Pion-Dressing Effects *in* N *and* Δ *Masses and Strong Form Factors*

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Content

- Relativistic (Hamiltonian) theory & constituent-quark model
- Reminder of baryon spectroscopy produced by the relativistic constituent-quark model (RCQM)
- Examples of N electromagnetic form factors from the RCQM
- Failures of the RCQM for baryon resonances (strong decays)
- Framework of a relativistic coupled-channels (CC) theory
- Application to πNN and $\pi N\Delta$ systems (on hadronic level)
- Construction of a CC RCQM with $\{QQQ\pi\}$ d.o.f.
- Microscopic πNN and $\pi N\Delta$ vertex form factors containing explicit π's
- Consistent π dressing of N and Δ within the CC RCQM
- Summary and outlook

Invariant $\{QQQ\}$ Quark-Model Mass Operator

$$\widehat{M}\,|P,J,\Sigma,F_{abc}\rangle = M\,|P,J,\Sigma,F_{abc}\rangle = M\,|M,V,J,\Sigma,F_{abc}\rangle$$

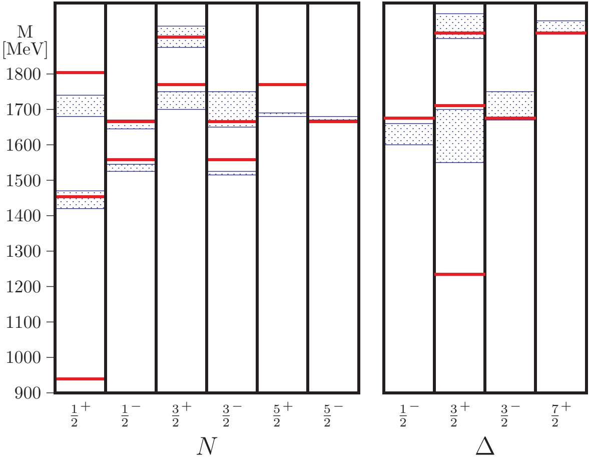
P	.....	four-momentum eigenvalues
$(M\,,V$	.....	mass resp. velocity eigenvalues)
J,Σ	.....	intrinsic spin $\widehat{=}$ total angular momentum, with z-component Σ
F_{abc}	.....	flavor content

$$\widehat{M} = \widehat{M}_{free} + \widehat{M}_{int} = \sqrt{\widehat{H}^2_{free} - \widehat{\vec{P}}^2_{free}} + \sum_{i<j}^{3} \widehat{V}_{ij}$$

$$\widehat{M}^{rest\ frame}_{int} = \sum_{i<j}^{3}[\widehat{V}^{conf}_{ij} + \widehat{V}^{hf}_{ij}] = \sum_{i<j}^{3}[\widehat{V}^{conf}_{ij} + \widehat{V}^{GBE}_{ij}]$$

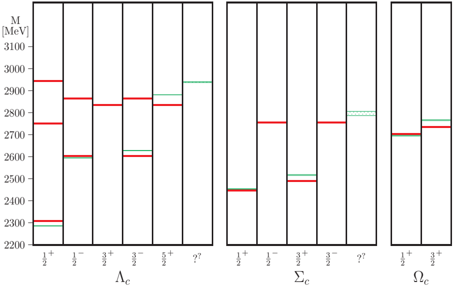
$\widehat{M}$ is fulfilling the Poincaré algebra.

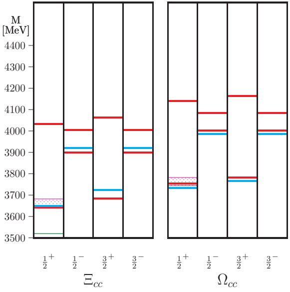
N and Δ Spectroscopy from $\{QQQ\}$ RCQM



J.P. Day, K.-S. Choi, and W. Plessas: Few-Body Syst. 54 (2013) 329

Charm Baryon Spectra





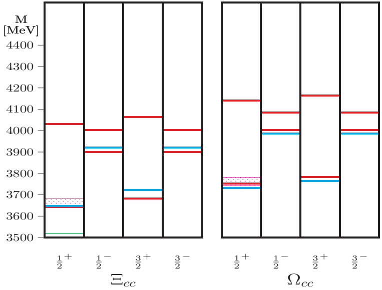
Left panel – single charm:

red	Universal GBE RCQM prediction
green	Experiment – PDG

Right panel – double charm:

red	Universal GBE RCQM prediction
green	SELEX experiment (2002)
cyan	Bonn RCQM
magenta	Lattice QCD

DOUBLE-CHARM BARYON SPECTRA

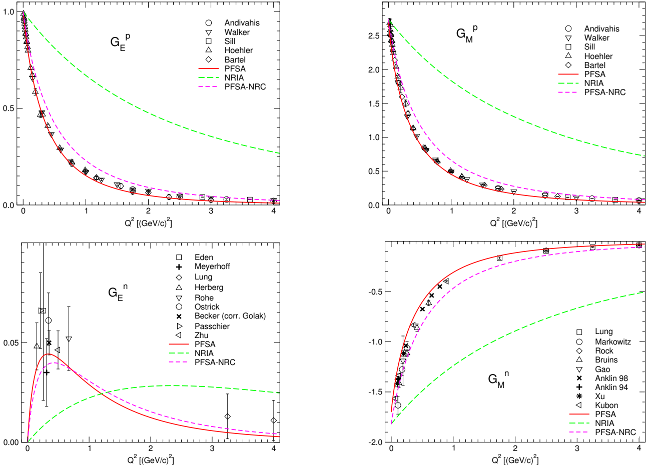


red	Universal GBE RCQM prediction
green	M. Mattson et al.: Phys. Rev. Lett. 89 (2002) 112001 (SELEX experiment)
cyan	S. Migura, D. Merten, B. Metsch, and H.-R. Petry: Eur. Phys. J. A 28 (2006) 41 (Bonn RCQM)
magenta	L. Liu et al.: Phys. Rev. D 81 (2010) 094505 (Lattice QCD)

