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Wave length shifter scanning for Luminosity spectrometer at ZEUS

Miroslav Helbich

Abstract

Wave length shifters(WLS) must be corrected for attenuation in order to guarantee the linearity of the Beam Pipe Calorimeter(BPC), module to be used for the spectrometer luminosity measurement. In order to make sure that energy deposited in any depth produces the same signal attenuation in the WLS must be corrected. This is done by producing special reflecting masks printed on Tyvek paper. The corrected attenuation is less than 2% over the active length of 16cm, which assures that deviations from linearity are well below 1%.

1 Introduction

After the HERA luminosity upgrade in 2001, the older luminosity monitoring system is expected to have severe problems due to increased synchrotron radiation and multiple events - pile up. Therefore a new luminosity spectrometer has been proposed [1] and is being constructed. It consists of two small electromagnetic calorimeters which measure coincidences of electron-positron pairs converted in the photon window and then bent by the dipole magnet. For the calorimeters, we make use of the old Beam Pipe Calorimeters(BPC's) [2] used to measure electrons scattered through small angles. However, in order to fit within the limited space allowed by the proton beam pipe and the photon beam, the WLSs of x-channels[1] had to be rebuilt. This required a new mechanical structure for readout as well as WLSs of new shapes.

The calorimeter must be a linear device, which means that the output of the ADC cards should be linearly proportional to the energy deposited in its active volume. However, more energetic electrons penetrate deeper into the fiducial volume than those of lower energy ones. The position of shower maximum as determined by MC EGS4 studies is given by

$$z_{max} = 0.7(log(E[GeV]/0.0106) - 0.5). \tag{1}$$

[1] y-channels in BPC notation, but in spectrometer setup the calorimeter is rotated.

This means that light deposited deeper within the volume must travel shorter distance in the WLS. Therefore, this less attenuated light is enhanced relative to energy deposited near the front. A back-of-the-envelope calculation gives the following relation between the attenuation and nonlinearity. Assume for simplicity that all the energy is deposited at shower max. Then for E=1GeV, $z_{max} = 2.8cm$ while for E=25GeV, $z_{max} = 5.1cm$. If we use 25GeV electrons to calibrate the detector, 1GeV electrons would give us lower readout energy by $\frac{\Delta E}{E} = \frac{attenuation}{cm}(5.1cm - 2.8cm)$. So if we require deviations from linearity to be below 1%, this requires the total attenuation over 16cm should be less than 7%. For our spectrometer setup, our acceptance requires energies larger than 4-5GeV, depending on running conditions, which means that nonuniformity should be less than $\approx 12\%$.

A more detailed calculation using EGS4 [2] taking into account the shape of electromagnetic shower, gives a similar result and shows that if attenuation over the length of the WLS is less than 5%, the nonlinearity is below 1% for $E = 1 - 25GeV$, which is our goal.

2 WLSs and Reflecting mask

Wavelength shifters are made of PMMA plastic base, doped with a fluorescent dye of 30ppm Y7. There are three types of WLSs with shapes like on figure 1, but differing bending radii. The absorption spectrum of fluorescent dye Y7 matches well the emission spectrum of the SCSN38 scintillator. The dye emission spectrum matches bialkali photocatode (Hamamatsu R5600-03). For references on the radiation sensitivity see [3].

In order to reduce attenuation in the WLSs, two major hardware changes were required. First, the free end of the WLS was aluminized as a reflector. This decreased the attenuation from $\sim 50\%$ to $\sim 9\%$. To improve uniformity, which was the goal of this measurement, we used special reflecting masks printed on Tyvek[2] paper.

The measured light yield at the open end of WLS can be written as a function of position in terms of primary and secondary light components absorbed. The latter comes from reflections from the mask back into the WLS. The intensity of light with and without mask can be written as

$$I_b(x) = I_p(x)[1 + (1 - b(x)).r] \tag{2}$$

$$I(x) = I_p(x)[1 + r] \tag{3}$$

where I_p is the signal obtained from light absorbed in the WLS on it's first passage through it, $b(x)$ is the position dependent blackness of the reflecting mask (e.g. the fraction of black area on it), and r is a coefficient which depends on the amount of dye Y7. As we can see, we can achieve uniform response by tuning $b(x)$. In this terminology

[2] It is in fact not a paper but a kind of plastic. The choice to use Tyvek paper comes from its high reflectivity $\approx 99\%$.

$I(x)$ is intensity that would be measured with no black areas(b=0) and $I_b(x)$ is the corrected intensity we want to be uniform. Choosing the following constraints

$$b(x=0) = 0 \qquad \text{we start with white Tyvek} \tag{4}$$

and

$$I_b(x) = I_b(x=0) = I(x) \qquad \text{corrected spectrum is uniform} \tag{5}$$

we can solve equations (2-5) for blackness to be

$$b(x) = \frac{1+r}{r}\frac{I(x) - I(x=0)}{I(x)} \tag{6}$$

where x=0 is the position of the aluminized end. The mask was produced by filling a two dimensional histogram with values 1 or 0 according to the calculated fraction b(x), and randomly distributed in the transverse direction. This histogram was plotted on a high quality ink-jet printer, not a laser printer(in which Tyvek would melt!).

