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Fermilab Trigger and DAQ Roadmap

Kurt Biery

CPAD Workshop

06 October 2015

Fermilab Environment

Neutrino Experiments

- DUNE, SBND, NOvA, MicroBooNE, MINOS, CONNIE, etc.

Dark Matter & Dark Energy

- DESI, DAMIC, DarkSide, etc.

Involvement in CMS

R&D

- MKIDs

Active testbeam program

Generally manageable data rates (streaming DAQ)

- Mu2e: ~30 GB/s into processor farm (HLT)
- DUNE: 4.6 TB/s before ZS, several GB/s after ZS

Time-window-based events

Detector R&D Activities in Fermilab SCD/RSE*

Direct Involvement

- MKIDs
- CONNIE/DAMIC
- Optical Links
- Rad-Hard Sensors
- CAPTAN+X
- Testbeam Detectors & DAQ

Indirect & Support Activities

- Off-the-Shelf DAQ
- *artdaq*
- RTI DDS SBIR(s)
- PREP
- Teststands

* Scientific Computing Division, Real-Time Systems Engineering Department

Fermilab SCD/RSE Engineers, Developers, and Scientists

DAQ Controls and Detectors group

- Gustavo Cancelo, Ted Zmuda, Ken Treptow, Neal Wilcer

Detector Electronics group

- Ryan Rivera, Alan Prosser, Mark Bowden, Rick Kwarciany, Greg Deuerling, John Chramowicz

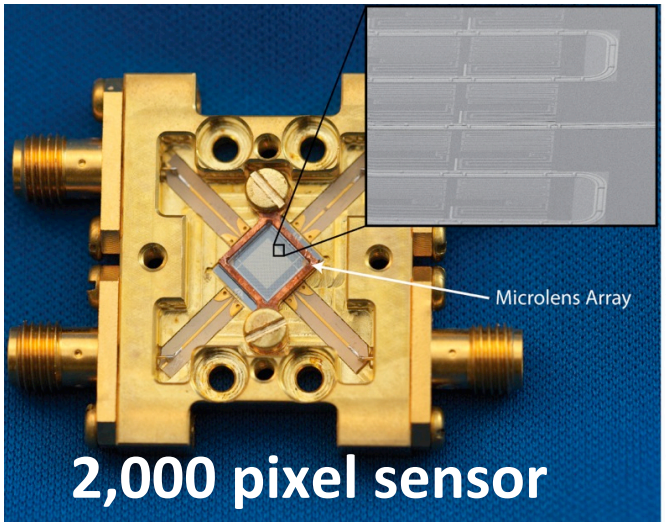
Physics Research Equipment group

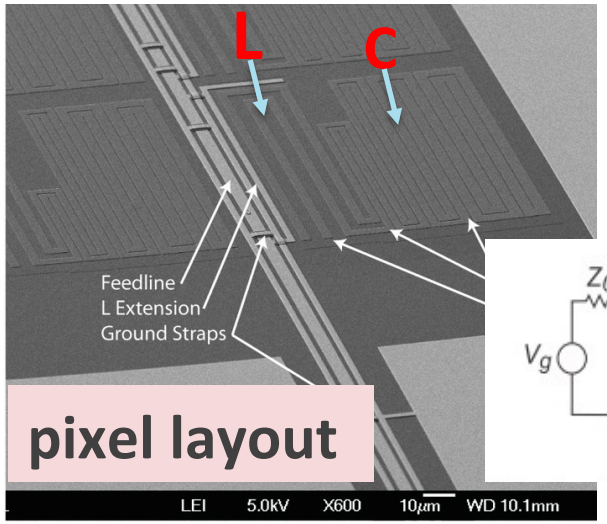
- Lorenzo Uplegger, Jason Greskoviak, Thinh Pham

Real-Time Software Infrastructure group

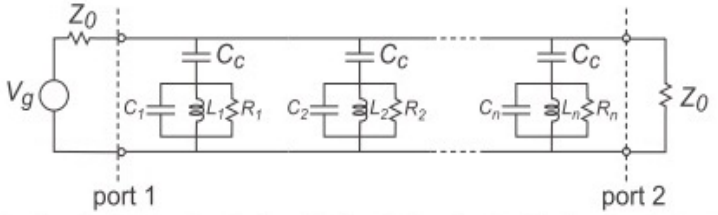
- Ron Rechenmacher, Gennadiy Lukhanin, John Freeman, Eric Flumerfelt, Wes Ketchum

MKID: Superconductor Detectors for Optical-NIR Cosmology



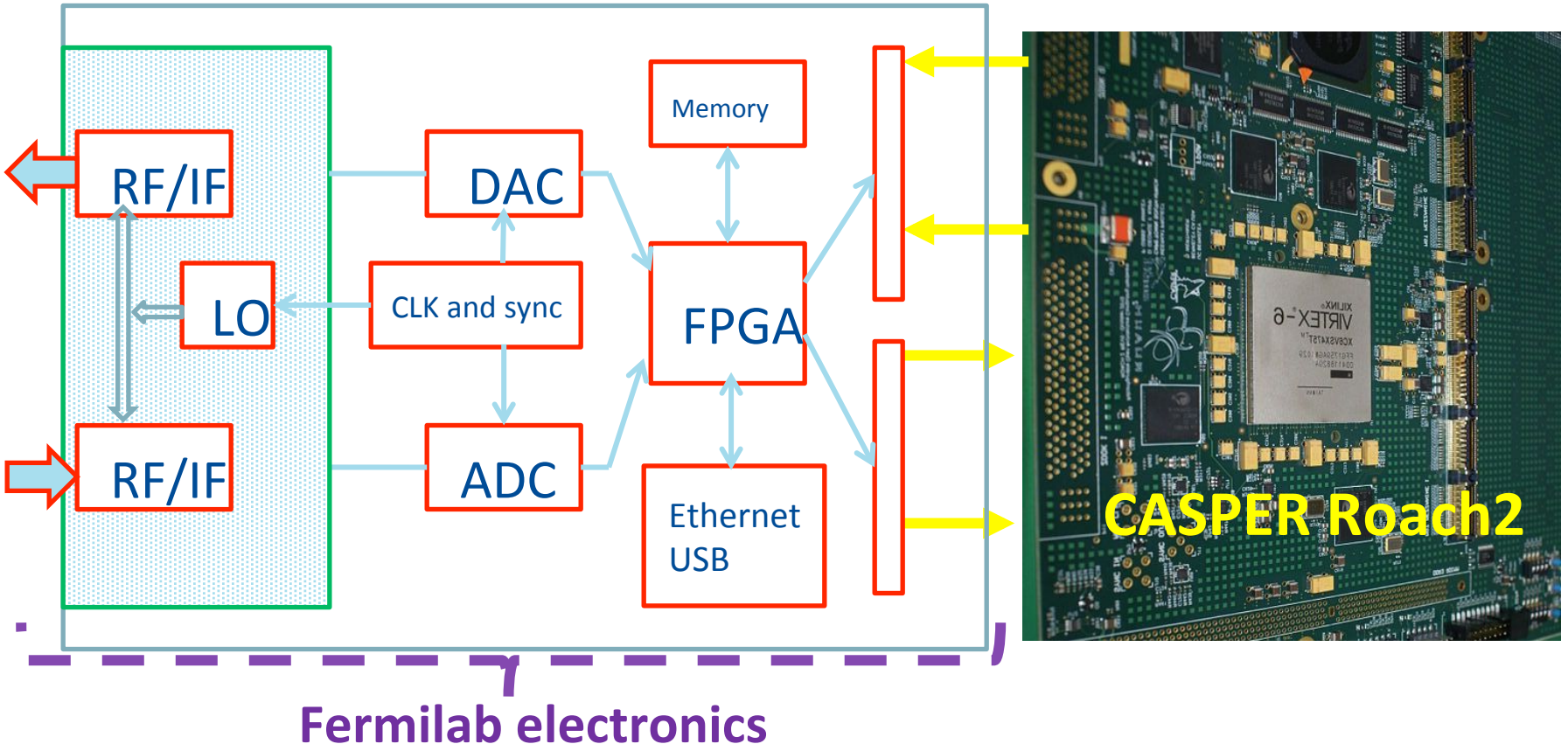


Equivalent electronic circuit.



