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Engineering at FERMILAB

Scientific Computing Division

Gustavo Cancelo

Engineering retreat

20 February 2018

Real Time Systems Engineering

Scientific Computing	
Panagiotis Spentzouris	Division Head
Systems for Scientific Applications	
Adam Lyon	Associate Head
Real-Time Systems Engineering	
Elizabeth Buckley-Geer	Department Head
Alan Prosser	Deputy Department Head
Kurt Biery	

The Scientific Computing Division (SCD) designs, develops and maintains hardware, firmware and software solutions for HEP and Astrophysics experiments in the areas of data acquisition (DAQ) and real-time systems.

DAQ Controls And Detectors	
Gustavo I Cancelo	Group Leader
Chris Stoughton Kenneth R Treptow Neal G Wilcer Ted J Zmuda	
Real-Time Software Infrastructure	
Ronald D Rechenmacher	Group Leader
(Kurt Biery) Eric Flumerfelt John Freeman Wesley Ketchum Gennadiy A Lukhanin	

Detector Electronics	
Ryan A Rivera	Group Leader
(Lorenzo Uplegger) Assistant Group Leader	
John Chramowicz Gregory A Deuerling Lindsey Gray Richard K Kwarciany (Alan Prosser)	
Physics Research Equipment	
Lorenzo Uplegger	Group Leader
Matthew Cowans Jason Greskoviak (Alan Prosser)	
	On-Call

