Light Baryon Resonances:
Restrictions & Perspectives

Igor Strakovsky
The George Washington University

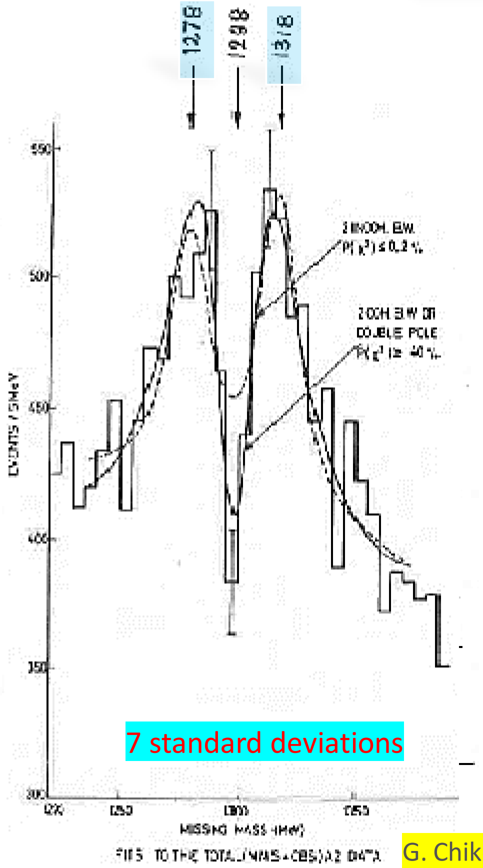
- Where did **N'** come from?
  Completeness of unitarity multiplets.
- Unitarity partners:
  Experimental evidences.
  (Quasi) bound states of πN.
- Restrictions for **N'**.
- Summary.

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

Supported by **DE-SC0016583**

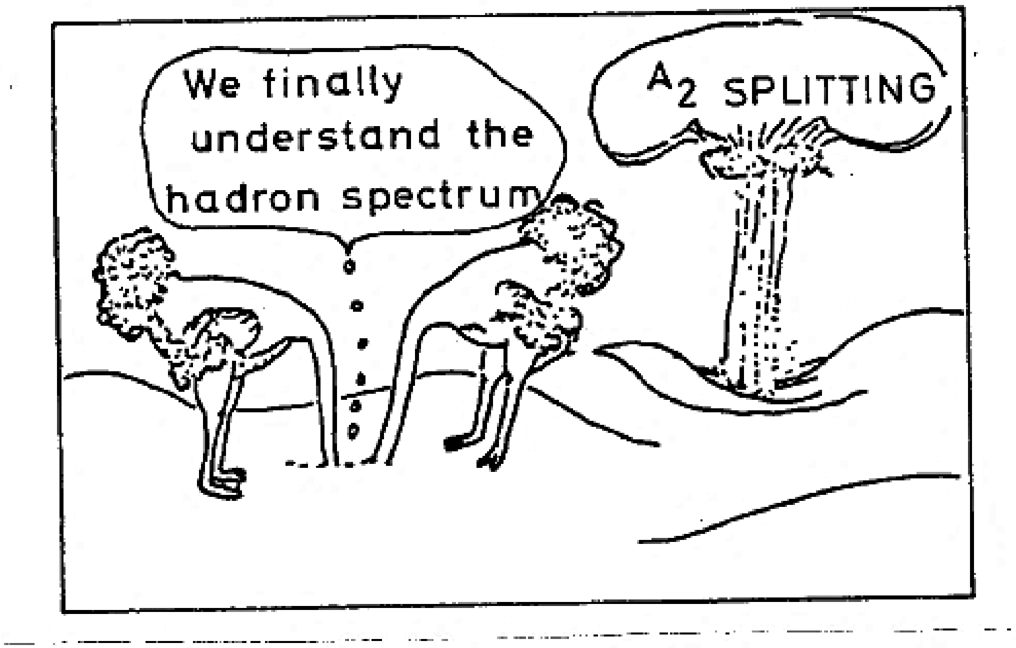
§ ‘A2 splitting’

Evidence by the Maglič group that $a_2(1320)$ mass had anomalous fine structure



7 standard deviations

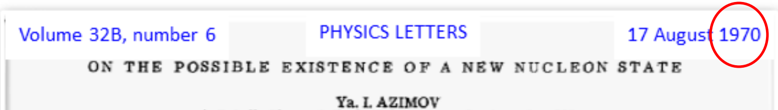
G. Chikovani *at al*, Phys Lett ***25B***, 44 (1967)



- Followed by at least a dozen confirmations from low statistics experiments, which also started to see splitting of other well established resonances…

Courtesy of Chris Damerell, 2002

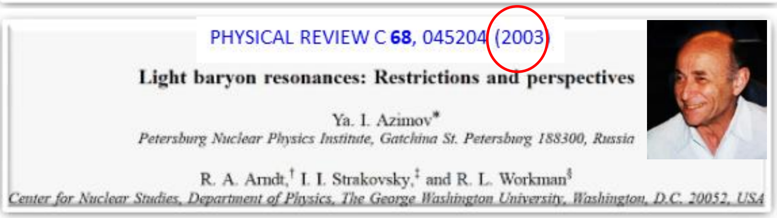
Where Did N' from



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

Ya. I. Azimov*
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R. A. Arndt,† I. I. Strakovsky,‡ and R. L. Workman§
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- Baryon spectroscopy continues to motivate extensive experimental program, with most studies focused on missing resonance problem.
- If we believe in SU(3), then every resonance has to have ``family" (Unitarity Partners) .
- Given underpopulation of conventional **3q** 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.

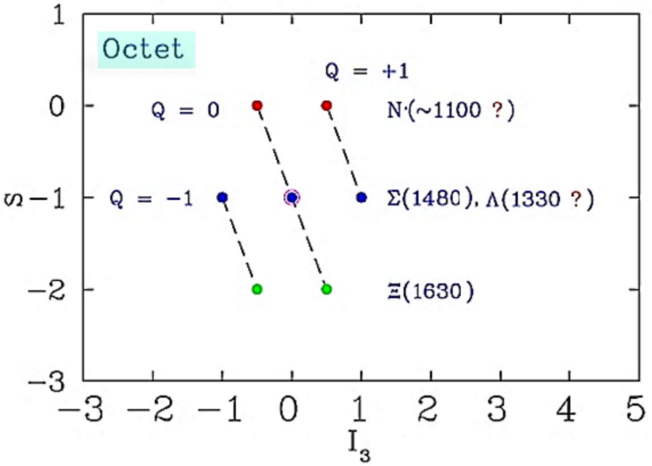
- PDG has **109 Baryon Resonances** (**64** of them are **4*** & **3***).
- In case of **SU(6) X O(3)**, **434** states would be present if all revealed multiplets were fleshed out (**three 70** and **four 56**).

- LQCD results are similar.

- 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 .

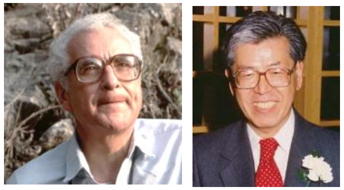
Unitarity Partners (?)

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



$$M = a_0 + a_1 Y + a_2 \left[I\,(I+1) - \frac{1}{4} Y^2 \right]$$

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

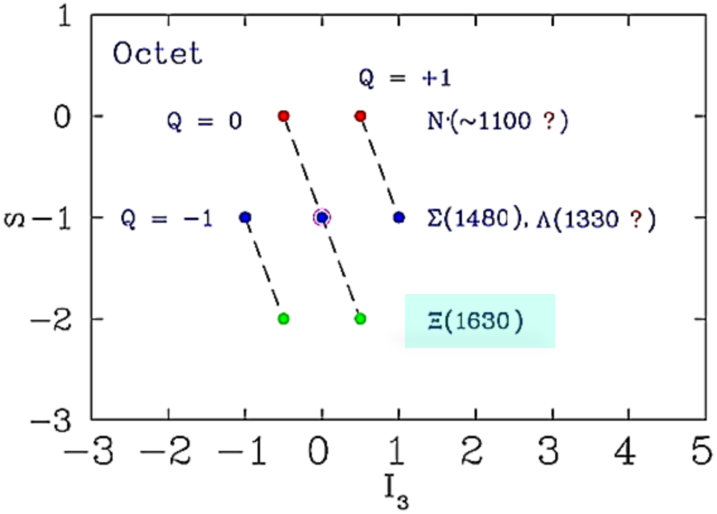


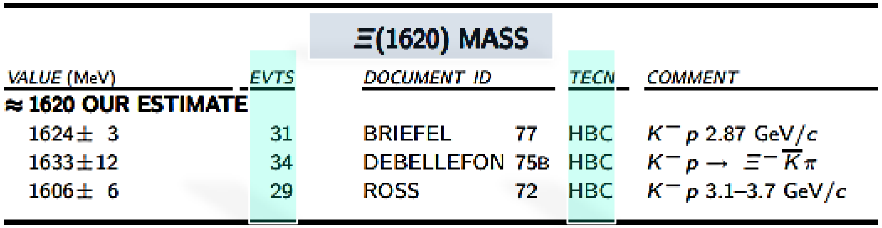
State	Mass (MeV)	Width (MeV)	Decay Modes	Hadron Production Xsections
N'	$\sim$1100 ?	<0.05	$N\gamma$?	$< 10^{-4}$ of "normal"
Λ	1330 ?		$\Lambda\gamma$	$\sim 10\mu b$
Σ	1480	30-80 ?	$\Lambda\pi$, $\Sigma\pi$, $N\bar{K}$	$\sim 1\mu b$
Ξ	1630	20-50 ?	$\Xi\pi$	$\sim 1\mu b$

On base of positive observations.

- PhotoProd Xsection has additional ~α/π factor.
- ElectroProd has ~(α/π)².

