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LIQUID ARGON CALORIMETER POSITION RESOLUTION

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Liquid Argon Calorimeter Position Resolution

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1. Introduction

Electron identification in the calorimeter requires matching the energy deposit to a charged track. The standard tower size of $\delta\eta = 0.05$ by $\delta\phi = 0.05$ is too coarse for this purpose, so the electromagnetic calorimeter will include a "fine" section with better position resolution. This note discusses an EGS Monte Carlo calculation of the position resolution achievable as a function of the width of the strips in the fine section. It is anticipated that strips will be used because the resolution is needed primarily in phi, rather than z.

The resolution has been found for strip widths of 1 cm to 5 cm, for longitudinal thicknesses of one to thirteen gaps (0.7–9 radiation lengths), with and without electronic noise, and for various incident angles. The effects of pileup, which are likely to be significant, have not been included. For a fine section that is one LAr gap thick, with 2 cm wide strips and electronic noise of 5 MeV per strip, the resolution is 3 mm for 20 GeV electrons at the center of the strip, and 2.4 mm averaged across the width of the strip. The resolution in z at $\eta = 0$ is a few cm. Substantially better resolution in z (or η) can be achieved with u and v strips at angles $\pm\alpha$ with respect to the z axis.

2. EGS Model

The electromagnetic section of the detector is taken be 4 mm lead sheets separated by 4 mm of LAr and a 1.5 mm G-10 readout board. The EGS model does not include the G-10. In front of the first lead sheet is 20 cm of aluminum followed by 15 cm of vacuum, representing the coil (Figure 1). Two hundred 20 GeV electrons have been generated at each of several incident angles (ϕ). In each case, the centroid of the shower is at $y = 0$ at shower maximum (layer 7 of the LAr). Unless otherwise stated, the results below are for normal incidence.

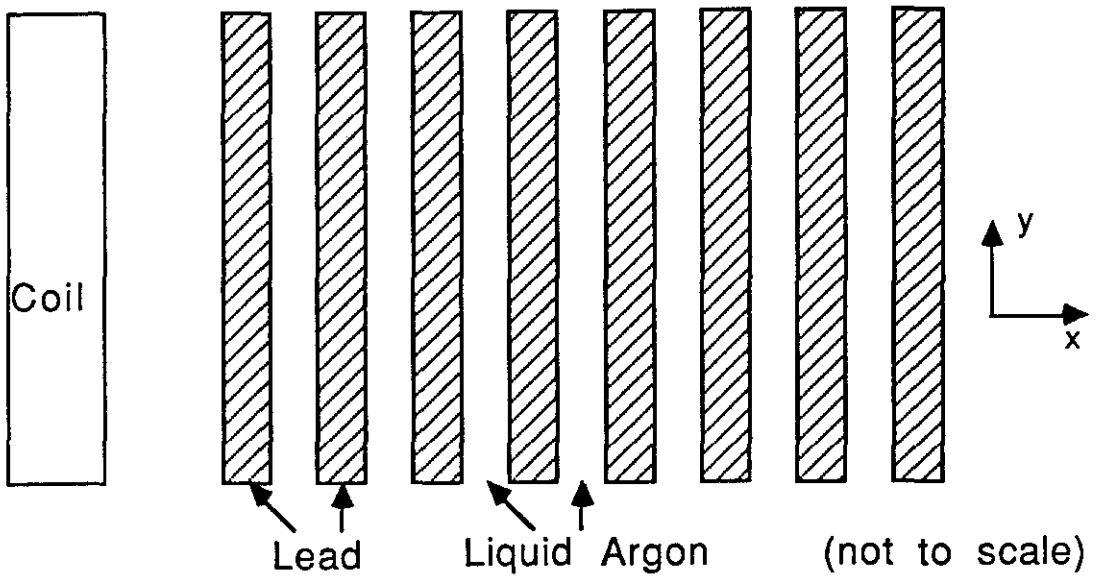

Figure 1. Geometry used in EGS model of the liquid argon electromagnetic section.

The EGS energy cutoff was 1 MeV. No significant difference was found using 100 keV, but 10 MeV gave showers that peaked substantially faster, since a large fraction of the shower energy is carried by MeV energy photons.

The energy deposited in each LAr layer is recorded in 1 mm bins in y for each incident electron. These fine bins are then summed offline to give strips of the desired width in $r - \phi$ and longitudinal depth. The strips are assumed to be long in z compared to the size of the shower.

