Study of Baryon Resonances from Charmonium Decays

Bing-Song Zou

Institute of Theoretical Physics and

Institute of High Energy Physics, CAS, Beijing

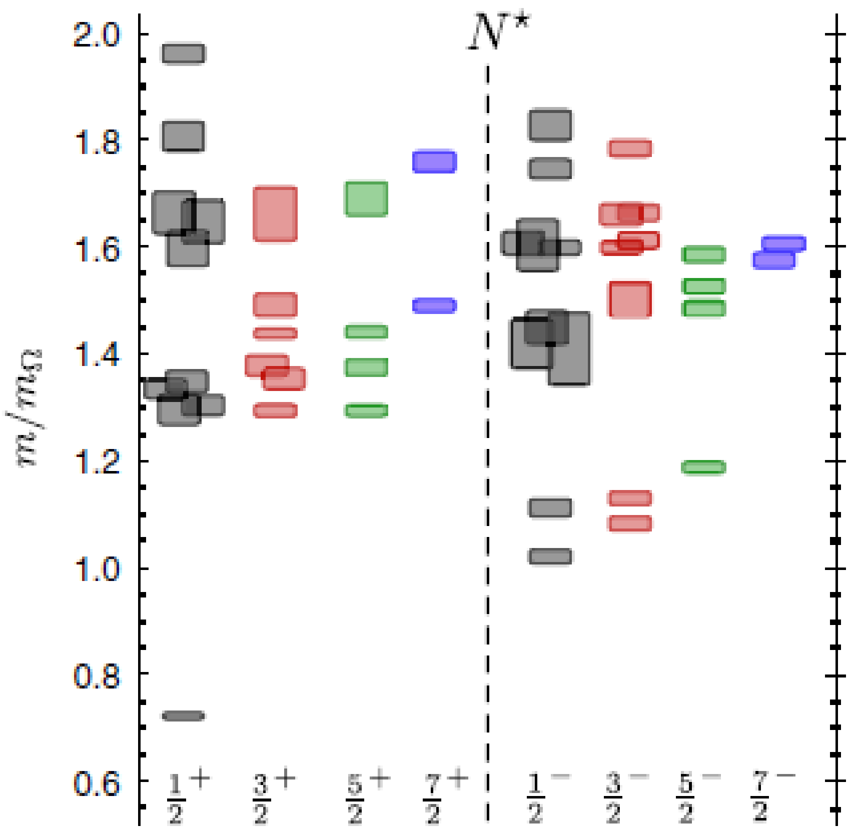
Outline:

- Quenched & unquenched quark models
- Important results on N* from $\bar{c}c$ decays
- Hyperon production and prospects

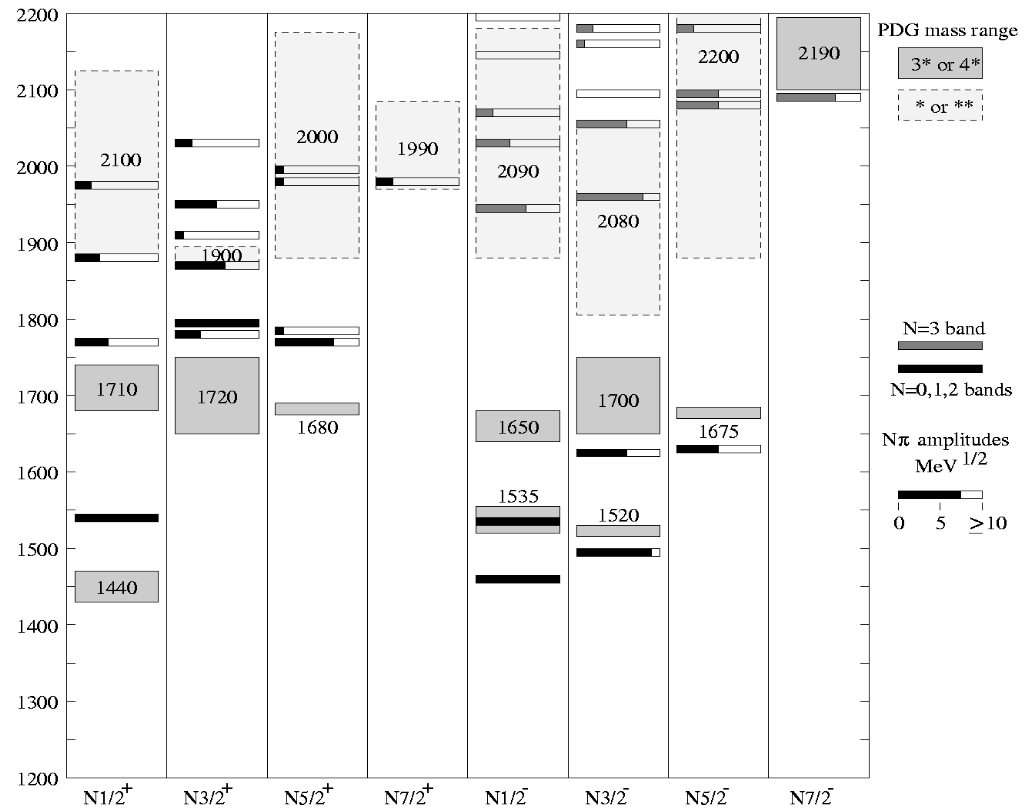
1. Quenched & unquenched quark models

Problems for quenched q^3 picture for baryon resonances:

1) "Missing resonances" ; 2) mass ordering for the lowest ones



Lattice, R.Edwards et al, PRD84(2011)074508



q^3 model, Capstck&Roberts, PPNP45(2000)S241

$1/2^-$ 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 $g_{N^*N\eta}$**

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

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

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

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

$\pi^- p \to n\phi$ & $pp \to pp\phi$ & $pn \to d\phi \to$ 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)

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 ?

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

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

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

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

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

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

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

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 + …

Draging out $\bar{q}q$ from gluon field –
an important excitation mechanism for hadrons !
multiquark components are important for hadrons !

