Penta-quark states with strangeness, hidden charm and beauty

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R. Molina, E. Oset, T. S. H. Lee, …

Outline :

1. Introduction
2. Baryon spectroscopy with strangeness
3. From Strangeness to charm & beauty
4. Conclusions

1. Introduction

Spectrum is important for us to understand the structure of particles.

atomic spectrum → atomic quantum theory

nuclear spectrum → shell model, collective motion

hadron spectrum → ? Important discovery

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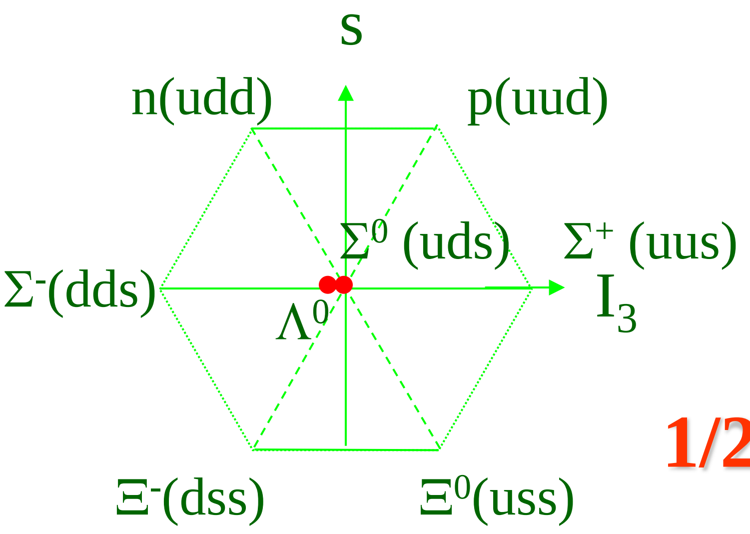
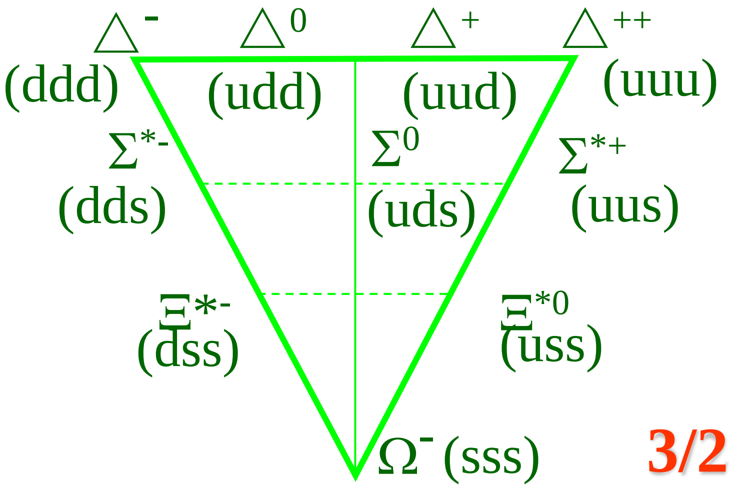
L=0



1/2 +



3/2 +

SU(3) 3q-quark model for baryons

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

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

$L=1$, $J^P=1/2^-$ Hadron spectrum

PDG $\Lambda^*(1405)$, $\Lambda^*(1670)$

$N^*(1535)$, $N^*(1650)$

$\Sigma^*(1620)$

? $\Xi^*(1620)$, ?$\Xi^*(1670)$

L=1, $J^P=1/2^-$ Hadron spectrum

PDG	**Λ*(1405) ,**	**Λ*(1670)**
	N*(1535) ,	**N*(1650)**
	?	**Σ*(1620)**

3q-quark Mass Order Reverse

uds (L=1) $1/2^-$ ~ Λ*(1405)

uud (L=1) $1/2^-$ ~ N*(1535)

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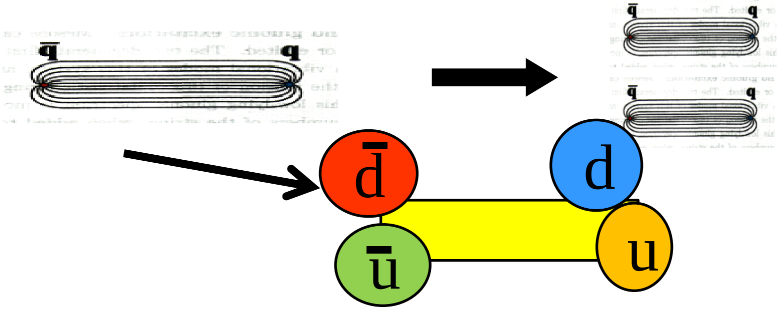

gluons → $\bar{q}q$: crucial for quark confinement and hadron structure

to be more challenging than atomic and nuclear structures

The number of constituents in a hadron is not a constant!

L=1, $J^P=1/2^-$ Hadron spectrum

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N*(1535) , N*(1650)

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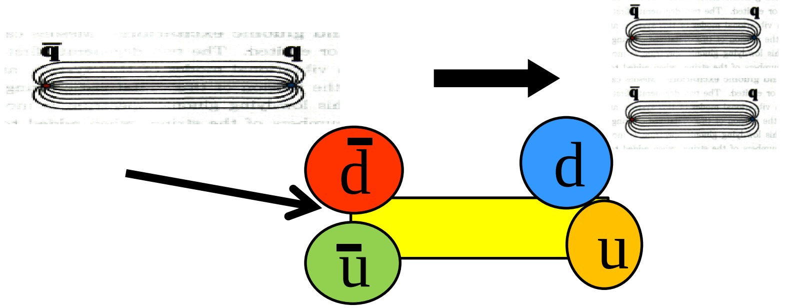


gluons → $\bar{q}q$: crucial for quark confinement and hadron structure

UNQUENCHED

Λ*(1405) ~ [ud][su] $\bar{u}$

N*(1535) ~ [ud][us] $\bar{s}$

Σ*(1390) ~ [us][ud] $\bar{d}$

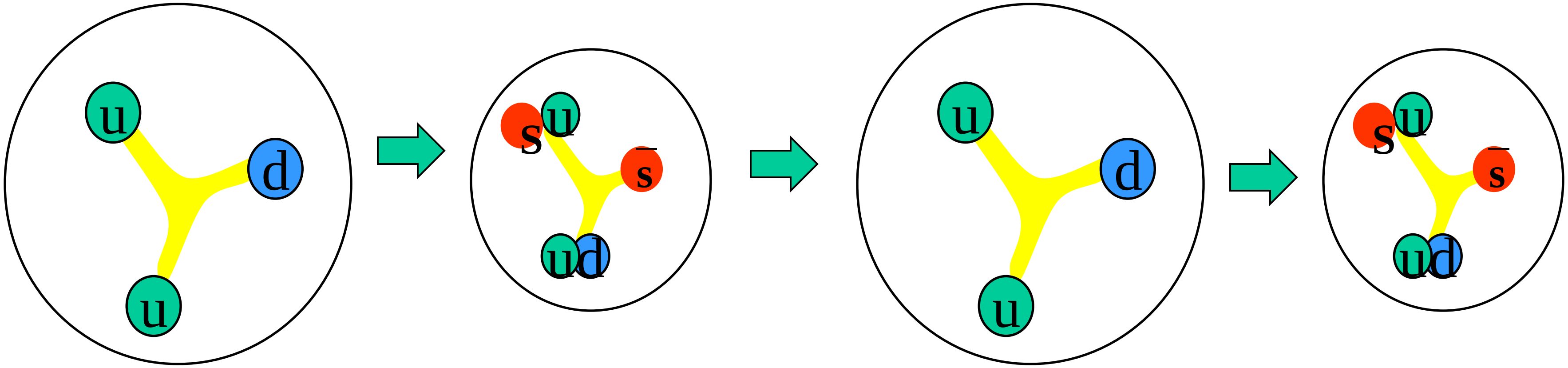
Λ*(1670) ~ [us][ds] $\bar{s}$

Zou et al, NPA835 (2010) 199 ; CLAS, PRC87(2013)035206

to be more challenging than atomic and nuclear structures

The number of constituents in a hadron is not a constant!

The breathing mode for the N*(1535)



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

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

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

$\gamma p \to p\eta'$ & $pp \to pp\eta'$ → large $g_{N^*N\eta'}$

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

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

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

Important implications:

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

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

multiquark components are important for hadrons!

Alternative pictures :

Hadronic molecules	**Penta-quark states**
N*(1440) ~ $N\sigma$	**N*(1440) ~ [ud][ud]** $\bar{q}$
N*(1535) ~ $K\Sigma$-$K\Lambda$	**N*(1535) ~ [ud][us]** $\bar{s}$
Λ*(1405) ~ KN-$\Sigma\pi$	**Λ*(1405) ~ [ud][sq]** $\bar{q}$

**Kaiser, Weise, Oset, Ramos,
Oller, Meissner, Hyodo, Jido,
Hosaka, …**

Successful extension to $3/2^-$ baryon nonet, 1^+ & 2^+ meson nonets

Oset et al.

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Experiment knowledge on hyperon states still very poor !

Ω* in PDG:

***** $\Omega(1672)\ 3/2^{+}$,

*** $\Omega\ (2250)$

** $\Omega\ (2380)$, $\Omega\ (2470)$

Ξ* in PDG:

***** $\Xi(1320)\ 1/2^{+}$, $\Xi(1530)\ 3/2^{+}$

*** $\Xi(1690)$, $\Xi(1820)\ 3/2^{-}$, $\Xi(1950)$, $\Xi(2030)$

** $\Xi(2250)$, $\Xi(2370)$

* $\Xi(1620)$, $\Xi(2120)$, $\Xi(2500)$

$\Sigma*$ in PDG

****
$\Sigma\ (1189)1/2^+$ $\Sigma*(1385)3/2^+$ $\Sigma*(1670)3/2^-$
$\Sigma*(1775)5/2^-$ $\Sigma*(1915)5/2^+$ $\Sigma*(2030)7/2^+$

***
$\Sigma*(1660)1/2^+$ $\Sigma^*(1750)1/2^-$ $\Sigma^*(1940)3/2^-$
$\Sigma*(2250)??$

**
$\Sigma*(1620)1/2^-$ $\Sigma*(1690)??$ $\Sigma*(1880)1/2^+$
$\Sigma*(2080)3/2^+$ $\Sigma*(2455)??$ $\Sigma*(2620)??$

*
$\Sigma*(1480)??$ $\Sigma*(1560)??$ $\Sigma*(1580)3/2^-$
$\Sigma*(1770)1/2^+$ $\Sigma*(1840)3/2^+$ $\Sigma*(2000)3/2^-$
$\Sigma*(2070)5/2^+$ $\Sigma*(2100)7/2^-$ $\Sigma*(3000)??$
$\Sigma*(3170)??$

All from old experiments of 1970-1985 !!