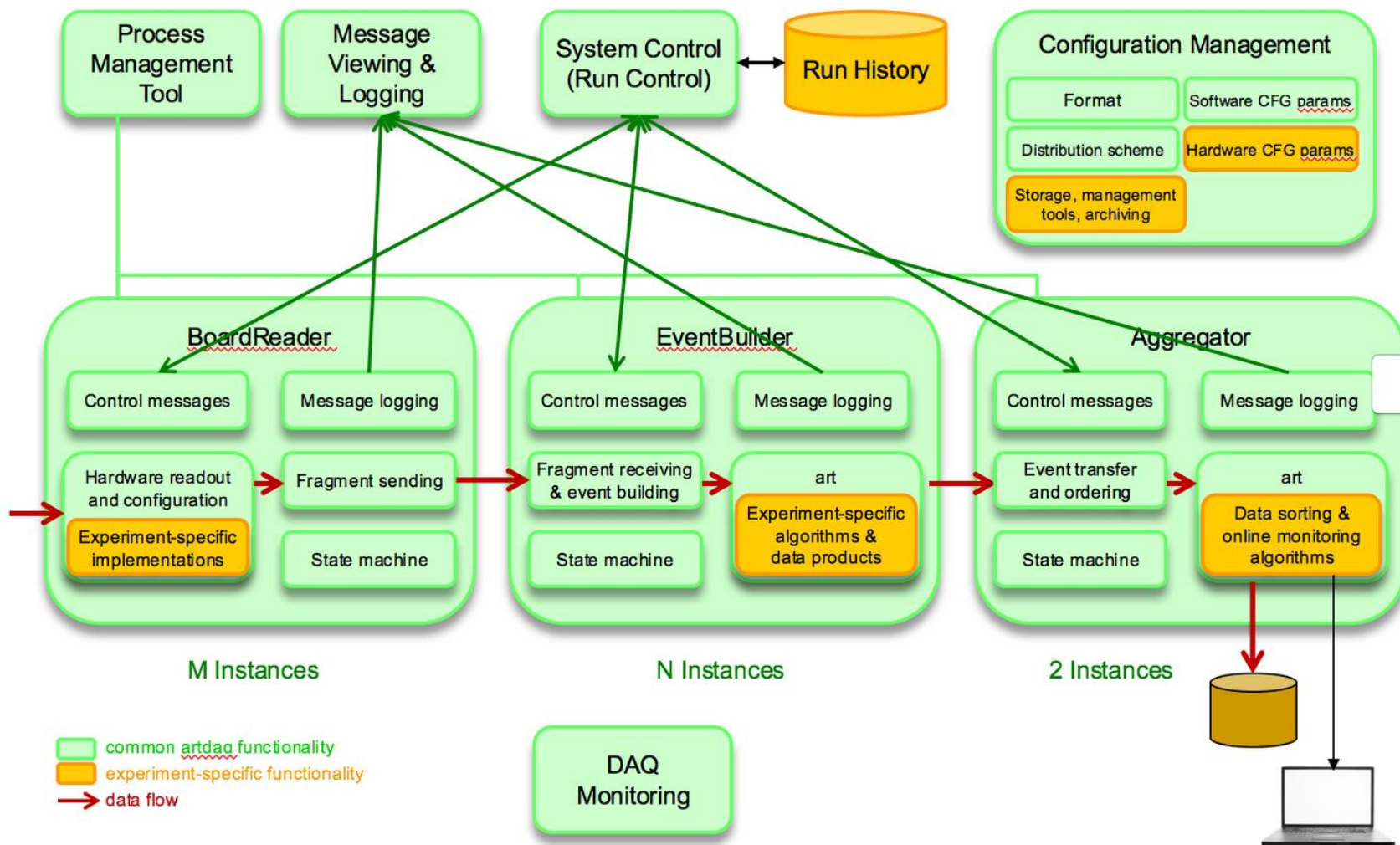
Real Time Systems Engineering

- We are a versatile group of mostly senior level Technicians, Engineers, Scientists and Computer professionals.
- We develop electronic hardware, firmware and software with emphasis on Data Acquisition.
- We get involved in the science.
 - CMS, neutrino experiments, Detector R&D, CMB-S4, dark matter, dark energy.
- We get involved with detectors and test beams.
- We are at the cutting edge of EE for new detectors.
 - Low noise, high speed, mixed analog/digital electronic design.
 - From conceptual design, layout, characterization and production.
 - Cold and warm electronics for cryogenic detectors.
 - Mathematical modeling and simulations.
 - Data analysis.
 - Detector characterization.
 - Optoelectronics.
- We build and support the systems that we develop.

ART and ARTDAQ: Software Engineering for DAQ

- Used in **MANY** current/future neutrino, muon, test-beam experiments
 - protoDUNE, Mu2e, SBND, ICARUS, DUNE, etc.
- Scalable: test stands through production experiments
- Flexible: extensive use of software plugins
 - Experiment-specific pieces (e.g. readout of custom electronics) typically developed by experiments.
- Uses the art event handling toolkit for event filtering and data quality monitoring
 - Events are written to disk in art/ROOT format, so the data is ready for further analysis in art
- Software and hardware engineers in the division work in partnership with experiments to deploy the DAQ systems that the experiments need.

artDAQ block diagram



- <https://cdcv.s.fnal.gov/redmine/projects/artdaq-demo/wiki>

OTS is used at FNAL's test beam and CCD DAQ

The screenshot displays the OTS interface with the following components:

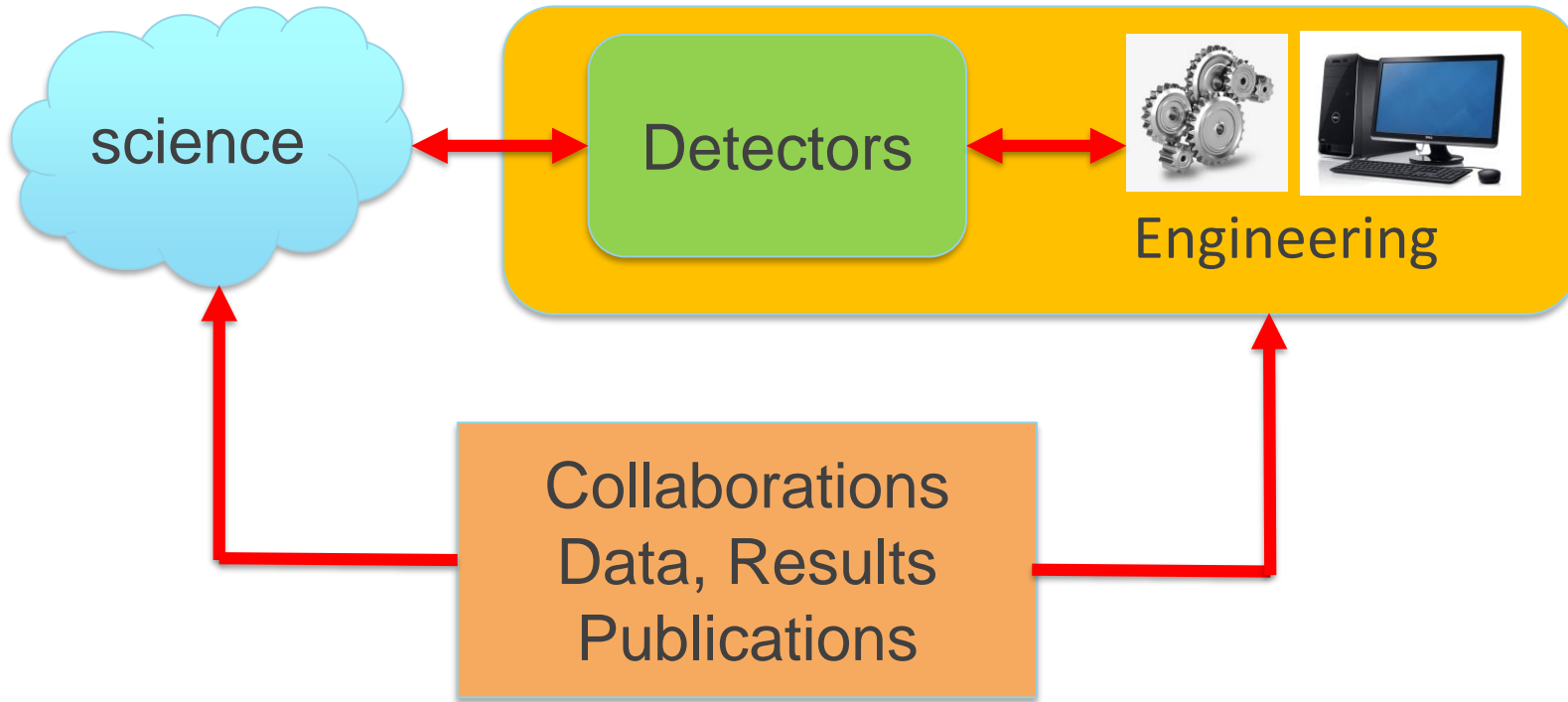
- Top Bar:** Browser address bar (ftbf-daq-08.fnal.gov), navigation buttons (Layouts, Tile, Show Desktop, Full Screen), and user information (Welcome to ots, Administrator, Sign out).
- Left Panel:** Desktop icons for State Machine, Chat, Logbook, Visualizer, Macro Maker, Console, Configure, Config Subsets, and Smart Launch.
- State Machine Window:** A state transition diagram showing states: Halted (H) Previous State, Configured (C), Halted (H) Previous State, and Running (R). A 'Parameter Setup' button is visible at the bottom.
- FTBF Status Window:**
 - Time: 14:10:20
 - Mode: Non-Muon Mode
 - Mtest Energy: 120 GeV
 - MTest Mode: Proton
 - Diagram: Schematic of the beamline with components like Switchyard CDC, Cerenkov, Absorber #1, Absorber #2, MT6.1A, MT6.1B, Gas Area, and MT6.2B.
 - Counters Table:
- Counters Table:**