Totally different predictions for the lowest Ξ^* & Ω^* :

	$\bar{q}q^4$ (L=0)	q^3 (L=1)
Ξ^* ($1/2^-$)	[us][ds] $\bar{d}$ ~ 1540 MeV	uss ~ 1800 MeV
Ω^*($1/2^-$)	[us] ss $\bar{u}$ ~ 1840 MeV	sss ~ 2000 MeV
	Yuan-An-Wei-Zou-Xu, PRC87(2013)025205	Capstick-Isgur, PRD34(1986)2809

$q^3 - \bar{q}q^4$ mixing : $\bar{q}q$ production mechanism

$^3P_0$ or instanton ($^1S_0 + {}^3P_0 + \ldots$)

Ω^*($3/2^-$) ~ 1750 MeV

An-Metsch-Zou, : arXiv:1304.6046

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, …

Σ* ~ 1430 MeV **Oller, Meissner, Oh, Khemchandani, ...**

Ξ* ~ 1610 MeV **Oh, Ramos, Oset, …**

Σ^* in PDG: **** Σ (1189)$1/2^+$ Σ^*(1385)$3/2^+$ Σ^*(1670)$3/2^-$
Σ^*(1775)$5/2^-$ Σ^*(1915)$5/2^+$ Σ^*(2030)$7/2^+$

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

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

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

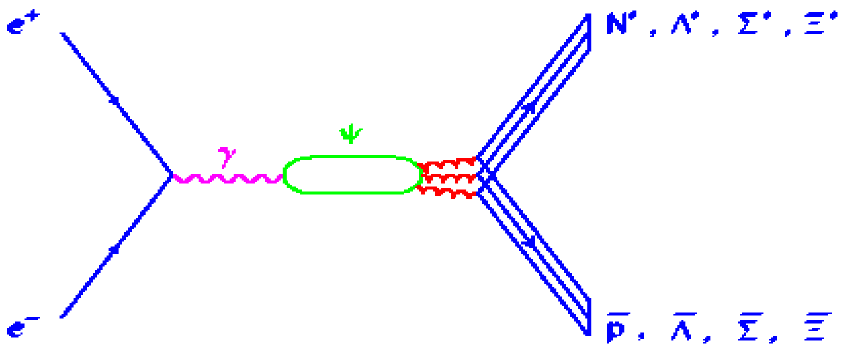
Ξ^* in PDG: **** Ξ(1320) $1/2^+$, Ξ(1530) $3/2^+$
*** Ξ(1690) , Ξ(1820) $3/2^-$, Ξ(1950) , Ξ(2030)
** Ξ(2250) , Ξ(2370)
* Ξ(1620) , Ξ(2120) , Ξ(2500)

Ω^* in PDG: Ω(1672) $3/2^+$ **** , Ω (2250)***, Ω (2380) **, Ω (2470) **

Experiment knowledge on hyperon states still very poor !

2. Important results on N* from $\bar{c}c$ decays

$$J/\Psi \rightarrow \bar{B}BM \Rightarrow N^*, \Lambda^*, \Sigma^*, \Xi^*$$



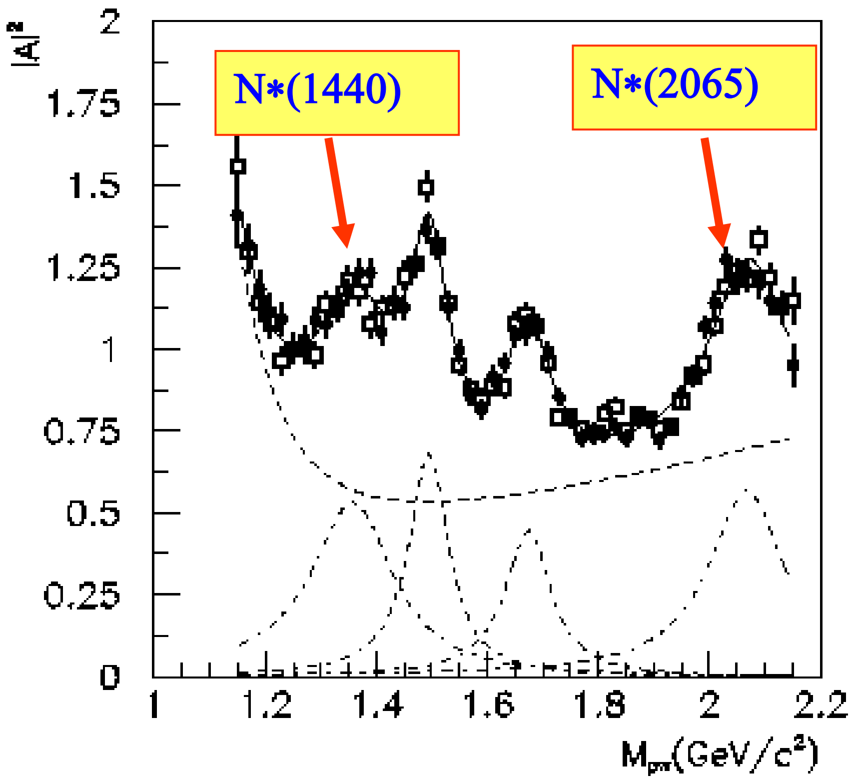
an ideal isospin and low spin filter from $\bar{c}c$ annihilation

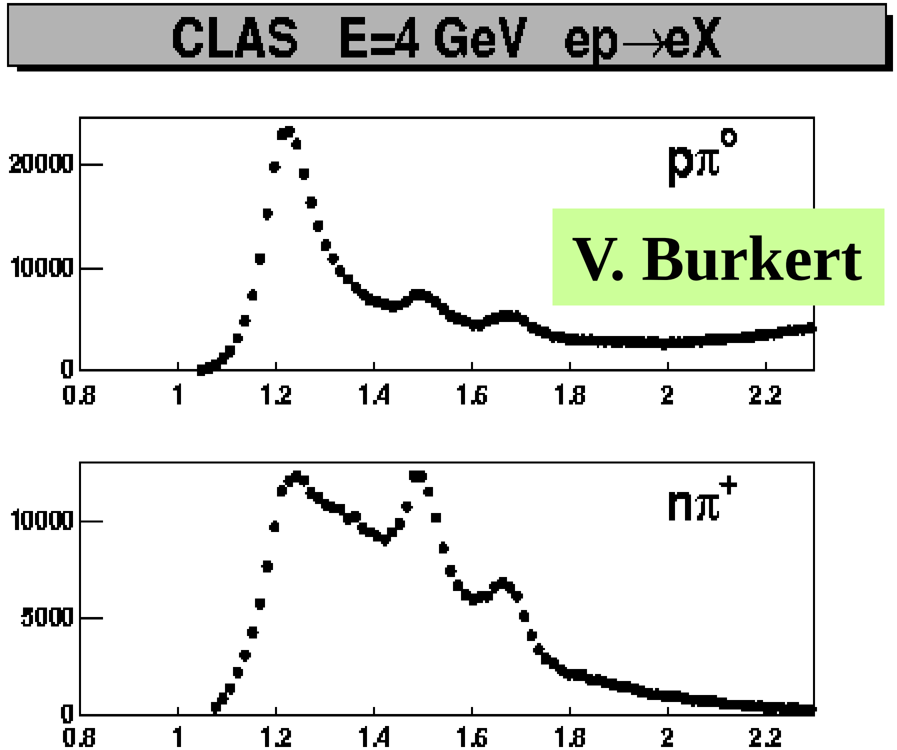
No contamination from t/u-channel scattering as in πN and γN

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

(1) Observation of "missing" N* above 2 GeV with low spin

$J/\psi \rightarrow \bar{p} n \pi^+$ & $\bar{n} \pi^- p$ BESII Collaboration, PRL97 (2006)062001





The first experiment "seeing" N*(1440) in πN mass spectrum

BESII	$M = 1358 \pm 17$,	$\Gamma = 179 \pm 56$	MeV
PDG06	$M = 1365 \pm 15$,	$\Gamma = 190 \pm 30$	MeV

