Experimental results in charmonium decays from BES

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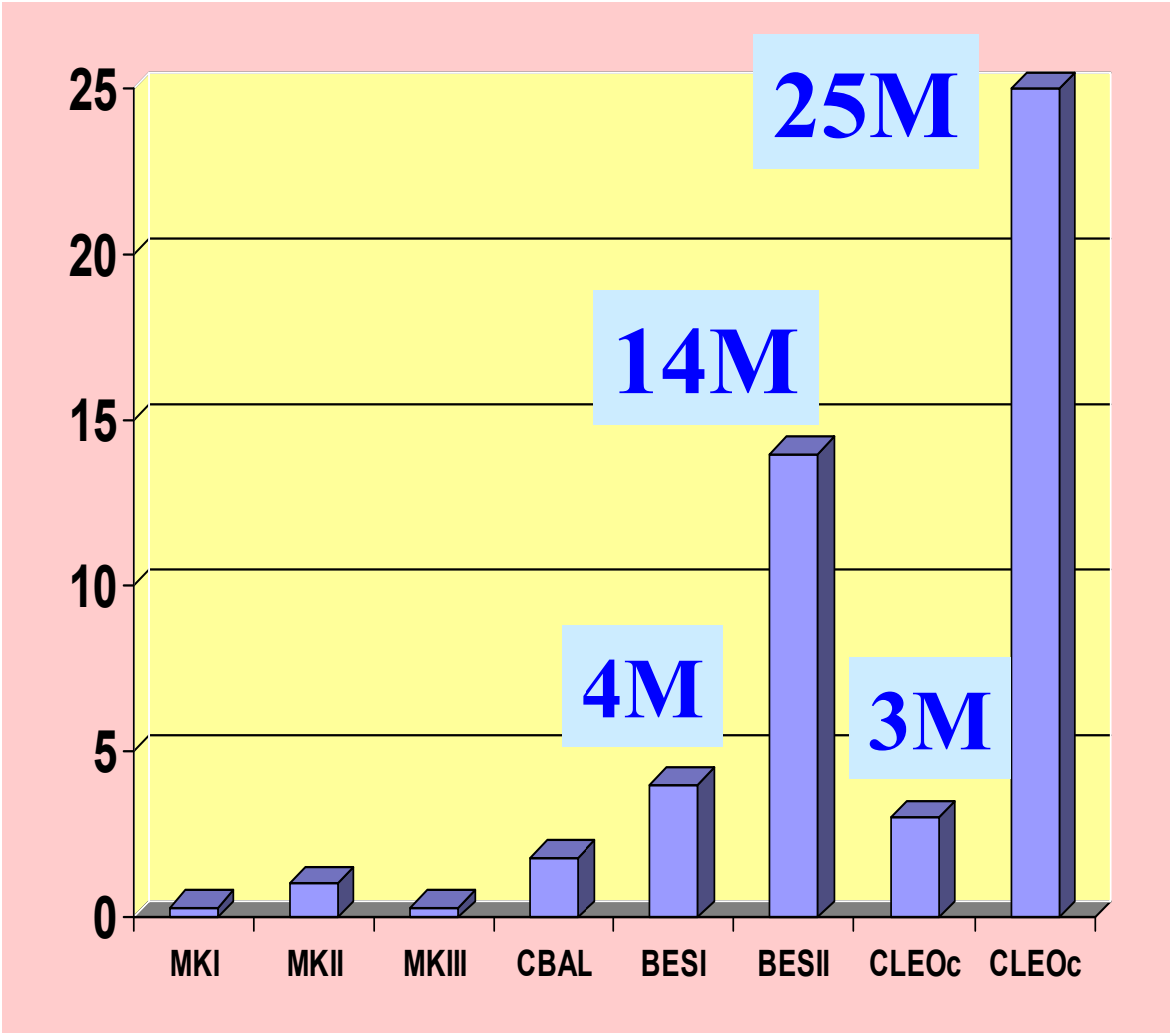
for BES collaboration

Charm 2007

Aug. 5-8, 2007

Data samples



6.42 pb^{-1} data at Ecm=3.65 GeV for background study.

outlines

- ψ' decays
  - Leptonic decays
  - Radiative decays
  - Hadronic decays
- χ_{cJ} decays
  - VV
  - PPP
- σ production in ψ (2S) $\rightarrow \pi^+ \pi^-$ Jψ
- Jψ , ψ (2S)$\rightarrow \pi/\eta + \Lambda\Lambda$-bar

$\psi(2S) \longrightarrow \tau^+\tau^-$

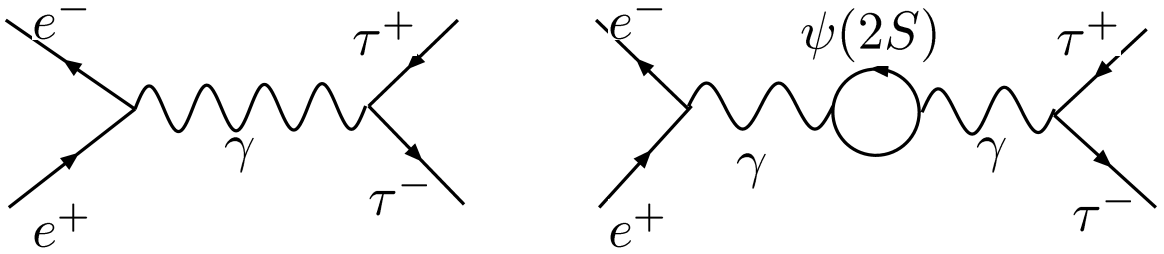
- First observation by DASP: PLB73,109(1978), no BR
- First measurement by BESI: PRD65, 052004 (2002)
  B=$(0.271 \pm 0.043 \pm 0.055)\%$

$$\frac{Br_{ee}}{v_e(3/2-v_e^2/2)} = \frac{Br_{\mu\mu}}{v_\mu(3/2-v_\mu^2/2)} = \frac{Br_{\tau\tau}}{v_\tau(3/2-v_\tau^2/2)}$$

$$\text{with } v_l = \sqrt{1-(4m_l^2/M^2_{\psi(2S)})}$$

$$\text{Br}_{ee} \simeq \text{Br}_{\mu\mu} = \frac{\text{Br}_{\tau\tau}}{0.3885}$$

Br_{ee}	$Br_{\mu\mu}$	$Br_{\tau\tau}/0.3885$
$7.5 \pm 3.1 \times 10^{-3}$	$(7.3 \pm 0.8) \times 10^{-3}$	$(7.0 \pm 1.1 \pm 1.4) \times 10^{-3}$



$$\sigma^0(s) = \frac{4\pi\alpha^2}{3}\frac{\beta(3-\beta^2)}{2} \times \left\{ 1 + \frac{\xi^2}{s}\frac{2(s-M^2)}{(s-M^2)^2+M^2\Gamma^2} + \frac{\xi^4}{s^2}\frac{1}{(s-M^2)^2+M^2\Gamma^2} \right\}$$

σ^0_{QED} σ^0_{INT} σ^0_{RES}

$$\sigma(s) = \frac{1}{\sqrt{2\pi}\Delta}\int_0^\infty d\sqrt{s'}e^{-(\sqrt{s}-\sqrt{s'})^2/2\Delta^2}\int_0^\beta dx\ \sigma^0(s'(1-x))\frac{F_i(x,s')F_c(\beta)F_f(\beta)}{[1-\Pi(s'(1-x))]^2}$$

where $\xi^2 = \frac{3M^2}{\alpha_s}\Gamma_{ll}(1+\frac{2m_l}{M^2})^{-1}(1-\frac{4m_l^2}{M^2})^{-1/2}$, $\beta = \sqrt{1-\frac{4m_\tau^2}{s}}$

$F_i(x,s)$: initial state radiation correction;

$F_c(\beta)$: coulomb correction;

$F_f(\beta)$: final state radiation correction;

$\Pi(s)$: vacuum polarization effect correction

Ref.

