Fermi National Accelerator Laboratory

FERMILAB-Conf-98/020

Fast Scintillation Counters with WLS Bars

V. Bezzubov[1], D. Denisov[2], S. Denisov[1], H.T. Diehl[2], A. Dyshkant[1], V. Evdokimov[1], A. Galyaev[1], P. Goncharov[1], S. Gurzhiev[1], A.S. Ito[2], K. Johns[3], A. Kostritsky[1], A. Kozelov[1], and D. Stoianova[1]

[1]*Institute for High Energy Physics, Protvino 142284, Russia*
[2]*Fermi National Accelerator Laboratory, P.O. Box 500, Batavia, Illinois 60510*
[3]*University of Arizona, Tucson, Arizona 85721*

January 1998

Published Proceedings of *Scintillating Fibers '97*,
University of Notre Dame, Indiana 46556, November 3-6, 1997

Operated by Universities Research Association Inc. under Contract No. DE-AC02-76CH03000 with the United States Department of Energy

FERMILAB-Conf-98/020

Fast Scintillation Counters with WLS Bars

V.Bezzubov[1],D.Denisov[2],S.Denisov[1],H.T.Diehl[2], A.Dyshkant[1],V.Evdokimov[1],A.Galyaev[1],P.Goncharov[1],S.Gurzhiev[1], A.S.Ito[2],K.Johns[3],A.Kostritsky[1],A.Kozelov[1],D.Stoianova[1]

[1] *Institute for High Energy Physics, Protvino 142284, Russia*
[2] *Fermi National Accelerator Laboratory, Batavia, Illinois 60510*
[3] *University of Arizona, Tucson, Arizona 85721*

Abstract. The DØ collaboration is building 4608 scintillation counters to upgrade forward muon system for the next Fermilab Collider run. Each counter consists of 12.7mm thick scintillator plate with two WLS bars along two sides for the light collection. With average 10^2 photoelectrons from *mip* particle the counters provide time resolution below $1ns$ and have good energy resolution. Results of Bicron 404A scintillator and Kumarin 30 WLS aging under irradiation up to $3Mrad$ are presented. With specially designed magnetic shielding counters can operate in magnetic filed up to $500G$.

INTRODUCTION

The goal of the DØ Upgrade [1] is to exploit the physics potential to be presented by the Fermilab Main Injector and Tevatron. An integrated luminosity of 2 fb^{-1} is expected with instantaneous luminosity of up to $2 \cdot 10^{32} cm^{-2}s^{-1}$ accompanied by a reduction in a bunch spacing. This factor of 10 increase in integrated luminosity over previous run will provide an opportunity for significant improvements sweeping the wide range of physics studied at the DØ experiment. Capability to identify and trigger on muons is one of the key features necessary to exploit these possibilities. The upgraded DØ muon system features full coverage for $|\eta| < 2$.

The proposed layout of the forward ($1.0 < |\eta| < 2.0$) muon system includes three layers of scintillation counters for triggering on events with muons on both sides of the detector [2]. Counters are arranged in $R - \phi$ geometry to match central tracking detector trigger segmentation and muon bending direction in the toroidal magnets.

Advantage of the scintillation counters is their ability to count substantially less background hits than other types of detectors [3,4]. Decrease of the gate width from $100ns$ to $20ns$ reduces the number of background hits per plane by ten

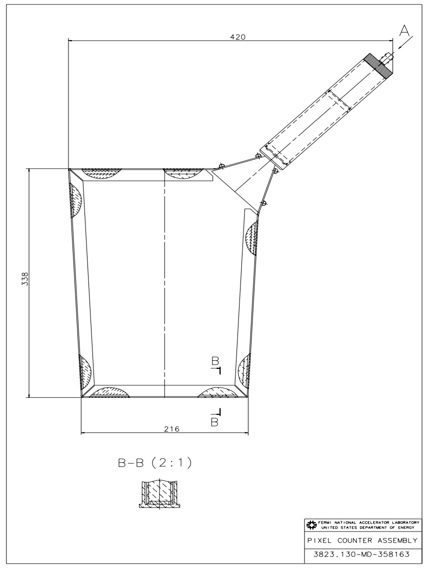

FIGURE 1. Design of the scintillation counter.

times (keeping 100% efficiency of muon detection). The *mip* energy deposition in $12.7mm$ scintillator is $2.5MeV$. Setting detection threshold at $0.5MeV$ will reduce counting rate due to neutrons by a factor of 3 [4] in comparison with gas detectors. Scintillation counters can be easily made of any specific size matching required $R - \phi$ geometry.

In this article we present design and results of studies of the scintillation counters for the DØ forward muon system upgrade.

