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Particle identification with the cluster counting technique for the IDEA drift chamber

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IDEA (Innovative Detector for an Electron-positron Accelerator) is a general-purpose detector concept, designed to study electron-positron collisions in a wide energy range from a very large circular leptonic collider.Its drift chamber is designed to provide an efficient tracking, a high precision momentum measurement, and an excellent particle identification by exploiting the cluster counting technique. The ionization process by charged particles is the primary mechanism used for particle identification (dE/dx). However, the significant uncertainties in the total energy deposition represent a limit to the particle separation capabilities. The cluster counting technique (dN/dx) takes advantage of the Poisson nature of the primary ionization process and offers a more statistically robust method to infer mass information. This paper will describe the simulation campaign and the two beam tests performed at CERN to investigate and prove the potentials of the cluster counting technique.

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1. Introduction

The ionization of matter by charged particles is the primary mechanism used for particle identification (dE/dx). Anyway, the large uncertainties in the total energy deposition represent a limit to the particle separation capabilities: even in the most favorable momentum region (*relativistic rise*), the typical separation between the energy loss curves related to different particles is smaller than the spread around the relative mean values [1]. The cluster counting technique (dN/dx) takes advantage from the primary ionization *Poissonian* nature and offers a more statistically significant way to infer the mass information [1]. The efficacy of this method relies on the number of primary ionization being independent from cluster size and gas gain fluctuations and being insensitive to highly ionizing δ-rays. This technique will be widely explored with the **IDEA** drift chamber [2, 3]

2. The cluster counting technique: dN/dx

The process of energy loss of a charged particle crossing a medium is a discrete process: a particle traversing a gas leaves a track of ionization consisting of a sequence of clusters with one or more electrons which are all released in a single act of **primary ionization**. This is a typical *Poissonian* process: the generation of clusters in a medium is the result of a number of the order of the Avogadro number of independent random events, whose sum gives the mean specific ionization [1]. The main advantage of the *Poissonian* distribution is that its *Gaussian* limit is achieved when the mean value reaches 20, that is of the order of 1 cm track length for the most commonly used gas mixtures. Instead, the energy distribution follows a *Gaussian* shape just in thick and dense material (because of *central limit theorem*), but this situation is not helpful for the drift chambers [1]. Analytical evaluations, reported in Figure 1 shows that the cluster counting technique improves the particle separation capabilities by a factor of 2 with respect to the dE/dx technique. The plot

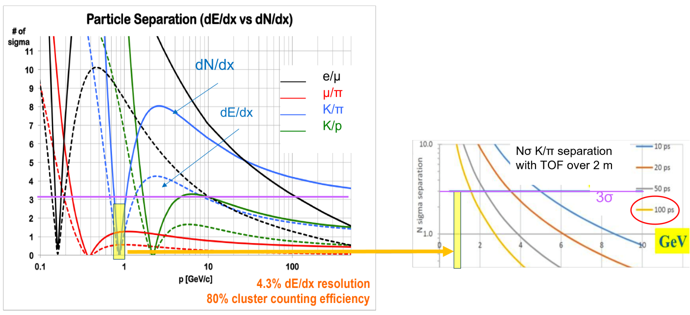

Figure 1: Left: Analytic evaluation of particle separation capabilities achievable with dE/dx (solid curves) and dN/dx (dashed curves). The region between 0.85 GeV/c and 1.05 GeV/c where a different technique is needed is highlighted in yellow. Right: PID performance as a function of the time resolution by using a time of flight technique over 2 m to recover the particle identification around 1 GeV.

shows the particle separation power in terms of the numbers of standard deviation (sigma) as a function of momentum in a mixture of 90% He and 10% iC_4H_{10}. Solid curves refer to separation with the cluster counting technique and dashed curves refer to the optimal energy loss truncated mean technique. A cluster counting efficiency of 80% is assumed in the calculations. The technique gives excellent performances over the whole momenta range, it fails just in small gaps along the

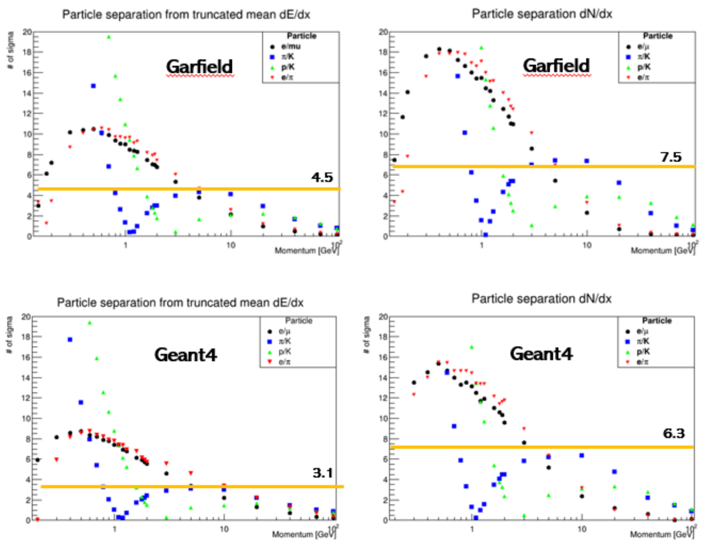

Figure 2: Particle separation capabilities results from a simulation of the ionization process in 200 drift cells, 1 cm wide, in He/iC_4H_{10} = 90/10 gas mixture that has then been performed both in Garfield++ (top) and in Garfield-modelled Geant4 (bottom) by using the ionization energy loss method (left) and cluster counting technique (right).

momentum range analyzed. This promising results require more detailed investigations, so that a custom campaign of simulations to confirm the potentials of this technique, followed by two beam tests at CERN/H8 has been performed.

