ATLAS QA Procedures for Silicon Microstrip Detectors

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ATLAS SCT

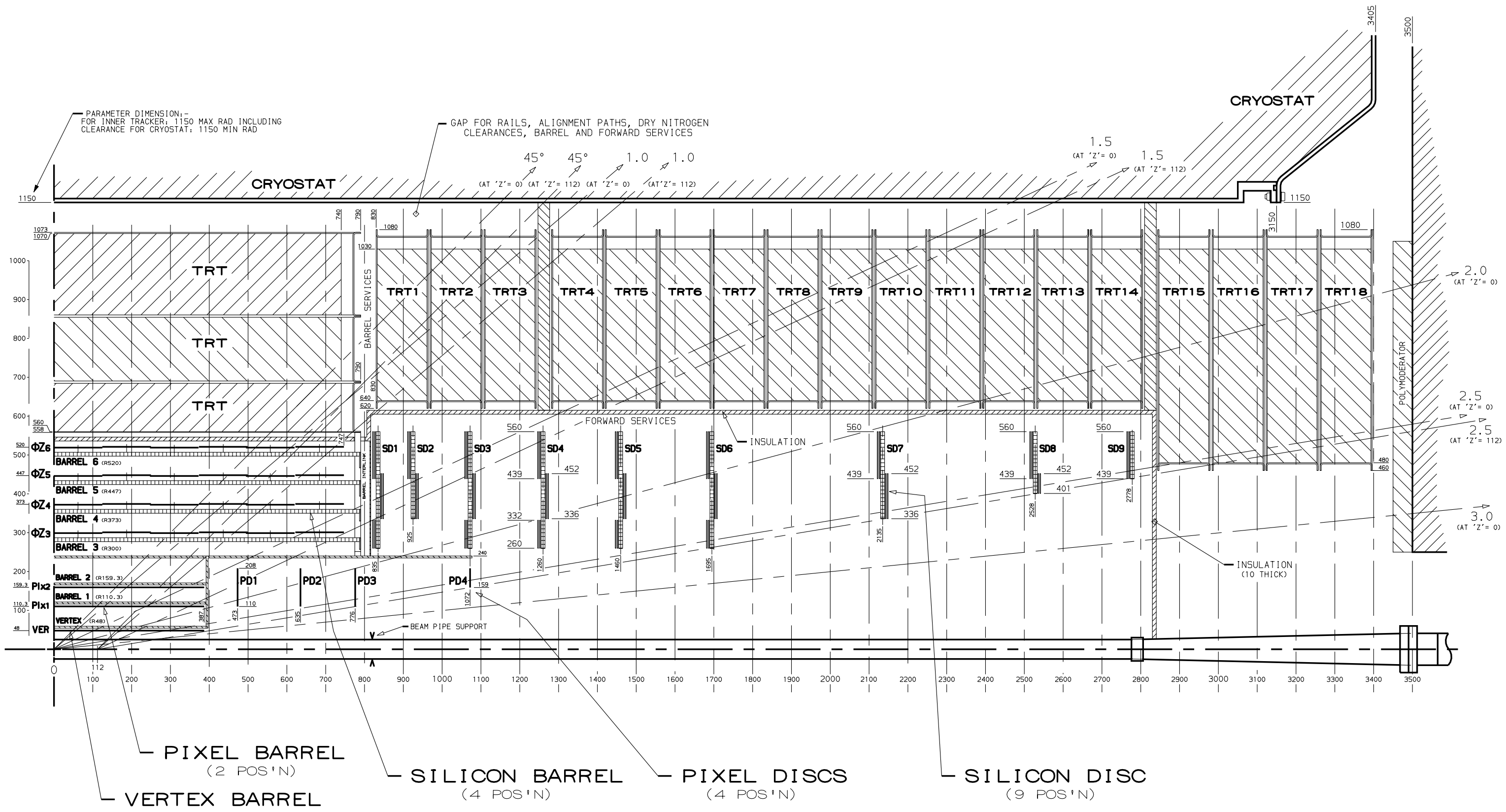
1st Workshop on QA Issues in Silicon Detectors, CERN, 17-18th May 2001

- Overview
  - The ATLAS SCT
  - Sensor Specifications
  - From Prototypes to Production
- Quality Assurance
  - QA Strategy
  - Acceptance Criteria
  - Tests by the Manufacturer
  - Tests by ATLAS
  - Irradiations
  - DAQ and database uploads
  - Essential Equipment
- Summary

This talk is available as a PDF file from www.hep.phy.cam.ac.uk/silicon

The ATLAS SemiConductor Tracker

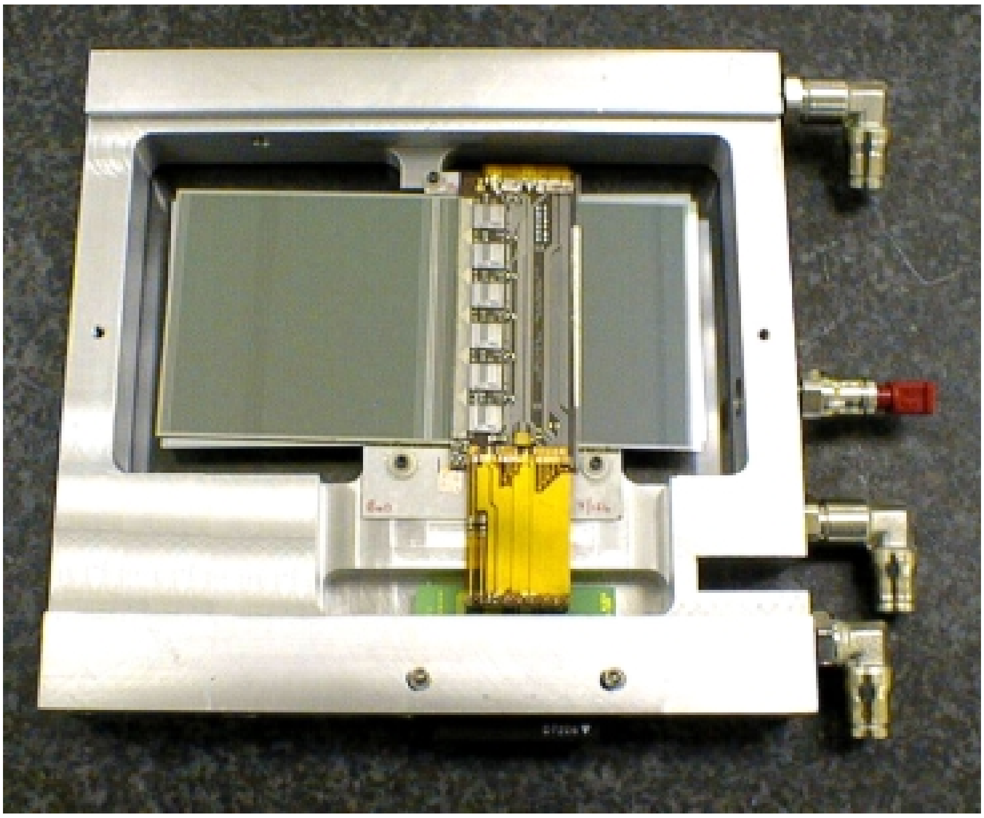
The SCT comprises 4 barrel layers and 9 end-cap wheels on each side, incorporating a total of ~60m^2 of silicon. The barrel region uses ~10600 sensors with rectangular geometry, and the end-cap wheels use ~8700 wedge shape sensors.



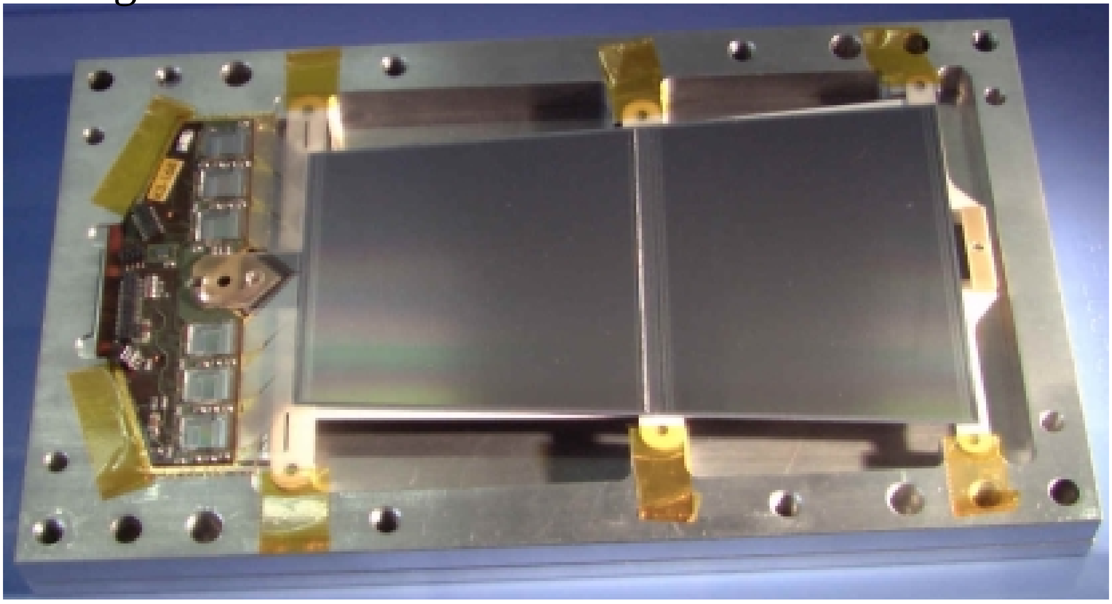
Cross-Section through right side of ATLAS Inner Detector

