

# Evidence for a Narrow $S = +1$ Baryon Resonance in Photoproduction from the Neutron

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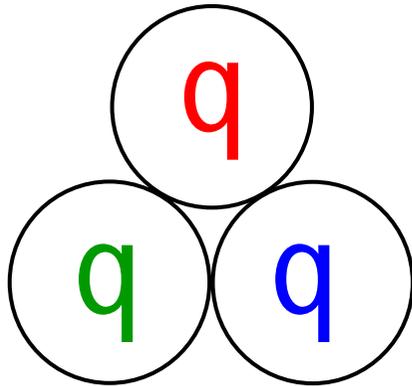
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Shibata lab.

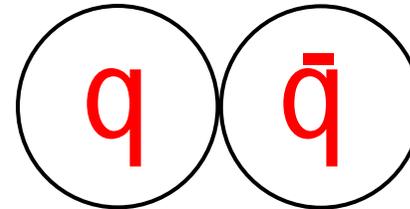
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# 1. Introduction

Hadron is formed from quarks.



Baryon



Meson

Quark has "color" (r, g, b and their anticolors).  
Observed particles must be "colorless".

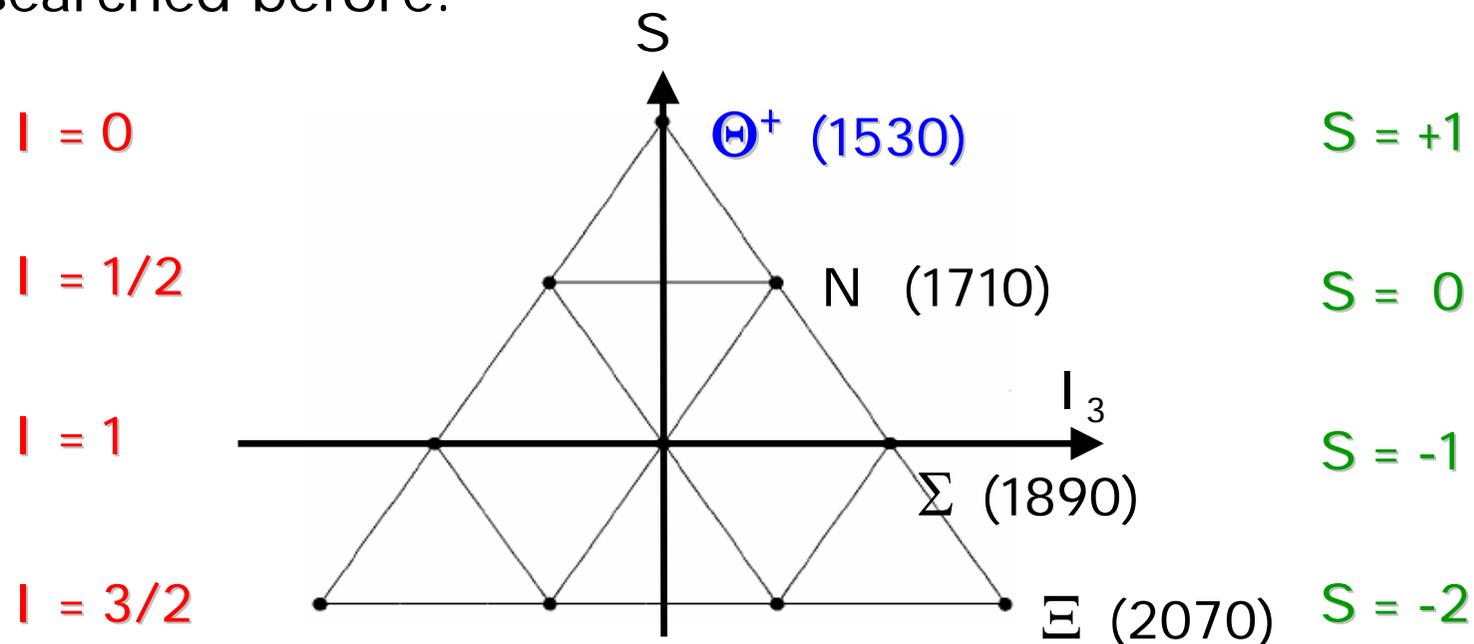
For example, quark configuration  $qqqq\bar{q}$  is also possible.