The new N*(2065) peak in πN mass spectrum

$$M = 2068 \pm 3 ^{+15}_{-40}\ \mathrm{MeV/c^2},\ \Gamma = 165 \pm 14 \pm 40\ \mathrm{MeV/c^2}$$

$J/\psi \rightarrow \bar{n}$ N*(2065) with L=0 (small excess energy)

limits its J^P to be $3/2^+$ or $1/2^+$ (spin filter)

PWA of $J/\psi \rightarrow \bar{p}p\pi^0 \rightarrow$ N*(2040) $3/2^+$ & N*(2100)$1/2^+$

BESII, PRD80(2009)052004

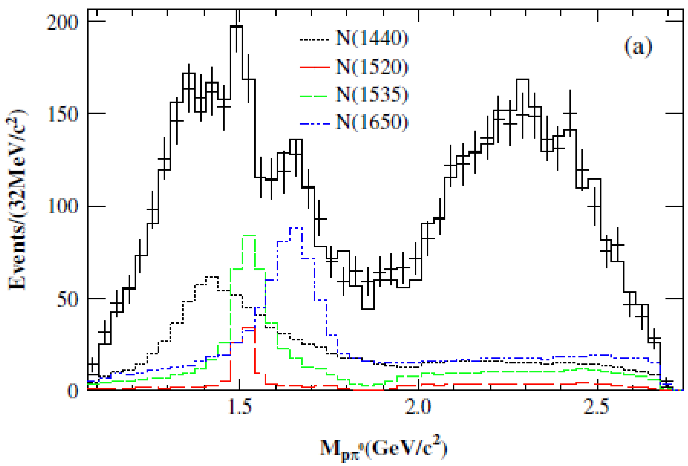
New N*(2040) $3/2^+$ also needed in η' production

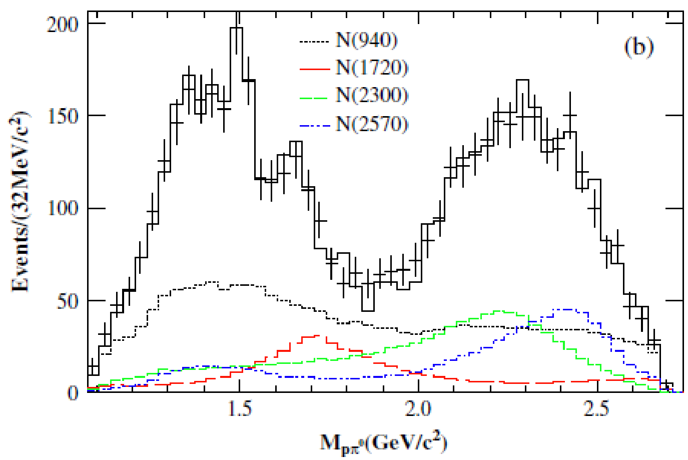
Huang-Haberzettl-Nakayama, PRC87 (2013) 054004

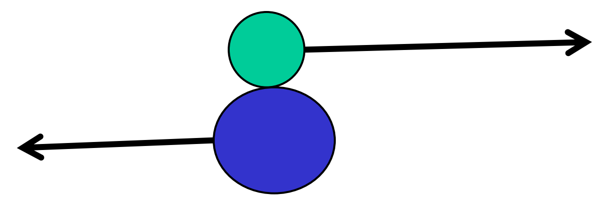
Observation of Two New N^* Resonances in the Decay $\psi(3686) \to p\bar{p}\pi^0$

