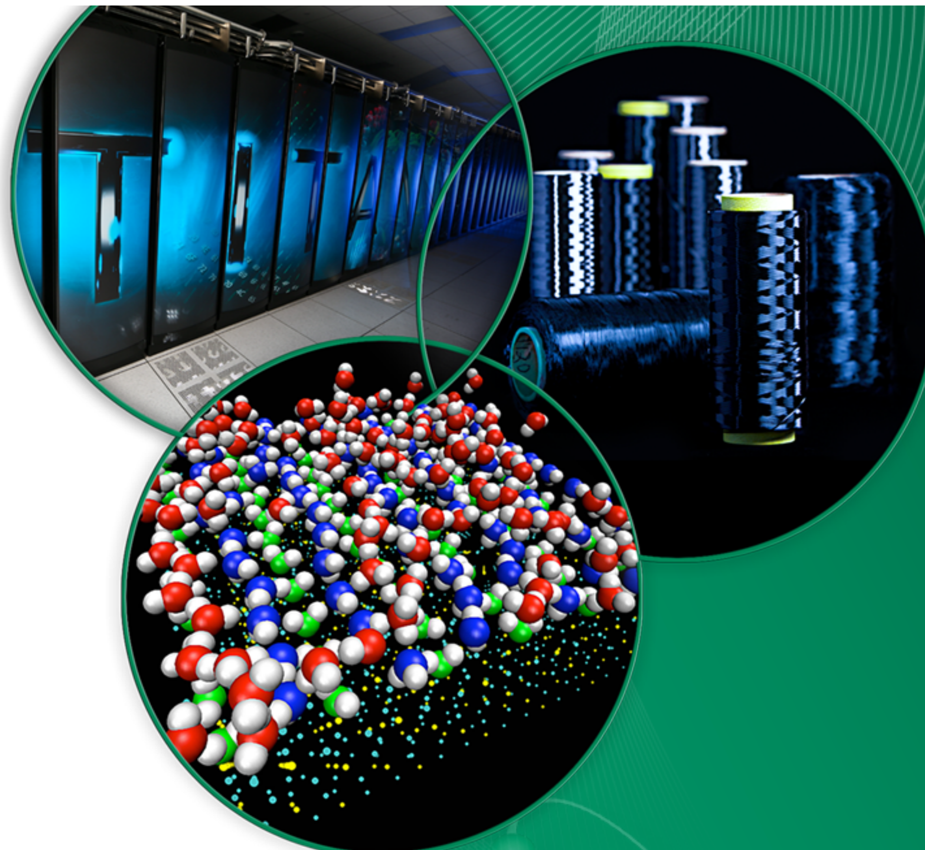
A new Differential And Errant Beam Current Monitor for the SNS* Accelerator

W. Blokland and C. Peters

Spallation Neutron Source
Oak Ridge National Laboratory



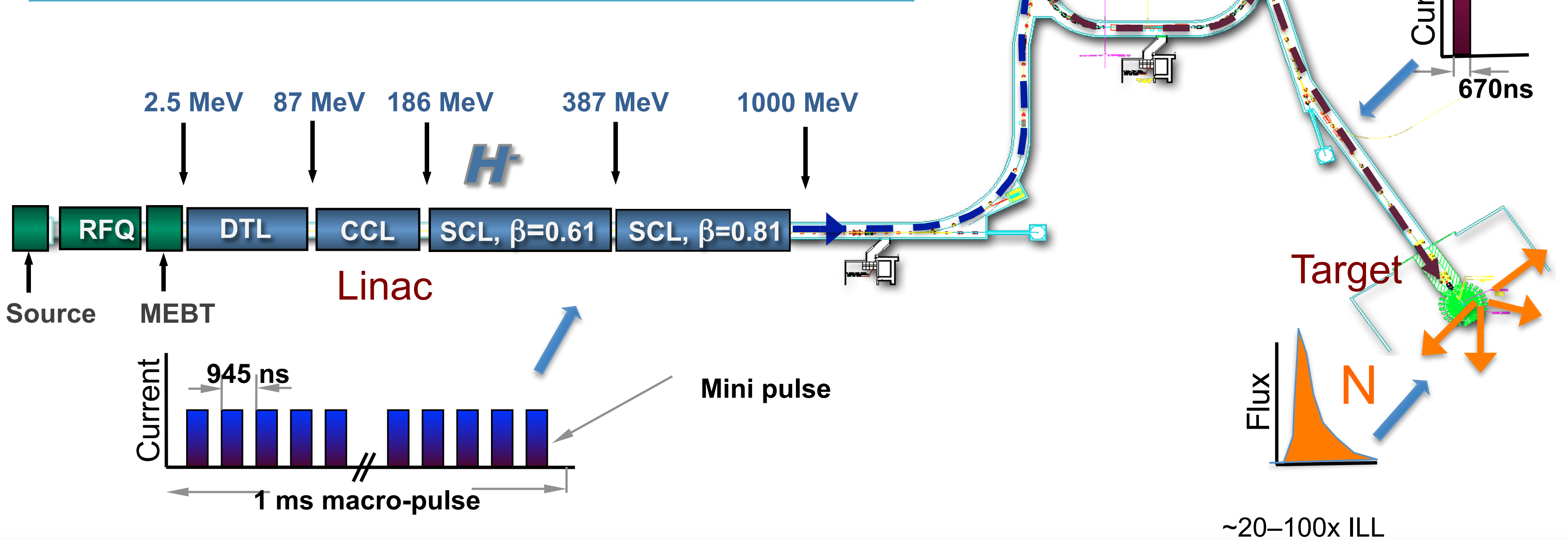
IBIC 2013
International Beam Instrumentation Conference

* ORNL/SNS is managed by UT-Battelle, LLC, for the U.S. Department of Energy under contract DE-AC05-00OR22725

Spallation Neutron Source

- Neutron scattering facility to research properties of materials
- 1 GeV Protons create neutrons through spallation

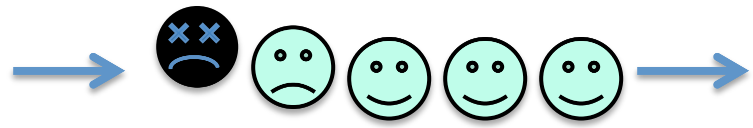
Power on Target	1.4 MW at 1.0 GeV (1.2 MW now)
Pulse on Target	1.5 E14 protons (24μC)
Macro-pulse in Linac	~1000 mini pulses of ~24mA avg over 1ms at 60Hz



Introduction

Errant Beam at SNS; any beam outside the normal operation envelope:

- Too high peak density beam on target
- Current drops or missing mini pulses
- Abrupt beam losses

