

N* structure beyond three dressed quarks and their Q^2 evolution

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Outline:

- **Quenched & unquenched quark models**
- **Q^2 dependence of N^* transition form factors**
- **Prediction of superheavy N^* & Λ^* states**
with hidden charm and beauty
- **Conclusion**

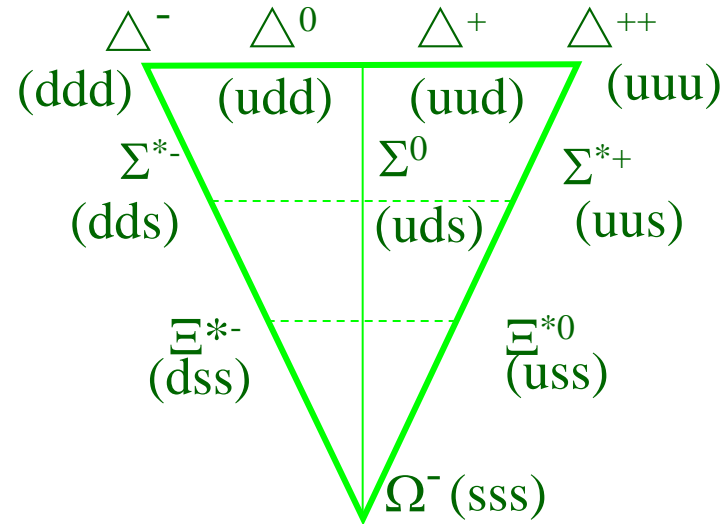
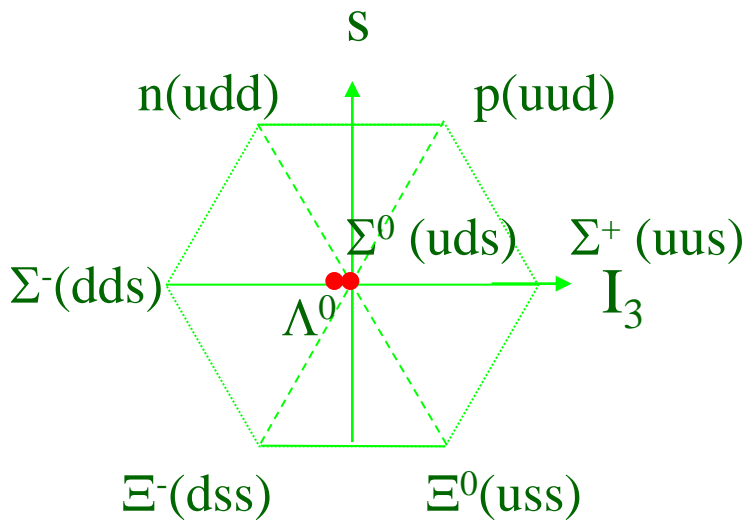
1. Quenched & unquenched quark models

SU(3) 3q-quark model for baryons

1/2 +

spin-parity

3/2 +



Successful for spatial ground states !

Prediction $m_{\Omega^-} \cong 1670 \text{ MeV}$

experiment $m_{\Omega^-} \cong 1672.45 \pm 0.29 \text{ MeV}$

quench vs un-quench for mesons

$\bar{q}q \ ^3S_1$ nonet

$\phi(1020) \quad \bar{s}s$

$K(892) \quad \bar{s}d$

$\omega(782) \quad \bar{u}u + \bar{d}d$

$\rho(770) \quad \bar{u}u - \bar{d}d$

$\bar{q}q \ ^3P_0$ or \bar{q}^2q^2 nonet ?

$a_0(980) \quad \bar{u}u - \bar{d}d, \quad [\bar{u}\bar{s}][us] - [\bar{d}\bar{s}][ds]$

$f_0(980) \quad \bar{s}s, \quad [\bar{u}\bar{s}][us] + [\bar{d}\bar{s}][ds]$

$\kappa(800) \quad \bar{s}d, \quad [\bar{s}\bar{u}][ud]$

$f_0(600) \quad \bar{u}u + \bar{d}d, \quad [\bar{u}\bar{d}][ud]$

$D^*_{s0}(2317) \sim \bar{s}c \ (L=1) + [\bar{q}\bar{s}][qc] + DK + \dots$

$D^*_{s1}(2460) \sim \bar{s}c \ (L=1) + D^*K + \dots$

$X(3872) \sim \bar{c}c \ (L=1) + [\bar{q}\bar{c}][qc] + D^*D + \dots$

Problem of quenched quark models for baryons

- Mass order reverse problem for the lowest excited baryons

$uud (L=1) \frac{1}{2}^- \sim N^*(1535)$ **should be the lowest**

$uud (n=1) \frac{1}{2}^+ \sim N^*(1440)$

$uds (L=1) \frac{1}{2}^- \sim \Lambda^*(1405)$

harmonic oscillator $(2n + L + 3/2) \hbar\omega$

- Strange decays of $N^*(1535)$: **PDG \rightarrow large $g_{N^*N\eta}$**

$J/\psi \rightarrow \bar{p}N^* \rightarrow \bar{p} (K\Lambda) / \bar{p} (p\eta) \rightarrow$ **large $g_{N^*K\Lambda}$**

