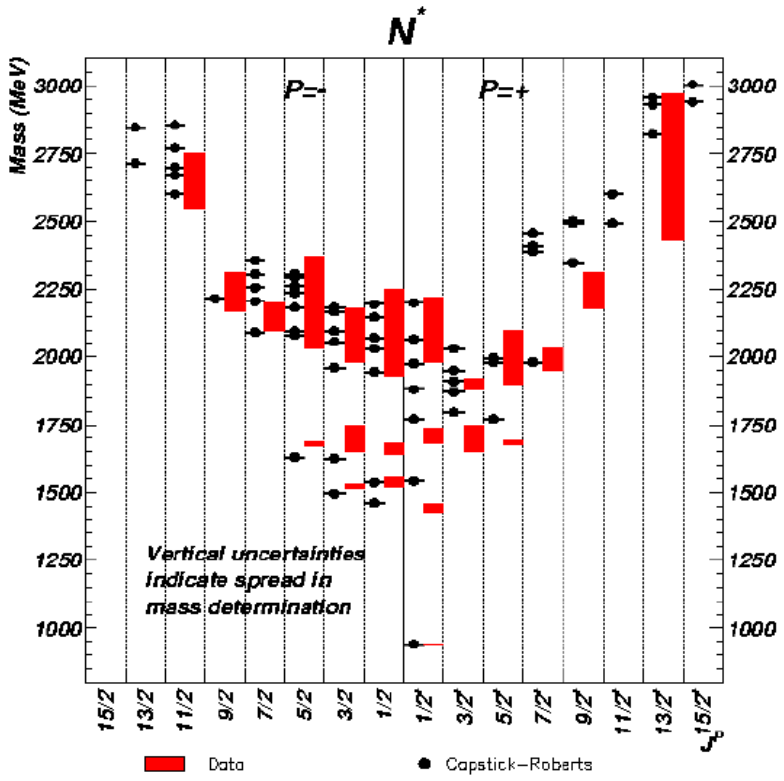
What is the universe made of?

- The Standard Model contains the following:
  - Bosons (γ, $W^{\pm}$, Z^0, g)
  - Leptons ($e^{\pm}$, $\mu^{\pm}$, $\tau^{\pm}$, ν_e, ν_μ, ν_τ + *antineutrinos*)
  - Quarks (*u*, *d*, *c*, *s*, *b*, *t* + *antiquarks*)
- All particles start out massless
  - Mass comes from Higgs mechanism
  - Accounts for ~2% of nucleon mass
- Most mass due to non-perturbative QCD effects
  - Need to know the structure of the nucleon

N* Spectrum Predictions

- Theory agrees with experiment qualitiatively, but not quantitatively
- Theory predicts many more states than have been observed



$SU(3)_F$ Multiplets

With only *qqq* states, $SU(3)_F$ gives four multiplets

one singlet: (Λ)

two octets:
$$\begin{pmatrix} N^0 & N^+ \\ \Sigma^- & \Sigma^0\ \Lambda & \Sigma^+ \\ \Xi^- & \Xi^0 \end{pmatrix}$$

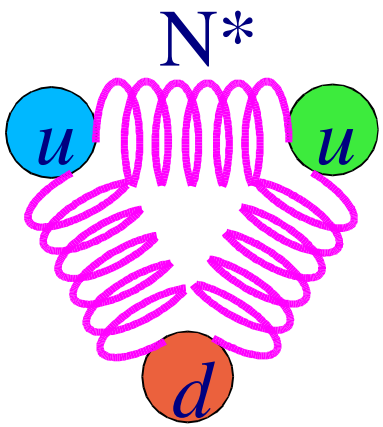
one decuplet:
$$\begin{pmatrix} \Delta^- & \Delta^0 & \Delta^+ & \Delta^{++} \\ \Sigma^- & \Sigma^0 & \Sigma^+ \\ \Xi^- & \Xi^0 \\ \Omega^- \end{pmatrix}$$

$SU(3)_F$ *requires* the existence of a Ξ state for each N *and* one for each Δ

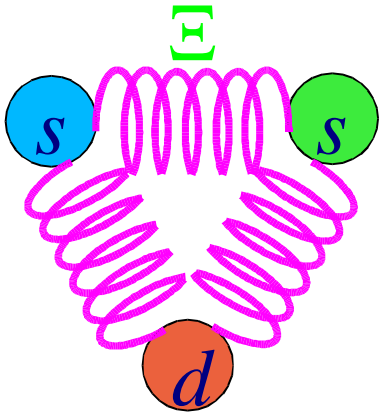
2001 RPP: 22 N, 22 Δ...11Ξ

where are the other 33?

