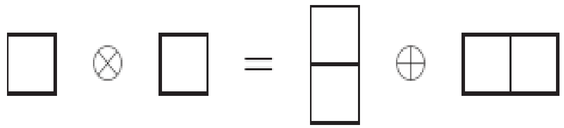
The Interacting Quark Diquark Model

qD model

▪ Diquark

- Two strongly correlated quarks (S wave)

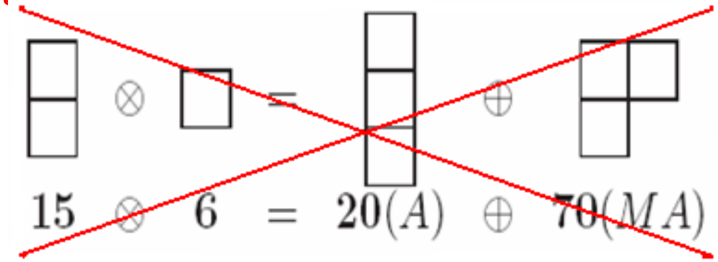
- Baryon in 1_c color representazion → diquark in bar-3_c
- Diquark WF:

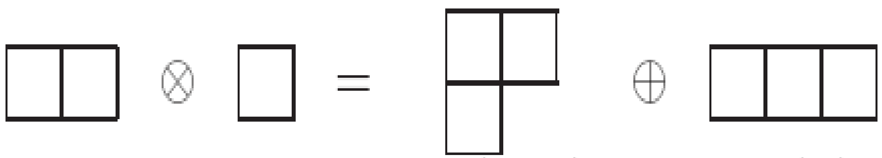


$$6 \otimes 6 = 15 \oplus 21$$

Ψ_D (spin-flavor) antysymmetric → 15 (A) repr. not present

- **SU(6) representations for baryons**





$$21 \otimes 6 = 70(MS) \oplus 56(S)$$

- Problem of missing resonances

Scalar & axial-vector diquarks

- **21 $SU(6)_{sf}$ representation**
  - Decomposed in $SU(2)_s$ x $SU(3)_f$
  - [bar-3,0] & [6,1] representations. Notation: [flavor,spin]

- **“Good” & “bad” diquarks**
  - According to OGE-calculations, [bar-3,0] is energetically favored [Wilczek, Jaffe]
  - [bar-3,0]: good (scalar) diquark
  - [6,1]: bad (axial-vector) diquark

Problem of missing resonances

▪ 3-quark QMs

▪ Excessive number of th. states (much more than experimental ones)

▪ Several experiments (CLAS, CB-ELSA, TAPS, GRAAL, SAPHIR, etc.) provided no evidence for these states.

▪ Possible explanation: resonances weakly coupled to the single pion, may decay in 2 (or more) pions/other mesons.

• qD models

• The number of missing resonances decreases notably

• 15 representation for diquark is neglected

Evidences of diquark correlations

- **Regge behavior of hadrons**

  Baryons arranged in rotational Regge trajectories ($J=\alpha+\alpha' M2$) with the same slope of the mesonic ones.

- **$\Delta I = 1/2$ rule in weak nonleptonic decays**

  Neubert and Stech, Phys. Lett. B **231** (1989) 477; Phys. Rev. D **44** (1991) 775

- **Regularities in parton distribution functions and in spin-dependent structure functions**

  Close and Thomas, Phys. Lett. B **212** (1988) 227

- **Regularities in $\Lambda(1116)$ and $\Lambda(1520)$ fragmentation functions**

  Jaffe, Phys. Rept. **409** (2005) 1 [Nucl. Phys. Proc. Suppl. **142** (2005) 343]
  Wilczek, hep-ph/0409168

- **Any interaction that binds π and ρ mesons in the rainbow-ladder approximation of the DSE will produce diquarks**

  Cahill, Roberts and Praschifka, Phys. Rev. D **36** (1987) 2804

- **Indications of diquark confinement**

  Bender, Roberts and Von Smekal, Phys. Lett. B **380** (1996) 7

the Interacting qD model

E. Santopinto, PRC72, 022201 (2005)

- **Hamiltonian**

$$H = \frac{p^2}{2m} - \frac{\tau}{r} + \beta r + [B\delta_{S_{12},1} + C\delta_0] +$$

$$+ (-1)^{l+1} 2Ae^{-\alpha r}[(\vec{s}_{12} \cdot \vec{s}_3) + (\vec{t}_{12} \cdot \vec{t}_3) + (\vec{s}_{12} \cdot \vec{s}_3)(\vec{t}_{12} \cdot \vec{t}_3)]$$