Liu&Zou, PRL96 (2006) 042002; Geng,Oset,Zou&Doring, PRC79 (2009) 025203

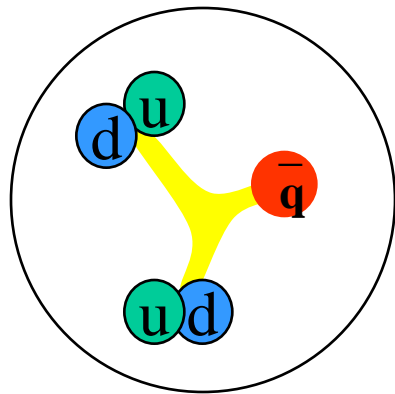
$\gamma p \rightarrow p\eta' \text{ \& } pp \rightarrow pp\eta' \rightarrow$ **large $g_{N^*N\eta'}$**

M.Dugger et al., PRL96 (2006) 062001; Cao&Lee, PRC78(2008) 035207

$\pi^- p \rightarrow n\phi \text{ \& } pp \rightarrow pp\phi \text{ \& } pn \rightarrow d\phi \rightarrow$ **large $g_{N^*N\phi}$**

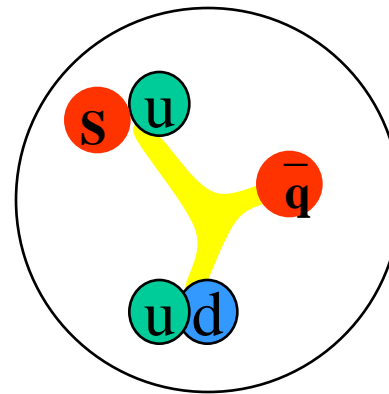
Xie, Zou & Chiang, PRC77(2008)015206; Cao, Xie, Zou & Xu, PRC80(2009)025203

New Scheme for $N^*(1535)$ and its $1/2^-$ nonet partners



$$\bar{q} \quad 1/2^+$$

$$\left. \begin{array}{l} [ud] \\ [ud] \end{array} \right\} L=1$$



$$\bar{q} \quad 1/2^-$$

$$\left. \begin{array}{l} [ud] \\ [us] \end{array} \right\} L=0$$

Zhang et al, hep-ph/0403210

$$N^*(1535) \sim uud (L=1) + \varepsilon [ud][us] \bar{s} + \dots$$

$$N^*(1440) \sim uud (n=1) + \xi [ud][ud] \bar{d} + \dots$$

$$\Lambda^*(1405) \sim uds (L=1) + \varepsilon [ud][su] \bar{u} + \dots$$

$N^*(1535)$: $[ud][us] \bar{s} \rightarrow$ larger coupling to $N\eta, N\eta', N\phi$ & $K\Lambda$, weaker to $N\pi$ & $K\Sigma$, and heavier !

B.C. Liu & B.S.Zou, PRL96 (2006) 042002

Important implications:

- $\bar{q}q\underline{q}q$ in S-state more favorable than $q\underline{q}q$ with $L=1$!
& $\bar{q}q\underline{q}q$ in S-state more favorable than $\bar{q}q$ with $L=1$!

$1/2^-$ baryon nonet $\sim \bar{q}q^2q^2$ state + ...

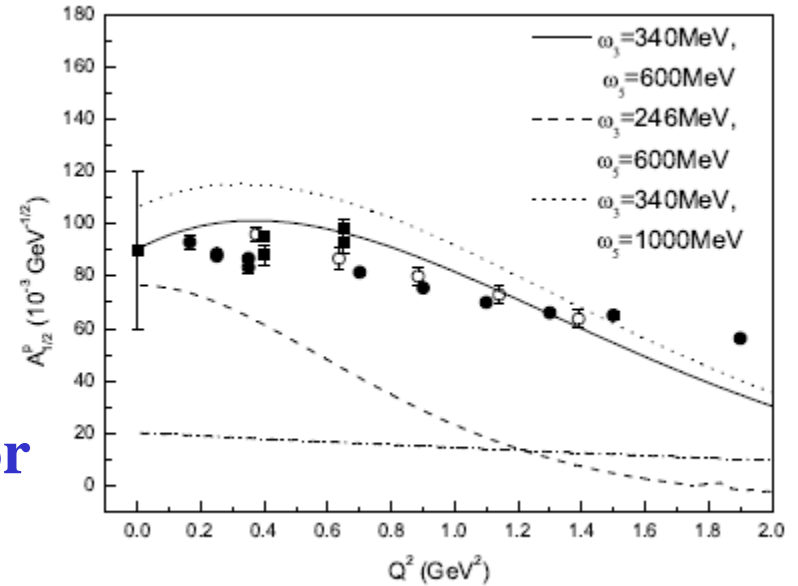
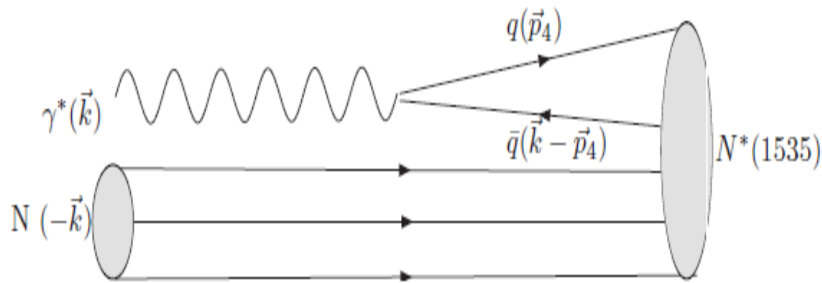
0^+ meson octet $\sim \bar{q}^2q^2$ state + ...

multiquark components are important for hadrons!

