Measurements of $\psi' \to J/\psi$ + Neutrals

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1 Motivations

1. For $\psi' \to J/\psi+$ neutrals, the published results based on much smaller data sets from different groups do not agree well with each other [1], see Table 1. Meanwhile, BES results about $\mathcal{B}(\chi_{cJ} \to h)$ [2] are systematically lower than those of PDG (based on much smaller data samples), and BES used $\mathcal{B}(\psi' \to \gamma\chi_{cJ})$ from PDG to extract $\mathcal{B}(\chi_{cJ} \to h)$, so it is important to measure the branching fractions for these modes.

Table 1: ψ' and χ_{cJ} decay branching fractions listed in PDG98.

$\psi' \to$	PDG98	cited Br	Experiments	data	events
$\pi^0\pi^0 J/\psi$	$(17.9 \pm 1.8)\%$	$0.184 \pm 0.019 \pm 0.013$	E760(97)	$\times 10^6$	157
	$(18.4 \pm 2.7)\%(96)$	0.18 ± 0.06	DASP(75)	$\cdots$	$\cdots$
$\eta J/\psi$	$(2.7 \pm 0.4)\%$	$(2.5 \pm 0.6)\%$	MKII(80)	1.0	166
		$(2.18 \pm 0.14 \pm 0.35)\%$	CBAL(80)	0.78	386
		$(3.6 \pm 0.5)\%$	CNTR(78)	0.63	164
$\pi^0 J/\psi$	$(9.7 \pm 2.1) \cdot 10^{-4}$	$(15 \pm 6) \cdot 10^{-4}$	MKII(80)	1.0	7
		$(9 \pm 2 \pm 1) \cdot 10^{-4}$	CBAL(80)	0.78	23
$\gamma\chi_{c1}$	$(8.7 \pm 0.8)\%$	$(9.0 \pm 0.5 \pm 0.7)\%$	CBAL(86)	1.8	$\cdots$
		$(7.1 \pm 1.9)\%$	CNTR(77)	0.63	$\cdots$
$\gamma\chi_{c2}$	$(7.8 \pm 0.8)\%$	$(8.0 \pm 0.5 \pm 0.7)\%$	CBAL(86)	1.8	$\cdots$
		$(7.0 \pm 2.0)\%$	CNTR(77)	0.63	$\cdots$
$\chi_{c1} \to \gamma J/\psi$	$(27.3 \pm 1.6)\%$	6 results agree very well	$\cdots$	$\cdots$	$\cdots$
$\chi_{c2} \to \gamma J/\psi$	$(13.5 \pm 1.1)\%$	6 results agree well	$\cdots$	$\cdots$	$\cdots$

2. For $\psi' \to (\pi^0, \eta)J/\psi$, their decays are related with Charge Symmetry Breaking. In QCD, if u, d quark masses neglected, the interactions of u, d quarks are identical termed

as Charge Symmetry (CB) [3]. CB is broken due to the differences (a) between u, d masses and (b) between electromagnetic interactions where the long distance electromagnetic interactions serve as background, its influence on wave functions is small. In the limit of massless quarks, $\psi' \to (\pi^0, \eta) J/\psi$ are forbidden; for massive quarks, the π^0 decay is still forbidden by CS. But it can proceed via $\pi^0 \sim \eta \sim \eta'$ mixing caused by CSB [4]. For CSB transition $\psi' \to \pi^0 J/\psi$ and CS allowed transition $\psi' \to \eta J/\psi$, the transition amplitude $\mathcal{A}(\psi' \to \pi^0 J/\psi) \propto m_d - m_u$, $\mathcal{A}(\psi' \to \eta J/\psi) \propto m_s - \hat{m}$, $\hat{m} = \frac{1}{2}(m_u + m_d)$. Based on PCAC (partially conserved axial-vector currents) and $\pi^0 \sim \eta \sim \eta'$ mixing, one has [5]:

$$
\begin{aligned}
r = \frac{\Gamma(\psi' \to \pi^0 J/\psi)}{\Gamma(\psi' \to \eta J/\psi)} &= N_C \left(\frac{m_d - m_u}{m_d + m_u}\right)^2 \\
&\times \left(\frac{m_\pi}{m_\eta}\right)^4 \times \left(\frac{p_\pi}{p_\eta}\right)^3 \left[1 + \mathcal{O}\left(\frac{m_q}{\Lambda_{QCD}}\right)\right]
\end{aligned}
$$

where $\frac{m_\pi^2}{m_\eta^2} = \frac{3}{4} \cdot \frac{m_d + m_u}{m_s}$ was used. p_π, p_η are π, η's momenta in the ψ' rest frame, Λ_{QCD} is typical energy scale of strong interactions, but the theoretic uncertainty is of 30% order $(\frac{m_q}{\Lambda_{QCD}})$ or higher. For typical $\frac{m_d - m_u}{m_d + m_u} \approx 0.3$, $r \approx 2 \times 10^{-2}$, $r \approx 0.25$ if $m_u = 0$. From the ratio r, we can derive the information about (current) strange quark mass m_s [3]:

$$
R^2 = \left(\frac{m_s - \hat{m}}{m_d - m_u}\right)^2 = \left(\frac{p_\pi}{p_\eta}\right)^3 \cdot \frac{27}{16} \cdot \frac{\Gamma(\psi' \to \eta J/\psi)}{\Gamma(\psi' \to \pi^0 J/\psi)}
$$

which is related with CKM element V_{us} and direct CP violation parameter ϵ'/ϵ in $K^0 - \overline{K^0}$ system ($\epsilon'/\epsilon \propto m_s^{-2}$).

