Novel Resistive-Plate WELL sampling element for (S)DHCAL

S. Bressler, P. Bhattacharya, A. Breskin, A.E.C. Coimbra, D. Shaked-Renous, A. Tesi
Weizmann Institute of Science, Rehovot, Israel

L. Moleri
Technion - Israel Institute of Technology, Haifa, Israel

M. Chefdeville, G. Vouters, J. Karyotakis, C. Drancourt
Univ. Grenoble Alpes, Univ. Savoie Mont Blanc, CNRS, IN2P3-LAPP, Annecy, France

M. Titov
CEA Saclay / Irfu, France

T. Geralis
NCSR Demokritos/INPP, Greece

Abstract

Digital and Semi-Digital Hadronic Calorimeters (S)DHCAL were suggested for future Colliders as part of the particle-flow concept. Though studied mostly with RPC-based techniques, investigations have shown that Micro Pattern Gaseous Detector (MPGD)-based sampling elements could outperform in terms of average pad multiplicity or at higher rates. An attractive, industry-produced, robust, particle-tracking detector for large-area coverage, e.g. in (S)DHCAL, could be the novel single-stage Resistive Plate WELL (RPWELL). It is a single-sided THick Gaseous Electron Multiplier (THGEM) coupled to the segmented readout electrode through a sheet of large bulk resistivity. We summarize here the preliminary test-beam results obtained with 6.5 mm thick (incl. electronics) 48 × 48 cm² RPWELL detectors. Two configurations are considered: a standalone RPWELL detector studied with 150 GeV muons and high-rate pions beams and a RPWELL sampling element investigated within a small-(S)DHCAL prototype consisting of 7 resistive Micro-MEsh Gaseous Structure (MICROMEGAS) sampling elements followed by 5 RPWELL ones. The sampling elements were equipped with a Semi-Digital readout electronics based on the MICROROC chip.

Keywords: Micropattern gaseous detectors (MPGD), THick Gaseous Electron Multiplier (THGEM), Resistive Plate WELL (RPWELL), Digital hadron calorimetry (DHCAL), Semi DHCAL (SDHCAL), Resistive electrodes, MICROROC, ILC, CLIC, CEPC

1. Introduction

The particle-flow [1] is the leading concept towards reaching the challenging targeted jet energy resolution in future collider experiments (\(\frac{\sigma_E}{E} = 0.05\%\) corresponding to \(\frac{\sigma_E}{E} = 3\%\) for 100 GeV jets). Particle-flow calorimeters [2, 3] are key ingredients in the design of experiments optimized for this concept. Having very high granularity, they allow separating the energy deposited by the individual constituents of the jets and measure the energy of each of them in the most adequate subsystem. Digital and Semi-Digital Hadronic Calorimeters (S)DHCAL) are attractive tools to achieve very high granularity while using cost-effective readout solutions. A typical (S)DHCAL consists of alternating layers of absorbers and sampling elements. Hadronic showers are mostly formed in the absorber, of which the material defines the total calorimeter’s depth. The resulting signals are measured by sampling pad-readout elements (typically of 1 cm²), defining the granularity. In (S)DHCAL, the measurement of the energy of individual particles relies on the approximate linear relation between the particle energy and the number of fired pads. Thus, the targeted jet-energy resolution calls for high detection efficiency at low average pad multiplicity. Detection elements based on the glass-RPC technology have been so far the most studied ones [4, 5, 6]. Depending on the operation voltage, they can yield an average pad multiplicity of 1.5 - 2 at 90 - 95% efficiency, in 1 m² detectors [5, 6]. Detection elements based on the MICROMEGAS have demonstrated superior properties: 98% efficiency (at optimal operation voltage) with average pad multiplicity close to unity, in 1 m² detectors [7, 8] demonstrating also uniform response over the entire sensitive area. A detection efficiency of 95% at similar average pad multiplicity was demonstrated with 16 × 16 cm² resistive-MICROMEGAS prototypes, introduced to reduce the probability of discharges induced by highly ionizing particles [9]. Elements based on
2. The Resistive Plate WELL

