Five-quark components in $N^*(1535)$

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Outline

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Introduction

Properties of $N(1535)$

Breit-Wigner mass=1525 to 1545 MeV;

Breit-Wigner full width=125 to 175 MeV;

Decay modes	Fraction (Γ_i/Γ)	p (Mev/c)
$N\pi$	$35-55\%$	468
$N\eta$	$45-60\%$	186
$N\pi\pi$	$1-10\%$	426
$p\gamma, helicity=1/2$	$0.15-0.35\%$	481
$n\gamma, helicity=1/2$	$0.004-0.29\%$	480

Data extracted from:

Particle Group Data, Phys. Lett. **B667**, 1 (2008).

Motivations

1. The inverse mass ordering of $N^*(1535)$ and $N^*(1440)$ predicted by CQM;

2. Strong $N^*(1535)K\Lambda$ and $N^*(1535)N\eta'$ coupling:

$$\frac{g_{N^*(1535)K\Lambda}}{g_{N^*(1535)p\eta}} = 1.3 \pm 0.3;$$

[B. C. Liu and B. S. Zou, Mass and $K\Lambda$ coupling of $N^*(1535)$, Phys. Rev. Lett., ***96****, 042002 (2006) .]*

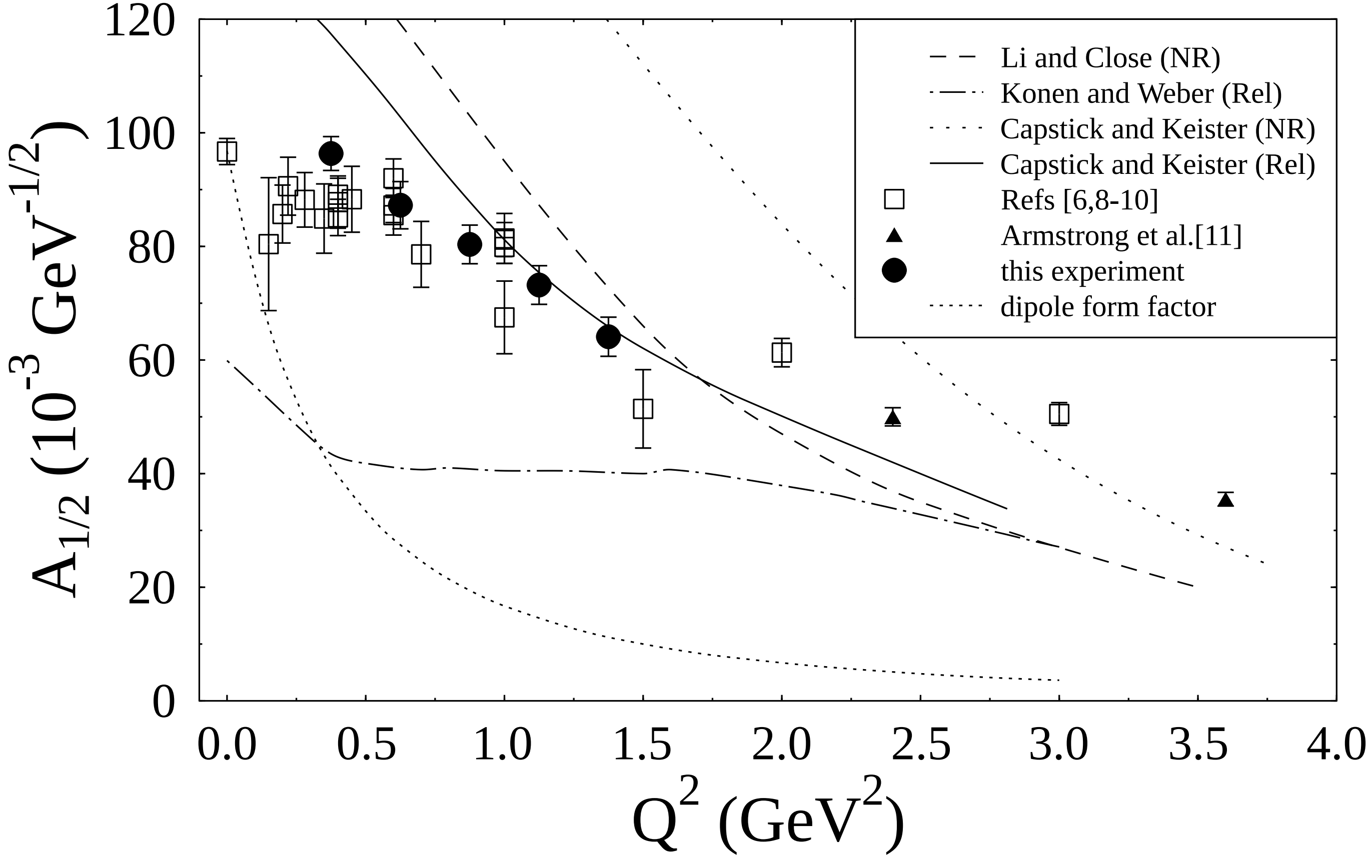
$$\frac{g^2_{N^*(1535)N\phi}}{4\pi} = 0.13;$$

