Performance and production of the COLUTA ADC ASIC for the ATLAS HL-LHC Liquid Argon Calorimeter

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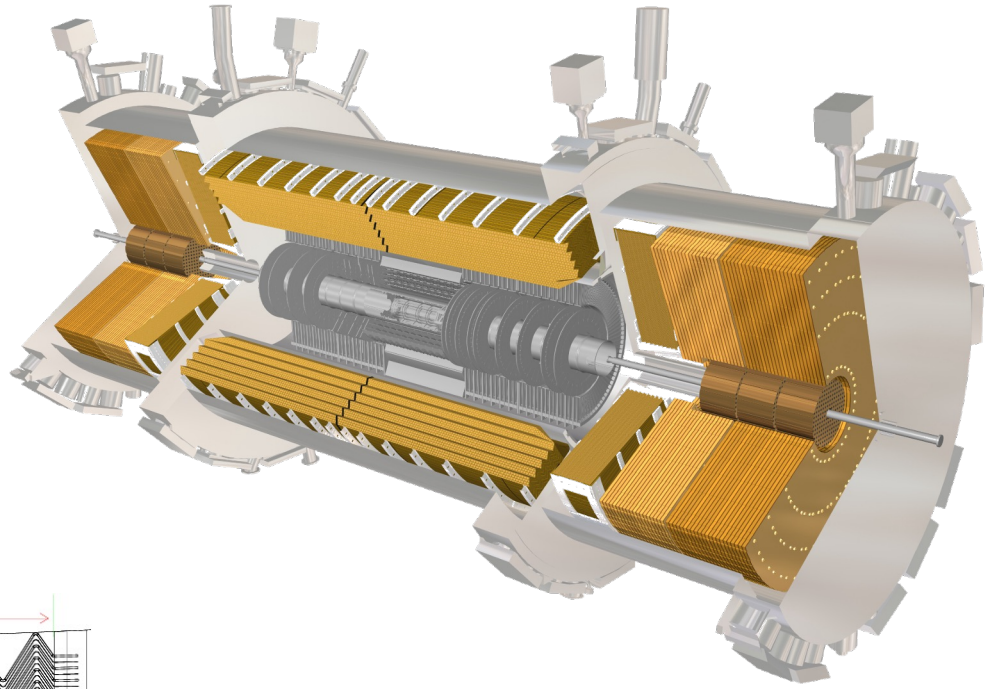
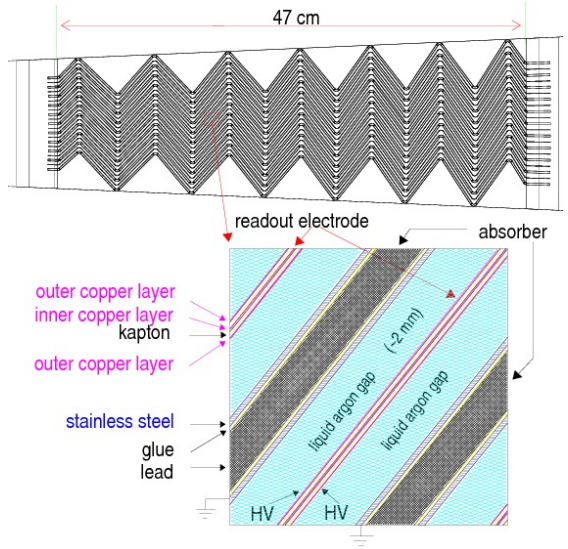
Liquid Argon Calorimeter (LAr)

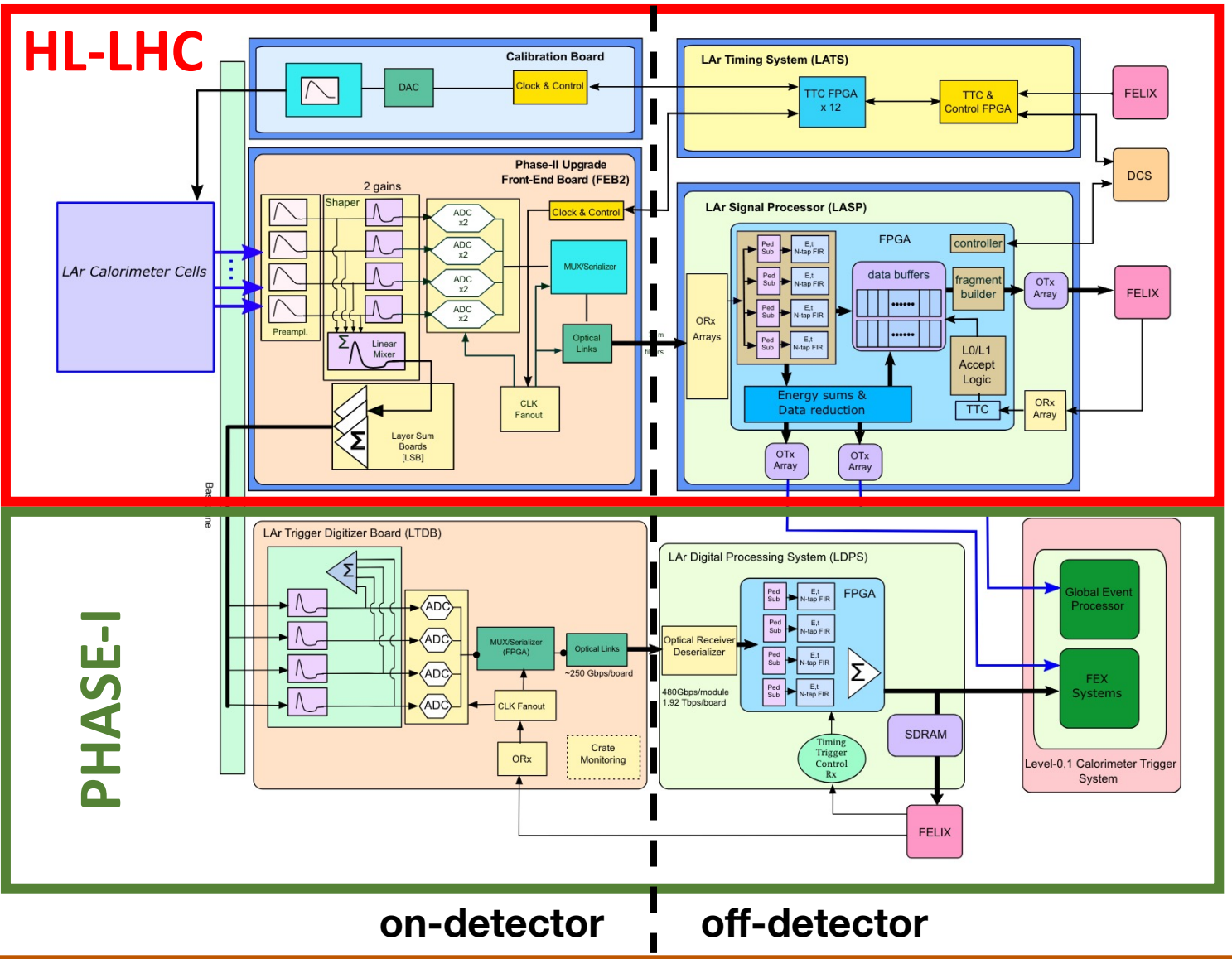
- Sampling calorimeter with **liquid argon** as the active medium, and lead, copper, and tungsten as the passive material
- Measures energy, position, and timing of **electromatic showers** and hadronic jets
- Accordion geometry allows for full azimuthal coverage
- **182,468 cells** are read off at a rate of **40 MHz** (bunch crossing rate) and sent off the detector or analysis





- Calorimeter Electronics will be upgraded, but the calorimeter itself will not
- Cryostat will not be open, performance continues to exceed expectations

