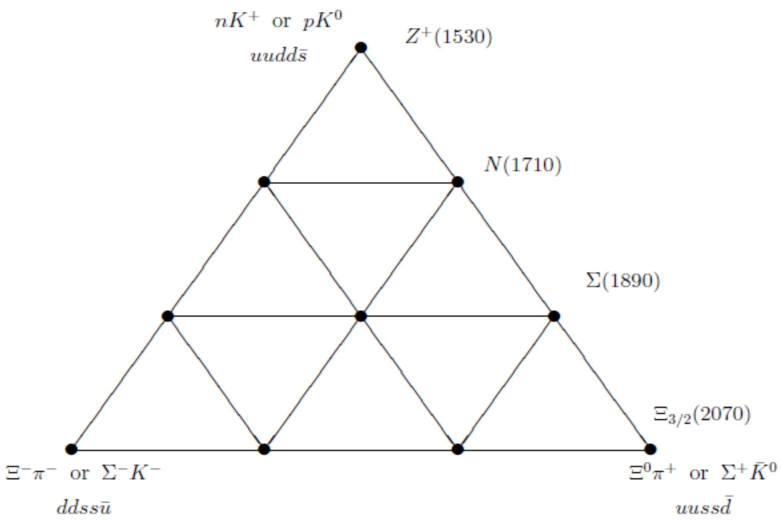
Penta-quark states with strangeness, hidden charm and beauty

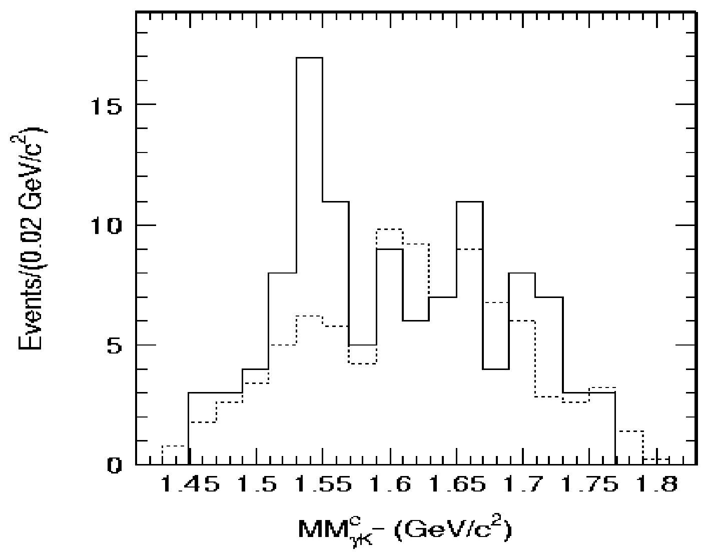
Bing-Song Zou
Institute of Theoretical Physics, CAS

1) F.Huang, Z.Y.Zhang, Y.W.Yu, B.S.Zou, PLB 586 (2004) 69
2) B.S.Zou, D.O.Riska, PRL95(2005)072001
3) B.C.Liu, B.S.Zou, PRL96(2006)042002
4) J.J.Wu, S.Dulat, B.S.Zou, PRD 80(2009) 017503
5) J.J.Wu, R.Molina, E.Oset, B.S.Zou, PRL105(2010) 232001
6) P.Gao, B.S.Zou, A.Sibirtsev, NPA867(2011)41
7) W.L.Wang, F.Huang, Z.Y.Zhang, B.S.Zou, PRC84 (2011) 015203
8) J.J.Wu, L.Zhao, B.S.Zou, PLB709(2012)70
9) C.S.An, B.S.Zou, PRC89(2014) 055209
10) J.Shi, B.S.Zou, arXiv:1411.0486

Pentaquark θ(1540)

D.Diakonov et al., "Exotic anti-decuplet of baryons: Prediction from chiral solitons", ZPA359 (1997) 305 816 cites





T.Nakano et al., "Evidence for Narrow S=+1 Baryon Resonance in Photo-production from Neutron", PRL91 (2003) 012002 . 963 cites

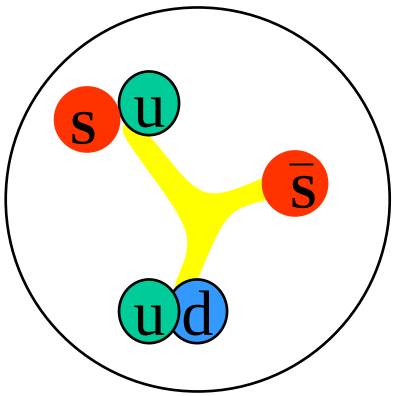
R.Jaffe, F.Wilczek, "Diquarks and Exotic Spectroscopy", PRL91(2003)232003 716 cites

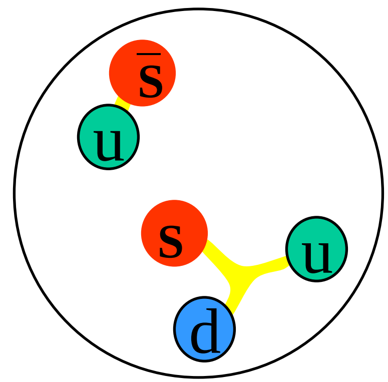
F.Huang, Z.Y.Zhang, Y.W.Yu, B.S.Zou, "A study of pentaquark θ state in the chiral SU(3) quark model", PLB 586 (2004) 69 70 cites

不能给出 θ(1540)

B.S.Zou, D.Riska, PRL 95 (2005) 072001

“ $\bar{s}s$ component of the proton and the strangeness magnetic moment”

