
NATIONAL
INSTRUMENTS™

Reconfigurable Oscilloscopes for Applications in Scientific Research

Brian Glass

NI Scientific Research & Big Physics

brian.glass@ni.com

NATIONAL INSTRUMENTS

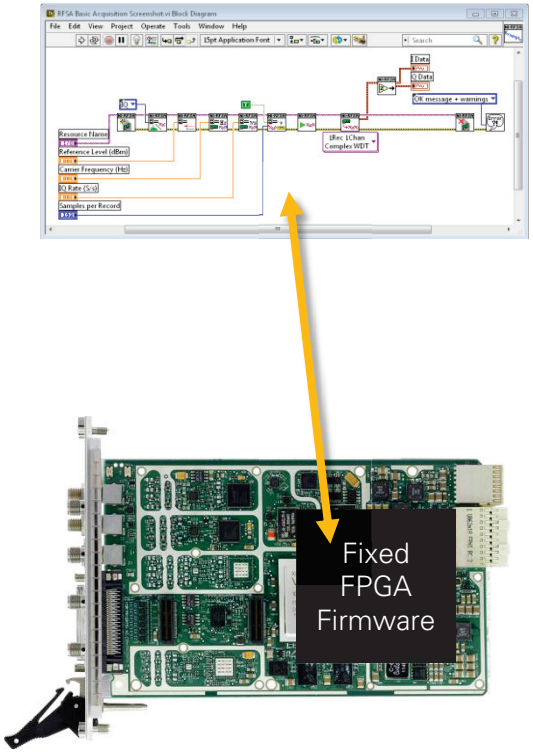
Contents

- Introduction
  - Software-Designed Instruments
  - Features & Benefits of FPGAs in Oscilloscopes
- Reconfigurable Oscilloscopes
- Software Experience
- Scientific Research Application Examples

Software-Designed Instruments

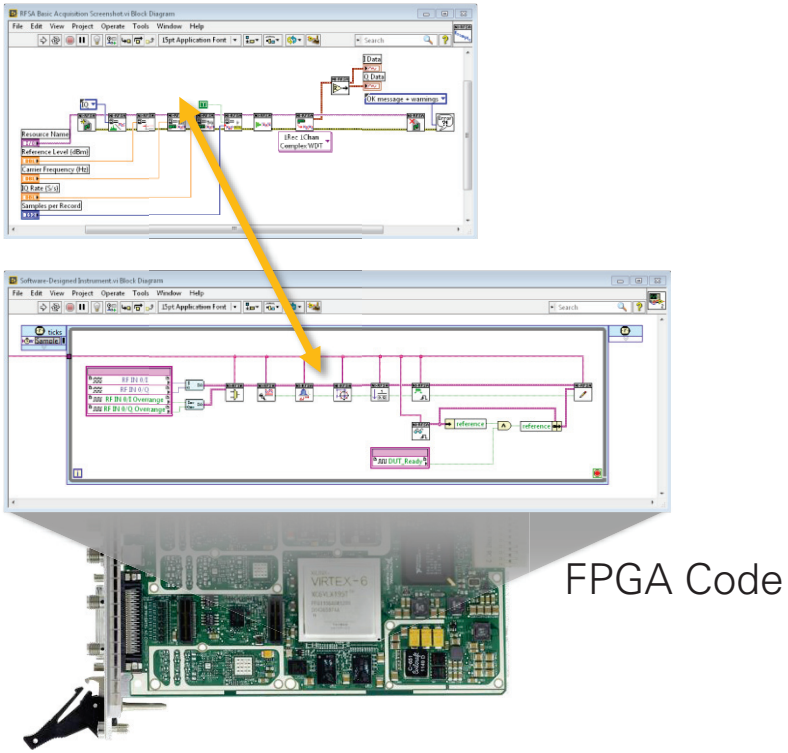
Typical Modular Instrument

- Software on the PC using the Instrument's API



Software-Designed Instrument

- Host-Software controlling Instrument through API or custom interface



Features & Benefits of FPGAs in Oscilloscopes

High-Throughput Processing

- Inherently parallel
- High clock rate
- Algorithm-specific pipelining

Low-Latency Decision Making

- Custom logic in a single clock cycle

Complete Determinism

- Design implemented in a custom circuit

Re-programmable by user

Signal Processing

Real-Time Control

Custom Triggering

NI FlexRIO

- Interchangeable I/O
- Analog or digital
- Module Development Kit

- Virtex-5 or Kintex-7 FPGA
- 132 digital I/O lines
- Up to 2 GB of DRAM

- Synchronization
- Clocking/triggers
- Data streaming

Software Designed Oscilloscopes

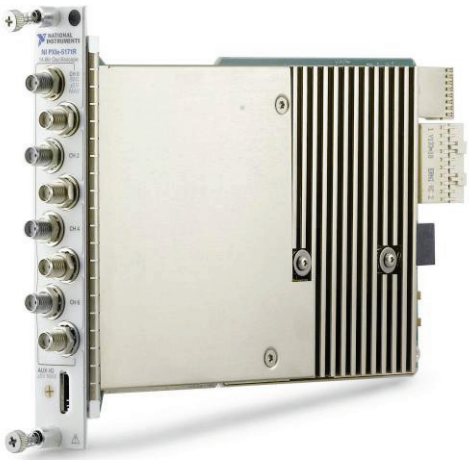
NI 5761 FAM

Resolution	14-Bit
Sampling Rate	250 MS/s
Channels	4
Coupling	AC or DC
Bandwidth	500 MHz

+

Calibration
8 Channels
AC and DC coupling
PXIe Gen2 x8
Instrument Design Libraries