HL-LHC LAr Readout Electronics



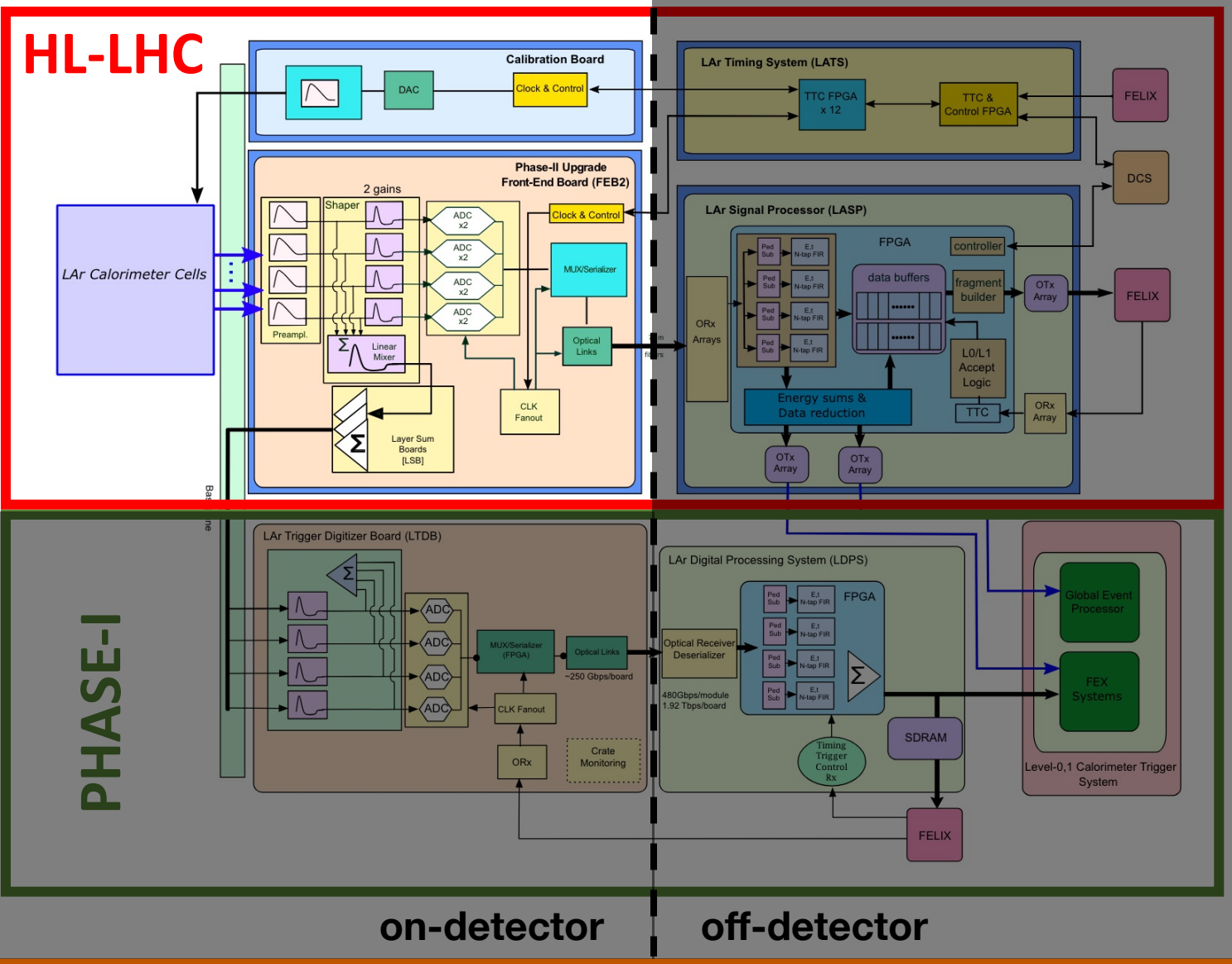
HL-LHC:

- Upgrade electronics currently in preparation, to be installed for use in Run 4
- Cover full range of energy expected in the HL-LHC, from ~ 50 MeV – 3 TeV
- Linearity of 0.1%
- Low electric noise, below intrinsic calorimeter resolution
- 11-bit precision at high energy
- All data sent off detector
  - ~180 Gbps per Front-End-Board
  - ~275 Tbps for the full calorimeter

Phase-I:

- Updated L1 Trigger to have finer granularity
- Already Commissioned - used for Run 3

HL-LHC LAr Readout Electronics



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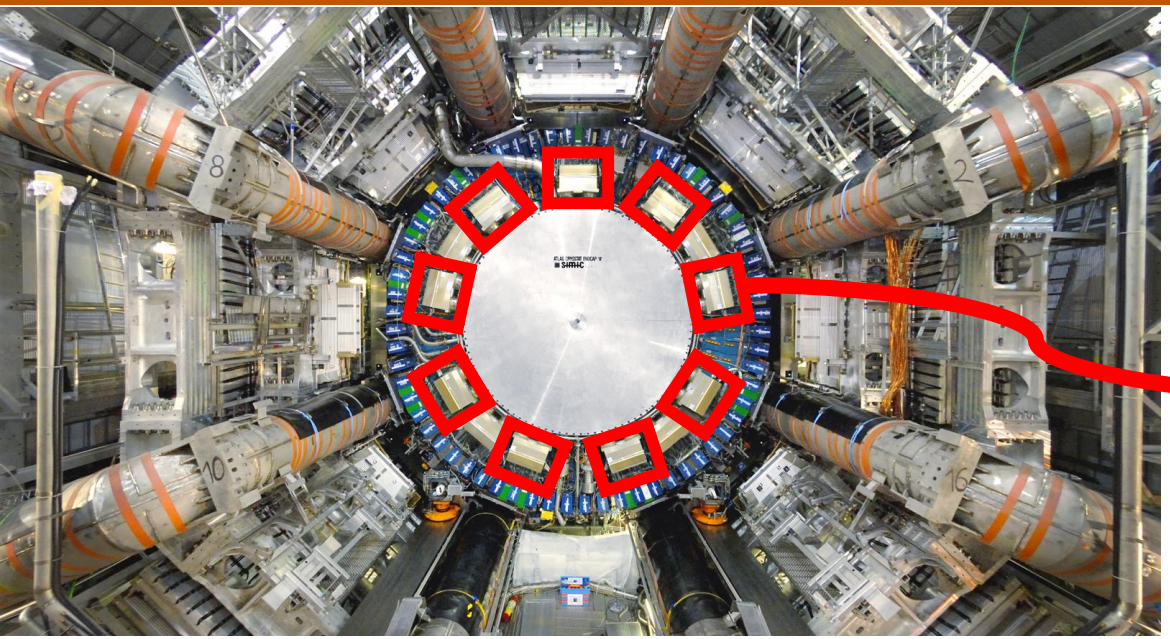
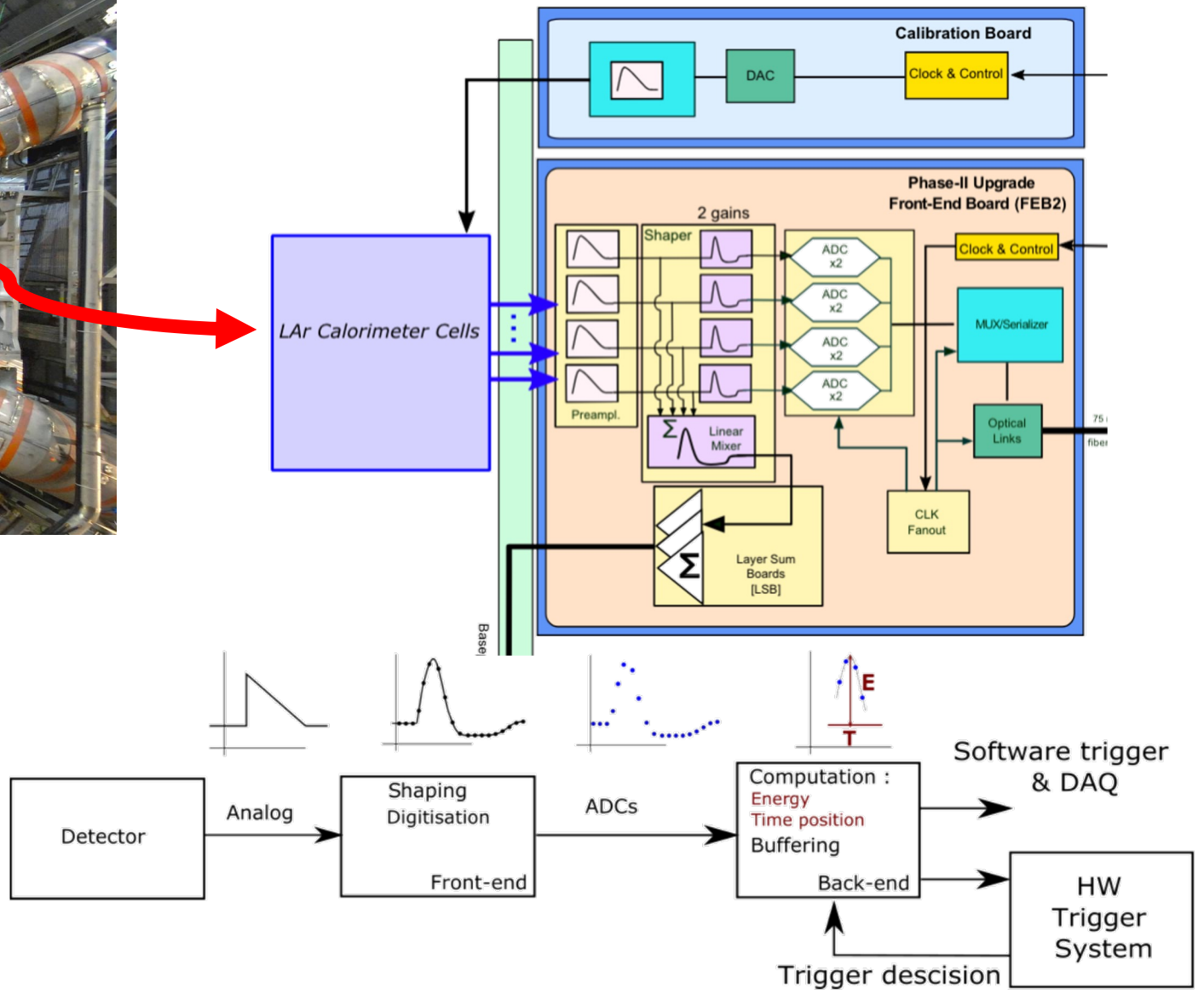
On Detector Electronics

