Direct measurement of the branching fractions for K^0 and K^{*0} production in J/ψ decays

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Charged Particle Identification

Combined particle confidence level

$$CL(i) = \int_{\chi^2}^{\infty} P(z,n)dz$$

Where i = 1, 2, 3, 4 and 5 denotes e, μ, π, K and proton.

$$\chi^2 = \Delta_{TOF}^2 + \Delta_{dE/dx}^2 + \Delta_{measure}^2$$

$$\Delta_{TOF} = \frac{T_{measure} - T_{expect}}{\sigma_{TOF}}$$

$$\Delta_{dE/dx} = \frac{dE/dx_{measure} - dE/dx_{expect}}{\sigma_{dE/dx}}$$

$$\Delta_{BSC} = \frac{E_{measure} - E_{expect}}{\sigma_E}$$

$$P(z,n) = \frac{1}{2^{\frac{n}{2}}}(z)^{\frac{n}{2}-1} e^{-\frac{n}{2}}$$

For π, CL(π)>0.1%, and CL(π)>CL(K)

For K, CL(K)>0.1%, and CL(K)>CL(π)

For proton, $\frac{CL(p)}{CL(\pi)+CL(K)+CL(p)} > 0.6$

Data Sample (April 2001, February 2003, December 2003, January 2004)

Integrated luminosity

Processes used : $e^+e^- \to e^+e^-$, $e^+e^- \to J/\psi \to e^+e^-$

$$\mathcal{L} = \frac{N_{e^+e^-}^{obs}}{\sigma_{Bhabha} \cdot \varepsilon_{Bhabha} + \sigma_{J/\psi \to e^+e^-} \cdot \varepsilon_{J/\psi \to e^+e^-} + \sigma_{int} \cdot \varepsilon_{int}}$$

$$\sigma_{had}^{obs} = \sigma_{J/\psi \to e^+e^-} \cdot \varepsilon_{J/\psi \to e^+e^-} + \sigma_{int} \cdot \varepsilon_{int} = \frac{N_{had}^{obs}}{\epsilon_{had} \cdot \mathcal{L}}$$

Integrated luminosity and the observed inclusive hadronic cross section correlate with each other

Through a χ^2 fit to the observed inclusive cross sections with J/ψ resonance parameters fixed at PDG value, we can get $\mathcal{L}$ at each energy point.

Divide all energy points into 16 energy regions (Add $\mathcal{L}$ with their weights)

Observed Cross Section

Selection of the candidate events

At least two charged tracks should be well reconstructed
θ of each charged track must satisfy $|cos\theta| < 0.80$

For $e^+e^- \rightarrow K_S^0 + X$, each track from the region

$$|cos\theta| < 0.80(\text{for ours}, 0.93)$$

$$\sqrt{V_x^2 + V_y^2} < 8.0cm(for\ ours, 12.0cm)$$

$$|V_z| < 22.0cm(for\ ours, 20.0cm)$$

The best fit value of laboratory decay distance in xy plane for K_S^0 is required to be displaced at least 0.004mm from the interaction point.

For $e^+e^- \rightarrow K^{*0} + X$, each track from the region

$$|cos\theta| < 0.80$$

$$\sqrt{V_x^2 + V_y^2} < 2.0cm$$

$$|V_z| < 20.0cm$$

Observed Cross Section

Fit to the mass spectra

Reconstruct K_S^0 and K^{*0} by examining the invariant mass spectra of $\pi^+\pi^-$ and $K^-\pi^+$

For K_S^0 (the same as ours)
If more than one combination satisfies the above selection criteria in one event, only those with the longest decay are retained.

For K^{*0}
If more than one combination satisfies the above selection criteria in one event, only those with largest $\mathrm{CL}_K * \mathrm{CL}_\pi$ is retained.

Table 3: Fitted results of mass and the resolution of the selected inclusive $\pi^+\pi^-$, $K^-\pi^+$, and K^+K^- events for M.C. samples.

	K_S^0	K^{*0}
Fitted Mass [MeV]	497.13 ± 0.03	889.85 ± 0.14
Resolution [MeV]	6.54 ± 0.29	7.91 ± 0.38

function for the signals and a third order polynomial for the background, we obtain the fitted masses and the resolutions, which are shown in Table 3.

