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Design and Construction of Detector and Data Acquisition Elements for Proton Computed Tomography

Cooperative Research and Development Final Report

CRADA Number: FRA-2011-0001

Fermilab Technical Contact: Peter Wilson

Summary Report
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In accordance with Requirements set forth in Article XI.A(3) of the CRADA document, this document is the final CRADA report, including a list of Subject Inventions, to be forwarded to the Office of Science and Technical Information as part of the commitment to the public to demonstrate results of federally funded research.

CRADA number: FRA 2011-0001

CRADA Title: Design and Construction of Detector and Data Acquisition Elements for Proton Computed Tomography

Parties to the Agreement: Northern Illinois University and Fermi Research Alliance

Abstract of CRADA work:

Proton computed tomography (pCT) offers an alternative to x-ray imaging with potential for three dimensional imaging, reduced radiation exposure, and in-situ imaging. Northern Illinois University (NIU) is developing a second generation proton computed tomography system with a goal of demonstrating the feasibility of three dimensional imaging within clinically realistic imaging times.

The second generation pCT system is comprised of a tracking system, a calorimeter, data acquisition, a computing farm, and software algorithms. The proton beam encounters the upstream tracking detectors, the patient or phantom, the downstream tracking detectors, and a calorimeter. Figure 1 shows the schematic layout of the PCT system. The data acquisition sends the proton scattering information to an offline computing farm. Major innovations of the second generation pCT project involve an increased data acquisition rate (MHz range) and development of three dimensional imaging algorithms.

The Fermilab Particle Physic Division and Northern Illinois Center for Accelerator and Detector Development at Northern Illinois University worked together to design and construct the tracking detectors, calorimeter, readout electronics and detector mounting system.

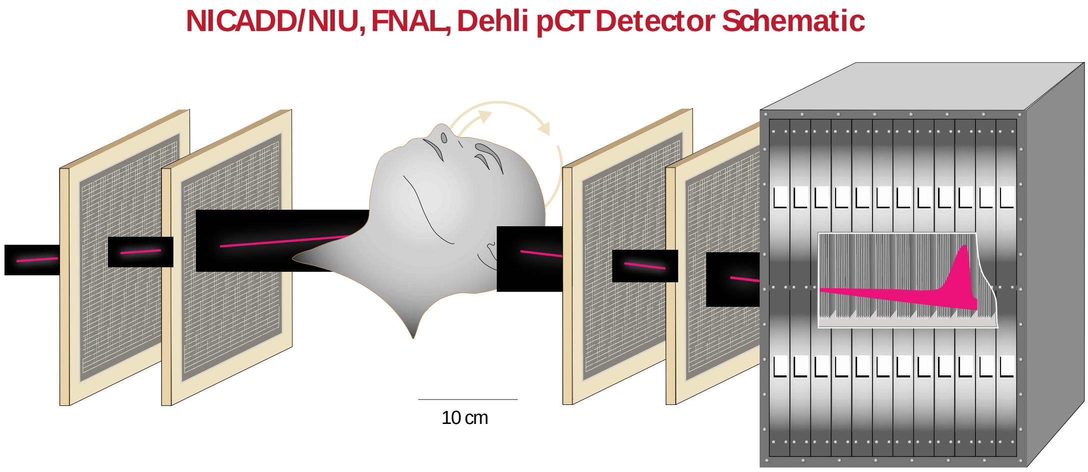

Figure 1: Schematic of proton tomography detector system. Protons delivered from left transit two upstream x-y tracking stations, the patient (or phantom) and two downstream x-y tracking stations. Finally, a downstream scintillator range stack is used to measure the residual proton energy.

Summary of Research Results:

The Fermilab and NIU teams developed the tracking system for the PCT system based on scintillating fiber technology previously used in high energy physics experiments. One innovative component of this design is the use of Silicon Photomultiplier (SiPM) photodetectors to convert the scintillation light into electrical signals for readout. The use of SiPMs allows for a compact design relative multi-anode PMTs. Each tracking station consists of an x-y pair of fiber layers made of 0.5 mm diameter fibers arranged in a half-cell stagger to provide complete coverage. The fibers are glued to a low mass foam substrate that is stretched on a carbon fiber frame. A total of about 2100 fibers are needed for the four tracker stations. Figure 2 shows one of the assembled x-y tracking stations with SiPMs mounted to a printed circuit board interfaced to the fibers. Fermilab technical staff working with scientific staff and students from NIU carried out assembly of the fiber tracker stations in a Fermilab cleanroom facility.

