Optimization of the HCAL for a Future e+e- Linear Collider with Energy Flow Jet Reconstruction

Participants
S. Chekanov, S. Kuhlmann, S. Magill, B. Musgrave
Argonne National Laboratory

Collaborating Institutions
Northern Illinois University, Stanford Linear Accelerator Laboratory, University of Texas at Arlington

Contact Person
Steve Magill
srm@anl.gov

Overview
An e+e- linear collider is a precision instrument that can elucidate standard model physics near the electroweak energy scale as well as discover new physics processes in that regime, should they exist. In order to take advantage of the physics anticipated from a machine of this type, the collection of standard high energy physics detector components comprising an experiment must be optimized, sometimes in ways not yet realized at current experiments. One such example is the hadron calorimeter (HCAL). This detector component will be used to measure jets from decays of vector bosons and heavy particles such as top, higgs, etc. For example, it will be important to be able to distinguish, in the final state of an e+e- interaction, the presence of a Z or W vector boson by its hadronic decay mode into 2 jets. This means that the dijet mass must be measured to a precision of ~3 GeV, or, in terms of jet energy resolution, sigma/E ~ 30%/$\sqrt{E}$, something not yet achieved in any existing calorimeter. It is expected that the best way to achieve such a precision is to use Energy-Flow jet reconstruction techniques, i.e., use tracking to reconstruct charged particles (~60% of jet energy), electromagnetic calorimetry to reconstruct photons (~25% of jet energy), and hadronic calorimetry to measure the energy of neutral hadrons (~15% of jet energy). The E-flow algorithm requires that charged and neutral hadron showers in the calorimeter be separable; then only the neutral showers are measured in the calorimeter. This means that the calorimeters must be highly granular, both transversely and longitudinally, to achieve the best 3-D shower reconstruction. Development of a calorimeter of this type requires a realistic simulation of both the physics processes and the shower development that occurs in materials, as well as the development and application of E-flow algorithms to separate and match showers to tracks, leading to the final optimal jet reconstruction.

Performance and Deliverables
We propose to develop, in simulation, a design for a hadron calorimeter (HCAL) which can be used to reconstruct jets in E-flow algorithms. This design will be optimized for at least 30%/$\sqrt{E}$ jet energy resolution on the hadronic decay to jets of vector bosons by varying the thickness and type of absorber in the HCAL for best containment and single

particle energy resolution, by tuning the transverse granularity and the longitudinal segmentation of cells for best shower separation, by testing both analog (traditional) and digital readout methods, and by perfecting the full E-flow algorithm.

HCAL Absorber/Active Media Properties
Physics event generation within the Java Analysis Studio (JAS) program, developed at SLAC, is flexible in the choice of absorber and active media type and thickness within the limits of the HCAL volume. The generation has recently been converted to full simulation within GEANT4. We have been able to get many simulated data sets of physics processes and single particles with different HCAL sandwich geometries. At ANL, we also have a standalone GEANT3 program which can be used to test geometries very different than that in JAS – even different volumes if needed. Presently, this program is used as a quick check of the performance of a new geometry before it is implemented in JAS. We will optimize the HCAL by comparing dense calorimeters (W, Pb) to less dense versions (Cu, SS, Brass) using as performance measures the containment of hadronic showers, the density of hits, and single particle energy resolution.

HCAL Transverse Granularity/Longitudinal Segmentation
This can also be changed in JAS – currently in projective cells within some wide limits in both transverse and longitudinal dimensions. It should be possible to optimize the 3-D granularity of cells for generic E-flow algorithms and then determine an optimal active media for the ultimate cell size. The methods developed here can be applied to various total detector geometries, i.e., SD, LD, TESLA. The main performance measure here is the ability to separate showers from charged and neutral hadrons – a crucial component of any E-flow algorithm.

Analog versus Digital Readout
Once the optimal 3-D granularity is determined, the choice of readout method can be evaluated by comparing jet resolutions with both analog and digital readout. It may be advantageous to consider both a "best" analog version and a "best" digital version of the HCAL for eventual test beam evaluation if, in fact, both types can satisfy the resolution criterion. Testing both options will allow for future advances in readout technology which might favor one option over another.

Energy-Flow Algorithms
For the first time in calorimeter development, it is necessary to include the reconstruction programs in the optimization of the detector. It is anticipated that the choice of E-flow methods will play a key role in the ultimate achievement of the best jet energy resolution. We plan to implement the following E-flow algorithm :
The algorithm begins with association of calorimeter hits to extrapolated tracks, removing hits along the path of the projected track from further analysis after evaluating variables such as E/p ratio, hit density, etc. Next, or possibly first if it is advantageous, photons will be identified in the EM calorimeter, probably using shape information of the electromagnetic energy deposits. At this point, jets can be found using the charged tracks and photons. The remaining calorimeter hits in, for example,

a cone centered on this jet will be associated with the jet – these are predominantly due to the energy deposit of neutral hadrons. The ultimate test is the dijet mass for Z and W vector bosons found in this manner. This method requires no traditional calorimeter cell clustering.

Future Plans
Ultimately, it is presumed that there will be several competing HCAL designs which meet the jet energy resolution goal in simulation - possibly a "best" analog and a "best" digital HCAL. The sandwich construction lends itself easily to testing of different readout configurations inside an absorber structure. Our future plans will include these options as part of a test beam program proposal that will ultimately lead to a single choice of an optimal HCAL design for the LC detector.

Budget
For FY 2003, the budget is used only for travel to workshops, a dedicated server for generation and storage of simulated data, and a summer (undergraduate) student. In subsequent years, as the optimization choices become apparent, equipment and additional personnel will be needed to support a test beam program, assumed to start in FY 2005.

	FY 2003	FY 2004	FY2005	TOTAL
Staff + Post-Docs	0	$55K	$55K	$110K
Summer Students	$6K	$6K	$12K	$24K
Subtotal	$6K	$61K	$67K	$134K
Computing	$4K	$3K	$3K	$10K
Travel	$3K	$6K	$10K	$19K
Materials & Services	0	0	$54K	$54K
TOTAL	$13K	$70K	$134K	$217K