MT6SC1	MT6SC2	MT6SC3	MT6SC4
1368385 Cnts	1477657 Cnts	1499063 Cnts	2889352 Cnts

Summary Counts:

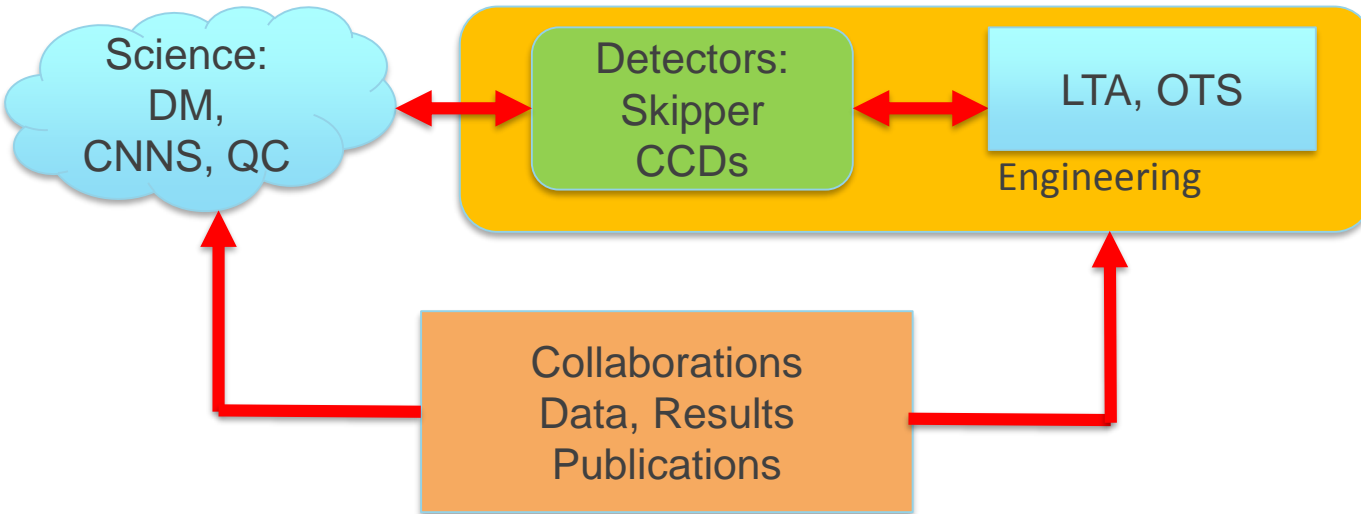
 - SC1+SC2+SC3+Spill: 710326 Cnts
 - Experiment Triggers: 991518 Cnts
 - Next Spill: -72459 Sec
- Bottom Right:** Next Run Number: 324, Elapsed: 0:01:20, Setup Alarm, Toggle View.
- Footer:** Version 4.3.38 | Make Snapshot | © 2001-2012 Fermilab | Security, Privacy, Legal | Fermilab logo