The range stack detector is constructed of 96 rectangular scintillator tiles (27cm x 36cm, 3.2cm thick) that are grooved for a wavelength shifting readout fiber. Each WLS fiber is readout using by an SiPM at each end resulting in 192 channels. The primary development and testing for the range stack detector was carried out by NIU with Fermilab providing specialized machining capabilities for components.

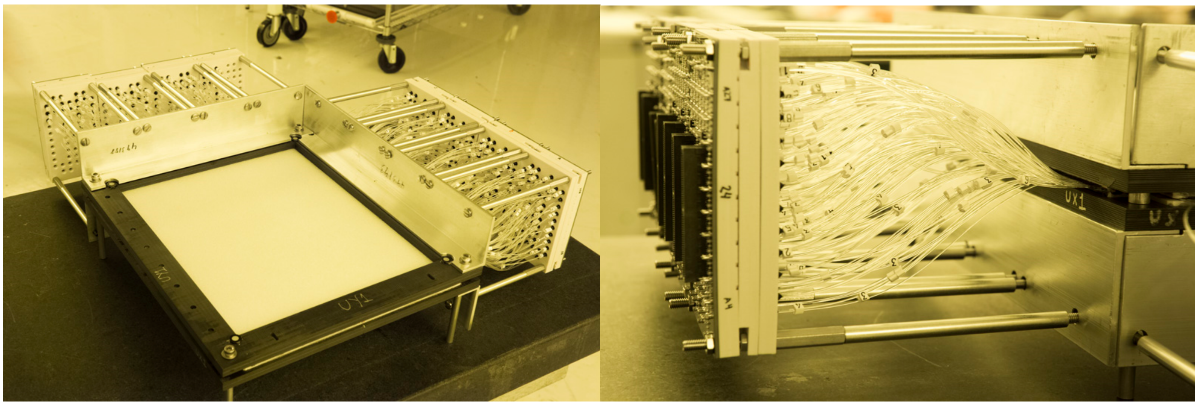

Figure 2: A tracker x-y plane with fibers routed to SiPM mounting blocks (left). This upstream plane has an area of 20 x 24 cm^2 while downstream planes are 24 x 30 cm^2. SiPM mounting block with connectors for plug-in of readout electronics (right).

Custom digitization and readout electronics were developed for the PCT system. Since the range detector and the trackers both use SiPMs, a common readout electronics design was developed for the two systems incorporating a preamplifier, digitizer and Ethernet interface in a single "PADE" printed circuit board. The each PADE board provides readout for 32 SiPM channels. The different mechanical requirements for the tracker and range detectors are handled by the design of an interface board on which the SiPMs are mounted. A field programmable gate array (FPGA) on the PADE board provides data formatting and synchronization. Two different FPGA firmware versions adapt the PADE boards to the needs of the tracker and range detectors. The system is designed to collect data at a sustained rate of 3 million proton interactions every second. Figure 3 shows the assembled PADE PC board.

The complete PCT detector system including readout electronics and power supplies is mounted on a custom designed moveable cart as shown in Figure 4. The cart was designed by Fermilab and assembled by NIU students working with Fermilab technical staff. Alignment marks were built into the tracker components and used to do an overall alignment of the components when mounted on the cart.

The completed PCT scanner was moved from Fermilab to the proton treatment center of the Central DuPage Hospital (CDH) in Warrenville, IL in May 2014 for commissioning. Figure 5 shows the completed system in a treatment room at CDH. The portable cart allows the system to be easily moved from storage to a treatment room for testing.