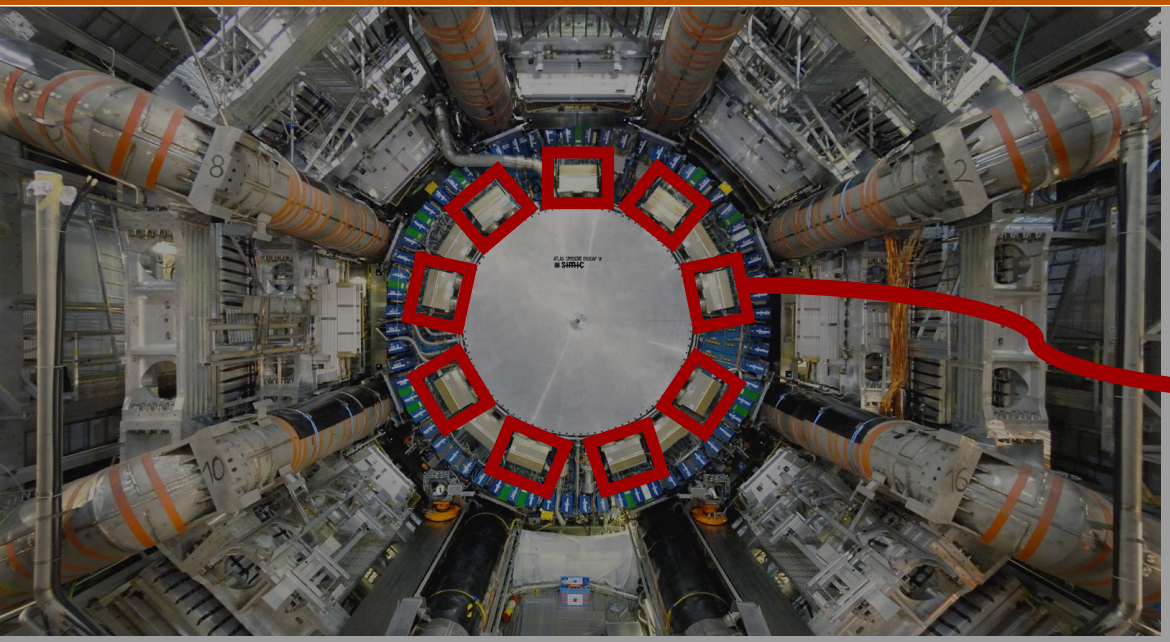


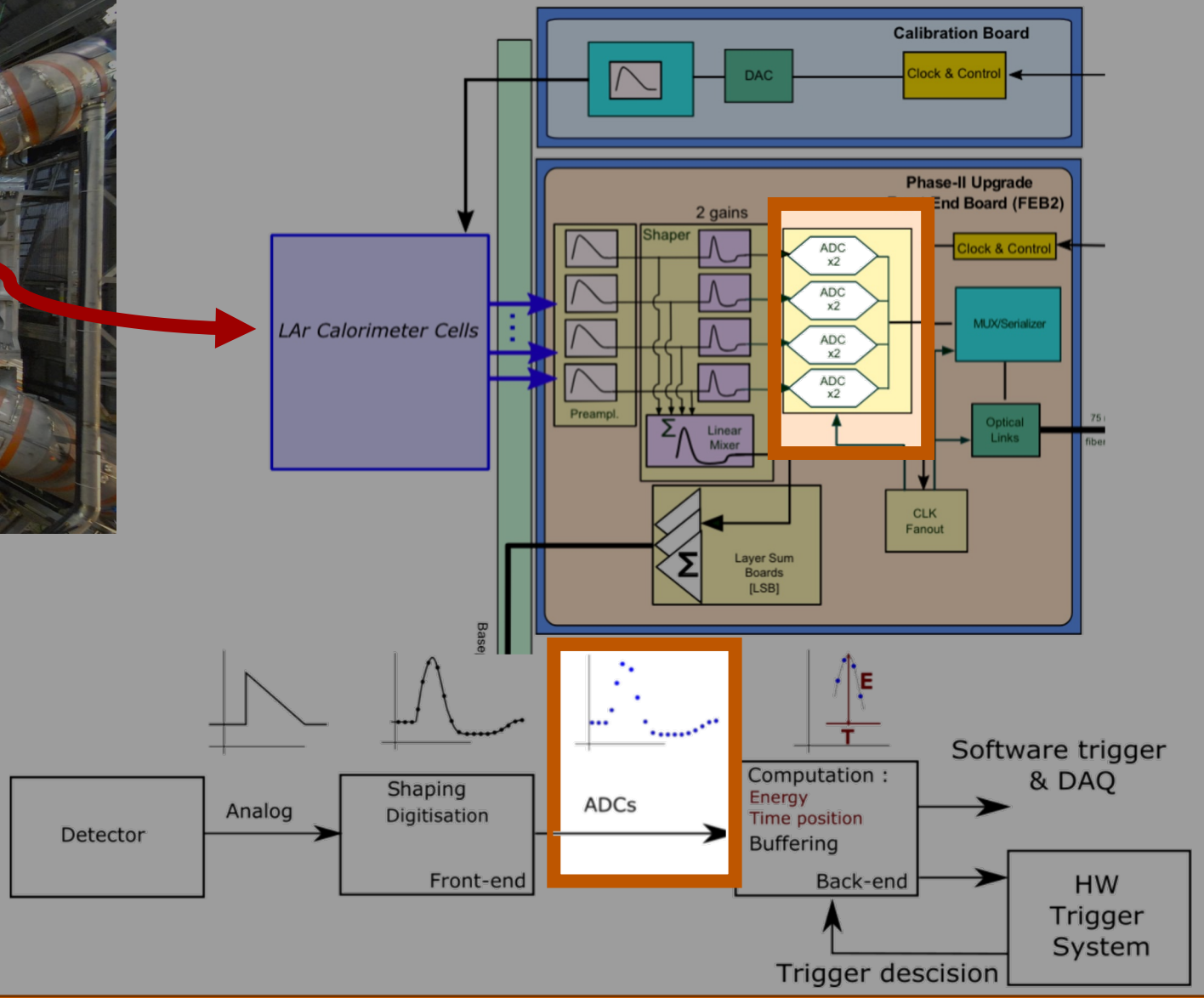


The on detector electronics:

- take a signal from the calorimeter shape and amplify the signal
- sample and digitize the signal
- send the signal off through optical fibers

On Detector Electronics





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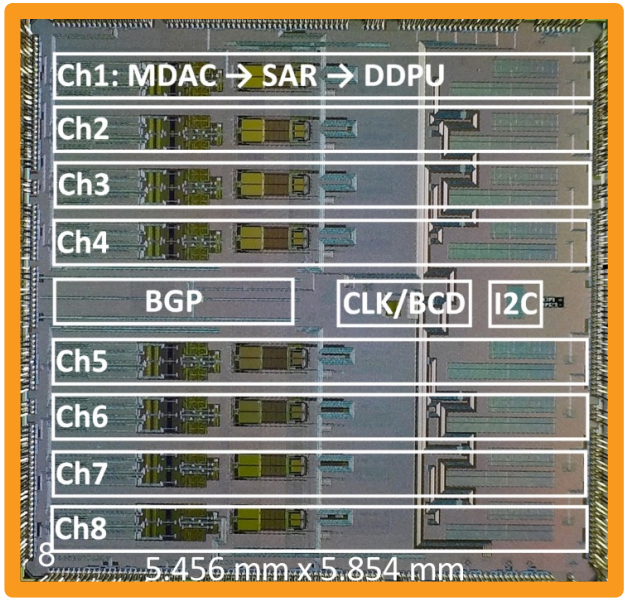
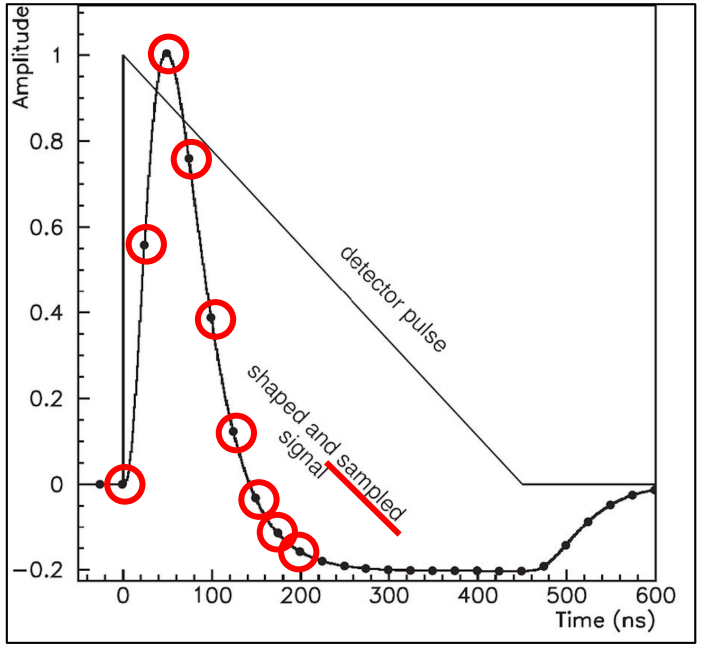
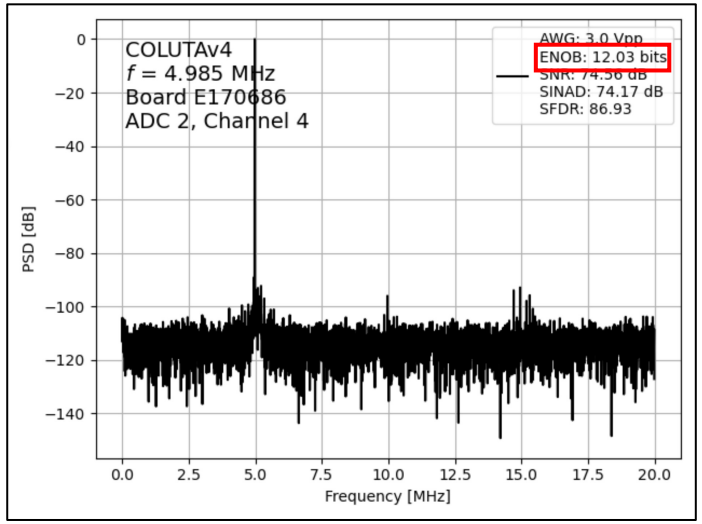
COLUTA- Analogue to Digital Converter