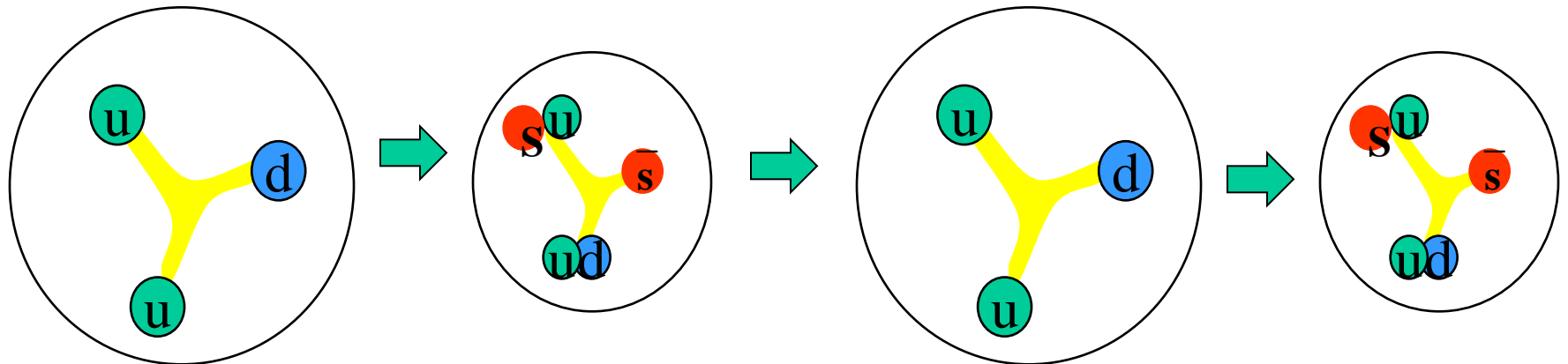
Could also be in the form of meson-baryon configuration

2. Q^2 dependence of N^* transition form factors

1) $N^*(1535)$

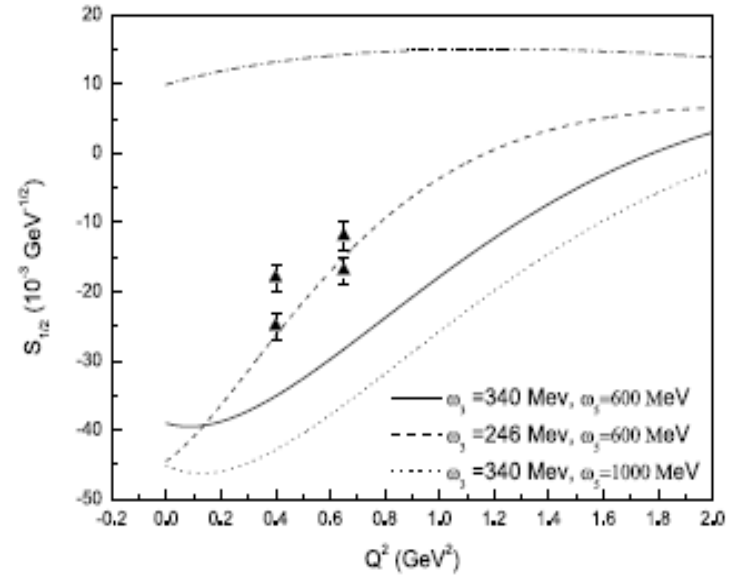
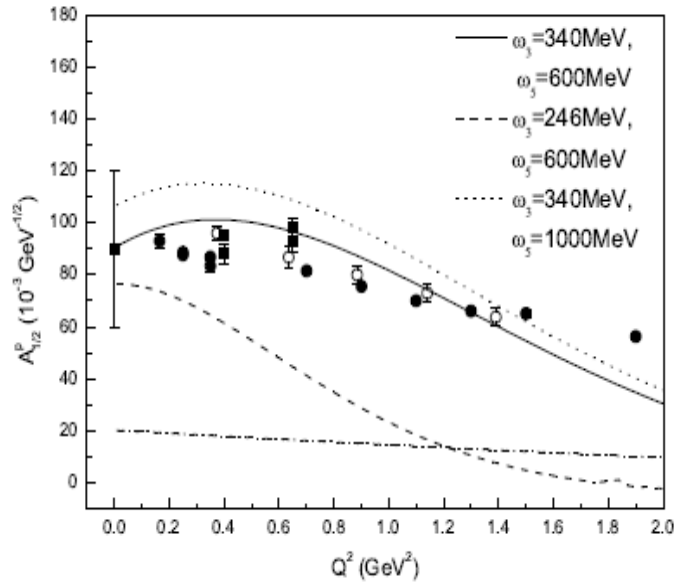