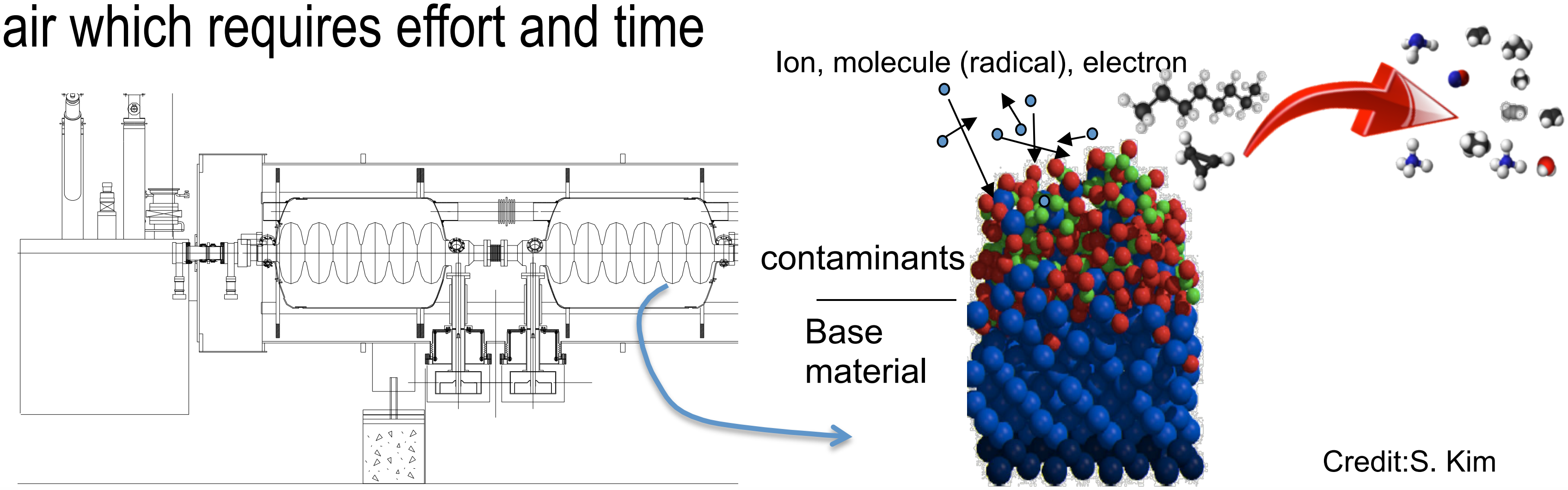


Many ways to abort errant beam but the main mechanism for aborting on beam loss is the Beam Loss Monitor System but:

- **Medium Energy Beam Transport (MEBT):** Beam Loss Monitors are not effective because the beam energy is too low. Existing MEBT Differential Current Monitor protects chopper target & scraper
- **Super Conducting Linac (SCL):** Beam Loss Monitors are designed to abort in about 20 µs BUT now we suspect damage to superconducting cavities to occur with even shorter pulses.

Why is even short errant beam (<15 μs) important?

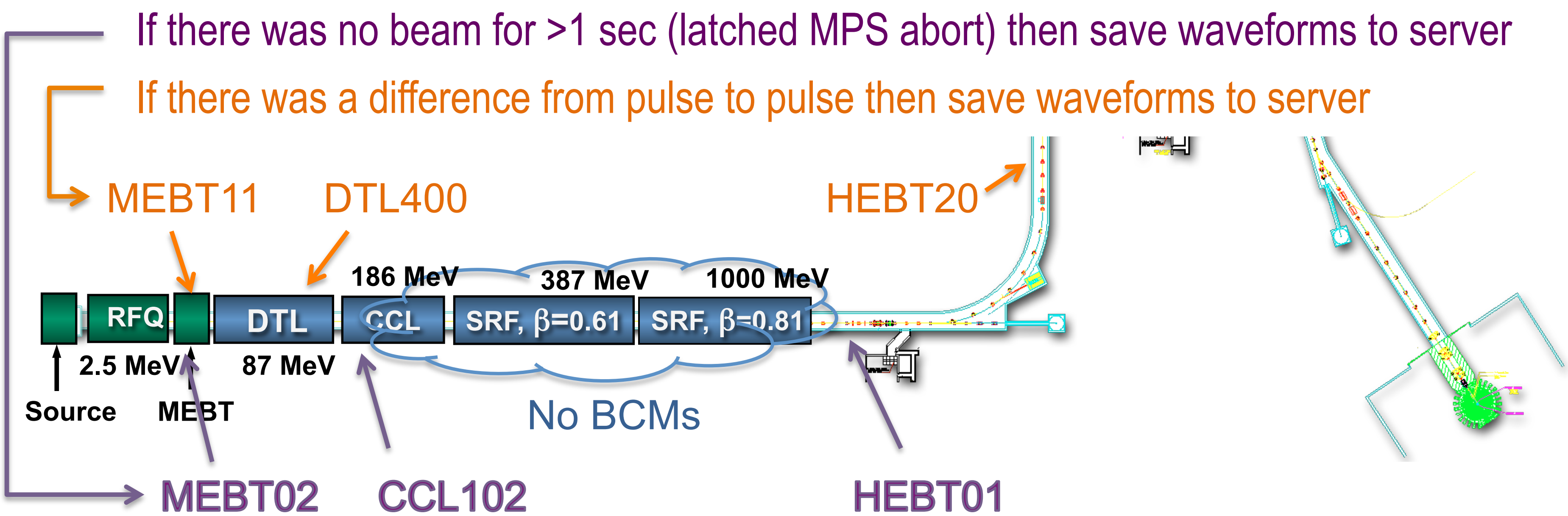
- Errant beam in SCL leads to accumulating damage [1]
  - Suspected mechanism: beam hitting cavity surface releases gas or particulates followed by ionization or redistribution, creating an environment for arcing. The arcing can damage the cavity surface.
- This degrades SCL cavity performance over time
  - Increased tripping probability with time -> Cavity fields must be lowered
- Recovery all but one cavity but requires warm up and conditioning and/or repair which requires effort and time



