PLAUSIBLE EXPLANATION FOR THE $\Delta_{5/2+}(2000)$ PUZZLE

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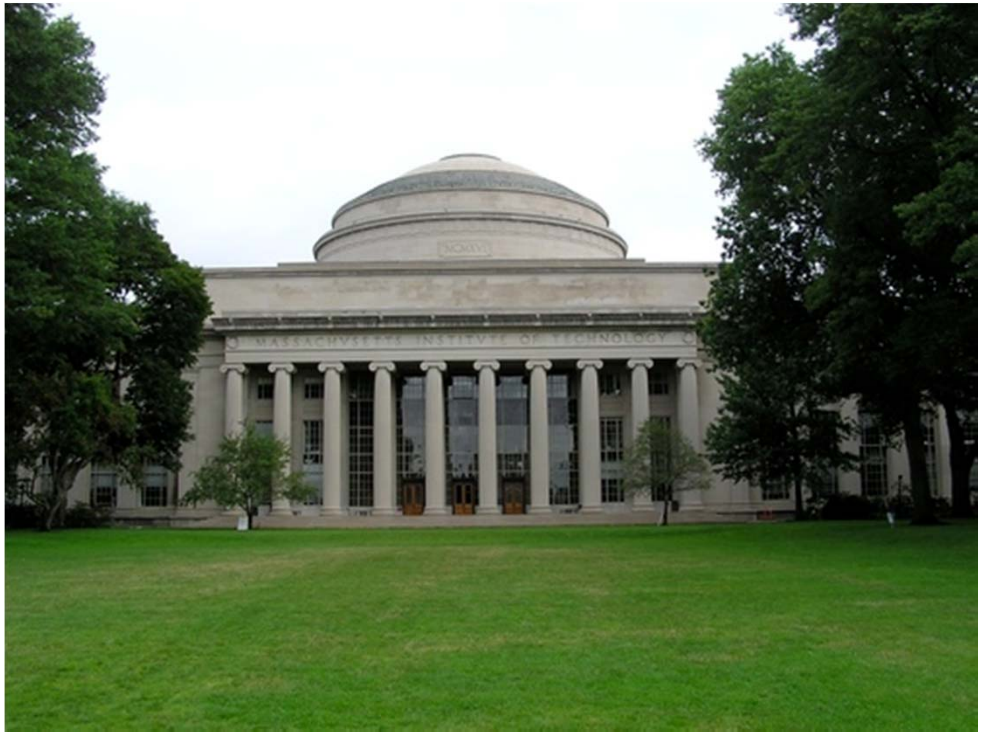

References

i) Ju-Jun Xie, A. Martínez Torres, E. Oset and P.González
Phys. Rev. C 00, 005200 (2011).

ii) P. González, E. Oset and J. Vijande
Phys. Rev. C 79, 025209 (2009).

iii) P. González, J. Vijande and A. Valcarce
Phys. Rev. C 77, 065213 (2008).

Motivation

There is a puzzle concerning the PDG-cataloged $\Delta_{5/2+}(2000)$ F_{35} (**) Its estimated mass does not correspond to any experimentally extracted resonance.

K. Nakamura et al. (Particle Data Group), JPG 37, 075021 (2010)

$\boxed{\Delta(2000)\ F_{35}}$ $I(J^P) = \frac{3}{2}(\frac{5}{2}^+)$ Status: ∗∗

OMITTED FROM SUMMARY TABLE

The latest GWU analysis (ARNDT 06) finds no evidence for this resonance.

Δ(2000) BREIT-WIGNER MASS

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
≈ 2000 OUR ESTIMATE				
1724 ± 61	VRANA	00	DPWA	Multichannel
1752 ± 32	MANLEY	92	IPWA	$\pi N \to \pi N$ & $N\pi\pi$
2200 ± 125	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

N. Suzuki et al. (EBAC), PRL 104, 042302 (2010) : $\Delta_{5/2+}(1738)$

3q Model Description

In 3q models the lowest $\Delta_{5/2+}$ state is the orbital symmetric (56, 2^+) in the N=2 energy band with mass about 1900 MeV : $\Delta_{5/2+}$ (1905) (****).

Δ(1905) BREIT-WIGNER MASS

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
1865 to 1915 (≈ 1890) OUR ESTIMATE				
1857.8 ± 1.6	ARNDT	06	DPWA	$\pi N \rightarrow \pi N, \eta N$
1881 ±18	MANLEY	92	IPWA	$\pi N \rightarrow \pi N$ & $N \pi \pi$
1910 ±30	CUTKOSKY	80	IPWA	$\pi N \rightarrow \pi N$
1905 ±20	HOEHLER	79	IPWA	$\pi N \rightarrow \pi N$
1873 ±77	VRANA	00	DPWA	Multichannel

There is a 3q state, orbital mixed symmetric (70, 2^+) close in energy : $\Delta_{5/2+}$ (2000) (N. C.). D. M. Manley, Phys. Rev. Lett. 52, 2122 (1984).

