Recent BES Results on Charmonium Physics

Ping Wang

IHEP, Beijing 100039, China

for the BES Collaboration

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QCD AND HIGH ENERGY HADRONIC INTERACTIONS

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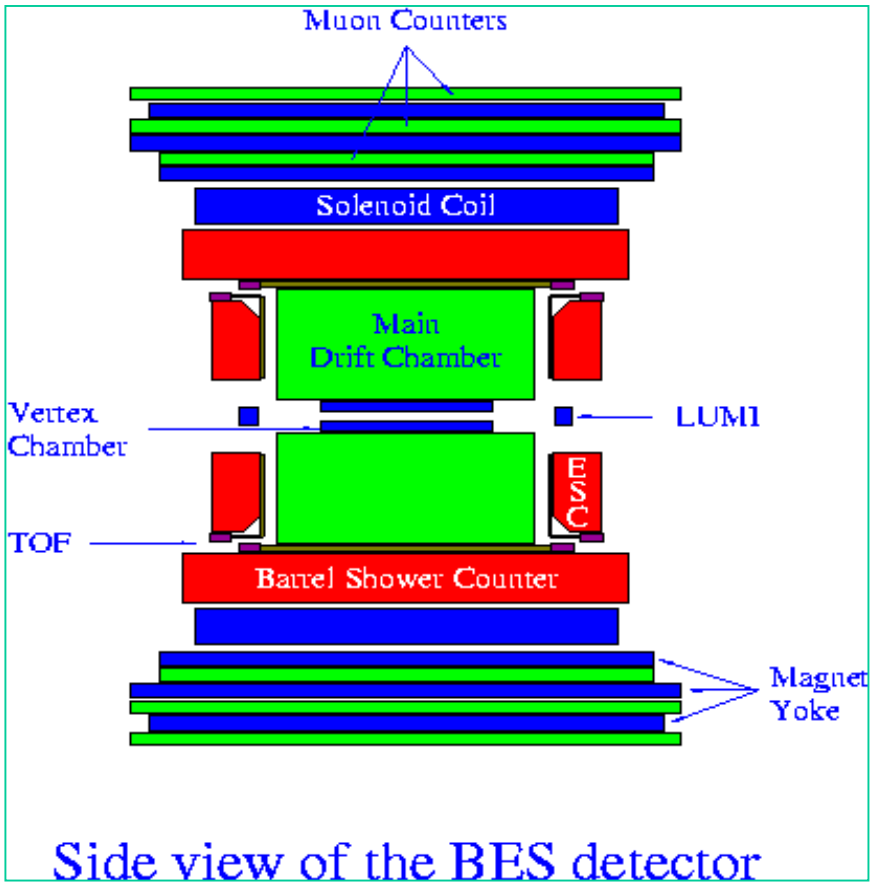
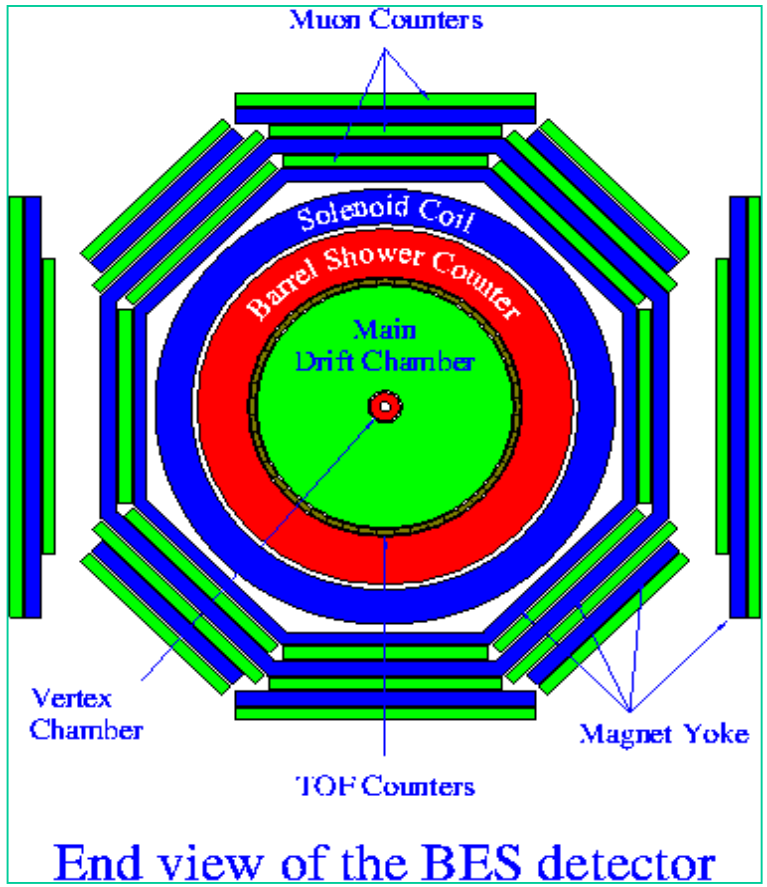
- **Introduction**
- **New state searches and observations**
- **New decay modes observations**
- **Measurements with improved accuracies**
- **Summary**

INTRODUCTION

BESII Detector



Side view of the BES detector



End view of the BES detector

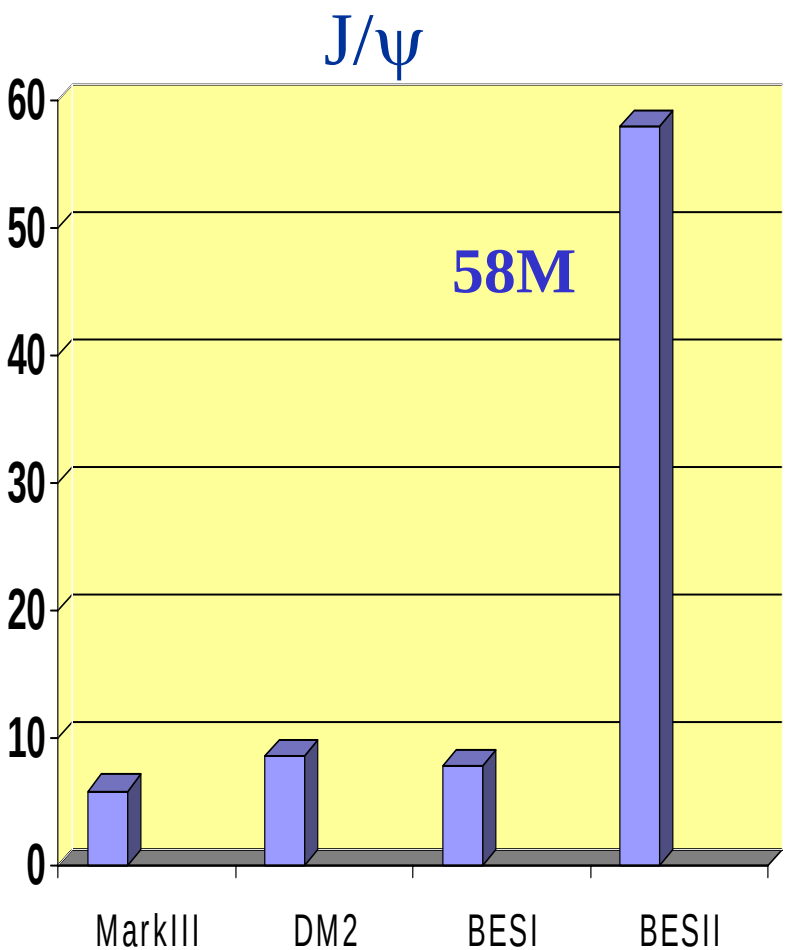
VC: σ_{xy} = 100 μm
MDC: σ_{xy} = 220 μm
$\sigma_{dE/dx}$ = 8.5 %
$\Delta p/p = 1.7\sqrt{(1+p^2)}$