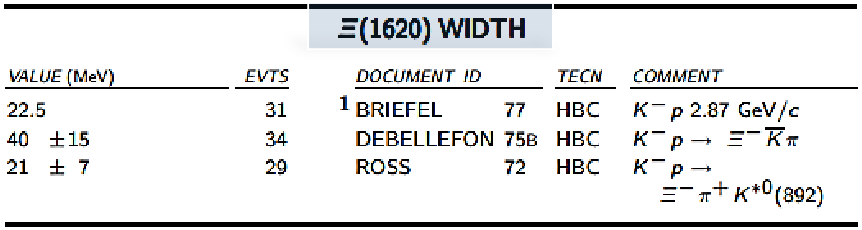
PDG for $\Xi(1620)1/2(?^{?})$ *





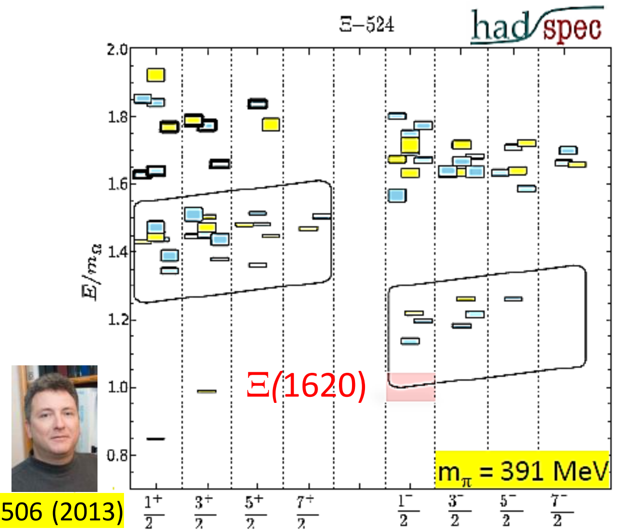
$\Xi(1620)$ MASS

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



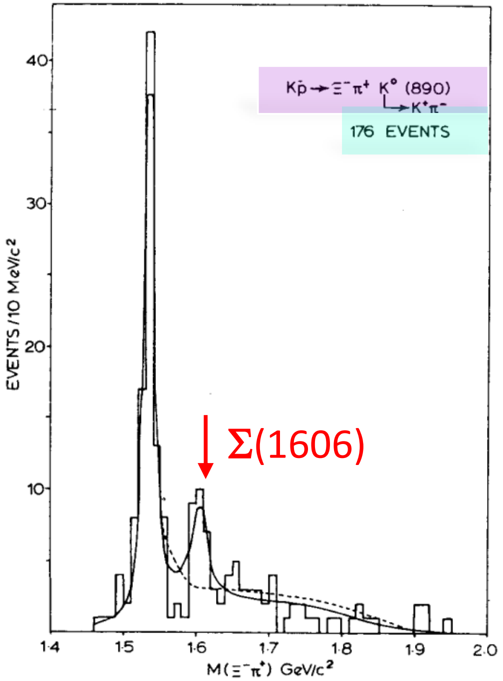
$\Xi(1620)$ WIDTH

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



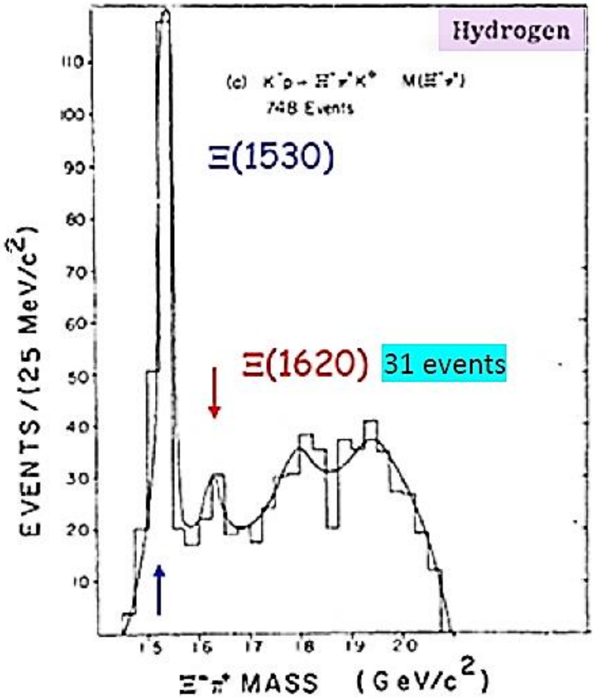
R. G. Edwards *et al*, Phys Rev D **87**, 054506 (2013)

$\Xi(1606)$ via $K^-p \rightarrow \Xi^-\pi^+K^*(892)$ from
$\Xi(1620)$ via $K^-p \rightarrow \Xi^-\pi^+K^0$ from
$\Xi(1620)$ via $\Xi^-Cu \rightarrow \Xi^-\pi^+X$ from WA89



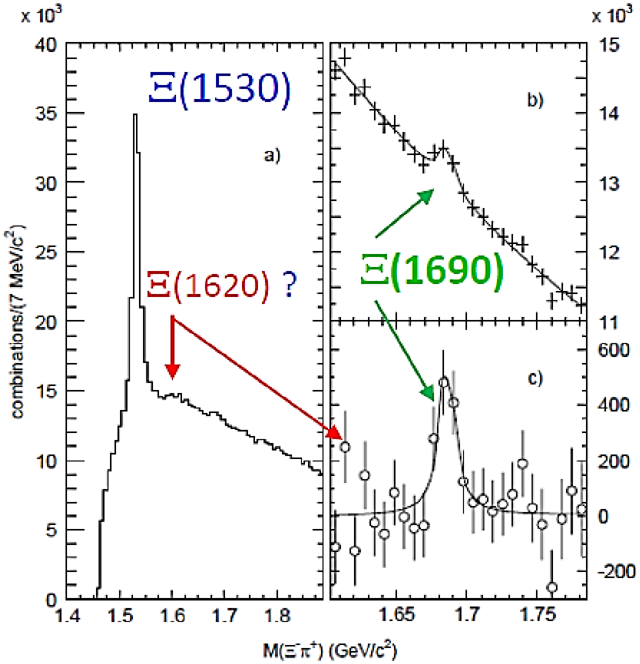
M = 1605.5±5.6 MeV
Γ = 20.8±7.4 MeV

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



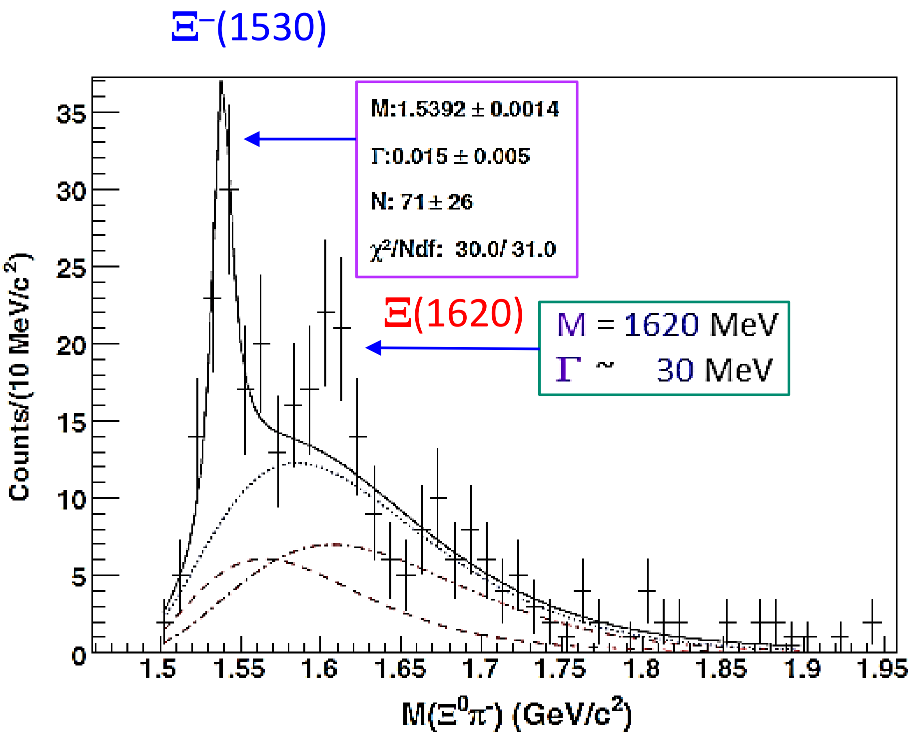
M = 1624±3 MeV
Γ = 22.5 MeV

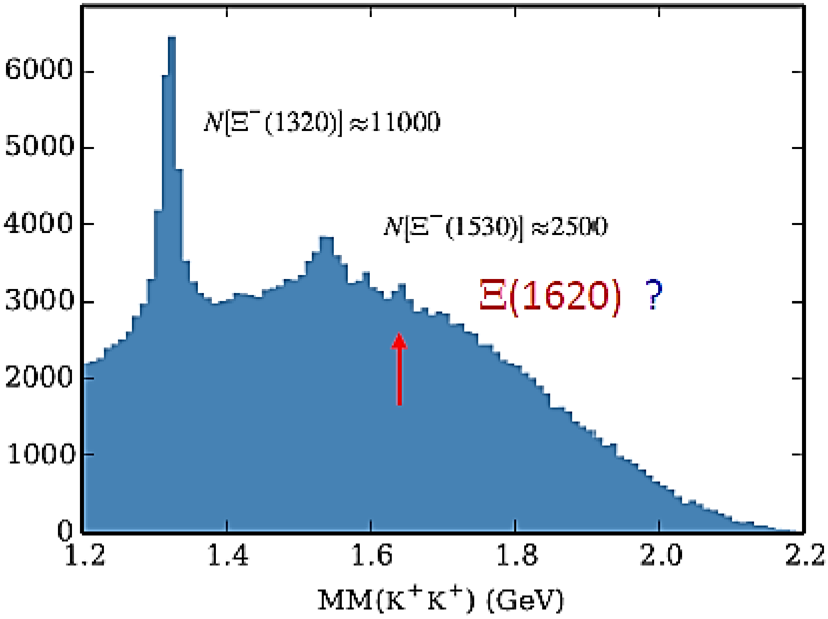
E. Briefel *et al*, Phys Rev D **16**, 2706 (1977)



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

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



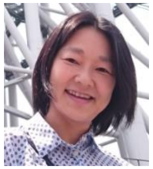


L. Guo *et al*, Phys Rev C **76**, 025208 (2007)

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

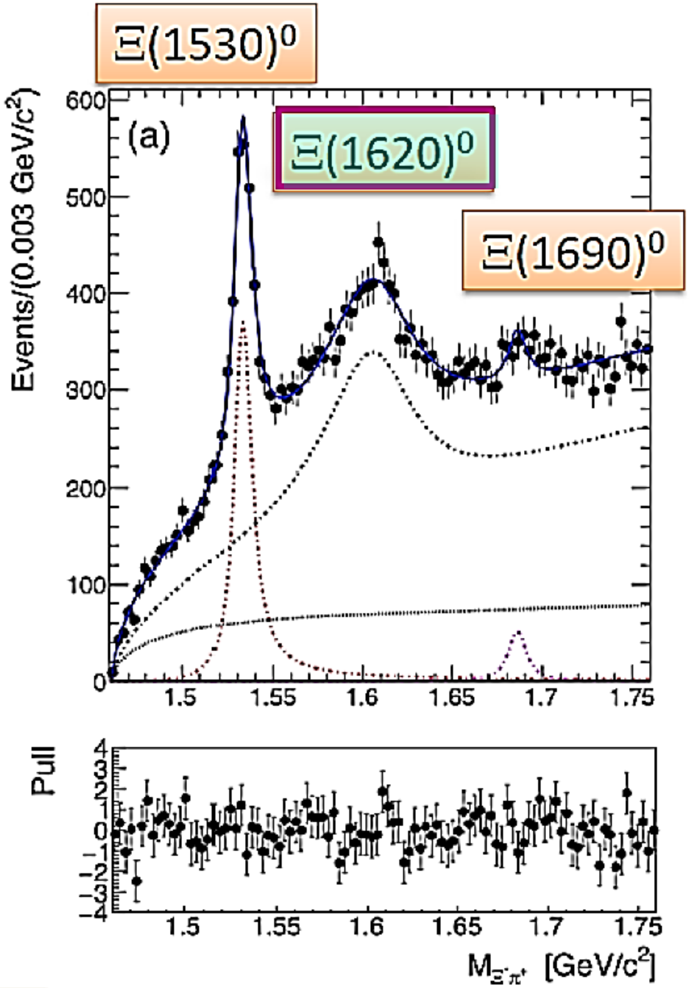
$\Xi(1620)$ via $\Xi_c^+ \to \Xi^-\pi^+\pi^-$ from

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

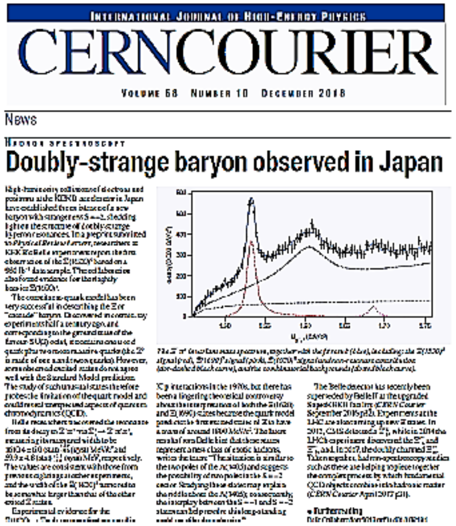


M = **1610.4** ±6.0 (stat)$^{+6.1}_{-4.2}$(syst) MeV

Γ = **59.9** ±4.8 (stat)$^{+2.8}_{-7.1}$(syst) MeV



- Invariant mass spectrum in sideband region.