ISSUE Q
ATLAS INNER TRACKER GEOMETRY
DIMENSIONS FOR TDR 1997
1-TB-0035-060-00-Q
04MAR97

Barrel Module

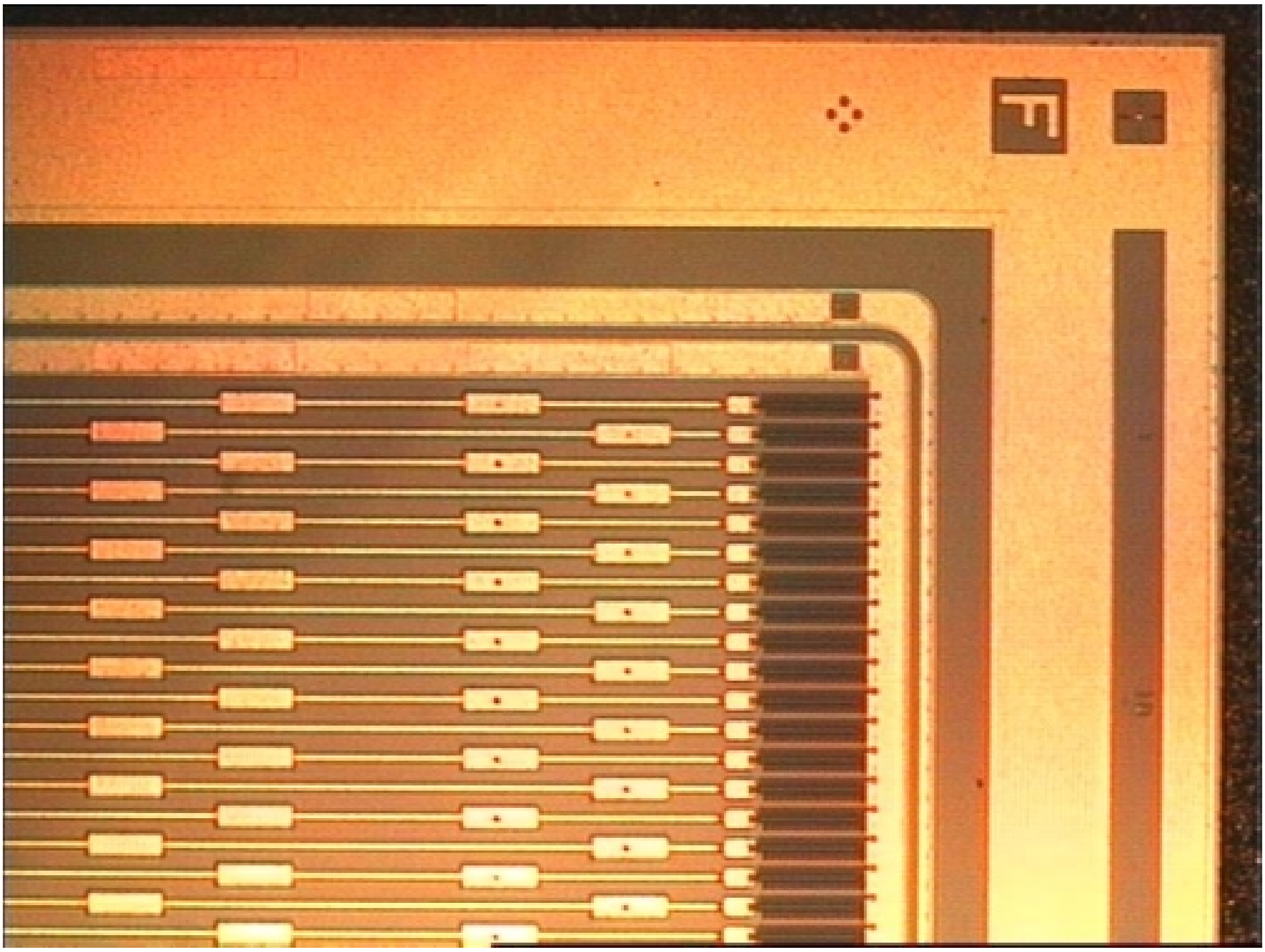


Wedge module



Barrel Sensor Design

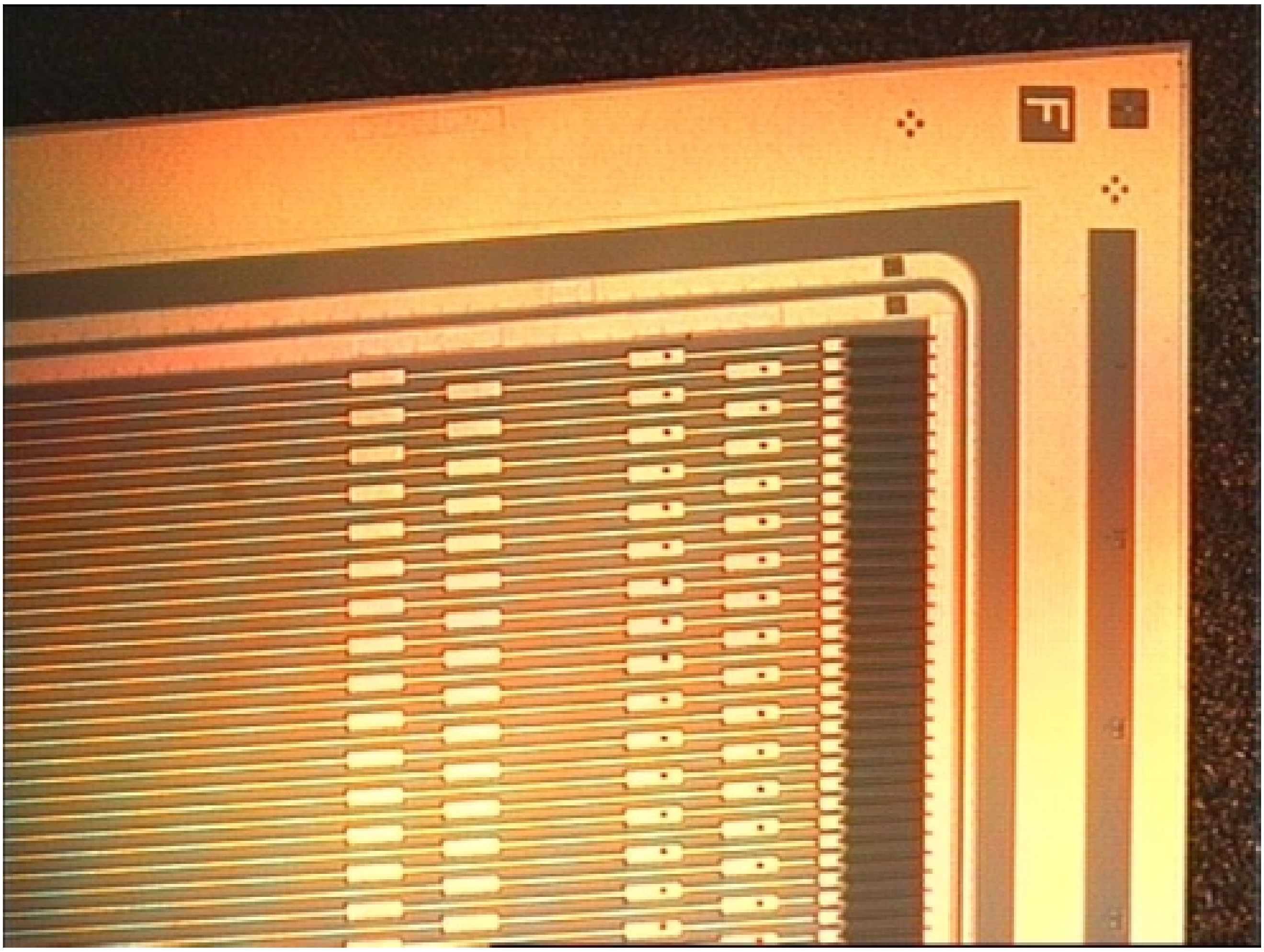
Hamamatsu barrel



- 64 x 63.6mm (active area 62 x 61.6mm) x 285µm
- 768 AC-coupled strips at 80µm pitch (+2 dummies)
- Polysilicon bias resistors
- Reach-through protection 5-10µm implant-to-bias rail
- Strip metal width / Implant width = 16-22 / 16-20 µm
- HV contact: metallised non-passivated n-implant on back, also front contacts to edge-implants for pre-irradiation QA
- Three different edge termination designs from 3 manufacturers

Wedge Sensor Design

Hamamatsu W12



• Five geometries: W12, W21&W22, W31&W32

	Length(mm)	Outer Width(mm)	Inner Width(mm)	Pitch(μrad)
W12	61.06	55.488	45.735	207
W21	65.085	66.13	55.734	207
W22	54.435	74.847	66.152	207
W31	65.54	64.636	56.475	161.5
W32	57.515	71.814	64.653	161.5

• Otherwise essentially the some design as barrels (except CiS wedge detectors have implanted resistors instead of polysilicon)

From Prototypes to Production

0. Prototyping (1996-1999)

Development of design and specifications. General 'free-for-all' in which the (many) silicon groups within ATLAS designed and prototyped sensors with their favorite manufacturer. Five+ manufacturers were involved during this phase.

Baseline design changed from n-on-n to p-on-n midway through this phase (despite a successful program of n-on-n development work).

1. Sensor Qualification (Early 1999)

Interested manufacturers were invited to supply several of their optimised prototype sensors that should meet ATLAS specifications. The prototypes were evaluated extensively by ATLAS both before and after irradiation to $\sim 3x10^{14}p.cm^{-2}$.

Only those manufacturers that had supplied *several* prototypes (nominally 10) with identical processing that gave consistent characteristics and were within all ATLAS specifications before and after irradiation were invited to bid during the tendering process.

Following evaluation of the qualified prototypes, a Final Design Review in May 1999 recommended the procurement of a *preseries* production.

2. Tendering (Summer 1999)

Of four qualified manufacturers, three were successfully awarded contracts to supply the microstrip sensors for the SCT:

- Hamamatsu (73% of total order) - barrels and all wedge shapes
- CiS (17%) - all wedge shapes
- SINTEF (10%) - barrel only

3. PreSeries Production (Jan-April 2000)

Manufacturers were initially required to supply a preseries production, which comprised ~5% of their total delivery. The preseries was used to demonstrate:

- that the quality of the produced sensors will be maintained, with charactersitics consistent with the qualified sensors.
- the ability to comply with delivery schedules
- the ability of both the manufacturer and ATLAS to effectively implement the QA procedures
- compatibility of QA data between the manufacturer and different ATLAS institutes
- the effectiveness of packaging, labelling, transportation and other procedural and QA issues

A Production Readiness Review in August 2000 approved the release of funds for the full series production.

4. Series Production (Jan 2001 to late 2002)
.... Is currently underway!

Manufacturers are contractually obliged to deliver detectors in regular monthly shipments, distributed to the 7 module-building clusters in ATLAS:

- CE: Freiburg, MPI, Nikhef, Prague, Potvino
- UK-V: Glasgow, Lancaster, Liverpool, Manchester, RAL, Sheffield, Valencia
- CS: Australia, CERN, Cracow, Geneva, Llubljana, MSU, Prague, MPI
- Nordic: Bergen, Oslo, Uppsala
- Japan: Hiroshima, Tsukuba/KEK, Kyoto edu, Okayama
- USA: LBL, UCSC
- UK-B: Birmingham, Cambridge, QMW, RAL

red indicates QA institute

Each of the module-building clusters has one or two institutes that receives the detectors and performs all the QA. The receiving ATLAS institute has three months to perform all QA tests before payment is due.

Eg: Schedule at Cambridge:

- *total delivery: 2300 Hamamatsu barrels*
- *monthly batch size: 120*
- *Jan 2001 to August 2002.*

QA Strategy

The Manufacturer

Following the process of qualification of a detector from a particular manufacturer, it is the responsibility of the manufacturer to ensure no changes in processing occur during production that may modify:

• any parameters relevant to ATLAS specifications

• any pre- and post-irradiation electrical behaviour

from that observed during the qualification program.

ATLAS

As consistency of processing is ensured, the role of ATLAS is mainly that of a visual examination and IV measurement on every detector as a basic check on quality. However, on a subset of detectors (~10%), an extensive evaluation of detector characteristics is performed as a check on processing consistency and as a verification of the manufacturers tests.

Furthermore, samples of detectors (<1%) will be regularly irradiated throughout production to ensure that the post-irradiation behaviour of the qualified detectors is being maintained.

Acceptance Criteria - Mechanical Properties

Not all mechanical properties are easily quantifiable, and some may be quantified somewhat arbitrarily. However, it is important to state all possible problems and to set reasonable limits where possible to ensure that manufacturers are contractually obliged to take back detectors that are mechanically defective

- Quality of cut edges: Edge chipping to be avoided, no chips or cracks to extend inwards by > 50µm
- Damage and Defects: Device free from scratches and other defects that ATLAS judges could compromise the detector performance during the lifetime of the experiment. The criteria were mainly established in collaboration with the manufacturer during the pre-series production, and may continue to evolve.
- Thickness: 285 +/- 15µm
- Uniformity of thickness: 10µm
- Flatness: Sensors must be flat to 200µm when unstressed
- Mask alignment tolerance: <3µm misalignment
- Bond Pads: Metal quality, adhesion and bond pad strength to be such as to allow successful uniform bonding to all readout strips using standard bonding techniques.
- Alignment fiducials: Must be visible

Acceptance Criteria - Electrical Properties

- Total leakage current at 20^{o}C:
  <6μA@150V and <20μA@350V
- Leakage current stability: to increase by no more than 2μA @150V in dry air over 24 hours
- Depletion Voltage < 150V
- R_{bias} = 1.25 +/- 0.75 MΩ
- $C_{coupling}$ >= 20 pF/cm @ 1kHz
- $C_{interstrip}$ < 1.1pF/cm @ 100kHz @ 150V bias
- $R_{interstrip}$ > 2 x R_{bias} at operating voltage
- Strip metal resistance < 15Ω/cm
- Strip quality: a mean of >99% good readout strips per detector in each delivery batch, with no detector having less than 98% good strips.

A strip is counted as defective if any of the following conditions apply:

- *An electrical short through the dielectric with 100V applied between the metal and substrate*
- *Metal break or metal short between neighbours*
- *Implant break or implant short between neighbours*
- *Implant strip connection via resistor to bias rail broken*

Quality Control by the Manufacturer

The manufacturer is expected to perform sufficient checks to ensure consistency of processing and to maintain all electrical parameters within ATLAS specifications.

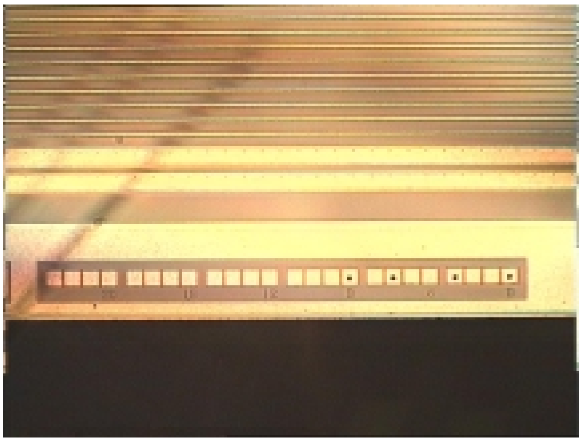
In addition, the manufacturer is expected to perform the following test measurements on each detector, and to supply the results to ATLAS:

- IV to 350V
- Depletion Voltage
- Determine strip dielectric shorts with 100V across across the dielectric (and must ground the strip metals afterwards!)
- Determine strip metal breaks
- Determine strip metal shorts to neighbours

Special Actions by the Manufacturer

• A unique ATLAS serial number must be marked on each detector using identification “scratch” pads (done automatically before/after strip probing), and delivered to ATLAS with the serial number barcoded on the package:

eg Detector 20220900200148:



ID pads on detector, binary coded decimal

Detector packaging

• Specific test information is supplied with each detector, as well as properties such as the substrate origin and orientation.

• The manufacturer interacts directly with the ATLAS-SCT database in Geneva to perform the following actions:

- register the existence of each new detector
- upload all test data (using ATLAS-supplied java routines)
- register shipment details to the ATLAS institute

Typical Manufacturer DataFile, uploaded for each delivered Detector

#General information ITEM section
%ITEM
SERIAL NUMBER 20220900201846
Mfr serial number STN11024-01846

#Test information Test section
%TEST
TEST DATE (DD/MM/YYYY) 03/04/2001
PROBLEM NO
PASSED YES
Run number 20220900201846

#Test data Data section
%DATA
TEMPERATURE (C) 27
I_LEAK150V (microA) 0.12092
I_LEAK350V (microA) 0.16074
Substr Origin 066
Substr Orient 111
Substr R Upper (kOhm.cm) 8
Substr R Lower (kOhm.cm) 4
Thickness (micron) 291
Vdep (V) 70
R Bias Upper (MOhm) 1.36
R Bias Lower (MOhm) 1.28

Substrate info, thickness, and electrical properties

#Defects section
%DEFECT
#DEFECT NAME
Pinhole 87
Pinhole 104
Pinhole 148
Short
Open

Strip defects: pinholes, metal breaks and metal opens

#IV raw data Raw data section
%RAWDATA
DATA
#IV

10	46.5
20	63.66
30	73.47
40	80.96
50	87.32
60	92.4
70	96.45

IV data from 0 to 350V, in 10V steps

Acceptance Tests by ATLAS

Detailed writeup in document FDR/99-7 available from
www.hep.phy.cam.ac.uk/silicon

- Compulsory tests on every sensor
  (Detector placed on probestation chuck)
  - Visual examination (~8 mins)
  - IV scan to 500V

- Tests on a subsample (~10%)
  (Detector mounted into frame)
  - Depletion
  - Full Strip Test
  - Metal Resistance
  - (interstrip capacitance)

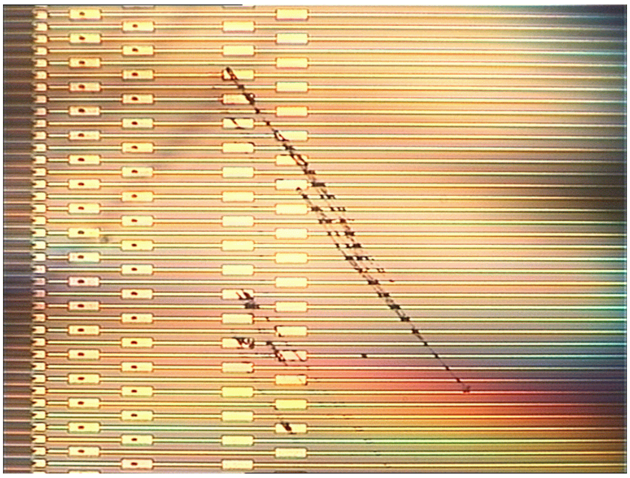
Every test is registered in the ATLAS database, together with relevant test data including PASS and PROBLEM flags, raw data, optional comments, images etc..

Visual Inspections

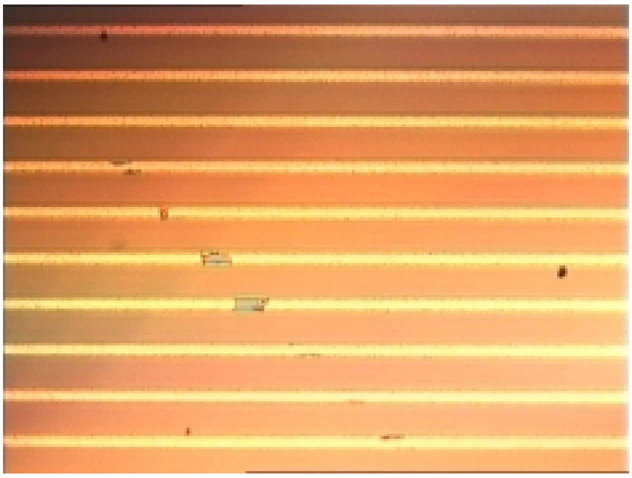
Full sensor area scanned under a microscope (automated probestation). Sensor must be free from “gross defects and scratches” and edge chips must not exceed 50μm.

What is a “gross defect”?