It's exotic **five-quark** state !

It is valuable to study QCD.

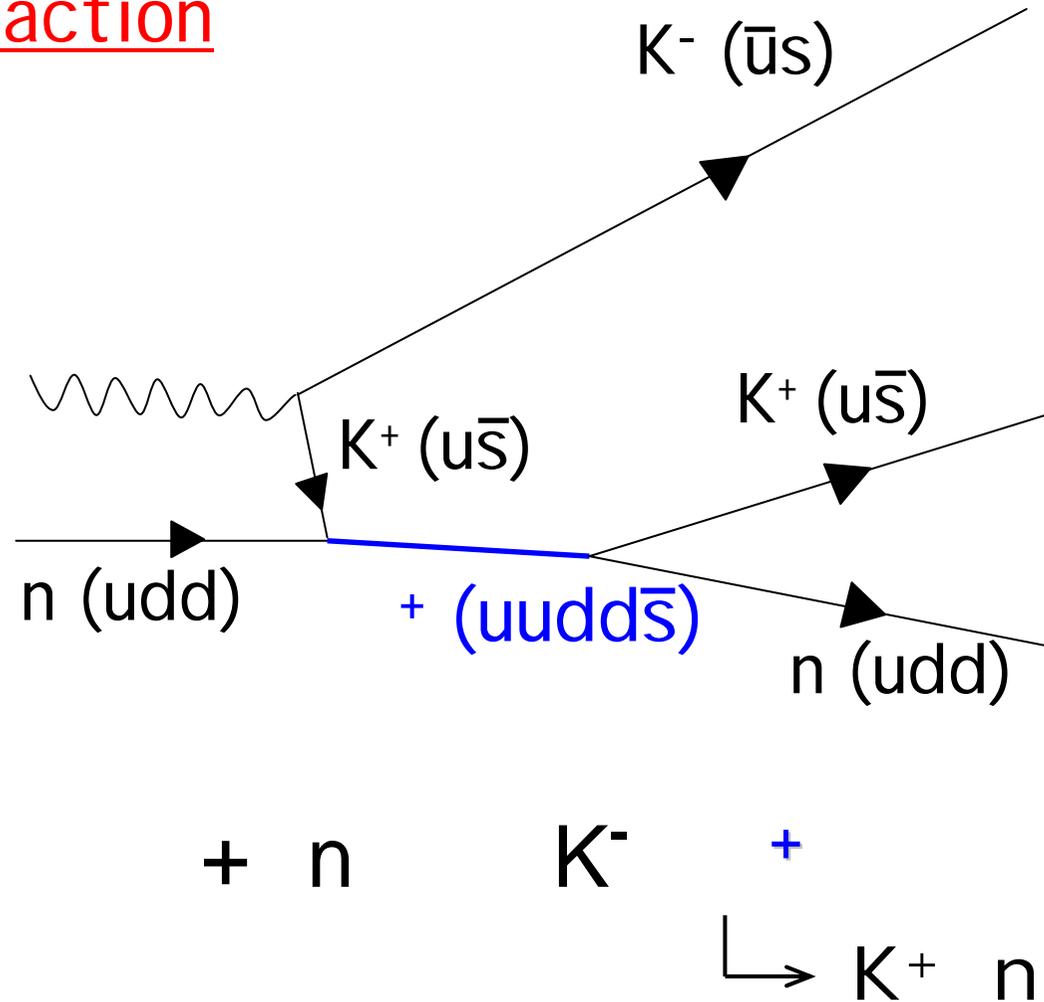
# Prediction of five-quark states

- **Five-quark state** is first predicted by A. Manohar in 1984.
- Ten types five-quark states were theoretically predicted by Diakonov, Petrov and Polyakov (1997).
- They were considered to be a **molecular meson-baryon** resonance or **penta-quark**.
- $\Theta^+$  has a quark configuration  $uudd\bar{s}$  and  $S = +1$ .
- The region of its mass ( $1530 \text{ MeV}/c^2$ ) had never been searched before.



