New ψ(2s) Results from BES

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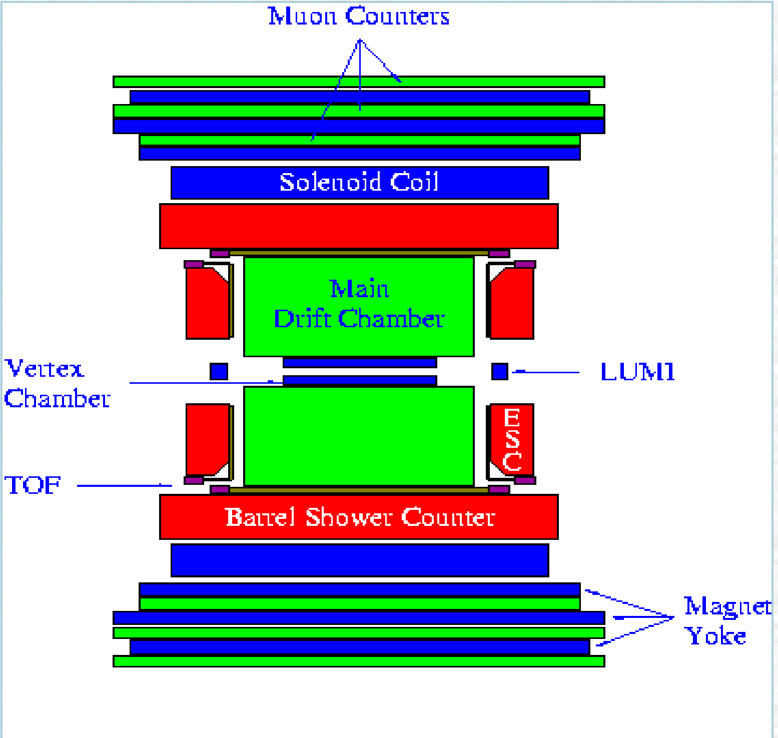
The Beijing Electron Positron Collider

L ~ ~5×10^{30} /$cm^2\cdot s$ at J/ψ peak

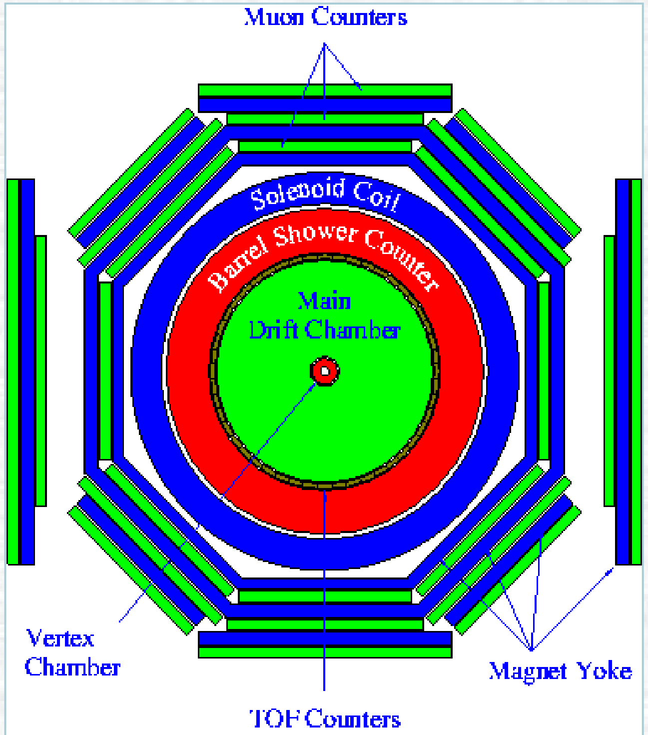
E_{cm}~2-5 GeV

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

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

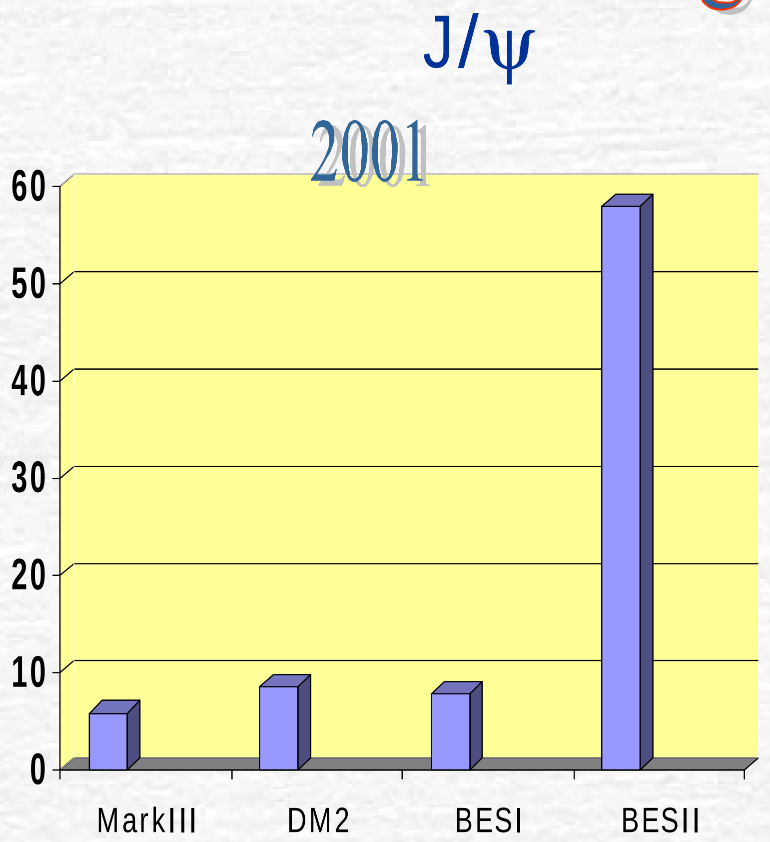
B field: 0.4 T

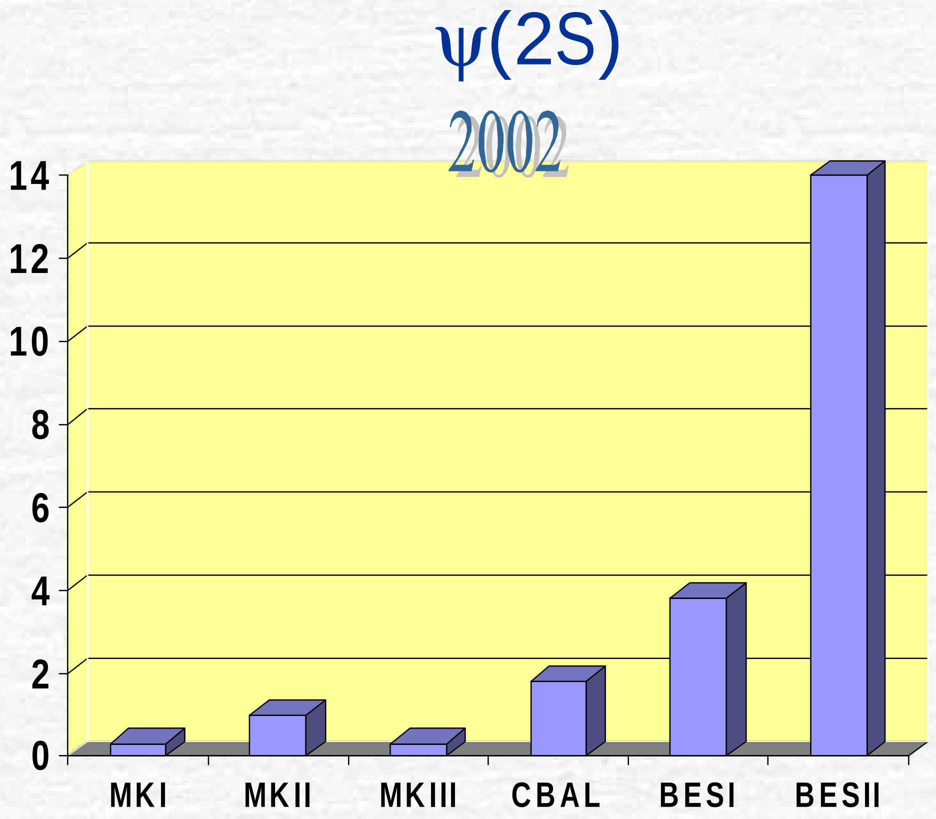
Data Collected with BESI and BESII

Detector	E_{CM}(GeV)	Physics	Data Sample
BES I	3.097	J/ψ	7.8×10^6
	3.686	$\psi(2S)$	3.96×10^6
	4.03	D_S, D	$22.3pb^{-1}$
	3.55, m_τ scan	m_τ	$5pb^{-1}$
BES II	2-5 GeV R scan	R, α_{QED}, g-2	6+85 points
	$\psi(2S)$ scan	res. para.	24 points
	3.097	J/ψ	58×10^6
	ψ'' scan	res. para.	$\sim 2.2pb^{-1}$
	3.686	$\psi(2S)$	$\sim 14 \times 10^6$

World J/ψ and ψ(2S) Samples (10^6)

