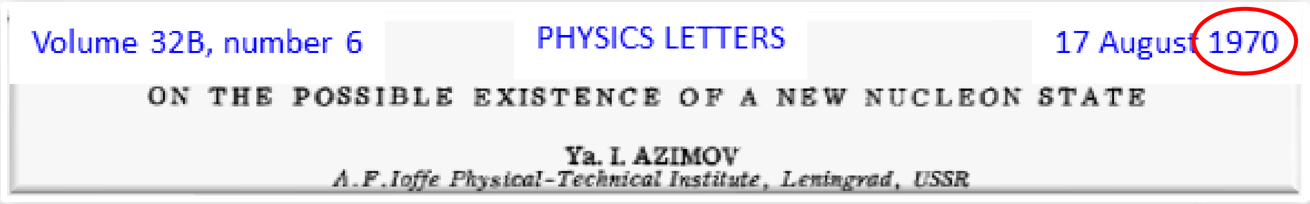
Light Baryon Resonances: Restrictions and Perspectives

Igor Strakovsky
The George Washington University

Dedicated to *Yakov Isaakovich Azimov*
[May 22, 1938, SPb – December 6, 2016, SPb]

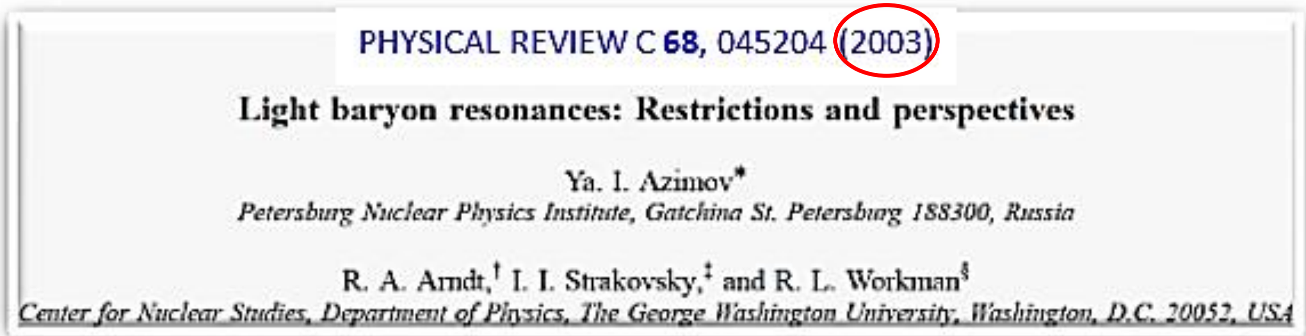
Supported by DE-SC0016583



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

Where Did N' from

- If we believe in SU(3), then every resonance must have ``family" (Unitarity Partners).
- Given underpopulation of conventional **3q** states, it is difficult to identify unconventional states.
- Baryon spectroscopy continues to motivate extensive experimental program, with most studies focused on missing resonance problem. →
- If, however, **N'** state was to be found with mass between **N** & Δ, it would undoubtedly have ***exotic*** structure.

- PDG has **133 Baryon Res** (**69** 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** & **four 56**).

- LQCD results are similar.

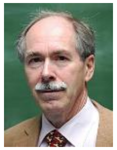
R. Koniuk & N. Isgur, Phys Rev Lett **44**, 845 (**1980**)

- 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 **Ξ(1620)** & **Σ(1480)**, considered now to have **1*** status according to PDG .

- Gell-Mann anticipated existence of *multiquark states* including *pentaquarks* based on CQM.

M. Gell-Mann, Phys Lett **8**, 214 (**1964**)

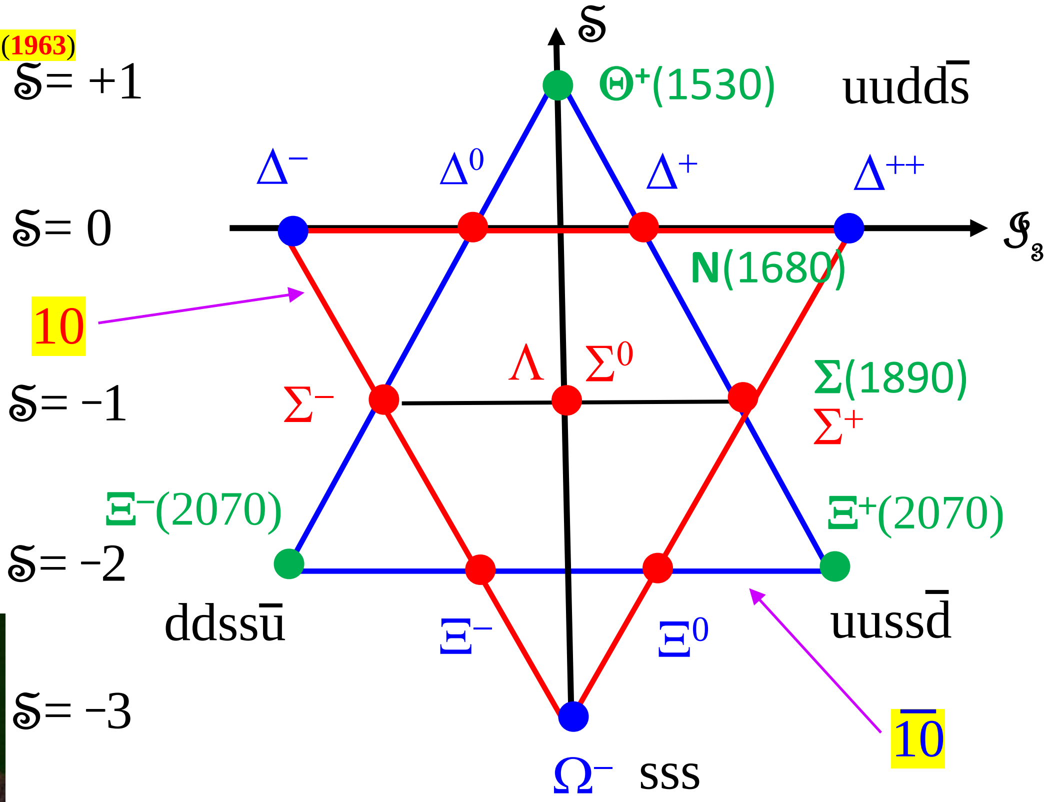
Anyone can ask Big Questions, but it is not easy to ask questions that would suggest new pathways leading to real progress of our understanding. Courtesy of Gerard 't Hooft, **2022**



What Else ?

10 & $\overline{10}$ – *P wave Multiplets*

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



$K_L p \to K^+ n$

$K_L p \to K_S \Xi^+$

D. Diakonov, V. Petrov, & M.V. Polyakov, Z. Phys. A **359**, 305 (**1997**)

- ***Big Question*** is if there is *no exotics* then **WHY ?**

Was Progress Delayed by Prejudice ?

M. Aguilar-Benitez *et al*, Phys Lett B **170**, 289 (**1986**)

- *The evidence for strangeness* **+1** *baryon resonances was reviewed in our 1976 edition [**1**], and more recently by Kelly [**2**] and by Oades [**3**].*
  *Two new partial-wave analyses [**4**] have appeared since our 1984 edition.*
  Both claim that the P_{13} and perhaps other waves resonate.

- *However, the results permit no definite conclusion – the same story heard for 15 years.*
  The standards of proof must simply be much more severe here than in a channel in which many resonances are already known to exist.
  The general prejudice against baryons not made of three quarks and the lack of any experimental activity in this area make it likely that it will be another 15 years before the issue is decided.

References:

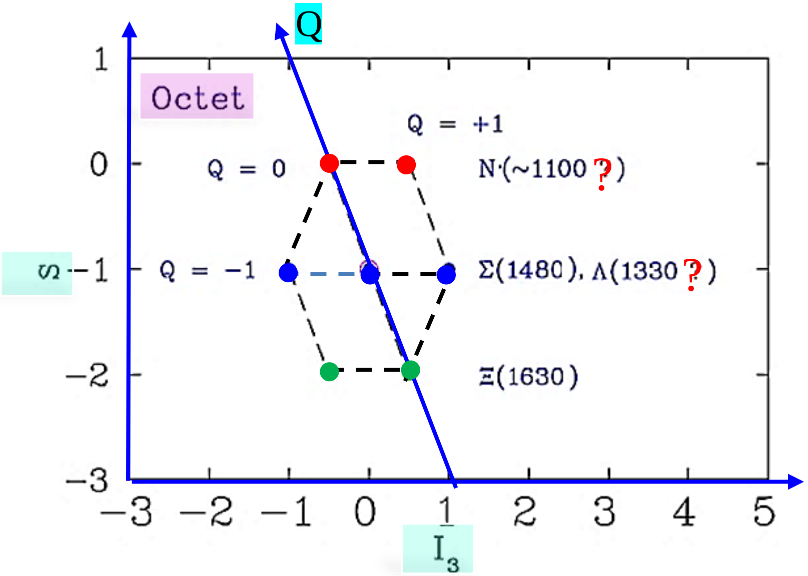
[**1**] Particle Data Group (T.G. Trippe *et al*.) Rev Mod Phys **48**, No 2, Part II (1976)
[**2**] R.L. Kelly, in *Proceedings of the Meeting on Exotic Resonances* (Hiroshima, 1978) edited by I. Endo *et al*.
[**3**] G.C. Oades, in *Low and Intermediate Energy Kaon-Nucleon Physics* (1981) edited by E. Ferrari and G. Violini
[**4**] K. Hashimoto, Phys Rev C **29**, 1377 (1984); R.A. Arndt and L.D. Roper, Phys Rev D **31**, 2230 (1985)

Unitarity Partners (?)

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

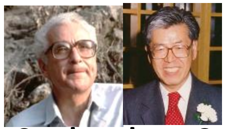
8 – S wave Multiplet

- 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 well
  could be 8.
- There is no prediction of $1/2^-$ in ChSA
  (no predictions for negative parity @ all).



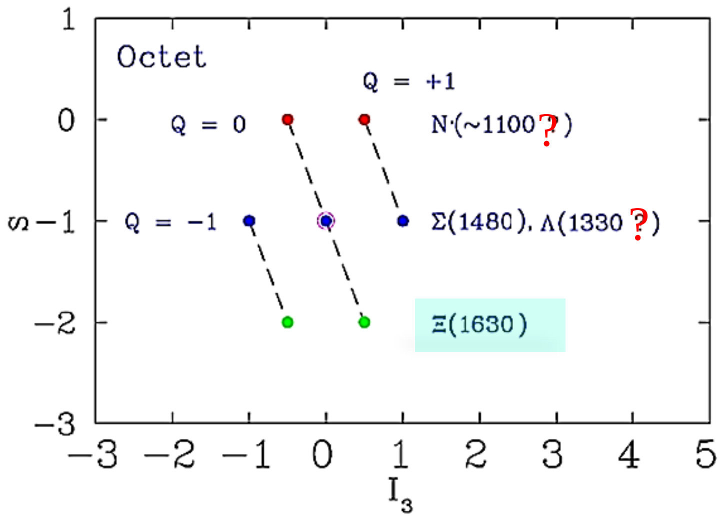
$$M = a_0 + a_1 Y + a_2 \left[I(I+1) - \frac{1}{4} Y^2 \right]$$

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



$\Xi(1620)$

What is Known about Ξ(1620)



Citation: R.L. Workman *et al.* (Particle Data Group), Prog.Theor.Exp.Phys. **2022**, 083C01 (2022)

PDG particle data group **Ξ(1620)**

$I(J^P) = \frac{1}{2}(?^?)$ Status: *

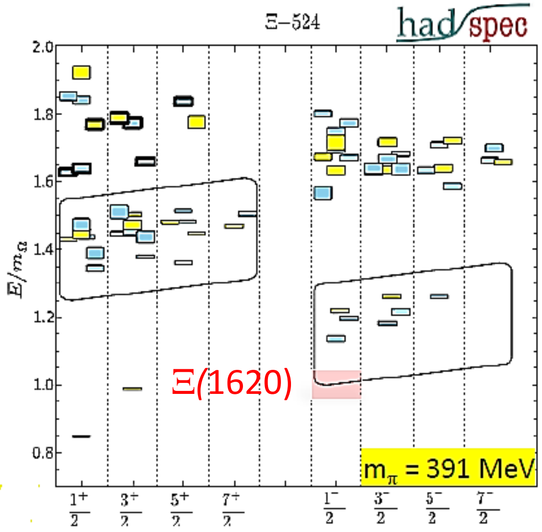
J, *P* need confirmation.

