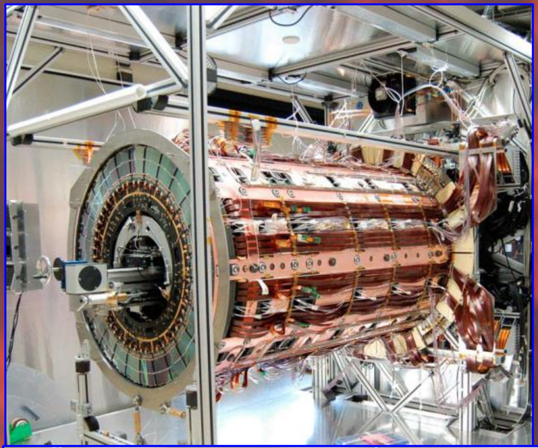
The Operation and Performance of the ATLAS Semi-Conductor Tracker in the 3 years covering 2010-2012
LS1 Activities, Lessons learned

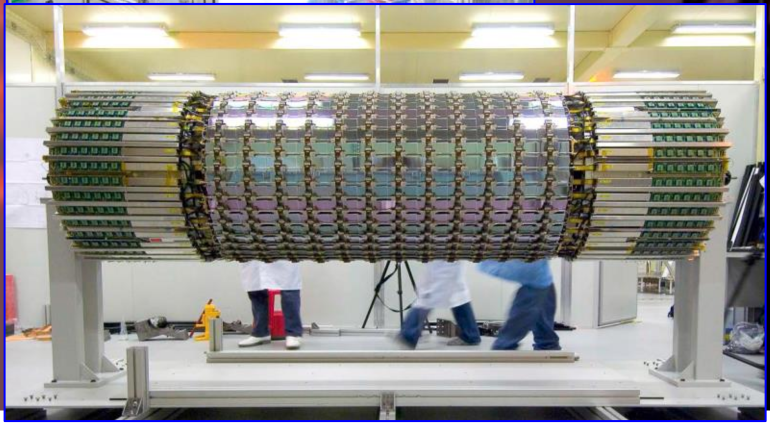


Steve McMahon

RAL

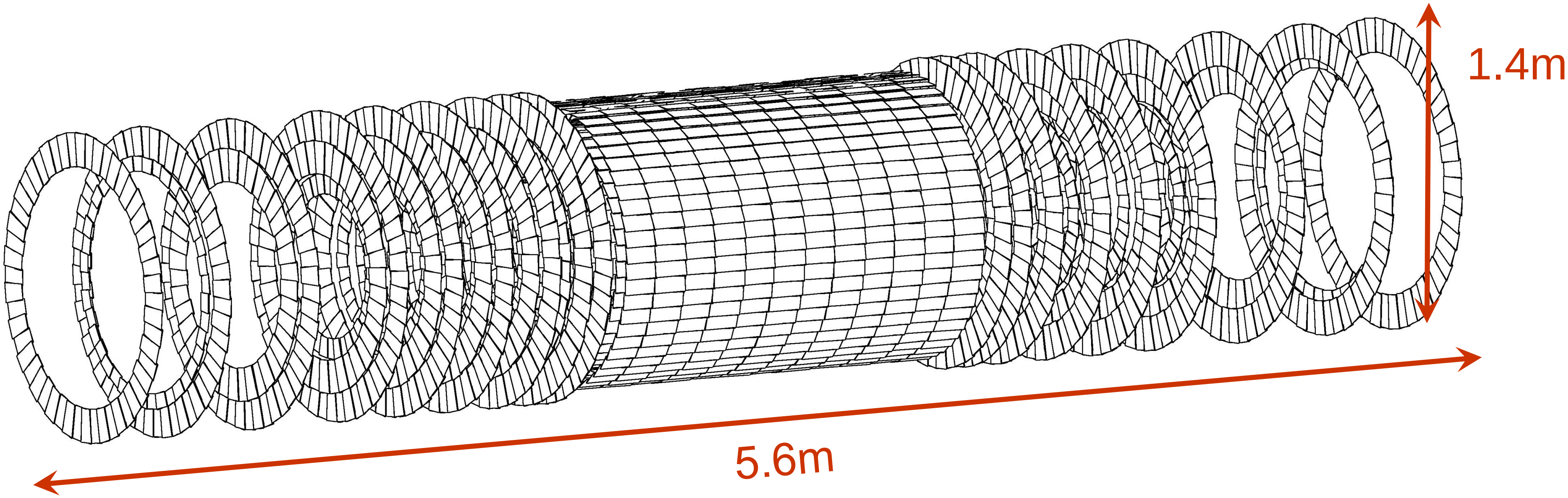
on behalf of the SCT

HSTD9-Hiroshima : 5th September 2013



The Semi Conductor Tracker (SCT)

- 61 m^2 of silicon with 6.2 million readout channels
- 4088 silicon modules in 4 Barrels and 18 Disks (9 each end) : $|\eta| < 2.5$
- 30cm < R < 52cm, space point resolution $r\phi$ ~16μm / R~580μm
- Designed for 700fb^{-1} integrated luminosity



- C_3F_8 Cooling (-7°C to +4.5°C silicon) to limit radiation damage
- Radiation hard: tested to 2×10^{14} 1-MeV neutron equivalent/cm^2
- Lightweight: 3% X0 per layer

The SCT Sensor Details

General

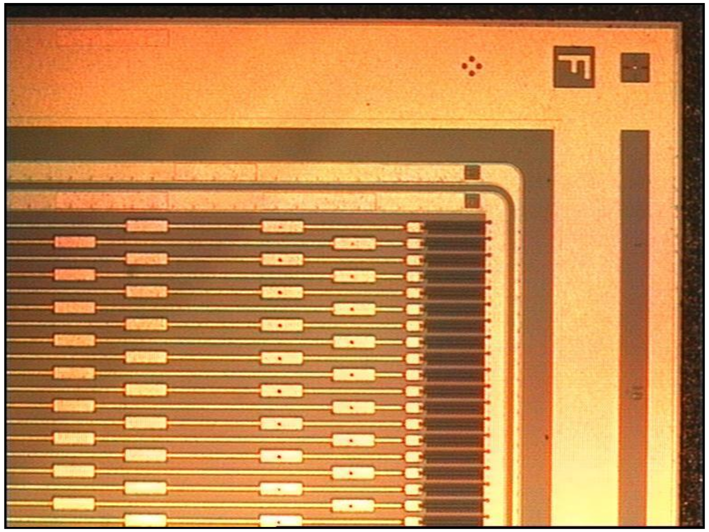
- Single sided p-in-n
- 285 μm thick
- 768 (6x128) + 2 : AC-coupled strips

SCT:Barrel

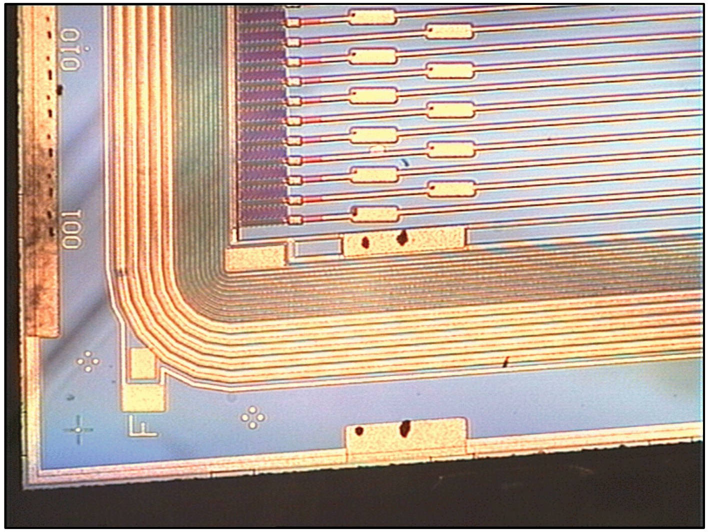
- 8448 sensors
- 8081 sensors with <111>
- 367 sensors with <100>
- 64.0 x 63.6mm
- 80μm strip pitch
- 100% supplied by Hamamatsu

SCT:End-Cap

- 6944 <111> wedge sensors
- 56.9 - 90.4μm strip pitch
- 5 "wedge types"
- 82.8% Hamamatsu
- 17.2% CiS (some oxygenated)

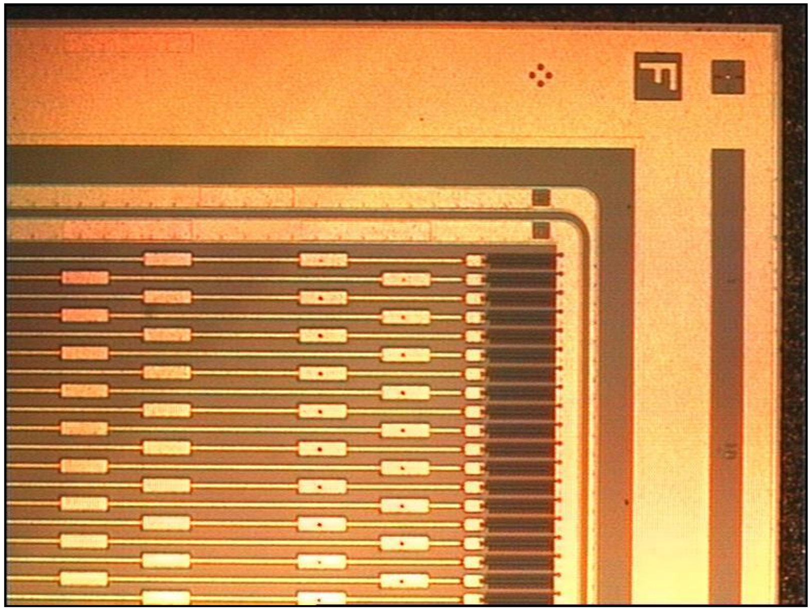


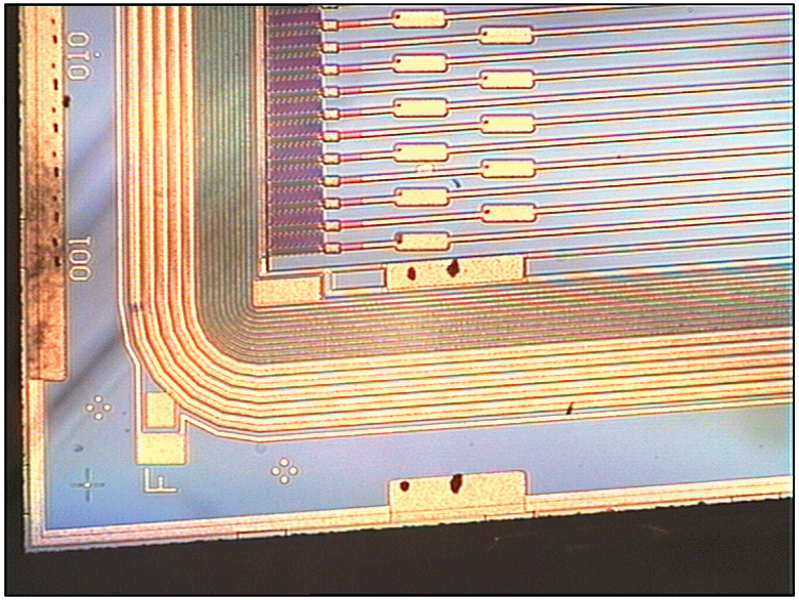
HPK-Barrel



CiS End-Cap

“Same specification, different species”

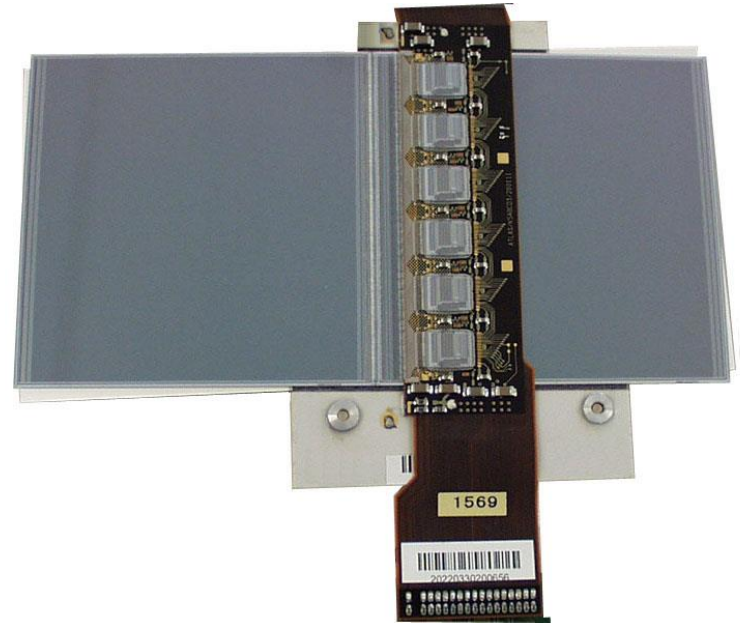




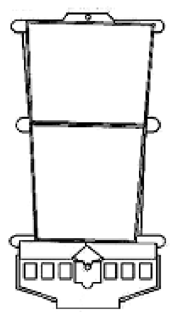
	HPK (left)	CiS
Bias Resistors (1.5MΩ)	Polysilicon	Implant
Strip metal/implant widths (μm)	20/16	16/20
Guard design	Single floating	Multi-guard

