E13-2000-127

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TEST OF LONG SCINTILLATING COUNTER PROTOTYPES FOR **CDF-II**

Presented at the 8th Pisa Meeting
on Advanced Detectors «Frontier Detectors for Frontier Physics»,
May 21–27, 2000, La Biodola, Isola d'Elba, Italy

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1. Introduction

Long plastic scintillator counters have been and are planned to be widely used in particle physics experiments. In these detectors the light is usually sent to the photocathode of the photomultiplyer tube (PMT) from the end of the scintillation bar through a "fish tail" or a strip-light plexiglass light guide. This standard scintillation counter design has essential disadvantages:

- light propagates along scintillation bars due to multiple total internal reflection, therefore, slight natural and radiation degradation of basic parameters of scintillation bars (light output, transparency, surface polishing quality) with time results in a considerably decreasing light signal on the far end of extended counters;
- effective light collection from the scintillation bar end through a plexiglass light guide requires an expensive PMT with a large area photocathode because the light collection efficiency is determined by the ratio of the photocathode area to the scintillation bar end area;
- plexiglass light guides and large PMT's occupy considerable space, which results in appearance of insensitive zones, smaller geometrical efficiency, and a large size of experimental setups;
- scattered magnetic field is usually present at the locations of scintillation counters, which requires that PMT's should be shielded; large PMT's are very sensitive to magnetic fields and thus long, sophisticated light guide configurations are often necessary to keep PMT's away from the magnetic field.

The present paper deals with designs and first investigations of new-generation scintillation counters that are almost free of the above disadvantages. In these counters light collection occurs via wavelength shifting fibers and light is detected by new ultra compact PMT's.

The work was carried out in the frame of the R&D programme for development of CDF trigger muon systems [1]. Prototype trigger muon scintillation counters for the CDF II subsystems CSP (Central Scintillator uPgrade), BSU (Barrel Scintillator Upgrade) and WSU (Wall Scintillator Upgrade) were developed and tested [2].

2. Counter design

Plastic wavelength shifting fibers allow to create very compact light collection systems which are successfully used in scintillation sandwich calorimeters [3, 4]. Small amount of light collected from each scintillation layer of the calorimeter traversed by a particle with minimum ionization is not critical because the detector signal is formed by a large number of layers. We used a similar method to collect light from large scintillation bars. The investigation was carried out with two rectangular counters measuring $180\times17\times2$ cm^3 (BSU), $300\times30\times2$ cm^3 (CSP) and a trapezoid counter measuring $180\times40\times30\times1.5$ cm^3 (WSU).

The counter design is shown in Fig. 1. Bars were made of scintillator UPS-923A on the basis of polystyrene doped with PTP (2%) and POPOP (0.03%) at the Institute "Monokristall" (Kharkov) [5]. All surfaces of the scintillator bars were polished.

The bars have a small notch for an ultra-compact PMT in a corner (Fig. 1). The area of the notch is only a few tenths of a per cent of the total counter's area. Therefore, the notches only insignificantly affect the geometrical efficiency of the counters. Wavelength shifting fibers with diameter 1 *mm* (20 for the CSP and BSU counters, and 15 for the WSU counters) were glued by optical glue parallel to one another along the narrow long side of the bar. The fiber ribbon was made into a bundle at the notch and glued inside the cylindrical adapter. The adapter end was milled to have a necessary flat surface for the optical contact with the PMT photocathode. The other end of the fibers was blackened in a first set of measurement, than grinded flat with sending paper and a small piece of aluminium foil applied with optical glue. This very simple technique provided a reflectivity of about 60%.

Aluminium foil strips were fixed to all ends of the scintillation bar to reflect the outgoing light back. A light-reflecting aluminium strip was also glued by optical glue to the outer side of the wavelength shifting fiber ribbon to increase the light capture efficiency. The counter was wrapped up in aluminized paper and black plastic for light tightness. The aluminized paper surface was like orange skin, which prevents mirror reflection and thus improves transport of light from the scintillator to the wavelength shifting fiber light guide.