3. Position Reconstruction

The position of an electron is obtained using the energy from three adjacent strips — the one with the largest energy and each of its neighbors. The full set of 200 showers is first used to derive the average and rms of the energy in each of the three strips as a function of the position of the shower with respect to the center of the strip. Table I gives the results for 2 cm wide strips consisting of LAr layer 7 only. For example, if the shower is offset from the center of the strip by 4 mm, there is on average 17 ± 9 MeV in the first strip, 126 ± 25 MeV in the second and 6 ± 6 MeV in the third.

The position of the shower in each event is found by fitting the observed energies (E_i) to the average values (P_i). Specifically, it is the value of y that minimizes:

$$\chi^2 = \sum_{i=1}^{3} \left[\frac{P_i(y) - \alpha(y) E_i}{\sigma_{P_i}(y)} \right]^2, \tag{3.1}$$

where α is an overall scale factor to allow for longitudinal fluctuations and different incident energies:

$$\alpha = \frac{\sum_{i=1}^{3} \left[\frac{E_i P_i(y)}{\sigma^2_{P_i}(y)} \right]}{\sum_{j=1}^{3} \left[\frac{E_j^2}{\sigma^2_{P_j}(y)} \right]}. \tag{3.2}$$

Both when deriving the averages and when finding the position for a particular shower, the recorded strip energies are modified by the addition of Gaussian noise: $E_i \rightarrow E_i + \text{Gauss}() * \text{Noise}$, where "Noise" can be zero.

Table II contains the resolution for various widths, noise levels, and longitudinal depths. This information is presented graphically in Figure 2. In all cases, the resolution is for showers at normal incidence to the center of the strip. The effects of noise are shown in Figure 3 for 2 cm strips, layer 7 only. Note that this noise can be electronic or pileup. The noise values used in Figure 2 are those expected for very low noise preamp (equivalent $R_s = 5\Omega$) outside of the cryostat.

Table I. Mean and rms of the energy deposited (MeV) in each of the three strips as a function of the position of the shower with respect to the center of the strip. Results are based on 2 cm strips and 5 MeV noise.

Position (cm)	P_1	P_2	P_3
-1.0	2 +/- 5	73 +/- 20	73 +/- 20
-0.9	3 +/- 5	93 +/- 22	52 +/- 17
-0.8	4 +/- 6	105 +/- 23	40 +/- 14
-0.7	4 +/- 6	113 +/- 24	31 +/- 12
-0.6	5 +/- 6	119 +/- 24	26 +/- 11
-0.5	5 +/- 6	123 +/- 25	21 +/- 10
-0.4	5 +/- 6	126 +/- 25	17 +/- 9
-0.3	7 +/- 6	129 +/- 25	15 +/- 8
-0.2	8 +/- 7	130 +/- 26	13 +/- 8
-0.1	8 +/- 7	130 +/- 26	11 +/- 9
0.0	10 +/- 8	130 +/- 26	10 +/- 7
0.1	11 +/- 8	130 +/- 26	8 +/- 8
0.2	13 +/- 8	129 +/- 26	7 +/- 7
0.3	15 +/- 9	128 +/- 25	6 +/- 7
0.4	17 +/- 9	126 +/- 25	6 +/- 6
0.5	21 +/- 10	123 +/- 26	5 +/- 6
0.6	25 +/- 11	119 +/- 25	5 +/- 6
0.7	31 +/- 11	113 +/- 24	4 +/- 6
0.8	39 +/- 13	105 +/- 22	4 +/- 6
0.9	52 +/- 17	93 +/- 21	4 +/- 6
1.0	72 +/- 21	73 +/- 20	2 +/- 6

