Fermi National Accelerator Laboratory

E789 and P865: High-Rate Fixed-Target Studies of Charm and Beauty

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E789 AND P865: HIGH-RATE FIXED-TARGET STUDIES
OF CHARM AND BEAUTY

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Abstract

Experiment 789 at Fermilab used the high-rate E605/E772 spectrometer to study low-multiplicity charm and beauty decays. Preliminary results on charm and beauty production are presented based on analysis of $\approx 100\%$ of the charm data and $\approx 50\%$ of the beauty data. A new experiment is proposed to improve charm and beauty sensitivity by several orders of magnitude.

1. Description of E789

Experiment 789 studied charm and beauty production in 800-GeV pN collisions using the high-rate E605/E772 spectrometer (Figure 1) in Fermilab's Meson-East laboratory, upgraded with a 16-plane silicon-microstrip array and a vertex trigger processor [1]. Beam of intensity $\approx (1-6) \times 10^{10}$ protons per 20s spill was incident on thin wire targets 0.1 – 0.2 mm high and 0.8 – 3 mm thick. For the charm data the SM12 analyzing magnet was operated at 900 or 1000 amperes, and Au and Be targets were used to study the A-dependence of D production. For the beauty data a 3-mm-thick Au target was used and the SM12 current was 1500 amperes, optimizing acceptance for the J/ψ while simultaneously accepting direct two-prong B^0 decays. (Insufficient running time was available for a dedicated $B^0 \rightarrow$ dihadron run.) In the 1991 run, 4×10^8 (9×10^8) events were recorded on 240 (770) 8-mm tapes during the charm (beauty) running periods. Typical interaction rates were ≈ 2 MHz in the charm mode and ≈ 50 MHz in the beauty mode.

The silicon detectors were arrayed from 40 – 115 cm downstream of the target in two arms covering the angular ranges $\pm(20-60)$ mr above and below the beam axis. The detectors, type "B" from Micron Semiconductor, were of 5×5 cm^2 area, 300 μm thickness, and 50 μm pitch. In each arm, planes measuring the bend (y-z) view alternated with planes at $\pm 5°$ stereo angles. Signals from 8,544 strips were individually read out via Fermilab 128-channel amplifier cards [2] and LBL discriminators [3] synchronized to the accelerator RF. The discriminated signals were transmitted through ≈ 400 ns of multiconductor cable to coincidence registers.
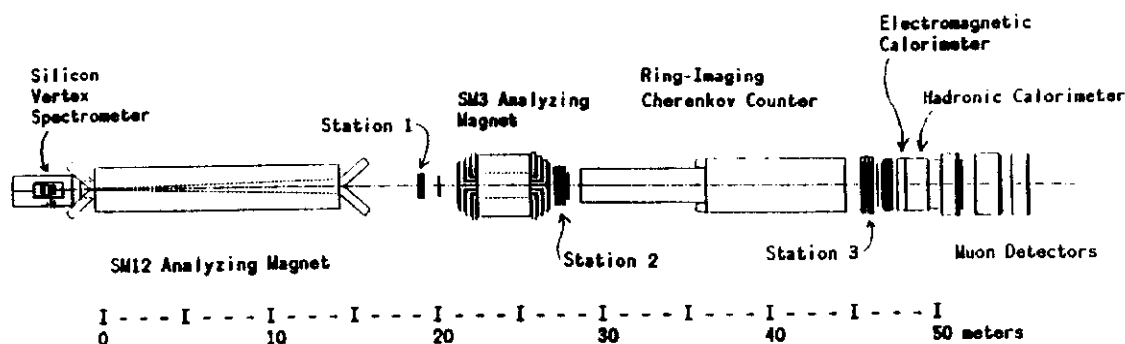
Figure 1: E789 apparatus (plan view).

The vertex processor [1], which found tracks in the bend-view drift chambers and silicon detectors and selected events with candidate decay vertices downstream of the target, was used in the charm running and provided a rejection factor of ≈ 10 against non-charm events with charm efficiency of $\approx (50-60)\%$ (caused primarily by silicon-plane inefficiencies) for decays outside the target. The thin target localized the primary interaction vertex, simplifying the design of the processor, which needed only to determine the position of the decay vertex.

