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A Digital Hadron Calorimeter with Resistive Plate Chambers for the Linear Collider

G. Drake, J. Repond, D. Underwood, A.B. Wicklund, L. Xia
HEP Division, Argonne National Laboratory, 9700 S. Cass Ave., Argonne, IL 60439, USA

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We report on the development of a digital hadron calorimeter for the future International Linear Collider. Te calorimeter is of the sandwich type with iron absorber plates and resistive plate chamber as active medium. The readout pads are very finely segmented, with an area of 1 cm^2, and are being read out digitally. We present the design, construction and testing of various prototype chambers as well as the development of a readout system capable of handling a large number of channels. We plan to construct a 1 m^3 prototype section of the calorimeter containing approximately 400,000 channels. The section will undergo testing in various particle beams.

Keywords: Calorimetry; Linear Collider; Resistive Plate Chamber; Particle flow.

1. Calorimetry at Linear Collider

The International Linear Collider (ILC) will be an ideal machine to make precision measurements, and it requires unprecedented detector resolution.

The goals for jet energy resolution of the ILC detector is set to be $30\%/\sqrt{E}$ or better. This can not be achieved by any existing calorimetry, we need both novel idea, namely, Particle Flow Algorithms (PFA), and specially designed calorimetry.

2. Particle flow algorithms and digital hadron calorimeter

Table 1. Measurement of jet components and their contribution to jet energy resolution.

Particles in jets	Energy fraction	Detector	Contribution to jet resolution $[\sigma^2]$
Charged particles	65%	Tracker	Negligible
Photons	25%	ECal ($15\%/\sqrt{E}$)	0.05^2 E_{jet}
Neutral Hadrons	10%	ECal+HCal ($50\%/\sqrt{E}$)	0.16^2 E_{jet}
(Confusion)			$\leq 0.24^2$ E_{jet} (to get $30\%/\sqrt{E}$)

The Particle Flow Algorithms use the information from the whole detector to reconstruct jet energy, i.e., to measure charged particles of a jet in central tracking

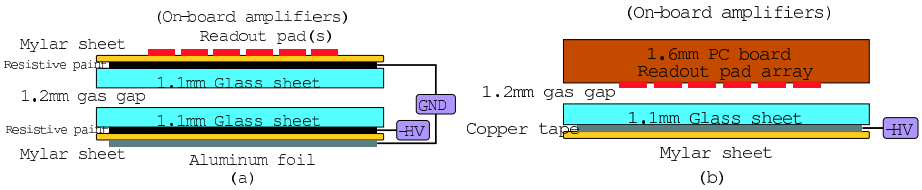

Fig. 1. Schematic design of RPC: a. base line design; b. new design.

detector, photons in electromagnetic calorimeter, and neutral hadrons in both electromagnetic and hadron calorimeters, as shown in table 1. However, this relies on clear separation of jet particles which requires very fine segmentation throughout the calorimetry.

For a hadron calorimeter, it would be too expensive to have both fine segmentation, thus, huge number of readout channels, and detailed information for each readout channel. Monte Carlo studies showed that a digitally readout hadron calorimeter with fine pixels is enough to separate jet particles while preserves single particle energy resolution. A digital hadron calorimeter can significantly reduce the cost of reading out huge number of channels by simplifying the readout electronics. In addition, a digital HCal does not require its active medium to have any energy resolution, and thus, inexpensive detectors, such as resistive plate chamber (RPC), become excellent candidates for the active medium.

3. Resistive Plate Chambers

Resistive Plate Chamber (RPC)[1] is a particle detector based on simple, inexpensive and reliable technology. RPC has nearly 100% detection efficiency on charged particles passing through its gas volume with very low noise rate. It can also provide good position information.

The configuration of a typical RPC is shown in figure 1a. When a particle passes through the gas volume, it creates primary ionizations. Depending on the applied electric field, the primary ionizations can develop into an avalanche or a streamer. By choosing high voltage, RPC can run in either avalanche mode or streamer mode.

Figure 1a also shows our baseline design, in which the chamber has one gas gap enclosed by two glass sheets. High voltage is applied through resistive paint on the outer surface of the glass sheets, and a signal pick-up pad is attached to the chamber to get the induced signal from avalanche or streamer occurred in gas volume.

