7.1.3 Proton diffractive background

This background is discussed in detail in Ref. 79. Here we explain the method and result briefly. By removing the diffractive(CAL-quiet) requirement in the elastic J/ψ candidate selection, 20% more events were selected in the mass region 2.85-3.25GeV. By visually scanning these events, it was determined that about 5% were most likely due to the proton diffractive process(the other 15% were most likely events with $Q^2 > 4\text{GeV}^2$ so that the beam electron enter the RCAL). This procedure, event selection with and without the CAL-quiet requirement, was also applied to the Monte Carlo diffractive J/ψ generated using PYTHIA.[76,77] It was thus determined that the proton diffractive process accounts for $15 \pm 7(\text{stat.}) \pm 7(\text{theo.})\%$ of the J/ψ cross section. The statistical error is due to the small number of real data events in the diffractive tail. The theoretical error is due to the uncertainty in the mass distribution of the hadrons X. The mass distribution was parameterized as $d\sigma/dM_x^2 \sim M_x^{-n}$ (with n varying between 2 and 3).

7.2 Fitting of the invariant mass spectrum

The final sample of elastic $J/\psi \to e^+e^-$ events contains non-J/ψ background as can be seen from the invariant mass spectrum. The discussion in Section 7.1 helps to understand the nature of the background. Subtraction of the continuum background is more easily and reliably done either by the maximum likelihood fitting method, or by the naive baseline subtraction method.

In the maximum likelihood(ML) method, the invariant mass spectrum is fitted with assumed functions $f^{(\text{signal})}$ and $f^{(\text{noise})}$, with the number of signal events as one of the free parameters. Monte Carlo studies show that the signal distribution is well described by a Gaussian term $g(m; m_{J/\psi}, \sigma)$ and a Bremsstrahlung tail $b(m; m_{J/\psi}, \sigma)$ which is a convolution of a Gaussian function and a Bremsstrahlung factor.[78]

A Gaussian distribution of m with mean μ and variance σ^2 is

$$g(m;\mu,\sigma) = \frac{1}{\sigma\sqrt{2\pi}} e^{-(m-\mu)^2/2\sigma^2} \tag{64}$$

The Bremsstrahlung tail is described by

$$b(m;m_{J/\psi},\sigma) = C \int_0^{m_{J/\psi}-\Delta m} \frac{1}{m_{J/\psi}-\mu} g(m;\mu,\sigma)\, d\mu \tag{65}$$

where Δm is a cutoff parameter to be tuned by the Monte Carlo data and C is the normalization constant. The J/ψ signal is a combination of a Gaussian and a Bremsstrahlung tail. The width σ is due to the finite resolution of the track momentum. The mass shift $(m_{J/\psi} - \mu)$ in each Gaussian component of the Bremsstrahlung tail is caused by the Bremsstrahlung radiation of e^+ and e^- in the detector.

Backgrounds are fitted by polynomials with fitting parameters a_i (approximately normalized). The complete fit function for the J/ψ candidate sample is a combination of signals and background.

$$\begin{aligned} f^{(fit)}(m;m_{J/\psi},\sigma,c_\psi) = {} & c_\psi \left((1-c_{\text{tail}})\, g(m;m_{J/\psi},\sigma) + c_{\text{tail}} b(m;m_{J/\psi},\sigma)\right) \\ & + (1-c_\psi)\left(1 + a_1 m + a_2 m^2 + \cdots\right) \end{aligned} \tag{66}$$

where $m_{J/\psi}$, σ and c_ψ are free parameters to be determined by the real data. c_{tail} in Eq. (66) and Δm in Eq. (65) are prefixed by Monte Carlo data[78], with the results $c_{\text{tail}} = 0.375$ and $\Delta m = 5\text{MeV}$. The invariant mass spectrum of pion contamination and Bethe-Heitler e^+e^- pairs can be roughly treated as a uniform distribution plus a linear term.

Figure 39 shows the invariant mass distribution of the elastic and inelastic Bethe-Heitler events together with the the elastic $J/\psi \to e^+e^-$ candidates. The fitting results are summarized in Table 18. The number of Bethe-Heitler events are estimated from the theoretical cross section and the detector simulation. The number of pion pairs are estimated independently using a contamination level of $9 \pm 3\%$ in the mass peak region and $30 \pm 5\%$ outside the mass peak region. This is in good agreement with the ML fitting result.