Important role for N^* EM form factor
 An & Zou, EPJA39(2009)195

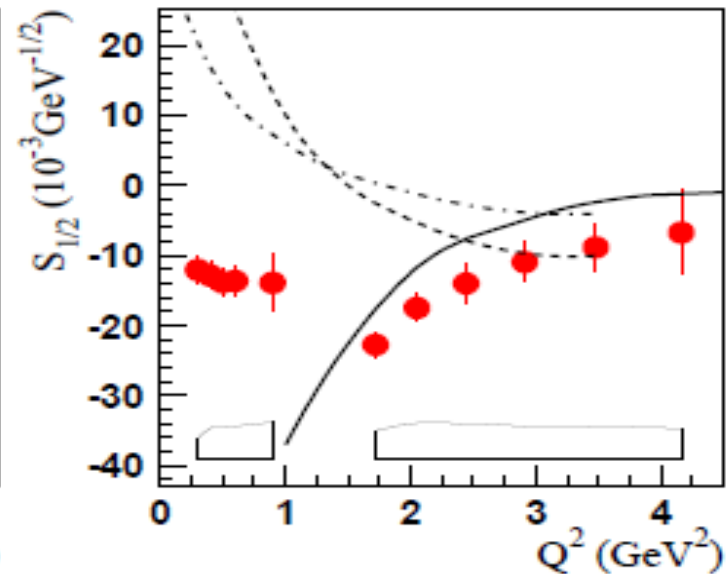
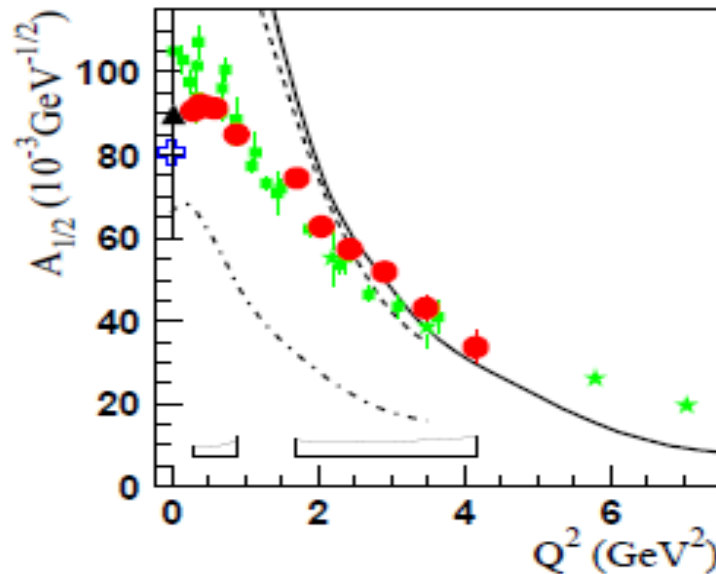


breathing mode with $\bar{q}qqq$ of smaller size than qqq

Breathing model : An & Zou, EPJA39(2009)195

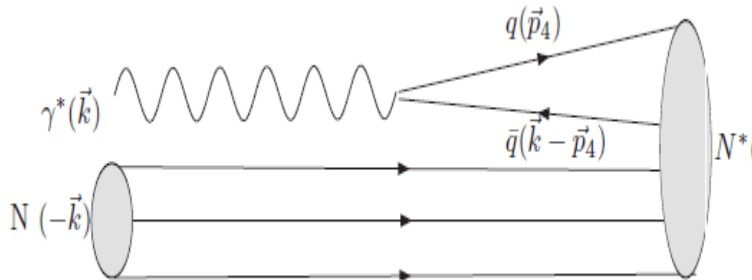
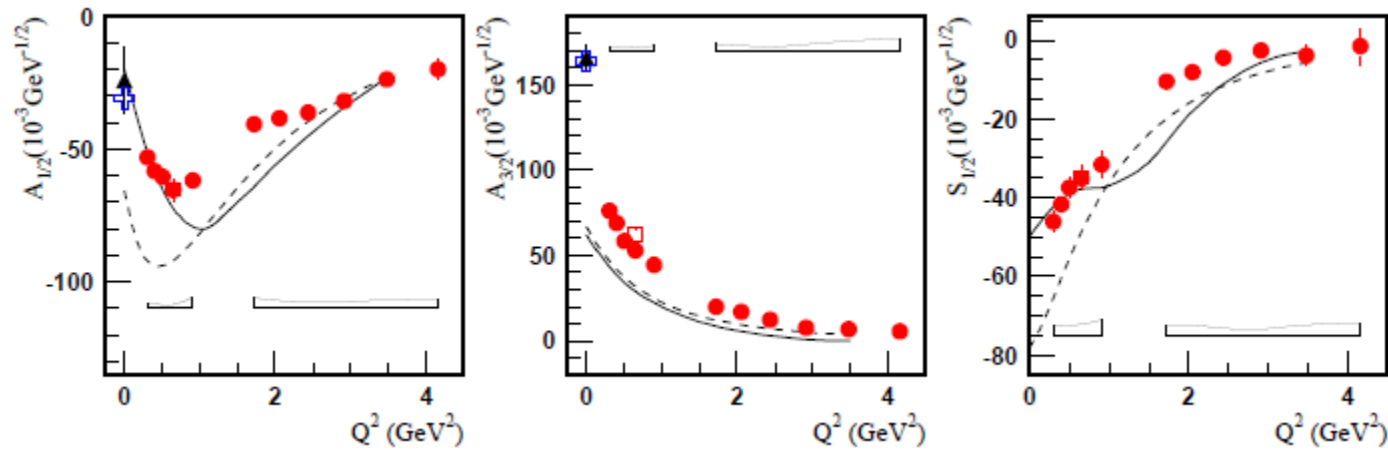


