Study of $e^+e^- \to \gamma_{ISR}q\bar{q}$

Shen Peixun[1] Li Gang[2] Yu Chunxu[1]

NanKai University[1] Institute of High Energy Physics[2]

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The observed cross section is:

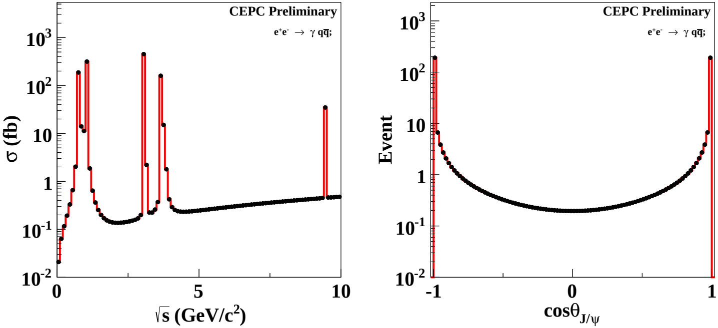
$$\sigma_{\mathrm{obs}}(s) = \int \sigma_B(s(1-x)) \cdot W(s,x) dx \tag{1}$$

The $W(s,x)$ is the radiator, $\sigma_B(s)$ is the Born cross section. For the narrow resonance, the $\sigma_B(s)$ is given by the standard Breit-Wigner formula:

$$\sigma_0(s) = \frac{12\pi m^2 \Gamma_{ee}^2}{(s-m^2)^2 + m^2\Gamma^2}, \tag{2}$$

where m and Γ are the mass and width of resonance, Γ_{ee} is the partial width to e^+e^-.

Distributions for σ and polar angle



Formula for polar angle of γ_{ISR}

The polar angle distribution for γ_{ISR}:

$$P(\theta) = \frac{\sin^2\theta - \frac{x^2\sin^4\theta}{2(x^2-2x+2)} - \frac{m_e^2}{E^2}\frac{(1-2x)\sin^2\theta - x^2\cos^4\theta}{x^2-2x+2}}{(\sin^2\theta + \frac{m_e^2}{E^2}\cos^2\theta)^2}, \tag{3}$$

where $s = 4E^2$, E is the beam energy, m_e is the electron mass, $x = E_\gamma/E$.
The probability for the hard photon inside the opening angle θ_m

$$P(0 \leq \theta \leq \theta_m) = \frac{h(\theta_m)}{h(\pi)}, h(\theta_m) = \int_0^{\theta_m} P(\theta)\sin\theta d\theta, \tag{4}$$

where

$$\begin{aligned} h(\theta) = {} & \frac{L-1}{2} + \frac{m_e^2}{2E^2}\frac{\cos\theta}{\sin^2\theta + \frac{m_e^2}{E^2}\cos^2\theta} - \frac{1}{2}\ln\frac{1+\sqrt{1-\frac{m_e^2}{E^2}}\cos\theta}{1-\sqrt{1-\frac{m_e^2}{E^2}}\cos\theta} \\ & \frac{x^2\cos\theta}{2(x^2-2x+2)}(1 - \frac{m_e^2}{E^2}\frac{1}{\sin^2\theta + \frac{m_e^2}{E^2}\cos^2\theta}), \qquad L = 2\ln\frac{\sqrt{s}}{m_e} \\ & \propto A(\theta) + B(\theta)\frac{x^2}{x^2-2x+2} \end{aligned} \tag{5}$$

Cross section and cut efficiency for $\cos\theta < 0.98$

Assuming the detection region is: $\cos\theta < \cos\theta_0$, the probability for the photon:

$$\begin{aligned} P &= 2(P(\frac{\pi}{2}) - P(\theta_0)) \\ &\propto \frac{L-1}{2} - A(\theta_0) - B(\theta_0)\frac{x^2}{x^2-2x+2} \end{aligned} \tag{6}$$

Here, $B(\theta_0)$ is a positive number. We can see that the radiative photon tends to along the beam direction when its energy large.

91.2 (GeV)	ω	ϕ	J/ψ	$\psi(2S)$	$\Upsilon(1S)$
σ_{obs} (fb)	178.5	318.8	452.5	159.0	16.3
ϵ (%)	15.59	15.59	16.60	16.61	16.83

The result is consistent with the conclusion from Eq. 6.