Quality Assurance for the ATLAS Pixel Sensor

1st Workshop on Quality Assurance Issues in Silicon Detectors

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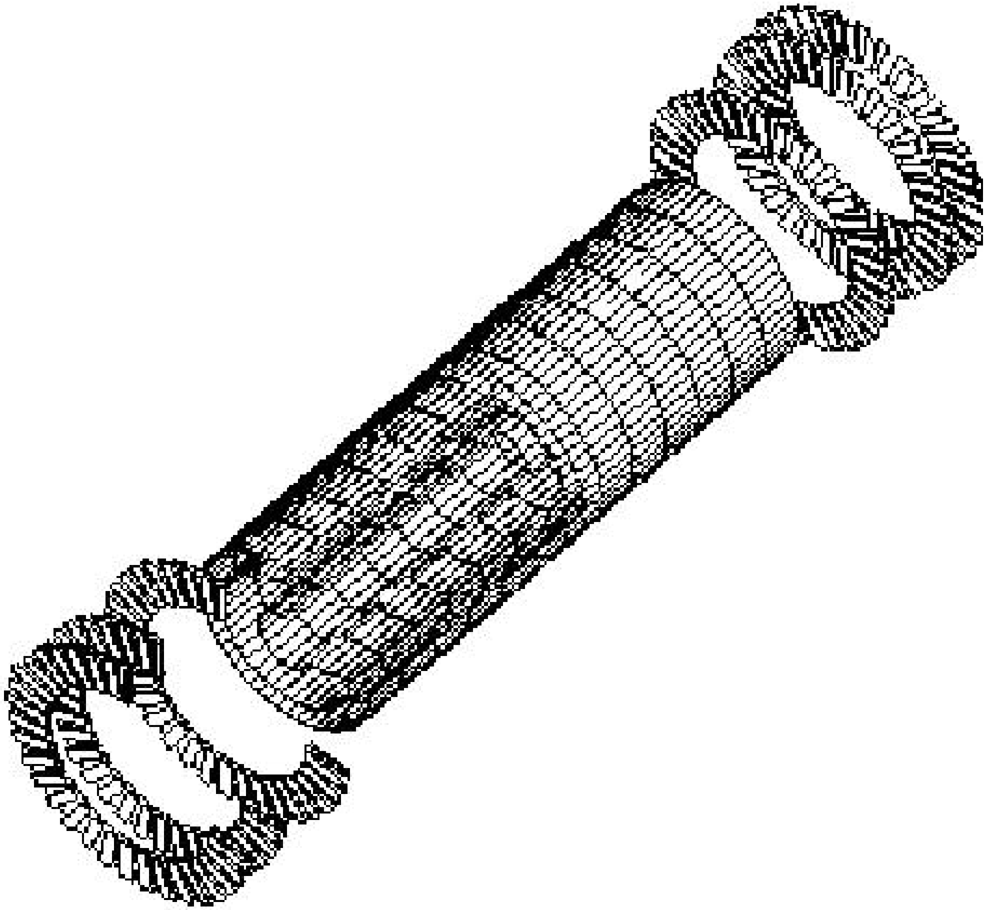
Contents:

- role of the pixel sensor
- overall QA concept
- measurement of bulk parameters
  - sensor breakdown
  - time stability
  - sensor depletion
  - radiation hardness
- cross calibration

Introduction

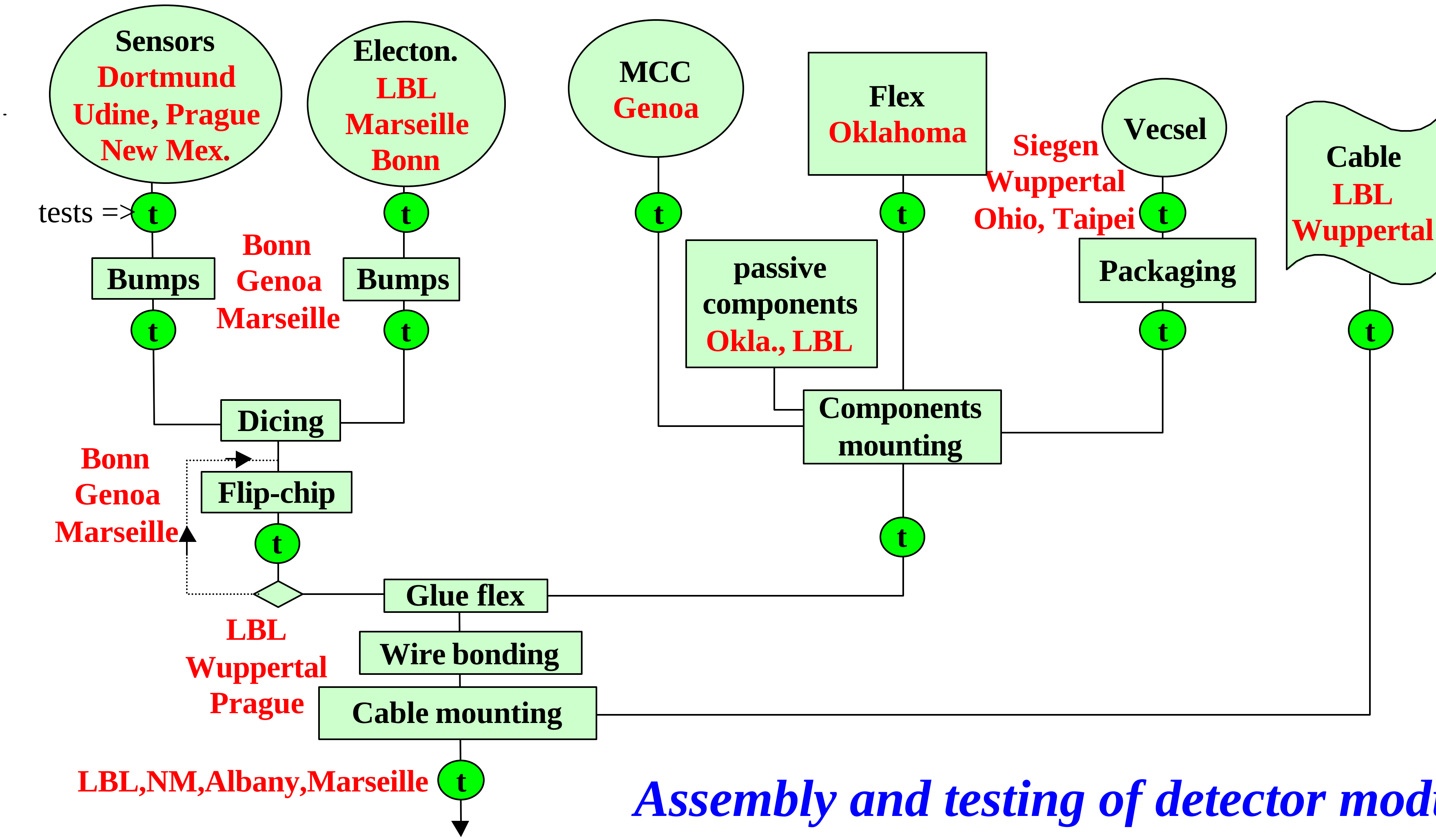
Why systematic quality assurance for the ATLAS pixel detector?

