Missing Hyper-baryon Search

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1) P.Gao, J.Shi, B.S.Zou, PRC86 (2012) 025201
2) J.Shi, B.S.Zou, PRC91(2015) 035202
3) J.J.Xie, J.J.Wu, B.S.Zou, PRC90 (2014) 055204
4) J.J.Wu, B.S.Zou, Few Body System 56 (2015) 165
5) C.S.An, B.S.Zou, PRC89 (2014) 055209

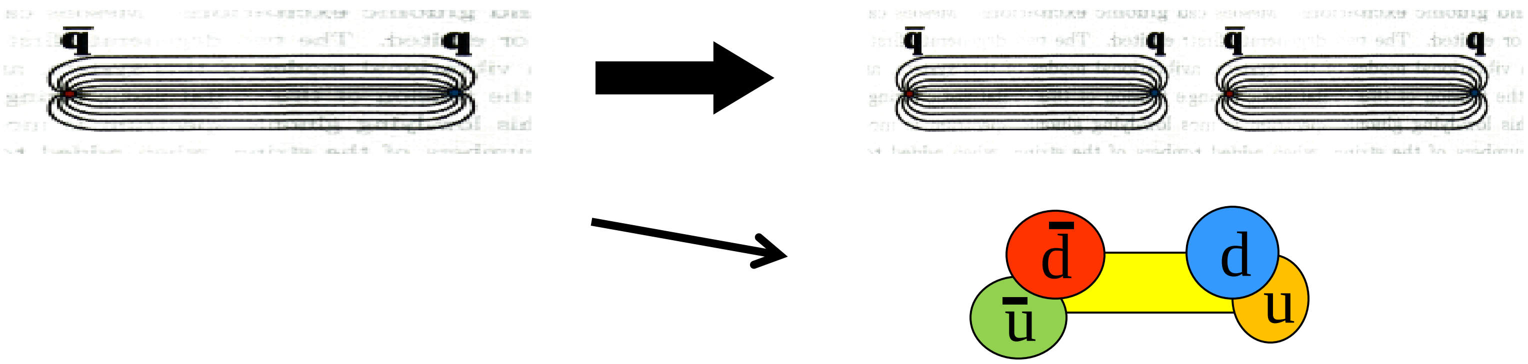
Outline :

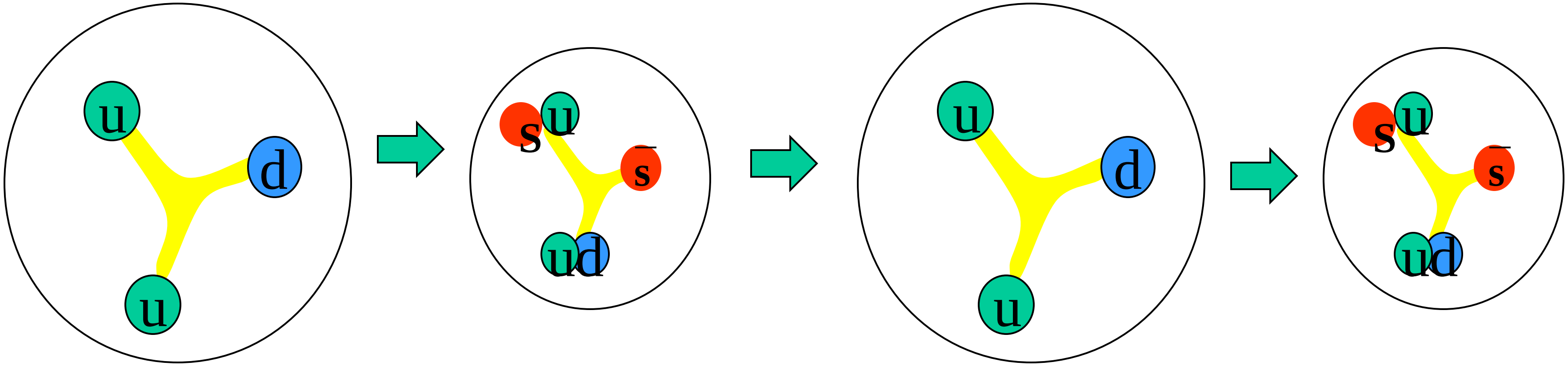
1. Why hyperon resonances ?
2. New results on Σ* & Λ* from CB data
3. Possible new sources for Σ* & Λ*
4. Conclusions and Prospects

1. Why hyperon resonances ?

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

crucial for quark confinement & hadron structure





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

$1/2^-$ 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) : **PDG** → large $g_{N^*N\eta}$

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

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

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

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

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

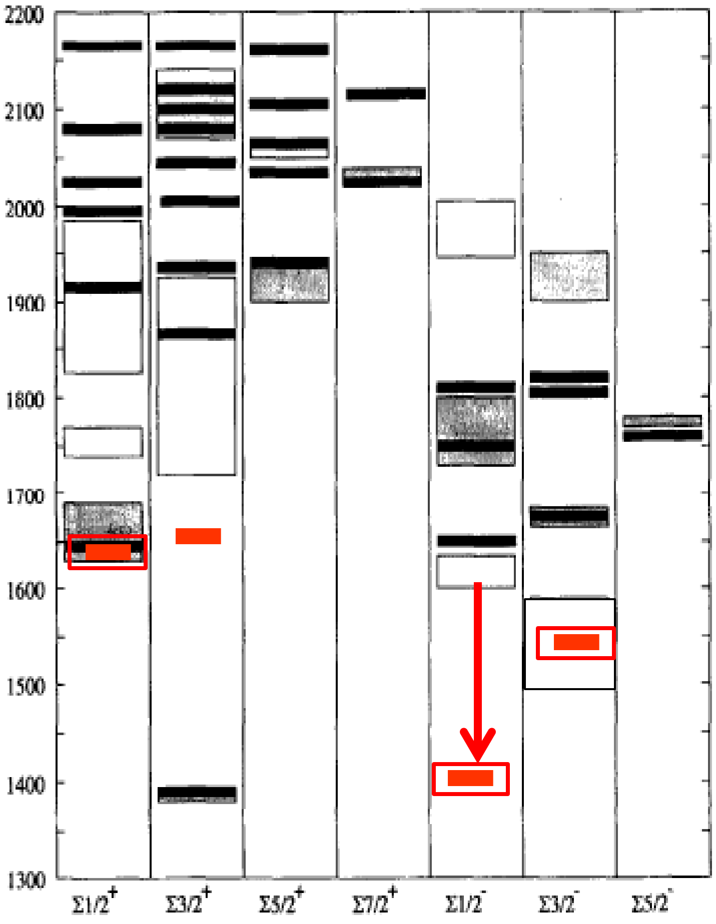
Xie, Zou & Chiang, PRC77(2008)015206; Cao, Xie, Zou & Xu, PRC80(2009)025203

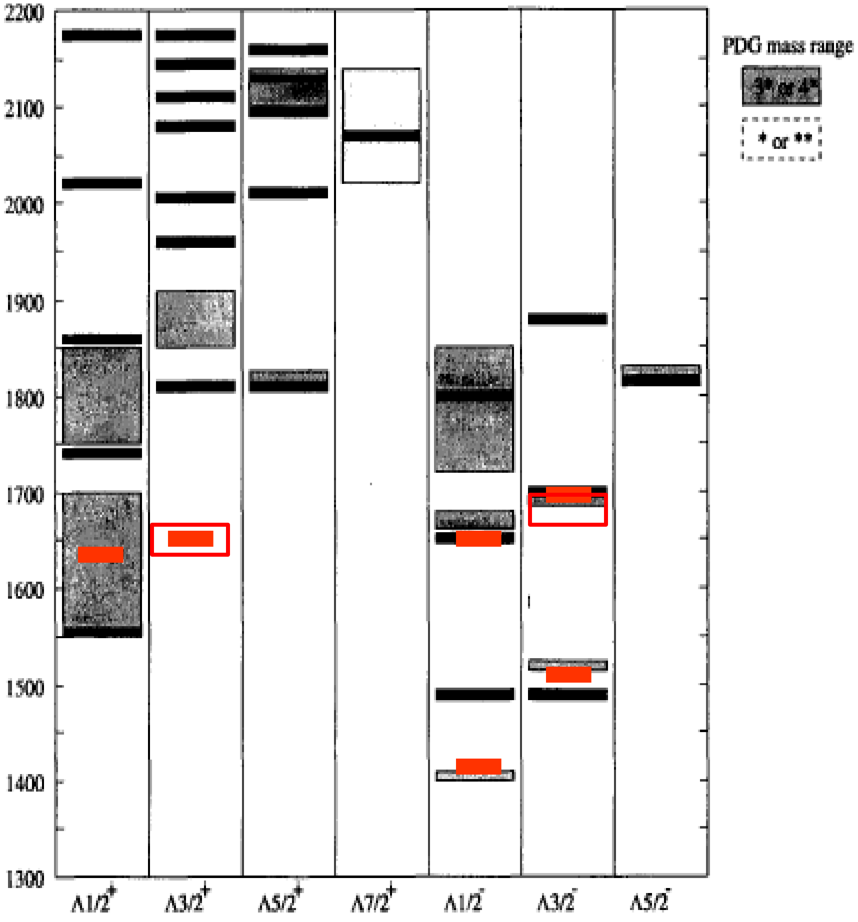
- Strange decays of Λ*(1670) : **PDG** → large $g_{\Lambda^*\Lambda\eta}$

