Performance of full System Tests for the ATLAS Inner Tracker Strip Detector.

Overview and results from the System Test at DESY

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On behalf of the ITk Strip End Cap System Tests Community

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HELMHOLTZ

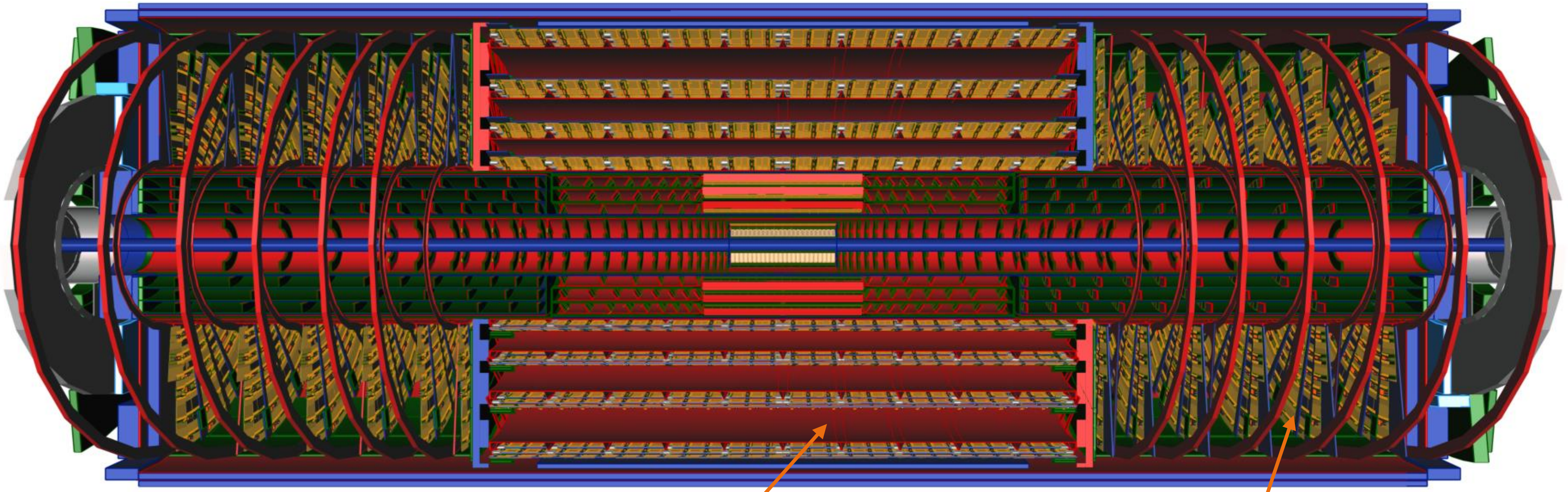
Introduction

The ATLAS Inner Tracker

A new silicon strip detector for the HL-LHC phase

- Current ATLAS Inner Detector (ID) will be replaced by a new Inner Tracker (ITk)
  - All-silicon detector solution
  - Better performance in harsher conditions
  - More readout channels
  - Better spatial resolution
  - Higher radiation tolerance
  - Lower material budget

