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A new analogue sampling readout system for the COMPASS RICH-1 detector

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Abstract

A new electronic readout for CsI-coated multiwire proportional chambers (MWPC), used as photon detectors in the COMPASS ring imaging Cherenkov (RICH) detector, is described. A prototype system comprising more than 5000 channels has been built and tested in high-intensity beam conditions. It is based on the APV25-S1 analogue sampling chip, and replaces the GASSIPLEX chip readout used previously. The APV25 chip, although originally designed for Silicon microstrip detectors, is shown to perform well even with "slow" signals from an MWPC, maintaining a signal-to-noise ratio (SNR) of 9. For every trigger the system reads out three consecutive amplitudes in time, thus allowing to extract information on both the signal amplitude and its timing. This information is used to reduce pile-up events in a high-rate environment. Prototype tests of the new readout electronics on a central RICH photocathode in nominal COMPASS beam conditions showed that the effective time window is reduced from more than 3 μs for the GASSIPLEX to less than 400 ns for the APV25 chip. This leads to a significant improvement of the signal-to-background ratio (SBR) with respect to the original readout. A gain by a factor of 5–6 was experimentally verified in the very forward region of phase space, where pile-up due to the muon beam halo is most significant. Owing to its pipelined architecture, the new readout system also considerably reduces the dead time per event, thus allowing to make use of trigger rates exceeding 50 kHz.

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1. Introduction

COMPASS (COmmon Muon and Proton Apparatus for Structure and Spectroscopy) [1] is a multi-purpose two-stage magnetic spectrometer, built for the investigation of the gluon and quark structure and the spectroscopy of hadrons using high intensity muon and hadron beams ($100-300\,\mathrm{GeV}/c$) from CERN's Super Proton Synchrotron (SPS). Scattering a polarised beam of $160\,\mathrm{GeV}/c$ μ^+ from a polarised deuterium target, results on the deuteron spin-dependent structure function g_1^{d} [2–4], on transverse spin asymmetries [5,6], and on the gluon polarisation in the nucleon [7] have been obtained from the first phase of data taking between 2001 and 2004. The second phase of COMPASS started in 2006 and will continue at least until 2010. The successful completion of the spin program as well as hadron spectroscopy requires increased beam intensities up to 10^8 part./s and trigger rates exceeding 50 kHz. Good particle identification (PID) is a prerequisite for both the spin structure and the spectroscopy studies, in particular in the charm sector. The COMPASS RICH-1

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detector [8] is a gas-filled ring imaging Cherenkov (RICH) detector which identifies particles with momenta between 5 and 43 GeV/c, with a large horizontal and vertical acceptance of 250 and 180 mrad, respectively. Cherenkov photons produced in the radiator gas (80 m^3 of C_4F_{10}) are focused by a VUV mirror wall onto the photon detectors, consisting of eight multiwire proportional chambers (MWPC) with CsI photocathodes with a total active surface of 5.3 m^2. The photocathodes are segmented into 82944 pads of 8×8 mm^2 size. The quantum efficiency of the photocathodes was estimated to be about 20% in the wavelength region of maximum sensitivity of the system. The MWPCs operate with pure CH_4 gas at atmospheric pressure with a gain of about 4×10^4.

2. Motivation for upgrade

In the first phase of data taking the performance of the COMPASS RICH-1 detector suffered from two limitations of the front-end electronics: (a) the long peaking time of 1 μs of the GASSIPLEX analogue signal processor chip, leading to considerable pile-up of out-of-time signals in a high-intensity environment as COMPASS, and (b) the long dead time of 5 μs after a readout cycle, necessary to permit baseline fluctuations to fade away after the reset signal. Since the GASSIPLEX chip uses a track and hold circuit to detect the peak signal of each of its 16 input channels, eight of which are then multiplexed onto one output line, the extraction of timing information from the data is not possible. The effective time window, during which pile-up hits cannot be distinguished from in-time hits, was extracted by comparing Monte-Carlo simulations with real data. Fig. 1 shows the distribution of reconstructed charged particle masses in the kaon mass region, obtained from Monte-Carlo simulations for different time windows of the RICH-1 front-end electronics. The curve corresponding to a time window of 3.2 μs was found to agree well with real data. As can be seen from this figure, the signal-to-background ratio (SBR) can be improved considerably by reducing the time gate to a value of the order of 400 ns. A further reduction of the time gate beyond this value, however, is not expected to yield a much more improved SBR due to a large background component which is correlated in time with the signal, as shown in Section 5.2.

