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B Physics Working Group Summary

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B PHYSICS WORKING GROUP SUMMARY

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ABSTRACT

Calculations of the B_c spectrum of energy levels, transitions between levels, and weak decays of the ground state, as well as their production and observation at hadron colliders, are summarized. Also, recent experimental B Physics results from the CDF and DØ Tevatron experiments are reviewed and future prospects are discussed.

1. Introduction

Jeff Appel opened the B Physics working group sessions by emphasizing the need in the physics community to focus our efforts. It is timely to attempt to identify a single, major objective in the area of B Physics and to direct our efforts towards achieving a specific goal, perhaps in the area of CP nonconservation in B decays. Clearly, this will require considerable cooperation among physicists, laboratories, and funding agencies, all of which are essential for the future of the field. Some other possible areas of concentration are $B^{\circ} - \overline{B}^{\circ}$ mixing and rare B decays. Hopefully, this greater focus can be achieved at the Workshop on B Physics at Hadron Accelerators in Snowmass this summer.

In the context of this workshop it would be impossible to systematically cover the rich phenomenology of B physics in a few hours. Thus, the conveners chose to concentrate on a few selected topics of current interest. As the B_s meson has recently been observed both at LEP and at the Tevatron, it seemed appropriate to discuss the next meson, namely the B_c. Both CDF and DØ were asked to highlight recent B Physics results from the very successful recent run Ia at the Tevatron Collider. Upgrades of these experiments for Tevatron runs Ib and II were also discussed.

2. Theory

The novel hadronic states with both charm and beauty provide very interesting systems to explore. The B_c mesons are especially attractive theoretically since both quarks are heavy and reasonably reliable calculations are possible. In a sense, the B_c system is the "hydrogen atom" of meson spectroscopy. Estia Eichten presented results obtained in collaboration with Chris Quigg on the B_c meson spectrum of energy levels, the transitions

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between these states, the weak decays of the ground state, and the prospects for experimental observation of the B_c meson.[1] Kingman Cheung then presented calculations of the production cross section for the B_c meson through fragmentation.[2]

Using the Buchmuller-Tye potential with parameters fit to the $c\bar{c}$ and $b\bar{b}$ systems Eichten and Quigg calculated the B_c meson spectrum, which is shown in Fig. 1. The predicted ^1S_o ground state mass is $M(B_c) = 6.258 \pm 0.020$ GeV/c^2 and the hyperfine splitting is

$$M(B_c^*) - M(B_c) = 73 \pm 5 \text{ MeV}/c^2$$

Errors were estimated by using alternative potentials which have also been used to fit to the $c\bar{c}$ and $b\bar{b}$ spectra. Another source of uncertainty in these results is the values of the quark masses one assumes. In Fig. 1 the values $M_c = 1.48$ GeV/c^2 and $M_b = 4.88$ Gev/c^2 were chosen. The BD threshold is indicated in Fig. 1 and lies in the region of the 3P states. Certainly, the 3D states are bound, while the 3S states are not.

The prominent transitions between these states are electromagnetic and hadronic. Both electromagnetic E1 and M1 transitions occur as do hadronic transitions with the emission of an S-wave pion pair.

The B_c ground state will decay weakly through one of three possible processes: b quark decay, c quark decay, and $\bar{b}c$ annihilation. The branching fractions were calculated assuming these quark processes occur with the initial quarks bound in the Buchmuller-Tye potential. The binding energy is significant and has an important effect on the decay rates, as does the values of the quark masses. In Table I the branching fractions for various channels are shown for both current and constituent quark masses.