[J. J. Xie and B. S. Zou, The role of $N^*(1535)$ in $pp \to pp\phi$ and $\pi p \to p\phi$ reactions, Phys. Rev. C ***77****, 015206 (2008) .]*

$$\frac{g^2_{N^*(1535)N\eta'}}{4\pi} = 1.15;$$

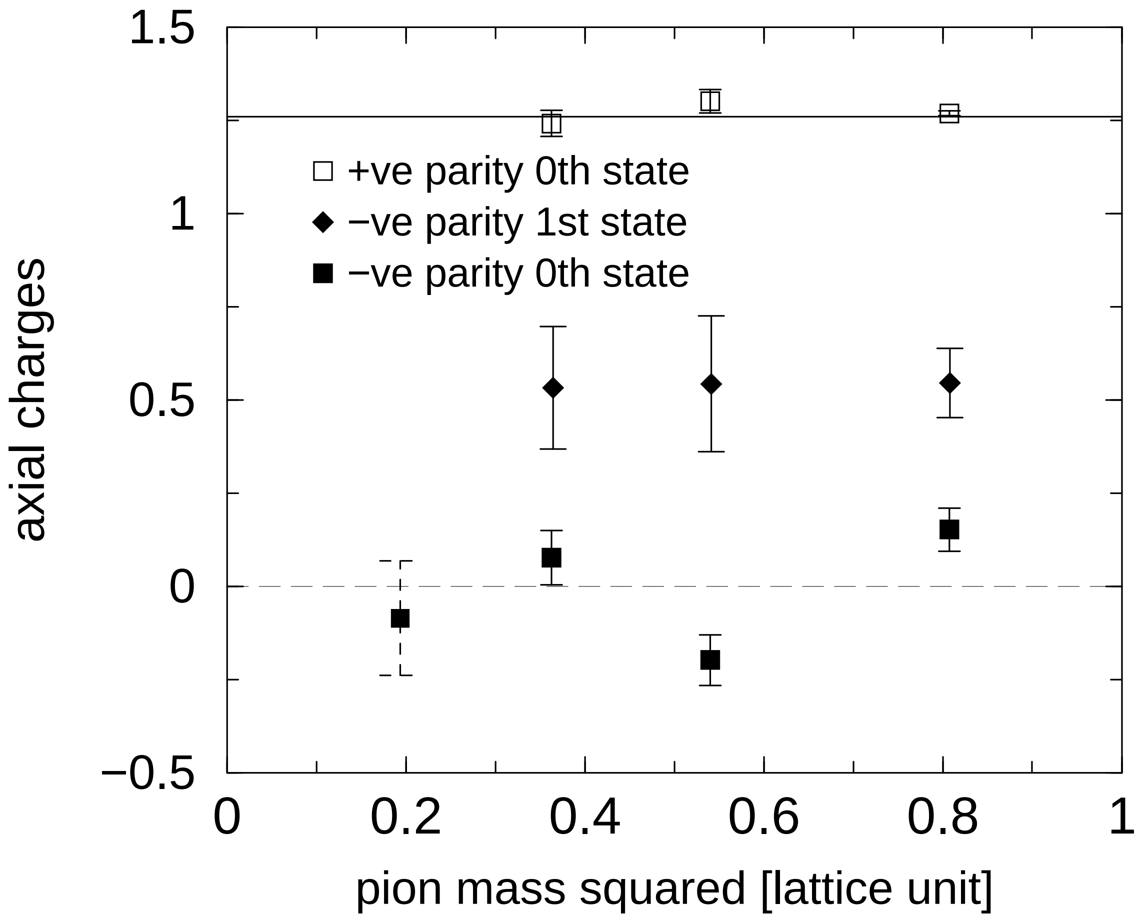
[Xu Cao and Xi-Guo Lee, Role of $N^*(1535)$ in η' production, Phys. Rev. C ***78****, 035207 (2008) .]*