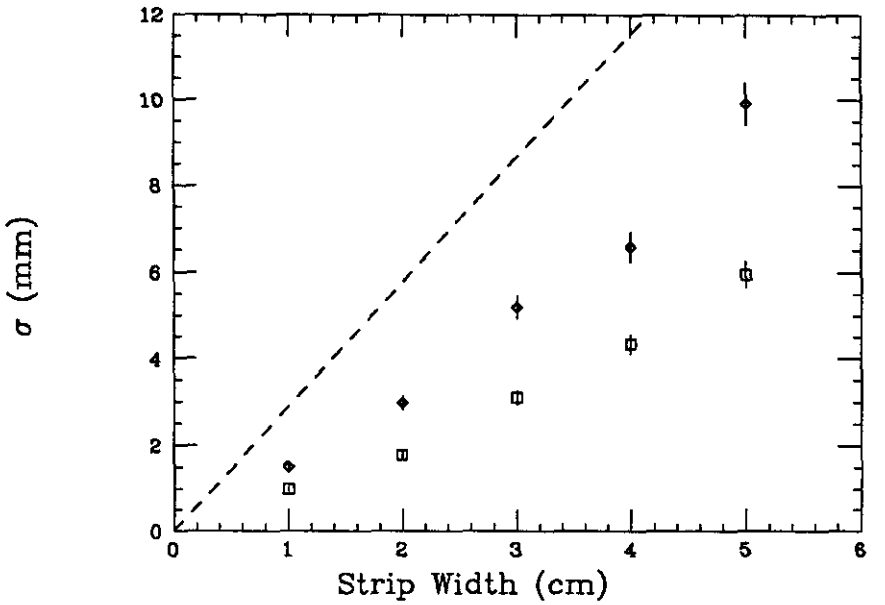

Figure 2. Position resolution for one layer only (diamonds) or thirteen ganged layers (squares), as a function of strip width. Electrons are at normal incident to the center of the strip. Noise is taken to be 5 MeV per strip for one layer and 25 MeV for thirteen. Dashed line is $\sigma = \text{Width}/\sqrt{12}$.

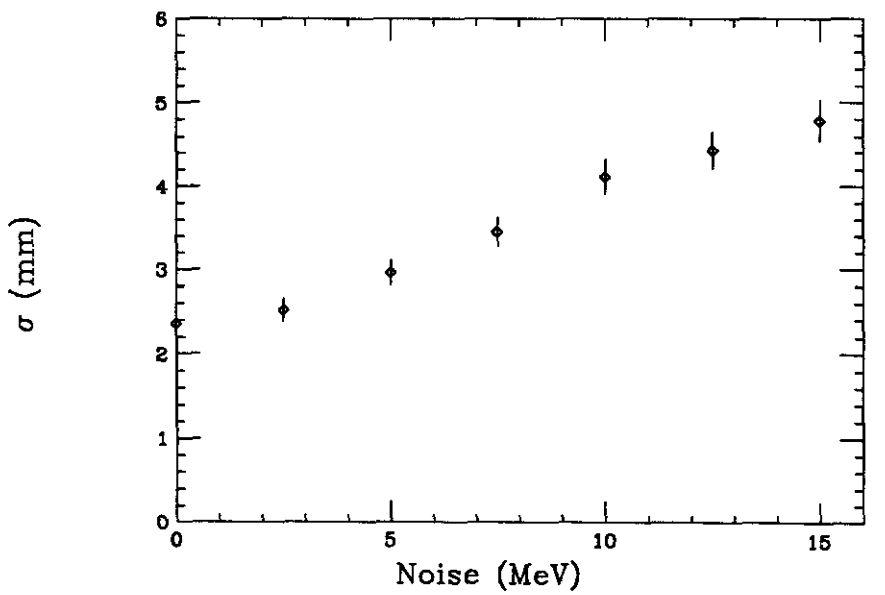

Figure 3. Resolution at the center of a 2 cm wide strip, layer 7 only, as a function of Gaussian noise per strip (electronic or pileup).

Table II. Position resolutions for various strip widths (cm), noise levels and longitudinal depths. Electrons are at normal incidence to the center of the strips.

Ganged	Noise	Resolution for Width =				
Layers	(MeV)	1.0	2.0	3.0	4.0	5.0
1	0.	1.3 ± 0.1	2.4 ± 0.1	3.5 ± 0.2	4.9 ± 0.3	6.9 ± 0.4
1	5.	1.5 ± 0.1	3.0 ± 0.2	5.2 ± 0.3	6.6 ± 0.3	9.9 ± 0.5
13	0.	0.9 ± 0.1	1.4 ± 0.1	2.0 ± 0.1	2.7 ± 0.1	3.8 ± 0.2
13	25.	1.0 ± 0.1	1.8 ± 0.1	3.1 ± 0.2	4.4 ± 0.2	6.0 ± 0.3

If several layers are ganged to form the fine section, the strips will be projective. Nevertheless, because of mechanical constraints, electrons may not necessarily enter the calorimeter exactly parallel to the ganging angle. For the EGS model described here, this is equivalent to electrons incident at $\phi \neq 0$. For angles up to 10 degrees off-normal, no significant deterioration is seen in the position resolution in the case of thirteen ganged layers. Larger angles have not been tested. Figure 4 shows the resolution for 2 cm strips, one layer or thirteen ganged layers, for electrons at $\phi = 0$ or $\phi = 4.6$ degrees, as a function of location of the shower with respect to the center of LAr layer 7. The substantial improvement near the edges of the strip is due to increased energy sharing between strips.

4. Some Design Considerations

In order to keep the number of channels to a reasonable number, the area of each fine section should be approximately that of a tower 0.025 by 0.025 in $\phi - \eta$ (6.3 cm by 6.3 cm at $\eta = 0$). A strip of width 2 cm, therefore, has a length of $\delta\eta = 0.079$. For the purposes of forming trigger towers, this is a poor match to the rest of the EM section, which has $\delta\eta = 0.05$. It may be simpler to make the fine section only a single gap thick and exclude it from the trigger, even though the position resolution in this case is approximately 70% worse.

