# SiD Detector – Hadron Calorimeter Plan for LOI and Beyond

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## Introduction

This plan addresses SiD HCal development and technology choices to be described in the forthcoming Letter of Intent (LOI), in the scenario where there will be two detectors for the ILC. It also identifies the steps to be taken after the LOI and for the preparation of the EDR, assuming that SiD is selected as one of the two detectors.

The timescale for the submission of the LOI is taken to October 2008, followed by the EDR in 2010-11. The plan encompasses HCAL technology selection, PFA development, and overall engineering requirements.

## Requirements

The hadron calorimeter is a critical component of the SiD detector as it provides essential information for the identification and reconstruction of jets and other physics objects via a Particle Flow Algorithm. The basic requirements for this device are:

- It must efficiently allow tracking of charged particles through its volume.
- It must have sufficient depth such that any energy loss in the coil, and/or energy measured with degraded resolution (relative to the HCal) in the outer detectors (such as a TCMT) does not significantly impact jet energy resolutions at all jet energies.
- It must have a sufficiently small cell size to allow true separation and association of closely spaced energy clusters with the correct tracks – at a level that does not significantly degrade the jet energy resolution.
- It must have a sufficient sampling so as not to significantly degrade the jet energy resolution via the sampling term.
- Its outer radius must limit the cost of the solenoid and muon system to reasonable levels – requiring the radial size of each active layer to be as small as possible.
- It must have sufficient rate capability so as not to lose information, particularly in the forward directions – using a change of technology, if necessary.

## Technologies for the Hadron Calorimeter

A number of possible implementations have been proposed for the HCal active layers; gaseous technology in the form of RPC's, GEM's, and micromegas; and plastic technology in the form of scintillator tiles. These are not described in detail here having been the subject of many presentations. The recently proposed micromegas implementation would be very similar to the GEM version, with the GEM foils replaced by the micromegas mesh.

## Technology selection for the HCal Active Layers

There are many factors that will play into the final selection of a technology for the SiD HCal. *The main issue will be the quality of overall ECal and HCal physics performance versus the cost of the HCal, which is, in turn, driven mainly by the performance versus segmentation and the cost of achieving a given segmentation. Additionally, there is the issue of achieving greater depth (in units of hadronic interaction lengths) for the HCal. This can affect cost either through the choice of absorber and/or by potentially increasing the outer diameter of the HCal, and thus the size of the coil.* More detailed factors are listed below:

Performance criteria:
1) MIP Efficiency/pad
2) Hit multiplicity/MIP
3) Uniformity of response across active layers
4) Need for or ease of calibration
5) Recovery time after hit(s)
6) Recovery time after a "significant beam event"
7) Rate of discharges (gas)
8) Track-cluster separability
9) PFA jet resolution at a) Z-pole, b) 250, 500, 1000 GeV
10) Magnetic field issues – signal location offsets in barrel and endcaps (gas)
11) Response to neutrons

Technology issues:
1) Maturity and previous history
2) Reliability
3) Availability of components (in quantity)
4) Active layer thickness
5) Smallest readout unit size
6) Technical risk of approach
7) Ease of assembly/testing/installation/commissioning (often referred to as "scalability").
8) Effects of aging on performance

Cost:
1) Overall HCal cost
2) Active layer cost as a percentage of total cost
3) System development costs
4) Costs for assembly and test

**Steps Forward**

There is a conflict between the time required for building and testing large HCal prototypes and the schedule for the LOI. However the various phases of development identified below should be as coherent as possible with the LOI and EDR dates.

