Progress on Hyperon Resonances

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Puze Gao, Jun Shi, B. S. Zou, Phys. Rev. C86 (2012) 025201
Jun Shi, B. S. Zou, ArXiv: 1411.0486 [hep-ph]
C. S. An, B. Metsch, B. S. Zou, Phys. Rev. C87 (2013) 065207
C. S. An, B. S. Zou, Phys. Rev. C89 (2014) 055209

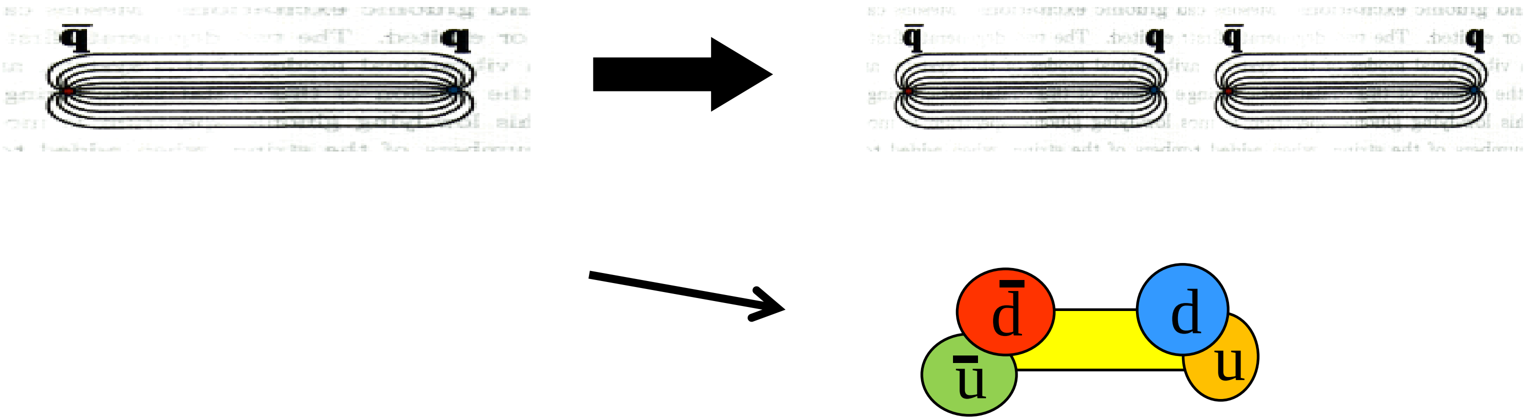
Outline :

1. Why hyperon resonances ?
2. New results on Σ* & Λ* from CB data
3. Prediction on Ω* from NJL unquenched quark model
4. Conclusions and Prospects

1. Why hyperon resonances ?

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

crucial for quark confinement & hadron structure

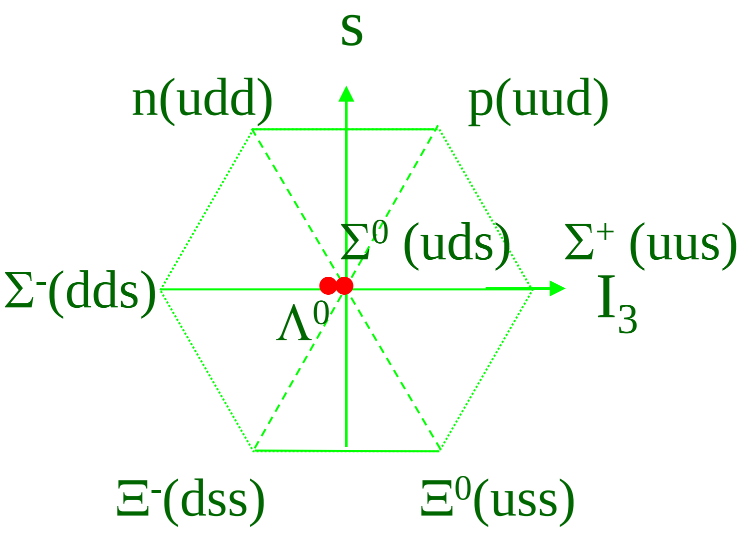


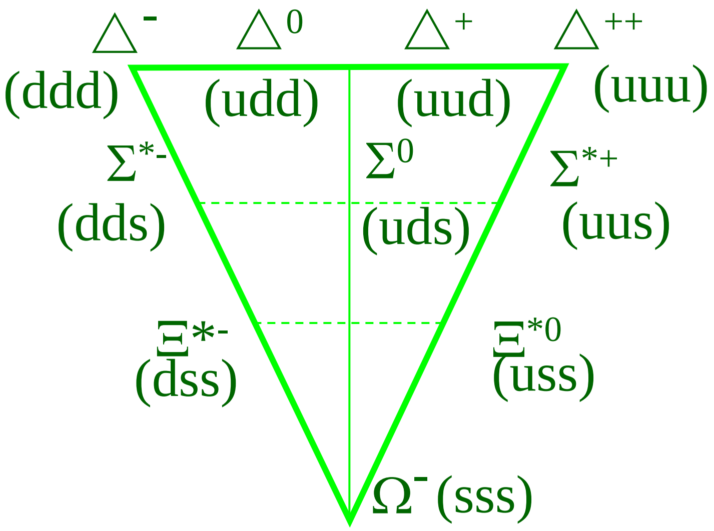
quenched or unquenched quark models give very different predictions of hyperon spectrum