3. The simulations results

A dedicated simulation analysis has been developed to study the potentials of the cluster counting technique and the ionization process in the helium based drift chamber, by using *Garfield++*[1] and *Geant4*[2] [4]. In particular, to simulate the clusters generation in the IDEA drift chamber, an algorithm has been developed which can reproduce the cluster distribution and the cluster size distribution in Geant4, by using only the energy loss by charged particles simulated by Geant4. The particle separation power obtained with the two software is reported in Figure 2. The simulations results confirm that cluster counting technique improves the particle separation capabilities with respect to the traditional method of the dE/dx. However, the power separation capabilities in Geant4 are slightly different with respect to Garfield++. Moreover, a substantial lack of experimental data on cluster density and cluster population for He based gas has been encountered. The only possible way to prove the cluster counting technique potentials and to validate the simulations results is an experimental measurement.

[1]https://garfieldpp.web.cern.ch/garfieldpp/
[2]Geant4, a simulation toolkit, https://geant4.web.cern.ch/node/1

4. The first beam test

To validate the simulations results two beam tests have been performed. The first one has been conducted at CERN/H8 in parasitic mode, by using a muon beam at 165 GeV/c. TThe experimental setup consisted of: a pack of drift tubes with different cell size, wire materials and wire diameters (Figure 3), two trigger scintillator tiles, a portable gas system, a Wave Dream Board, WDB, [5]. On

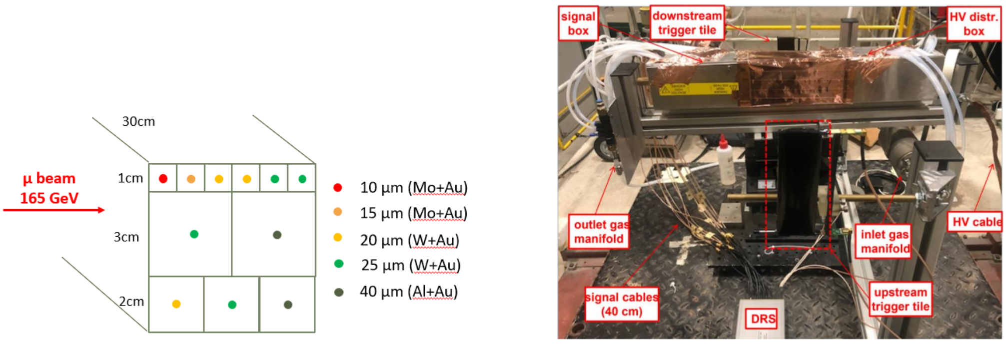

Figure 3: Left: Pictorial representation of the drift tube pack. Right: a picture of the beam test setup at CERN.

the right of Figure 3 the beam test setup is shown.

4.0.1 The Wave Dream Board

The flagship of the acquisition system is the Wave Dream Board (WDB), developed at PSI [5]. The most interesting feature of the WDB is its interface which is completely similar to the one of an oscilloscope with 16 channel, as shown in Figure 4, where a typical event of a track passing through the 6 drift tubes with 1 cm cell size is visible. The WDB provides HV to the two scintillator tiles

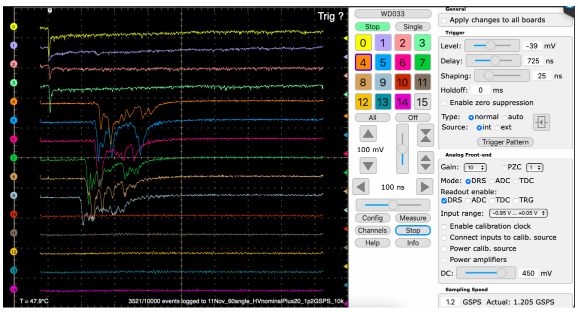

Figure 4: WDB interface. The channels from 0 to 3 correspond to the 4 signals from the two scintillator tiles, the ones from 4 to 10 correspond to the 6 tubes with 1 cm cell size, the ones from 11 to 12 correspond to the tubes with 3 cm cell size, the ones from 13 to 15 correspond to the tubes with 3 cm cell size.

and sets up the trigger pattern logic.

4.1 The data collected during the first test beam

During the first test beam, a 165 GeV/c muon beam has been used to collect data with two different gas mixtures, at different angles between the wire direction and the beam line and by performing an HV scan. Table 1 summarizes the data collected at the different configurations. The nominal HV corresponds to a gas gain of 2×10^5.