Digitizes the PreAmp/Shaper output at bunch crossing rate of 40 MHz with a 14-bit dynamic range and > 11-bit precision



- 15-bit, 40 MHz ADC
  - Custom ADC ASIC designed in 65 nm CMOS
  - 8 channels – matches pre-amp/shapper output, 4 channels x 2 gains
  - 3-bit Multiplying DAC (**MDAC**) + 12-bit Successive Approximation Register (**SAR)**
  - Digital Data Processing Unit (**DDPU**) applies calibrations and transmits data (15 bits of ADC + 1 overflow) at 640 Mbps
  - **Fully compatible** with PA/S
  - eLink interface to lpGBT (optical transmission off-detector)





COLUTA - Production

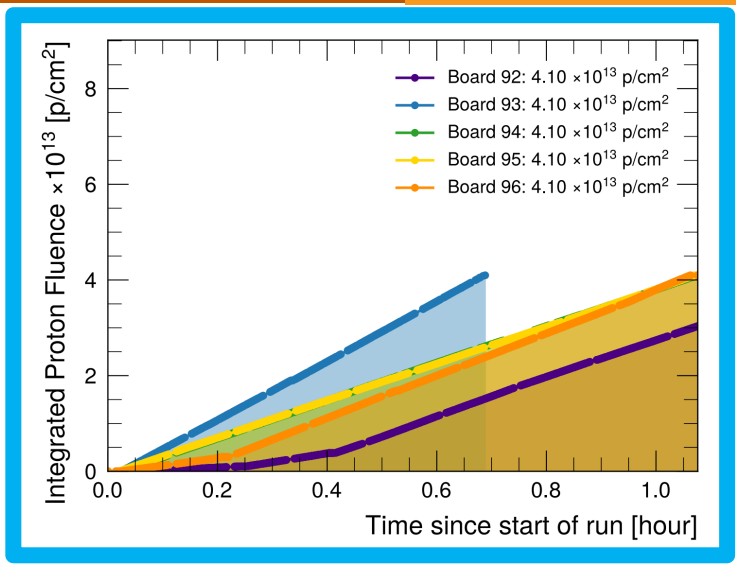
- 9k Chips produced in Engineering run
  - Used for quality control testing and test stand validation
  - Installed in first full FEB2 boards for integration
- For production we need a total of 80k chips
  - All the wafers have been produced
  - 4k have already been packaged and are being QC tested

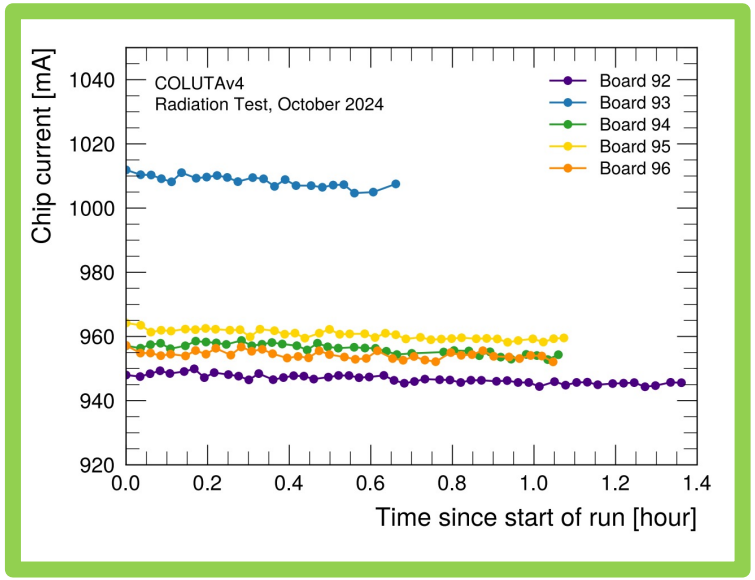
Radiation Testing

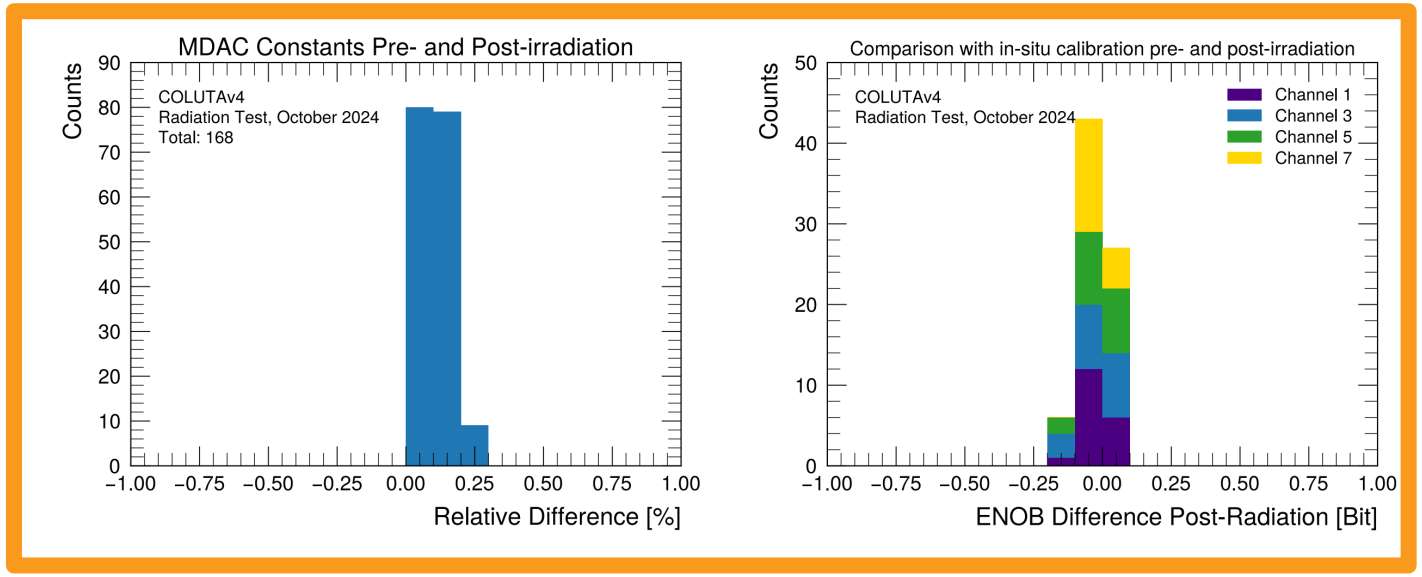
Plan to test radiation hardness for at least 10 chips from each lot

First Engineering and Production chips tested at Massachusetts General Hospital in the proton therapy beam

- Each COLUTA chip was Irradiated to the required HL-LHC dosage (TID up to 1 MRad)
- Each chip fully functional during and after irradiation
- No significant degradation observed in calibration constants or analogue performance
- Observed three instances of triple redundant configuration it corruption
  - In line with pre-production tests and below required specification
- Number of Single-event upset — a transient, erroneous ADC code in the output data — within specification