BESIII, PRL110(2013)022001

N*(2300)1/2⁺ , N*(2570)5/2⁻   cf talks by Liang & Yuan







For πN scattering at 2.2 GeV,

L= r × p = 1 fm × 900 MeV=4.5

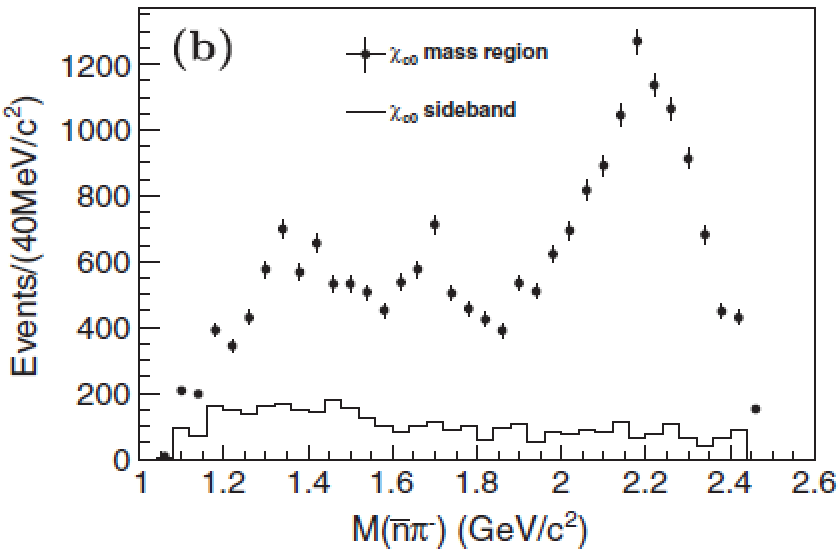
J = 7/2 or 9/2

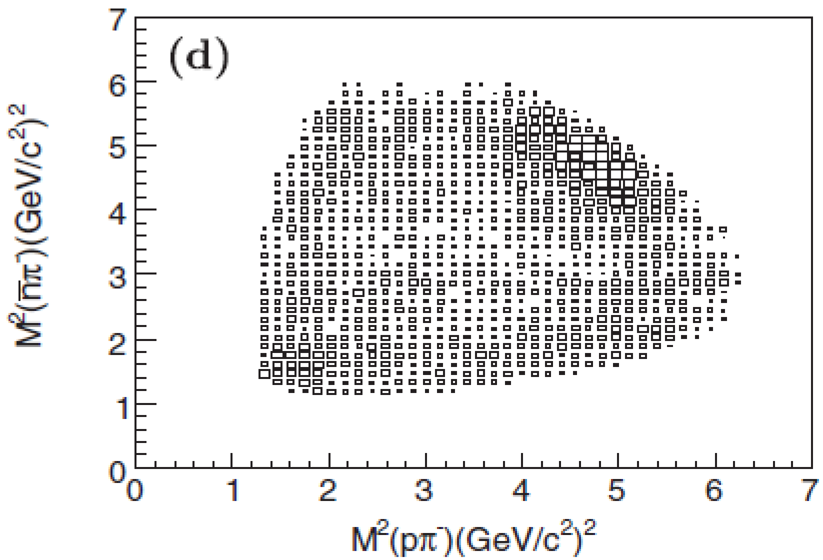
For $\bar{c}c \to \bar{N}N^*(2300)$,

L= r × p = 0.3fm × 400 MeV=1

J ≦ 5/2

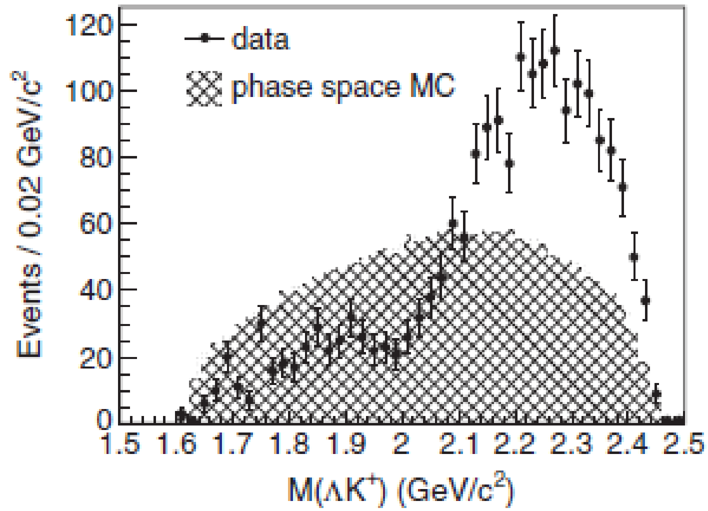
$\chi_{c0} \to \bar{p} n \pi^+$

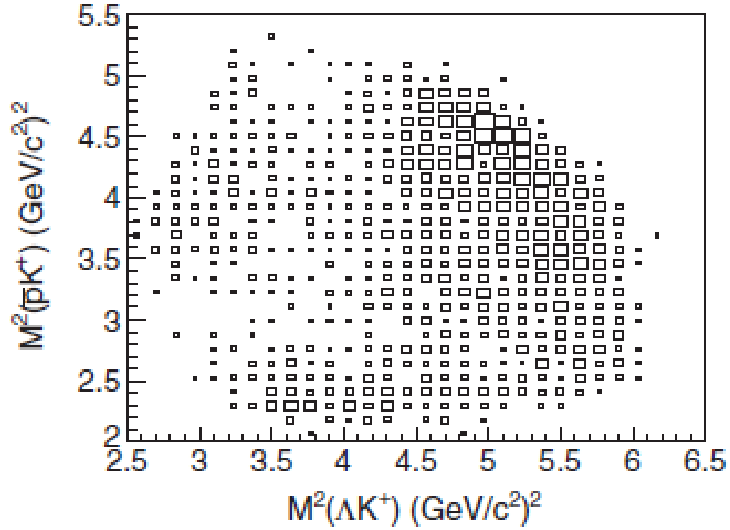




BESIII, PRD86(2012)052011

$\chi_{c0} \to \bar{p} K^+ \Lambda$

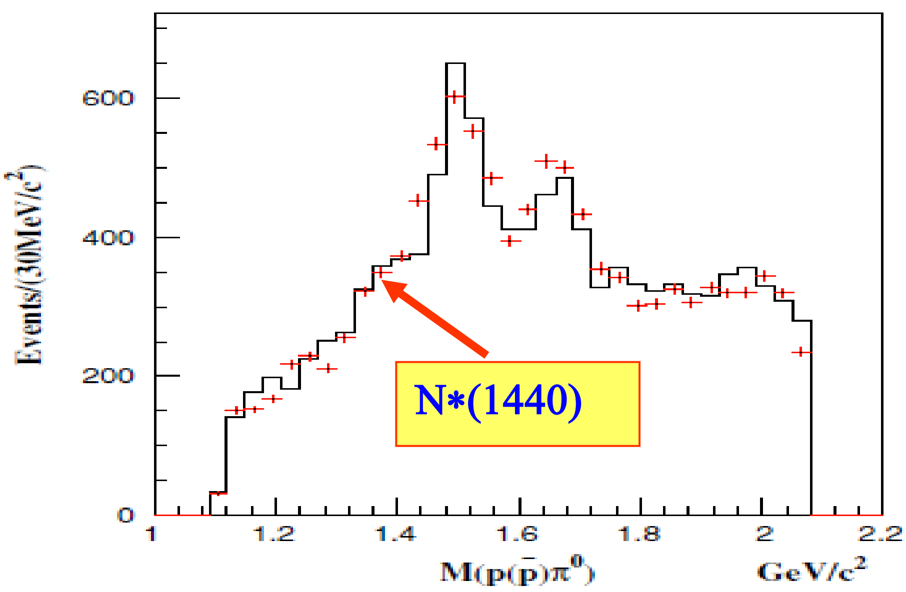




BESIII, PRD87(2013)012007

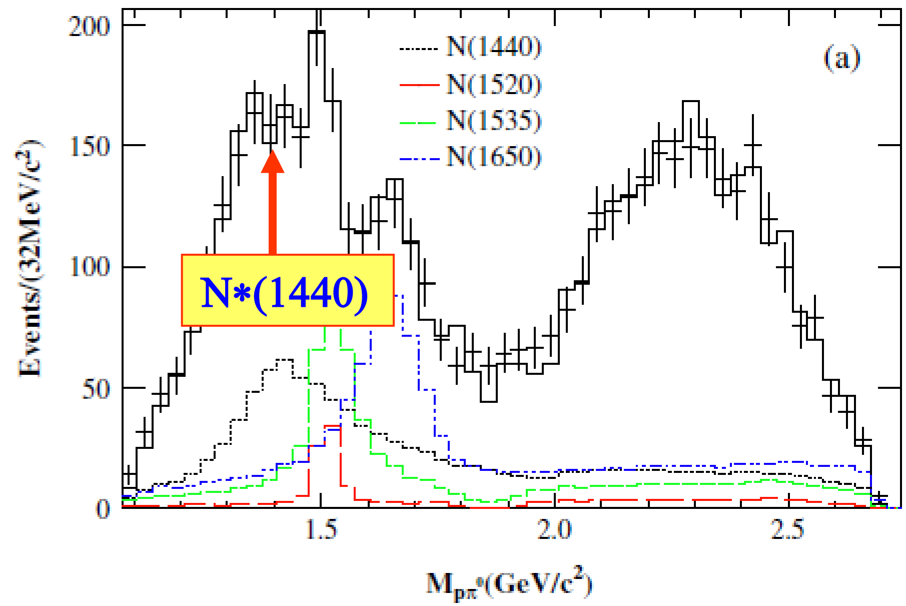
(2) N*(1440) production from J/ψ and ψ' decays

$J/\psi \rightarrow \bar{p}p\pi^0$



BESII, PRD80(2009)052004

$\psi' \rightarrow \bar{p}p\pi^0$



BESIII, PRL110(2013)022001

$$Q_{\bar{p}p\pi} = \frac{B(\psi(2S) \rightarrow \bar{p}p\pi)}{B(J/\psi \rightarrow \bar{p}p\pi)} = (12.4 \pm 1.5)\%$$

N*(1440) is much favored in ψ' decays !

