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ACTIVITY ON IMPROVING PERFORMANCE OF TIME-OF-FLIGHT DETECTOR AT CDF

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The paper describes activity on improving the time resolution of the Time-of-Flight detector at CDF. The main goal of the detector is the identification of kaons and pions for b-quark (B-meson) flavor tagging. Construction of the detector has been described as well as proposals on detector design changes to improve its time resolution. Monte-Carlo simulation of the detector response to MIP was performed. The results of the simulation showed that the proposed modifications (at least with currently available materials) bring modest or no improvement of the detector time resolution. An automated set-up was assembled to test and check out the changes in the electronic readout system of the detector. Sophisticated software has been developed for this set-up, to provide control of the system as well as processing and presentation of data from the detector. This software can perform various tests using different implementations of the hardware set-up.

Приводится описание работ по улучшению временного разрешения времяпролетного детектора установки CDF. Основной задачей детектора является разделение каонов и пионов для определения типа b-кварков. Описано устройство детектора, а также предложения по его изменению для улучшения временного разрешения. Было проведено моделирование методом Монте-Карло отклика детектора на прохождение МИЧ. Результаты моделирования показали, что предложенные изменения (с использованием доступных в настоящее время материалов) не приведут к улучшению временного разрешения детектора. Для проверки предложенных изменений в системе считывания была сконструирована автоматизированная установка. Для управления установкой, а также для обработки и представления данных было разработано комплексное программное обеспечение. Этот пакет программ позволяет проводить разнообразные тесты параметров системы с различными конфигурациями оборудования.

1. CDF II DETECTOR

The proton-antiproton collider (Tevatron) at Fermilab that has the highest energy of colliding particles is a unique instrument for research on the frontier of high-energy and particle physics, and will retain this role in the next several years. The CDF detector, during data taking runs of 1992–1996, has brought a number of results of principal scientific significance, including the experimental discovery of top quark [1].

In 2001 the second stage of research at Tevatron (Run II) started. The accelerator system (Tevatron) has been upgraded, and the estimated luminosity is expected to be increased up to $2{\cdot}10^{32}$ cm$^{-2}\cdot$s^{-1} (this is almost an order of magnitude higher than the luminosity reached during Run I). The center mass energy is increased from 1.8 to 2.0 TeV. The increase of luminosity and energy together will bring sizable widening of detector capabilities in solving of new physical problems and more detailed investigation of problems studied before. This requires a number of changes in the detector CDF set-up [2]. A number of new systems have been added, together with upgrade of the existing elements. These changes have affected all the detector parts — tracking, calorimetry and muon subsystems.

2. TIME-OF-FLIGHT DETECTOR AT CDF

As part of the program of CDF upgrade, investigations on possible improvements of time resolution of the Time-of-Flight detector (ToF) have been carried out. The main physical task of the detector is the separation of kaons from pions for the purpose of flavor tagging of b quarks (B mesons). At a time resolution of 100 ps it allows separation of $K^{\pm}$ from $\pi^{\pm}$ at the level of 2σ up to 1.6 GeV/c. In the CDF I detector, kaon tagging was made using dE/dx. The separation at the level of 2σ is possible at a momentum of 300–600 MeV/c using this technique. Above 600 MeV/c the energy losses of kaons and pions become almost identical and the old system of identification using this parameter cannot distinguish them, while most of the kaons from B-meson decay have momentum higher than 600 MeV/c, up to several GeV/c (Fig. 1). The larger part of such kaons can be identified by the ToF system.

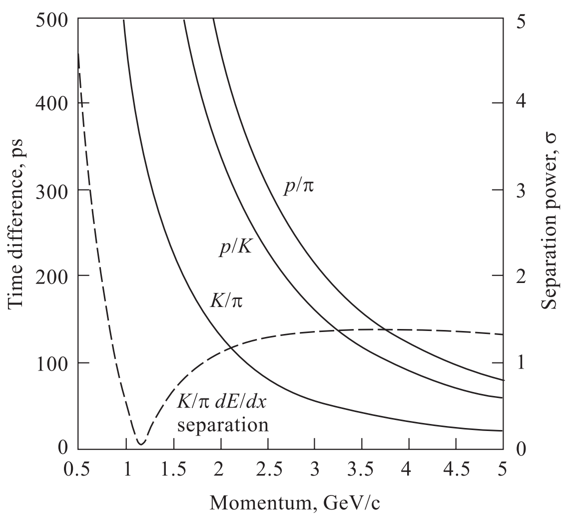

Fig. 1. Time difference as a function of momentum between p/π and K/p traversing a distance of 140 cm and separation power assuming a resolution of 100 ps. The dashed line shows the K/π separation power from the dE/dx measurement in the Central Outer Tracker