## 2. Principle of experiment

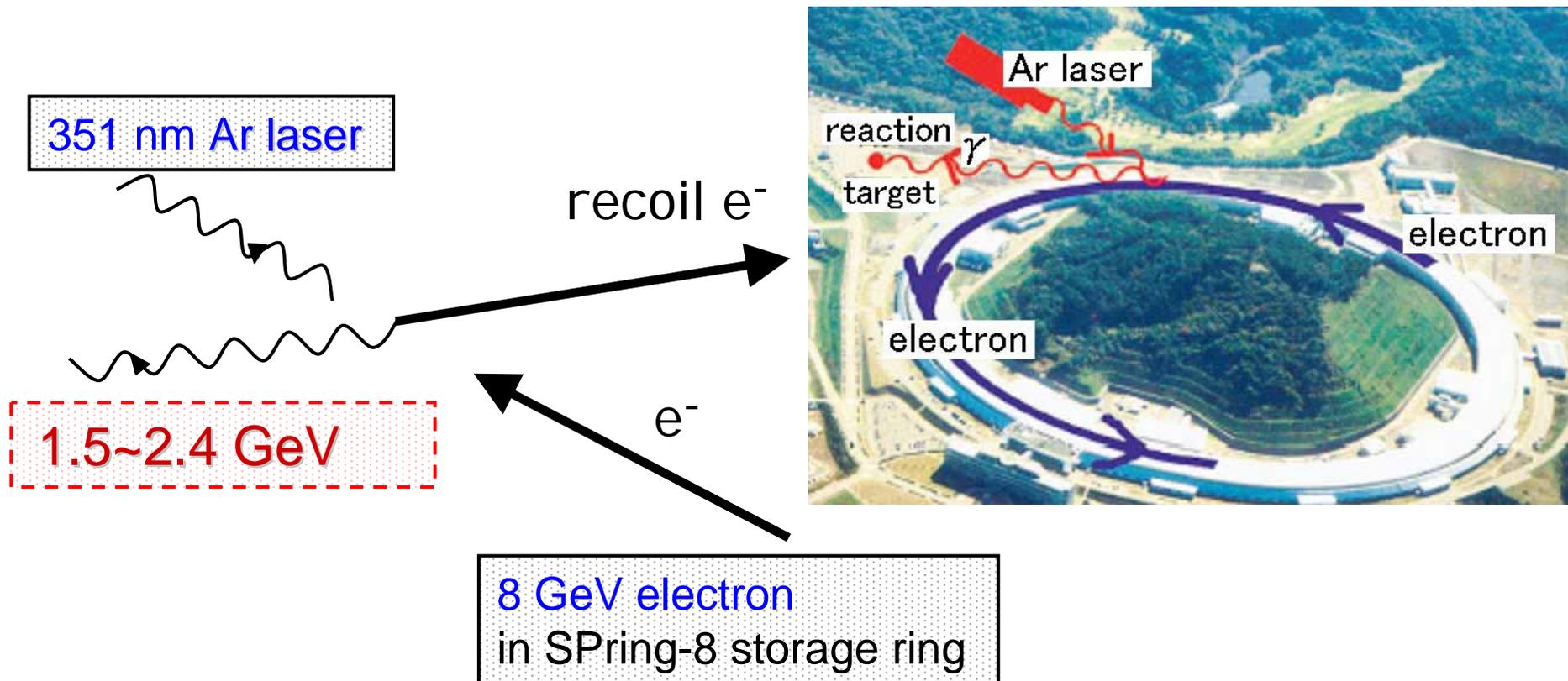
### N reaction



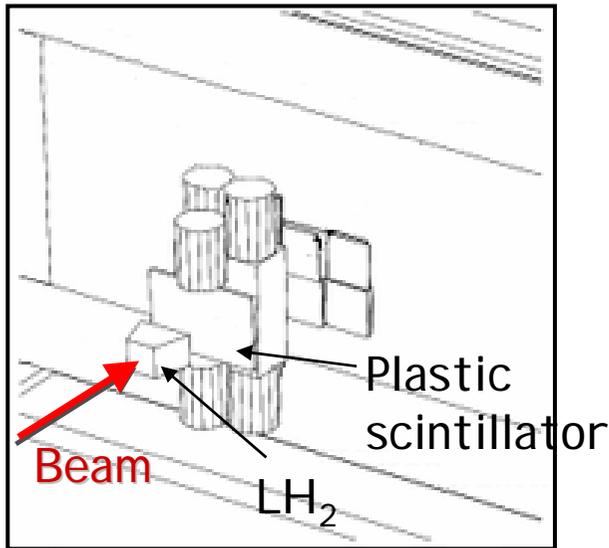
### 3. Experiment at LEPS

The experiment was carried out at LEPS (Laser-Electron Photon