The TARGETX ASIC for the Belle II Muon Detector Scintillator Upgrade

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***Abstract*—In order to cope with the much higher backgrounds expected for the Belle II and SuperKEKB upgrades, the K_{Long} and Muon (KLM) innermost barrel layers and endcap resistive plate chambers have been replaced with wavelength-shifting fiber embedded scintillator strips. Hamamatsu silicon photomultipliers (MPPCs) are used to instrument these strips. While the individual photo-electron resolution is expected to deteriorate due the neutron dose, the use of waveform sampling ASICs for readout will allow gain and threshold tracking, to compensate for these effects. Instrumentation of the more than 20,000 channels of readout is achieved in a very cost-effective manner using a variant of an ASIC initially designed for low-cost instrumentation of a future Cherenkov Telescope Array. The TARGETX is a 16-channel, 1 GSa/s Switched Capacitor Array transient waveform recorder with built-in, encoded triggering and 16k storage samples per channel storage depth. Measured performance meets or exceeds all requirements. Over 25,000 channels have been fabricated and results from the production verification will be reported.**

I. Introduction

EXTENDING the physics reach of the Belle II detector is an important goal of the upgrade [1]. For the the K_{Long} and Muon (KLM) system the upgrade to scintillator strips is required for rate reasons [2]. At the same time, by being able to measure the deposited charge, improvements in low momentum muon and K_{Long} identification are expected. Undetected K_{Long} are a problematic background for missing energy decays, a major staple of the Belle II physics program.

The 14 layers of the Endcap KLM are segmented into quadrants, with 150 (75x and 75y) scintillator strips per plane. Ten 15-channel preamplifier cards are cabled to a readout card containing 10 TARGETX ASICs. Combined the Endcap KLM has 2 ends by 4 quadrants by 14 layers, or a total of 16,800 channels of readout. The inner 2 barrel layers have a slightly more complicated numerology, though consist of roughly another 3,000 channels of readout, putting the KLM scintillator total to just over 20,000 channels of readout. To account for yield losses and spares, over 25,000 channels (1,600 ASICs) have been fabricated and production tested.

II. ASIC Requirements

The requirements for the readout of silicon photomultipliers are rather similar to those for the telescope camera of the future Cherenkov Telescope Array. It was therefore natural to adapt the TeV Array Readout with GSa/s sampling and Event Trigger (TARGET) [3] for the Belle II scintillator muon upgrade. The specifications of this TARGETX variant are listed in Table I.

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TABLE I
TARGETX Specifications.

Item	Value	Unit/comment
Number of channels	16	1 ASIC per 15-ch pre-amp
Storage cells/channel	16,384	512 windows of 32 samples
Sampling rate	0.4 - 1.2	Giga-samples/s
Dynamic range	9-10	bits (12-bit ADC) 1-2mV noise, 1V amplitude
Wilkinson conversion	2-8	microseconds
Sustained trigger rate	30	kHz
Trigger threshold	0.61	mV (on-chip, 12-bit DAC)
Trigger outputs	5	bits (hit channel encoded)