Quark models : I. Aznauryan et al., arXiv:1102.0597



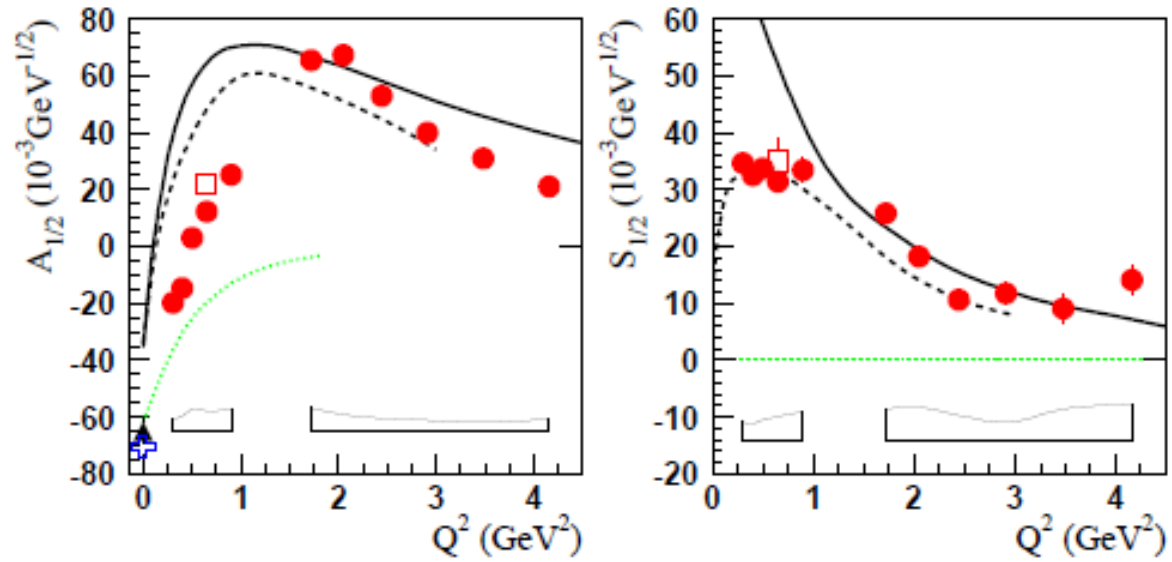
2) $N^*(1520)$

Quark models : I.Aznauryan et al., arXiv:1102.0597



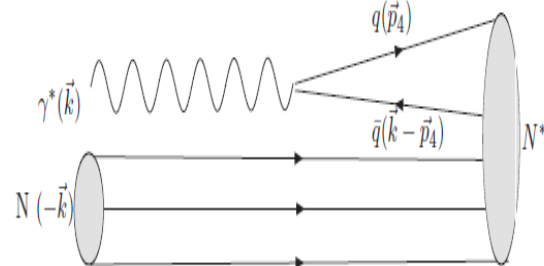
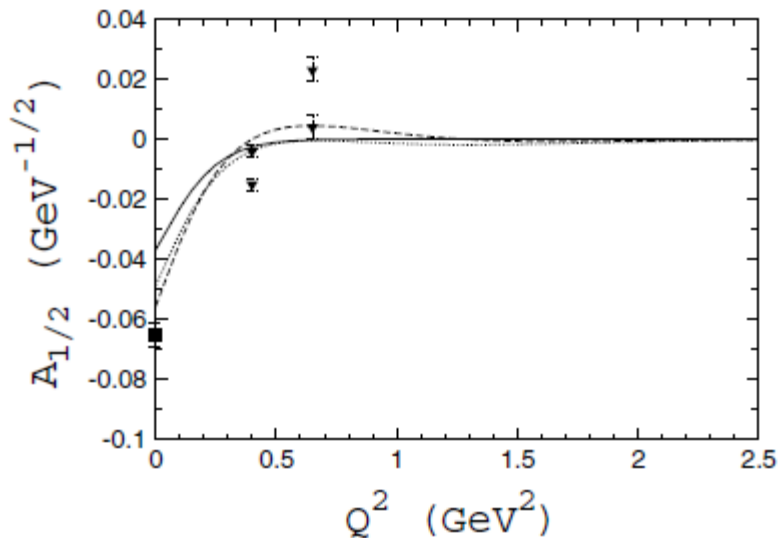
should also be important.

3) $N^*(1440)$



Quark models : I.Aznauryan et al., arXiv:1102.0597

Li & Riska, PRC74(2006)015202



small !

3. Prediction of superheavy N^* & Λ^* states with hidden charm and beauty

Many proposed dynamically generated states
and multi-quark states

Problem:

None of them can be clearly distinguished from qqq or $\bar{q}q$
due to tunable ingredients and possible large mixing of
various configurations

Solution: Extension to hidden charm and beauty for baryons

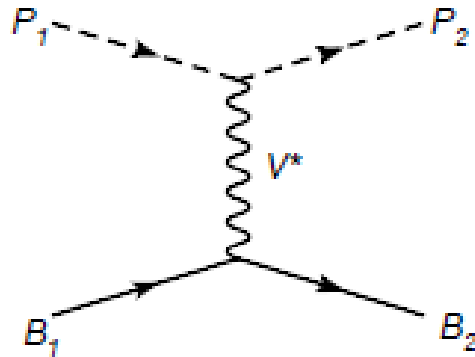
$N^*(1535)$ $\bar{s}suud$

$N^*(4260)$ $\bar{c}cuud$ J.J.Wu, R.Molina, E.Oset, B.S.Zou.
Phys.Rev.Lett. 105 (2010) 232001

$N^*(11050)$ $\bar{b}buud$ J.J.Wu, B.S.Zou. arXiv:1011.5743.

$K\Sigma, K\rho \rightarrow \bar{D}\Sigma_c, \bar{D}_s\Lambda_c \rightarrow B\Sigma_b, B_s\Lambda_b$ bound states