- *large number of detector parts (1718 modules fitted with one sensor tile and 16 front-end chips each)*
- *parts not easily accessible after assembly (central position, cooling and radiation)*
- *every bad pixel degrades performance*



» $1.1 \cdot 10^8$ pixel channels in total

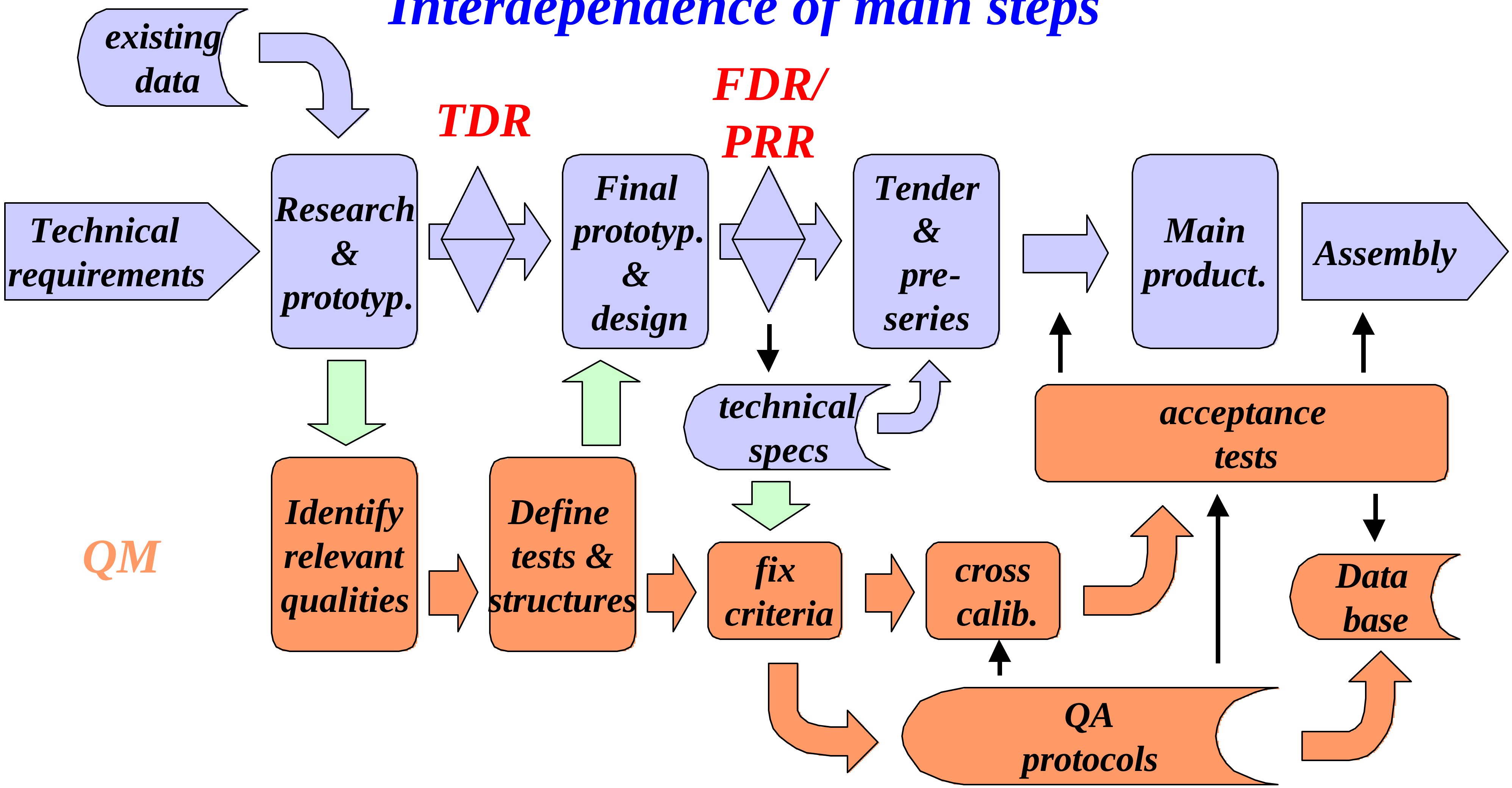
Detector production



Assembly and testing of detector modules

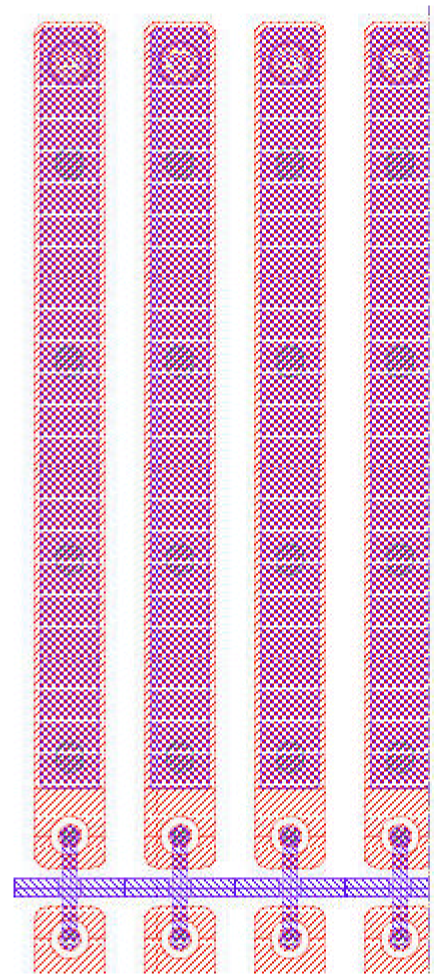
Development, production and QM

Interdependence of main steps



Pixel sensor design requirements

- ***pixel size 50µm x 400µm***
  - *50 µm pitch*
  - *12µm diameter bump connection*
- ***total active area 1.8m^2 (1718 modules)***
  - *high yield*
  - *testability*
- ***10 years operation***
  - *fault tolerance*
- ***harsh radiation environment***
  - *up to 10^{15} MeV n eq./cm^2*
  - *fluence and 500 kGy ion. dose*



Development Strategy

Design studies

- performed
  within ATLAS

- prototype sensors
  concerning
  - isolation technique
  - design of the pixel cell

Studies on silicon

- performed
  within ROSE

- various Si impurities
  concerning
  - damage parameters
  - fabrication process

Radiation tolerant sensors

Sensor Concept

- n^+-in-n pixel
- oxygenated Si substrate
- moderated p-spray isolation
- bias grid for testability
- 3 sensor tiles per wafer
- various test and monitor structures
- 2nd prototyping for yield optimization

