Test Beam Upgrade in IHEP and Its Applications*

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Abstract The construction and the performance of the test beam have been introduced in this report. Some applications of the test beam and results were described. Magnetic spectrometer system and the on-line data acquisition system, as well as off-line data analysis provided abilities to recognize the different kinds of particles and to give out the track of a single particle with known momentum. The e^- beam, hadron beam as well the mixed beam of e, π, and proton were contained in this test beam.

Key words: Test beam, Secondary beam particle, Single particle events, MWPC, Prototype.

1. Introduction

The test beam running on the linear electron accelerator (LINAC) of BEPC is one and only beam line of particles with middle energy in China [1]. The beam line derived from LINAC by magnets provided the e^- particles beam with momentum up to 1.3GeV/c and intensity around 2.5A, and the frequency of the pulse repetition rate to be of 25Hz. This beam line is called E2 line with about 10^{10}/s electrons, which are used to hit target or to fly directly into DUMP. After hitting the target by E2 electrons, the secondary particle beam will be accepted by the magnetic spectrometer system at the 15^o angle with respect to E2 line. This secondary particle beam is called as E3 beam line, i.e. the most useful test beam. The D2 magnet at E3 line is used to measure the momentum of particles. The particles out of the D2 passed through a window on the shielding wall toward the detectors of the magnetic spectrometer system. The shielding wall and the window played a role of reducing the background.

The secondary particle beam is a mixed beam of particles, which includes γ, $e^{\pm}$, $\pi^{\pm}$, proton and little $\mu^{\pm}$(through $\pi^{\pm}$ decay), and the production of them will depend on the materials of the target. The W-C, pure C, Cu and Be targets have been adopted for various purposes of test.

The momentum of the secondary beam (E3) particles can be adjusted between 300MeV/c and 1.1GeV/c by D2 magnet according to different requirement.

The selection and the measurement of the secondary particles were completed by the magnet spectrometer and on-line data acquisition systems. And these systems were upgraded during the years from 2004 to 2005.

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2. Magnetic spectrometer system [2]

This system consisted of a series of apparatus, which include two quadruple magnets LQ1 and LQ2, two bending magnets D1 and D2, the vacuum tube with 70mm in diameter as well a series of particle detectors with different function. LQ1 and LQ2 are used to focus the charged particles of E3 beam. D1 magnet makes particle on 14^o angle deflection, and the magnet D2 bends particle with 17^o angle with respect to D1 bending but on the reverse direction. Furthermore, D2 magnet is very important tool for analyzing particle momentum. The momentum resolution $\Delta p/p$ was measured to be about 1% under the condition of the acceptance of the beam detector to be 1cm×1cm.

There are three kinds of detectors with associated readout electronics in this system. Two scintillation counters, SC1 and SC2, are used to measure the time of flight (TOF) of the particle in the secondary particle beam and to define the beam cross section. The coincidence of SC1 and SC2 is used to select required beam particles and to reject the background events. In order to improving the performance of the scintillation counters, new counters have been manufactured and tested to replace previously used counters. The time resolution for TOF measurement is ～270ps. The detection efficiency of each scintillation counter is no lower than 93% under the high voltage of the plateau.

The threshold Cherenkov counter (ČC) [3] to be used for electron identification is placed between two scintillation counters at the secondary beam (E3) line. The radiator of ČC is gas CO_2 with length of 1.2m, and the gas pressure is about 1.2atm. The efficiency of ČC for selecting electrons is (99.0±0.5)%.

High voltages 1950V～2000V are put on SC1, SC2 and ČC.

At the downstream of the E3 beam line, multi-wire proportional chambers (MWPC) [4] have been arranged. These chambers are used to select the single particle events from recorded events and to determine the coordinates of a particle respectively on X and Y cathode planes in each chamber. Each chamber consists of one anode wire plane and two cathode strip planes. 35 plated gold tungsten wires, with 20μm in diameter of each and 2mm pitch between two wires, are stretched in each anode plane, and these wires were connected in parallel to give only one output. Every cathode plane contains 16 strips, each of which is composed by 6 parallel wires with 50μm in diameter of each wire, and the effective width of each strip is 4.2mm. Two cathode planes are placed on the two sides of the anode plane, and the directions of them are perpendicular each other to form two-dimensional coordinates. The distance between anode plane and each cathode plane is 6mm. The operation gas in the MWPC is Ar(90%)+CO_2(10%) mixture. The effective operation area of each MWPC is $5.5cm^2$. The intrinsic error of the position determination for each chamber is 50μm[4]. Total detection efficiency of three chambers is approximately 97%.

