Relativistic separable interaction kernel of the neutron-proton system with inelasticities for partial-wave states with $J > 1$

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BS equation for scattered states:

$$T(p',p;P) = V(p',p;P) + \frac{i}{4\pi^3}\int d^4k\, V(p',k;P)\, S_2(k;P)\, T(k,p;P)$$

V - interaction kernel, T - scattering matrix

Two-particle Green function:

$$S_2^{-1}(k;P) = \left(\tfrac{1}{2}\, P\cdot\gamma + k\cdot\gamma - m\right)^{(1)} \left(\tfrac{1}{2}\, P\cdot\gamma - k\cdot\gamma - m\right)^{(2)}$$

m - nucleon mass, P - np-pair full momentum, k - relative momentum

BS equation for a bound state:

$$\Phi^{JM}(p;P) = \frac{i}{(2\pi)^4} S_2(p;P) \int d^4k V(p,k;P)\Phi^{JM}(k;P)$$

Φ^{JM} - BS amplitude, J - np-pair total angular momentum, M is its z-axis projection

Partial-wave decomposition:

$$T_{\alpha\beta,\gamma\delta}(p',p;P_{(0)}) = \sum_{JMab} (\mathcal{Y}_{aM}(-\boldsymbol{p'})U_C)_{\alpha\beta} \otimes (U_C \mathcal{Y}^{\dagger}_{bM}(\boldsymbol{p}))_{\delta\gamma}\ T_{ab}(p'_0,|\boldsymbol{p'}|;p_0,|\boldsymbol{p}|;s)$$

U_C - charge conjugation matrix, a or b - ${}^{2S+1}L_J$, M - total momentum J projection

Spin-angle functions:

$$\mathcal{Y}_{JM:LS\rho}(\boldsymbol{p})U_C = i^L \sum_{m_L m_S m_1 m_2 \rho_1 \rho_2} C^{S_\rho \rho}_{\frac{1}{2}\rho_1 \frac{1}{2}\rho_2} C^{JM}_{Lm_L S m_S} C^{S m_S}_{\frac{1}{2}m_1 \frac{1}{2}m_2} Y_{Lm_L}(\boldsymbol{p}) u^{\rho_1}_{m_1}{}^{(1)}(\boldsymbol{p}) u^{\rho_2}_{m_2}{}^{(2)}{}^{T}(-\boldsymbol{p})$$

Separable interaction kernel:

$$V_{l'l}(p'_0,|\boldsymbol{p'}|;p_0,|\boldsymbol{p}|;s) = \sum_{i,j=1}^{N} \lambda_{ij}(s) g_i^{[l']}(p'_0,|\boldsymbol{p'}|) g_j^{[l]}(p_0,|\boldsymbol{p}|)$$

N - rank of a separable kernel, λ - matrix of model parameters,
g - separable model functions, $s = P^2$ - full np-pair energy

$$g(p,P) = \frac{p_c - p^2}{((p^2-\beta^2)^2+\alpha^4)^n}$$

Scattering matrix:

$$S = \frac{1 - K_i + iK_r}{1 + K_i - iK_r} = \eta \, \exp(2i\delta),$$

$$K_r = \tan\delta, \quad K_i = \tan^2\rho,$$

δ - phase shift, ρ - inelasticity

$$\eta^2 = \frac{1 + K^2 - 2K_i}{1 + K^2 + 2K_i}, \quad K^2 = K_r^2 + K_i^2$$

Elastic scattering: $\rho = 0$, $\delta = \delta_e$, $\eta = 1$ and $S = S_e = \exp(2i\delta_e)$