Alternative Interpretation

$\boxed{\Delta(2000)\ F_{35}}$ $I(J^P) = \frac{3}{2}(\frac{5}{2}^+)$ Status: $**$

OMITTED FROM SUMMARY TABLE

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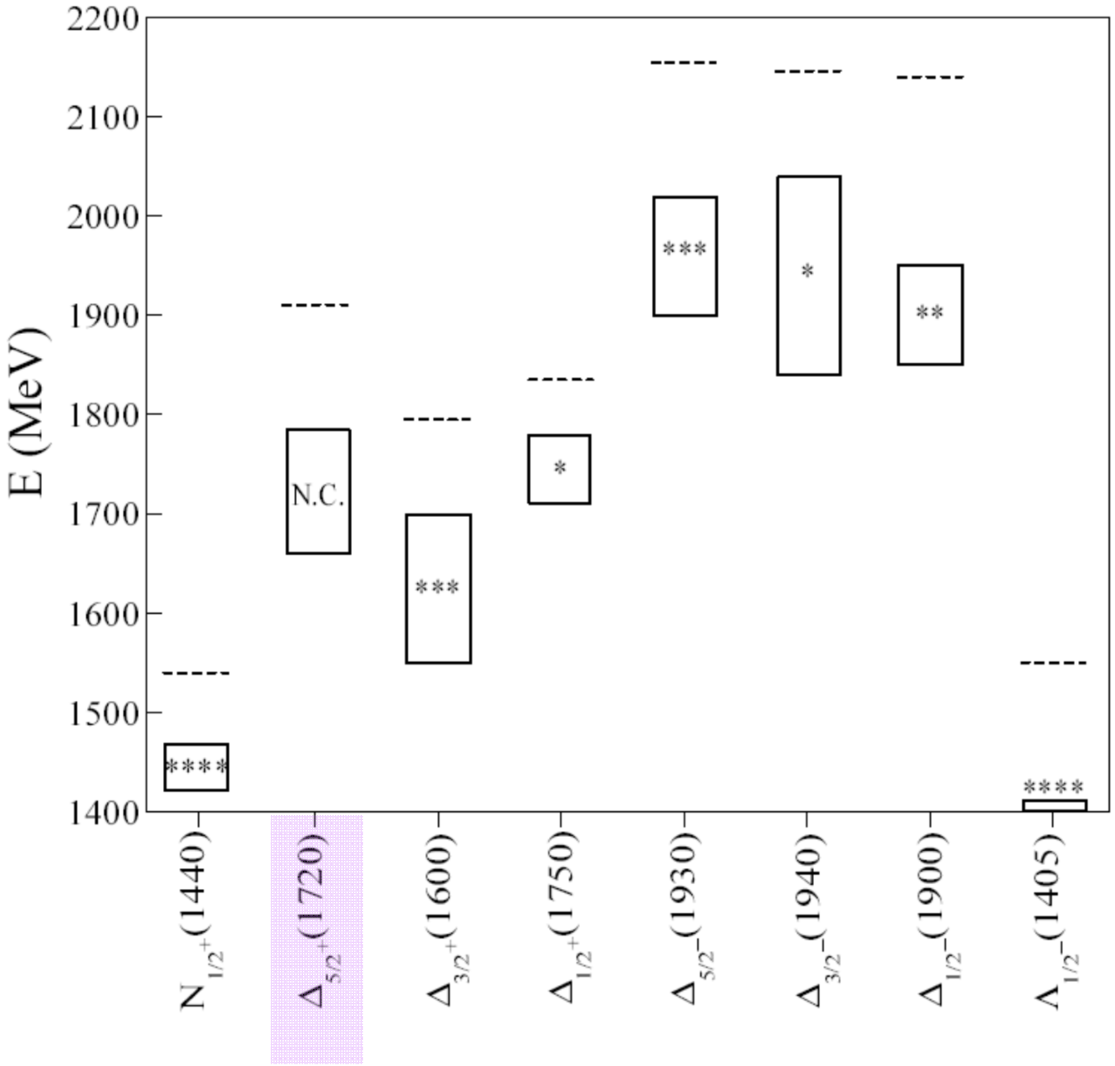
Δ(2000) BREIT-WIGNER MASS

VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
≈ 2000 OUR ESTIMATE				
1724 ± 61	VRANA	00	DPWA	Multichannel
1752 ± 32	MANLEY	92	IPWA	$\pi N \to \pi N$ & $N\pi\pi$
2200 ± 125	CUTKOSKY	80	IPWA	$\pi N \to \pi N$

$\Delta_{5/2+}$ (2200) may be assigned to a 3q state in the N = 4 energy band.

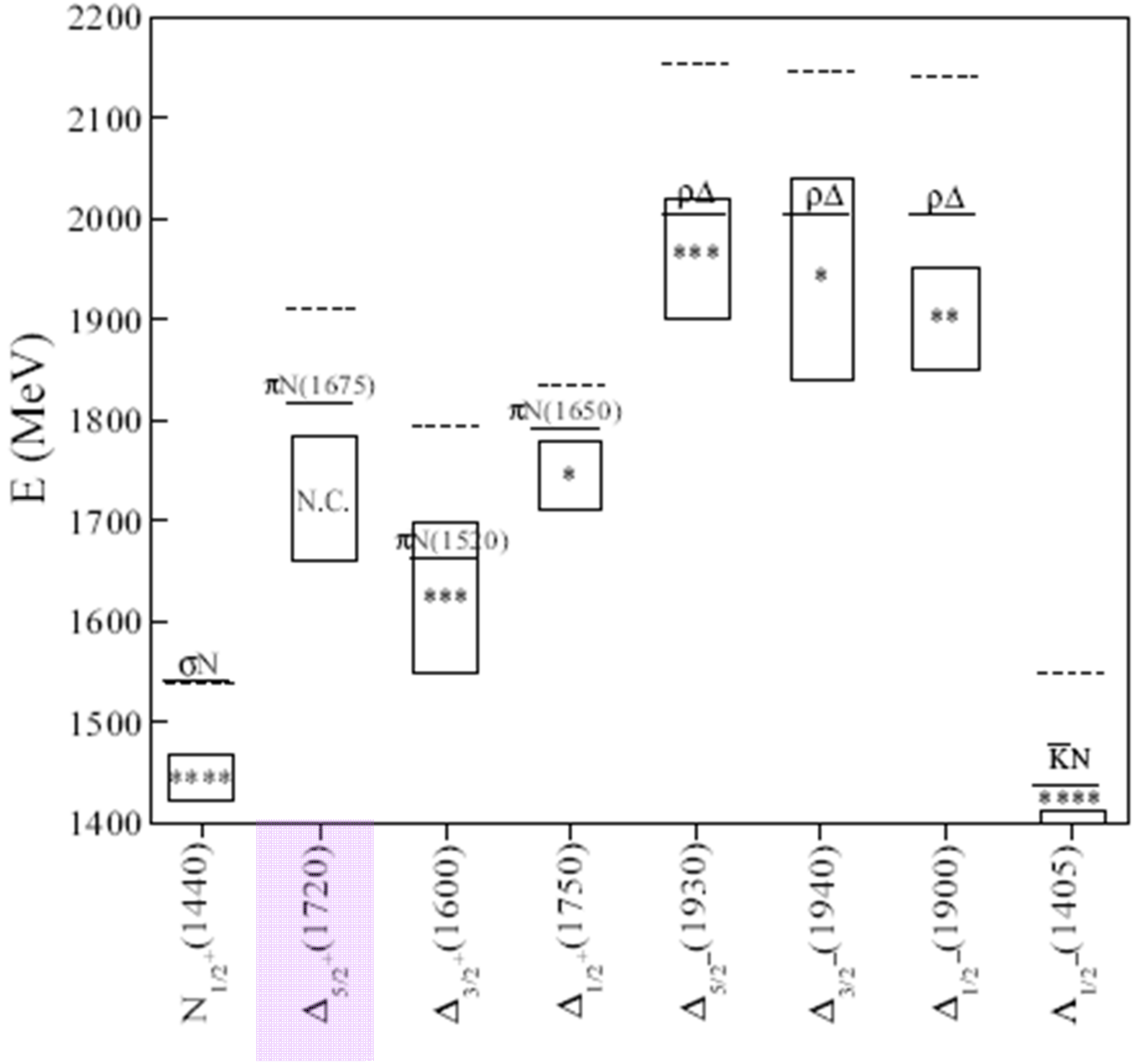
$\Delta_{5/2+}$ (1740) (N.C.) might be a Dynamically Generated Resonance.

