Homework for HDWG:
Light Nucleon Resonance Revival

Igor Strakovsky
The George Washington University

- Where did **N'** come from?
  Completeness of unitarity multiplets.
- Unitarity partners:
  Experimental evidences.
  (Quasi) bound states of πN.
- Restrictions for **N'**.
- Summary.

GW INS Data Analysis Center — Institute for Nuclear Studies, The George Washington University

Supported by **DE-SC0016583**

Where Did N' From

Volume 32B, number 6 PHYSICS LETTERS 17 August 1970

ON THE POSSIBLE EXISTENCE OF A NEW NUCLEON STATE

Ya. I. AZIMOV
A.F.Ioffe Physical-Technical Institute, Leningrad, USSR

PHYSICAL REVIEW C 68, 045204 (2003)

Light baryon resonances: Restrictions and perspectives

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- Baryon spectroscopy continues to motivate **extensive experimental program**, with most studies focused on **missing resonance problem**.
- Given **underpopulation** of conventional **3-q** states, it is difficult to identify unconventional states.
- If, however, N' state was to be found with **mass** between **N** & **Δ**, it would **undoubtedly** have exotic structure.

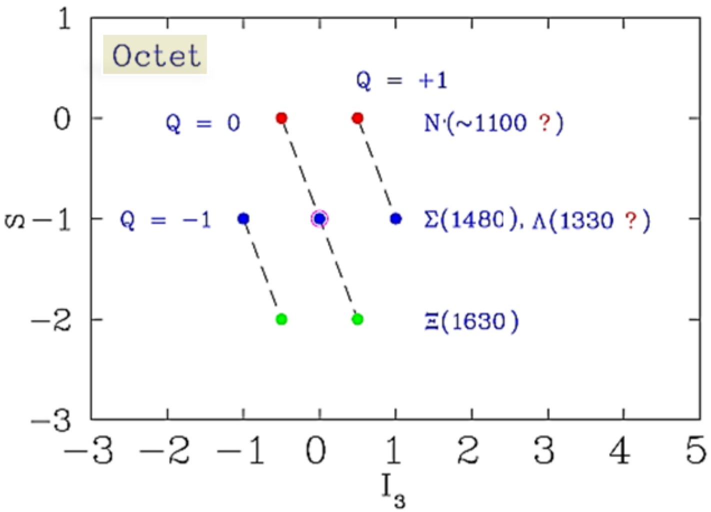
- PDG has **109 Baryon Resonances** (**64** of them are **4*** & **3***).
- In case of **SU(6) x O(3)**, **434** states would be present if all revealed multiplets were fleshed out (**three 70** and **four 56**).

- Such baryon state (called here **N'**, for brevity and according to tradition, though its **isospin** could be **1/2**) was suggested to complete **unitary multiplet** of hyperon resonance states **Σ(1480)** & **Ξ(1620)**, considered now to have **1*** status according to PDG.

- If we believe in **SU(3)**, then every resonance has to have ``**family**" (**Unitarity Partners**)

Unitarity Partners (?)

Ya. Azimov, R. Arndt, IS, R. Workman, Phys Rev C **68**, 045204 (2003)



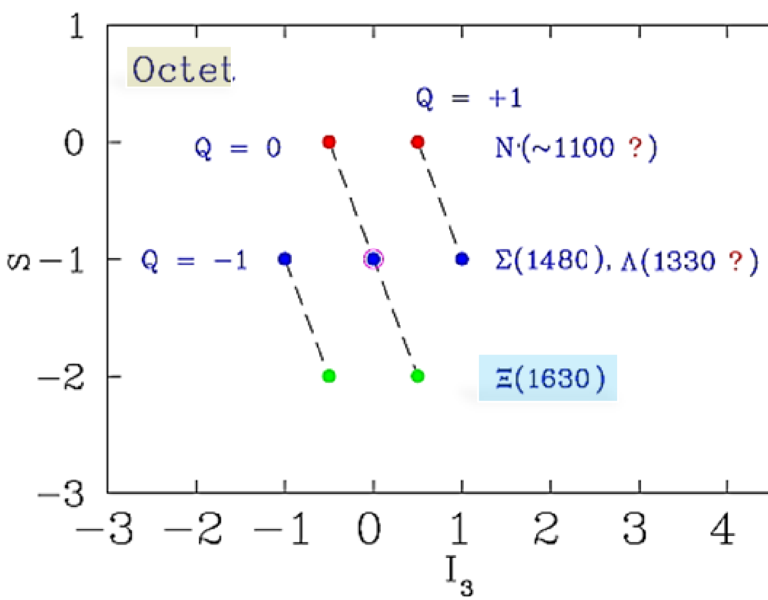
- Gell-Mann-Okubo **mass formula**.
- **Mixing** is able to **shift** some masses.

State	Mass (MeV)	Width (MeV)	Decay Modes	Hadron Production Xsections
N′	~1100 ?	<0.05	Nγ ?	$< 10^{-4}$ of "normal"
Λ	1330 ?		Λγ	$\sim 10\mu b$
Σ	1480	30-80 ?	$\Lambda\pi$, $\Sigma\pi$, $N\bar{K}$	$\sim 1\mu b$
Ξ	1630	20-50 ?	$\Xi\pi$	$\sim 1\mu b$

On base of positive observations.

- PhotoProd Xsection has additional ~(α/π) factor.
- ElectroProd has ~$(\alpha/\pi)^2$.

Completeness of Unitary Multiplet



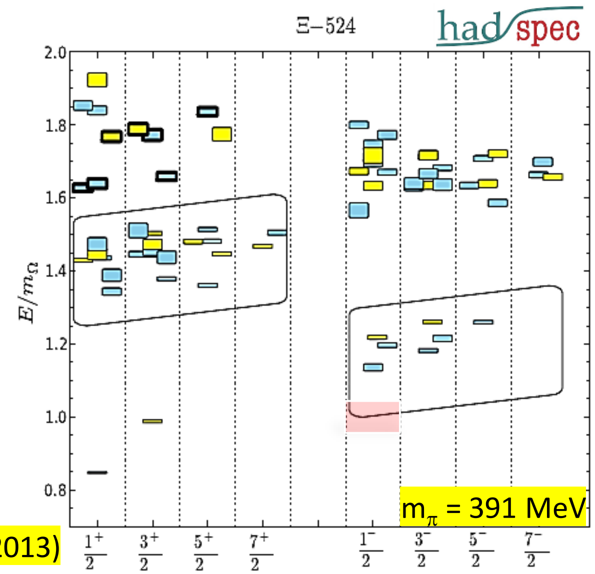
PDG for $\Xi(1620)1/2(?^?)$ ★

Ξ(1620) MASS

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
≈ 1620 OUR ESTIMATE					
1624 ± 3	31	BRIEFEL	77	HBC	$K^- p$ 2.87 GeV/c
1633 ± 12	34	DEBELLEFON	75B	HBC	$K^- p \rightarrow \Xi^- \overline{K} \pi$
1606 ± 6	29	ROSS	72	HBC	$K^- p$ 3.1–3.7 GeV/c

Ξ(1620) WIDTH

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
22.5	31	[1] BRIEFEL	77	HBC	$K^- p$ 2.87 GeV/c
40 ± 15	34	DEBELLEFON	75B	HBC	$K^- p \rightarrow \Xi^- \overline{K} \pi$
21 ± 7	29	ROSS	72	HBC	$K^- p \rightarrow \Xi^- \pi^+ K^{*0}(892)$

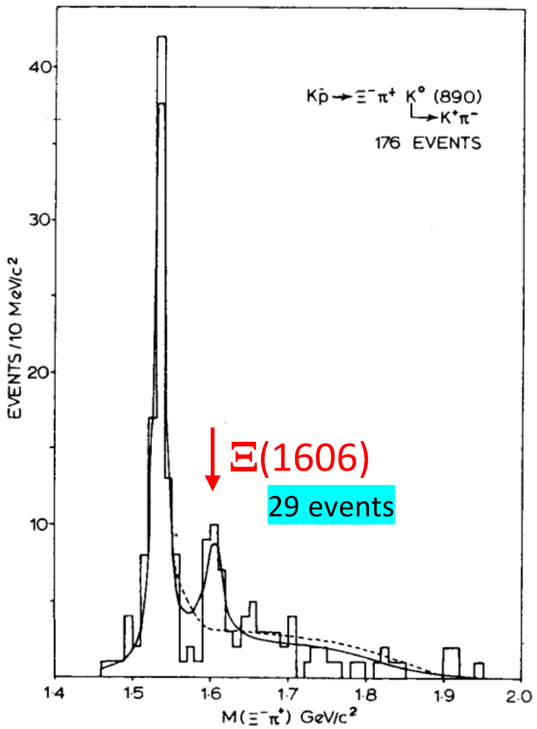


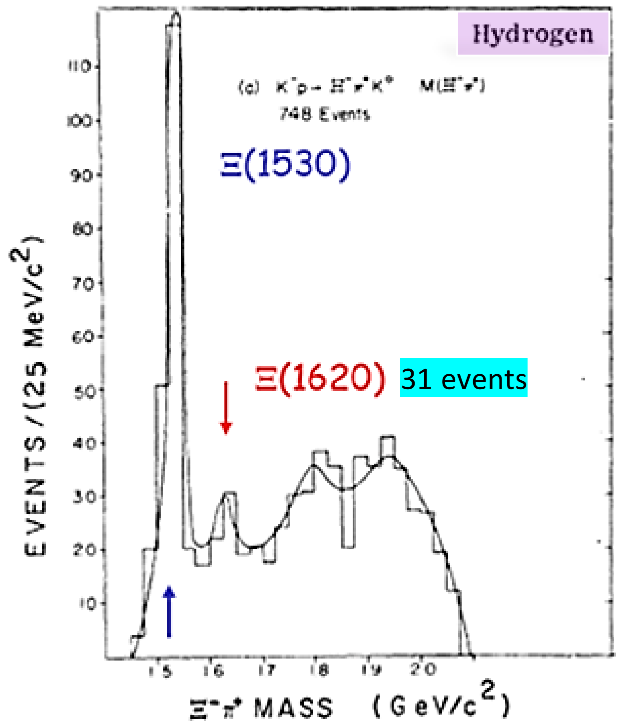
R. G. Edwards *et al*, Phys Rev D **87**, 054506 (2013)