Common features of ψ' and N*(1440)

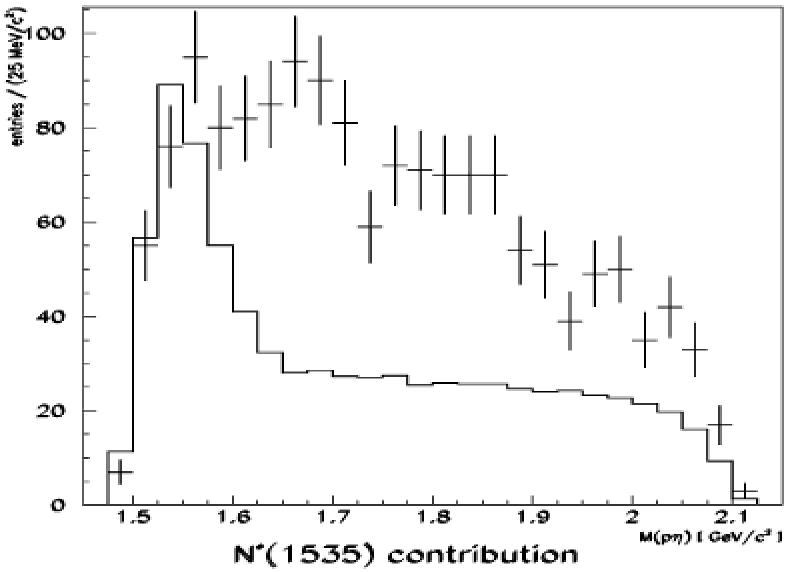
"Radial" excitation of J/ψ and N
Large coupling to σJ/ψ and σN

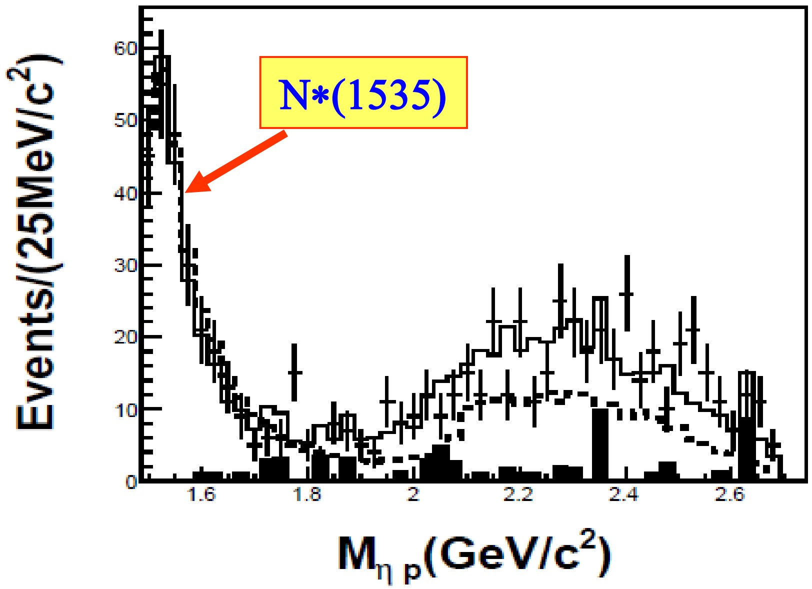
"Radial" excitations like to pull out $\bar{q}^2 q^2$ (0^+) from sea, hence favor transition between each other

N*(1440) has large 7-quark (σN) components !

Also a possible reason for $\rho\pi$ puzzle of ψ decays

$J/\psi \to \bar{p}p\eta$ ## $\psi' \to \bar{p}p\eta$





BESI, PLB510 (2001) 75

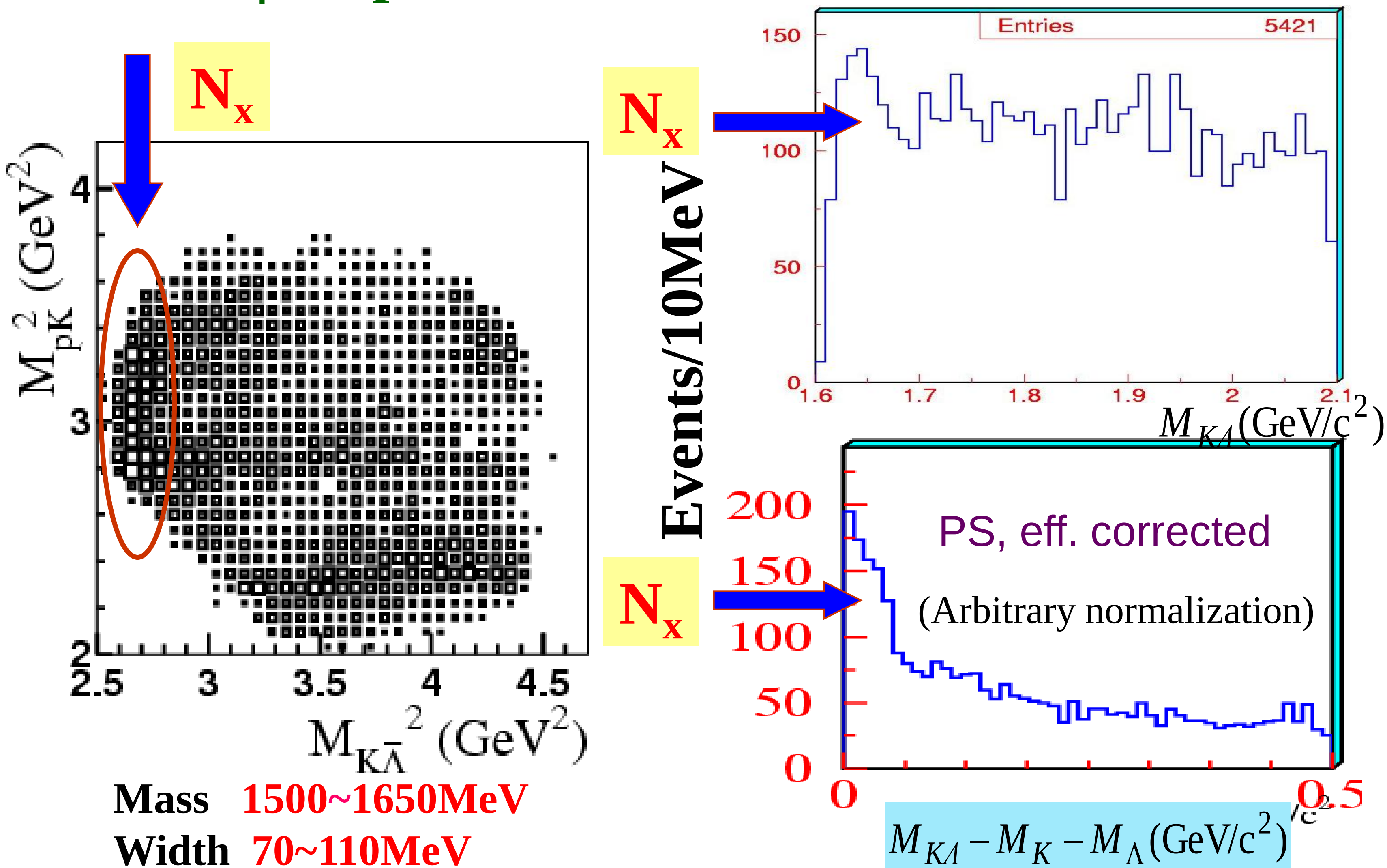
BESIII, arXiv:1304.1973

$$Q_{p\bar{p}\eta} = \frac{B(\psi(2S) \to \eta p\bar{p})}{B(J/\psi \to \eta p\bar{p})} = (3.2 \pm 0.4)\%$$

N*(1535) is suppressed in ψ' decays

(3) N* and Λ* observed in J/ψ → $\bar{\Lambda}$ K N

N* in J/ψ → p K^- $\bar{\Lambda}$ + c.c.



