A Lead Fluoride Calorimeter for Hall A

Kathy McCormick[1] and Sirish Nanda[2]

[1]Rutgers, The State University of New Jersey, Piscataway, NJ 08855
[2]Thomas Jefferson National Accelerator Facility, Newport News, VA 23606

1 Introduction

A nine-cell prototype calorimeter of lead fluoride (PbF_2) has been constructed and tested in Hall A. The calorimeter was placed in the focal plane of the left HRS, in the usual position of the gas Čerenkov detector. Electrons elastically scattered from the liquid H_2 target were incident on the calorimeter, and a resolution of $1.6\% \oplus 3.6\%/\sqrt{E}$ was measured, for electron energies from 1 to 4 GeV.

2 Calorimeter Construction

The material lead fluoride is a Čerenkov radiator which was first seriously investigated as a possible electromagnetic calorimeter material around 1989 [1]. The properties of PbF_2 compared to other common calorimeter materials are shown in Table 1. It is very dense ($\rho = 7.66$ g/cm^3) in comparison to "old-style" lead glass calorimeter materials such as SF–5, and on par with new calorimeter materials like lead tungstate ($PbWO_4$). Lead Fluoride has a short radiation length ($X_0 = 0.95$ cm) and small Molière radius ($r_M = 2.22$ cm), which allows it to be built into a compact calorimeter. Its index of refraction varies from 1.937 at 300 nm to 1.749 at 800 nm. It has no need of temperature stabilization, excepting the fact that it is very fragile and can crack if handled outside of room temperature. The samples of lead fluoride that we tested began to transmit around 250 nm and leveled-out at about 80 – 90% transmission around 400 nm (see Fig. 1).

The blocks used for the 9-cell prototype were manufactured by Shanghai SICCAS High Technology Corporation in China. A photo of one of the blocks is shown in Fig. 2. Each block was 150 mm long. The blocks were tapered from a 26 mm^2 front face to a 30 mm^2 rear face. Each block was viewed by a round, 28 mm diameter Photonis XP2972 PMT. The high voltage for the PMT was supplied by a LeCroy high voltage crate via LeCroy 1461N high voltage cards.

Several types of wrapping and coupling of PMTs to the rear (30 mm^2) block face were tested. Different glues were tested first. An approximately three inch long block of PbF_2 was used for the different coupling tests. The block was first wrapped in one layer of Tyvec paper ($\approx$80 μm thick), then a test PMT was successively coupled to the block with two different types of UV glues (DYMAX OP-19 and DYMAX 9-20318-LV) and a type of organic glue

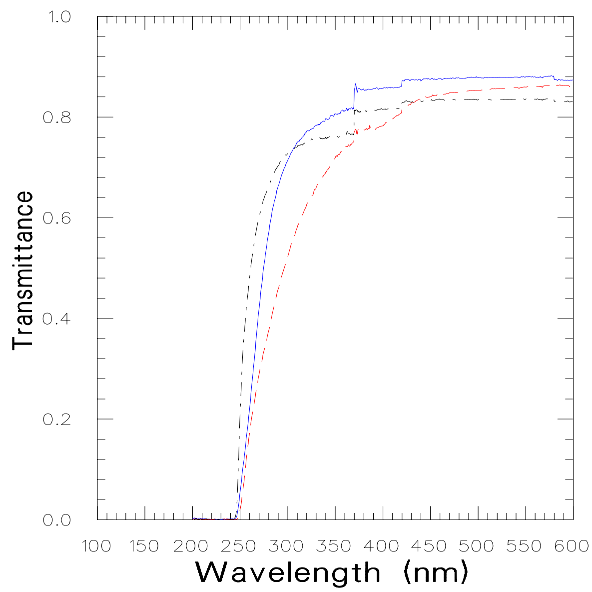

Figure 1: Transmission versus wavelength for three samples of PbF_2. The abrupt jumps around 370 nm and 420 nm are artifacts of the scanning procedure. This scan was taken across the lateral dimension of the samples, where their thickness was approximately 3 cm.

