Advanced silicon pixel detectors for particle tracking and photon science applications

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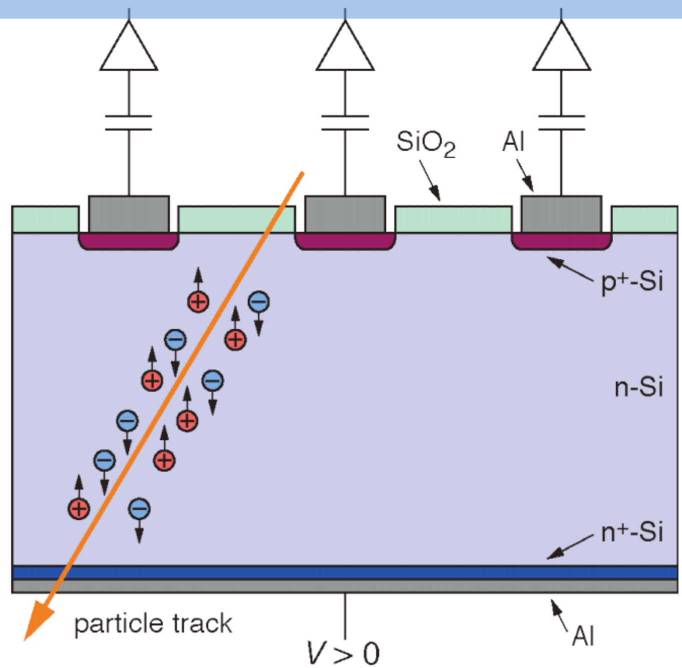
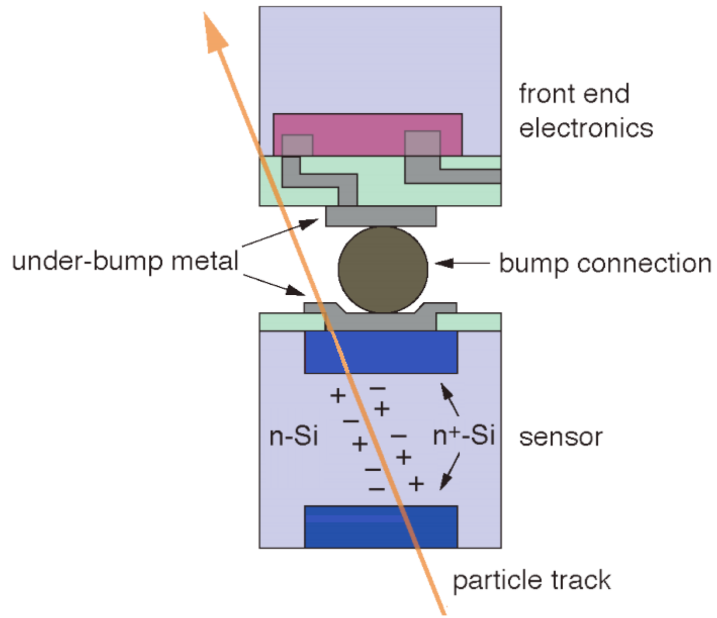
Chinese Materials Conference – Chengdu, Sichuan
July 10-14, 2019

Pixel detector





Thin Silicon wafer (~300 µm) with implanted strips or pixels.

- Each implant is connected to a readout electronics channel.
- Through going charged particles generate electron-hole pairs.
- Electron-hole pairs drift in electric field.

From the signals measured by the electronics the position of the particle can be deduced to a few micrometer precision.

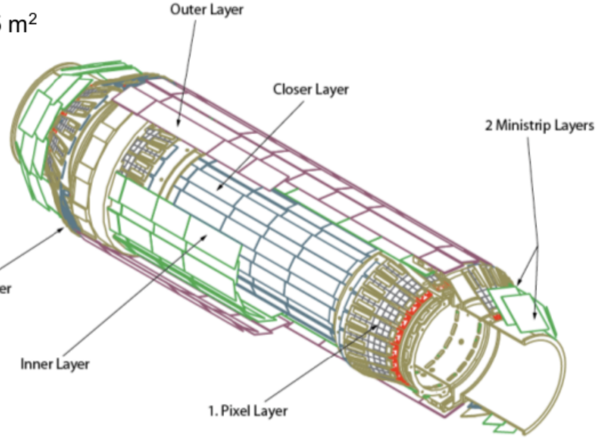
Reconstruction of particles track.