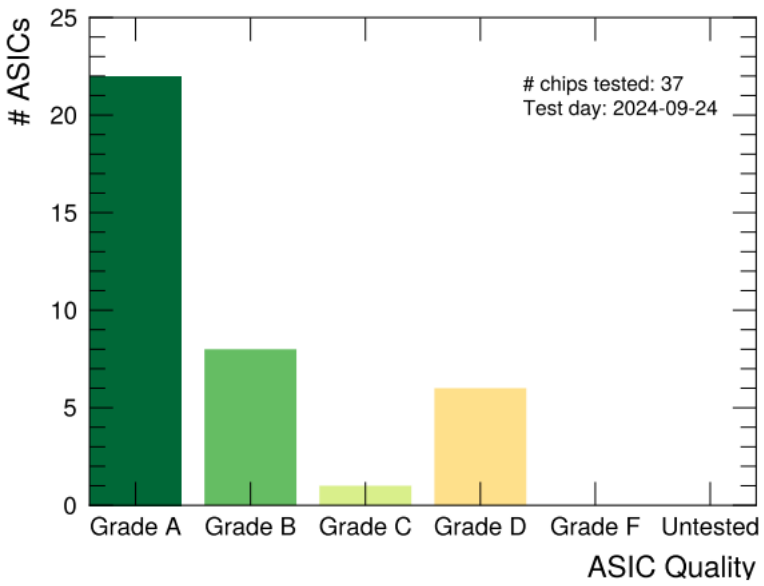


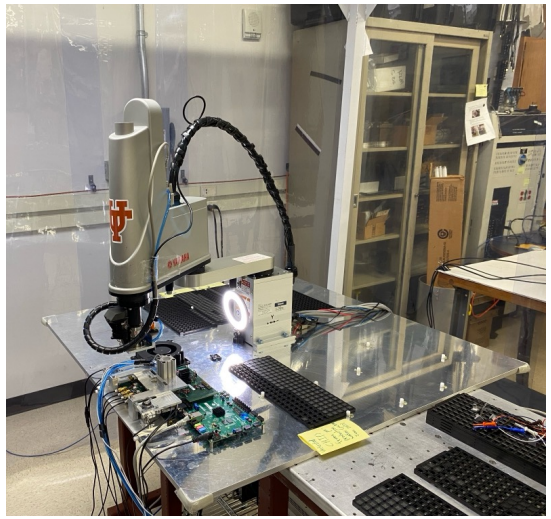


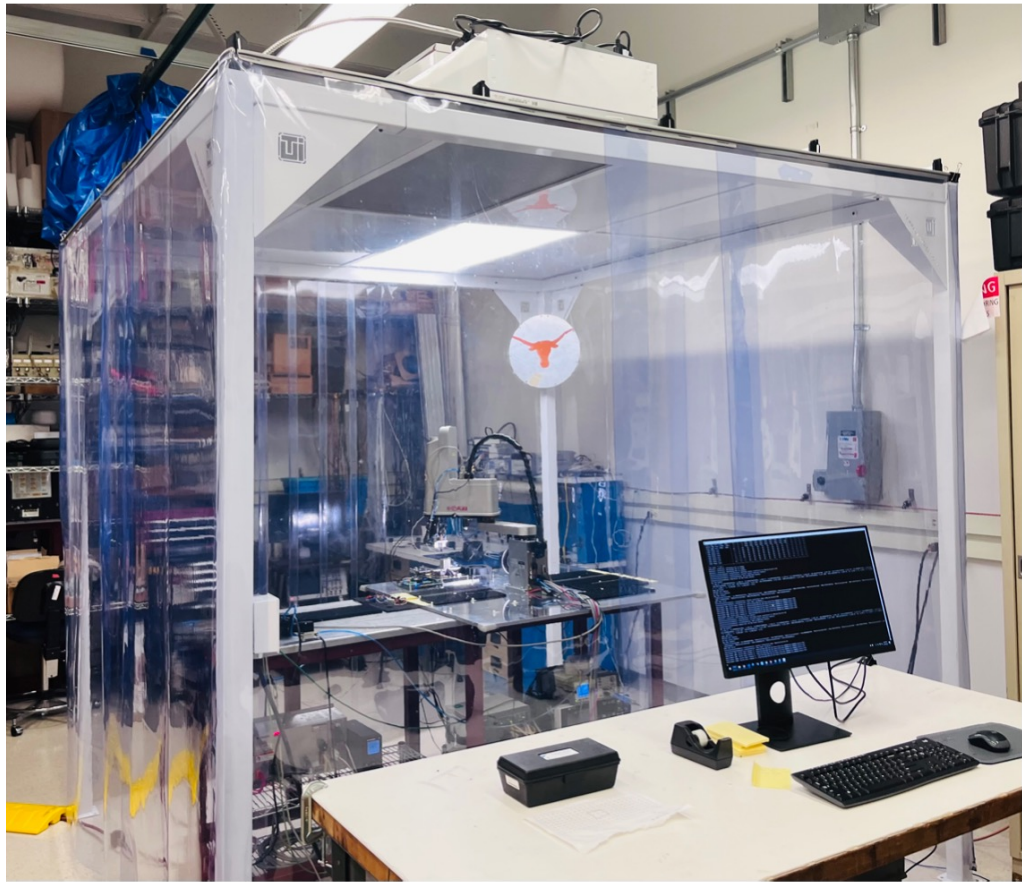


Quality Control

- Every chip will be tested for quality
  - Assigned a ranking on a A, B, C, D, F scale
  - Primarily evaluated on ENOB
- Test stands at UT Austin in clean room with robotic arm placing chips on a precision test board
- Currently have a 90% yield of A/B quality chips

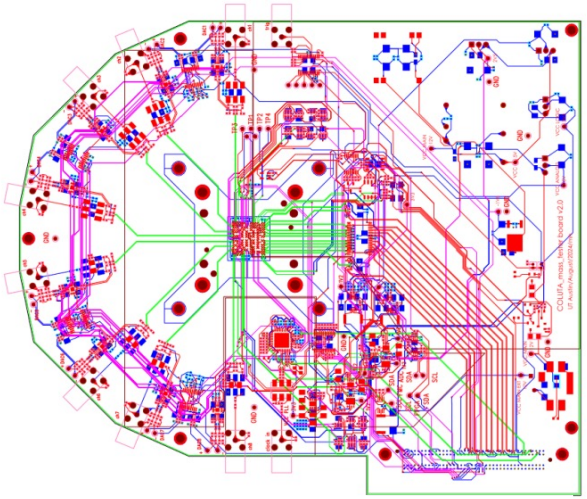


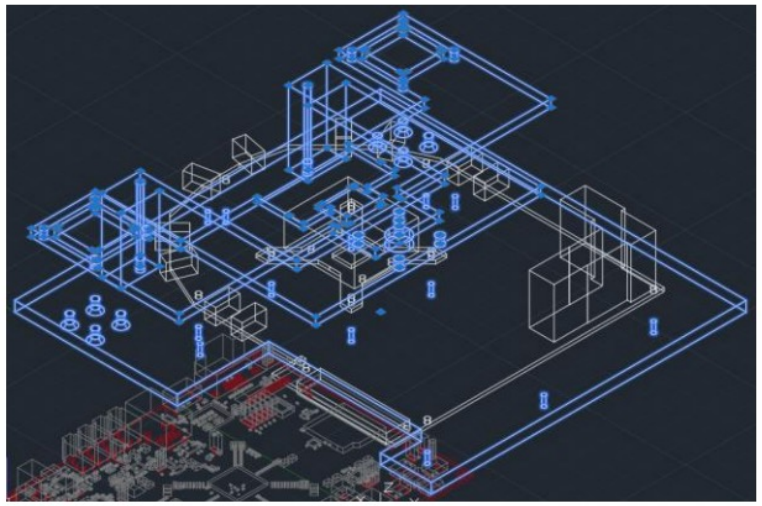




Ongoing Work

- Longevity testing, including accelerated aging, vibrating and heating tests are almost finished
- Finalizing quality control specifications coordinating with collaborators on production standards
- Currently improving the mass test stand for quality control testing
  - Improved socket reliability, performance and speed of testing
- Designing Mass Testing Database
  - Local teststand uploads data to remote EOS Storage, to a COLUTA database on CERN OKD and transfers it to MongoDB for a user friendly interface
- Preparing for future radiations tests to be done a BNL with a Cobalt 60 source





