Recent BES results from J/ψ decays

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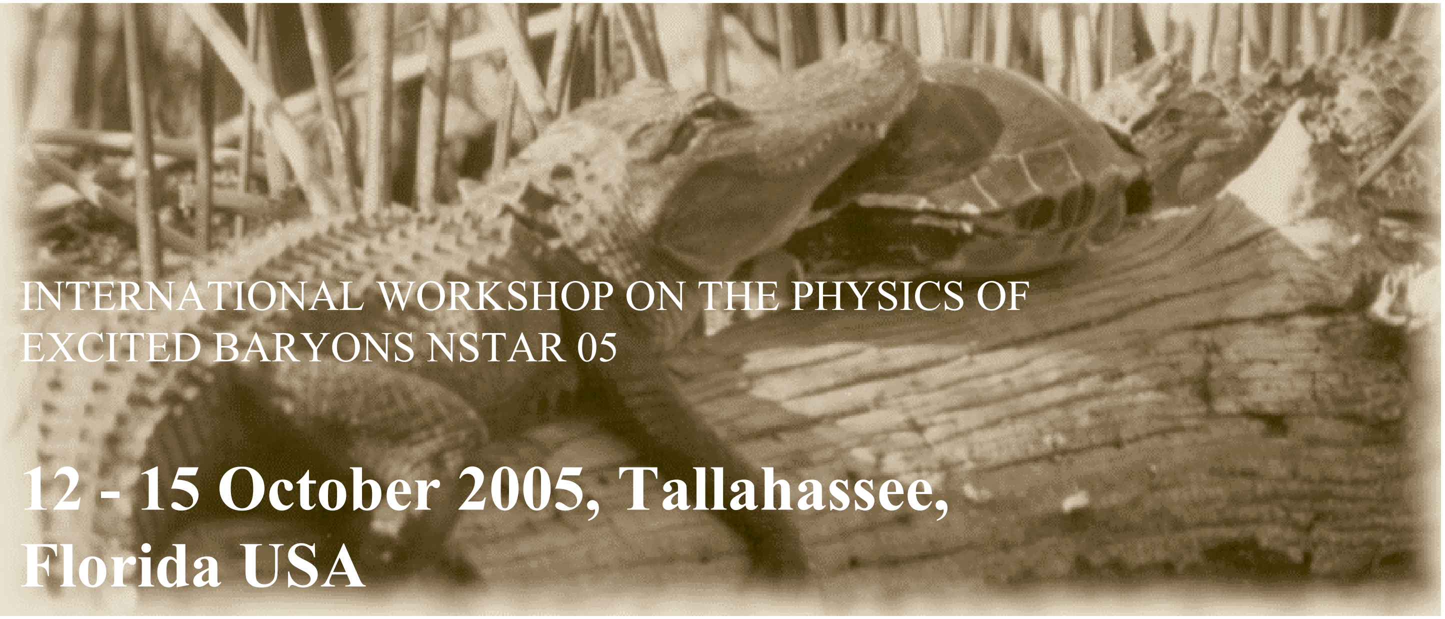
(Representing BES Collaboration)



OUTLINE

- **Introduction**
- **Multi-quark search and study**
- **Study of the excited baryon states**
- **$J/\psi \rightarrow p\bar{p}$, $\Lambda\bar{\Lambda}$, and $\Sigma^0\bar{\Sigma}^0$**
- **Summary**

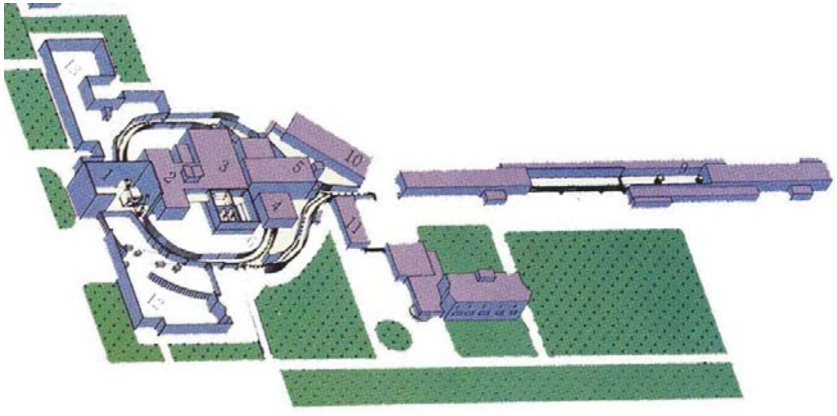
INTRODUCTION

The Beijing Electron Positron Collider (BEPC)

L ~ 5 ×10^{30} /cm^2·s at J/ψ peak

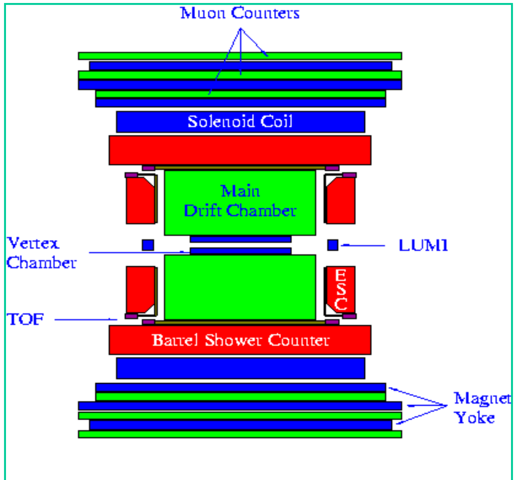
E$_{cm}$~ 2-5 GeV

A unique e^+e^- machine
in the τ-charm energy
region since 1989 – until now.

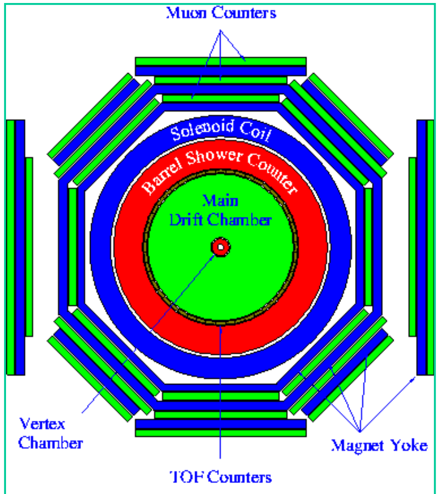


BESII Detector

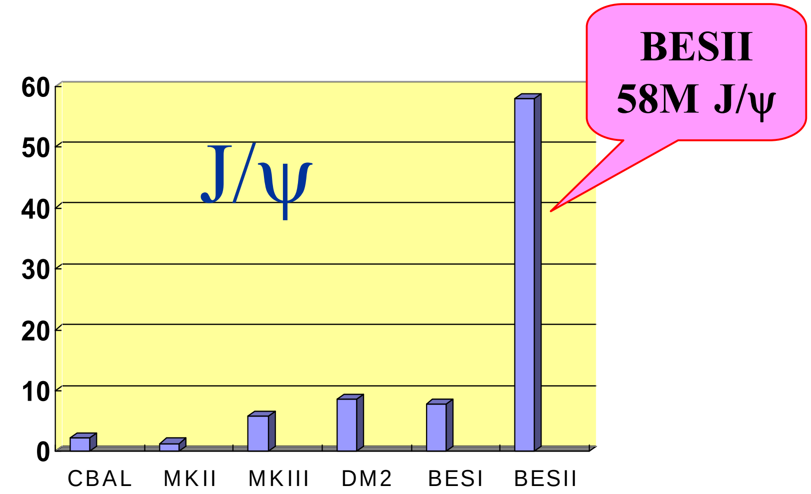
World J/ψ and ψ(2S) Samples ($\times 10^6$)

