MIPP Differential Cherenkov Counters

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Abstract

Notes on the MIPP and MTest Beam Cherenkov Counters. Win Baker put this into a powerpoint document. Edited in LaTeXby H. Meyer.

1 MIPP Beamline Differential Cherenkov Counters

Two differential Cherenkov counters are used in the Main Injector Particle Production (MIPP) experiment to identify the incident particles entering the MIPP spectrometer. They are located just downstream of the last magnet in the secondary beamline and just upstream of the MIPP spectrometer. The beam originates at the primary production target where particles are produced by the extracted Main Injector proton beam.

These two nearly identical counters were not fully tuned but were deemed adequate for the first MIPP run. Subsequently a third similar counter was built for the Meson Test Beam Facility (MTBF). There, time was available to tune the counter fully using the beam. The purpose of this note is to apply what was learned to the MIPP counters and to point out the differences therein.

Following this introduction is a report describing what was accomplished in MTBF. Perhaps most importantly, the primary mirror, M1 in Figure 1 of the report, was rocked vertically and horizontally to align the optical axis of the counter to the beam. That mirror is supported at three points forming an equilateral triangle. At each point a motor drive can move the mirror back and forth in the beam direction. At each point there is also a ten turn potentiometer to encode the position. The support at the top of the triangle was used to provide rotation about the horizontal axis, and the other two were moved in equal but opposite directions to give rotation about the vertical axis. The primary mirror in the downstream MIPP counter has a similar suspension and drive, but the position readout was originally by linear encoders. These proved to be unstable with time and have now been replaced with potentiometers. The primary mirror in the upstream counter in MIPP is supported by a gimbal that permits independent horizontal and vertical rotation. The position readout of this mirror is with two potentiometers.

Mirror rocking curves for the MIPP counters have not yet been done. The main difference between these two counters is that the upstream one is designed to operate at a Cherenkov angle of 5 milliradians and the downstream one at 7 milliradians. The MTBF counter also operates at 7 milliradians. The effect of a misaligned counter is shown in Figure 6 of the following report. As the pressure is raised the ring of Cherenkov light (BEAM in the figure) starts to migrate into the anticoincidence (outer) phototube at a lower pressure than if the primary mirror were aligned to the beam. This then. implies a higher beam momentum than it actually is. This does not confuse the identity of the particle only its momentum. Proper alignment also means more photons at the pressure curve mass peaks.

For the ranges of pressures and energies over which we operate these two counters in MIPP some interesting relations between them can be derived. These relations did not hold for the first MIPP run as the counters were not aligned with the beam.

If both counters are filled with the same gas then the peak for a given particle in the 7 mr (downstream) counter will always be a fixed interval in pressure (density) higher than in the 5 mr (upstream) counter independent of the beam energy. For nitrogen this difference is 0.6454 psia (3.14 mlb/cft) and for C4F8O it is 0.1280 psia (4.83 mlb/cft) at NTP.

It should be noted that over the region these counters are used with nitrogen all light that does not pass through the hole in the focal plane mirror is reflected by it and sent to the outside(second) phototube and can be put in anticoincidence with the inner tube. The outer diameter of this mirror corresponds to a Cherenkov angle of 30 mr. When using a heavier gas like C4F8O, however, Cherenkov light from lighter particles can lie outside the focal plane mirror and is then not available to be put in anticoincidence. This effect appears as a step in the pressure curve.

2 MTBF Differential Cherenkov Counter

2.1 A Brief Description

The downstream threshold Cherenkov counter in the MTest beam has been replaced with a differential Cherenkov counter for cleaner particle mass definition. A schematic of the optical configuration of this counter is given in Figure 1. This counter head is 2.92 meters long, is made of aluminum and contains all of the optical elements. Integral with and upstream of this is a beam tube 15.6 meters long within which the Cherenkov radiation is produced. All inner surfaces, save for the optical elements, are painted black to reduce unwanted scattered light and to preserve the Cherenkov angle of the retained light. The cosine of this angle is equal to 1/n*beta, where beta is the fractional velocity of the particle and n is the index of refraction of the gas filling the counter, typically nitrogen.