- **Non-rel. Kinetic energy + Coulomb + linear confining terms**
- **Splitting between scalar & axial-vector diquarks**
- **Exchange potential**
-

Rel. Interacting qD model

J. Ferretti, E. Santopinto & A. Vassallo, PRC83, 065204 (2011)

- **Relativistic extension of the previous model (point-form formalism).**

$$M = E_0 + \sqrt{q^2 + m_1^2} + \sqrt{q^2 + m_2^2} + M_{\text{dir}}(r) + M_{\text{cont}}(r) + M_{\text{ex}}(r),$$

$$M_{\text{dir}}(r) = -\frac{\tau}{r}(1 - e^{-\mu r}) + \beta r.$$

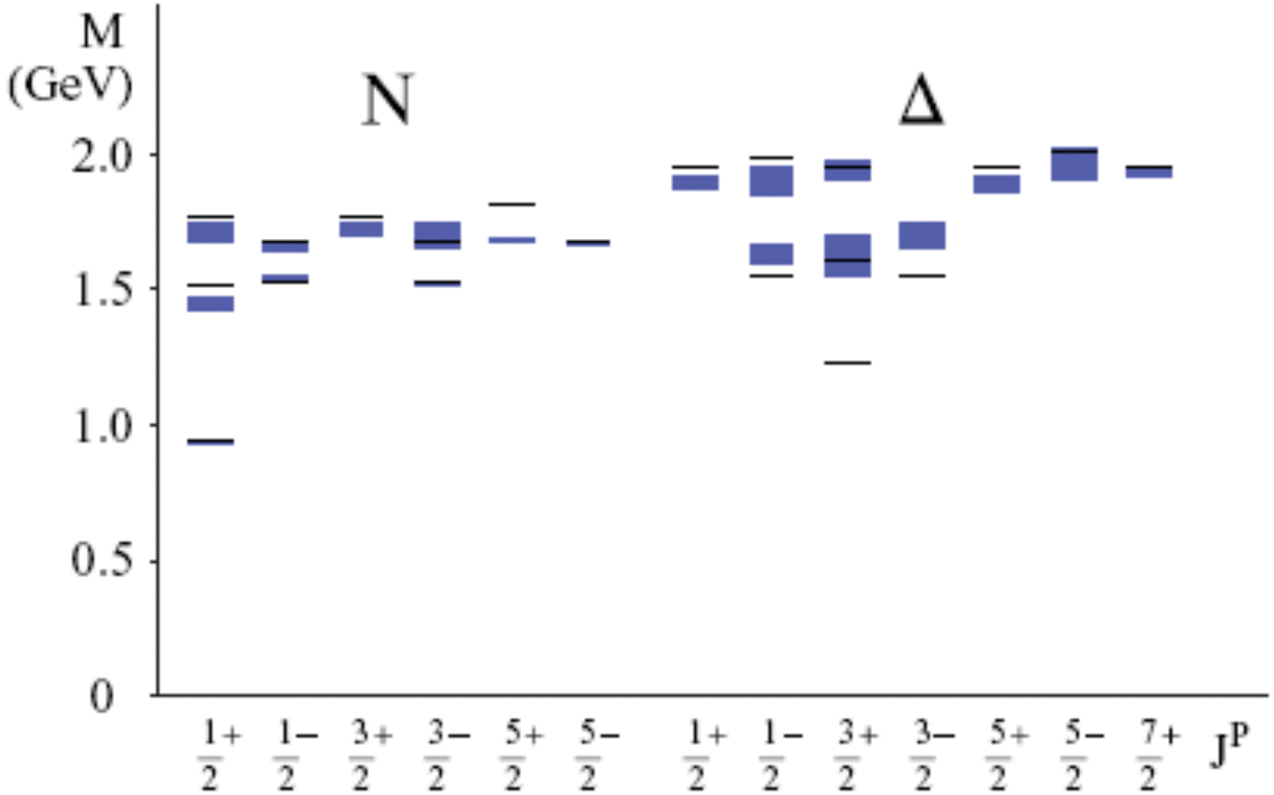
$$M_{\text{ex}}(r) = (-1)^{l+1} e^{-\sigma r}[A_S(\vec{s}_1 \cdot \vec{s}_2) + A_I(\vec{t}_1 \cdot \vec{t}_2) + A_{SI}(\vec{s}_1 \cdot \vec{s}_2)(\vec{t}_1 \cdot \vec{t}_2)],$$

$$M_{\text{cont}} = \left(\frac{m_1 m_2}{E_1 E_2}\right)^{1/2+\epsilon} \frac{\eta^3 D}{\pi^{3/2}} e^{-\eta^2 r^2}\, \delta_{L,0}\delta_{s_1,1} \left(\frac{m_1 m_2}{E_1 E_2}\right)^{1/2+\epsilon}$$