Largest from BES





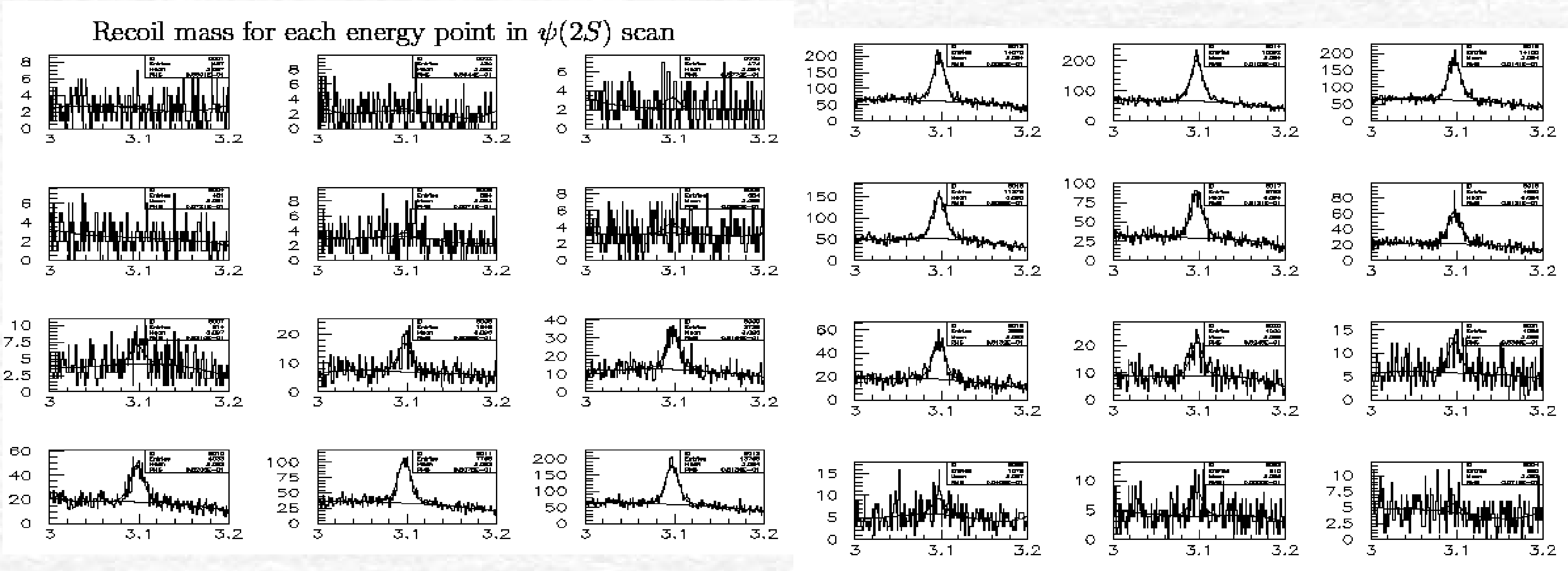
$\psi(2S)$ Scan

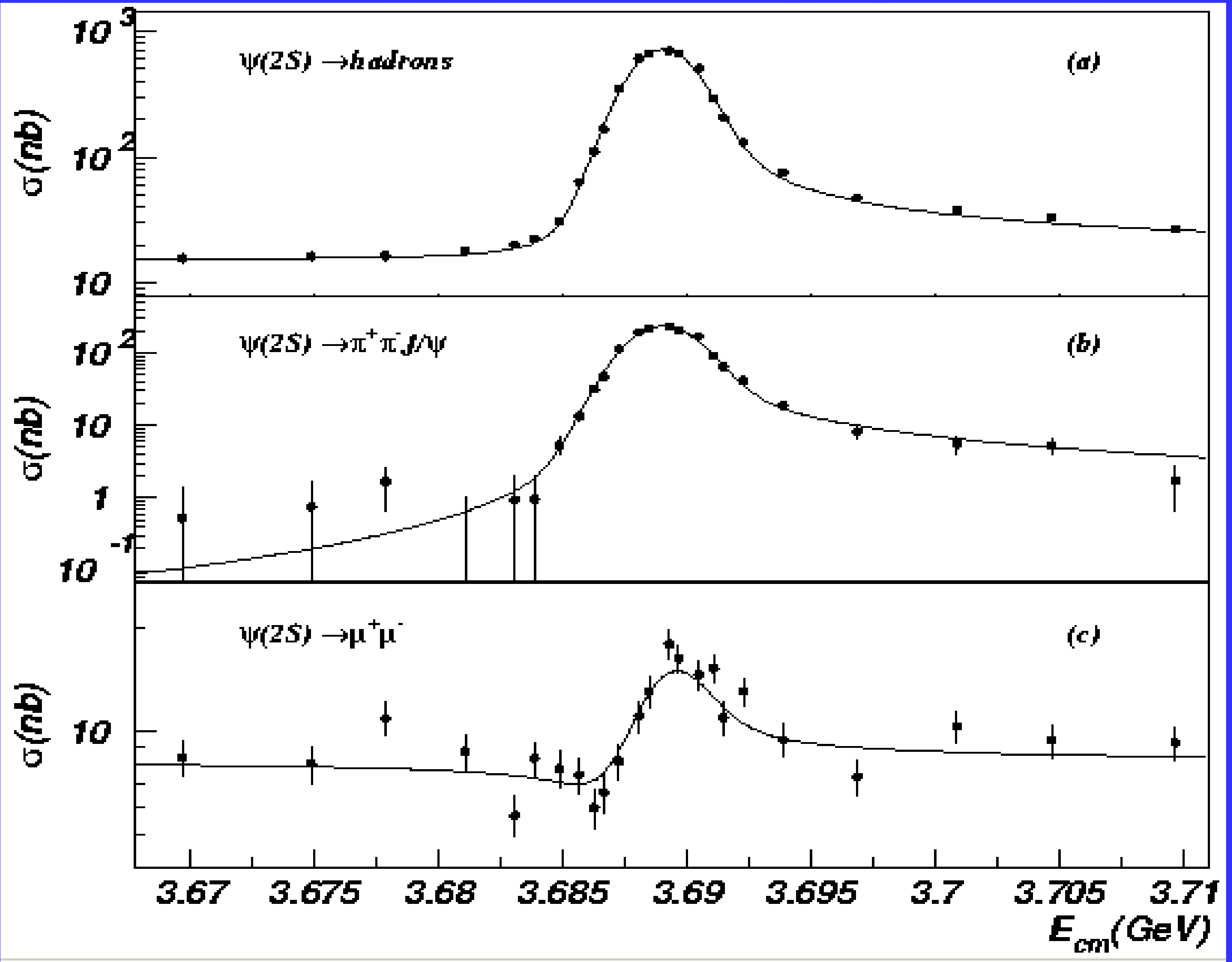
Purpose: Improve accuracies of $\psi(2S)$ parameters: Γ, Γ_h, Γ_μ, $\Gamma_{\pi\pi\ J/\psi}$, B(h), B(μ), and B($\pi^+ \pi^- J/\psi$).

Group	yr	Γ(KeV)	Γ_h(KeV)	$B(\mu\mu)(10^{-3})$	$B(\pi^+\pi^- J/\psi)$ (%)
MARKI	75	228 ± 56	224 ± 56	9.3 ± 1.6	32 ± 4
SPEC	75			7.7 ± 1.7	
DASP	79	202 ± 57		9.9 ± 3.2	36 ± 6
E760	92	306 ± 39			
E760	97			8.3 ± 0.86	28.3 ± 2.9
E835	00			7.4 ± 0.53	
PDG	00	277 ± 31		10.3 ± 3.5	31.0 ± 2.8

$\Psi(2S) \to \mu^+ \mu^-$ and $\Psi(2S) \to \pi^+ \pi^- J/\psi$ are important for identifying $\Psi(2S)$ decays in B-factory and other experiments.

- *Scanned 24 energy points between 3.67 and 3.71 GeV.*
- *Integrated luminosity = 1150* nb^{-1}
- *Four channels:* $\psi(2S) \rightarrow$ *hadrons,* $\mu^+\mu^-$, e^+e^-, *and* $\pi^+\pi^- J/\psi$
- *For number of* $\pi^+\pi^- J/\psi$, *fit* $\pi^+\pi^-$ *recoil mass spectrum.*





ψ(2S) →hadrons
(a)
ψ(2S) →π⁺π⁻J/ψ
(b)
ψ(2S) →μ⁺μ⁻
(c)
σ(nb)
3.67
3.675
3.68
3.685
3.69
3.695
3.7
3.705
3.71
E_cm(GeV)

Fitting

- Fit observed $\sigma_h(W)$, $\sigma_{\pi\pi\, J/\psi}(W)$, $\sigma_e(W)$, and $\sigma_\mu(W)$.
- Include resonance and continuum production plus interference, beam spread (Δ), ISR and FSR.
- Assume $\Gamma_e = \Gamma_\mu = \Gamma_\tau /0.3885$, $\Gamma_t = \Gamma_h + \Gamma_\mu + \Gamma_e + \Gamma_\tau$.
- Determine Γ_h, Γ_μ, $\Gamma_{\pi\pi\, J/\psi}$, $M(\psi(2S))$, Δ, and R.
- Results:
  - R = 2.15 $\pm$ 0.17 consistent with BES R measurement (R = 2.25 $\pm$ 0.06 at 3.55 GeV).
  - Δ = 1.298 $\pm$ 0.007. Agrees with expected beam spread.

