The Descriptions of J/ψ Decay in Lund Area Law

Dai Yumei

July 12,2001

1. Motivation
2. J/ψ decay modes
3. The distributions of J/ψ decay
4. J/ψ decay pictures
5. Lund area law
6. Summary

Motivation

- The study of J/ψ decay is one of the most important subjects in BES physics.

- Lund generator JETSET implements a routine to simulate the heavy onia decay in following processes

  $e^+e^- \Rightarrow \gamma^* \Rightarrow 1^{--}\ Q\bar{Q}$ onia resonance $\Rightarrow$ (ggg or ggγ) $\Rightarrow$ shower $\Rightarrow$ hadrons.

  The flavors of $Q\bar{Q}$ are normally $b\bar{b}$ or $t\bar{t}$. The energy involved at J/ψ is too small to allow a separation into two or three jets. In other word, the mass of J/ψ is too far small for a jet language to be of any use.

- Lund area law and its generator LUARLW was proved to be reasonable between $2-5$ Gev by comparing with R scan data at BEPC/BES

- We are going to develop a new Monte Carlo packet which may simulate the J/ψ decay.

J/ψ decay modes

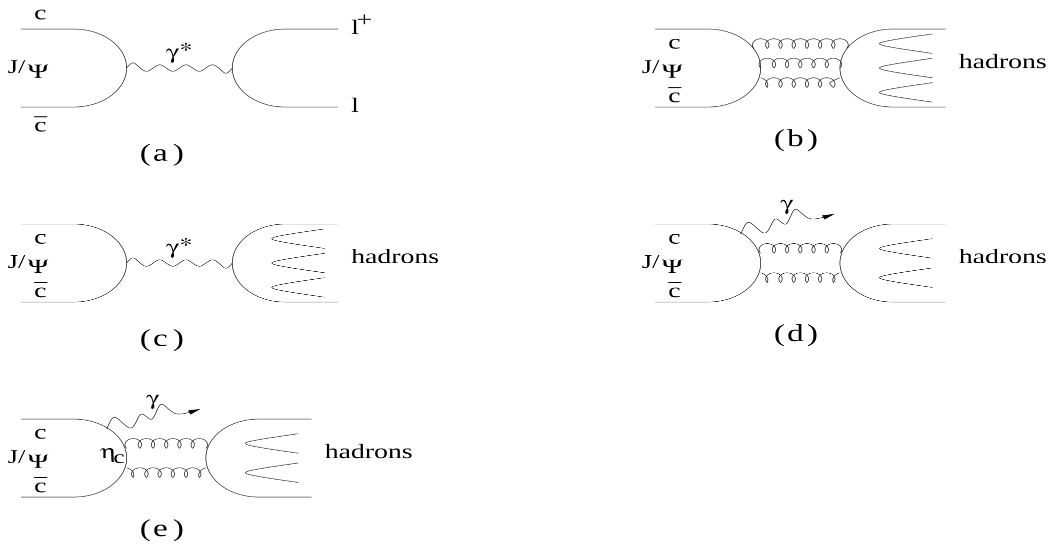


Figure 1: *J/ψ decay modes*

(a) lepton decay.

(b) hadronic decay.

(c) electromagnetic decay.

(d) radiative decay into hadrons.

(e) radiative decay transition to the η_c.

The distributions of J/ψ decay

The differential decay rate for $Q\bar{Q} \to ggg$ is

$$\frac{1}{\Gamma_{3g}} \frac{d\Gamma}{dx_1 dx_2 dR} = \frac{27}{8(\pi^2 - 9)}[\bar{\sigma}_U(1 + cos^2\beta) + 2\bar{\sigma}_L sin^2\beta + 2\bar{\sigma}_T sin^2\beta cos2\gamma - 2\bar{\sigma}_I sin^2\beta sin2\gamma], \quad (1)$$

The differential decay rate for $Q\bar{Q} \to \gamma gg$ is

$$\frac{1}{\Gamma_{\gamma gg}} \frac{d\Gamma}{dx_\gamma dcos\theta} = \frac{3}{4(\pi^2 - 9)}[\sigma_0(x_\gamma) + \sigma_1(x_\gamma)cos^2\theta], \quad (2)$$

The decay rates of J/ψ are calculated in perturbative QCD using the lowest order expression and first QCD corrections.

