Recent results of charmonium Physics from BES

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BES I

BES II

BES Collaboration

• China

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7. Shandong University, Jinan 250100
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• United States of America

1. California Institute of Technology, Pasadena, California 91125
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1. Introduction

BES (Beijing Spectrometer)

- General purpose solenoidal detector at Beijing Electron Positron Collider (BEPC).
- Beam energy range $(1.0 \sim 2.5)$ GeV.

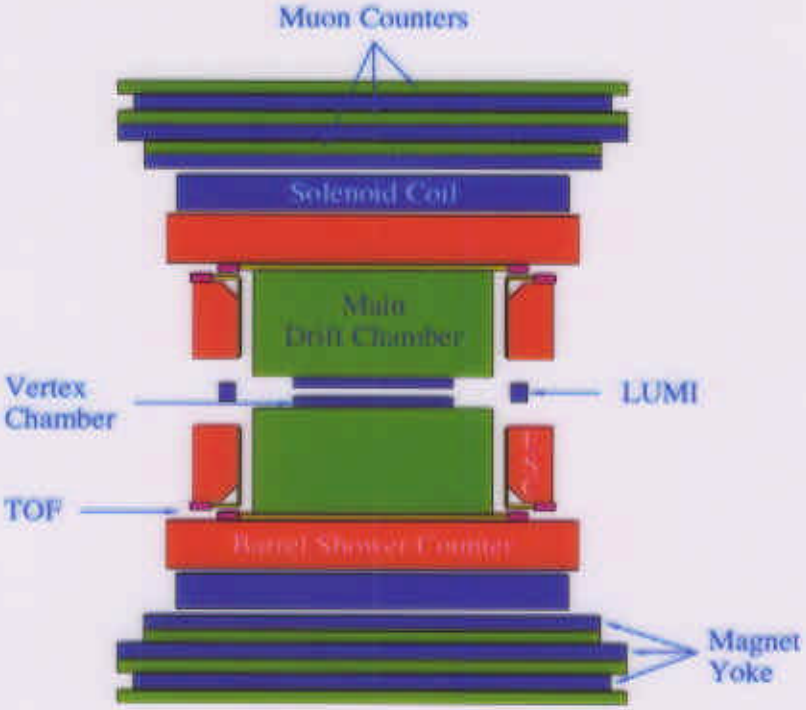
BESII- BES upgraded version

Table 1. Performance of BESI and BESII

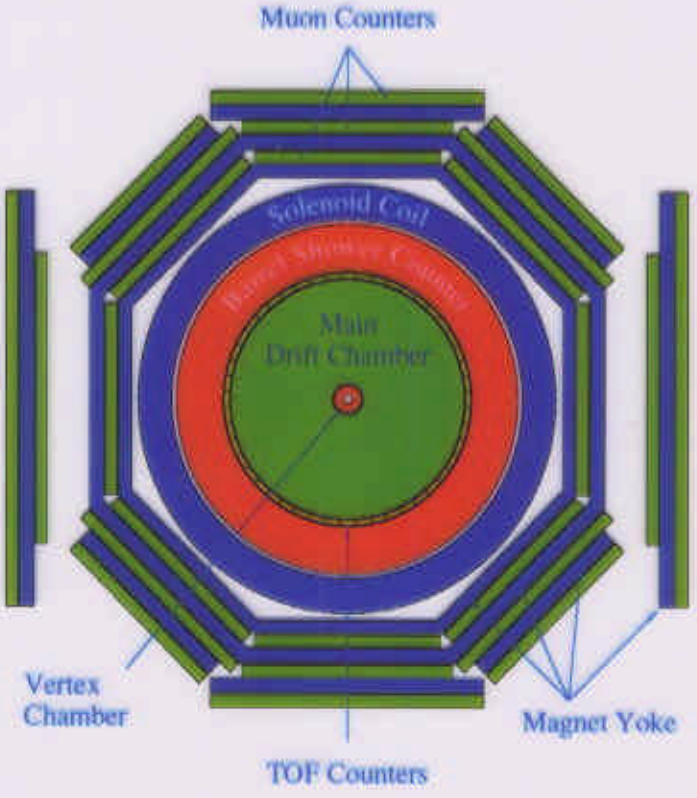
Detector	Parameter	BESI	BESII
VC(CDC)	$\sigma_{xy}(\mu)$	200	100
MDC	$\sigma_{xy}(\mu)$	200-250	
	$\Delta p/p$ (%)	$1.76\sqrt{1+p^2}$	$1.78\sqrt{1+p^2}$
	$\sigma_{dE/dx}$ (%)	7.9	8.4
BTOF	σ_T (ps)	375	180
	L_{atten} (m)	1.0-1.2	3.5 - 5.5
ETOF	σ_T (ps)		720
BSC	$\Delta E/\sqrt{E}$ (%)	23.8	22
ESC	$\Delta E/\sqrt{E}$ (%)	24	22
MUON	σ_z(cm)	5.5	5.5
DAQ	Dead time (ms)	20	8

Table 2. Data Collected with BESI and BESII

Detector	E_{CM}(GeV)	Physics	Data Sample
BESI	3.097	J/ψ	7.8×10^6
	3.686	$\psi(2S)$	3.8×10^6
	4.03	D_S, D	$22.3pb^{-1}$
	3.55, m_τ scan	m_τ	$5pb^{-1}$
BESII	2-5 R scan	R, α_{QED}, g-2	6+85 points
	$\psi(2S)$ scan	$\psi(2S)$ width	24 points
	3.097	J/ψ	22×10^6



Side view of the BES detector



End view of the BES detector

2. $\psi(2S)$ Hadronic Decays

- **Br. of 11 hadronic decays measured for the 1st time**

  $\omega K^+K^-, \omega p\overline{p}, \phi\pi^+\pi^-, \phi K^+K^-, \phi p\overline{p},$
  $\phi f_0(980), \pi^0\pi^+\pi^- p\overline{p}, \eta\pi^+\pi^- p\overline{p},$
  $K^*K^-\pi^+ + c.c., K^*\overline{K}^* + c.c., K^*\overline{K_2}^* + c.c..$

- **PQCD 15% rule tested**

$$Q_h = \frac{B(\psi(2S) \to h)}{B(J/\psi \to h)} = \frac{B(\psi(2S) \to e^+e^-)}{B(J/\psi \to e^+e^-)} = (14.7 \pm 2.3)\%.$$

Q_h of 3 channel are lower then PQCD by factor of 2 or more
$(\phi K^+K^-, \omega p\overline{p}, K^*\overline{K_2}^* + c.c.)$,
other channels agree with PQCD prediction.