The DELPHI Vertex Detector

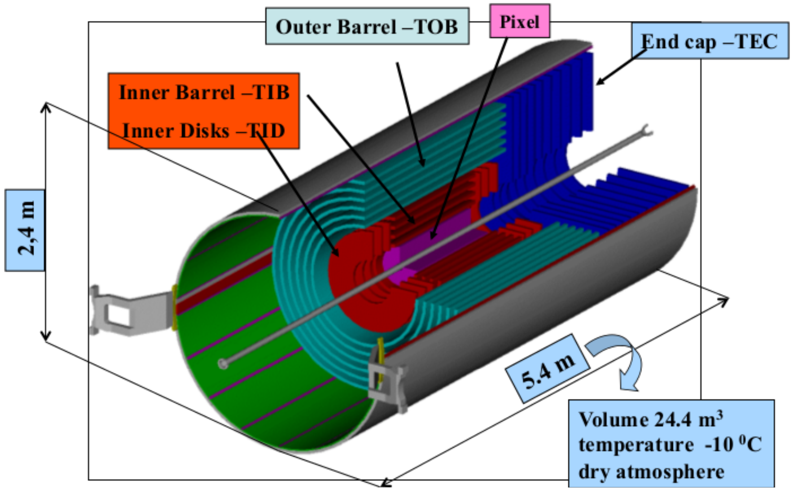
Sensor surface ~1,5 m^2

888 Silicon sensors

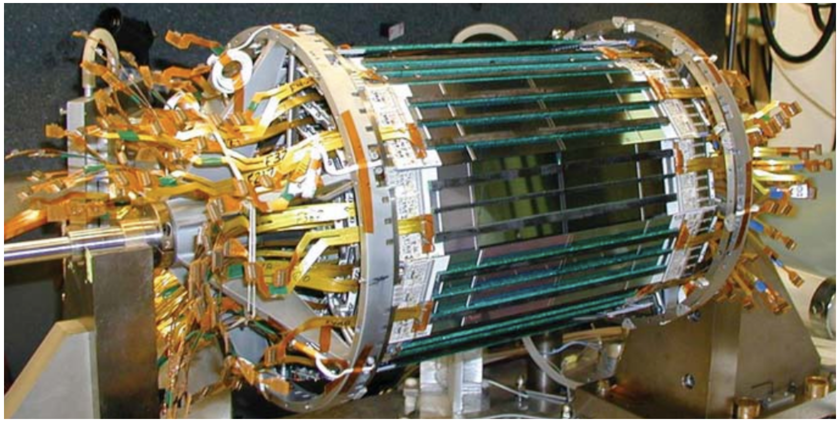
Length ~1 m
Diameter ~ 20 cm



The CMS Inner Tracker



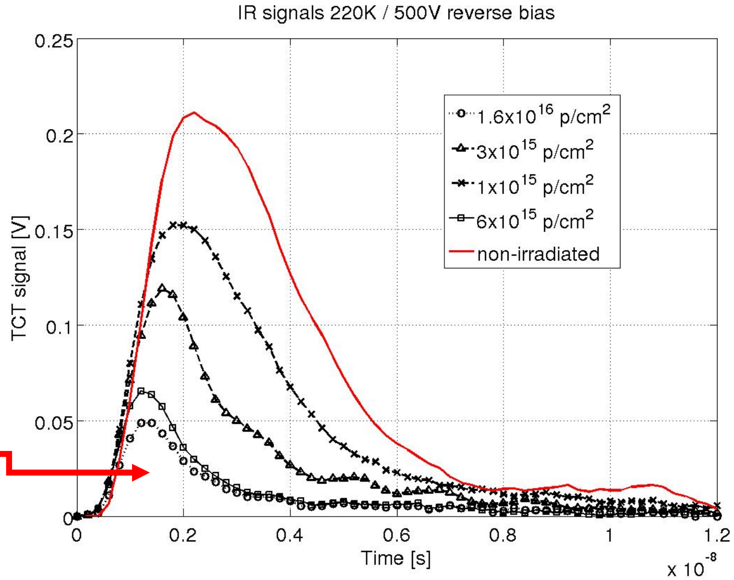
The CDF Vertex Detector

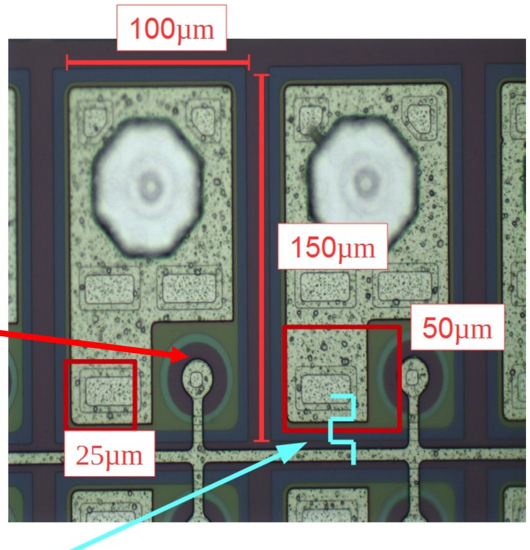


Motivation and background

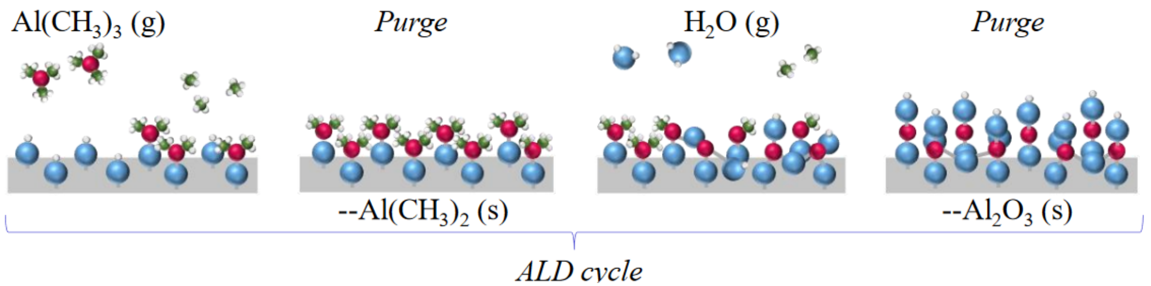
Need for upgrades of existing detectors

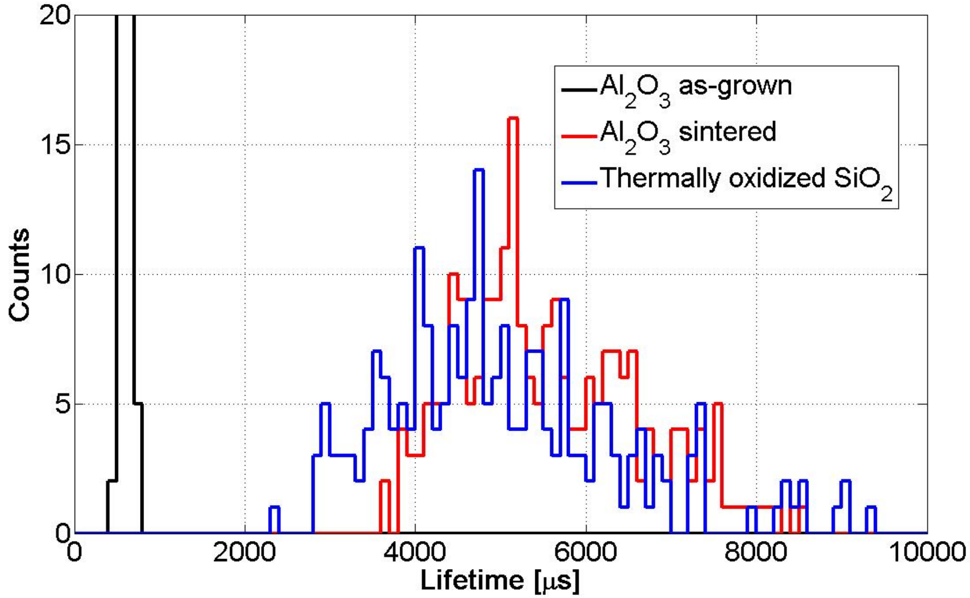
- Physicists want to discover more rare particle decay processes;
- Luminosity of LHC must be increased to create more p –> p collisions;
- More collisions mean more radiation damage:
  - Signal degrades 100% -> 20% or less
  - Physical distance within which the electrons are collected degrades from several hundreds of µm to 20-40 µm
- Pixels must be resistively connected with each other;
- Integrated bias resistors allow electrical quality assurance prior very expensive Flip-Chip bump bonding;





Passivation – Atomic Layer Deposition (ALD)





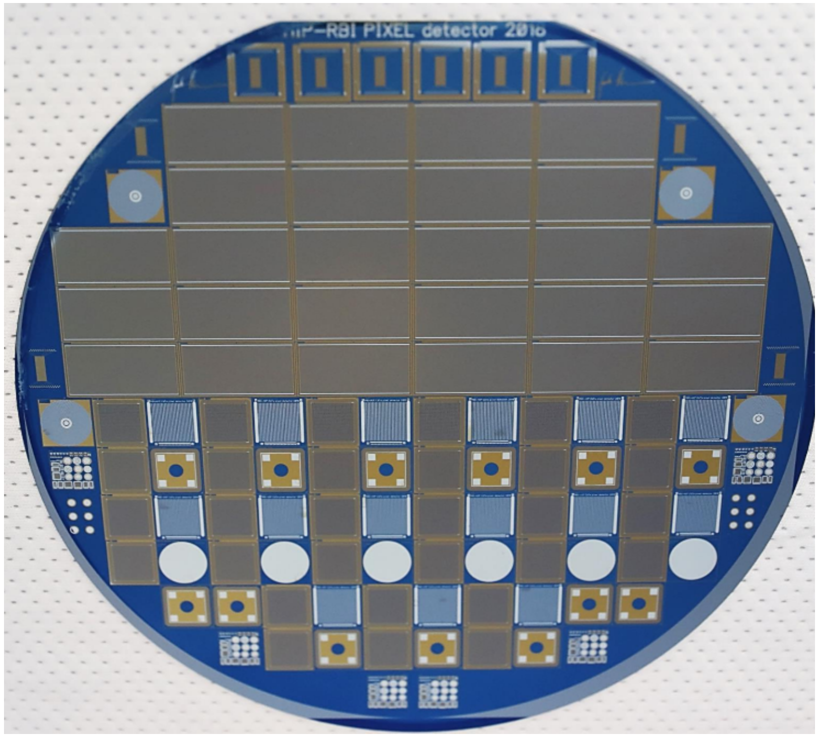
- The electrical passivation properties can be studied by lifetime (τ_{eff}) measurement
- τ_{eff} is the combination of bulk lifetime (τ_{bulk}) and surface recombination (τ_{surf})
- High τ_{eff} can only be measured if $\tau_{surf} \rightarrow 0$, i.e. Si surface is passivated
- Thermally oxidized Si-SiO_2 interface is known to produce best possible $\tau_{surf} \rightarrow 0$
- Oxidized p-type reveals bulk lifetime (τ_{bulk}) (BLUE distribution) and thus it is reference value for passivation studies
- SiO_2 is removed → ALD Al_2O_3 deposition + repeated lifetime measurement (RED distribution)