Hadron spectroscopy with strangeness

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

$1/2^-$ 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

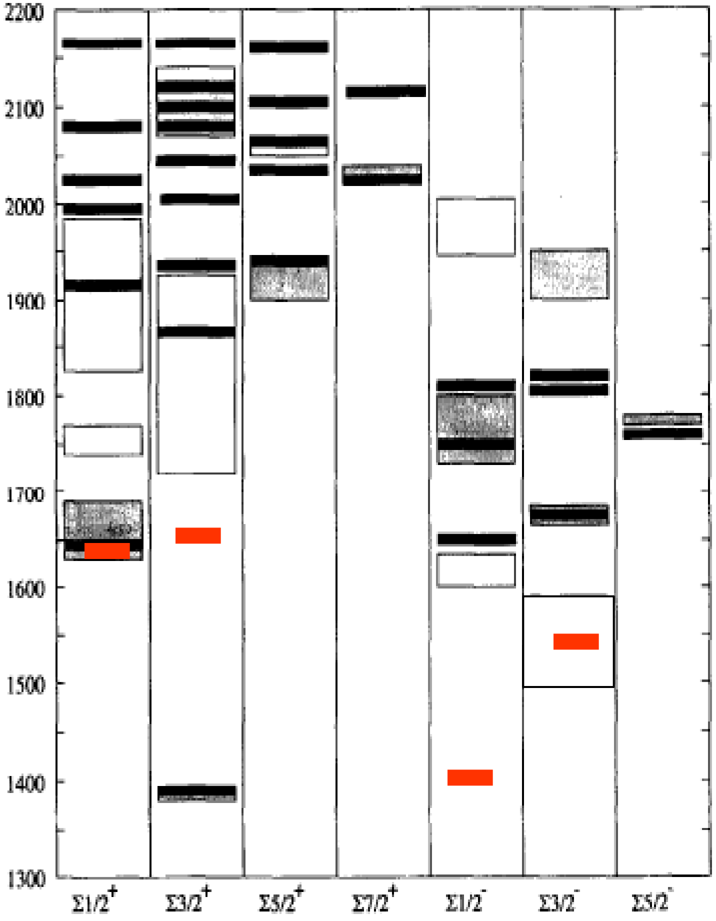
- **Strange decays of N*(1535) and Λ*(1670) :**

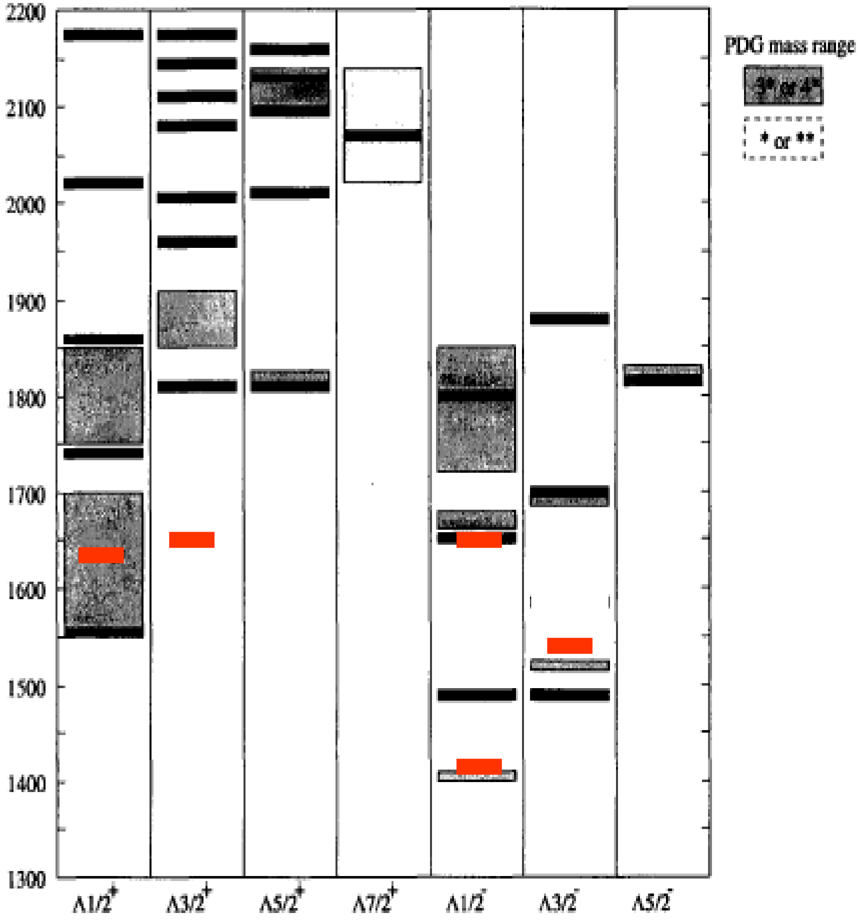
N*(1535) large couplings $g_{N^*N\eta}$, $g_{N^*K\Lambda}$, $g_{N^*N\eta'}$, $g_{N^*N\phi}$

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

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) & Σ*(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^* !

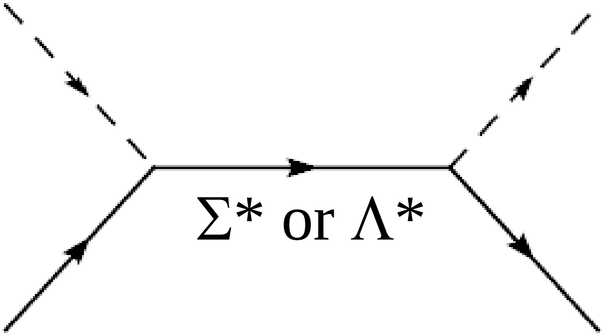
2. New results on Σ* & Λ* from CB data

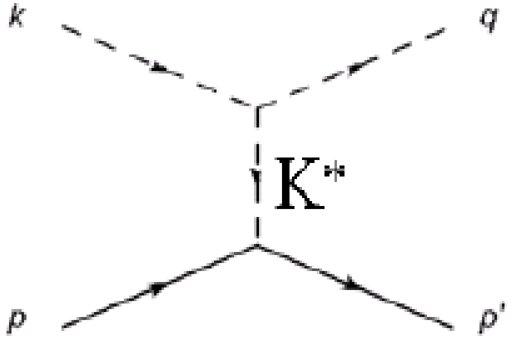
Crystal Ball: Prakhov et al., **PRC 80**(2009) 025204

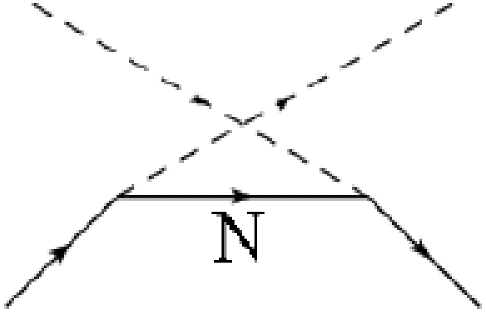
$$K^- + p \rightarrow \pi^0 + \Lambda \quad \& \quad K^- + p \rightarrow \pi^0 + \Sigma^0$$

