

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

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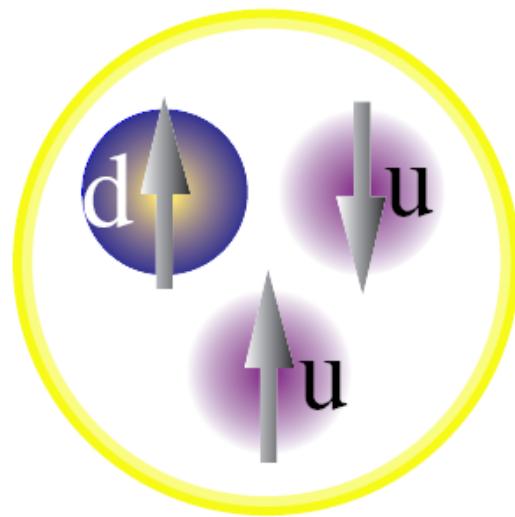
Outline:

- **Introduction -- 5-quark components in the proton**
- **New scheme for $N^*(1535)$ and its $1/2^-$ nonet partners
with large 5-quark components and breathing mode**
- **Prediction of superheavy N^* & Λ^* states
with hidden charm and beauty**
- **Conclusion**

1. Introduction: 5-quark components in the proton

Classical picture of the proton

Constituent Quarks

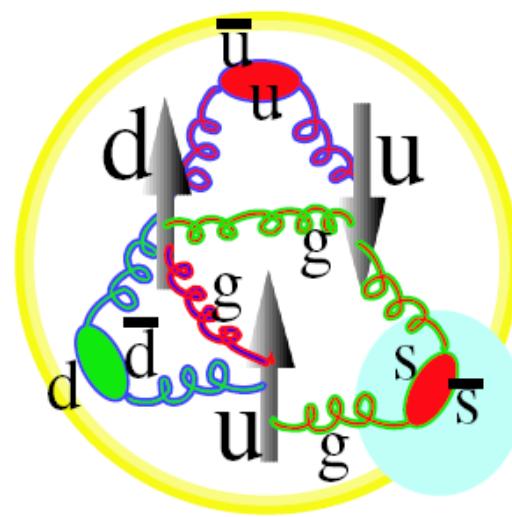


$$(Q^2 = 0 \text{ GeV}^2)$$

baryon octet

masses, magn. momenta

Parton Distributions



$$(Q^2 > 1 \text{ GeV}^2)$$

structure functions

momentum, spin

$$\bar{u}(x) = \bar{d}(x), \quad \bar{s}(x) = s(x)$$

1964–1974

1974–1992

Flavor asymmetry of light quarks in the nucleon sea

Deep Inelastic Scattering (DIS) + Drell-Yan (DY) process



$$\bar{d} - \bar{u} \sim 0.12 \quad \text{for a proton}$$

Garvey&Peng, Prog. Part. Nucl. Phys. 47, 203 (2001)

Table 1. Values of the integral $\int_0^1 [\bar{d}(x) - \bar{u}(x)] dx$ determined from the DIS, semi-inclusive DIS, and Drell-Yan experiments.

Experiment	$\langle Q^2 \rangle$ (GeV $^2/c^2$)	$\int_0^1 [\bar{d}(x) - \bar{u}(x)] dx$
NMC/DIS	4.0	0.147 ± 0.039
HERMES/SIDIS	2.3	0.16 ± 0.03
FNAL E866/DY	54.0	0.118 ± 0.012

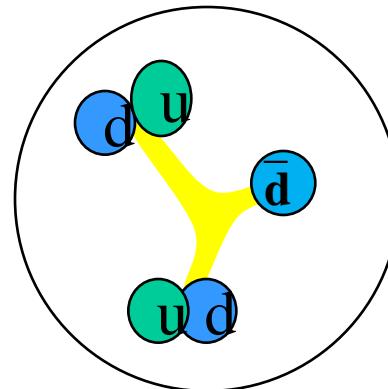
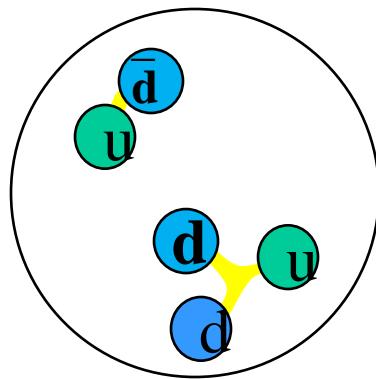
Two major theoretical schemes for $\bar{d} - \bar{u} \sim 0.12$