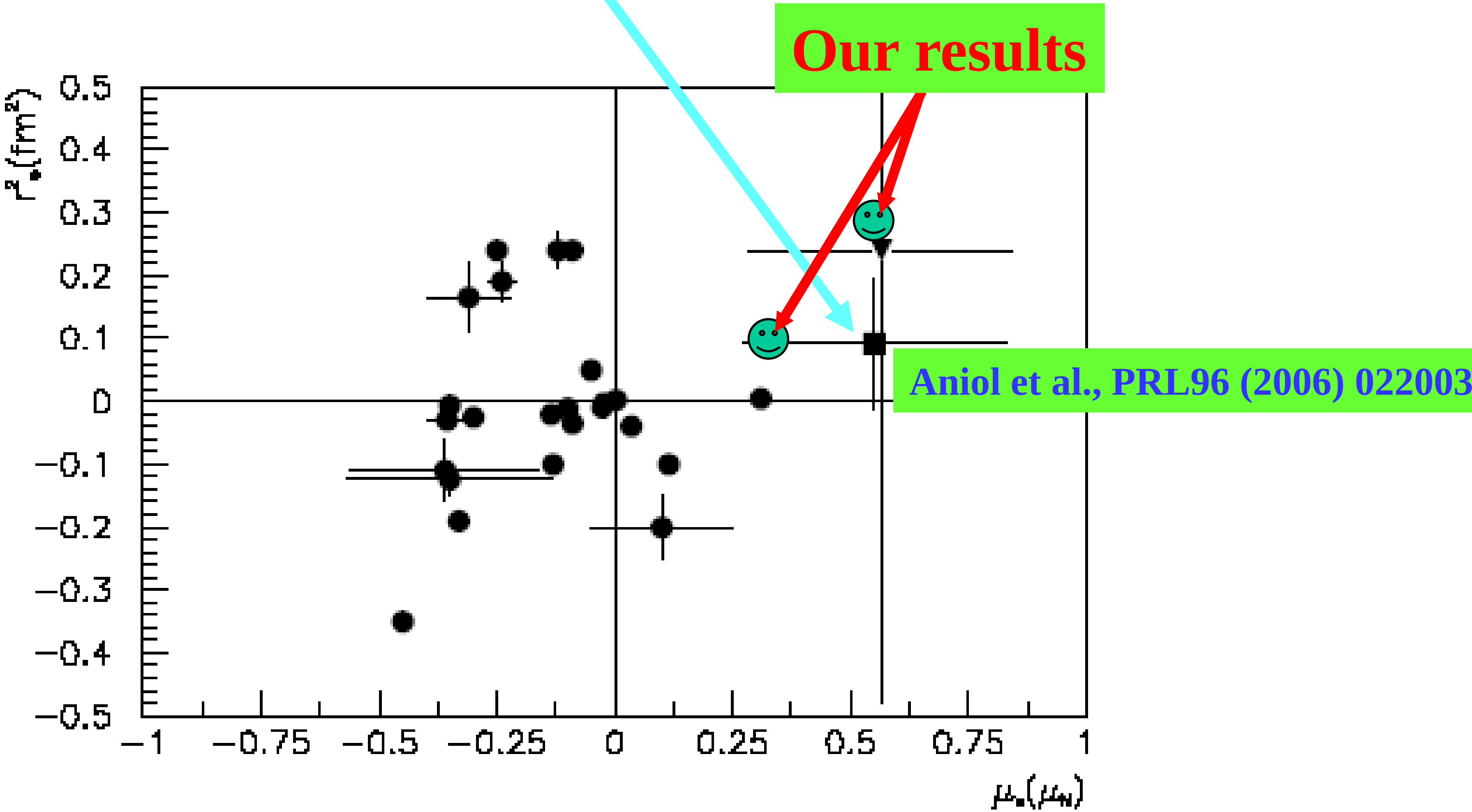




Pentaquark vs Meson Cloud

有色集团 无色集团

Theory vs experiment for μ_s and r_s



Zou&Riska, PRL95(2005)072001; Riska&Zou, PLB636 (2006) 265
An-Riska-Zou, PRC73 (2006) 035207

第29卷 第3期 高能物理与核物理 Vol.29, No.3
2005年3月 HIGH ENERGY PHYSICS AND NUCLEAR PHYSICS Mar., 2005

$J^P = \frac{1}{2}^-$ Pentaquarks in Jaffe and Wilczek's Diquark Model*

ZHANG Ao[1] LIU Yan-Rui[1] HUANG Peng-Zhi[1] DENG Wei-Zhen[1] CHEN Xiao-Lin[1] ZHU Shi-Lin[1,2;1)]

	(Y, I)	I_3	flavor wave functions	masses (MeV)
p_8	$(1, \frac{1}{2})$	$\frac{1}{2}$	$[su][ud]_{-}\bar{s}$	1460
n_8		$-\frac{1}{2}$	$[ds][ud]_{-}\bar{s}$	1460
Σ_8^+	$(0,1)$	1	$[su][ud]_{-}\bar{d}$	1360
Σ_8^0		0	$\frac{1}{\sqrt{2}}([su][ud]_{-}\bar{u} + [ds][ud]_{-}\bar{d})$	1360
Σ_8^-		-1	$[ds][ud]_{-}\bar{u}$	1360
Λ_8	$(0,0)$	0	$\frac{[ud][su]_{-}\bar{u} + [ds][ud] - \bar{d} - 2[su][ds]_{-}\bar{s}}{\sqrt{6}}$	1533
Ξ_8^0	$(-1, \frac{1}{2})$	$\frac{1}{2}$	$[ds][su]_{-}\bar{d}$	1520
Ξ_8^-		$-\frac{1}{2}$	$[ds][su]_{-}\bar{u}$	1520
Λ_1	$(0,0)$	0	$\frac{[ud][su]_{-}\bar{u} + [ds][ud]_{-}d + [su][ds]_{-}\bar{s}}{\sqrt{3}}$	1447

$1/2^-$ baryon nonet with strangeness

- **Mass pattern : quenched or unquenched ?**

uds (L=1) $1/2^-$ ~ $\Lambda^*(1670)$ ~ $[us][ds]\bar{s}$

uud (L=1) $1/2^-$ ~ $N^*(1535)$ ~ $[ud][us]\bar{s}$

uds (L=1) $1/2^-$ ~ $\Lambda^*(1405)$ ~ $[ud][su]\bar{u}$

uus (L=1) $1/2^-$ ~ $\Sigma^*(1390)$ ~ $[us][ud]\bar{d}$

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

- **Strange decays of N*(1535) and Λ*(1670) :**

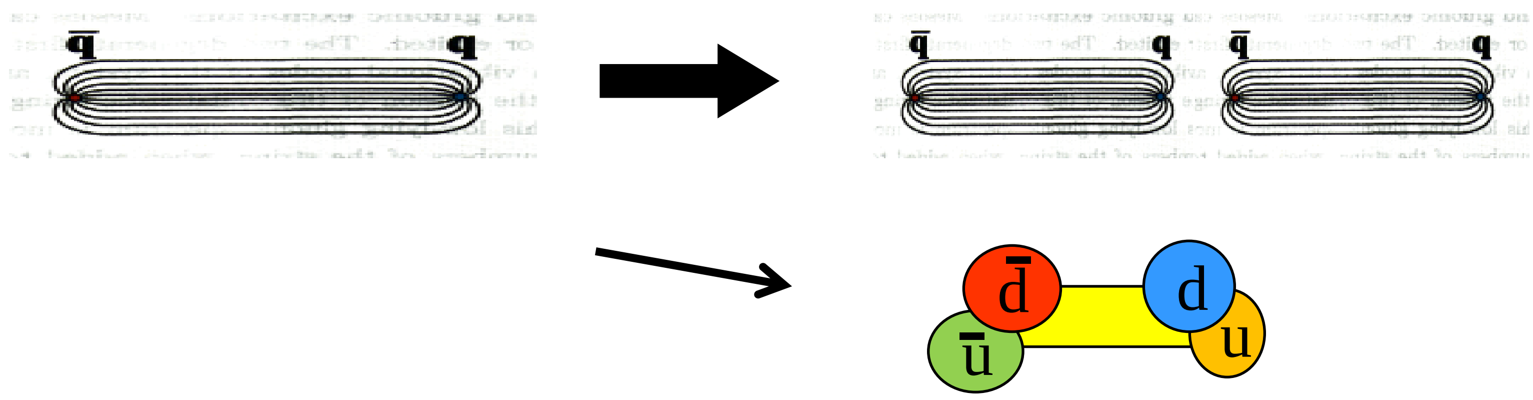
N*(1535) large couplings $g_{N^*N\eta}$, $g_{N^*K\Lambda}$, $g_{N^*N\eta'}$, $g_{N^*N\phi}$