Good passivation ($\tau_{surf} \rightarrow 0$) is achieved by field effect, negative oxide charge in Al_2O_3 is repulsing e^- to recombine into surface states

J. Härkönen et al., "Processing of n+/p−/p+ strip detectors with atomic layer deposition (ALD) grown Al2O3 field insulator on magnetic Czochralski silicon (MCz-si) substrates", NIMA 826, 2016
J. Härkönen et al., Atomic Layer Deposition (ALD) grown thin films for ultra-fine pitch pixel detectors, NIMA 831, 2016

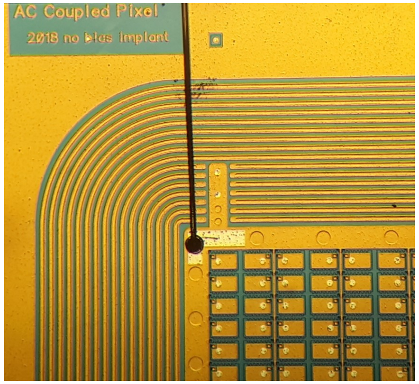
Structures
processed at Micronova nanofabrication center in Finland

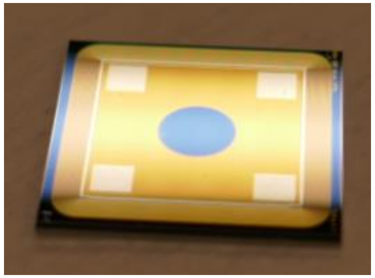
HIP – RBI PIXEL detector 2018



- Pixel detectors:
  - AC-coupled pixel sensor, 100×150 µm pitch to match PSI46dig
  - DC-coupled pixel sensor, 50×50 µm pitch to match RD53A

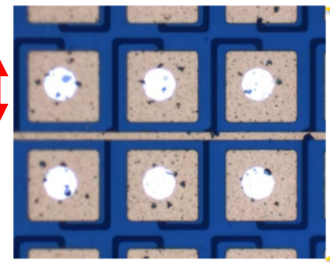
- Pad diodes
- MOS capacitors
- Resistor reference structures
  → easier testing of certain properties

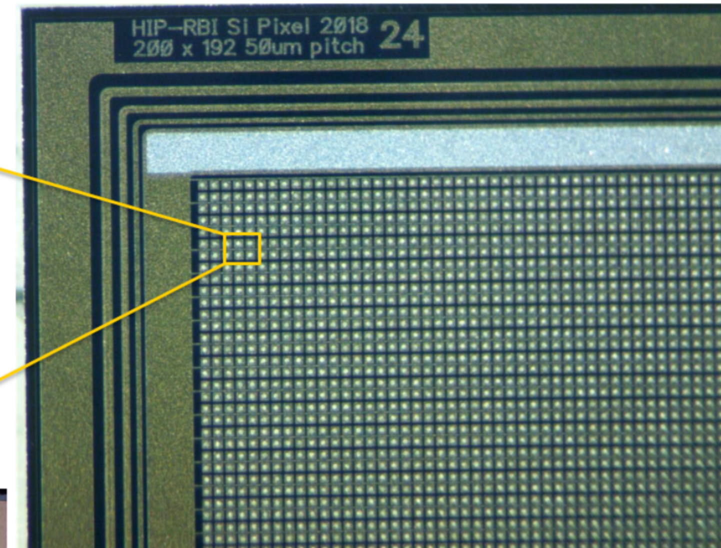




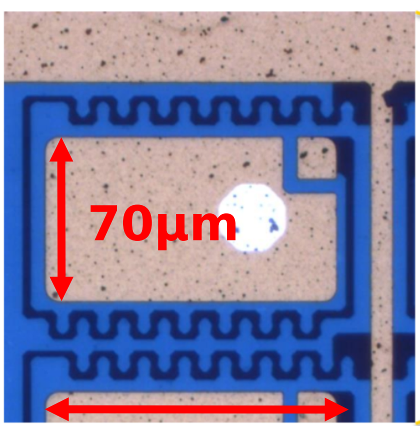
J. Ott et al., *Processing of AC-coupled n-in-p pixel detectors on MCz silicon using atomic layer deposited aluminium oxide*, Nuclear Instruments & Methods in Physics Research A (2019), in press.