Ξ quark structure



Replace two *u* quarks with *s* quarks ⇒

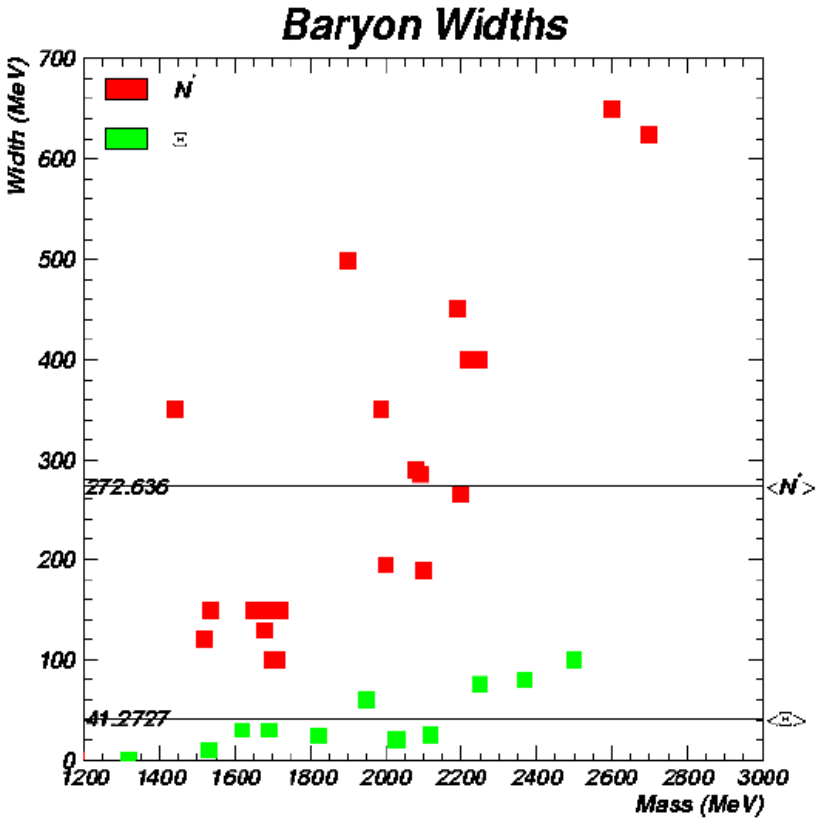


- Except for the quark content, $\psi_{N^*}=(\text{octet})\psi_{\Xi}$
- Properties should be related

So what?