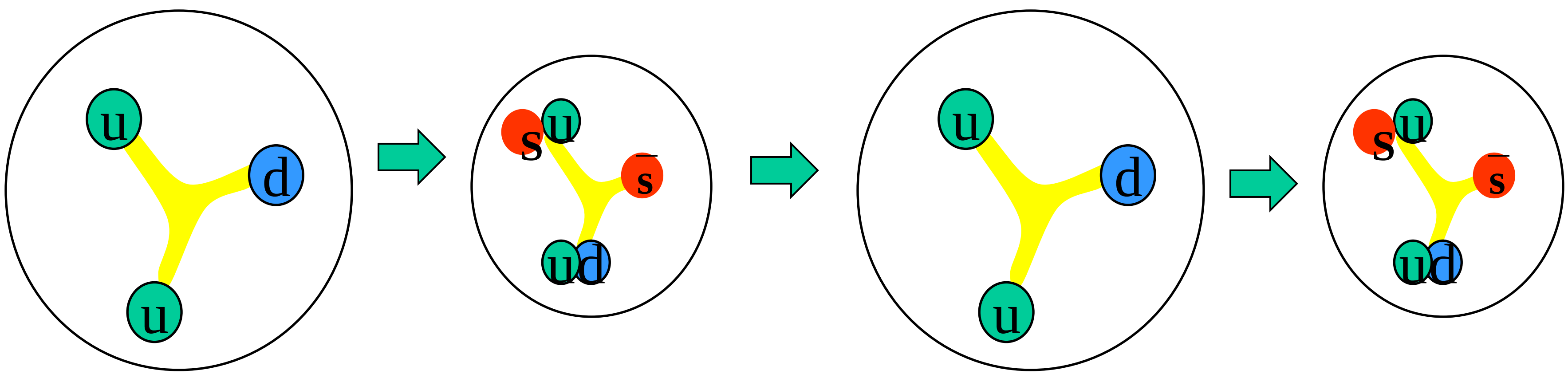
Λ*(1670) large coupling $g_{\Lambda^*\Lambda\eta}$

B.C.Liu, B.S.Zou, PRL96(2006)042002 ,"Mass and KΛ Coupling of the N*(1535)"