ATL-PHYS-PUB-2021-024



17,888 sensors

165m^2 of silicon

60 million strips

Dose up to 50 MRad

ITk Strip *Barrel*

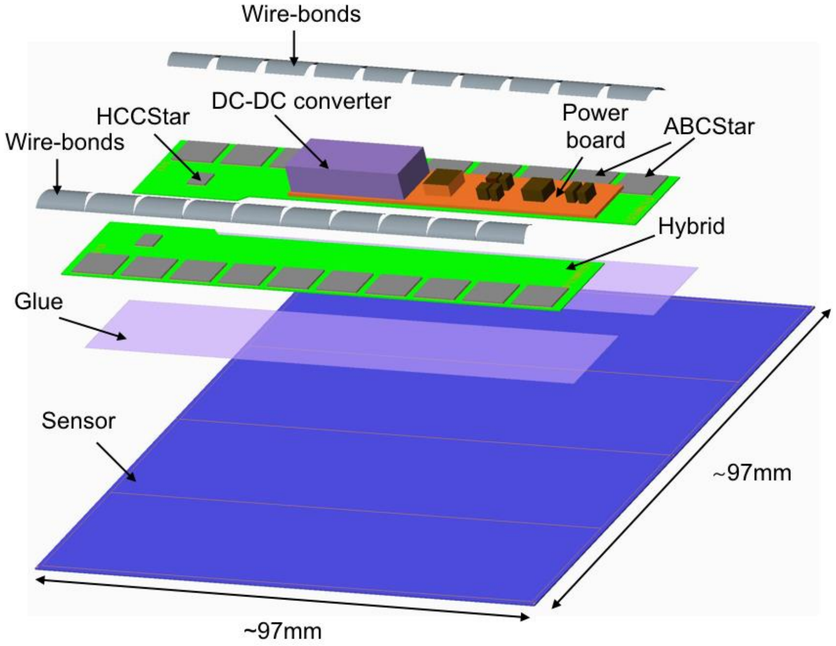
ITk Strip *End Cap*

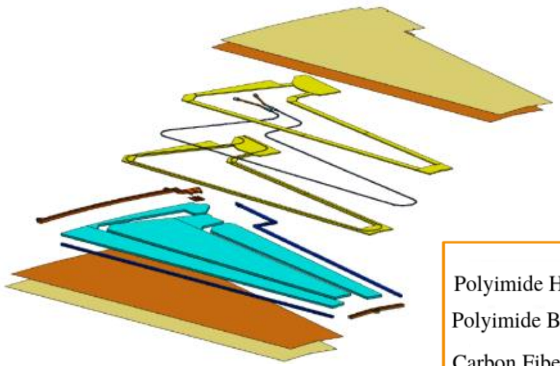
ATL-TDR-025

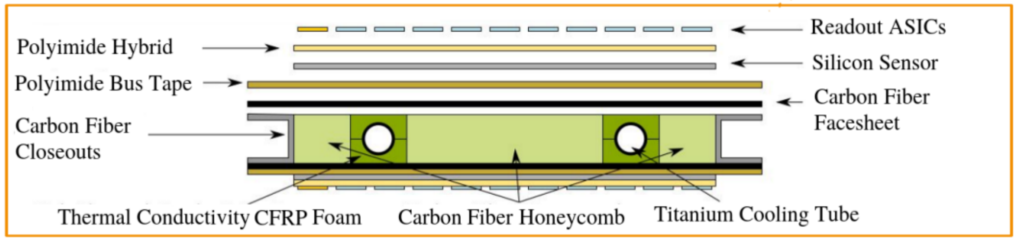
Overview of the Detector Concept

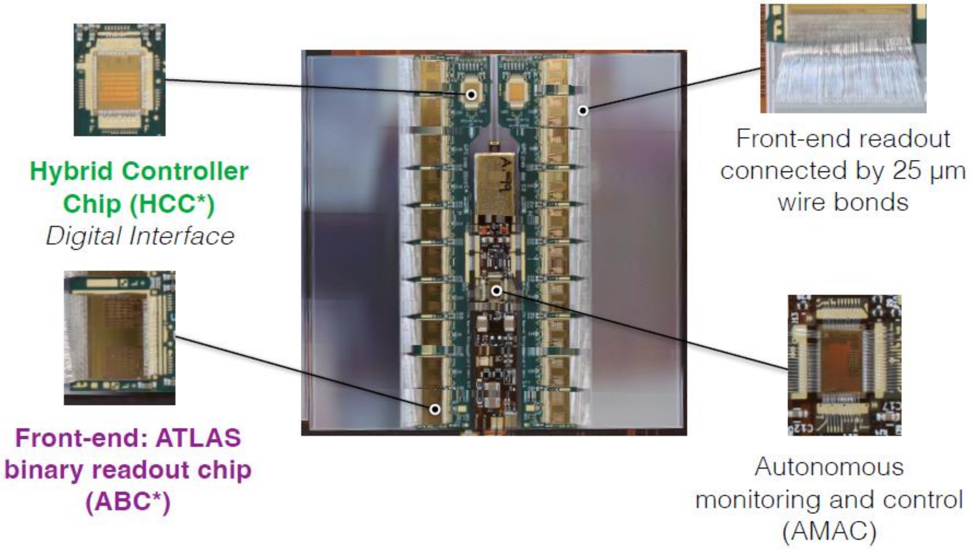
Silicon strip detector modules

- Silicon strip detector module consists of
  - n^{+}-in-p silicon **strip sensor**
  - Glued on PCB with readout chips (**“hybrid”**)
  - Glued on PCB with power control (**“powerboard”**)
  - Connections via **wire bonds**
  - Different types/shapes depending on location in the detector
  - Modules are directly glued on local support structures **(“cores”)**