The SCT Modules

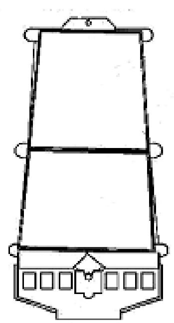
- Back-to-back sensors, glued to highly thermal conductive substrates for mechanical/thermal stability, wire-bonded to form ~12cm long strips
- 40 mrad stereo angle between strips on opposite sides
- 1536 channels (768 on each side)
- 5.6W/module (rising to ~9W after 10 yrs LHC)
- up to 500V sensor bias (nominal 150V)
- Readout by 12 rad-hard ASICs (binary hit-no-hit)



- 2112 barrel modules
- one shape



Outer module



Middle module

- 1976 end-cap modules
- 3 shapes

- Each module has its own HV and LV supply
- Multiple modules on single cooling loop

SCT Detector Configuration

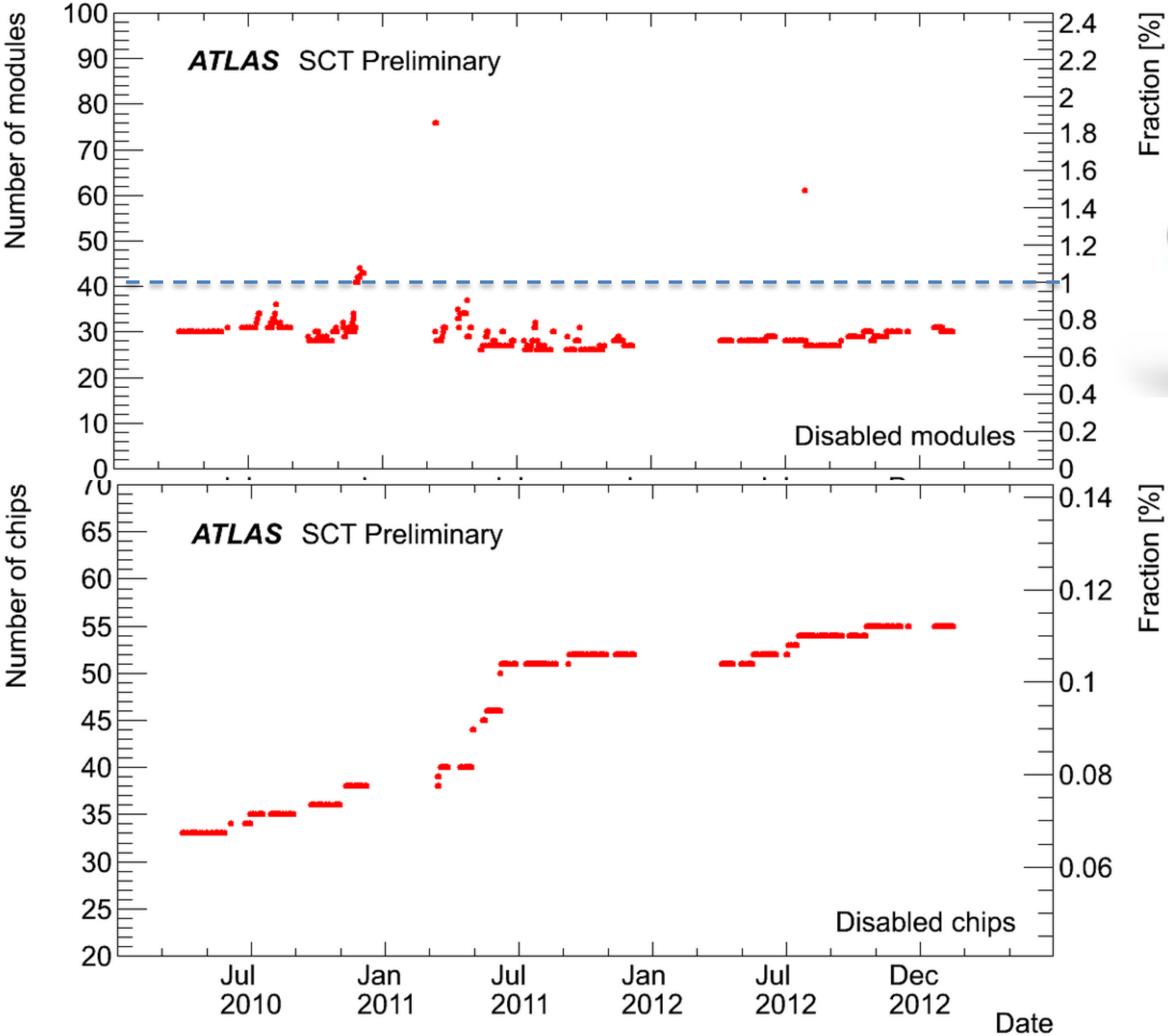
How many of the: modules, chips and strips are in the standard physics configuration and how stable are these numbers over time?

We put a lot of effort into operational stability and high up time.

Evolution of the Detector Configuration

Modules (4088)

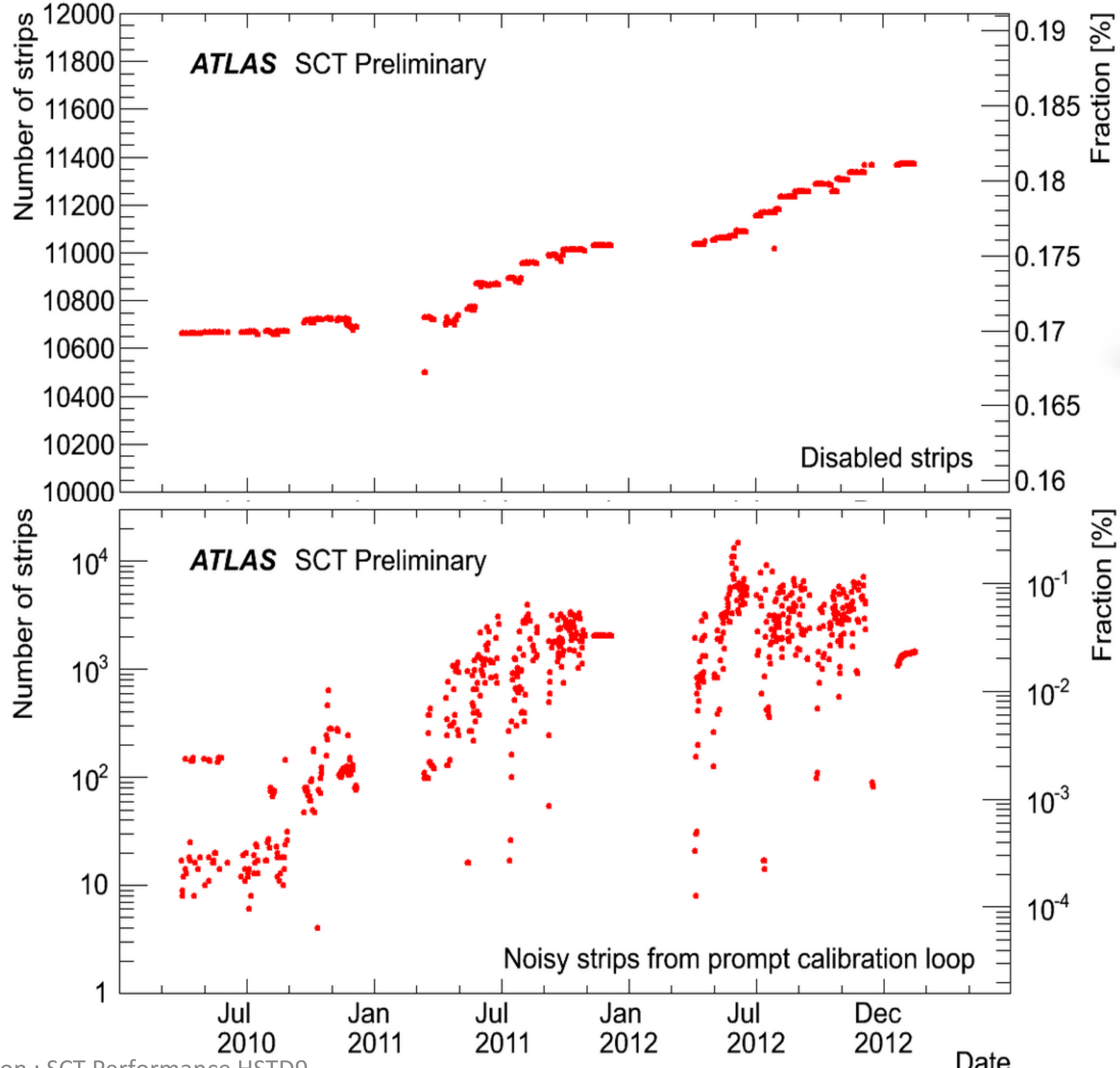
Chips (49,056)



Note the scale

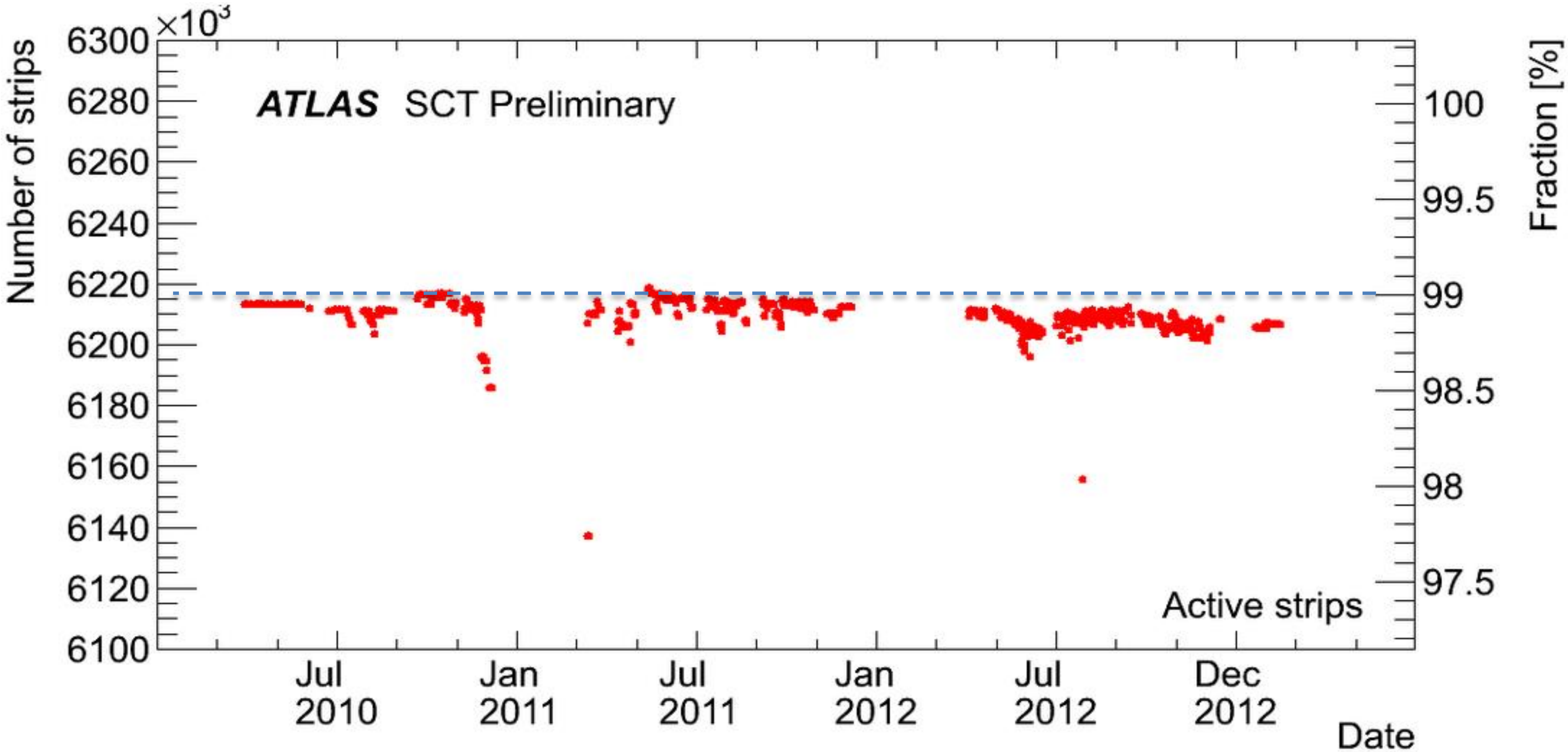
Evolution of the Detector Configuration - 2

