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METHODS OF PHYSICAL EXPERIMENT

Advanced Setup for Performance Studies of Small Straw Tracker Prototypes for the SPD Detector

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Abstract—A multi-functional setup has been developed for testing first prototypes of the SPD Straw Tracker. The setup was successfully operated during test beams at CERN in 2024 and 2025, combining a wide range of detectors and front-end electronics. It includes a reference timing system formed by four trigger scintillator counters with coincidence logic. The reference tracking system consists of a set of Micromegas detectors equipped with TIGER-based readout electronics, and a silicon TimePix4 detector. The setup is dedicated for performance studies of straw prototypes. One of the prototypes is a combined construction of three double-layers of straws with diameters of 5, 10, and 20 mm. Another one is reproducing the concept of the SPD Straw Tracker geometry which uses stereo-angle layers ("U" and "V") additional to the layers "X" where the straws are aligned with the longitudinal SPD detector axis. This prototype consists of four XUVX double-layers. Several types of readout electronics are tested with those prototypes. All readout components have own independent data acquisition systems (DAQ). The developed offline synchronization approach allows to merge data acquired with different DAQs for further analysis.

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Straw-tube trackers are widely used in High Energy Physics experiment because of their low material budget, mechanical simplicity and relatively low cost. Straw trackers are used in several major detectors, such as, for example, the NA62 [1], and are also considered for future projects. Modern straws are typically made of thin polymer films, Kapton or Mylar, with wall thicknesses starting from about 12 μm and up to ≈40 μm, depending on the application and mechanical requirements [2]. A thin anode wire is placed in the center of the straw and the straw volume is filled with two or three component gas mixture. Each tracker straw operates as a drift tube, providing precise coordinate measurements of a track.

The presented work concentrates on beam tests and performance evaluation of straw prototypes of the SPD Straw Tracker [3]. The measurement program pursues two goals. The first is precise measurements of electron drift times to estimate the straw spatial resolution as well as to evaluate the tracking performance of prototypes. The second goal is the measurement of ionization energy loss (dE/dx), which provides the basis for particle identification (PID). These goals demand different front-end shaping regimes and motivate systematic comparison of available readout electronics.

MEASUREMENT PRINCIPLES

When a charged particle crosses a straw tube at time T_0, it creates clusters of ionization electrons that drift toward the central anode wire (Fig. 1), where charge amplification by a factor ~4E4 occurs due to the avalanche process. The measured arrival time of the first

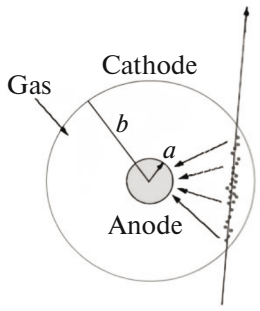


Fig. 1. Ionization and electron drift in a straw tube.

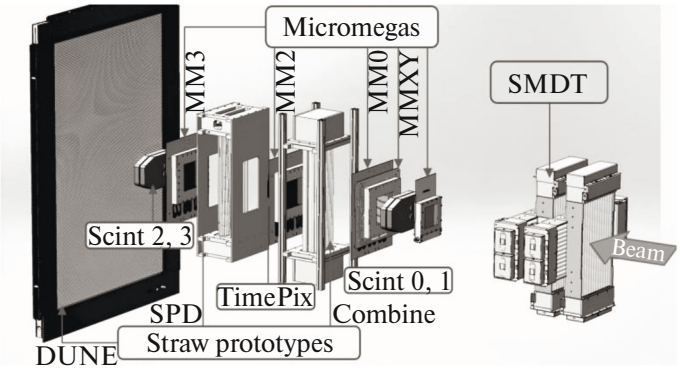


Fig. 2. Experimental StrawTrackerRD setup at CERN SPS.

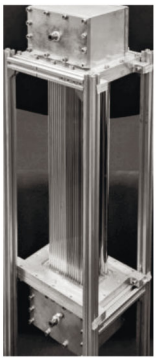


Fig. 3. Combined straw prototype.



Fig. 4. uSPD straw prototype.

electrons relative to a reference time T_0 yields the drift time t_d, which is converted to the radial coordinate of the track using an experimentally determined time—coordinate relation, so-called RT-curve. The RT-curve encapsulates detector-specific characteristics such as gas composition, detector geometry and operation voltage. Additionally, the time resolution significantly influenced by parameters of readout electronics. Accurate determination of the leading-edge time requires front-end electronics with short peaking time.

In contrast, the dE/dx measurement relies on integrating the charge of the ionization avalanche. This favors longer peaking times and charge-sensitive readout chains to capture major part of the signal charge. So, readout electronics of a straw tracker with PID option should compromise the optimal peaking time.

In practice, the tested readout architectures allow selecting the optimal shaping mode for each measurement campaign. Some programmable ASICs developed for other detector types can operate in both timing and charge-integration modes, as, for example the TIGER ASIC [4], but their parameters are not well suited for straw applications. A major objective of the test beam measurement program is therefore the comparative testing and selection of electronics that provides the best compromise between the time and charge performance.

