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Array of Cherenkov radiators for PHOBOS at RHIC

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Abstract

An array of Cherenkov radiators ("the Cherenkov counters") for the measurement of the vertex position of heavy-ion gold–gold collisions for the PHOBOS experiment at relativistic heavy ion collider is described. These simple, versatile, and highly efficient detectors provide a low bias and easily understood hardware (on-line) vertex trigger. This trigger is ready for the data-acquisition system in about 650 ns. The position resolution of the vertex distribution found by the Cherenkov counters is approx. 4 cm and is very stable as function of the centrality of the collisions. The general characteristics of the Cherenkov counters, their design parameters, and performance are presented, along with the implementation of the hardware vertex trigger used for PHOBOS during the 2001 run. © 2002 Elsevier Science B.V. All rights reserved.

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1. Introduction

The Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory has delivered the first collisions between Au nuclei at the highest center-of-mass energies achieved in the laboratory to date. PHOBOS, one of the four RHIC experiments, is designed to track charged particles in a magnetic field, determine the interaction vertex, and measure the multiplicity of charged particles produced in heavy-ion gold–gold collisions. The experiment consists of several subsystems: single-layer Si pad multiplicity detectors, two Si spectrometer arms utilizing planes of silicon pad and strip detectors, two time-of-flight walls, two zero degree calorimeters, and the trigger detectors. A complete description of the experimental layout can be found in Ref. [1]. The present paper provides a detailed description of the vertex trigger detectors, the Cherenkov counters.

As for any collider, the vertex-collision point delivered by RHIC is not exact and fluctuates, depending on the machine conditions. For example, it was found during the 2000 and 2001 runs that the position of the interaction vertex varied from designed interaction point (z) by about ± 60 cm. The determination of the interaction point in PHOBOS is done with very good precision by the silicon detectors; however, this is

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the result of an "off-line" analysis of the data stored on "tape". Furthermore, most of the standard physics analysis of PHOBOS is limited to events within a vertex range of about ± 12 cm from the designed interaction point (z). Thus, a reliable, rapid and simple on-line vertex trigger is desirable to limit the interaction range of the data stored.

This trigger had to be reliable because only a very small fraction of the events rejected by the vertex trigger were recorded, rapid because the DAQ required a signal in about 700 ns to accept or reject the data, and simple to facilitate its implementation and maintenance. The vertex trigger was implemented with these specifications, providing a distribution profile that triggers the data from the vertex (z) positions within ± 15 cm in range and 4 cm resolution. Only about $\frac{1}{3}$ of the events selected with a "minimum bias trigger" had a valid vertex trigger.

Cherenkov radiators were chosen to build the trigger vertex counter. They provide a good time resolution, since the radiator is not sensitive to low-energy particles from the background, do not require complicated readout electronics (cost effective), and are able to withstand large doses of radiation. The main characteristics of PHOBOS Cherenkov counters constructed for the on-line vertex determination are: their good triggering efficiency (100% for central and semi-peripheral Au–Au collisions), allowing an unbiased selection of events, and the simplicity of the geometry and the design based on a linear radiator-phototube array, making these detectors relatively easy to simulate and understand. The modular design of these counters allowed us to match the relative time delay of the response for each radiator, crucial to achieving a good timing resolution.

2. Geometry and design characteristics

The Cherenkov counters are two sets of 16 radiators located at -5.5 and $+5.5$ m from the nominal interaction point (z). The radiators form a ring that encircles the beam line parallel to the z-axis. The active area subtends 37% of the solid angle over a range of $4.5 < |\eta| < 4.7$ in pseudo-rapidity units. The beam pipe is a Be tube of 5 cm exterior radius; the distance between the center of the radiators and the beam pipe is 8.57 cm. Fig. 1 is a drawing of a complete Cherenkov counter and Fig. 2 shows the elements of one of the unit modules, where (a) is the radiator, (b) is the magnetic shield, and (c) is the phototube.