Table I. Branching Fractions for B_c Semi-Inclusive Weak Decays

Decay Channel	Current Quarks	Constituent Quarks
$(c\bar{c})e\nu_e$	8.9%	9.9%
$(c\bar{c})\mu\nu_\mu$	8.8	9.9
$(c\bar{c})\tau\nu_\tau$	1.7	1.9
$(c\bar{c})\bar{u}d$	26.6	27.1
$(c\bar{c})\bar{c}s$	10.2	7.7
$(s\bar{b})e\nu_e$	3.9	4.3
$(s\bar{b})\mu\nu_\mu$	3.5	4.0
$(s\bar{b})\bar{u}d$	11.6	2.3
$\tau\nu_\tau$	8.6	9.7
$s\bar{c}$	16.2	23.2

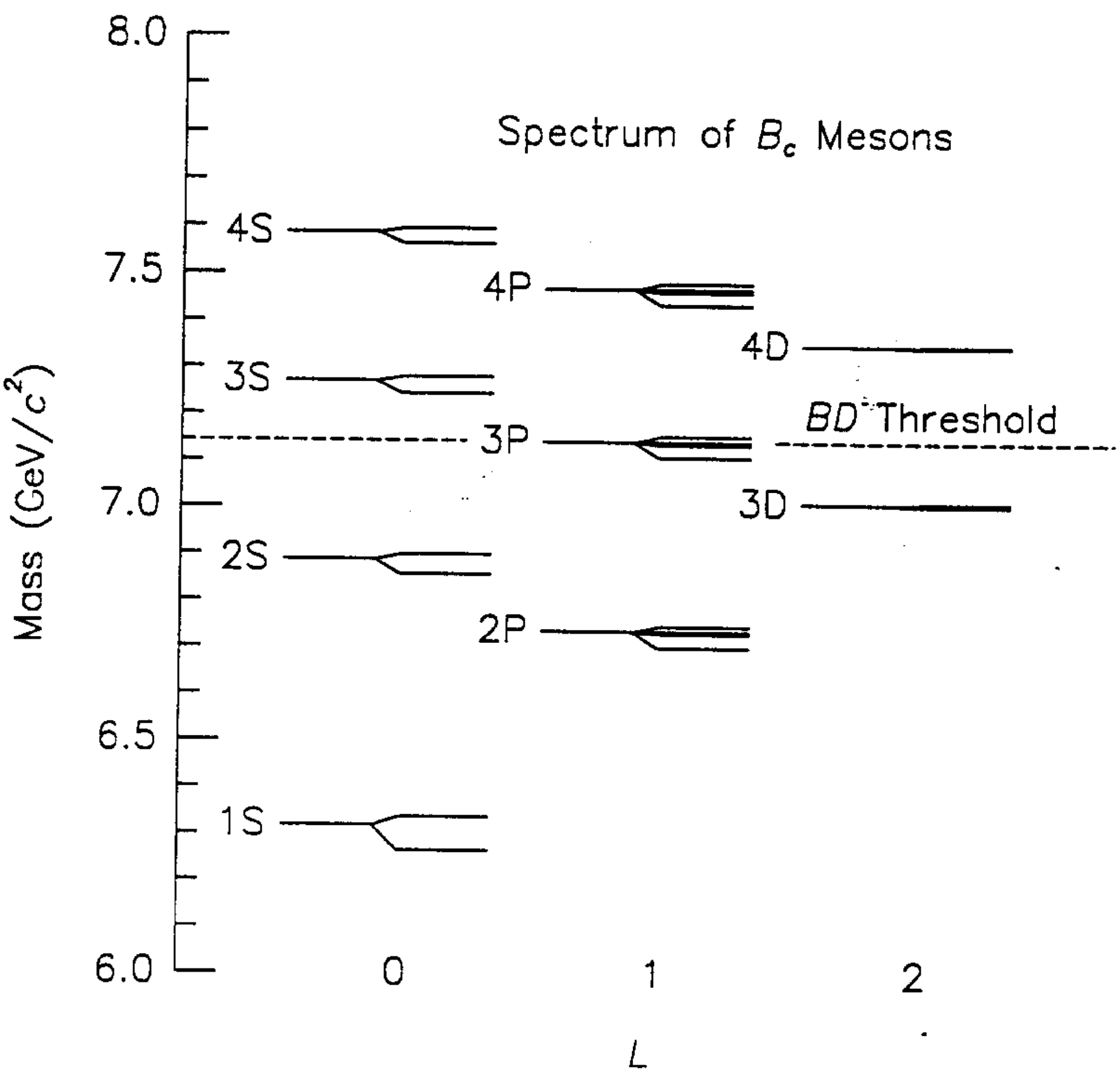

Fig. 1. The energy level spectrum of the $\overline{b}c$ meson system.

