The Bareness of Constituent Quark Models

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Project P19035, Structure of Baryon Resonances

Collaborators:
L. Canton (Padova), W. Plessas (Graz)

Outline

Constituent Quark Models

as effective models for baryons at low-energy

Relevant Degrees of Freedom

massive constituent quarks with model-interaction

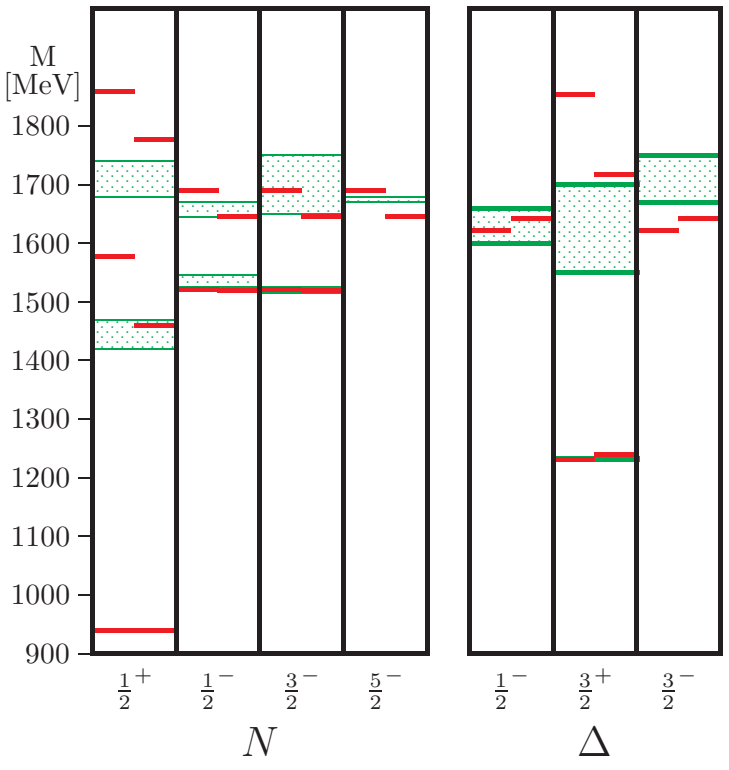
Description of Baryon Properties

Baryons: 3q-eigenstates of (invariant) mass operator

Dynamical properties: extracted from transition amplitudes

Relativity: Apparently required for realistic description

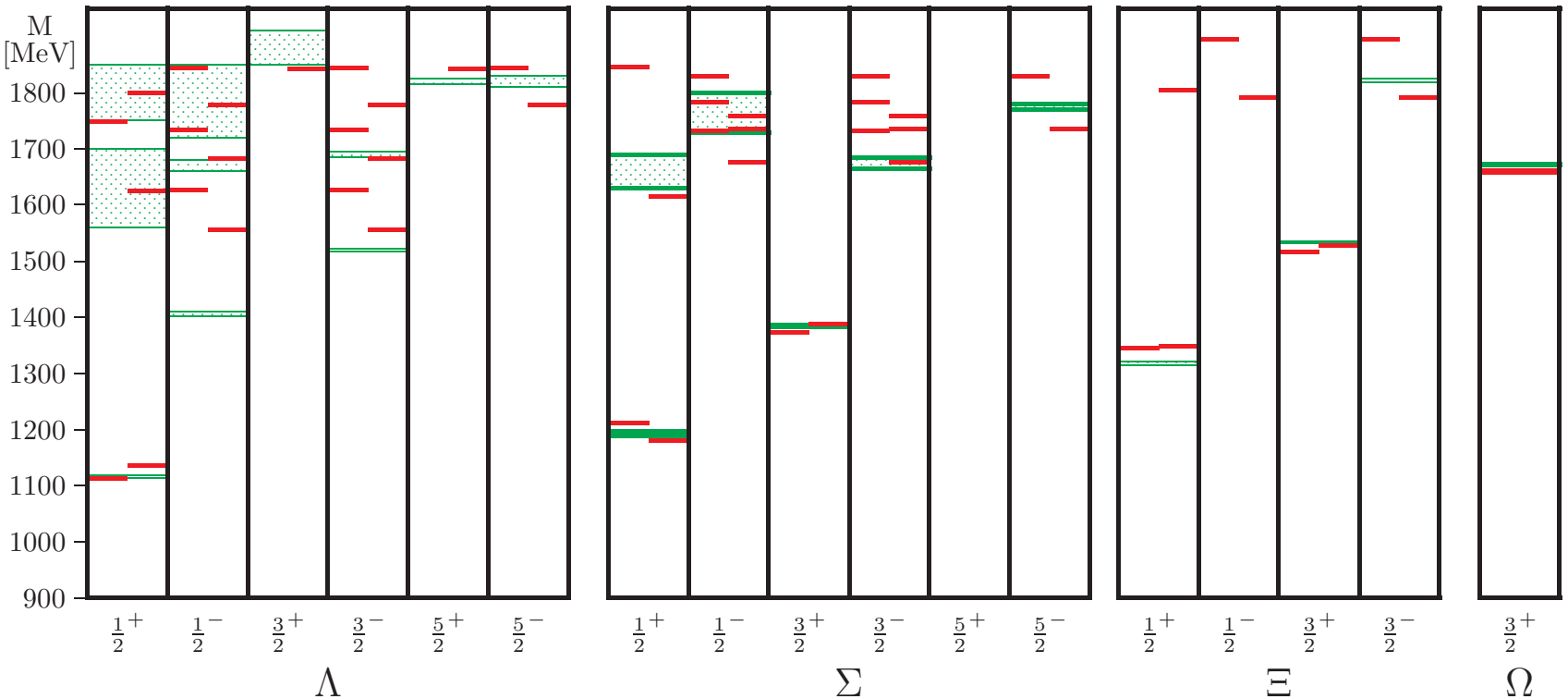
CQM Nucleon and Delta Spectra Comparison



