N* as a Flavor Partner of the Ω+. Where are we now?

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Based on work in collaboration with
R. Arndt, Ya. Azimov, W. Briscoe, M. Polyakov, R. Workman

- Antidecuplet
- Is N* = N(1710) ?
- How to search for alternatives ?
  Modified PWA
- Theoretical expectations
- Experimental evidence for N*
- Summary

Eta Photoproduction Workshop, Bochum, DE, Feb 23-25, 2006
Tentative unitary Antidecuplet with $\Theta^+$

- **GMO**: equidistant, expected $\delta m(\sigma) = (M_\Phi - M_\Theta)/3$ depends on $\sigma$-term
  - $= 107$ MeV at $\sigma = 67$ MeV [SAID]
  - $= 180$ MeV at $\sigma = 45$ MeV [Karlsruhe]

- $\delta m$ agrees with the GW SAID $\sigma$-term, if $M_\Theta = 1540$ MeV and $M_\Phi = 1862$ MeV

- Mixing tends to shift GMO masses for $N^*$ and $\Sigma^*$ stronger, than for $\Theta$ and $\Phi$

**SAID**: [R. Arndt et al, Phys Rev C 69, 035213 (2004)]
**Karlsruhe**: [G. Hoehler, Springer, 1983]
N(1710) - What was known


\( \chi_{SA} \)

DPP97 1710 (inp)  ~40 (est)

\[ \text{PWA-BW} \]

\begin{tabular}{lll}
Ref & Mass(MeV) & Width(MeV) \\
KH79 & 1723\( \pm \) 9 & 120\( \pm \) 15 \\
CMU80 & 1700\( \pm \)50 & 90\( \pm \)30 \\
KSU92 & 1717\( \pm \)28 & 480\( \pm \)230 \\
GW04 & not seen & &
\end{tabular}

\[ \text{PWA-Pole} \]

\begin{tabular}{llll}
Ref & Re(MeV) & -2xIm(MeV) \\
CMU80 & 1690\( \pm \)20 & 80\( \pm \)20 \\
CMU90 & 1698 & 88 \\
KH93 & 1690 & 200 & (Sp) \\
GW04 & not seen & &
\end{tabular}

- It would be more natural for the same unitary multiplet (with \( \Theta^+ \) and \( \mathbf{N}^* \)) to have comparable widths
- The spread of \( \Gamma \), separated by PDG, is very large
Standard Resonances in Standard PWA
[R. Arndt, W. Briscoe, IS, R. Workman, M. Pavan, Phys Rev C 69, 035213 (2004)]

- One of the most convincing ways to study N*\(s\) and Δ*\(s\) is \(\pi N\) PWA

- Standard PWA reveals only wide resonances, but not too wide (\(\Gamma < 500 \text{ MeV}\))

- PWA (by construction) tends to miss narrow resonances with \(\Gamma < 30 \text{ MeV}\)
Narrow Resonances in PWA

• We assume the existence of a Res and refit over the whole database

• Insertion of narrow resonances in PWA for
  elastic case: \[ e^{2i\delta} \Rightarrow e^{2i\delta_R} e^{2i\delta_B} \]
  \[ e^{2i\delta_R} = (M_R - W + i \Gamma_R/2)/(M_R - W - i \Gamma_R/2) \]

  inelastic case: \[ \eta \ e^{2i\delta} \Rightarrow <a | S | a> = r_a \ A(W) \ e^{2i\delta_R} + (1 - r_a) \ B(W) \]
  \[ r_a = BR(R \rightarrow a) \quad |A(M_R)| = 1 \quad \Sigma r_a = 1 \]
  \[ \eta \leq 1 \Rightarrow r_a |A(W)| + (1 - r_a) |B(W)| \leq 1 \]

• How does this insertion change \( \chi^2 \)?
  (Will it decrease?)
Modified $\pi N$ PWA


\begin{itemize}
  \item $\Delta \chi^2$ due to insertion of a resonance into $P_{11}$ ($J^P = \frac{1}{2}^+$)
  \item At $|M_R - W| \gg \Gamma_R$, Res contributes $\sim \Gamma_{el}/(M_R - W)$
  \item Two candidates: $M_R = 1680\, \text{MeV}$, $1730\, \text{MeV}$
    $\Gamma_{\pi N} < 0.5\, \text{MeV}$, $< 0.3\, \text{MeV}$
  \item The procedure is less sensitive to $\Gamma_{tot}$
\end{itemize}
Modified PWA

