STRUCTURE OF THE DI- AND -TRIBARYONIC EXOTIC COMPOUNDS

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DIBARYONS

Δ Resonance

$I(J^P) = 3/2(3/2^+)$

$m_\Delta = 1232$ MeV

$\Gamma_\Delta = 115$ MeV

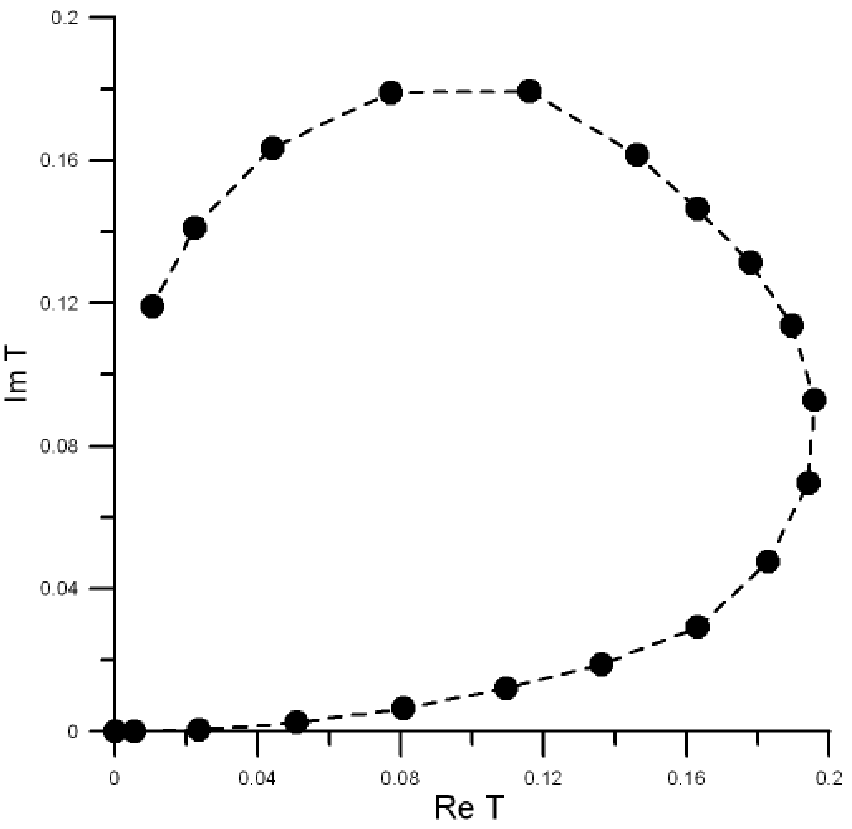
$\Delta \rightarrow \pi N$

$J^P = 2^+$ Dibaryons (ΔN, $\Delta\Lambda$, $\Delta\Lambda_C$)

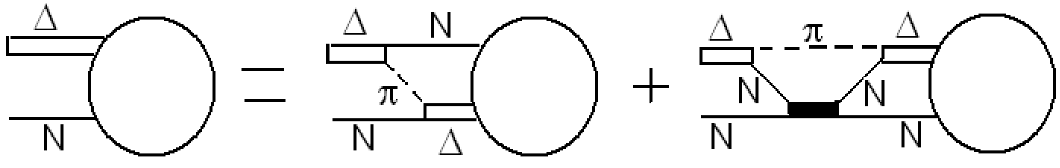
$J^P = 3^+$ Dibaryon ($\Delta\Delta$)

ΔN $I(J^P) = 1(2^+)$ Dibaryon

- NN $^1D_2$ amplitude 1880 < W < 2260 MeV.
- Hoshizaki resonance at
- W = 2144 – i55 MeV



