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Nonuniformities in Organic Liquid Ionization Calorimeters

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NONUNIFORMITIES IN ORGANIC LIQUID IONIZATION CALORIMETERS[1)]

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Hermeticity and uniformity in SSC calorimeter designs are compromised by structure and modularity. Some of the consequences of the cryogenic needs of liquid argon calorimetry are relatively well known. If the active medium is an organic liquid (TMP, TMS, etc.), a large number of independent liquid volumes is needed for safety and for rapid liquid exchange to eliminate local contamination. Modular construction ordinarily simplifies fabrication, assembly, handling and preliminary testing at the price of additional walls, other dead regions and many nonuniformities.

Here we examine ways of minimizing the impact of some generic nonuniformities on the quality of calorimeter performance. Figure 1 shows schematic features of an SSC calorimeter[2)]. Most modules weigh ≈20 tons.

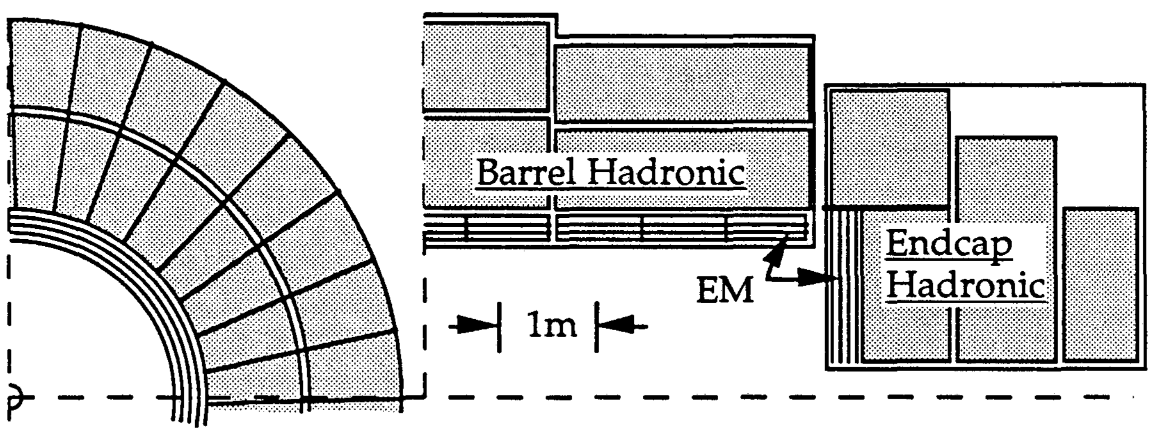

Figure 1. Schematic of an SSC calorimeter. The Barrel is subdivided axially into three bays. The eleven EM modules are of 2π azimuthal width. Azimuthally segmented hadronic modules are slightly pinwheeled to avoid projective cracks. The Barrel and each Endcap is enclosed by a thin walled safety shield filled with inert gas. Preamps are accessible at the outer radius.

1. MODULE BOUNDARIES AND INTERNAL PLATE STRUCTURE

Careful design of the internal structure can minimize the thicknesses of nearly projective module boundaries. Figure 2 shows an azimuthal wedge module of the Barrel hadronic section. Some or all of the absorbing ground plates are strong enough to support large in-plane stresses. The advantages of internally supported vs free standing or bulging walls are first, that the boundaries of the sensitive region are well defined, so that dimensions of the dead regions can be predicted and corrected. Second, buckling of the walls is resisted, so they can support in-plane bending stresses.

If the materials of the walls and the plates are similar, spot welding is possible after assembly. Even without welding the walls can be strengthened by taking advantage of a favorable pressure difference. The maximum difference in hydraulic head within the calorimeter is 0.6 atmospheres (even less within individual modules). For TMP the vapor pressure is low; if other gases are excluded and the modules are not overfilled, the internal pressures are less than an atmosphere, and the thin walls are pushed against the internal structure. For TMS, with a much higher vapor pressure, this works only if the liquid supply for each module does not add significantly to the hydraulic head

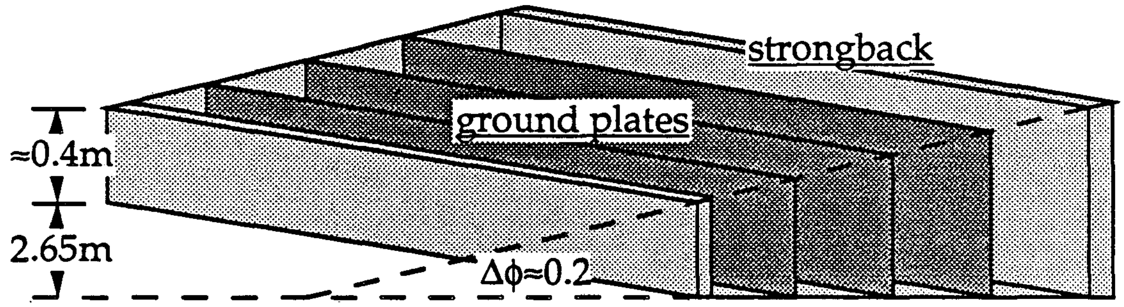

Figure 2. Barrel hadronic module showing structural use of internal ground plates.

