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The new Forward Tracker System for the HADES FAIR Phase-0 experiment

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As part of the FAIR phase-0, the HADES experiment underwent a hardware upgrade that included updating existing components, data-acquisition systems, and the integration of new detectors. In particular, the new Straw Tracking Stations (STS) enlarge the HADES acceptance to low polar angles, crucial for the FAIR phase-0 physics program, including hyperon reconstruction. The STS has eight double layers of straws arranged in four azimuthal orientations for a full 3D track reconstruction and resolving ambiguities in multi-track events. Pre-commissioning tests showed a possible spatial resolution of single straw tubes of about 0.13 mm for minimum ionizing particles (MIPs). The STS system was installed at HADES in 2020 and tested during a dedicated commissioning beamtime in February 2021. The collected data was used to develop the calibration and track reconstruction methods. The STS is one of the PANDA systems in early operation during the FAIR Phase-0, and will become part of the PANDA Forward Tracker at the start of FAIR Phase-1. A description of the STS system and a summary of the results from the experiment beamtime in 2022 are presented.

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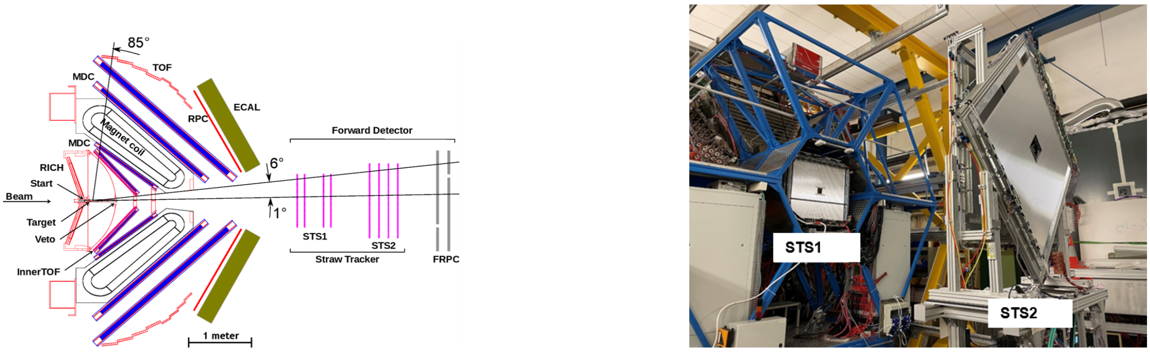
1. Introduction

The High Acceptance Di-electron Spectrometer (HADES) is designed to study nuclear matter and the properties of baryonic resonances by measuring charged hadrons, leptons, and photons produced through proton, secondary pion, or heavy ion-induced reactions at a few GeV [1]. HADES operates at the Heavy-ion Synchrotron (SIS18) accelerator at the GSI Helmholtz Center for Heavy Ion Research in Darmstadt, Germany, and it is part of FAIR. One of the topics of the FAIR Phase-0 physics program is hyperon studies, including single and multi-strangeness production, and hyperon electromagnetic decays. To achieve these measurements, the HADES spectrometer was upgraded by improving some of its already operating systems, and integrating additional new detectors. In particular, a Forward Detector (FD) consisting of two Straw Tracking Stations (STS) and a Forward Resisitive Plate Chamber (fRPC) was installed in 2020 and 2021 (Fig. 1a). The FD increases the HADES polar angle acceptance to the region from θ = 1° - 6 °. Detailed simulation feasibility studies for the measurement of electromagnetic decays [2] showed that the FD plays a crucial role in the hyperon reconstruction. It was determined that *e.g.* 41% of the daughter protons of the $\Lambda(1520)$ decay are within the FD acceptance. A production run in February and March of 2022, was carried out with the upgraded HADES. These proceedings describe the STS calibration method.