- Refitting
  - **Worse** description
    - a Res with corresponding $M$ and $\Gamma$ is not supported
  - **Better** description
    - a Res may exist
    - effect can be due to various corrections (*eg*, thresholds)
    - both possibilities can contribute
    Some additional checks are necessary

- A true Res should provide the effect only in a particular PW

- While NonRes source may show similar effects in various PWs
Check other Partial Waves

- $\Delta \chi^2$ due to insertion of a Res into $S_{11} (J^P = 1/2^-)$

- $\Delta \chi^2$ due to insertion of a Res into $P_{13} (J^P = 3/2^+)$

- No effects at $M = 1680$ MeV and possible (small) effects at $M = 1730$ MeV
\[ D_{15} \text{ within } \pi N \text{ PWA} \]

[R. Arndt, W. Briscoe, IS, R. Workman, M. Pavan, Phys Rev C 69, 035213 (2004)]

- Because of a special interest to \( N(1675)D_{15} \), let us check the situation

\[ \begin{align*}
\text{Amplitude} \quad &\quad \text{ImT-TT<ImT [unitarity limit]} \\
\text{W (MeV)} \quad &\quad 1080 \quad 1380 \quad 1680 \quad 1980 \quad 2280
\end{align*} \]

- \( N(1675)D_{15} \) has a standard BW and pole
- It is unnatural to have two nearby resonances with the same quantum numbers

\[ \begin{align*}
\text{SAID-BW: } &M = 1676.2 \pm 0.6 \text{ MeV} \\
\Gamma/2 & = 75.9 \pm 1.5 \text{ MeV} \\
\chi & = 0.400 \pm 0.002 \\
\text{Pole: } &1659 - i73 \text{ MeV}
\end{align*} \]
**N(1675)D_{15} - What is known**


<table>
<thead>
<tr>
<th><strong>Ref</strong></th>
<th>Mass(MeV)</th>
<th>Width(MeV)</th>
<th>$\Gamma_{\pi N}/\Gamma$</th>
</tr>
</thead>
<tbody>
<tr>
<td>KH79</td>
<td>1679±8</td>
<td>120±15</td>
<td>0.38±0.03</td>
</tr>
<tr>
<td>CMU80</td>
<td>1675±10</td>
<td>160±20</td>
<td>0.38±0.05</td>
</tr>
<tr>
<td>KSU92</td>
<td>1676±2</td>
<td>159±7</td>
<td>0.47±0.02</td>
</tr>
<tr>
<td>GW04</td>
<td>1676.2±0.6</td>
<td>151.8±3.0</td>
<td>0.400±0.002</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Ref</strong></th>
<th>Re(MeV)</th>
<th>-2xIm(MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMU80</td>
<td>1660±10</td>
<td>140±10</td>
</tr>
<tr>
<td>KH93</td>
<td>1656</td>
<td>126</td>
</tr>
<tr>
<td>GW04</td>
<td>1659</td>
<td>146</td>
</tr>
</tbody>
</table>
$N(1675)D_{15}$ - What is known
Other Channels

- $\Gamma_{\pi N}/\Gamma = 0.40 \pm 0.05$ [PDG]
- $\Gamma_{\pi \Delta}/\Gamma = 0.496 \pm 0.003$ [KSU92]
- $\Gamma_{\rho N}/\Gamma = 0.03 \pm 0.02$ [KSU92]
- $\Gamma_{K \Lambda}/\Gamma = 0.036$ [Ruth80]
- $\Gamma_{\eta N}/\Gamma = 0.00 \pm 0.01$ [CMU00]

- There is really no room for large BR of $N(1675)D_{15}$ into other decay channels
Conclusion from Modified $\pi N$ PWA for S- and P-waves


- 1680 MeV – only one partial wave ($P_{11}$) reveals the effect: support to the resonance, $\Gamma_{\pi N} < 0.5$ MeV
- 1730 MeV – $P_{11}$ may also reveal a resonance with $\Gamma_{\pi N} < 0.3$ MeV but differently: resonance is still possible, if accompanied by different corrections

- The Res at 1730 MeV may appear in $P_{13}$ or $S_{11}$ (less probable), if accompanied by different corrections [eg, thresholds: $N\omega(1720)$, $N\rho(1710)$ ?, $K\Sigma(1685)$]
- The rest of partial waves ($D_{15}$, etc) do not support narrow states
**Θ⁺ Flavor Partner, N*(JP = 1/2⁺)**


- If Θ⁺ ≤ 1 MeV, then expected structure for decays of the Θ⁺-partner N* looks as follows:
  - Γ(N*→πΔ) ~ 6 MeV [forbidden for 10, open due to 10-8 mixing]
  - Γ(N*→ηN) ~ 0.5 - 2 MeV
  - Γ(N*→KΛ) ~ 0.5 - 1.5 MeV
  - Γ(N*→πN) ~ 0.3 - 0.5 MeV [non-trivial cancellation due to mixing is required]
  - Γ(N*→ππN) [out of πΔ]?
  - Γ(N*→KΣ) is small?

