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The NA62 spectrometer acquisition system

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ABSTRACT: The NA62 low mass spectrometer consists of 7000 straw tubes operating in vacuum. The front-end electronics is directly mounted on the detector and connected by a flexible PCB. The front-end board provides the amplification, shaping, discrimination and time measurements of the analogue signals from 16 channels. After digitisation the data is sent to a VME 9U read-out board. The data, once matched with the trigger, is sent to the next step and used by the trigger level 1 algorithm. The front-end and read-out systems of the detector will be presented along with the first results of the detector performances.

KEYWORDS: Control and monitor systems online; Gaseous imaging and tracking detectors; Front-end electronics for detector readout; Data acquisition concepts

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1 The NA62 experiment

NA62 is a fixed target experiment at CERN [1], it aims at measuring the Branching Ratio (BR) of $K^+ \rightarrow \pi^+ \nu \bar{\nu}$ predicted to be $(9.11 \pm 0.72) \times 10^{-11}$ by the Standard Model (SM) [4]; such a rare process requires a significant technological challenge to achieve the needed background suppression ($O(10^{12})$), and to identify ~ 100 signal events within two years of data taking. The measurement of this branching ratio with an accuracy of 10% allows one to put constraints on several models concerning New Physics and a direct measurement of the CKM matrix element V_{td} .

NA62 has been designed to be an hermetic detector for ultra-rare kaon decays; this feature allows one to reduce efficiency problems of vetoes at very low energy and protects the measurement from low energy products of hadronic interactions. The apparatus consists of a long (~ 250 m from target to dump) beam line. The detector can be ideally divided in two groups of sub-detectors. In both sectors, particle identification and spectrometer detectors are foreseen, in order to identify and measure 4-momentum of particles. The beam related detectors are a CEDAR detector called K-TAG [2] able to identify the beam kaon component, and a silicon spectrometer (GigaTraKer [3]) measures the kaon 4-momentum. The second group contains sub-detectors dedicated to measure the K^+ decay products. Particle identification and veto techniques are commonly adopted.

The experimental apparatus has been almost fully commissioned during a pilot run from mid-October to mid-December 2014. The first year of data taking started in June 2015.

A large fraction of the rejection power of the experiment is given by kinematic rejection, which relies on the measurements performed by the beam (GTK) and decay products (Straw Tracker) spectrometers. They are both designed to work in vacuum. The first (GTK) is a small area silicon pixel detector, while 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 NA62 straw tracker

The NA62 STRAW Spectrometer is composed of 4 chambers and 1 dipole magnet (0.36 T, 270 MeV/c p_T kick). A schematic of the chamber and a picture of one view are reported in figure 1a and figure 1b. The chambers are separated by 10 m, except for the last one (15 m), and the magnet is placed between the second and the third one. The spectrometer is integrated in 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 of 4 views (X, Y, U and V), arranged in 2 modules (figure 1b), leaving a hexagonal hole of ~ 12 cm diameter for the un-decayed beam and with 2.1 m acceptance. Each view is composed by 4 layers of straws with a pattern that guarantees the geometrical coverage for tracks with an angle up to ~ 50 mrad from the normal to the view plane. This design should guarantee an average position resolution $\sigma < 130$ μm for the individual view.

The elementary active component is a drift tube ($\varnothing = (9.75 \pm 0.05)$ mm and 2.1 m long) realized with a 36 μm thick Mylar wall straw, with Cu-Au metallization (50–20 nm), produced by ultrasonic welding from a ~ 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. The chosen gas mixture is Ar:CO₂ (70%:30%), with an operating voltage of 1750 V (expected gain 10^5).

The electronics has been designed in order to fit the experimental requirements:

- Overall particle rate 15 MHz
- Single channel max rate 700 kHz and mean rate 60 kHz
- Total MIP charge generated 100 fC and 10 fC of effective charge
- anode and cathode resistance are 180 Ω and 70 Ω respectively
- Total number of channels 7168
- The anode and cathode resistance are 180 Ω and 70 Ω respectively.

The general scheme of the system is presented in figure 2. The front-end electronics is placed directly on the detector and is sealing the gas volume, for this reason is called COVER. A COVER reads-out 16 channels and is connected to the detector using a flexible PCB connector called WEB, it hosts the high voltage resistors and decoupling capacitors. After digitization and time measurements the data are sent to the Straw Read-out Board (or SRB) where the data are selected, packaged and sent to the PC-farm, each board can read-out 16 COVERS (equivalent to 256 channels).

