Meson electro-production in the region of the Roper and the N(1535) resonance in chiral quark models

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Outline

- Motivation and aims
- Basics of the method: incorporating quasi-bound quark-model states into the coupled channel formalism
- The underlying quark model: Cloudy bag model
- Scattering and electro-production amplitudes in the region of P11 resonances
- Negative parity resonances
  - S11 wave scattering and electro-production amplitudes
  - Preliminary results on S31, D13 and D33 resonances
- Summary

The Coimbra - Ljubljana collaboration: baryon resonances in quark models with meson clouds

Coimbra: João da Providencia, Manuel Fiolhais, Pedro Alberto, Luis Amoreira, Luis Alvares Ruso;

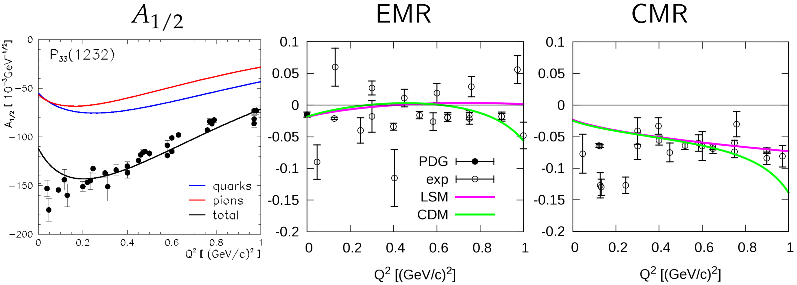
Ljubljana: Mitja Rosina, Simon Širca, B. G.

- $\Delta(1232)$ using
  - linear σ-model with quarks (LSM)
  - Nambu – Jona-Lasino models
- $\Delta(1232)$ and $N(1440)$ using
  - chromodiectric model with pions and σ-mesons
- Second resonance region
  - Cloudy bag model

Flashback: electro-excitation of $\Delta(1232)$

Helicity amplitudes for electro-excitation of $\Delta(1232)$ in quark models with pion cloud, PLB **373** (1996) 229.

The pion cloud contributes almost half of the strength of the M_{1+} multipole and dominates the E_{1+} amplitudes.



Aims of the present work

- Construct a coupled-channel approach that includes many-body states of quarks (and mesons) in the scattering formalism.
- Use the same approach for calculating scattering and electro-production amplitudes.
- Check the applicability of the method in a simple model of quarks coupled to mesons focusing on the second resonance region.
- Investigate whether the resonances in this region can be explained in terms of quarks (and mesons), or whether exotic degrees of freedom are needed.
- Study the role of the meson cloud.
- Establish a contact between the observed resonances and the quark-model calculations using bound-state boundary conditions.

Some general features of the method

- Advantages
  - **Baryons** are treated as **composite particles** from the very beginning; the strong and electro-weak **form-factors** are derived **from** baryon **internal structure** and not inserted a posteriori; as a consequence the method introduces a much **smaller number of free parameters**.
  - The physical resonances appear as **linear superpositions** of bare resonances.
  - The **bare** quark-meson and quark-photon **vertices** are **modified** through **meson loops** as well as through **mixing of resonances** and coupling to the **background**.
  - The **meson cloud** around baryons is included in a consistent way also **in** the **asymptotic states**.
  - The method yields a symmetric K matrix and hence respects the **unitarity of the S matrix**.
- Present limitations
  - Because of the complex structure of the baryons in the model, the method does not support a very large set of ingredients.
  - **No** inclusion of **meson-meson interaction** or **four-point interaction**.

Hamiltonian

The meson field linearly couples to the quark core; no meson self-interaction or four-point interaction

$$H_{\text{meson}} = \int \mathrm{d}k \sum_{lmt} \omega_k \, a^\dagger_{lmt}(k) a_{lmt}(k) + \left[V_{lmt}(k) a_{lmt}(k) + V_{lmt}(k)^\dagger \, a^\dagger_{lmt}(k) \right]$$

$V_{lmt}(k)$ induce also radial excitations of the quark core, e.g. $1s \longrightarrow 2s$, $1s \longrightarrow 1p_{1/2}$, $1s \longrightarrow 1p_{3/2}$, ... transitions.

For example: $V(k)$ from Cloudy Bag Model (s, p and d wave pions):

$$V^{s \to p_{1/2}}_{1=0,t}(k) = \frac{1}{2f} \frac{k^2}{\sqrt{4\pi^2 \omega_k}} \sqrt{\frac{\omega_{\mathrm{p}_{1/2}} \omega_{\mathrm{s}}}{(\omega_{\mathrm{p}_{1/2}} + 1)(\omega_{\mathrm{s}} - 1)}} \frac{j_0(kR_{\mathrm{bag}})}{kR_{\mathrm{bag}}} \sum_{i=1}^{3} \tau^i_t$$

$$V^{s \to s}_{1mt}(k) = \frac{1}{2f} \frac{k^2}{\sqrt{12\pi^2 \omega_k}} \frac{\omega_{\mathrm{s}}}{\omega_{\mathrm{s}} - 1} \frac{j_1(kR_{\mathrm{bag}})}{kR_{\mathrm{bag}}} \sum_{i=1}^{3} \sigma^i_m \tau^i_t$$

Constructing the K-matrix

Aim: include many-body states of quarks in the scattering formalism (Chew-Low type approach)

Construct K-matrix in the spin-isospin (JI) basis:

dressed states

$$K^{JI}_{M'B'\,MB} = -\pi \sqrt{\frac{\omega_M E_B}{k_M W}}\ \langle \Psi^{MB}_{JI}(W) || V_{M'}(k) || \Psi_{B'} \rangle$$

by using principal-value (PV) states

$$|\Psi^{MB}_{JI}(W)\rangle = \sqrt{\frac{\omega_M E_B}{k_M W}} \left\{ \left[a^\dagger(k_M) |\Psi_B\rangle \right]^{JI} - \frac{\mathcal{P}}{H - W} \left[V(k_M) |\Psi_B\rangle \right]^{JI} \right\}$$

normalized as

$$\langle \Psi^{MB}(W) | \Psi^{M'B'}(W') \rangle = \delta(W - W') \delta_{MB,M'B'} (1 + \mathbf{K}^2)_{MB,MB}$$