In preparation for a baseline choice for the LOI, we propose to hold a series of HCal reviews in Spring 2008. There will be three reviews:

i) January 2008. This initial review will allow all available information on all potential HCal technologies to be presented (in a report and by presentation). Each technology can then be compared against the performance and technological criteria described above, both from the standpoint of its present status, and what additional information can be expected on the timescale of the LOI review process. This review will also identify additionally needed information that should be provided at the second review. *A feature of this first review should also be the presentation of the first conceptual engineering design for the HCal for each technology. This should allow the SiD Engineering*

*Group to determine how many parallel designs to carry forward during the LOI preparation.*

ii) March 2008. This review, and updated reports from each technology option, will provide the most complete available information for the LOI baseline decision.

iii) May 2008. The final review will be a presentation of the deliberations of the review committee regarding the LOI baseline, and possible alternatives. *The result of this review should be the final baseline HCal choice for the LOI. This will then allow the period May-October 2008 for the writing of the HCal section of the LOI.*

We now discuss the possible status of, and availability of information for, the various options in the Spring of 2008.

1) Initial prototyping and basic measurements of efficiency, hit multiplicity, operational robustness, etc. on small scale systems. A large amount of work has been completed (with the possible exception of the micromegas option?).

   *Schedule:* Each technology option will be asked to prepare a report on this for the first HCal review in January 2008.

2) Development of high density readout and operation of a number of active layers in a stack to establish a first level of scalability, and some level of comparison with shower simulations for single particles. This includes the "Slice Test" of RPC/GEM at Fermilab in Summer/Fall 2007, and elements of the CALICE HCal stack tests at CERN in 2007/8. The successful operation of the detector modules for these tests provides some information on reliability and robustness. The tests of the CALICE scintillator/SiPM stack using single incident particle data will provide the first comparison with GEANT4 simulations. To a limited extent, similar information will be available from the RPC/GEM Slice Test also.
   For the scintillator HCal option, the issue of high density readout requires the development of direct SiPM-on scintillator-tile configurations and the associated electronics board

   *Schedule*: RPC Slice Test results, results from a limited number of GEM chamber, and comparisons of the scintillator HCal results with simulations, should be available for the Spring 2008 reviews. Initial results from trials of scintillator tile readout using directly coupled SiPM's should be available on the same timescale. However, the full results are not expected until later in 2008.

3) The results from phases 1) and 2) on stack operations, electronic readout implementations and scalability, simulation comparisons, and cost should then be evaluated during the Spring 2008 reviews before proceeding with further larger scale prototypes – the scintillator/SiPM option being the only technology that will have results from a full size stack by the time of the reviews. (Note that for three technologies these two steps have not fully proceeded in the same order. For instance RPCs and GEMs have already demonstrated reasonable scalability but have not been tested in large numbers. On the other hand a scintillator-SiPM stack has seen beam but scalability is not yet demonstrated.)

   *Schedule*: The technical results, performance data (energy resolution, simulation comparisons,…), and availability of significant funding, should all be input to decisions on which large prototypes to pursue. However, it is already known that there is a RPC $1m^3$ stack planned for late 2008, to be followed by a GEM stack. Micromegas plans (in Europe) are not yet known. A re-evaluation of these plans will be needed depending on the outcome of the reviews, the outcome of the LOI process, and the method(s) of funding large scale prototypes post-LOI.

Goals for the $1m^3$ stack Test(s):

a) Large scale tests of technologies
   - If gas, stability of gas calorimeter systems with large channel count.
   - Rate of discharges, associated damage/recoverability
   - Uniformity of response across planes, plane-to-plane
   - Stability of response over a ten day period
   - Noise rate vs. threshold as measured by number of active channels during no beam conditions or away from an identified muon.

b) Test of traditional calorimetry performance over a range of energies and species(to ensure we at least have a rationale basis for comparison w/o the confusion inherent with PFA and the ever present claim that it can be optimized.)

- Single particle energy resolution with fixed sampling fractions
- Pion rejection/efficiency with respect to electron ID (for tracks partially showering in the HCal).

c) Study of shower shape and verification of simulations (needed to really trust PFAs)
    - Shower shapes vs. particle type and beam energies
        i. Average shower depth starting point
        ii. Average shower width vs. depth
        iii. Moments of transverse energy depositions
        iv. Hits/layer within cone
        v. Hits/layer in rings outside cone
        vi. Longitudinal shower profiles
        vii. Hits vs. energy for each particle type
    - Effects of threshold selection(s)
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d) Tests of PFA components (cluster forming/connecting, topological associations,..)
    - PFA response at fixed energies.
    - An open issue that will require study is the degree of agreement required between data and simulations. This may entail a determination as to how well the simulations must be "tuned" to achieve agreement for all particle types?

