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Detecting Beauty Baryons and Heavy Beauty Mesons with the J/Ψ Trigger*

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ABSTRACT

We note that the combination of a vertex detector with a J/Ψ trigger should enable one to measure the masses and lifetimes of various beauty baryons and heavy beauty mesons at the SSC or Tevatron II.

It has been pointed out that the occurence of a J/Ψ decaying into $\mu^+\mu^-$ at a point displaced from the primary interaction vertex is an efficient trigger for beauty pair production[1]. The possibility of studying CP violating and other rare decay modes of beauty using this trigger at SSC has been discussed and an approved experiment, E771, will use this technique at Tev II in 1988. Hadrons containing the beauty quantum number are at present the only known source of long lived states decaying into J/Ψ. The average branching ratio of the lightest beauty mesons, B_u and B_d, into J/Ψ has been measured to be[2]

$$B(B_{u,d} \to J/\Psi + X) = (1.09 \pm 0.19 \pm 0.22)\% \qquad (1)$$

This result is in satisfactory agreement with theoretical expectations

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based on the spectator model[3] in which the b quark decays independently of the other quark in the B meson. We would thus expect the same branching ratio into $J/\Psi+X$ for most beauty hadrons. For $b\bar{c}$ mesons, the situation is more complex: (i) On the one hand this branching ratio is expected to be reduced by the lifetime ratio $\tau_D/(\tau_B+\tau_D)$ due to the possibility that the charm quark will decay before the b quark. This amounts to a reduction factor of roughly 3.5. (ii) On the other hand (almost) all B_c decays lead to a $c\bar{c}$ pair in the final state. The latter will hadronize mostly into D and $\bar{D}$ mesons. Yet sometimes a J/Ψ will emerge. Using either a quark level description for the inclusive rate or summing over $J/\Psi+\pi,\rho,A_1,D_s$ one estimates $\Gamma(B_c\to J/\Psi+X) = (5-8)\cdot\Gamma(B_d\to J/\Psi+X)$ and therefore

$$B(B_c\to\Psi+X) \approx 2\% \qquad (2)$$

The production ratios of various beauty states can be estimated by the rule of thumb based on studies of hadronization at lower energy that the probabilities to pull a strange quark, a di-quark, or a charm quark from the vacuum are roughly 1/3, 1/10, and 1/100 respectively.

In order to fully reconstruct a beauty state, we will need a totally charged exclusive final state with a reasonably large branching ratio. Although the vast majority of B decays involve neutral particles, nature has been kind in decreeing that, when a B decays into a J/Ψ, the remaining hadronic state is predominantly of low multiplicity. For example, in the case of $B_0\to J/\Psi+X$, roughly half of the decays have $X = K$ or K^*[2] .

$$B(B_d\to J/\Psi + K^*) = (0.37\pm0.16)\ B(B\to J/\Psi+X) \qquad (3)$$

$$B(B_d\to J/\Psi + K^{*0})B(K^{*0}\to K^+\pi^-) = (0.26\pm0.12)\ B(B_d\to J/\Psi+X) \qquad (4)$$

$$B(B_u\to J/\Psi + K^-) = (0.08\pm0.04)\ B(B_u\to J/\Psi+X) \qquad (5)$$

Apparently, the J/Ψ takes a sufficient amount of the initial state

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energy to ensure that the remaining hadrons are of low multiplicity. Based on this observation, we would expect the dominant J/Ψ +X final states of the B_s and B_c to be $J/\Psi + \Phi$ and $J/\Psi + \pi, \rho, A_1$ respectively. The Φ has a 50% branching ratio into K^+K^-. Thus it seems clear that the SSC will be able to identify and study these heavy beauty mesons. Similarly, we would expect the beauty baryons to decay into J/Ψ+X with X being, about 50% of the time, a hyperon or decuplet particle. A particularly clean decay chain results from the beauty baryon consisting of a b quark and an isotopic singlet combination of u and d quarks. One should be able to identify events of the form

$$\Lambda_b(\mathrm{bud}) \rightarrow J/\Psi + \Lambda \rightarrow J/\Psi + p + \pi^- \qquad (6)$$

The isosinglet Λ_b is forbidden to decay into $J/\Psi + \Lambda + \pi$ or $J/\Psi + \Sigma^*$ so that eq. 6 might be the dominant J/Ψ containing decay. The isovector combination would have the observable decay chain:

$$\Sigma_b(\mathrm{buu}) \rightarrow J/\Psi + \Sigma^{*+} \rightarrow J/\Psi + \Lambda + \pi^+ \rightarrow J/\Psi + p + \pi^- + \pi^+ \qquad (7)$$

The negatively charged Σ_b would have an analogous final state containing $p\pi^-\pi^-$. The strange beauty baryons (bds) and (bss) might also be accessible at Tev II and should certainly be evident at SSC. They would have the following prominent decay modes with a fair fraction of totally charged final states.

