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First measurement of dE/dx with a GEM-based TPC☆

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ABSTRACT

In this work we present the first measurement of the specific energy loss (dE/dx) and an analysis of the resulting charged-particle identification (PID) capabilities of a large-scale TPC with GEM-based gas amplification. The data has been recorded inside the FOPI spectrometer at GSI, Germany, using reactions of 1.7 GeV/c pions impinging on a carbon target.

In the specific energy loss spectrum clear bands for pions, kaons, protons and deuterons are observed. The specific energy loss resolution is studied as a function of the total particle momentum and as a function of the track length. It is found to be $\sim 15\%$, consistent with expectations.

1. Introduction

Time Projection Chambers (TPCs) are widely used as central tracking detectors. Their low material budget and large solid angle coverage combined with particle identification (PID) capabilities through the measurement of the specific energy loss make them an ideal choice for many experiments.

On the downside, an important limitation of TPCs so far has been the necessity of gating structures. Their purpose is to prevent ions produced in the gas amplification stage – traditionally realized with Multi Wire Proportional Chambers (MWPCs) – from drifting back into the active volume, where they would lead to distortions of the drift field. As a consequence, trigger rates of experiments employing TPCs have been limited to the low kHz regime.

The application of Gas Electron Multipliers (GEMs) [1] as amplification stage promises to lift this limitation: the intrinsic ion-backflow suppression of GEM foils [2] will allow the operation of TPCs without gating techniques and the inevitable dead times they entail, thus opening the possibility of using TPCs as continuously running tracking devices even in high rate experiments.

Obviously, the traditional traits of MWPC-driven TPCs should not be compromised by the introduction of GEMs – most importantly the energy resolution, where gain fluctuations in (multi-) GEM systems will play a role. In this work, we present the first measurement of specific energy loss "dE/dx" for the purpose of PID with a triple-GEM-TPC for different particles, using reactions of 1.7 GeV/c pions impinging on a carbon target.

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2. Experimental setup in FOPI

In 2011 a GEM-based TPC (called the "FOPI GEM-TPC" from here on) was installed in the FOPI spectrometer for a dedicated 3-week physics campaign. FOPI is located at the GSI Helmholtz-zentrum für Schwerionenforschung in Darmstadt, Germany and was originally constructed in 1990. A recent description of the entire spectrometer can be found in Ref. [3].

2.1. The GEM-TPC for FOPI

The FOPI GEM-TPC [4,5] was completed in the end of 2010. To date, it is the detector with the largest active volume of this kind. It features a stack of three GEMs as gas amplification stage with a gap of 2 mm in between the foils (cf. Fig. 12.3 of [5]). The potential differences over the three GEMs ΔU_{G1}, ΔU_{G2}, ΔU_{G3}, the voltage drops over the transfer gaps in between the foils ΔU_{T12}, ΔU_{T23} and the induction gap between the last foil and the readout plane ΔU_{I} are given in Table 1, along with the exact dimensions and the most important technical details of the detector. The cylindrical field cage has been designed to fit into the inner gap of the FOPI spectrometer (see Section 2.3).

A peculiarity of the FOPI GEM-TPC which is of special importance for the analysis presented in this work is the readout plane. It consists of 10,254 *hexagonally shaped* pickup pads with 3.0 mm outer diameter. Fig. 1 shows a section of the outer region of the readout plane in a close-up view.

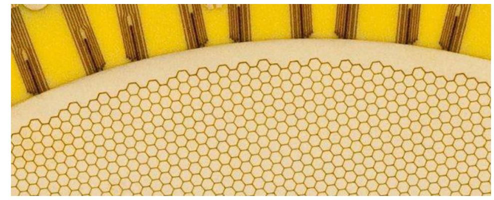

Fig. 1. Detail of the pad plane as installed in the GEM-TPC for FOPI. The 10,254 hexagonal pickup electrodes have an outer diameter of 3.0 mm.

