The Use of WLS Fibers in a Hadronic Calorimeter for the HyperCP Experiment

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Abstract. Preliminary results are presented on the operational aspects of an iron-scintillator sampling hadronic calorimeter used in the HyperCP experiment at Fermilab during the 1996-1997 fixed target run. The calorimeter used wavelength shifter fibers for light collection from scintillator sheets. Details of how the 2 m $\times$ 2 mm fibers were polished, sputtered, and used for the readout are discussed. The average reflectivity of the sputtered fibers was 0.85 ± 0.05, and the average attenuation lengths were 3.48 ± 0.34 m. The calorimeter was designed to trigger on the proton (anti-proton) from Λ ($\overline{\Lambda}$) decays, suppressing triggers from secondary interactions and background muons.

I INTRODUCTION

The primary goal of HyperCP is to look for direct CP violation in non-leptonic decays of Ξ and Λ hyperons. CP violation should manifest itself as a difference in the angular distributions of the daughter baryons between parent hyperon and anti-hyperon. We expect to achieve a sensitivity of 2×10^{-4} in the difference of the slopes of the Λ ($\overline{\Lambda}$) decay angular distributions. To achieve this sensitivity, an enormous sample of 75 billion triggers has been accumulated with a high-rate trigger and data acquisition system. A key component of the trigger was a hadronic calorimeter used to trigger on the large energy of the proton (anti-proton) from Λ ($\overline{\Lambda}$) decays.

II E871 SPECTROMETER

Figure 1 shows the elevation and plan views of the HyperCP spectrometer. A charged hyperon secondary beam of 150 GeV/c momentum with a 19.5 mrad angle to the horizontal was defined by a target assembly followed by a collimator with a 4.88 μsr solid angle acceptance embedded in a 6 m long 1.67-T dipole magnet.

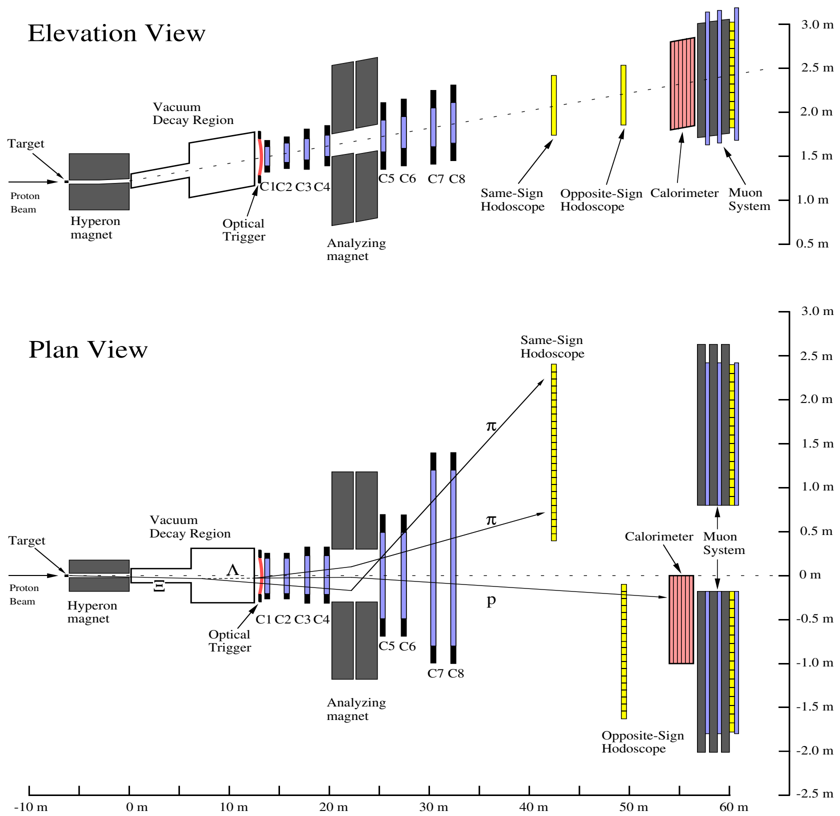

FIGURE 1. Elevation and plan views of the HyperCP spectrometer.