For most of the calorimeter the ground plates are of uranium or lead, clad with aluminum or stainless steel (Figure 3). Thin (≤1mm-thick) sheets are seam-welded to the top and bottom of the cladding frame to form a vacuum tight enclosure. With lead as the absorber the box can be vacuum-filled; voids in a uranium-filled box can be vacuum-filled with lead. The cost of uranium in this application is relatively low because it does not require machining or special handling. Internal studs can transfer large local forces perpendicular to the plates. The frame can be notched at the walls for tension straps and low inductance signal-ganging busses.

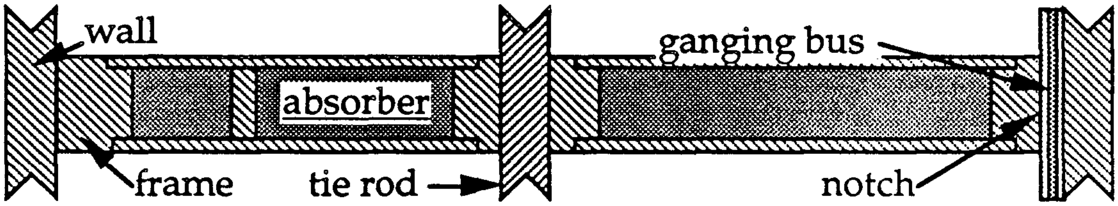

Figure 3. Composite absorbing ground plate showing possible penetrations. The plates and module walls provide well determined mechanical and electrical boundaries for the towers.

To hold the modules together the forces perpendicular to the plates can be supplied by tension in the walls and/or banding at the edges and/or penetrating tie rods. The first two methods require relatively heavy nonprojective strongbacks and frequent, nearly projective edges. Tie rods avoid these but require sealed inserts in the ground plates. Tie rods seem most appropriate for the Endcaps, where large flat ground plates are otherwise appropriate to the geometry. Similar considerations apply to the choice of signal-ganging straps vs cylindrical feedthroughs.

Unless the ground sheets are fastened to heavy end walls, considerable friction is needed to support the insides of modules with vertical plates (Figure 2). Given average density 8, a horizontal projection of 1m from the supporting strongback, a coefficient of friction of 0.2 and 1% occupancy by support spacers (insulators) in the sensitive gaps, the required spacer-compression is 400 atmospheres. Similarly, if the walls, bands and/or tie rods occupy 1% of the cross sectional area of the module, the same average tension is needed in them. The internal structure of the outer hadronic calorimeter can be simplified at lower cost if the absorber is of stainless steel or copper rather uranium or lead. Then e/h compensation requires relatively thick (4-5cm) plates, a large sampling ratio and poorer energy resolution.

2. TILES AND PADS

It is not certain that uranium or lead can be cleaned well enough as absorbing tiles, or that affordable methods exist for cladding individual tiles. An interesting, probably clean absorber-material is heavimet, which is readily machinable. Plates are made by rolling billets of scintered tungsten (with ≤7% iron and nickel)[3]. If the price is $20/lb, the EM tiles would cost $4-5M.

Problems of cladding are avoided with thin tiles of stainless steel, aluminum, ceramic or a 'clean' plastic. Metalized insulating tiles are especially useful, because capacitively coupled pads on opposite sides provide high voltage decoupling. Also, many small pads can be etched on one sheet, and insulator-cladding of absorbing tiles would solve several problems.