Unquenched dynamics: gluons → $\bar{q}q$

crucial for quark confinement & hadron structure

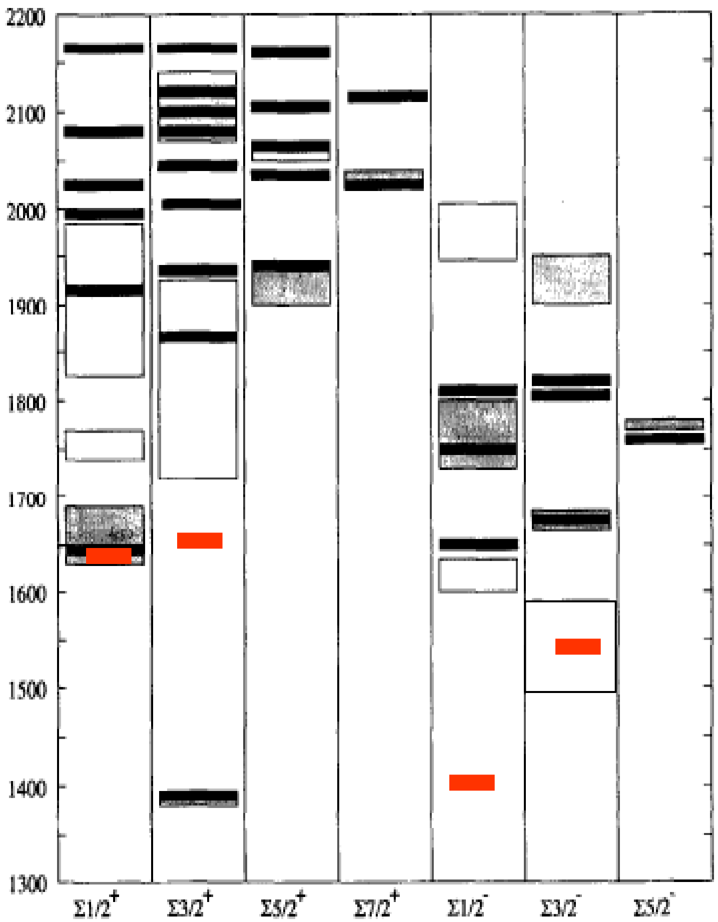


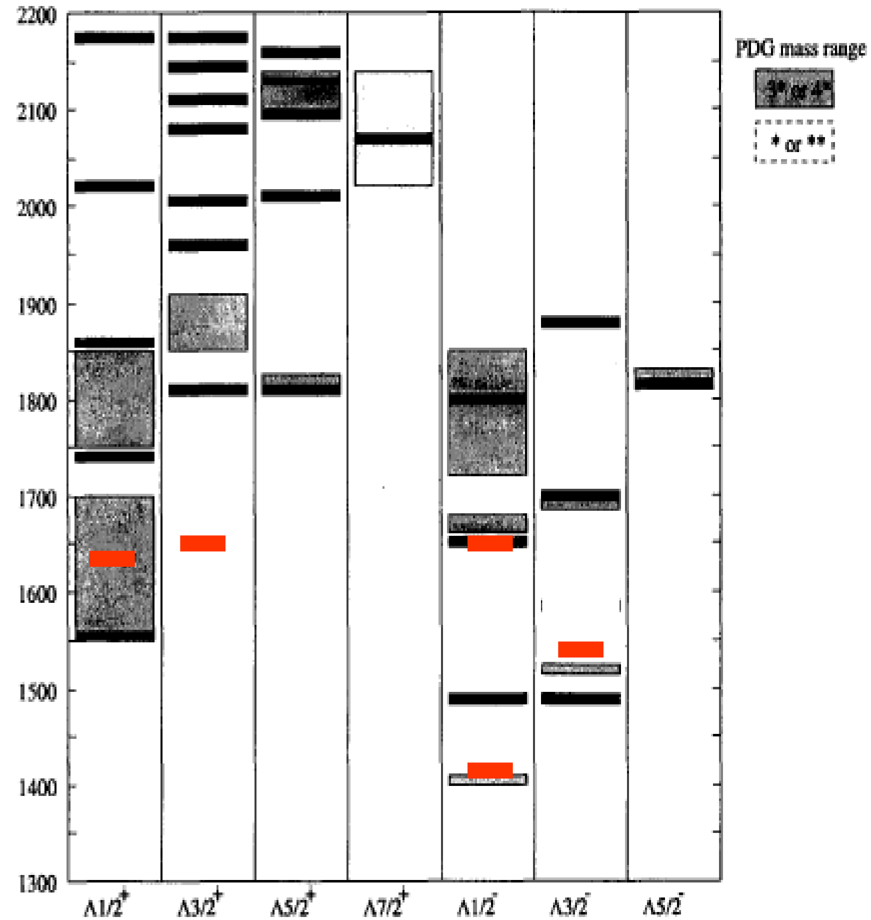


quenched or unquenched quark models give very different predictions of hyperon spectrum

Distinctive

Predictions by quenched - & unquenched - quark models



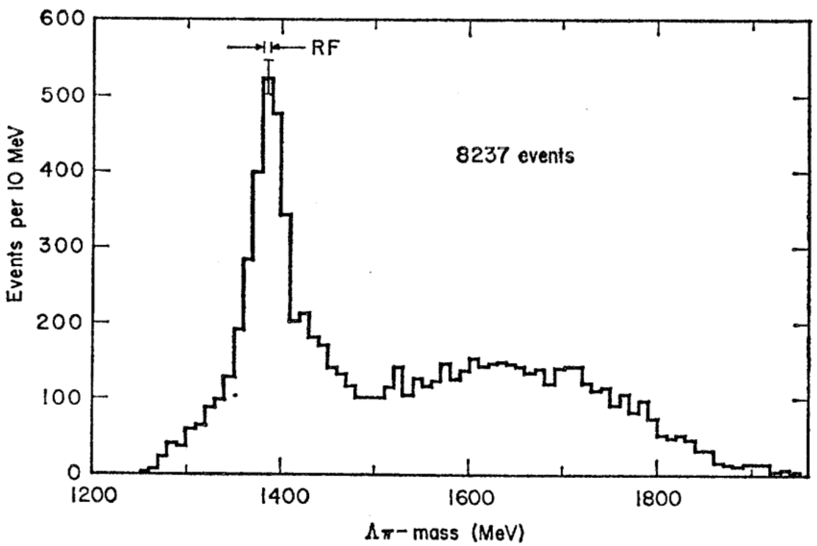


Quenched quark model: Capstick-Roberts, Prog.Part.Nucl.Phys. 45 (2000) S241-S331
Unquenched model: Helminen-Riska , Nucl. Phys. A 699 (2002) 624
A.Zhang, S.L.Zhu et al., HEPNP 29 (2005) 250