The Time-of-Flight detector consists of 216 bars, made of scintillating plastic; each bar is 279 cm long and 4×4 cm in cross-section. The bars are arranged in a cylinder structure at a radial distance of 138 cm from the beam axis parallel to it. Two PMTs read the light from both the bar ends. The photomultiplier tubes are attached to these bars via parabolic concentrator (Winston cone) to optimize the timing resolution. The signal from PMT goes to the preamplifier, mounted directly behind the phototube base, and further to the special board, where the time difference between the bunch crossing and the signal from the particle is determined. For correction of timing information from the discriminator, the amplitude of signal is also used [3].

The test of a detector prototype containing 20 bars has shown that timing resolution of the system can reach 100–125 ps [4].

In order to improve the timing resolution (down to 70–80 ps), a number of modifications have been proposed:

- Change of the light readout scheme to collect light from the bar using a ribbon made of light guide fibers, placed at the long side of the bar.
- Use of a bundle of scintillating double-clad fibers instead of solid bulk of plastic scintillator to reduce time dispersion.

Some changes have also been proposed for readout electronics:

- Use of double-threshold rise time compensating discriminator to reduce the discriminator slewing contribution to the total time dispersion.
- Location of discriminator and Time-to-Analog Converter (TAC) directly after PMT, without using a preamplifier, thus avoiding signal distortion caused by the preamplifier and spreading of fast signal when propagating along the long wire.
- Use of Fast Analog-to-Digital Converters (FADC) placed directly after the phototube to perform immediate digitization of signal from the detector with timing registration. Signal shape could be restored then using interpolation algorithms.

3. MONTE-CARLO SIMULATION OF THE DETECTOR RESPONSE

To test the efficiency of the proposed changes in the detector construction, a Monte-Carlo simulation of the detector response has been performed. A program for simulation of the detector response to the charged particle has been created. We compared the distribution of signals from a detector, which was made using standard design (bar of scintillating plastic, $279\times4\times4$ cm, signal readout performed by PMT, attached to the bar ends) with the distribution of signals from a detector made of scintillating fiber array of similar geometry (Fig. 2).

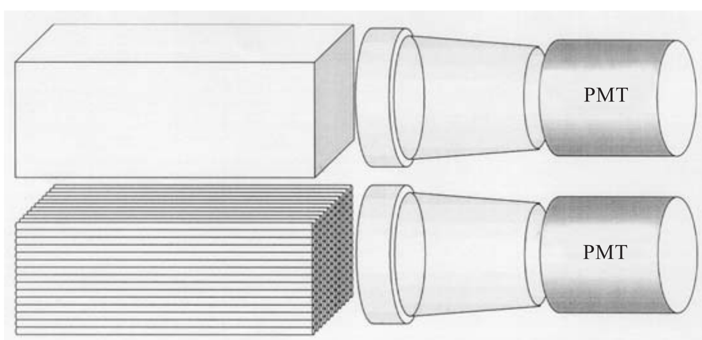

Fig. 2. Detector shemes: original configuration — with bar of scintillator plastic (top), and proposed change — bundle of scintillating fibers (bottom)

The following values of detector parameters were used:

- Double-clad fibers by Bicron, 0.5 mm in radius, reflection index of core — 1.60, first and second claddings — 1.49 and 1.42 respectively, attenuation length — 220 cm; rise time is 1.413 ns and fall time — 3.1 ns.

- PMT Hamumatsu R5946 were considered, with quantum efficiency 20 % and transit time (8.5 ± 0.35) ns.