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

Ξ(1620) WIDTH

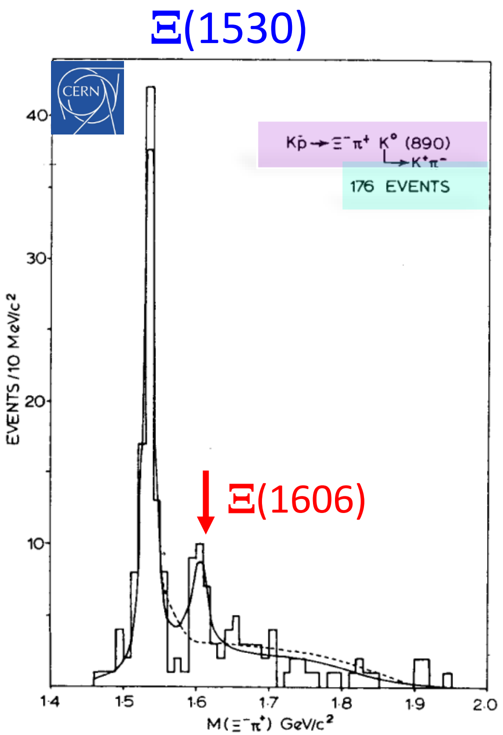
VALUE (MeV)	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
22.5	31	[1] BRIEFEL	77	HBC	$K^- p$ 2.87 GeV/c
40 ±15	34	DEBELLEFON	75B	HBC	$K^- p \to \Xi^- \overline{K} \pi$
21 ± 7	29	ROSS	72	HBC	$K^- p \to \Xi^- \pi^+ K^{*0}(892)$



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

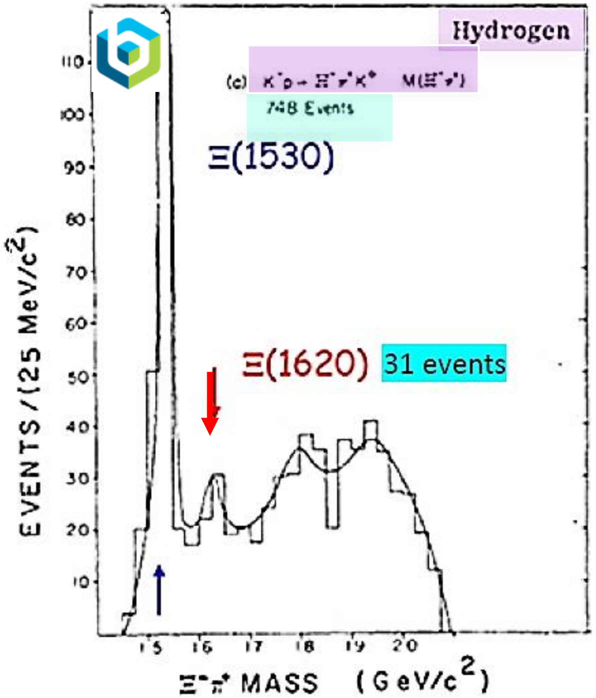
Bump Hunting

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



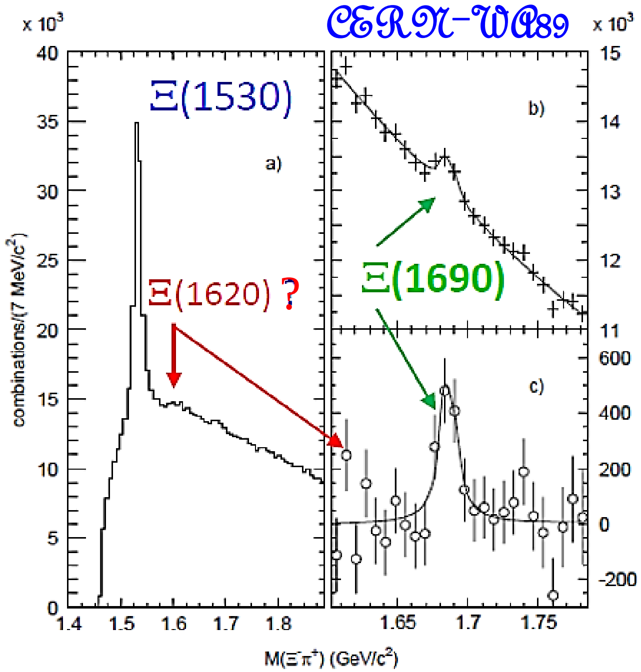
M = 1605.5±5.6 MeV
Γ = 20.8±7.4 MeV

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



M = 1624±3 MeV
Γ = 22.5 MeV

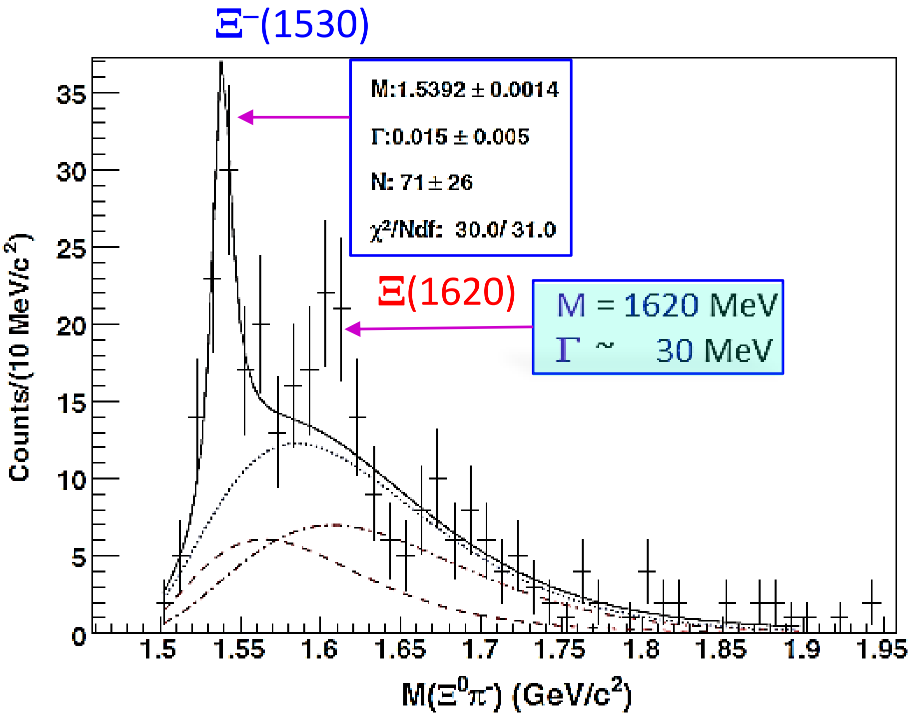
E. Briefel *et al*, Phys Rev D **16**, 2706 (1977)



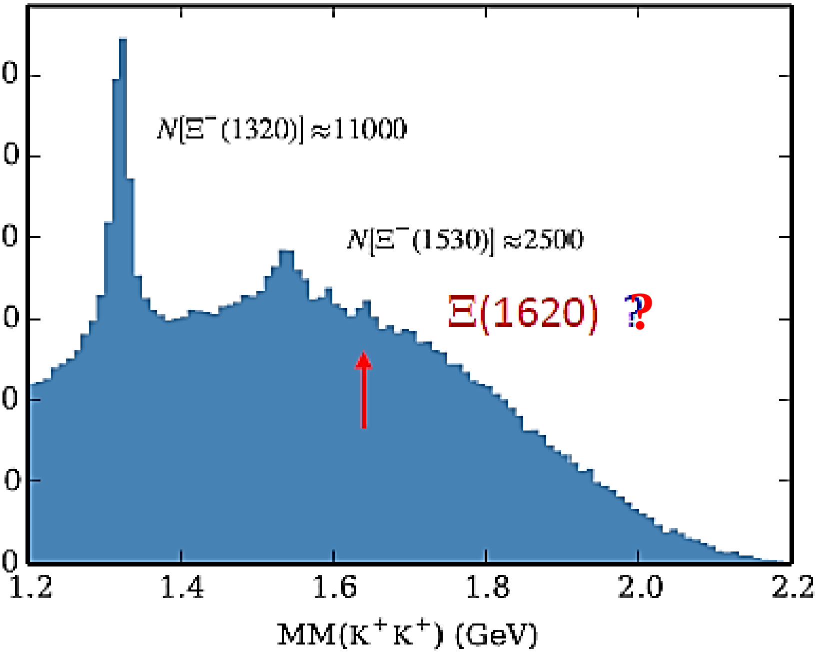
M.I. Adamovich *et al*, Eur Phys J C **5**, 621 (1998)

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

Bump Hunting



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

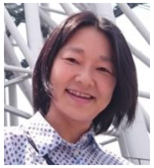


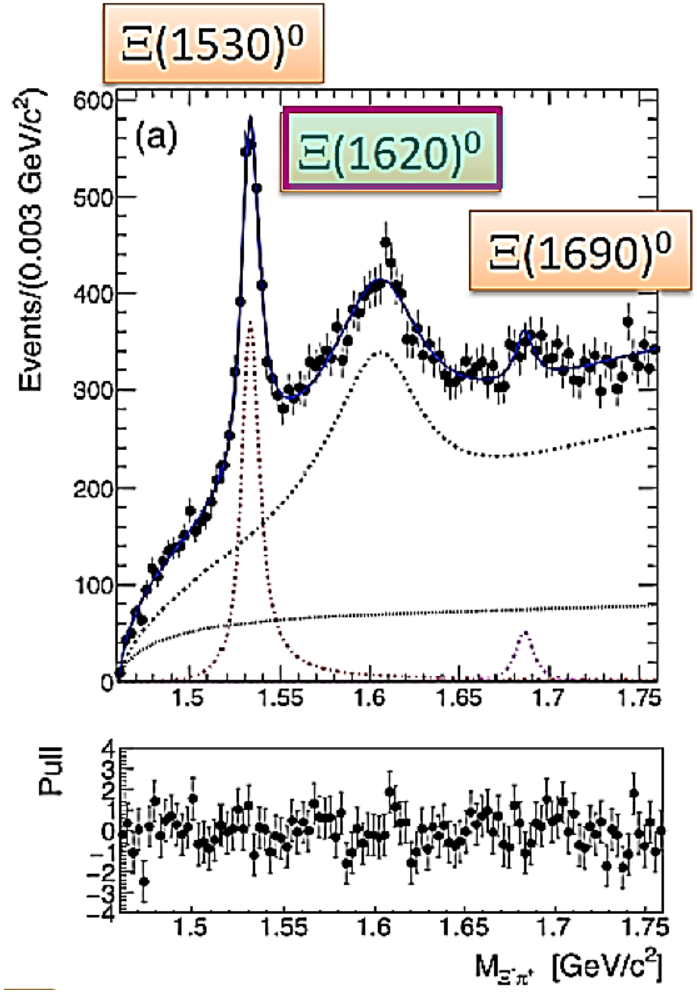
J.T. Goetz *et al*, Phys Rev C **98**, 062201 (**2018**)

Bump Hunting

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

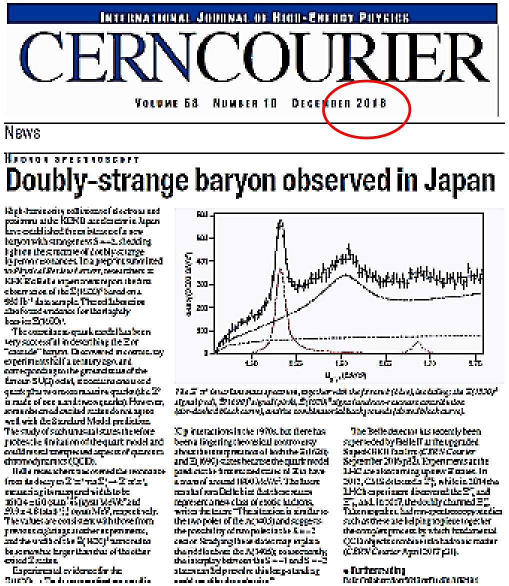
M. Sumihama *et al*, Phys Rev Lett **122**, 072501 (**2019**)





- Invariant mass spectrum in sideband region.

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



INTERNATIONAL JOURNAL OF HIGH-ENERGY PHYSICS

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VOLUME 58 NUMBER 10 DECEMBER 2018

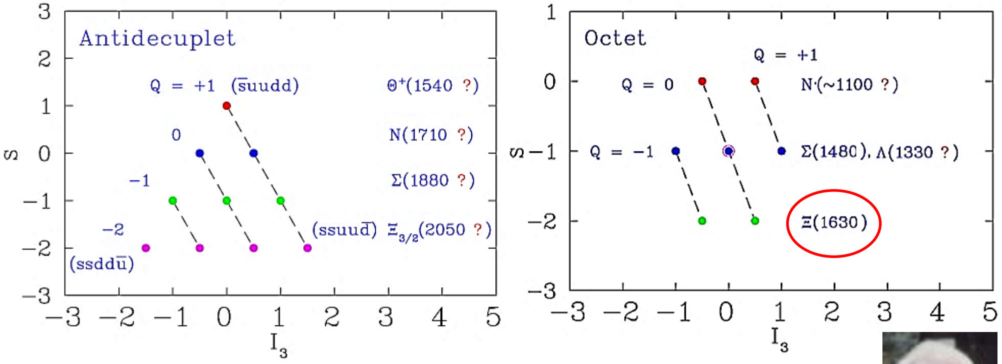
News

HADRON SPECTROSCOPY

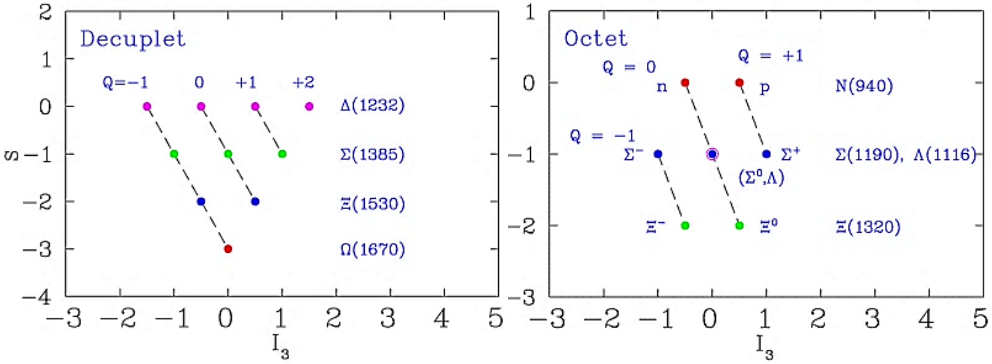
Doubly-strange baryon observed in Japan

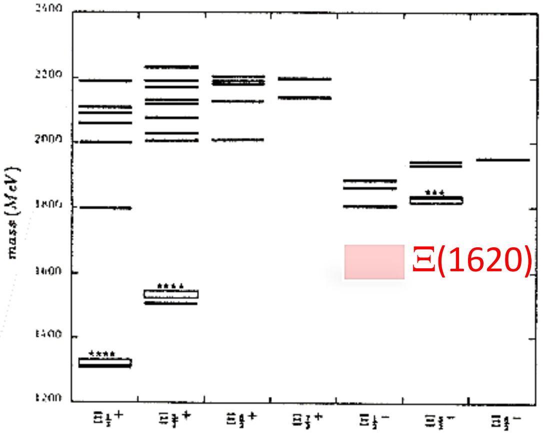
Possible Nature of Ξ(1620)

- 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 well
  could be 8.
- There is no prediction of $1/2^-$ in ChSA
  (no predictions for negative parity @ 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 coupled channels.