Mass 1500~1650MeV

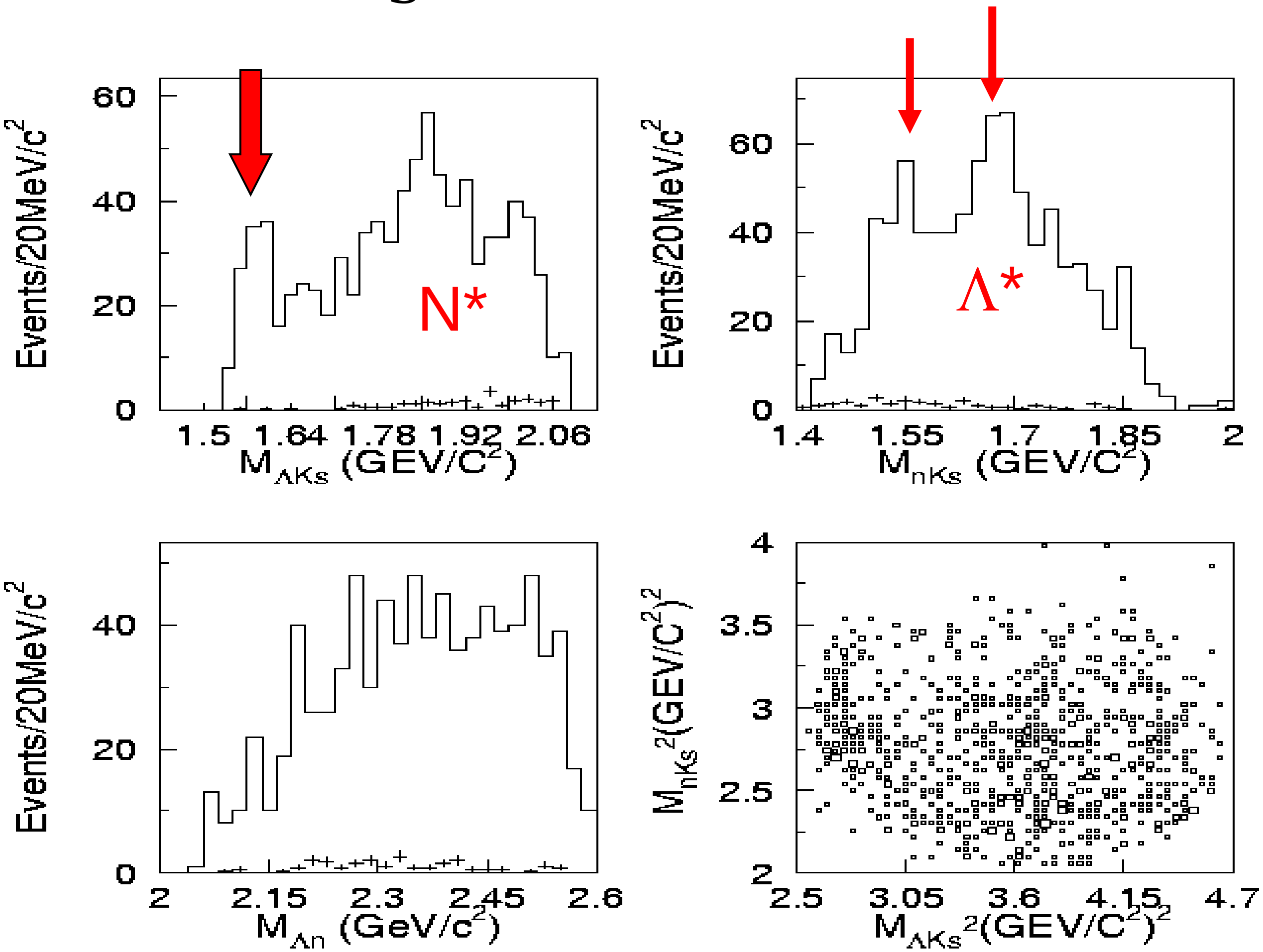
Width 70~110MeV

J^P favors 1/2-

H.X.Yang, BES, IJMPA20 (2005) 1985

$J/\psi \to nK_S^0\overline{\Lambda}$

Phys. Lett. B659 (2008) 789



- **An enhancement near ΛK_S threshold is evident**
- **N* and Λ* found in the ΛK_S and nK_S spectrum**

a) Assuming N_x to be purely N*(1535) :

B.C. Liu, B.S. Zou, PRL96 (2006) 042002; PRL98 (2007) 039102

From relative branching ratios of

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

$$g_{N^*K\Lambda}/g_{N^*p\eta}/g_{N^*N\pi} \sim 2:2:1$$

b) N_x as dynamical generated with unitary chiral theory:

N*(1535) + non-resonant part

L.S.Geng, E.Oset, B.S. Zou, M.Doring, PRC79 (2009) 025203

$$g_{N^*K\Lambda}/g_{N^*p\eta}/g_{N^*N\pi} \sim 1.2:2:1$$

Phenomenology : Large $g_{N^*K\Lambda}$ → large $\bar{s}s$ in N*(1535)

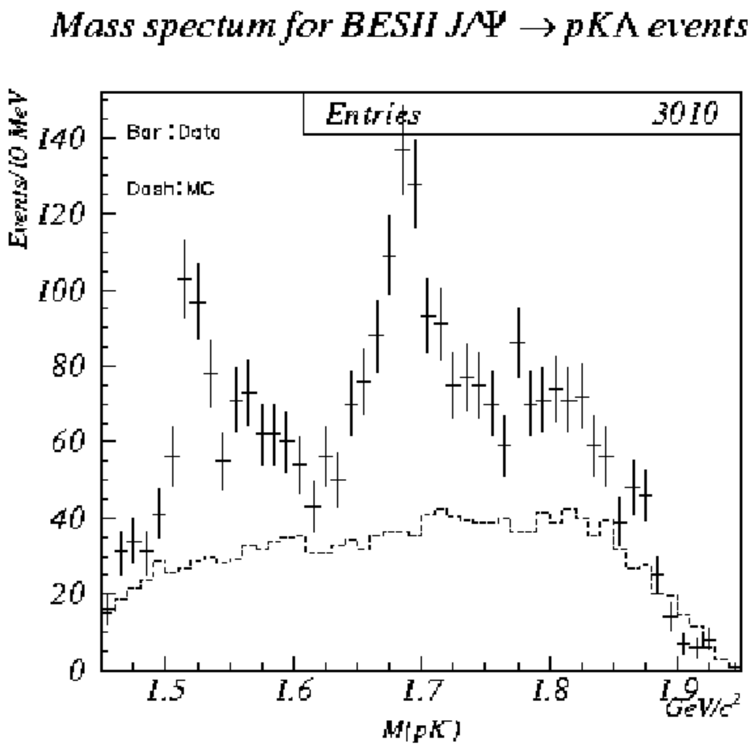
$\bar{s}$[su][ud] or $K\Lambda$-$K\Sigma$ state

