A proposal for dealing with the CSX scintillator aging problem.

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1 Introduction

The CMX arches span 270 degrees in azimuth and cover the region $0.6 < \eta < 1.0$. They comprise 8 layers of drift chambers, sandwiched between 2 layers of scintillation counters which are read out from opposite ends for accurate timing. Good timing resolution ~3 ns was critically important for background rejection in run I. In run II it will also serve to identify bunch crossings because the chamber drift time (1.4μs) is longer than the bunch interval. The 1.8 m - long counters were constructed from 2" - thick NE114 (now BC 416) scintillator [1], as were the longer (3.2m) CSP counters which cover the vertical walls of the central region.

Evidence of inefficiency (~83%) in the CSX turned up in the course of run I [2] and it and it shows up more vividly(Fig. 1) in a later analysis of run 1 data [3]. Similar measurments showed that the CSP were also inefficient(~92%). These measurements prompted an investigation which eventually revealed that the counters were aging prematurely, a condition which was manifest when the counters were unwrapped 2(a): the scintillator was found to be yellow, a condition which usually corresponds to a loss of transparency at the scintillator emission wavelength and that can also correspond to a loss of brightness. Measurements of the transmittance of scintillator samples showed a bulk (not surface) loss of transparency at the scintillator emission wavelength (between 410 nm and 480 nm for NE 114).

These effects can be brought about by radiation damage but estimates of the accumulated dose (based on TLD measurments) exclude radiation as the principal cause of aging. This conclusion is supported by the observation that a number of spare CSXs, which had been kept in the warehouse and had therefore never been exposed to the beam, are subject to the same effects. It is therefore reasonable to conclude that that premature aging had occurred and that, since it is a bulk effect, it probably corresponds to oxidation of the color centers due to poor deoxigenation of the scintillator during the manufacturing process.

In order to evaluate the effect of this deterioration in quantitative terms it was necessary to measure the light output in absolute terms and to evaluate the rate of deterioration so as to understand the counters' present and future limitations. We focussed our attention on the longer CSPs which, because of their length, were better suited to measurements of attenuation length. The results of these studies are summarized in the next section. Because they refer to the same scintillator, they are relevant to both CSPs and CSX.

2 Scintillator aging studies and projections

After calibrating our DAQ system by single photon counting [4], the absolute light output, i.e. the number of photoelectrons reaching the PMT photocathode when the counter is traversed (normally) by a cosmic muon, was measured as a function of distance from thePMT. The results of such measurements for three counters are shown in Fig. 2. The full circles represent the data taken with one of our deteriorated counters ("30 NW" for counter No. 30 on the West end of the North Wall). The open circles are the data from an identical counter ("Test counter 32"), made of *undeteriorated* NE114 The third data set was taken with a counter made of new polystyrene - based scintillator [5].

The deterioration of "30NW" is evident. Other counters were also measured and the results for a representative number of them are similar, with fluctuations of ∼+/- 30 % , corresponding to: (1) fluctuations in the photoefficiency of PMTs and(2) in the scintillator quality (purchasing records indicate a fluctuationsof +/- 30 % from batch to batch).

In order to evaluate the rate of deterioration and to distinguish between deterioration in brightness and in attenuation, we compared the output of the aging counters to that of the undeteriorated NE 114 (test counter 32)at two points: the "near end" (i.e. that closest to the PMT), evaluated by extrapolating the data backwards as shown in Fig. 2 and a point 20 cm from the far end (i.e. 300 cm from the photocathode). For the period 1992 - 1998 (Δt = 6 years) we define

$$\begin{aligned} N_{x,0} &= \textit{light output at } t = 0 \\ N_{x,6} &= \textit{light output at } t = t + \Delta t \end{aligned}$$

where $x =$ "near" or "far". Then, assuming the deterioration is exponential, i.e.

