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

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

J.J.Wu, B.S.Zou. arXiv:1011.5743

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

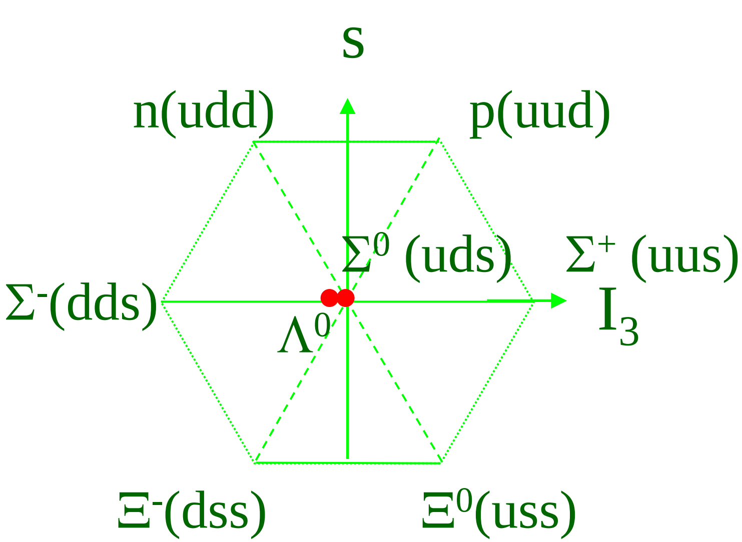
Outline:

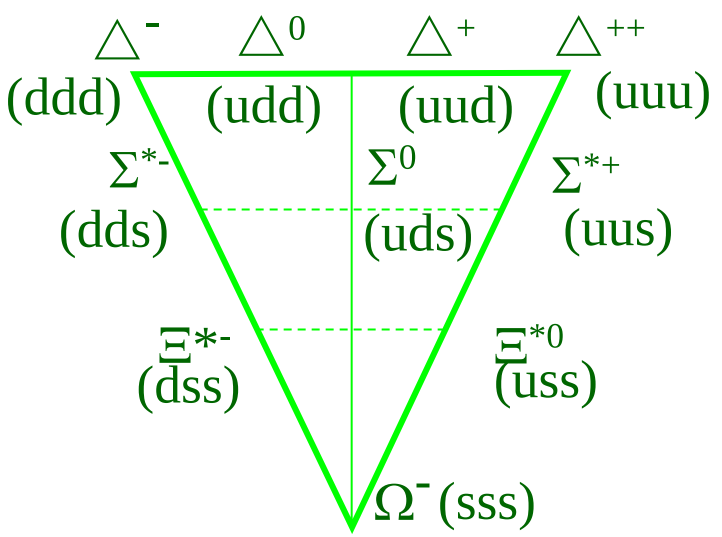
- Quenched & unquenched quark models
- Prediction of superheavy N* & Λ* states
  with hidden charm and beauty
- Conclusion

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 MeV**

experiment $m_{\Omega^-} \cong$ **1672.45 ±0.29 MeV**

quench vs un-quench for 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 ?

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

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

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

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

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

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

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

Problem of quenched quark models for baryons

- **Mass order reverse problem for the lowest excited baryons**

uud (L=1) ½ - ~ N*(1535) **should be the lowest**

uud (n=1) ½ + ~ N*(1440)

uds (L=1) ½ - ~ Λ*(1405)

harmonic oscillator (2n + L + 3/2) hω

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

J/ψ → $\bar{p}$N* → $\bar{p}$ (KΛ) / $\bar{p}$ (pη) → large $g_{N^*K\Lambda}$

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

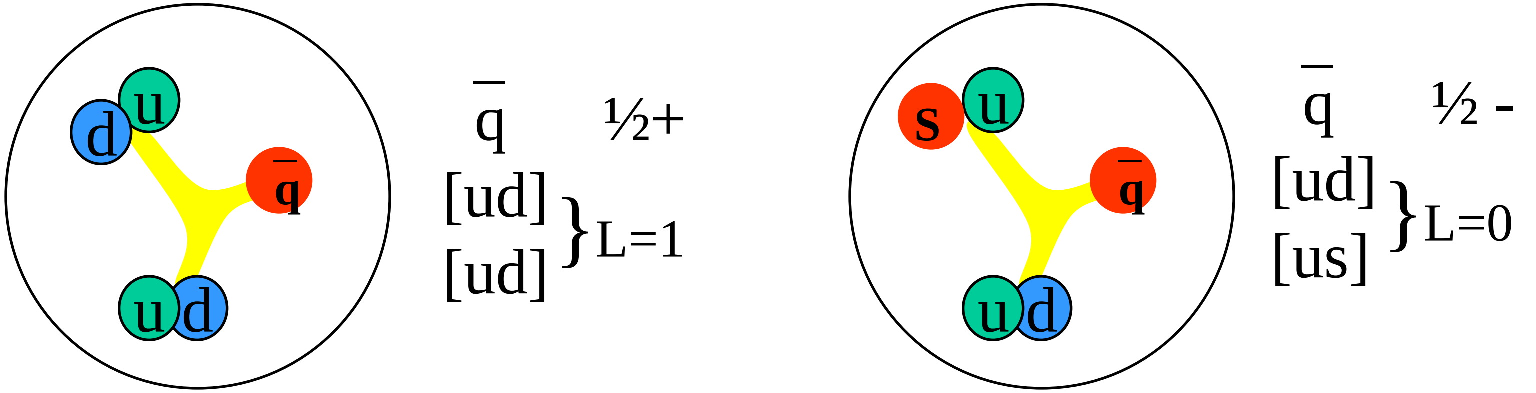
γp → pη' & pp→ppη' → large $g_{N^*N\eta'}$