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

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

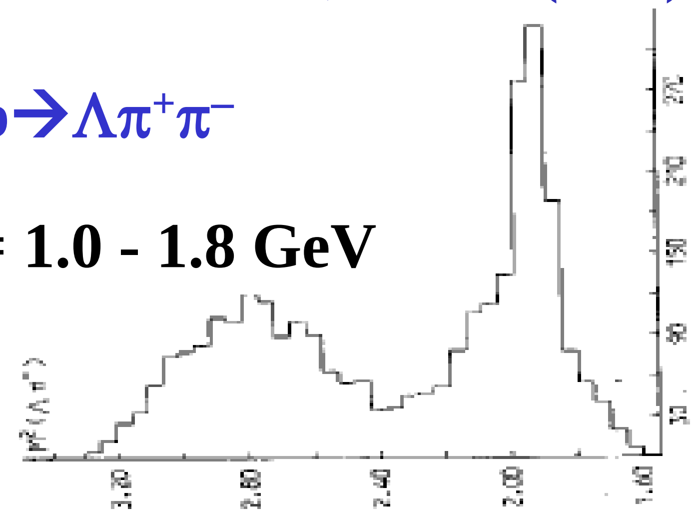
Huwe, PR181(1969)1824

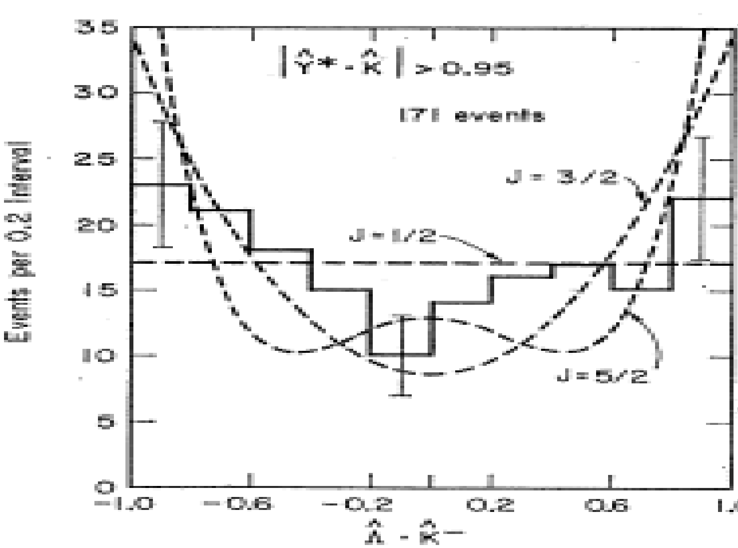


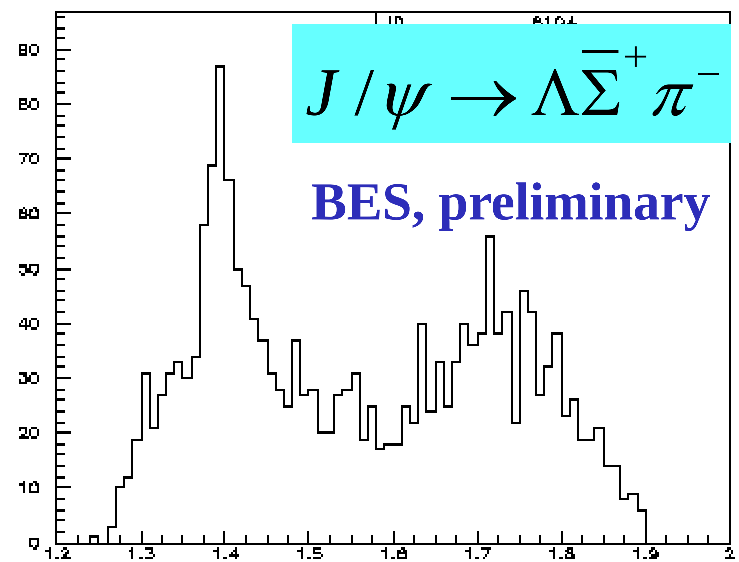
Cameron et al., NPB143(1978)189

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

$P_K = 1.0 - 1.8$ GeV







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

BES, preliminary

BES, NSTAR04

$M_{\pi\Lambda}$

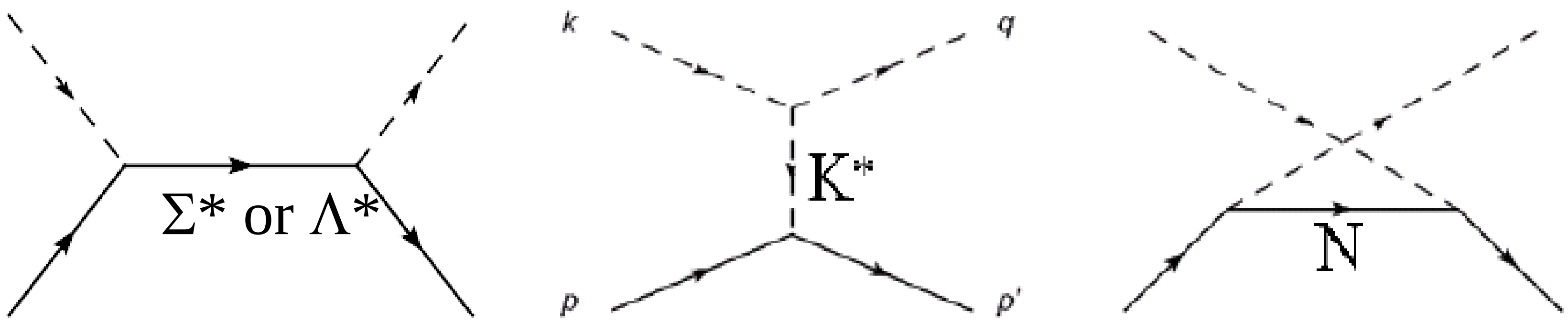
New results on Σ* & Λ* from CB data

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

$$K^- + p \to \pi^0 + \Lambda \quad \& \quad K^- + p \to \pi^0 + \Sigma^0$$

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

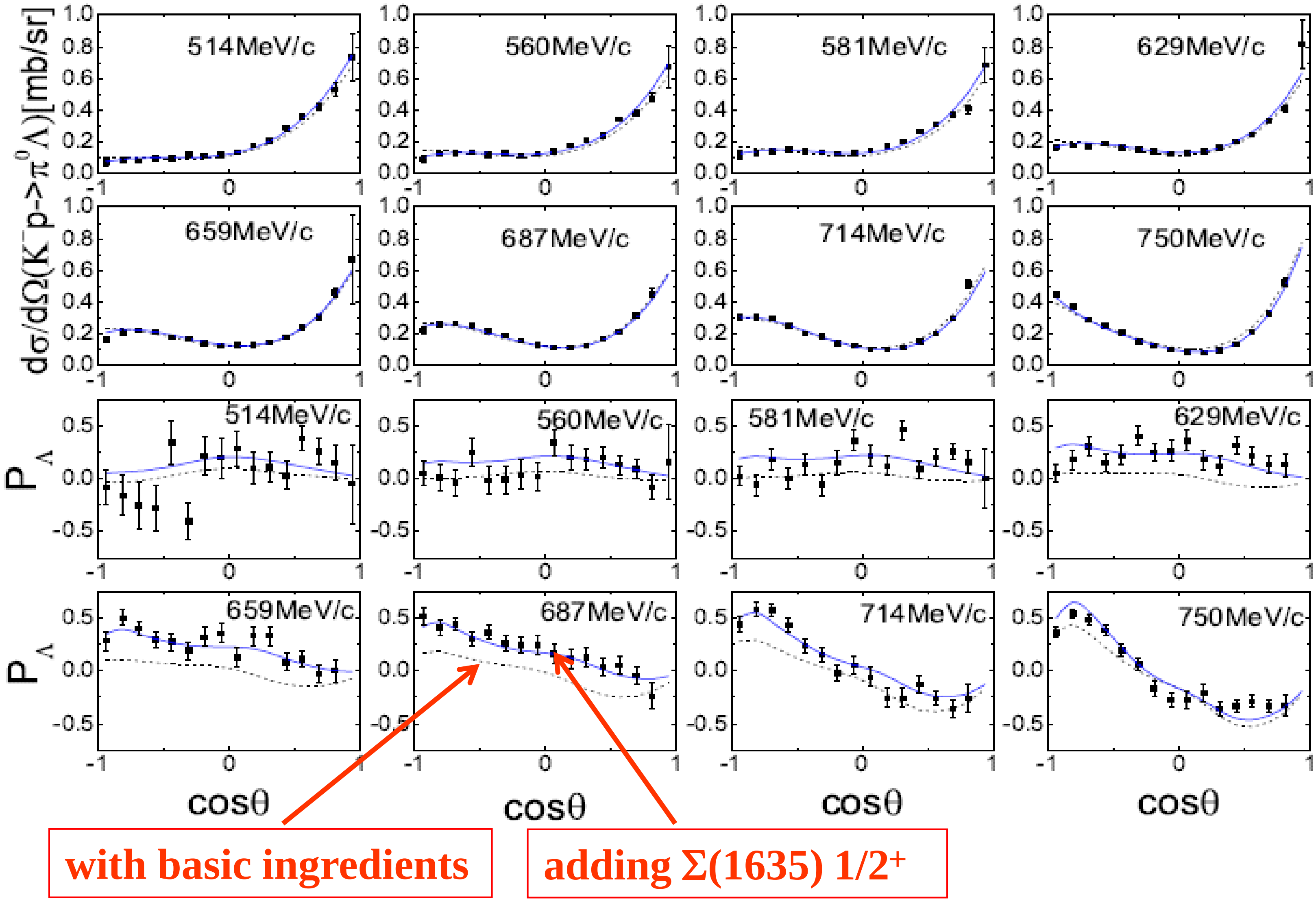
The high precision new data can give valuable information on Σ* & Λ*



P.Gao, B.S.Zou, A.Sibirtsev, NPA867(2011)41

NPA referee: "这是一项优秀的、清晰简明的、令人信服的工作。我希望我们能看到更多像这样的分析。" "This is an excellent, clear, concise and convincing piece of work. I wish we saw more analyses like this."