The next two sections will describe in details the COVER and SRB functionalities and architecture. The last one will present some results from the NA62 Pilot run (October-December 2014).

3 The front-end: COVER

The front-end electronics modularity is following the straw mechanical fixation and gas distribution modularity (figures 3a and 3b). There are 16 straws in the basic unit of gas, high voltage and

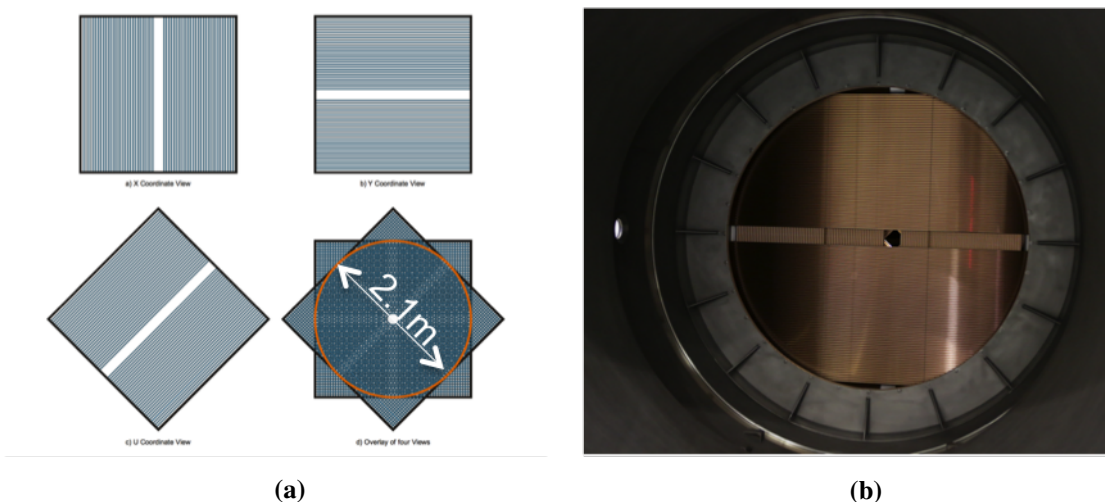


Figure 1. (a) Schematics of the views combination; (b) final chamber installed on the beam line.

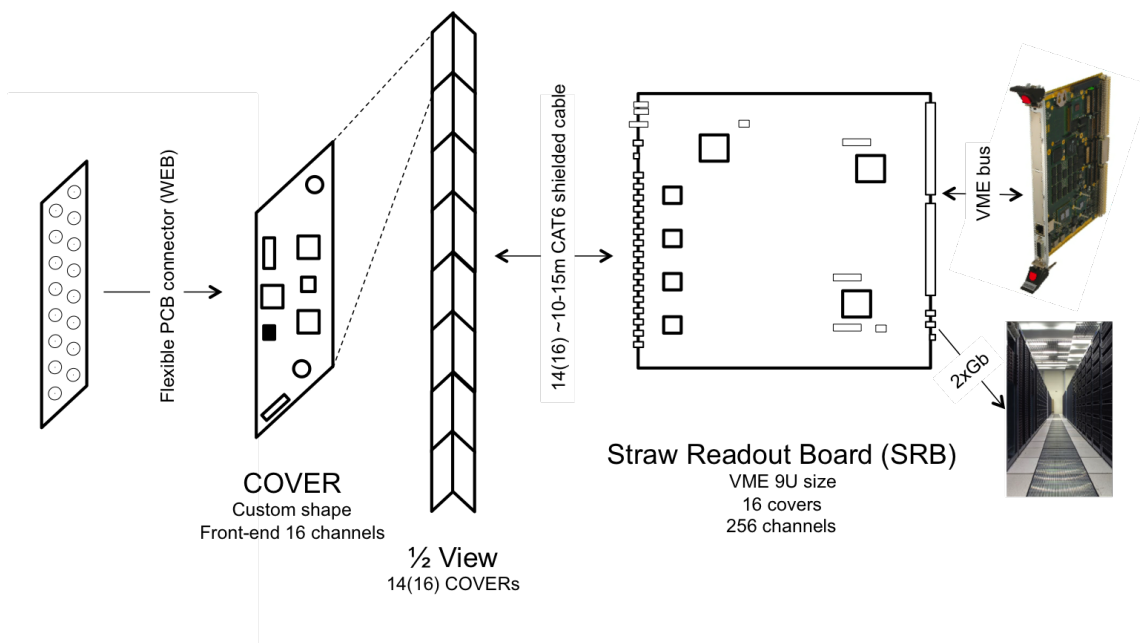


Figure 2. System overview.