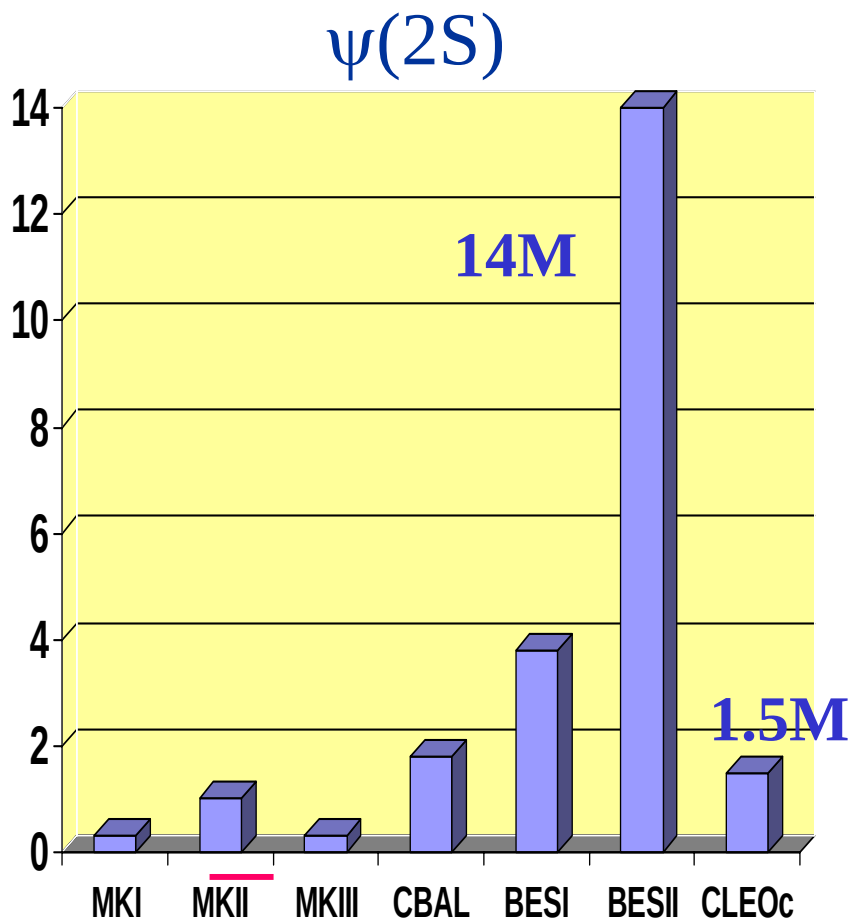
TOF: σ_T = 180 ps
BSC: $\Delta E/\sqrt{E}$ = 22 %
σ_ϕ = 7.9 mr
σ_z = 2.3 cm

μ counter: $\sigma_{r\phi}$ = 3 cm
σ_z = 5.5 cm
B field: 0.4 T

INTRODUCTION

World J/ψ and ψ(2S) Samples (×10⁶)



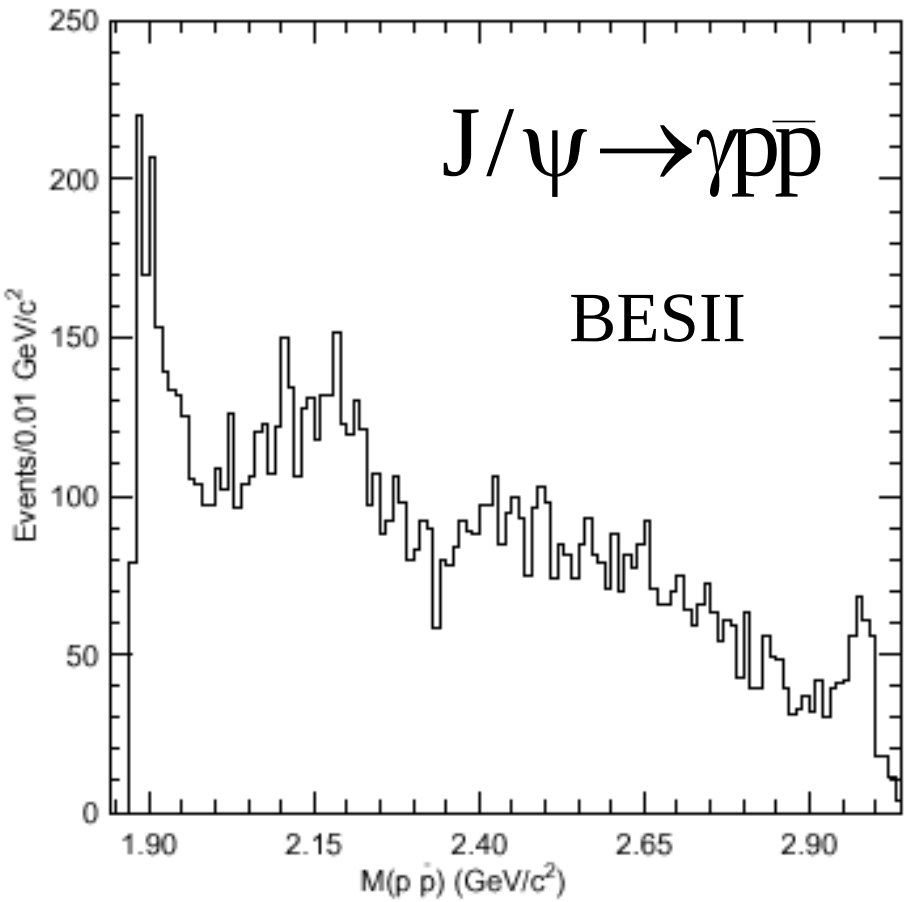


New States Searches & Observations

1. $J/\psi \rightarrow \gamma p\bar{p}$
2. σ analyses
3. Excited Baryon searches
4. Pentaquark state searches

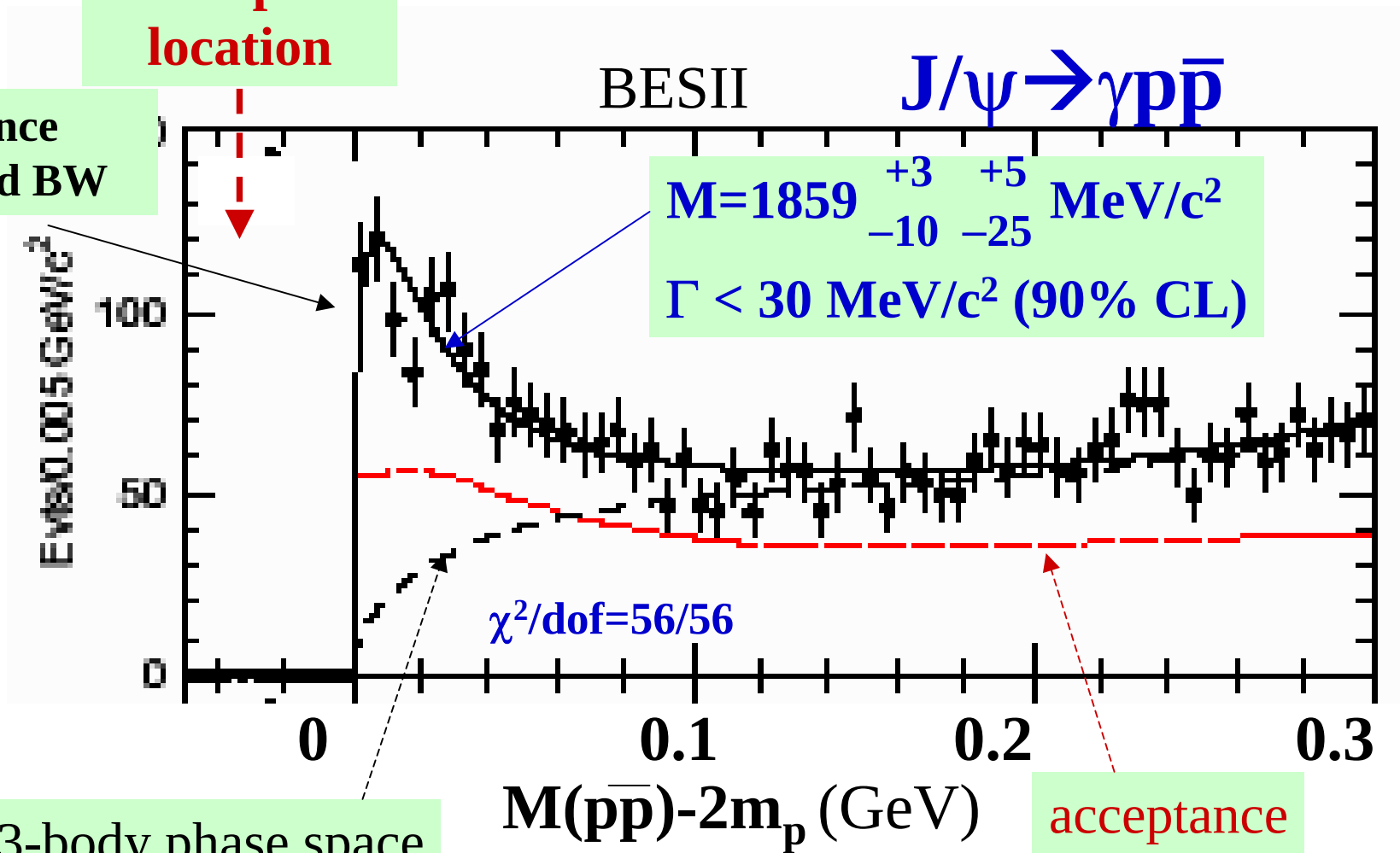
1. $J/\psi \to \gamma p\bar{p}$

$p\bar{p}$ masses for selected events



Besides η_c peak, there is a clear enhancement near threshold.