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

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







Σ*(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

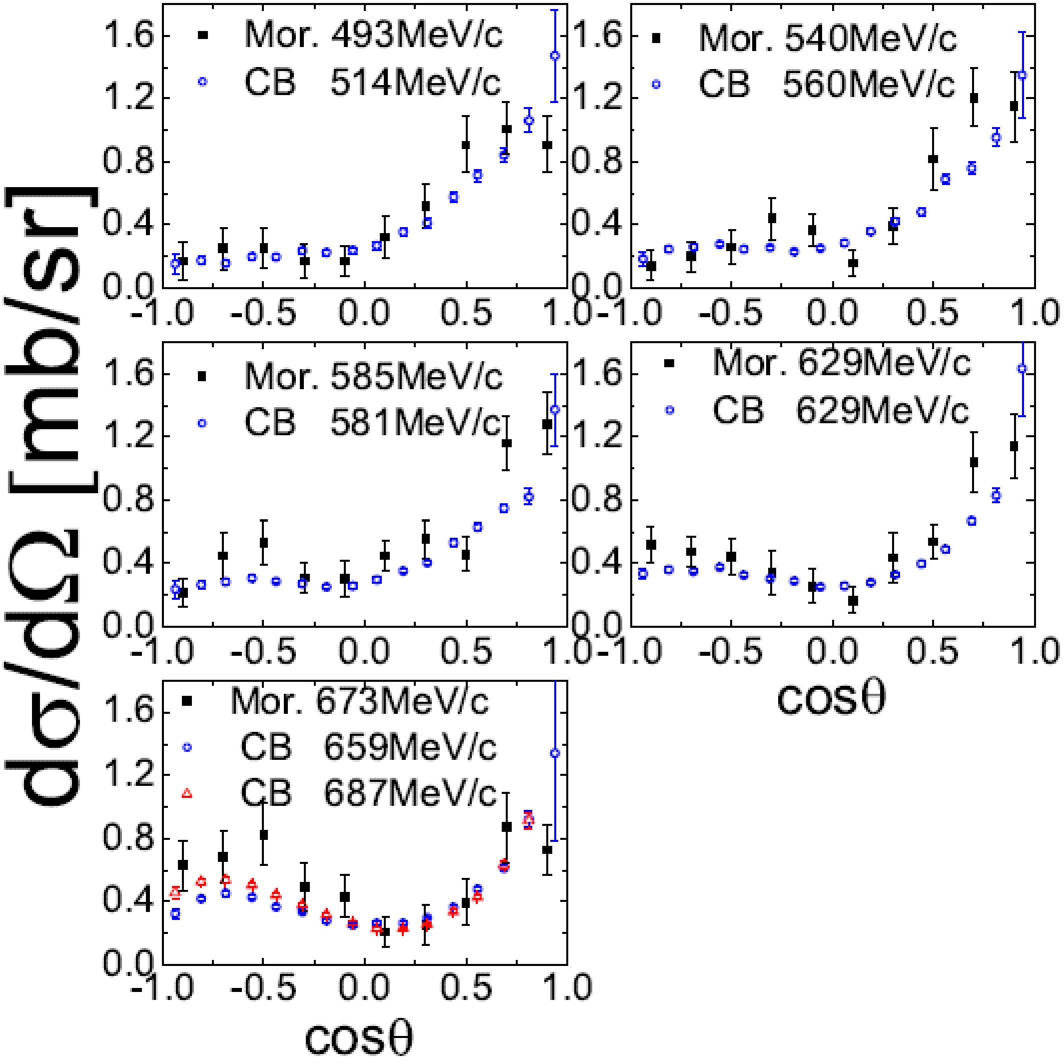
Other later multi-channel analyses claim to Σ*(1660)1/2⁺

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

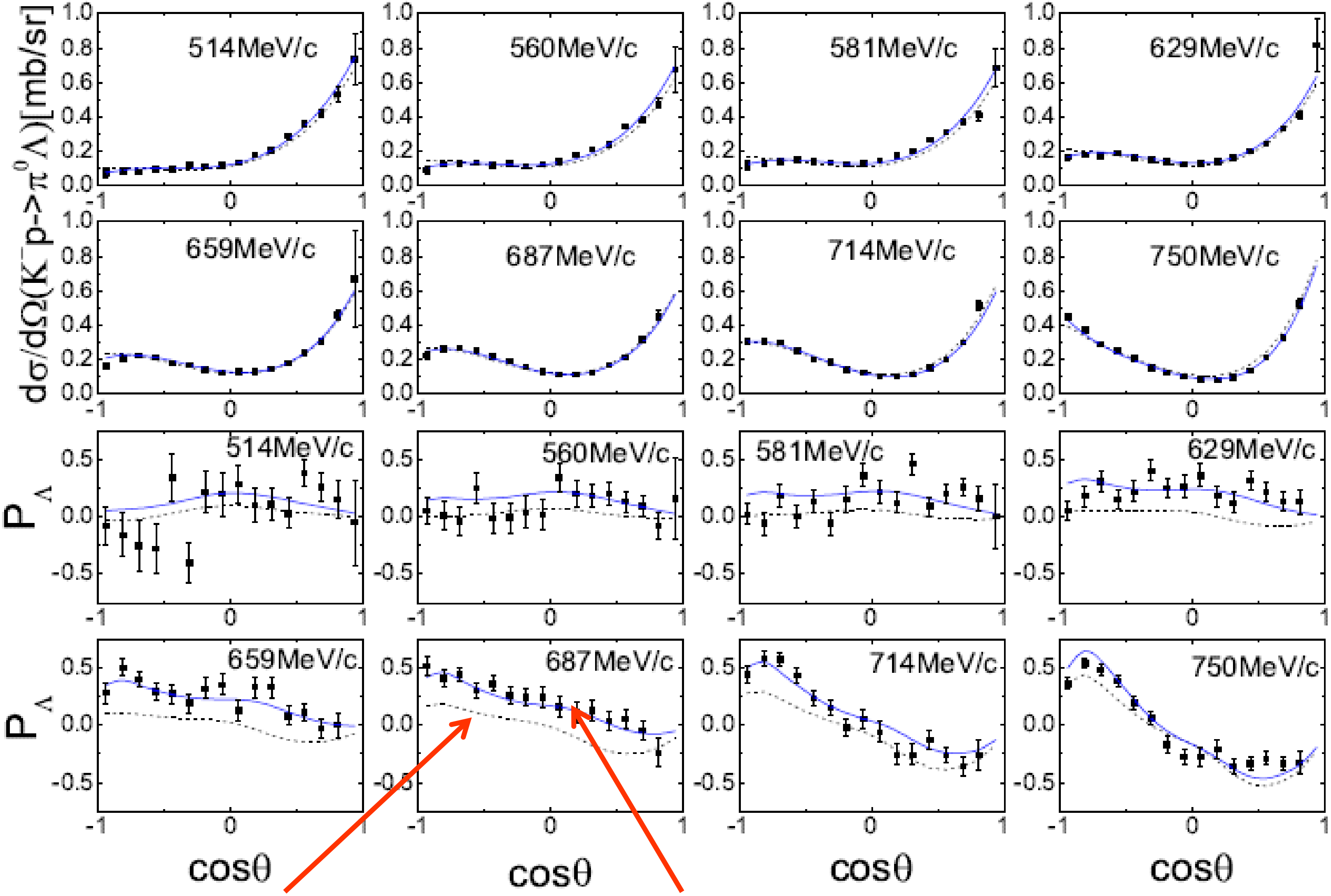
W.A. Morris et al., PRD17, 55 (1978)

