Where did N’ come from?
Completeness of unitarity multiplets.

Unitarity partners:
Experimental evidences.
(Quasi) bound states of πN.

Restrictions for N’.
Summary.
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.

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.

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

<table>
<thead>
<tr>
<th>State</th>
<th>Mass (MeV)</th>
<th>Width (MeV)</th>
<th>Decay Modes</th>
<th>Hadron Production Xsections</th>
</tr>
</thead>
<tbody>
<tr>
<td>N'</td>
<td>~1100 ?</td>
<td>&lt;0.05</td>
<td>Nγ ?</td>
<td>&lt; 10^{-4} of ”normal”</td>
</tr>
<tr>
<td>Λ</td>
<td>1330 ?</td>
<td></td>
<td>Λγ</td>
<td>~ 10μb</td>
</tr>
<tr>
<td>Σ</td>
<td>1480</td>
<td>30-80 ?</td>
<td>Λπ, Σπ, NÑ</td>
<td>~ 1μb</td>
</tr>
<tr>
<td>Ξ</td>
<td>1630</td>
<td>20-50 ?</td>
<td>Ξπ</td>
<td>~ 1μb</td>
</tr>
</tbody>
</table>

On base of positive observations.

PhotoProd Xsection has additional ~ (α/π) factor.
ElectroProd has ~ (α/π)^2.
Completeness of Unitary Multiplet

![Graph showing the completeness of unitary multiplet](image)
### $\Xi(1620)$ Mass

<table>
<thead>
<tr>
<th>Value (MeV)</th>
<th>EVTS</th>
<th>DOCUMENT ID</th>
<th>TECH</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\approx 1620$ Our Estimate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1624± 3</td>
<td>31</td>
<td>BRIEFEL</td>
<td>HBC</td>
<td>$K^- p$ 2.87 GeV/c</td>
</tr>
<tr>
<td>1633± 12</td>
<td>34</td>
<td>DEBELLEFON</td>
<td>HBC</td>
<td>$K^- p \rightarrow \Xi^- K^\pi$</td>
</tr>
<tr>
<td>1606± 5</td>
<td>29</td>
<td>ROSS</td>
<td>HBC</td>
<td>$K^- p$ 3.1–3.7 GeV/c</td>
</tr>
</tbody>
</table>

### $\Xi(1620)$ Width

<table>
<thead>
<tr>
<th>Value (MeV)</th>
<th>EVTS</th>
<th>DOCUMENT ID</th>
<th>TECH</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>22.5</td>
<td>31</td>
<td>BRIEFEL</td>
<td>HBC</td>
<td>$K^- p$ 2.67 GeV/c</td>
</tr>
<tr>
<td>40 ± 15</td>
<td>34</td>
<td>DEBELLEFON</td>
<td>HBC</td>
<td>$K^- p \rightarrow \Xi^- K^\pi$</td>
</tr>
<tr>
<td>21 ± 7</td>
<td>29</td>
<td>ROSS</td>
<td>HBC</td>
<td>$\Xi^- \pi^+ K^*(892)$</td>
</tr>
</tbody>
</table>
$\Xi(1606)$ via $K^{-}p \rightarrow \Xi^{-}\pi^{+}K^{0}$ from

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

- Curves are from two **maximum likelihood** fits for this reaction: solid line is assuming $\Xi(1606)$ & $\Xi(1530)$ & broken line is without former.

$M = 1605.5 \pm 5.6$ MeV

$\Gamma = 20.8 \pm 7.4$ MeV
$\Xi(1620)$ via $K^- p \rightarrow \Xi^- \pi^+ K^0$ from

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

$\Xi(1530)$

$\Xi(1620)$

$M = 1624 \pm 3$ MeV
$\Gamma = 22.5$ MeV
\( \Xi(1620) \) via \( \gamma p \rightarrow K^+ K^*\Xi^0 \) & \( K^+ K^+ \Xi^- \) from

\( \Xi^-(1530) \)

\[
\begin{align*}
M: & \quad 1.5392 \pm 0.0014 \\
\Gamma: & \quad 0.015 \pm 0.005 \\
N: & \quad 71 \pm 26 \\
\chi^2/Ndf: & \quad 30.0/31.0
\end{align*}
\]


\( M = 1620 \text{ MeV} \)  
\( \Gamma \sim 30 \text{ MeV} \)
\( \Xi(1620) \) via \( \Xi_c^+ \rightarrow \Xi^- \pi^+ \pi^- \) from


\\\[ M = 1610.4^{\pm 6.0 \text{ (stat)}}_{-4.2}^{+5.1 \text{(syst)}} \text{ MeV} \]
\\\[ \Gamma = 59.9^{\pm 4.8 \text{ (stat)}}_{-7.1}^{+2.8 \text{(syst)}} \text{ MeV} \]

