Digital Hadron Calorimetry with Glass RPC Active Detectors

A. Ghezzi, T. Tabarelli de Fatis, G. Tinti
Università di Milano Bicocca and INFN, Milano, Italy
M. Piccolo
Laboratori Nazionali di Frascati, INFN, Frascati (Roma), Italy

Glass RPC detectors are an attractive candidate for the active part of a highly granular digital hadron calorimeter (DHCAL) at the ILC. A numerical study, based on the GEANT3 simulation package, of the performance of such a calorimeter is presented in this work. A simplified model for the RPC response, tuned on real data, is implemented in the simulation. The reliability of the simulation is demonstrated by comparison to existing data collected with a large volume calorimeter prototype exposed to a pion beam in an energy range from 2 GeV to 10 GeV. In view of an optimization of the readout pitch, a detailed study of the energy and position resolution at the single hadron level for different read-out pad dimensions is presented. These results are then used in a parametric form to obtain a preliminary estimate of the contribution of DHCAL to the reconstruction of the energy flow at the ILC detector.

1. INTRODUCTION

Common wisdom, based both on experimental results from LEP and from simulation for higher energy e^+e^- interactions, leads to believe that the "energy flow" technique might provide the best possible resolution on jet energy, jet direction and jet invariant mass. This technique requires building very segmented calorimeters both longitudinally and transversely and leads naturally to the use of gas detectors, at least in the hadronic part. Digital (track counting) calorimetry in this framework seems to be the logical choice and is one of the options proposed for the ILC detector. Out of the possible active detectors one could use to implement digital calorimetry are parallel plate detectors, thanks to the easy of construction, the lack of privileged directions (in contrast to wire chambers), the possibility to shape them almost at will and the possibility to cover large surfaces at low cost.

An R&D programme (CaPiRe experiment) was launched in 2003 aimed at the design and characterization of RPC detectors based on glass electrodes for this application. Preliminary results, showing that glass RPCs can stand the flux of particles expected in the hadron calorimeter at the ILC, have been reported elsewhere [2]. This is instead a report of a numerical study of the performance of a Digital Hadron Calorimeter (DHCAL) using glass RPCs as active detectors. After a discussion of the basic features of the calorimeter implemented in our simulation and of a comparison to existing data (Section 2), a detailed study of the energy resolution at the single hadron level for different read-out configuration is addressed (Section 3. Finally (Section 4) an estimate of the contribution of DHCAL to the reconstruction of the energy flow at the ILC detector is performed.

2. DHCAL SIMULATION: MODEL PARAMETERS AND VALIDATION

A standalone simulation of a detector similar in geometry to the hadron calorimeter proposed for the TESLA detector [1] has been implemented with the GEANT3 package [3], which performs particle tracking and interactions in the detector media. The GEISHA model is used for hadron cascades. Our DHCAL model consists of 39 stainless steel layers 2 cm thick, interleaved by 38 planes of sensitive elements. The transverse dimensions of the detector are of little relevance in this study.

Track counting is performed by Resistive Plate Chambers (RPC) with glass electrodes. They are assumed to be housed in a 20 mm gap between the stainless steel planes and are described with coarse detail in the simulation: the active element is a 2 mm gas-filled gap; all the other elements (the 2 mm thick glass electrodes, the readout plane

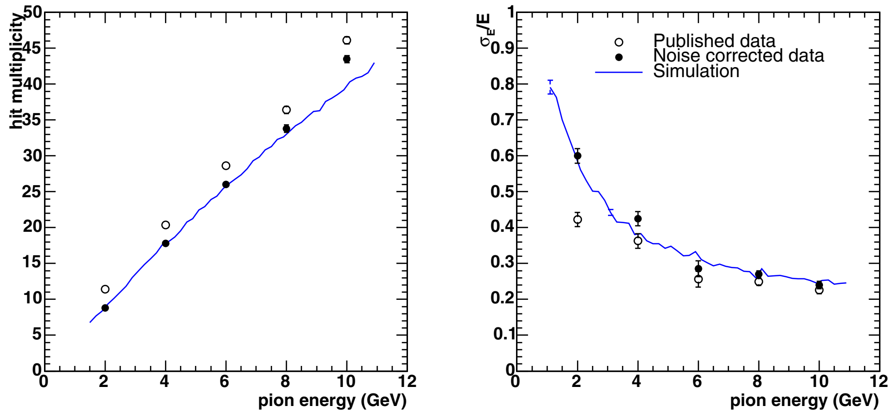

Figure 1: Response (left) and energy resolution (right) of the MONOLITH prototype exposed to a pion beam. Real data (dots) are compared to our simulation (line). A noise subtraction procedure has been applied to published data as explained in the text.