3. ELECTROMAGNETIC TOWERS

In Figure 4 we compare EM cells with various absorbers and either thick

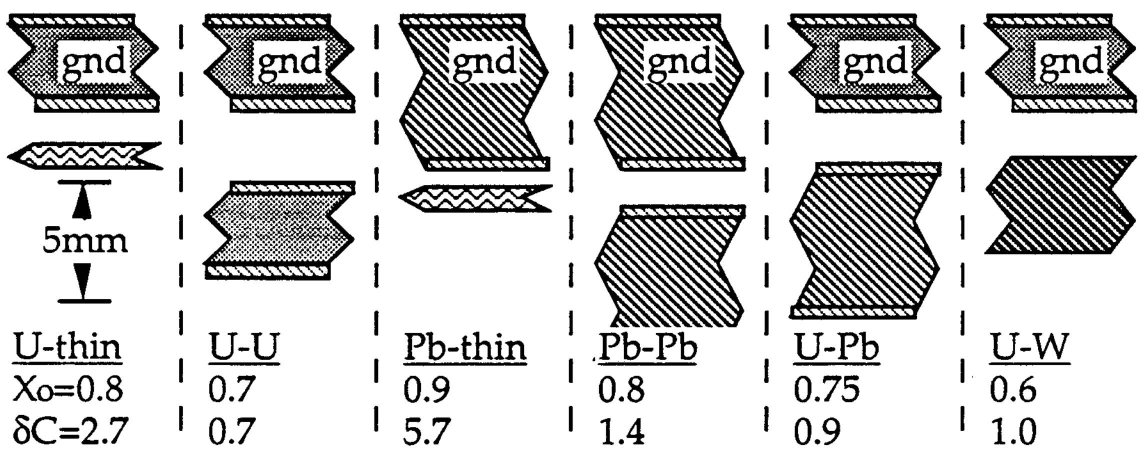

Figure 4. Combinations of ground plate and tile materials to give e/h-compensated EM calorimeters with one radiation length sampling thickness. Lead and uranium are clad with 0.5 mm-thick aluminum. With thin tiles there are two gaps per cell. X_0 is the radiation length in cm, δC is the capacitance-density in pf cm^{-2}/r.l.

or thin tiles. Each is e/h-compensated with one radiation length sampling thickness. The sampling ratios are taken to be 1 and 4 for uranium-TMP and lead (or heavimet)-TMP, respectively. With fixed sampling thickness the requirement of e/h compensation permits direct comparisons of EM designs. The advantages of thick relative to thin tiles are less capacitance (x4) and easier tolerances on the wider gaps. Thin tiles avoid cladding and operate at lower voltage. The advantages of uranium over lead are smaller capacitance and wider gaps. Lead needs less voltage and is intrinsically cheaper.

The maximum gap area of an EM tower with $\Delta\phi=\Delta\eta\approx0.025$ is ≈1000 cm^2. With $\delta C\leq1$pf cm^{-2} (Figure 4) and two samplings in depth, the capacitance is well enough matched to typical FET preamplifiers. With thin tiles (and larger capacitance) the alternatives include more segmentation, larger preamps or smaller signal to noise ratios. A less appealing option for EM towers is transformer matching, which is considered below for hadronic towers.

The EM section needs the best performance possible for electron identification and for good energy and spatial resolution. Because EM showers and towers are both narrow and shallow, they are much more vulnerable than their hadronic counterparts to energy degradation by nonuniformities.

3. HADRONIC TOWERS

Figure 5 shows two cells of a large capacitance hadronic tower with an electrostatic transformer[6)] of ratio n=3. The advantages of the EST over the ferrite transformer are intrinsically small ganging inductance and viability in a magnetic field. For an e/h-compensated tower of given volume, absorbing material and gap width, a (perfect) transformer of ratio n provides an n-

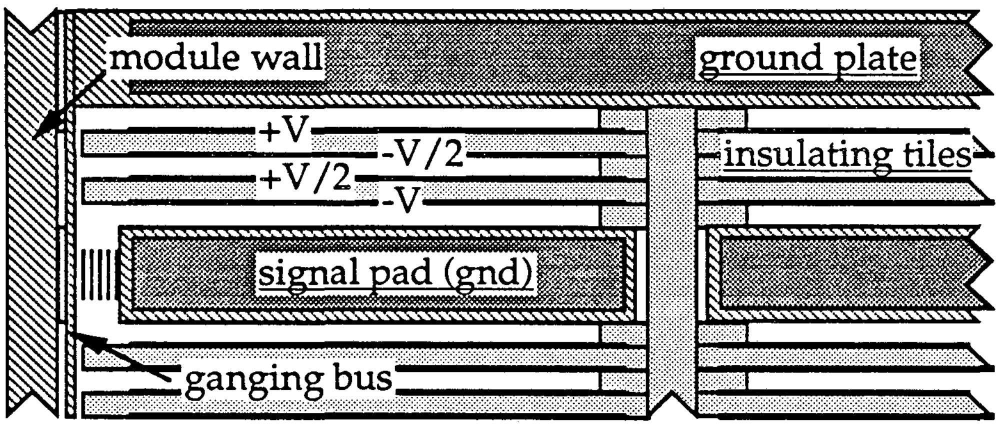

Figure 5. Two cells of a hadronic tower with an electrostatic transformer of ratio n=3. V is the total voltage across each gap; the high voltages are distributed horizontally to the insulating tiles by means of resistive surfaces on the spacer-insulators. Signal-ganging at ground potential uses very low inductance busses next to the module walls. Not to scale.