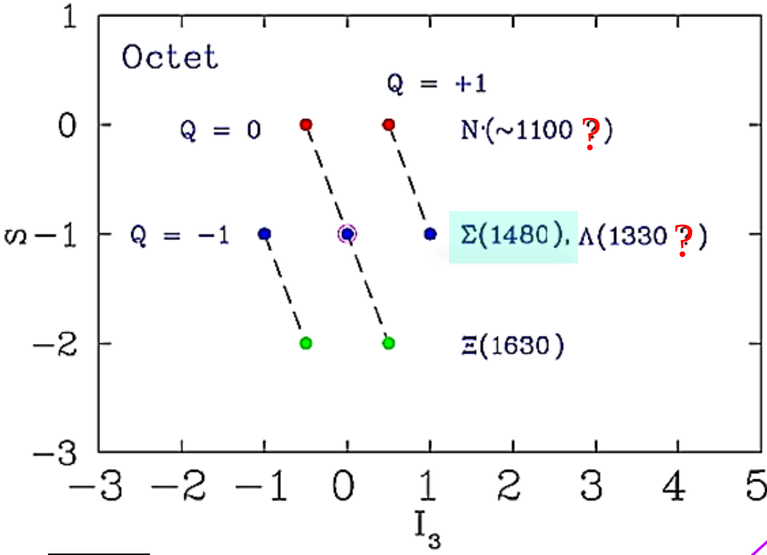
A. Ramos, E. Oset, & C. Bennhold, Phys Rev Lett **89**, 252001 (**2002**)

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

K. Chan, R. Chen, Z.F. Sun, & X. Liu, Phys Rev D **100**, 074006 (**2019**)

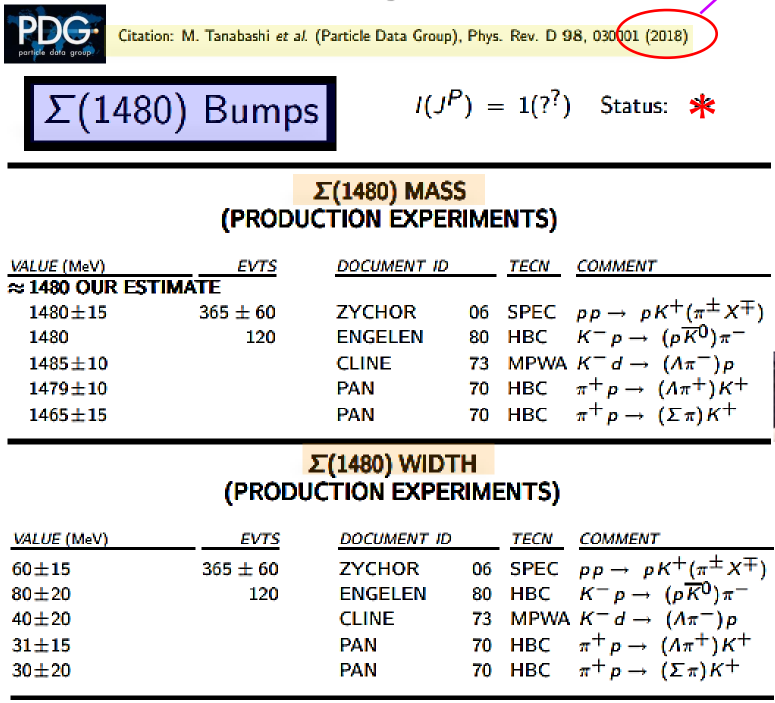
$\Sigma(1480)$

What is Known about Σ(1480)



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

- *We want to reiterate our standing requests:*
  - *Please continue to inform us of mistakes and omissions.*
  - *We reemphasize that it is inappropriate to make reference to this [PDG] compilation instead of to the original work; we provide the references, please use them.* A.H. Rosenfeld *et al*, Rev Mod Phys **40**, 77 (**1968**)



Citation: M. Tanabashi *et al.* (Particle Data Group), Phys. Rev. D 98, 030001 (2018)

Σ(1480) Bumps

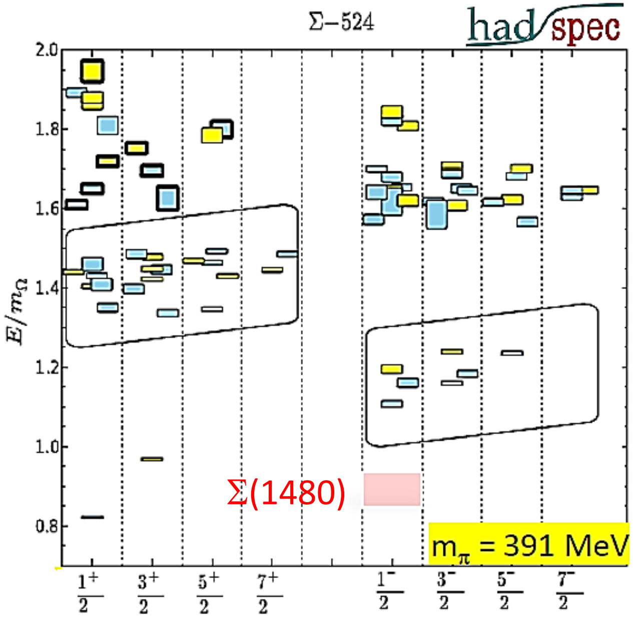
$I(J^P) = 1(?^?)$ Status: *

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	$\pi^+p \to (\Sigma\pi)K^+$

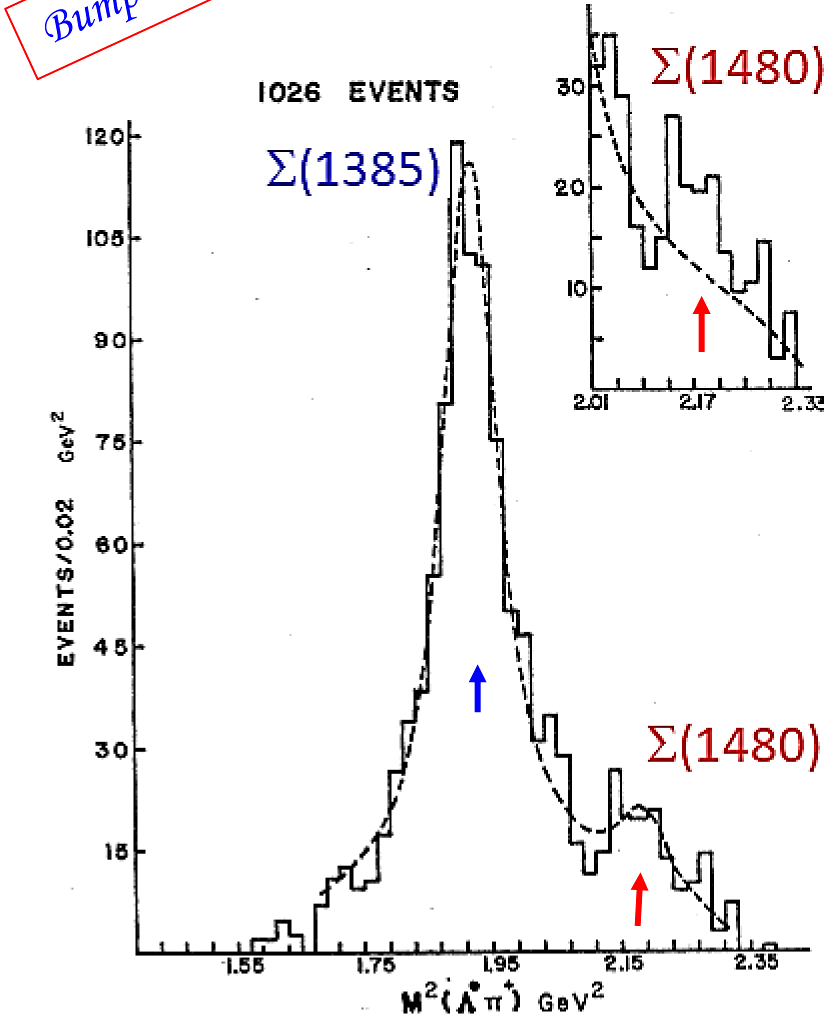


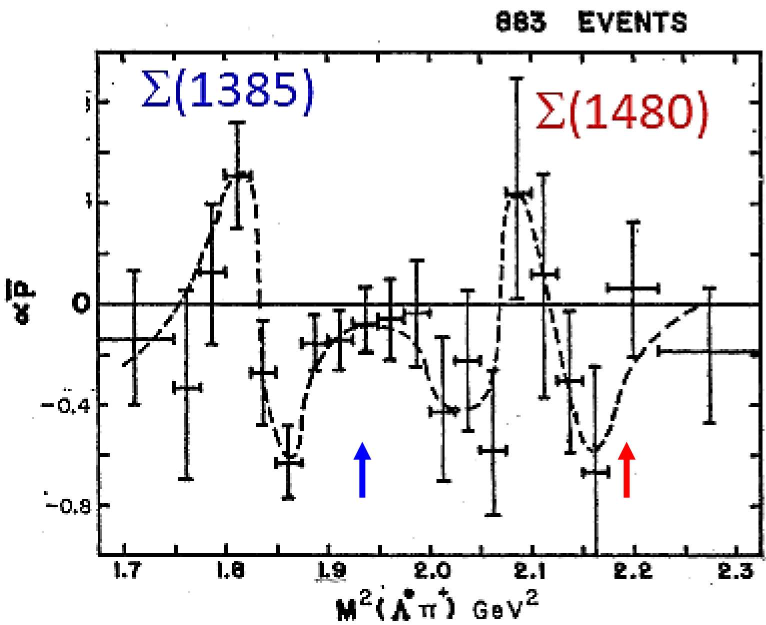
R. G. Edwards *et al*, Phys Rev D **87**, 054506 (**2013**)

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

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

Bump Hunting





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

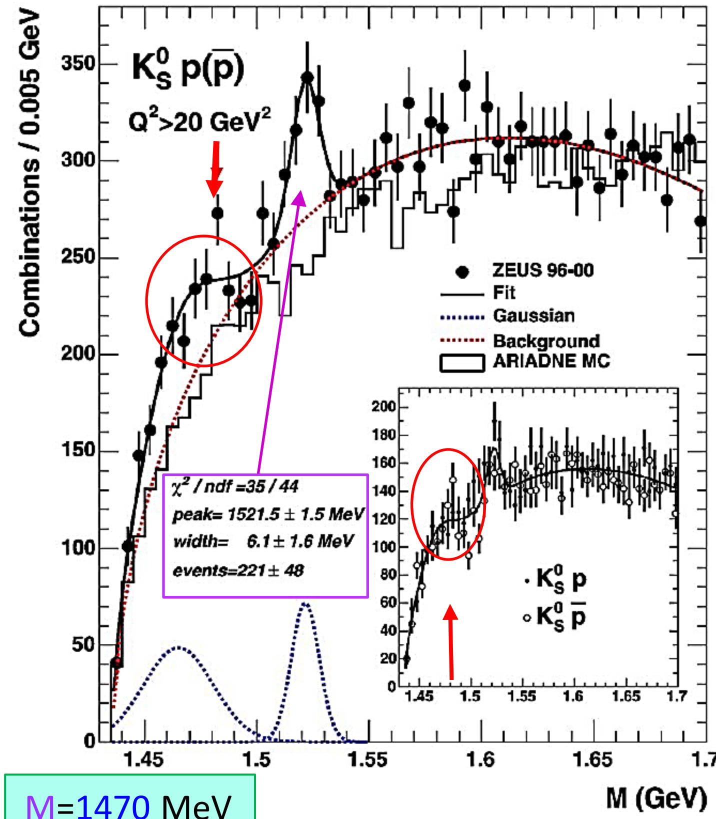
- Estimate statistical significance at 3σ, or even 4σ, for $\Sigma(1480)$ both peak in mass distribution & polarization effect were reported.