$$N_{x,t} = N_{x,0} \exp -\Delta t / \tau_x$$

we use the data N_{x0} and $N_{x,6}$ to calculate a "deterioration lifetime" τ_x for both ends

$$\tau_x = \Delta t / \ln\left(N_{x,0}/N_{x,6}\right)$$

If, for the near end, we use $N_{near,0} = 105 p.e.$ and $N_{near,6} = 35 p.e.$, and for the far end we use $Nfar, 0 = 40 p.e.$ and $N_{far,6} = 5.5.p.e.$, we obtain:

$$\tau_{near} = 6.2 years, i.e. 15\% peryear$$

$$\tau_{far} = 2.9 years, i.e. 30\% peryear$$

Using these "deterioration" constants, we then estimated that, by the end of 2003 , the counter output at the far end would be reduced to 0.7 p.e. Assuming poisson statistics and a discriminator threshold of 1 p.e., this would correspond to less than 50% efficiency.

On the basis of this information, it was decided to intervene and a scheme was devised for refurbishing the" wall" CSP counters by adding wavelength - shifting - fiber to one side. For more information on this procedure, the reader is referred to [7]

Our evaluation of the deterioration rate is obviously subject to several sources of uncertainy. Fluctuations in the scintillator quality and PMT efficiency are statistical and mean that some counters are not going to deteriorate as fast, but that others will do so faster. This in fact represents a *more dismal* situation because some counters will start dropping out before the time projected on the basis of the averages reported above. The "systematic" uncertainties derive from the uncerainty in the actual period of deterioration (e.g. the date of production is uncertain by almost a year) and our assumptions regarding its initial performance (see above). We estimate that these uncertainties could influence our estimates of the deteroration rate by about +/-30 %

Because the CSX are shorter (1.8 m vs. 3.2m) they do not suffer as badly from deterioration in counter transparency. On the basis of the above measurments, we would expect $\sim$ 8 p.e. from a cosmic at 20 cm from the far end. However, because they are shorter, we can expect more light from the reflected component. In fact, from bench measurents on 19 counters, we obtained between 10 and 14 p.e. This is sufficient to make the probability of zero negligible, i.e. for it to be possible to obtain full efficiency by increasing the PMT gain. We therefore embarked on the task of re-plateauing the counters one by one, in situ, using cosmic muons. At the same time we measured absolute output at the far end by substituting, wherever possible [9], the counter's PMT with one that had been calibrated using the method outlined in the above section. This work is summarized in [8]. Note that the averages are lower than measured on the bench. This is due to a systematic error in the cable attenuation and because the photoefficiency of the calibrated PMT was lower than the average photoefficiency. For a correct interpretation of these data, their averages should be renormalized to 12 p.e. .

Deterioration rates at the far end of the CSXs were evaluated from the data taken at the middle (i.e. 160 cm from the photocathode) of the CSPs. This obtains a deterioration rate of $25\%/year$. The light output from the far end of the CSX counters at the end of 2003 can be expected to be $(12p.e.)(0.75)^5) = 2.9p.e.$, i.e. $< 95\%$ and, since we need a coincidence of two counters, the efficiency drops to 90%. In 2004 it would be $< 77\%$ and in 2005 $< 58\%$.

It should be emphasized that, for all of the above estimates, we have taken the inefficiency to be the probability that one observes zero photoelectrons. This assumes that one would be able to operate with a threshold of one photoelectron. In fact, this mode of operation is very susceptible to noise and it may not be possile. More reliable estimates would be obtained by putting the limit of operability at 2 photoelectrons. In this case, inefficiencies will turn up a lot sooner.

Finally, we address the supposition that the construction of the new shielding "snouts" might make us less dependent the CSX. The background affecting the CSX during run I originated mainly from interactions of the beam with the plug and the toroids. The snout was introduced to reduce it. The commissioning run showed that we do indeed get singles suppression factors of ~ 3 between shielding in/shielding out situations. However this does not make the CSX unneccessary, even if it implied that he background has been suppressed by a factor of 3 with respect to run 1. This is not necessarily the case because the geometry has changed, e.g. the additional material due to the extended plug η coverage could well produce additional background.

We conclude this section by emphasizing that we cannot count on these counters surviving run II and that the evidence evidence we have outlined above does not support optimism.

