3D Double-Sided sensors for the CMS phase-2 vertex detector

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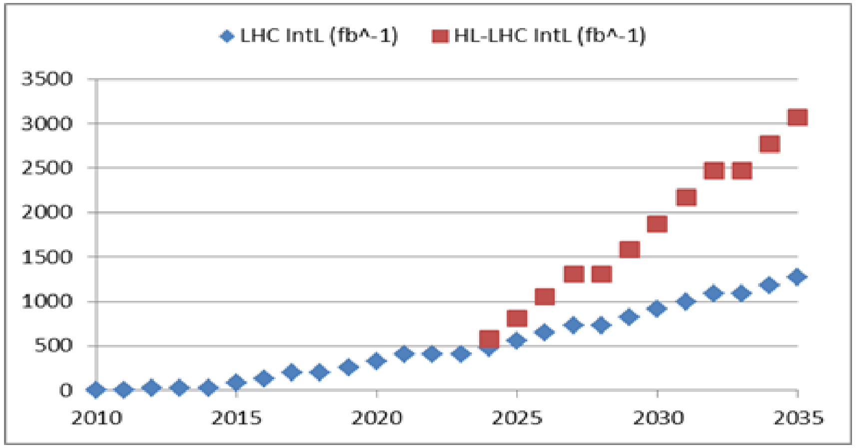
Outline

- Motivation
- 3D pixel technology and manufacturing
- Electrical characterization
- PSI46 Read Out Chip (ROC) and interconnections
- Radiation resistance studies
- Summary

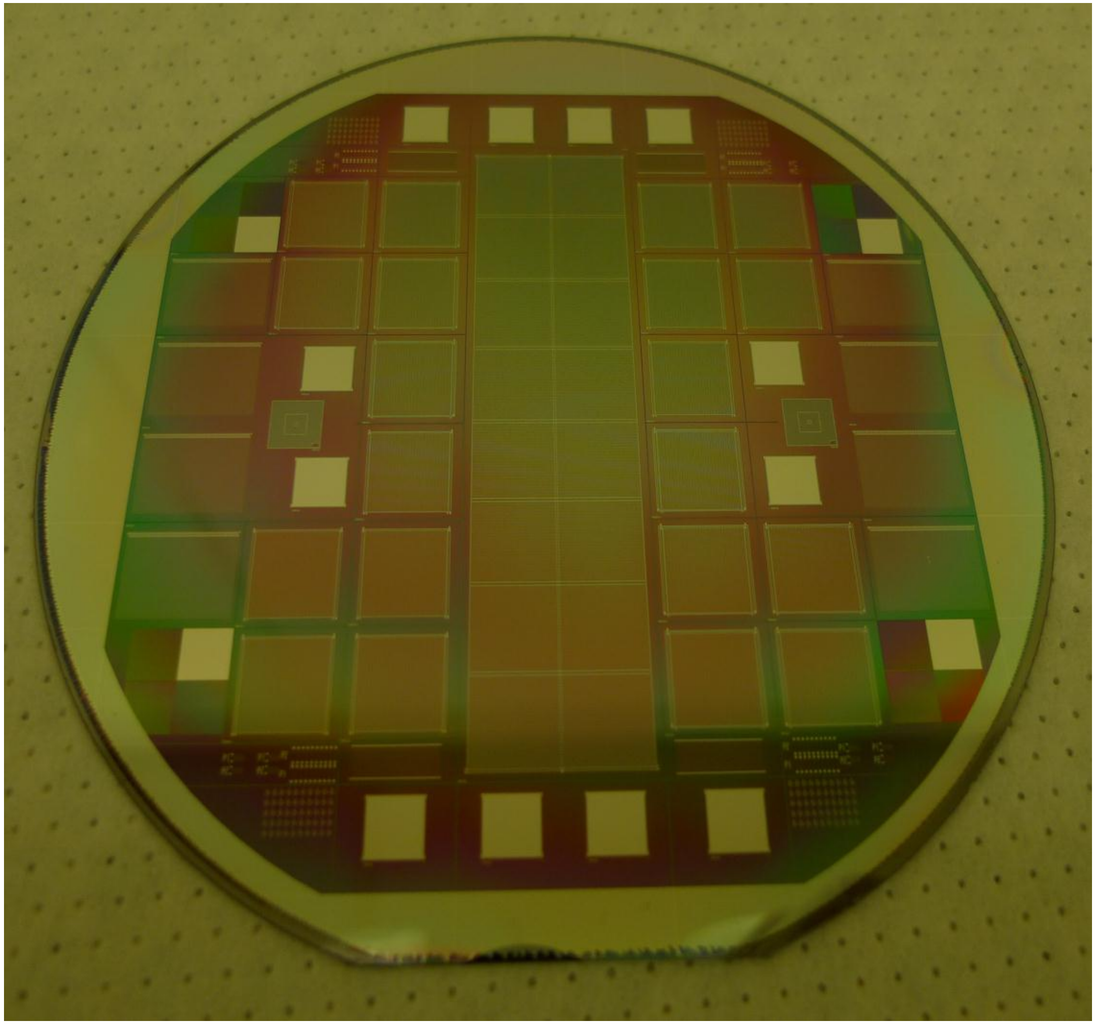
Motivation

- LHC experiments are expected to undergo a constant increase of radiation levels, a possible HL-LHC scenario will get things tougher



