

Assembly of the Cerenkov luminosity monitor for CDF Run II

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Abstract

A brief description is presented of the assembly of the Cerenkov Luminosity Counter (CLC) which has been adopted as the luminosity monitor for Run II of the CDF experiment at Fermilab. The full monitor consists of two arrays of 48 gas-filled, reflective cones which are hand-wrapped from pre-cut aluminized mylar sheets. The cones are mounted on an installation in 3 layers of 16 cones each, all pointing directly to the interaction region. The monitor meets all performance requirements and will sit in the 3 degree hole around the beam line in the upgraded CDF detector.

Introduction

1.1. Collider Detector at Fermilab (CDF)

The Tevatron particle accelerator at Fermi National Laboratory (Fermilab) produces the highest energy collisions presently achieved. Beams of protons and anti-protons are accelerated around the 4-mile circular Tevatron ring and collide at a center-of-mass energy of 1.8 Tev (1,800,000,000,000 electron Volts). Surrounding the collision point is the Collider Detector at Fermilab (CDF), one of two major collider detectors located on the Tevatron ring, the other one being D0. About one million times per second, protons and anti-protons collide and burst into showers of secondary particles. The interactions of these particles interact with the different sections of the detector provide a means of identifying the particles and measuring their trajectory, momentum, and energy. By "reconstructing" the collisions and analyzing the data, physicists can study matter and energy in its most fundamental form.

Using data accumulated from 1992 to 1994 (Run 1), physicists working at CDF discovered evidence of collisions producing the "top" quark¹, a previously undiscovered elementary particle, and provided the first direct measurement of its mass and production cross section. This discovery marked a major success for the Standard Model of Elementary Particles², which had predicted the existence of an additional quark.

1.2. Luminosity Measurements

Luminosity is a number describing the intensity of a particle beam and is measured in $\text{cm}^{-2}\text{sec}^{-1}$. Knowing the beam luminosity is crucial in many applications such as determining the total cross section, which is the standard unit of measure for describing the probability that a particular type of interaction will occur when two specific particles collide. In order to measure the luminosity, we must first count the number of occurrences of a particular type of interaction which has a well-known cross section (typically inelastic proton-anti-proton scattering). Dividing the event rate by the cross section of the process gives the luminosity.

$$L = N/\sigma \quad (1)$$

where L is the luminosity, N is the number of events per second, and σ is the cross section.

Once the luminosity is known, the cross section for other processes can be quickly found by dividing the number of events by the luminosity.

The Tevatron is currently undergoing an upgrade for Run II (scheduled for 2000-2002) which is expected to increase the luminosity by an order of magnitude over that achieved in Run I and provide an average instantaneous luminosity of about $2 \times 10^{32} \text{ cm}^{-2}\text{sec}^{-1}$. This corresponds to an average of about six inelastic proton-anti-proton interactions per beam crossing, a significant increase over the 1.8 interactions per beam crossing in Run I.³

At such high intensities, it becomes much more complicated to make accurate luminosity measurements. The CDF collaboration has therefore adopted a new type of luminosity monitor for Run II which makes use of Cerenkov radiation⁴, the light emitted by a charged particle when its velocity exceeds the velocity of light in the same medium.

1.3. Cerenkov Luminosity Counter (CLC)

During Run I, the beam luminosity was measured by counting the rate of hits in scintillating counters placed on either side of the collision point. This technique will not be sufficient in Run II because at such high luminosities, the old detector becomes saturated and produces the same signal for different numbers of particles. The scintillating counters also have the disadvantage of being dominated by particles coming from secondary interactions within other sections of the detector rather than particles coming directly from the interaction region.³

The new monitor, called a Cerenkov Luminosity Counter (CLC), consists of two arrays of 48 gas-filled, reflective cones placed on either side of the collision point. A schematic drawing of the CLC detector can be seen in figure 1. As charged particles coming from the interaction region pass through the cones, they emit Cerenkov light, which is collected into a photo-multiplier tube (PMT). Using the amplitude and time of arrival of the Cerenkov light, one can determine the event rate for inelastic proton-anti-proton scattering, which can be substituted into equation (1) to determine the luminosity.³