Ansatz for the channel PV states

$$|\Psi_{JI}^{MB}\rangle = \sqrt{\frac{\omega_M E_B}{k_M W}} \Big\{ [a^\dagger(k_M)|\Psi_B\rangle]^{JI}$$

free meson (defines the channel)

$$+ \sum_{\mathcal{R}} c_{\mathcal{R}}^{MB} |\Phi_{\mathcal{R}}\rangle$$

bare (genuine) baryons (3q)

$$+ \sum_{M'B'} \int \frac{\mathrm{d}k\, \chi^{M'B'MB}(k,k_M)}{\omega_k + E_{B'}(k) - W} [a^\dagger(k)|\Psi_{B'}\rangle]^{JI} \Big\}$$

meson "clouds" with amplitudes χ

Above the meson-baryon (MB) threshold:

$$K_{M'B'\,MB}(k,k_M) = \pi \sqrt{\frac{\omega_M E_B}{k_M W}} \sqrt{\frac{\omega_{M'} E_{B'}}{k_{M'} W}}\, \chi^{M'B'\,MB}(k,k_M)$$

2π decay through intermediate hadrons ($\Delta(1232)$, $N(1440)$; σ, ρ, ...)

Equations for meson amplitudes (Lippmann-Schwinger)

$$\chi^{M'B'\,MB}(k,k_M) = -\sum_{\mathcal{R}} c_{\mathcal{R}}^{MB}\, V_{B'\mathcal{R}}^{M'}(k) + \mathcal{K}^{M'B'\,MB}(k,k_M) + \sum_{M''B''}\int \mathrm{d}k'\, \frac{\mathcal{K}^{M'B'\,M''B''}(k,k')\chi^{M''B''\,MB}(k',k_M)}{\omega_k' + E_{B''}(k') - W}$$

with kernels

$$\mathcal{K}^{M'B'\,MB}(k,k') = \sum_{B''} f_{BB'}^{B''}\, \frac{\mathcal{V}_{B''B'}^{M'}(k')\,\mathcal{V}_{B''B}^{M}(k)}{\omega_k + \omega_k' + E_{B''}(\bar{k}) - W}$$

($f_{BB'}^{B''}$ are spin-isospin coefficients)

The solution assumes the form

$$\chi^{M'B'MB}(k,k_M) = -\sum_{\mathcal{R}} c_{\mathcal{R}}^{MB}\, \mathcal{V}_{B'\mathcal{R}}^{M'}(k) + \mathcal{D}^{M'B'MB}(k,k_M)$$

Solving the coupled equations

Dressed vertices then satisfy:

$$\mathcal{V}^{M}_{B\mathcal{R}}(k) = V^{M}_{B\mathcal{R}}(k) + \sum_{M'B'} \int \mathrm{d}k' \, \frac{\mathcal{K}^{MB\,M'B'}(k,k')\,\mathcal{V}^{M'}_{B'\mathcal{R}}(k')}{\omega'_k + E_{B'}(k') - W}$$

and similarly the background part of the amplitude:

$$\mathcal{D}^{M'B'\,MB}(k,k_M) = \mathcal{K}^{M'B'\,MB}(k,k_M) + \sum_{M''B''} \int \mathrm{d}k' \, \frac{\mathcal{K}^{M'B'\,M''B''}(k,k')\mathcal{D}^{M''B''\,MB}(k',k_M)}{\omega'_k + E_{B''}(k') - W}$$

The coefficients $c^{MB}_{\mathcal{R}'}$ in front of the quasi-bound states satisfy a set of equations:

$$\sum_{\mathcal{R}'} A_{\mathcal{R}\mathcal{R}'}(W)\, c^{MB}_{\mathcal{R}'}(W) = \mathcal{V}^{M}_{B\mathcal{R}}(k_M)$$

$$A_{\mathcal{R}\mathcal{R}'} = (W - M^0_{\mathcal{R}})\delta_{\mathcal{R}\mathcal{R}'} + \sum_{\mathcal{B}'} \int \mathrm{d}k \, \frac{\mathcal{V}^{M'}_{B'\mathcal{R}}(k)\, V^{M'}_{B'\mathcal{R}'}(k)}{\omega_k + E_{B'}(k) - W}$$

Mixing of bare resonances

To solve the set of equations, diagonalize A to obtain U, along with the poles of the K matrix, and wave-function normalization Z:

$$UAU^T = \begin{bmatrix} Z_{\mathcal{R}}(W)(W - M_{\mathcal{R}}) & 0 & 0 \\ 0 & Z_{\mathcal{R}'}(W)(W - M_{\mathcal{R}'}) & 0 \\ 0 & 0 & Z_{\mathcal{R}''}(W)(W - M_{\mathcal{R}''}) \end{bmatrix}$$

As a consequence, $\Phi_{\mathcal{R}}$ mix:

$$|\widetilde{\Phi}_{\mathcal{R}}\rangle = \sum_{\mathcal{R}'} U_{\mathcal{R}\mathcal{R}'} |\Phi_{\mathcal{R}}\rangle \qquad \widetilde{\mathcal{V}}_{B\mathcal{R}} = \frac{1}{\sqrt{Z_{\mathcal{R}}(W)}} \sum_{\mathcal{R}'} U_{\mathcal{R}\mathcal{R}'} \mathcal{V}_{B\mathcal{R}'}$$