Table 1: Data collected during the first test beam

Gas mixture	HV scan	angle (deg)
90%He-10% iC4H10	nominal HV, ±10,±20,+30	0,15,30,45,60
80%He-20% iC4H10	nominal HV, 10,±20	0,15,30,45,60

4.2 The analysis results

An algorithm has been developed to count electron peaks in each collected waveform: the "*derivative algorithm*" (DERIV), based on the imposition of cuts on the maximum waveform amplitude.
In details, the algorithm searches for a peak in a waveform by comparing the amplitude, the first and the second derivative with a proper threshold, chosen by studying rms values.
The distributions of the number of peaks found by the derivative algorithm have been studied. An example is reported in Figure 5, where the number of electrons found by the algorithm is compatible with the one expected according to the physics of the process The electron peaks found have to

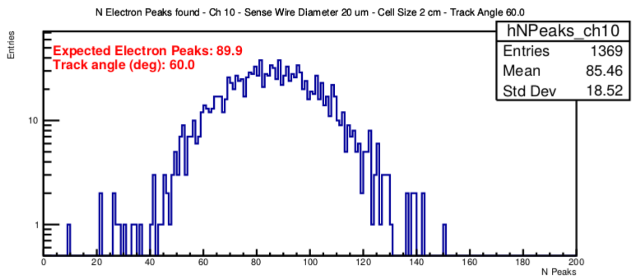

Figure 5: Distribution of the number of peaks for 2 cm drift cell by applying the derivative algorithm.

be associated in clusters by means of another custom algorithm, named "clusterization algorithm". The procedure of the algorithm consists of:

- association of electron peaks consisting in consecutive bins (difference in time == 1 bin) electrons to a single electron in order to eliminate fake electrons.
- considering the contiguous electrons peaks which are compatible with the electrons diffusion time (2.5 ns or 3 bins) as belonging to the same ionization cluster.

An example of the result obtained with the clusterization algorithm is illustrated in Figure 6, where the red triangles mark the peaks found by the derivative algorithm and the blue triangles mark the number of clusters found by the clusterization algorithm[3]. An example of the distribution of the clusters found by the clusterization algorithm is shown in Figure 7. The red line depicted on the plots of Figure 7 is the result of a Gaussian fit. The mean is compatible with the expected one and the sigma correspond to the root square of the mean proving the expected Poisson nature of the

[3]The position of the clusters is taken as the position of the last electron in the cluster.

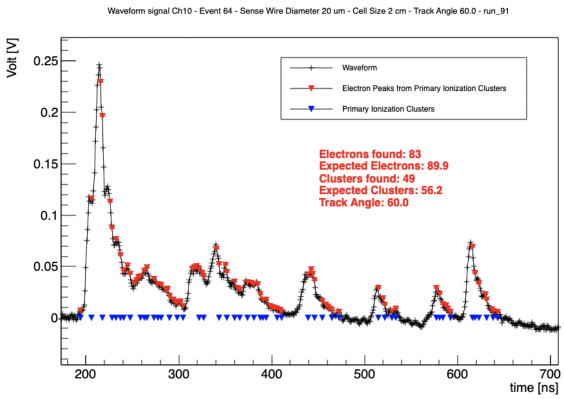

Figure 6: A typical event acquired with a 2 cm cell size drift tube. The red triangles mark the peaks found by the derivative algorithm. The blue triangles mark the number of clusters found by the clusterization algorithm.

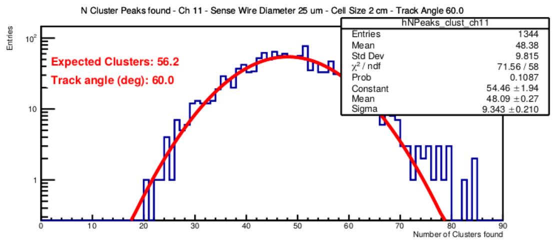

Figure 7: Distribution of the number of clusters as obtained with the clusterization algorithm for the 2 cm cell size drift tube at 60°.

clusters distribution. The first beam test gives promising results: a reasonable number of data have been collected and analyzed, two promising algorithm have been implemented and the distributions obtained are compatible with the ones expected from the physics of the ionization process. Anyway, a single beam energy was exploited and the parasitic mode prevented different tests, with different gas mixture percentages. The second beam test aimed to collect data at different beam energies, even if the relativistic rise could not be exploited. The setup for the second beam test was similar to the one used for the first test. During the beam test, a large data set (2 million waveforms) at different configurations was collected by varying not only the high voltage, the angle between the beam and the setup and the gas mixture, but also the sampling rate. The analysis of the data collected during this test is ongoing.

5. Conclusion

Using unoptimezed cluster counting algorithms gave promising results in reproducing expected physical distributions. The data analysis of the second beam test will give us a broad view on the ionization phenomenon and on the cluster counting performances for the helium based drift chamber.

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