The individual radiators are made of BC-800 acrylic and are cylinders of 4.0 cm in length, and 2.5 cm diameter. At the end of the radiator, a hybrid photomultiplier tube assembly, H5211 from Hamamatsu (phototube R1924), is attached with silicon elastomer. Surrounding the tube is a 2-mm mu-metal magnetic shield. The tube inside the magnetic shield is made light tight with tape, while the light guide and radiator are wrapped with a layer of diffusing white Teflon tape and a layer of black vinyl.

Each module is then mounted in a mechanical structure. The mechanical structure for the mounting of the phototube assemblies is split in half, designed to be installed around the fixed beam

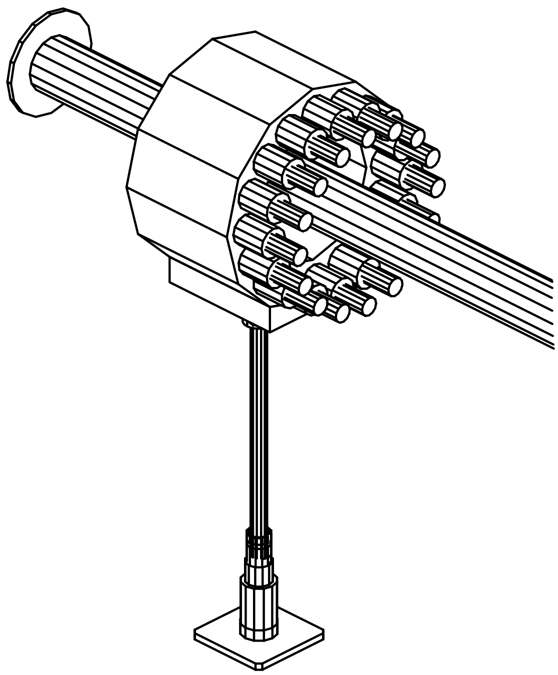

Fig. 1. Drawing of a Cherenkov counter and a section of the Be beam pipe.

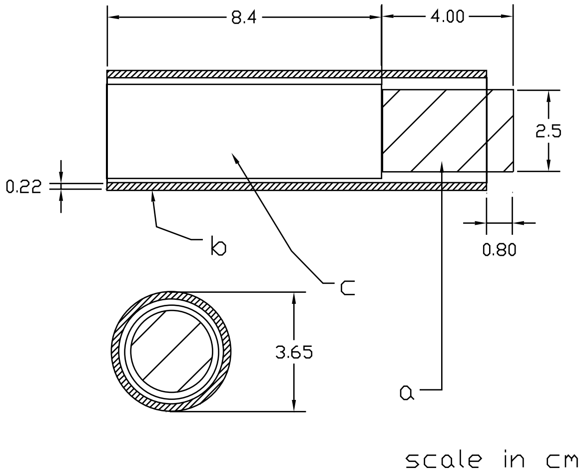

Fig. 2. The elements of one of the unit modules of the Cherenkov counters: the radiator (a), the magnetic shield (b), and the phototube (c).

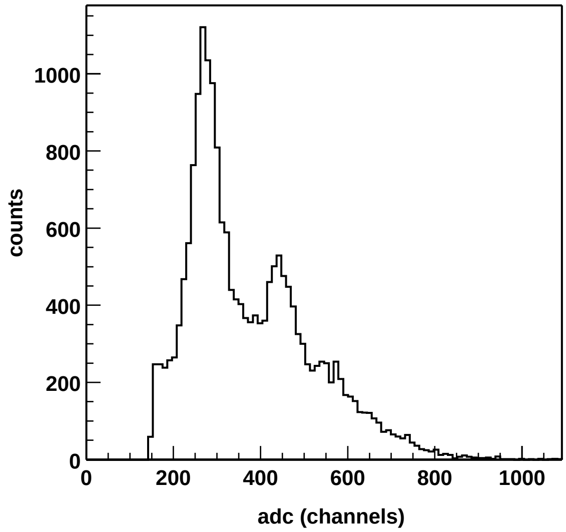

Fig. 3. The spectrum of pulse height distribution (ADC) from one module of the negative Cherenkov counter from a typical run.