$J^P=2^+$ πNN Faddeev Equations



$$\Delta \to \pi N$$

P_{33} πN Interaction

$$V_3(p_3, p'_3) = \lambda_3 g_3(p_3) g_3(p'_3),$$

$$t_3(\omega_3; p_3, p'_3) = g_3(p_3)\tau_3(\omega_3) g_3(p'_3),$$

$$\tau_3^{-1}(\omega_3) = \lambda_3^{-1} - \int_0^\infty p_3^2 dp_3 \frac{[g_3(p_3)]^2}{\omega_3 - \sqrt{m_N^2 + p_3^2} - \sqrt{m_\pi^2 + p_3^2} + i\epsilon}.$$

$$\tau_3^{-1}(W; q_3) = \lambda_3^{-1} - \int_0^\infty p_3^2 dp_3 \frac{[g_3(p_3)]^2}{W - \sqrt{q_3^2 + (\sqrt{m_N^2 + p_3^2} + \sqrt{m_\pi^2 + p_3^2})^2} - \sqrt{q_3^2 + m_N^2} + i\epsilon},$$

$$g_3(p_3) = p_3 \exp(-p_3^2/\beta_3^2) + C p_3^3 \exp(-p_3^2/\alpha_3^2),$$

$^3S_1$ NN Interaction

$$V_1(p_1, p_1') = \sum_{m=1}^{2} \lambda_1^m g_1^m(p_1) g_1^m(p_1'),$$

$$t_1(\omega; p_1, p_1') = \sum_{m,n=1}^{2} g_1^m(p_1) \tau_1^{mn}(\omega) g_1^n(p_1'),$$

$$\tau_1^{mn}(\omega) = \frac{G_1^{mn}(\omega)}{G_1^{11}(\omega) G_1^{22}(\omega) - G_1^{12}(\omega) G_1^{21}(\omega)},$$

$$G_1^{mn}(\omega) = \frac{1}{\lambda_1^m} \delta_{mn} - (-)^{m+n} \int_0^\infty p_1^2 dp_1 \frac{g_1^m(p_1) g_1^n(p_1)}{\omega - 2\sqrt{M^2 + p_1^2} + i\epsilon}.$$

$$g_1^m(p_1) = \frac{1}{p_1^2 + [\alpha_1^m]^2}$$

Faddeev Equation

$$T_3(W;q_3) = \int_0^\infty dq_3' M(W;q_3,q_3')\tau_3(W;q_3')T_3(W;q_3'),$$

$$M(W;q_3,q_3') = K_{23}(W;q_3 q_3') + 2\sum_{mn}\int_0^\infty dq_1 K_{31}^m(W;q_3,q_1)\tau_1^{mn}(W;q_1)K_{13}^n(W;q_1 q_3'),$$

$$K_{23}(W;q_3,q_3') = \frac{1}{2}q_3 q_3' \int_{-1}^1 \frac{d\cos\theta\, g_3(p_3)\, g_3(p_3') b_{23}^{\frac{3}{2}\frac{3}{2}} \hat{p}_3 \cdot \hat{p}_3'}{W - \sqrt{M^2+q_3^2} - \sqrt{\mu^2+q_3^2+{q_3'}^2+2q_3 q_3'\cos\theta} - \sqrt{M^2+{q_3'}^2} + i\epsilon},$$

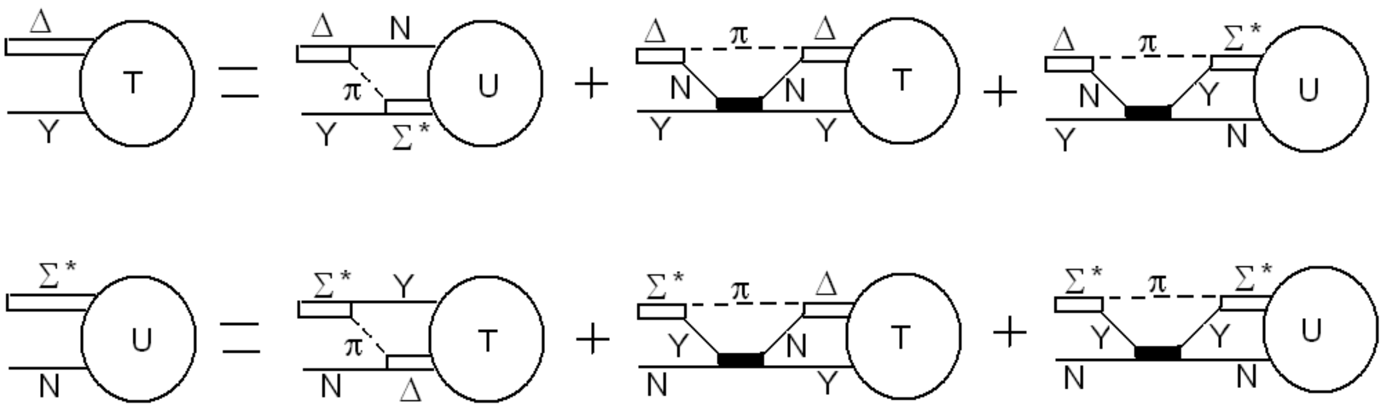
$$K_{31}^m(W;q_3,q_1) = \frac{1}{2}q_3 q_1 \int_{-1}^1 \frac{d\cos\theta\, g_3(p_3)\, g_1^m(p_1) b_{31}^{\frac{3}{2}0} \hat{p}_3 \cdot \hat{q}_1}{W - \sqrt{M^2+q_3^2} - \sqrt{M^2+q_1^2+q_3^2+2q_1 q_3\cos\theta} - \sqrt{\mu^2+q_1^2} + i\epsilon},$$