Fitting Result

Parameter	BES	MARK I	PDG2002
Γ_t (keV)	264 ± 27(10.1 %)	228 ± 56 (24.6 %)	300 ± 25 (8.3 %)
Γ_h (keV)	258 ± 26(10.1 %)	224 ± 56 (25.0 %)	
$\Gamma_{\pi\pi\ J/\psi}$ (keV)	85.4 ± 8.7 (10.1 %)		
Γ_μ (keV)	2.44 ± 0.21 (8.8 %)	2.1 ± 0.3 (14.29 %)	2.19 ±0.15 (6.8 %)
B_h (%)	97.8 ± 0.15 (0.16 %)	98.1±0.3 (0.31 %)	98.10 ±0.30 (0.31 %)
$B_{\pi\pi\ J/\psi}$ (%)	32.3 ± 1.4 (4.4 %)	32 ± 4 (12.5 %)	30.5 ± 1.6 (5.2 %)
B_μ (%)	0.93 ± 0.08 (8.5 %)	0.93 ±0.16(17.2 %)	0.7 ±0.09(12.9 %)

Discussion

- Width variation

Γ_t(keV) :300 → 264.5(12%)

- Improved precision

B_h (%) : 0.31 → 0.16

$B_{\pi\pi\ J/\psi}$(%) : 5.2 → 4.4

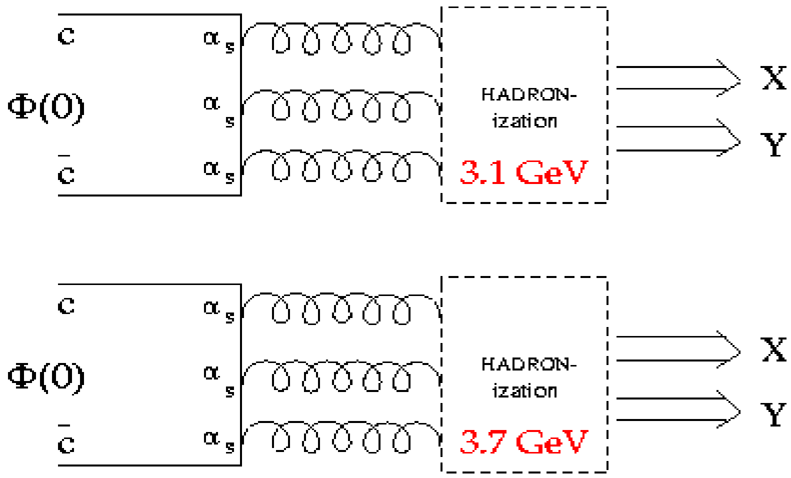
B_μ (%) : 13 → 8.5

- First measurement of $\Gamma_{\pi\pi\ J/\psi}$

Phys. Lett. B550, 24 (2002)

ψ(2S) Hadronic Decays

Expectations: T. Applequist and D. Politzer, Phys. Rev. Lett. 51, 43 (1975).



$$\mathcal{B}(\psi \rightarrow Final\ State) \propto \Gamma(\psi \rightarrow Final\ State)$$

$$\frac{\mathcal{B}[\psi(2S) \rightarrow X+Y]}{\mathcal{B}[J/\psi \rightarrow X+Y]} = \frac{\mathcal{B}[\psi(2S) \rightarrow \mu^+\mu^-]}{\mathcal{B}[J/\psi \rightarrow \mu^+\mu^-]} f(\alpha_s(s)) = (12.2 \pm 2.0)\%$$

- Most of Channels follow the rule
- VP states like $\rho\pi$ ~~and~~ $K^* K$ *are* strongly suppressed. *"$\rho\pi$ Puzzle"*
  - First seen by MarkII with suppression factor ~20.
  - BES finds suppression ~60.
- BES also finds suppression in VT channels

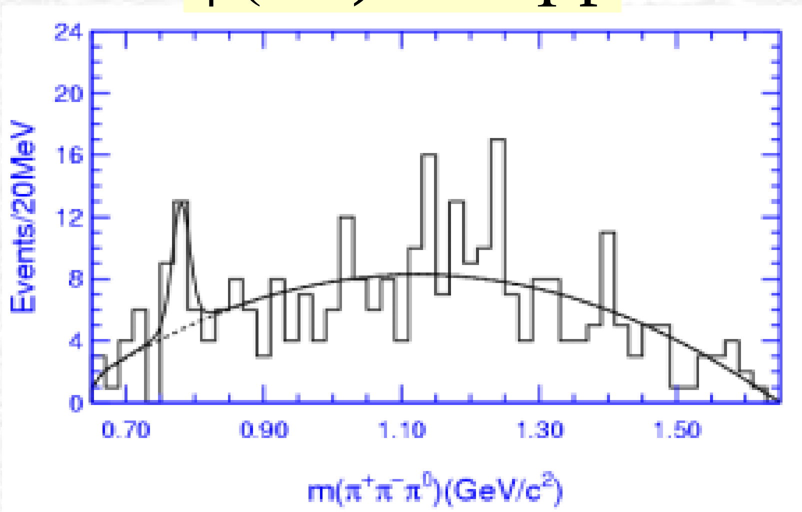
Important to measure other channels

New channels with ω's and ϕ's

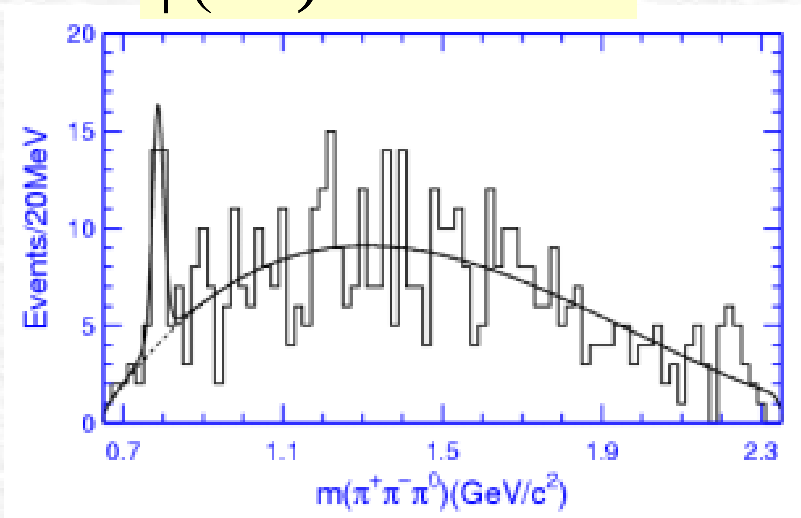
- $\psi' \to \omega\pi^+\pi^- \to \pi^0\pi^+\pi^-\pi^+\pi^-$
- $\psi' \to b_1^\pm\pi^\mp \to \omega\pi^+\pi^- \to \pi^0\pi^+\pi^-\pi^+\pi^-(*)$
- $\psi' \to \omega f_2(1270) \to \omega\pi^+\pi^- \to \pi^0\pi^+\pi^-\pi^+\pi^-(*)$
- $\psi' \to \omega K^+K^- \to \pi^0\pi^+\pi^-K^+K^-$
- $\psi' \to \omega p\bar{p} \to \pi^0\pi^+\pi^-p\bar{p}$
- $\psi' \to \phi\pi^+\pi^- \to K^+K^-\pi^+\pi^-$
- $\psi' \to \phi f_0(980) \to \phi\pi^+\pi^- \to K^+K^-\pi^+\pi^-$
- $\psi' \to \phi K^+K^- \to K^+K^-K^+K^-$
- $\psi' \to \phi p\bar{p} \to K^+K^-p\bar{p}$

Using 4 M BESI sample.