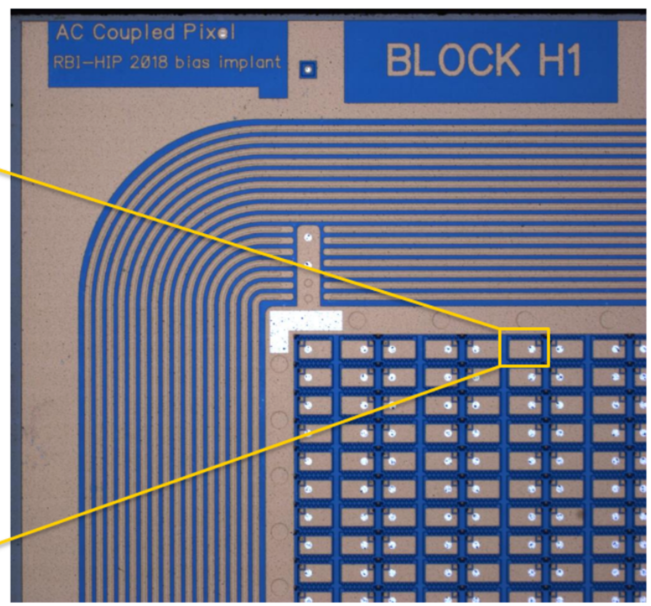
RD53 sensor





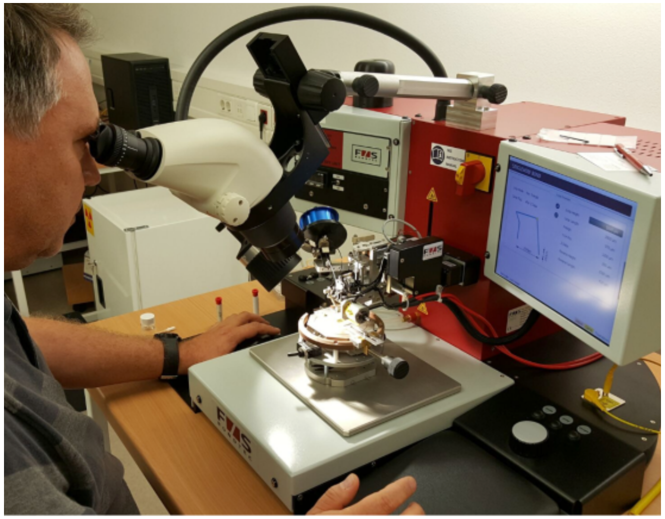
PSI46dig sensor

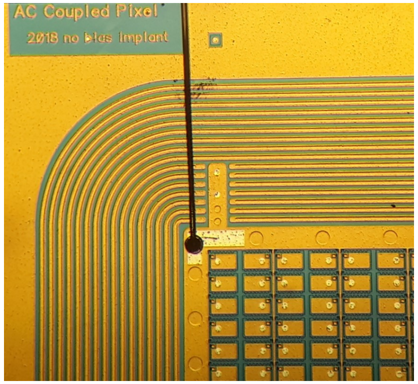


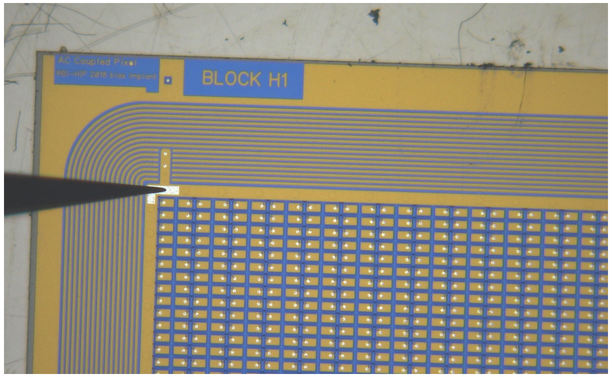


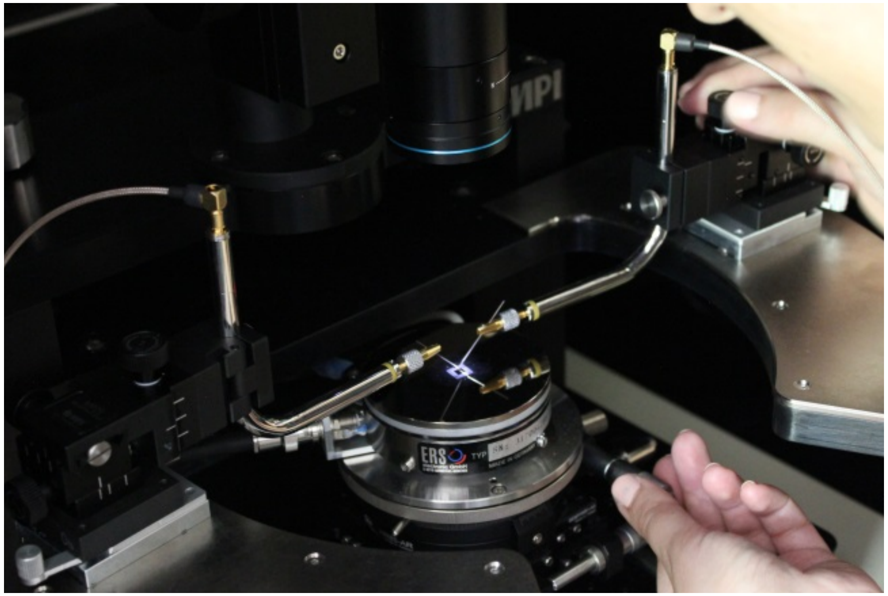
Presented at 33rd RD50 Workshop, CERN, Geneva, Switzerland, November 28th 2018
J. Ott et al.,
Processing of pixel detectors on p-type MCz silicon using atomic layer deposition (ALD) grown aluminium oxide

CV/IV Characterization
Capacitance-Voltage and Current-Voltage



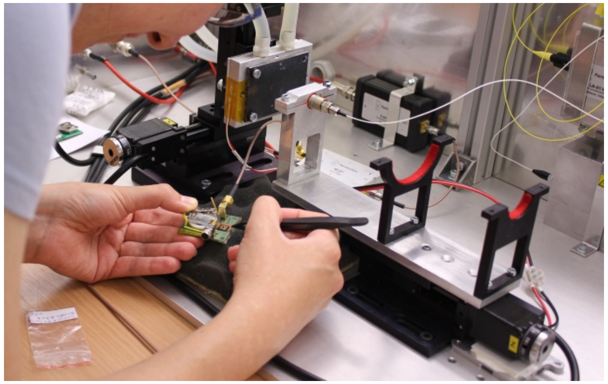


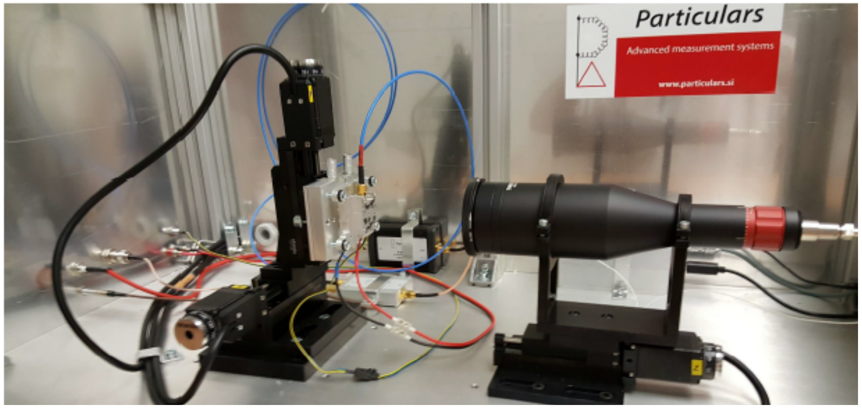


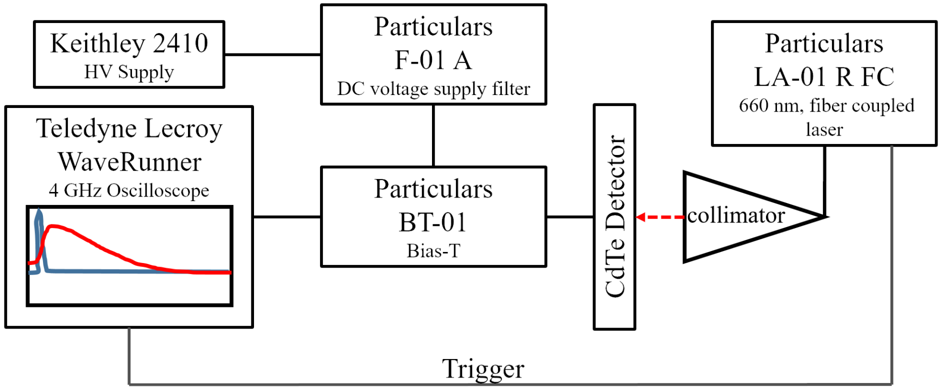


Characterization with Transient Current Technique (TCT)

- Raster scanning surface TCT setup from Particulars d.o.o
- Currently with two wavelengths 660 nm (RED) and 1064 nm (IR)
- Readout with 5 GHz Lecroy Waverunner oscilloscope