Table 3. BES measured $B(\psi(2S) \to X)$ and 15% rule test

X	$B_{\psi(2S)\to X}(10^{-5})$ (BES)	$B_{J/\psi\to X}(10^{-4})$ (PDG98)	Q_X	
ωK^+K^-	$13.1 \pm 4.4 \pm 3.9$	7.4 ± 2.4	$(17.7 \pm 9.8)\%$	
$\omega p\overline{p}$	$6.7 \pm 2.3 \pm 1.4$	13.0 ± 2.5	$(5.2 \pm 2.3)\%$	↙
$\phi\pi^+\pi^-$	$17.6 \pm 2.2 \pm 2.4$	8.0 ± 1.2	$(22.0 \pm 5.3)\%$	
ϕK^+K^-	$6.1 \pm 1.8 \pm 1.5$	8.3 ± 1.3	$(7.3 \pm 3.0)\%$	↙
$\phi p\overline{p}$	$0.86 \pm 0.50 \pm 0.20$	0.45 ± 0.15	$(18.9 \pm 13.4)\%$	
ϕf_0	$6.6 \pm 1.7 \pm 0.8$	3.2 ± 0.9	$(20.5 \pm 8.1)\%$	
$K^*K^-\pi^+ + c.c.$	$63.1 \pm 4.6 \pm 8.2$	no data	?	
$K^*\overline{K}^* + c.c.$	$4.10 \pm 0.90 \pm 0.60$	2.9 ± 0.7	$(14.2 \pm 5.1)\%$	
$K^*\overline{K_2}^* + c.c.$	$8.34 \pm 4.80 \pm 2.72$	67 ± 26	$(1.25 \pm 0.97)\%$	↙
$\pi^0\pi^+\pi^- p\overline{p}$	$36.5 \pm 3.8 \pm 5.5$	23 ± 9	$(15.9 \pm 6.9)\%$	
$\eta\pi^+\pi^- p\overline{p}$	$25.8 \pm 6.8 \pm 7.3$	no data	?	
$\eta p\overline{p}$	$< 19. CL90\%$	20.9 ± 1.8	$< 9.0\% CL90\%$	

Preliminary.

3. $\psi(2S)$ Baryon Pair Decays

- **BES measured 8 channels branching fractions**
  5 for the 1st time (See Table 4)

- **PQCD 15% rule test**
  Q_h agree with PQCD 15% expectations.

- **Flavor SU(3) symmetry test**

  - **Definition** of phase-space-corrected reduced branching ratio $\mid M_i \mid^2$

$$\mid M_i \mid^2 = \frac{B(\psi(2s) \to B_i\overline{B_i})}{\pi p^*/\sqrt{s}}$$

    (p^* is the momentum of the baryon in the $\psi(2s)$ rest frame).

  - **SU(3) flavor symmetry**
    In the context of flavor SU(3), a pure $c\bar{c}$ state is a flavor singlet
    → In the limit of SU(3) flavor symmetry,$\mid M_i \mid^2$ should be the same for every baryon B_i in the same multiplet.

  - **The SU(3) relation works reasonably well for $J/\psi \to B\overline{B}$.** See Table 5. (although there may be some preference for $p\overline{p}$ mode).
    This relation has not been tested for the $\psi(2s)$.

  - **SU(3) flavor symmetry test in $\psi(2S) \to B\overline{B}$**
    BES measured $\mid M_i \mid^2$ listed in Table 5.
    The results show a trend to smaller values for the higher masses, only marginally consistant to flavor-SU(3) symmetry prediction, similar to J/ψ case.

Table 4. Branching ratios of $J/\psi, \psi(2S) \to B\overline{B}$

(limits at 90% CL)

Decay	B($\psi(2S)$) (10^{-4})		B(J/ψ) (10^{-3})	Q_h
	BES	PDG98	(PDG98)	(BES)
$p\overline{p}$	$2.26 \pm .41$	1.9 ± 0.5	2.14 ± 0.10	10.6 ± 1.9
$\Lambda\overline{\Lambda}$	$1.89 \pm .30$	< 4	1.35 ± 0.14	14.0 ± 2.7
$\Sigma^0\overline{\Sigma}^0$	$1.2 \pm .5$		1.27 ± 0.17	9.2 ± 4.1
$\Xi^-\overline{\Xi}^+$	$1.0 \pm .3$	< 2	0.9 ± 0.2	11 ± 4
$\Delta^{++}\overline{\Delta}^{--}$	$1.34 \pm .35$		1.10 ± 0.29	12.2 ± 4.5
$\Sigma^{*-}\overline{\Sigma}^{*+}$	$1.1 \pm .4$		1.03 ± 0.13	11 ± 4
$\Xi^{*0}\overline{\Xi}^{*0}$	$< .85$			
$\Omega^-\overline{\Omega}^+$	$< .77$			

Table 5. Reduced branching fractions for $J/\psi, \psi(2s) \to B_i\overline{B}_i$

(limits at 90% CL)

Decay	$\mid M_i \mid^2 (J/\psi)(10^{-3})$ (PDG98)	$\mid M_i \mid^2 (\psi(2S))(10^{-4})$ (BES)
$p\overline{p}$	1.71 ± 0.08	1.67 ± 0.37
$\Lambda\overline{\Lambda}$	1.24 ± 0.13	1.51 ± 0.24
$\Sigma^0\overline{\Sigma}^0$	1.26 ± 0.17	1.00 ± 0.42
$\Xi^-\overline{\Xi}^+$	1.1 ± 0.2	0.91 ± 0.27
$\Delta^{++}\overline{\Delta}^{--}$	1.16 ± 0.30	1.15 ± 0.30
$\Sigma^{*-}\overline{\Sigma}^{*+}$	1.47 ± 0.19	1.06 ± 0.39
$\Xi^{*0}\overline{\Xi}^{*0}$		< 0.97
$\Omega^-\overline{\Omega}^+$		< 1.17

All preliminary (BES)