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

π^-p → nϕ & pp → ppϕ & pn → dϕ → 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



Zhang et al, hep-ph/0403210

N*(1535) ~ uud (L=1) + ε [ud][us] $\bar{s}$ + …

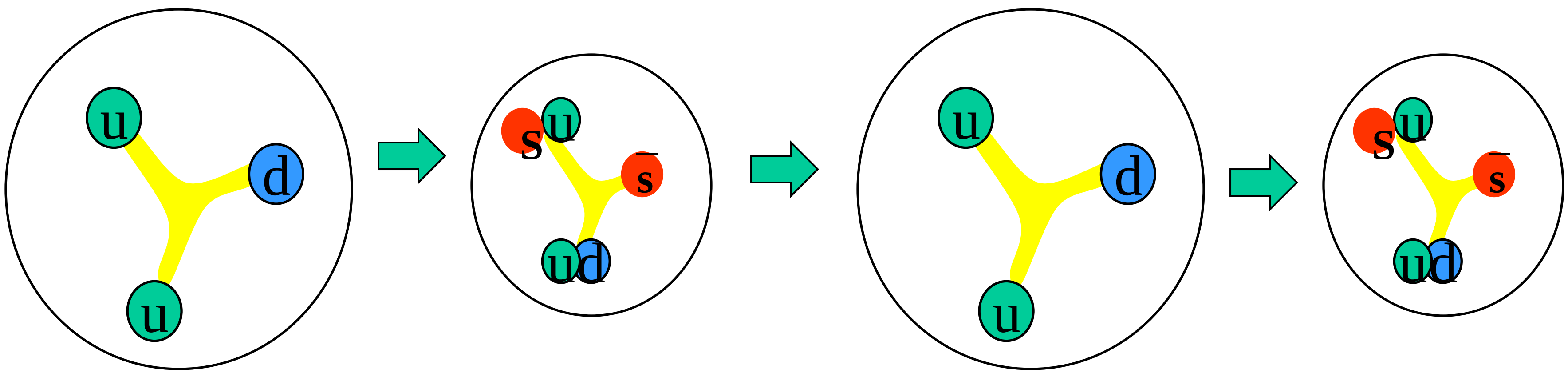
N*(1440) ~ uud (n=1) + ξ [ud][ud] $\bar{d}$ + …

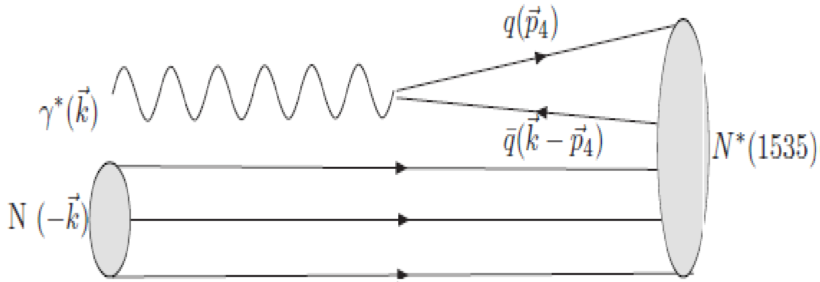
Λ*(1405) ~ uds (L=1) + ε [ud][su] $\bar{u}$ + …

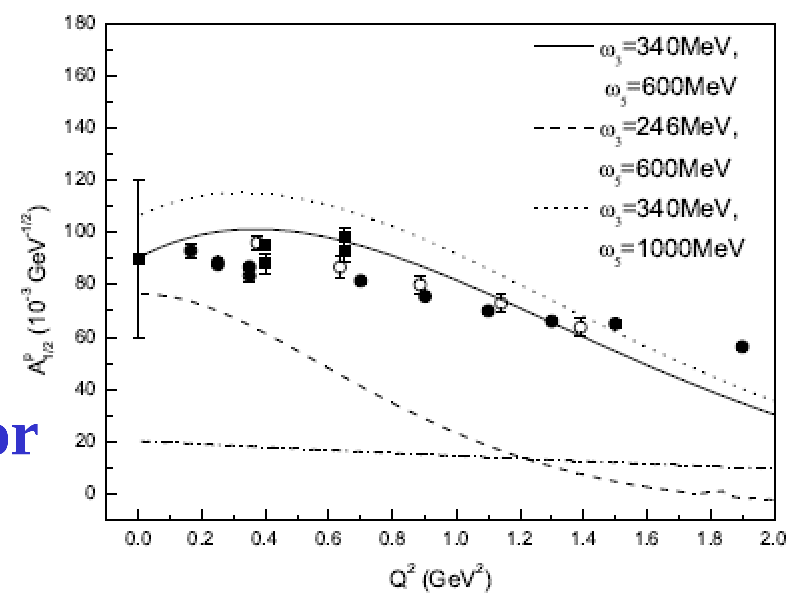
N*(1535): [ud][us] $\bar{s}$ → larger coupling to Nη, Nη', Nϕ & KΛ, weaker to Nπ & KΣ, and heavier !

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

The breathing mode for the N*(1535)







Important role for N* EM form factor

An & Zou, EPJA39(2009)195

Important implications:

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

$1/2^-$ baryon nonet ~ $\bar{q}q^2q^2$ state + …

0^+ meson octet ~ $\bar{q}^2q^2$ state + …

multiquark components are important for hadrons!