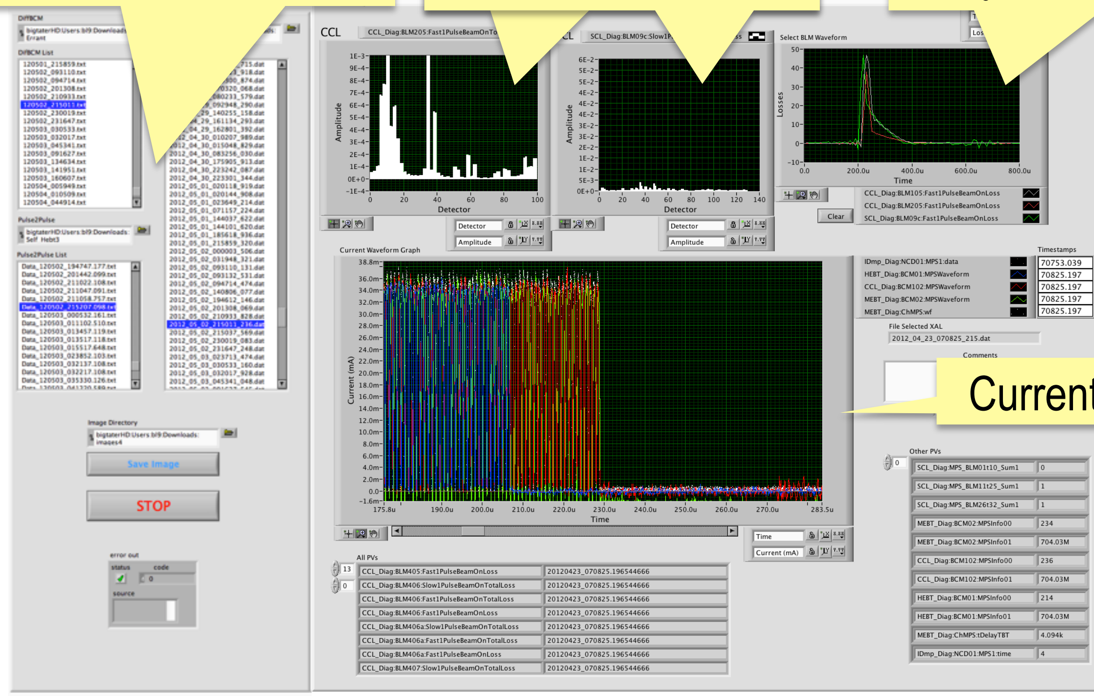
Errant Beam Investigation

Acquire data from current monitors, loss monitors, selected RF waveforms and accelerator setup when beam is aborted [2,3].

- Operator controlled scripts to save loss monitor and RF data to file
- Modified several standard beam current monitors to acquire and analyze every beam pulse @60Hz (no abort capability)



Errant Beam Analysis



< 10% of BLM trips were due to the Ion Source/LEBT

- BLM trips occur in the first week of a new source installation

> 90% of BLM trips were due to Warm Linac RF faults

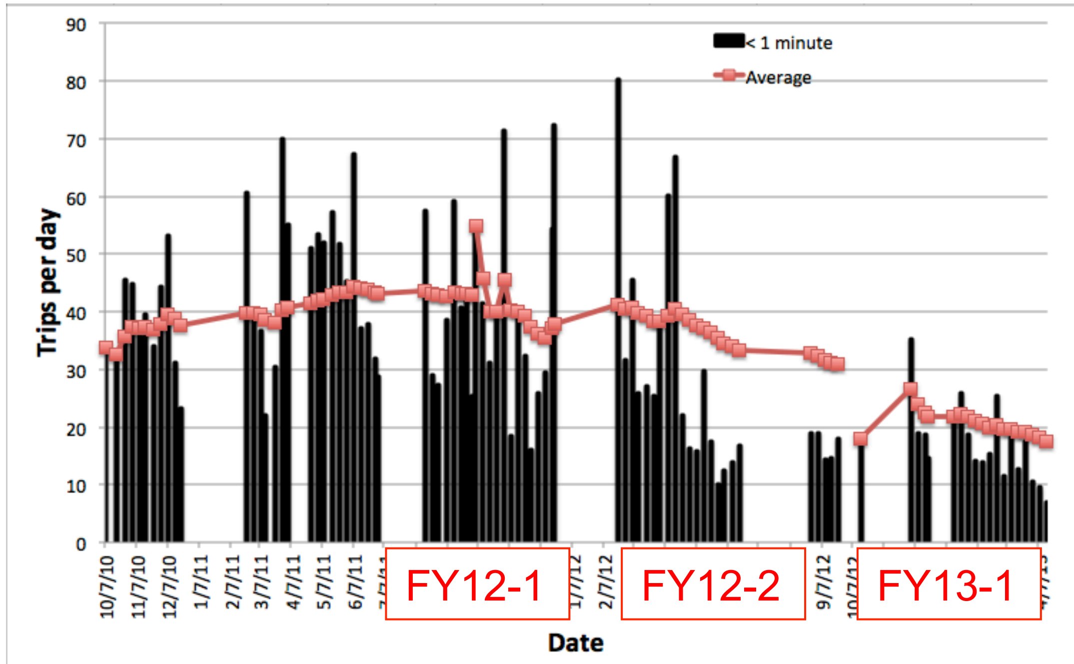
- RF faults occur at different times during the pulse

The majority of trips originate in the Warm Linac

RF Adjustments: gradient changes, resonant frequency changes, and preventative maintenance on vacuum systems

→ fault frequency reduced by more than a factor of two.

→ SCL downtime was reduced by a factor of six



Errant beam loss from 30 to 15 events a day

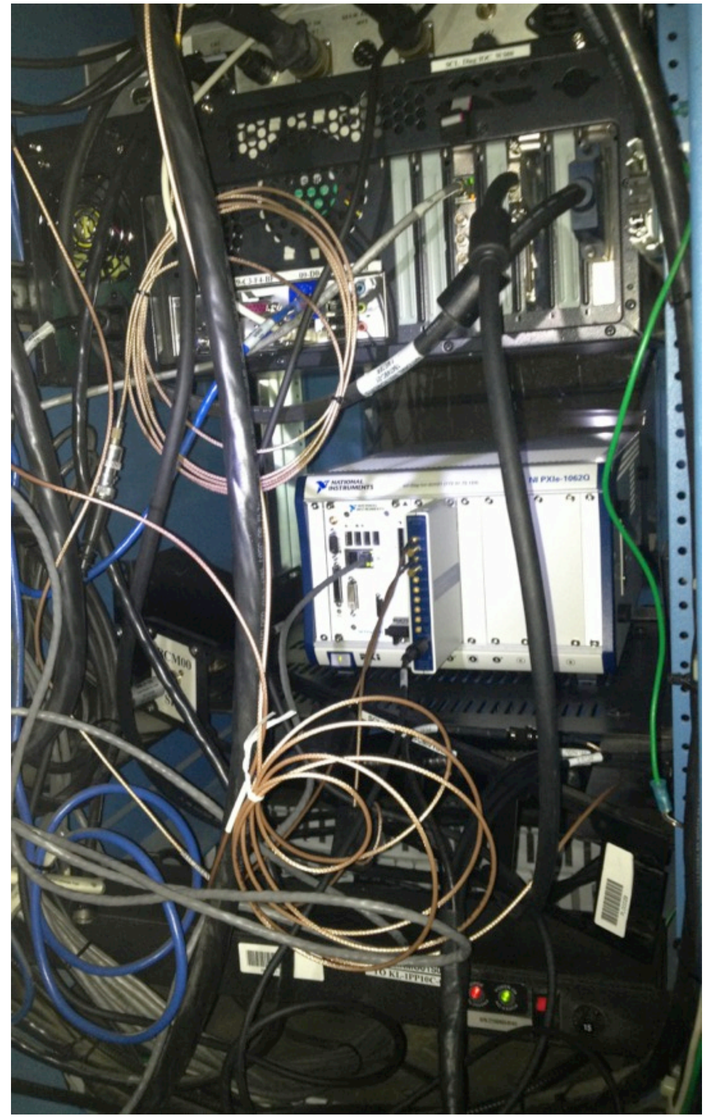
BUT still need to reduce impact of remaining errant beam (losses or no losses) → differential current and errant beam monitor to abort as fast as possible or about ~5 µs