=



PXIe-517xR

PXIe-5171R Reconfigurable Oscilloscope

User Programmable

- Xilinx Kintex-7 410T FPGA
- 1.5 GB DRAM memory

High Density

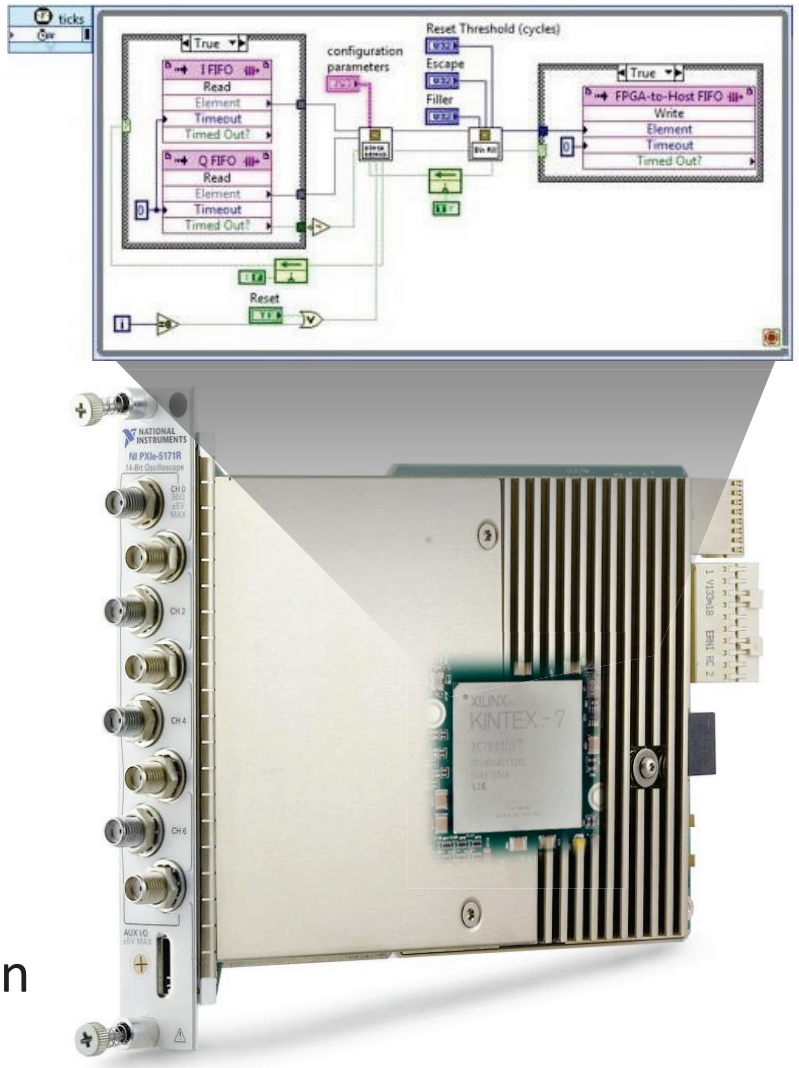
- 8 analog input channels
- 250 MS/s, 14-bit resolution
- 250 MHz bandwidth
- 0.2 to 5 V_{pp} input ranges

High Throughput

- PCIe Gen2 x8 (>3.2 GB/s)
- P2P streaming

Customizable Digital IO

- 8 lines up to 50 MHz
- Timing, triggering, communication



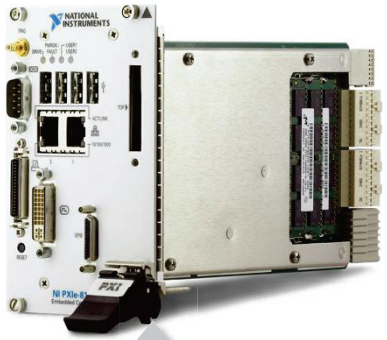
Instrument Design Libraries

User code

Closed driver

Open driver code

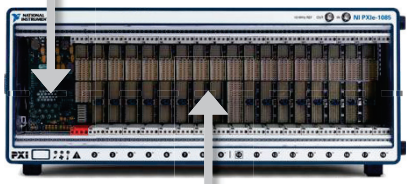
Embedded Controller (CPU)