Using Ξ to study N*

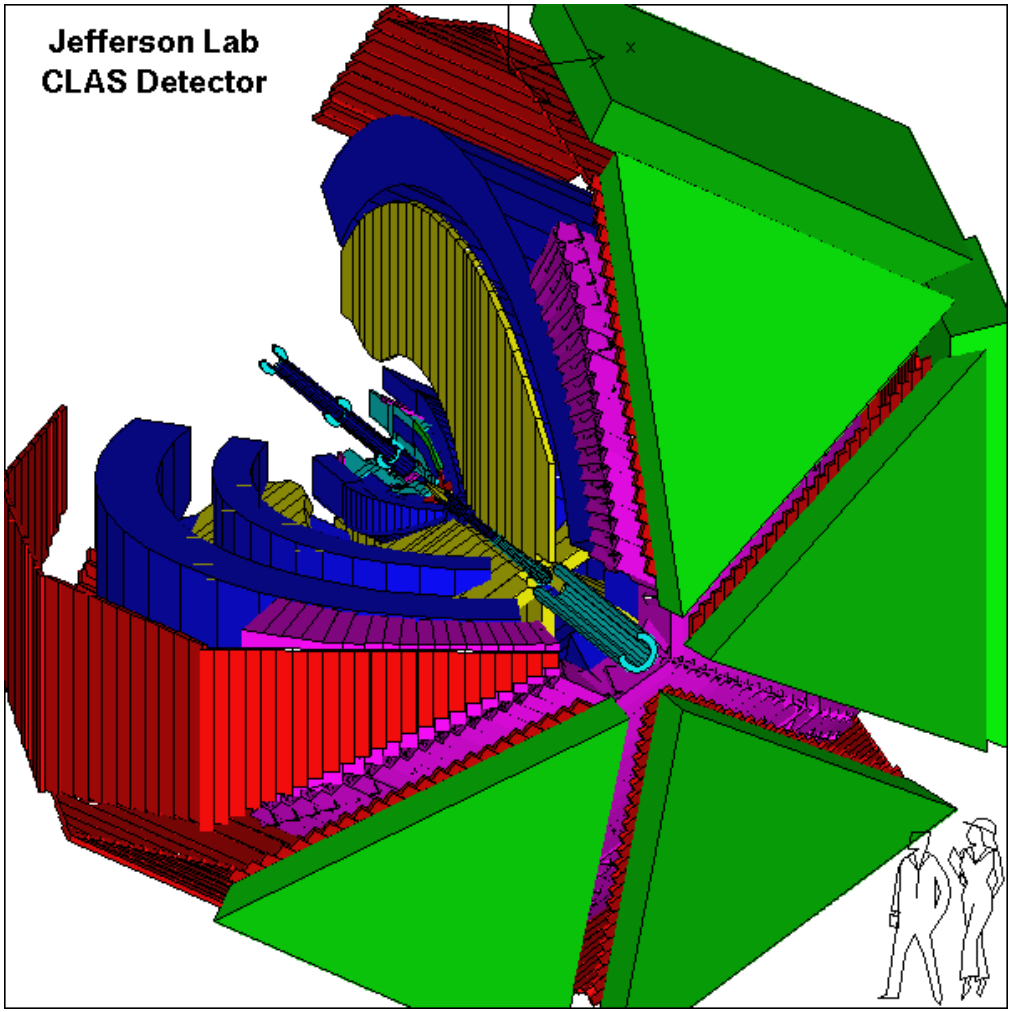
- Ξ states are systematically narrower than N* states
  - Easier to distinguish from one another
- A new method for learning about the N* (and Δ*) states



Ξ Photoproduction

- Create the Ξ by photoproduction: $\gamma p \rightarrow K^+K^+\Xi^-$
  - First exclusive measurement of Ξ photoproduction on the proton; best means of studying spectrum
- Detect Ξ in missing mass of K^+K^+ system
- In $\gamma p \rightarrow K^+K^+X$, missing (X) particle must:
  - have $S = -2$
  - have $Q = -1$
  - be a baryon
- The Ξ^- is the only possibility

The CLAS detector



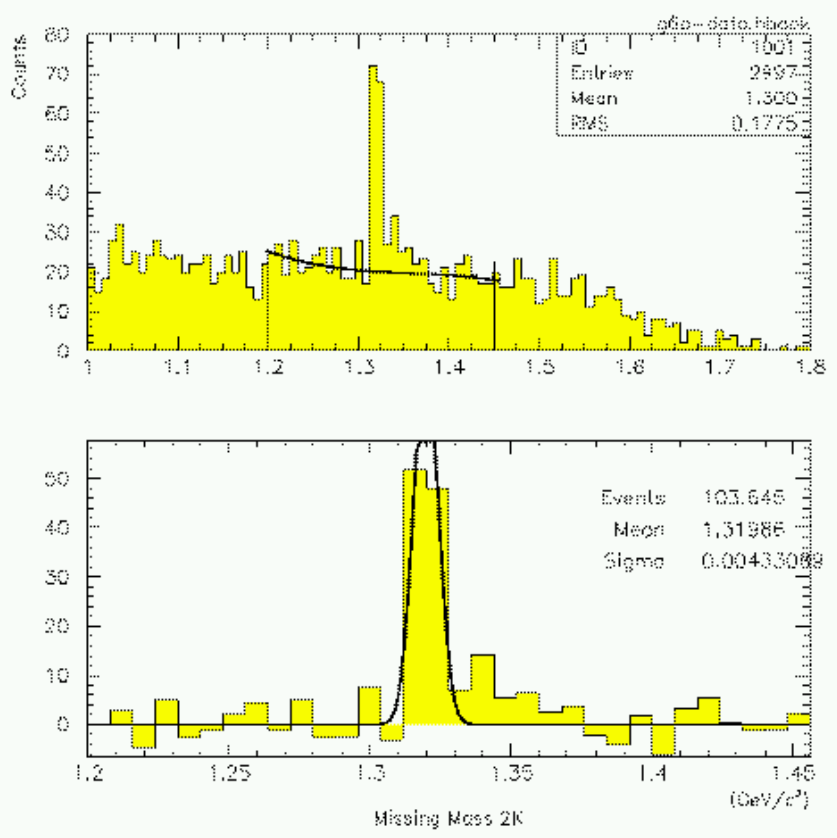
Toroidal magnetic field (yellow coils) bends charged particles toward or away from beamline

