

# **Structure of nucleon resonances from BES & world data**

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# **Outline:**

- **Introduction**
- **N\*(1440)**
- **N\*(1535)**
- **Prospects**

# 1. Introduction

**A well-known problem for classical qqq models:**

**Mass order reverse problem for the lowest excited baryons**

**uud ( $L=1$ )  $\frac{1}{2}^- \sim N^*(1535)$       should be the lowest**

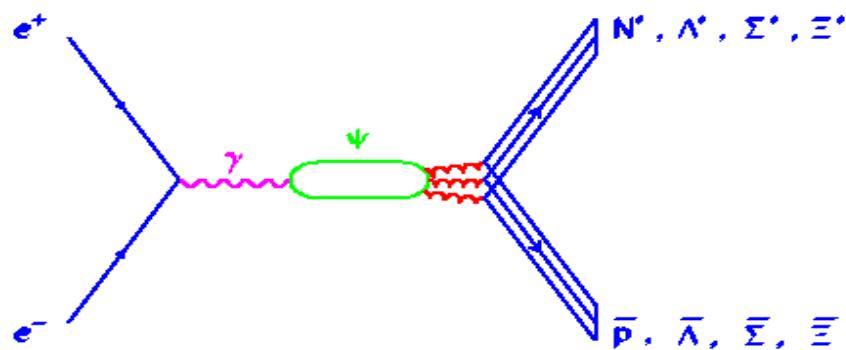
**uud ( $n=1$ )  $\frac{1}{2}^+ \sim N^*(1440)$**

**uds ( $L=1$ )  $\frac{1}{2}^- \sim \Lambda^*(1405)$**

**harmonic oscillator (  $2n + L + 3/2$  )  $h\omega$**

# BES experiments on $\bar{c}c$ decays

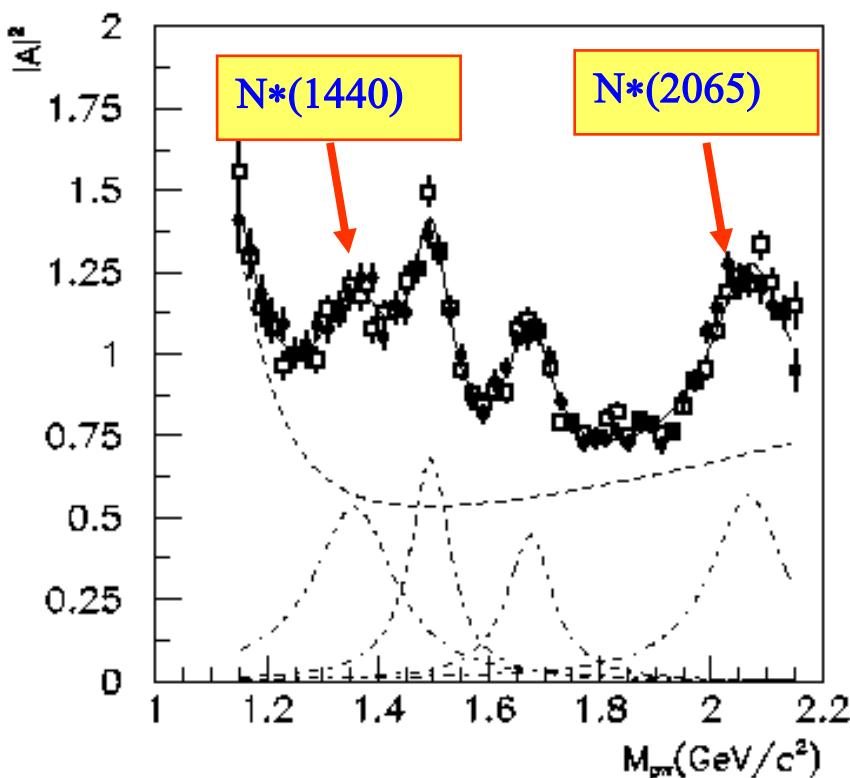
$$J/\Psi \rightarrow \bar{B}BM \Rightarrow N^*, \Lambda^*, \Sigma^*, \Xi^*$$



New mechanism for baryon production & an ideal isospin filter  
No contamination from t/u-channel scattering as in  $\pi N$  and  $\gamma N$   
high statistics extension to  $\psi', \chi_{cJ}, \eta_c$