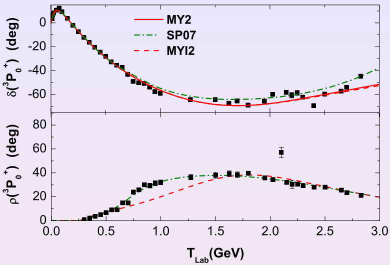
Complex interaction kernel: $V = V_r + iV_i$

$$V_{l'l}(p'_0, |\mathbf{p}'|; p_0, |\mathbf{p}|; s) = \sum_{m,n=1}^{N} \left[\lambda^r_{mn}(s) + i\lambda^i_{mn}(s)\right] g_i^{[l']}(p'_0, |\mathbf{p}'|) g_j^{[l]}(p_0, |\mathbf{p}|)$$

$$\lambda^i_{mn}(s) = \theta(s - s_{th}) \left(1 - \frac{s_{th}}{s}\right) \bar{\lambda}^i_{mn}$$

s_{th} is the inelasticity threshold where $s = 2mT_{\text{Lab}} + 4m^2$

Results: ${}^3P_0^+$



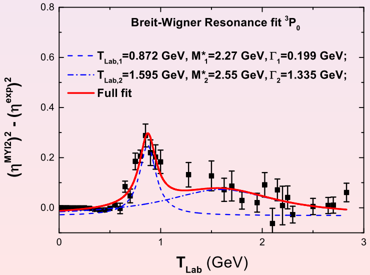
MY2 - **M**odified **Y**amaguchi-type rank-**2** separable kernel

MYI2 - **M**odified **Y**amaguchi-type separable kernel with **I**maginary part, rank-**2**

SP07 - A.T. Aerts, P.J. Mulders, J.J. de Swart, Phys. Rev. **D17**, 260 (1978)

Experimental data:
SAID program - http://gwdac.phys.gwu.edu

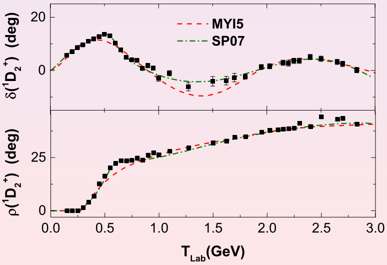
$$\Delta\eta(T_{\rm Lab}) = (\eta^{\rm MYIN}(T_{\rm Lab}))^2 - (\eta^{\rm exp}(T_{\rm Lab}))^2$$

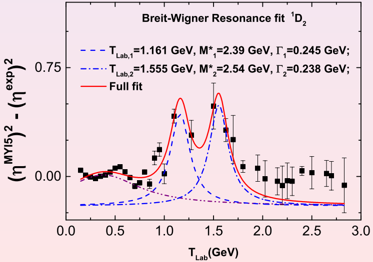


$$g_i(p_0,\mathbf{p}) = \frac{\left(-p_0^2+\mathbf{p}^2\right)^i \prod_{k=1}^{i} \left(-p_0^2+\mathbf{p}^2+pc_{ik}\right)^{(k-1)}}{\prod_{k=1}^{i}\left(\left(p_0^2-\mathbf{p}^2-\beta_{ik}^2\right)^2+\alpha_{ik}^4\right)^k},\quad i=1\dots5$$

$$\lambda_{mn}^r(s) = \left(\frac{s_0}{s}-1\right)\bar{\lambda}_{mn}^r$$

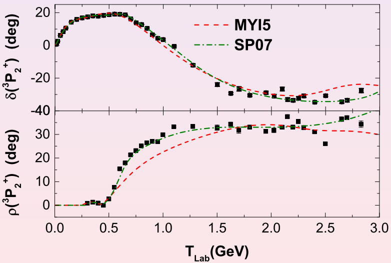
s_0 reproduces the sign change of the phase shifts at the $T_{\rm Lab}$ experimental value where they are equal to zero

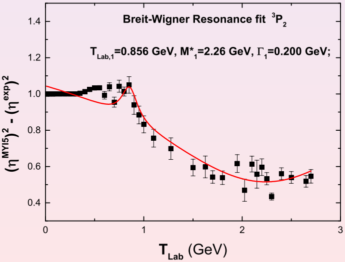




$$g_i(p_0,\mathbf{p}) = \frac{\sqrt{\left(-p_0^2+\mathbf{p}^2\right)^{(2i-1)}}\prod_{k=1}^{i}\left(-p_0^2+\mathbf{p}^2+pc_{ik}\right)^{(k-1)}}{\prod_{k=1}^{i}\left(\left(p_0^2-\mathbf{p}^2-\beta_{ik}^2\right)^2+\alpha_{ik}^4\right)^k}, \begin{cases} i=1\dots5 & - \text{ for } {}^3P_2^+ \\ i=2\dots3 & - \text{ for } {}^3F_2^+ \end{cases}$$