The new scheme for the $1/2^-$ nonet predicts:

Λ^* [us][ds] $\bar{s}$ ~ 1575 MeV

Σ^* [us][du] $\bar{d}$ ~ 1360 MeV Zhang et al, hep-ph/0403210

Ξ^* [us][ds] $\bar{u}$ ~ 1520 MeV

Prediction of other unquenched models:

(1) 5-quark model Helminen & Riska, NPA699(2002)624

$\Sigma^*(1/2^-)$ ~ $\Lambda^*(1/2^-)$

(2) K Λ-KΣ dynamics Weise, Oset et al.

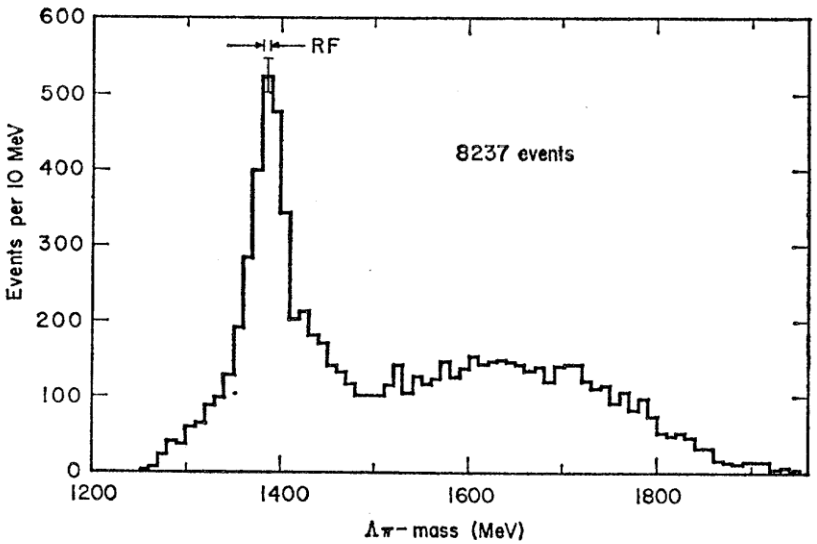
broad non-resonant $\Sigma^*(1/2^-)$ structure

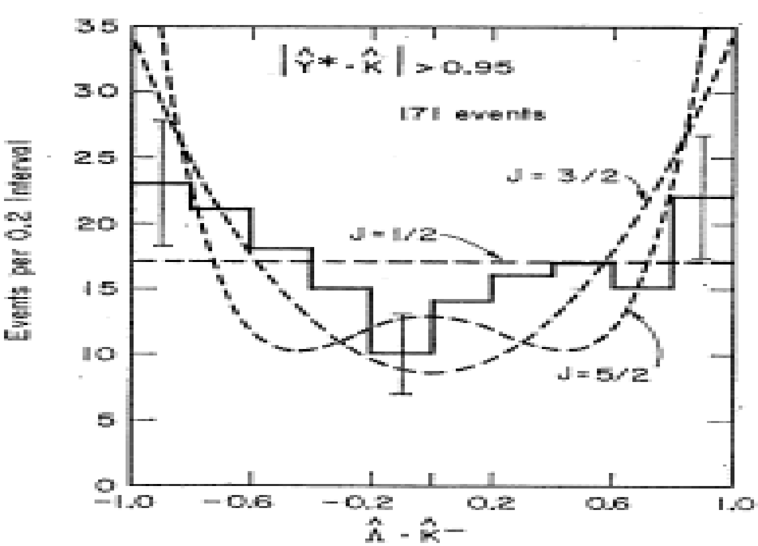
Jido-Oset et al , NPA725(2003)181

Important to look for the $\Sigma^*(1/2^-)$ around 1380 MeV !

