

# Covariant Mesonic Decays of Baryon Resonances and Coupled-Channels Effects

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Theoretical  
Framework

RCQM  
ROM

Spectroscopy

Spectra  
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Decay Widths  
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CC RCQM

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Vertex FFs

## Theoretical Framework

Relativistic constituent-quark model (RCQM)  
Invariant mass operator

## Spectroscopy and Mass-Operator Eigenstates

Ground-state and excitation spectra  
Rest-frame baryon states in 3D

## Hadronic Decays of $\{QQQ\}$ Baryon Resonances

Covariant benchmark results for  $\pi$ ,  $\eta$ , and  $K$  decays

## Coupled-Channels Constituent-Quark Model

Explicit inclusion of mesonic decay channels

## Summary and Outlook

# Relativistic Constituent Quark Model (RCQM)

- ▶ Low-energy hadrons governed by **valence-quark d.o.f.** Conventionally, mesons as  $Q\bar{Q}$  and baryons as  $QQQ$ , with proper  $Q-\bar{Q}$  and  $Q-Q$  dynamics, respectively.
- ▶ Has a **limited range** of validity.
- ▶ Set up in a **relativistic** (i.e. Poincaré-invariant) quantum theory.
- ▶ Perform **high-accuracy microscopic calculations** (of relativistic two- and three-quark systems), including all possible **spatial**, **spin**, and **flavor** dependencies, by advanced few-body methods.

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## Relativistic quantum mechanics

i.e. **quantum theory** respecting **Poincaré invariance**

(theory on a Hilbert space  $\mathcal{H}$  corresponding to a finite number of particles, not a field theory)

### Invariant mass operator

$$\hat{M} = \hat{M}_{free} + \hat{M}_{int}$$

### Eigenvalue equations

$$\hat{M} |P, J, \Sigma\rangle = M |P, J, \Sigma\rangle \quad , \quad \hat{M}^2 = \hat{P}^\mu \hat{P}_\mu$$

$$\hat{P}^\mu |P, J, \Sigma\rangle = P^\mu |P, J, \Sigma\rangle \quad , \quad \hat{P}^\mu = \hat{M} \hat{V}^\mu$$

$P^\mu$  ... 4-momentum,  $J$  ... baryon spin,  $\Sigma$  ... spin projection

## Interacting mass operator

$$\begin{aligned}\hat{M} &= \hat{M}_{free} + \hat{M}_{int} \\ \hat{M}_{free} &= \sqrt{\hat{H}_{free}^2 - \hat{\vec{P}}_{free}^2} \\ \hat{M}_{int}^{rest\ frame} &= \sum_{i < j}^3 \hat{V}_{ij} = \sum_{i < j} [\hat{V}_{ij}^{conf} + \hat{V}_{ij}^{hf}]\end{aligned}$$

fulfilling the **Poincaré algebra**

$$\begin{aligned}[\hat{P}_i, \hat{P}_j] &= 0, & [\hat{J}_i, \hat{H}] &= 0, & [\hat{P}_i, \hat{H}] &= 0, \\ [\hat{K}_i, \hat{H}] &= -i\hat{P}_i & [\hat{J}_i, \hat{J}_j] &= i\epsilon_{ijk}\hat{J}_k & [\hat{J}_i, \hat{K}_j] &= i\epsilon_{ijk}\hat{K}_k, \\ [\hat{J}_i, \hat{P}_j] &= i\epsilon_{ijk}\hat{P}_k, & [\hat{K}_i, \hat{K}_j] &= -i\epsilon_{ijk}\hat{J}_k, & [\hat{K}_i, \hat{P}_j] &= -i\delta_{ij}\hat{H}\end{aligned}$$

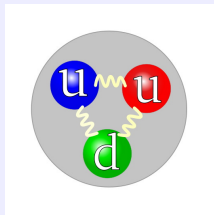
$\hat{H}, \hat{P}_i$  ... time and space translations,

$\hat{J}_i$  ... rotations,  $\hat{K}_i$  ... Lorentz boosts

# Baryons

Baryons are considered as colorless bound states of **three constituent quarks**.

Here the proton:



- ▶ 'Constituent' quarks are quasiparticles with dynamical mass, NOT the original QCD degrees of freedom (i.e. the 'current' quarks).
- ▶ 'Constituent' quarks are confined and interact via hyperfine interactions associated with  $SB_{\chi}S$ , i.e. Goldstone-boson exchange (GBE).

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# Q-Q Dynamics from (Low-Energy) QCD

- **Confinement** according to the string tension of QCD (linearly rising potential as in lattice QCD)
- Low-energy QCD of three flavors  $u, d, s$ :  
**s**pontaneous **b**reaking of **c**hiral **s**ymmetry ( $SB\chi S$ ):

$$SU(3)_L \times SU(3)_R \rightarrow SU(3)_V$$

- appearance of  $(N_f^2 - 1)$  **Goldstone bosons**  $\vec{\phi}$
- generation of quasiparticles with dynamical mass, i.e. **constituent quarks**  $\psi$
- effective Lagrangian:  $\mathcal{L}_{\text{int}} \sim ig\bar{\psi}\gamma_5\vec{\lambda}^F \cdot \vec{\phi}\psi$

A. Manohar and H. Georgi: Nucl. Phys. B 234 (1984) 189

E.V. Shuryak: Phys. Rep. **115**, 152 (1984)

L.Ya. Glozman and D.O. Riska: Phys. Rep. **268**, 263 (1996)