There are several nice signals for observing the B_c at the Tevatron, which include the following:

$$B_c \to \pi^+ + J/\psi \quad (\hookrightarrow \ell^+ + \ell^-) \qquad (\text{B.R.} \simeq 0.4\%)$$

$$B_c \to J/\psi \,(\hookrightarrow \ell^+ + \ell^-) + D_s^* \,(\hookrightarrow \gamma + \pi + \phi,\ \phi \hookrightarrow K^+ + K^-) \qquad (\text{B.R.} \simeq 5\%)$$

$$B_c \to \tau + \nu_\tau \qquad (\text{B.R.} \simeq 8\%)$$

The combined brancing ratios for the first two processes are, respectively, about 0.4% x 7% $\simeq 3 \times 10^{-4}$ and 5% x 100% x 2.7% x 50% x 6.9% $\simeq 5 \times 10^{-5}$. One can expect about 10^7 B_c's will be produced in a 100 pb^{-1} run assuming $\sigma(B_c)/\sigma(\bar{b}b) \simeq 10^{-3}$. Further assuming an efficiency of about 1% one can expect about 30 $B_c \to \pi^+ \psi$ events, about 5 $B_c \to D_s^* \psi$ events. There is also some hope that $B_c \to \tau \nu_\tau$ would be seen in such a data sample.

The production of the B_c system at the Tevatron is expected to be dominated by heavy quark fragmentation. Kingman Cheung[2] has calculated the distribution in transverse momentum, P_T, in terms of the parton distribution functions, $f_i(x)$, the parton cross section $d\hat{\sigma}(ij \to \bar{b}X)$, and the fragmentation function $D(z,\mu)$:

$$d\sigma(B_c(P_T)) = \sum_{i,j} \int dx_1 f_{i/p}(x_1) \int dx_2 f_{j/p}(x_2) \int_0^1 dz\, d\hat{\sigma}(ij \to \bar{b}(P_T / z)\ X) D_{\bar{b}\to B_c}(z,\mu)$$

Here the subprocesses are $gg \to b\bar{b}$, $g\bar{b} \to g\bar{b}$, and $q\bar{q} \to b\bar{b}$ and μ is the factorization scale between the hard subprocesses and the soft fragmentation. These leading order calculations indicate it is, indeed, reasonable to expect 10^7 B_c's in a 100 pb^{-1} Tevatron run. At the SSC, of course, the cross section is considerably larger and the P_T spectrum is much harder.

3. B Physics at DØ

In the recent Tevatron run Ia the DØ detector performed very well, as was reported by Kamel Bazizi. B Physics objectives included measuring the total b cross section, the direct J/ψ and Υ production cross sections, and $B^\circ - \bar{B}^\circ$ mixing. Both inclusive single muons and dimuons were measured. The inclusive muon cross section $d\sigma/dP_T d\eta$ for the process $P\bar{P} \to b\bar{b} \to \mu X$ was measured over the range $6 < P_T < 22$ GeV/c and $|\eta| < 1.0$ and the results agree very well with the ISAJET next-to-leading order calculations.

The DØ experiment was successful in isolating dimuon events from jets by requiring $\Delta R(\text{jet-}\mu) > 0.7$ for both muons. The opposite sign dimuon distribution showed prominent signals at the J/ψ and Υ masses, while for the same sign dimuons the signal was absent, as expected. Dimuons where at least one muon was not isolated from a jet $(\Delta R(\text{jet} - \mu) < 0.7)$ were also measured. For these non-isolated dimuons the opposite sign pairs also showed the J/ψ signal, while the Y was not apparent. Of course, the same sign dimuons showed no signal.

The inclusive J/ψ cross section $P\overline{P} \to b\overline{b} \to J/\psi(\to\mu\mu)X$ has been measured out to $P_T = 20$ GeV/c. Preliminary results for $d\sigma/dP_T dy$ agree reasonably well with previous CDF data, which went only to $P_T = 14$ GeV/c, but the theoretical calculations still fall somewhat below both data sets. The B production cross section remains an unresolved issue needing to be addressed both experimentally and theoretically.