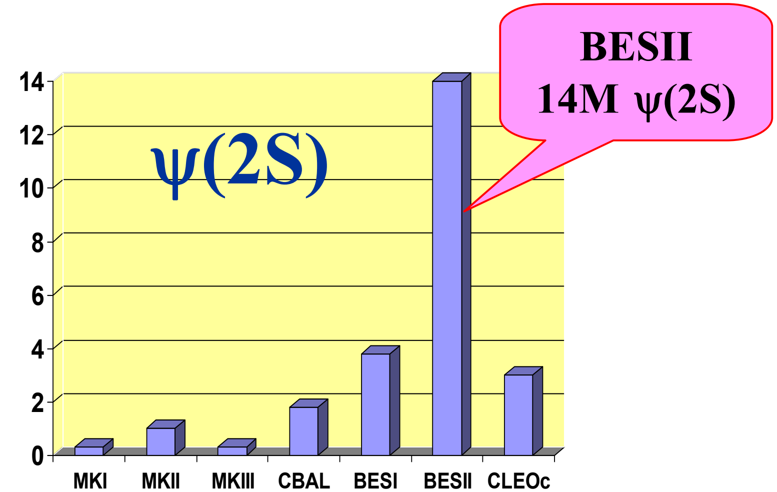


Side view of the BES detector



End view of the BES detector





VC: $\sigma_{xy} = 100\ \mu m$

MDC: $\sigma_{xy} = 220\ \mu m$

$\sigma_{dE/dx} = 8.5\ \%$

$\Delta p/p = 1.78\sqrt{(1+p^2)}$

μ counter: $\sigma_{r\phi} = 3$ cm

$\sigma_z = 5.5$ cm

TOF: $\sigma_T = 180$ ps

BSC: $\Delta E/\sqrt{E} = 21\ \%$

$\sigma_\phi = 7.9$ mr

$\sigma_z = 2.3$ cm

B field: 0.4 T

Introduction to PWA

- **construct amplitude A_i for i-th possible partial wave**

$$A_i = A^i_{prod} \cdot P^i_X \cdot BW^i_X \cdot A^i_{decay}$$

- **differential cross section is**

$$\frac{d\sigma}{d\Phi} = \left| \sum_i A_i \right|^2 + A_{bg}$$

- **likelihood function**

$$\ln L = \sum_{i=1}^{N} \ln\left(\frac{d\sigma}{d\Phi} / \sigma \right)$$

- **maximum likelihood method**

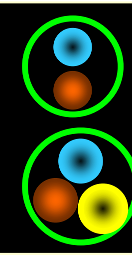
MULTI-QUARK SEARCH

- **Hadrons consist of 2 or 3 quarks：**

Naive Quark Model：

Meson（ $q\ \bar{q}$ ）

Baryon（q q q）

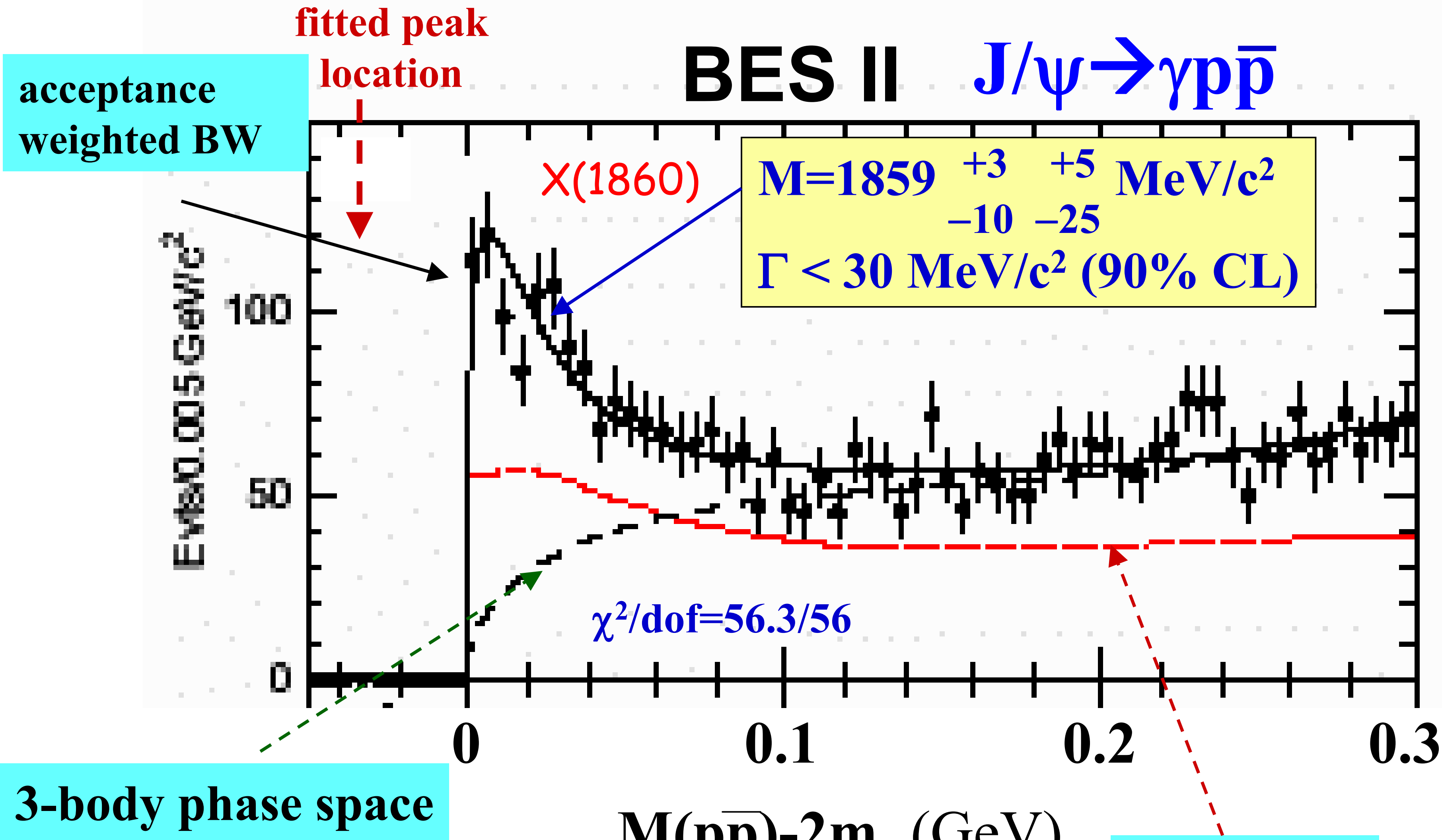


- **New forms of hadrons:**
  - **Multi-quark states： Number of quarks ≥ 4 ,**
  - **for instance, pentaquark**
  - **Hybrids： $q\bar{q}g$， qqqg …**
  - **Glueballs： gg， ggg …**

Multi-quark states, glueballs and hybrids have been searched for experimentally for a very long time, but none is established.

New Observation of X(1835) in $J/\psi \to \gamma\eta'\pi^+\pi^-$ at BESII

Observation of an anomalous enhancement near the threshold of $p\bar{p}$ mass spectrum at BES II



Phys. Rev. Lett. 91, 022001 (2003)

X(1860) from BES has large BR to $p\bar{p}$

- **BES measured:**

$$BR(J/\psi \to \gamma X(1860)) \bullet BR(X(1860) \to p\bar{p}) \sim 7 \times 10^{-5}$$

- **For a 0^{-+} meson:**

$$BR(J/\psi \to \gamma X(1860)) \sim 0.5 - 2 \times 10^{-3}$$

- **So we would have:**

$$BR(X(1860) \to p\bar{p}) \sim 4 - 14\%$$

(This BR to $p\bar{p}$ might be the largest among all PDG particles)

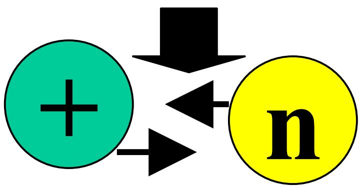
Considering that decaying into $p\bar{p}$ is only from the tail of X(1860) and the phase space is very small, *such a BR indicates X(1860) has large coupling to $p\bar{p}$!*

$p\bar{p}$ bound state (baryonium)?

There is lots & lots of literature about this possibility

deuteron:

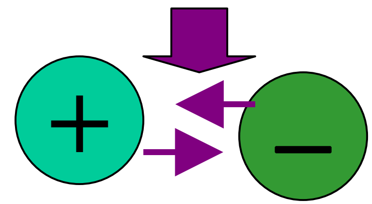
attractive nuclear force



loosely bound 3-q 3-q color singlets with $M_d = 2m_p - \varepsilon$

baryonium:

attractive force?



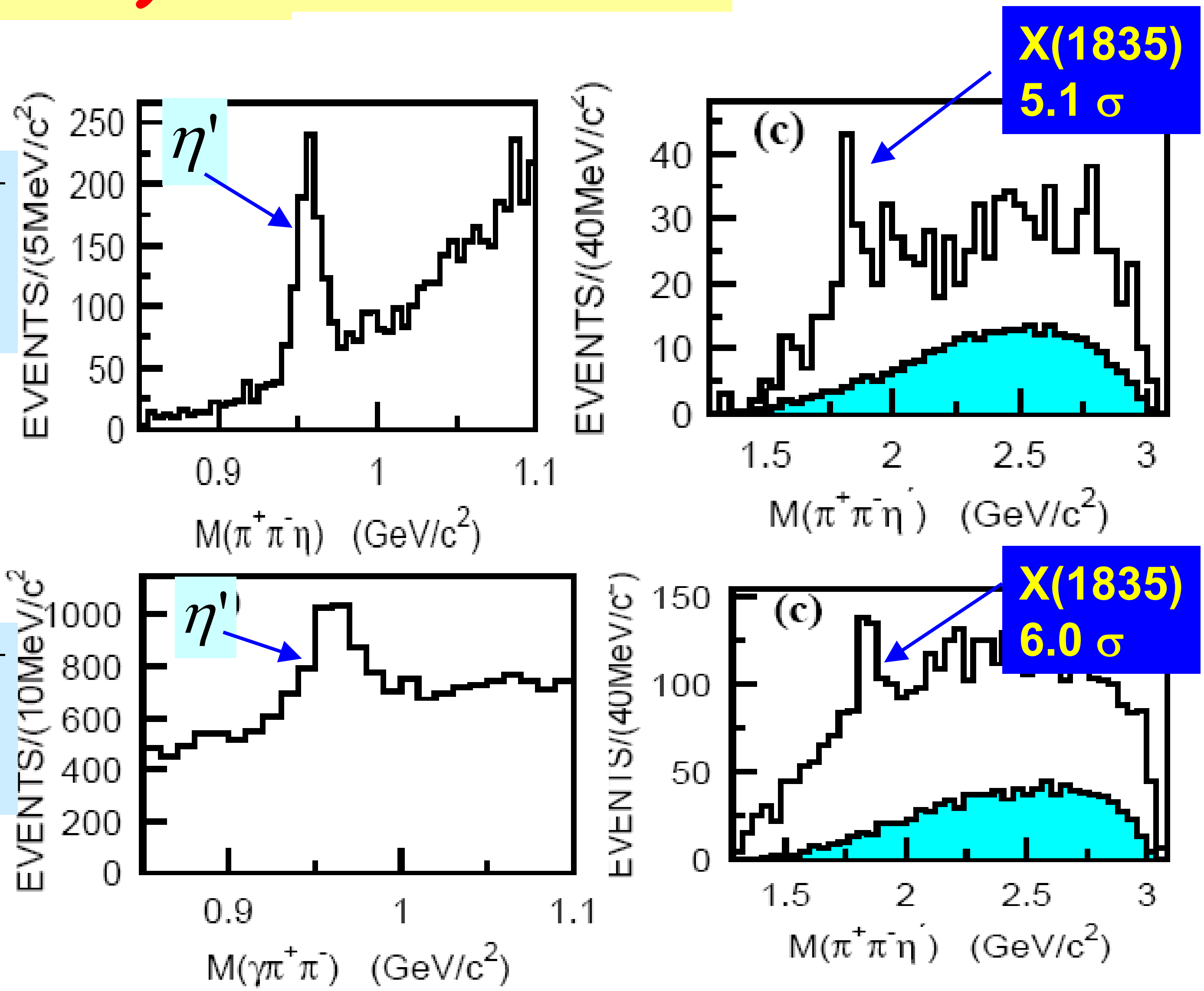
loosely bound 3-q 3-q color singlets <u>with</u> $M_b = 2m_p - \delta$?

Observations of this structure in other decay modes are desirable.