- **Numerical solution with variational program**
- **Parameters fitted to nonstrange baryon spectrum**

Rel. Interacting qD model

J. Ferretti, E. Santopinto & A. Vassallo, PRC83, 065204 (2011)



Resonance	Status	M^{expt} (MeV)	J^P	L^P	S	s_1	n_r	M^{calc} (MeV)
$N(939)\ P_{11}$	****	939	$\frac{1}{2}^+$	0^+	$\frac{1}{2}$	0	0	939
$N(1440)\ P_{11}$	****	1420–1470	$\frac{1}{2}^+$	0^+	$\frac{1}{2}$	0	1	1513
$N(1520)\ D_{13}$	****	1515–1525	$\frac{3}{2}^-$	1^-	$\frac{1}{2}$	0	0	1527
$N(1535)\ S_{11}$	****	1525–1545	$\frac{1}{2}^-$	1^-	$\frac{1}{2}$	0	0	1527
$N(1650)\ S_{11}$	****	1645–1670	$\frac{1}{2}^-$	1^-	$\frac{1}{2},\frac{3}{2}$	1	0	1671
$N(1675)\ D_{15}$	****	1670–1680	$\frac{5}{2}^-$	1^-	$\frac{3}{2}$	1	0	1671
$N(1680)\ F_{15}$	****	1680–1690	$\frac{5}{2}^+$	2^+	$\frac{1}{2}$	0	0	1808
$N(1700)\ D_{13}$	***	1650–1750	$\frac{3}{2}^-$	1^-	$\frac{1}{2},\frac{3}{2}$	1	0	1671
$N(1710)\ P_{11}$	***	1680–1740	$\frac{1}{2}^+$	0^+	$\frac{1}{2}$	1	0	1768
$N(1720)\ P_{13}$	****	1700–1750	$\frac{3}{2}^+$	0^+	$\frac{3}{2}$	1	0	1768
$\Delta(1232)\ P_{33}$	****	1231–1233	$\frac{3}{2}^+$	0^+	$\frac{3}{2}$	1	0	1233
$\Delta(1600)\ P_{33}$	***	1550–1700	$\frac{3}{2}^+$	0^+	$\frac{3}{2}$	1	1	1602
$\Delta(1620)\ S_{31}$	****	1600–1660	$\frac{1}{2}^-$	1^-	$\frac{1}{2}$	1	0	1554
$\Delta(1700)\ D_{33}$	****	1670–1750	$\frac{3}{2}^-$	1^-	$\frac{1}{2}$	1	0	1554
$\Delta(1900)\ S_{31}$	**	1850–1950	$\frac{1}{2}^-$	1^-	$\frac{1}{2}$	1	1	1986
$\Delta(1905)\ F_{35}$	****	1865–1915	$\frac{5}{2}^+$	2^+	$\frac{3}{2}$	1	0	1952
$\Delta(1910)\ P_{31}$	****	1870–1920	$\frac{1}{2}^+$	2^+	$\frac{3}{2}$	1	0	1952
$\Delta(1920)\ P_{33}$	***	1900–1970	$\frac{3}{2}^+$	2^+	$\frac{3}{2}$	1	0	1952
$\Delta(1930)\ D_{35}$	***	1900–2020	$\frac{5}{2}^-$	1^-	$\frac{3}{2}$	1	0	2005
$\Delta(1950)\ F_{37}$	****	1915–1950	$\frac{7}{2}^+$	2^+	$\frac{3}{2}$	1	0	1952
$N(2100)\ P_{11}$	*	1855–1915	$\frac{1}{2}^+$	0^+	$\frac{1}{2}$	0	2	1893
$N(2090)\ S_{11}$	*	1869–1987	$\frac{1}{2}^-$	1^-	$\frac{1}{2}$	0	1	1882
$N(1900)\ P_{13}$	**	1820–1974	$\frac{3}{2}^+$	2^+	$\frac{1}{2}$	0	0	1808
$N(2080)\ D_{13}$	**	1740–1940	$\frac{3}{2}^-$	1^-	$\frac{1}{2}$	0	1	1882
$\Delta(1750)\ P_{31}$	*	1708–1780	$\frac{1}{2}^+$	0^+	$\frac{1}{2}$	1	0	1858
$\Delta(1940)\ D_{33}$	*	1947–2167	$\frac{3}{2}^-$	1^-	$\frac{1}{2}$	1	1	1986