Left Red: Bhaduri-Cohler-Nogami (OGE), Right Red: Goldstone-Boson Exchange,

Green: Experiment (PDG)

CQM Hyperon Spectra Comparison



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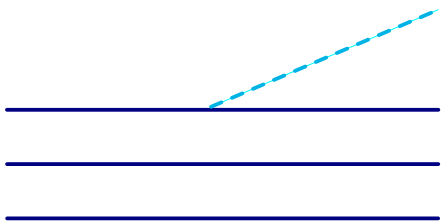
Point-Form Spectator Model (PFSM)
in Relativistic Quantum Mechanics (RQM)

RQM: Hamiltonian $\longrightarrow$ invariant mass operator

Point-Form: kinematic subgroup is Lorentz-group

Spectator Model:



- Meson couples to quark 1, quarks 2 and 3 are spectators

momentum transfer: $p_1^\mu - p_1'^\mu = \tilde{q}^\mu \neq Q^\mu = P^\mu - P'^\mu$

$\longrightarrow$ PFSM includes effective many-body contributions!

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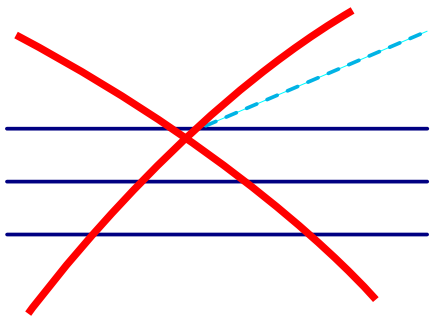

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$\longrightarrow$ PFSM includes effective many-body contributions!

Strategy to define PFSM

- Formal definition of vertex and spectator-constraints
- Adjust expression to satisfy global constraints and sensible limit-behaviours for transition amplitudes

T. M., K. Berger, L. Canton, W. Plessas, R. F. Wagenbrunn, Phys. Rev. D**76**, 074020 (2007)

$\longrightarrow$ Poincaré-invariance

PFSM results for electromagnetic nucleon form factors

→ Relativistic predictions are generally close to experiment

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PFSM results for partial decay widths

→ Relativistic decay predictions generally too small

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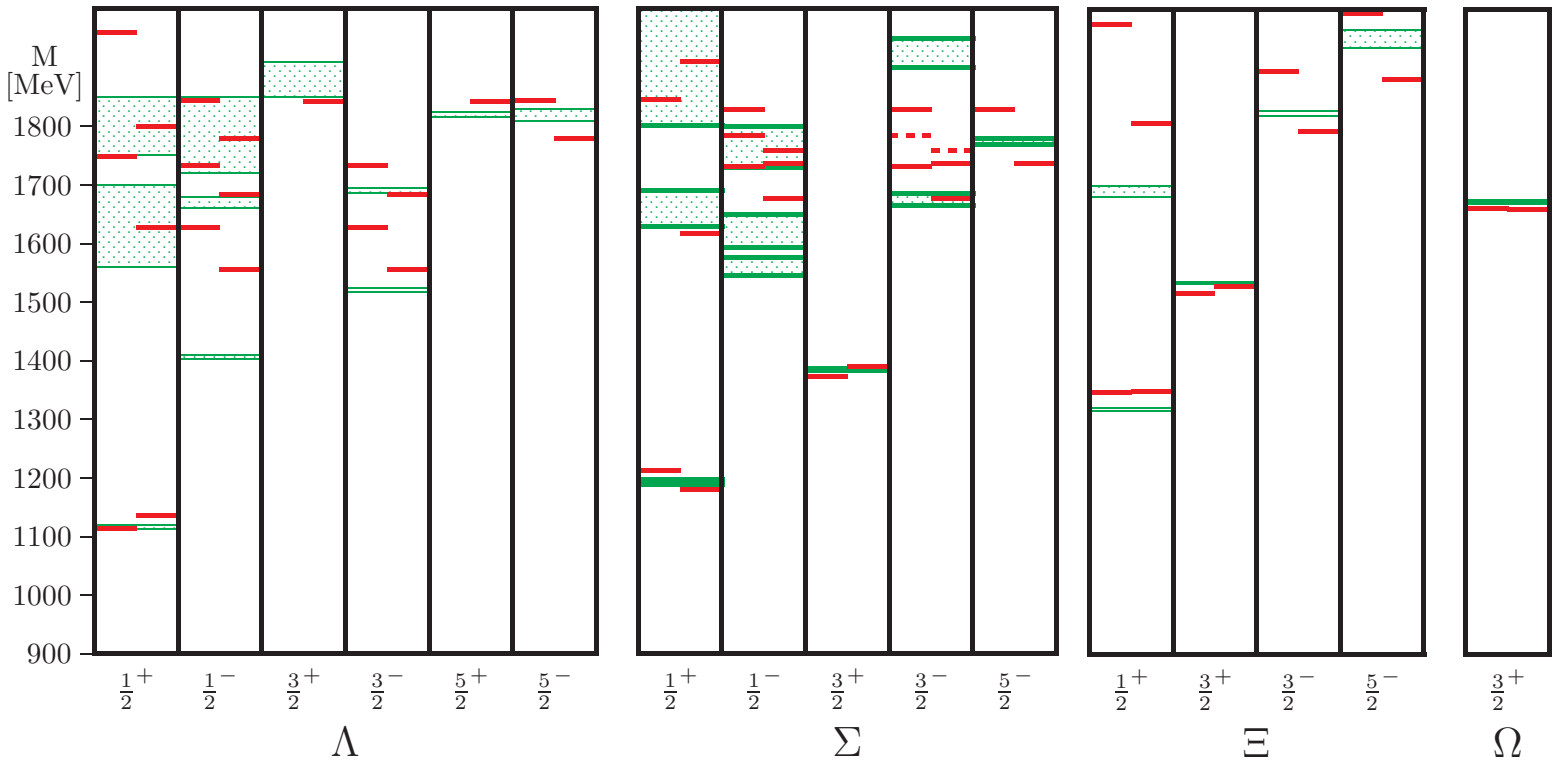
Hyperon Spectra Including 2-star Resonances