INTERNATIONAL JOURNAL OF HIGH-ENERGY PHYSICS

CERNCOURIER

VOLUME 58 NUMBER 10 DECEMBER 2018

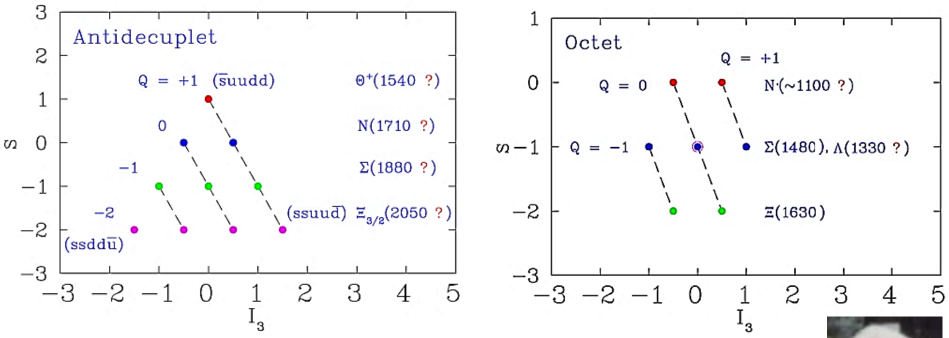
News

HADRON SPECTROSCOPY

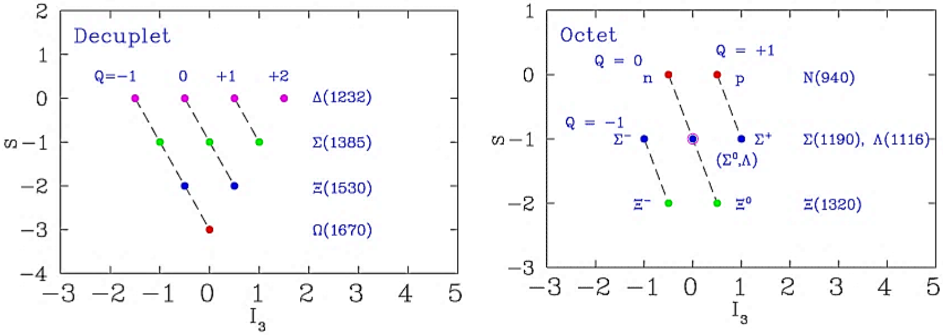
Doubly-strange baryon observed in Japan

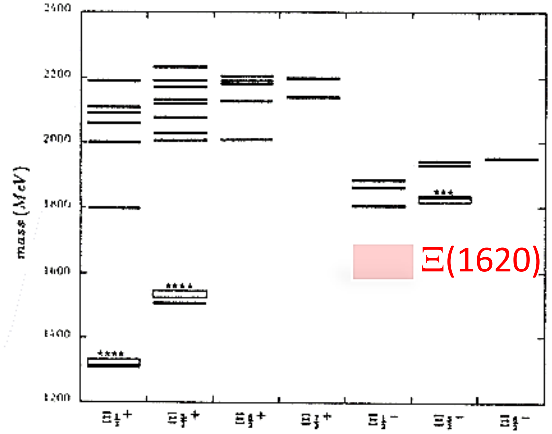
Possible Nature of Ξ(1620)

- 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 10,
  then its intrinsic structure must be different,
  & its flavor structure must be different as wel
  could be 8.
- There is no prediction of $1/2^-$ in ChSA
  (no predictions for negative parity at all).



J.J. de Swart, Rev Mod Phys **35**, 916 (1963)





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

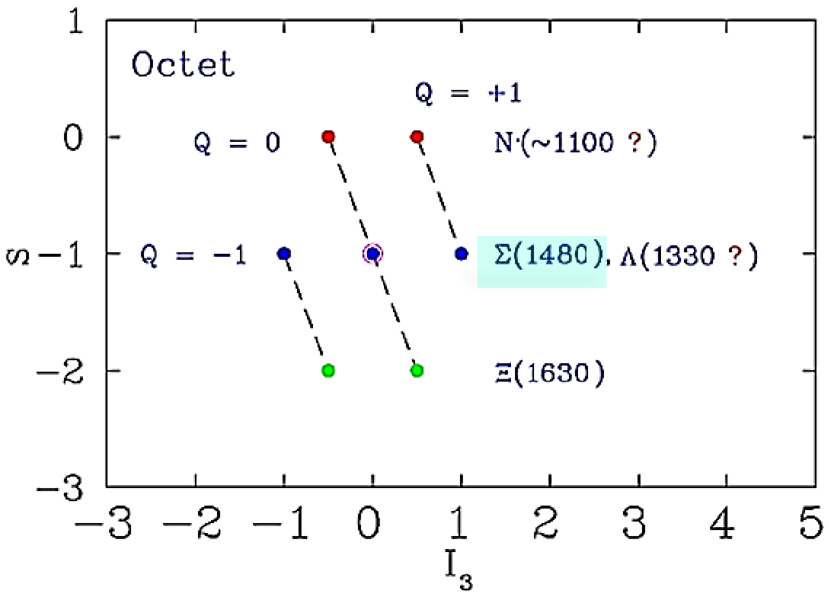
- Ξ(1620) resonance as dynamically generated from some coupled channels.

A. Ramos, E. Oset, & C. Bennhold, Phys Rev Lett **89**, 252001 (2002)

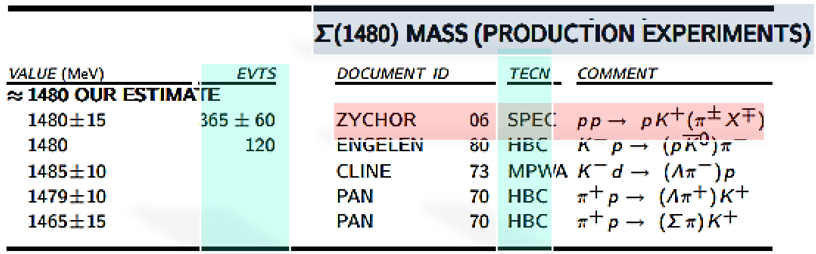
- Ξ(1620) resonance can be explained as $\overline{K}\Lambda$ molecular state with $I(J^P) = 1/2(1/2^-)$.

Kan Chan *et al*, Phys Rev D **100**, 074006 (2019)

for Σ(1480)1(?$^{?}$) ★

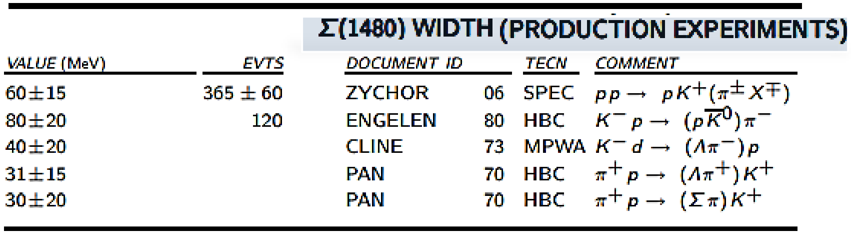


- Σ(1480), if exists, looks to be good partner of Ξ(1620).



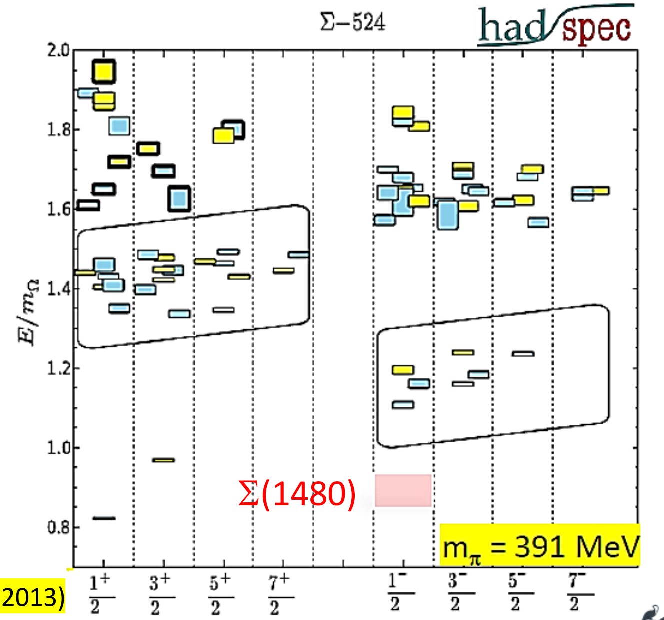
Σ(1480) MASS (PRODUCTION EXPERIMENTS)

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)