Solution for the K matrix

$$K_{MB,M'B'} = \pi \sqrt{\frac{\omega_M E_B}{k_M W}} \sqrt{\frac{\omega_{M'} E_{B'}}{k_{M'} W}} \left[\sum_{\mathcal{R}} \frac{\widetilde{\mathcal{V}}^M_{B\mathcal{R}} \widetilde{\mathcal{V}}^{M'}_{B'\mathcal{R}}}{(M_{\mathcal{R}} - W)} + \mathcal{D}_{MB,M'B'} \right]$$

and for the T matrix

$$T_{MB,M'B'} = K_{MB,M'B'} + \mathrm{i} \sum_{M''K''} T_{MB,M''B''} K_{M''B'',M'B'}$$

Approximation: separable kernels

$$\frac{1}{\omega_k + \omega'_k + E_{B''} - W} \approx \frac{(\omega_M + \omega_{M'} + E_{B''} - W)}{(\omega_k + E_{B''} - E_{B'})(\omega'_k + E_{B''} - E_B)}$$

$$W = E_B + \omega_M = E_{B'} + \omega_{M'}$$

The approximation has the property:

$$\mathcal{K}^{M'B'\,MB}(k, k_{M'})^{\text{approx}} = \mathcal{K}^{M'B'\,MB}(k, k_{M'})^{\text{exact}}$$

and preserves the symmetry of the K-matrix: $K_{MB,M'B'} = K_{M'B',MB}$ and, as a consequence, the unitarity of the S-matrix.

Further simplification; for $\mathcal{V}_{BB'}$ entering the kernel $\mathcal{K}^{M'B'\,MB}(k, k_M)$:

$$\mathcal{V}^M_{BB'}(\text{dressed}) = r^M_{BB'}\, V^M_{BB'}(\text{bare}) \qquad r^M_{BB'} = \text{const}$$

e.g. $r^{l=1\,\text{pions}}_{N\Delta} = 1.3$, as determined by solving the coupled equations in the $P33$ partial wave. Most $r^M_{BB'} = 1$.

Including the γN channel

Only the strong $T_{MB,M'B'}$ appears on the RHS:

$$T_{MB,\gamma N} = K_{MB,\gamma N} + \mathrm{i} \sum_{M'K'} T_{MB,M'B'} K_{M'B',\gamma N}$$

$$K_{M'B',\gamma N} = -\pi \sqrt{\frac{\omega_\gamma E_N}{k_\gamma W}} \langle \Psi_{JI}^{M'B'} || V_\gamma || \Psi_N \rangle$$

Choosing a resonance, $\mathcal{R} = N^*$, the principal-value state can be split into the resonant and background parts:

$$|\Psi_{JI}^{MB}\rangle = \sqrt{\frac{\omega_M E_B}{k_M W}} \Big\{ \widetilde{c}_{\mathcal{N}^*}^{MB} |\widetilde{\Phi}_{\mathcal{N}^*}\rangle + \widetilde{c}_{\mathcal{N}^*}^{MB} \sum_{M'B'} \int \frac{\mathrm{d}k \quad \widetilde{\mathcal{V}}^{M'}{}_{B'\mathcal{N}^*}}{\omega_k + E_{B'} - W} [a^\dagger(k) |\widetilde{\Psi}_{B'}\rangle]^{JI}$$

$$+ [a^\dagger(k_M) |\widetilde{\Psi}_B\rangle]^{JI} + \sum_{\mathcal{R} \neq N^*} \widetilde{c}_{\mathcal{R}}^{MB} |\widetilde{\Phi}_{\mathcal{R}}\rangle + \cdots \Big\}$$

$$= -K_{MB\,M'B'} \sqrt{\frac{k_M W}{\pi^2 \omega_M E_B}} \frac{1}{\widetilde{\mathcal{V}}^{M'}_{B'\mathcal{N}^*}} |\widehat{\Psi}^{\mathrm{res}}_{\mathcal{N}^*}\rangle + |\Psi_{JI}^{MB\,(\mathrm{bkg})}\rangle$$

Note $\widetilde{c}_{\mathcal{N}^*}^{MB} = \frac{\widetilde{\mathcal{V}}^{M}_{B\mathcal{N}^*}}{W - M_{N^*}}$ and $\sqrt{\frac{\pi \omega_\gamma E_N}{k_\gamma W}} \, \widetilde{\mathcal{V}}^{M}_{B\mathcal{N}^*} = \sqrt{\Gamma_{B\mathcal{N}^*}}$

Evaluation of the amplitudes

The resonant part of the amplitude can then be written as:

$$\mathcal{M}^{(\mathrm{res})}_{MB\,\gamma N} = \sqrt{\frac{\omega_\gamma E_N^\gamma}{\omega_M E_B}}\,\frac{1}{\pi \mathcal{V}_{BN^*}}\,\underbrace{\langle \Psi^{(\mathrm{res})}_{N^*}(W)|\tilde{V}_\gamma|\Psi_N\rangle}_{A_{N^*}}\,T_{MB\,MB}$$

while the resonance pole is absent in the eq. for the background part:

$$\mathcal{M}^{(\mathrm{bkg})}_{MB\,\gamma N} = \mathcal{M}^{K\,(\mathrm{bkg})}_{MB\,\gamma N} + \mathrm{i}\sum_{M'B'} T_{MB\,M'B'}\,\mathcal{M}^{K\,(\mathrm{bkg})}_{M'B'\,\gamma N}$$

The **helicity amplitude** A_{N*} for electro-excitation:

$$A_{N^*} \equiv \langle \Psi^{(\mathrm{res})}_{N^*}(W)|\tilde{V}_\gamma|\Psi_N\rangle$$

The resonant state takes the form:

$$|\Psi^{(\mathrm{res})}_{N^*}(W)\rangle = \frac{1}{\sqrt{Z_{N^*}}}\left\{|\widetilde{\Phi}_{N^*}\rangle - \sum_{MB}\int \frac{\mathrm{d}k \quad \widetilde{\mathcal{V}}^M_{BN^*}(k)}{\omega_k + E_B - W}\,[a^\dagger(k)|\Psi_B\rangle]^{JI}\right\}$$

Cloudy Bag Model

Provides a consistent parametrization of the baryon-meson and baryon-photon coupling constants and form factors in terms of "f_π" and the bag radius R_{bag}.