Strips Dead and Noisy (6.3M)



Note the scale

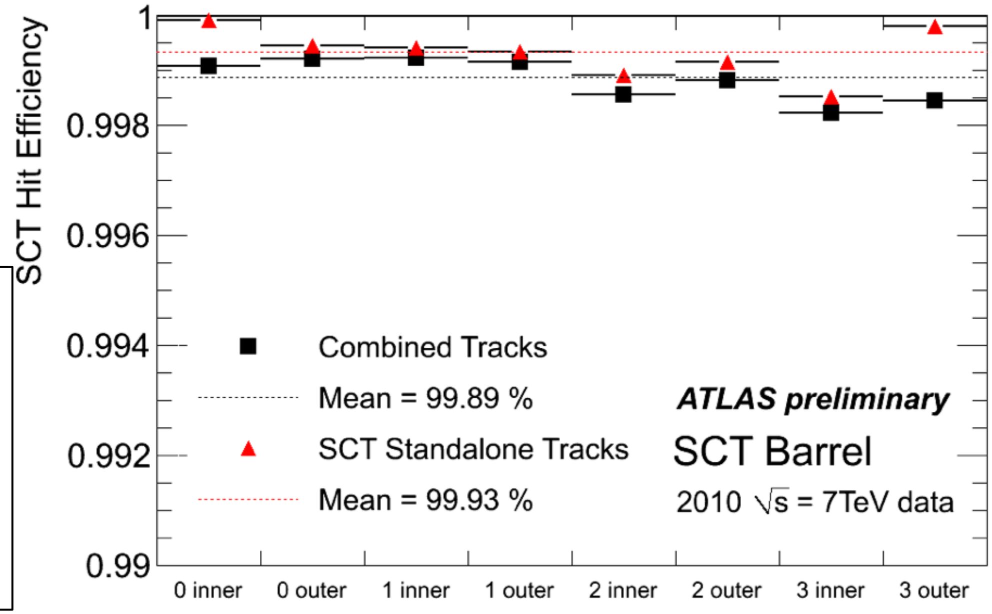
Number/Fraction of strips in the bulk event reconstruction : total 6.3M

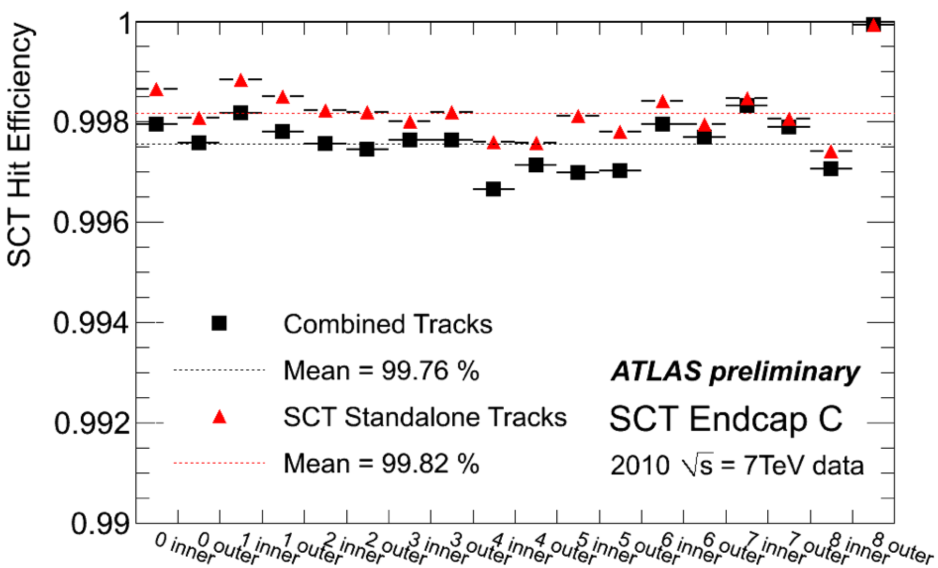


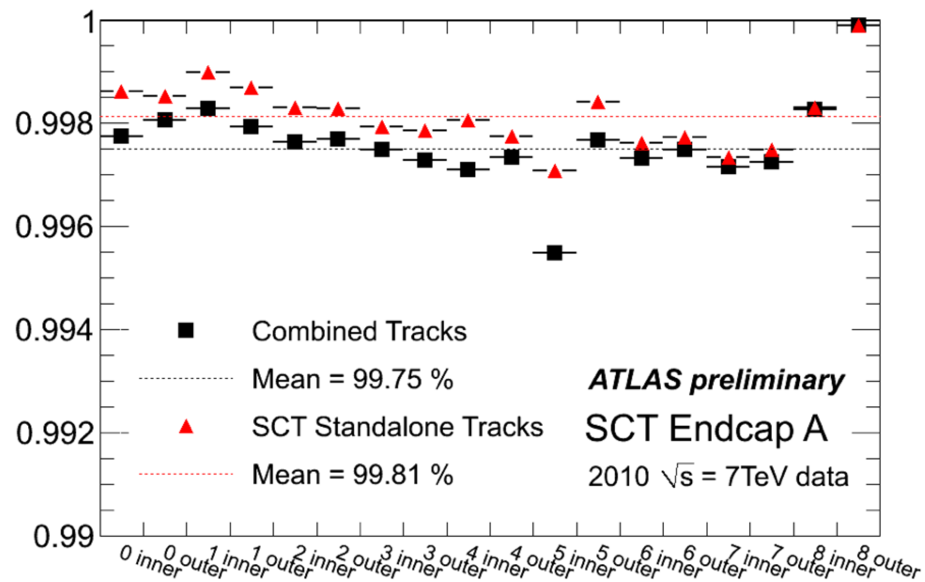
Without removing the masked noisy-strips we are above 99% throughout the 3 years

Intrinsic Hit Efficiency

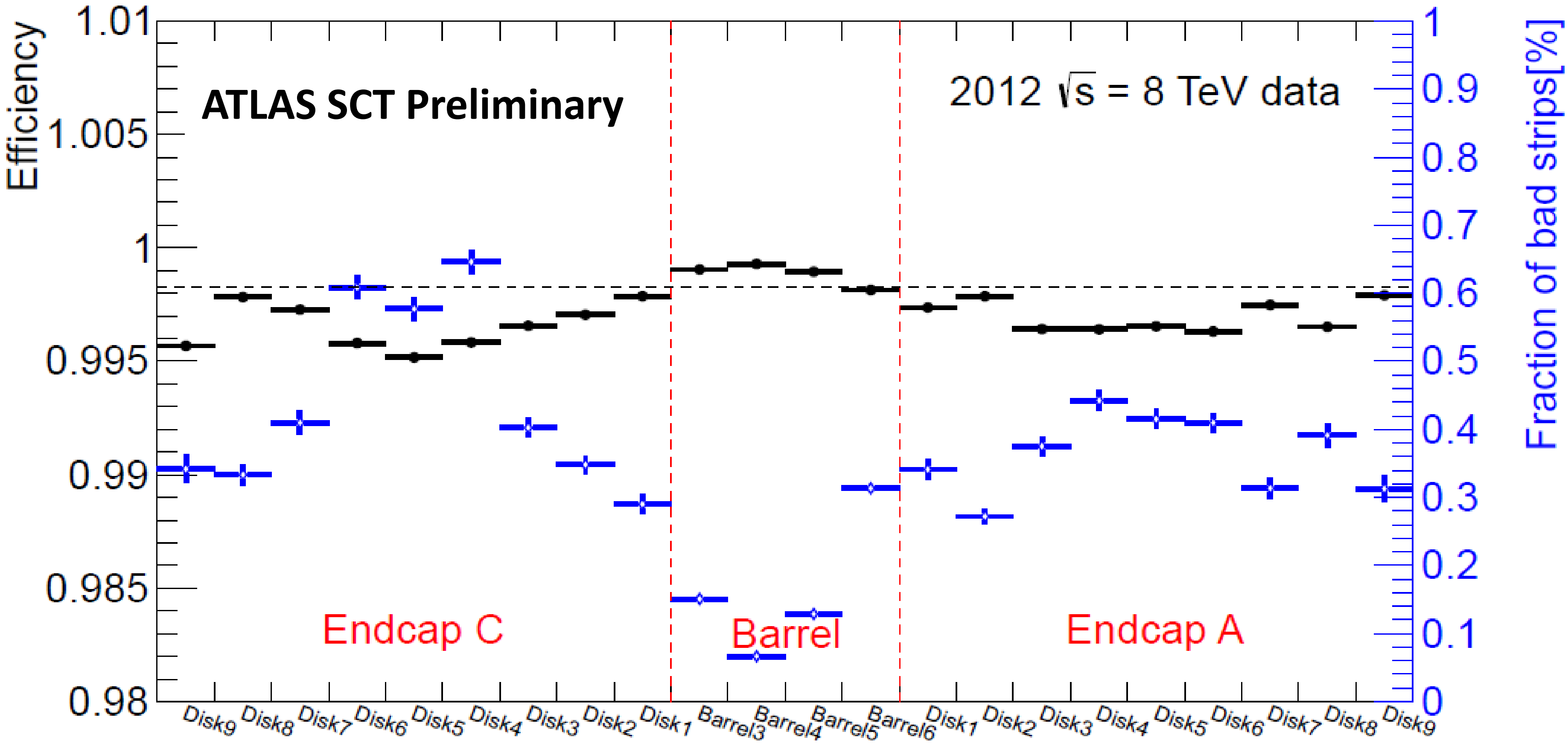
- #Hits/#Possible hits on tracks
- Takes account of missing modules/chips
- Require P_T>1GeV/c
- Require ≥7 hits for SCT standalone
- Require ≥ 6 hits for ID combined







