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.

Supported by DE-SC0016583

Where Did N' From

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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

Ya. I. Azimov*
Petersburg Nuclear Physics Institute, Gatchina St. Petersburg 188300, Russia

R. A. Arndt,† I. I. Strakovsky,‡ and R. L. Workman§
Center for Nuclear Studies, Department of Physics, The George Washington University, Washington, D.C. 20052, USA

- 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.

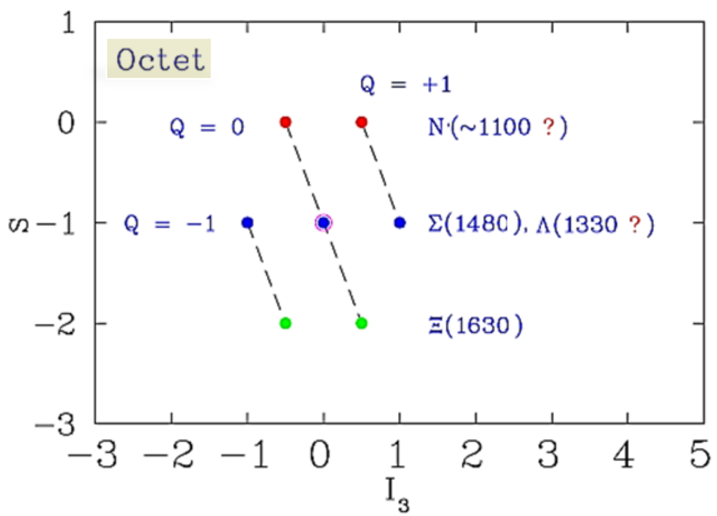
- PDG has **109 Baryon Resonances** (**64** of them are **4*** & **3***).
- In case of **SU(6) x O(3)**, **434** states would be present if all revealed multiplets were fleshed out (**three 70** and **four 56**).

- 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)



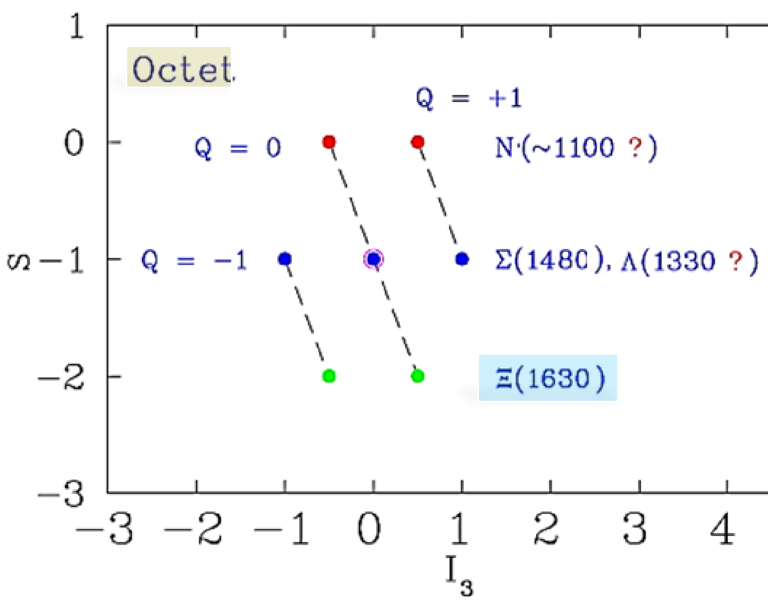
- Gell-Mann-Okubo **mass formula**.
- **Mixing** is able to **shift** some masses.

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 ~(α/π)².

Completeness of Unitary Multiplet

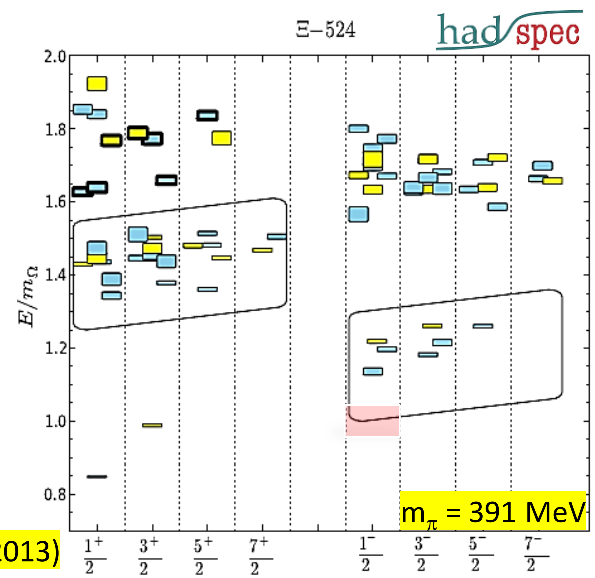


$\Xi(1620)$ MASS

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	$K^- p \to \Xi^- \overline{K} \pi$
1606 ± 6	29	ROSS	72	HBC	$K^- p$ 3.1–3.7 GeV/c

$\Xi(1620)$ 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	$K^- p \to \Xi^- \overline{K} \pi$
21 ± 7	29	ROSS	72	HBC	$K^- p \to \Xi^- \pi^+ K^{*0}(892)$

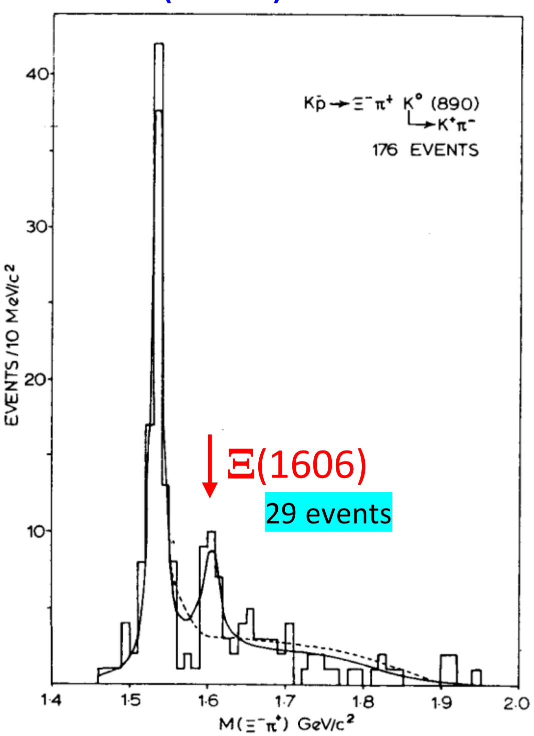


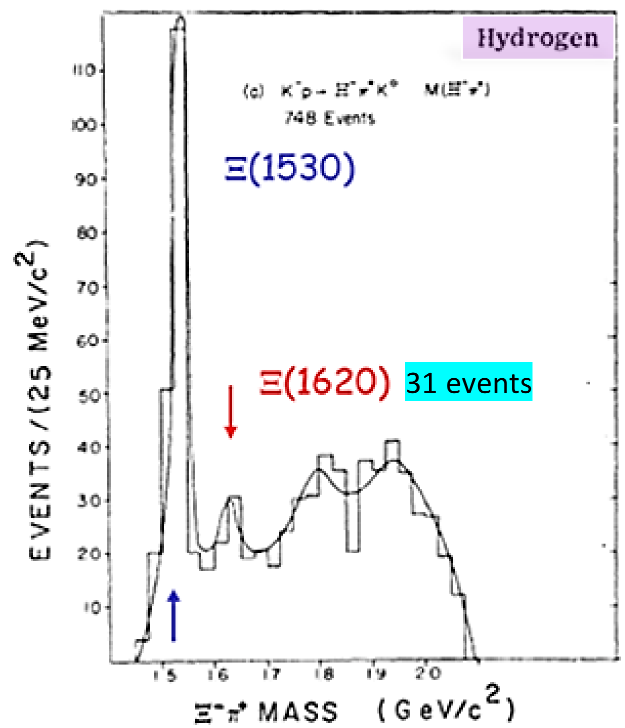
R. G. Edwards *et al*, Phys Rev D **87**, 054506 (2013)

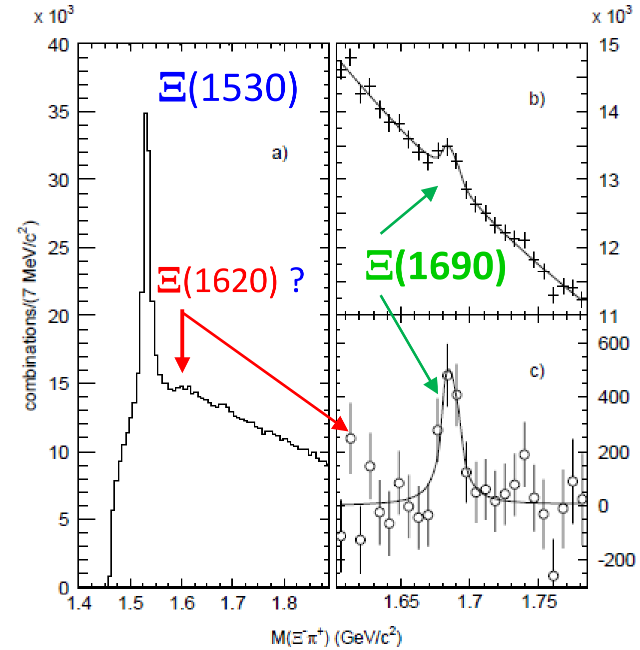
$\Xi(1606)$ via $K^- p \rightarrow \Xi^- \pi^+ K^{*0}(892)$ from CERN

