

Recent results on charmonium decays at BESII

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for the BES Collaboration

Hadron'07

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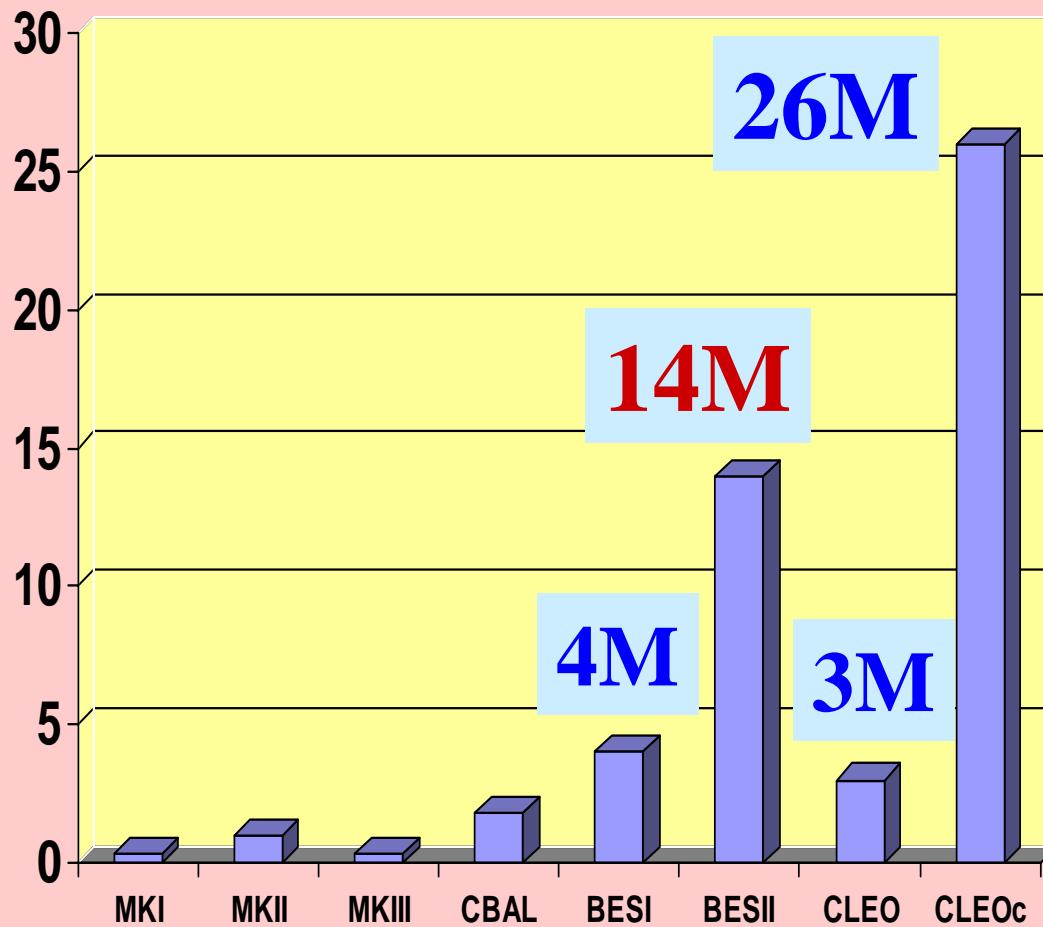
The Beijing Spectrometer (BES) at BEPC



1989-2005
Ecm=2-5 GeV
 $L_{peak}=10 \times 10^{30} / \text{cm}^2 \text{s}$
@ ψ' energy

ψ' Data samples

outlines



**6.42 pb⁻¹ data at Ecm=3.65 GeV
for continuum background study.**

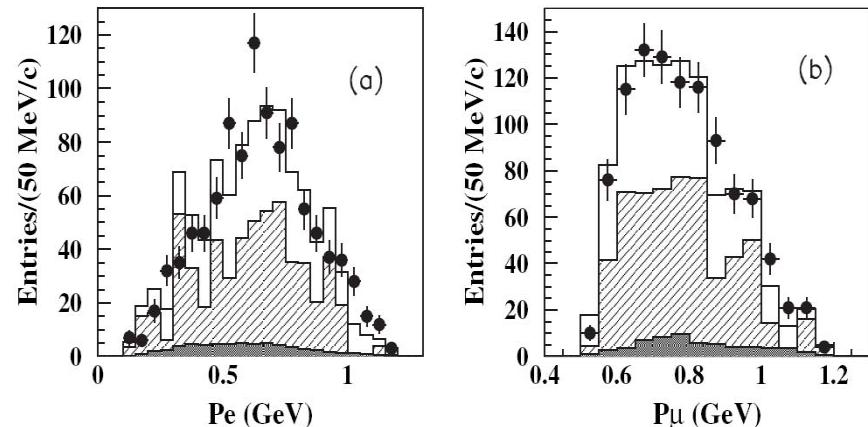
- ψ' decays
 - Leptonic decays
 - Radiative decays
 - Hadronic decays
- χ_{cJ} decays
- PPP
- J/ ψ decays via ψ' sample
 - Rare and forbidden
 - light dark matter (LDM)

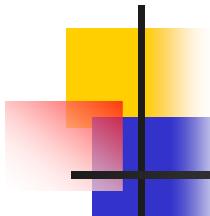
J/ ψ and $\psi(3770)$ decays in
Shen and Rong's talks.

ψ' leptonic decays: $B(\psi' \rightarrow \tau^+ \tau^-)$

- First observation by DASP: ZPC1, 233(1979), no BR
- First measurement by BESI: PRD65, 052004 (2002)
 - $B = (0.271 \pm 0.043 \pm 0.055)\%$
- Improvements:
 - Continuum contribution measured in data
 - Efficiency and background estimation
 - Interference subtraction more reasonable
- Results:
 - 1015 evts at resonance
 - 146 evts at continuum
 - $B = (0.308 \pm 0.021 \pm 0.038)\%$
 - Lepton universality tested at the 20% level.