Implementation of DBCM

- Existing MEBT DBCM:
  - Obsolete hardware & No VHDL programmers available
- New platform:
  - PXIe Real-Time Controller with FlexRIO FPGA and 14-bit 2 channel 100MS/s digitizer
  - Programmable in LabVIEW
    - Both the FPGA code and Real-Time code
    - Multiple programmers in our group

Implementation of DBCM

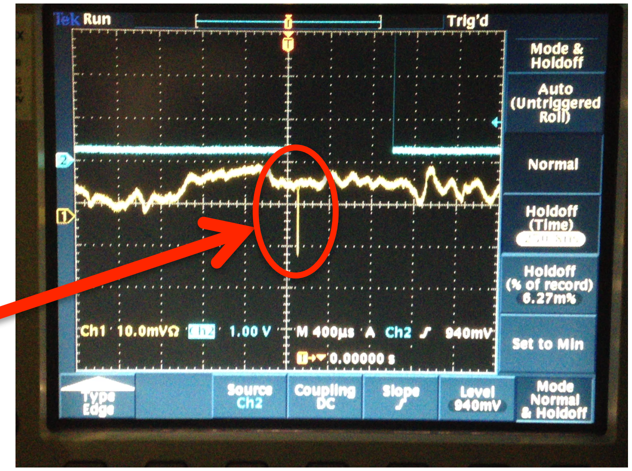
- Existing MEBT DBCM:
  - Obsolete hardware & No VHDL programmers available
- New platform:
  - PXIe Real-Time Controller with FlexRIO FPGA and 14-bit 2 channel 100MS/s digitizer
  - Programmable in LabVIEW
    - Both the FPGA code and Real-Time code
    - Multiple programmers in our group

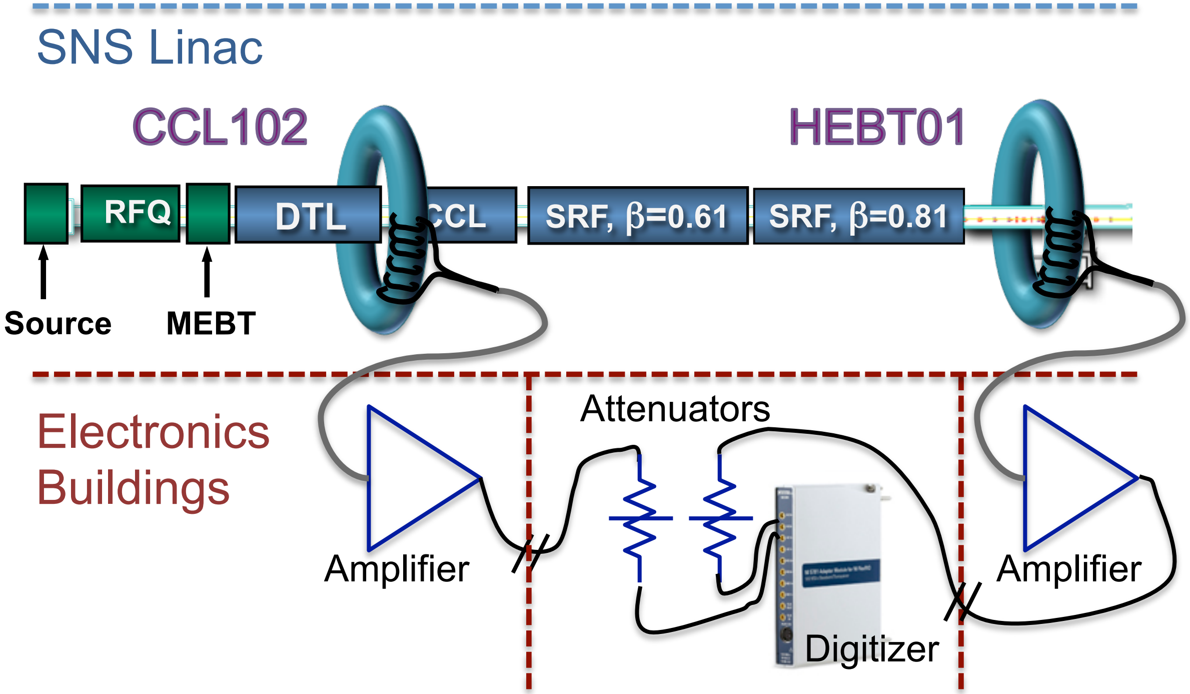


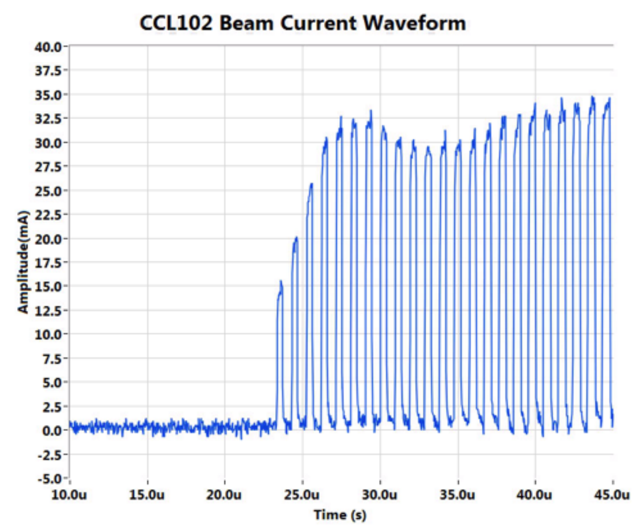
Layout of DBCM

- Wideband current transformers:
  - 1 GHz with 1 ms droop time constant
  - Nearest one before and after SCL
  - Long cable lengths (500-1200ft)