facility at SPring-8) in Hyogo, Japan.

Beam photons are produced by **Compton backscattering** of laser light. Recoil photons are measured.

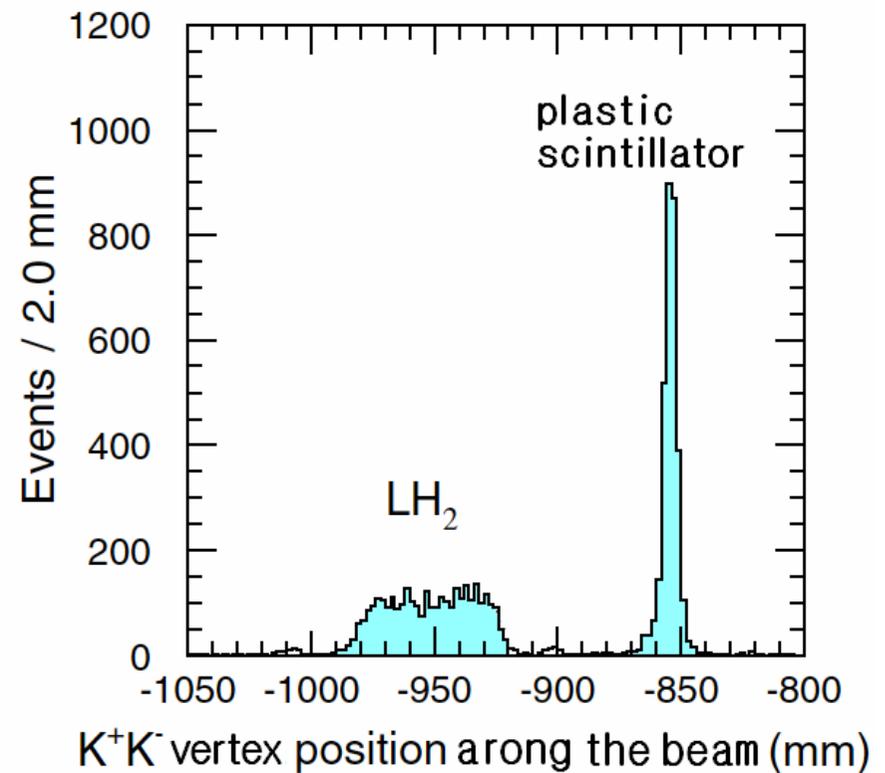
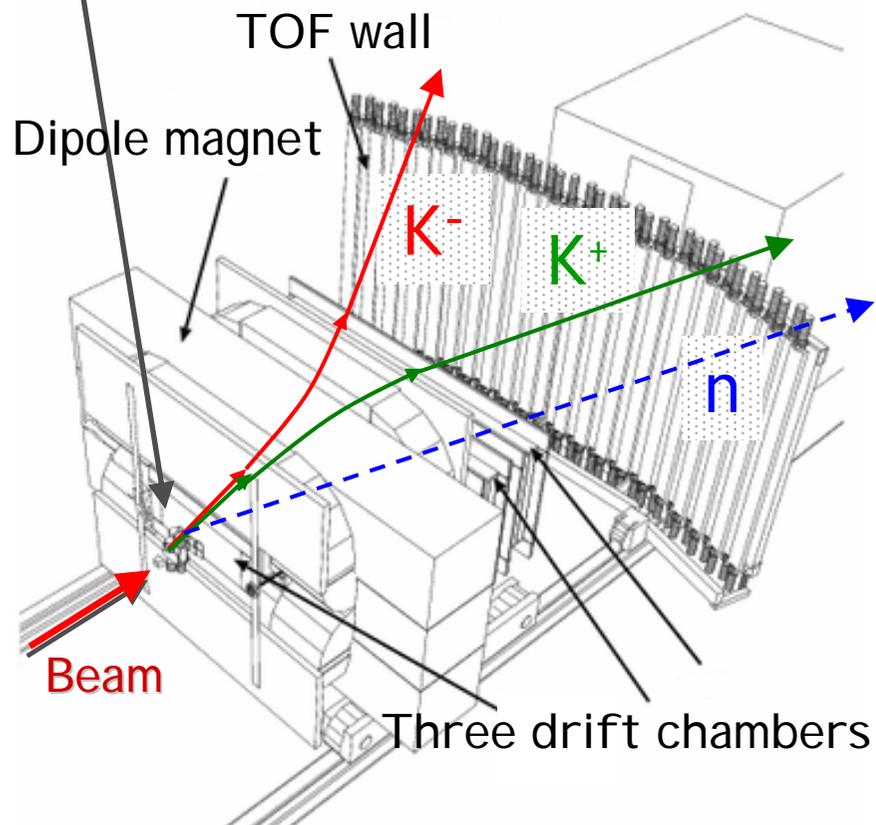