0 missing resonances below 2 GeV

Model Parameters

$m_q = 200$ MeV	$m_S = 600$ MeV	$m_{AV} = 950$ MeV
$\tau = 1.25$	$\mu = 75.0\ \text{fm}^{-1}$	$\beta = 2.15\ \text{fm}^{-2}$
$A_S = 375$ MeV	$A_I = 260$ MeV	$A_{SI} = 375$ MeV
$\sigma = 1.71\ \text{fm}^{-1}$	$E_0 = 154$ MeV	$D = 4.66\ \text{fm}^2$
$\eta = 10.0\ \text{fm}^{-1}$	$\epsilon = 0.200$	

Rel. Interacting qD model – strange B.

E. Santopinto & J. Ferretti, arXiv: 1412.7571

▪ Model

- Model extended to strange sector
- Hamiltonian:

$$M = E_0 + \sqrt{\vec{q}^{\,2} + m_1^2} + \sqrt{\vec{q}^{\,2} + m_2^2} + M_{\text{dir}}(r) + M_{\text{ex}}(r)$$

$$M_{\text{ex}}(r) = (-1)^{L+1}\; e^{-\sigma r}\left[A_S\, \vec{s}_1 \cdot \vec{s}_2 + A_F\, \vec{\lambda}_1^f \cdot \vec{\lambda}_2^f + A_I\, \vec{t}_1 \cdot \vec{t}_2\right]$$

$$M_{\text{dir}}(r) = -\frac{\tau}{r}(1 - e^{-\mu r}) + \beta r.$$

- Gursey-Radicati inspired exchange interaction
- Parameters fitted to strange baryon spectrum

Rel. Interacting qD model – strange B.

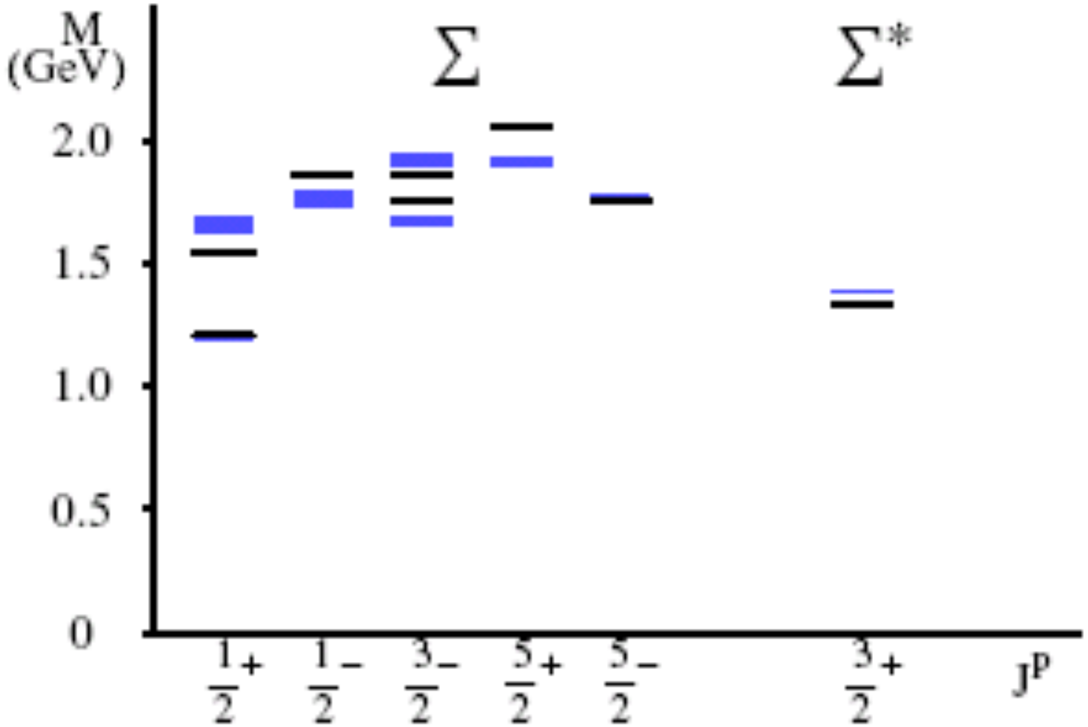
E. Santopinto & J. Ferretti, arXiv: 1412.7571