readout. The electronics is based on a 8-channel analogue front-end chip (CARIOCA [5]) containing a fast preamplifier, semi-gaussian shaper, a tail cancellation circuitry, base-line restorer and a discriminator. The ion tail cancellation is of utmost importance for straws with high rate of particles. Pile-up at high particle rate would cause loss of both efficiency and time resolution. The front-end board thus contains 2 CARIOCA chips, each serving 8 straws; one I2C controlled chip with 16 DACs for controlling the threshold.

Both leading and trailing edges from the straws signals provide useful information. The leading edge time depends on the particle track distance from the wire so by measuring this time one can

obtain the precise crossing position of the particle through the straw. The trailing edges occur at the same time for all straws hit by the same particle, independently from their crossing distance from the wire. This is due to the arrival of the last primary ionization cluster close to the wall. The trailing edge time is used as a validation of straws on a track, thus reducing false hits and improving track fitting.

The frontend board is also used as a cover for the working gas volume, so it was built gas tight, always using multiple blind vias for passing the signals from bottom to top side. It contains high voltage filter and connector to provide straws with HV power.

The time measurement is performed on an FPGA located directly on the board. Leading and trailing are treated in parallel and the TDC time resolution is of 0.78 ns.

Clock is provided externally in order to reduce electromagnetic noise. All the connectivity of the board is provided by a RJ45 connector linked to the read-out board using a shielded cat6 Ethernet cable. The 4 twisted pairs are driving LVDS signals: 1 is the external clock (40 MHz), 2 are the data links and the last one is implementing the command link.

4 The read-out: SRB

The Straw Read-out Board is a custom 9U VME board. It is based on Altera Cyclone V FPGAs and can handle data from a maximum of 256 channels, that is translated in 8 boards per station. All the boards are host in the same VME crate, and all the interface is provided by the VME bus using a Single Board Computer as bridge.

In figure 4 the board is presented and the main components are highlighted. The chips will be here described and their main functionalities described:

Front-end. These chips are implementing the command and data links from/to the COVERS. Each chip is responsible for 4 covers (64 channels). Data coming from the covers are duplicated and send to both Event Manager and Board Manager. A coarse time is also generated on the chip in order to reduce the load on the counters placed directly on the COVERS.

Trigger Manager or TM. It is directly connected to the TTC-rx connector and will receive the trigger signals digitizing them and sending to the Event Manager. In the future firmware development it could be able to generate trigger primitives.

Event Manager or EM. This FPGA is the data processor. It receives the data stream from all the front-ends and performs time ordering. In parallel receives the triggers time stamps from the TM and performs the data selection opening a tunable time window (from 25 to 400 ns) around the trigger time. Before transmission data are encapsulated in Ethernet frames implementing UDP as transport-layer.

Board Manager or BM. This element is the manager of the VME bridge able to communicate with a Single Board Computer (SBC) located on the same bus. The bridge is able to fully configure and control the hardware from the SRBs to the COVERS. The chip is also able to store up to 2 GB of raw data (no selection or time order is applied) in a dedicated DDR3 memory and download them directly to the SBC using the VME bus. This last feature is widely used in order to debug the detector and part of the firmware.

In figure 5 are reported in detail the data and command paths.