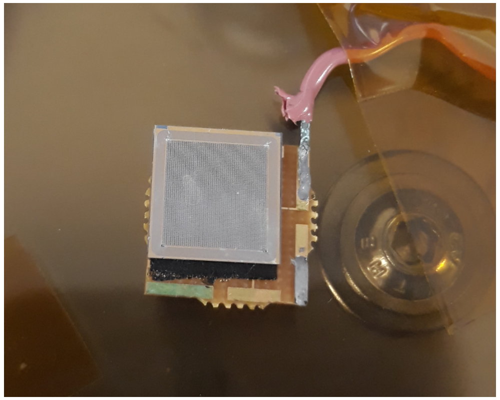




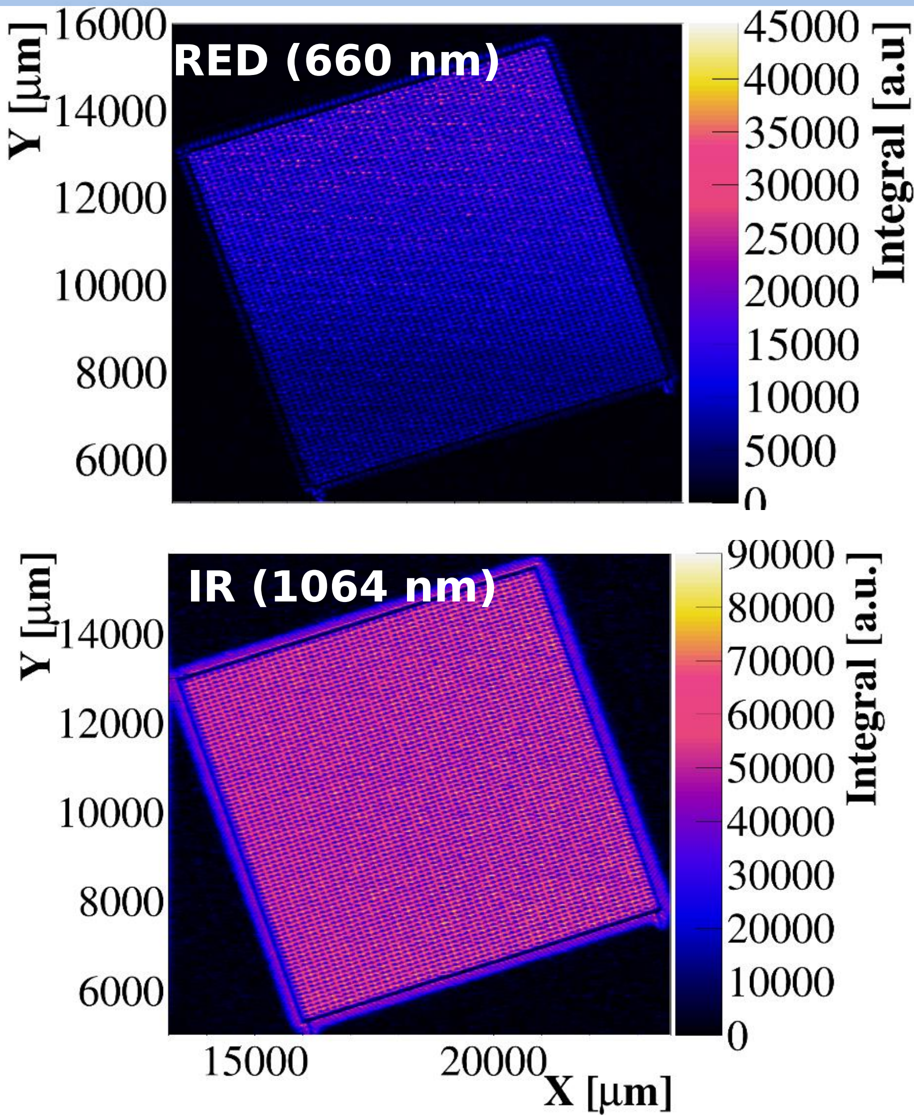
Gamma irradiation

- Gamma irradiation facility, Radiation Chemistry and Dosimetry Laboratory @ RBI
- ^{60}Co total activity 2640 TBq
- 7.2 Gy / s
- 96 source pencils assembled in 24 source rods
- Rods assembled in cylindrical position with a diameter and length of 32 cm

Detectors were placed inside the cylinder for a total dose of 68, 80 and 100 Mrad

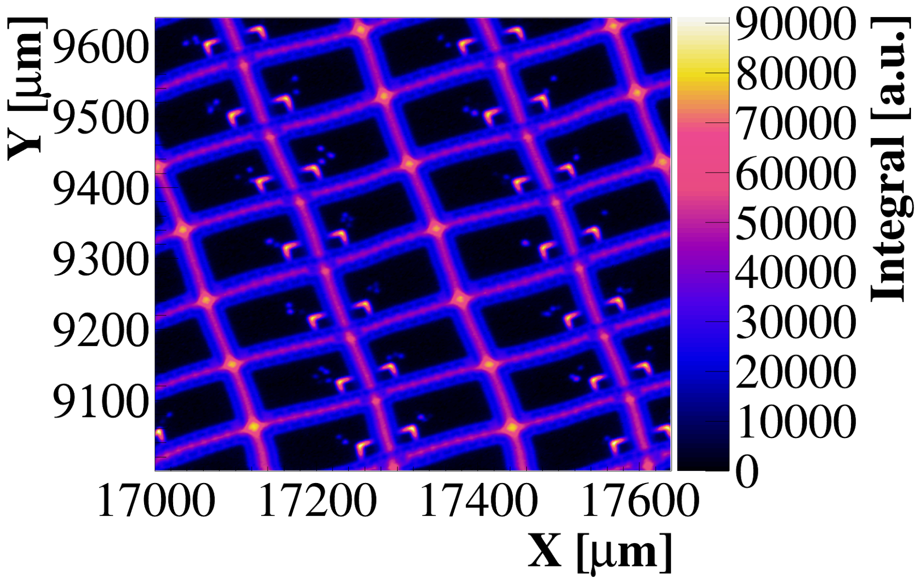


Results – TCT scans

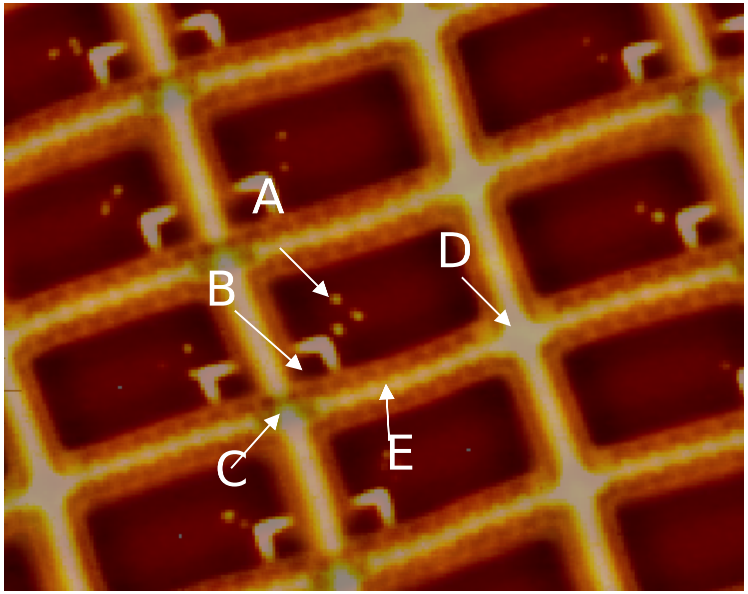


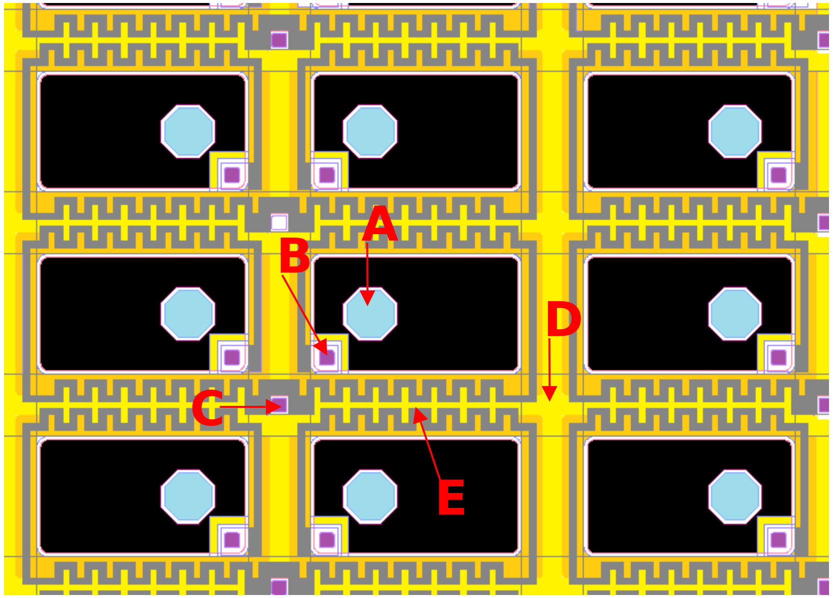
Each TCT xy-scan consist of about 62 000 data points with a scanning resolution of 40 µm