3. The transitions $\psi' \to (\eta, \pi\pi) J/\psi$ are typical nonperturbative processes. Based on gauge invariance, PCAC, current algebra, for chromo-electric E1E1 dominant transitions $\psi' \to \pi\pi J/\psi$ and $\Upsilon' \to \pi\pi\Upsilon$, and chromo-magnetic M1M1 transitions $\psi' \to \eta J/\psi$ and $\Upsilon' \to \eta\Upsilon$, multipole expansion predicts [6]:

$$
\begin{aligned}
\frac{\Gamma(\psi' \to \pi\pi J/\psi)}{\Gamma(\Upsilon' \to \pi\pi\Upsilon)} \approx \frac{\langle r^2\rangle^2_{\psi'}}{\langle r^2\rangle^2_{\Upsilon'}} &\approx 10 \qquad \text{vector gluon} \\
&\approx 1 \qquad \text{scalar gluon}
\end{aligned}
$$

which is sensitive to the gluon spin, and

$$
\frac{\Gamma(\psi' \to \eta J/\psi)}{\Gamma(\Upsilon' \to \eta\Upsilon)} \approx \left(\frac{m_b}{m_c}\right)^4 \cdot \left(\frac{p_\eta(\psi')}{p_\eta(\Upsilon')}\right)^3 \sim 300
$$

4. For $\psi' \to (\eta, \pi^+\pi^-) J/\psi$, according to triangle anomalies of axial-vector current, multipole expansion also gives [7]:

$$
\begin{aligned}
\frac{\Gamma(\psi' \to \eta J/\psi)}{\Gamma(\psi' \to \pi^+\pi^- J/\psi)} \approx \frac{4\pi^2 f_\pi^2 p_\eta^3 m_\eta^4 \times 19.6}{m_Q^2 (m_{\psi'} - m_{J/\psi})^7} &\approx 0.14 \qquad \text{if } m_Q = \tfrac{1}{2} m_{J/\psi} \\
&\approx 0.10 \qquad \text{if } m_Q = \tfrac{1}{2} m_{\psi'}
\end{aligned}
$$

where pion decay constant $f_\pi = 130$ MeV. It measures the triangle anomalies associated with quark and gluon color charges as $\pi^0 \to \gamma\gamma$ which measures quark color charges.

2 Monte Carlo

- for $\psi' \to \pi\pi J/\psi$, $m_{\pi\pi}$ is generated according to

$$\frac{d\sigma}{dm_{\pi\pi}} \propto (phase \;\; space) \times (m_{\pi\pi}^2 - 4m_\pi^2)^2$$

  and the phase space factor is

$$PS = \left\{m_{1S}^4 + m_{2S}^4 + m_{\pi\pi}^4 - 2(m_{1S}^2 m_{\pi\pi}^2 + m_{2S}^2 m_{\pi\pi}^2 + m_{1S}^2 m_{2S}^2)\right\}^{1/2} \times \sqrt{\frac{(m_{\pi\pi}^2 - 4m_\pi^2)}{4m_{2S}^2}}$$

  $\pi\pi$ system is S-wave dominant, and uniform in the ψ' frame, uniform for π in the $\pi\pi$ system, $1 + cos^2\theta^*$ for leptons in the J/ψ frame with respect to the beam direction, and final state radiation of α^3 order is taken into account. $\pi^0 \to \gamma\gamma$ is isotropic. MC and data coincide very well from analysis of $\psi' \to \pi^+\pi^- J/\psi$ [8].

- for $\psi' \to (\pi^0, \eta) J/\psi$, the angular distribution is $1 + cos^2\theta$ for J/ψ in the ψ' frame, other distributions are same as those of $\pi\pi J/\psi$.

- for $\psi' \to \gamma\chi_{c1,2} \to \gamma\gamma' J/\psi$, pure electric dipole transition is applied, i.e, the angular distributions are $1 - \frac{1}{3}cos^2\theta$ for $\psi' \to \gamma\chi_{c1}$ in the ψ' frame and $1 + \frac{1}{5}cos^2\theta^*$ for $\chi_{c1} \to \gamma' J/\psi$ in the χ_{c1} frame; $1 + \frac{1}{13}cos^2\theta$ for $\psi' \to \gamma\chi_{c2}$ in the ψ' frame and $1 + \frac{21}{73}cos^2\theta^*$ for $\chi_{c2} \to \gamma' J/\psi$ in the χ_{c2} frame [9]; Input helicity amplitude when simulating, the event generator will automatically produce corresponding angular distributions via $\mathcal{D}^J_{mm'}$.

The event generator takes phase space, angular distributions and the final state radiation into account

3 Event Selection

The event selection criteria are listed as following:

- General Cuts
  - charged tracks: events with two good helix fit tracks and zero net charge ($Netchrgs = 0$) are selected, and require the event vertex within $V_{xy} < 1.5$cm, $|V_z| < 15$cm, and each track within $|cos\theta| < 0.8$.
  - photons: neutral clusters hit Barrel Shower Counter (BSC) at least 2 layers $N_{lays} \geq 2$ and do not hit the central ribbon range ($|Z_{sc}| < 4cm$). In order to remove radiative photons from charged particles, require the angle between the photons and the charged particles satisfy $cos\theta_{\gamma\sim chrg} < 0.96$. And the angle between the direction of the neutral track hitting on BSC and its developing direction in BSC satisfy $cos\theta_{\gamma\sim dev} > 0.8$.

– electrons: The ratios of the energy deposit $E_{sc1,2}$ in BSC to the momenta $p_{1,2}$ satisfying $(\frac{E_{sc1}}{p_1}-1)^2+(\frac{E_{sc2}}{p_2}-1)^2 \leq 0.36$ are used to select electron pairs.

– μ ID: not use μ-Counter (due to its small coverage $|cos\theta| < 0.6$) to get larger acceptance, but use kinematic fit, dE/dx and $E_{SC}/p < 0.5$ to select muons. there are HARDLY any hadron backgrounds for these modes.

– Confidence level cuts, require the confidence level for kinematic fit and dE/dx satisfying CL(fit)> 1%, CL(dE/dx)$_{chrgs}$ > 1%.

3.1 $\psi' \to \pi^0\pi^0 J/\psi$

for this transition, due to low background, after 4-C kinematic fit, we require

- CL(4C)> 1%, CL(dE/dx)> 1%
- for 4-photons, the lowest $\delta m = \sqrt{(m_{\gamma_1\gamma_2}-m_{\pi^0})^2+(m_{\gamma_3\gamma_4}-m_{\pi^0})^2}$ is selected and $\delta m < 80MeV/c^2$ is required.
- $2.9 < m_{\mu^+\mu^-} < 3.3GeV/c^2$ is required, due to the final state radiation, no contraint on $m_{e^+e^-}$ is required.