- Parameters

Parameter	Value (Fit 1)	Value (Fit 2)	Parameter	Value (Fit 1)	Value (Fit 2)
m_n	200 MeV	159 MeV	m_s	550 MeV	213 Mev
$m_{[n,n]}$	600 MeV	607 MeV	$m_{[n,s]}$	900 MeV	856 MeV
$m_{\{n,n\}}$	950 MeV	963 MeV	$m_{\{n,s\}}$	1200 MeV	1216 MeV
$m_{\{s,s\}}$	1580 MeV	1352 MeV	τ	1.20	1.02
μ	75.0 fm^{-1}	28.4 fm^{-1}	β	2.15 fm^{-2}	2.36 fm^{-2}
A_S	350 MeV	-436 MeV	A_F	100 MeV	193 MeV
A_I	250 MeV	791 MeV	σ	2.30 fm^{-1}	2.25 fm^{-1}
E_0	141 MeV	150 MeV	ϵ	0.37	–
D	6.13 fm^2	–	η	11.0 fm^{-1}	–

Rel. Interacting qD model – strange B.

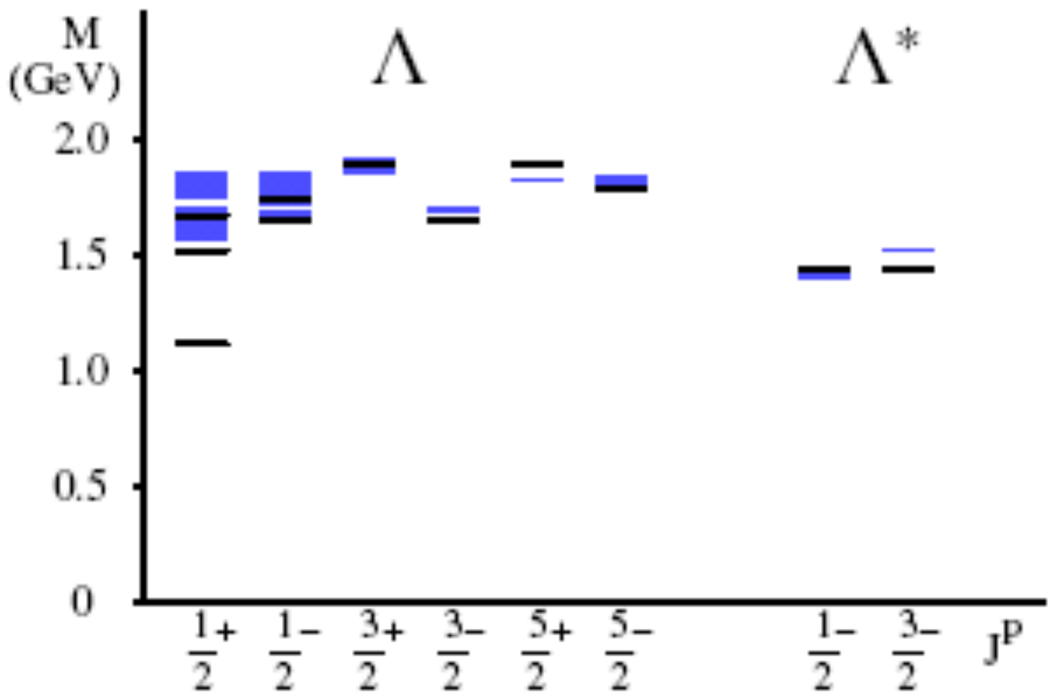
E. Santopinto & J. Ferretti, arXiv: 1412.7571