(a) **(b)**

Figure 1: (a) HADES scheme, including FD components. (b) STS in parking position

2. The STS Detector

Each of the two Straw Tracking Stations STS1 and STS2, have four double layers of gas-filled straws. Their design is based on the Straw Tube Tracker (STT) and Forward Tracker (FT) of the PANDA experiment [3, 4]. Each straw is made of 27μm thin Al-Mylar film tube walls (cathode), with a 20 μm thin gold-plated W/Re wire extending along its axis (anode). They have inner $\varnothing$ = 10 mm, and length of 76 cm and 125 cm for STS1 and STS2, respectively. The gas mixture used is Ar/CO_2 (90:10) at 2 bar absolute pressure. The over-pressure results in a self-supporting structure reducing the amount of additional supporting material. To achieve a full 3-D track reconstruction and resolve ambiguities in multi-track events, four azimuthal orientations are used: for STS1, ϕ = 0°, 90°, 90° and 0° whereas for STS2, ϕ = 0°, 90°, 45°, -45° from first to last double layer. A charged particle crossing a straw, ionizes the gas molecules enclosed within the straw along its path through the straw tube. The anode is typically set at HV ~ 1800 V. The voltage difference

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between the anode and cathode generate an electric field which separates the ionization electrons from the ions. The electrons drift towards the wire, where they are collected. The charge signals are amplified and shaped using the PASTTREC-ASICs on front-end mounted electronic boards [3, 5]. The leading edge time t_{LE} and trailing edge time t_{TE} are measured in multi-hit TDCs implemented in the Trigger Readout Board version 3 (TRB3) [4]. By measuring the drift time of the first electrons reaching the wire, the information about the shortest distance from the particle trajectory to the wire can be obtained. A spatial resolution of 0.13 mm (σ) for MIPs [6] was determined from pre-commissioning tests. The STS is shown in Fig. 1b.

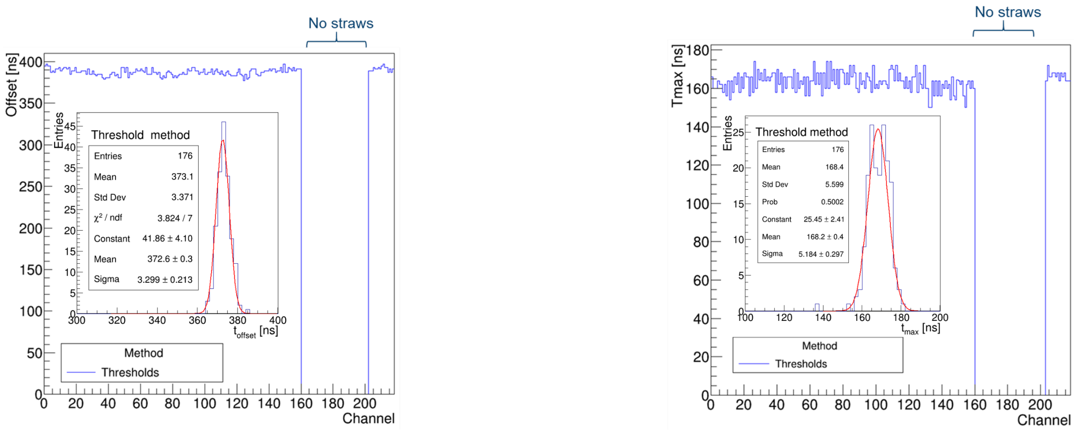
3. STS Calibration

The straws deliver a time measurement denoted as $TDC_{raw} = t_{ref} + t_{off} + t_{drift}$, where t_{ref} is an event-specific reference time, t_{off} is a channel-specific offset caused by the electronic components in the readout and trigger chain, and t_{drift} is the drift time of the earliest arriving electrons to the wire, generated by the particle passage through the straws. For the track reconstruction only t_{drift} is needed. The calibration task is to correct the additional contributions included in the TDC_{raw}.

(a) **(b)**

Figure 2: (a)Raw TDC time spectra of a single channel in STS1.1. (b)Expanded view in the main distribution with corresponding t_{off} and t_{max} shown by the blue-dotted lines.

Fig. 2a shows the TDC_{raw} time spectrum of a single straw of the first double layer of the STS. A typical drift time distribution is seen on top of a linear background. The latter are signals generated by particles not correlated with the event trigger time. The sharp leading edge at around 370 ns is generated by the electrons with the shortest drift times, corresponding to particles crossing close to the anode wire. Such electrons have larger velocities due to the stronger electric field at that region of the straw. In contrast, the larger drift times correspond to particles crossing closer to the straw wall. Several effects influence the time spectrum *e.g.* electron diffusion, electronics settings, gas gain and the velocity change over the straw radius [7]. The time-of-flight ToF of particles crossing the STS is measured by the fRPC, located about half a meter downstream of the last STS double-layer. At this moment, the calibration of the fRPC is not defined, meaning that the precise time-of-flight is not available. However, the particles used for the calibration have high momentum and nearly constant velocities. Therefore, at this stage of the calibration, ToF can be taken as a constant and is not explicitly shown in the TDC_{raw} definition.