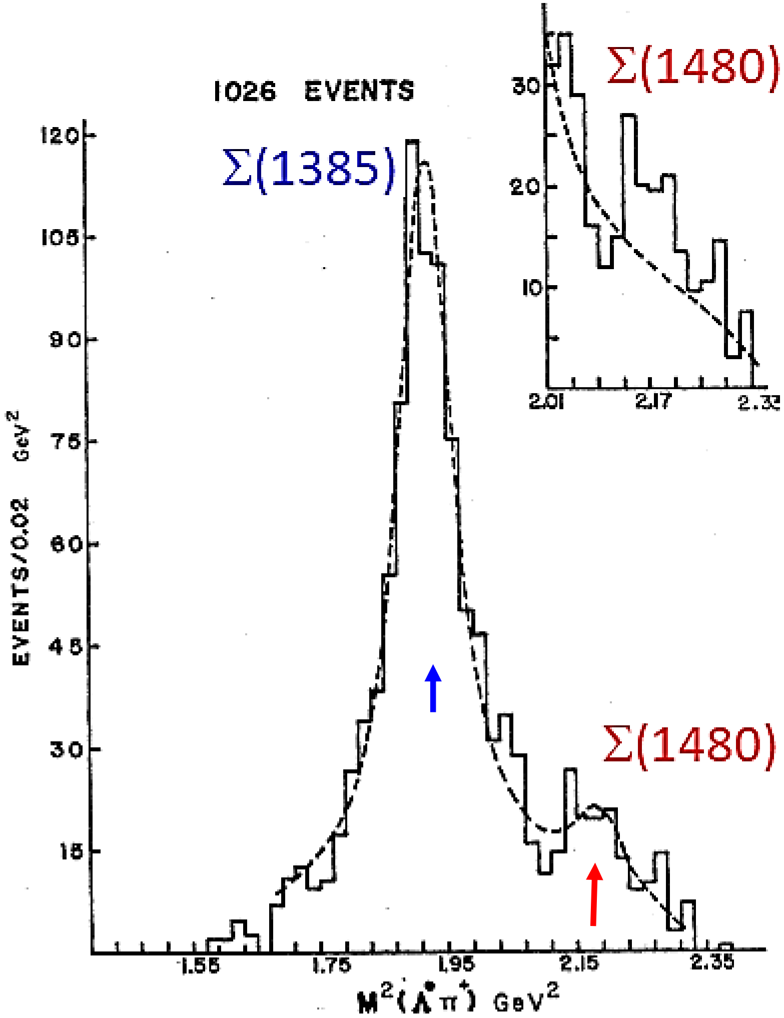
VALUE (MeV)	EVTS	DOCUMENT ID		TECN	COMMENT
60±15	365 ± 60	ZYCHOR	06	SPEC	$pp \to pK^+(\pi^\pm X^\mp)$
80±20	120	ENGELEN	80	HBC	$K^- p \to (p\overline{K}^0)\pi^-$
40±20		CLINE	73	MPWA	$K^- d \to (\Lambda\pi^-)p$
31±15		PAN	70	HBC	$\pi^+ p \to (\Lambda\pi^+)K^+$
30±20		PAN	70	HBC	$\pi^+ p \to (\Sigma\pi)K^+$

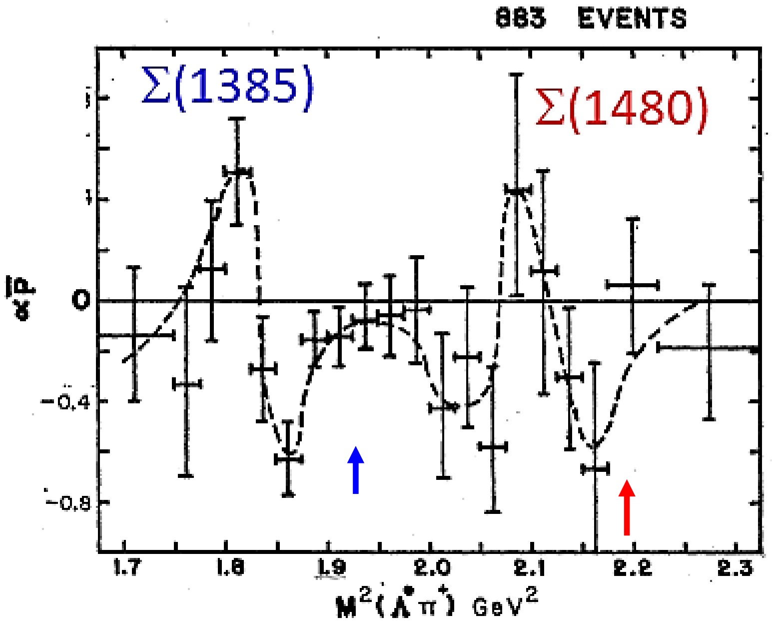


R. G. Edwards *et al*, Phys Rev D **87**, 054506 (2013)

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

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





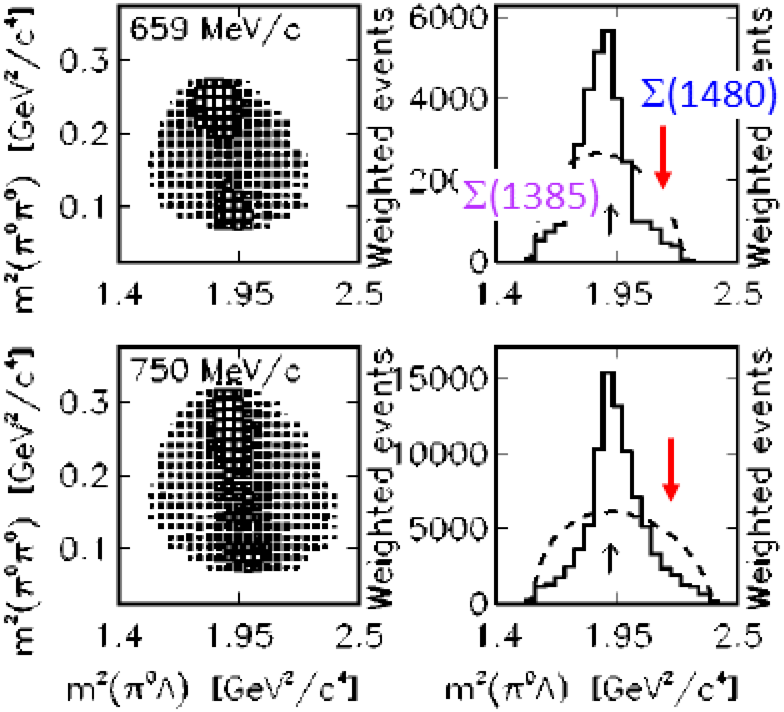
- Similar behavior for true resonance Σ(1385) & suspected Σ(1480).

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

M = 1475±15 MeV Γ = 30±15 MeV

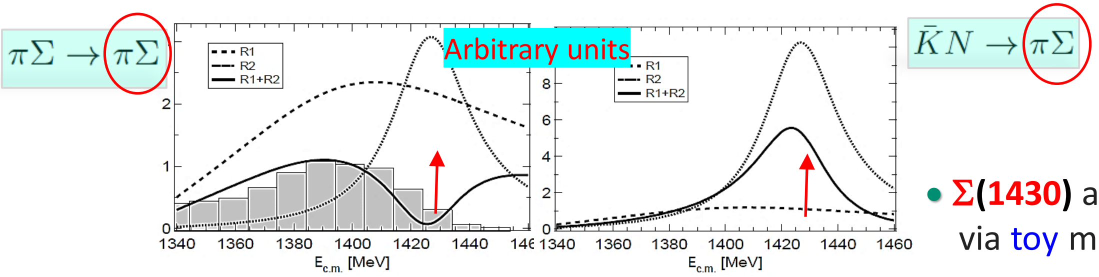
Σ(1480) via $K^{-}p\rightarrow\pi^0\pi^0\Lambda$ from

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



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

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

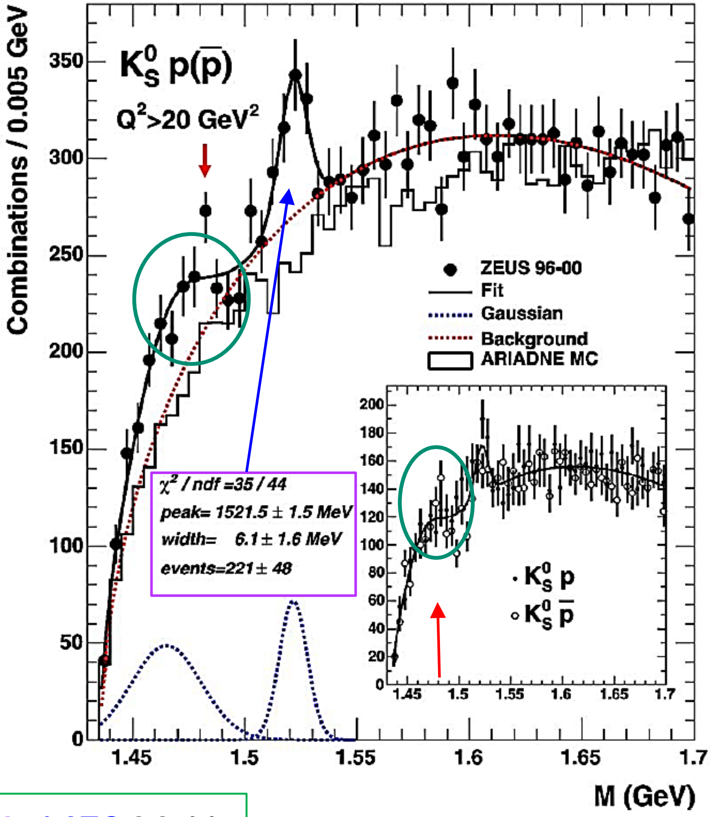


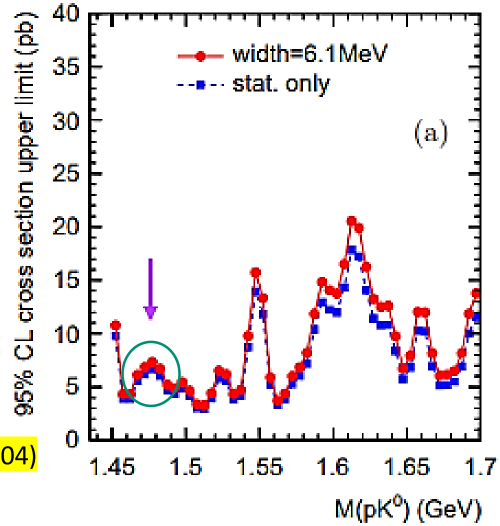
- **Σ(1430)** as cusp via toy model.