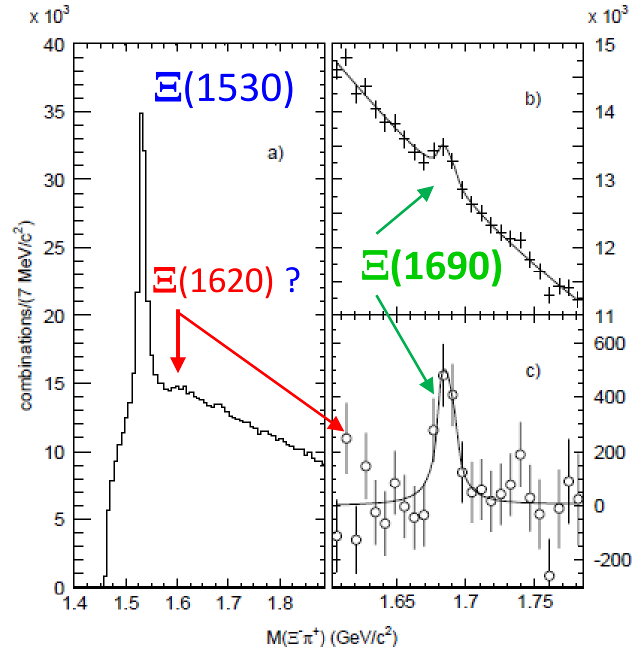
$\Xi(1606)$ via $K^- p \to \Xi^- \pi^+ K^{*0}(892)$ from CERN

$\Xi(1620)$ via $K^- p \to \Xi^- \pi^+ K^0$ from BROOKHAVEN NATIONAL LABORATORY

$\Xi(1620)$ via $\Xi^- Cu \to \Xi^- \pi^+ X$ from WA89







M = 1605.5±5.6 MeV
Γ = 20.8±7.4 MeV

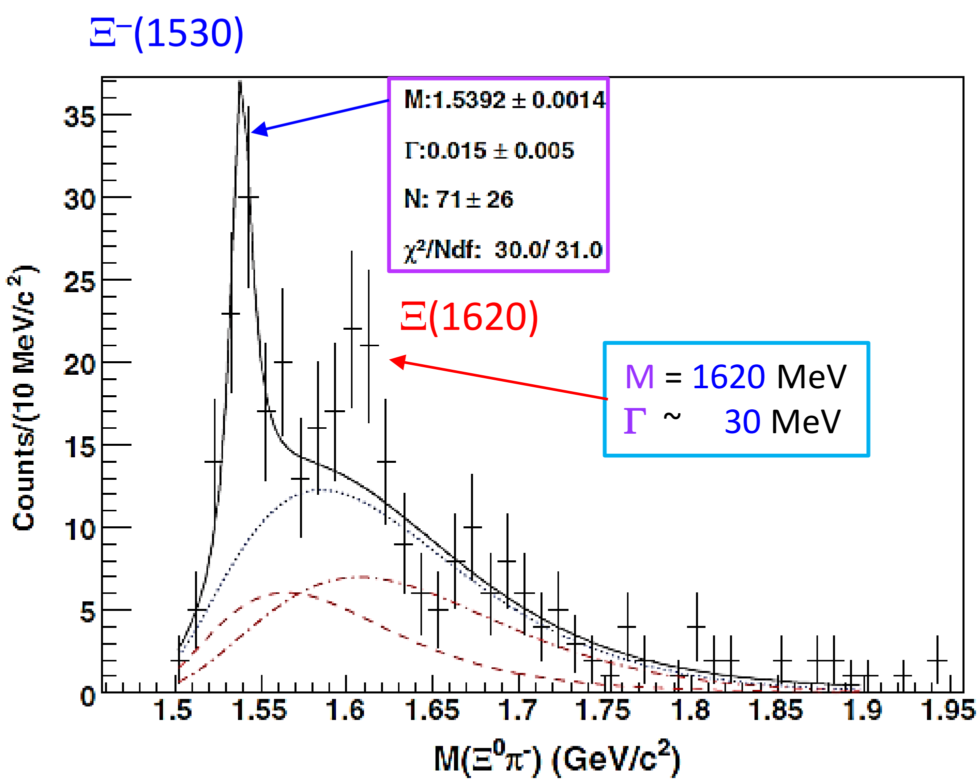
M = 1624±3 MeV
Γ = 22.5 MeV

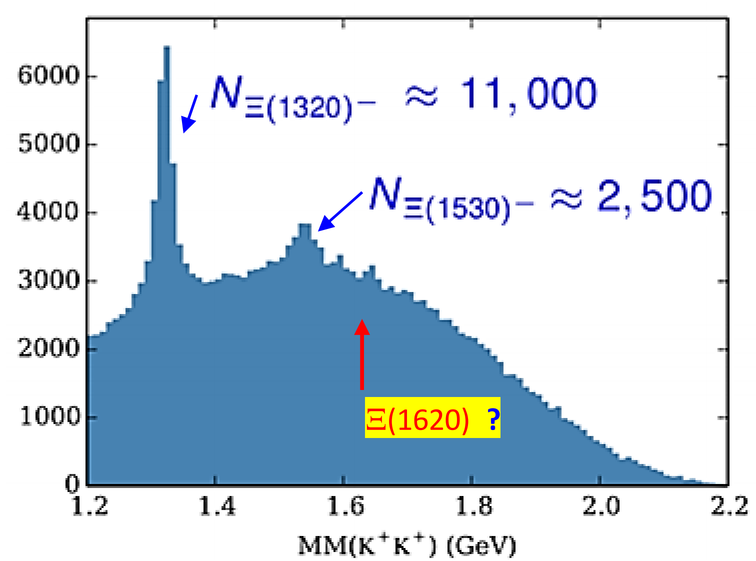
M.I. Adamovich *et al*, Eur Phys J C **5**, 621 (1998)

R.T. Ross *et al*, Phys Lett **38B**, 177 (1972)

E. Briefel *et al*, Phys Rev D **16**, 2706 (1977)

$\Xi(1620)$ via $\gamma p \to K^+ K^{*0} \Xi^0$ & $K^+ K^+ \Xi^-$ from clas



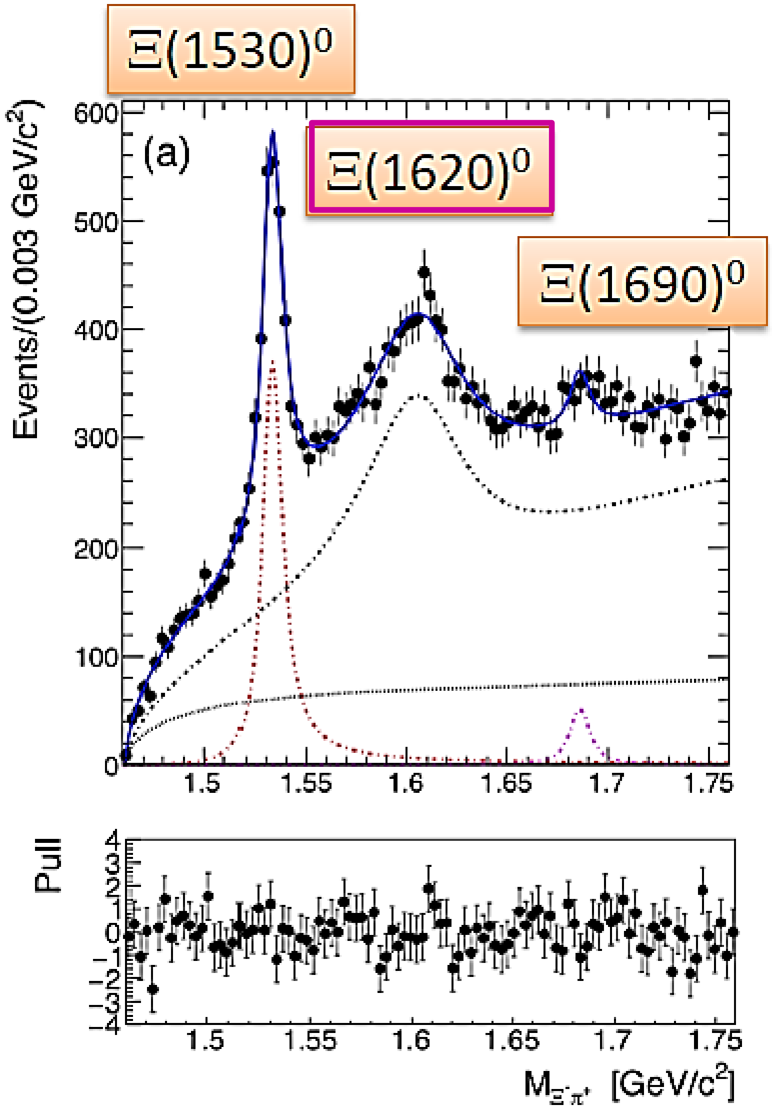


L. Guo *et al*, Phys Rev C **76**, 025208 (2007)

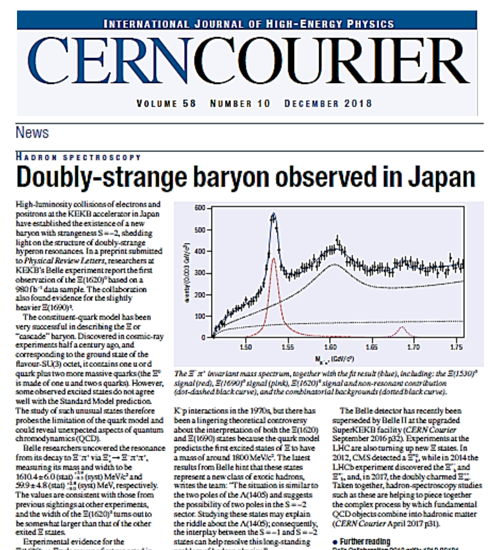
J.T. Goetz *et al*, Phys Rev C **98**, 062201 (2018)

$\Xi(1620)$ via $\Xi_c^+ \rightarrow \Xi^- \pi^+ \pi^+$ from

M. Sumihama *et al*, Phys Rev Lett **122**, 072501 (2019)



$\mathbf{M} = \mathbf{1610.4} \pm 6.0\,(\text{stat})^{+6.1}_{-4.2}(\text{syst})$ MeV
$\mathbf{\Gamma} = \mathbf{59.9} \pm 4.8\,(\text{stat})^{+2.8}_{-7.1}(\text{syst})$ MeV


INTERNATIONAL JOURNAL OF HIGH-ENERGY PHYSICS

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VOLUME 58 NUMBER 10 DECEMBER 2018

News

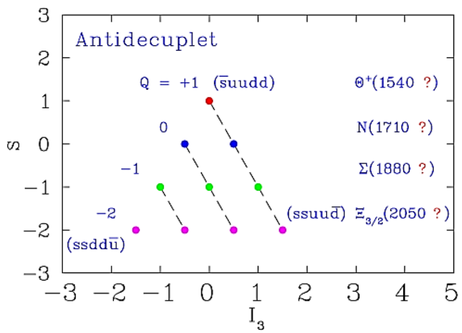
HADRON SPECTROSCOPY

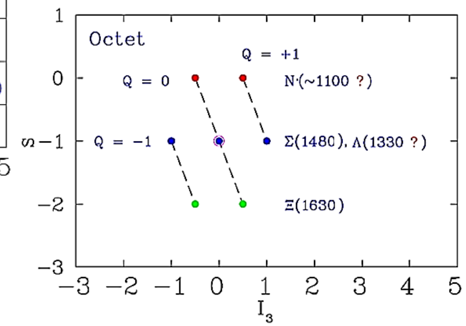
Doubly-strange baryon observed in Japan

Invariant mass spectrum in sideband region.

