

Silicon sensor probing and radiation studies for the LHCb Silicon Tracker

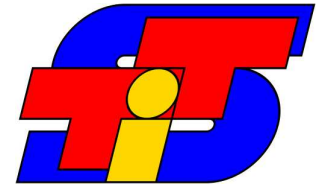
Cristina Lois Gómez

Physik-Institut der Universität Zürich
Universidade de Santiago de Compostela

lois@physik.unizh.ch



LHCb Silicon Tracker group

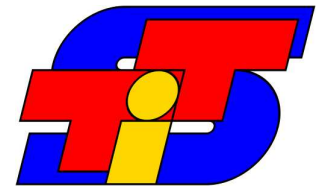


On behalf of LHCb Silicon Tracker Group, ≈ 50 researchers from 6 institutes:

- Max-Planck-Institut für Kernphysik, Heidelberg
- Kiev Institute for Nuclear Research
- Laboratoire de Physique des Hautes Energies, Lausanne
- Budker Institute for Nuclear Physics, Novosibirsk
- Universidade de Santiago de Compostela
- Physik-Institut der Universität Zürich



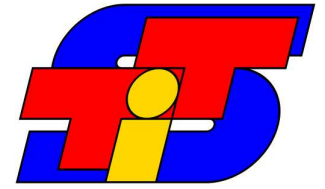
Overview



- LHCb spectrometer and the Silicon Tracker



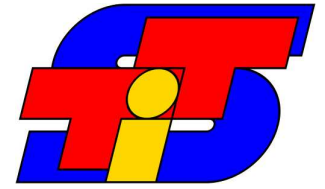
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- LHCb spectrometer and the Silicon Tracker
- Sensor quality assurance program and results on first sensors



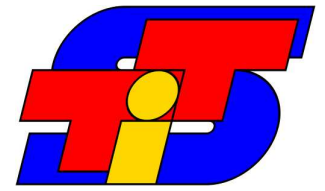
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- Sensor quality assurance program and results on first sensors
- Irradiation tests with IT prototype sensors



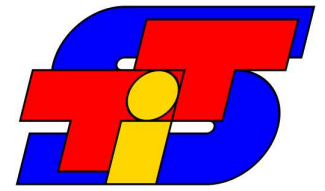
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- **Summary**



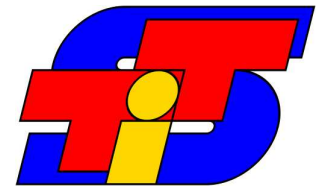
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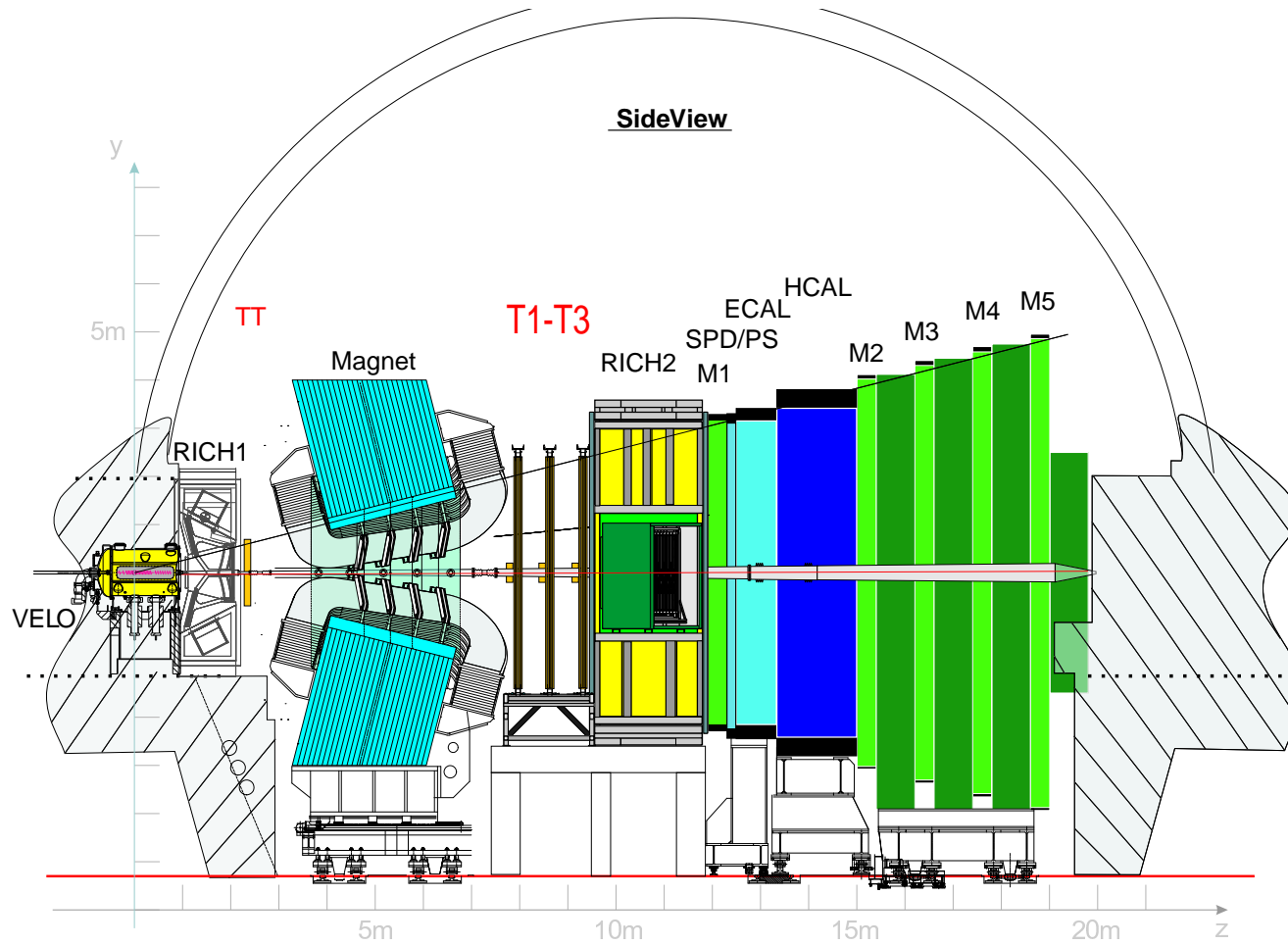


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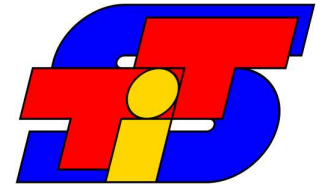


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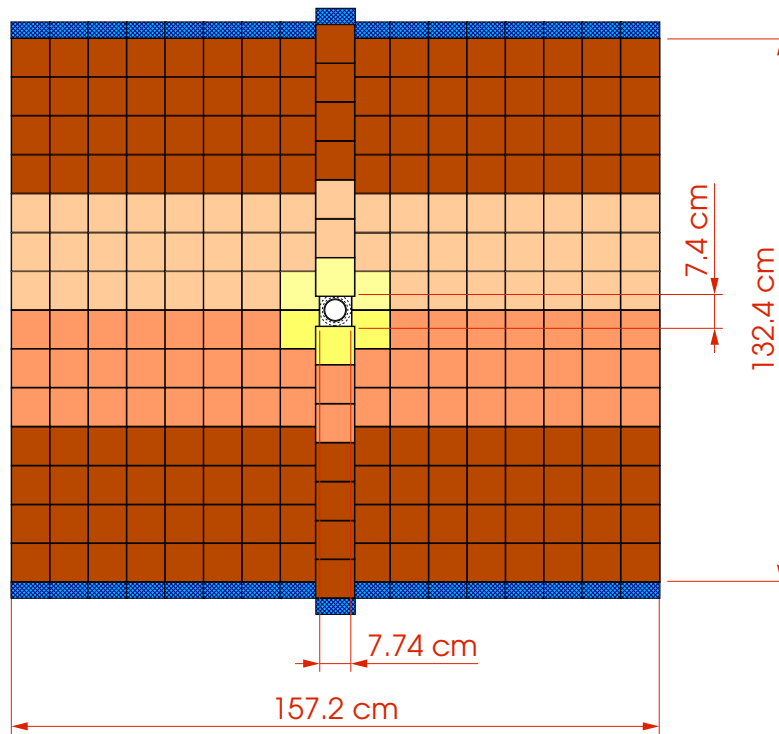
LHCb spectrometer



