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CONCEPTUAL ENGINEERING DESIGN FOR A SPACAL CALORIMETER FOR THE SDC

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The purpose of this note is to describe the accompanying set of drawings giving a brief description of the motivation and implementation of the SPACAL design for the SDC detector. Issues concerning the unit cell size, mounting, and construction schedule are discussed, as well as channel counts, power and cooling requirements, safety issues, and crane limitations. This document will be updated regularly as work progresses.

1. INTRODUCTION

Recent results from test beam studies of the SPACAL design calorimeter modules show that the physics capabilities such as linearity, energy resolution, speed, and electron identification are more than adequate for the SDC[1][2] . This has focused attention on the need for a detailed engineering design showing how such a calorimeter might be constructed. Although work has just started in this area, it is important that preliminary results be presented to answer specific questions about this design. It is our intent to update this memo regularly as work progresses so that it reflects the most recently formulated SDC requirements. The design illustrated here is for the so called "Short Coil" magnet design. The design can be modified for other magnet options. The modifications required will be mentioned briefly.

A unit cell is described in some detail, paying particular attention to the structural integrity of each cell. The motivation driving the design choices for the unit cell are given, showing that design need not compromise performance.

The large scale modular construction plan is illustrated, pointing out the impact of the choice of a 35 ton crane for calorimeter construction inside the hall. Safety issues which impact the design choice are discussed.

Finally, some details concerning the total channel count, materials needed, power and cooling requirements are given. The costs associated with each stage in this design are not addressed in this note.

The design is implemented at UCSD with the I-DEAS package[3] , a commercially available computer aided design software package that is in use in several national labs as well as industry. This is important as it will allow us to easily engage the help of professional engineers in those places.

2. THE UNIT CELL

The basic building block of the SPACAL calorimeter is the projective tower shown in figure 5. In the present concept it is constructed out of grooved lead sheets bonded together with scintillating fibers in the grooves. Bonding methods currently being studied include brazing, riveting and gluing. The lead to fiber volume ratio is 4:1. The lead sheets are 2 mm in thickness, and the fibers are 1 mm in diameter. Typically, about a quarter of the fibers extend from the inner face of the tower to the outer face, with three quarters of the fibers beginning at a variety of depths due to the projectivity. The towers have no longitudinal segmentation. The center to center fiber distance is 2 mm, with the fibers arranged in a square array. The radiation length of the lead-fiber combination is about 7 mm and the interaction length is about 204 mm. The towers range in depth from 1.9 m (9.3 λ_I) at $\eta = 0$ to 2.4 m (11.8 λ_I) beyond $\eta = 0.725$.

Each tower is read out with a single low gain phototube which monitors the approximately 2000 fibers. The tower size is matched to the size of an electromagnetic shower at the front end. This determines the $\Delta\phi = \Delta\eta = 0.025$ size of the towers in the barrel. With towers of this size, the transverse spread of the electron and pion showers can be a very powerful tool for electron/hadron discrimination[2] . Towers of this size will also have very low occupation reducing the problem of pileup of events from neighboring beam buckets. Good spatial resolution is also achieved which can be useful in electron identification near the core of a jet.

For the end cap, at $\eta > 1.5$, towers are kept at a constant size in $R\Delta\theta$ and $R\Delta\phi$ to keep the tower size comparable to the shower size. This gives a channel count of 28000 in the barrel and 7954 in each end cap for a total of 43908. Each tower is bonded to a steel or aluminum sleeve, 2 mm in thickness, wrapping around the tower, and extending 50 cm down the sides of the tower (see fig. 6). Although steel provides greater strength, the thermal properties of aluminum are closer to that of lead. This sleeve provides support for the phototube, light pipe,

and fiber ends, as well as allowing the adjacent towers to be connected into rings. The sleeve does not extend far enough into the calorimeter to be sampled by any primary electromagnetic showers. Only the tails of the hadronic showers will reach back to the region of the sleeves, and these cover such a large transverse area that there will be no significant effect due to the loss of active area which represents about 3% of the active volume.

3. RINGS

The towers will be joined together into rings. The barrel calorimeter will be composed of 112 rings with each ring made up of 250 towers. The inner diameter of the barrel rings is 2.25 m, with the lead/fiber extending to 4.15 m. In η regions where this makes the radial dimension of the towers greater than 2.4 m, the towers are truncated at 2.4 m as shown in fig. 7. The phototube and mounting are tilted in ϕ, and occupy 0.2 m at the back of the towers. The inner face of the towers is parallel to the surface of the solenoid, while the outer face is perpendicular to a radial track. All towers are projective in η while there is a 3 degree offset from purely radial in the ϕ view. Alternating rings will be offset in opposite senses (see fig. 3).

The weight of the barrel rings is typically in the range of 30 to 40 tons. For the short modules at the end of the barrel where the weight of the rings is smaller, several rings will be bonded together to form a large ring with a weight of 30 tons.

A gap of 20 cm exists between the barrel and end cap. This gap allows for the passage of tracking cables, and magnet connections. It is also used for bringing the light out of the short modules by coupling the scintillating fibers to clear fibers and mounting the phototubes at larger radius behind the calorimeter.

The rings will be reinforced with a steel cone during the assembly. Adjacent rings will be tied together at the steel sleeves. The rings are mounted on rails at

many points around the annulus. They will be rolled into the iron return yoke, and fixed into place. The only installation required will be bolting the rings into place and cabling up the electronics. Unit cell tests can be performed at this stage to ensure that all channels are active before the next ring goes in.

