Electromagnetic Calorimeter Studies with the Pulse-Height Analyzer

Martin Nagel Jesse Smock Eric Erdos

September 13, 2004

1 Overview

Theories beyond the Standard Model (SM) of particle physics, such as Supersymmetry (SUSY), need to be tested at higher energies than those achieved by current particle colliders. Therefore, the Next Linear Collider (NLC) was proposed and is currently being discussed by the international High Energy Physics (HEP) community. Various designs for the required detectors have been proposed and the best solution has to be identified through extensive simulations before implementation. Our group at the University of Colorado at Boulder, led by Dr. Uriel Nauenberg, focuses on the design of a scintillator based electromagnetic calorimeter, which measures the energy of electrons and photons.

2 Calibration of the pulse-height analyzer

2.1 Motivation

To evaluate the performance of our detector design, extensive simulations have to be carried out. Part of these simulations require the measurement and recording of voltage pulses from photomultiplier tubes. This is done using a LabView digital pulse-height analyzer, a software tool that simulates an actual instrument (therefore also called a virtual instrument VI), including graphical display and automated storage of the received signals. In order to ensure the proper performance of the pulse-height analyzer and its associated equipment, we compared its results with those obtained with an oscilloscope.

2.2 Setup

This section focuses on the experimental setup of the pulse generator, the oscilloscope, and the LabView equipment.

		Pulse width[a]							
		$17ns$		$30ns$		$50ns$		$80ns$	
Pulse height	$144mV$[b]	0.35[c]	0.35[d]	-	0.72	1.30	1.30	-	-
	$720mV$	1.73	1.73	3.60	-	6.48	6.48	-	10.8

---

[a] including a rise and fall time of $5ns$ each

[b] obtained through a 5× attenuator

[c] green-colored entries refer to data points for device 3 in Figure 2

[d] red-colored entries refer to data points for device 5 in Figure 3

Table 1: Settings of the pulse generator and resulting input charge in $10^{-10}C$

2.2.1 Oscilloscope Setup

To determine a reference value for the integrated voltage, the pulse generator (BNC Pulse Generator Model 8010) was connected to a properly calibrated oscilloscope (Tektronix 2440 Digital Oscilloscope). The voltage was integrated over one pulse by using the tickmarks on the oscilloscope for several different settings of the pulse height (the constant output of the pulse generator was varied by means of a 5× attenuator) and the pulse width (see Table 1) The integrated voltage was then divided by 50Ω (because of the 50Ω impedance of the pulse generator) to obtain the input charge for the calibration plots (Figures 2 and 3). The calculation of the integrated voltage did not include the bias voltage produced by the pulse generator ($\sim 100mV$).

2.2.2 LabView Setup

To obtain the measured charge for the calibration plots, the pulse generator was connected to the pulse-height analyzer: More specifically, the pulse generator output was attached to a signal splitter (Mini-Circuits splitter ZFRSC-2050) and then connected to two independent input channels of a National Instruments digitizer (National Instruments PXI-5122 Digitizer). Two of these digitizers were tested separately, called device 3 and 5, respectively. One of the signals from the splitter was delayed by 5ns by means of a longer cable. By using the input of the two channels alternatingly, the maximum sampling rate of the digitizer of 10ns was effectively increased to $5ns$, leading to a higher temporal resolution. The digitizer output was connected to the LabView digital pulse-height analyzer. Around 2000 pulses were sampled for each of the different pulse generator settings. The record length varied from 40 to 80 data points, depending on the size of the pulse.

2.3 Analysis

The bias voltage created by the pulse generator was measured from the LabView data and subtracted from the sampled voltages. The voltage was then integrated for each of the pulses sampled by LabView. The pulse integrals were plotted