S. Weinberg: Phys. Rev. Lett. **105**, 261601 (2010)

L.Ya. Glozman, W. Plessas, K. Varga, and R.F. Wagenbrunn: Phys. Rev. D **58**, 094030 (1998)

## Goldstone-Boson-Exchange (GBE) Relativistic Constituent Quark Model (RCQM)

$$H_0 = \sum_{i=1}^3 \sqrt{\vec{p}_i^2 + m_i^2}$$

$$V_{conf}(\vec{r}_{ij}) = V_0 + C r_{ij}$$

$$V_{hf}(\vec{r}_{ij}) = \left[ \sum_{F=1}^3 V_{\pi}(\vec{r}_{ij}) \lambda_i^F \lambda_j^F + \sum_{F=4}^7 V_K(\vec{r}_{ij}) \lambda_i^F \lambda_j^F + V_{\eta}(\vec{r}_{ij}) \lambda_i^8 \lambda_j^8 + \frac{2}{3} V_{\eta'}(\vec{r}_{ij}) \right] \vec{\sigma}_i \cdot \vec{\sigma}_j$$

L.Ya. Glozman, W. Plessas, K. Varga, and R.F. Wagenbrunn: Phys. Rev. D **58**, 094030 (1998)

Extended version (EGBE RCQM):

K. Glantschnig, R. Kainhofer, W. Plessas, B. Sengl, and R.F. Wagenbrunn: Eur. Phys. J. A **23**, 507 (2005)

# GBE RCQM Parametrization

$$V_{conf}(\vec{r}_{ij}) = V_0 + Cr_{ij}$$

$$V_0 = -416 \text{ MeV}, C = 2.33 \text{ fm}^{-2}$$

$$\gamma = \pi, K, \eta, \eta':$$

$$\begin{aligned} V_\gamma(\vec{r}_{ij}) &= \frac{g_\gamma^2}{4\pi} \frac{1}{12m_i m_j} \left\{ \mu_\gamma^2 \frac{e^{-\mu_\gamma r_{ij}}}{r_{ij}} - 4\pi \delta(\vec{r}_{ij}) \right\} \\ &= \frac{g_\gamma^2}{4\pi} \frac{1}{12m_i m_j} \left\{ \mu_\gamma^2 \frac{e^{-\mu_\gamma r_{ij}}}{r_{ij}} - \Lambda_\gamma^2 \frac{e^{-\Lambda_\gamma r_{ij}}}{r_{ij}} \right\}, \end{aligned}$$

$$\Lambda_\gamma = \Lambda_0 + \kappa \mu_\gamma$$

$$\frac{g_8^2}{4\pi} = 0.67, m_u = m_d = 340 \text{ MeV}, m_s = 500 \text{ MeV},$$

$\mu_\gamma$  as measured (taken from PDG)

$$\left(\frac{g_0}{g_8}\right)^2 = 1.34, \Lambda_0 = 2.87 \text{ fm}^{-1}, \kappa = 0.81$$

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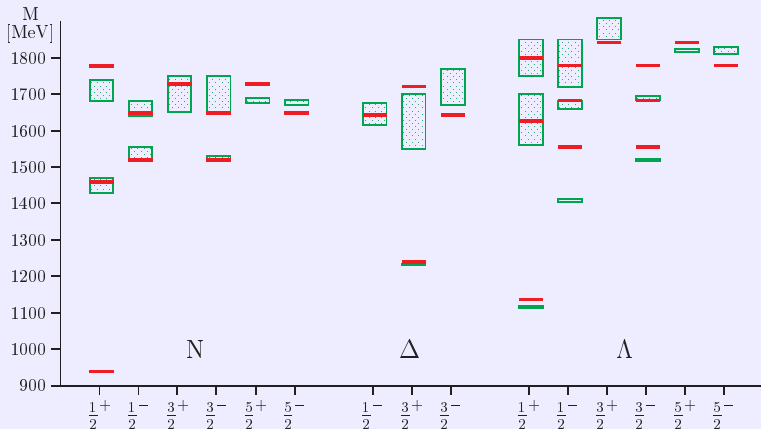
# Baryon **Spectroscopy**

## and

# Mass-Operator **Eigenstates**

# Light Baryon Spectra

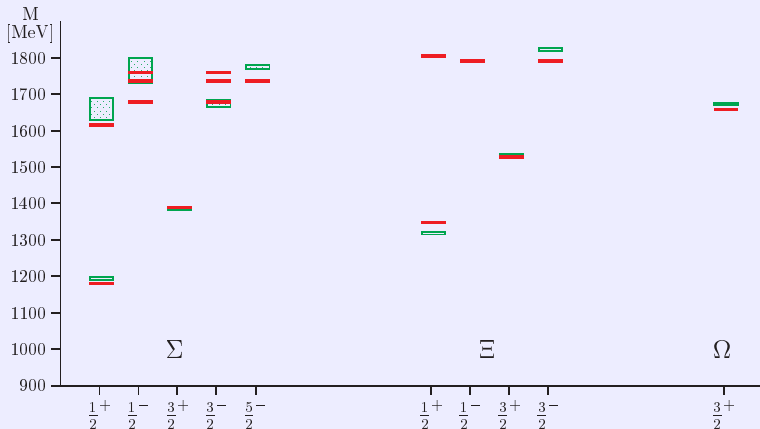
## Excitation spectra of the GBE RCQM:



L.Ya. Glozman, W. Plessas, K. Varga, and R.F. Wagenbrunn: Phys. Rev. D **58**, 094030 (1998)

# Strange Baryon Spectra

## Excitation spectra of the GBE RCQM:



L.Ya. Glozman, W. Plessas, K. Varga, and R.F. Wagenbrunn: Phys. Rev. D **58**, 094030 (1998)

## Mass operator eigenstates

$$\hat{M} |P, J, \Sigma, T, M_T\rangle = M |P, J, \Sigma, T, M_T\rangle$$

represented in configuration space

$$\langle \vec{\xi}, \vec{\eta} | P, J, \Sigma, T, M_T \rangle = \Psi_{PJ\Sigma TM_T}(\vec{\xi}, \vec{\eta})$$

with  $\vec{\xi}$  and  $\vec{\eta}$  the usual Jacobi coordinates.

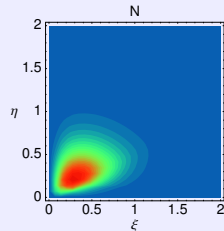
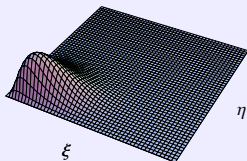
Picture the baryon wave functions through  
**spatial probability density distributions**

$$\rho(\xi, \eta) = \xi^2 \eta^2 \int d\Omega_\xi d\Omega_\eta \Psi_{PJ\Sigma TM_T}^*(\xi, \Omega_\xi, \eta, \Omega_\eta) \Psi_{PJ\Sigma TM_T}(\xi, \Omega_\xi, \eta, \Omega_\eta)$$

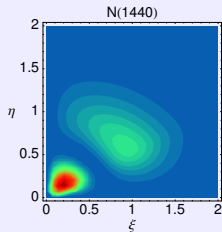
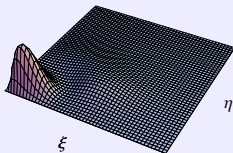
# Pictures of Baryons (rest frame)



N GBE CQM



N(1440) GBE CQM



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

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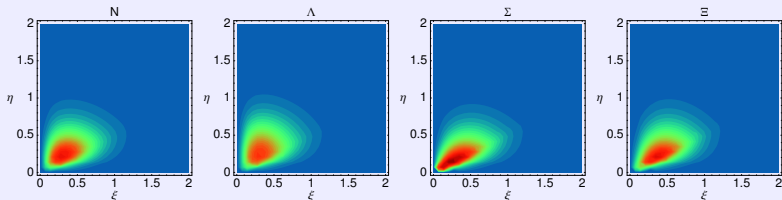
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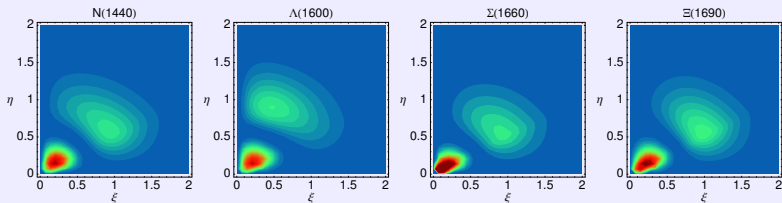
Vertex FFs

# Spatial Probability Density Distributions

$\rho(\xi, \eta)$  for the  $\frac{1}{2}^+$  octet baryon ground states  $N(939)$ ,  $\Lambda(1116)$ ,  $\Sigma(1193)$ ,  $\Xi(1318)$ :

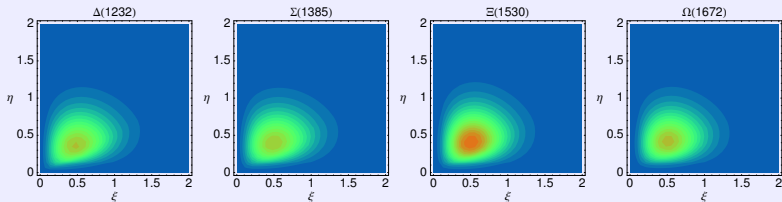


$\rho(\xi, \eta)$  for the  $\frac{1}{2}^+$  octet baryon states  $N(1440)$ ,  $\Lambda(1600)$ ,  $\Sigma(1660)$ ,  $\Xi(1690)$ :

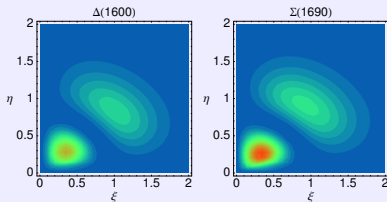


# Spatial Probability Density Distributions

$\rho(\xi, \eta)$  for the  $\Sigma_c^{3+}$  decuplet baryon states  $\Delta(1232)$ ,  $\Sigma(1385)$ ,  $\Xi(1530)$ ,  $\Omega(1672)$ :



$\rho(\xi, \eta)$  for the  $\Sigma_c^{3+}$  decuplet baryon states  $\Delta(1600)$ ,  $\Sigma(1690)$ :