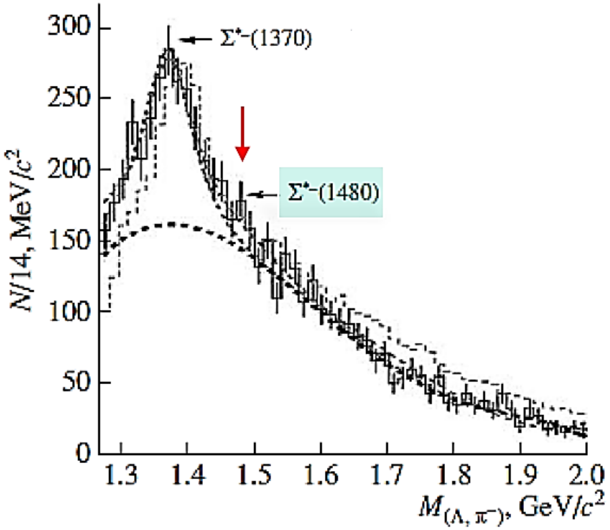
D. Jido, J.A. Oller, E. Oset, A. Ramos, & U.-G. Meissner, Nucl Phys A **725**, 181 (2004)

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

$\Sigma(1480)$ via $pC^{12} \to \Lambda\pi^- X$ @ 10 GeV/c from



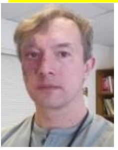




P. Zh. Aslanyan, Phys At Nucl **40**, 525 (2009)

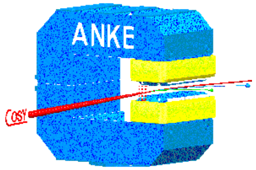
M=1470 MeV
Γ ~ 30 MeV

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

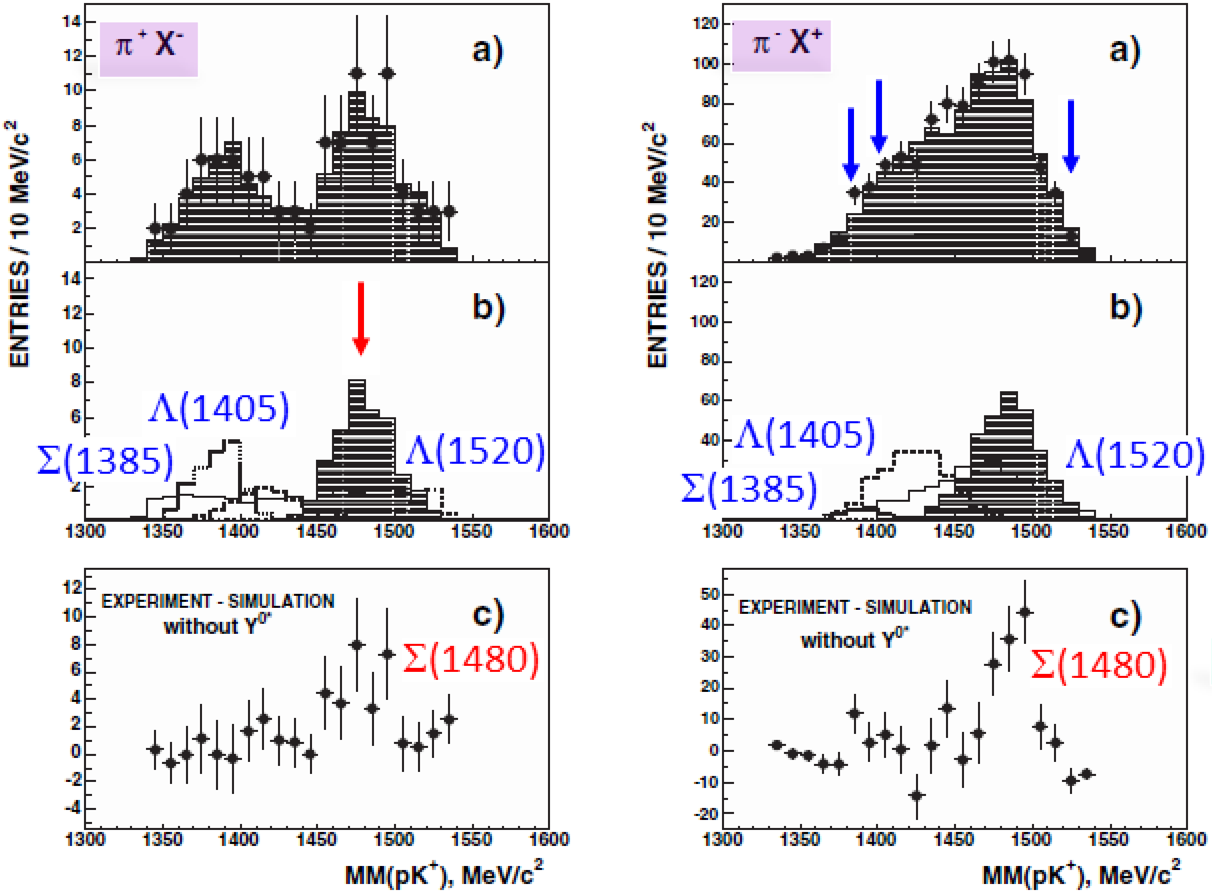


H. Abramowicz *et al*, DESY–16–065 (2016)

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



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



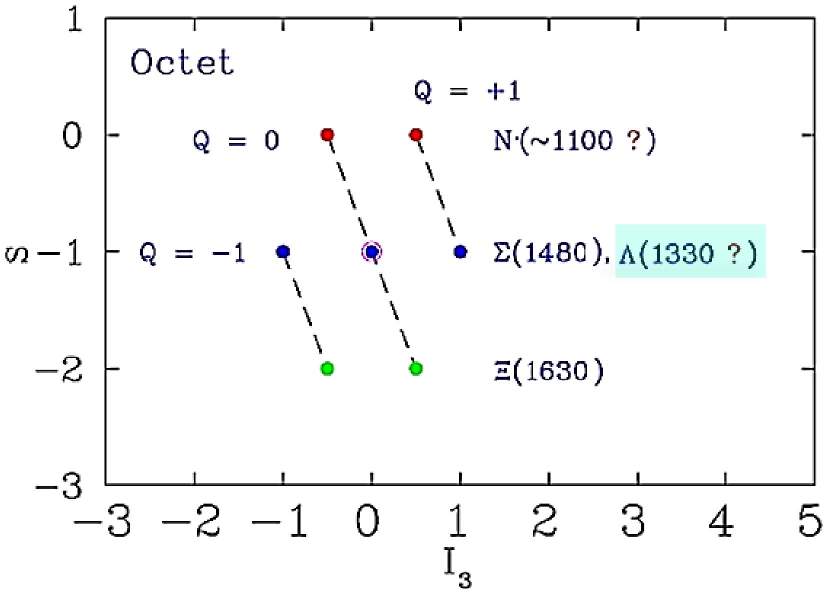
- Production cross section is of order of few hundred **nb**.

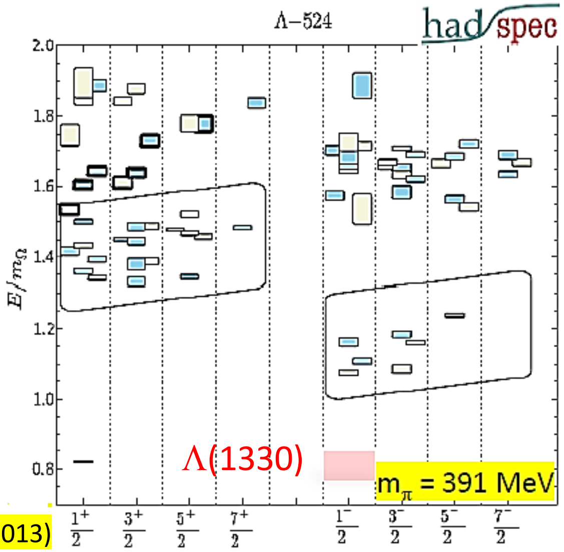
M = 1480 ± 15 MeV Γ = 60±15 MeV

- 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

Λ(1330)?(??)



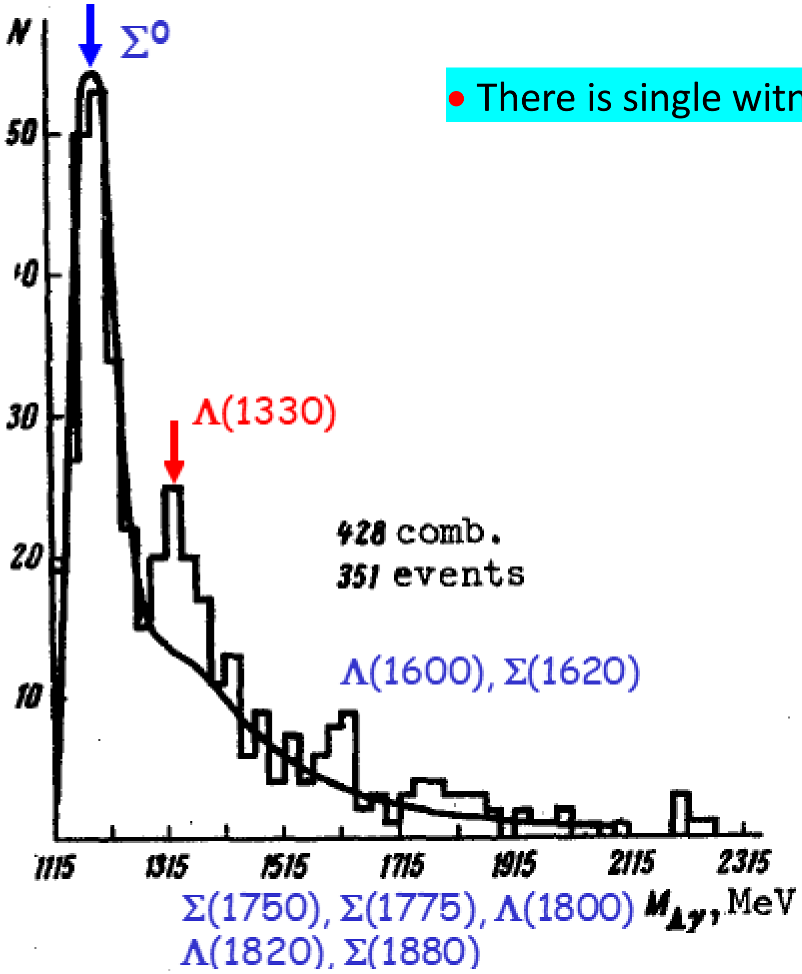


R. G. Edwards *et al*, Phys Rev D **87**, 054506 (2013)

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

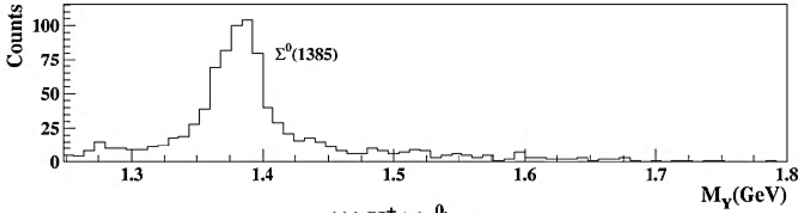
G. Bozoki *et al*, Phys Lett **28B**, 360 (1968)
N.P. Bogachev *et al*, JETP Lett **10**, 105 (1969)

- There is single witness.

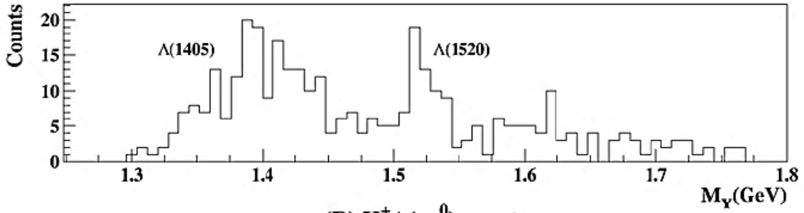


M = 1327.5±3.5 MeV
Γ = 20.0±4.4 MeV

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

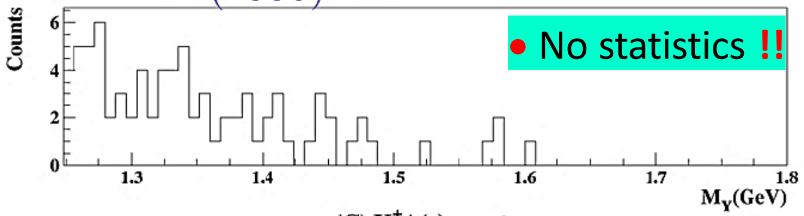


(A) $K^+\Lambda(\pi^0)$ events



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

$\Lambda(1330)$?