From the ground state calculation: $R_{\mathrm{bag}} = 0.83$ fm, $f_\pi = 76$ MeV (reproducing the experimental value of $g_{\pi NN}$)

similar results for $0.75\ \mathrm{fm} < R_{\mathrm{bag}} < 1.0\ \mathrm{fm}$

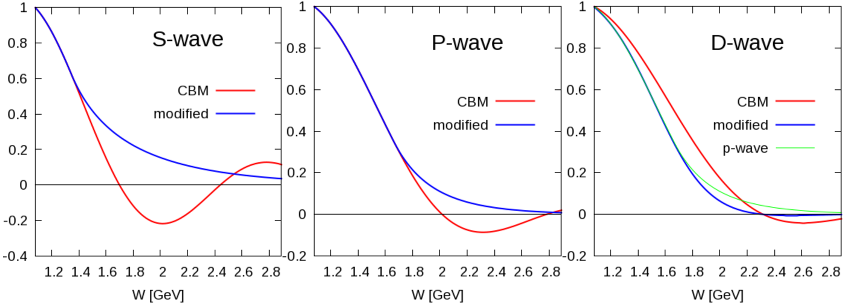
Free parameters: bare masses of the resonances

Form factors of S-, P- and D-wave mesons-quark interaction

Determined by the bag radius $R_{\text{bag}} = 0.83$ fm

Equivalent dipole momentum cut-off:

$\Lambda_S = 510$ MeV/c, $\Lambda_P = 550$ MeV/c, $\Lambda_D = 550$ MeV/c



π-quark vertex: S, P, and D-wave pions

$$V^{\pi}_{l=0,t}(k) = \frac{1}{2f_\pi}\sqrt{\frac{\omega_{p_{1/2}}\omega_s}{(\omega_{p_{1/2}}+1)(\omega_s-1)}}\,\frac{1}{2\pi}\,\frac{k^2}{\sqrt{\omega_k}}\,\frac{j_0(kR)}{kR}\sum_{i=1}^{3}\tau_t(i)\,\mathcal{P}_{sp}(i)$$

$$V^{\pi}_{1mt}(k) = \frac{1}{2f_\pi}\,\frac{\omega_s}{(\omega_s-1)}\,\frac{1}{2\pi}\,\frac{1}{\sqrt{3}}\,\frac{k^2}{\sqrt{\omega_k}}\,\frac{j_1(kR)}{kR}\sum_{i=1}^{3}\tau_t(i)$$
$$\times\left(\sigma_m(i) + \frac{\omega_{p_{1/2}}(\omega_s-1)}{\omega_s(\omega_{p_{1/2}}+1)}\,S^{[\frac{1}{2}]}_{1m}(i) + \frac{2\omega_{p_{3/2}}(\omega_s-1)}{5\omega_s(\omega_{p_{3/2}}-2)}\,S^{[\frac{3}{2}]}_{1m}(i)\right)$$

$$V^{\pi}_{2mt}(k) = \frac{1}{2f_\pi}\sqrt{\frac{\omega_{p_{3/2}}\omega_s}{(\omega_{p_{3/2}}-2)(\omega_s-1)}}\,\frac{\sqrt{2}}{2\pi}\,\frac{k^2}{\sqrt{\omega_k}}\,\frac{j_2(kR)}{kR}\sum_{i=1}^{3}\tau_t(i)\,\Sigma^{[\frac{1}{2}\,\frac{3}{2}]}_{2m}(i)$$

$$\mathcal{P}_{sp} = \sum_{m_j}|sm_j\rangle\langle p_{1/2}m_j| \quad S^{[\frac{3}{2}]}_{1m} = \frac{\sqrt{15}}{2}\sum_{m_jm_j'}C^{\frac{3}{2}m_j}_{\frac{3}{2}m_j'1m}|p_{3/2}m_j\rangle\langle p_{3/2}m_j'|$$

$$S^{[\frac{1}{2}]}_{1m} = \sqrt{3}\sum_{m_jm_j'}C^{\frac{1}{2}m_j}_{\frac{1}{2}m_j'1m}|p_{1/2}m_j\rangle\langle p_{1/2}m_j'| \quad \Sigma^{[\frac{1}{2}\,\frac{3}{2}]}_{2m} = \sum_{m_sm_j}C^{\frac{1}{2}m_s}_{\frac{3}{2}m_j2m}|sm_s\rangle\langle p_{3/2}m_j|$$

η-quark and K-quark vertex (S-wave)

$$V^{\eta}(k) = \frac{1}{2f_\eta}\sqrt{\frac{\omega_{p_{1/2}}\omega_s}{(\omega_{p_{1/2}}+1)(\omega_s-1)}}\,\frac{1}{2\pi}\,\frac{k^2}{\sqrt{\omega_k}}\,\frac{j_0(kR)}{kR}\sum_{i=1}^{3}\lambda_8(i)\,\mathcal{P}_{sp}(i)$$

$$V_t^{K}(k) = \frac{1}{2f_K}\sqrt{\frac{\omega_{p_{1/2}}\omega_s}{(\omega_{p_{1/2}}+1)(\omega_s-1)}}\,\frac{1}{2\pi}\,\frac{k^2}{\sqrt{\omega_k}}\,\frac{j_0(kR)}{kR} \times \sum_{i=1}^{3}(V_t(i)+U_t(i))\,\mathcal{P}_{sp}(i)$$

$$t = \pm\tfrac{1}{2},\; V_{\pm t} = (\lambda_4 \pm \mathrm{i}\lambda_5)/\sqrt{2}\;\; U_{\pm t} = (\lambda_6 \pm \mathrm{i}\lambda_7)/\sqrt{2}$$

$f_\eta = f_\pi$ or $f_\eta = 1.2 f_\pi$

$f_K = 1.20 f_\pi$.