(Meltmount). The various block-pmt combinations were then put in a light-tight box and cosmic data was taken for approximately 2 hours with each different coupling combination. The resulting ADC spectra are shown in Fig. 3. The mean of each spectrum was taken as an indication of the light collection efficiency. As seen in the figure, the mean was lowest for the Meltmount coupling and increased by 5% for the 9-20318-LV UV glue and by 31% for the OP-19 UV glue. The shape of the distribution is well described by a Landau distribution for the Meltmount and 9-20318 LV coupling, but it becomes broader for the OP-19 glue. This distribution was reproducible, but no explanation was found for its different shape. Given the large mean seen in the OP-19 spectrum, the coupling of the Photonis tubes to the PbF_2 blocks for the test run was done with this glue.

Next the effect of different wrappings on the light collection was studied. The pmt-block combination coupled with Meltmount was successively wrapped with Tyvec paper (80 μm), two layers of Teflon tape (50 μm) and one layer of aluminized mylar wrapped with one layer of black paper (together 100 μm). The results of two hour cosmic runs with each of the different wrappings are shown in Fig. 4. In this case, wrapping with aluminized mylar yielded the lowest ADC response, followed by the teflon wrapping and lastly Tyvec wrapping with the highest response. From this test it was decided to wrap the blocks in the test calorimeter with Tyvec paper, of envelope grade and thickness. A layer of black paper

	PbF_2	$SF-5$	$PbWO_4$
Lead (% by weight)	85	55	>85
density (g/cm^3)	7.66	4.08	8.28
radiation length (cm)	0.95	2.36	0.89
Moliere radius (cm)	2.22	3.7	2.19
Index of refraction	1.82	1.67	2.30
Radiation type	Č	Č	scintillation

Table 1: Comparison of Lead Fluoride with other calorimeter materials

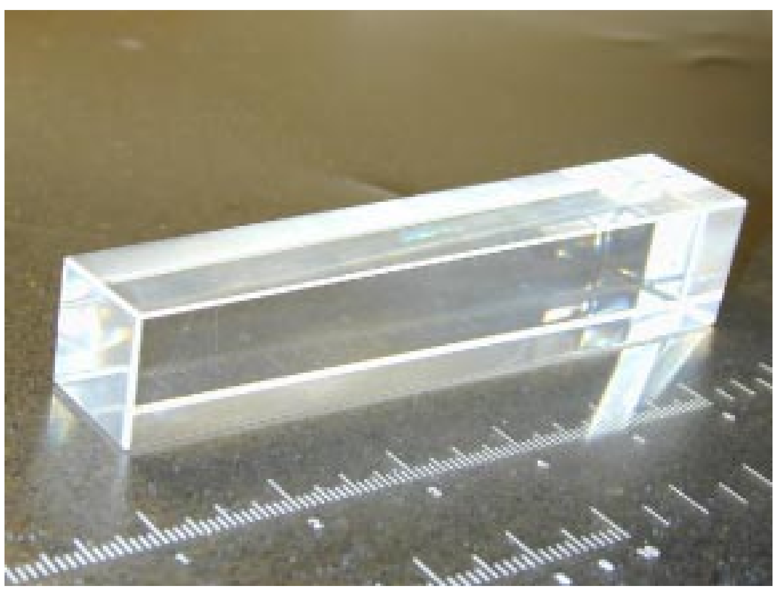

Figure 2: Photo of a block of lead fluoride (PbF_2). The blocks used in the test calorimeter were 150 mm long with a 26 mm^2 front face and a 30 mm^2 rear face.

