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CHARM PHYSICS AT FERMILAB E791

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ABSTRACT

Experiment 791 at Fermilab's Tagged Photon Laboratory has just accumulated a high statistics charm sample by recording 20 billion events on 24000 8mm tapes. A 500 GeV/c π^- beam was used with a fixed target and a magnetic spectrometer which now includes 23 silicon microstrip planes for vertex reconstruction. A new data acquisition system read out 9000 events/sec during the part of the Tevatron cycle that delivered beam. Digitization and readout took 50 μS per event. Data was buffered in eight large FIFO memories to allow continuous event building and continuous tape writing to a wall of 42 Exabytes at 9.6 MB/sec. The 50 terabytes of data buffered to tape is now being filtered on RISC CPUs. Preliminary results show $D^0 \to K^-\pi^+$ and $D^+ \to K^-\pi^+\pi^+$ decays. Rarer decays will be pursued.

INTRODUCTION

In the E791 proposal to Fermilab, we presented a plan to collect and fully reconstruct a minimum of 100,000 mesons and baryons containing a charm quark. A primary motivation for this experiment is to search for rare charm decays that probe the standard model. This was the fourth in a series of charm experiments at the Tagged Photon Laboratory (TPL) with the same underlying spectrometer: E516[1], E691[2], E769[3], and now E791. With the exception of E516, we have used an open, unsophisticated trigger and have seen large numbers of charm particles by recording and reconstructing large numbers of events. Mesons and baryons with a charm quark are characterized by a high mass and a decay length of a few millimeters to a couple of centimeters. These two characteristics are difficult, expensive, and risky to trigger on. A similar problem exists for a large fraction of beauty decays at hadron colliders. At the time of the 791 proposal, three developments made it possible to continue the conservative TPL philosophy of an open trigger. New fast front ends made it possible to digitize and read out events in tens of micro–seconds. Exabyte tape drives and 8mm tapes made it possible to store and handle large amounts of data at a reasonable cost. RISC CPU chips, such as the MIPS R3000 and its rapidly improving cousins, made it possible to keep the offline computing budget below a quarter of the total E769 $\rightarrow$ E791 upgrade cost.

BEAM CHOICE, TRIGGER, TARGET DISCS, AND BEAM TRACKING

At the Tagged Photon Lab we now use pions rather than photons. High energy photons produce more charm per hadronic interaction than pions, but it is just not possible to get enough photons. We chose to use pions rather than protons because pions have a stiffer gluon distribution for a given momentum. Charm is primarily produced by gluon–gluon fusion. We doubled the E769 beam momentum of 250 to 500 GeV/c for E791 because this is estimated to increase the charm cross section by 80% and to triple the miniscule beauty cross section [4]. The beam was negative; a π^+ beam would have been heavily contaminated with protons.

A loose E_T trigger was used to enrich charm and reduce the raw interaction trigger rate. Energy was measured in electromagnetic and hadronic calorimeters [5]. Events were rejected if two beam particles in coincidence might fake an E_T trigger. The beam rate was 2 MHz.

The target consists of five parts, one 0.5mm thick platinum disk followed by four 1.6mm thick diamond disks. Fig. 1 shows the z positions of the disks as determined by primary vertices found by our Silicon Microvertex Detector (SMD). The thinness of the disks provides a strong constraint on the z position of a primary vertex and the air gaps in between provide volumes for reconstructing secondary vertices uncontaminated by secondary interactions. Dense materials ($\rho = 21.4$ and 3.3 g/cc) were chosen to allow thin targets which would still cause 2 % of the incident pions to interact. Thin targets also provide a better chance for

Table 1.