$$(\mathrm{bus}) \rightarrow J/\Psi \;\; \Xi^{*0} \rightarrow J/\Psi \;\; \Xi^- \;\; \pi^+ \rightarrow J/\Psi \;\; \Lambda\, \pi^- \;\; \pi^+ \rightarrow J/\Psi \;\; p\, \pi^- \, \pi^- \, \pi^+ \qquad (8)$$

$$(\mathrm{bss}) \rightarrow J/\Psi + \Omega^- \rightarrow J/\Psi\; \Lambda\; K^- \rightarrow J/\Psi\; p\, \pi^-\; K^- \qquad (9)$$

The charm-beauty baryon and the strange-charm-beauty baryon are probably just below threshold for visibility at Tev II but may be clearly identifiable at SSC. Possibly prominent decay chains might be

$$(bcd) \rightarrow J/\Psi + (scd) \rightarrow J/\Psi \ \Xi^- \pi^+ \rightarrow J/\Psi \ p \ \pi^- \pi^- \pi^+ \quad (10)$$

$$(bcs) \rightarrow J/\Psi + (css) \rightarrow J/\Psi \ \Omega^- \pi^+ \rightarrow J/\Psi \ p \ \pi^- K^- \pi^+ \quad (11)$$

In addition to determining masses and lifetimes of the charm-beauty baryons, the J/Ψ tag might yield the first observations of the strange-charm baryons in eq. 10 and 11.

Finally, at the SSC it might be possible to isolate the doubly charmed beauty baryon with the decay chain

$$(bcc) \rightarrow J/\Psi + (scc) \rightarrow J/\Psi + (css) + "W" \rightarrow J/\Psi + \Omega^- + "W" + "W" \quad (12)$$

"W" is used to denote an off-shell W decaying into totally charged final states such as π or A_1.

In table I we summarise the above considerations. We consider an experiment with the above mentioned separated J/Ψ trigger producing some number, N_0, of reconstructed $J/\Psi \rightarrow \mu^+ \mu^-$ from decay of $B_{u,d}$. N_0 has been estimated to be about $3 \cdot 10^7$ in a typical year-long run at SSC or about $3 \cdot 10^5$ in the similar experiment at Tev II. The production cross section of the $B_{u,d}$ is taken as σ_0.

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State	σ_{prod}	decay chain	No. of events
$b\bar{d}$	σ_0	$J/\Psi\ K^{*0} \to J/\Psi\ K^+\pi^-$	$0.3\ N_0$
$b\bar{s}$	$\sigma_0/3$	$J/\Psi\ \varphi \to J/\Psi\ K^+\ K^-$	$0.07\ N_0$
$b\bar{c}$	$10^{-2}\sigma_0$	$J/\Psi\ D^* \to J/\Psi$ + charged	$6\cdot10^{-3}N_0$
bdu I=0	$10^{-1}\sigma_0$	$J/\Psi\ \Lambda \to J/\Psi\ p\ \pi^-$	$0.03\ N_0$
bdd I=1	$10^{-1}\sigma_0$	$J/\Psi\ \Sigma^* \to J/\Psi\ p\ \pi^-\ \pi^-$	$0.03\ N_0$
buu I=1	$10^{-1}\sigma_0$	$J/\Psi\ \Sigma^* \to J/\Psi\ p\ \pi^-\ \pi^+$	$0.03\ N_0$
bus	$.03\ \sigma_0$	$J/\Psi\ \Xi^{*0} \to J/\Psi\ p\ \pi^-\pi^-\ \pi^+$	$7\cdot10^{-3}\ N_0$
bss	$.01\ \sigma_0$	$J/\Psi\ \Omega^- \to J/\Psi\ p\ \pi^-\ K^-$	$3\cdot10^{-3}\ N_0$
bcd	$10^{-3}\sigma_0$	$J/\Psi+(scd)\to J/\Psi+\Xi^-\pi^+$	$10^{-6}\ N_0$
bcs	$3\cdot10^{-4}\sigma_0$	$J/\Psi+(css)\to J/\Psi+\Omega^-\pi^+$	$10^{-6}\ N_0$
bcc	$10^{-5}\sigma_0$	$J/\Psi+(ccs)\to J/\Psi+(css)+\pi^+ \to J/\Psi+\Omega^-+\pi^++\pi^+$	$10^{-8}\ N_0$

Table I. Estimates of production cross sections of beauty hadrons relative to that of the lightest beauty meson and number of observed events with totally charged final states containing a J/Ψ relative to the number N_0 of observed $J/\Psi + X$ decays of the lightest beauty meson. N_0 may be of order of 10^8 per year in a suitable experiment at the SSC.

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