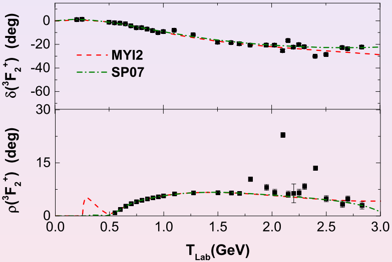
${}^3\boldsymbol{P_2^+}$:

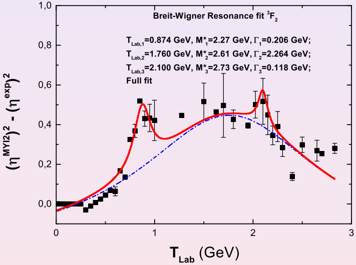




Results: ${}^3P_2^+$-${}^3F_2^+$

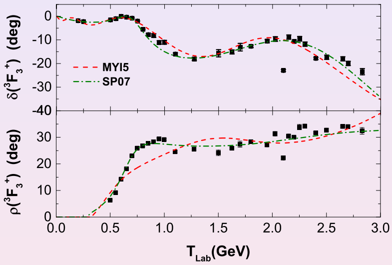
${}^3F_2^+$:

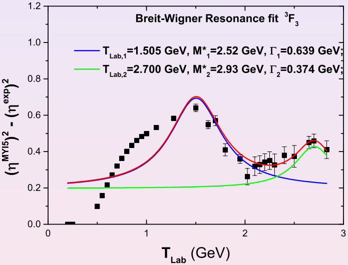




Results: ${}^3F_3^+$

g_i, λ^r, λ^i are defined by the same formulae as for ${}^3P_2^+$ partial-wave state





Even if we increase a number of used parameters and/or a rank of the kernel, **the deviations of our description from the experimental data remain the same**. It could indicate that the **observed "objects" are real, not model-dependent**.

Breit-Wigner formula:

$$\Delta\eta(T_{\rm Lab}) = C + \sum_{i=1,2} (2A_i/\pi)\, \frac{\Gamma_i^*}{4(T_{\rm Lab} - T_{\rm Lab}{}_i^*)^2 + \Gamma_i^{*\,2}},$$

where A_i, C - constants, $T_{\rm Lab}{}_i^* = (M_i^{*\,2} - 4m^2)/(2m)$, M_i^*, Γ_i^* - effective mass and width of i-th resonance

Table: Dibaryons in all considered partial-wave states

$T_{\rm Lab}$(GeV)	M^*(GeV)	Γ^*(GeV)	State
0.856 (GeV)	2.26	0.200	$^3P_2$
0.872 (GeV)	2.27	0.199	$^3P_0$
0.874 (GeV)	2.27	0.206	$^3F_2$
1.161 (GeV)	2.39	0.245	$^1D_2$
1.505 (GeV)	2.52	0.639	$^3F_3$
1.555 (GeV)	2.54	0.238	$^1D_2$
1.595 (GeV)	2.55	1.335	$^3P_0$
1.760 (GeV)	2.61	2.264	$^3F_2$
2.100 (GeV)	2.73	0.118	$^3F_2$
2.700 (GeV)	2.93	0.374	$^3F_3$

A.T. Aerts, P.J. Mulders, J.J. de Swart, Phys. Rev. **D17**, 260 (1978)
P.J. Mulders, A.T. Aerts, J.J. de Swart, Phys. Rev. **D21**, 2653 (1980)

Conclusion:

- np-scattering partial-wave states with $J > 1$ have been considered using a relativistic separable kernel approach based on the Bethe-Salpeter equation
- found deviations of calculated results from experimental data are interpreted as dibaryon resonances
- these deviations cannot be removed by increasing a number of parameters and/or a rank of the used kernel

Plans:

- finalize our calculations and compare our results with model predictions
- see how other potentials describe the same phase shift and inelasticity experimental data

THANK YOU
FOR YOUR ATTENTION!