(a) **(b)**

Figure 3: (a) t_{off} and (b) t_{max} vs channel for STS1.1, and corresponding values distribution.

The t_{ref} is an absolute time measured by the detector closest to the interaction point. The first step of the calibration is to retrieve the event-specific t_{ref}, and subtract it from the recorded STS TDC_{raw} within the specific event. The second step is to determine the signal offset t_{off}. The latter is done by first subtracting the linear background, and defining a reference value V_{ref} given by the maximum amount of entries. A lower L_{thr} and upper U_{thr} threshold are defined as 10% and 75% of V_{ref} respectively. Then t_{off} is obtained by determining the slope of the leading edge, defined by L_{thr} and U_{thr}. Fig. 3a shows the t_{off} values obtained for all the straws belonging to the first double-layer of the STS. It was verified that the straw-to-straw variations are systematic, most likely attributed to electronics settings, by implementing a second method based on a fit with an empirical function as in [3]. In addition, the t_{off} distribution is shown with a corresponding Gaussian fit with μ_{offset} = 372.6 ns and σ_{offset} = 3.3 ns. The maximum drift times t_{max} were also determined for each channel following the same procedure as t_{off}. Fig. 3b shows the t_{max} obtained for all straws within the first double layer of the STS and its corresponding distribution and Gaussian fit. Here, μ_{max} = 168.2 ns and σ_{max} = 5.2 ns. A slight difference in the t_{max} values is seen for even and odd straw channels, resulting in a narrow double peak structure in the distribution. This effect increases the width by about 2 to 2.5 ns compared to the t_{off} distribution, which characterizes the overall time resolution. The double structure was not seen in other beam time periods. The effect has a negligible impact on the space-drift time relation and spatial resolution but is still under investigation. Fig. 2b shows a zoom to the TDC_{raw} spectrum shown in Fig. 2a. The blue-dotted lines depict the t_{off} and t_{max} for this specific channel. Fig. 4a shows the drift time distribution obtained after background subtraction, t_{ref} and t_{off} correction. The end of the spectra is given by the t_{max}. The space-drift time relation $r(t_{drift})$ is obtained by performing a running integral as:

$$r(t_{drift}) = \left(\frac{\sum_{i=0}^{i_{dt}} N_i}{N} \right) \times (R_{max} - R_{min}) + R_{min}, \tag{1}$$

where $r(t_{drift})$ is the radius for the specific drift time t_{drift}, $\sum_{i=0}^{i_{dt}} N_i$ is the number of hits with drift time less than t_{drift}, N is the total integral of the t_{drift} spectrum, and R_{max} = 5.05 mm, is the maximum straw radius taking into account the expansion due to its over-pressure, and $R_{min} = 0.1$ mm the minimum allowed radius. The integral limits are determined by the start of the spectrum and t_{max}. Fig. 4b shows the result of applying Eq. 1 to the t_{drift} spectrum shown in Fig. 4a. The integral is shown in blue. It is parametrized with a polynomial of 4^{th} order (red line). The parametrization in this example is given by: $r(t_{drift}) = -0.240 + 0.059 t_{drift} - 2.13 \times 10^{-4} t_{drift}^2 + 5.77 \times 10^{-7} t_{drift}^3 - 1.59 \times 10^{-9} t_{drift}^4$. The $r(t_{drift})$ curve is obtained for each channel and is used for the track reconstruction as explained in [3, 4].

(a) **(b)**

Figure 4: (a) t_{off} and (b) t_{max} vs channel for STS1.1, and corresponding values distribution.

4. Summary and conclusions

The new tracking system STS was used during the HADES production run in 2022. Clean measured drift time distributions were obtained, on top of a linear background generated by particles uncorrelated with the event trigger time. The collected data was used to develop the calibration method, which included the determination of the signal offset t_{off}, maximum drift time values t_{max}, and a space - drift time relation $r(t_{drift})$ for each straw. The straw-to-straw variations observed in the t_{off} and t_{max} values are systematic and under investigation. The 5.2 ns spread measured for the t_{max} values corresponds to very small differences of the active tube radius, below 40 μm.

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