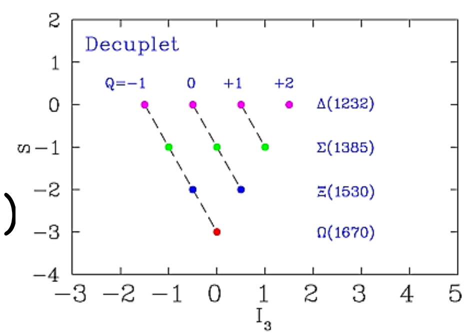
Possible Nature of Ξ(1620)

- If $\overline{10}$ is predicted to be $1/2^+$ (P-wave)
  Where is ground (S-wave) state ($1/2^-$) ?

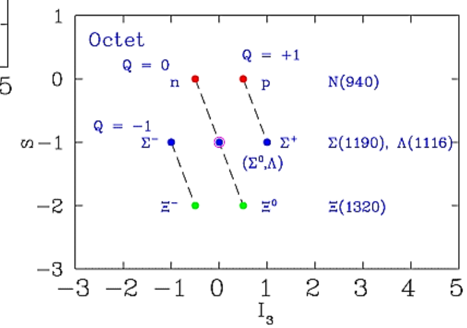


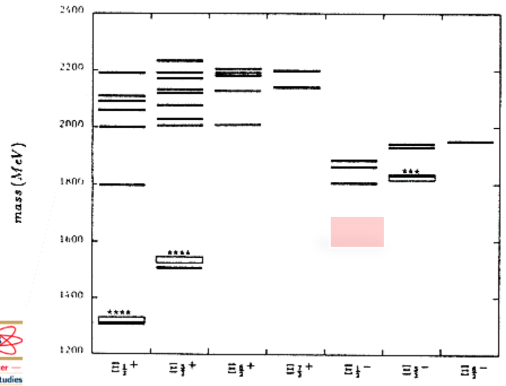


- If this state is analogue to $\overline{10}$
  then its intrinsic structure must be different,
  & its flavor structure must be different as well,
  could be 8.



- There are *no predictions* of $1/2^-$ in ChSA
  (no predictions for negative parity at all)

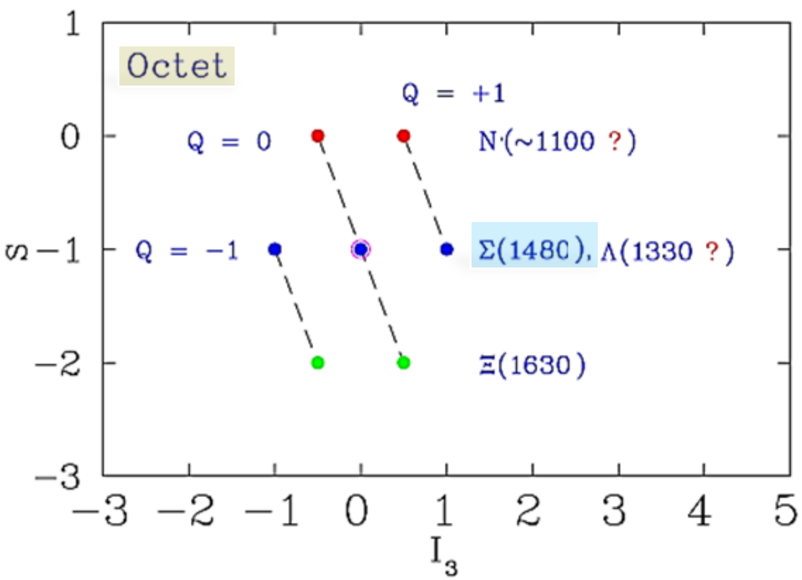




Ξ(1620)

S. Capstick & N. Isgur, Phys Rev D **34**, 2809 (1986)


Completeness of Unitary Multiplet



- Σ(1480), if exists, looks to be good partner of Ξ(1620).

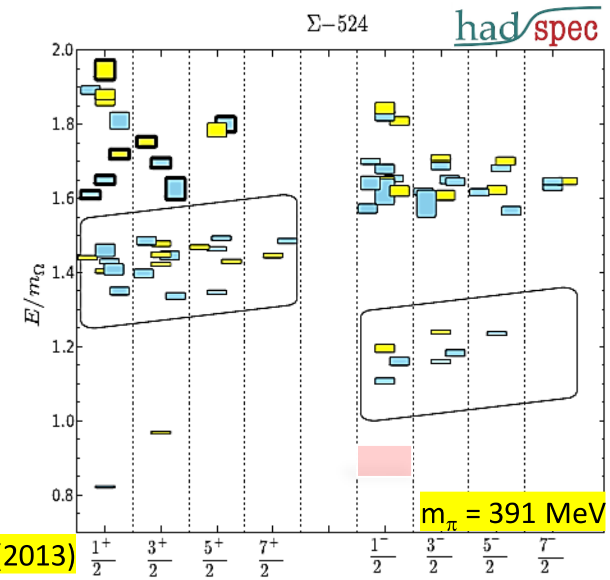
PDG particle data group for $\Sigma(1480)1(?^?)$ ⋆

Σ(1480) MASS (PRODUCTION EXPERIMENTS)

VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
≈ 1480 OUR ESTIMATE					
1480±15	365 ± 60	ZYCHOR	06	SPEC	$pp \to pK^+(\pi^\pm X^\mp)$
1480	120	ENGELEN	80	HBC	$K^- p \to (pK^0)\pi^-$
1485±10		CLINE	73	MPWA	$K^- d \to (\Lambda\pi^-)p$
1479±10		PAN	70	HBC	$\pi^+ p \to (\Lambda\pi^+)K^+$
1465±15		PAN	70	HBC	$\pi^+ p \to (\Sigma\pi)K^+$

Σ(1480) WIDTH (PRODUCTION EXPERIMENTS)

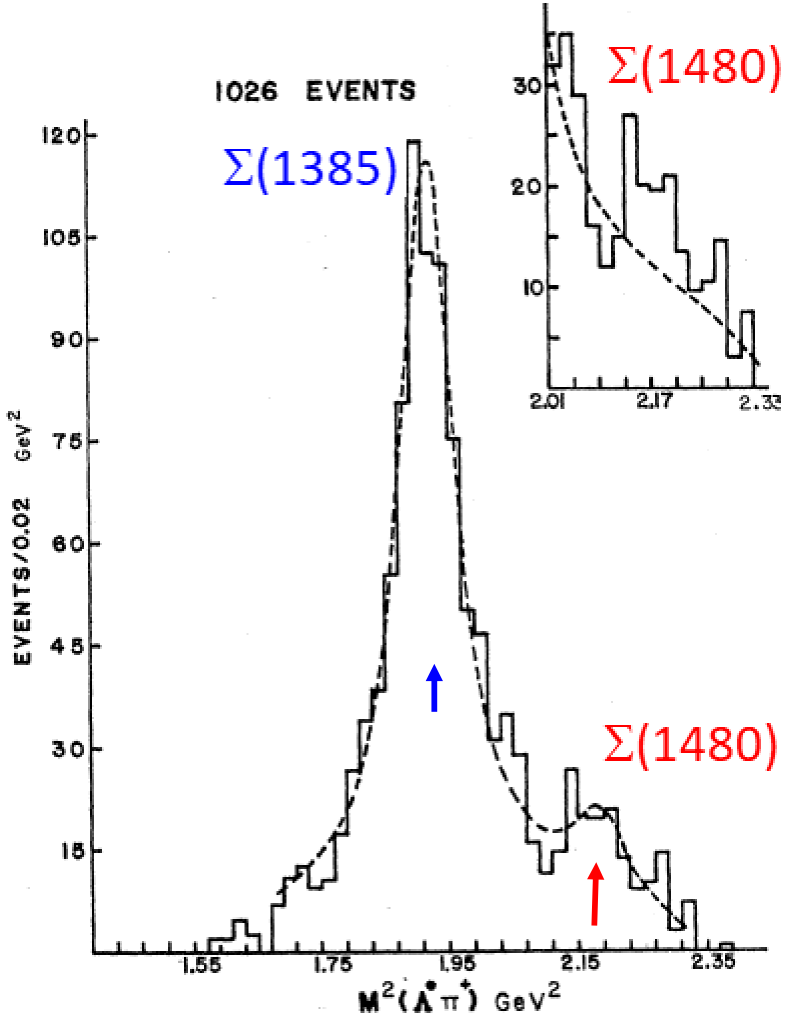
VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
60±15	365 ± 60	ZYCHOR	06	SPEC	$pp \to pK^+(\pi^\pm X^\mp)$
80±20	120	ENGELEN	80	HBC	$K^- p \to (p\overline{K}^0)\pi^-$
40±20		CLINE	73	MPWA	$K^- d \to (\Lambda\pi^-)p$
31±15		PAN	70	HBC	$\pi^+ p \to (\Lambda\pi^+)K^+$
30±20		PAN	70	HBC	$\pi^+ p \to (\Sigma\pi)K^+$

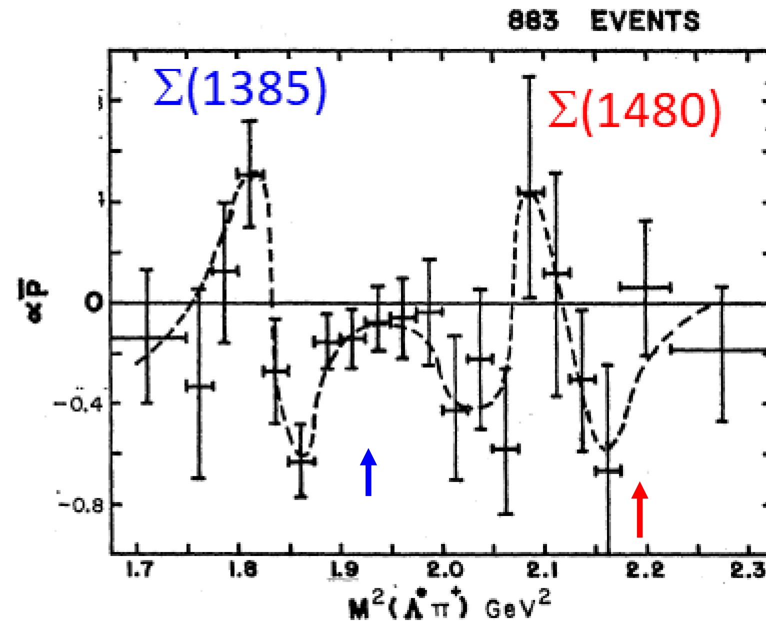


R. G. Edwards *et al*, Phys Rev D **87**, 054506 (2013)

$\Sigma(1480)$ via $\pi^+ p \rightarrow \pi^+ K^+ \Lambda$, $\pi^0 K^+ \Sigma^+$ from

Yu-Li Pan *et al*, Phys Rev D **2**, 449 (1970)





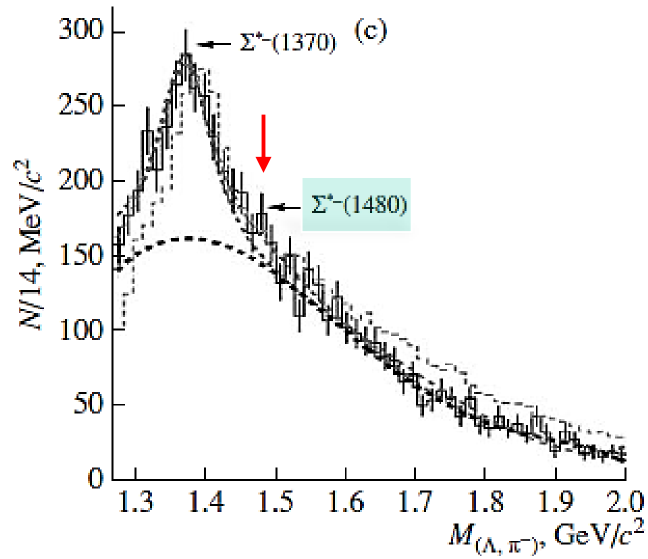
M = 1475±15 MeV Γ = 30±15 MeV

- Similar behavior for **true** resonance Σ(1385) & **suspected** Σ(1480).

