High Dynamic Range Diamond Detector Acquisition System for Beam Wire Scanner Applications

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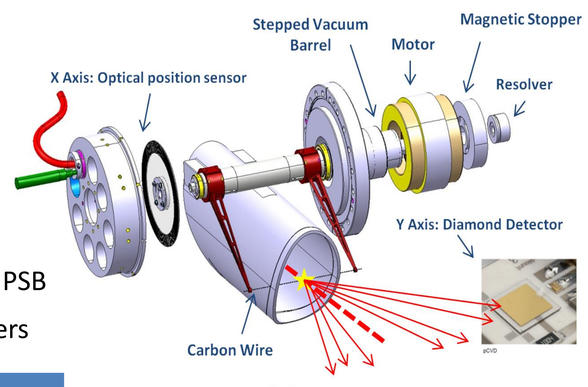
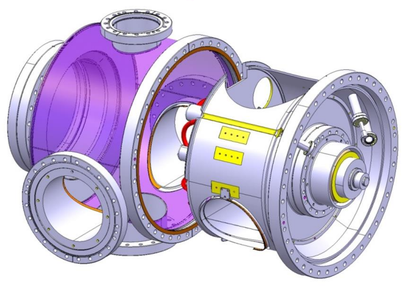
Abstract: *A secondary particle shower acquisition system is under design for the CERN beam wire scanners upgrade. The new acquisition system is based on a polycrystalline diamond detector. Beam synchronous digitization will be performed in the tunnel, near the detector to fully exploit its large dynamic range and fast response. Two integrator ASICs (ICECAL and QIE10) are being characterized and compared for detector readout with the complete acquisition chain prototype, including the optical digital data transmission, at 4.8Gbps, with the GBT protocol and versatile link components (VTRx). The new electronic design aims to cover the whole dynamic range required for all CERN wire scanners with a single configuration without tuneable parameters, and be capable of bunch-by-bunch measurements with an integration time of 25ns. To be fully independent of the scanner location and beam parameters, a dynamic range of 10e6 is required.*

Motivation:

- Beam Wire Scanners Upgrade
- New detector used (pCVD)
- High dynamic range needed
- Low noise measurements
- One single system for LHC, SPS, PS & PSB
- Avoid the need of tuneable parameters



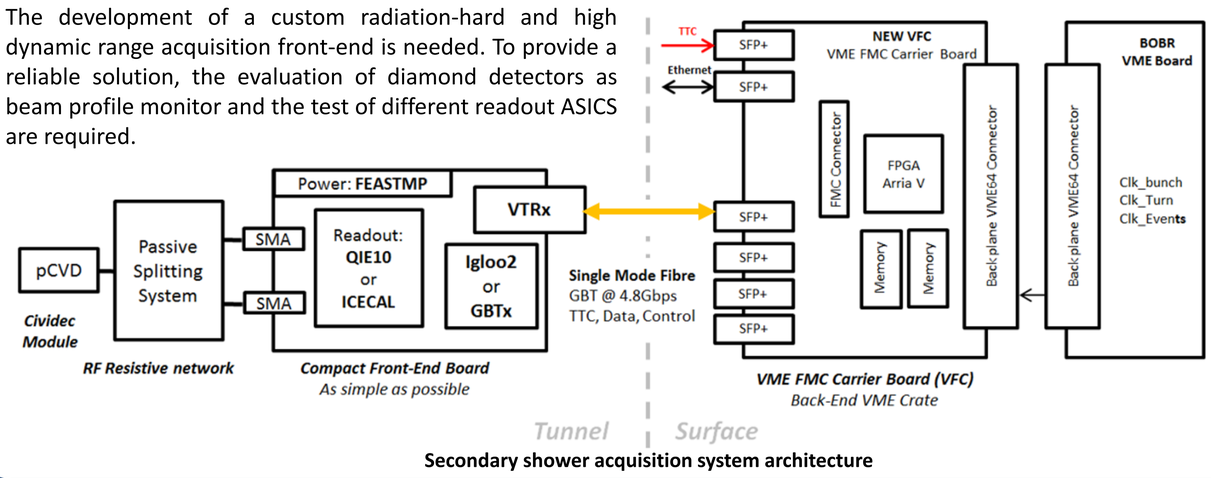
SYSTEM REQUIREMENTS	
Dynamic Range	1.6fC – 1.6nC (1e6)
Integration Window	25ns (40Mhz)
Synchronization	LHC, SPS, PS, & PSB: Bunch by Bunch
Link Distance	up to 250m
Ionizing Radiation	100Gy/year