The decay width for the electromagnetic decay into leptons

$$\Gamma(J/\psi \to l^+l^-) = \frac{16}{3}\pi\alpha^2 e_c^2 N_c \frac{|\Psi(0)|^2}{M_{J/\psi}^2}(1 - \frac{16}{3}\frac{\alpha_s}{\pi}), \quad (3)$$

the electromagnetic decay width into hadrons

$$\Gamma(J/\psi \to q\bar{q}) = 3\sum e_q^2 \cdot \Gamma(J/\psi \to l^+l^-), \quad (4)$$

the decay width via the three gluons

$$\Gamma(J/\psi \to ggg) = \frac{40}{81}(\pi^2 - 9)\alpha_s^3 \frac{|\Psi(0)|^2}{m_c^2}(1 + \frac{49\alpha_s}{10\pi}), \quad (5)$$

the radiative width for γgg mode

$$\Gamma(J/\psi \to \gamma gg) = \frac{32}{9}(\pi^2 - 9)\alpha_s^2 \alpha e_c^2 \frac{|\Psi(0)|^2}{m_c^2}(1 - \frac{9\alpha_s}{10\pi}). \quad (6)$$

These decay widthes will be used as the weights in Monte Carlo to produce the corresponding decay events.

J/ψ decay pictures

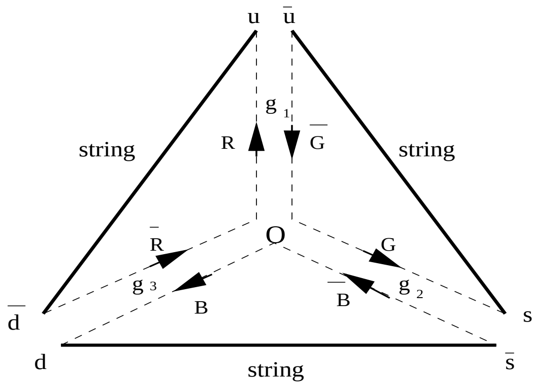


Figure 2: *An example of the color-current plot for three gluons string system and the the possible gluon split.*

- The gluon is flavorless and is always part of an overall color neutral system, which may be represented by a color and an anticolor line.
- Each gluon is split non-perturbatively into quark-antiquark pair. The flavor of the produced pair is taken be $u\bar{u}$, $d\bar{d}$ or $s\bar{s}$ with equal probability.
- A color singlet string is formed from each $q\bar{q}$ pair.

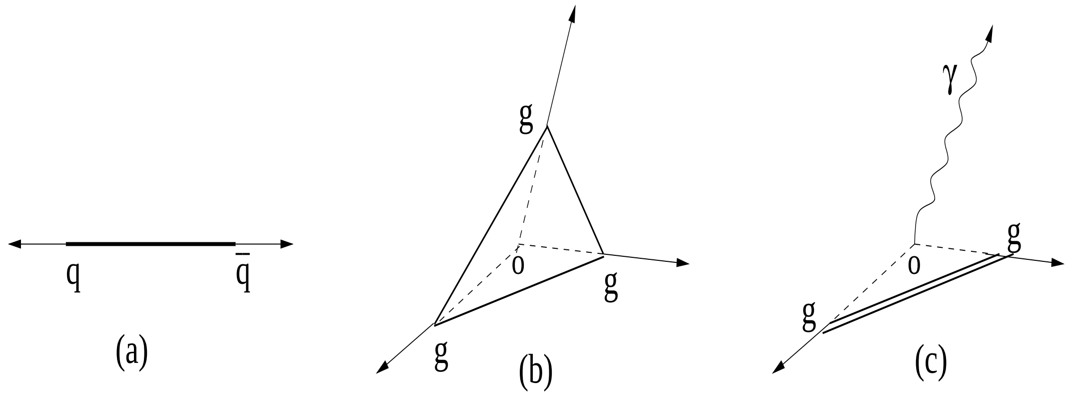


Figure 3: *The string figures of* $J/\psi \rightarrow hadrons$ *and* $\gamma+$ *hadrons. (a)the electromagnetic decay, (b) the hadronic decay, (c) the radiative decay into hadrons and the radiative M1 transition to* η_c.

- In string fragmentation language, the decay channel in Fig.(c) corresponds to a single string in Fig.3(a).

- A ggg state in Fig.(b) corresponds to a closed string triangle with the three gluons at the corners, see Fig.3(b).