Figure 1b shows our new design in which signal pad has been built into the chamber itself and can collect signal charge directly. We tested both configurations

4. Test result

We have built and tested over 10 RPCs at Argonne, with different design parameters. Here, we will focus on the baseline design and the new design. For result shown

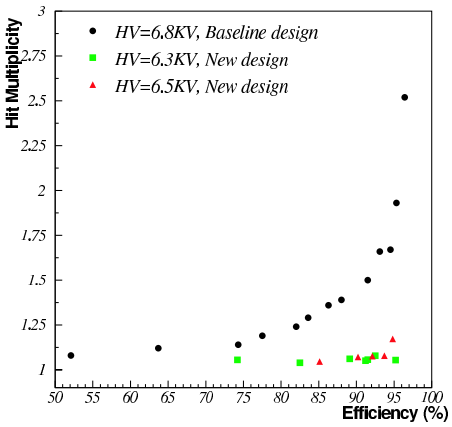

Fig. 2. RPC hit multiplicity as a function of detection efficiency.

here, we used a gas mixture of R134A : IsoButane : SF_6 = 94.5 : 5.0 : 0.5.

4.1. *RPC signal and efficiency*

Our RPC chambers were first tested with a large signal pad, using cosmic ray triggered by four scintillation counters. The signal was sent to a charge integration amplifier. Depending on operating voltage, a typical avalanche signal has a charge of 1 - 10pc, and a streamer signal has a charge of over 30pc. For chosen charge threshold, in our case 0.1pc which is over 3 times of the pedestal width, the RPC efficiency is always nearly 100%, once the operating voltage is above a turn-on voltage. There is a region above the turn-on voltage that RPC can run in pure avalanche mode. This region is called the 'avalanche plateau'. For our RPC configuration and gas mixture, the avalanche plateau is about 0.5 - 0.6 KV.

The avalanche mode is our preferred running mode, for its mild signal, higher rate capability and lower noise rate.

4.2. *RPC signal cross talk*

After knowing a chamber's basic properties, we focused on digitally reading out avalanche signals from multiple readout pads. We used a readout board that has an array of 8×8 signal pads of 1×1 cm^2 size on one side, and 64 UPC1663 amplifiers on the other side. Analog signal from each pad was amplified and sent to a VME board, on which it was compared to a programmable threshold and converted to digital bit. The bit was set to 1 (hit) if signal amplitude is greater than threshold, or 0 (no hit) otherwise. The digital hit pattern was then readout through VME bus. We used cosmic ray to do the test, and a trigger signal from 4 scintillation counters was readout together with RPC hit pattern.

Ideally, one expect to have one and only one hit per charged particle passing.

However, due to the finite lateral size of an avalanche, signal charge is shared between one or more signal pads, and results in multiple hits. 'Hit multiplicity' is defined as the number of digital hits fired for a single particle passing. Raising the hit threshold will reduce hit multiplicity, but at the same time, reduce detection efficiency. By scanning the hit threshold, we got the correspondence between hit multiplicity and detection efficiency, as shown in figure 2. The baseline design has an average multiplicity of 1.6 - 1.7 for 95% efficiency, and the new design has a multiplicity of about 1.1 which is almost independent of efficiency.

During this test, both design showed very low noise. The baseline design has a noise rate of 0.1Hz/cm^2, and the new design has a noise rate of 0.2 - 0.3Hz/cm^2.

5. Prototype section and its electronic readout

Our R&D effort on RPC shows that both of our designs meet the requirement of a digital HCal. Our next step is to construct a prototype calorimeter section and test it in particle beams. This will not only validate the RPC approach, concept of electronic readout, but will also measure hadronic showers with unprecedented resolution, and validate Monte Carlo simulation of hadronic showers which is crucial for ILC detector optimization.

The proposed prototype section is 1 m^3 in size. It has 40 layers, with 20 mm steel plates as absorber sandwiched by RPCs. The lateral hit size would be 1 cm^2, and to be readout layer by layer. The whole section would have some 400,000 readout channels, which bring the major challenge for the electronic readout system.

The readout system would be built around a front-end ASIC, which will sit on RPCs, read signals from 64 channels and convert them to digital hit pattern. Data from every 32 ASICs will be feed into a data concentrator, and a VME based data collector will get all data from the data concentrators.

The conceptual design of the front-end ASIC has been specified and the design effort is on-going at Fermilab. First submission is expected by the end of 2004.

6. Summary and outlook

A digital hadron calorimeter with very fine segmentation is a practical way to achieve the goal of jet energy resolution for the ILC detector. RPC would be an excellent choice for the active medium of such a digital HCal. The goal of our group is to construct a 1m^3 prototype test section, and bring it in particle beams by 2006.

We will finish the RPC R&D in 2004, design and prototype the front-end ASIC, specify the entire readout system and prototype subcomponents by early 2005. The construction of the prototype section will hopefully begin by the end of 2005.

References

1. For more information on RPCs, see e.g. http://mars.fis.uc.pt/ rpc2001/talks.html.