Proposed System Architecture Overview:

A front-end will be placed near the detector for digitalization to avoid transmission over long coaxial cables and maintain the pCVD signal dynamics and quality. Once digitalized, the data will be sent through an optical link at 4.8Gbps following the GBT protocol. The optical link provides data transmission, front-end slow control and systems synchronization. The Back-End solution envisaged is based on the new VFC board developed by the CERN's BE-BI group.

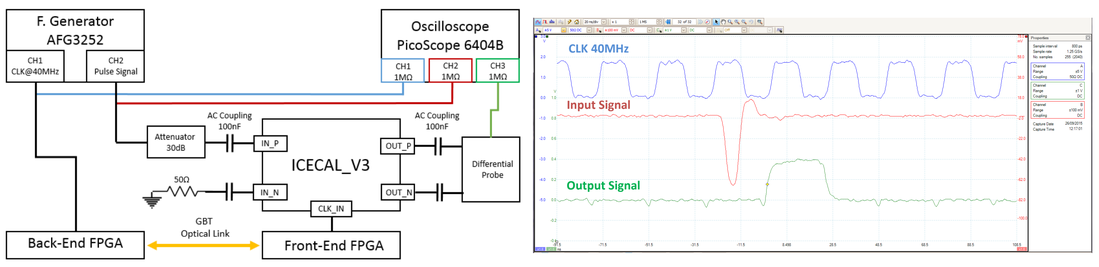
The development of a custom radiation-hard and high dynamic range acquisition front-end is needed. To provide a reliable solution, the evaluation of diamond detectors as beam profile monitor and the test of different readout ASICS are required.



Secondary shower acquisition system architecture

Preliminary Tests with ICECAL_V3:

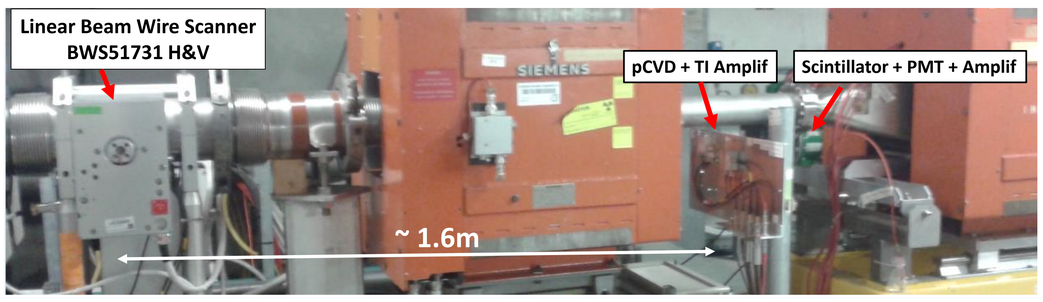
ICECAL is an integrator ASIC developed by the University of Barcelona for the LHCb experiment. Each of its 4 channels can reach 1e3 (12 bits) dynamic range. A custom mezzanine was developed on this project to host the ASIC in a front-end system for tunnel digitalization. The ASIC functionality was tested, once mounted on the board, to check its correct operation. The set-up shown on the following picture aims to reproduce the testing conditions used by the ASIC designers, but using our specific GBT optical link clock recovery scheme.