The distribution of the response time of the detector has been obtained, taking into account a number of factors: rise and decay time of scintillator, dispersion of optical path of photons propagating through the scintillator, and PMT transit time dispersion. The plots obtained in simulation are presented on Figs. 3 and 4. The results of simulation indicated that using the scintillating fibers could not help us to get a better timing resolution.

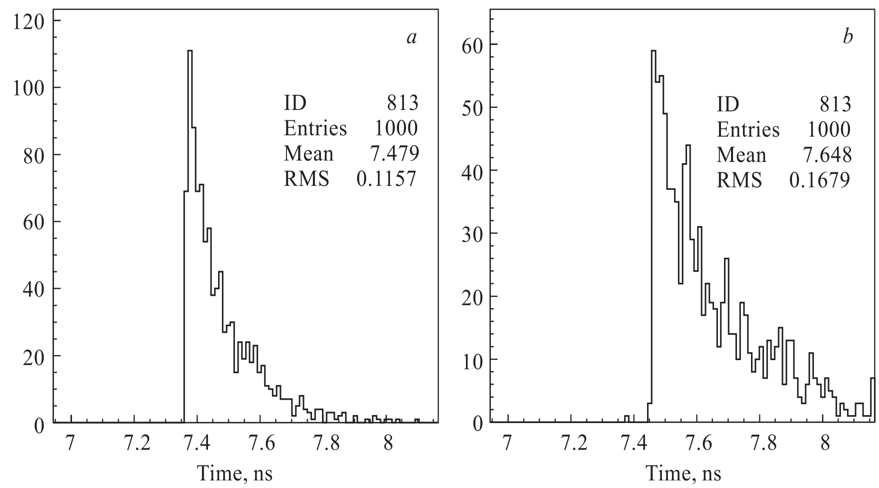

Fig. 3. Distribution of time of photon propagation along the scintillating bar (*a*) and the bundle of scintillating fibers (*b*)

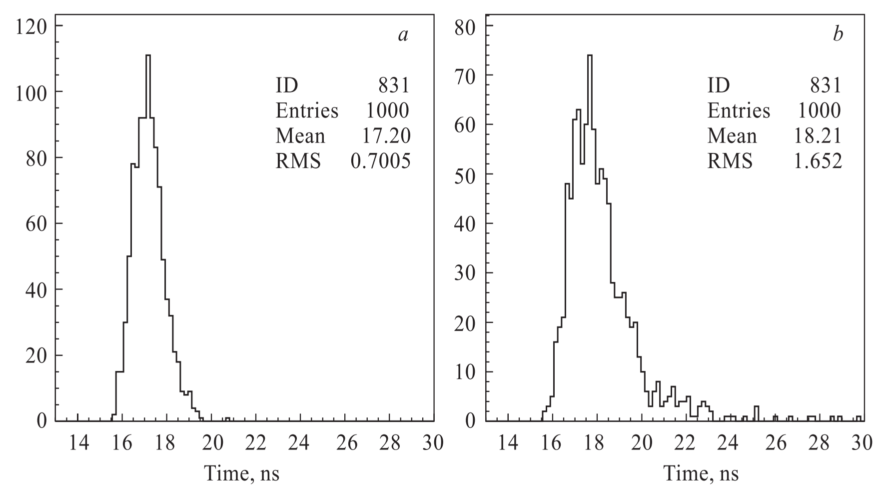

Fig. 4. Distribution of time interval between passage of the particle through the detector and getting signal from the first photon for the detector scheme using the scintillating bar (*a*) and the bundle of scintillating fibers (*b*)

4. SET-UP FOR STUDYING THE PERFORMANCE OF TIME-OF-FLIGHT DETECTOR PROTOTYPES

To develop the methods of readout and analysis of signal from the detector, we prepared a test set-up based on electronic equipment in the VME standard controlled by an IBM-compatible personal computer (PC). The set-up scheme is presented on Fig. 5.