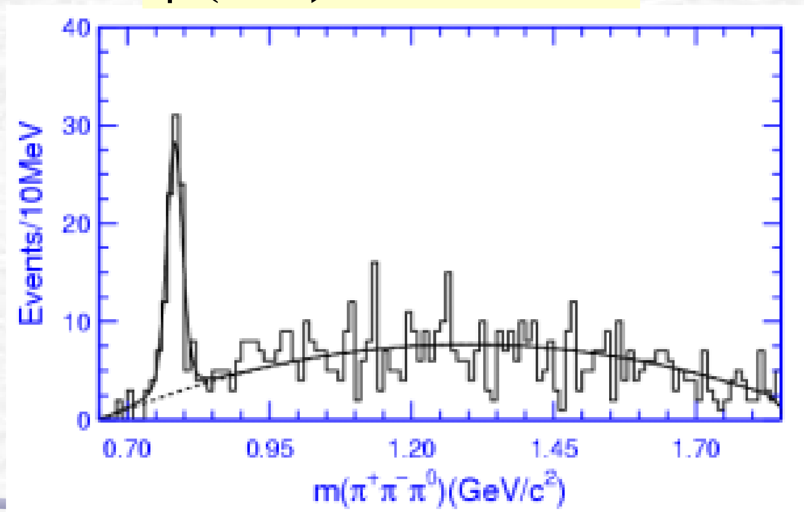
$\psi(2S) \to \omega p\bar{p}$



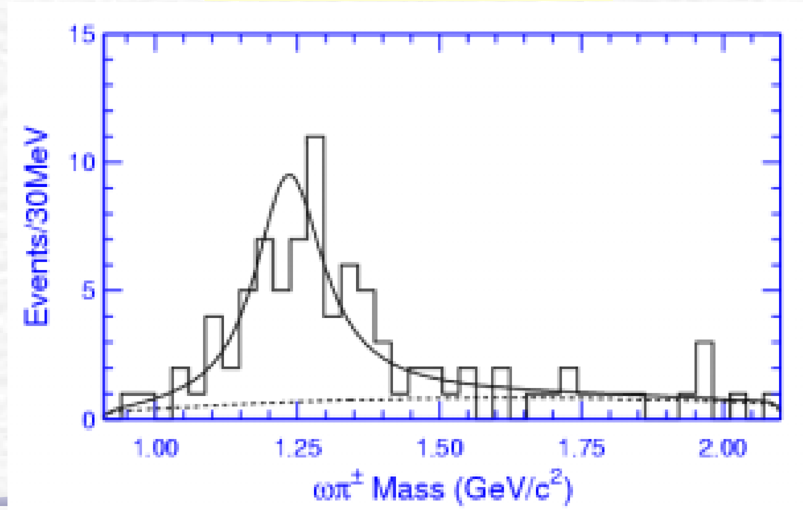
$\psi(2S) \to \omega K^+K^-$



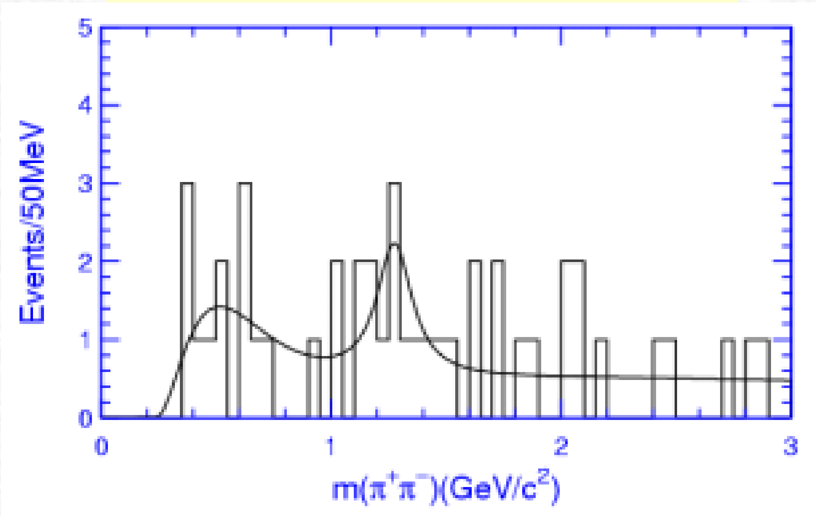
$\psi(2S) \to \omega\pi^+\pi^-$



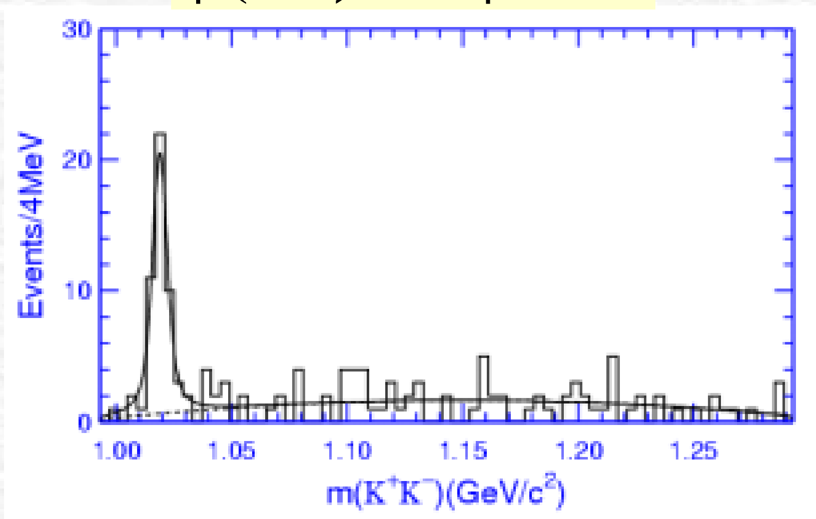
$\psi(2S) \to b_1\pi$



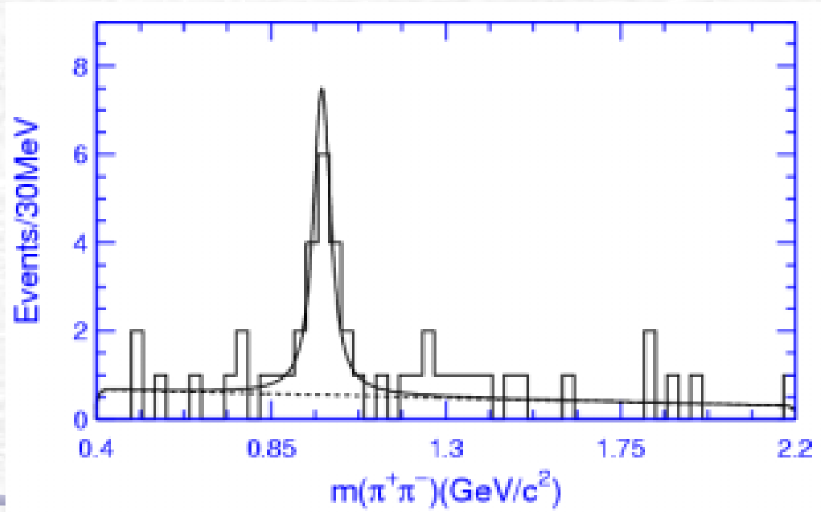
$\psi(2S) \rightarrow \omega f_2(1270)$



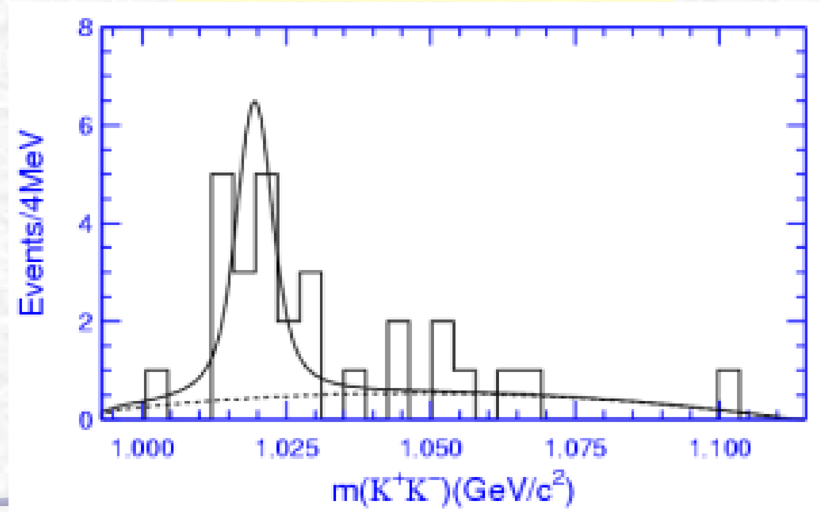
$\psi(2S) \rightarrow \varphi \pi^+ \pi^-$



$\psi(2S) \rightarrow \varphi f_0(980)$



$\psi(2S) \rightarrow \varphi K^+ K^-$



Results

Channels	$B_{\psi(2S)}(\times 10^{-4})$	$B_{J/\psi}(\times 10^{-4})$	$Q_h = \frac{B_{\psi(2S)}}{B_{J/\psi}}(\%)$
$\omega\pi^+\pi^-$	$4.9 \pm 0.6 \pm 0.8$	72.0 ± 10.0	6.8 ± 1.7
$b_1^\pm \pi^\mp$	$3.3 \pm 0.6 \pm 0.5$	30.0 ± 5.0	11.0 ± 3.3
$\omega f_2(1270)$	$1.2 \pm 0.4 \pm 0.2$	43.0 ± 6.0	2.7 ± 1.1
ωK^+K^-	$1.5 \pm 0.3 \pm 0.2$	7.4 ± 2.4	20.1 ± 8.5
$\omega p\bar{p}$	$0.8 \pm 0.3 \pm 0.1$	13.0 ± 2.5	6.0 ± 2.9
$\phi\pi\pi$	$1.5 \pm 0.2 \pm 0.2$	8.0 ± 1.2	19.1 ± 5.1
$\phi f_0(980)$	$1.1 \pm 0.4 \pm 0.2^*$	3.2 ± 0.9	33.7 ± 15.6
ϕK^+K^-	$0.6 \pm 0.2 \pm 0.1$	8.3 ± 1.3	7.7 ± 2.5
$\phi p\bar{p}$	$0.12 \pm 0.06 \pm 0.02$ < 0.3	0.45 ± 0.15	26.7 ± 16.2 < 57.8

$B(f_0(980) \to \pi^+\pi^-) = 0.52$

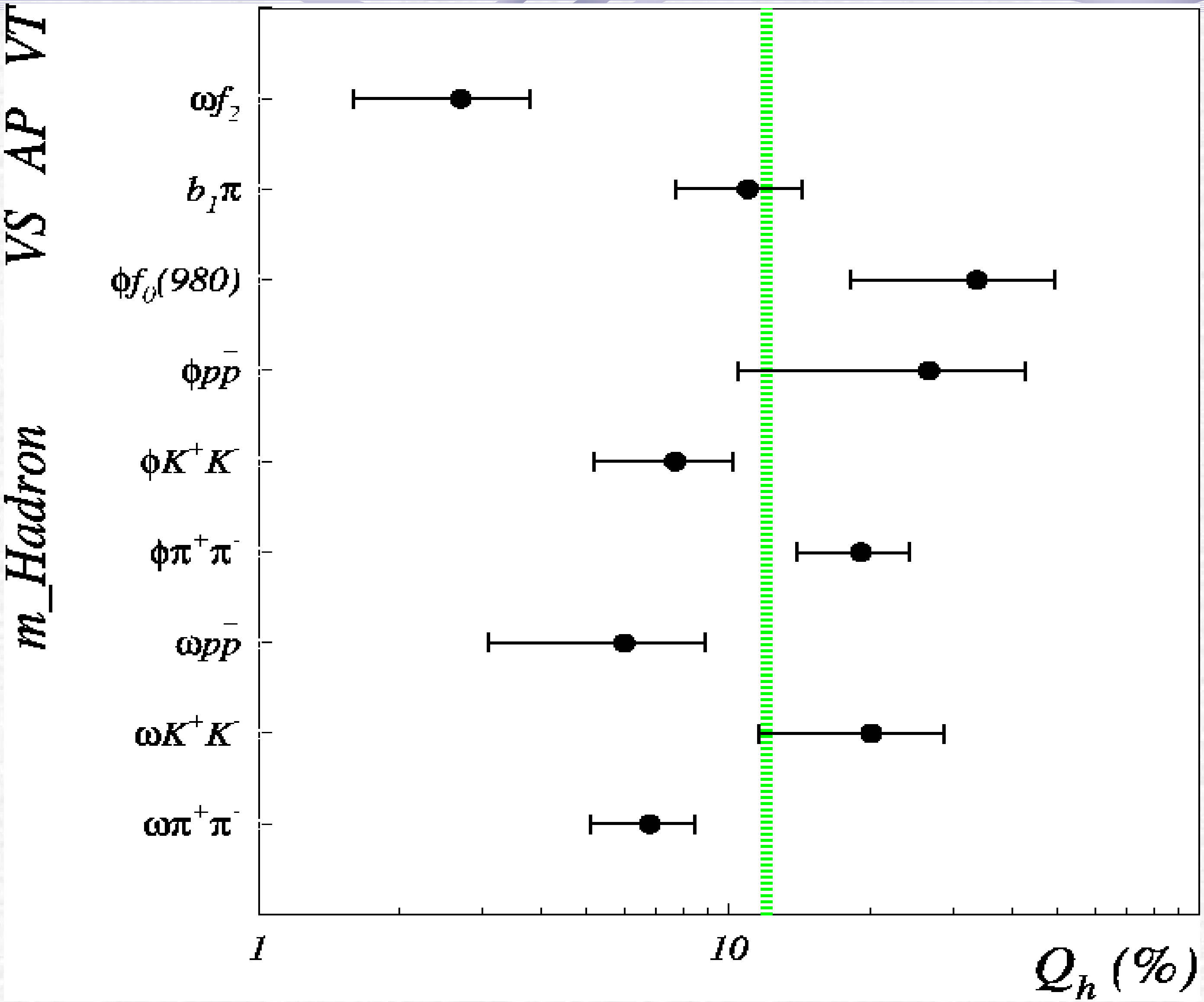
$Q = B(\psi(2S) \to h)/B(J/\psi \to h)$

Accepted by Phys. Rev. D

Experimental Results

BESI :