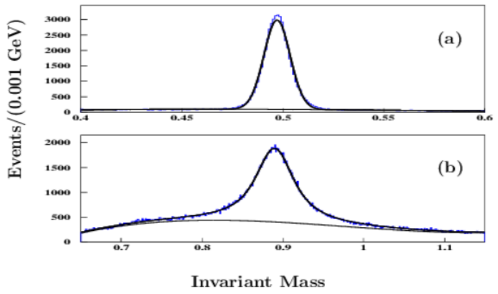

Figure 1: The distributions for the inclusive (a) $\pi^+\pi^-$, and (b) $K^-\pi^+$ events for M.C. samples.

The invariant masses are denoted by $M_{\pi^+\pi^-}$ and $M_{K^-\pi^+}$, respectively, and the invariant mass spectra is fitted with a Breit-Wigner convoluted with a Gaussian resolution function for the signals and a polynomial function for background.
(After this work, we compared the dynamic variables of MC and DATA as well as detection efficiency)

Observed Cross Section

Background contamination

Possible contaminations : $e^+e^- \to (\gamma)e^+e^-$, $e^+e^- \to (\gamma)\mu^+\mu^-$

Accounted for the luminosity, we can estimate the number of background events at each point are less than 10^{-3}, thus we can neglect the influence of these background processes.

Observed Cross Section

Monte Carlo simulation

At this step, the article estimates the detection efficiencies of these two processes.(γ^* samples, we use 3.050, 3.060, 3.080, 3.090, 3.095, 3.099, 3.1015, 3.112, 3.120 to estimate other points)

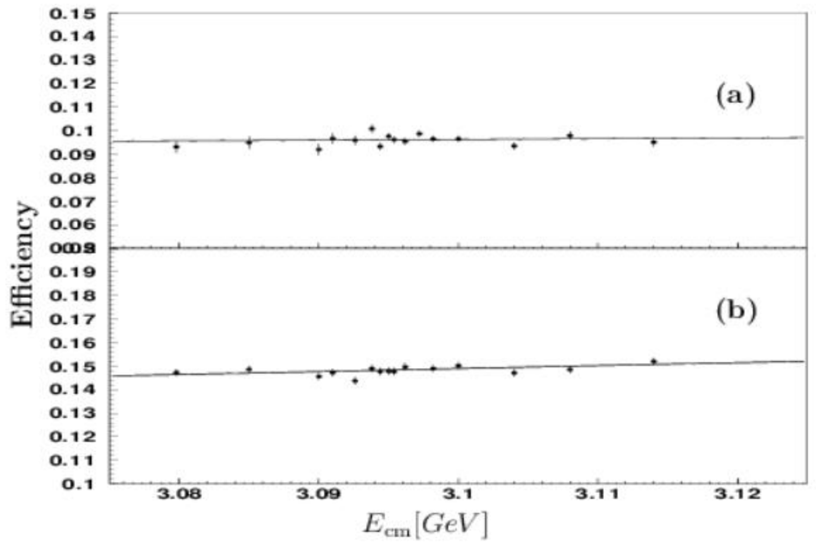

Figure 4: The distributions of the energy dependent efficiencies for (a) $e^+e^- \to K^0_S + X$ and (b) $e^+e^- \to K^{*0} + X$ processes, where the lines indicate the expected efficiencies.

Table 5: The energy dependent detection efficiencies for $e^+e^- \to K^0_S + X$ and $e^+e^- \to K^{*0} + X$ processes, including the branching fractions for the decays $K^0 \to K^0_S \to \pi^+\pi^-$ and $K^{*0} \to K^+\pi^-$, where the errors are statistical error.