Before upgrading the system, only two chambers were used. Now another chamber was placed in the MWPC system (MWPC1, MWPC2 and MWPC3), so that the measured accuracy of the single track could be improved.

3. On-line data acquisition

The on-line data acquisition system has been improved during the years from 2004 to 2005.

The layout of the system is shown in Figure 1. In this system, NIM modules are used to accept signals from detectors, whereas the analog-digital conversion, data transportation as well the conversation between the system and computer are performed by CAMAC electronics system. The high voltage equipment for detectors is not shown in this Figure.

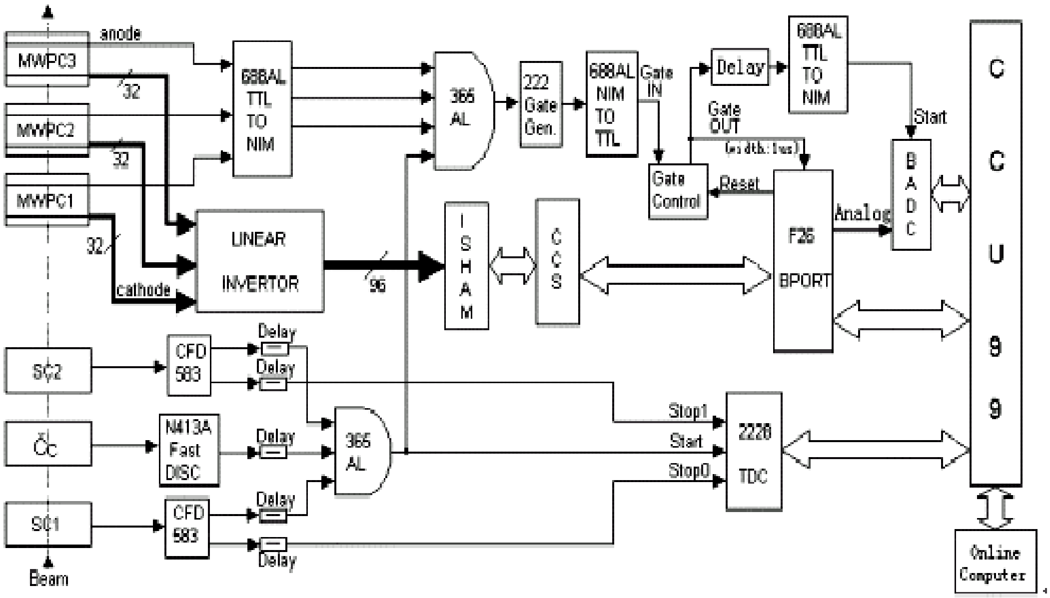


Figure 1. Configuration of the on-line data acquisition system

As above mentioned, that the counters SC1 and SC2 in this system are used to select beam particles and to measure the time of flight (TOF) of the particle between SC1 and SC2 if certain distance is fixed on them. The output signals from scintillation counters are transmitted into the constant fraction discriminators (CFD) by 50Ω coaxial cables with 30m length, then the NIM pulses with 30ns width from out of CFD are put in the 4-logic unit to do coincidence, and the output from 4-logic unit will be sent to a TDC(LeCroy 2228A) as a common start time signal, at same time, the timer signals out of CFD are sent separately into two channels of TDC as stop time signals. The subtraction of two time differences is made to get TOF of the particle with reduced time swing. For the ČC, the output signal from XP2020Q photomultiplier with low noise and high sensitivity is transmitted into a fast discriminator (CAEN Mod. N413A), and the output of which coincides with signals of SC1 and SC2 to select electrons from E3 beam. Otherwise, if the output from ČC is used to do anti-coincidence with signals of SC1 and SC2, then electrons will be rejected, and the hadrons beam will be obtained.

Because there was no enough CAEN C205 ADC modules [5] were used in the analysis of data from the three MWPC, therefore instead of C205 modules, the BADC (Brilliant ADC)-ISHAM (Integrated Sample and Hold Analog Module) data acquisition and processing system has been used for accepting and analyzing the induced signals from cathode strips of three MWPC. The ISHAM modules are arranged into a special crate, and the controller of which is CCS module. The communication between BADC and CCS is realized by BPORT(Mod.2002) module. The output of the parallel anode wires is amplified by means of the integrated charge preamplifier, and then by main amplifier with formed output. This output is of TTL level and 800ns width. After TTL-NIM level conversion, the outputs of three MWPC are sent to the logic unit to coincide with signals of SC1, SC2 and ČC. This 6-fold coincidence is used as a trigger signal as well serves the