CLAS Data sets

- All Ξ studies to date have used "mined" data
  - Data were not taken to look for Ξ physics
- Existing data sets were compatible with Ξ studies
  - *g6a*: $3.2 < E_\gamma < 3.9$ GeV
  - *g6b*: $3.0 < E_\gamma < 5.2$ GeV
  - *g6c*: $4.8 < E_\gamma < 5.4$ GeV

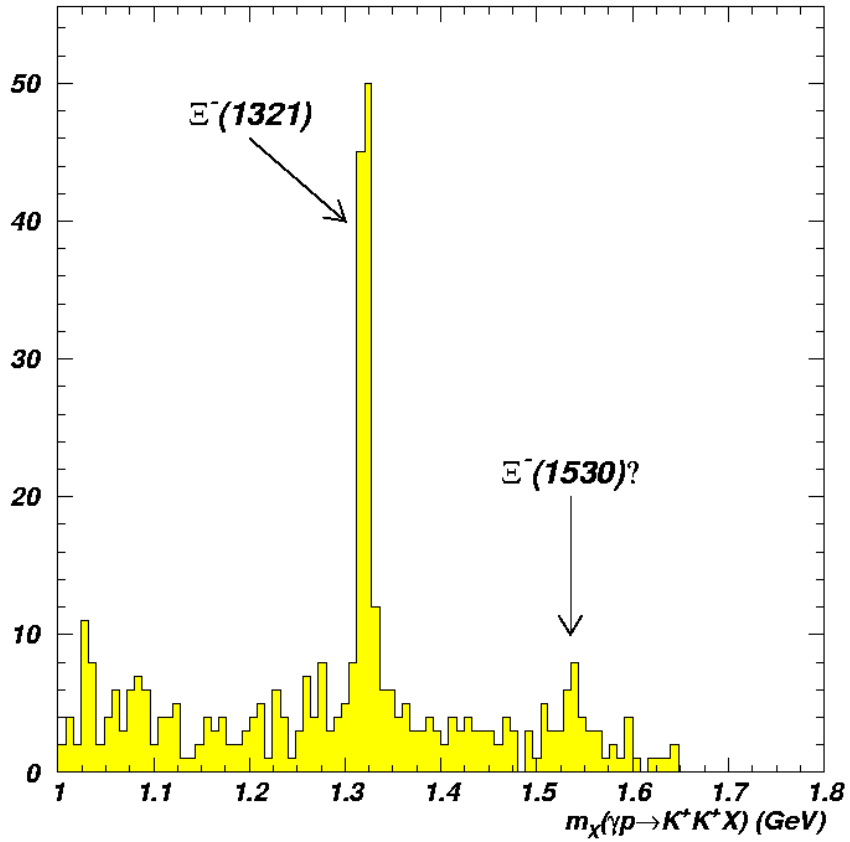
g6a final missing mass

- Select K^+K^+ events in *g6a*
- Plot m_X of $\gamma p \in K^+K^+X$
- Fit background to 3rd-order polynomial
- 104 ± 16 events in peak