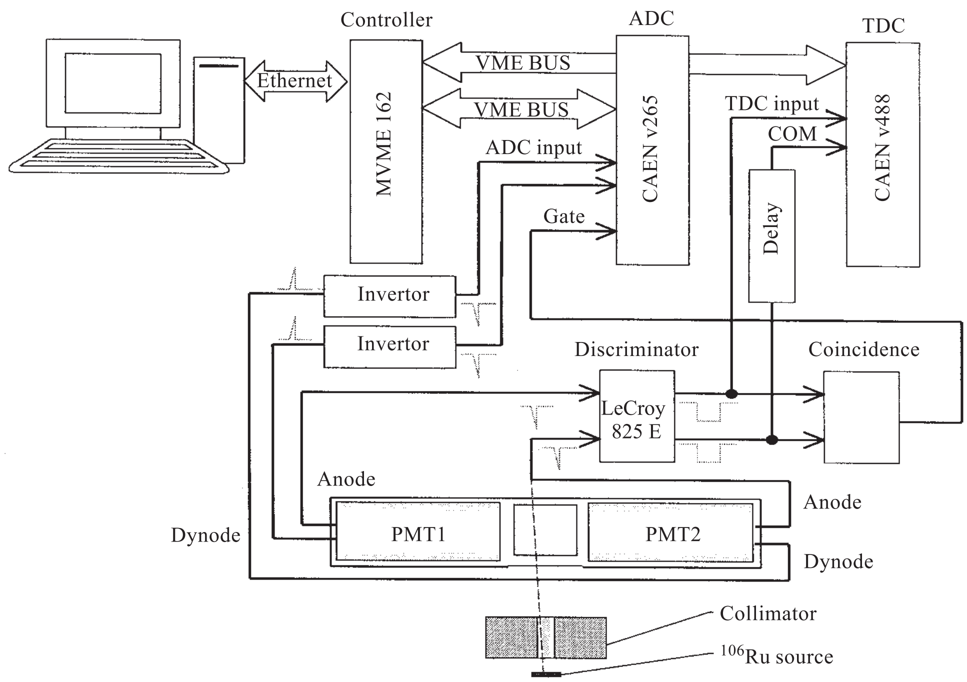

Fig. 5. Construction of the set-up for studying the performance of the Time-of-Flight detector prototypes

Two PMTs read a small plastic scintillator bar placed between them. A ^{106}Ru source with $\sim 0.5 \cdot 10^6$ Bq activity with collimator was used to generate an MIP beam. Signals readout was performed by VME modules managed by a Motorola MVME 162 controller. Data exchange with the PC was performed via network using the Ethernet port of the controller. To measure the time differences between signals, we used 8-channel programmable Time-to-Digital Converter (TDC) CAEN v488. The signals from the PMT anodes were delivered to its input through the discriminator, while signals from the last dynodes were digitized by the CAEN v265 charge-integrating Analog-to-Digital Converter (ADC).

Special software based on LabView visual instrumental programming system was written to control the functioning of the set-up and to perform data analysis and visualization. Using this software, we can get distribution of signal amplitudes and time difference by running continuous tests in automatic mode. The program has modular structure and can easily be modified for testing different detector systems.

Using this set-up, we developed the procedure to study the dependence of time resolution on the signal amplitude and detector parameters (discriminator type and threshold values, gate width of ADC, etc.). A comparison of two discriminator constructions — single-threshold and double-threshold with rise time compensation — was performed. Using double-threshold discriminator, we prove that it is possible to reduce the dispersion of the time response of system from 1.3 to 0.7 ns. The software developed can be used to perform investigations with other implementation of the readout electronics, thus allowing a better timing resolution.

CONCLUSION

The paper describes activity on improving the time resolution of the Time-of-Flight detector at CDF. The main goal of the detector is the identification of kaons and pions for b-quark (B-meson) flavor tagging. Construction of the detector has been described as well as proposals on detector design changes to improve its time resolution. Monte-Carlo simulation of the detector response to MIP was performed. The results of the simulation showed that the proposed modifications (at least with currently available materials) bring modest or no improvement of the detector time resolution. An automated set-up was assembled to test and check out the changes in the electronic readout system of the detector. Sophisticated software has been developed for this set-up, to provide control of the system as well as processing and presentation of data from the detector. This software can perform various tests using different implementations of the hardware set-up.

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