J.J.Wu, R.Molina, E.Oset, B.S.Zou, PRL 105 (2010) 232001



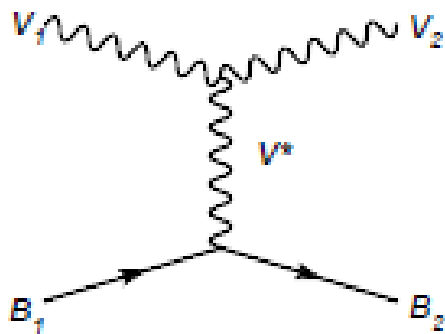
$$\mathcal{L}_{VVV} = ig\langle V^\mu [V^\nu, \partial_\mu V_\nu] \rangle$$

$$\mathcal{L}_{PPV} = -ig\langle V^\mu [P, \partial_\mu P] \rangle$$

$$\mathcal{L}_{BBV} = g(\langle \bar{B}\gamma_\mu [V^\mu, B] \rangle + \langle \bar{B}\gamma_\mu B \rangle \langle V^\mu \rangle)$$

$$V_{ab}(P_1 B_1 \rightarrow P_2 B_2) = \frac{C_{ab}}{4f^2} (E_{P_1} + E_{P_2}),$$

$$V_{ab}(V_1 B_1 \rightarrow V_2 B_2) = \frac{C_{ab}}{4f^2} (E_{V_1} + E_{V_2}) \vec{\epsilon}_1 \cdot \vec{\epsilon}_2,$$



$$T = [1 - VG]^{-1}V$$

$$T_{ab} = \frac{g_a g_b}{\sqrt{s} - z_R}$$

	(I, S)	z_R (MeV)	g_a		
N^*	$(1/2, 0)$		$\bar{D}\Sigma_c$	$\bar{D}\Lambda_c^+$	
		4269	2.85	0	
Λ^*	$(0, -1)$		$\bar{D}_s\Lambda_c^+$	$\bar{D}\Xi_c$	$\bar{D}\Xi'_c$
		4213	1.37	3.25	0
		4403	0	0	2.64

TABLE III: Pole positions z_R and coupling constants g_a for the states from $PB \rightarrow PB$.

	(I, S)	z_R (MeV)	g_a		
N^*	$(1/2, 0)$		$\bar{D}^*\Sigma_c$	$\bar{D}^*\Lambda_c^+$	
		4418	2.75	0	
Λ^*	$(0, -1)$		$\bar{D}_s^*\Lambda_c^+$	$\bar{D}^*\Xi_c$	$\bar{D}^*\Xi'_c$
		4370	1.23	3.14	0
		4550	0	0	2.53

TABLE IV: Pole position and coupling constants for the bound states from $VB \rightarrow VB$.

	(I, S)	M	Γ	Γ_i					
N^*	$(1/2, 0)$			πN	ηN	$\eta' N$	$K\Sigma$	$\eta_c N$	
		4261	56.9	3.8	8.1	3.9	17.0	23.4	
Λ^*	$(0, -1)$			$K N$	$\pi\Sigma$	$\eta\Lambda$	$\eta'\Lambda$	$K\Xi$	$\eta_c\Lambda$
		4209	32.4	15.8	2.9	3.2	1.7	2.4	5.8
		4394	43.3	0	10.6	7.1	3.3	5.8	16.3

TABLE V: Mass (M), total width (Γ), and the partial decay width (Γ_i) for the states from $PB \rightarrow PB$, with units in MeV.

	(I, S)	M	Γ	Γ_i					
N^*	$(1/2, 0)$			ρN	ωN	$K^*\Sigma$		$J/\psi N$	
		4412	47.3	3.2	10.4	13.7		19.2	
Λ^*	$(0, -1)$			$K^* N$	$\rho\Sigma$	$\omega\Lambda$	$\phi\Lambda$	$K^*\Xi$	$J/\psi\Lambda$
		4368	28.0	13.9	3.1	0.3	4.0	1.8	5.4
		4544	36.6	0	8.8	9.1	0	5.0	13.8

TABLE VI: Mass (M), total width (Γ), and the partial decay width (Γ_i) for the states from $VB \rightarrow VB$ with units in MeV.

Super-heavy narrow N^* and Λ^* with hidden charm
Definitely not qqq states !

