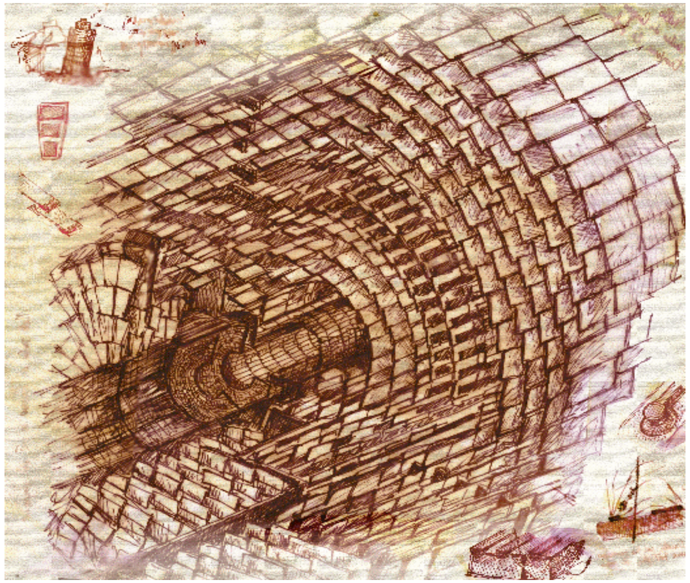
Quality Assurance of Silicon Sensors in the CMS Tracker



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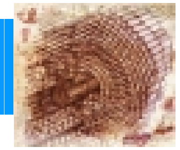
On behalf of the CMS Silicon Tracker Collaboration

1st Workshop on QA Issues in Silicon Detectors,

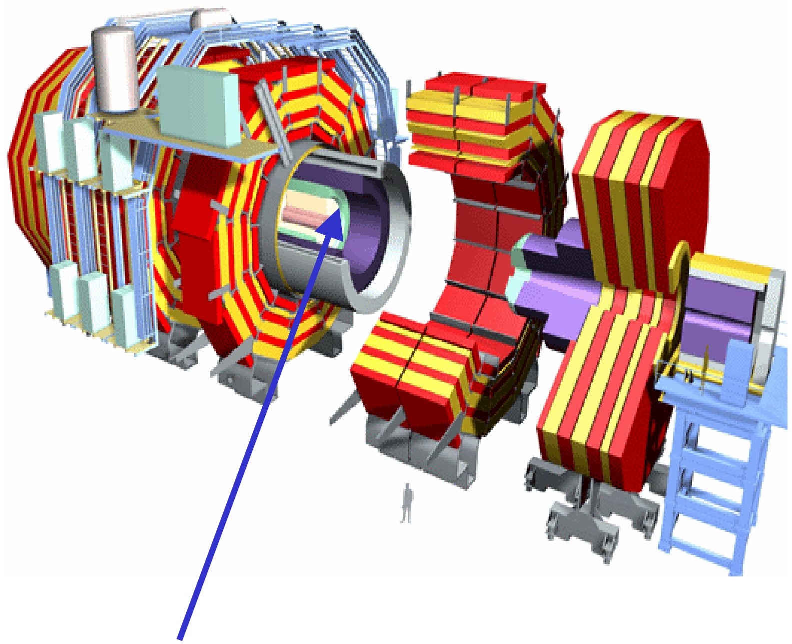
CERN May 17-18 2001

Outline



- Introduction
- The CMS Silicon Sensor choice of technology
- Production scenario
- Organization and plans
- Production and tests performed by companies
- Sensors Qualification performed by CMS
- Preliminary experience with Milestone sensors
- Conclusion

Introduction

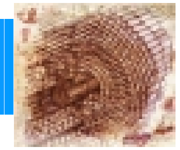


CMS Silicon Tracker
~ 210 m^2 Silicon μstrip sensors

The challenge:

- ~ 25.000 silicon sensors to be produced and tested in about 2.5 years.
- QC&A key point to succeed for the timely construction of such large system.
- Automatic sensor testing and tracing of possible failures
- Monitor the radiation tolerant technology during construction

General remarks



The choice of sensor technology has big implication on the project

- radiation tolerant
- simple and reliable for easy manufacturing and testing
- compatible with qualified companies to be mass produced
- cost effective

More than one qualified supplier will participate to the manufacturing

- minimize the risk of production

Qualification of sensors will be carry out by CMS home institutes

- share the large load of sensor qualification

Quality plan, control and assurance

We started to address the problem of quality on sensors about 1.5 years ago.

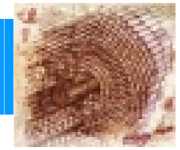
Lot of care have been devoted to define in great details the sensor specifications, procedures and acceptance criteria for testing, organization, documentation, communication, analysis of risks, etc.
Fortunately we had the deadline of PRR in June 2000 that force us to present a Quality Plan Document.

Second half of 2000 and beginning of 2001 we implemented our plan (yes… *"we almost made what we said").*

Since the beginning of 2001 we are debugging our quality control system and make sure that procedures are correctly followed.

Lately we are applying it with success to the Milestone Sensors.