Immediately downstream of the decay region were four high-rate proportional wire chambers, followed by an analyzing magnet composed of two BM109 dipoles having a combined p_t kick of 1.43 GeV/c, followed by another four high-rate proportional wire chambers. The analysis magnet had sufficient strength to ensure that the protons and pions from the Ξ, Λ, and K decays were always well separated from each other as well as from the charged beam in the downstream portion of the spectrometer. This allowed a simple, yet selective, trigger to be formed by requiring the coincidence of charged particles in the hodoscopes at the rear of the spectrometer and on either side of the channeled beam. A hadronic calorimeter on the proton side was used to make the trigger "blind" to muons and to reduce the trigger rate from interactions of the channeled beam in the spectrometer. A simple muon system at the rear of the spectrometer allowed access to rare and forbidden decay physics.

III HADRONIC CALORIMETER

Due to the high flux expected for HyperCP, the hadronic calorimeter was designed to be used at the trigger level. In order for this to work, the calorimeter had to be fast since fluxes greater than 300 kHz were encountered. The calorimeter had to have a large dynamic range since it had to detect muons (for calibration purposes), and it had to contain hadronic showers in order to avoid trigger biases. Good position resolution was not necessary.

The calorimeter contained 64 layers of 2.41 cm Fe and 0.5 cm PS scintillator. Its total length was 238.92 cm, and its transverse size was 99.0 $\times$ 98.0 cm^2. It was split into 8 cells, four longitudinal and two lateral, each cell containing 256 fibers. The division into 8 cells was designed for simplicity of readout. The total interaction length was 9.6λ_I, and the corresponding radiation length was 88.5$X_\circ$. It had a sampling fraction of 3.54%. A side view of the calorimeter is shown in Fig. 2 where the particles are incident perpendicular to the absorber plates.

IV SCINTILLATORS AND FIBERS

The calorimeter incorporated a combination of scintillator and fiber, where the scintillator was the active medium. The scintillator, chosen for its speed, light output, and cost was Kuraray SCSN-38 [1]. It has a polystyrene base, butyl-PBD first fluor and PBD second fluor, with an emission frequency centered at 428 nm. Bicron BCF-92 [2] (G2) wavelength shifting fibers embedded in keyhole shaped grooves were used to carry light to acrylic light guide mixers. The fibers were 2 mm in diameter and 2 m long. This particular fiber is very bright and has a short decay time of τ=2.7 ns. It absorbs light at 405 nm and emits at 492 nm. The use of fibers rather than light guides allowed for a more hermetic calorimeter, they minimized the needed photocathode area, and they greatly simplified the mechanical design. There was a total of 32 fibers in each plane of scintillator with a spacing between grooves of 3 cm.

The fibers were read out at one end with the other end polished and sputtered with aluminum. The polishing process involved installing the fibers in a 1.8 m $\times$ 1.9 cm PVC tube that could hold up to 75 fibers. The ends to be polished were inserted in a ceramic sleeved mold to provide rigidity, and kapton tape was used to seal the bottom. Water was added to the mold, up to a depth of 7.6 cm. In steps, never exceeding a total depth of 2.5 cm, the mold was slowly immersed in liquid nitrogen, remaining there for 15 minutes. This ensured that the individual fibers were frozen in place as a complete unit for polishing.

After the fibers were frozen, the mold was inserted into a polishing machine [3] which used a 2-cutting head process. The first head of four carbon steel blades provided the rough cut, making a series of three passes, each pass cutting $\sim$1/16". The second head of two diamond blades provided the fine cut, making two passes, the first pass taking a 1 mil step and the other taking a 1/2 mil step. Polished