Evidence for the predicted $\Sigma^*(1/2^-)$

Huwe, PR181(1969)1824

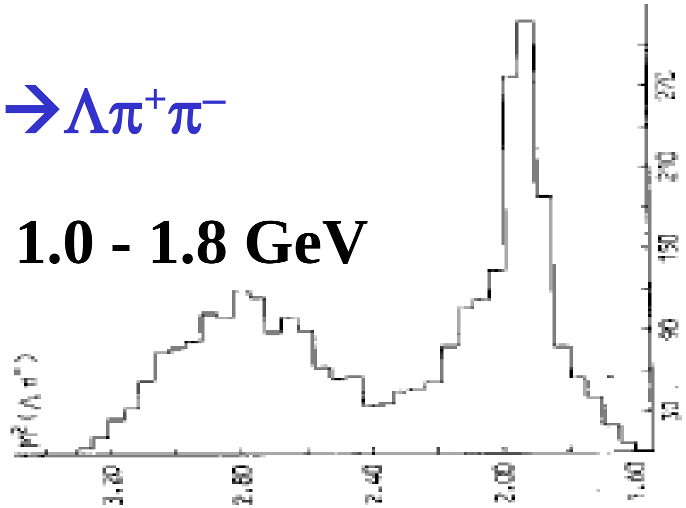


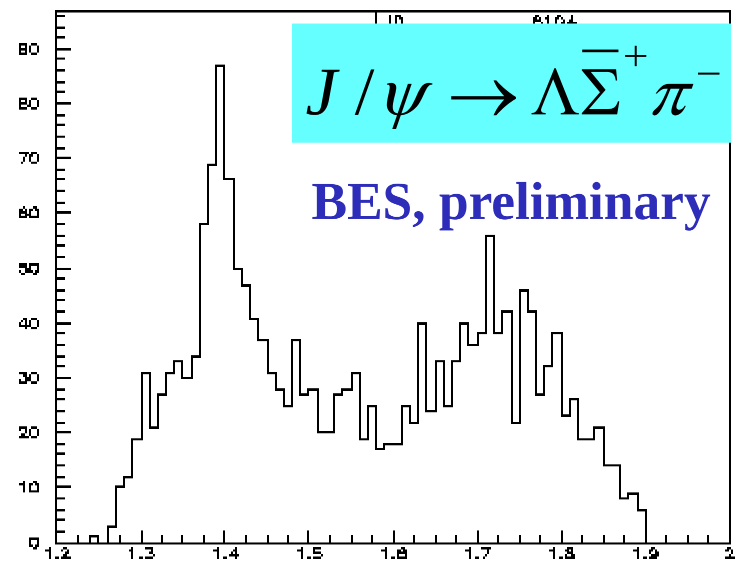


Cameron et al., NPB143(1978)189

$K^- p \rightarrow \Lambda\pi^+\pi^-$

P_K = 1.0 - 1.8 GeV



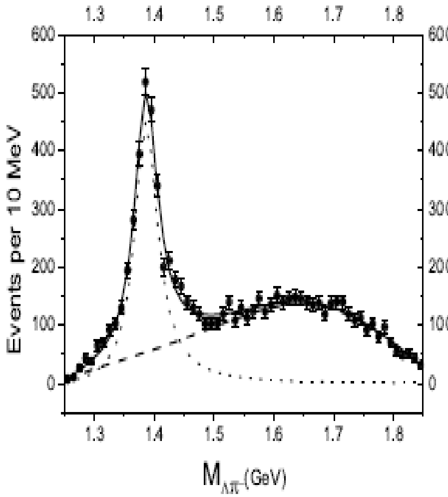


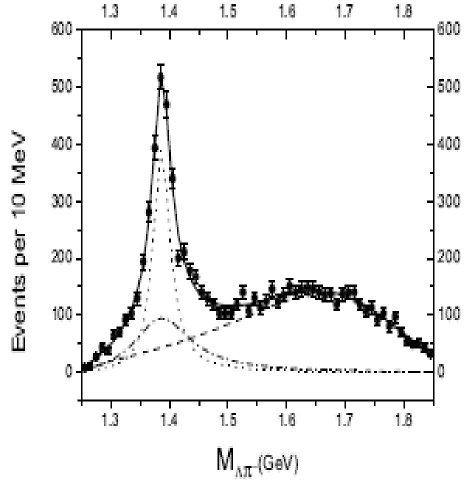
$$J/\psi \rightarrow \Lambda\bar{\Sigma}^+\pi^-$$

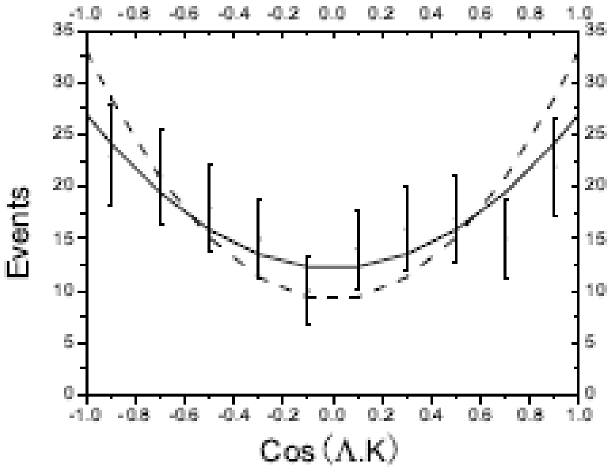
BES, preliminary

BES, NSTAR04

$M_{\pi\Lambda}$







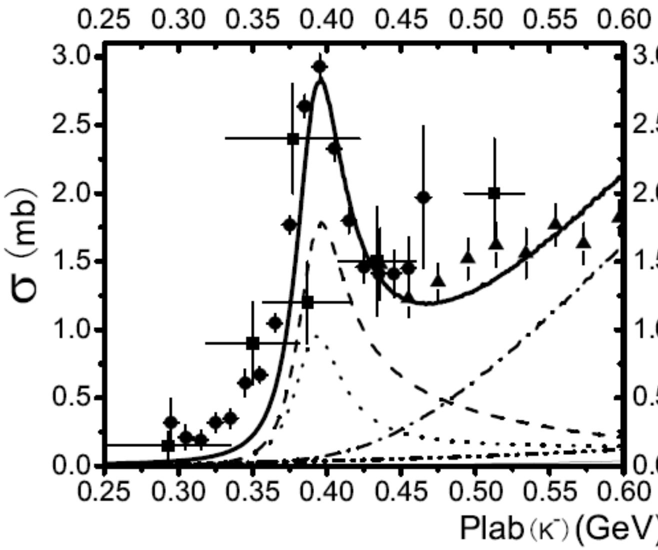
	$M_{\Sigma^*(3/2)}$	$\Gamma_{\Sigma^*(3/2)}$	$M_{\Sigma^*(1/2)}$	$\Gamma_{\Sigma^*(1/2)}$	χ^2/ndf(Fig.1)	χ^2/ndf(Fig.2)
Fit1	1385.3 ± 0.7	46.9 ± 2.5			$68.5/54$	$10.1/9$
Fit2	$1386.1^{+1.1}_{-0.9}$	$34.9^{+5.1}_{-4.9}$	$1381.3^{+4.9}_{-8.3}$	$118.6^{+55.2}_{-35.1}$	$58.0/51$	$3.2/9$