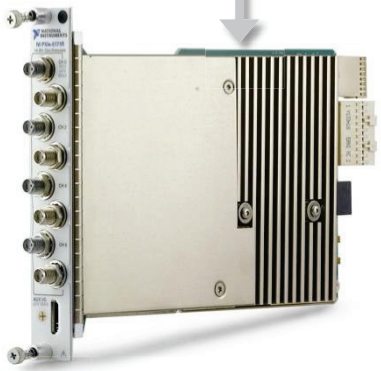
PCI Express

Host

FPGA

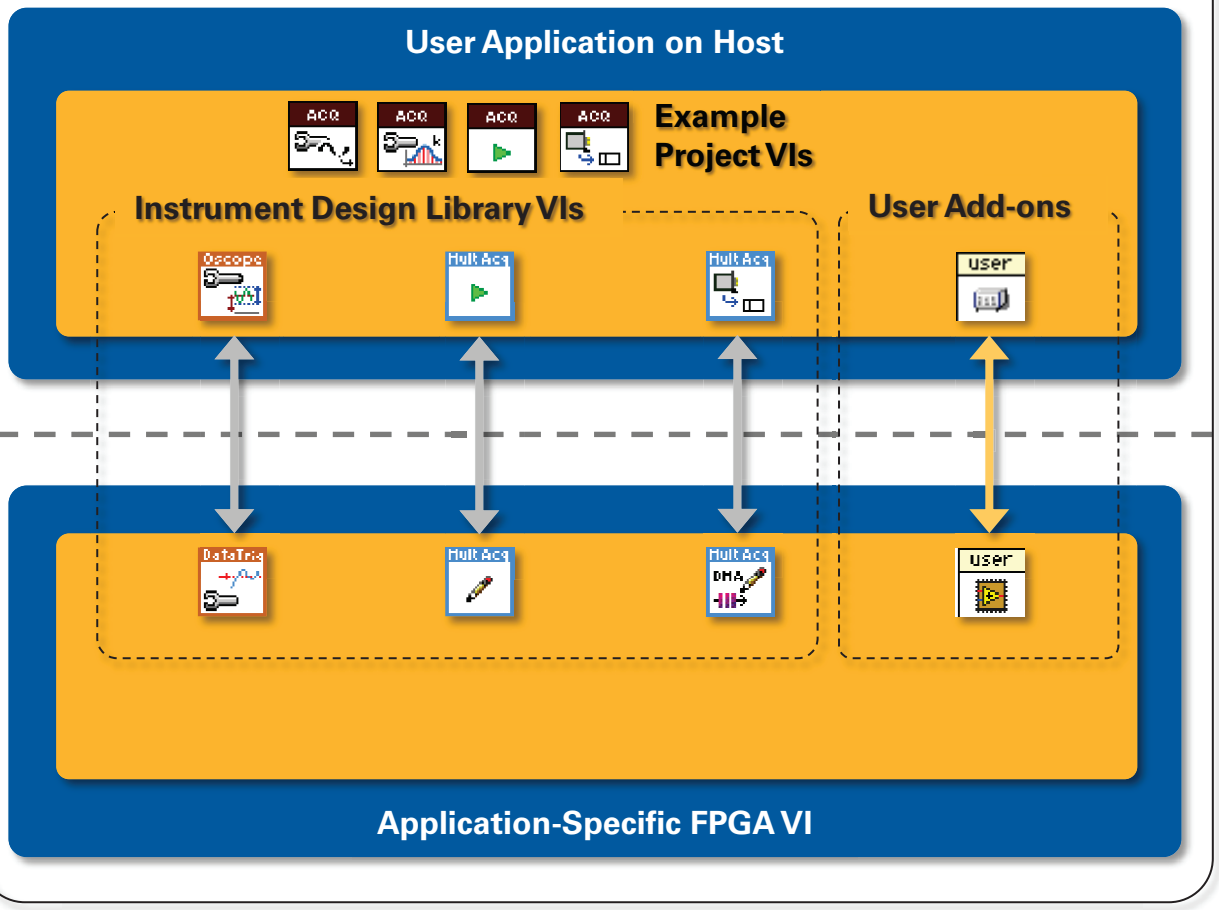


PCI Express



Software-Designed Instrument
(Oscilloscope)

Sample Project with user modifications

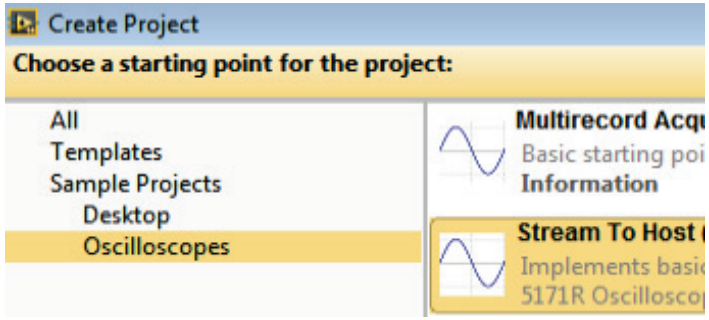


NATIONAL INSTRUMENTS

Programming Experience

Sample Projects

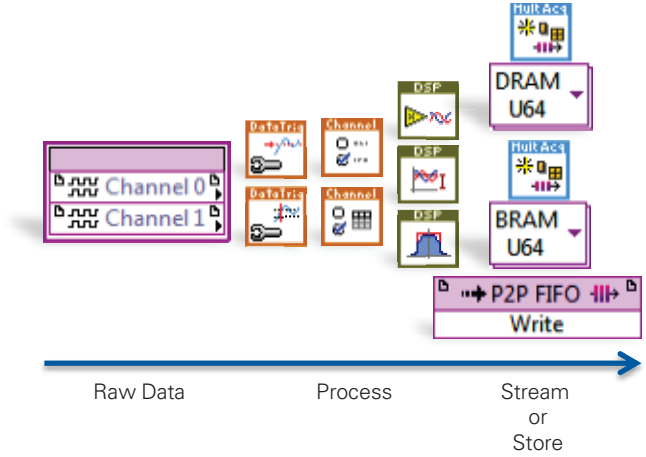
- Functionality out of the box
- Built on IDLs



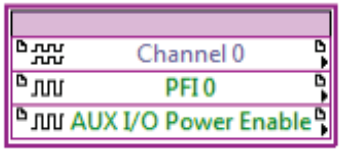
1. Triggered Multirecord-Acquisition
2. Stream to Host

Customize Your Instrument

- Custom IP with LabVIEW FPGA
- Integrate VHDL code

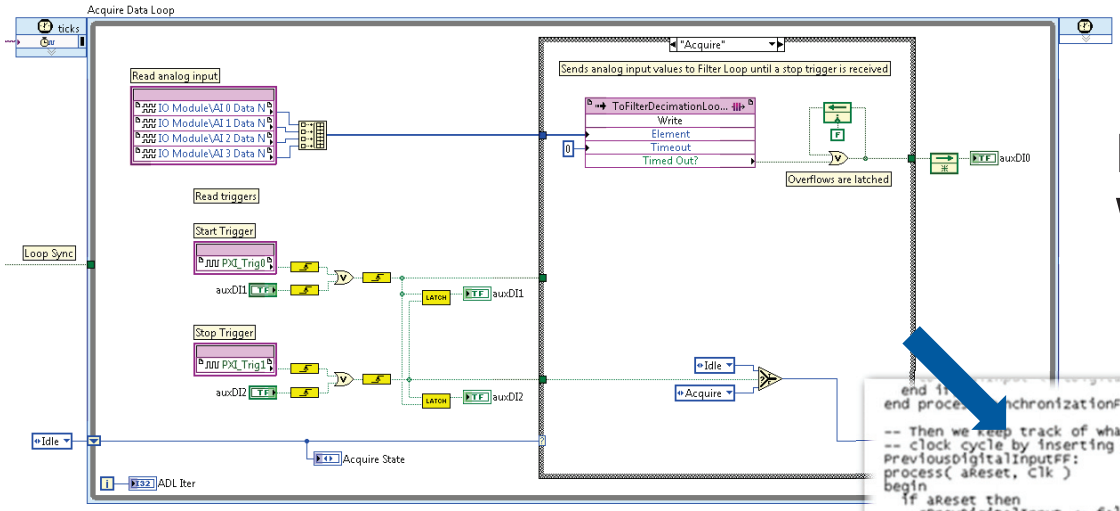


- Fixed logic for management of ADCs, memory, and other ICs
- Easy access to I/O



Software Deployment

FPGA Interface C API and RIO Linux support



Program FPGA on Windows host

```
end process SynchronizationFFs;

-- Then we keep track of what the digital input was on the previous
-- clock cycle by inserting another flip flop
PreviousDigitalInputFF:
process( aReset, Clk )
begin
  if aReset then
    cPrevDigitalInput <= false;
  elsif rising_edge(Clk) then
    cPrevDigitalInput <= cDigitalInput;
  end if;
end process PreviousDigitalInputFF;

-- Then we have a little combinatorial logic to detect a rising edge
cRisingEdgeDetected <= cDigitalInput and not cPrevDigitalInput;

-- And finally we have a register that increments when that rising
-- edge is detected.
CounterRegister:
process( aReset, Clk )
begin
```