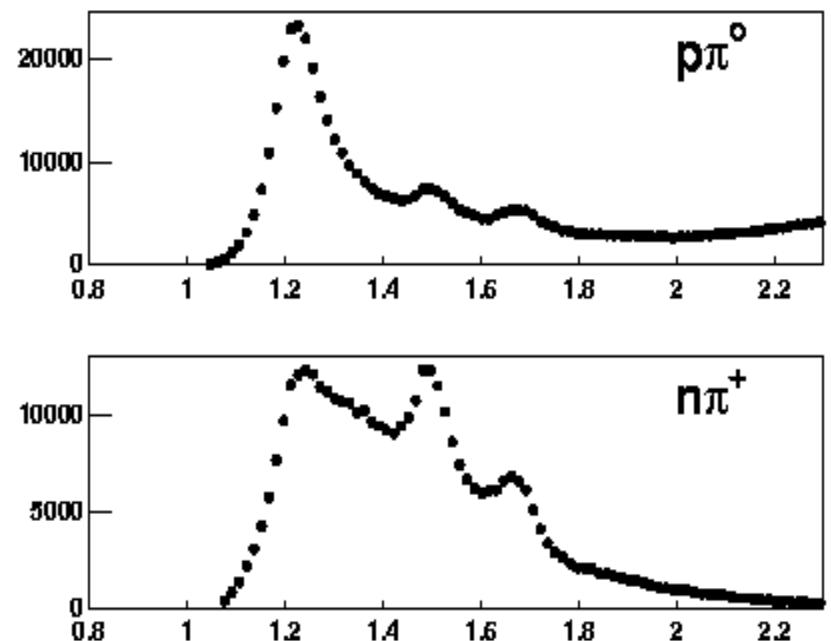
## 2. $N^*(1440)$

$J/\psi \rightarrow \bar{p}n\pi^+ \text{ & } \bar{n}\pi^-p$



V. Burkert

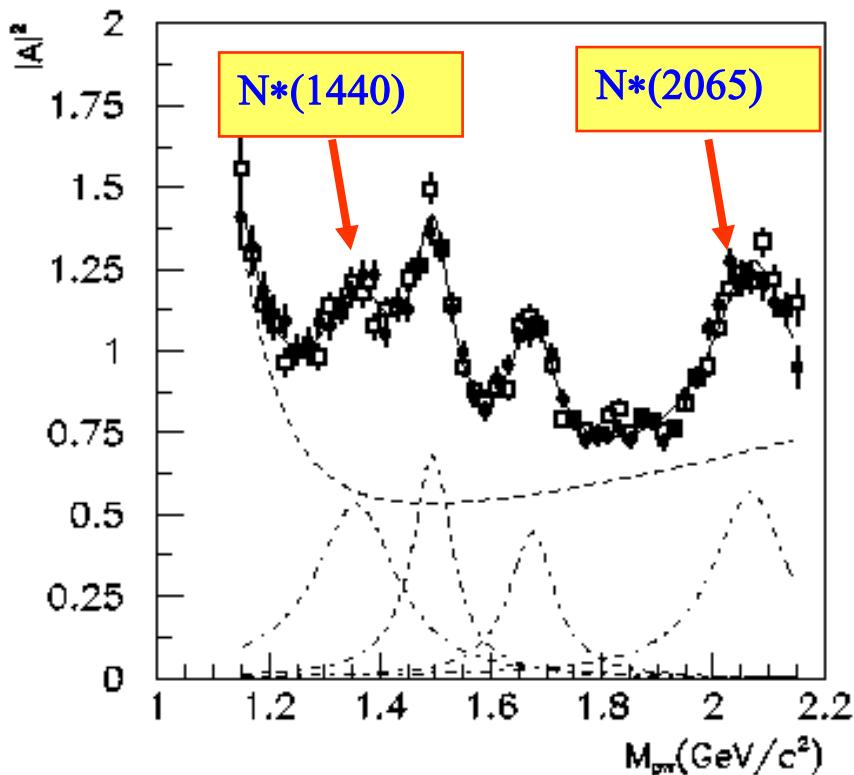
CLAS E=4 GeV ep → eX



Observation of two new  $N^*$  peaks in  $\pi N$  mass spectrum

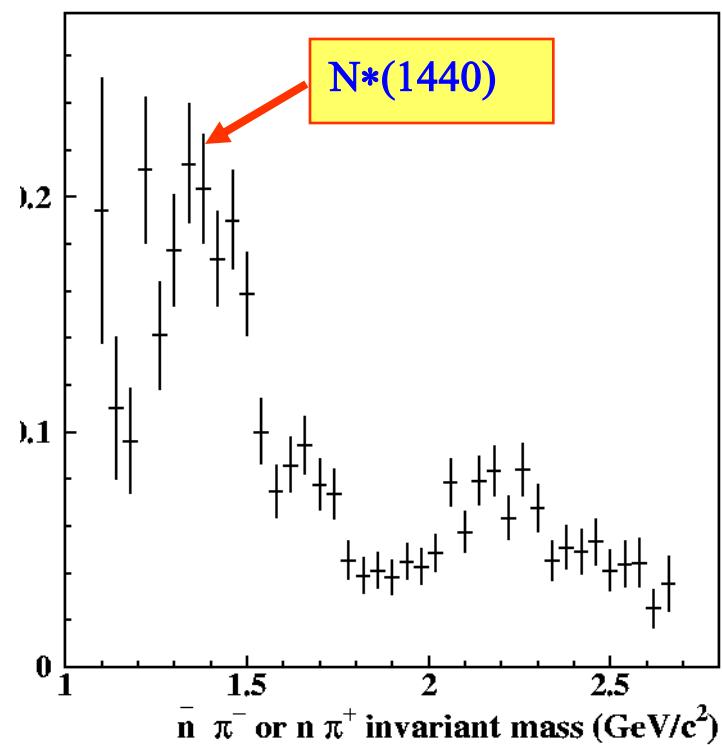
BES, Phys.Rev.Lett.97(2006)062001

$J/\psi \rightarrow \bar{p}n\pi^+ \text{ & } \bar{n}\pi^-p$



BES, PRL97(2006)062001

$\psi' \rightarrow \bar{p}n\pi^+ \text{ & } \bar{n}\pi^-p$



BES, PRD74(2006)012004

**$N^*(1440)$  is much favored in  $\psi'$  decays !**

## Common features of $\psi'$ and $N^*(1440)$

“Radial” excitation of  $J/\psi$  and  $N$   
Large coupling to  $\sigma J/\psi$  and  $\sigma N$



“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 components !

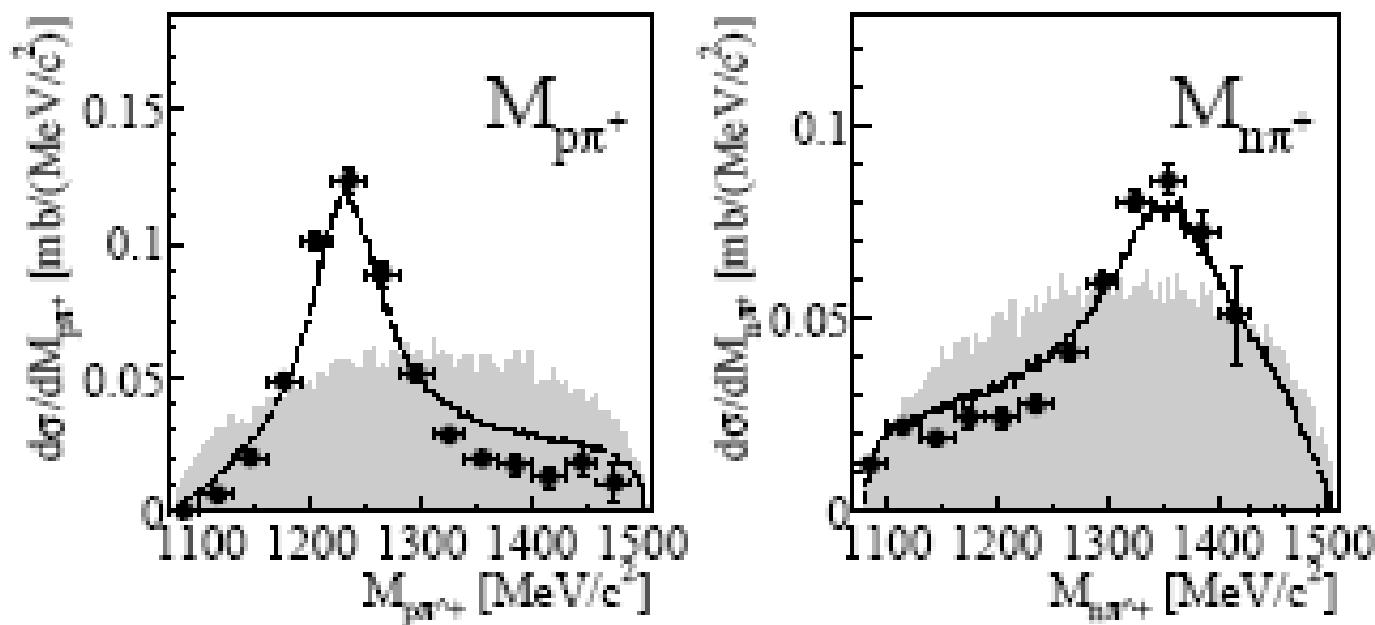
Also a possible reason for rp puzzle of  $\psi$  decays

# The first experiment “seeing” $N^*(1440)$ in $\pi N$ mass spectrum

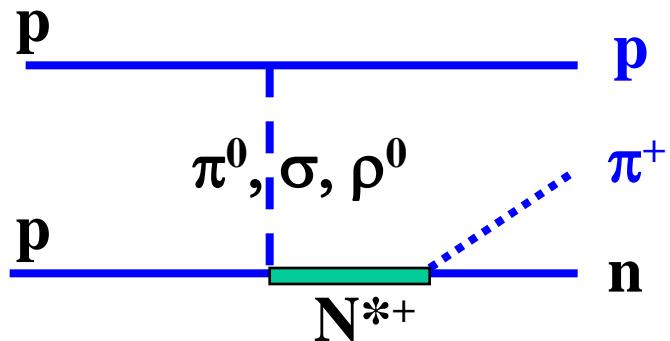
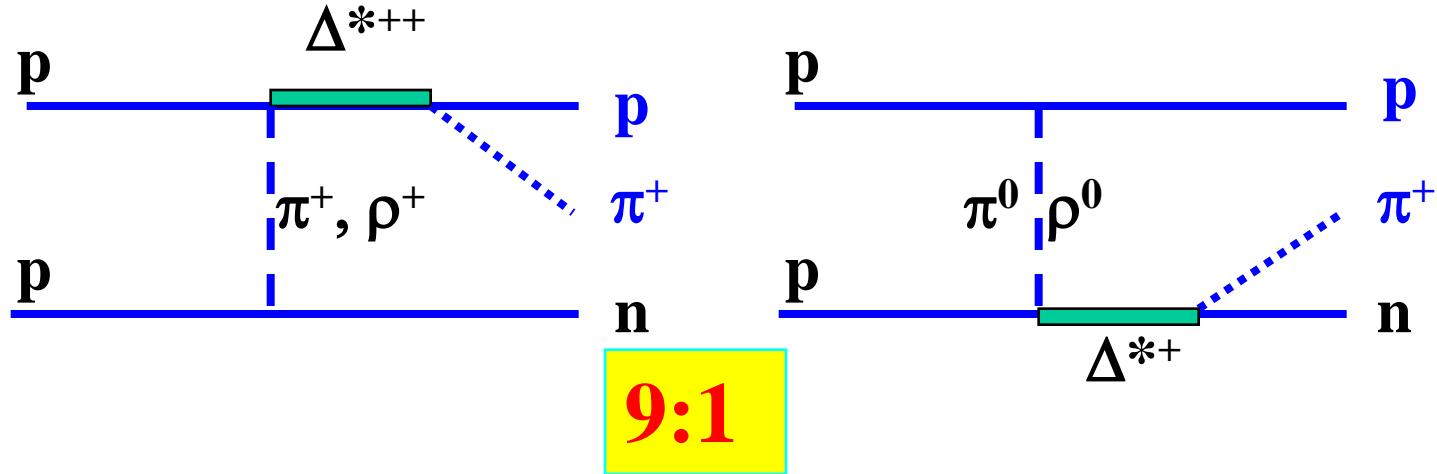
BESII	$M = 1358 \pm 17$ ,	$\Gamma = 179 \pm 56$	MeV
PDG08	$M = 1365 \pm 15$ ,	$\Gamma = 190 \pm 30$	MeV