BES Preliminary

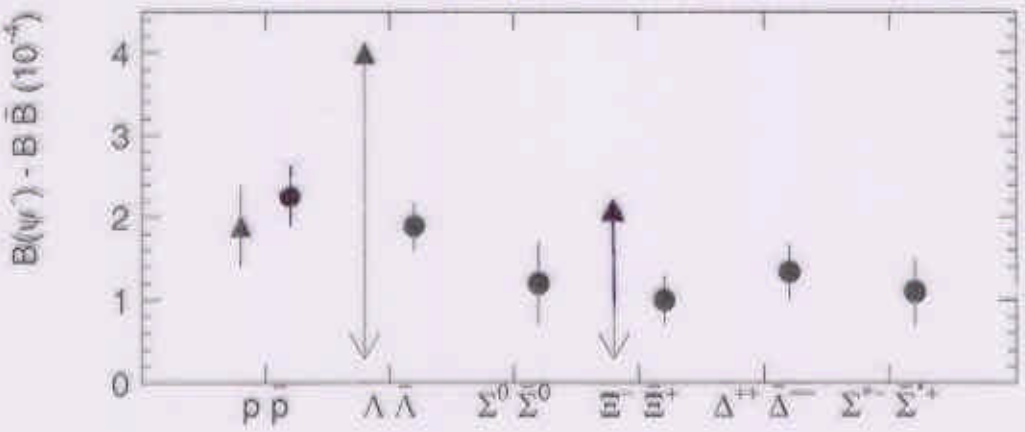


FIG. Comparison of measured branching fractions (circles) with previous measurements (triangles).

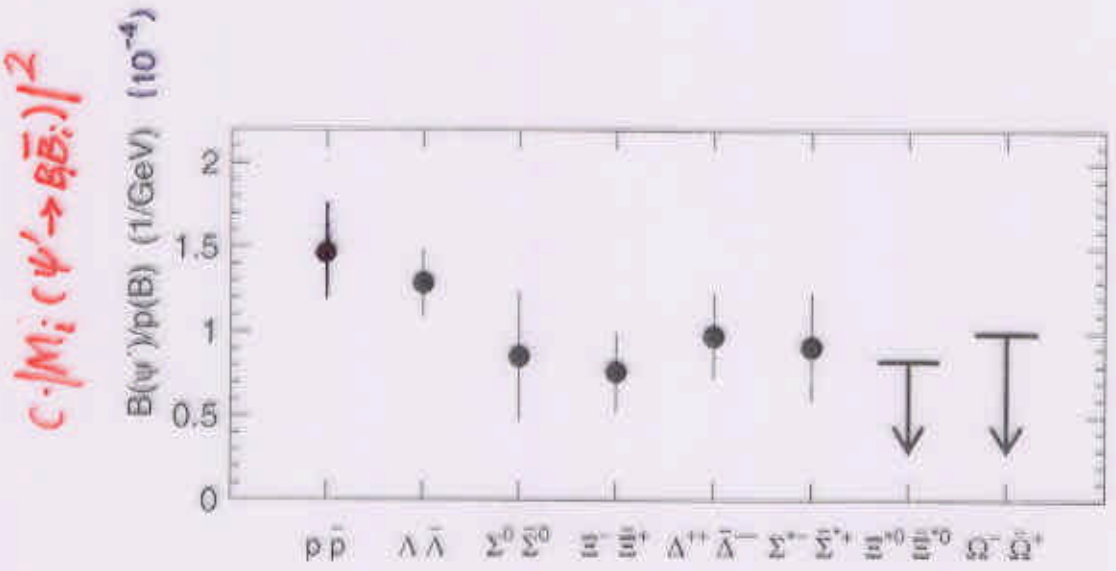


FIG. The reduced branching fractions $|M_i|^2$ for $\psi(2S) \to B_i\overline{B_i}$ decays.

4. $\psi(2S)$ Radiative Decays

Studied channel: $\psi(2S) \to \gamma(\pi\pi, K\overline{K}, \eta\eta) \to 5\gamma, \gamma 2P, \gamma 4P$.

- $\psi(2S) \to \gamma\pi\pi \to 5\gamma, \gamma 2P$ mode.
  $B(\psi(2S) \to \gamma f_2(1270), \gamma f_J(1710))$,
  $B(\chi_{c0} \to \pi^0\pi^0)$, $B(\chi_{c2} \to \pi^0\pi^0)$ measured
- $\psi(2S) \to \gamma K\overline{K} \to \gamma 2P, \gamma 4P$ mode.
  $B(\psi(2S) \to \gamma f_J(1710) \to \gamma K^+K^-, \gamma K_S^0 K_S^0)$ measured
- $\psi(2S) \to \gamma\eta\eta \to 5\gamma$ mode.
  $B(\chi_{c0} \to \eta\eta)$, $B(\chi_{c2} \to \eta\eta)$ measured

Results summerized in Table 6.

- All branching ratios in Table 6 are the **1st measurement**.
- $\frac{B(\chi_{c0}\to\eta\eta)}{B(\chi_{c0}\to\pi^0\pi^0)} = 0.73 \pm 0.31 \pm 0.23$
  is consistant with Flavor SU(3) symmetry prediction.

Table 6. Branching ratios measured by BES

Process	Branching ratio
$\psi(2S) \to \gamma f_2(1270)$	$(2.37 \pm 0.26 \pm 0.37) \times 10^{-4}$
$\psi(2S) \to \gamma f_J(1710) \to \gamma\pi\pi$	$(3.51 \pm 0.90 \pm 1.46) \times 10^{-5}$
$\psi(2S) \to \gamma f_J(1710) \to \gamma K^+K^-$	$(5.8 \pm 2.0 \pm 1.0) \times 10^{-5}$
$\psi(2S) \to \gamma f_J(1710) \to \gamma K_S^0 K_S^0$	$(2.2 \pm 1.0 \pm 1.2) \times 10^{-5}$
$\chi_{c0} \to \pi^0\pi^0$	$(2.80 \pm 0.32 \pm 0.60) \times 10^{-3}$
$\chi_{c2} \to \pi^0\pi^0$	$(9.2 \pm 2.7 \pm 5.3) \times 10^{-4}$
$\chi_{c0} \to \eta\eta$	$(2.03 \pm 0.84 \pm 0.61) \times 10^{-3}$
$\chi_{c2} \to \eta\eta$	$< 1.28 \times 10^{-3} (90\% CL)$

Preliminary

5. η_c Mass and Full Width

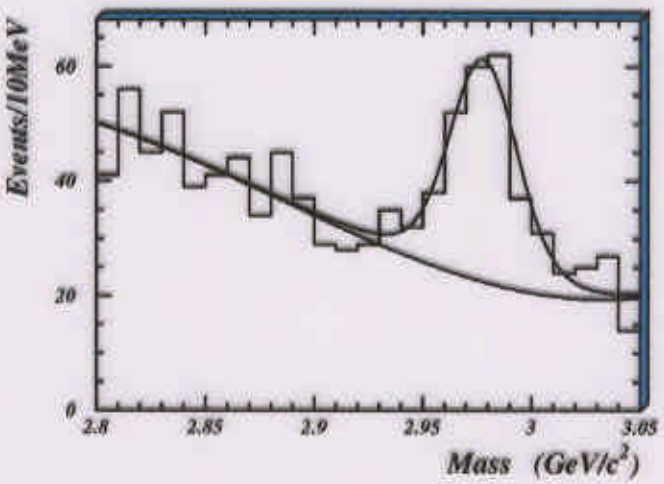
- using $\psi(2S)$ data to determine M_{η_C} (PRD 60(1999)072001)
- using J/ψ data to improve the accuracy
- results will be published by PRD soon