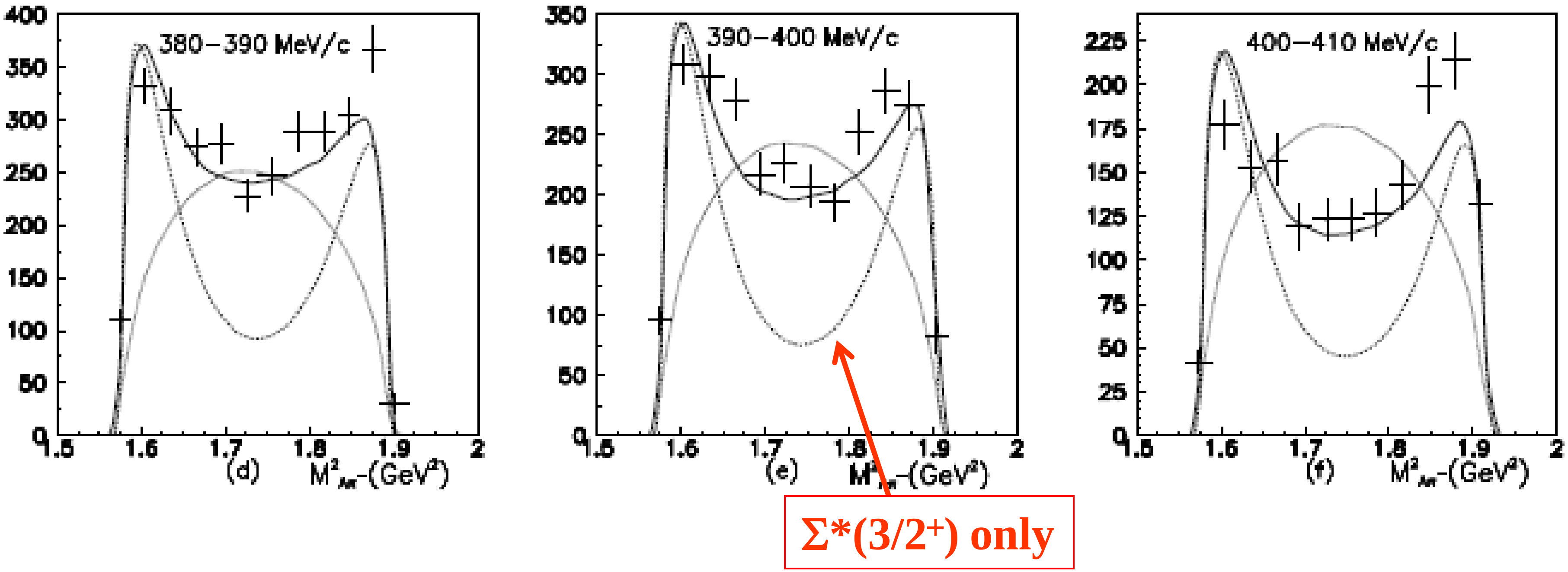
J.J.Wu, S.Dulat, B.S.Zou, PRD80 (2009) 017503

$$K^- p \to \Lambda^* \to \Sigma^{*-}_{3/2}\pi^+ \to \Lambda\pi^+\pi^-$$

$$K^- p \to \Lambda^* \to \Sigma^{*-}_{1/2}\pi^+ \to \Lambda\pi^+\pi^-$$

$P_K \approx 0.4$ GeV



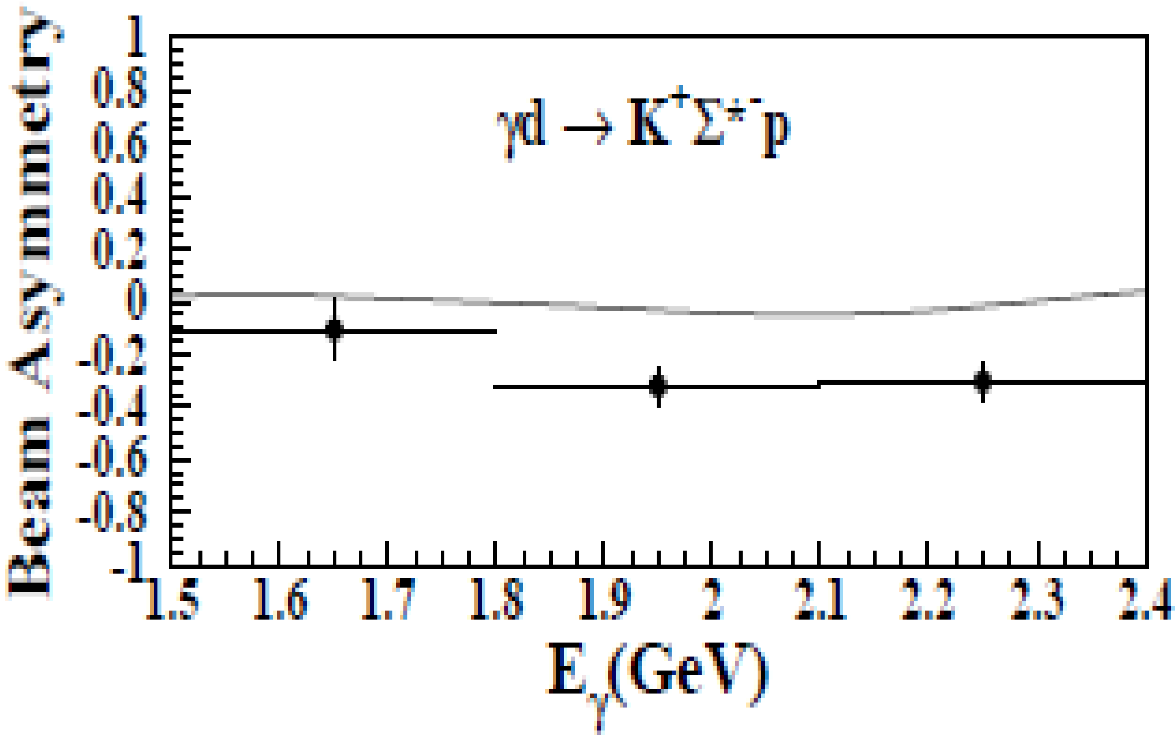


J.J.Wu, S.Dulat, B.S.Zou, Phys. Rev. C81 (2010) 045210

Other evidence: failed to reproduce data with Σ∗(1385)