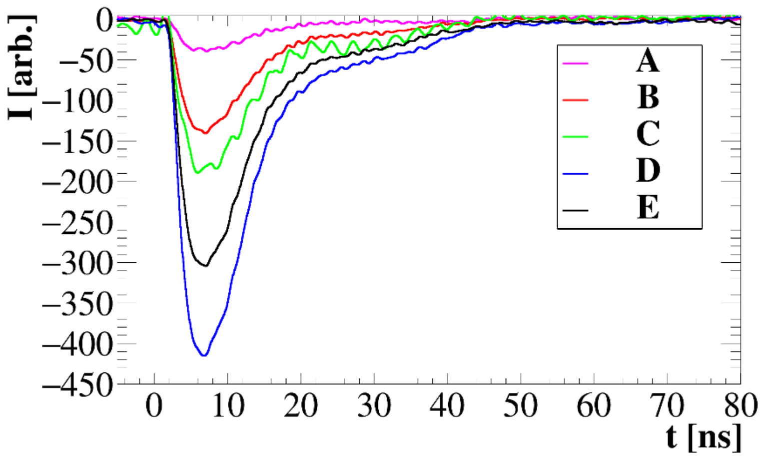
Combination of RED and IR scans allows to study underlying components



TCT Area Scans

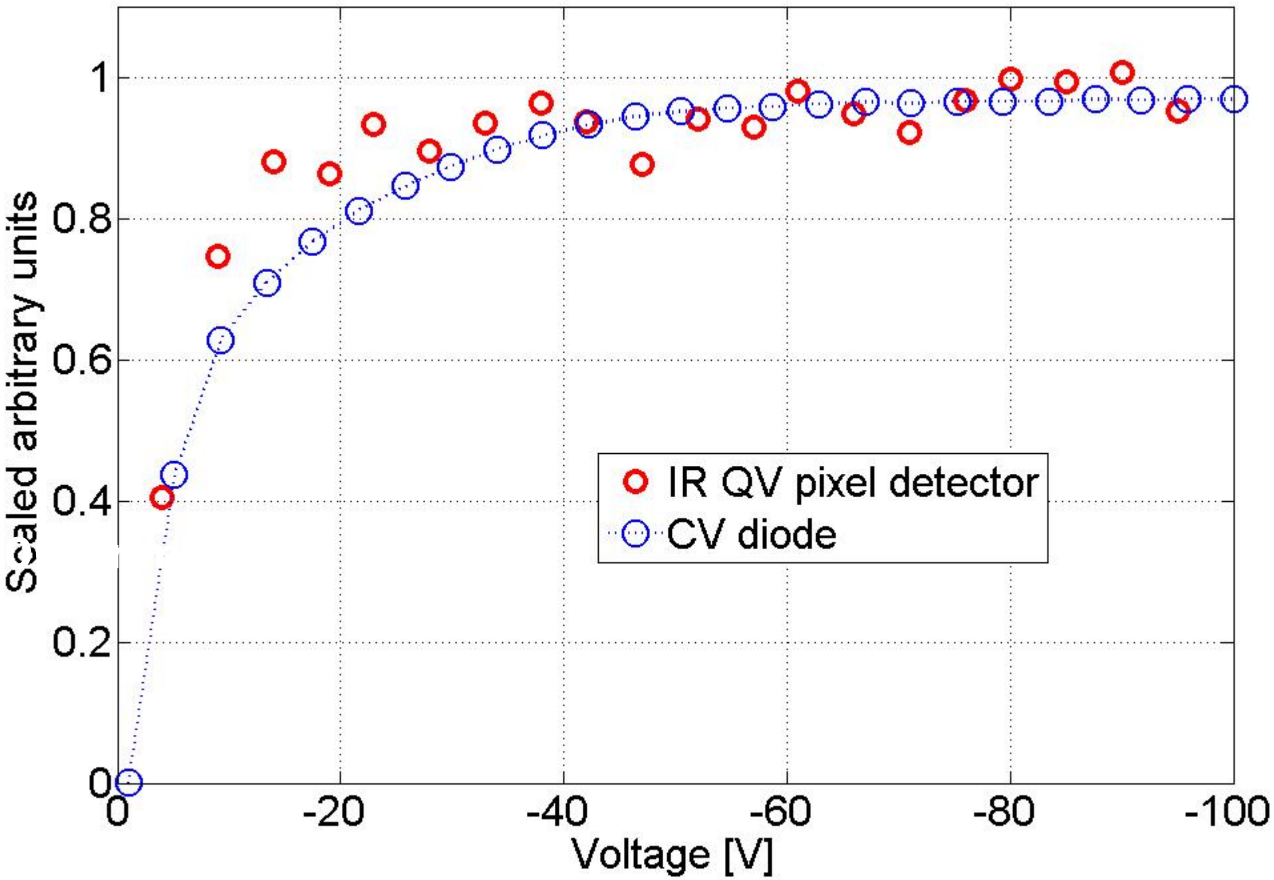






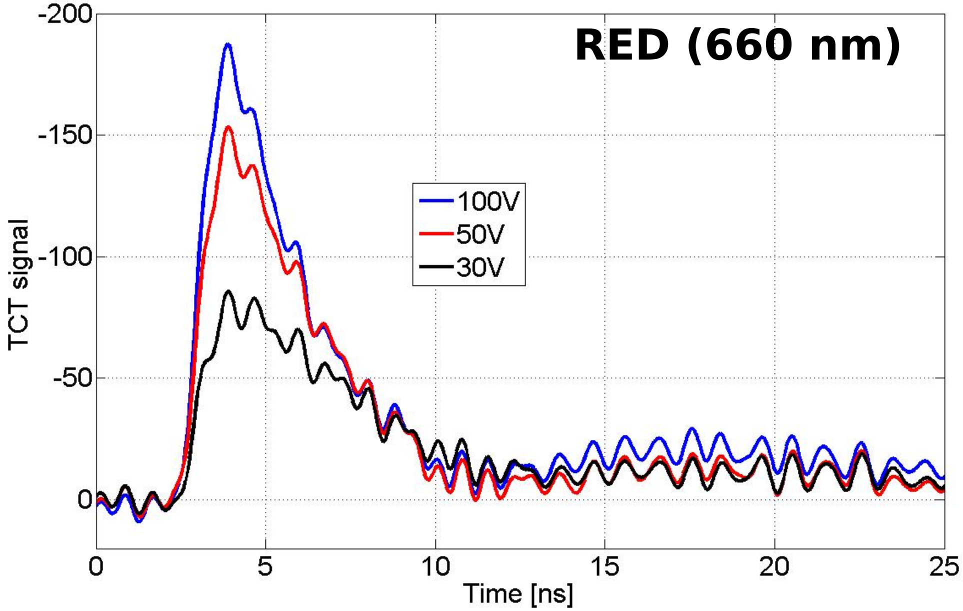
Since all points in the area maps consist of full transient current signal, the mapping can be used to study the response of different areas and components