Real Time Systems Engineering, R&D and science



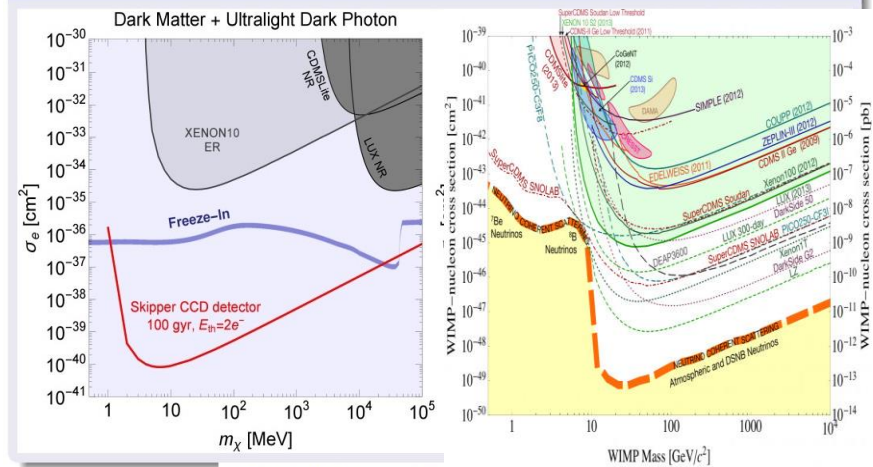
- Engineering supports and participates of Detector R&D and science, often improving the detector-engineering realization.
- We aim for experiments that push the envelope of detector and engineering in a tightly coupled design.

Low energy detectors for Dark Matter and Coherent Neutrino scattering



- Skipper CCDs achieve <0.1 electron of noise (RMS) (zero quantum noise)
- LTA electronics and OTS DAQ will be used for the SENSEI detector in search of Dark Matter.
- SENSEI will explore unprecedented low energies of the DM phase space. [REF Javier Tiffenberg]

Electron recoil sensitivity computed by LDRD collaborators: Rouven Essig, Jeremy Mardon, Tomer Volansky, Tien-Tien Yu.



3rd Berkeley Workshop on the Direct Detection of Dark Matter

December 6, 2016

SENSEI and the 20K channel skipper CCD experiments



The current Low Threshold Electronics reads 1 CCD (4 channels)

- We are designing a 4 CCD version (16 channels).

SENSEI science reach: light dark matter, dark photon, etc. \$500K funding from SIMONS foundation.

Applications: DM, CNNS, nuclear safety.

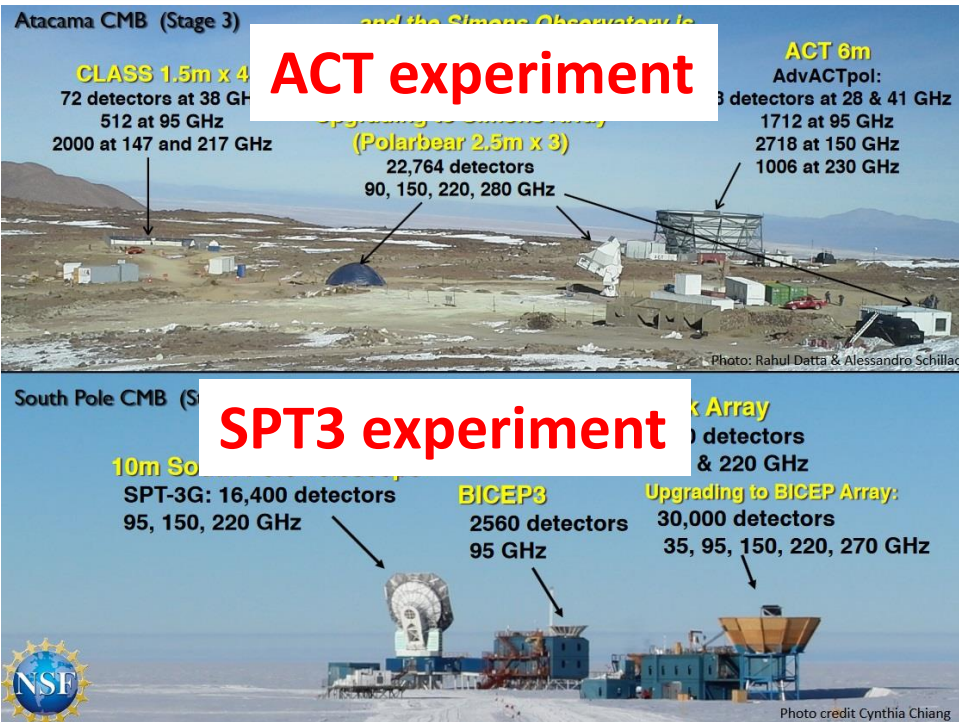
Current experiments with CCDs: CONNIE, DAMIC.

LTA/OTS design has generated one of the best engineering collaborations with Latino America:

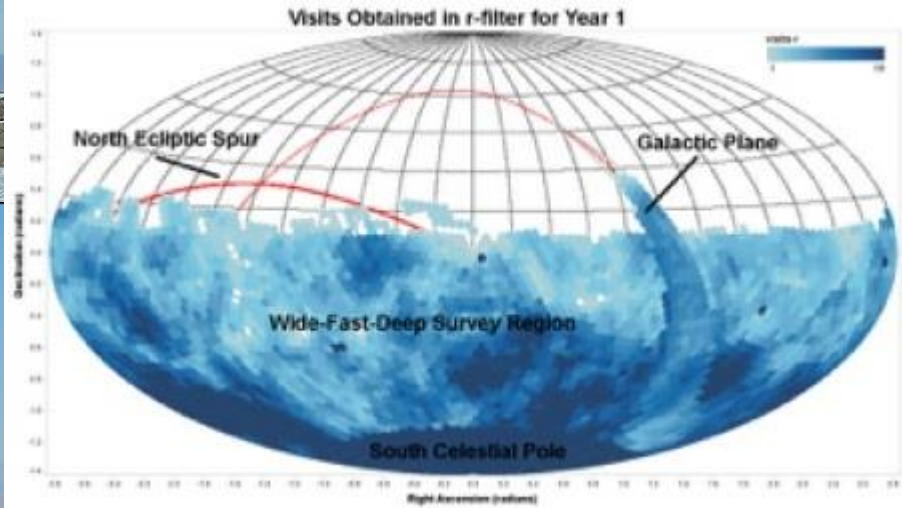
Univ. del Sur (Argentina), CNEA (Argentina), UNAM (Mexico), Univ. of Asuncion (Paraguay)

It has generated 4 Master thesis, one PhD thesis.

DAQs for Dark energy and the evolution of the universe



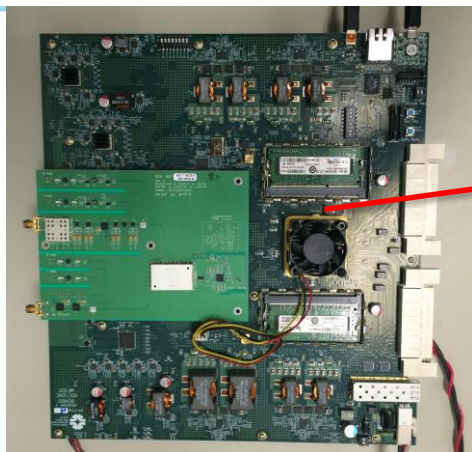
LSST will generate >1 billion galaxy catalog.
Opportunities for spectroscopic surveys!!



- CMB future: CMB S4
 - A collection of CMB telescopes at the South pole and Atacama
 - Superconducting detectors: Frequency Multiplexed TES or MKIDS.
- Future optical surveys:
 - High and low resolution spectroscopy.
 - 100,000 channels high res spectrometer?
 - Low res MKIDs based instrument? Could cover the near infrared spectrum!

Electronics and DAQ

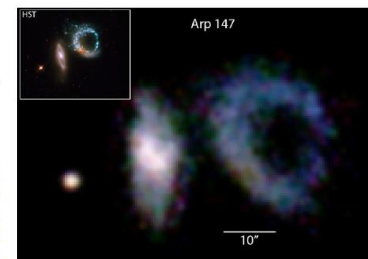
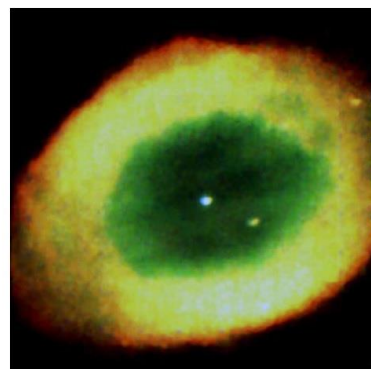
Warm electronics for superconducting detectors (fMESSI)



fMESSI for CMB
MKIDs and quantum
sensors

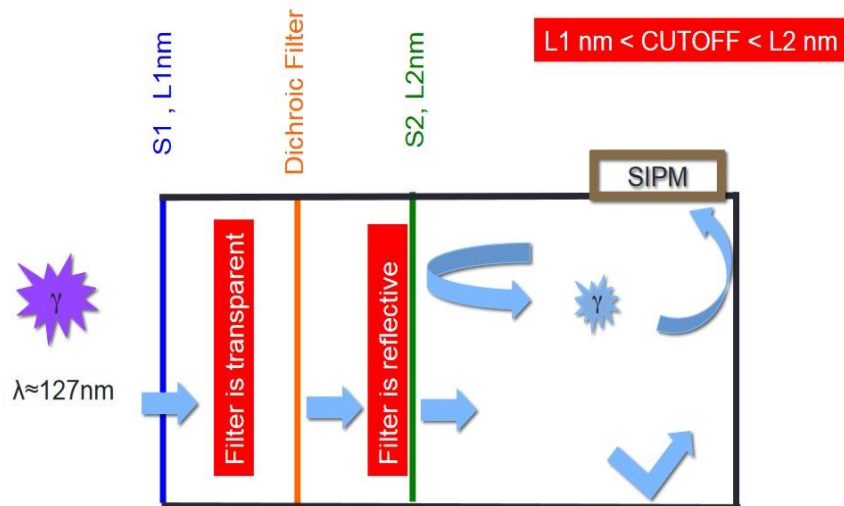
- Total of 75 boards are operational. 2 astronomical instruments
- Science achieved:
 - DARKNESS instrument (coronagraph) at Palomar. Three rounds of observations.
- CMB and MKIDs R&D:
 - Fermilab: CMB-s4 R&D, and MKIDs optical.
 - NIST
 - ANL.
 - U Chicago.
 - Arizona State University.