LEPS, PRL102(2009)012501

Y. Oh, C. M. Ko, and K. Nakayama, PRC77(2008) 045204



Something new ?   **Σ*(1/2⁻) ?**

P.Gao, J.J.Wu, B.S.Zou, Phys. Rev. C 81 (2010) 055203

J/ψ decay **branching ratio * 10^4**

$\bar{p}\,\Delta(1232)^+$	3/2+	< 1	} SU(3) breaking
$\bar{\Sigma}^-\,\Sigma(1385)^+$		3.1 ± 0.5	
$\bar{\Xi}^+\,\Xi(1530)^-$		5.9 ± 1.5	
$\bar{p}\,N^*(1535)^+$	1/2-	10 ± 3	} SU(3) allowed
$\bar{\Sigma}^-\,\Sigma(1360)^+$		?	
$\bar{\Xi}^+\,\Xi(1520)^-$		?	

It is very important to check whether under the Σ(1385) and Ξ(1520) peaks there are $1/2^-$ components ?

2. 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

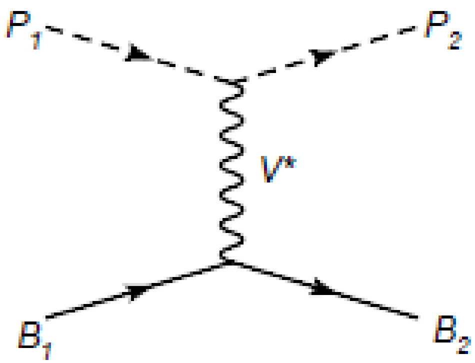
N*(1535) $\bar{s}suud$

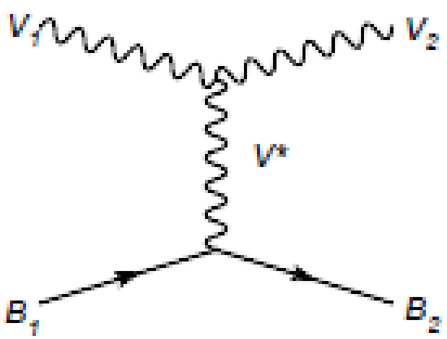
N*(4260) $\bar{c}cuud$ J.J.Wu, R.Molina, E.Oset, B.S.Zou. Phys.Rev.Lett. 105 (2010) 232001

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

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

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





$$\begin{aligned}
\mathcal{L}_{VVV} &= ig\langle V^\mu [V^\nu, \partial_\mu V_\nu]\rangle \\
\mathcal{L}_{PPV} &= -ig\langle V^\mu [P, \partial_\mu P]\rangle \\
\mathcal{L}_{BBV} &= g(\langle \bar{B}\gamma_\mu [V^\mu, B]\rangle + \langle \bar{B}\gamma_\mu B\rangle\langle V^\mu\rangle)
\end{aligned}$$

$$\begin{aligned}
V_{ab(P_1B_1\to P_2B_2)} &= \frac{C_{ab}}{4f^2}(E_{P_1}+E_{P_2}), \\
V_{ab(V_1B_1\to V_2B_2)} &= \frac{C_{ab}}{4f^2}(E_{V_1}+E_{V_2})\vec{\epsilon}_1\cdot\vec{\epsilon}_2,
\end{aligned}$$

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

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

	(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 $PB \to PB$.

	(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 $VB \to VB$.

	(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
	$(0,-1)$			$\bar{K}N$	$\pi\Sigma$	$\eta\Lambda$	$\eta'\Lambda$	$K\Xi$	$\eta_c\Lambda$
Λ*		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 $PB \to PB$, 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
	$(0,-1)$			$\bar{K}^* N$	$\rho\Sigma$	$\omega\Lambda$	$\phi\Lambda$	$K^*\Xi$	$J/\psi\Lambda$
Λ*		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 $VB \to VB$ 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

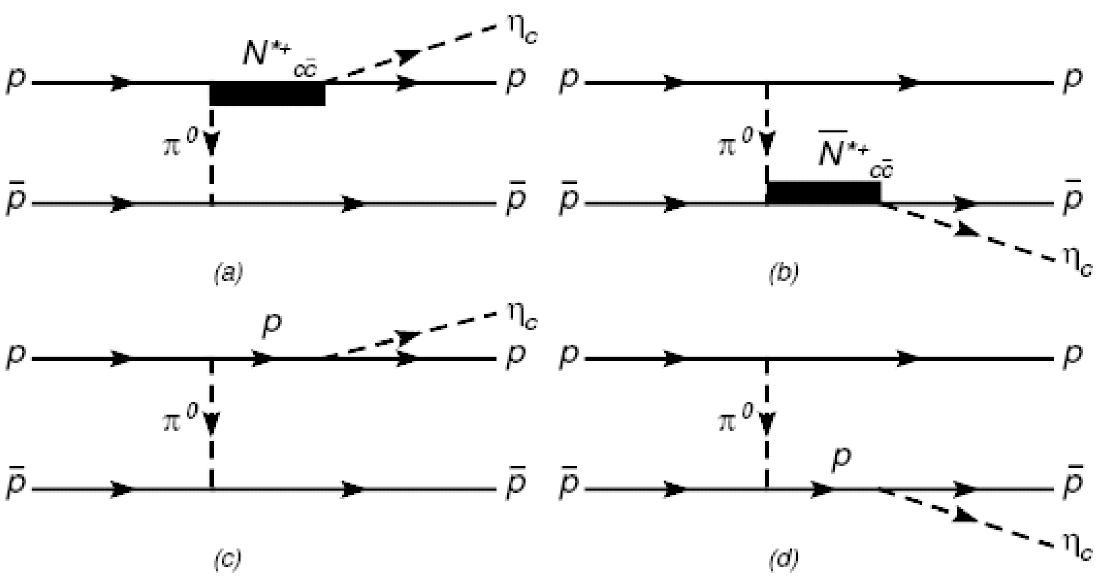
J. Hofmann, M.F.M. Lutz, Nucl. Phys. A 763 (2005) 90