Universal GBE RCQM: $M(\Xi_{cc}) = 3673$ MeV

LHCb (2017): $M(\Xi_{cc}^{++}) = 3621.40 \pm 0.72(\text{stat}) \pm 0.27(\text{syst}) \pm 0.14(\Lambda_c^+)$ MeV

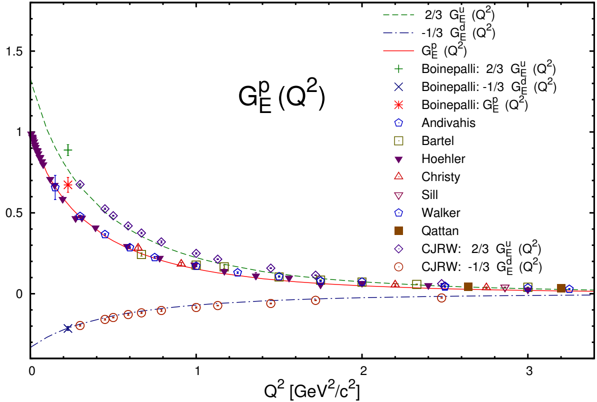
Covariant N Elastic E.M. Form Factors



R.F. Wagenbrunn, S. Boffi, W. Klink, W. Plessas, and M. Radici: Phys. Lett. B511 (2001) 33

Flavor Composition of Proton Electric FF

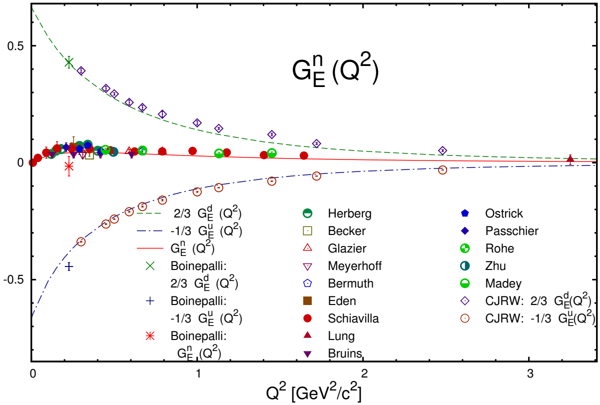
$$G_E^p = \frac{2}{3} G_E^u - \frac{1}{3} G_E^d$$



M. Rohrmoser, Ki-Seok Choi, and W. Plessas: Few-Body Syst. 58 (2017) 83

Flavor Composition of Neutron Electric FF

$$G_E^n = \frac{2}{3} G_E^d - \frac{1}{3} G_E^u$$



M. Rohrmoser, Ki-Seok Choi, and W. Plessas: Few-Body Syst. 58 (2017) 83

Relativistic Results for Pion Decay Widths

	Decay	Experiment (MeV)	Relativistic GBE (MeV)	Relativistic OGE (MeV)
$\Delta(1232)$	$\to N\pi$	$(119 \pm 1)^{+5}_{-5}$	35	31
$N(1440)$	$\to N\pi$	$(195 \pm 30)^{+113}_{-55}$	30	59
$\Lambda(1600)$	$\to \Sigma\pi$	$(53 \pm 38)^{+60}_{-10}$	3	33
$\Sigma(1660)$	$\to \Sigma\pi$	$\Gamma_{tot} = 40 - 200$	10	24
$\Sigma(1660)$	$\to \Lambda\pi$	$\Gamma_{tot} = 40 - 200$	8	5
$\Xi(1690)$	$\to \Xi\pi$	$\Gamma_{tot} < 30$	0.8	1.8

T. Melde, W. Plessas, R. Wagenbrunn: Phys. Rev. C 72 (2005) 015207; ibid. 74 (2006) 069901

T. Melde, W. Plessas, B. Sengl: Phys. Rev. C 76 (2007) 025204

Similar characteristics obtained for η and K decays

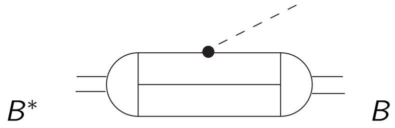
T. Melde, W. Plessas, B. Sengl: Phys. Rev. D 77 (2008) 114002

Resonance Description

- Challenge in Quantum Chromodynamics (QCD)
- All kinds of approaches (quark models, functional approaches, lattice QCD etc.) struggle with proper description of hadron resonances
- Resonances to be described as poles in the complex plane (in the lower half-plane of the unphysical energy sheet)
- Involves complex eigenvalues/poles and non-square-integrable pole residues (Gamow-type functions)

Quark Models for Hadrons up to now

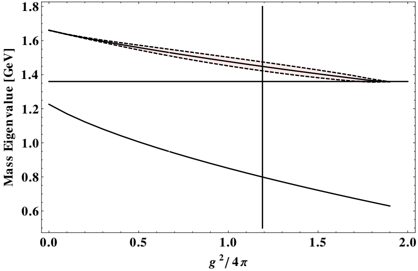
- Resonance character is not properly taken into account in existing RCQMs
- Resonances so far usually described as excited bound states
- Decays: Transition matrix element between excited bound states and (final) ground state
- Transition operator based on some assumption about the decay mechanism