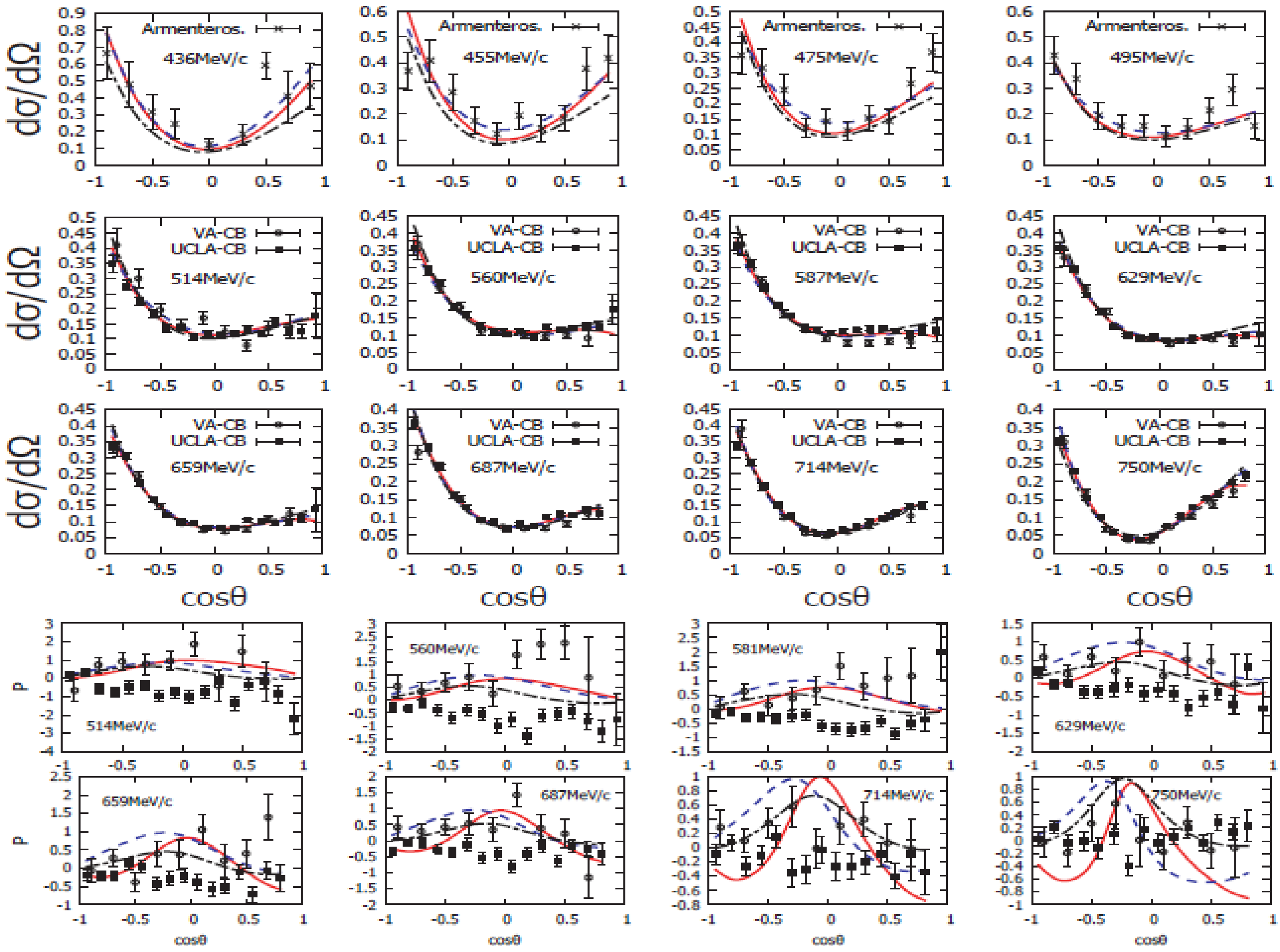
new CB data on $K^-p \rightarrow \pi^0\Lambda$: No $\Sigma(1620)\ 1/2^-$ needed !!



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

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

Fits to new CB data on $K^-p \rightarrow \pi^0\Sigma^0$ J.Shi, B. S. Zou, ArXiv: 1411.0486



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

Strong support for unquenched quark model!

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 $\Omega^* \rightarrow \gamma\, \Omega$

→ excitation mechanism for sss states

Super τ–c 10^{12} J/ψ & 10^{11} ψ' & ψ''

Complete N*, Λ*, Σ*, Ξ*, Ω* spectra

Establish the lowest $1/2^-$ Λ*, Σ*, Ξ* and Ω* !

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

Solution: **Extension to hidden charm and beauty for baryons**

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

N*(4260) $\bar{c}$**cuud** **Wu, Molina, Oset, Zou, PRL105 (2010) 232001**
Wang, Huang, Z.Y.Zhang, Zou, PRC84 (2011) 015203

N*(11050) $\bar{b}$**buud** **J.J.Wu, L.Zhao, B.S.Zou. PLB709(2012)70**

$\bar{d}u\bar{b}b$ states ?

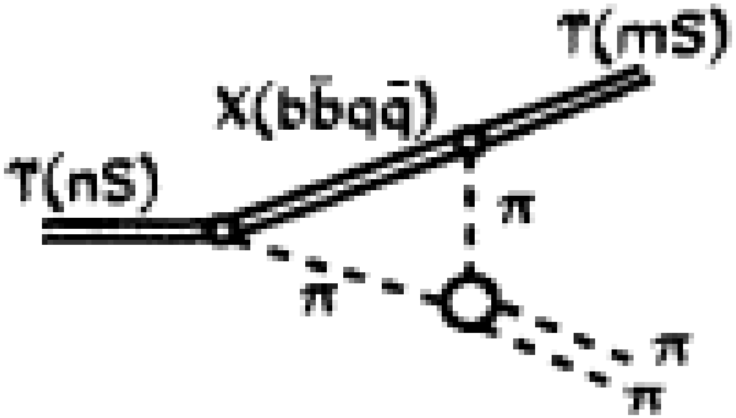
RAPID COMMUNICATIONS

PHYSICAL REVIEW D VOLUME 51, NUMBER 9 1 MAY 1995

$\Upsilon(3S)\to\Upsilon(1S)\pi\pi$ decay: Is the $\pi\pi$ spectrum puzzle an indication of a $b\bar{b}q\bar{q}$ resonance?

V. V. Anisovich,[1,2] D. V. Bugg,[1] A. V. Sarantsev,[1,2] and B. S. Zou[1]
[1]Queen Mary and Westfield College, London E1 4NS, United Kingdom
[2]Petersburg Nuclear Physics Institute, Gatchina, 188350, Russia
(Received 22 August 1994; revised manuscript received 2 February 1995)

The $\pi\pi$ mass spectrum in $\Upsilon(3S)\to\Upsilon(1S)\pi\pi$ has a peculiar double peak structure. This structure and the $\Upsilon(1S)\pi$ spectrum are reproduced by introducing a triangle singularity associated with a $b\bar{b}\pi$ resonance ($J^P=1^+$) in the mass range 10.4–10.8 GeV.



