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Recommendation on HCAL choice for SiD baseline

SiD Task Force on HCAL Baseline
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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 the series of update reports, including the ILC Technical Design Report[2]. Since that choice was made nearly ten years ago, the technologies have advanced considerably. In particular, recent advances in the application of Silicon Photomultipliers (SiPM)[3] to readout planes of tiles of scintillators mounted on large 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.

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[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 the RPC's 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 technology 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 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] has led to the possibility of individual tiles read out by a single SiPM. The current state-of -the-art consists of a large panels of scintillator tiles mounted on PCBs with each tile having a small concave dimple where an SiPM is placed. The shape of the dimple is chosen so as to make the response to a mip uniform across the tile. Beam tests of a hadron calorimeter constructed with this method have been carried out at DESY, Fermilab and CERN.

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

Calorimeters with RPCs using a 'digital' and 'semi digital' approach 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:

<u>Calibration:</u> The calibration of the RPC's requires setting the gain of the chamber via the HV and/or the threshold of a discriminator. Usually the HV is set on a per chamber basis. With single bit readout, there is no going back to the data for calibration adjustments, nor is there a peak to see from mips going through. This raises questions of the medium and long term stability. There is inadequate knowledge of the stability and performance of the "one-glass" RPC's.

The scintillator should be intrinsically stable, as it will be far away from any radiation damage. There will be an LED for testing each channel and maintaining the SiPM gain. This is expected to be ~12 bit analog system, so as long as the SiPM gain is made reasonably stable, one can play with isolated min-I's in the pixels for calibration checks.

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

Response Uniformity: The RPC's have significant pixel to pixel cross talk, possible from spreading of the avalanche, which may be alleviated in the "one-glass" RPC. However, the signal is so broad that the proponents favour a "digital" readout, and there is minimal ability to count mips in a single pixel, thus leading to relatively small pixels. Non-uniformities were present in the test modules of the DHCAL group 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 and can probably be overcome in the future.

The scintillator should have very little pixel to pixel crosstalk, and should be able to count mips, thus permitting larger pixels. The scintillator, with its large fraction of hydrogen, will be more sensitive to neutrons. If the electronics can gate out-of-time neutrons, this is probably an advantage.

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 close to breakdown, and can produce large signals. However, 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. There is no significant experience with the "one glass" RPC.

The RPC glass is quite fragile and needs to be handled with care.

Scintillator can craze if it is stressed or brown from radiation damage. Neither is a likely problem with small tiles and 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). The HV of 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.

Recommendation

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