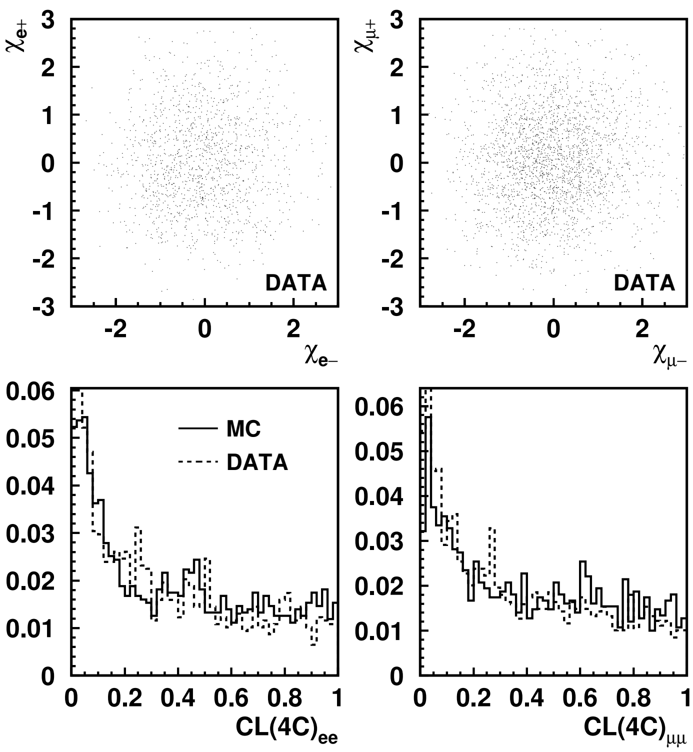

Figure 1: $\psi' \to \gamma\gamma\gamma\gamma\ell^+\ell^-$, $\chi^{e^+}_{dE/dx}$ v.s $\chi^{e^-}_{dE/dx}$ and $\chi^{\mu^+}_{dE/dx}$ v.s $\chi^{\mu^-}_{dE/dx}$; CL(4C)$_{\gamma\gamma\gamma\gamma e^+e^-}$ and CL(4C)$_{\gamma\gamma\gamma\gamma\mu^+\mu^-}$.

Fig. 1 plot $\chi^{\ell^+}_{dE/dx}$ and $\chi^{\ell^-}_{dE/dx}$ (upper) distributions which centered at (0,0) within 3σ dE/dx separation as expected. The lower show the comparison of the confidence level for kinematic fit between MC and data, MC and data agree well.

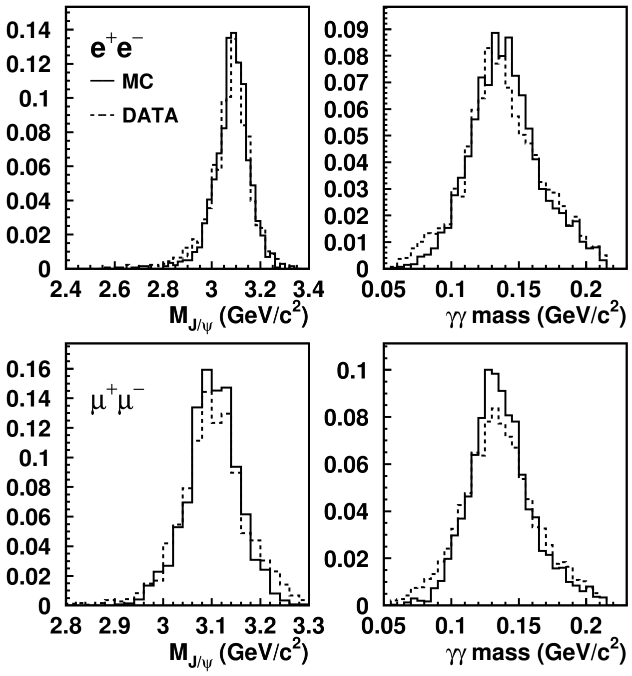

Figure 2: $\psi' \to \gamma\gamma\gamma\gamma\ell^+\ell^-(\ell = e, \mu)$, $M_{\ell^+\ell^-}$ and $M_{\gamma\gamma}$

Fig. 2 show $M_{\ell^+\ell^-}$ and $M_{\gamma\gamma}$ distributions, the comparison between MC and data is also presented.

Gaussian fits to $\gamma\gamma$ mass yield $N^{obs}_{e^+e^-} = 1290 \pm 42$, $N^{obs}_{\mu^+\mu^-} = 2336 \pm 58$ events , MC gives the acceptance $\varepsilon_{e^+e^-} = (2.78 \pm 0.05)\%$, $\varepsilon_{\mu^+\mu^-} = (4.76 \pm 0.08)\%$. After subtracting the backgrounds from $\psi' \to \eta J/\psi \to 3\pi^0\ell^+\ell^-$ with two low energy photons undetected (70 and 133 events for e^+e^- and $\mu^+\mu^-$ final states respectively from MC), we have

$$\mathcal{B}(\psi' \to \pi^0\pi^0 J/\psi)_{e^+e^-} = (19.78 \pm 0.66 \pm 2.13)\%$$
$$\mathcal{B}(\psi' \to \pi^0\pi^0 J/\psi)_{\mu^+\mu^-} = (20.87 \pm 0.53 \pm 2.39)\%$$

the errors are statistical and systematic respectively, and the combined one:

$$\mathcal{B}(\psi' \to \pi^0\pi^0 J/\psi)_{\ell^+\ell^-} = (20.44 \pm 0.41 \pm 2.16)\%$$

- $\psi' \to \gamma\gamma\ell^+\ell^-$

  To separate photons from $\psi' \to \gamma_{1,2}\chi_{c1,2}$ and from $\chi_{c1,2} \to \gamma'_{1,2}J/\psi$, an extra constraint with $\ell^+\ell^-$ forming a resonance J/ψ is required (5-C kinematic fit) to improve energy resolution of photons. After general cuts and 5-C fit, we require

  - CL(5C)$> 1\%$, CL(dE/dx)$_{chrgs} > 1\%$

Fig. 3 and Fig. 4 plot $\gamma\gamma$ mass $M_{\gamma\gamma}$, J/ψ and high energy photon mass $M_{J/\psi\gamma_{high}}$ after the above preselection, there are prominent η and $\chi_{c1,2}$ signals

