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NA62 spectrometer: a low mass straw tracker

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Abstract

The NA62 experiment at CERN, aiming at a precision measurement of the ultra-rare decay $K^+ \to \pi^+\nu\bar{\nu}$, relies on kinematical rejection up to 10^5 ($\approx 10^{12}$ is needed in total). One of the limiting factors to achieve this goal is the multiple scattering in the magnetic spectrometer for kaon decay products; therefore an almost massless ($\approx$1.5% X0) straw tracker has been designed to operate in vacuum, to be able to install it inside the decay volume. A vacuum tight prototype was built and tested in 2010: efficiency ($\approx$99%), rate capability and single straw resolution ($\approx$200 μm) were verified. The construction of the first chamber started in 2011.

Keywords: Tracking detector, rare kaon decays, gaseous detector

1. Introduction

NA62 is a fixed target experiment [1] [2] at CERN, now in its final stage of development and initial stage of construction. The experiment aims to measure the decay rate (branching ratio or BR) of $K^+ \to \pi^+\nu\bar{\nu}$ predicted to be $(8.0 \pm 0.8) \times 10^{-11}$ by the Standard Model (SM); such a rare process requires a significant technological challenge to achieve the needed background suppression ($O(10^{12})$), i.e. to identify 100 signal events rejecting $O(10^{12})$ background ones. The measurement of this branching ratio with an accuracy of 10% allows to put constraints on several models concerning New Physics, like SM4 (SM with 4 generations), LHT (Littlest Higgs with T-parity) and RSc (Randall Sundrum with custodial protection) and MFV (minimal flavour violation). NA62 is an hermetic detector for ultra rare kaon decays, specifically designed to measure $K^+ \to \pi^+\nu\bar{\nu}$ using kaons decaying in flight; this technique allows to reduce efficiency problems of vetoes at very low energy and protects the measurement from low energy products of hadronic interactions. The implementation consists in a long ($\approx$ 250 m) beam line, equipped with two spectrometers (one to measure the momentum of K^+ and the other for its decay products), a long decay region ($\approx$ 70 m longitudinal and $\approx$ 2.5 m transverse) kept in vacuum ($< 10^{-6}$ mbar) and surrounded by photon vetoes. The setup includes also particle identification detectors (Cherenkov detectors CEDAR and RICH), forward photon vetoes and a muon detection system.

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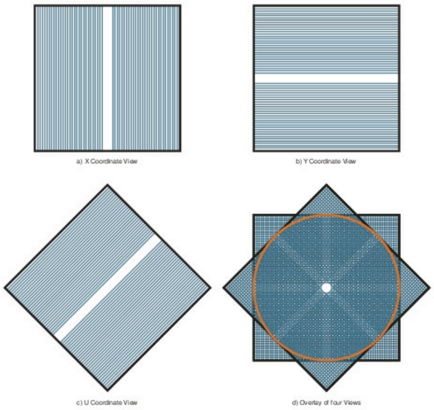

Fig. 1. Composition of the chamber by views

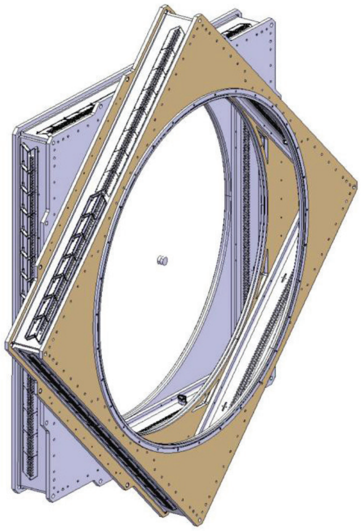

Fig. 2. Assembly of 2 modules

A large fraction of the rejection power of the experiment is given by kinematical rejection, which relies on the measurements performed by the beam and decay products spectrometers. They are both designed to work in vacuum, but while the former is a small area silicon pixel detector the latter is a 35 m long and 2 m wide straw based tracker. This last choice is determined by the need to minimize multiple scattering, which is the limiting factor in the achievable momentum resolution; thus the spectrometer has to be gas based and capable to operate in vacuum.

