Performance Measuremements of Histe-V VLPC Photon Detectors for E835 at FNAL

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Abstract. A set of 144 VLPC chips has been used by experiment E835 at FNAL for the readout of its scintillating fiber detector. During the data taking, the fibers have been exposed to rates up to 2.5×10^4 mips/sec, corresponding to 3.5×10^6 photons/sec on each VLPC pixel surface.

This paper reports about a study on rate dependence of gain and quantum efficiency throughout the run, as well as VLPC failure statistics during operation. No significant aging effects are observed. A review about the overall system performance is given.

INTRODUCTION

In the last decade, significant progress has been made to exploit the scintillating fibers in high energy physics experiments. A major contribution to this achievement comes from the photodetecting device used: the VLPCs [1] are solid state photosensitive devices, pioneered by M.Atac, produced by Rockwell International in collaboration with Fermilab, for the future upgrade of the D0 tracking system [2].

The promising results obtained from a cosmic ray test on a prototype, using Histe-IV VLPCs, done in collaboration with D0 [3], led to the approval of the construction of a scintillating fiber tracking system for the E835 collaboration. The next generation of devices, Histe-V, was expected to have reduced noise and slightly higher quantum efficiency (QE) and was conceived by the D0 experiment as an intermediate step for the development of the final version. As well as a thorough characterization of the chips, to study VLPC QE, gain and noise at different rates, the construction of a medium size detector for a real experiment was the ideal follower of the cosmic ray test. A detailed report of the performance of the detector is given elsewhere [4–6]: this paper wants to focus on the response homogeneity, short and long term stability of the photosensitive devices.

THE VLPC SETUP

We assembled 160 Histe-V arrays in 10 modules (referred to as *cassettes*), with 128 VLPC channels each: 9 cassettes were used, 1 was kept as a spare. The system was designed so that a large fraction of spare chips was available to compensate for channel losses during the run: out of 1152 pixels, only 860 were actually coupled to scintillating fibers.

Cassettes

Cassette Assembly. Each VLPC array is made of 8 round pixels, 1mm diameter, aligned in a row. The chips were indium soldered on gold plated AlN substrates. The poor quality of the metalization process will turn out to be the major source of problems for these devices. A gold wirebond brings the signal from the VLPC pixel to the substrate. To allow safe handling of the devices, the VLPC+substrate ensembles (referred to as *hybrids*) were glued on plastic (Torlon) carriers.

All hybrids were characterized [4] and sorted in order to group arrays with comparable gains and QEs within the same power supply channel. Clear fibers were then glued on the Torlon carriers, facing the VLPC pixels at a distance of approximately $100\mu m$. Direct contact was avoided in order to prevent chip damage. Ribbon cables (multi-layered copper-Kapton strips) were micro-welded on the VLPC substrates. Each cassette houses 16 such assemblies (VLPC hybrid+cable+fibers).

Controls

Cryogenic system. A 12-cassette cryostat [4,7], built at Fermilab, was used to maintain the VLPCs at a temperature T=6.5K. The dewar was put at a distance of about 1 meter upstream of the interaction vertex. The cryogenic system was operated smoothly for most of the data taking period, keeping the devices at a constant temperature, within ΔT=4mK. Nonetheless, a few unexpected warm-ups occured, due to scheduled shutdowns, and to failures in the liquid helium supply system.

Power supply. The VLPC bias voltage is provided by a 32 channel CAMAC module, custom made in Ferrara. A built-in 11-bit ADC monitors the current drawn by the chips. A maximum current of 200 μA was allowed for each channel, supplying 32 VLPC pixels. Most channels drew currents between 10 and 20 μA, i.e. 2.5 to 5 μA per VLPC chip. VLPCs were operated at 6.4 Volts until the spring 1997, when, in order to improve the signal equalization, some bias voltages were slightly adjusted. In the range between 6 and 6.5 V, I_{bias} depends exponentially on bias voltage: $\delta I/I = 2.5 \cdot \delta V$(in Volts).

Analog signal readout. The signals from the VLPCs, amplified by QPA02 preamps [8] are sent to 32 splitter-discriminator-or NIM modules: the description of the digital readout chain can be found in [6]. The analog outputs were sent to ADCs: initially, only 538 VLPC pixels (coupled to 430 inner fibers and 108 outer fibers, at wider polar angles), were read out by ADCs, mostly for calibration and diagnostic purposes. During the December 1996 shutdown, the ADC coverage was extended to almost all the fibers: the system homogeneity and stability was satisfactory enough to exploit the fibers for a dE/dx measurement. Most data were taken with a 150-nsec-long ADC gate; it was broadened to 250 nsec from March to June 1997, during the scan of the η_c resonance, taken at low luminosity. A 16% increase of the signal is measured with wider gates.