narrower width (35MeV) than Λ*(1405)

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

Alternative pictures :

Hadronic molecules	Penta-quark states
N*(1440) ~ Nσ	N*(1440) ~ [ud][ud] $\bar{q}$
N*(1535) ~ KΣ-KΛ	N*(1535) ~ [ud][us] $\bar{s}$
Λ*(1405) ~ KN-Σπ	Λ*(1405) ~ [ud][sq] $\bar{q}$

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

Distinguishable model predictions for Σ* of **$3/2^-$ and $1/2^+$**

	qqq	$\bar{q}q^6$ or $\bar{K}\pi N$-$\pi\pi Y$	
$3/2^-$	Σ*(1650)	Σ*(1570)	Gal 2011
$1/2^+$	Σ*(1720)	Σ*(1630-1656)	Oset 2008

Experiment knowledge on hyperon states still very poor !

Ω^* in PDG:

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

*** $\Omega(2250)$

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

Ξ^* in PDG:

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

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

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

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

Σ^* in PDG2012

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

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

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

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

All from old experiments of 1970-1985 !!

No established $1/2^-$ Σ^* , Ξ^*, Ω^* !

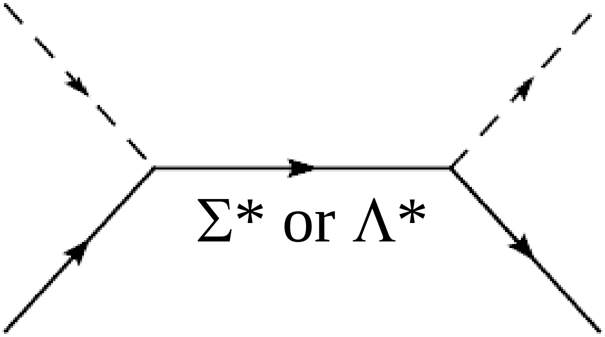
2. New results on Σ* & Λ* from CB data

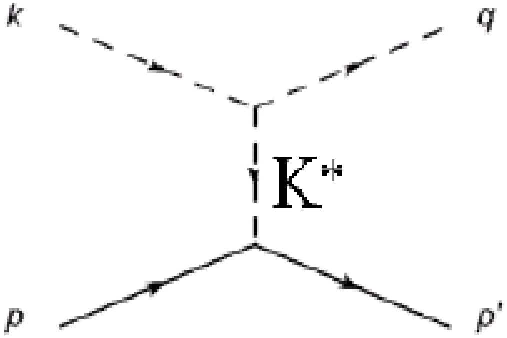
Crystal Ball: Prakhov et al., **PRC 80**(2009) 025204

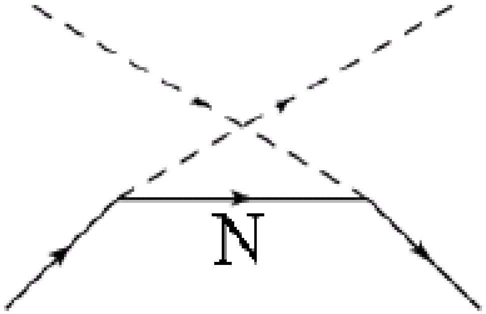
$K^- + p \rightarrow \pi^0 + \Lambda$ & $K^- + p \rightarrow \pi^0 + \Sigma^0$

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

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







$\Sigma^*(1620)1/2^-$ → supporting evidence for quenched qqq models ?

Problem : evidence for its existence is very shaky !

Among 4 references listed in PDG for it:

One without PWA for J^P

Two based on multi-channel analysis gave contradicted BRs

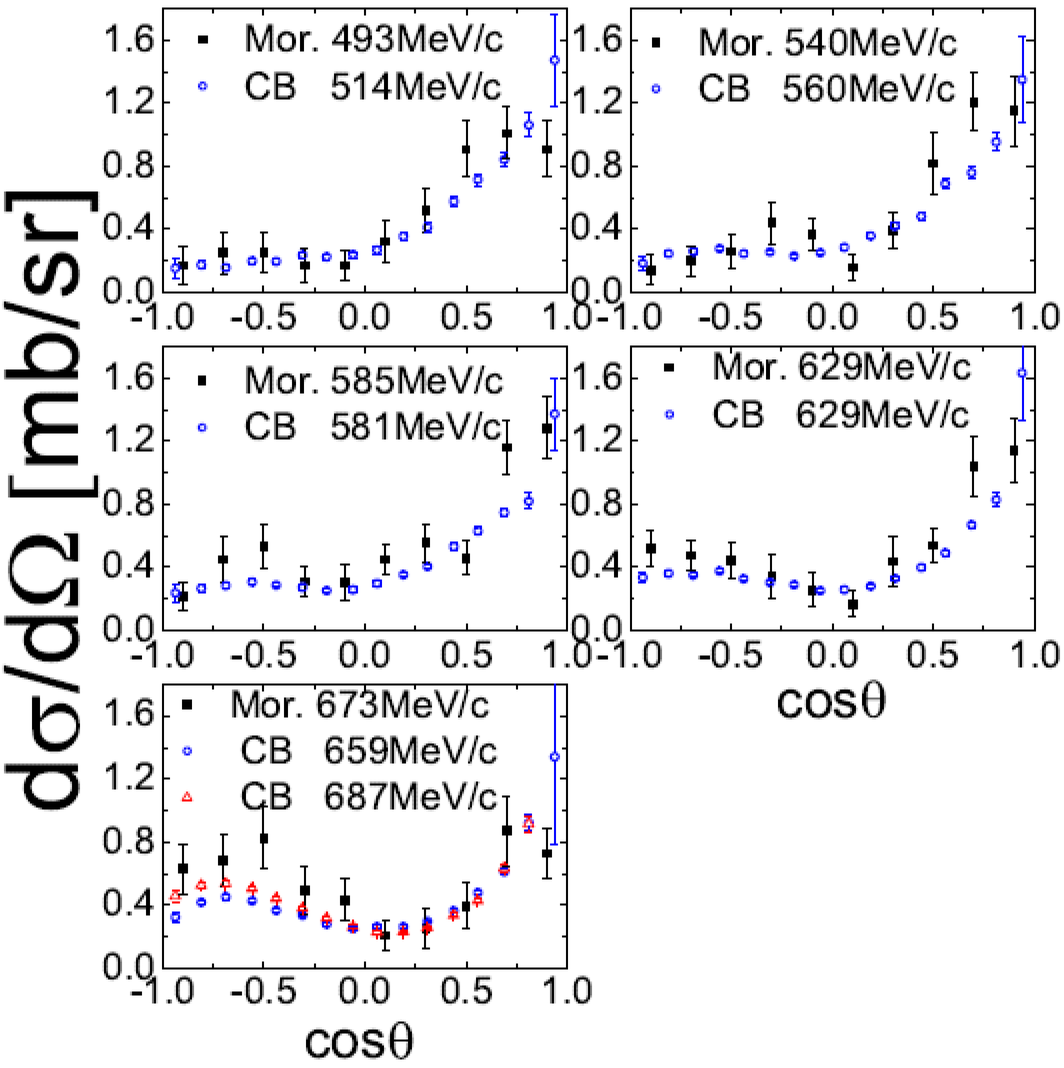
Other later multi-channel analyses claim to $\Sigma^*(1660)1/2^+$