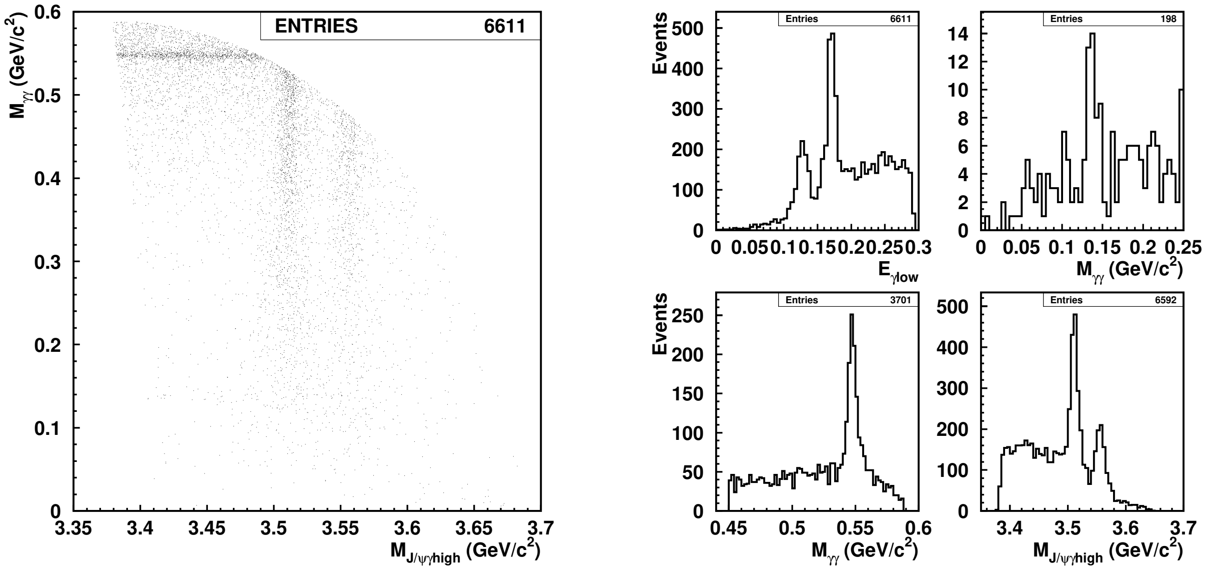

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Figure 3: $\psi' \to \gamma\gamma\mu^+\mu^-$, $M_{\gamma\gamma}$ and $M_{J/\psi\gamma_{high}}$

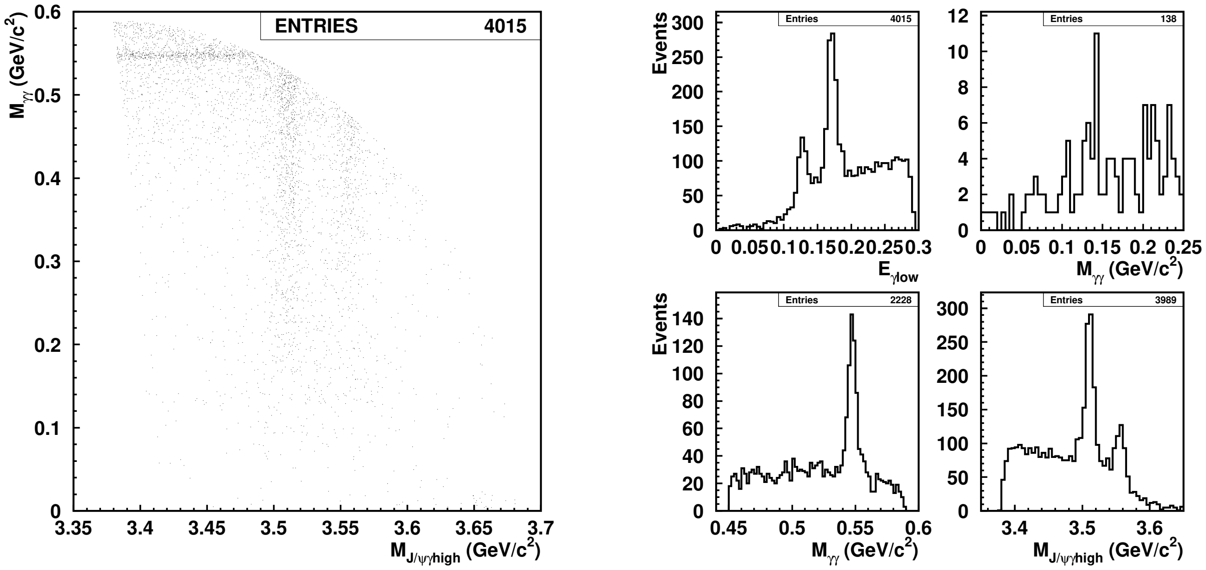

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Figure 4: $\psi' \to \gamma\gamma e^+e^-$, $M_{\gamma\gamma}$ and $M_{J/\psi\gamma_{high}}$

- Kinematic Features

  For $\psi' \to (\pi^0, \eta)J/\psi$ and $\psi' \to \gamma\chi_{c1,2} \to \gamma\gamma' J/\psi$, they have different kinematic features as shown in Fig. 5 from MC, the angles between high energy photon and J/ψ and between two photons are quite different.