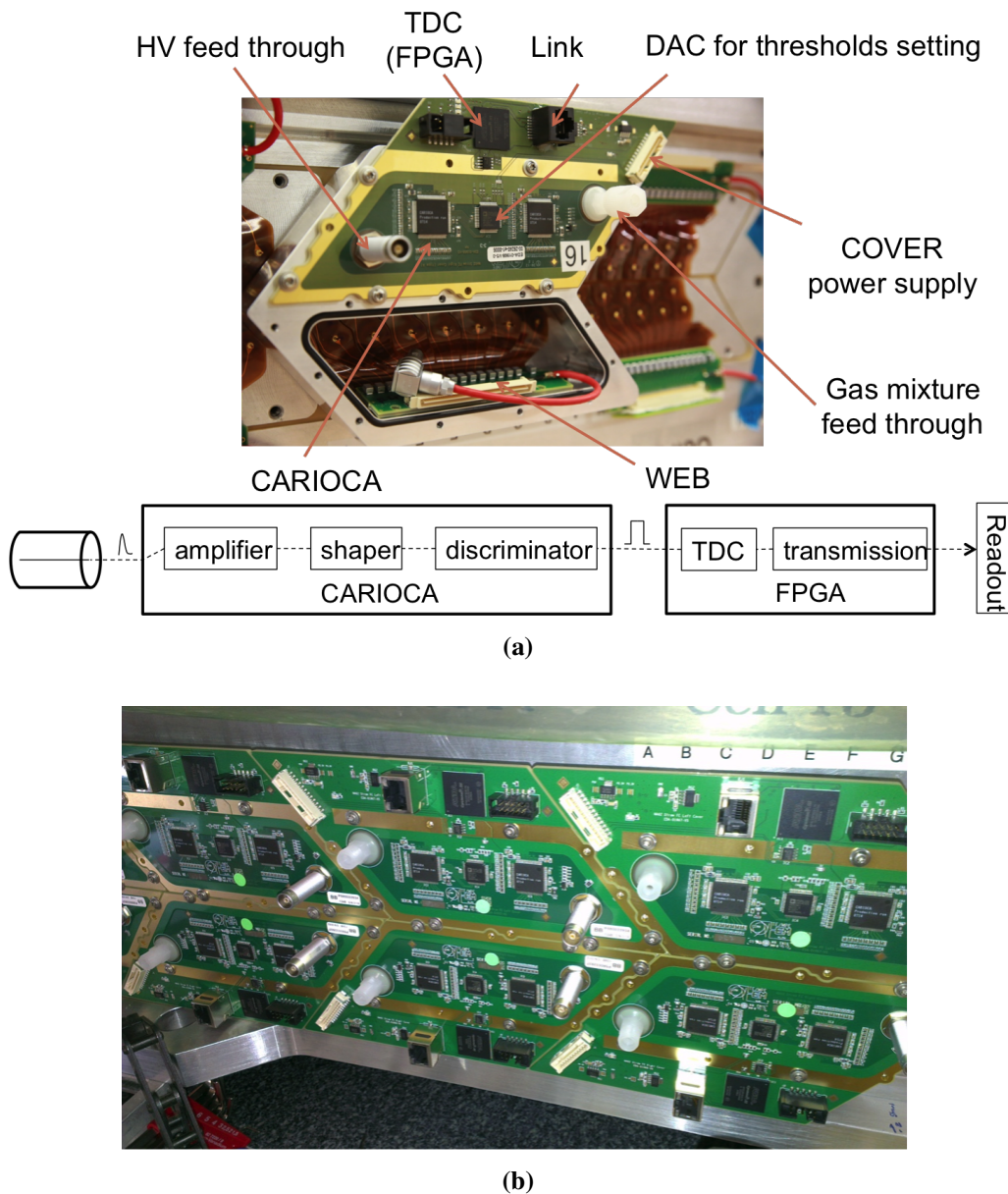


Figure 3. (a) Details and schematic of the COVER; (b) COVERs mounted on the detector.

5 First results from 2014 Pilot Run

The read-out system was in trigger-less mode in order to study the detector performances and was tested up to the 30% of the nominal intensity (~ 5 MHz per chamber), limit imposed by the Gigabit Ethernet. The data shown in this section has been collected in the last ten days of the run with stable conditions. The reference detector used was the charged hodoscope that was also part of the trigger logic.

An on line monitoring system was implemented in order to monitor the detector performances. It was able to handle data from one full spill and plot it in an interactive ROOT GUI.

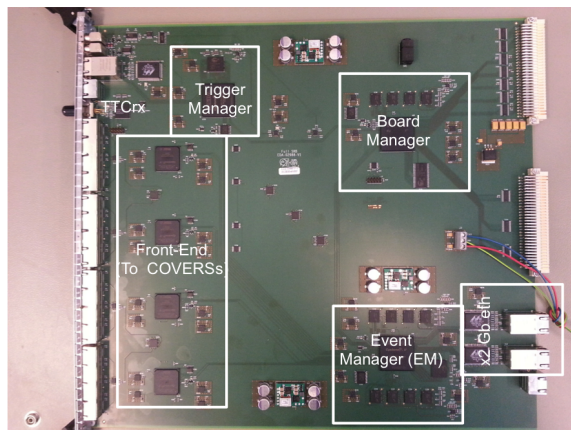


Figure 4. The Straw Readout Board or SRB.