The 4-th gave two comparable solutions with and without it by fitting $K^- n \rightarrow \pi^- \Lambda$ data

W.A. Morris et al., PRD17, 55 (1978)

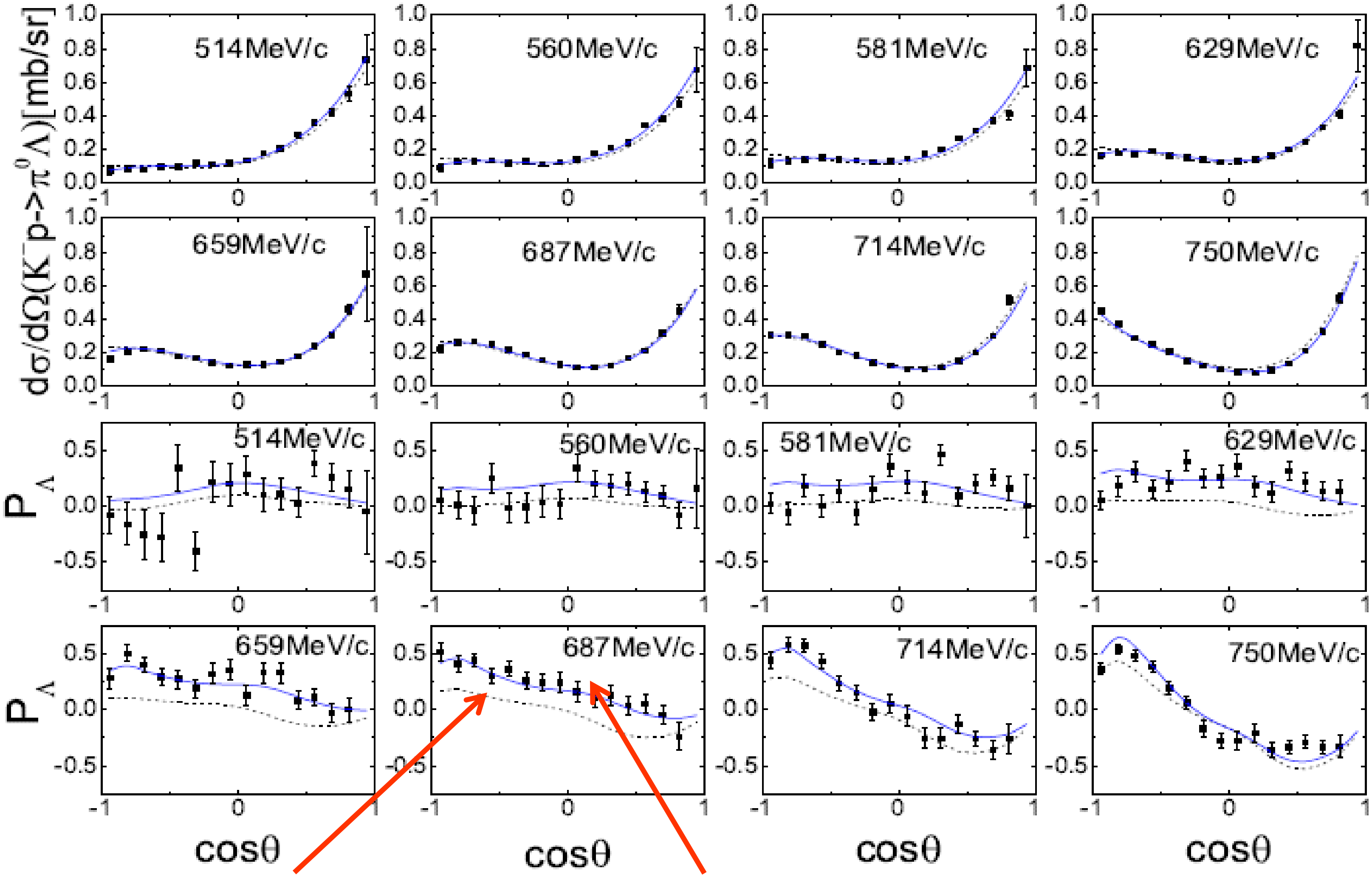
Is the new CB data compatible with the old $K^- n \rightarrow \pi^- \Lambda$ data analyzed by W.A. Morris et al., claiming possible $\Sigma^*(1620)1/2^-$?

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



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

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



with basic ingredients

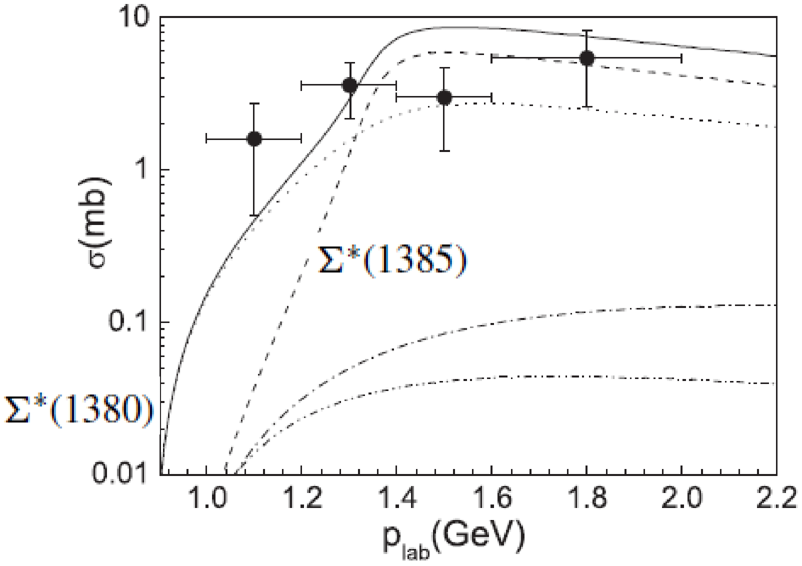
adding $\Sigma(1635)\ 1/2^+$ & $\Sigma(1542)3/2^-$

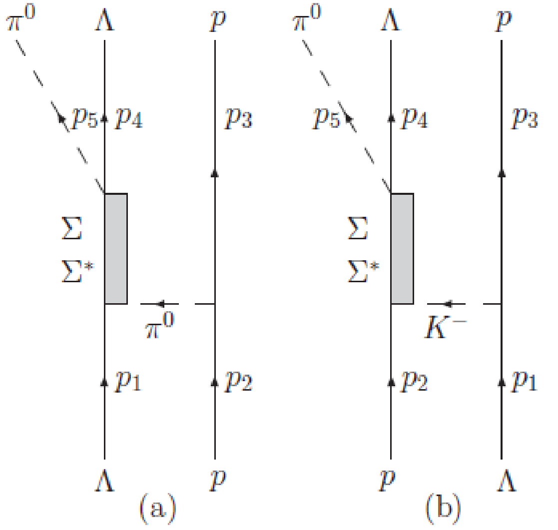
Polarization data – crucial for clarifying ambiguities !