1. E. A. Kuraev and V. S. Fadin, Yad. Fiz. 41, 733(1985).
2. F. A. Berends, et. al. , Phys. Lett. 63B, 432(1976)
3. J. M. Wu, High Energy Phys. Nucl. Phys. 17, 379 (1993)

Event Selection and Results

$$\psi(2S) \to \tau^+\tau^-,\ \tau^+ \to \mu^+\bar{\nu}_\tau\nu_\mu,\ \tau^- \to e^-\nu_\tau\bar{\nu}_e$$

Particle indentification:

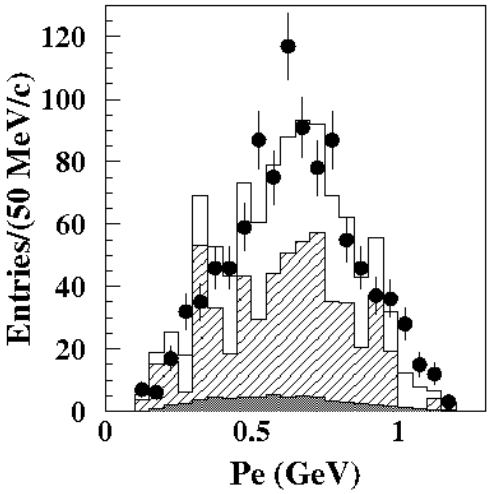
e: $CL_e > 0.01,\ E/P > 0.65,\ P < 1.2\text{GeV}.$

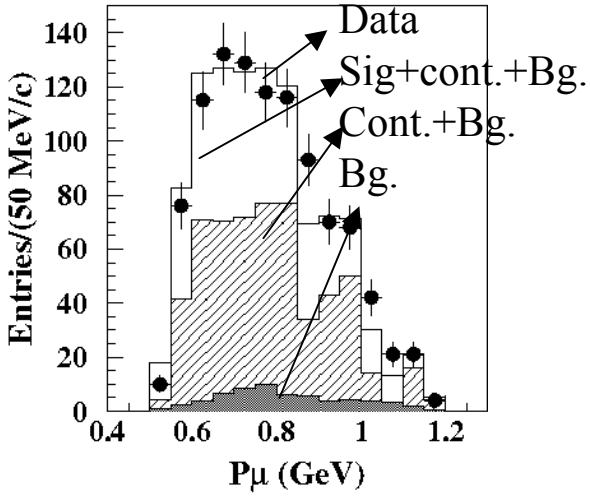
μ : $muid \geq 2,\ 0.5\text{GeV} < P < 1.2\text{GeV}$

To require no photon is observed.

$$Br_{\tau\tau} = \frac{\frac{N^{obs} - N^{obs}_{con} - N^{normal}_{bg}(Br_{\tau\tau})}{\epsilon_{e\mu}\cdot Br(e\mu)} - \sigma^{\tau\tau}_{Int}(Br_{\tau\tau})\cdot L_{3.686}}{N_{\psi(2S)}}$$

- Results:
  1015 events at resonance.
  516 at continuum.
  B=$(3.08 \pm 0.21 \pm 0.38)\times 10^{-3}$
  Lepton universality checked





- Improvement:
  Continuum contribution measured in data.
  Efficiency and background estimation .
  Interference subtraction more reasonable

PRD **74, 112003 (2006)**

$\psi(2S)$ radiative decays

- **Only limited modes measured by BESI**
  - $\gamma\eta, \gamma\eta'$ **[PRD58,097101(1998)]**
  - $\psi(2S) \to \gamma KK, \gamma\pi\pi$ [PRD67,032004(2003)]
- **Try to measure more modes**
  - **Expected 1% Br, but only 0.05% observed**
  - **Potential channels for hadron spectroscopy study, including search for non-$q\bar{q}$ states, provided statistics is enough(CLEOc or BESIII)**
- **Br($\psi(2S) \to \gamma + X$)**
  - **2-prong:** $\pi^+\pi^-, K^-K^+,$ **$p\bar{p}$,** $\eta\pi\pi$
  - **4-prong:** **2(**$\pi^+\pi^-$**)**, $\pi^+\pi^- K^-K^+, \pi^+\pi^-$ **$p\bar{p}$, 2(**K^+K^-**)**, $K_S K^+\pi^- + \text{c.c.}$
  - **6-prong:** **3(**$\pi^+\pi^-$**)**, $2(\pi^+\pi^-) K^-K^+$

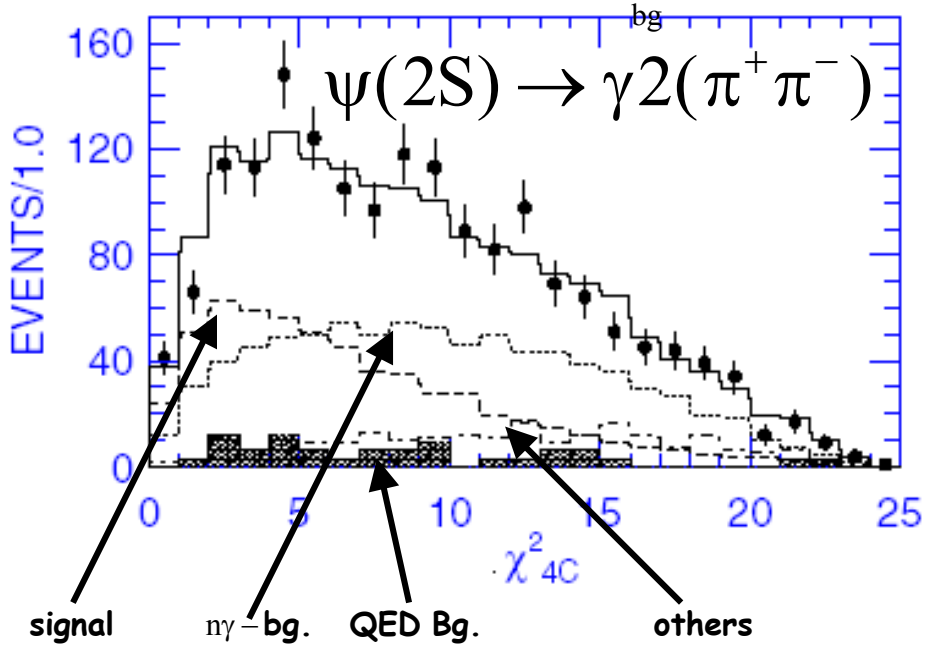
Observation of ψ' radiative decays (PRL99,011802)

Background including

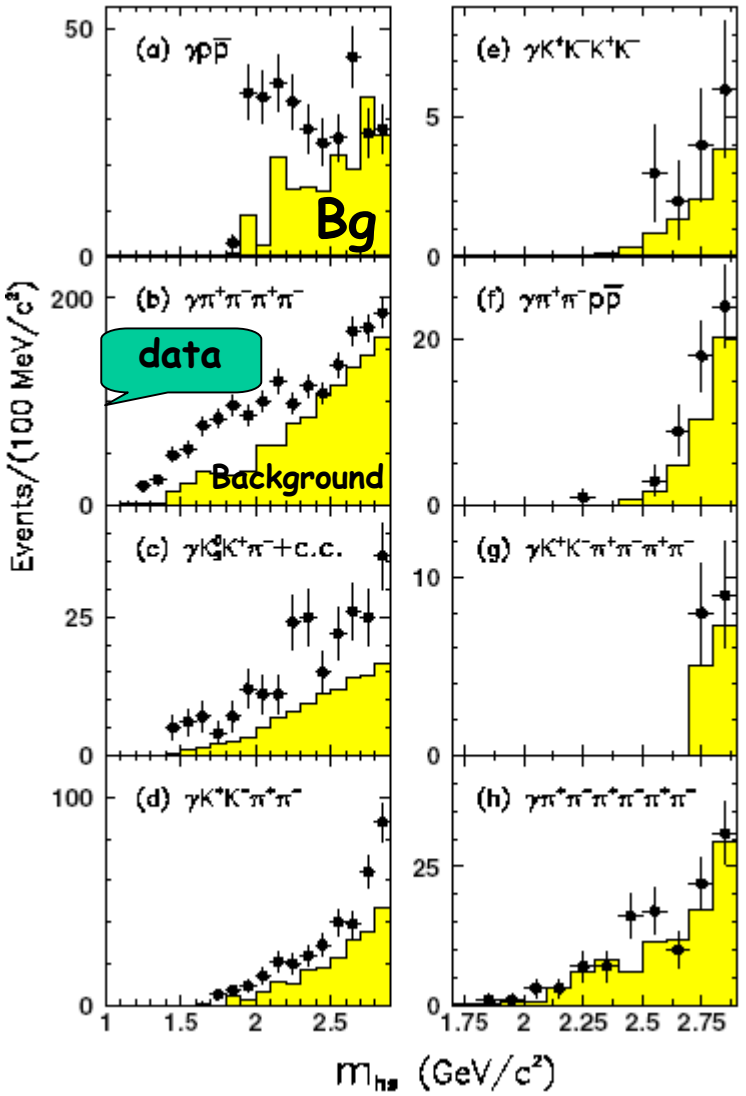
1. **QED processes**
2. **multi-photo processes,**