- Leads generally to short-comings in decay widths

Improvements: Coupled-Channels Approach

- Relativistic coupled-channel (CC) mass operator
  - Additional meson degrees of freedom are explicitly taken into account
  - Proven: More realistic resonance decay width results for a simple scalar-meson toy model



	Mass	Width
GS	800.0 MeV	0.0 MeV
RS	1440.0 MeV	26 MeV

R. Kleinhappel, W. Schweiger, and W. Plessas: Few-Body Syst. 54 (2013) 339

Framework

Coupled-channel mass-operator eigenvalue equation
to include π or $\{Q\bar{Q}\}$ to a (bare) baryon ground/resonant state $\widetilde{B}$

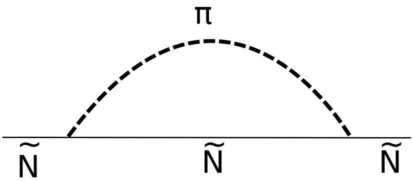
$$\begin{pmatrix} M_{\tilde{B}} & K & 0 \\ K^\dagger & M_{\tilde{B}+i} & K \\ 0 & K^\dagger & M_{\tilde{B}+j} \end{pmatrix} \begin{pmatrix} |\psi_B\rangle \\ |\psi_{B+i}\rangle \\ |\psi_{B+j}\rangle \end{pmatrix} = m \begin{pmatrix} |\psi_B\rangle \\ |\psi_{B+i}\rangle \\ |\psi_{B+j}\rangle \end{pmatrix},$$

- $M_{\tilde{B}}$ bare baryon mass operator of, e.g., $\tilde{N}$, $\tilde{\Delta}$, but also $\{QQQ\}_{\tilde{N}}$, $\{QQQ\}_{\tilde{\Delta}}$ etc.
- $M_{\tilde{B}+i}$ free mass operator of $\tilde{N}+\pi$, $\tilde{\Delta}+\pi$ channels, but also $\{QQQ\}+\pi$, $\{QQQ\}+\{Q\bar{Q}\}$ etc.
- $M_{\tilde{B}+j}$ free mass operator of $\tilde{N}+\pi+\pi$, $\tilde{\Delta}+\pi+\pi$, but also $\{QQQ\}+\pi+\pi$, $\{QQQ\}+\{Q\bar{Q}\}+\{Q\bar{Q}\}$ channels etc.
- K channel-coupling interaction
- m mass eigenvalue

Dressing

the bare nucleon $\widetilde{N}$ with π's

on the macroscopic (hadronic) level



The Nucleon with Explicit Pions

Coupled-channel mass-operator eigenvalue equation
for π-dressing of the bare nucleon $\widetilde{N}$

$$\begin{pmatrix} M_{\tilde{N}} & K \\ K^\dagger & M_{\tilde{N}+\pi} \end{pmatrix} \begin{pmatrix} |\psi_N\rangle \\ |\psi_{N+\pi}\rangle \end{pmatrix} = m \begin{pmatrix} |\psi_N\rangle \\ |\psi_{N+\pi}\rangle \end{pmatrix},$$

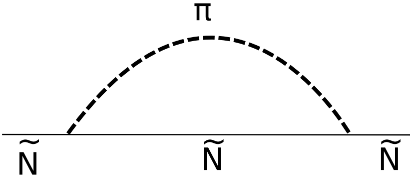
where m is now a real mass eigenvalue (of the π-dressed N).
After Feshbach elimination of the $|\psi_{N+\pi}\rangle$ channel:

$$[M_{\tilde{N}} + \underbrace{K(m - M_{\tilde{N}+\pi})^{-1}K^\dagger}_{V_{opt}}]|\psi_N\rangle = m|\psi_N\rangle.$$

It is an exact eigenvalue equation of a two-channels problem, yielding m and $|\psi_N\rangle$ of the dressed (i.e. realistic) N.

πNN Eigenvalue Equation

$$\langle \tilde{N} : v | [M_{\tilde{N}} - \underbrace{K(m - M_{\tilde{N}+\pi})^{-1} K^{\dagger}}] | \psi_N \rangle = m \langle \tilde{N} : v' | \psi_N \rangle$$



Transition interaction K $\sim$ pseudovector Lagrangian density

$$\mathcal{L}^{PV}_{\pi \tilde{N} \tilde{N}}(x) = -\frac{f_{\pi \tilde{N} \tilde{N}}}{m_\pi} \bar{\psi}(x) \gamma^\mu \gamma_5 \vec{\tau} \psi(x) \cdot \partial_\mu \vec{\phi}(x)$$

πNN Eigenvalue Equation ctd.

$$\Bigg[m_{\tilde{N}} + \int \frac{d^3 k_\pi}{(2\pi)^3} \frac{1}{2\omega_\pi 2\omega_{\tilde{N}} 2m_{\tilde{N}}} \mathcal{F}_{\pi\tilde{N}\tilde{N}}(\vec{k}_\pi^2) \langle \tilde{N} | \mathcal{L}_{\pi\tilde{N}\tilde{N}}(0) | \tilde{N}, \pi : v, \vec{k}_\pi \rangle \times \left(m - \sqrt{m_{\tilde{N}}^2 + \vec{k}_\pi^2} - \sqrt{m_\pi^2 + \vec{k}_\pi^2} \right)^{-1} \times \mathcal{F}^*_{\pi\tilde{N}\tilde{N}}(\vec{k}_\pi^2) \left\langle \tilde{N}, \pi : v, \vec{k}_\pi | \mathcal{L}^\dagger_{\pi\tilde{N}\tilde{N}}(0) | \tilde{N} \right\rangle \Bigg] \langle \tilde{N} : v | \psi_N \rangle = m \langle \tilde{N} : v | \psi_N \rangle \,,$$

where the form factors $\mathcal{F}_{\pi\tilde{N}\tilde{N}}(\vec{k}_\pi^2)$ take into account the extended structures of the interaction vertices.