Spectrometer Upgrade	E769 $\longrightarrow$	E791
Beam Momentum	250 GeV/c	500 GeV/c
Beam Type	$\pi^\pm$, $K^\pm$, p	π^-
Target Foil Types	W, Cu, Al, Be	Pt, Diamond
No. of Target Foils	26	5
Drift Chamber Gas	49% Ar, 49% C_2H_6, 1.5% C_2H_5OH	89% Ar, 10% CO_2, 1% CF_4
Downstream $\mu^\pm$ Planes	1	2
Silicon μ-strip Planes	13	23
Detector Channels	17000	24000
Typical Event Size	3200 bytes	2400 bytes
Readout Time	840 μS	50 μS
Tape Writing Speed	0.5 MB/sec	9.6 MB/sec
Tape Change Interval	6 minutes	3 hours
Tapes Written	9000	24000
Events to Tape	400 million	20 billion

short-lived particles like the Λ_c^+ and Ξ_c^0 to decay in air. The two different materials, platinum (A=195) and carbon (A=12), allow a measurement of the dependence of the charm cross section on atomic number.

Four new silicon microstrip planes were added to a pair of silicon planes and eight PWC planes already in place for beam tracking. The motivation was to determine the transverse position of the primary vertex in each event with little ambiguity.

SILICON MICROSTRIPS AND SPECTROMETER

For E791 six silicon microstrip planes have been added to our downstream SMD [6] bringing the downstream plane total to 17. This added tracking redundancy should increase the efficiency for reconstructing charm particles. The rest of the tracking system consists of two analysis magnets, two PWC planes, and 35 drift chamber planes spread among 4 DC modules. The only new addition to the drift chambers is the non-flammable gas shown in Table 1. Two gas Čerenkov counters identify kaons, pions, and protons [7]. Calorimeters [5] provide provide electron identification and π^0 reconstruction. A second downstream wall of muon scintillators has been added to help associate muon hits with tracks.

HIGH SPEED PARALLEL DATA ACQUISITION

The DA system [8] was crucial to recording a high statistics charm sample. 24000 channels were digitized by ADCs, TDCs, and latches; and then read out by 96 parallel controllers. Once data was buffered into a controller, we could take another trigger. Digitization and readout typically took 50 μS. The Tevatron had 23s spill and 34s interspill periods. Events were taken at the rate of 9000 per second during the spill. Eight parallel 80MB FIFO memories were used to buffer the Tevatron cycle. Each FIFO was attached to a specific set of front end controllers and contained a particular segment of each event. The FIFOs were read out continuously by a six crate VME system containing a total of 54 CPU cards. Each VME crate was attached to each FIFO to form a 6 × 8 switching matrix. Six events could thus be built in parallel. The CPUs also compressed events and prepared them for writing to tape. Seven 8mm Exabyte 8200 tape drives were attached to each VME crate. Thus, a total of 42 Exabyte tape drives continuously recorded events in parallel at 9.6 MB/sec. Each 8mm tape holds 2.3 gigabytes, 13 times as much as a 9-track tape at half the cost per tape. When 3 hours of beam time elapsed, all 42 tapes were changed at once.

E791 had a higher particle multiplicity and added 40% more channels than E769. We nevertheless made the event size 25% smaller than E769 by suppressing ADC zeroes and reducing the SMD word size from 16 to 8-bits. TDC and ADC word sizes were held at 16-bits by using Phillips 10C6 TDCs and LeCroy FERA 4300B ADCs. Smaller event records increased the charm density on tape.

During a six month run from July 1991 until January 1992, 20 billion physics events were recorded on 24000 tapes. We should be able to substantially exceed our goal of a minimum of 100,000 fully reconstructed charm particles.

RISC FILTERING, CHARM PEAKS, AND PHYSICS POTENTIAL

The Ohio State University and the University of Mississippi are each running 1000 MIP farms composed of stripped down DECstation 5000 Model 200 workstations. Each workstation contains a 25 MHz MIPS R3000 RISC CPU. The hardware architecture of these farms is similar to the system of RISC CPUs that was used previously by E769 [9]. The Mississippi DECstations can be seen in operation in Fig. 2. Expansions are planned at both universities. Farms to be built at CBPF–Rio de Janeiro and Fermilab are planned. About a third of the computing power necessary to analyze the experiment in a timely fashion is running now.

