dE/dx measurement in a He-based gas mixture

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Abstract **PACS**: 29.40.Cs

The performance of a prototype drift chamber operating in a He-based gas mixture as a specific ionisation detector is presented. In spite of the small number of primary ions, Helium performs quite satifactorily in measuring energy losses for charged particles: with $50\,\mathrm{GeV}/c$ pions, we have measured in a $90\%\mathrm{He}-10\%i\mathrm{C_4H_{10}}$ mixture a relative energy loss resolution of 3.1% with 75 samples $3\,\mathrm{cm}$ long, using a modified Truncated Mean technique with 80% accepted fraction.

The dependence of the resolution on several parameters such as the operating voltage, the truncation fraction, the number and length of the samples is discussed.

1 Introduction

As a result of the R&D programme for its big drift chamber [1], the KLOE collaboration choosed $90\%\mathrm{H}e-10\%i\mathrm{C_4H_{10}}$ as the optimal gas mixture for its long X_0 ($\simeq 1300$m), excellent operational stability, high efficiency, good spatial resolution and, last but not least, non flammability and simplicity (it is a binary mixture). In this paper we present results demonstrating that its performances are extremely good also from the point of view of the $\mathrm{d}E/\mathrm{d}x$ measurement.

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2 Experimental setup

The analysis described in this paper is relative to data collected on a $50\mathrm{GeV}/c$ pion beam at the CERN SPS in september '94 with a small size prototype of the KLOE drift chamber (prototype 0.3). A detailed description of the prototype and of the data taking conditions can be found in [2]; only the points relevant to the $\mathrm{d}E/\mathrm{d}x$ measurement are mentioned in the following. The prototype consists of an array of 7×7 approximately square cells of $(3\times\pi)\mathrm{cm}^2$ area each, with a field to sense wire ratio of 3:1. We consider in the present analysis only the 25 innermost cells, whose gain is made homogeneous by the external ones, which act as guard wires. After preamplifiers with a gain of 1 mV/fC on a $50\,\Omega$ load [3] and post-amplifiers with gain $\simeq 3$, the analog outputs from the sense wires were fed to LRS2249W ADC's with a $3.9\,\mu\mathrm{s}$ wide gate.

2.1 Data sample and quality cuts

We collected data at five HV settings, every 50V between 1750 and 1950V, both with and without a magnetic field of 0.6T parallel to the wires. At the two highest operating voltages there was a non negligible saturation of the ADC, hence the corresponding data have been used in the gas gain saturation studies, see next section, but not in the $\mathrm{d}E/\mathrm{d}x$ anlaysis.

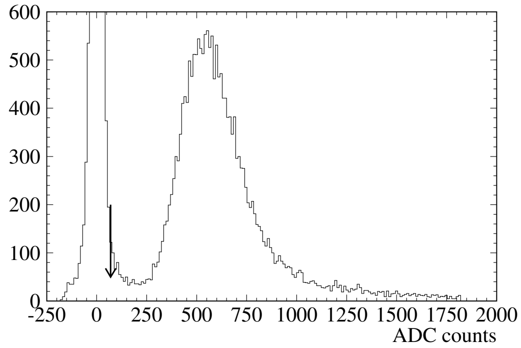

Fig. 1: *Typical ADC spectrum. The arrow shows the three sigma cut.*

The ADC spectrum in one of our 3 cm cells is shown in fig.1. A cell is defined as 'hit' if its ADC reading, pedestal subtracted, exceeeds three times the pedestal width. The relative width σ_{REL} of the peak is typically $\simeq 25\%$. On average about 5 cells are hit [4]. We select a clean sample of events by further requiring to have at least 4 hit cells, a drift time of the first electron less than $2.5\,\mu\mathrm{s}$ and impact parameter less than 1.5 cm. The combined efficiency of these cuts is about 80%.

3 Results

After equalisation of the response of the cells,[1] we calculate the Truncated Mean (TM) to estimate the most probable value of the energy loss distribution ($\mathcal{E}_{\mathrm{MP}}$). Truncated Means are plotted in fig.2 for different fractions of accepted events. We observe that in our $90\%\mathrm{He}-10\%i\mathrm{C}_4\mathrm{H}_{10}$ gas mixture the most probable energy loss ($\simeq 136$ pC at 1850V) is correctly reproduced accepting 80% of the hits. Since for a $50\mathrm{GeV}/c$ beam the energy loss, regardless of the particle species and the momentum bite of the beam itself, lays on the relativistic plateau, we can combine several 5-hits events to simulate arbitrarily long tracks. The effect of the truncation

[1] We scale each ADC reading by the factor $\mathrm{MP}_i/\langle\mathrm{MP}\rangle$, MP_i being the Most Probable energy loss in the i-th cell, and $\langle\mathrm{MP}\rangle$ the same quantity averaged over all the cells.