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But ... deficiency in strong decays still needs to be explained!

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Hypothesis

- Relativistic CQMs yield **bare** baryon results!

→ Resonances are so far described as invariant *bound states*

Implications

- Experimental data might not (yet) be reproduced
  (indeed our theoretical strong decays are too small)

→ Hadronic dressing needs to be implemented consistently

→ Baryon masses are expected to shift (considerably)

→ Relativistic CQMs only provide intermediate results!

Advantages

- Hopefully a better description of the experimental data
  (especially for strong decays)

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Connection between structure and reaction models

- Compare RCQM results with **bare inputs** in dynamical hadron reaction models (e.g. Sato-Lee, Polinder-Rijken)

→ Devise hadron reaction model consistent with RCQM

RCQM specific challenges

- Double-counting problem needs to be addressed
  (multi-body structure of PFSM is the key)
- Off-shell extension must be consistent
  (all particles remain on mass shell, energy not conserved)

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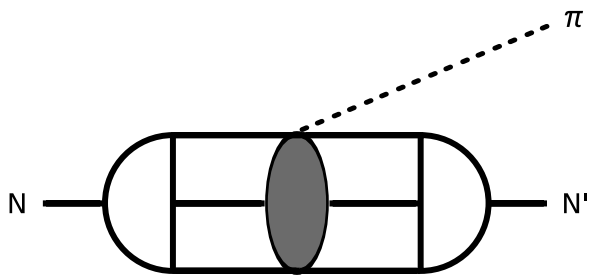
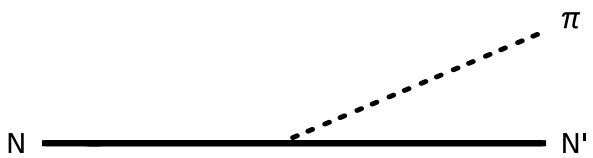
Structure of meson-baryon interaction vertices