The Cherenkov light strikes the objective mirror, M1, which is 30 cm in diameter and made of glass. It has a thin spot in its center to minimize beam scattering. This spot is 7.5 cm in diameter where the glass thickness is reduced to approximately 2.5 mm. The remainder of the mirror is 13.0 mm thick. It has a focal length of 2.54 meters. Cherenkov light is focused to a ring image of radius equal to the Cherenkov angle times

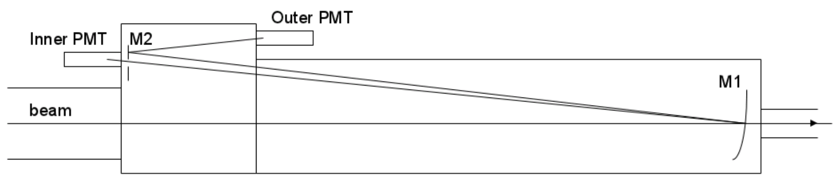

Figure 1: Differential Cherenkov Counter Optics

the focal length. The focal plane mirror, M2, has a hole in its center which lets light at Cherenkov angles up to 7 milliradians pass through to a photomultiplier tube, the Inner PMT. Light at larger angles up to 30 mr is reflected and collected by a second PMT, the Outer PMT. This glass mirror is 15 cm in diameter. The phototubes are both Hamamatsu type R2256-02. These are 12 stage 5 cm diameter tubes with quartz windows which transmit light farther into the ultraviolet than standard glass tubes (650 to 160 nm.) Operating in differential mode, the outer tube is placed in anticoincidence with the inner one. This enables one to distinguish more clearly minority particles.

2.2 Operation

Gas filling and emptying is controlled by the IFix console in the MTest Control Room Two modes of operation are possible: manual and automatic. In the former, one opens and shuts the supply valves or the pump down valves at the keyboard. The monitor displays the absolute pressure of the gas in the counter in pounds per square inch (psia) and also its density in pounds per cubic foot (lbs/cft) which incorporates the temperature. For an ideal gas the density is proportional to n1. In the automatic mode one can set the desired density and the system will go there within some error that you specify.

The graphs that follow are pressure curves taken during the initial tune-up of this counter and before final alignment of the objective mirror, M1, with the beam. Figures 2 and 3 are taken with beams of +8 and -8 GeV/C respectively. Figure 4 is with a +20 GeV/C beam. Figure 5 is Figure 4 expanded vertically and truncated to show more clearly the kaon peak.

It is recommended that the user take such a pressure (density) curve under the beam conditions they plan to use; beam conditions can change over time. As of 7/1/2008 the coincidence results are scaled on ACNET on page S17-1. The inner phototube has the outer tube in anticoincidence and this is in coincidence with the two time-of-flight scintillation counters, S1 and S2. On ACNET this is labeled MTSCL8. Also scaled separately are the inner and outer phototubes each in coincidence with S1. These are labeled MTSCL6 and MTSCL7 respectively. The S1*S2 coincidence is labeled MTSCL5.