LabVIEW generates VHDL and compiles with Xilinx

Resulting bitfile and C header file ready for use in Linux

Bitfile.lvbitx

<projectname.h>

NATIONAL INSTRUMENTS

Scientific Research Application Examples

ITER Microfission Chamber Neutron Diagnostic

Measurement of neutron source strength and fusion power at ITER Tokamak

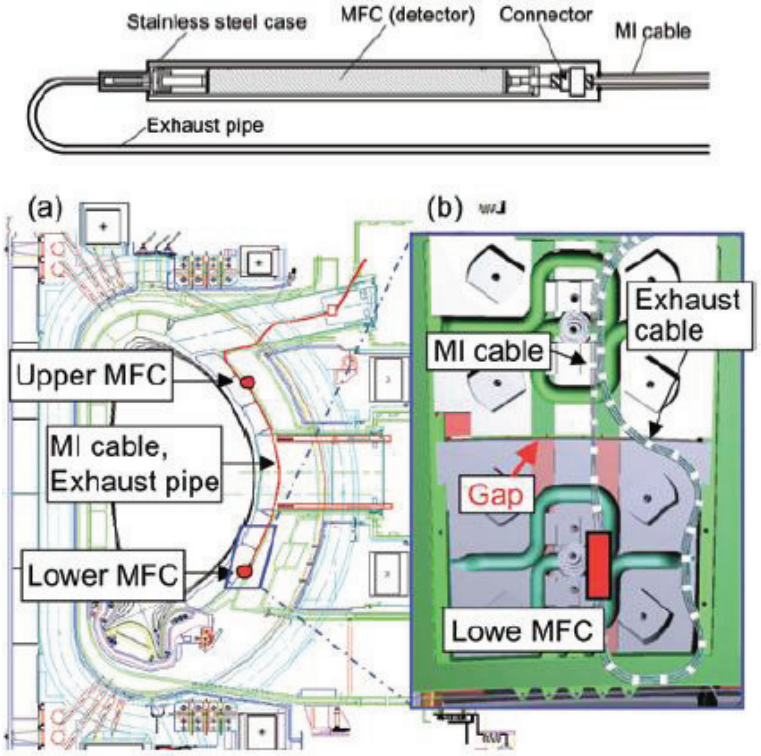


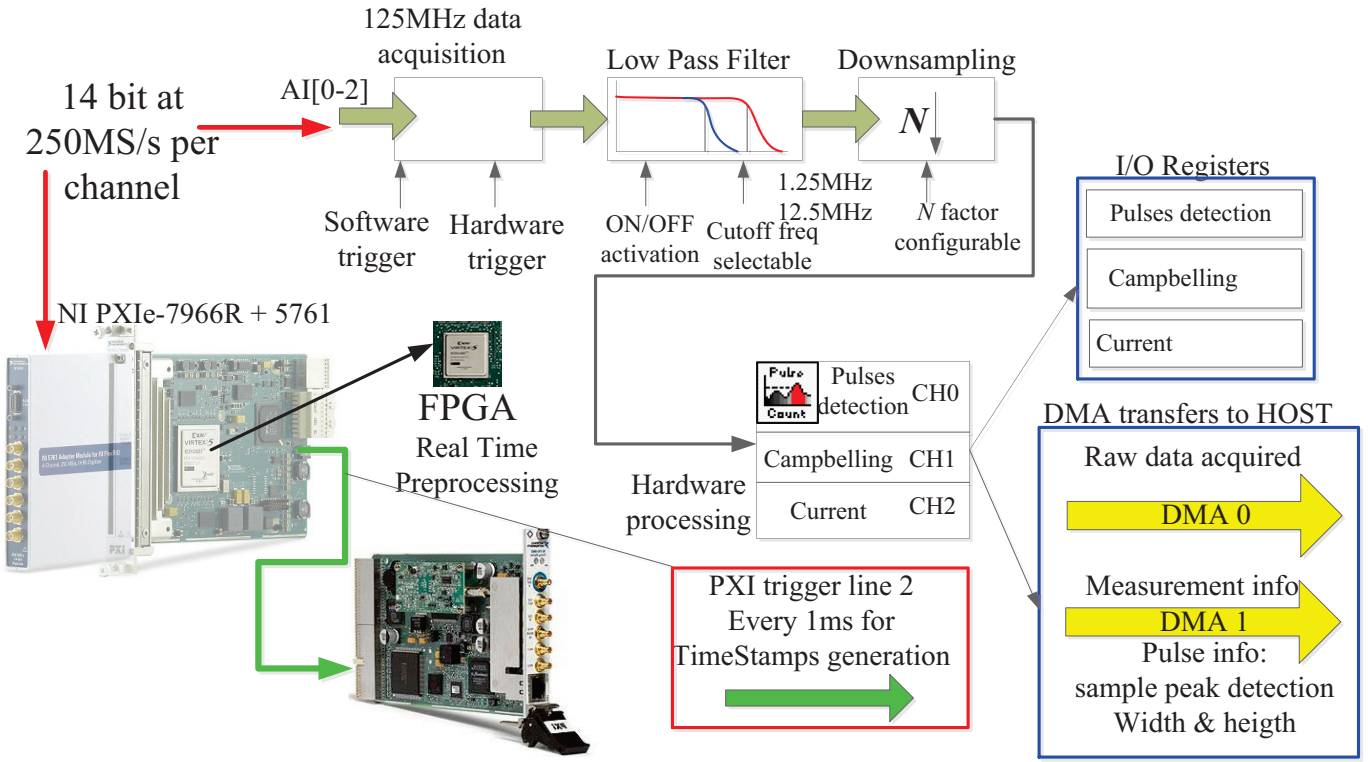
Figure credit: M. ISHIKAWA, et al., 2008

