A Time-Of-Flight Detector For CDF

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Abstract— **The new CDF-II detector improves it's particle identification power incorporating a Time-of-Flight detector (TOF), with a technique based on plastic scintillators and fine-mesh photomultipliers. The expected time-of-flight resolution of 100 ps will provide at least two standard deviations separation between $K^{\pm}$ and $\pi^{\pm}$ for momenta $p < 1.6$ GeV/c, complementing the technique of dE/dX provided by the new drift chamber, thus improving the $K^{\pm}$ identification for neutral B meson flavour determination. We present results based on the first data collected by the CDF-II experiment in the run IIa.**

I. Introduction

Following the succesful Run I data taking period at the Fermilab Tevatron from 1992 to 1996, the CDF detector has undergone a major upgrade for the Run II of the Tevatron which now (first half of 2001) is starting the commisioning phase. During the Run I the particle identification in CDF was exclusively based on dE/dX in the central drift chamber that provided a separation of about 1 standard deviation between kaons and pions for transverse momenta greater than 2 GeV/c. In January 1999, Fermilab granted scientific approval for the addition of a Time-of-Flight detector (TOF) to the CDF upgrade. The proposed TOF system will have a resolution of about 100 ps and will be capable of identifying kaons from pions by their flight time difference with at least 2 standard deviation separation up to kaon momenta of 1.6 GeV/c. The new TOF detector complements the dE/dX measurement from the new drift chamber since it distinguishes $K^{\pm}$ and $\pi^{\pm}$ in the region of cross-over in dE/dX. Such an addition will significantly improve a broad spectrum of B physics capabilities for CDF, resulting in an enhancement of the b flavour identification which is crucial to improve the statistical precision in CP violation measurements and $B_s^0 - \bar{B}_s^0$ oscillations.

II. The TOF system

The TOF detector consists of 216 bars (279 cm long and with a cross section of about $4x4$ cm^2) made of Bicron BC-408 scintillator, characterized by its long attenuation length ($\sim$ 250 cm) and fast rise time ($\sim$ 0.9 ns). The bars are installed at a radius of $\sim$ 138 cm from the beam line in the 4.7 cm of radial space between the main drift chamber and the cryostat of the superconducting solenoid. The material thickness of tracking system before the TOF is less than 10% of radiation length and the system covers a pseudo-rapidity zone of roughly $|\eta| < 1$. A Hamamatsu R7761, 19-stage, fine mesh photomultiplier tube (PMT) is attached to each end of the scintillator bars, for a total of 432 PMTs in the system. These tubes can operate in the 1.4 T magnetic field produced by the CDF solenoid, but with reduced gain. An initial analysis of the performance of the tubes indicated an intrinsic resoution better than 100 ps and an average gain reduction factor of 500 in a 1.4 T magnetic field. The tubes may operate at positive voltages up to 2500 V and exhibit very stable gains in the magnetic field. A custom designed high voltage base is attached to the PMTs. The differential signal formed from the anode and the last dynode stage of the PMT is fed through a preamplifier, which drives a differential signal over 10 m of cable to the front end electronics. The signal is fed into a leading edge discriminator whose output serves as the start signal for the Time to Amplitude Conversion (TAC) circuit. The TAC is stopped by a common stop signal produced by a precision clock with a design jitter less than 25 ps. Together with the timing measurement, the system also implements a gated integration of the pulse charge, used to correct the time measurement for pulse height dependence.

III. Kaon identification and flavour tagging with TOF

Particle identification with the TOF system is performed by measuring the difference (time-of-flight) in the time of arrival of the particle at the scintillator with the collision time t_0. The mass of the particle m can be determined from the momentum p, the path-length L, measured by the CDF tracking system, and the time-of-fligth t, by the formula:

$$m = \frac{p}{c}\sqrt{\frac{c^2t^2}{L^2} - 1}.$$

In Figure 1 is shown the time-of-flight difference between K/π, p/K and p/π, together with the separation provided by dE/dX. The average statistical separation is shown as well assuming a time-of-flight resolution of 100 ps. From the plot it is apparent how the TOF improves substantilally the K/π separation in the critical momentum region of $p < 1.6$ Gev/c.