3 proposed course of action

It is clear that we cannot refrain from acting in the hope that aging *might* have stopped. It is equally clear that we want to defer deciding on an eventual remedy as long as possible, preferably until we can do it on the basis of further evidence regarding the rate of deterioration and the importance of the CSX for background rejection and crossing identification. However, we should be careful that the long lead times involved in planning and funding do not compromise our ability to implement the remedy should the worst come to worst.

On the basis of these considerations we propose:

a) to optimize our means of monitoring the condition of the CSX. A monitoring strategy would include sending the outputs of a sample of counters to ADCs and installing a number of test counters before and behind a sample of counters to enable quick and continuous monitoring of their efficiency. Most importantly, we must arrange to monitor efficiencies and backgrounds closely by looking at real data e.g. $J/\Psi \rightarrow \mu\mu$. However it will be some time before we are collecting reliable data and statistics will take longer to accumulate.

b)At the same time, we should prepare for the worst by evaluating different alternatives and, putting the necessary resources on standby (not least of which are the funding agencies, which must be given advance notice) and testing tecnologies which are new to CDF in operating conditions.

An important consideration in evaluating the alternatives is the longest access time at our disposal, which is of the order of 6 months. This circumstance favors solutions which allow us to prepare things while we are running so that we need only mount them during the access period.

A set of different scenarios have already been considered and are briefly outlined briefly here.

3.1 Refurbishing the existing counters

A tried and tested solution involves "refurbishing the counters as was done for the CSPs [7]. However, it requires that we dismount the counters, refurbish them and remount them during the access, which is dificult without extreme concentration of resources. Because of this and other practical consideations it is not a viable option.

3.2 Replacing the Inner counters

The inner scintillators would be replaced with new counters, read out of both ends with wavelength - shifter ribbon. The new counters could be prepared during the run. Activity during the access, would be restricted to dismounting the present (inner) and instaling the new ones. This alternative is altogether feasible but relatively costly because it requires the purchase of new scintillator, wls fiber and PMTs (two per counter). The following is an evaluation of the costs:

$$
\begin{array}{lcl}
materials & scintillator: 150\ ctrs * 12.6l/ctr * \$60/l & = \$113000 \\
 & PMTs: 2/ctr * 150\ ctrs * \$400/PMT & = \$120000 \\
 & electronics: 300\ chan * \$100/chan & = \$30000 \\
manpower & 1\ tech\ FTE\ for\ 1\ year\ for\ construction & \\
 & 2techs\ 1/2\ time\ for\ 6\ months\ for\ mounting &
\end{array}
$$

- Funding: prospects for non-DOE/NSF funding are uncertain.

Dubna would be interested in producing the scintillator but funding must be sought. Italy could seek funding but prospects are uncertain.

3.3 Substituting the inner counters with RPCs

Another alternative is to replace the inner CSX with Resistive Plate Chambers (RPC) [10]. When operated in avalanche mode (at 9.4 kV with a mixture of 97.6% TetraFluoroEthane $C_2H_2F_4$, 0.3% Hexaflouride(SF_6) and 3% iso-Butane C_4H_{10} at normal pressure and temperature), these chambers are able to tolerate rates up to $\sim 100Hz/cm^2$ with timing characteristics comparable to those of scintillators. Typical pulse duration is 4-5 ns (FWHM), time jitter is 1.5 ns and and pulse amplidude of is few mV into 100 Ω. The RPCs are readout by pick-up strips which can, in principle, be used to obtain better segmentation. However, their least disputed advantage, is their relatively low cost and the ease with which they can be accomodated.

The RPC shown in fig. 3 covers a Φ interval of 15 degrees and the signal is read out from each of the ends of ganged groups of 6 adjacent Φ strips. Just as is done for the scintillators, the two signals are used to improve timing resolution for better background rejection Apart from the frontend electronics needed to process the signal at the strip output, the electronic chain, beginning with the discriminators could remain the same.