# Hadronic Decays of Baryon Resonances

---

$\pi$ ,  $\eta$ , and  $K$  decay widths

of

$N$ ,  $\Delta$ ,  $\Lambda$ ,  $\Sigma$ ,  $\Xi$  resonances

# Decay Widths and Transition Amplitude

Hadronic **decay widths** for a particular decay mode  $m$

$$\Gamma^m = 2\pi\rho_f |F(i \rightarrow f)|^2$$

$\rho_f$  .... relativistic phase-space factor

Transition amplitude  $\hat{=}$  ME of decay operator  $\hat{D}^m$

$$F(i \rightarrow f) = \langle P', J', \Sigma', T', T'_3, Y' | \hat{D}^m | P, J, \Sigma, T, T_3, Y \rangle$$

to be calculated from microscopic three-quark ME's

$$\langle p'_1, p'_2, p'_3; \sigma'_1, \sigma'_2, \sigma'_3; f_{i'_1}, f_{i'_2}, f_{i'_3} | \hat{D}^m | p_1, p_2, p_3; \sigma_1, \sigma_2, \sigma_3; f_{i_1}, f_{i_2}, f_{i_3} \rangle$$

↑  
boosted 3-body states

↑  
boosted 3-body states

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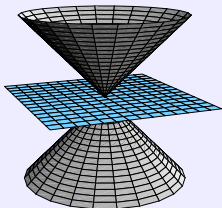
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Invariant hypersurfaces in Minkowski space:

instant

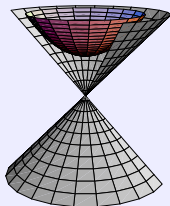


$$x^0 = 0$$

$$J_i, P_i$$

$$P^0 = H, K_i$$

point

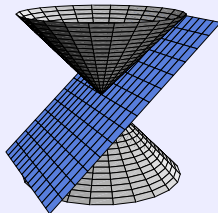


$$x^2 - a^2 = 0$$

$$J_i, K_i$$

$$P^\mu$$

front



$$x^0 + x^3 = 0$$

$$P^+, \vec{P}^\perp, E^1, E^2, J_z, K_z$$

$$P^-, F^1, F^2$$

are **interaction-free** and **interaction-dependent** generators

# Transition Matrix Element in Point Form

$$\begin{aligned} \text{Incoming baryon state: } |V, M, J, \Sigma\rangle &\hat{=} |P, J, \Sigma\rangle \\ \text{Outgoing baryon state: } |V', M', J', \Sigma'\rangle &\hat{=} |P', J', \Sigma'\rangle \end{aligned}$$

$$\begin{aligned} F(i \rightarrow f) &= \langle V', M', J', \Sigma' | \hat{D}^m | V, M, J, \Sigma \rangle = \\ &= \frac{2}{MM'} \sum_{\sigma_i \sigma'_i} \sum_{\mu_i \mu'_i} \int d^3 \vec{k}_2 d^3 \vec{k}_3 d^3 \vec{k}'_2 d^3 \vec{k}'_3 \\ &\times \sqrt{\frac{(\sum_i \omega'_i)^3}{\prod_i 2\omega'_i}} \prod_{\sigma'_i} D_{\sigma'_i \mu'_i}^{* \frac{1}{2}} \{R_W [k'_i; B(V')]\} \Psi_{M' J' \Sigma'}^* (\vec{k}'_1, \vec{k}'_2, \vec{k}'_3; \mu'_1, \mu'_2, \mu'_3) \\ &\times \langle p'_1, p'_2, p'_3; \sigma'_1, \sigma'_2, \sigma'_3 | \hat{D}_{rd}^m | p_1, p_2, p_3; \sigma_1, \sigma_2, \sigma_3 \rangle \\ &\times \sqrt{\frac{(\sum_i \omega_i)^3}{\prod_i 2\omega_i}} \prod_{\sigma_i} D_{\sigma_i \mu_i}^{\frac{1}{2}} \{R_W [k_i; B(V)]\} \Psi_{M J \Sigma} (\vec{k}_1, \vec{k}_2, \vec{k}_3; \mu_1, \mu_2, \mu_3) \\ &\times 2M V_0 \delta^3 (M \vec{V} - M' \vec{V}' - \vec{q}) \end{aligned}$$

$$\text{where } p_i = B_c(V)k_i, \quad p'_i = B_c(V')k'_i, \quad \text{and } \omega_i = \sqrt{\vec{k}_i^2 + m_i^2}$$

# Point-Form Spectator-Model (PFSM) Operator

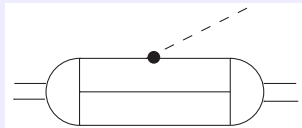
**Hadronic decay operator** in the point-form spectator model

$$\begin{aligned} & \langle p'_1, p'_2, p'_3; \sigma'_1, \sigma'_2, \sigma'_3 | \hat{D}_{rd}^m | p_1, p_2, p_3; \sigma_1, \sigma_2, \sigma_3 \rangle = \\ & - 3\mathcal{N} \frac{ig_{qqm}}{2m_1} \frac{1}{\sqrt{2\pi}} \bar{u}(p'_1, \sigma'_1) \gamma_5 \gamma^\mu \mathcal{F}^m u(p_1, \sigma_1) Q_\mu \\ & \quad \times 2p_{20} \delta(\vec{p}_2 - \vec{p}'_2) 2p_{30} \delta(\vec{p}_3 - \vec{p}'_3) \delta_{\sigma_2 \sigma'_2} \delta_{\sigma_3 \sigma'_3} \end{aligned}$$

with

$$p_1'^\mu - p_1^\mu = \tilde{q}^\mu \neq Q^\mu = P'^\mu - P^\mu; \quad \tilde{q}^\mu = \xi Q^\mu$$

$$\mathcal{N} = \left( \frac{M}{\sum_i \omega_i} \right)^{3/2} \left( \frac{M'}{\sum_i \omega'_i} \right)^{3/2}$$