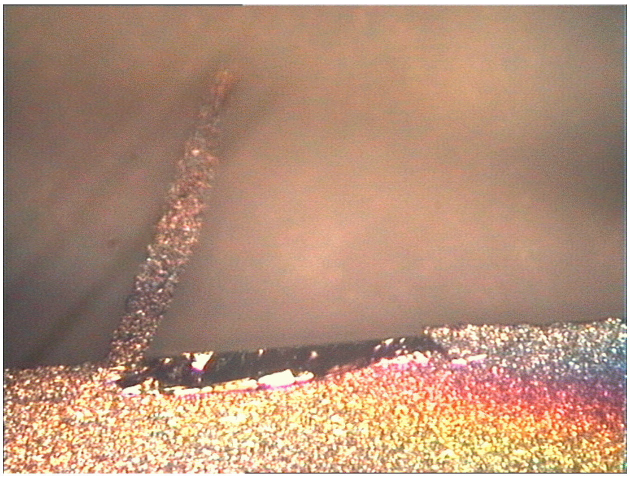
› *Requires judgement by operator, and agreement with manufacturer:*



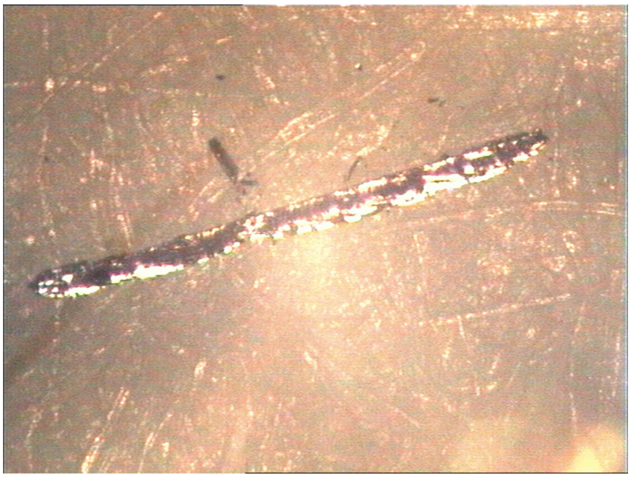
REJECT



ACCEPT



Rear Edge Chip REJECT

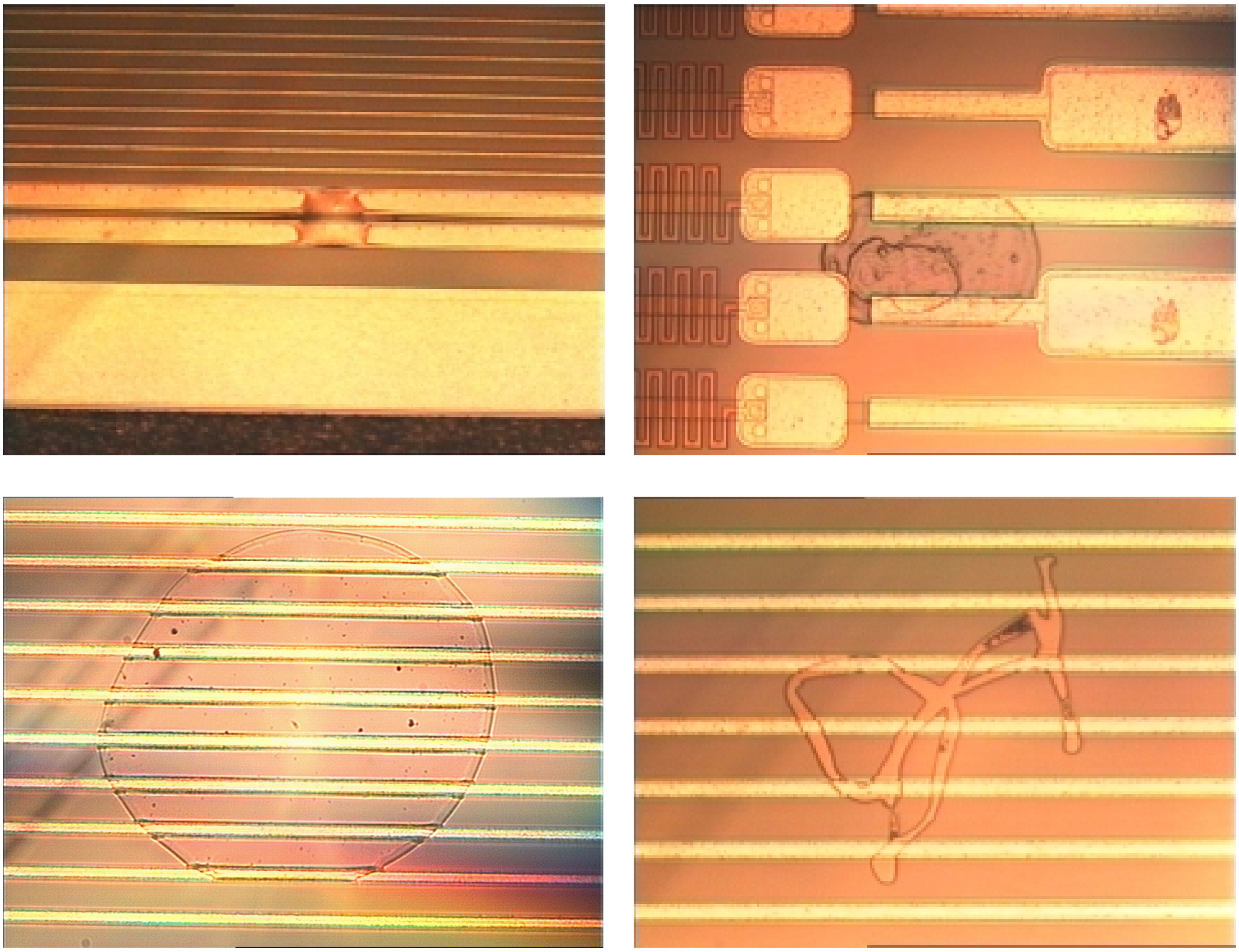


Debris in packaging from edge chipping poses danger

Visual Inspections

What about general visual curiosities?

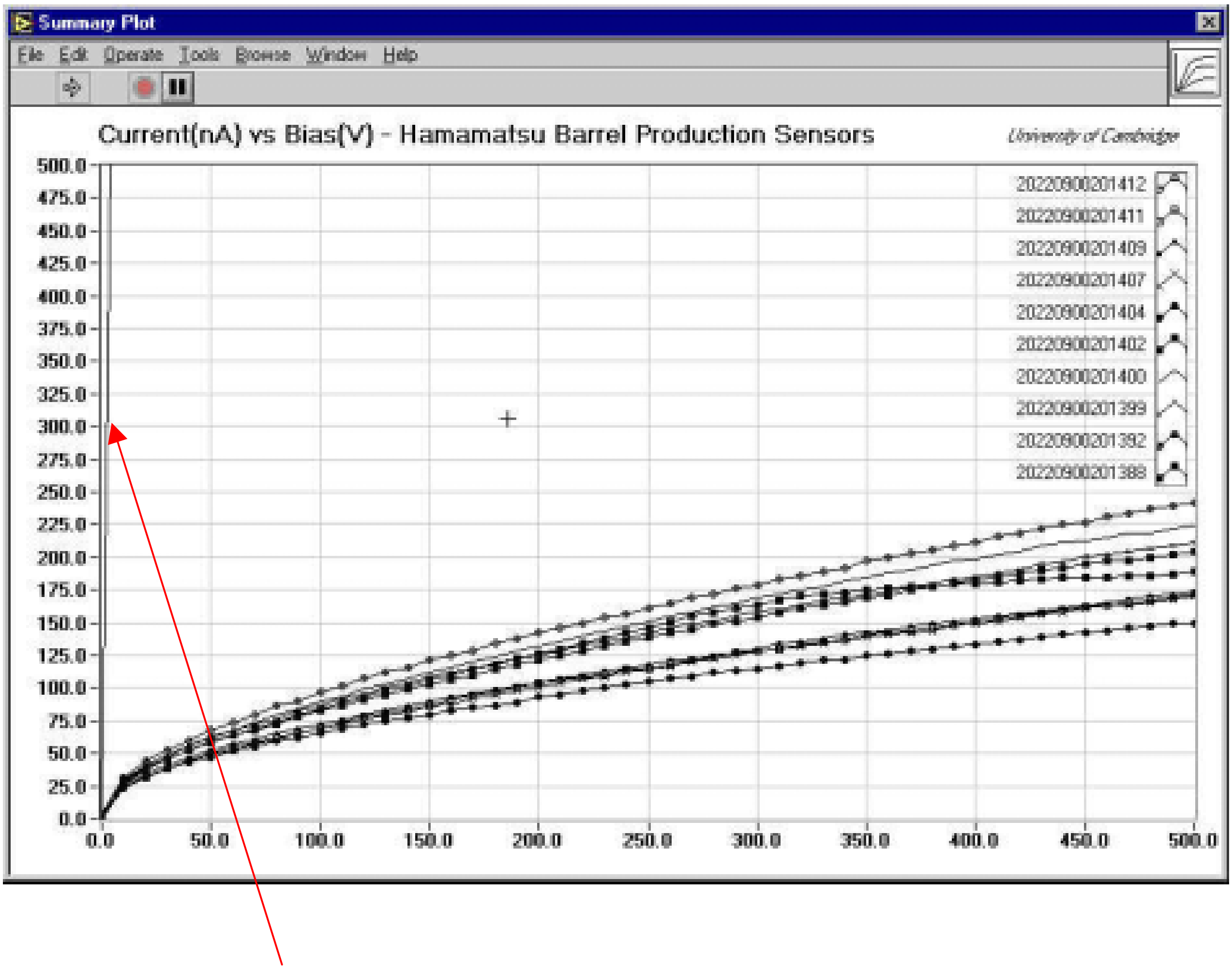
Almost certainly harmless, but if frequently occurs (eg observed several times in a batch of ~100 sensors), choose as candidate for irradiation:



Leakage Current Tests

Measure from 0 to 500V in 10V steps, reject if any of the following apply:

- I> 6μA@150V
- I>20μA@350V
- ΔI(ATLAS-manufacturer) > 2μA@150V or 4μA@350V

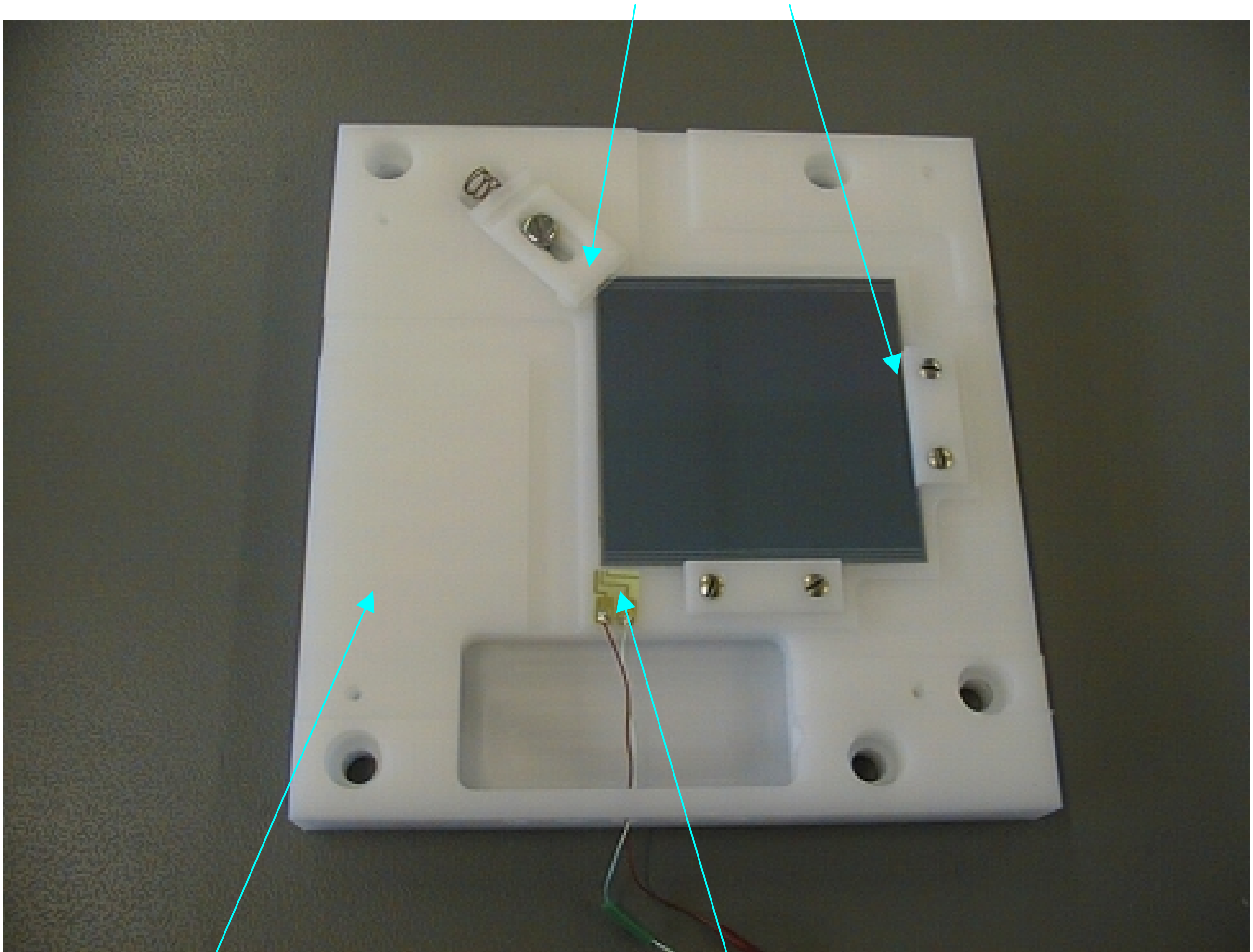


Fails ΔI test only

NB: Hamamatsu agreed ΔI rejection criteria to be tightened to 1μA

For more extensive tests (on ~10% of total sample), detectors are held and bonded into a frame to minimise risk of damage by excessive handling