Candidates to be dominantly DGR (PRC 2008)



Quark model results by Capstick and Isgur, PRD 34, 2809 (1986)

A meson-baryon threshold lies in between the calculated 3q mass and the experimental mass.



An attractive meson-baryon interaction could give rise to a DGR as a bound state below the meson-baryon threshold :

$$\Lambda\ (1405)\ ,\ \ \Delta_{5/2-}\ (1930)\ ,\ \ldots$$

The identification of $\Delta_{5/2+}(1740)$ as a $\pi N(1675)$ bound state could explain why it is only extracted in some data analyses, those reproducing the $\pi\ \pi\ N$ production cross section data.

DESCRIPTION OF $\Delta_{5/2+}$ (1740) AS A π N(1675) BOUND STATE

INDEX

i) $N_{5/2-}(1675)$ as DGR from the $\rho\Delta$ interaction.

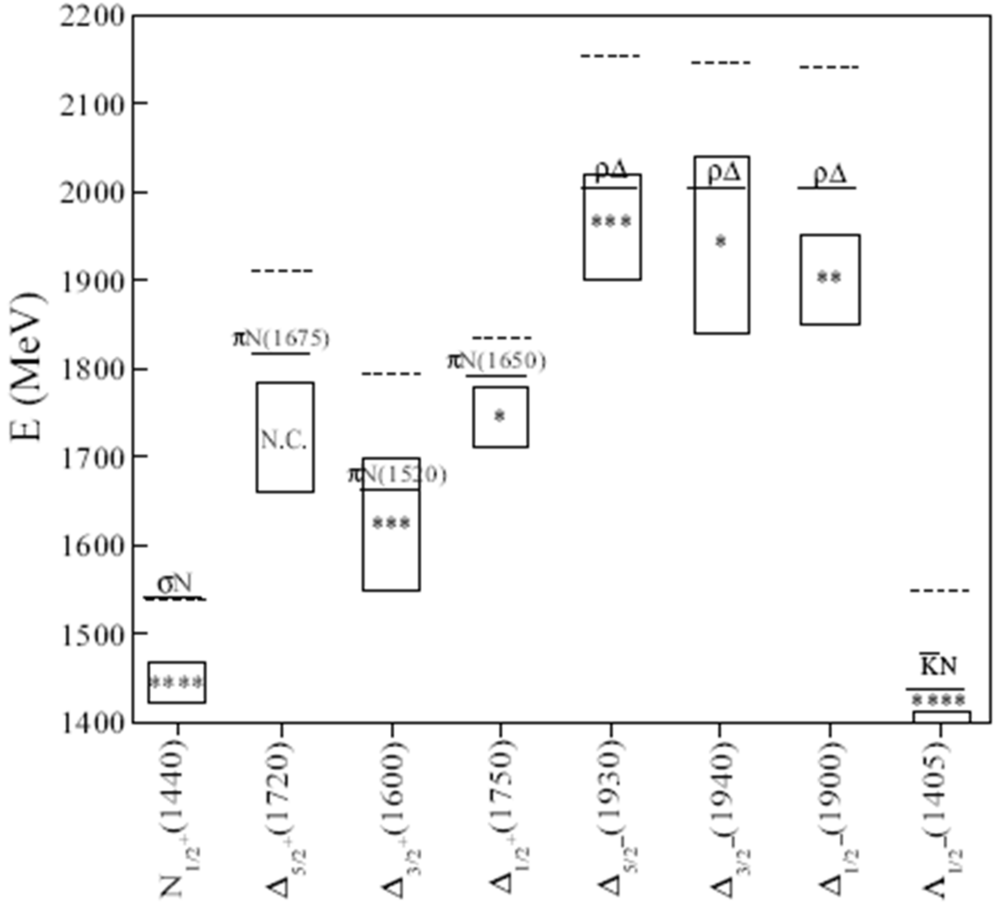
ii) $\Delta_{5/2+}(1740)$ as a plausible DGR from $\pi(\rho\Delta)_{N(1675)}$ in the Fixed Center Approximation.