3. The electromagnetic transition $\gamma^* N \to N^*(1535)$;



[CLAS Collaboration, The $ep \to e'p\eta$ reaction at and above the $S_{11}(1535)$ baryon resonance, Phys. Rev. Lett., ***86****, 1702 (2001) .]*

4. The small (or vanishing) axial charge of $N^*(1535)$



Toru T. Takahashi and Teiji Kunihiro, Axial charges of N(1535) and N(1650) in lattice QCD with two flavors of dynamical quarks, Phys. Rev. D ***78****, 011503 (2008), and Takahashi's talk*

5. Recent studies of the five-quark components in baryons:

[1] B. S. Zou and D. O. Riska, The $s\bar{s}$ component of the proton and the strangeness magnetic moment, Phys. Rev. Lett. **95**, *072001 (2005) .*

[2] Q. B. Li and D. O. Riska, Five-quark components in $\Delta(1232) \to N\pi$ decay, Phys. Rev. C **73**, *035201 (2006) .*

[3] C. S. An, D. O. Riska and B. S. Zou, Strangeness spin, magnetic moment and strangeness configurations of the proton, Phys. Rev. C **73**, *035207 (2006) .*

[4] Q. B. Li and D. O. Riska, The Role of five-quark components in gamma decay of the Delta(1232), Nucl. Phys. A **766**, *172 (2006) .*

[5] B. S. Zou and D. O. Riska, The Strangeness form-factors of the proton, Phys. Lett. B **636**, *265 (2006) .*

[6] Q. B. Li and D. O. Riska, The Role of q anti-q components in the N(1440) resonance, Phys. Rev. C **74**, *015202 (2006) .*

[7] B. Juliá-Díaz and D. O. Riska, The Role of $qqqq\bar{q}$ components in the nucleon and the N(1440) resonance, Nucl. Phys. A **780**, *175 (2006) .*

[8] C. S. An, Q. B. Li, D. O. Riska and B. S. Zou, The $qqqq\bar{q}$ components and hidden flavor contributions to the baryon magnetic moments, Phys. Rev. C **74**, *055205 (2006) .*

[9] Q. B. Li and D. O. Riska, TThe Role of 5-quark components on the nucleon form-factors, Nucl. Phys. A **791**, *406 (2007) .*