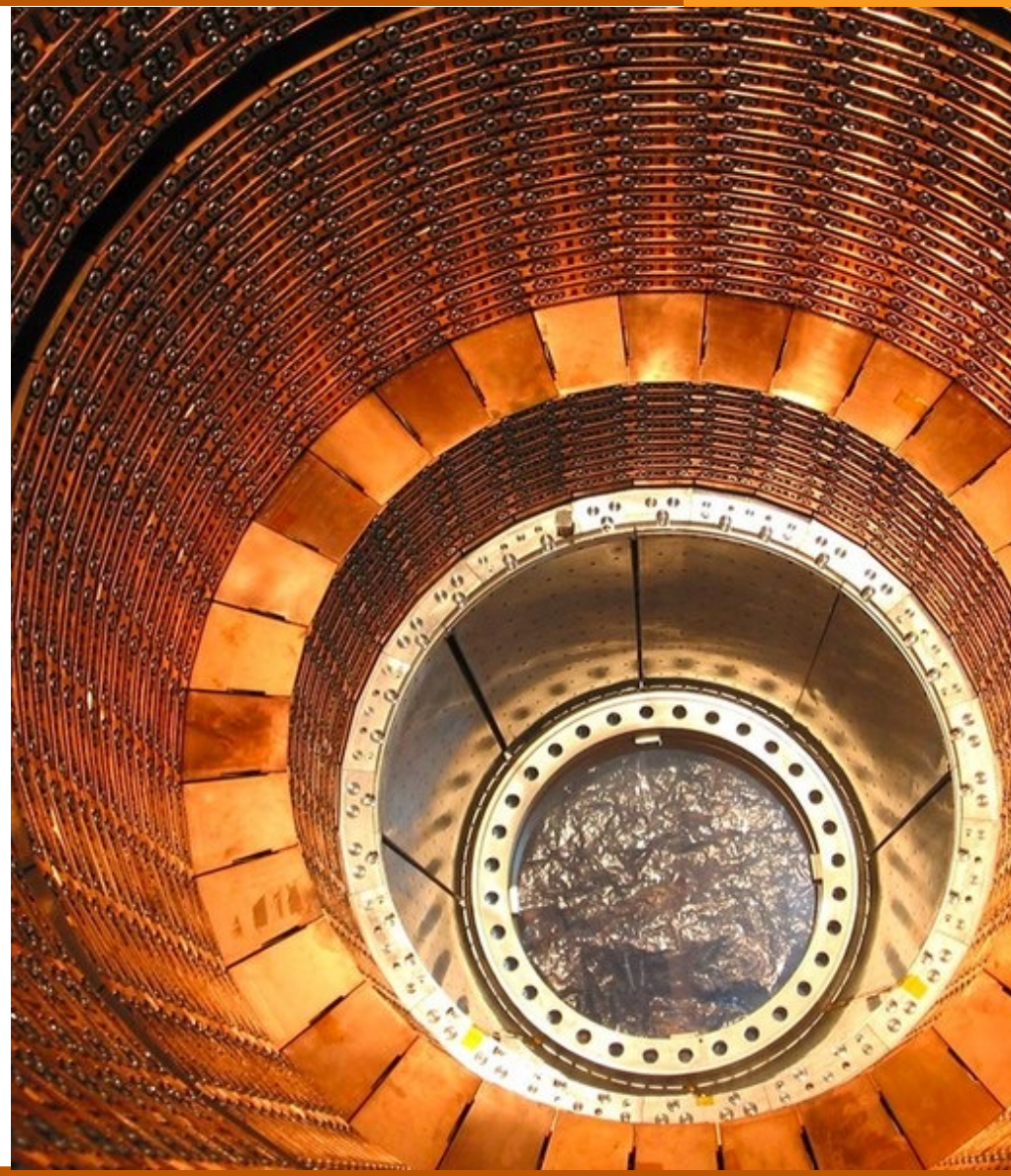
Final Thoughts

COLUTA

- Engineering run chips are already being used for half-crate tests at BNL
- First lot of production chips have been packaged
  - Radiation testing showed performance **exceeded specifications**
  - Precision testing also **exceeded specifications**
    - Putting the finishing touches on the QC testing protocol
    - Expected yield ~90% A/B grade chips
  - Expected to begin packaging all 80k COLUTA chips early next year
- Development ongoing for final quality control protocol
- **COLUTA is ahead of scheduled and exceeds all performance specifications**

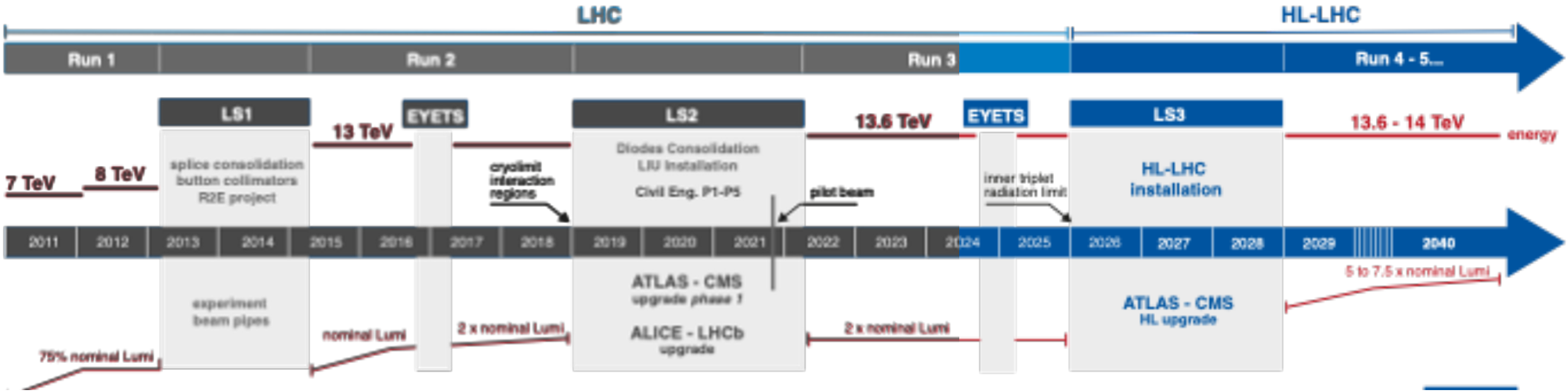
LIQUID ARGON

- Integration setups are being constructed for testing the full calibration to readout chain
- **On schedule** for installation into ATLAS cavern beginning in 2027
- Designed to run through 2041

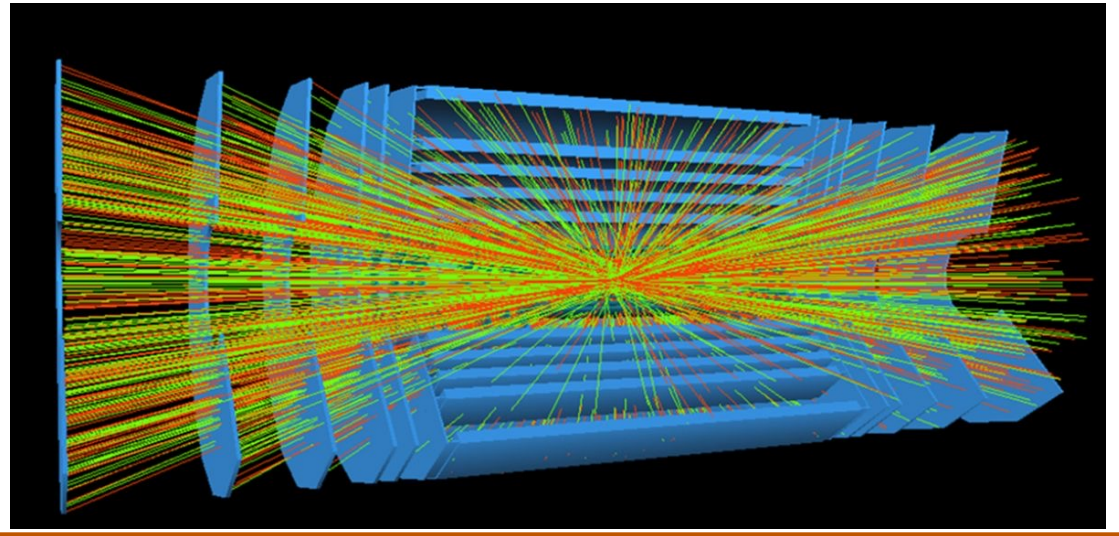


THANK YOU!

High Luminosity LHC (HL-LHC)