Trigger Tracker

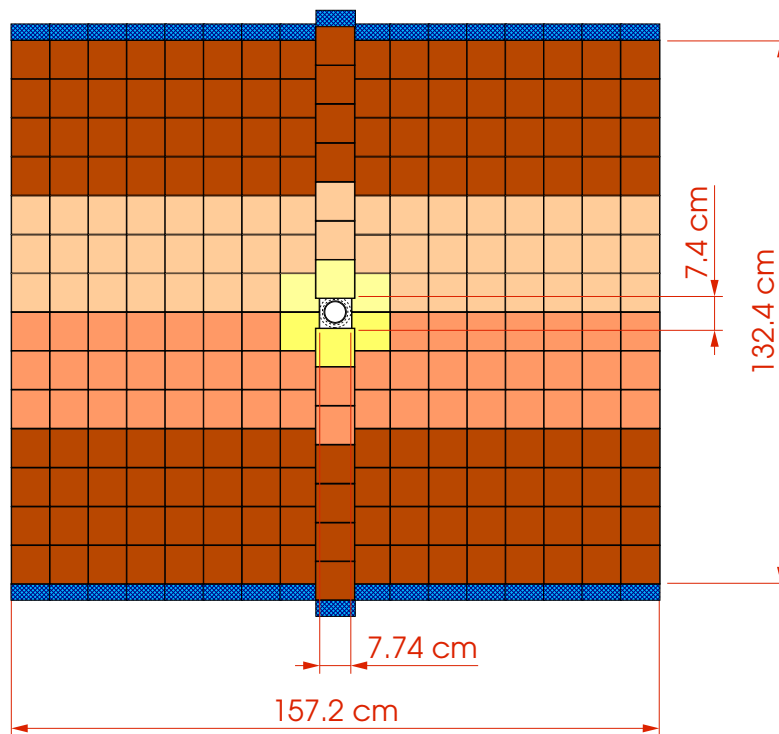


- 4 detection layers



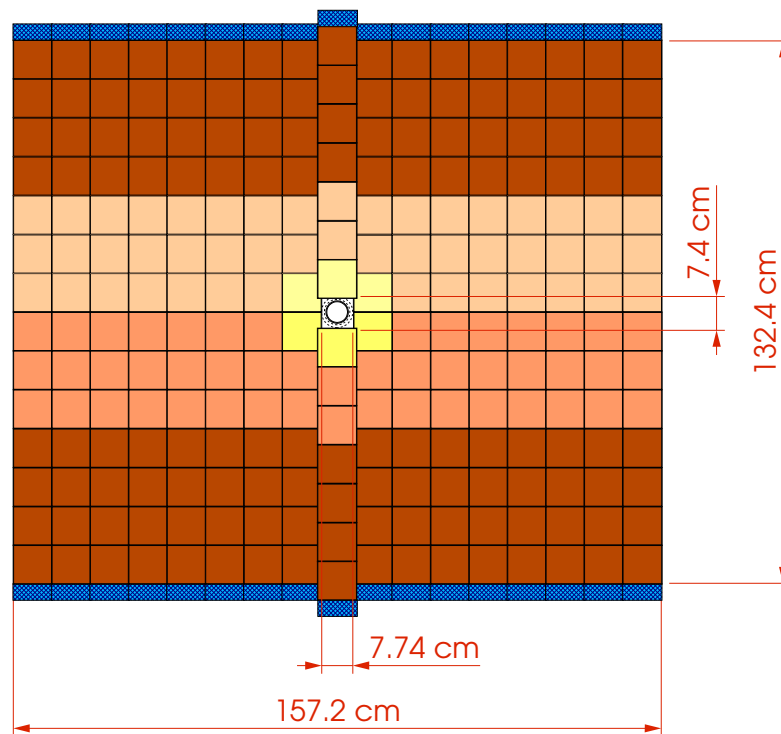
Trigger Tracker

- 4 detection layers
- 14- and 7-sensor modules, several readout sectors



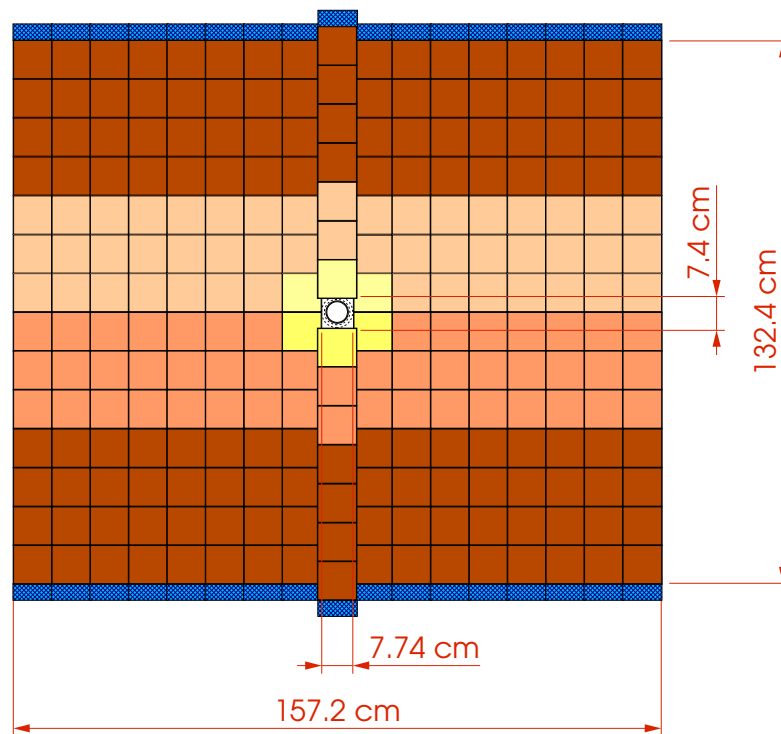
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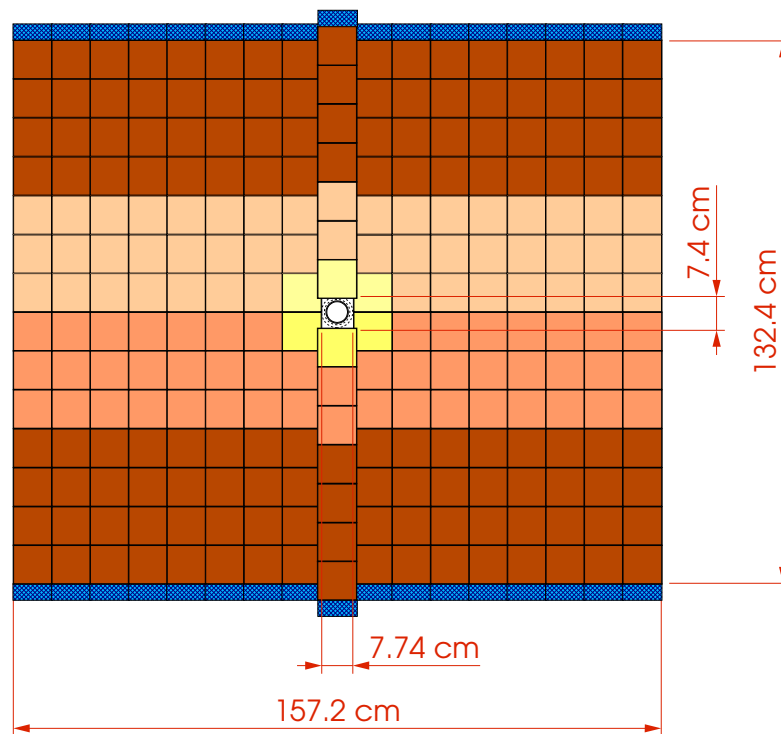
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- silicon microstrip detectors type CMS-OB2