Belle Collaboration, PRL108 (2012) 122001 → Z_b(10610), Z_b (10650)

"Observation of Two Charged Bottomoniumlike Resonances in Υ(5S) Decays"

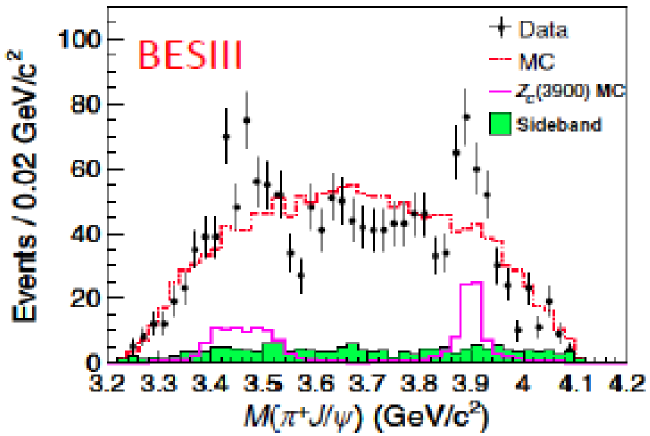
important to confirm them and find their partners

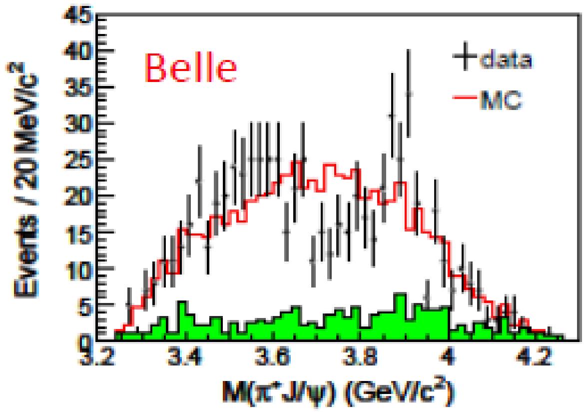
Zc(3900) production from Y(4260) decays

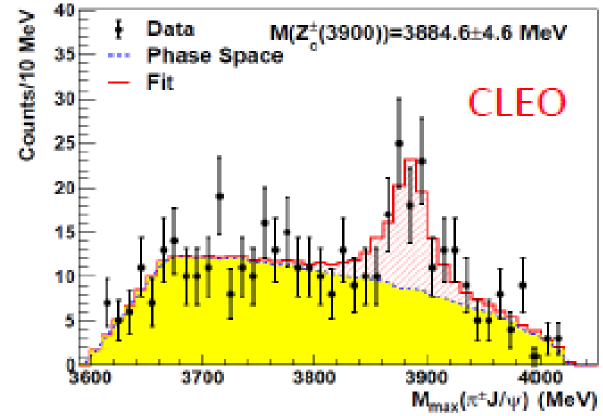
$\bar{d}uc\bar{c}$ states ?

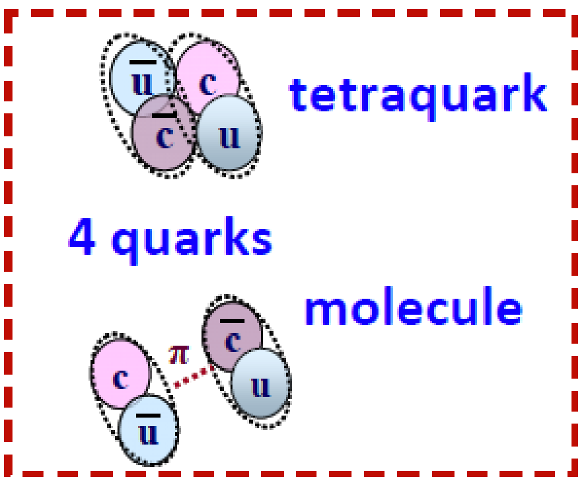
PRL 110, 252001 (2013) PHYSICAL REVIEW LETTERS 21 JUNE 2013

Observation of a Charged Charmoniumlike Structure in $e^+e^- \to \pi^+\pi^- J/\psi$ at $\sqrt{s} = 4.26$ GeV

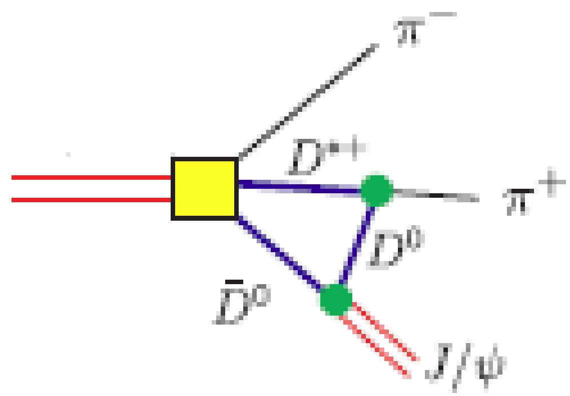


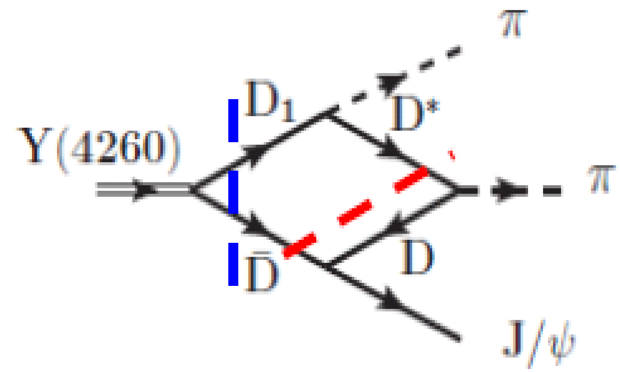






Exotic!