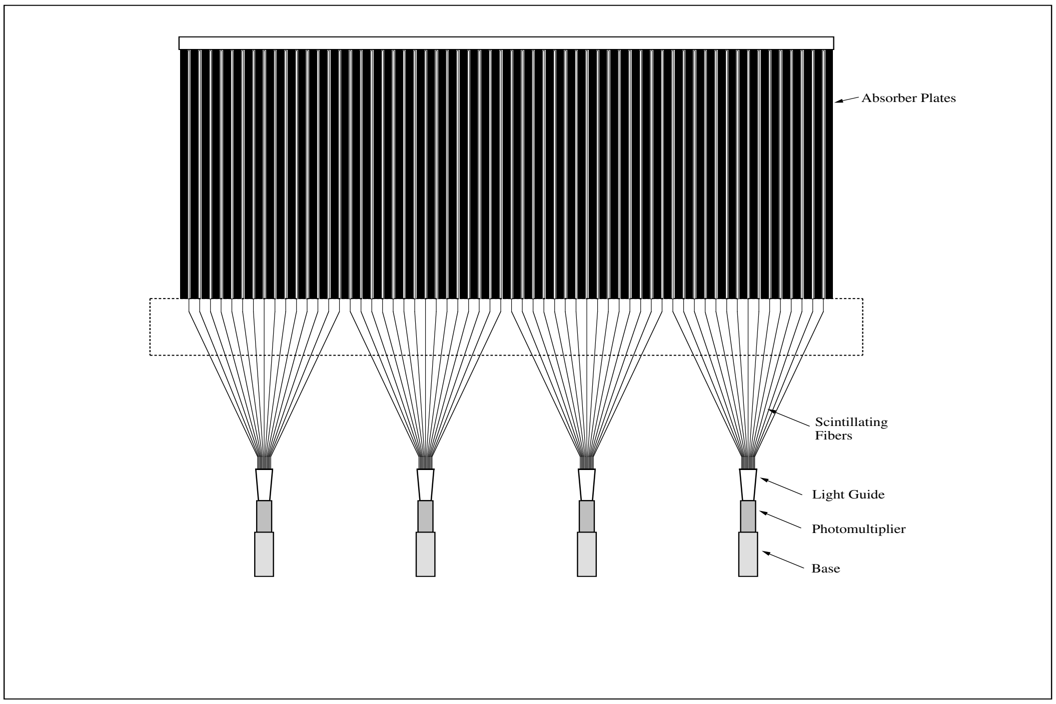

FIGURE 2. Side view of the hadronic calorimeter.

fiber ends were inspected individually for defects using a magnifying glass. Rejects, accounting for 2%, were polished again.

The fibers were aluminized in a 10-foot tubular vessel utilizing a sputtering magnetron gun driven by a DC power supply at 300 Watts. The average sputtering time was 20 minutes. For good reflectivity, 99.999% pure aluminum targets were situated a distance of 15.2 cm away from the substrate. The sputtering process was started after achieving a 10^{-6} Torr vacuum and then backfilling with "sputtering grade" Argon gas to 2 milliTorr pressure. The coating was approximately 250 nm thick and was monitored using an oscillating quartz crystal sensor device. Mylar and kapton tape were used as packaging to protect fibers from being coated insitu and in protecting the handling of fibers in installation. Ultimately, groups of 500 fibers were coated at a time. UV-curing epoxy was put on the sputtered ends for protection.

The sputtered fibers were then tested for reflectivity. Since this was a destructive procedure, only 8-10 fibers were tested from each batch. The fibers were measured twice, once with the sputtered end intact, and the other with the end cut off. A setup consisting of a UV lamp, a photodiode, a picoampmeter, and a PC was used for this measurement. The fibers were tested by exciting them with the UV lamp source and measuring their output current. The lamp source was moved in 10 cm increments along the length of the sputtered fiber, and the subsequent output currents were measured. The sputtered end of the fiber was cut off at a 45° angle about 2 mm from the end and painted black. The light output was measured again. Taking the ratio of the light output at each source position for the two measurements yielded average reflectivities of 0.85±0.05 and attenuation lengths (long component) of 3.48±0.34 m. This corresponded to a difference in light output of 6% from top to bottom of the calorimeter, well within specifications.