Meson cloud picture: Thomas, Speth, Henley, Meissner, Miller, Weise, Oset, Brodsky, Ma, ...

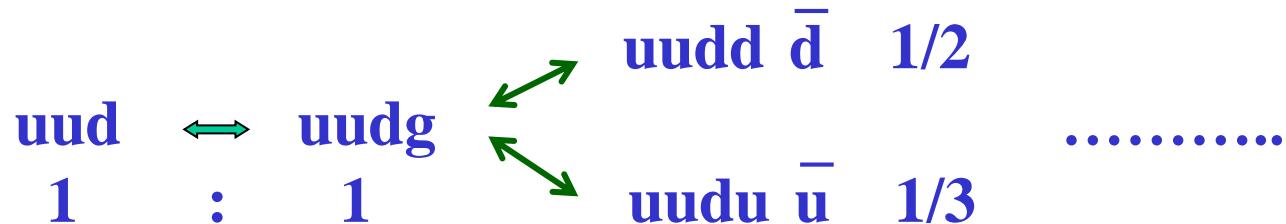
$$| p \rangle \sim | uud \rangle + \varepsilon_1 | n \text{ (} udd \text{) } \pi^+ (\bar{d}u) \rangle + \varepsilon_2 | \Delta^{++} \text{ (} uuu \text{) } \pi^- (\bar{u}d) \rangle + \varepsilon' | \Lambda \text{ (uds) } K^+ (\bar{s}u) \rangle \dots$$

Penta-quark picture : Riska, Zou, Zhu, ...

$$| p \rangle \sim | uud \rangle + \varepsilon_1 | [ud][ud] \bar{d} \rangle + \varepsilon' | [ud][us] \bar{s} \rangle + \dots$$



Detailed balance model : Zhang, Ma, Zou, Yang, Alberg, Henley



$$p = 0.168 (\text{uud}) + 0.168 (\text{uudg}) + 0.084 (\text{uudd } \bar{d}) + 0.056 (\text{uudu } \bar{u}) + 0.084 (\text{uudgg}) + \dots \quad \bar{d} - \bar{u} \sim 0.124$$

(uud+ng) 50% (uudd \bar{d} +ng) 22.4% (uudu \bar{u} +ng) 15.0%

With $\sim 25\%$ $\bar{q}qqqq$ components in the proton, the “spin crisis” and single spin asymmetry may also be naturally explained.

An-Riska-Zou, PRC73 (2006) 035207; F.X.Wei, B.S.Zou, hep-ph/0807.2324

$$\Delta_u = 0.85 \pm 0.17$$

$$\Delta_d = -(0.33 \sim 0.56)$$

$$\Delta_u = \frac{4}{3}|A_{3q}|^2$$

$$\Delta_d = -\frac{1}{3}(1 - P_{s\bar{s}})$$

$$\Delta L_q = \frac{4}{3}(P_{d\bar{d}} + P_{s\bar{s}})$$

We must go beyond the simple 3q models,
meson cloud vs penta-quark not settled yet.