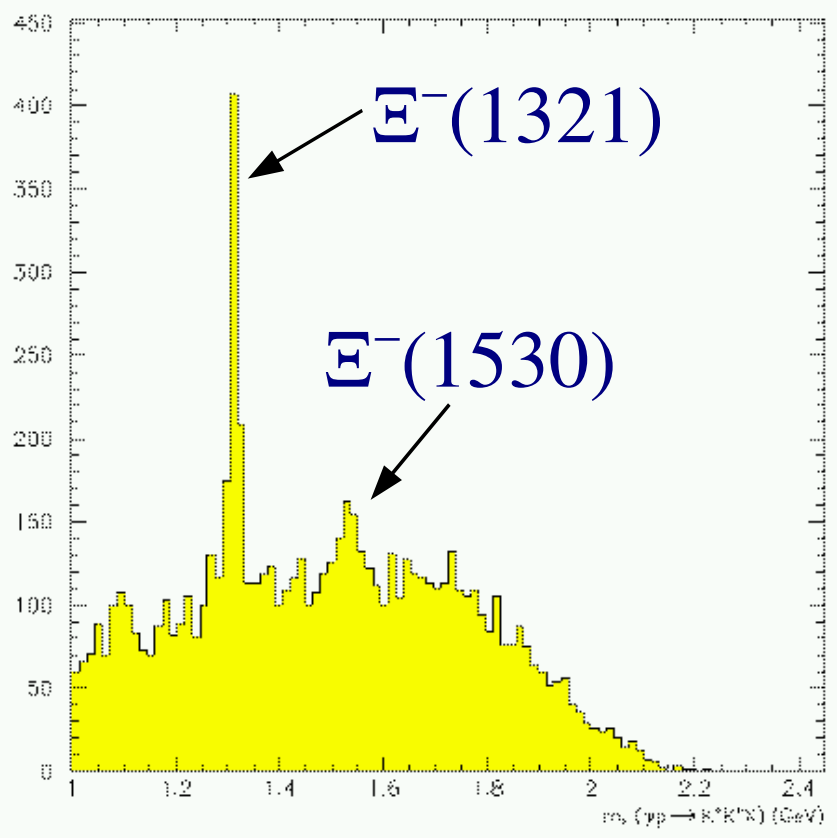
Where's the Ξ(1530)?

- Tighter K^+ PID cuts improve background suppression
- Ξ(1530) may be peeking through