No established $1/2^-$ Σ^* , $\Xi*$, $\Omega*$!

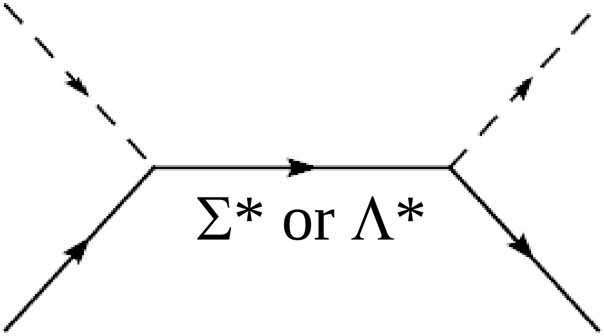
New results on Σ* & Λ* from CB data

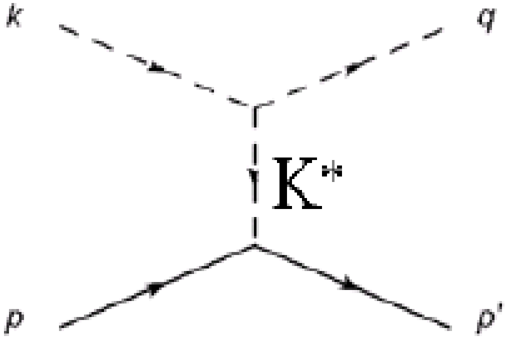
Crystal Ball: Prakhov et al., **PRC 80**(2009) 025204

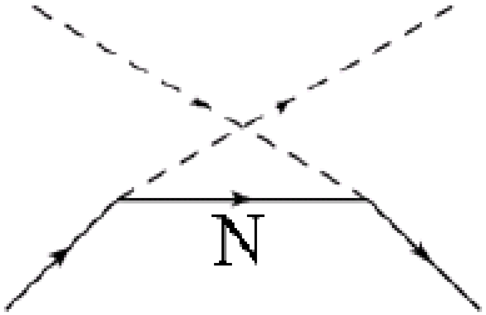
$$K^- + p \rightarrow \pi^0 + \Lambda \qquad \& \qquad K^- + p \rightarrow \pi^0 + \Sigma^0$$

p_K=514-750 MeV, $\sqrt{s} = 1569 - 1676\ \mathrm{MeV}$

The high precision new data can give valuable information on Σ* & Λ*





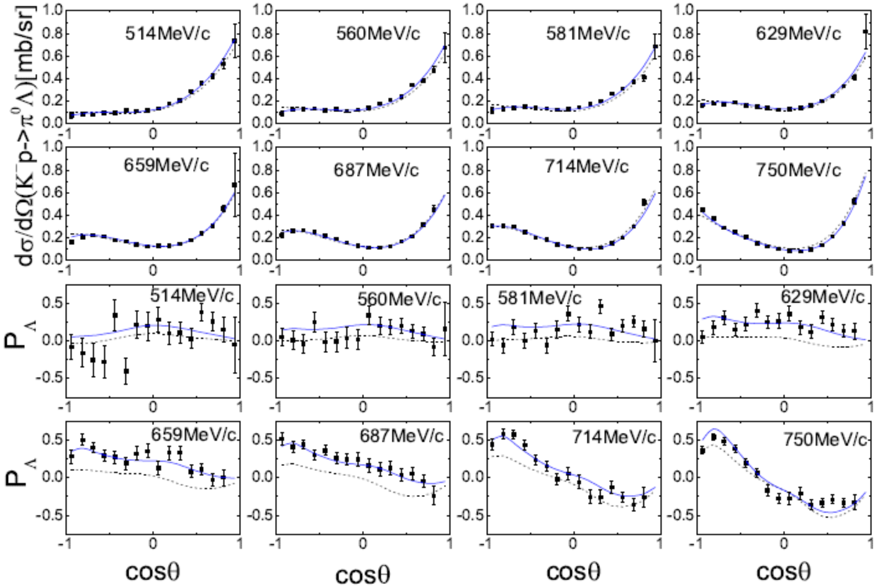


1)P.Gao, J.Shi, B.S.Zou, PRC86 (2012) 025201
2) J.Shi, B.S.Zou, PRC91(2015) 035202

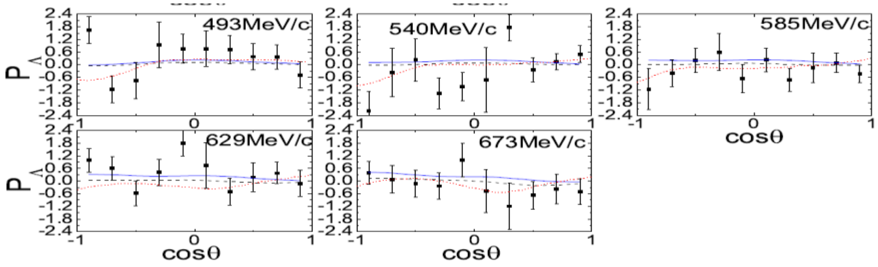
P.Gao, J.Shi, B.S.Zou, PRC86 (2012) 025201

$$K^- + p \rightarrow \pi^0 + \Lambda \text{ (new)} \;\; \& \;\; K^- + n \rightarrow \pi^- + \Lambda \text{ (old)}$$

new CB data on $K^-p \rightarrow \pi^0\Lambda$



old CB data on $K^-n \rightarrow \pi^-\Lambda$



Basic ingredients:

$\Sigma(1189)1/2^+$, $\Sigma(1385)3/2^+$, $\Sigma(1775)5/2^-$, $\Sigma(1670)3/2^-$,t-K*,u-P

Addition:

(data 348;
para: 18)

Σ 1/2$^+$ χ^2=572 1633 MeV

1/2$^-$ χ^2=572+327

3/2$^+$ χ^2=572+371

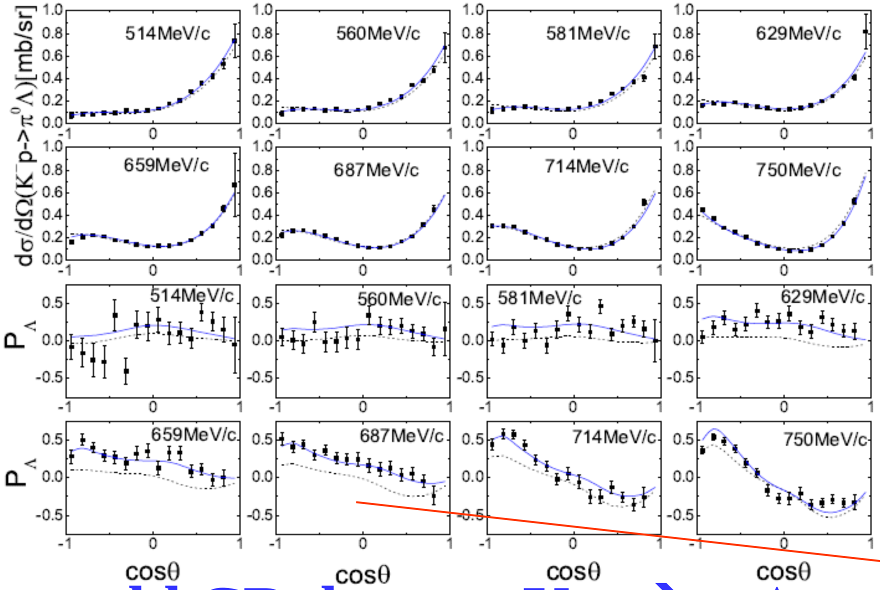
3/2$^-$ χ^2=572+820

P.Gao, J.Shi, B.S.Zou, PRC86 (2012) 025201

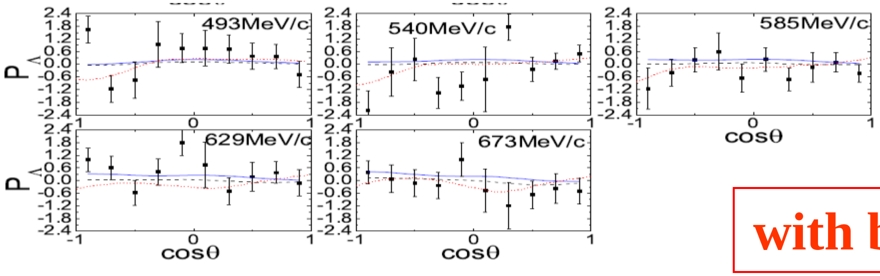
$$K^- + p \to \pi^0 + \Lambda \text{ (new)} \ \& \ K^- + n \to \pi^- + \Lambda \text{ (old)}$$

Σ(1660)1/2$^+$ is definitely needed, while Σ(1620) 1/2$^-$ is not needed at all !

new CB data on K$^-$p→π^{0}Λ



old CB data on K$^-$n→π$^-$Λ



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Addition:

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Σ 1/2$^+$	**χ^2=572**	**1633 MeV**
1/2$^-$	χ^2=572+327	
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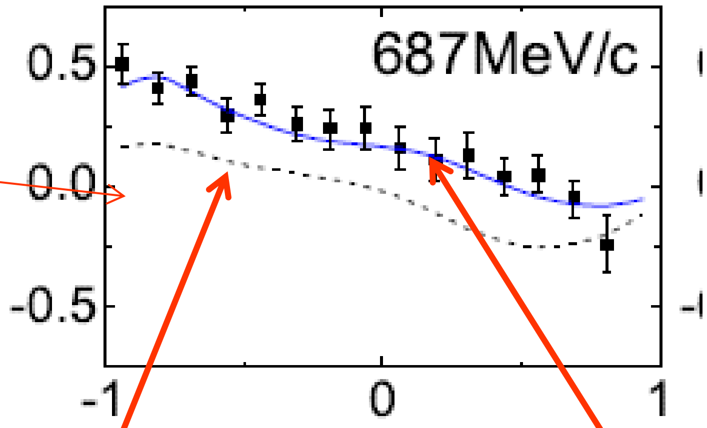


with basic ingredients

adding Σ(1635) 1/2$^+$

P.Gao, J.Shi, B.S.Zou, PRC86 (2012) 025201

$$K^- + p \rightarrow \pi^0 + \Lambda \text{ (new)} \ \ \& \ \ K^- + n \rightarrow \pi^- + \Lambda \text{ (old)}$$

Σ(1660)1/2$^+$ is definitely needed, while Σ(1620) 1/2$^-$ is not needed at all !