The front-end electronics presently available are eight-channel full custom chips in GaAs technology developed for ATLAS (see detailed description in [11]) These electronics are is mounted at the strip outputs on the edges of the RPC (see fig. 3b) and the amplified signal of every strip is sent by flat cable to an external receiver located close to the detector.

Note that the η strips are ignored in the scheme outlined above. However, they could esily be used if one decided one needed η segmentation. Furthermore one can easily improve the segmentation (both η and Φ) by reducing the ganging multiplicity). There are 60 η strips (each 2.9 cm wide) and 48 Φ strips (each 2.3 cm wide)

The basic RPC unit is a trapeizoid:140 cm for long side,105 cm for short side and 190 cm height. It is 4-5 cm thick, including the mechanical support (The RPC thickness is 1 cm). The weigth for m^2 is about 13. Kg including a mechanical structure.A total of 34 RPC's (18 West side and 16 East side) would replace the CSX layer on the inner face. There is ample room (about 15 cm) to accomodate them. To reduce the losses due to the effective fiducial volume the counters should ovelapped.

For an average charge of 40 pC per count and a maximum rate of $100hz/cm^2$, each chamber is no expected to draw more than about 1 μA . The system of 34 RPC should therefore require no more than 8 HV power supplies (mod.A400 CAEN). The total numer of signals is 34 * 14 = 544 (same as for the CSX) however, it would be wise to purchase enough frontend electronics to provide for improved the segmentation while they are still available.

The cost estimates are as follows:

$RPCchambers:$	$34\ chambers * \$1000/chamber$	=	\$30000
$Frontendelectronics$	$1000\ channels * \$10/channel$	=	\$10000
HV	$8\ channels * \$850/channel$	=	\$6800
$HV\ Controller$		=	\$10000
$Gas\ and\ Cables$		=	\$20000
$manpower$	$1/2\ tech\ FTE\ for\ 1\ year\ for\ testing$		
	$2\ techs\ 1/2\ time\ for\ 6\ months\ for\ mounting$		

- funding: prospects for non-DOE/NSF funding reasonable

RPC chambers: both Italy and Korea interested in seeking funding
frontend electronics: those developed for Atlas presently available and cheap.
RPC prototypes and limited funding for tests should be easy to get

4 Conclusions

We have demontrated that the CSX could become inefficient in the course of run II. Although projections are uncertain, we can not avoid planning for the worst while monitoring run - time conditions and performance. Shpould remedial action become necessary we must begin planningng now if we are to be ready for the 2003-2004 shutdown.

We have considered the alternatives and favour the RPC solution on the basis of cost, ease of installation and the possibility of introducing η segmentation in the event that background is worse than expected. This would be an important concession (along the lines of the extra shieldin but considerably cheaper) to the reality that we really dont know what to expect. However, because the tecnology is new to CDF, it is necessary that we equip and test a prototype in operating conditions as soon as possible.

Replacement of the inner scintillator is a viable and well - understood alternative but considerably more costly. Interested parties are welcome to assess funding prospects.

References

[1] Bicron Corp.

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[7] S. Cabrera et al., N.I.M **333**, 333, 2000.

[8] J. Fernandez et. al., CDF Note **3989**.

[9] This was not done for the external counters because the support structure makes it virtually impossible to access the counters.

[10] R. Santonico Nucl. Inst. and Meth. 187 1981 377 I. Crotty et al. Nucl. Instr. and Meth. A 337 1994 370