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|                       | $N^*, \Delta^*$<br>$\rightarrow N\pi$ | Experiment<br>[MeV]        | Relativistic |           | Nonrel. EEM |      |
|-----------------------|---------------------------------------|----------------------------|--------------|-----------|-------------|------|
|                       |                                       |                            | GBE          | OGE       | GBE         | OGE  |
| Theoretical Framework | $N(1440)$                             | $(227 \pm 18)_{-59}^{+70}$ | 30           | 59        | 7           | 27   |
| RCQM                  | $N(1520)$                             | $(66 \pm 6)_{-5}^{+9}$     | 21           | 23        | 38          | 37   |
| RQM                   | $N(1535)$                             | $(67 \pm 15)_{-17}^{+28}$  | 25           | <b>39</b> | 559         | 1183 |
| Spectroscopy          | $N(1650)$                             | $(109 \pm 26)_{-3}^{+36}$  | 6.3          | 9.9       | 157         | 352  |
| Spectra               | $N(1675)$                             | $(68 \pm 8)_{-4}^{+14}$    | 8.4          | 10.4      | 13          | 16   |
| Eigenstates           | $N(1700)$                             | $(10 \pm 5)_{-3}^{+3}$     | 1.0          | 1.3       | 2.2         | 2.7  |
| Decays                | $N(1710)$                             | $(15 \pm 5)_{-5}^{+30}$    | <b>19</b>    | <b>21</b> | 8           | 6    |
| Decay Widths          | $\Delta(1232)$                        | $(119 \pm 1)_{-5}^{+5}$    | 35           | 31        | 89          | 85   |
| Decay Systematics     | $\Delta(1600)$                        | $(61 \pm 26)_{-10}^{+26}$  | 0.5          | 5.1       | 93          | 86   |
| CC RCQM               | $\Delta(1620)$                        | $(38 \pm 8)_{-6}^{+8}$     | 1.2          | 2.8       | 76          | 177  |
| Meson Channels        | $\Delta(1700)$                        | $(45 \pm 15)_{-10}^{+20}$  | 3.8          | 4.1       | 10.4        | 9.1  |
| Summary               |                                       |                            |              |           |             |      |
| Addenda               |                                       |                            |              |           |             |      |
| Vertex FFs            |                                       |                            |              |           |             |      |

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

Similar results in a Bethe-Salpeter approach by Bonn group, see B. Metsch: EPJA **35**, 275 (2008)

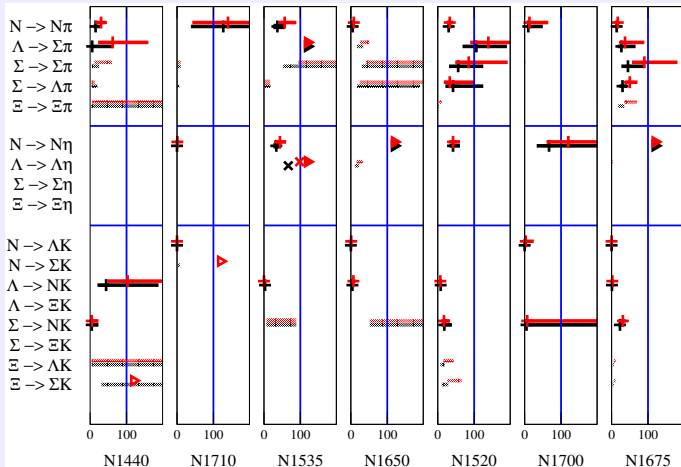
# $\eta$ Decay Widths of $N^*$

| $N \rightarrow N\eta$ | Experiment<br>[MeV]               | Relativistic |            | Nonrel. EEM |      |
|-----------------------|-----------------------------------|--------------|------------|-------------|------|
|                       |                                   | GBE          | OGE        | GBE         | OGE  |
| $N(1520)$             | $(0.28 \pm 0.05)_{-0.01}^{+0.03}$ | 0.1          | 0.1        | 0.04        | 0.04 |
| $N(1535)$             | $(64 \pm 19)_{-28}^{+28}$         | <b>27</b>    | <b>35</b>  | 127         | 236  |
| $N(1650)$             | $(10 \pm 5)_{-1}^{+4}$            | 50           | 74         | 283         | 623  |
| $N(1675)$             | $(0 \pm 1.5)_{-0.1}^{+0.3}$       | <b>1.5</b>   | 2.4        | 1.1         | 1.8  |
| $N(1700)$             | $(0 \pm 1)_{-0.5}^{+0.5}$         | <b>0.5</b>   | <b>0.9</b> | 0.2         | 0.3  |
| $N(1710)$             | $(6 \pm 1)_{-4}^{+11}$            | 0.02         | 0.06       | 2.9         | 9.3  |

With theoretical masses

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

# Decay Widths of Octet Baryon Resonances



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

# Decay Widths of Decuplet Baryon Resonances



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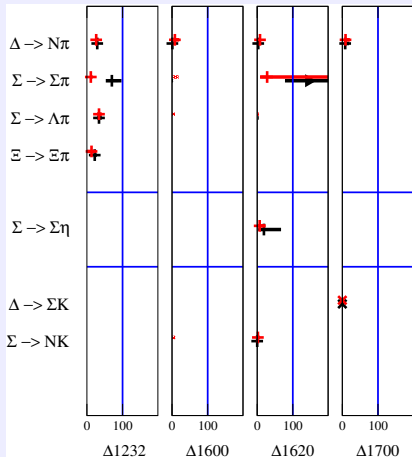
## CC RQM