3 Experimental setup

The experimental setup used for scanning is sketched in figure 1. The WLS was mounted on the fixed stand with Tyvek paper located on the back side. The signal was read from a small Hamamatsu photo-multiplier(PMT) R5600U-03, the one used in actual detector. To get the same frequency spectrum hitting the WLS as under experimental conditions, a UV LED was used to flash light onto a BPC-type scintillator. This scintillator was fixed to a movable stand with step motor interfaced to the computer. The signal was read out with 11bit ADC. To reduce background, the LED had to be light tight so as not to shine on the WLS directly. We also built a small housing to insulate the PMT from the outside world and to fix the WLS as well.

The attenuation over the length of WLS was to be measured. The most important issues to be solved were the following

- bumps: The Tyvek must be folded carefully. Any scratch or folding on the reflective sides has $\sim 2-3\%$ effect on single point measurements. This problem has been solved.
- alignment: The signal depends very strongly on the relative scintillator - WLS separation. This produces $\sim 1\%$ per $\sim 0.1mm$ separation difference on measurement of attenuation. Hence the fixed holder for WLS must be very parallel to the moving stand(to precision $\leq 0.1mm$ over the entire distance) otherwise, we would introduce big systematic errors. To check this, we took second measurement with reverted direction of WLS and PMT on the other side of the stand, while leaving stand itself fixed, so that any systematics due to alignment changes sign. Comparing both measurements we conclude that attenuation measured in normal direction was by 1.5% larger than in the opposite case. This means we have +0.8% systematics in each measurement with normal direction. This had to be checked before any set of measurements was taken.

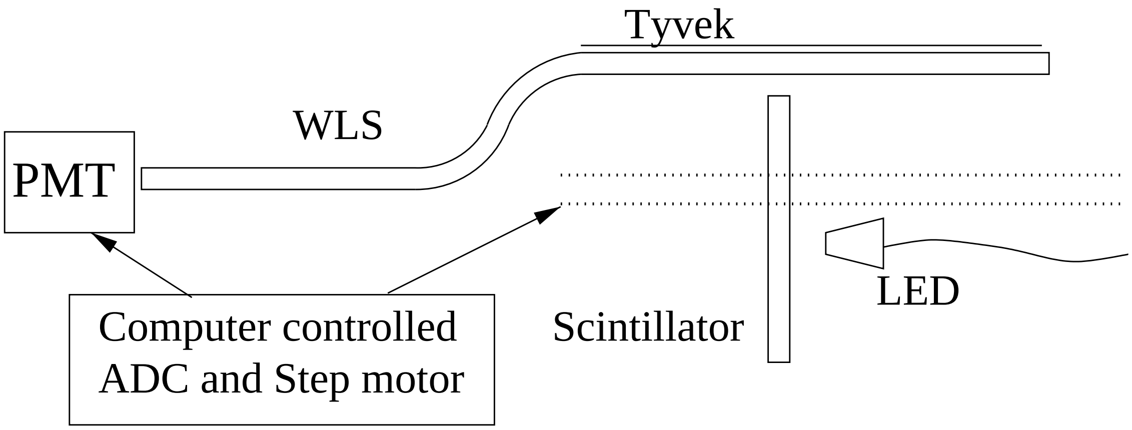

Figure 1: Schematics of experimental setup for WLS scanning.

- WLS fixing: to achieve that the scintillator - WLS distance stays the same the holder must be aligned, but also the WLS has to be tightly fixed to it. We successfully solved this problem.
- Table shaking: When the motor moves, the table shakes a bit, thus altering our measurement by $\sim 0.3\%$. Therefore we took measurements a short while after stopping the motor.
- Background: There were few light sources of light in the room, like the LED or the monitor. Covering the LED to prevent light hitting directly the WLS, the background decreased from $\sim 3\%$ to $\sim 0.5\%$ with systematic increase of 0.3%. The effects of alignment and background tend to cancel each other in our setup.

Overall, we conclude that the systematic bias is $+0.5 \pm 0.3\%$. Reproducibility of the measurement is within $\pm 1\%$ independent of type or piece of WLS.

4 Results

As stated in the previous section, measurement precision was 0.3% systematic and 1% measurement to measurement statistical error. This is sufficient to make sure that the produced Tyveks satisfy the criteria described in section 1. The typical reflection coefficient r in formula (2) was determined to be $r = 40 \pm 4\%$ by comparing light yields with completely white or black Tyvek, respectively. In order not to propagate this larger error, we produced a set of Tyveks and choose the one with the lowest attenuation. Then the set of Tyveks with the required reflecting patterns, and including the additional 2mm of side reflectors, were produced and tested piece by piece. Final testing indicated, that about 25% had severe defects due to sharpness of the printed pattern or incorrect folding. The final set satisfied the criterion, that attenuation over 16cm was less than 2%. An example is shown in figure 2.