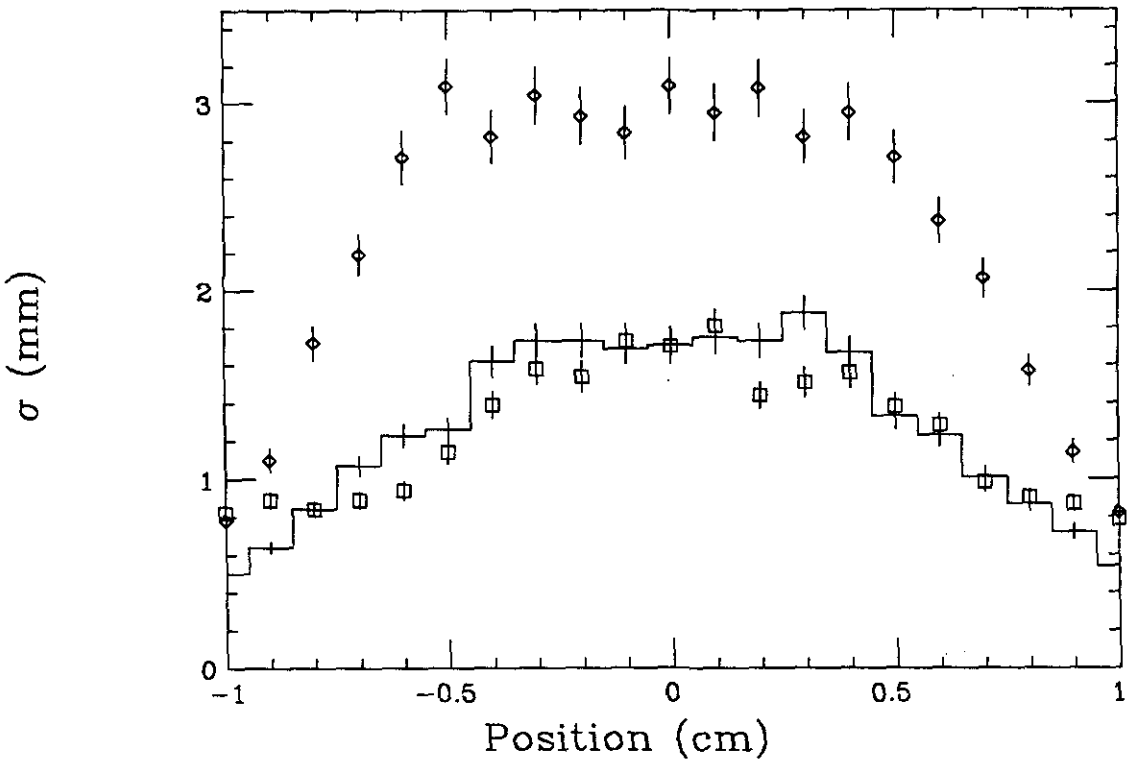

Figure 4. Resolution vs position of shower with respect to the center of layer 7. The histogram and square marks are for thirteen ganged layers, with electrons incident at $\phi = 0$ and $\phi = 4.6$ degrees, respectively. The diamonds are for a single layer only with normal incident electrons. In all cases, the strips are 2 cm wide and signals include 5 or 25 MeV of Gaussian noise.

The z or η resolution is poor for simple $r - \phi$ strips — approximately $\delta\eta/\sqrt{12}$ or 6 cm for 2 cm wide strips at $\eta = 0$. This can be improved by using u and v strips that are at angles of $\pm\alpha$ with respect to the z axis. The resolutions are then:

$$\sigma_{r\phi} = \frac{\sigma_u}{\sqrt{2}\cos\alpha}, \qquad \sigma_z = \frac{\sigma_u}{\sqrt{2}\sin\alpha}. \tag{4.1}$$

For $\sigma_u = 3.0$ mm and $\alpha = 30$ degrees, $\sigma_{r\phi} = 2.4$ mm and $\sigma_z = 4.2$ mm. Not only do uv strips give better z resolution, they may also be easier to build mechanically. The tradeoff is that each strip has to cover nearly twice the area of an $r\phi$ strip

to achieve the same $r\phi$ resolution. They are, therefore, more susceptible to pileup noise.

5. Conclusions

Position resolutions of a few millimeters can be achieved with strips of reasonable width and length, even without ganging in depth. A more detailed design of the fine section will require further study of the effects of pileup and nearby jets. Further study is also needed to establish what resolution is required for electron identification.