independent signal to noise ratio with signal amplitude $\propto n^{-1}$, output capacitance $\propto n^{-2}$ and preamp size $\propto n^{-1}$. Besides saving preamp power, the transformer increases impedances into a range (50-100 ohms) where simple cables are available, and charge transfer is less degraded by lead inductance.

If absorbing tiles are substituted for the thin insulating tiles in Figure 5, the sampling thickness is reduced by a factor of n; but without voltage-decoupling the required supply voltage is increased by a factor of n. If, alternatively, all the tiles are made thin, the sampling thickness is increased by a factor of two. The EST and the low voltage ganging strap shown in Figure 5 have very low internal inductances, so that signals from all parts of a deep tower are sampled uniformly in time.

4. VISIBILITIES OF NONUNIFORMITIES

The effect of a nonuniformity can be minimized by eliminating the integral of its visibility[5], defined by:

$$v=S/S_0-A/A_0$$

v is the local fractional measurement error in shower energy. S is the signal and A is the absorbed energy per unit path length; subscript 0 refers to the average in the normal calorimeter. To minimize the effect of each nonuniformity the absorbing and sensitive regions are arranged so that $\int v d\tau=0$, where τ refers to the volume in common with an average shower.

The alternative of modelling a nonuniformity by Monte Carlo is often difficult and time consuming; but the average dependences of shower width and absorption on material and shower depth are more easily learned. In simplest approximation[6], which we use below, A is proportional to density. For most significant nonuniformities it is convenient to use <v>, the average of v over a calorimeter cell length.

Figure 6 shows three common nonuniformities. In Figure 6a the

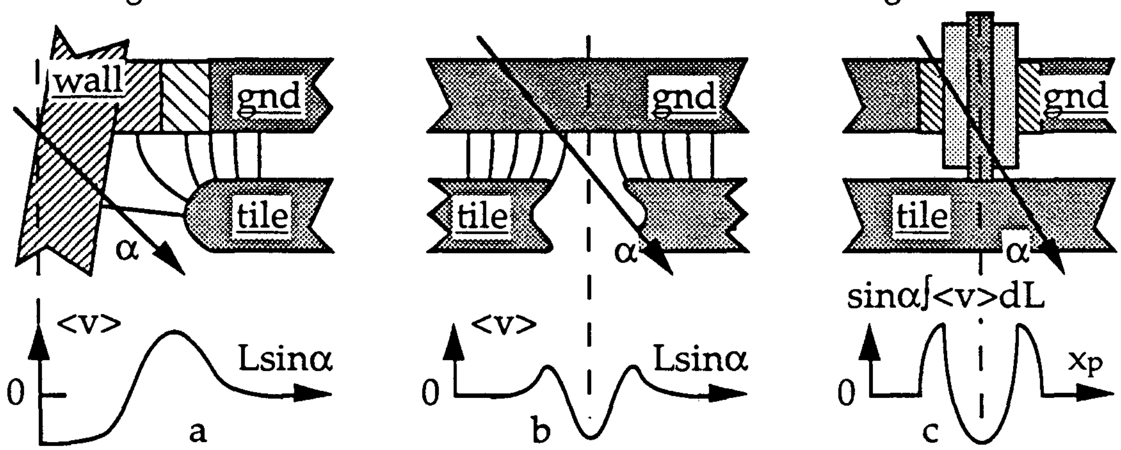

Figure 6. Correction of nonuniformities. <v> is the visibility averaged (vertically) over a calorimeter cell. Shower depth along the trajectory and obliquity with respect to the plane or axis of the nonuniformity are measured by L and α. x_p is measured perpendicular to the trajectory. The graphs under a and b show the corrected visibilities along the trajectories; c shows the visibility integrated along the trajectory as a function of the impact parameter of the trajectory on the axis.

absorption in the ground plate is reduced locally to offset the energy lost in the wall, and the tiles are operated at high voltage to collect charge near the wall. In Figure 6b the signal lost in the cracks between neighboring tiles is corrected by thinning the thick tiles. An alternative is to reduce the density of the absorbing ground plate over the width of the no-signal region. In Figure 6c the ground plate is thinned outside the no-signal region to correct for a cylindrical feedthrough.