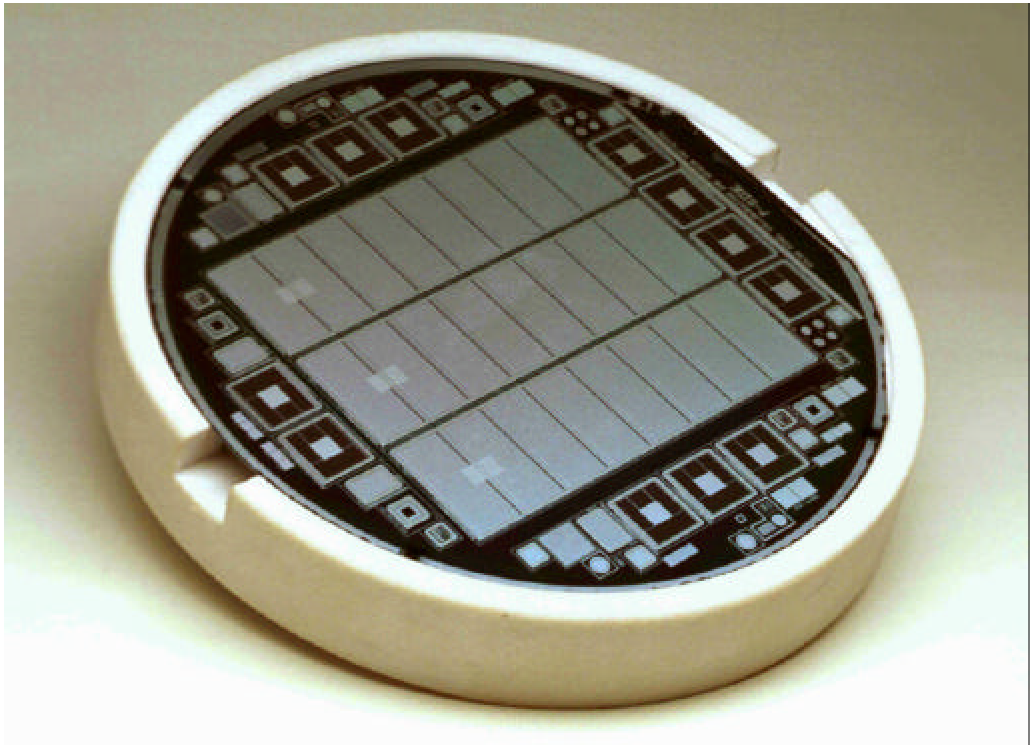


Photo of prototype 2 wafer

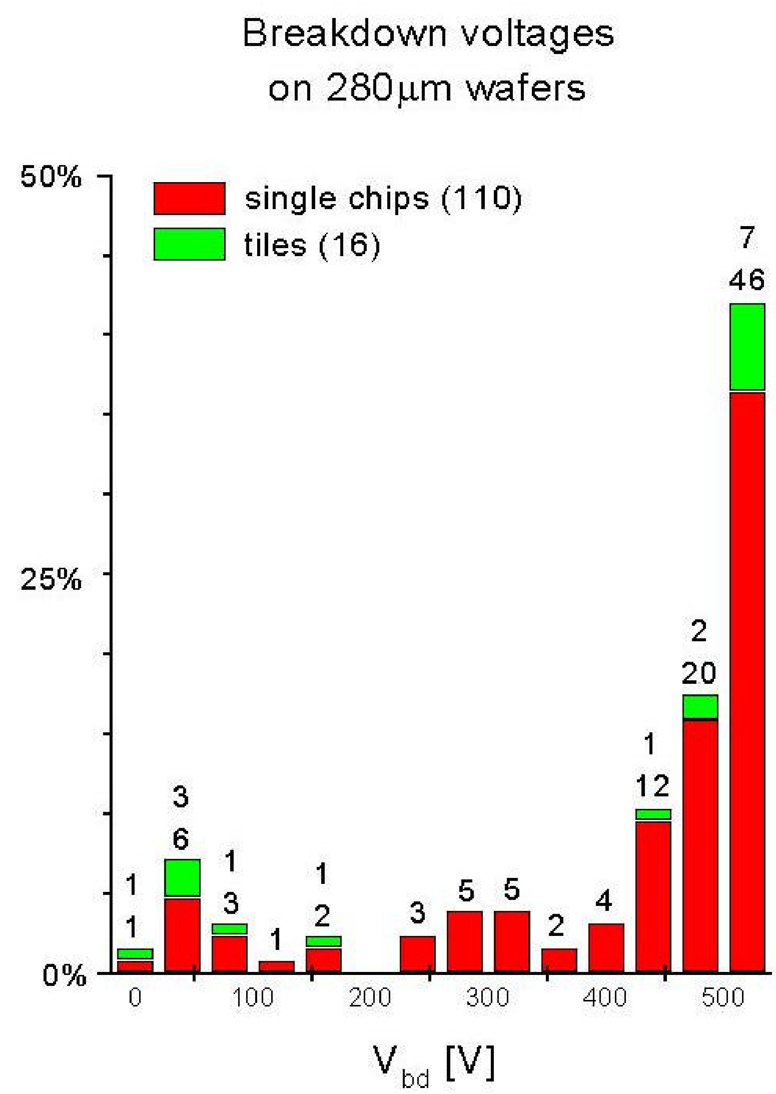
Quality Assurance

Quality test plan for sensor production:

- *I-V characteristics on every sensor before bonding, depletion measurement on every wafer*

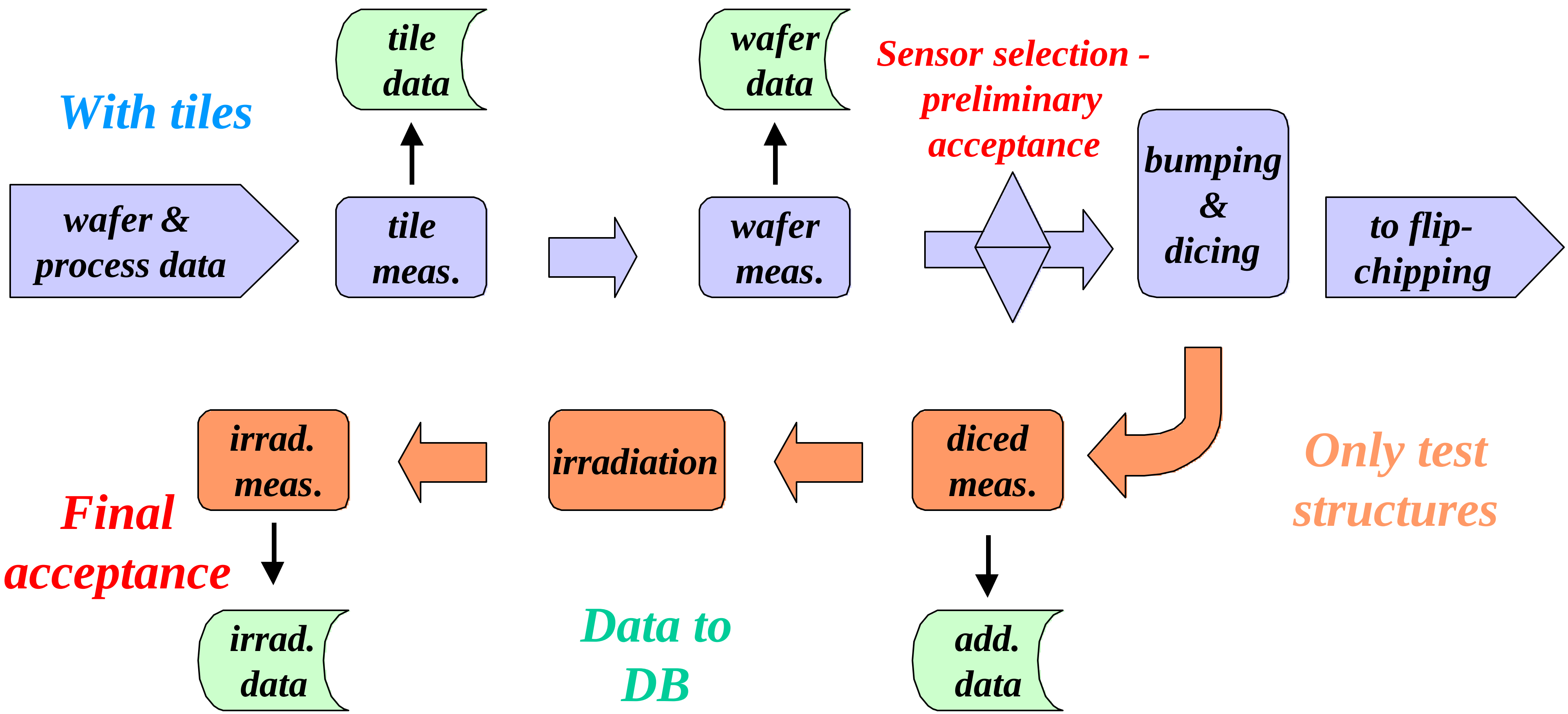
- *process parameters on special test structures (e.g. p-spray dose)*