4 M ψ(2s)

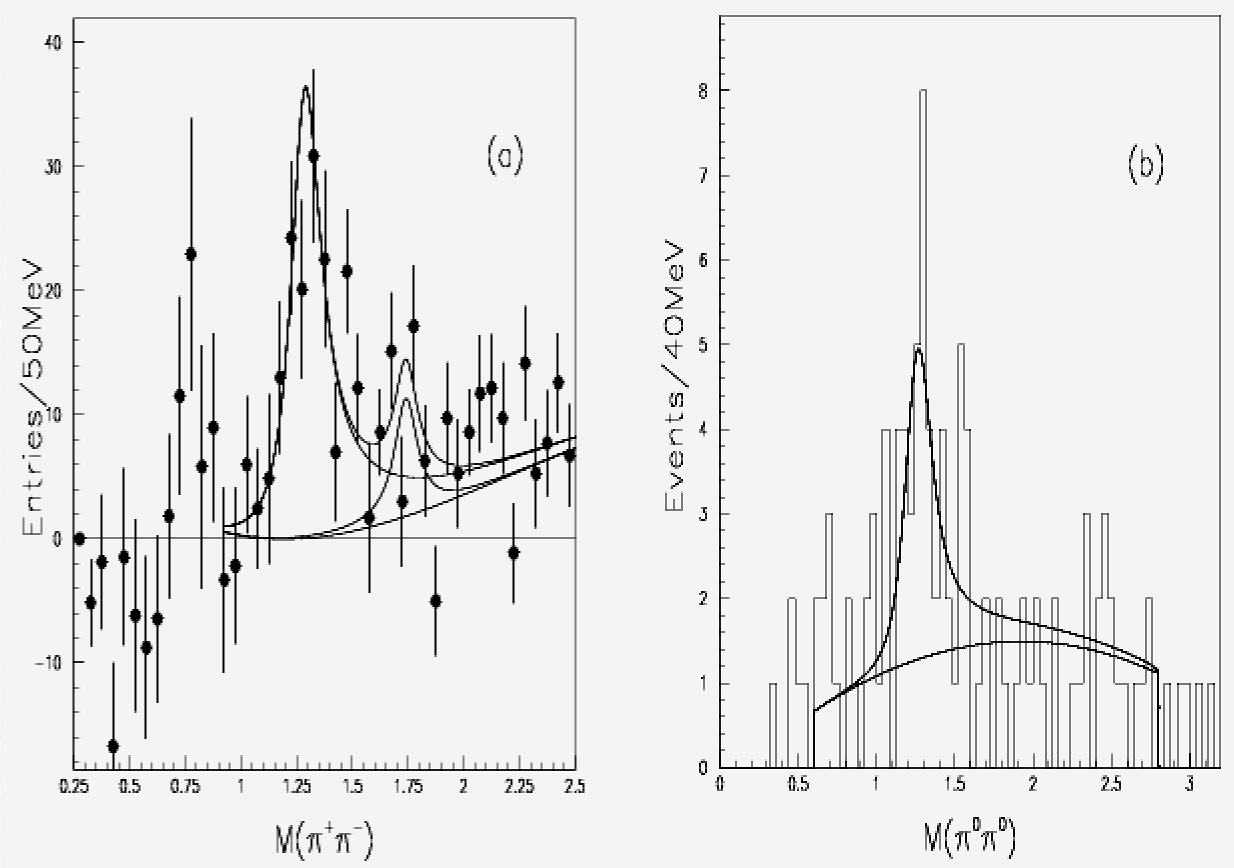


Radiative decays into two pseudoscalar mesons

- Radiative decays also expected to obey 12% Rule.
- Study $\psi(2s) \rightarrow \gamma \pi \pi$, γ K K-bar, and $\gamma\eta\eta$.
- Charged modes:
  - 2 (4 for $K_S K_S$) oppositely charged tracks; $\geqslant 1 \gamma$.
  - Use PID and kinematic fit. Prob > 1%.
  - Separate $\pi^+ \pi^-$ and $K^+ K^-$ based on chisquare probability.
- Neutral modes:
  - $\geqslant 5 \gamma$. Prob > 1%.
  - use 6C kinematic fit on all combinations. Select best.
  - also require $|M_{\gamma\gamma} - M_\pi| < 70$ MeV; $|M_{\gamma\gamma} - M_\eta| < 70$ MeV

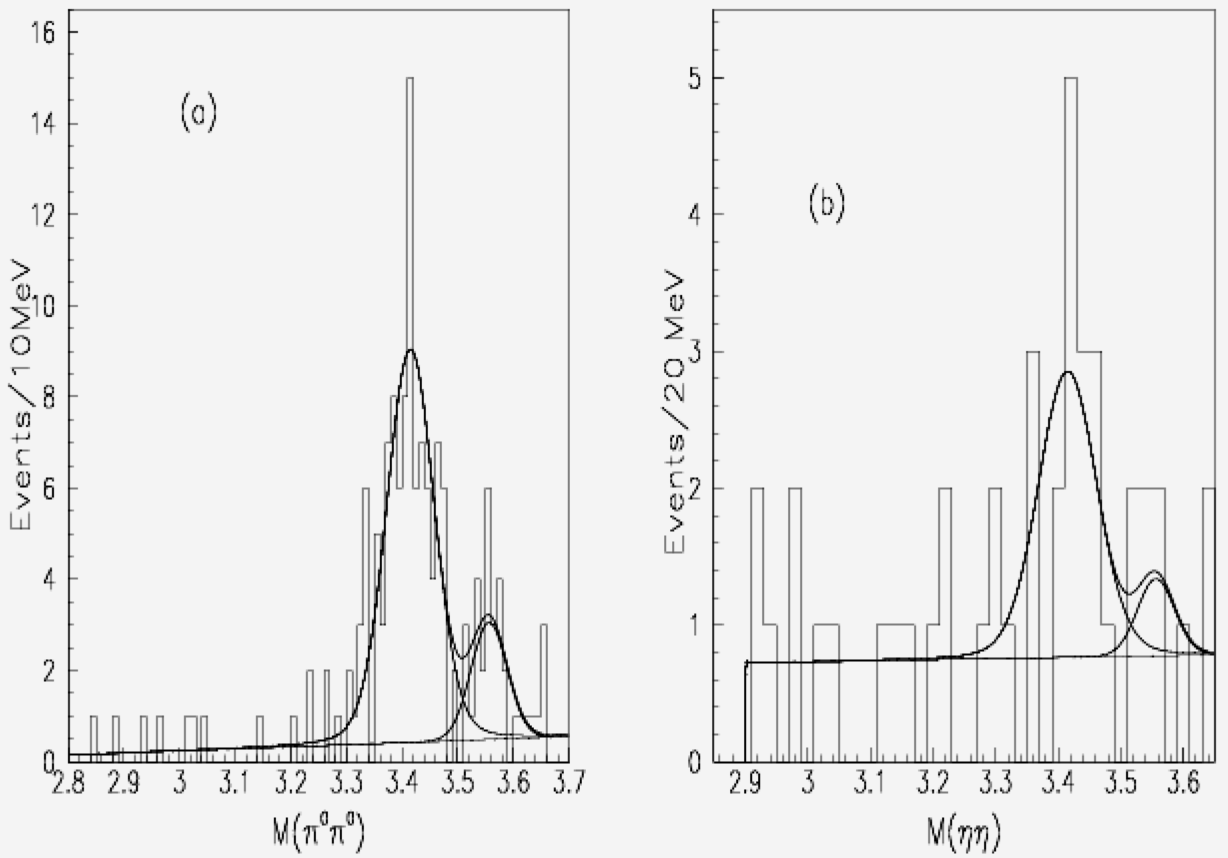
Using 4 M BESI sample.

Radiative decays into two pseudoscalar mesons



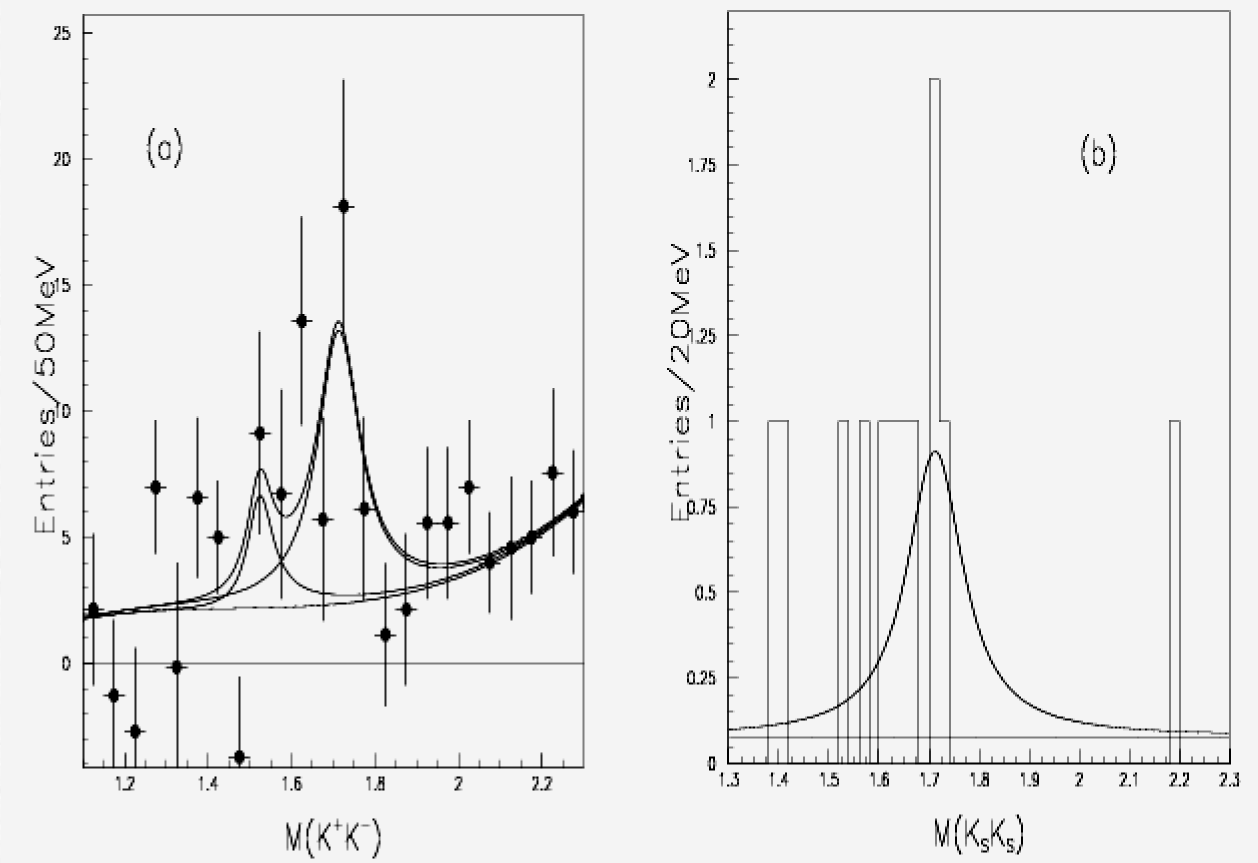
f_2(1270) and f_0(1710) in charged mode.