Final alignment of this counter to the beam is/was accomplished by

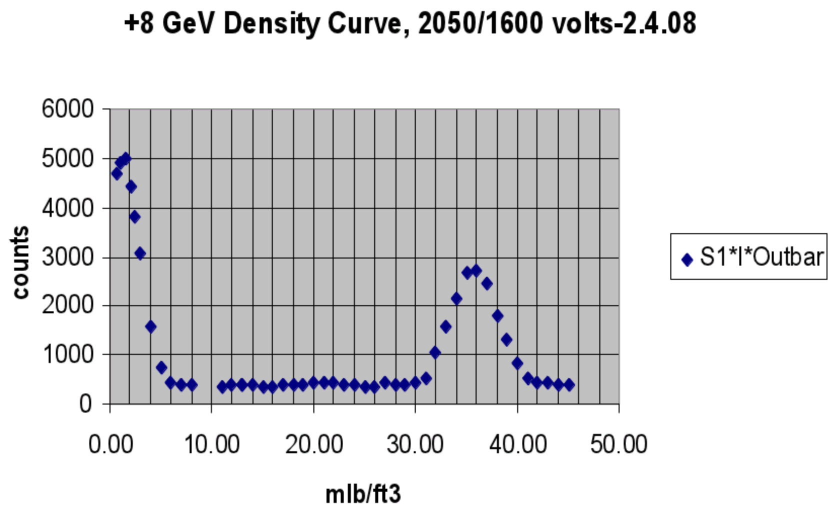

Figure 2: +8 GeV Beam. Left peak is electrons. Right peak is pions.

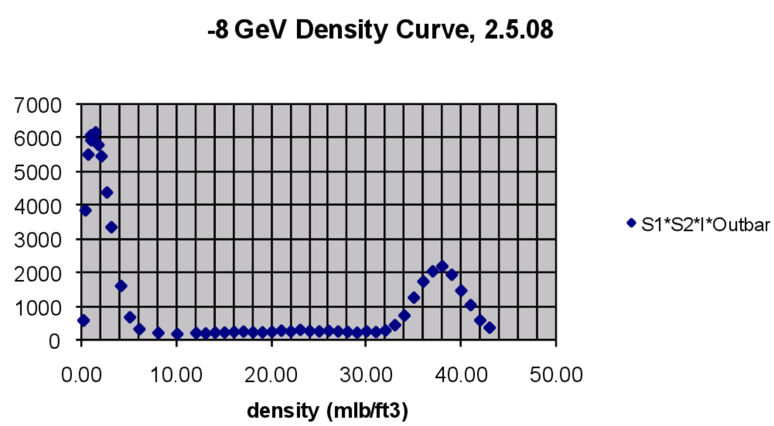

Figure 3: -8 GeV Beam. Left peak is electrons. Right peak is pions.

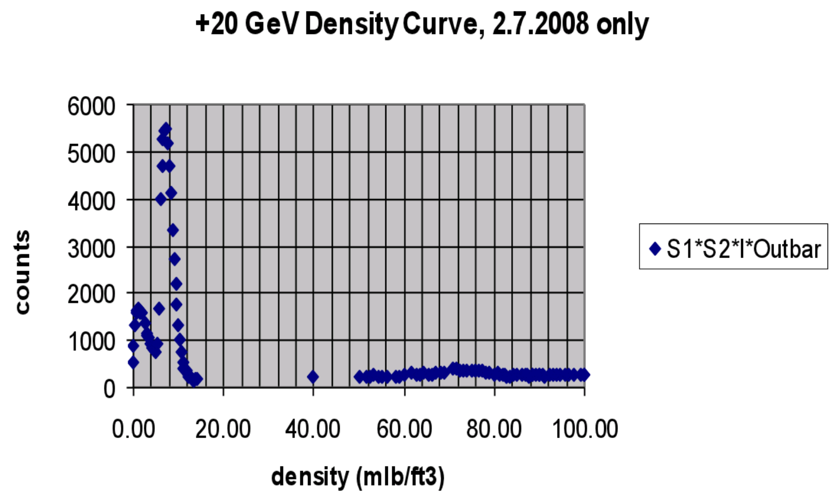

Figure 4: +20 GeV/C Density Curve: Peaks to left are electrons and pions. Kaons are to the right.