1. $J/\psi \to \gamma p\bar{p}$



It can be fitted as an S-wave resonance

1. $J/\psi \to \gamma p\bar{p}$

- Any PDG particle can be excluded.
- Its mass and unexpected narrow width suggest a possible interpretation as “deutron like” proton-antiproton bound state (baryonium)

2. σ analyses

σ in $J/\psi \to \omega\pi^+\pi^-$

BES II Preliminary

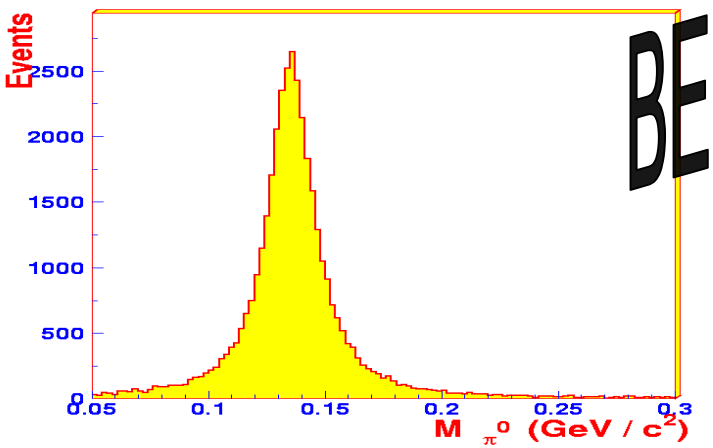


Figure 1: π^0 signal

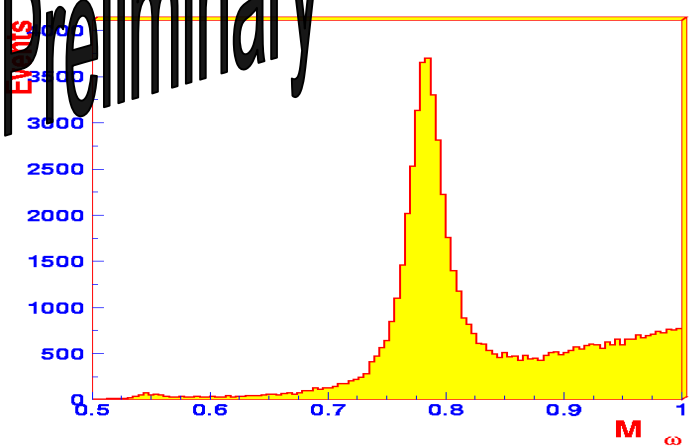


Figure 2: ω signal

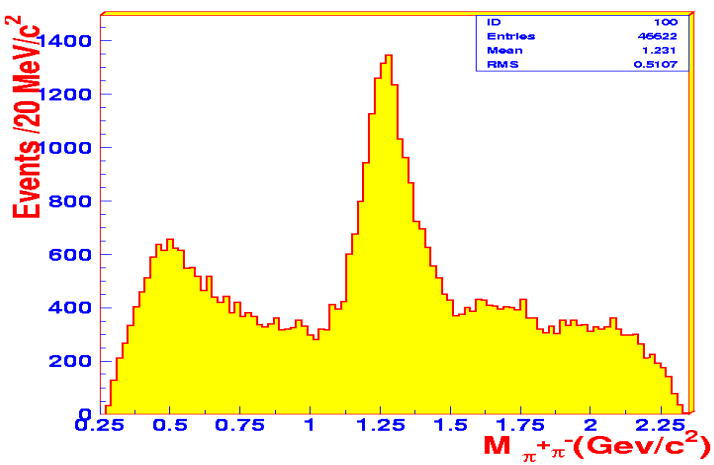
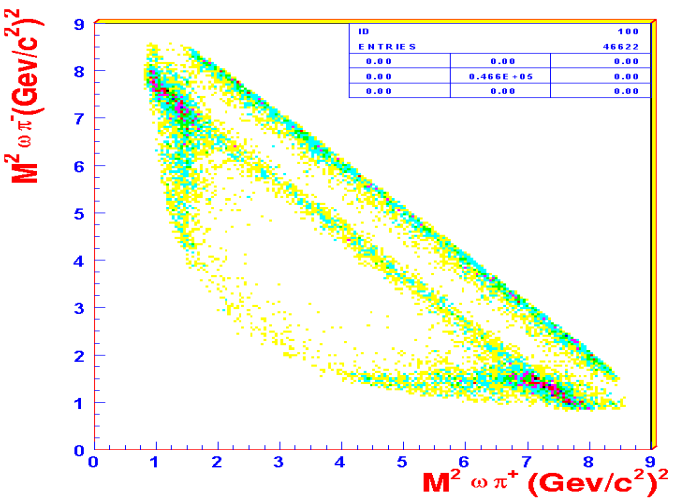


Figure 3: The invariant mass spectrum of $\pi^+\pi^-$



2. σ analyses

Pole position of the σ

If the σ amplitude is written as:

$$f = \frac{G_\sigma}{M^2 - s - iM\Gamma_{tot}(s)},$$

$$\Gamma_{tot}(s) = g_1 \frac{\rho_{\pi\pi}(s)}{\rho_{\pi\pi}(M^2)} + g_2 \frac{\rho_{4\pi}(s)}{\rho_{4\pi}(M^2)},$$

$$g_1 = f(s) \frac{s - m_\pi^2/2}{M^2 - m_\pi^2/2} \exp[-(s - M^2)/a].$$

pole: (542 ±10 ± 40) – i(249 ±25 ±50) MeV

If $\Gamma(s) = \Gamma_0 \rho_{\pi\pi}(s)/ \rho_{\pi\pi}(M^2)$

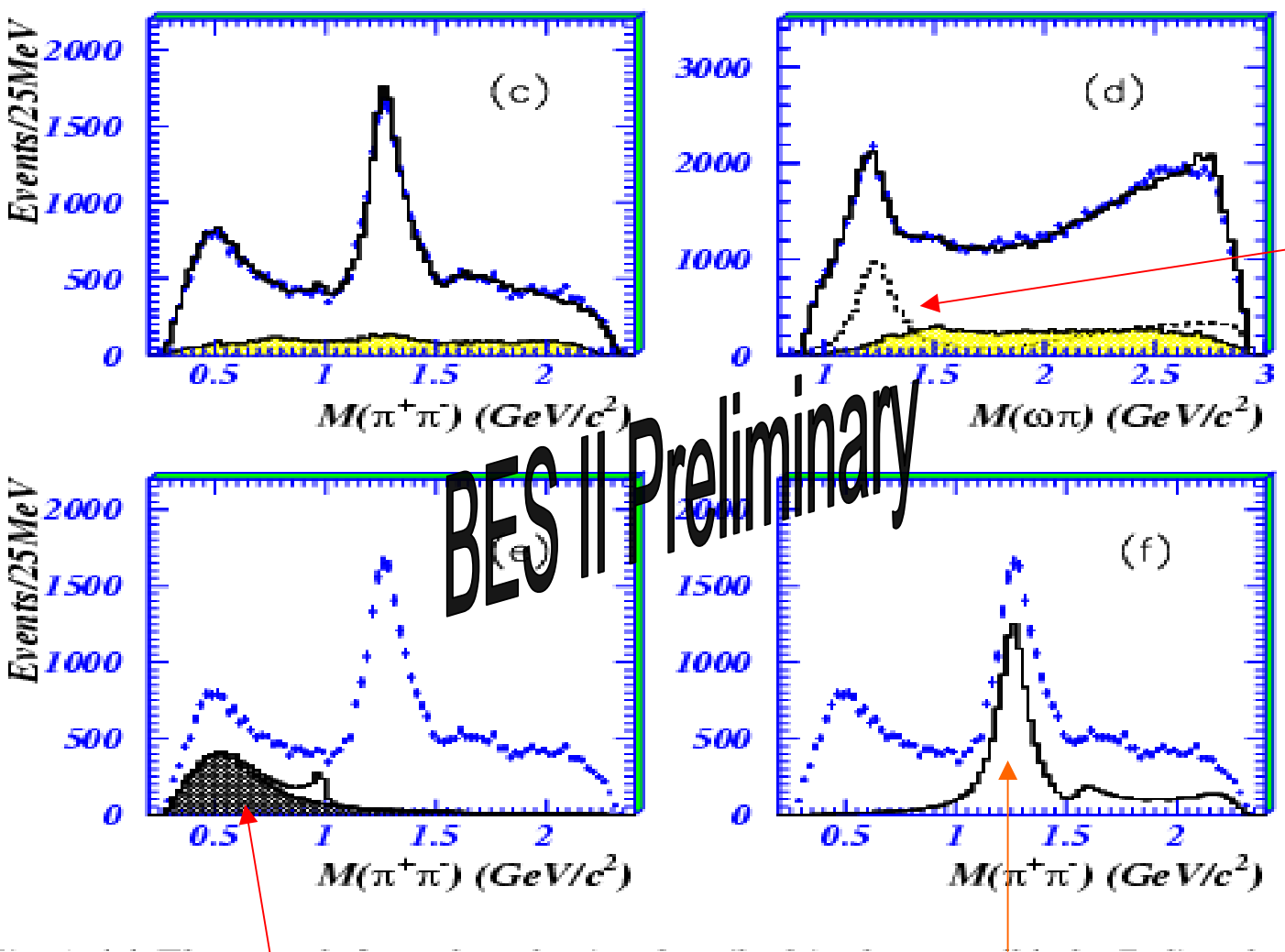
pole: (570 ± 20 ± 45) – i(274±25 ±50) MeV