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

Bump Hunting

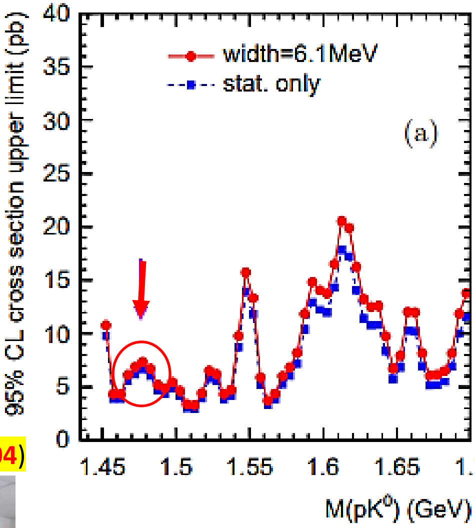
$\Sigma(1480)$ via $e^{+}p \rightarrow e'K^{0}pX$ from

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

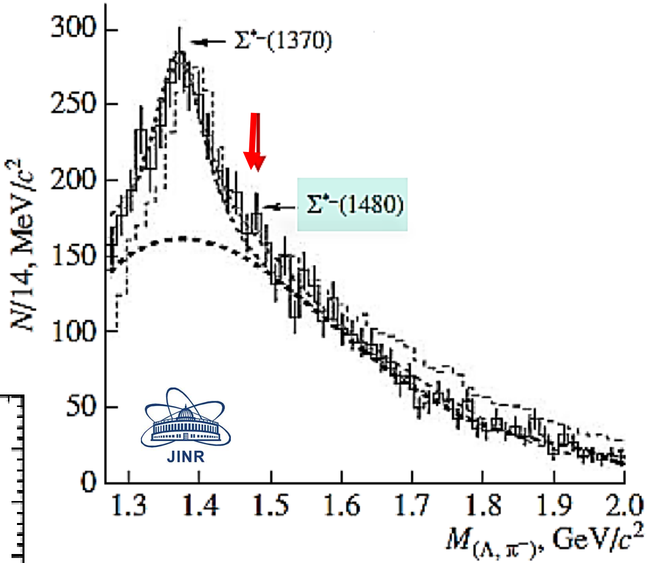


M=1470 MeV
Γ ~ 30 MeV

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



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

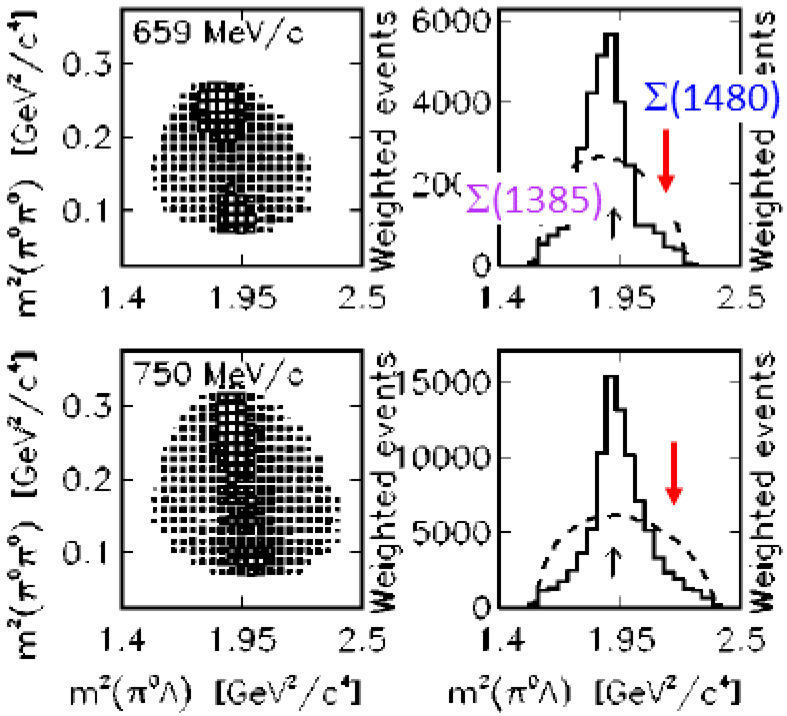


P.Zh. Aslanyan, Phys Part Nucl **40**, 525 (**2009**)

Bump Hunting

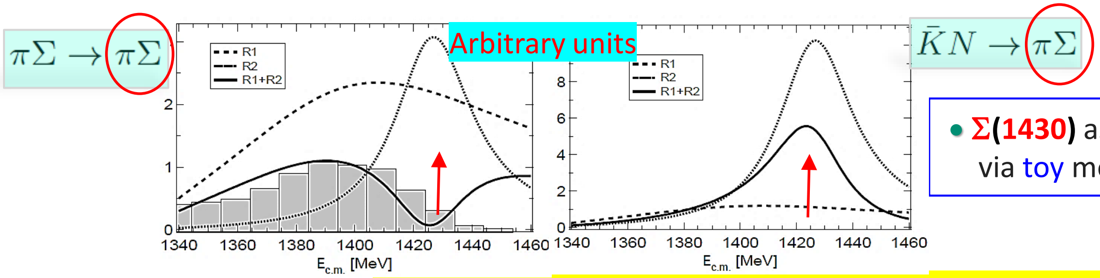
Σ(1480) via $K^-p \to \pi^0\pi^0\Lambda$ from

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



- *In our data, we do not see trace of either Σ(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.

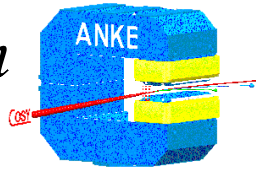


- **Σ(1430)** as cusp via toy model.

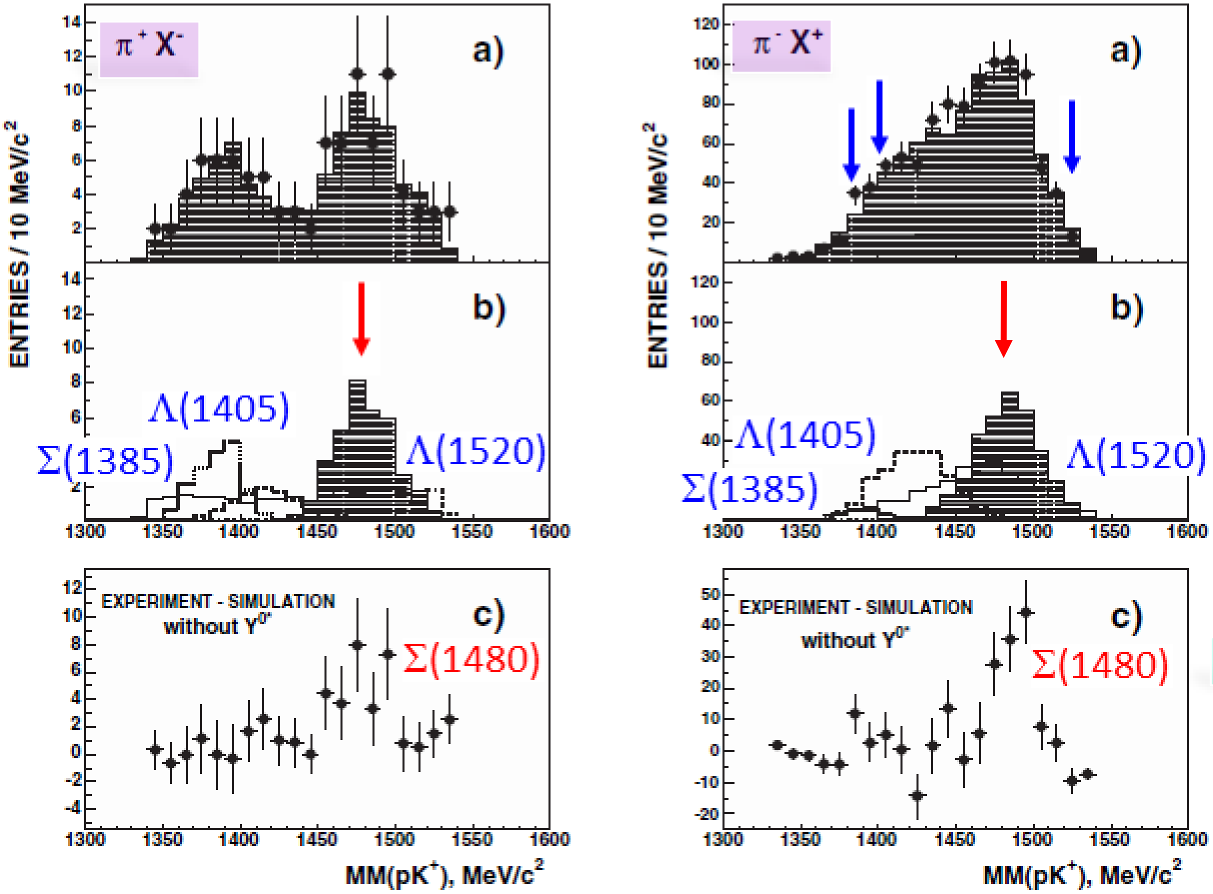
D. Jido, J.A. Oller, E. Oset, A. Ramos, & U.-G. Meissner, Nucl Phys A **725**, 181 (**2004**)

Bump Hunting

$\Sigma(1480)$ 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**.

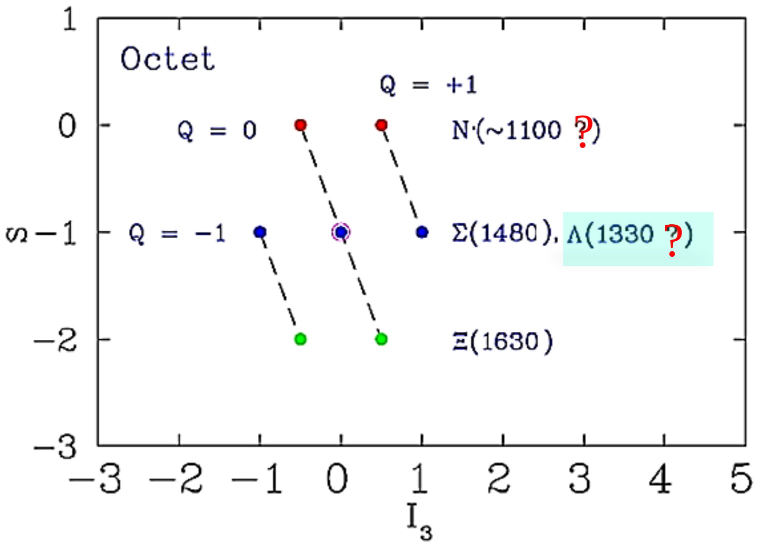
M = 1480 ± 15 MeV Γ = 60±15 MeV

- Since isospin has not been determined here, it could either be observation of Σ(1480), or, alternatively, Λ(1480) – not listed in PDG.

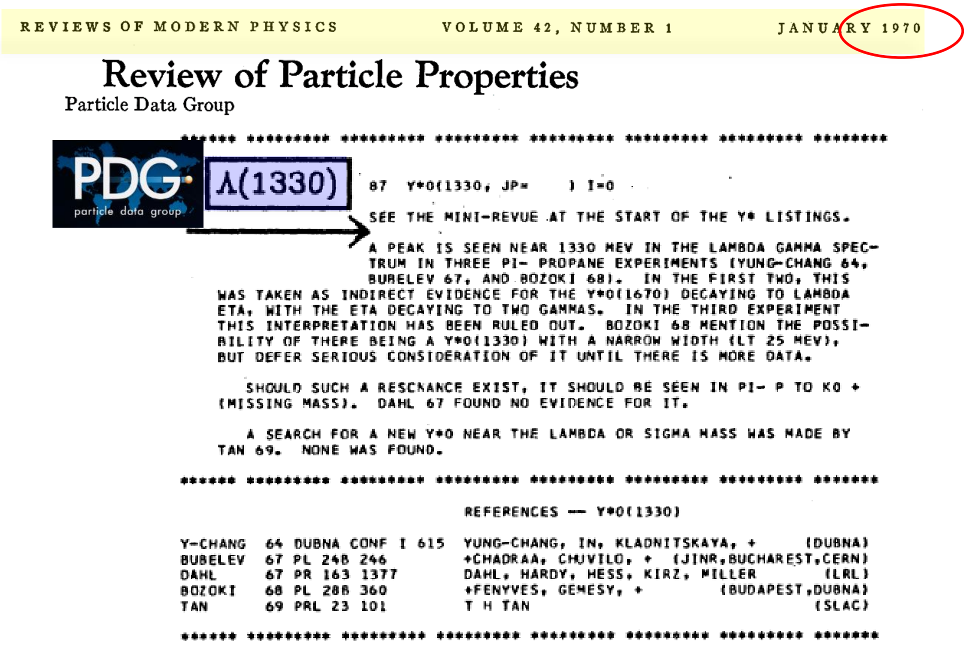

Lambda $1/2^+$
Lambda(1380) $1/2^-$
Lambda(1405) $1/2^-$
Lambda(1520) $3/2^-$
Lambda(1600) $1/2^+$

$\Lambda(1330)$

What is Known about Λ(1330)



- Λ(1330), if exists,
  looks to be good partner of Ξ(1620) & Σ(1480).



REVIEWS OF MODERN PHYSICS VOLUME 42, NUMBER 1 JANUARY 1970

Review of Particle Properties

Particle Data Group

PDG particle data group

Λ(1330)

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87  Y*0(1330, JP=     ) I=0

SEE THE MINI-REVUE AT THE START OF THE Y* LISTINGS.