The end cap structure is similar in scheme to the barrel, except that the number of towers in each ring is not kept fixed. Because the tower size is nearly constant in the end cap, the number of towers in each ring gets smaller for smaller radii. This is illustrated in fig. 10.

4. SYSTEM ISSUES

4.1 Materials

The total weight of the barrel will be 3176 tons, with each end cap weighing 911 tons. This is predominantly lead. There is no difficulty in obtaining this quantity of lead, rolled into sheets ready to be grooved. In one process lead sheets are grooved by forcing them to pass between two rolls with the required profile. In another process, lead is extruded with the grooves in it. Both processes have been demonstrated successfully and used by SPACAL.

The 172,000 km of fibers required can be obtained from a variety of domestic and foreign suppliers. Due to the cost of the fibers, which make up a substantial fraction of the cost of the calorimeter, other fiber diameters are being considered. Tests have been performed with 0.5, 1.0, and 1.5 mm diameter fibers. Monte Carlo studies show that the energy resolution for pions and electrons is dominated by sampling fluctuations, and these scale roughly as the square root of the fiber diameter. Fiber costs, on the other hand, depend primarily on the length of fiber used. This means that maintaining the same lead to fiber ratio of 4:1, the calorimeter cost can be reduced by the square of the fiber diameter, while the energy resolution grows only with the square root of the fiber diameter. Fabrication costs can also be brought down substantially by moving to thicker

fibers. The current SDC energy resolution requirements can be satisfied with 2 mm diameter fibers.

The fibers will have aluminum sputtered on the end closest to the beam. This lengthens the effective attenuation length of the fibers and improves the response to hadrons. With effective attenuation lengths on the order of 8 m, we are insensitive to fluctuations in the starting point of hadronic showers.

4.2 Power and cooling

Currently, beam tests are being performed with phototubes. We are also investigating alternatives which can operate in high magnetic fields. For the purposes of estimating the power requirements, phototubes will be assumed. High rate bases will dissipate about 0.5 VA per tube for a total of about 20k VA for the bases alone. Additional trigger electronics mounted on the back of the calorimeter will likely dwarf this usage. Similar arguments hold for the cooling requirements. The heat dissipation required to keep the phototubes cooled will be a small fraction of the cooling needed for the associated electronics.

The present hall design includes a 35 ton crane for the assembly of the calorimeter, and a 75 ton crane for the assembly of the muon steel and return yoke. Increasing the capacity of the calorimeter crane beyond 35 tons would greatly ease the staging of the ring structure. A 50 ton crane is common in even modest experimental halls at BNL, SLAC, and FNAL. Consideration should be given to the impact that a 35 ton crane limit imposes on the construction schedule of any calorimeter.

4.3 Alternative options

Athough this design has been directed toward solving the problems associated with the "Short Coil" magnet option, alternative calorimeter options can accomodate other magnet choices. It is possible to build the end cap out of a lead and steel mixture, to facilitate the flux return in an "I" type design.

For a "Long Coil" design, it would be possible to build the end plug out of the lead and steel mixture. These design options will be considered in more detail if they are recommended by the magnet task force.

4.4 Safety

There are two issues of concern for the safety of the calorimeter and the people working with it. The first is the structural integrity of the calorimeter itself. The second is the concern about working with the large quantities of toxic lead that are required for this calorimeter.

The first issue is being studied in detail now, in order to understand the loading of the rings, the internal stresses built up, and the amount of sleeving needed to safely cantilever the individual modules. The first long projective module is in production now, and these questions will be answered in the next few months.

We know very well the precautions necessary to work with lead. No study is needed in this regard. We will just have to make sure that they are observed.

Overall, the safety issues will not be a difficult hurdle in the construction of a scintillating fiber calorimeter.

4.5 Acknowledgements

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REFERENCES

1) D. Acosta *et al.*, Results of prototype studies for a spaghetti calorimeter, Nucl. Inst. Meth. **A294**, 193, 1990.

2) D. Acosta *et al.*, Electron pion separation with a scintillating fiber calorimeter, Submitted to NIM 11/90.

3) I-DEAS, Structural Dynamics Research Corporation, 2000 Eastman Dr., Milford, Ohio, 45150.

FIGURE CAPTIONS

1. Side view of one quarter of the barrel calorimeter and end cap showing the 56 ring structure of the barrel and the 45 ring structure of the end cap. Some of the rings are bonded together because they are light enough to be handled as one piece.
2. Perspective view of half the calorimeter, showing the ring structure.
3. The end view of a single ring of the barrel calorimeter. The 3 degree offset from radial lines is difficult to see on this scale.
4. Detail of a single ring, showing 60 towers.
5. A group of four projective towers, showing phototube supports, light pipes, fibers, lead and steel support sleeve.
6. Steel sleeve 2 mm thick to support tower and connect together into ring structure.
7. Side view of the barrel rings. 56 rings are shown in a cross section through the middle. One quarter of the barrel is shown. Rings have been joined where they are light enough to be handled together.
8. Side view of the end cap rings. 45 rings are shown in a cross section through the middle. One quarter of the end cap is shown. Rings have been joined where they are light enough to be handled together.
9. This shows the end view of an end cap, with the front face of all towers.
10. End view of the end cap showing the ring structure only.
11. Perspective view of the end cap.
12. Perspective view of the barrel.