PERFORMANCE OF THE SYSTEM

The system was operated continuously for about 1 year of data taking; the total integrated luminosity amounts to 143 pb^{-1}. Experiment 835 [9] at Fermilab studies the direct formation of charmonium states from $\bar{p}p$ annihilations: most data (122 pb^{-1}) were taken with instantaneous luminosity $\mathcal{L} \simeq 2 \cdot 10^{31}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, at $3.4 \leq \sqrt{s} \leq 3.7$ GeV, for studies on ψ' and χ states, and search of the η_c'. The rest of the data, at $\mathcal{L} \simeq 10^{31}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, was taken in the energy range of η_c and J/ψ. The luminosity was kept constant adjusting the jet target density to compensate the decrease in the beam current.

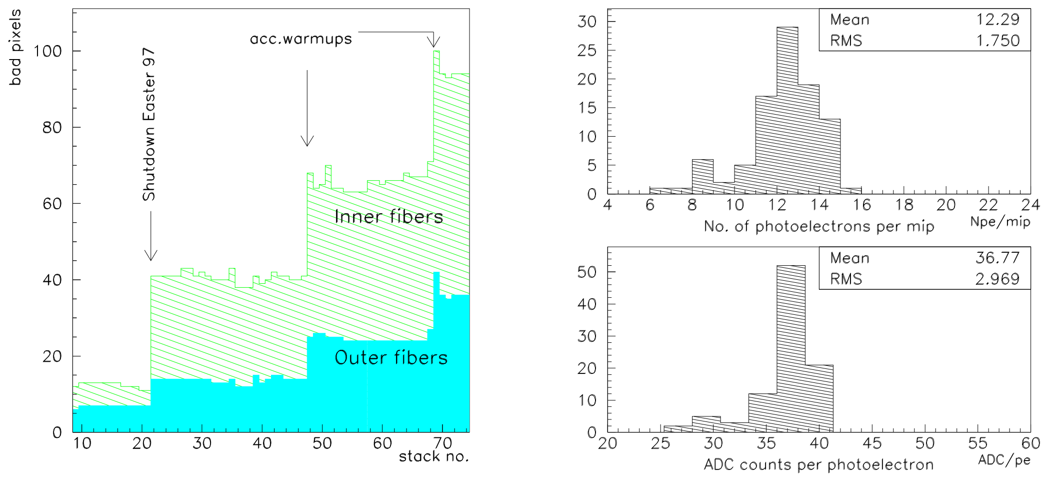

FIGURE 1. (a) Dead pixels vs stack number; (b) Detector calibration: Npe/mip (top) and ADC/pe (bottom) distributions for 1 cassette.

PIXEL LOSSES. At the end of the run, 94 out of 860 pixels no longer produced a signal, most losses occured after warmup cycles (see fig.1a), and are due to the breakage of the electrical contact between the metalized plate that supports the

VLPC and the copper-Kapton flex cable that brings the signal from the cold to the warm end of the cassette. The pixel failures did not cause significant efficiency losses, as most tracks crossed more than one fiber.

DETECTOR CALIBRATION. Various changes were done on the readout chain during the run: FERA gate delay and width, VLPC bias supply, connector cards to the FERA inputs. Samples of both hadron and electron tracks were used, to calculate the normalization constants for each channel, defined as ADC/mip ratio. The ADC/mip ratio can be decoupled in two separate contributions:

$$\frac{ADC}{mip} = \frac{ADC}{pe} \times \frac{N_{pe}}{mip}$$

The ADC/pe ratio (ADC counts per photoelectron) is a function of the VLPC and preamp gains, the signal attenuation along the cables, the gate width to the ADC. The Npe/mip ratio (no. of photoelectrons per mip) depends on the fiber light yield and transmission properties, the transparency of the optical couplings, the reflectivity of the fiber ends, and finally the VLPC QE.

The ADC/pe ratio was measured during the Easter 1997 shutdown, replacing the fiber bundles from the tracker with a pulsed LED. The ADC/pe and Npe/mip distributions are shown in fig.1b.

LONG TERM STABILITY. The integrated dose received by each fiber during the run adds up to a total of 0.8 kRad in the forward direction (0.4 at large angles). To estimate the aging effects on the whole system (i.e: on fiber light yield, on connection transparencies, as well as on VLPC intrinsic characteristics), all the contributions due to changes in the readout chain had to be deconvoluted.