Radiative decays into two pseudoscalar mesons



χ_{c0} and $\chi_{c2} \rightarrow \pi^0\pi^0$ and $\eta\eta$.

Radiative decays into two pseudoscalar mesons



f_0(1710) and hint of f'_2 (1525) in charged mode.

Radiative decays into two pseudoscalar mesons

Mode	$B(\times 10^{-4})$
$\psi(2S) \to \gamma f_2(1270)$ from $\gamma\pi^+\pi^-$	$2.08 \pm 0.19 \pm 0.33$
$\psi(2S) \to \gamma f_2(1270)$ from $\gamma\pi^0\pi^0$	$2.90 \pm 1.08 \pm 1.07$
$\psi(2S) \to \gamma f_2(1270)$ from $\gamma\pi\pi$	$2.12 \pm 0.19 \pm 0.32$
$\psi(2S) \to \gamma f_0(1710) \to \gamma\pi\pi$ from $\gamma\pi^+\pi^-$	$0.301 \pm 0.041 \pm 0.124$
$\psi(2S) \to \gamma f_0(1710) \to \gamma K^+K^-$	$0.302 \pm 0.045 \pm 0.066$
$\psi(2S) \to \gamma f_0(1710) \to \gamma K_S^0 K_S^0$	$0.206 \pm 0.094 \pm 0.108$

Final state	$B(\psi(2S) \to)(\times 10^{-4})$	$B(J/\psi \to)(\times 10^{-4})$	$B(\psi(2S))/B(J/\psi)$
$\gamma f_2(1270)$	$2.12 \pm 0.19 \pm 0.32$	13.8 ± 1.4	$(15.4 \pm 3.1)\%$
$\gamma f_0(1710) \to \gamma K^+K^-$	$0.302 \pm 0.045 \pm 0.066$	$4.25^{+0.60}_{-0.45}$ [8]	$(7.1^{+2.1}_{-2.0})\%$

Decays are consistent with 12% rule.

Radiative decays into two pseudoscalar mesons

Mode	$B(\times 10^{-3})$	$B \times B(\psi(2S) \to \gamma\chi_{c0,2})(\times 10^{-4})$
$\chi_{c0} \to \pi^0\pi^0$	$2.79 \pm 0.32 \pm 0.57$	$2.42 \pm 0.28 \pm 0.44$
$\chi_{c2} \to \pi^0\pi^0$	$0.98 \pm 0.27 \pm 0.56$	$0.67 \pm 0.19 \pm 0.38$
$\chi_{c0} \to \eta\eta$	$2.02 \pm 0.84 \pm 0.59$	$1.76 \pm 0.73 \pm 0.49$
$\chi_{c2} \to \eta\eta$	< 1.37	< 0.93

Flavor SU(3) symmetry predicts branching fractions to $\pi^0\pi^0$ and $\eta\,\eta$ should be same except for a phase space factor and a barrier factor $p^{(2s+1)}$.

Prediction:

$$B(\chi_{c0} \to \eta\eta)/B(\chi_{C0} \to \pi^0\pi^0) = 0.95$$

Our measurement:

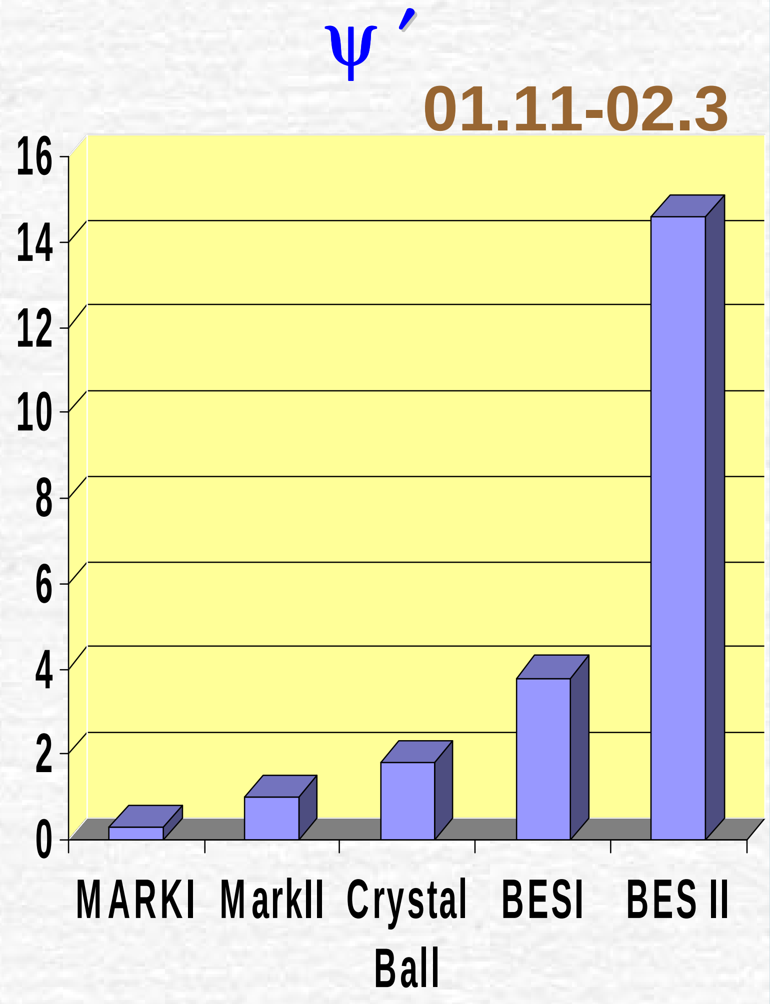
$$B(\chi_{c0} \to \eta\eta)/B(\chi_{c0} \to \pi^0\pi^0) = 0.73 \pm 0.30 \pm 0.25$$

Accepted by Phys. Rev. D

Year 2002 ψ(2S) run

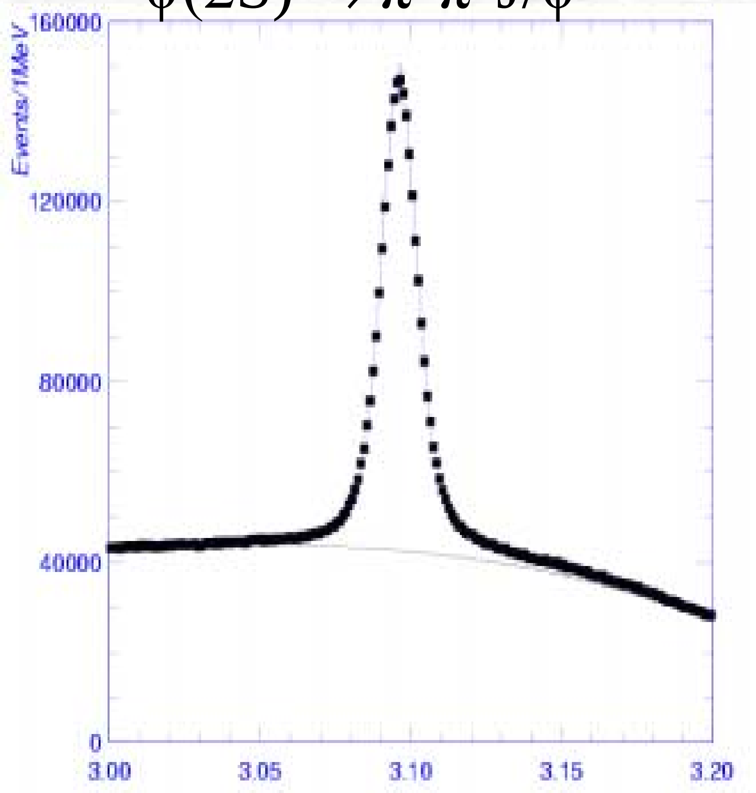
BES obtained 14 M ψ(2S) events.