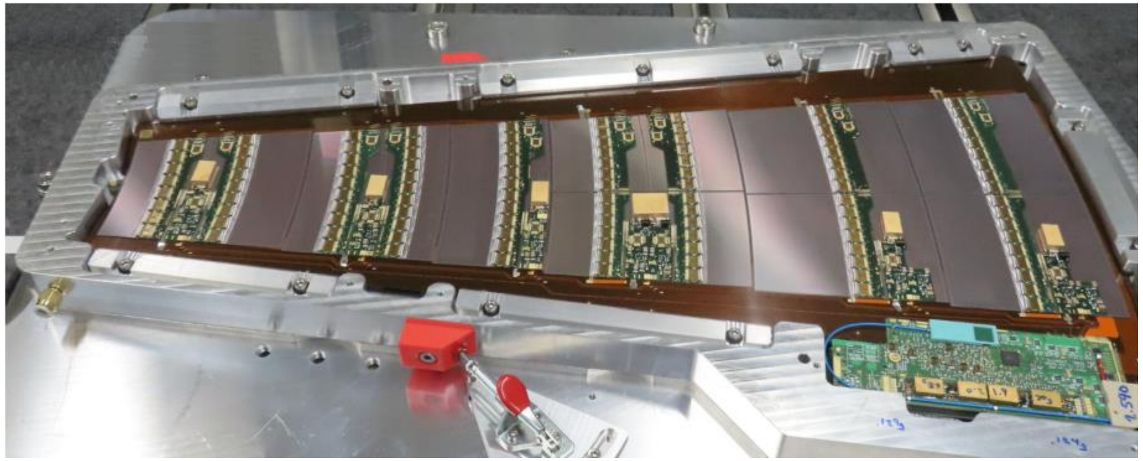


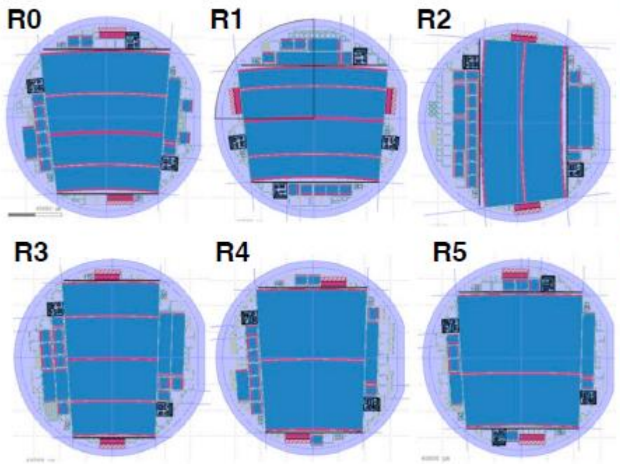


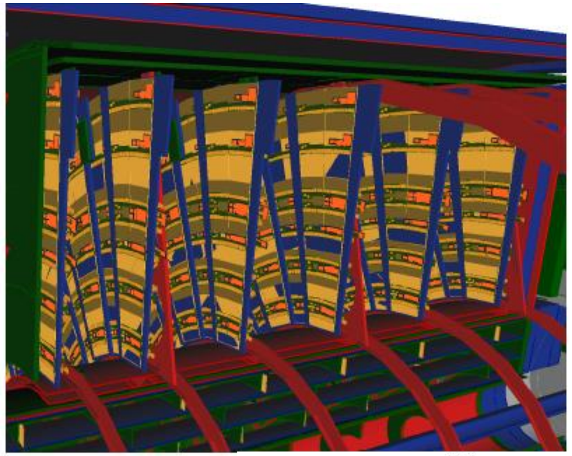


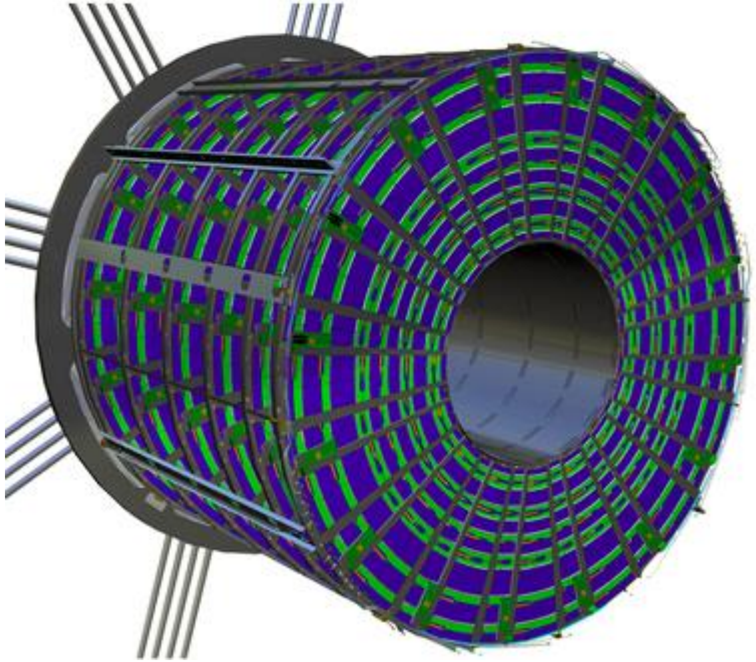
Overview of the detector concept

Petals as building blocks of the end caps

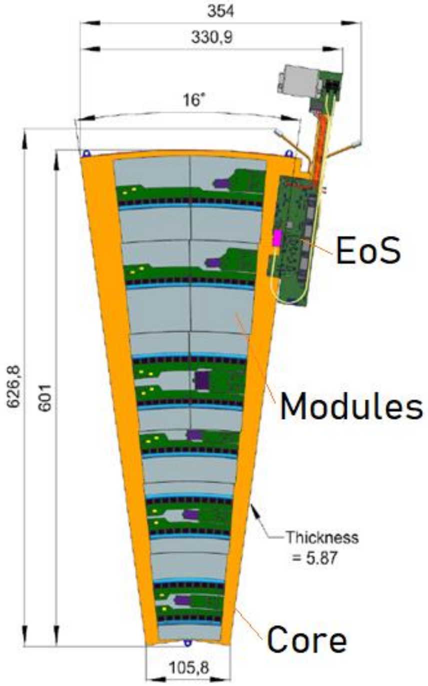








- Main building blocks of the strips end-cap detector are the **petals**
  - Core loaded on both sides with 6 modules (9 silicon crystals) – R0 to R5
  - **End-of-substructure (EoS)** board as off-detector
- **Global support** structure providing mechanical support and connections to the services
  - Arranged in six disks, each disk populated with 32 petals



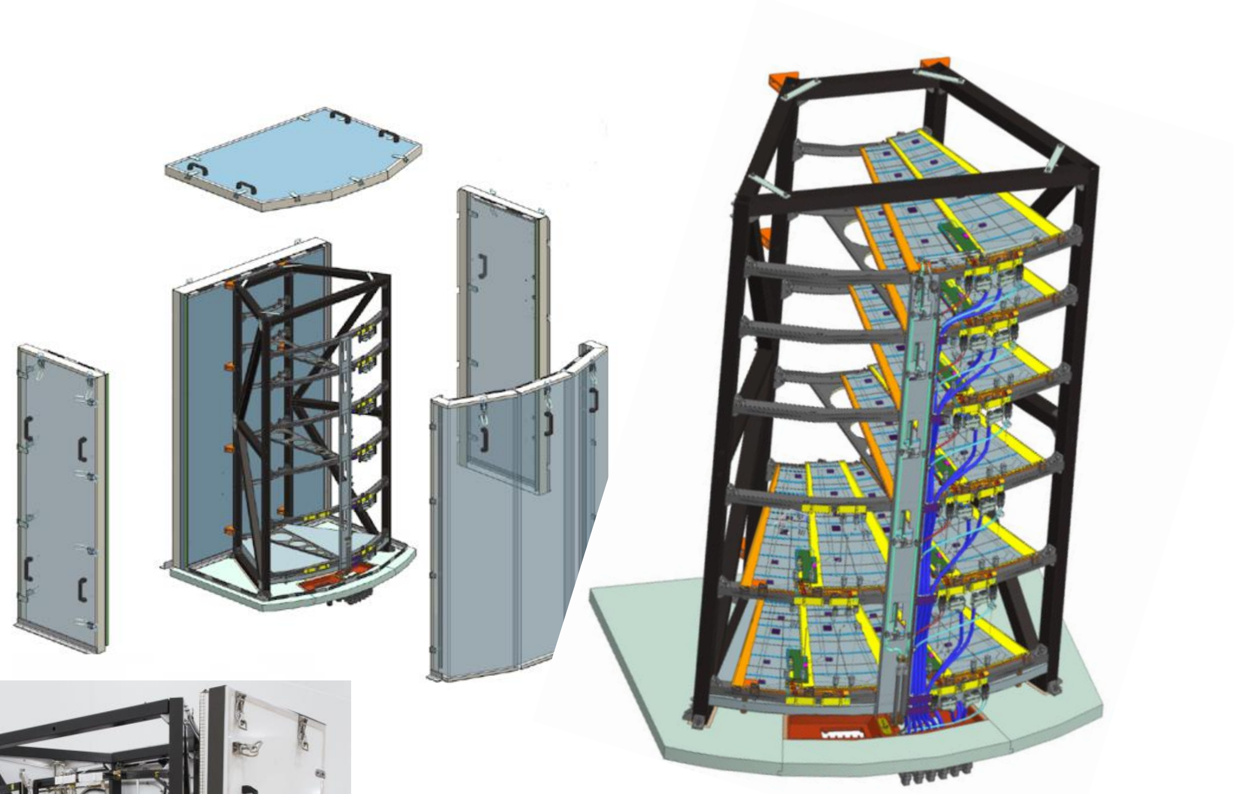
ITk Strips EC System Test

ITk Strips End Cap System Test

An overview

ATLAS ITk Strips System Test

- ⅛ section of carbon fibre end cap structure
- Testing up to 12 petals in realistic conditions
- Petals are supplied with real ITk services (CO_2 cooling, PSUs, DAQ, …)
- Detector volume enclosed by aluminum-foam composite plates and flushed with dry air
- LUCASZ cooling plant attached to reach up to -35 °C

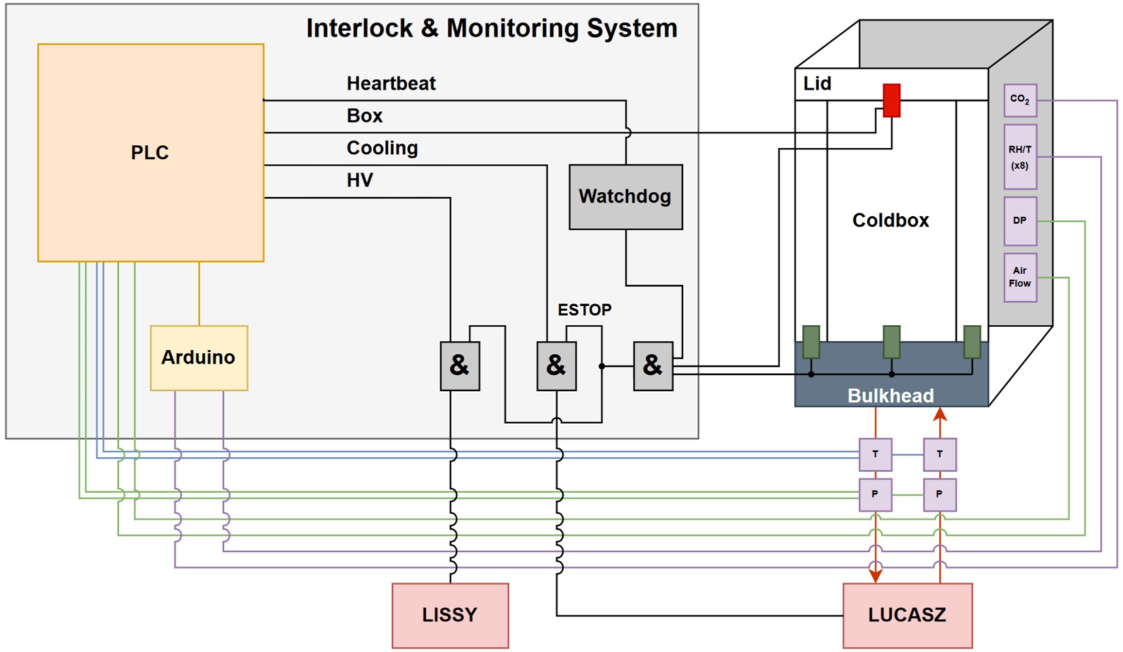


Interlock & Monitoring System

System Test Instrumentation

Interlock & Monitoring System (IMS)