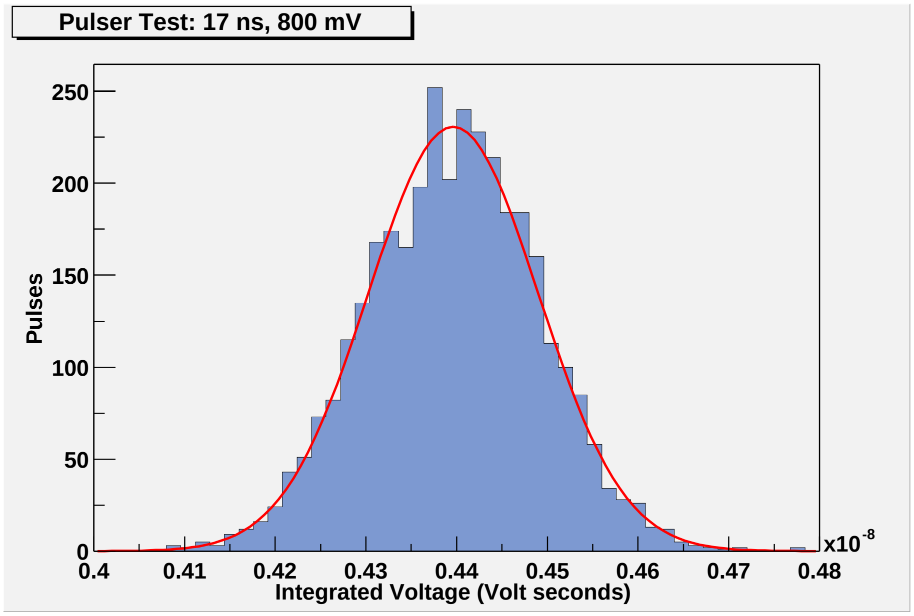

Figure 1: Histogram of integrated pulses and gaussian fit

on a histogram, and a gaussian fit was taken to find the most probable value (MPV) (See Figure 1). The MPV was multiplied by two (because the signal was split into two) and divided by 50Ω (because of the 50Ω impedance of the pulse generator) to get the measured charge. The measured charge (as obtained by the pulse-height analyzer) was then plotted versus the input charge (measured from the oscilloscope), and a straight line was fitted to the data points. The slope and intercept of the line were used to determine whether or not the National Instrument Digitizers and LabView software were properly calibrated.