Hidden charm N^* by other approaches

$\bar{c}c$ - N bound states in topological soliton model ~ 3.9 GeV

C. Gobbi, D.O. Riska, N.N. Scoccola, Phys. Lett. B 296 (1992) 166

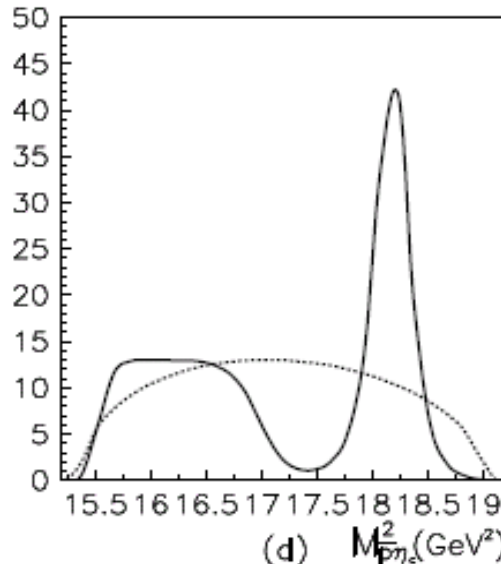
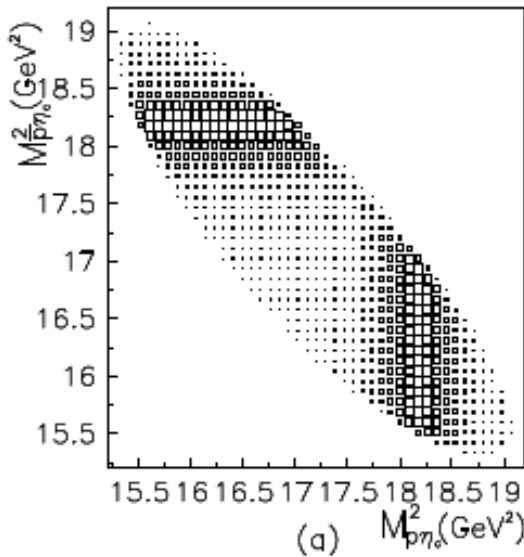
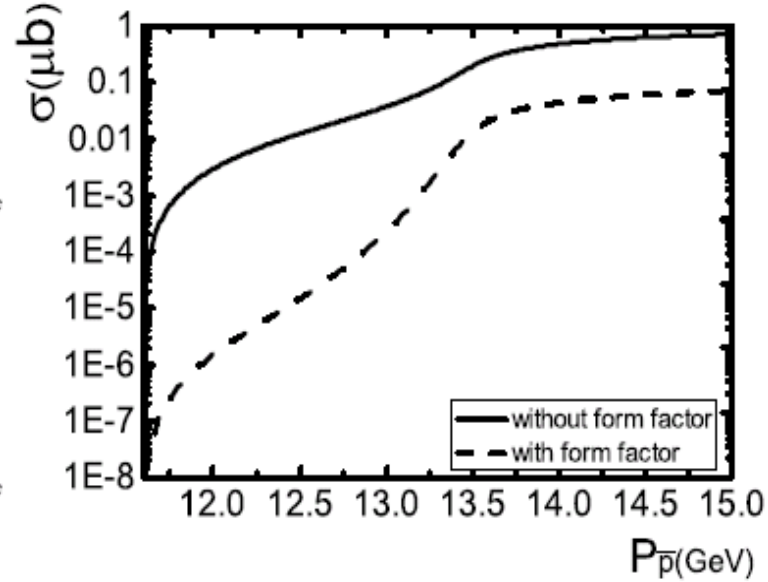
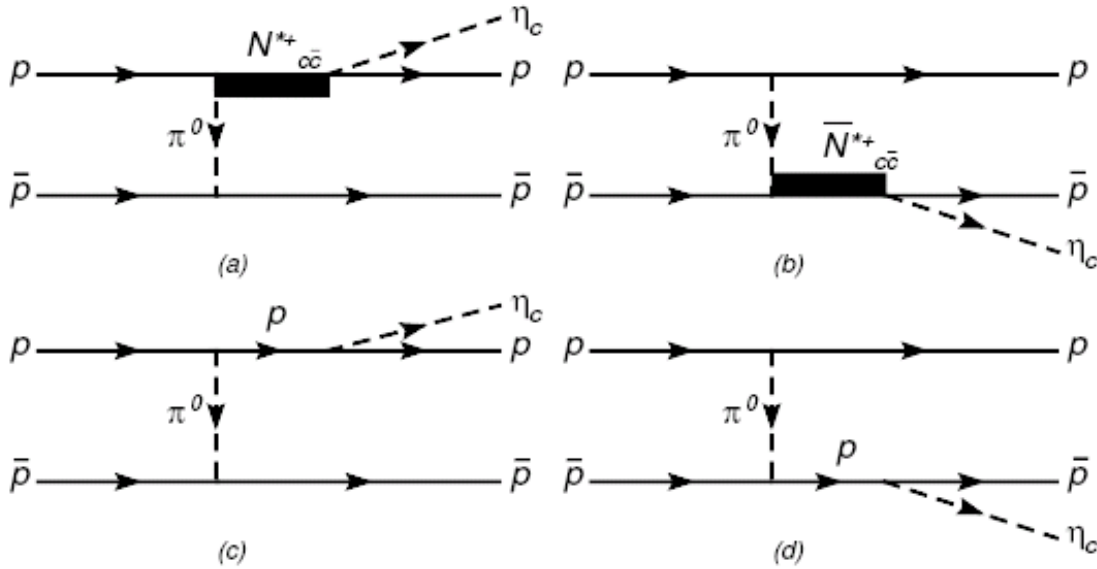
$\bar{D}\Sigma_c - \eta_c N - \eta' N$ coupled channel state ~ 3.5 GeV

J. Hofmann, M.F.M. Lutz, Nucl. Phys. A 763 (2005) 90

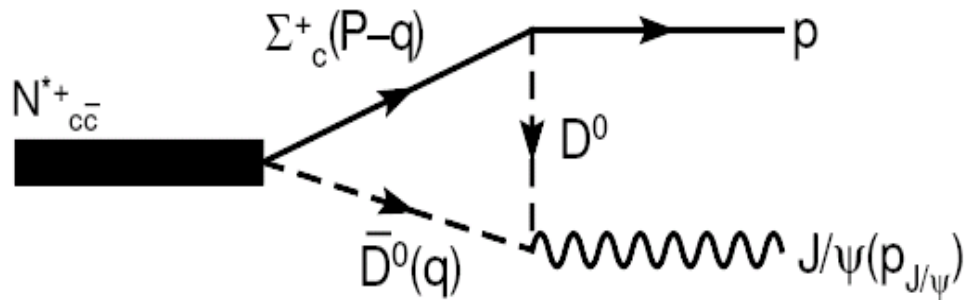
$\bar{D}\Sigma_c$ state in a chiral quark model ~ 4.3 GeV