- Sine the photon γ dose not take part in the fragmentation, the γgg state in Fig.(d) corresponds to a double string running between the two gluons, see Fig.3(c).

If the 4-momentums of the three gluons in states ggg are k_1, k_2 and k_3 respectively, then the 4-momentums of the three strings are

$$P_1 = \frac{1}{2}(k_2+k_3), \quad P_2 = \frac{1}{2}(k_3+k_1), \quad P_3 = \frac{1}{2}(k_1+k_2). \tag{7}$$

Similarly, if the 4-momentums of the two gluons and the photon in states $gg\gamma$ are k_1, k_2 and k_3 respectively, then the 4-momentums of the two strings are

$$P_1 = P_2 = \frac{1}{2}(k_1 + k_2). \tag{8}$$

The invariant masses of the strings are $s_i = P_i^2$.

Lund area law

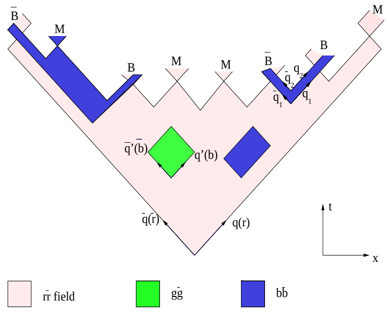


Figure 4: *String fragmentation in $t-x$ space. The produced new pairs $(q\bar{q})$ and $(q\bar{q}q\bar{q})$ may form mesons and baryons if they carry with the correct flavor quantum number, otherwise they just behave like the vacuum fluctuations and do not lead any observable effects in experiments.*

The string fragmentation in Lund model is Lorentz invariant and factorizationable. The exclusive probability for a string or a sub-string fragmenting into n-hadrons in its center of mass system may be written as the area law

$$d\wp_n = \delta^2(P - \sum_{j=1}^{n} p_{\circ j}) \prod_{j=1}^{n} d^2 p_{\circ j} \delta(p_{\circ j}^2 - m_{\perp j}^2) exp(-b\mathcal{A}_n). \tag{9}$$

Finishing the integral of area law, the exclusive distribution for producing just n particles has following form