This technique has several advantages over the scintillating counters. The CLC provides amplitude measurements with sufficient resolution to distinguish between one and two particles. Since particles are counted rather than hit segments, the CLC does not saturate as easily as the previous detector. Also, because the amount of light emitted by a charged particle is proportional to the length of the particle's path inside the counter, primary particles coming from the interaction region will traverse the entire length of the cones and produce a large signal. Secondary particles,

on the other hand, will cross the counter at much larger angles and travel a shorter path across the cones, resulting in a smaller signal. In addition, light from secondary particles will suffer large losses due to undergoing many reflections before reaching the PMT. Thus by applying appropriate thresholds on the amplitude, the CLC can select for and count only primary particles while discarding secondary particles, resulting in luminosity measurements with much smaller uncertainties than those provided by the Run I detector.⁵

Experimental Procedure

2.1. Cone Production

Each of the 3 different cone sizes has the same basic design. The major elements of the cone include the following: the cone itself which is made from a sheet of 100 μm thick mylar coated with a 600 angstrom thick aluminum layer, a front cap which fixes the small end of the cone in the proper position, and a light collector which directs the Cerenkov light onto the face of the PMT. The cone, along with the light collector and PMT, forms a self-sufficient counting element of the detector.

Let us now turn to a more detailed description of cone production. First, a shape with the appropriate dimensions is drawn on a sheet of aluminized mylar and cut out using a sharp scalpel. Extreme care must be taken so that the mylar is not kinked and the integrity of the aluminized surface is not compromised by scratches, smudges, excess dust, etc.

At the small end of the shape, a 1cm wide strip of the aluminum coating is sanded off using 320 grit sandpaper, while protecting the rest of the aluminized surface with a piece of excess mylar. Next, radiation-resistant epoxy is applied in a 30 micron thick, uniform layer onto the sanded region of the mylar. A front cap of the appropriate size, as pictured in figure 2, is then placed onto the epoxy, and the mylar is rolled tight around the front cap. This becomes the starting point for the rolling process.

The cone is hand-wrapped in a spiral by aligning the outer edge of the mylar sheet with a reference line which is drawn down the center of the shape while placing pieces of Scotch tape at various places along the length of the cone. The cone is rolled in such a way that the seam is invisible from the direction of the incoming particle.

When the rolling process is completed, a sample light collector with the appropriate size is fitted into the large end of the cone. If the light collector does not fit tightly at the predetermined length of the cone, the diameter of the large opening must be adjusted by removing some pieces of tape and re-rolling the cone. When the sample light collector fits properly, the actual light collector is inserted and welded to the mylar using an ultrasonic spot welder. A close up view of the light collector can be seen in figure 3.

Reinforcements are then put into place to ensure that the cone remains intact while in operation. Rings of heat-shrunk plastic are placed over the two ends and strips of mylar are welded into rings and placed at several places along the length of the cone. In addition, the front cap is fixed in place at the small end of the cone by two copper wires in case the epoxy does not hold under the intense radiation.

Finally, a laser is used to align the light collector with respect to the cone. The light collector is adjusted until the laser light passing through the collector also passes through the central hole in the front cap. When properly aligned, the light collector is fixed in place with epoxy, as can be seen in figure 3. The completed cone is then wrapped in saran wrap and placed in storage in order to minimize the accumulation of dust or other impurities inside the cone.

2.2. Assembly of the CLC

The installation which supports the array consists of the following: a hollow cylindrical tube, a round aluminum plate with attachments for holding the PMT's and light collectors at the end of the tube which is farthest from the interaction point, and two smaller aluminum plates which hold the small ends of the cones at the end of the tube closest to the interaction point.

The entire assembly will be immersed in isobutane gas which will be delivered by two sets of gas tubes. One set of tubes is distributed in the gaps between the inner cones and fixed to the installation using epoxy, as can be seen in figure 4. The second set of gas tubes will be distributed around the outer layer of cones.

A set of optical fibers is also distributed around the installation and fixed using epoxy, as seen in figure 4. The fibers will be used as part of a calibration system to ensure that all cones produce similar signals when using the same PMT. When all gas tubes and fibers are in place, the array is ready to be assembled.

To install a cone, the light collectors attached to the cones are fit snugly into the holders on the large aluminum plate. The small end of the cone is then fixed in its proper position on the small

plate using a plastic screw and nut. The cones are installed in 3 layers of 16 cones each, all pointing directly to the interaction region. Figure 5 shows the installation with the inner layer of cones assembled.