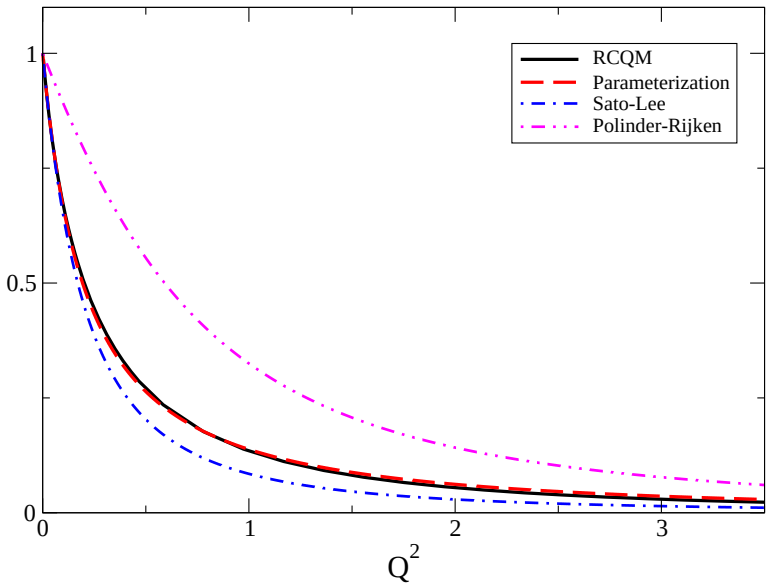


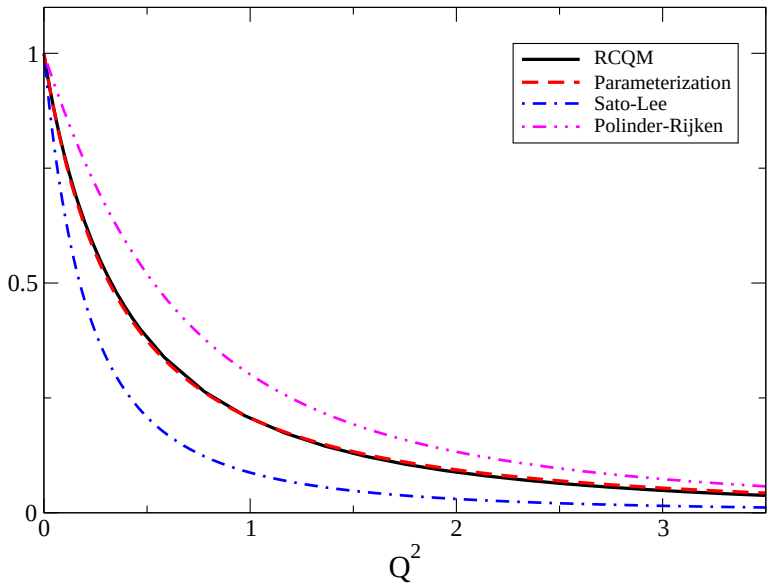
Form factors (in rest-frame of initial resonance)

$$G_{\pi NN} = \frac{1}{f_{\pi NN}} \frac{m_\pi \sqrt{2\pi}}{\sqrt{2M_N}} \frac{\sqrt{E'_N + M'_N}}{E'_N + M'_N + \omega} \frac{F^{\mathrm{RCQM}}_{i\to f}}{Q_z}$$

$$G_{\pi N\Delta} = -\frac{1}{f_{\pi N\Delta}} \frac{3\sqrt{2\pi}}{2} \frac{m_\pi}{\sqrt{E'_N + M'_N}\sqrt{2M_\Delta}} \frac{F^{\mathrm{RCQM}}_{i\to f}}{Q_z}$$

Relativistic Nucleon and Delta Vertex Functions





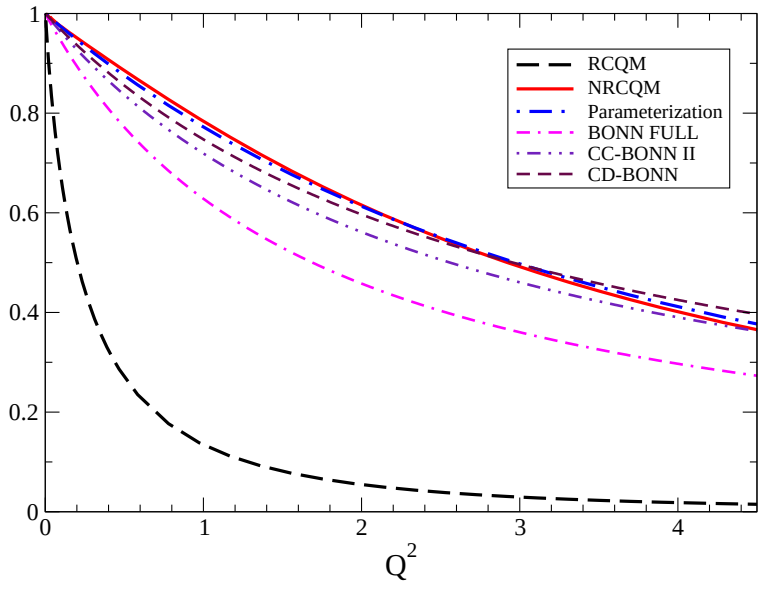
Parameterization

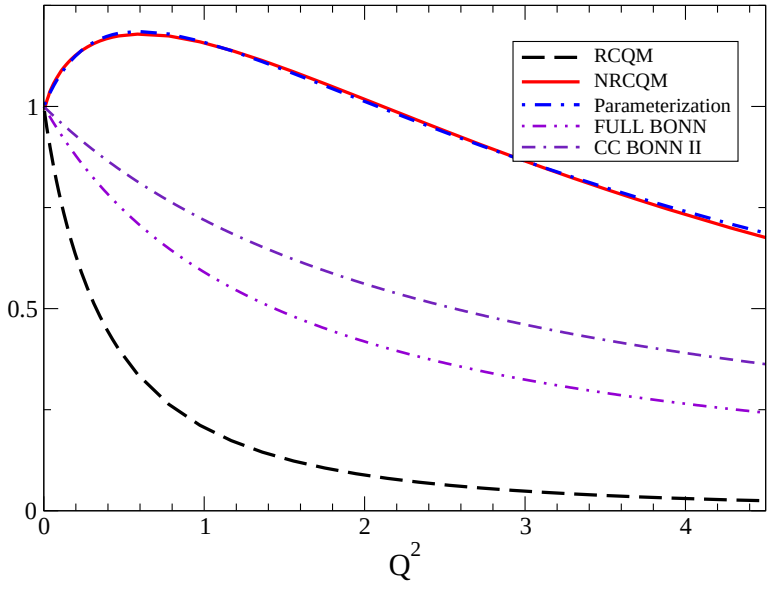
$$G\left(\vec{Q}^2\right) = \frac{1}{1 + \left(\frac{\vec{Q}}{\Lambda_1}\right)^2 + \left(\frac{\vec{Q}}{\Lambda_2}\right)^4}$$