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

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







M = 1605.5±5.6 MeV
Γ = 20.8±7.4 MeV

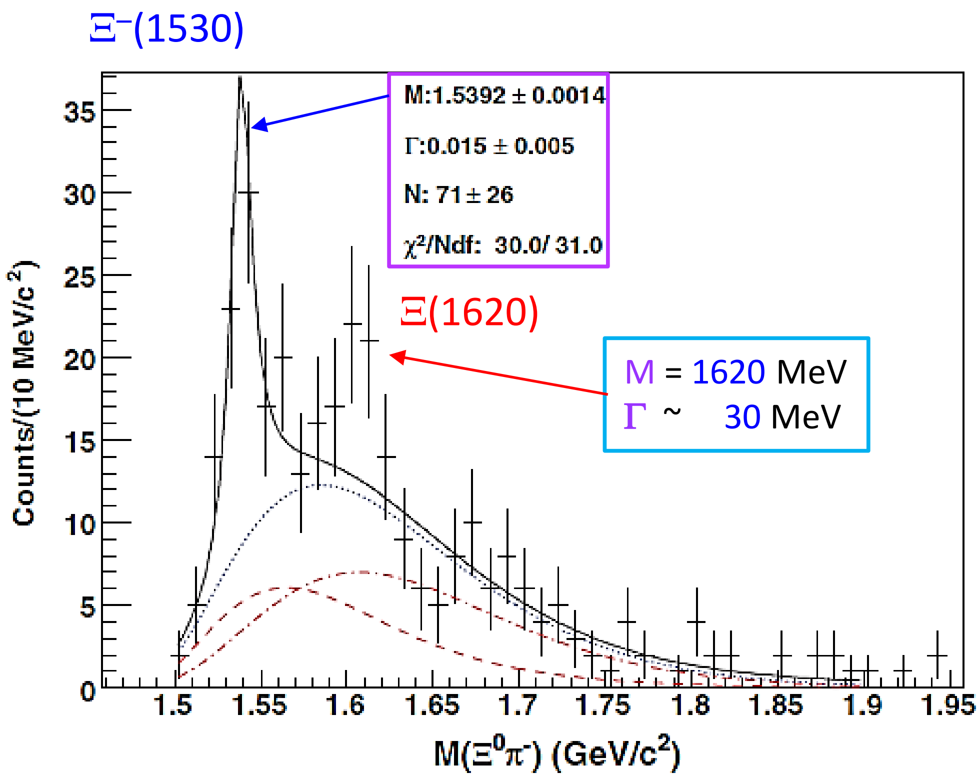
M = 1624±3 MeV
Γ = 22.5 MeV

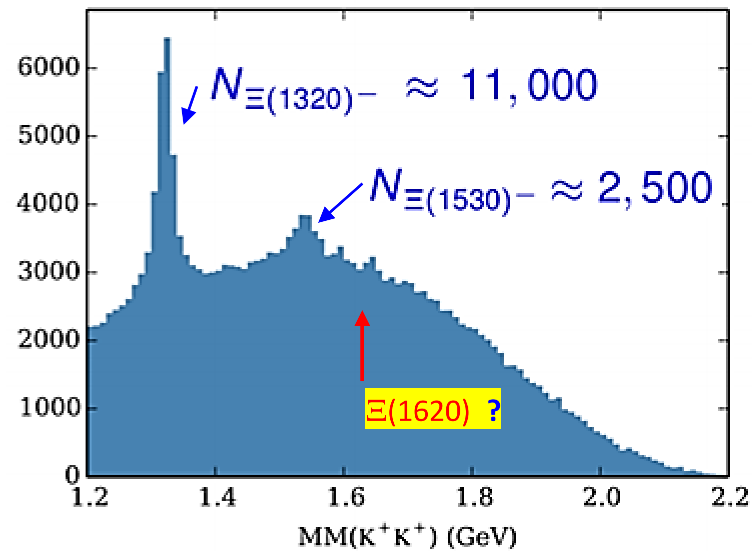
M.I. Adamovich *et al*, Eur Phys J C **5**, 621 (1998)

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



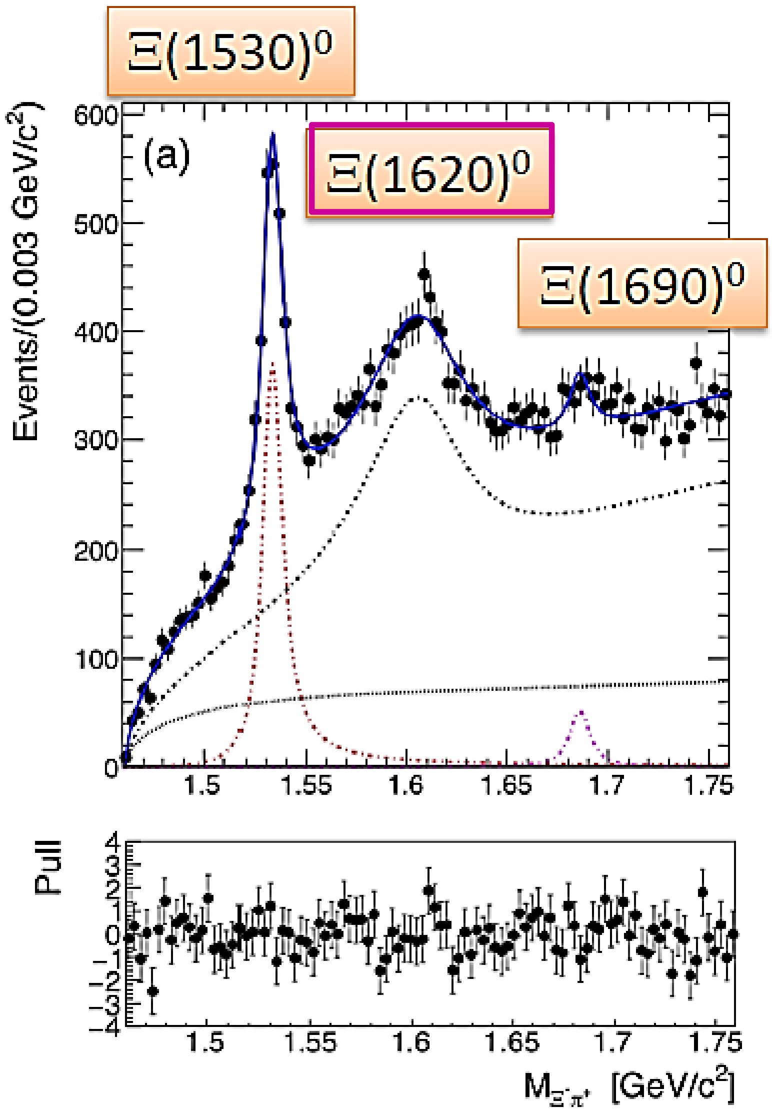


L. Guo *et al*, Phys Rev C **76**, 025208 (2007)

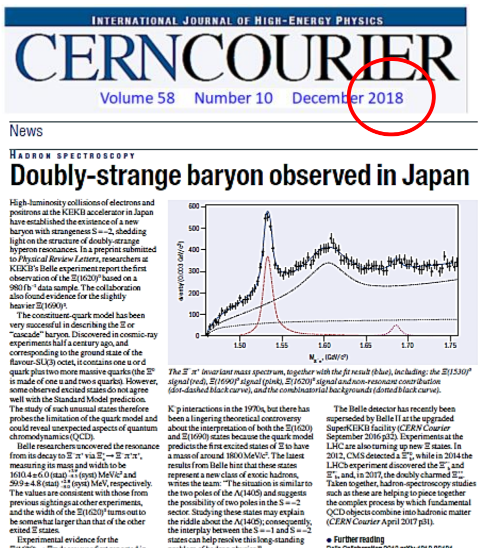
J.T. Goetz *et al*, Phys Rev C **98**, 062201 (2018)

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

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



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


International Journal of High-Energy Physics
CERN COURIER
Volume 58 Number 10 December 2018

News

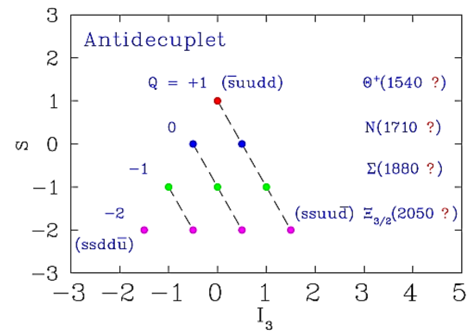
Hadron spectroscopy

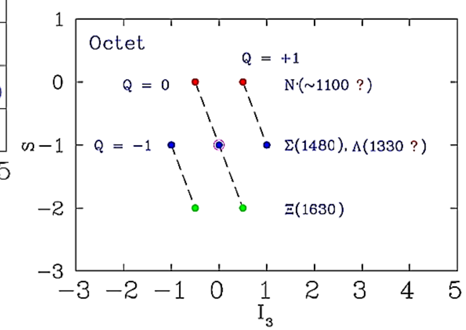
Doubly-strange baryon observed in Japan

Invariant mass spectrum in sideband region.