- New generation of vertex detectors must deal with fluences about $1*10^{16}$ neq/cm²
- Here we are going to assess the radiation resistance of 3D double-sided pixel sensors in terms of:
  - Increase of the depletion voltage (Vfd)
  - Reduction of the CCE

CNM Production and Description



6 wafers:
Wafers 5,6,7,8:
- **285 μm thickness**

Wafer 11:
- **230 μm thickness**

Wafer 3:
- **285 μm thickness**
- **Resistor bias grid**

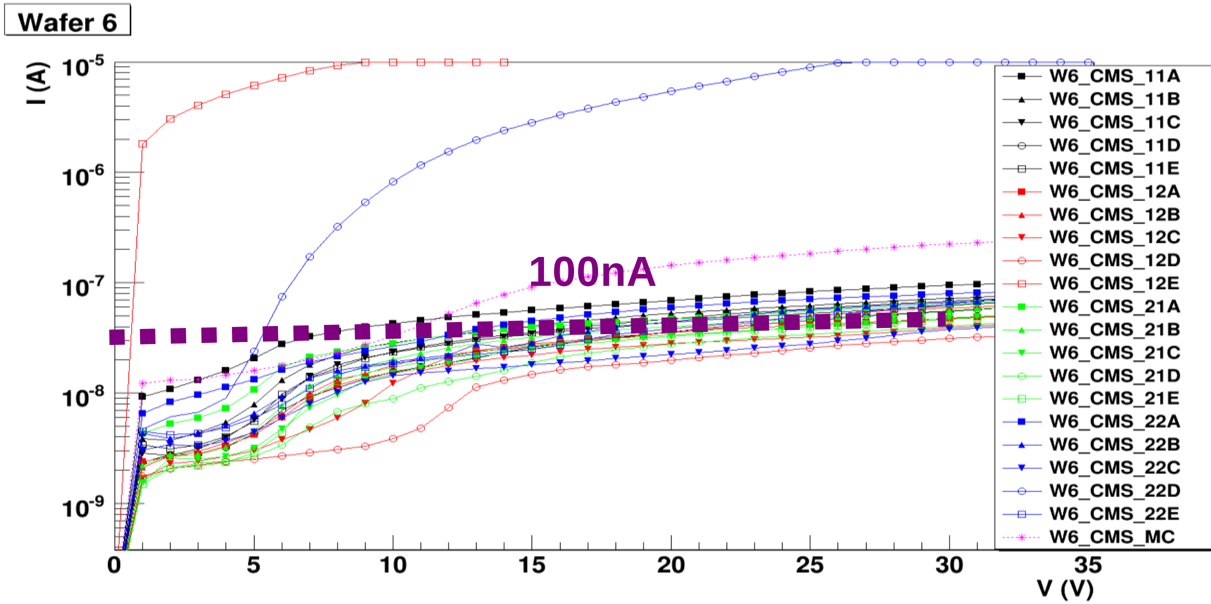
Each wafer includes:

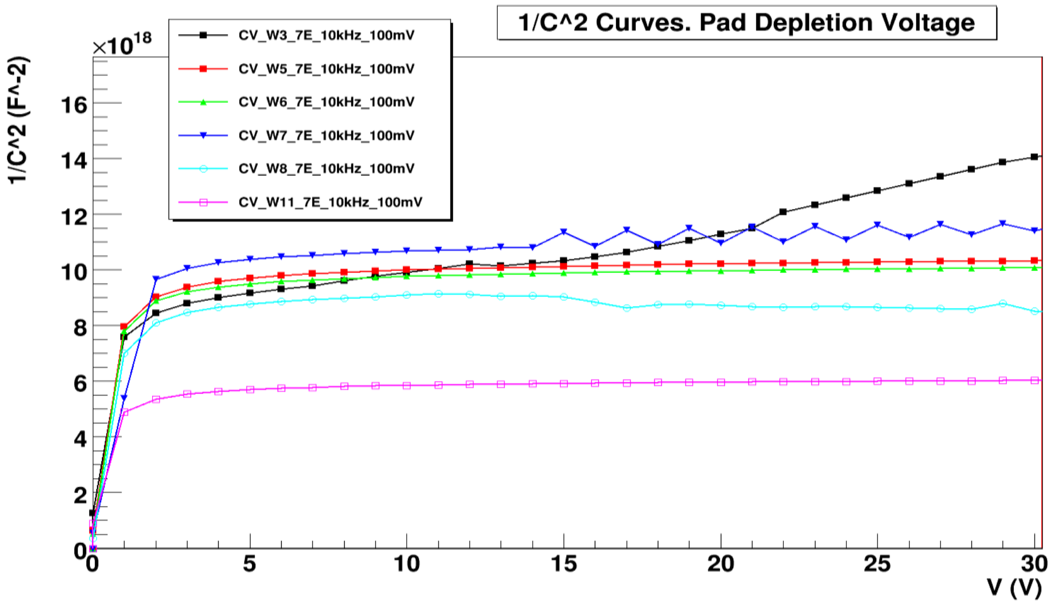
- **1 Full Module (8x2)**
- **20 Single Chips**
- **8 Strip sensors**
- **12 Pad**
- **Test structures**