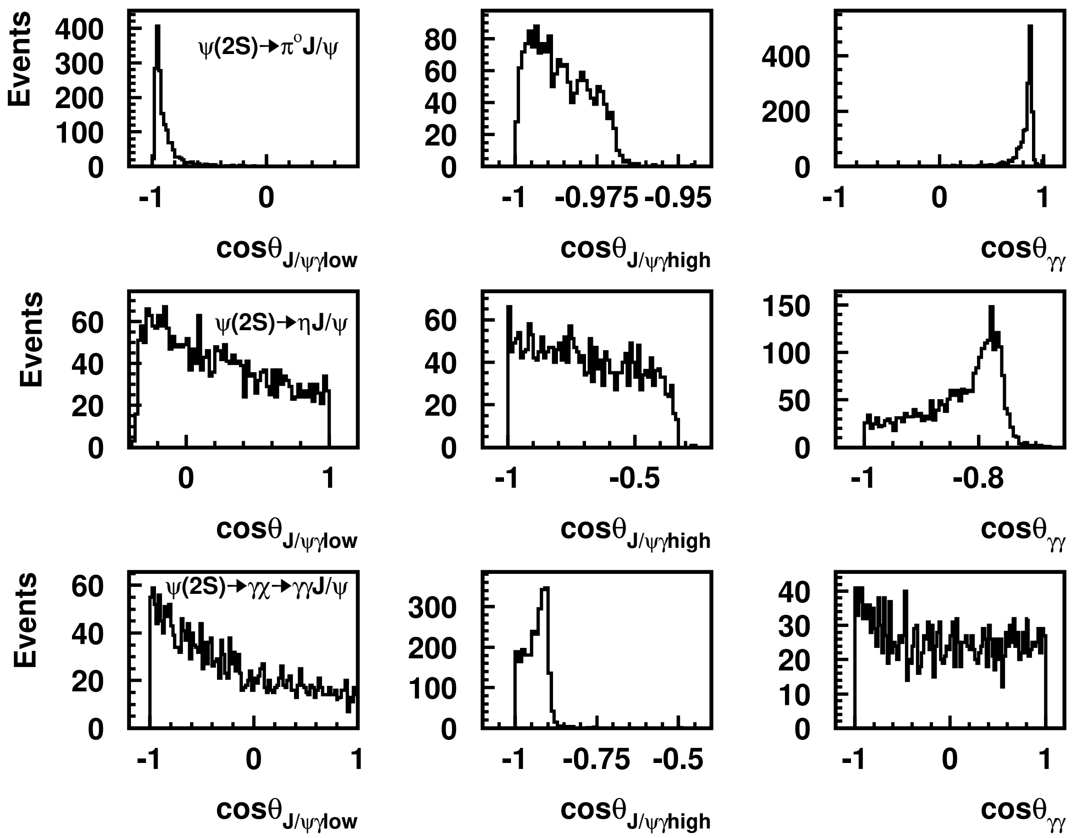

Figure 5: Kinematic features for $\psi' \to (\pi^0, \eta)J/\psi$ and $\gamma\chi_c \to \gamma\gamma J/\psi$

3.2 $\psi' \to \eta J/\psi$

For $\psi' \to \eta J/\psi$, we require $M_{J/\psi\gamma_{high}} < 3.49GeV/c^2$ to suppress backgrounds from $\psi' \to \gamma\chi_{c1,2} \to \gamma\gamma' J/\psi$.

Fig. 6 plot the B-W fits to $\gamma\gamma$ mass after the above selection , yielding $N^{obs}_{\mu^+\mu^-} = 811 \pm 39$, $N^{obs}_{e^+e^-} = 457 \pm 27$, MC gives the acceptance $\varepsilon_{\mu^+\mu^-} = (25.9 \pm 0.22)\%$, $\varepsilon_{e^+e^-} = (14.24 \pm 0.10)\%$, We have

$$\begin{aligned} \mathcal{B}(\psi' \to \eta J/\psi)_{\mu^+\mu^-} &= (3.51 \pm 0.17 \pm 0.36)\% \\ \mathcal{B}(\psi' \to \eta J/\psi)_{e^+e^-} &= (3.60 \pm 0.21 \pm 0.42)\% \end{aligned}$$

and the combined one

$$\mathcal{B}(\psi' \to \eta J/\psi)_{\ell^+\ell^-} = (3.55 \pm 0.13 \pm 0.35)\%$$

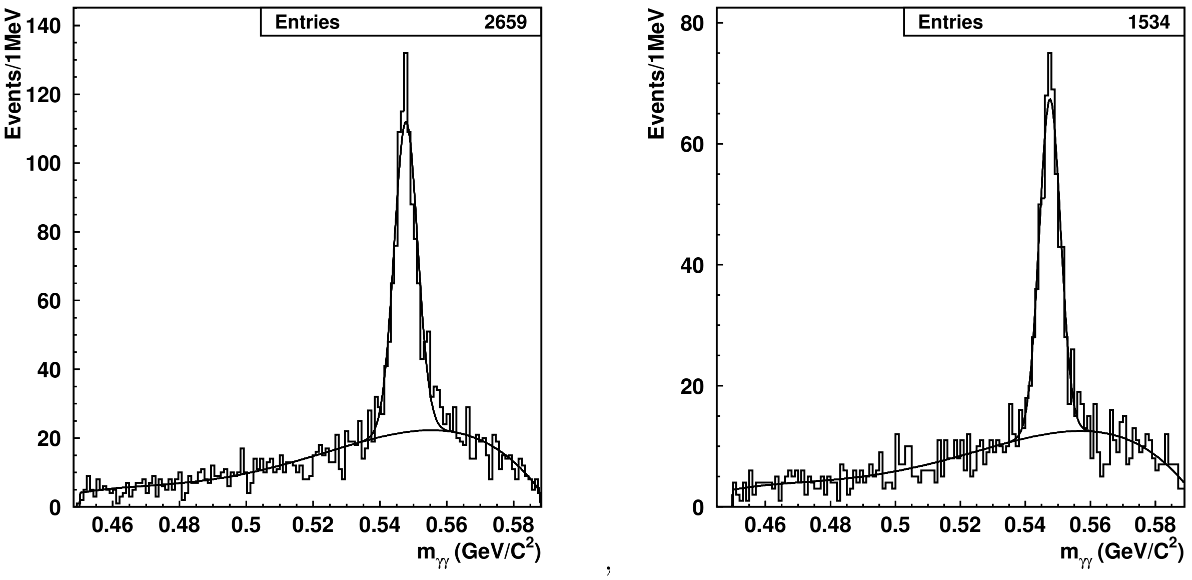

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Figure 6: $\psi' \to \gamma\gamma\ell^+\ell^-$, B-W fit to $\gamma\gamma$ mass for $\mu^+\mu^-$ (left) and e^+e^- final states (right)

3.3 $\psi' \to \pi^0 J/\psi$

For $\psi' \to \pi^0 J/\psi$, we require $M_{J/\psi\gamma_{high}} < 3.47GeV/c^2$, $cos\theta_{\gamma,\gamma} > 0.5$, $cos\theta_{\gamma_{high},J/\psi} < -0.95$ to suppress backgrounds. Combine $\gamma\gamma e^+e^-$ and $\gamma\gamma\mu^+\mu^-$ final states. MC gives $\varepsilon_{\mu^+\mu^-} = (5.055\pm0.02)\%$ and $\varepsilon_{e^+e^-} = (2.67\pm0.02)\%$ (low acceptance ε due to $M_{J/\psi\gamma_{high}} < 3.47GeV/c^2$ which rejects $\sim 65\%$ events), mass resolution is $\sigma_m^{e^+e^-} = 7.0$MeV and $\sigma_m^{\mu^+\mu^-} = 6.8$MeV, B-W fit yields 35.7 ± 6.3 events, we have

$$\mathcal{B}(\psi' \to \pi^0 J/\psi)_{\ell^+\ell^-} = (2.06 \pm 0.36 \pm 0.32) \times 10^{-3}$$