Five-Quark Components in $N(1535)$

$$
\begin{aligned}
|N(1535)\rangle &= \sqrt{P_{3q}}|qqq\rangle + \sqrt{P_{5q}}\sum_i A_i|qqqq_i\bar{q}_i\rangle\,, && (1)\\
|qqq\rangle &= \frac{1}{2}\sum_{ms} C^{\frac{1}{2},s_z}_{1m,\frac{1}{2},s}\{\phi_{1m}(\vec{\kappa}_2)\phi_{00}(\vec{\kappa}_1)[|\frac{1}{2},t_z\rangle_+|\frac{1}{2},s\rangle_+ - |\frac{1}{2},t_z\rangle_-|\frac{1}{2},s\rangle_-] - \phi_{00}(\vec{\kappa}_2)\phi_{1m}(\vec{\kappa}_1)[|\frac{1}{2},t_z\rangle_+|\frac{1}{2},s\rangle_- \\
&\quad +|\frac{1}{2},t_z\rangle_-|\frac{1}{2},s\rangle_+]\}\,, && (2)\\
|qqqq_i\bar{q}_i\rangle &= \sum_{a,b,c}\sum_{Y,y,T_z,t_z}\sum_{S_z,s_z} C^{[1^4]}_{[31]_a[211]_a} C^{[31]_a}_{[F^{(i)}]_b[S^{(i)}]_c}[F^{(i)}]_{b,Y,T_z}[S^{(i)}]_{c,S_z}[211;C]_a(Y,T,T_z,y,\bar{t},t_z|1,1/2,t)\\
&\quad (S,S_z,1/2,s_z|1/2,s)\bar{\chi}_{y,t_z}\bar{\xi}_{s_z}\varphi_{[5]}\,. && (3)
\end{aligned}
$$

Here

$$P_{3q} + P_{5q} = 1; \textstyle\sum_i A_i^2 = 1 \qquad (4)$$

$[F^{(i)}]_{b,Y,T_z}$, $[S^{(i)}]_{c,S_z}$ and $[211;C]_a$ denote the flavor, spin and color wave functions of the four quark subsystem, respectively.

Color-Spin Type Hyperfine Interaction:

$$H_{CS} = -C_{CS} \sum_{i<j}^{N} \boldsymbol{\lambda}_i^C \cdot \boldsymbol{\lambda}_j^C \vec{\sigma}_i \cdot \vec{\sigma}_j \,. \tag{5}$$

Flavor-Spin Type Hyperfine: Interaction:

$$H_{FS} = -C_{FS} \sum_{i<j}^{N} \boldsymbol{\lambda}_i^F \cdot \boldsymbol{\lambda}_j^F \vec{\sigma}_i \cdot \vec{\sigma}_j \,. \tag{6}$$

configuration	flavor-spin	C_{FS}	color-spin	C_{CS}
1	$[31]_{FS}[211]_F[22]_S$	-16	$[31]_{CS}[211]_C[22]_S$	-16
2	$[31]_{FS}[211]_F[31]_S$	$-40/3$	$[31]_{CS}[211]_C[31]_S$	$-40/3$
3	$[31]_{FS}[22]_F[31]_S$	$-28/3$	$[22]_{CS}[211]_C[31]_S$	$-16/3$
4	$[31]_{FS}[31]_F[22]_S$	-8	$[211]_{CS}[211]_C[22]_S$	0
5	$[31]_{FS}[31]_F[31]_S$	$-16/3$	$[211]_{CS}[211]_C[31]_S$	$+8/3$

For $N^*(1535)$, two lowest energy configuration:

$$[31]_{FS}[211]_F[22]_S \; : \; \yng(3,1)_{FS} \; \yng(2,1,1)_F \; \yng(2,2)_S \, , \tag{7}$$

$$[31]_{FS}[211]_F[31]_S \; : \; \yng(3,1)_{FS} \; \yng(2,1,1)_F \; \yng(3,1)_S \, , \tag{8}$$

Flavor $[211]_F$:

$$[211]_F \Longrightarrow \yng(2,1,1)_F \Longrightarrow [uuds\bar{s}(udds\bar{s})] \tag{9}$$

For Roper, the lowest energy configuration [An, Li, Zou and Riska, Phys. Rev. C **74**, 055205, (2006)]:

$$[4]_{FS}[22]_F[22]_S \; : \; \yng(4)_{FS} \yng(2,2)_F \yng(2,2)_S \, , \tag{10}$$