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 *

New evidence for Σ(1380)1/2⁻ from $\Lambda p \rightarrow \Lambda p \pi^0$



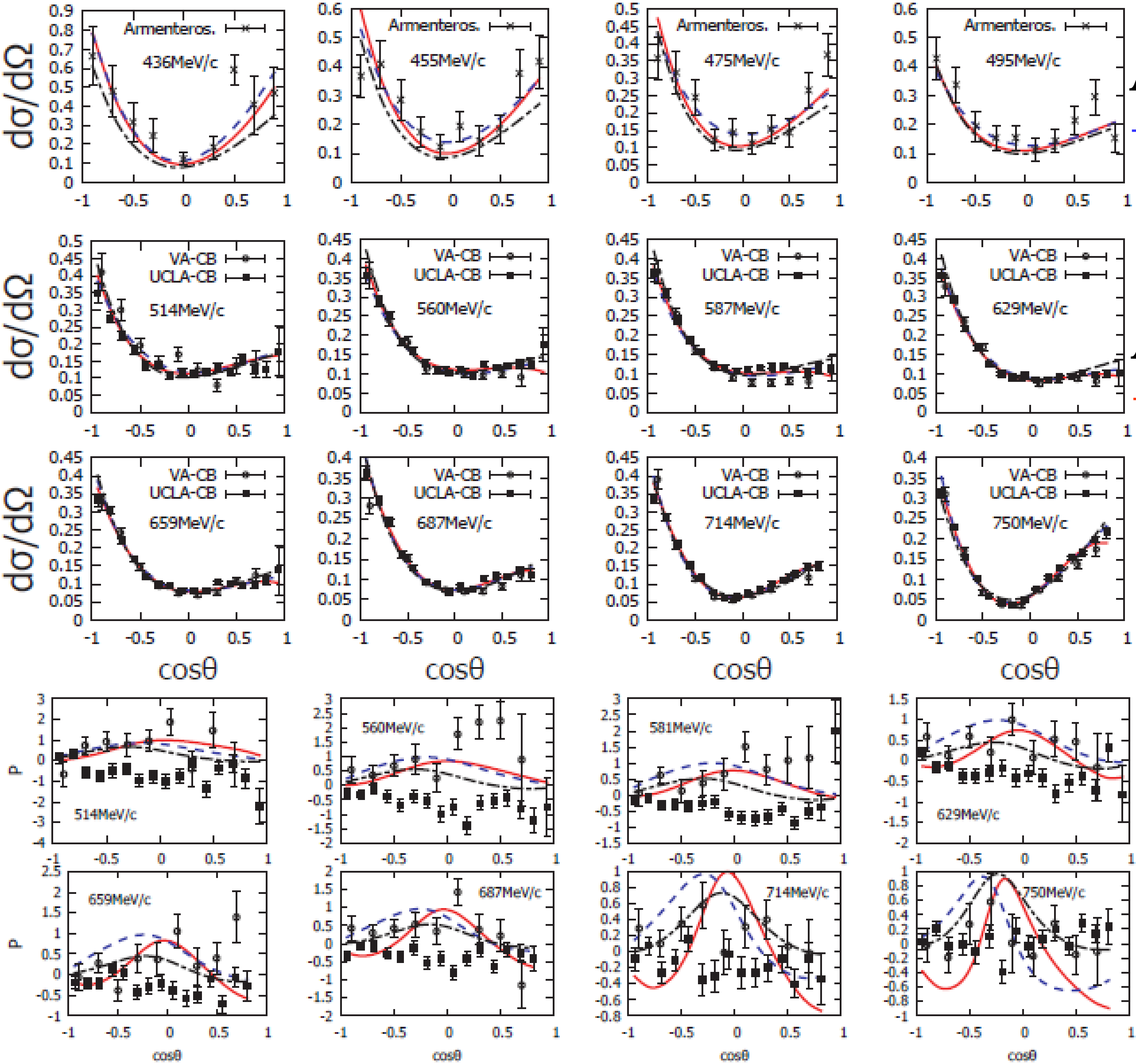


J.J.Xie, J.J.Wu, B.S.Zou, PRC90 (2014) 055204

Fits to new CB data on $K^-p \rightarrow \pi^0\Sigma^0$

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

$\Lambda^*(1670)1/2^-$ **** + $\Sigma^*(1600)1/2^+$ *** → $\chi^2 = 763$ for 236 data points



$\Lambda^*(1670)1/2^-$ &$\Lambda^*(1600)1/2^+$

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

→ $\chi^2 = 540$

$\Lambda^*(1670)1/2^-$ &$\Lambda^*(1600)1/2^+$

+ $\Lambda^*(1680)3/2^+$ (new)

→ $\chi^2 = 419$

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

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

Strong support for unquenched quark model!

Shi&Zou, PRC91(2015) 035202 :

new $\Lambda^*(1680)3/2^+$ M=1682±1 MeV, Γ=132±1 MeV

Further supports for a new $\Lambda^*(1680)3/2^+$
from coupled channel analysis of KN reactions

Kamano, Nakamura, Lee, Sato, PRC92 (2015) 025205 :

M=1681+2 −8 MeV, Γ=10+22 −8 MeV

Fernandez-Ramirez, Danilkin, Manley, Mathieu, Szczepaniak
PRD93 (2016) 034029 :

M=1690±4 MeV, Γ=46±11 MeV

Liu&Xie, PRC86(2012)055202

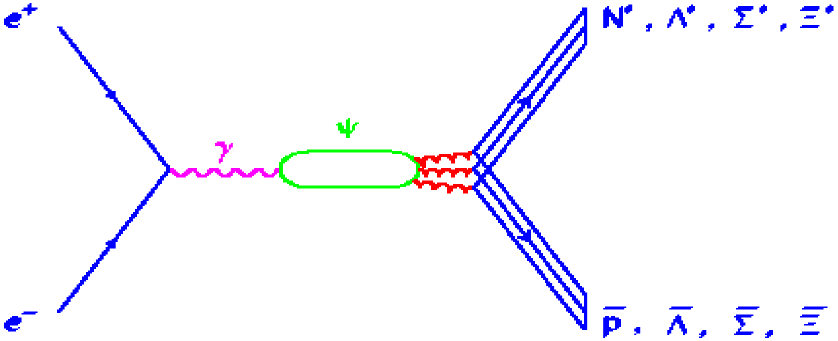
new $\Lambda^*(1670)3/2^-$ $\rightarrow \Lambda\eta$ with width of 1.5 MeV

$[us]\{ds\}\ \bar{s}$

3. Possible new sources for Σ* & Λ*

1) charmonium decays

$$J/\psi \to \bar{B}BM \quad \Rightarrow \quad N*,\ \Lambda*,\ \Sigma*,\ \Xi*,$$



an ideal isospin and low spin filter from $\bar{c}c$ annihilation

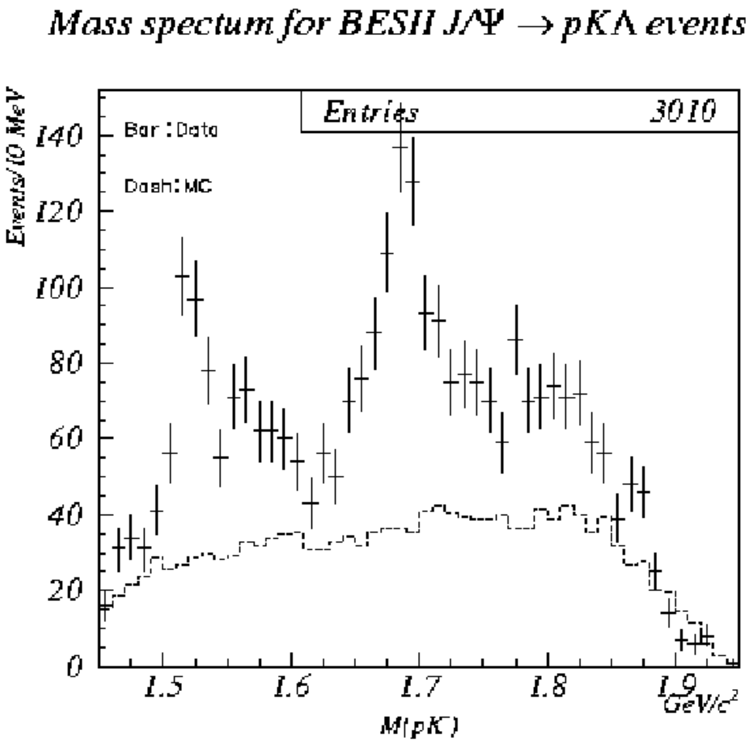
No contamination from t/u-channel scattering as in πN and KN