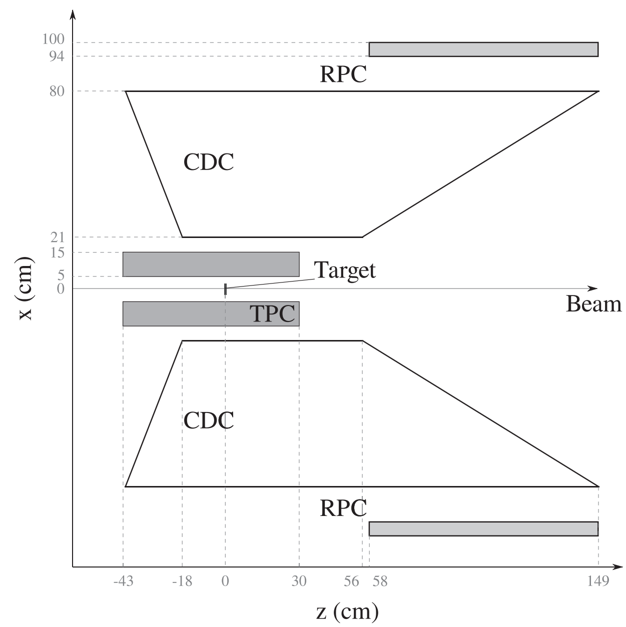

Fig. 2. Cross-section of the GEM-TPC + FOPI setup. Only the detectors relevant for this analysis are shown. The given dimensions are rounded values.

2.2. Readout electronics

For signal readout the AFTER ASIC [6] was chosen, which has been originally developed for the T2K experiment [7]. It features a low-noise charge preamplifier and a 511 cell analog buffer per channel with adjustable sampling frequency and shaping time.

Table 1
Key parameters of the experimental setup.

Environment	
Beam	π^-, 1.7 GeV/c
Rate	$\sim 1.5 \times 10^4\ \pi^-\ s^{-1}$
Target	C, 10 mm (2.6% λ_I)
Magnetic field	0.6 T Solenoid
Detector	
Drift length	727.8 mm
Inner ⌀	104.0 mm
Outer ⌀	308.0 mm
Drift gas	Ar/CO_2 (90/10), 1 atm
Drift field	234 V cm^{-1}
e^- drift velocity	16.5 μm ns^{-1}
Effective gain	$\sim 1 \times 10^3$
GEM parameters	50 μm thickness
	140 μm pitch
	70 μm hole ⌀
Gaps between foils/	2 mm/
last foil and readout	4 mm
ΔU_{G1}, ΔU_{G2}, ΔU_{G3}	324 V, 296 V, 259 V
ΔU_{T12}, ΔU_{T23}, ΔU_{I}	604 V, 604 V, 1208 V
Readout	10,254 hex. pads
Electronics	
Sampling clock	15.55 MHz
Buffer time bins	511
Peaking time	116 ns
Dynamic range	120 fC (11-bit ADC)
Sensitivity	394 e^-/ADC channel
Mean noise σ_N	678 e^- (RMS: 126 e^-)
Input capacitance	13–16 pF per pad
Threshold	4.5σ_N (per channel)

Each AFTER chip has 72 channels, of which 64 are connected to pads on the pad plane (4 additional, internal channels of the chip are used for common mode noise correction [8]). In total, 42 front-end cards equipped with 4 AFTER chips each have been connected via 11 ADC boards to read out all channels of the detection plane. The mean noise performance of the fully connected readout during data taking has been found to be $\sigma_N \sim 680\, e^-$ ENC per channel, calculated using the width of baseline fluctuations and the single-channel sensitivity. The input capacitance to the preamplifier was estimated to be between 13 and 16 pF per pad, dominated by the ASIC packaging and the trace lengths. Table 1 summarizes the settings and performance during data taking. More information about the readout electronics can be found in Refs. [5,8].

2.3. Physics campaign inside the FOPI spectrometer

For the analysis presented here, only the barrel detectors of FOPI are of interest. A sketch of the involved systems is shown in Fig. 2. The GEM-TPC surrounded the target, covering the full azimuthal angle and the polar angular region $26^\circ < \theta < 159^\circ$ for primary tracks reaching the outer wall of its volume.[2] The GEM-TPC in turn was placed inside FOPI's Central Drift Chamber (CDC), which covered the polar angle range $22^\circ < \theta < 122^\circ$ with respect to the target with its inner wall. The CDC offers a good spatial resolution of $\sigma_{x,y} \sim 300$ μm

[2] For the data presented here only a part of the physical drift length (approx. $-24\ \mathrm{cm} < z < +30\ \mathrm{cm}$ in Fig. 2) has been read out due to the choice of the drift field, as summarized in Table 1.