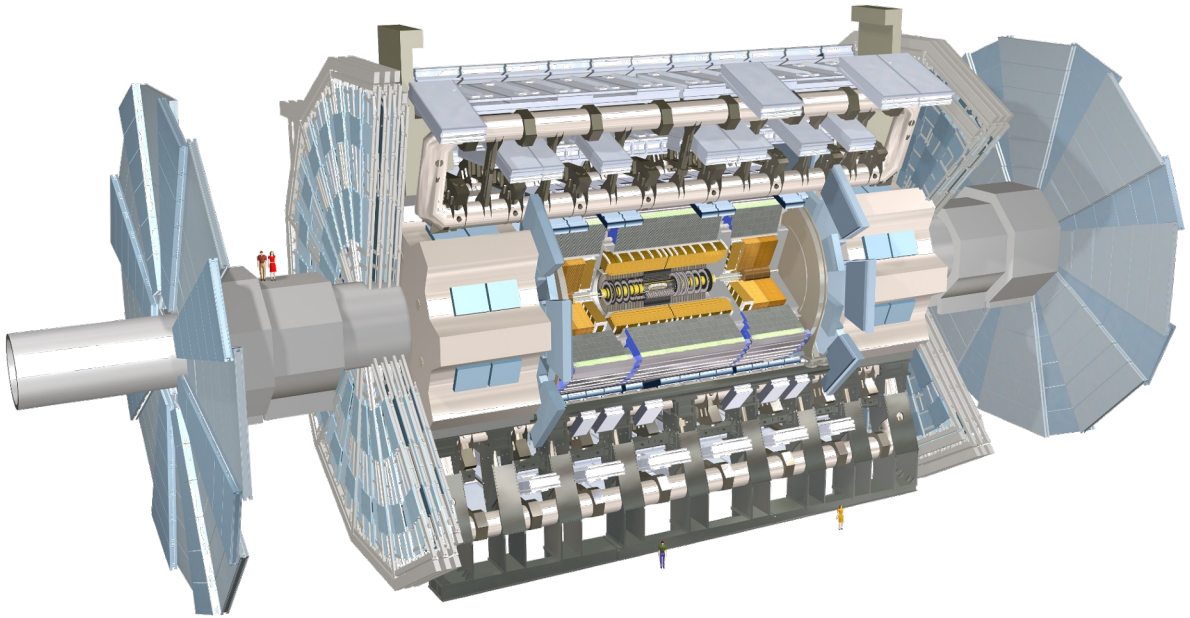


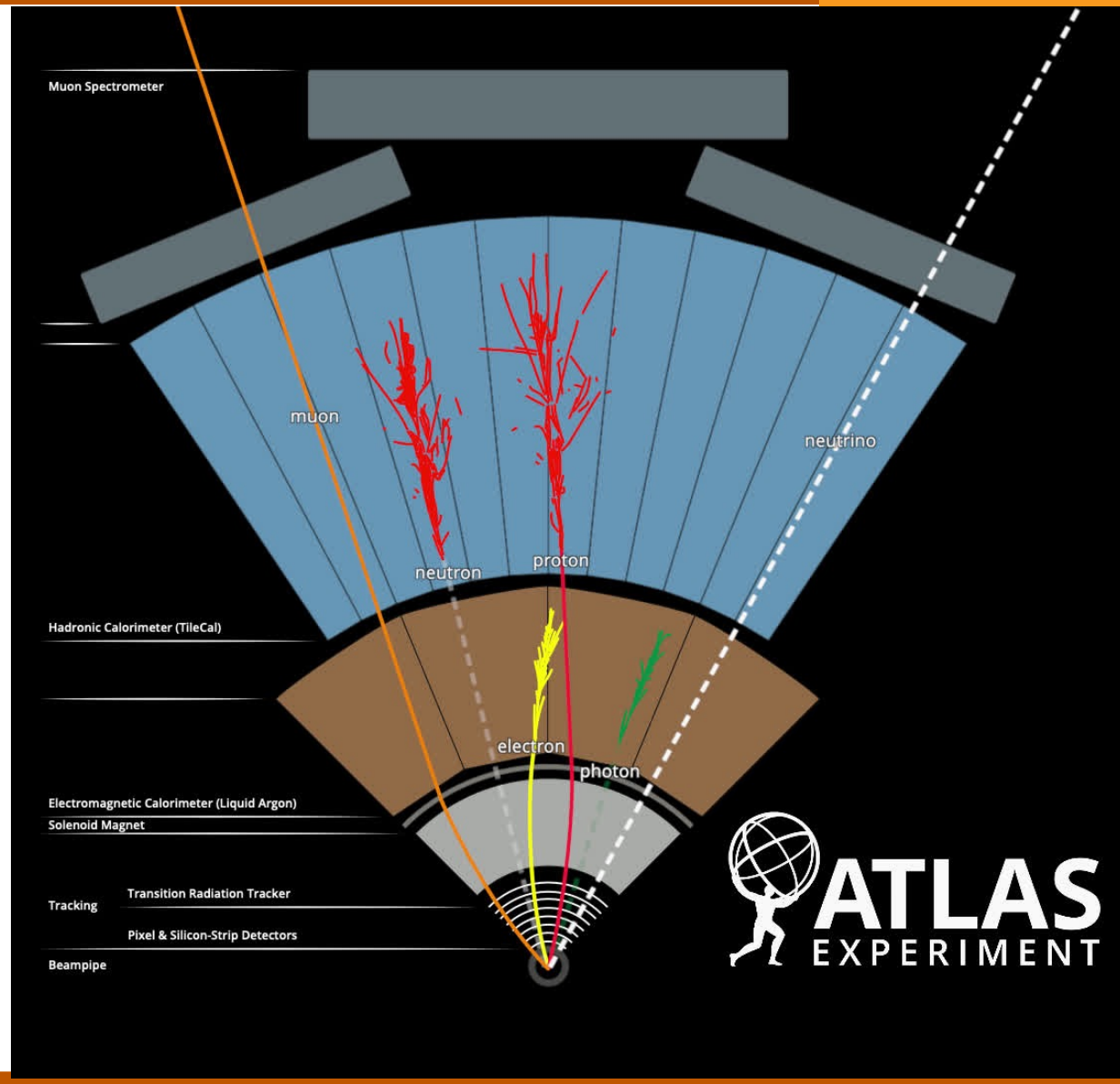
- The HL-LHC with have an integrated luminosity **10 times** greater than the current LHC
- The increased luminosity makes it harder to trigger on signal events
- Larger backgrounds from in-time and out-of-time pileup events



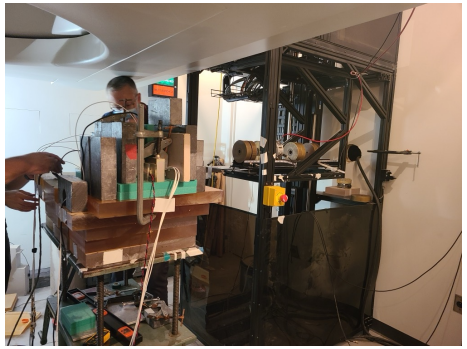
ATLAS Experiment

- ATLAS is an multi-purpose detector
  - Designed to measure a wide range of particles
  - Formed of concentric layers of different subdetectors, each with a unique goal

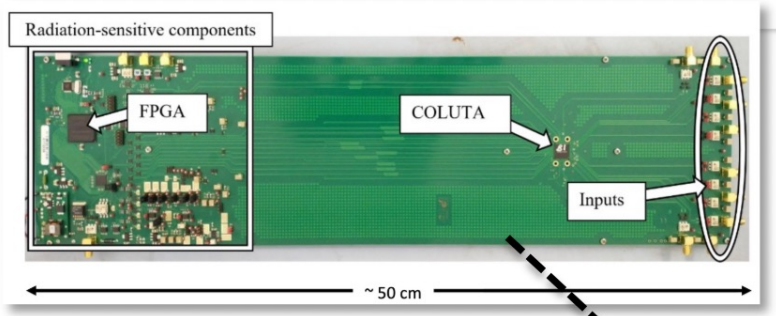


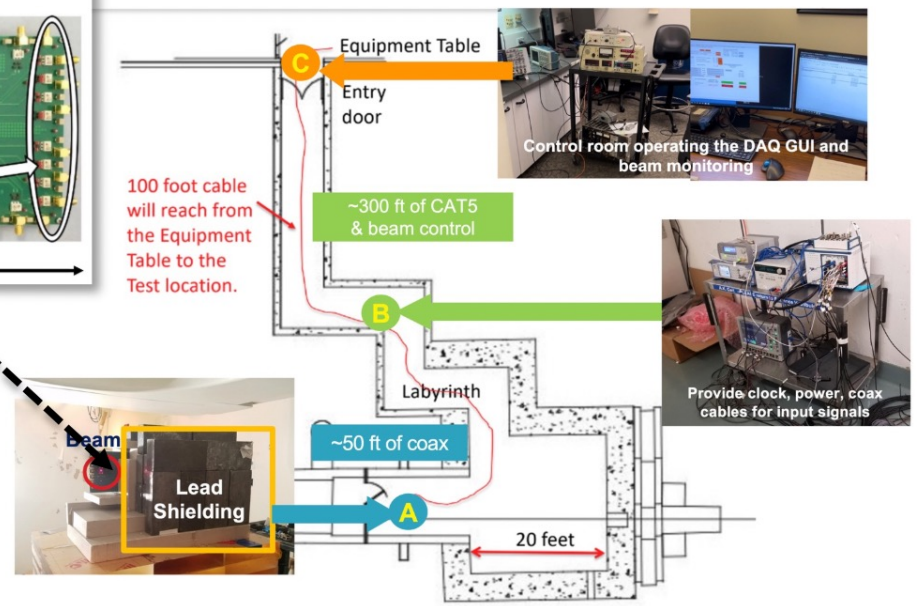


Radiation Testing



MGH Proton Therapy Beam Facility





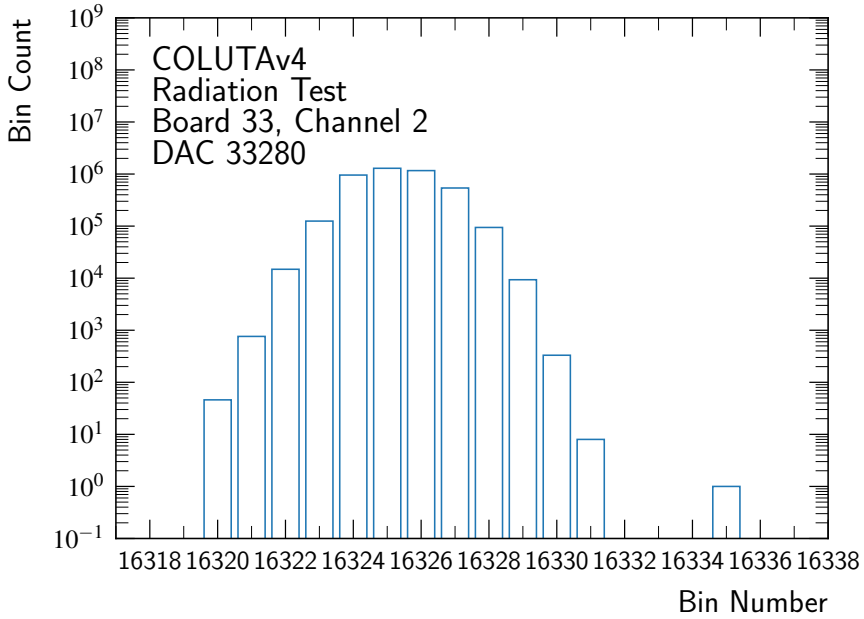
	TID [Gy]	NIEL [n_{eq}/cm^2]	SEE [$h_{>20\,MeV}/cm^2$]
FEC (barrel)	1400 (1.5)	4.1×10^{13} (2)	1.0×10^{13} (3)
FEC (endcap)	210 (1.5)	6.0×10^{12} (2)	1.2×10^{12} (3)
LVPS between TileCal fingers (barrel)	430 (1.5)	1.1×10^{13} (2)	2.8×10^{12} (3)
HEC and FEC LVPS (endcap)	81 (1.5)	2.0×10^{12} (2)	4.1×10^{11} (3)
LVPS new position (barrel)	18 (1.5)	5.1×10^{11} (2)	1.1×10^{11} (3)
LVPS new position (endcap)	33 (1.5)	5.2×10^{11} (2)	8.6×10^{10} (3)