[11] G. Aielli et al. Nucl. Instr. and Meth. A 409 1998 291

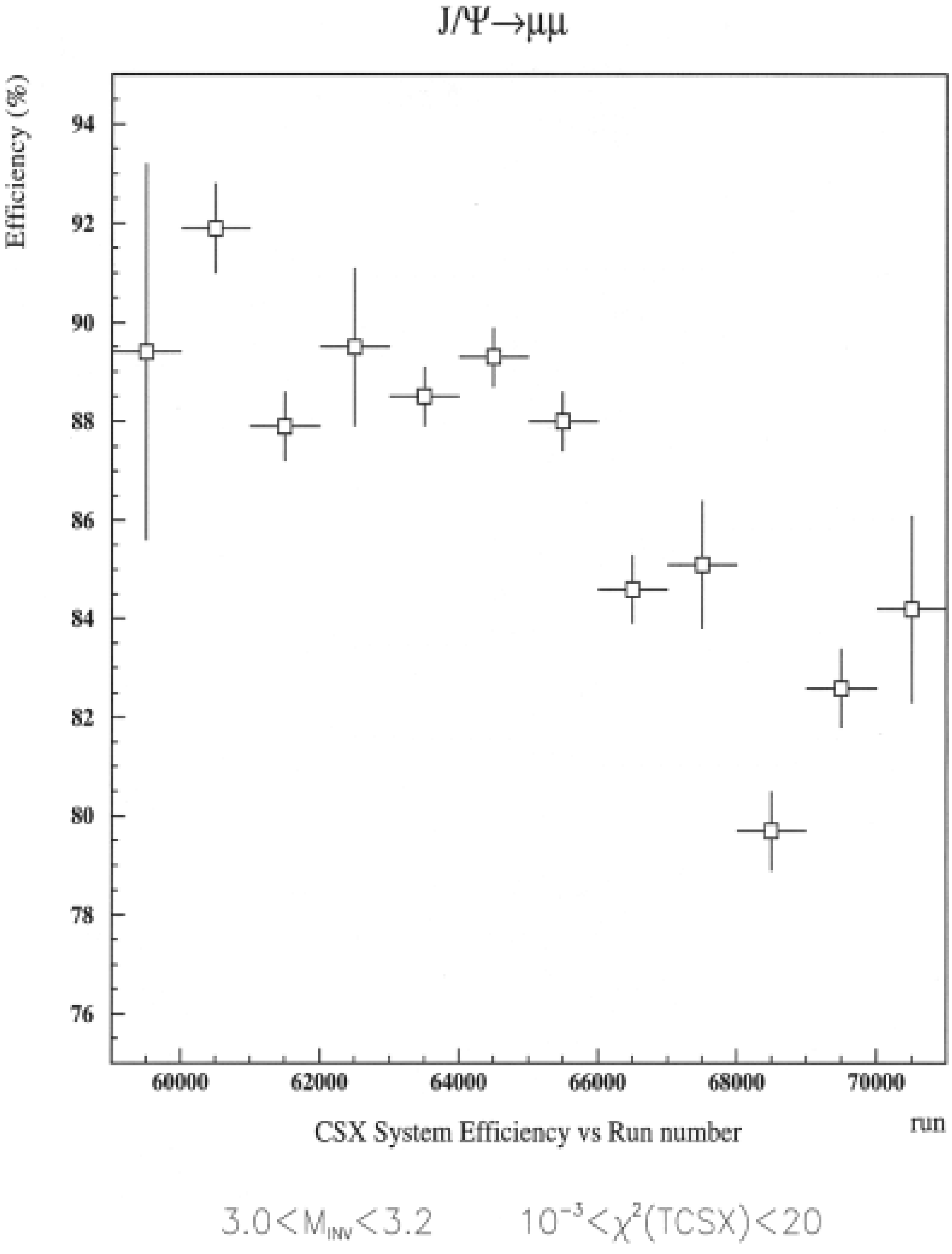

Figure 1: CSX efficiency for muons as a function of Run 1 run number. Measured using $J/\psi \to \mu\mu$ data