HEBT BCM01 Waveform

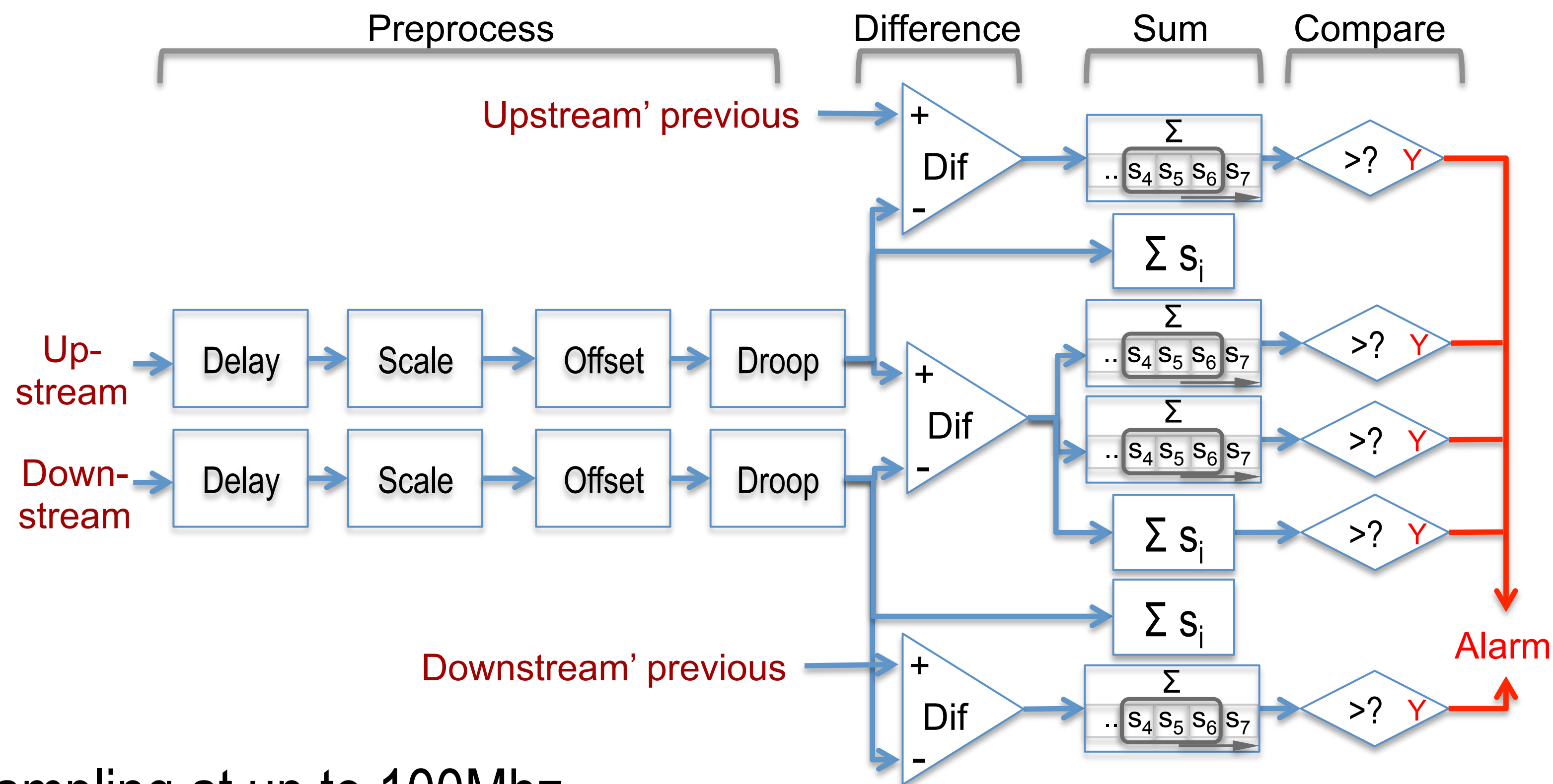






FPGA Processing

Account for difference in cable lengths, calibration, drifts, and droop.

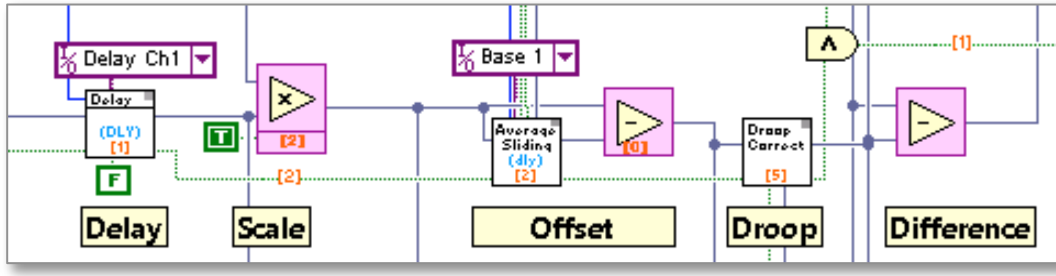


Sampling at up to 100Mhz
Pipeline delay 15 clocks cycles: 150ns

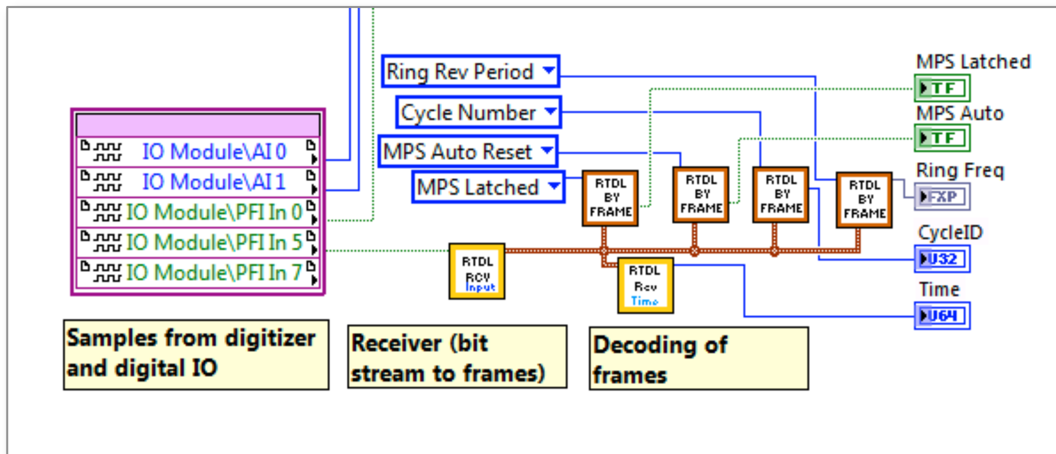
FPGA processing

Features:

- Send three waveforms
  - Any of the preprocessing stages
  - Differential signals
  - Sliding windows outputs
- Alarm status on each sample
  - Which threshold exceeded
- SNS Timing Library
  - Receive timing link and data link data [4]. We don't need a separate (and custom) timing decoder!



