

Construction of a Prototype Hadronic Calorimeter with Digital Readout (LCRD)

Calorimetry

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Argonne National Laboratory
Boston University
University of Chicago
Fermi National Accelerator Laboratory
University of Iowa

FY 2005: \$105,000

Project name

Construction of a Prototype Section of a Digital Hadron Calorimeter

Classification (accelerator/detector:subsystem)

Detector

Institution(s) and personnel

Argonne National Laboratory: Gary Drake (electronics engineer), Steve Kuhlmann (staff scientist), Steve Magill (staff scientist), Brian Musgrave (scientist emeritus), José Repond (staff scientist), Dave Underwood (staff scientist), Barry Wicklund (staff scientist), Lei Xia (postdoctoral research associate)

Boston University: John Butler (professor), Meenakshi Narain (professor)

University of Chicago: Mark Oreglia (professor)

Fermilab: James Hoff (electronics engineer), Abderrezak Mekkaoui (electronics engineer), Ray Yarema (electronics engineer)

University of Iowa: Edwin Norbeck (professor), Yasar Onel (professor)

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Project overview

We propose to construct a 1 m³ prototype section of a digital hadron calorimeter. The section will consist of 40 steel plates, each 20 mm thick, interleaved with Resistive Plate Chambers (RPCs) as the active medium. The segmentation of the readout will be extremely fine, 1 cm² laterally and layer-by-layer longitudinally. The electronic readout will be reduced to a single bit per readout channel. This novel idea of a so-called digital hadron calorimeter (DHCAL) will be tested thoroughly in test beams at Fermilab. The tests will be either in stand-alone mode or together with a prototype of the

electromagnetic calorimeter placed in front of the DHCAL. The proposed technology of a digital hadron calorimeter with RPCs is equally applicable to all three International Linear Collider detector design efforts, namely the SiD, the Large, and the Huge detectors.

The purpose of constructing a prototype section and subsequent tests in particle beams are:

- **Test of a calorimeter with RPCs:** even though RPCs have been employed in a large number of HEP experiments, to date no calorimeter with RPCs as active medium has been built and tested. Our tests will validate the use of RPCs in calorimetry.
- **Tests of the novel idea of a DHCAL:** in simulation studies of a DHCAL the resolution obtained for hadrons is comparable to the results obtained with analog readout. Experimental verification of this and validation of the concept of a DHCAL is needed.
- **Study of design parameters:** measurements with different configurations of the prototype section will provide a better understanding of the dependence of the response to the various design parameters, such as the choice of absorber, the size of the active gap, the segmentation of the readout, etc.
- **Measurement of hadronic showers:** traditional calorimeters measure energy with a coarse segmentation, thus integrating over large volumes. Our DHCAL prototype section will measure hadronic showers with unprecedented spatial resolution, thus providing very detailed information on hadronic showers.
- **Validation of Monte Carlo simulation of hadronic showers:** the measurements obtained in a particle beam will be essential to validate the Monte Carlo simulation of hadronic showers. To date differences of up to 60% are observed when comparing the results on shower shapes based on different MC models of the hadronic shower. The design of a detector for the International Linear Collider is driven by the application of Particle Flow Algorithms for the measurement of hadronic jets. A realistic simulation of hadronic showers is a prerequisite for the development of a reliable design of such a detector.
- **Comparison with an Analog Hadron Calorimeter:** Currently the CALICE collaboration is assembling a prototype section of a hadron calorimeter using scintillator tiles and analog readout. The lateral size of the tiles is about a factor of 10 larger than the readout pads of the DHCAL.

The present proposal is a follow-up on last year's proposal. The current overall status of the project is briefly summarized here:

- R&D concerning the RPCs is essentially complete. A design to be used for the prototype section has been developed.
- A concept for the electronic readout system has been proposed. The cost of the readout is approximately \$1.4/readout channel.
- The front-end of the electronic readout is based on a custom ASIC. The design of the ASIC, contributed by Fermilab, is nearly complete.

- The mechanical structure, consisting of a movable table and the absorber plates, has been designed and is currently being assembled at DESY.
- A detailed document outlining the special needs for test beams has been submitted to the Fermilab directorate.