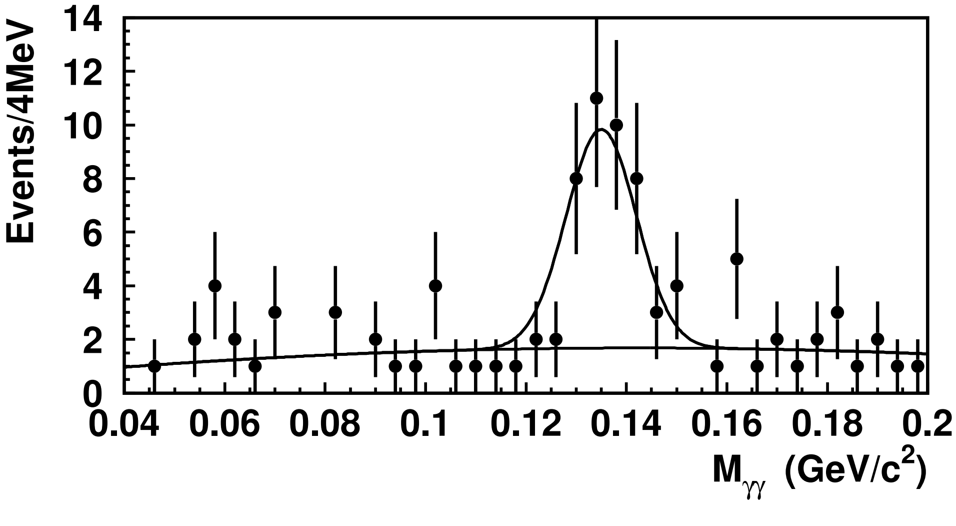

Figure 7: $\psi' \to \gamma\gamma\ell^+\ell^-$, B-W fit to $\gamma\gamma$ mass

3.4 $\psi' \to \gamma\chi_{c1,2} \to \gamma\gamma J/\psi$

We require J/ψ momentum $p_{J/\psi} > 0.225$GeV to reject $\psi' \to \eta J/\psi$, MC indicates linear backgrounds from $\psi' \to \pi^0\pi^0 J/\psi$.

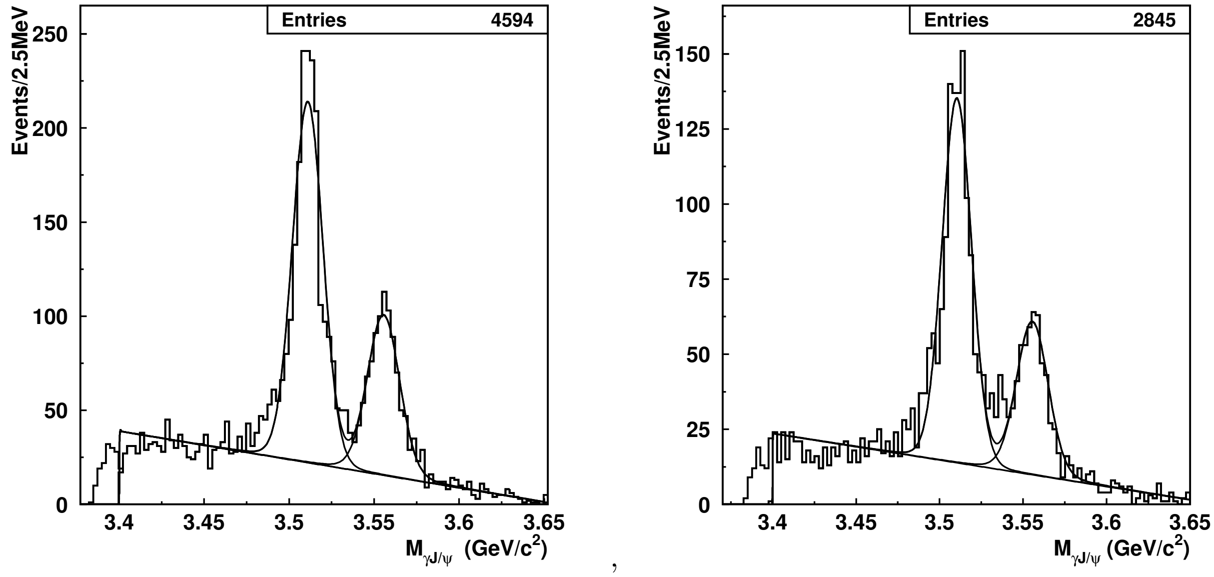

Figure 8: $\psi' \to \gamma\gamma\ell^+\ell^-$, B-W fits to $M_{J/\psi,\gamma_{high}}$ for $\mu^+\mu^-$ and e^+e^- final states

Fig. 8 plot B-W fits to $M_{J/\psi,\gamma_{high}}$, the fits and MC give
$N^{\mu\mu}_{\chi_{c1}} = 1749 \pm 45$, $\varepsilon^{\mu\mu}_{\chi_{c1}} = (23.44 \pm 0.23)\%$, $N^{\mu\mu}_{\chi_{c2}} = 837 \pm 35$, $\varepsilon^{\mu\mu}_{\chi_{c2}} = (21.3 \pm 0.21)\%$,
$N^{ee}_{\chi_{c1}} = 1086 \pm 32$, $\varepsilon^{ee}_{\chi_{c1}} = (13.16 \pm 0.13)\%$, $N^{ee}_{\chi_{c2}} = 503 \pm 26$, $\varepsilon^{ee}_{\chi_{c2}} = (12.33 \pm 0.12)\%$,
we have

$$\begin{aligned} \mathcal{B}(\psi' \to \gamma\chi_{c1})_{\mu^+\mu^-} &= (12.02 \pm 0.31 \pm 1.38)\% \\ \mathcal{B}(\psi' \to \gamma\chi_{c1})_{e^+e^-} &= (13.30 \pm 0.39 \pm 1.49)\% \end{aligned}$$

and the combined

$$\mathcal{B}(\psi' \to \gamma\chi_{c1})_{\ell\ell} = (12.52 \pm 0.24 \pm 1.38)\%$$

and

$$\begin{aligned} \mathcal{B}(\psi' \to \gamma\chi_{c2})_{\mu^+\mu^-} &= (12.80 \pm 0.54 \pm 1.59)\% \\ \mathcal{B}(\psi' \to \gamma\chi_{c2})_{e^+e^-} &= (13.29 \pm 0.69 \pm 1.73)\% \end{aligned}$$

and the combined

$$\mathcal{B}(\psi' \to \gamma\chi_{c2})_{\ell^+\ell^-} = (13.00 \pm 0.43 \pm 1.61)\%$$

or the joint

$$\begin{aligned} &\mathcal{B}(\psi' \to \gamma\chi_{c1}) \cdot \mathcal{B}(\chi_{c1} \to \gamma J/\psi)_{\ell\ell} \\ &\quad = (3.42 \pm 0.07 \pm 0.32)\% \\ &\mathcal{B}(\psi' \to \gamma\chi_{c2}) \cdot \mathcal{B}(\chi_{c2} \to \gamma J/\psi)_{\ell\ell} \\ &\quad = (1.76 \pm 0.06 \pm 0.16)\% \end{aligned}$$

4 Results and Discussions

The measurements of $\psi' \to J/\psi +$ neutrals are listed in Table 2.