Contents of QC&A document



1.Introduction

2.Sensor Production Network and Activity Plan during production

3.Overview of sensor design and specifications
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4.Tests and acceptance requirement to be fulfilled by the companies
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QC&A document

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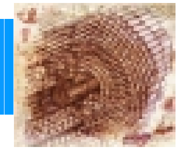
Silicon Sensor choice of technology



Requirement: To operate the detector up to 10 years of LHC with a S/N >10

Major issue: Radiation damage greatest source of concern (1 Mrad/year in the inner layer)

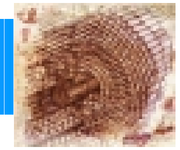
Radiation damage bulk effects

- Increasing of leakage current (e.g. noise)
- Increasing of depletion voltage after inversion (e.g risk of breakdown)
- Decreasing of charge collection (e.g signal)

Radiation damage surface effects

- Increasing of interstrip capacitance (e.g noise)

Silicon Sensor technology

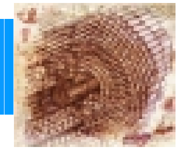


After an extensive R&D program our choices for the Silicon Sensors are:

- Single sided p-type implant strips on n-type substrate
- Integrated AC coupling of read-out strips
- Polysilicon resistor biasing of the p^+ implant strips
- Low resistivity substrate (1.5-3.0 MΩ/ in the inner tracker)
- Silicon lattice orientation <100> in place of the common <111>
- Metal overhanging over the p^+ strip

- Well suitable for meeting our requirements with a good safety margin.
- Compatible with high volume industrial production on 6” wafer.
- Relative inexpensive technologies.

Production scenario

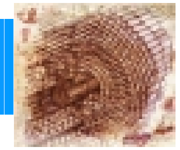


Suppliers are requested to deliver fully tested sensors following our technical specifications and satisfying our acceptance criteria.

CMS home institutes are responsible for qualifying and monitoring the production.

- 100 % sensor testing during pre-production (~ 5% production)
- Full test on sample of sensors (~ 5%) during production (if pre-production OK)
- Sample radiation tests for monitoring radiation tolerance
- Sample test-structures tests for monitoring the process stability

General rules



Given the fact that we will have multiple suppliers, multiple test centers and the production will last over 2 years, it is very relevant to assure:

- Production homogeneity between different vendors
- Stability of production during the whole period
- Quality tests homogeneity between different home institutes

- Companies are not allowed to perform any authorized change (design, process, even packaging) during production.

- Test centers will follow uniform procedures for testing, common acceptance criteria, with standard test setups.

- Test centers will perform regularly inter-calibration, testing the same sensors to assure the consistency of results.

- Test centers will keep track of possible source of non-conformities to monitor and to keep under control potential sources of problems

Organization and plans

Qualification tests will be performed in:

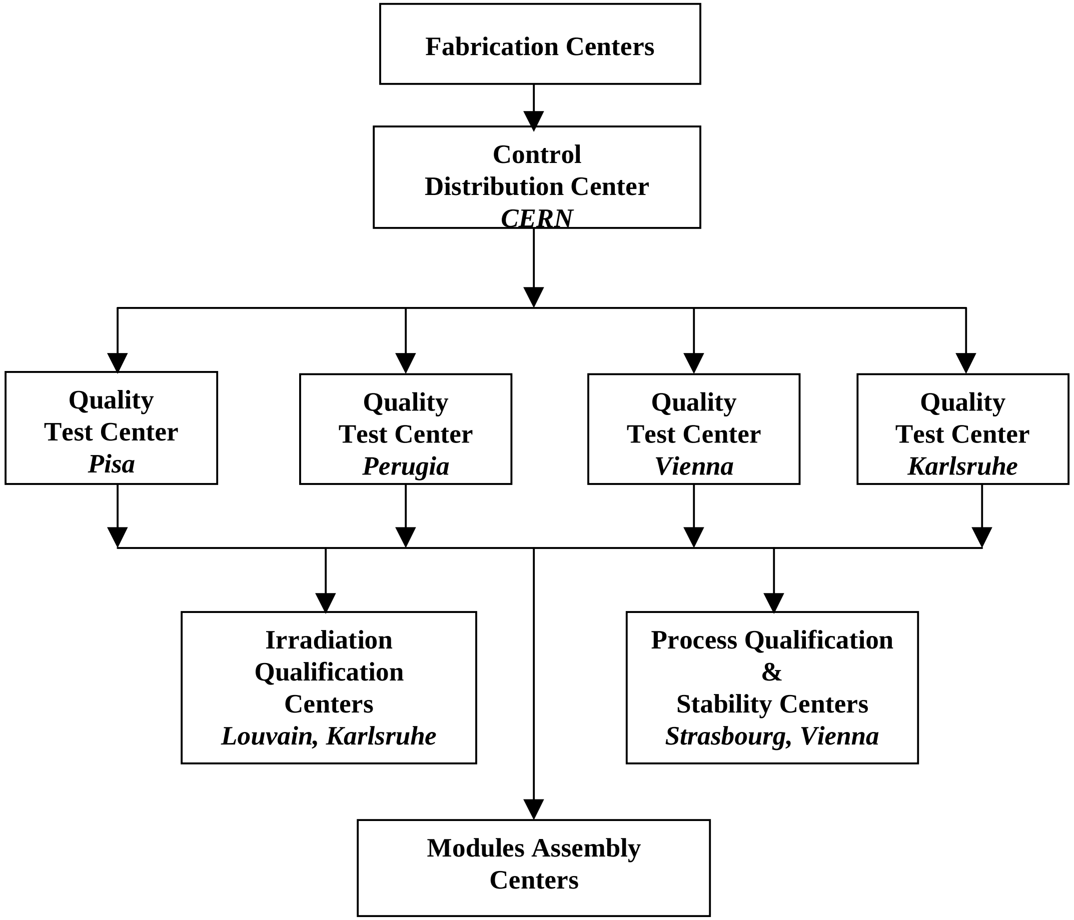
Louvain, Karlsruhe, Perugia, Pisa, Strasbourg, Wien

Each center has availability of:

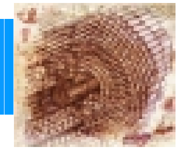
- Clean room with temperature and humidity control
- Automatic probe stations and instruments for testing
- Trained technicians and physicists

A Production Committee will centrally coordinate the whole sensor production and interact with companies.