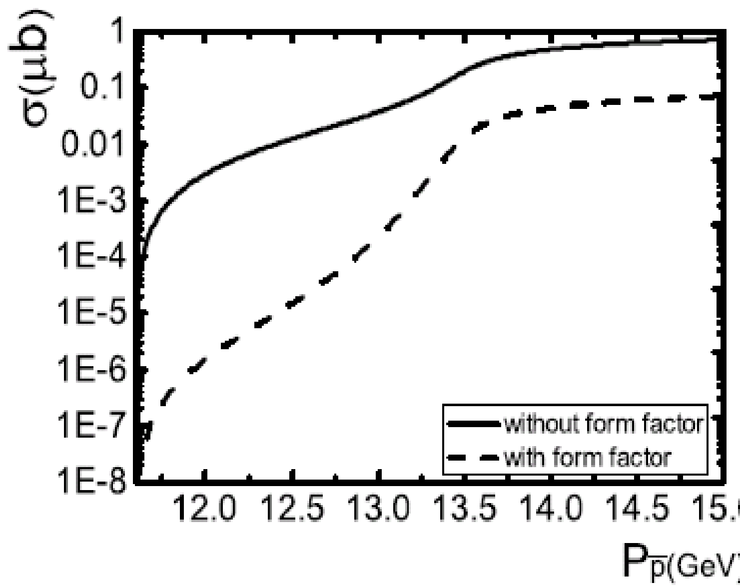
$\bar{D}\Sigma_c$ state in a chiral quark model ~ 4.3 GeV

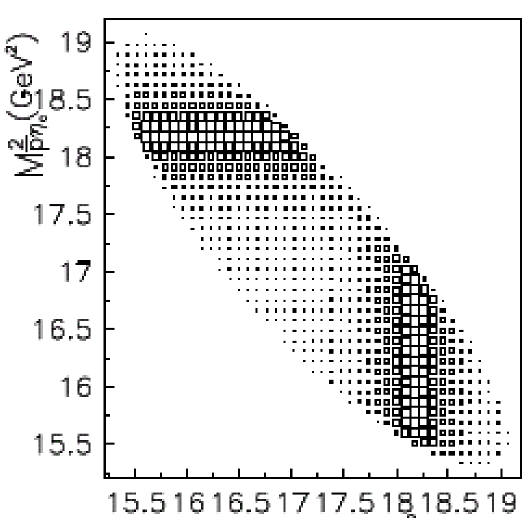
W.L.Wang, F.Huang, Z.Y.Zhang, B.S.Zou, arXiv:1101.0453

How about the coupled-channel Bethe-Salpeter approach
by P.Bruns, M.Mai, Ulf-G. Meissner ?

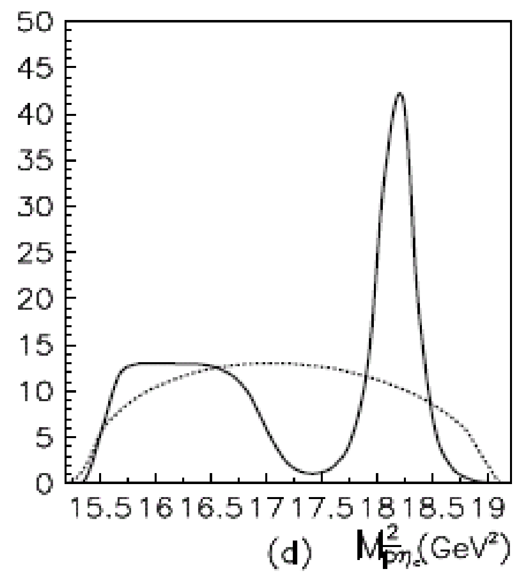
Prediction for PANDA







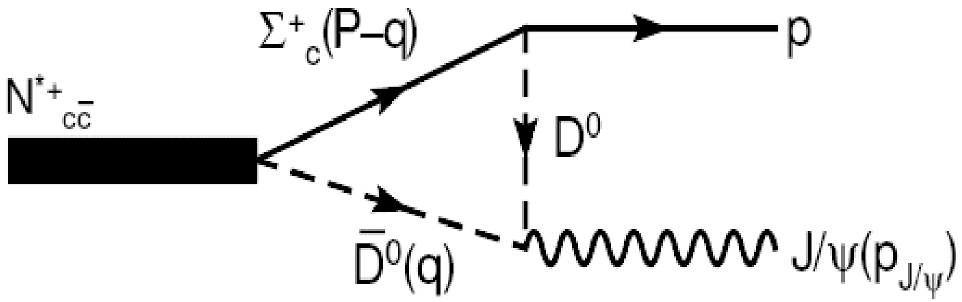
(a)



(d)