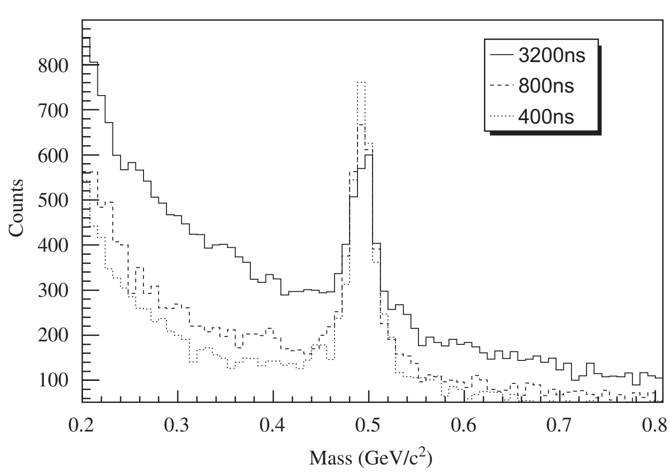

Fig. 1. Distribution of reconstructed charged particle masses in the kaon mass region for different effective time windows of RICH-1.

Table 1
Fraction of events lost due to dead time for different readout architectures of COMPASS RICH-1, as a function of trigger rate

Trigger rate (kHz)	10	20	30	40	50
GASSIPLEX	5%	10%	13%	17%	20%
APV25 (20 MHz)	0	2%	11%	23%	33%
APV25 (40 MHz)	0	0	0.5%	2.5%	5%

We chose to make use of the APV25-S1 analogue readout chip to shorten the effective time gate of the RICH-1 readout to a value of this order. In addition, the pipelined architecture of the APV25 chip, described in Section 3, allows to overcome the limitation given by the dead time of the GASSIPLEX, essential for operation of RICH-1 with trigger rates of 50 kHz and beyond, as envisaged for the hadron program of COMPASS. Table 1 shows the fraction of events lost due to dead time of the different readout systems as a function of the trigger rate. The two options for the APV25 correspond to a readout of the multiplexed signal at 20 and 40 MHz, respectively.

3. Principle of sampling readout

The APV25 chip is a 128-channel preamplifier/shaper ASIC with analogue pipeline, originally developed for the CMS Silicon microstrip tracker [9], and successfully adopted for the COMPASS GEM [10] and Silicon [11] tracking detectors.

Each channel of the APV25 consists of a charge-sensitive preamplifier followed by an inverter stage with unit amplification to allow signals of both polarity to be processed, and a CR-RC type shaping amplifier. Its time constants are adjustable within a wide range from 50 to 350 ns by changing the bias of the analogue stages via feedback transistors, thus opening the possibility to use the APV25 to read "slow" detectors as MWPCs. The amplifier output amplitudes are sampled at a frequency of 40 MHz and stored in a 192 cell analogue pipeline. Upon arrival of an external trigger at the chip, the cells corresponding to the known trigger latency (up to 4 μs) are flagged for readout. The analogue levels of the flagged cells for 128 channels are then multiplexed at 20 or 40 MHz onto a single differential output. In order to get information on the signal shape, and thus on the timing, not only the sample corresponding to the peak of the expected signal is transferred, but in addition two samples on the rising edge of the signal are read out, as shown in Fig. 2. In our system, the time gap between these individual samples sent out by the APV25 can be varied in steps of 25 ns from 25 ns to