# Spectrometer



Two targets:

- Plastic scintillator  
composed of Hydrogen and Carbon nuclei
- Liquid-hydrogen (LH<sub>2</sub>)



Two sets of events from two targets are clearly distinguished.

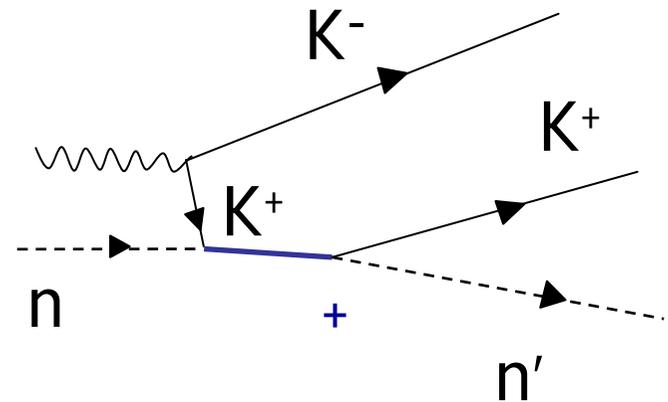
# Analysis method

$K^+$ ,  $K^-$  were identified.

$P_{K^+}$ ,  $P_{K^-}$  were measured.

+ mass was calculated using missing-mass  $MM_{K^-}$ .

$$\begin{aligned}(MM_{\gamma K^-})^2 &= (P_\gamma + P_n - P_{K^-})^2 \\ &= (P_{K^+} + P_{n'})^2 = M_{\Theta^+}^2\end{aligned}$$