If Γ = constant

pole: (542 ± 20 ± 40) – i(269 ±30 ±55) MeV

Global fit

2. σ analyses



3. Excited Baryon searches

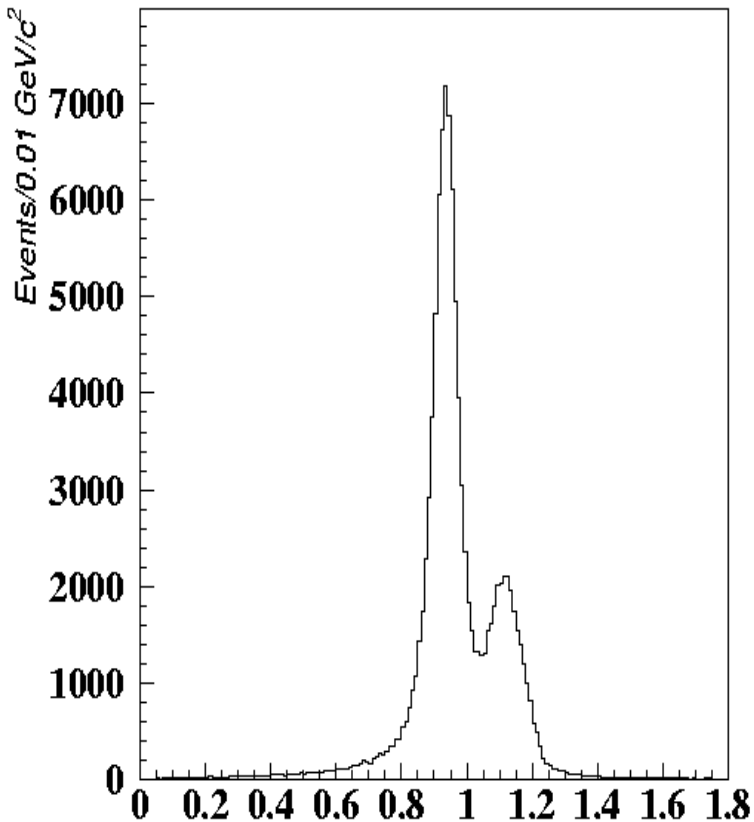
- Probe the internal structure of light quark baryons
- Obtain a better understanding of the strong interaction force in the non-perturbative regime
- $J/\psi \to p\pi^{-}\bar{n}$

3. Excited Baryon searches

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

- Events selection

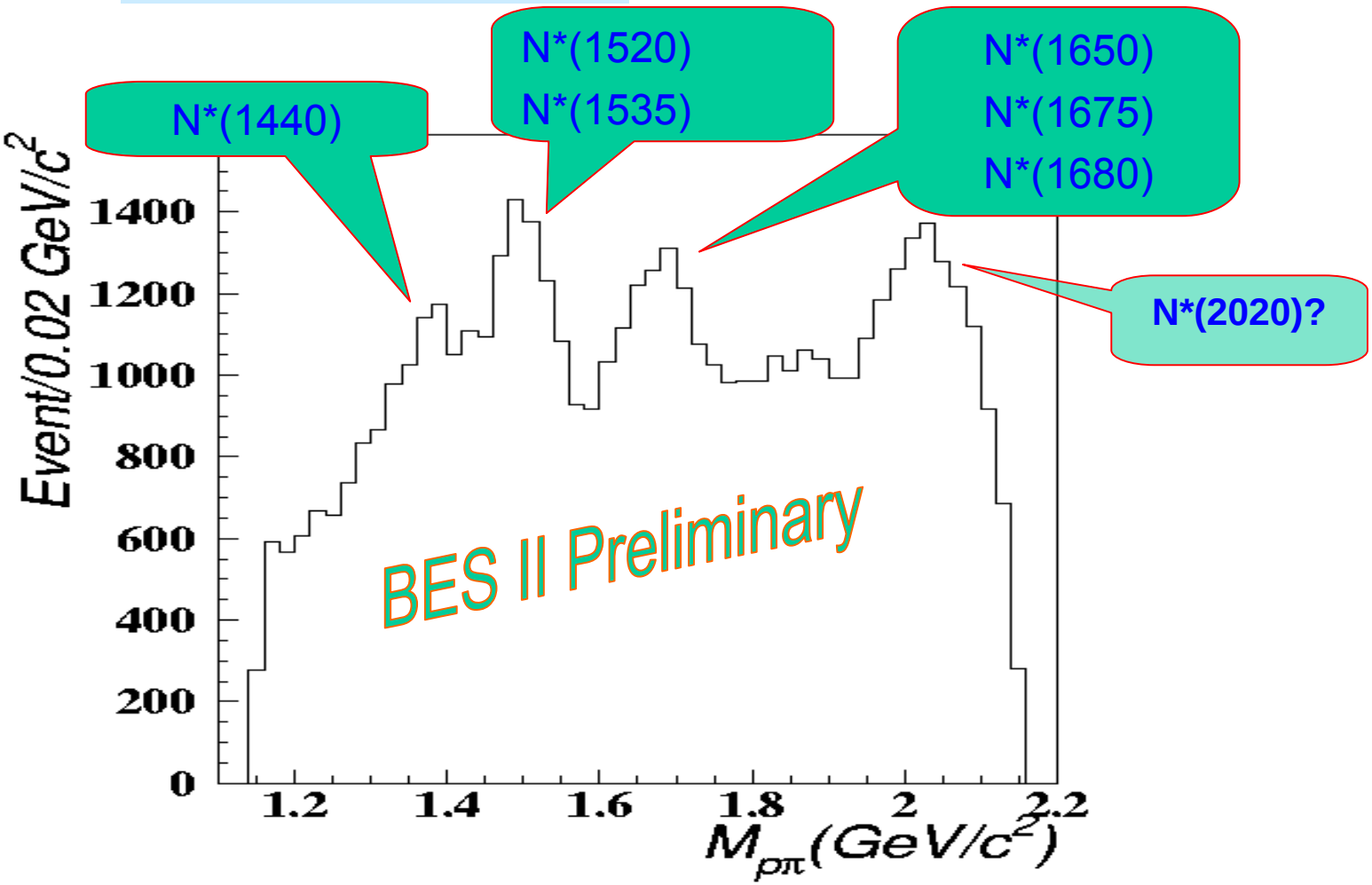
- **2 good charged tracks**
- **Q1+Q2 = 0**
- **$|\cos\theta| < 0.8$**
- **PID: TOF and dE/dx**
- ***Prob*(χ^2, 1C) > 0.06**
- **$M_{p\pi} > 1.15$ GeV**



Missing mass (n)

3. Excited Baryon searches

N* in $J/\psi \to p\pi^- \bar{n}$



4. Pentaquark state search

Current experimental results

LEPS @ Spring-8 reported a new resonance Θ,

Close to NK threshold, in $\gamma^{12}C \to K^+K^-X$

***S* = +1, M = 1540 MeV, Γ < 25 MeV, 4.6 σ**

A 5-quark system ($uudd\bar{s}$) candidate!

DIANA @ ITEP, CLAS @ Jlab, SAPHIR @ ELSA

report similar results subsequently.

HERMES, ZEUS and SVD Collaboration: M ~ 1527 MeV

A strange meson-baryon molecule state or a pentaquark state?