V CALORIMETER READOUT

Each cell of 16×16=256 fibers was potted in opaque epoxy which was attached to an acrylic light guide that mixed the light before reaching the green extended R329 Hamamatsu [4] PMT's. A high-rate transistor base was designed to provide good gain stability with rate, with about a 300 μA maximum stable operating rate [5]. The signals from the calorimeter were sent to the fast electronics room via RG-8 cabling, where they were split. The summed output of the signals was discriminated to provide an energy trigger.

The other portion of the signals from the calorimeter was sent to ADC's. These were 14-bit flash ADC's, with 1 μs conversion times, designed and fabricated to digitize the calorimeter signals for the data acquisition system.

The calibration of the calorimeter was performed by using particles of well measured energy impacting it, such as the protons from Λ decays. Cell-to-cell gains were adjusted during the run using muons which produced 1.6 photoelectrons per plane of scintillator. A light pulser system using a Nitrogen laser and PIN diodes was also used to monitor the time dependence of the calibration.

VI CALORIMETER TRIGGER PERFORMANCE

Figure 3 shows how the calorimeter performed. The minimum proton momentum from a Λ decay was around 70 GeV/c. The trigger threshold was set to a conservative value of about 50 GeV. The left plot is the trigger acceptance as a function of energy for charged particles entering the calorimeter. Typical efficiencies were greater than 99%. The right plot is the uncalibrated sum of the ADC's for a momentum cut between 100 GeV/c and 120 GeV/c. The preliminary (uncalibrated) estimate of the calorimeter resolution is $\sigma/E = 80\%/\sqrt{E} \oplus 2.5\%$.

The calorimeter trigger proved to be a vital component of the main triggers, reducing the trigger rate for Ξ's and K's by about a factor of six. The fast response of the wavelength shifting fibers allowed us to use the calorimeter as a trigger in a very useful way.

VII ACKNOWLEDGEMENTS

We thank the Fermilab staff for their contributions to this experiment and for machining the keyhole shaped grooves in the scintillators and in the fiber polishing

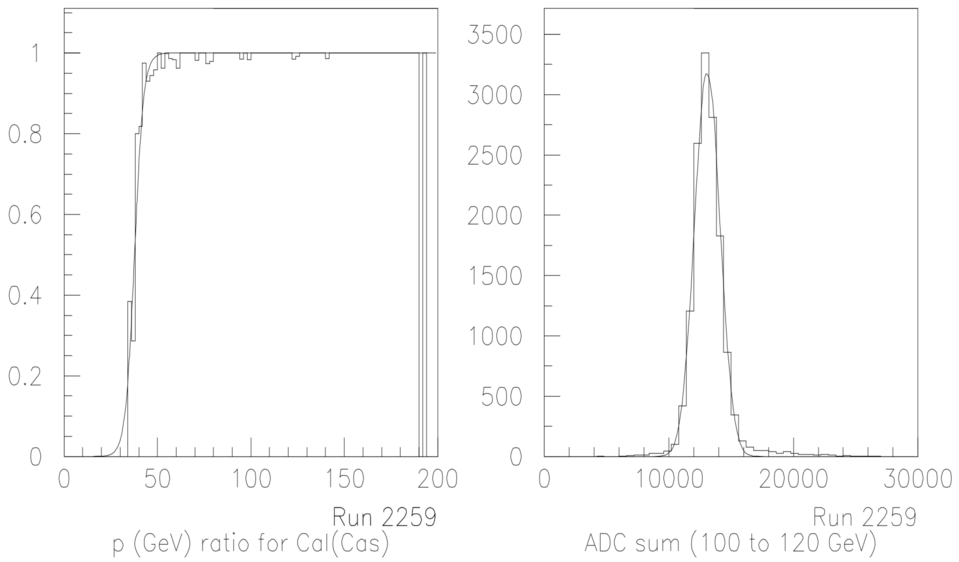

FIGURE 3. Calorimeter energy and resolution.

and sputtering processes. Thanks especially to Phyllis Deering for the machining of the keyhole shaped grooves in the scintillators, and thanks to Eileen Hahn for the sputtering of the fibers. This work was supported in part by the U.S. Department of Energy and the National Science Foundation.

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