PRD74,112003(2006)





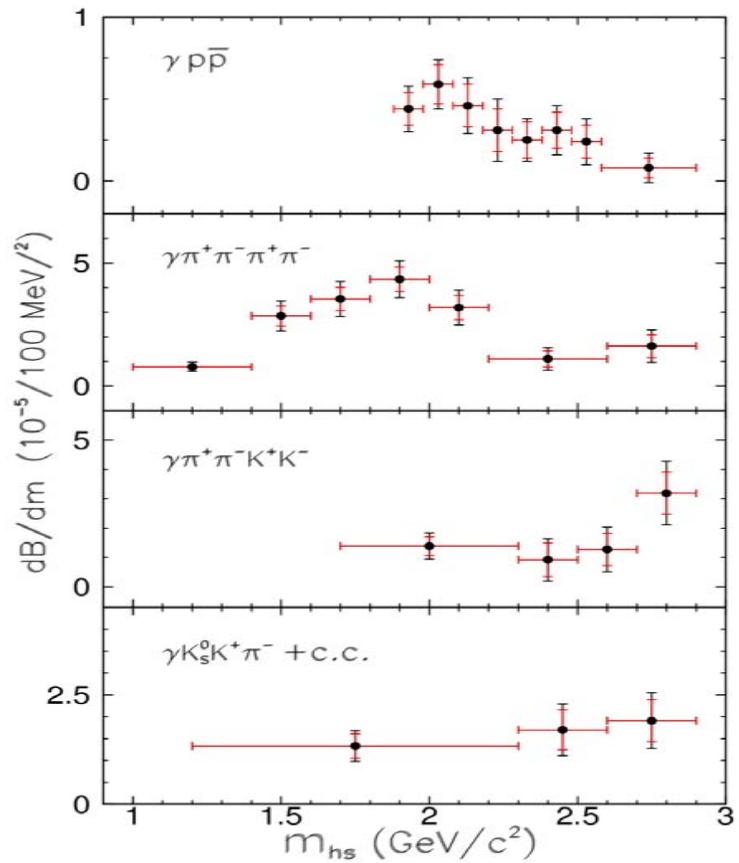
ψ' radiative decays

- Only limited modes measured by BESI
 - $\gamma\eta, \gamma\eta'$ [PRD58, 097101 (1998)]
 - $\psi' \rightarrow \gamma KK, \gamma\pi\pi$ [PRD67, 032004 (2003)]
- Try to measure more modes
- $B(\psi' \rightarrow \gamma + X)$
 - 2-prong: $\pi^+\pi^-$, K^+K^- , ppbar, $\eta\pi^+\pi^-$
 - 4-prong: $2(\pi^+\pi^-)$, $\pi^+\pi^-K^+K^-$, $\pi^+\pi^-$ ppbar, $2(K^+K^-)$, $K_S K^+\pi^- + \text{c.c.}$
 - 6-prong: $3(\pi^+\pi^-)$, $2(\pi^+\pi^-)K^+K^-$
- Published in
 - PRL99, 011802 (2007)
 - PRD74, 072001 (2006)

Observation of ψ' radiative decays

- Expected 1% BR, but only 0.05% observed.
- Potential channels for hadron spectroscopy study, including search for non-qqbar states, provided statistics is enough (BESIII?).
- ~ 0.1% more observed in this analysis.

Mode	BR ($\times 10^{-5}$) [$m < 2.9 \text{ GeV}/c^2$]
$\gamma p\bar{p}$	$2.9 \pm 0.4 \pm 0.4$
$\gamma \eta'$	$12.6 \pm 2.9 \pm 1.5$
$\gamma 2(\pi^+\pi^-)$	$39.6 \pm 2.8 \pm 5.0$
$\gamma K_S K^+ \pi^- + c.c.$	$25.6 \pm 3.6 \pm 3.6$
$\gamma \pi^+\pi^- K^+ K^-$	$19.1 \pm 2.7 \pm 4.3$
$\gamma \pi^+\pi^- p\bar{p}$	$2.8 \pm 1.2 \pm 0.7$
$\gamma 2(K^+K^-)$	< 4.0
$\gamma 3(\pi^+\pi^-)$	< 17
$\gamma 2(\pi^+\pi^-) K^+ K^-$	< 22