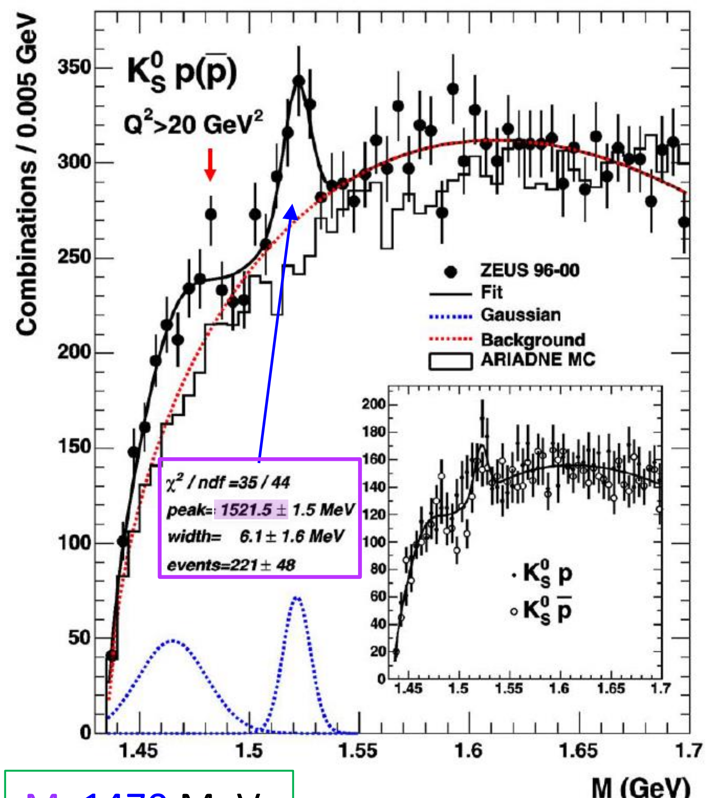
- Estimate statistical significance at **3σ**, or even **4σ,** for Σ(1480) both peak in **mass distribution** & **polarization** effect were reported.

$\Sigma(1480)$ via $e^+p \to e'K^0pX$ from

$\Sigma(1480)$ via $pC^{12} \to \Lambda\pi^- X$ from

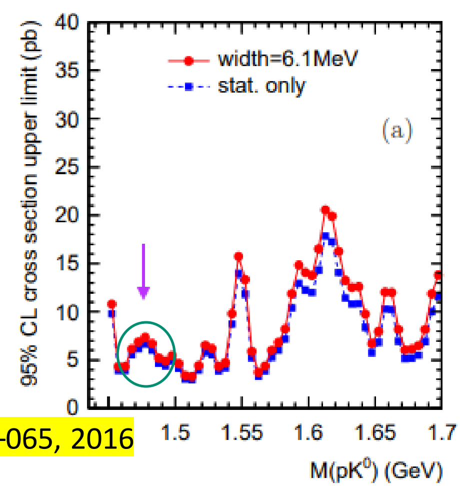


P. Zh. Aslanyan, Phys At Nucl **40**, 525 (2009)



M=1470 MeV
Γ ~ 30 MeV

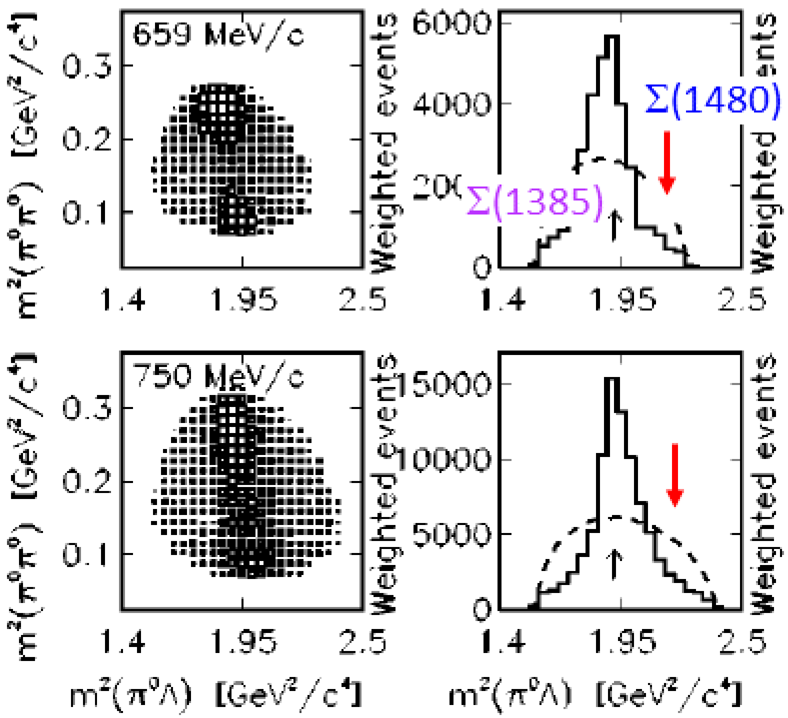
S. Chekanov *et al*, Phys Lett B **591**, 7 (2004)



H. Abramowicz *et al*, DESY–16–065, 2016

$\Sigma(1480)$ via $K^- p \to \pi^0 \pi^0 \Lambda$ from

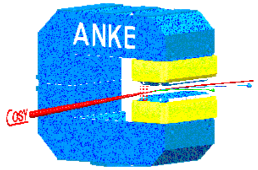
S. Prakhov *et al*, Phys Rev C **69**, 042202(R) (2004)



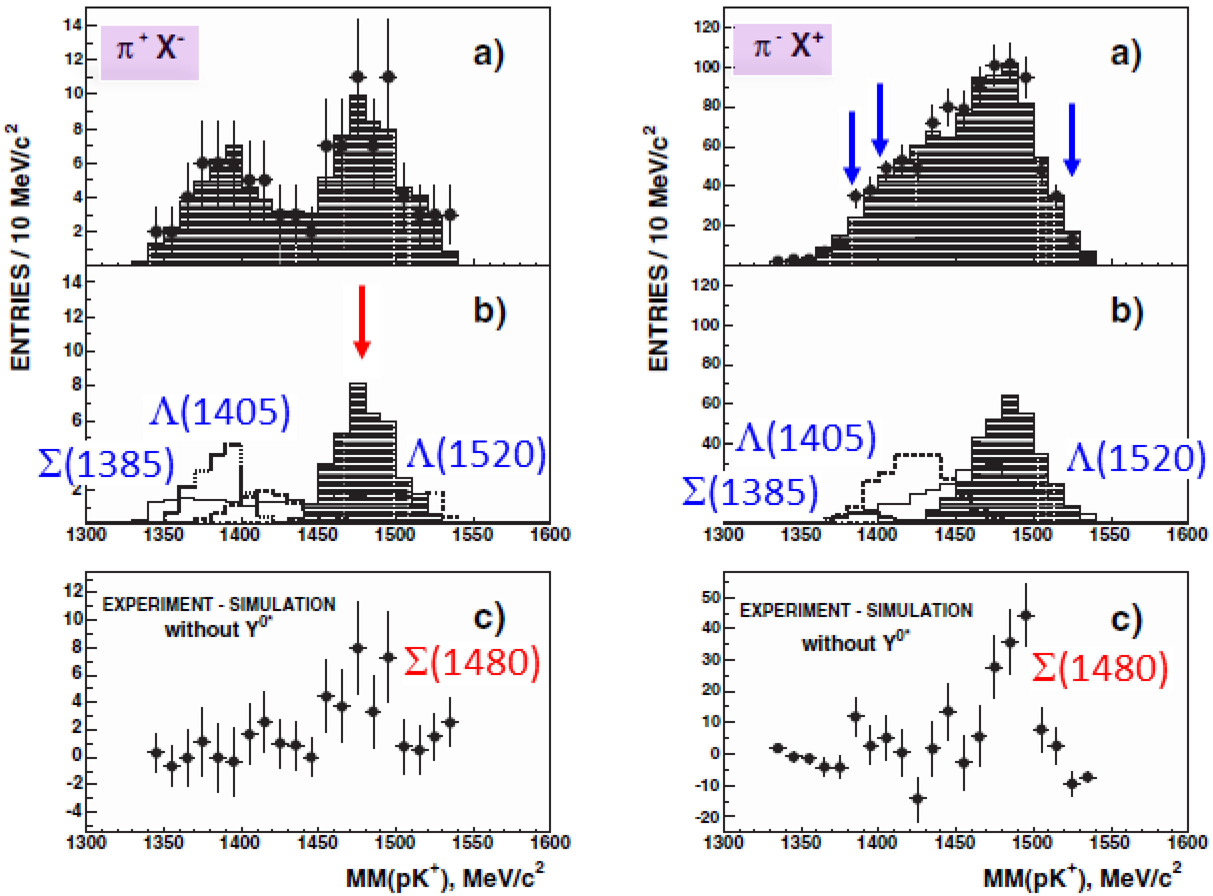
- *"In our data, we do not see trace of either $\Sigma(1480)$ or other light Σ^* states."*

- Case of $K^- p \to \pi^0 \pi^0 \Lambda$ is worse because of **two** identical **pions** @ **low K-momenta**.