If the latter, it will be the first multi-quark state.

4. Pentaquark state search

Need more experimental facts

(through different processes)

BES investigates the pentaquark state Θ in the hadronic decays of charmonium

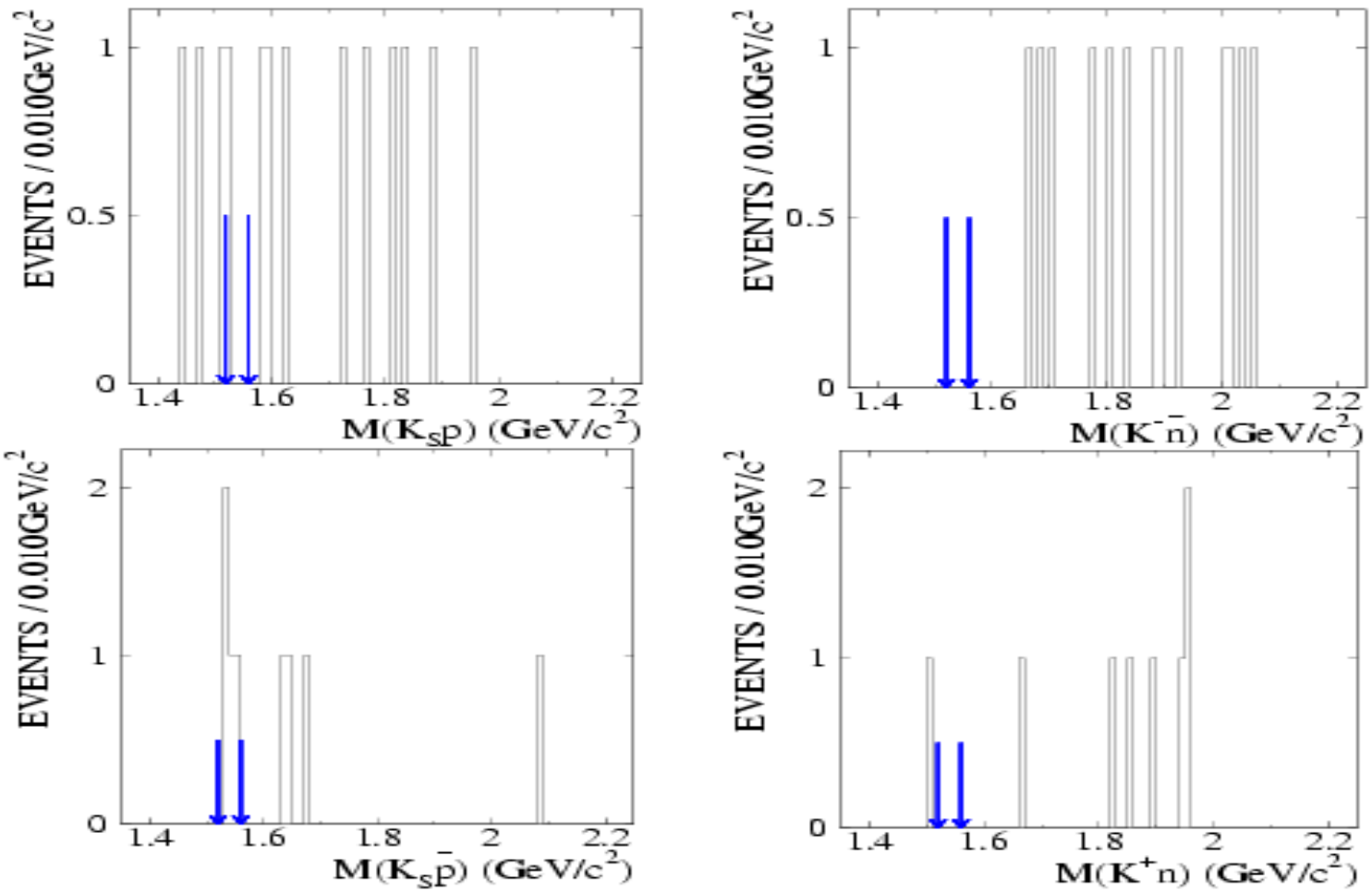
$\psi(2S)$ & $J/\psi \rightarrow \Theta \bar{\Theta} \rightarrow (K_S p)(K^- \bar{n})$ & $(K_S \bar{p})(K^+ n)$

$\Theta \rightarrow K_S p$ or $K^+ n$

$\bar{\Theta} \rightarrow K^- \bar{n}$ or $K_S \bar{p}$

4. Pentaquark state search

Individual Mass Distributions of $\psi(2S) \rightarrow K_S p K^- \bar{n}$ and $K_S \bar{p} K^+ n$ Decays



4. Pentaquark state search

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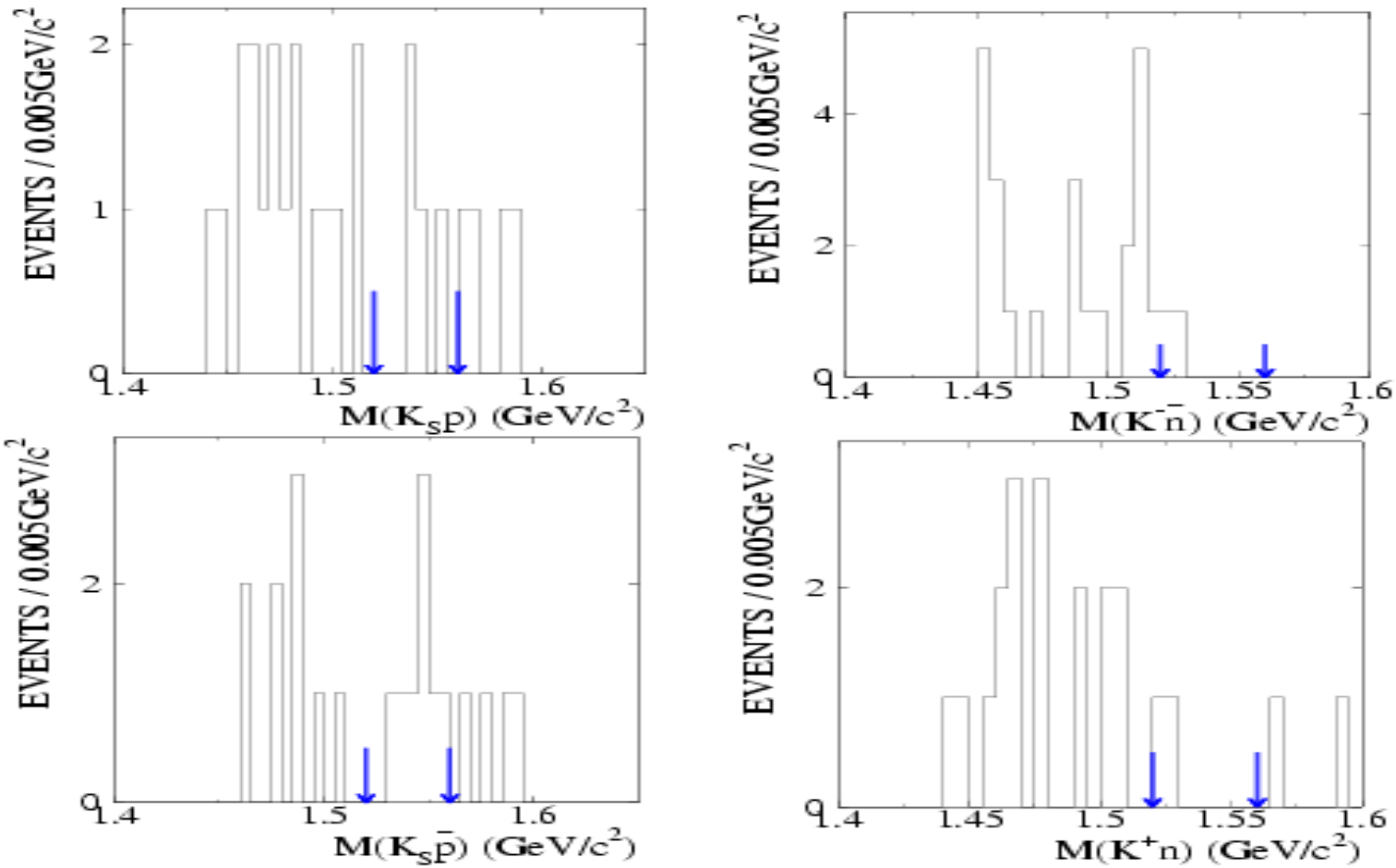
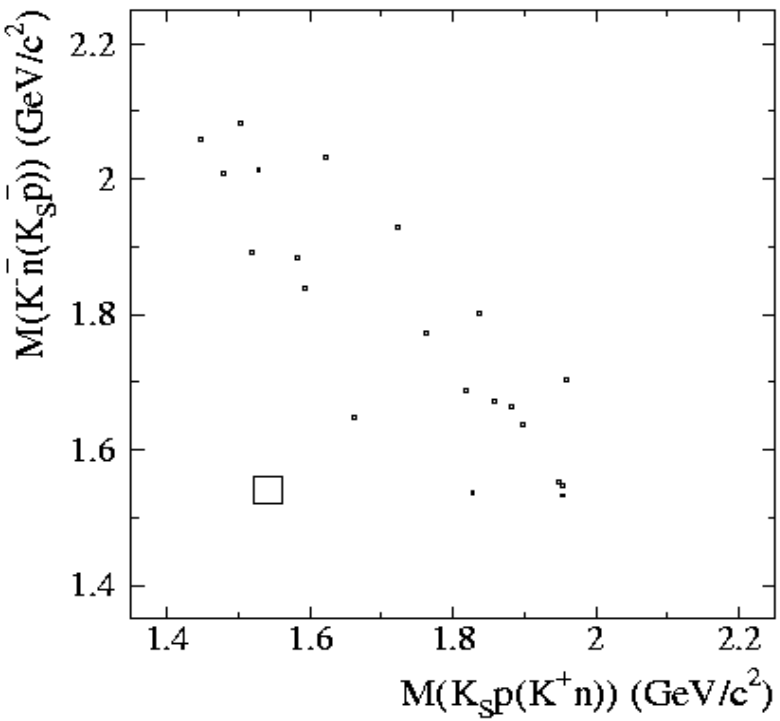
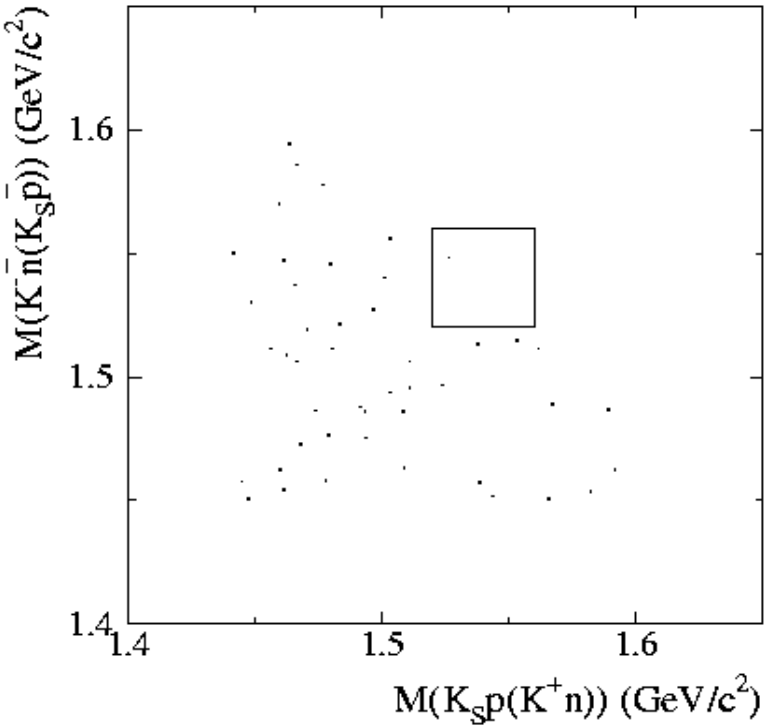