In parallel, the results from complete PFA's will be evaluated for positive/negative implications for each active layer technology.

*Schedule*: A comprehensive review of simulation and PFA results impacting the SiD HCal will be carried out in parallel with the hardware/performance reviews. It is acknowledged that, due to funding issues and the LOI schedule, decisions for technical choice(s) to be included in the LOI may be based solely on simulation/PFA and small or partial prototype results.

4) Once a choice has been made (unique or leading candidate) for the LOI, then this technology will be subjected to further extensive testing during the 2-3 year period of writing the EDR. The goal will be to provide the input for a complete HCal and overall SiD calorimeter system designs for the final EDR.

**Implications for Simulation and PFA development.**

For whichever stacks, or partial stacks, are to be exposed to beam, we must have detailed simulations that provide the items for data/simulation comparison described above. This should include all possible beam particle types, anticipated energies, and incident angles.

Since a major driver for the technology choice is performance vs. segmentation, there is an urgent need to move the simulation work on to higher center of mass energies up to 1 TeV. Until we understand the segmentation requirements from jets at the higher energies, we cannot make progress in addressing the issue of fine segmentation for each technology. A critical part of the SiD LOI, but especially the EDR, will be to offer convincing evidence that we can achieve the required jet energy and jet-jet mass resolutions over the complete range of energies for the ILC via PFA, and that we have one or more HCal technology choice(s) that can deliver the required input to the PFA.

Schedule: PFA development should concentrate on physics processes at 500 GeV CM. A recommended program starts with the process e+e- -> ZH where Z -> ll and H -> dijet at 500 GeV. This lets the PFA performance be obtained on ~120 GeV jets – where it must be used most. Starting with only 2 jets with an unambiguous mass shows only PFA performance without adding jet combination confusion. The next step is to include the hadronic decays of the Z – now 4 jets with the same jet energies, but filling up more of the detector. At this point, PFA performance can be used to optimize some detector parameters, e.g., IR of ECAL, CAL granularity, B-field. Also, the PFA performance can be evaluated in terms of fraction of branching ratio to hadrons that can be used in analysis – the PFA goal can be cast in useable luminosity instead of jet E resolution. Then, the next process to be investigated should be e+e- -> tt - lower E jets, but 6 of them. The PFA performance should not be compromised at this stage. Lastly, one could try e+e- -> qq at 500 Gev to get 250 GeV jets. These should be very challenging for PFA, but not too useful for e+e- physics analyses. We would not include Z-Pole in the document, but would continue to use it as a tool for development, comparisons, etc. We think this program is possible on the timescale of the reviews, especially with the recent release of the PFA template.

**Engineering Studies**

Since SiD will be in a competitive situation on the LOi's with respect to other concepts, a first-level of engineering studies must be completed in the next 8 months. Since the thickness of the active gaps for all technologies is expected to be in the range 7mm – 10mm, a first pass study for the HCal might use a generic value and steel absorber to get engineering activities underway. It is anticipated that this can begin late in 2007, now the first SLAC, FNAL, ANL SiD Engineering Group is in place. The areas that need consideration for the LOI are:

- Basic parameters of HCal module design (number of depth layers, absorber plate material and thickness, number of azimuthal divisions, number of barrel sections in z , design of endcap modules)
- FEA study of initial HCal structure
- Support of barrel, endcaps and solenoid
- Assembly procedure for barrel and endcaps.
- Magnetic force effects
- Effects on module sizes, support, of tungsten vs. steel.

Schedule: A first pass engineering study should be available by March 2008, to allow studies of subsystem variations while the LOI is prepared.