The light guide was made of multiple cladding wavelength shifting S-type fibers Y11 (200 *ppm*) and K27 (200 *ppm*) from Kuraray (Japan) and Pol.Hi.Tech. (Italy). The fiber core was of polystyrene doped with a spectrum shifter Y11 or K27. The inner cladding was of polymethyl methacrylate (PMMA), the outer cladding was of fluorinated PMMA. The light capture efficiency of these fibers is 5.34% as opposed to 3.4% of single-cladding ones.

The photodetector was a new ultra compact Hamamatsu PMT R5600 16 *mm* in diameter and 11.5 *mm* long. The effective diameter of the photocathode was 8 *mm*.

3. Measurements and results

The light yield of the counters was investigated with cosmic muons selected by a telescope of two small scintillation counters (4×7 cm^2). The counter to be studied was placed between them. Moving the telescope along the counter axis, we measured dependence of the light yield on the distance from the bar edge. A LeCroy ADC 2249A charge-digital converter measured the PMT signal amplitude. The spectrometric channel was calibrated in absolute units, i.e. in the number of photoelectrons created on the PMT photocathode. Thus, spectra of the number of photoelectrons arising from passage of a cosmic muon through the counter were obtained. The calibration was done by means of a LED, using light flashes of low intensity. The calibration method and measurements are detailed in [5, 6, 7].

Figures 2-3 present the results of counter prototype tests using the Y11 fibers. Figure 2 shows the light yield dependence on the distance from the counter front edge for the BSU and WSU counters. To estimate the quality of the reflector made by the above-mentioned simple technology, the counters were tested with blackened and aluminized ends of fibers.

The experimental data was fitted by the exponential function $A\times exp(-x/\lambda)$. The effective attenuation length for the BSU prototype is about 200 *cm* with blackened fiber ends and 290 *cm*, with ends aluminized. The light reflection coefficient from the end is ~50%. These characteristics for the CSP prototype are shown in Fig. 3. The effective attenuation lengths are about 270 and 470 *cm* for different light collection conditions. The reflection coefficient is about 60%.

The wavelength shifting fibers have a greater transparency to their own emission than the scintillator. Therefore, the effective attenuation length in such counters depends basically on the fiber transparency, but the scintillator transparency is essential too. The effective attenuation length is larger in the WSU prototype (Fig. 2) due to the configuration of the bars that leads to absorption of more scintillating light in the WSU counter.

The dopant Y11 feature overlap of the emission and absorption spectra. The reabsorption effect shifts the emission spectrum to the long wave region, where the absorption is less significant while photons are propagating in the fibers. Thus, the reabsorption process increases the attenuation length when the light way in the fiber increases. Therefore, the effective attenuation length in the CSP prototype ($\lambda \approx 470$ *cm*) is larger than in BSU ($\lambda \approx 290$ *cm*).

We assembled a WSU counter with two different fiber ribbons (Y11 and K27) glued on the opposite sides of the trapezoidal scintillating bar to directly compare their quality. Ends of fibers are blackened. The test showed that the light yield of Y11 was 1.4 times better than that of K27 (Fig. 4). The effective light attenuation length was 1.2 times larger for Y11. Therefore, it is more preferable to use ribbons with Y11, especially for long counters (~3 *m*).

4. Conclusion

The investigations have shown that the long counters with readout by wavelength shifting fiber ribbons provide good light yield uniformity. The effective attenuation length is $\lambda=290$ *cm* in the BSU counter, $\lambda=470$ *cm* in the CSP counter and $\lambda=350$ *cm* in the WSU. The light yield from the far end from a particle with minimum ionization was about 37 photoelectrons for the BSU counter, about 25 photoelectrons for the CSP counter and about 21 photoelectrons for the WSU. The amount of light is sufficient for CDF needs even taking into account some expected reduction of light yield with time. Therefore, there is no need in a double layer of spectrum-shifting fibers, which allows approximately a 20% increase in light yield but makes the counter design more complicated.