An alternative method of the continuum background subtraction is the naive baseline subtraction(BS) method. In this method, the MC events and real candidates were divided into three invariant mass bins of equal width(for simplicity): the left(2.45-2.85GeV), the center(2.85-3.25GeV) and the right(3.25-3.65GeV) bins.

$$N_{\text{signal}} = N_{\text{center}} - 0.5\left(N_{\text{left}} + N_{\text{right}}\right) \tag{67}$$

$$\epsilon = \frac{N_{\text{signal}}}{N_{\text{generated}}} \tag{68}$$

Number of candidates	89
Number of J/ψ	52 ± 10
Number of Bethe-Heitler pairs	23 ± 5
Number of pion pairs	14 ± 4
$m_{J/\psi}$	$3.092 \pm .012$ GeV
σ	$.026 \pm .012$ GeV

Table 18: Numbers of J/ψ, Bethe-Heitler, and pion pairs in the J/ψ sample

Both methods assume that the invariant mass distribution of J/ψ is well reproduced by the Monte Carlo program. Cross sections determined by the two methods should agree if there were no systematic effects in the invariant mass reconstruction.

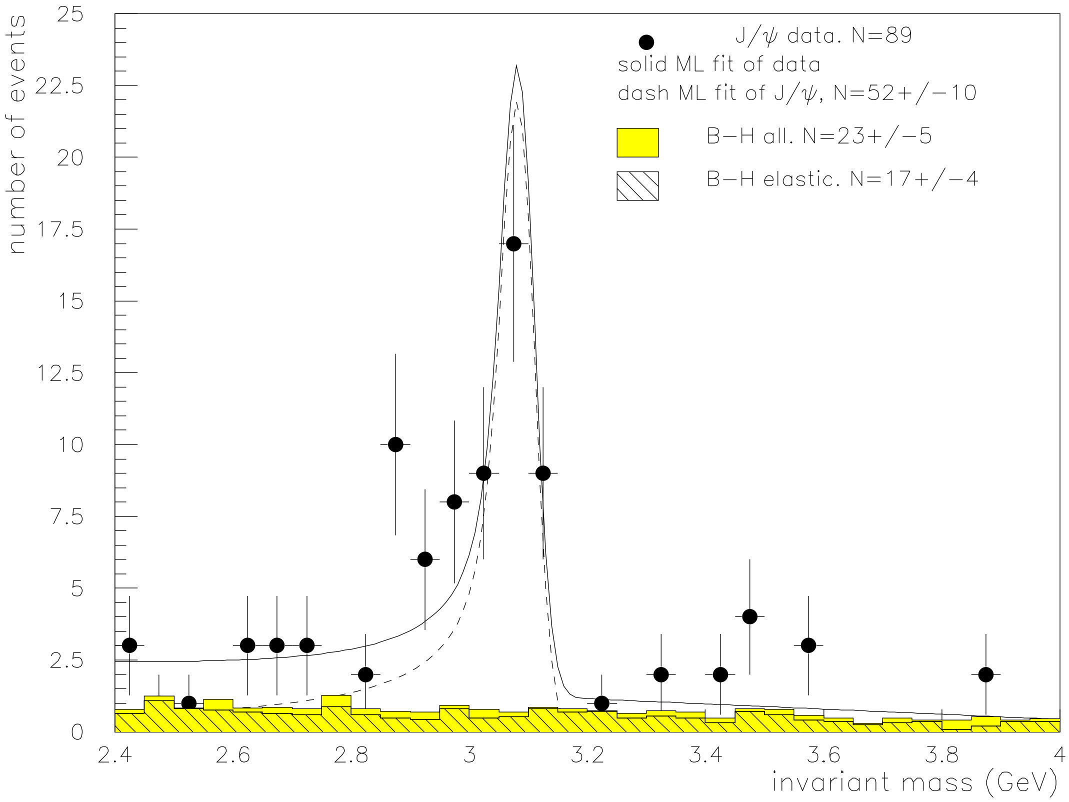

Figure 39: Invariant mass distribution of the elastic $J/\psi \to e^+e^-$ data($\bullet$) overlaid with Monte Carlo Bethe-Heitler background normalized to the data luminosity. The data is fitted by the maximum likelihood method with the function in Eq. (66). Dashed lines are fit curves of J/ψ(Gaussian and Bremsstrahlung tail). Solid lines include non-J/ψ(polynomials).

7.3 Resolution

Finite resolution in reconstructed kinematical variables can be a source of systematic errors. The interesting kinematic variables for elastic $J/\psi \to e^+e^-$ are $\sqrt{s_{\gamma p}}$, $t \approx p_t^2$ of J/ψ, and cosine of the lepton decay angle $\cos\theta_{\text{decay}}$. Rapidity of J/ψ, y_{rap}, is approximately proportional to $-\log s_{\gamma p}$.

All these variables were reconstructed using the CTD measurements of e^+e^- tracks.