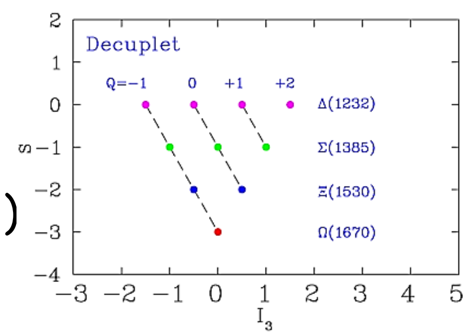
Possible Nature of Ξ(1620)

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

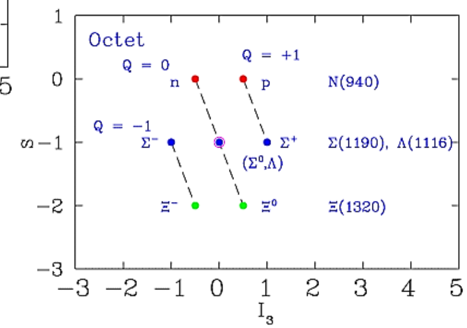


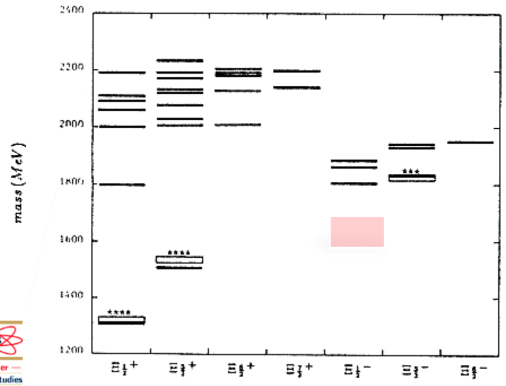


- If this state is analogue to $\overline{10}$
  then its intrinsic structure must be different,
  & its flavor structure must be different as well,
  could be 8.



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



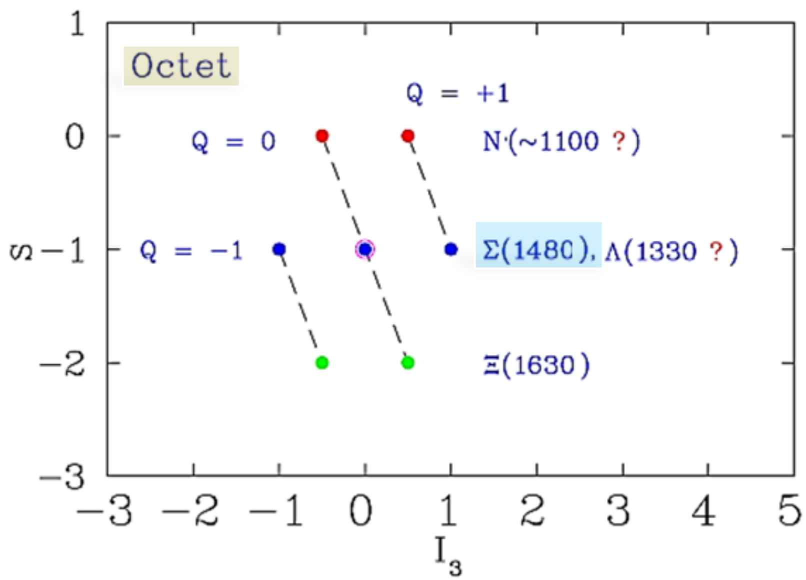


Ξ(1620)

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

GW INS — Data Analysis Center — Institute for Nuclear Studies THE GEORGE WASHINGTON UNIVERSITY

Completeness of Unitary Multiplet



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

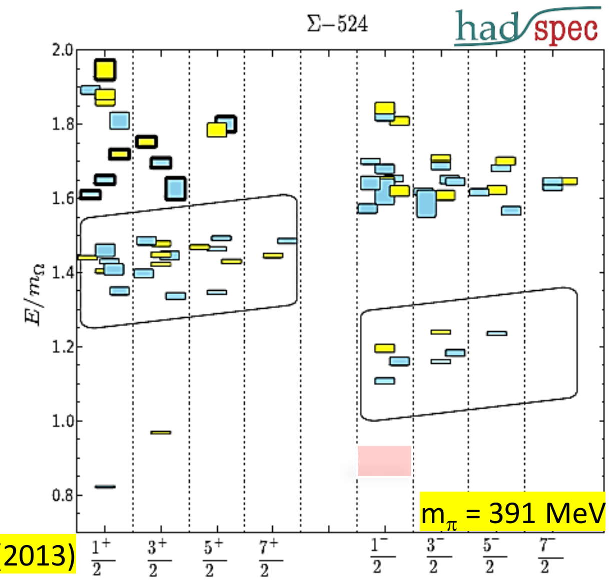
for $\Sigma(1480)1(?^?)$ ☆

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	$K^- p \to (p\overline{K}^0)\pi^-$
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)

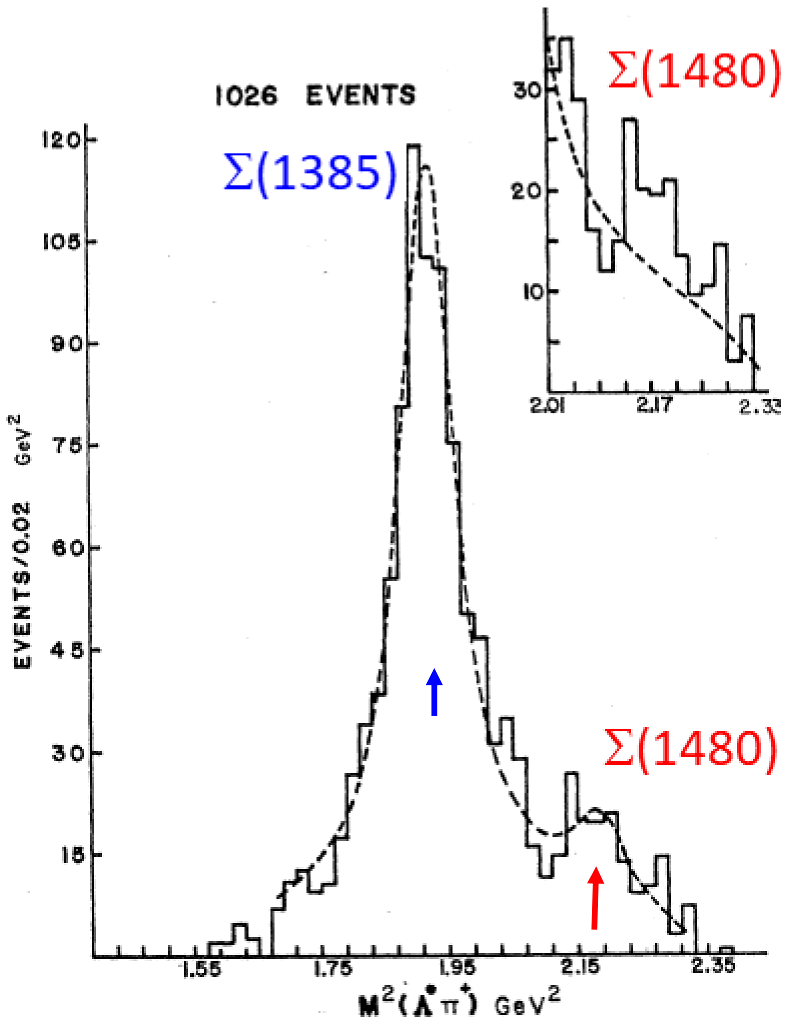
VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
60±15	365 ± 60	ZYCHOR	06	SPEC	$pp \to pK^+(\pi^\pm X^\mp)$
80±20	120	ENGELEN	80	HBC	$K^- p \to (p\overline{K}^0)\pi^-$
40±20		CLINE	73	MPWA	$K^- d \to (\Lambda\pi^-)p$
31±15		PAN	70	HBC	$\pi^+ p \to (\Lambda\pi^+)K^+$
30±20		PAN	70	HBC	$\pi^+ p \to (\Sigma\pi)K^+$

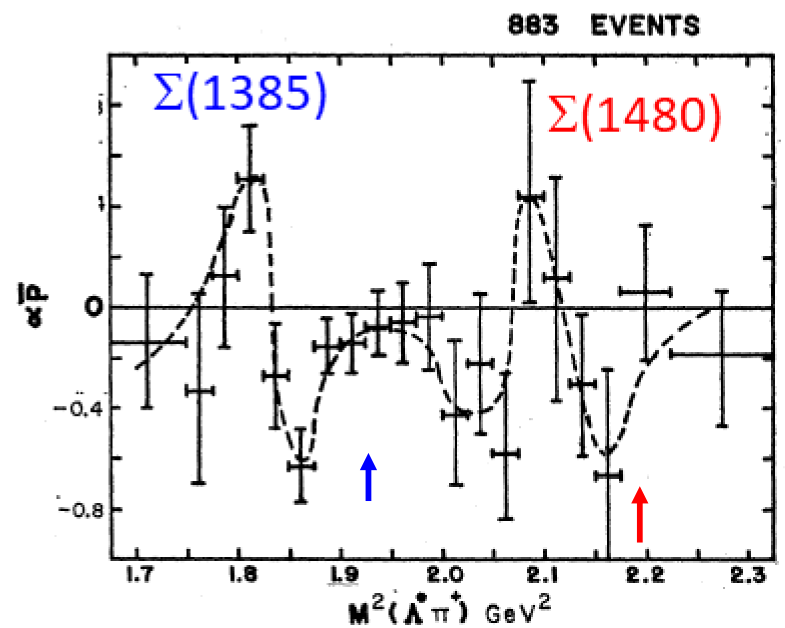


R. G. Edwards *et al*, Phys Rev D **87**, 054506 (2013)

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

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





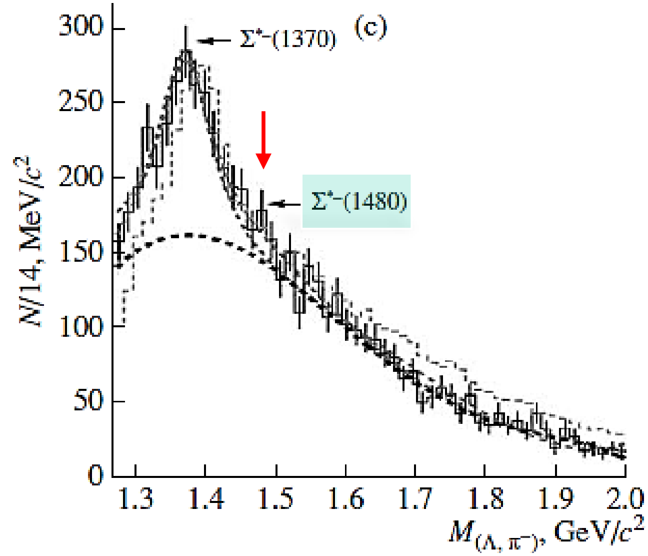
$M = 1475 \pm 15$ MeV $\Gamma = 30 \pm 15$ MeV

- Similar behavior for **true** resonance $\Sigma(1385)$ & **suspected** $\Sigma(1480)$.