In the actual calculations we employed form factors from four different approaches.

Meson-Baryon Interaction Vertices (FF's)

Form factors $\mathcal{F}_{\pi\tilde{N}\tilde{N}}(\vec{k}_\pi^2)$ from

- Relativistic constituent-quark model (RCQM)
  Phenomenological meson-baryon model by Sato-Lee (SL)
  Meson-nucleon potential by Polinder-Rijken (PR Multipole)

$$\mathcal{F}_{\pi\tilde{N}\tilde{N}}(\vec{k}_\pi^2) = \frac{1}{1+\left(\frac{\vec{k}_\pi}{\Lambda_1}\right)^2+\left(\frac{\vec{k}_\pi}{\Lambda_2}\right)^4}$$

- Phenomenological meson-baryon model by
  Kamano, Nakamura, Lee, and Sato (KNLS)

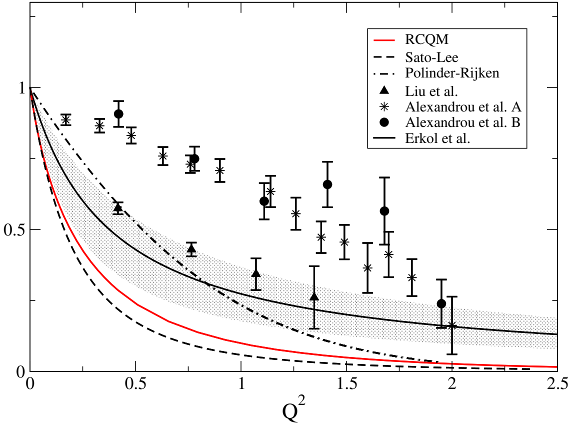
$$\mathcal{F}_{\pi\tilde{N}\tilde{N}}(\vec{k}_\pi^2) = \left(\frac{\Lambda^2}{\vec{k}_\pi^2+\Lambda^2}\right)^2$$

- Meson-nucleon potential by Polinder-Rijken (PR Gaussian)

$$\mathcal{F}_{\pi\tilde{N}\tilde{N}}(\vec{k}_\pi^2) = \exp^{-\vec{k}_\pi^2/\Lambda^2}$$

$\pi\widetilde{N}\widetilde{N}$ Vertex Predicted by the $\{QQQ\}$ RCQM

$G_{\pi\widetilde{N}\widetilde{N}}(Q^2)$:



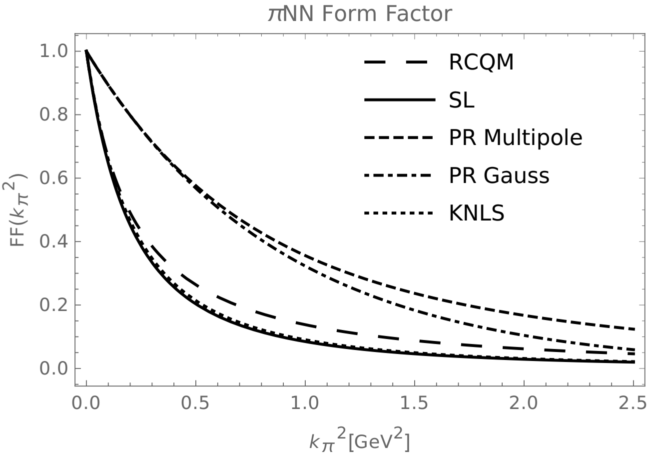
T. Melde, L. Canton, and W. Plessas: Phys. Rev. Lett. **102**, 132002 (2009)

$\mathcal{F}_{\pi\widetilde{N}\widetilde{N}}(\vec{k}_\pi^2)$ Parametrizations

	RCQM	SL	KNLS	PR Gauss	PR Multipole
$\frac{f_N^2}{4\pi}$	0.0691	0.08	0.08	0.013	0.013
λ_1	0.451	0.453			0.945
λ_2	0.931	0.641			1.102
Λ			0.656	0.665	

RCQM	Relativistic constituent-quark model
SL	Meson-baryon model by Sato-Lee
KNLS	Meson-baryon model by Kamano, Nakamura, Lee, and Sato
PR Gauss	Meson-nucleon potential by Polinder-Rijken (Gaussian form)
PR Multipole	Meson-nucleon potential by Polinder-Rijken (multipole form)

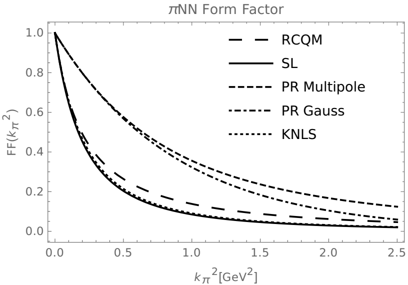
Momentum Dependences of $\mathcal{F}_{\pi\tilde{N}\tilde{N}}(\vec{k}_\pi^2)$

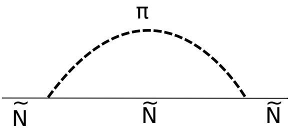


Pionic Effects on Nucleon Mass (Hadronic)