# Another experiment “seeing” $N^*(1440)$ in $\pi N$ mass spectrum

CELSIUS-WASA Collaboration, nucl-ex/0612015



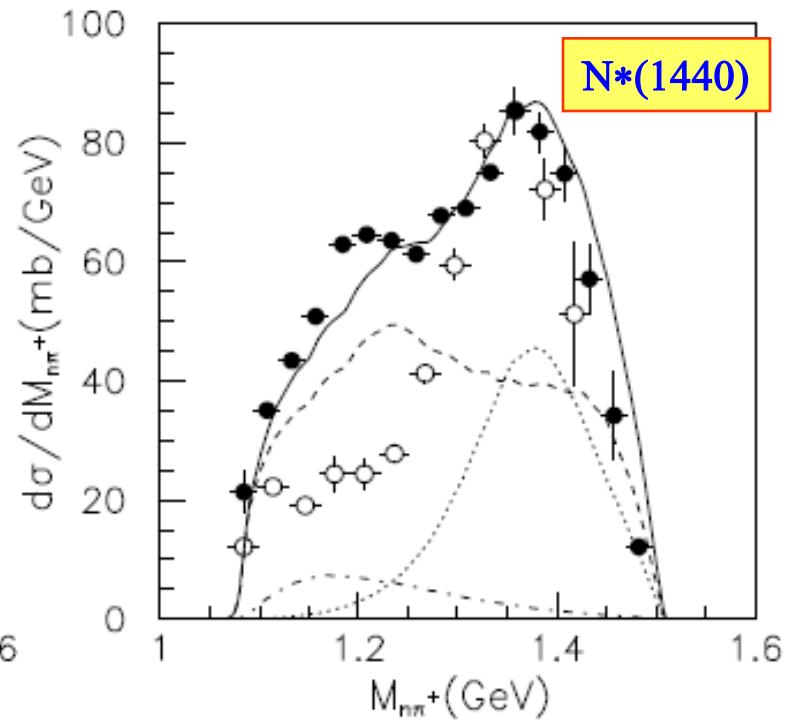
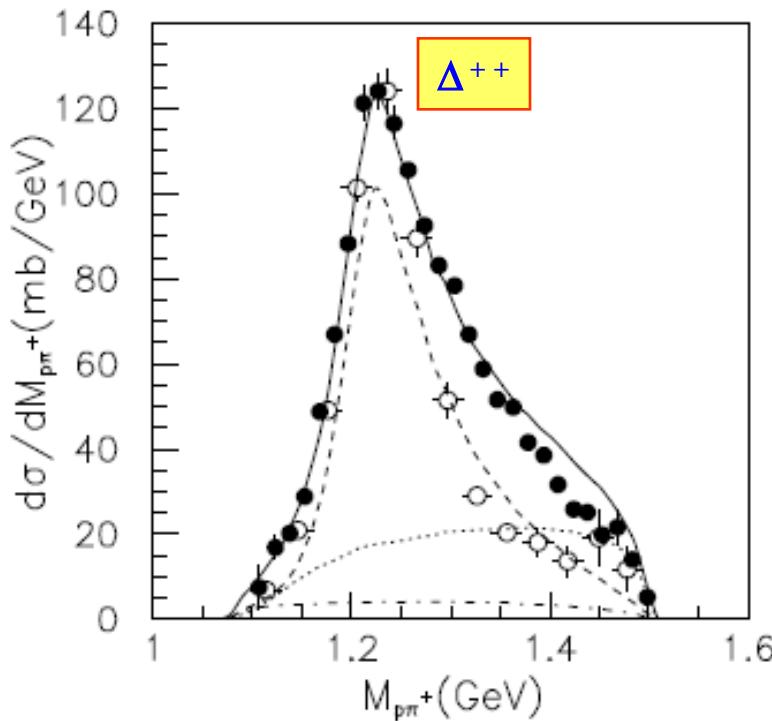
Higher energies and Dalitz plots are needed at COSY&CSR !



A quite good isospin filter !  
Look for “missing”  $N^*$  by  
 $\sigma p$  production !

# Theoretical study on $pp \rightarrow pn\pi^+$

Z.Ouyang,J.J.Xie,B.S.Zou &H.S.Xu, Nucl.Phys.A 821(2009)220; IJMPE(2009)



Including  $N^*(1440)$  by  $\sigma$  exchange is crucial to reproduce data



A.V. Sarantsev et al., Phys. Lett. B659, 94 (2008).