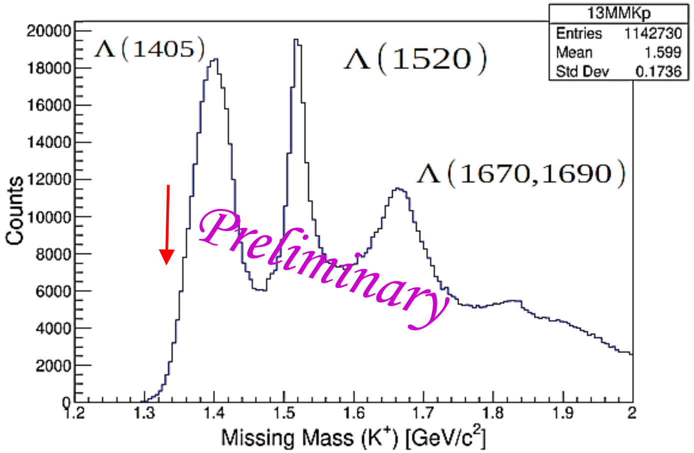


- No statistics !!

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

S. Taylor, PhD Thesis, Rice U, May 2000

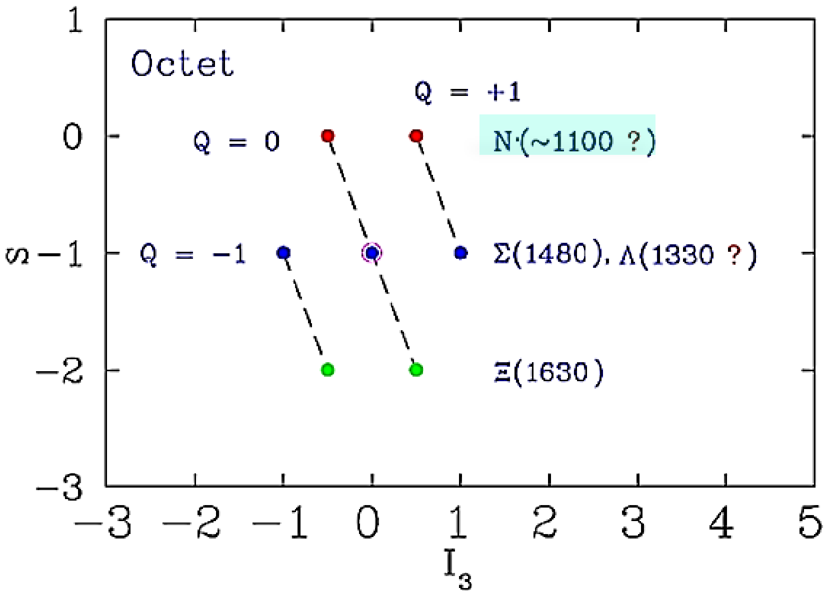
- No evidence in this decay channel.

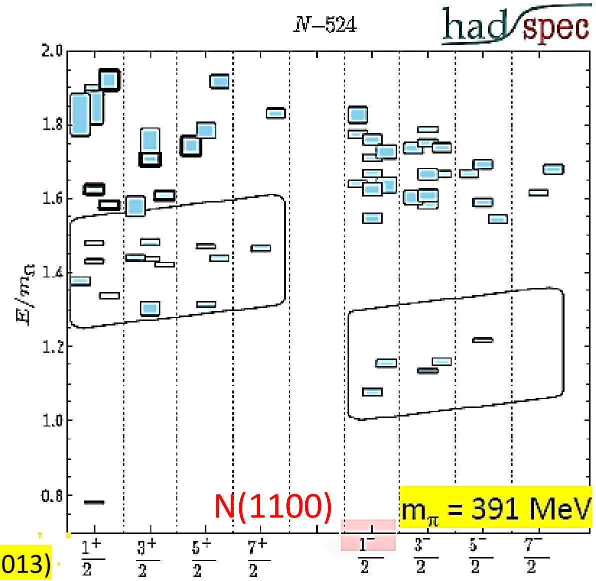


U. Shrestha & K. Hicks, November 2019

Completeness of Unitary Multiplet

N(1100)?(??)





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

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.

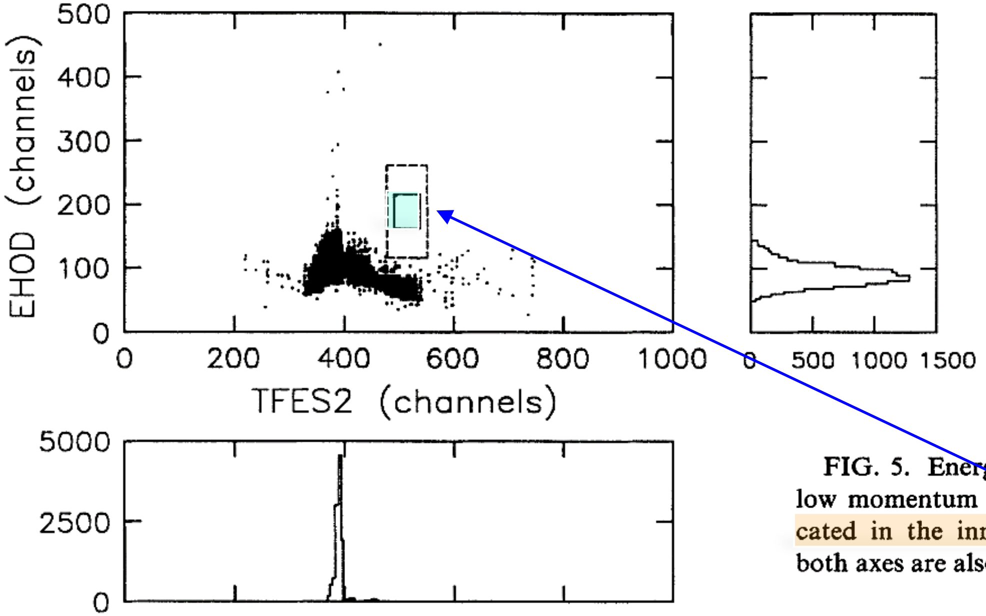


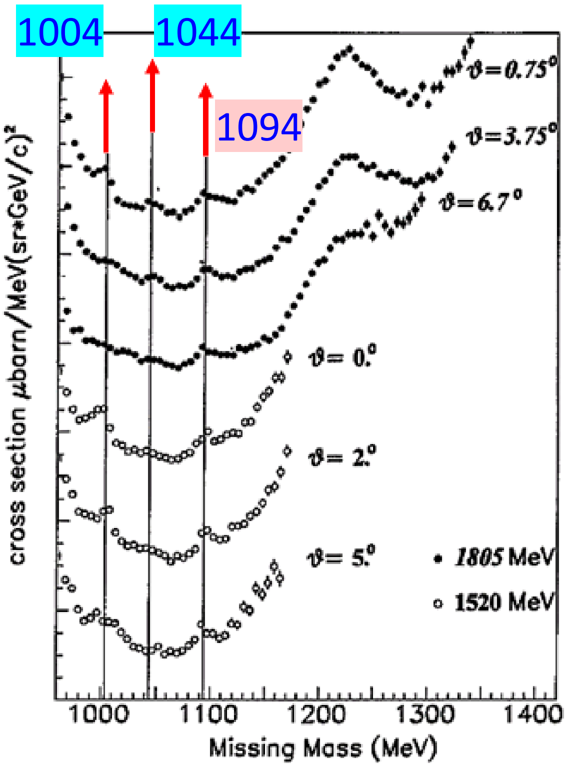
FIG. 5. Energy loss vs time-of-flight in the low momentum bite. The X^{++} should be located in the inner rectangle. Projections on both axes are also shown.

- 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.

$pp\to\pi^+pX^0$, $M_X > 960$ 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.



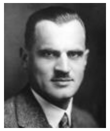
- This study renewed interest, both theoretical & experimental, in subject.

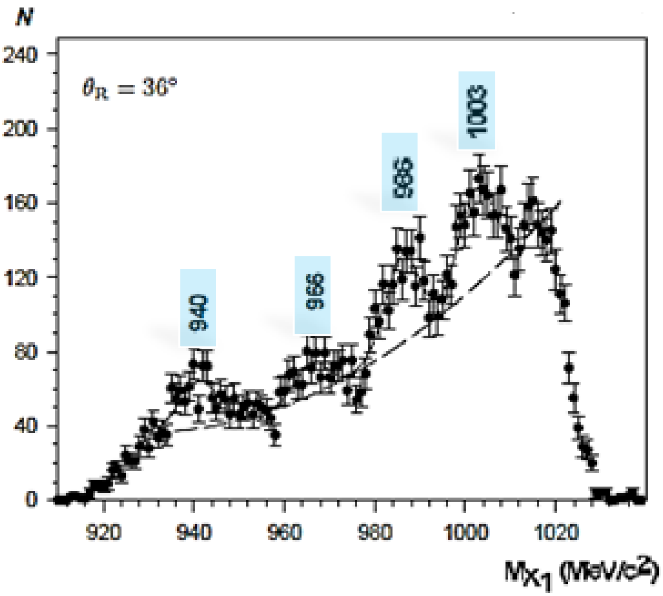
- If correct, such baryons would have **I=1/2**, masses of 1004, 1044, & 1094 MeV, & widths less than **4–15** MeV.

- 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.