pipe. It consists of two pieces of Teflon anodized aluminum tube to form an inner and outer shell, 30.48 and 20.32 cm O.D., respectively. The mu-metal shields are press fit in a longer Delrin tube. The 4.45 cm O.D. Delrin tube makes single point contact with the outer and inner shells, and is supported on the sides by the Delrin spacers that separate the inner and outer shells. Fixed to this tube is an oil impregnated bronze lead nut running on a stainless-steel lead screw. The pitch of the lead screw is about 0.75 mm per turn with a total range of about 100 mm. This is what gives the ability for timing calibration over a significant range. The ends of the lead screw are supported by anodized aluminum caps that align the inner and outer shells and the Delrin spacers. The entire assembly is held on the bottom half by a yoke on a two axis adjustable stand, bolted to a fixed concrete block. This is to help center it around the beam pipe.

The ability to move the individual modules along the z-axis with good precision was crucial for the ‘‘time calibration’’ described in Section 3.

3. Response and calibration

During the RHIC running periods it is expected that each Cherenkov counter will give a common response to a given event, thus it was necessary to study the individual module responses and then match the gain and the timing of every module. The gain calibration was performed during the 2000 RHIC running period. Recording the pulse height distributions from beam–beam interactions at different high voltage settings, the parameters of the gain curve for each of the modules was obtained. Fig. 3 is the spectrum of the analogue to digital converter (ADC) signal from one of the modules of the negative paddle counter from a typical run. The first peak in the spectrum (one radiating particle) was used to estimate the calibration curve. The energy resolution ($\sigma_E/\Delta E$) of the individual modules range from 10% to 15%. The signal-to-noise ratio for the one radiating particle peak was about 6:1 for all the modules.

Using the gain curve of the individual modules, the gain of all 16 modules were matched. That is, the HV for the individual modules was set in such a way that the first peak in the spectrum corresponded to a particular ADC channel. Then between the 2000 and 2001 run period, the time calibration was performed off-line. First, the time resolution for the individual modules, $\sigma_{\text{cosmics T}}$, was determined using cosmic rays and a finger

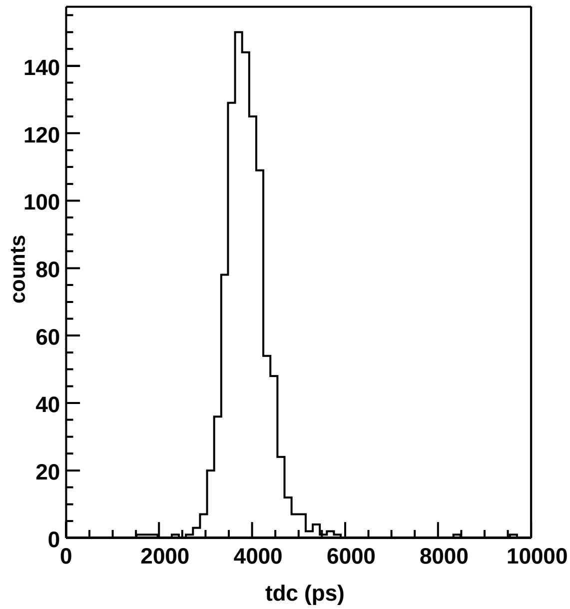

Fig. 4. The time distribution (TDC) from one module of the Cherenkov counters from a bench test using a finger scintillator and cosmic rays.

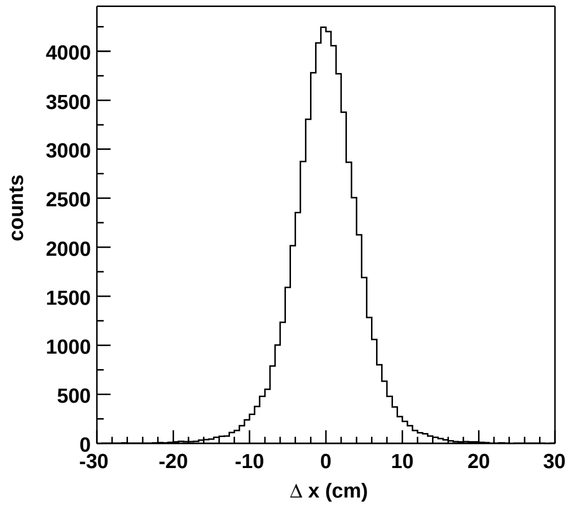

Fig. 5. The vertex distribution of the time difference between the positive and negative OR signals of the Cherenkov counters for valid vertex minimum bias Au + Au collisions.