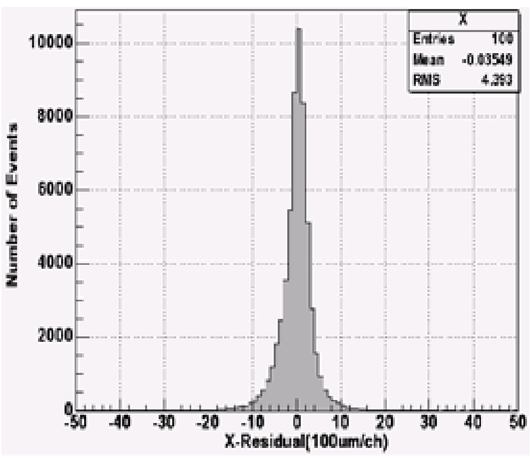
Gate (after 1μs widen) of BADC. Furthermore, this Gate signal is used to trigger a discriminator to produce a 200ns width signal for reading events from ISHAM to BADC after 200ns delay with respect to Gate signal. In fact, the Gate signal will be transported to ISHAM for the charge read in. The induced charge signals on the cathode strips are magnified by charge amplifier at first, and then are transmitted to the linear inverter by 32 twisted-pair cable. The inverted signals with negative polarity are put into the ISHAM modules (each module can accept 24 channel signals). All of the amplifiers are assembled close to chamber body. Because there was a great lot of noise in the previously used preamplifier (amplifying for current), which was used to amplify the anode signal, so a new charge integrated preamplifier was used to replace it. A Gate controller module has been used to control the events read in BADC one by one, such that the ambiguity of the events could be avoided. High voltages applied on three MWPC are 3750V～3800V.

4. Off-line Analysis

Once running data acquisition is completed, the TOF and 96 channels information of MWPC (2×16 channels for each chamber) will be stored in data file for each event.

By using the off-line data analysis of the three chambers, as mentioned above, the X and Y coordinates of the hit point of single particle in each chamber can be determined by calculating the centre of gravity of the distribution of induced charges on strips in two cathode planes of a chamber [6].

In this way, the projections of a single particle track respectively onto X-Z plane and Y-Z plane may be reconstructed by fitting the X and Y coordinates of the three chambers for the single particle. Figure 3-a and Figure 3-b show the residual distribution to be obtained from the fitting with based on least square of the linearity. About 80 thousand events of electron with 800MeV/c were adopted in this treatment. The localization accuracy for single track to be less than 300μm has been reached [7].



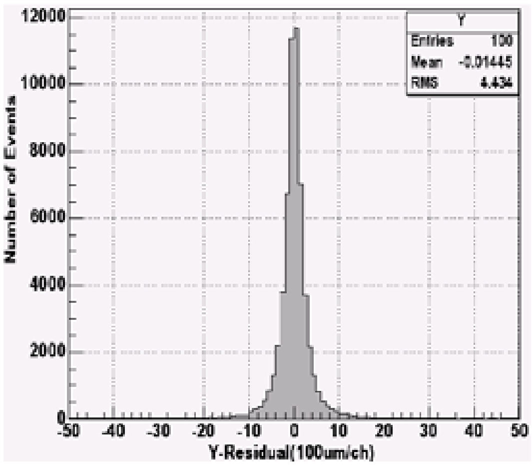


Figure 3-a X Residual Distribution Figure 3-b Y Residual Distribution

The single particle event is very significant in the application of the test beam. Criterion of recognizing the single particle event is described as follows:

1) The minimal effective value of the charge (ADC channels) induced on cathode strip should be over certain threshold which depending on calibrated pedestal of BADC.

2) The number of the induced strips is at range of 3～7 adjacent strips in each cathode plane.
3) There is only one peak in the distribution of the charges on adjacent induced strips, and such distribution is quasi-Gaussian. Only one such distribution in each of six planes is required. In addition, at two sides of the peak, the charge value should be monotonously dropped down.
4) The sum of charges for total induced strips has to be less than 440pc.

A single particle event will be obtained as above requirements are satisfied. Because of the imperfection of the MWPC and associated electronics, so according to above criterion of selection, only about 40% of total recorded events were identified as the single particle events, and it leads many single particle events were lost. By analyzing a great lot of events of the beam particle, the frequency of the recorded single particle events is only 1.5～2Hz as the pulse rate of the primary electron beam is 25pulses/s and the intensity of the beam is not too high. However total counting rate to be 5～10/s of secondary beam particles were usually observed.