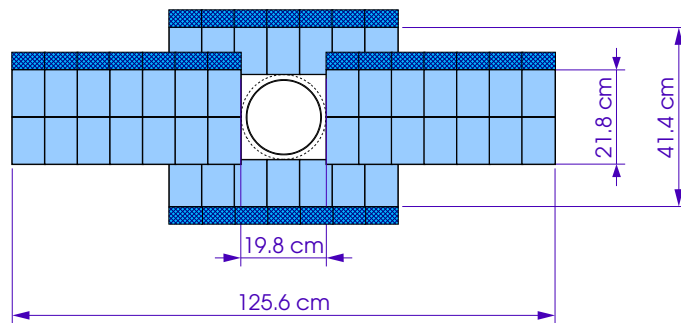




- 4 detection layers
- 14- and 7-sensor modules, several readout sectors
- all readout hybrids outside of acceptance
- silicon microstrip detectors type CMS-OB2
 - 500 μm thick
 - p-on-n, single-sided
 - 183 μm pitch, $w/p = 0.25$
 - dimensions $9.4 \times 9.6 \text{ cm}^2$

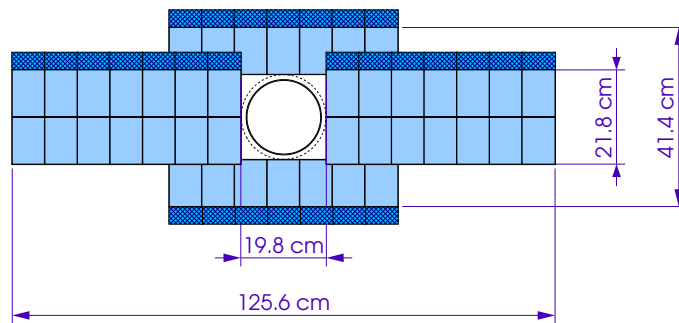
Inner Tracker

- 3 stations (T1-T3)



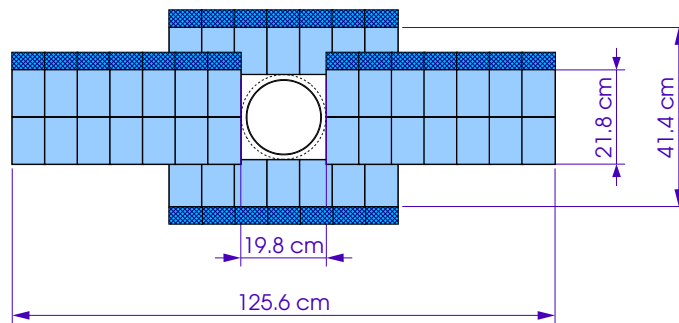
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- 3 stations (T1-T3)
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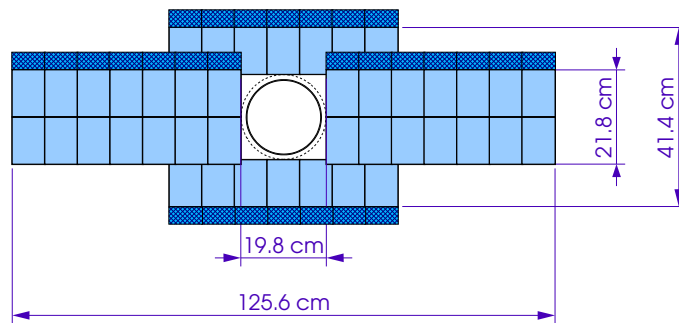
Inner Tracker

- 3 stations (T1-T3)
- 4 detection layers per station
- 4 individual boxes per station



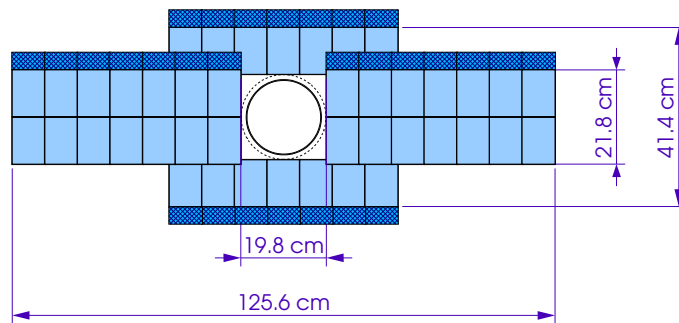
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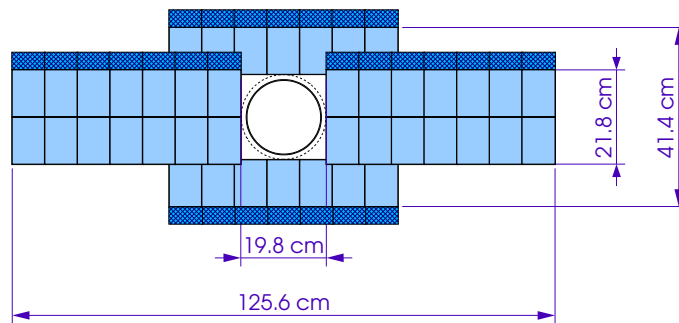


Inner Tracker

- 3 stations (T1-T3)
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- silicon microstrip detectors (HPK-320, HPK-410)



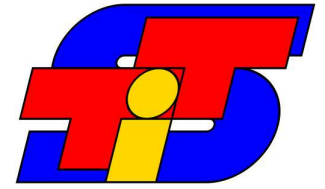
Inner Tracker



- 3 stations (T1-T3)
- 4 detection layers per station
- 4 individual boxes per station
- 1- and 2-sensor modules
- silicon microstrip detectors (HPK-320, HPK-410)
 - 320 μm / 410 μm thick
 - p-on-n, single-sided
 - 198 μm pitch, $w/p = 0.25$
 - dimensions $11 \times 7.8 \text{ cm}^2$



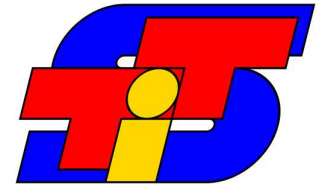
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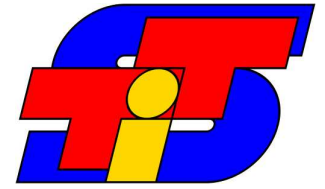
Sensor quality assurance program



- Required to ensure excellent performance of modules



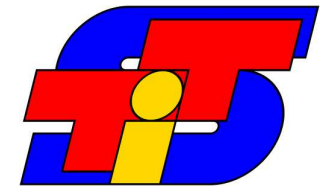
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Sensor quality assurance program

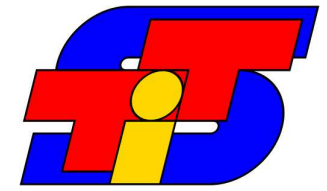


- Required to ensure excellent performance of modules
- Results for first batches of sensors

Sensor type	Delivered	Total production
HPK-320	14	194
HPK-410	35	386
HPK-500	98	1000



Sensor quality assurance program



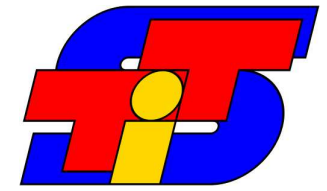
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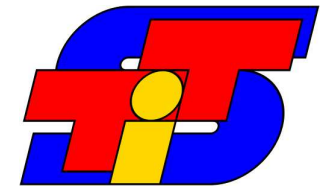
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- Two stages:
 - tests performed by HPK prior to shipment



Sensor quality assurance program



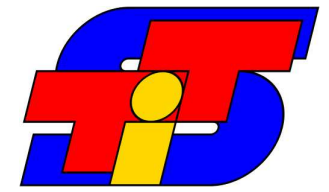
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HPK-320	14	194
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- Two stages:
 - tests performed by HPK prior to shipment
 - tests performed by our group after reception