Sensor Production Network



Production by companies



Companies are responsible to deliver silicon sensors following our Technical Design and Quality Control Specifications, term and condition of the contract.

- Design the sensor masks and propose them to us for approval
- Procure the silicon substrate
- Process and cut the wafers
- Tests the whole sensor production
- Provide electronic documentation of test results
- Pack, bar-code and deliver to the distribution center

Tests by companies

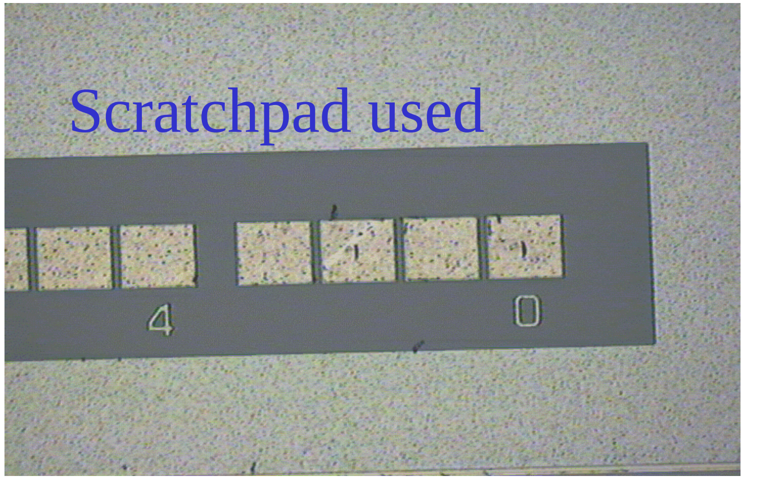
We asked 3 different tests on each sensor:

- Global Tests (I-V, C-V)
- Strip Tests (cap-scan, poly res.)
- Various tests on structures in sample to monitor the process

Optical inspection of sensors after dicing

Identification of each sensors by a row of scratch pads

NB:These tests are foreseen for Milestone Sensors. In case of need may be revised for the production