Note also that the simple technology for making a reflector on the far ends of the fibers allows a light reflection coefficient about 60%. More sophisticated technologies (e.g. deposition of aluminium, etc) allow larger reflection coefficients (up to 80—90%) but are more labour consuming and increase the cost of the detector.

The developed scintillation counters have appreciable advantages over the standard ones with "fish tail" and strip light guides:

- simple design (absence of complicated light guides and big photomultipliers);
- smaller losses for multiple reflection and bulk absorption in the scintillator because light is collected from the longer side of the scintillation bar and light propagates mainly along its smaller side; as a result, requirements to the surface polishing quality, transparency and light output of the scintillator are less severe and the counter characteristics are much less influence by natural and radiation degradation of these parameters with time;
- smaller insensitive areas and compact size of the detector due to the use of wavelength fibers and small-size PMT's;
- the possibility of using counters in magnetic fields with simple shielding or without any shielding because of ultra compact photomultipliers R5600 with their very low sensitivity to external magnetic fields.

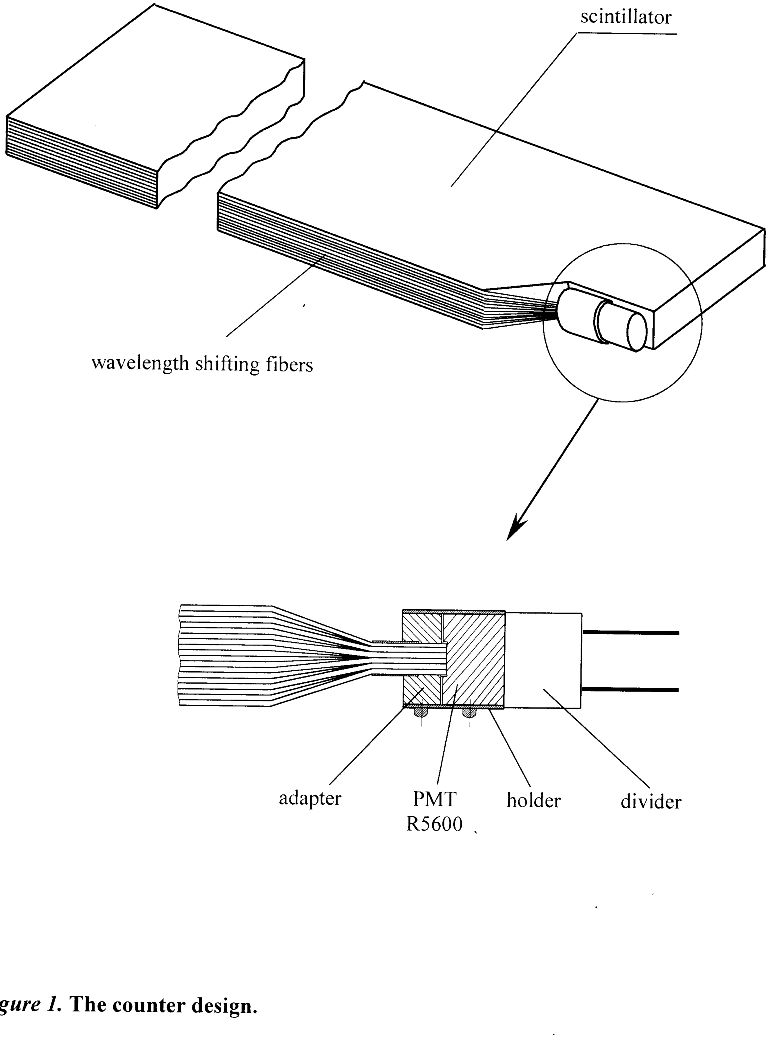

Figure 1. **The counter design.**

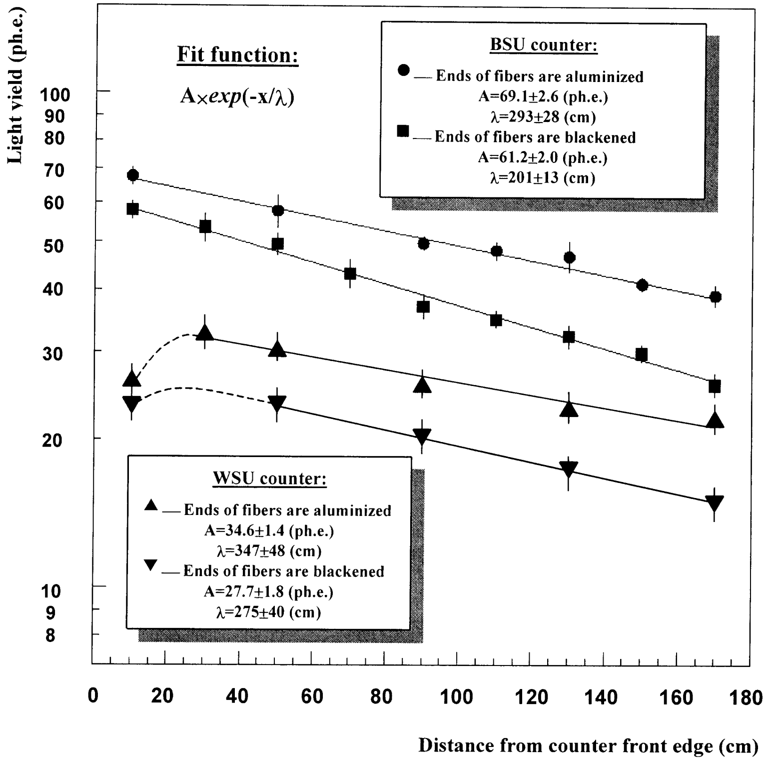

Figure 2. **Attenuation curve with and without mirroring the far end of the fibers (BSU and WSU counters).**

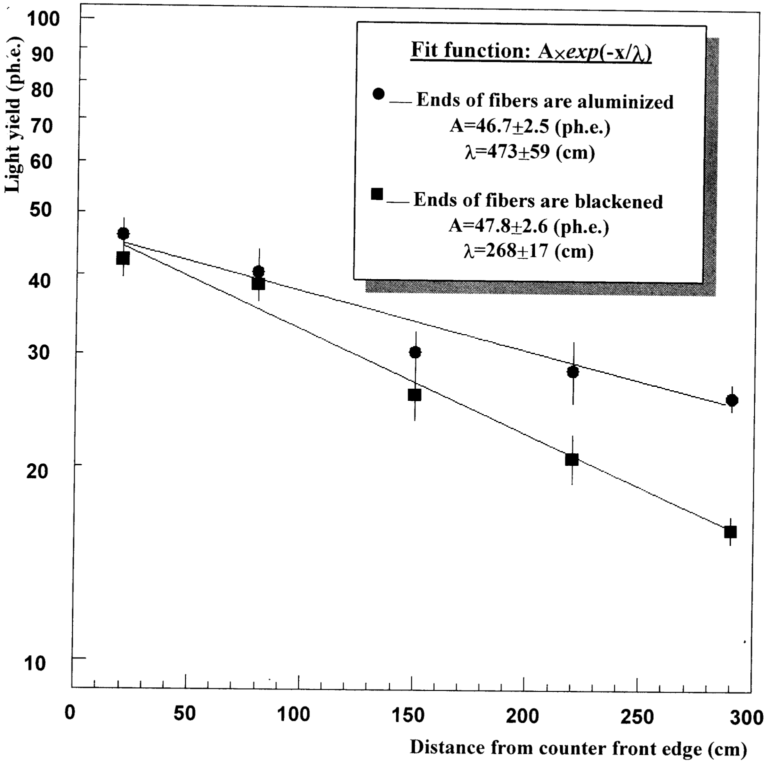

Figure 3. Attenuation curve with and without mirroring the far end of the fibers (CSP counter).