$\Sigma(1480)$ via $pp \rightarrow K^+pX^0$ from



I. Zichor *et al*, Phys Rev Lett **96**, 012002 (2006)



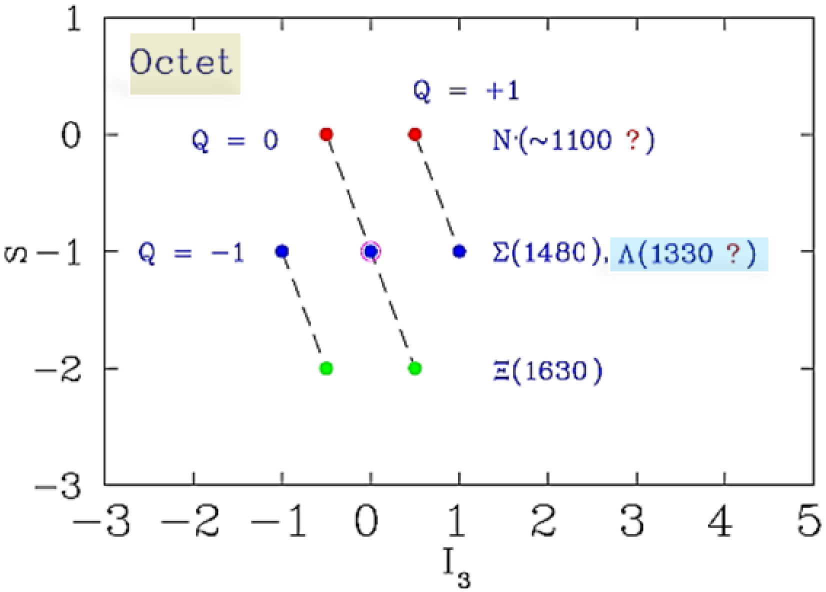
- Production **cross section** is of order of **few hundred nb**.

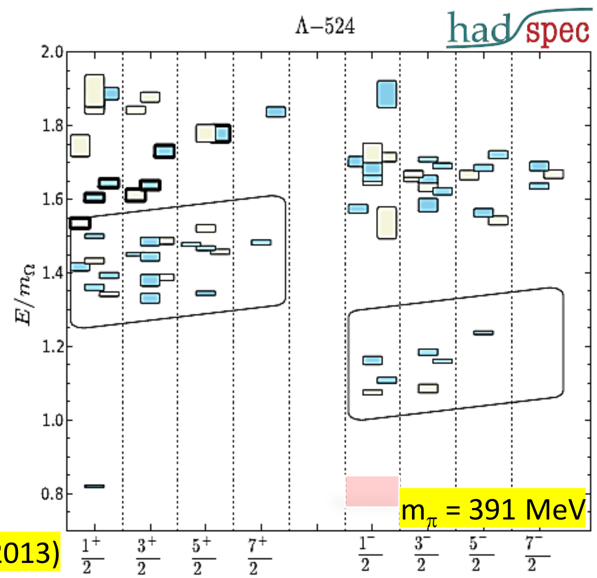
$M = 1480 \pm 15$ MeV $\quad \Gamma = 60 \pm 15$ MeV

365 $\pm$ 60 events

- Since **isospin** has not been determined here, it could either be observation of $\Sigma(1480)$, or, alternatively, $\Lambda(1480)$ – not listed in PDG.

Completeness of Unitary Multiplet





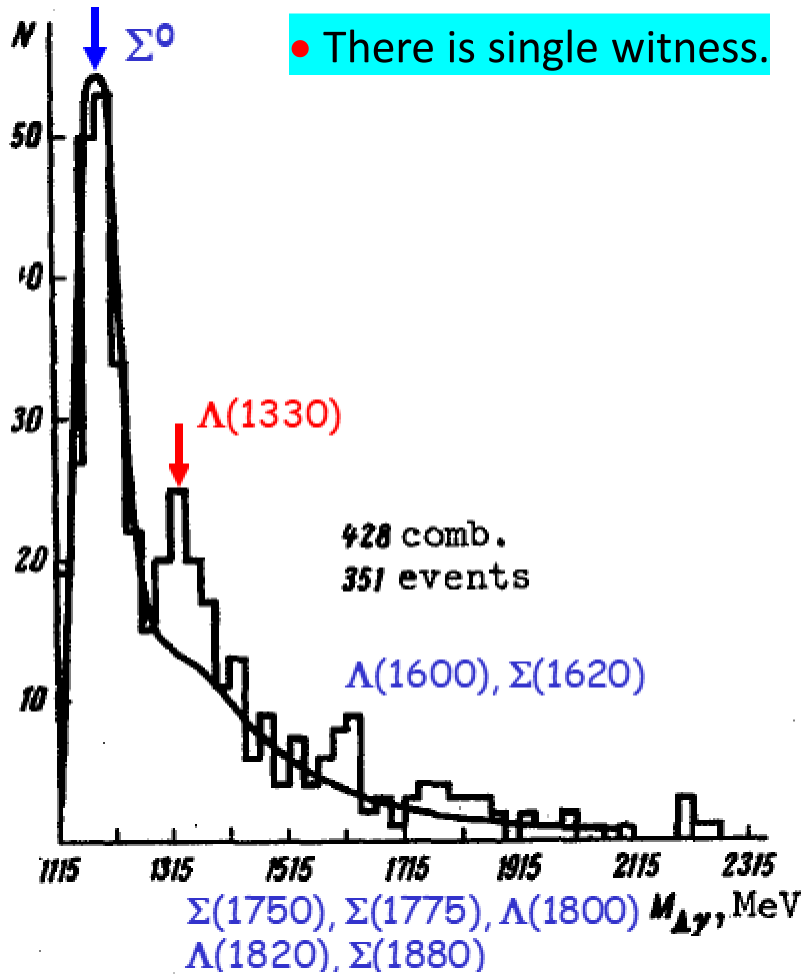
R. G. Edwards *et al*, Phys Rev D **87**, 054506 (2013)

$\Lambda(1330)$ via $\pi^- p \rightarrow \Lambda\gamma X^0$ from

JINR

G. Bozoki *et al*. Phys Lett **28B**, 360 (1968)
N.P. Bogachev *et al*, JETP Lett **10**, 105 (1969)

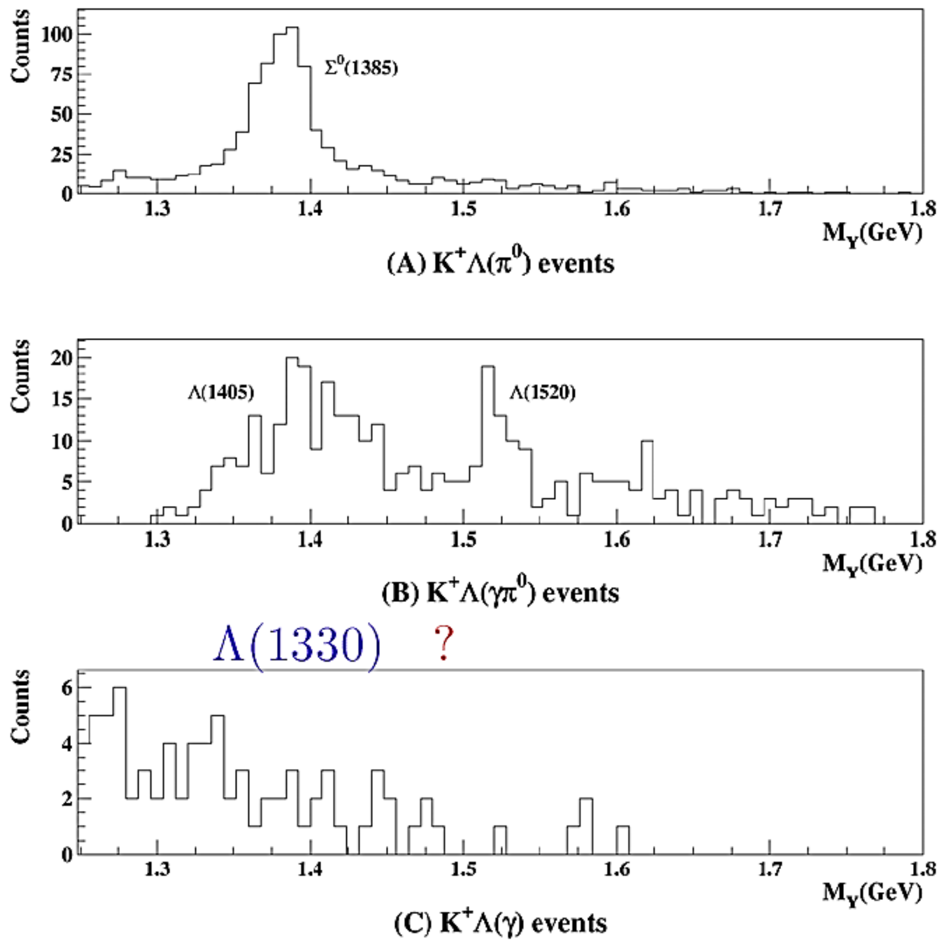
- There is single witness.



$M = 1327.5 \pm 3.5$ MeV
$\Gamma = 20.0 \pm 4.4$ MeV

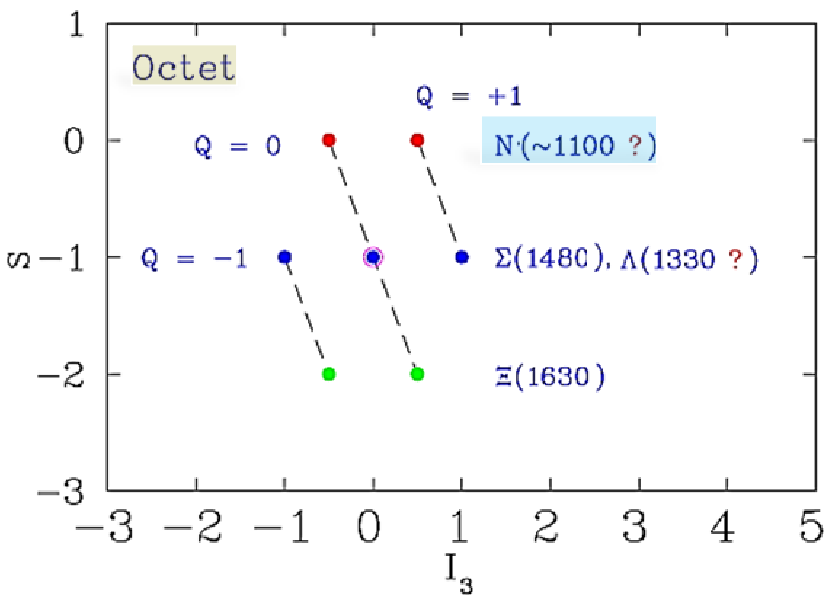
$\Lambda(1330)$ via $\gamma p \to K^+\Lambda X^0$ from CLAS

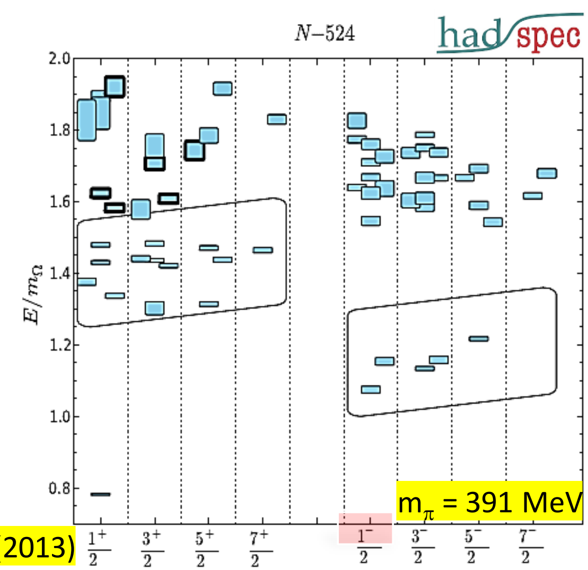
S. Taylor, Ph.D. Thesis, Rice U, May 2000



- No statistics !!