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

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



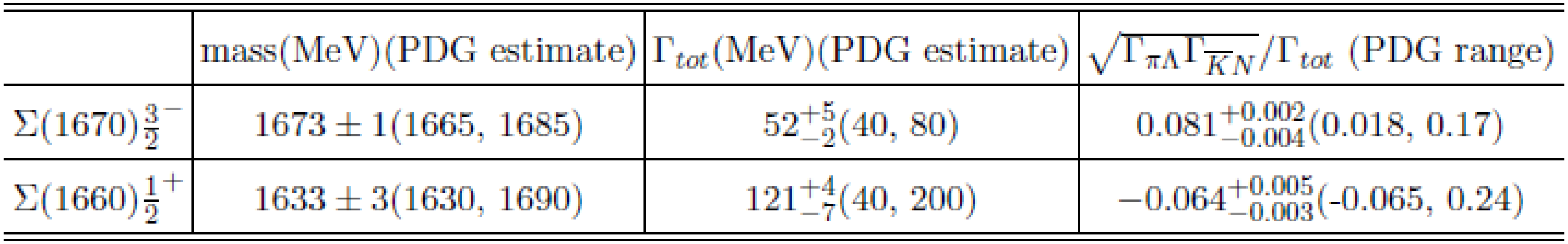
new CB data on $K^-p \rightarrow \pi^0\Lambda$



with basic ingredients

adding Σ(1635) 1/2⁺

Adding * Σ(1660)1/2$^+$, χ^2 =572 for 348 data points with 18 tunable parameters. $\Delta\chi^2$ =1008 !**



	mass(MeV)(PDG estimate)	Γ_{tot}(MeV)(PDG estimate)	$\sqrt{\Gamma_{\pi\Lambda}\Gamma_{\overline{K}N}}/\Gamma_{tot}$ (PDG range)
$\Sigma(1670)\frac{3}{2}^-$	1673 ± 1(1665, 1685)	52^{+5}_{-2}(40, 80)	$0.081^{+0.002}_{-0.004}$(0.018, 0.17)
$\Sigma(1660)\frac{1}{2}^+$	1633 ± 3(1630, 1690)	121^{+4}_{-7}(40, 200)	$-0.064^{+0.005}_{-0.003}$(-0.065, 0.24)

Replace Σ(1660)1/2$^+$ by Σ(1/2$^-$) : $\chi^2 = 899$ with M < 1360 MeV

Not Σ(1620) 1/2$^-$

by Σ(3/2$^+$) : $\chi^2 = 943$

by Σ(3/2$^-$) : $\chi^2 = 1392$

Add both Σ(1660)1/2$^+$ & Σ(1/2$^-$) : $\Delta\chi^2 = 24$ with M = 1432 MeV

Γ > 1000 MeV

No Σ(1620) 1/2$^-$!!

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

Add $\Sigma(3/2^+)$: $\Delta\chi^2 = 85$ with M ~ 1840 MeV PDG $\Sigma(1840)3/2^+$?

Add $\Sigma(3/2^-)$: $\Delta\chi^2 = 37$ with M ~ 1542 MeV PDG-GAL $\Sigma(1580)\ 3/2^-$?

Add $\Sigma(1/2^+)$: $\Delta\chi^2 = 31$ with M ~ 1610 MeV two $\Sigma(1/2^+)$ ~1633 MeV ?