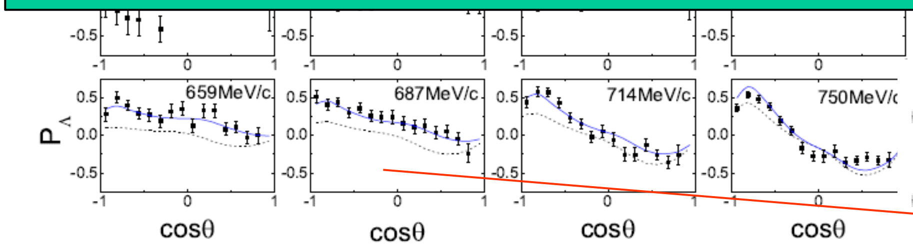
CB Λ Polarization data is crucial for discriminating Σ(1620)1/2$^-$ from Σ(1635) 1/2$^+$.

PDG2014 downgrades Σ(1620)1/2$^-$ from ** to *

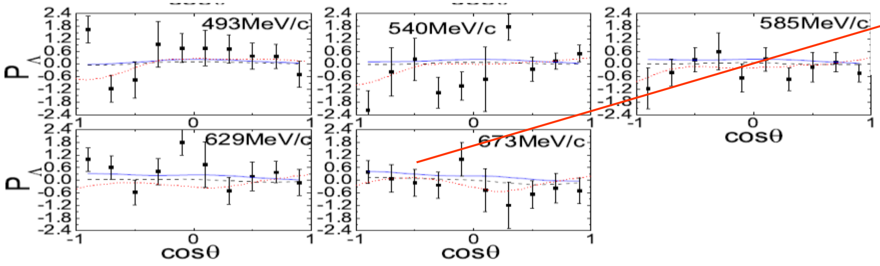
,u-P

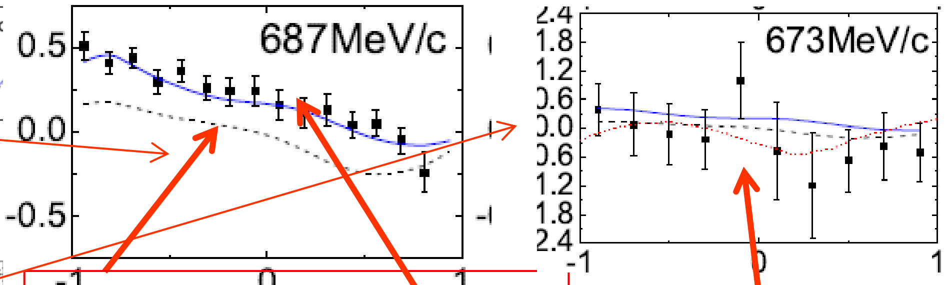
para: 18)

3/2- χ^2=572+820



old CB data on K$^-$n→π$^-$Λ





with basic ingredients

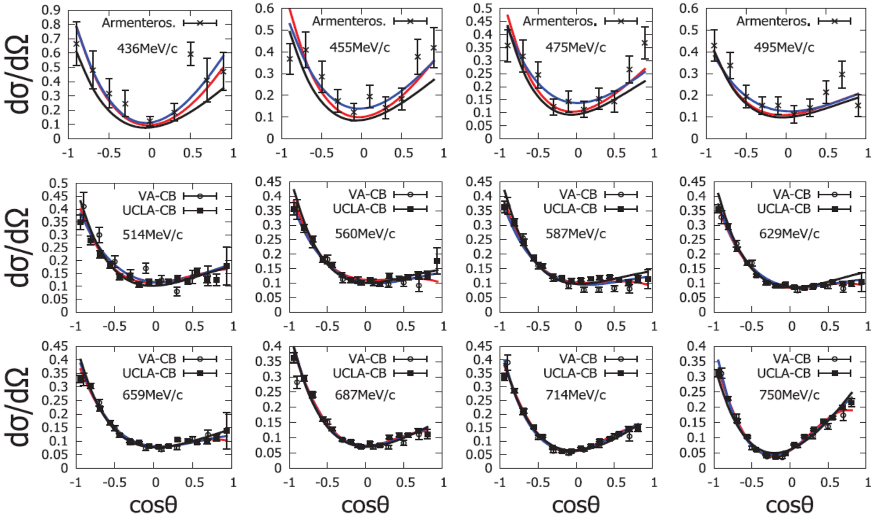
adding Σ(1635) 1/2$^+$

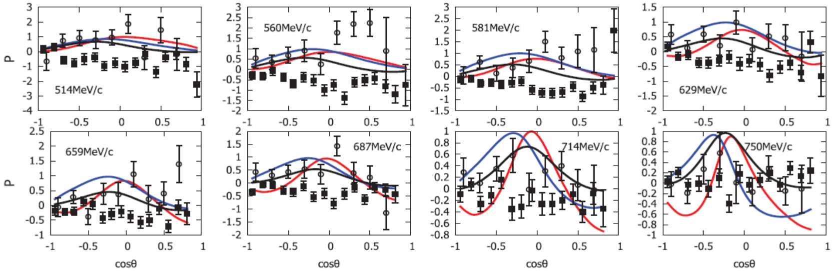
Old fit with Σ(1620) 1/2$^-$

J.Shi, B.S.Zou, PRC91(2015) 035202

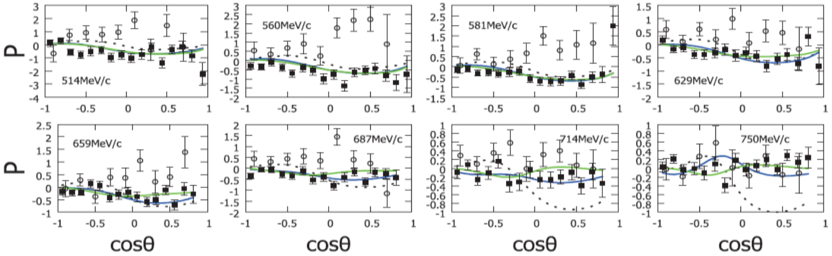
$K^- + p \rightarrow \pi^0 + \Sigma^0$ (new)

Λ*(1680)3/2$^+$ replaces Λ*(1690)3/2$^-$ ****





VA



UCLA

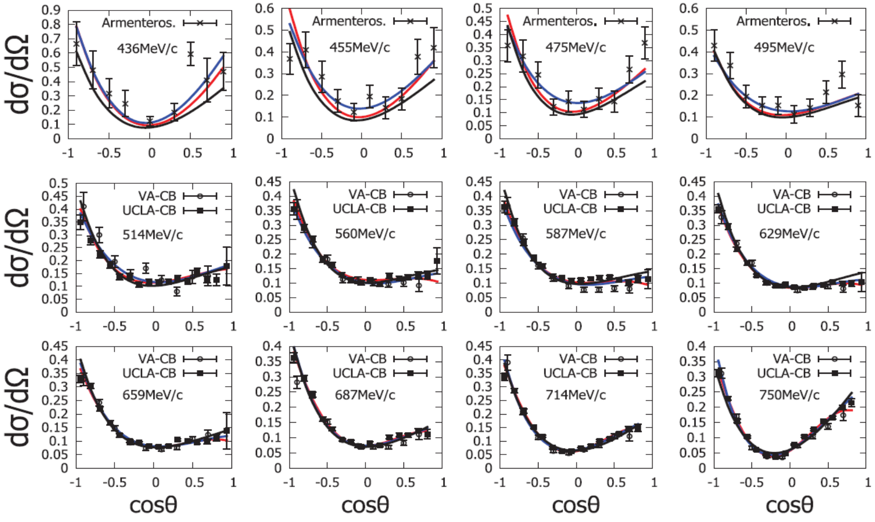
Basic ingredients: Λ(1115)1/2$^+$, Λ(1405)1/2$^-$, Λ(1520)3/2$^-$, Λ(1670)1/2$^-$, ~~Λ(1690)3/2$^-$~~, t-K*,u-P