The identification of a charged kaon can be used to tag B mesons, both in the opposite as well as in the same side tags. In particular the opposite side kaon tag, which is

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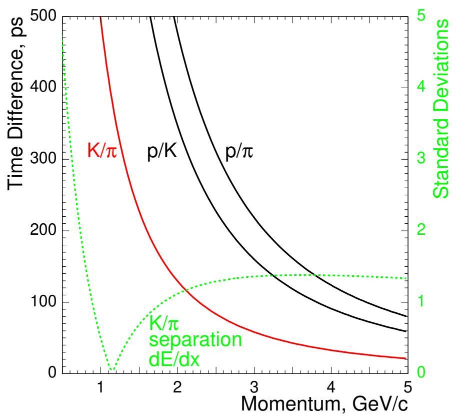

Fig. 1. The time-of-flight difference (in ps) between $K/\pi, p/\pi$ and K/p.

based on identifying the flavour of the second B hadron in the collision to infer the flavour of the B hadron of interest, was not established in Run I. The Figure 2 shows that a significant fraction of kaons from the second B hadron are in the identification range of the CDF detector. Combined with the same side kaon tag, the TOF is expected to double the flavour tag effectiveness for $B_s^0/\bar{B}_s^0$ mesons.

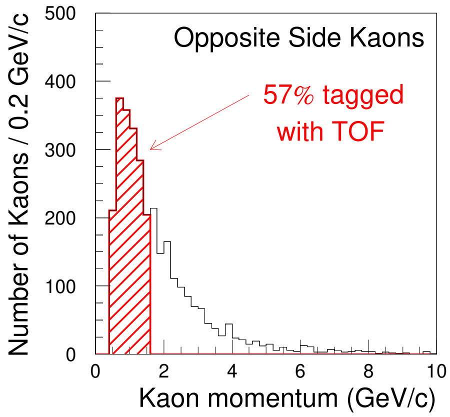

Fig. 2. The momentum spectrum of kaons from B decay opposite the reconstructed $B^0/\bar{B}^0 \to J/\psi K_s^0$.

IV. First Results

A TOF test system with 20 130 cm bars was installed inside the CDF solenoid at the end of the Run I to learn how to achieve the best timing resolution (100 ps) from a full system. From a fit to the TOF mass spectrum of the data (see Figure 3) the flight time resolution averaged over all the tubes was $220-250$ ps. It's worth noting here that this poor resolution could be explained observing that the test sytem suffered from a very reduced statistic (only 5% coverage), resulting in a poor resolution in the t_0 determination and in a reduced power for the the time slewing correction. Moreover the 16-stage PMTs used in the test system showed very low amplitude signals within the 1.4 T magnetic field. All these problems are addressed in the design of the full system. Using cosmic ray muons, a resolution of about 110 ps with 16-stage PMTs has been obtained, while the 19-stage PMTs show a comparable timing performance. A track matching efficiency about 95%, and an occupancy of $10-20\%$ (depending on the luminosity) has been obtained by the simulation.

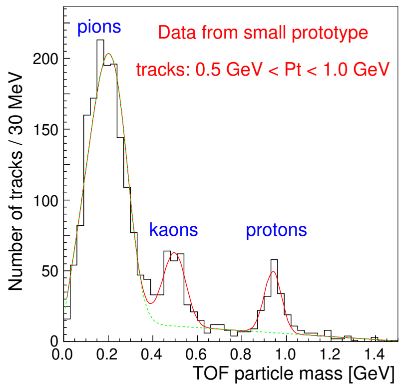

Fig. 3. The measured TOF mass spectrum with the TOF prototype. The solid line is a fit that includes contributions from pions, kaons, protons and linear background.

The installation of the TOF system, with the exclusion of the elctronics, was completed in the middle of 2000. Currently the commisioning phase of the detector is going on, and we expect to have the system ready by the end of summer 2001. In November 2001 for the IEEE NSS/MIC conference, we will be able to present the complete system performances, together with the first preliminary results on particle identification and flavour tag, obtained with TOF and based on the first Run II physics data collected by CDF.