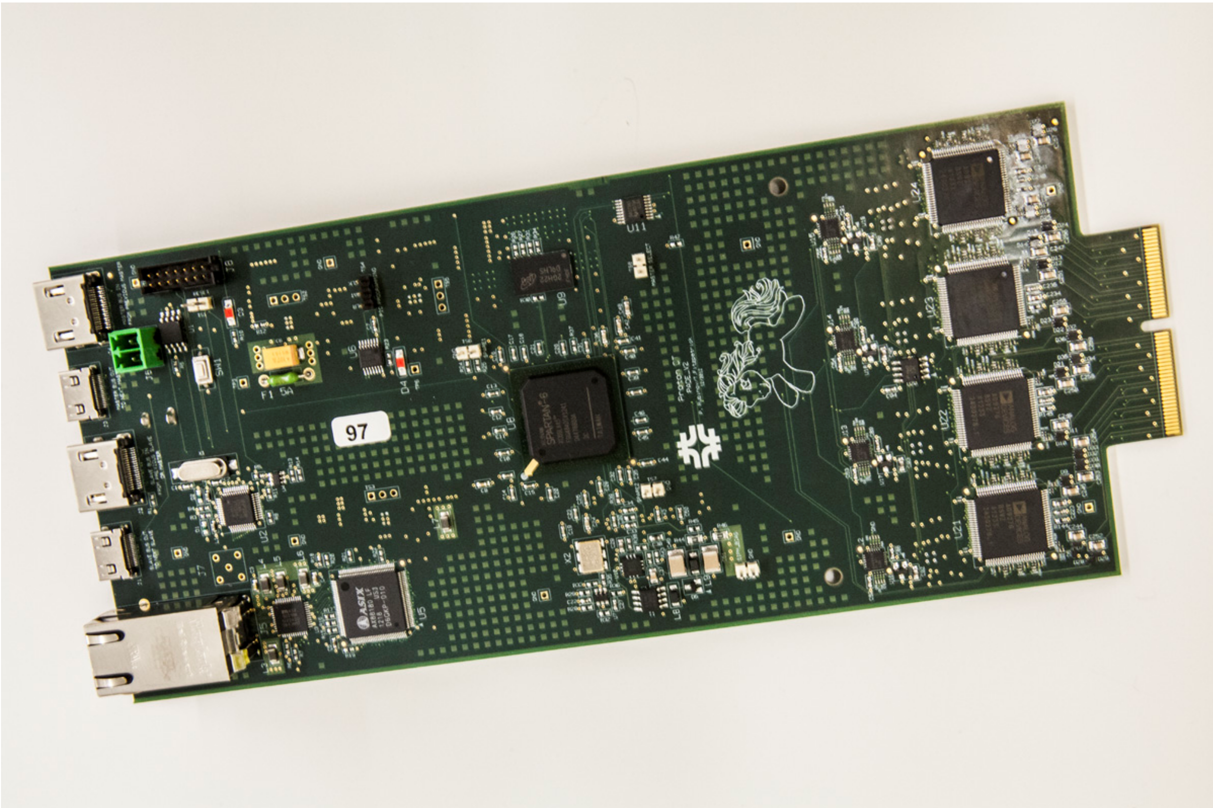

Figure 3: The PreAmplifer Digitizer Ethernet (PADE) printed circuit board.