Sensor held in by very light spring pressure between 3 delrin clamps



Delrin support block

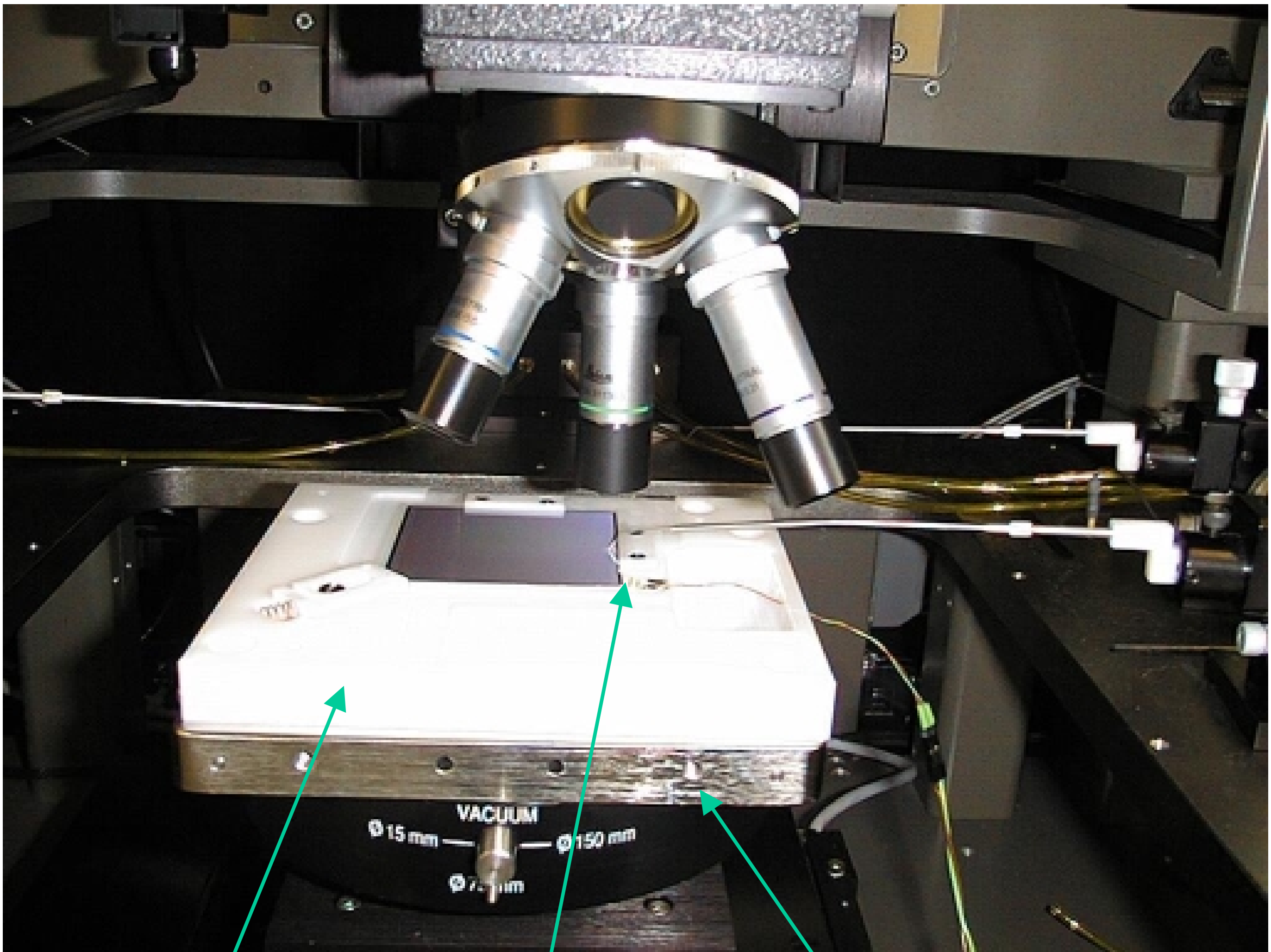
Bias connections, bonded to bias rail (gnd) and edge implant (HV)

Leakage Current Stability Test at Cambridge

5 detectors on support blocks, with bias connections wire bonded out to soldered leads.

Environment Chamber

Full Strip Test Setup at Cambridge



Support Block, held down by chuck vacuum

Probestation Chuck

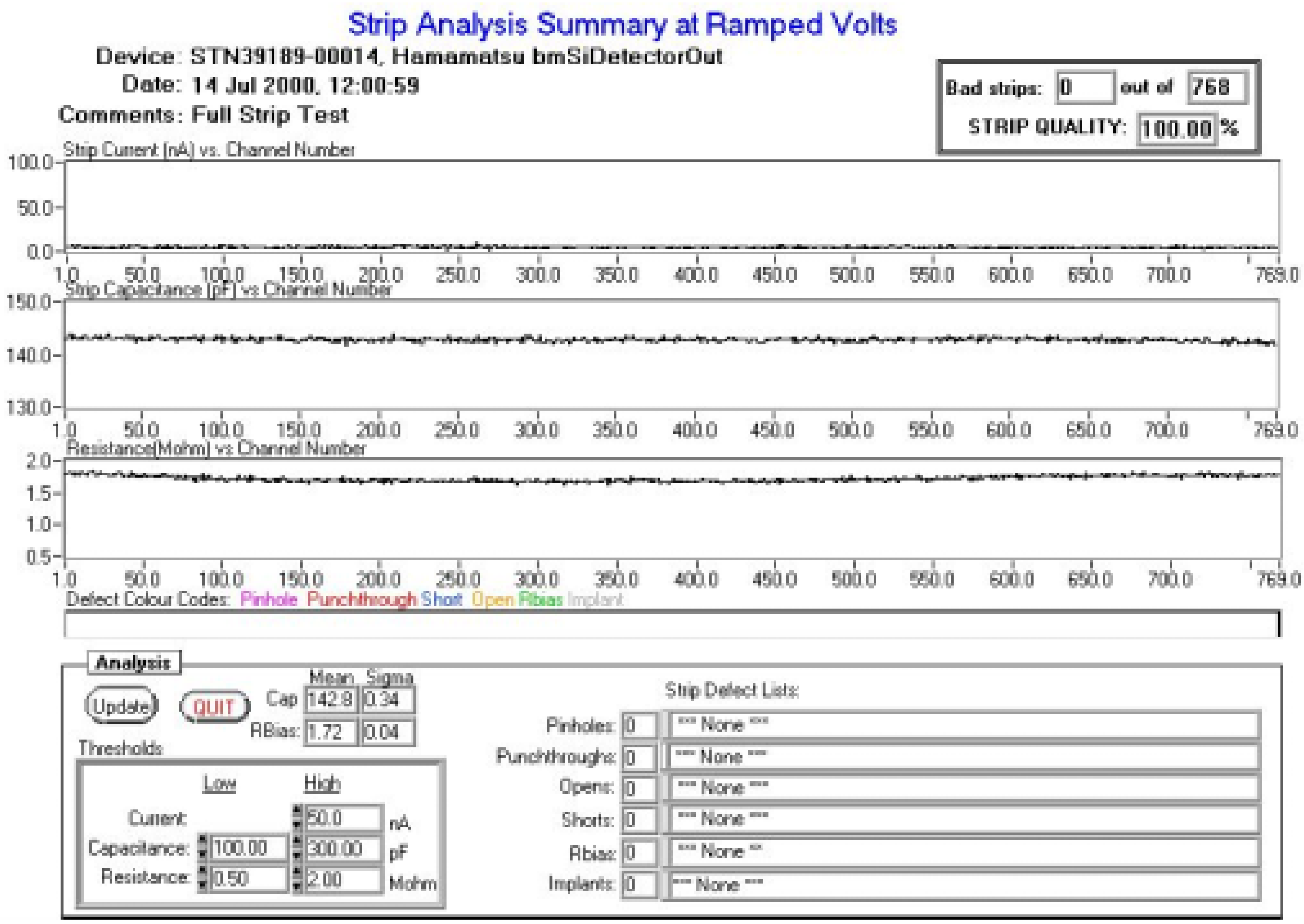
Wire bonds to bias connections

ATLAS Full Strip Test

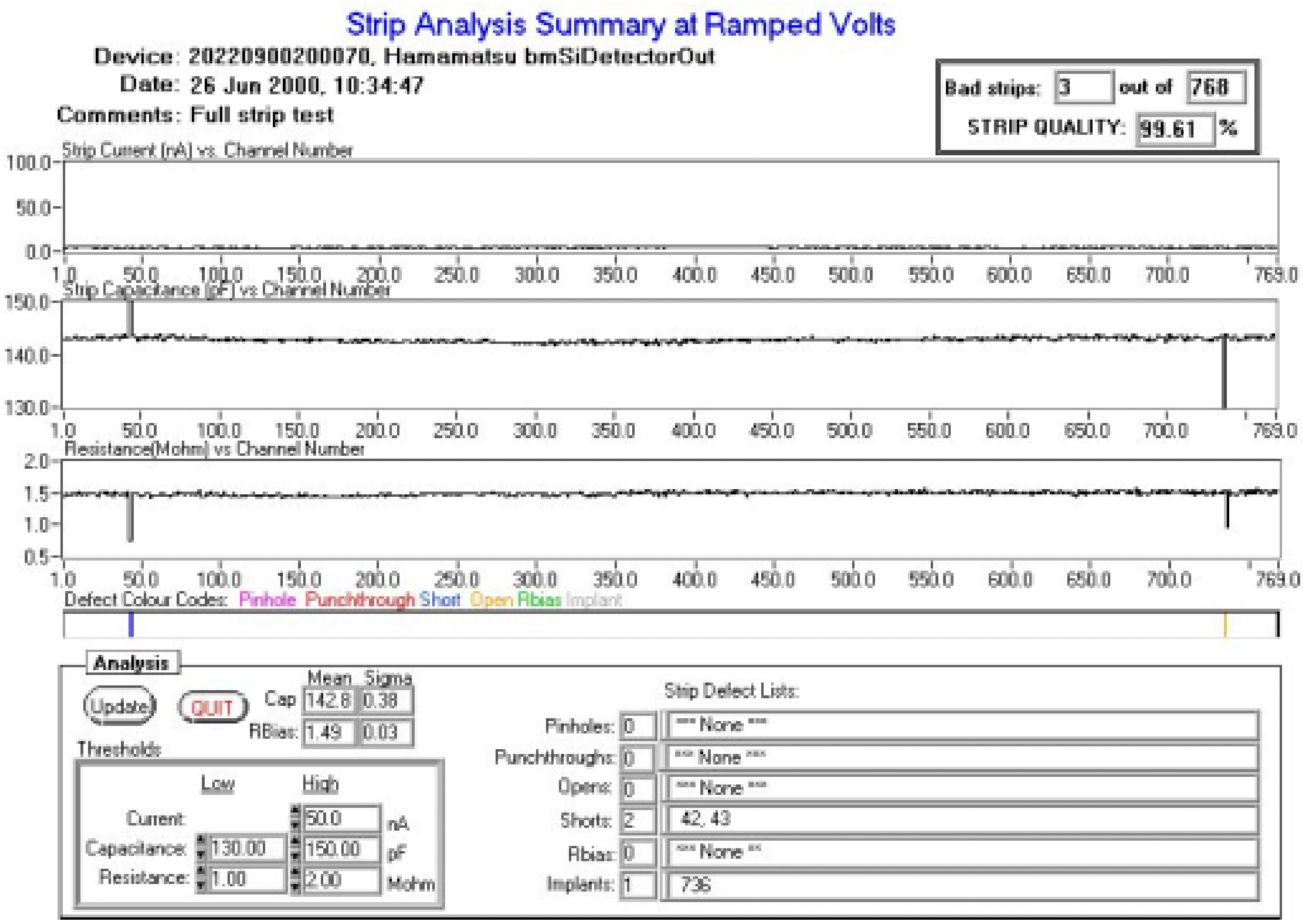
With the sensor partially biassed (to ~50% of full depletion voltage), step through every strip to probe the strip metal. For every strip, apply 100V across strip dielectric to determine robustness of dielectric, then return strip metal to ground and model CR in series on the measured impendance @100 Hz between strip metal and bias rail

› $C = C_{coupling}$ $R = R_{bias}$

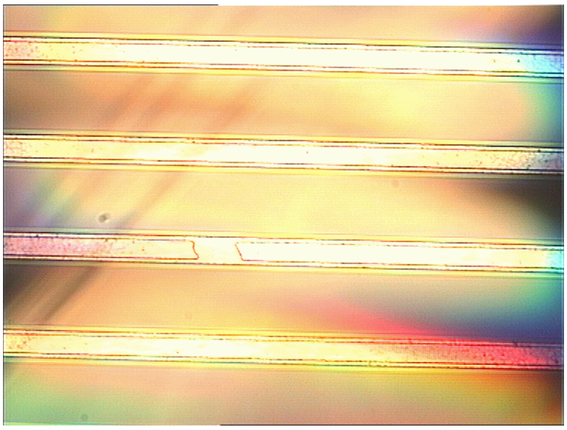
Sensitive to any strip defect, and any general processing defect that may effect operation of sensor, and yields the bias resistance and coupling capacitance for every strip.