   $\psi(2S) \to \gamma +$ **hadrons,** $\pi^0 +$ **hadrons**
3. **other bg.**

$$\chi^2_{obs} = w_s \chi^2_{sig} + \sum_{bg} w_{bg} \chi^2_{bg}$$



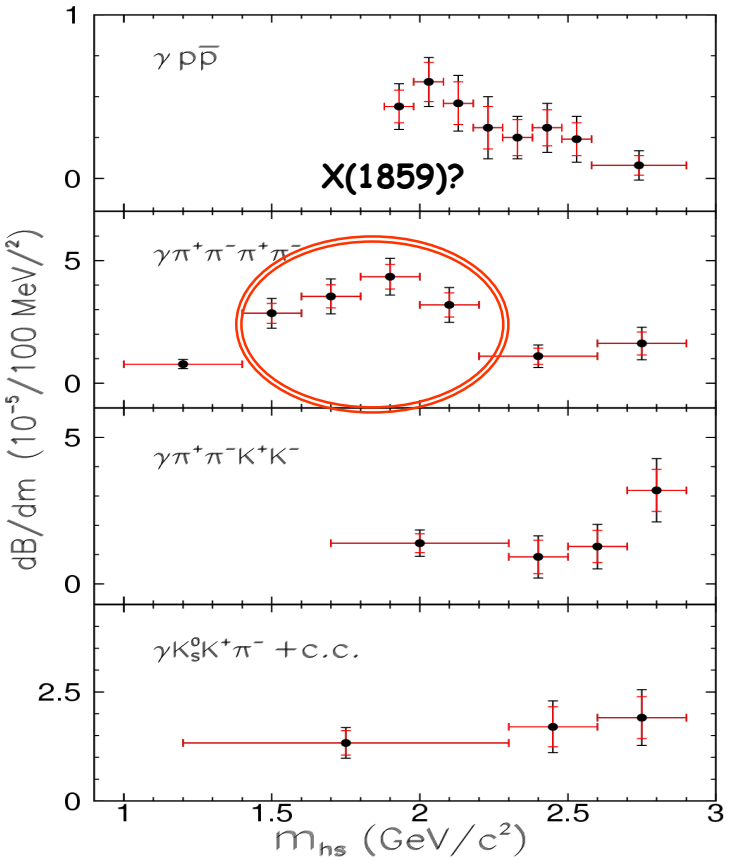
$m_{\text{hadrons}} < 2.9\text{GeV}$



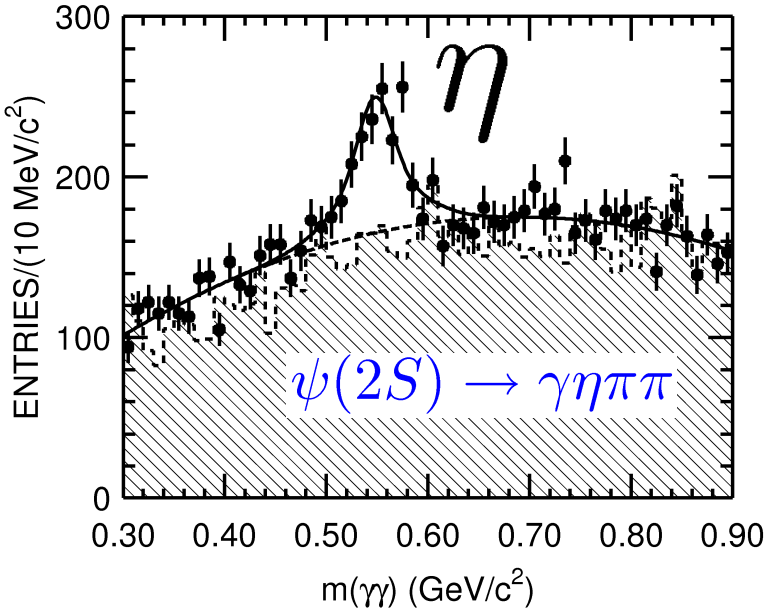
Observation of ψ' radiative decays (PRL99,011802)

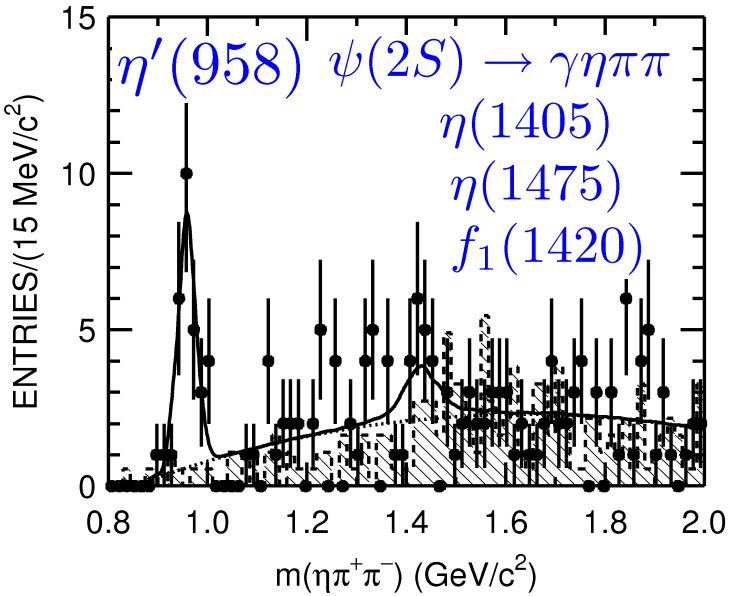
Mode	BR [m_{hs}<2.9 GeV/c^2] ($\times 10^{-5}$)
γ pp-bar	2.9 ± 0.4 ± 0.4
γ 2($\pi^+\pi^-$)	39.6 ± 2.8 ± 5.0
γ $K_S K^+\pi^-$+c.c.	25.6 ± 3.6 ± 3.6
γ $\pi^+\pi^- K^+K^-$	19.1 ± 2.7 ± 4.3
γ$K^{*0}K^+\pi^-$+c.c.	37.0 ±6.1± 7.2
γK^{*0} K^{*0}-bar	24.0 ±4.5± 5.0
γ $\pi^+\pi^-$ppbar	2.8 ± 1.2 ± 0.7
γ 2(K^+K^-)	< 4.0
γ 3($\pi^+\pi^-$)	< 17
γ 2($\pi^+\pi^-$)K^+K^-	< 22

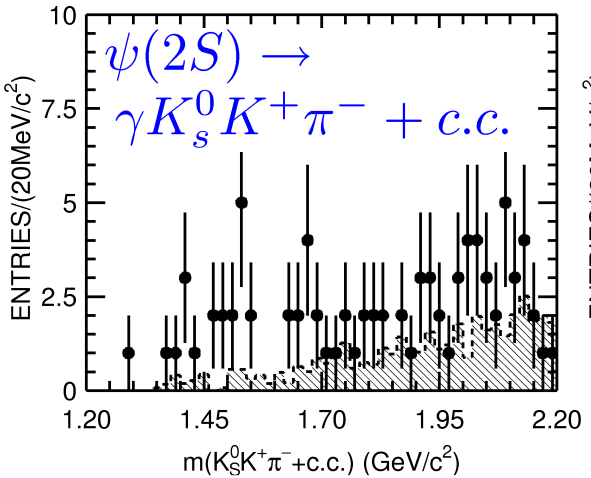
$$\mathrm{Br}[\psi(2S) \to \gamma X(1859) \to \gamma p\bar{p}] < 5.4 \times 10^{-6}$$

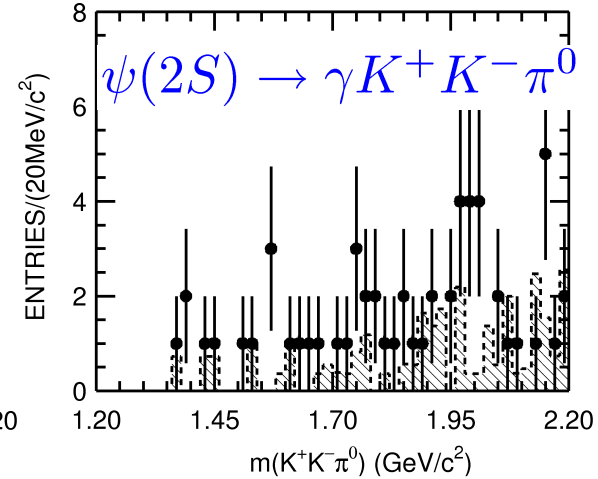


$\psi(2S) \to \gamma\eta\pi\pi,\ \gamma K\bar{K}\pi$ (PRD74,072001)









$$\frac{B(\psi\to\gamma\eta(1405/1475)\to\gamma K\bar{K}\pi)}{B(\psi\to\gamma f_1(1420)\to\gamma K\bar{K}\pi)} = 3.5$$

$\psi(2S) \to \gamma\eta\pi\pi,\ \gamma K\bar{K}\pi$ (PRD74,072001)

Summary of branching fractions for $\psi(2S)$ decays into $\gamma\eta\pi\pi$ and $\gamma K\bar{K}\pi$ final states.