Preprocessing code

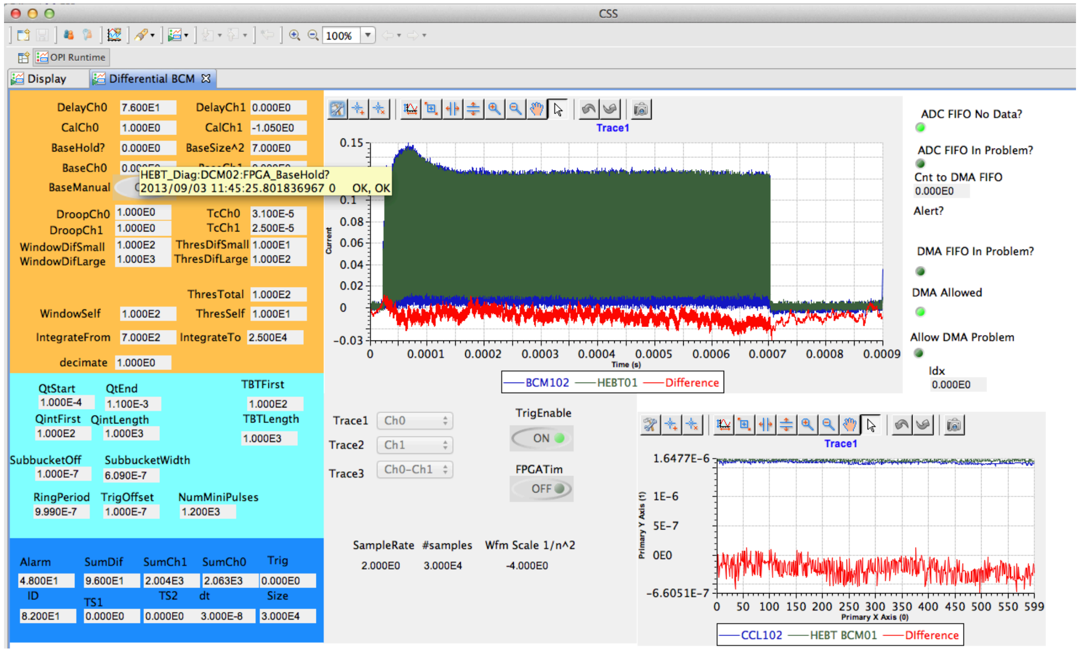


Timing Decoding code

Real-Time Processing

- All time-critical µs signal processing including abort is done in FPGA

- Real-time code @60Hz:
  - Storing of errant beam waveforms
  - Calculate statistics
  - Interface with control system using native LabVIEW EPICS [5]
    - automatic creation of PVs and console screens



CSS screen for DBCM

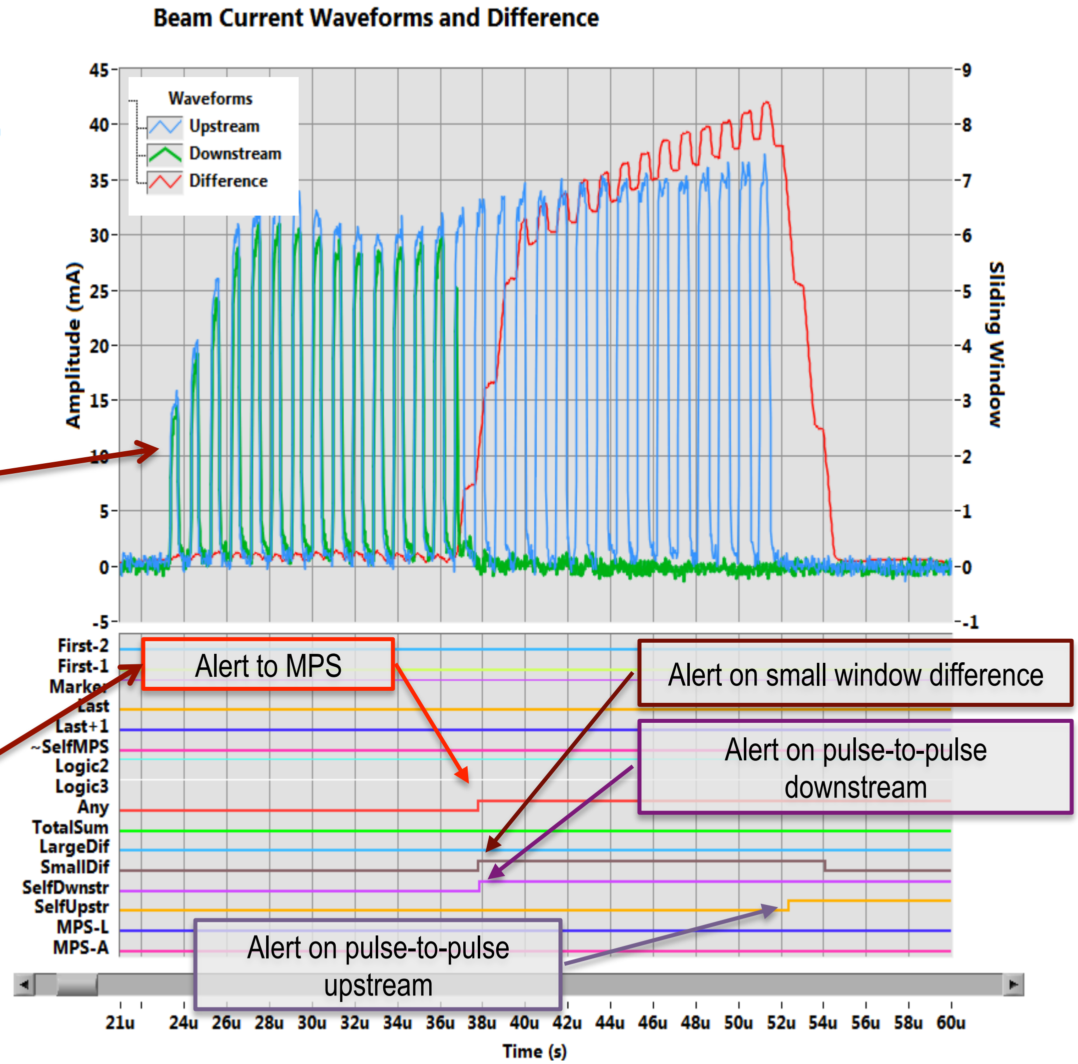
Initial Results

- Example of the errant beam we want to abort
- Analyzed to be due to a Warm Linac RF drop