Completeness of Unitary Multiplet





R. G. Edwards *et al*, Phys Rev D **87**, 054506 (2013)

$\mathcal{N}'$ *below Pion Threshold via* $pp \rightarrow nX^{++}$ *from* TRIUMF

S. Ram *et al*, Phys Rev D **49**, 3120 (1994)

- Direct experimental searches for ***N'*** have begun rather recently.

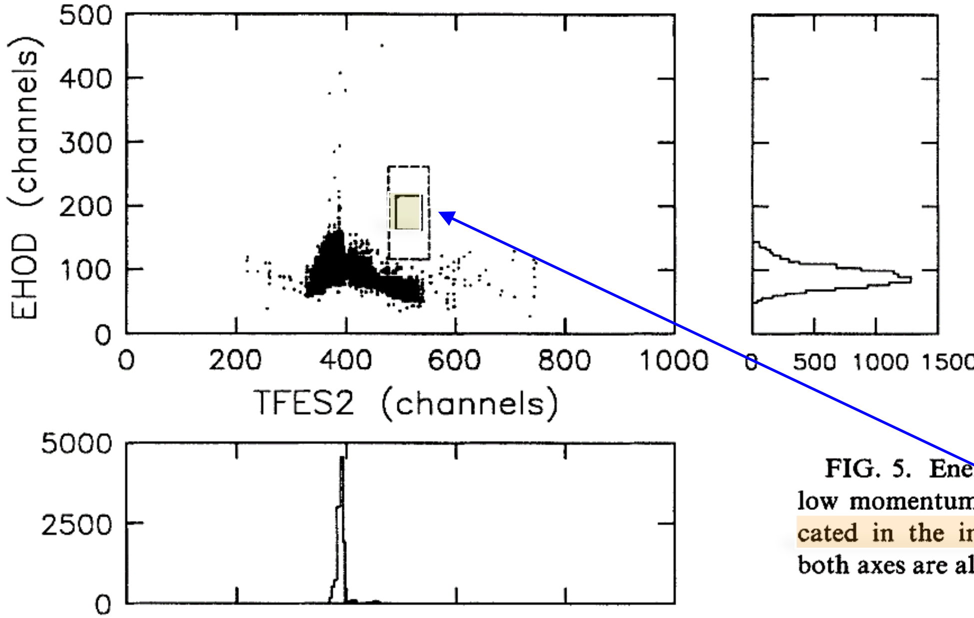
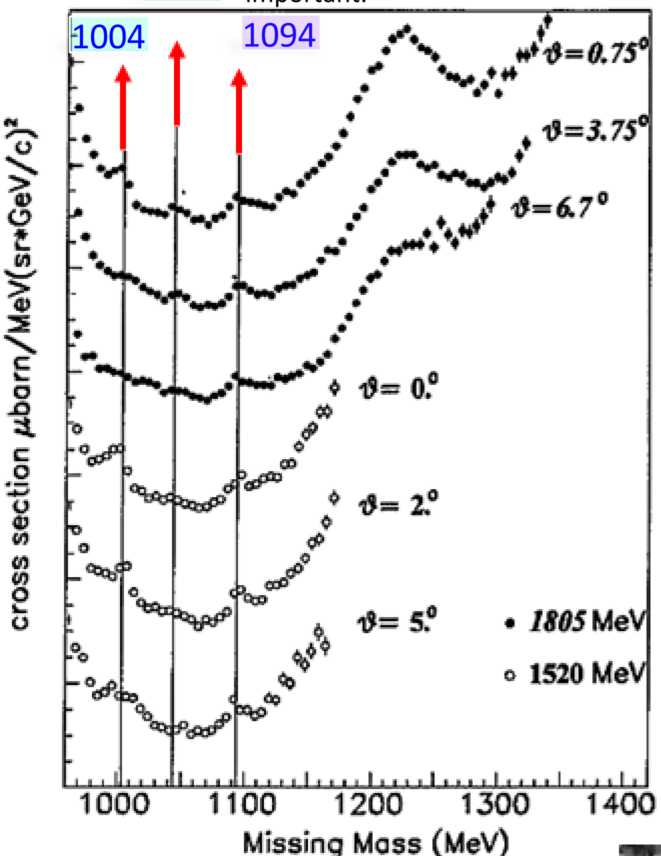


FIG. 5. Energy loss vs time-of-flight in the low momentum bite. The X^{++} should be located in the inner rectangle. Projections on both axes are also shown.

- **No baryon** was detected with **I=3/2** & $m_N < m_X < m_N + m_\pi$, & production cross section > $\mathbf{10^{-7}}$ of backward elastic **np** cross section

$pp \to \pi^+ p X^0$, $\mathcal{M}_X > 960$ MeV from
$pd \to ppX$ from

- **Two** of these could decay only **radiatively**, while for **3rd** (slightly above πN thr) radiative decay channel could also be important.

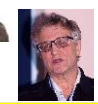


B. Tatischeff *et al*, Phys Rev Lett **79**, 601 (1997)
B. Tatischeff *et al*, Eur Phys J A **17**, 245 (2003)

- This study renewed interest, both theoretical & experimental, in subject.

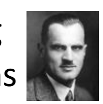
- If correct, such baryons would have **I=1/2**, masses of **1004**, **1044**, & **1094** MeV, & widths less than **4–15** MeV.

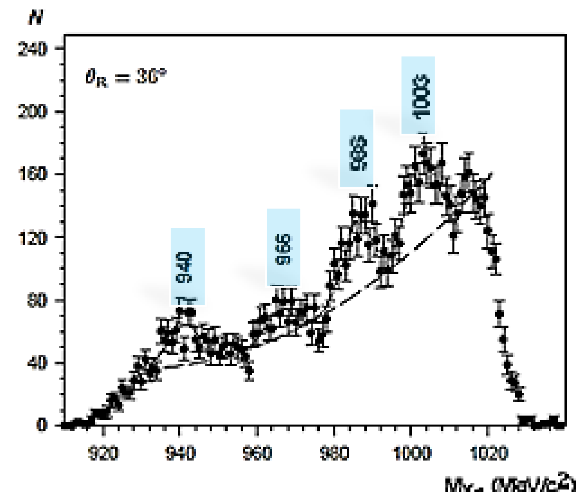
- Existence of these states was opposed in

A.I. L'vov & R.L. Workman, Phys Rev Lett **81**, 1346 (1998)

on basis of their **non-observation** in **Compton** scattering on protons or neutrons loosely bound in deuterons.

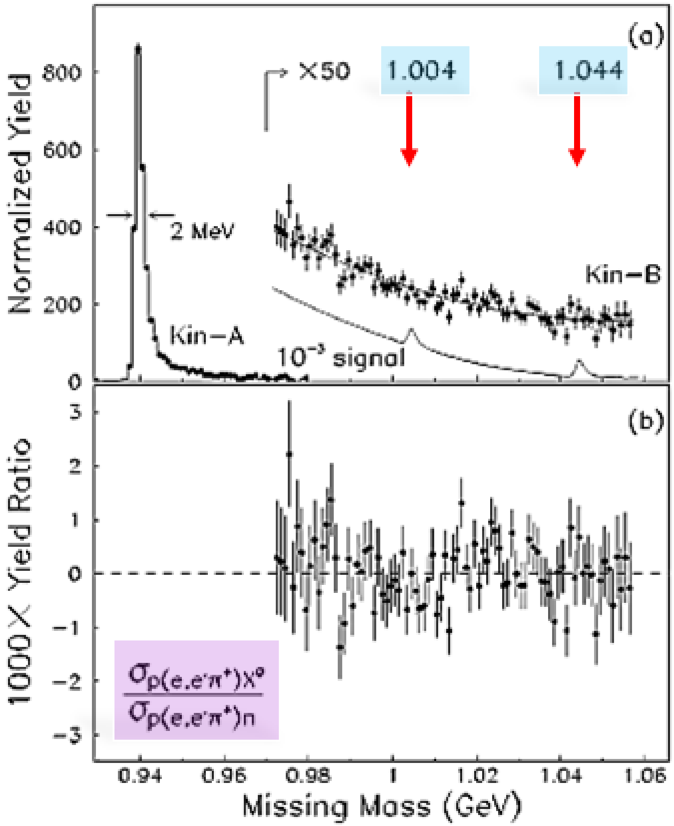




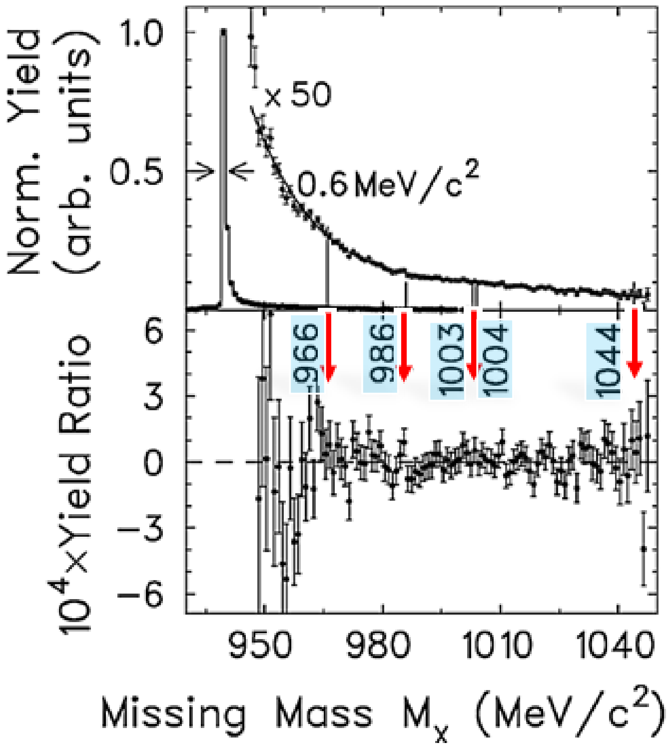
L. Fil'kov *et al*, Eur Phys J A **12**, 369 (2001)


ElectroProd @ Jefferson Lab *Hall A* for $ep \rightarrow e'\pi^+X^0$

ElectroProd @ A1 for $ep \rightarrow e'\pi^+X^0$ [$ed \rightarrow e'pX^0$]