E_{cm} [GeV]	$\epsilon_{K^0_S}$	$\epsilon_{K^{*0}}$
3.0814	0.0931 ± 0.0025	0.1473 ± 0.0016
3.0878	0.0949 ± 0.0026	0.1486 ± 0.0016
3.0919	0.0920 ± 0.0024	0.1456 ± 0.0016
3.0934	0.0967 ± 0.0022	0.1472 ± 0.0016
3.0949	0.0959 ± 0.0020	0.1437 ± 0.0016
3.0961	0.1008 ± 0.0018	0.1490 ± 0.0016
3.0967	0.0933 ± 0.0016	0.1477 ± 0.0016
3.0973	0.0976 ± 0.0015	0.1478 ± 0.0016
3.0977	0.0962 ± 0.0014	0.1477 ± 0.0016
3.0985	0.0954 ± 0.0014	0.1497 ± 0.0016
3.0995	0.0987 ± 0.0014	0.1559 ± 0.0016
3.1005	0.0965 ± 0.0014	0.1490 ± 0.0016
3.1027	0.0965 ± 0.0014	0.1502 ± 0.0016
3.1061	0.0935 ± 0.0016	0.1471 ± 0.0016
3.1105	0.0979 ± 0.0018	0.1485 ± 0.0016
3.1171	0.0951 ± 0.0019	0.1520 ± 0.0016

Observed Cross Section

Observed cross section

The observed cross section for $e^+e^- \to M + X$

$$\sigma^{obs}_{e^+e^-\to M+X} = \frac{N^{obs}_{e^+e^-\to M+X}}{\mathcal{L} * \varepsilon_{e^+e^-\to M+X}}$$

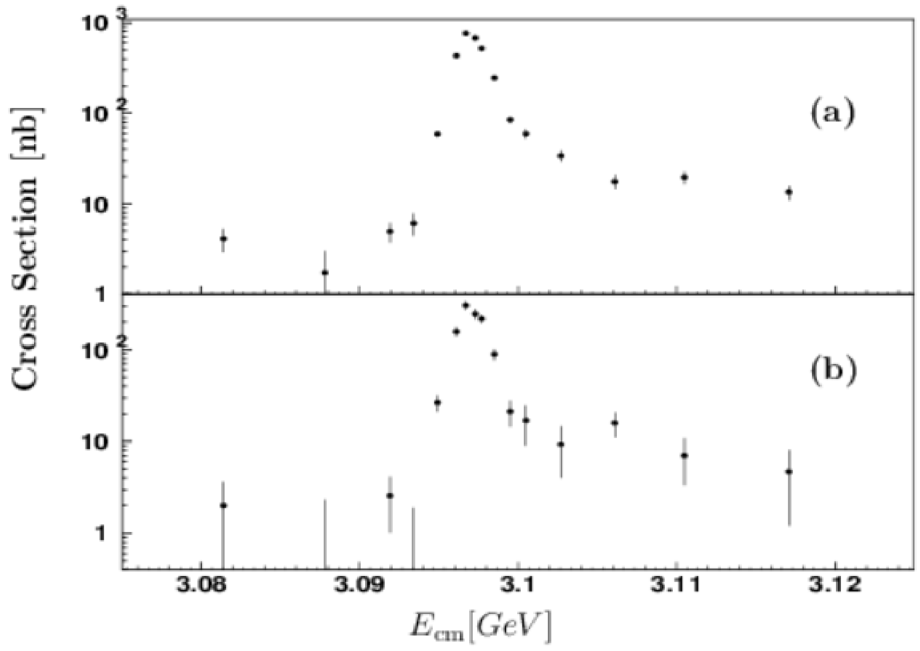

Table 6: The observed cross sections for $e^+e^- \to K^0 + X$ and $e^+e^- \to K^{*0} + X$ processes at each combined energy point, where the errors are the combined energy dependent and data sets dependent errors.

E_{cm} [GeV]	$\sigma^{obs}_{K^0}$ [nb]	$\sigma^{obs}_{K^{*0}}$ [nb]
3.0814	4.11 ± 1.16	2.00 ± 1.63
3.0878	1.73 ± 1.31	0.33 ± 2.01
3.0919	4.93 ± 1.23	2.57 ± 1.57
3.0934	6.11 ± 1.70	0.15 ± 1.75
3.0949	59.78 ± 4.77	26.93 ± 5.47
3.0961	423.43 ± 21.45	153.33 ± 18.68
3.0967	735.33 ± 45.30	294.02 ± 30.74
3.0973	654.74 ± 35.06	236.50 ± 28.78
3.0977	510.01 ± 32.44	214.63 ± 23.22
3.0985	246.36 ± 15.15	89.50 ± 12.55
3.0995	84.76 ± 6.81	21.18 ± 6.77
3.1005	59.36 ± 6.94	16.88 ± 7.89
3.1027	33.95 ± 4.54	9.28 ± 5.28
3.1061	17.54 ± 3.23	15.84 ± 4.84
3.1105	19.54 ± 3.16	7.02 ± 3.70
3.1171	13.36 ± 2.45	4.66 ± 3.45