Achievements in previous years

Our project was initiated in 2002. In the following we shall briefly highlight the major achievements since then:

- 1) We have constructed ten chambers using as resistive plates glass of 0.85 and 1.10 mm thickness. The chambers feature either one or two gas gaps and have resistive paint layers with surface resistivity varying between $\sim 100 \text{ k}\Omega$ and $\sim 50 \text{ M}\Omega$. The designs of the chambers vary significantly, with some chambers featuring only one glass plate, others having only one or no resistive layers. The active area of the chambers is approximately $20 \times 20 \text{ cm}^2$. A larger chamber with an area of $30 \times 90 \text{ cm}^2$ has also been built.
- 2) The electronic signal induced on the pick-up pad(s) has been characterized with respect to its timing characteristics and charge using a high resolution digital oscilloscope.
- 3) A cosmic ray test stand was built.
- 4) The chambers were tested extensively with a single readout pad of $17 \times 17 \text{ cm}^2$. The signals were measured with an ADC and also shaped, amplified, discriminated and counted. The chambers were found to be very quiet (the noise rate is about 50 Hz) and highly efficient ($>95\%$) in both avalanche and streamer mode.
- 5) The chambers were tested using different gas mixtures. For each mixture the overall efficiency and the fraction of streamers was determined as a function of applied high voltage. A default mixture for running in avalanche mode was established.
- 6) The efficiency as a function of position on the chamber was measured at the University of Chicago. As expected, the efficiency showed a dip at the location of the spacers holding the glass plates apart. The loss of efficiency is consistent with being limited to the area of the spacers.
- 7) A high voltage system based on the Cockcroft-Walton technology has been developed. First prototypes of the HV system have been tested with our prototype chambers and they performed satisfactorily.
- 8) The mechanical properties of the glass were measured to establish the bending due to gas pressure and the electric force.
- 9) A VME based multi-channel readout system has been designed, fabricated and assembled. The software for the data acquisition has been written and the system has been commissioned to take either triggered cosmic ray data or untriggered events for noise measurements.
- 10) The chambers were read out with 64 pads, each of 1 cm^2 . The signals were analyzed with an ADC system. The lateral distribution of the induced charge around the pad hit was measured.

- 11) The hit multiplicity as a function of particle detection efficiency (adjustment of the discriminator threshold) was measured for several chambers based on different designs and as a function of applied HV.
- 12) Lower limits on the rate capability of the chambers were measured as a function of applied high voltage using a radioactive source, providing the rate, together with cosmic rays for the efficiency measurement.
- 13) A conceptual design of the readout system for a 1 m³ prototype section has been developed. The system is based on a front-end ASIC and contains a data concentrator, a data collector, and a timing and trigger system. Preliminary costs for the various subsystems of the electronic readout have been estimated. The design accommodates both RPCs and Gas Electronic Multipliers (or GEMs) as active detectors. The latter are currently being investigated by the University of Texas at Arlington.
- 14) The design of the front-end ASIC has been specified in a detailed document. The engineering of the chip has been started and is being provided by Fermilab. The digital part of the chip is complete.
- 15) The response of the 1 m³ prototype to single particles of various energies has been simulated using the GEANT4 package. Comparison of the response to electrons and pions using scintillator or RPCs as active medium showed that both electromagnetic and hadronic showers appear narrower when using RPCs. The reasons for this different behavior have been established. The narrower showers constitute a clear advantage for the application of Particle Flow Algorithms.
- 16) In collaboration with other institutions developing calorimeter prototypes for the ILC, a technical note detailing the needs for test beams has been drafted and submitted to Fermilab.
- 17) Progress with our R&D activities has been presented at meetings of the Linear Collider community and also at conferences dedicated to detector developments.
- 18) A digital hadron calorimeter with RPCs as active medium has been chosen as the default option for the SiD detector design effort.

Description of project activities in the following years

For FY2005 we plan the following activities:

- 1) We will construct additional large chambers with dimensions matched to the planned prototype section.
- 2) We will test the performance of these chambers, in particular the uniformity of the response.
- 3) We will develop a design for the 1 m³ prototype section and start constructing the first chambers.
- 4) We will design and prototype the front-end boards containing the readout pad and the front-end ASIC.
- 5) We will complete the design of the ASIC and submit the design for a prototype run.

- 6) We will measure the performance of the prototype ASIC in great detail using specially designed test fixtures.
- 7) We will design and prototype the data concentrator boards.
- 8) We will design and prototype the VME based data collector system.
- 9) We will design and prototype the timing and trigger system.
- 10) We will design and prototype the high voltage distribution system
- 11) We will develop a gas distribution system.