		RCQM	SL	KNLS	PR Gauss	PR Multipole
m_N	(MeV)	939	939	939	939	939
$m_{\tilde{N}}$	(MeV)	1067	1031	1037	1025	1051
$m_N - m_{\tilde{N}}$	(MeV)	-128	-92	-98	-86	-112

with $\pi\widetilde{N}\widetilde{N}$ vertex form factors in:

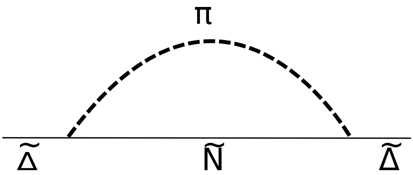




Dressing

the bare $\widetilde{\Delta}$ with π's

on the macroscopic (hadronic) level



The $\widetilde{\Delta}$ with Explicit Pions

Coupled-channel mass-operator eigenvalue equation
for π-dressing of the bare $\widetilde{\Delta}$

$$\begin{pmatrix} M_{\tilde{\Delta}} & K \\ K^{\dagger} & M_{\tilde{N}+\pi} \end{pmatrix} \begin{pmatrix} |\psi_{\Delta}\rangle \\ |\psi_{N+\pi}\rangle \end{pmatrix} = m \begin{pmatrix} |\psi_{\Delta}\rangle \\ |\psi_{N+\pi}\rangle \end{pmatrix} .$$

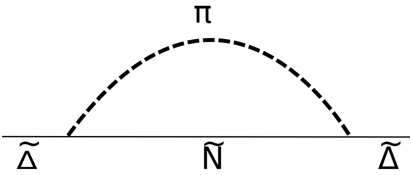
After Feshbach elimination of the $|\psi_{N+\pi}\rangle$ channel:

$$[M_{\tilde{\Delta}} + \underbrace{K(m - M_{\tilde{N}+\pi})^{-1}K^{\dagger}}_{V_{opt}}]|\psi_{\Delta}\rangle = m|\psi_{\Delta}\rangle.$$

It is an exact eigenvalue equation for $|\psi_{\Delta}\rangle$,
yielding (above the πN threshold) in general
a complex mass m of the dressed (i.e. realistic) Δ.

$\pi N\Delta$ Eigenvalue Equation

$$\langle\tilde{\Delta} : v|[M_{\tilde{\Delta}} - \underbrace{K(m - M_{\tilde{N}+\pi})^{-1}K^{\dagger}}]|\psi_{\Delta}\rangle = m\langle\tilde{\Delta} : v'|\psi_{\Delta}\rangle$$



Transition interaction $K \sim$ pseudovector Lagrangian density

$$\mathcal{L}^{PV}_{\pi\tilde{N}\tilde{\Delta}} = -\frac{f_{\pi\tilde{N}\tilde{\Delta}}}{m_{\pi}}\bar{\psi}(x)\vec{T}\psi^{\mu}(x)\partial_{\mu}\phi(x) + h.c.$$

$\pi N \Delta$ Eigenvalue Equation ctd.

$$\left(m_{\tilde{\Delta}} + \int \frac{d^3 k_\pi}{(2\pi)^3} \frac{1}{2\omega_\pi 2\omega_N 2m_{\tilde{\Delta}}} \mathcal{F}_{\pi\tilde{N}\tilde{\Delta}}(\vec{k}_\pi^2) \langle \tilde{\Delta} | \mathcal{L}_{\pi\tilde{N}\tilde{\Delta}}(0) | \tilde{N}, \pi : \vec{k}_\pi \rangle \right.$$
$$\times \left(m - \sqrt{m_{\tilde{N}}^2 + \vec{k}_\pi^2} - \sqrt{m_\pi^2 + \vec{k}_\pi^2} \right)^{-1} \mathcal{F}^*_{\pi\tilde{N}\tilde{\Delta}}(\vec{k}_\pi^2)$$
$$\left. \times \langle \tilde{N}, \pi : \vec{k}_\pi | \mathcal{L}^\dagger_{\pi\tilde{N}\tilde{\Delta}}(0) | \tilde{\Delta} \rangle \right) \langle \tilde{\Delta} : v | \psi_\Delta \rangle = m \langle \tilde{\Delta} : v | \psi_\Delta \rangle \,,$$

where the form factors $\mathcal{F}_{\pi\tilde{N}\tilde{\Delta}}(\vec{k}_\pi^2)$ take into account the extended structures of the interaction vertices.

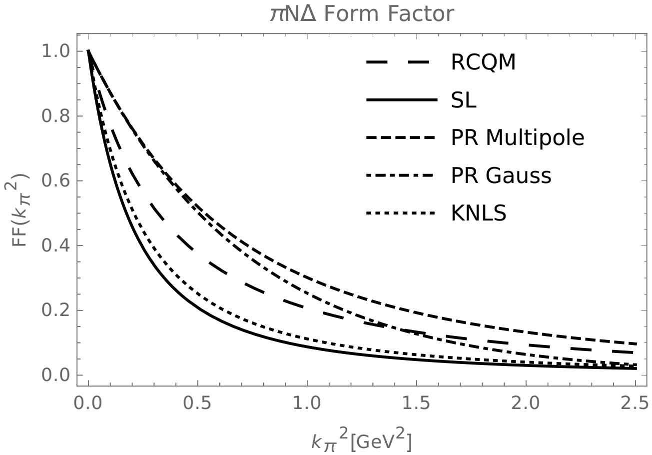
In the actual calculations we employed form factors again from four different approaches.