$\psi' \rightarrow \gamma\pi^+\pi^-$ and γK^+K^-

BES preliminary

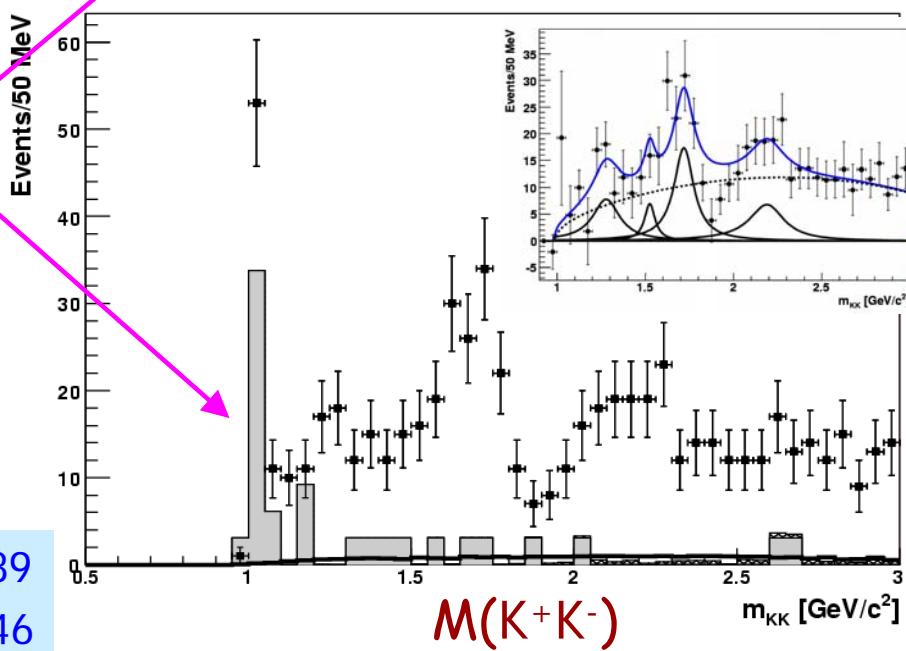
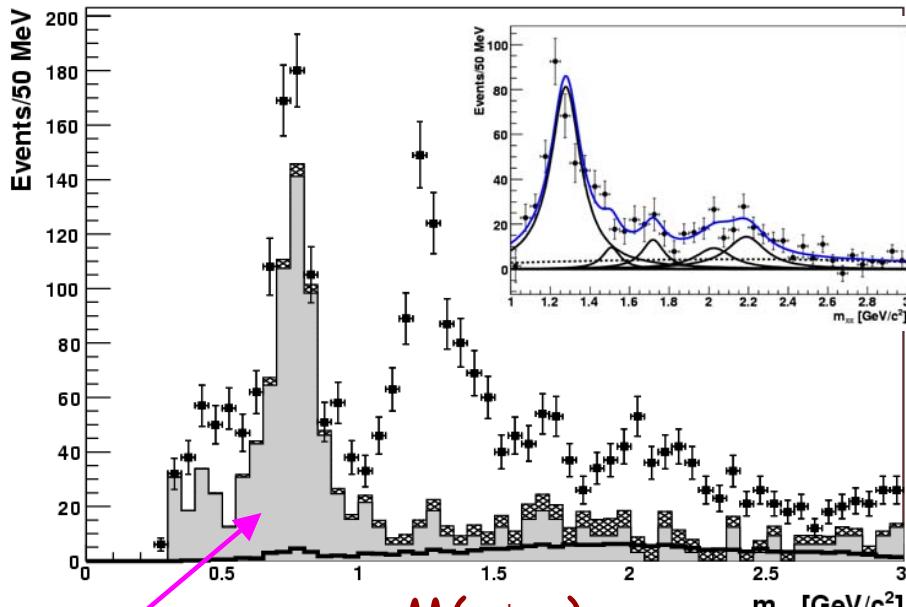
Mode	BR ($\times 10^{-5}$)
$\gamma f_2(1270) \rightarrow \gamma\pi^+\pi^-$	$22 \pm 1 \pm 2$
$\gamma f_0(1500) \rightarrow \gamma\pi^+\pi^-$	$1.5 \pm 0.7 {}^{+0.9}_{-0.4}$
$\gamma f_0(1710) \rightarrow \gamma\pi^+\pi^-$	$2.4 \pm 0.6 {}^{+0.8}_{-1.1}$
$\gamma f_4(2050) \rightarrow \gamma\pi^+\pi^-$	$2.8 \pm 0.9 {}^{+0.8}_{-0.6}$
$\gamma f_0(2200) \rightarrow \gamma\pi^+\pi^-$	$4.6 \pm 1.0 {}^{+4.5}_{-0.9}$
$\gamma f_2(1270) \rightarrow \gamma K^+K^-$	$1.9 \pm 0.6 {}^{+1.0}_{-0.6}$
$\gamma f'_2(1525) \rightarrow \gamma K^+K^-$	$0.69 \pm 0.44 {}^{+0.41}_{-0.21}$
$\gamma f_0(1710) \rightarrow \gamma K^+K^-$	$3.1 \pm 0.6 {}^{+1.1}_{-0.7}$

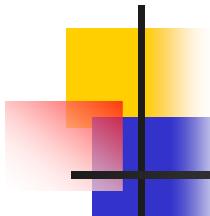
- Fit with incoherent BWs
- ISR produced ρ and ϕ consistent with prediction

$\gamma f_2(1270) \rightarrow \gamma\pi^+\pi^-$ helicity amplitudes

Positive solution	Negative solution
$x = 0.20 \pm 0.09 \pm 0.25$	$x = -0.26 \pm 0.09 \pm 0.24$
$y = -0.26 \pm 0.08 \pm 0.05$	$y = -0.25 \pm 0.09 \pm 0.06$
$\rho_{stat} = 0.53$	$\rho_{stat} = -0.43$
$\rho_{sys} = 0.44$	$\rho_{sys} = -0.41$

$$\text{J}/\psi: x=0.89 \\ y=0.46$$





ψ' hadronic decays

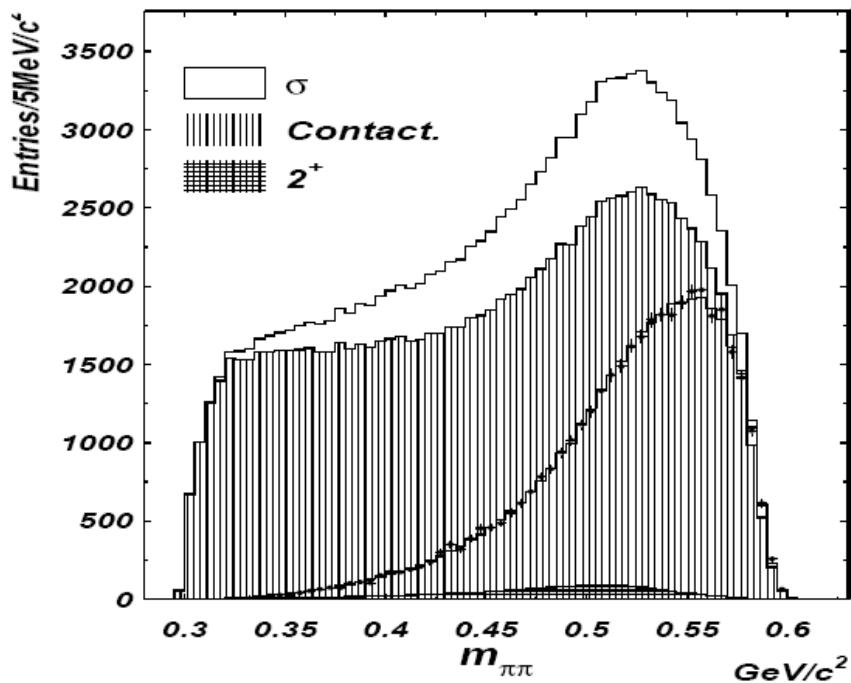
- Test 12% rule, new phenomena?
- $B(\psi' \rightarrow X)$
 - σ in $\psi' \rightarrow \pi^+ \pi^- J/\psi$
 - Baryon pairs
 - $p n \pi + C.C.$
 - $\Lambda \bar{\Lambda} \pi^0, \Lambda \bar{\Lambda} \eta$
 - ...

$$Q_h = \frac{B_{\psi' \rightarrow X}}{B_{J/\psi \rightarrow X}} = \frac{B_{\psi' \rightarrow e^+ e^-}}{B_{J/\psi \rightarrow e^+ e^-}} = 12\%$$