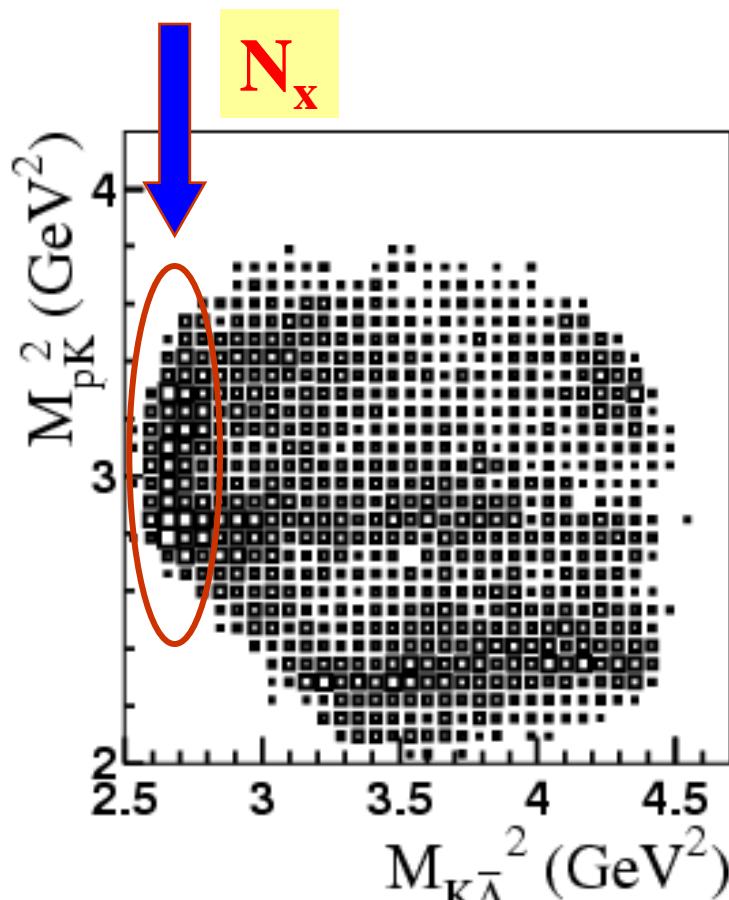


X.Cao, B.S.Zou, H.S.Xu, Phys. Rev. C 81(2010) 065\*\*

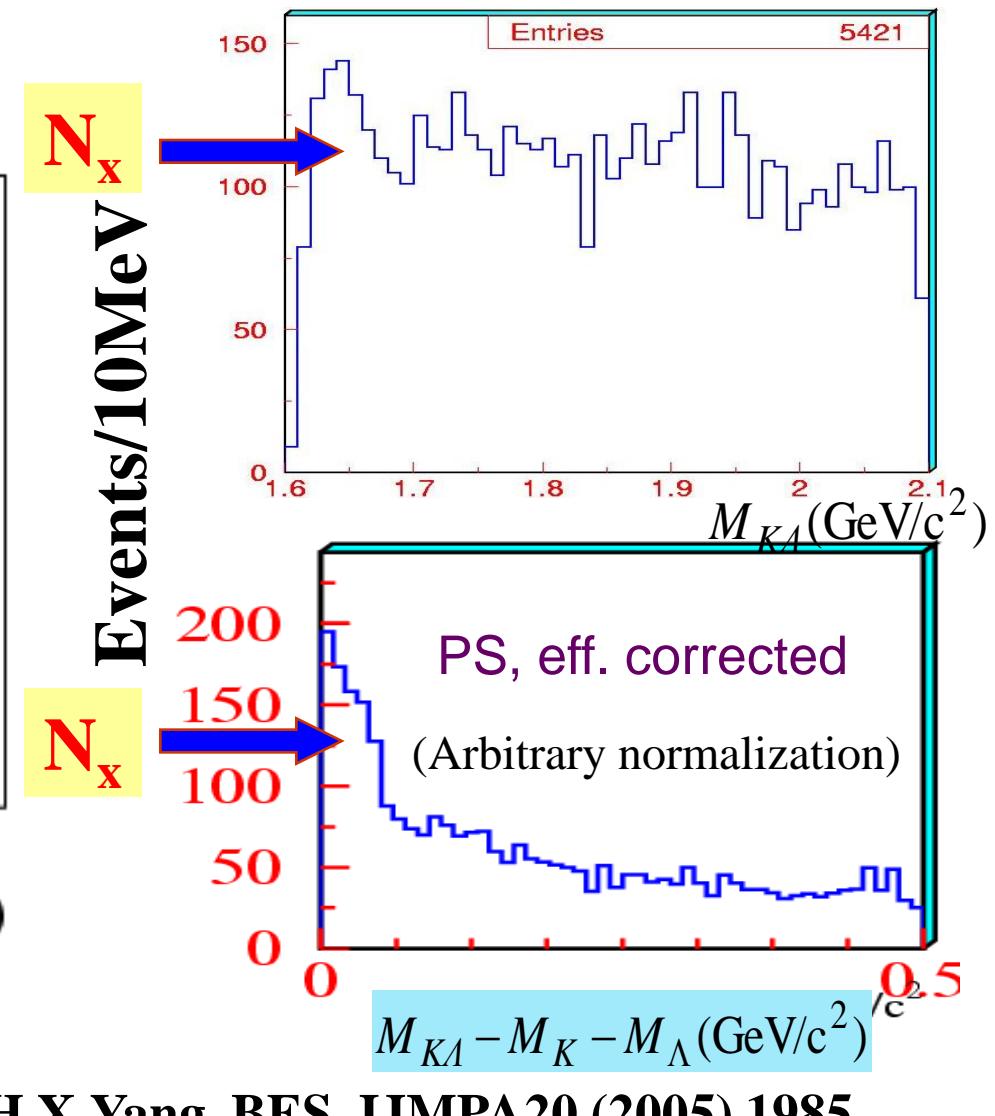
**Both analyses demand larger  $\sigma N/\pi\Delta$  ratio for  $N^*(1440)$**

### 3. $N^*(1535)$

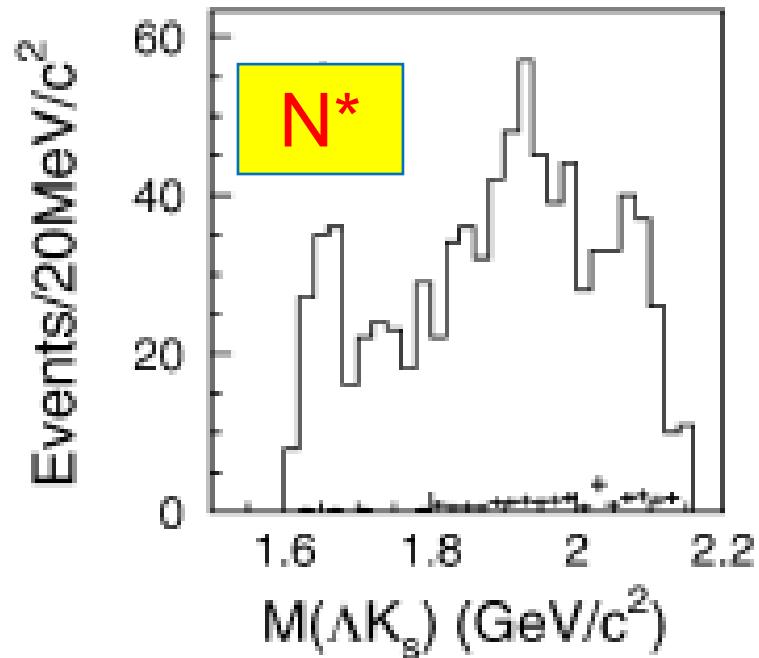
$N^*$  in  $J/\psi \rightarrow p K^- \bar{\Lambda} + c.c.$



Mass **1500~1650MeV**  
Width **70~110MeV**  
 $J^P$  **favors 1/2-**

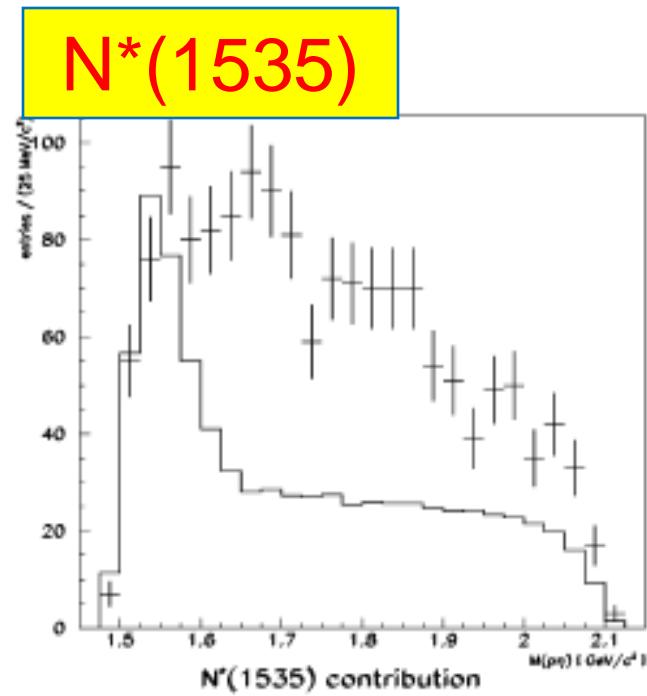


$J/\psi \rightarrow n K_s^0 \bar{\Lambda}$



Phys. Lett. B659 (2008) 789

$J/\psi \rightarrow p \bar{p} \eta$



Phys. Lett. B510 (2001) 75

## 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  $g_{N^*K\Lambda}$   $\rightarrow$  large  $\bar{s}s$  in  $N^*(1535)$