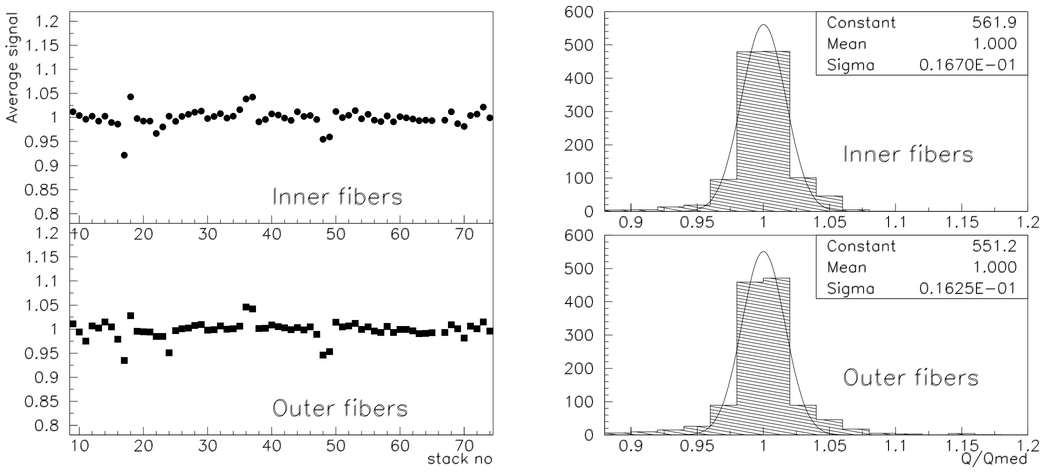

FIGURE 2. Average Signal vs time during the 1997 data taking

Fig.2a shows the time variation of the renormalized average signal, throughout the 1997 run. The average signal distribution over the whole run has a spread $\sigma_Q/Q = 1.6\%$ (fig.2b).

Rate effects. During the characterization of the devices, rate effects on the VLPCs were observed on the test stand, when all the devices were simultaneously irradiated with an LED source [10]. The final answer on all possible rate dependent effects could only come from a real running experiment. Fig.3a shows the rate of tracks per fiber (i.e: per VLPC pixel) as a function of the polar angle θ, with respect to the beam axis, in the LAB frame. The minimum bias rate per fiber is constant between 15 and 40 degrees, at both high and low CM energy.

We analyzed data from a set of runs not affected by changes in the readout chain (therefore using only 1 calibration constant), taken at both high and low $\mathcal{L}$. The average signal dependence from $\mathcal{L}$ of fibers in this angular range is shown in Fig.3b, from $\mathcal{L} = 0.5$ (upper curve) to $2.5 \times 10^{31}\mathrm{cm}^{-2}\mathrm{s}^{-1}$ (lower curve).

The excellent homogeneity along the fiber length (the average signal variation from the far to the near end - left to right in the figure - is $\approx 3.5\%$), is due to the high reflectivity of the mirrored end, as well as the high attenuation length of the scintillating fiber. Both the average signal and its slope show negligible rate dependence ($< 1\%$).

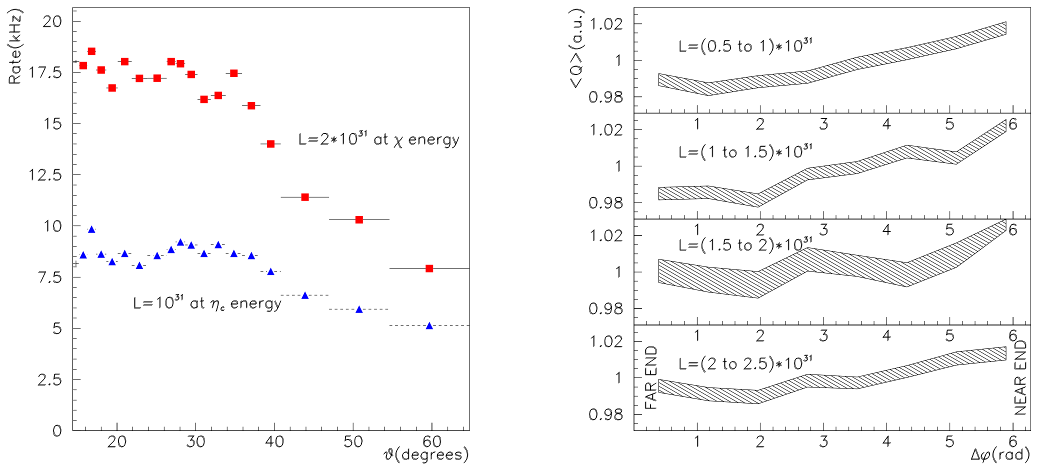

FIGURE 3. (a) Minimum bias rates (N.tracks per second per fiber) vs θ ; (b) Average signal along the fiber ($\Delta\varphi$ is the azimuthal distance from the fiber end) with increasing $\mathcal{L}$: the same normalization constant has been used for the whole data set.

Crosstalk An estimate of the crosstalk between neighboring pixels can be given exploiting the VLPC channels that are not directly coupled to scintillating fibers. Most of these spare pixels are adjacent to channels actually coupled to fibers. Selecting events having one or both neighboring pixels hit by real tracks, we estimate an average crosstalk level about 1% (with a threshold at 80 ADC counts).

CONCLUSIONS

Experiment 835 at Fermilab has operated a system of 144 VLPC arrays, coupled to two layers of scintillating fibers, for approximately one year of data taking. Despite 11% of the channels were lost during cryo-cycles, the VLPCs showed impressive homogeneity and stability. Effects of radiation damage and rate dependence of the signals from the devices were investigated: the devices showed no variations at percent level.

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