2. Preliminary Results from E789

Figure 2 shows dihadron invariant mass spectra from the charm data sample for various lifetime cuts. Cherenkov π/K particle identification has not been used in this analysis, as the RICH was not optimized for the low momenta characteristic of charm decays. Rather, each plot contains two entries per event, one for the $\pi^+ K^-$ and the other for the $\pi^- K^+$ particle assignments. The correct particle assignments give a sharp peak ($\sigma \approx 6$ MeV), corresponding to either the D^0 or $\overline{D^0}$. The wrong particle assignments give a much broader peak ($\sigma \approx 50$ MeV). A limit on possible $D - \overline{D}$ production-rate asymmetry can be derived from the numbers of D^0 and $\overline{D^0}$ observed. At the 10% level, no significant asymmetry is observed (or expected) at the $x_F \approx 0.05$ characterizing these data. Our preliminary D cross section is consistent with previous measurements reported by E653 [4] and E743 [5]. The systematics of the A-dependence and normalization are still under study.

Figure 3a shows the invariant mass spectrum from a preliminary analysis of $\approx 50\%$ of the beauty dimuon data sample. Figure 3b shows the spectrum of events in which both tracks have impact parameters at the target center greater than $150\,\mu$m and the pair vertex satisfies $0.7 < z_{\text{vertex}} < 5$ cm, indicating a decay downstream of the target. In the J/ψ mass region, 22 events satisfy these requirements. To

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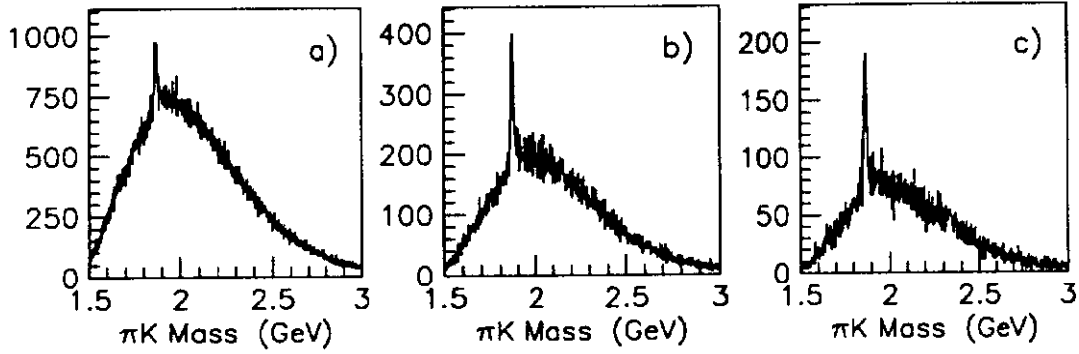
Figure 2: Dihadron invariant mass spectra from the charm data sample for three lifetime cuts: a) $\tau/\sigma_\tau > 3.9$, b) $\tau/\sigma_\tau > 6$, c) $\tau/\sigma_\tau > 7.9$.

estimate background due to tails of the target distribution (arising from possible vertex tracking errors or large Coulomb scatters in the silicon planes), we also study events with reconstructed vertices upstream of the target (Figure 3c). No upstream events are observed near the J/ψ region, supporting the likely beauty origin of the downstream J/ψ events. There is also a significant excess of continuum events in the downstream sample, attributed to semileptonic decays of $b\bar{b}$ pairs.

Figure 3: Dimuon invariant mass spectra from the beauty data sample: a) all events, b) $0.7 < z_{\text{vertex}} < 5\,\text{cm}$, c) $-5 < z_{\text{vertex}} < -0.7\,\text{cm}$.