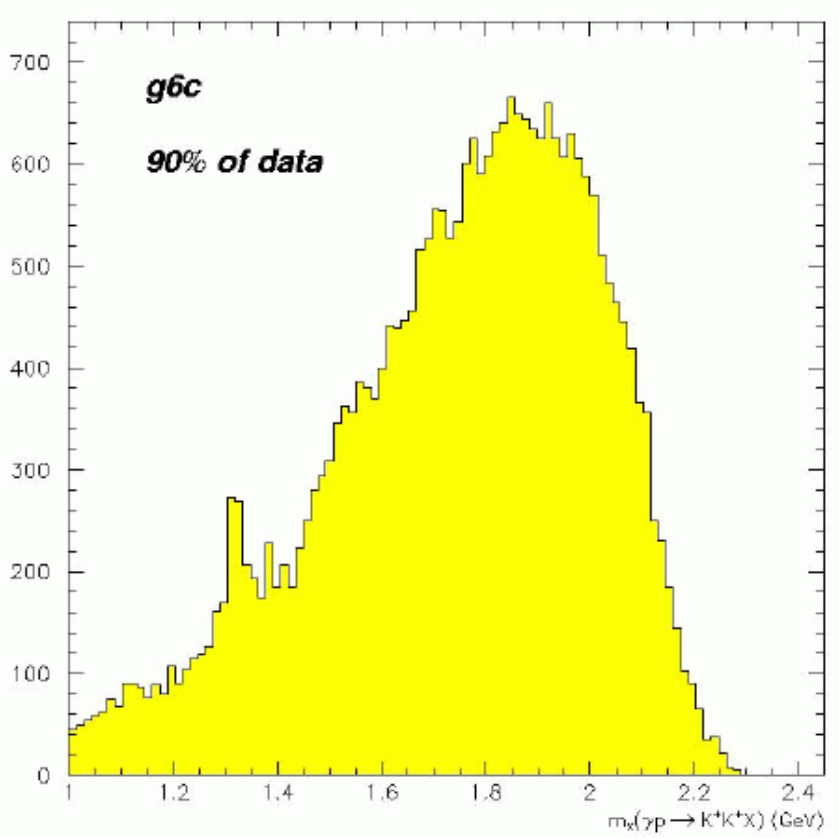
g6b missing mass

- *g6b* is analyzed the same way as *g6a*
- Both ground state and $\Xi^-(1530)$ are seen
- Background is higher due to higher photon flux



g6c missing mass

- *g6c* analyzed same as *g6a*, *g6b*
- Beam flux much higher
- More analysis needed to find signals from higher mass states

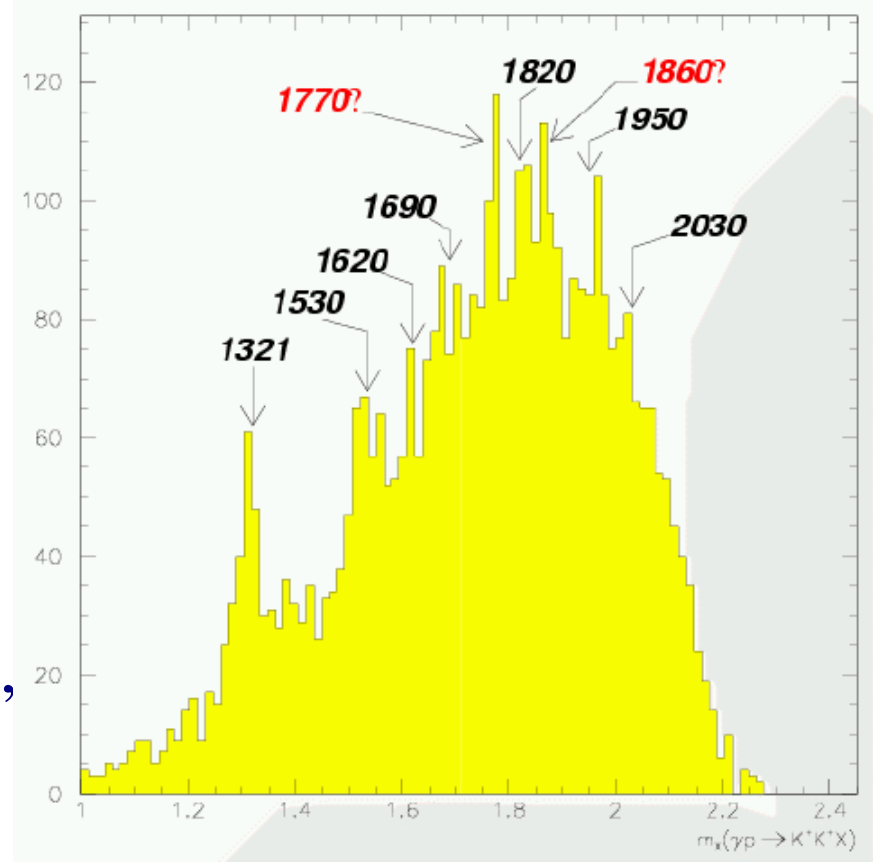


g6c Background Suppression

- Main backgrounds due to K/π misidentification
- Background processes:
  - $\gamma p \rightarrow \pi^+\pi^+\Delta^-$
  - $\gamma p \rightarrow K^+\pi^+\Sigma^-$
- Neither Δ^- nor Σ^- decays via proton
  - $\Delta^- \rightarrow \pi^- n$
  - $\Sigma^- \rightarrow \pi^- n$
- Requiring a proton should cut the background