Fission Chamber based on the neutron diagnostics use case

- Pulse count rates corresponding to 100 kW – 1.5 GW
- 1 ms update rate for counting, campbelling, and current measurement methods
- Timestamps from 1588 network
- Raw data streaming for archiving

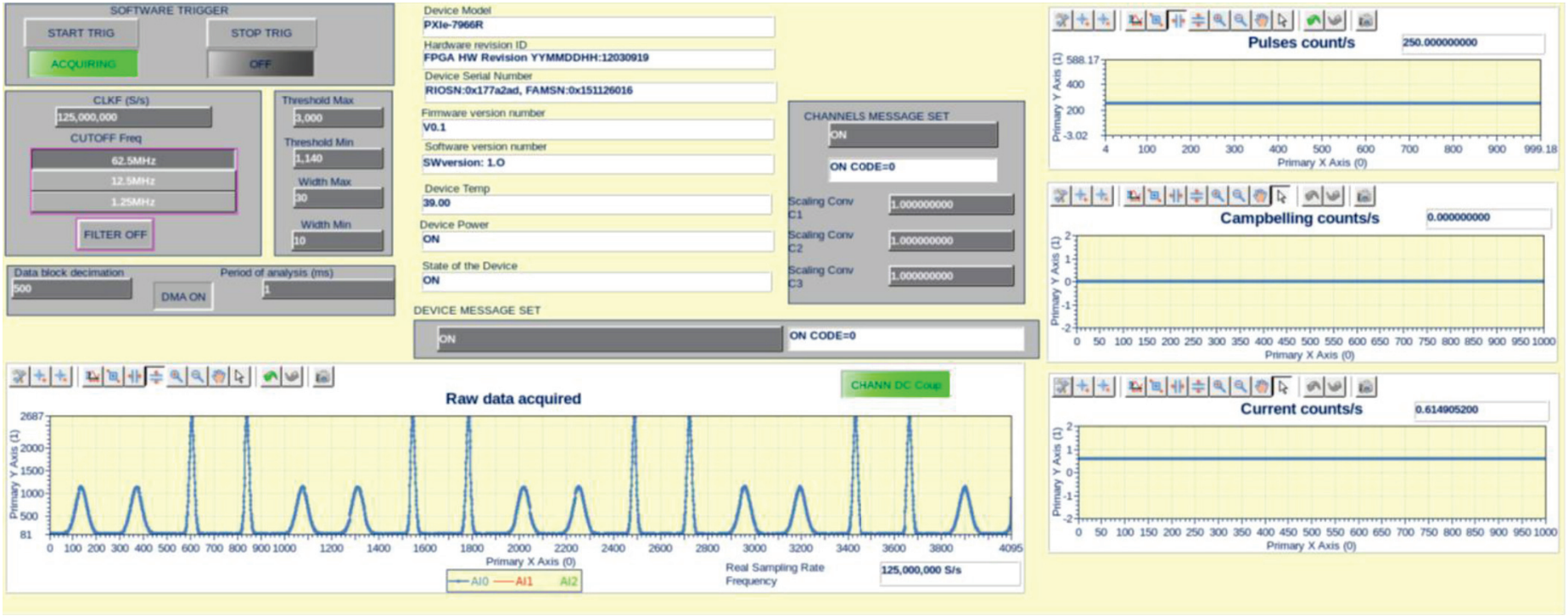
Hardware Implementation

- Data acquisition at 250 MS/s
- Filtering, decimation, and three counting methods performed on FPGA
- Data streaming via DMA over PCIe link
- Timestamps from 1588 module over PXI trigger bus



Software Implementation

- EPICS-based Nominal Device Support programmed with open source Linux RIO driver and FPGA Interface C API
- FC human machine interface: CA Client created with CSS.
  - Permits control, configuration, and results monitoring