BES: X(1835) in $J/\psi \to \gamma\eta'\pi^+\pi^-$

$$J/\psi \to \gamma\eta'\pi^+\pi^-$$
$$\eta' \to \eta\pi^+\pi^-$$

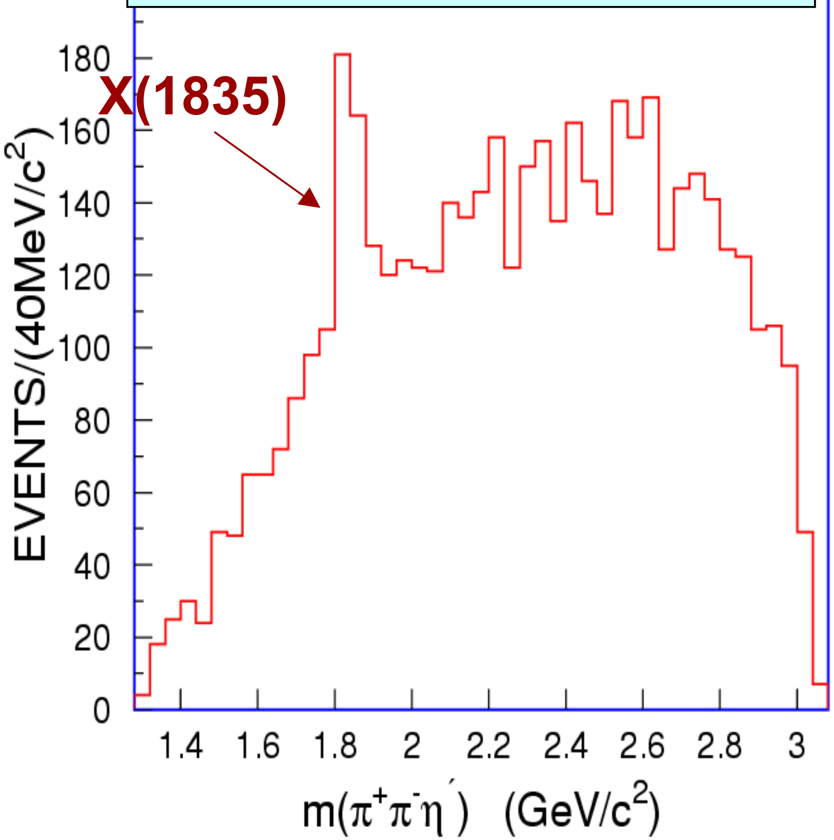
$$J/\psi \to \gamma\eta'\pi^+\pi^-$$
$$\eta' \to \gamma\rho$$

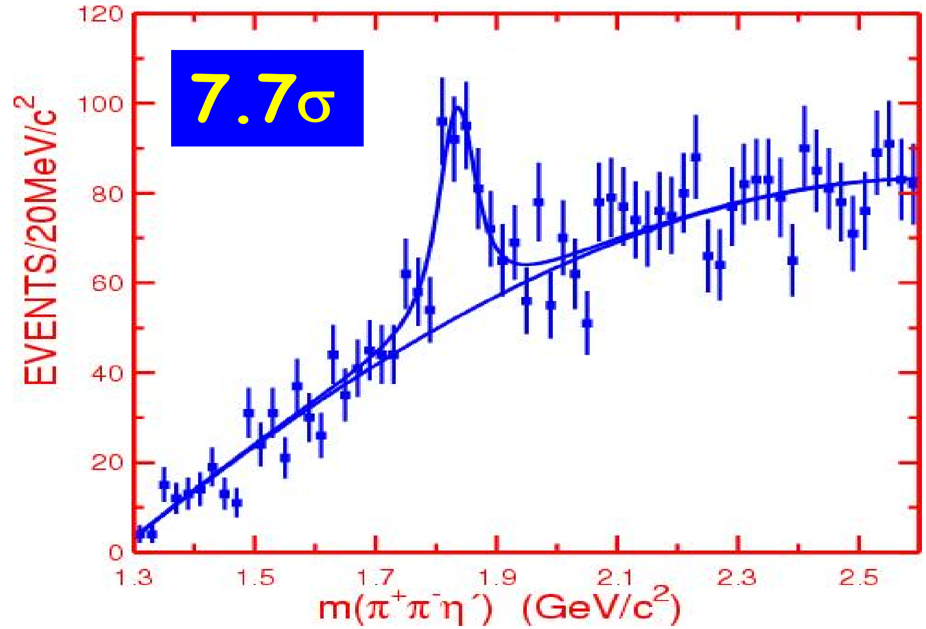


Combine two channels

$$J/\psi \to \gamma \pi^+ \pi^- \eta'$$

Statistical Significance 7.7 σ





$$N_{obs} = 264 \pm 54$$

$$M = 1833.7 \pm 6.1 \pm 2.7 \text{ MeV/c}^2$$

$$\Gamma = 67.7 \pm 20.3 \pm 7.7 \text{ MeV/c}^2$$

hep-ex/0508025, accepted by PRL

$$B(J/\psi \to \gamma X)B(X \to \pi^+\pi^-\eta') = (2.2 \pm 0.4 \pm 0.4) \times 10^{-4}$$

$$c.f.:\ B(J/\psi \to \gamma X)B(X \to p\bar{p}) = (7.0 \pm 0.4^{+1.9}_{-0.8}) \times 10^{-5}$$

X(1835) same as X(1860)?

- X(1835) mass is consistent with the mass of the S-wave resonance X(1860) indicated by the $p\bar{p}$ mass threshold enhancement.

  Its width is 1.9σ higher than the upper limit of the width obtained from $p\bar{p}$ mass threshold enhancement.

- On the other hand, if the FSI effect is included in the fit of the $p\bar{p}$ mass spectrum, the width of the resonance near $p\bar{p}$ mass threshold will become larger.

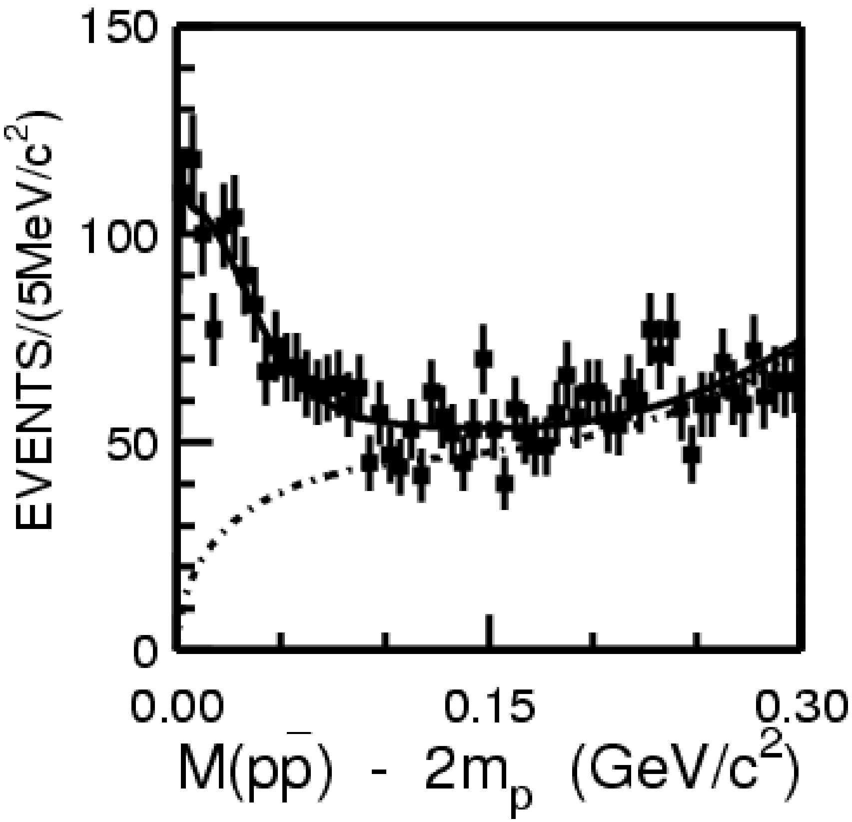
- It is likely to be a $p\bar{p}$ bound state since it dominantly decays to $p\bar{p}$ when its mass is above $p\bar{p}$ mass threshold.

- However, other possible interpretations of the X(1835) are not excluded.

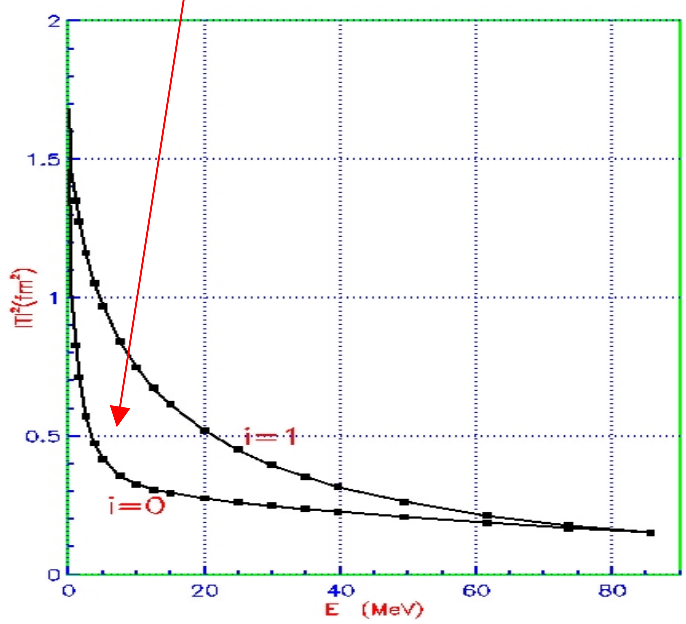
Fit to J/ψ → $\gamma p\bar{p}$ including FSI

$M = 1831 \pm 7\ \mathrm{MeV}/c^2$

$\Gamma < 153\ \mathrm{MeV}/c^2$ (90% CL)