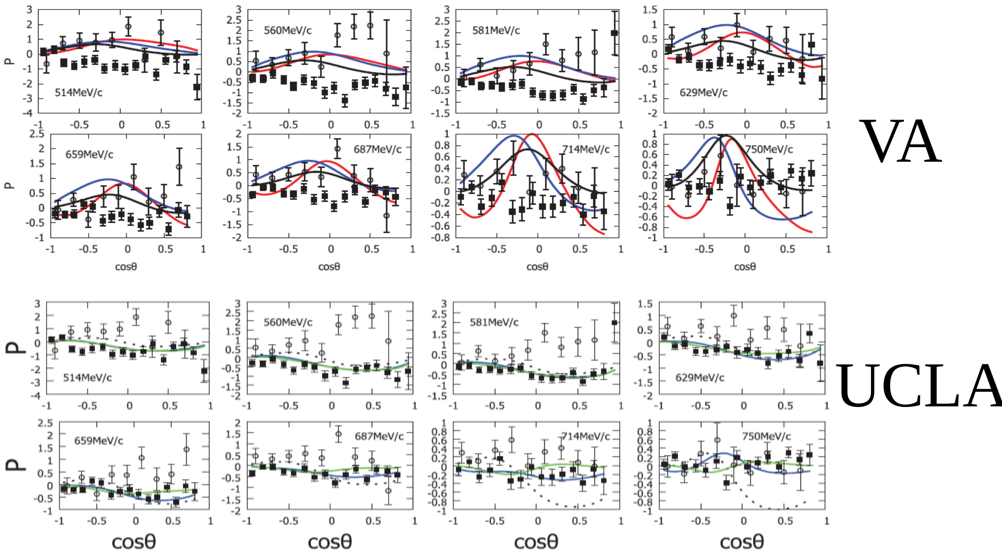
Addition:

	Only dσ/dΩ	dσ/dΩ + P (VA)	dσ/dΩ + P (UCLA)
data	236	308	360
1/2$^+$	1576.3	1575.0	1557.1
3/2$^+$	1679.8	1687.0	1665.6
3/2$^-$	1511.2	1506.0	1585.4
χ^2	419	551	882

J.Shi, B.S.Zou, PRC91(2015) 035202 $K^- + p \to \pi^0 + \Sigma^0$ (new)

Λ*(1680)3/2⁺ replaces Λ*(1690)3/2⁻ ****





Basic ingredients: Λ(1115)1/2$^+$, Λ(1405)1/2$^-$, Λ(1520)3/2$^-$, Λ(1670)1/2$^-$, ~~Λ(1690)3/2$^-$~~, t-K*,u-P

Addition:

Λ(1600)1/2+

Λ(1680)3/2+

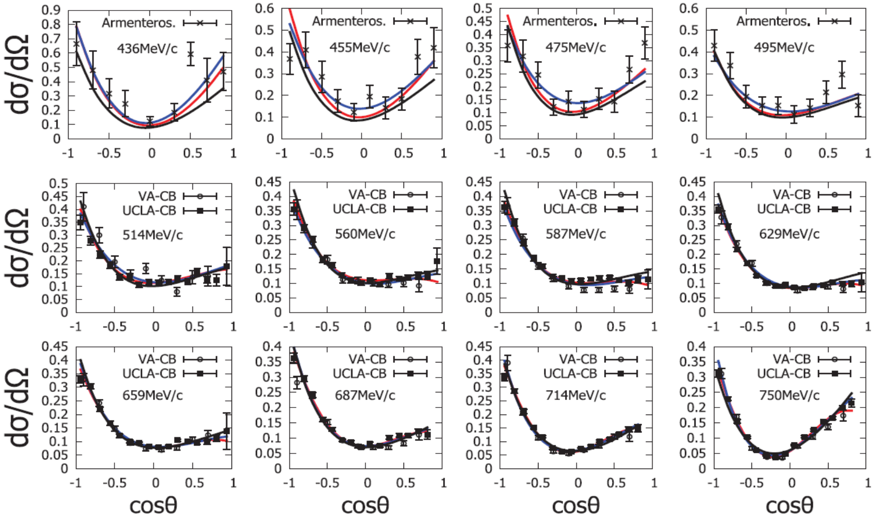
Modification of Λ(1520)3/2$^-$'s tail

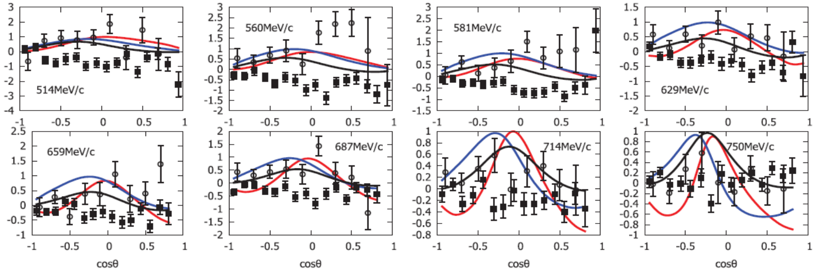
	Only dσ/dΩ	dσ/dΩ + P (VA)	dσ/dΩ + P (UCLA)
data	236	308	360
1/2$^+$	1576.3	1575.0	1557.1
3/2$^+$	1679.8	1687.0	1665.6
3/2$^-$	1511.2	1506.0	1585.4
χ2	419	551	882

J.Shi, B.S.Zou, PRC91(2015) 035202

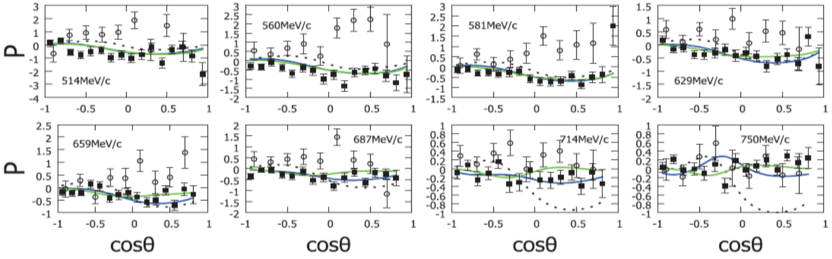
$K^- + p \to \pi^0 + \Sigma^0$ (new)

Λ*(1680)3/2⁺ replaces Λ*(1690)3/2⁻ ****





VA



UCLA

Basic ingredients: Λ(1115)1/2⁺, Λ(1405)1/2⁻, Λ(1520)3/2⁻, Λ(1670)1/2⁻, ~~Λ(1690)3/2⁻~~ , t-K*,u-P

Addition:

Λ(1600)1/2+

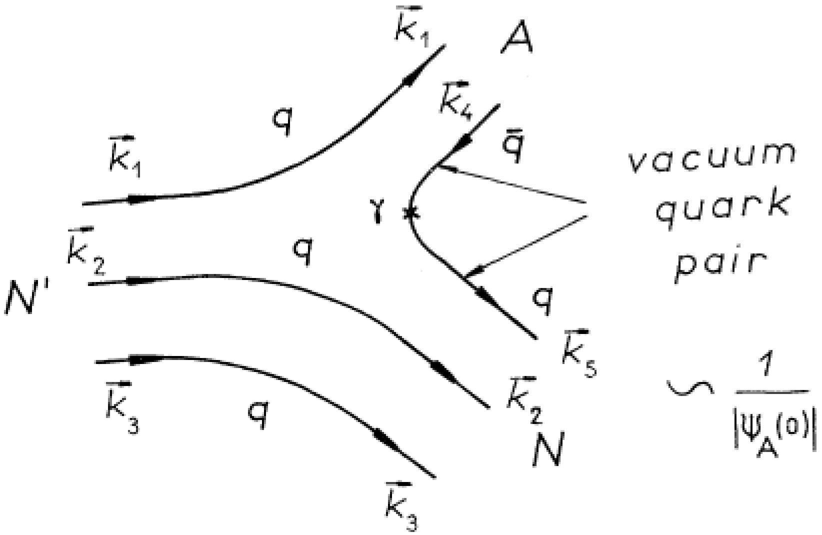
Λ(1680)3/2+

Modification of Λ(1520)3/2⁺'s tail

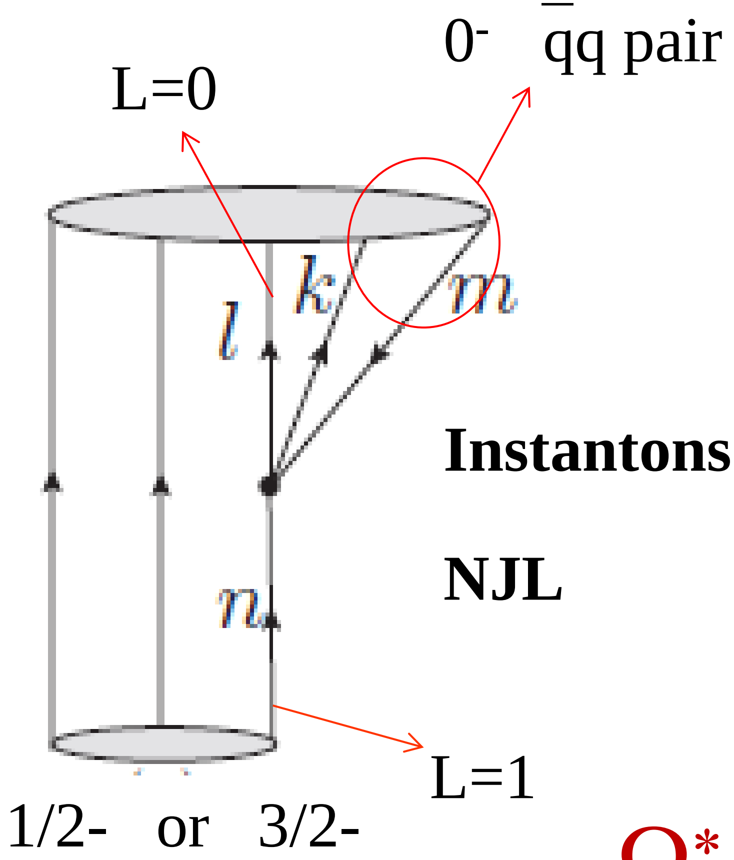
	Only dσ/dΩ	dσ/dΩ + P (VA)	dσ/dΩ + P (UCLA)
data	236	308	360
1/2⁺	1576.3	1575.0	1557.1
3/2⁺	1679.8	1687.0	1665.6
3/2⁻	1511.2	1506.0	1585.4
χ2	419 **540**	551	882
Λ(1690)3/2⁻ δ χ2	0.9	0.6	3.2