Table 7. BES results on M_{η_C} and Γ_{η_C}

Data sample	$7.8 \times 10^6 J/\psi$	$3.79 \times 10^6 \psi(2S)$
Studied channels	$\gamma\pi^+\pi^-\pi^+\pi^-$ $\gamma\pi^+\pi^- K^+K^-$ $\gamma K^0_S K^\pm\pi^\mp$ $\gamma\phi\phi(\to \gamma K^+K^-K^+K^-)$ $\gamma K^+K^-\pi^0$	$\gamma\pi^+\pi^-\pi^+\pi^-$ $\gamma\pi^+\pi^- K^+K^-$ $\gamma K^0_S K^\pm\pi^\mp$ $\gamma K^+K^-K^+K^-$
M_{η_C} **(MeV)**	$2976.6 \pm 2.9 \pm 1.3$	$2975.8 \pm 3.9 \pm 1.2$
	$2976.3 \pm 2.3 \pm 1.2$	
Γ_{η_C} **(MeV)**	$11.0 \pm 8.1 \pm 4.1$	

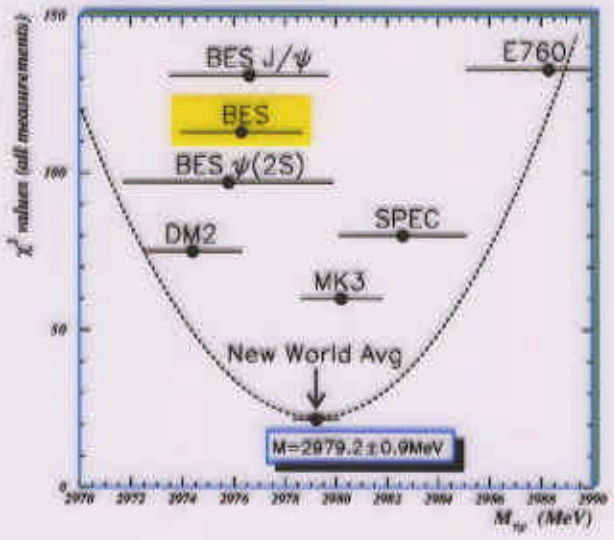
Table 8. Comparison of M_{η_C} and Γ_{η_C}

Group	**Ref.**	**yr.**	M_{η_C}**(MeV)**	Γ_{η_C}**(MeV)**
CBAL	PRD 34,711	1986	$2984.0 \pm 2.3 \pm 4.0$	11.5 ± 4.5
MRK3	PRD 33,629	1986	2980.2 ± 1.6	$10.1^{+33.0}_{-8.2}$
SPEC	PLB 187,191	1987	$2982.6^{+2.7}_{-2.3}$	$7.0^{+7.5}_{-7.0}$
DM2	NP B350,1	1991	2974.4 ± 1.9	
E760	PRD 52,4839	1995	$2988.3^{+3.3}_{-3.1}$	$23.9^{+12.6}_{-7.1}$
BES	PRD	2000	$2976.3 \pm 2.3 \pm 1.2$	$11.0 \pm 8.1 \pm 4.1$



$N_{\eta_c} = 168.3 \pm 26.8$

Combined 4 prong invariant mass in η_c region for
$J/\psi \to \gamma\eta_c(\eta_c \to \pi^+\pi^-\pi^+\pi^-, \pi^+\pi^- K^+K^-, K^\pm K^0_S\pi^\mp, \phi\phi)$, and
$\psi(2S) \to \gamma\eta_c(\eta_c \to \pi^+\pi^-\pi^+\pi^-, \pi^+\pi^- K^+K^-, K^\pm K^0_S\pi^\mp, K^+K^-K^+K^-)$



The curve of χ^2 versus $m_{\eta c}$ for a fit including all existing measurements.
(The height of data point has no meaning here.)

6. $\psi(2S)$ Decay Widths

- **Purpose**

  Improve accuracies of $\Gamma_t, B(h), B(\mu), B(\pi^+\pi^- J/\psi), B(J/\psi X)$

Table 9. $\psi(2S)$ decay width and branching ratios

Group	yr.	$\Gamma_t(keV)$	$B(\mu\mu)(10^{-3})$	$B(\pi^+\pi^- J/\psi)$	$B(J/\psi X)$
MARK I	75	228 ± 56	9.3 ± 1.6	0.32 ± 0.04	0.57 ± 0.08
SPEC	75		7.7 ± 1.7		
DASP	79	202 ± 57	9.9 ± 3.2	0.36 ± 0.06	0.51 ± 0.12
E760	92	306 ± 39			
	97			0.283 ± 0.029	
PDG	96	277 ± 31		$*0.324 \pm 0.026$	$*0.57 \pm 0.08$
PDG	98	277 ± 31		$*0.302 \pm 0.019$	$*0.542 \pm 0.030$

- **Data sample:**

  $E_{cm} \sim$ (3.67, 3.71) GeV, 24 points, $\sim 790nb^{-1}$ (BESII)

- **Method – line shape fit**

  1. Breit-Wigner formular for resonance $(e^+e^- \to R \to f)$

$$\sigma_0(W) = \frac{4\pi(2J+1)\Gamma_e\Gamma_f}{(W^2 - M_R^2) + \Gamma_t^2 - M_R^2}$$