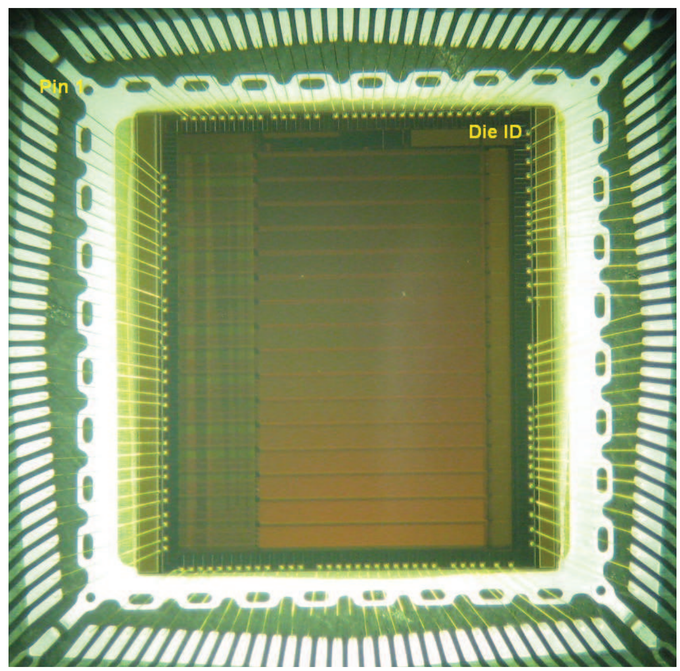

Fig. 2. Die photograph of the packaged TARGETX ASIC, fabricated in the TSMC 0.25μm CMOS process. The die is physically large (7 × 8.6mm) in order to contain the approximately quarter million sample storage cells.

Fig. 2 shows a die photograph of the 128-pin wire-bonded TARGETX ASIC. The TSMC 0.25μm CMOS process was chosen as a price-performance optimization point for this die size and required performance. Fabricated on an Engineering wafer run, production costs for additional parts are now dominated by packaging costs.

III. Measured Performance

A suite of verification, characterization and calibration tests are performed on every production TARGETX, including noise, pedestal, signal fit quality, and so forth.