2. The STRAW Spectrometer

The NA62 STRAW Spectrometer is composed by 4 chambers and 1 dipole magnet (0.36 T, 270 MeV/c p_T kick). The chambers are separated by 10 m, except for the last one (15 m), and the magnet is between the second and the third one. Everything is integrated within the decay volume, a 100 m long and 2.5 m wide vacuum tube ($< 10^{-6}$ mbar), putting a tight constraint on the acceptable total leak rate ($< 10^{-1}$ mbar l/s). Each chamber is composed by 4 views (X,Y,U,V) (Fig. 1), arranged in 2 modules (Fig. 2), leaving a hole of ≈12 cm diameter for the undecayed beam and with 2.1 m acceptance (⊘). Each view is composed by 4 layers of straws with a pattern (Fig. 3) that guarantees the geometrical coverage for tracks with an angle up

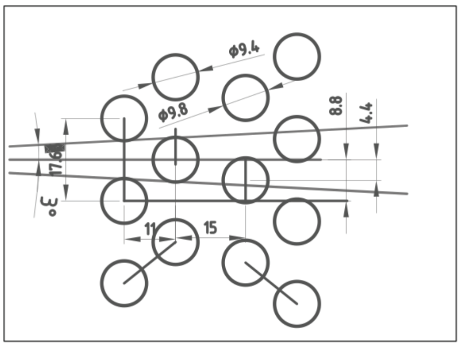

Fig. 3. Straw pattern

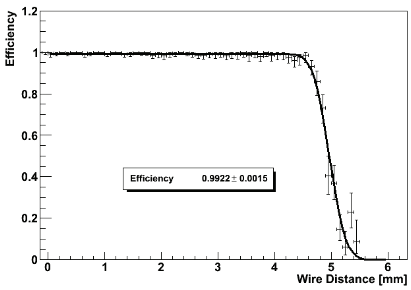

Fig. 4. Straw efficiency

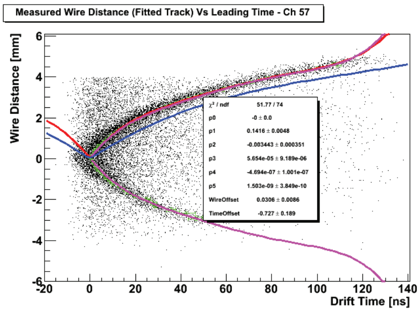

Fig. 5. Space-time relation fitted on data (red line); the blue line shows the MagBoltz [4] simulation without any contamination

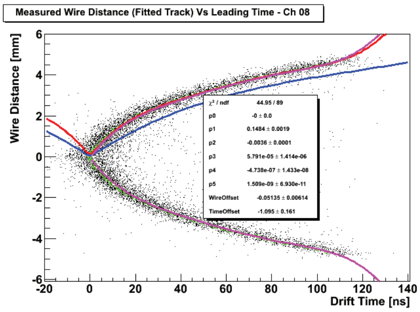

Fig. 6. Space-time relation fitted on MC (red line); the blue line shows the MagBoltz [4] simulation without any contamination