Images from Palomar

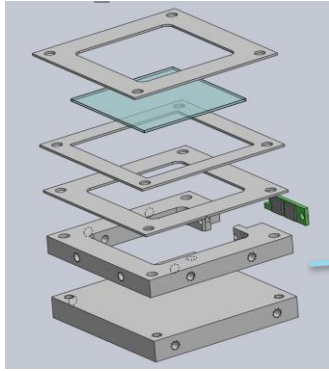


DUNE photon detector

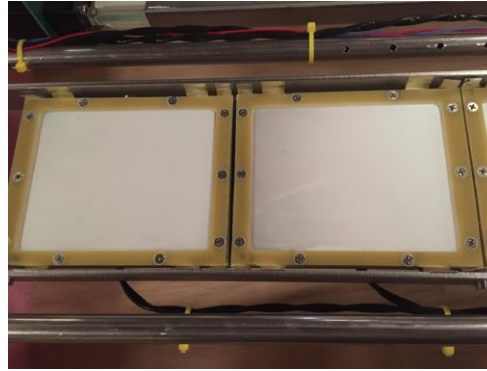
- The DUNE far photon detector must provide T0 for non beam events, proton decay candidates and supernova neutrinos with high efficiency. It is also important in the discrimination of backgrounds.
 - The technical objective is to achieve a photon detection efficiencies $> 1\%$.
- That efficiency has not been achieved by other detectors, so we picked up an interesting idea of a device called ARAPUCA developed by Ettore Segreto (UNICAMP, Brazil) et al and created a collaboration for ARAPUCA R&D.



DUNE photon detector



ARAPUCAs



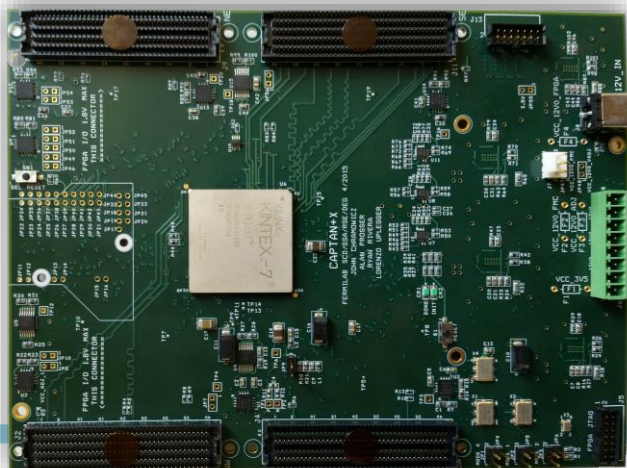
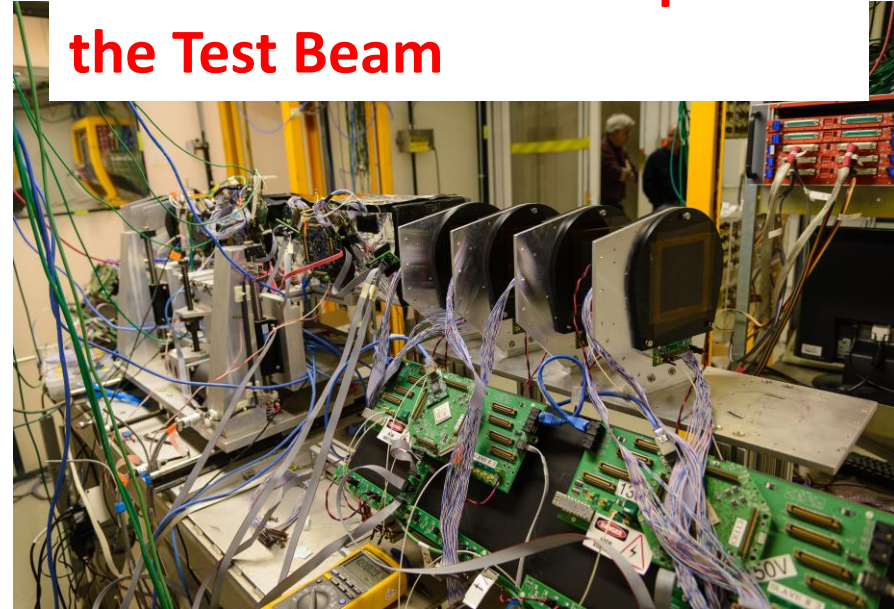
Currently
funded by
LDRD

- Status: 1st year of LDRD finished successfully.
- Achievements:
 - Improved ARAPUCA design.
 - Optical measurements and 2 LAr tests at TallBo.
 - Last run compared IU light bar technology and ARAPUCAs. Data analysis pending.
 - We created an ARAPUCA collaboration and the PD consortium leader is from our community.
 - We developed active ganging of SiPMs and made it work at TallBo. It was used by IU bars.
- 2nd year of LDRD: too many things to do.
 - Trying to include more collaborators.