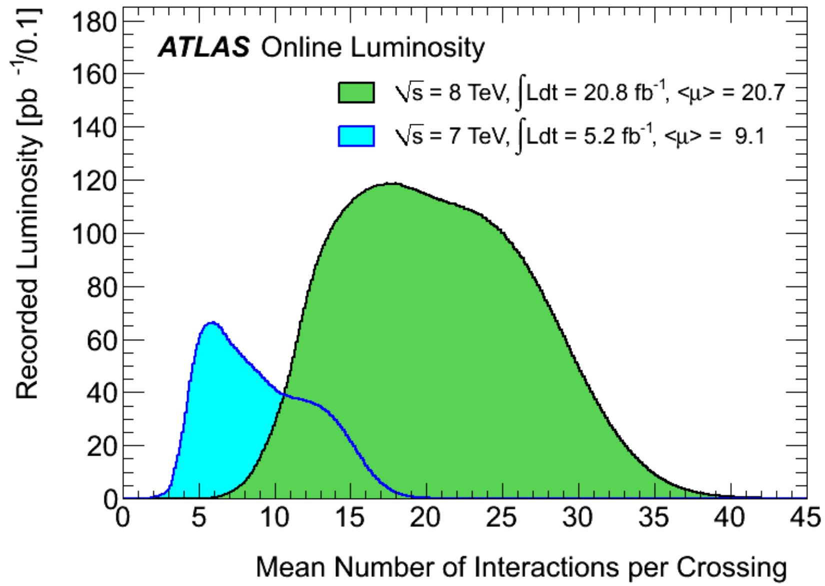
SCT single Hit Efficiency

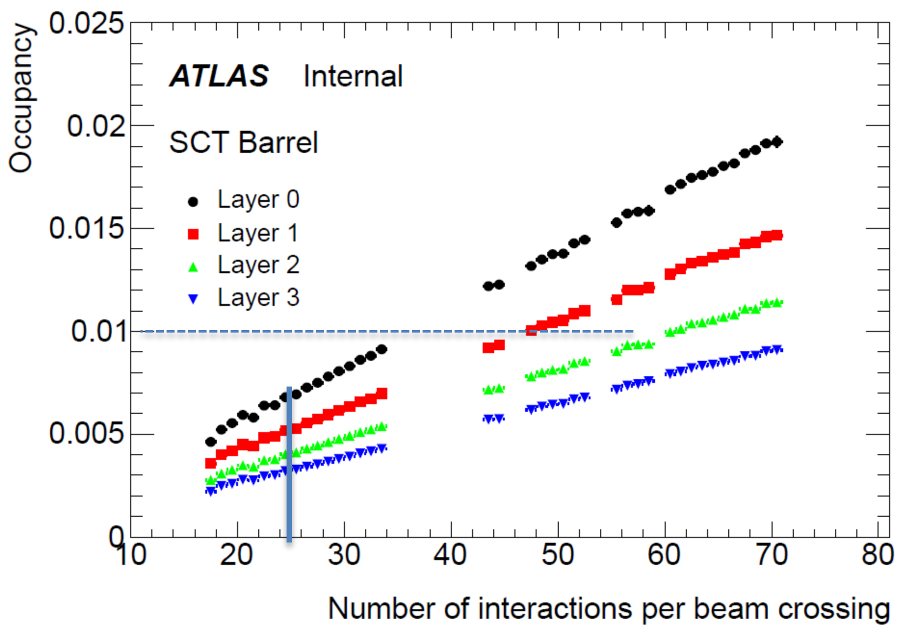


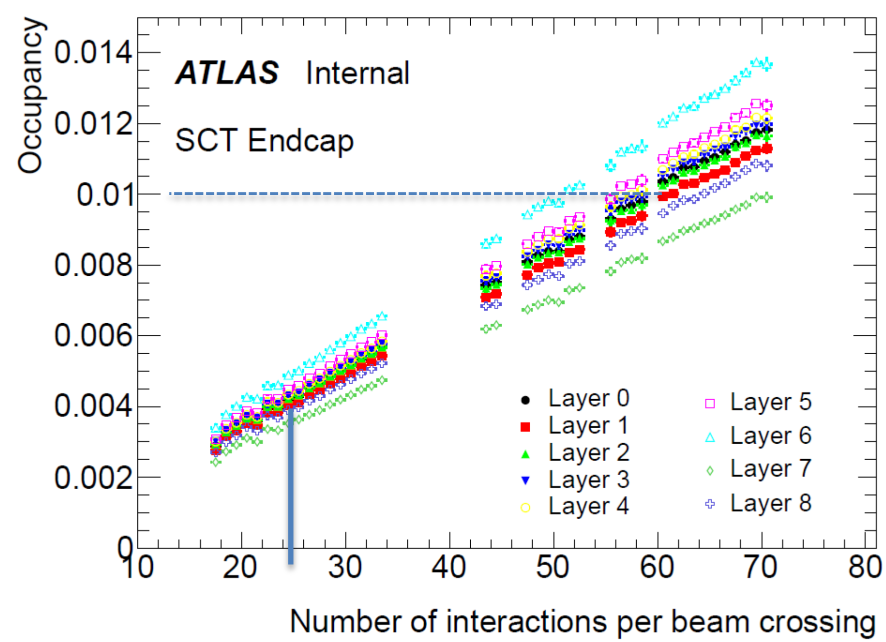
Taken from a special run in 2012 with a low number of p-p interactions per crossing

SCT Strip Occupancies

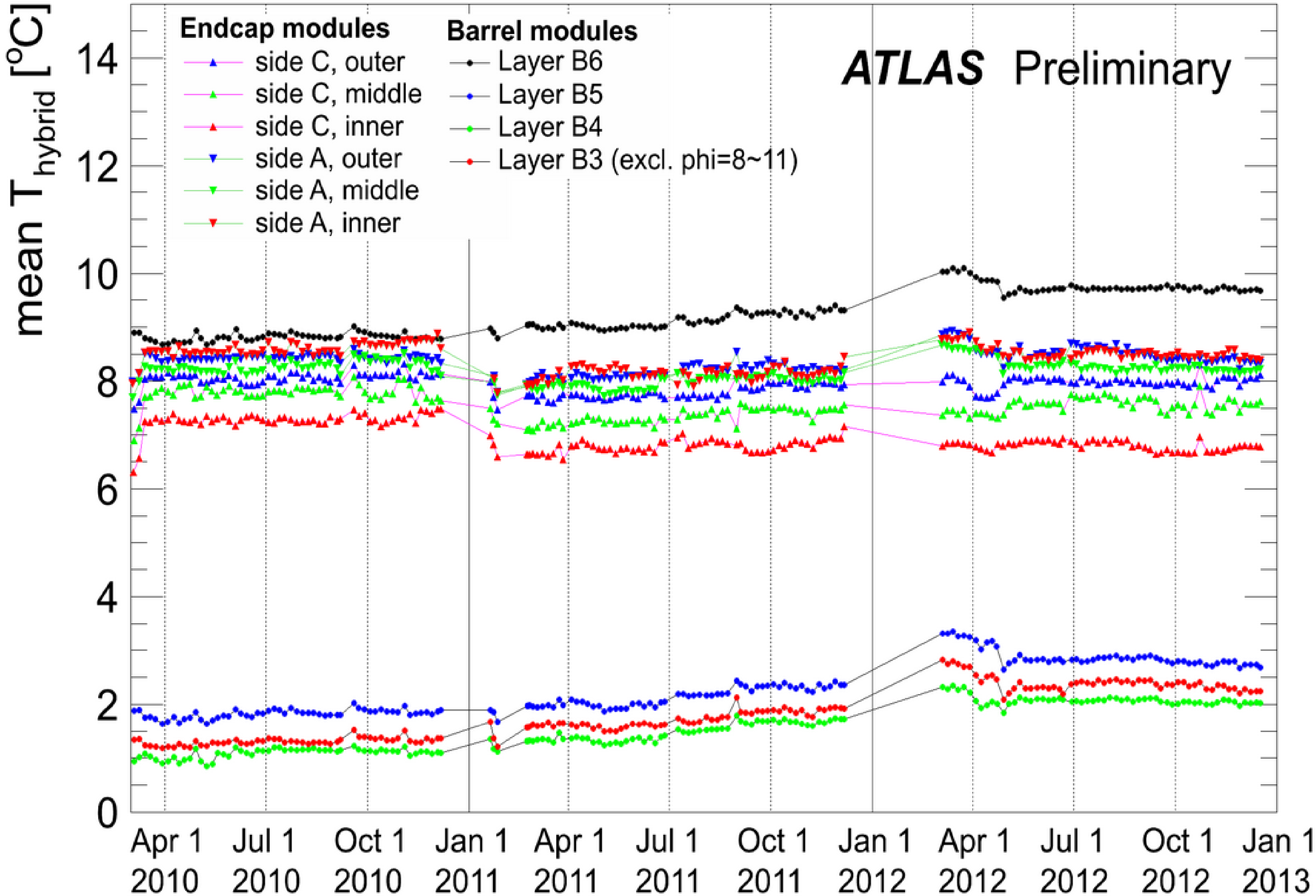
Detector occupancies for different parts of the SCT as a function of the number of interactions per proton-proton crossing
Note the SCT was designed for 1% occ at 25ns





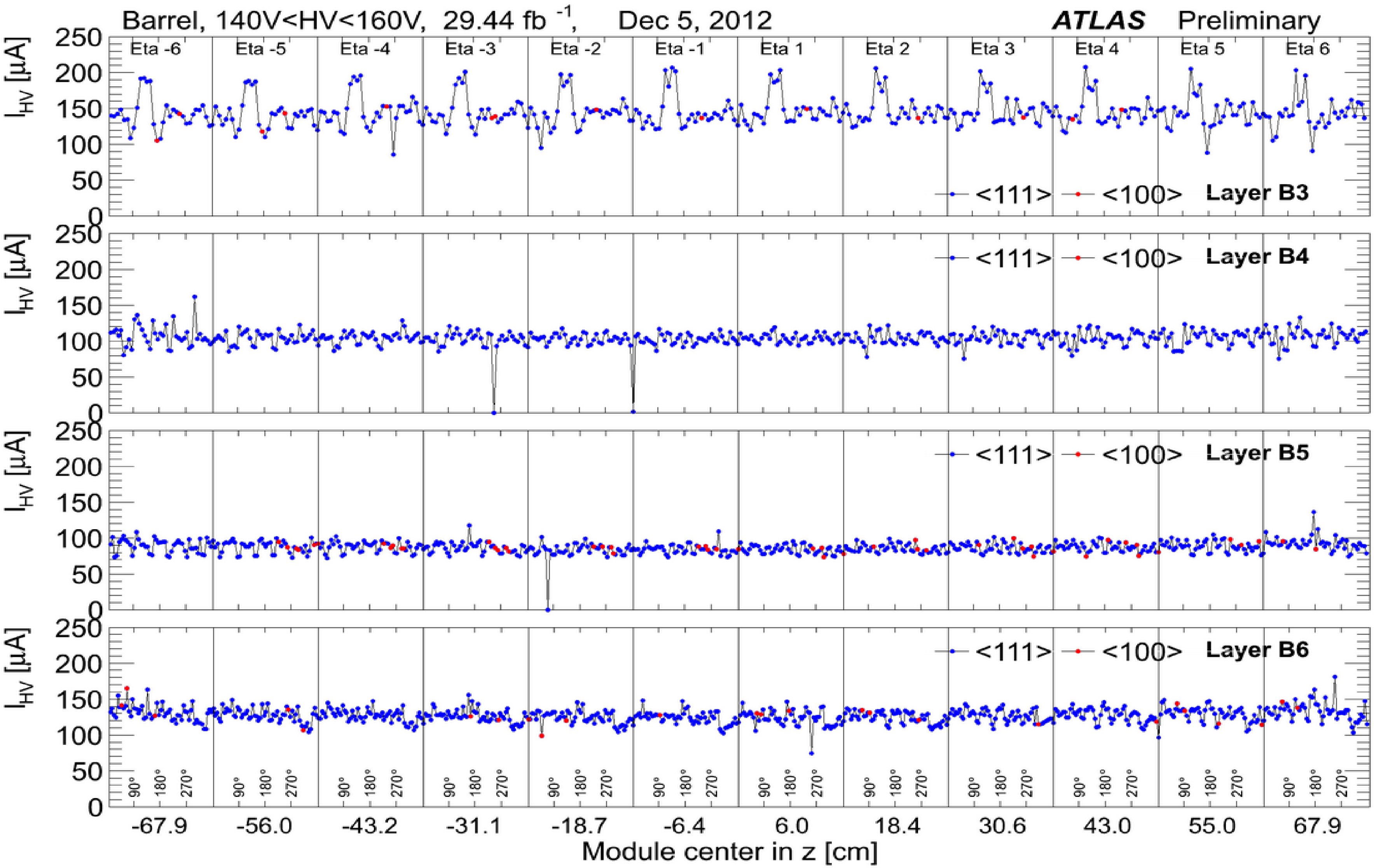


Temperature Stability



Important to understand the evolution of the temperature of the sensors to understand radiation damage.
Note these results are a direct measurements of the hybrid temperature
Note we also need to understand the dT between hybrid and the surface of the sensor.