A PEAK IS SEEN NEAR 1330 MEV IN THE LAMBDA GAMMA SPEC-
TRUM IN THREE PI- PROPANE EXPERIMENTS (YUNG-CHANG 64,
BUBELEV 67, AND BOZOKI 68).  IN THE FIRST TWO, THIS
WAS TAKEN AS INDIRECT EVIDENCE FOR THE Y*0(1670) DECAYING TO LAMBDA
ETA, WITH THE ETA DECAYING TO TWO GAMMAS.  IN THE THIRD EXPERIMENT
THIS INTERPRETATION HAS BEEN RULED OUT.  BOZOKI 68 MENTION THE POSSI-
BILITY OF THERE BEING A Y*0(1330) WITH A NARROW WIDTH (LT 25 MEV),
BUT DEFER SERIOUS CONSIDERATION OF IT UNTIL THERE IS MORE DATA.

   SHOULD SUCH A RESCNANCE EXIST, IT SHOULD BE SEEN IN PI- P TO K0 +
(MISSING MASS).  DAHL 67 FOUND NO EVIDENCE FOR IT.

   A SEARCH FOR A NEW Y*0 NEAR THE LAMBDA OR SIGMA MASS WAS MADE BY
TAN 69.  NONE WAS FOUND.

****** ********* ********* ********* ********* ********* ********* *******

                         REFERENCES -- Y*0(1330)

Y-CHANG   64 DUBNA CONF I 615  YUNG-CHANG, IN, KLADNITSKAYA, +      (DUBNA)
BUBELEV   67 PL 24B 246        +CHADRAA, CHUVILO, +  (JINR,BUCHAREST,CERN)
DAHL      67 PR 163 1377       DAHL, HARDY, HESS, KIRZ, MILLER        (LRL)
BOZOKI    68 PL 28B 360        +FENYVES, GEMESY, +         (BUDAPEST,DUBNA)
TAN       69 PRL 23 101        T H TAN                               (SLAC)

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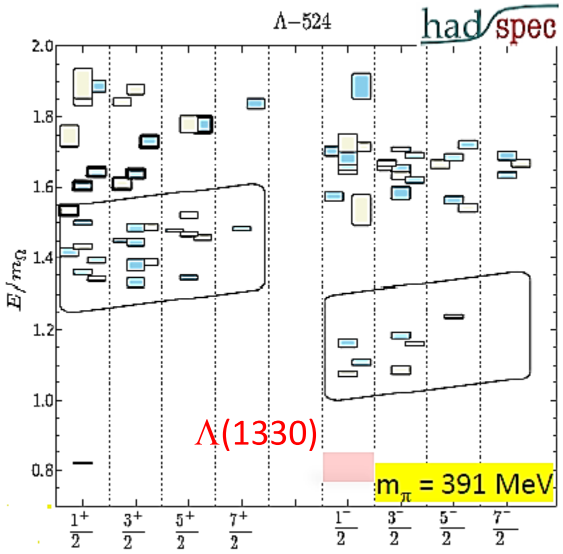
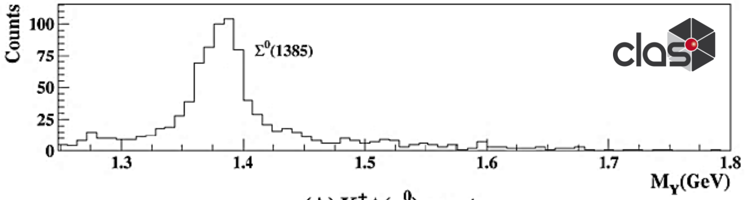


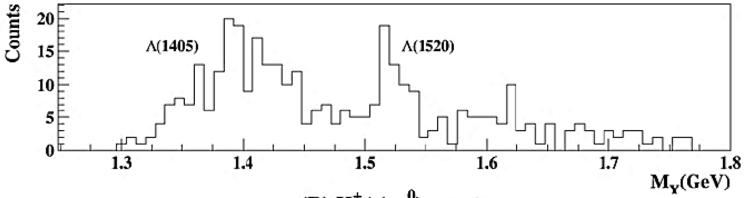
R. G. Edwards *et al*, Phys Rev D **87**, 054506 (**2013**)

Bump Hunting

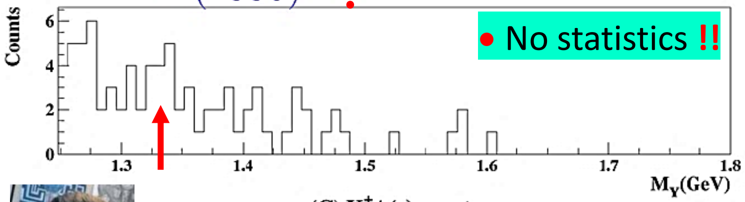
$\Lambda(1330)$ via $\pi^- d \rightarrow p\pi^-\Lambda\gamma$ from SLAC
$\Lambda(1330)$ via $\gamma p \rightarrow K^+\Lambda X^0$ & $\pi^+ X^0$ from clas



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



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

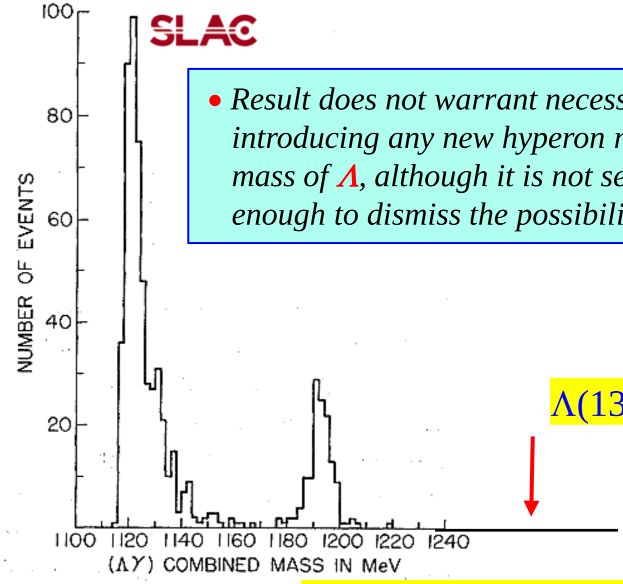


$\Lambda(1330)$?

- No statistics !!

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

Simon Taylor, PhD Thesis, Rice U, May **2000**

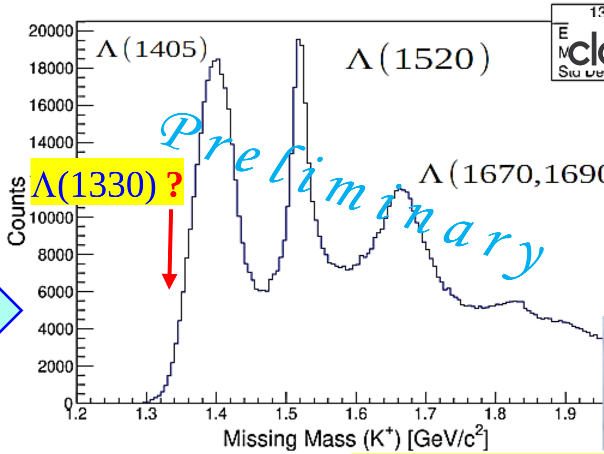


- *Result does not warrant necessity of introducing any new hyperon near mass of Λ, although it is not sensitive enough to dismiss the possibility entirely.*

$\Lambda(1330)$?

Tai Ho Tan, Phys Rev Lett **23**, 101 (**1969**)

No evidence in this decay channel



$\Lambda(1330)$?

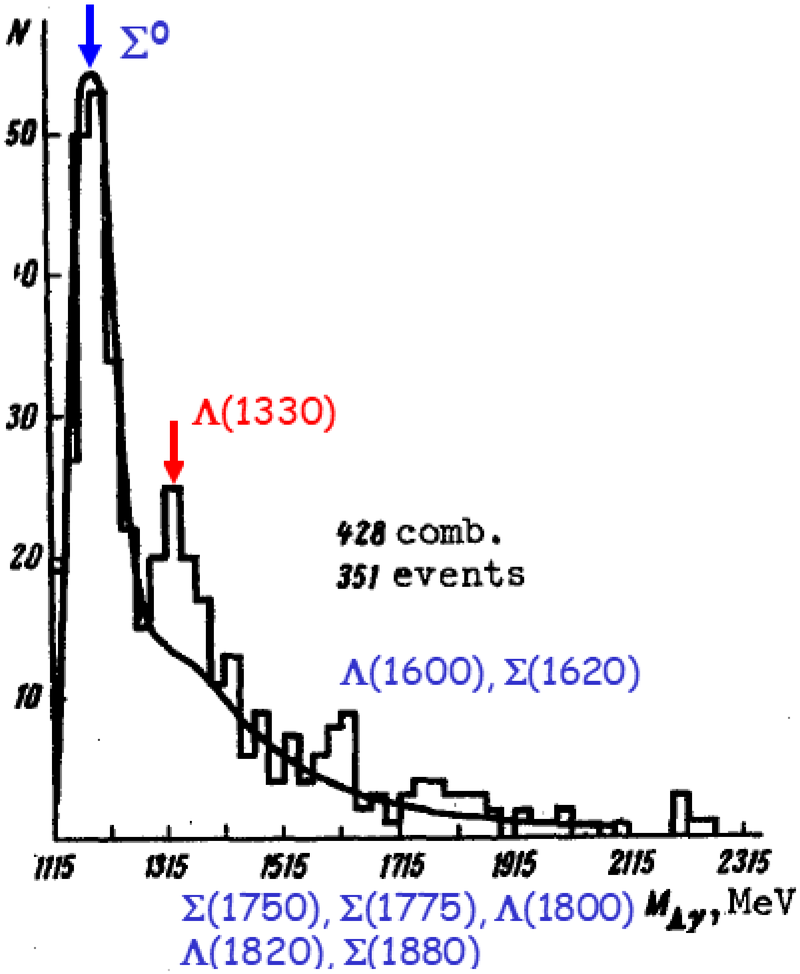
U. Shrestha & K. Hicks, November **2019**

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

Bump Hunting

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

- There is single witness.

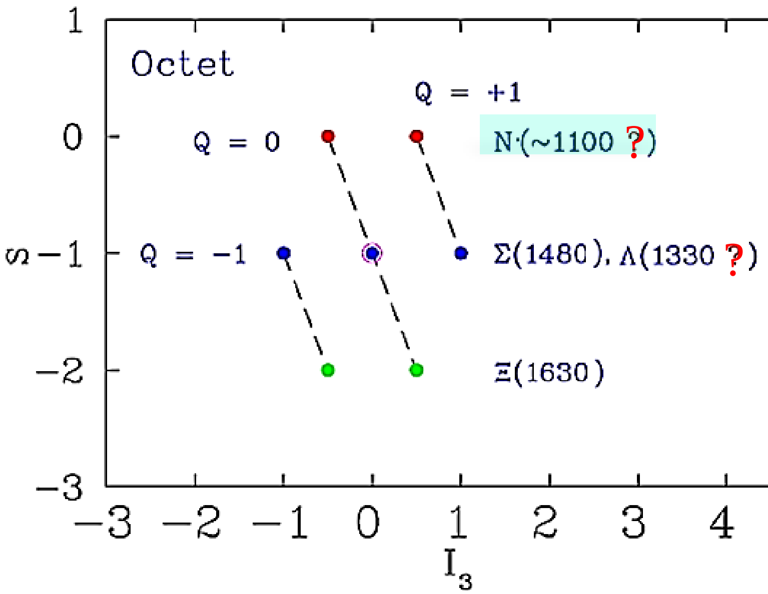


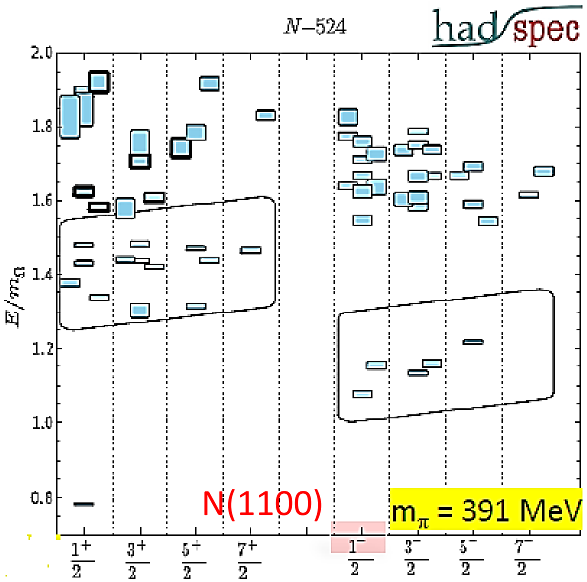
M = 1327.5±3.5 MeV
Γ = 20.0±4.4 MeV

N’(1100)

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**)

Bump Hunting

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

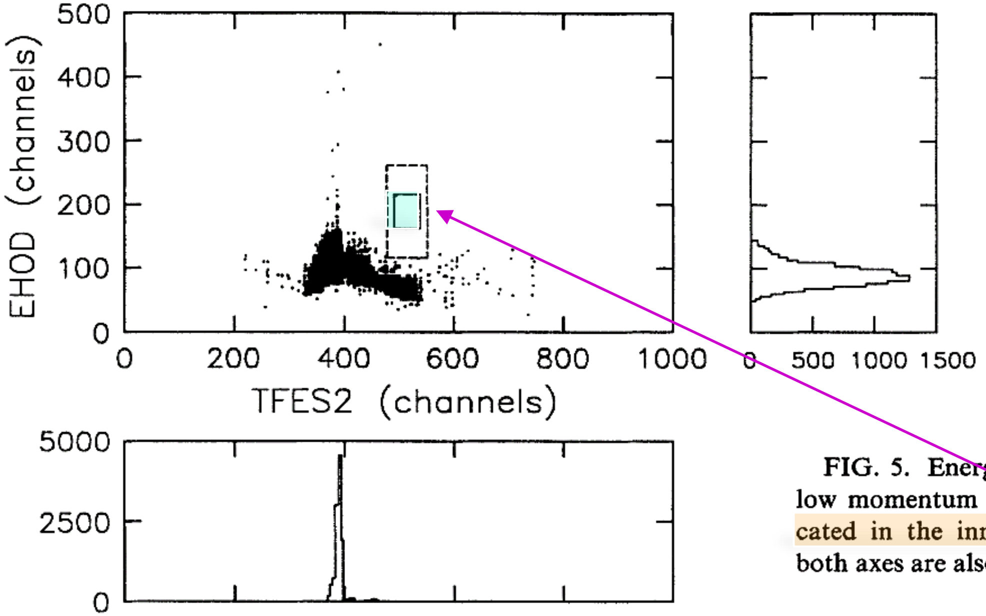


FIG. 5. Energy loss vs time-of-flight in the low momentum bite. The X^{++} should be located in the inner rectangle. Projections on both axes are also shown.