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

- Mass order reverse problem for the lowest excited baryons

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

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

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

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

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

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

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

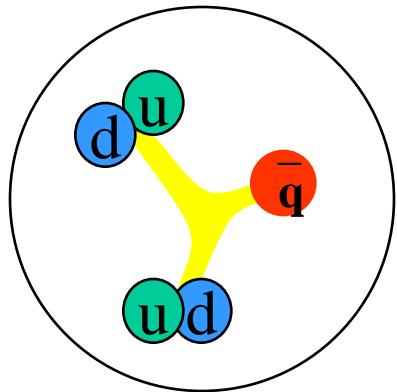
$\gamma p \rightarrow p\eta' \text{ & } pp \rightarrow pp\eta' \rightarrow \text{large } g_{N^*N\eta'}$

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

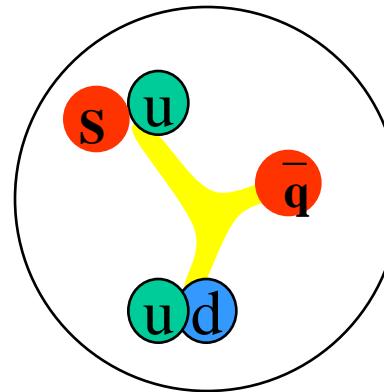
$\pi^- p \rightarrow n\phi \text{ & } pp \rightarrow pp\phi \text{ & } pn \rightarrow d\phi \rightarrow \text{large } g_{N^*N\phi}$

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}
[ud]
[ud] }
 $L=1$



\bar{q}
[ud]
[us] }
 $L=0$

Zhang et al, hep-ph/0403210

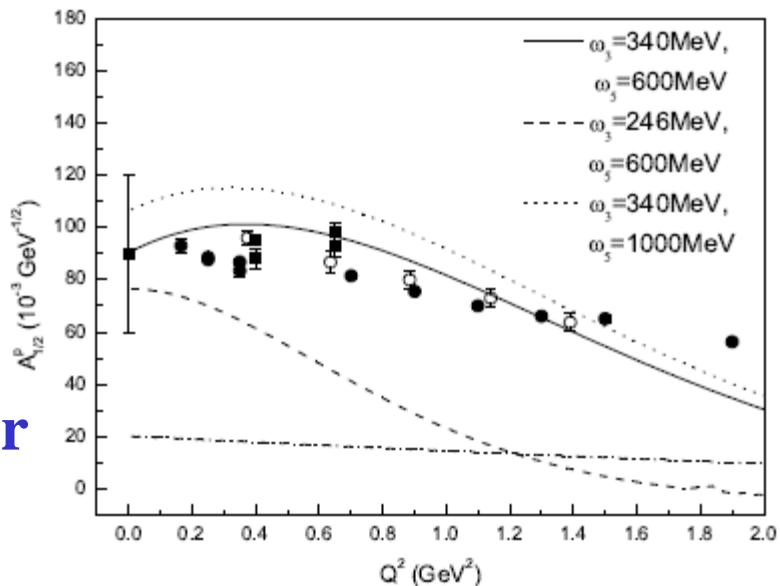
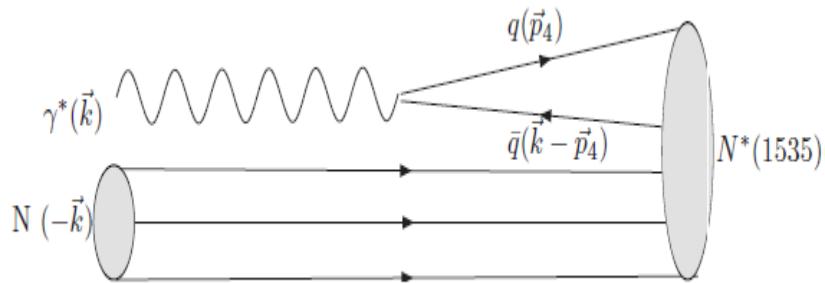
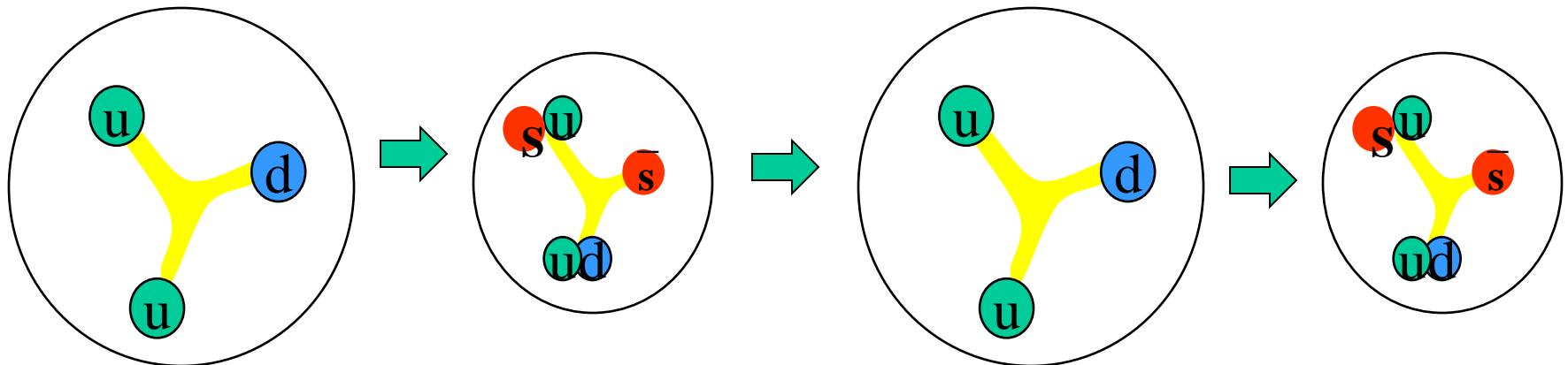
$$N^*(1535) \sim uud \text{ (L=1)} + \varepsilon [ud][us] \bar{s} + \dots$$

