November 3, 2015
Revised January 31, 2016

Recommendation on HCAL choice for SiD baseline

SiD Task Force on HCAL Baseline
(J. Brau, M. Breidenbach, R. Rusack)

Preamble.

About a decade ago, the SiD collaboration adopted glass Resistive Plate Chambers (RPC's) as a baseline for the active media in the hadronic calorimeter. This choice was presented in the 2007 Reference Design Report[1] and discussed in a series of update reports, including the ILC Technical Design Report[2]. Since that choice was made there have been many advances in detector technology. In particular, the application of silicon photomultipliers (SiPM)[3] to read out planes of tiles of scintillators mounted on large area printed circuit boards (PCB) has raised the question of whether this would be a better alternative for the active media of the HCAL.

In this report we discuss the relative merits of the RPC and scintillator tile technologies for this application. Our focus is on technical aspects and the cost of implementation only. The task force made use of reports and presentations made by experts in both technologies and a presentation to the task force by Jan Strube on the status of simulations of hadronic showers with RPC's and scintillator tiles[4].

RPC's are a mature technology that has been used extensively in many experiments for the detection of muons. Glass RPC's have been successfully employed in the Belle experiment. The CALICE RPC group, led by J. Repond (ANL), has conducted many test beam measurements of glass RPC's as a hadron calorimeter with many results reported in the literature. Scintillator calorimeters also have a long history of applications in calorimetry at colliders dating back to CDF and D0.

---

[1] ILC Reference Design Report Volume 4 – Detectors, arXiv:0712.2356 [physics.ins-det].
[2] The International Linear Collider Technical Design Report – Volume 4: Detectors, arXiv:1306.6329 [physics.ins-det].
[3] SiPMs are also called Multi-Pixel Photon Counters or MPPCs by one manufacturer. The technology is the same.

[4] Oskar Hartbrich, "AHCAL ILD vs. Testbeam Simulation Models & Data," https://agenda.linearcollider.org/event/6795/contribution/1/material/slides/0.pdf; Christian Grefe, "Status of W-DHCAL Analysis," http://agenda.linearcollider.org/event/6301/session/20/contribution/147/material/slides/0.pdf.

The advantage of RPCs is that they can be made in large volumes at a reasonable cost. Sampling scintillator calorimeters have the intrinsic advantage that the sampling of the shower is *a priori* greater than in over sampling gas-based calorimetry, no matter what method is used to amplify the ionization in the gas. In the past, the main drawback for scintillator has been the need for relatively expensive photodetectors, which has changed with the introduction of low-cost Geiger mode pixelated APDs (SiPMs) into the market.

Findings:

Current state of the technology:

Recent advances in SiPM technology and significant reductions in their cost[5] have led to the possibility of individual tiles read out by a single SiPM. The current state-of -the-art consists of large panels of scintillator tiles mounted on PCBs. The presently favored version of the design has surface mounted SiPMs mounted onto the readout PCB and scintillator tiles with an indentation (dimple) on the face of the tile in contact with the PCB, where the SiPM is located. . Beam tests of a hadron calorimeter constructed in this way have been carried out at DESY, Fermilab and CERN.

The progress made with RPC-based hadron calorimeters, in the context of the CALICE collaboration, has been very impressive. The invention of the technique to overcome the dead or stale gas problem of earlier devices by using a fishing line to channel the gas through the chambers, and the use of glasses with a resistivity optimized for the application have addressed many of the concerns with using RPCs for calorimetery.

Since the signal response is very broad the baseline RPC calorimeter is built with small cells and the number of active cells is counted in a shower. This is the 'digital' approach (DHCAL) and there is the variant known as the 'semi digital' calorimeter (SDHCAL), where the response amplitude is assigned two data bits. Both DHCAL and SDHCAL calorimeters have been built and operated in test beams at CERN and in the US. Results from these tests have been reported at several venues.