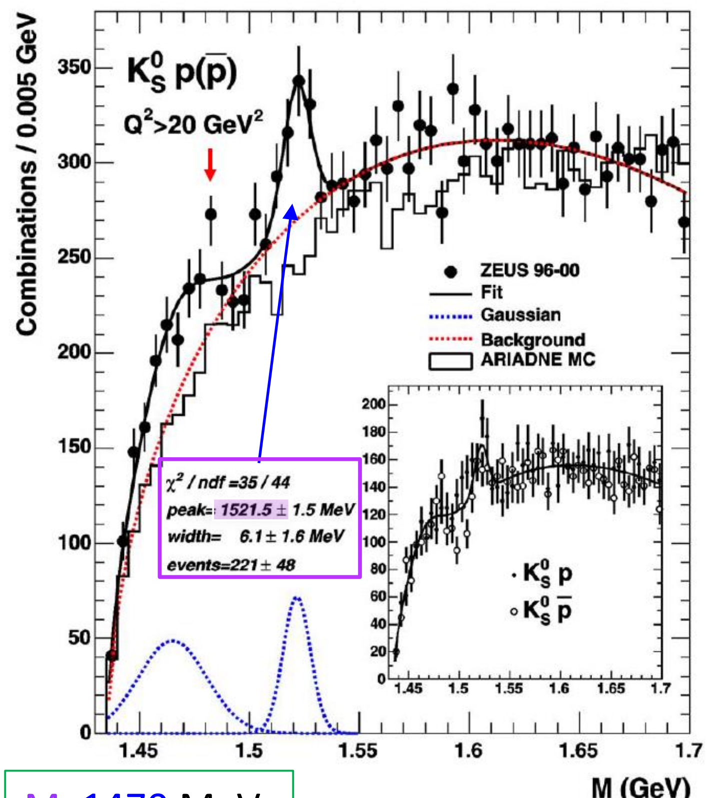
- Estimate statistical significance at **3σ**, or even **4σ,** for $\Sigma(1480)$ both peak in **mass distribution** & **polarization** effect were reported.

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

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

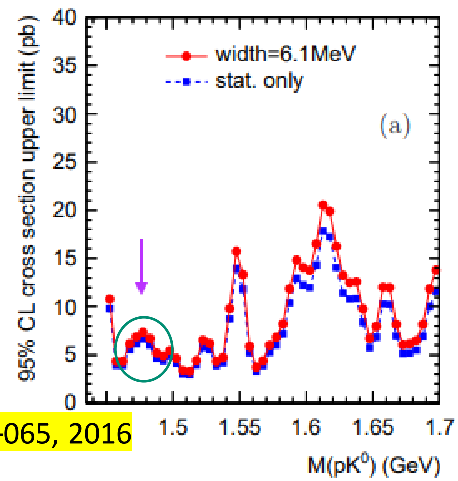


P. Zh. Aslanyan, Phys At Nucl **40**, 525 (2009)



M=1470 MeV
Γ ~ 30 MeV

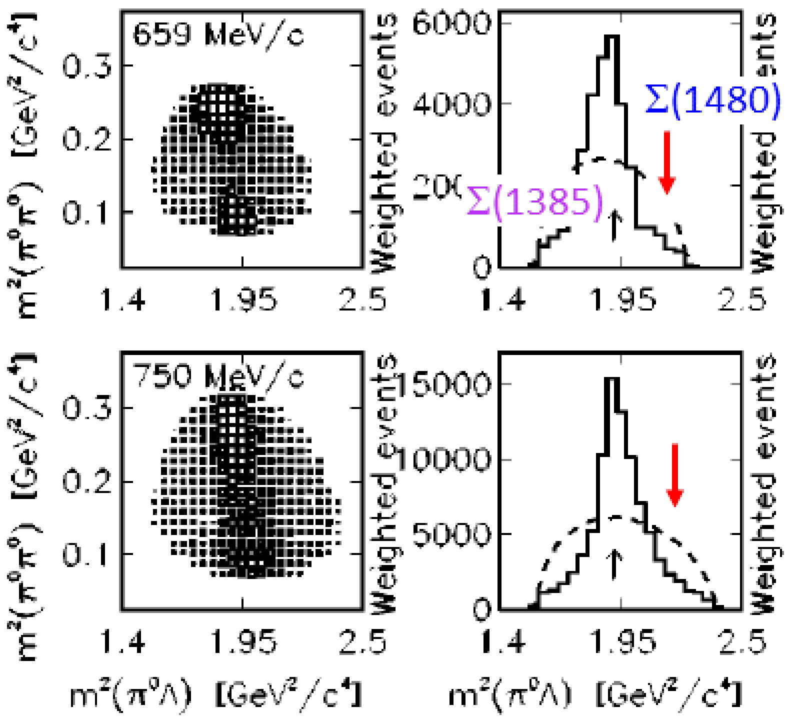
S. Chekanov *et al*, Phys Lett B **591**, 7 (2004)



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

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

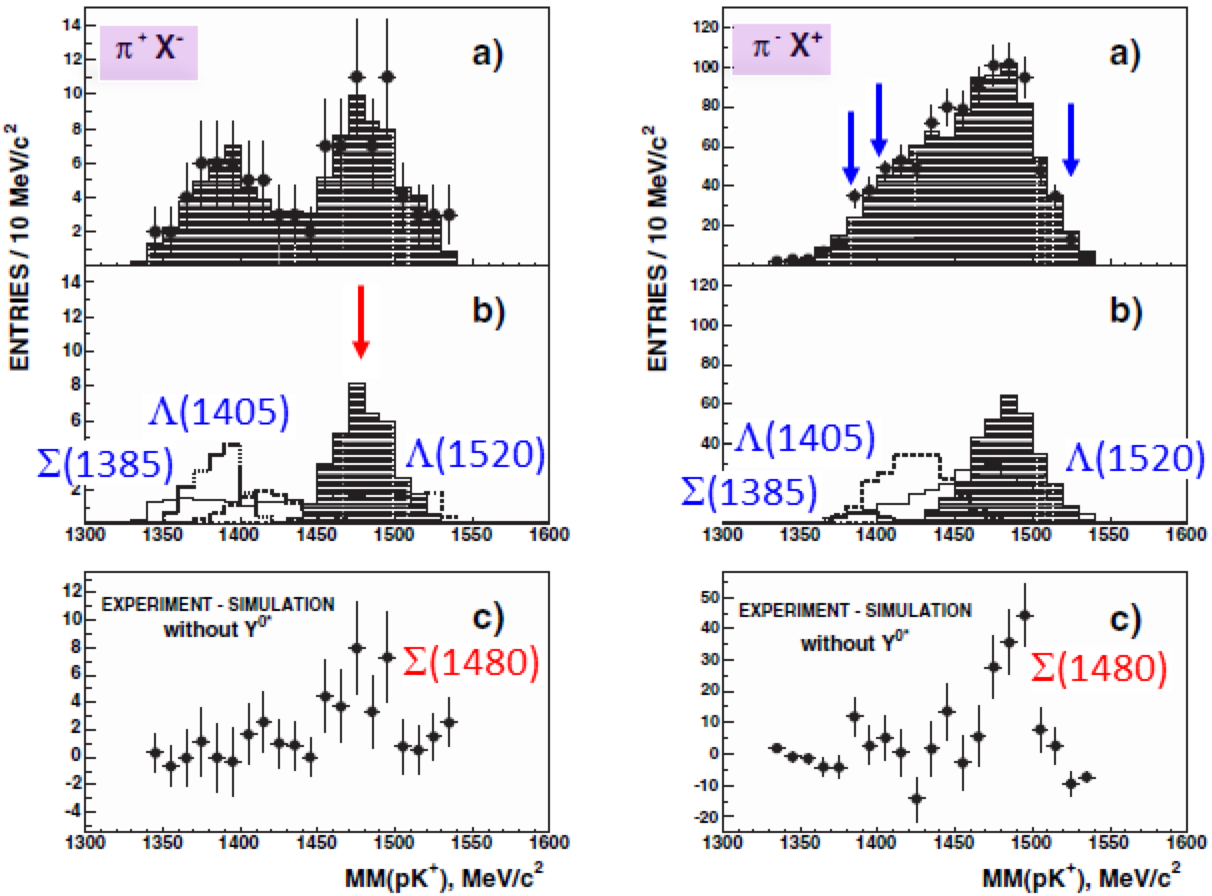
S. Prakhov *et al*, Phys Rev C **69**, 042202(R) (2004)



- *"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 $pp \to K^+ p X^0$ from ANKE