$$b_{ij}^{I\ I} = (-)^{I\ +\tau\ -I}\sqrt{(2I_i+1)(2I_j+1)}W(\tau_j\tau_k I\tau_i; I_i I_j),$$

$$q_i \to q_i e^{-i\phi},$$

$$W = 2151 - i60\ \text{MeV}$$

$J^P=2^+$ $\Delta\Lambda$ Faddeev Equations



$$\Delta \to \pi N$$

$$\Sigma^*(1385) \to \pi\Lambda,\ \pi\Sigma$$

πΛ–πΣ Interaction

$$V_2^{YY'}(p_2, p_2') = \gamma_2 g_2^{Y}(p_2) g_2^{Y'}(p_2'),$$

$$t_2^{YY'}(p_2, p_2'; \omega_0) = g_2^{Y}(p_2)\tau_2(\omega_0) g_2^{Y'}(p_2'),$$

$$\tau_2^{-1}(\omega_0) = \frac{1}{\gamma_2} - \sum_Y \int_0^\infty p_2^2 dp_2 \frac{[g_2^Y(p_2)]^2}{\omega_0 - \sqrt{m_\pi^2 + p_2^2} - \sqrt{m_Y^2 + p_2^2} + \mathrm{i}\epsilon}.$$

$$g_2^\Lambda(p_2) = p_2(1 + Ap_2^2)\exp(-p_2^2/\beta_2^2), \quad g_2^\Sigma(p_2) = B g_2^\Lambda(p_2),$$

$$0.25 < A < 0.45$$

$^3S_1$ NY Interaction

$$V_3^{YY'}(p_3, p_3') = \gamma_3^{YY'} g_3^Y(p_3) g_3^{Y'}(p_3'),$$

$$t_3^{YY'}(p_3, p_3'; \omega_0) = g_3^Y(p_3) \tau_3^{YY'}(\omega_0) g_3^{Y'}(p_3'),$$