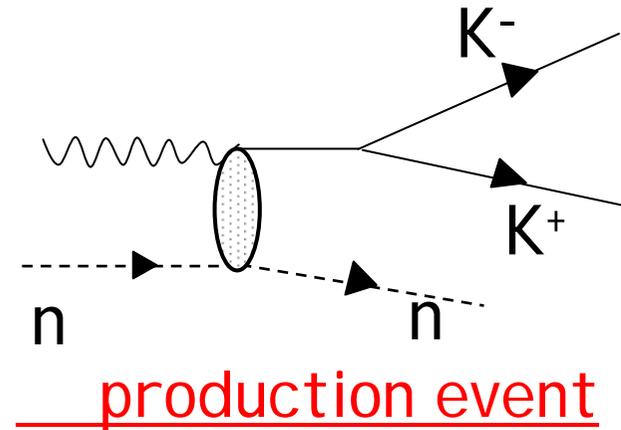
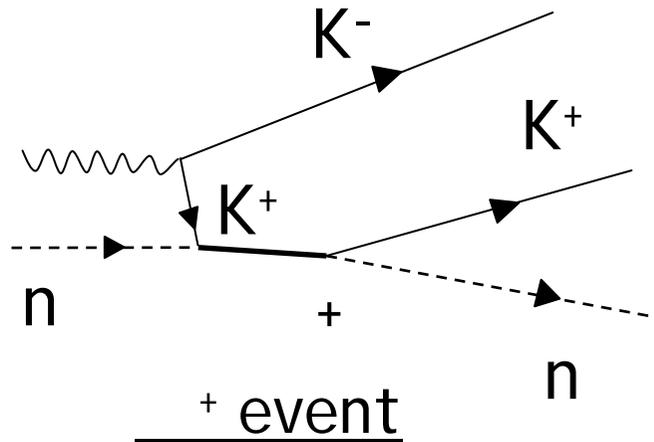


$MM_{K^-}$  distribution at 1.4 ~ 1.8 GeV was studied.

# Event selection

## Cuts

- Vertex cut (select the events from plastic scintillator)
- **Photoproduction of meson** excluded

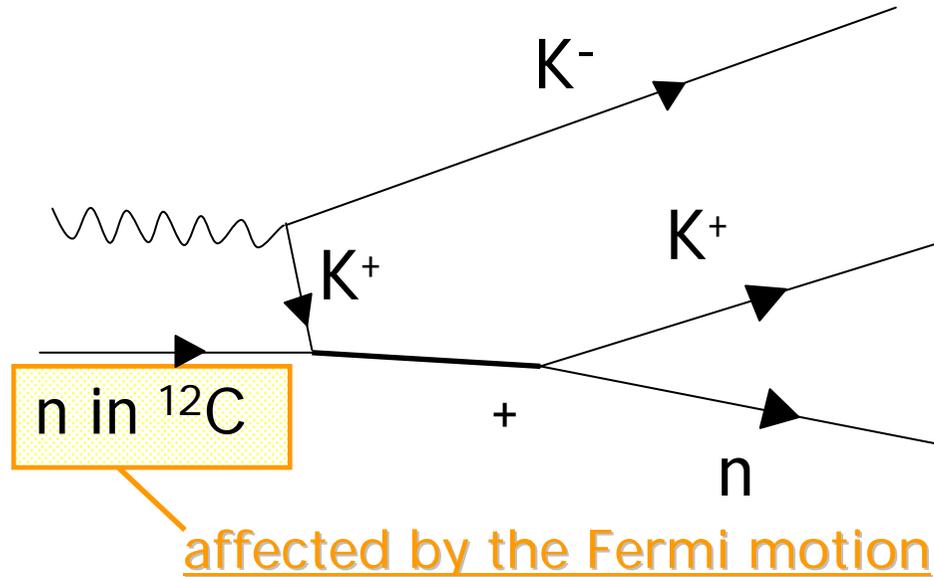


· etc.

After these cut, 109 events satisfied all the criteria.

# Correction for the Fermi motion

- Nucleons in nuclei are affected by **the Fermi motion**.



The effect of Fermi motion is removed using equation below.