The Resistive Plate WELL (RPWELL) \[11\] has followed a series of other Resistive THick Gaseous Electron Multiplier (THGEM)-based sampling elements developed over the past years at Weizmann Institute \[12, 13\]. It is a robust, industrially mass-produced, single-stage particle-tracking gas-avalanche detector. With its discharge-free operation also in harsh radiation fields, large dynamic range, close-to-unity MIP detection efficiency and \(\sim 200 \mu m\) RMS resolution \[14\] it becomes an attractive new candidate for particle tracking over large-area coverage. As a few-millimeter thin detector, it could become a candidate of choice as sampling element for (S)DHCAL. The RPWELL (Fig. 1) is a single-sided THGEM electrode coupled to a segmented readout electrode through a thin sheet of large bulk resistivity \((10^9 - 10^{10} \Omega cm)\) material. The latter has the role of quenching large-size avalanches and preventing discharge development. Past laboratory and accelerator studies have been performed with moderate-size prototypes, with \(1 \text{ cm}^2\) square pads and SRS/APV25 readout electronics. They operated equally well in Ne- and Ar-based gas mixtures \[15\] and in intense hadronic beams. The figure of merit is MIP detection efficiency \(\geq 98\%\) at \(\leq 1.2\) pad multiplicity (Fig. 2) \[15\].

Having in mind their application to (S)DHCAL, techniques were developed for producing large-area \((48 \times 48 \text{ cm}^2)\) 4.5 mm thick (excluding electronics) detectors, incorporating \(10^{10} \Omega cm\) silicate glass resistive plates (Fig. 3). Five such detectors were built and equipped with a pad-anode (defining a circular-shaped active area) embedding ILC-(S)DHCAL MICROROC chips \[16\] resulting in a total thickness of 6.5 mm. The RPWELL differed by their electrode quality, of which the thickness variation ranged from 5\% (best) to 25\% (worst), affecting significantly their stability and hence performance.
3. Performance in a standalone mode

During August 2018, the first (S)DHCAL sampling element prototype built (with 25% electrode thickness variation) has been investigated at CERN/SPS, in Ar(7%)CO₂, with muons and high-rate pions. Preliminary analysis results confirm that the performance of this prototype would be suitable for (S)DHCAL since a ≥ 95% detection efficiency across most of the surface was achieved with a pad multiplicity of ~1 in most events. The average pad multiplicity value was 1.7 due to a small number of events with tens of pads firing - probably indicating a discharge. Some efficiency variations as well as the small number of discharges are attributed to the large electrode-thickness variations (thus gain).

4. Performance within a small-(S)DHCAL prototype

During November 2018, a small-(S)DHCAL prototype (Fig. 4) consisting of four 16×16 cm² bulk MICROMEGAs and three 48×48 cm² resistive MICROMEGAS sampling elements followed by five 48×48 cm² RPWELL ones has been investigated at CERN/PS using a low energy (2-6 GeV) pion beam. The 12 sampling elements were equipped with a semi digital readout electronics based on the MICROROC chip and read out with a single DAQ system. The RPWELLs with large thickness variations were excluded in some of the measurements. These were carried out with 8-layer (S)DHCAL consisting of 3 16 × 16 cm² and 3 48 × 48 cm² resistive MICROMEGAS sampling elements followed by 2 48 × 48 cm² RPWELL ones.

The hits associated with a single shower are grouped based on time selection. A pion shower profile recorded in all the sampling elements of the 8-layer prototype and a beam profile in the 5 RPWELL detectors are shown in Fig. 5 and 6 respectively.

For each recorded shower, the shower origin was defined as the layer in which at least three pads fired. This layer was denoted by Layer 0 and it served as a reference to define the
5. Summary and discussion

First studies of RPWELL-based sampling elements for (S)DHCAL have been carried out in a standalone mode and within a small-(S)DHCAL prototype (incorporating also MICROMEGAS-based sampling elements). More stringent QA/QC tests will have to be applied in the future to ensure good control of the thickness of the WELL electrode to a level better than 5%. The $48 \times 48$ cm$^2$ RPWELL was operated under 150 GeV muon and high rate pion beams. Up to some instabilities attributed to the thickness variations, detection efficiency greater than 95% and an average pad multiplicity close to ”1” were recorded. In the small-(S)DHCAL prototype, low energy pion showers were recorded, and the response of the RPWELL is consistent with the shower depth. Based on the data collected, the estimation of the expected pion energy resolution in a full RPWELL-based (S)DHCAL is ongoing.

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