Once produced, the reflective masks were glued to the aluminum cassette holding the WLSs in the calorimeter. A typical measurement for the cases without and with the final Tyvek reflector are shown in figures 3,4.

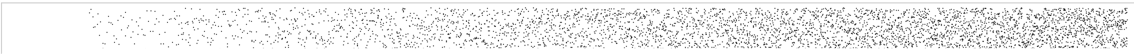

Figure 2: Example of Tyvek paper.

As a cross-check, we measured attenuation in the WLSs used in old BPC and compared the results with previous measurements made at the time of its construction [2]. Results for the WLS attenuation agree, but the mask is not correcting for all attenuation at the level as claimed but rather leave $\sim 4.5\%$ effect. It is probably due ink color fading out with time. Anyway, it is still below the 5% level, so that linearity was maintained over the period of BPC data taking.

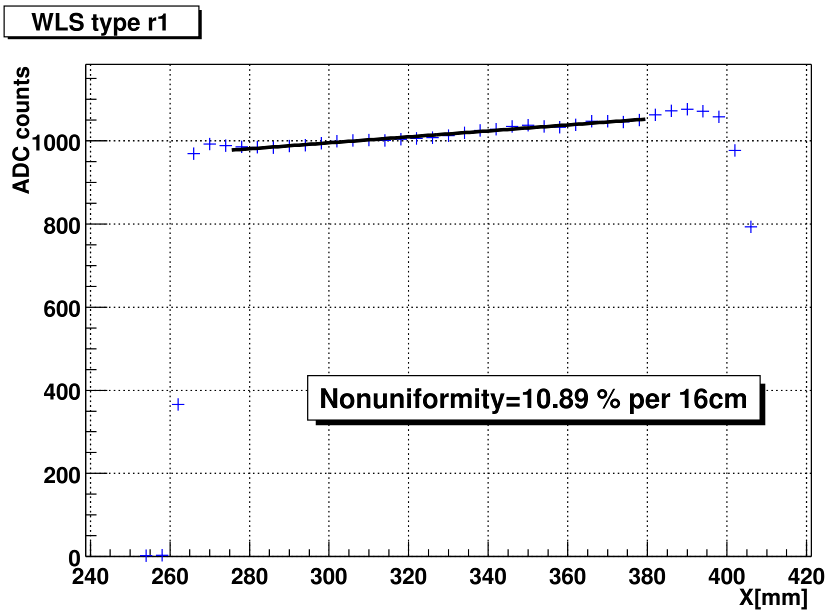

Figure 3: Example of attenuation for one shape of Wavelength shifter. Factor of 0.5% should be subtracted due to systematic bias as described in section 3.

5 Conclusions

The correction pattern for attenuation in the wavelength shifters was printed on Tyvek papers. Nonuniformity over the length of WLS was reduced from $\approx 8-10\%$ to $\leq 2\%$. This guarantees that any deviation from linearity of the absolute energy scale due to this effect is negligible.

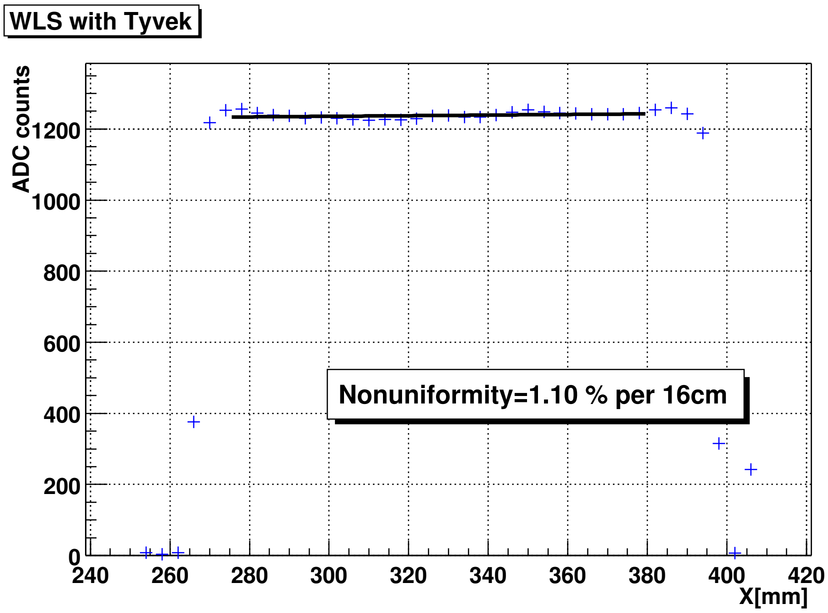

Figure 4: Example of attenuation using Tyvek with correcting pattern printed on. Factor of 0.5% should be subtracted due to systematic bias as described in section 3.

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References

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