Global tests

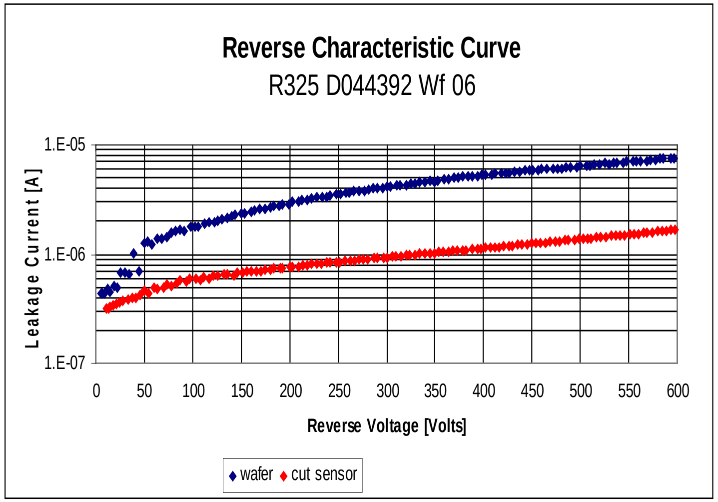
Global Tests: I-V, C-V

- I-V measurement up to 600V

no breakdown below 500V

Class A sensors (if after dicing)
I_{tot}< 5 μA @ 300V and
I_{tot}< 10μA@ 450V

Class B sensors (if after dicing)
I_{tot}< 10 μA@ 300V and
I_{tot}< 20 μA@ 450V



STMicroelectronics

- C-V

100V <V_{dep}< 300V

Strip tests

- Measurement of Poly resistors

$1.2M\ \Omega < R_{poly} < 1.8\ M\Omega$

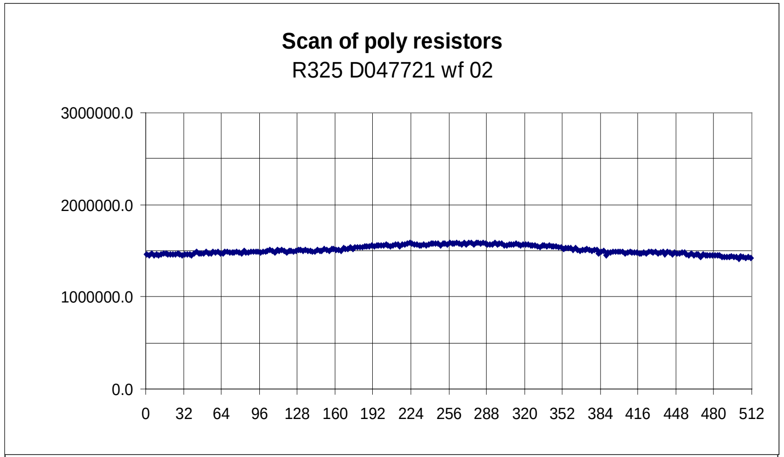
- Identification of pin-holes

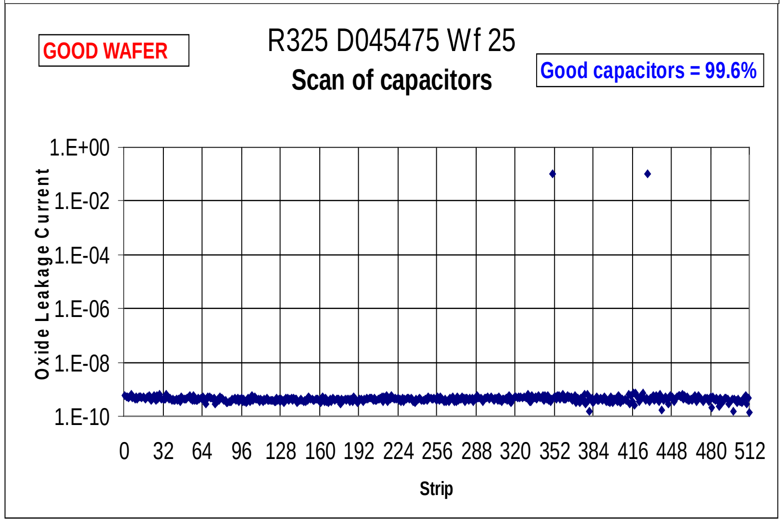
$I_{diel} > 1$ nA @ 400 V

- Identification of leaky strips

$I_{leak} > 100$ nA @ 400 V
(measurement requested to be performed only for class B sensors)

Maximum number of defected strips accepted 1 %



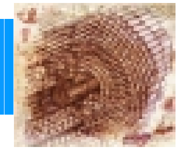


Distribution Center

Sensors will be delivered by the companies to one Control Distribution Center (CERN) and from here dispatched to the Quality Test Centers.

- Receives sensors from producers.
- Crosschecks the producer electronic documentation and inserts it into the dB.
- Distributes sensors to the Quality Test Centers.
- Monitors centrally the flow of production.
- Keeps contact with companies.

Test centers



• Quality Test: perform during the pre-production measurements on every sensors. If these tests will meet our requirement, we will test only on a sample basis afterward.

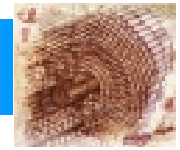
• Process Stability: perform measurements on samples of test structures to monitor the process stability during the entire delivery period.

• Radiation Tolerance: perform on sample of sensors and test structures irradiation and measurements to monitor the process radiation tolerance over the entire delivery period.

• Bonding Test: perform bonding tests on sample of test structures to monitor the bonding quality of sensor.

• Sensors will be accepted provided they pass all the tests carried out by the collaboration.

Quality Test Centers



There are 4 QTC: Perugia, Pisa, Karlsruhe and Wien.

Operations to be performed have been fully specified.

- Receive and register sensors and test structures from the Distribution Center
- Optically inspect the sensors.
- Perform electrical tests.
- Insert test and inspection results into the production dB.
- Pack, register, select and distribute fraction of sensors and test structures to Process and Irradiation Qualification Centers
- Ship the sensors to Module Assembly Centers.

All the test centers are fully operative and are currently testing Milestone sensors whose delivery started in mid April.

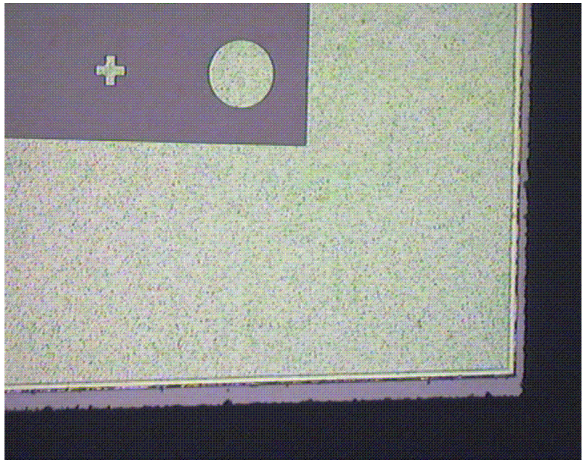
Visual and Optical Inspection

Performed in each center before electrical characterization.

Simple set-up: XY table connected to a PC controlled by LabView

- Package is surveyed and opened
- Sensor is visually inspected for macroscopic defects
- Edges of the sensor are optically inspected
- Dimensions are measured and recorded

Package is designed in such way to leave the sensor during inspection inside its box to minimize handling



Test set-ups

Great care has been dedicated to standardize the test-setups.

It is relevant to make sure that a sensor tested in any center give us the same results.

Lyon Central Database

Download
Standard Input File
Measurement Parameters
Acceptance Parameters

4 Test Centers

Common Data Analysis

Upload
Standard Output Files
Result of measurements
List of eventual failures

Calibration of test centers

- Since the tests will be shared between different centers, we have to make sure that the results are homogeneous between them.
- We are planning to perform a calibration of the set-ups, before and occasionally during the production.
- A simple but efficient idea would be to circulate for testing between the centers the same set of devices.

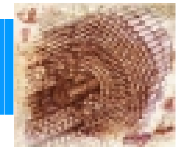
	Vienna	Perugia	*ST*
I@300	2029	1965	*1830*
I@450	3025	3345	*2665*
Vbreak	No break	No break	*No break*
Vdep	130	132	
Ctot	1648	1554	
<Rpoly>	1.38	1.37	*1.37*
<Istrip>	4.98	3.96	
<Cac>	609	608	
<Idiel>	0.12	0.10	
Rpoly bad	0	0	*0*
Istrip bad	1 (133)	1 (133)	
Cac bad	9 (165, 249, 257, 281, 372, 435, 476, 482, 492)	9 (165, 249, 257, 281, 372, 435, 476, 482, 492)	
Idiel bad	6 (249, 257, 281, 372, 435, 476)	6 (249, 257, 281, 372, 435, 476)	*5 (257, 281, 372, 435, 476)*
Total bad	10 (133, 165, 249, 257, 281, 372, 435, 476, 482, 492)	10 (133, 165, 249, 257, 281, 372, 435, 476, 482, 492)	

Test set-ups

• All test centers are equipped with automatic probe stations and high quality measuring instruments (Keithley and or HP)

• In addition two probe stations are equipped with automatic loading system that allows us to test 24 sensors without any interruption

Electrical Tests



- Global Tests (I-V, C-V)
- Strip Test (cap-scan, poly resistors, single strip current)

All the potential source of non-conformity during testing have been classified and coded.
Test results and eventual failures will be recorded into the Database.