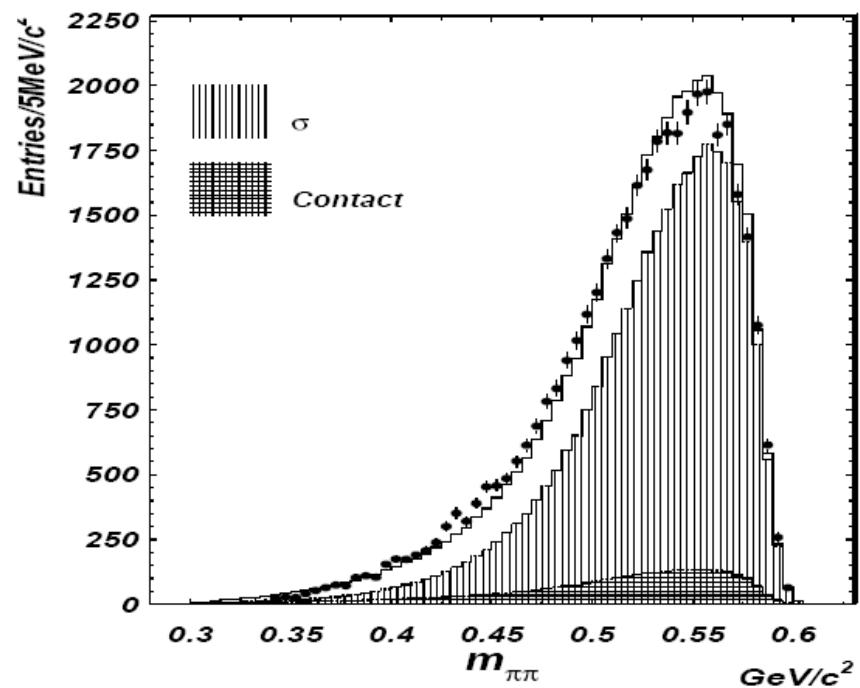
σ production in $\psi' \rightarrow \pi^+ \pi^- J/\psi$

- Resolve the controversial since 1957.
- Establish σ as a particle together with other evidence.

Breit-Wigner parameterization



CHUA+FSI from $\pi\pi$ scattering



σ production in $\psi' \rightarrow \pi^+ \pi^- J/\psi$

- Measure the pole position (552 - i232 MeV)
- Agree with results from BES $J/\psi \rightarrow \omega \pi^+ \pi^-$
- World largest σ signal (with $\sim 40,000$ tagged events)

Fit results of the two models and all the Breit-Wigner parameterizations

Model	Constant Γ	Γ with ρ	P.K.U.	Zou&Bugg	Guo&Oset
Pole(MeV/ c^2)	(553 \pm 15 \pm 47)	(559 \pm 6 \pm 26)	(554 \pm 13 \pm 65)	(541 \pm 9 \pm 95)	469 - i203
N_σ	$-i(254 \pm 23 \pm 54)$	$-i(179 \pm 7 \pm 18)$	$-i(240 \pm 4 \pm 19)$	$-i(253 \pm 8 \pm 33)$	(input)
N_{contact}	140308	72735	133208	171586	30765
$-\ln L$	121625	63133	111230	157741	3039
$\chi^2_{\text{obs.}}/ndf$	-16174.5	-16166.8	-16171.0	-16174.3	-15974.1
C.L.	217.83/196	227.54/196	224.07/196	217.88/196	392.73/208
	0.1362	0.0608	0.0825	0.1357	3×10^{-13}

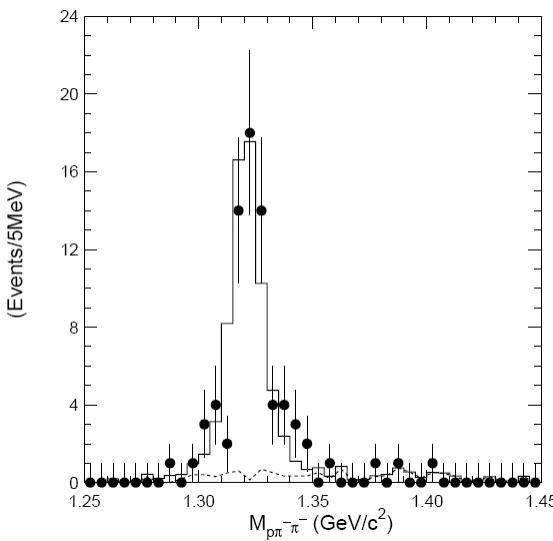
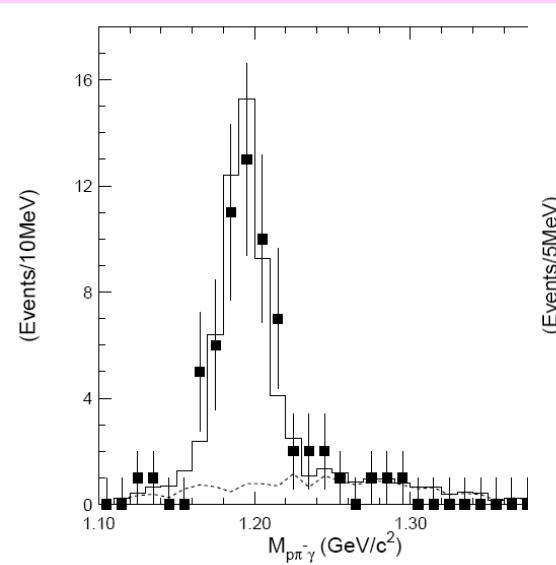
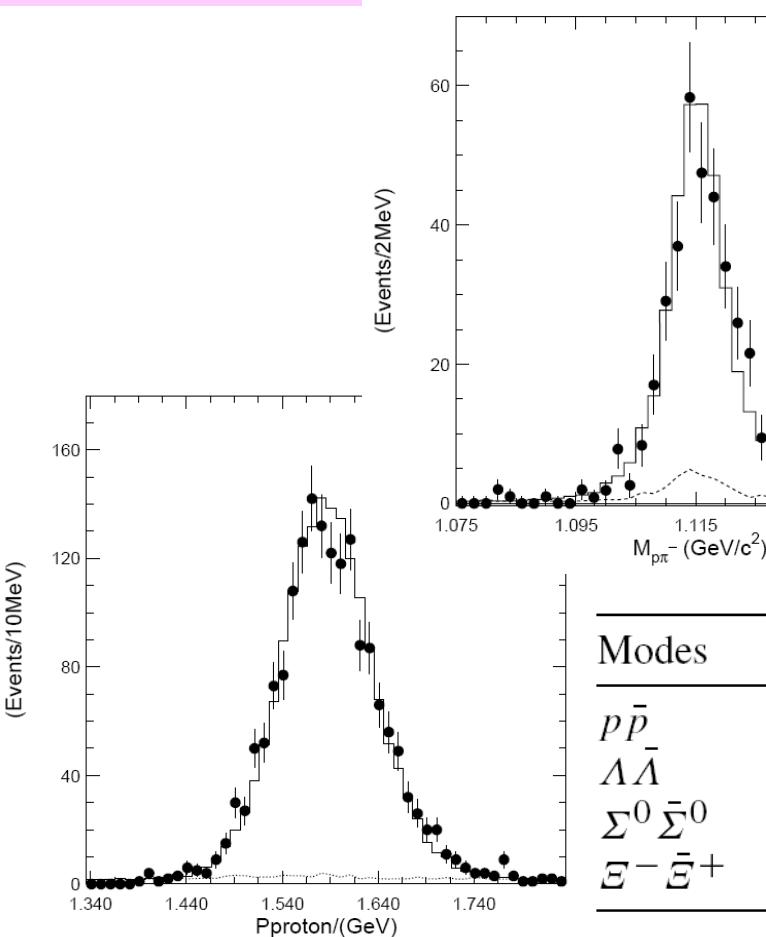
Pole position:

$$(552^{+84}_{-106}) - i(232^{+81}_{-72}) \text{ MeV}/c^2$$

$\psi' \rightarrow BB\bar{b}$

PLB648, 149 (2007)

- First measurement by BESI, re-measure BR with a larger ψ' data sample. SU(3) symmetry observed.
- “12% rule” tested.

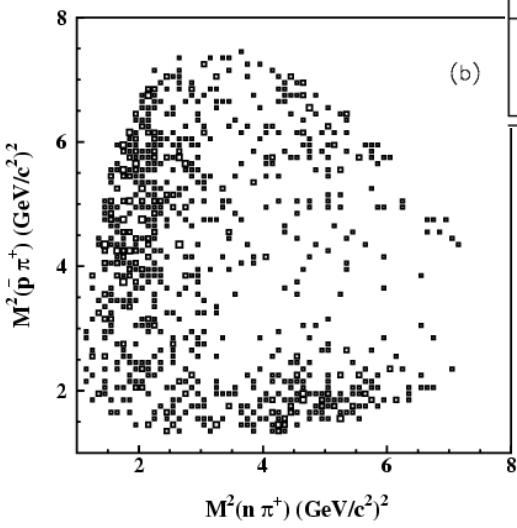
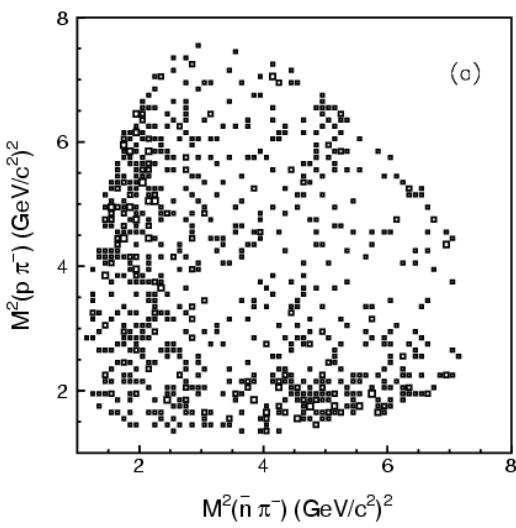
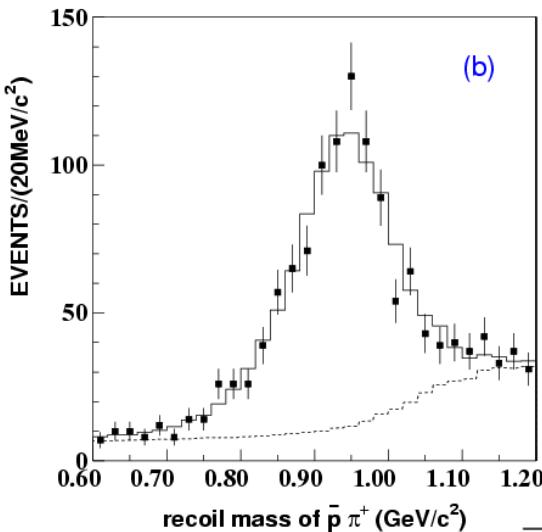
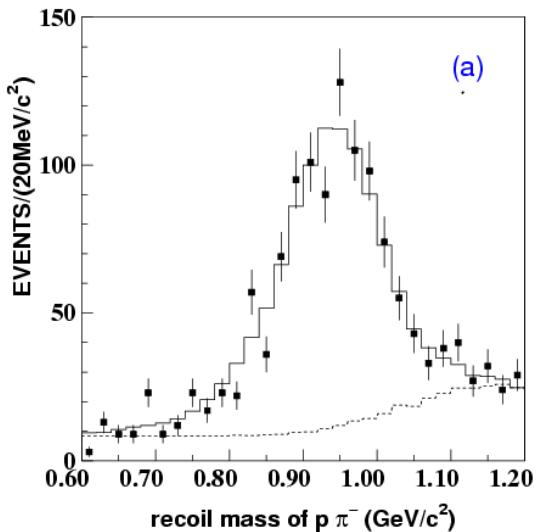


Agree with CLEOc results!

Modes	BRs ($\times 10^{-4}$)	Q (%)
$p\bar{p}$	$3.36 \pm 0.09 \pm 0.25$	14.9 ± 1.4
$\Lambda\bar{\Lambda}$	$3.39 \pm 0.20 \pm 0.32$	16.7 ± 2.1
$\Sigma^0\bar{\Sigma}^0$	$2.35 \pm 0.36 \pm 0.32$	16.8 ± 3.6
$E^- \bar{E}^+$	$3.03 \pm 0.40 \pm 0.32$	16.8 ± 4.7

Baryonic decays

$$\psi(2S) \rightarrow p\bar{n}\pi^- + c.c.$$



Rich structure (N^* 's), statistics (~ 850 evts in each mode) still low for a partial wave analysis.