$\mathcal{F}_{\pi\widetilde{N}\widetilde{\Delta}}(\vec{k}_\pi^2)$ Parametrizations

	RCQM	SL	KNLS	PR Gauss	PR Multipole
$\frac{f_\Delta^2}{4\pi}$	0.188	0.334	0.126	0.167	0.167
λ_1	0.594	0.458			0.853
λ_2	0.998	0.648			1.014
Λ			0.709	0.603	

RCQM	Relativistic constituent-quark model
SL	Meson-baryon model by Sato-Lee
KNLS	Meson-baryon model by Kamano, Nakamura, Lee, and Sato
PR Gauss	Meson-nucleon potential by Polinder-Rijken (Gaussian form)
PR Multipole	Meson-nucleon potential by Polinder-Rijken (multipole form)

MOMENTUM DEPENDENCES OF $\mathcal{F}_{\pi\tilde{N}\tilde{\Delta}}(\vec{k}_\pi^2)$

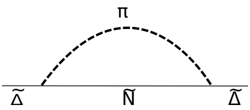


π Effects on Δ Mass and Width (Hadronic)

	RCQM	SL	KNLS	PR Gauss	PR Multipole
$m_{\widetilde{N}}$	1067	1031	1037	1025	1051
$Re[m_\Delta]$	1232	1232	1232	1232	1232
$m_{\widetilde{\Delta}}$	1300	1290	1259	1321	1335
$Re[m_\Delta] - m_{\widetilde{\Delta}}$	-68	-58	-27	-89	-103
$2\ Im[m_\Delta] = \Gamma$	4	23	7	16	8
$\Gamma_{\mathrm{exp}}(\Delta \to \pi N)$			~ 117		

(all figures in MeV)

Decay to bare $\widetilde{N}$:

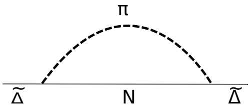


π Effects on Δ Mass and Width (Hadronic)

	RCQM	SL	KNLS	PR Gauss	PR Multipole
m_N	939	939	939	939	939
$Re[m_\Delta]$	1232	1232	1232	1232	1232
$m_{\tilde{\Delta}}$	1309	1288	1261	1329	1346
$Re[m_\Delta] - m_{\tilde{\Delta}}$	-77	-56	-29	-97	-114
$2\ Im[m_\Delta] = \Gamma$	42	63	27	52	52
$\Gamma_{\rm exp}(\Delta \to \pi N)$			~ 117		

(all figures in MeV)

Decay to realistic N:



Summary on Dressing $\widetilde{N}$ and $\widetilde{\Delta}$ with π's (on the macroscopic scale)

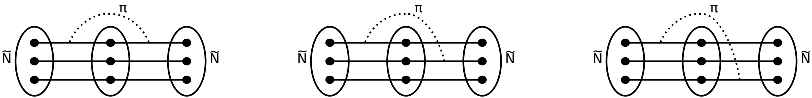
In this way learned by the CC approach:

- Dressing effect on nucleon (ground-state) mass
- Dressing effect on Δ (resonance) mass and width
- Tested different existing models for $\pi\widetilde{N}\widetilde{N}$ and $\pi\widetilde{N}\widetilde{\Delta}$ vertex form factors
- The $\Delta \to \pi N$ remains still much too small
- Higher-order effects have been studied $\to$ minor corrections

Microscopic picture:

Development of a coupled-channels RCQM

to include explicit π's on the microscopic level



Dressing a Composite Cluster State

Coupled-channel mass-operator eigenvalue equation
to include π or $\{Q\bar{Q}\}$ to a composite quark-cluster state $\left|\psi_{\widetilde{cl}}\right\rangle$

$$\begin{pmatrix} M_{\widetilde{cl}} & I & 0 \\ I^\dagger & M_{\widetilde{cl+i}} & I \\ 0 & I^\dagger & M_{\widetilde{cl+j}} \end{pmatrix} \begin{pmatrix} \left|\psi_{cl}\right\rangle \\ \left|\psi_{cl+i}\right\rangle \\ \left|\psi_{cl+j}\right\rangle \end{pmatrix} = m \begin{pmatrix} \left|\psi_{cl}\right\rangle \\ \left|\psi_{cl+i}\right\rangle \\ \left|\psi_{cl+j}\right\rangle \end{pmatrix},$$

- $M_{\widetilde{cl}}$ mass operator of bound/confined cluster, e.g., $\{Q\bar{Q}\}_{\tilde{\rho}}$, $\{QQQ\}_{\tilde{N}}$, or $\{QQQ\}_{\tilde{\Delta}}$ etc.
- $M_{\widetilde{cl+i}}$ free mass operator of, e.g., $\{Q\bar{Q}\}_{\tilde{\rho}}+\pi$, $\{QQQ\}_{\tilde{N}}+\pi$, or $\{QQQ\}_{\tilde{\Delta}}+\pi$ etc.
- $M_{\widetilde{cl+j}}$ free mass operator of e.g., $\{Q\bar{Q}\}_{\tilde{\rho}}+\pi+\pi$, $\{QQQ\}_{\tilde{N}}+\pi+\pi$, or $\{QQQ\}_{\tilde{\Delta}}+\pi+\pi$ etc.
- I channel-coupling interaction
- m mass eigenvalue

A $\{QQQ\}$ Cluster with Explicit Pions

Coupled-channels mass-operator eigenvalue equation
for π-dressing of a given bare $\{\widetilde{QQQ}\}$ cluster state

$$\begin{pmatrix} M_{\widetilde{QQQ}} & I \\ I^\dagger & M_{\widetilde{QQQ}+\pi} \end{pmatrix} \begin{pmatrix} |\psi_{QQQ}\rangle \\ |\psi_{QQQ+\pi}\rangle \end{pmatrix} = m \begin{pmatrix} |\psi_{QQQ}\rangle \\ |\psi_{QQQ+\pi}\rangle \end{pmatrix}$$

After Feshbach elimination of the $|\psi_{QQQ+\pi}\rangle$ channel:

$$[M_{\widetilde{QQQ}} + \underbrace{I(m - M_{\widetilde{QQQ}+\pi})^{-1} I^\dagger}_{V_{opt}}]|\psi_{QQQ}\rangle = m|\psi_{QQQ}\rangle.$$

It is an exact eigenvalue equation for $|\psi_{QQQ}\rangle$, yielding in general a complex eigenvalue m of the π-dressed $\{QQQ\}$ system.