COUNTERS DESIGN

The size of the muon trigger planes is from $7 \times 7\ m^2$ for counters closest to interaction region to $12 \times 12\ m^2$ for counters situated near walls of the collision hall. The counters are arranged in $R - \phi$ geometry with 0.1 *eta* and 4.5^o *phi* segmentation. The total number of counters is 4608. The counters sizes vary from $10 \times 15\ cm^2$ to $60 \times 106\ cm^2$. The counter design is optimized to provide good time resolution and uniformity for background rejection, high efficiency of muon detection and reasonable cost for production of 4608 counters. The selected design is shown in Fig. 1 for counter with sizes $216 \times 338\ mm^2$. It consists of $12.7mm$ thick Bicron 404A scintillator plate cut to trapezoidal shape with two Kumarin 30 WLS bars [5] for light collection. The bars are $4.2mm$ thick and $12.7mm$ wide. They are installed along two sides of the counter and bended at 45^o to collect light on the phototube. Use of WLS bars provides higher efficiency of light collection in comparison with optical fibers. Parameters of scintillator and WLS are presented in Table 1.

TABLE 1. Characteristics of scintillating materials.

Material	Decay time, ns	Peak emission, nm	Attenuation length, m
Bicron 404A scintillator	2.0	408	1.7
Kumarin 30 WLS	2.7	460	1.4

Green extended phototube 115M from MELZ [6] is used for light detection (Table 2). The scintillator and WLS bars are wrapped with Tyvek material [7] (for better light collection) and black paper (for light tightness). The wrapped counter is placed into 1 mm thick aluminum container with stainless steel part for connection of phototube assembly.

TABLE 2. 115M phototube characteristics.

Diameter of photocathode, mm	20
Quantum efficiency at 500 nm, %	$15^{+5}_{-2.5}$
Non-uniformity of response of photocathode, %	< 10
Operating voltage for anode sensitivity of 100 A/Lm, kV	1.8 ± 0.2
Gain at operating voltage with anode sensitivity of 100 A/Lm	$2 \cdot 10^6$
Rise time, ns	3

PROTOTYPE COUNTERS PERFORMANCE

Counters performance has been studied at Fermilab 125 GeV/c pion test beam. On Fig. 2 the dependence of counter efficiency and time resolution vs high voltage is presented for counters of 3 different sizes: "large" - $60 \times 106\ cm^2$, "typical" - $24 \times 34\ cm^2$ and "small" - $17 \times 24\ cm^2$. Single threshold electronics has been used with detection threshold set at $10mV$. Time resolution achieved is 0.5-1.0ns. At high phototube gain time resolution is limited by photoelectron statistics. Small counters produce more photoelectrons and their light collection time is faster what improves time resolution [8]. Counters detection efficiency on platou is above 99.9%.

In order to make efficient energy deposition cut number of photoelectrons should be large to reduce statistical fluctuations and non-uniformity should be reasonably low. Non-uniformity was measured by irradiating counters in different points by Sr^{90} radioactive source and cross checked by cosmic ray studies. For all counters sizes measured *rms* non-uniformity is less than 10%.

In Table 3 average number of photoelectrons detected for cosmic ray muons passing counter perpendicular to its surface is presented. Calibration of ADC scale in number of photoelectrons has been done by LED producing single photoelectron pulses. The number of photoelectrons is large and *mip* amplitude distribution is mainly determined by Landau fluctuations.

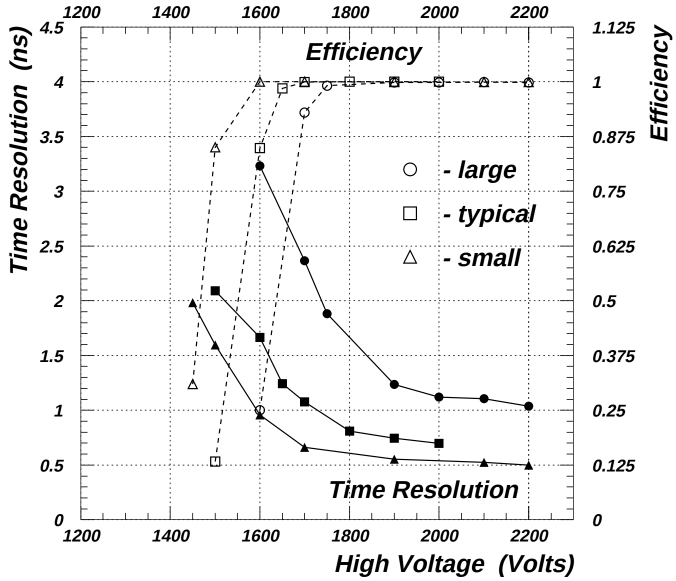

FIGURE 2. Time resolution and detection efficiency of scintillation counters.

TABLE 3. Average number of photoelectrons.