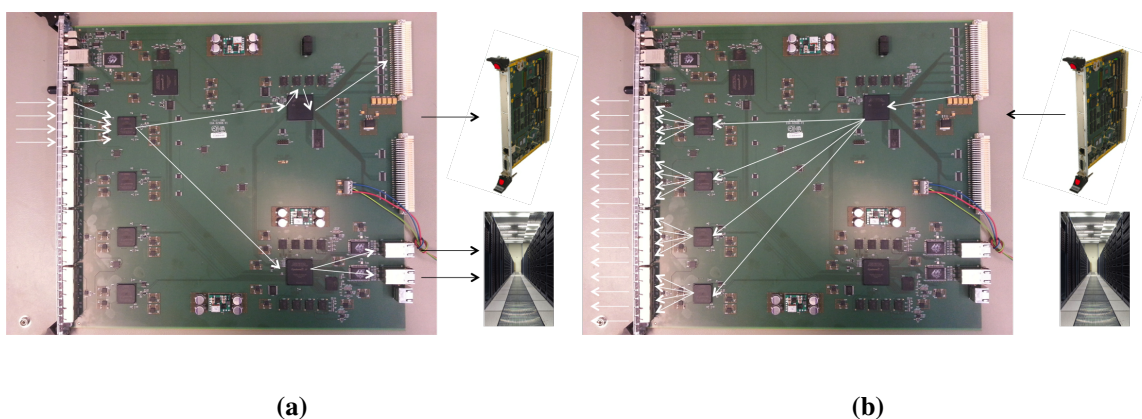


Figure 5. The data (a) and command (b) Data (right) and command (left) paths on the SRB.

A crucial step has been the detector calibration:

- Radius-Time curve (r-t curve)
- Time alignment
- Geometrical alignment
- Local magnetic field correction

As first approximation the r-t curve has been computed using a GARFIELD simulation [7], no channel-by-channel fine tuning has been applied. An important upgrade will be the use of a muon run in order to calibrated the detector using an auto-calibration method [8].

Time alignment is performed channel-by-channel using the leading time cumulative distribution (figure 6a) with a precision of 5 ns.

Both geometrical alignment and magnetic field corrections have not been applied during the run.

The time resolution associated to the track has been computed as the mean value of the trailing edges of all the hits associated with the track during the reconstruction (figure 8). The preliminary result is ~ 6 ns that is within the expectations (< 10 ns).

The missing mass squared using the nominal beam direction has also been computed, the preliminary result is reported in figure 7a. A major improvement of the resolution will follow the introduction of the measured beam particle track fit using the beam spectrometer (GTK).