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

# Decay Widths of Singlet Baryon Resonances



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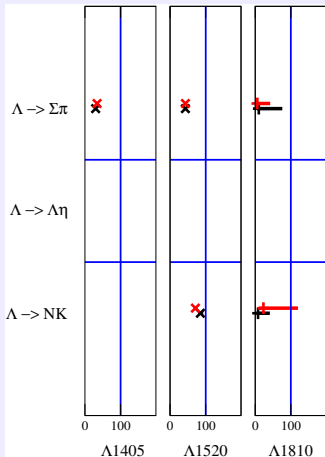
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T. Melde, W. Plessas, and B. Sengl: Phys. Rev. D 77, 114002 (2008)

# New Quark-Model Classification

Particle Data Group: J. Phys. G **37**, 075021 (2010)  
 Phys. Rev. D **86**, 010001 (2012)

| multiplet | $(LS)J^P$                       |                      |                       |                      |                      |  |
|-----------|---------------------------------|----------------------|-----------------------|----------------------|----------------------|--|
| octet     | $(0 \frac{1}{2}) \frac{1}{2}^+$ | $N(939)^{100}$       | $\Lambda(1116)^{100}$ | $\Sigma(1193)^{100}$ | $\Xi(1318)^{100}$    |  |
| octet     | $(0 \frac{1}{2}) \frac{3}{2}^+$ | $N(1440)^{100}$      | $\Lambda(1600)^{96}$  | $\Sigma(1660)^{100}$ | $\Xi(1690)^{100}$    |  |
| octet     | $(0 \frac{1}{2}) \frac{1}{2}^+$ | $N(1710)^{100}$      |                       | $\Sigma(1880)^{99}$  |                      |  |
| octet     | $(1 \frac{1}{2}) \frac{1}{2}^-$ | $N(1535)^{100}$      | $\Lambda(1670)^{72}$  | $\Sigma(1560)^{94}$  |                      |  |
| octet     | $(1 \frac{1}{2}) \frac{3}{2}^-$ | $N(1650)^{100}$      | $\Lambda(1800)^{100}$ | $\Sigma(1620)^{100}$ |                      |  |
| octet     | $(1 \frac{1}{2}) \frac{5}{2}^-$ | $N(1520)^{100}$      | $\Lambda(1690)^{72}$  | $\Sigma(1670)^{94}$  | $\Xi(1820)^{97}$     |  |
| octet     | $(1 \frac{1}{2}) \frac{3}{2}^-$ | $N(1700)^{100}$      |                       | $\Sigma(1940)^{100}$ |                      |  |
| octet     | $(1 \frac{1}{2}) \frac{5}{2}^-$ | $N(1675)^{100}$      | $\Lambda(1830)^{100}$ | $\Sigma(1775)^{100}$ | $\Xi(1950)^{100}$    |  |
| decuplet  | $(0 \frac{3}{2}) \frac{3}{2}^+$ | $\Delta(1232)^{100}$ | $\Sigma(1385)^{100}$  | $\Xi(1530)^{100}$    | $\Omega(1672)^{100}$ |  |
| decuplet  | $(0 \frac{3}{2}) \frac{5}{2}^+$ | $\Delta(1600)^{100}$ | $\Sigma(1690)^{99}$   |                      |                      |  |
| decuplet  | $(1 \frac{1}{2}) \frac{1}{2}^-$ | $\Delta(1620)^{100}$ | $\Sigma(1750)^{94}$   |                      |                      |  |
| decuplet  | $(1 \frac{1}{2}) \frac{3}{2}^-$ | $\Delta(1700)^{100}$ |                       |                      |                      |  |
| singlet   | $(1 \frac{1}{2}) \frac{1}{2}^-$ | $\Lambda(1405)^{71}$ |                       |                      |                      |  |
| singlet   | $(1 \frac{1}{2}) \frac{3}{2}^-$ | $\Lambda(1520)^{71}$ |                       |                      |                      |  |
| singlet   | $(0 \frac{1}{2}) \frac{1}{2}^+$ | $\Lambda(1810)^{92}$ |                       |                      |                      |  |

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



**Coupled-channels** mass operator for  $i + 1$  d.o.f.:

$$\begin{pmatrix} M_i & K^\dagger \\ K & M_{i+1} \end{pmatrix} \begin{pmatrix} |\psi_i\rangle \\ |\psi_{i+1}\rangle \end{pmatrix} = m \begin{pmatrix} |\psi_i\rangle \\ |\psi_{i+1}\rangle \end{pmatrix}$$

- ▶  $i = Q\bar{Q}$  →: Meson dressing of bare  $Q\bar{Q}$  states
- ▶  $i = QQQ$  →: Meson dressing of bare  $QQQ$  states

Feshbach reduction:

→ **non-Hermitian** mass operator

$$(M_i - \underbrace{K^\dagger (m - M_{i+1})^{-1} K}_{V_{opt}}) |\psi_i\rangle = m |\psi_i\rangle$$

→ **complex** eigenvalue problem

- ▶ real eigenvalues  $m$ : **bound states**
- ▶ complex eigenvalues  $m$ : **finite-width resonances**