Concerns:

Calibration: The response of each cell is determined by the HV applied to the chamber and the threshold of the cell's discriminator. The inter-cell calibration cannot be found with a mip signal; instead it is carried out by finding a weight for each cell from the overall RPC efficiency and the hit uniformity. Furthermore without a pulse spectrum it is not possible to recalibrate the data once they are taken. This leads to stringent requirements placed on the detector to achieve the necessary medium and long term stability. While test beam data has not shown detector response fluctuations in either time or position, long-term stability in a real detector have not been demonstrated. Moreover,

[5] Figures as low as $1 have been suggested by reputable manufacturers for the cost of SIPMs in large quantities.

there is little experience of the stability and performance of the currently preferred "one-glass" RPC.

On the other hand, plastic scintillator and the SiPM should be intrinsically stable, since with the expected levels they should not suffer any radiation damage. With a ~12-bit analog readout, the intercalibration between cells can be measured with mips and maintained with an LED light injection system.

Response Uniformity: The RPC's have significant pixel-to-pixel cross talk, possibly caused by the spreading of the avalanche. This may be alleviated in the "one-glass" RPC, which have other potential advantages: they are thinner and can have a finer cell size. Non-uniformities have been found in the test modules of the DHCAL due to bending of the large area PCBs and incomplete charge collection at the physical edges of the detector. Solutions to avoid these non-uniformities have been proposed, but need to be demonstrated.

The scintillator option should have very little pixel-to-pixel crosstalk, since the cells are optically isolated. With the large dynamic range of the readout, larger pixels than in the RPC design are possible.

Response Linearity. The DHCAL option loses linearity above about 10 GeV as more energy is deposited in a single cell. Solutions like the SDHCAL have been studied to circumvent this problem, but they have not been completely resolved. In the scintillator tile calorimeter this has not been observed.

Stability of SiPMs due to temperature variations: SiPMs are inherently temperature sensitive due to the nature of the avalanche process. In some experiments temperature stabilization is achieved using thermoelectric (Peltier) coolers, which require a significant power to operate. In the MAGIC detector, stability of the SiPMs is maintained by a feedback loop that keeps the dark current at a constant level. The solution to this still has to be demonstrated in the environment of the ILC, but no serious obstacles are foreseen.

Robustness: The RPC's operate in avalanche mode at about 6.3 kV and can produce large signals. (Breakdown or steamer mode sets in at about 7.2 kV.) It should not be a major problem to protect the electronics.

Perhaps of more concern are aging problems. Belle had serious problems due to small amounts of water in the gas which formed HF with the electrochemistry of the chamber. It is probable that the Belle experience can be avoided. There is no significant experience with the "one glass" RPC.

The RPC glass is quite fragile and needs to be handled with care; although no glass was broken during the test beam experience.

Scintillator can craze if it is stressed or brown from radiation damage. Neither is a likely problem with small tiles at the ILC.

Single point failure mechanisms: The RPC's would likely have a common gas system, which is the only plausible culprit for a total system problem. The RPC's could also have problems with the gas supply to a segment of chambers. Both approaches could lose significant segments with a short in the HV (RPC) or power for the electronics (both). R&D includes development of an HV and LV power supply system that can be controlled channel by channel. The HV of nearly 7kV for the RPC's does present a high voltage issue not faced by the scintillators.

Gas systems leaks and operation: Ensuring good flow and recovery from a large system is possible, but will be expensive. The chambers are expected to fit in an 8 mm gap, so the flow will probably be from chamber to chamber across the ~6 m of the HCal.

Costs: Cost models have been developed for both scintillators and RPC's, but they have been done by different groups and are not straightforward to compare. The dominant cost of either is probably the large area, multi-layer PC boards, which are sufficiently similar to ignore differences, as is the electronics on the boards. The scintillator and SiPM's cost more than glass, but are offset by the lack of high voltage systems and gas systems. Perhaps the biggest uncertainty is labor, where some level of robotic assembly will be required. At this time, the overall difference is small compared to the errors.

Simulation: It is difficult to reliably simulate signals of the response of RPCs. Future attention to this issue may improve the simulation.

Recommendation

In consideration of the above points, the task force unanimously recommends that SiD adopt scintillator as the baseline technology.