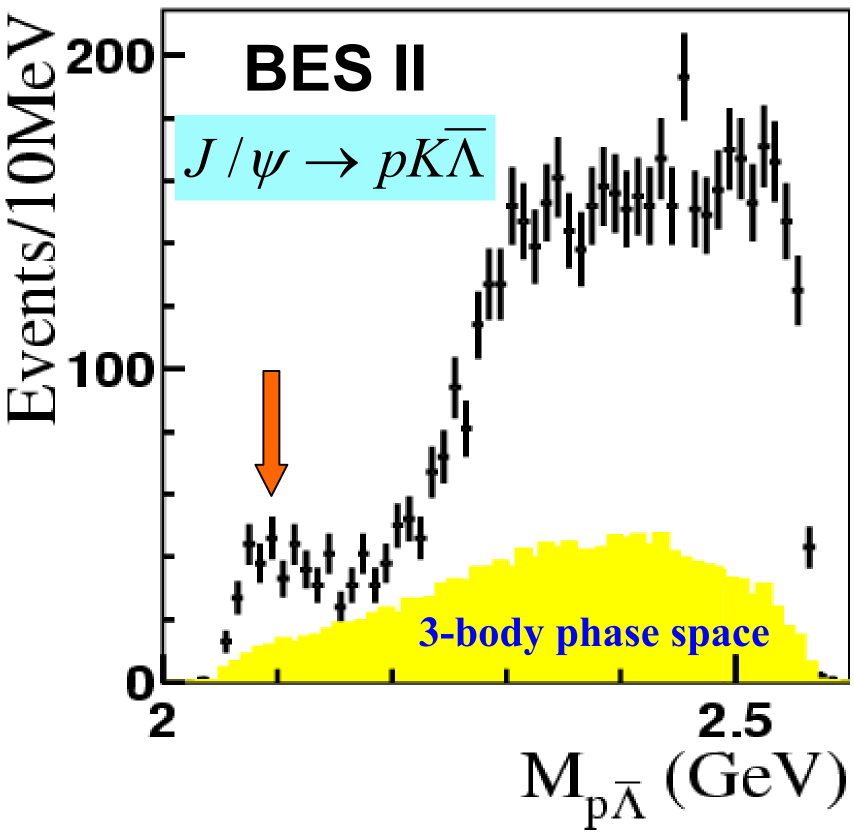
Include FSI curve from A.Sirbirtsev et al.(hep-ph/ 0411386) in the fit (I=0)

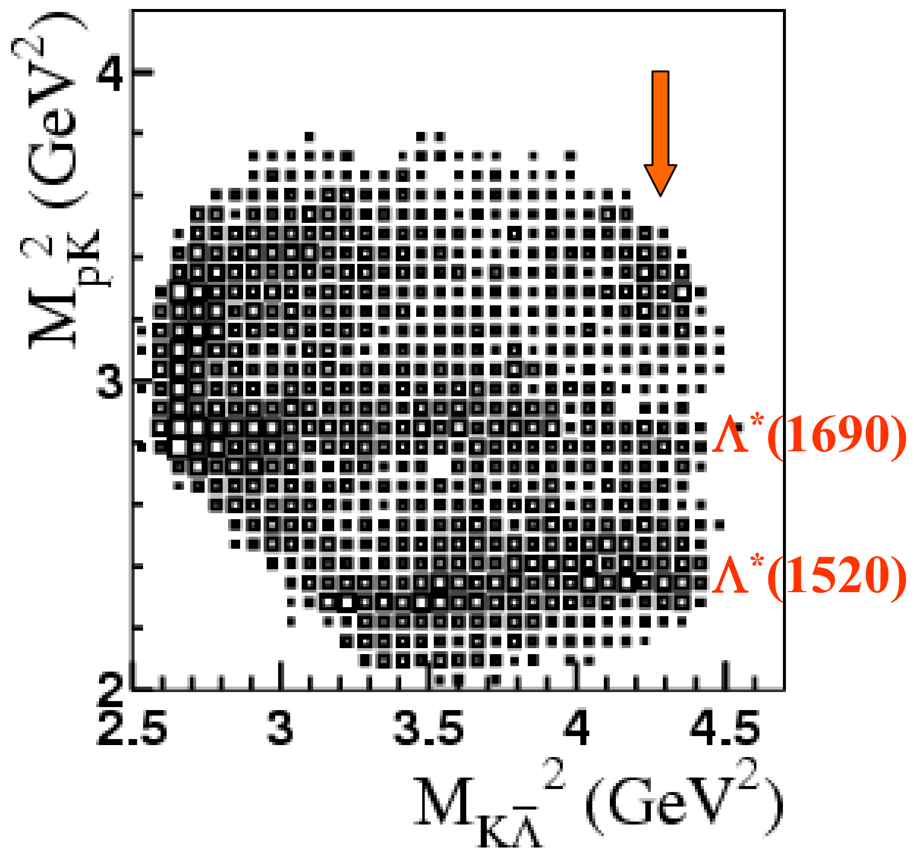


In good agreement with X(1835)

$$J/\psi \rightarrow pK^{-}\bar{\Lambda} + c.c.$$

Observation of an anomalous enhancement near the threshold of $p\bar{\Lambda}$ mass spectrum at BES II





For a S-wave BW fit: $M = 2075 \pm 12 \pm 5$ MeV/c^2

Phys. Rev. Lett. 93, 112002 (2004) $\Gamma = 90 \pm 35 \pm 9$ MeV/c^2

Possible Interpretations

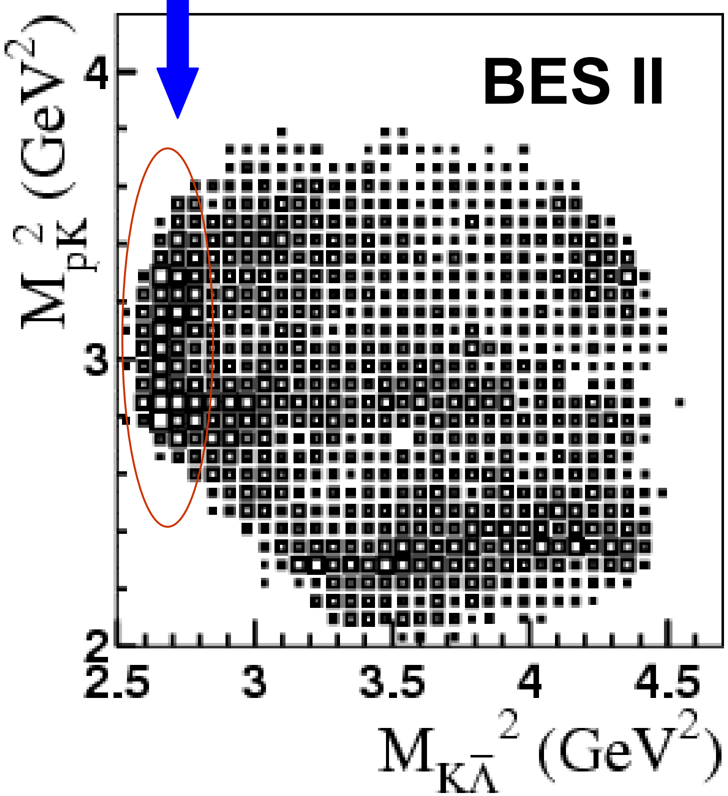
- FSI? Theoretical calculations are needed.

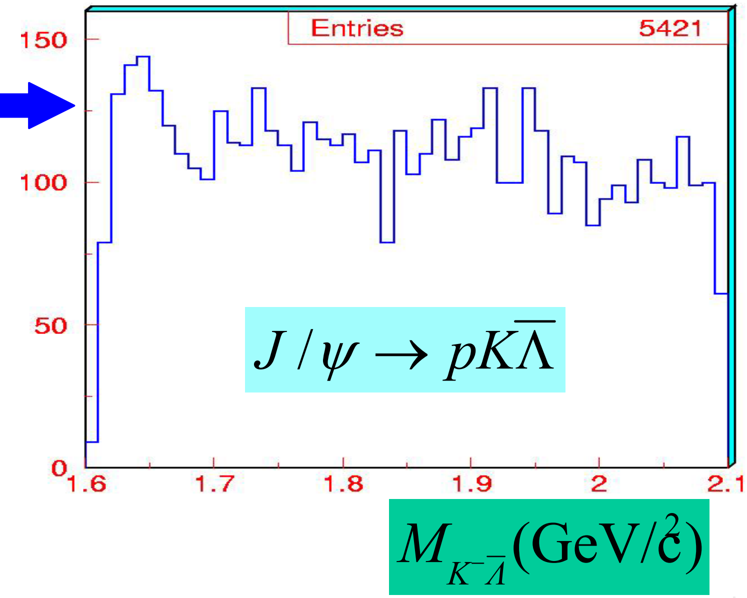
- Conventional K* or a multi-quark resonance?
  - Finding other decay modes $K\pi$, $K\pi\pi$ etc. would help to understand its nature.
  - We are now studying

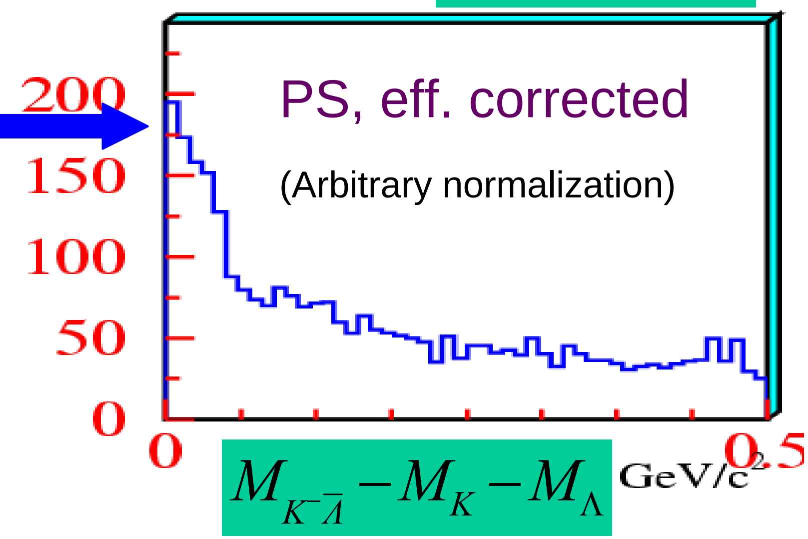
    $J/\psi \to KK\pi, KK\pi\pi$

Observation of a strong enhancement near the threshold of $K^-\bar{\Lambda}$ mass spectrum at BES II

N_X^*







- **A strong enhancement is observed near the mass threshold of $M_{K\bar{\Lambda}}$ at BES II.**

- **Preliminary PWA with various combinations of possible N* and Λ* in the fits —— the structure N_x* has:**