The CAPTAN+/OTS system for the Test beam

- CAPTAN+ is a general purpose board based on a Xilinx 7 series and up to 10 Gbps data transfers. Featuring:
 - Gigabit Ethernet, 4 FMC connectors, 400 GPIO
 - Single DC 12V Input Power Block
- CAPTAN user community:
 - Fermilab: PPD, SCD, Test Beam Facility
 - Purdue University
 - University of Colorado Boulder
 - INFN Milano and Lecce
 - UNAM, Mexico
 - Universidad Nacional del Sur, Argentina
 - Instituto Balseiro, CNEA, Argentina
 - Universidad Nacional de Asuncion, Paraguay

CAPTAN based telescope at the Test Beam

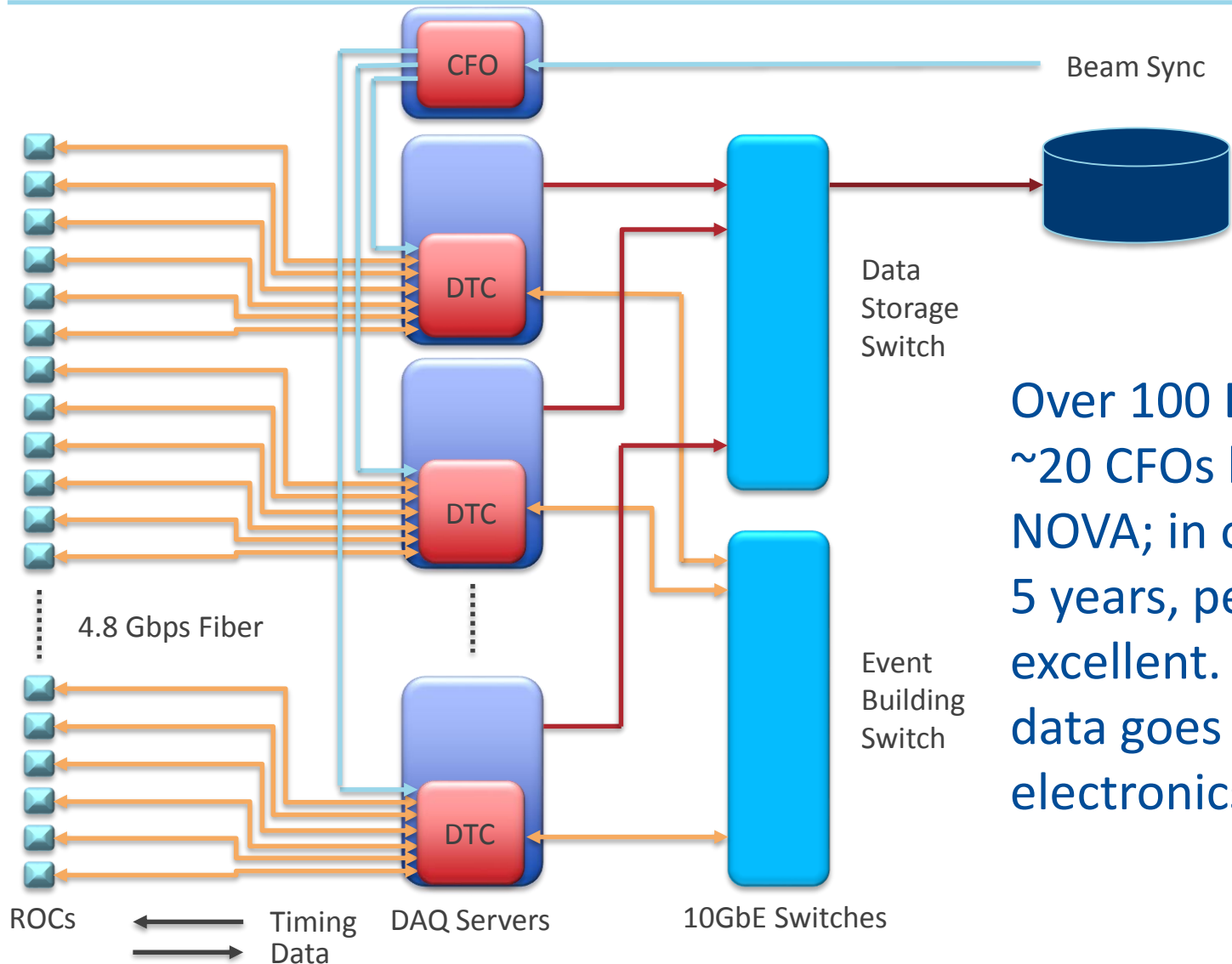


Also used in the
Replacement of old
NIM modules



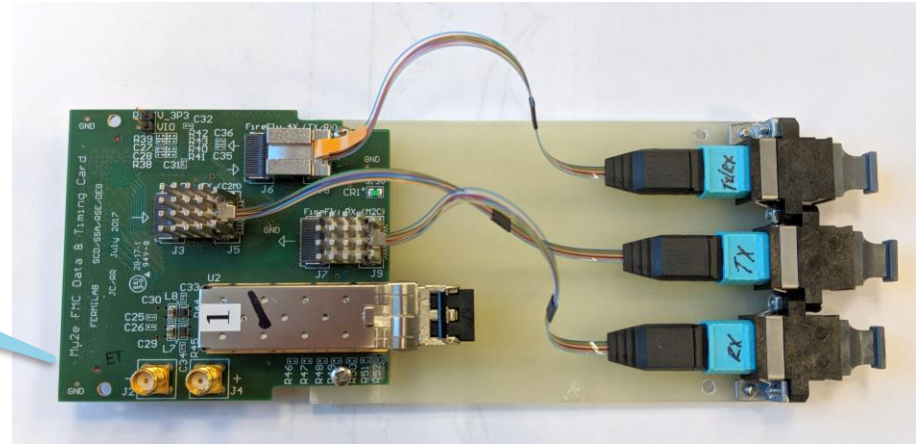
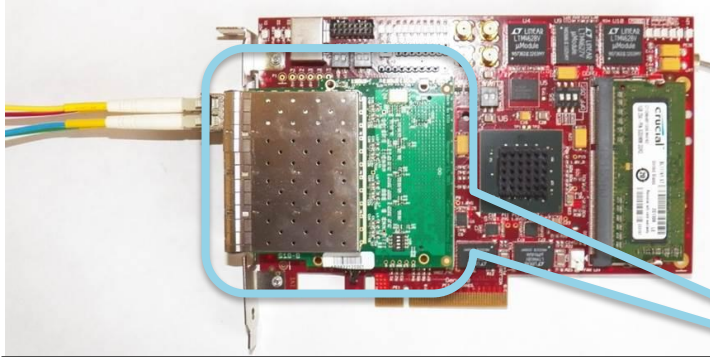
milab

NOVA and Mu2e DAQ and Timing Systems



Over 100 DTCs and ~20 CFOs built for NOVA; in operation for 5 years, performing excellent. All NOVA data goes through this electronics.

DTC / CFO Board & FMC Card for Mu2e



Data Transfer Controller (DTC)

- Commercial PCIe board
- Custom FMC Card
- Custom Firmware
- 6 – 4.8Gbps ROC links
- 1 – Timing System link
- 1 – 10Gb Ethernet link
- Collects data from ROCs
- Builds and Filters Events

Command Fanout (CFO)

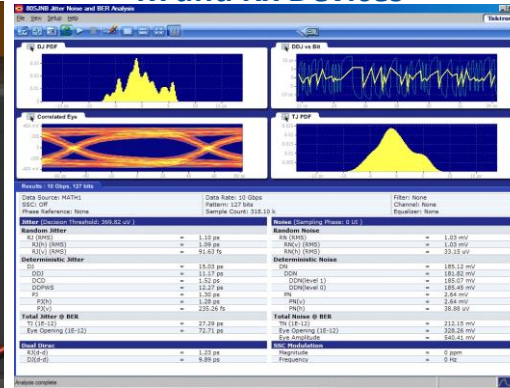
- Commercial PCIe board
- Custom FMC Card
- Custom Firmware
- Fans out system clock