After the off-line data analysis is finished, then some histograms, for example, the distribution of the induced probability of strips on X-plane (or on Y-plane), the distribution of the angle between the projection of single particle track on X-Z plane (or on Y-Z plane) and Z axial can be obtained. To inspect the distribution of the induced strips, one may know that which output of strip is abnormal. And if by using a cut on the angle distribution, the almost parallel particle beam will be obtained for special purpose.

A TOF spectrum of π^+ and proton mixture particles with 800MeV/c momentum is displayed in Figure 4[7]. The distance between SC1 and SC2 is 5.5m in this TOF measurement. Using proper cut on this TOF distribution, then π^+ beam and proton beam can be separately gained.

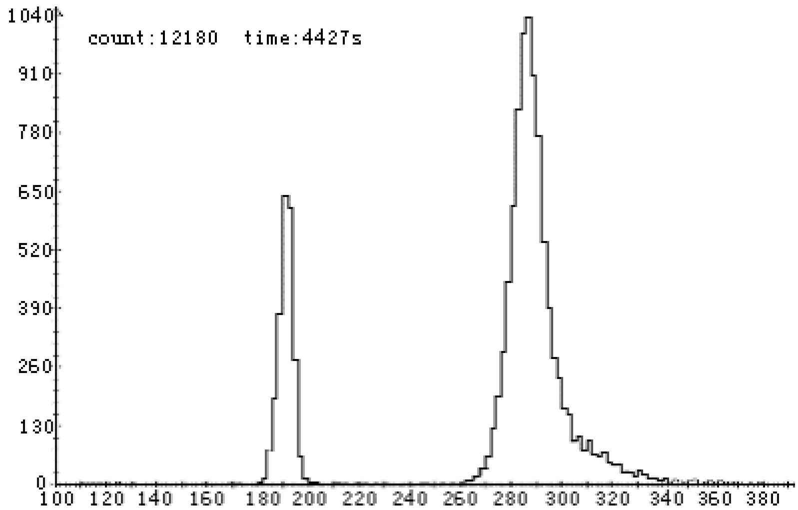


Figure 4. TOF spectrum of π^+ and proton with 800MeV/c

5. Applications of the test beam

In this section, the applications of the test beam on the prototype of BESIII sub-detectors as well on the other field will be described. The barrel and end-cap TOF prototypes, the module of the electromagnetic calorimeter(EMC), the main drift chamber(MDC) with 1:1 prototype, the luminosity monitor and RPC board (it is component of the muon counter) were tested at E3 beam line from January to the end of June in 2005. Beyond that, some applications have been done at the E2 beam line.

5.1 Beam test on TOF prototypes

Total 2.64 million events of the electron with 800MeV/c momentum were employed for the time resolution measurement of TOF modules. For the barrel TOF prototype with $5\times6cm^2$ cross section and 2.3m length to be made up by EJ 200 organic-plastic scintillation materials, the time resolution to be 90ps～94ps was attained on average. Figure 5 exhibited the variation of the time resolution versus the hit position by particle, two curves in this figure respectively corresponding to different materials to be used to envelop the scintillation materials and reflect the photons.

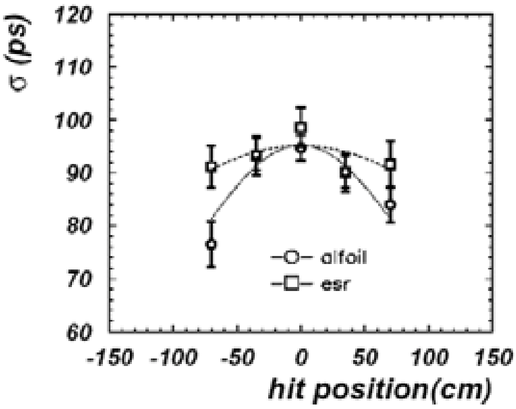


Figure 5. Time resolution versus position

The end-cap TOF prototype with 43cm length was made by BC404 scintillation material. The feature of this scintillation material is able to speedily transfer the photons. The time resolution is 70ps to be better than that of barrel TOF

At same time, the new VME electronics system, which serves the TOF counter, has been checked.

5.2 Calibration of the electromagnetic calorimeter(EMC) on the test beam.

The measurements of the energy resolution and the position resolution, as well as the test of relation between the measured energy and the energy of incident electron have been completed at the E3 beam. The module of EMC consists of 5×5 CsI(Tl) sub-modules, the area of the front end (facing to beam entrance) of each module is $6.5\times6.5cm^2$. The distribution of deposited energy of the electromagnetic shower in tested module is shown in Figure 6. Data of 2.8 million electrons with 1GeV/c were taken for this test. The energy resolution of roughly 2.9% , and 6～7mm position resolution were obtained. The relation between the measured energy and the energy of incident electron is displayed in Figure 7. The ordinate of this figure represents the electrons energy measured by calorimeter modules and associated VME electronics, so the unit of the coordinate is ADC channels. The energy of incident electrons was taken respectively to be 400MeV, 600MeV, 800MeV and 1000MeV in this measurement. The linearity of the relation in Figure 7 is very satisfactory. And this perfect linearity proved, that the particle momentum to be measured by using magnetic spectrometer is correct.