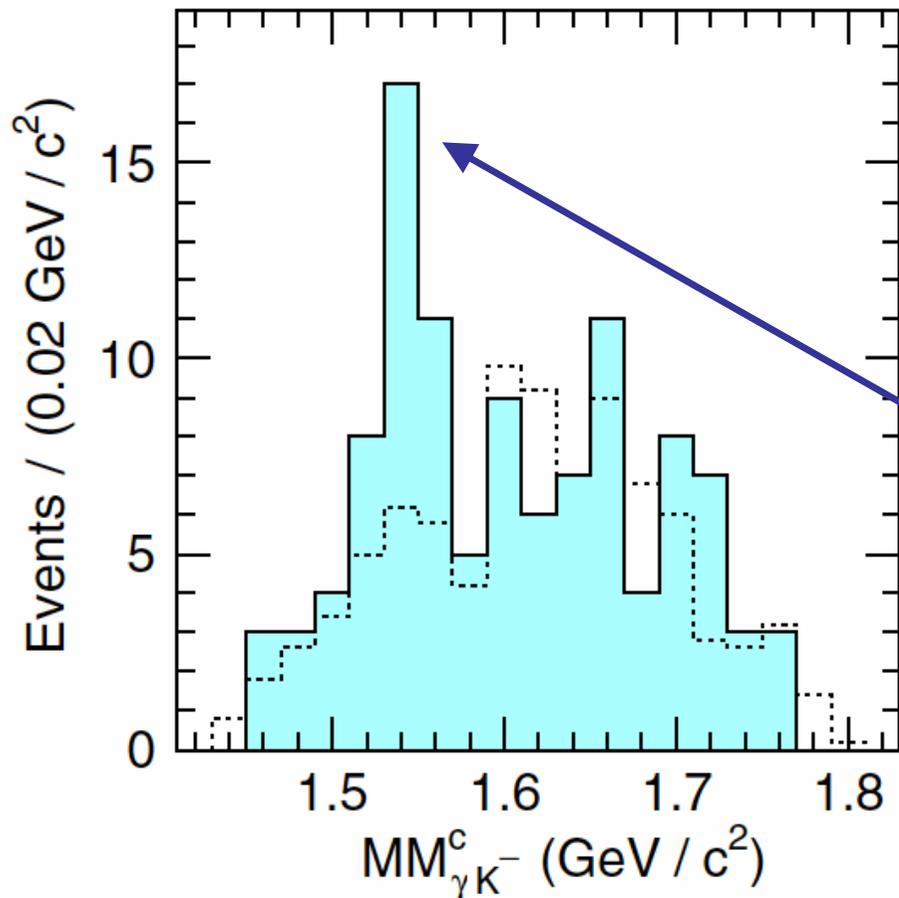
$$MM_{\gamma K^-}^c = M_{\Theta^+} = MM_{\gamma K^-} - MM_{\gamma K^+ K^-} + M_N$$

Two missing mass  $MM_{K^-}$  and  $MM_{K^+ K^-}$  have the same Fermi motion Its effect is canceled.

# 4. Result

After the correction for the Fermi motion

The  $MM^c_{\gamma K^-}$  spectrum



solid histogram: events from plastic scintillator

dotted histogram: background events from the  $LH_2$  normalized by a fit in the region above  $1.59 \text{ GeV}/c^2$

A peak was observed.

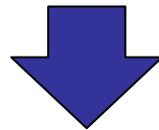
Mass:  $1.54 \pm 0.01 \text{ GeV}/c^2$

Width:  $25 \text{ MeV}/c^2$

Gaussian significance: 4.6

## 5. Summary

- Five-quark states had been theoretically predicted.
- $^+$  ( $uudd\bar{s}$ ) was predicted at the mass of **1530 MeV**.
- The experiment was carried out at the LEP of Spring-8.  
Beam: High energy photon 1.5~2.4 GeV  
Target: n in  $^{12}\text{C}$
- The events were selected with several cuts.
- The Fermi motion was corrected.
- **A sharp baryon resonance peak was found.**  
Mass:  $1.54 \pm 0.01 \text{ GeV}/c^2$   
Width: 25 MeV/ $c^2$   
Gaussian significance: 4.6



It's a molecular meson-baryon resonance  
or a penta-quark baryon<sup>+</sup>.