  Mass 1500~1650 MeV/c^2

  Width 70~110 MeV/c^2

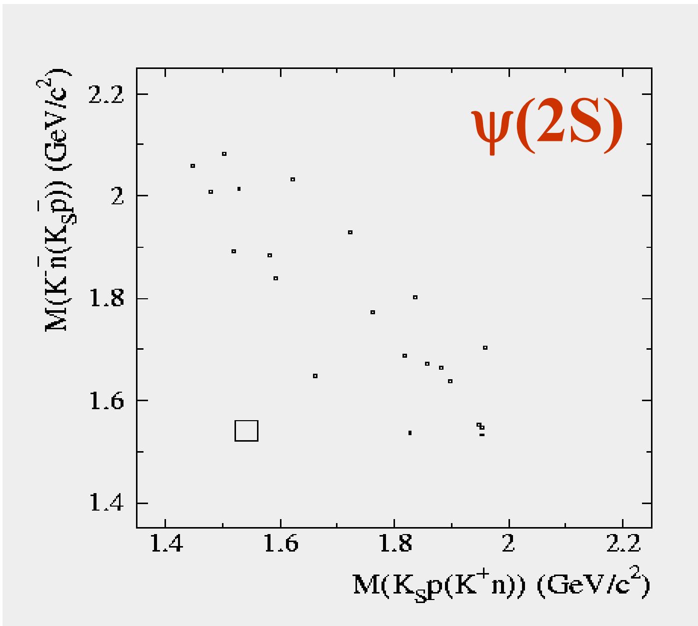
  J^P favors 1/2^-

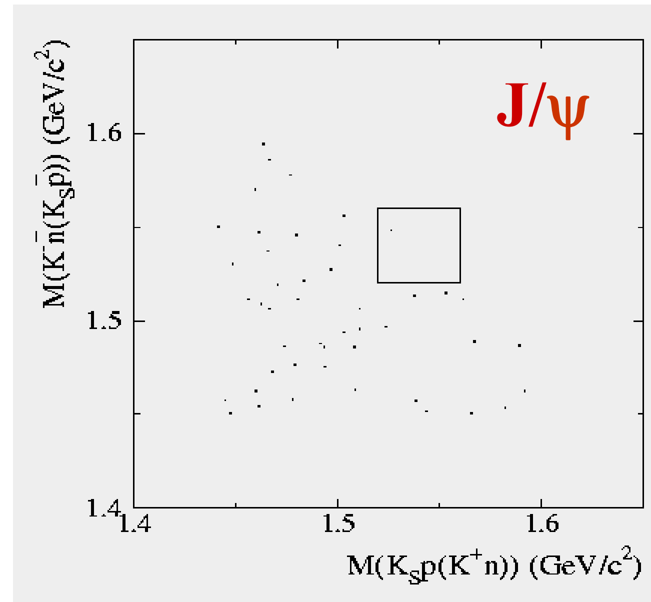
  → consistent with N*(1535) (or it is a new N_X*?)

Most importantly:

Large BR(J/ψ → pN_X*) BR(N_X*→ KΛ) ~ 2 X 10^{-4}
suggests *N_X* has strong coupling to KΛ.*
could be a KΛ molecular state (5-quark system).

Search for Θ^+(1540) pentaquark at BESII





Upper limits @ 90% C.L.

BR ($\psi(2S) \rightarrow \Theta\bar{\Theta} \rightarrow (K_Sp)(K^-\bar{n}) + (K_S\bar{p})(K^+n)$) < 0.84×10^{-5}

BR ($J/\psi \rightarrow \Theta\bar{\Theta} \rightarrow (K_Sp)(K^-\bar{n}) + (K_S\bar{p})(K^+n)$) < 1.1×10^{-5}

Phys. Rev. D 70, 012004 (2004)

Upper limits @ 90% C.L.

$$\mathcal{B}(\psi(2S) \to \Theta K^- \bar{n} \to K_S^0 p K^- \bar{n}) < 1.0 \times 10^{-5}$$

$$\mathcal{B}(\psi(2S) \to \bar{\Theta} K^+ n \to K_S^0 \bar{p} K^+ n) < 2.6 \times 10^{-5}$$

$$\mathcal{B}(\psi(2S) \to K_S^0 p \bar{\Theta} \to K_S^0 p K^- \bar{n}) < 0.60 \times 10^{-5}$$

$$\mathcal{B}(\psi(2S) \to K_S^0 \bar{p} \Theta \to K_S^0 \bar{p} K^+ n) < 0.70 \times 10^{-5}$$

$$\mathcal{B}(J/\psi \to \Theta K^- \bar{n} \to K_S^0 p K^- \bar{n}) < 2.1 \times 10^{-5}$$

$$\mathcal{B}(J/\psi \to \bar{\Theta} K^+ n \to K_S^0 \bar{p} K^+ n) < 5.6 \times 10^{-5}$$

$$\mathcal{B}(J/\psi \to K_S^0 p \bar{\Theta} \to K_S^0 p K^- \bar{n}) < 1.1 \times 10^{-5}$$

$$\mathcal{B}(J/\psi \to K_S^0 \bar{p} \Theta \to K_S^0 \bar{p} K^+ n) < 1.6 \times 10^{-5}$$

EXCITED BARYON STATES

- Probe the internal structure of light quark baryons
- Search for missing baryons predicted by quark model
- Obtain a better understanding of the strong interaction force in the non-perturbative regime

Key issues:

- **N*(1440)** first radial excitation

  M = 1345-1470, Γ = 160-450 MeV/c²

- **N*(1535)** first L=1 excitation

  M = 1495-1555, Γ = 90-250 MeV/c²

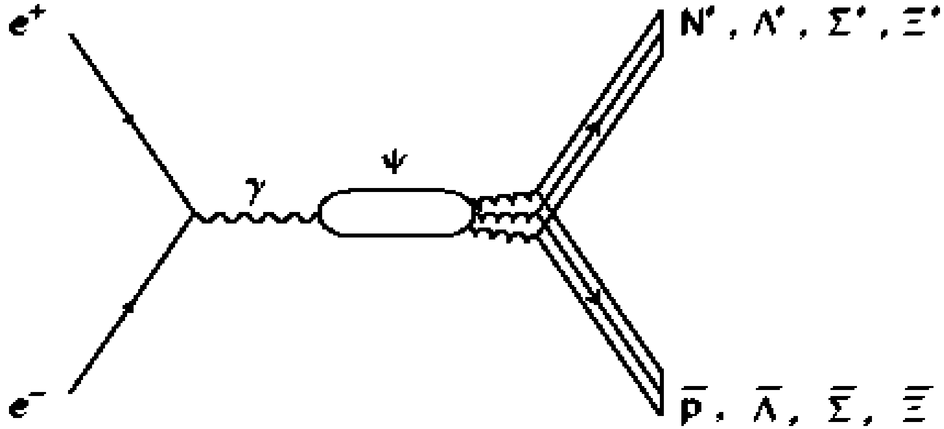
- **Missing N* resonances**

  Hybrid (qqqg), 3-quark, diquark-q

Baryon spectroscopy at BES@BEPC

Experimental advantages:

$J/\psi \rightarrow \bar{p}N^*, \bar{\Lambda}\Lambda^*, \bar{\Sigma}\Sigma^*, \bar{\Xi}\Xi^*$



For $J/\psi \rightarrow N\bar{N}\pi$ and $J/\psi \rightarrow N\bar{N}\pi\pi$, Nπ and Nππ systems are limited to be pure isospin 1/2.

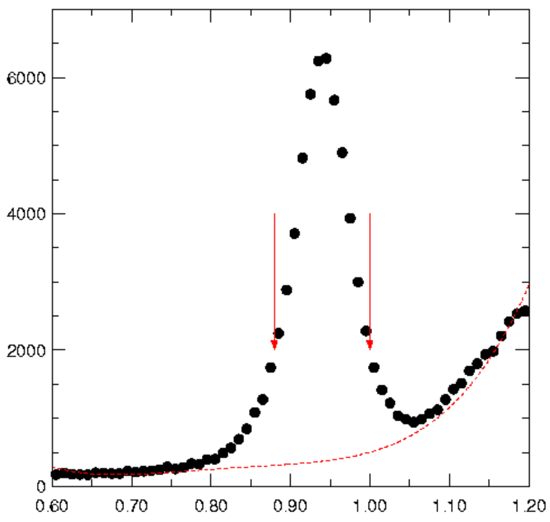
Missing N* with small couplings to πN & γN, but large coupling to gggN: $\Psi \rightarrow \bar{p}p\eta, \bar{p}p\varpi, \bar{p}p\eta', \bar{p}p\phi, \bar{p}\Lambda K, \bar{p}\Sigma K, \ldots$

Not only N*, but also: $\Lambda^*, \Sigma^*, \Xi^*$ $\Psi \rightarrow \Xi\Lambda K, \Xi\Sigma K, \ldots$

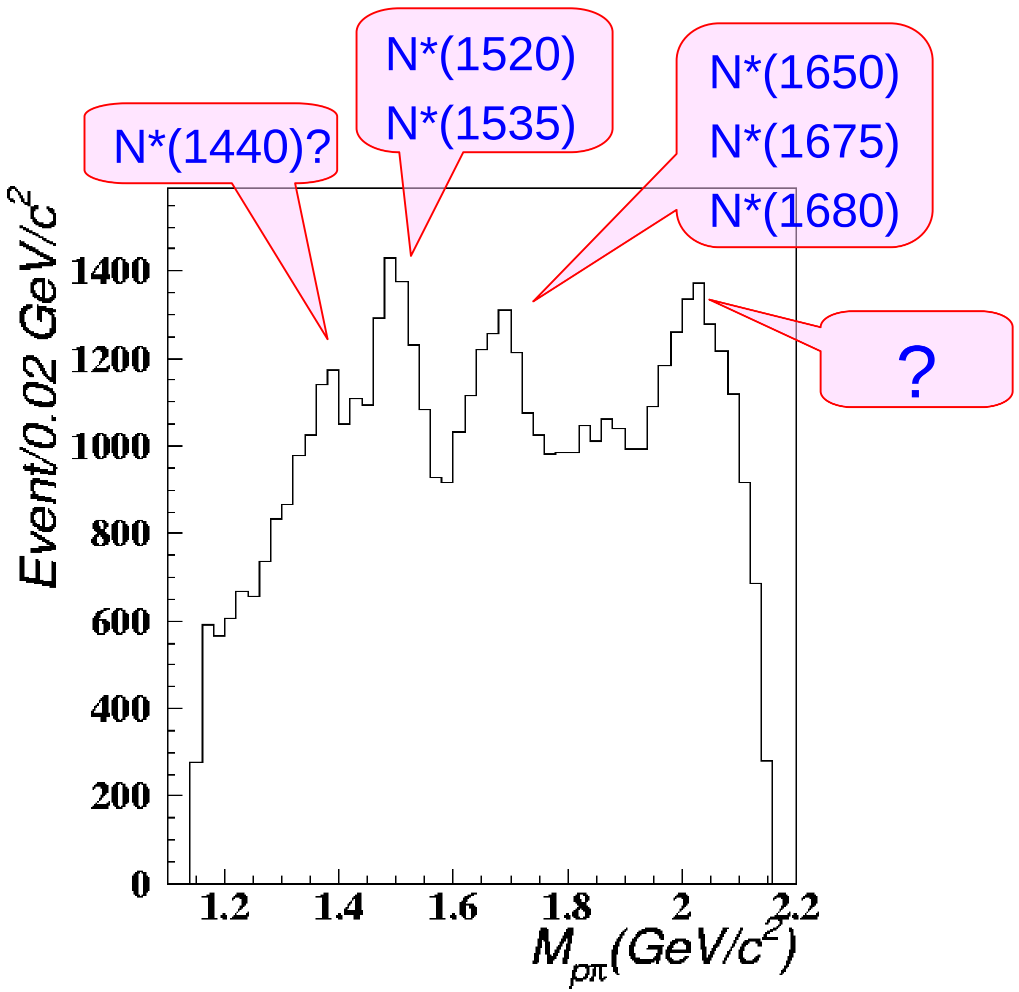
Less allowed spins due to threshold effect, hence less overlap effects.

