Fermilab

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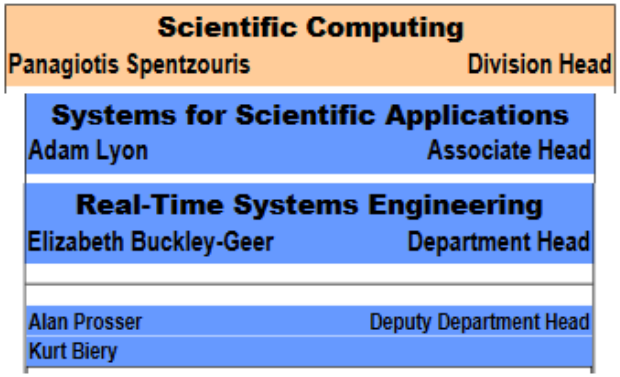
Engineering at FERMILAB
Scientific Computing Division

Gustavo Cancelo

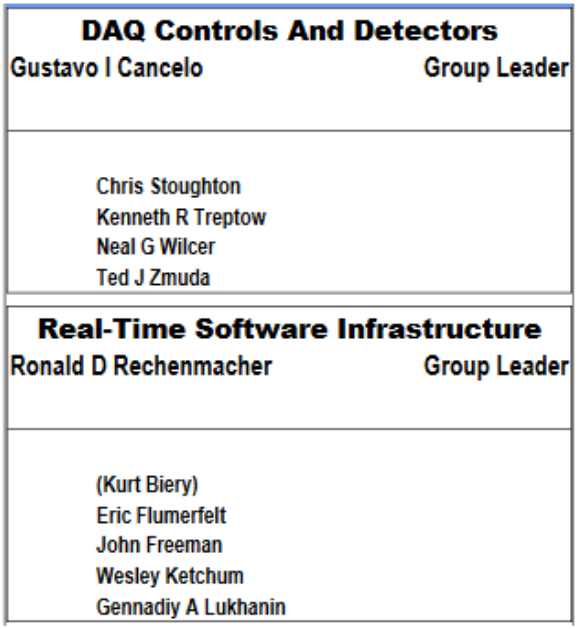
Engineering retreat

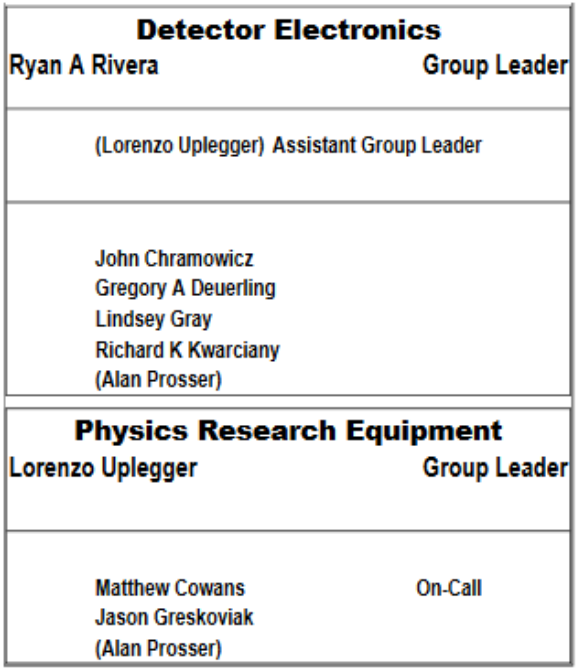
20 February 2018

Real Time Systems Engineering



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.