ρ-quark vertex ($S=\frac{1}{2}$, S-wave and $S=\frac{3}{2}$, D-wave)

$$V^{\rho}_{l=0mt}(k) = \frac{1}{2f_\rho}\sqrt{\frac{\omega_s}{(\omega_s-1)}}\,\frac{1}{2\pi}\,\frac{k^2}{\sqrt{\omega_k}}\,\frac{j_0(kR)}{kR}\sum_i \tau_t(i)$$
$$\times\left(\frac{\sqrt{8}}{3}\sqrt{\frac{\omega_{p_{1/2}}}{\omega_{p_{1/2}}+1}}\,\Sigma^{[\frac{1}{2}]}_{1m} + 3\sqrt{\frac{\omega_{p_{3/2}}}{\omega_{p_{3/2}}-2}}\,\Sigma^{[\frac{1}{2}\,\frac{3}{2}]}_{1m}(i)\right)$$
$$V^{\rho}_{l=2mt}(k) = \frac{1}{2f_\rho}\sqrt{\frac{\omega_{p_{3/2}}\omega_s}{(\omega_{p_{3/2}}-2)(\omega_s-1)}}\,\frac{1}{2\pi}\,\frac{1}{3}\,\frac{k^2}{\sqrt{\omega_k}}\,\frac{j_2(kR)}{kR}\sum_{i=1}^{3}\tau_t(i)\Sigma^{[\frac{1}{2}\,\frac{3}{2}]}_{1m}(i)$$

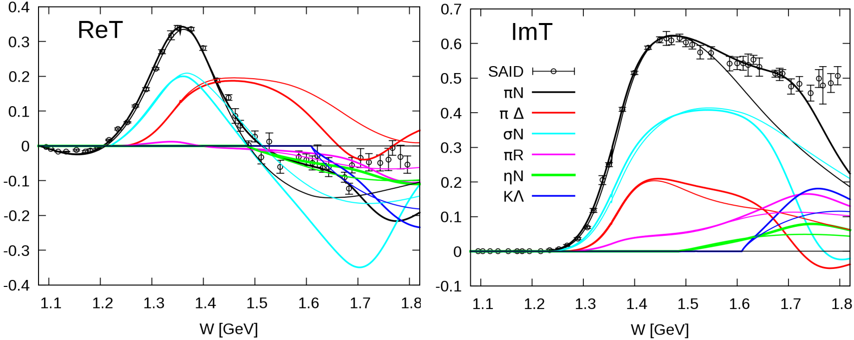
$f_\rho = 200$ MeV

$$\Sigma^{[\frac{1}{2}]}_{1m} = \sum_{m_s m_j} C^{\frac{1}{2}m_s}_{\frac{1}{2}m_j 1m}|sm_s\rangle\langle p_{1/2}m_j| \quad \Sigma^{[\frac{1}{2}\,\frac{3}{2}]}_{1m} = \sum_{m_s m_j} C^{\frac{1}{2}m_s}_{\frac{3}{2}m_j 1m}|sm_s\rangle\langle p_{3/2}m_j|$$

P11 $\pi N \to MB$

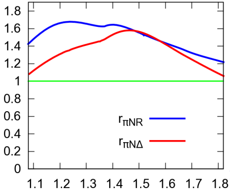
Channels: πN, $\pi\Delta$, σN, MπR (preliminary: ηN, $K\Lambda$)

Parameters of the σN-channel: $g_{\sigma NR} = 1\,, \quad m_\sigma = 450\text{ MeV}\,, \quad \Gamma_\sigma = 550\text{ MeV}$

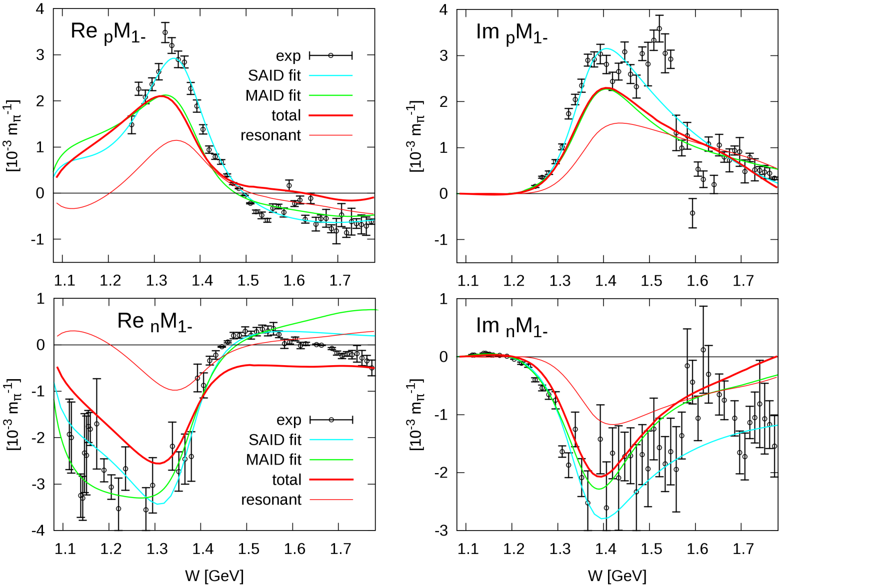


Thin lines: only $N(1440$ included $((1s)^2(2s)^1)$

Thick lines: $N(1710)$ added $((1s)^1(2p)^2)$ with $g_{\pi NN(1710)} = 0$ and $g_{\sigma NN(1710)} \approx g_{\sigma NN(1440)}$