MICROSCOPIC $\widetilde{QQQ}$ AND $\widetilde{QQQ}+\pi$ BASIS STATES

Bare $\widetilde{QQQ}=\tilde{B}$ mass-operator confined/bound states:

$$M_{\widetilde{QQQ}}|\tilde{B}:v;n,J,\Sigma\rangle = m_{\widetilde{QQQ}}|\tilde{B}:v;n,J,\Sigma\rangle\,,$$

where

$$M_{\widetilde{QQQ}} = M^{\mathrm{free}}_{\widetilde{QQQ}} + V^{\mathrm{conf}}$$

Bare $\widetilde{QQQ}+\pi$ states:

$$M_{\widetilde{QQQ}+\pi}|\tilde{B},\pi:v;\vec{k}_1,\vec{k}_2,\vec{k}_\pi\rangle = (\omega_{\widetilde{QQQ}}+\omega_\pi)|\tilde{B},\pi:v;\vec{k}_1,\vec{k}_2,\vec{k}_\pi\rangle$$

with corresponding completeness relations.

The CC RCQM and its Solution

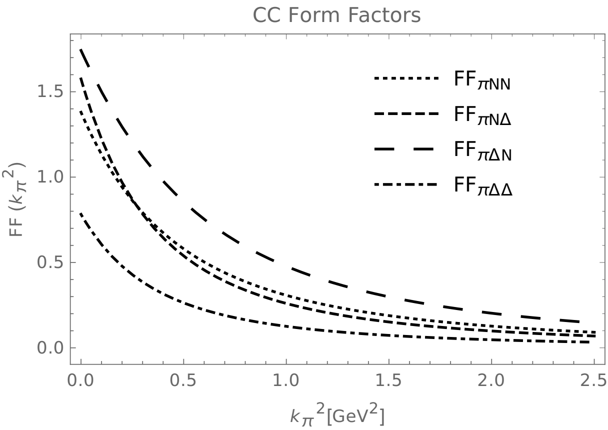
- Determine the eigenstates of the bare $\widetilde{QQQ}$ system under a given confinement
- Calculate the optical potential $I(m - M_{\widetilde{QQQ}+\pi})^{-1} I^\dagger$ of the complex eigenvalue equation
- Solve the eigenvalue equation consistently $\rightarrow$ m_{QQQ} and $|\psi_{QQQ}\rangle$
- Equating the microscopic optical potential with the hadronic one (including vertex FF's)

$$\int I(m - M_{\widetilde{QQQ}+\pi})^{-1} I^\dagger \sim \\ \sim \int \mathcal{F}_{\pi\tilde{B}\tilde{B}}(\vec{k}_\pi^2) K (m - M_{\tilde{B}+\pi})^{-1} K^\dagger \mathcal{F}^*_{\pi\tilde{B}\tilde{B}}(\vec{k}_\pi^2)$$

allows to determine the various strong $\pi\tilde{B}\tilde{B}$ FF's $\mathcal{F}_{\pi\tilde{B}\tilde{B}}(\vec{k}_\pi^2)$

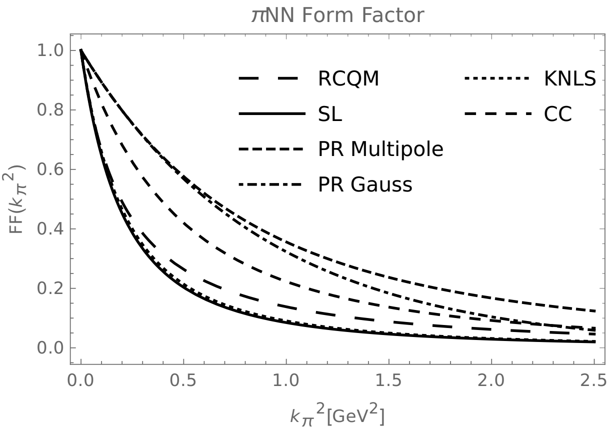
STRONG $\pi\widetilde{N}\widetilde{N}$, $\pi\widetilde{N}\widetilde{\Delta}$, $\pi\widetilde{\Delta}\widetilde{N}$, $\pi\widetilde{\Delta}\widetilde{\Delta}$ FORM FACTORS

As predicted by the CC RCQM



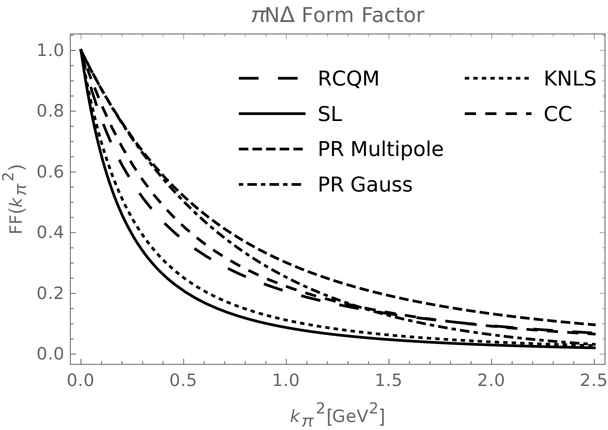
Strong $\pi\widetilde{N}\widetilde{N}$ Form Factor