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

## **Evidence for large $g_{N^*K\Lambda}$ from $pp \rightarrow p K^+ \Lambda$ , $\gamma p \rightarrow K^+ \Lambda$**

B.C.Liu, B.S.Zou, PRL 96 (2006) 042002; PRL98 (2007) 039102

B. Julia-Diaz, B.Saghai, H.T.S.Lee, F.Tabakin, PRC 73, 055204 (2006)

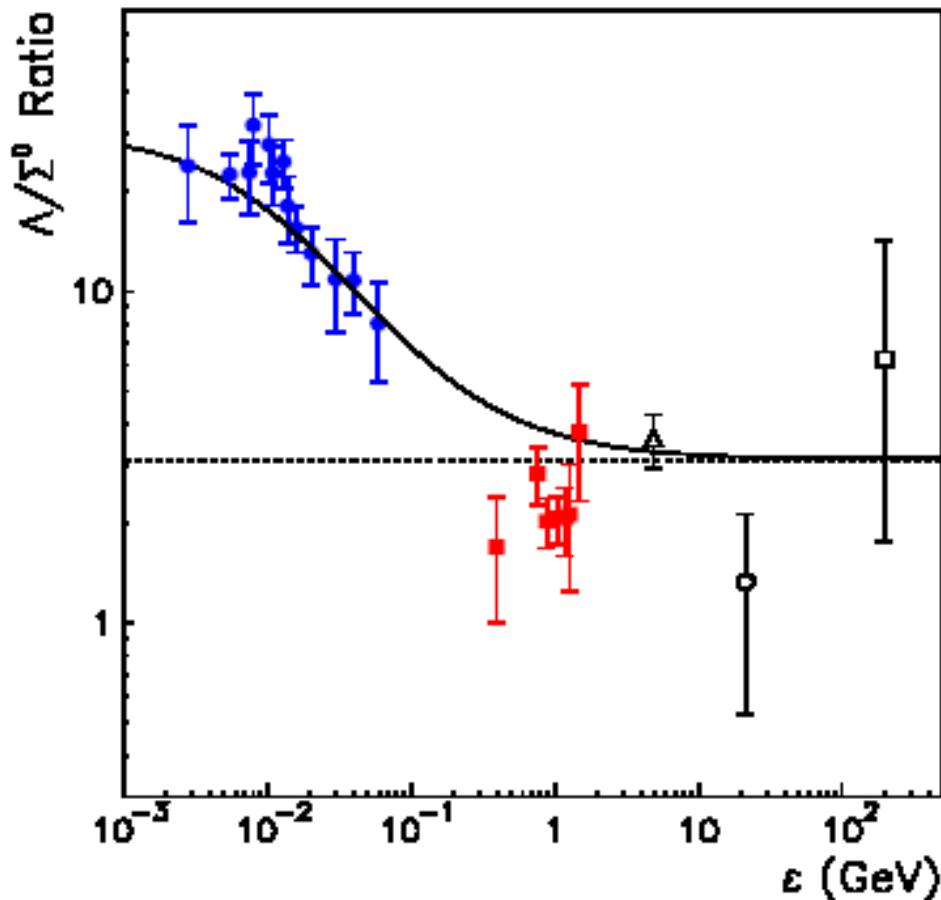
$\gamma p \rightarrow p\eta'$  &  $pp \rightarrow pp\eta' \rightarrow$  large  $g_{N^*N\eta'}$

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

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

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

# Evidence for weaker $g_{N^*K\Sigma}$ from $pp \rightarrow p K^+ \Lambda$ / $pp \rightarrow p K^+ \Sigma^0$

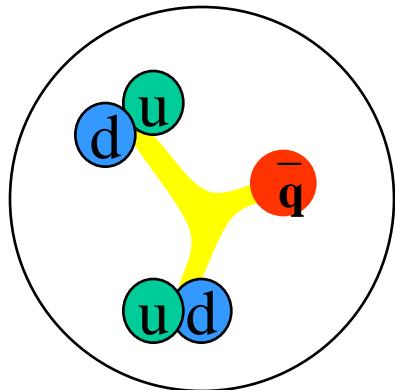


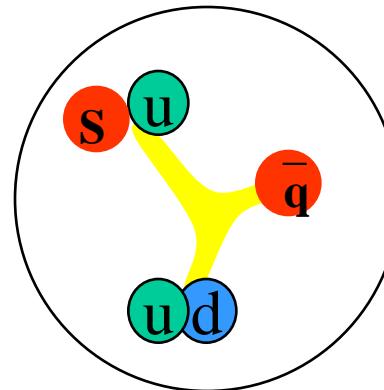
A.Sibirtsev et al.,  
EPJA29 (2006) 363

Fig. 3. The  $\Lambda/\Sigma^0$  cross-section ratio as a function of the excess energy  $\epsilon$ . The solid circles show the ratio obtained for the  $pp \rightarrow K^+ \Lambda p$  and  $pp \rightarrow K^+ \Sigma^0 p$  reactions at COSY [2]. Solid

[2] P.Kowina et al., EPJA22 (2004) 293

# Nature of $\text{N}^*(1535)$ and its $1/2^-$ octet partner



$$\begin{array}{c} \bar{q} \\ [ud] \\ [ud] \end{array} \}^{1/2+}_{L=1}$$


$$\begin{array}{c} \bar{q} \\ [ud] \\ [us] \end{array} \}^{1/2-}_{L=0}$$

Zhang et al, hep-ph/0403210

$$\text{N}^*(1535) \sim uud \text{ (L=1)} + \varepsilon [ud][us] \bar{s} + \dots$$

$$\text{N}^*(1440) \sim uud \text{ (n=1)} + \xi [ud][ud] \bar{\bar{d}} + \chi \bar{[ud]}[ud][ud]u + \dots$$

$$\Lambda^*(1405) \sim uds \text{ (L=1)} + \varepsilon [ud][su] \bar{\bar{u}} + \dots$$

**N<sup>\*</sup>(1535): [ud][us]  $\bar{s}$  → larger coupling to  $\text{N}\eta, \text{N}\eta', \text{N}\phi & \text{K}\Lambda$ , weaker to  $\text{N}\pi & \text{K}\Sigma$ , and heavier !**

## 4. Prospects

Easier to pull out  $\bar{q}q$  pair(s) than spatial excitation

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

$\Lambda^*$  [us][ds]  $\bar{s}$  ~ 1575 MeV

$\Sigma^*$  [us][du]  $\bar{d}$  ~ 1360 MeV

$\Xi^*$  [us][ds]  $\bar{u}$  ~ 1520 MeV

**J/ψ decay      branching ratio \* 10<sup>4</sup>**

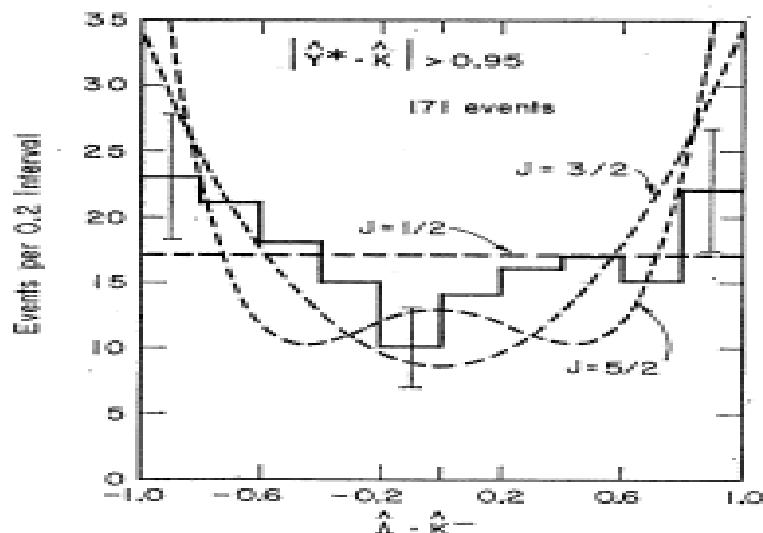
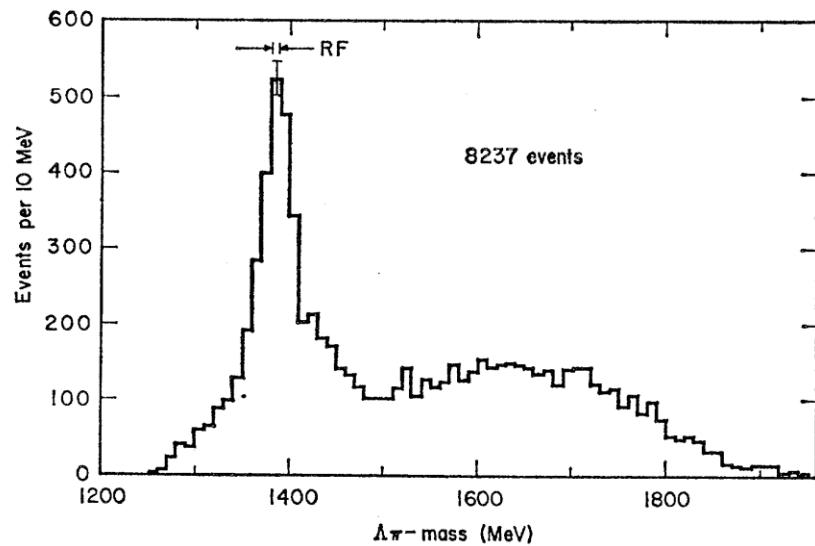
$\bar{p} \Delta(1232)^+$	3/2+	< 1	}	SU(3) breaking
$\bar{\Sigma}^- \Sigma(1385)^+$		$3.1 \pm 0.5$		
$\bar{\Xi}^+ \Xi(1520)^-$		$5.9 \pm 1.5$		

$\bar{p} N^*(1535)^+$	1/2-	$10 \pm 3$	}	SU(3) allowed
$\bar{\Sigma}^- \Sigma(1360)^+$		?		
$\bar{\Xi}^+ \Xi(1530)^-$		?		