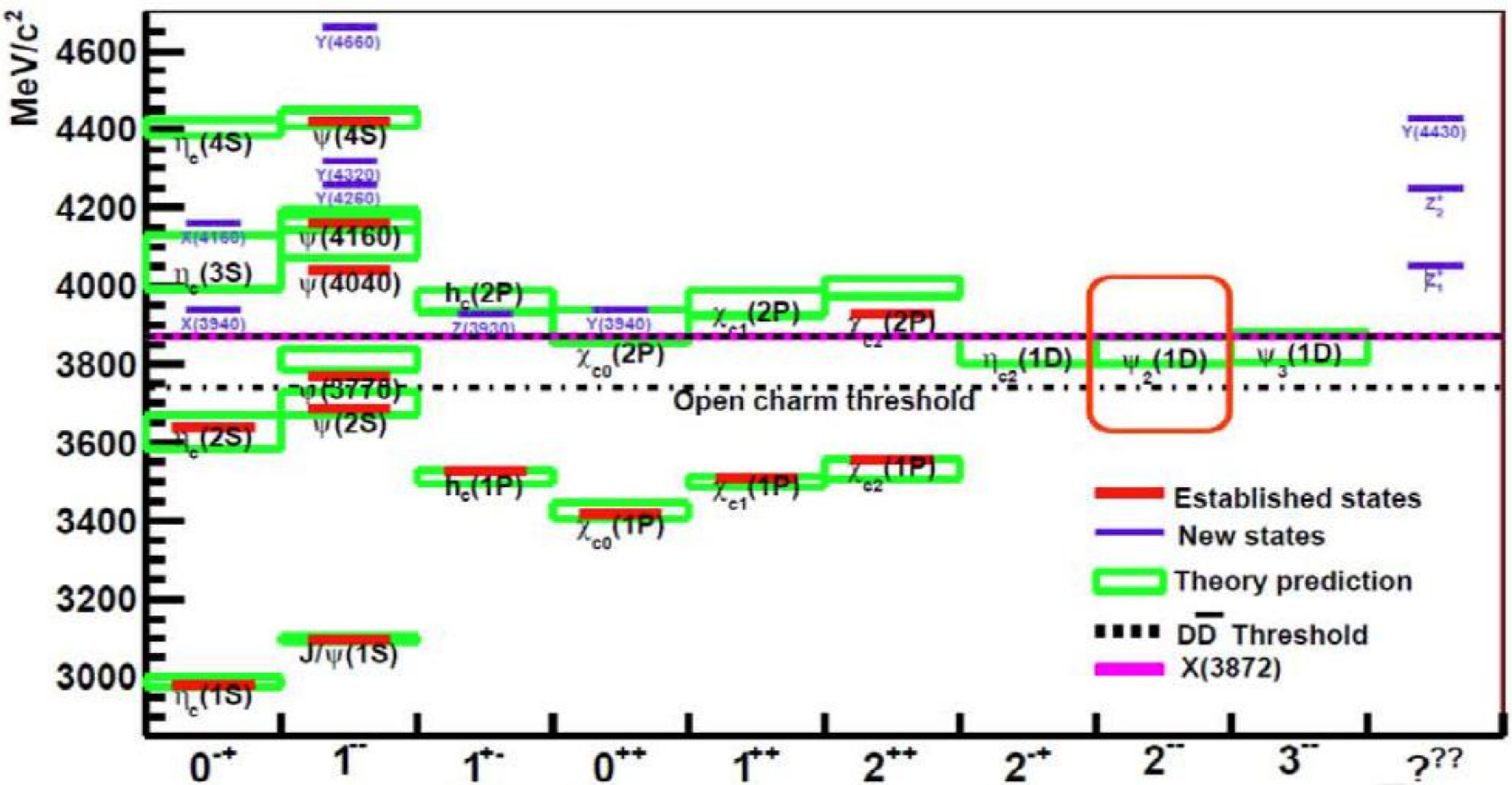
D.Y.Chen, X.Liu, PRD84(2011)034032

Q.Wang,C.Hanhart,Q.Zhao PRL111(2013)132003

Best playgrounds for unquenched quark models:

for baryon $sss \rightarrow sss\ \bar{q}q$

for meson $\bar{c}c \rightarrow \bar{c}\,c\ \bar{q}\,q$



我国强子物理实验装置展望与建议

1) 核子结构方面　　ep

CEBAF12GeV　　Ecm : ~ 5 GeV

EIC　　Ecm : 20 ~ 100 GeV　　15y later ?

EIC@HIAF　　Ecm : ~ 12 GeV

预期10年内世界领先

also super-heavy N* ($\bar{c}$cuud) and cqq states

2) 强子谱方面

ep@ELSA, ep@CEBAF, πN&KN@JPARC,

$\bar{p}$p@PANDA (2018), e+e–@BEPCII, B工厂

超级 τ-c 工厂：强子谱方面有很多独到之处

XYZ & Ω* ！

Best playgrounds for unquenched quark models:

for baryon $sss \rightarrow sss\,\bar{q}q$

for meson $\bar{c}c \rightarrow \bar{c}\,c\,\bar{q}\,q$

完善 **XYZ, Ω*, N*, Λ*, Σ*, Ξ*** 谱 → 激发模式

3）核子宇称破坏过程　　（S.L.Zhu)

ADS: A_L(pp) 能量依赖测量
CSR & SSRF:　原子核宇称混合激发态

4）Prospects at CCP -- CepC, SppC, HZF, …

- **CCP – Circular Collider of Particles (e$^+$e$^-$, pp, ep, …)**
- **Superheavy N*&Λ* with hidden $\bar{c}c$ or $\bar{b}b$ @ ep, pp**
- **XYZ production from γ*γ*, $\mathbb{P}\mathbb{P}$, γ*$\mathbb{P}$ by (e$^+$e$^-$, pp, ep)**

  → XYZ&$\mathbb{P}$ structure, $\bar{q}q$ production mechanisms

谢谢大家！

1) F.Huang, Z.Y.Zhang, Y.W.Yu, B.S.Zou, PLB 586 (2004) 69
“A study of pentaquark θ state in the chiral SU(3) quark model”

2) B.S.Zou, D.O.Riska, PRL95(2005)072001
“ $\bar{s}s$ component of the proton and the strangeness magnetic moment”

3) B.C.Liu, B.S.Zou, PRL96(2006)042002
“Mass and KΛ Coupling of the N*(1535)”

4) J.J.Wu, S.Dulat, B.S.Zou, PRD 80(2009) 017503: “Evidence for a new Σ* resonance with JP=1/2− in the old data of the K−p → Λπ+π− reaction”

5) J.J.Wu, R.Molina, E.Oset, B.S.Zou, PRL105(2010) 232001
“Prediction of narrow N* and Λ* resonances with hidden charm above 4 GeV”

6) P.Gao, B.S.Zou, A.Sibirtsev, NPA867(2011)41: “Analysis of the new Crystal Ball data on K−p → π0Λ reaction with beam momenta of 514–750 MeV/c”

7) W.L.Wang, F.Huang, Z.Y.Zhang, B.S.Zou, PRC84 (2011) 015203
“ΣcD and ΛcD states in a chiral quark model”

8) J.J.Wu, L.Zhao, B.S.Zou, PLB709(2012)70
“Prediction of super-heavy N* and Λ* resonances with hidden beauty”

9) C.S.An, B.S.Zou, PRC89(2014) 055209: “ Low-lying Ω states with negative parity in an extended quark model with Nambu–Jona-Lasinio interaction

10) J.Shi, B.S.Zou, arXiv:1411.0486， “Analysis of the Crystal Ball data on *K*−*p*→*π*0Σ0 reaction with center-of-mass energies of 1536~1676 MeV”