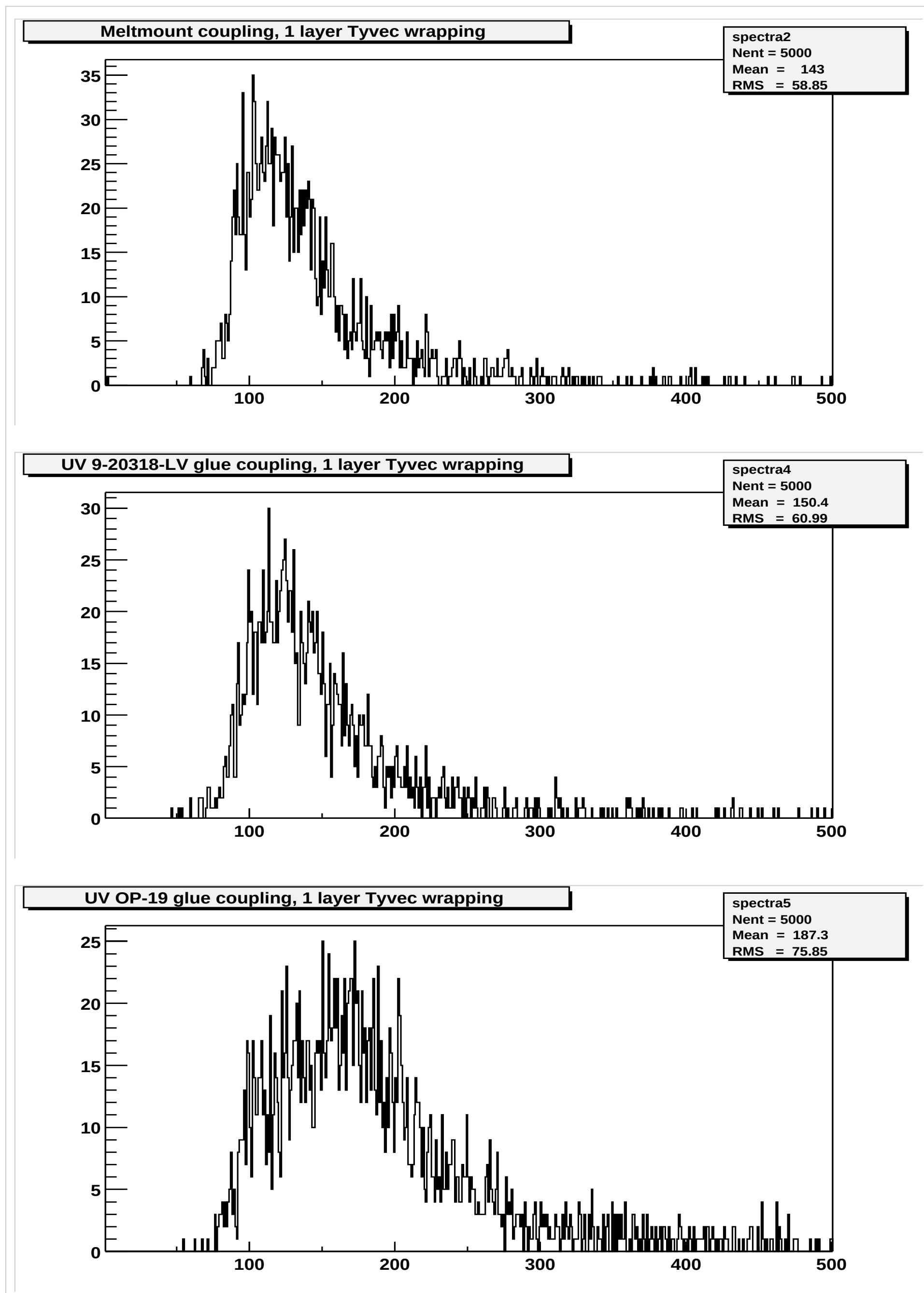

Figure 3: ADC spectra for different glue couplings of the PMT-block combination.

was also added to the test calorimeter blocks to make sure they were light-tight. The final block+pmt assembly for the test run is seen in Fig. 5.

Before the calorimeter was put into the focal plane, a rough gain matching between the blocks was performed using a blue LED. The LED was placed on the front of each block and the ADC response was recorded as a function of high voltage on the PMT. For two of the blocks, this calibration was found to be about 7% off once the calorimeter was installed in the focal plane, while the high-voltage for the rest of the calorimeter blocks was within about 2% of the calibrated value. The change was probably caused by mis-positioning or mis-alignment of the LED during the initial calibration where the LED was placed manually on the face of each block.

3 Beam Test

The calorimeter (and a subset of the DVCS proton array detectors) was tested with beam March 3-6, 2002. The calorimeter was placed in the left HRS detector stack, in the usual position of the gas Čerenkov (i.e. between S1 and S2). S0 was in the detector stack, positioned before S1. Several triggers were available during the calorimeter testing: T1 was the OR of the 9 calorimeter blocks, T3 was the AND of the two S0 PMTs, T4 was the AND of S0 and S1, T5 was the AND of T1 and T3 and T8 was a 1024 Hz pulser.