W.L.Wang, F.Huang, Z.Y.Zhang, B.S.Zou, arXiv:1101.0453

Prediction for PANDA



$\bar{p}p \rightarrow \bar{p}p\eta_c$
0.07 -- 0.7 μb



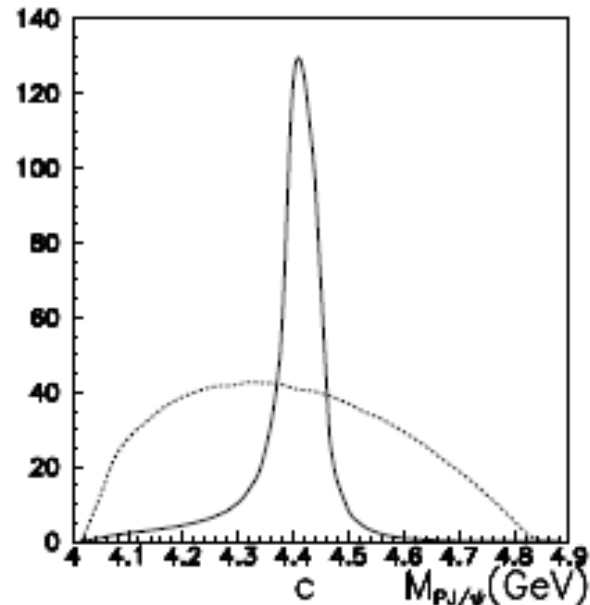
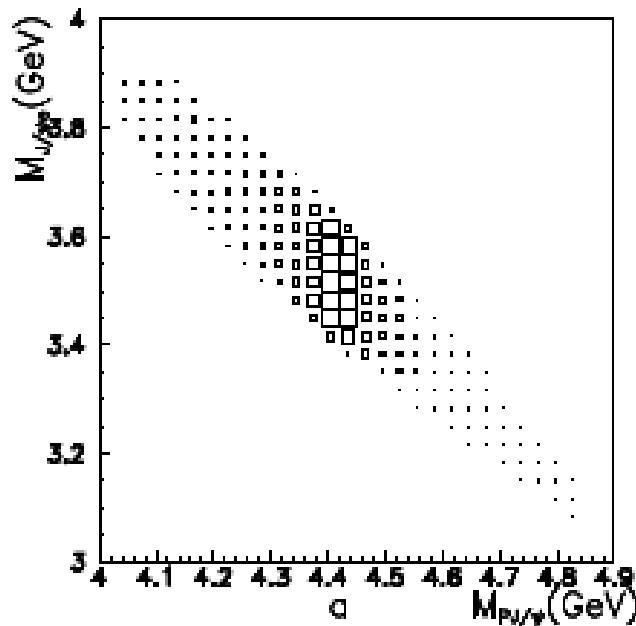
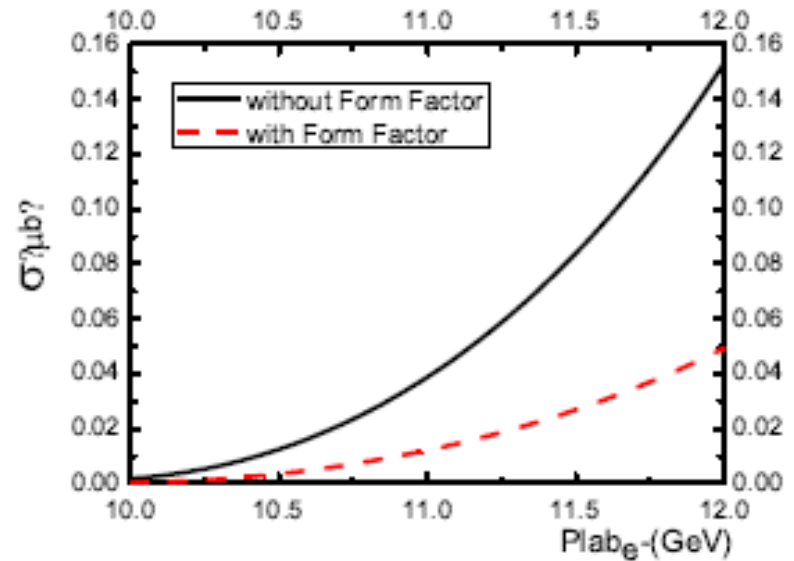
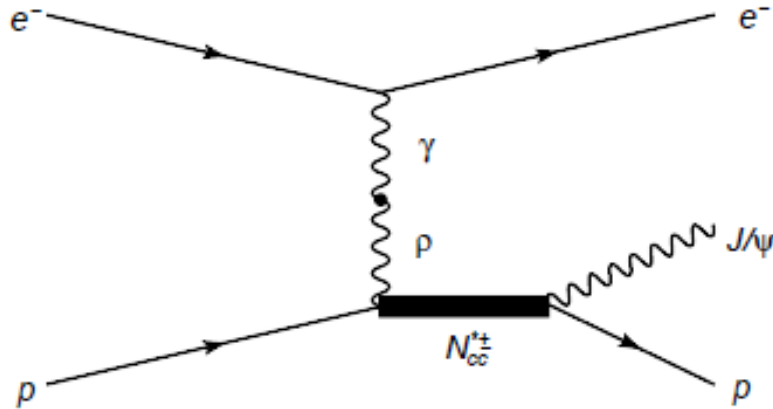
3 orders of magnitude smaller than $N^* \rightarrow p\eta_c$

$$\bar{p}p \rightarrow \bar{p}pJ/\psi \sim 0.03 \text{ nb}$$

~ 250 events per day at PANDA/FAIR by $L=10^{31} \text{ cm}^{-2}\text{s}^{-1}$

These Super-heavy narrow N^* and Λ^* can be found at PANDA !

Prediction for 12GeV@JLab



Conclusion

- 5-quark components are important for N^*
- Superheavy narrow N^* and Λ^* are predicted to exist
 $\bar{D}\Sigma_c, \bar{D}_s\Lambda_c \rightarrow B\Sigma_b, B_s\Lambda_b$ bound states
 $\sim 4.2 \text{ GeV} \quad \sim 11 \text{ GeV}$
- They are definitely not qqq baryons
- They can be looked for at 12GeV@Jlab and PANDA
maybe also at JPARC, RHIC , EIC?
- They may play important role for the puzzling large rate of J/ψ production in γp and $\bar{p}p$ reactions