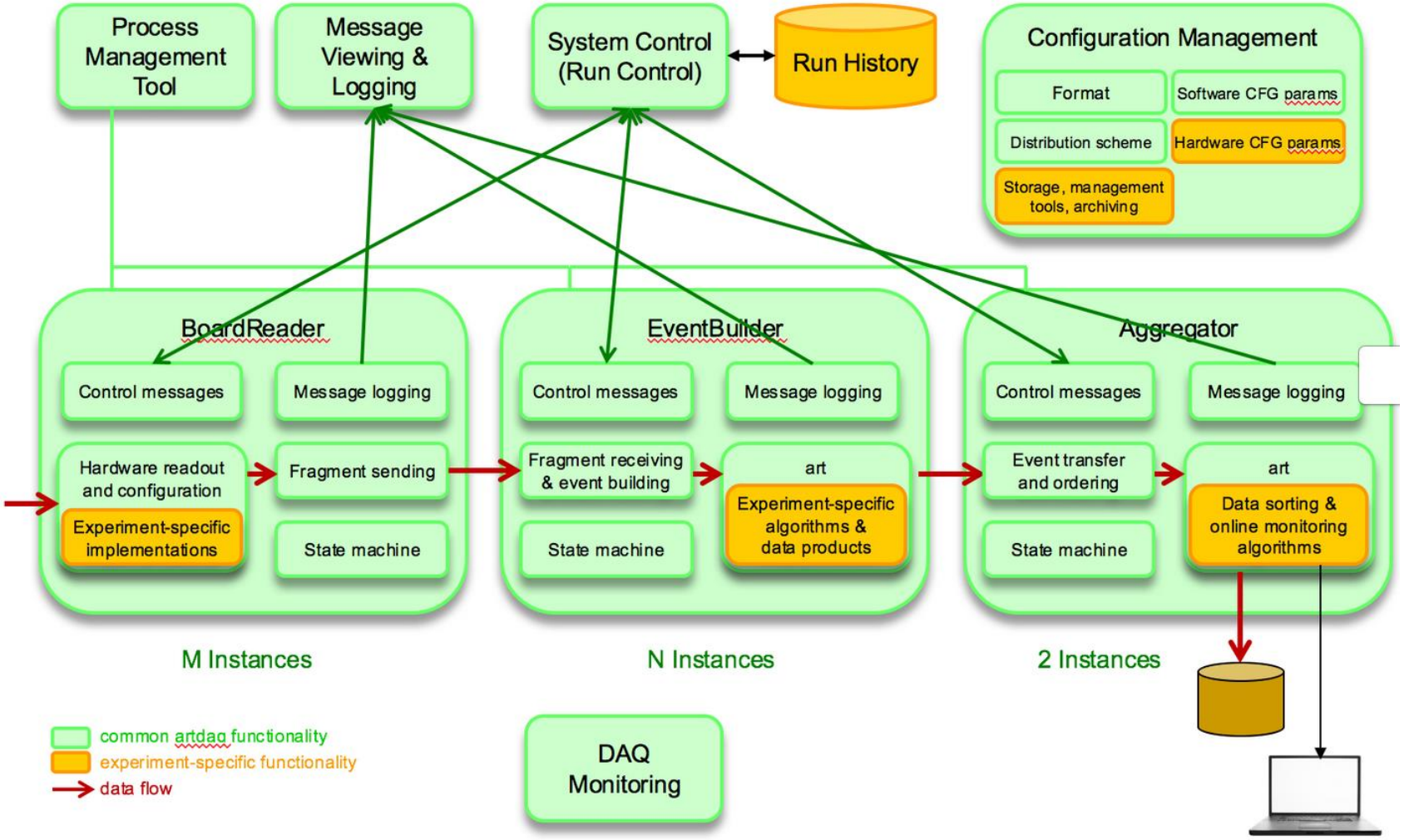
Real Time Systems Engineering

- 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

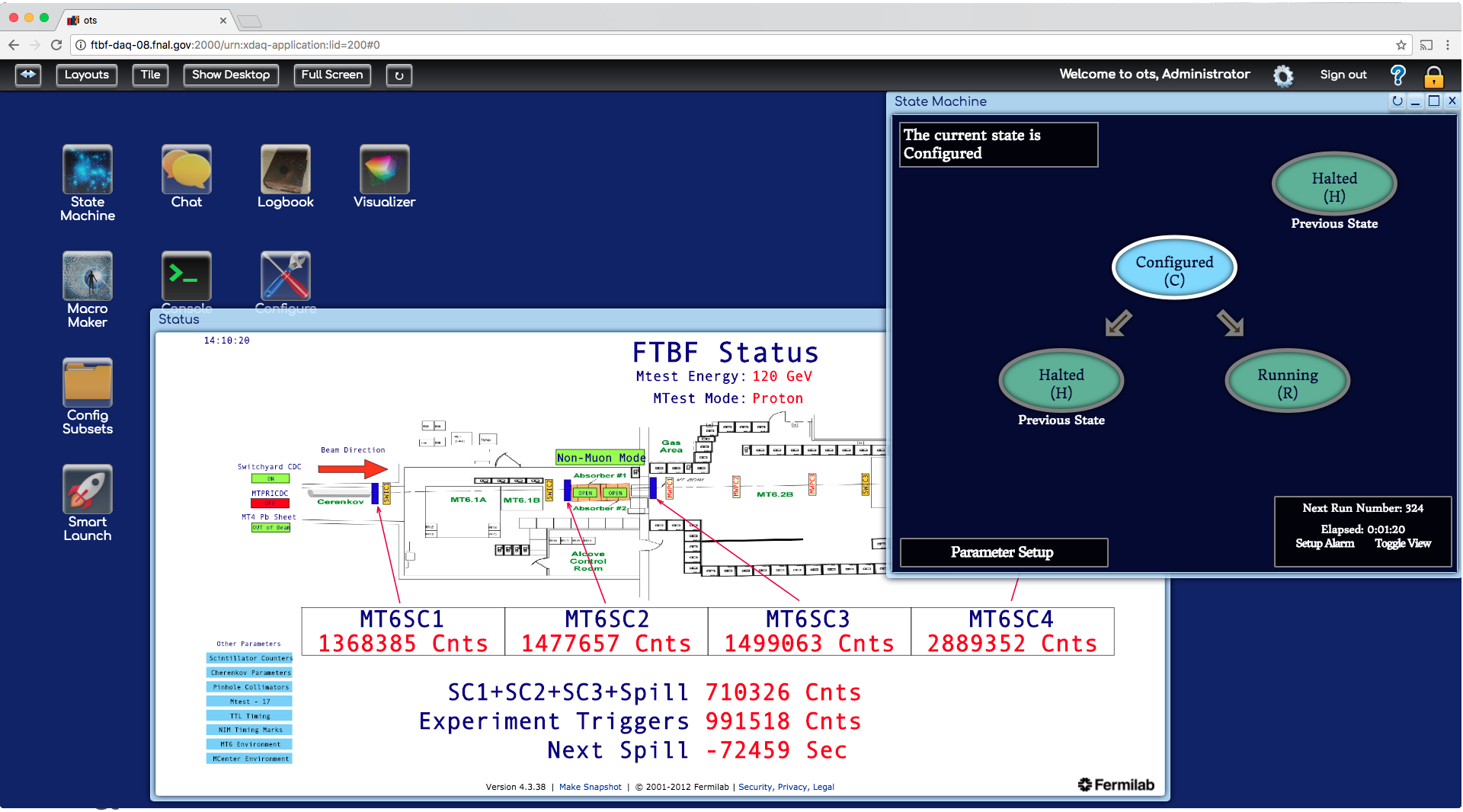
- Used in MANY current/future neutrino, muon, test-beam experiments
  - protoDUNE, Mu2e, SBND, ICARUS, DUNE, etc.
- Scalable: test stands through production experiments
- Flexible: extensive use of software plugins
  - Experiment-specific pieces (e.g. readout of custom electronics) typically developed 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