Detection of implant breaks, strip metal defects

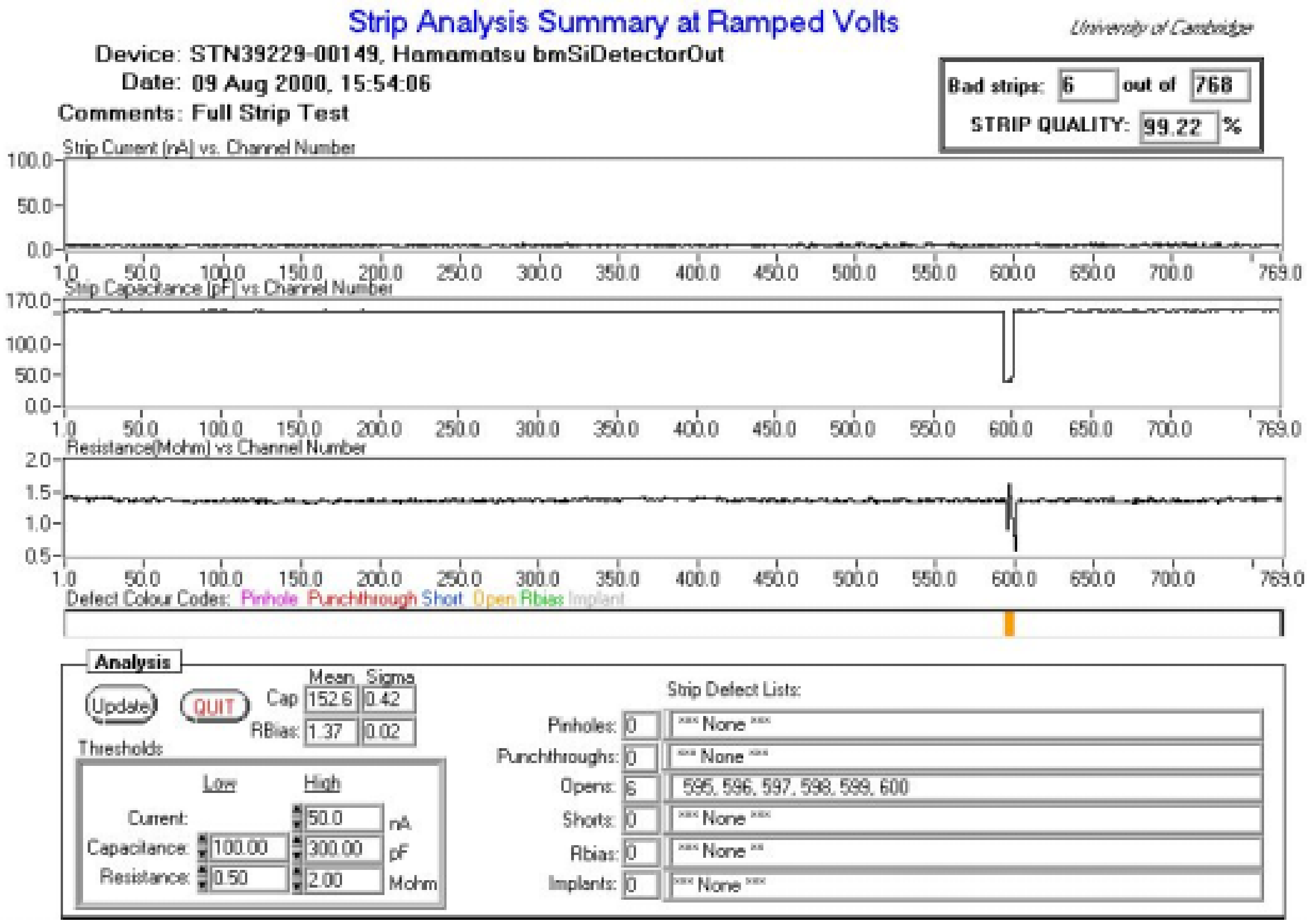


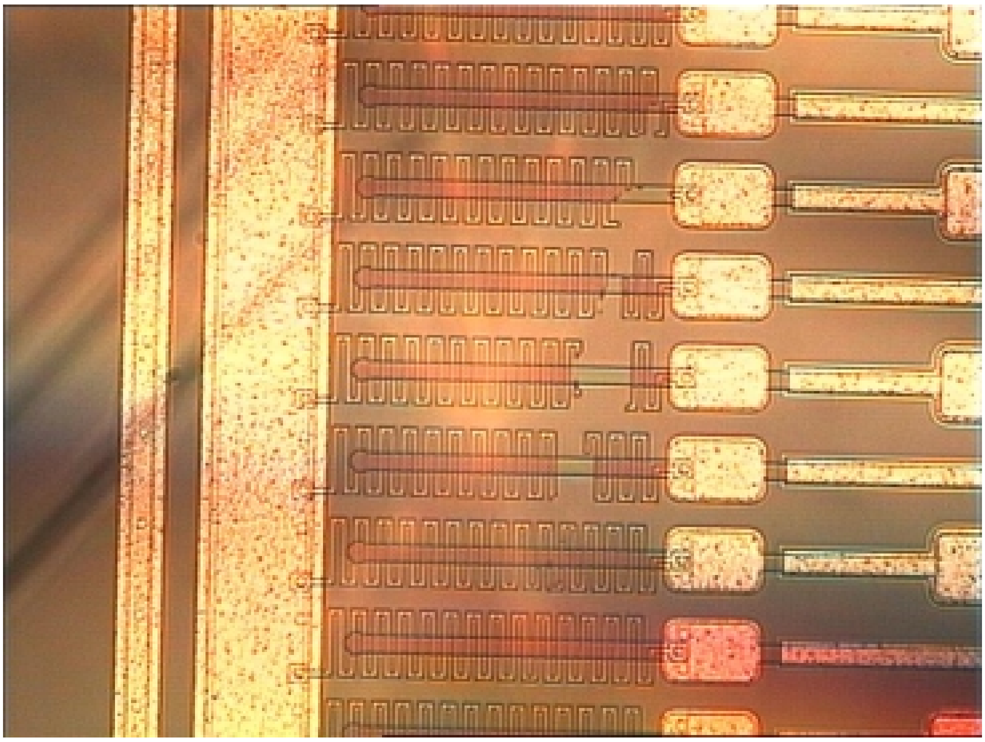
Metal short



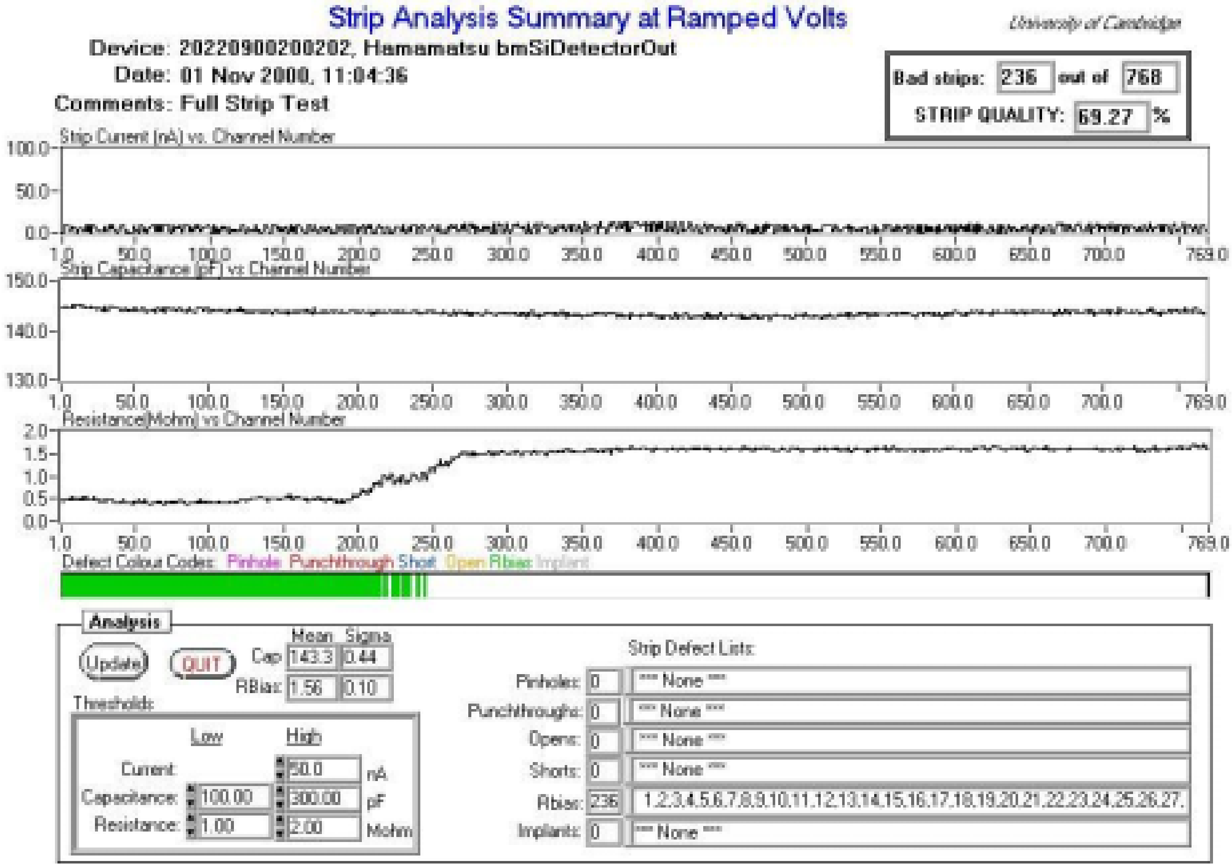
Implant break

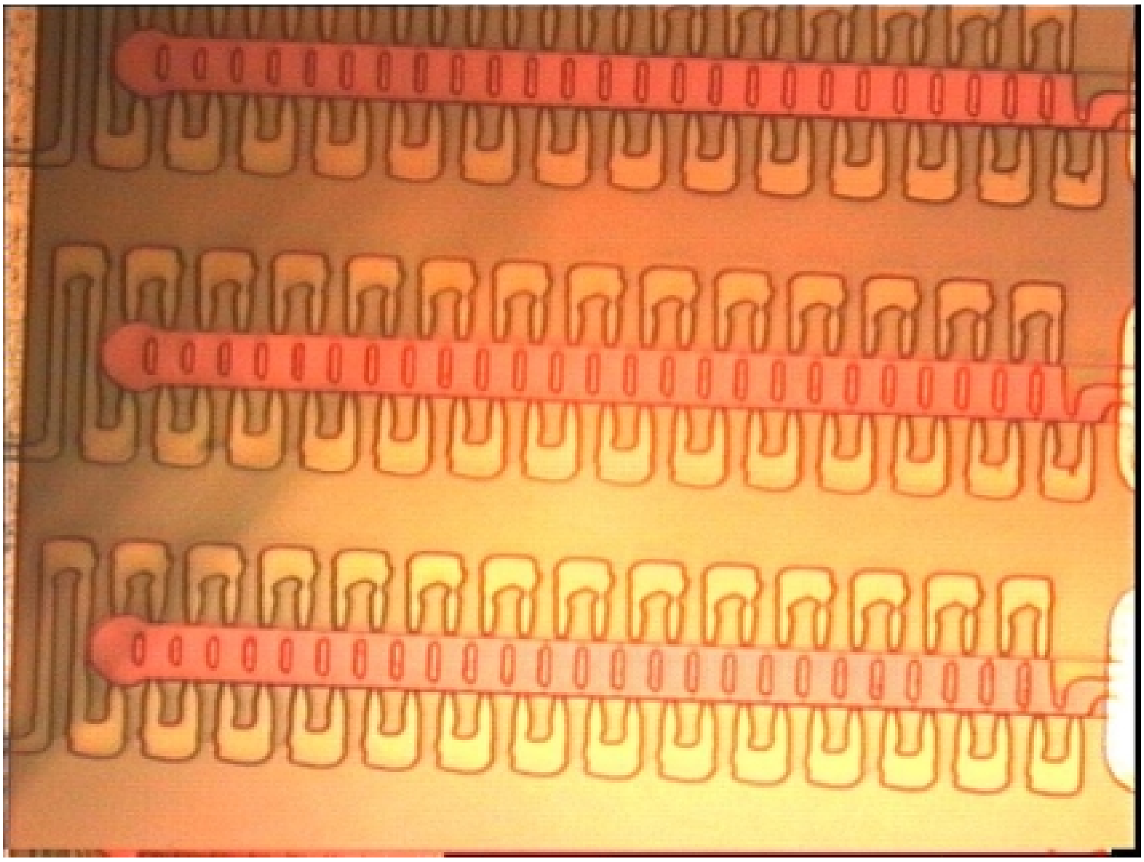
Detection of broken resistors





Detection of Resistor Process Defect

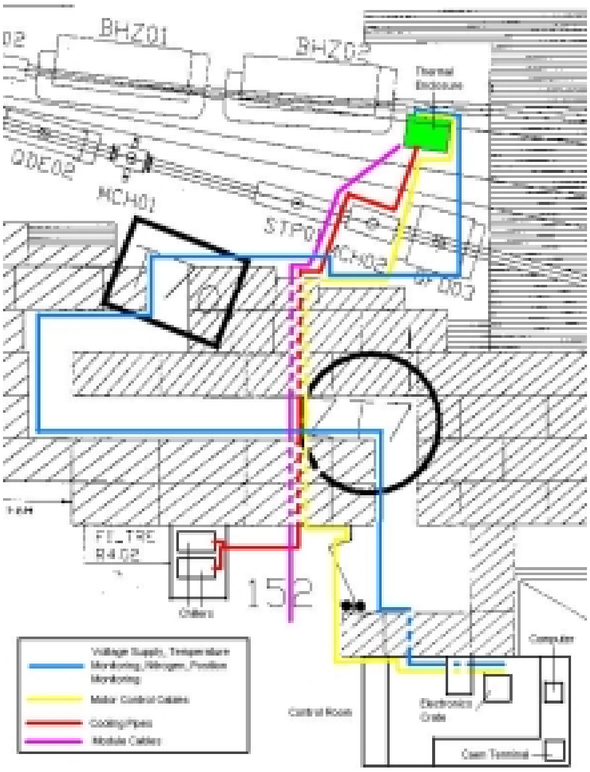




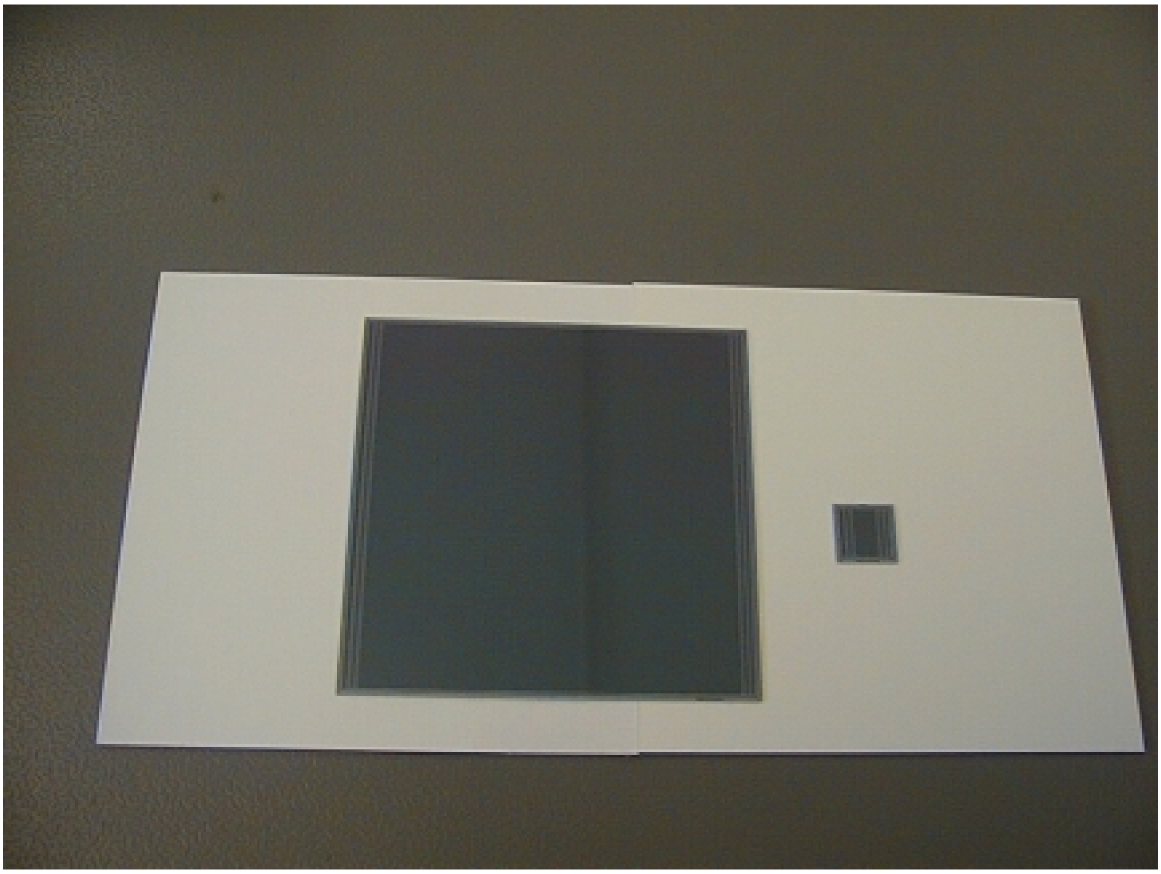
Irradiations

Samples of detectors will continue to be irradiated throughout production, to ensure that the post-irradiation performance observed from qualified detectors is being maintained.