- *both at vendor and at institutes (acceptance tests) for better control*



Flow of acceptance testing

Main measurement steps



Tests to perform

Grouped in topical order

	measurements	qualities tested
tile quality tests	visual inspection, I-V testing, I-t testing	visible damage, breakdown voltage, time stability
wafer quality tests	visual insp., I-V on sensors, diodes and MOS, C-V on diodes and MOS, I-V_{gate} on GCD and MOSFET, planarity meas.	alignment, depletion voltage, oxide characteristics, p-spray dose, planarity
tests after dicing	thickness meas., I-V_{gate} on GCD, interpixel measurements, implantation meas.	thickness, bump bonding effects, interpixel resistance and capacitance , sheet resistances
tests after irradiation	I-V on sensors and diodes, C-V on diodes, I-V_{gate} on GCD and MOSFET	radiation hardness

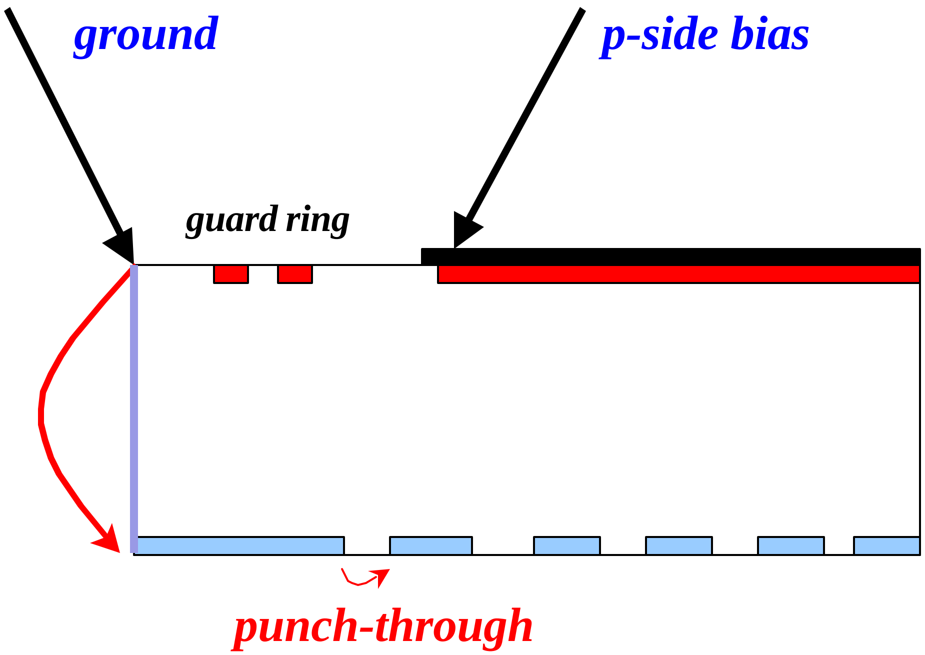
Testing responsibilities

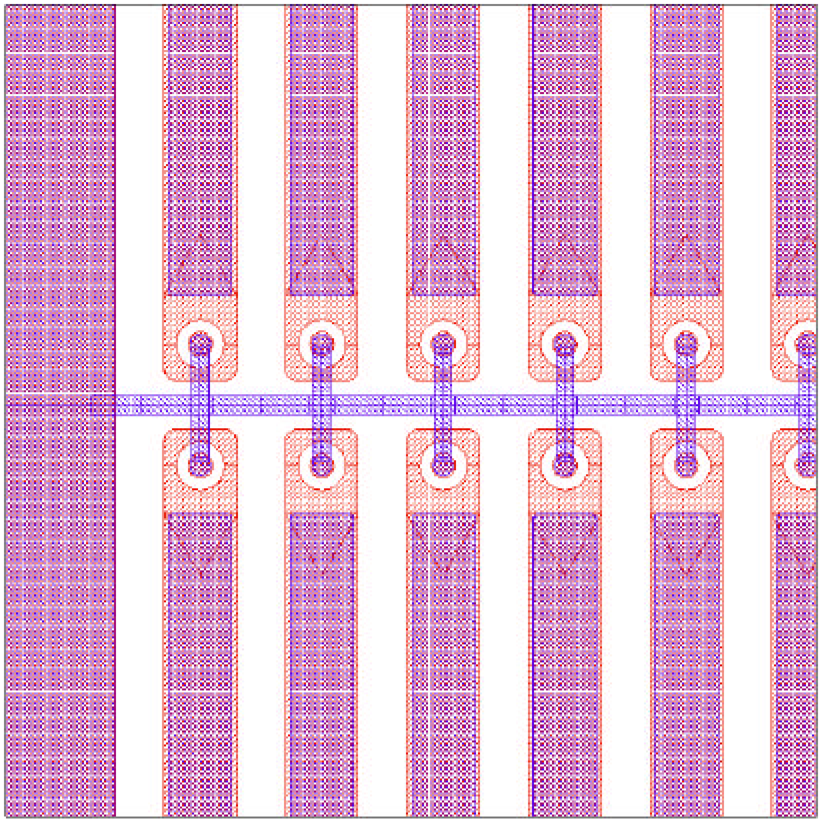
vendor	ATLAS institutes
• provides process data	• check process data against measurements
• tests pixel quality on sensor tiles on wafer level	• test pixel quality on sensors tiles, single chips and mini chips
• performs diagnostic tests on wafer level for depletion, oxide quality and capacitance, and p-spray dose	• perform all diagnostic tests on wafer level and on diced test structures
	• measure test structures after irradiating them

Breakdown & leakage current

I-V tests before bonding using bias grid

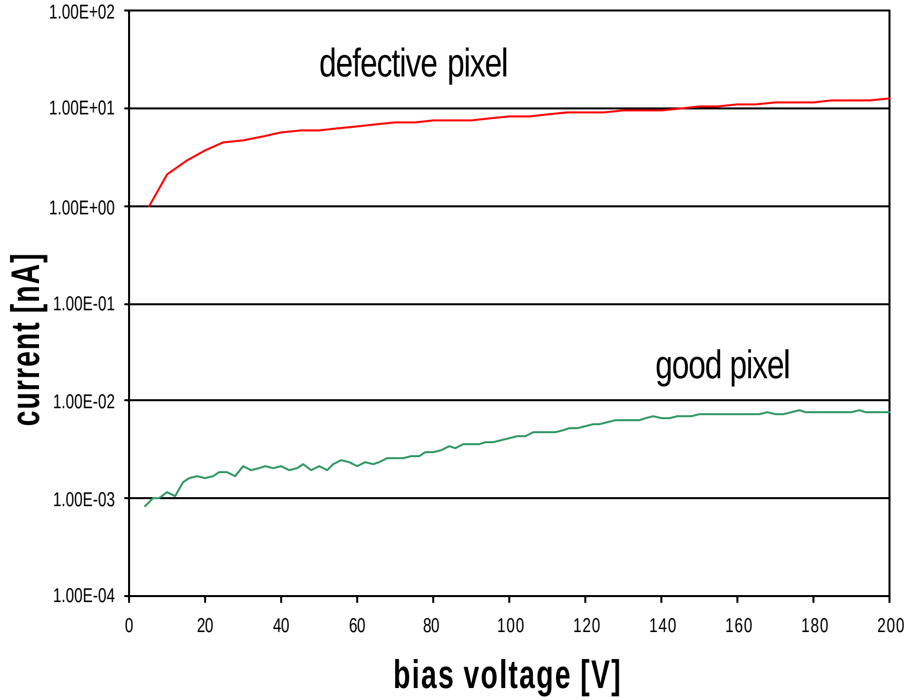
- punch-through effect across a bias grid allows testing of all pixels using only two probes on wafer p-side