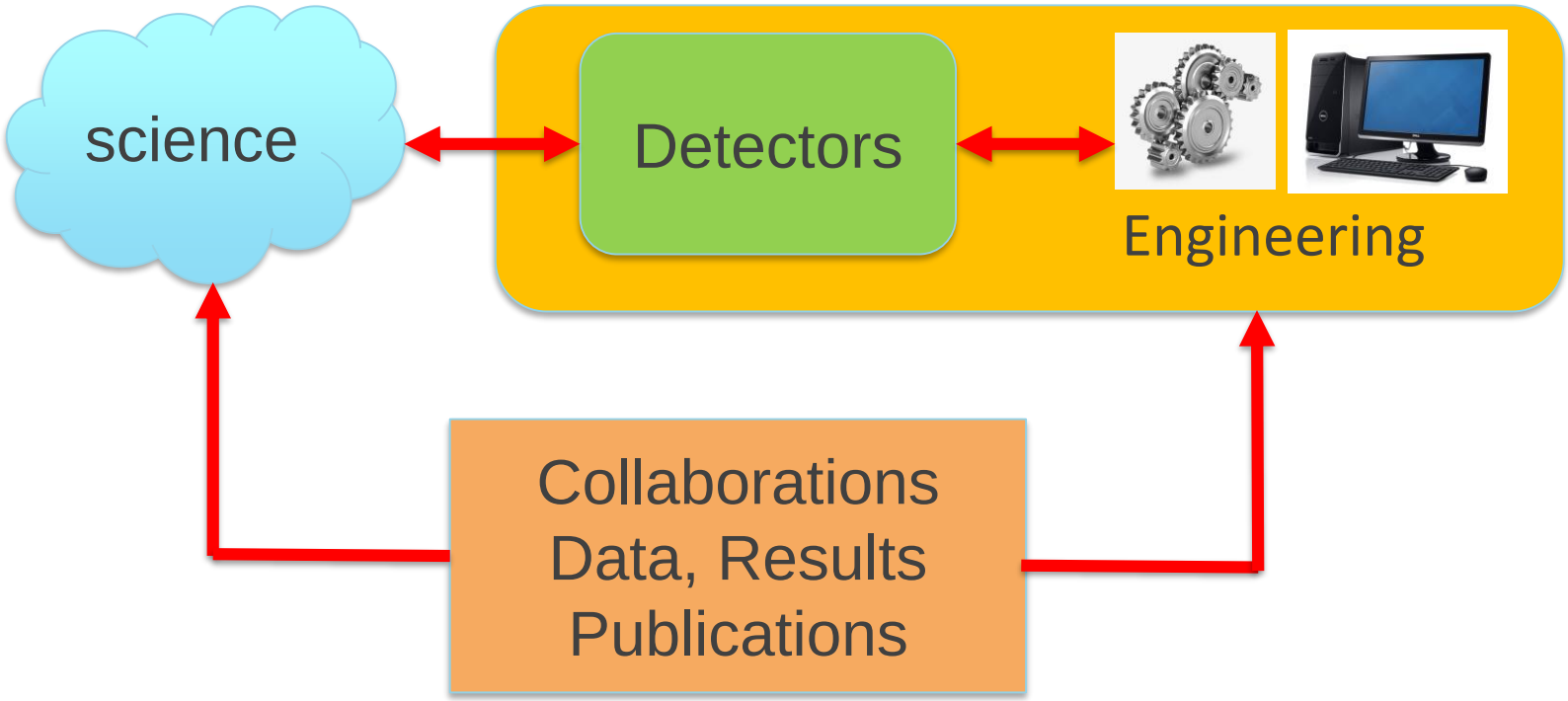


- https://cdcvs.fnal.gov/redmine/projects/artdaq-demo/wiki

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

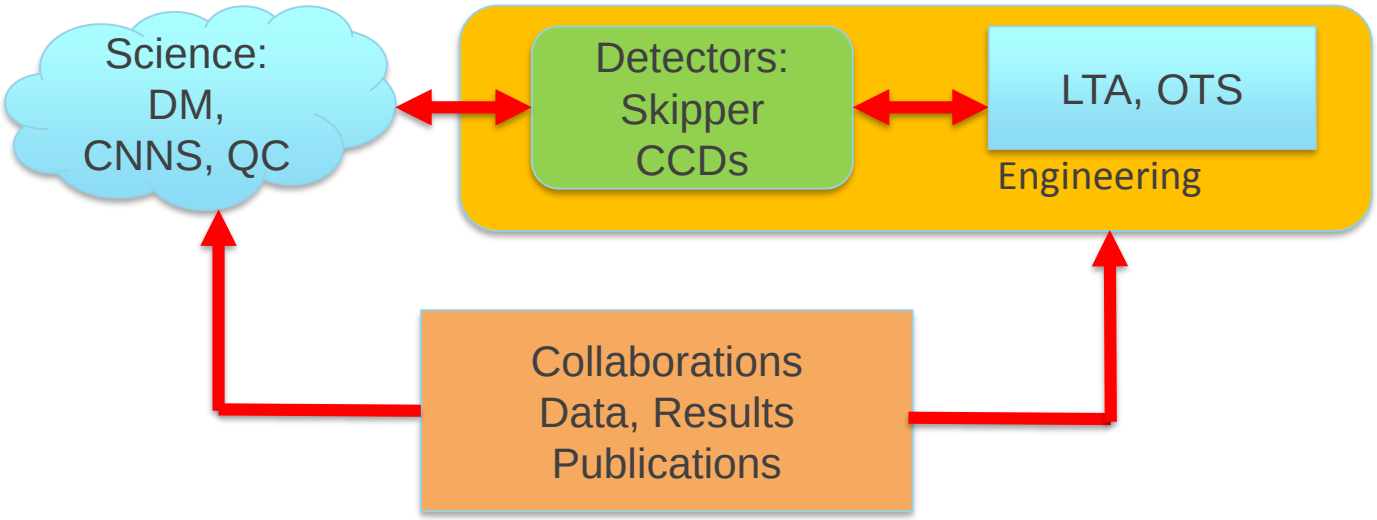


Real Time Systems Engineering, R&D and science

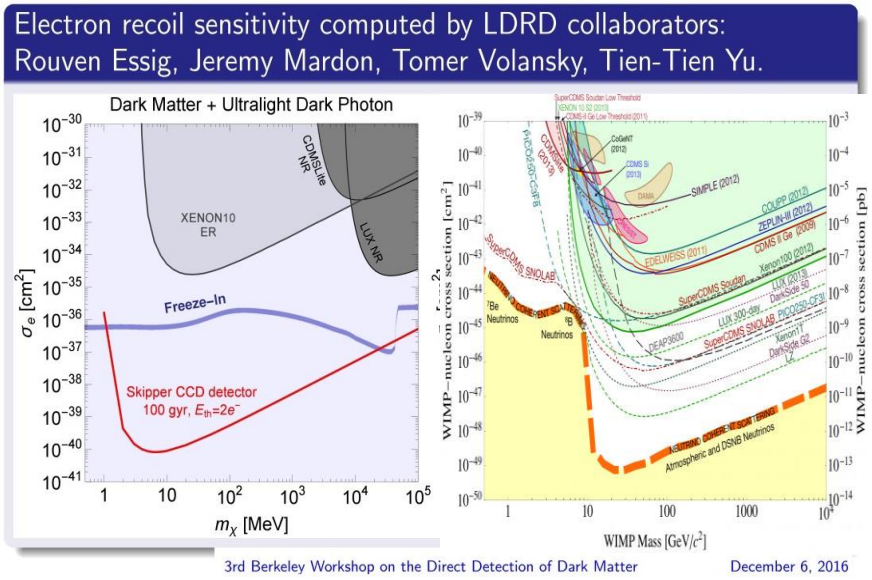


- Engineering supports and participates of Detector R&D and science, often improving the detector-engineering realization.