Counter size, cm^2	14×14	46×32	106×60
Average number of photoelectrons	184	115	61

Now we turn to specific studies performed to ensure reliable long term operation of the scintillation counters.

SCINTILLATOR AND WLS RADIATION AGING

An important characteristic for detectors operating under heavy radiation is stability of their parameters during long run. An estimation of the total radiation dose for integrated luminosity of 2 fb^{-1} for the hottest region gives $\sim 1krad$ for the scintillation counters. Aging of scintillation counters under radiation depends mainly upon radiation hardness of the scintillation materials. We performed detailed studies of scintillator and WLS aging under irradiation to ensure reliable operation of counters over long term run. The studies have been done using set of Cs^{137} radioactive sources producing close to uniform irradiation in the sample volume with the rate of $5.3 rad \cdot s^{-1}$. On Fig. 3 Bicron 404A scintillator light output as a function of accumulated dose is shown. Up to $1 Mrad$ dose radiation damage is below 20%.

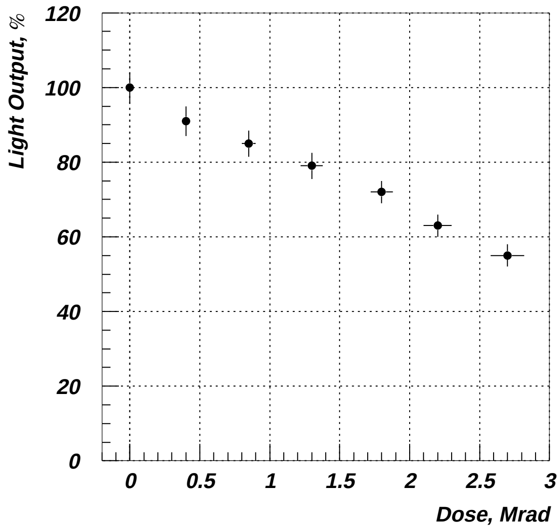

FIGURE 3. Bicron 404A scintillator light output vs accumulated dose.

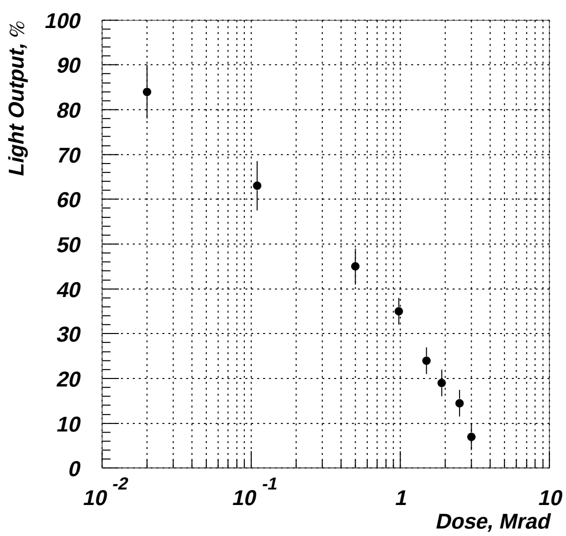

FIGURE 4. Light output for pair: non-irradiated Bicron 404A scintillator and irradiated Kumarin 30 WLS.

On Fig. 4 the light output for pair of non-irradiated Bicron 404A scintillator and irradiated Kumarin 30 WLS bar is presented. WLS demonstrates considerably faster radiation aging than scintillator.

In order to study aging at closer to real conditions time scale and irradiation flux prototype counter with sizes $33 \times 22\ cm^2$ was placed for 9 months in the DØ collision hall during fixed target run operation. The total accumulated neutron dose was $49krad$ and gamma dose was $30krad$. The decrease of the signal before/after irradiation is $11 \pm 3\%$ and can be attributed to aging of WLS.

PHOTOTUBE MAGNETIC SHIELDING

The fringe magnetic field of the DØ detector superconducting solenoid and toroidal magnet reaches $350G$ in the area where phototubes are situated [9]. In order to reduce magnetic field in the phototube area down to $\sim 1G$ necessary for normal operation shielding made of $1.2mm$ thick mu-metal and soft steel tube with 3 or $6mm$ thick wall has been designed [2]. The soft steel flange mounted on the counter case (see Fig. 1) serves as a part of the shield also. For the field perpendicular to the tube axis no reduction in output pulse has been observed up to $700G$. For the field parallel to the tube axis the reduction in pulse amplitude vs magnetic field is presented in Fig. 5. The effect of magnetic field on phototube gain is less than 10% up to $350G$ for $48mm$ external shield diameter.