**It is very important to check whether under the  $\Sigma(1385)$  and  $\Xi(1520)$  peaks there are 1/2- components ?**

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

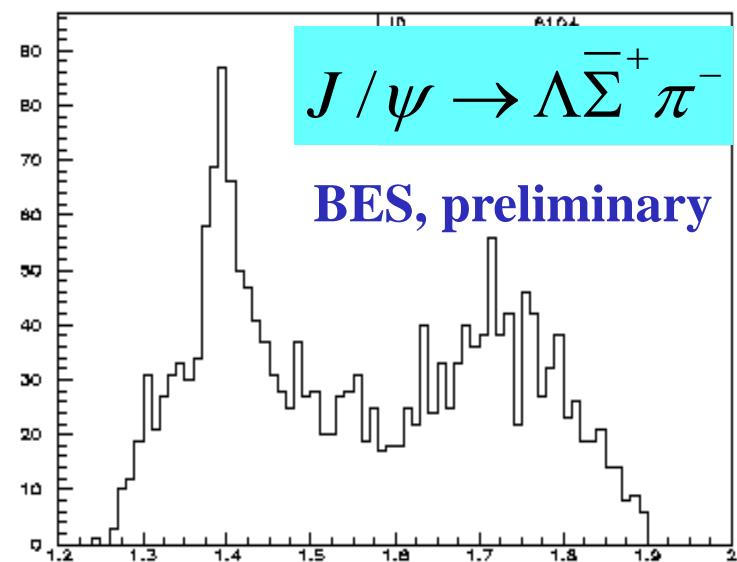
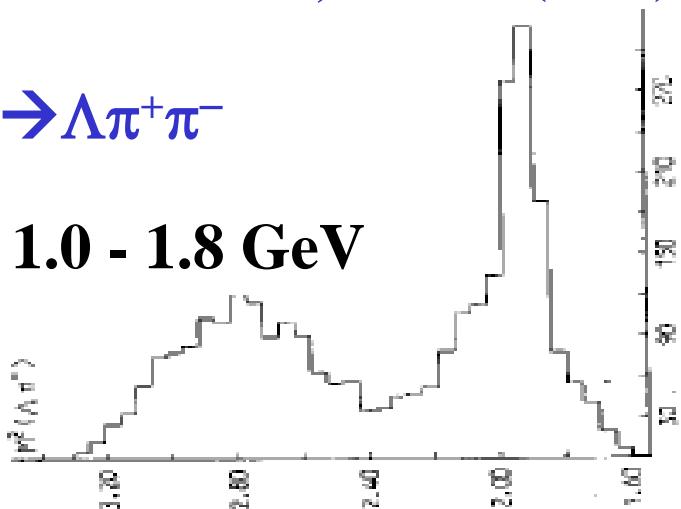
Huwe, PR181(1969)1824



Cameron et al., NPB143(1978)189

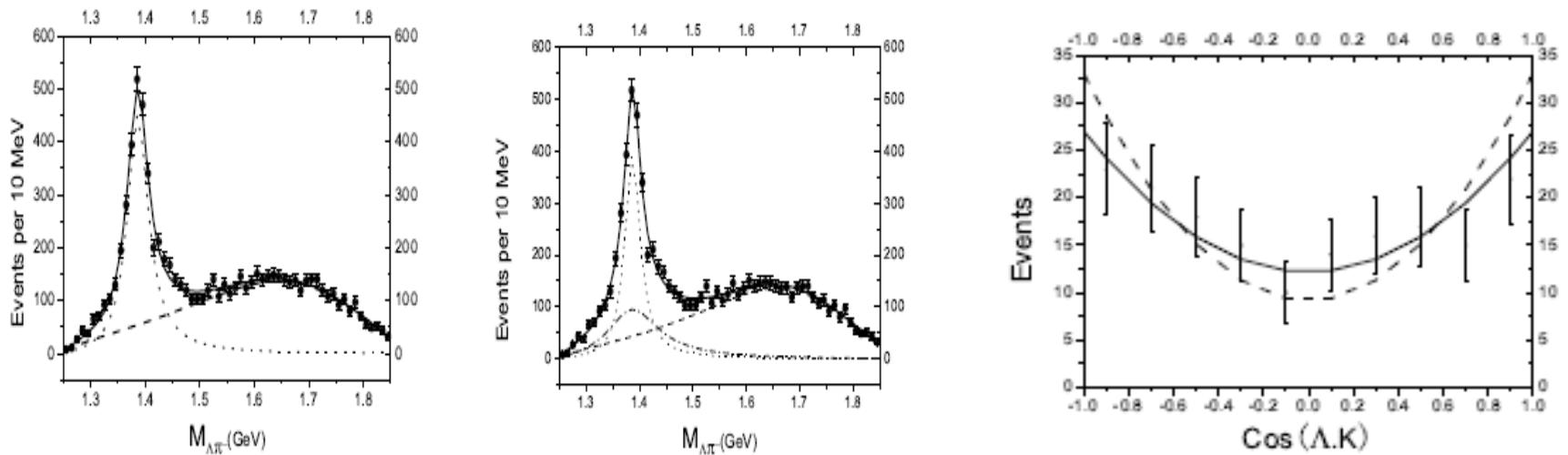


$$P_K = 1.0 - 1.8 \text{ GeV}$$



BES, NSTAR04

$M_{\pi\Lambda}$

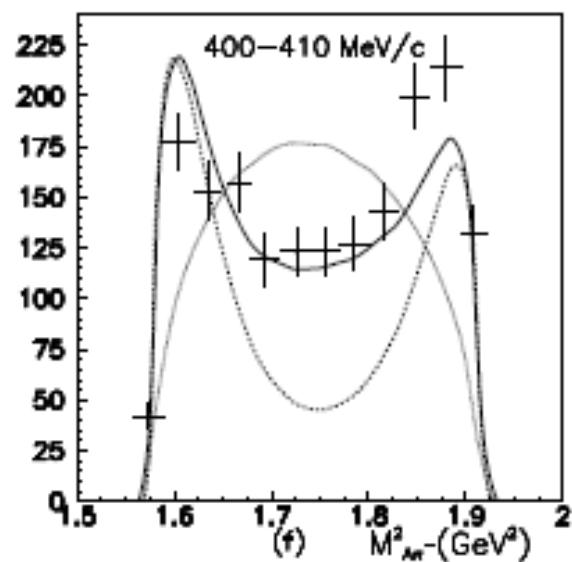
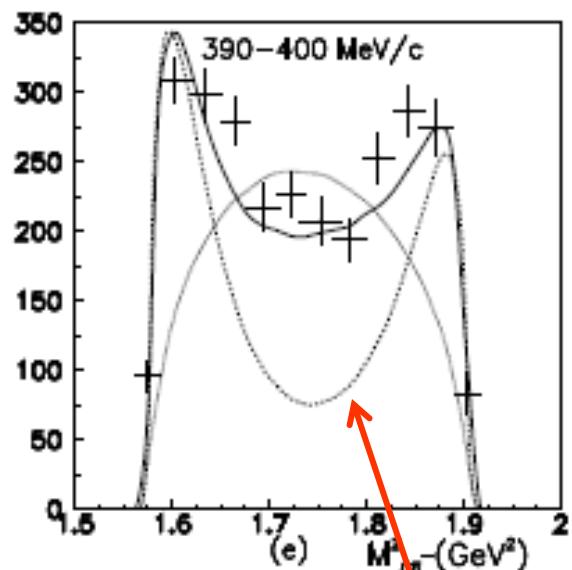
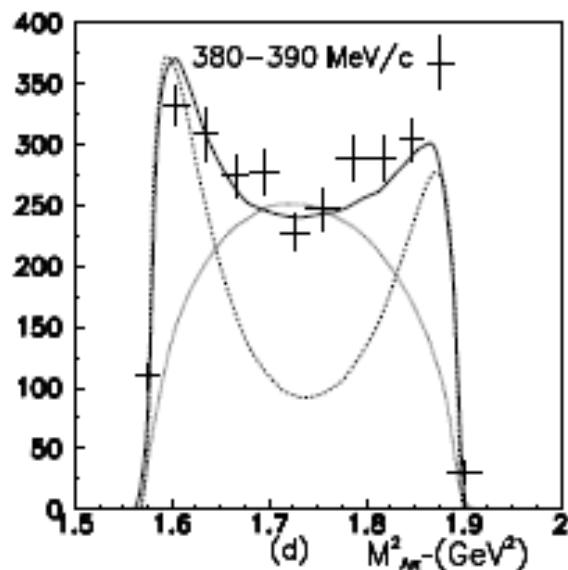
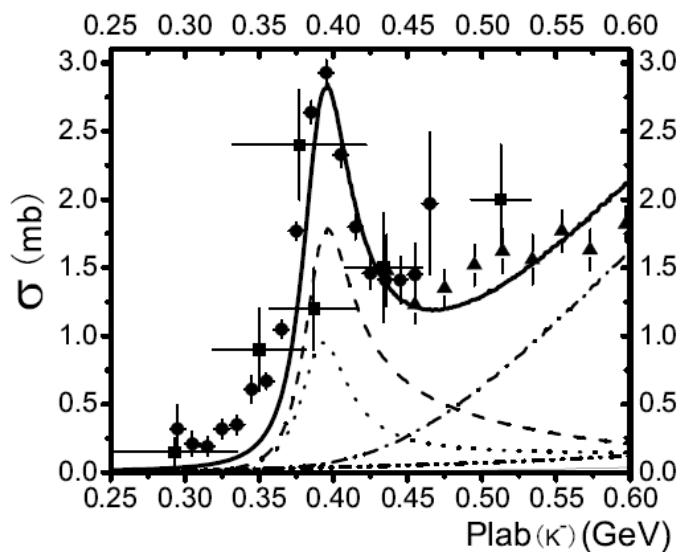