Invariant mass spectrum in sideband region.
• If 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 at all).
Completeness of Unitary Multiplet

\[ \Sigma(1480) \], if exists, looks to be a good partner of \( \Xi(1620) \).
### \( \Sigma(1480) \) Mass (Production Experiments)

<table>
<thead>
<tr>
<th>Value (MeV)</th>
<th>Events</th>
<th>Document ID</th>
<th>Tech</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>( 1480 \pm 15 )</td>
<td>365 ± 60</td>
<td>ZYCHOR 06</td>
<td>SPEC</td>
<td>( p p \rightarrow p K^+(\pi^\pm \chi_T) )</td>
</tr>
<tr>
<td>1480</td>
<td>120</td>
<td>ENGELEN 80</td>
<td>HBC</td>
<td>( K^- p \rightarrow (p K^0) \pi^- )</td>
</tr>
<tr>
<td>1485 ± 10</td>
<td></td>
<td>CLINE 73</td>
<td>MPWA</td>
<td>( K^- d \rightarrow (\Lambda\pi^-) p )</td>
</tr>
<tr>
<td>1479 ± 10</td>
<td></td>
<td>PAN 70</td>
<td>HBC</td>
<td>( \pi^+ p \rightarrow (\Lambda\pi^+) K^+ )</td>
</tr>
<tr>
<td>1465 ± 15</td>
<td></td>
<td>PAN 70</td>
<td>HBC</td>
<td>( \pi^+ p \rightarrow (\Sigma\pi) K^+ )</td>
</tr>
</tbody>
</table>

### \( \Sigma(1480) \) Width (Production Experiments)

<table>
<thead>
<tr>
<th>Value (MeV)</th>
<th>Events</th>
<th>Document ID</th>
<th>Tech</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>60 ± 15</td>
<td>365 ± 60</td>
<td>ZYCHOR 06</td>
<td>SPEC</td>
<td>( p p \rightarrow p K^+(\pi^\pm \chi_T) )</td>
</tr>
<tr>
<td>80 ± 20</td>
<td>120</td>
<td>ENGELEN 80</td>
<td>HBC</td>
<td>( K^- p \rightarrow (p K^0) \pi^- )</td>
</tr>
<tr>
<td>40 ± 20</td>
<td></td>
<td>CLINE 73</td>
<td>MPWA</td>
<td>( K^- d \rightarrow (\Lambda\pi^-) p )</td>
</tr>
<tr>
<td>31 ± 15</td>
<td></td>
<td>PAN 70</td>
<td>HBC</td>
<td>( \pi^+ p \rightarrow (\Lambda\pi^+) K^+ )</td>
</tr>
<tr>
<td>30 ± 20</td>
<td></td>
<td>PAN 70</td>
<td>HBC</td>
<td>( \pi^+ p \rightarrow (\Sigma\pi) K^+ )</td>
</tr>
</tbody>
</table>
\[
\Sigma(1480) \text{ via } \pi^+ p \rightarrow \pi^+ K^+ \Lambda, \pi^0 K^+ \Sigma^+ \text{ from }
\]


\[\Sigma(1480) \]
\[\Sigma(1385) \]

\[M = 1475 \pm 15 \text{ MeV} \quad \Gamma = 30 \pm 15 \text{ MeV}\]

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

• Estimate statistical significance at \(3\sigma\), or even \(4\sigma\), for \(\Sigma(1480)\) both peak in mass distribution & polarization effect were reported.
\[ \Sigma(1480) \text{ via } e^+p \rightarrow e'K^0pX \text{ from} \]


\[ M = 1470 \text{ MeV} \]
\[ \Gamma \sim 30 \text{ MeV} \]

H. Abramowicz et al, DESY–16–065
$\Sigma(1480)$ 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 $\Sigma(1480)$ or other light $\Sigma^*$ states.”

• Case of $K^- p \rightarrow \pi^0 \pi^0 \Lambda$ is worse because of two identical pions @ low K-momenta.
\[ \Sigma(1480) \text{ via } pp \rightarrow K^+pX^0 \text{ from} \]


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

- Since isospin has not been determined here, it could either be observation of \( \Sigma(1480) \), or, alternatively, \( \Lambda(1480) \) – not listed in PDG.
$\Sigma(1480)$ via $pC^{12}\rightarrow\Lambda\pi^-X$ @ 10 GeV/c from P. Zh. Aslanyan, Phys At Nucl 76, 969 (2013)

• $\Lambda\pi^-$ spectrum for all combinations with bin size 8 MeV.
Completeness of Unitary Multiplet

![Graph showing the completeness of unitary multiplet with points for different Q and I₃ values.]