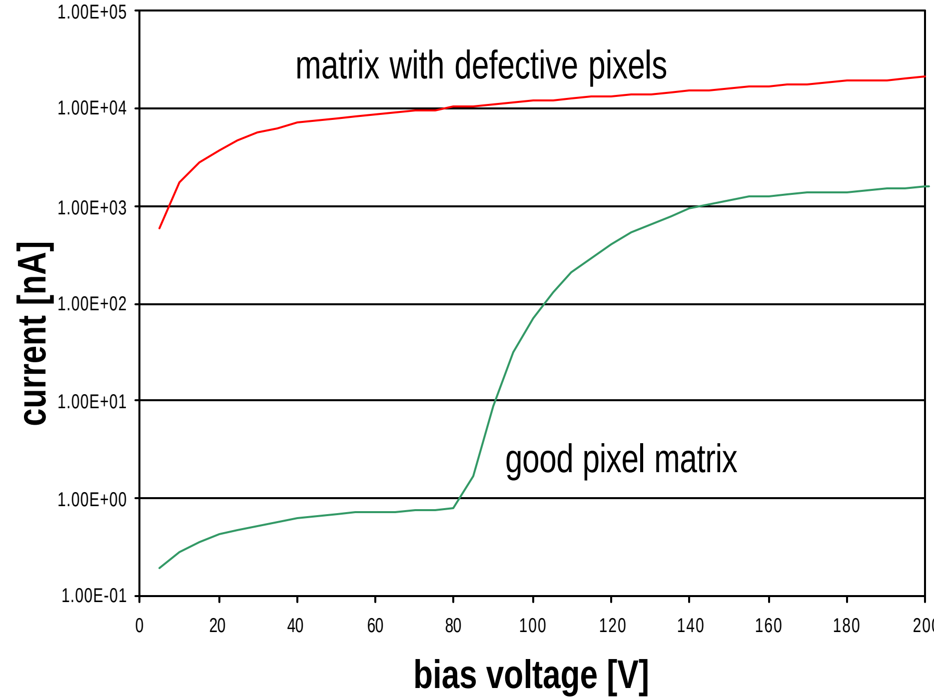


Testability of pixel quality

I-V tests on test pixels using punch-through



current through single pixel



current through punch-through array

Leakage current indicative for quality of every pixel

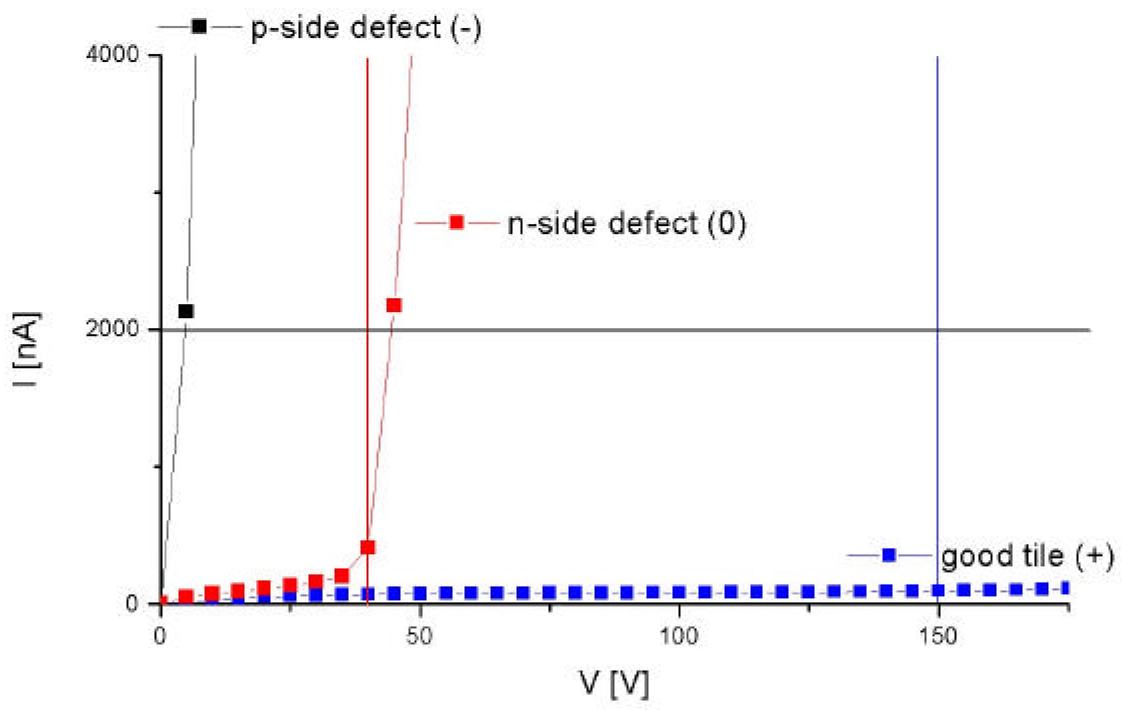
Breakdown & leakage current

Tile classification by pixel quality

- *I-V measurements of leakage current show pixel quality*

- *breakdown voltage indicates type of defect*

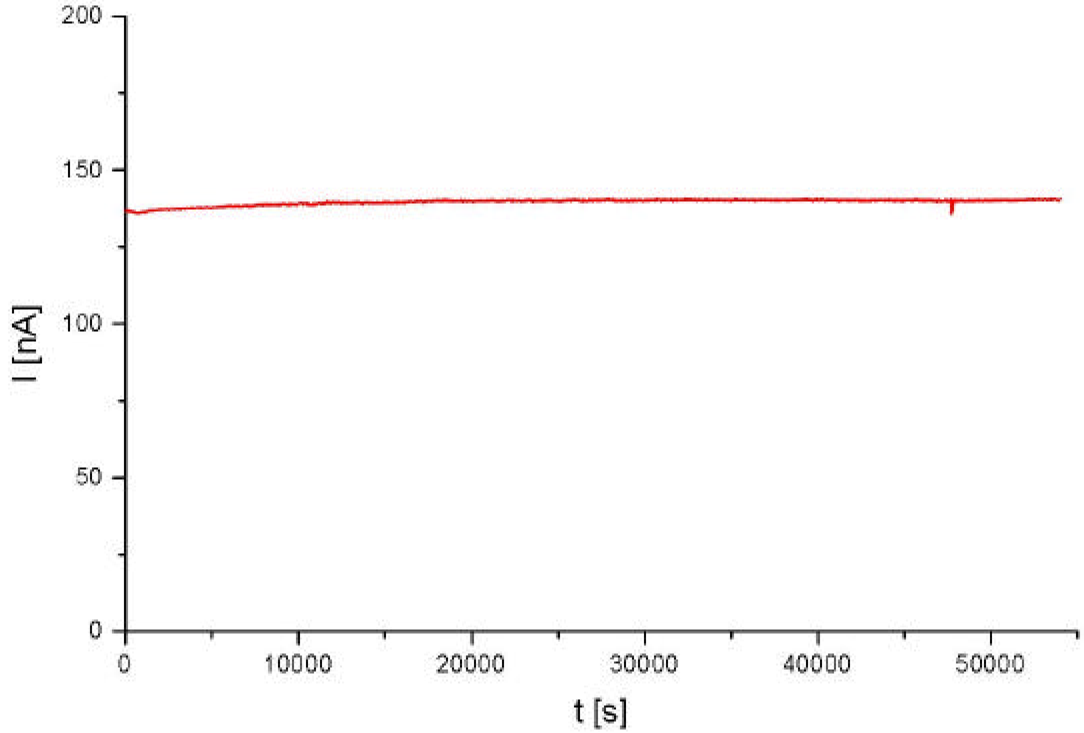
- *tile classification possible taking in account current slope and operation voltage*