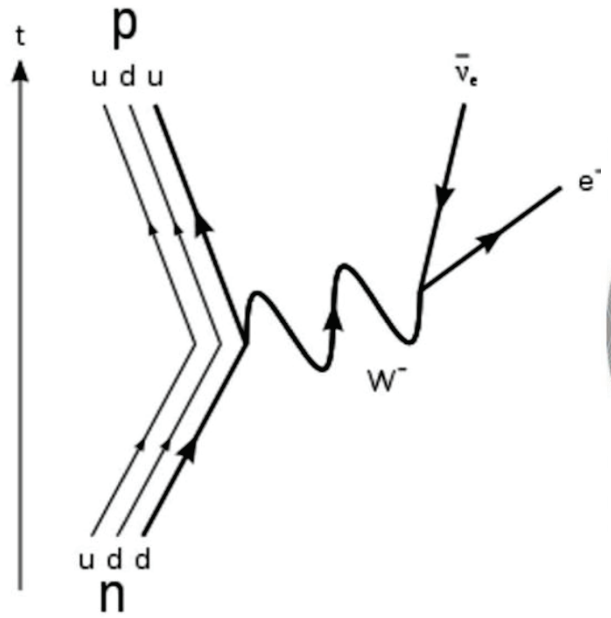


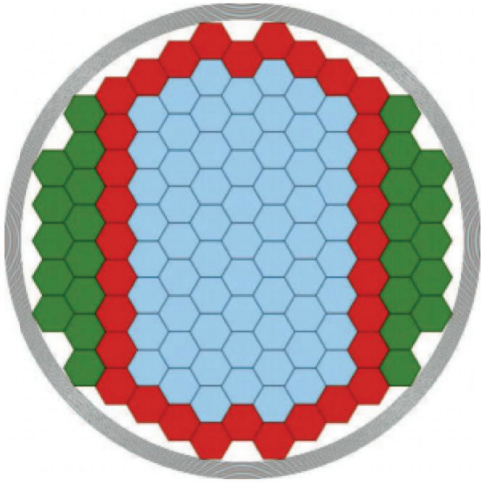
NATIONAL INSTRUMENTS

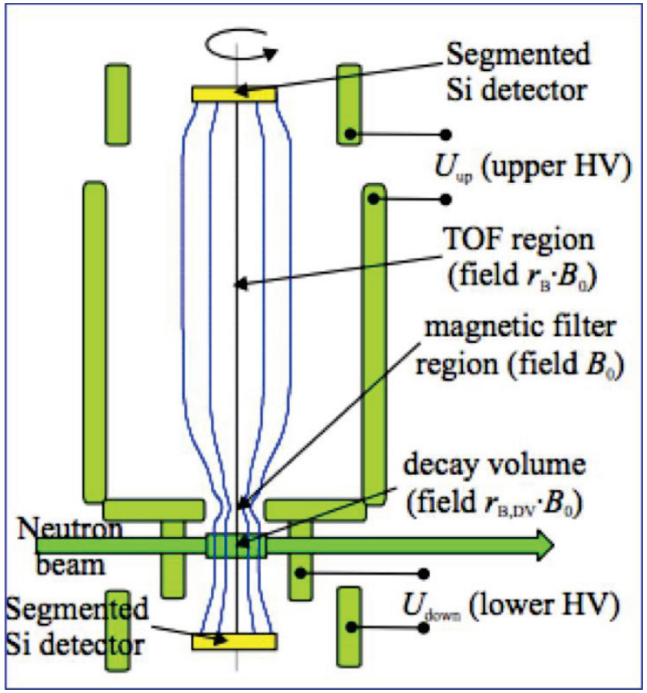
Nab Neutron Spectrometer

Determine a and b neutron beta decay parameters by measuring proton and electron energies to high precision

$$\frac{dw}{dE_e d\Omega_e d\Omega_\nu} \propto p_e E_e (E_0 - E_e)^2 \times \left[1 + a\frac{\vec{p}_e \cdot \vec{p}_\nu}{E_e E_\nu} + b\frac{m_e}{E_e} + \langle \vec{\sigma}_n \rangle \cdot \left(A\frac{\vec{p}_e}{E_e} + B\frac{\vec{p}_\nu}{E_\nu} + D\frac{\vec{p}_e \times \vec{p}_\nu}{E_e E_\nu} \right)\right]$$