iii) $\Delta_{1/2+}(1750)$ as DGR partner of $\Delta_{5/2+}(1740)$.

iv) Consistency checks in the $I = 3/2, 1/2$ sectors.

v) Summary

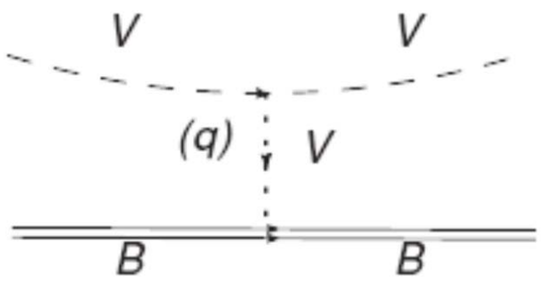
$N_{5/2-}(1675)$ as effective DGR from the $\rho\Delta$ interaction (PRC 2009)



$\Delta_{5/2-,\ 3/2-,\ 1/2-}$: Quark Pauli blocked states explained as $\rho\Delta$ bound states

The same $\rho\Delta$ interaction, very attractive in the I=1/2 channel, provides an alternative description of $N_{5/2-}(1675)$ as a bound state.

$\mathrm{VB} \rightarrow \mathrm{VB}$



$\rho\Delta \rightarrow \rho\Delta$

$$V_{ij} = -\frac{1}{4f^2} C_{ij}(k^0 + k'^0)\vec{\epsilon}\,.\vec{\epsilon}\,'$$

$$\rho\Delta, I = \tfrac{1}{2} \;:\; C = 5,$$
$$\rho\Delta, I = \tfrac{3}{2} \;:\; C = 2,$$
$$\rho\Delta, I = \tfrac{5}{2} \;:\; C = -3.$$

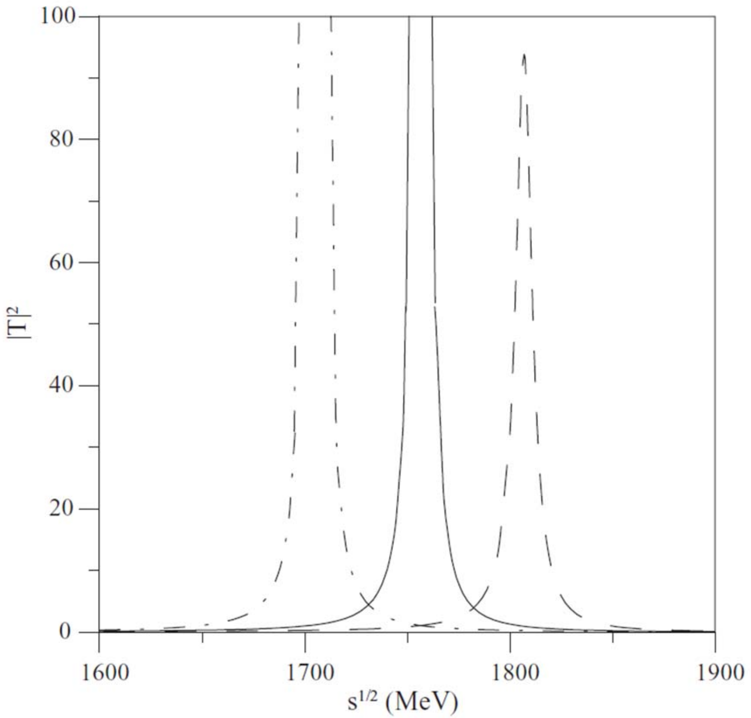
$$T = \frac{V}{1 - VG}\vec{\epsilon}\,.\vec{\epsilon}\,'$$

G : Loop function for intermediate ρΔ state

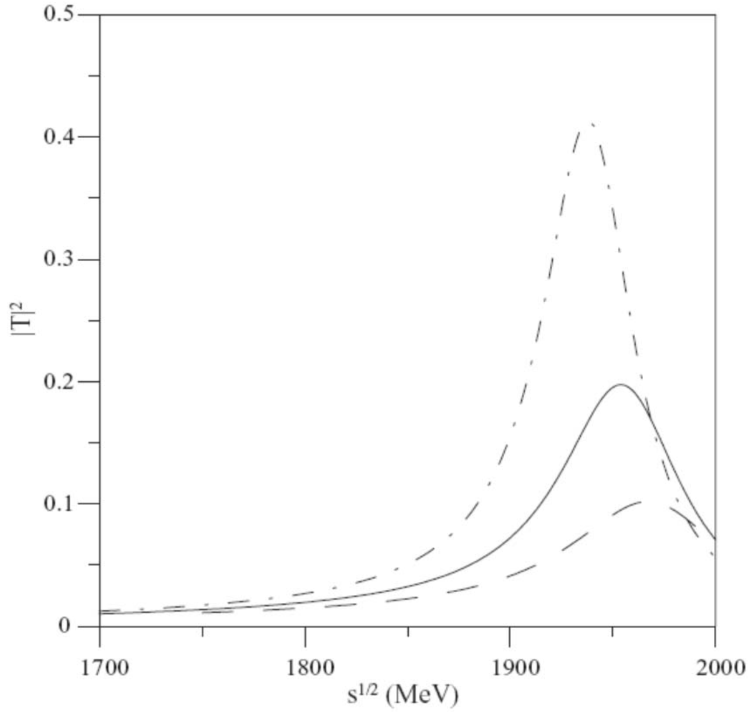
$$G(s_{\Delta\rho}) = i\int \frac{d^4q}{(2\pi)^4}\frac{2M_\Delta}{[(P-q)^2 - M_\Delta^2 + i\epsilon](q^2 - m_\rho^2 + i\epsilon)}$$