high statistics extension to ψ’, χ_{cJ}, η_c

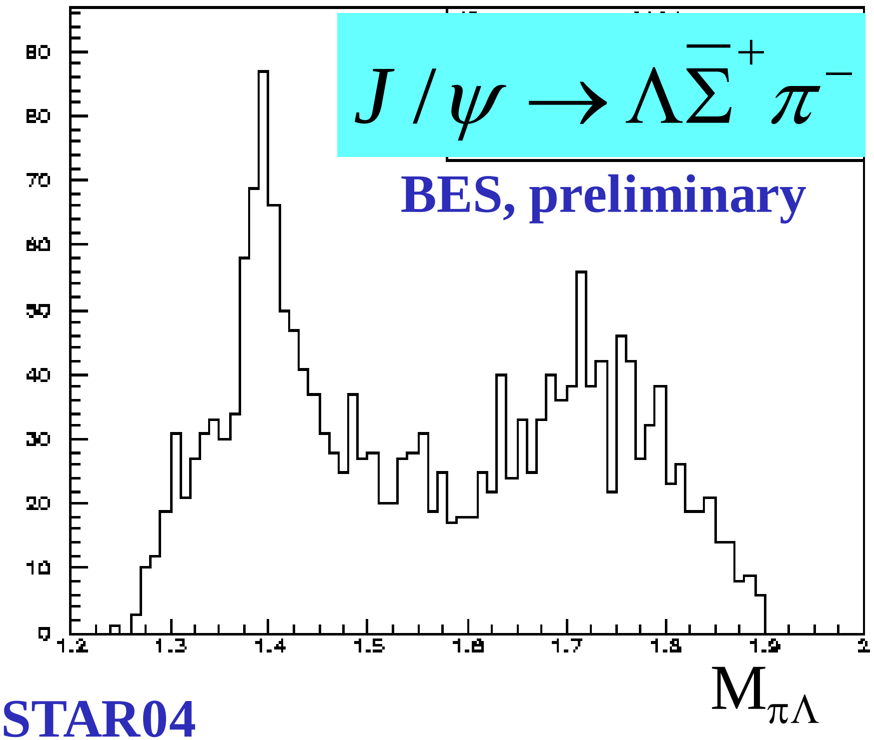
The new picture for the $1/2^-$ octet predicts:

Σ^* [us][du] $\bar{d}$ ~ 1380 MeV

Ξ^* [us][ds] $\bar{u}$ ~ 1540 MeV



Mass spectum for BESII $J/\Psi \to pK\Lambda$ events



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

BES, preliminary

$M_{\pi\Lambda}$

BES, NSTAR04

J/ψ decay		branching ratio * 10^4	
$\bar{p}\,\Delta(1232)^+$	$3/2^+$	< 1	
$\bar{\Sigma}^-\,\Sigma(1385)^+$		3.1 ± 0.5	} SU(3) breaking
$\bar{\Xi}^+\,\Xi(1530)^-$		5.9 ± 1.5	
$\bar{p}\,N^*(1535)^+$	$1/2^-$	10 ± 3	
$\bar{\Sigma}^-\,\Sigma(1380)^+$		?	} SU(3) allowed
$\bar{\Xi}^+\,\Xi(1540)^-$		?	

It is very important to check whether under the $\Sigma(1385)$ and $\Xi(1530)$ peaks there are $1/2^-$ components ?

$\psi(2S) \rightarrow \Lambda\bar{\Sigma}^{+}\pi^{-}$+c.c.

106 M

PRD 88, 112007(2013)

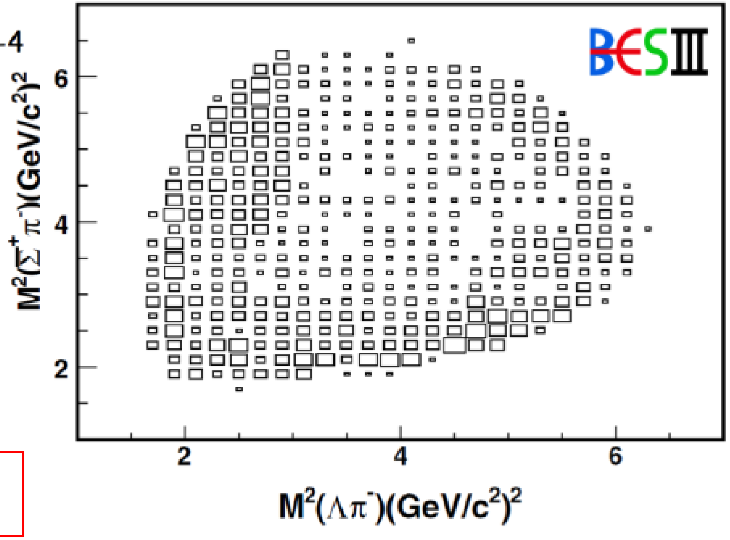
- BR first measurements:

  $B(\psi(3686)\text{->}\Lambda\bar{\Sigma}^{+}\pi^{-}+cc) = (1.40\pm0.03\pm0.13)\times10^{-4}$

  $B(\psi(3686)\text{->}\Lambda\bar{\Sigma}^{-}\pi^{+}+cc) = (1.54\pm0.04\pm0.13)\times10^{-4}$

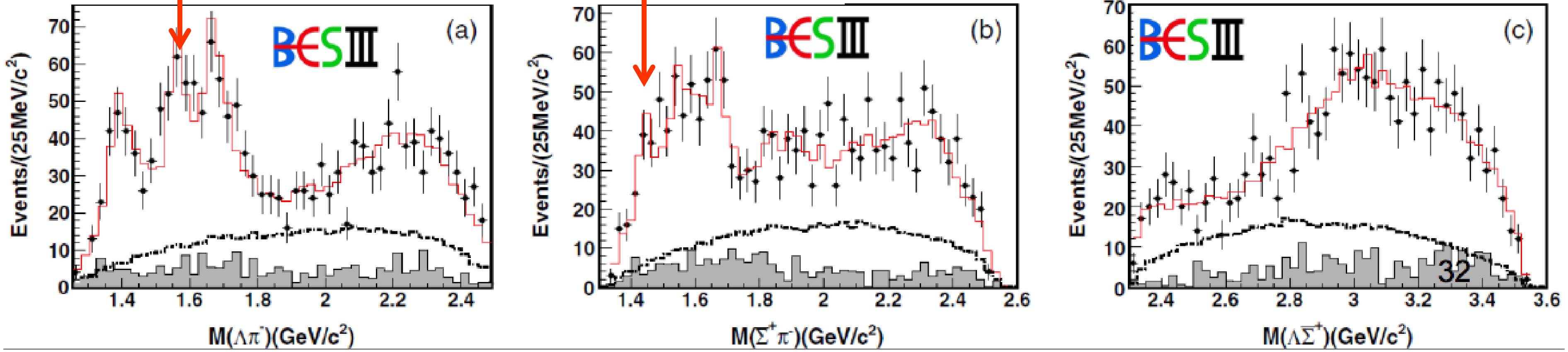
$$Q_{\Lambda\bar{\Sigma}^{-}\pi^{+}} = \frac{\mathcal{B}(\psi(3686)\to\Lambda\bar{\Sigma}^{-}\pi^{+})}{\mathcal{B}(J/\psi\to\Lambda\bar{\Sigma}^{-}\pi^{+})} = (9.3\pm1.2)\%$$

- PWA used to determine detection efficiency

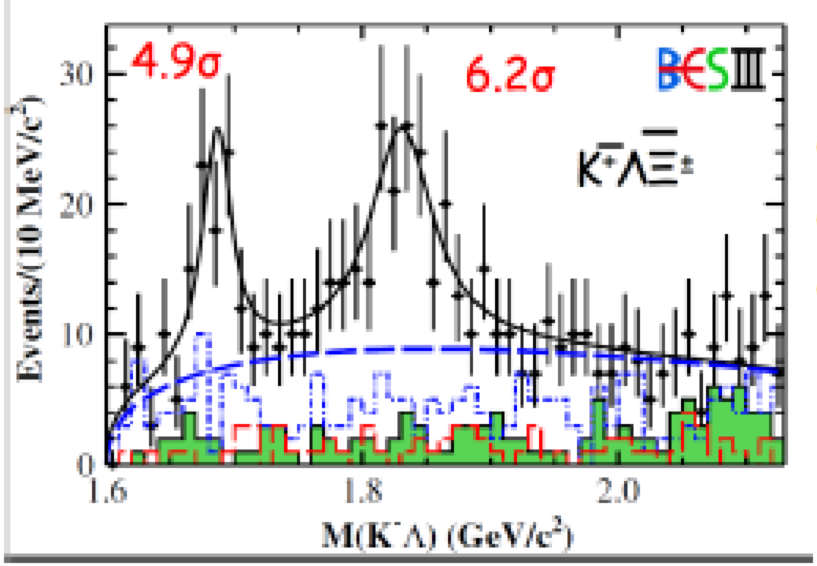


$\Sigma(1580)\ 3/2^{-}$

$\Lambda(1405)\ 1/2^{-}$



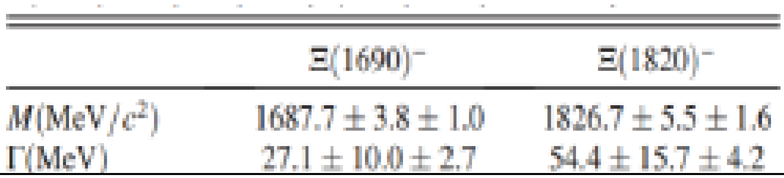
Observation Ξ^* of $\psi(2S) \to (\gamma)K^- \Lambda\bar{\Xi}^+$+c.c.