Conclusion

The construction of the CLC has been the sole responsibility of the high energy group at the University of Florida. The simple design makes the CLC relatively easy to build and operate. This along with its ability to count primary particles while rejecting secondary particles suggest that the CLC monitor is ideal for making reliable luminosity measurements for Run II. Assembly of the monitor is nearly complete and initial calibrations have begun.

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Footnotes and References

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⁴ J.D. Jackson, *Classical Electrodynamics*, 3rd edition, (John Wiley & Sons, New York, 1998).

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Figure Captions

FIG. 1. The CLC Detector

FIG. 2. Photograph of the small end of the cone with front cap.

FIG. 3. Photograph of the large end of the cone with light collector.

FIG. 4. Photograph of the installation without cones.

FIG. 5. Photograph of the installation with inner layer of installed cones.

Figures

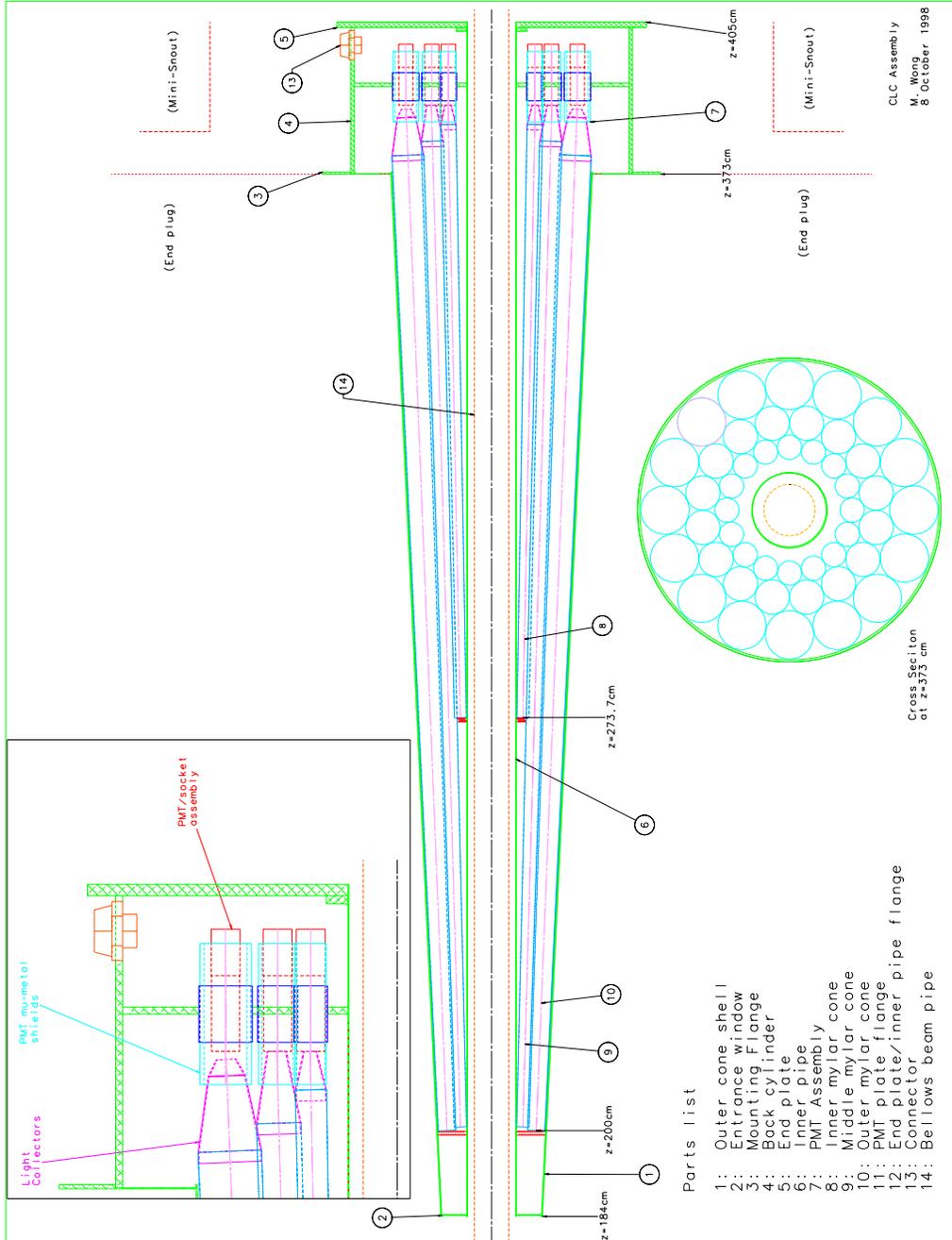


FIG. 1.