$$g_3^Y(p_3) = \frac{1}{1 + (p_3/\alpha_3^Y)^2},$$

$$A = 0.25 \Longrightarrow E = 57 - i2.6 \ \ \mathbf{MeV}$$

$$A = 0.35 \Longrightarrow E = 61 - i3.2 \ \ \mathbf{MeV}$$

$$A = 0.45 \Longrightarrow E = 65 - i3.8 \ \ \mathbf{MeV}$$

$J^P=2^+$ $\Delta\Lambda_C$ Dibaryon

$$\Lambda \to \Lambda_C(2286),$$

$$\Sigma^*(1385) \to \Sigma_C^*(2520),$$

$$V_2(p_2, p_2') = \gamma_2 g_2^{\Lambda_C}(p_2) g_2^{\Lambda_C}(p_2'),$$

$$g_2^{\Lambda_C}(p_2) = p_2(1 + Ap_2^2)\exp(-p_2^2/\beta_2^2),$$

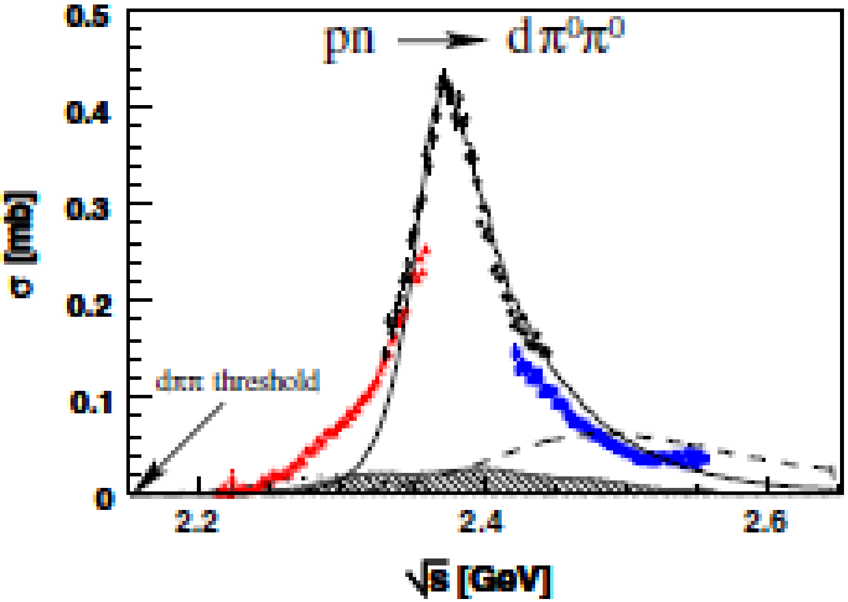
$$A = 0.1 \Longrightarrow E = -14.6 \ \ \mathrm{MeV}$$

$$A = 0.4 \Longrightarrow E = -4.0 \ \ \mathrm{MeV}$$

$$A = 0.7 \Longrightarrow E = 7.0 - i0.01 \ \ \mathrm{MeV}$$

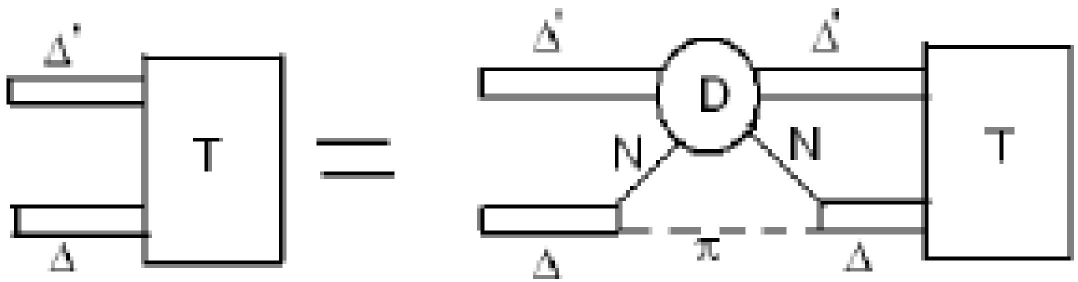
I(J^P)=0(3$^+$) ΔΔ Dibaryon

$$(\text{ABC Resonance})$$



$$W = 2370 - i35 \ \mathbf{MeV}$$

ΔΔ Faddeev Equation



$$\Delta' = \text{stable } \Delta$$

$$m_{\Delta'} = 1232 \text{ MeV}$$

$$V_{\pi\Delta'} = 0$$

$$\text{D} = 1(2^{+}) \text{ Dibaryon}$$

NN $^1D_2$ Amplitude

3-channel separable potential

1) NN (d-wave)
2) NN' (s-wave)
3) NΔ' (s-wave)