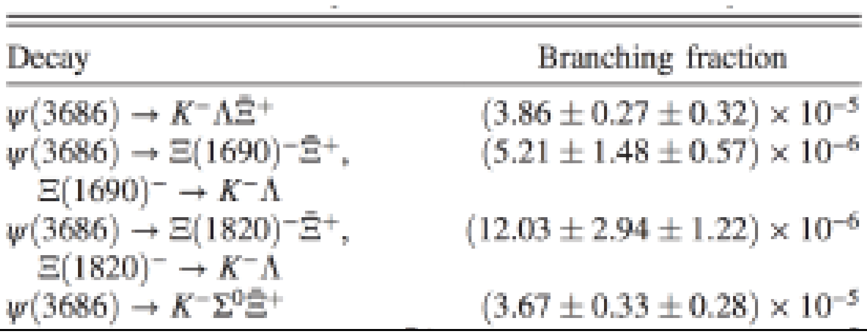
106 M $\psi(2S)$

PRD 91, 092006 (2015)

- $\Xi(1690)^-$ and $\Xi(1820)^-$ observed in M(KΛ)
- Mass and width consistent with PDG
- First observation in Charmonium decay



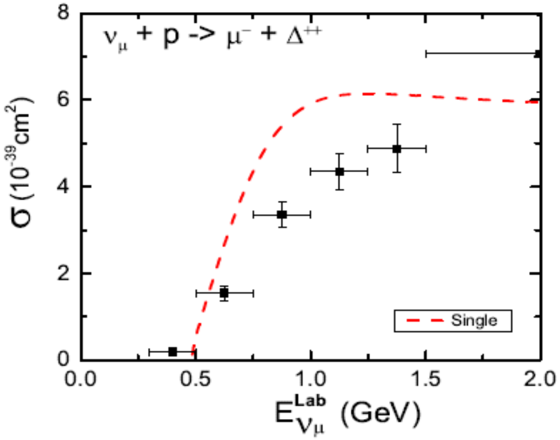
	$\Xi(1690)^-$	$\Xi(1820)^-$
$M(\mathrm{MeV}/c^2)$	$1687.7 \pm 3.8 \pm 1.0$	$1826.7 \pm 5.5 \pm 1.6$
$\Gamma(\mathrm{MeV})$	$27.1 \pm 10.0 \pm 2.7$	$54.4 \pm 15.7 \pm 4.2$

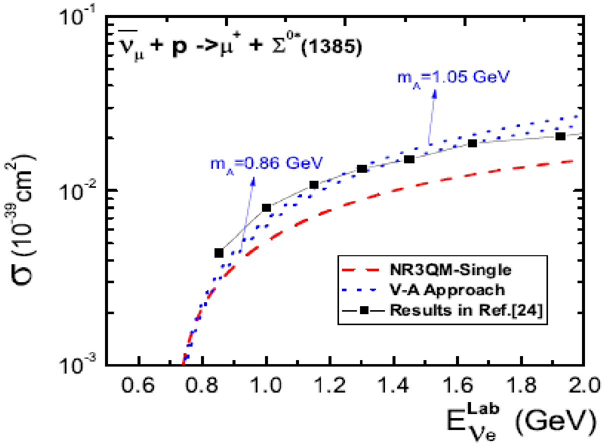


Decay	Branching fraction
$\psi(3686) \to K^-\Lambda\bar{\Xi}^+$	$(3.86 \pm 0.27 \pm 0.32) \times 10^{-5}$
$\psi(3686) \to \Xi(1690)^-\bar{\Xi}^+$, $\Xi(1690)^- \to K^-\Lambda$	$(5.21 \pm 1.48 \pm 0.57) \times 10^{-6}$
$\psi(3686) \to \Xi(1820)^-\bar{\Xi}^+$, $\Xi(1820)^- \to K^-\Lambda$	$(12.03 \pm 2.94 \pm 1.22) \times 10^{-6}$
$\psi(3686) \to K^-\Sigma^0\bar{\Xi}^+$	$(3.67 \pm 0.33 \pm 0.28) \times 10^{-5}$

What's J^p of $\Xi(1690)$? $\Xi(1540)$ in $\bar{\Xi}\Xi\pi$?

2) $\bar{\nu}_{e/\mu} + p \to e^+/\mu^+ + \pi + \Lambda/\Sigma$, **Wu, Zou, FBS 56 (2015) 165**

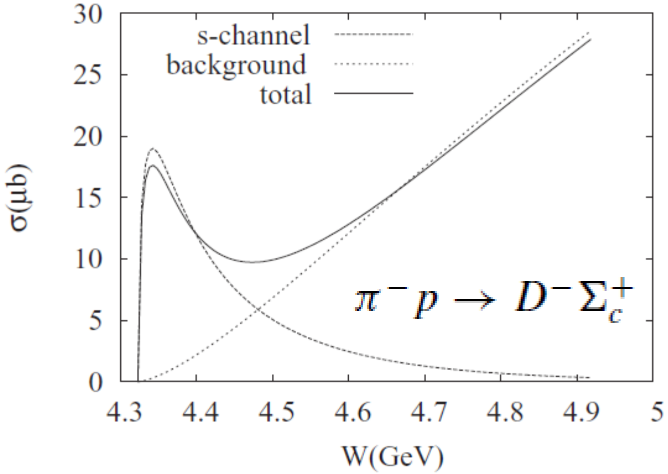




MiniBooNE → an ideal place for studying Σ* & Λ* below Kp threshold

3) $\Lambda_c^+ \longrightarrow \Lambda\pi^+\pi^0$ **BR=3.6%**

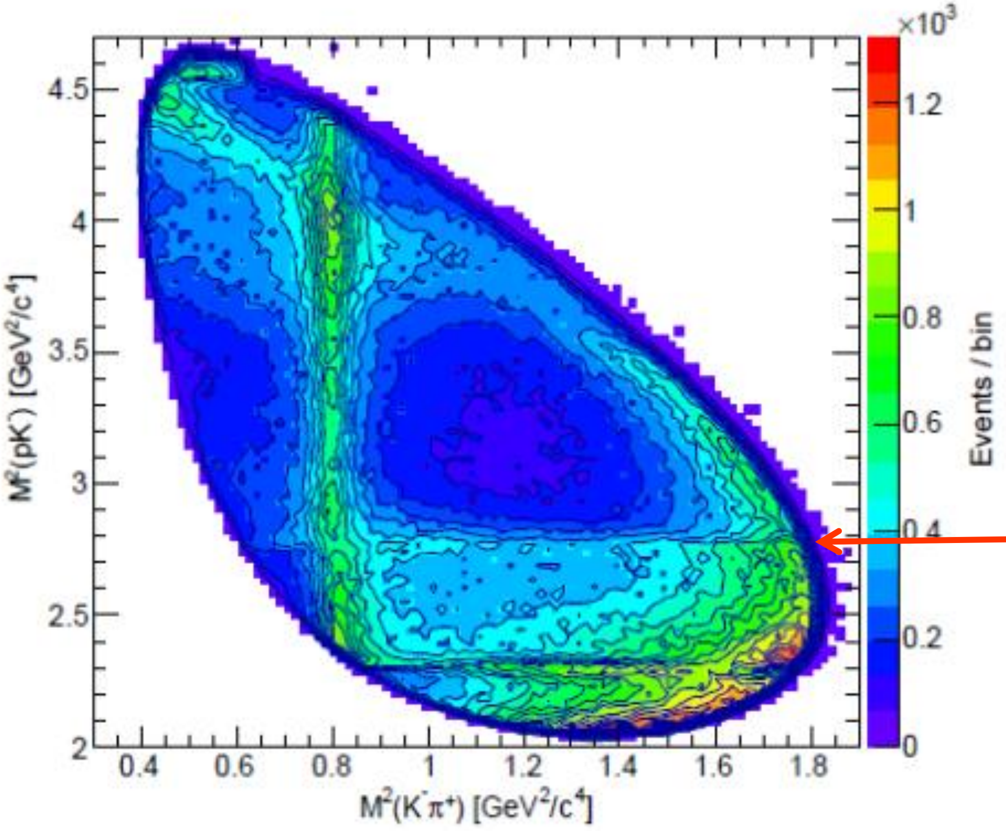
Λ_c production from πp, γp, e+e– at BESIII, JPARC, JLAB, BelleII