The detectors are irradiated with 24 GeV/c protons to $3 \times 10^{14} p.cm^{-2}$ at the T7 irradiation facility at the PS. During irradiation, the detectors are chilled in nitrogen to $-8^{o}C$, and biased at 100V with all strip metals grounded. The irradiation takes typically 6-10 days, and following irradiation the detectors are annealed for 7 days at $25^{o}C$ to bring them to the minimum of the anneal point.



Miniature ("baby") Detectors



5-10% of production detectors are accompanied by fully-diced miniature detectors. These will be used by ATLAS for routine quality control of post-irradiation performance.

They are duplicates of the large detector, except only 10x10mm, and with only 98 8-mm long strips.

Irradiation of miniature detectors is relatively easy, and can be carried out at different radiation facilities.

Acceptance Criteria

During Irradiation

• Detector leakage current should increase in a stable and monotonic fashion

Post-Irradiation and post-anneal

•Total leakage current <250μA up to 450V @ -18^{o}C

• Leakage Current stability: to vary by no more than 3% in 24 hours at 350V at -10^{o}C

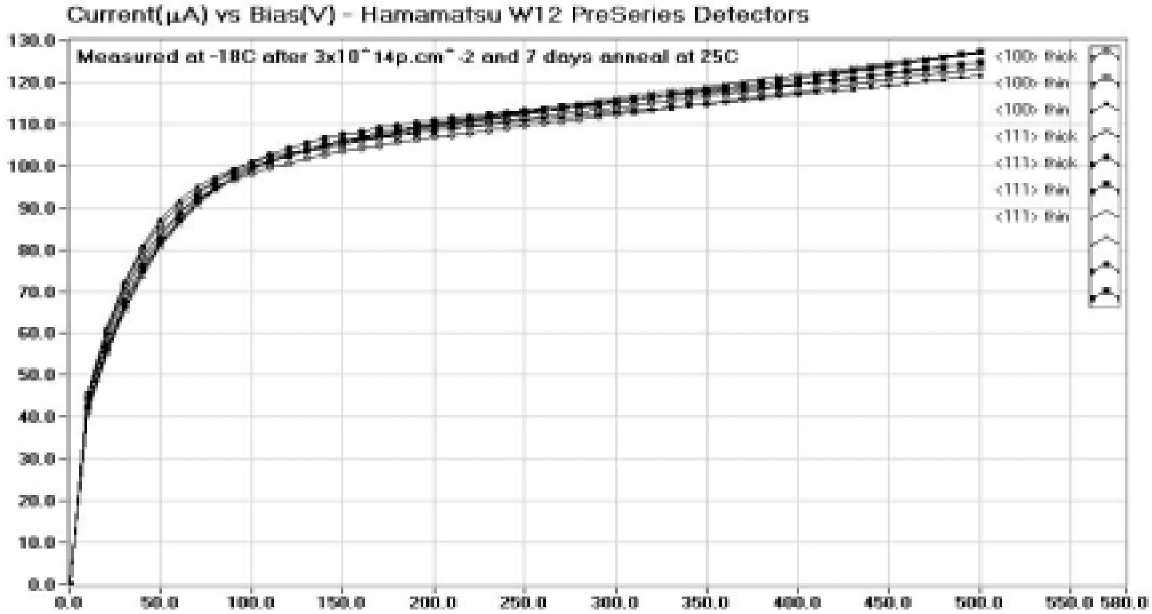
• Strip defects: Number of strip defects (dielectric & metal) within pre-irradiation acceptance level

•R_{bias} to remain within pre-irradiation limits

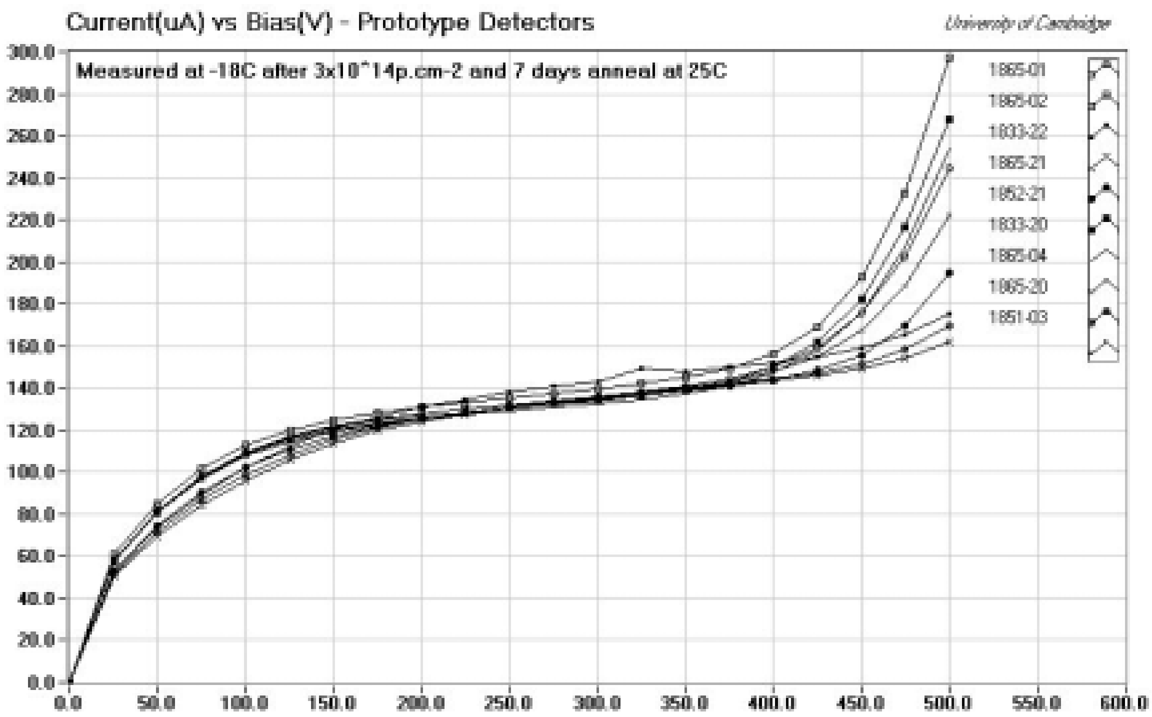
• Charge collection: Maximum operating voltage for >90% of maximum achievable charge : 350V (checked with SCT128A analogue readout at 40MHz)

• Microdischarge: must be <5% increase in measured noise on any channel due to microdischarge when raising detector bias from 300V to 400V (checked with readout electronics running at 40MHz)

Post-Irradiation Leakage Currents

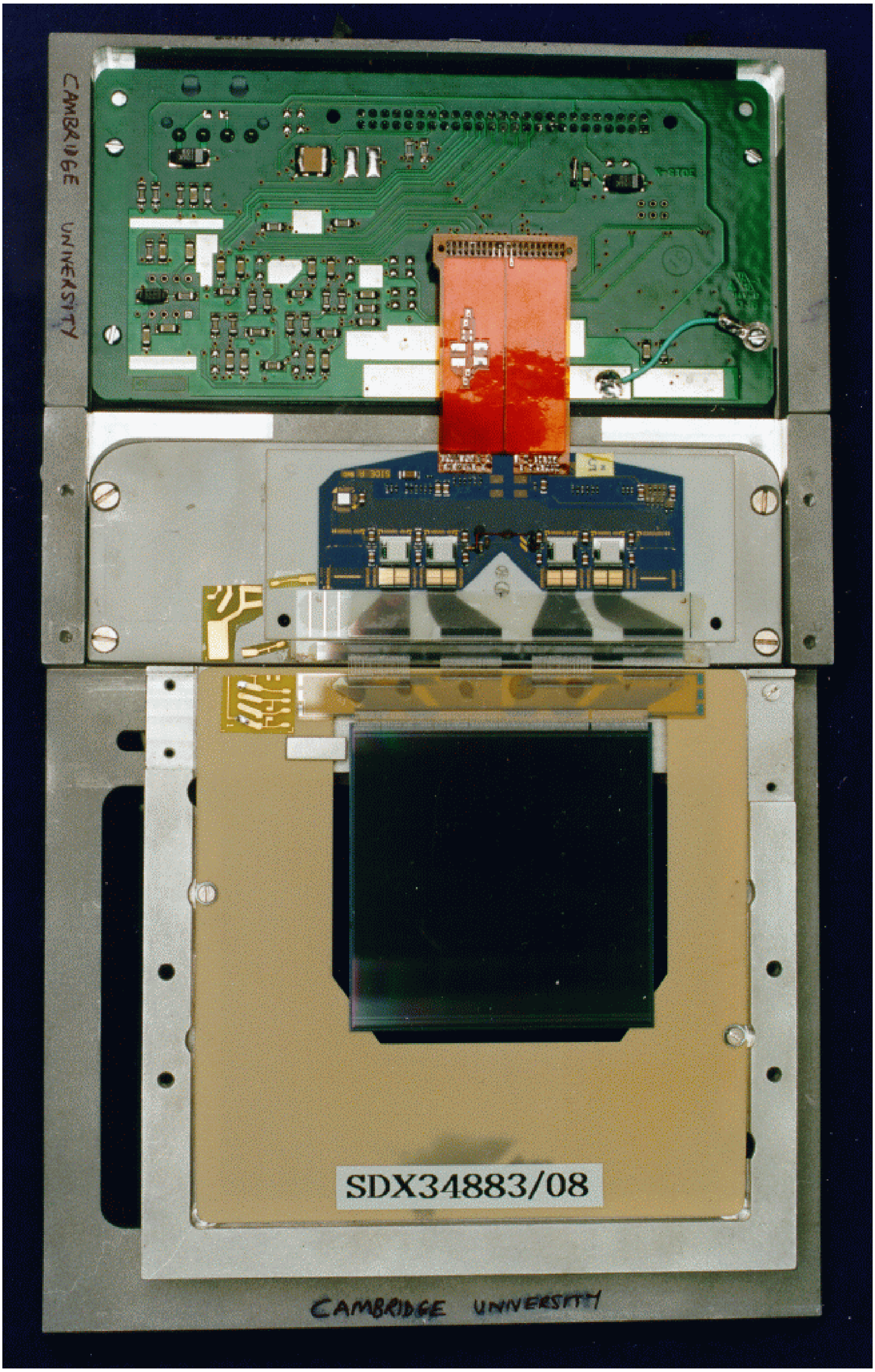


Qualification W12 detectors from Hamamatsu



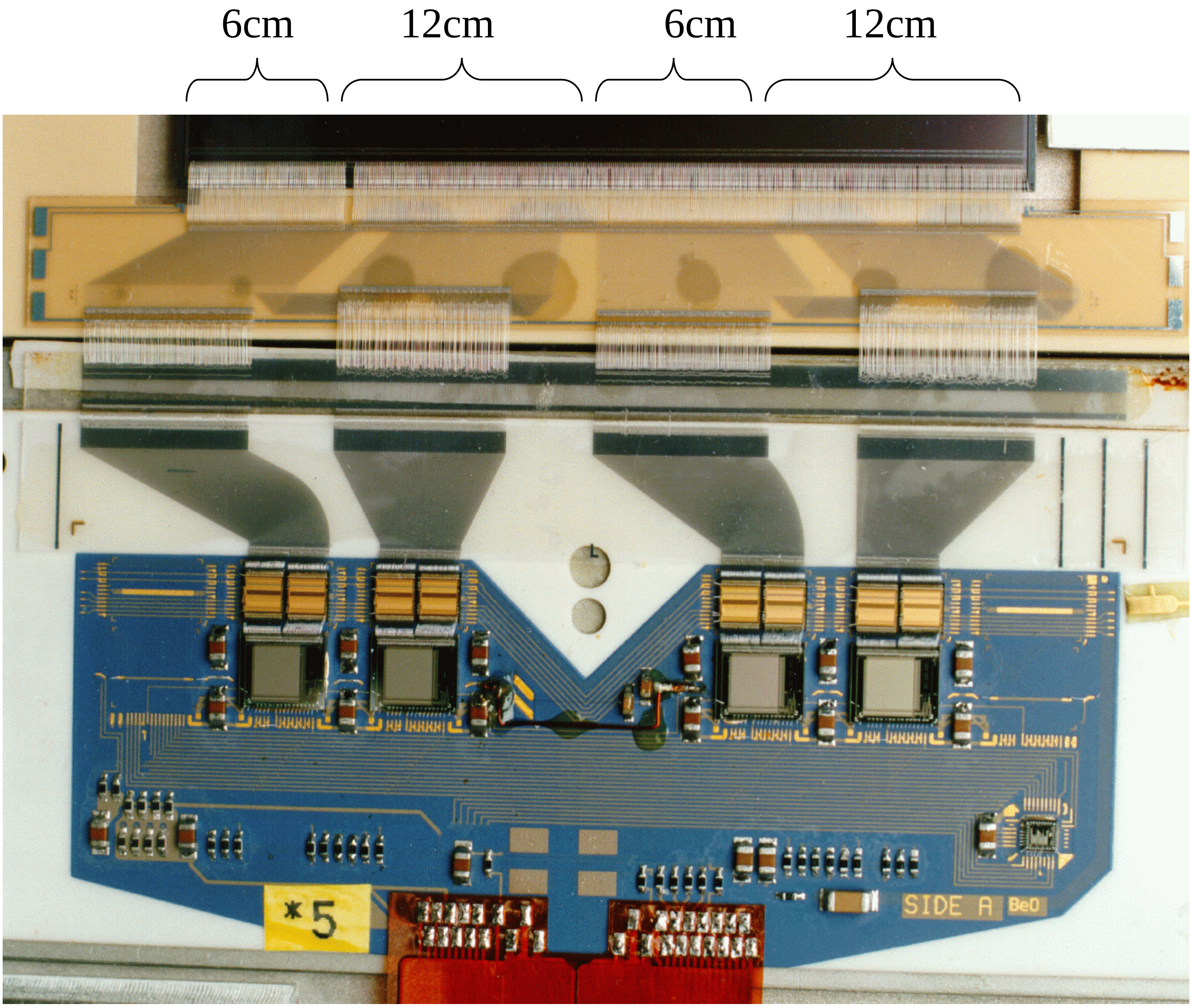
Early prototypes from non-qualified manufacturer, showing current increase from 400V due to microdischarge.