The LHRS angle and momentum was set to detect elastically scattered electrons at eight different kinematical settings from 0.977 GeV to 3.980 GeV (see Table 2). To make sure that the elastically scattered electrons covered the calorimeter uniformly, Q3 was defocused by approximately 50%.

Beam Energy (GeV)	Scattered Electron Energy (GeV)	Run Numbers
1.201	0.977	3527
	1.02736	3525 3526
	1.1000	3529 3530
	1.1322	3528
5.754	2.00	3536
	3.00	3535
	3.471	3532
	3.98	3534

Table 2: The test run kinematics.

Figures 6 and 7 show the event distribution over the face of the calorimeter. Each

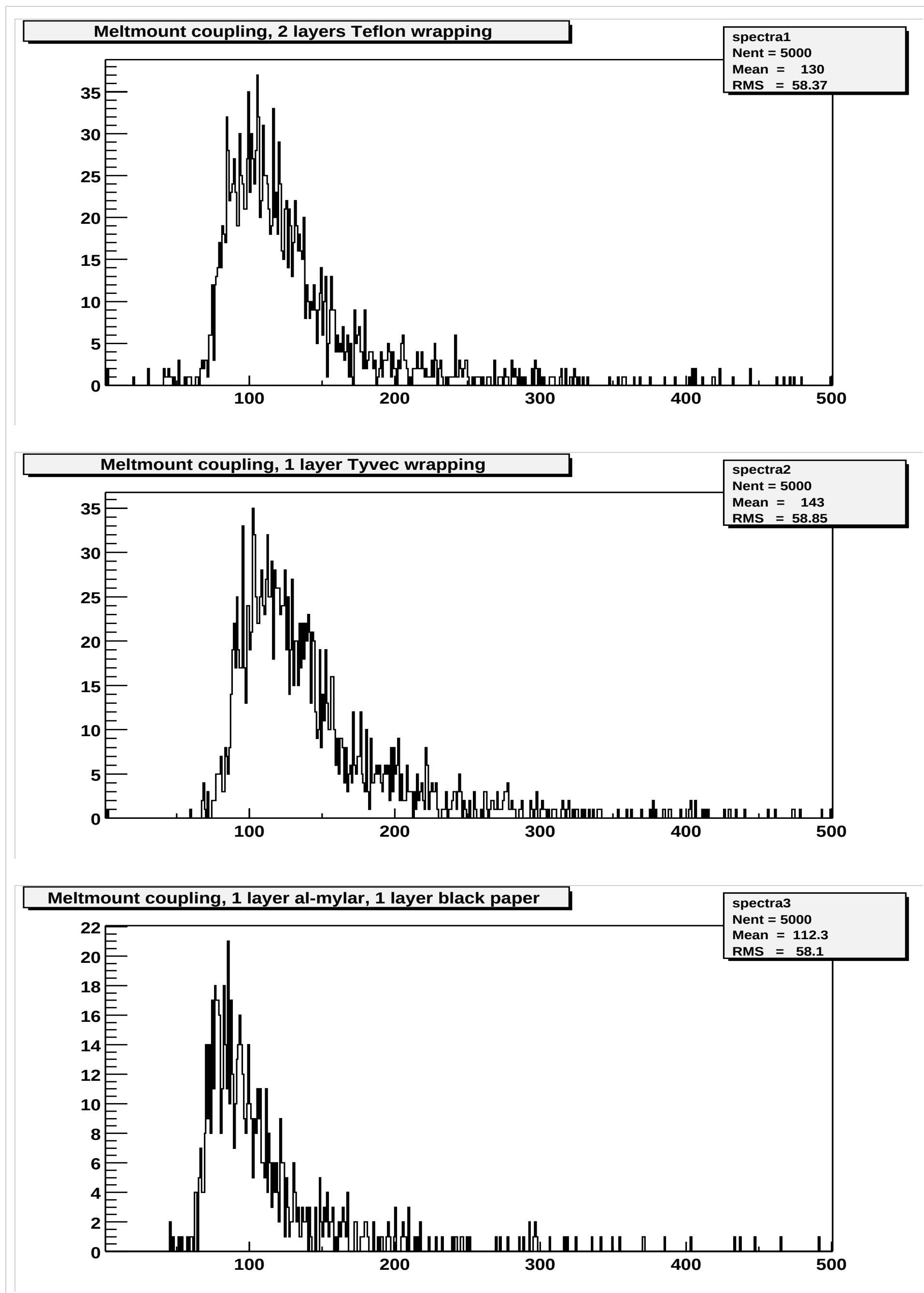

Figure 4: ADC spectra for different wrappings of the PMT-block combination.