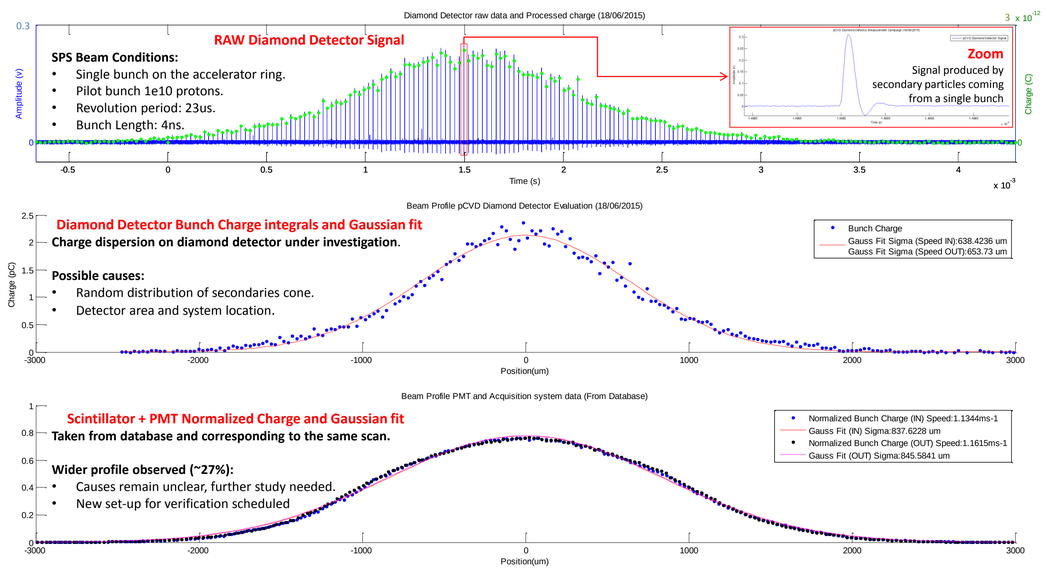


Simplified schematic of the ICECAL preliminary testing (left) and oscilloscope screenshot (right)

pCVD Diamond Detectors as beam profile monitors:

A pCVD Diamond detector and transimpedance amplifier were placed on the SPS complex, near an operational linear Beam Wire Scanner, in order to asses the detector performance for secondary particles detection and beam profile monitor. A nearby operational acquisition system, consisting on a scintillator attached to a photo-multiplier tube (PMT) and a pre-amplifier, was used for comparison. The measurements were collected on the surface with a LeCroy Scope at 2.5GSPS. Around 80m of CK50 cables were used for signal transmission.



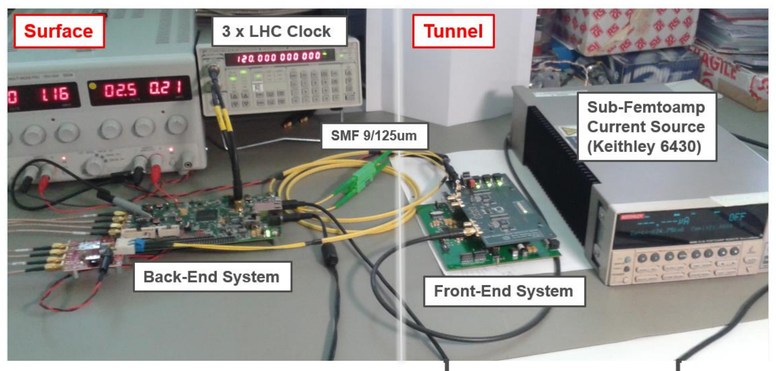


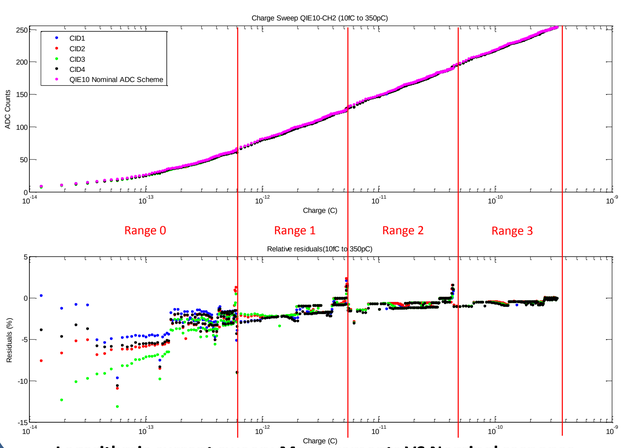
Full Acquisition System Prototype for QIE10p5 Evaluation:

A complete test set-up has been evaluated under laboratory conditions. The back-end system for prototype is based on an Igloo2 development kit.