3. Proposal 865

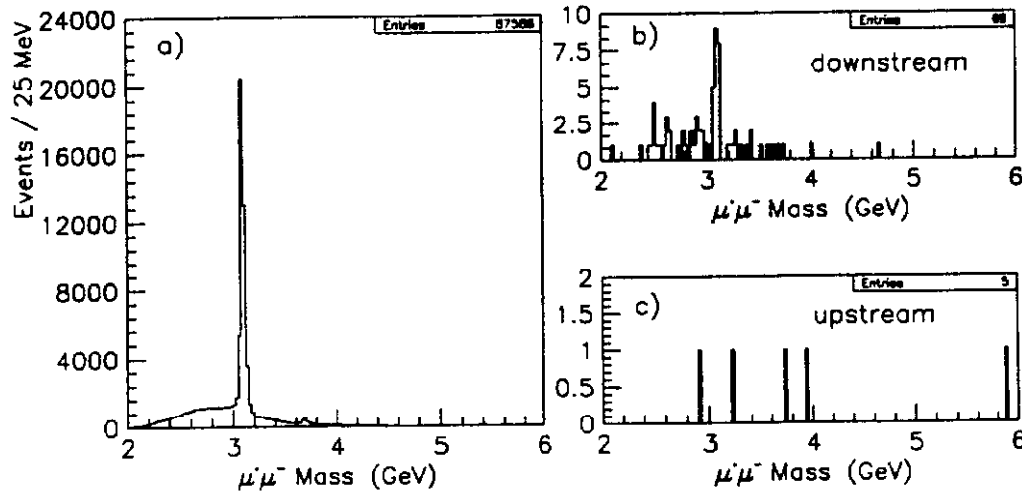The sensitivity of E789 is limited primarily by its small acceptance ($\lesssim 10\%$ per prong). We have proposed a new apparatus [6] (Figure 4) which retains the high interaction-rate capability of E789 while achieving acceptance of $\approx 70\%$ per prong. This allows studies of charm at the level of 10^{11} produced and $10^7 - 10^8$ fully reconstructed events, and of beauty at the level of 10^8 produced and 10^4 fully reconstructed events, giving access to such physics as $b \to s\gamma$ transitions, B_s mixing, beauty semileptonic form factors, doubly-Cabibbo-suppressed charm decays, semileptonic D_s and charmed-baryon decays, and D^0 mixing and CP violation.
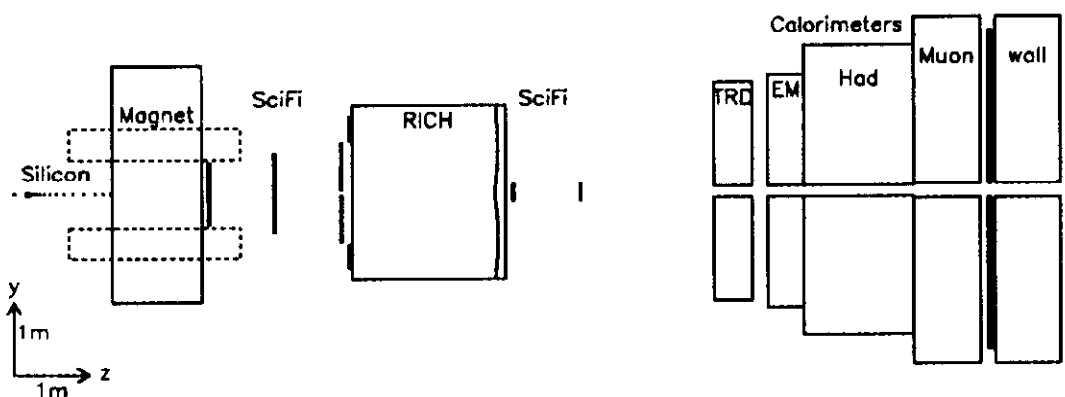

Figure 4: P865 apparatus (elevation).