$M_{\Sigma^*(3/2)}$	$\Gamma_{\Sigma^*(3/2)}$	$M_{\Sigma^*(1/2)}$	$\Gamma_{\Sigma^*(1/2)}$	$\chi^2/ndf$ (Fig.1)	$\chi^2/ndf$ (Fig.2)
Fit1 $1385.3 \pm 0.7$	$46.9 \pm 2.5$			68.5/54	10.1/9
Fit2 $1386.1^{+1.1}_{-0.9}$	$34.9^{+5.1}_{-4.9}$	$1381.3^{+4.9}_{-8.3}$	$118.6^{+55.2}_{-35.1}$	58.0/51	3.2/9

$$K^- p \rightarrow \Lambda^* \rightarrow \Sigma_{3/2}^{*-} \pi^+ \rightarrow \Lambda \pi^+ \pi^-$$

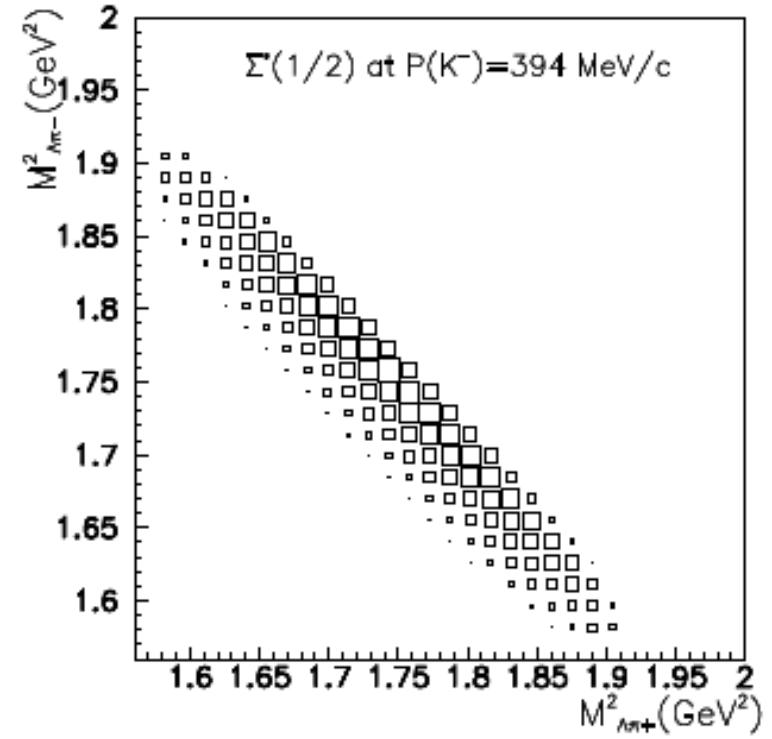
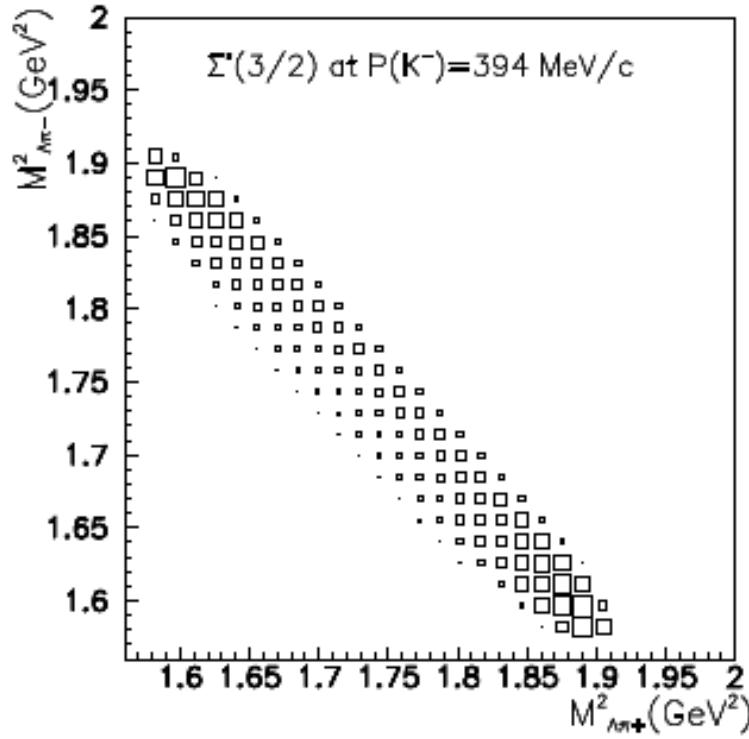
$$K^- p \rightarrow \Lambda^* \rightarrow \Sigma_{1/2}^{*-} \pi^+ \rightarrow \Lambda \pi^+ \pi^-$$