Even if the visibility integral vanishes, the effect of the nonuniformity on a shower may not. Dimensions and shape are important, as is the contribution of the nonuniformity to the shower evolution. For a given obliquity and visibility-amplitude, small symmetric shapes like those in Figures 6b and 6c, when folded into the evolving shower, have less effect than asymmetric ones like Figure 6a. This last may acquire symmetry if the shower leaves one module and enters another; but a gap between modules adds to the wave length.

As an example of a corrected wall-nonuniformity, Figure 7 shows an idealized model of a tower with a thin signal tile. The general constraint of e/h compensation means that the average absorptions and signals are essentially independent of cell thickness; i.e., the same for hadronic or EM towers.

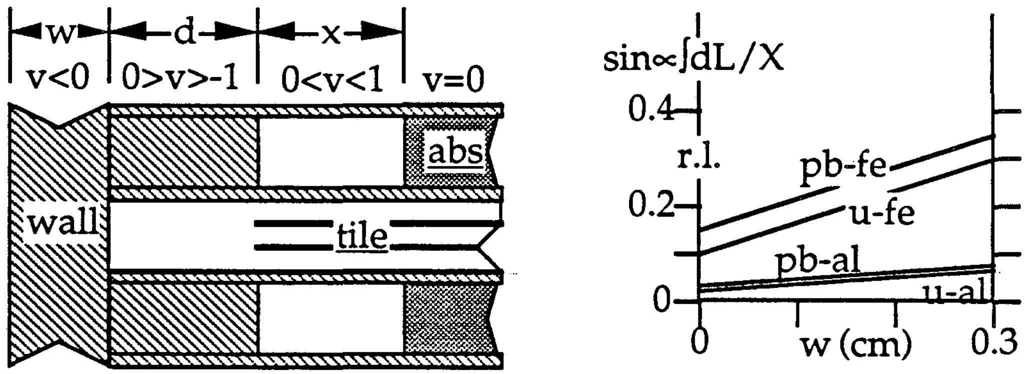

Figure 7. Corrected nonuniformity at the module boundary. Dimensions are exaggerated for clarity. v is the visibility, averaged over a cell length. The graph shows, for d=0.3cm, the width of the correction zone in radiation lengths as a function of wall thickness w.

The boundary region is divided into three zones for which the ranges of <v> are indicated above. w measures the wall, which is taken to be of the same material as the cladding, d measures a high voltage insulation zone and x is the width of a low density zone with $S=S_0$; to eliminate the visibility:

$$x=(wA_w/A_o+dA_d/A_o)/(1-A_x/A_o)$$

For d=0.3cm the graph shows how the effective thickness of the nonuniformity depends on w for several combinations of cladding and absorber. For w=0.3cm the effective thickness in r.l. of the corrected nonuniformity is about twice that of the wall itself. For $\sin\alpha=0.2$, therefore, a 0.3cm thick steel wall adds ≈1.7r.l. to the shower evolution. The length along the trajectory to the edge of the normal calorimeter $L=(w+d+x)/\sin\alpha=6$cm. For the same wall thickness of aluminum the corresponding numbers are 0.32r.l. and 4cm. For a given wall thickness and pinwheel angle, the impact of nearly projective walls on the uniformity is far greater for the EM than for the hadronic. For the latter, a large pinwheel angle means that the towers are either greatly misaligned or constructed in a way that emphasizes internal nonuniformities.

5. CONCLUSIONS

In organic liquid calorimetry the internal structures of the modules, especially the absorbing ground plates made by cladding lead or uranium with aluminum or stainless steel, can be used to minimize the thicknesses of nearly projective walls.

To first order the energy lost in these walls can be corrected in a boundary region of variable sensitivity. Aluminum is the best structural material because it minimizes the measurement error for energy lost in the walls and nearby dead regions. With walls a few millimeters thick, the deep hadronic modules need only small (≤ 0.1) pinwheel angles for uniformity, thereby avoiding the alternative problems of significant tower misalignment or internal nonuniformities in the tower structures.

For the EM section the sacrifice of depth is an important consequence of the wall nonuniformity. With full azimuth EM modules the nearly projective walls are effectively eliminated; relatively small azimuthal pinwheel angles suffice for the smaller nonuniformities at the internal tower boundaries. The effective widths of some nonuniformities can be narrowed by collecting charge beyond the transverse boundaries of the signal pads; this favors the use of high voltage absorber-tiles in the EM towers.

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