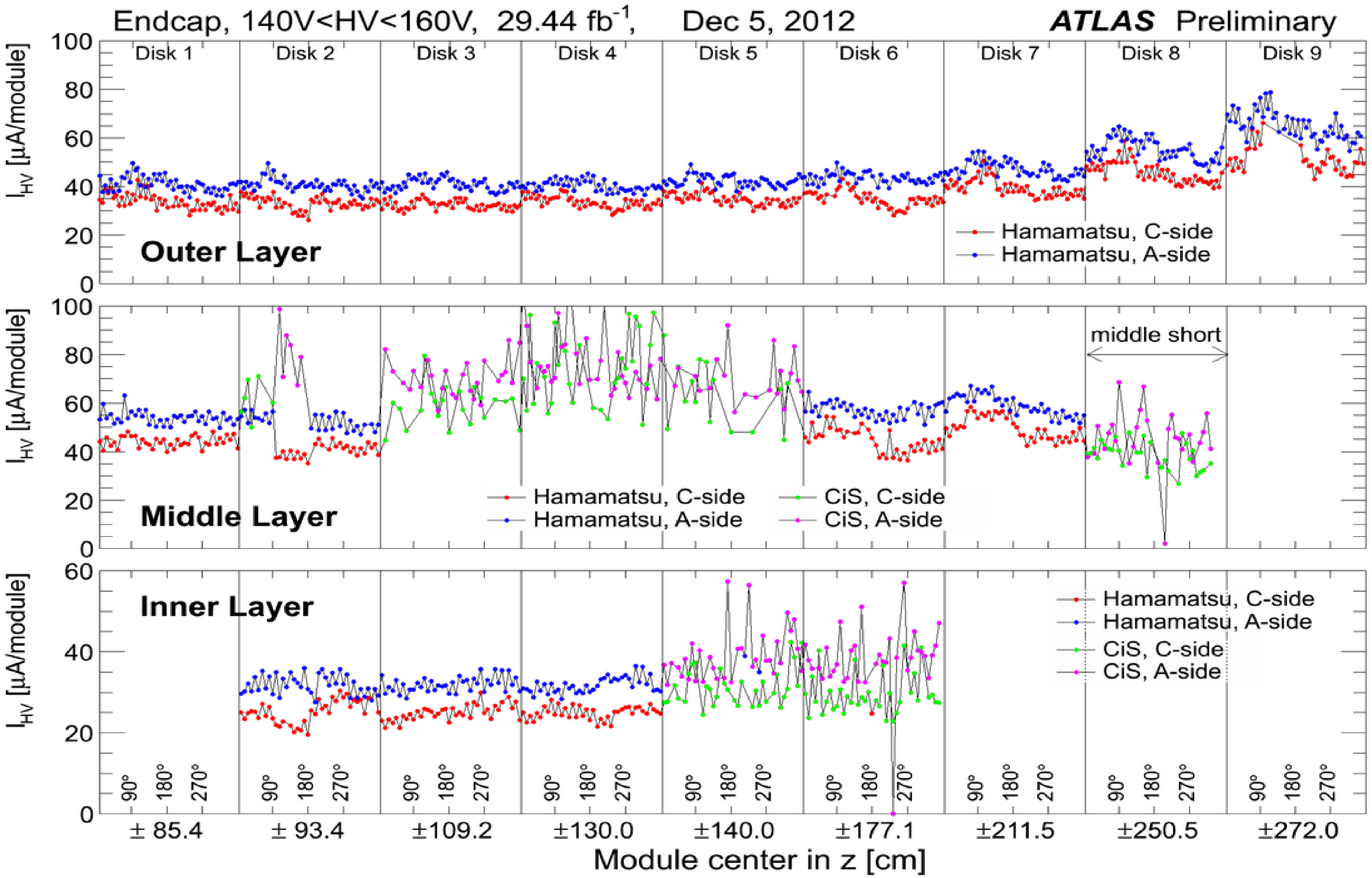
SCT Leakage currents in the Barrels



Snapshot taken in December 2012

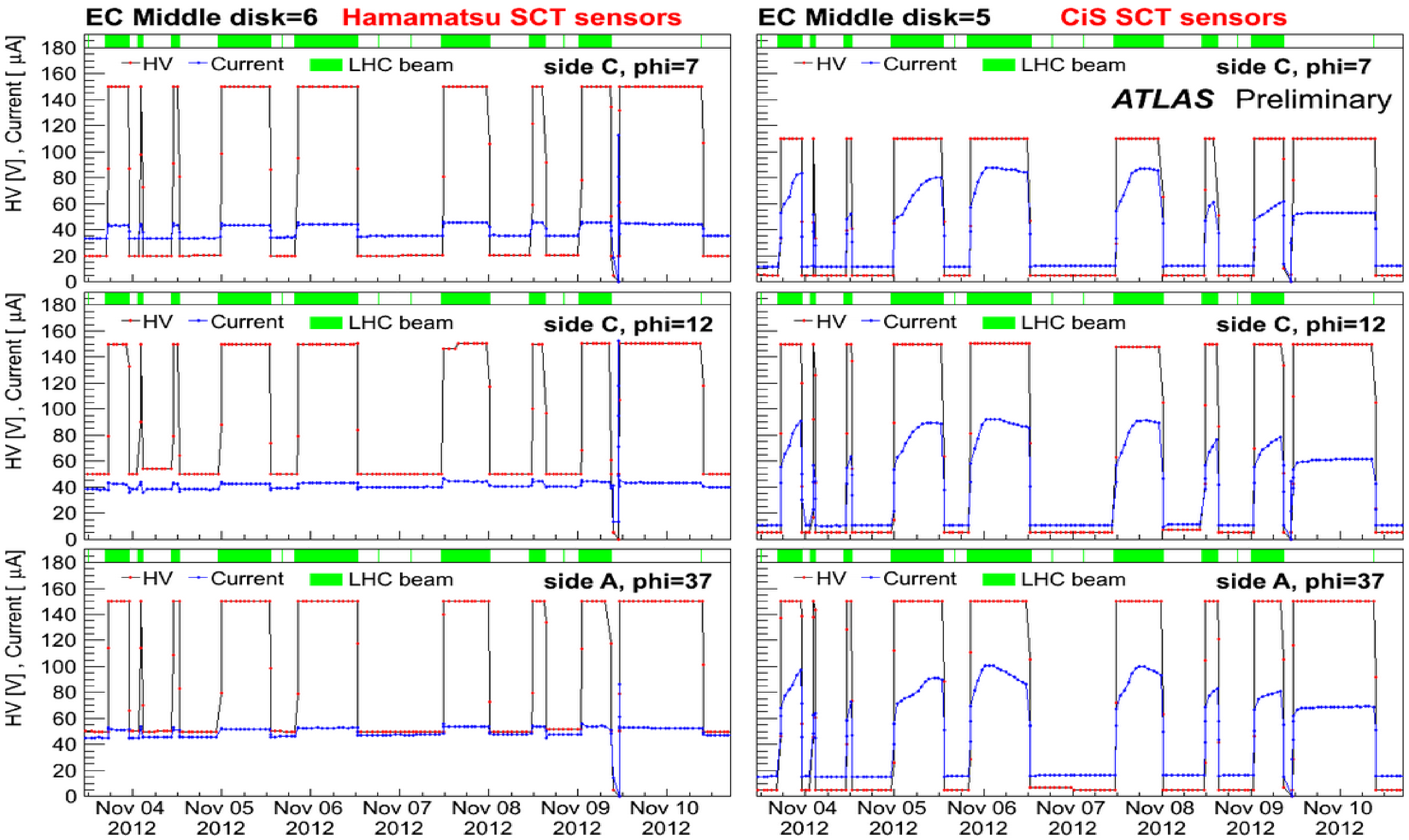
Note that these values are the "raw" (unscaled) values

SCT Leakage currents in the End-Caps



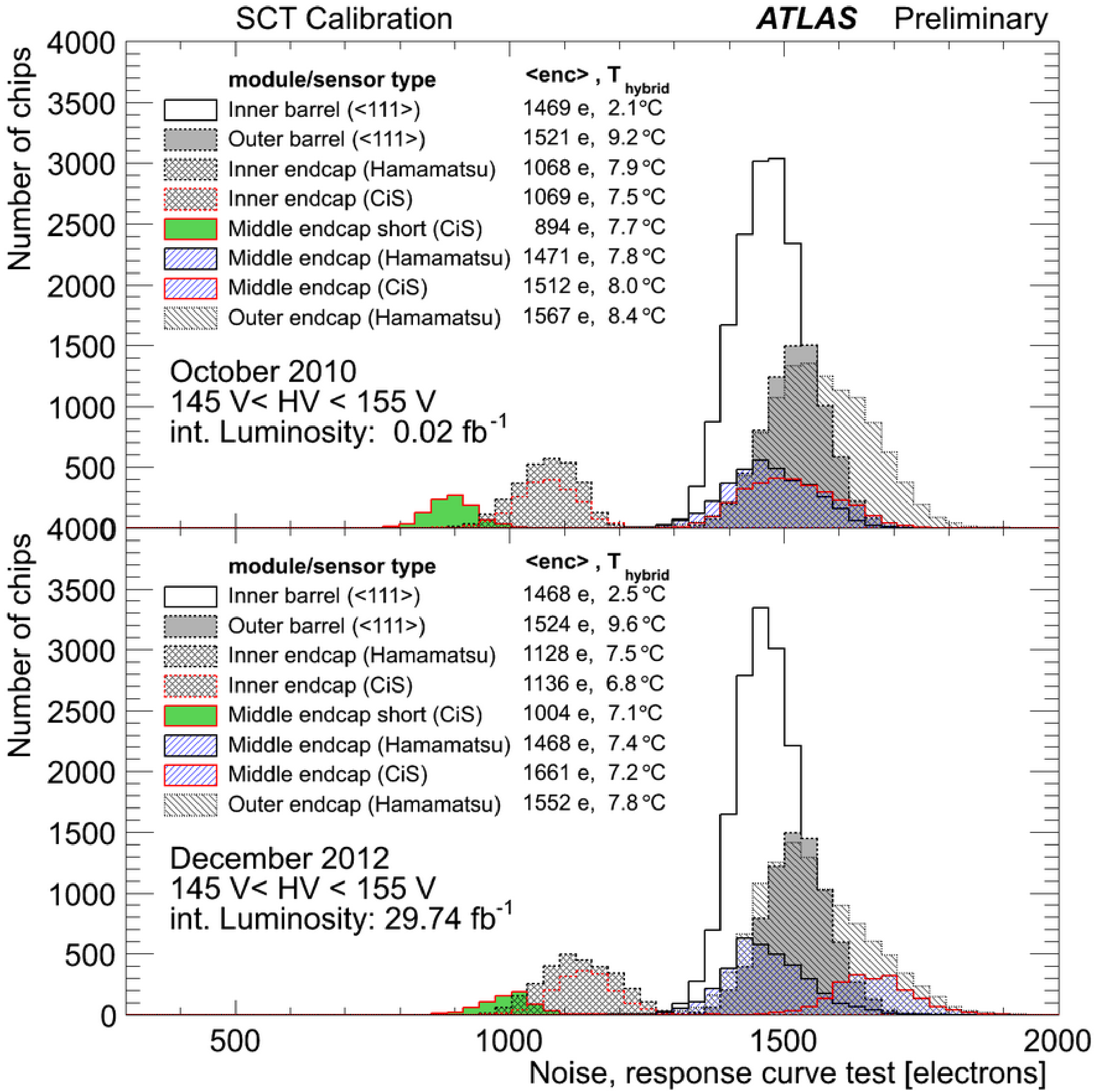
Snapshot taken in December 2012

Current in the End-Caps : HPK & CiS

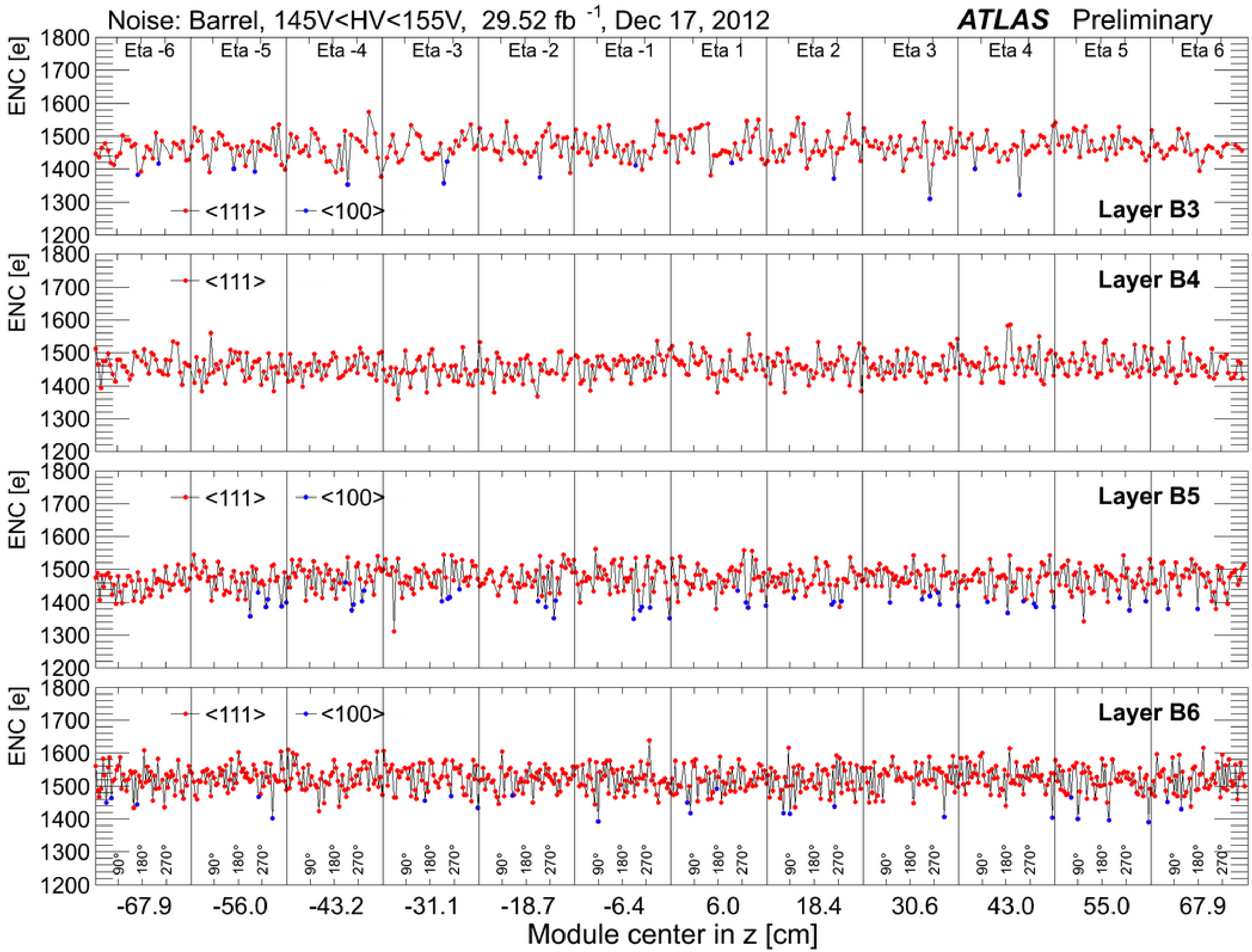


Snapshot taken in 2012 : Shows the Voltage and Current histories for individual modules