FIG. 2.



FIG. 3.



FIG. 4.

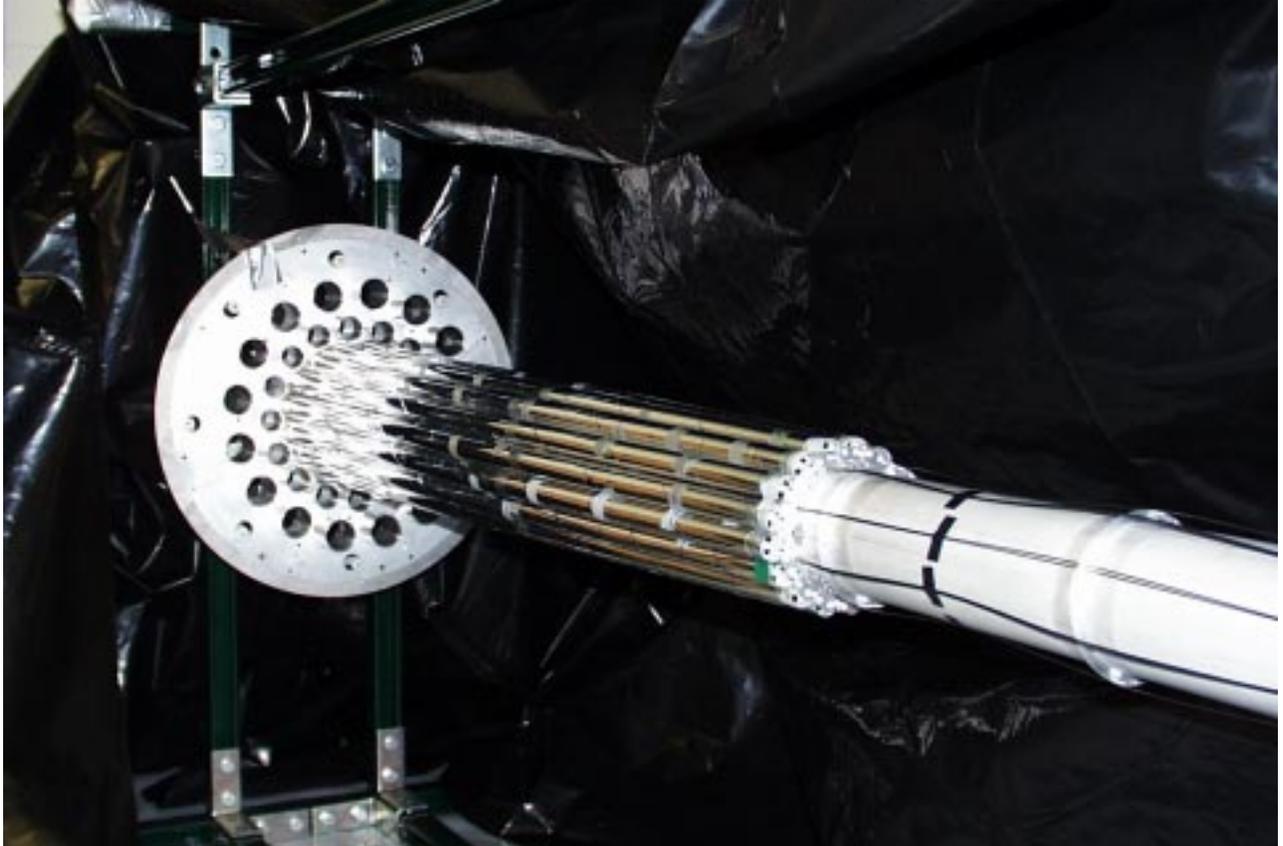


FIG. 5.