The DØ experiment was successful in measuring $B^\circ - \overline{B}^\circ$ mixing by observing the dimuon channel. Comparing same sign and opposite sign dimuons gave the preliminary result

$$R = [N(\mu^+\mu^+)+N(\mu^-\mu^-)]/N(\mu^+\mu^-) = 0.43 \pm 0.10$$

From this value of R the mixing parameter χ was determined to be

$$\chi = f_d\,\chi_d + f_s\,\chi_s = 0.21 \pm\ 0.05\ (\text{stat}) \pm\ 0.05\ (\text{syst})$$

in agreement with previous CDF and UA1 results.

These preliminary results on the inclusive muon cross section, J/ψ production, and $B^\circ - \overline{B}^\circ$ mixing demonstrate clearly that DØ performed very well in its "maiden" Tevatron run. There was good efficiency for b tagging, low decay and punchthrough problems, and full coverage in the η region expected. With further analysis the η region will be extended, the b cross section measurement improved, and, hopefully, the gluon distribution at small x will at least be constrained.

4. B Physics at CDF

Preliminary results from CDF based on about 50% of Tevatron run Ia ($12 pb^{-1}$) were presented by William Wester. A sample of about 42,000 J/ψ's have been accummulated in the dimuon channel. CDF has also been quite successful in identifying charged kaons, allowing the following B decays to be reconstructed:

$B_u^+ \to J/\psi + K^+$ (80 ± 11 events)

$B_d^o \to J/\psi + K^{*o}$, $K^{*o} \hookrightarrow K^\pm + \pi^\mp$ (44 ± 9 events)

$B_s^o \to J/\psi + \phi$, $\phi \hookrightarrow K^+ + K^-$ (14.0 ± 4.7 events)

The B masses were determined to be

$$M\,(B_u) = 5278.2 \pm\ 2.6\ \text{MeV/c}^2$$
$$M\,(B_d) = 5279.6 \pm\ 2.9\ \text{MeV/c}^2$$

and

$M(B_s) = 5383.3 \pm 4.5$ MeV/c^2

These B_u and B_d masses are in excellent agreement with the Particle Data Group[3] values. This is the first time the B_S has been identified in hadron collider data and the mass agrees well with the preliminary value from LEP, $M(B_S) = 5375 \pm 8 \pm 5$ MeV/c^2, also reported at this workshop.[4]

Barry Wicklund stressed how very well the silicon vertex detector (SVX) performed in the CDF experiment during the recent Tevatron run Ia. In analyzing the $B^+ \to J/\psi + K^+$ events it was shown that making the cut $c\tau > 100$ μm improves the signal/background very substantially. Even more impressive is how the SVX allows the prompt J/ψ events to be separated from the $B^\pm \to J/\psi + K^\pm$ events. The J/ψ events in the sideband ($J/\psi + K$ events outside the B mass region) very clearly are centered around $c\tau = o$, allowing prompt J/ψ's to be subtracted from the signal, and thus permitting a measurement of the B lifetime. Improved tracking also enabled CDF to reconstruct the decay $B \to J/\psi + K_S$ as John Skarka[5] reported. The additional requirement that the $K_S \to \pi^+\pi^-$ vertex point to the $J/\psi \to \mu^+\mu^-$ vertex was essential.

5. CDF AND DØ Upgrades

John Skarha[5] also emphasized the importance of improvements in vertex detection in the planned CDF upgrade. The coverage in η will be extended significantly in the upgraded silicon vertex detector (SVX II), which will be about 1 m in length.

Ron Lipton's[6] discussion of the planned DØ upgrade emphasized improvements in data acquisition and trigger paths. With an upgraded Tevatron luminosity of 5×10^{31} $cm^{-2}s^{-1}$ one hopes to acquire muon triggers at a rate of a few kHz, as compared to a few Hz in present detectors.

6. Acknowledgements

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