Prediction of the CC RCQM in comparison to other models



Strong $\pi\widetilde{N}\widetilde{\Delta}$ Form Factor

Prediction of the CC RCQM in comparison to other models

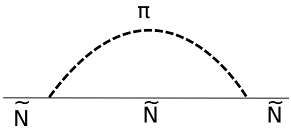


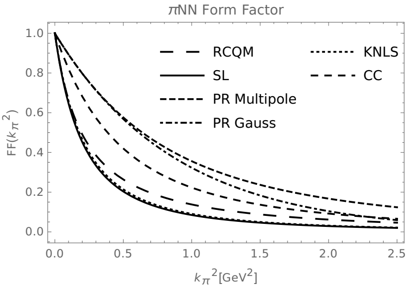
π Effects on Nucleon Mass (Microscopic)

Predictions of the CC RCQM compared to hadronic models:

		CC RCQM	RCQM	SL	KNLS	PR Gauss
m_N	(MeV)	939	939	939	939	939
$m_{\tilde{N}}$	(MeV)	1217	1067	1031	1037	1025
$m_N - m_{\tilde{N}}$	(MeV)	-278	-128	-92	-98	-86

with:





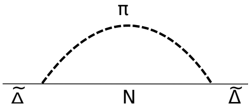
π Effects on Δ Mass and Width (Microscopic)

Predictions of the CC RCQM compared to hadronic models:

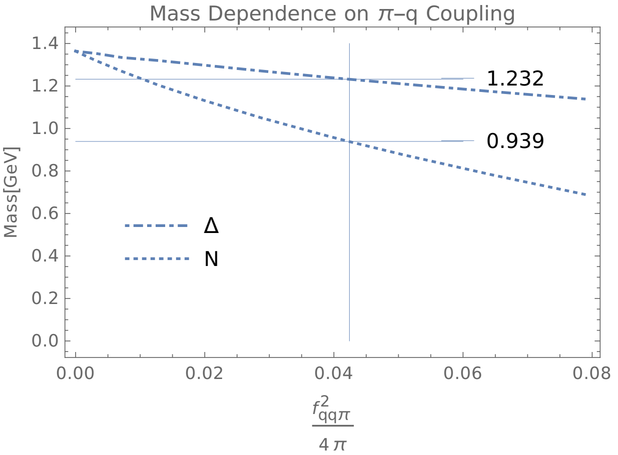
	CC RCQM	RCQM	SL	KNLS	PR Gauss
m_N	939	939	939	939	939
$Re[m_\Delta]$	1232	1232	1232	1232	1232
$m_{\tilde{\Delta}}$	1312	1309	1288	1261	1329
$Re[m_\Delta] - m_{\tilde{\Delta}}$	-80	-77	-56	-29	-97
$2\ Im[m_\Delta] = \Gamma$	38	42	63	27	52
$\Gamma_{\mathrm{exp}}(\Delta \to \pi N)$			~ 117		

(all figures in MeV)

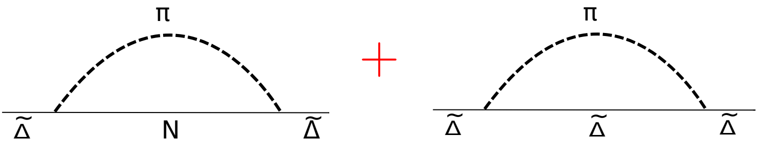
Δ decay to realistic N:



π Effects on the Bare $\widetilde{N}$ and $\widetilde{\Delta}$ Masses



Inclusion of $\pi\widetilde{N}\widetilde{\Delta}$ and $\pi\widetilde{\Delta}\widetilde{\Delta}$ Channels into the CC RCQM

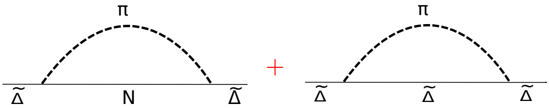


π Effects on Δ Mass and Width (Microscopic)

Predictions of the CC RCQM compared to hadronic models:

		CC RCQM	KNLS
m_N	(MeV)	939	939
$Re[m_\Delta]$	(MeV)	1232	1232
$m_{\tilde{\Delta}}$	(MeV)	1436	1306
$Re[m_\Delta] - m_{\tilde{\Delta}}$	(MeV)	-204	-74
$2\ Im[m_\Delta] = \Gamma$	(MeV)	116	56
$\Gamma_{\rm exp}(\Delta \to \pi N)$	(MeV)	~ 117	

Δ decay to realistic N:



Summary and Outlook

What has been learnt:

- Valence-quark contributions are obviously not sufficient to describe all features of baryon ground and resonant states
- Specifically, in order to get reasonable hadronic decay widths of resonant states further degrees of freedom are needed
- Pions do already a good/most of the job for the N and the Δ

Future projects:

- Test the CC RCQM wave functions with regard to their electromagnetic and weak structures
- Attack e.m. transition form factors $N \to \Delta$, $N \to N^*$, ...
- Get to photo- and electro-production of mesons
- Extend the concept to further resonant states N^*, Δ^*, Y^*, ...

Thank you very much for your attention!