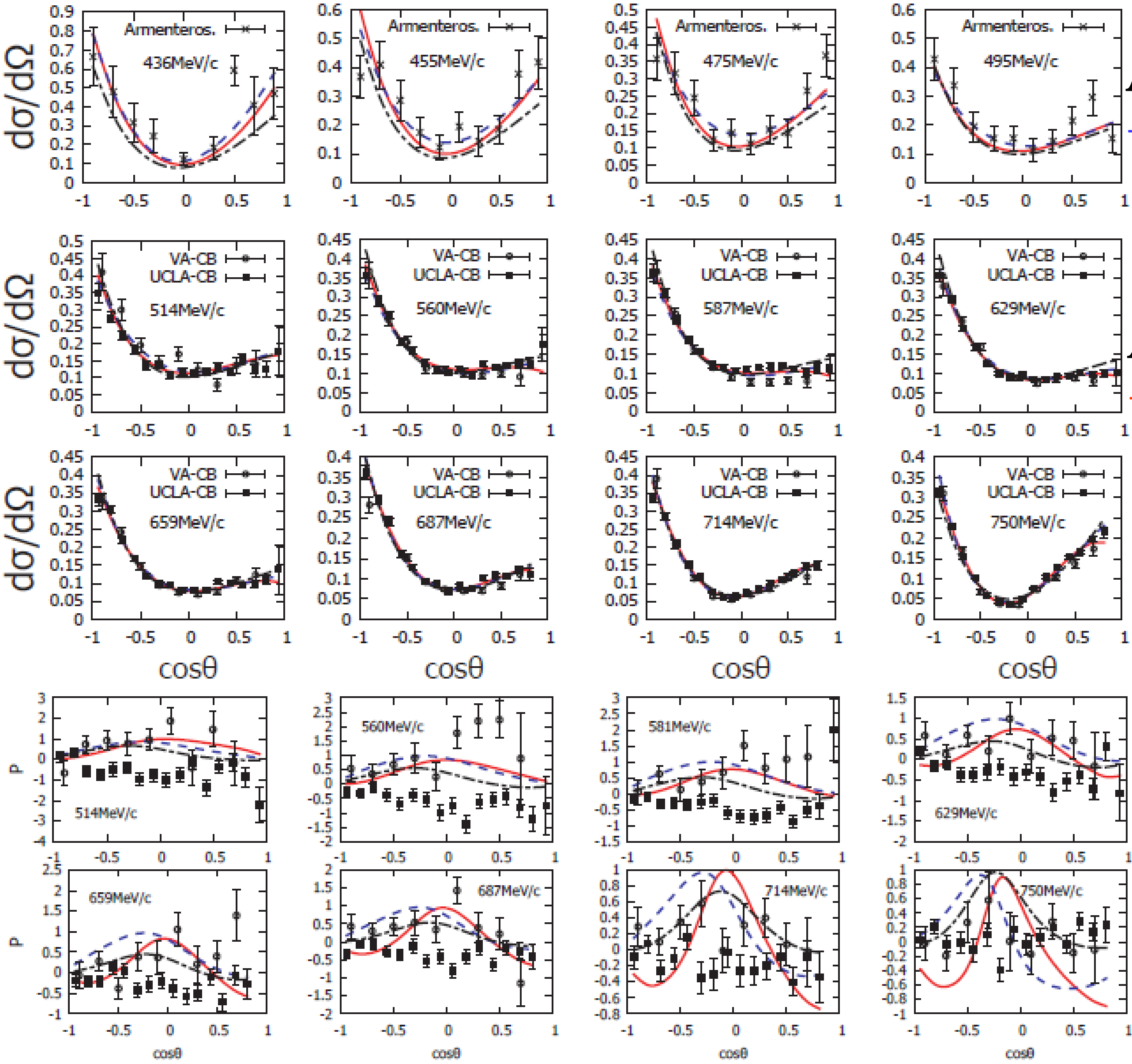
as claimed by Oset et al.

For details : Puze Gao, Jun Shi, B. S. Zou, PRC86 (2012) 025201

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

$\Lambda^*(1670)1/2^-$ **** + $\Sigma^*(1600)1/2^+$ *** → $\chi^2 = 763$ 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 $\Lambda^*(1690)3/2^-$ ****

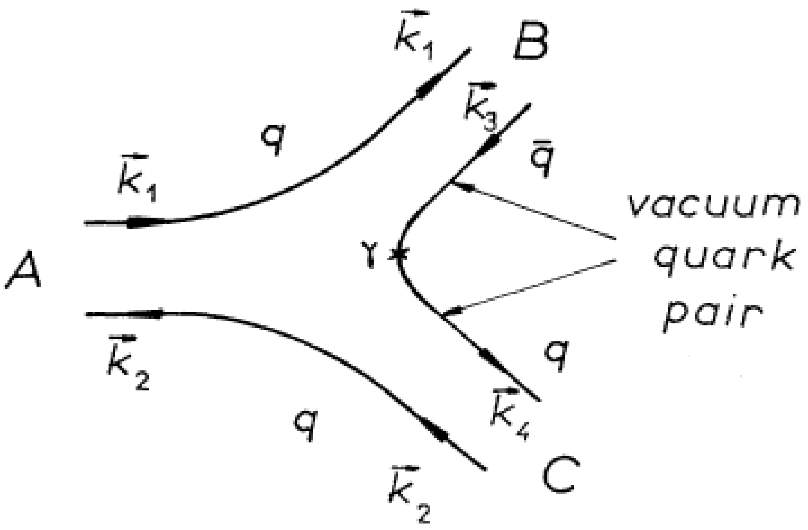
Strong support for unquenched quark model!

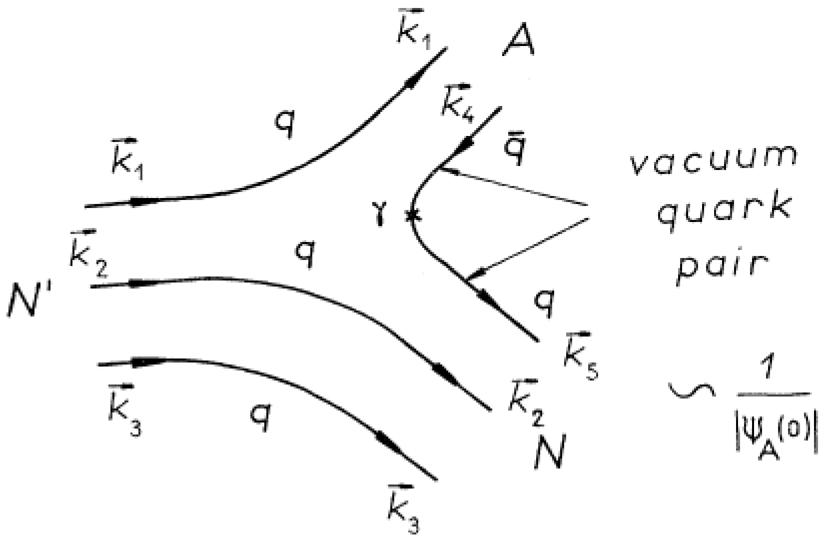
3. Ω* from NJL unquenched quark model

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

1) **Perturbative $^3S_1$** **failed for 1^- and 1^+ decays**

2) **Non-perturbative $^3P_0$** **quite successful & popular**





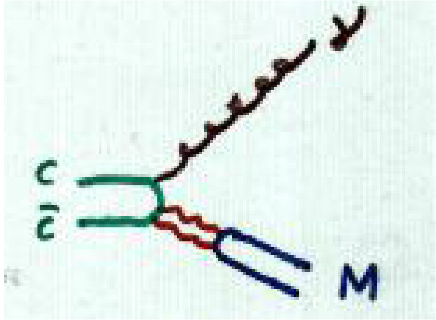
A. Le Yaouanc et al., **Phys.Rev. D8 (1973) 2223**