- We aim for experiments that push the envelope of detector and engineering in a tightly coupled design.

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]



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).

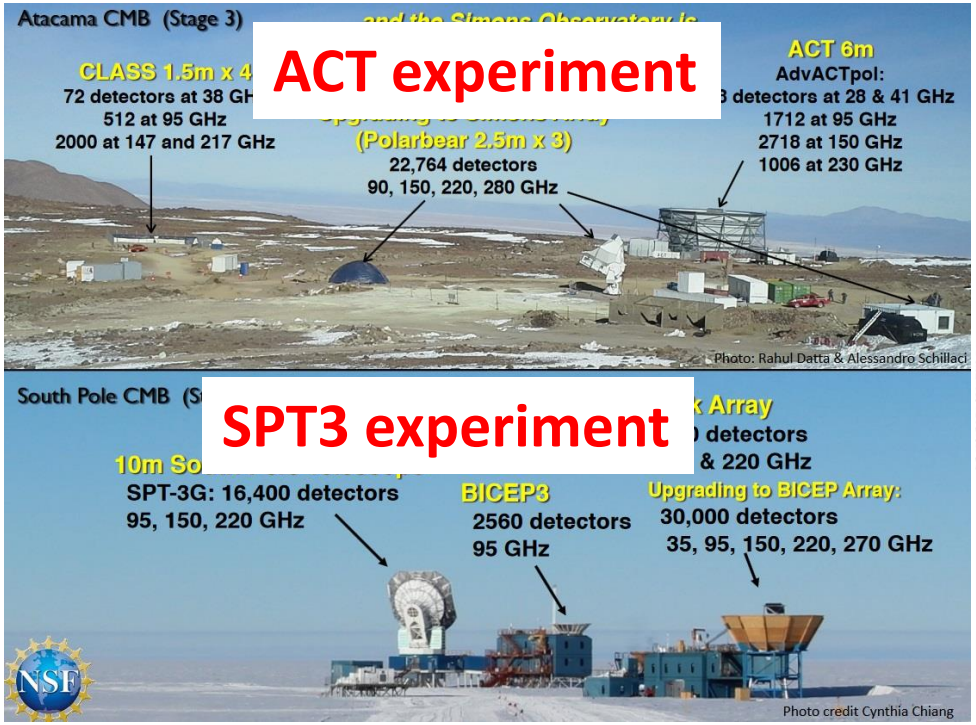
SENSEI science reach: light dark matter, dark photon, etc. $500K funding from SIMONS foundation.