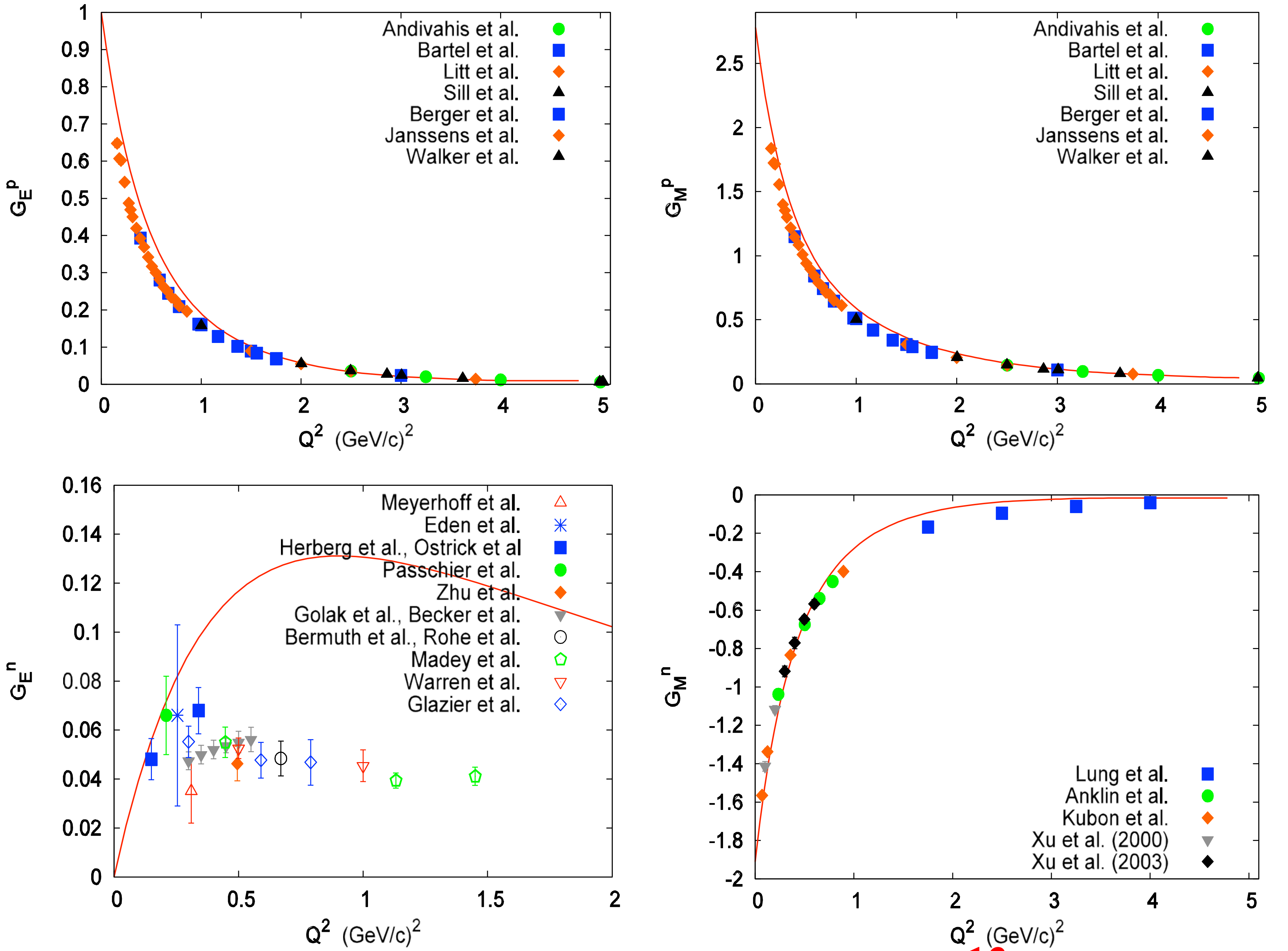


Rel. Interacting qD model

E. Santopinto & J. Ferretti, arXiv: 1412.7571

- **Lambda & Lambda* states**





G_E^p
Q^2 (GeV/c)^2
Andivahis et al.
Bartel et al.
Litt et al.
Sill et al.
Berger et al.
Janssens et al.
Walker et al.
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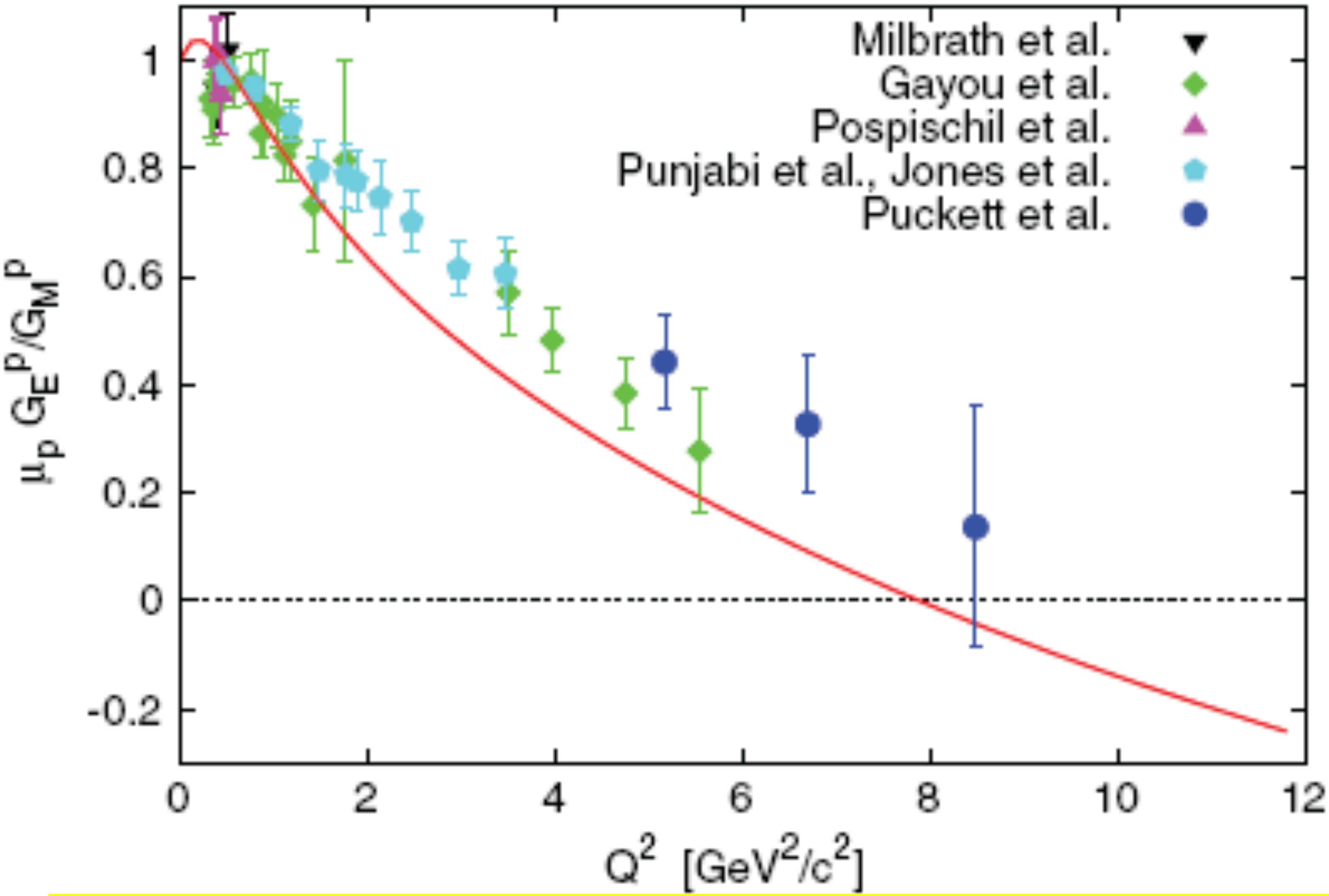
Berger et al.
Janssens et al.
Walker et al.
G_E^n
Q^2 (GeV/c)^2
Meyerhoff et al.
Eden et al.
Herberg et al., Ostrick et al
Passchier et al.
Zhu et al.
Golak et al., Becker et al.
Bermuth et al., Rohe et al.
Madey et al.
Warren et al.
Glazier et al.
G_M^n
Q^2 (GeV/c)^2
Lung et al.
Anklin et al.
Kubon et al.
Xu et al. (2000)
Xu et al. (2003)

Ratio $\mu_p\ G_E^p/G_M^p$

De Sanctis, Ferretti, Santopinto, Vassallo, Phys. Rev. C ***84****, 055201 (2011)*



Interacting Quark Diquark model , *E. Santopinto, Phys. Rev. C* ***72****, 022201(R) (2005)*

LQCD shows no q-diquark evidence of the type of the Lichtenberg Model.

q-diqu. m. does not mix different diquark configurations.