		RCQM	SL	PR
N	$\frac{f_N^2}{4\pi}$	0.0691	0.08 / 0.08	0.013 / 0.075
	Λ_1	0.451	0.453	0.940
	Λ_2	0.931	0.641	1.102
Δ	$\frac{f_\Delta^2}{4\pi}$	0.188	0.334 / 0.434	0.167 / 0.478
	Λ_1	0.594	0.458	0.853
	Λ_2	0.998	0.648	1.014

Nonrelativistic limit of the vertex functions

Nonrelativistic Nucleon and Delta Vertex Functions



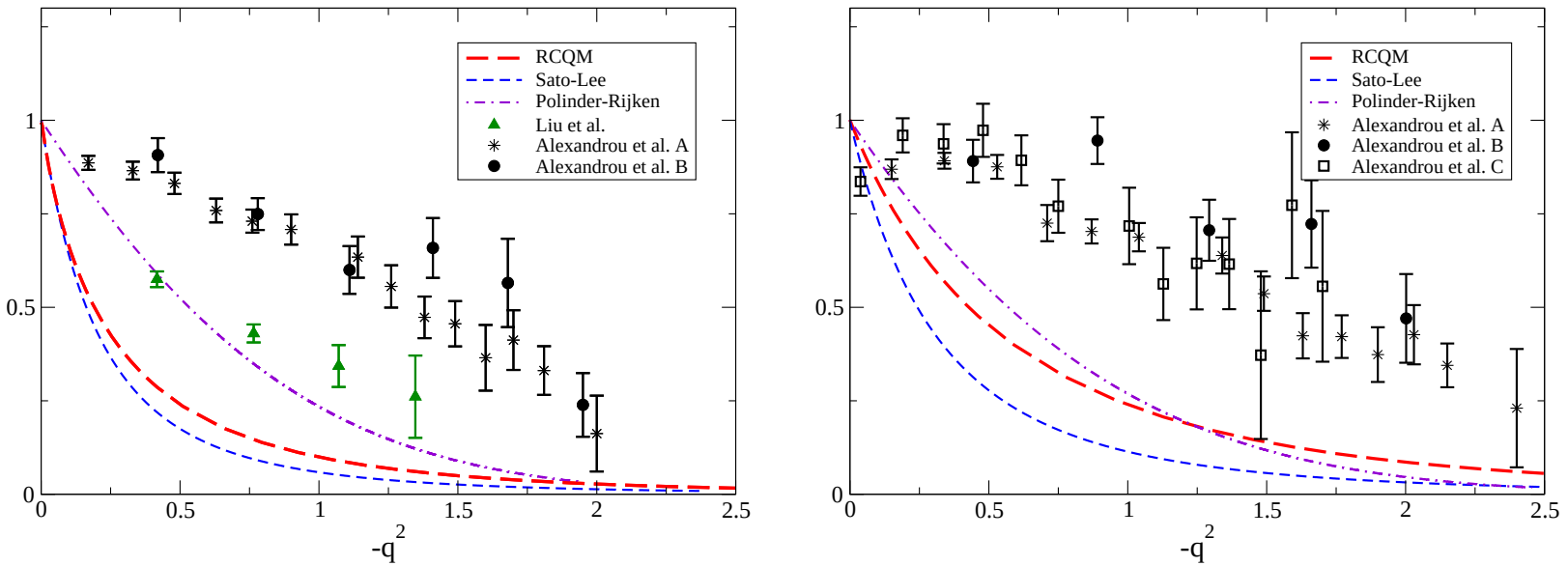


Parameterization

	CQM	BONN FULL	CC-BONN II	CD-BONN
N				
$\frac{f^2_{NN\pi}}{4\pi}$	0.084	0.079	0.079	0.075
Λ_1	1.91	1.3	1.6	1.72
Λ_2	2.63	∞	∞	
Δ				
$\frac{f^2_{\Delta N\pi}}{4\pi}$	0.235	0.224	0.35	
Λ_1	0.785($\star$)	1.2	1.6	
Λ_2	2.90($\star$)	∞	∞	

$$(\star)\ f_{\Delta N\pi} G\left(\vec{Q}^2\right) = -\frac{A}{1+\left(\frac{\vec{Q}}{\Lambda_1}\right)^2} + B\left(\frac{1}{1+\left(\frac{\vec{Q}}{\Lambda_2}\right)^2}\right)^2$$

Comparison to Lattice Results



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

C. Alexandrou, *et al.* A: $m_\pi = 0.411$, quenched
C. Alexandrou, *et al.* B: $m_\pi = 0.384$, dynamical
C. Alexandrou, *et al.* C: $m_\pi = 0.353$, hybrid

Summary

- Hypothesis: RCQMs provide bare baryon properties

→ First meson-baryon interaction vertices in line with phenomenological meson-baryon models

Road Map and Wish List

- Further meson-baryon Interactions (especially in strange sector)
- Consistent meson-baryon model starting from RCQM
- Energy shifts due to hadron dressing
- Refitting of baryon spectra (with bootstrap method)
- Recalculation of electromagnetic nucleon form factors
- Recalculation of strong baryon decays