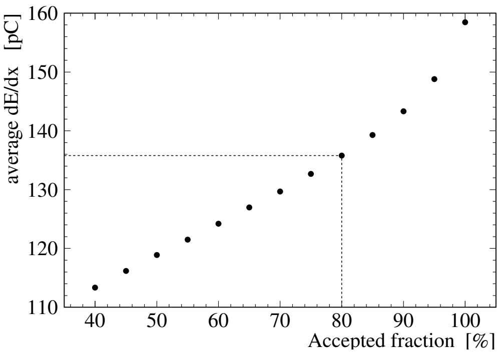

Fig. 2: *Truncated Means vs. accepted fraction.*

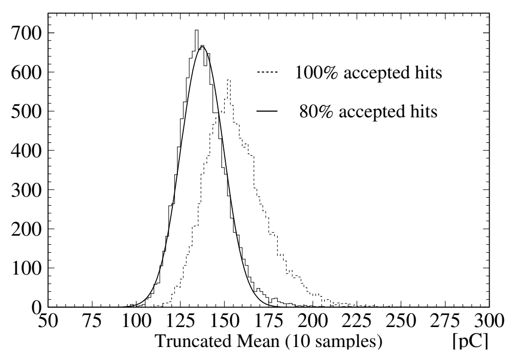

Fig. 3: *Effect of the Truncation in samples of 10 hits.*

is pictorially shown in fig.3: even with samples of only 10 hits, the distribution of the average shifts towards the correct $\mathcal{E}_{\mathrm{MP}}$, shrinks considerably and becomes fairly gaussian at 80% truncation. Completely gaussian distributions are obtained for $\mathcal{N}$ (total number of hit cells) $\geqslant$20.

3.1 $\mathrm{d}E/\mathrm{d}x$ *resolution*

In fig.4 the $\mathrm{d}E/\mathrm{d}x$ resolution $\sigma_{\mathrm{d}E/\mathrm{d}x} \equiv \sigma(\mathrm{TM})/\langle\mathrm{TM}\rangle$ is plotted vs. the number of used hits (80% accepted fraction). A fit with a power function is superimposed to the points, showing that the scaling law is very close to the Poisson limit of -0.5. The resolution exhibits a mild dependence on the accepted fraction (fig.5):

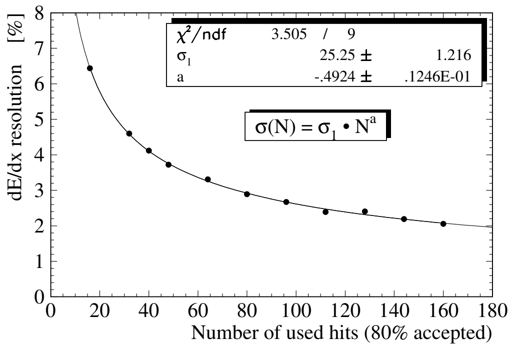

Fig. 4: $\mathrm{d}E/\mathrm{d}x$ *resolution vs. number of used hits.*

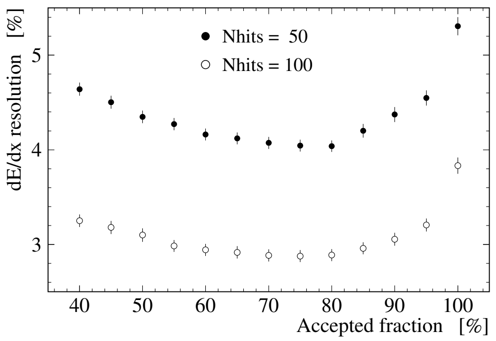

Fig. 5: $\mathrm{d}E/\mathrm{d}x$ *resolution vs. TM accepted fraction.*

a broad minimum is observed between $\sim$60% and 90%, while both for bigger (inclusion of the Landau tail) and smaller accepted fractions (loss in statistics) $\sigma_{\mathrm{d}E/\mathrm{d}x}$ deteriorates.

3.2 Linearity of the measurement

Apart from trivial saturation of the ADC, pulse height saturation may originate from non linearity of the gas amplification. The latter may also result in an artificial reduction of the Landau tails, since at very big gains space charge at the anode could decrease the effective amplification.

Fig.6 shows the MP pulse height as a function of the operating voltage. Since we find the same slopes within the errors in the 'low' and the 'high' HV regimes, we conclude that there is no gas gain saturation. Saturation could also show up by a