- Pixelated RF resonator array.
  - **1,000 pixels multiplexed in frequency coupled to each RF feed/readout-line.**
- Superconducting sensors with MeV energy gap. More than just a single photon detector:
  - **Can provide energy resolution (E/ΔE) in the visible and near infrared spectrum of ~80 to do low resolution spectroscopy at large scale without filters, and photon tagging with 1usec resolution.**
  - **Low resolution spectroscopy of >1 billion galaxies, QSO and other objects from DES & LSST data. (No other known instruments can do that).**

Two-Board Readout



- Fermilab electronics generates MKIDs excitations and readout MKID signals at 4 Gs/s. Converts IF from/to RF with a wide bandwidth and high gain design.
- The signal processing is shared between the AC/DAC board and the CASPER2 board.

A 10K to 20K pixel Fermilab DAQ

- MKID signal generation:
  - 8 GB/s for 1K pixel. 80GB/s 10K pixel system.
  - Tunable frequency and power for each resonator.
- MKID acquisition:
  - 6 GB/s for 1K pixel. 60GB/s for a 10K pixel system.
- Scalable to 20K (even 30 K) pixel is reasonable.
- Data output bandwidth is about ~100 MB/s
  - 1K photons/pixel/s, 10K pixels, 10 B/photon.
  - Data crunching of x1000 in the FPGA.
- Software pipeline runs on main computer.
  - Inherited from ARCONS project (UCSB).

Further MKIDs Development

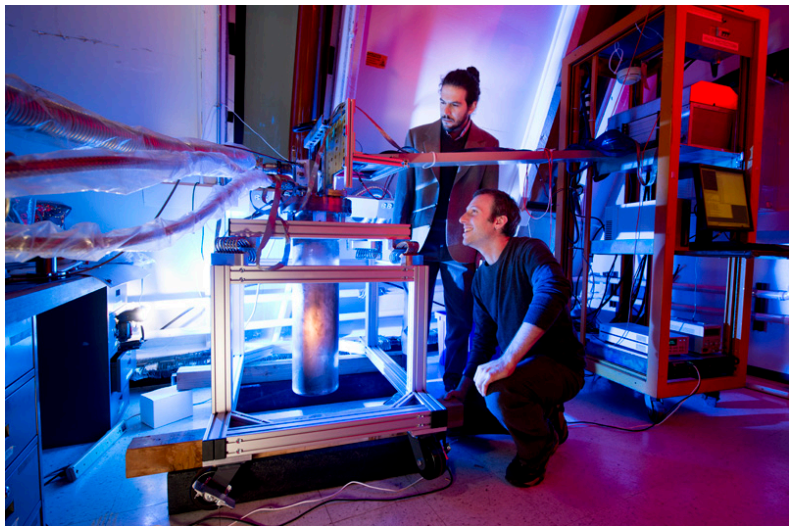
100K pixel instrument architecture

- Faster DACs and ADCs to allow for more channels per RF feed line.
  - **Goal: 2000 MKIDs per feed line, frequency multiplexed at 2 MHz separation between MKIDs.**
- 50 total RF feed lines. (i.e. 50 in, 50 out).
  - **50 RF up/down converters and low noise amplifiers (5 kelvin noise temperature).**
- Improved signal and data processing to channelize 2000 MKIDs per feed line.
- Calibration using RF and optical signals.
- High bandwidth:
  - Raw data: 400 GB/s
  - Trigger-less DAQ.
  - Data reduction: ~200 MB/s to storage.

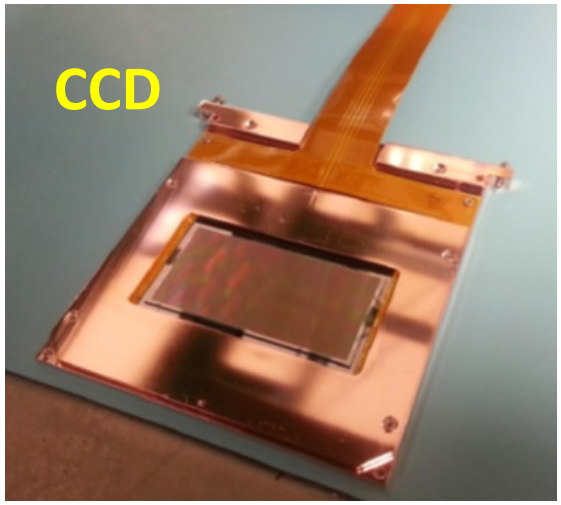
Uses in post-LSST spectroscopy and more.

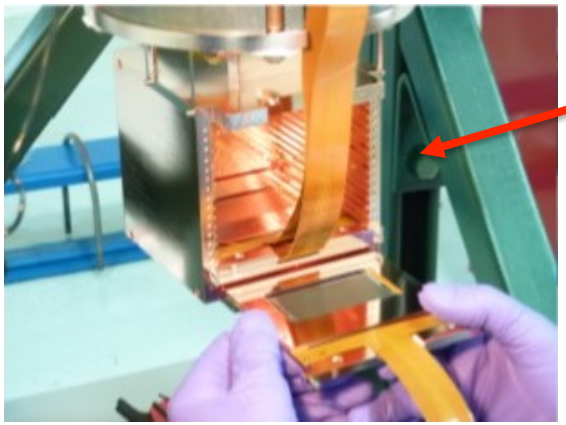
CCDs for Dark Matter Searches and Neutrino Studies

DAMIC at SNOLAB



CONNIE at Angra 4GW nuclear reactor





A CCD detector box hosts 20, 8 Mpixel CCDs.
CCDs work at 140K and vacuum

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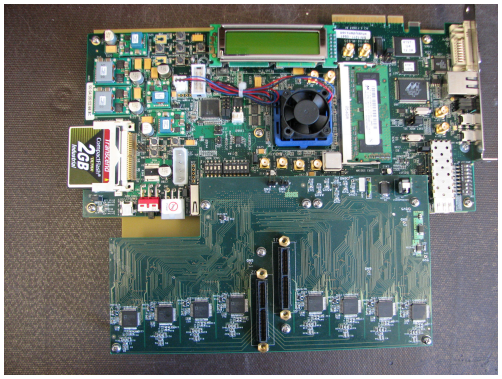
CONNIE and DAMIC Upgrades

- A 1 Kilogram detector requires on the order of 100 CCDs with 36 Mpixels each.
- A 1 Kg detector will have more pixels than LSST and 100 times the CCD mass of LLST.
- Fermilab has completed the R&D for a new DAQ compatible with 1 Kg detector.
- The design is undergoing with the goal of operating in late 2016 or early 2017.