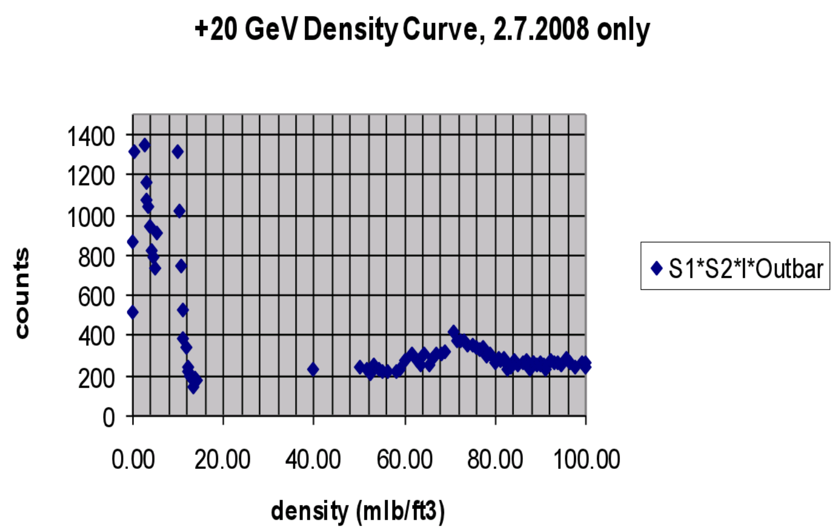

Figure 5: +20 GeV/C Density Curve truncated to show kaon peak to the right

remotely adjusting the primary mirror, M1. The effect of misalignment is shown in Figure 6 in which M1 does not center the focused light on the center of the focal plane mirror M2. As the gas pressure (index) is increased, the radius of the Cherenkov ring of light increases but only partially reflects from M2. This partial reflection continues until a high enough index is reached where all the ring of light goes to the outer phototube. This effect reduces the resolution of the counter.

The primary mirror, M1, has three points of suspension which are attached to three drive shafts that can move back and forth along the beam direction. One is at the top of the mirror, one on the east side and one on the west side. As these do not provide orthogonal motions it is recommended that the east and west drives be moved in equal but opposite amounts to obtain rotation about a vertical axis. The top drive can be moved independently to provide rotation about a horizontal axis. Drive shaft position is encoded by a ten turn potentiometer on each shaft. These are read out on ACNET on a scale of 0 to 100. Rotation about the horizontal axis of 1 mr using the top drive requires a change of 3.4 counts. Rotation of 1 mr about the vertical axis requires a total change of 2.4 counts on the east and west drives (in opposite directions, i.e. plus 1.2 on one, minus 1.2 on the other). On ACNET page S17-3 the east drive is MT6CA1, the west drive is MT6CA2 and the top drive is MT6CA3. Motion can be made using the ACNET page or using the toggle switches in the control box located in the power supply alcove (reinstall fuses). There are no mechanical stops on these potentiometers, so care must be taken not to go below a count of 10 or above a count of 90. Hex nuts on three threaded rods through the mirror support plane can be used to lock the mirror in position.

The pressure curves in Figures 7 and 8 show the individual phototube counting rates before and after alignment respectively. These were taken with the 120 GeV/C primary proton beam. It should not be necessary for the user to perform this operation, unless significant changes are made in the beamline optics.

The Figure 9 curve was made in a 32 GeV/C beam after mirror alignment. Note that it is a semilogarithmic plot. The kaon peak is an order of magnitude above the background level between it and the pion peak. Compare this with Figure 5 where even though at a lower momentum the kaon peak is comparable to the background.

2.3 Performance

Density curves indicate that this counter can tag electrons, muons, pions, kaons and protons over a range of momenta. The lowest momentum that can be tagged for a given particle is determined by the particular gas used and the pressure for which the counter is approved. This counter is approved for 1.5 atmospheres maximum.

The following table shows the lowest momenta, in GeV/C, at which this counter can in principal detect these particles in two gasses: nitrogen and C4F8O.