Mode	$B_{\psi(2S)\rightarrow X}(10^{-4})$	$Q_h(\%)$
$p\bar{n}\pi^-$	$2.45 \pm 0.11 \pm 0.21$	12.1 ± 1.6
$p\bar{n}\pi^+$	$2.52 \pm 0.12 \pm 0.22$	13.1 ± 1.8

PRD74, 012004 (2006)

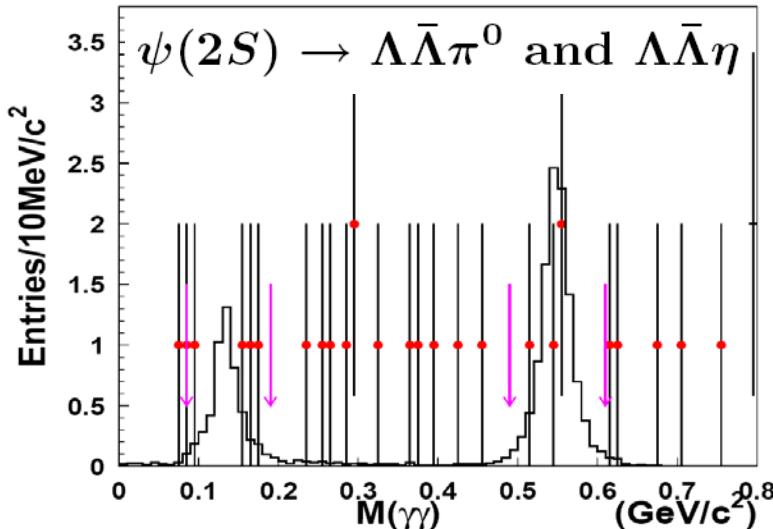
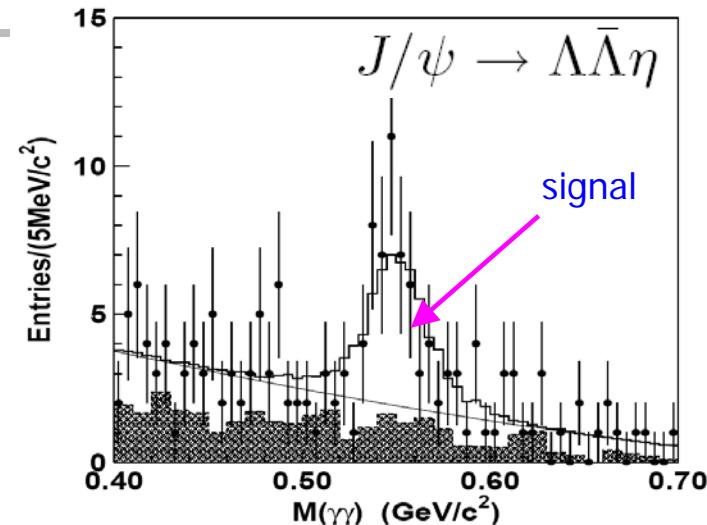
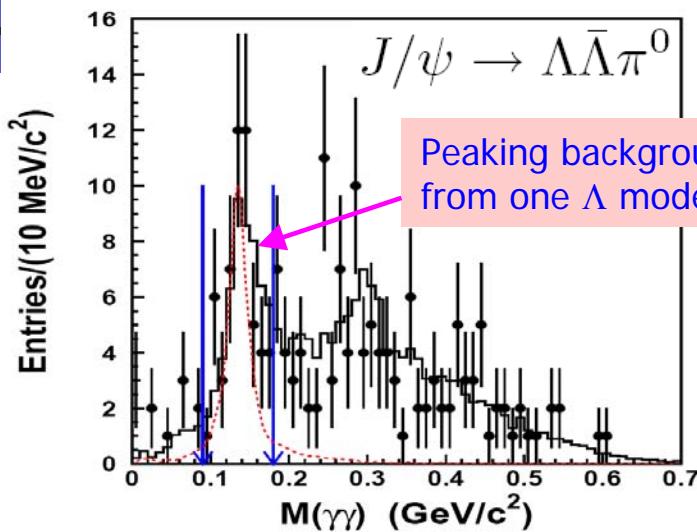
Test I-spin symmetry
(prediction: 1:2:2)

$$B(\psi' \rightarrow p\bar{p}\pi^0) : B(\psi' \rightarrow p\bar{n}\pi^-) : B(\psi' \rightarrow \bar{p}n\pi^+) = 1 : 1.86 \pm 0.27 : 1.91 \pm 0.27$$

$\psi'(J/\psi) \rightarrow \Lambda\bar{\Lambda} + \pi^0/\eta$

arXiv: 0707.1127 [hep-ex]
To appear in PRD

- BESI/DMII: $B(\Lambda\bar{\Lambda}\pi^0) \sim 2 \times 10^{-4}$: Isospin-violation!

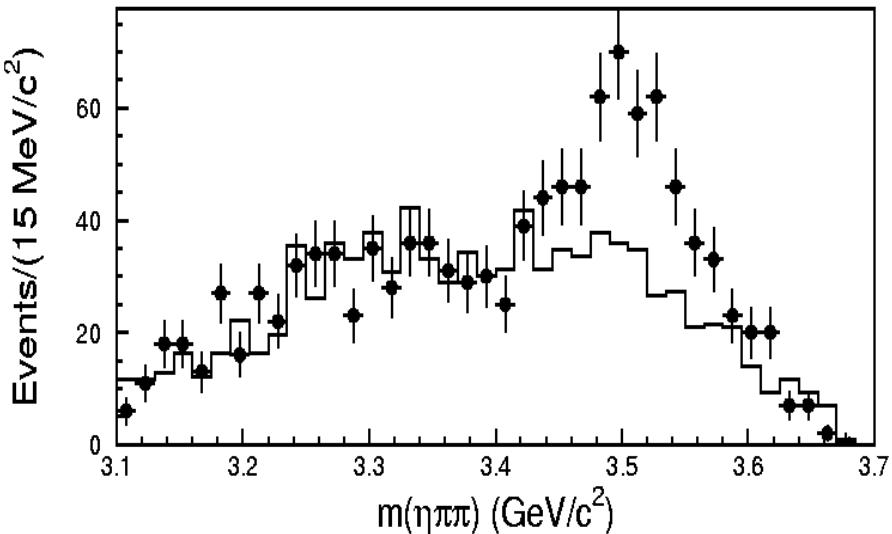
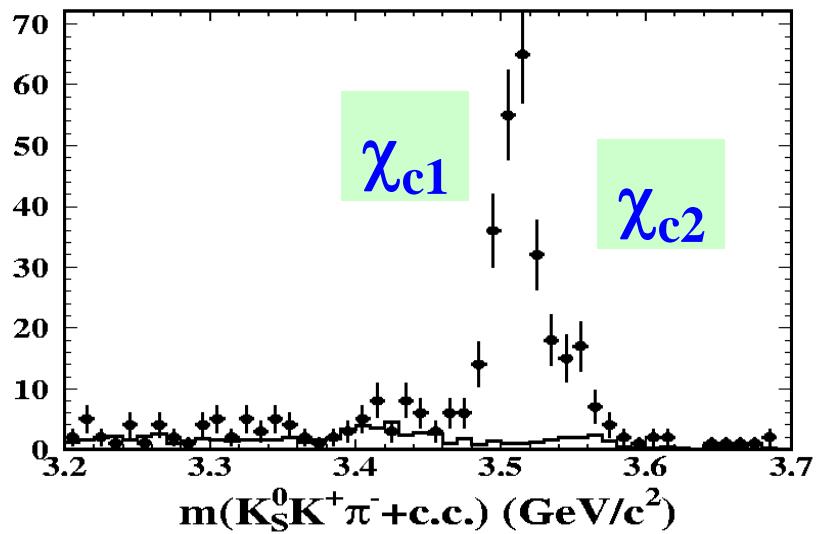