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



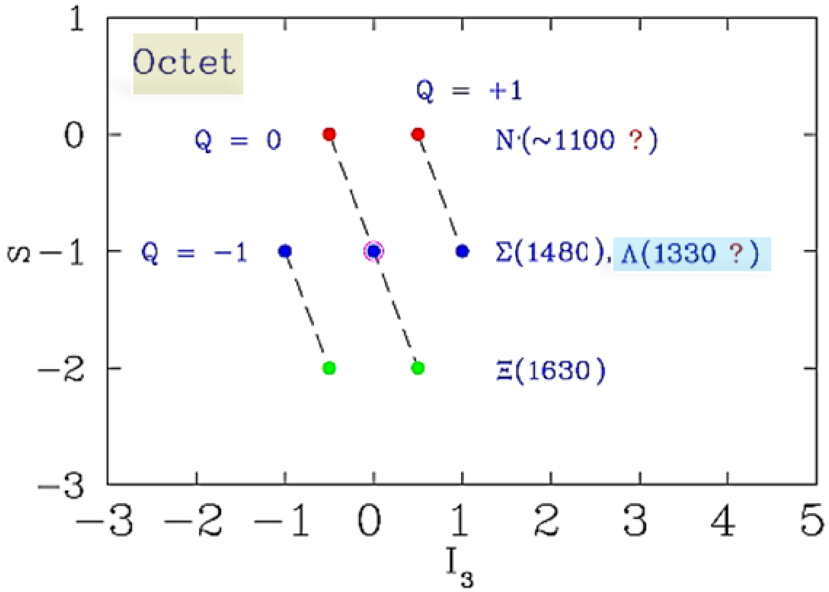
- Production **cross section** is of order of **few hundred nb**.

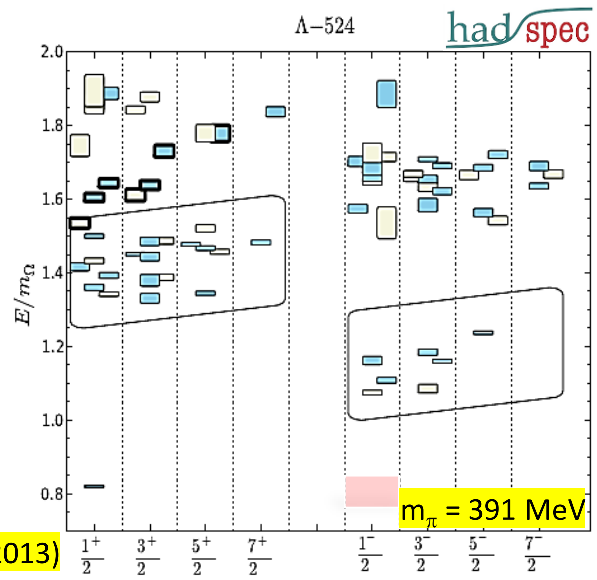
$M = 1480 \pm 15$ MeV $\quad \Gamma = 60 \pm 15$ MeV

365 ± 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



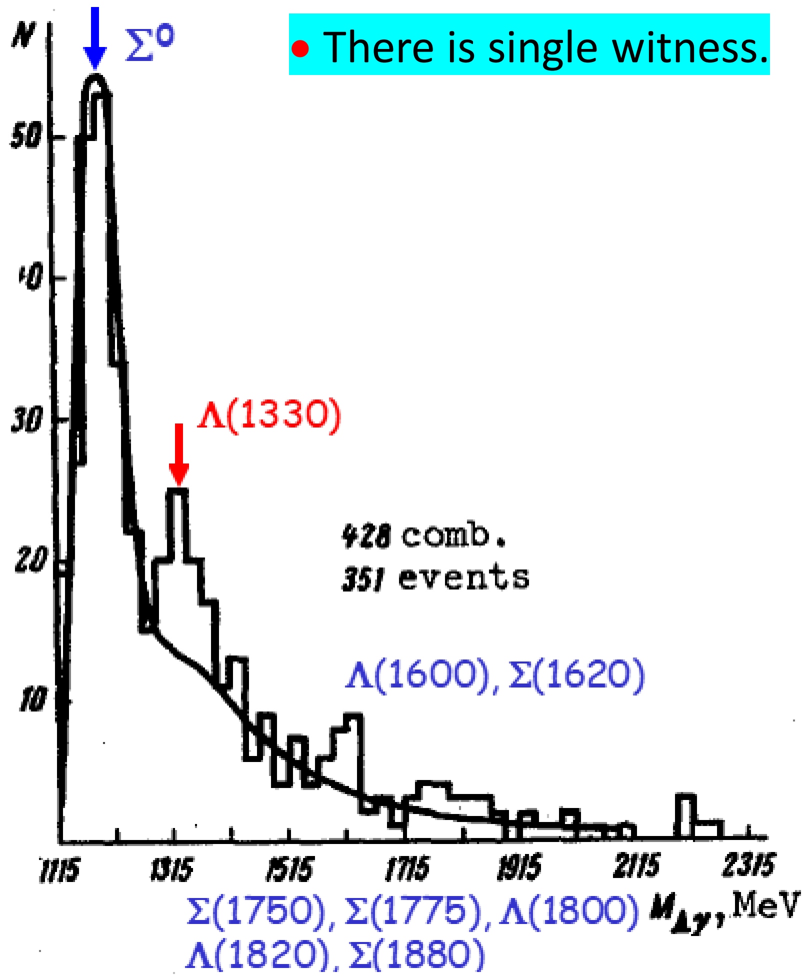


R. G. Edwards *et al*, Phys Rev D **87**, 054506 (2013)

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

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

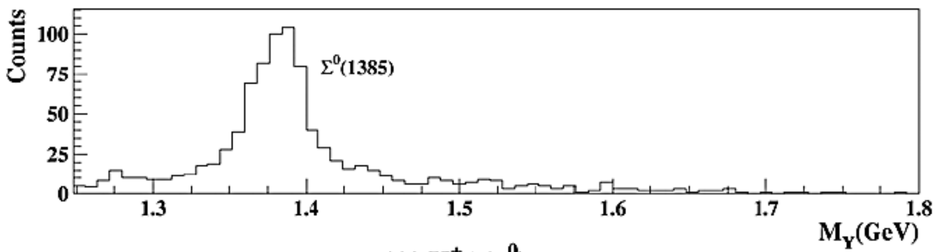
- There is single witness.



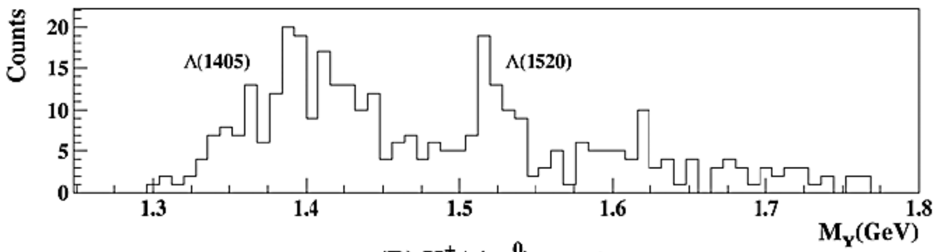
$M = 1327.5 \pm 3.5$ MeV
$\Gamma = 20.0 \pm 4.4$ MeV

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

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

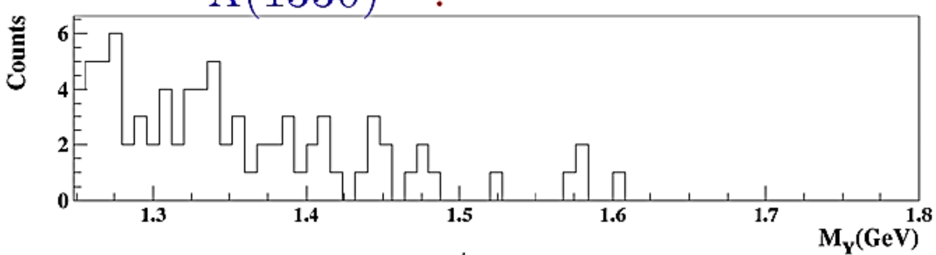


(A) $K^+\Lambda(\pi^0)$ events



(B) $K^+\Lambda(\gamma\pi^0)$ events

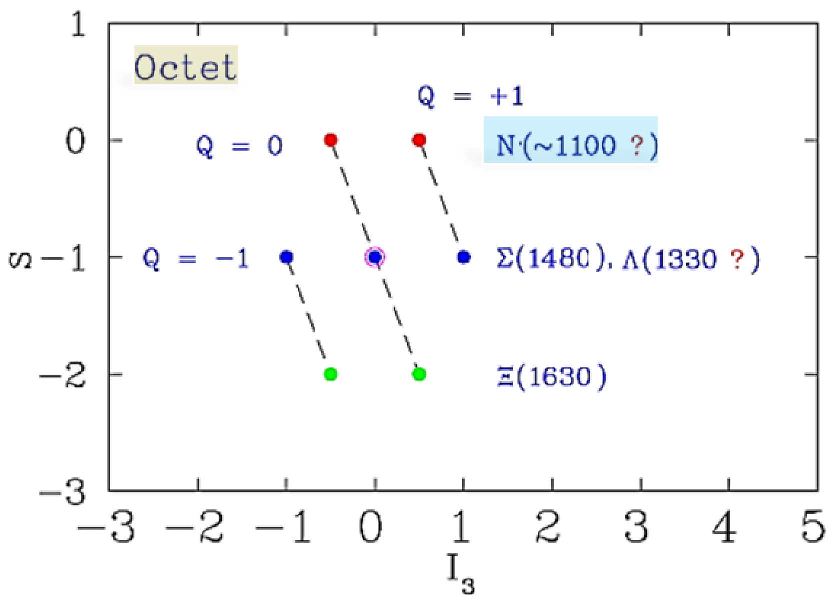
$\Lambda(1330)$?