We have some preliminary results, two months after the end of our run. A $K_S^0 \rightarrow \pi^+\pi^-$ mass plot appears in Fig. 3. Fig. 4 shows a mass plot of the decay $D^0 \rightarrow K^-\pi^+$. Fig. 5 has two $D^+ \rightarrow K^-\pi^+\pi^+$ mass plots. Charge conjugate states are implicitly included. The lower D^+ plot only uses central drift chamber tracks which pass through both analysis magnets. A significant separation, $\sigma(\Delta z)$, between primary and secondary vertices and p_t

balance around the decaying particle direction is required in all mass plots as shown. All plots use a preliminary tracking program and a rough, single bend point approximation for magnetic fields. Čerenkov particle ID information was not used, but will be later.

When analysis proceeds, we intend to explore a number of physics topics such as:

- Studying and measuring the lifetimes of charm [10] and charm–strange [11] baryons in decays such as $\Lambda_c^+ \to pK^-\pi^+$, $\Lambda_c^+ \to pK_S^0$, $\Lambda_c^+ \to \Lambda\pi^+$, and $\Xi_c^0 \to \Xi^-\pi^+$.

- Finding branching ratios for doubly Cabibbo suppressed decays [12] like $D^+ \to K^+\pi^+\pi^-$ and $D^0 \to K^+\pi^-$ and for singly suppressed decays like $D^0 \to K_S^0 K_S^0$ and $D_S^+ \to \phi\mathrm{K}^+$.

- Measuring Cabibbo suppressed semi-leptonic decays to find the V(cd)/V(cs) KM matrix ratio (e.g. BR($D^0 \to \pi^-\ell^+\nu$) / BR($D^0 \to K^-\ell^+\nu$)) [13,14].

- Searching for $D^0 \Leftrightarrow \overline{D}{}^0$ mixing, using the π in $D^{*+} \to \pi^+ D^0$ to tag the D^0 [15].

- Searching for flavor changing neutral currents in decays such as $D^+ \to \pi^+\mu^+\mu^-$.

- Searching for CP violation in decays such as $D^0 \to K^+K^-$ [16].

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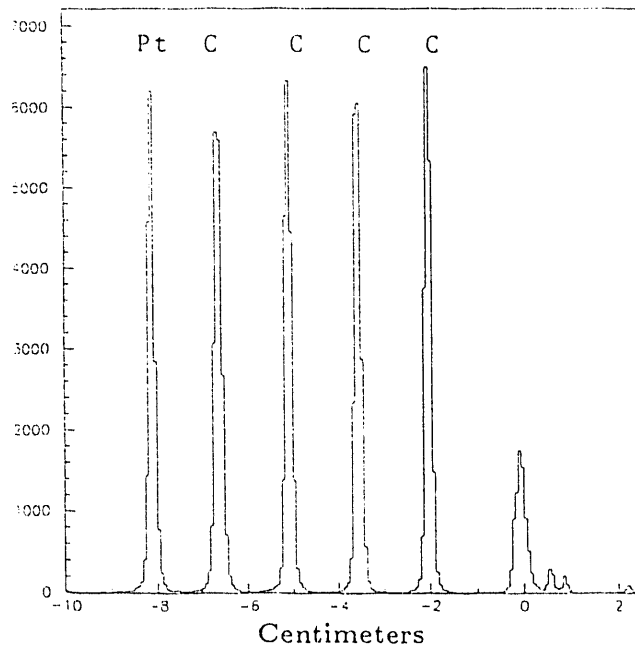
Fig. 1. Primary vertices from tracks show the z positions of our targets, 1 Pt and 4 diamond.

Fig. 2. Rack mounted workstations filtering data; a very cost effective means of computing. A pair of 10 tape Exabyte EXB-10 autoloaders provides an input buffer of over 40 gigabytes. Ethernet distributes events. These particular workstations are DECstation 5000/200s with MIPS R3000 CPUs. Other current possibilities include the Hewlett Packard–Apollo 9000/705, the DECstation 5000/25, the Silicon Graphics Indigo, the IBM RS/6000-320H, and the Sun SPARCstation 2. Running your own benchmarks and comparison shopping is often useful.