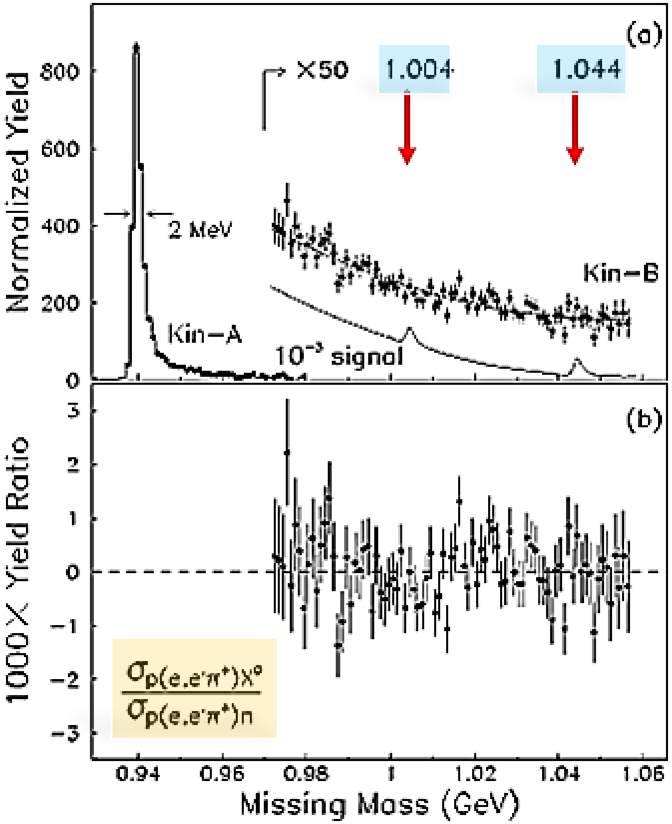


L. Fil'kov *et al,* Eur Phys J A **12**, 369 (2001)

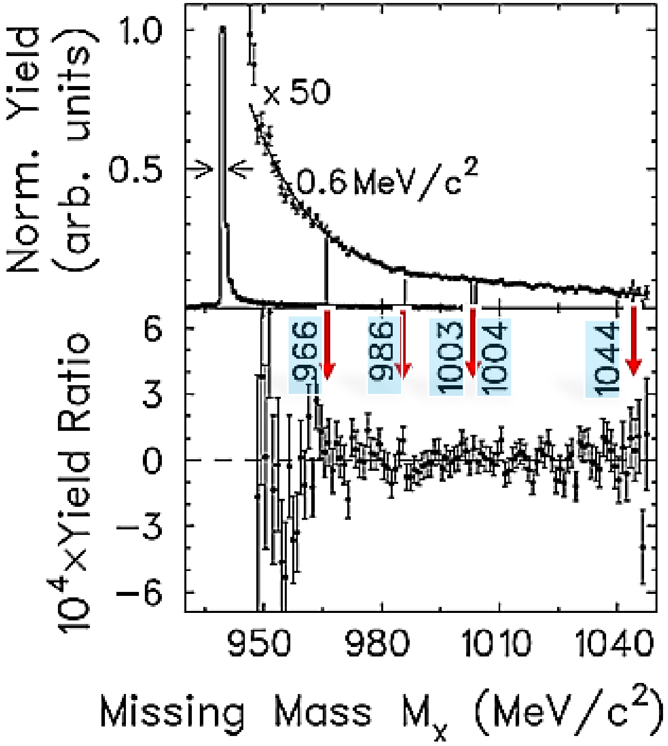
B. Tatischeff *et al*, Phys Rev Lett **79**, 601 (1997)
B. Tatischeff *et al,* Eur Phys J A **17**, 245 (2003)

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

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

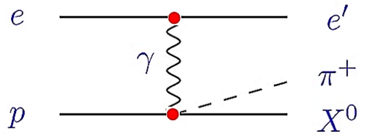


X. Jiang *et al*, Phys Rev C **67**, 028201 (2003)

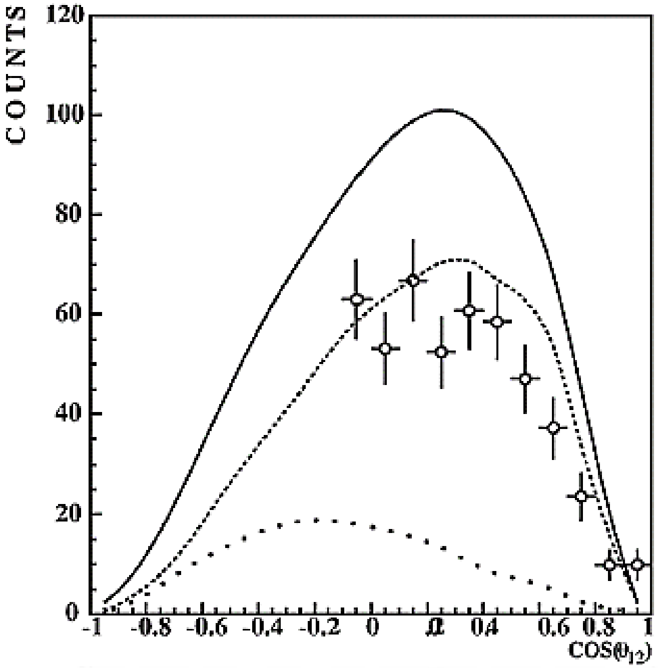


M. Kohl *et al*, Phys Rev C **67**, 065204 (2003)

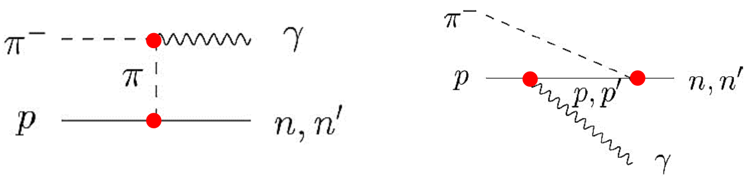
- No signals were found up to missing mass of about 1100 MeV @ level of **10^{-4}**.

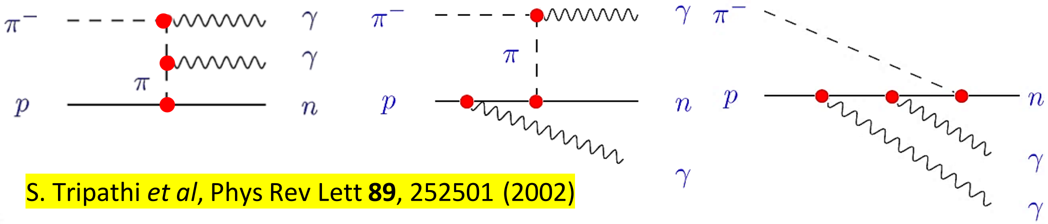


$\pi^- p \to n'\gamma \to n\gamma\gamma$ @ *rest from* TRIUMF

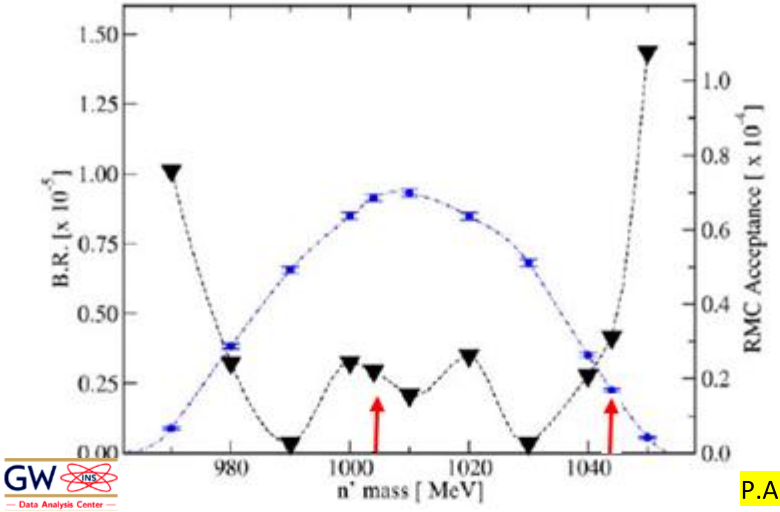


- BR($\pi^- p \to n\gamma\gamma$) = [3.05±0.27(stat)±0.31(syst)] x10^{-5}
- This means that up to stat & syst uncertainties (each about **10%**) there were **no contributions** of **n'** cascade.





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



- Thus **no evidence** for **n'**-mediated capture was found for 970 < $M_{n'}$ < 1050 MeV/c^2, 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 from

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 $\Gamma < 20$ MeV.

- We assume existence of narrower Resonance, add it to amplitude, then re-fit over whole database.

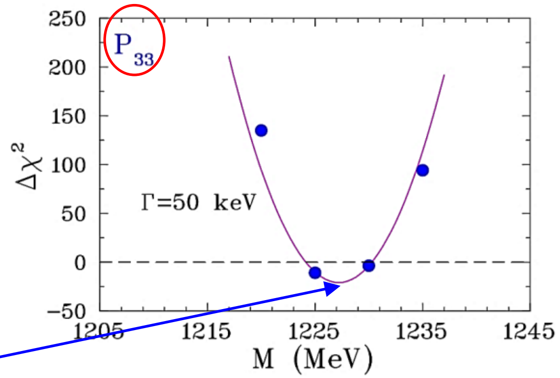
- Refitting
  - If worse description:
    - ⇒ Resonance with corresponding M & Γ is not supported.
  - If better description:
    - ⇒ Resonance may exist.
    - ⇒ Effect can be due to various corrections (*eg*, thresholds).
    - ⇒ Both possibilities can contribute.
  - Some additional checks are necessary.

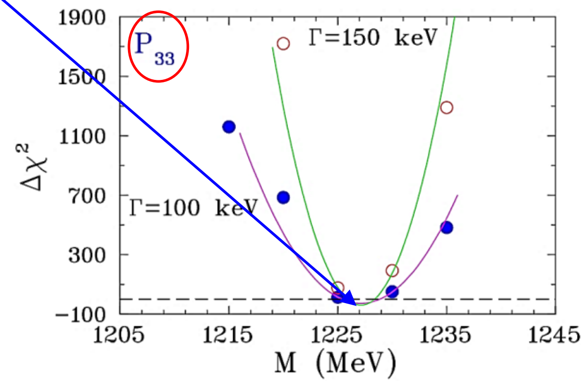
- True Resonance should provide effect only in single particular **PW**.

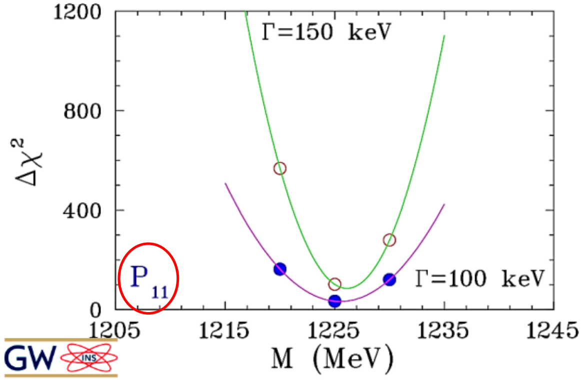
- While non-Resonance source may show similar effects in various **PWs**.