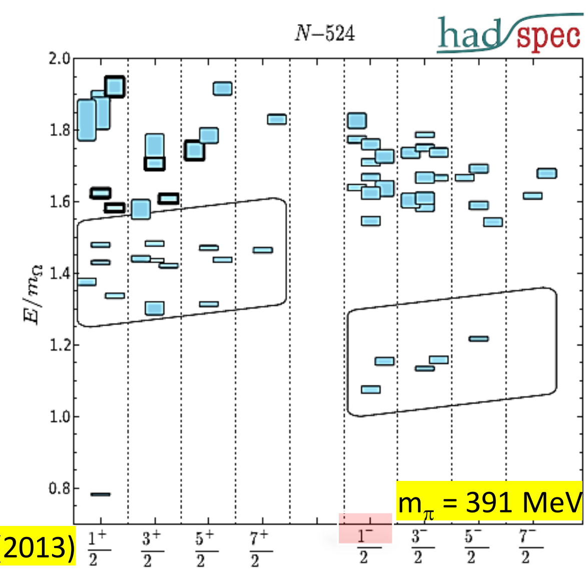


(C) $K^+\Lambda(\gamma)$ events

- No statistics **!!**

Completeness of Unitary Multiplet





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

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

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

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

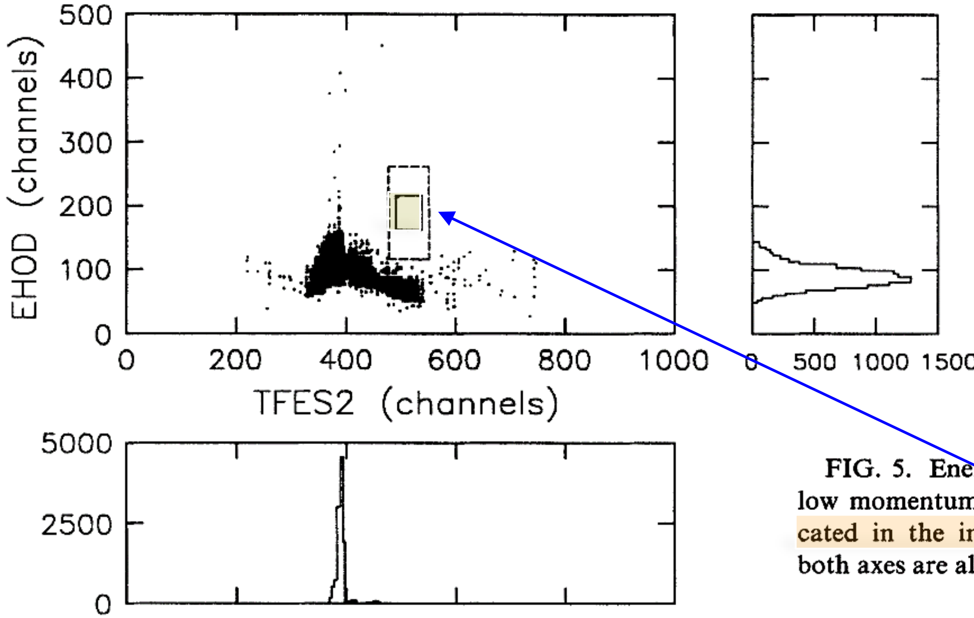
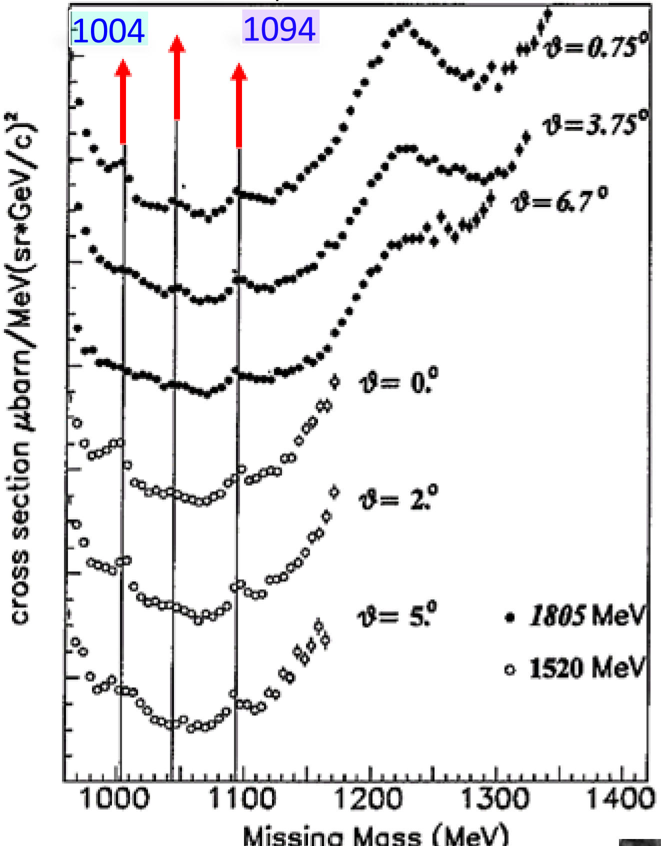


FIG. 5. Energy loss vs time-of-flight in the low momentum bite. The X^{++} should be located in the inner rectangle. Projections on both axes are also shown.

- **No baryon** was detected with
  I=3/2 & $m_N < m_X < m_N + m_\pi$,
  & production cross section > **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)

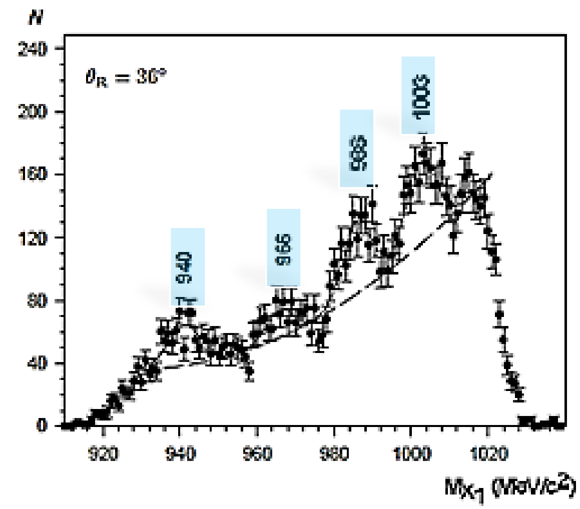
- This study renewed interest, both theoretical & experimental, in subject.

- 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)

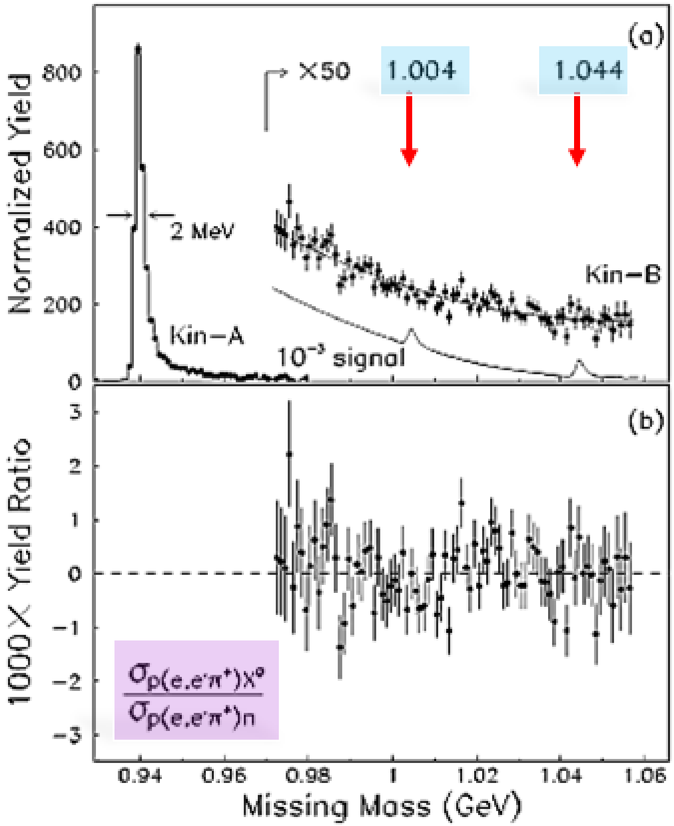
on basis of their **non-observation** in **Compton** scattering on protons or neutrons loosely bound in deuterons.