$$\begin{aligned}
&= \frac{2M_\Delta}{16\pi^2}\Bigg(a(\mu) + \ln\frac{M_\Delta^2}{\mu^2} + \frac{m_\rho^2 - M_\Delta^2 + s_{\Delta\rho}}{2s_{\Delta\rho}}\ln\frac{m_\rho^2}{M_\Delta^2} \\
&\quad + \frac{\overline{q}}{\sqrt{s_{\Delta\rho}}}\{\ln[s_{\Delta\rho} - (M_\Delta^2 - m_\rho^2) + 2\overline{q}\sqrt{s_{\Delta\rho}}] \\
&\quad + \ln[s_{\Delta\rho} + (M_\Delta^2 - m_\rho^2) + 2\overline{q}\sqrt{s_{\Delta\rho}}] \\
&\quad - \ln[-s_{\Delta\rho} + (M_\Delta^2 - m_\rho^2) + 2\overline{q}\sqrt{s_{\Delta\rho}}] \\
&\quad - \ln[-s_{\Delta\rho} - (M_\Delta^2 - m_\rho^2) + 2\overline{q}\sqrt{s_{\Delta\rho}}]\}\Bigg)
\end{aligned}$$

$N_{5/2-,\,3/2-,\,1/2-}$



$\Delta_{5/2-,\,3/2-,\,1/2-}$



Fine tunned $a_{\rho\Delta}$ (μ = 800 MeV) = -2.28 to get $N_{5/2-}$ at 1675 MeV.

Note that $\Delta_{5/2-}$ (1930) is reproduced as well.

Assignments

$N_{5/2-}$ (1675) (****)

$N_{3/2-}$ (1700) (***)

$N_{1/2-}$ (1650) (****)

$\Delta_{5/2-}$ (1930) (***)

$\Delta_{3/2-}$ (1940) (*)

$\Delta_{1/2-}$ (1900) (**)

Fixed Center Approximation (FCA) to the three-body problem

R. Chand and R. H. Dalitz, Ann. Phys. 20, 1 (1962)

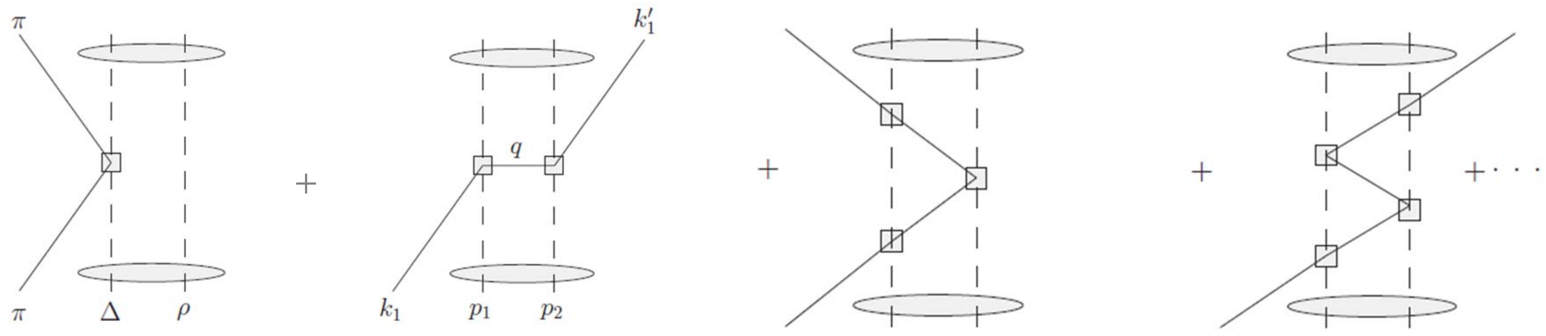
Two Center Model

The projectile is scattered, one by one, by the two particles (fixed centers) in the target which suffers no distortion.

10 – 25 % accuracy in $k^- d$

A. Gal, Int. J. Mod. Phys. A 22, 226 (2007)

The $\pi(\rho\Delta)_{N(1675)}$ system : Fixed Center Approximation



$$t_1 \quad + \quad t_1 G_0 t_2 \quad + \quad t_1 G_0 t_2 G_0 t_1 \quad +$$

$$t_1 = \frac{5}{9} t_{\Delta\pi}^{I=3/2} + \frac{4}{9} t_{\Delta\pi}^{I=1/2}$$

Brueckner Formula

$$T_1 = t_1 + t_1 G_0 T_2$$
$$T_2 = t_2 + t_2 G_0 T_1$$

$$t_2 = \frac{5}{6} t_{\rho\pi}^{I=2} + \frac{1}{6} t_{\rho\pi}^{I=1}$$

$$\boxed{T = T_1 + T_2 = \frac{t_1 + t_2 + 2 t_1 t_2 G_0}{1 - t_1 t_2 G_0^2}}$$

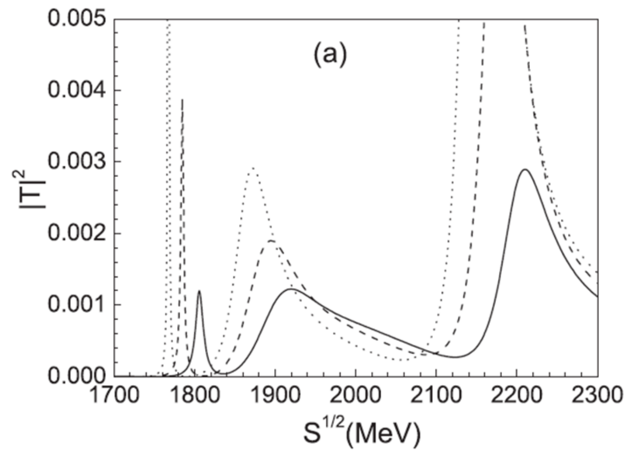
$$G_0(s) = \sqrt{\frac{M_{N^*}}{E_{N^*}}} \sqrt{\frac{M_{N^*}}{E'_{N^*}}} \int \frac{d^3\vec{q}}{(2\pi)^3} F_{N^*}(q) \times \frac{1}{q^{0^2} - \vec{q}^{\,2} - m_\pi^2 + i\epsilon}.$$