From the beam testing of the calorimeter, we have acquired a important information, that the approximate 1/3 single particle events in E3 beam were lost after using the selection of the single particle events from chamber data.

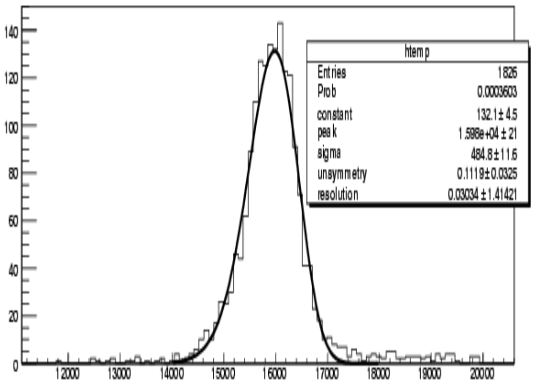


Figure 6. Distribution of the shower energy

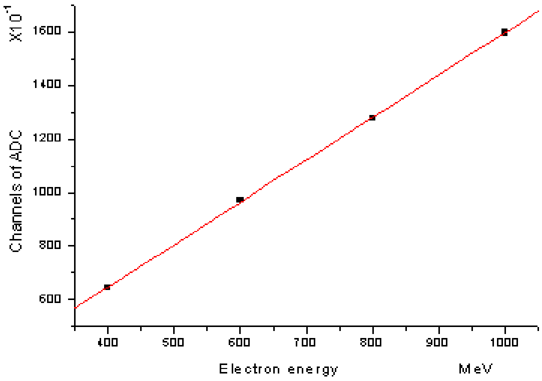


Figure 7. Linearity of Energy Response

5.3 The beam test of MDC prototype with 1:1 scale and test of RPC

A lot of different test for the MDC prototype have been accomplished. The track resolution of the particle, the detection efficiency of the unit in the chamber, the influence of the system noise on operation of the chamber and so on were studied in detail. The performance of the VME electronics system served for MDC was particularly investigated, for instance, the effect of changing high voltage for the operation of the chamber was studied, how to choose the time threshold of the electronics for gaining the optimized operation parameters. Under the beam environment, the problem about the performance of the chamber to be affected by grounding and the spatial electromagnetic noise was solved. Totally 600 thousand electrons with different momentum as well 70 thousand pion and proton mixed particles were used to measure the drift time and the dE/dX distribution of the MDC prototype.

By using the analysis of data taken from beam test on MDC, the single track resolution and the dE/dX value were obtained to be respectively ? and ? . These results are in good agreement with the prediction of the design calculation.

For the beam test of the RPC, 270 thousand with 800MeV/c momentum and 60 thousand with 1.0GeV/c momentum π^+ and proton mixed particles have been used to measure the detection efficiency. To analyze the TOF spectrometer of π^+ and proton (800MeV/c momentum) indicate, that the number of π^+ is approximately 25% of the number of proton in beam mixture. But instead of μ, only π is of significant for RPC measurement.

Under the normal operation of high voltage, detection efficiency of RPC to be 94%～97% was obtained.

In addition to the above-mentioned utilities, the test beam was used on some other fields too. We have used secondary particles to be produced by hitting target with E2 beam to radiate agricultural seeds at a wider angular range. Radioactive damage test on some materials, for instance, optical fibers, RPC and so on was done by E2 electrons (with high intensity) for a long time. Integrating dosimeter of Qinghua University experimental group was checked on E2 beam line.

6. Conclusion

The applications of the test beam shows, that the performance of our test beam is successful. A series of different measurements and tests were accomplished at the secondary particle beam (E3 beam). Some measured results are compatible with the results of prediction by design and calculation. The test beam are expected for more applications.

But some shortages in our test beam were already discovered during the running. So further improvement has to be done. The single particle events rate should be increased in the test beam, so the ability of two tracks separation and the readout of single track must be improved. Ability of the momentum resolution has to be improved by using accurate measurement of the curvature of the particle trajectory. The background and the noise interference for the test beam have to be depressed. The running test beam will be stable and reliable for a long time.

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