Channels	Number of events	Branching fraction ($\times 10^{-4}$)
$J/\psi \rightarrow \Lambda\bar{\Lambda}\pi^0$	< 10	< 0.64
$J/\psi \rightarrow \Lambda\bar{\Lambda}\eta$	44 ± 10	$2.62 \pm 0.60 \pm 0.44$
$\psi(2S) \rightarrow \Lambda\bar{\Lambda}\pi^0$	< 7.0	< 0.49
$\psi(2S) \rightarrow \Lambda\bar{\Lambda}\eta$	< 7.6	< 1.2
$J/\psi \rightarrow \Sigma^+ \pi^- \bar{\Lambda}$	335 ± 22	$7.70 \pm 0.51 \pm 0.83$
$J/\psi \rightarrow \bar{\Sigma}^- \pi^+ \Lambda$	254 ± 19	$7.47 \pm 0.56 \pm 0.76$

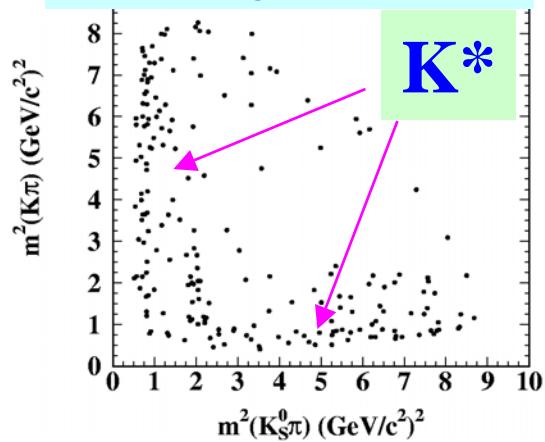
First measurement!

χ_{cJ} decays into PPP

PRD74, 072001 (2006)
 $\chi_{cJ} \rightarrow KK\pi$ and $\eta\pi\pi$

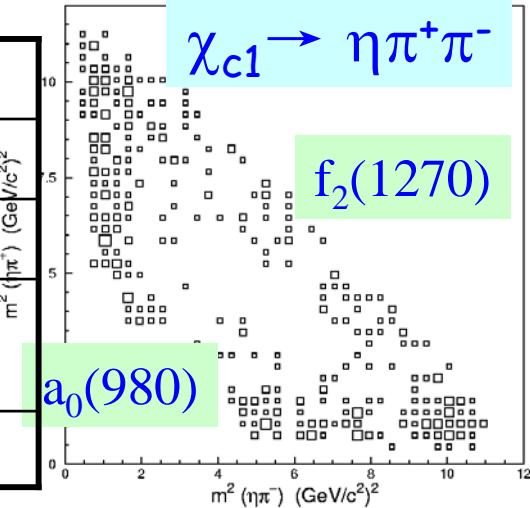


$\chi_{c1} \rightarrow K_S K^+ \pi^- + C.C.$



$B(\chi_{c1} \rightarrow K_S K^+ \pi^- + c.c.)$	$(4.1 \pm 0.3 \pm 0.7) \times 10^{-3}$
$B(\chi_{c2} \rightarrow K_S K^+ \pi^- + c.c.)$	$(0.8 \pm 0.3 \pm 0.2) \times 10^{-3}$
$B(\chi_{c1} \rightarrow \eta \pi^+ \pi^-)$	$(6.1 \pm 0.8 \pm 1.0) \times 10^{-3}$
$B(\chi_{c1} \rightarrow a_0^+ \pi^- \rightarrow \eta \pi^+ \pi^-)$	$(2.0 \pm 0.5 \pm 0.5) \times 10^{-3}$
$B(\chi_{c1} \rightarrow f_2(1270)\eta)$	$(2.1 \pm 0.5 \pm 0.4) \times 10^{-3}$

$\chi_{c1} \rightarrow \eta \pi^+ \pi^-$



$\chi_{c0} \rightarrow PPP$ is forbidden by spin-parity; $\eta\pi^+\pi^-$ mode is first observation.

C-violation: $J/\psi \rightarrow \gamma\gamma$

- No QED background with $\psi(2S) \rightarrow \pi^+ \pi^- J/\psi$

Select two low momentum pions, and two high energy photons.