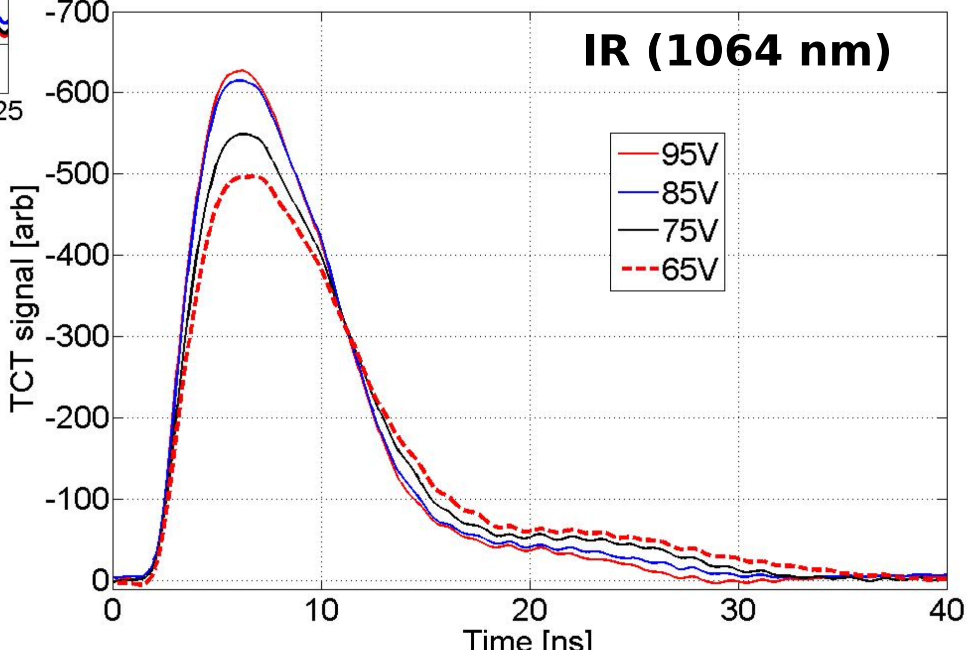
Results – Full depletion voltage



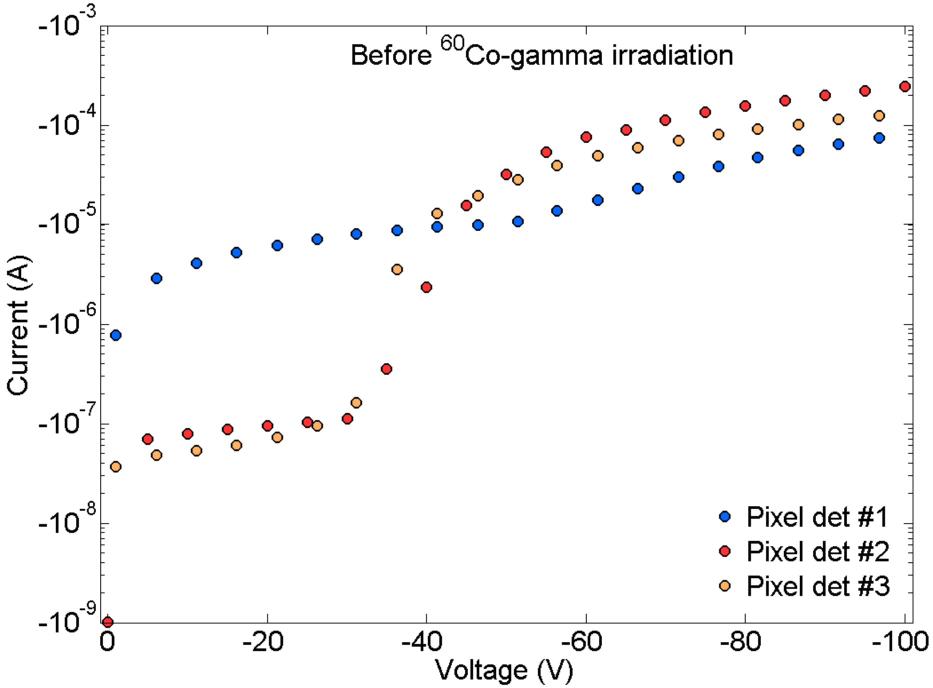
The IR laser generates a collected charge, as well as the capacitance signal from the CV measurement, which saturates between -40 and -70 V

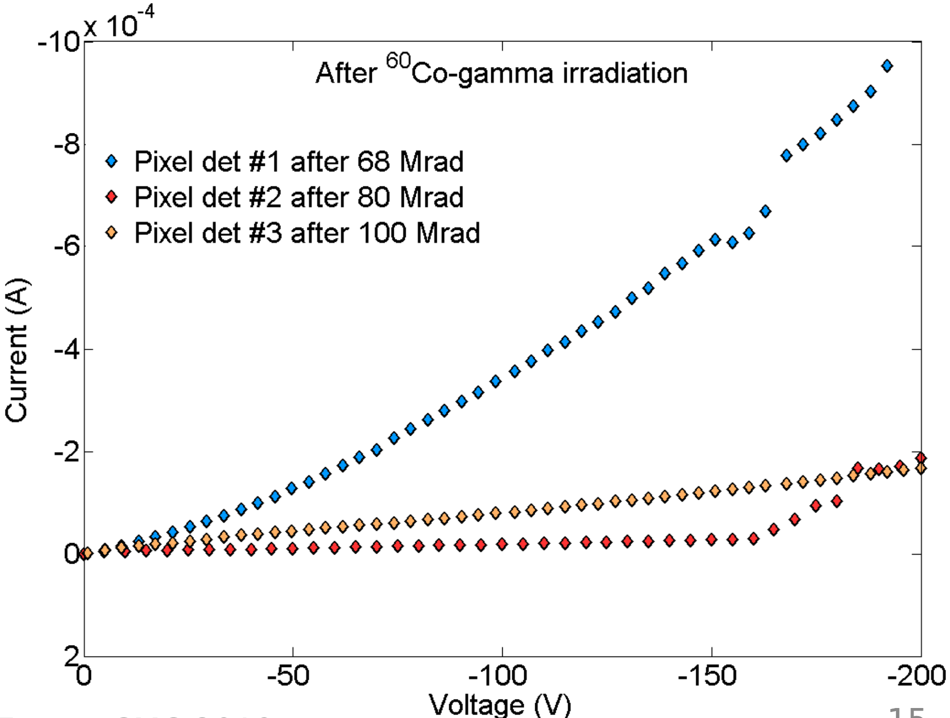
Results – TCT scans @ different voltages





Results – IV characterization





Conclusions

We have successfully designed, manufactured and characterized novel fine pitch $n^+/p^-/p^+$ pixel detectors made on 150mm size p-type Magnetic Czochralski silicon (p-MCz Si) wafers.

- Atomic Layer Deposition (ALD) technology has many properties, which make it very attractive process method for radiation detectors.

- With ALD technology it is possible to realize very high capacitance and resistance densities.

- This enables AC-coupling of small pixels connected with each other by metal-nitride thin film bias resistors.

- Our results show that during the ^{60}Co gamma irradiation the “fixed oxide charge” remains rather unchanged but positive “mobile ionic oxide charge” accumulates.

- Flip-Chip bonding of experimental pixel sensors with CMS ROC chips foreseen in the near future.