N' is a ficticious particle with $m_{N'}=m_\pi+m_N$ and P_{13} quantum numbers

NN-NN'-NΔ' T-matrix

$$V_1^{mn}(p_1, {p_1}') = \lambda_1 g_1^m(p_1) g_1^n({p_1}'); \quad m, n = 1 - 3,$$

$$t_1^{mn}(\omega_1; p_1, p_1') = g_1^m(p_1)\tau_1(\omega_1) g_1^n(p_1'),$$

$$\tau_1^{-1}(\omega_1) = \lambda_1^{-1} - \sum_{r=1}^{3} \int_0^\infty p_1^2 dp_1 \frac{[g_1^r(p_1)]^2}{\omega_1 - \sqrt{m_N^2 + p_1^2} - \sqrt{m_r^2 + p_1^2} + i\epsilon}.$$

$$g_1^n(p_1) = \frac{p_1^\ell}{[1 + p_1^2/(\alpha_1^n)^2]^{1+\ell/2}} \left[1 + A_1^n \frac{p_1^2}{1 + p_1^2/(\alpha_1^n)^2}\right],$$

NN $^1D_2$ Amplitude

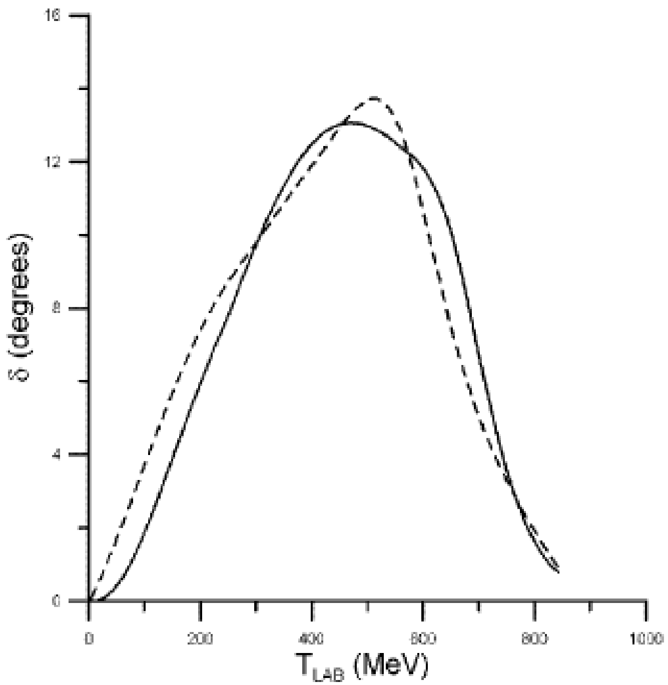


FIG. 2: The $^1D_2$ NN phase shift δ. Dashed: Arndt *et al.* [20]. Solid: Eq. (10) best fit for $A_1 = A_2 = A_3 = 1$.

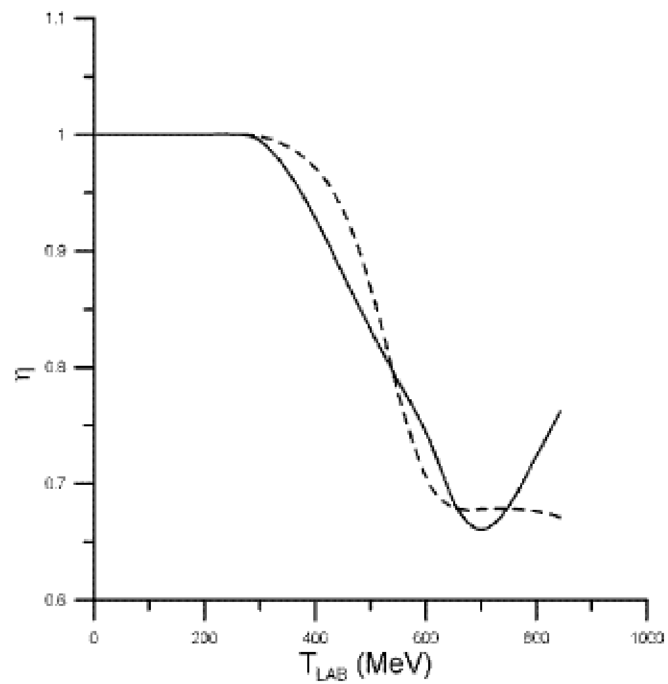


FIG. 3: The $^1D_2$ NN inelasticity η. Dashed: Arndt *et al.* [20]. Solid: Eq. (10) best fit for $A_1 = A_2 = A_3 = 1$.