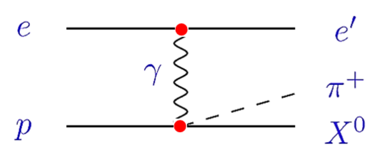


X. Jiang *et al*, Phys Rev C **67**, 028201 (2003)

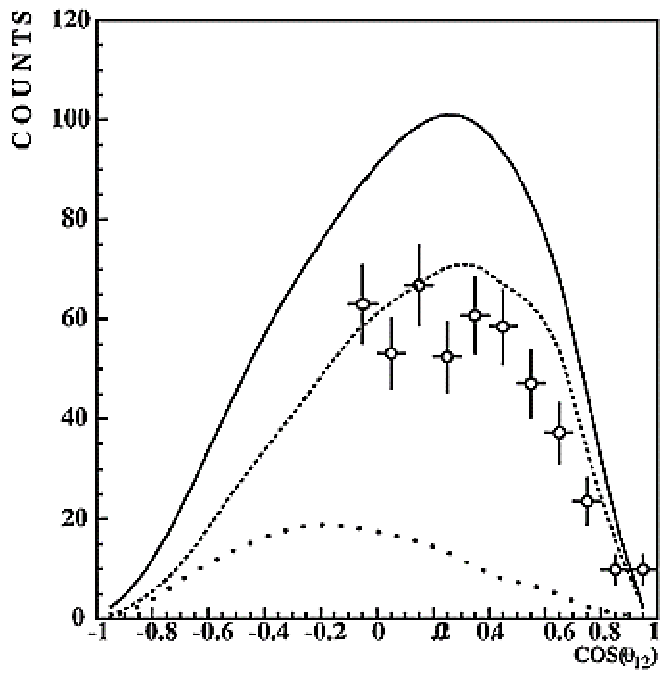


M. Kohl *et al*, Phys Rev C **67**, 065204 (2003)

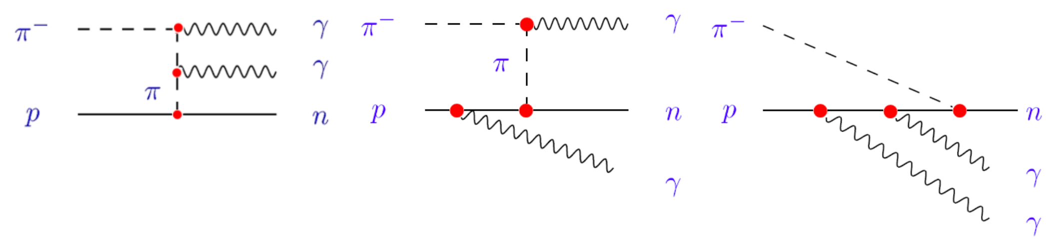
- No signals were found up to missing mass of about **1100** MeV @ level of **10⁻⁴**.



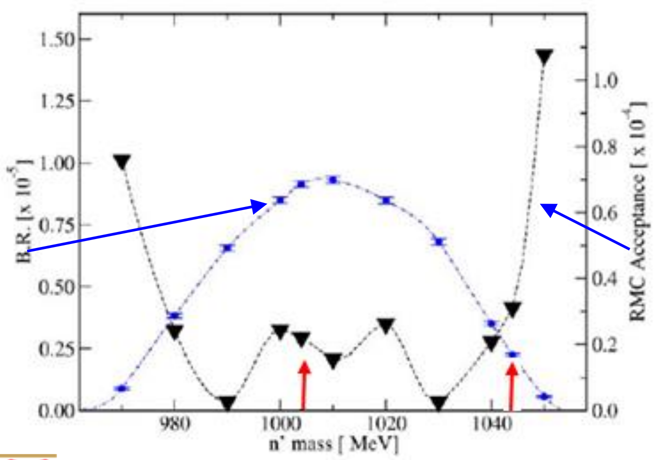
$\pi^- p \rightarrow n'\gamma \rightarrow n\gamma\gamma$ @ *rest from* TRIUMF



- BR($\pi^- p \rightarrow n\gamma\gamma$) = [3.05±0.27(stat)±0.31(syst)] x10^{-5}
- This means that up to stat & syst uncertainties (each about **10%**) there were no contributions of **n'** cascade.



S. Tripathi *et al*, Phys Rev Lett **89**, 252501 (2002)



- Thus **no evidence** (90% C.L.) for **n'**-mediated capture was found for 970 < $M_{n'}$ < 1050 MeV, measured spectrum being completely consistent with direct two photon capture only.

P.A. Zołnierczuk *et al,* Phys Lett B **597**, 131 (2004)

Narrow Resonances in [Modified] PWA

R. Arndt, Ya. Azimov, M. Polyakov, IS, R. Workman, Phys Rev C **69**, 035208 (2004)

- **Conventional PWA** (by construction) tends to miss **narrow Res** with Γ **< 20** MeV.

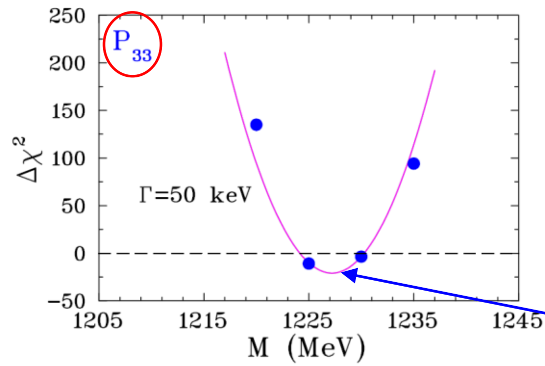
- We assume **existence** of narrower Resonance, **add** it to **amplitude**, then **re-fit** over **whole database** (~30k data for πN elastic).

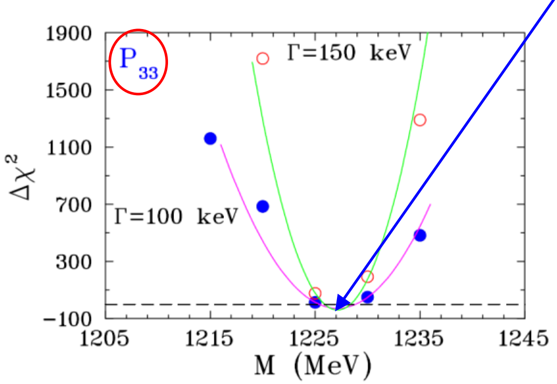
- **Refitting**
  - **If worse description**:
    - ⇒ Resonance with corresponding **M** & Γ is not supported.
  - **If better description**:
    - ⇒ Resonance **may** exist.
    - ⇒ Effect can be due to various corrections (*eg*, thresholds).
    - ⇒ Both possibilities can contribute.
  - Some additional checks are necessary.

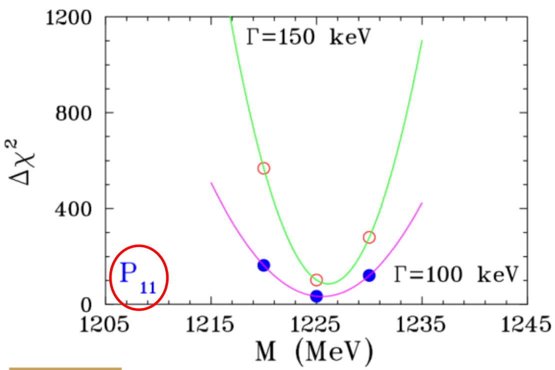
- **True Resonance** should provide effect only in **single** particular PW.

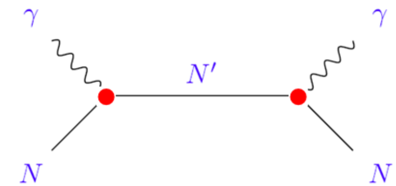
- While **non-Resonance** source may show similar effects in various PWs.

for (Quasi) Bound States of πN

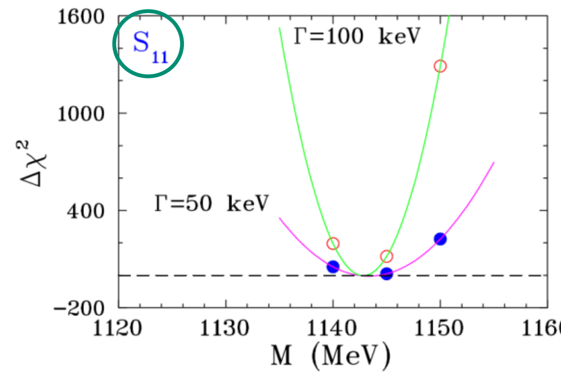








- This case is close to $\pi\pi N$ thr.



SAID:

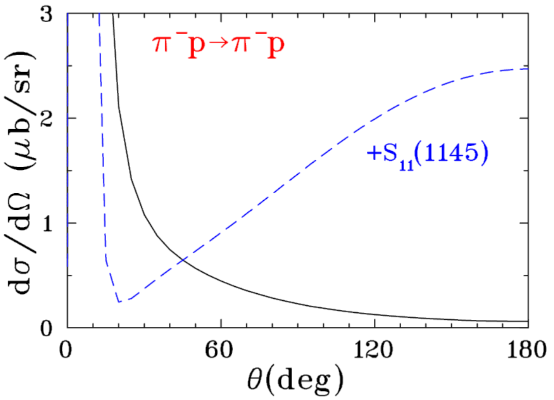
S-, P-, & D-waves

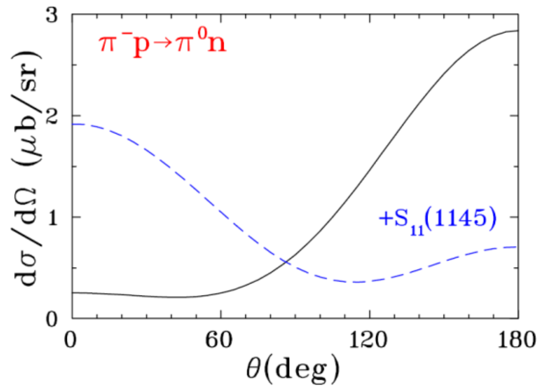
T_π = 0 – 500 MeV & gives χ^2 = 5805

M = 1100 – 1295 MeV & Γ = 50 – 300 keV

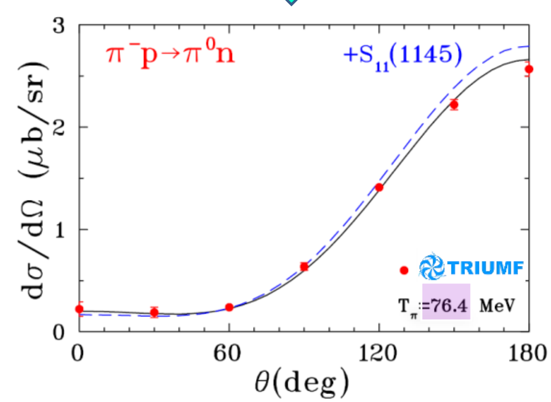
for (Quasi) Bound States of πN

S_{11}: M = **1145** MeV, Γ = **50** keV [T_π = **79.5** MeV]





ΔT = 3.1 MeV



- We find no evidence for elastic πN resonances in region between πN thr & 1300 MeV having width Γ **>** **50** keV.
- Present πN data cannot exclude even **purely elastic** (or inelastic) narrow resonances with Γ **<** **50** keV.
- Insertion of **trial** narrow resonances may be good "technical trick" to check quality of PWA **fit** to set of experimental data.