4. Pentaquark state search



$\psi(2S)$



J/ψ

No clear pentaquark state $\Theta(1540)$ (or $\bar{\Theta}$) was observed

4. Pentaquark state search

Upper limits @ 90% C.L.

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

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

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

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

4. Pentaquark state search

Upper limits @ 90% C.L.

$$\mathcal{B}(\psi(2S) \to \Theta\bar{\Theta} \to K^0_S p K^- \bar{n} + K^0_S \bar{p} K^+ n)$$

$$< \frac{2.30}{0.686 \times (2.85 \pm 0.08)\% \times (14.0 \times 10^6)} = 0.84 \times 10^{-5}$$

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

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

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

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

New Decay Modes Observations

$\psi(3770) \rightarrow \pi^+\pi^- J/\psi$

$\psi(2S) \rightarrow \gamma\chi_C$ is covered in Dr. C.Z.Yuan's talk

1. $\psi(3770) \to \pi^+\pi^- J/\psi$

- **$\psi(3770)$ is thought to decay entirely to pure $D\bar{D}$**
- **Lipkin: It could decay to non-$D\bar{D}$ with a large BR**

  Phys. Lett. B 179, 278 (1986)
- **Kuang: $\Gamma(\psi(3770) \to \pi^+\pi^- J/\psi)$ = (25~ 113) keV**

  Phys. Rev. D 65, 094024 (2002)

BESII: 27.7 pb^{-1} @~3.773 GeV

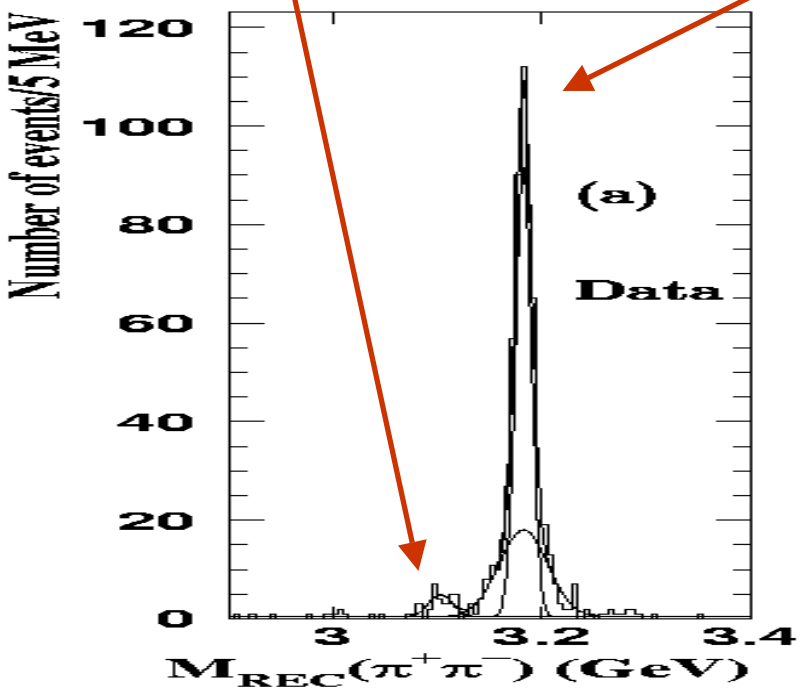
BES Preliminary

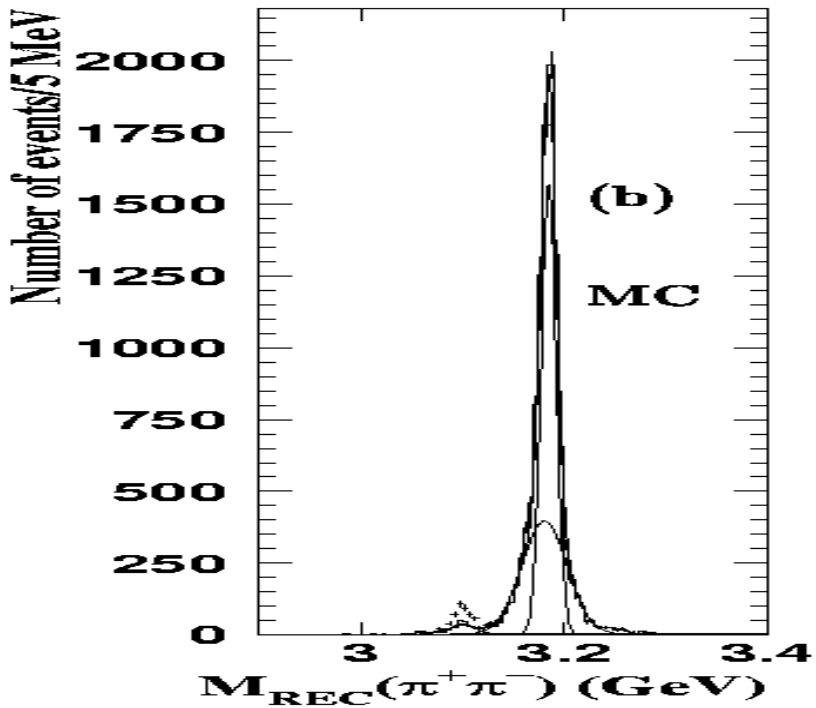
1. $\psi(3770) \rightarrow \pi^+\pi^- J/\psi$