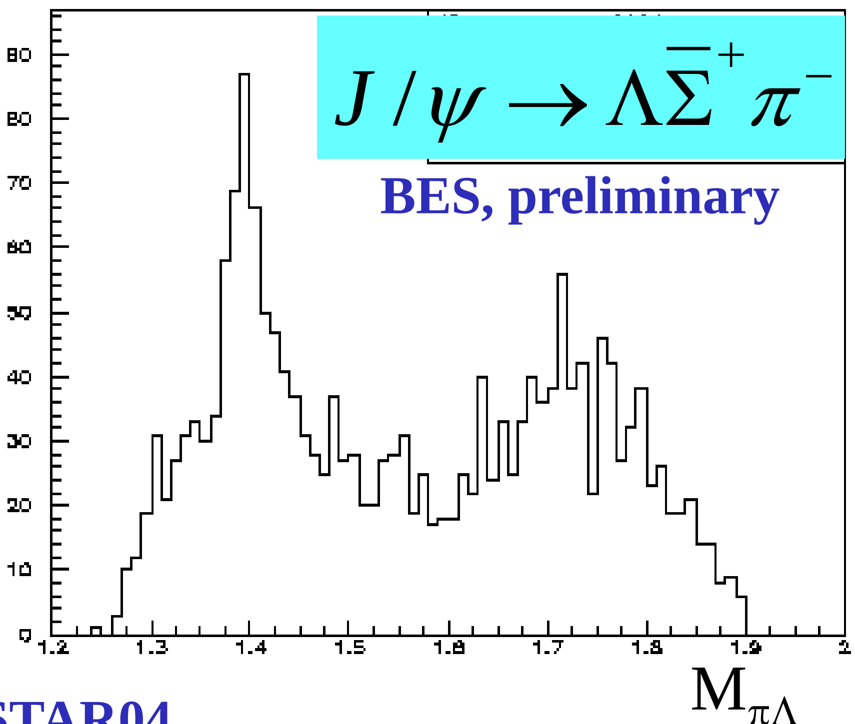
3. Hyperon production and Prospects

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

Σ^* [us][du] $\bar{d}$ ~ 1380 MeV

Ξ^* [us][ds] $\bar{u}$ ~ 1540 MeV





BES, NSTAR04

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
$\bar{\Sigma}^-\,\Sigma(1380)^+$		?	
$\bar{\Xi}^+\,\Xi(1540)^-$		?	

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

Many more interesting channels:

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

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

BESIII: $\Lambda^* \rightarrow \gamma\Lambda, \gamma\Sigma$; $\Sigma^* \rightarrow \gamma\Lambda, \gamma\Sigma$; $\Xi^* \rightarrow \gamma\Xi$!

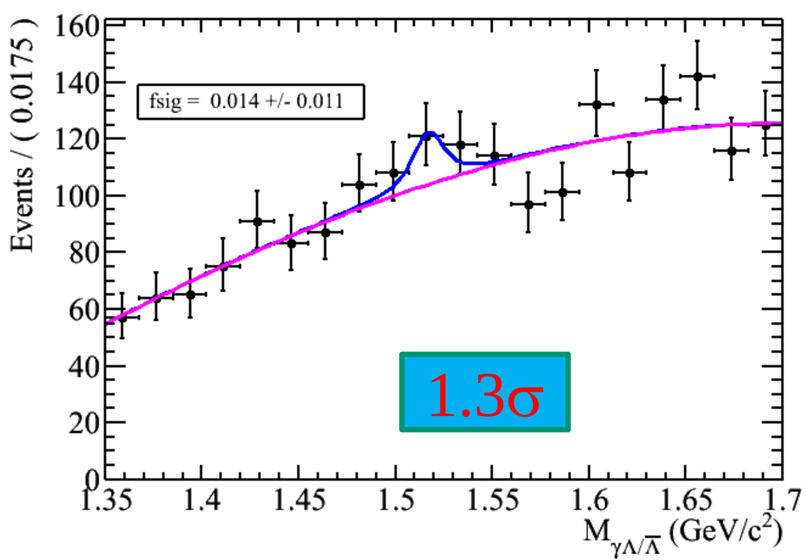
Theory and experiment results for **Λ(1520)** radiative decay

Experiment	$\Gamma(\Lambda(1520) \to \gamma\Lambda)$ (keV)	Model	$\Gamma(\Lambda(1520) \to \gamma\Lambda)$ (keV)
Phys. Rev. Lett. 21, 1715 (1968)	**134±23**	**NRQM**	156
Nucl. Phys. B279, 49 (1987)	**33±11**	**RCQM**	215
Phys. Lett. B604, 22(2004)	**159±33**	**χQM**	85
Phys.Rev.C71, 054609(2005)	**167±43**	**MIT bag**	46
		Chiral bag	32
		Algebraic model	85.1

S.L.Zhu

BESIII: $J/\psi \to \gamma\Lambda\bar{\Lambda}$

PRD 86 (2012) 032008



J/Ψ decay branching ratios (BR$\times 10^3$) for some interested channels

$p\bar{p}$	$\Lambda\bar{\Lambda}$	$\Sigma^0\bar{\Sigma}^0$	$\Xi\bar{\Xi}$	$\Lambda\bar{\Sigma}^-\pi^+$	$pK^-\bar{\Lambda}$	$pK^-\bar{\Sigma}^0$
2.1 ± 0.1	1.4 ± 0.1	1.3 ± 0.2	1.8 ± 0.4	1.1 ± 0.1	0.9 ± 0.2	0.3 ± 0.1
$p\bar{n}\pi^-$	$p\bar{p}\pi^0$	$p\bar{p}\pi^+\pi^-$	$p\bar{p}\eta$	$p\bar{p}\eta'$	$p\bar{p}\omega$	$K^-\Lambda\bar{\Xi}^+$?
2.0 ± 0.1	1.1 ± 0.1	6.0 ± 0.5	2.1 ± 0.2	0.9 ± 0.4	1.3 ± 0.3	$K^+\bar{\Lambda}\Xi^-$?

