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A new system of STRAW chambers operating in vacuum for the NA62 experiment

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Abstract. Large $2.15 \times 2.15 \text{ m}^2$ area straw tube chambers have been developed to meet the specific requirements of the NA62 experiment. The main goal of the NA62 experiment at the CERN SPS is to measure the branching ratio of the ultra-rare $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ decay with 10% accuracy. This can be achieved by detecting about 100 Standard Model events with 10% background in 2 - 3 years of data taking. A low mass tracking system is necessary to achieve a high resolution on kinematic quantities while timing resolution is mandatory to match the outgoing pion with the incoming kaon. Design, construction and first performance are reported.

1. Introduction

High energy particle physics experiments often require large dimension tracking chambers achieving good spatial resolution and built of minimal amount of material to minimize multiple coulomb scattering effects when used as elements of a magnetic spectrometer. Among these detectors are straw tube chambers based on an already well known technique. However, more than twenty years after the first proposal to use such kind of detector, there was no chamber reliably operating in vacuum, except for the chamber of the COSY-TOF collaboration [1], which was placed in vacuum together with its outer frame. The NA62 experiment is located in the CERN North Area and makes use of the primary 400 GeV proton beam from the SPS to produce a secondary unseparated charged hadron beam. The beam line layout and the detector setup have been optimized to study $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ decays [2] based on decay-in-flight technique of high momentum ($75 \text{ GeV}/c$) kaons. Details about the already achieved performance and sensitivity can be found in [3]. A pilot run took place in autumn 2014 to commission the sub-detectors and readout system. The STRAW chamber system was fully commissioned and its performance found to meet the design requirements. In June 2015, NA62 began to take physics data, and will continue throughout 2018.

2. A new type of STRAW tubes

Overpressure inside a straw tube leads to radial and longitudinal deformations. The effect of radial deformation can be minimized for example, by adopting a layout where the straws

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are sufficiently separated from each other. Longitudinal deformation may become critical as it spontaneously destroys the straightness of the straw. An axial pre-tension guarantees straight straws during the operation of the detector and minimizes the need for supporting material. However, classical fabrication of straws by film winding and subsequent gluing of wound layers with elastic glue substantially elongates [4] with time and can completely loosen the initial pretension that again will lead to deformation of straws. As a consequence, ultrasonic welding along the straw axis has been used. Thin-wall tubes (straws) are the elementary components used in the chambers. The 9.82 mm diameter drift tubes are made of 36 μm Mylar film, coated with 50 nm of copper and 20 nm of gold on the inside. They are welded along the straw axis using an ultrasonic welding machine developed at JINR (Figure 1). A straw seam visual quality control and a set of tests allow to produce straws within the strict tolerances defined in [5]. Straw tubes are filled with a mixture of 70% Argon and 30% CO_2 at atmospheric pressure and are themselves operated in vacuum. Gas leakage per meter of straw does not exceed 0.5×10^{-6} litre/min at 1 bar overpressure. A straw tube withstands a pressure of up to 9 bar.

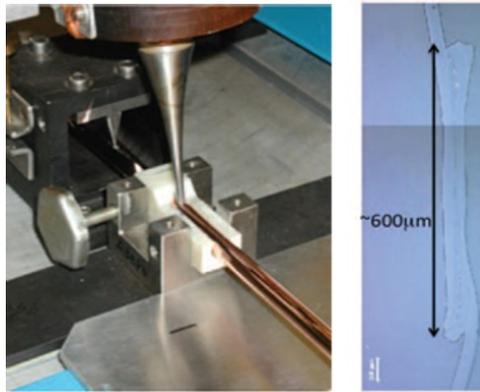


Figure 1. Left: Detail of the straw welding machine. Right: Microscope image showing the cross-section of the weld.

3. Straw chamber assembly and performance

Each straw chamber is composed of two square-shape modules with reinforced sides to withstand the strength of tube pretension (more than 700 kg on each module side). One module contains two views measuring X (0°), Y (90°) coordinates and the second module contains the U (-45°) and V ($+45^\circ$) views (Figure 2-left). A straw view consists of four straw layers, 112 straws each. Each view has a gap of about 12 cm without straws near the centre, such that, after overlaying the four views, an octagon shaped hole is created for the beam passage. As the beam has an angle of $+1.2$ mrad and -3.6 mrad in the horizontal plane, upstream and downstream of the spectrometer magnet, respectively, this hole is not centred on the Z axis, but has custom offsets (along the X direction) as a function of the chamber Z-position. Each chamber has a circular active area with an outer diameter of 2.1 m. High detection redundancy is provided through a straw arrangement with four layers per view, which guarantees at least two hits per view (Figure 2-right). Up to 99.98% detection efficiency is obtained within a straw tube diameter of 9.4 mm.