Acknowledgements

Radiation chemistry and dosimetry laboratory & Gamma irradiation facility

Micronova Nanofabrication Centre

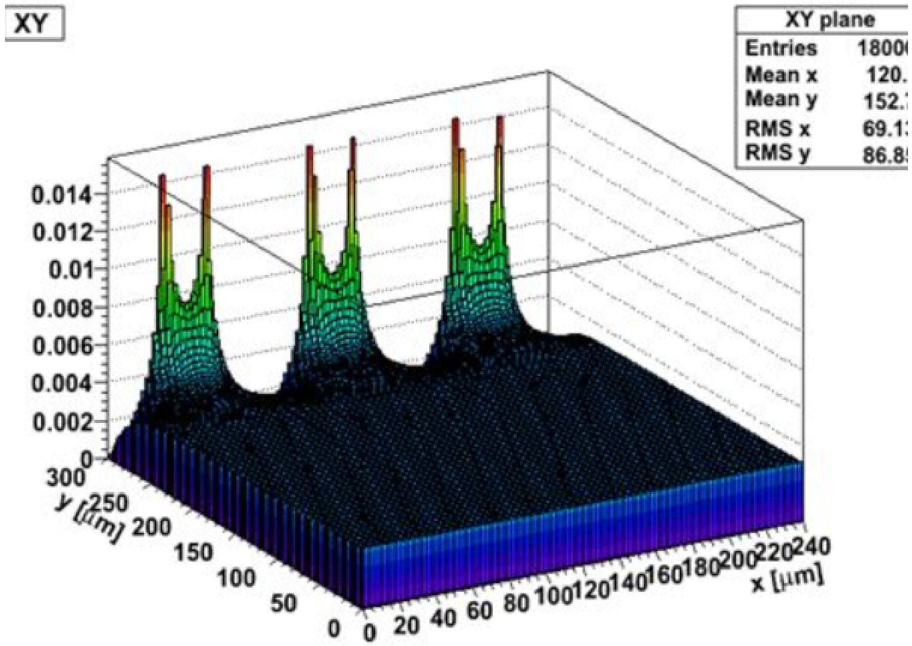
This study has been partially funded by the Horizon 2020 ERA Chair project, grant agreement 669014 (Particle and Radiation Detectors, Sensors and Electronics in Croatia, PaRaDeSEC, http://lnr.irb.hr/PaRaDeSEC/).

Thank you for your attention!

Backup slides

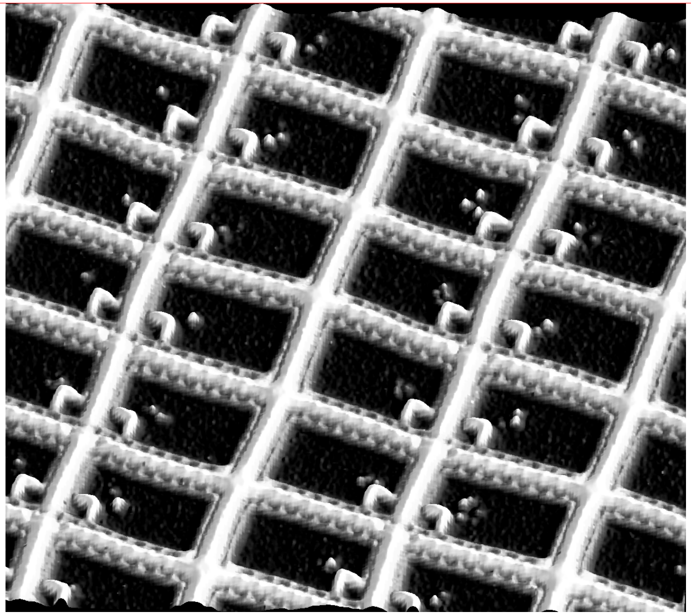
Patterning a thin entrance window to side of the illumination

- The back side, i.e. side of illumination of a pixel detector can be patterned mesh-like by one additional mask level
- The metal grid can be formed e.g. by TiW/W/Al layers
- Metal grid forms a hard mask for RIE etching



Devis Contrato and Gregor Kramber
2ndRD50 Workshop - CERN, 18-20 May 2003

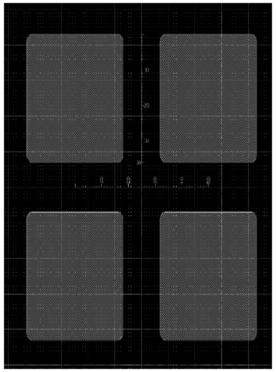
Laser scan of pixelated back side



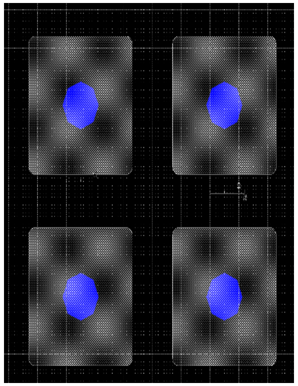
- p^+ implant on windows is removed by plasma etching
- Entrance window is finished by thin ~2-4nm ALD dielectric layer
- Pixelated back side is assumed to form Weighting Field and thus to enhance CCE

Detector design – RD53 pixel detector

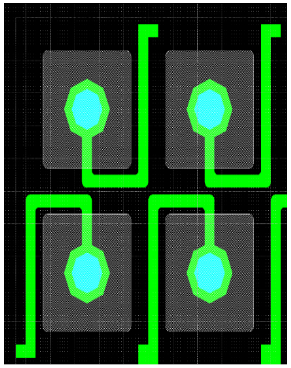
CERN joint collaboration developing future CMOS read-out ASIC for all LHC experiments



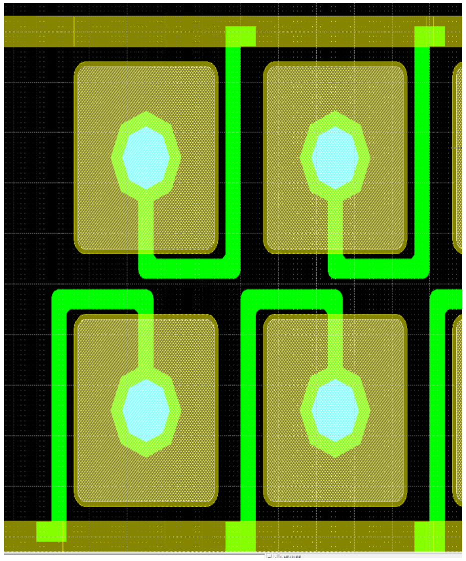
1st level – Implant



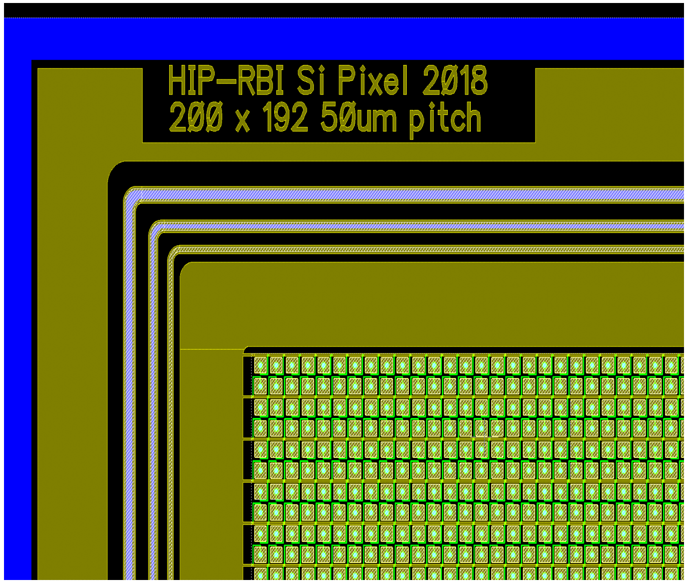
2nd level – contact opening to field insulator



3rd level – bias resistor made of TiN by ALD



4th level – metals



Chip consist of 200 x 192 => 38400 pixels