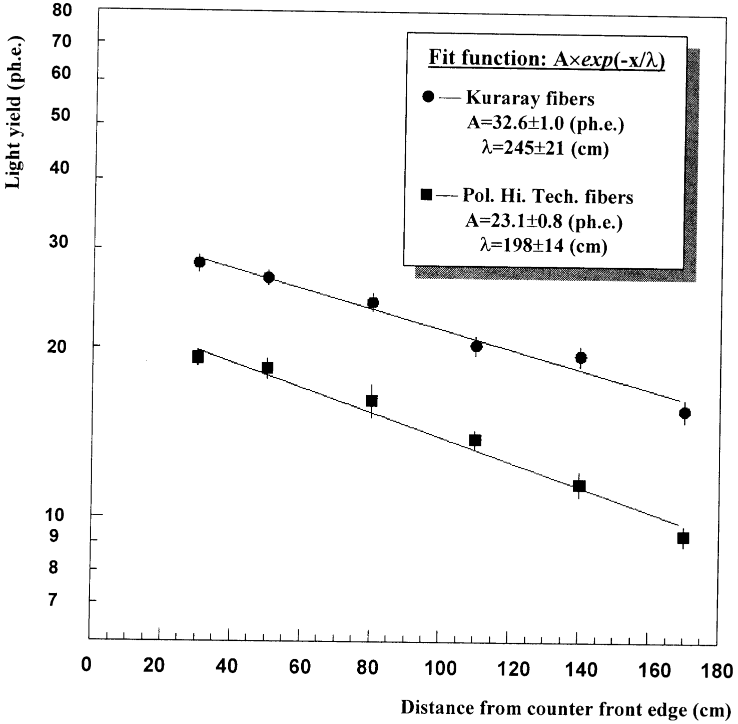

Figure 4. **Attenuation curve with the different type of fibers (WSU counter).**

The extreme simplicity of the counter design and the optimal active-to-total surface ratio make this technique very attractive and recommendable.

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Received by Publishing Department
on May 31, 2000.

Будагов Ю. и др. E13-2000-127

Испытания прототипов длинных сцинтилляционных счетчиков для CDF-II

Проведены испытания прототипов длинных (до 3 м) сцинтилляционных счетчиков нового типа, разработанных для CDF-II. Спектросмещающая волоконная лента использовалась для сбора света, а новый сверхминиатюрный фотоумножитель R5600 — для детектирования света. Эффективность регистрации минимально ионизирующей частицы была высокой на всех прототипах. Светосбор от дальнего конца счетчиков составлял более чем 20 фотоэлектронов.

Работа выполнена в Лаборатории ядерных проблем им. В.П.Джелепова ОИЯИ и в Национальном институте ядерной физики, Пиза, Италия.

Препринт Объединенного института ядерных исследований. Дубна, 2000

Budagov Ju. et al. P13-2000-127

Test of Long Scintillating Counter Prototypes for CDF-II

New type long (up to 3 m) scintillating counter prototypes, developed for CDF-II, have been tested. The shift-spectrum fiber ribbons were used for light collection, and modern ultra compact photomultipliers R5600 were used for light detection. The efficiency for m.i.p. was excellent for all prototypes. The light yield from the far end of the counters was found to be more than 20 photoelectrons.

The investigation has been performed at the Dzhelepov Laboratory of Nuclear Problems, JINR and at the Istituto Nazionale di Fisica Nucleare, Pisa, Italy.

Preprint of the Joint Institute for Nuclear Research. Dubna, 2000

Макет Т.Е.Попеко

Подписано в печать 14.06.2000
Формат 60 × 90/16. Офсетная печать. Уч.-изд. листов 1,14
Тираж 325. Заказ 52078. Цена 1 р. 40 к.

Издательский отдел Объединенного института ядерных исследований
Дубна Московской области