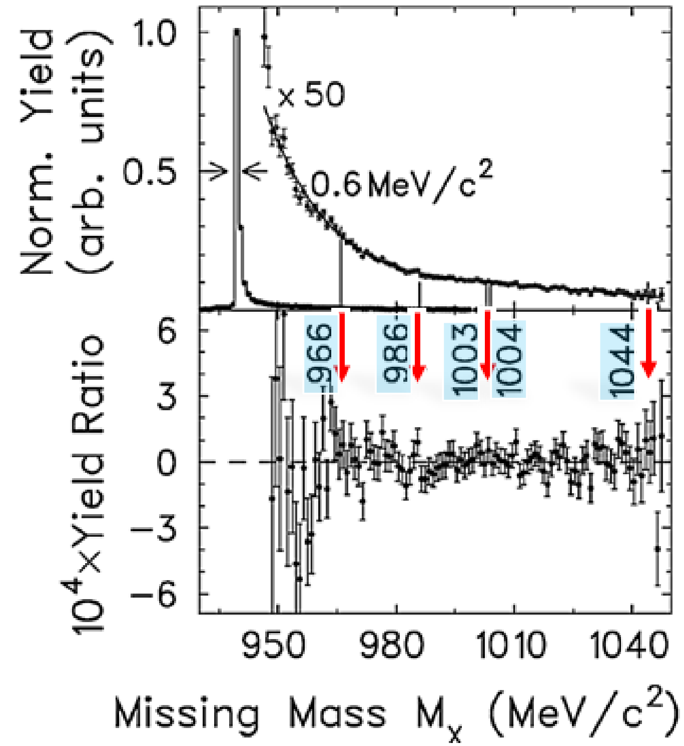
L. Fil'kov *et al*, Eur Phys J A **12**, 369 (2001)

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

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

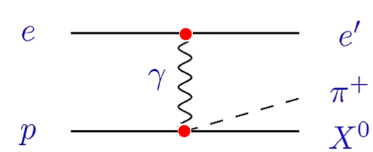


X. Jiang *et al*, Phys Rev C **67**, 028201 (2003)



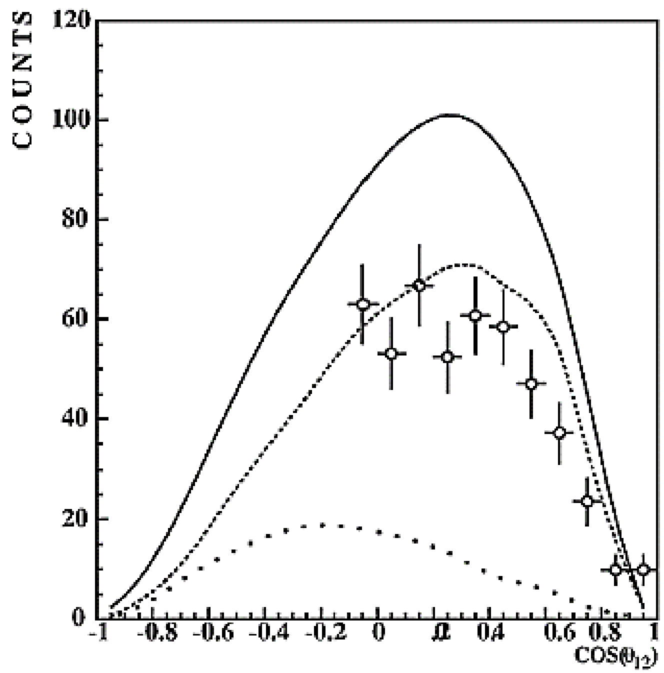
M. Kohl *et al*, Phys Rev C **67**, 065204 (2003)

- No signals were found up to missing mass of about **1100** MeV @ level of $\mathbf{10^{-4}}$.

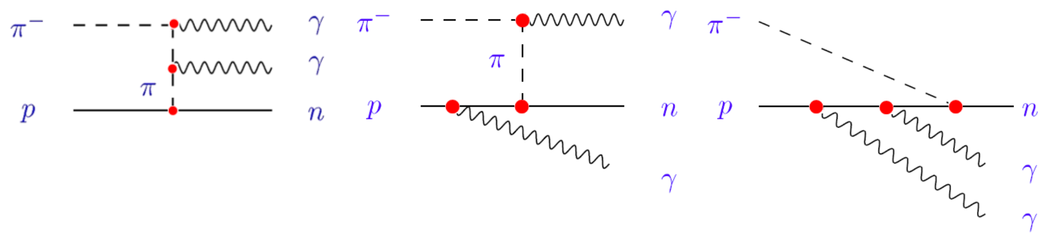


GW — Data Analysis Center — Institute for Nuclear Studies, The George Washington University

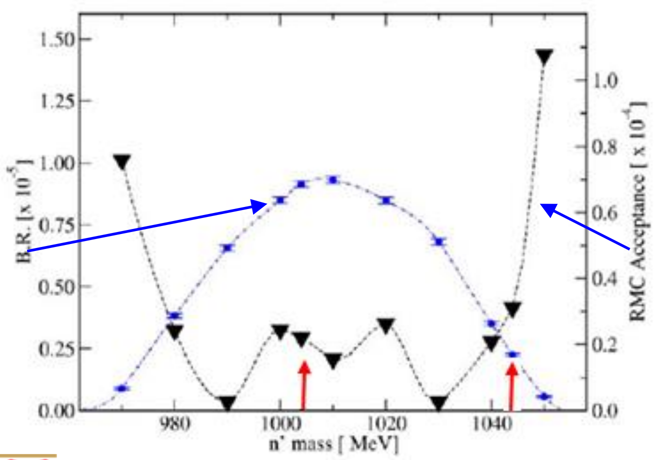
$\pi^- p \to n'\gamma \to n\gamma\gamma$ @ *rest from* TRIUMF



- BR($\pi^- p \to n\gamma\gamma$) = [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.

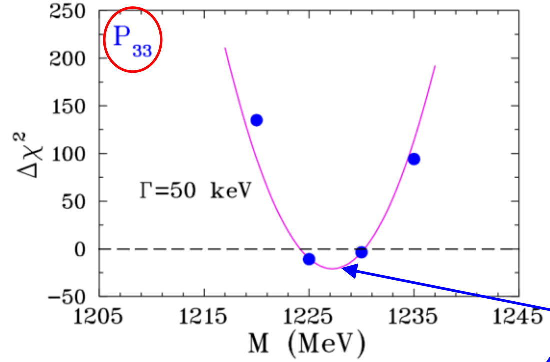
- We assume **existence** of narrower Resonance, **add** it to **amplitude**, then **re-fit** over **whole database** (~30k data for πN elastic).

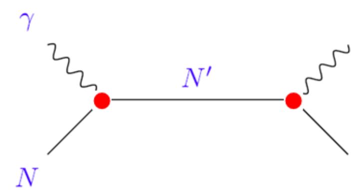
- **Refitting**
  - **If worse description**:
    - ⇒ Resonance with corresponding ***M*** & Γ is not supported.
  - **If better description**:
    - ⇒ Resonance **may** exist.
    - ⇒ Effect can be due to various corrections (*eg*, thresholds).
    - ⇒ Both possibilities can contribute.
  - Some additional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

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

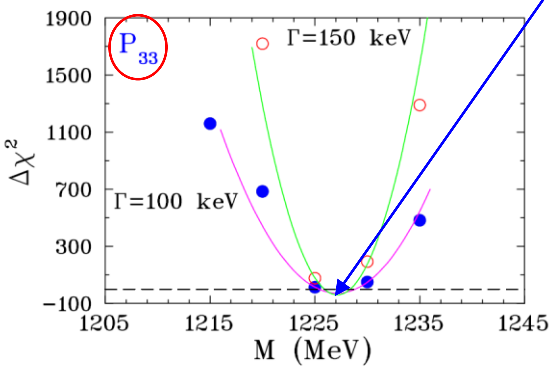
- While **non-Resonance** source may show similar effects in various PWs.

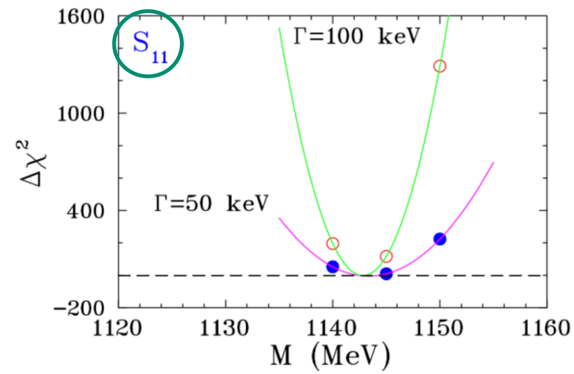
for (Quasi) Bound States of πN

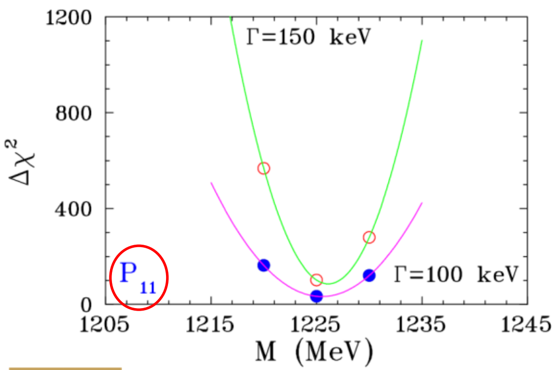




• This case is close to ππN thr.