Integral Equation

$$T(W;q_3) = \int_0^\infty dq_3' M(W;q_3,q_3')\tau_3(W;q_3')T(W;q_3'),$$

$$M(W;q_3,q_3') = 2\int_0^\infty dq_1 K_{31}(W;q_3,q_1)\tau_1(W;q_1)K_{13}(W;q_1 q_3'),$$

$$K_{31}(W;q_3,q_1) = \frac{1}{2}q_3 q_1 \int_{-1}^{1} d\cos\theta \frac{g_3(p_3)\, g_1^{N\Delta'}(p_1)\hat{p}_3\cdot\hat{q}_1}{W - \sqrt{m_1^2+q_1^2} - \sqrt{m_2^2+q_1^2+q_3^2+2q_1q_3\cos\theta} - \sqrt{m_3^2+q_3^2} + i\epsilon}.$$

$$\tau_3^{-1}(W;q_3) = \lambda_3^{-1} - \int_0^\infty p_3^2 dp_3 \frac{[g_3(p_3)]^2}{W - \sqrt{q_3^2 + (\sqrt{m_N^2+p_3^2} + \sqrt{m_\pi^2+p_3^2})^2} - \sqrt{q_3^2+m_{\Delta'}^2} + i\epsilon},$$

$$m_{\Delta'} \to 1211 - i(2/3)49.5\ \text{MeV}$$

$$\mathcal{D}_{03}: \quad M = 2363 \pm 20, \quad \Gamma = 65 \pm 17 \quad (\text{MeV}).$$

Conclusions

- Faddev method can explain ΔN and $\Delta\Delta$ resonances
- It predicts a $\Delta\Lambda$ resonance about 60 MeV above $\pi\Lambda N$ threshold with width 6-8 MeV
- Possible $\Delta\Lambda_C$ bound state

TRIBARYONS

- We use Malfliet-Tjon type two-body interactions adjusted to the low-energy data of the Nijmegen ESC08c models

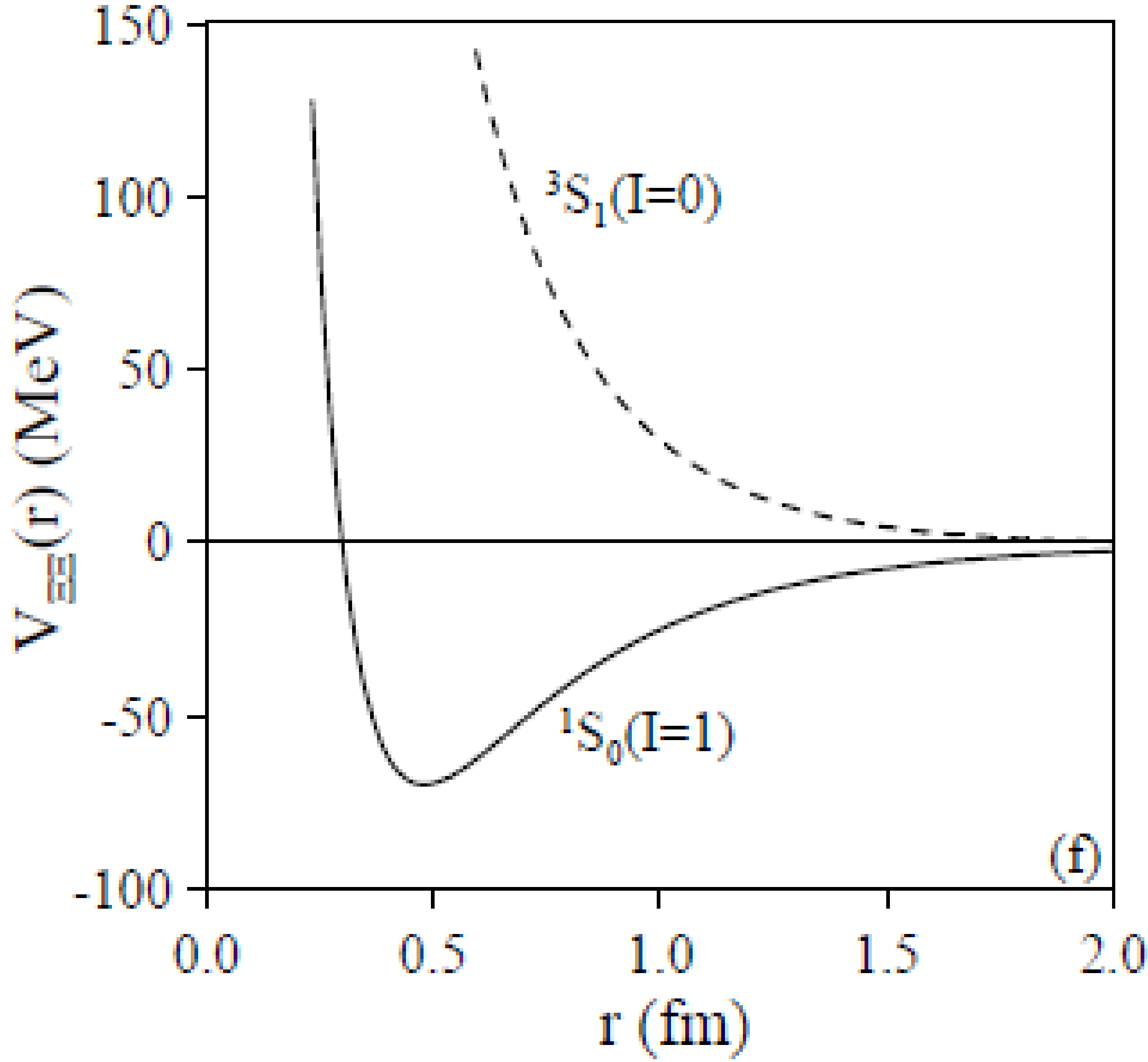
Malfliet-Tjon models of the S-wave NN, NΛ, NΞ, and $\Xi\Xi$ interactions