Applications: DM, CNNS, nuclear safety.

Current experiments with CCDs: CONNIE, DAMIC.

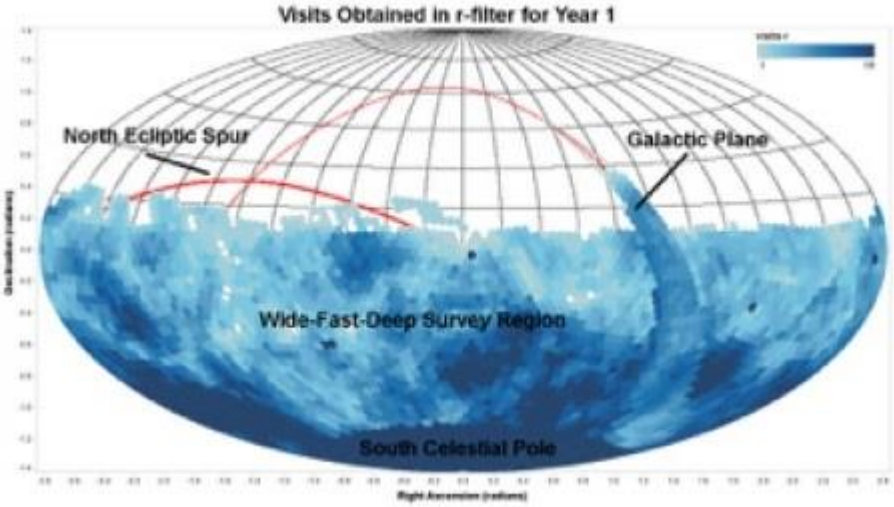
LTA/OTS design has generated one of the best engineering collaborations with Latino America:
Univ. del Sur (Argentina), CNEA (Argentina), UNAM (Mexico), Univ. of Asuncion (Paraguay)
It has generated 4 Master thesis, one PhD thesis.

DAQs for Dark energy and the evolution of the universe



LSST will generate >1 billion galaxy catalog.

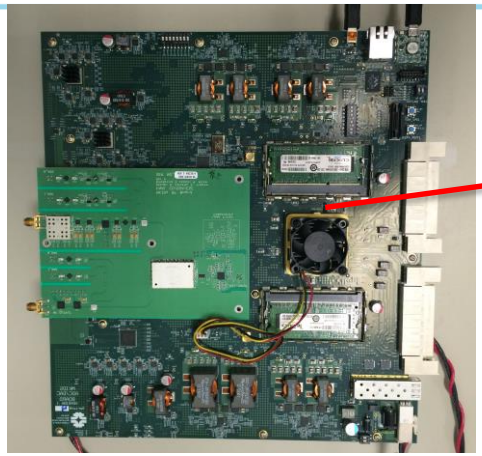
Opportunities for spectroscopic surveys!!

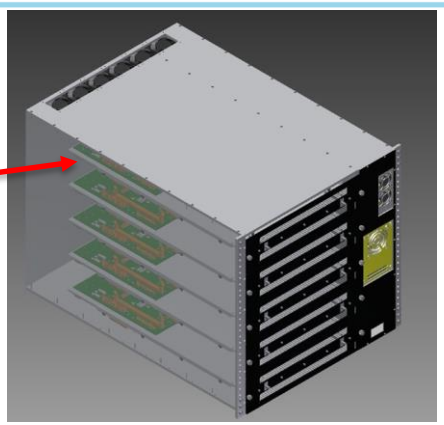


- CMB future: CMB S4
  - A collection of CMB telescopes at the South pole and Atacama
  - Superconducting detectors: Frequency Multiplexed TES or MKIDS.
- Future optical surveys:
  - High and low resolution spectroscopy.
  - 100,000 channels high res spectrometer?
  - Low res MKIDs based instrument?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

Electronics and DAQ

Warm electronics for superconducting detectors (fMESSI)

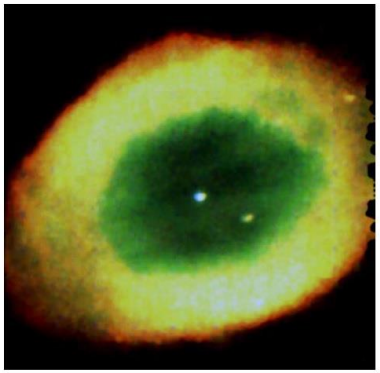


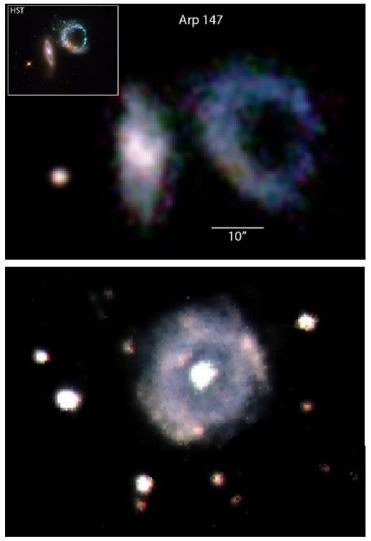


fMESSI for CMB MKIDs and quantum sensors

- 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.