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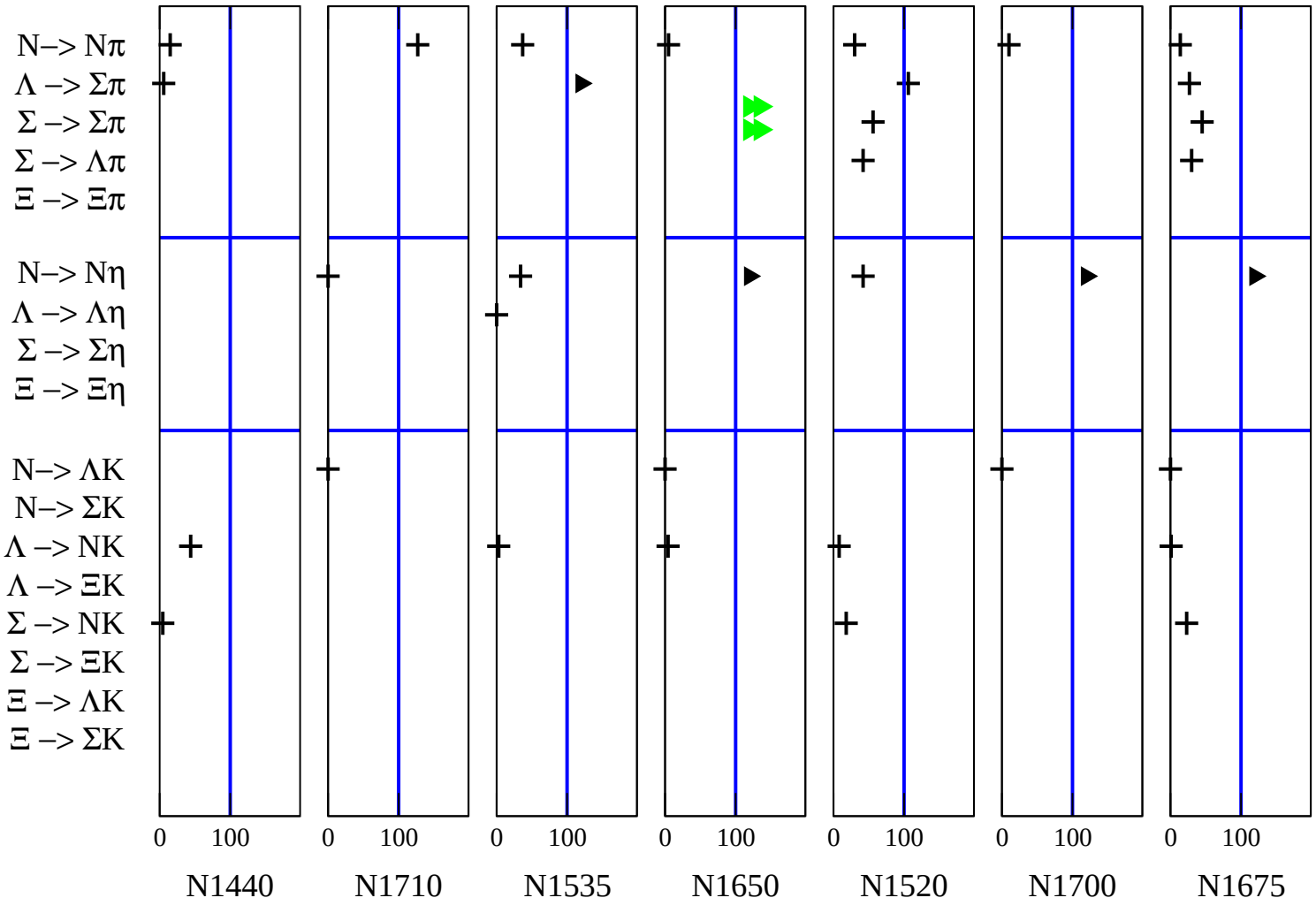