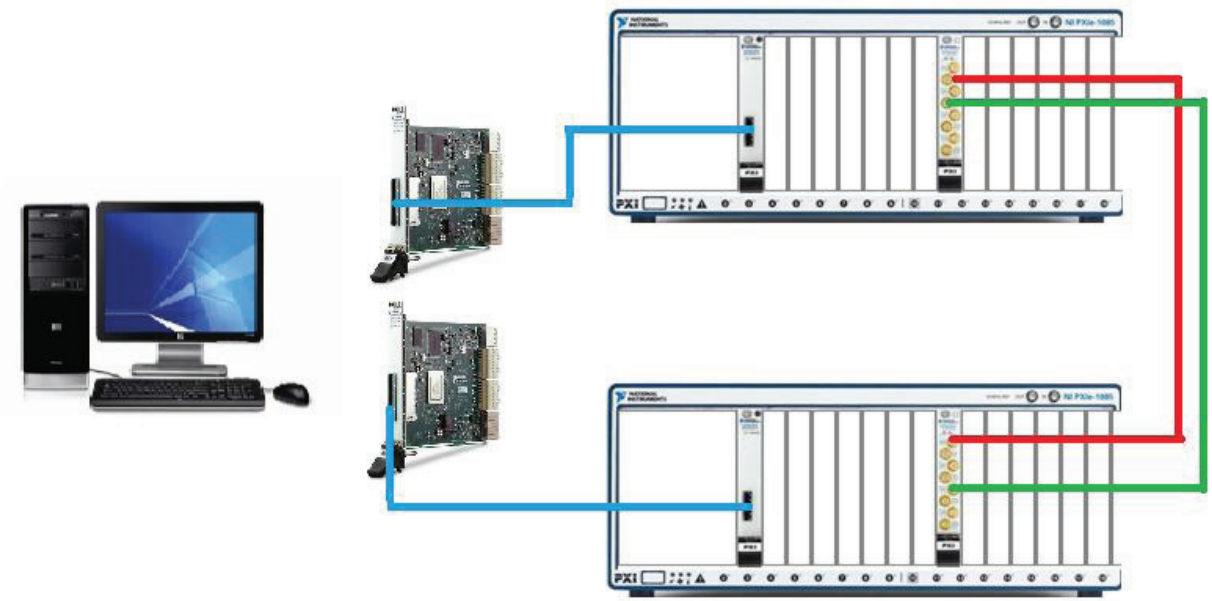




NATIONAL INSTRUMENTS

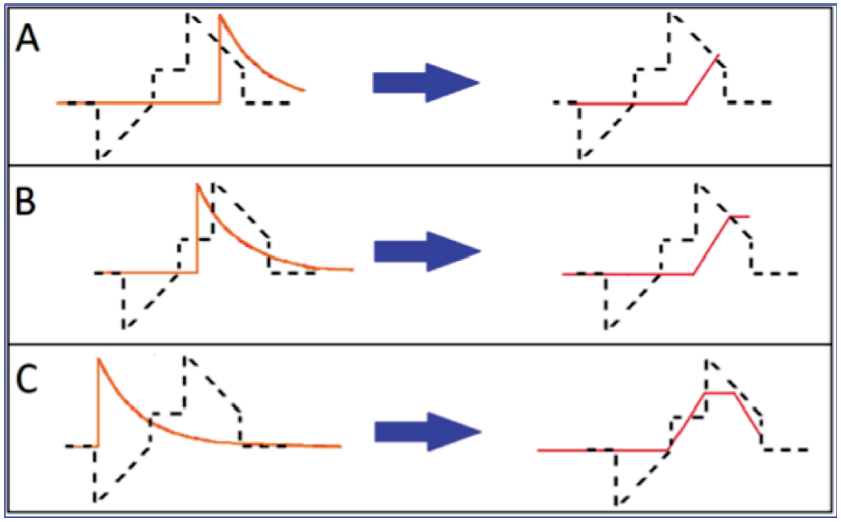
System Requirements

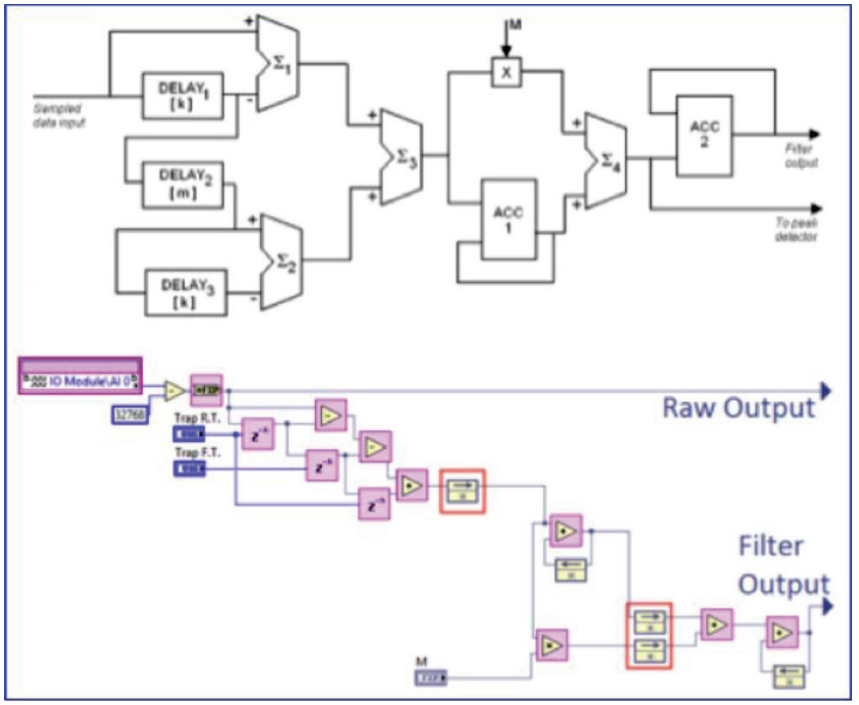
- 256 synchronized channels with PXIe-5171R
- Readout energy and timing from each pixel
- Event rates up to 10 kHz with no dead-time
- Continuous data buffering in onboard DRAM



Signal Processing

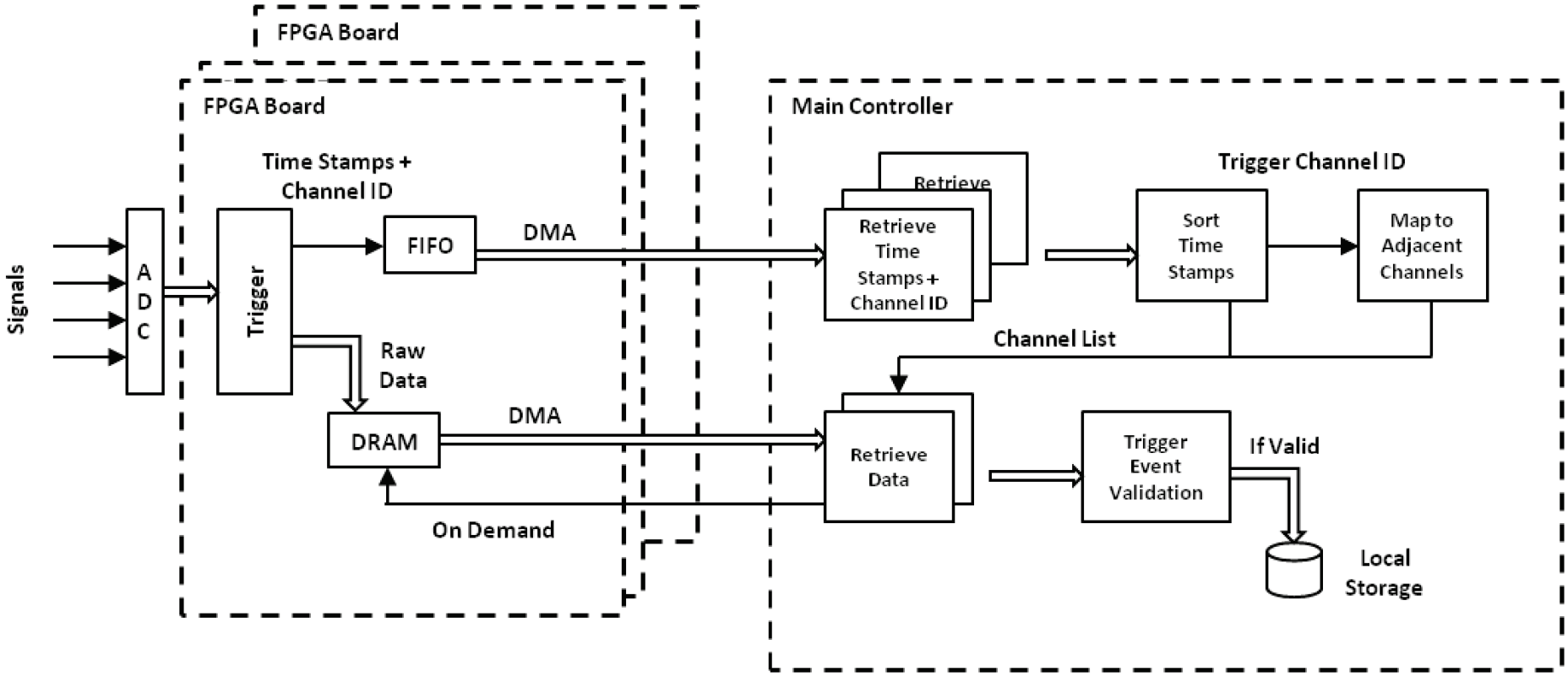
- Trapezoidal FIR filter implemented in LabVIEW FPGA
- Low-threshold triggering below noise level
- Energy, timestamp, and channel number sent to host