Analog and digital Multiplexer R&D (left and right pictures respectively)

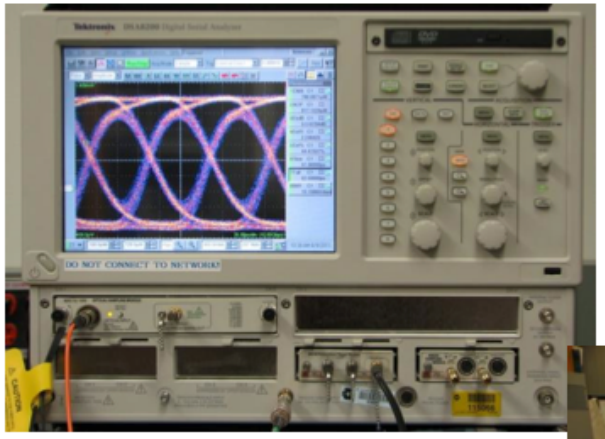
Optical Links

Participating in the Versatile Links+ project

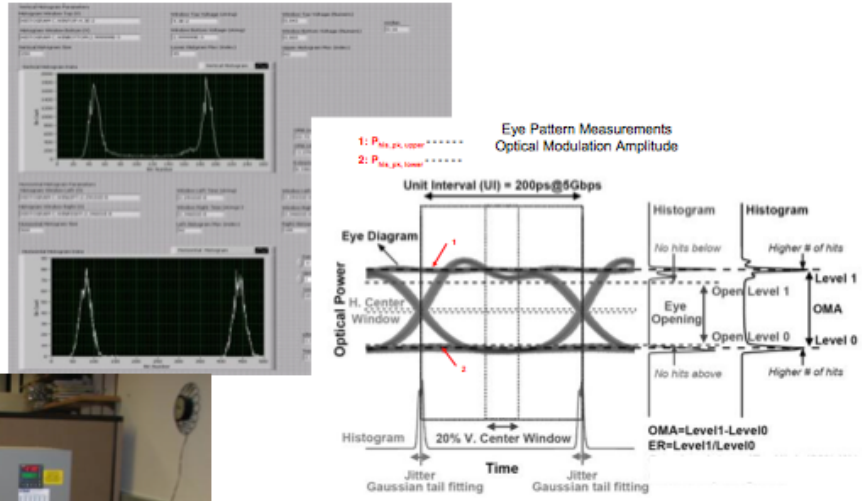
- VL & VL+ are common projects of ATLAS and CMS to develop the optical physical layer for the GBT-based data links
- Successfully developed bi-directional/configurable single mode or multi-mode data links operating at 4.8 Gbps and resistant to calorimeter grade radiation levels
- VL+ goals are development of array optics in flexible formats (division between Tx and Rx channel counts)
- Fermilab role is testing and evaluation of commercial (not rad-hard) receiver components
- May be an opportunity to contribute to system specification and testing for VL+

Optical Link Test and Measurement Facilities

Digital Signal Analyzer (Eye Patterns, Jitter)



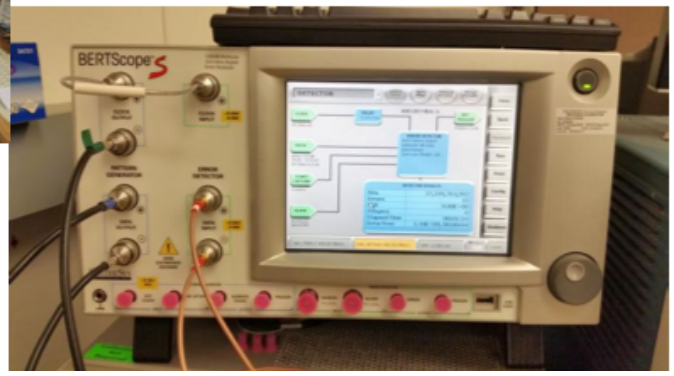
Labview VIs (Histogram Analysis)



Variable Optical Attenuators
(Receiver Sensitivity)

Environmental Chamber
(Temperature/humidity test)

BERTScope BSA12500B (BER Testing)



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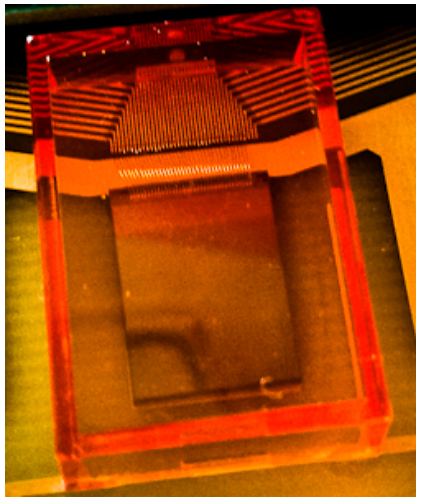
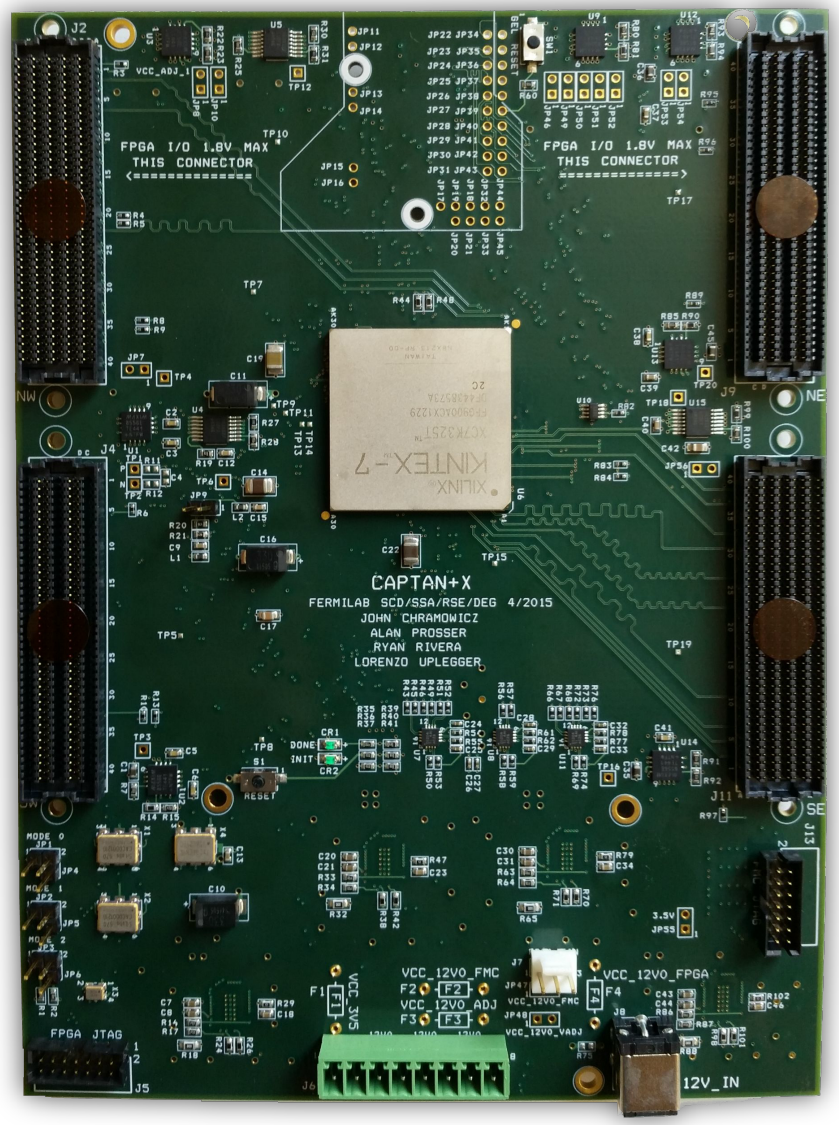
Rad-Hard Sensor R&D