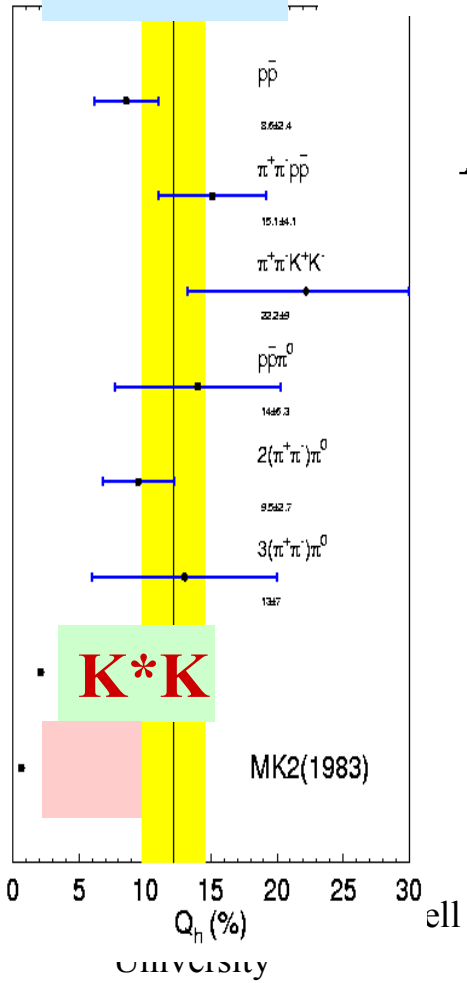
Channel ($\psi(2S) \to$)	$n^{sig.}$	ε (%)	$\mathcal{B}_{\psi(2S)\to}(\times 10^{-4})$	$\mathcal{B}_{J/\psi\to}(\times 10^{-4})$	$\frac{\mathcal{B}(\psi(2S))}{\mathcal{B}(J/\psi)}$(%)
$\gamma\eta\pi^+\pi^-$ [a]	418±60	8.69	8.71±1.25±1.64	–	–
$\gamma\eta\pi^+\pi^-$ [b]	–	–	3.60±1.42±1.83	39±7.3	9.2±6.2
$\gamma\eta'(958)$	23±5	7.58	1.24±0.27±0.15	43.1±3	2.9±0.7
$\gamma\eta(1405) \to \gamma\eta\pi^+\pi^-$	10±7	5.06	0.36±0.25±0.05	3.0±0.5	12±10
	< 24	5.06	< 1.0	3.0±0.5	< 40
$\gamma\eta(1475) \to \gamma\eta\pi^+\pi^-$	< 20	4.80	< 0.83	3.0±0.5	< 35
$\gamma\eta(1405) \to \gamma K\overline{K}\pi$ [c]	< 11	1.46	< 0.9	28 ± 6	< 4.1
$\gamma\eta(1475) \to \gamma K\overline{K}\pi$ [c]	< 16	1.47	< 1.5	28 ± 6	< 6.8
$\gamma\eta(1405) \to \gamma K\overline{K}\pi$ [d]	< 9	0.61	< 1.3	28 ± 6	< 5.9
$\gamma\eta(1475) \to \gamma K\overline{K}\pi$ [d]	< 9	0.59	< 1.4	28 ± 6	< 6.4

[a] all processes in the $\psi(2S) \to \gamma\eta\pi^+\pi^-$;
[b] all processes excluding $\psi(2S) \to \gamma\chi_{c1} \to \gamma\eta\pi^+\pi^-$;
[c] the decay mode is $\gamma K^0_S K^+\pi^- + c.c.$;
[d] the decay mode is $\gamma K^+K^-\pi^0$.

$\psi(2S)$ hadronic decays

$$Q_h = \frac{Br_{\psi(2S)\to X}}{Br_{J/\psi\to X}} = \frac{Br_{\psi(2S)\to e^+e^-}}{Br_{J/\psi\to e^+e^-}} \approx 12\%$$

MARK-II M. Appelquist and H. D. Politzer, PRL34, 43 (1975)

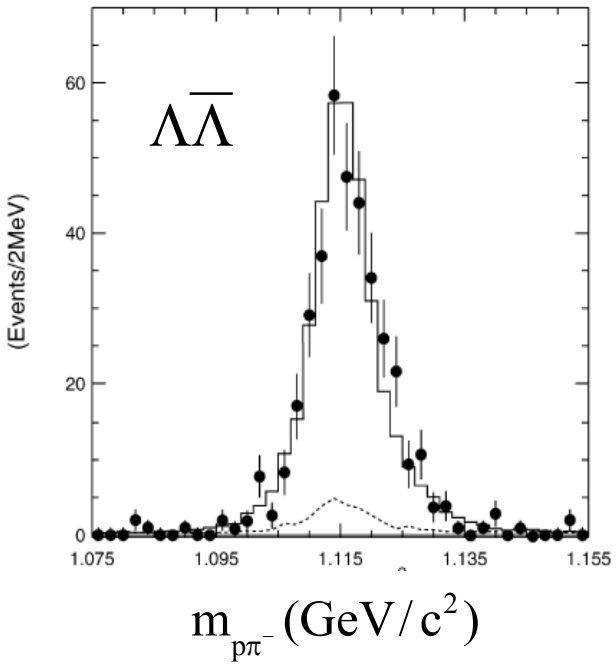


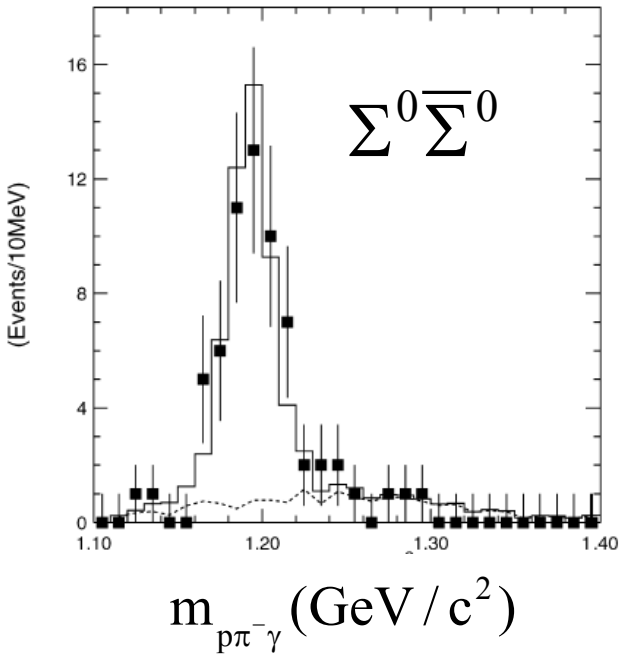
Extensively studied by BES II

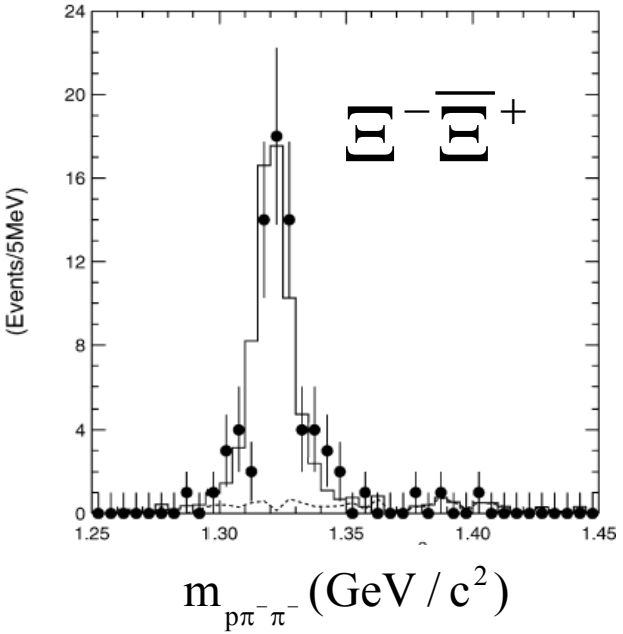
- *2-body:* $\psi(2S) \to p\bar{p}, \Lambda\bar{\Lambda}, \Xi^-\bar{\Xi}^+$
- *3-body :* $p\bar{n}\pi^-,\ \bar{p}n\pi^+$
- *Multi-body :* $\pi^0 2(\pi^+\pi^-), \pi^0 2(\pi^+\pi^-)K^+K^-$

$\psi(2S) \to p\bar{p},\ \Lambda\bar{\Lambda},\ \Sigma^0\bar{\Sigma}^0,\ \Xi^-\bar{\Xi}^+$ (PLB648, 149 (2007))

- **First measurement by BESI, re-measure BR with a larger $\psi(2S)$ data sample. SU(3) symmetry observed.**
- **"12% rule" tested.**







$\psi(2S) \to p\bar{p},\ \Lambda\bar{\Lambda},\ \Sigma^0\bar{\Sigma}^0,\ \Xi^-\bar{\Xi}^+$ (PLB648, 149 (2007))

Channel	PDG06	CLEO-c
$p\bar{p}$	$2.65 \pm 0.22 \pm 0.36$	$2.87 \pm 0.12 \pm 0.15$
$\Lambda\bar{\Lambda}$	$2.5 \pm 0.7 \pm 0.27$	$3.28 \pm 0.23 \pm 0.25$
$\Sigma^0\bar{\Sigma}^0$	$2.1 \pm 0.7 \pm 0.4$	$2.63 \pm 0.35 \pm 0.21$
$\Xi^-\bar{\Xi}^+$	$1.5 \pm 0.7 \pm 0.15$	$2.38 \pm 0.30 \pm 0.21$