EXPERIMENTAL SETUP

The StrawTrackerRD test beam setup (Fig. 3) integrates straw prototypes under the test, micromegas, and Timepix4 [5] silicon pixel detector as a reference tracking system, and scintillator counters as a reference timing system. These parts are read out with several independent DAQ systems. Two straw prototypes have been tested with the developed setup. The first, a combined prototype, contains three double-layers of straws with diameters of 5, 10, and 20 mm. These diameters are defined by design of straw trackers for the future experiments: 5 mm straws for DUNE [6], 10 mm for SPD [3], and 20 mm for SHiP [7]. This allows direct comparison of their performance under identical conditions. The second is an SPD-type prototype reproducing the XUVX stereo configuration foreseen for SPD tracking, where the U-layers are oriented at +2° and the V layers at −2° relative to the

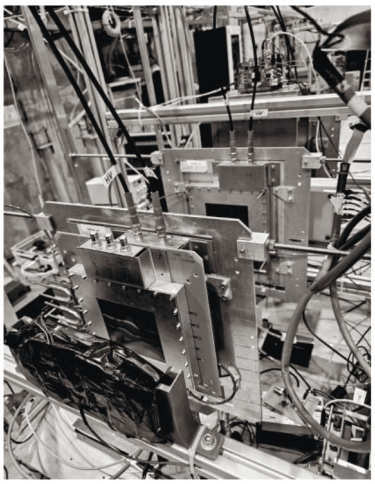


Fig. 5. Micromegas detector modules with TIGER readout.

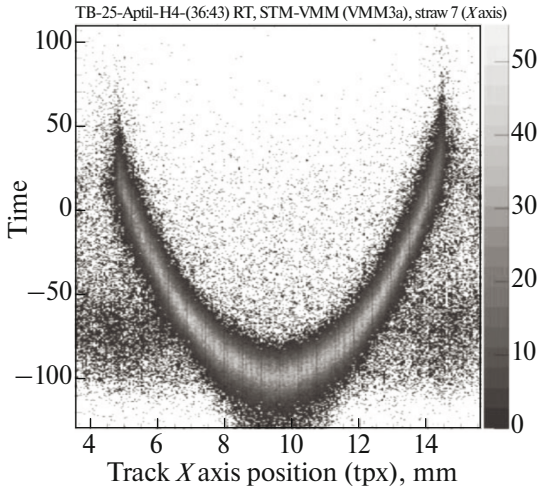


Fig. 6. Measured RT curve (radius–time relation) for a 10 mm straw.

X direction. The DUNE straw tubes are made of aluminized Mylar with 20 um wall thickness and have 20 μm gold-plated tungsten anode wires. For other straw types cathode is made of 36 um thick Mylar foil with copper-gold metallization and the anode wire has 30 um diameters. During the tests the prototypes were operated at atmospheric pressure under a small continuous gas flow of about 0.5–2 L/h.

READOUT ELECTRONICS AND DAQ

Several front-end and DAQ options have been tested to compare timing and charge performance. For the combined prototype an ATLAS sMDT-type readout with an ASD chip [8] are used. The uSPD prototype is operated with the dedicated ST-VMM3 readout based on the VMM3a ASIC [9] with external signal digitization, and also with an NA64 straw readout option [10]. The ASD and NA64 electronics have short, at the level of ~12 ns, peaking time, while VMM3a offers programmable peaking time in the range 25–200 ns. For detailed straw performance studies custom slow and fast preamplifiers were used together with the CAEN DT5725 and SAMPIC [11] digitizers to read out a single straw.

Micromegas planes of the reference coordinate system (Fig. 6) are read out with TIGER ASICs [4]. The Timepix4 detector (500 μm Si, 448 × 512 pixels of 55 × 55 μm) provides a precise space-time reference via the SPIDR4 [5] readout. The precise measurement of the track time T0 four scintillator counters are used. The scintillator signals are processed by CFDs and distributed via fan-outs into individual DAQs of the straw and tracking readouts. T0 is used as the reference time and also serves the offline data synchronization. Data merging is done offline using a common trigger or special synchronization signals recorded by triggerless systems. A 40 MHz master clock serves as global reference; for controllers requiring 10 MHz (e.g., GEMROC), the signal is frequency-divided while maintaining a common phase.

RESULTS AND DISCUSSION

The setup is developed in year 2022 and is used for measurements with SPS and PS test beams. At SPS, 75–150 GeV muon beam is used to study the straw spatial resolution and tracking performance using micromegas and Timepix4 detectors for reference tracking. At PS, secondary beams are used to measure dE/dx for low momenta (500 MeV/c–2 GeV/c) pions and electrons to probe the PID performance, and for tracking performance studies with particle moment up to 15 GeV/c. For reference tracking AZALEA silicon telescope [12] is used instead of the micromegas.