- Testing sensor candidates for CMS HL-LHC upgrade, before and after irradiation; comparing performance
- Current focus on 3D and thin silicon n-on-n and n-on-p; also testing new prototypes designed at Fermilab with smaller pitches and slimmer edges
- Working in close collaboration with SINTEF which will provide thinned sensors down to 100um
- Currently limited by Read Out Chip (ROC) radiation hardness, but new ROCs soon
- Continue to test sensor prototypes, before/ after irradiation, until proven suitable for HL-LHC; successful sensors used in inner layer of pixel detector for Phase II upgrade



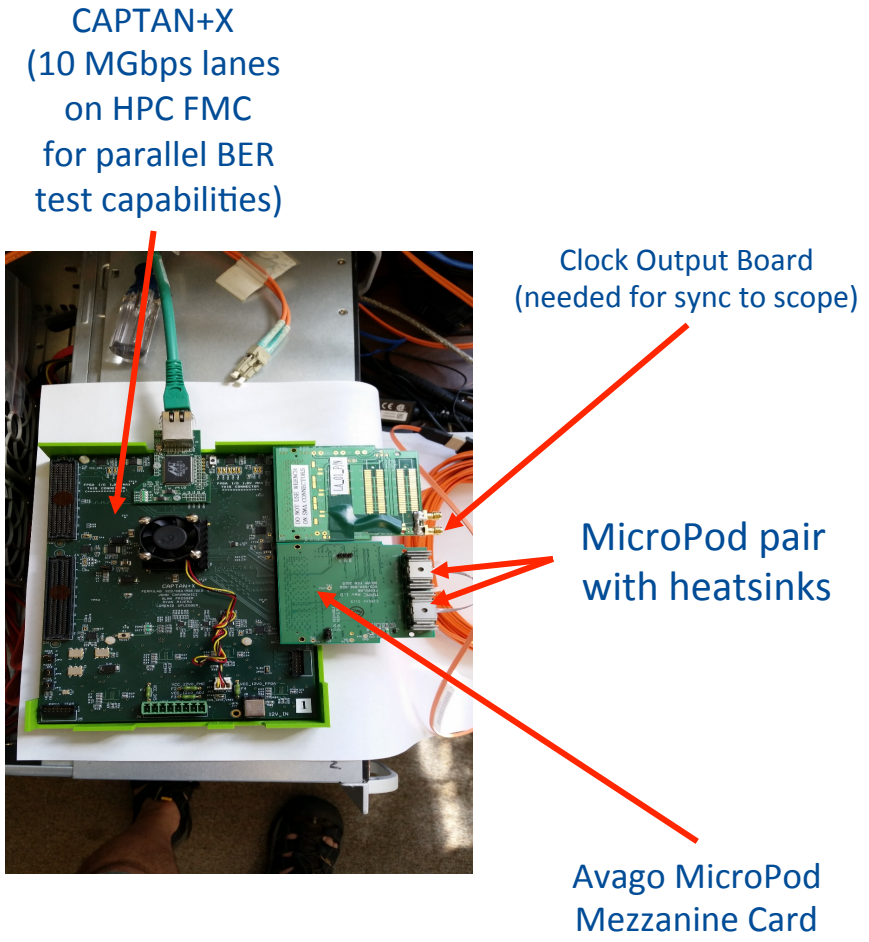
CAPTAN+X

- Compact And Programmable daTa Acquisition Node
- CAPTAN+ (“CAPTAN plus”) is the next generation CAPTAN card.
  - A leap from Xilinx 4 series to 7 series.
  - The ‘X’ stands for “eXtreme” for its support of 10G links.
- **Features:**
  - Gigabit Ethernet
  - 4 FMC connectors
    - 2 HPC, 2 LPC
    - High-speed Links per FMC:
      - SE=10, NW=4, NE=1, SW=1.
  - 400 GPIO



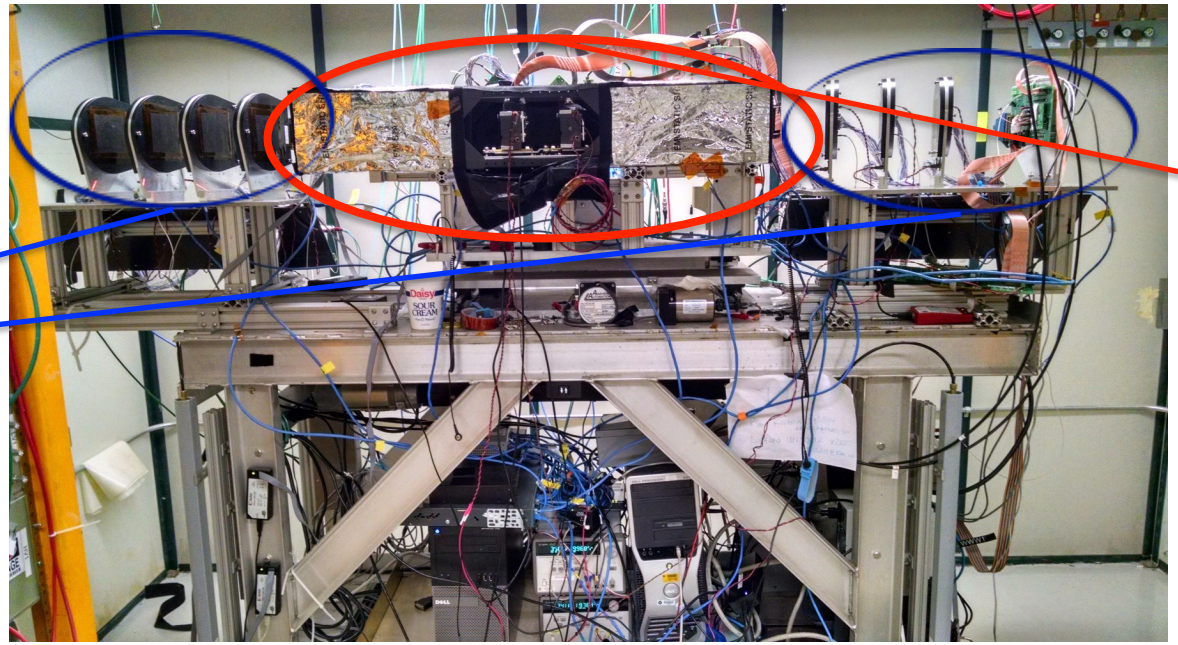
CAPTAN+X Uses and Plans

- Originally developed in 2008/2009, the CAPTAN system was designed to handle common data acquisition, control, and processing tasks.
- Examples of such applications are tracker readout systems, R&D test stands, and parallel data processing.
- Modular, so it can be used in a wide range of applications.
- Groups at Fermilab and other institutes in the US, China, and Europe have acquired the system for their test-stands. We worked with them to provide hardware and software support.
- Will be used in our Off-the-Shelf DAQ, optical link testing, and other efforts.