and the empty gaps) are modelled as a continuous medium of 1 g/cm^2 average density. An approximate description of the digitization process has been implemented, based on our present knowledge of the RPC behaviour. The active part of each RPC is segmented in 2 mm $\times$ 2 mm elementary cells, matching the typical transverse dimensions of a spark in streamer mode. Digital signals are induced on readout pads if at least one of the elementary cells subtended by it fires. This is assumed to happen with 95% efficiency when an ionizing particle crosses an elementary cell. No induction from cells farther apart from the pad is included. As discussed hereafter, the transverse pad dimensions have been varied from 1 $\times$ 1 cm^2 to 10 $\times$ 10 cm^2.

The reliability of this simulation of the DHCAL response to hadrons depends on the description of hadron interactions and on the assumption made in the description of the digitization at the readout stage. This has been studied by comparing our simulation to existing data collected with a small prototype of the MONOLITH experiment exposed to a pion beam of energy from 2 GeV to 10 GeV [4]. The prototype consisted in 20 iron planes 5 cm thick, instrumented with glass RPC readout by 1 cm readout strips on one side of the chambers. A part form these differences in the detector layout, accounted for in the simulation, the simulation is run under the same assumptions adopted in the DHCAL description: a digital readout of the fired strips is considered, without induction on adjacent strips. This is a rude approximation, as, for this read-out pitch, an average hit multiplicity of about 1.4 hits/plane has been observed with isolated tracks. To account for this in the comparison to the MONOLITH prototype data a 1.4 scale factor on the hit multiplicity predicted by the simulation is introduced.

As shown in figure 1, a fair agreement between our simulation and real data is observed, once data are corrected for a residual noise of about two strips fired at null pion energy. At variance with real data our simulation seems to show the onset of saturation around 8-10 GeV (figure 1 left). Yet, the description of the data in terms of energy resolution is adequate for the purposes of this study and validates our simulation model in the energy range most relevant for hadron calorimetry at the ILC, where the spectrum of neutral hadrons is expected to peak at low energy with an average energy of around 10 GeV.

3. SINGLE HADRON ENERGY RESOLUTION

A full characterization of the response to single hadrons of DHCAL with glass RPC detectors in terms of linearity and energy resolutions has been performed for several different read-out pitch configurations. Our results for single pions of energy ranging from 2 GeV to 40 GeV and impinging on the calorimeter at normal incidence are summarized in figure 2. The response of the baseline analog calorimeter proposed in the TESLA TDR [1], based on plastic

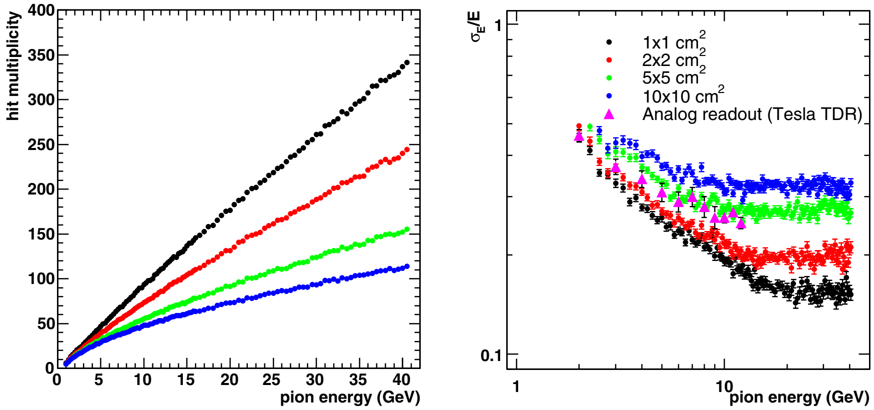

Figure 2: Single hadron response and energy resolution for different pad read-out dimensions.

scintillators as active medium, is also shown for comparison.

As expected deviations from linearity grow more important with increasing pad dimensions. The resolution correspondingly worsens and the onset of saturation appears at lower energies for larger pad sizes. Yet, the behaviour is satisfactory in the most relevant energy region for neutral hadrons at the ILC, at least up to 2 cm *times* 2 cm pad sizes. In this region, DHCAL also presents an energy resolution better than the expected performance of the baseline analog calorimeter proposed the TESLA detector [1] (see figure 2-right). For 1×1 cm^2 pads, the resolution can be parameterized with a stochastic term of $55\%/\sqrt{E(\mathrm{GeV})}$ and a constant term of about 10%. For the option with 2×2 cm^2 pads, the constant term is about 16%. These results agree with the one presented in an earlier study [5].