Waveforms:

1. Upstream
2. Downstream
3. Difference after short sliding window

Alert was given in <1.5 µs (could be faster with lower thresholds and still avoid false alerts)



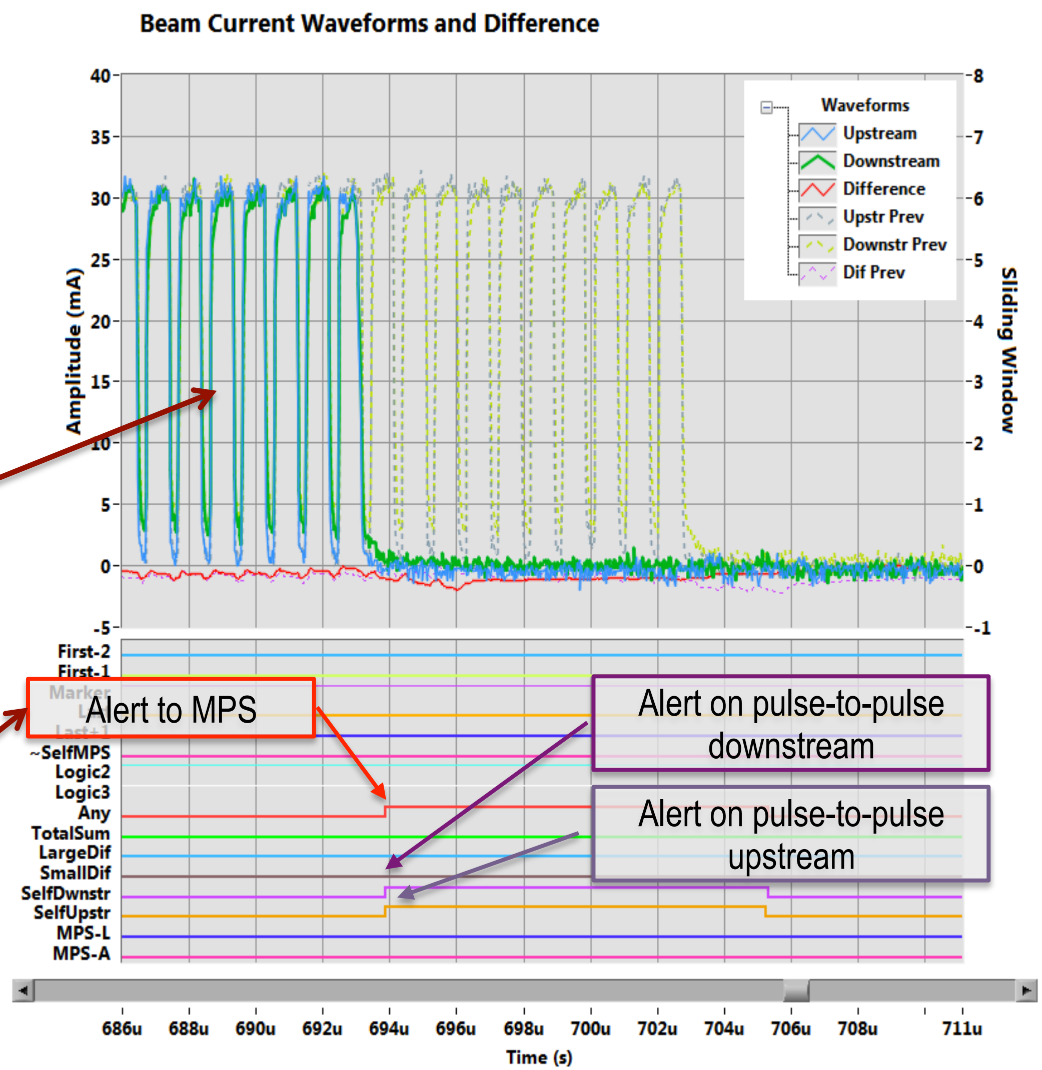
Initial Results

- Example of truncated beam.
- Analyzed to be due to a RFQ RF field drop

Waveforms for errant pulse AND previous pulse:

1. Upstream
2. Downstream
3. Difference

Alert in ~1µs

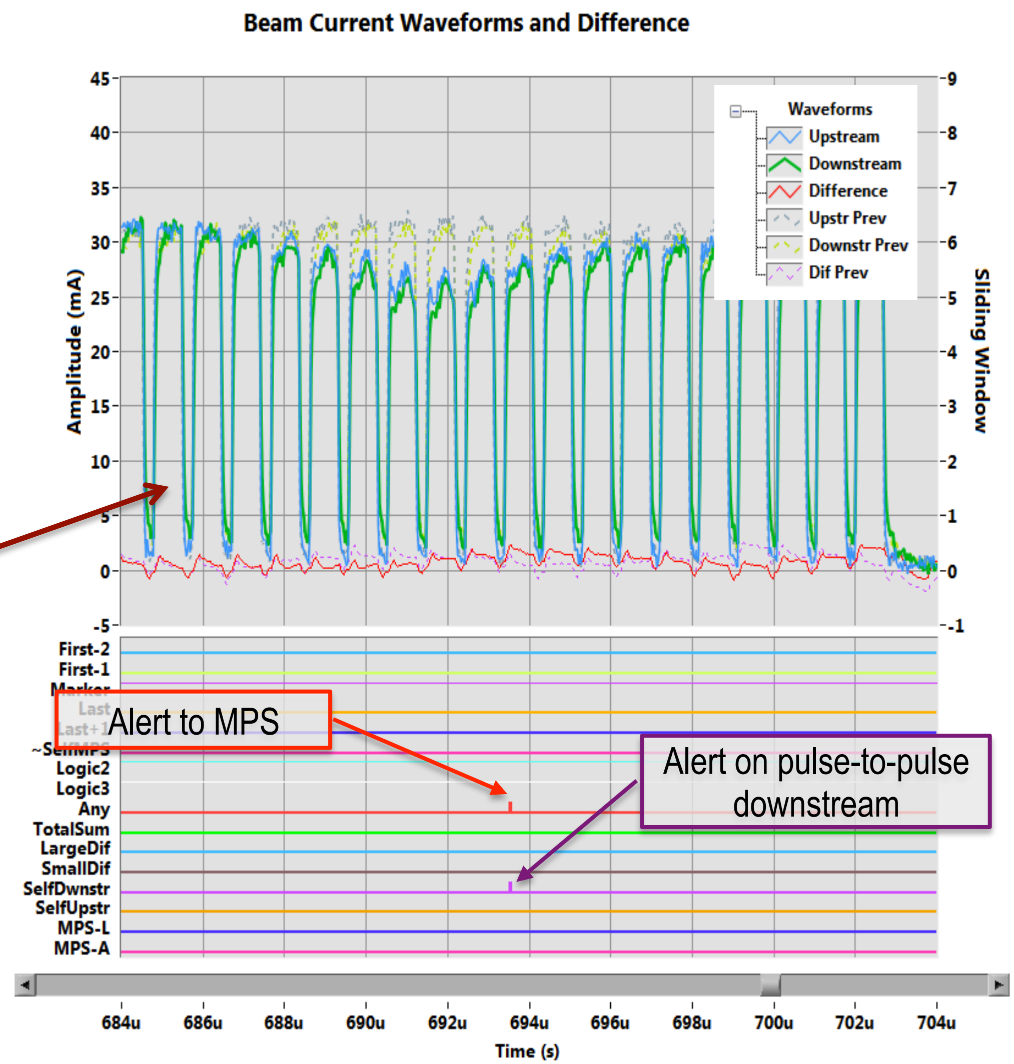


Initial Results

- Example of slow drop in current from pulse-to-pulse
- Analyzed to be due to RF Fill problem

Waveforms for errant AND previous beam pulse:

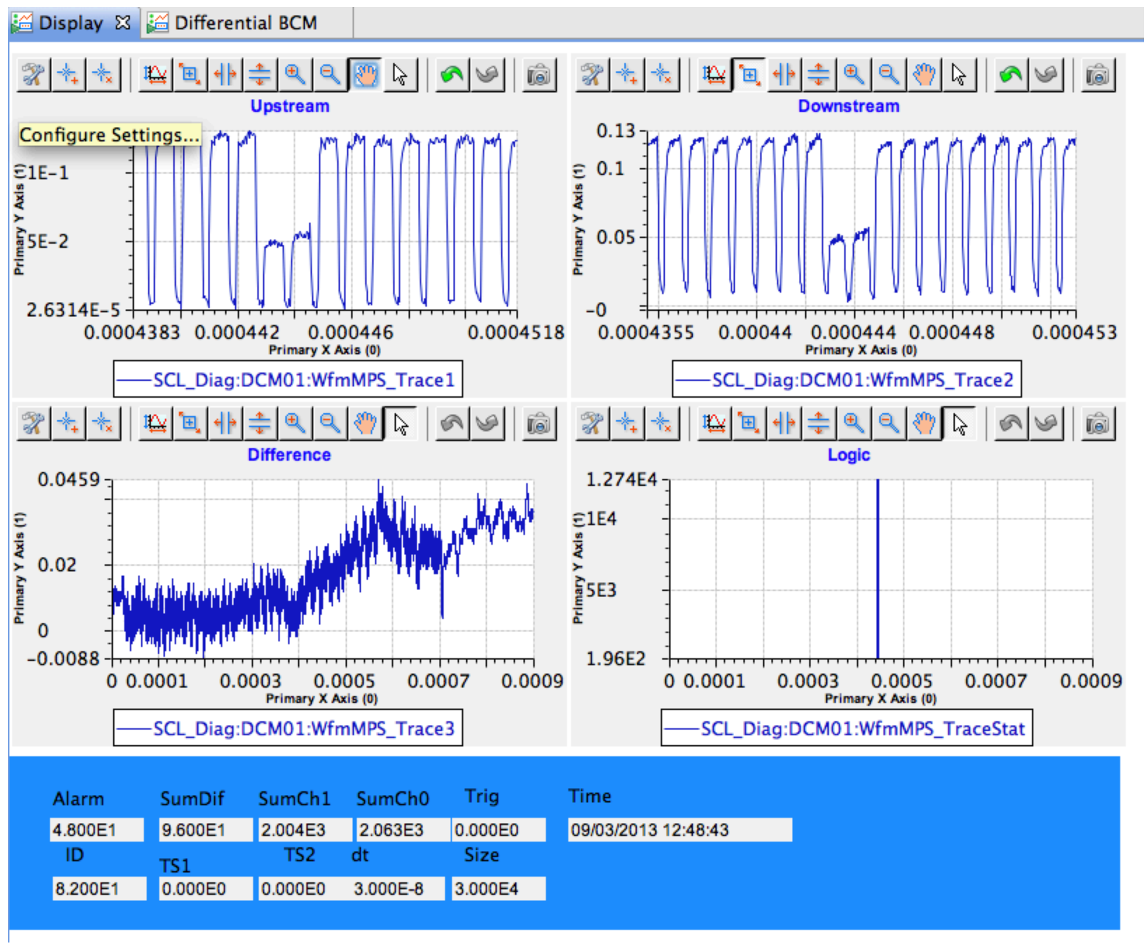
1. Upstream
2. Downstream
3. Difference



Initial Results

- Abrupt drop in few mini pulses
- Analyzed to be due to LEBT Chopper

Any loss in beam current can lead to RF feed-forward loop issues on the next pulse causing beam loss -> further investigate



Discussion

- With the used threshold settings and signal-to-noise, the DBCM can abort in about 1 μs BUT the existing of signal cable delays (2.5 μs), abort cable delay (1 μs), and beam propagation time (1.5 μs) gives a total delay of about 6 μs. Shorter cables should give us 5 μs
- High performance platform with Timing decoding and EPICS interface
- Near term future:
  - Automatically categorize errant beam types
  - Separate between "interesting" and "abort" and save the "errant after" beam pulse
  - Hook up to front-end abort
- Long term future:
  - Shorter cables (through tunnel) and lower bandwidth transformers with better signal-to-noise and closer locations to further reduce abort time.

REFERENCES
[1] S. Kim et al., "The Status of the Superconducting Linac and SRF Activities at the SNS," 16th International Conference on RF Superconductivity, Sep 23-27, 2013, Paris.
[2] W. Blokland, "Errant Beam: Tools and Data," SNS Errant Beam Committee, May 2012, Oak Ridge, TN.
[3] C. S. Peters, "Errant Beam Update," Accelerator Advisory Committee, May 7, 2013, Oak Ridge, TN.
[4] R. Dickson, "LabVIEW FPGA SNS Timing User Guide," SNS, May 7 2013, Oak Ridge, TN.
[5] S. Zhukov, "Pure LabVIEW Implementation of EPICS Communication Protocol," Big Physics and Science Summit at NIWeek, August 7-8, 2012. Austin, TX.