- Γ(N*→all) ~ 10 MeV [ΓπN/Γtot < 10 %]

Ratio of modes πN and ηN is sensitive to the mixing
Preliminary Evidences for Narrow State(s) of \( M \sim 1700 \) MeV

- **GRAAL**: \( \gamma n \rightarrow \eta n, K^0 \Lambda, \text{and } K^+ \Sigma^- \)
- **CB-ELSA**: \( \gamma n \rightarrow \eta n \)
- **JLab Hall A**: \( H(e,e'\pi^+)X^0 \)
- **STAR**: \( AuAu \rightarrow \Lambda K_s \)
- **COSY-TOF**: \( pp \rightarrow \Lambda K^+ p \)
- **ITEP**: \( \pi^- p \rightarrow \pi^- p \) and \( K^0 \Lambda \) [in preparation]
GRAAL [V. Kuznetsov, hep-ex/0409032, NSTAR 2004, March 2004]

$\gamma n \rightarrow \eta n$ vs $\gamma p \rightarrow \eta p$

$\gamma n \rightarrow \eta n$  $\gamma p \rightarrow \eta p$

- For 10, $\sigma(\eta) >> \sigma(p)$ [M. Polyakov, A. Ratke, Eur Phys J A 18, 691 (2003)]
- Fermi motion for n-target is a problem
MAID about GRAAL Observation

[V. Kuznetsov, hep-ex/0601002, NSTAR 2005, Oct 2005]

- **MAID2000** demonstrates a shoulder structure near N(1675)D_{15}

- **MAID2000** claims to reproduce the rise in the ratio of the neutron/proton cross sections

- However, the experimental structure looks more narrow
MAID about GRAAL Observation

[V. Kuznetsov, hep-ex/0601002, NSTAR 2005, Oct 2005]

- The N(1675)D_{15} signature is a strong (incorrect ?) angular dependence in Xsection

- Larger spin steepens Xsection dramatically

- Same problem for Σ behavior
Very preliminary: $\gamma n \rightarrow \eta n$

- The SAID solution for the $\eta$ production off proton scaled by factor 0.6, as has been suggested by previous experiments, fits well the Xsection off the neutron in the region of the $N(1535)D_{15}$ below $W \sim 1.62$ GeV.

- The sum of the SAID solution, scaled by 0.6, and the simulated contribution of a narrow state ($M = 1.675$ GeV, $\Delta W = 10$ MeV), fits well Xsection on the neutron up to $W \approx 1.7$ GeV!

- This state appears as a wider bump in Xsection due to Fermi motion.
Very preliminary: $\gamma n \rightarrow \eta n$

No correction  Correction for Fermi motion

Narrow state?
Very-very preliminary: $\gamma n \rightarrow K^0\Lambda, K^+\Sigma$

Quantum numbers of $N(1720)$ are unknown but it could be $P_{11}, P_{13}$, or less likely $S_{11}$. 

$N(1680)$ ?

Wide bins

Narrow bins
Independent CB-ELSA measurements confirm the GRAAL observation.
Very-very preliminary $H(e,e'\pi^+)X^0$, data taken in May of 2004

- $E_0 = 5$ GeV
- $\theta_{e'} = 6^\circ$
- $\theta_{\pi} = 0^\circ$
- $\Delta\Theta = \pm 2^\circ$
- $\sigma_{MM} = 1.3$ MeV

- Signal N(1680) and N(1730) (if any) is small (agrees with expectations)

- The UL result is strong for $\Gamma \sim 1$ MeV and becomes softer for $\Gamma \sim 10$ MeV

- Extraction of $\Gamma_{\pi N}$ needs model assumptions
Preliminary: AuAu → ΛK_s

Min. bias Au+Au collisions 200 GeV, σ < upper 10% σ(tot)

M = 1734±0.5±5 MeV
Γ < 4.6±2.4 MeV

Σ(1693)-N(1693)?
Summary

- Narrowness of $\Theta^+$ required reanalysis of all its flavor partners.
  
