Development of the BCM' system for beam abort and luminosity monitoring in ATLAS based on a segmented polycrystalline CVD diamond system and dedicated front-end ASIC

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Abstract

The High Luminosity upgrade of Large Hadron Collider (HL-LHC) will increase the LHC luminosity and with it the density of particles on the detector by an order of magnitude. For protecting the inner silicon detectors of the ATLAS experiment and for monitoring the delivered luminosity, a radiation hard beam monitor was developed based on polycrystalline Chemical Vapor Deposition (pCVD) diamond detectors and a new dedicated rad-hard front-end ASIC. Due to the large range of particle flux through the detector, flexibility is very important. To satisfy the requirements imposed by the HL-LHC, our solution is based on segmenting diamond sensors into devices of varying size and reading them out with new multichannel readout ASICs divided into two independent parts - each of them serving one of the tasks of the system. This paper describes the system design including detectors, electronics, mechanics and services and presents preliminary results from the most recent detectors fabricated, using our prototype ASIC with data from beam tests at CERN.

Keywords: ATLAS detector, ITk, beam conditions monitor, pCVD diamond detectors, test beam

1. Introduction

The Large Hadron Collider, located at CERN, will be upgraded to the High-Luminosity LHC in the coming years, which will increase collision rate to up to 200 inelastic p-p collisions per bunch crossing. The ATLAS detector will also be upgraded and a novel Beam Conditions Monitoring Prime (BCM') system will be installed in the new silicon Inner Tracker (ITk) [1]. BCM' will provide bunch-by-bunch online luminosity information, background monitoring and serve as a protection system for aborting the beam in case unstable beam conditions are detected. The system will be based on highly radiation tolerant polycrystalline Chemical Vapor Deposition (pCVD) diamonds [2] and a custom front-end Calypso ASIC [3].

2. System overview

The operating principle of the BCM' will be similar to the BCM detector [4], currently operational in the ATLAS detector. The BCM' will consist of two detector rings with a $\sim$ 10 cm radius mounted symmetrically at ± 1.9 m from the interaction point. Each ring will have four detector stations, each station equipped with one silicon, a 3D pCVD diamond and two 10×10 mm^2 planar pCVD diamond detectors for luminosity measurements. A 5×5 mm^2 planar pCVD diamond on each station will serve the beam abort functionality. All pCVD diamond detectors will be 500 μm thick. Detector stations will be inclined at $\sim 45^o$ towards the beam, which will increase the particle ionization path and effectively

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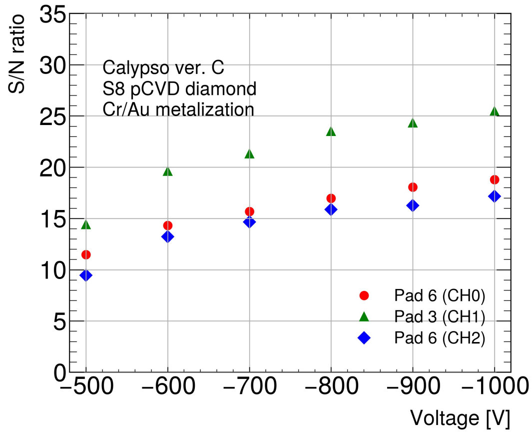
remove erratic leakage currents in diamonds. The location at ±1.9 metre allows to discriminate background events from collisions at the interaction point based on their Time-of-Flight. Currently the beam abort condition is met if three out of four detector stations on each ring trigger on a background event with elevated ionization in two consecutive beam orbits. Additional beam abort algorithms are being looked into. The front-end readout Calypso ASIC was developed in 65 nm technology and is suitable for our rad-hard environment with the total ionization dose of 3 MGy. It features two separate front-end (FE) amplifiers for the abort and luminosity functionality, a fast 1 ns rise time, 200 ps jitter and 200 e^- noise at 2 pF detector capacitance. Gain and constant fraction discriminator (CFD) settings of each of the ASIC's four channels can be configured separately. Outputs are LVDS signals with Time-of-Arrival and Time-over-Threshold information. An increased 256 step CFD threshold range, internal pulser, I^2C addressing and bandgap reference voltage were added in the latest submission of the ASIC.

3. Recent CERN SPS H6A test beam results

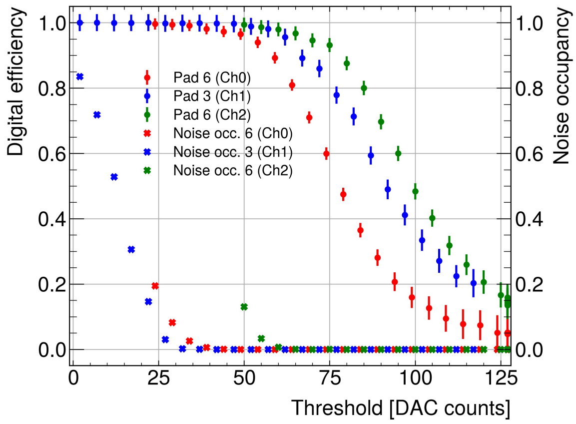
Detectors from different wafers with various pad geometry, metallization and different bias voltage polarities have been tested with Calypso ASIC in high gain luminosity FE configuration in multiple test beam campaigns in CERNS SPS H6A during the last 2 years [5]. 120 GeV pion beam with MALTA telescope [6] for tracking and a series of DRS4 chips for readout was used in the setup. Using the detectors with the final 6:3:6 pad ratio mask design we measured analog signal to noise (S/N) ratio of 25 for Pad 3 at ±1000 V, with the complete voltage scan plotted in Figure 1. The system can reliably achieve a S/N ratio > 20 at ±800 V bias voltages. Threshold scan shown in Figure 1 shows Calypso ASIC can be run at adequate efficiency and low noise occupancy for all three tested detector channels. This measurement used Calypso ASIC version C with 128 CFD threshold steps of $\sim$ 100 e^- per step. One detector was irradiated with fast neutrons in TRIGA reactor at JSI to the fluence of 1×10^{15} n/cm^2. Testbeam measurements of the irradiated detector showed a high detection efficiency > 99% for MIPs at 5σ threshold.

4. Conclusions

Development of the novel BCM' detector is well underway. The full feature FE Calypso ASIC design was submitted and the recent test beam results of pCVD diamond detectors and Calypso FE readout show good performance and indicate the detector will meet the specifications.



(a)



(b)

Figure 1: (a): Signal to noise ratio measured at different bias voltages with the final 6:3:6 detector pad ratio for the S8 pCVD diamond. (b): Threshold scan for the same diamond at -1000 V.

Funding

The BCM' project is supported by the Slovenian Research Agency (grant No. J1-3032 and P1-0135).

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