Scintillating Fibre Tracker Front-End Electronics for LHCb upgrade

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I. Introduction

The LHCb detector will be upgraded during the next LHC shutdown in 2018/19. The tracker system will be replaced by new technologies in order to cope with the increased hit occupancy and the higher radiation dose: A detector made of scintillating fibres read out by silicon photomultipliers (SiPM) is envisaged[1]. The detector will consist of 12 planes of 5 layers of 250μm fibres stacked (see figure 1), covering a total area of 5x6m^2 and leading to a total of over 500k SiPM channels which need to be read out at 40MHz. The desired spacial resolution on the reconstructed hit is 100μm. The scintillating fibres will act as a light generator and signal transmission medium to guide the scintillation light to the SiPMs sitting at the outer boundaries of the detector.

Fig. 1. Scintillating fibres mat cross section

Even if this technology has proven to achieve high efficiency and spatial resolution, its integration within a LHC experiment bears new challenges. Several SiPMs from different manufacturers and with different signal properties are currently discussed for the readout.

The low **P**ower **A**SIC for the S**CI**ntillating **FI**bres **T**racker (PACIFIC) is developed to readout the SiPMs with no interface components between devices and ASIC. The ASIC will handle 64 or 128 channels with analog signal processing and digitization. A current prototype includes 8 channels.

II. Silicon Photo Multipliers

The multi-channel SiPM arrays have been adapted to the detector geometry reducing the dead area between channels. A total of 64 channels are arranged in a single die with common cathode connection and channel size of 0.23x1.32mm^2. With a total number of 96 micro-cells. Two dies are packaged together with only 0.25mm of dead area between them (see figure 2).

Two different manufacturers (Ketek and Hamamatsu) have provided samples for characterization. The pixel size is 57.5x62.5μm for the 2014 trenched detectors from Hamamatsu. Ketek provided two different versions with 82.5x62.5μm and 60x62.6μm pixel size.

To maximize the photon detection efficiency (PDE), the detectors with trenches are typically operated with a high over-voltage (3.5V) which is significantly higher than that used in earlier experiments[2]. This results in better channel-to-channel gain uniformity. The time response for the SiPM is an important characteristic to achieve fast signal shaping and integration but with short recovery time. The recovery time constant for the pixel (20ns for Hamamatsu and 100ns for KETEK) was chosen such that no significant dead time occurs due to the signal and noise induced discharge rate of the pixel.

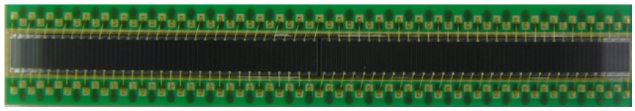


Fig. 2. Multi channel SiPM prototype

The SiPMs are placed in a region with a low level of ionising radiation. A moderate ionising dose of 40 to 80 Gy after 50fb^{-1} is estimated to be present in the worst case region. The dominating radiation effect is produced by the neutron flux for which a fluence of 10^12 neutrons cm^2 is expected (for an operation time equivalent to 50fb^{-1}.

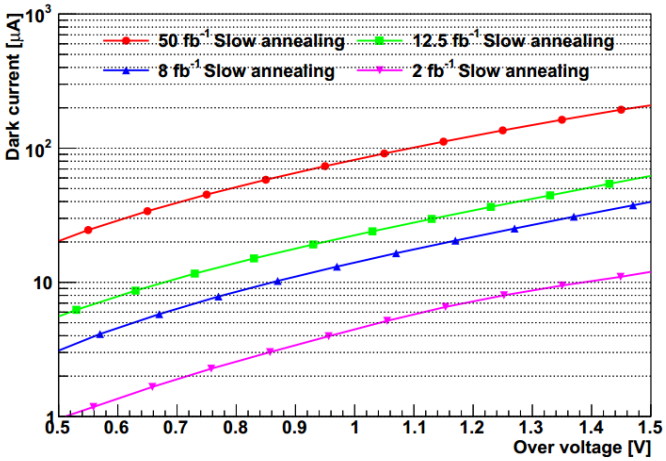
The main effect of the neutron radiation is an increase of the dark count rate. For this reason it is planned to operate the SiPMs at a temperature of -40°C for which the device presents much smaller dark count rate and it's increment with the neutron irradiation is kept to a reasonable level. Irradiation studies have been done in the LHCb cavern, in the neutron irradiation facility at Ljubljana and with a Pu-Be neutron source. The dark current is reduced by a factor of two when the temperature is reduced by 10 °C, as seen in figure 3.

The non-triggered full bunch crossing read-out scheme for the LHCb Upgrade requires data reduction by zero suppression. This will be done by searching and building clusters from hits of neighbouring channels. The clustering will be performed on 128 detector channels with clusters comprising at least two channels.

III. Readout ASIC

The PACIFIC ASIC will readout the previously described SiPM sensors. First measurements of the signal produced by the 2.5m scintillating fibres showed a large dispersion in the time of arrival of the light (see figure 4, depending on the impact point of the crossing particle. This effect is increased if a mirror is placed at the end of the fibres.

The ASIC must deal with this delay and also with two very different decay times of the different sensors (20ns for Hamamatsu and 100ns for Ketek). For this reason a simple gated integrator design was choosen.