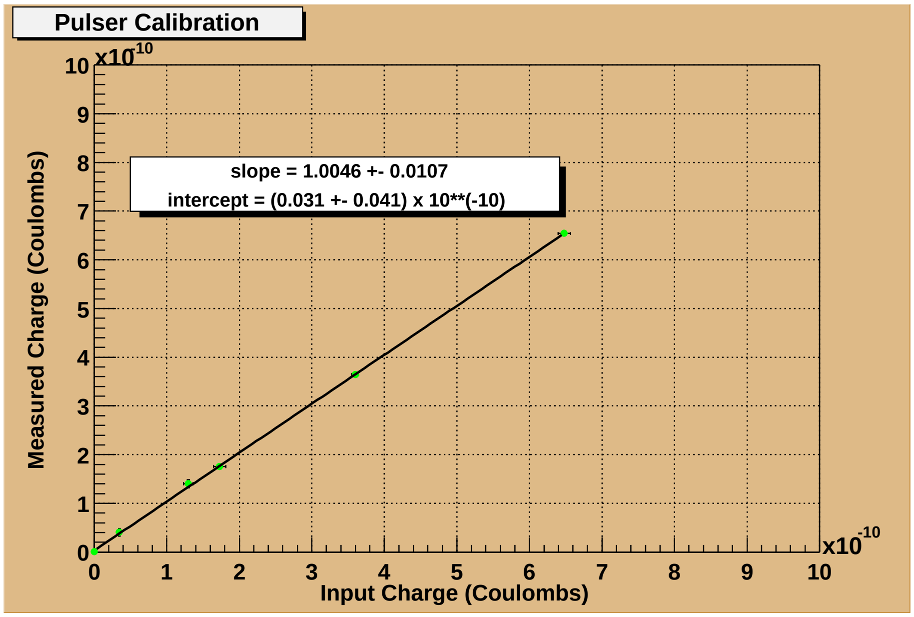

Figure 2: Calibration data from Device 3

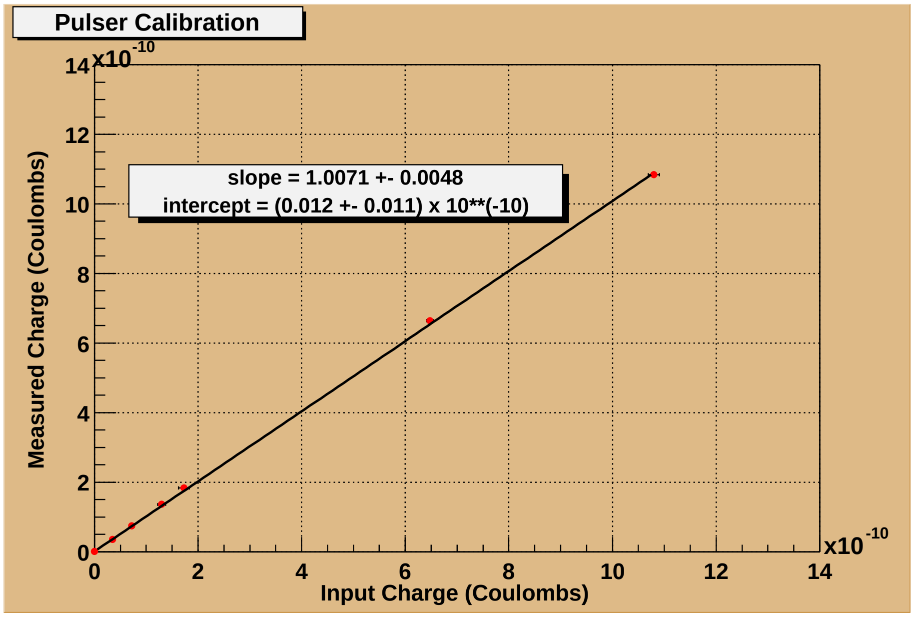

Figure 3: Calibration data from Device 5

For both devices, the slopes of the fitted lines were one, within the statistical error margin. The intercepts of both lines were zero, again with statistical error (see Figures 2 and 3). The results from the pulse-height analyzer agreed with the data from the oscilloscope. We therefore concluded that the pulse-height analyzer was giving accurate results and was suitable to be used for further measurements.

3 Pulse-height comparison

3.1 Motivation

Our design of the electromagnetic calorimeter consists of a cylinder comprised of layers of individual scintillator tiles alternating with tungsten layers. An optical fiber is embedded in each scintillator tile to absorb light emitted within the scintillator by the passage of a charged particle (bremsstrahlung/radiative relaxation of excited states of the scintillator material). The scintillator tiles themselves are wrapped in a reflective film in order to guarantee maximal light absorption. We compared two different reflective materials (DuPont[1] Tyvek 1020 and 3M[2] Radiant Light film VM2000) in order to determine which of them would yield a higher reflectivity and therefore a larger pulse-height and better resolution.

3.2 Setup

In this section we describe the experimental setup and the equipment used for the pulse-height analysis.

3.2.1 Phototube setup

The phototubes were assembled in the following way: the scintillator material was glued to an acrylic lightguide using Bicron Optical Cement, which in turn was placed on the phototube (Electron Tubes type 9814B). The scintillators had different dimensions: the top and bottom tubes had scintillators of area $1cm \times 1cm$ and height $1.9cm$, the center tube employed a $1cm$ thick scintillator of area $5cm \times 5cm$. The faces of the scintillator were covered with reflective material: aluminum foil in case of the top and bottom tubes, Tyvek or Radiant Light film, respectively, for the center tube. The purpose of the reflective material was to ensure that light emitted inside the scintillator in a direction other than towards the phototube was reflected until it entered the tube.

Originally, only the top and bottom tubes were used as double coincidence triggers for the signal from the center tube, which was connected directly to the digitizer. However, with this setup, we picked up a lot noise signals. We assumed that these noise signals were caused by unrelated signals from the top

---

[1] DuPont Building, 1007 Market Street, Wilmington, DE 19898, USA

[2] 3M Center, St. Paul, MN 55144-1000, USA

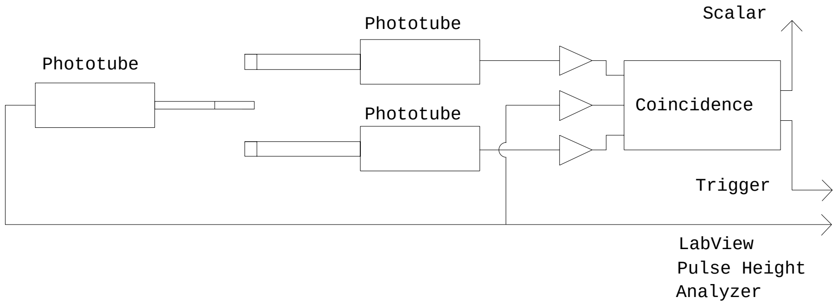

Figure 4: Phototube setup

and bottom tubes that happened to occur in the allowed time window and therefore triggered the VI, while in fact there was no signal from the center tube. To avoid these complications, we decided to include the center signal in the coincidence cicuit, which significantly reduced the noise signals.

Another modification was related to the alignment of the phototubes. At first, all three tubes were stacked vertically on top of each other, so that not only the scintillators were aligned vertically, but also the lightguides attached to the scintillators. Thus, a particle going vertically through all three lightguides could trigger a signal through Cherenkov radiation, if the gain of the tubes was high enough. To avoid this problem, the center tube was rotated 180° with respect to the other tubes, while maintaining the vertical alignment of the scintillators.

As mentioned above, the three phototubes were alligned in a vertical line, so that only a particle coming straight down could trigger a simultaneous signal in all three phototubes (see Figure 4). The phototubes were driven by a high voltage dc power source, set at $2.0kV$ for the top and bottom tubes (Power Designs Inc., model HV-1547), and at $1.7kV$ for the center tube (Power Design Inc., model 1570B).