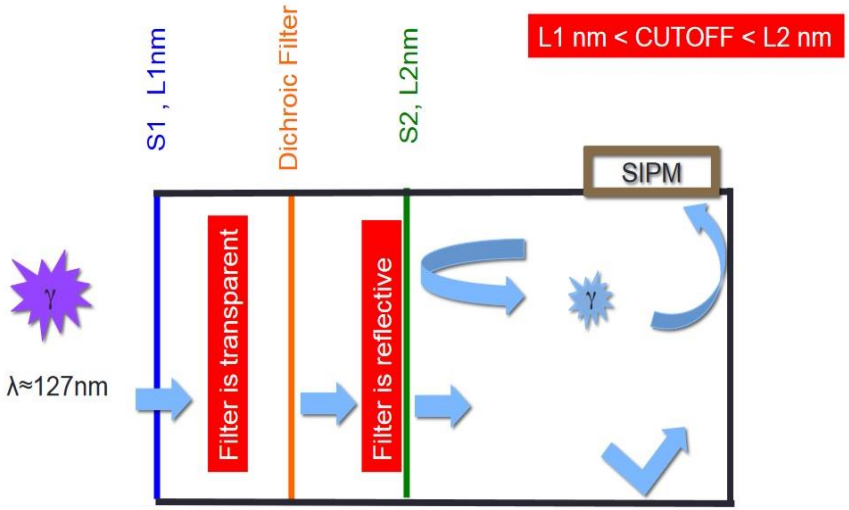
Images from Palomar



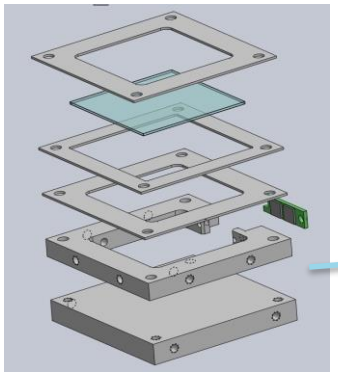


DUNE photon detector

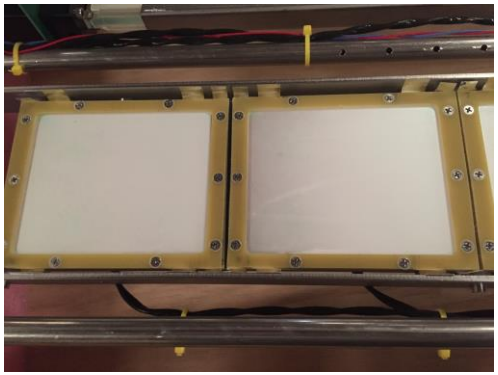
- The DUNE far photon detector must provide T0 for non beam events, proton decay candidates and supernova neutrinos with high efficiency. It is also important in the discrimination of backgrounds.
  - The technical objective is to achieve a photon detection efficiencies > 1%.
- That efficiency has not 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