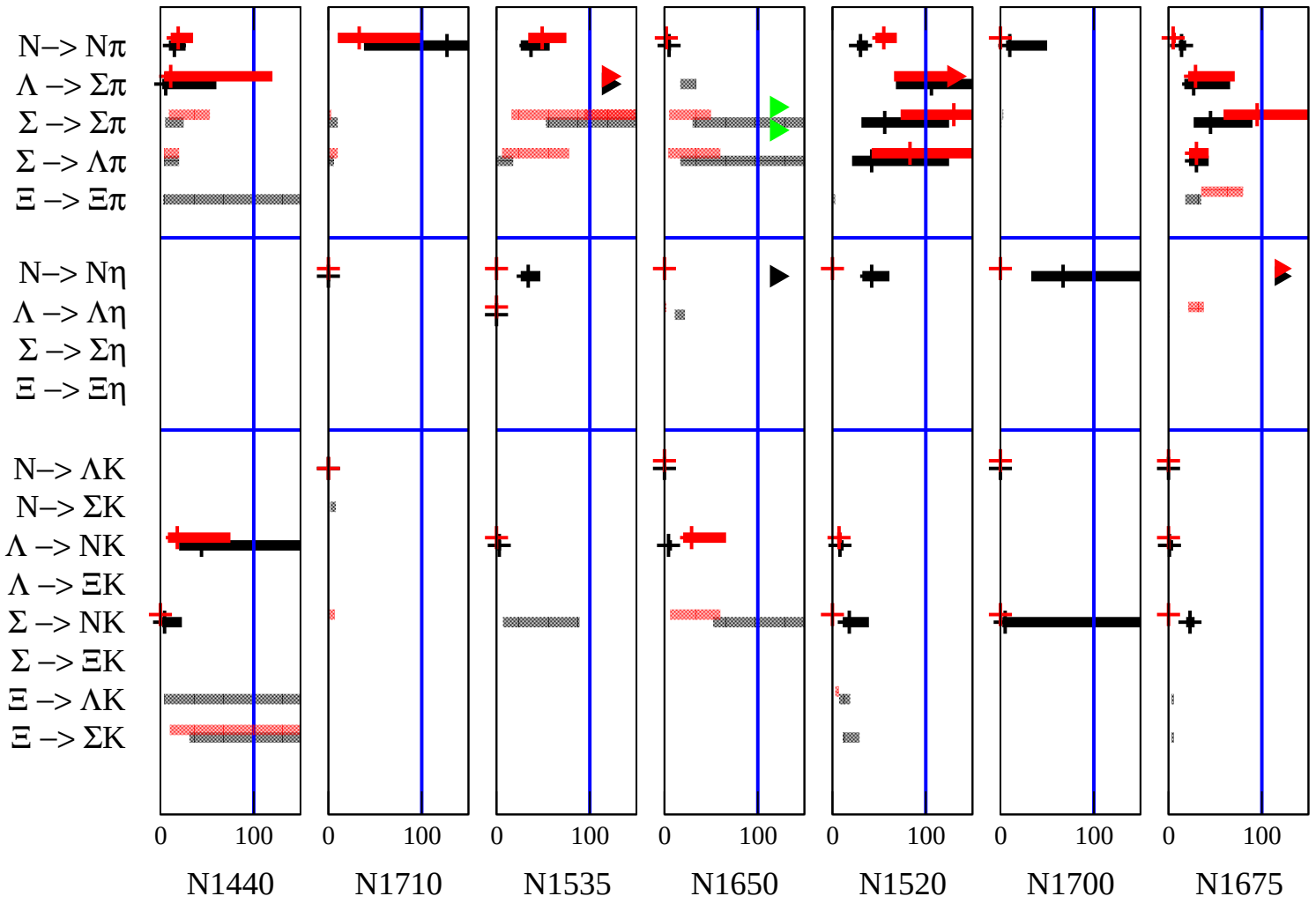
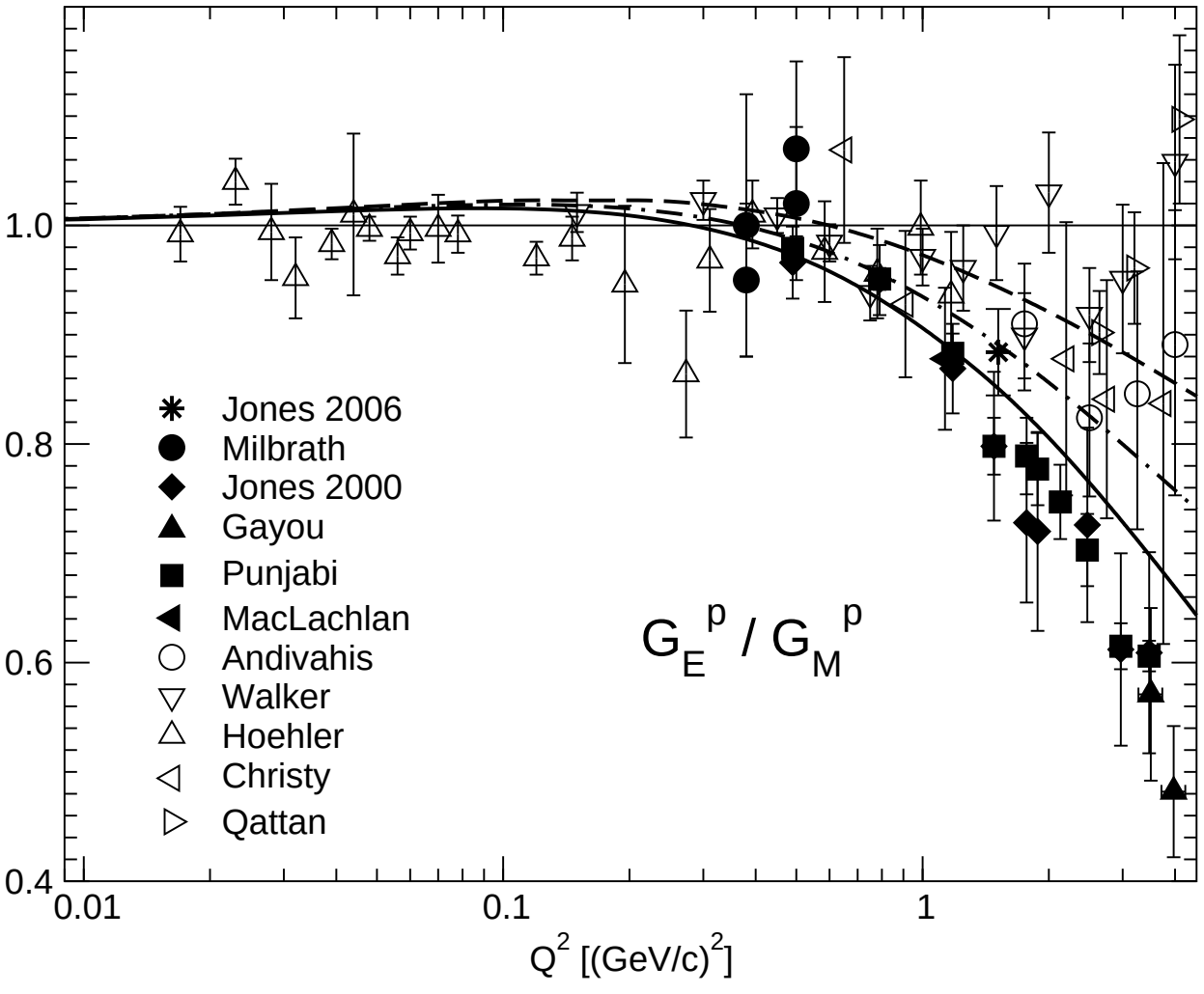
Decay Systematics / Estimates