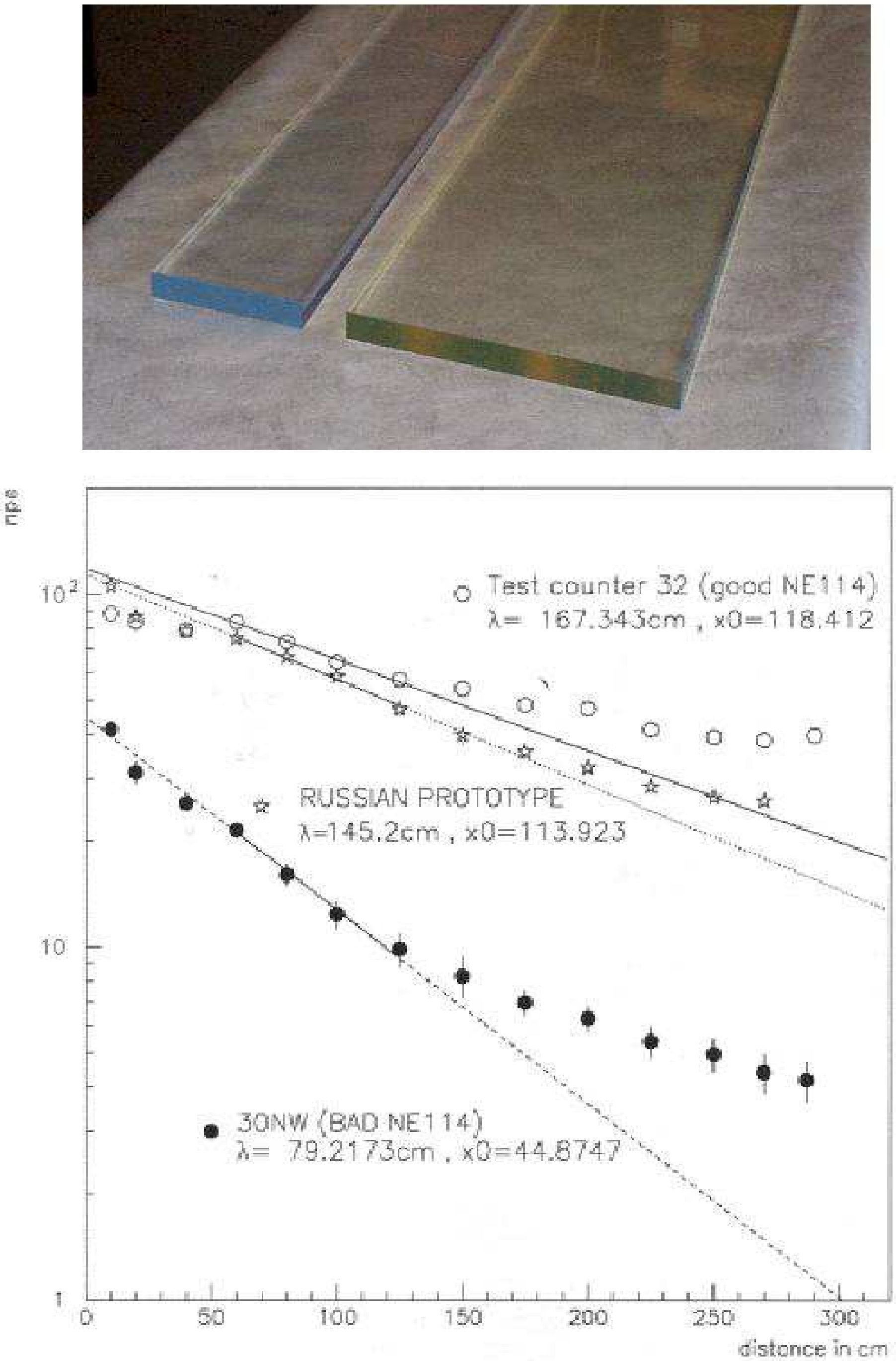

Figure 2: (Top) A comparison of aged (yellow) and undeteriorated (blue) scintillator. (Bottom) Absolute light output (i, p.e. per muon) as a function of distance from the PMT (in cm), for three different counters: "Test counter 32", made fro NE114 (good), "Russian Prototype" made from polystyrene-based scintillator (good), "30NW" (aged).