- Sends encoded Beam Sync
- Sends event by event commands to DTCs

SCD/RSE High Speed Links Test and Measurement Facilities

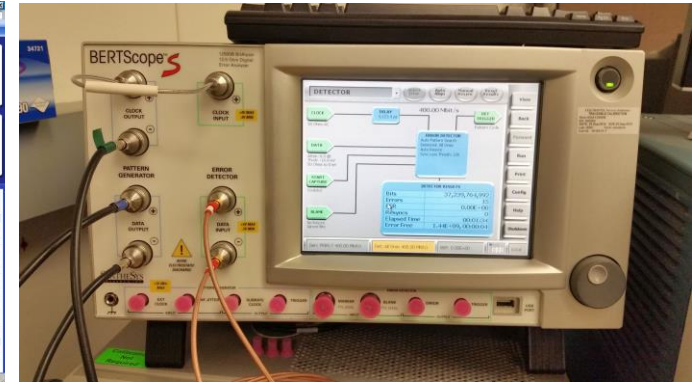
Variable Optical Attenuators



Jitter Decomposition Tx and Rx Devices



BERTScope BSA12500B (BER Testing)



Versatile Link VTRx (Tx/Rx; 4.8G)*



VTTx (Tx x 2; 4.8G)*

Collaborators:

Academia Sinica (Taiwan), CERN, FNAL, Oxford, SMU.

CERN:

The 7 channel Pixel Opto Hybrid transmitter module (RSE designed, tested, and delivered 120 of these modules for use on the CMS FPix detector and the Precision Proton Spectrometer at CERN).

RSE leads the specification of the Versatile Link Plus project.

Mu2e optical link project.

Summary

- RSE department is very busy.
 - We are well aligned with Fermilab's program. And we will continue on that path.
 - We strongly collaborate across the Lab, nationally and internationally.
- In the last 15 years we have seen an important increase of engineer labor cost for projects.
- Projects are only willing to pay for top notch engineering that they can't find somewhere else.
 - That's our strength.
- Engineer managers now engage a lot more in the science and in search for funding to keep the department competitive.
- We want to thank the division for investing in engineering to allow RSE to be at the cutting edge of EE and Software.