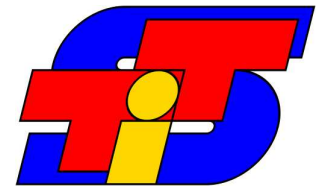


Tests performed by the ST group





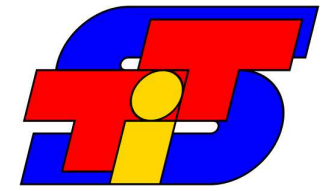
Tests performed by the ST group



- Visual inspection



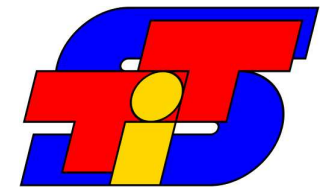
Tests performed by the ST group



- Visual inspection
- IV curves



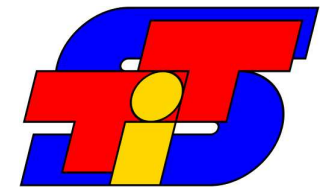
Tests performed by the ST group



- Visual inspection
- IV curves
- CV curves



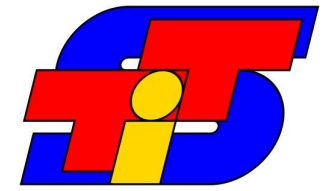
Tests performed by the ST group



- Visual inspection
- IV curves
- CV curves
- Metrological measurements



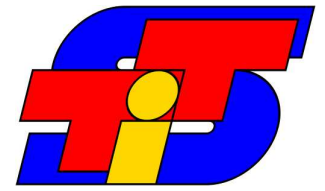
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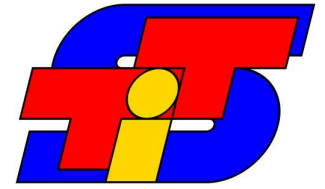
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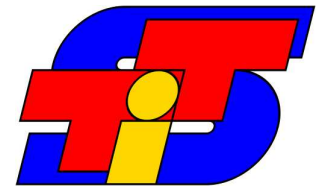
Visual inspection



- Examine sensors under microscope:
 - take note of scratches/defects
 - look for chipped edges
 - look for pad bondability/contamination
 - check serial # on scratch-pad



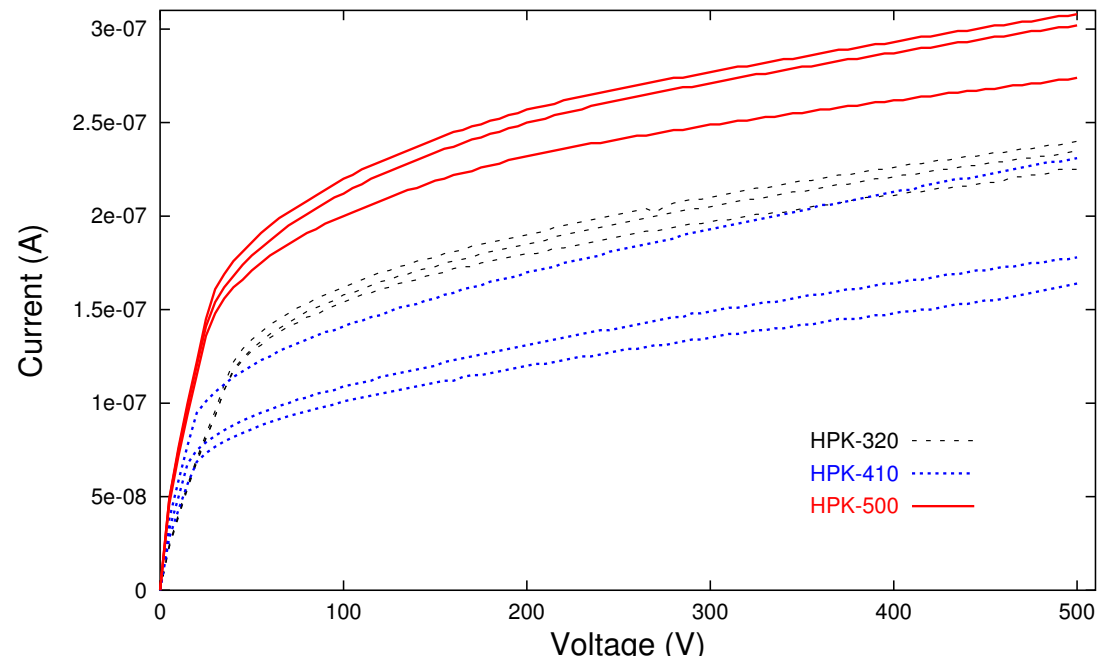
Visual inspection



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 - look for chipped edges
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 - check serial # on scratch-pad
- sensors very good: no deep scratches or big defects found