$$V^{ij}(r) = -A\frac{e^{-\mu_A r}}{r} + B\frac{e^{-\mu_B r}}{r}$$

these models give

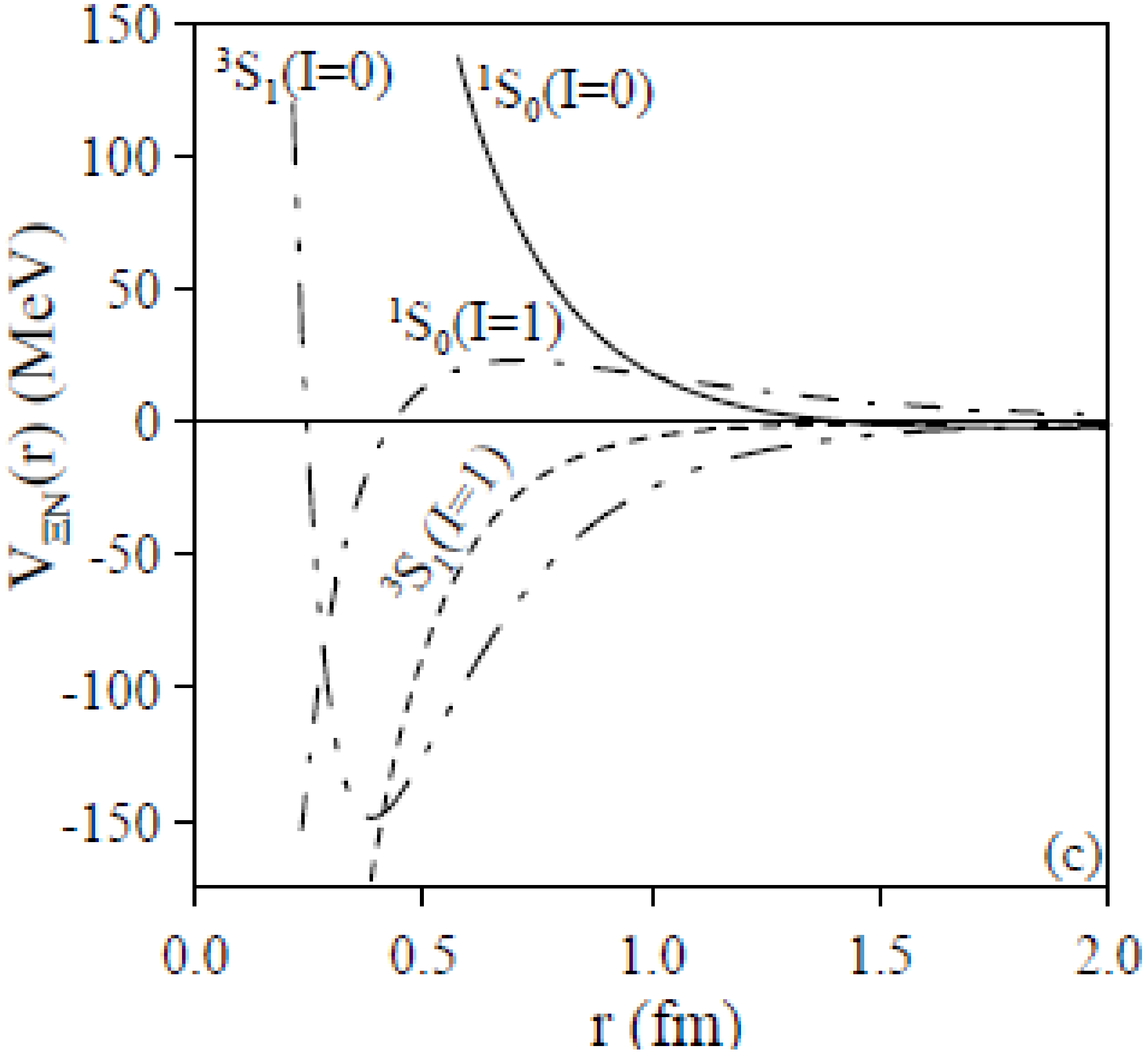
Triton binding energy of 8.3 MeV

Hypertriton separation energy of 0.14 MeV



150
100
50
0
-50
-100
0.0
0.5
1.0
1.5
2.0
r (fm)
V_ΞΞ(r) (MeV)
3S1(I=0)
1S0(I=1)
(f)

Nijmegen ΞN S-wave interactions



The state NN Ξ

$$(I, J^P) = (1/2, 3/2^+)$$

NN $\longrightarrow^3 S_1(I=0)$

NΞ $\longrightarrow^3 S_1(I=0),^3 S_1(I=1)$

B=17.2 MeV

The decay process $\mathrm{N}\Xi \to \Lambda\Lambda$

which takes place in the channel $(\mathrm{I},\mathrm{J}^P) = (0, 0^+)$

does not contribute in a pure S-wave configuration

Maximal isospin states

The decay process $N\Xi \longrightarrow \Lambda\Lambda$ can not occur if the Ξ hypernucleus is in a state of maximal isospin, i.e., if it consists only of neutrons and negative Ξ's or only protons and neutral Ξ's . Therefore, these states, if bound, would be stable.

$^{2}_{\Xi}H \quad (1, 1^{+})$ (B=1.6 MeV)

$^{3}_{\Xi}H \quad (3/2, 1/2^{+})$ (B=3.0 MeV)

$^{3}_{\Xi\Xi}He (3/2, 1/2^{+})$ (B=4.5 MeV)

$^{4}_{\Xi\Xi}He \quad (2, 0^{+})$ (B=7.4 MeV)

and perhaps a full periodic table of stable Ξ hypernuclei

The $\Lambda\Lambda N - \Xi N N$ $(1/2, 1/2^+)$ resonance

1) Separable potentials tailored to the ESC08 models in all S-wave interactions.

2) Calculation in the complex plane to search for either a bound state or a resonance

3) Found a $\Lambda\Lambda N$ resonance at E=23.4 -i0.045 MeV, just below the Ξd threshold.

4) In spite of the large phase space available (about 23 MeV) the width is very small (about 0.09 MeV).

5) This behavior is due to the fact that the uncoupled $\Xi N N$ system has a bound state very near the Ξd threshold.

Conclusions

1) ESC08c models predict stable and unstable di- tri- and up –baryons.
2) Other models (chiral quark models, effective field theories, lattice models) contain also considerable amounts of attraction and may generate similar results.