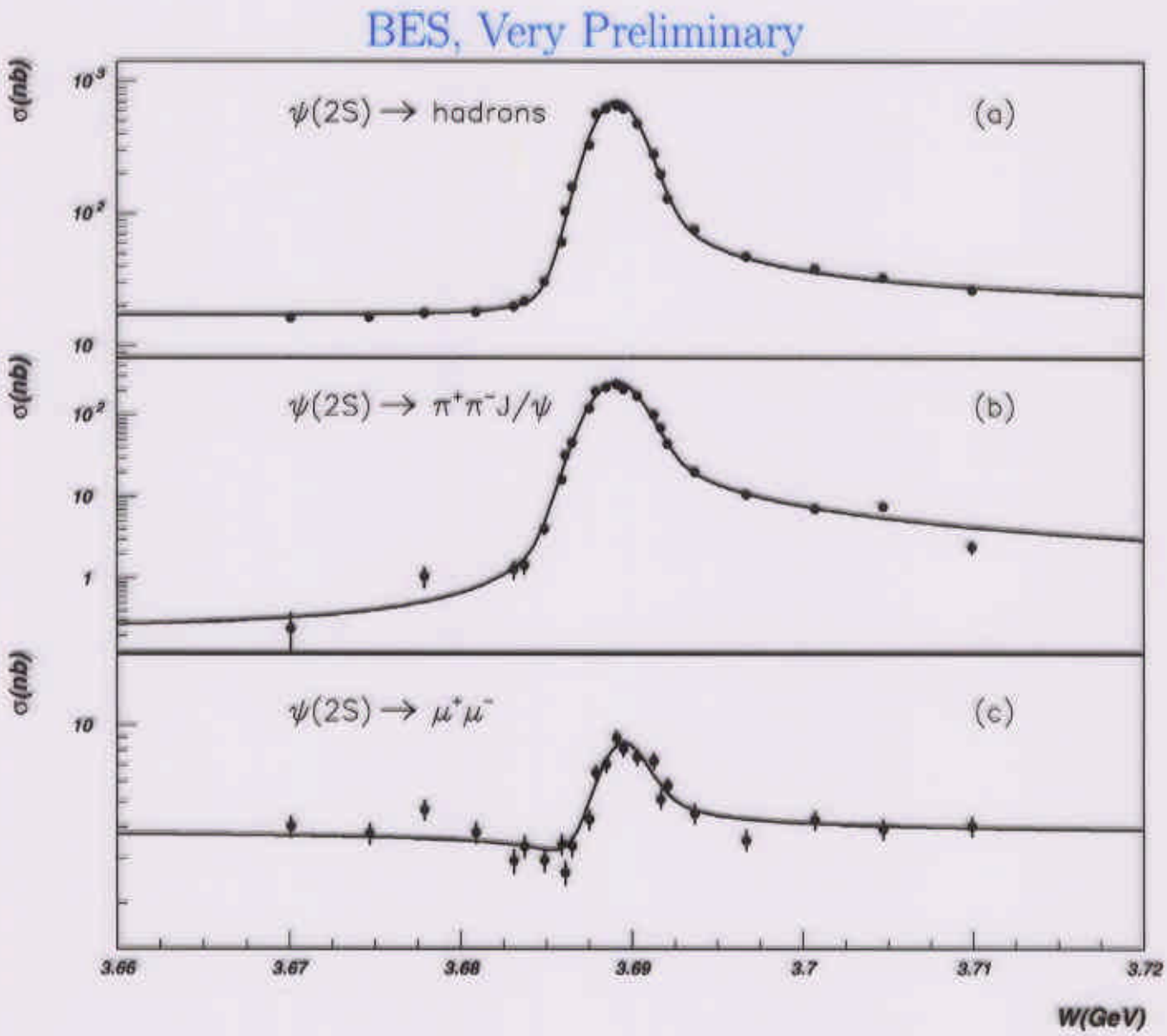
  2. Initial radiative correction (Kuraev-Fadin structure function)

$$\sigma(W) = \int_0^1 dx \sigma_0(W)[W^2(1-x)]B(x,W)$$

  3. Gaussian energy spread function
  4. Observed resonance cross section

$$\sigma^R(W) = \int_{-\infty}^{+\infty} \sigma(W')G(W,W')dW'$$

- **Results will be reported soon**



The total cross sections for $e^+e^- \to hadrons, \pi^+\pi^- J/\psi, \mu^+\mu^-$

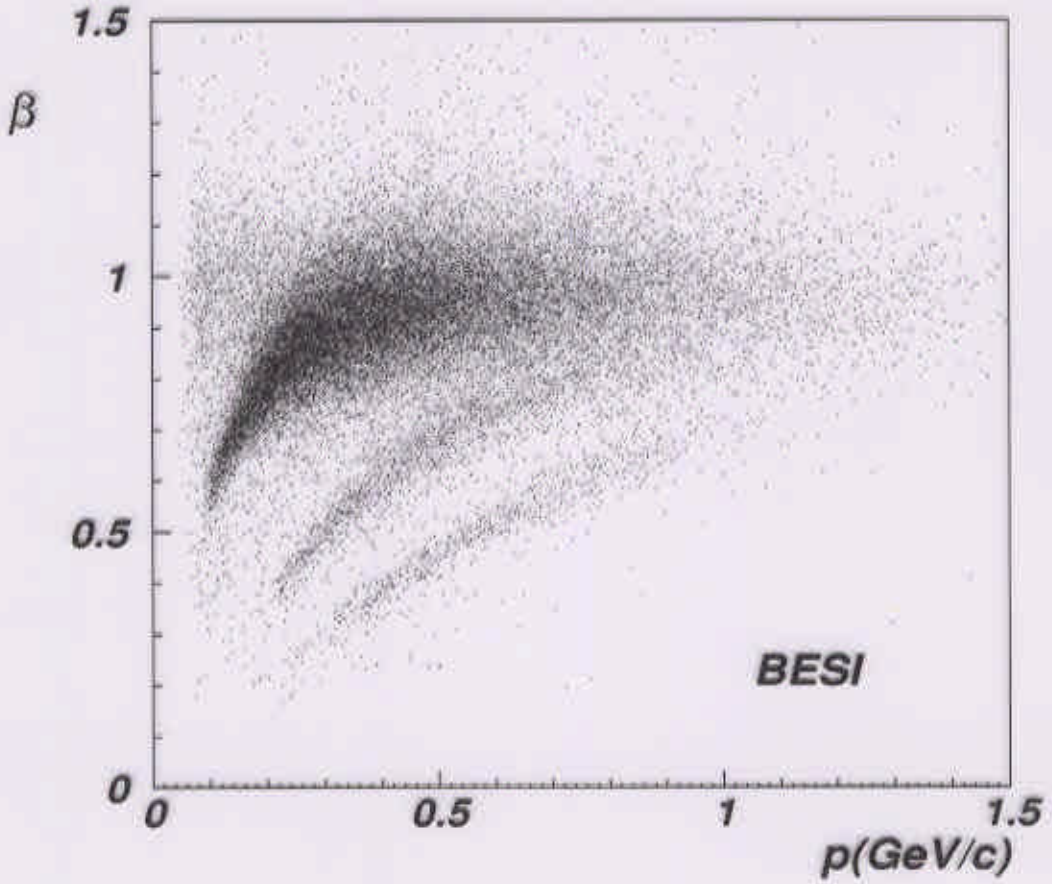
in the vicinity of $\psi(2S)$ resonance.