BESII, CPC36(2012)1040 : **BR ($\psi' \rightarrow \bar{\Omega}\Omega$) = $(5 \pm 2) \times 10^{-5}$**

super τ-c 10^{12} J/**Ψ** & 10^{11} **Ψ'**

⬇

Completing N*, Λ*, Σ*, Ξ* spectra

Establish the lowest Λ*, Σ*, Ξ* and Ω* !

⬇

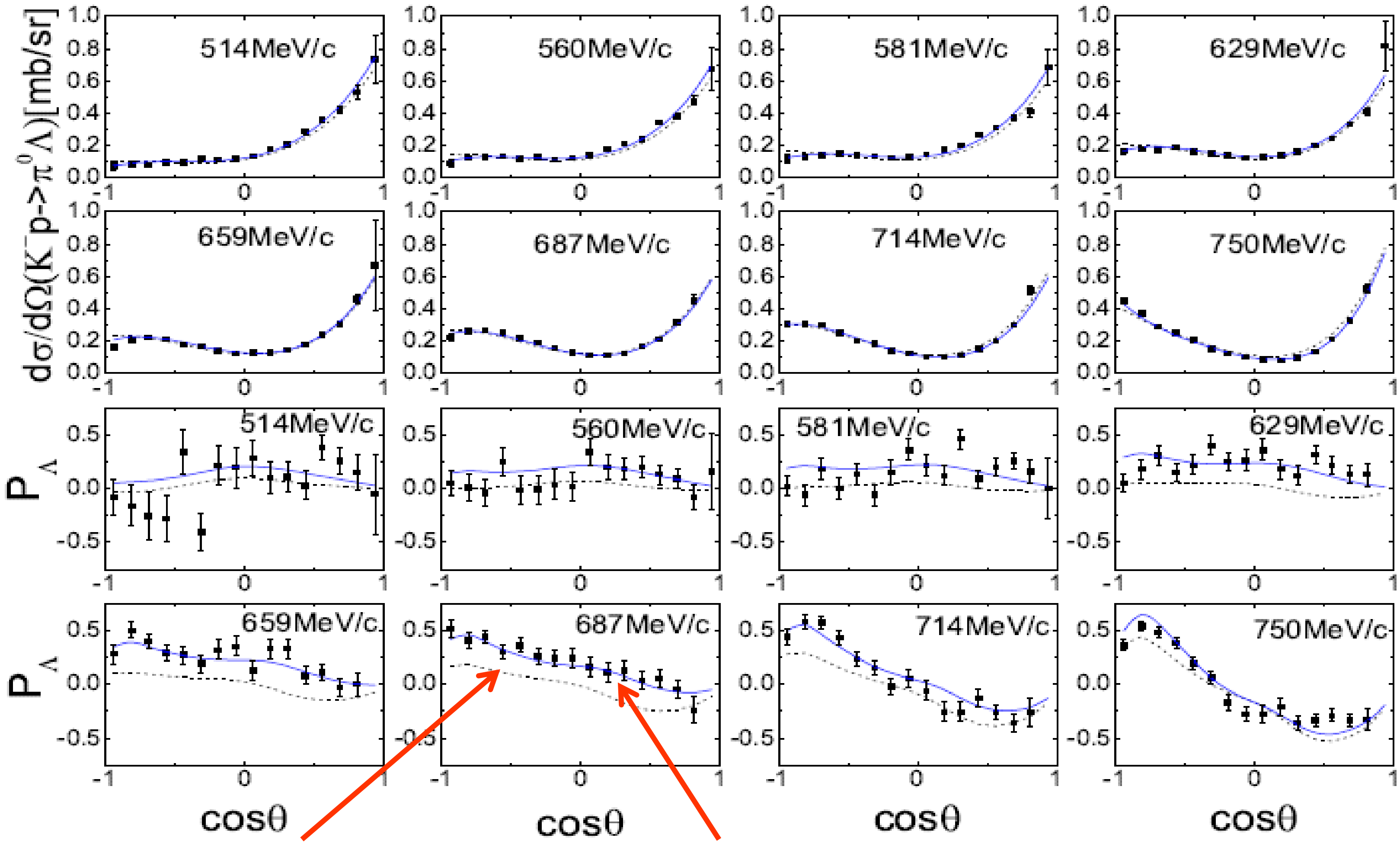
Excitation mechanism of baryonic states

Thanks !

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

PRC 80(2009)025204

Puze Gao, Jun Shi, B. S. Zou, Phys. Rev. C86 (2012) 025201



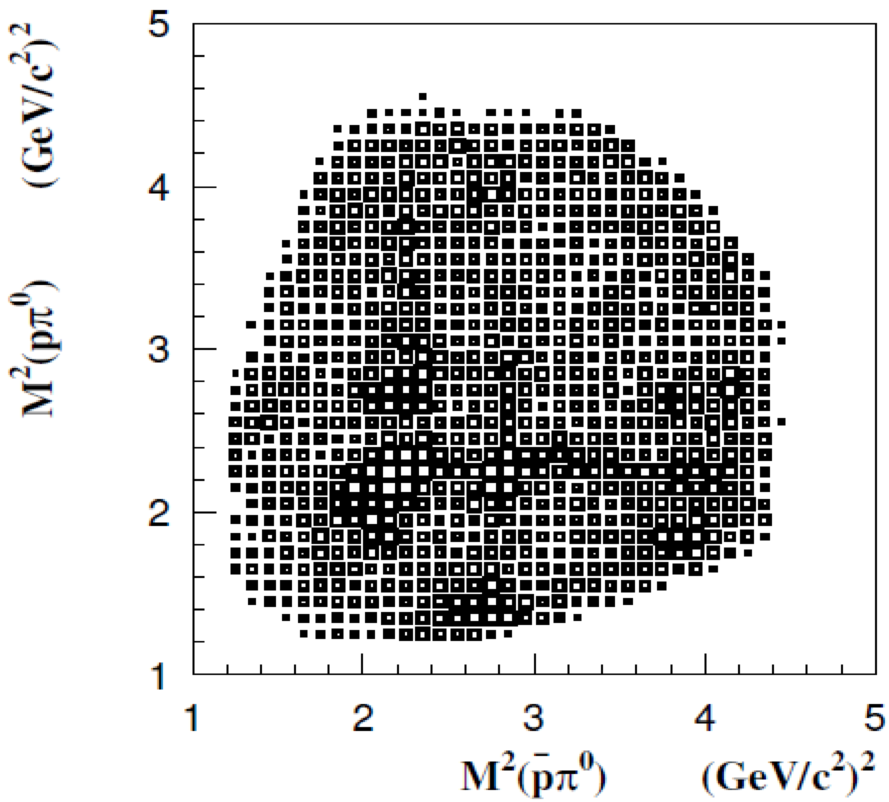
with basic ingredients

adding $\Sigma(1635)\ 1/2^+$

No $\Sigma(1620)\ 1/2^-$

Polarization data – crucial for clarifying ambiguities !

$J/\psi \to p\bar{p}\pi^0$



$\psi(3686) \to p\bar{p}\pi^0$