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

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

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 !

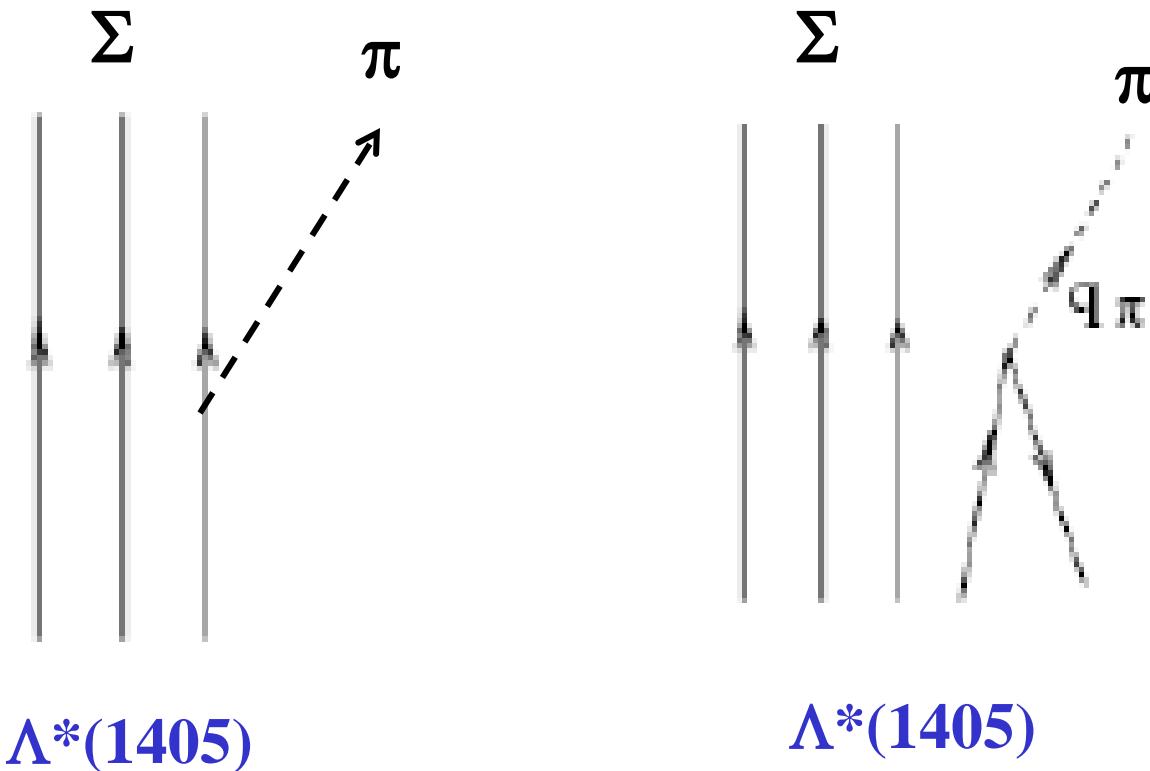
The breathing mode for the N*(1535)