- Octet
  - Q = 0
  - Q = -1
  - Q = +1
- N (~1100 ?)
- Σ(1480), Λ(1330 ?)
- Ξ(1630)
\( \Lambda(1330) \) via \( \pi p \rightarrow \Lambda\gamma\chi^0 \) from


- There is single witness.

\[ M = 1327.5 \pm 3.5 \text{ MeV} \]
\[ \Gamma = 20.0 \pm 4.4 \text{ MeV} \]
\( \Lambda(1330) \) via \( \gamma p \rightarrow K^+ \Lambda \chi^0 \) from


- No statistics.
Completeness of Unitary Multiplet
Direct experimental searches for $N'$ have begun rather recently.

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

**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.
$pp \rightarrow \pi^+ pX^0, \ M_X > 960 \text{ MeV} @$

$pd \rightarrow ppX @$

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

- If correct, such baryons would have $I=\frac{1}{2}$, 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.

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


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

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


\[\pi^- p \rightarrow n'\gamma \rightarrow n\gamma\gamma \text{ @ rest from TRIUMF}\]

- BR\((\pi^- p \rightarrow n\gamma)\) = \([3.05\pm0.27(\text{stat})\pm0.31(\text{syst})] \times 10^{-5}\)

- This means that up to stat & syst uncertainties (each about 10%) there were no contributions of \(n'\) cascade.


- Thus no evidence (90% C.L.) for \(n'\)-mediated capture was found for \(970 < M_{n'} < 1050 \text{ MeV}/c^2\), measured spectrum being completely consistent with direct two photon capture only.

**Narrow Resonances in [Modified] PWA**


- 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 (~30k data).

**Refitting**

- If worse description:
  - Resonance with corresponding $M$ & $\Gamma$ 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 the effect only in single particular PW.

- While **non-Resonance** source may show similar effects in various PWs.
for (Quasi) Bound States of $\pi N$

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

SAID:

$S^-, P^-, & D$-waves

$T_{\pi} = 0 - 500$ MeV & gives $\chi^2 = 5805$

$M = 1100 - 1295$ MeV & $\Gamma = 50 - 300$ keV
for (Quasi) Bound States of $\pi N$

$S_{11}: M = 1145 \text{ MeV}, \Gamma = 50 \text{ keV} [T_\pi = 79.5 \text{ MeV}]$

- We find no evidence for elastic $\pi N$ resonances in region between $\pi N$ thr & 1300 MeV having width $\Gamma > 50$ keV.

- Present $\pi N$ data cannot exclude even purely elastic (or inelastic) narrow resonances with $\Gamma < 50$ 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 $\pi N$ Threshold**


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**Purely Hadronic**

\[
\frac{g_{\pi NN'}^2}{g_{\pi NN}^2} < 10^{-2} \quad \Gamma_{N'} < 50 \text{ keV}
\]

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

\[
\frac{\sigma(pp \rightarrow \pi^+pX^0)}{\sigma(pp \rightarrow \pi^+pn)} \sim 10^{-3} - 10^{-4}
\]

***Hadronic & EM***

\[
\frac{W(\pi^-p \rightarrow n'\gamma)}{W(\pi^-p \rightarrow n\gamma)} < \sim 10^{-5}
\]

\[
\Gamma_{N' \rightarrow N \gamma} < 5 \text{ eV}
\]

\[
\frac{Y(ep \rightarrow e'\pi^+X^0)}{Y(ep \rightarrow e'\pi^+n)} < 10^{-4}
\]

\[
\frac{Br_{\gamma}^2 \Gamma_{p'}}{Br_{\gamma} \Gamma_{\Delta}} < 3 \times 10^{-3}
\]

\[
\frac{Y(ed \rightarrow e'pX^0)}{Y(ed \rightarrow e'pn)} < 10^{-4}
\]

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6/1/2019

MENU-2019, Pittsburgh, PA, June 2019

Igor Strakovsky 29
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.'

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.
Thank you for invitation & your attention
Unitary $SU(3)_F$ Multiplets

Octet
- $Q = 0$
- $Q = +1$  
- $Q = -1$
- $\Sigma^+$
- $\Sigma(1190), \Lambda(1116)$
- $\Sigma^0, \Lambda$
- $\Xi^-$
- $\Xi^0$
- $\Xi(1320)$

Decuplet
- $Q = -1$
- $Q = 0$
- $Q = +1$
- $Q = +2$
- $\Delta(1232)$
- $\Sigma(1385)$
- $\Xi(1530)$
- $\Omega(1670)$

Octet
- $Q = 0$
- $Q = +1$
- $Q = -1$
- $\Sigma(1486), \Lambda(1330)$
- $\Xi(1630)$

Antidecuplet
- $Q = +1$ (ssuddd)
- $Q = 0$
- $Q = -1$
- $Q = -2$
- $\Theta^+(1540)$
- $N(1710)$
- $\Sigma(1360)$
- $\Xi_{3/2}(2060)$

Mixing is able to shift some masses.