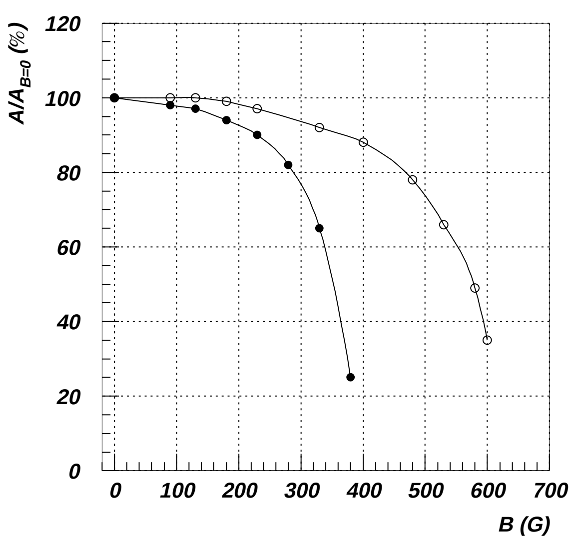

FIGURE 5. Relative gain change of 115M photomultiplier in magnetic field parallel to the tube axis: solid circles - $3mm$ steel tube wall ($42mm$ external diameter shield), empty circles - $6mm$ steel tube wall ($48mm$ external diameter shield).

PHOTOTUBE AGING

Phototubes gain decreases during operation due to the interaction of accelerated electrons with surface of dinodes and anode. This aging is commonly represented in terms of accumulated anode charge [10]. For integrated luminosity of $2fb^{-1}$ the maximum accumulated anode charge will be $\sim 20C$. In Fig. 6 typical 115M phototube aging curve is presented. The drop of phototube gain is less than 5% for accumulated charge of $20C$. This drop in gain could be compensated by adjusting electronics threshold or phototube operating voltage.

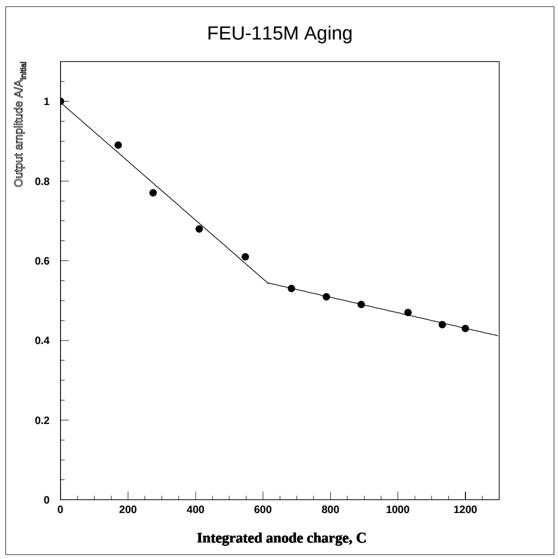

FIGURE 6. Phototube gain as a function of integrated anode charge.

CONCLUSIONS

Scintillation counter design based on light collection by two WLS bars has been developed for the forward DØ muon system upgrade. Average number of photoelectrons for the counter with sizes $1.3 \times 60 \times 106$ cm^2 is 61 providing high *mip* detection efficiency, good amplitude resolution and time resolution of $1ns$. Use of fast and transparent scintillator and WLS determines counters response uniformity of 10% and high time resolution. Proposed magnetic shielding design provides counters operation in the filed up to $500G$. Degradation of counters performance starts at accumulated doses of $0.1Mrad$ and mainly determined by radiation aging of Kumarin 30 WLS bars.

REFERENCES

1. The DØ Collaboration, "The DØ Upgrade", Preprint Fermilab-FN-641, 1995.
2. V. Abramov *et al.*,"Technical Design Report for the DØ Forward Trigger Scintillation Counters", DØ Note 3237, Fermilab, 1997.
3. B. Baldin *et al.*, "Upgrade of the DØ forward muon system with pixel scintillation counters", DØ Note 2358, Fermilab, 1994.
4. Yu. Nikolaev *et al.*, "The efficiency of plastic scintillators to neutrons and gammas", Preprint SDC-93-512, SSC Laboratory, 1993.
5. S. Belikov *et al.*, "Physical Characteristics of the SOFZ-105 Polymethyl Methacrylate Secondary Emitter", Instruments and Experimental Technique, 36, p.390, 1993.
6. S. Belikov *et al.*, "Characteristics of Phototube 115M for Electromagnetic Calorimeter of PHENIX Experiment", Preprint IHEP 96-42, Protvino, 1996.
7. DuPont Nonwovens, Tyvek type 1056D.
8. Chi Peng Cheng *et al.*, Nucl. Instr. and Meth. A252(1986) 67.
9. R.Yamada *et al.*, "2-D and 3-D display and plotting of 3-D magnetic field: Calculation for upgraded DØ detector", DØ Note 2023, Fermilab, 1994.
10. "Photomultiplier tube: Principle to Application", Hamamatsu, 1994.