Flavor $[22]_F$:

$$[22]_F \Longrightarrow \yng(2,2)_F \Longrightarrow [\xi_d(uudd\bar{d}) + \xi_s(uuds\bar{s})] \tag{11}$$

Applications

1. The axial charge of $N^*(1535)$

[An and Riska, Eur. Phys. J. A **37**, 263, (2008)]

configuration	flavor-spin	A_n
1	$[31]_{FS}[211]_F[22]_S$	0
2	$[31]_{FS}[211]_F[31]_S$	$+5/6$
3	$[31]_{FS}[22]_F[31]_S$	$-1/9$
4	$[31]_{FS}[31]_F[22]_S$	$-4/15$
5	$[31]_{FS}[31]_F[31]_S$	$+17/18$

Probabilities of the five-quark components in $N^*(1535)$:

$$g_A^* \simeq \sum_n A_n P_n = -\frac{1}{9}P_3 + \frac{5}{6}P_5^{(2)} - \frac{1}{9}P_5^{(3)} - \frac{4}{15}P_5^{(4)} + \frac{17}{18}P_5^{(5)}\,. \tag{12}$$

(1) First two configurations:

$$\begin{aligned} & g_A^{N^*N^*} = -\frac{1}{9}P_3 + \frac{5}{6}P_5^{(2)}, \\ taking \qquad & g_A^{N^*N^*} = 0 \Longrightarrow \frac{P_3}{P_5^{(2)}} = 15/2, \\ & P_5^{(1)} \geq P_5^{(2)} \Longrightarrow P_3 \leq 80\%. \end{aligned} \tag{13}$$

(2) First three configurations:

$$\begin{aligned} & g_A^{N^*N^*} = -\frac{1}{9}P_3 + \frac{5}{6}P_5^{(2)} - \frac{1}{9}P_5^{(3)}, \\ taking \qquad & g_A^{N^*N^*} = 0, P_5^{(1)} = (2 \sim 5)P_5^{(2)}, P_5^{(2)} = P_5^3, \\ & \Longrightarrow P_3 = 50\% \sim 60\%. \end{aligned} \tag{14}$$

If $g_A^{N^*N^*} \sim +0.3$, then we need larger probabilities for the strangeness components in $N^*(1535)$.

2. The electromagnetic transition $\gamma^* N \to N^*(1535)$.

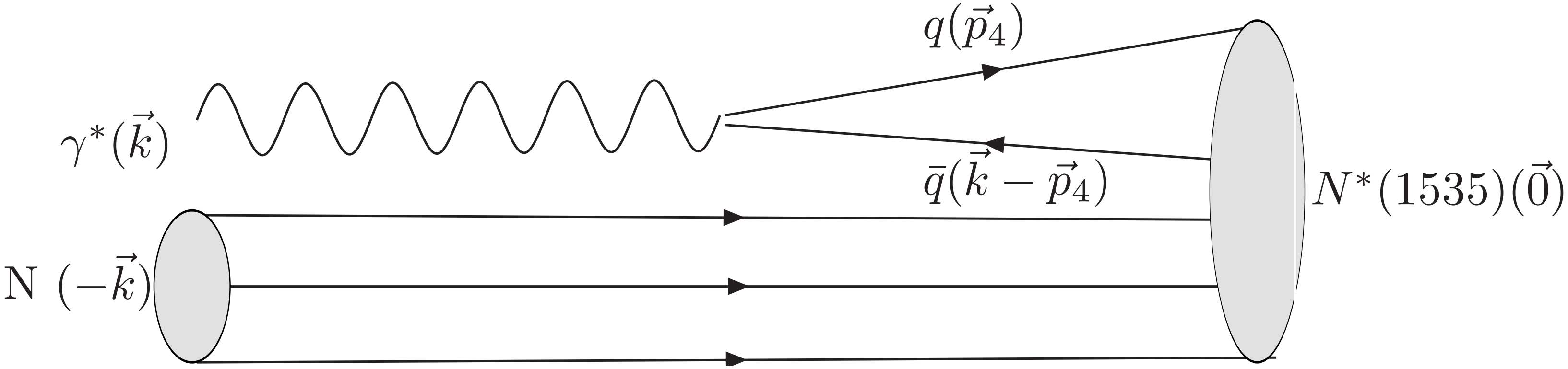
[An and Zou, Eur. Phys. J. A **39**, 195, (2009)]