Mechanisms for $\bar{q}q$ pair production

$^3P_0$ can not produce 0^- $\bar{q}q$ pair



A. Le Yaouanc et al., **PRD8 (1973) 2223**



Instantons

NJL

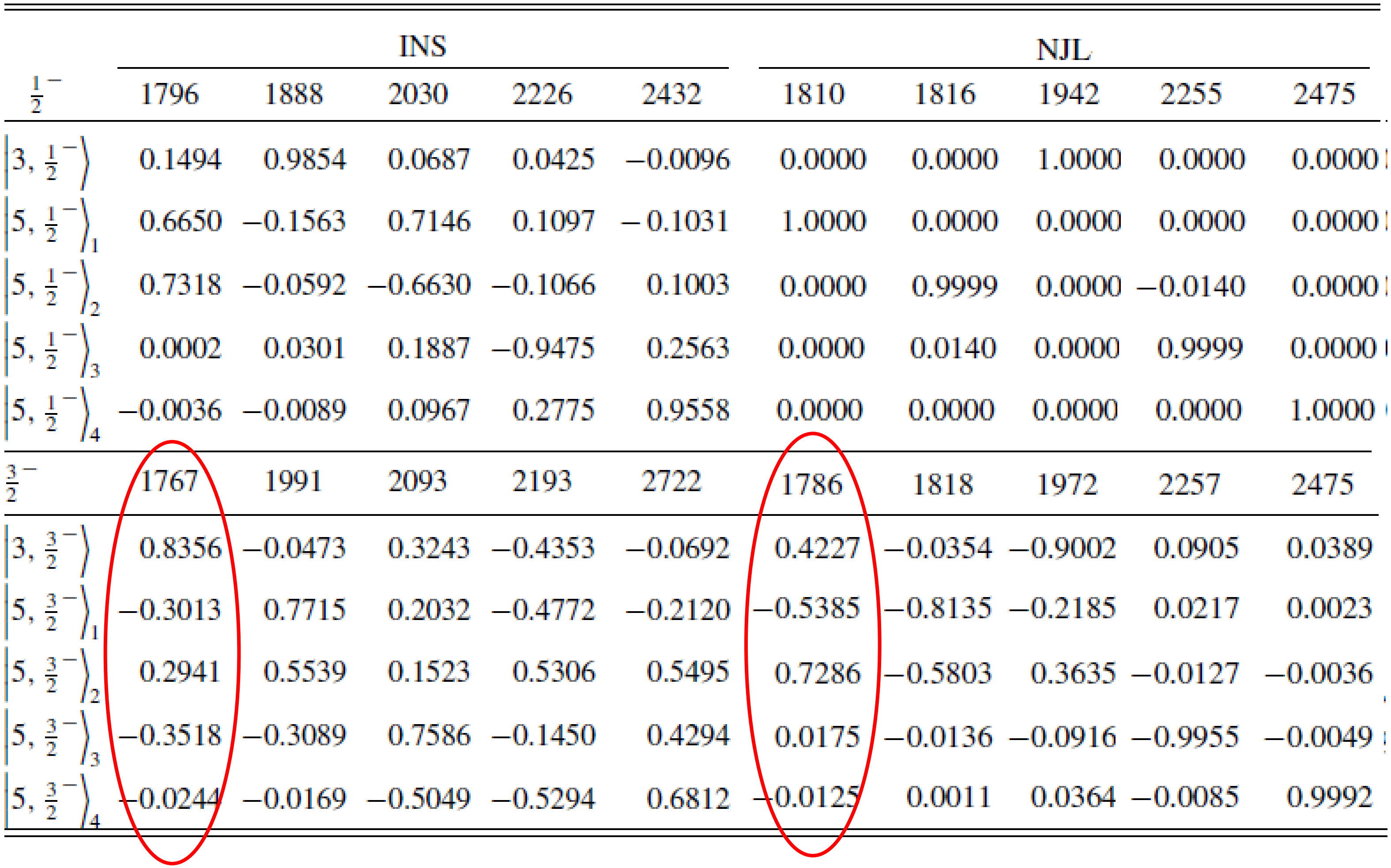
Ω^*

1)C.S.An, B.S.Zou, PRC89(2014) 055209

2)C.S.An, B.C.Metsch, B.S.Zou, PRC 87(2013) 065207

for baryon sss → sss $\bar{q}q$

$$H = \begin{pmatrix} H_3 & V_{\Omega_3 \leftrightarrow \Omega_5} \\ V_{\Omega_3 \leftrightarrow \Omega_5} & H_5 \end{pmatrix}$$



	INS					NJL				
$\frac{1}{2}^-$	1796	1888	2030	2226	2432	1810	1816	1942	2255	2475
$\|3, \frac{1}{2}^-\rangle$	0.1494	0.9854	0.0687	0.0425	−0.0096	0.0000	0.0000	1.0000	0.0000	0.0000
$\|5, \frac{1}{2}^-\rangle_1$	0.6650	−0.1563	0.7146	0.1097	−0.1031	1.0000	0.0000	0.0000	0.0000	0.0000
$\|5, \frac{1}{2}^-\rangle_2$	0.7318	−0.0592	−0.6630	−0.1066	0.1003	0.0000	0.9999	0.0000	−0.0140	0.0000
$\|5, \frac{1}{2}^-\rangle_3$	0.0002	0.0301	0.1887	−0.9475	0.2563	0.0000	0.0140	0.0000	0.9999	0.0000
$\|5, \frac{1}{2}^-\rangle_4$	−0.0036	−0.0089	0.0967	0.2775	0.9558	0.0000	0.0000	0.0000	0.0000	1.0000
$\frac{3}{2}^-$	1767	1991	2093	2193	2722	1786	1818	1972	2257	2475
$\|3, \frac{3}{2}^-\rangle$	0.8356	−0.0473	0.3243	−0.4353	−0.0692	0.4227	−0.0354	−0.9002	0.0905	0.0389
$\|5, \frac{3}{2}^-\rangle_1$	−0.3013	0.7715	0.2032	−0.4772	−0.2120	−0.5385	−0.8135	−0.2185	0.0217	0.0023
$\|5, \frac{3}{2}^-\rangle_2$	0.2941	0.5539	0.1523	0.5306	0.5495	0.7286	−0.5803	0.3635	−0.0127	−0.0036
$\|5, \frac{3}{2}^-\rangle_3$	−0.3518	−0.3089	0.7586	−0.1450	0.4294	0.0175	−0.0136	−0.0916	−0.9955	−0.0049
$\|5, \frac{3}{2}^-\rangle_4$	−0.0244	−0.0169	−0.5049	−0.5294	0.6812	−0.0125	0.0011	0.0364	−0.0085	0.9992

Predictions for the lowest Ω^* by various models:

$\Omega^*(x/2^-)$ as sss (L=1) : ~ 2020 MeV

Chao, Isgur, Karl, PRD38(1981)155

$\Omega^*(1/2^-)$ as $\bar{K}\Xi$ bound state: ~ 1805 MeV

W.L.Wang, F.Huang, Z.Y.Zhang, F.Liu, JPG35 (2008) 085003

$\Omega^*(x/2^-)$ as $\bar{u}usss$ (L=0) : ~ 1820 MeV

Yuan-An-Wei-Zou-Xu, PRC87(2013)025205

$\Omega^*(3/2^-)$ as sss - $\bar{u}usss$ mixture : ~ 1780 MeV

by instanton/NJL interaction

An-Metsch-Zou, PRC87(2013) 065207; An-Zou, PRC89 (2014) 055209

Very important to find the lowest Ω^* ($1/2^-$ or $3/2^-$)

$\psi(2S) \rightarrow \bar{\Omega}\Omega$ BR = $(5 \pm 2) \times 10^{-5}$

M. Ablikim et al. (BESII Coll.), CPC36(2012)1040

$\psi(2S) \rightarrow \bar{\Omega}\Omega^*$ with $\Omega^* \rightarrow \gamma\,\Omega$

3700 – 1670 => 2030

→ excitation mechanism for sss states

The summary of the results for strangeness hadron

	Our analysis	Unquenched	Quenched	PDG
Σ* (1/2-)	1380 Gao-Wu-Zou PRC81,055203 Xie-Wu-Zou PRC90, 055204 Chen-Zou PRC88, 024304 Wu-Dulat-Zou PRD 80, 017503; 81,045210;	1360 -1420 S. L. Zhu, etc. HEPNP29(2005)250	1650	1620 ** → *
Σ*(1/2+)	1633 P.Gao, J.Shi, B.S.Zou, PRC86 (2012) 025201	1630&1656 Torres-Khemehandami-Oset EPJA35 (2008) 295	1720	1660 ***
Λ*(3/2+)	1680 J.Shi, B.S.Zou, PRC91(2015) 035202	1700 C. Helminen, D. O. Riska, NPA 699(2002) 624	1900 S. Capstick, N. Isgur, PRD **34**, 2809 (1986); S.Capstick, W. Roberts, PPNP **45**, S241(2000)	1890 ***
Ω*(3/2-)	?	1780 **An-Metsch-Zou, PRC87(2013) 065207;** **An-Zou, PRC89 (2014) 055209**	2020 **Chao, Isgur, Karl, PRD38(1981)155**	-

Strong support for unquenched quark model!