Testbeam Detectors and DAQ

- The pixel telescope is 8 silicon pixel planes leftover from CMS, with space for 2-4 DUTs in the middle. Pixel size is 100 µm x 150 µm. Data acquisition with the CAPTAN system.
- Newer strip telescope is based on CAPTAN too. Dead-timeless, 16cm^2 coverage, and 5µm track resolution.



Strip telescope

Pixel telescope

Mean resolution of 7µm on the DUT.

Testbeam Opportunities

- Testbeam is our test bed for Off-the-Shelf DAQ (more on this later) and other initiatives

- It would be very nice to have easy-to-use DAQ system with integrated detector readout (strips, wire chamber, transient detectors)
  - Mandy and her team have succeeded in getting MIDAS running; OtS DAQ and artdaq could be complementary or integrated/bridged

Investigation of Internet-of-Things Hardware

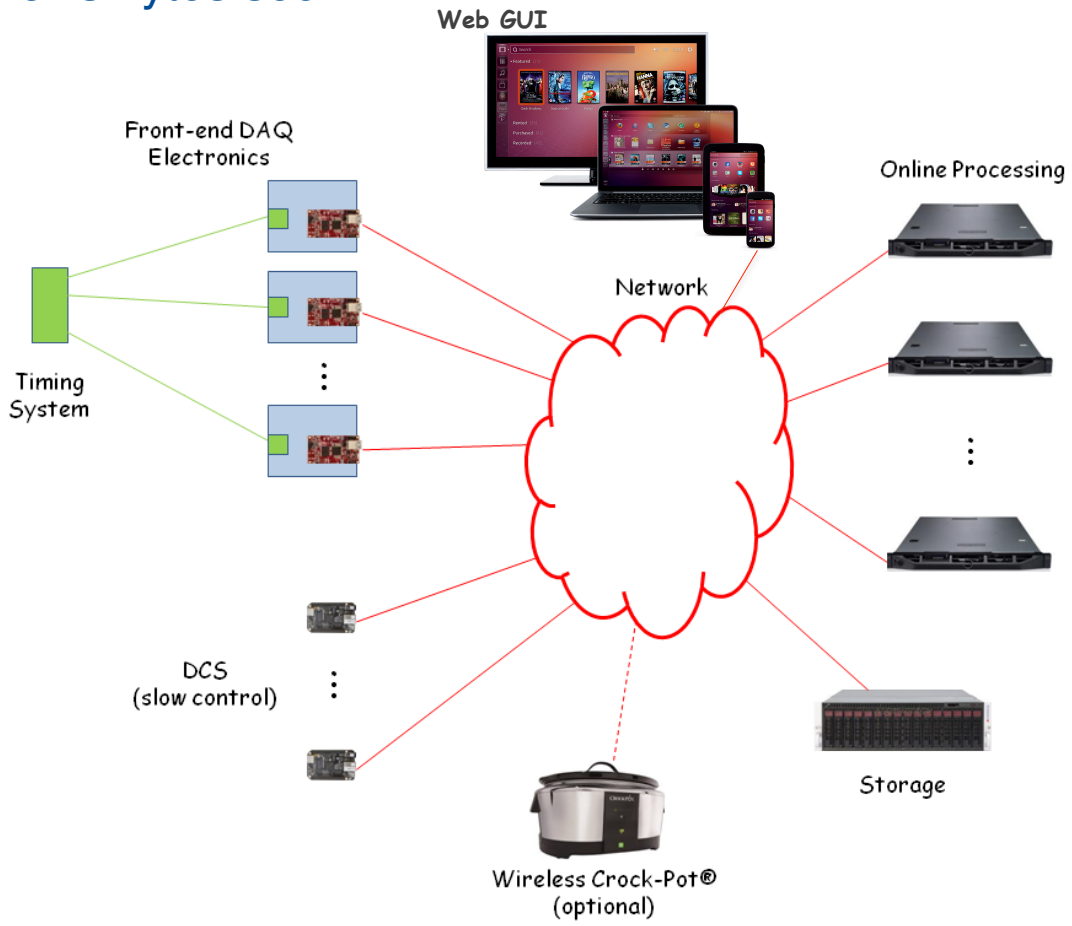
- Trends:
  - **Tighter budgets** for experiments leading to reluctance to subsidize DAQ development.
  - Industry moving from centralized crates and backplane systems to **distributed systems** connected by high speed links.
  - **Ethernet** and **Internet Protocol** has been the one communication technology standard that has far outlived any other. IoT market value was $1.9 trillion in 2013 and estimated up to $19 trillion by 2020.
    - $6K for a 1U 48-port 10G Ethernet switch with throughput > 1000 VME Crates!

Off-the-Shelf DAQ LDRD

- 2 years of effort for OtS DAQ **proof-of-concept**:
  - Survey the market for candidate IoT boards.
  - Focus on 1 board in each range (Low, Mid, and High) to populate initial menu.
  - Develop a JavaScript GUI for control and readout using web browser.
  - Develop host and embedded APIs for socket based communicated between *artdaq* and candidate boards.
  - Develop sample reusable firmware components.
  - Test and catalog available features and supported data rates.

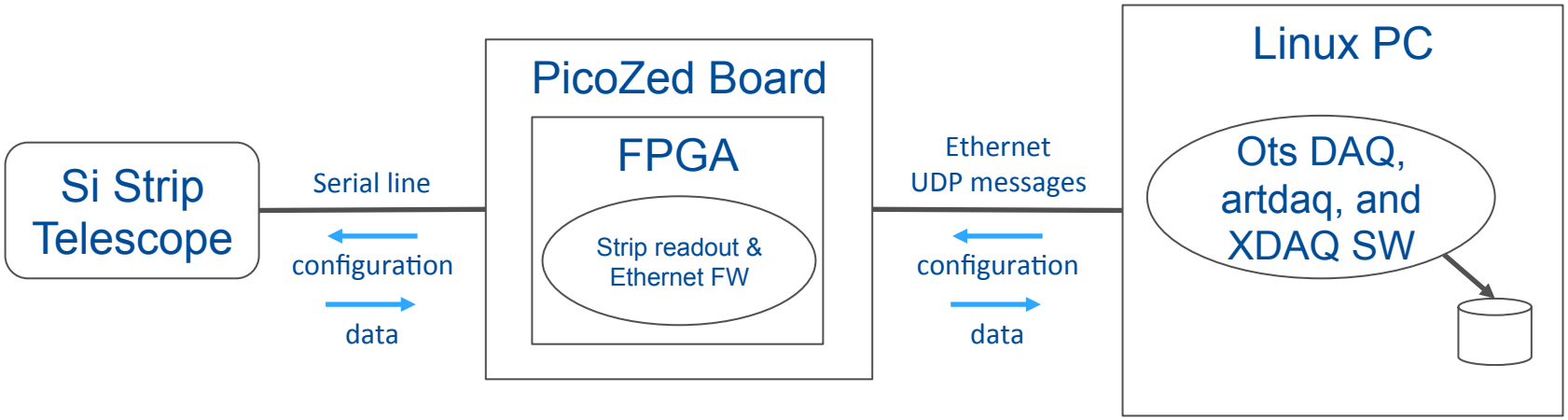
Off-the-Shelf DAQ Model

- We are developing a **low cost**, data acquisition architecture **as a service**, based on commercial **IoT** technology that is **scalable** from a few MBytes/sec to hundreds of GBytes/sec.