scintillator and was found to be between 350 and 400 ps. Fig. 4 is the spectrum of the time to digital converter (TDC) signals from a bench cosmic ray test of one of the Cherenkov counters. After this test, but in the experimental hall and triggering with a collimated ^{106}Ru source of 3.5 MeV beta particles, the time difference between the signal of a common finger scintillator and the signal from the individual Cherenkov modules was recorded using a TDC. At this stage the relative time mismatches were from the signal cables, electronics (constant fraction discriminators), and phototubes.

Having tabulated the relative time delays among the 16 modules of each counter, the intrinsic response was corrected using delay cables for the gross time matching, and by displacing the modules on their mechanical structures along the z-direction for the fine time tuning (for time differences of <180 ps or 6 cm). It took several iterations to match the counters from each side to within 50 ps (mean of TDC distributions). Fig. 5 is the vertex distribution from the time difference between the positive and negative "OR" spectra of the positive (CP) and negative (CN) signals for valid vertex minimum bias Au + Au collisions. The exact meaning of the OR signals is given in Section 4. The time resolution achieved for the Cherenkov counters' vertex is about $\sigma_T = 4$ cm or 268 ps, so that total Cherenkov counter resolution $2\sigma_T/\mathrm{sqrt}(2) = 380$ ps. This is about the same as the time resolution found for the individual modules for the tests with the cosmic rays, which shows the good time matching of the individual modules.

4. Vertex-trigger implementation and performance

The minimum bias or level zero trigger (L0) used in PHOBOS during the summer 2000 run selected events based on multiplicity and occupancy coincidences between the positive (PP) and negative paddles (PN) counters. This trigger selected collision events, as well as various forms of background. The background rejection was then achieved either through hardware (on-line) or via software (off-line). This is depended on the machine conditions, the physics analysis and the capabilities of the data-acquisition system at different points during the run. An extended description of the paddle counters as well as the

PHOBOS minimum bias trigger can be found in Ref. [2].

After the background rejection, a large number of the selected events fell out of the z-range acceptance region of the PHOBOS physics analysis. The vertex trigger was then implemented to select events within the acceptance of $-15<z<15$ cm. Fig. 6 shows the details of the vertex-trigger implementation. To the left of the diagram the individual modules of the counters for the negative and positive side are represented by CP_{0-15} and CN_{0-15}, respectively. The signal from each phototube is split and sent to a Fastbus ADC (LeCroy 1881M), and to a constant fraction discriminator (CFD LeCroy 3420). The use of CFD discriminators eliminates most of the signals' slewing. There are two outputs from the CFD. The standard output-discriminated signal from each channel is sent to a Fastbus TDC (LeCroy 1875A) for off-line analysis. The second signal is the OR signal. This output is a logic OR of the 16 input channels which exceed the set threshold. The leading edge of this signal is given by the time of the fastest signal arriving to the discriminator. The OR signals from the positive and negative sides are then discriminated (reshaped) and sent to a time to analogue converter (TAC Canberra 2043). The CN signal serves as the start of the TAC and the CP as the stop. Separate gating of the TAC (from the coincidence of CP and CN) eliminates unwanted events from the vertex selection. The valid vertex output of the TAC is reshaped and set in coincidence with a valid L0-paddle signal to create the final vertex-trigger logic signal. A non-valid vertex trigger pulse is used to"fast-clear'' the events before they are recorded by the data-acquisition system.The time elapsed from the moment that a Au–Au interaction takes place to the moment when the vertex-trigger signal is ready is about 650 ns. The time scale for the logic sequence is represented at the bottom of Fig. 6.