$$P_K \approx 0.4 \text{ GeV}$$



**$\Sigma^*(3/2^+) \text{ only}$**

J.J.Wu, S.Dulat, B.S.Zou, Phys. Rev. C81 (2010) 045210



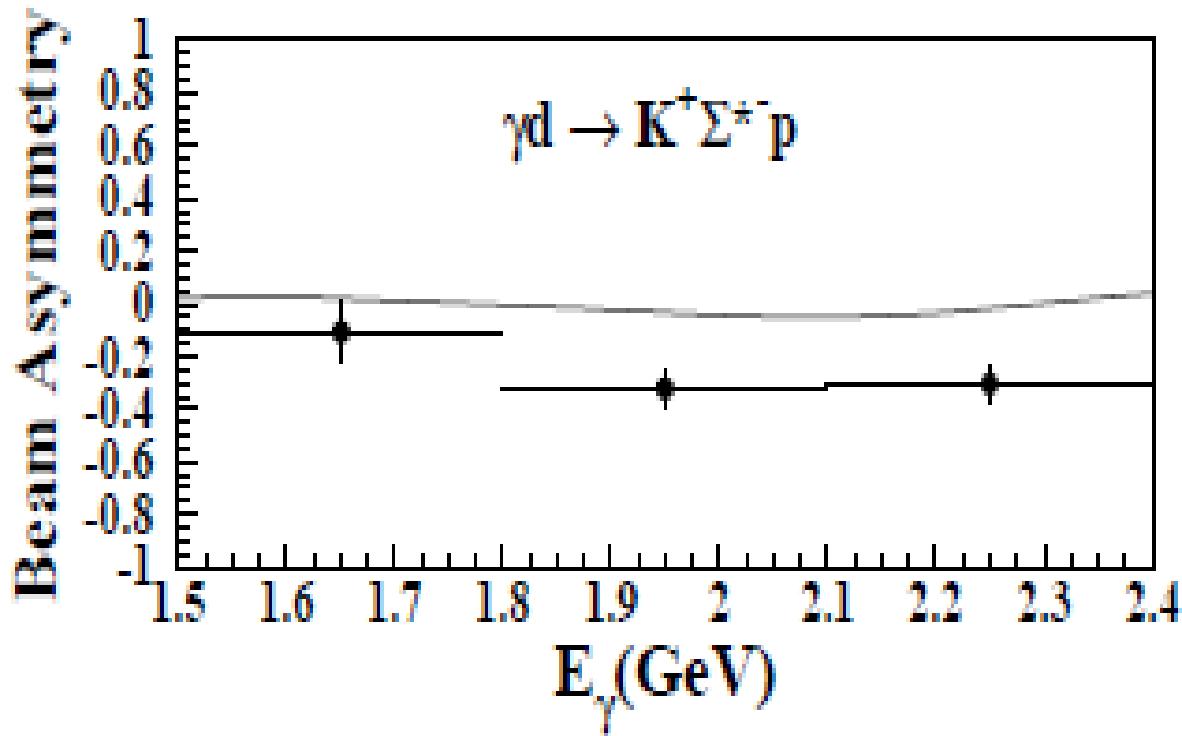
$\Sigma^*(3/2^+) & \Sigma^*(1/2^-) \rightarrow$  different Dalitz plots & mass spectra

**Both are needed to reproduce the data !**

## Other evidence: failed to reproduce data with $\Sigma^*(1385)$

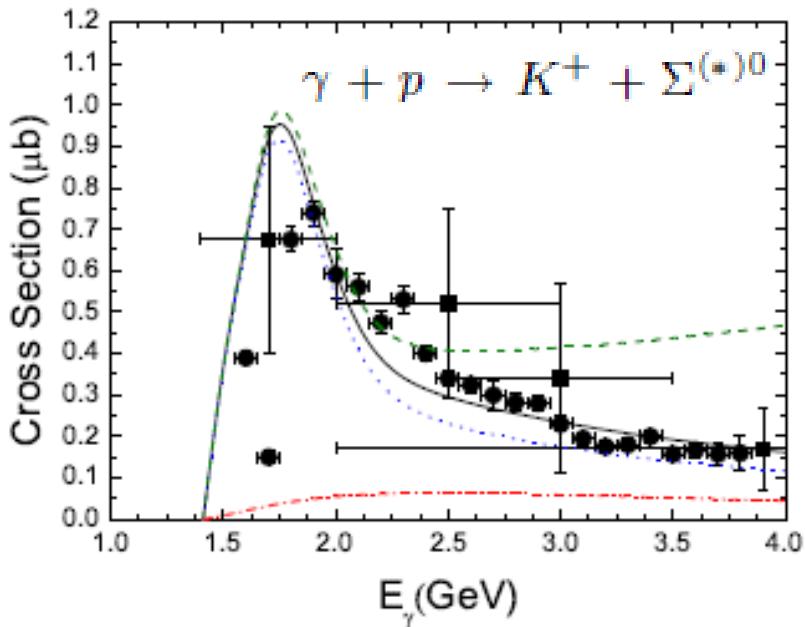
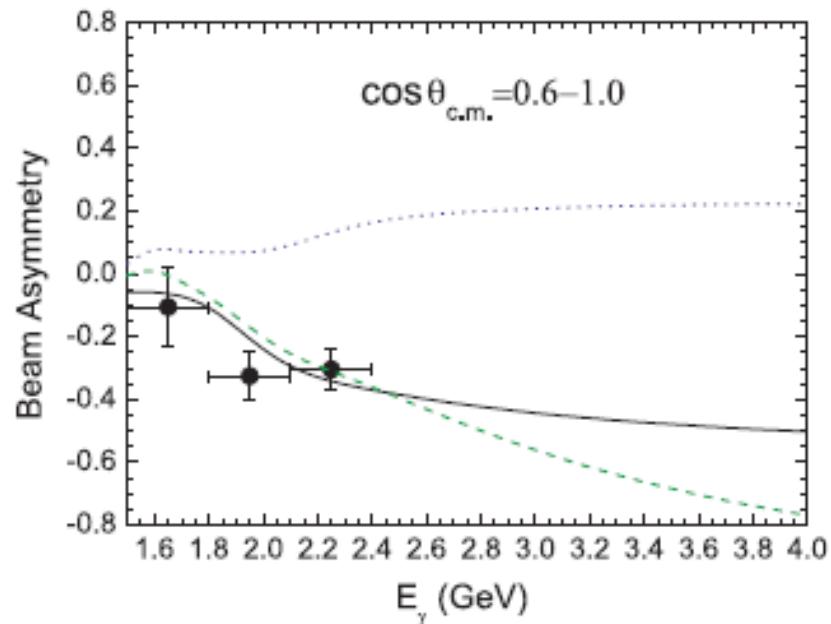
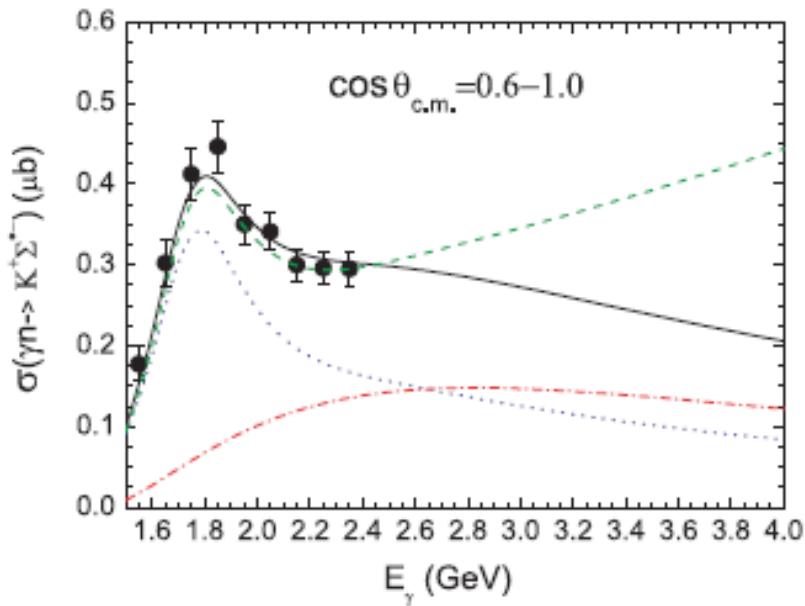
LEPS, PRL102(2009)012501

Y. Oh, C. M. Ko, and K. Nakayama, PRC77(2008) 045204



Something new ?       $\Sigma^*(1/2^-)$  ?

P.Gao, J.J.Wu, B.S.Zou, Phys. Rev. C 81 (2010) 055203



dot lines:  $\Sigma^*(3/2^+)$  with  $h=1.00$   
dashed :  $\Sigma^*(3/2^+)$  with  $h=1.11$   
solid: including  $\Sigma^*(1/2^-)$

P.Gao, J.J.Wu, B.S.Zou,  
Phys. Rev. C 81 (2010) 055203

## Prospects :

2001 58M J/  $\Psi$

2003 14M  $\Psi'$

2009 BEPCII double ring upgrade      200M J/ $\Psi$  & 100M  $\Psi'$

$10^{10}$  J/ $\Psi$  &  $10^9$   $\Psi'$  &  $10^8 \chi_{cJ}$ ,  $\eta_c$  are expected



Completing N\*,  $\Lambda^*$ ,  $\Sigma^*$ ,  $\Xi^*$  spectra & exploring baryon structure

CEBAF, CLEO-c, JPARC(kaon beam), COSY, CSR, PANDA, ...

competition & complementary



Nature of baryon excitations !

Thanks !