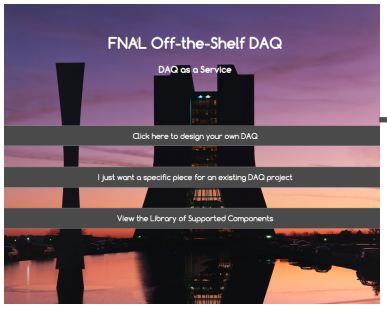


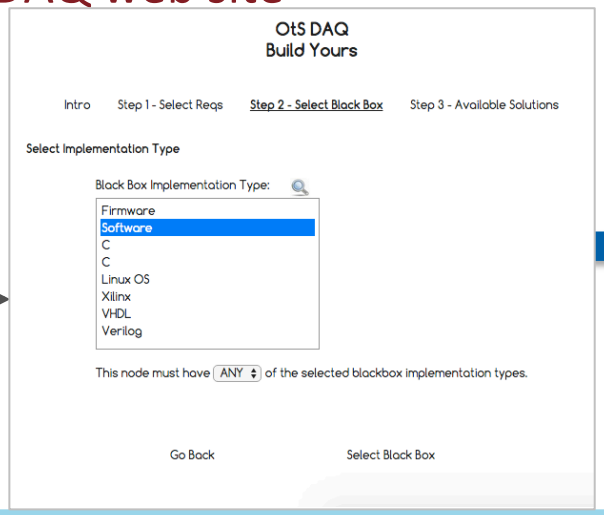
Off-the-Shelf DAQ - Status

Demonstration of detector readout (at FTBF)