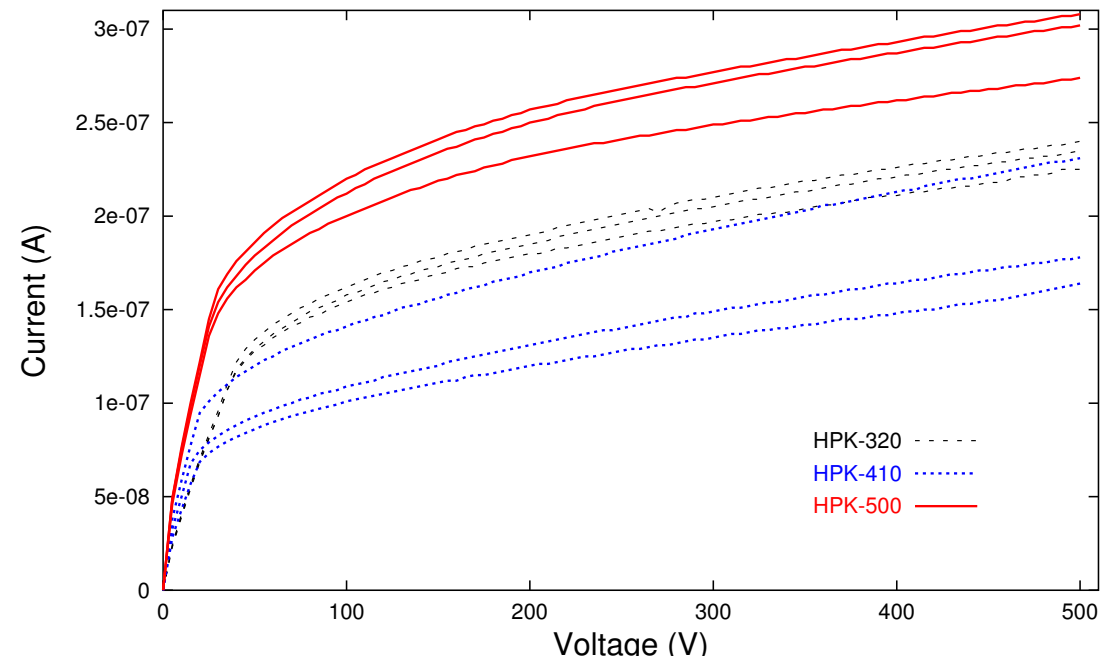
Leakage Currents

- IV curves taken up to 500 V, at $T \sim 20$ °C, RH < 30%



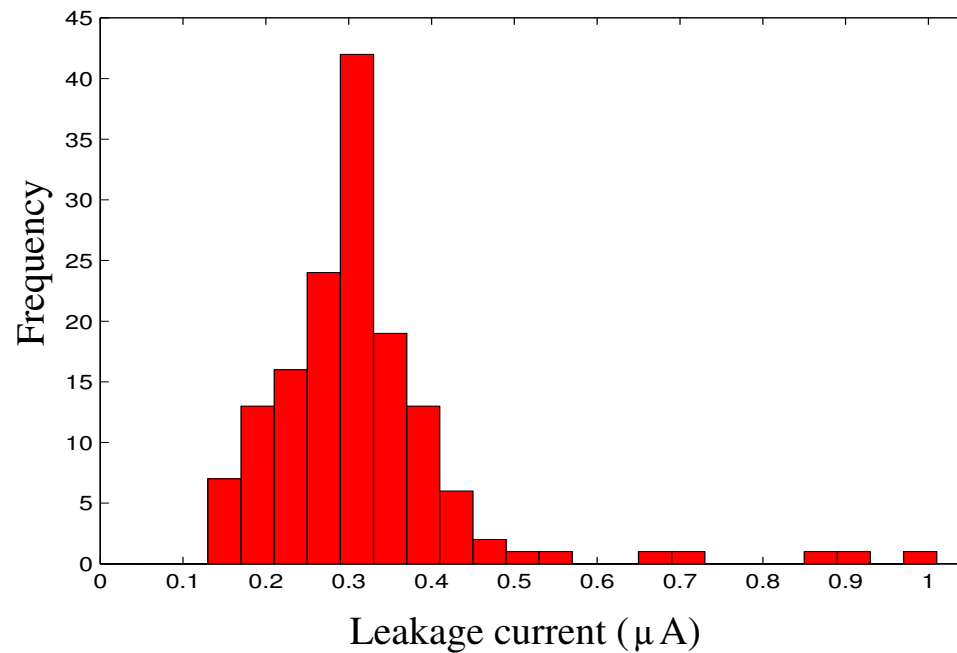
Leakage Currents

- IV curves taken up to 500 V, at $T \sim 20$ °C, RH < 30%
- Great uniformity in currents; no breakdown below 500 V



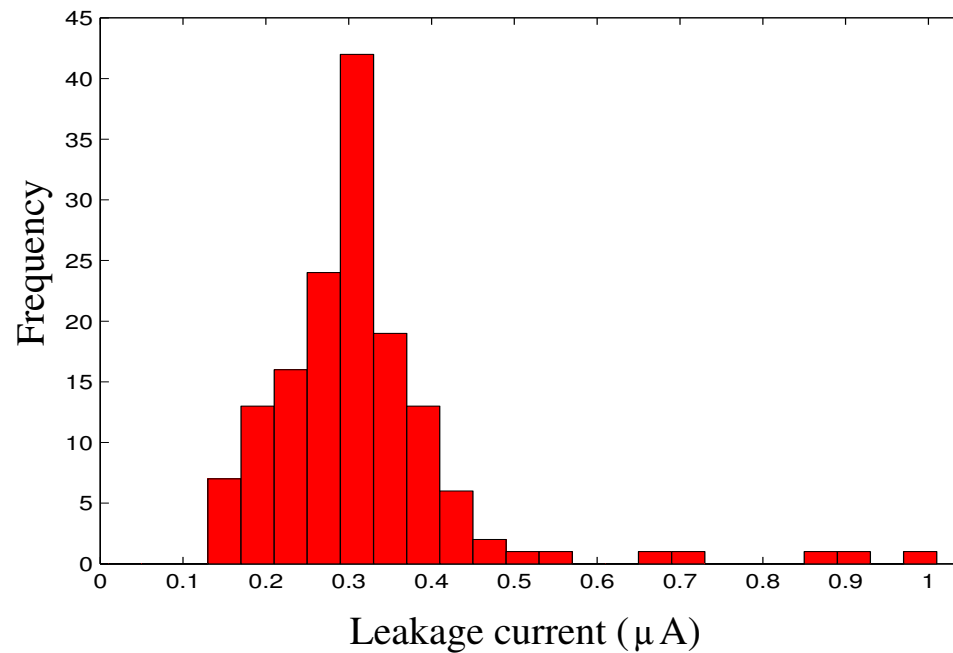
Leakage Currents

- Observed low currents; typically $I < 400$ nA at 500 V



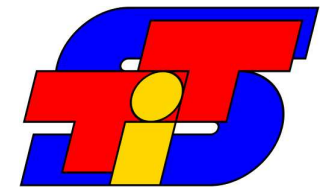
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- All sensors fulfill specifications





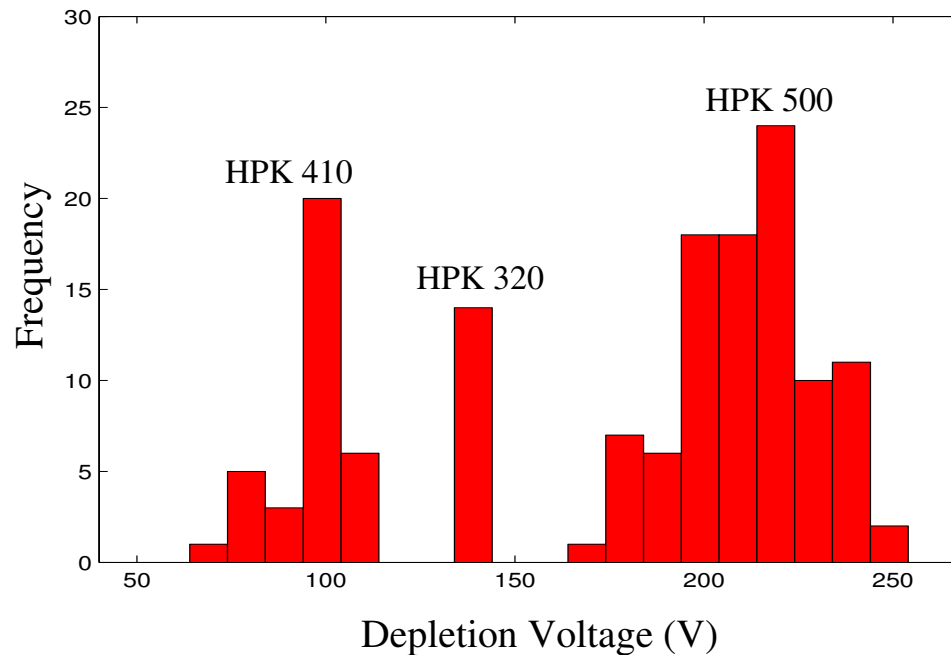
Full depletion voltage



- CV curves taken at $T \sim 20$ °C, $RH < 30\%$, $f = 1$ kHz

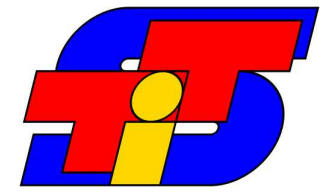
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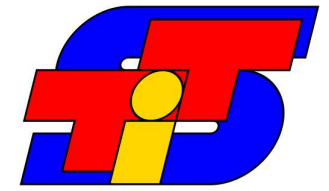
Metrology measurements



- optical metrology machine
Mahr OMS 600



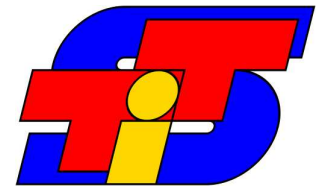
Metrology measurements



- optical metrology machine
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- flatness, length, width,
parallelity, etc.