Outline :

1. Introduction
2. Hadron spectroscopy with strangeness
3. From Strangeness to charm & beauty
4. Conclusions

3. From strangeness to charm & beauty

Many N^* & Λ^* are proposed dynamically generated states and multi-quark states

Problem:

None of them can be clearly distinguished from qqq due to tunable ingredients and possible large mixing of various configurations

PDG2010: “The clean Λ_c spectrum has in fact been taken to settle the decades-long discussion about the nature of the $\Lambda(1405)$ —true 3-quark state or mere $\bar{K}N$ threshold effect?— unambiguously in favor of the first interpretation.”

although Λ_c (2595) $1/2^-$ was proposed to be DN molecule by Tolos et al., CPC33(2009)1323. Haidenbauer et al., EPJA47(2011)18

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, L.Zhao, B.S.Zou. PLB709(2012)70

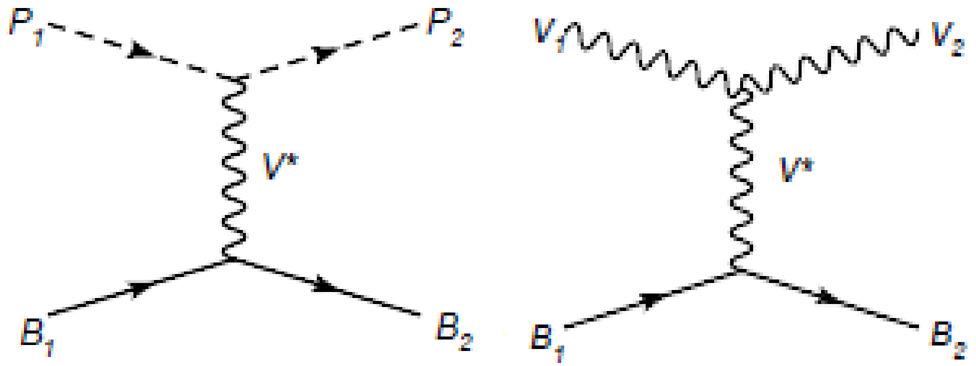
Λ*(1405) $\bar{q}quds$

Λ*(4210) $\bar{c}cuds$ J.J.Wu, R.Molina, E.Oset, B.S.Zou.
Phys.Rev.Lett. 105 (2010) 232001

Λ*(11020) $\bar{b}buds$ J.J.Wu, L.Zhao, B.S.Zou. PLB709(2012)70

KΣ, $\bar{\mathrm{K}}$p → $\bar{\mathrm{D}}\Sigma_c$, $\bar{\mathrm{D}}_s\Lambda_c$ → $\mathrm{B}\Sigma_b$, $\mathrm{B}_s\Lambda_b$ bound states

J.J.Wu, R.Molina, E.Oset, B.S.Zou, PRL 105 (2010) 232001
J.J.Wu, T.S.H.Lee, B.S.Zou, PRC85(2012)044002
J.J.Wu, L.Zhao, B.S.Zou. PLB709(2012)70



$$L_{VVV} = ig\left\langle V^{\mu}\left[V^{\nu},\partial_{\mu}V_{\nu}\right]\right\rangle$$

$$L_{PPV} = -ig\left\langle V^{\mu}\left[P,\partial_{\nu}P\right]\right\rangle$$

$$L_{BBV} = g\left\langle \bar{B}\gamma_{\mu}\left[V^{\mu},B\right]\right\rangle + g\left\langle \bar{B}\gamma_{\mu}B\right\rangle\left\langle V^{\mu}\right\rangle$$

$\bar{\mathrm{D}}\Sigma_{\mathrm{c}}$ Valencia 4269MeV

EBAC 4301-4318MeV

$$T = V + VG^{Valencia}T$$

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

$$T(q_1,q_2) = V + \int q_3^2 dq_3\; V(q_1,q_3)G(q_3)T(q_3,q_2)$$

$$G^{Valencia} = \int \frac{dp^4}{(2\pi)^4}\frac{2m_B}{(p^2-m_B^2)((P-p)^2-m_M^2)}$$

$$G(q_3) = \frac{1}{\sqrt{S} - E_M - E_B},$$

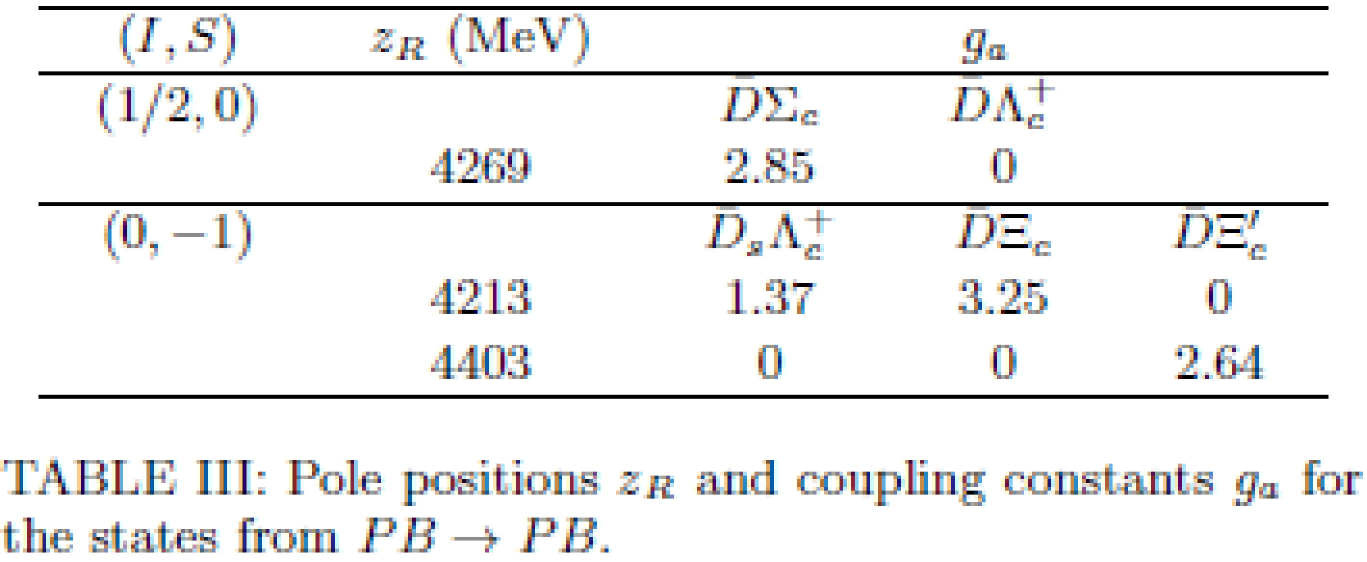
$$G_V^{\mu\nu} = \frac{p_V^{\mu}p_V^{\nu}/m_V^2 - g^{\mu\nu}}{p_V^2 - m_V^2} \sim \frac{p_V^{\mu}p_V^{\nu}/m_V^2 - g^{\mu\nu}}{-m_V^2} \sim \frac{-g^{\mu\nu}}{-m_V^2}$$

$$VF^{I,V}_{P_1B_1->P_2B_2} = C^{I,V}_{P_1B_1->P_2B_2}\frac{M_V^2}{4f^2}G_V^{\mu\nu}\bar{u}_{B_2}\gamma_{\mu}(p_{P_1}+p_{P_2})_{\nu}u_{B_1}$$

$$VF^{I,V}_{V_1B_1->V_2B_2} = C^{I,V}_{V_1B_1->V_2B_2}\frac{M_V^2}{4f^2}G_V^{\mu\nu}\bar{u}_{B_2}\gamma_{\mu}(p_{V_1}+p_{V_2})_{\nu}u_{B_1}(-\varepsilon_{V_1}\cdot\varepsilon_{V_2})$$

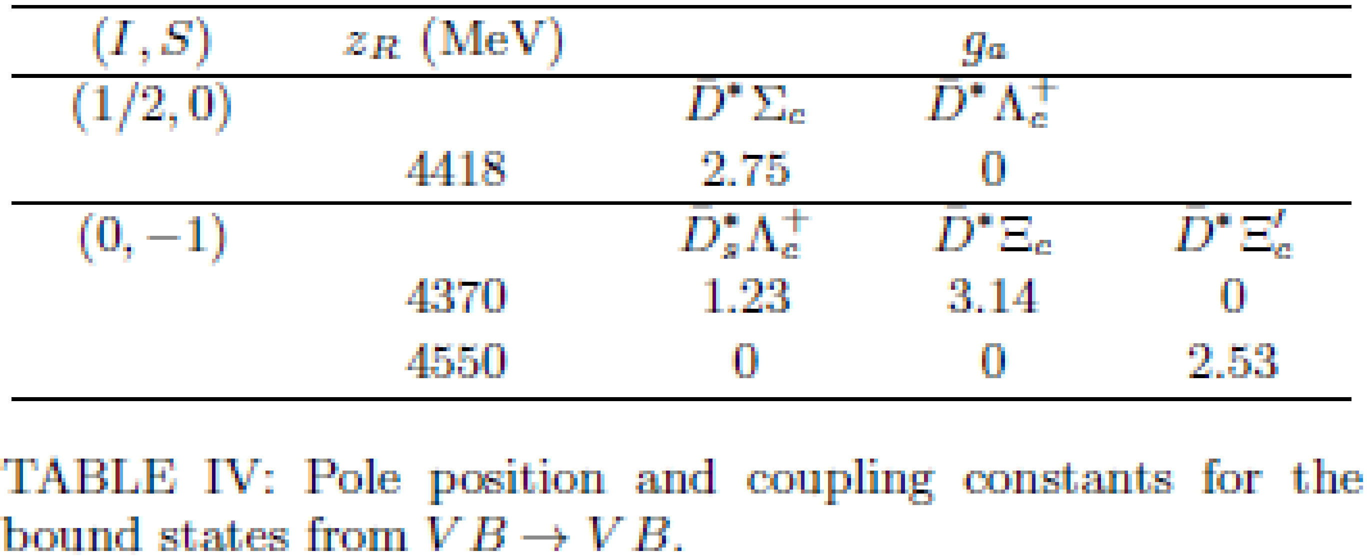
$$V_{ab(P_1B_1\to P_2B_2)} = \frac{C_{ab}}{4f^2}(E_{P_1}+E_{P_1})$$

$$V_{ab(V_1B_1\to V_2B_2)} = \frac{C_{ab}}{4f^2}(E_{V_1}+E_{V_2})\vec{\varepsilon}_1\cdot\vec{\varepsilon}_2$$



