Calorimeter Prototype Construction

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This paper reviews the progress with the planning and construction of a prototype section Digital Hadron Calorimeter. A brief introduction summarizes the concept of a Digital Hadron Calorimeter and lists the reasons for building and testing a prototype section. The remainder of the paper outlines the current status and the plans for the future.

1. A DIGITAL HADRON CALORIMETER

The optimization of the design of the Linear Collider detector for the application of Particle Flow Algorithms[1] requires a calorimeter with unprecedented spatial segmentation. In order to best separate energy clusters in the calorimeter belonging to charged and neutral particles, a segmentation of the readout of 1 cm^2 laterally (or smaller) and layer-by-layer longitudinally is being investigated for the electromagnetic and hadronic sections (HCAL) of the calorimeter. Within the Particle Flow Paradigm the role of the HCAL is limited to the measurement of energies of neutral hadrons, i.e. neutrons and K^0_L. Due to the low density of hadronic showers and the resulting small probability that a single pad of 1 cm^2 is hit by more than one particle in a given hadronic shower, a simple one-bit or digital readout is expected to be sufficient. Indeed, detailed Monte Carlo simulations show that the energy resolution for single hadrons is preserved in such a digital hadron calorimeter (DHCAL).

2. MOTIVATION FOR THE CONSTRUCTION A PROTOTYPE SECTION

The various groups involved in the development of a HCAL for the LC detector aim at building a 1 m^3 prototype section containing 40 layers of active readout interleaved with 20 mm thick steel plates as absorber. The main motivations for the construction of such a prototype section are the following:

- Test of the novel idea of a digital HCAL and comparison with the performance of a more traditional approach based on scintillator.
- Test and comparison of different technical implementations of a calorimeter with fine granularity.
- Study of various design parameters of the readout, like the segmentation, and of the absorber.
- Precision measurement of hadronic showers. Data of hadronic showers with the proposed fine segmentation do not yet exist.
- Validation of the Monte Carlo simulation of hadronic showers. Current simulations of hadronic showers based on a variety of standard Monte Carlo codes show differences of up to 60% in e.g. shower radii. The optimization of the design of the LC detector requires a more reliable simulation tool.

3. COMPARISON OF DIFFERENT ACTIVE MEDIA

Currently three different readout technologies are being investigated for the HCAL: scintillator tiles[2] with analog, i.e. multi-bit readout, Gas-electron Multipliers (GEMs)[3] and Resistive Plate Chambers (RPCs)[4], both with digital readout. Table I compares several of their features, where entries which do not compare favorably with the other competing technologies or are a concern have been set in bold letters. This comparison demonstrates that the three technologies have different strengths and weaknesses, which, therefore, justifies their parallel development at this early stage of detector development for the LC.

Table I: Comparison of Active Media for the HCAL

	Scintillator	**GEMs**	**RPCs**
Technology	Proven	**Relatively new**	Relatively old
Electronic readout	Analog (multi-bit) or Semi-digital (few-bit)	Digital (single-bit)	Digital (single-bit)
Thickness (inclusive electronic readout)	8 mm	8 mm	8 mm
Segmentation	**3 x 3 cm^2**	1 x 1 cm^2	1 x 1 cm^2
Pad multiplicity for MIPs	Small cross talk	Measured at 1.27	**Measured at 1.6**
Sensitivity to low energy neutrons	Yes	No	No
Recharging time	Fast	Fast?	**Slow (20ms/cm^2)**
Reliability	Proven	**Sensitive**	Proven (glass RPCs)
Calibration	**Challenge**	Depends on efficiency	Not a concern (high ϵ)
Assembly	**Labor intensive**	Relatively straight forward	Simple
Cost	**Not cheap (SiPM?)**	**Expensive foils**	Cheap
Cost of electronic readout	Expensive	Expensive	Expensive

According to simulation studies, scintillator is sensitive to low energy neutrons, whereas GEMs and RPCs are not. The low sensitivity of the gaseous detectors to neutrons can be explained by the low density of their active medium (gas) and the resulting low cross section for neutron interactions in the active gap. As a consequence of this difference, showers measured with scintillator appear wider than showers measured with gaseous detectors. If confirmed by measurement, this might prove an important advantage for gaseous detectors, since the identification of energy deposits from charged and neutral particles will be easier. On the other hand, the reduced sensitivity of gaseous detectors to neutrons might lead to an unwanted decrease in single particle resolutions.

4. STATUS OF R&D CONCERNING THE ACTIVE MEDIA

Table II summarizes the tests performed with the two choices of technology for the digital version of the HCAL. For more details, refer to [4] for the US RPC and [3] for the GEM effort. As can be seen from Table II, the development of RPCs is virtually complete, whereas some further testing is still needed for the GEM development. Two independent groups, one in Russia and one in the US, are developing RPCs for the DHCAL. Their efforts have been mostly independent, but have lead to a similar chamber design for the prototype section. The default chambers consist of two glass plates, each about 1 mm thick, separated by a gas gap of 1.2 mm. The glass plates are coated with resistive paint with a surface resistivity of the order of 1 - 50 M$\Omega/\square$.