Fig. 3. $K_S^0(498) \to \pi^+\pi^-$ mass plot.
Cuts: $\sigma(\Delta z) > 15$ $\cos\theta < 0.8$
p_t unbalance around $K_S^0 < 0.1$ GeV/c.
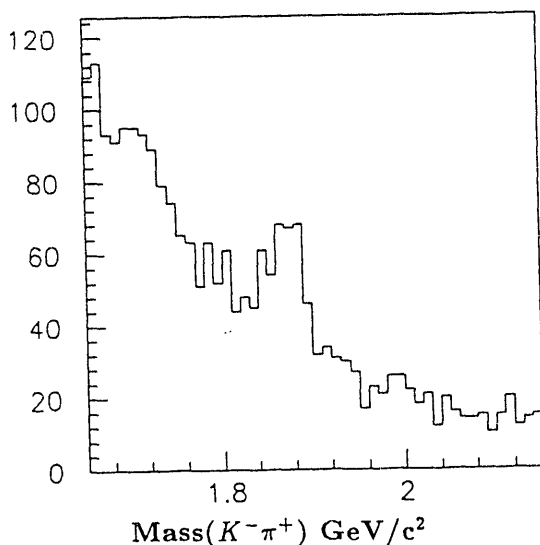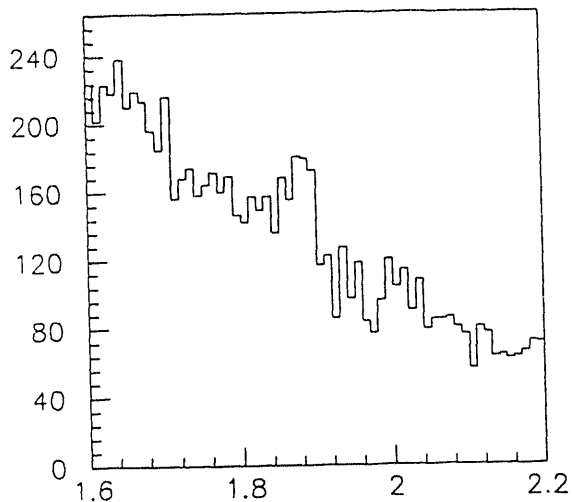

Fig. 4. $D^0(1865) \to K^-\pi^+$ mass plot
Cuts: $\sigma(\Delta z) > 10$ $\tau < 1.6$ ps
p_t unbalance around $D^0 < 0.35$ GeV/c.
Distance to any target center > 1.0 mm.
Secondary vertex distance of closest approach
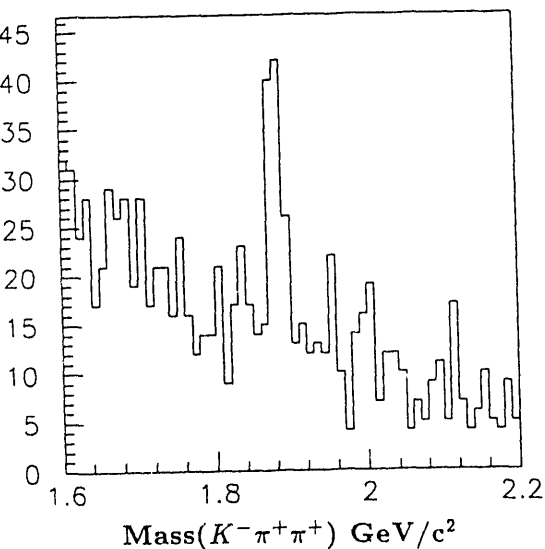/ primary vertex DCA < 0.75 for both tracks.

Fig. 5. $D^+(1869) \to K^-\pi^+\pi^+$ mass plots
Cuts: $\sigma(\Delta z) > 8$ $\tau < 3.0$ ps
p_t unbalance around $D^+ < 0.35$ GeV/c.
Distance to any target center > 1.0 mm.
The bottom plot alone demands hits in all
4 drift chamber modules for all 3 tracks.

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