ENC Noise (2010 – 2012)

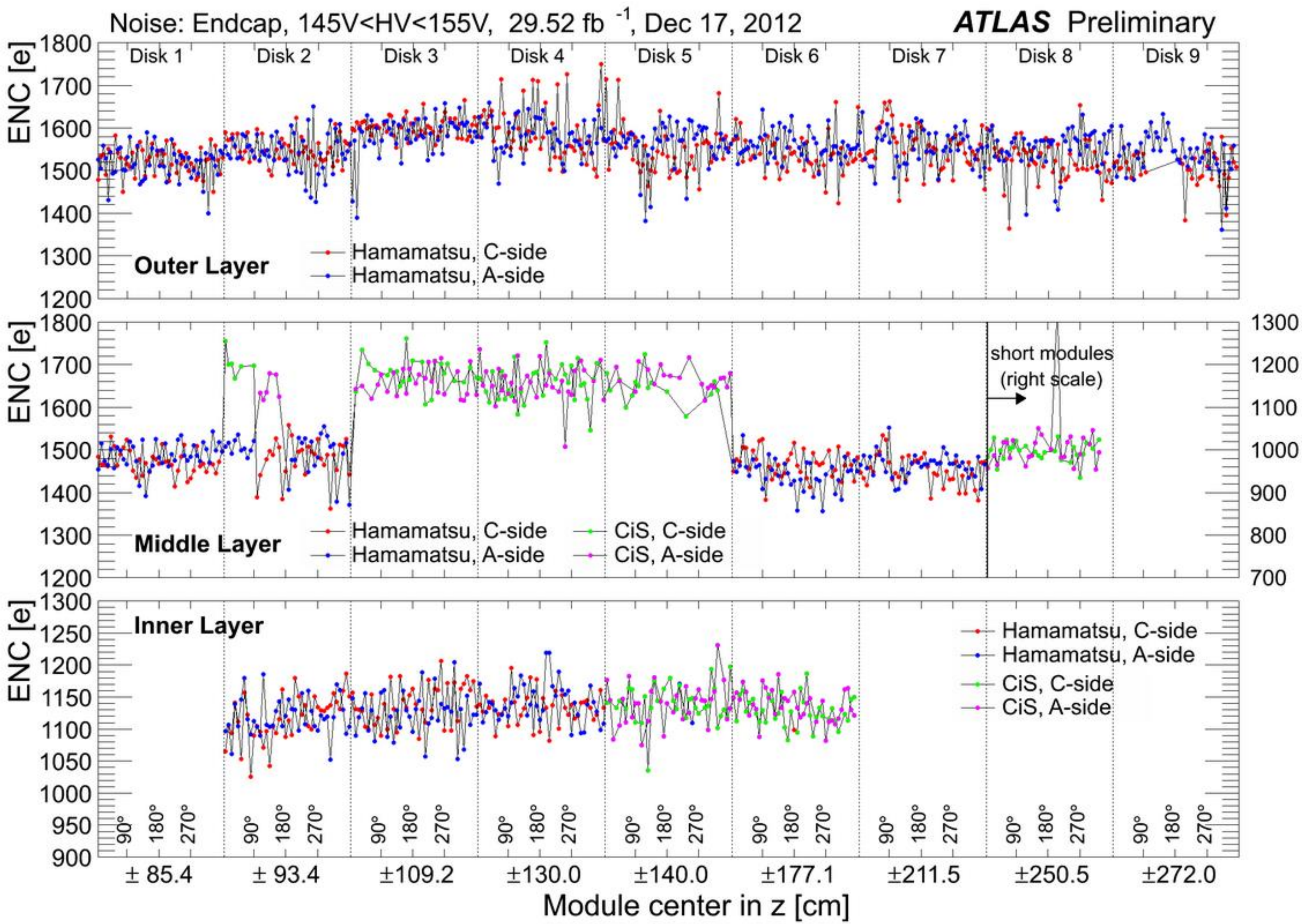


ENC Noise in the Barrel



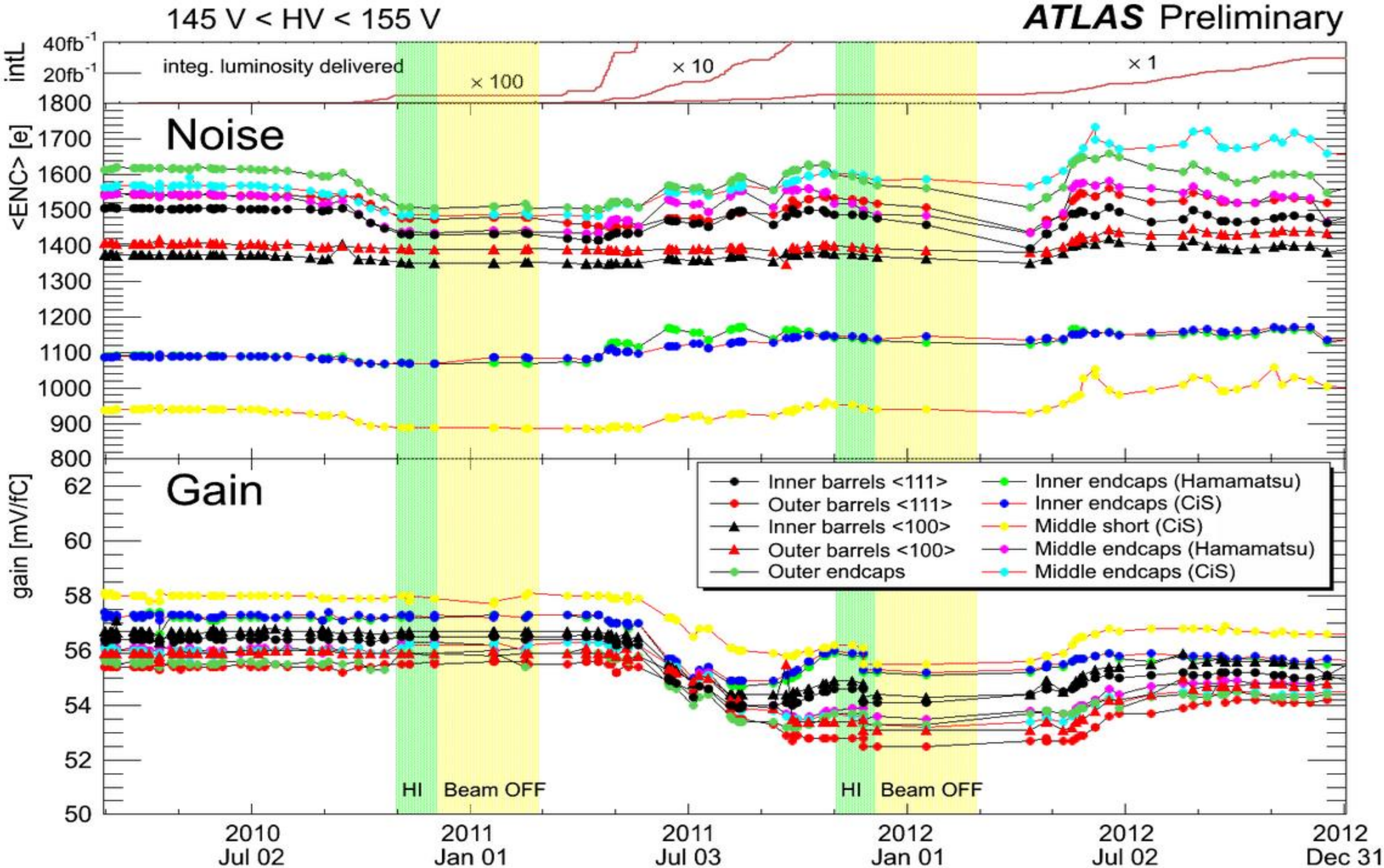
Snapshot taken in December 2012

ENC Noise in the End-Caps

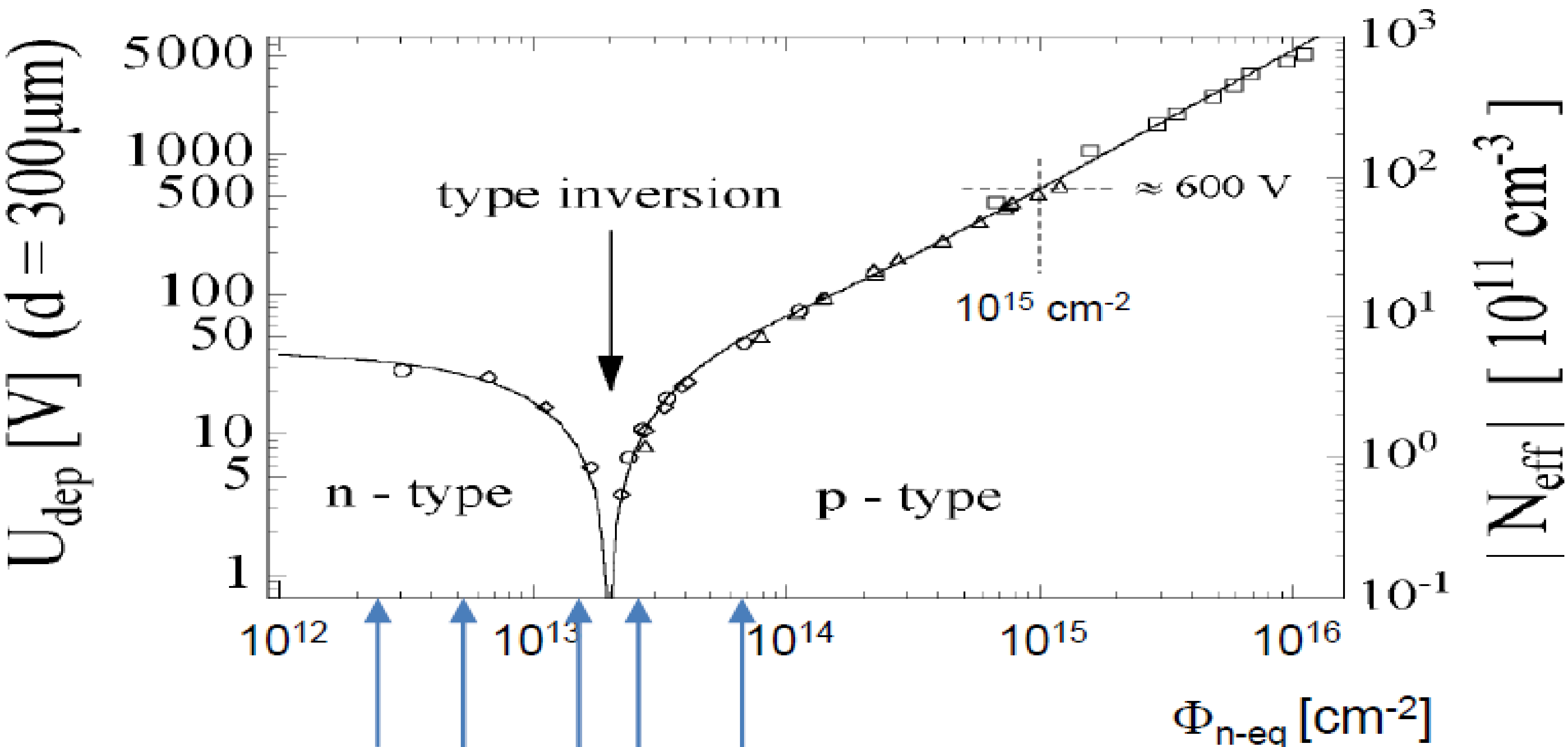


Snapshot taken in December 2012

Time Evolution of Noise & Gain : B & EC



Expected Radiation Dose and Depletion Voltage Shift – Status as of End 2012



B6: 2.8x10^{12}
B3: 5.1x10^{12}
B2: 1.7x10^{13}
B1: 2.7x10^{13}
B0: 6.6x10^{13}

SCT

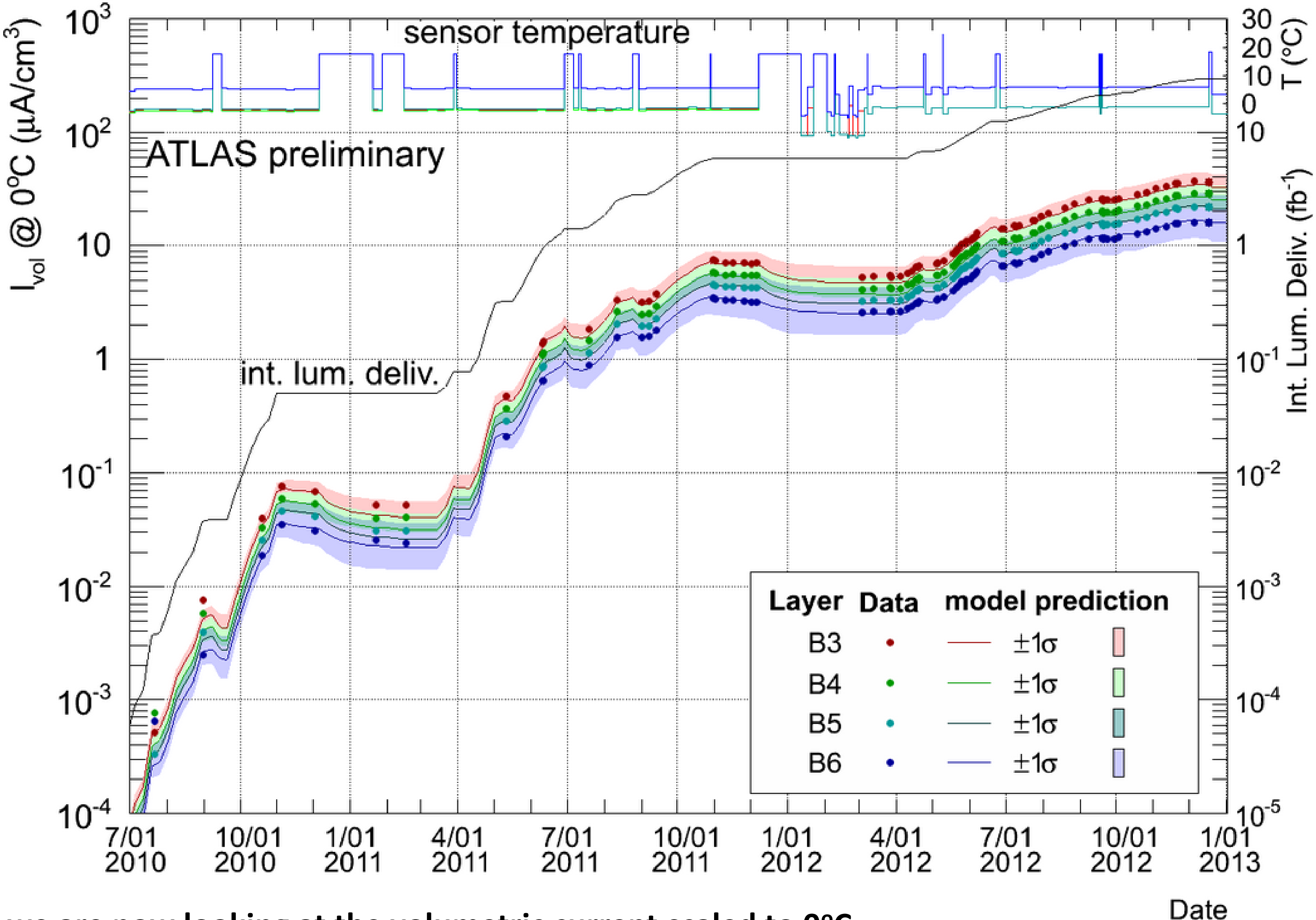
Pixel

For HPK initial Vd = 60-80V

1 MeV n-eq fluence received

Integrated luminosity delivered = 5.8 (7 TeV) + 23.8 (8 TeV) fb^{-1} + using the Fluka simulation

Evolution of Leakage current in SCT Barrels compared to a prediction



Note we are now looking at the volumetric current scaled to 0°C
Fluka used to convert luminosity to flux of 1MeV neutron-equivalent
Effective band gap = 1.21eV (see A. Chilingarov RD50 Technical note RD-50-2011-1

LS1 Activities (2013-2015)

- **SCT power and cooling were switched off in February 2013.**
  - The SCT will remain warm throughout most of LS1
  - Cooling and powering of SCT is expected to return in Mid 2014

- **Numerous SCT consolidation activities**
  1. Upgrade/expansion of SCT-DAQ
     - Installation of an additional 38 Read-Out Drivers (RODs)
     - These will remove a critical DAQ bottleneck and will allow us to be able to read out the SCT up to **$3x10^{34}$ $cm^{-2}s^{-1}$** u(assuming 25ns bunch spacing)
     - Installation of new TX optical engines in the Back Of Crate (BOC) cards
  2. Commissioning of new Thermosiphon cooling system
     - See following slide and diagram in back up.
  3. Testing/repair of evaporative heaters

Cooling : Why the Thermosiphon?

- Although the *compressor based* cooling system has been very reliable up to the end of 2012, the compressors themselves are problematic and need extensive support by a team of engineers & technicians
  - Concerns about long term reliability
  - Filter changes (clogging)
- Thermosiphon offers several significant advantages:
  - Cleanliness (no moving parts)
  - Fewer connections
  - Accessibility (interventions possible without interruption to cooling)
  - Reliability
- Commissioning of new system foreseen for Summer 2014
  - Initially with bypass (dummy load), then SCT
  - Compressor system will remain operational as a backup

Problems and some Lessons Learned

There were some problems along the way: The commissioning of the evaporative cooling system was problematic, small failures on the thermal management between sub-detector. One big headache were the TXs. I will focus on the last one and try and draw some conclusions for the future.

SCT Optical communication General