- Who can solve this puzzle **?**

Boundaries for N' below/above πN Threshold

Ya. Azimov, R. Arndt, IS, R. Workman, Phys Rev C **68**, 045204 (2003)

Purely Hadronic

$$\frac{g^2_{\pi NN'}}{g^2_{\pi NN}} < 10^{-2} \qquad \Gamma_{N'} < 50\ keV$$

GW INS Data Analysis Center, Institute for Nuclear Studies, The George Washington University

$$\frac{\sigma(pp \to nX^{++})}{\sigma(pn \to np)} < 10^{-7} \qquad [\frac{\Gamma_{N'}}{\Gamma_\Delta} < 4\ 10^{-4}]$$

TRIUMF

$$\frac{\sigma(pp \to \pi^+ pX^0)}{\sigma(pp \to \pi^+ pn)} \sim 10^{-3} - 10^{-4} \quad ?$$

Jefferson Lab, Thomas Jefferson National Accelerator Facility

Hadronic & EM

$$\frac{W(\pi^- p \to n'\gamma)}{W(\pi^- p \to n\gamma)} <\sim 10^{-5}$$

TRIUMF

$$\Gamma_{N' \to N\gamma} < 5\ eV \qquad Br^2_\gamma\, \Gamma_{p'} < 10\ eV$$

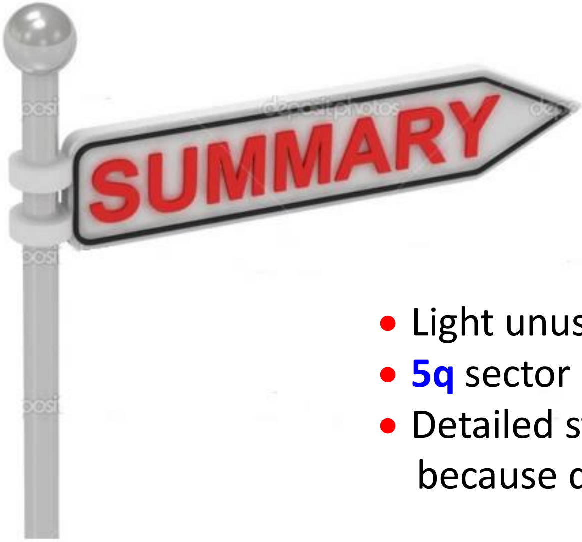
GW INS Data Analysis Center, Institute for Nuclear Studies, The George Washington University

$$\frac{Y(ep \to e'\pi^+ X^0)}{Y(ep \to e'\pi^+ n)} < 10^{-4} \qquad [\frac{Br_\gamma\, \Gamma_{p'}}{Br_\gamma\, \Gamma_\Delta} < 3\ 10^{-3}]$$

Jefferson Lab, Thomas Jefferson National Accelerator Facility

$$\frac{Y(ed \to e'pX^0)}{Y(ed \to e'pn)} < 10^{-4}$$

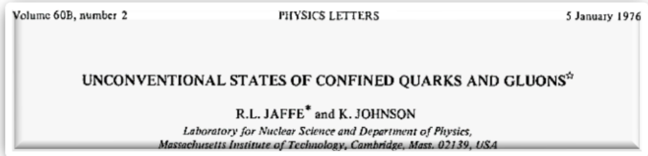
A1



Spectroscopy of Baryons

- Light unusual resonances have no place in **3q** sector.
- **5q** sector could accept them.
- Detailed study is required
  because question of exotics is still active.

- *`…<u>either</u> these states will be found by experimentalists or our confined, quark-gluon theory of hadrons is as yet lacking in some fundamental, dynamical ingredient which will forbid the existence of these states or elevate them to much higher masses.'*


Volume 60B, number 2 PHYSICS LETTERS 5 January 1976

UNCONVENTIONAL STATES OF CONFINED QUARKS AND GLUONS☆

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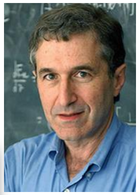
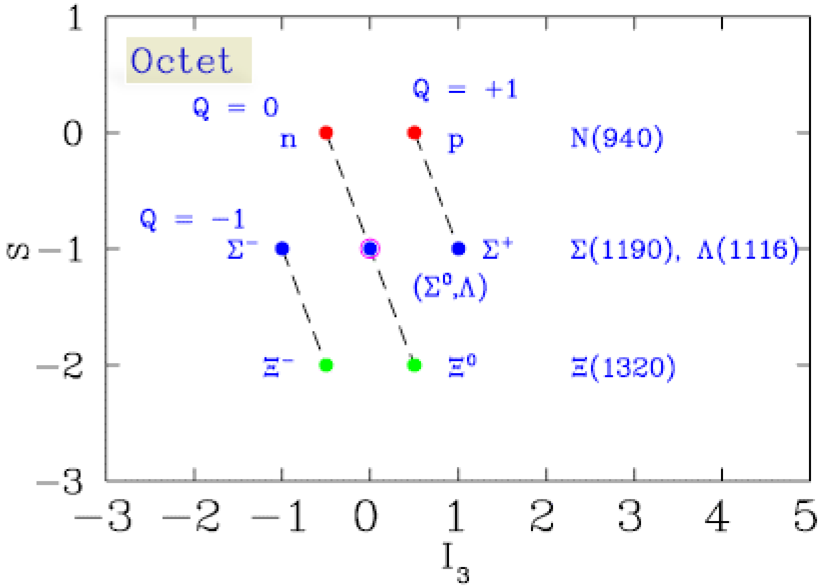
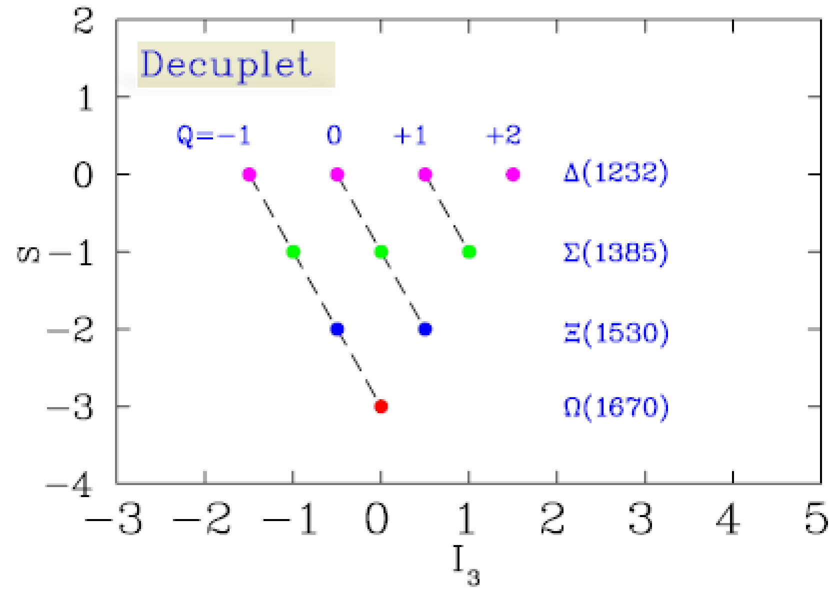


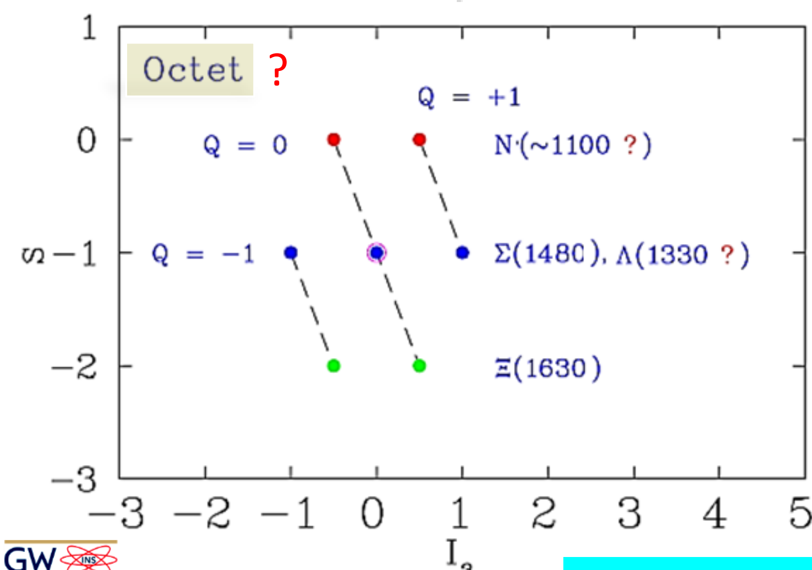
- Production of multiquark hadrons may be **new kind of hard processes**; it is related with **higher Fock components**.

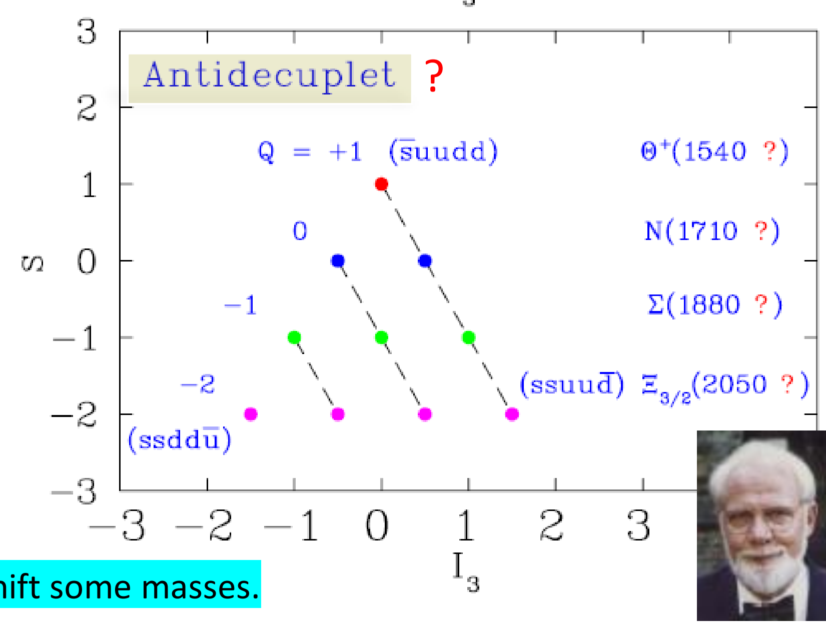
- This our **hypothesis** may suggest **new experiments**.

Unitary $SU(3)_F$ Multiplets









- Mixing is able to shift some masses.