Evidence for two new N* peaks

$$J/\psi \to p\bar{n}\pi^- + c.c.$$



Missing mass spectrum (GeV/c^2)

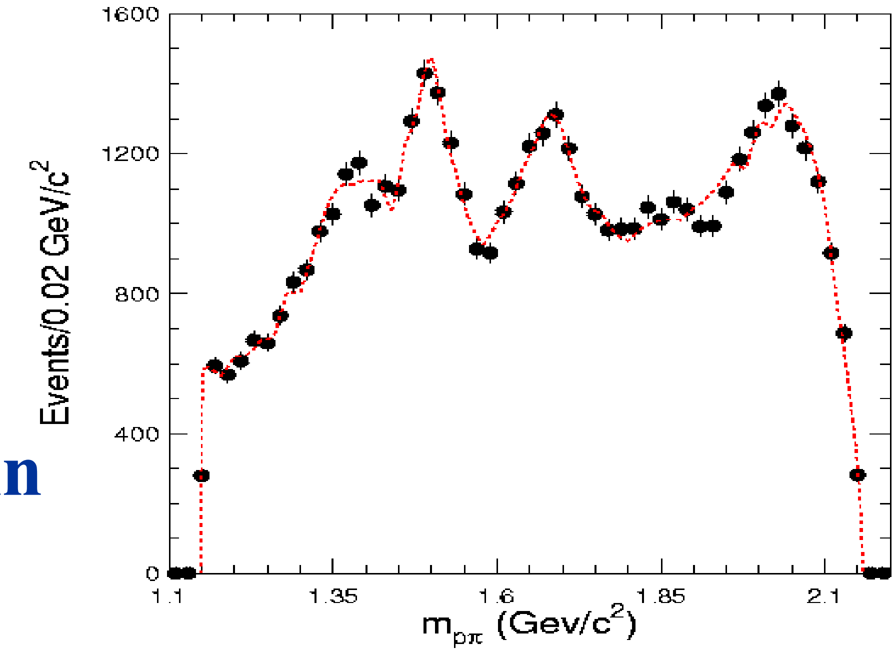


- **Fitting formula**

$$\frac{q^{2l+1}k}{(M^2 - M_0^2) + M_0^2\Gamma_0^2}$$

k **: momentum of** $\overline{n}$

q **: proton momentum in M_x frame**



➢ **Possible new N* resonance**

$$M = 2065 \pm 3^{+15}_{-30}\,\mathrm{MeV/c^2} \quad \Gamma = 175 \pm 12 \pm 40\,\mathrm{MeV/c^2}$$

➢ **preliminary PWA favors 3/2+**

hep-ex/0405030

MASS AND KΛ COUPLING OF N*(1535)

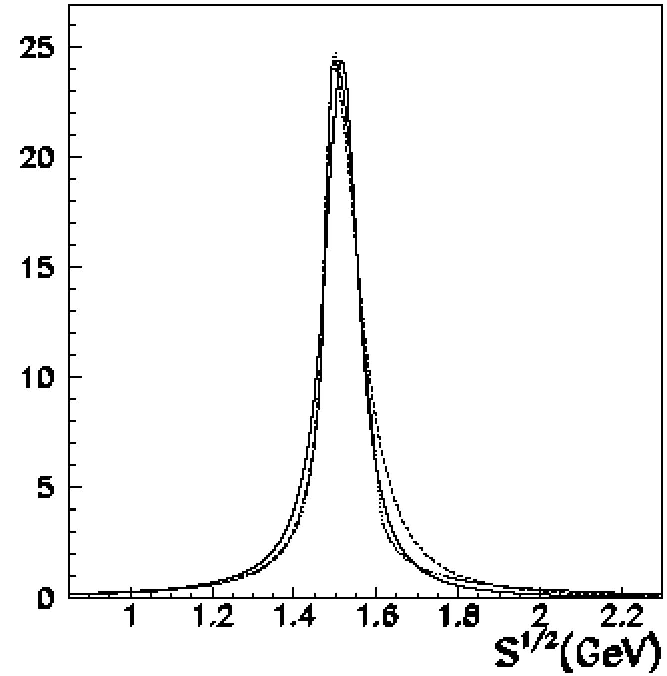
B.C. Liu and B.S. Zou, nucl-th/0503069

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

Phys. Lett. B510 (2001) 75

$g_{N^*K\Lambda}/g_{N^*p\eta}/g_{N^*p\pi} \sim 1.3 : 1 : 0.6$

Smaller N*(1535) BW mass



$$\Gamma_{N^*}(s) = \Gamma^0_{N^*}\left[0.8\rho_{\pi N}(s) + 2.1\rho_{\eta N}(s) + 3.5\rho_{\Lambda K}(s)\right]$$

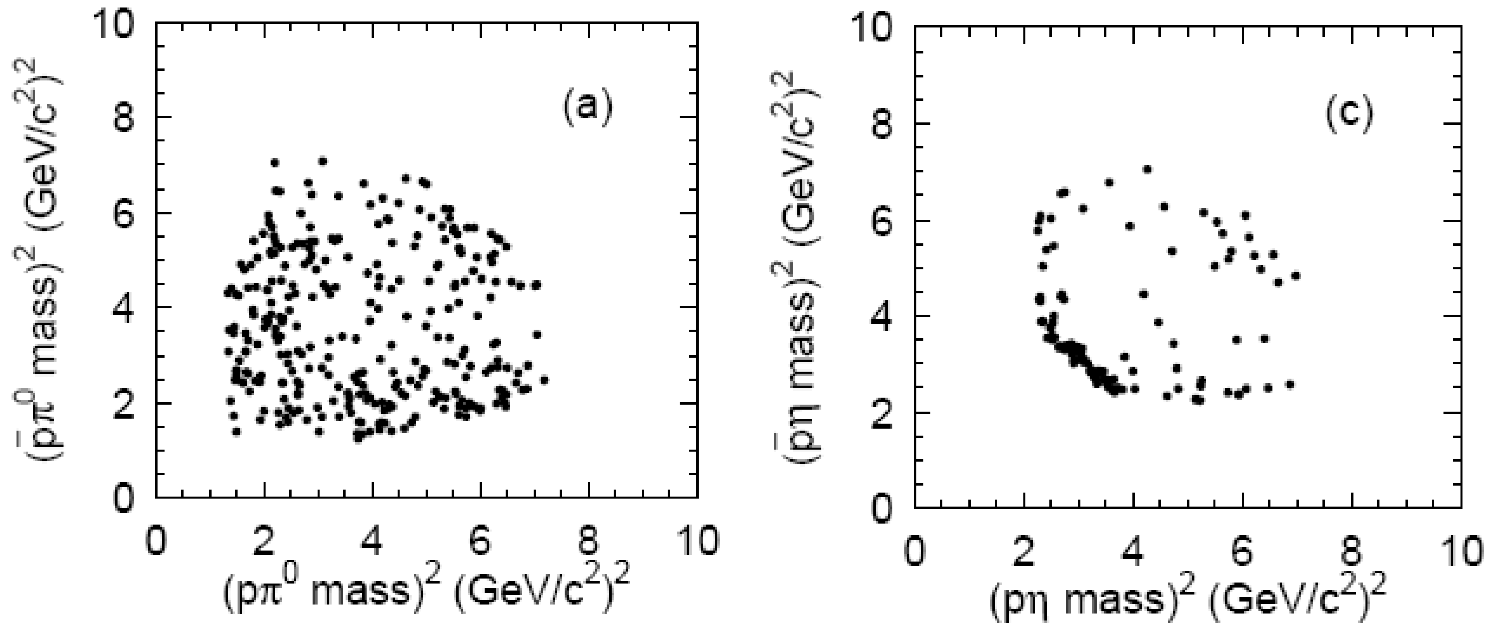
$$M_{N^*} \approx 1400 MeV$$

$$\Gamma^0_{N^*} = 270 MeV$$

$\psi(2S) \rightarrow p\bar{p}\pi^0(\eta)$

For N* study,

- studied in earlier J/ψ decays at BES
- Decay into $p\bar{p}\pi^0(\eta)$ is dominated by two-body via an excited state of the nucleon



$$\mathcal{B}(\psi' \rightarrow p\bar{p}\pi^0) = (13.2 \pm 1.0 \pm 1.5) \times 10^{-5},$$
$$\mathcal{B}(\psi' \rightarrow p\bar{p}\eta) = (5.8 \pm 1.1 \pm 0.7) \times 10^{-5},$$