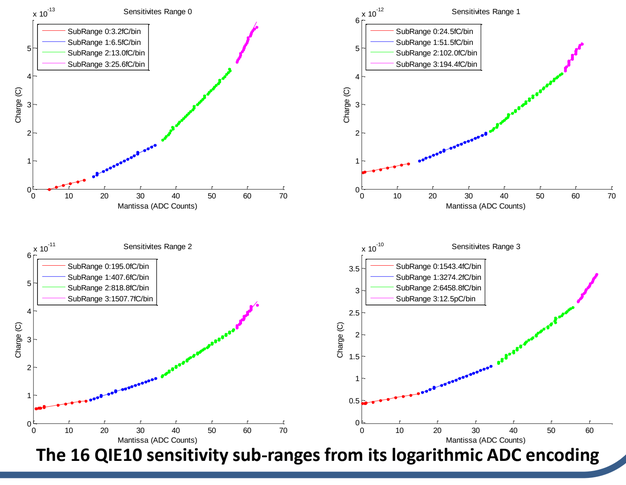
The set-up was used for the QIE10 front-end evaluation. This charge integrator and digitalization ASIC reach a dynamic range of 1e5 (3.2fC-340pC) encoded with 8 bits by using a pseudo-logarithmic digitalization scheme. The charge encoding algorithm contains 16 sensitivity levels divided on 4 ranges.

The front-end was characterized in terms of linearity, difference with respect to the nominal response and sensitivities in each subrange. Linear sweeps with a Keithley current source were done. Each point on the following charts corresponds to the average value detected during 25us with constant current.





Logarithmic current sweep: Measurements VS Nominal response



The 16 QIE10 sensitivity sub-ranges from its logarithmic ADC encoding

Autonomous Front-Ends for QIE10 & ICECAL evaluation:

The readout system needs to be evaluated with two different integrator ASICs, for this, a modular design is used. Each readout ASIC candidate is hosted in a custom Radiation-Tolerant mezzanine with a SAMTEC connector that fits on a motherboard, the Igloo2 UMd board (designed by CMS) that drives the optical link.

Igloo2 UMd Board:

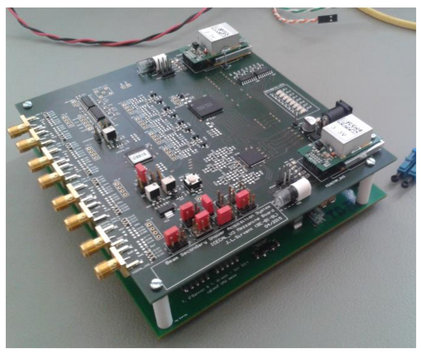
Acts as the front-end motherboard, equipped with a flash-based FPGA Igloo2, radiation tolerant components and a versatile link transceiver (VTRx) to drive the optical link with the GBT protocol.

QIE10p5 Mezzanine:

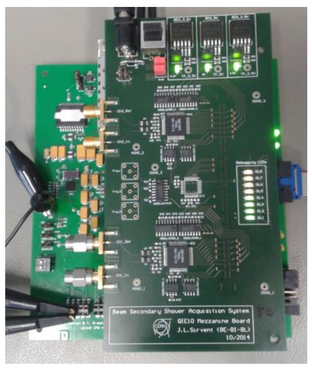
Equipped with two QIE10 ASICS, each, features one high dynamic range (1e5) channel. Radiation-tolerant linear regulators are used as POL regulators.

ICECAL_V3 Mezzanine:

Contains an ICECAL integrator ASIC, with 4 input channels. The ASIC output provides an analog voltage every 25ns, that is digitalized by an ADC. The mezzanine is powered with radiation hard FESTMP modules.



ICECAL_V3 Front-End configuration



QIE10 Front-End configuration

References:

- J.L. Sirvent et al. *"Secondary particle acquisition system for the CERN beam wire scanners upgrade".* 2015 Journal of Instrumentation (JINST) 10 C04021. DOI: 10.1088/1748-0221/10/04/C04021
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Summary:

Diamond detectors have demonstrated to be a promising solution for secondary particle detection to determine the transverse beam intensity distribution and its width. Further investigations are required to understand the beam profile difference with respect to the scintillator/PMT system, a second set-up will be installed for more tests. The QIE10 digital readout electronics systems have been fully tested under laboratory conditions showing the specified performance. The QIE10 front-end will be installed in the SPS tunnel and its performance tested under operational conditions. The ICECAL testings are on-going.

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