THE DESIGN AND EXPECTED PERFORMANCE OF A FAST SCINTILLATOR HADRON CALORIMETER*

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I. Introduction

We consider a calorimeter of the type developed by W. Willis, et al., for the ISR 807 experiment.¹ Figure 1 shows the basic concept. The calorimeter consists of a stack of alternating metal (copper or uranium) and scintillator plates 20 cm wide, 120 cm long and 1.5 mm thick. Light generated in the scintillator passes out through the edges and into wavelength shifter bars that lie between the stacks. The light from the scintillator is absorbed in the shifters and excites lower-frequency emission that then passes down the shifter to phototubes in the rear. The 807 geometry has in fact separate shifters for the front electromagnetic and rear hadronic parts of the calorimeter but we will not be considering this complication here. We will also restrict the discussion to copper plates.

A typical pulse from the 807 calorimeter is shown in Figure 2. This was generated by 4-GeV electrons but the pulses from hadrons and at different energies are not significantly different. The width and shape of this pulse comes from the convolution of a number of sources:

- The time spread of energy deposition by a shower including time of flight of slow protons and neutrons,
- scintillator phosphor rise and decay times,
- shifter rise and decay times,
- phototube response,
- time delays in the light collection from different parts of the calorimeter and time dispersion in transmission.

The objective of the first phase of this study was to isolate these separate contributions, estimate how they could be speeded up and find what costs are involved. For this phase we have run Monte Carlo for (a), made measurements using single photon counting for (b), and (c). Observe (d) with a fast scope, observe (e) and (f). From these observations we estimated that a fast calorimeter could be made with pulses whose full width half maximum would be of the order of 7 nsec.

In the second phase we constructed an extremely crude calorimeter whose pulses should have the same characteristic as in a real device. With this we have observed signals whose mean width was 7 nsec and whose width at 10% of maximum height was 15 nsec. Clipping could reduce these widths to 6 and 12 nsec respectively. We conclude that gate times of less than 20 nsec would be appropriate for such a calorimeter.

A third phase is underway to build a good test calorimeter to confirm these results.

II. Discussion

a. Energy Deposition

A Monte Carlo program used and modified by Alan Stevens has calculated the time distribution of energy deposition for both a copper and a uranium calorimeter.

meter. The results in 5 nsec bins are shown below. For copper they are plotted in Fig. 3.

Time Interval	Copper	Uranium
0- 5 nsec	97.2	91
5-10	2.2	6.0
10-15	0.5	2.1
15-20	0.1	0.7
20-25		0.2
25-30		0.1

These results show a fast initial spike 2 nsec wide followed by an exponentially falling slow component whose time constant is 4 nsec and whose total fraction is about 10% for copper and 20% for uranium.

b. Scintillator

ISR 807 uses an acrylic scintillator that contains among other ingredients Napthalene whose published³ decay time is 96 nsec. We have not measured the response of this scintillator without shifter but the observed long tail on the shifted signal (Fig. 2) is presumably from this decay.

More conventional scintillators contain some combination of fast UV scintillating chemicals such as PBD (emission max ~ 370 nm) and wavelength shifters such as POPOP that lower the emission frequency to a more convenient visible range ~ 430 nm. These scintillators are faster than Napthalene scintillators but slower than scintillators without the shifter. Such scintillators (eg NE111 and Pilot U) emit in the UV (370 and 390 nm respectively) and have shorter attenuation lengths than conventional scintillator but these are not a disadvantage when the light path to a separate shifter is short.

We have looked at the pulse distributions from two fast UV emitting scintillators: NE111 and BC420 (similar to Pilot U). Both give pulses less than 2 nsec FWHM and less than 5 nsec at 10%. Published data² gives pulse distribution for NE111 as shown in Fig. 4. We expect that polystyrene scintillators using on the chemical PBD without shifters have similar response at lower cost. The cost of scintillator for a hadron calorimeter using BC420 or Pilot U is about 140 K\$ per m² in a 0.4 m² lot. The cost for polystyrene should be about half this.

c. Wavelength Shifter

Conventional calorimeters (such as that in the ISR 807 experiment) use the shifter BBQ whose absorption maximum at 430 nm matches many conventional scintillators. We measured (see Sec. 3) the response of BBQ illuminated by NE111 and observed a FWHM of 12 nsec and width at 10% of 30 nsec. We also measured the response of POPOP and BBOT each illuminated with NE111 and observed FWHM's of 6.4 and 4.9 nsec respectively and width at 10% of 12.5 and 17.2 nsec respectively (see Fig. 5). Clearly both BBOT and POPOP are much faster than BBQ, with BBOT preferred over POPOP. The absorption maxima for the POPOP and BBOT are at 360 and 398 nm suggesting that good combinations would be NE111 (or Polystyrene UV) and POPOP or Pilot U (or Polystyrene UV-390) and BBOT. The latter combination is preferred because of the faster wavelength shifter

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and also because the further UV emitting scintillators NE111 and Polystyrene UV have shorter attenuation lengths (8 cm and 16 cm respectively) compared with Pilot U and Poly UV-390 (100 cm and 20 cm).