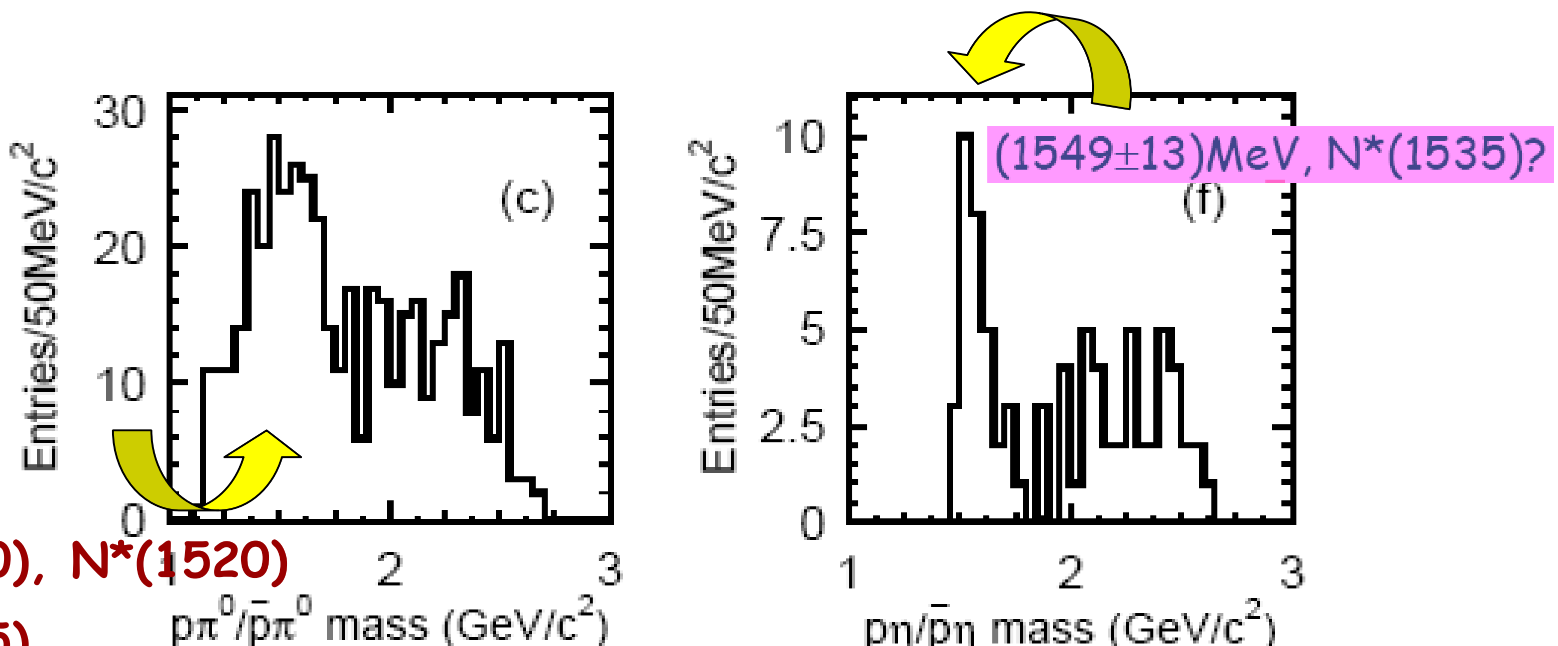
Phys.Rev.D71:072006,2005

$\psi(2S) \to pp\pi^0(\eta)$

$$Q_{p\bar{p}\pi^0} = \frac{\mathcal{B}(\psi' \to p\bar{p}\pi^0)}{\mathcal{B}(J/\psi \to p\bar{p}\pi^0)} = (12.1 \pm 1.9)\%$$

$$Q_{p\bar{p}\eta} = \frac{\mathcal{B}(\psi' \to p\bar{p}\eta)}{\mathcal{B}(J/\psi \to p\bar{p}\eta)} = (2.8 \pm 0.7)\%$$

Phys.Rev.D71:072006,2005



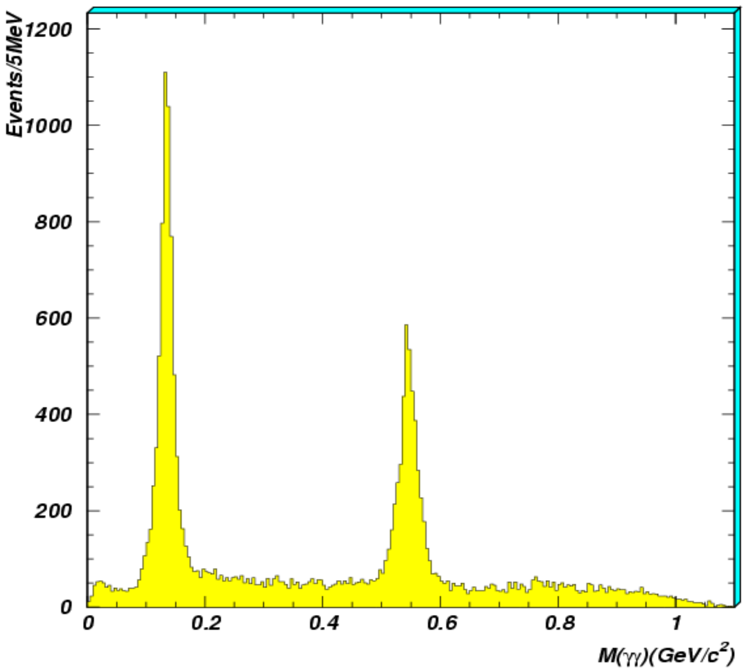
N*(1440), N*(1520)

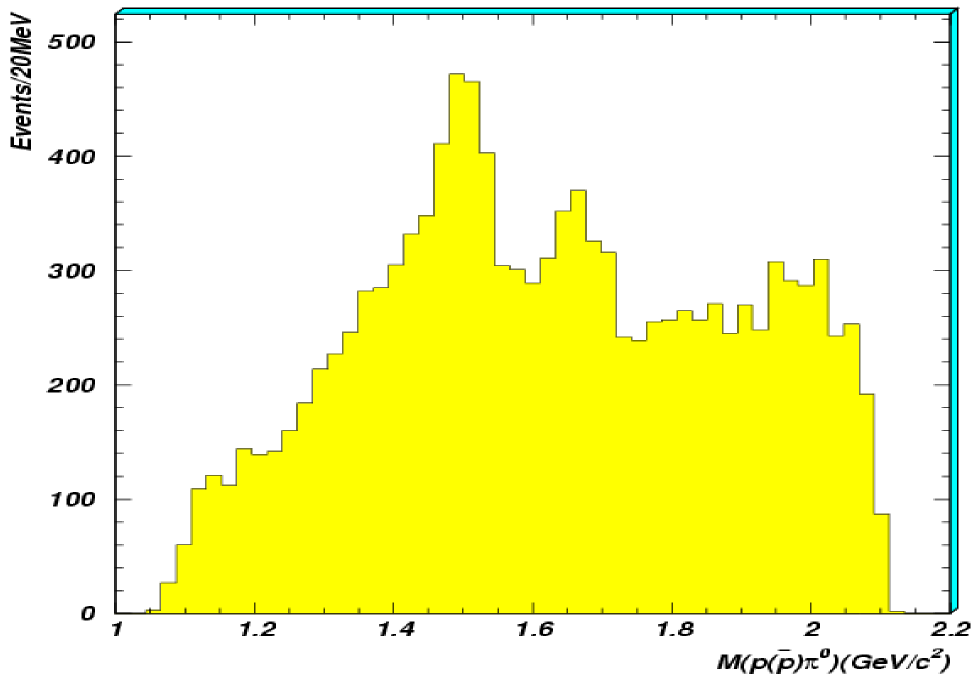
N*(1535) …

$p\bar{p}\pi^0$ $p\bar{p}\eta$

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

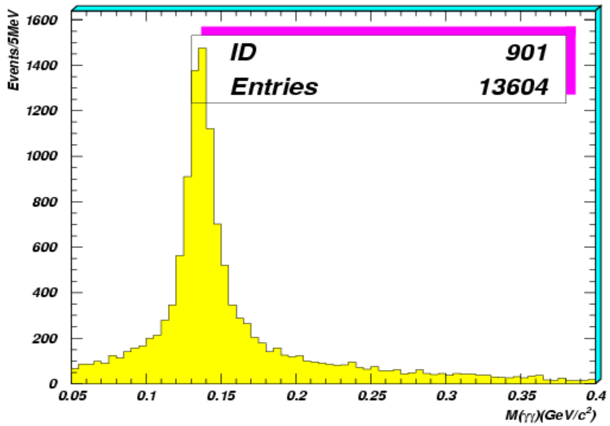
BESII 58M (preliminary)

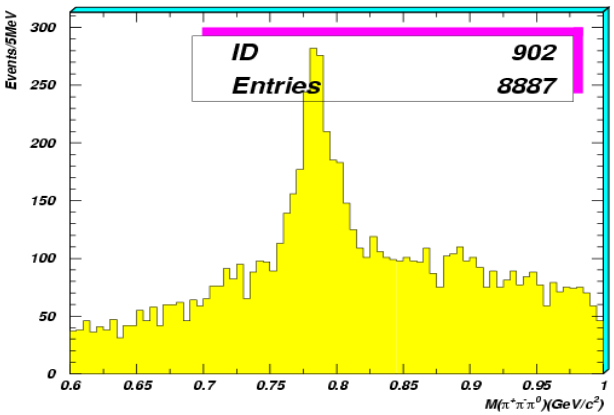




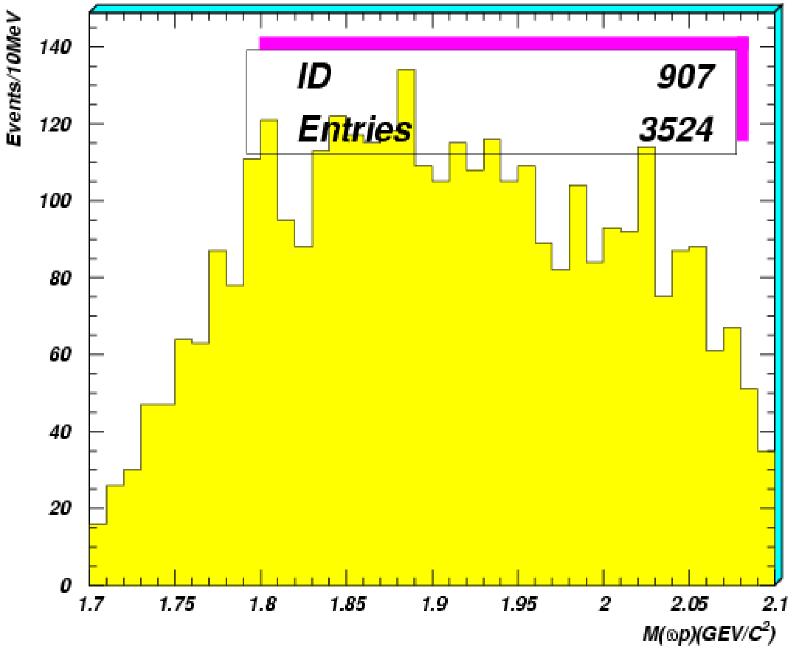
PWA is being performed

$J/\psi \to p\bar{p}\omega$ from BESII data





BESII 58M (preliminary)