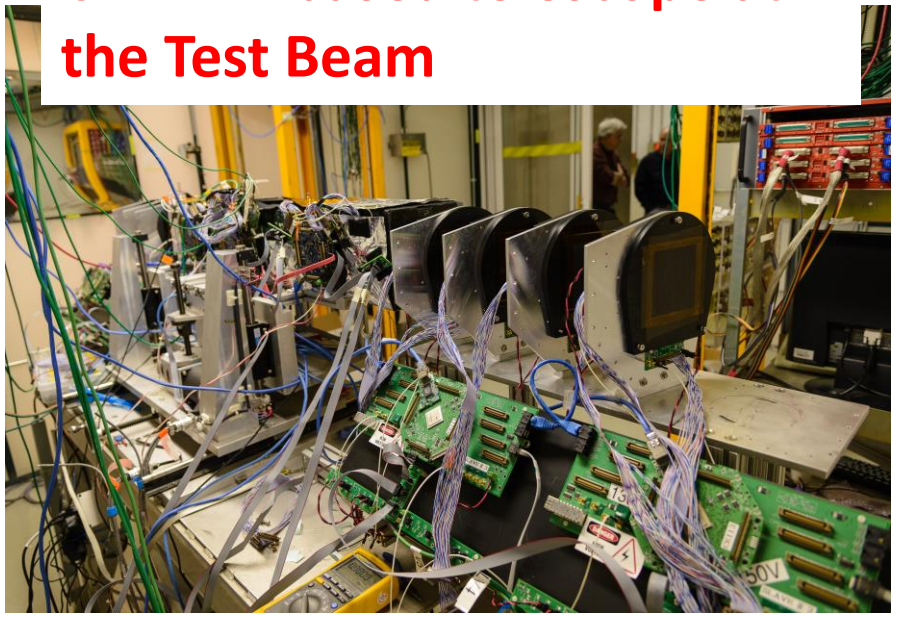
Currently funded by LDRD

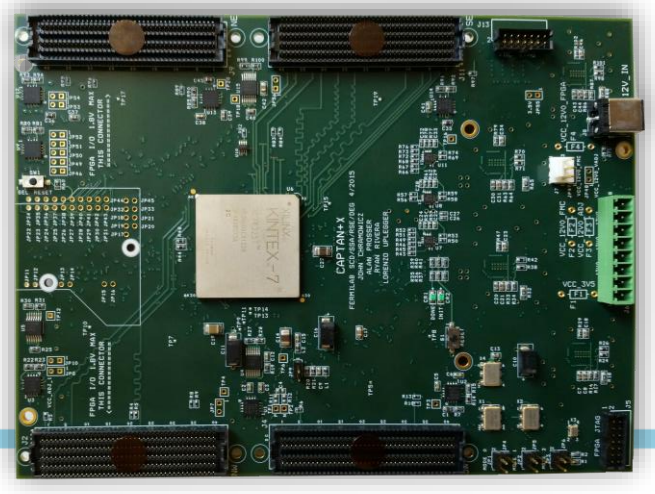
- Status: 1st year of LDRD finished successfully.
- Achievements:
  - Improved ARAPUCA design.
  - Optical measurements and 2 LAr tests at TallBo.
  - Last run compared IU light bar technology and ARAPUCAs. Data analysis pending.
  - We created an ARAPUCA collaboration and the PD consortium leader is 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

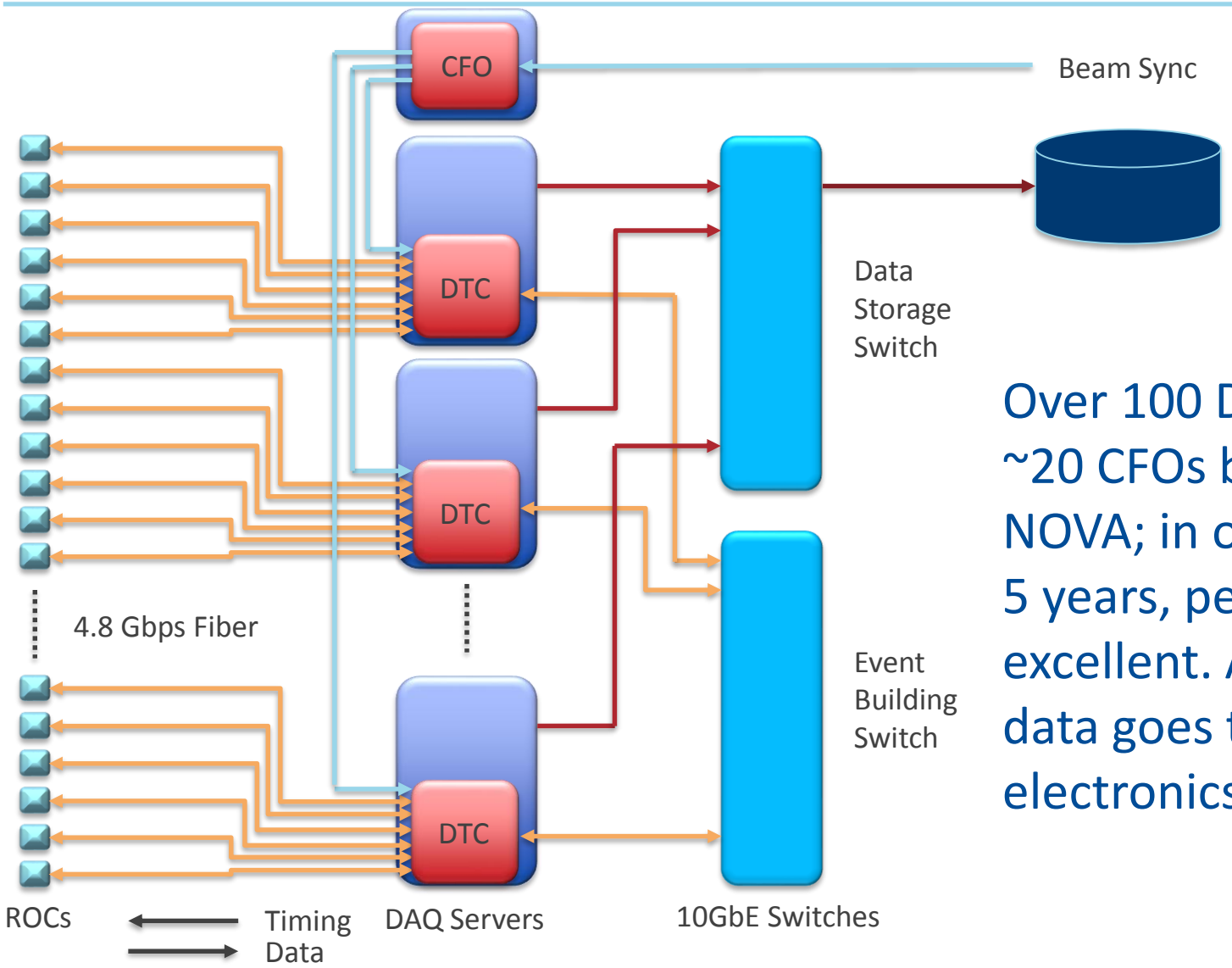
CAPTAN based telescope at the Test Beam





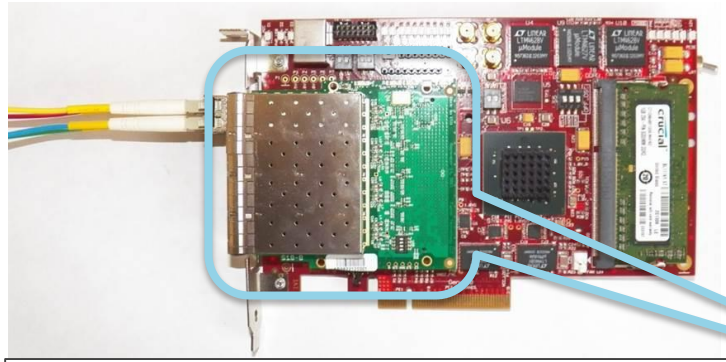
Also used in the Replacement of old NIM modules