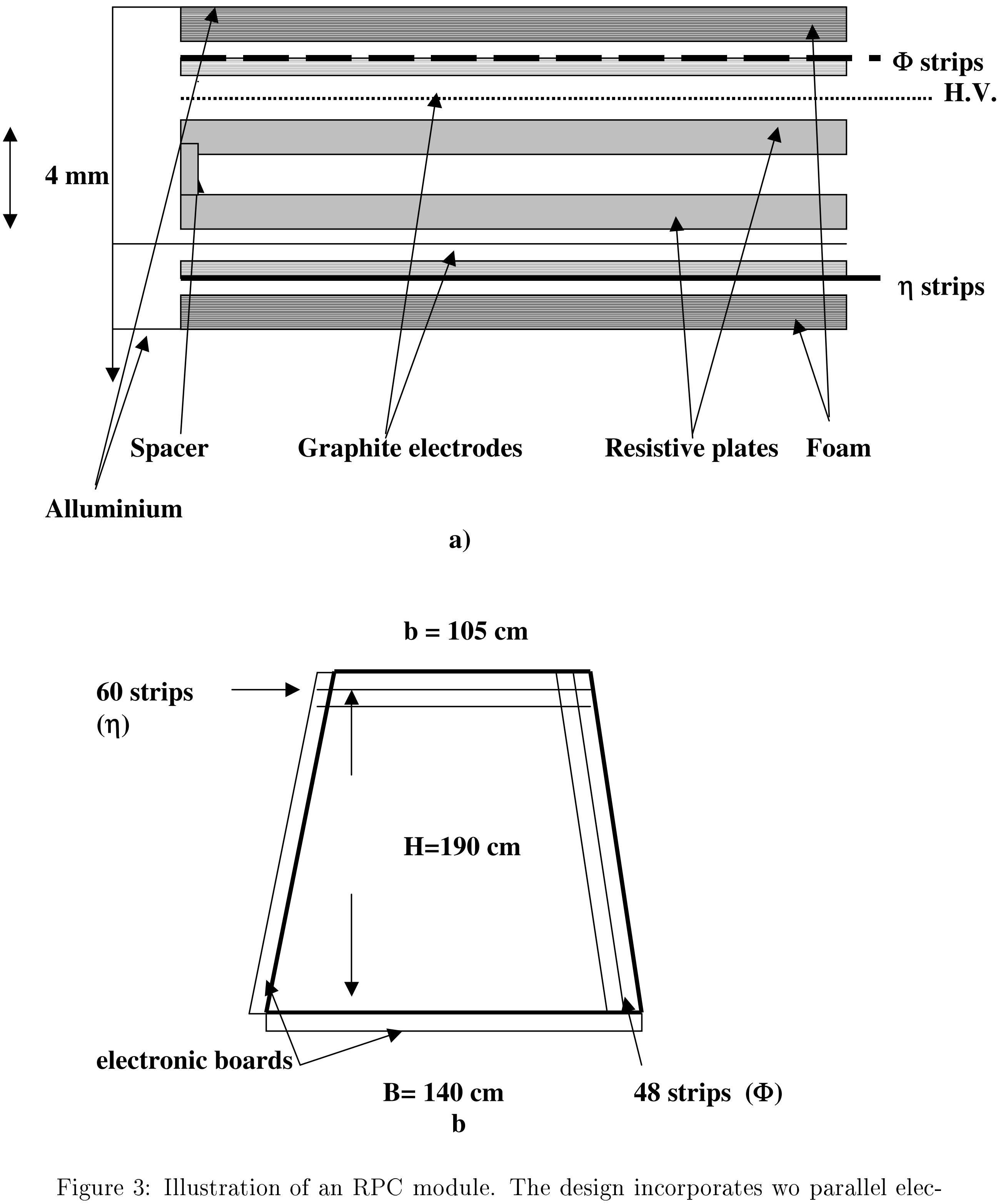

Figure 3: Illustration of an RPC module. The design incorporates wo parallel electrode plates of phenolic polimers (bakelite) with a volume resistivity $\rho = 10^{10\pm1}\ \Omega\ cm$ and a 2 mm gap. Two planes of external pick-up strips are oriented so as to allow for segmentation in both the η and Φ directions. The efficiency is expected to be 98% including the losses due to the spacers located in the counter to provide a constant gap of 2mm.