Our function: $\frac{N^{obs}}{\varepsilon * \mathcal{L} * 0.692}$

Measurement of $\mathcal{B}$ (J/ψ → $\mathcal{M}$ + X)

Expected cross section

The expected observed cross section $\sigma^{expect}_{e^+e^-\to M+X}(E_{cm})$ consists pf two components:

$$\sigma^{expect}_{e^+e^-\to M+X}(E_{cm}) = \sigma^{expect}_{J/\psi\to M+X}(E_{cm}) + \sigma^{continuum}_{e^+e^-\to M+X}(E_{cm})$$

$$\sigma^{\text{expect}}_{J/\psi\to\mathcal{M}+X}(s) = \int_0^\infty ds' G(s,s') \cdot \int_0^1 dx \cdot \sigma^{\text{B}}_{J/\psi\to\mathcal{M}+X}(s'(1-x))F(x,s')$$

$$G(s,s') = \frac{1}{\sqrt{2\pi}\xi} e^{-\frac{(\sqrt{s}-\sqrt{s'})^2}{2\xi^2}} \quad \sigma^{\text{expect}}_{J/\psi\to\mathcal{M}+X}(s) = \int_0^\infty ds' G(s,s') \cdot \sigma^{\text{sim}}_{J/\psi\to\mathcal{M}+X}(s')$$

$$\begin{aligned}\sigma^{\text{sim}}_{J/\psi\to\mathcal{M}+X}(s) &= \frac{12\pi\Gamma^{\text{ee}}\Gamma^{\text{tot}} \cdot \mathcal{B}(J/\psi\to\mathcal{M}+X)}{s^2} \cdot \\ &[(1+\delta)A^{\beta-2}\phi(\cos\theta,\beta) + \\ &(-\beta+\frac{3}{4}\beta^2)A^{\beta-1}\phi(\cos\theta,\beta+1)],\end{aligned}$$

$$\beta = \frac{2\alpha}{\pi}(\ln\frac{s}{m_e^2} - 1),$$

$$(1+\delta) = 1 + \frac{\alpha}{\pi}(\frac{\pi^2}{3} - \frac{1}{2}) + \frac{3}{4}\beta - \frac{\beta^2}{24}(\frac{1}{3}\ln\frac{s}{m_e^2} + 2\pi^2 - \frac{37}{4})$$

$$A = \sqrt{(1-\frac{M^2}{s})^2 + (\frac{M\Gamma^{\text{tot}}}{s})^2},$$

$$cos\theta = \frac{1}{A}(\frac{M^2}{s} - 1),$$

$$\phi(cos\theta,\beta) = \frac{\pi\beta\sin(\theta(1-\beta))}{\sin\theta\sin(\pi\beta)}.$$

$$\sigma^{\text{continuum}}_{e^+e^-\to\mathcal{M}+X}(s) = h(s) \cdot \sigma^{\text{B}}_{\mu^+\mu^-}(s)$$

where $\sigma^{\text{B}}_{\mu^+\mu^-}(s)$ is the Born cross section for $e^+e^- \to \mu^+\mu^-$ and $h(s)$ is a factor determined from fit.

Measurement of $\mathcal{B}$ (J/ψ → $\mathcal{M}$ + X)