PWA is being performed

$J/\psi \to p\bar{p}$, $\Lambda\bar{\Lambda}$, and $\Sigma^0\bar{\Sigma}^0$

The angular distribution of two baryon final states can be written as:

$$dN/d\cos\theta_B \propto 1 + \alpha \cos^2\theta_B$$

θ_B **is the angle between the baryon direction and the positron beam direction.**

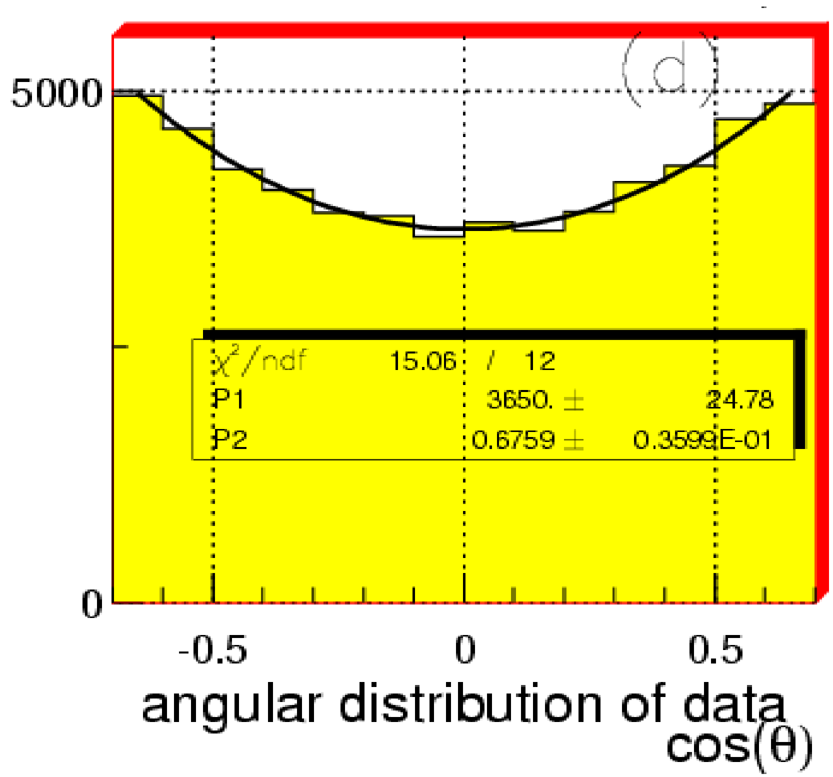
α predicted by different models from first-order QCD

α	pp-bar	ΛΛ-bar	$\Sigma^0\Sigma^0$-bar
Model [1]	**0.46**	**0.32**	**0.31**
Model [2]	**0.69, 0.70**	**0.51**	**0.43**

[1] M. Claudson, S.L. Glashow, M.B.Wise, Phys. ReV. D25, 1345 (1982)

[2] C. Carimalo, Int. J. Mod. Phys. A2, 249 (1987)

J/ψ → pp-bar (Phys. Lett. B591（2004）42—48)



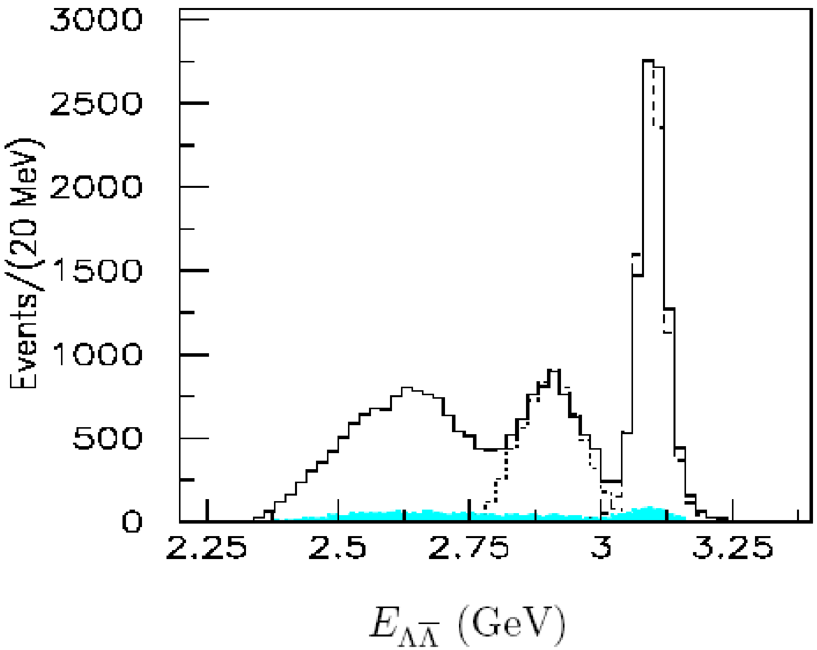
$\alpha = 0.676 \pm 0.036 \pm 0.042$

$Br = (2.26 \pm 0.01 \pm 0.14) \times 10^{-3}$

0.69, 0.70

- **The Br is within one σ of PDG value.**
- **Angular distribution is in good agreement with prediction [2].**

$J/\psi \rightarrow \Lambda\Lambda$-bar and $\Sigma^0\Sigma^0$-bar



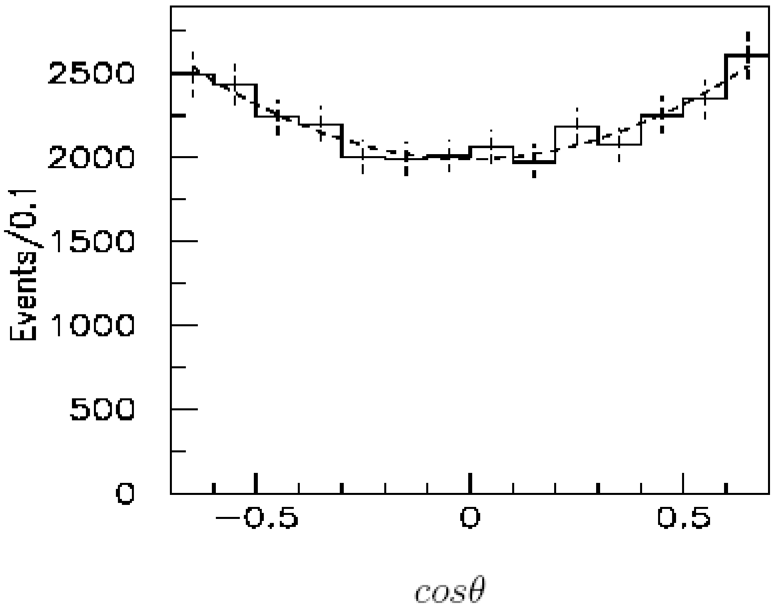
hep-ex/0506020

BESII preliminary

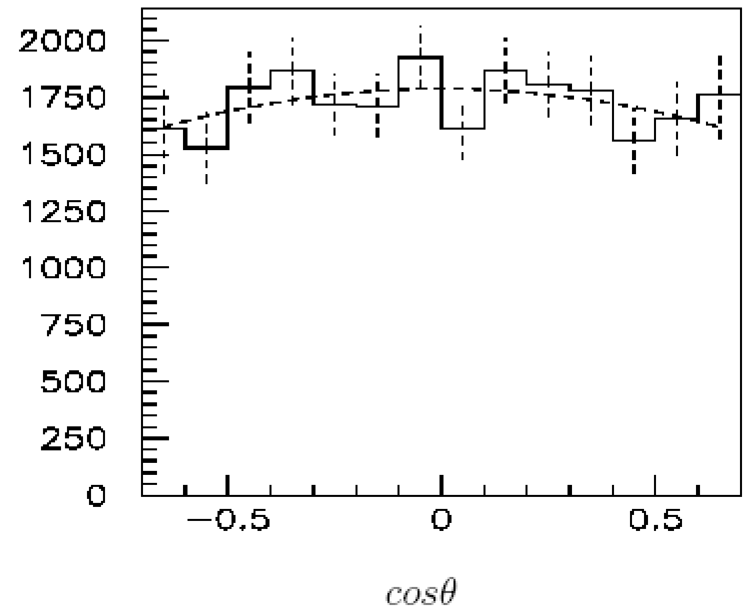
Energy distribution of $\Lambda\Lambda$-bar for $J/\psi \rightarrow \Lambda\Lambda$-bar + X

- A clear peak centered at the J/ψ mass from the decay $J/\psi \rightarrow \Lambda\Lambda$-bar is observed. [$\Lambda \rightarrow p\pi$]
- The enhancement centered at 2.9 GeV is mostly due to the decay $J/\psi \rightarrow \Sigma^0\Sigma^0$-bar, where Σ^0 decays to $\Lambda\gamma$.

$J/\psi \to \Lambda\Lambda$-bar



$J/\psi \to \Sigma^0\Sigma^0$-bar



α=0.65±0.12±0.08

α=-0.22±0.17±0.09

Br=(2.05±0.03±0.11) ×10^{-3}

Br=(1.40±0.03±0.07) ×10^{-3}

- **The α value for $J/\psi \to \Lambda\Lambda$-bar is consistent with the previous measurements.**
- **The α value for $J/\psi \to \Sigma^0\Sigma^0$-bar is negative, which agrees with that of BESI while conflicts with the theoretical expectation.**

SUMMARY

Using BESII's 58 million J/ψ (&14M ψ(2S)) events

- New Observation of X(1835) in $J/\psi \rightarrow \gamma\eta'\pi^+\pi^-$.
- **Observation of an anomalous enhancements near the threshold of $p\overline{\Lambda}$ in $J/\psi \rightarrow pK^-\overline{\Lambda}$; and evidence of N_X^* was observed near $K\Lambda$ mass threshold, suggesting a resonant or bound state.**
- **No pentaquark state θ(1540) seen.**
- N(2065) observed in $J/\psi \rightarrow p\bar{n}\pi^-$, favors 3/2+.
- **Measurement on $\psi(2S) \rightarrow p\bar{p}\pi^0(\eta)$ reported, and some enhancements are observed.**
- **Precise measurements of $J/\psi \rightarrow p\bar{p}$, $\Lambda\overline{\Lambda}$, and $\Sigma^0\overline{\Sigma}^0$.**