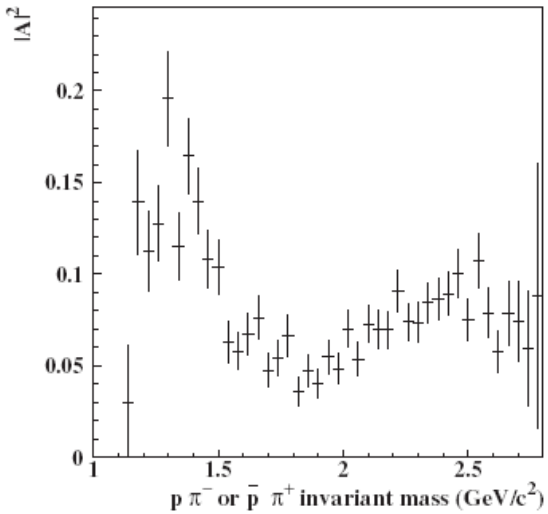
modes	BESII:BRs ($\times 10^{-4}$)	Q (%)
$p\bar{p}$	$3.36 \pm 0.09 \pm 0.25$	14.9 ± 1.4
$\Lambda\bar{\Lambda}$	$3.39 \pm 0.20 \pm 0.32$	16.7 ± 2.1
$\Sigma^0\bar{\Sigma}^0$	$2.35 \pm 0.36 \pm 0.32$	16.8 ± 3.6
$\Xi^-\bar{\Xi}^+$	$3.03 \pm 0.40 \pm 0.32$	16.8 ± 4.7

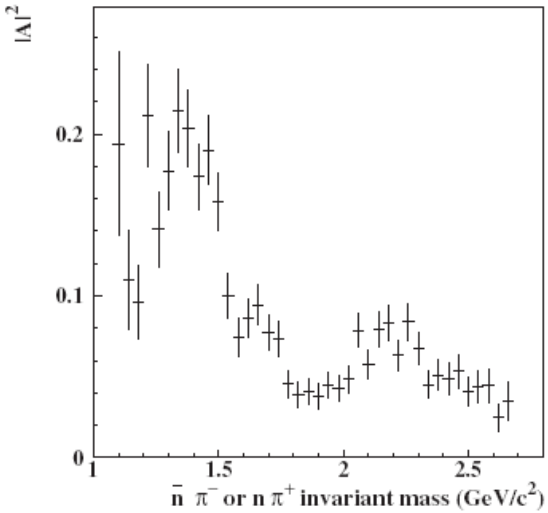
$$\frac{dN}{d\cos\theta} \propto (1 + \alpha \cos\theta),$$

$$\alpha(\psi(2S) \to p\bar{p}) = 0.85 \pm 0.24 \pm 0.32$$

$\psi(2S) \to p\bar{n}\pi^- + c.c.$ (PRD74, 012004 (2006))

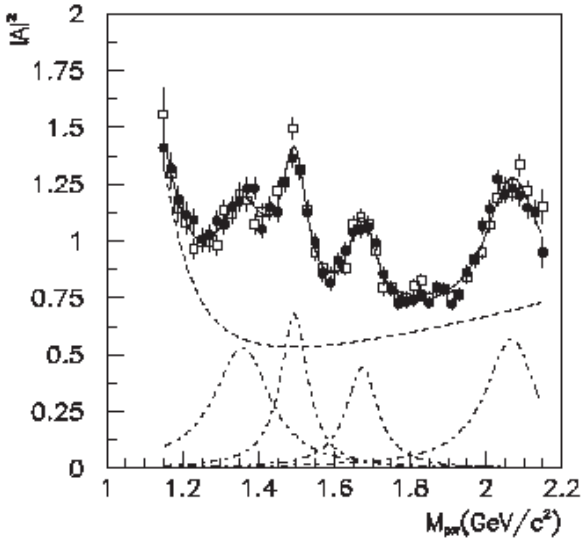
Mode	$B_{\psi(2S)\to X}(10^{-4})$	$B_{J/\psi\to X}(10^{-3})\dagger$	$Q_h(\%)$
$p\bar{n}\pi^-$	$2.45 \pm 0.11 \pm 0.21$	2.02 ± 0.17	12.1 ± 1.6
$p\bar{n}\pi^+$	$2.52 \pm 0.12 \pm 0.22$	1.93 ± 0.17	13.1 ± 1.8





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

850 **events in each mode**



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

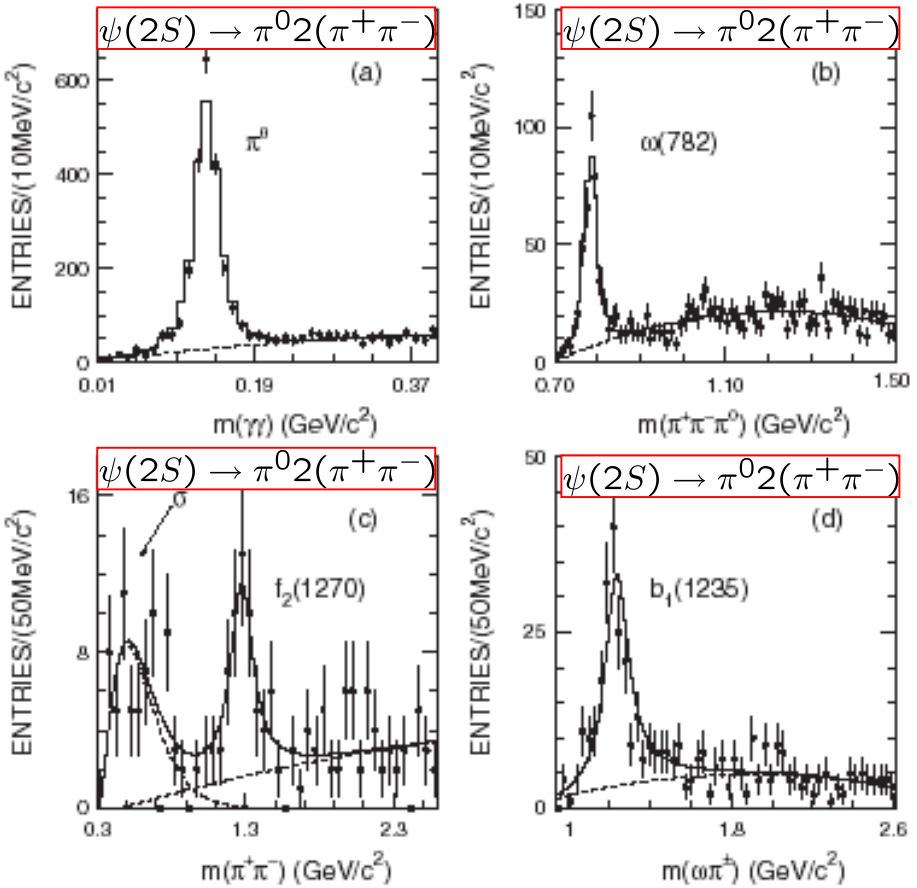
100,000 **events obtained**

PRL97, 062001

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

$\psi(2S) \to \pi^0 2(\pi^+\pi^-),\ \pi^0 2(\pi^+\pi^-)K^+K^-$

- First measurement for $\psi(2S) \to \pi^0 2(\pi^+\pi^-)K^+K^-$
- Measurement of $\psi(2S) \to \omega f_2(1270)$ cross checks previous BESII result.



PRL 99,011802(2007)

Mode: $\psi(2S) \to$	N^{Sig}	$\epsilon(\%)$	$\mathcal{B}(\times 10^{-4})$	$\mathcal{B}^{\rm PDG}(\times 10^{-4})$	$Q_h(\%)$
$\pi^0 2(\pi^+\pi^-)$	2173 ± 53	6.32	$24.9 \pm 0.7 \pm 3.6$	23.7 ± 2.6	10.5 ± 2.0
$\omega\pi^+\pi^-$	386 ± 23	3.74	$8.4 \pm 0.5 \pm 1.2$	6.6 ± 1.7	11.7 ± 2.4
$\omega f_2(1270)$	57 ± 13	3.65	$2.3 \pm 0.5 \pm 0.4$	2.0 ± 0.6	5.4 ± 0.6
$b_1^\pm \pi^\mp$	202 ± 21	3.24	$5.1 \pm 0.6 \pm 0.8$	3.6 ± 0.6	17.0 ± 4.2
$\pi^0 2(\pi^+\pi^-)K^+K^-$	65 ± 17	0.46	$10.0 \pm 2.5 \pm 1.8$	—	—