$$d\wp_n(s, \mathcal{A}) = F_n(s, \mathcal{A}) d\mathcal{A}. \tag{10}$$

•String $\Rightarrow$ 2 hadrons

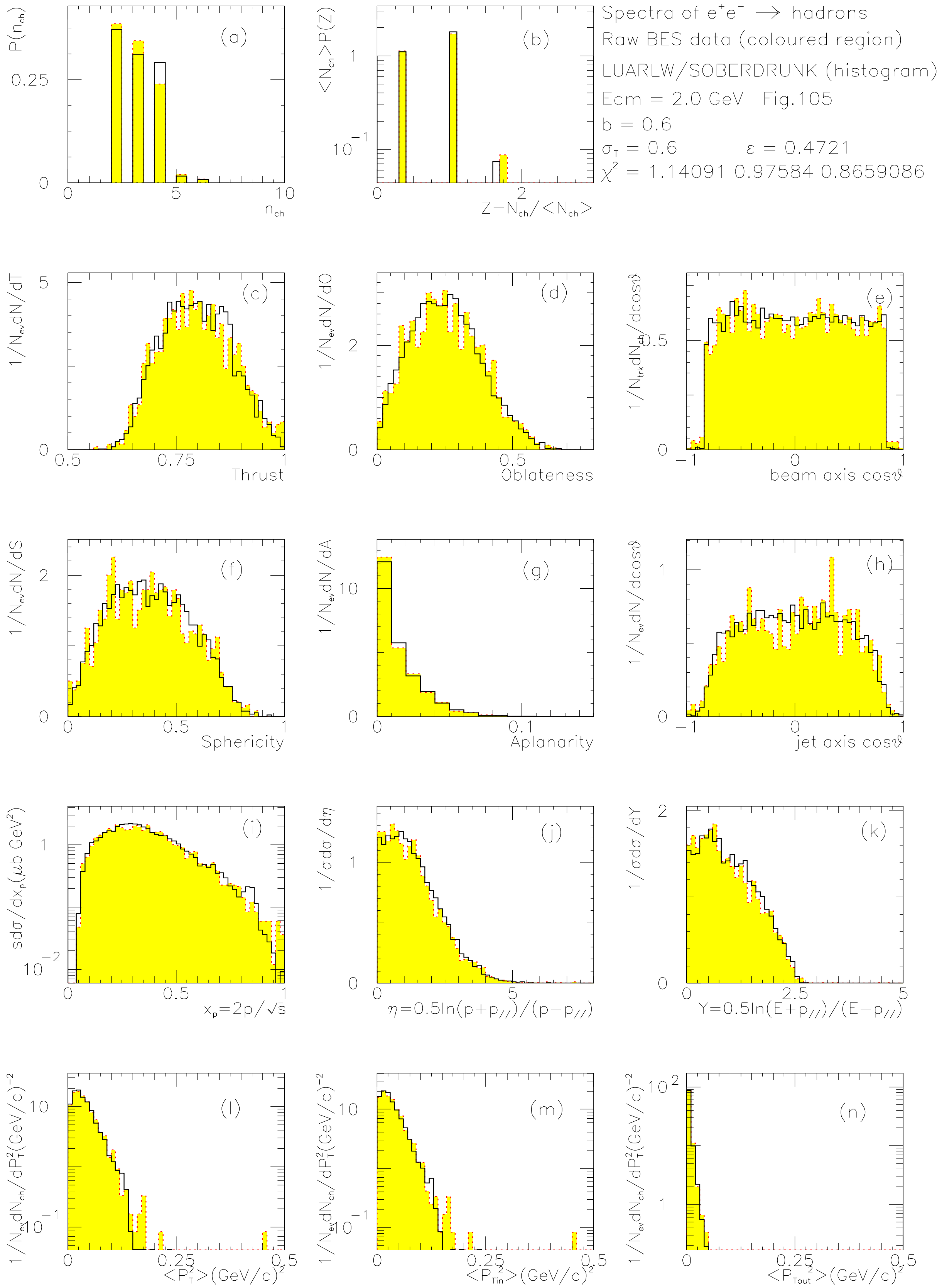
$$\wp_2 = \frac{C_2}{\sqrt{\lambda}} [exp(-b\mathcal{A}_2^{(1)}) + exp(-b\mathcal{A}_2^{(2)})]. \tag{11}$$

•String $\Rightarrow$ 3 hadrons

$$d\wp_3 = \frac{C_3}{\sqrt{\Lambda}} exp(-b\mathcal{A}_3) d\mathcal{A}_3, \tag{12}$$

•String $\Rightarrow$ $4, 5, 6$ hadrons

$$d\wp_n = \frac{ds_1 ds_2}{\sqrt{\lambda(s, s_1, s_2)}} \cdot exp(-b\Gamma) \wp_{n_1}(s_1, \mathcal{A}_1) \wp_{n_2}(s_2, \mathcal{A}_2) \tag{13}$$


Spectra of e+e- → hadrons
Raw BES data (coloured region)
LUARLW/SOBERDRUNK (histogram)
Ecm = 2.0 GeV Fig.105
b = 0.6
σT = 0.6 ε = 0.4721
χ2 = 1.14091 0.97584 0.8659086
(a) P(nch) nch
(b) <Nch>P(Z) Z=Nch/<Nch>
(c) 1/NevdN/dT Thrust
(d) 1/NevdN/dO Oblateness
(e) 1/NtrkdNch/dcosϑ beam axis cosϑ
(f) 1/NevdN/dS Sphericity
(g) 1/NevdN/dA Aplanarity
(h) 1/NevdN/dcosϑ jet axis cosϑ
(i) sdσ/dxp(μb GeV2) xp=2p/√s
(j) 1/σdσ/dη η=0.5ln(p+p//)/(p−p//)
(k) 1/σdσ/dY Y=0.5ln(E+p//)/(E−p//)
(l) 1/NevdNch/dP2T(GeV/c)−2 <P2T>(GeV/c)2
(m) 1/NevdNch/dP2T(GeV/c)−2 <P2Tin>(GeV/c)2
(n) 1/NevdNch/dP2T(GeV/c)−2 <P2Tout>(GeV/c)2

Summary

In this work, we try to apply the Lund area law to the processes of J/ψ, and give complete descriptions and calculations. Based on these, we are going to develop a new Monte Carlo packet which may simulate the processes of $e^+e^- \to$ continuum and resonant (finally including all ψ-family particles) hadronic states between $2-5$ GeV.