A significant sensitivity limit is posed by radiation damage in the silicon detectors. To configure detectors which can survive at the desired sensitivity, we choose suitable maximum and (in one view) minimum angles for the instrumented aperture, arranging the silicon detectors along the beam axis with a small gap through which pass the uninteracted beam and secondaries below the minimum angle (Figure 5). Thus the rate is spread approximately equally over several silicon planes, with large-angle secondaries measured close to the target and small-angle secondaries farther downstream. Along the beam axis the spacing of detectors increases approximately geometrically, making the lever arm for vertex reconstruction independent of production angle. The instrumented angular range is $|\theta_x| \leq 200\,\text{mr}$, $8 \leq \theta_y \leq 150\,\text{mr}$, corresponding to the rapidity range $|y| \lesssim 1.5$. To maximize the rate capability of the spectrometer, the tracking is performed entirely with silicon and scintillating-fiber planes.

The scintillating fibers are read out using the solid-state "visible-light photon counters" (VLPCs) under development by a collaboration among Fermilab, UCLA,

4

Optical   Silicon
trigger

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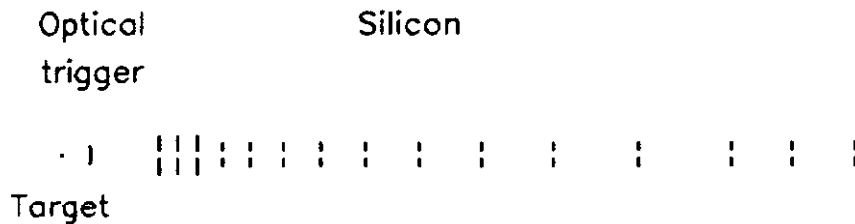 || | : : : : : : : : : : : :
Target

Figure 5: Detail of P865 vertex region.

and Rockwell International Science Center [7]. VLPCs are also key to the pro-
posed Cherenkov-based optical impact-parameter trigger [8] and fast ring-imaging
Cherenkov counter [9]. VLPCs are highly suitable for these applications due to their
high quantum efficiency, low noise, and high speed. Quantum efficiency as high as
85% for green light has been achieved [10], and 30-MHz rate capability has been
demonstrated, with single-electron noise rates of several kHz [11].

In addition to the Level-1 optical trigger, other triggering strategies appear
promising. These include calorimetric E_t and high-p_t-lepton requirements and a trig-
ger processor to reconstruct vertices and invariant masses. At each trigger level, just
enough rejection should be provided to meet the input bandwidth of the succeeding
level, so as to trigger on charm and beauty as efficiently as possible without restrict-
ing attention only to modes with final-state leptons. High-bandwidth data-recording
technology and inexpensive workstations now or soon-to-be available should make
feasible a recorded sample of $\sim 10^{11}$ events, key to the desired charm sensitivity.

P865 seeks to study the physics described above within the next few years, then
upgrade the apparatus for a sensitive study of B CP violation by decade's end. This
might be accomplished by increasing the interaction rate a factor ≈ 10, employing
(for example) radiation-hardened silicon pixel detectors to cope with the increased
event complexity and radiation dose. Alternatively, the beauty production cross
section might be increased by moving to a higher-$\sqrt{s}$ interaction region. A promising
idea under study [12] is to arrange collisions between a high-energy proton beam
in the Tevatron, SPS, or HERA proton ring and a lower-energy beam, for example
by storing protons in the HERA electron ring or constructing a small, inexpensive
storage ring adjacent to the Tevatron or SPS. At $\sqrt{s} \approx (150-200)$ GeV, this scheme
can provide a factor ≈ 100 increase in beauty cross section while retaining sufficient
Lorentz boost to ease triggering, particle identification, and coverage of a large
acceptance.

4. Summary

Experiment 789 explores the feasibility of studying beauty and charm physics in a high-rate fixed-target environment. Over 3000 neutral $D \rightarrow \pi K$ events have been observed from Au and Be targets. A preliminary analysis of $\approx 50\%$ of the dimuon beauty data yields 22 J/ψ events with decay vertices more than 7 mm downstream of the target; these are candidate $b \rightarrow J/\psi + X$ decays. Analysis is underway to determine $\sigma(b\bar{b})$ at 800 GeV. Analysis of the dihadron beauty data and $J/\psi \rightarrow e^+e^-$ data is also in progress. A new experiment, P865, has been proposed as the next step in charm and beauty sensitivity, with the ultimate goal of studying CP violation in beauty decays.

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