- 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.

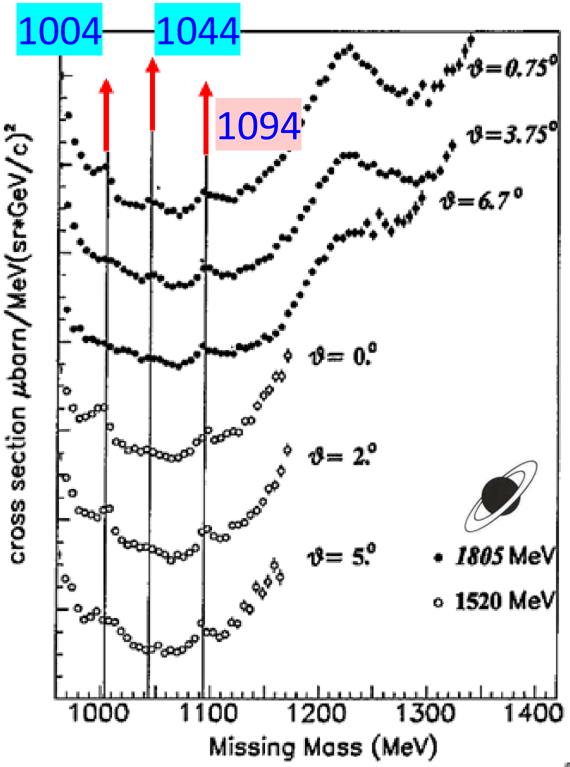
Bump Hunting

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

$pd \to ppX$ from

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

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



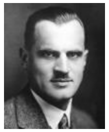
B. Tatischeff *et al*, Phys Rev Lett **79**, 601 (**1997**)
B. Tatischeff *et al,* Eur Phys J A **17**, 245 (**2003**)

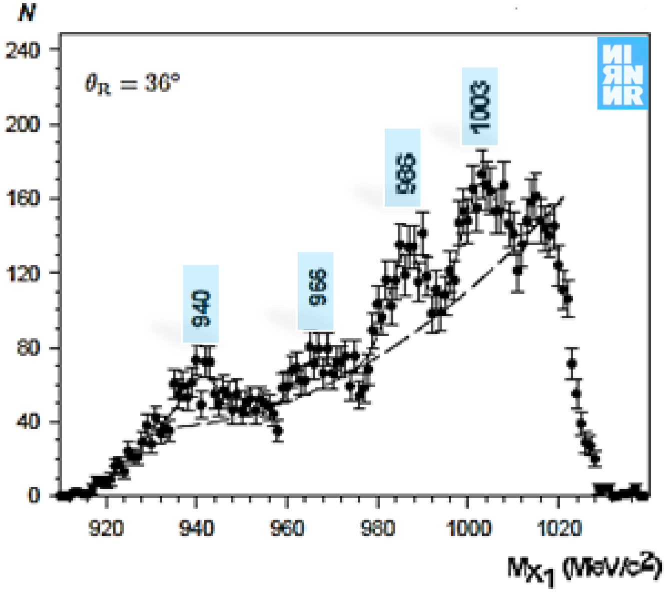
- If correct, such baryons would have **I=1/2**, masses of 1004, 1044, & 1094 MeV, & widths less than **4**–**15** MeV.

- 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 nucleons loosely bound in deuterons.



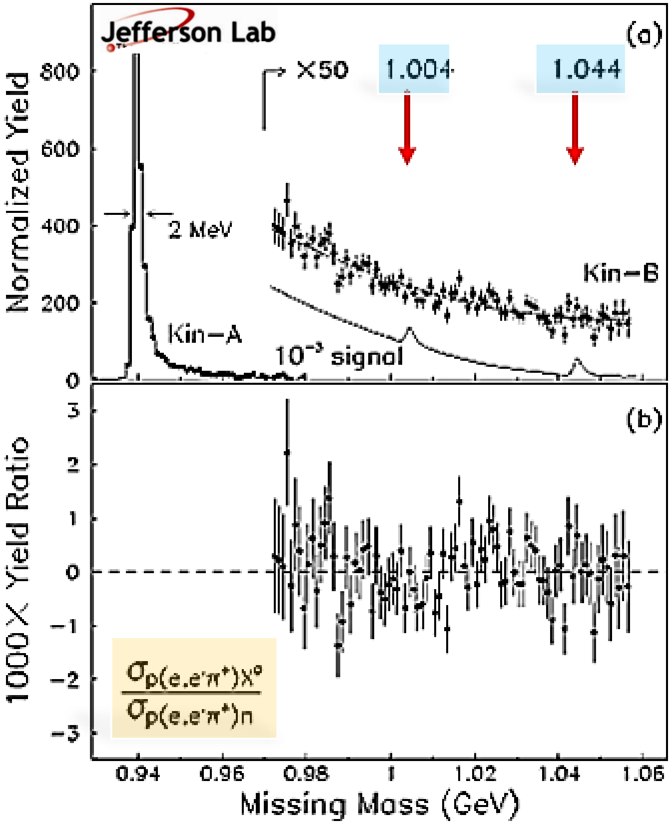


L. Fil'kov *et al,* Eur Phys J A **12**, 369 (**2001**)

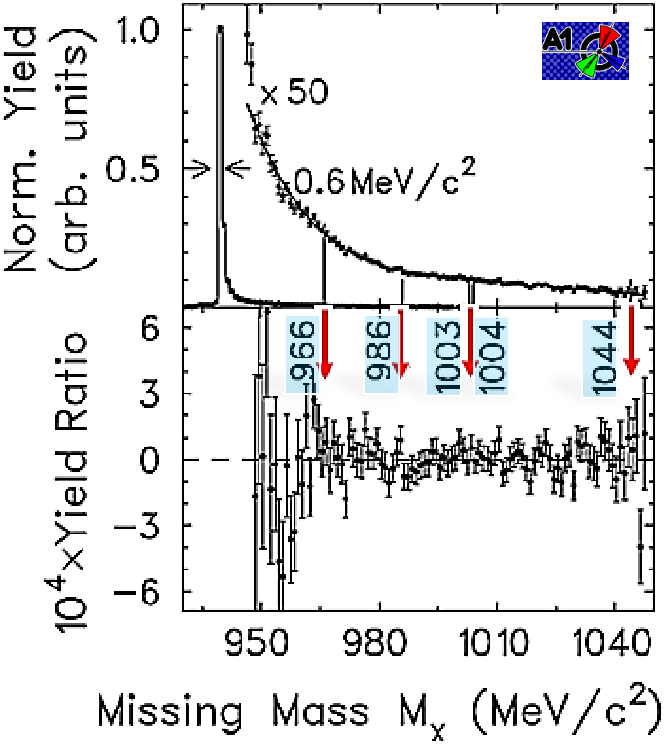

Bump Hunting

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

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

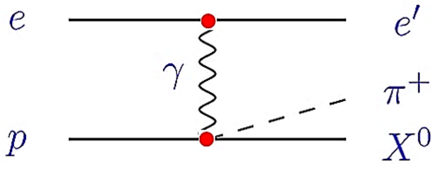


X. Jiang *et al*, Phys Rev C **67**, 028201 (2003)

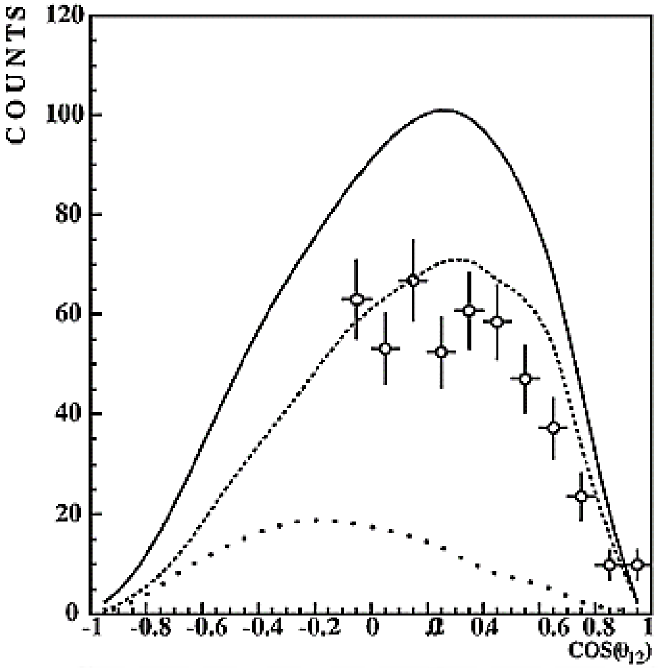


M. Kohl *et al*, Phys Rev C **67**, 065204 (2003)

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

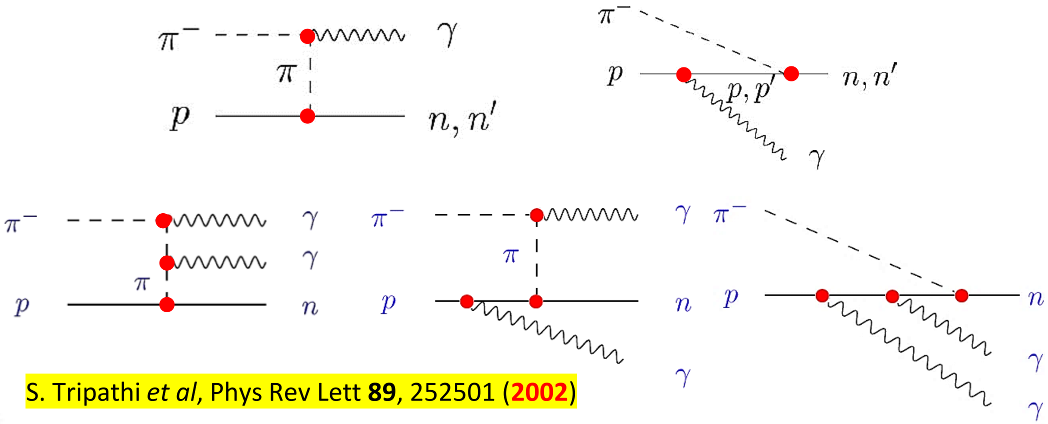


$\pi^- p \to n'\gamma \to n\gamma\gamma$ @ *rest from* TRIUMF

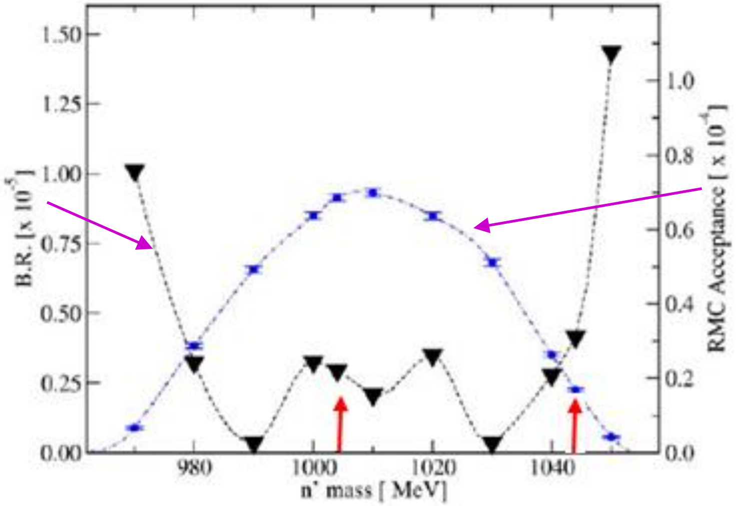


- BR($\pi^- p \to n\gamma\gamma$) = [3.05±0.27(stat)±0.31(syst)] x10^{-5}

- 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,
  measured spectrum being completely
  consistent with direct **two photon capture** only.

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

- Further hadro-production experiment is required to settle the issue.

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 refit over whole DB.