  We did it for `N(1710)` using modified $\pi N$ PWA.

- If $\Theta^+$ is indeed a narrow state with $\Gamma_{\Theta} \leq 1$ MeV, then other members of the flavor 10 are, most probably, narrow as well.
  
  Their properties are sensitive to the structure of mixing which can be rather complicated.

- Further measurements/analyses are necessary!!
Backup
Very preliminary: \( pp \rightarrow \Lambda K^+ p \)

\( \mathbf{P}_{\text{beam}} : 3.30 \text{ GeV/c} \)

\[ m^2(K\Lambda) \text{ GeV}^2/c^4 \]

\[ m^2(p\Lambda) \text{ GeV}^2/c^4 \]

\( N'(1710) \) contributes strongly

Influence of \( p\Lambda \)-FSI

In progress: Investigation of Dalitz plots \( \rightarrow \) width
$P_{11}$ within $\pi N$ PWA

[R. Arndt, W. Briscoe, IS, R. Workman, M. Pavan, Phys Rev C 69, 035213 (2004)]

$N(1440)P_{11}$ [SAID]
- BW: $M = 1468.0 \pm 4.5$ MeV
  $\Gamma/2 = 180 \pm 13$ MeV
  $\chi = 0.750 \pm 0.024$
- Pole: $1357-i80$ MeV ($1^{\text{st}}$ sh)
  $1385-i83$ MeV ($2^{\text{nd}}$ sh)

$\text{Sp}(W) = |dT/dW|$ peak at $W=M$ (pole)
at NR $\rightarrow 0$ [G. Hoehler, ]

$\text{Im}T - T^* T < \text{Im}T$ [unitarity limit]
- If Θ⁺ does not survive, `damned' questions revive

- `Why are there no strongly bound exotic states..., like those of two quarks and two antiquarks or four quarks and one antiquark ?'
  [H. Lipkin, Phys Lett 45B, 267 (1973)]

- `...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.'
  [R. Jaffe and K. Johnson, Phys Lett 60B, 201 (1976)]
Separation of Res and Nres in $\gamma p \rightarrow \pi N$, $I=1/2, 3/2$

[R. Arndt, W. Briscoe, IS, R. Workman, L. Tiator, in progress]

- **A-form:** $T=(1+i\tau_{\pi N})(\text{Born}+A)+Rt_{\pi N}+(C+iD)(\text{Im}\tau_{\pi N}-|t_{\pi N}|^2)$
- **C-form:** $T=(1+i\tau_{\pi N})(\text{Born}+A)+Rt_{\pi N}e^{i\phi}$
**Θ⁺ and Φ - What is known**


<table>
<thead>
<tr>
<th>Experiment</th>
<th>Mass (MeV)</th>
<th>Width (MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LEPS</td>
<td>1540 ± 10</td>
<td>&lt;25</td>
</tr>
<tr>
<td>DIANA</td>
<td>1539 ± 2</td>
<td>&lt; 9</td>
</tr>
<tr>
<td>CLAS (d)</td>
<td>1542 ± 5</td>
<td>&lt;21</td>
</tr>
<tr>
<td>SAPHIR</td>
<td>1540 ± 4 ± 2</td>
<td>&lt;25</td>
</tr>
<tr>
<td>ITEP (ν)</td>
<td>1533 ± 5</td>
<td>&lt;20</td>
</tr>
<tr>
<td>CLAS (p)</td>
<td>1555 ± 10</td>
<td>&lt;26</td>
</tr>
<tr>
<td>PDG average</td>
<td>1539.2 ± 1.6</td>
<td>-</td>
</tr>
<tr>
<td>GWU</td>
<td>1545</td>
<td>≤1</td>
</tr>
<tr>
<td>LBNL</td>
<td>1540</td>
<td>0.9 ± 0.3</td>
</tr>
<tr>
<td>NA49</td>
<td>1862 ± 2</td>
<td>&lt;18</td>
</tr>
</tbody>
</table>

The measured mass looks similar to expectation of the $\chi_{SA}$

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

Only one pw $P_{01}$ admits the effect at 1540 - 1450 MeV with $\Gamma < 1$ MeV

[R. Arndt, IS, R. Workman, Phys Rev C 68, 042201 (2003)]

With additional assumption and unknown systematics

[R. Cahn and G. Trilling, Phys Rev D 69, 011501 (2004)]