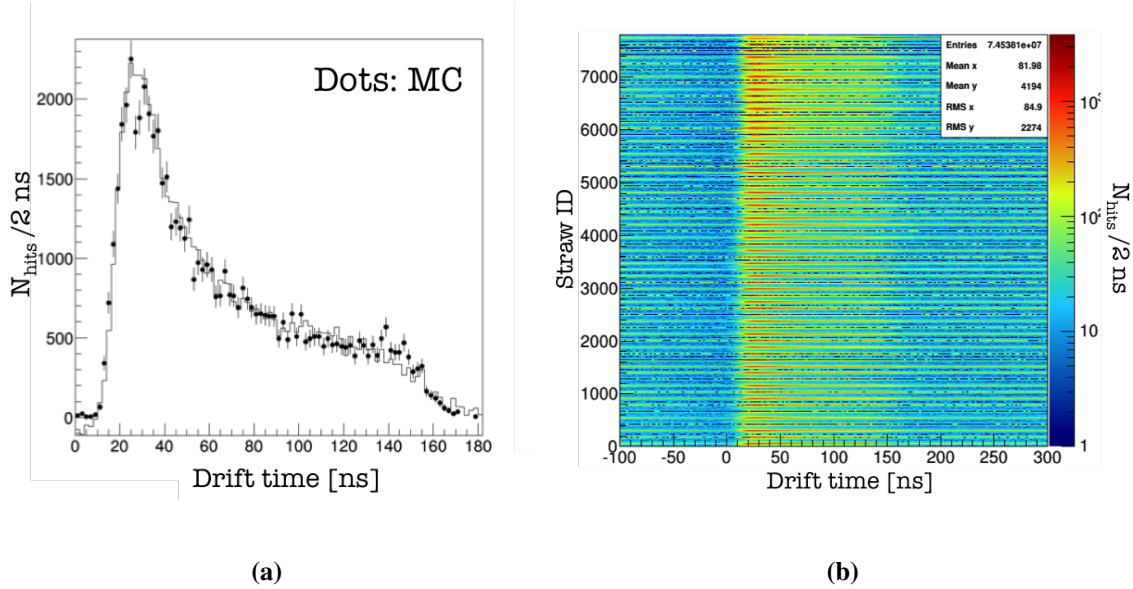


Figure 6. (a) Data-Montecarlo leading distribution comparison; (b) leading distribution channel-by-channel alignment.

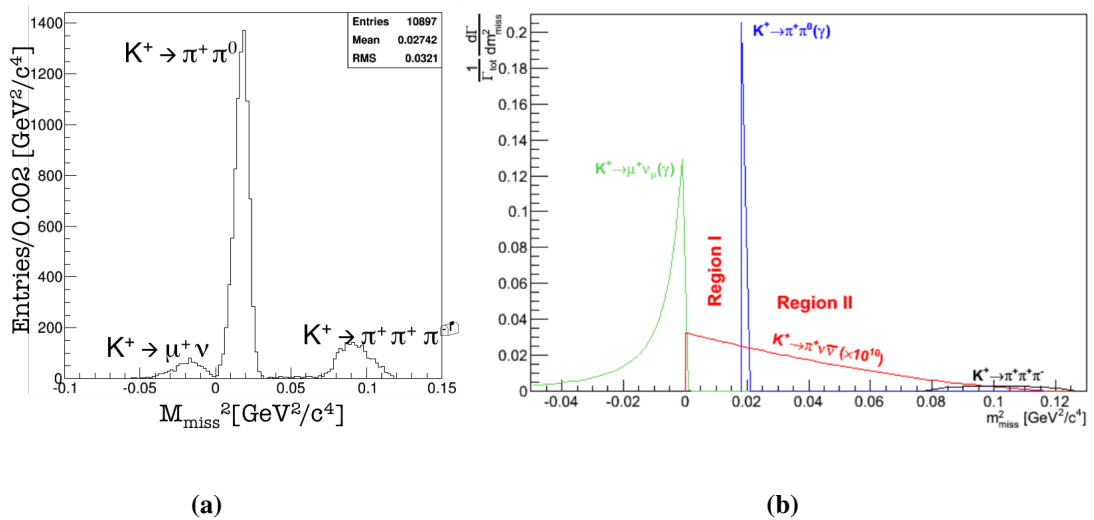


Figure 7. (a) Missing mass squared for single pion reconstructed in the straws with a momentum below 35 GeV, the nominal beam direction has been used for the vertex reconstruction; (b) analytical computation of theoretical behaviour of the missing mass squared for the signal channel and the main backgrounds.

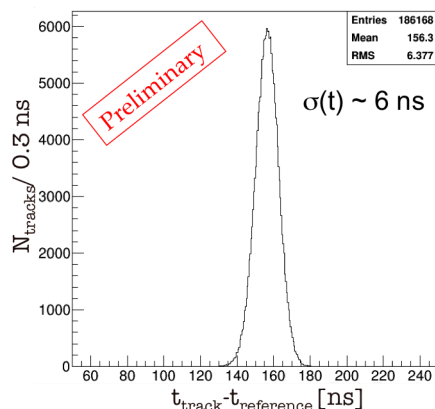


Figure 8. Time resolution of the trailing edges computed using hits belonging from a reconstructed track.

6 Conclusions

The NA62 spectrometer data acquisition system has been almost fully commissioned during the 2014 Pilot Run. The maximum beam intensity achieved was about 30% of the nominal. The main functionalities have been tested: commands and hardware control, thresholds stability and data path. Extended data quality studies are ongoing with data collected during the 2015 run (June–November). One very important goal will be test the detector with a beam intensity as close as possible to nominal.

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