Important role for N* EM form factor

**50% 5q components in $\Lambda^*(1405)$
to reproduce $\Gamma(\Lambda^* \rightarrow \Sigma\pi) = 50$ MeV**

An, Saghai, Yuan, He, PRC81(2010)045203



4-quark components in mesons

$\bar{q}q$ 3S_1 nonet

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

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

$\omega(782)$ $\bar{u}u + \bar{d}d$
 $\rho(770)$ $\bar{u}u - \bar{d}d$

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

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

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

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

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

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

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

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

Important implications:

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

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 $\bar{q}\bar{q}$
due to tunable ingredients and possible large mixing of
various configurations

Solution: Extension to hidden charm and beauty for baryons

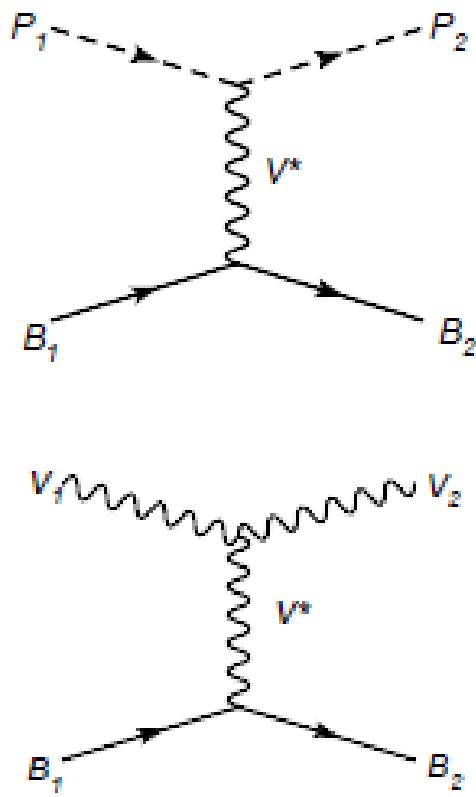
$N^*(1535)$ $\bar{s}uud$

$N^*(4260)$ $\bar{c}uud$ J.J.Wu, R.Molina, E.Oset, B.S.Zou.
arXiv:1007.0573[nucl-th]

$N^*(11050)$ $\bar{b}uud$ J.J.Wu, B.S.Zou. to be submitted.

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

J.J.Wu, R.Molina, E.Oset, B.S.Zou. arXiv:1007.0573[nucl-th]



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

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

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

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

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

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

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

	(I, S)	z_R (MeV)	g_a	
\mathbf{N}^*	$(1/2, 0)$		$D\Sigma_c$	$D\Lambda_c^+$
		4269	2.85	0
$\mathbf{\Lambda}^*$	$(0, -1)$		$D_s\Lambda_c^+$	$D\Xi_c$
		4213	1.37	3.25
		4403	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	
\mathbf{N}^*	$(1/2, 0)$		$\bar{D}^*\Sigma_c$	$\bar{D}^*\Lambda_c^+$
		4418	2.75	0
$\mathbf{\Lambda}^*$	$(0, -1)$		$\bar{D}_s^*\Lambda_c^+$	$\bar{D}^*\Xi_c$
		4370	1.23	3.14
		4550	0	2.53

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

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.