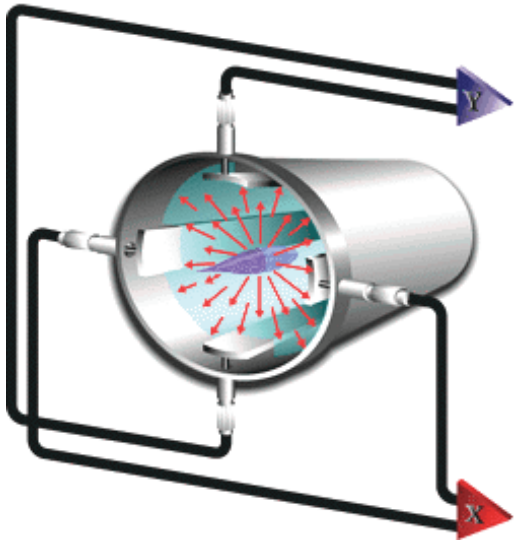
Proton-Electron Coincidence

- Global coincidence performed on host CPU
- Beta decay triggers retrieval of record with adjacent pixels

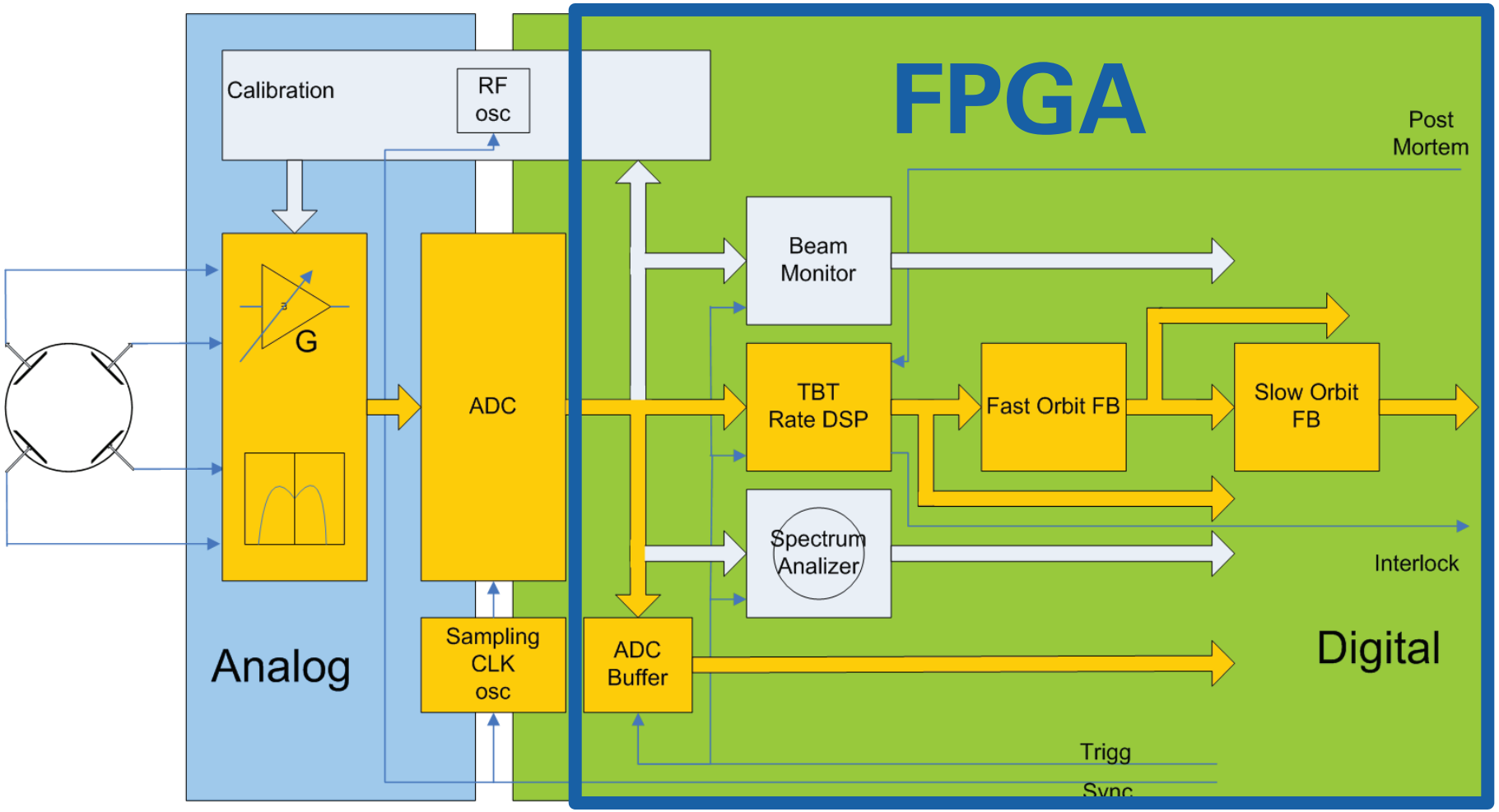


Beam Position Monitor

- Acquire signals up to 500 MHz on 4 channels (±X, ±Y) plus reference
- RF downconversion
- Calculate position and phase-information
- Provide data to control system
- Parallel time and frequency domain signal processing



BPM High-Level Architecture



Summary – Reconfigurable Oscilloscopes

- New PXIe-5170R and PXIe-5171R
  - High Channel Density Oscilloscope - 8ch at 250MS/s, 14-Bit
  - Xilinx Kintex-7 FPGA, Programmable with LabVIEW and VHDL
  - Stream up to 3.2 GB/s over PCIe Gen2 x8 Bus
- Open FPGA for Scientific Research Applications
  - In-line Signal Processing
  - Real-Time Control
  - Custom Triggers without Dead-Time
- Out of the Box Oscilloscope Functionality
  - Sample Projects for Record-based Acquisition and Streaming
  - Deployable under Linux in C programming environment

Resources

Thank you for your attention!

- **NI PXIe-5171R** - 250 MHz, 250 MS/s, 14-Bit, Software-Designed Oscilloscope
  http://sine.ni.com/nips/cds/view/p/lang/en/nid/212657

- **Building a New Class of Instrument: Software-Designed Instrumentation**
- http://www.ni.com/newsletter/51599/en/

- **Get Better Measurements Faster Using Oscilloscopes With User-Programmable FPGAs**
  http://www.ni.com/white-paper/52320/en/