# Transition Interaction at Quark Level

**Interaction Lagrangian**, consistent with GBE dynamics:

$$\mathcal{L}_{\text{int}} = ig\bar{\psi}\gamma^5\vec{\lambda}^F \cdot \vec{\phi}\psi$$

→ **Transition ME**:

$$\langle v; \vec{k}_1, \mu_1; \vec{k}_2, \mu_2; \vec{k}_{\text{meson}} | K | v'; \vec{k}'_1, \mu'_1; \vec{k}'_2, \mu'_2 \rangle \sim$$

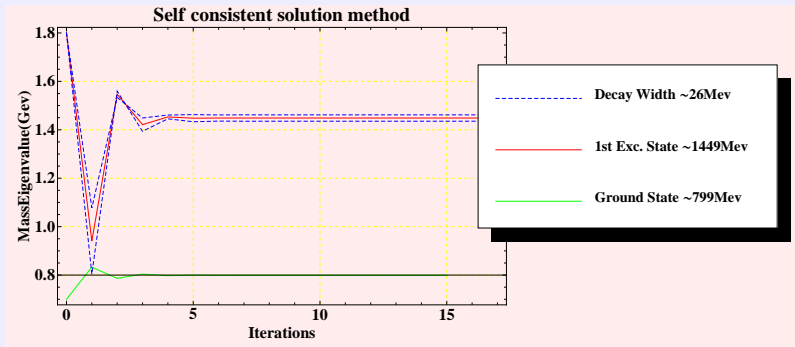
$$\sim \bar{u}(k_2, \mu_2)\gamma^5 u(k'_2, \mu'_2) + \bar{u}(k_1, \mu_1)\gamma^5 u(k'_1, \mu'_1)$$

with anti/quark Dirac spinors

$$u(k, \mu) = \sqrt{\omega + m} \begin{bmatrix} \chi^\mu \\ \frac{\vec{\sigma} \cdot \vec{k}}{\omega + m} \chi^\mu \end{bmatrix}, \quad \chi^\mu = \begin{cases} \begin{bmatrix} 1 \\ 0 \end{bmatrix}, & \mu = +\frac{1}{2} \\ \begin{bmatrix} 0 \\ 1 \end{bmatrix}, & \mu = -\frac{1}{2} \end{cases}$$
$$\bar{u}(k, \mu) = \sqrt{\omega + m} \left[ \chi^{\mu\dagger}, -\chi^{\mu\dagger} \frac{\vec{\sigma} \cdot \vec{k}}{\omega + m} \right],$$

# Selfconsistent Solution of Complex EV Problem

Iterative solution:



Theoretical  
Framework

RQM  
RQM

Spectroscopy

Spectra  
Eigenstates

Decays

Decay Widths  
Decay Systematics

CC RQM

Meson Channels

Summary

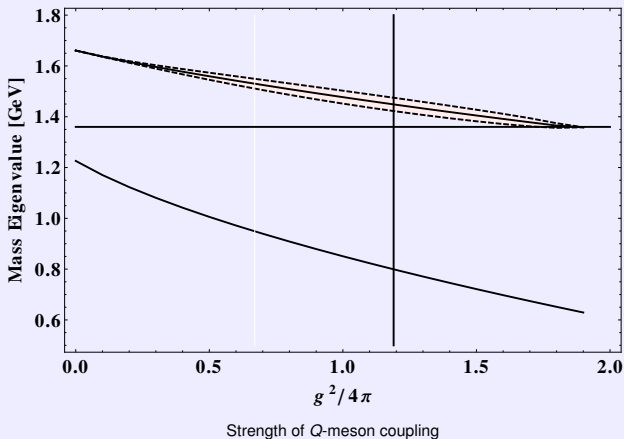
Addenda

Vertex FFs

# CC Effects on Ground State and Resonance

Toy model without spin and flavor d.o.f. for

$$i = Q\bar{Q}, \quad i + 1 = Q\bar{Q} \text{ meson} :$$



Theoretical  
Framework

RCQM  
ROM

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Addenda

Vertex FFs

# Summary and Conclusions

- ▶ RCQM with  $\{QQQ\}$  configurations only:
  - ▶ **Covariant benchmark results** established for hadronic baryon decays
  - ▶ **Decay widths** systematically **too small**
- ▶ RCQM with coupling to  $\{QQQm\}$  channels:
  - ▶ Realistic description of **bound states** and **resonances** possible
  - ▶ **Resonances** do get **finite widths**
- ▶ Presently under way: Construct full-fledged **CC RCQM** with all **spin** and **flavor** d.o.f.

Theoretical  
FrameworkRCQM  
RQM

## Spectroscopy

Spectra  
Eigenstates

## Decays

Decay Widths  
Decay Systematics

## CC RCQM

Meson Channels

## Summary

## Addenda

## Vertex FFs

Thank you very much  
for  
your attention!