Development of the OtS DAQ web site

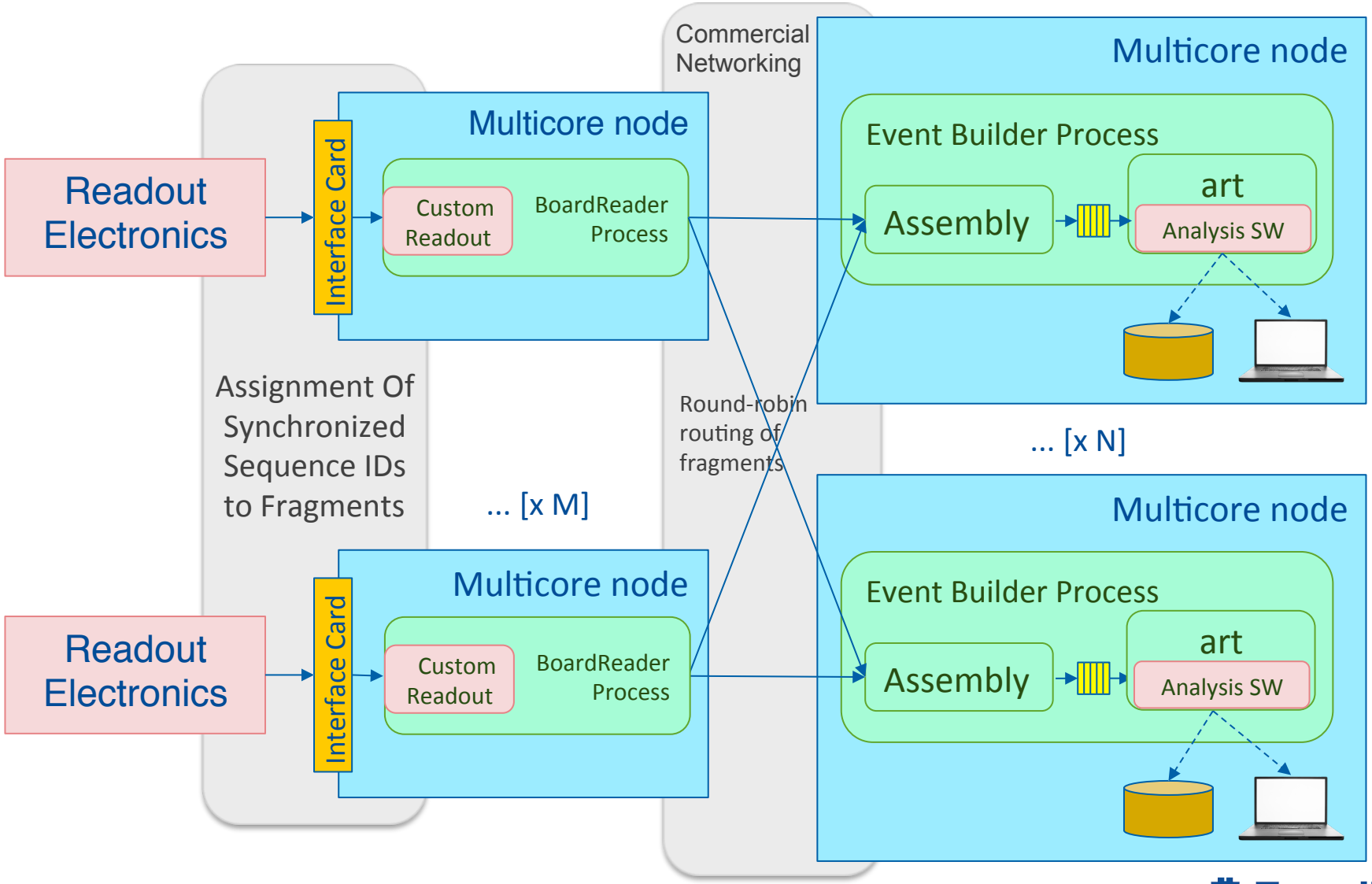




To: User
Subject: Your OtS DAQ

Tar files can be downloaded from here:
Location of FW: URL1
Location of SW: URL2

artdaq: DAQ software framework



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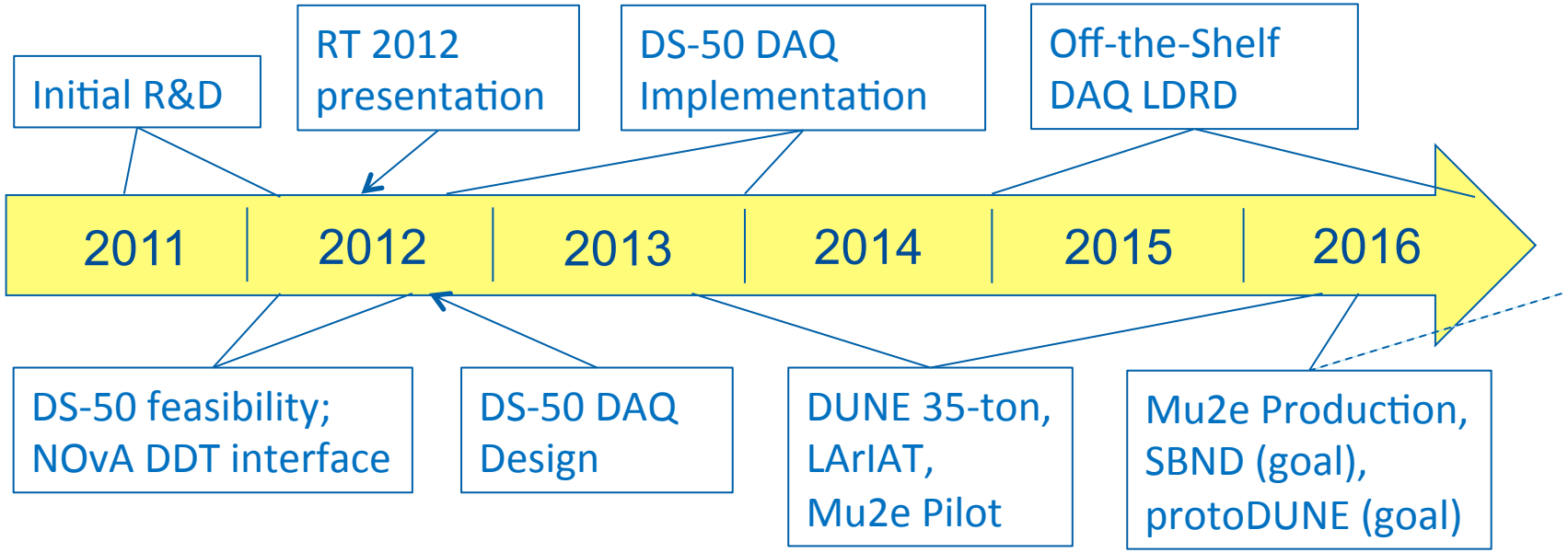
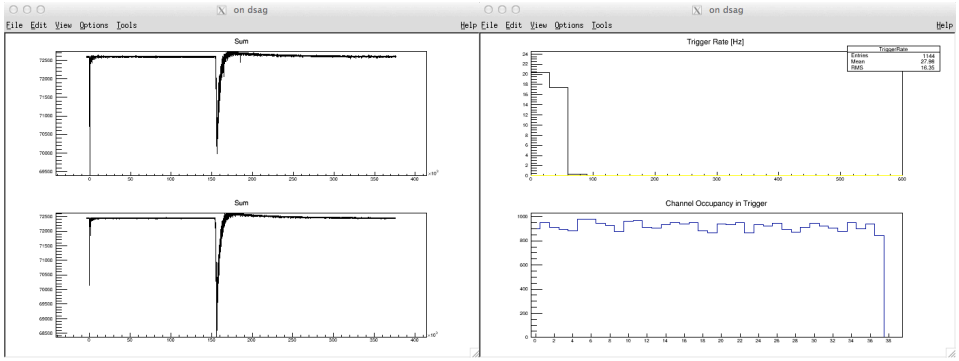
artdaq Features

- Core functionality provided; experiment-based customizations expected
- Data streaming with event filtering
- Integration with *art* analysis framework
- Easy configuration of number and location of processes in a distributed system
- Data written to disk in ROOT format

artdaq Timeline





Sample DS-50 online monitoring histograms

artdaq Future Plans

- DUNE, Mu2e, SBND, others
- Multi-layer systems
  - Software triggering; flexible disk-writing and analysis options
  - DUNE: trigger on events with zero-suppressed data and store full data from accepted events
  - Mu2e: trigger on tracker and calorimeter data and read out CRV for accepted events
  - SBND: write supernova stream locally on readout PCs
- Use of RTI DDS (Phase II SBIR)
- Distributed Monte Carlo particle generation
- Common Run Control? (DUNE and SBND)

DOE Phase-II SBIR – RTI DDS

"Scalable High Performance Data Distribution Middleware for High Energy Physics Applications"

- Real-Time Innovations, Inc.
  - Their focus is on the industrial internet of things (IIoT)
- SBIR timeframe: April 2014 – April 2016

Middleware is RTI DDS (Data Distribution Service)

- DDS is OMG specification, v1.0 in 2003…v1.4 in 2015
- Loosely-coupled publish-subscribe communication
- Resilient to faults; data-centric architecture
- Flexible quality-of-service for data delivery
- RTI involved in the development of the specification and creation of their implementation (RTI Connext)

RTI DDS

Phase-II SBIR technical objectives:

- Fast zero-copy transport for structured data over Infiniband
  - Transfers between application-level memory regions using position independent data structures
- Safe, efficient, and portable DDS API for Modern C++
  - Easier-to-learn and safer API; clean migration to C++11
- Queuing and Request/Reply over DDS
  - Load balancing across queue consumers
  - [something about request/reply]
- Developing C++ applications without IDL
  - Header files can be annotated to define messages

Zero-copy is still under development, rest are available now.

Uses of RTI DDS in *artdaq*

Distributing events to online monitoring

- Loose coupling means that consumers may come and go
- DDS content filtering could provide trigger selection without any extra code in *artdaq*

Graceful handling of failed processor nodes

- The queuing service could automatically re-route data around failed nodes

Ease of use

- Message definition without IDL; Modern C++ API

Take advantage of future enhancements to RTI DDS

- Security enhancements for WAN; web-based technologies

Ongoing discussions about licensing

RTI DDS in EPICS

- New SBIR proposal being considered, RTI and folks from BNL (STAR)
- We would be very interested in the progress and results of this SBIR
- This could give us a handle on making a step toward providing systems that provide both DAQ and slow controls

Physics Research Equipment Pool (PREP)

"Provides and supports electronic instrumentation for high energy physics research"

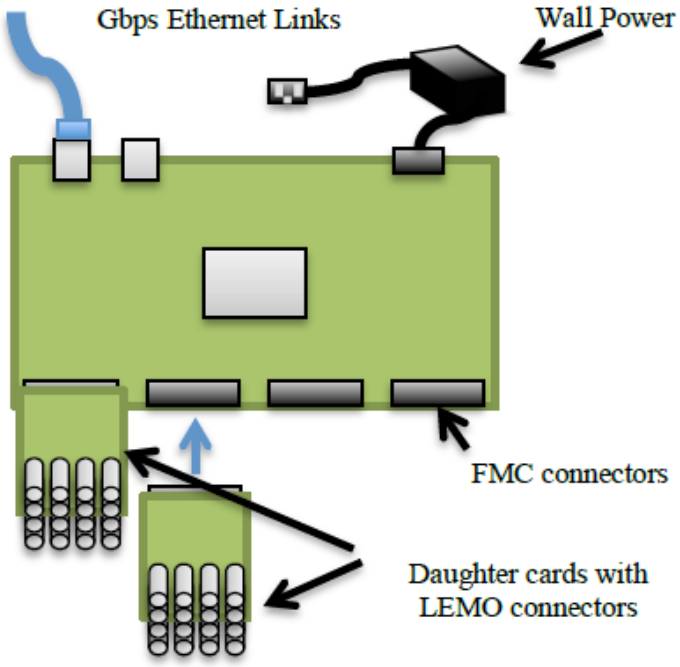
- Very successful
- Easy-to-use commercial modules
- 50-100 items checked out per month
- Modules are showing their age