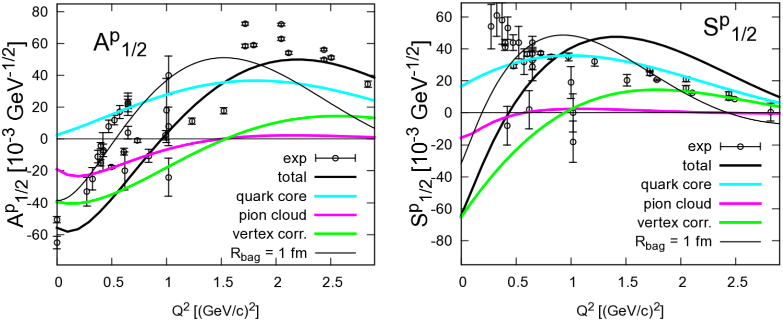


P11 photoproduction ($\gamma p \to \pi N$, $\gamma n \to \pi N$)



P11 helicity amplitudes

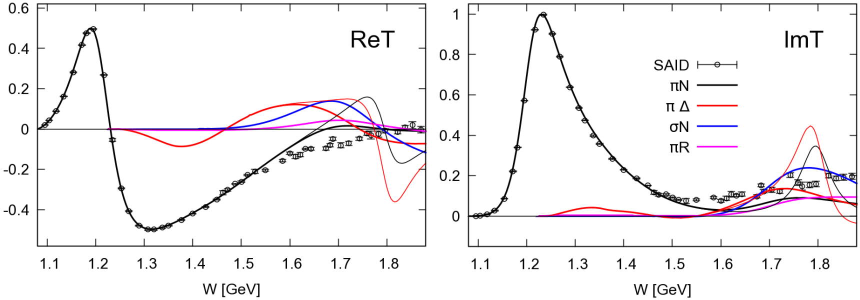
Meson-cloud effects dominates the behaviour of the amplitudes at low Q^2



P33 $\pi N \to MB$

Channels: πN, $\pi\Delta$, πR, $\sigma\Delta$, $\qquad g_{\pi N\Delta} = 1.05\, g_{\pi N\Delta}(CBM)$

Resonances: $\Delta(1232)$, $\Delta(1600)$ at K-matrix pole $M_R = 1780$ MeV.



Thin lines: only πN and $\pi\Delta$ channels included

Thick lines: πR, $\sigma\Delta$ channels added

Assuming $(1s)^1(2p)^2$ configuration for the $N(1720)$P13 and $\Delta(1910)$P31 resonances and keeping the same $R_{\rm bag}$: $g_{\pi NN^*} = 0$.

S11 resonances

Single-quark excitations $1s \to 1p_{1/2}$ and $1s \to 1p_{1/3}$

$$\Phi(1535) = -\sin\vartheta_s|^4\mathbf{8}_{1/2}\rangle + \cos\vartheta_s|^2\mathbf{8}_{1/2}\rangle$$
$$= c_A^1|(1s)^2(1p_{3/2})^1\rangle + c_P^1|(1s)^2(1p_{1/2})^1\rangle_1 + c_{P'}^1|(1s)^2(1p_{1/2})^1\rangle_2$$

$$\Phi(1650) = \cos\vartheta_s|^4\mathbf{8}_{1/2}\rangle + \sin\vartheta_s|^2\mathbf{8}_{1/2}\rangle$$
$$= c_A^2|(1s)^2(1p_{3/2})^1\rangle + c_P^2|(1s)^2(1p_{1/2})^1\rangle_1 + c_{P'}^2|(1s)^2(1p_{1/2})^1\rangle_2$$

$$c_A^1 = \tfrac{1}{3}(2\cos\vartheta_s - \sin\vartheta_s)\,, \qquad c_A^2 = \tfrac{1}{3}(\cos\vartheta_s + 2\sin\vartheta_s)\,, \qquad \vartheta_s \approx -30^\circ$$

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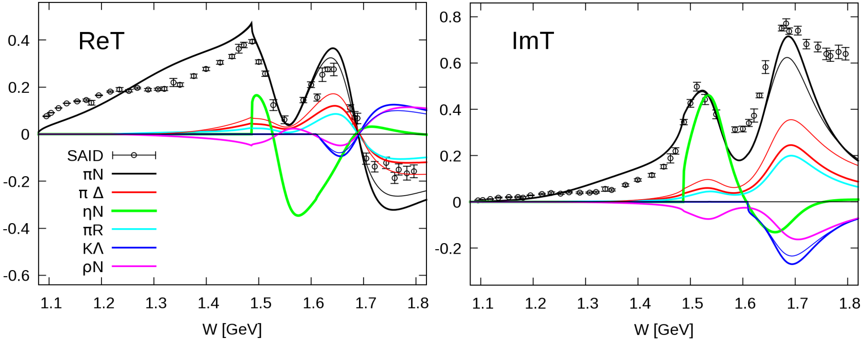
ϑ_s is a free parameter in the calculation

S11 $(N\frac{1}{2}^-(1535)$ and $N\frac{1}{2}^-(1650))$ $\pi N \to MB$



Modified QM:

$$g_{M\Delta N^*} = 0.5\, g_{M\Delta N^*}{}^{\mathrm{CBM}}$$

S11 resonances

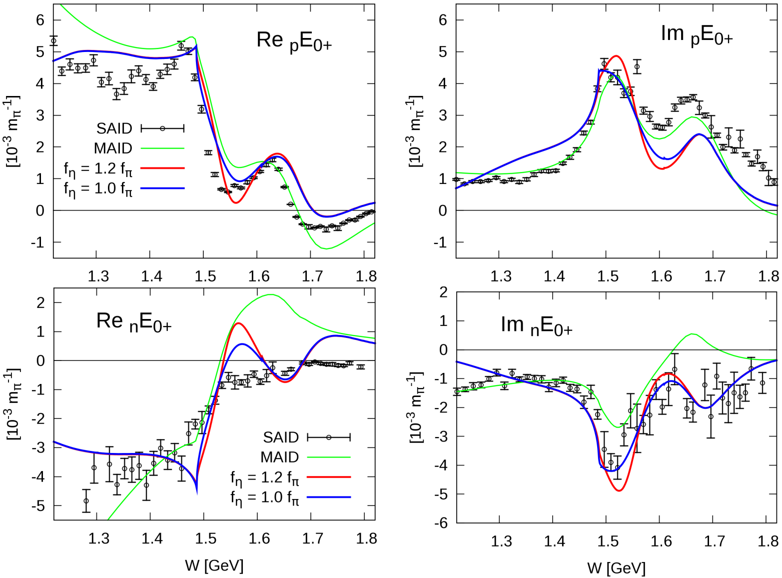
$N\frac{1}{2}^{-}(1535)$

	Γ_{tot}	Γ_i/Γ_{tot}					
	[MeV]	πN	ηN	$\pi\Delta$ D-wave	$\rho_1 N$ S-wave	πR	$K\Lambda$
Quark Model	95	0.43	0.54	0.02	0.01	0	0
Modified QM	94	0.43	0.54	0.01	0.01	0	0
PDG	125 -175	0.35 - 0.35	0.529 $\pm$0.02	0.01 $\pm$0.01	0.02 $\pm$0.01	0.08 $\pm$0.02	

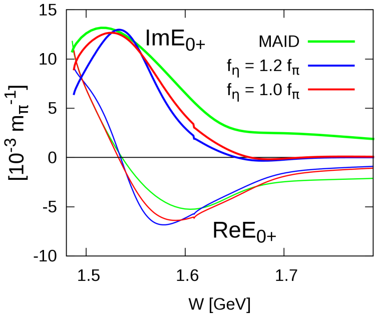
$N\frac{1}{2}^{-}(1650)$

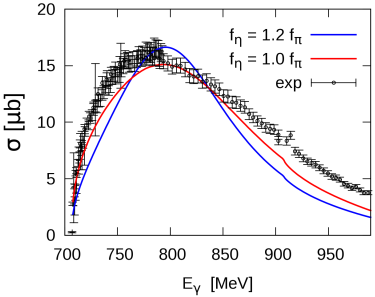
	Γ_{tot}	Γ_i/Γ_{tot}					
	[MeV]	πN	ηN	$\pi\Delta$ D-wave	$\rho_1 N$ S-wave	πR	$K\Lambda$
Quark M.	134	0.63	0.01	0.19	0.03	0.05	0.09
Modified	122	0.72	0.01	0.08	0.03	0.05	0.10
PDG	145 -185	0.60 - 0.95	0.023 $\pm$0.022	0.02 $\pm$0.01	0.01 $\pm$0.01	0.03 $\pm$0.01	0.029 $\pm$0.004

S11 photoproduction ($\gamma p \to \pi N$, $\gamma n \to \pi N$)