Time stability

I-t tests at operation voltage

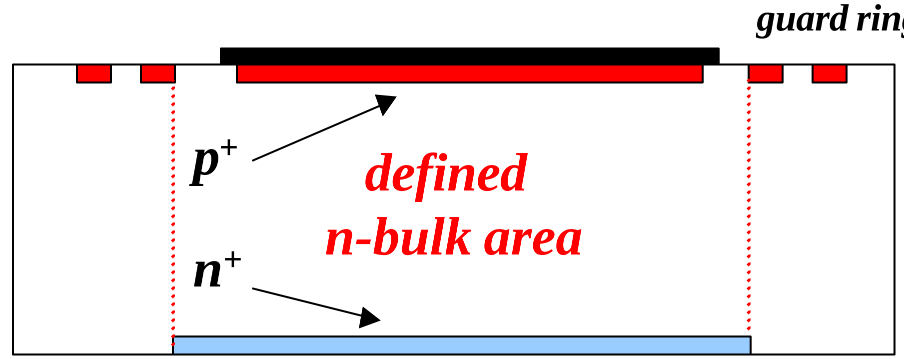
- *I-t tests on tiles show if leakage current increases significantly over 15h*
- *similar tests could be done on mini sensor chips after irradiation*
- *long time burn-in could be done after assembly on module level*



Measured at 150V bias

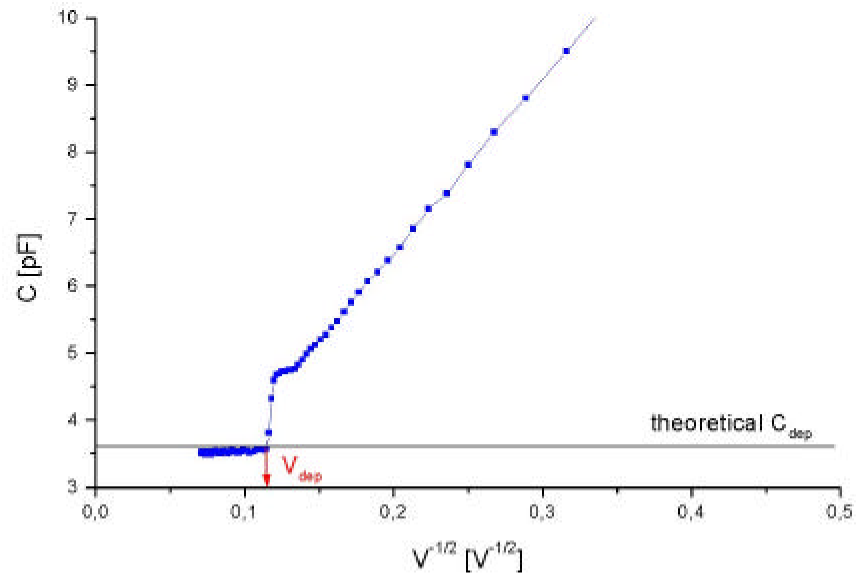
Sensor depletion

Diagnostic measurement by diode capacitance



- *test diodes on production wafer for well defined capacitance measurements*

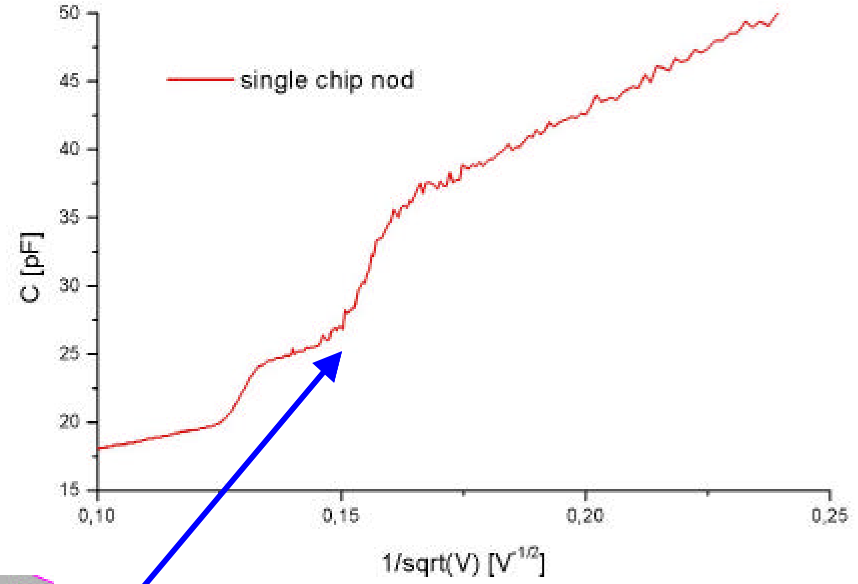
- *full depletion visible by levelling out of C vs. $V^{-1/2}$ curve (suppression of possible constant stray capacitances)*



Diode depletion vs. Sensor depletion

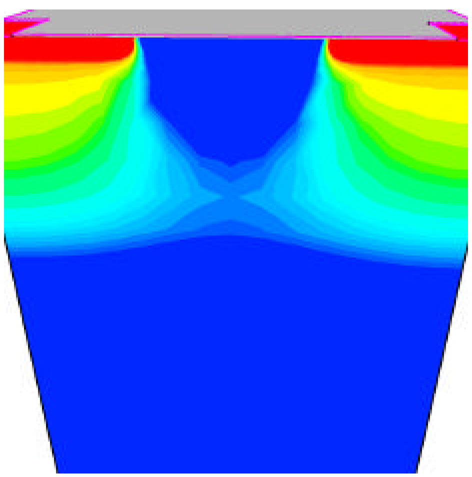
In unirradiated n^+-in-n sensors, two ‘depletion’ cases are reached

- pinch-off between neighbouring pixels by growing depletion zones from p-side and p-spray
- full depletion of whole sensor volume (as in diode)