After completion of the straw chamber installation, their actual position relative to the beam axis has been measured by the CERN survey group with an accuracy of 0.3 mm.

The straw readout electronics is based on the CARIOCA chip [6], an 8-channels charge-sensitive preamplifier-shaper-discriminator with base-line restoration and tail cancellation. The gain is 15 mV/fC and the peaking time $\sim 8 - 10$ ns. The leading time of the straw signal is used

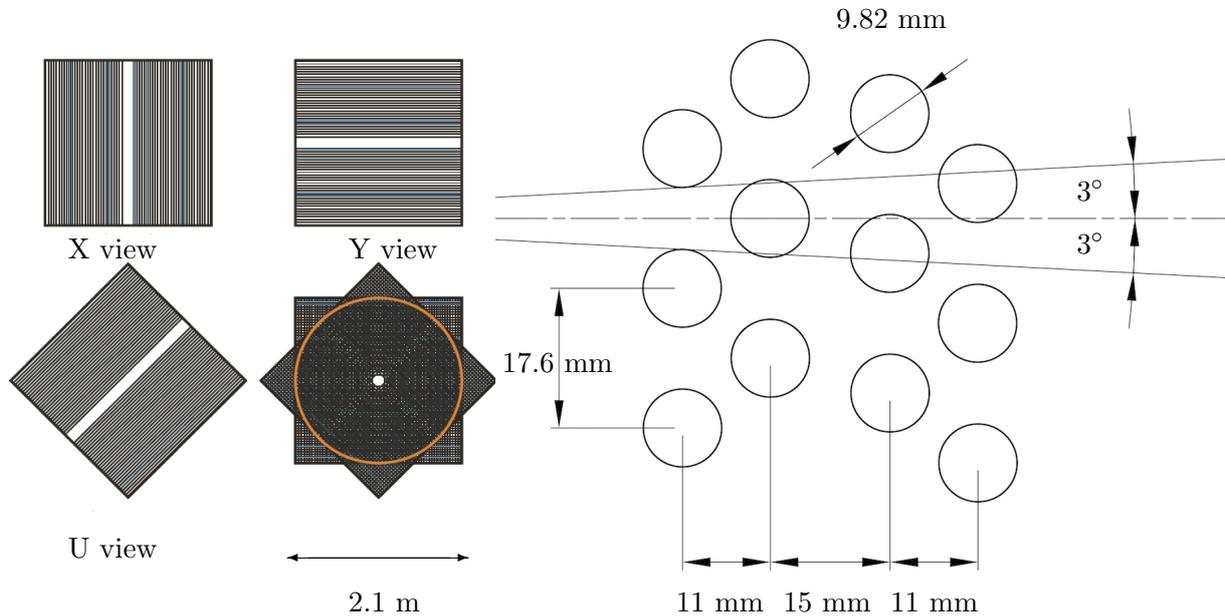


Figure 2. Left: One straw chamber is composed of four views (X, Y, U, V) and each view measures one coordinate. Right: Each view includes four layers of straws providing at least two straws hit per track.

for the track position measurement using radial distance-time correlation. The trailing time is the same for each particle (maximum drift time at the straw wall), and can be used for trigger purpose. Each cell (16 straws) has an individual HV power cable and readout board. The read out board is based on two CARIoca chips and an ALTERA FPGA (software 16-ch TDC). Data are transmitted to the straw readout board (SRB). Each group of 8 SRBs is installed into a single 9U VME rack (32 SRBs in total).

Four MPOD crates for high and low voltage power supply have been installed and integrated in the Detector Control system of the experiment through a user-friendly interface. On-line monitoring has been developed for quality control of the recorded data.

The experimental drift time distribution was compared with the results of a GARFIELD simulation [7] with good agreement. Reconstruction of $K^+ \rightarrow \pi^+\pi^+\pi^-$ decays using the straw spectrometer leads to a reconstructed kaon mass resolution of $0.9 \text{ MeV}/c^2$ in line with the design expectations.

In conclusion, a new type a Straw chambers has been developed and built successfully. The performance of the STRAW chambers operating in vacuum has been estimated and meets the requirements of the NA62 experiment in terms of material budget (1.8% of a radiation length in total), space resolution (close to $130 \mu\text{m}$) and excellent efficiency.

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