3.2.2 Electronics setup

The signals from the three phototubes were fed into three different discriminators (LeCroy model 821), with their threshold voltage set to $100mV$ for the top and bottom phototubes, and $50mV$ for the center phototube, respectively. The threshold was set at different levels, since the signal from the center tube was split in two and used as input signal for the analysis. The output from the three discriminators was applied to a LeCroy 4-fold logic unit (model 365AL), set to triple coincidence, so that only a simultaneous signal from all three phototubes was allowed to be detected (simultaneous meaning within a $20ns$ window, because this was the temporal width of the discrimator signal). This corresponds to one very fast particle going vertically through all three detectors. The output from the logic unit was used as input for a digital scalar (Ortec model 430) to keep track of the number of pulses, as well as an external trigger for a 14-bit digitizer (National Instruments PXI-5122). The signal from the center tube was split again, and then connected to two independent input channels of the digitizer, with one of the signals delayed by 5ns by means of a longer cable. By using the input of the two channels alternatingly, the maximum sampling rate of the digitizer of $10ns$ was effectively increased to $5ns$, leading to a higher temporal resolution.

3.3 Analysis

The signal analysis was carried out with the LabView digital pulse-height analyzer. Each pulse was integrated over 80 data points (corresponding to $400ns$). The distribution of the resulting integrated pulse-height was then plotted in a histogram (number of pulses for which the integrated pulse-height falls within a certain range element vs. integrated pulse-height). The pulse rate itself (number of recorded signals per unit time) varied between 3 and 4 pulses/hour for both Tyvek and Radiant Light film and was not affected by the type of reflective material used; the pulse rate was thus not taken into account in the analysis.

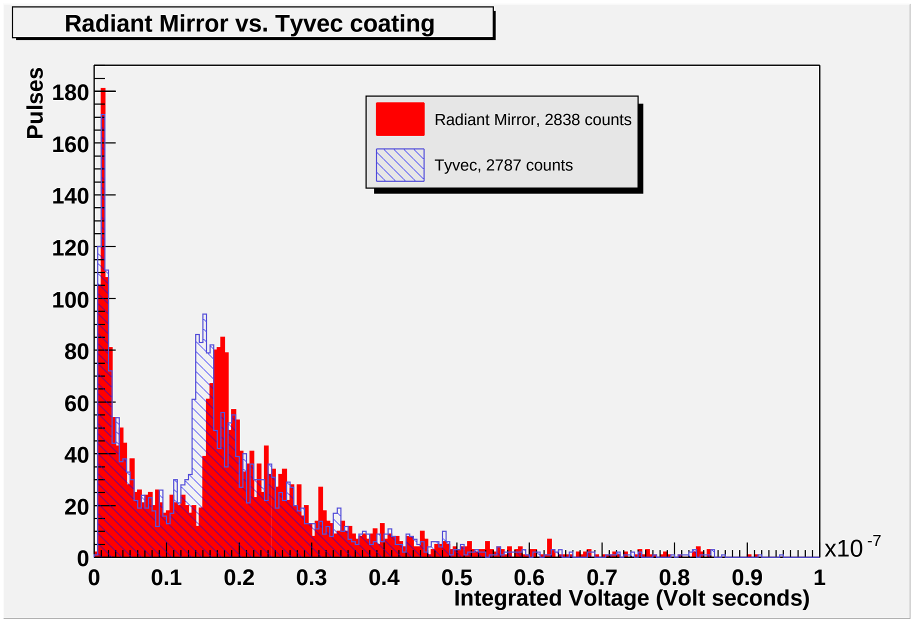

Figure 5: Tyvec compared to Radiant Mirror

Comparison of the results showed a difference in behaviour between Tyvek and Radiant Light film: In each case, two distinct maxima could be observed, the first and higher one very close to zero, the second one around $0.15 \cdot 10^{-7} Vs$. We assume the first one to be caused by Cherenkov radiation when a particle is going through both lightguides, as opposed to through the scintillators themselves, and the second one to be related to a particle actually going through all three scintillators. In order to identify any differences between Tyvek and Radiant Light film, both plots were displayed on top of each other (see Figure 5). One can clearly see that the second peak was shifted to the right in case of Radiant Light film as reflective material, meaning that the average integrated pulse-height (ignoring the 'noise' contribution from the first peak) was higher for Radiant Light film compared to Tyvek. We therefore concluded that Radiant Light film had a higher reflectivity, since a higher light intensity (more photons) reaching the phototube leads to a larger output pulse of the phototube, provided a constant gain.

As a result of these experiments, Radiant Light film should be chosen as the reflective material to wrap the scintillator in, due to its higher reflectivity.