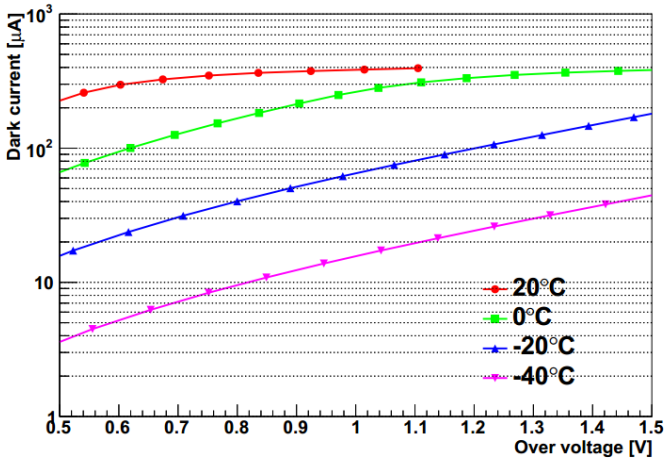


Fig. 3. Left: results of irradiation with neutrons to the equivalent flux expected for an integrated luminosity of 50fb^{-1}. Right: results of irradiation to an equivalent flux expected for an integrated luminosity of 8fb^{-1}. All plots are given for fully annealed detectors after one week annealing at 40° (detector is Hamamatsu with no trenches).

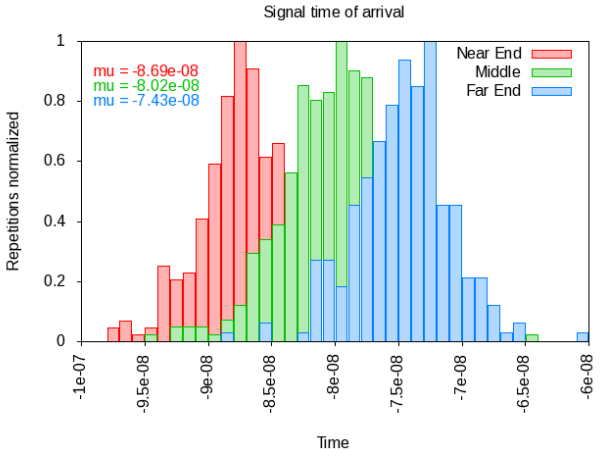


Fig. 4. Signal arrival time

The blocks diagram of the ASIC channel is shown in figure 5: The first stage is a current conveyor with low input impedance (≈34Ω) and high bandwidth. It is followed by a fast shaper (≈10ns shaping time to cope with signal arrival times) and the gated integrator. This design generates an output integrating around 90% of the signal before the end of the current bunch crossing (25ns). The digitization is done using a 2 bits non-linear flash ADC operating at 40MHz (it is based on three hysteresis comparators). To account for the different signal time constants of the different SiPM types the shaping parameters can be configured. Digital slow control (based on standard I2C) and serialization of the digital output is also included (serialization takes 4 bits, from two channels at 160MHz). The power consumption has been kept bellow 8mW per channel.

During 2013 two prototypes where submitted including just the current conveyor in the first prototype (PACIFICr0), adding shaper and integrator in the second (PACIFICr1). A third prototype has been submitted in 2014 to provide usable electronics for a test system with the full processing chain with direct digital output (PACIFICr2) and comprising 8 channels.

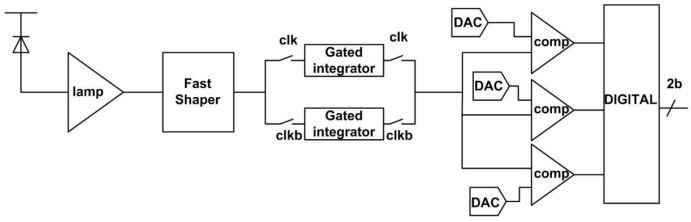


Fig. 5. PACIFICr2 Blocs diagram

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Abstract

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A detector made of scintillating fibres read out by silicon photomultipliers (SiPM) is envisaged for this upgrade. Even if this technology has proven to achieve high efficiency and spatial resolution, its integration within a LHC experiment bears new challenges. The detector will consist of 12 planes of 5 to 6 layers of 250μm fibres stacked covering a total area of 5x6m^2. The desired spacial resolution on the reconstructed hit is 100μm.

SiPMs have been adapted to the detector geometry reducing the dead area between channels. A total of 64 channels are arranged in a single die with common cathode connection and channel size of 0.23x1.32mm^2. Two dies are packaged together with only 0.25mm of dead area between them. Radiation tolerance of such devices is an important challenge. Operation at low temperatures will be crucial to achieve the desired performance. Several manufacturers have produced prototypes for testing with different characteristics but same form factor. This size leads to a total of over 500k channels which need to be read out at 40MHz.

The PACIFIC ASIC will readout of SiPMs with no interface components between devices and ASIC. It will handle 64 or 128 channels with analog signal processing and digitization. A current prototype comprises 8 channels. The first stage is a current conveyor followed by a fast shaper ($\approx$10ns to cope with signal arrival times) and a gated integrator. The digitization is done using a 2 bits non-linear flash ADC operating at 40MHz. The power consumption has been kept bellow 8mW per channel.