- Cold petals are at risk if humidity enters the coldbox volume
- People could be endangered by the sensor HV
- Developed an interlock system for the System Test using industrial off-the-shelf components
- System decides when to open coldbox and turn on HV and cooling
- Web interface to see sensor/interlock monitoring data
- Also to be used during end cap integration



Interlock Connection Box (DESY)

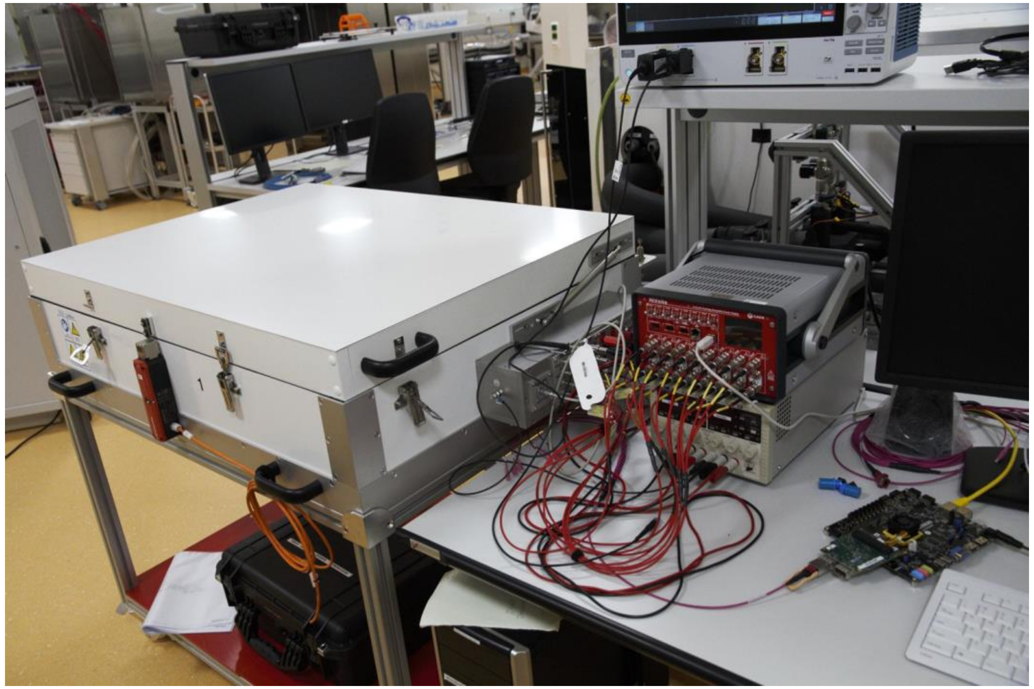
IMS

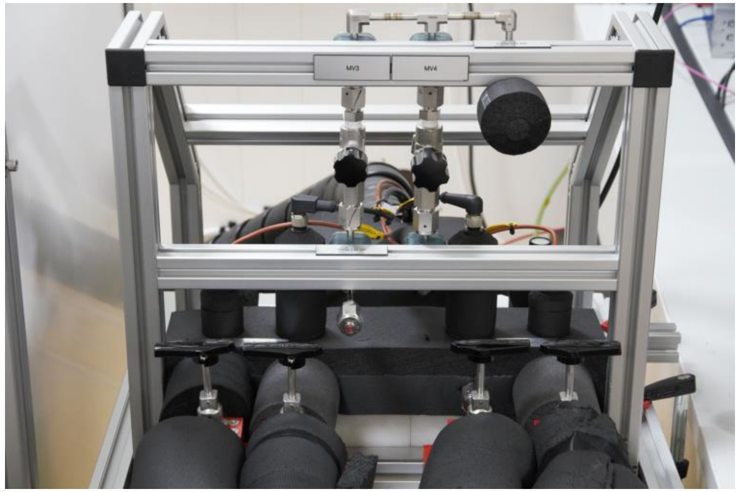
Petal Coldbox

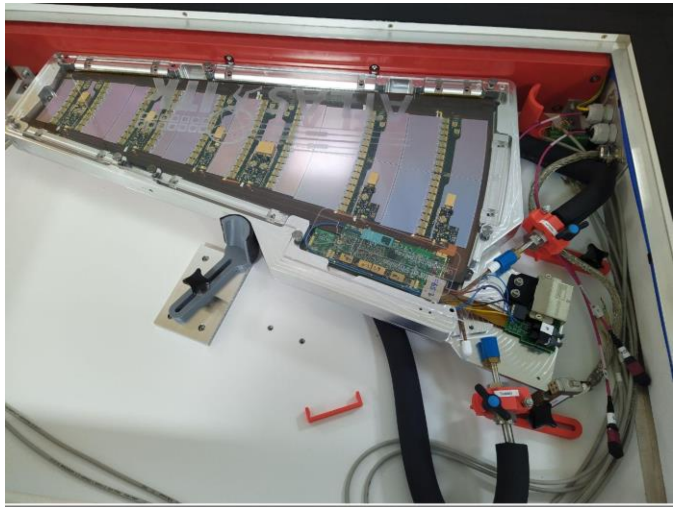
Testing single petals

Petal Coldbox for End Cap Integration

- Testing a single petal with CO_2 cooling (MARTA)
- Used for testing loaded petals before insertion into the end cap
- For petal pre-production: Commissioning the coldbox, performing extensive studies of the readout and noise behaviour







Petal Noise Studies

Threshold Scan

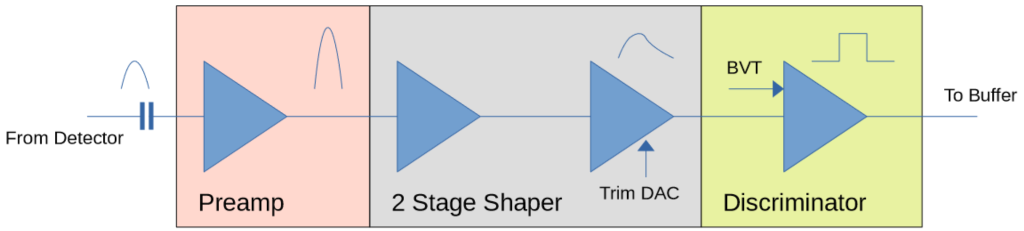
The fundamental measurement with the petal