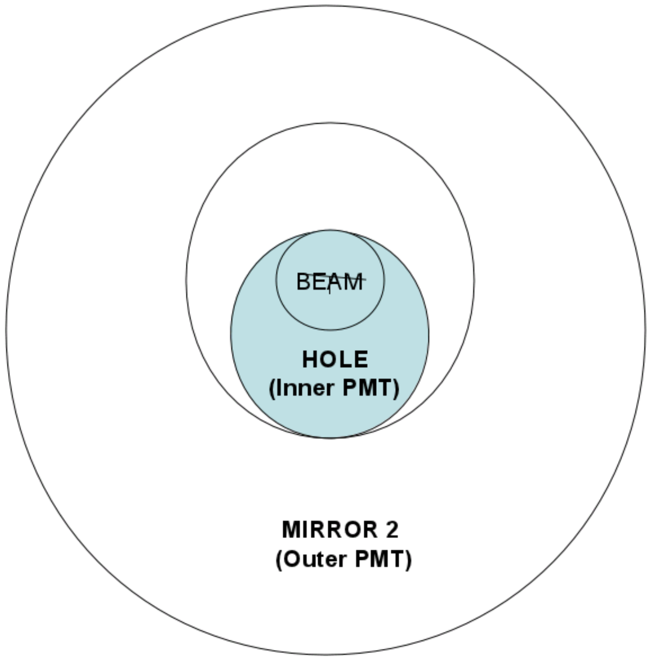

Figure 6: Beam Mirror Misalignment – not to scale

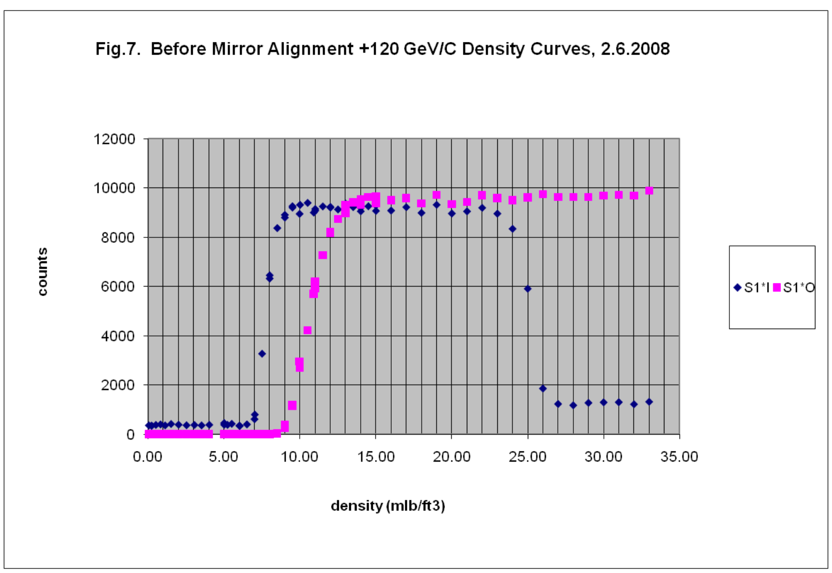

Figure 7: Before mirror alignment +120 GeV/c density curves, 6 Feb. 2008

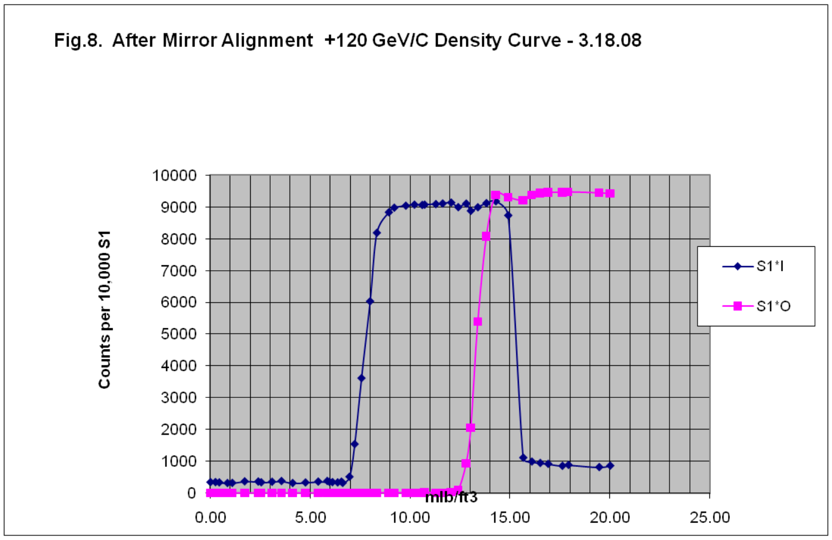

Figure 8: After mirror alignment +120 GeV/c density curve, 18 March 2008

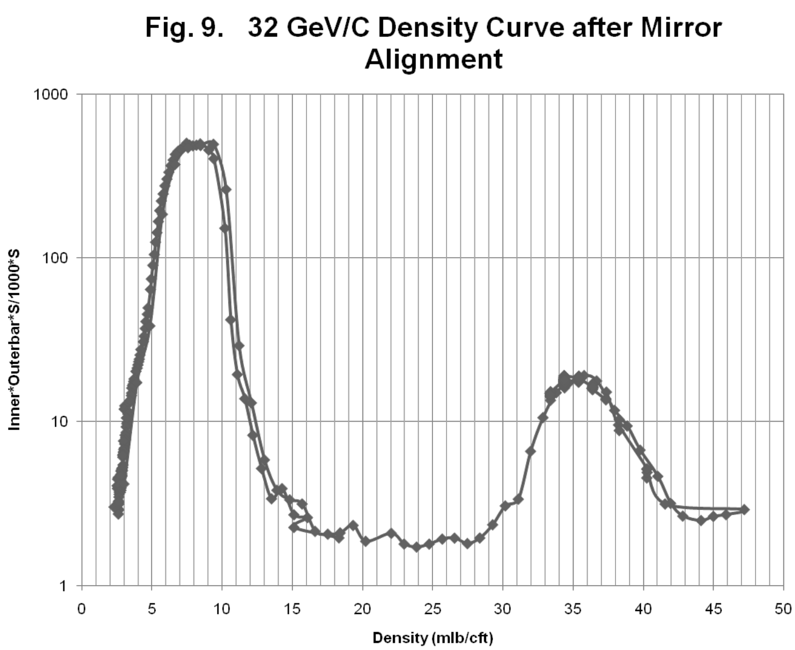

Figure 9: 32 GeV/c density curve after mirror alignment

	electron	muon	pion	kaon	proton
Nitrogen	0.02	4.0	5.0	18	35
C4F8O	0.01	1.8	2.4	8.0	15

The second gas is a substitute for C4F10 which has become very expensive if available at all. It is considerably denser than nitrogen and hence scatters beam particles more. Other gasses can be used, although they are not now plumbed into the system. To use helium, nitrogen flushing of the phototube housings will need to be activated.

The highest momentum at which a particle can be identified is determined by the velocity resolution of the counter combined with the characteristics of the beam. When carefully aligned the inherent resolution of the counter is quite small. Contributors to this are chromatic dispersion of the gas and variations in the index of refraction along the counter due to temperature non-uniformity and transients while filling or emptying the vessel. Coma, due to the off-axis use of the objective mirror, should be small. Scattering in the gas can increase the angular spread of the beam.

More significant effects are due to the beam. For the best resolution the beam particles should be parallel to the axis of the counter. In this installation the counter is located in the final section of the MTest beamline. Here the beam is converging onto a focus downstream in the test area. The angle of convergence is determined by quadrupole magnets and collimators upstream. Another effect is due to the momentum spread, and therefore the velocity spread and angular spread , of the beam.

2.4 Maintenance

The beam windows are very thin metal, a few mils, and are subject to mechanical fatigue. Therefore pressure reversals on them should be minimized. The operating program monitors the number of reversals and indicates when a safe number has been exceeded, mandating a window change.

The phototubes are outside the pressure vessel and can therefore by changed without invading it. Care must be taken to cover all light leaks. For example, ring spacers for the phototubes were made of fiberglass and therefore transmit enough light to be noticeable.

After the volume has been opened to air, it should be pumped to vacuum for some time to remove any water vapor, which absorbs ultraviolet light.