5. ELECTRONIC READOUT SYSTEM

With a channel count of 400,000 for the prototype section alone, the design of the electronic readout system for the DHCAL poses a real challenge. Figure 1 shows our conceptual design of the readout system, which is equally applicable to the RPC and GEM case. To keep the cost per channel at an affordable level, multiplexing is already performed at the earliest possible stage.

The system consists of four distinct parts: a front-end ASIC reading out 64 individual pads, a data concentrator reading out twelve ASICs, a VME-based data collection system, and a timing and trigger system. The overall design of the readout system is coordinated by Argonne, the front-end ASIC is being engineered at Fermilab, and groups at Boston University, University of Chicago, University of Iowa, University of Texas at Arlington, and University of Washington have taken responsibility for the design and prototyping of the various other subsystems.

Table II: Summary of Measurements Performed on RPCs and GEMs

Measurement	RPC RU	RPC US	GEMs
HV dependence	yes	yes	ongoing
Single pad efficiencies	yes	yes	ongoing
Geometrical acceptance	yes	yes	no
Test with different gases	yes	yes	yes
Multipad efficiencies	yes	yes	ongoing
Hit multiplicities	yes	yes	ongoing
Noise rates	yes	yes	no
Rate capability	yes	yes	no
Tests in 5 T field	yes	no	no
Tests in particle beams	yes	no	no
Long term tests	ongoing	ongoing	ongoing
Design of larger chamber	yes	ongoing	ongoing

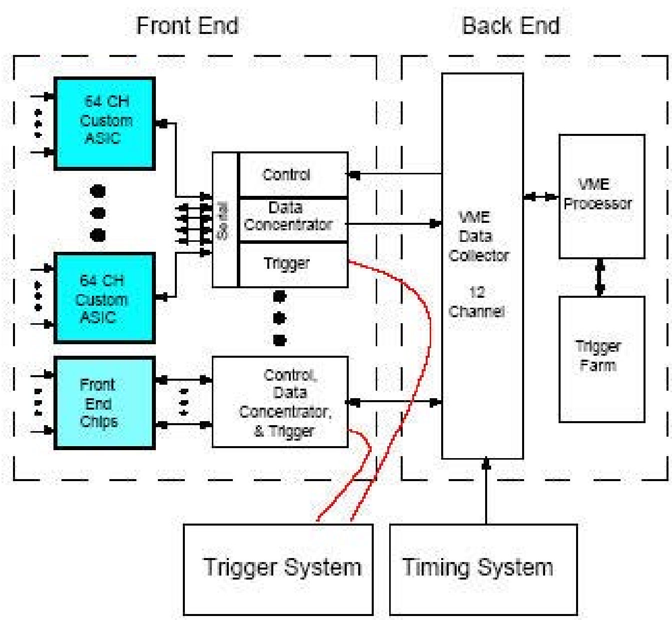

Figure 1: Conceptual design of the electronic readout system.

6. COST AND FUNDING

Table III summarizes the projected M&S costs for the DHCAL. A large contingency of at least 50%, reflecting the pre-design status of the project, is not reflected in the quoted numbers. The grand totals for the RPC and GEM columns reflect the cost of building a DHCAL with either of these technologies, independently of the other. The grand total in the last column indicates the cost for building both systems, assuming a shared back-end of the readout system. The lower cost of the front-end ASIC in the GEM column is only applicable, if the set-up cost for production has already been covered by the RPC project.

The groups have applied for financial support from both DOE and NSF in the US. In particular, University of Texas at Arlington, University of Oregon and Argonne National Laboratory submitted a detailed Major Research Instrumentation (MRI) proposal requesting $964,00 to the NSF. A decision on the funding is expected by mid-2005.

Table III: Overview of M&S Costs for the DHCAL

Item	**RPC**	**GEM**	**Total**
Active detector	20	200	220
Front-end ASIC	225	125	350
Front-end boards	50	50	100
Data concentrator boards	85		85
Data collector boards	60		60
Power supplies, cables, etc.	60		60
Grand total	500	680	875

Table IV: Major activities of the DHCAL Project

Year	**Detector**	**Activity**
2005	RPC	Develop and test larger chambers
	GEM	Cosmic ray studies with stack of GEMs
		Initiate long foil production and testing
	Both	Prototype ASICs
		Specify remainder of electronic readout system
		Design and prototype electronic readout subsystems
2006	Both	Produce chambers
		Produce ASICs
		Produce other subsystems of the electronic readout
2007	Both	Move to test beam
		Data taking
2008	Both	Data taking
		Design of the LC hadron calorimeter

7. SUMMARY AND OUTLOOK

The proposed construction of and tests with a fine granularity hadron calorimeter prototype are essential to validate the concept of a digital hadron calorimeter and its technical implementation and to provide a basis for the fine tuning of the modeling of hadronic showers. Assuming the project benefits from the requested funding starting in fiscal year 2006, a complete test section will be available for tests by early 2007. Table IV summarizes the major activities of the project over the next few years. The tuning of the hadron shower simulation codes will initiate in 2007 and will be performed in parallel with the data taking. For more details on the DHCAL project, visit *www.hep.anl.gov/repond/DHCAL_US.html*.

Acknowledgments

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References

[1] See talks in the *Simulation and Reconstruction* session, track 8.
[2] F. Sefkow, these proceedings.
[3] A. White, these proceedings.
[4] L. Xia, these proceedings.