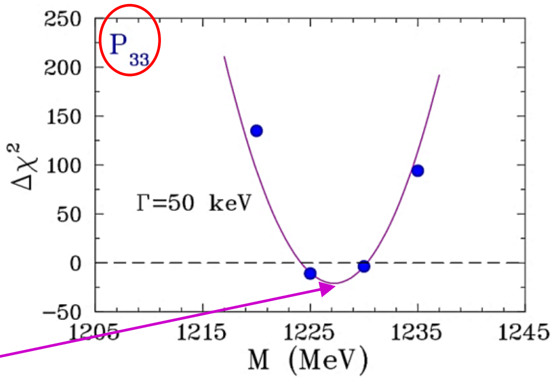
- Refitting
  - If worse description:
    - ⇒ Resonance with corresponding M & Γ is not supported.
  - If better description:
    - ⇒ Resonance may exist.
    - ⇒ Effect can be due to various corrections (*eg*, thresholds).
    - ⇒ Both possibilities can contribute.
  - Some additional checks are necessary.

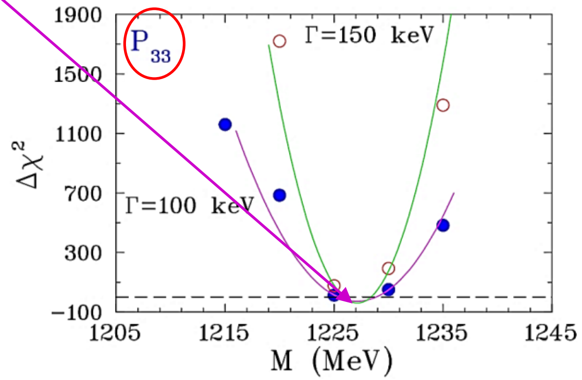
- True Resonance should provide effect only in single **PW**.

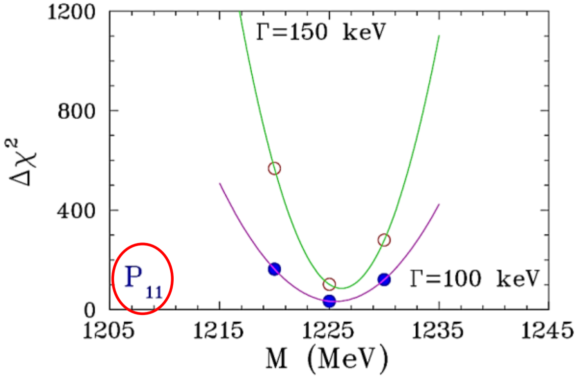
- While non-Resonance source may show similar effects in various **PWs**.

for (Quasi) Bound States of πN

- This case is close to **ππN** thr.



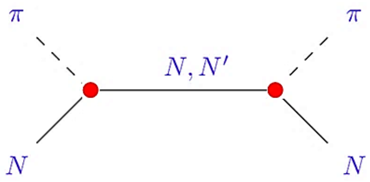


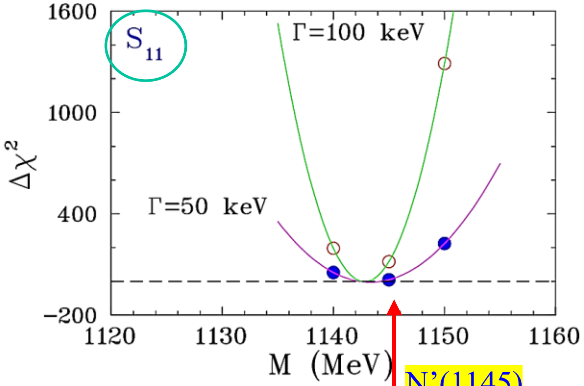


S-, P-, & D-waves

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

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

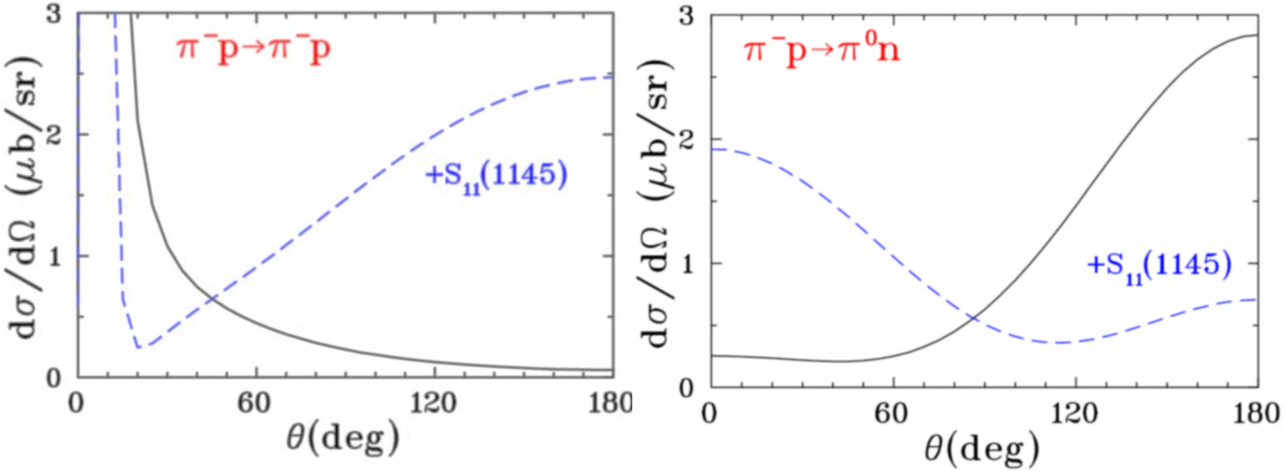




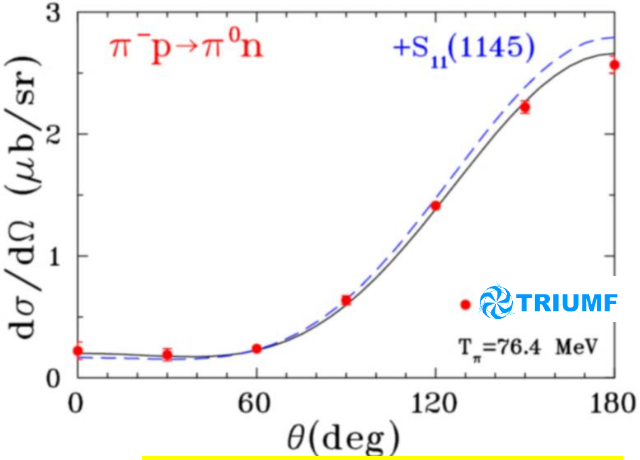
N’(1145)

for (Quasi) Bound States of πN

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



ΔT = 3.1 MeV



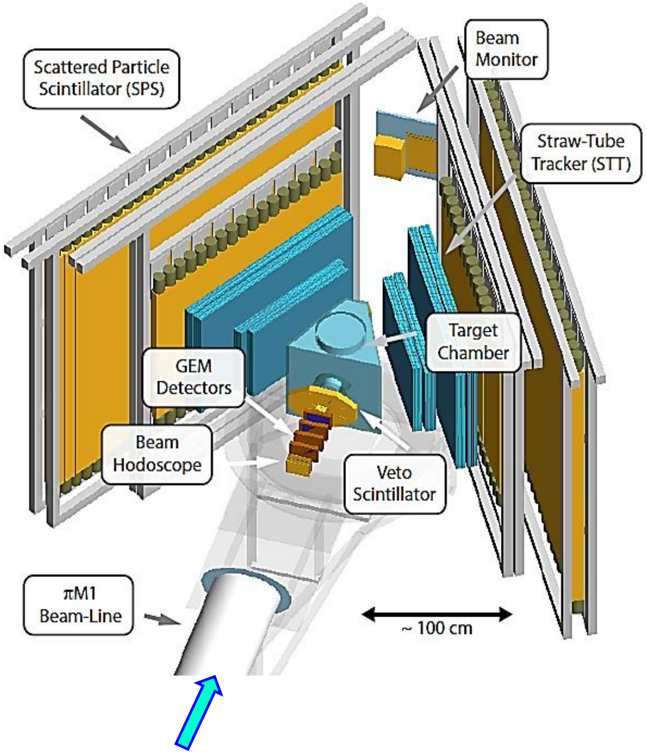
A. Bagheri *et al*, Phys Rev C **38**, 885 (1988)

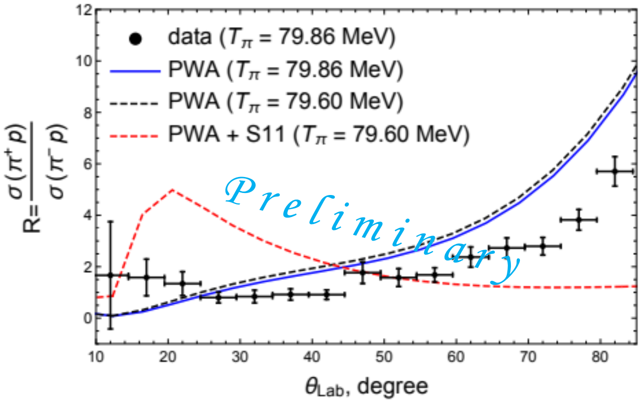
- We find ***no evidence*** for elastic πN resonances in region between πN thr & 1300 MeV having width Γ > 50 keV.
- Present πN data ***cannot exclude*** even purely elastic (or inelastic) narrow resonances with Γ < 50 keV.
- Insertion of trial narrow resonances may be good "technical trick" to check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

- How can solve this puzzle ?

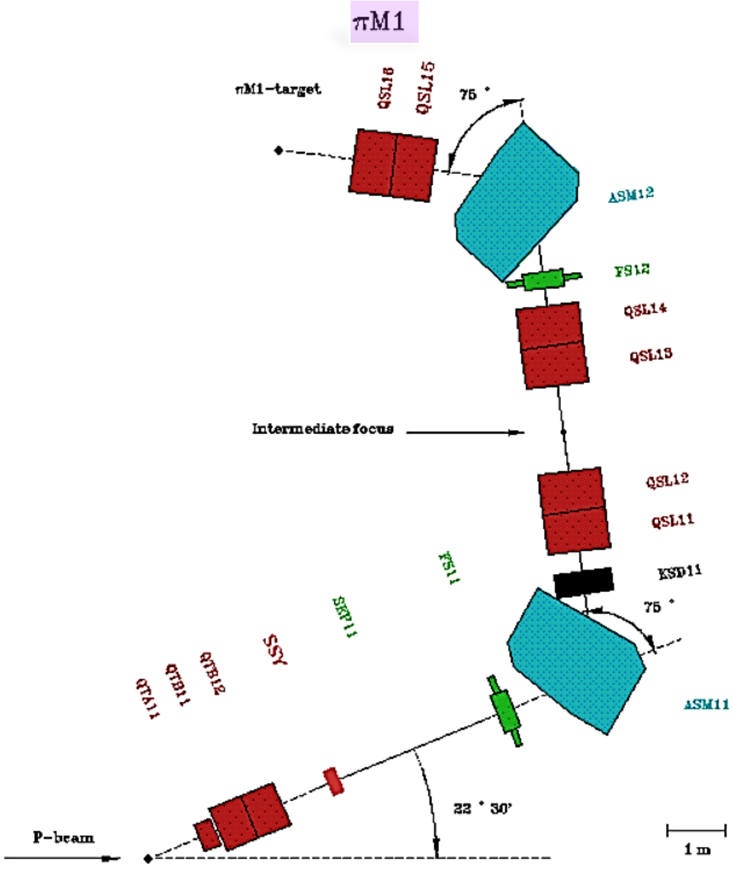
MUSE
HADES
J-PARC

Capability for $\mathcal{N}'$





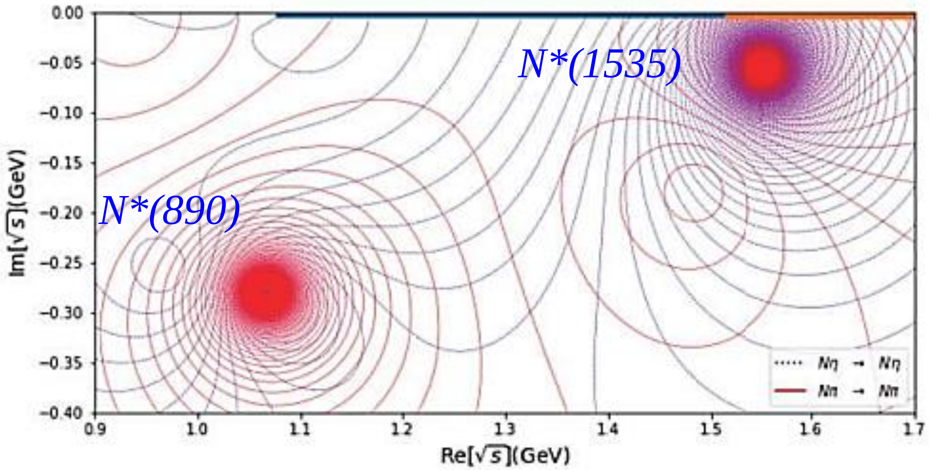
Ievgen Lavrukhin, PhD Thesis, GW, 2020



On *Low-Lying* $1/2^-$ *Octet Baryon*

C. Chen, W.Q. Niu, & H.Q. Zheng, Chi P C **46**, 081001 (2022)

- Recently proposed *N*(890)1/2⁻* baryon is studied in flavor ***SU(3)*** scheme with *K*-matrix unitarization, by fitting to low-energy cross section & phase shift data.