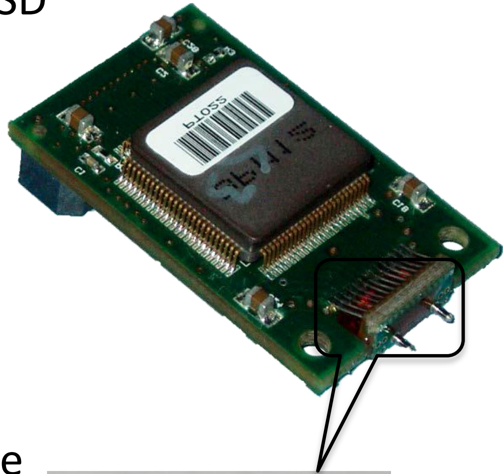
- Two way optical communication between the module and readout.

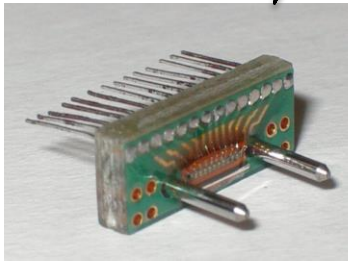
- Each module is served by **3** optical fibres.
  - **2 Fibres** (one on each side serving 6 chips) take the data from the module to the readout electronics (RODs) in the counting room.
  - The transmission is done by VCSELs. The VCSEL technology is proton implant (now redundant)

  - **1 Fibre** takes the clock and control from the counting room to the module.
  - The transmission is done by VCSELs. The technology is oxide confinement.
  - The VCSELs are commercial, the packaging is custom, in-house. There is nothing particularly complex about the packaging..

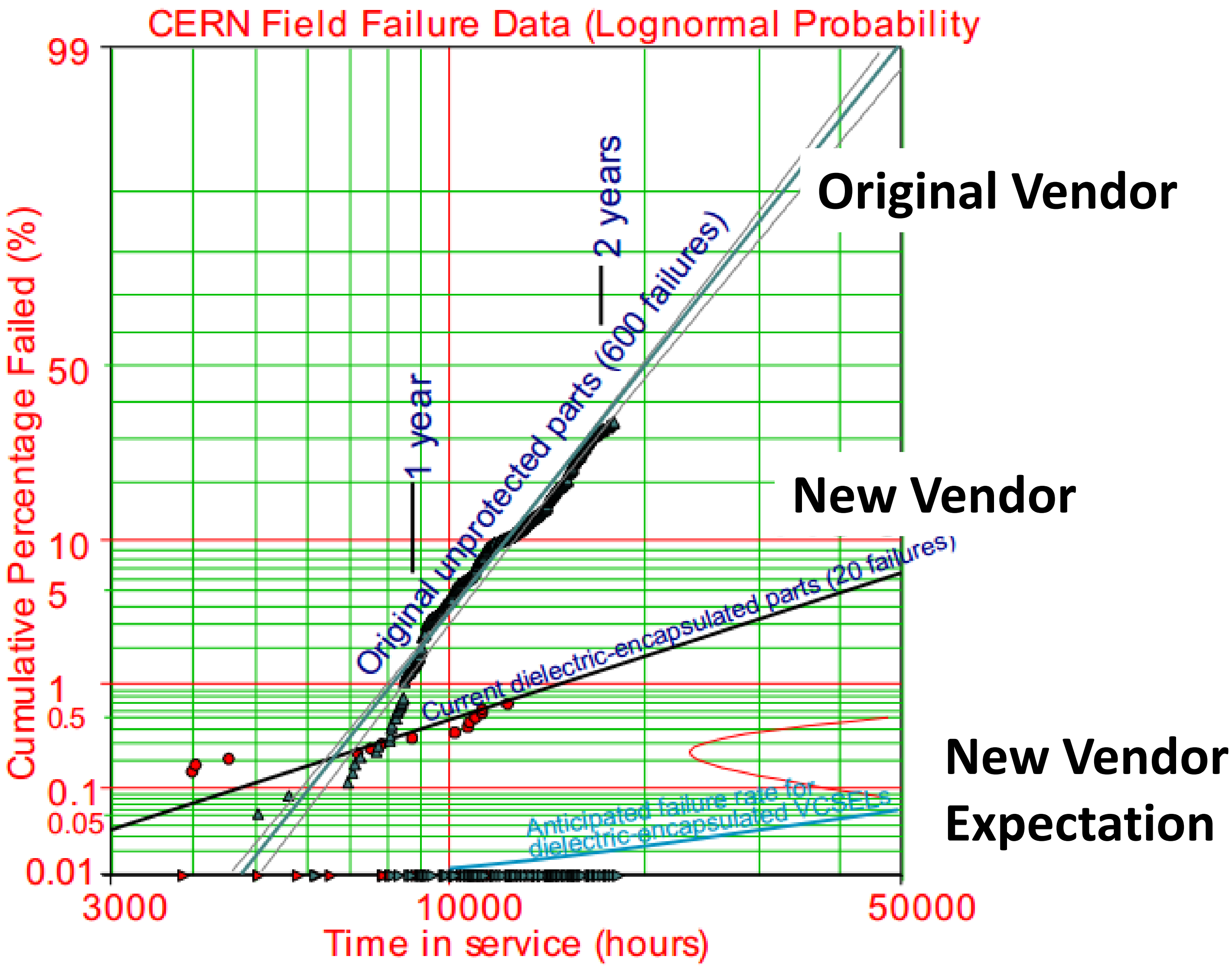
The off detector TX problem(s)

- **First batch of VCSELs failed**
  - Failure rate at peak ~2 arrays/day (each arrays serves 12 modules)
  - Rolling replacement policy, no significant loss of physics data
  - Identified ESD precautions as a weak point and ensured strict ESD controls for new production
- **Second batch also failed …**
  - Identified ingress of humidity as an issue
  - replaced all VCSELs with humidity resistant VCSEL from a new vendor
- **Third batch also “failed” …**
  - Much much lower rate of failures but still factors above what we were expecting based on vendors reliability data.
  - Failure rates in bench tests were incompatible with rates measured in the counting rooms
  - ***humidity not the full story.***
- Still trying to understand all causes of failures (not purely academic ..)
- Now focussing on developments using commercial VCSEL packages





SCT - VCSEL Failure Rates



Conclusions

- The SCT has had an outstanding 3 years and has contributed to the rich and diverse program of ATLAS physics.
- We have installed, commissioned and maintained a fantastic strip detector with accumulated channel failures at the 1% level. We also have a very high efficiency, data taking efficiency (>99%).
- We have put great emphasis on configuration stability reliability and up time during operations.
- The effects of radiation damage (*increase in leakage currents*) are entirely consistent with our expectations (Hamburg/Dortmund model) based on our knowledge of the: integrated flux and sensors temperature without any need for scaling or tuning.
- We are currently consolidating the detector during the first long shut-down of the LHC to improve the cooling system and expand the DAQ system to be able to cope with 3 times the design luminosity.
- We have had a few problems which we have circumvented and are using the lessons learned in our planning for the next generation of large scale tracking detector. Reliability will be a big issue in the future….