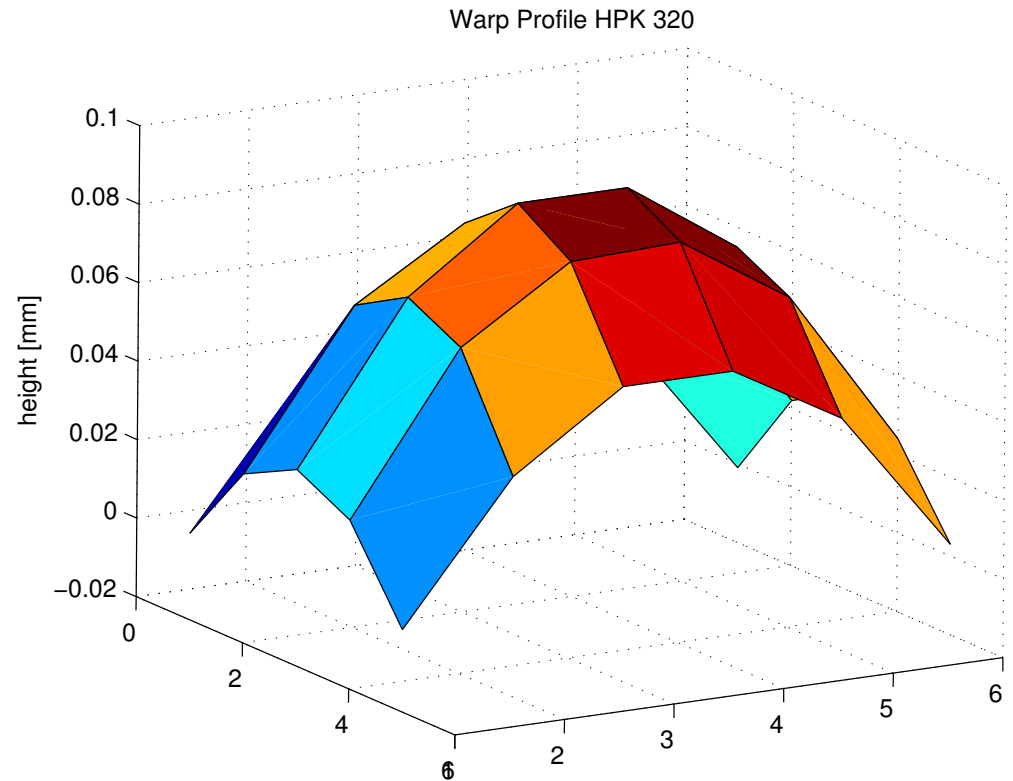


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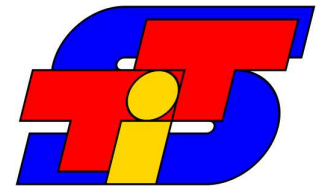
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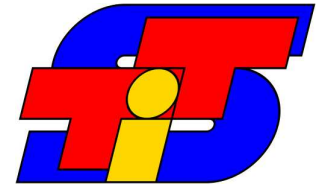
Other tests



- Coupling capacitances



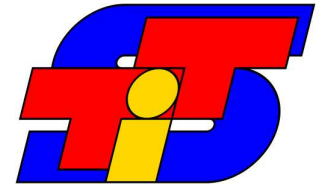
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- Coupling capacitances
- Other features of leakage currents:



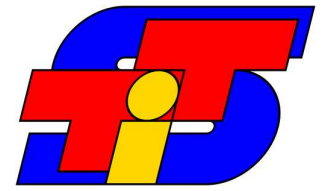
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- Coupling capacitances
- Other features of leakage currents:
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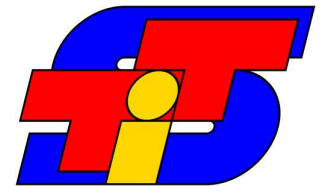
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- Coupling capacitances
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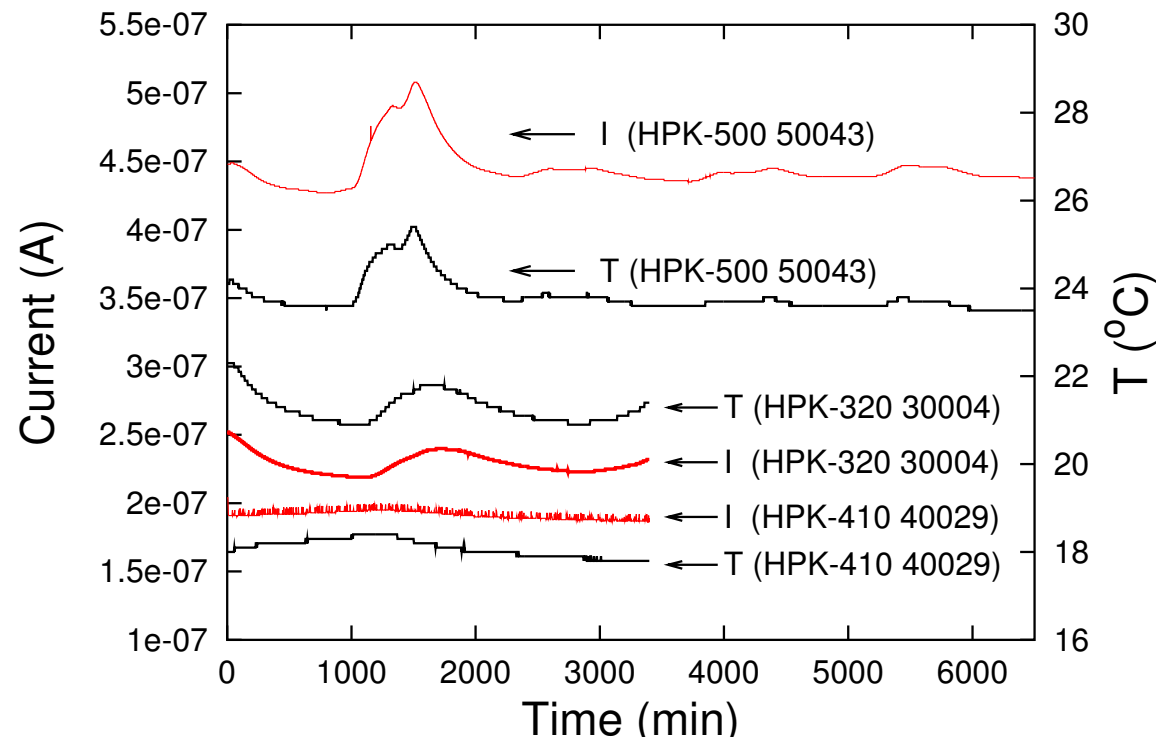
Other tests



- Coupling capacitances
- Other features of leakage currents:
 - Dependence on mechanical strain
 - Reproducibility
 - Stability over ~ 24 h

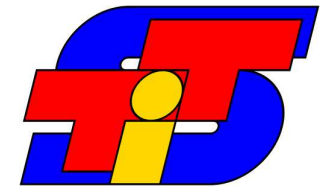
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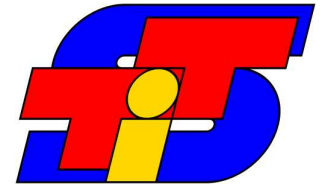
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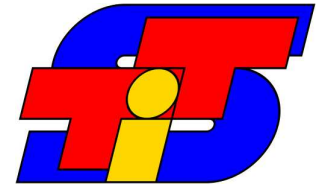
Irradiated Sensors



- 3 IT Multi-Geometry prototype sensors (5 regions; same thickness, dimensions and material characteristics as HPK-320)



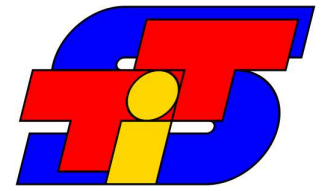
Irradiated Sensors



- 3 IT Multi-Geometry prototype sensors (5 regions; same thickness, dimensions and material characteristics as HPK-320)
- 1 CMS-OB2 test-structure (monitor diode, mini-detector, isolated elements of strips, polysilicon, coupling capacitances,...)