	Test	Acceptance criteria
Global	IV	$I_{tot} < 5\ \mu A$ at $V_{bias} = 350V$ $I_{tot} < 10\mu A$ at $V_{bias} = 450V$ $V_{break} > 500V$
	CV	$100\ V < V_{dep} < 300\ V$
Strip by strip @V_{bias}=400 V	Pinholes	Current through AC pad: $I_{diel} < 1nA$
	Poly Resistors	$1.5 \pm 0.3 M\Omega$
	Leaky Strips	$I_{leak} < 100nA$
	Total Defect Strips	$\leq 1\%$

NCD1	Optical inspection failed
NCD2	Total current exceeding
NCD3	Breakdown voltage lower
NCD4	Depletion voltage out of range
NCD5	Percentage leaky strip exceeding
NCD6	Percentage polyresistors out of range exceeding
NCD7	Percentage coupling capa. out of range exceeding
NCD8	Percentage pin-holes exceeding
NCD9	Percentage of shorted strips exceeding
NCD10	Percentage total strips defected exceeding

Test results

A set of standard plot and a summary is automatically generated in each lab after the sensor test is completed.

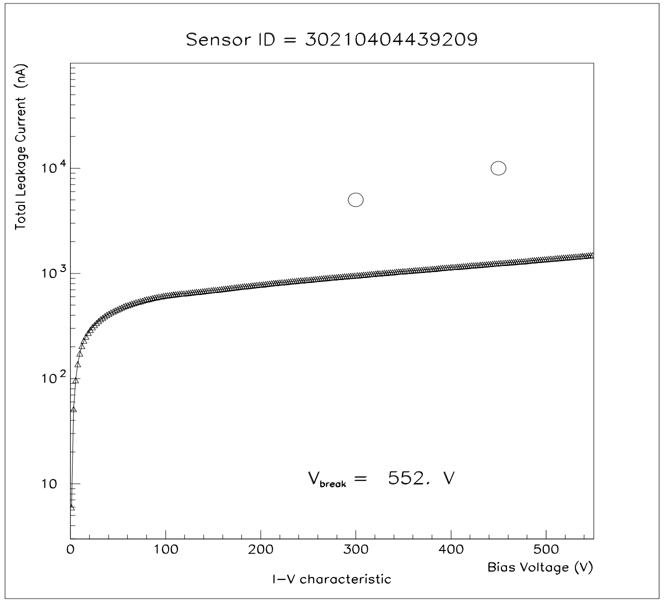
Sensor ID = 30210404439209

Date = 01−04−06 time 14.49.41 Operator = Nicoleta Dinu
Temperature (I−V) = 21. °C Humidity (I−V) = 45. %

V_{break} = 552. V I_{tot} at 300 V = 1008. nA
V_{depl} = 107. V I_{tot} at 450 V = 1485. nA

C_{tot} at V_{depl} = 1560. pF

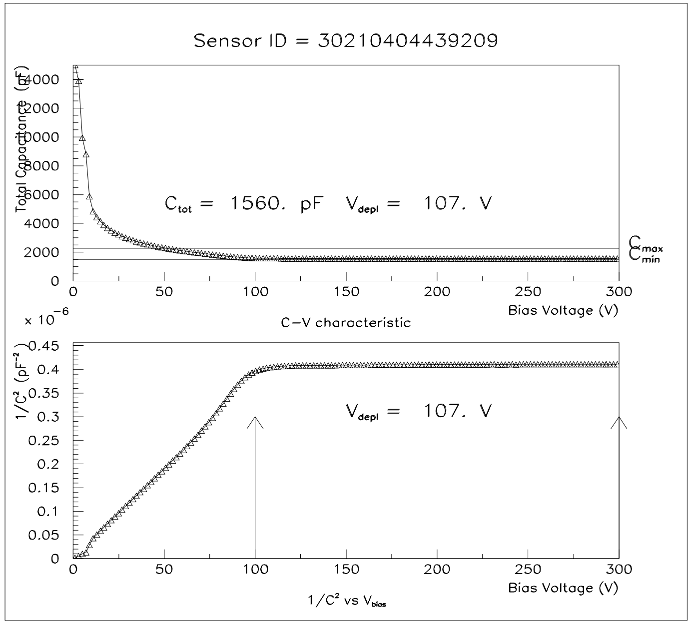
Scan Measurements	# of Bad Strips	Flag
<Poly. Res.> (MΩ) = 1.46	0	.0.
$<I_{Single\ Strip}>$ (nA) = 1.72	1	.0.
$<C_{AC}>$ (pF) = 597.	4	.0.
$<I_{Diel}>$ (nA) = 0.00	4	.0.
Total Nr. Bad Strips = 228 261 429 479	4	.0.
I−V measurement		.0.
C−V measurement		.0.
Global Status		.0.