Backup Slides

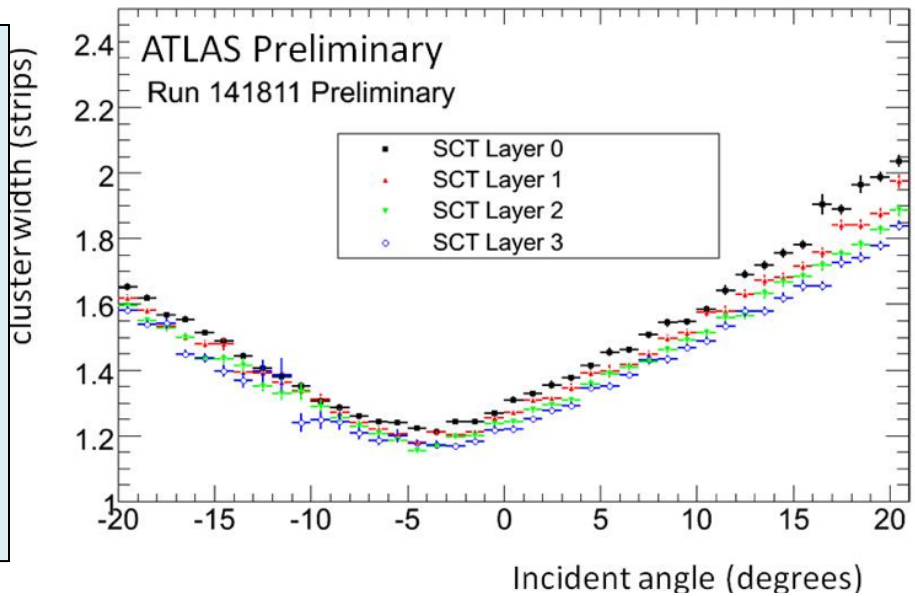
Breakdown of Physics Configuration

	Endcaps	Barrel	SCT	Fraction (%)
Total	19	11	30	0.73
Cooling	13	0	13	0.32
LV	1	6	7	0.17
HV	5	1	6	0.15
Readout	1	4	4	0.09

Component	Endcaps	Barrel	SCT	Fraction (%)
Modules	20	11	30	0.73
Chips	17	38	55	0.11
Strips	7252	4111	11363	0.18

Lorentz Angle

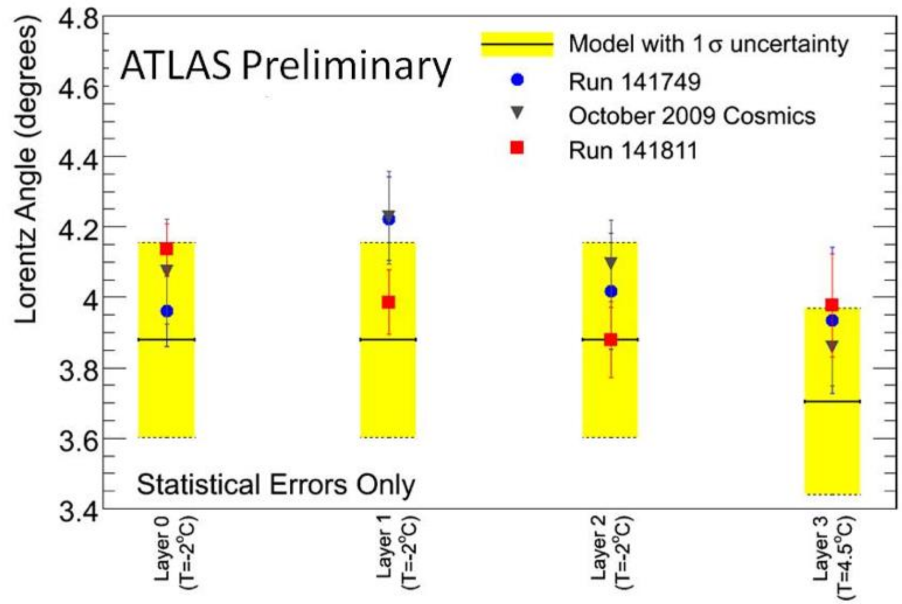
- Carrier drift direction is deflected in B-field
- Lorentz angle - track incidence angle at which the minimum cluster size (#hits in cluster) is detected
- Lorentz angle is function of B-field, voltage and temperature



Prediction sensitive to:

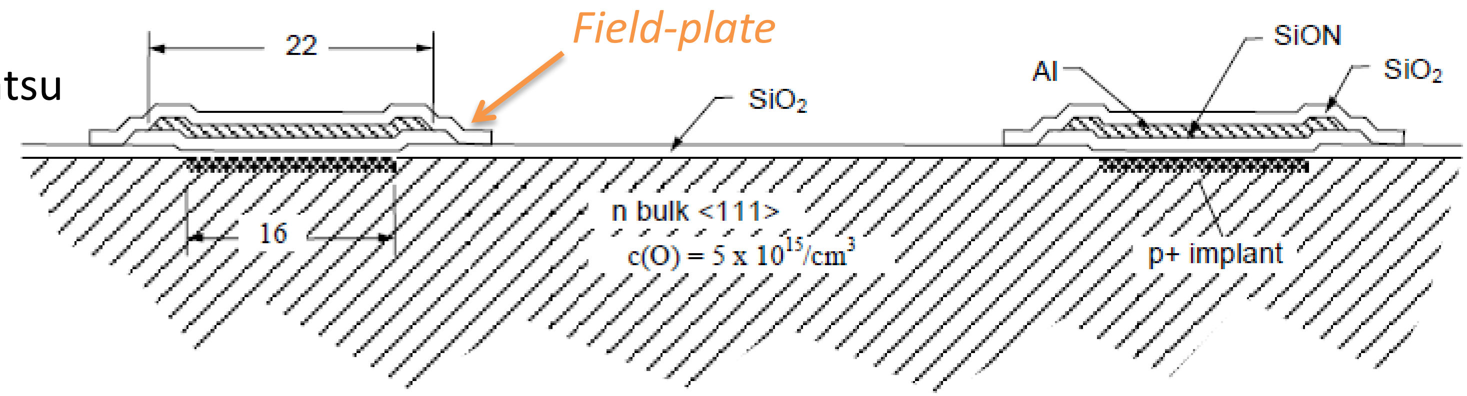
- model of signal digitisation in simulation
- radiation damage

✓ Measurements with cosmic ray and collision data both compatible with model predictions

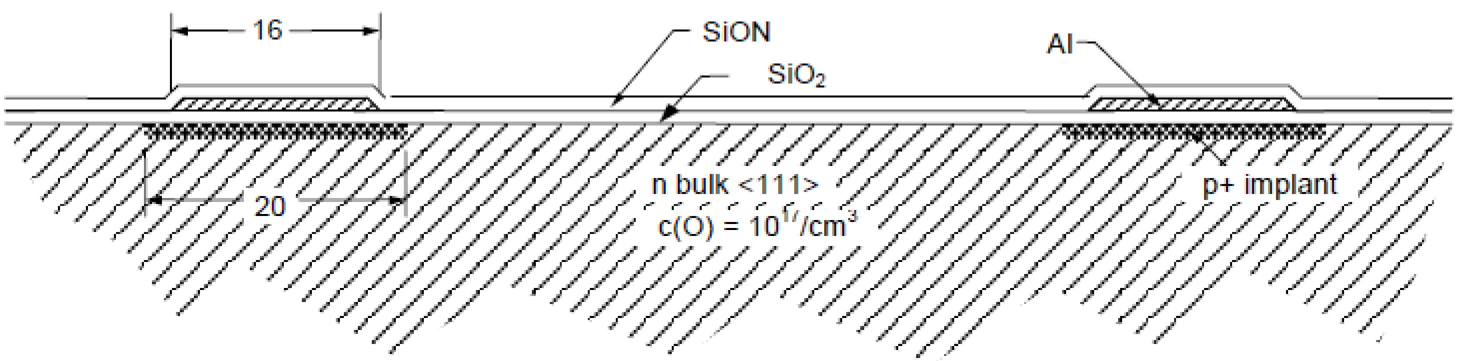


Why CiS (but not Hamamatsu)?

Hamamatsu



CiS

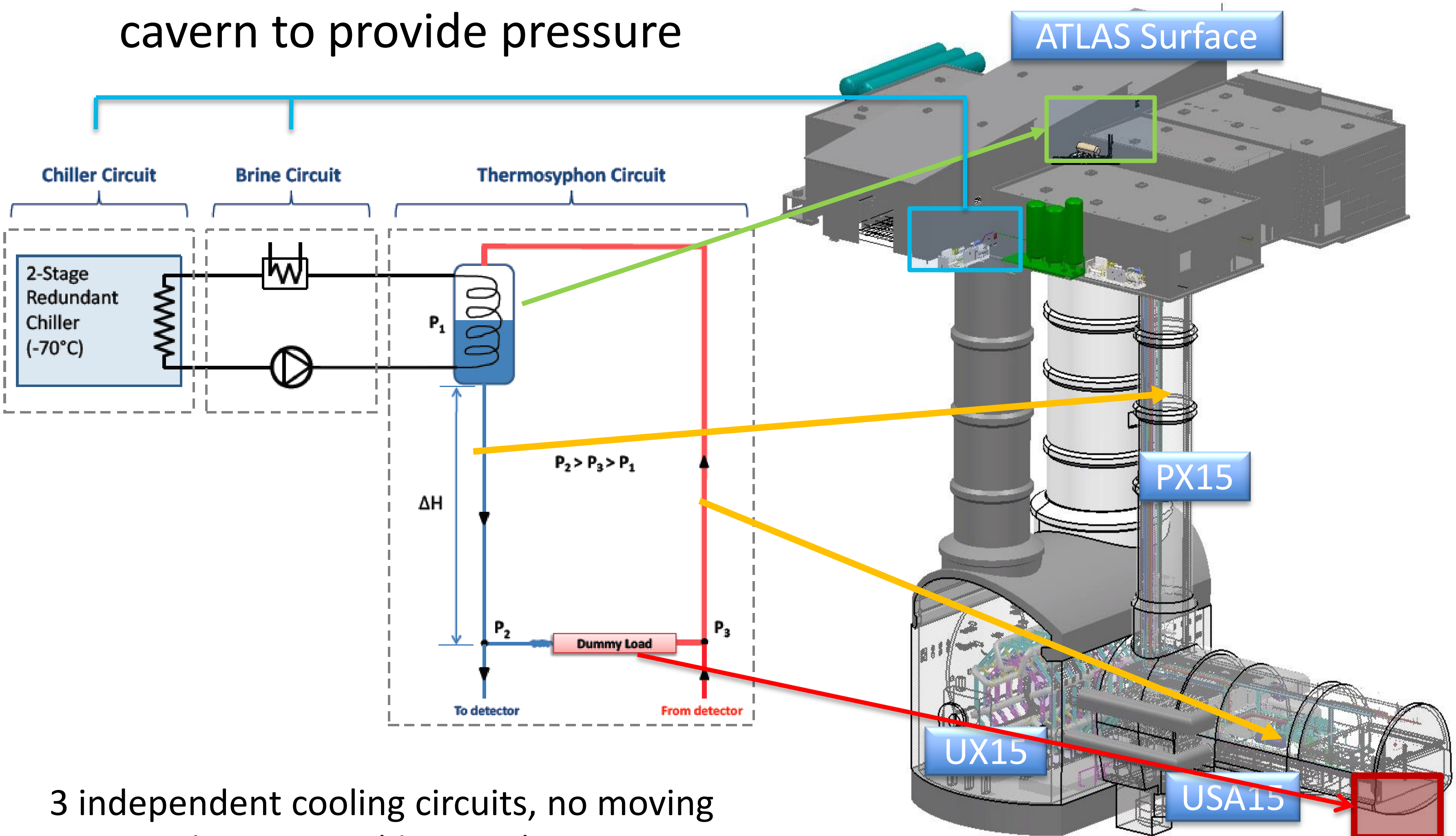


Origin of high noise and high current not fully understood, but CiS SCT sensors have known design and processing issues that impact on leakage current:

- Lack of field plate overlapping strip implants (field plates can suppress microdischarge)
- Resistive passivation leads to more surface charge migration

The Thermosiphon Project

Replace the compressor system for cooling the SCT (and pixels) using 90m drop of C_3F_8 feed from the surface to the cavern to provide pressure



3 independent cooling circuits, no moving parts in the primary (detector) circuit