D. B. Lichtenberg and L. J. Tassie, Phys. Rev. 155, 1601 (1967).

$$M_{\mathrm{tr}}(r) = V_0 \; e^{-\frac{1}{2}\nu^2 r^2} (\vec{s}_2 \cdot \vec{S})(\vec{t}_2 \cdot \vec{T}) \;\; ,$$

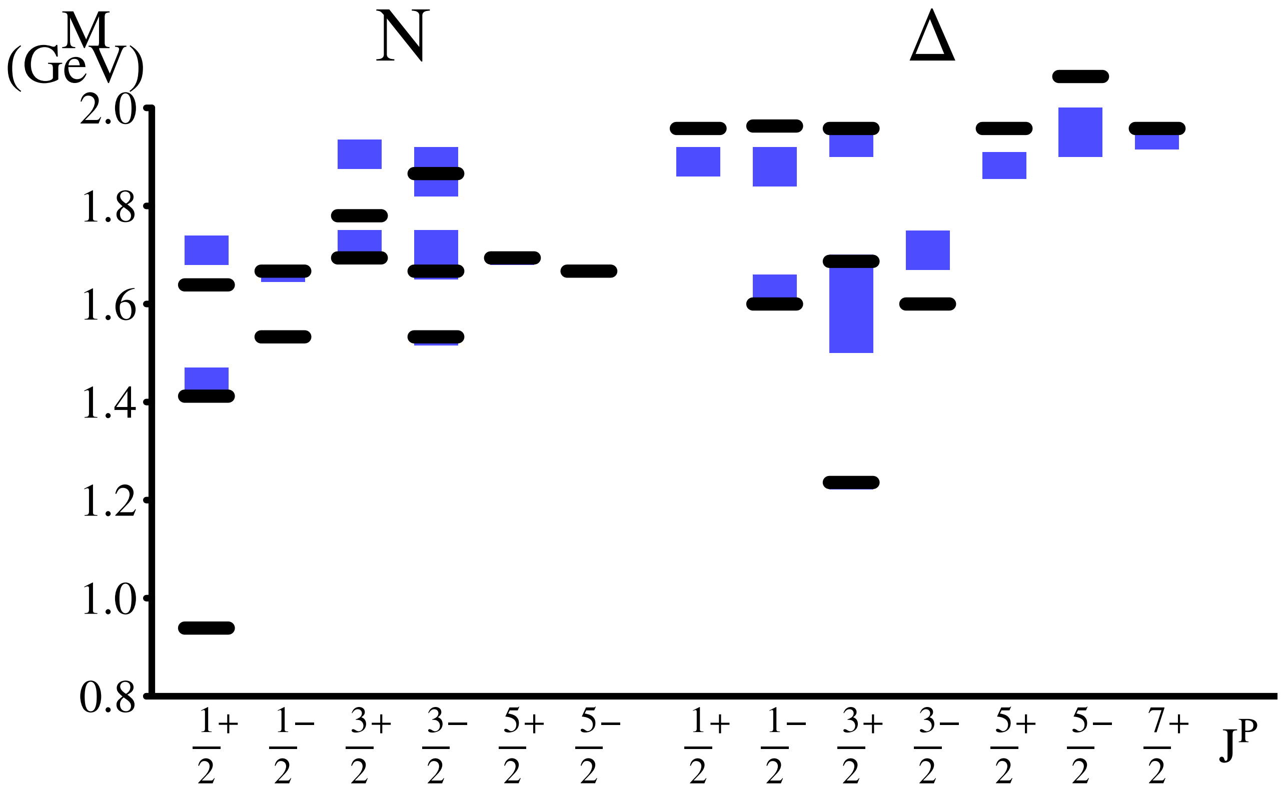
$$\langle \, s_1', m_{s_1}' \, | \, S_\mu^{[1]} \, | s_1, m_{s_1} \rangle \neq 0 \text{ for } s_1' \neq s_1 \;\; ,$$

$$\langle 1 \| \, S_1 \, \| 0 \rangle = 1 \;\; ,$$

$$\langle 0 \| \, S_1 \, \| 1 \rangle = -1$$

$$\begin{aligned} \langle \Phi' | \, M_{\mathrm{tr}} \, | \Phi \rangle \;\; &= \;\; \tfrac{1}{4} V_0 \delta_{s_1', s_1 \pm 1} \delta_{S \frac{1}{2}} \delta_{t_1', t_1 \pm 1} \delta_{T \frac{1}{2}} \\ &\times \;\; \langle \Phi'(\vec{r}) | \, e^{-\frac{1}{2}\nu^2 r^2} \, | \Phi(\vec{r}) \rangle \;\; , \end{aligned}$$

$$|N\rangle = a_S \, |q D_S, L = 0\rangle + a_{AV} \, |q D_{AV}, L = 0\rangle$$


M
(GeV)
N
Δ
2.0
1.8
1.6
1.4
1.2
1.0
0.8
1+/2
1−/2
3+/2
3−/2
5+/2
5−/2
1+/2
1−/2
3+/2
3−/2
5+/2
5−/2
7+/2
J^P

Thank you for your attention