χ_{cJ} decays

- **To test the color octet mechanism of χ_{cJ} decays**

$$|\chi_{cJ}\rangle = c_0|(c\bar{c})_1\rangle + c_1|(c\bar{c})_8 g\rangle$$

J. Bolz et.al. Eur. Phys. J.C2,705
W. M. H. Wong, Eur. Phys. J. C14,643

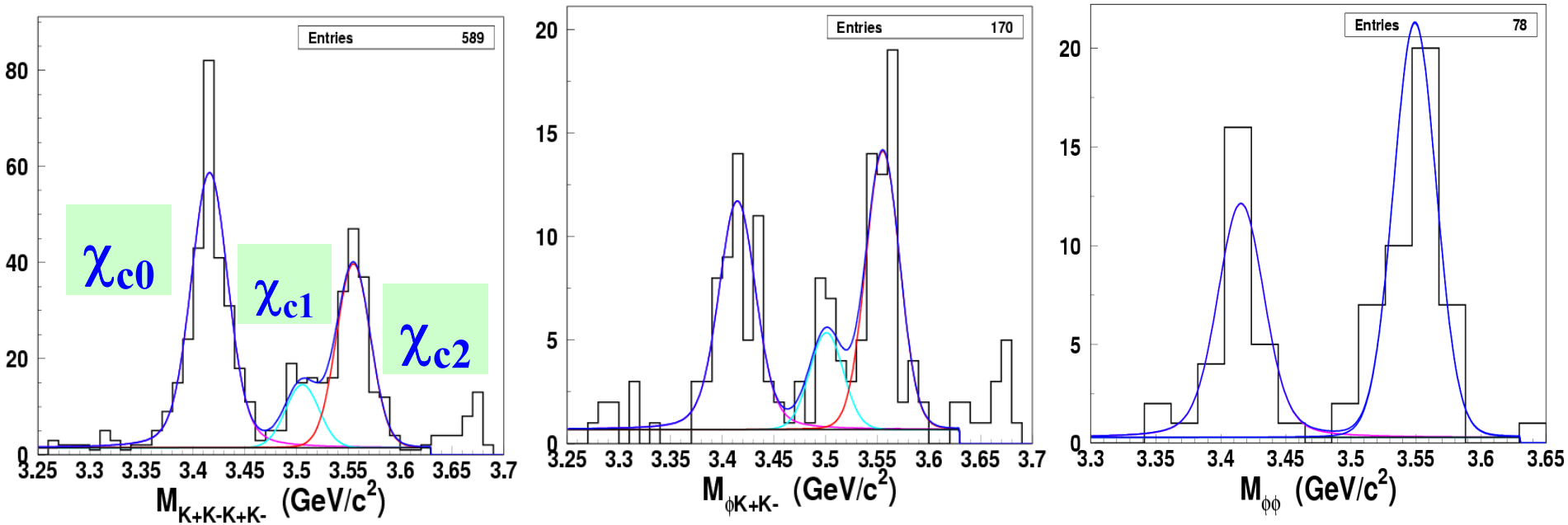
In pQCD picture, the decay of $\chi_{c0} \to \phi\phi,\ \omega\omega$ is highly suppressed by the helicity selection rule.
B$(\chi_{c0} \to \phi\phi) = (9 \pm 5) \times 10^{-4}$

phenomenological model

- $\chi_{c0} \to \phi\phi$**: Quark-pair creation model. H.Q. Zhou, et.al. PLB611,123**

- $\chi_{c0} \to SS$**: $q\bar{q}$-glueball mixing scheme. Q. Zhao, PRD72, 074001.** $M = x_i|G> + y_i|s\bar{s}> + z_i|n\bar{n}>$

$\chi_{cJ} \to \phi\phi$ (PLB642,197) Pair production of vectors



Channel	$2(K^+K^-)(\times 10^{-3})$		$\phi K^+K^-(\times 10^{-3})$	$\phi\phi(\times 10^{-3})$	
	BES-II	PDG	BES-II	BES-II	PDG
χ_{c0}	$3.47 \pm 0.22 \pm 0.48$	2.3 ± 0.5	$1.02 \pm 0.22 \pm 0.15$	$0.94 \pm 0.21 \pm 0.14$	1.0 ± 0.6
χ_{c1}	$0.68 \pm 0.13 \pm 0.10$	0.42 ± 0.19	$0.44 \pm 0.14 \pm 0.07$	–	–
χ_{c2}	$1.88 \pm 0.18 \pm 0.28$	1.8 ± 0.5	$1.46 \pm 0.21 \pm 0.22$	$1.48 \pm 0.26 \pm 0.23$	2.4 ± 0.9

BES: preliminary

$\chi_{cJ} \to 2(K^+K^-)$ Cornell University

Improved precision over PDG (BESI) results on $\chi_{cJ} \to KKKK$ and $\phi\phi$.

First measurement of $\chi_{cJ} \to \phi KK$.

$\chi_{cJ} \to K^0_S K^+ \pi^- + c.c.$

Event selection:

1. $\chi^2_{4C}(\gamma K^{\pm}\pi^{\mp}\pi^+\pi^-) < 15.$

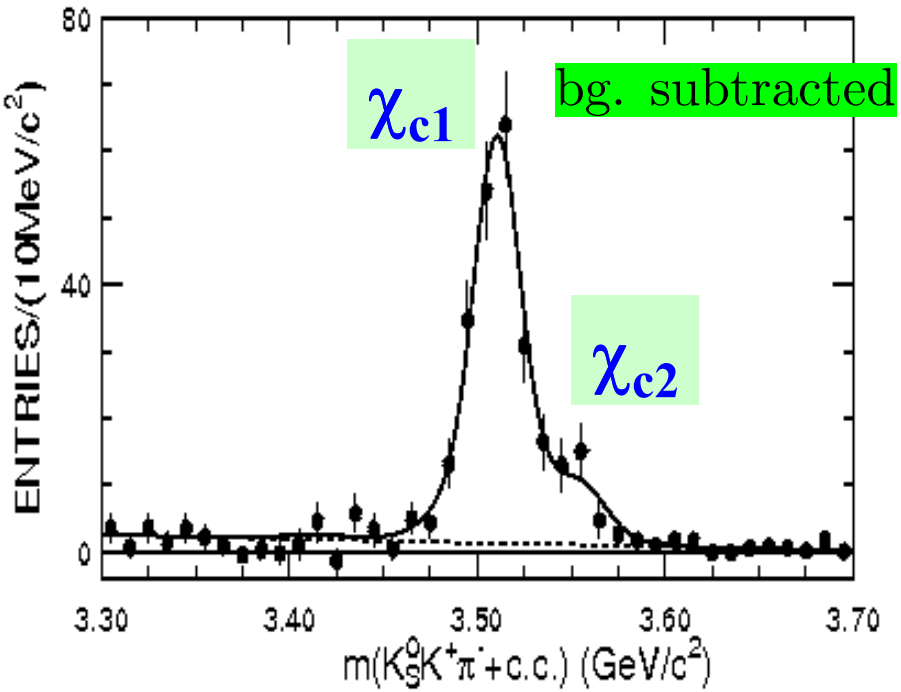
   $\chi^2_{4C}(\gamma K^{\pm}\pi^{\mp}\pi^+\pi^-) < \chi^2_{4C}(\gamma\pi^+\pi^-\pi^+\pi^-)$

2. $|\mathbf{m}^{\pi^+\pi^-}_{\mathbf{recoil}} - 3.1| > 0.05\mathbf{GeV}$.

3. $\mathbf{K^0_S}: |\mathbf{m}_{\pi^+\pi^-} - \mathbf{m}_{\mathbf{K^0_s}}| < 0.15\mathbf{GeV}$,

   and $\mathbf{L_{xy}} > 0.5\mathbf{cm}$

Fit with
χ_{c1}: Breit-Wigner convoluted with the mass resolution function.



PRD 74,072001

	χ_{c0}	χ_{c1}	χ_{c2}
N^{sig}	3.9 ± 4.6	220 ± 16	28.4 ± 7.6
Significance	0.9σ	22.0σ	4.8σ

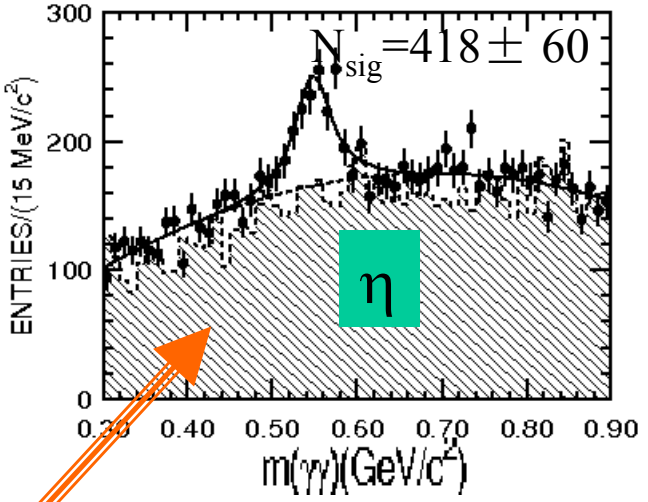
$\chi_{c0} \to$ PPP is suppressed by spin-parity selection;