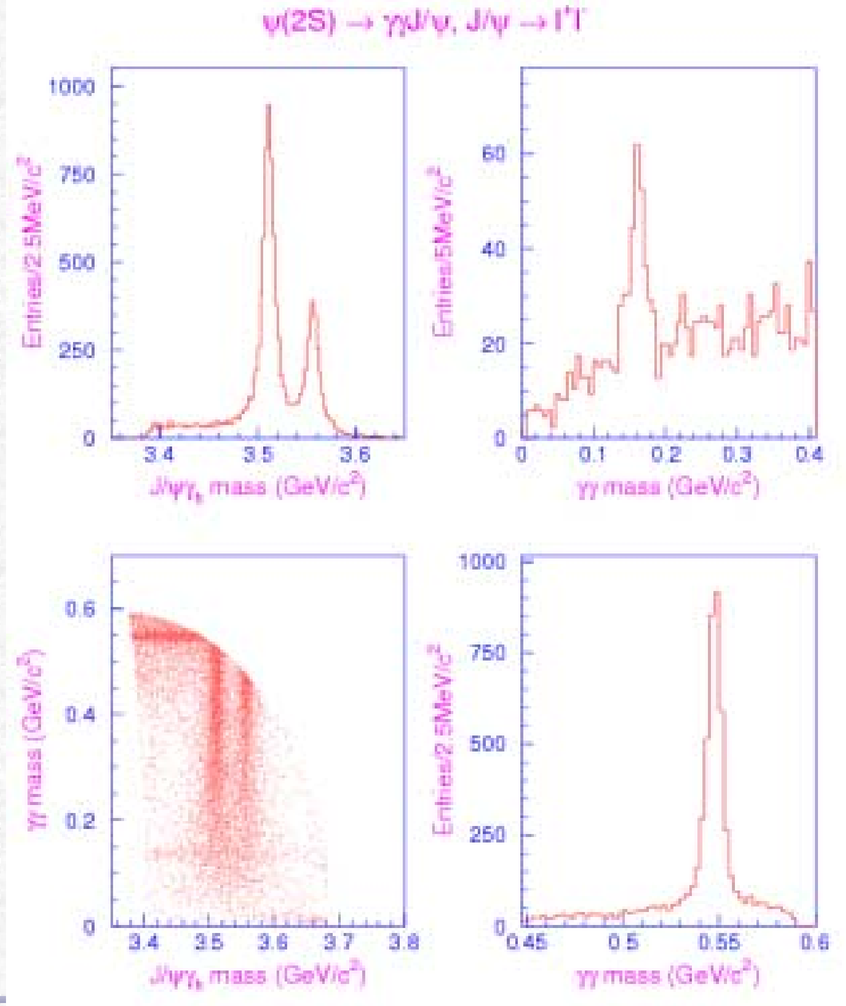
Now CLEOc will run at ψ(2S).



14M ψ(2S) (preliminary)

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





$\chi_{cJ} \to \Lambda\ \Lambda$-bar

- Color octet mechanism (COM) important for P-wave quarkonium decays.

  G. T. Bodwin *et al.*, Phys Rev. Lett. **D51**, 1125 (1995).
  H.-W. Huang and K.-T. Chao, Phys. Rev. **D54**, 6850 (1996).
  J. Bolz *et al.*, Phys. Lett. **B392**, 198 (1997).

- BES $\Gamma(\chi_{c0})$ agrees with COM.

  Phys. Rev. Lett. **81**, 3091 (1998).

- COM and a nucleon wave function give reasonable agreement with BES $\Gamma(\chi_{cJ} \to p$ p-bar) and other results.

- Generalizing to other baryons, the partial widths of other baryons can be predicted:

  $\Gamma(\chi_{cJ} \to \Lambda\ \Lambda$-bar) ~½ $\Gamma(\chi_{cJ} \to p$ p-bar) for χ_{c1} and χ_{c2}.
  S. M. Wong, Eur. Phys. J. **C14**, 643 (2000).

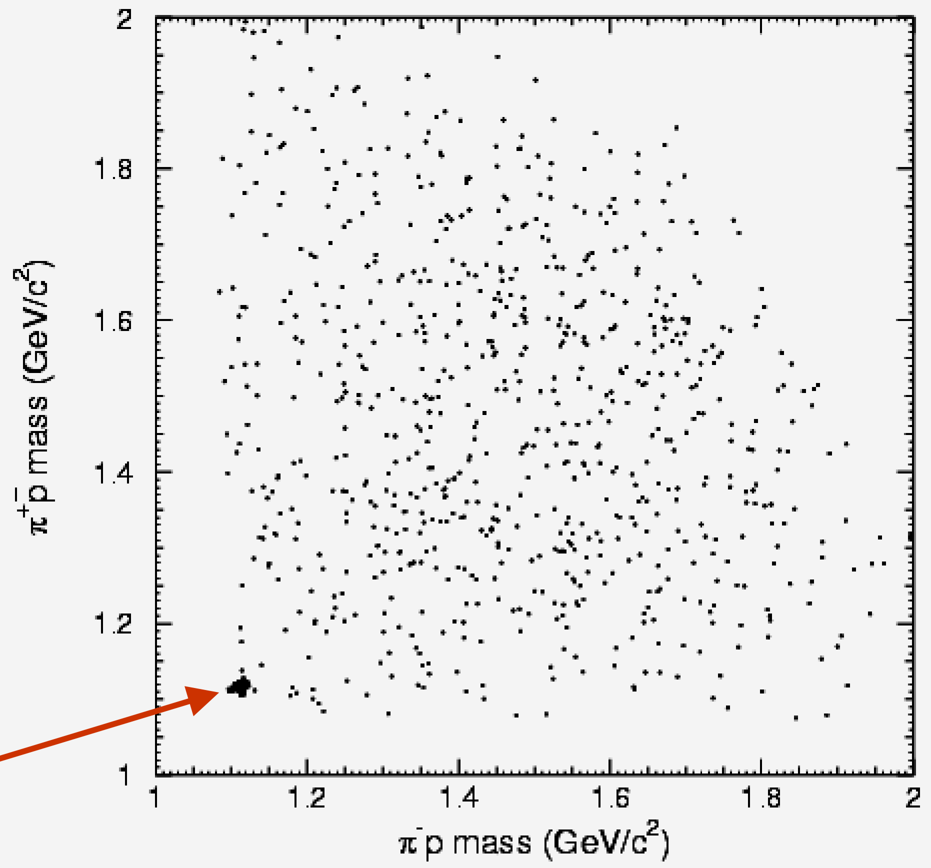
$\chi_{cJ} \rightarrow \Lambda\ \Lambda$-bar

Here we study:

$\psi(2s) \rightarrow \gamma\chi_{cJ} \rightarrow \gamma\Lambda\ \Lambda$-bar
$\rightarrow \gamma p\pi^-$ p-bar π^+.

- Select events with 4 charged tracks and > 0 γ's.
- Use PID for charged tracks. Prob > 0.01
- 4C kinematic fit. Select smallest chi-square and require Prob > 0.01.

See clear $\Lambda\ \Lambda$-bar signal.



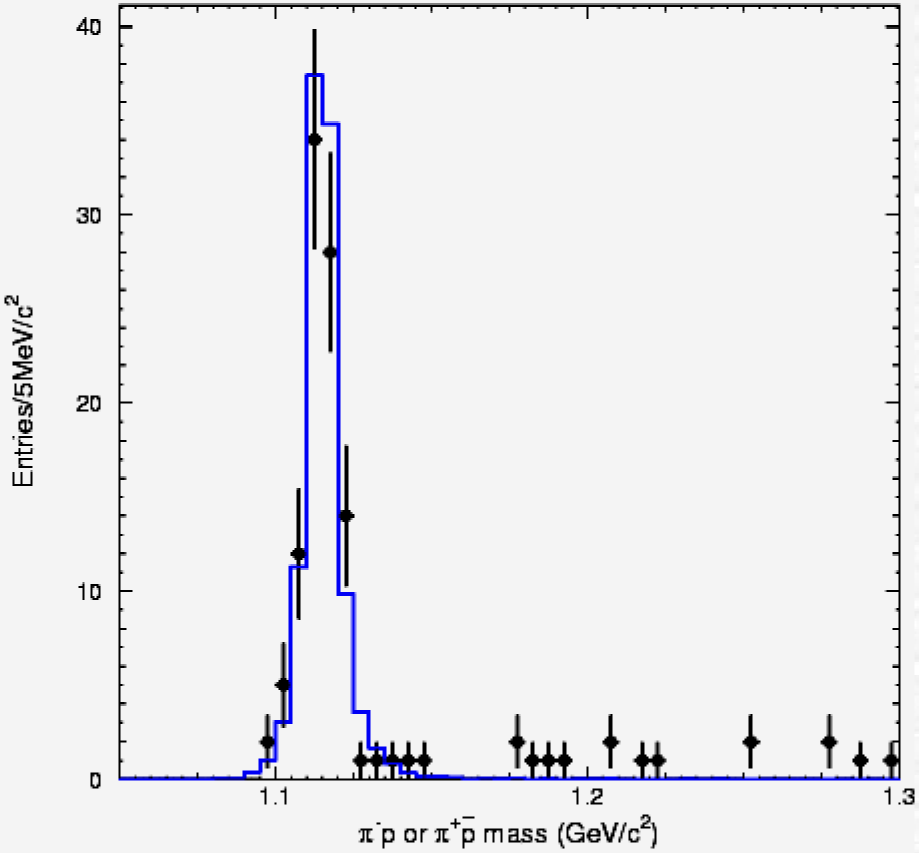
$\chi_{CJ} \rightarrow \Lambda\ \Lambda$-bar

- Select events around cluster.

  See clear lambda peak in m(πp).