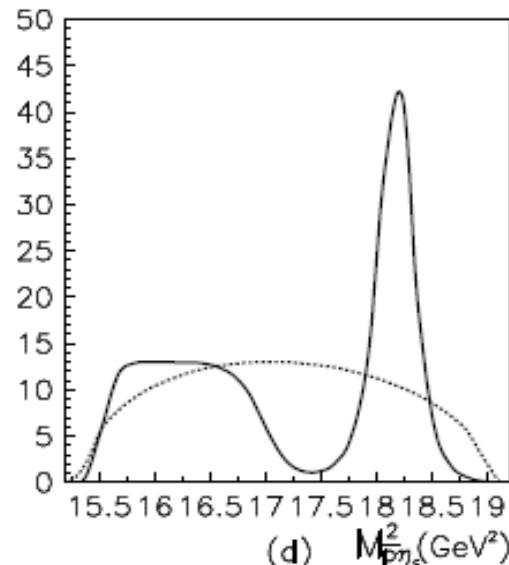
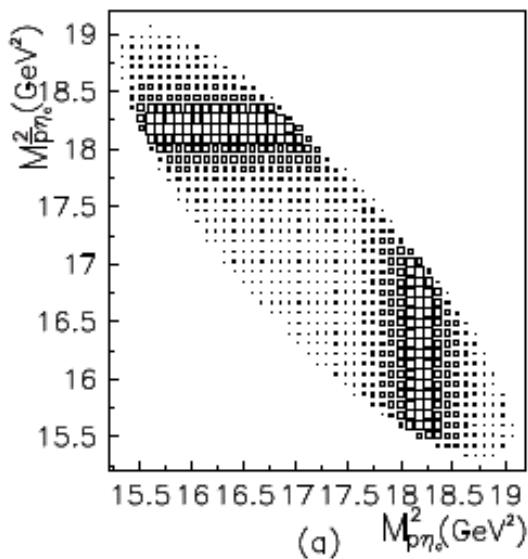
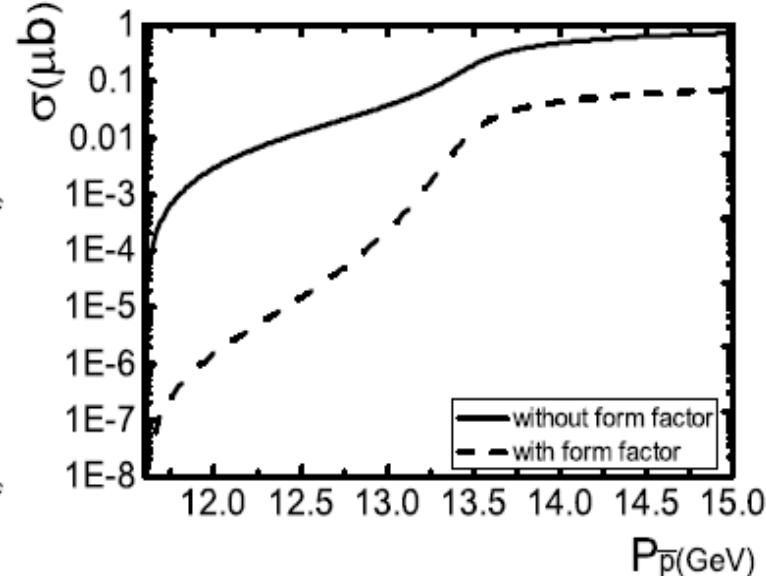
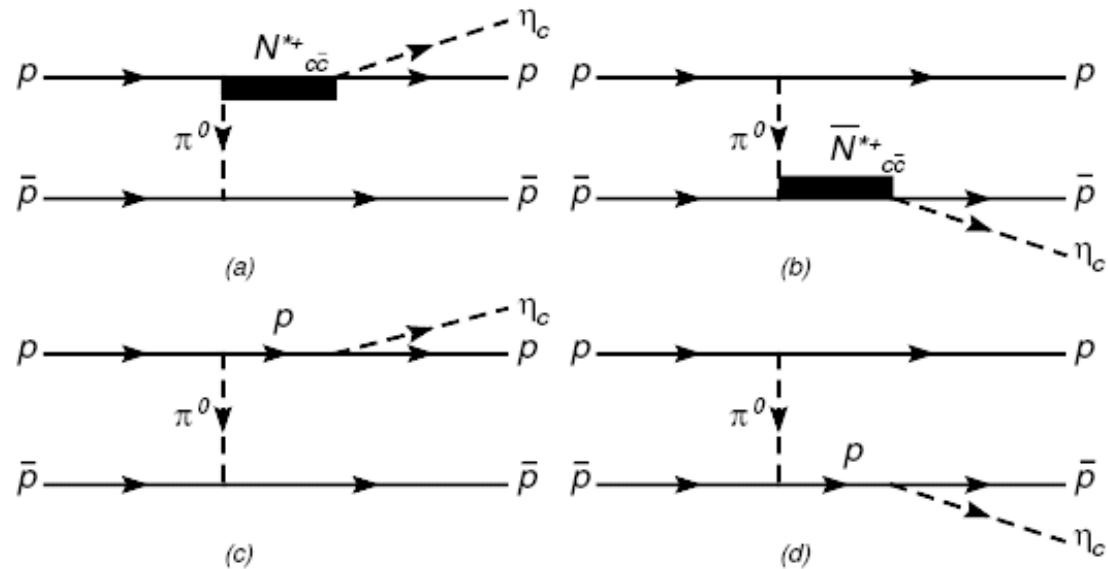
	(I, S)	M	Γ			Γ_i	
N^*	$(1/2, 0)$			ρN	ωN	$K^* \Sigma$	$J/\psi N$
		4412	47.3	3.2	10.4	13.7	19.2
Λ^*	$(0, -1)$			$K^* N$	$\rho \Sigma$	$\omega \Lambda$	$\phi \Lambda$
		4368	28.0	13.9	3.1	0.3	4.0
		4544	36.6	0	8.8	9.1	0
						5.0	13.8