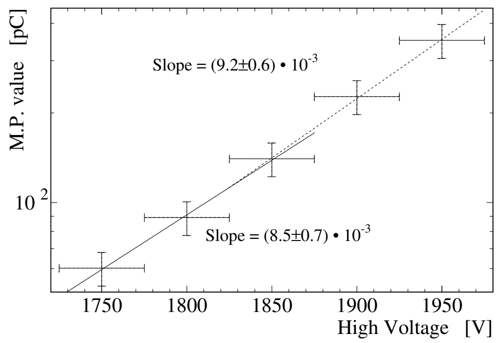

Fig. 6: *Most probable energy loss vs. operating voltage.*

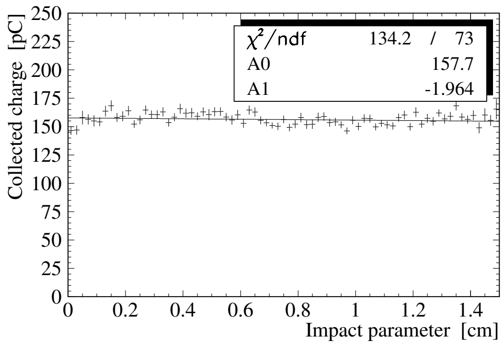

Fig. 7: *Collected charge as a function of the track's impact parameter.*

decrease of the collected charge with the drift distance: the ionisation clusters arrive more grouped in time to the anode if they originate from distant tracks, therefore saturation phenomena would be more likely. Fig.7 depicts the average collected charge vs. drift distance: we observe a 2% decrease of the collected charge over the entire cell width. This modest effect is however an upper limit to space charge effects, since the same trend could also be caused by the presence of electronegative agents in the gas mixture or by the finite integration gate.[2]

We measure essentially the same resolution at 1800 and 1850V, while at 1750V $\sigma_{\mathrm{d}E/\mathrm{d}x}$ is $\sim 13\%$ worse. Using 75 hits, which is an expected average over several reactions in KLOE, we measure therefore, with $50\mathrm{GeV}/c$ pions and 80% accepted fraction, a $\mathrm{d}E/\mathrm{d}x$ resolution of $(3.3\pm0.1)\%$. The error is not only statistical, but includes variations of the cuts and run-to-run differences.

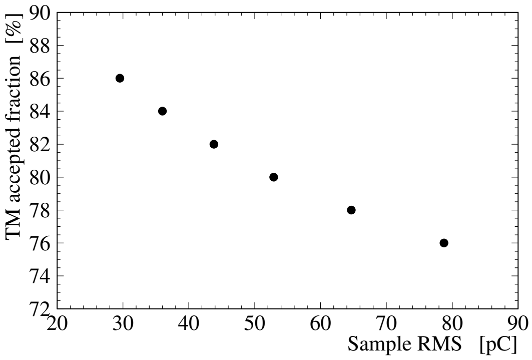

Fig. 8: *TM accepted fraction vs. RMS of the samples.*

A magnetic field of 0.6T does not significantly affect this result, both because of the wide integration gate and of the small Lorentz angle in the mixture [2].

3.3 Optimisation of the truncation fraction

To improve the analysing power of the $\mathrm{d}E/\mathrm{d}x$ measurement, we tune the accepted fraction of the TM on the shape of the particular sample under consideration. Using the correlation between accepted fraction a sample RMS shown in fig. 8, we obtain a $\mathrm{d}E/\mathrm{d}x$ resolution of $(3.1\pm0.1)\%$.

3.4 Resolution vs. sample thickness

The dependence of the $\mathrm{d}E/\mathrm{d}x$ resolution on the number $\mathcal{N}$ and the length x of the samples has been parametrised [5] as $\sigma_{\mathrm{d}E/\mathrm{d}x} \propto \mathcal{N}^a \cdot x^b$; in the same reference the authors find for Argon $a = -0.46$, $b = -0.32$. In our mixture (fig.4), $a = -0.49 \pm 0.01$. To measure b, we have simulated 'supercells' of increasing length. From a fit to the ratio $\sigma_{\mathrm{REL}} \equiv \sigma_{\mathrm{peak}}/\langle\mathrm{peak}\rangle \propto x^b$ as a function of the size of

[2] The wide gate of 3.9μs guarantees in our case that practically all the charge is collected by the anode.

the supercell, we obtain the value $b = -0.40 \pm 0.01$. Finally, we determine the difference $a - b$ by sampling a track with a given total length with supercells of different length; fitting the TM resolution of the supercells again with a power law, we find $a-b = 0.07 \pm 0.01$, consistent with the separate determinations of a and b.

We want to stress that this result stems from the small value of the cluster multiplicity and of the limited Landau tails in Helium: the difference between the a and b exponents is to some extent a measurement of skewness of the energy loss distribution: in a completely symmetric distribution the two effects of decreasing the number of samples and increasing the sample thickness would balance out.

4 Conclusions

The $\mathrm{d}E/\mathrm{d}x$ resolution in the gas mixture $90\%\mathrm{He}-10\%i\mathrm{C_4H_{10}}$ has been measured. Up to operating voltages of $1900\mathrm{V}$ (gain of few 10^5 [2]) we have found negligible saturation. The dependence of the resolution on the number and the length of the samples has been extracted. We expect, from these measurements, a specific ionisation resolution in the KLOE detector of about 3.5%.

References

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[4] For a detailed discussion of these and other points in this paper see G. Finocchiaro, M. Piccolo and P. Valente: $\mathrm{d}E/\mathrm{d}x$ resolution in a $90\%\mathrm{He}-10\%i\mathrm{C_4H_{10}}$ gas mixture with $50\mathrm{GeV}/c$ pions, KLOE internal memo # 33, Oct. 1995, unpublished.

[5] W.W.M. Allison and J.H. Cobb, *Ann. Rev. Nucl. Part. Sci.* ***30**, 323, (1980).*