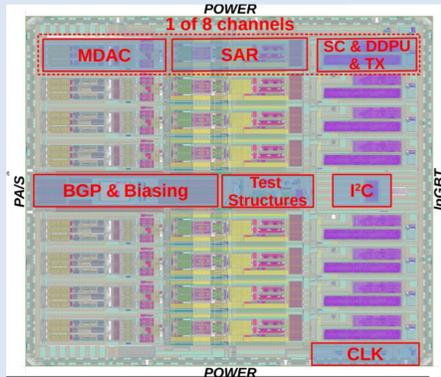# Production Testing of the COLUTA ASIC for the ATLAS HL-LHC Liquid Argon Calorimeter Readout

COLUTA ADC

- **COLUTA**—collaboration of Nevis labs at **Columbia University and UT Austin.**
- Design requirements:
  - Sampling frequency: 40 MSPS
  - Dynamic range: 15 bits
  - Precision: ≥ 11 ENOB
  - Power: <100 mW per channel
  - Radiation hardness requirements [3]:

ASIC	TID [kGy]	NIEL [n_{eq}/cm^2]	SEE [h$_{>20\,MeV}$/cm^2]
ADC	1.4	4.1×10^{13}	1.0×10^{13}

POWER
1 of 8 channels
MDAC | SAR | SC & DDPU & TX
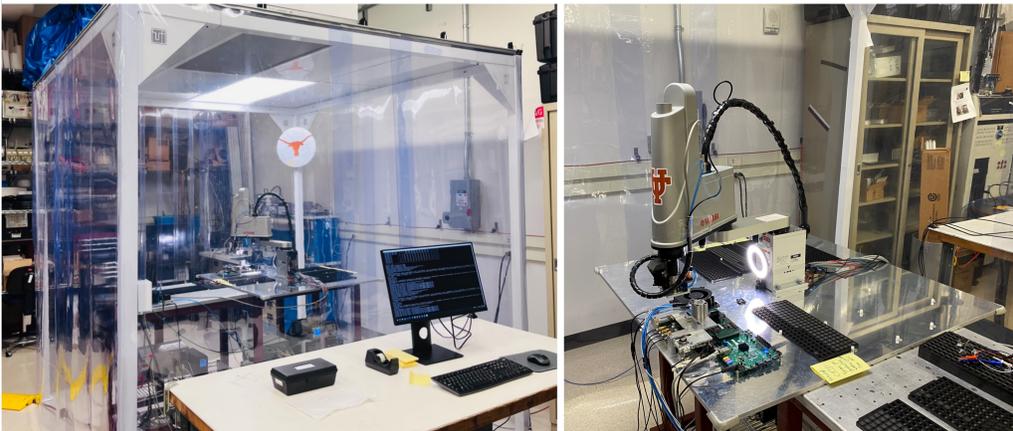PA/S | BGP & Biasing | Test Structures | I²C | lpGBT
CLK
POWER

- **Eight identical channels** consists of a **multiplying DAC (MDAC)** followed by a **two-stage pipeline SAR**.
- **Digital Data Processing Unit (DDPU)** combines SAR and MDAC bits and serializes the digital data at **640 Mbps per channel**.

Production Test Stand

Operational since June 2023 and tested 1000 pre-production chips

QA/QC Tests

1. **Dead-or-alive test**: measure chip health and **ability to configure and readout all channels**.
   - Quick evaluation of chip performance to discard dead or not functional chips.
2. **Performance test**: detailed series of **analog measurements** to evaluate **chip performance and assign chip grade**.
   - Measure the chip communication, chip power, and analog performance for each of the eight channels.
   - Determine calibration for each channel and evaluate the calibration constants against the ideal constants.
   - Measure calibrated channel baseline mean and width, sine wave performance, and INL/DNL.
- Chip graded into **three categories**: "**meets specs.**", "**does not meet specs.**", "**not functional**".

Preliminary Testing Yields
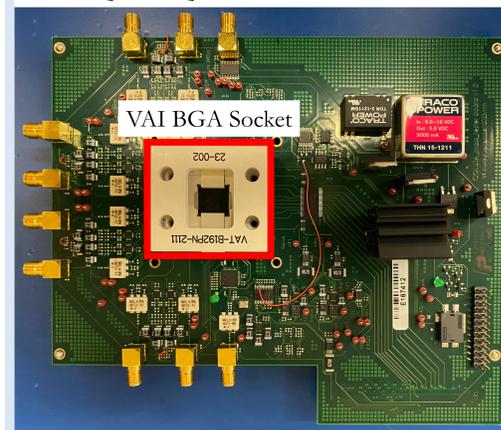

Production Testing

- **COLUTA ADC packaged in a 196-ball BGA package.**
- Perform **quality assurance and quality control (QA/QC)** for **80,000 COLUTA ADC chips** to be installed on **1524 on-detector front-end boards.**
- Built an **automated, robotic test setup to perform QA/QC testing.**
- **Custom test board with identical analog inputs** to measure uniformly the ADC performance.
- **Chip performance** evaluated using a **series of analog and digital measurements.**
- **Chip performance** and **QA/QC results** archived in an **online, CERN database.**

- **Each chip takes 5 minutes to test.**
- **Tested 1000 pre-production chips with first version of the QA/QC testboard.**
- **Observe >90% yield with optimal test conditions.**
- **Shipped 500 tested chips to be installed on prototype front-end boards.**