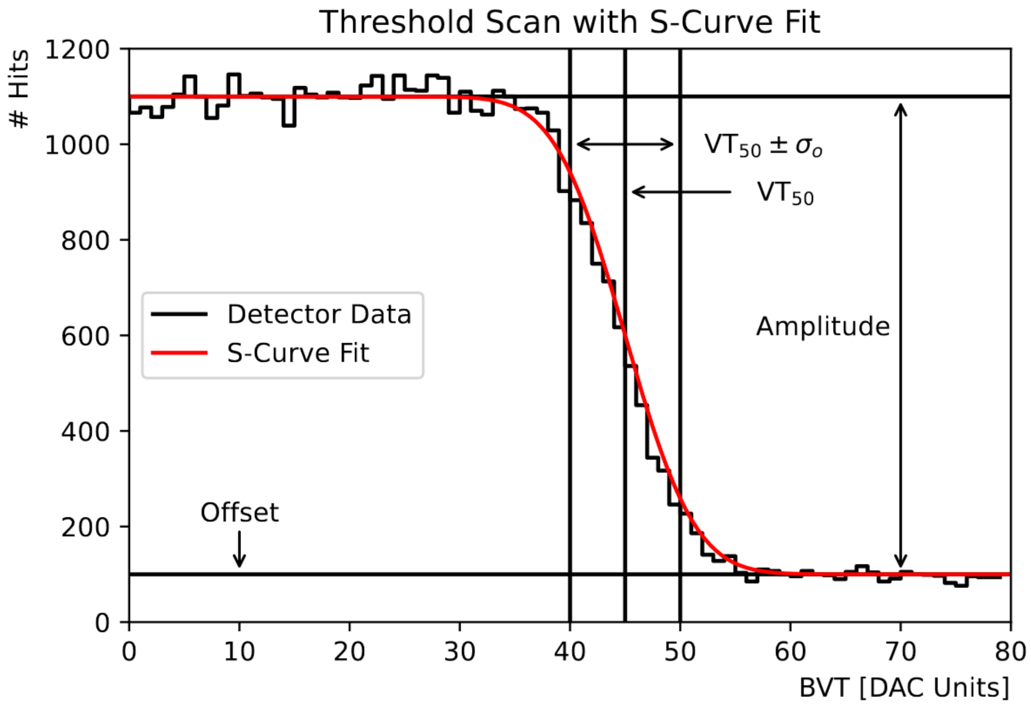
Readout Principle

- Charge signal from sensor gets digitised using a discriminator and a "threshold" voltage BVT
- Changing BVT affects sensitivity and noise

Threshold Scan

- With a known input signal/charge, scan different values of BVT
- The resulting "S-Curve" lets us know the channel threshold VT_{50} and the output noise σ_o



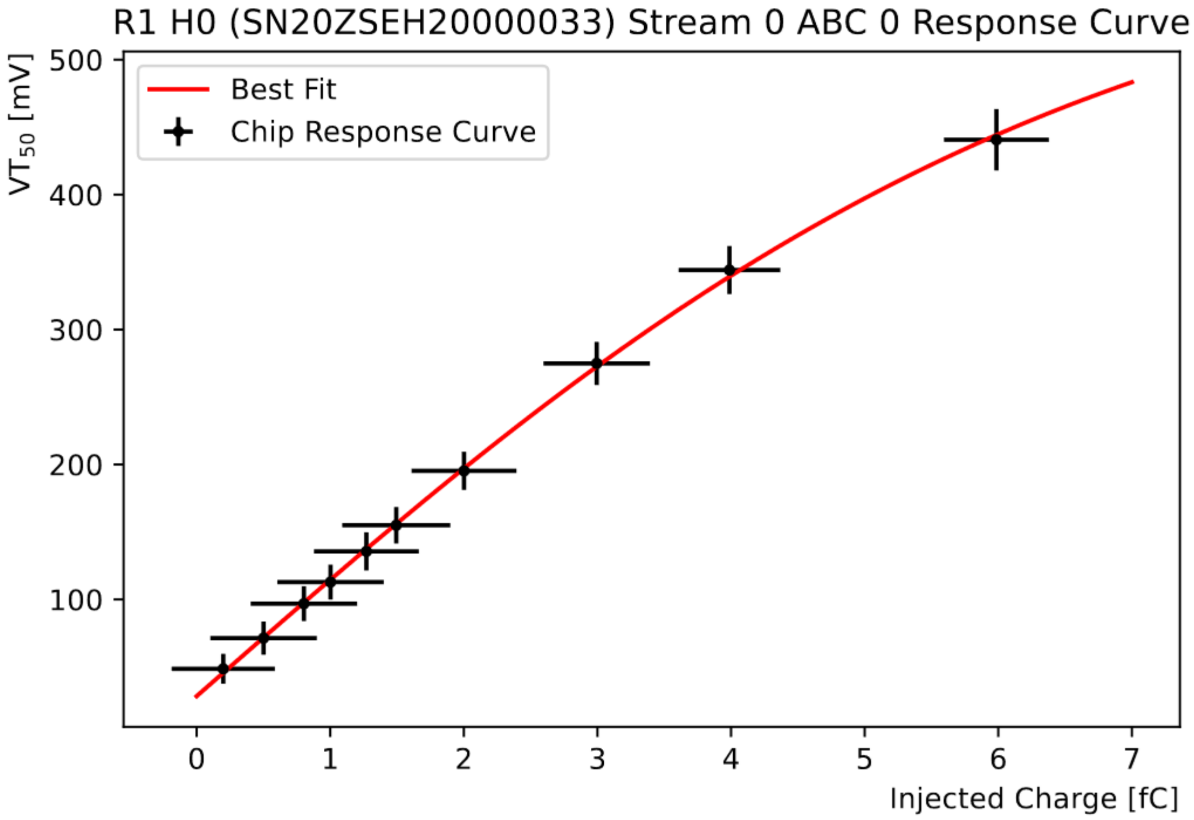


Response Curve (and 3-Point Gain)

Measuring detector noise

Response Curve Scan

- Perform threshold scans for multiple injected charges
- $VT_{50}(q)$ is fitted with a model function
- The detector gain G is defined as the slope of this curve
- ENC (Equivalent Noise Charge) is calculated as $ENC(q) = \sigma_o(q) / G(q)$ (convention q = 1 fC)
- The ENC is also called the “input noise”, since the digitisation effect has been divided out