Decay Systematics / Bonn Comparison



Electric/Magnetic Form Factor Ratio of the Proton



Poincaré Invariant Mesonic Decays

Decay Width

$$\Gamma_{i\to f} = \frac{|\mathbf{q}|}{4M^2}\,\frac{1}{2\Sigma+1}\frac{1}{2T+1}\sum_{M_\Sigma,M_{\Sigma'}}\sum_{M_T,M_{T'},M_{T_m}}|F_{i\to f}|^2$$

$\frac{|\mathbf{q}|}{4M^2}$: phase-space factor

$|F_{i\to f}|^2$: transition amplitude

Transition Amplitude

$$F_{i\to f} = \langle M', \mathbf{V}', \Sigma', M_{\Sigma'}, T', M_{T'}|\hat{D}^m_{rd}|M, \mathbf{V}, \Sigma, M_\Sigma, T, M_T\rangle$$

$\hat{D}^m_{rd}$: mesonic decay operator

Poincaré Invariant Transition Amplitude

$$\left\langle V',M',J',\Sigma'\right|\hat{O}\left|V,M,J,\Sigma\right\rangle = \frac{2}{MM'}\sum_{\sigma_i\sigma_i'}\sum_{\mu_i\mu_i'}\int d^3\vec{k}_2 d^3\vec{k}_3 d^3\vec{k}_2' d^3\vec{k}_3'$$

$$\sqrt{\frac{\left(\omega_1+\omega_2+\omega_3\right)^3}{2\omega_1 2\omega_2 2\omega_3}}\sqrt{\frac{\left(\omega_1'+\omega_2'+\omega_3'\right)^3}{2\omega_1' 2\omega_2' 2\omega_3'}}$$

$$\Psi^{\star}_{M'J'\Sigma'}\left(\vec{k}_i';\mu_i'\right)\prod_{\sigma_i'}D^{\star\frac{1}{2}}_{\sigma_i'\mu_i'}\left\{R_W\left[k_i';B\left(V'\right)\right]\right\}$$

$$\left\langle p_1',p_2',p_3';\sigma_1',\sigma_2',\sigma_3'\right|\hat{O}_{\mathrm{rd}}\left|p_1,p_2,p_3;\sigma_1,\sigma_2,\sigma_3\right\rangle$$

$$\prod_{\sigma_i}D^{\frac{1}{2}}_{\sigma_i\mu_i}\left\{R_W\left[k_i;B\left(V\right)\right]\right\}\Psi_{MJ\Sigma}\left(\vec{k}_i;\mu_i\right)$$

$$2MV_0\delta^3\left(M\vec{V}-M'\vec{V}'-\vec{Q}\right)$$

Point-Form Spectator Model

$$\langle p_1', p_2', p_3'; \sigma_1', \sigma_2', \sigma_3' | \hat{D}_{rd}^{pv,m} | p_1, p_2, p_3; \sigma_1, \sigma_2, \sigma_3 \rangle$$

$$= -3\mathcal{N} \frac{i\, g_{qqm}}{m_1 + m_1'} \frac{1}{\sqrt{2\pi}} \bar{u}(p_1', \sigma_1') \gamma_5 \gamma^\mu \mathcal{F}^m u(p_1, \sigma_1) q_\mu$$

$$\times 2p_{20}\delta^3\left(\mathbf{p}_2 - \mathbf{p}_2'\right) \delta_{\sigma_2\sigma_2'} 2p_{30}\delta^3\left(\mathbf{p}_3 - \mathbf{p}_3'\right) \delta_{\sigma_3\sigma_3'}$$

$pv \cdots$ pseudovector coupling

- Meson couples to quark 1, quarks 2 and 3 are spectators
- Spectator conditions together with overall momentum conservation determine momentum transfer $\tilde{q}^\mu = p_1^\mu - p_1'^\mu \neq q^\mu$ to meson-emitting quark
- PFSM provides effective many-body operator!