For FY2006 we plan the following activities. These activities will in part be supported by a separate MRI proposal submitted to the NSF. The dollar amounts are quoted excluding contingencies:

- 1) We will build the RPCs for the prototype section. We foresee building 120 chambers plus of the order of 10 spares.
- 2) We will build the electronic readout system for the prototype section including the front-end ASICs (\$225k), the front-end readout boards (\$50k), the data concentrator boards containing FPGAs(\$85k), and 40 VME cards (\$60k) for data collection.
- 3) We will purchase low voltage power supplies (\$50k), optical fibers and other transmission cables (\$5k) and 2 VME crates with power supplies (\$15k
- 4) We will build or purchase the High Voltage and gas distribution systems.

The following activities are planned for FY2007:

- 1) Transportation of the chambers to the Fermilab test beam.
- 2) Assembly of the prototype section.
- 3) Testing with particle beams.
- 4) Detailed Monte Carlo simulation of the response of the prototype section to single particles.

Responsibilities as currently assigned

Argonne National Laboratory	Construction of chambers Overall electronic system design Test fixtures for front-end ASIC VME based data collector system Transportation of RPCs to test beam
Boston	VME based data collector system
Chicago	Data concentrator boards
FNAL	Front-end ASICs Front-end readout boards
Iowa	High voltage distribution system Gas distribution system
UTA*	Timing and triggering system
Washington*	Data acquisition and VME programming

* not part of this proposal

Engineering and technical effort during FY2005

Engineering and technical support will be needed for the following tasks:

1. The design and construction of chambers for the prototype section.
2. The design and prototyping of the readout system for the prototype section, including the development of the front-end ASIC (provided by Fermilab), the design of the front-end board (located on the RPCs), the data concentrators and the data collector systems.
3. The design and fabrication of test fixtures for the prototype ASICs.

Current and Pending Support

The following concerns the Argonne Linear Collider Detector R&D group only. The funds are being used to support one postdoctoral research assistant, the design efforts (engineers) and the prototyping of parts of the electronic readout system.

Current

Project: Precision Measurements of Hadronic Showers
Funding agency: Argonne National Laboratory
Program: Laboratory Directed Research and Development (LDRD)
Status: Awarded
Duration: One year
Amount: \$181,500

The following concerns the Argonne Linear Collider Detector R&D group only. The funds are being requested for the front-end electronics of the prototype section. The proposal is being submitted jointly with the University of Oregon and the University of Texas at Arlington.

Pending

Project:	Development of Calorimeter Prototype Modules for International Linear Collider Test Beam Program
Funding agency:	NSF
Program:	MRI
Status:	to be submitted
Duration:	3 years
Amount:	\$950,000

Broader Impact

The challenges raised by the linear collider physics program promote the development of new detector technologies. The necessary fine granularity of the hadron calorimeter requires a novel technical approach. The proposed digital hadron calorimeter with Resistive Plate Chambers as active medium fulfills the physics criteria, but has never been built and tested before.

These technological challenges require close collaboration between industries, universities and national laboratories. The project involves a number of graduate and undergraduate students associated with the universities participating in this proposal. At Argonne the project will attract participation from high school teachers and summer students.

The detailed measurements of the response to single particles will further the understanding of hadronic showers and provide a unique data base for comparison with simulation. The results from this program will be disseminated through national and international conferences and workshops and published in peer-reviewed journals.

Facilities, Equipment and other Resources

All institutions included in this proposal have outstanding electronic engineering capabilities and electronic design facilities. Mechanical work will be mostly done at Argonne. The latter has a mechanical shop with many years of experience in designing and constructing calorimeters for high energy physics experiments.

Budget and budget justification

Institution	Item	FY2005	FY2006	FY2007
Argonne	Summer students, other professionals	Supported from base funds		
	Engineering			
	M&S for (prototype) electronics	30,000	40,000	
	Transportation of RPCs to testbeam			20,000
Boston	Students, other professionals	5,000	5,000	5,000
	Engineering	5,000	5,000	5,000
	M&S for (prototype) electronics	15,000	20,000	
Chicago	Engineering	5,000	5,000	5,000
	M&S for (prototype) electronics	15,000	20,000	
FNAL	Engineering	Funded elsewhere		
Iowa	Students, other professionals	5,000	5,000	5,000
	Engineering	5,000	5,000	5,000
	M&S for HV and gas system	15,000	20,000	
All	Travel	5,000	5,000	10,000
Total		105,000	130,000	55,000