Theoretical  
Framework

RCQM  
RQM

Spectroscopy

Spectra  
Eigenstates

Decays

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Decay Systematics

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Addenda

Vertex FFs

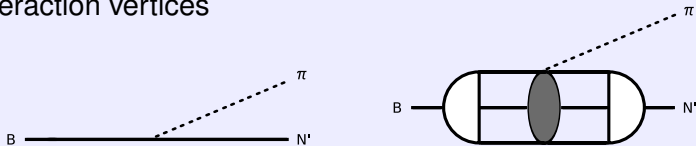
# Microscopic Description

of

# Meson-Baryon Interaction Vertices

# Meson-Baryon Interaction Vertices

## Interaction vertices



$$F_{i \rightarrow f} = (2\pi)^4 \langle f | \mathcal{L}_I(0) | i \rangle \equiv \langle V', M', J', \Sigma' | \hat{D}_{\text{rd}}^\pi | V, M, J, \Sigma \rangle$$

where

$$\langle p'_1, p'_2, p'_3; \sigma'_1, \sigma'_2, \sigma'_3 | \hat{D}_{\text{rd}}^\pi | p_1, p_2, p_3; \sigma_1, \sigma_2, \sigma_3 \rangle =$$

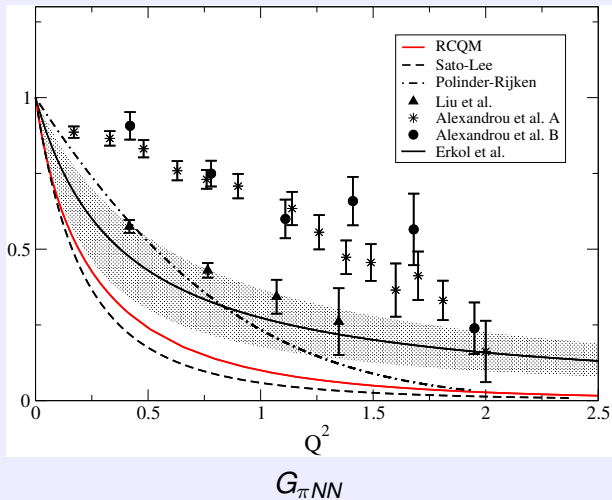
$$3\mathcal{N}_S \frac{ig_{qqm}}{2m_1 (2\pi)^{\frac{3}{2}}} \bar{u}(p'_1, \sigma'_1) \gamma_5 \gamma_\mu \lambda_m u(p_1, \sigma_1) \tilde{q}^\mu 2p_{20} \delta(\vec{p}_2 - \vec{p}'_2) 2p_{30} \delta(\vec{p}_3 - \vec{p}'_3) \delta_{\sigma_2 \sigma'_2} \delta_{\sigma_3 \sigma'_3}$$

and

$$G_{\pi NN}(Q^2) = \frac{1}{f_{\pi NN}} \frac{m_\pi \sqrt{2\pi}}{\sqrt{2M_N}} \frac{\sqrt{E'_N + M'_N}}{E'_N + M'_N + \omega} \frac{F_{i \rightarrow f}}{Q_z}$$

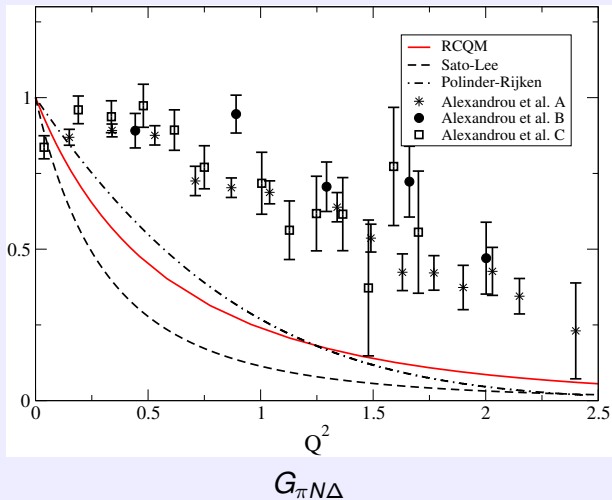
$$G_{\pi N\Delta}(Q^2) = -\frac{1}{f_{\pi N\Delta}} \frac{3\sqrt{2\pi}}{2} \frac{m_\pi}{\sqrt{E'_N + M'_N} \sqrt{2M_\Delta}} \frac{F_{i \rightarrow f}}{Q_z}$$

# $\pi NN$ Interaction Vertices



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

# $\pi N\Delta$ Interaction Vertices



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

# Form-Factor Parametrizations

$$G(\vec{q}^2) = \frac{1}{1 + \left(\frac{\vec{q}}{\Lambda_1}\right)^2 + \left(\frac{\vec{q}}{\Lambda_2}\right)^4}$$

$$G(Q^2) = \frac{1}{1 + \left(\frac{Q}{\Lambda}\right)^2}$$

|         |                           | RCQM   | SL    | PR    |           | LIU    | ERK    | ALX    |
|---------|---------------------------|--------|-------|-------|-----------|--------|--------|--------|
| Decays  | $N$                       |        |       |       | $\Lambda$ |        |        |        |
|         | $\frac{f_N^2}{4\pi}$      | 0.0691 | 0.08  | 0.075 |           | 0.0649 | 0.0481 | 0.0412 |
|         | $\Lambda_1$               | 0.451  | 0.453 | 0.940 |           | 0.747  | 0.614  | 1.65   |
|         | $\Lambda_2$               | 0.931  | 0.641 | 1.102 |           | -      | -      | -      |
| Summary | $\Delta$                  |        |       |       |           |        |        |        |
|         | $\frac{f_\Delta^2}{4\pi}$ | 0.188  | 0.334 | 0.478 |           |        |        |        |
|         | $\Lambda_1$               | 0.594  | 0.458 | 0.853 |           |        |        |        |
|         | $\Lambda_2$               | 0.998  | 0.648 | 1.014 |           |        |        |        |

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