‘Double depletion’ in single chip sensor

Near full sensitivity at lower voltage

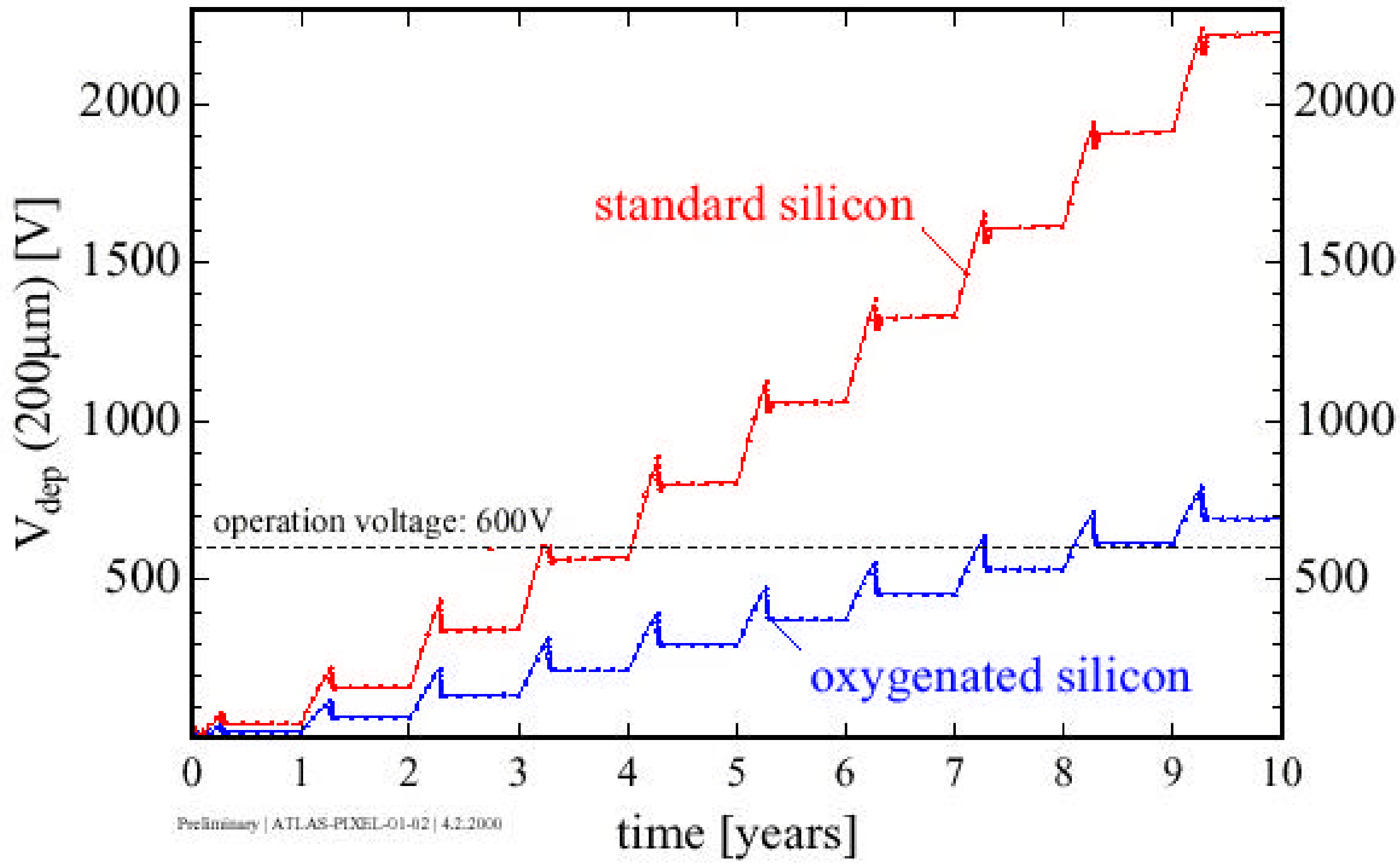


3D-simulation of e^--concentration

Sensor depletion after irradiation

Oxygenated Si shows slower raise in depletion voltage:

- ***less damage by charged particles (e.g.$p^{\pm}$)***
- ***saturation of reverse annealing at higher fluences***



ATLAS scenario for 100 d beam, 3 d at 20°C, 14 d at 17°C p.a.(b-layer)

Radiation hardness tests

Oxygenation testing

- after irrad. with 3.1×10^{14} MeV n eq./cm^2 protons
- depletion measurement on diode

Bulk damage testing

- after irrad. with 10^{15} MeV n eq./cm^2 protons (design fluence)
- I-V measurements on mini chip and diode (small structures)

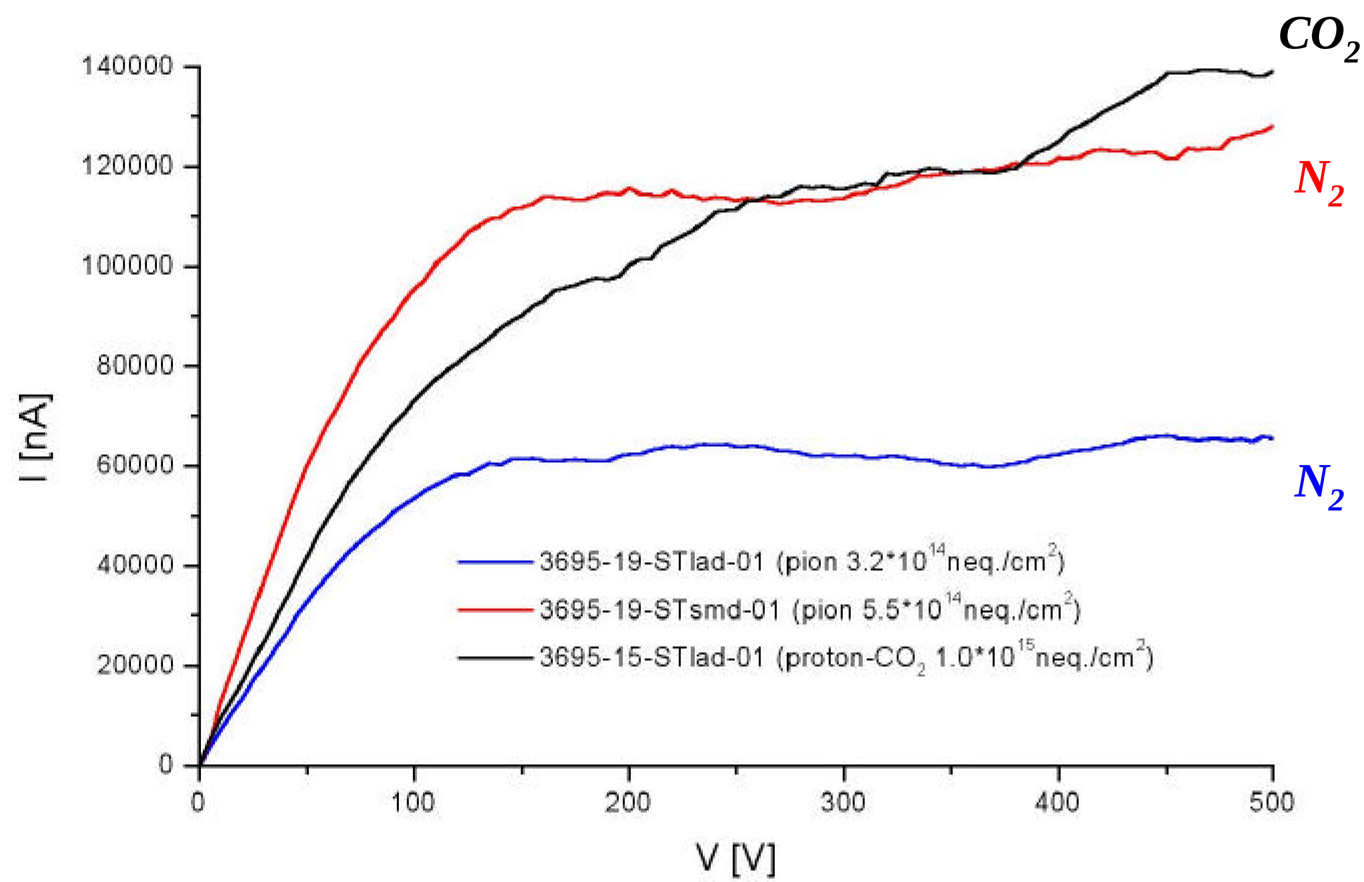
Surface damage testing

- after irrad. with 500 kGray low energetic electrons (design dose)
- interface generation current measurement on GCD
- p-spray measurement on MOSFET