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

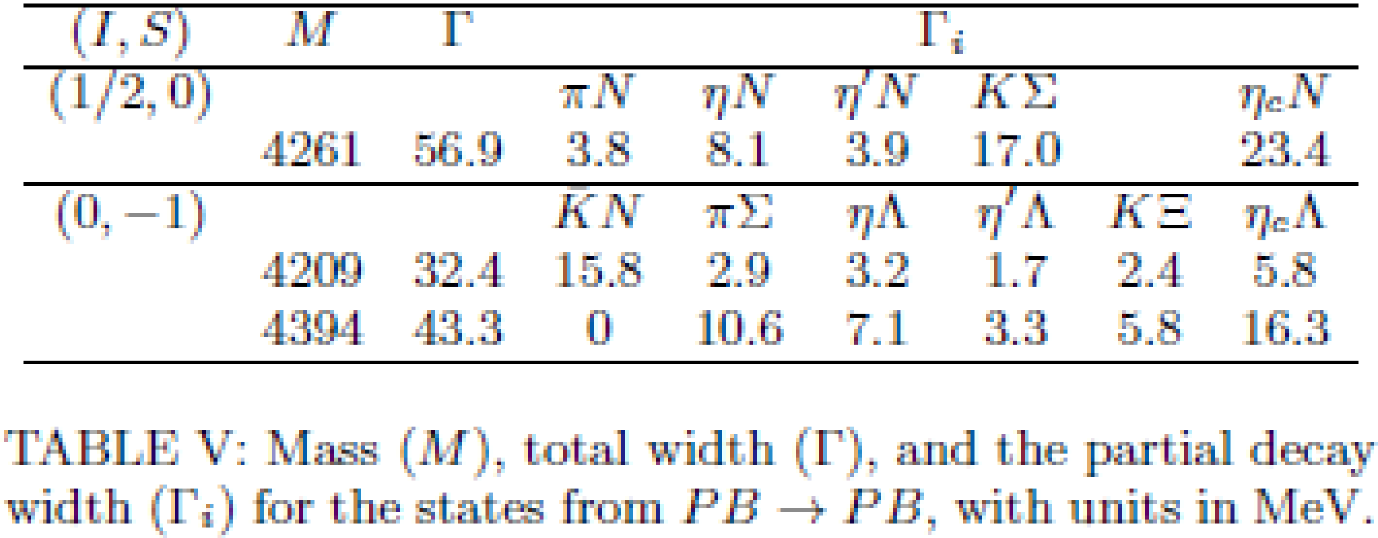


	(I, S)	z_R (MeV)	g_a		
N*	$(1/2, 0)$		$\bar{D}^*\Sigma_c$	$\bar{D}^*\Lambda_c^+$	
		4418	2.75	0	
	$(0, -1)$		$\bar{D}^*_s\Lambda_c^+$	$\bar{D}^*\Xi_c$	$\bar{D}^*\Xi'_c$
Λ*		4370	1.23	3.14	0
		4550	0	0	2.53

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

N*

Λ*

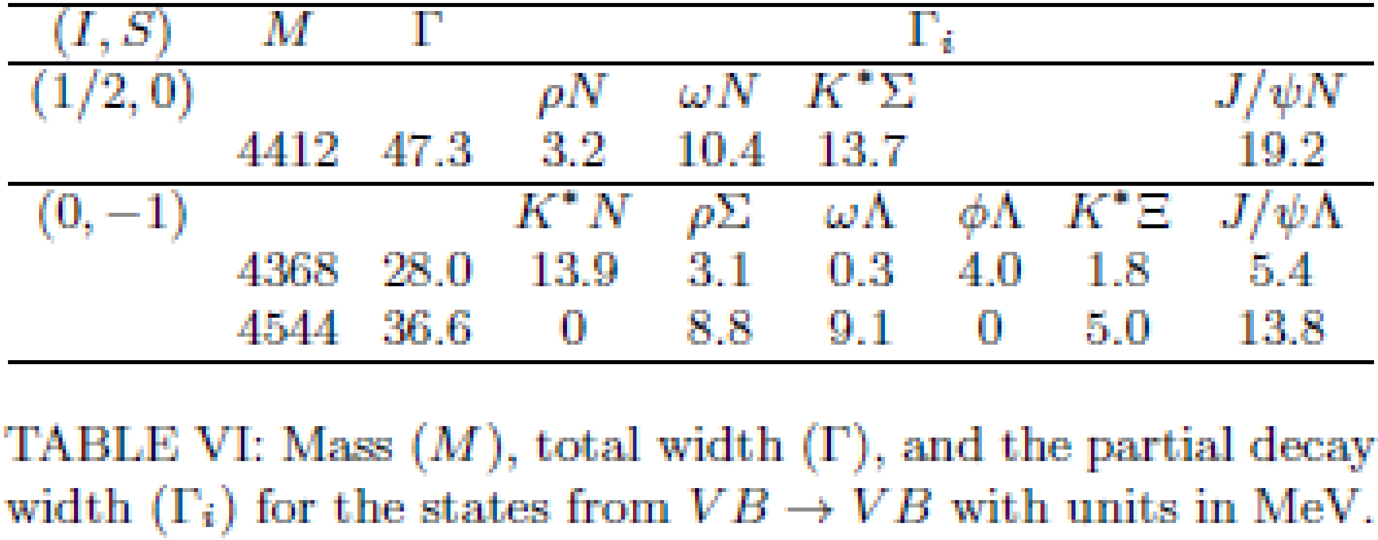


(I,S)	M	Γ	Γ_i					
$(1/2,0)$			πN	ηN	$\eta' N$	$K\Sigma$		$\eta_c N$
	4261	56.9	3.8	8.1	3.9	17.0		23.4
$(0,-1)$			$\bar{K}N$	$\pi\Sigma$	$\eta\Lambda$	$\eta'\Lambda$	$K\Xi$	$\eta_c\Lambda$
	4209	32.4	15.8	2.9	3.2	1.7	2.4	5.8
	4394	43.3	0	10.6	7.1	3.3	5.8	16.3

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.

N*

Λ*



(I,S)	M	Γ	Γ_i					
$(1/2,0)$			ρN	ωN	$K^*\Sigma$			$J/\psi N$
	4412	47.3	3.2	10.4	13.7			19.2
$(0,-1)$			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 $VB \to VB$ with units in MeV.

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

Definitely not qqq states !

Hidden charm N* by other approaches

$\bar{D}\Sigma_c$ + $\bar{D}^*\Sigma_c$ coupled channel state ~ 4.23 GeV

T. Uchino, W.H.Liang, E.Oset, arXiv:1504.05726

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

W.L.Wang, F.Huang, Z.Y.Zhang, B.S.Zou, PRC84(2011)015203

$\bar{D}\Sigma_c$ state in EBAC-DCC model ~ 4.3 GeV

J.J.Wu, T.S.H.Lee, B.S.Zou, PRC85(2012)044002

$\bar{D}\Sigma_c$ state in Schoedinger Equation method ~ 4.3 GeV

Z.C.Yang, Z.F. Sun, J. He, X.Liu, S.L.Zhu, CPC36(2012)6

$\bar{c}cqqq$ with 3 kinds of qq hyperfine interaction ~ 4.1 GeV

S.G.Yuan, K.W.Wei, J.He, H.S.Xu, B.S.Zou, EPJA48(2012)61

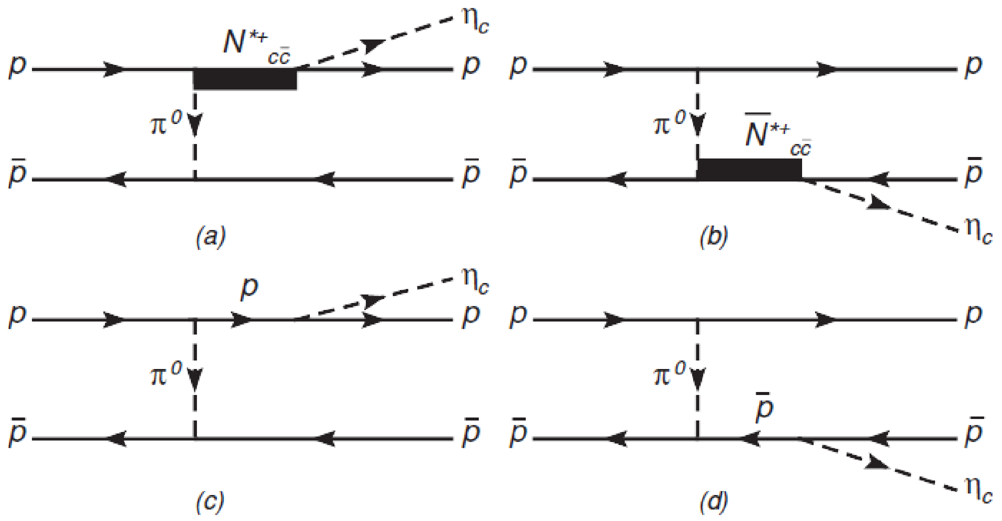
$\bar{D}\Sigma_c - \eta_c N - \eta' N$ coupled channel state ~ 3.5 GeV

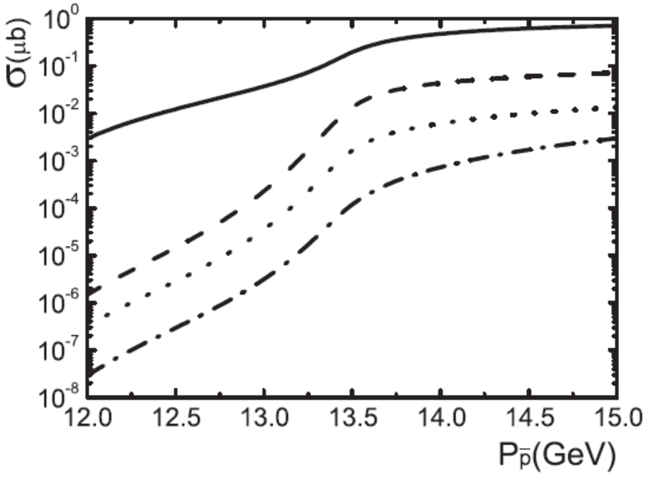
J. Hofmann, M.F.M. Lutz, Nucl. Phys. A 763 (2005) 90