Garcon, Xie, PRC **92** (2015)035201

new $\Lambda^*(1670)3/2^-$ with width of 1.5 MeV $[us]\{ds\}\ \bar{s}$

from $K^- p \rightarrow \Lambda\eta$ Liu&Xie, PRC86(2012)055202

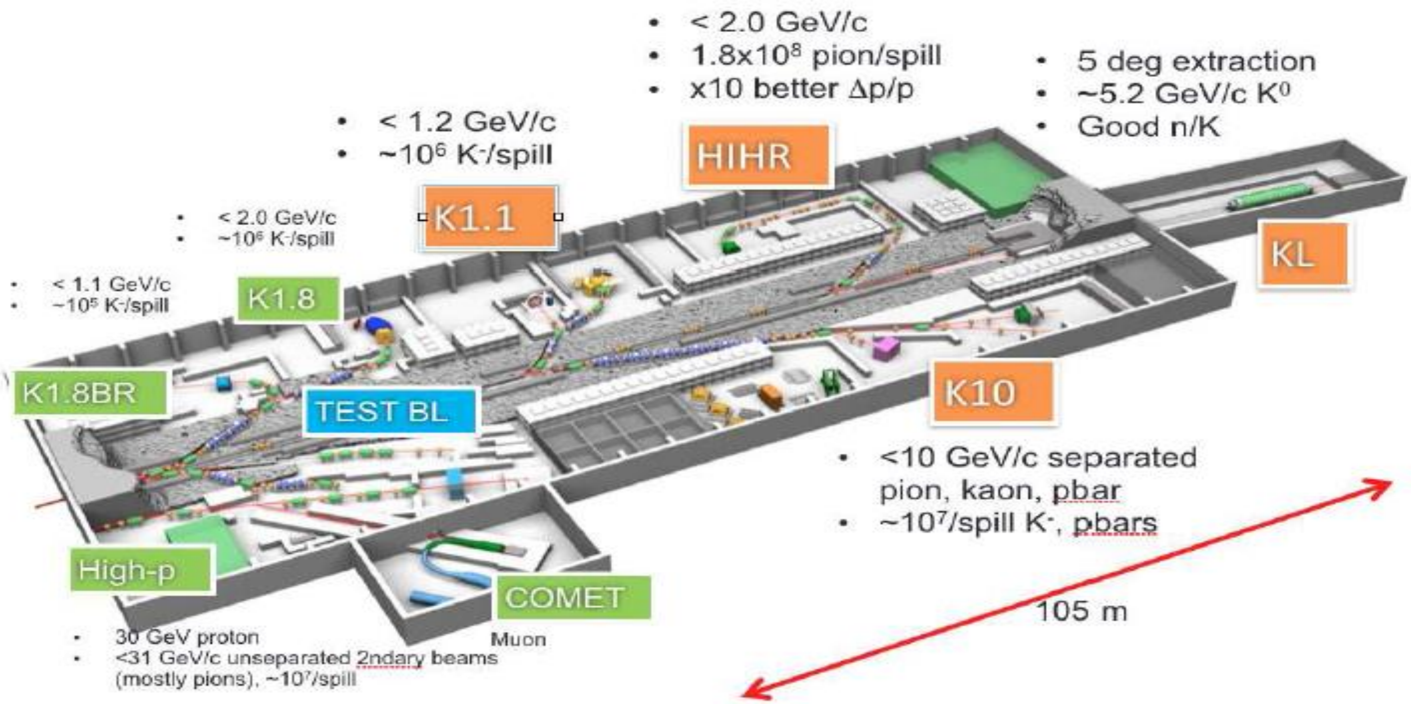


$\Lambda(1670)\ 3/2^-$?

Belle: $\Lambda_c^+ \rightarrow p\ K^-\ \pi^+$, PRL117 (2016) 011801

May be checked by BESIII on $\Lambda_c^+ \rightarrow p\ K^-\ \pi^+$ & $\Lambda\eta\ \pi^+$

4) K^-, K_L beam experiments at JPARC&Jlab



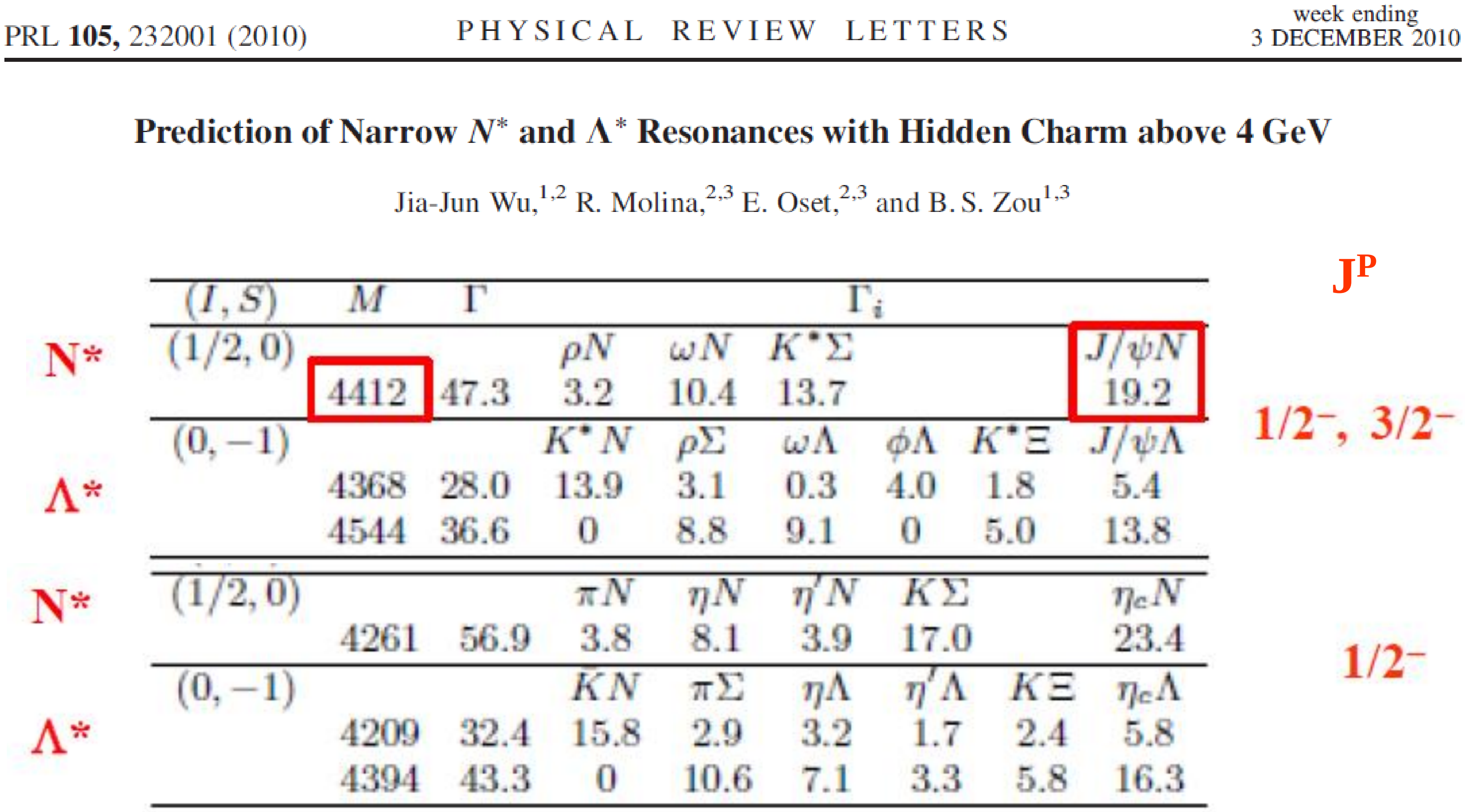
Elegant new source for Λ^*, Σ^*, Ξ^* & Ω^* hyperon spectroscopy