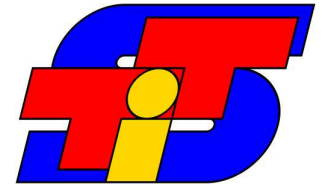
Irradiation



- T7 irradiation facility, at PS at CERN



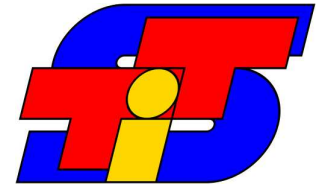
Irradiation



- T7 irradiation facility, at PS at CERN
- 24 GeV/c protons; hardness $k = 0.6$



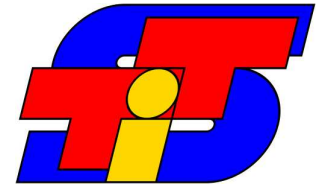
Irradiation



- T7 irradiation facility, at PS at CERN
- 24 GeV/c protons; hardness $k = 0.6$
- Fluences:
 - One sensor: 1.9×10^{13} p/cm² (~ 7 years innermost IT)
 - Remaining: 6.3×10^{13} p/cm² (~ 20 years innermost IT)



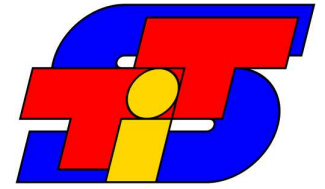
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- Proton fluences from aluminium foils activation measurements



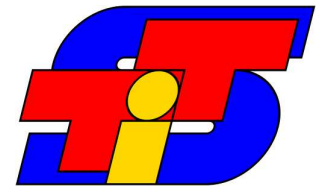
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- Annealing of 80 min at 60°C



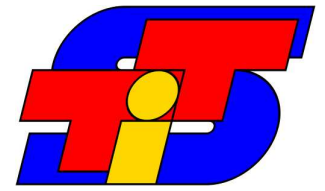
Electrical characterization



- Performed at room temperature; between measurements, -20°C



Electrical characterization



- Performed at room temperature; between measurements, -20°C
- Measured:
 - full depletion voltages
 - leakage currents \longrightarrow current related damage constant α
 - AC- and DC- strip tests: strip capacitances, inter-strip capacitances, coupling capacitances, strip currents

Full depletion voltages

- Extracted from total sensor capacitance

Sensor	Fluence (p/cm^{-2})	V_{depl} (V) before	V_{depl} (V) after
LHCb 5	1.9×10^{13}	55	40
LHCb 8	6.3×10^{13}	55	130
LHCb 1	6.3×10^{13}	55	130
Diode	6.3×10^{13}	120	115

Full depletion voltages

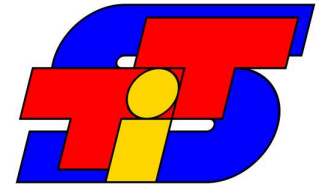
- Extracted from total sensor capacitance

Sensor	Fluence (p/cm^{-2})	V_{depl} (V) before	V_{depl} (V) after
LHCb 5	1.9×10^{13}	55	40
LHCb 8	6.3×10^{13}	55	130
LHCb 1	6.3×10^{13}	55	130
Diode	6.3×10^{13}	120	115

⇒ After lower fluence, depletion voltage lower than initial



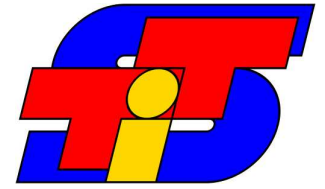
Leakage currents



- After irradiation $\Delta I = \alpha V \phi$



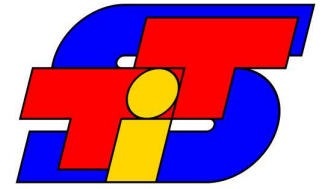
Leakage currents



- After irradiation $\Delta I = \alpha V \phi$
- Calculate the current related damage constant α

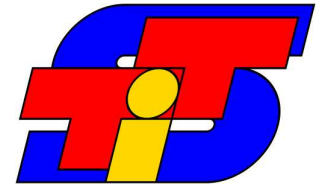


Leakage currents



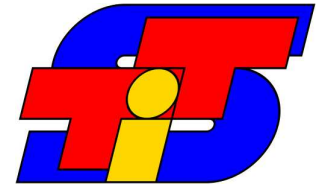
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- Use I at $V_{bias} = V_{depl.}$, normalized to $T = 20^\circ\text{C}$

Leakage currents



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- Obtained for 24 GeV proton, $\bar{\alpha} = 2.78 \times 10^{-17}$ A/cm

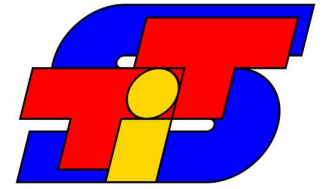
Leakage currents



- After irradiation $\Delta I = \alpha V \phi$
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- Use I at $V_{bias} = V_{depl.}$, normalized to $T = 20^\circ\text{C}$
- Obtained for 24 GeV proton, $\bar{\alpha} = 2.78 \times 10^{-17}$ A/cm
- Normalizing fluence to equivalent 1 MeV n, \rightarrow hardness factor $k_\alpha = 0.61$



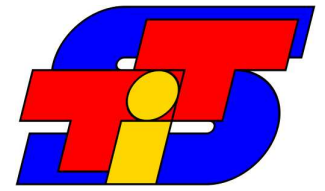
Strip tests



- total strip capacitances
 - inter-strip capacitances
 - coupling capacitances
- essentially unchanged after irradiation



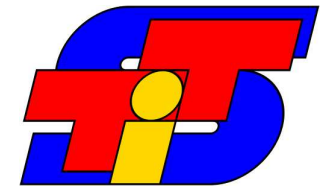
Overview



- LHCb spectrometer and the Silicon Tracker
- Sensor quality assurance program and results on first sensors
- Irradiation tests with IT prototype sensors
- **Summary**



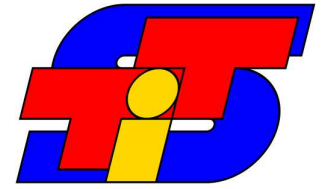
Summary



- LHCb Silicon Tracker uses silicon micro-strip detectors
 - $\sim 200 \mu\text{m}$ pitch
 - readout strips up to 38 cm in length



Summary

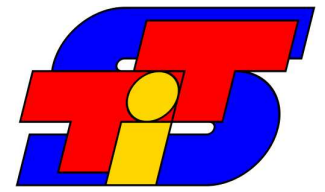


- LHCb Silicon Tracker uses silicon micro-strip detectors
 - $\sim 200 \mu\text{m}$ pitch
 - readout strips up to 38 cm in length
- Presented QA program
 - results on first sensors very satisfactory
 - low leakage currents; electrical parameters within specification

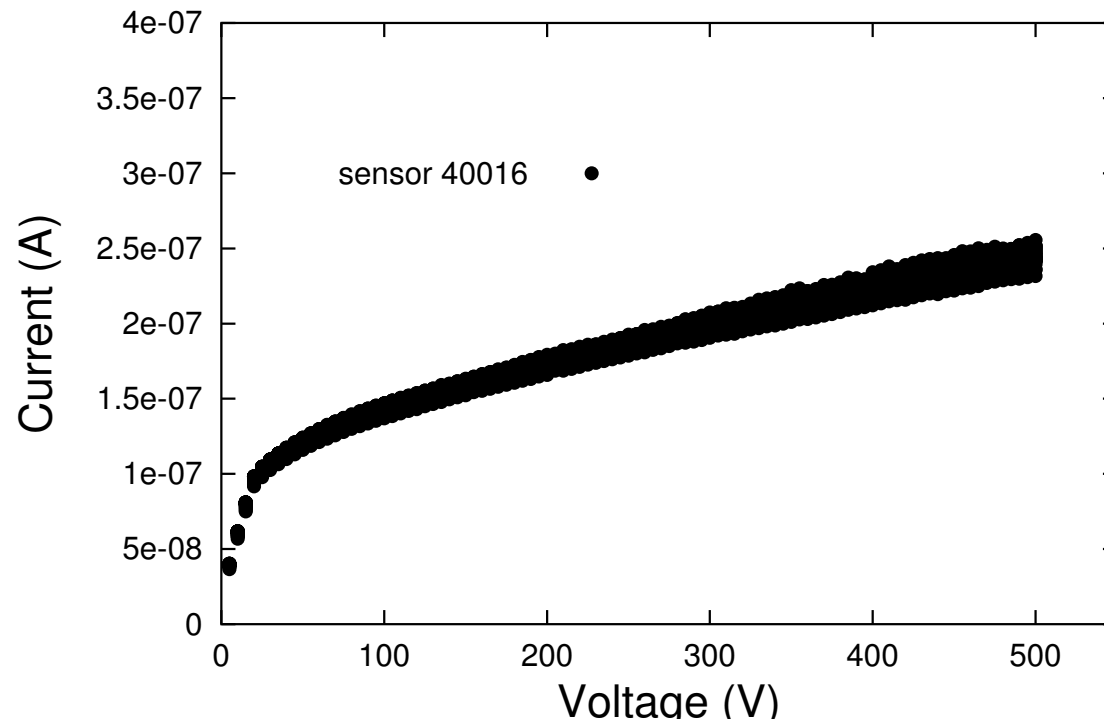
- LHCb Silicon Tracker uses silicon micro-strip detectors
 - $\sim 200 \mu\text{m}$ pitch
 - readout strips up to 38 cm in length
- Presented QA program
 - results on first sensors very satisfactory
 - low leakage currents; electrical parameters within specification
- Performed irradiation on IT prototype sensors with 24 GeV/c protons
 - depletion at 50 V after equivalent to 7 LHCb years in IT
 - current related damage constant $\alpha = 2.78 \times 10^{-17} \text{ A/cm}$, hardness factor $k_\alpha = 0.61$
 - strip capacitances, coupling capacitances: unchanged after irradiation