$M_{REC}(\pi^+\pi^-) = \{(Ecm - E_{\pi+\pi-})^2 - |P_{\pi+\pi-}|^2\}^{1/2}$ distribution

$\psi(3770) \rightarrow \pi^+\pi^- J/\psi$

ISR return $\psi(2S) \rightarrow \pi^+\pi^- J/\psi$





- $|M(J/\psi) - M(l^+l^-)| < 150$ MeV
- $|E(\pi^+\pi^- l^+l^-) - Ecm| < 2.5\,\sigma_{E(\pi+\pi- l+l-)}$

BES Preliminary

1. $\psi(3770) \to \pi^+\pi^- J/\psi$

***Prob*(χ^2, 4C) >1%**

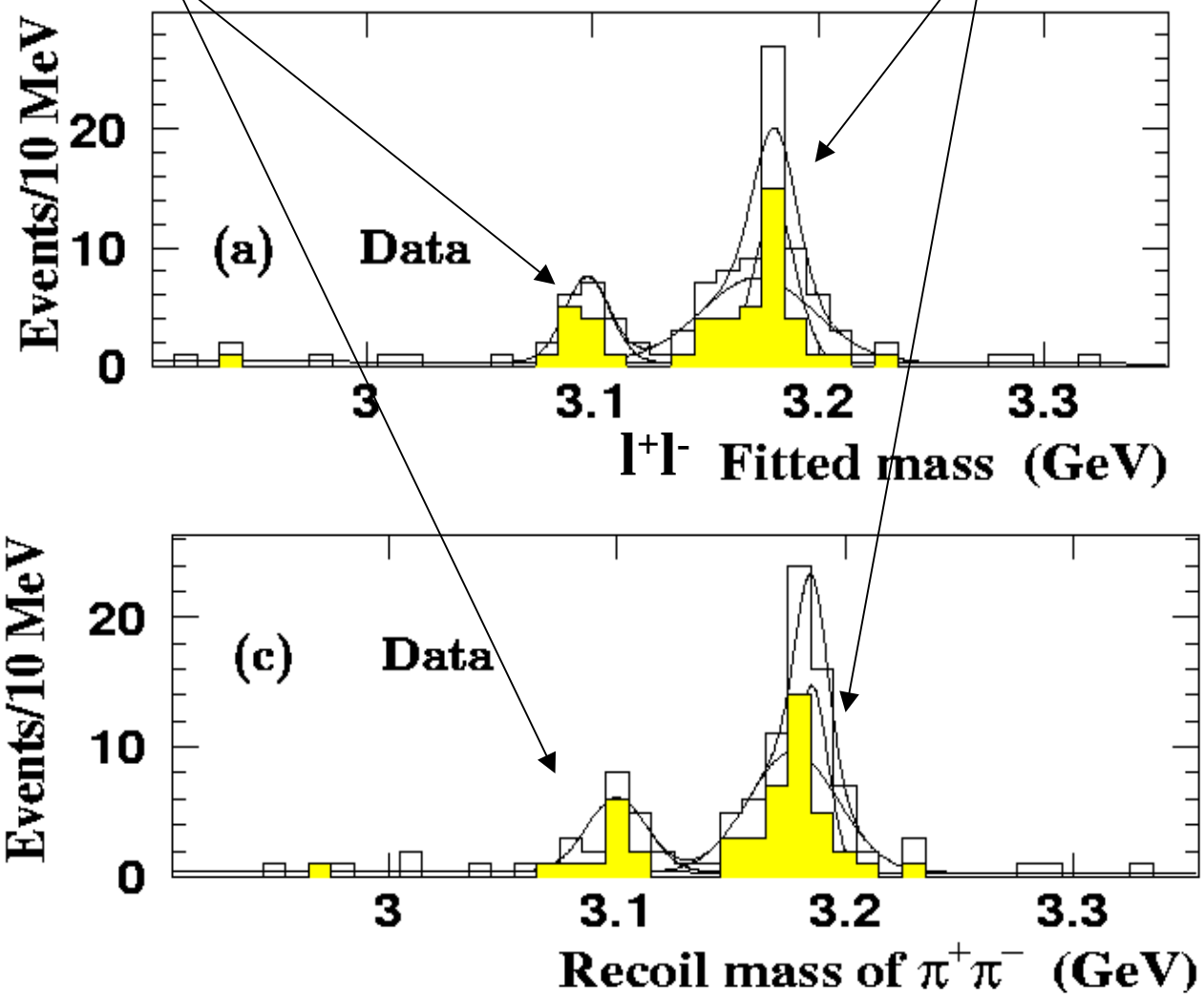
$\psi(3770) \to \pi^+\pi^- J/\psi$

ISR return $\psi(2S) \to \pi^+\pi^- J/\psi$

Open histo:
$J/\psi \to e^+e^-$ evt.

Shaded histo:
$J/\psi \to \mu^+\mu^-$ evt.

17.8±4.8 evt.
fitted



1. $\psi(3770) \rightarrow \pi^+\pi^- J/\psi$

BES Preliminary

- **Fitted Total evt.** 17.8 ±4.8
  Bkgd evt. 6.0 ± 0.5 ±0.6 (MC)
  Signal evt. 11.8 ±4.8

$B(\psi(3770) \rightarrow \pi^+\pi^- J/\psi) = (0.338 \pm 0.137 \pm 0.82)\%$

$\Gamma(\psi(3770) \rightarrow \pi^+\pi^- J/\psi) = (80 \pm 32 \pm 21)$ keV

- **BES has observed the hadronic transition of $\psi(3770) \rightarrow \pi^+\pi^- J/\psi$ for the first time**