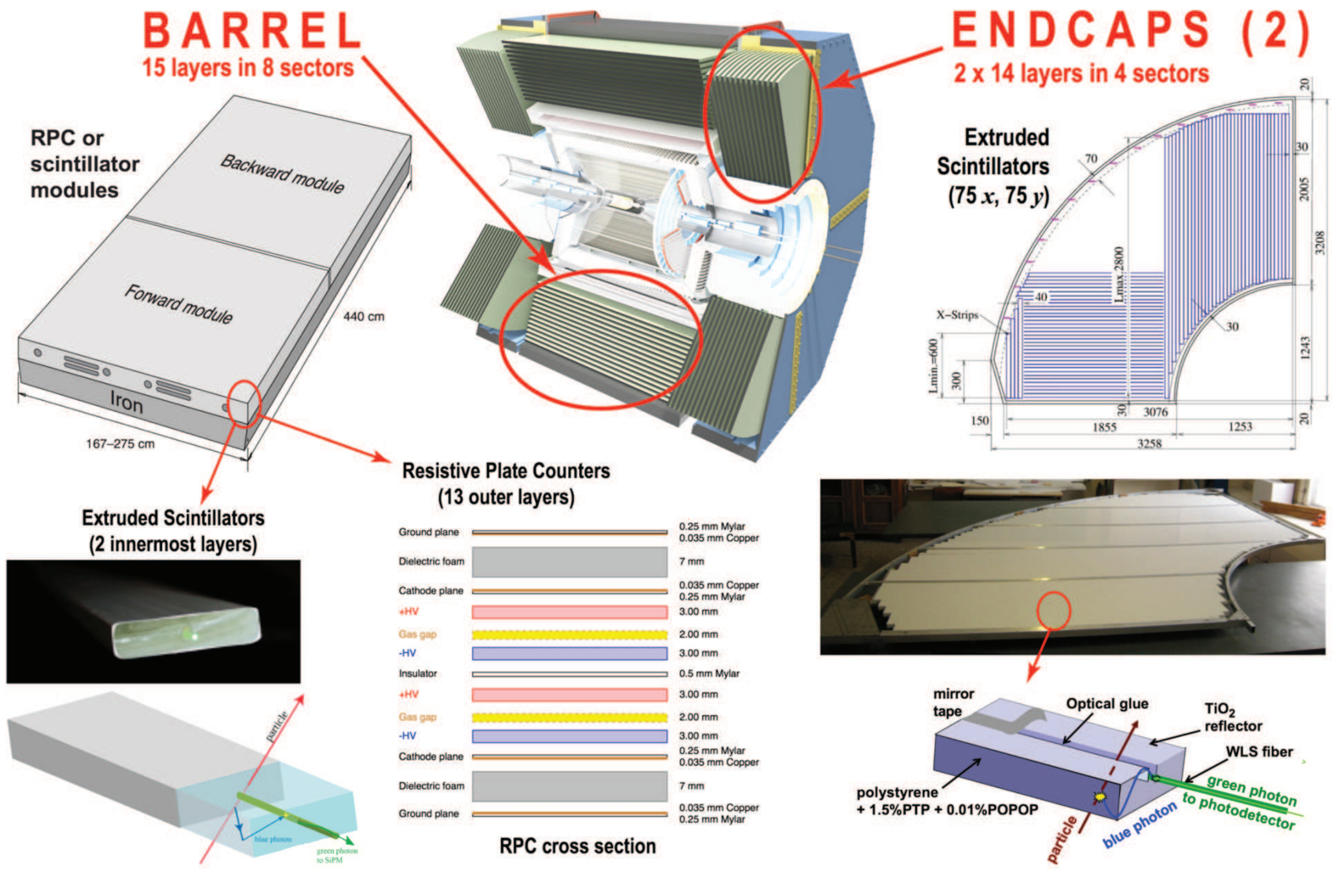

Fig. 1. Overview of the Belle II KLM scintillator upgrade, where the innermost barrel layers and endcap layers of detectors (sandwiched into gaps in the return yoke) replace resistive plate chambers in those locations, where they are expected to become too inefficient at higher neutron background rates. Geiger-mode silicon photodetectors (MPPCs) detect wavelength-shifted scintillation photons. To reduce costs and provide gain and threshold tracking as the MPPCs degrade due to neutron bombardment, the TARGETX ASIC has been developed.

The observed noise level is uniformly in the range of 1-2mV and the useable dynamic range is well over 1V, providing approximately 9-10 bits of single-sample Signal-to-Noise Ratio. Sampling is operated at approximately 1 Giga-sample per second and is delay-locked to the accelerator RF clock. At this sampling rate, while not intended for precision timing, the TARGETX performs reasonably well. As seen in Fig. 3 sub-100ps timing is attainable, meaning the timing of the detector will be dictated by the scintillator decay time and not necessarily the readout electronics. This level of timing performance opens new opportunities for background suppression.

Testing has verified that all specified performance parameters have been met for the entire TARGETX production lot.

IV. Summary

A low-cost yet high-performance ASIC has been developed for instrumentation of large numbers of photo-detector readout channels. Mass production of the scintillator KLM readout for the Belle II upgrade has been completed and readout will be installed after the completion of final module verification. Detailed information on yield and ensemble performance for over 20,000 channels of TARGETX ASICs will be reported.

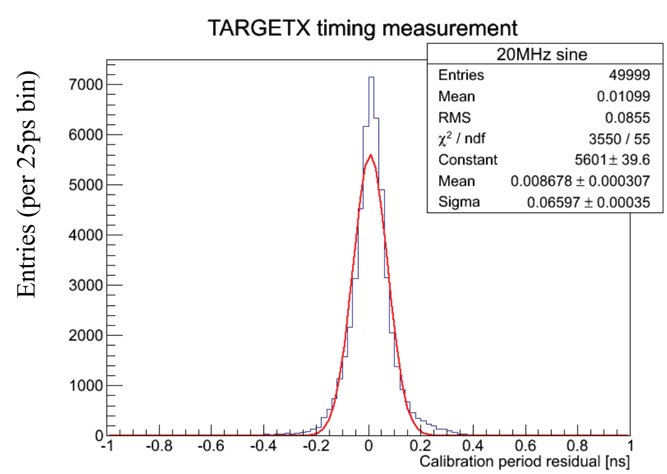

Fig. 3. Timing resolution estimated using fit to extract 50ns period of a 20MHz sine signal. While the TARGETX was not designed to provide high precision time resolution, sub-100ps timing is easily achieved.

References

[1] Belle II Technical Design Report, August 2010. **arXiv:1011.0352**.
[2] T. Aushev *et al.*, Nucl. Instrum. Meth. **A789** (2015) 134-142.
[3] K. Bechtol *et al.*, Astropart. Phys. **36** (2012) 156-165.