SAID:

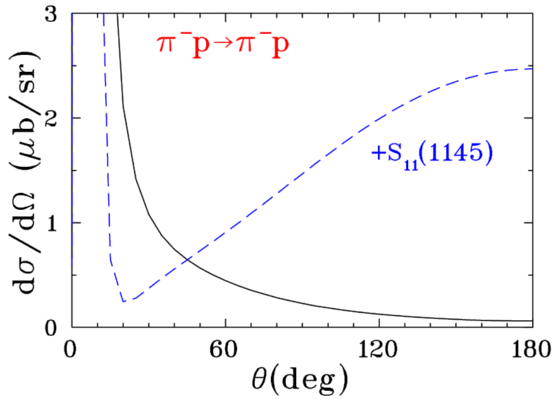
S-, P-, & D-waves

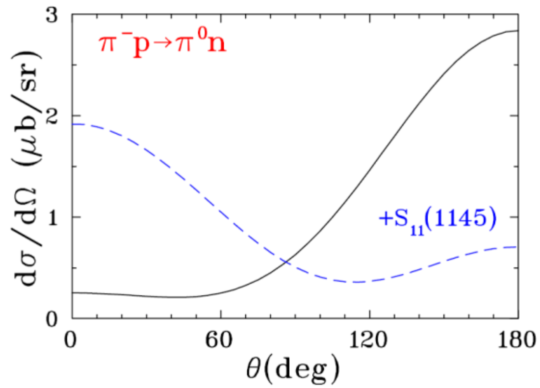
T_π = 0 – 500 MeV & gives χ^2 = 5805

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

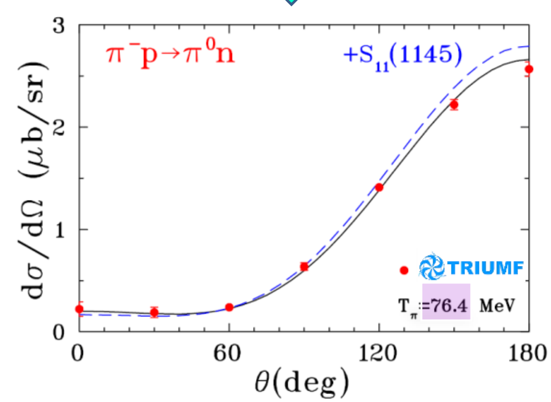
for (Quasi) Bound States of πN

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

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

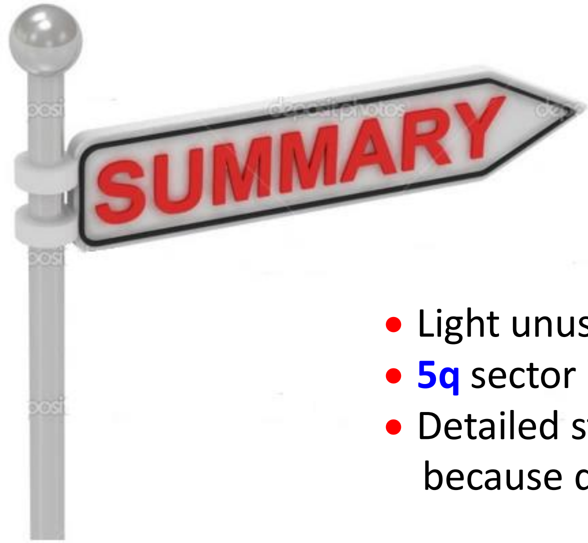
GW INS Data Analysis Center, Institute for Nuclear Studies, The George Washington University

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

Jefferson Lab, Thomas Jefferson National Accelerator Facility

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

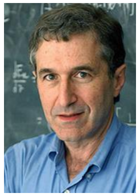
A1

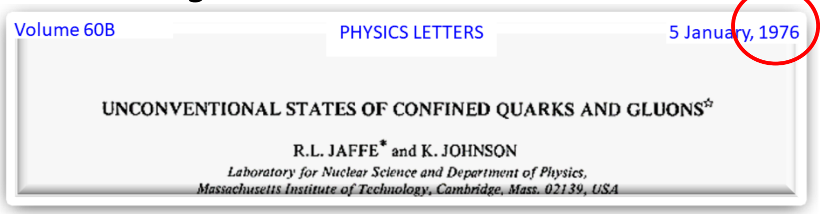


Spectroscopy of Baryons

- 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 PHYSICS LETTERS 5 January, 1976

UNCONVENTIONAL STATES OF CONFINED QUARKS AND GLUONS☆

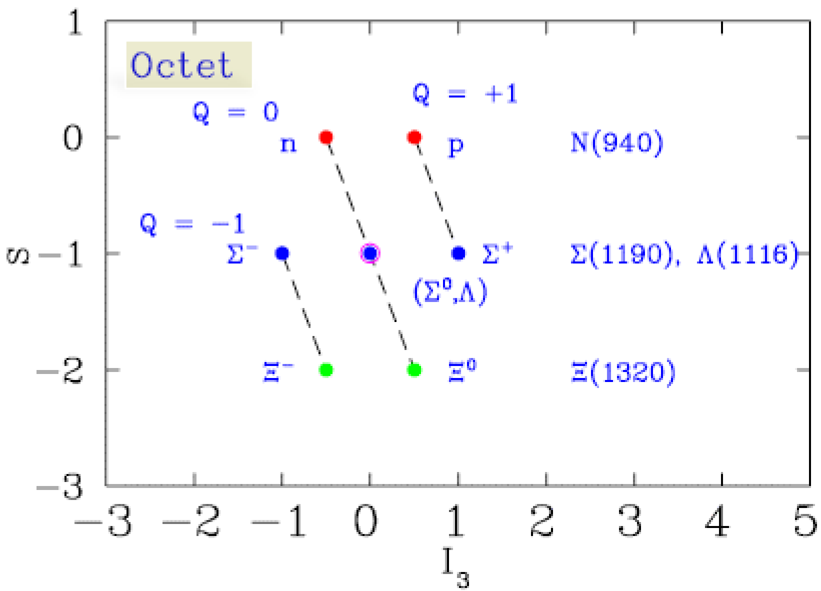
R.L. JAFFE* and K. JOHNSON

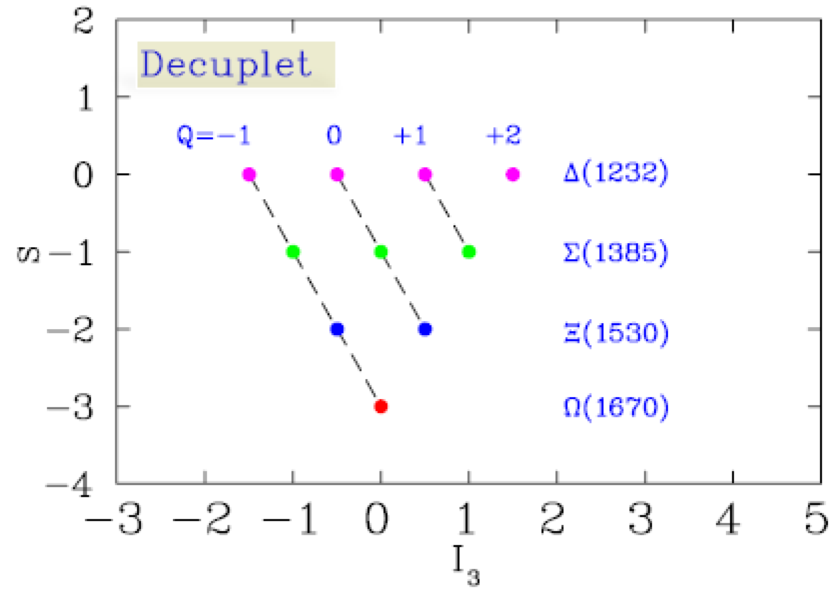
Laboratory for Nuclear Science and Department of Physics, Massachusetts Institute of Technology, Cambridge, Mass. 02139, USA

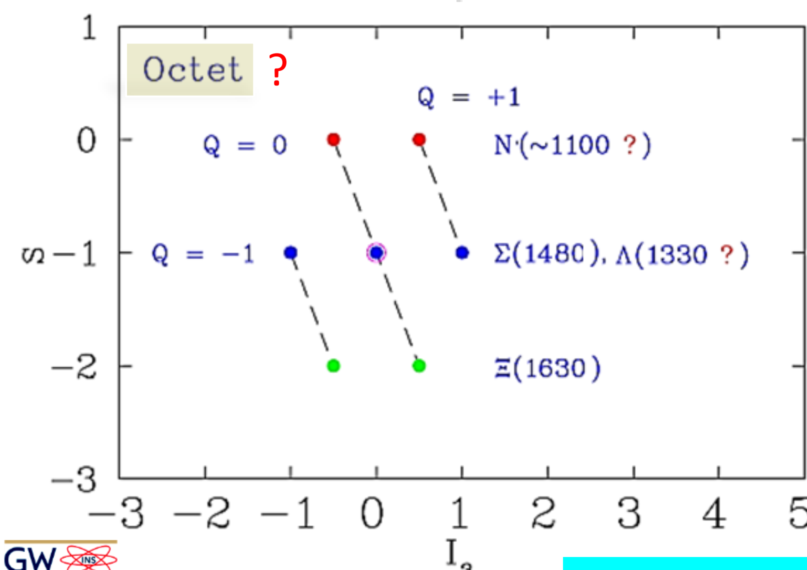
- Production of multiquark hadrons may be
  new kind of hard processes;
  it is related with **higher Fock components**.

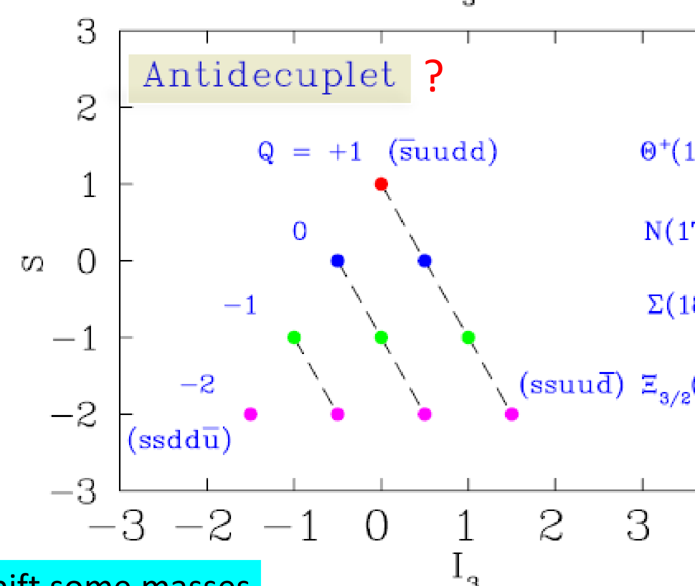
- This our **hypothesis** may suggest **new experiments**.

Unitary $SU(3)_F$ Multiplets









• Mixing is able to shift some masses.