For the 2000 and 2001 runs, the paddle counters were used to estimate the centrality of the collisions. The assumption was that the number of particles hitting the paddle counters in a collision increases monotonically with increasing number of participants, which is a measure of the reaction centrality [3]. Fig. 7 is a contour histogram of the mean of the vertex distribution as a function of the energy deposited in the paddle counters (Paddle Sum). From the most central (Paddle Sum>1500) to the peripheral bins

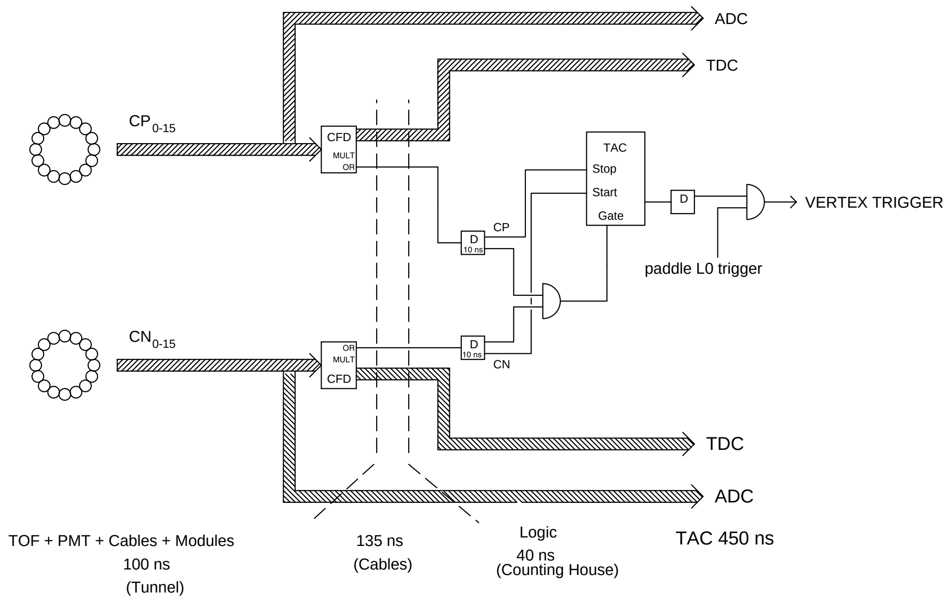

Fig. 6. Diagram of the vertex-trigger logic for PHOBOS.

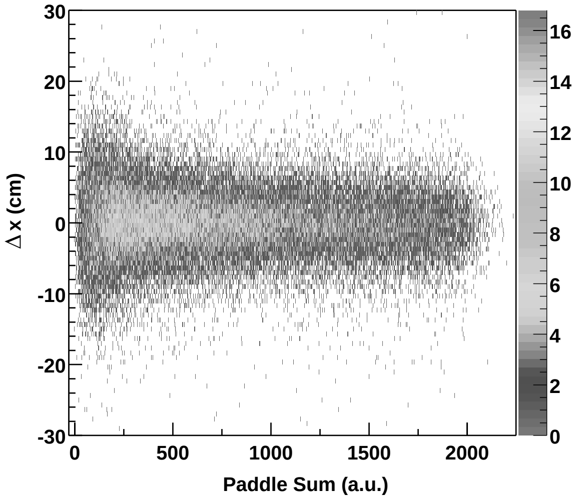

Fig. 7. Contour histogram of the vertex distribution as a function of the Paddle Sum (centrality).

(Paddle Sum < 200), the mean of the distribution remains constant. On the other hand, the sigma of the distributions goes from 3.64 cm for the most central events to 5.90 cm for the peripheral events. This is due to the efficiency of the detector, which is not optimal for the low multiplicity events. As for the other running conditions such as temperature luminosity, the vertex trigger has proven to be stable.

5. Final notes

The Cherenkov counters provided an effective on line vertex trigger during the 2001 physics run of RHIC; the Cherenkov counters achieved a signal-to-noise ratio of 6:1, with a vertex resolution of about 4 cm. The vertex trigger has proven to be constant as a function of the collision centrality and other running factors, thanks to the good performance of the Cherenkov counters. While the ability to localize the collision vertex is a necessary requirement for all the RHIC experiments, the PHOBOS's Cherenkov counters and vertex trigger are able to provide a vertex range selection in a reliable, consistent and rapid way.

Acknowledgements

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