B. Aubert et al. (BABAR Collaboration), PRD 78 (2008) 112002:

$$\Gamma(Y(4S)\rightarrow \eta Y(1S))/\Gamma(Y(4S)\rightarrow \pi^{+}\pi^{-}Y(1S)) = 2.41 \pm 0.40_{\text{stat}} \pm 0.12_{\text{syst}}$$

M. Ablikim et al. (BESIII Collaboration), PRD 86 (2012) 071101

$$\Gamma(\psi(4040)\rightarrow \eta J/\psi)/\Gamma(\psi(4040)\rightarrow \pi^{+}\pi^{-}J/\psi) > 2$$

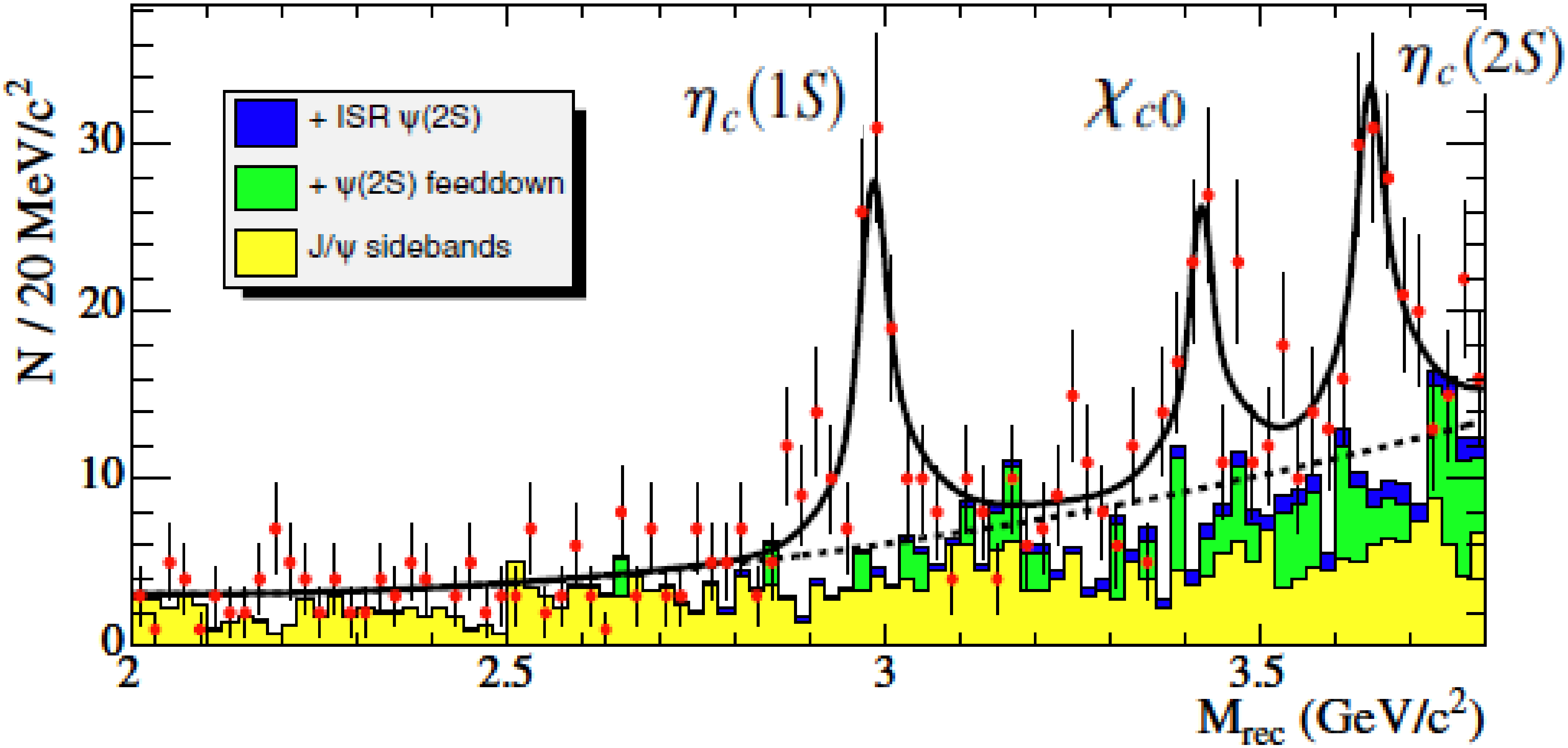


PDG:

$$\Gamma(J/\psi \rightarrow \gamma\eta) > \Gamma(J/\psi \rightarrow \gamma\sigma)$$

Gluons more favor to produce $\bar{q}q(^{1}S_{0})$ sometimes !

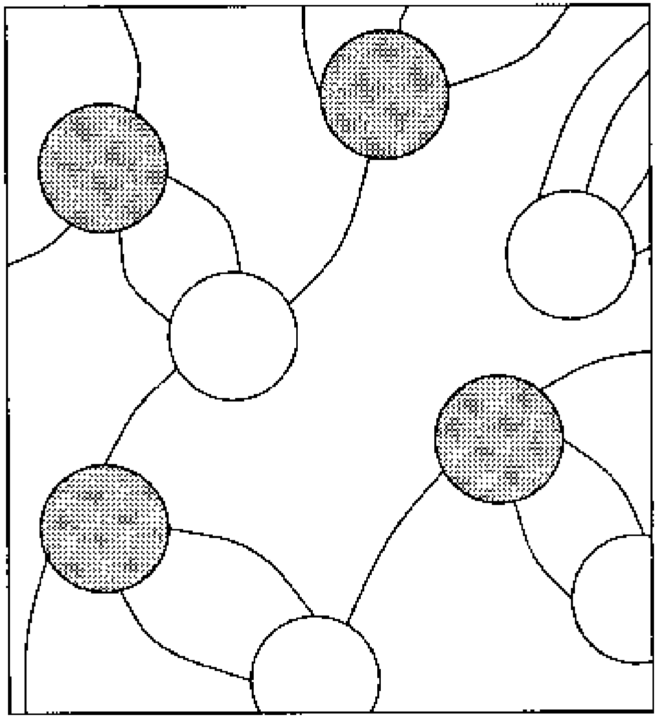
$e^+e^- \to J/\psi\ c\bar{c}$ **only 0^- and 0^+ $\bar{c}c$ observed !**