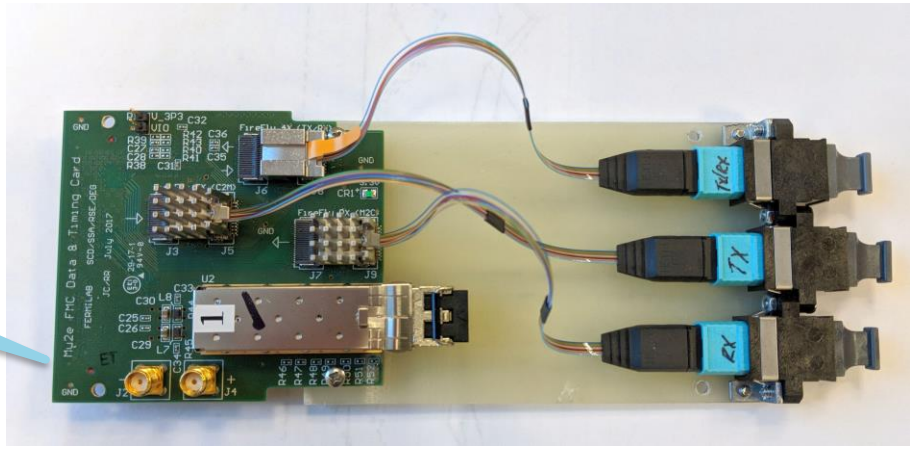
NOVA and Mu2e DAQ and Timing Systems



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





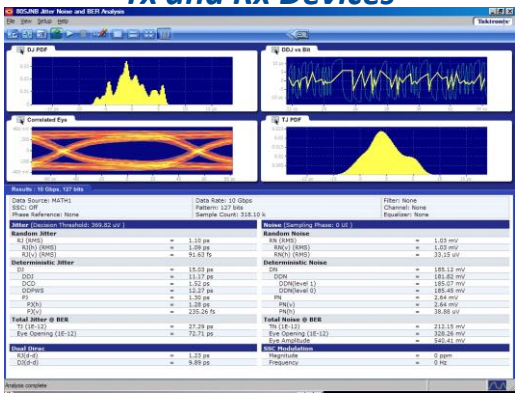
Data Transfer Controller (DTC)
- Commercial PCIe board
- Custom FMC Card
- Custom Firmware
- 6 – 4.8Gbps ROC links
- 1 – Timing System link
- 1 – 10Gb Ethernet link
- Collects data from ROCs
- Builds and Filters Events

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

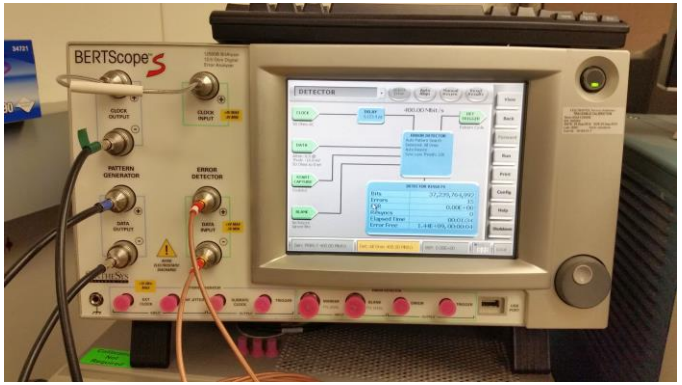
SCD/RSE High Speed Links Test and Measurement Facilities

Variable Optical Attenuators

Jitter Decomposition
Tx and Rx Devices

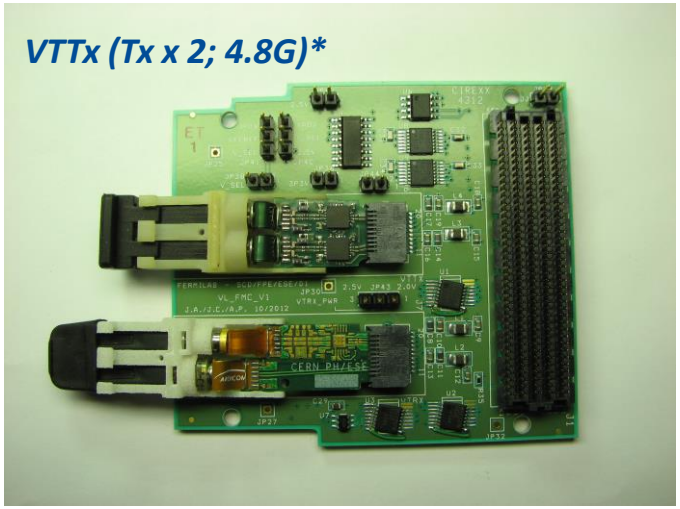


BERTScope BSA12500B (BER Testing)



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

VTTx (Tx x 2; 4.8G)*



Colaborators:
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.