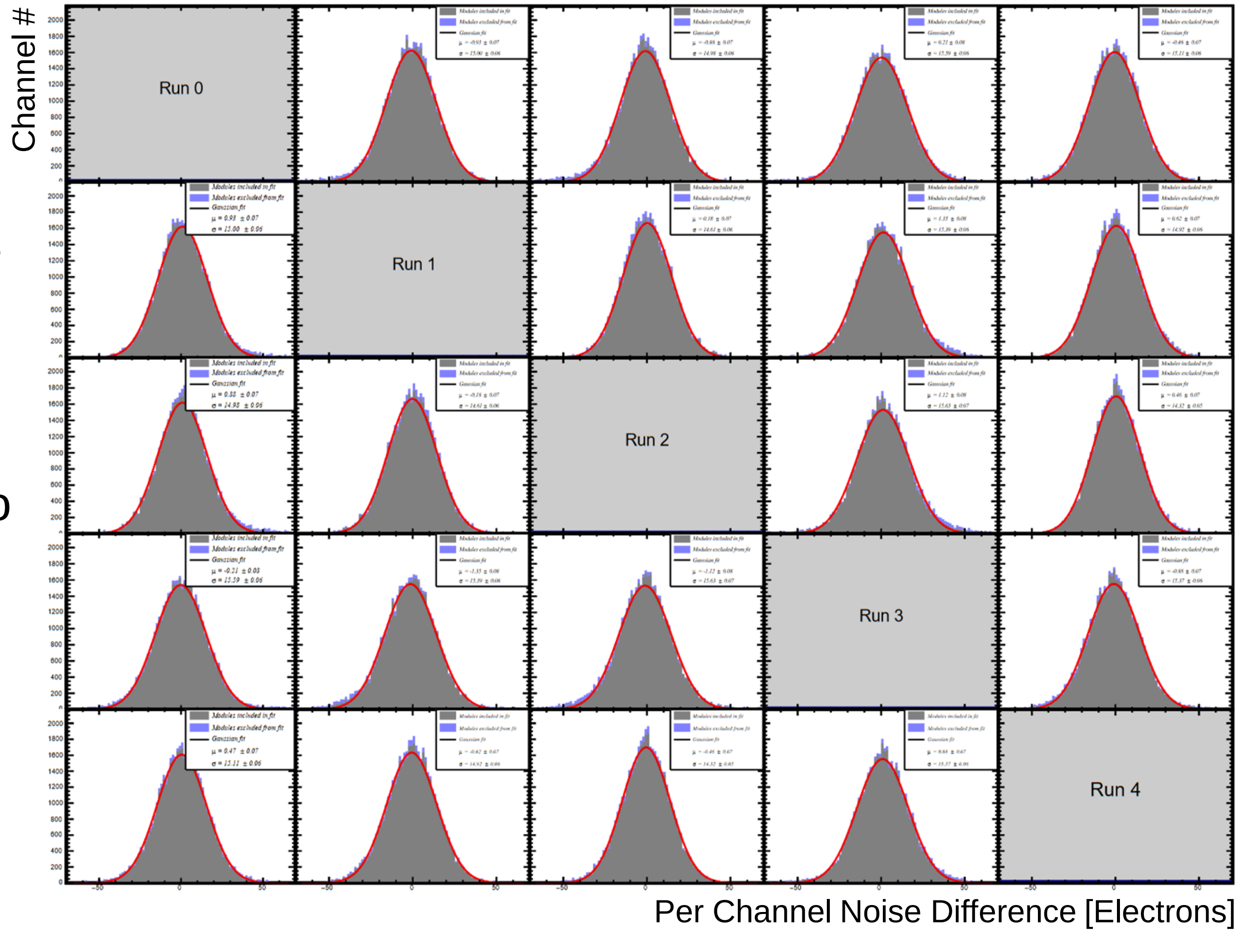


Repeatability

How good are these measurements?

Input Noise Values

- Take a full test of the petal five times in a row
- Compare the per-channel differences in input noise for all combinations of runs
- The histograms of differences are gaussian
- The per strip measurement uncertainty evaluates to just 15 e^-
- The mean absolute deviation of the distribution means is below 1 e^-

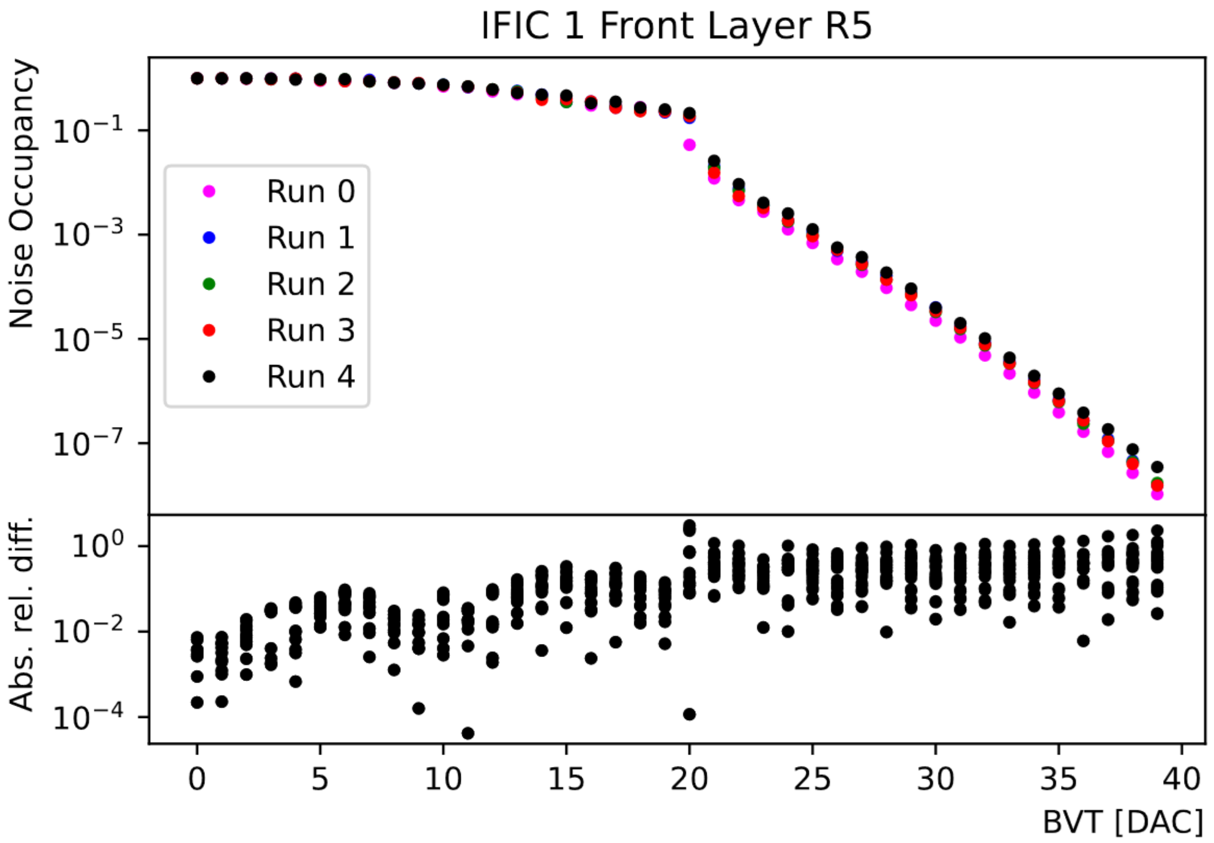


Repeatability

How good are these measurements?

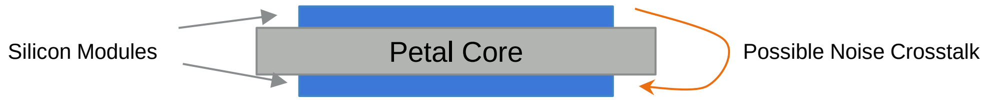
Noise Occupancy Curves

- A noise occupancy curve is just the threshold scan without any injected charge
- Results from five different runs were compared
- Important: NO < 1% (“Operating window”)
- No significant differences in the operating window where found between runs



Noise Crosstalk

Do petal sides talk to each other?