Table 2: Meaurements of $\psi' \to (2\gamma, 4\gamma) + J/\psi$

transitions	photons+e^+e^-	photons+$\mu^+\mu^-$	$e^+e^- + \mu^+\mu^-$ combined	PDG
$\pi^0\pi^0 J/\psi$	(1220 ± 40) $(19.78 \pm 0.66 \pm 2.13)\%$	(2203 ± 56) $(20.87 \pm 0.53 \pm 2.39)\%$	(3423 ± 69) $(20.44 \pm 0.41 \pm 2.16)\%$	fit $(18.4 \pm 2.7)\%$
$\eta J/\psi$	(457 ± 27) $(3.60 \pm 0.21 \pm 0.42)\%$	(811 ± 39) $(3.51 \pm 0.17 \pm 0.36)\%$	(1268 ± 47) $(3.55 \pm 0.13 \pm 0.35)\%$	386(CBAL) $(2.7 \pm 0.4)\%$
$\pi^0 J/\psi$	$e^+e^- + \mu^+\mu^-$	(35.7 ± 6.3)	$(2.06 \pm 0.36 \pm 0.32) \cdot 10^{-3}$	$(9.7 \pm 2.1) \cdot 10^{-4}$
$\gamma\chi_{c1}$	(1086 ± 32) $(13.30 \pm 0.39 \pm 1.49)\%$	(1749 ± 45) $(12.02 \pm 0.31 \pm 1.38)\%$	(2835 ± 54) $(12.52 \pm 0.24 \pm 1.38)\%$	$(8.7 \pm 0.8)\%$
$\gamma\chi_{c2}$	(503 ± 26) $(13.29 \pm 0.69 \pm 1.73)\%$	(837 ± 35) $(12.80 \pm 0.54 \pm 1.59)\%$	(1340 ± 44) $(13.00 \pm 0.43 \pm 1.61)\%$	$(7.8 \pm 0.8)\%$

- The precision for $\mathcal{B}(\psi' \to (\pi^0\pi^0, \eta)J/\psi)$ are improved, while $\mathcal{B}(\psi' \to (\pi^0 J/\psi, \gamma\chi_{c1,2}))$ are much larger than PDG values dominated by CBAL ones [10], but we observed much more events than other groups. CBAL used $\mathcal{B}(J/\psi \to \ell^+\ell^-) = (6.9 \pm 0.9)\%$; their results from different independent methods do not coincide well with each other; the angular distributions (based on fits to small data sets) used for acceptance correction do not well agree with data.

- $\psi' \to (\eta, \pi^0)J/\psi$ and Charge Symmetry Breaking (CSB):

ratis	*Theory*	*our results*
$r = \frac{\Gamma(\psi' \to \pi^0 J/\psi)}{\Gamma(\psi' \to \eta J/\psi)}$	$\approx 2\%$	$(5.8 \pm 1.3)\%$
$R = \frac{m_s - \hat{m}}{m_d - m_u}$	$30 - 50(PDG)$	23.2 ± 2.6

For CSB transition $\psi' \to \pi^0 J/\psi$ and CS allowed process $\psi' \to \eta J/\psi$, $r = (5.8 \pm 1.3)\%$ rules out $m_u = 0$, the ratio is a bit larger than theoretic prediction, but if the large theoretic uncertainty considered, the result is consistent with the prediction. Our result agrees well with those from CBAL and Mark II, their results are $(4 \pm 1)\%$ and $(6 \pm 2)\%$ respectively [1]. The ratio R is a bit smaller without considering the theoretic uncertainty.[1]

- Tests of non-pQCD Multipole expansion:

ratios	*Theory*	*our results*
$\frac{\Gamma(\psi' \to \eta J/\psi)}{\Gamma(\Upsilon' \to \eta \Upsilon)}$	≈ 300	$> 112 @ CL = 90\%$
$\frac{\Gamma(\psi' \to \pi^0\pi^0 J/\psi)}{\Gamma(\Upsilon' \to \pi^0\pi^0 \Upsilon)}$	≈ 10 *vector gluon* ≈ 1 *scalargluon*	14.6 ± 3.7

non-pQCD multipole expansion predicts the above ratios, our results agree well with theoretic predictions, and confirm the vector nature of gluon.

[1]Note: when calculate r, the systematic errors from ψ' total event number and $\mathcal{B}(J/\psi \to \ell^+\ell^-)$ cancel.

- Test of QCD triangle anomalies:

ratio	*Theory*	*our result*
$\frac{\Gamma(\psi'\to\eta J/\psi)}{\Gamma(\psi'\to\pi^+\pi^- J/\psi)}$	≈ 0.1	0.110 ± 0.007

The above ratio coincides very well with QCD prediction which measures the triangle anomalies associated with quark and gluon color charges.

5 Polarization of $\psi' \to \gamma\chi_{c1,2} \to \gamma\gamma' J/\psi$

Usually, the cascade transitions are simplified by pure E1 as expected in nonrelativistic limit. If the interactions between the electromagnetic field and the quarkonium system considered, the higher multipoles (v^2/c^2) arise naturally. As a results, the angular distributions change considerably. The deviation from the angular distributions of pure E1 suggests the contribution from the higher multipoles. Some models predict the higher multipole transition amplitude [11], the measurements of the amplitude can serve as tests of the predictions.