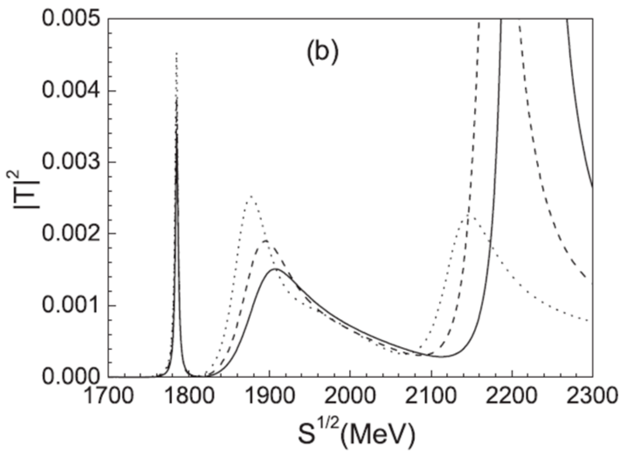
Parameters : $a_{\pi\rho}$, $a_{\pi\Delta}$

I = 3/2

$\Delta_{5/2+,\,3/2+,\,1/2+}$

$a_{\pi\rho} = -2.0$ $a_{\pi\Delta} = -3.0$





$a_{\pi\Delta} = -3.4, -3.0, -2.6$ $a_{\pi\rho} = -2.6, -2.0, -1.4$

It is plausible that $\Delta_{5/2+}(1740)$ is a DGR from $\pi(\rho\Delta)_{N(1675)}$ (there is a parameters interval giving rise to the bound state)

The existence of $\Delta_{5/2+}(1740)$ as a DGR from $\pi(\rho\Delta)_{N(1675)}$ implies that $\Delta_{1/2+,\,3/2+}$ partners should exist.

$$\Delta_{5/2+} : \pi\, N(1675)$$
$$\Delta_{3/2+} : \pi\, N(1700)$$
$$\Delta_{1/2+} : \pi\, N(1650)$$

PDG data				
Name	J^P	Estimated mass (MeV)	Extracted mass (MeV)	Status
$\Delta(1740)$	$5/2^+$		1752 ± 32 (1724 ± 61)	N.C.
$\Delta(1600)$	$3/2^+$	1550–1700	1706 ± 10 (1687 ± 44)	***
$\Delta(1750)$	$1/2^+$	≈ 1750	1744 ± 36 (1721 ± 61)	*

For Δ (1600) there is a quite lower meson-baryon threshold : π N(1520)

$\Delta_{1/2+}(1750)$ as DGR partner of $\Delta_{5/2+}(1740)$

$\Delta(1750)\ P_{31}$

$I(J^P) = \frac{3}{2}(\frac{1}{2}^+)$ Status: $*$

OMITTED FROM SUMMARY TABLE

The latest GWU analysis (ARNDT 06) finds no evidence for this resonance.

$\Delta(1750)$ BREIT-WIGNER MASS

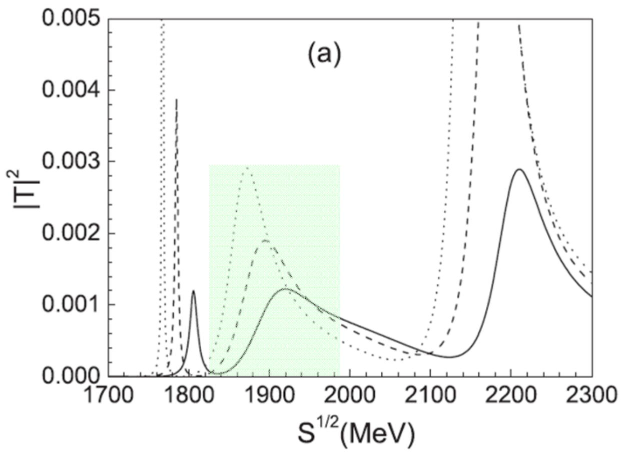
VALUE (MeV)	*DOCUMENT ID*		*TECN*	*COMMENT*
≈ 1750 OUR ESTIMATE				
1744 ±36	MANLEY	92	IPWA	$\pi N \to \pi N$ & $N\pi\pi$
• • • We do not use the following data for averages, fits, limits, etc. • • •				
1712 ± 1	PENNER	02C	DPWA	Multichannel
1721 ±61	VRANA	00	DPWA	Multichannel
1715.2±21.0	[1] CHEW	80	BPWA	$\pi^+ p \to \pi^+ p$
1778.4± 9.0	[1] CHEW	80	BPWA	$\pi^+ p \to \pi^+ p$

$\Delta_{1/2+}(1750)$ is a Quark Pauli blocked case as it was $\Delta_{5/2-}(1930)$

3q calculated mass is significantly higher than data

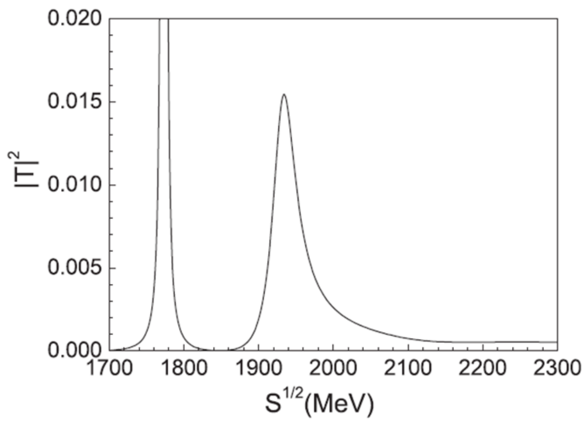
Consistency checks in the I = 3/2, 1/2 sectors