to 3 degrees from the normal to the view plane. The mechanical tolerances are quite tight, being 100 μm for the straw straightness and 200 μm for the position of the wire; this reflects also on the required quality of the aluminium frame, for which 100 μm tolerance between the two farthest points has been achieved. This design should guarantee an average resolution $\sigma < 130$ μm for the individual view. The elementary active component is a drift tube ($\oslash = (9.75 \pm 0.05)$ mm and 2.1m long) realized with a 36 μm thick mylar straw, with Cu-Au metalization (50-20 nm), produced by ultrasonic welding, from a $\approx$3 cm wide tape, and a 30 μm gold-plated tungsten wire. The straw is designed to be operated in vacuum, with an internal overpressure of 1 bar, and it is glued to the aluminium frame with a pretension of 1.5Kg; the combined effect of pretension and overpressure defines the shape of the straw, requiring additional constraints to obtain deviations better than 100 μm with respect to the nominal position. This is achieved adding 2 very light spacers at 1/3 and 2/3 of the length. Each spacer is made of two parallel 100 μm wires with thin ultem rings, one for each straw, glued in between and properly spaced; they are installed in the view frame in the mentioned positions, before inserting the straws. The few straws close to the undecayed beam passage have to be able to sustain a rate larger than 500 kHz. The anode and cathode resistance are 180 Ω and 70 Ω respectively. The tubes are grouped in cells of 16 for gas distribution and connection to the electronics. The front-end electronics is based on CARIOCA [3], and installed on a custom board that is also part of the gas manifold. The signals from straw tubes are collected (anode signal only) on one end by means of a flexible (kapton) circuit, which hosts high voltage resistors and decoupling capacitors. The chosen gas mixture is $ArCO_2$ 70%:30%, which, with the described configuration at an operating voltage of 1750 V, has a maximum drift time of $\approx$150 ns. The first module (2 views) is currently being built; the production of straws is complete, the frame has been vacuum tested, and the installation of straws in one view is complete.

3. Test of a 64 straws prototype

A prototype with 64 straws (4 individual cells) was built to test the mechanical construction process and its results, and to verify the performance of the individual straw tube with a prototype of the front-end. The 4 cells were arranged in 2 couples, each one resembling the smallest selfcontained portion of one view. Two different approaches, one per group, were used both for wire fixation and spacers technology. The prototype was inserted in a vacuum proof vessel to measure the leak rate and to demonstrate the capability to operate in vacuum.

3.1. Test beam setup

The test was performed using a 120 GeV/c hadron beam at CERN SPS. Fast scintillators were used as time reference ($\sigma_t \approx 200$ ps). An external tracker was used ($\sigma_x \approx 100$ μm at prototype position) to measure the space time relation in the straw and to perform efficiency and space resolution measurements. The prototype was put orthogonal to the beam.