Measuring Strip Noise Distribution using rebondable modules



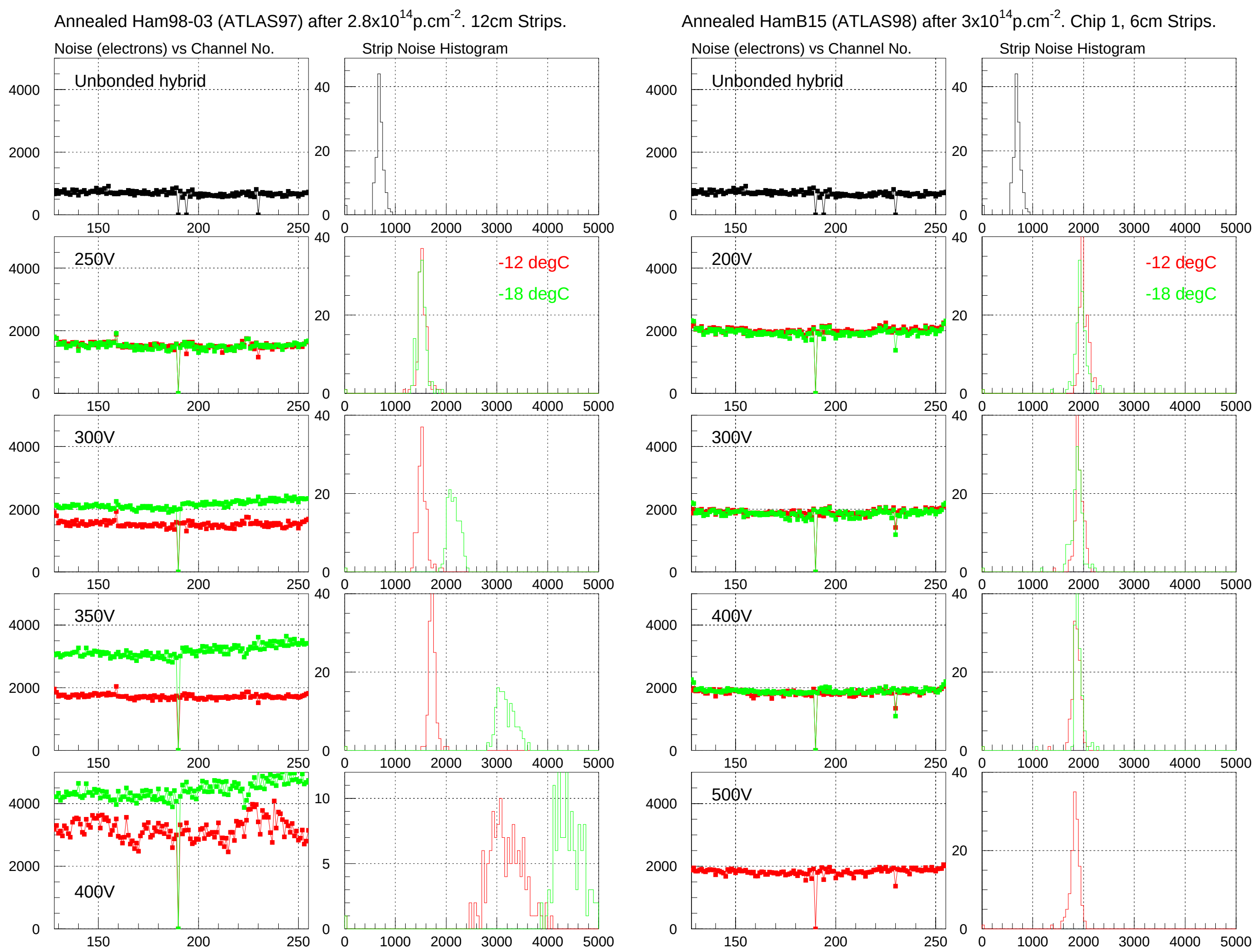
Detail of wirebonding scheme of rebondable binary module

Effective strip length connected to chip:



Strip Noise Distributions

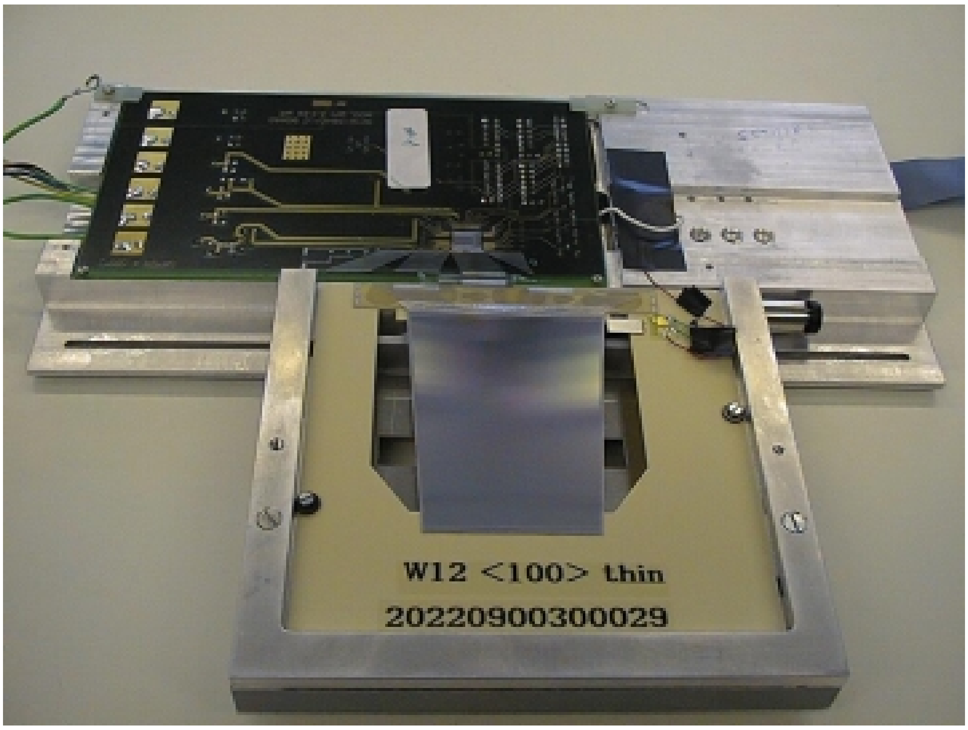
Binary Readout (LBIC/CDP) at 40MHz

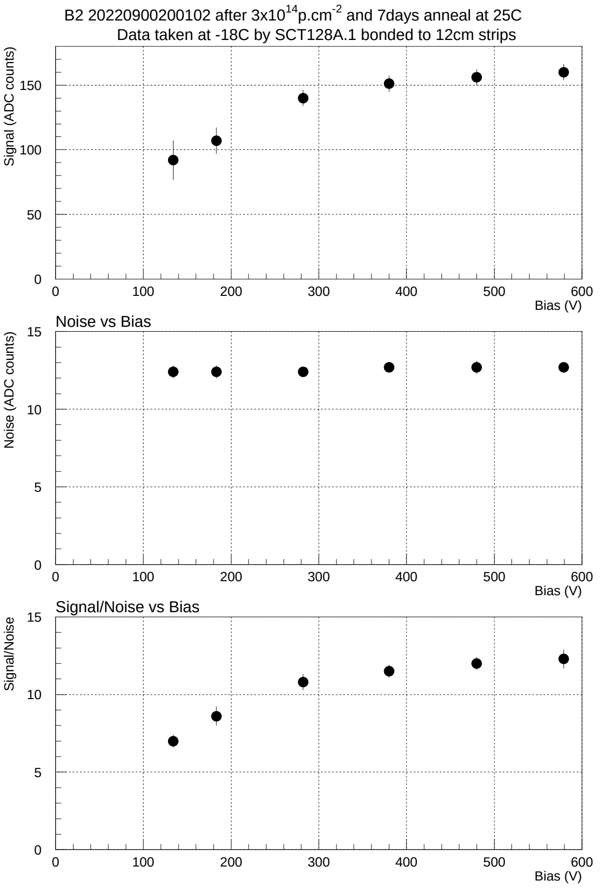


Early prototype, showing widespread microdischarge with increase bias

Detector from qualification batch, no signs of microsdischarge.

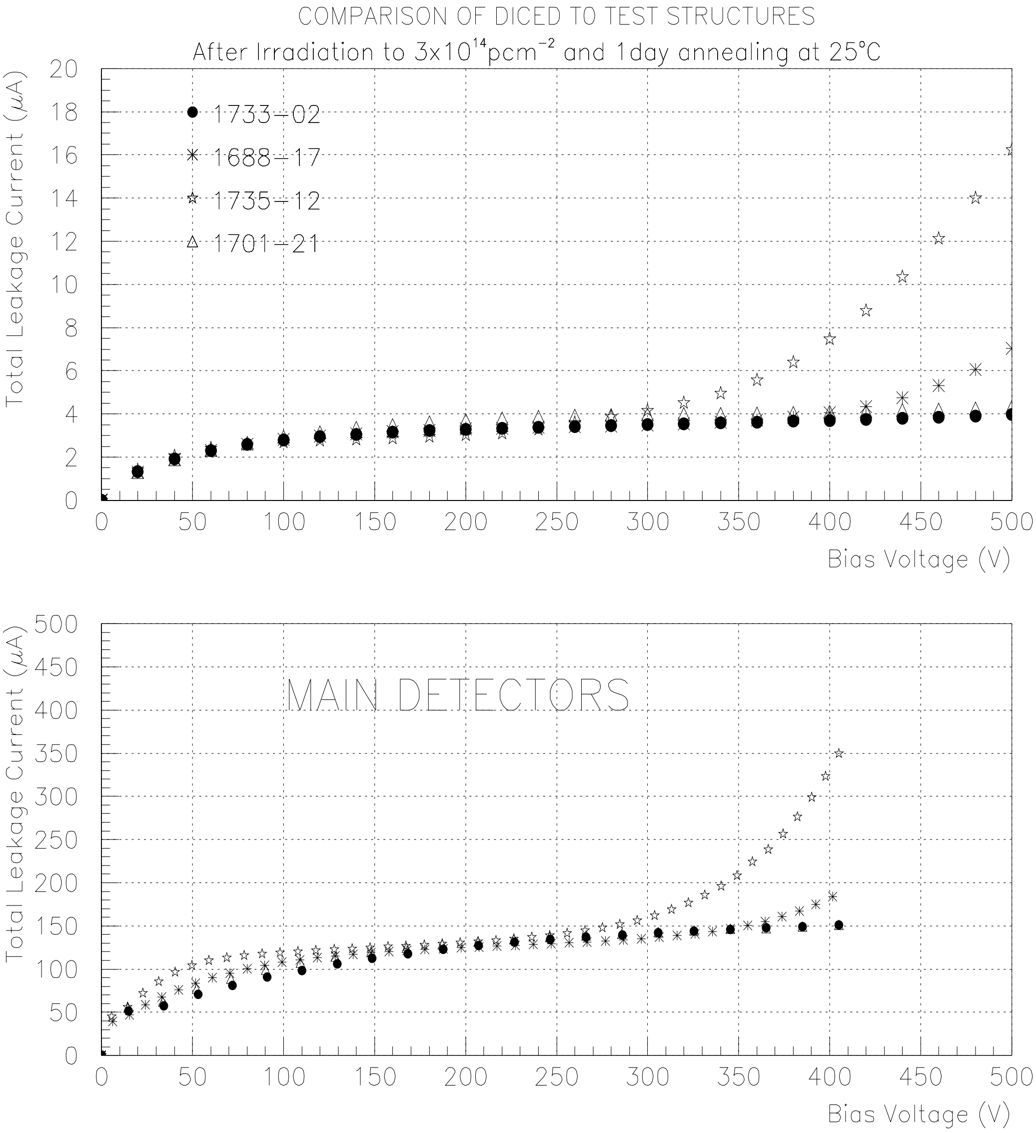
Charge Collection, using SCT128A





Miniature Detectors

We expect this to be a valuable tool in the monitoring of processing consistency, by means of post-irradiation checks of leakage current. Early work with Micron prototypes suggested a correlation of leakage currents between large detectors and miniature detectors. However this has not been conclusively established yet for Hamamatsu miniatures.



DAQ and Database Issues

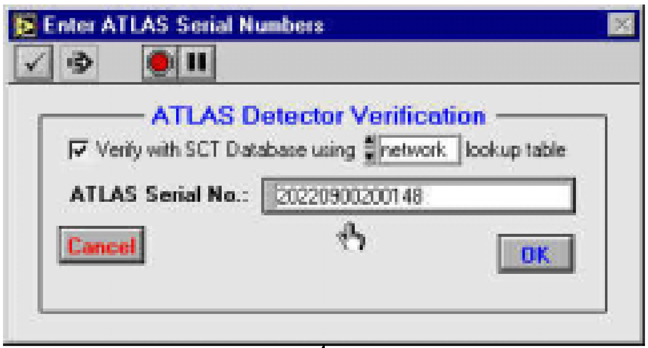
An error-free system requires complete automation of DAQ and file-management/backup, with zero manual intervention

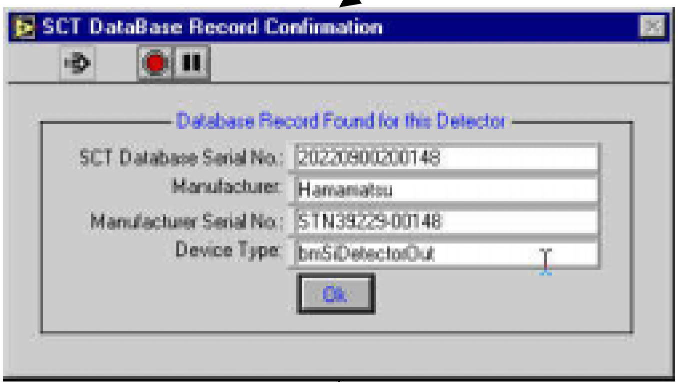
Test Procedures:

- DAQ implemented in LabView
- No data of any type is ever entered by hand
- Detector serial number entered by barcode reader
- Tests cannot start unless a detector is registered in the database and "owned" by the institute
- On completion of a test, handling of test data is completely automated:
  - creation of local data file
  - update of local electronic book-keeping
  - creation of local "database" file (contains all information required by database)
- Database files uploaded to Geneva database on a daily basis, using standalone java application. The java application takes care of file management (uploads all database files sequentially and archives each file if the upload for that file was successful)

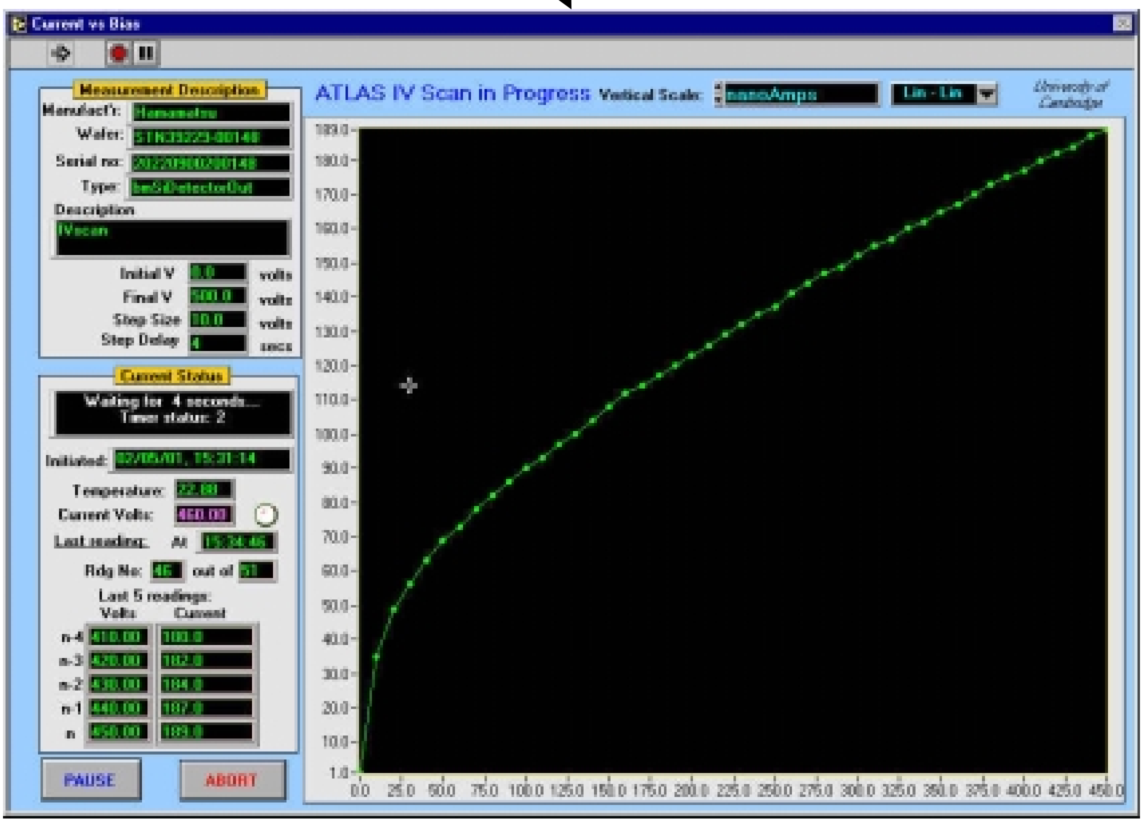
Example: IV scan for barrel detector 20220900200148