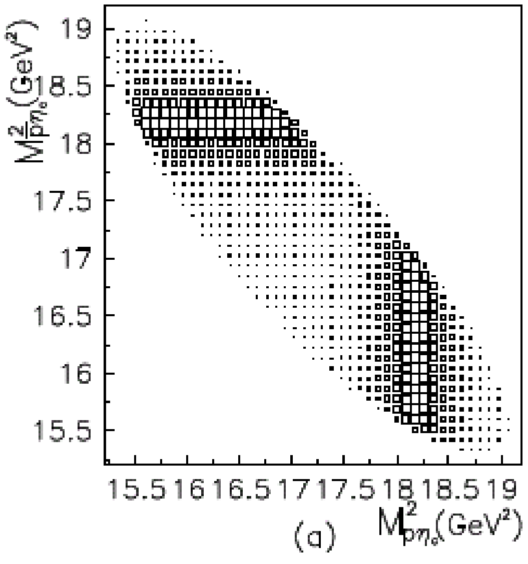
$\bar{c}c$-N bound states in topological soliton model ~ 3.9 GeV

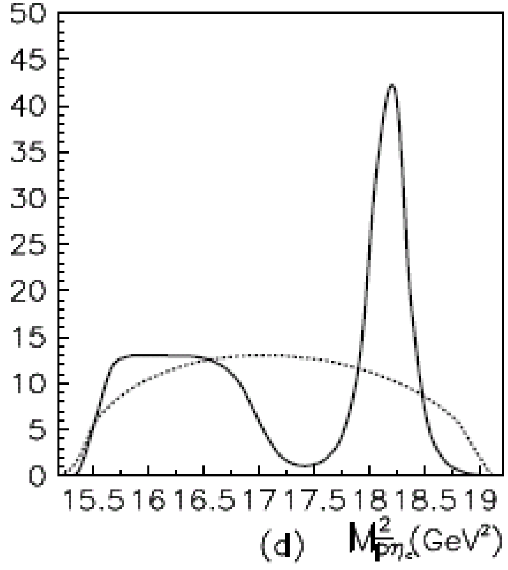
C. Gobbi, D.O. Riska, N.N. Scoccola, Phys. Lett. B 296 (1992) 166

Prediction for PANDA



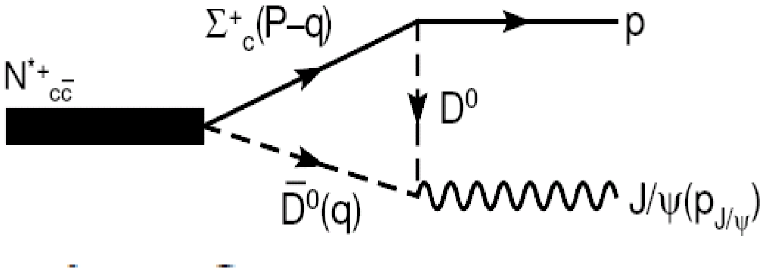


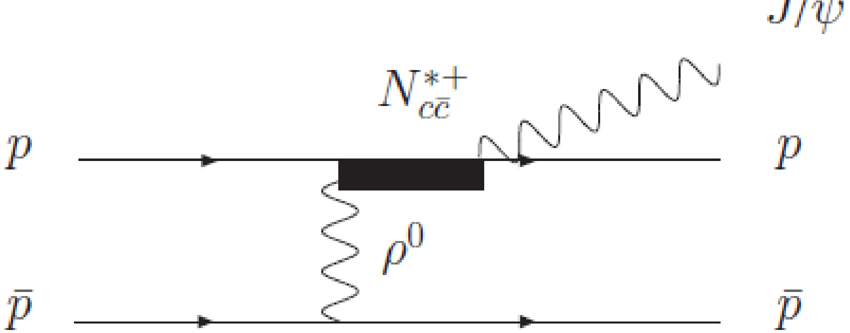




$\bar{p}p \rightarrow \bar{p}p\eta_c$

2 – 70 nb





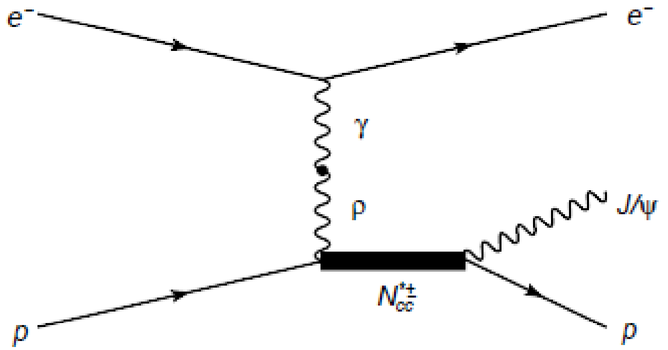
$$\Gamma_{R\to J/\psi p} = 0.01\ \text{MeV},$$

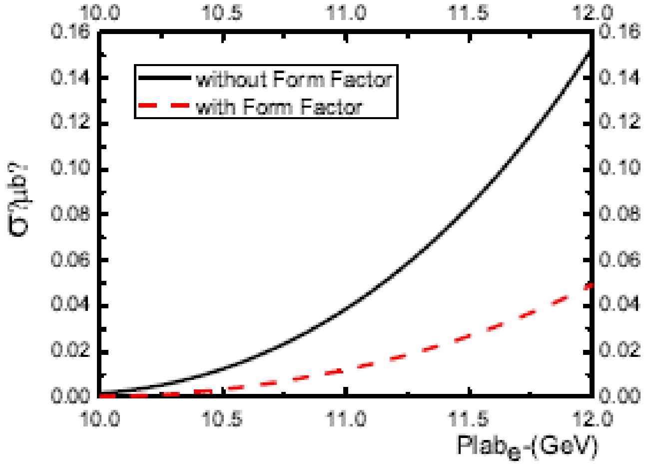
$\bar{p}p \rightarrow \bar{p}pJ/\psi \sim 0.1$ nb

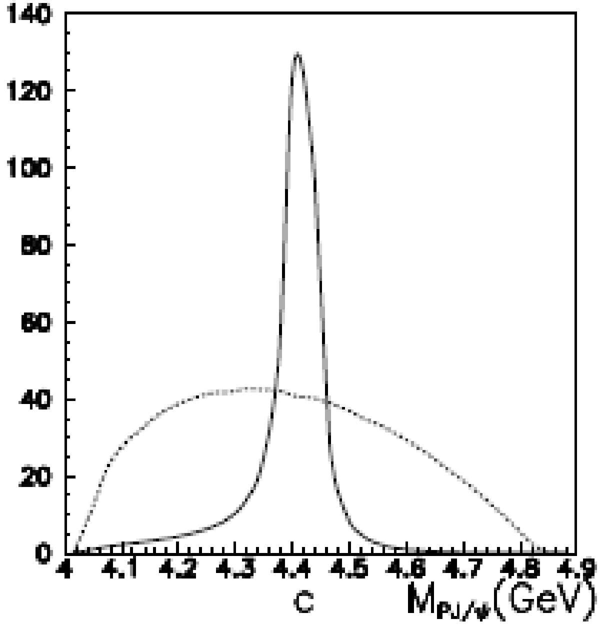
~ 100 events per day at PANDA/FAIR by L=10^{31} cm^{-2}s^{-1}

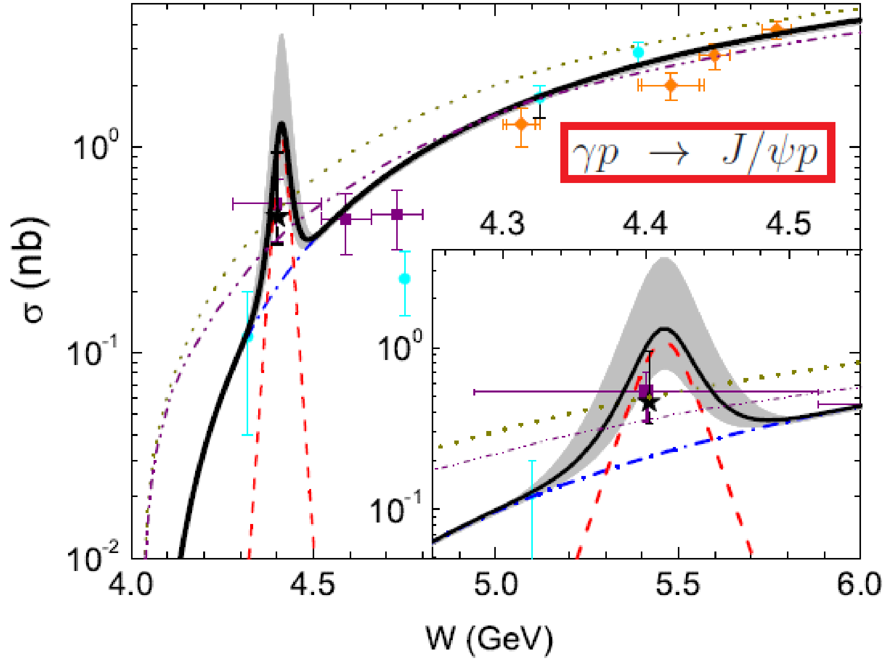
These Super-heavy narrow N* and Λ* can be found at PANDA !

Prediction for 12GeV@JLab









Y. Huang, J.He, H.F.Zhang and X.R.Chen, JPG41, 115004 (2014)

Outline :

1. Introduction
2. Hadron spectroscopy with strangeness
3. From Strangeness to charm & beauty
4. Conclusions

4. Conclusions

- **Hadron spectroscopy reveals unquenched quark picture**
- **Distinguishable prediction for hyperon spectroscopy is yelling for experimental confirmation**
- **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

  isovector meson partners $Z_b(10610)$, $Z_b(10650)$

- **Experimental confirmation of them will unambiguously establish multiquark dynamics**

- **They can be looked for at 12GeV@Jlab and PANDA**

  maybe also at JPARC, super-B, RHIC , EIC?

Xiao-Yun Wang, Xu-Rong Chen arXiv:1504.01075 $K^- p \to \eta_c\Lambda$

Thanks !