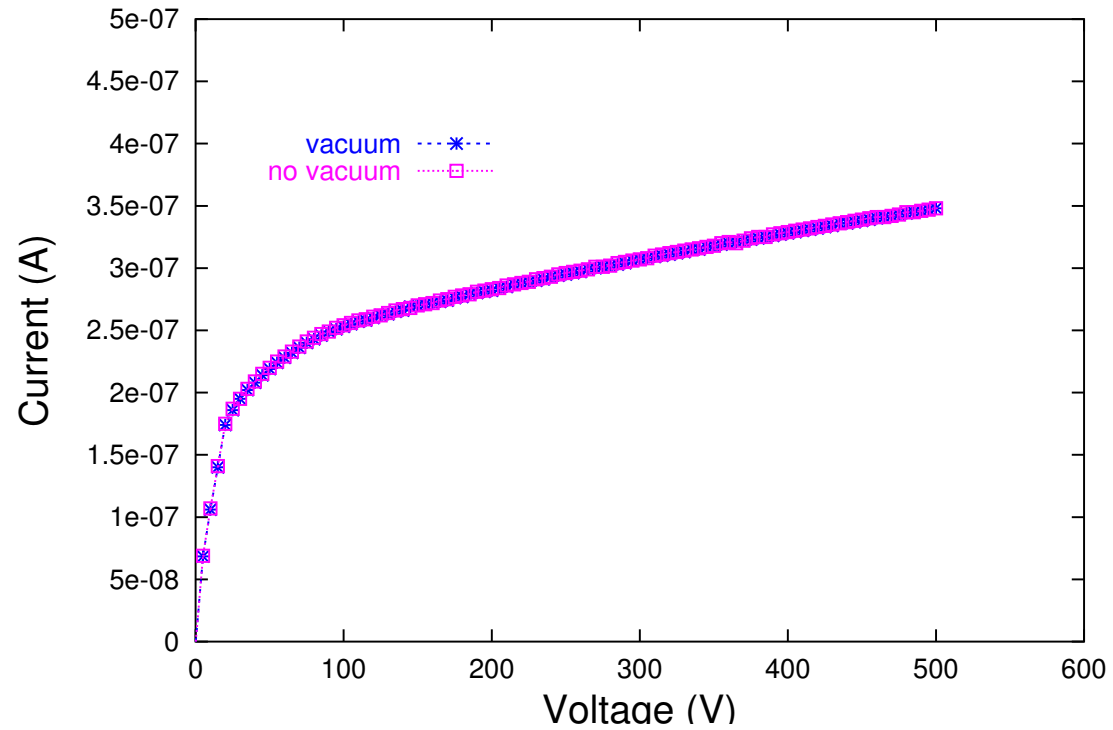
Back-slides

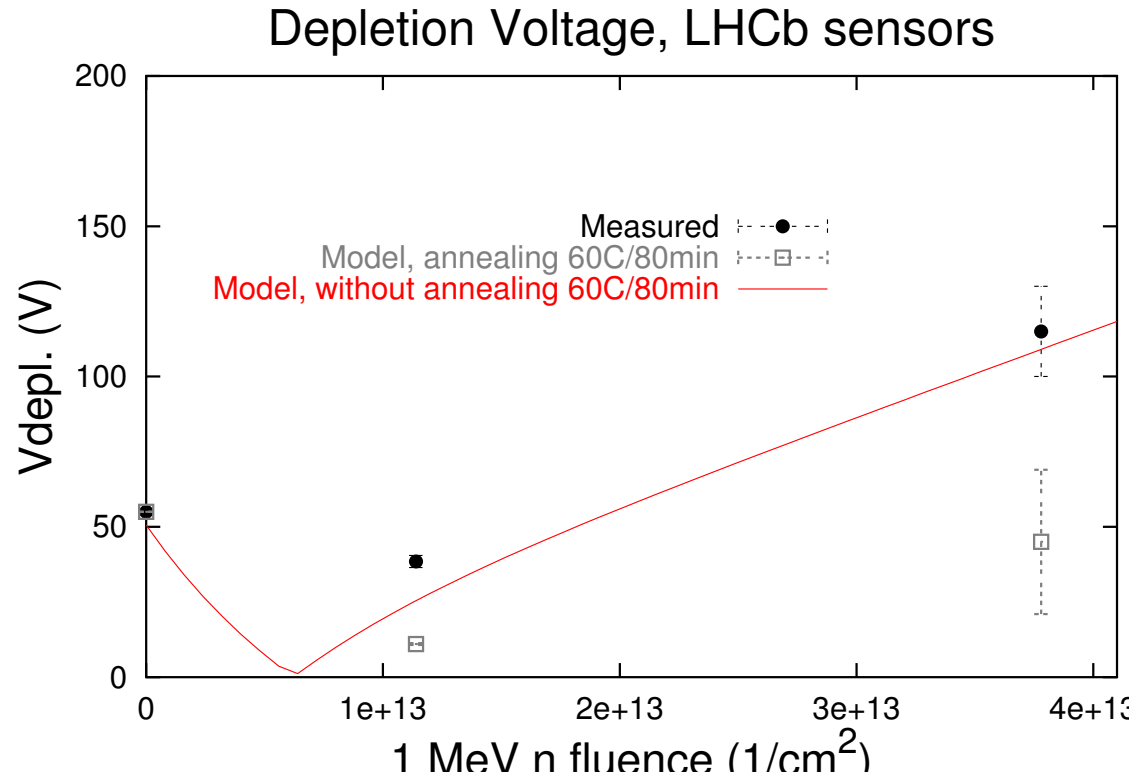


Reproducibility IV curves



No chuck vacuum effect





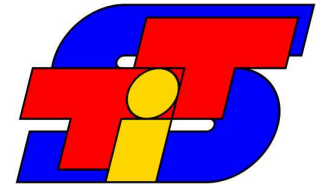
Leakage current:

$$I(T) = I(T_m) \left(\frac{T}{T_m} \right)^2 \exp \left(-\frac{E_g}{2k_B} \left\{ \frac{1}{T} - \frac{1}{T_m} \right\} \right)$$

- $E_g = 1.12$ eV band gap energy in silicon at room temperature
- k_B Boltzmann constant
- T and T_m in K
- relation true if current caused by generation current in the bulk material (case after irradiation)



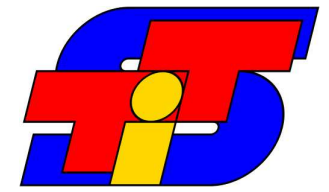
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- *LHCb Inner Tracker Technical Design Report.* CERN/LHCC 2002-029.
- O. Steinkamp. *Silicon strip detectors for the LHCb experiment.* Nucl. Instr. and Meth. A 541 (2005) 83.
- F. Lehner, C. Lois and H. Voss. *Measurements on irradiated silicon sensor prototypes for the Inner Tracker of LHCb.* LHCb note 2004-104.
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