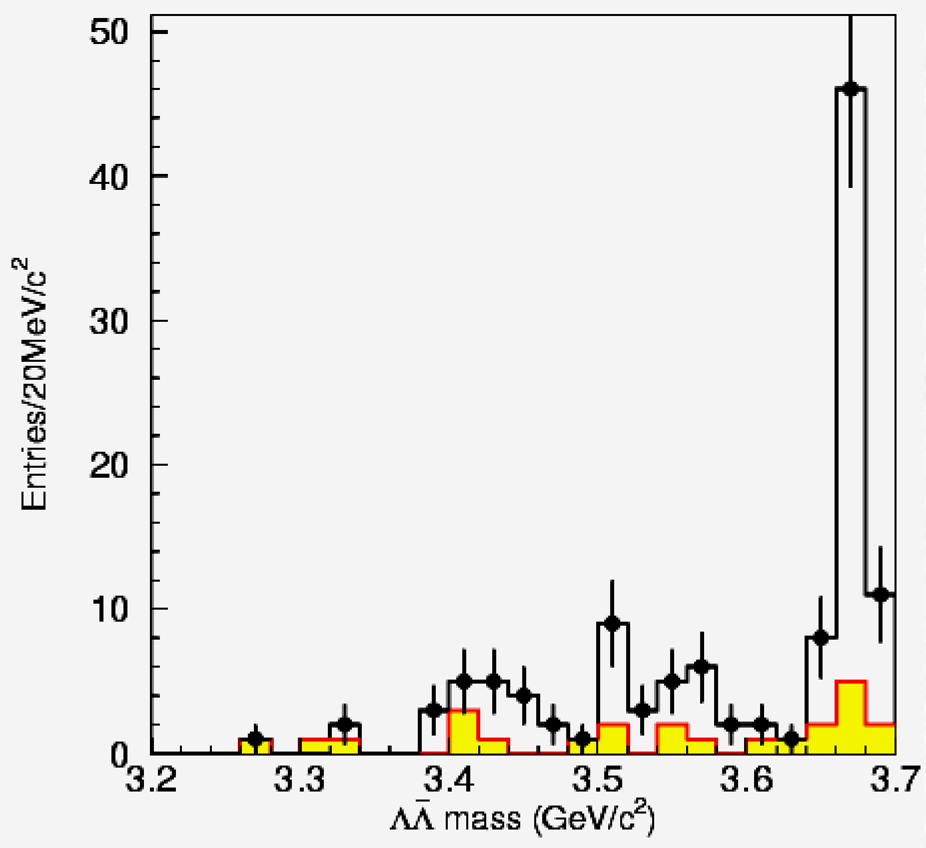
- m_{Λ} = (1114.3 $\pm$ 0.5) MeV/c^2.

  Agrees well with PDG .

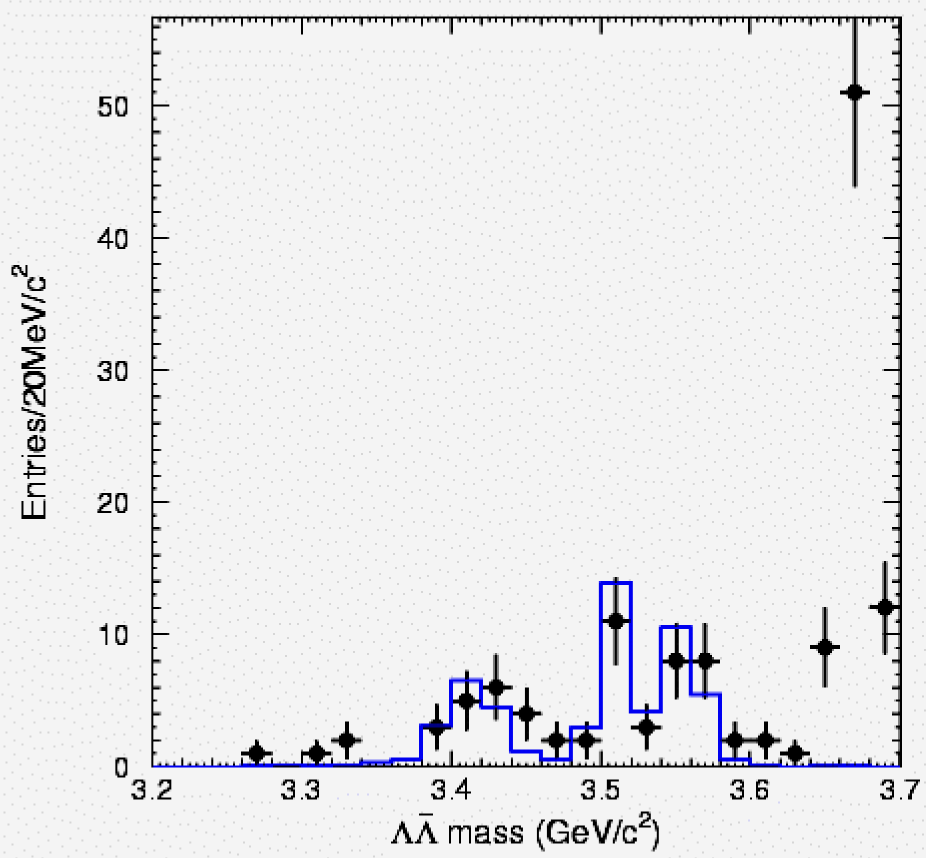


$\chi_{cJ} \rightarrow \Lambda\ \Lambda$-bar

Plot m($\Lambda\ \Lambda$-bar)



Sideband background



Monte Carlo Comparison

$\chi_{cJ} \rightarrow \Lambda\ \Lambda$-bar

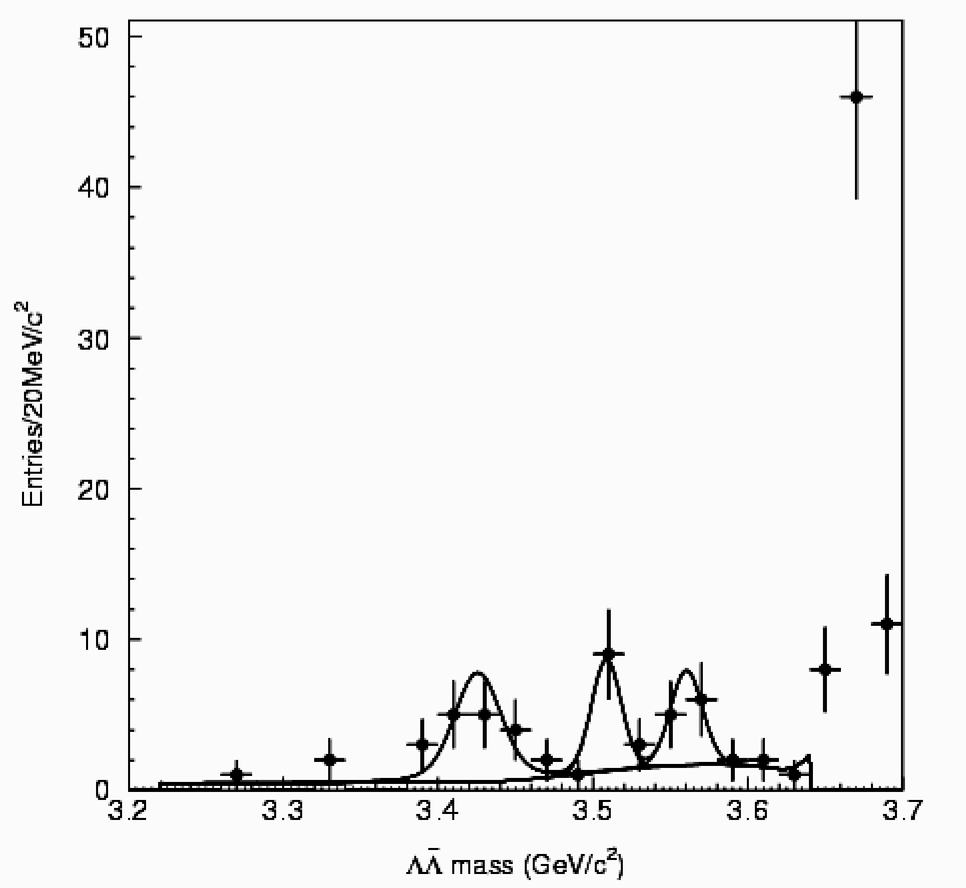
Main physics backgrounds:

$\psi(2s) \rightarrow \Lambda\ \Lambda$-bar

$\rightarrow \Sigma^0\ \Sigma^0$-bar

Fit:

- Monte Carlo background shape.
- Background level floating.
- Fix χ_{cJ} widths to PDG values.
- Use Monte Carlo mass resolutions.
- Fitted masses agree with PDG.



$\chi_{cJ} \to \Lambda\ \Lambda$-bar

Results

For $N(\psi(2s))$ use $\psi(2s) \to \pi^+\pi^- J/\psi$, $J/\psi \to p$ p-bar.

Many systematic errors cancel.

quantity	χ_{c0}	χ_{c1}	χ_{c2}
n^{obs}	$15.2^{+4.2}_{-4.0}$	$9.0^{+3.5}_{-3.1}$	$8.3^{+3.7}_{-3.4}$
ε (%)	6.07 ± 0.24	6.65 ± 0.25	6.09 ± 0.24
$N_{\psi(2S)}(10^6)$		14.9 ± 1.2	
$\mathcal{B}(\Lambda \to \pi^- p)$		0.639 ± 0.005	
$\mathcal{B}(\psi(2S) \to \gamma\chi_{cJ})$ (%)	8.7 ± 0.8	8.4 ± 0.7	6.8 ± 0.6
$\mathcal{B}(\chi_{cJ} \to \Lambda\bar{\Lambda})(10^{-4})$	$4.7^{+1.3}_{-1.2} \pm 1.0$	$2.6^{+1.0}_{-0.9} \pm 0.6$	$3.3^{+1.5}_{-1.3} \pm 0.7$
$n^{obs}_{\pi^+\pi^- J/\psi}$		1826 ± 44	
$\varepsilon_{\pi^+\pi^- J/\psi}$ (%)		17.88 ± 0.12	
$B(\chi_{cJ} \to$ p p-bar)(10^{-4})	2.2 ± 0.5	0.72 ± 0.13	0.74 ± 0.10

Preliminary!

Summary

- Measured $\psi(2s)$ decay modes containing ω's and ϕ's and radiative decays to two pseudoscalar mesons.

  These provide more information on 12 % Rule.

- Scan results improve on $\psi(2s)$ resonance parameters.

  First measurement of $\Gamma_{\pi\pi\ J/\psi}$.

- New preliminary results on B($\chi_{cJ} \rightarrow \Lambda\ \Lambda$-bar)

New 14 M *ψ(2s)* will provide many new results.

That’s all!

Thanks!