Further Δ states assignments



Δ(1905)	$5/2^+$	1865–1915	1881 ± 18 (1873 ± 77)	****
Δ(1920)	$3/2^+$	1900–1970	2014 ± 16 (1889 ± 100)	***
Δ(1910)	$1/2^+$	1870–1920	1882 ± 10 (1995 ± 12)	****

$I = 1/2$



$a_{\pi\Delta} = -3.4$

$a_{\pi\rho} = -1.4$

PDG data				
Name	J^P	Estimated mass (MeV)	Mass (MeV)	Status
$N(1680)$	$5/2^+$	1680–1690	1684 ± 4 (1679 ± 3)	****
$N(1720)$	$3/2^+$	1700–1750	1717 ± 31 (1716 ± 112)	****
$N(1710)$	$1/2^+$	1680–1740	1717 ± 28 (1699 ± 65)	***
$N(2000)$	$5/2^+$	≈ 2000	1903 ± 87	**
$N(1900)$	$3/2^+$	≈ 1900	1879 ± 17	**
$N(1900)$	$1/2^+$		1885 ± 30	N.C.

All results are fully consistent with existing data.

Summary

i) There is a puzzle concerning the PDG cataloged $\Delta_{5/2+}$ (2000) (**). Actually this entry may be representing two distinctive non-cataloged resonances : $\Delta_{5/2+}$ (1740) and $\Delta_{5/2+}$ (2200).

ii) There is a plausible explanation of $\Delta_{5/2+}$ (1740) as a Dynamically Generated Resonance (DGR) from π N(1675).

iii) The existence of $\Delta_{5/2+}$ (1740) provides an explanation to $\Delta_{1/2+}$ (1750) (*) as a DGR partner from π N(1650).

iv) A complete description of the light-quark bayon spectrum seems feasible from 3q + DGR states.

THE END

$$
\begin{aligned}
F_{N^*}(q) = \frac{1}{\mathcal{N}} \int_{|\vec{p}|<\Lambda, |\vec{p}-\vec{q}|<\Lambda} d^3\vec{p}\, \frac{M_\Delta}{E_\Delta(\vec{p})} \frac{1}{2\omega_\rho(\vec{p})} \\
\times \frac{1}{M_{N^*} - E_\Delta(\vec{p}) - \omega_\rho(\vec{p}) + i\left(\frac{\Gamma_\Delta+\Gamma_\rho}{2}\right)} \\
\times \frac{M_\Delta}{E_\Delta(\vec{p}-\vec{q})} \frac{1}{2\omega_\rho(\vec{p}-\vec{q})} \\
\times \frac{1}{M_{N^*} - E_\Delta(\vec{p}-\vec{q}) - \omega_\rho(\vec{p}-\vec{q}) + i\left(\frac{\Gamma_\Delta+\Gamma_\rho}{2}\right)}
\end{aligned}
$$

$$
\begin{aligned}
\mathcal{N} = \int_{|\vec{p}|<\Lambda} d^3\vec{p} \left(\frac{M_\Delta}{E_\Delta(\vec{p})} \frac{1}{2\omega_\rho(\vec{p})}\right)^2 \\
\times \frac{1}{\left[M_{N^*} - E_\Delta(\vec{p}) - \omega_\rho(\vec{p}) + i\left(\frac{\Gamma_\Delta+\Gamma_\rho}{2}\right)\right]^2}
\end{aligned}
$$

Harmonic Oscillator Model

Baryon (3q system): two relative (Jacobi) coordinates.

$$V_{ij}^{h.o.} \Longrightarrow E_\rho, E_\lambda$$

$$E^{h.o.} = (2n_\rho + l_\rho + \frac{3}{2})\omega + (2n_\lambda + l_\lambda + \frac{3}{2})\omega \equiv (N+3)\omega$$

Band Number: $N \equiv 2(n_\rho + n_\lambda) + l_\rho + l_\lambda \geq L$

Parity: $P = (-)^{l_\rho + l_\lambda} \equiv (-)^N$

$\Delta(1750)\ P_{31}$

The $\Delta(1750)$ is the lowest state with $J^P = \frac{1}{2}^+$

$L_{min} = 0$

$N = 0$, $L = 0$ is symmetry forbidden
(I=3/2, S=1/2, orbitally mixed symmetric)

$$\Downarrow$$

$$N = 2 \quad : \quad (70, 0^+)^{S = 1/2}$$

Quark Pauli Blocking is responsible for high mass prediction.

Existence of $\Delta_{1/2+}(1750)$ supports the existence of $\Delta_{5/2+}(1740)$ and viceversa.

$\Delta(1930)$

The $\Delta(1930)$ is the lowest state with $J^P = \dfrac{5}{2}^-$

$$L_{\text{min}} = 1 \Longrightarrow N \geq 1$$

N =1, L =1 is symmetry forbidden
(T=3/2, S=3/2, orbitally symmetric)

$$\Downarrow$$

$$N = 3 \qquad \Longrightarrow \qquad (56, 1^-)_3$$

Quark Pauli Blocking is responsible for high mass prediction.