Table I summarizes the response time data²⁻³ for both scintillators and shifters discussed plus NE110 for comparison.

Table I

Scintillator	A "Conventional" Scintillator				
	emission λ	rise time	fall time	FWHM	Attenuation
	nm	nsec	nsec	nsec	λ cm
NE111	370		1.7	1.55	8
Pilot U	391	0.5	1.36	1.97	100
NE110	434	1	3.3	3.3	400

Shifter	Published			Measured (w/NE111)
	absorption λ	emission λ	fall time	
	nm	nm	nsec	nsec
BBQ	430	505	---	12
POPOP	360	415	1.1	6.4
BBOT	398	432	1.6	4.9

Acrylic is the conventional base for the shifters. It is easy to handle but less radiation resistant than PVT. PVT is harder to handle, being inclined to craze. Polystyrene could possibly be employed although most polystyrene has an unsatisfactorily short attenuation length.

Table II shows attenuation lengths measured by the Penn and ISR groups. For the Penn measurements the bar was 1 cm $\times$ 2.5 cm. For the ISR it was 20 cm $\times$ 0.3 cm. In both cases the shifters are in acrylic.

Table II

Shifter	Concentration	Attenuation Penn	Length cm ISR
BBQ	80 mg/litre	---	152
POPOP	300 mg/litre	---	114
	100 mg/litre	97	190
	30-40 mg/litre	131	157
BBOT	100 mg/litre	70	---

The concentration of shifter should in general be as high as possible consistent with a sufficient attenuation length. These measurements are critically dependent on the surface condition of the bars and thus show some inconsistencies. The values should thus be taken as lower limits on the bulk attenuation.

d. Phototube

Typical 12 stage phototubes have responses similar to that measured⁶ for RCA 8850 and shown in Fig. 6a. FWHM is about 5 nsec and width at 10% about 12 nsec. The width comes primarily from variation in transit time in the dynodes. The RCA C31024 is a tube employing only 5 dynode stages. Gain of over 10^6 is achieved by using Gallium phosphide on all stages. The output from the tube is taken from a special coaxial pin further improving the high frequency response. A pulse from this tube is shown in Fig. 6b.

It has a FWHM of only about 1 nsec and at 10% about 3 nsec. The tube has a rather standard 2" photocathode and is very well suited to calorimeter use. Its cost is now just over 1000\$ but would be less in quantity.

e. Light Collection Time Delays

The measured mean velocity of light in the wavelength shifter bars is 0.5 times the velocity of light. The velocity of the shower itself is equal to that velocity. As a result light from the back of the shower arrives at the phototube earlier than that from the front. If the calorimeter is 1 m deep this causes a time spread of 3 nsec.

Time dispersion arises because of the finite aperture of the shifter bars. Light traveling straight down the bar takes a time $t = \lambda N/C$ (where N is the refractive index), yet the measured mean time was $2\lambda/c$ slower because of the finite angles of rays in the shifters. For a shifter and light guide about 4 ft long the resultant FWHM time spread is about 1 nsec.

f. Summary of Time Constants

The Table below gives the estimated or measured contributions (FWHM) to the expected output pulses of the ISR 807 calorimeter and a possible faster version.

	807	Fast Cal.
a. E. deposition	2	2
b. Scintillator	Acrylic ~ 15	Pilot U 1.5
c. Shifter	BBQ 12	BBOT 5
d. Phototube	standard 5	C31024 1
e. Light Collection	~ 5	~ 5
Overall	~ 20	~ 7
Observed	23	7

Numbers with approximate sign were estimated, the others measured. The observed overall value for the fast calorimeter was obtained from the test reported below.

III. Measurements

a. Single Photon Counting Measurements

The set-up used is shown in Fig. 7. The hole in front of the phototube #2 was adjusted to keep the counting rate from tube #2 to less than 1% of tube #1. The signals from both tubes were taken to constant fraction discriminators. The tube #1 high voltage was set so that the counting efficiency for a minimum ionizing particle passing through the trigger scintillator was about 70%. The tube #2 high voltage was set to obtain a similar efficiency for single photons. The time difference distribution between tubes 1 and 2 were observed on a "QVT". The distributions obtained are shown in Fig. 5 and reflect effects from the scintillator, shifter and dispersion down the shifter bar, but not from the phototubes except for the jitter in the system (about 1 nsec).