$\bar{p}p \rightarrow \bar{p}p\eta_c$

0.07 -- 0.7μb



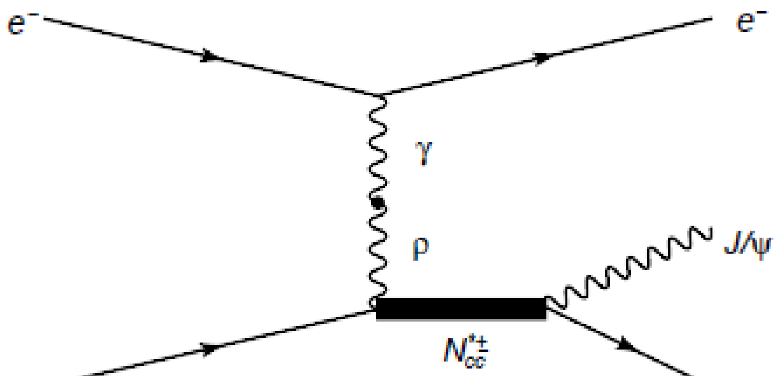
3 orders of magnitude smaller than N* → pη_c

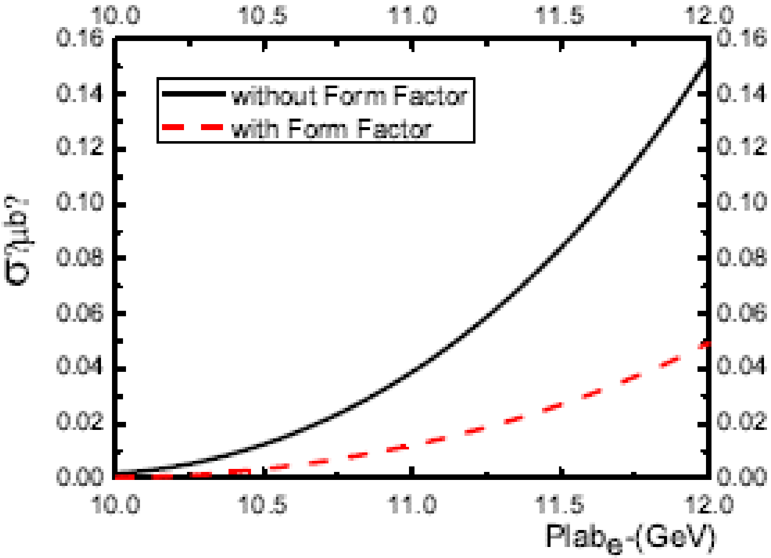
$\bar{p}p \rightarrow \bar{p}pJ/\psi$ ~ 0.03 nb

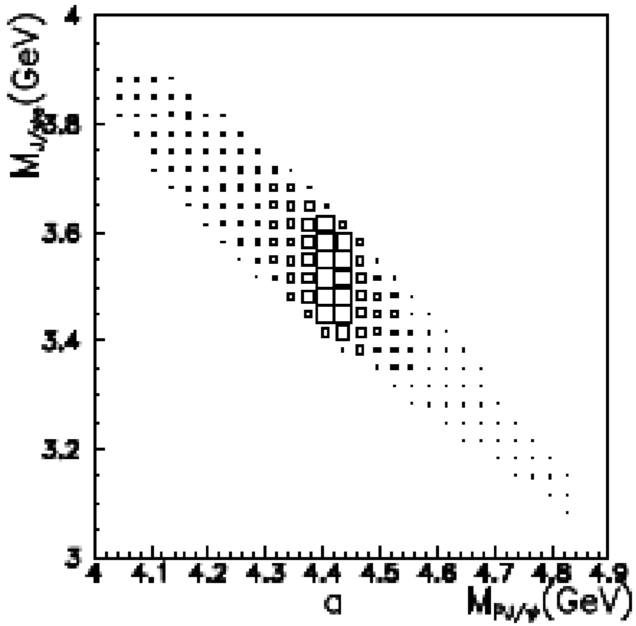
~ 250 events per day at PANDA/FAIR by L=10^{31} cm^{-2}s^{-1}

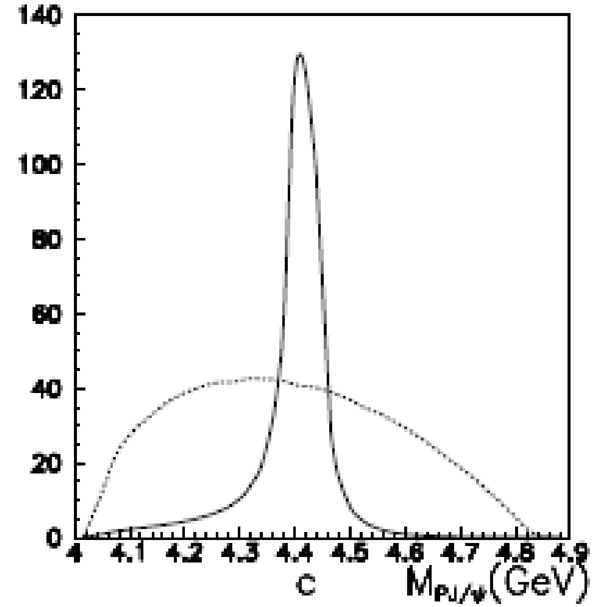
These Super-heavy narrow N* and Λ* can be found at PANDA !

Prediction for 12GeV@JLab









Conclusion

- **Superheavy narrow N* and Λ* are predicted to exist**
  $\bar{D}\Sigma_c$, $\bar{D}_s\Lambda_c$ → $B\Sigma_b$, $B_s\Lambda_b$ bound states
  ~ 4.2 GeV ~11 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**