Crosstalk

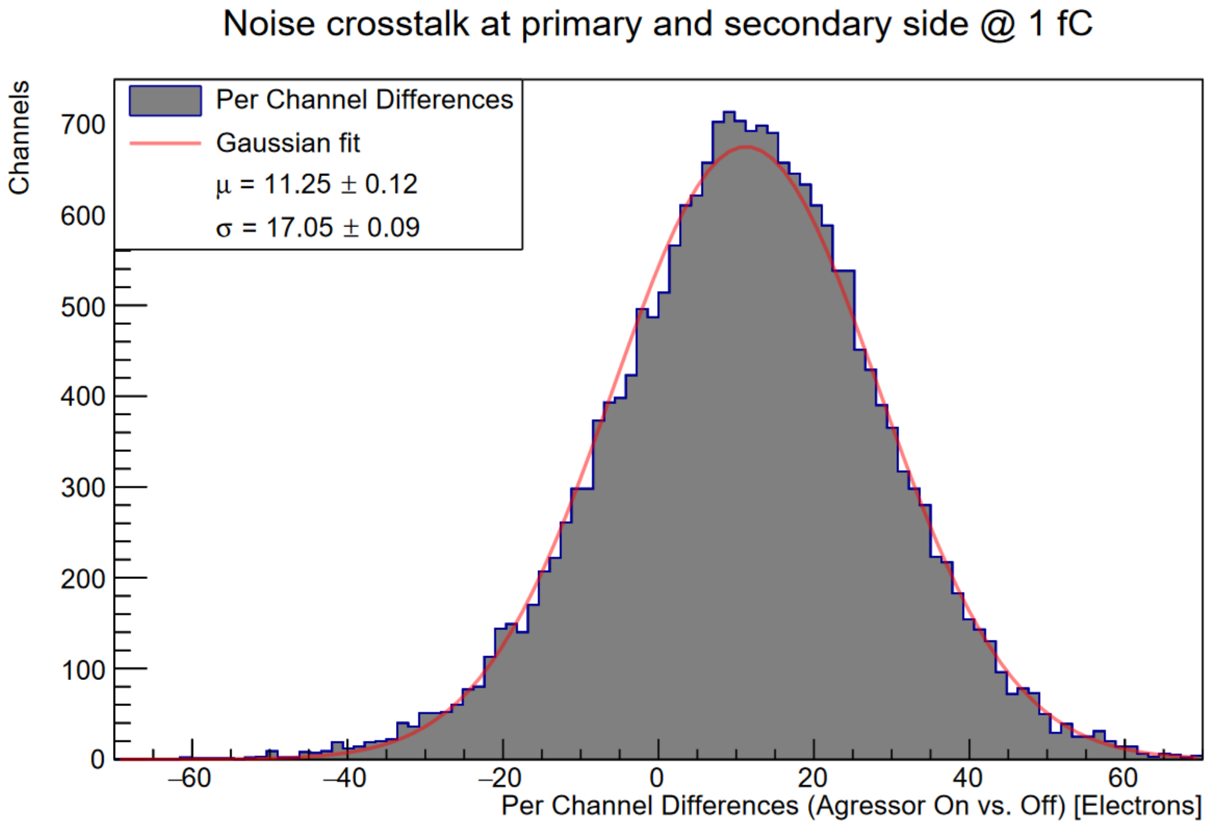
- Module noise could be influenced by electromagnetic interference
- A possible source: modules on the opposite petal side

Measurement

- Take noise data with one side powered off
- Compare to data with both sides powered on

Results

- Noise crosstalk between petal sides is about 11 e^-



Cosmic Muons at the System Test

Experimental Setup

Detecting cosmic particles

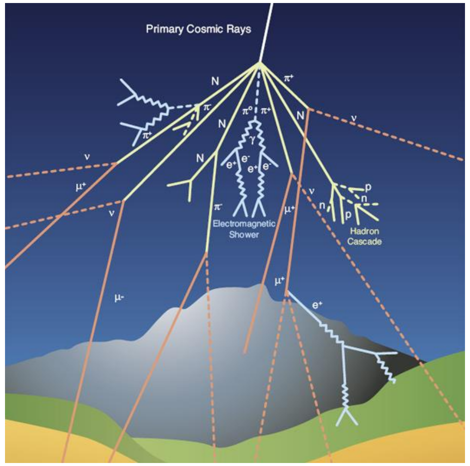
Cosmic Muons

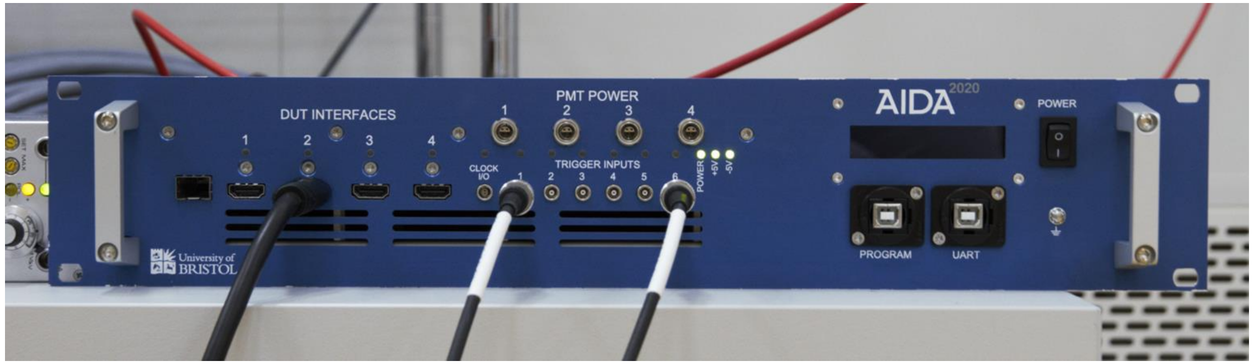
- High energy particles from cosmic sources are hitting the atmosphere
- The resulting cascade produces pions, which decay into muons
- These “cosmic” muons are present everywhere on earth (~ 1 / cm² / minute)

Trigger System

- Large external trigger szintillator placed above and below the System Test coldbox
- AIDA 2020 TLU used to generate trigger signals for ITSDAQ

[cds.cern.ch/images/CMS-PHO-GEN-2017-008-1]





Trigger Latency

How “slow” is our trigger signal?