$\chi_{c1} \to \eta\pi^+\pi^-,\ a_0(890)\pi$

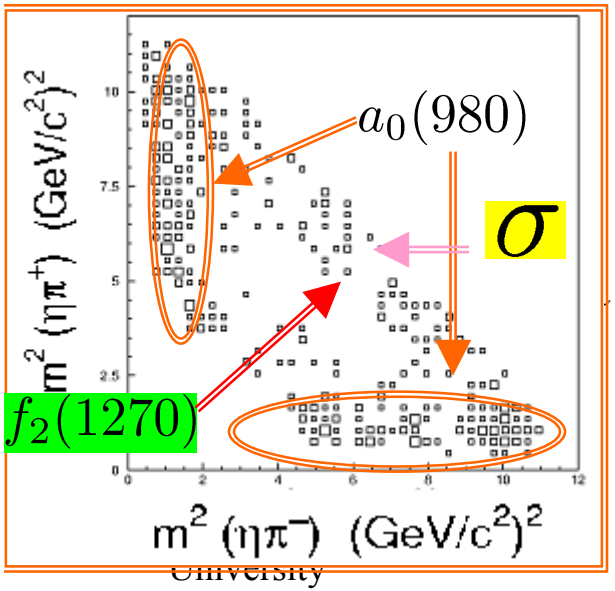
1. $\chi^2_{4C}(\pi^+\pi^-\gamma\gamma\gamma) < 15$
2. $|m(\pi^+\pi^-)_{recoil} - 3.1| > 0.05\mathbf{GeV}$
3. $\mathbf{M_{\gamma\pi\pi}}$ **<2.8GeV**

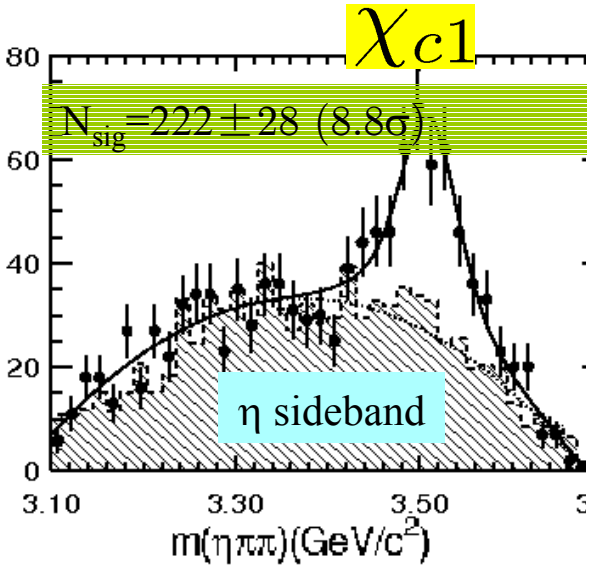
to reject $\psi(2S) \to$**neutrals+**J/ψ

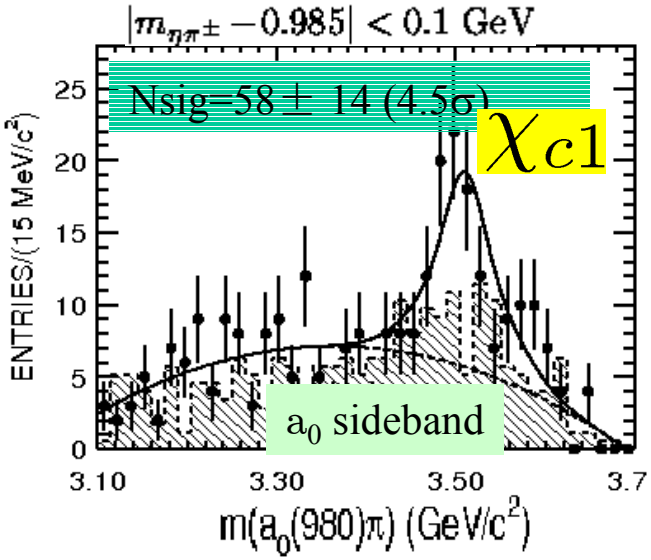
4. $|m_{\gamma\gamma} - m_\eta|$ **<0.04GeV**



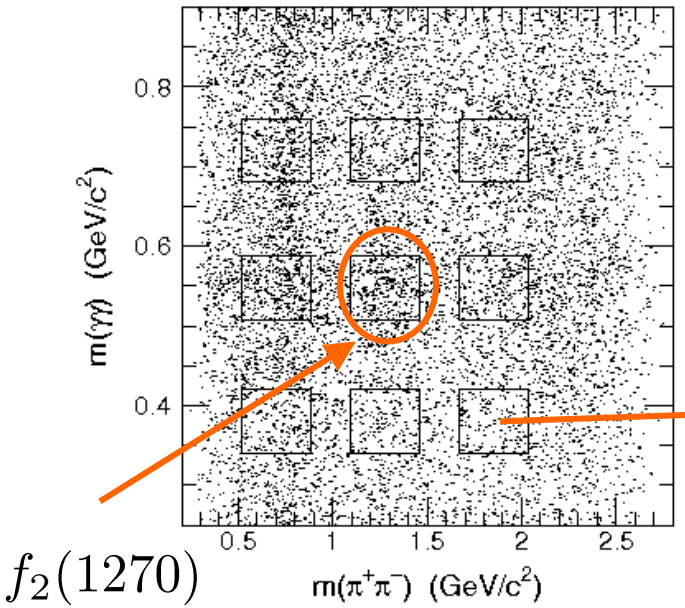
Main background:
$\psi(2S) \to \eta\pi^+\pi^-\pi^0$



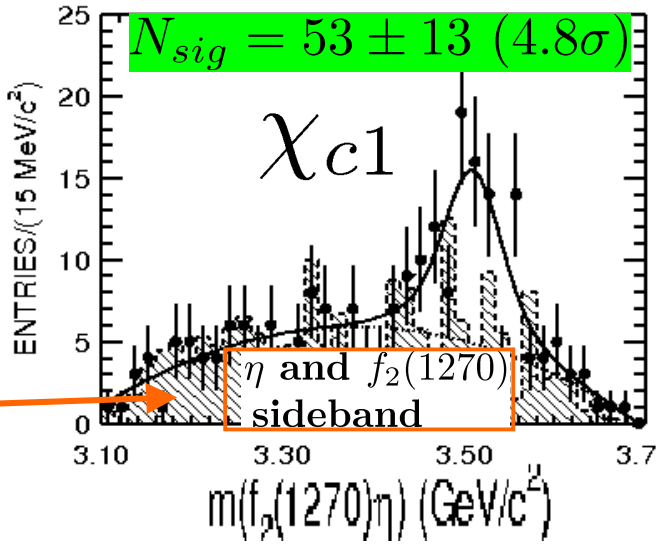




$\chi_{cJ} \to \eta f_2(1270)$



$f_2(1270)$



BES: $\chi_{cJ} \to KK\pi$ and $\eta\pi\pi$ (PRD 74,072001)

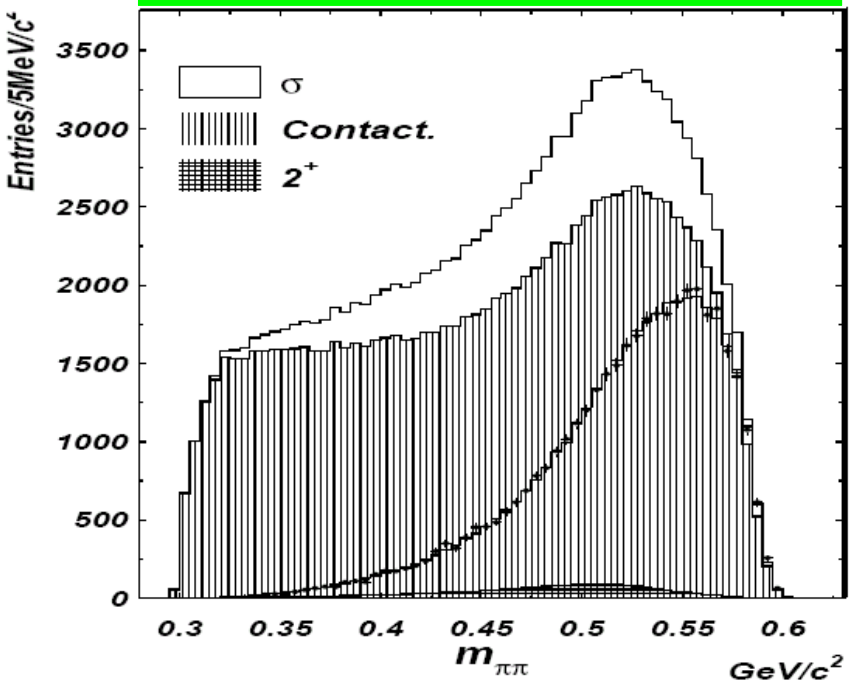
Mode	Br($\times 10^{-3}$)	Br($\times 10^{-3}$)(CLEO-c)
$\chi_{c1} \to K_S K^+\pi^- + c.c.$	$4.1 \pm 0.3 \pm 0.7$	$\bar{K}^0 K^+\pi^-$: $8.1 \pm 0.6 \pm 0.6 \pm 0.5$
$\chi_{c2} \to K_S K^+\pi^- + c.c.$	$0.8 \pm 0.3 \pm 0.2$	$\bar{K}^0 K^+\pi^-$: $1.3 \pm 0.2 \pm 0.1 \pm 0.1$
$\chi_{c1} \to \eta\pi\pi$	$6.1 \pm 0.8 \pm 1.0$	$5.0 \pm 0.3 \pm 0.4 \pm 0.3$
$\chi_{c1} \to a_0^+\pi^- \to \eta\pi^+\pi^-$	$2.0 \pm 0.5 \pm 0.5$	
$\chi_{c1} \to f_2(1270)\eta$	$2.1 \pm 0.5 \pm 0.4$	