Fitted branching fractions

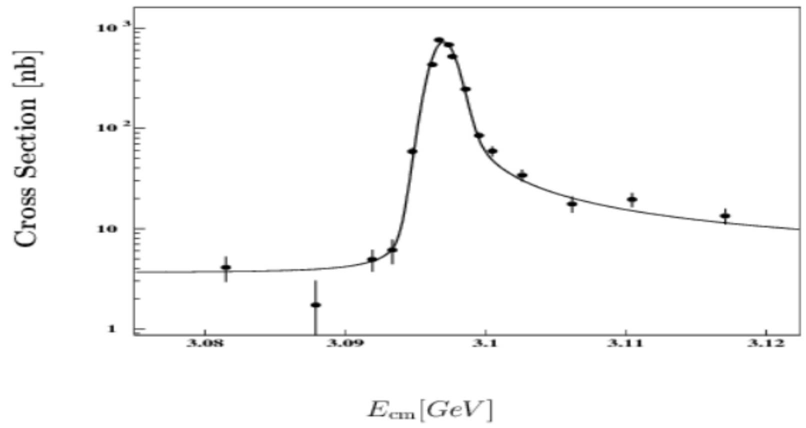

Figure 6: The observed cross sections for $e^+e^- \to K^0 + X$ versus the nominal c.m. energies.

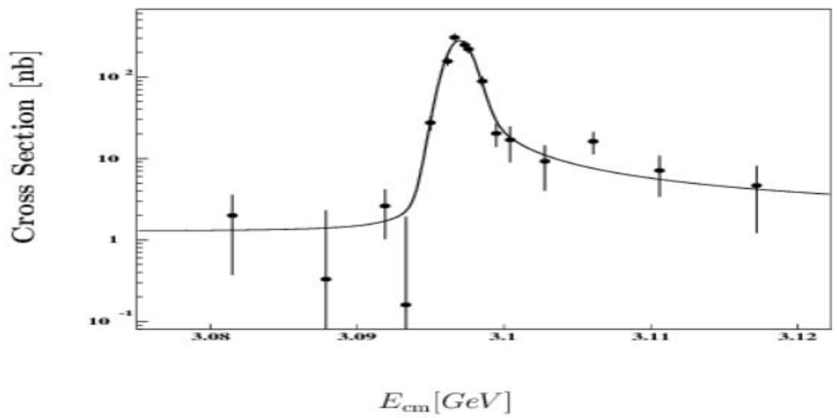

Figure 7: The observed cross sections for $e^+e^- \to K^{*0} + X$ versus the nominal c.m. energies.

Table 7: The measured values of the mass of J/ψ resonance, the energy spread of BEPC machine, the branching fraction for $J/\psi \to \mathcal{M} + X$ and h, which are obtained by fitting the observed cross sections discribed in text.

	χ^2/NDF	M [MeV]	$\Delta^{\rm BEPC}$ [MeV]	h	$\mathcal{B}(J/\psi \to \mathcal{M} + X)$ [%]
$\mathcal{M} = K^0$	$15.9/NDF$	3096.90 ± 0.03	0.90 ± 0.02	0.18 ± 0.03	20.4 ± 0.5
$\mathcal{M} = K^{*0}$	$10.3/NDF$	3096.90 ± 0.06	0.88 ± 0.05	0.06 ± 0.04	7.7 ± 0.4

Systematic Error Analysis

To estimate the systematic uncertainties of the branching fractions, the article shifts the measured observed cross section, Γ^{tot} and Γ^{ee} of J/ψ resonance by +/-1σ to measure the change of the branching fractions.

Table 9: The sources of the systematic uncertainties in the measured branching fractions.

Sources	Uncertanty [%] in $\mathcal{B}(J/\psi \to K^0 + X)$	Uncertanty [%] in $\mathcal{B}(J/\psi \to K^{*0} + X)$
$\Delta\sigma^{obs}$	5.5	3.8
$\Gamma^{ee}_{J/\psi}$	3.6	3.6
$\Gamma^{tot}_{J/\psi}$	0.0	0.0
Total	6.6	5.3

$$err^{tot} = \sqrt{\sum_i err^i}$$

Table 10: The branching fractions obtained from the fit, where the first errors are from the fit and the second are the systematic.

	$\mathcal{B}$ [%]
$J/\psi \to K^0 + X$	$20.4 \pm 0.5 \pm 1.3$
$J/\psi \to K^{*0} + X$	$7.7 \pm 0.4 \pm 0.4$

$$err_{sys}^{tanle10} = err_{sys}^{table9}(\% \to decimal) * \mathcal{B}$$

Eg: 0.066*20.4≈1.3

Calculating the relative changes of +σ and -1σ, respectively and choosing the greater one as the systematic error.