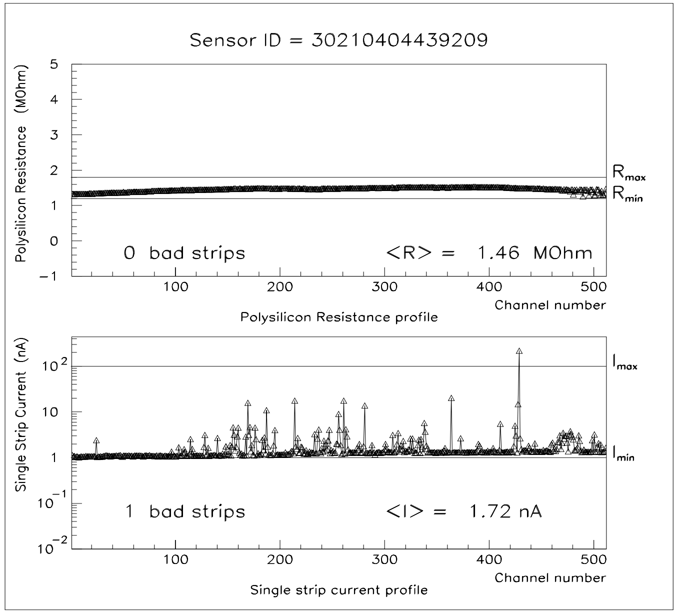


Summary

I-V

Results

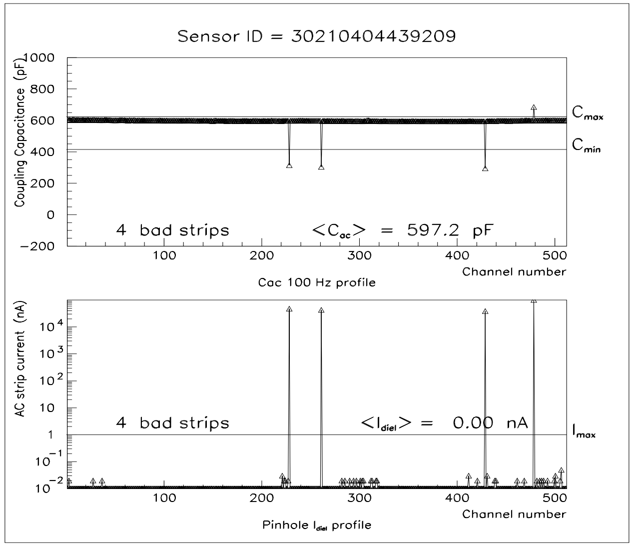


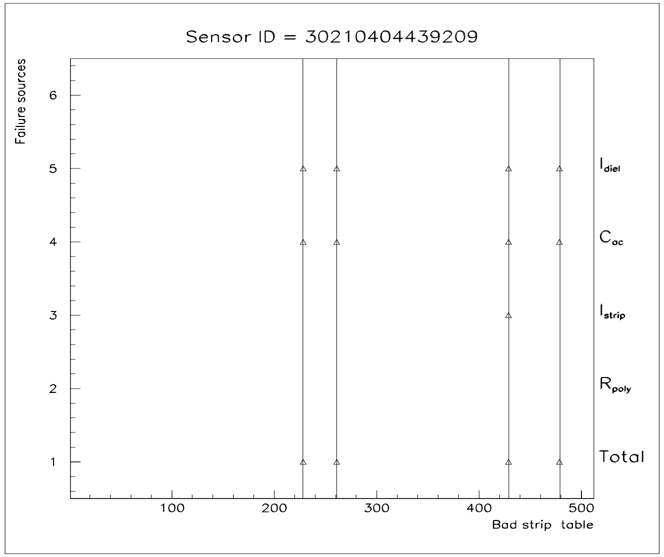


C-V

Poly resistors and Single Strip Current

Results

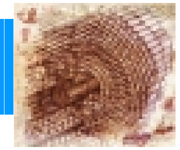




Coupling Capacitors and Pin holes identification

Summary of defective strips

Irradiation Qualification Centers



There are 2 IQC: Louvain and Karlsruhe

R&D studies have shown that radiation tolerance can be improved by adequate design, substrate and processing.

We will provide to suppliers design, indications for substrate and processing that should ensure an operability of sensors up to 10 years of LHC.

Even if the design will be fixed, substrates and process property could vary, modifying the sensor quality. We need to monitor radiation sensibility of sensors during the production

QTC's will send test structures and sample of sensors to IQC.

During Milestones ~ 20% test structures and ~ 5% of sensors irradiated.
During Production these numbers will be lower (~ 5% TS and <1% sensors)

Set-ups

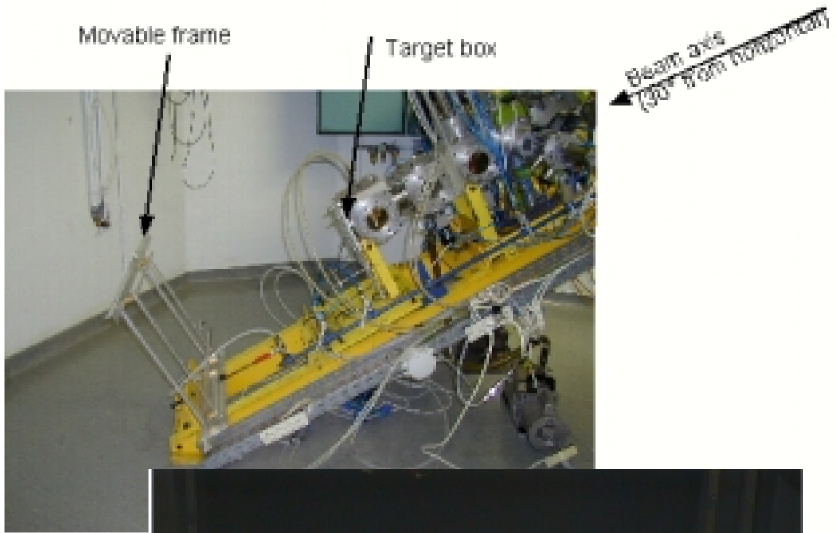
We are planning to use the neutron facility in Louvain and the proton beam facility of Karlsruhe.