Operators:

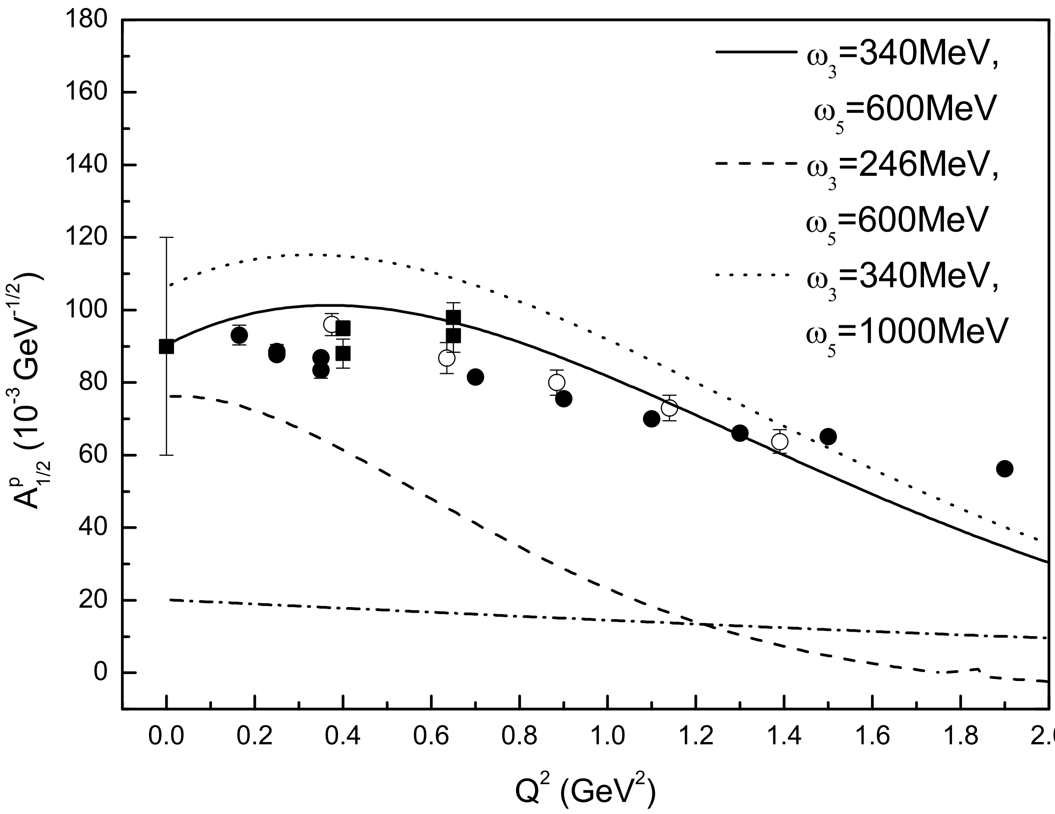
$$\hat{T}_A = -\sum_{i=1}^{n_q} \frac{e_i}{2m_i}[\sqrt{2}\hat{\sigma}_{i+}k_\gamma + (p'_{i+} + p_{i+})] \, ,$$
$$\hat{T}_{Aanni} = -\sum_{i=1}^{4} \sqrt{2} e_i \hat{\sigma}_{i+} . \tag{15}$$

Helicity amplitude $A^p_{1/2}$:

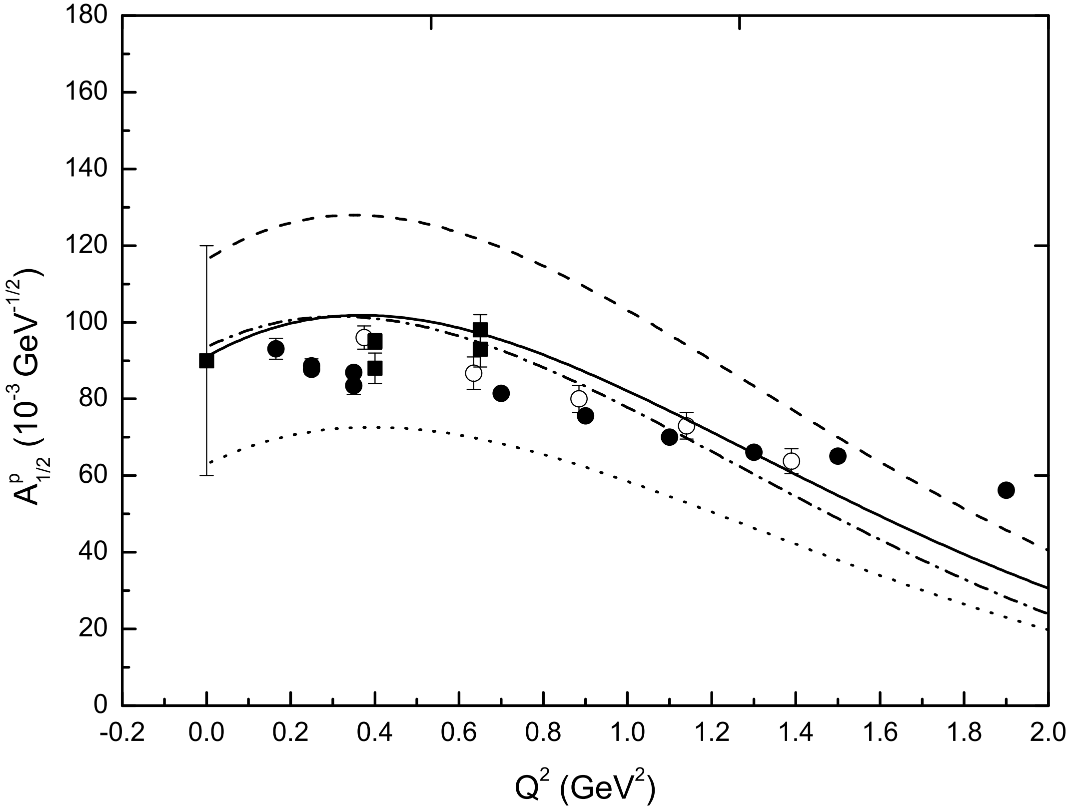
$$A^p_{1/2} = \frac{1}{\sqrt{2K_\gamma}} \langle N^*(1535), \frac{1}{2}, \frac{1}{2} | (\hat{T}_A + \hat{T}_{Aanni}) | p, \frac{1}{2}, -\frac{1}{2} \rangle . \tag{16}$$