Figure 5: A single PbF_2 calorimeter block coupled to a Photonis XP2972 PMT. The PMT is coupled to the block with OP-19 UV curable glue. The calorimeter block is wrapped with one layer of Tyvec paper and 1 layer of black paper to assure light tightness (see text).

point marks the x and y position of an event in the detector coordinate system. Both figures display only T5 events, i.e. coincidences between the calorimeter (T1) and S0 (T3). Figure 6 shows the full lateral extent of the calorimeter (approximately 9 cm of PbF_2). Around the outside of the crystal area, the outline of events from the 0.5 inch thick iron calorimeter box can be seen. Figure 7 shows the same distribution, only this time the distribution is cut on more than 50% of the scattered electron's energy being deposited into a single block. This cuts out most of the events that hit the edge of a block or that hit the iron containment box. We can also see from this figure that not all blocks were uniformly populated with events (there are about twice as many events in the blocks of the first column of the calorimeter than in the third), which tells us that we positioned the calorimeter with a slight tilt. We estimated from the block size ratios that the calorimeter was tilted by approximately 8°. Simulations were performed to study the effect of a tilt on the calorimeter resolution, but no effect was seen [2].

Before extracting the energy resolution of the nine-cell calorimeter, the blocks were gain matched again in software. The gain factors were determined by matching the edges of the ADC spectra for each of the nine blocks. The raw ADC spectrum for each block was then pedestal subtracted and multiplied by its gain factor. The sum of the nine corrected spectra was then performed. To extract the energy resolution, the corrected ADC sum was cut on events which struck the central block (block 5) of the array and deposited more than 75% of their energy in this block. The resulting distribution was then fit with a Gaussian distribution to extract its mean and sigma. This procedure was repeated for scattered electron energies up to 4 GeV.

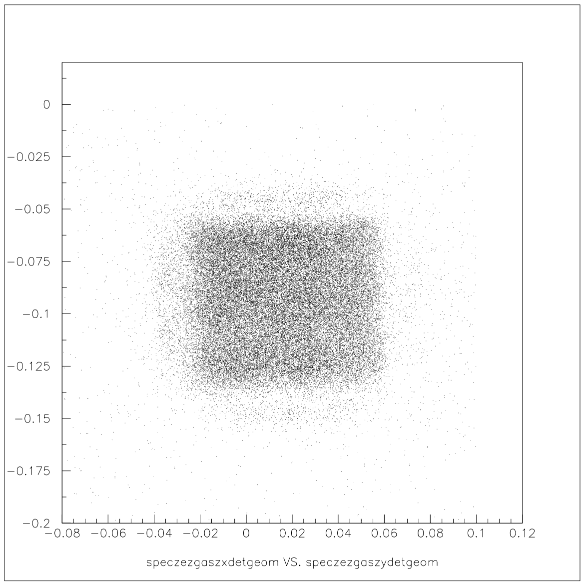

Figure 6: Spec_e.gas.xdetgeom vs Spec_e.gas.ydetgeom, the position of events in the detector coordinate system at the calorimeter.

The resolution as a function of energy is seen in Fig. 8, where the several measurements taken around 1 GeV are represented by a single typical resolution. The resolution improves as a function of energy, as expected from the statistical nature of the shower development. The resolution as a function of energy was fit with the function

$$\frac{\sigma}{E} = a \oplus \frac{b}{\sqrt{E}} \tag{1}$$

where a represents energy-dependent contributions to the resolution, such as calibration errors (gain mismatch), non-uniformities and non-linearities in photomultipliers, ADC's, etc. and shower leakages. The second term is associated with the light output of the crystals and describes the statistical nature of the shower process. The fit yields a resolution of $1.6\% \oplus 3.6\%/\sqrt{E}$.