1. Authentication of serial number

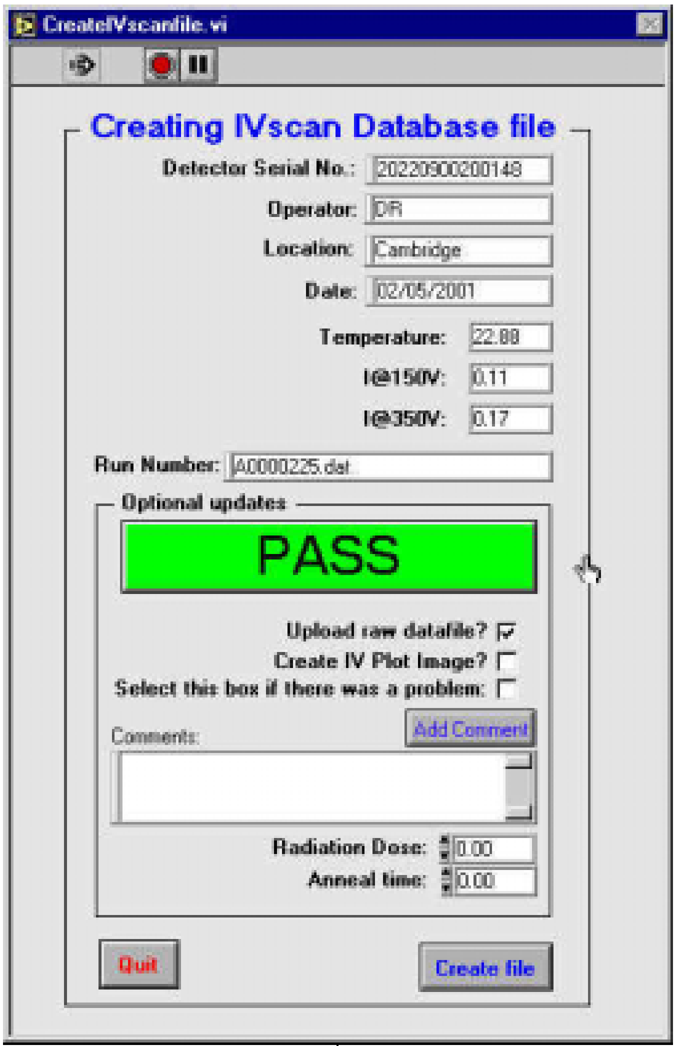




2. Confirmation (or otherwise!) of valid serial number



3. IV scan in progress

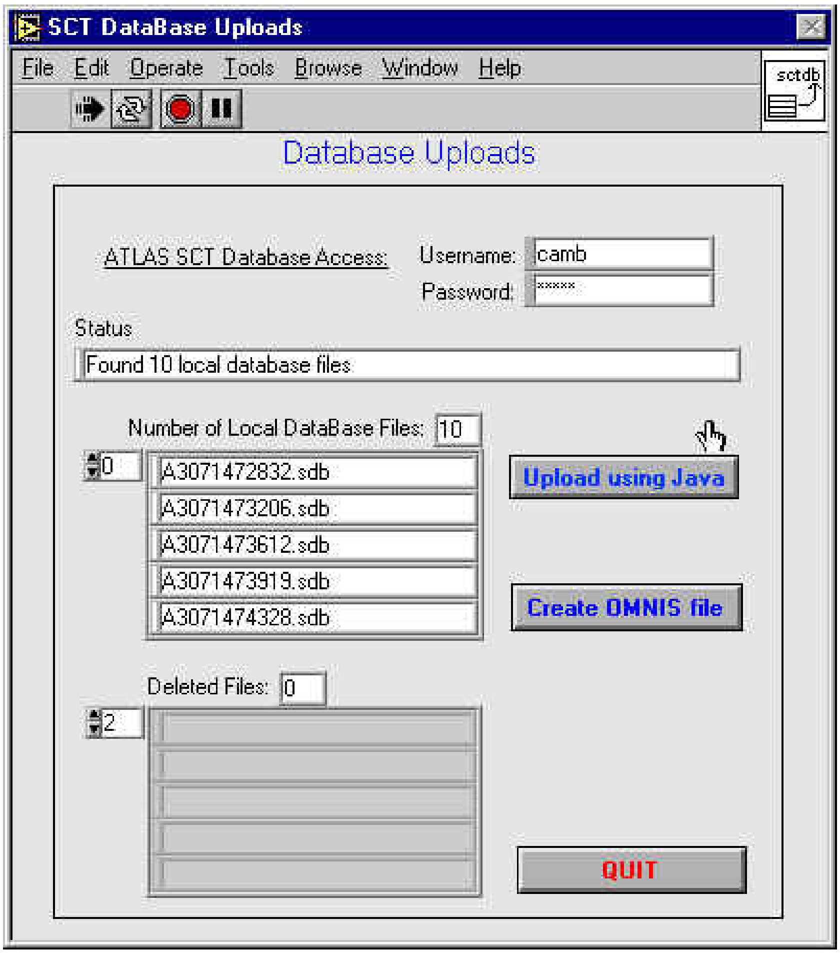


4. On completion, local raw data file is saved, and database entries are confirmed to operator, who is prompted for optional entries (comments, problems etc)

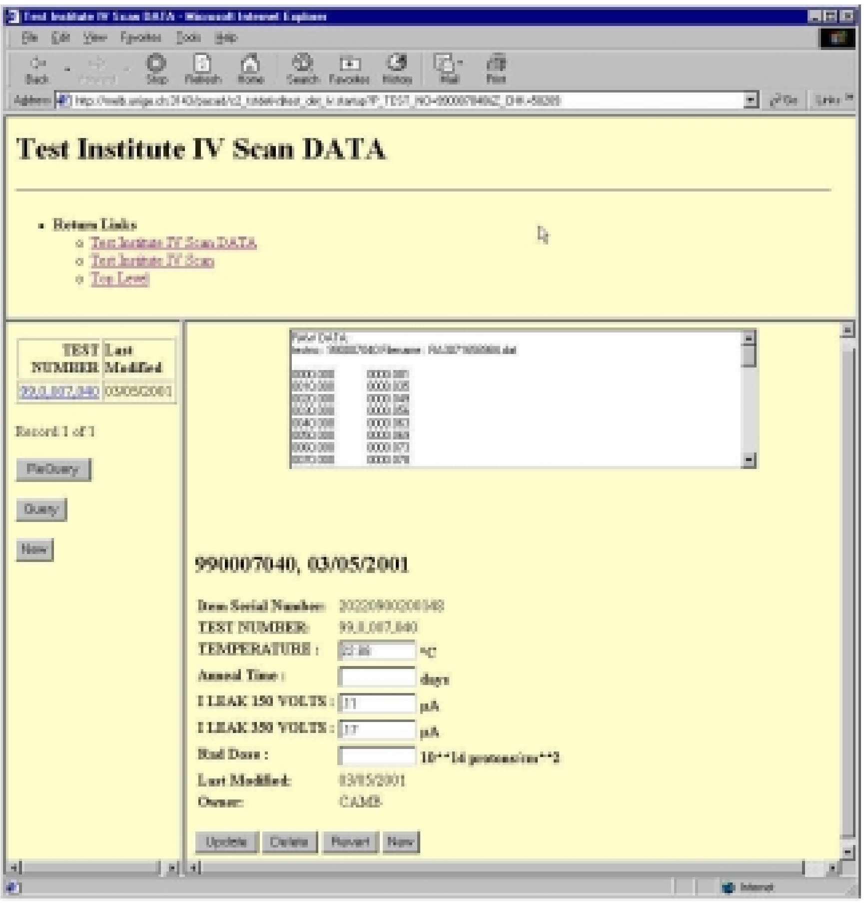
```
%NEWTEST
SERIAL NUMBER  : 20220900200148
TEST MADE BY   : DR
LOCATION NAME  : Cambridge
TEST DATE      : 02/05/2001
PASSED         : YES
PROBLEM        : NO
RUN NUMBER     : A0000225.dat
%DetIVscan
Temperature    : 22.88
I LEAK 150     : 0.11
I LEAK 350     : 0.17
%Test RawData
FILENAME   : Z:\sctdb\rawdata\RA3071658984.dat
```

5. Local database file is created

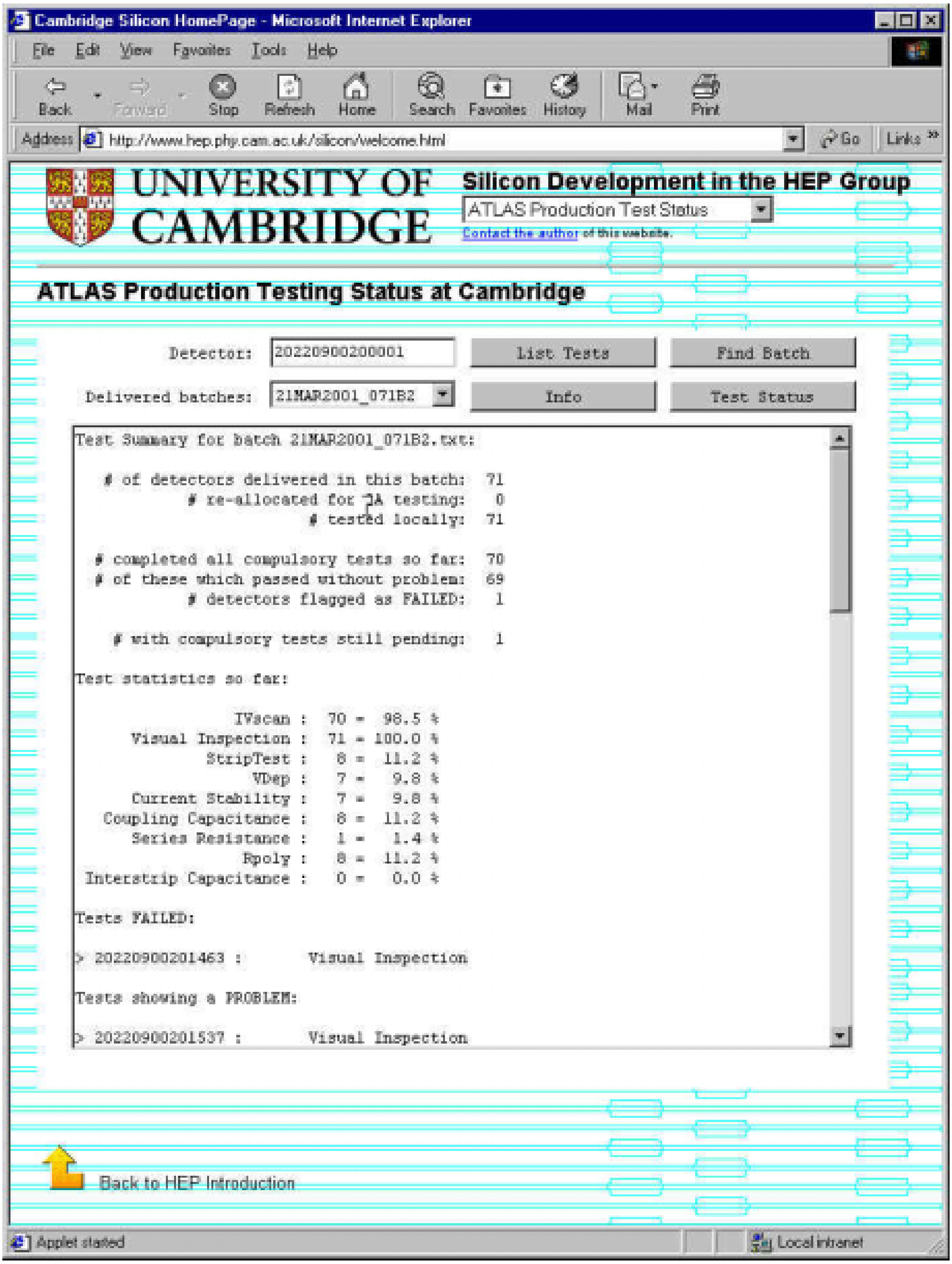
6. Database files are periodically uploaded into the database, using LabView/Java



7. Data available to SCT community from ATLAS SCT database webpage



Local book-keeping both electronic and on paper



Applet displaying test statistics at Cambridge

Essential Equipment for In-house QA

- Cleanroom environment, with temperature/humidity control
- High-power, quality optics with high resolution camera or video capture card
- Automatic probestation
  - *Summit, Wentworth, Alessi, Maehlum ...*
- Voltage sources and Picoammeters (x2)
  - *Keithley 487, 237, 6517 ...*
- LCR meters
  - *HP, Wayne-Kerr ...*
- Switching matrix
  - *Keithley, Pickering ...*
- Wire bonder (automatic if taking part in irradiation tests)
  - *mainly K&S 1470 (also Delvotec, Hesse&Knipps)*
- Environment chamber
  - commercial or ‘home-made’
- Warm and cold storage in dry air (eg chest freezers)
- Miscellaneous
  - temperature/humidity meters, micrometer,barcode reader
- Networked PCs, with LabView & database s/w

Summary

- ATLAS is taking delivery of production detectors
- Our QA procedures are now well established
- QA by the receiving institute is essential, particularly in the early stages of mass production

  Eg:
  - *severe edge chipping on rear side on early deliveries due to misinterpretation of specifications*
  - *some subtle but severe processing abnormalities passed unnoticed by the manufacturer*
  - *manufacturer is completely reliant on ATLAS for feedback on post-irradiation robustness*

- After a hesitant start, Hamamatsu production is now (May 2001) mostly on schedule