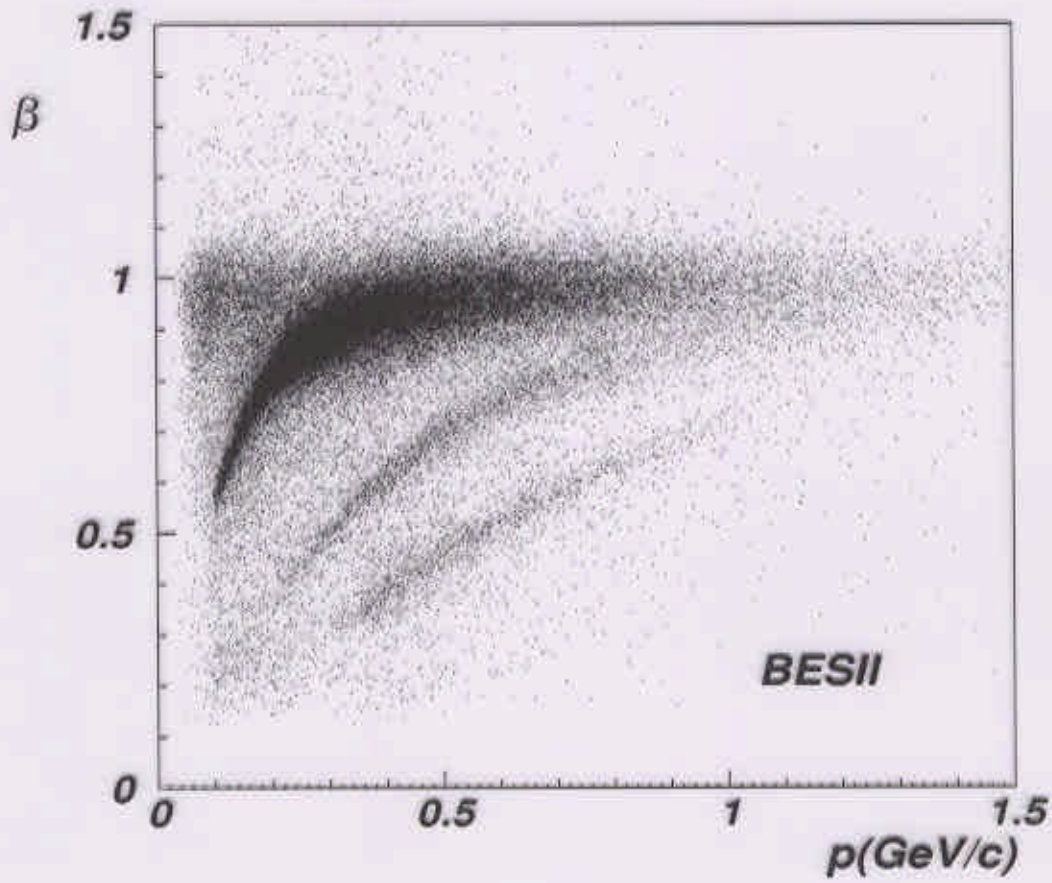
The solid curves represent the results of the fit to data.

7. Inclusive γ Spectrum of J/ψ Radiative Decays

- **Data sample** : $22 \times 10^6 J/\psi$ events. (BESII)
- **Data quality** : Inclusive spectra indicate good quality
- **Method** : γ **conversion** inside BES
  (measure momenta of converted e^+e^- with MDC,calculate energy of e^+e^-)
- **Energy resolution** : $\sim 1.5\%\sqrt{E_\gamma}$ at $E_\gamma = 0.75GeV$
- **Signals seen at** : $E_\gamma = 1.21,\ 1.40,\ 1.50,\ 1.548$ GeV
  correspond to : $\iota/\eta(1440),\ \eta'(958),\ \eta,\ e^+e^- \to \gamma\gamma.$
- **Signal appears at** : $E_\gamma = 0.745GeV$
  suggests the existence of $\xi(2230)$