$K^-p \rightarrow \Sigma^0\pi^0, \Sigma^{*0}\pi^0, \Lambda\eta, \Lambda\pi^0\pi^0$: $\Lambda^*(1680)3/2^+$, $\Lambda^*(1670)3/2^-$

$K^-p \rightarrow \Sigma^0\pi^0\pi^0$: $\Sigma^*(1380)1/2^-$, $\Sigma^*(1540)\ 3/2^-$

$K_Lp \rightarrow \Lambda\pi^+, \Sigma^0\pi^+, \Sigma^+\pi^0, \Sigma^{*0}\pi^+, \Sigma^{*+}\pi^0$: $\Sigma^*(1540)\ 3/2^-$

$K_Lp \rightarrow \Sigma^0\eta\pi^+, \Lambda\eta\pi^+$: $\Sigma^*(1380)1/2^-$, $\Sigma^*(1540)\ 3/2^-$, $\Lambda^*(1670)3/2^-$



PRL **105,** 232001 (2010) PHYSICAL REVIEW LETTERS week ending 3 DECEMBER 2010

Prediction of Narrow N^* and Λ^* Resonances with Hidden Charm above 4 GeV

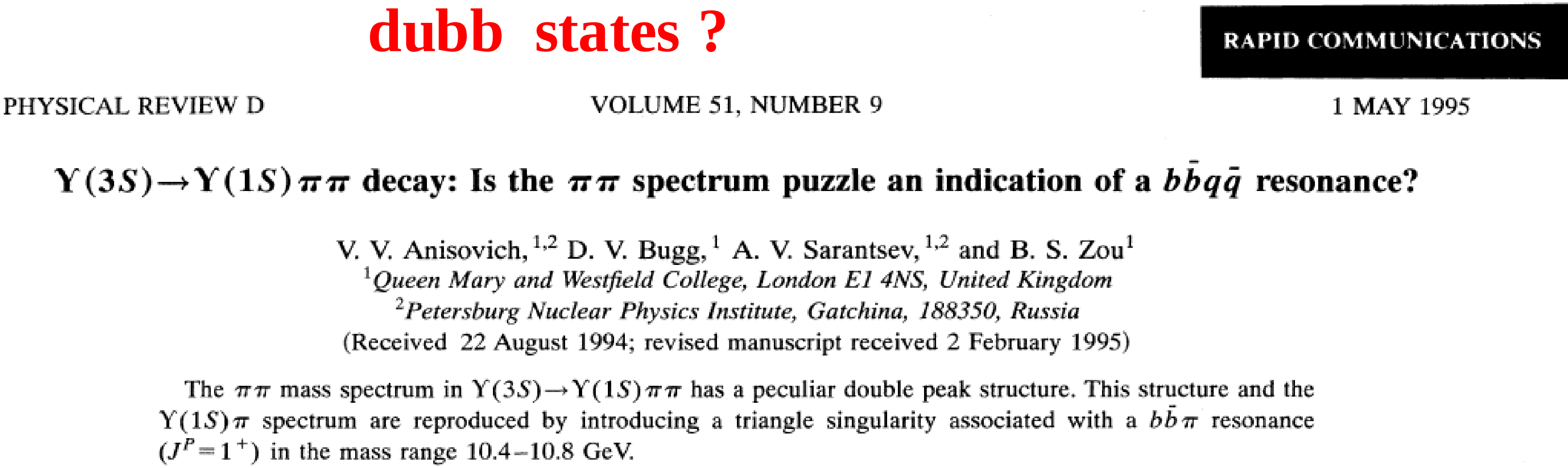
Jia-Jun Wu,[1,2] R. Molina,[2,3] E. Oset,[2,3] and B. S. Zou[1,3]

	(I,S)	M	Γ	Γ_i						J^P
N*	$(1/2,0)$			ρN	ωN	$K^*\Sigma$			$J/\psi N$	**1/2⁻, 3/2⁻**
		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	
N*	$(1/2,0)$			πN	ηN	$\eta' N$	$K\Sigma$		$\eta_c N$	**1/2⁻**
		4261	56.9	3.8	8.1	3.9	17.0		23.4	
Λ*	$(0,-1)$			$\bar{K}N$	$\pi\Sigma$	$\eta\Lambda$	$\eta'\Lambda$	$K\Xi$	$\eta_c\Lambda$	
		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	

LHCb ⟹ **$P_c^+(4380)$, $P_c^+(4450)$** **$\bar{D}\Sigma_c^*$, $\bar{D}^*\Sigma_c$**

K10@JPARC: $K^-p \rightarrow \eta_c\Lambda$, $J/\psi\Lambda$ ⟹ **$P_{cs}(4200\text{-}4600)$?!**

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



RAPID COMMUNICATIONS

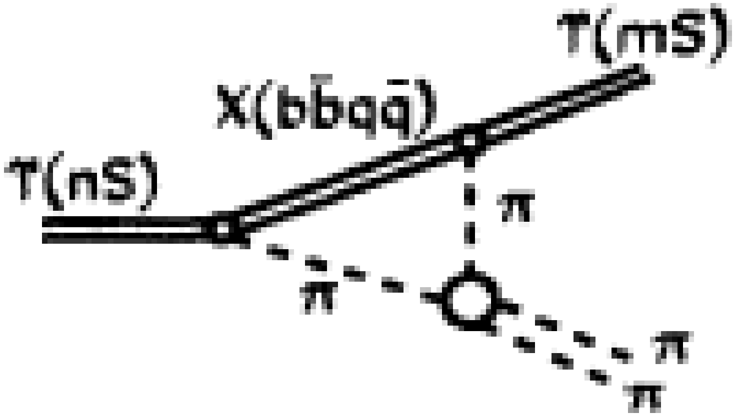
PHYSICAL REVIEW D VOLUME 51, NUMBER 9 1 MAY 1995

$\Upsilon(3S)\to\Upsilon(1S)\pi\pi$ 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"

Y.H.Chen, J.T.Daub, F.K.Guo, B.Kubis, Ulf-G.Meißner, **B.S.Zou**,
"The effect of **Z_b** states on Υ(3S)→Υ(1S)ππ decays", PRD93 (2016) 034030

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

K10@JPARC: $K^- p \rightarrow K^+ K^0 \Omega^*$ ⇨ $\Omega^*(1800)$?!

4. Conclusions and Prospects

- New hyperons support unquenched quark picture

new $\Sigma^*(1380)1/2^-$ replaces $\Sigma^*(1620)1/2^-$ **

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

new $\Lambda^*(1670)3/2^-$ with width of 1.5 MeV $[ud]\{ss\}\ \bar{s}$

$\rightarrow \Lambda\eta$ Liu&Xie, PRC86(2012)055202

new $\Sigma^*(1540)\ 3/2^-$

$3/2^-$ baryon nonet with strangeness

$\Lambda^*(1670) \sim [ud]\{ss\}\ \bar{s}$

$N^*(1520) \sim [ud]\{uq\}\ \bar{q}$

$\Lambda^*(1520) \sim [ud]\{su\}\ \bar{u}$

$\Sigma^*(1540) \sim [ud]\{sd\}\ \bar{d}$

pentaquark prediction: $\Xi(1630)1/2^-$, $\Xi(1690)3/2^-$ & $\Omega(1800)x/2^-$

- All these and more new hyperons can be studied by BESIII, BelleII & forthcoming K beam experiments !

Thanks !