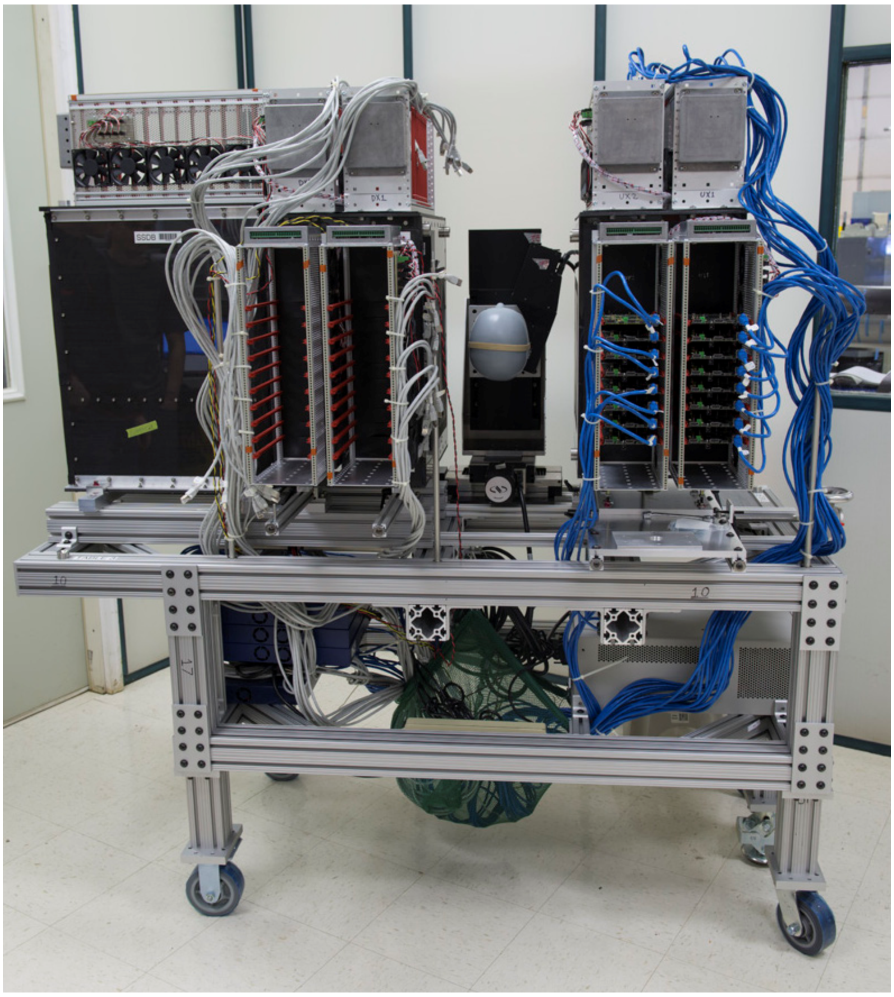

Figure 4: The PCT system assembled on the movable cart in a Fermilab cleanroom facility. The proton beam will enter from the right encountering two tracking stations, the head phantom, two more tracking stations and finally the range detector on the left. The tracker readout electronics is mounted in card cages mounted directly to the detector. Power supplies and a network hub are mounted below the detectors in the bottom of the cart.

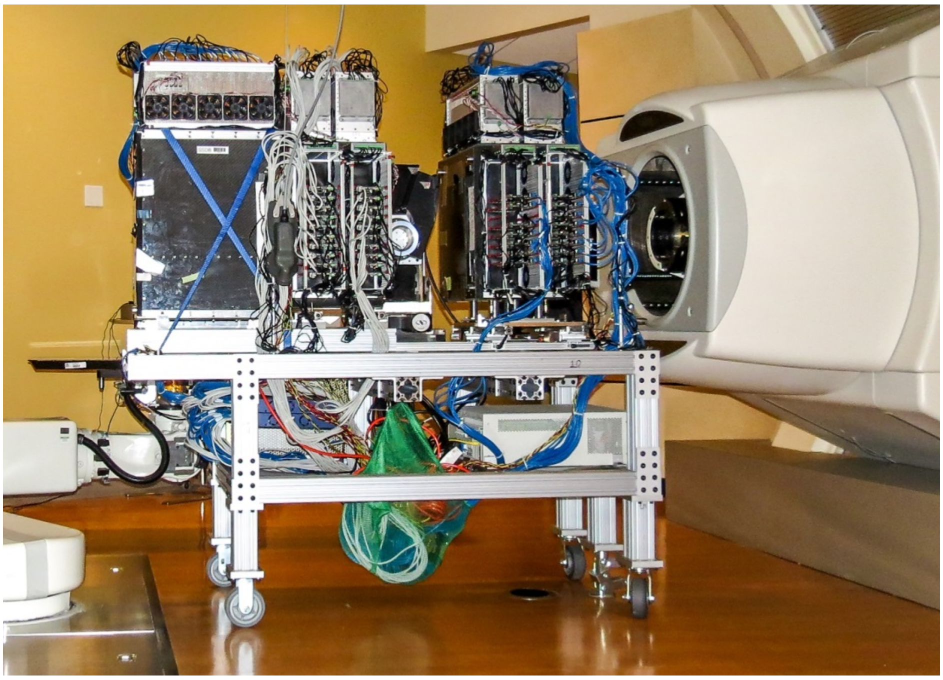

Figure 5: The PCT system in a patient treatment room at Central DuPage Hospital proton threatment facility. The proton beam enters the system from the right.

Subject Inventions listing: U.S. Patent number 8,766,180, Karonis et al. (2011) "High performance computing for three dimensional proton computed tomography (HPC-PCT)"

Report Date: 7/01/2015

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