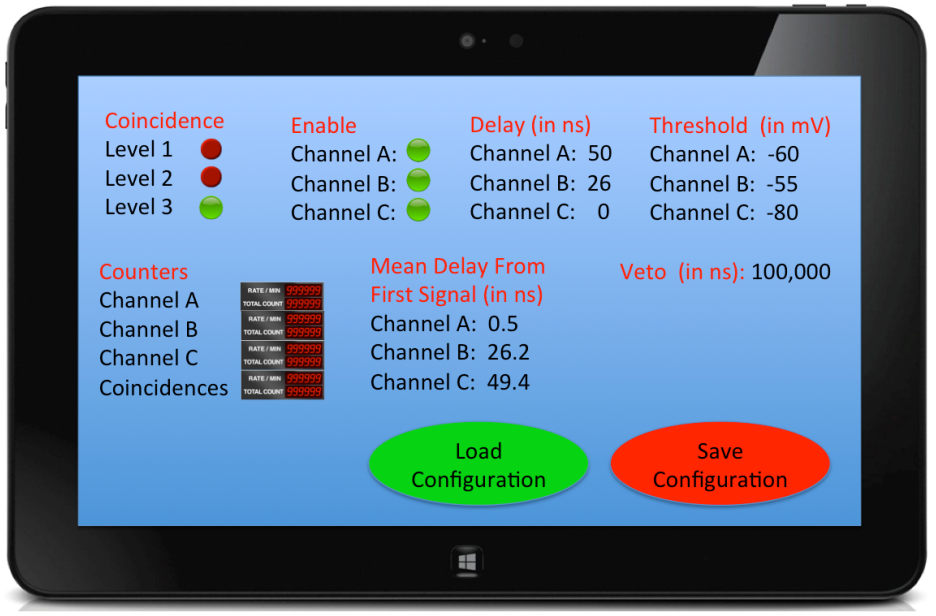
Lorenzo Uplegger (PREP manager) has proposed modernization efforts; described at earlier CPAD meeting, initial prototype submitted to Fermilab LDRD program

PREP in the FPGA Era

Vision: gradually replace aging commercial electronics with general-purpose FPGA boards and appropriate daughter cards

Initial candidate: NIM coincidence module





Teststands

Common tools for teststands, testbeam, full experiments

- Get started quickly and expand as needed
- Reduce “integration” time

Standard pattern(s) for computers, networking, OS

- Working with infrastructure experts to define patterns

Detector R&D Roadmap for FNAL SCD/RSE

Direct Involvement

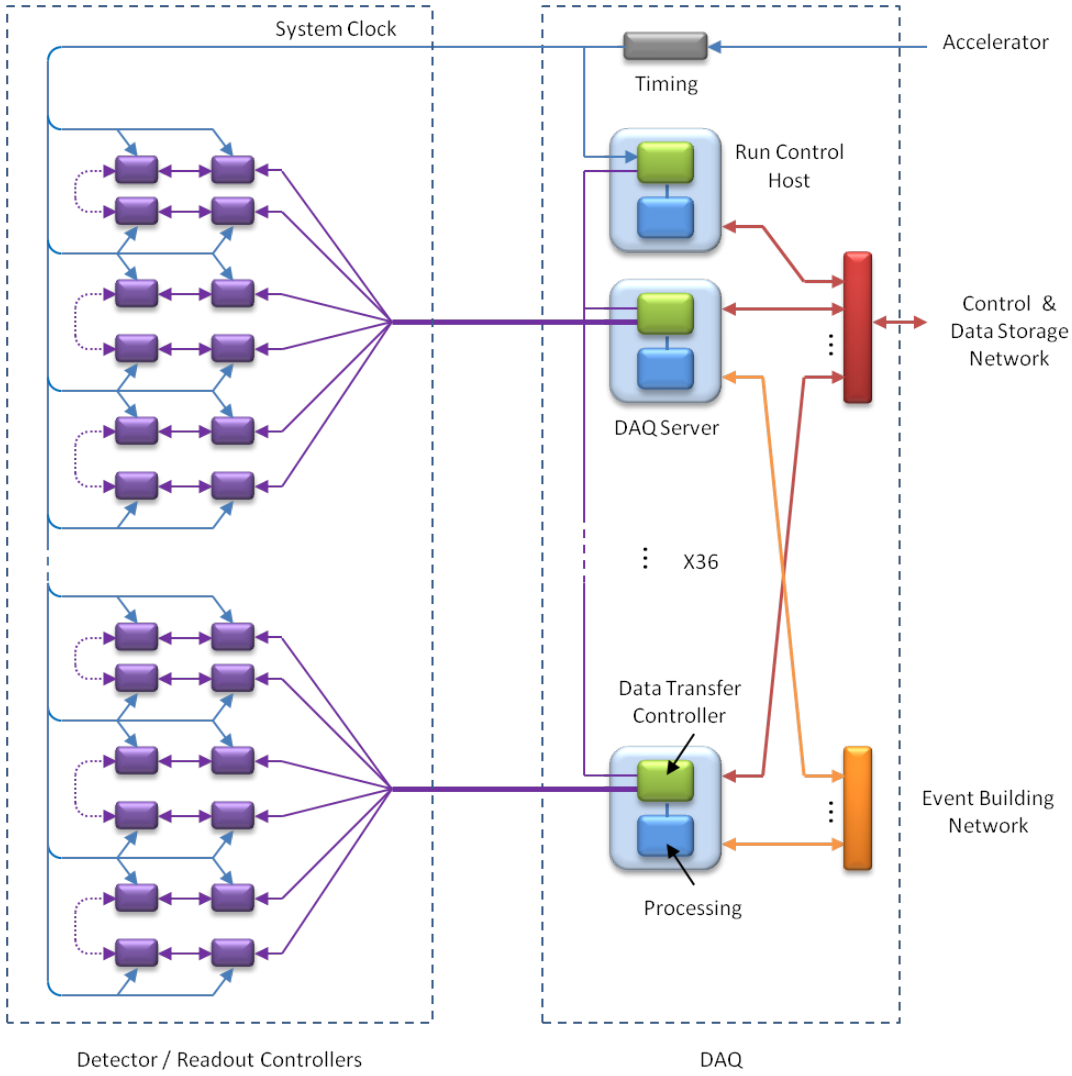
- MKIDs – 10K or 20K pixel instrument at SOAR in 2016; possible use in CMB; Phase 2 100K pixel or larger system
- CONNIE/DAMIC – DAQ for 1kg detectors
- Optical Links – system specification and testing for Versatile Link+
- Rad-Hard Sensors – continued testing of candidate detectors
- CAPTAN+X – deployment; reusable firmware blocks
- Testbeam Detectors and DAQ – ready-to-use system

Detector R&D Roadmap for FNAL SCD/RSE

Indirect and Support Activities

- Off-the-Shelf DAQ – complete the LDRD; work with testbeam, experiment, and university users
- *artdaq* – continue to partner with experiments; enhance functionality with RTI DDS; expand core functionality
- RTI DDS SBIR(s) – continue to provide input to RTI; incorporate DDS into *artdaq*; watch EPICS SBIR progress
- PREP – prototype NIM coincidence module; wider use of PREP model? (mentioned in workshop intro.)
- Teststands – refine model; work with experiments and universities

Mu2e DAQ System Design



- architecture supports both streaming (Tracker, Calorimeter) and triggered (CRV) readout

- DAQ Servers handle data readout, event building and processing

- bidirectional front-end interface for fast control and readout

- large front-end buffers for uniform data transfer

- all commercial DAQ hardware

- scalable… 1 GByte/sec per DAQ server

Mu2e Data Transfer Controller

Commercial card (Hitech Global HTG-K7-PCIE with FM-S18 FMC adapter)

Firmware and software working for control commands and data readout. Full data chain has been exercised. Pilot system with 6 DTCs/PCs ready soon.

Clock and control command fan-out functionality (dedicated PCIe card) being developed now.