A wide range of the straw operation and readout electronics parameters are being studied—voltages, thresholds, shaping parameters, gas composition and pressure. The offline merging allows to combine data from all independent readouts to study performance of several straw prototypes with the same data sets. Figure 6 demonstrates an example of data from the STM-VMM readout (straw signal time) and Timepix4 (reference coordinate measurements) merged offline on event-by-event basis to study the straw RT dependence.

CONCLUSIONS

We have developed and commissioned a flexible beam-test setup that integrates straw prototypes, Micromegas and Timepix4 detectors operated with independent readout systems. Offline data merging approach allows precise measurements of performance of the straw prototypes as functions of readout electronics parameters. The campaigns at SPS and PS

provided comprehensive datasets now being analyzed to derive straw spatial and charge resolution. The analysis results will be used to optimize readout electronics options and operation parameters for the SPD straw tracker.

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CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

REFERENCES

1. H. Danielsson, "Performance and operation of the straw detector in the NA62 rare kaon decay experiment," in *Proceedings of the IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC)* (IEEE, 2015), pp. 1–4. https://doi.org/10.1109/nssmic.2015.7581950
2. V. Bautin, S. Bulanova, T. Enik, E. Kuznetsova, A. Mukhamejanova, Y. Mukhamejanov, S. Romakhov, N. Saduyev, S. Sakhiyev, K. Salamatin, and D. Sosnov, "Ultrasonic welding technology for future Straw Trackers and performance studies with small-size tracker prototypes," Nucl. Instrum. Methods Phys. Res., Sect. A **1081**, 170767 (1081). https://doi.org/10.1016/j.nima.2025.170767
3. V. Abazov et al., "Technical design report of the spin physics detector at NICA," Natural Science Review **1**, 1 (2024). https://doi.org/10.54546/naturalscirev.100101
4. A. Rivetti, M. Alexeev, R. Bugalho, F. Cossio, M. D. da Rocha Rolo, A. di Francesco, M. Greco, W. Cheng, M. Maggiora, S. Marcello, M. Mignone, J. Varela, and R. Wheadon, "TIGER: A front-end ASIC for timing and energy measurements with radiation detectors," Nucl. Instrum. Methods Phys. Res., Sect. A **924**, 181–186 (2019). https://doi.org/10.1016/j.nima.2018.09.010
5. X. Llopart, J. Alozy, R. Ballabriga, M. Campbell, R. Casanova, V. Gromov, E. H. M. Heijne, T. Poikela, E. Santin, V. Sriskaran, L. Tlustos, and A. Vitkovskiy, "Timepix4, a large area pixel detector readout chip which can be tiled on 4 sides providing sub-200 ps timestamp binning," J. Instrum. **17**, C01044 (2022). https://doi.org/10.1088/1748-0221/17/01/c01044
6. V. Hewes et al., "Deep underground neutrino experiment (DUNE) near detector conceptual design report," Instruments **5**, 31 (2021). arXiv:2103.13910
7. M. Anelli, S. Aoki, G. Arduini, J. J. Back, A. Bagulya, W. Baldini, A. Baranov, G. J. Barker, S. Barsuk, M. Battistin, et al., "A facility to Search for Hidden Particles (SHiP) at the CERN SPS," arXiv Preprint (2015). arXiv:1504.04956
8. S. Abovyan, V. Danielyan, A. Grasser, O. Kortner, H. Kroha, R. Richter, and S. Simeonov, "Performance of the Amplifier-shaper-discriminator ASICs Produced for the ATLAS MDT Chambers at the HL-LHC," in *Proceedings of the IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC)* (IEEE, 2021), pp. 1–2. https://doi.org/10.1109/nss/mic44867.2021.9875490
9. G. Iakovidis, "VMM3a, an ASIC for tracking detectors," J. Phys.: Conf. Ser. **1498**, 012051 (2020). https://doi.org/10.1088/1742-6596/1498/1/012051
10. V. Yu. Volkov, P. V. Volkov, T. L. Enik, G. D. Kekelidze, V. A. Kramarenko, V. M. Lysan, D. V. Peshekhonov, A. A. Solin, and A. V. Solin, "Straw chambers for the NA64 experiment," Phys. Part. Nucl. Lett. **16**, 847–858 (2019). https://doi.org/10.1134/s1547477119060554
11. E. Delagnes, D. Breton, H. Grabas, J. Maalmi, P. Rusquart, and M. Saimpert, "The SAMPIC waveform and time to digital converter," in *Proceedings of the IEEE Nuclear Science Symposium and Medical Imaging Conference (NSS/MIC)* (IEEE, 2014), pp. 1–9. https://doi.org/10.1109/nssmic.2014.7431231
12. J. Brau, M. Breidenbach, D. R. Freytag, C. Kleinwort, U. Kraemer, B. A. Reese, S. Roelofs, M. Stanitzki, A. Steinhebel, D. Tsionou, and M. Wu, "Lycoris—A large-area, high resolution beam telescope," J. Instrum. **16**, P10023 (2021). https://doi.org/10.1088/1748-0221/16/10/p10023

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