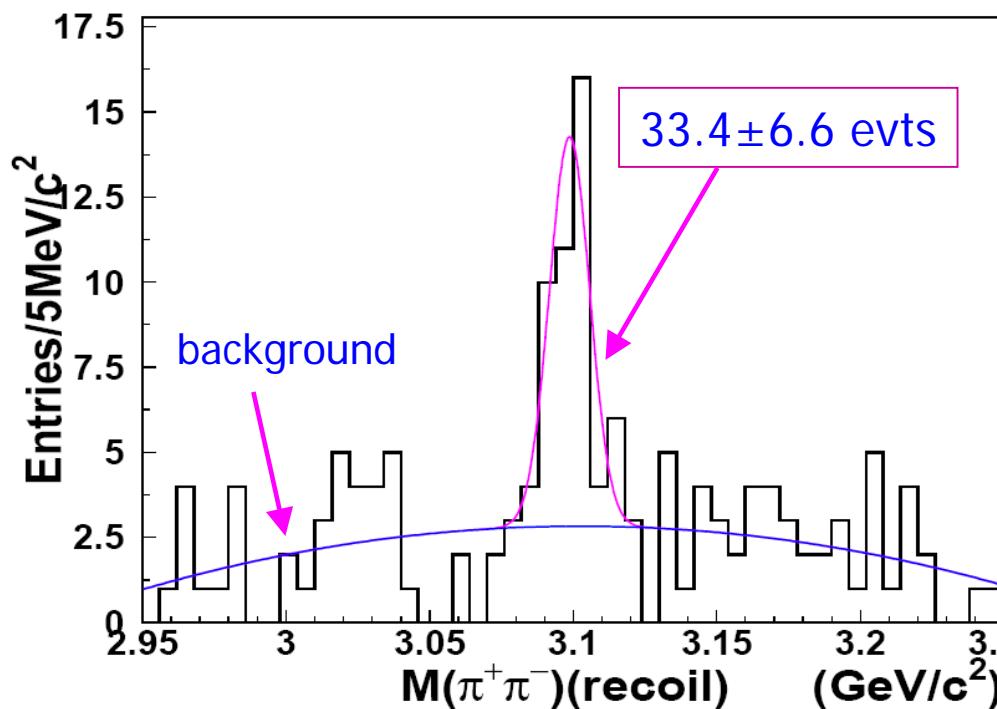


TABLE I: Peaking background events from different channels. The “Sum of four channels” includes $\gamma f_2(1810)$, $\gamma f_0(2020)$, $\gamma f_2(2150)$, and $\gamma f_4(2050)$.

Peaking background ($\psi(2S) \rightarrow \pi^+ \pi^- J/\psi, J/\psi \rightarrow$)	Number of events
$\gamma\pi^0$	$8.3^{+1.7}_{-1.2}$
$\gamma\eta$	16.4 ± 1.4
$\gamma\eta'$	1.5 ± 0.2
$\gamma f_2(1270) \rightarrow \gamma\pi^0\pi^0$	1.7 ± 0.3
$\gamma f_0(1500) \rightarrow \gamma\pi^0\pi^0$	negligible
$\gamma f_0(1710) \rightarrow \gamma\pi^0\pi^0$	0.4 ± 0.3
Sum of four channels	2.0 ± 1.0
Total	30.4 ± 2.4

$$\mathcal{B}(J/\psi \rightarrow \gamma\gamma) < 2.2 \times 10^{-5} \text{ at the 90\% C.L.}$$

CNTR(1977): $B < 5 \times 10^{-4}$

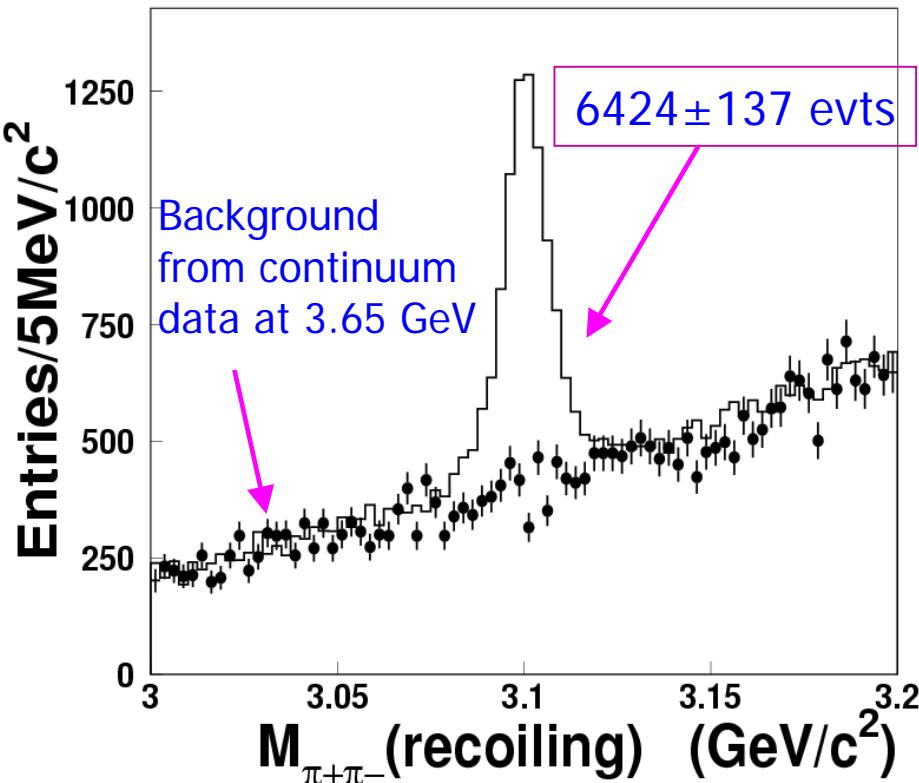
arXiv: 0709.3371 [hep-ex]
Submitted to PRD

J/ ψ → invisible

arXiv: 0710.0039 [hep-ex]
Submitted to PRL

- $\psi(2S) \rightarrow \pi^+ \pi^- J/\psi$ as a J/ψ sample by tagging $\pi^+ \pi^-$

Select two low momentum pions, and require no other particles in detector.



Peaking background

Background channel ($\psi(2S) \rightarrow \pi^+ \pi^- J/\psi, J/\psi \rightarrow$)	expected N_{bg}
$\mu^+ \mu^-$	2543 ± 254
$e^+ e^-$	2393 ± 240
$n \bar{n}$	1011 ± 85
$p \bar{p}$	42 ± 13
$n \bar{n} \pi^0$	29 ± 10
Total	6018 ± 360

Lower limit
of N_{bkg}

$$\frac{B(J/\psi \rightarrow \text{invisible})}{B(J/\psi \rightarrow \mu^+ \mu^-)} < 0.010 \quad @90\% \text{ C.L.}$$

More stringent constraint on NEW physics parameters:
(U-boson c-quark/LDM coupling)

P. Fayet, Phys. Rev. D **74**, 054034 (2006).
P. Fayet, Phys. Rev. D **75**, 115017 (2007).

Summary

- ⌚ ψ' leptonic decays, hadronic decays, radiative decays are studied to search for new phenomena and to test QCD predictions.
- ⌚ χ_c decays and J/ψ decays are studied using ψ' data sample, conservation laws and new physics are searched for (but not found).
- ⌚ More and better results are expected from BESIII in the near future (W.G. Li's talk).

Thanks a lot !