CLEO-c, PRD75,032002

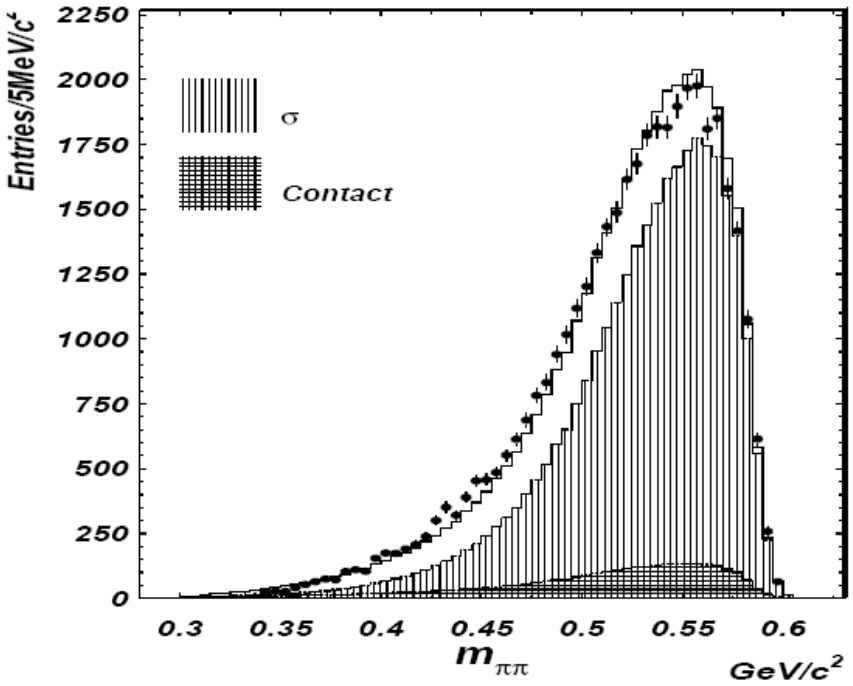
σ production in $\psi(2S) \to \pi^+\pi^- J/\psi$

- Resolve the controversial since 1957.
- Establish σ as a particle together with other evidence.
- Measure the pole position (552 - i232 MeV).

Breit-Wigner parameterization

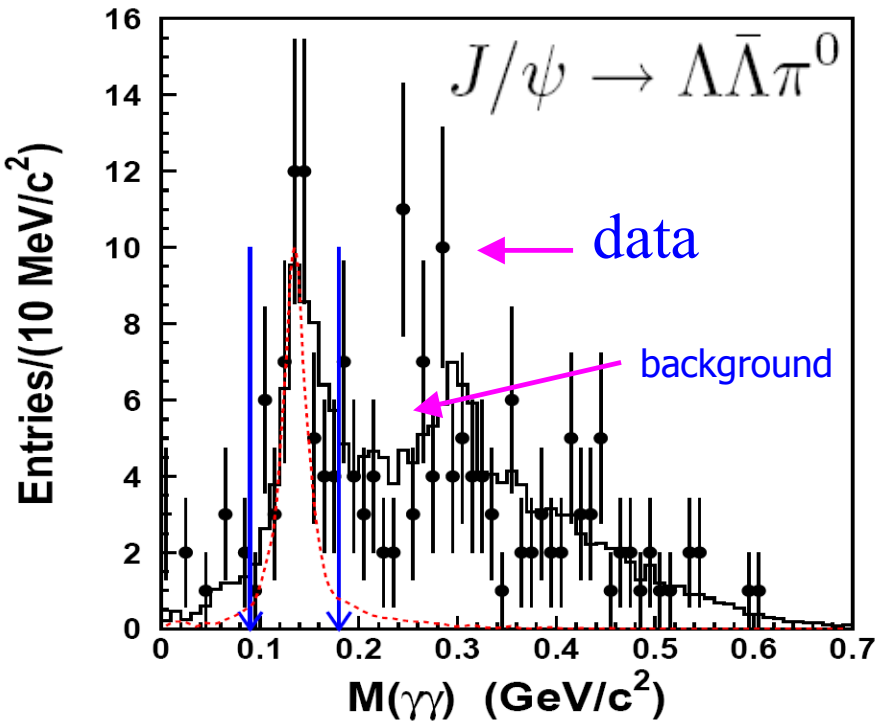


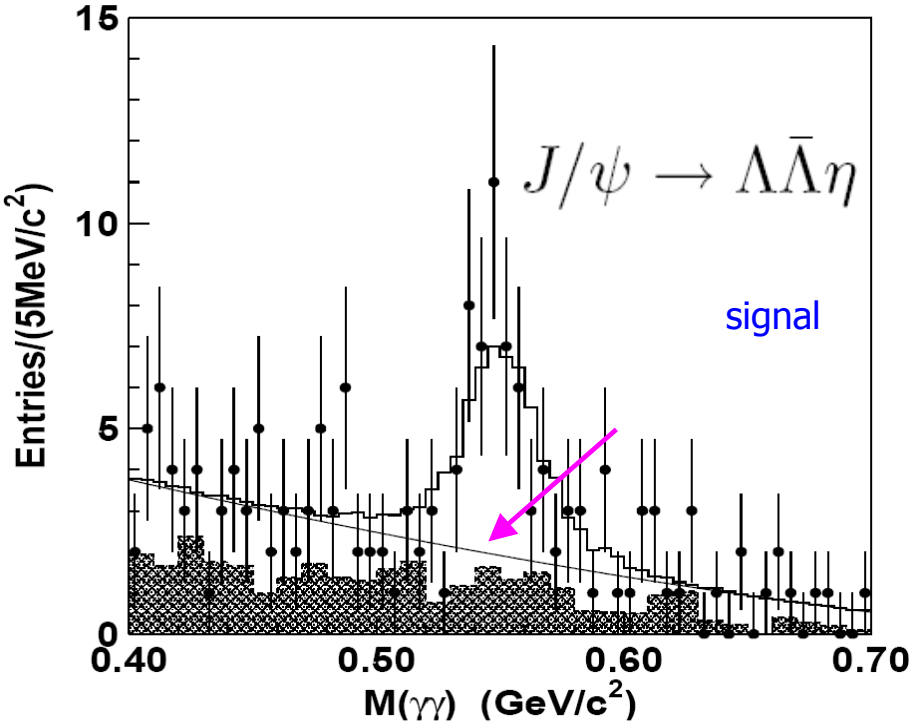
ChUT + S-wave $\pi\pi$ SFI

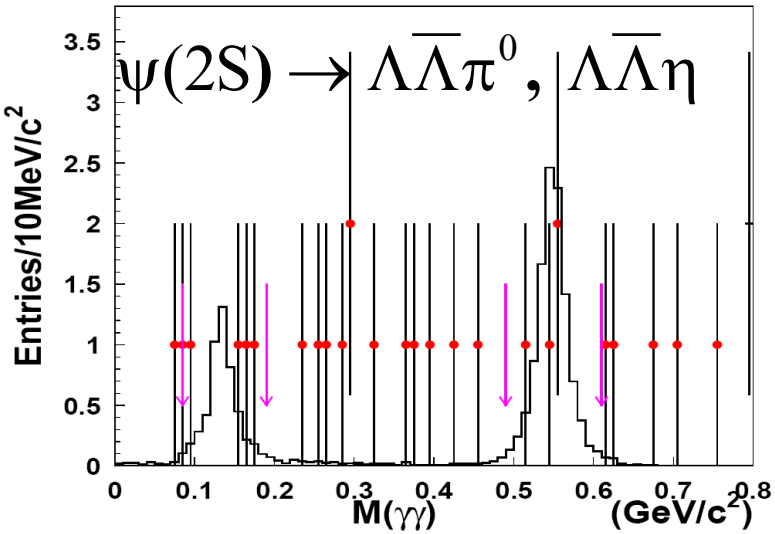


PLB645, 19 (2007)

$J/\psi,\ \psi(2S) \to \Lambda\bar{\Lambda}\pi^0, \Lambda\bar{\Lambda}\eta$ (hep-ex/0707.1127)







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

First measurement!

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.
- CLEOc will take the leading role in ψ' and χ_c decays soon, we are now preparing for the BESIII data taking and the physics analysis.

Thanks a lot !