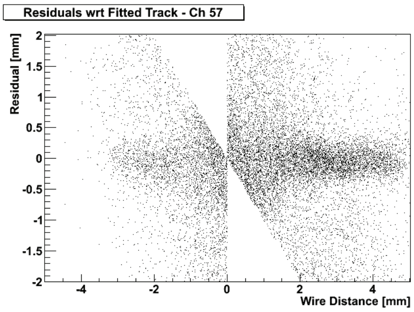

Fig. 7. Distribution of residuals on data

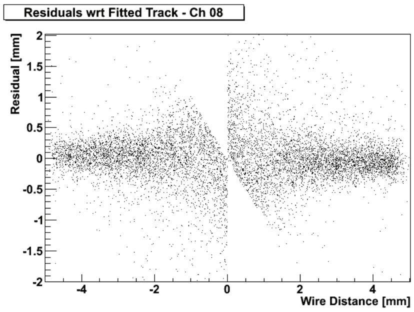

Fig. 8. Distribution of residuals on MC

3.2. Results

Fig. 4 shows the efficiency of the individual tube as a function of the distance from the wire. The straw illumination by the beam did not cover the tube in the whole transverse size, as it can be seen in Fig. 5; it was still possible to measure the space time relation on one side and find the position of the wire. The drift velocity was found to be slightly (≈15%) higher than expected, but simulation shows that this effect is compatible with a small (≈ 0.5%) water contamination of the gas mixture. As the external tracker was quite slow (≈ 300 Hz maximum rate) an accidental background due to mismatched tracks in the two detectors is visible and has been subtracted for the analysis. The residuals with respect to the expected distance of the track from the wire give an estimate of the resolution. Fig. 7 shows the residuals after alignment and calibration; it can be noticed that below 1 mm from the wire the constraint given by the drift based position measurement biases the estimate of the resolution. Figs. 7 and 8 show that the agreement between data and simulation is quite good. The average space resolution (Fig. 9) is ≈ 200 μm, which is fine for NA62 purposes, but worse than expected; the simulation shows that without any contribution of noise (blue points) the resolution would be significantly better. This effect is due to the time resolution of the leading edge being worsened by noise (Fig. 10); it reflects on the space resolution via the drift velocity, and its dependence from the distance from the wire, as shown by the simulation which includes noise (black points). The simulation starts from a GEANT4 [5] implementation of the geometry and, based on its output, generates ionization clusters, calculates drift time and diffusion contributions, exploiting results from MagBoltz. Once this information is available, the pulse shape of the signal is reproduced by summing the contribution of all the clusters, weighted with their charge, using a single cluster response function derived from laboratory measurements. Such a signal is then processed to simulate the time over threshold discriminator embedded in the CARIOCA. The contribution of noise is added by Fast Fourier Transform (Fig. 11) before the discrimination stage. The trailing edge time resolution (Fig. 12) is limited to 16 ns by

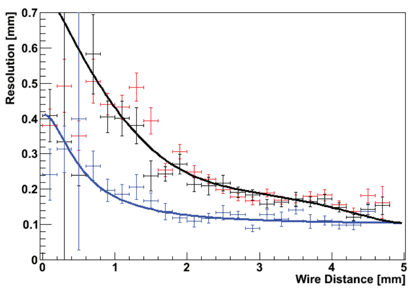

Fig. 9. Space resolution: MC without noise (blue), MC with noise (black), data (red); solid lines are the corresponding expectations. 100 μm constant contribution is due to the external tracker.

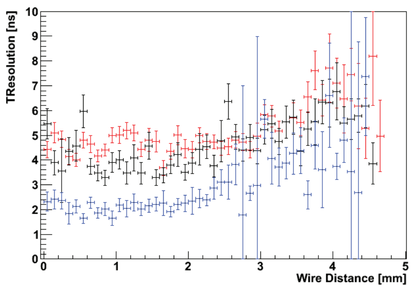

Fig. 10. Leading edge time resolution: MC without noise (blue), MC with noise (black), data (red)

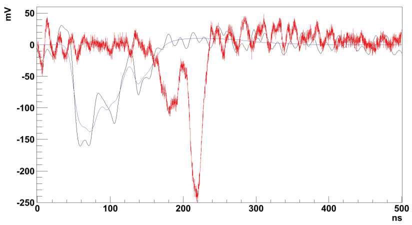

Fig. 11. Simulated signal without (blue) and with (black) noise, and a true signal (red) for comparison

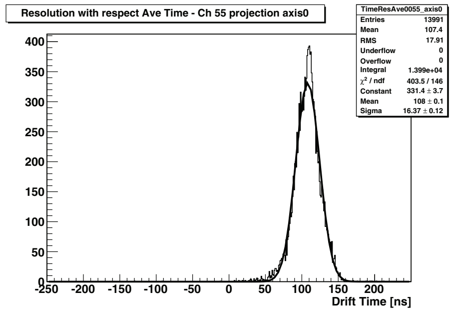

Fig. 12. Trailing edge time resolution

the slope of the signal given by the shaper; the amount of noise detected does not correspond to the intrisic (thermal) noise of the system, but it is due to external sources. However the simulation shows that also in ideal conditions, i.e. only with thermal noise, the trailing edge time resolution would not be better than 11 ns with the present front-end electronics.

4. Conclusions

A 64 straws prototype was built and tested; the chosen gas mixture, Ar:CO_2 70%:30%, was confirmed as final choice for the experiment, even though evidence of a small contamination of water during the test has been found. The estimated space resolution is fine for NA62, but limited by electronic noise, which affects significantly the time resolution. There is margin for improvement because the simulation shows that the intrinsic noise cannot account for the observed worsening of the time resolution.

For what concerns the final detector, the first module of the first chamber is being built, according to the technology based on the experience on the prototype. Using results from the test beam the estimated performance is as expected.

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