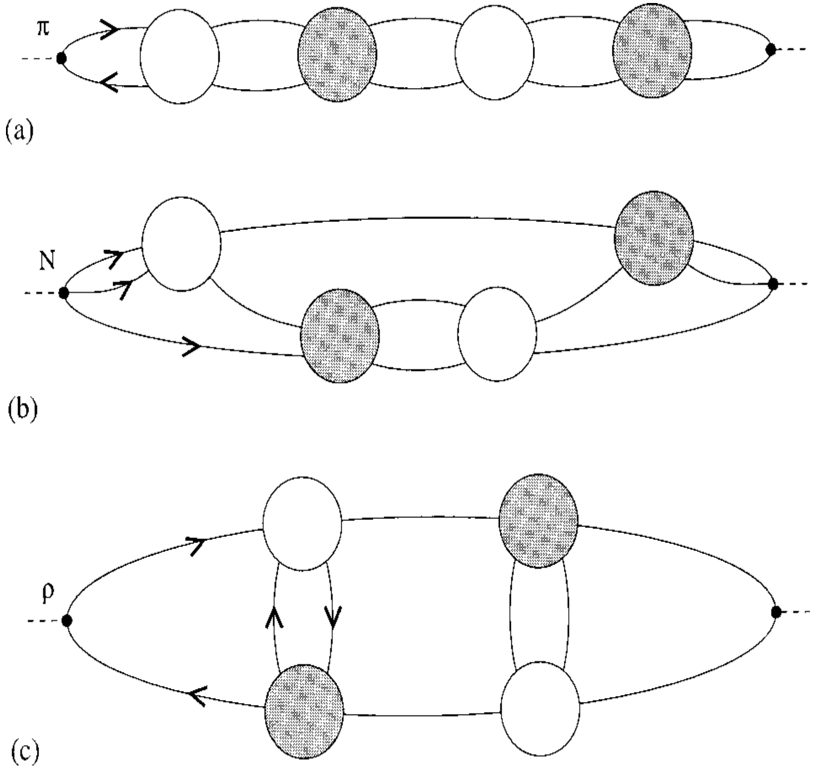


BaBar Collaboration, **Phys.Rev. D72 (2005) 031101**

Phenomenology of instantons in QCD

T. Schafer, E. Shuryak





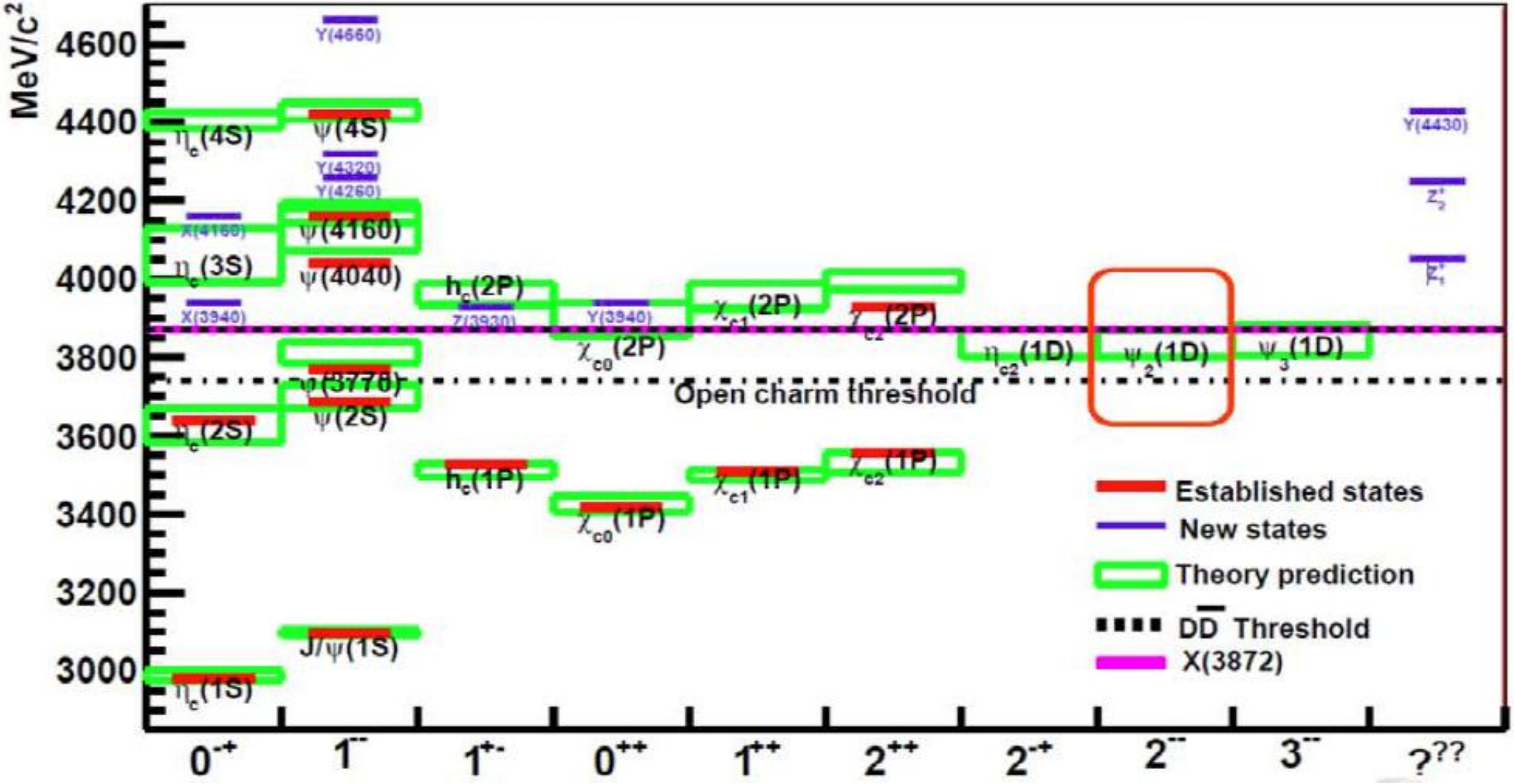
NJL model : **both 0^- & 0^+ important !**

$$\mathcal{L} = i\,\bar{\psi}\partial\!\!\!/\psi + \frac{\lambda}{4}\left[\left(\bar{\psi}\psi\right)\left(\bar{\psi}\psi\right) - \left(\bar{\psi}\gamma^5\psi\right)\left(\bar{\psi}\gamma^5\psi\right)\right] = i\,\bar{\psi}_L\partial\!\!\!/\psi_L + i\,\bar{\psi}_R\partial\!\!\!/\psi_R + \lambda\left(\bar{\psi}_L\psi_R\right)\left(\bar{\psi}_R\psi_L\right).$$