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.

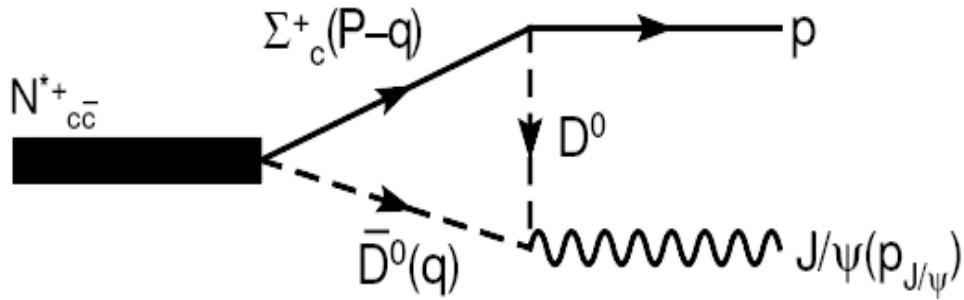
Super-heavy narrow N^* and Λ^* with hidden charm !

Definitely not qqq states !

Prediction for PANDA



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



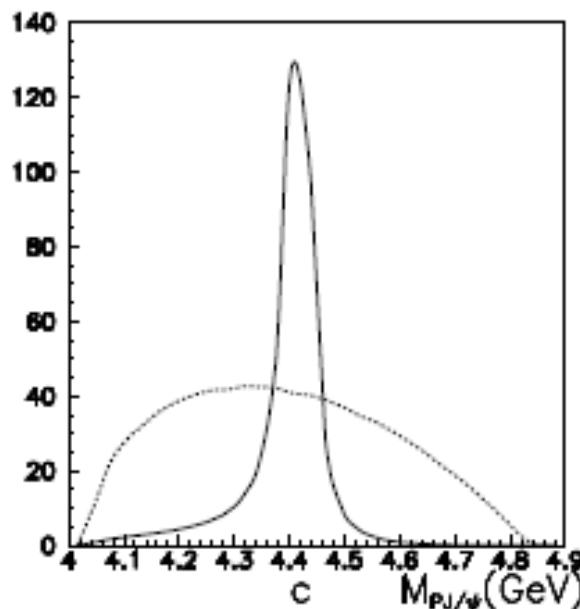
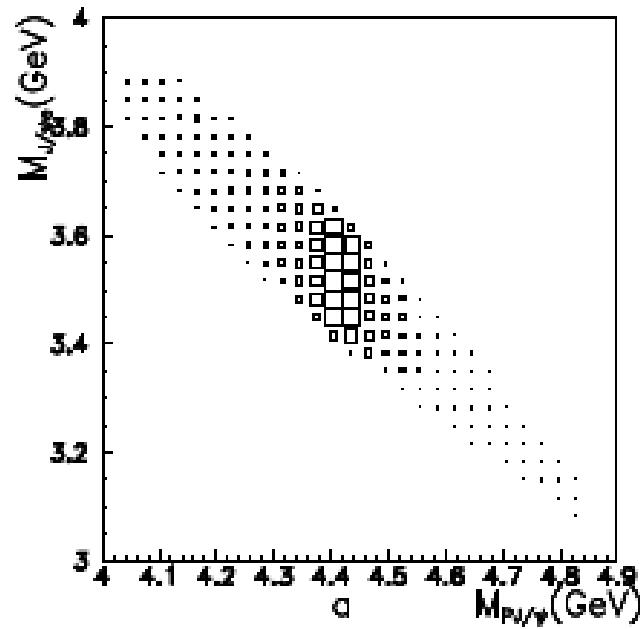
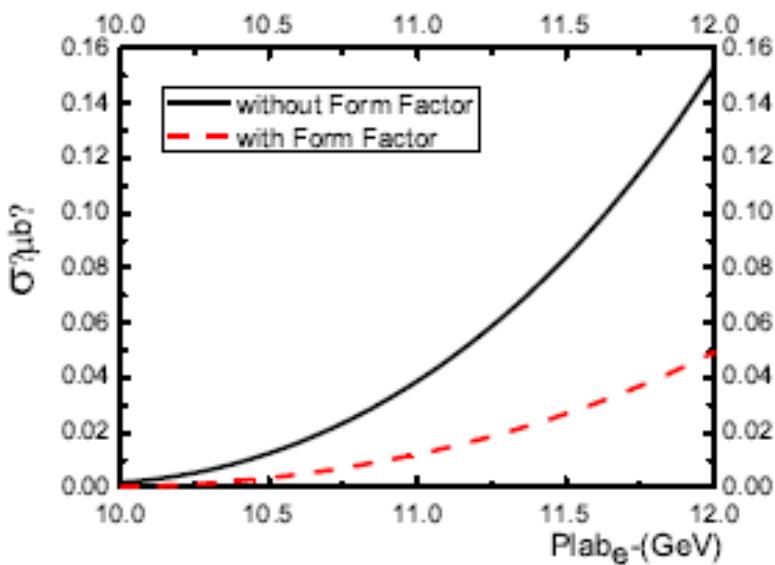