Trigger Latency

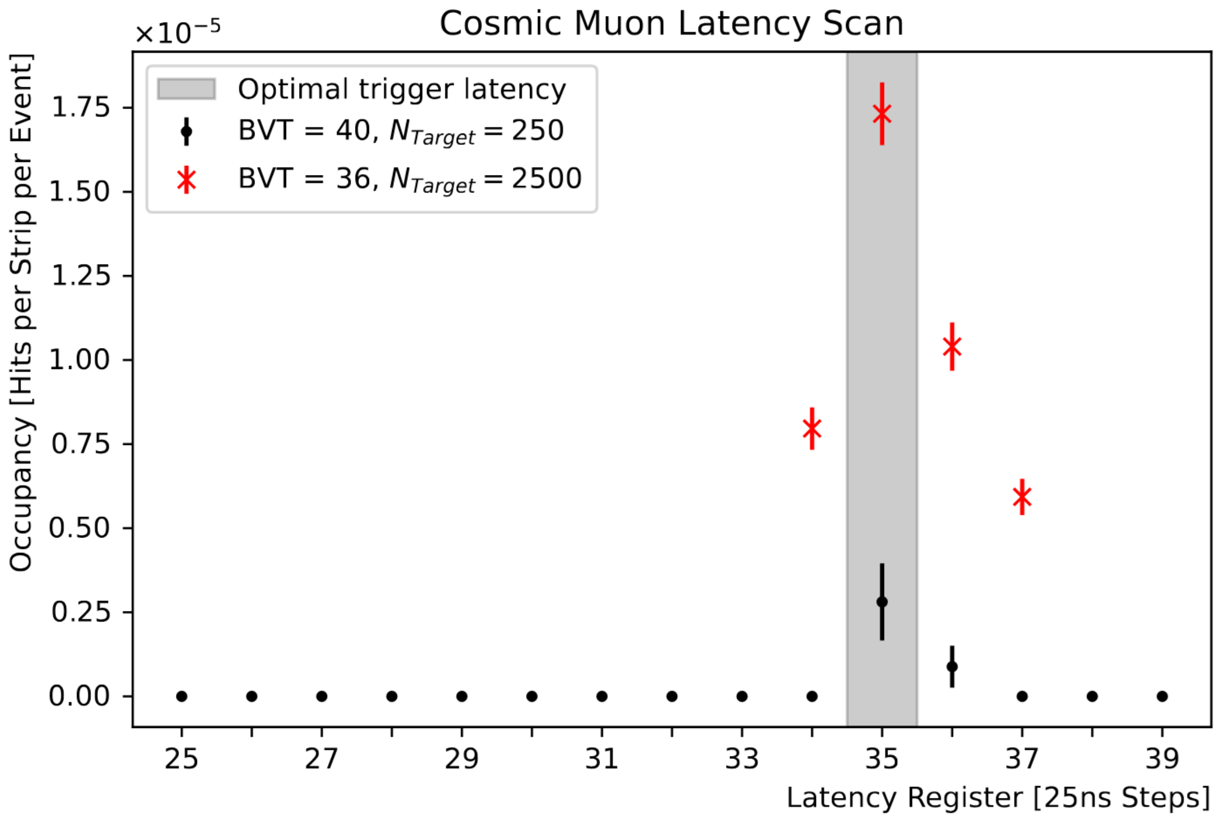
- Signal formation and processing in the trigger setup takes time
- When the trigger signal arrives, the muons are “long gone”
- 512 events (25 ns each) are stored in the buffer for 12.8 µs

Measurement

- Vary the latency between signal and trigger
- Take data at two different thresholds

Results

- Optimal threshold setting of BVT = 35 · 25 ns



Measuring Cosmic Muons

A real particle signal with the ITk Strips Petal

Setup

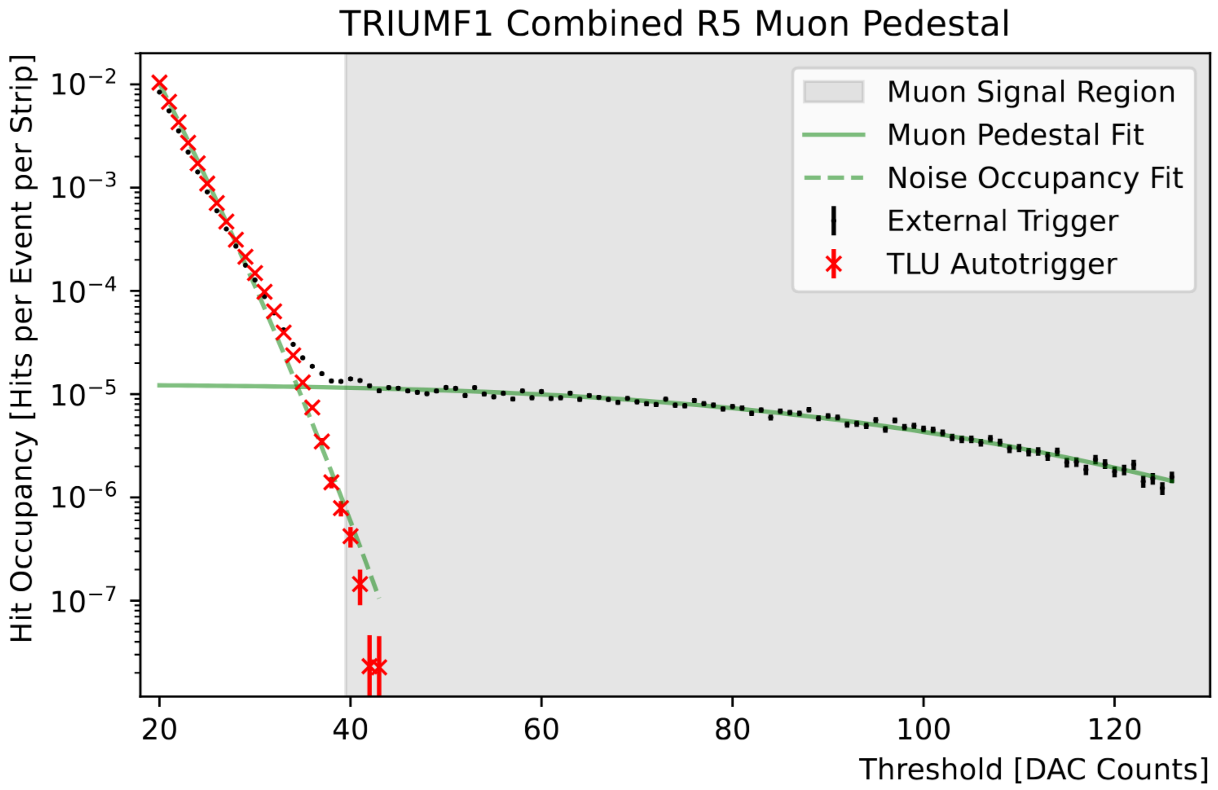
- TRIUMF1 petal in the system test with 0 °C CO_2 cooling

Measurement

- Take threshold scan with uncorrelated TLU “autotriggers” at 500 Hz
- Perform the same measurement with the external trigger signal (~ 0.6 Hz)

Results

- Hit occupancy matches well between runs at low thresholds
- Higher threshold exhibit a clear plateau caused by the muons



Conclusion

Conclusion and Outlook

Where we are, where we want to go

Setup

- Completed System Test setup with realistic electrical and cooling services
- Sucessfully inserted and tested first petal in the ST cold box

Measurements

- Characterised the reliability of the ITSDAQ results
- Measured the P/S noise crosstalk on a single petal
- Got first cosmic muon signal during a latency scan
- Made a detailed measurement of the cosmic muon signal in a threshold scan

Whats next?

- Insert more petals into the System Test structure
  - Test readout with multiple objects
  - Measure noise crosstalk between layers / discs
- Take cosmic muon data with multiple petals
  - Check for correlations between discs
  - Perform tracking with cosmic muon data and compare to MC simulations
- Integrate ATLAS command and control software with the System Test
  - Testbench for real detector
  - Training device for new detector operators

Thank you

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