Best playgrounds for unquenched quark models:

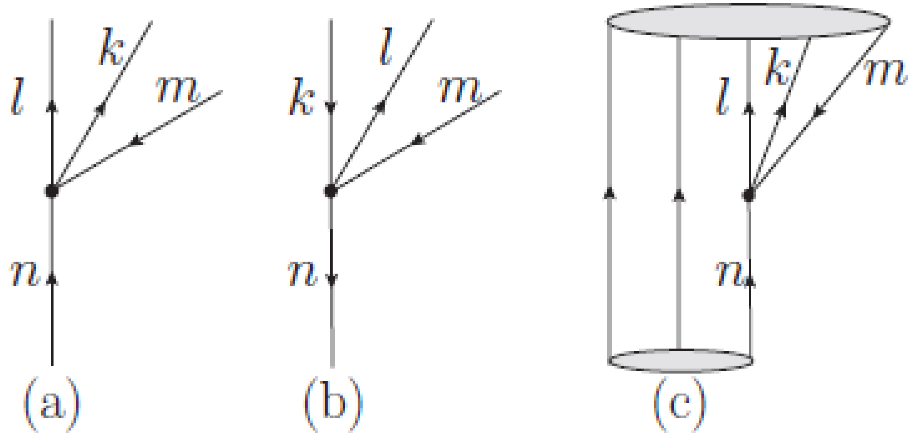
for baryon $sss \rightarrow sss\ \bar{q}q$

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



for baryon sss → sss $\bar{q}q$

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



(a) (b) (c)

$$H_N = H_o + H_{hyp} + \sum_{i=1}^{N} m_i$$

$$H_o = \sum_{i=1}^{N} \frac{\vec{p}_i^{\,2}}{2m_i} + \sum_{i<j}^{N} V_{conf}(r_{ij})$$

$$H_{qq}^{NJL} = \sum_{i<j}^{N} \sum_{a=0}^{8} \hat{g}_{ij}\lambda_i^a\lambda_j^a[1+\frac{1}{4m_im_j}\hat{\sigma}_i\cdot(\vec{p}_i'-\vec{p}_i)\hat{\sigma}_j\cdot(\vec{p}_j'-\vec{p}_j)]$$

from $\mathcal{L}_{NJL} = \frac{1}{2}g_s\sum_{a=0}^{8}[(\bar{q}\lambda^a q)^2 + (\bar{q}i\lambda^a\gamma_5 q)^2]$

Predictions for the lowest Ω* by various models:

Ω*(x/2^-) as sss (L=1) : ~ 2020 MeV

Chao, Isgur, Karl, PRD38(1981)155

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

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

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

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

Ω*(3/2^-) as sss - $\bar{u}$ussss 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 = $(5 \pm 2) \times 10^{-5}$

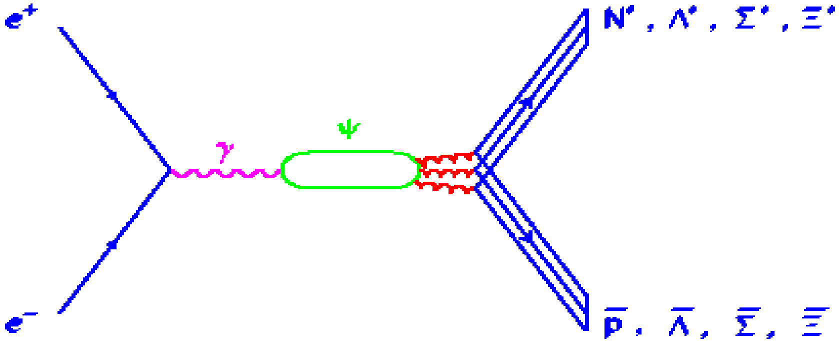
M. Ablikim et al. (BESII Coll.), CPC36(2012)1040

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

→ excitation mechanism for sss states

$\bar{c}c$ decays -- a important new source for baryons

$$\psi \to \bar{B}BM \Rightarrow N^*, \Lambda^*, \Sigma^*, \Xi^*, \Omega^*$$



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

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

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

3/7 new N* from PDG92 to PDG14 are from BESII & BESIII

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 [us]{ds} $\bar{s}$
  →$\Lambda\eta$ Liu&Xie, PRC86(2012)055202

- **Both $^1S_0$ and $^3P_0$ are important for non-perturbtive $\bar{q}q$ pair production from gluon field**

- **Distinguishable prediction for hyperon spectroscopy is yelling for experimental confirmation :**
  Very important to find the lowest Ω^* ($1/2^-$or $3/2^-$)
  at BES3 or super τ-charm

Many more interesting channels at super τ-charm :

$\bar{\Omega}\ \Xi\ \bar{K}$, $\bar{\Xi}\,\Xi\pi$, $\bar{\Lambda}\Lambda\gamma$, $\bar{\Sigma}\Lambda\gamma$, $\bar{\Sigma}\Sigma\gamma$, $\bar{\Xi}\,\Xi\gamma$, ...

with $\Omega \rightarrow \Lambda K$, $\Xi \rightarrow \Lambda\pi$

S.Dulat, J.J.Wu, B.S.Zou, PRD83 (2011) 094032
"Proposal and theoretical formalism for studying baryon radiative decays from $J/\psi \rightarrow \bar{B}B^* + \bar{B}^*B \rightarrow \bar{B}B\gamma$".

JLAB : $N^*, \Delta^* \rightarrow \gamma N$

Super τ -c: $\Lambda^* \rightarrow \gamma\Lambda, \gamma\Sigma$; $\Sigma^* \rightarrow \gamma\Lambda, \gamma\Sigma$; $\Xi^* \rightarrow \gamma\Xi$; $\Omega^* \rightarrow \gamma\,\Omega$!

Thanks !