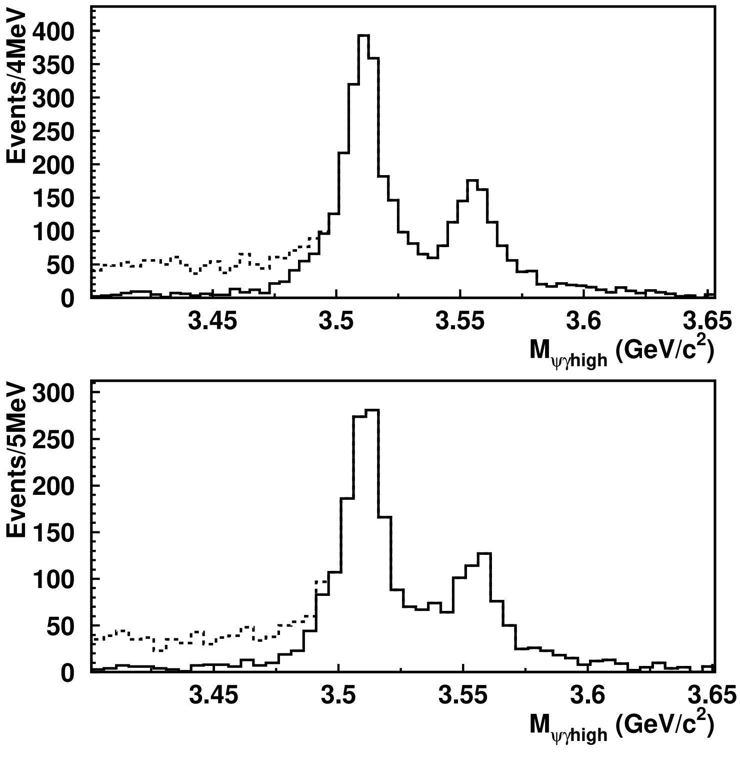

Figure 9: $\psi' \to \gamma\gamma'\ell^+\ell^-$, $\mathrm{M}_{\gamma_{high},J/\psi}$ (GeV/c^2) before (dashed) and after (solid) $cos\theta_{\gamma_{high},J/\psi} < -0.875$

Using the selected events, for χ_{c1}, χ_{c2}, we require $cos\theta_{\gamma_{high},J/\psi} < -0.875$ to suppress backgrounds from $\psi' \to \pi^0\pi^0 J/\psi$. For χ_{c1}, we require $m_{J/\psi\gamma_{high}} \in (3.48, 3.53)$ GeV/c^2, for χ_{c2}, we require $m_{J/\psi\gamma_{high}} \in (3.53, 3.58)$ GeV/c^2.

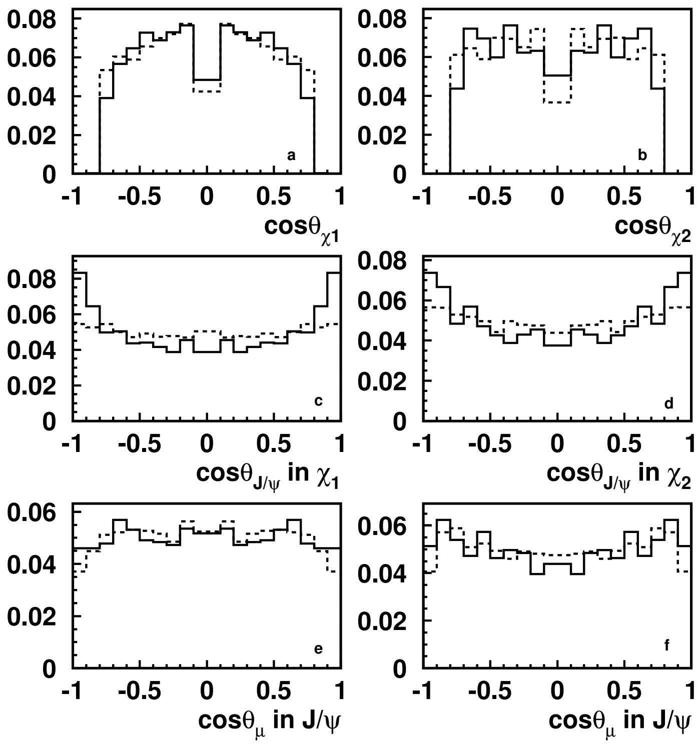

Figure 10: $\psi' \to \gamma\gamma'\mu^+\mu^-$, distributions of helicity angles in their mother rest frame, (MC-dashed for pure E1 transition, DATA-solid), similar plots for $\psi' \to \gamma\gamma' e^+e^-$.

From the comparison (Fig.10) of the angular distributions between MC for pure E1 transitions and data, the obvious deviation exists for $\chi_{c1,2} \to \gamma' J/\psi$. We conculde that for $\psi' \to \gamma\chi_{c1,2}$, pure E1 is a good approximation; for $\chi_{c1,2} \to \gamma' J/\psi$, the deviation suggests higher multipole contribution, quantitative analysis is to be performed, detailed study of the backgrounds is necessary, but it is expected the contribution from the backgrounds is uniform.

6 Summary

- Measurements of $\psi' \to J/\psi$+neutrals

  1. The measurements of the branching fractions for $\psi' \to (\pi^0 J/\psi$, $\pi^0\pi^0 J/\psi$, $\eta J/\psi$, $\gamma\chi_{c1,2} \to \gamma\gamma J/\psi)(J/\psi \to \mu^+\mu^-$, $e^+e^-)$ are presented. Limited by the precision of the ψ' total event number, only the precision of the branching ratios for $\psi' \to \pi^0\pi^0 J/\psi$, $\eta J/\psi$ are improved.
  2. $\frac{\Gamma(\psi' \to \pi^0 J/\psi)}{\Gamma(\psi' \to \eta J/\psi)}$ related with CSB is coincident with theoretic expectations within error, giving information about m_s which is concerned with V_{us} and ϵ'/ϵ.
  3. Tests of non-pQCD multipole expansion
     $\frac{\Gamma(\psi' \to \pi^0\pi^0 J/\psi)}{\Gamma(\Upsilon' \to \pi^0\pi^0 \Upsilon)}$ agrees well with the prediction of multipole expansion and confirms the vector nature of gluon, and $\frac{\Gamma(\psi' \to \eta J/\psi)}{\Gamma(\Upsilon' \to \eta\Upsilon)}$ is consistent with its prediction.

4. Test of QCD triangle anomalies
   $\frac{\Gamma(\psi'\to\eta J/\psi)}{\Gamma(\psi'\to\pi^+\pi^- J/\psi)}$ agrees well with prediction of QCD triangle anomalies associated with quark and gluon color charges.

- Polariztion of $\psi' \to \gamma\chi_{c1,2} \to \gamma\gamma' J/\psi$

  Analysis of the angular distributions for cascade radiative transitions $\psi' \to \gamma\chi_{c1,2} \to \gamma\gamma' J/\psi \to \gamma\gamma'\ell^+\ell^-$ indicates that pure electric-dipole transitions (E1) are good approximation for $\psi' \to \gamma\chi_{c1,2}$, while considerable higher multipole (M2 or E3) transitions contribute to $\chi_{c1,2} \to \gamma' J/\psi$, quantitative analysis is necessary.

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