4. ENERGY FLOW

A complete understanding of the performance of a RPC based DHCAL calorimeter and of its contribution to the energy flow reconstructions requires the development of a full simulation and event reconstruction in a complex detector, including the tracking device and the electromagnetic calorimeter. This is beyond the aim of this preliminary work. Some indications of the DHCAL contribution to the resolution of the energy flow algorithm can however be deduced already with a parametric approach. To this end, the energy flow resolution is parameterized as:

$$\sigma^2_{E.F} = \sigma^2_{c.p.} + \sigma^2_{e.m.} + \sigma^2_{n.h.} + \sigma^2_{confusion}, \tag{1}$$

where the first three terms describe the energy resolution of the detector to charged particles, photons and neutral hadrons respectively and the last term accounts for the finite capability of a real detector to fully disentangle the energy deposition in the calorimeters due to charged tracks, because of shower overlaps. WW and ZZ are generated with the PYTHIA 6.205 code [6] and the energy and momenta of the individual particles have been smeared according to the expected resolution on their measurement:

- The energy of the photons has been smeared according to the expected resolution of the ECAL calorimeter ($\sigma_{e.m.}/E_{e.m.} = 15\%/\sqrt{E(\mathrm{GeV})}$),
- The energy of neutral hadrons has been smeared according to the results of the DHCAL simulation for single hadrons discussed above, including the angular dependence,
- The energy of charged particles has been assumed to be perfectly reconstructed by the magnetic spectrometer.

Events are then clustered in jets and the energy of the jets compared to the one of the original parton. This "perfect energy flow" algorithm, unrealistic indeed, shows a resolution of about $16\%/\sqrt{E(\mathrm{GeV})}$. A more realistic energy flow

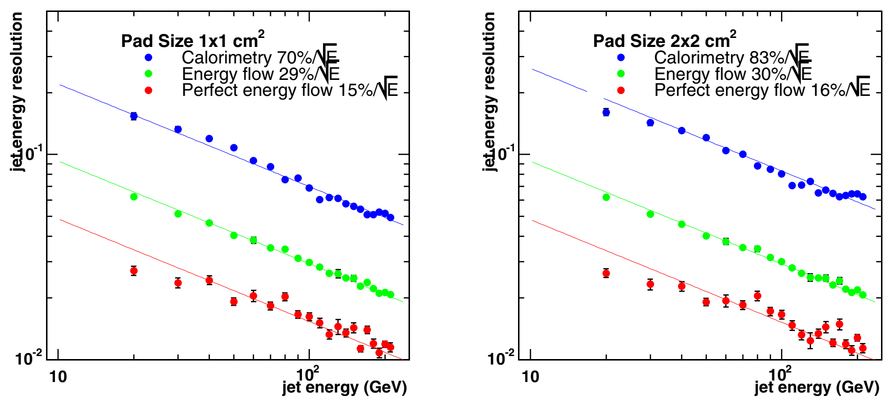

Figure 3: Jet energy resolution as a function of the jet energy for 1×1 cm^2 (left) and 2×2 cm^2 (right) DHCAL granularities. The three set of points have been computed assuming an energy measurement based solely on the calorimeter information, to the energy flow approach and to the "perfect energy flow" case (no confusion).

measurement has been simulated by adding an additional smearing to the jet energy resolution of $25\%/\sqrt{E(\text{GeV})}$ as expected for particle confusion in a real detector. This last term was estimated in [7] for a detector configuration with a granularity of 5 cm $\times$ 5 cm in the hadron calorimeter and may be somewhat overestimated in our case.

Our results are shown in figure 3: a resolution of about $30\%/\sqrt{E(\text{GeV})}$ is observed, dominated by the contribution of $\sigma_{confusion}$. Within the approximations discussed, little difference is observed between 1×1 cm^2 and 2×2 cm^2 granularities. indicating that the latter granularity already matches the desired performance to accomplish the ILC physics programme.

5. CONCLUSIONS AND OUTLOOK

Glass RPC detectors are attractive candidates as active detectors of the Digital Hadron Calorimeter at the ILC. A standalone simulation of the DHCAL response with RPC response has been developed and validated on existing data. A fast (parametric) simulation shows that the DHCAL with RPC detectors with read-out granularities of about 2×2 cm^2 matches the target performance for the ILC physics. Further studies aimed at the optimization of the detector geometry should address the full simulation within the ILC detector and the contribution of the highly granular DHCAL to the muon identification.

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