- All on-detector ASICs have been tested for radiation hardness
- Custom boards were designed to isolate the ASIC being tested

- COLUTA was tested at Massachusetts General hospital in Boston
  - SEE σ = 3.7 x10-10 cm2/bit
  - Expected 6140 SEE/channel over the lifetime of the HL-LHC

SEU Performance

- The calculated cross-section corresponds to:
  - ✓ 6140 SEUs/channel over the lifetime of the HL-LHC (including a safety factor of three).
  - ✓ 75% of these will be within 20 counts of the correct ADC code, (slight reduction in the energy resolution).
  - ✓ Less than 1% of them will be greater than 100 counts from the correct ADC code

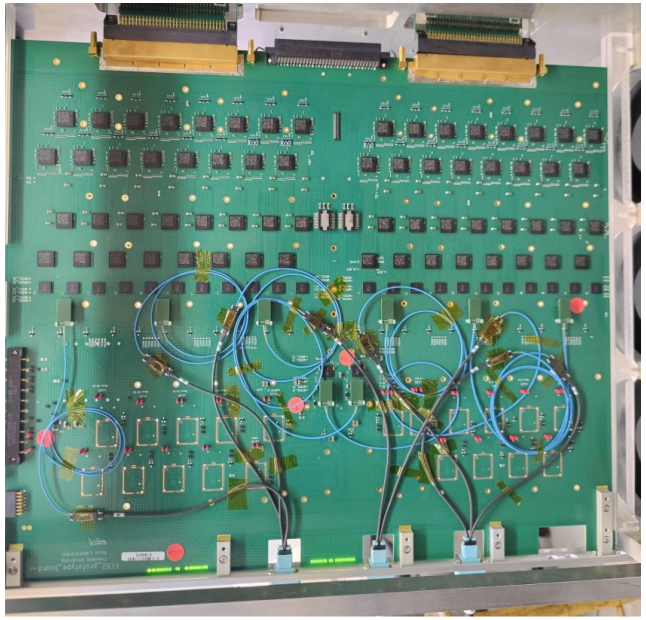


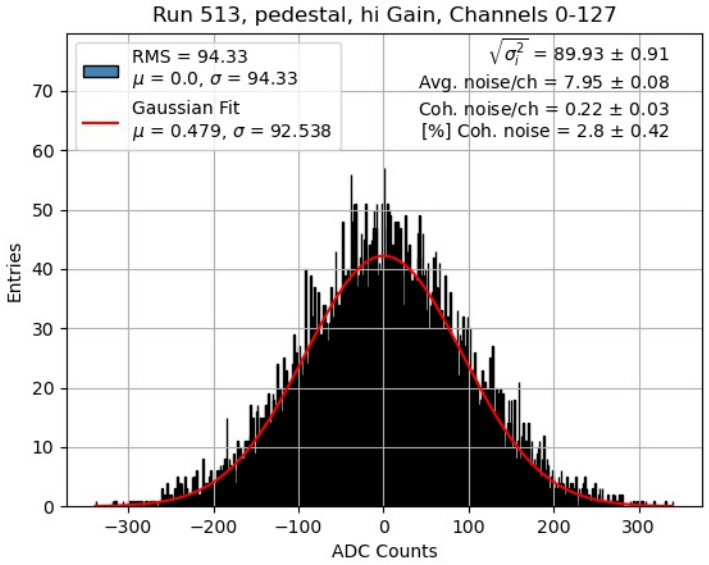
FEB2 Development

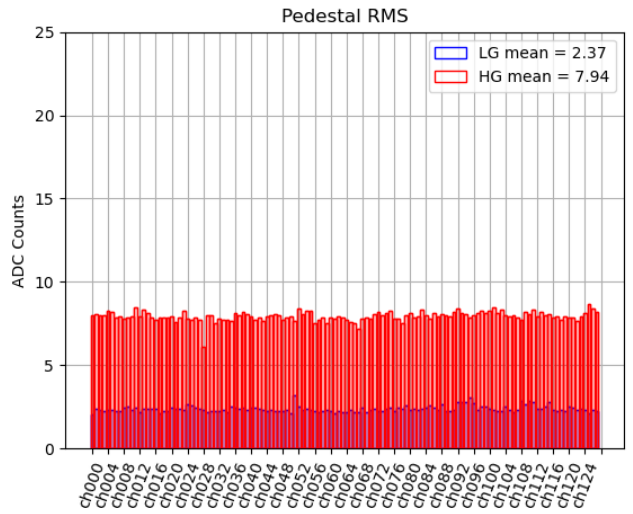
The Front End Boards (FEB2s) receive signals from calorimeter cells and perform analogue processing

- The FEB2 will be on the detector, must be entirely radiation hard, composed of two custom ASICs and optical readouts, all actively cooled
- Signals are digitized, serialized and transmitted off-detector via lpGBT protocol
  - 1524 FEB2s with up to 128 channels each
  - 32 ALFE Preamp/shapers, 32 COLUTA ADCs, and 22 lpGBT serializers

- **First full-size prototype** (with all 128 channels populated) is ready, and is currently being tested
- In particular, tests for radiation-hard powering solutions are in progress
  - Tested various solutions for on-board stepping down 48 V power supply to the voltages needed by the ASICs with the help of mezzanines

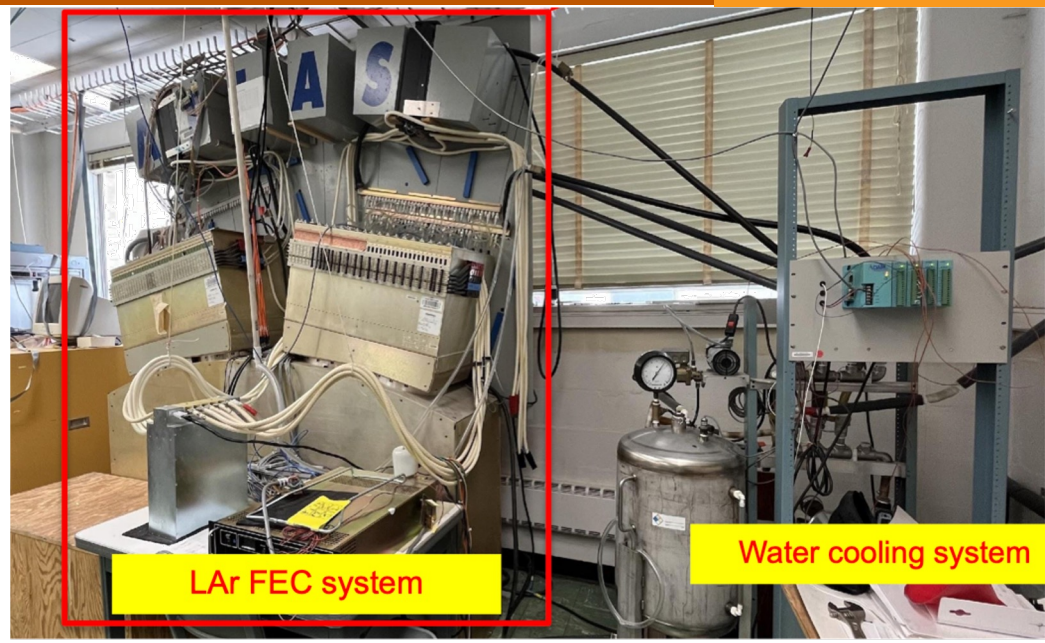


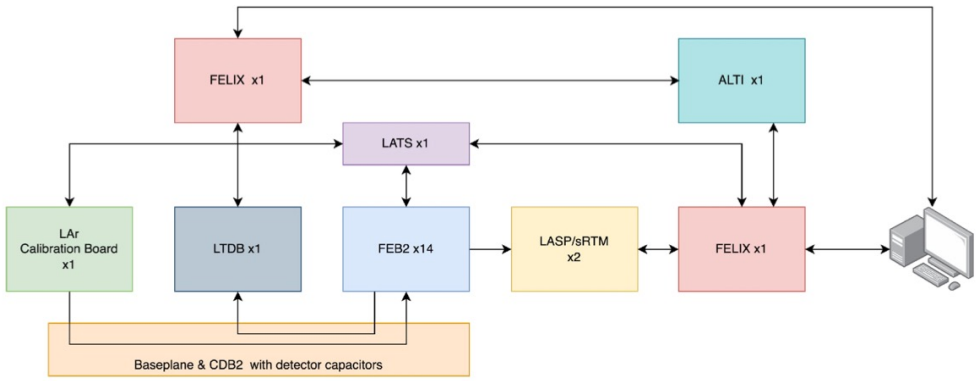




Integration at BNL

- Use BNL's high-fidelity reproduction of the mechanical and electrical properties of the LAr calorimeter
  - Detector cables/feedthrough
  - Power supplies
  - Front-End crates with baseplane
  - Water cooling system
- Measure coherent noise in a realistic setup
- **Half-crate test**: using 14 FEB2 (half a crate), simultaneously readout
  - Integrate FEB2, calibration board and off-detector LASP readout system
  - Testbed for firmware development





Block diagram of FEB2 FEC test