Testing for irradiation environment

Irradiation tests show so far:

- *irradiation with p of different energies and* π^+ *show comparable results*
- *irradiation in* CO_2 *and* N_2 *atmosphere cause no additional damage*



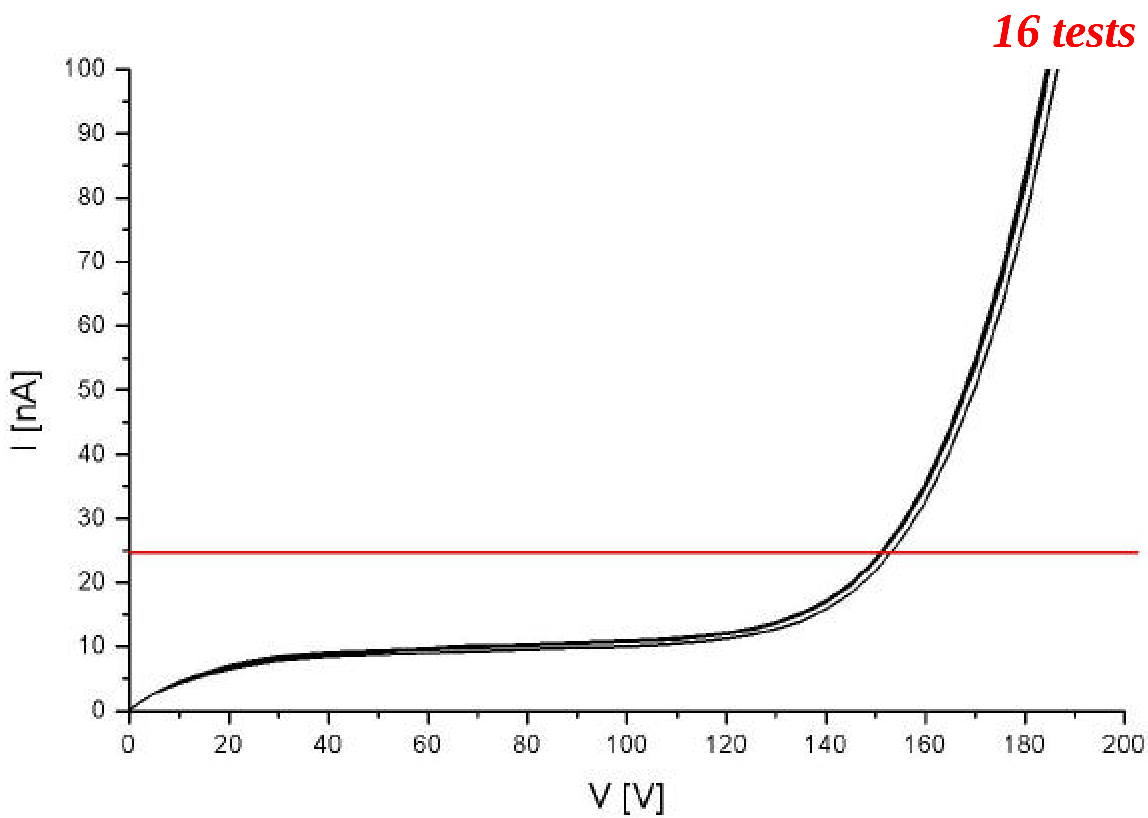
Measured at -30°C, normalized to 0°C

Calibration of measurement sites

Repeated tests on same dedicated structure:

- *show stability of measurements at participating labs (influence of time or environment)*
- *can be used to test readiness for new testing period*

I-V and C-V tests are used



16 I-V tests on diode

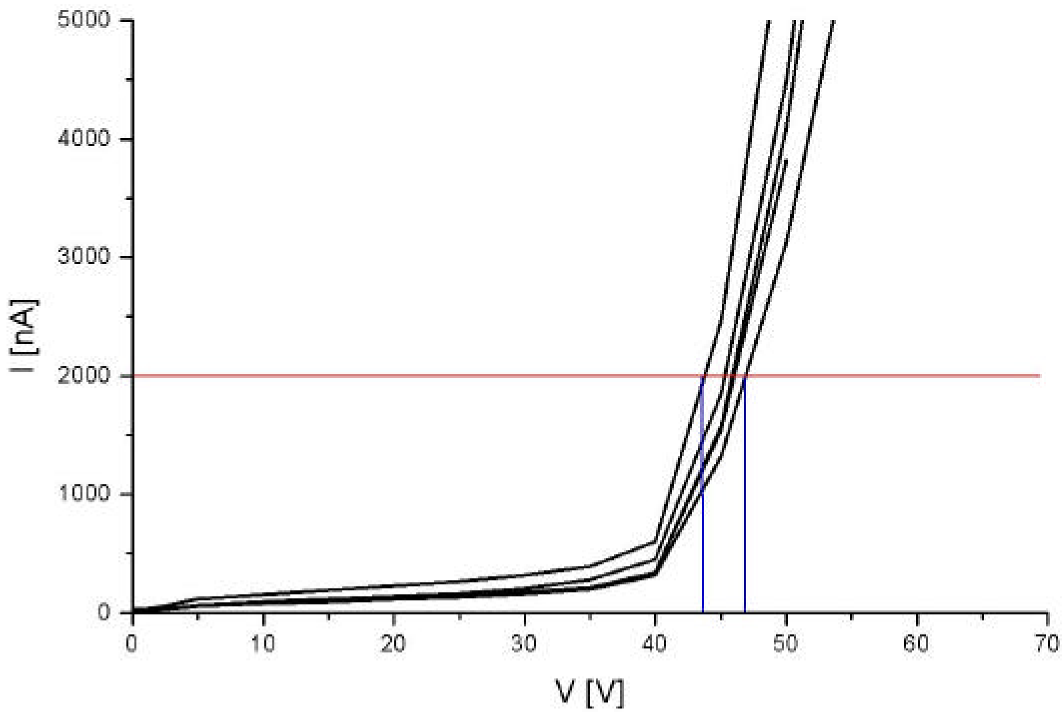
Cross calibration of measurement sites

Tests on same structures at different labs:

- *show comparability between labs*
- *indicate possible problem sources (handling, transport, humidity, set-up)*

All tests used

Currently ongoing



5 I-V tests on sensor tile

Summary

QM for the ATLAS pixel sensor

- *has been a dynamic process between different aspects of the project*
- *requires close collaboration for a long time period*

QA procedures have required

- *good understanding of the phenomena to be measured*
- *decisions on what exactly is crucial or worthwhile to know*

QC measurements have, until now

- *given us good tools for acceptance decisions*
- *ensured compatibility between different measurements / scenario and test*