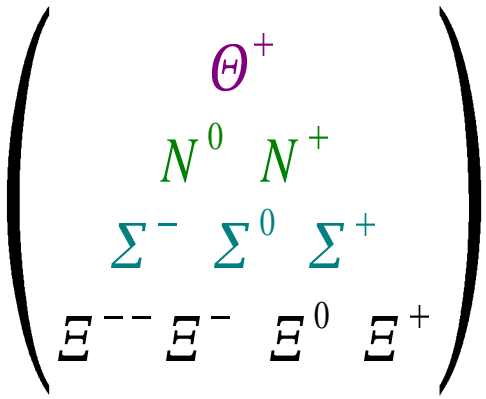
g6c missing mass with proton

- $\gamma p \rightarrow K^+K^+X$
  - $X \rightarrow pX'$
- Interesting structure starts to appear
  - Enhancements in spectrum at all known Ξ states
  - Persistent structures at 1770, 1860 MeV
    - Many possible explanations



What about those pentaquarks?

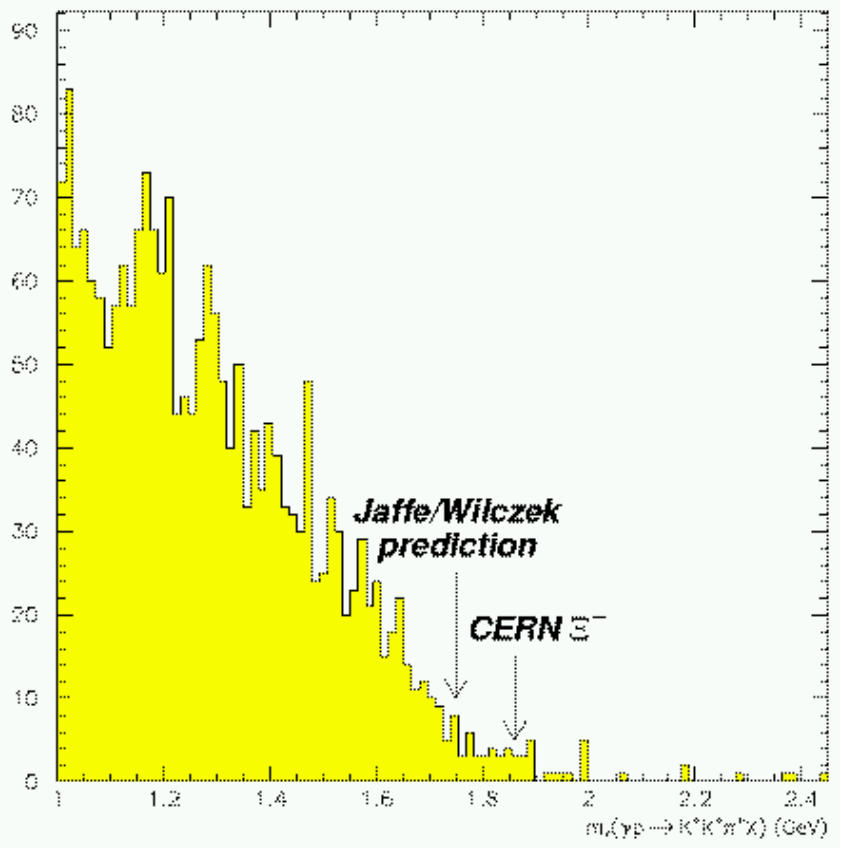
- The Θ^+ is a member of an anti-decuplet



- The Ξ^{--} and Ξ^+ cannot be *qqq* states
- Ξ^{--} should be seen in $\gamma p \rightarrow K^+K^+\pi^+\Xi^{--}$
- New report from CERN: $\Xi^{--}(1860)$

Ξ^{--} Pentaquark Search

- Search for Ξ^{--} state by looking for a peak in the missing mass of $\gamma p \rightarrow K^+K^+\pi^+X$
- No statement from *g6b*
  - Phase space dies out
  - More energy needed
  - *g6c* results coming



Conclusions

- Ξ physics is getting interesting
  - Lots of structure appearing to confirm known states
  - Possible new structure at 1770 and 1860 MeV
- Ξ pentaquarks are the next big thing to look for
  - CERN may already have seen Ξ^{--} at 1860 MeV
  - JLab data under analysis; new data needed
- The existing Ξ program at JLab will produce some of the best new information on Ξ pentaquarks in the next few years