Phenomenological Models

CMB (CUTKOSKY) :

$$\pi N \rightarrow \pi N$$

$$Channels: \pi N + (NR)\pi\pi N + (\pi\Delta, \rho N, \eta N, \sigma N, \omega N, \pi N^*, \rho\Delta)$$

KSU (MANLEY) :

$$\pi N \rightarrow \pi N + \pi N \rightarrow \pi\pi N$$

$$Channels: \pi N + (NR)\pi\pi N + (\pi\Delta, \rho N, \rho_3 N, \sigma N, \pi N^*)$$
$$+ \text{ Specific } (\eta N \text{ for } S_{11}, ..., \rho\Delta \text{ for } P_{31}, D_{35}, F_{37}))$$

Pitt - ANL (VRANA) : Expanded version of CMB + πN $\longrightarrow$ πNN + $\pi N \rightarrow \eta N$

VPI-GWU (ARNDT) :

$$\pi N \rightarrow \pi N + \pi N \rightarrow \eta N$$

$$Channels: \pi N + \eta N + \pi\Delta + \rho N$$

Since 2006 : EBAC (Excited Baryon Analysis Center)

JLMS Model : $\pi N \rightarrow \pi N \quad + \quad \pi N \rightarrow \eta N$

$$Channels : \pi N,\ \eta N,\ \pi\Delta,\ \rho N,\ \sigma N\ +\ bare\ N^*$$

Bare N* states : quark-core components of the nucleon resonances.

Program: Extraction of N* from the world data of meson production reactions induced by pions, photons and electrons:

$$\pi N \rightarrow \pi N,\ \pi N \rightarrow \eta N,\ \pi N \rightarrow \pi\pi N,\ \gamma N \rightarrow \pi N,\ \gamma N \rightarrow \pi\pi N,\ eN \rightarrow e\pi N$$

Model Dependency

For $\Delta(1930)$ (***) only the phenomenological analyses including the $\rho\Delta$ channel extract the resonance.

CMB (CUTKOSKY) : $\pi N \to \pi N$

$$Channels : \pi N + (NR)\pi\pi N + (\pi\Delta, \rho N, \eta N, \sigma N, \omega N, \pi N^*, \rho\Delta)$$

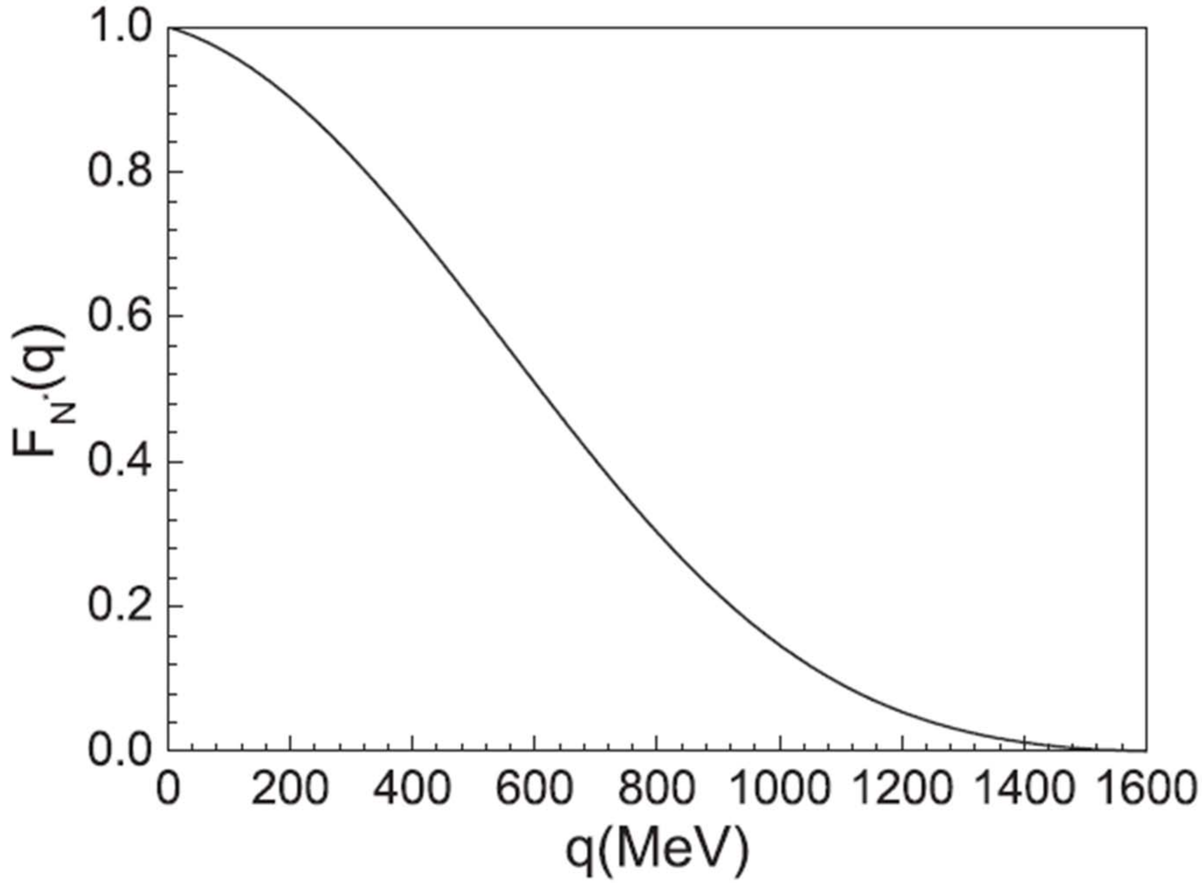
KSU (MANLEY) : $\pi N \to \pi N + \pi N \to \pi\pi N$

$$Channels : \pi N + (NR)\pi\pi N + (\pi\Delta, \rho N, \rho_3 N, \sigma N, \pi N^*)$$
$$+ \text{Specific } (\eta N \text{ for } S_{11}, ..., \rho\Delta \text{ for } P_{31}, D_{35}, F_{37}))$$

Pitt - ANL (VRANA) : Expanded version of CMB + $\pi N \to \eta N$

VPI-GWU (ARNDT) : $\pi N \to \pi N + \pi N \to \eta N$

$$Channels : \pi N + \eta N + \pi\Delta + \rho N$$



1.0
0.8
0.6
0.4
0.2
0.0
0
200
400
600
800
1000
1200
1400
1600
q(MeV)
F_N'(q)