- **Designing second version of the QA/QC testboard** based on results from first round of QA/QC testing.
- **QA/QC testboard v2 will improve uniformity of analog input.**

QA/QC Testboard v1
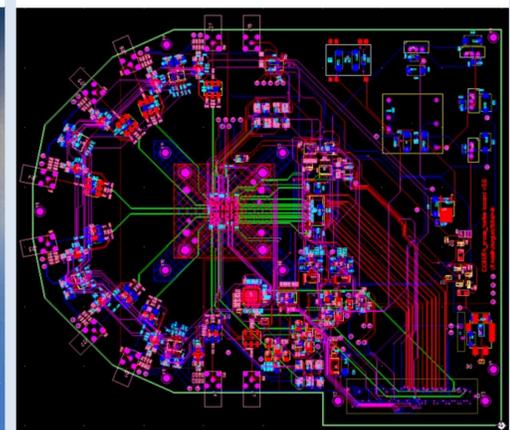

VAI BGA Socket

### Testboard v2 Schematic

Radiation Testing

- Measured **radiation hardness** of the **pre-production COLUTA chips**.
- Irradiated **five chips** with **226 MeV proton beam** at the Massachusetts General Hospital at Boston.
- Monitored the **chip health, communication errors, and single-event upsets (SEUs)** in the output digital data.
- **Each chip was irradiated beyond the required HL-LHC dosage. Exceed radiation tolerance requirement for each chip.**
- **Observe no latchups or single-event functional interrupts for any chip over the total irradiated dosage.**
- **Observed number of SEUs proportional to the instantaneous proton dose.**
- Count number of instances where the ADC configuration mismatched the expectation. **Measure the cross sections of the triple-redundant and single bit flips (DFF).**

$$\sigma_{\text{config}} = (2.27 \pm 1.31) \times 10^{-18}\,\text{cm}^2/\text{bit} \qquad \sigma_{\text{DFF}} = (4.20 \pm 0.03) \times 10^{-10}\,\text{cm}^2$$

$$\sigma_{\text{SEU}} = (1.37 \pm 0.07) \times 10^{-10}\,\text{cm}^2/\text{channel}$$
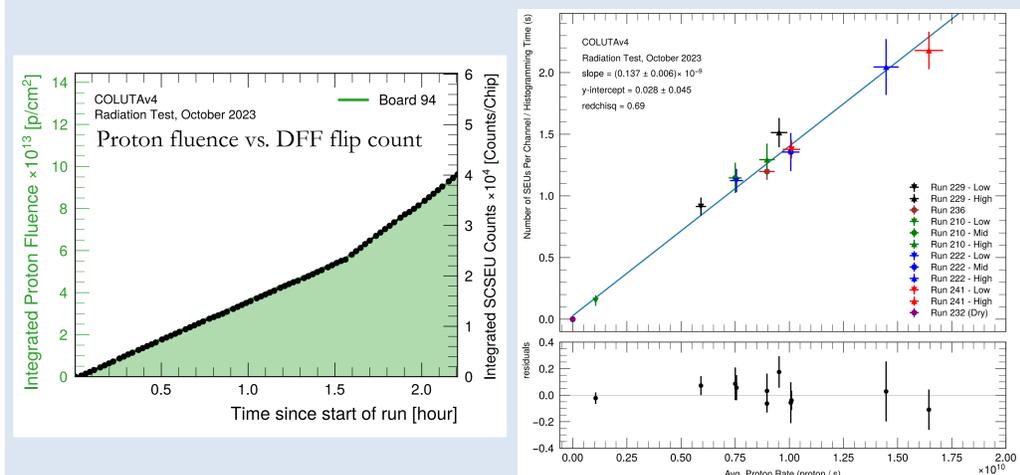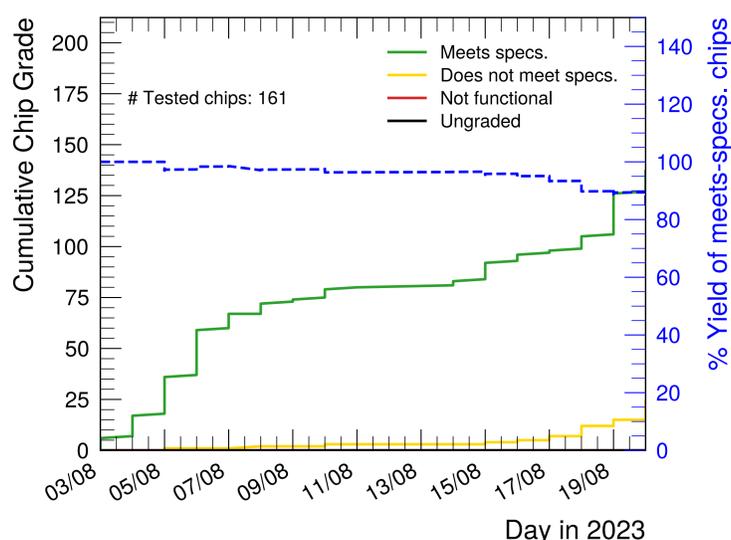
References

[1] ATLAS Collaboration, ATLAS Liquid Argon Calorimeter Phase-I Upgrade Technical Design Report, CERN LHCC-2013-017, ATLAS-TDR-022

[2] ATLAS Collaboration, The ATLAS experiment at the CERN Large Hadron Collider, JINST 3 (2008) S08003

[3] ATLAS Collaboration, LAr ADC: Specifications Document for HL-LHC, ATL-COM-LARG-2020-001

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