Since the scintillator and this jitter are small compared to the observed width we can interpret this width as that of the shifter without correction.

b. Calorimeter Experiment

In order to check the estimates given in Section II(f) prior to the construction of a full scale test we set up a crude experiment. Sixteen lead bricks (each 3-1/2" $\times$ 7-1/2" $\times$ 1-1/2") were placed in a row

with 15 4" x 4" x 1/8" pieces of NE111 scintillator between the bricks (see Fig. 8). Two shifter bars were tried: one 30" x 4" x 1/8" of POPOP the other 24" x 8" x 1/8" of BBOT. Both were blackened at the front end. A single RCA C31024 phototube was butted up to the back end of the shifter without a light guide, glue or grease. This device was placed in a somewhat broad (~ 6" diameter) 22 GeV π^- beam. A trigger was formed from the coincidence of one small 1/2" x 1/8" scintillator in front of the calorimeter and a second phototube looking at one of the 4" x 4" x 1/8", 1/3 of the way down the row. The second trigger phototube level was set to fire on at least one minimum ionizing particle at that point in the shower and thus vetoed triggers from a background of low energy tracks not in the beam direction.

It must be noted that this "calorimeter" had a cross section that contains only a small fraction of the approximately 8" diameter of a hadron shower. It also has limited sampling with a very high Z material. It is a very poor calorimeter. It should however provide a reasonable estimate of the pulse length seen by one 4" x 4" tower in a real calorimeter of the same depth.

The observed pulse height distribution is shown in Fig. 9 (for POPOP shifter). The σ for this distribution is 38% corresponding to 180% / $\sqrt{E}$. Under the circumstances this is a surprisingly good energy resolution.

A typical pulse is shown in Fig. 9 (for BBOT). Considerable pulse to pulse variations were observed, as expected in a calorimeter that does not contain the shower. The Table below gives the widths for successive pulses using both BBOT and POPOP.

Widths at half height nsec

POPOP: 5,12,8,14,10,16,11,11; mean 11;
BBOT: 8,9,6,5,7,5,7,10; mean 7.

Figure 10a shows the mean shapes that hopefully approximate the real shape that a larger calorimeter would give. Figure 10b shows the mean shape from BBOT after shaping by a 4 nsec 23% clip. This pulse has only 6 nsec full width at half maximum and only 12 nsec at 10%.

The question was raised as to whether the signal from neutrons at larger distances from the 4" x 4" shower case might be much slower. A further experiment was performed in which the beam was directed at a second stack of uninstrumented lead bricks set up alongside the instrumented stack. Observation of the signals in this instrumented stack showed no indication of signals arriving significantly (i.e., more than 5 nsec) later than had been observed before, i.e., we saw no evidence for a significant slow signal outside the core.

IV. Conclusion

We conclude that a scintillator with suitably chosen available components could give pulses with widths comfortably less than 10 nsec at half height and less than 20 nsec at 10% of height. Gates of 20 nsec seem not unreasonable. Work is needed to confirm this result with a full scale calorimeter and on electronics to digitize the signals. This is underway.

References

1. O. Botner, et al., Nucl. Inst. & Methods **179**, 45 (1981); also Ibid **196**, 303 (1982), and private communication.
2. J. Pronko, et al., Nucl. Inst. & Methods, **163**, 227 (1979); F. Galligaris, et al., Ibid **171**, 617 (1980).
3. Catalogs: National Diagnostics, Somerville, NJ, USA; Nuclear Enterprises, Edinburg, Scotland.
4. W. Kononenko, W. Selove, and G.E. Theodosion, UPR96E, U. of Pennsylvania, internal report; RA-Ong, DD23/OG563, Brookhaven Lab internal report.
5. Private communication, W. Willis and W. Wenzel, CERN, Geneva, Switzerland.
6. H.R. Kroll and D.E. Persyk, IEEE Trans. Nuc. Sci. **NS19**, 45 (1972); B. Leskovar and C.C. Lo, LBL 6456 Lawrence Berkeley Lab internal report.

Figure 1. Schematic representation of calorimeter being considered.

Figure 2. Pulse observed in ISR 807 calorimeter from 4 GeV electron.

Figure 3. Monte Carlo time distribution of energy deposition from a 5 GeV negative pion in the test calorimeter.

Figure 5. Pulses obtained using (a) POPOP and (b) BBOT shifters together with NE1112 scintillator.

Figure 4. Light pulse from NE111.

Figure 6. Output pulses from (a) RCA C31024 and (b) RCA 8850.

Figure 7. Arrangement for single photon measurement of scintillator and shift pulse length.

Figure 10. Average pulse shapes from the calorimeter experiment using BBOT (a) without and (b) with a 23% 4 nsec chip.

Figure 8. Calorimeter experiment to observe pulse length with fast scintillator shifter and phototube.

Figure 9. Typical signal from calorimeter experiment using BBOT shifter.

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