In summary, a nine-cell lead fluoride calorimeter was tested in Hall A. This calorimeter is a prototype of the calorimeter which will be used in the upcoming Hall A DVCS experiment [3], and a test for the suitability of lead fluoride as a calorimeter material in the

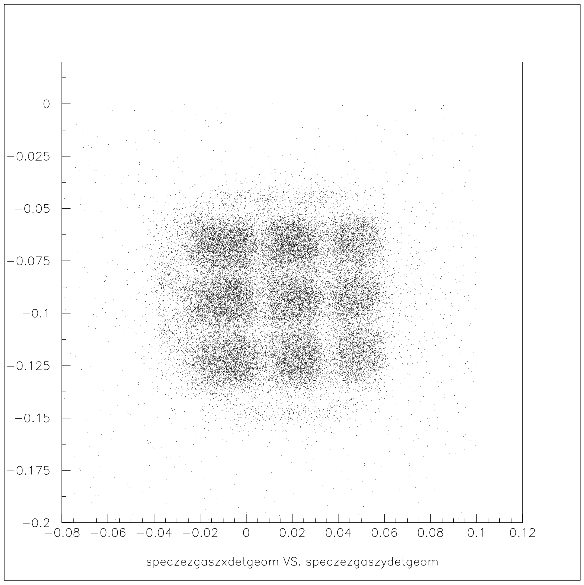

Figure 7: Spec_e.gas.xdetgeom vs Spec_e.gas.ydetgeom. This spectrum is cut on more than 50% of the scattered electron's energy being deposited in a single block.

Hall A environment. The calorimeter was mounted in the LHRS focal plane and its energy resolution was measured with scattered electrons to be $1.6\% \oplus 3.6\%/\sqrt{E}$.

[1] D.F. Anderson, M. Kobayashi, Y. Yoshimura and C.L. Woody, FermiLab Internal Report FERMILAB-Pub-89/189; D.F. Anderson *et al.*, Nucl. Instr. Meth. A **290**, 385 (1990).

[2] F. Sabatié, Private Communications.

[3] C. E. Hyde-Wright, P. Bertin, R. Ransome and F. Sabatié, JLab Experiment E00-110.

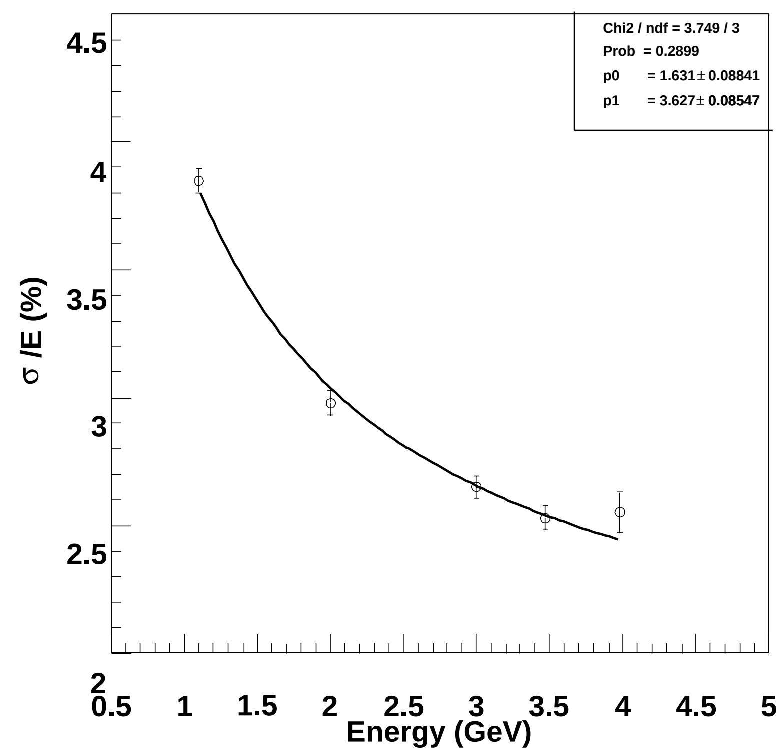

Figure 8: The resolution of the nine-cell PbF_2 test calorimeter as a function of energy. The data has been fit with the function $\sigma/E = a + b/\sqrt{E}$.