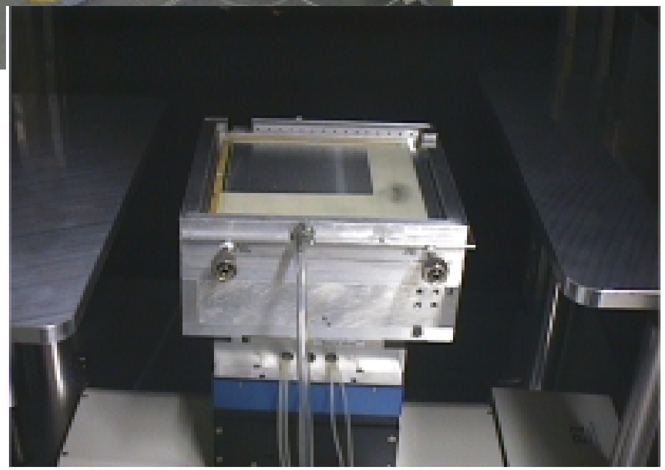
Irradiation will be performed in operative conditions with devices under bias and cold.

Electrical tests before and after irradiation will be performed in Louvain and Karlsruhe.
Results saved into the Database.

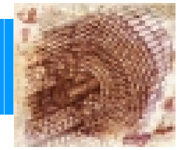
The hardware set-ups are ready and the irradiation should start soon.

Tests on sensors: C-V, I-V, C_{int}
on test structures: C-V, C_{int}, R_{int}, R_{poly}





Process Qualification Centers



There are 2 PQC: Wien and Strasbourg

The process quality and stability is responsibility of the companies. However, we will check all the critical parameters by measuring sample of test structures.

All test structures on a half moon are organized such that the contact pads are in line and the set of measurement can be automatically done by means of a probe card.

During Milestones ~ 10% of structures tested.
During Production 1 per batch should be enough to monitor the process parameters.

Tests on structures: C-V, I-V, C_{int}, R_{int}, R_{poly}, R_{p+} , R_{al}, $Vbreak_{Cac}$

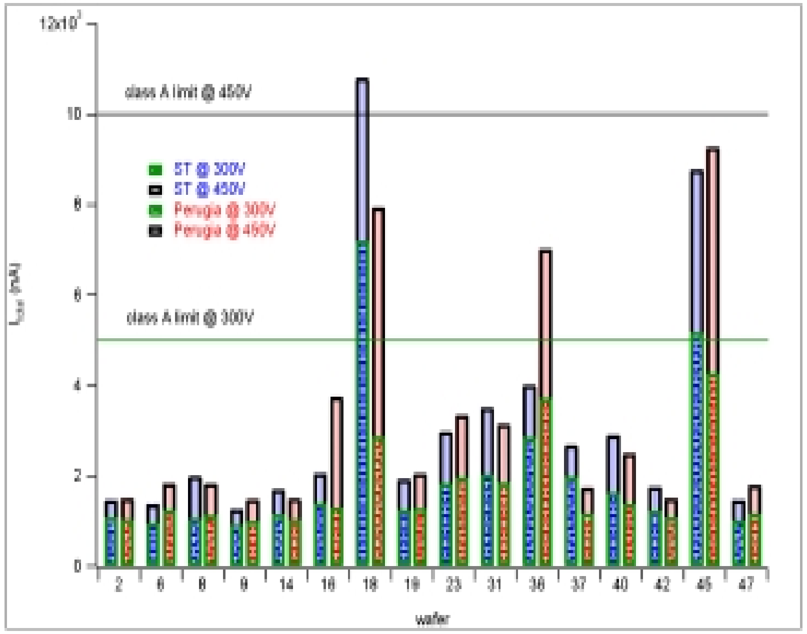
Current stability test on sample of sensors (I-t) @400V_{bias} is foreseen.

Preliminary experience with Milestone sensors

Production of 400 sensors is in progress.

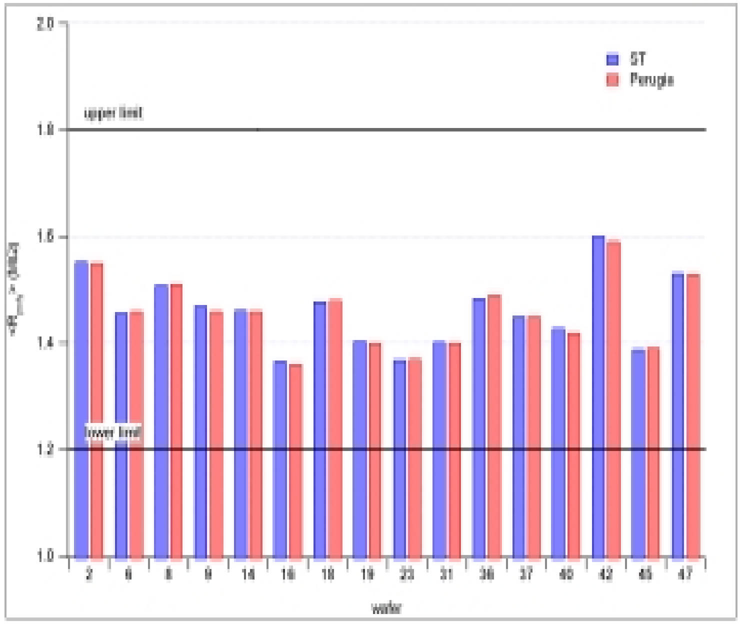
Purposes of this Milestone:

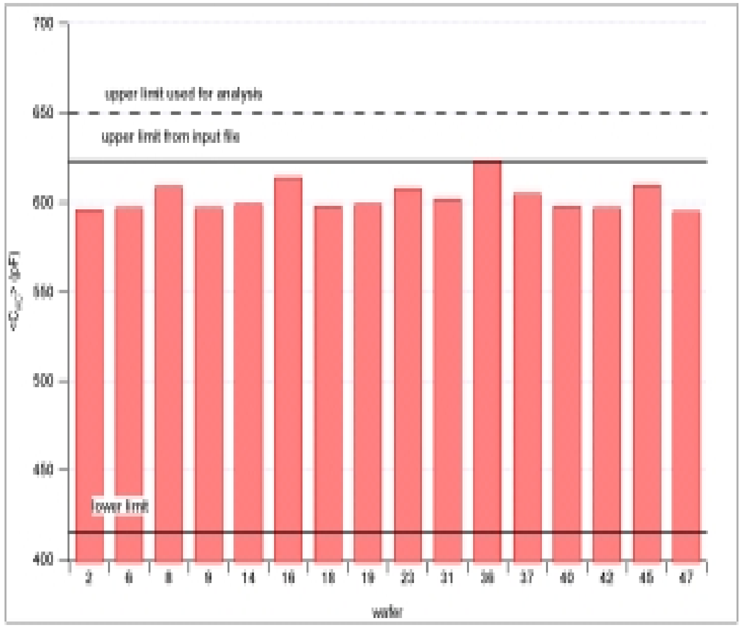
- Gain experience on the fabrication of final sensors
- Qualify companies
- Test the QC system
- Test the overall procedures
- Test the organization and logistic



Total current for a batch of sensors
No breakdown detected up to 550V

Poly resis. and AC cap.

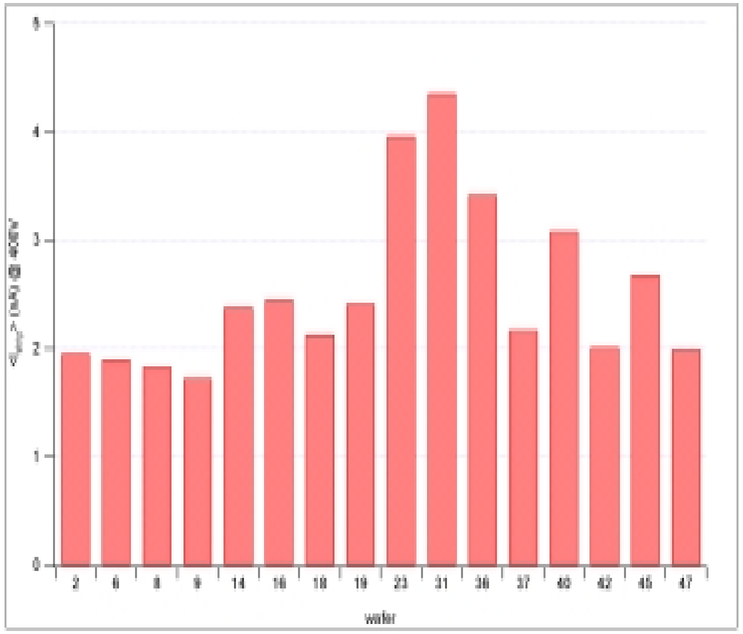


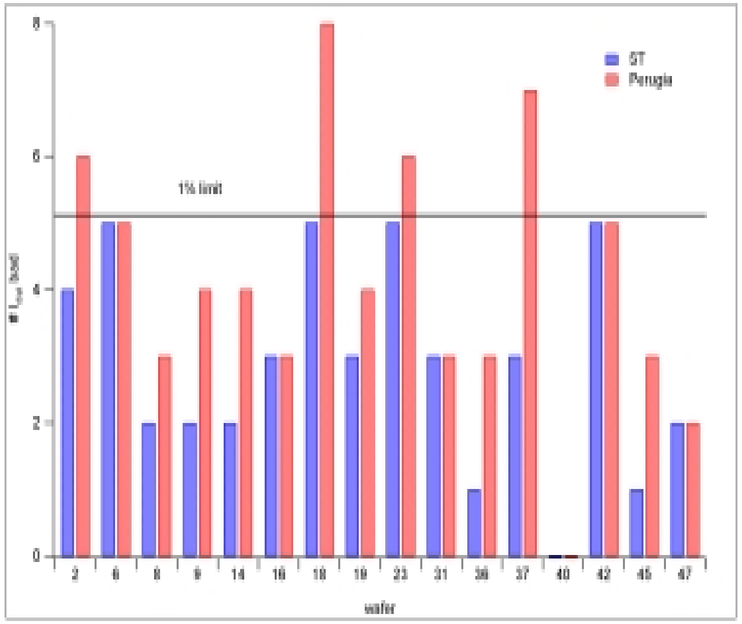


Poly-resistor mean values

AC capacitors mean values

Strip current and pinholes

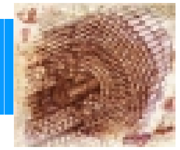




Strip current mean values

Pinholes

Conclusion



- The Quality Control and Assurance for the construction of ~ 210 m^2 silicon sensors to be produced in ~ 2.5 years for the CMS Tracker has been described.
- Automatic testing procedures and acceptance criteria for the sensor testing have been defined and proven to be conform between the test centers.
- Capability of tracking and analyze non conformities has been formulated.
- Comprehension of possible critical and risky activities is in hand.

Conclusion (2)

Contracts with the companies should be signed in June.

Production should start in autumn.

We are well aware of the challenging task but we believe we are approaching it in the appropriate way.