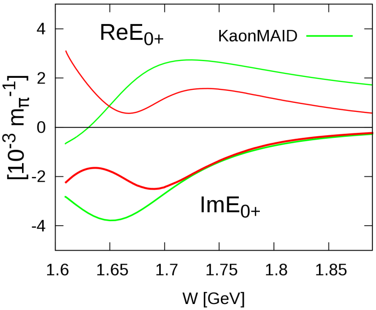


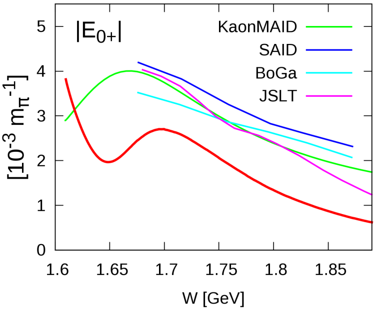
S11 $\gamma p \to \eta N$



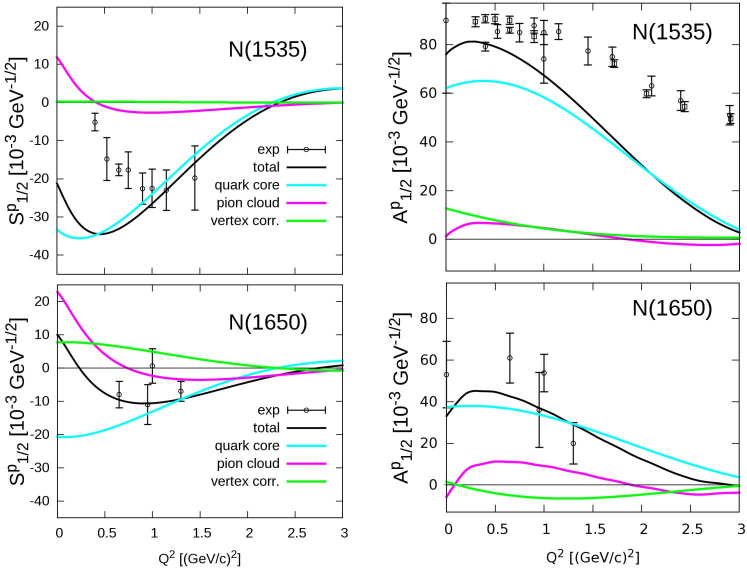


S11 $\gamma p \to K^+ \Lambda$

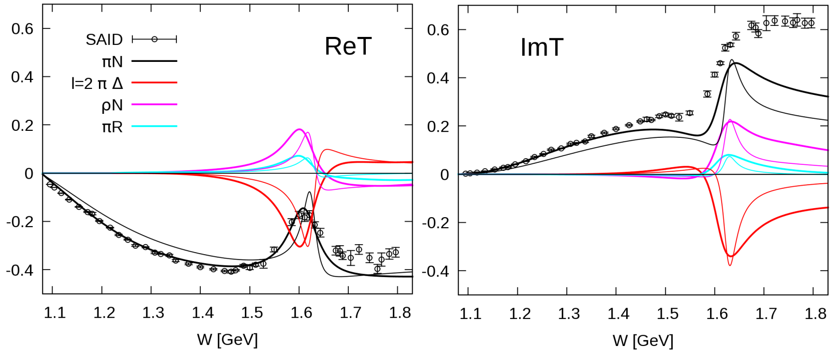




S11 helicity amplitudes



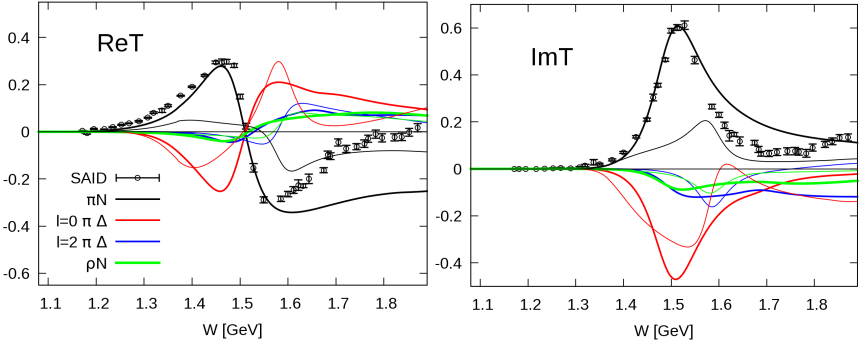
S31 $(\Delta\frac{1}{2}^-(1620))$ $\pi N \to MB$



Modified QM: $g_{MBN^*} = 2\, g_{MBN^*}{}^{\rm CBM}, \ \ K_{\rm background} = 1.2\, K_{\rm background}{}^{\rm CBM}$

	$\Gamma_{\rm tot}$	$\Gamma_i/\Gamma_{\rm tot}$			
	[MeV]	πN	$\pi\Delta$ D-wave	$\rho_1 N$ S-wave	πR
Quark Model	35	0.41	0.43	0.15	0.02
Modified QM	97	0.36	0.44	0.17	0.02
PDG	135-150	0.2 - 0.3	0.39±0.02	0.14±0.03	0.00±0.01

D13 ($N\frac{3}{2}^-(1520)$ and $N\frac{3}{2}^-(1700)$) $\pi N \to MB$



Quark model: no mixing of resonances

Modified QM: $g_{MNN^*} = 1.8\, g_{MNN^*}{}^{\rm CBM}$

S-wave: $g_{M\Delta N^*} = 0.37\, g_{MNN^*}{}^{\rm CBM}$, D-wave: $g_{M\Delta N^*} = 1.8\, g_{MNN^*}{}^{\rm CBM}$

K-matrix pole $M_{N^*} = 1650$ MeV

D13 resonance

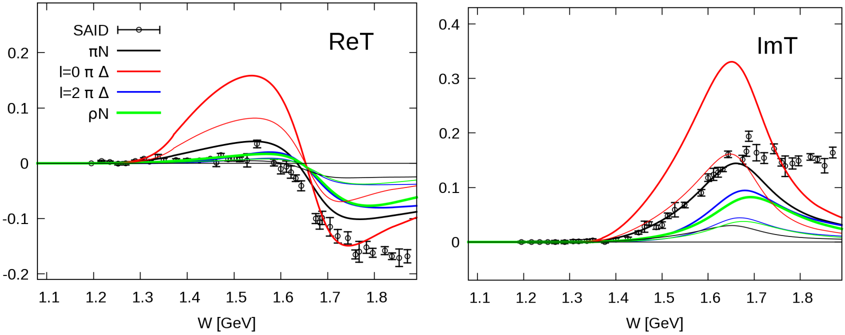
$N\frac{3}{2}^{-}(1520)$

	Γ_{tot} [MeV]	$\Gamma_i/\Gamma_{\text{tot}}$			
		πN	$\pi\Delta$ S-wave	$\pi\Delta$ D-wave	$\rho_1 N$ S-wave
Quark Model	169	0.16	0.81	0.01	0.01
Modified QM	130	0.60	0.33	0.01	0.01
PDG	100-125	0.55 - 0.65	0.15 ± 0.02	0.11 ± 0.02	0.09 ± 0.01

$N\frac{3}{2}^{-}(1700)$

	Γ_{tot} [MeV]	$\Gamma_i/\Gamma_{\text{tot}}$			
		πN	$\pi\Delta$ S-wave	$\pi\Delta$ D-wave	$\rho_1 N$ S-wave
Quark Model	557	0.01	0.94	0.05	0.00
Modified QM	134	0.00	0.33	0.63	0.03
PDG	50-150	0.05 - 0.15	0.11 ± 0.01	0.79 ± 0.01	0.07 ± 0.01

D33 $(\Delta\frac{3}{2}^-(1700))$ $\quad \pi N \rightarrow M B$



Modified QM: $g_{MNN^*} = 2.5\, g_{MNN^*}{}^{\mathrm{CBM}}$, K-matrix pole $M_{N^*} = 1650$ MeV

	Γ_{tot}	$\Gamma_i/\Gamma_{\mathrm{tot}}$			
	[MeV]	πN	$\pi\Delta$ S-wave	$\pi\Delta$ D-wave	$\rho_1 N$ S-wave
Quark Model	199	0.03	0.88	0.06	0.04
Modified QM	232	0.14	0.78	0.05	0.03
PDG	200-400	0.1 - 0.2	0.90±0.02	0.04±0.01	0.01±0.01

Summary

- Using the **same set of parameters** in all considered partial waves we have been able to **reproduce the main features** of π- and γ-induced production of pions, η mesons, and kaons.
- The role of the **meson cloud** turns out to be important in two aspects: it **enhances** the bare baryon-meson **couplings** and improves the behaviour of the helicity amplitudes in the region of **low** Q^2.
- The enhancement turns out to be **stronger in** the case of the **P11** and **P33** resonances **than** in the case of the **S11** resonances which are dominated by the contribution from the quark core.
- The couplings of the resonances to different inelastic channels are reasonably **well reproduced**, particularly in the ηN **channel**, but – probably – **overestimated** in the case of the σN and $K\Lambda$ channels.
- The coupling of **D-wave mesons** is not well described: the strength is too **weak at small** and too **strong at large momentum** transfer; similarly strength of the S-wave $\pi\Delta$ channel is overestimated.