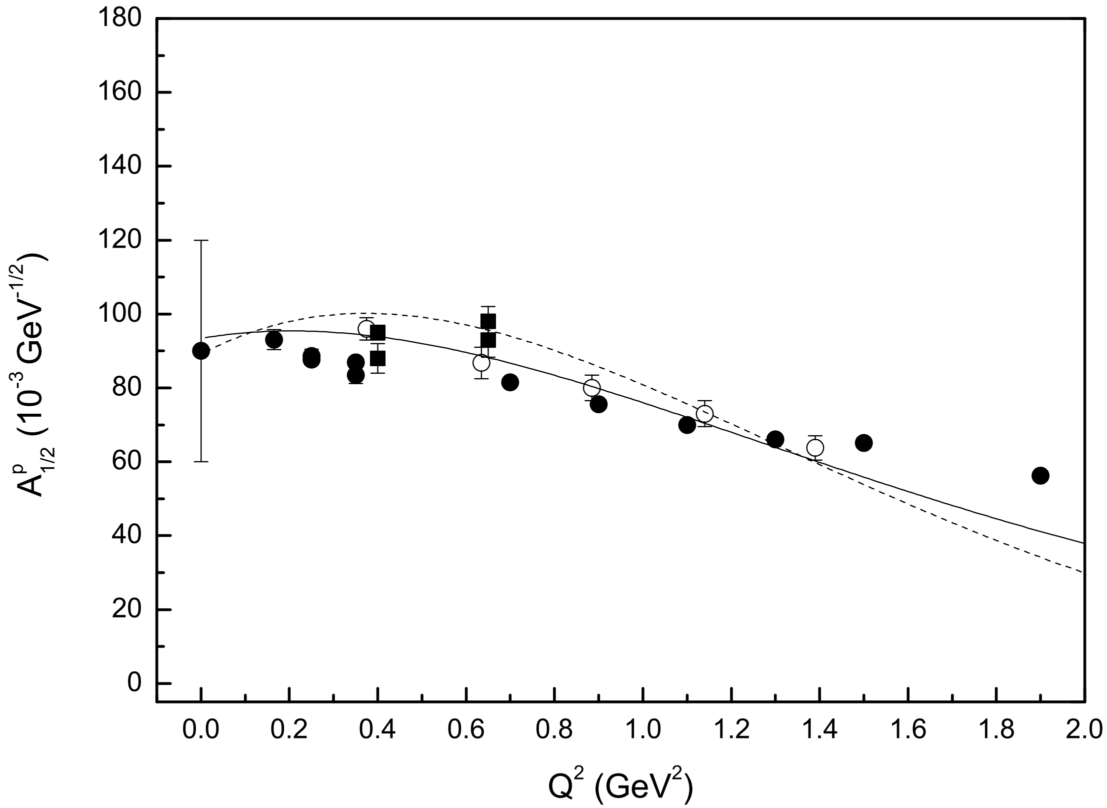
$q(\vec{p}_4)$
$\gamma^*(\vec{k})$
$\bar{q}(\vec{k}-\vec{p}_4)$
$N^*(1535)(\vec{0})$
N $(-\vec{k})$



Contributions of the lowest energy five-quark component in $N^*(1535)$, here we take the probability of the five-quark component to be $P_{5q} = 45\%$.



The solid line is obtained by taking the probability of the lowest energy $qqqq\bar{q}$ components in $N^*(1535)$ to be the totally P_{5q}, and the dash dot line $0.6P_{5q}$ MeV, i.e. the probability of the next-to-next-to-lowest-energy $qqqq\bar{q}$ components is $0.4P_{5q}$, and both the two lines are obtained by setting $P_{3q} = 55\%$. The dot line is obtained by setting $P_{3q} = 35\%$, and the dash line $P_{3q} = 75\%$, and both of the two lines are obtained by taking the probability of the lowest energy $qqqq\bar{q}$ component to be the totally P_{5q}.



Here the solid line is the result obtained by taking the phase factor between the three- and five-quark components in $N^*(1535)$ to be $+1$, and the probability for the five-quark component is $P_{5q} = 85\%$.

Summary

1. There may be 40% or more five-quark components in $N^*(1535)$.

2. The five-quark components in $N^*(1535)$ which have the largest probabilities should be the strangeness components, this is in agreement with the large branch ratio of $N\eta$ decay, and also the strong coupling $N^*(1535)K\Lambda$ and $N^*(1535)N\phi$.

3. The axial charge of $N^*(1535)$ obtained from our model is consistent with the LQCD result.

4. The non-diagonal transition $\gamma^* \to q\bar{q}$ plays a significant role in the electromagnetic transition $\gamma^* N \to N^*(1535)$. Our result fit the experimental data much better than that from the traditional constituent quark model, but it's still not good enough, the relativistic corrections should be taken into account.

Thank you a lot for your attentions.