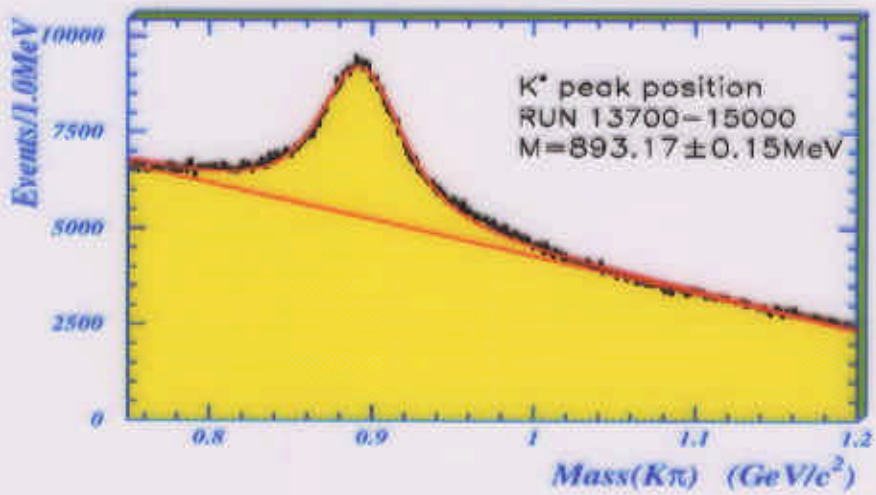
TOF Performance



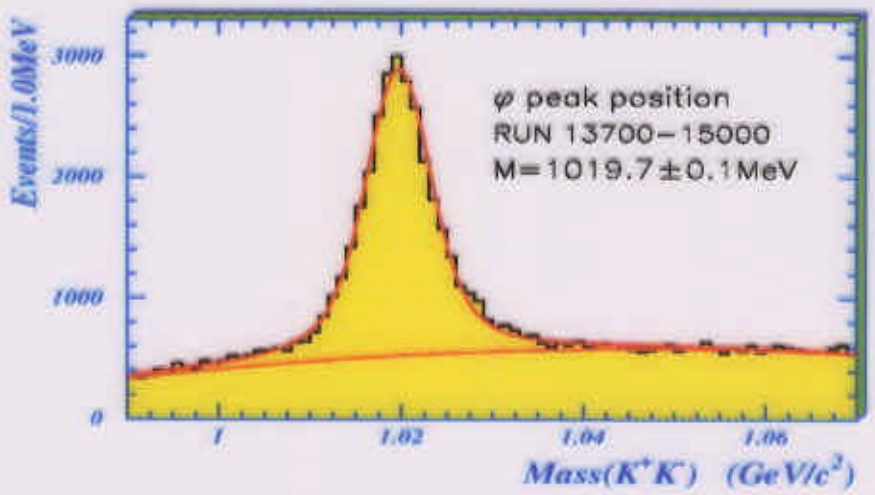


BES II

K^{*0} PDG: $M = 896.10 \pm 0.28$ MeV

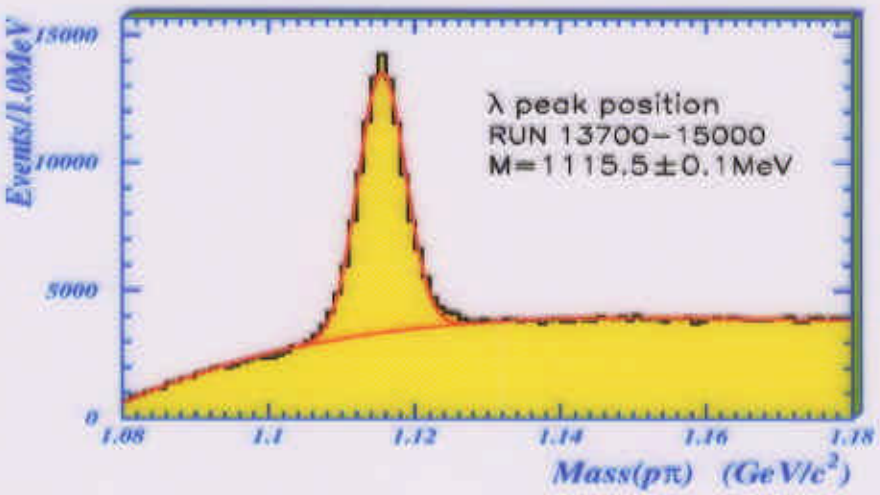


ϕ PDG: $M = 1019.413 \pm 0.008$ MeV

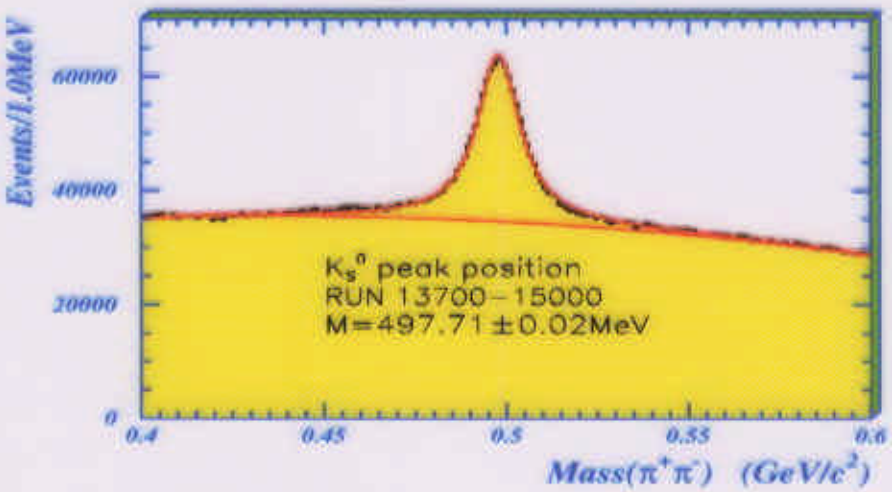


BES II

Λ PDG: $M = 1115.683 \pm 0.006$ MeV

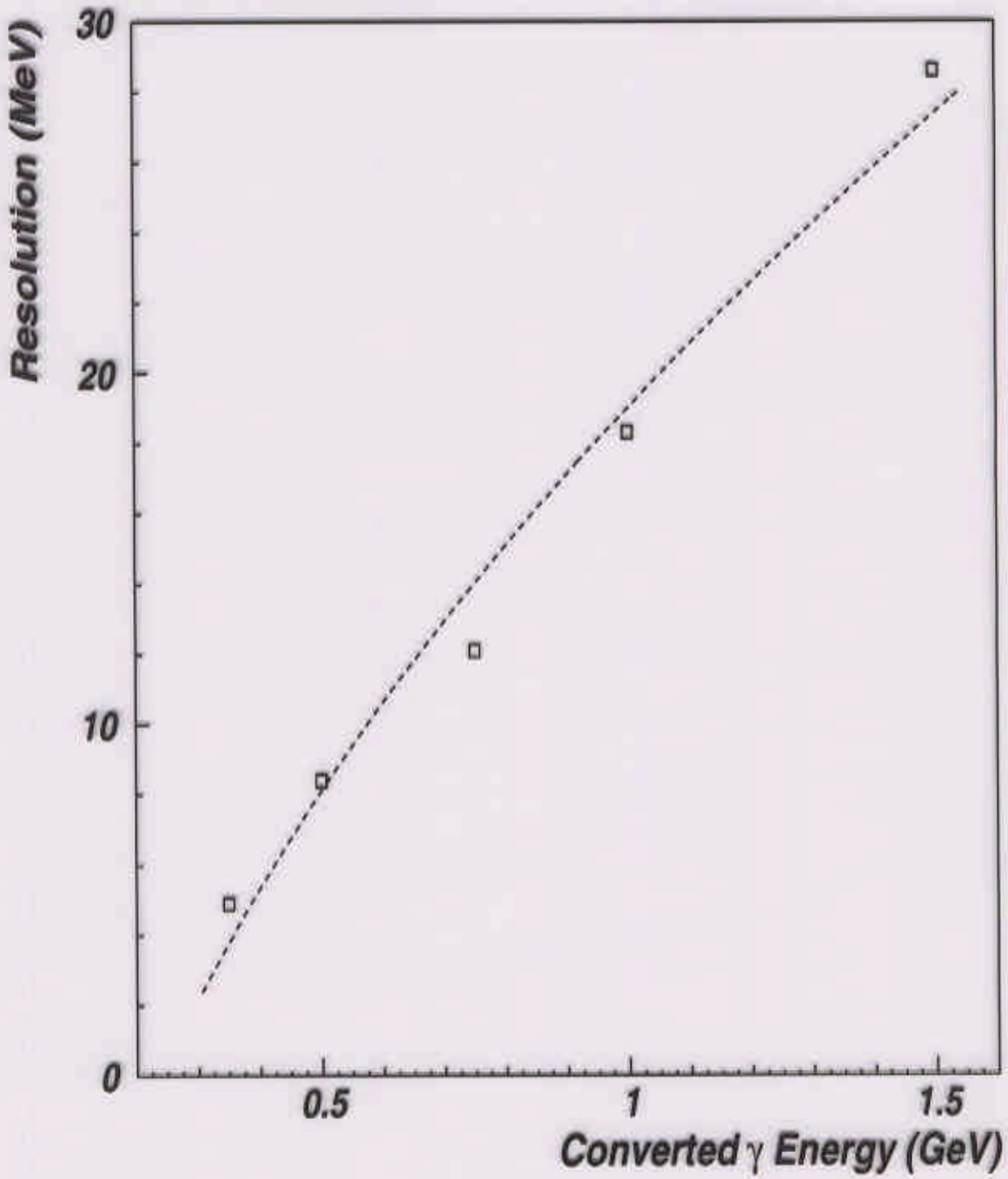


K_s^0 PDG: $M = 497.672 \pm 0.031$ MeV

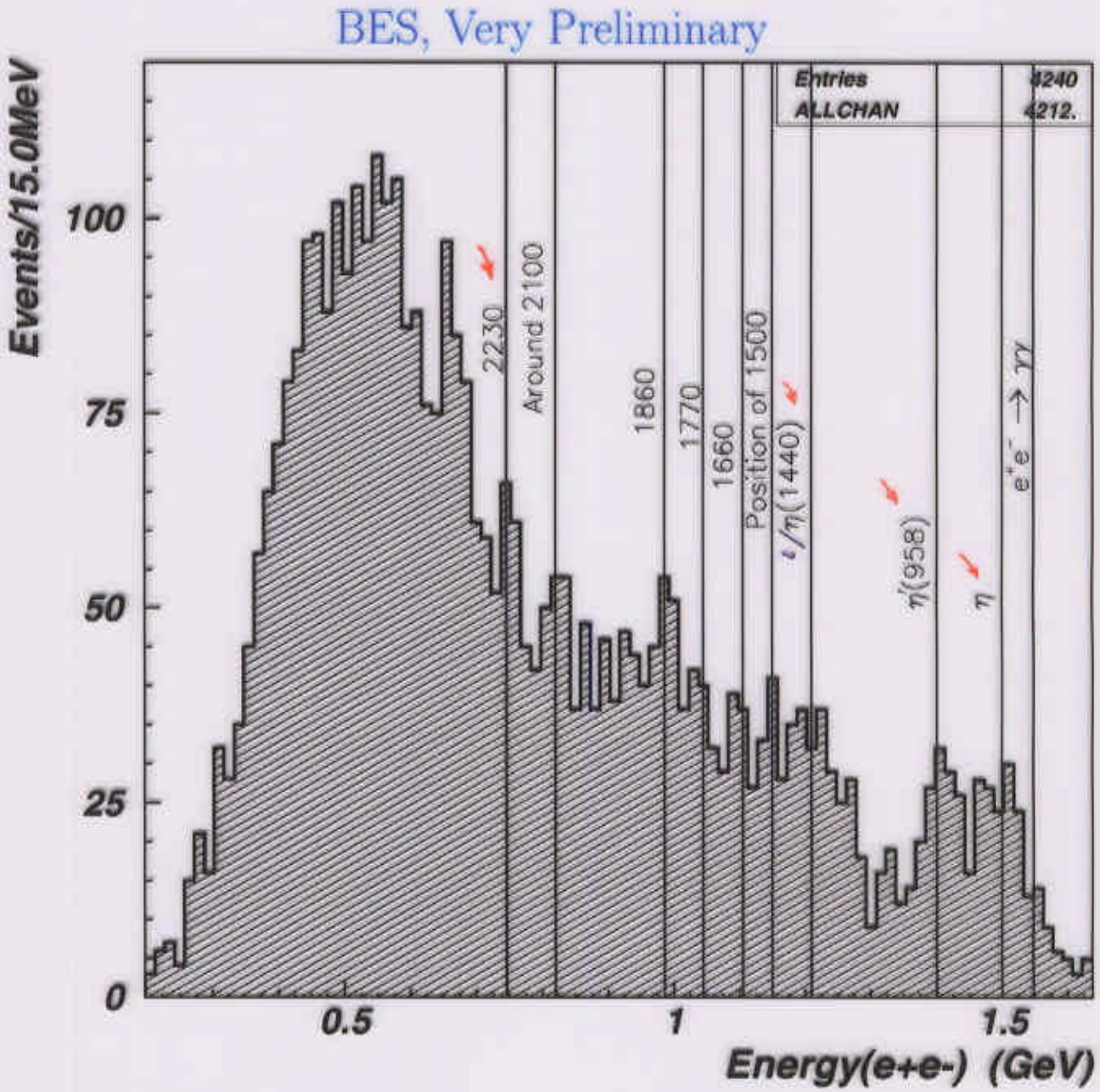


The energy resolutions of e^+e^- at different energy of converted photons:

Very preliminary!



Inclusive γ spectrum of J/ψ radiative decay



The distribution of $E_{e^+e^-}$ from 22M J/ψ sample.

The vertical lines are the energies of converted photons corresponding to X particle in $J/\psi \to \gamma X$ radiative decays.

8. Summary

- **$\psi(2S)$ Hadronic Decays**
  - 11 branching ratios measured for the 1st time
  - PQCD 15% rule tested
- **$\psi(2S)$ Baryon Pair Decays**
  - 8 branching ratios measured, 5 for the 1st time
  - PQCD 15% rule agrees with BES data
  - Flavor SU(3) symetry marginally agrees with BES data
- **$\psi(2S)$ Radiative Decays**
  - 8 branching ratios measured for the 1st time
  - Ratio of $B(\chi_{c0} \to \eta\eta, \pi^0\pi^0)$ consistant with Flavor SU(3) symetry
- **η_c Mass and Full Width**
  - $M_{\eta C}$ and $\Gamma_{\eta C}$ determined
  - $M_{\eta C}$ determined from BES J/ψ and $\psi(2S)$ samples consistant
- **$\psi(2S)$ resonance scan**
  - Right line-shape for $h, \mu^+\mu^-, \pi^+\pi^- J/\psi$ final states obtained
  - Results will be reported soon
- **Inclusive γ Spectrum of J/ψ Radiative Decays**
  - γ conversion method improving BES γ energy resolution
  - Inclusive γ Spectrum suggests the existence of $\xi(2230)$