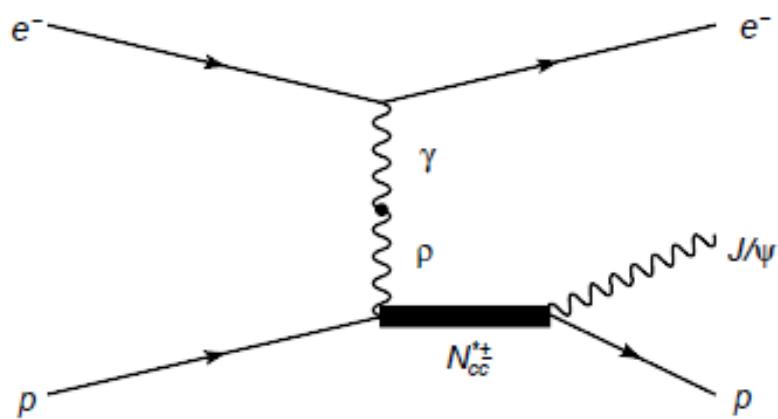
3 orders of magnitude smaller than $N^* \rightarrow p n_c$

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

~ 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

- Super heavy 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
- They are definitely not qqq baryons
- They can be looked for at 12GeV@Jlab and PANDA
maybe also at JPARC, RHIC , EIC?