Pole	location	$\lvert g_{N\pi}\rvert$	$\lvert g_{N\eta}\rvert$
$N^*(890)$	$1.066-0.280i$	0.617	0.436
$N^*(1535)$	$1.553-0.056i$	0.645	1.031

PDG particle data group 1510±10 – (0.130±20)i MeV

- Dispersive analysis of low energy **γN → πN**

Target	Pole Position
p	$0.882-0.190i$ $0.960-0.192i$
n	$0.882-0.190i$ $0.960-0.192i$

Y. Ma, W.Q. Niu, D.L. Yao, & H.Q. Zheng, arXiv:2005.10695 [hep-ph]

- N/D study of S_{11} channel **πN** amplitude

$\sqrt{s}=0.89-0.24i$ GeV – Situation is unstable

Q.Z. Li, Y. Ma, W.Q. Niu, Y.F. Wang, & H.Q. Zheng, arXiv:2102.00977 [nucl-th]

- Existence of *N*(890)* is further verified.

Boundaries for N' below/above πN Threshold

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

Purely Hadronic

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

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

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

Hadronic & EM

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

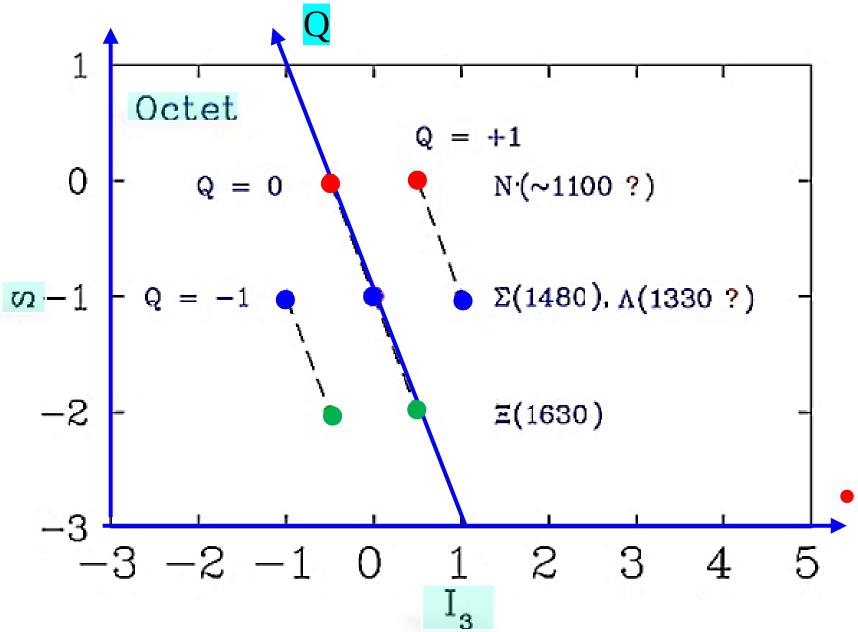
$$\Gamma_{N' \to N\gamma} < 5\ eV \qquad Br^2_{\gamma}\ \Gamma_{p'} < 10\ eV$$

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

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

Unitarity Partners (?)

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



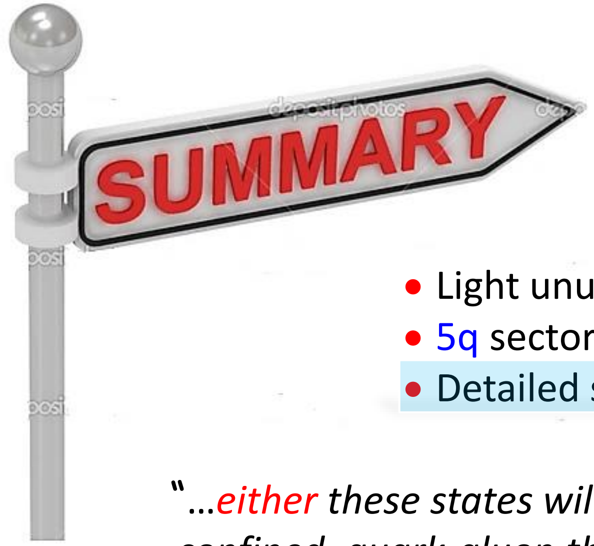
$$M = a_0 + a_1 Y + a_2 \left[I(I+1) - \frac{1}{4} Y^2 \right]$$

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

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 **?**	Λπ, Σπ, N$\bar{K}$	$\sim 1\mu b$
Ξ	1630	20-50 **?**	Ξπ	$\sim 1\mu b$

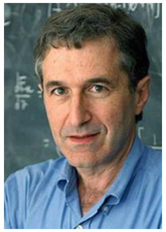
On base of positive observations.

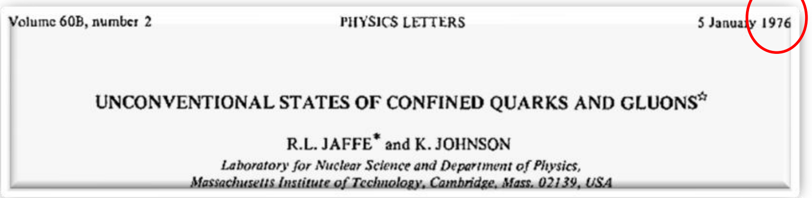
- PhotoProd Xsection has additional ~α/π factor.
- ElectroProd has $\sim(\alpha/\pi)^2$ factor.



- 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 yet lacking in some fundamental, dynamical ingredient which will forbid the existence of these states or elevate them too much higher masses.*"





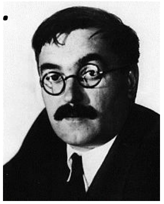
Volume 60B, number 2 PHYSICS LETTERS 5 January 1976

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

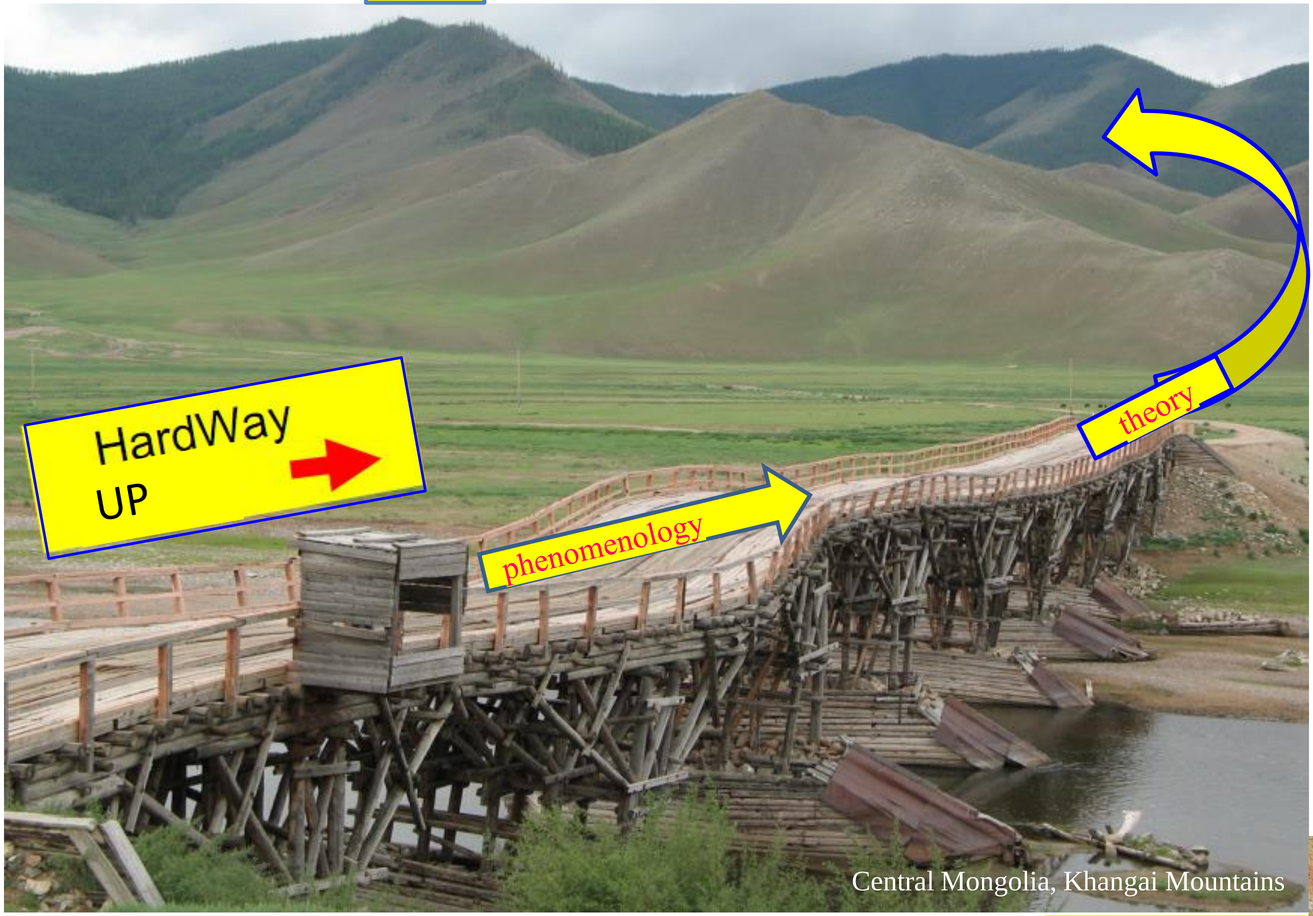
- Production of multiquark hadrons may be new kind of **hard processes**; it is related with higher *Fock* components.



- 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 → 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 hypothesis may suggest new experiments.

QCD



HardWay UP

experiment

phenomenology

theory

Central Mongolia, Khangai Mountains

Photo of Pavel Azimov

Do you have any questions to speaker?

igor@gwu.edu

My Papers with Yakov Azimov

Y.I. Azimov, I.I. Strakovsky, W.J. Briscoe, and R.L. Workman,
Legendre analysis of differential distributions in hadronic reactions,
Phys. Rev. C **95**, 025205 (2017) CI=3

P. Adlarson *et al.* [A2 Collaboration at MAMI],
Measurement of π^0 photoproduction on the proton at MAMI C,
Phys. Rev. C **92**, 024617 (2015) CI=**49**

I.I. Strakovsky, S. Prakhov, **Y.I. Azimov** *et al.* [A2 Collaboration],
Photoproduction of the ω meson on the proton near threshold,
Phys. Rev. C **91**, 045207 (2015) CI=35

M. Dugger *et al.* [CLAS Collaboration],
Beam asymmetry Σ for π^+ and π^0 photoproduction on the proton for photon energies from 1.102 to 1.862 GeV,
Phys. Rev. C **88**, 065203 (2013) CI=**47**

Y. Azimov and I. Strakovsky,
Exotics and PWA for πN scattering,
PoS **Hadron2013**, 034 (2013) CI=0

I.I. Strakovsky *et al.* [Crystal Ball at MAMI Collaboration],
Measurement of the $\gamma p \rightarrow \eta p$ reaction with the Crystal Ball detector at the Mainz Microtron (MAMI-C),
AIP Conf. Proc. **1374**, 439 (2011) CI=0

M.J. Amaryan, G. Gavalian, C. Nepali, M.V. Polyakov, **Y. Azimov**, W.J. Briscoe, G.E. Dodge, C.E. Hyde, F. Klein, V. Kuznetsov, I. Strakovsky, and J. Zhang
Observation of a narrow structure in $p(\gamma, K_S)X$ via interference with ϕ-meson production,
Phys. Rev. C **85**, 035209 (2012) CI=30

I.I. Strakovsky, Y. Qiang, **Y.I. Azimov**, W.J. Briscoe, H. Gao, D.W. Higinbotham, and V.V. Nelyubin,
Properties of the resonance $\Lambda(1520)$ as seen in the forward electroproduction at JLab Hall A,
AIP Conf. Proc. **1374**, 181 (2011) CI=0

E.F. McNicoll *et al.* [Crystal Ball at MAMI Collaboration],
Study of the $\gamma p \rightarrow \eta p$ reaction with the Crystal Ball detector at the Mainz Microtron(MAMI-C),
Phys. Rev. C **82**, 035208 (2010)
[erratum: Phys. Rev. C **84**, 029901 (2011)] CI=**153**

Y. Qiang, **Y.I. Azimov**, I.I. Strakovsky, W.J. Briscoe, H. Gao, D.W. Higinbotham, and V.V. Nelyubin,
Properties of the $\Lambda(1520)$ resonance from high-precision electroproduction data,
Phys. Lett. B **694**, 123 (2011) CI=16

Y.I. Azimov, K. Goeke, and I. Strakovsky,
How is exotics produced? Where to search for it?
eConf **C070910**, 206 (2007) CI=0

Y.I. Azimov, K. Goeke, and I. Strakovsky,
An explanation why the Θ^+ is seen in some experiments and not in others,
Phys. Rev. D **76**, 074013 (2007) CI=17

Y.I. Azimov, K. Goeke, and I. Strakovsky,
A possible explanation why the Θ^+ is seen in some experiments and not in others,
[arXiv:0704.3045 [hep-ph]] CI=3

Y. Qiang *et al.* [JLab Hall A Collaboration],
A search for Σ^0_5, N^0_5, and Θ^{++} pentaquark states,
Phys. Rev. C **75**, 055208 (2007) CI=10

Y.I. Azimov, V. Kuznetsov, M.V. Polyakov, and I. Strakovsky,
K-couplings for the antidecuplet excitation*,
Phys. Rev. D **75**, 054014 (2007) CI=8

I.I. Strakovsky, R.A. Arndt, **Y.I. Azimov**, M.V. Polyakov, and R.L. Workman,
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