for (Quasi) Bound States of πN

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



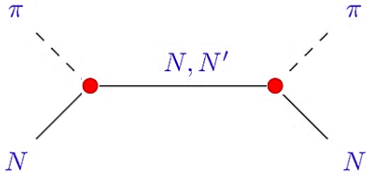


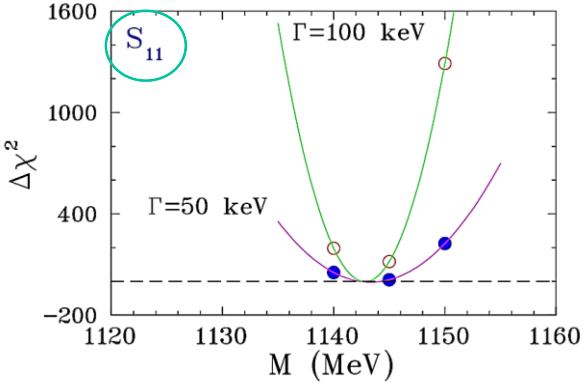


S-, P- & D-waves

SAID: T_π = 0 – 500 MeV & gives χ^2 = 5805

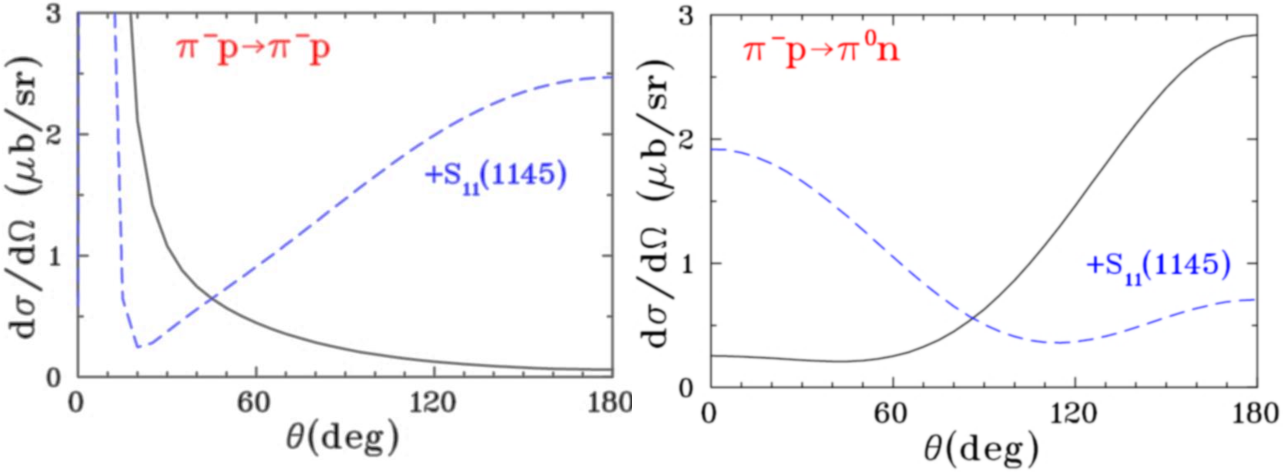
M = 1100 – 1295 MeV & Γ = 50 – 300 keV



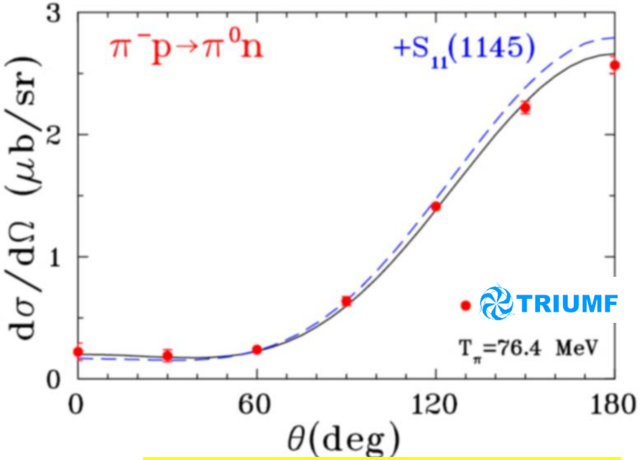


for (Quasi) Bound States of πN

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



ΔT = 3.1 MeV

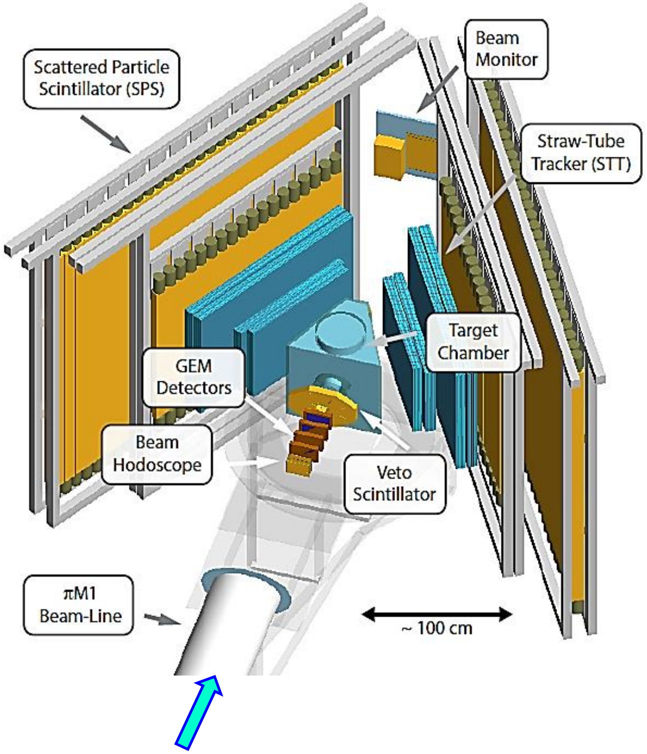


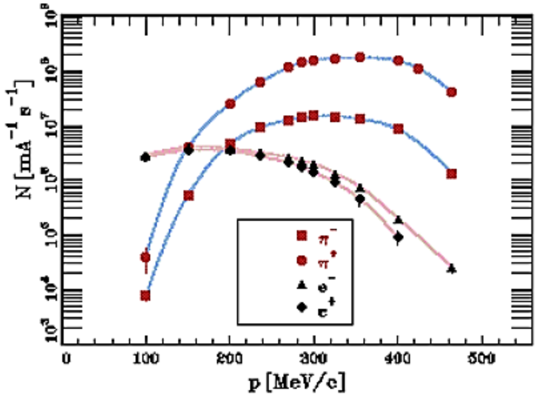
A. Bagheri *et al*, Phys Rev C **38**, 885 (1988)

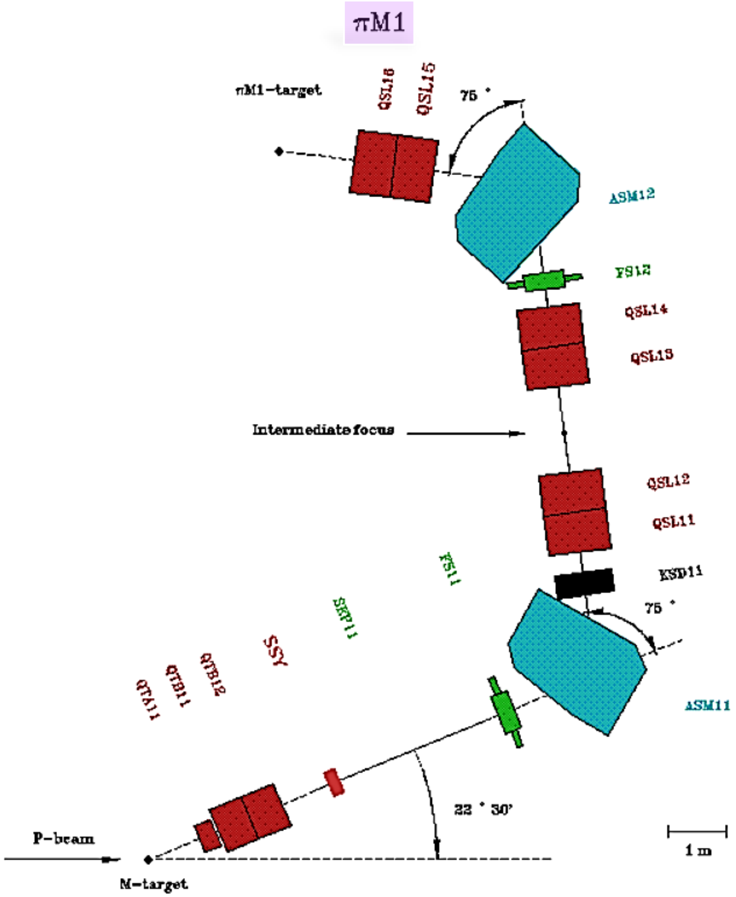
- We find **no evidence** for elastic πN resonances in region between πN thr & 1300 MeV having width Γ > 50 keV.
- Present πN data **cannot exclude** even purely elastic (or inelastic) narrow resonances with Γ < 50 keV.
- Insertion of trial narrow resonances may be good “technical trick” to check quality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

- How can solve this puzzle ?

Capability for N’







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

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

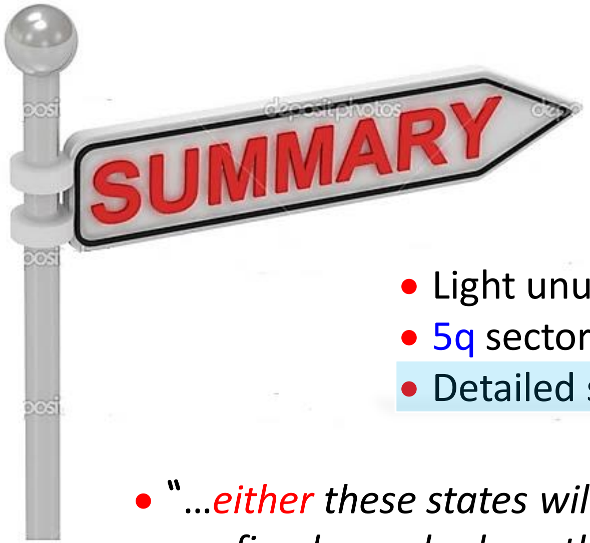
GW INS — Data Analysis Center — Institute for Nuclear Studies, The George Washington University

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

Jefferson Lab — Thomas Jefferson National Accelerator Facility

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

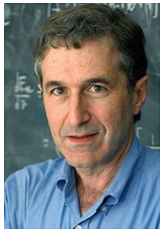
A1

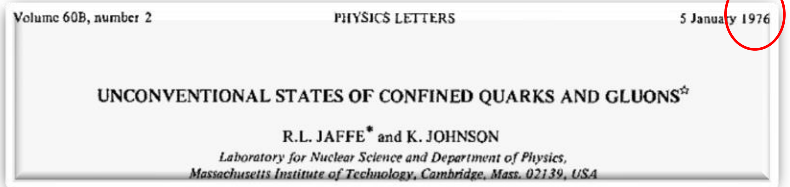


Spectroscopy of Baryons

- 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.

- "…*either 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☆

R.L. JAFFE* and K. JOHNSON

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

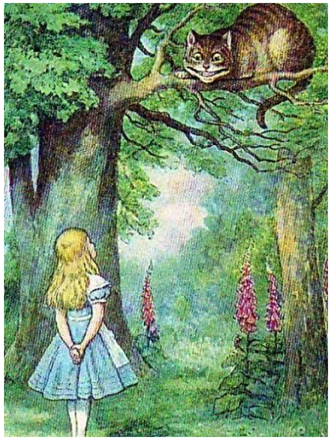
- Production of multiquark hadrons may be new kind of **hard processes**; it is related with higher Fock components.

- Hit **hard** to see what is it there inside.
  Make **two hadrons** hit each other **hard**.

- e^+e^- annihilation into hadrons: $e^+e^-\to q\bar{q}\to$ hadrons.
- Deep Inelastic lepton-hadron Scattering (DIS): $e^-p\to e^-X$.
- Hadron–hadron collisions.
- Hadrons/photons with large transverse momenta wrt to collision axis.

- This our hypothesis may suggest new experiments.

…The End…



This is just the beginning of the story...
We don't know yet which way it will go

"Would you tell me, please, which way I ought to go from here?"
"That depends a good deal on where you want to get to," said the **Cat**.
"I don't much care where ---" said **Alice**.
"Then it doesn't matter which way you go," said the **Cat**.
"--- so long as I get *somewhere*," **Alice** added as an explanation.
"Oh, you're sure to do that," said the **Cat** "if you only go long enough."