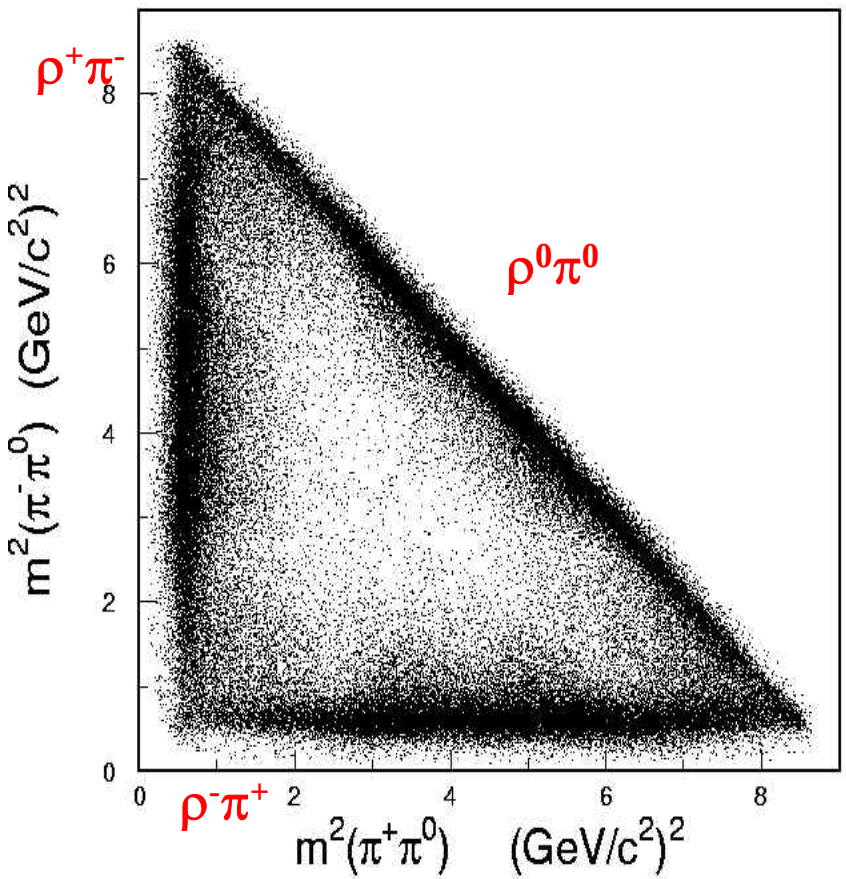
Measurements with Improved Accuracies

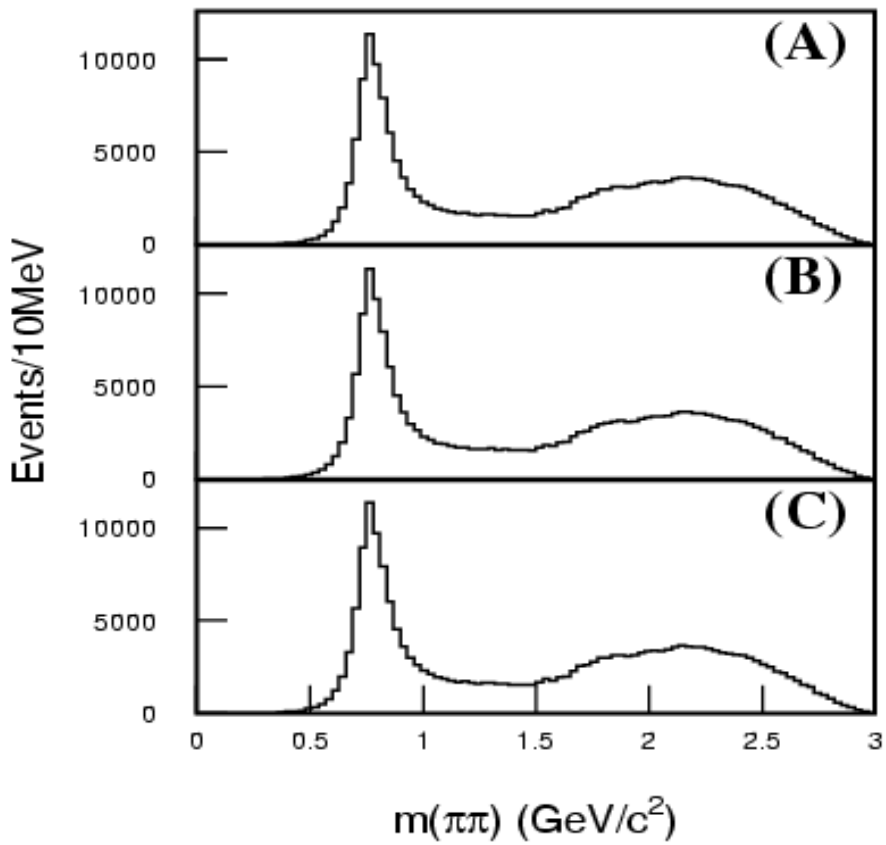
B($J/\psi \rightarrow \pi^+\pi^-\pi^0$)

ψ(2S) decays will be covered in C.Z.Yuan's talk

1. $B(J/\psi \rightarrow \pi^+\pi^-\pi^0)$

Measured from 58M J/Ψ evts.





1. $B(J/\psi \to \pi^+\pi^-\pi^0)$

Measured from 14M $\Psi(2S)$ evts.

Similar cuts used for decay I &II
Many systematic errors cancelled

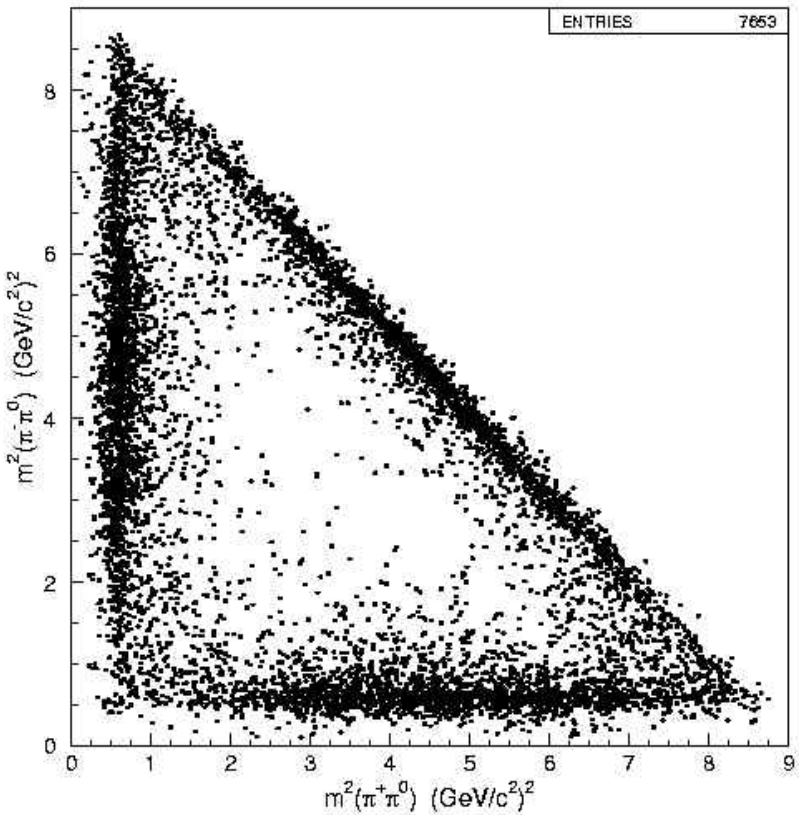
$$\psi(2S) \to \pi^+\pi^- \; J/\psi$$
$$\hookrightarrow \; \mu^+\mu^- \qquad (I)$$
$$and \; \hookrightarrow \; \pi^+\pi^-\pi^0 \qquad (II)$$

$$B(J/\psi \to \rho\pi) = \frac{N_I^{obs}/\epsilon_I}{N_{II}^{obs}/\epsilon_{II}/B(J/\psi \to \mu^+\mu^-)} \qquad (1)$$
$$= \frac{N_I^{obs}}{N_{II}^{obs}} \cdot \frac{\epsilon_{II}}{\epsilon_I} \cdot B(J/\psi \to \mu^+\mu^-), \qquad (2)$$

1. $B(J/\psi \to \pi^+\pi^-\pi^0)$

Measured from 14M $\Psi(2S)$ evt.

Systematic error



	f_c	Sys. err. (%)
MDC tracking		2.0
Kinematic fit	1.012	1.6
Photon efficiency		4.0
Backgrounds	0.985	1.5
MC model		1.6
$B(J/\psi \to \mu^+\mu^-)$		1.7
$B(\pi^0 \to \gamma\gamma)$		0.03
MC statistics		1.0
Sum	~ 1.0	5.6

$B(J/\psi \to \pi^+\pi^-\pi^0) = (20.97 \pm 0.21 \pm 1.17) \times 10^{-3}$

1. $B(J/\psi \rightarrow \pi^+\pi^-\pi^0)$

Discussions of BESII $B(J/\psi \rightarrow \pi^+\pi^-\pi^0)$ results

- 58M J/ψ : $B(J/\psi \rightarrow \pi^+\pi^-\pi^0) = (21.35\pm0.05\pm2.03)\times10^{-3}$
  14M ψ(2S) : $B(J/\psi \rightarrow \pi^+\pi^-\pi^0) = (20.97\pm0.21\pm1.17)\times10^{-3}$

- **Combining BESII Result :**
  $B(J/\psi \rightarrow \pi^+\pi^-\pi^0) = (2.11\pm0.12)\times10^{-2}$

- **Inconsistent with PDG02 :**
  $B(J/\psi \rightarrow \pi^+\pi^-\pi^0) = (1.5\pm0.2)\times10^{-2}$

- **Extensive and careful checks on MC and DATA consistencies had been made, such as**
  MDC reconstruction, kinematic fit, photon detection, Barrel Shower Counter performance, etc.
  The agreement between MC and DATA is reasonable.

SUMMARY

- **New States Searches & Observations:**

 # A near $p\bar{p}$ threshold enhancement in $J/\psi \to \gamma p\bar{p}$ found,

$$M = 1859^{+3}_{-10}{}^{+5}_{-25}\ \mathrm{MeV}/c^2$$

$$\Gamma < 30\ \mathrm{MeV}/c^2\ (90\%\ \mathrm{CL})$$

any PDG particle can be excluded.

 # Clear σ signal shown up in $J/\psi \to \omega\pi^+\pi^-$ decay

 # unobserved N*(2020)? appeared in $J/\psi \to p\pi^-\bar{n}$

 # No Pentaquark state seen in

J/ψ & $\psi(2S) \to \Theta\bar{\Theta} \to (K_S p)(K^-\bar{n})$ & $(K_S\bar{p})(K^+n)$

SUMMARY

- New Decay Modes Observations:

  Evidence of $\psi(3770)$ Non-$D\bar{D}$ decay to

  $\psi(3770) \rightarrow \pi^+\pi^- J/\psi$

SUMMARY

- Measurements with improved accuracies

BESII Results with 58M J/ψ & 14M ψ(2S) evts.

$$B(J/\psi \rightarrow \pi^+\pi^-\pi^0) = (2.11\pm0.12)\times10^{-2}$$

much higher than PDG value $(1.5\pm0.2)\times10^{-2}$

Thank you!

谢谢！