Electrical characterization

- Very Homogeneous behavior

- Current Values in the expected range



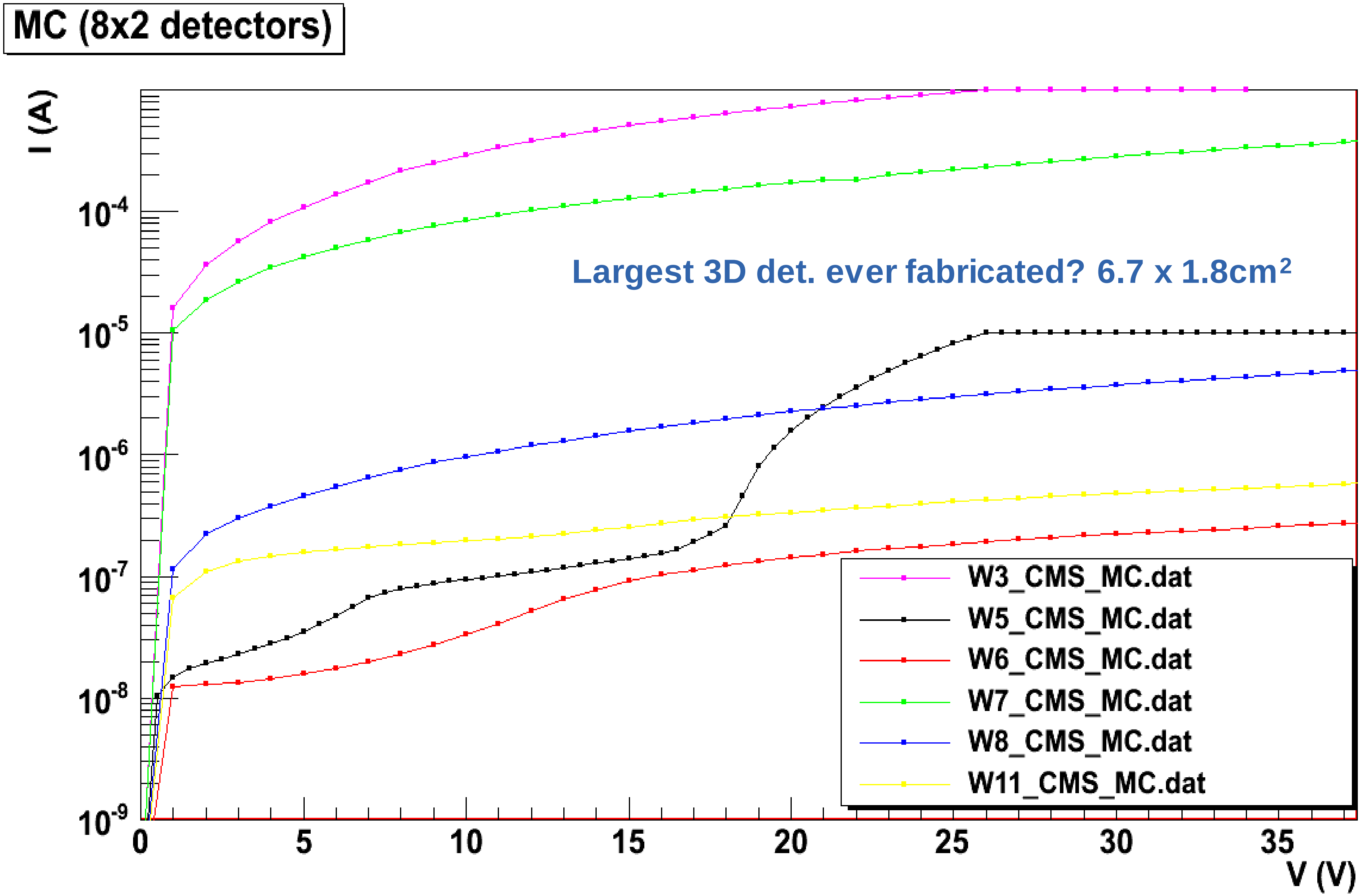


Measured Vfd (pad) ~ 1.5 V

Using Coaxial approximation, Extrapolating to sensor geom:

Vfd (3D-Detector) ~ 9 V

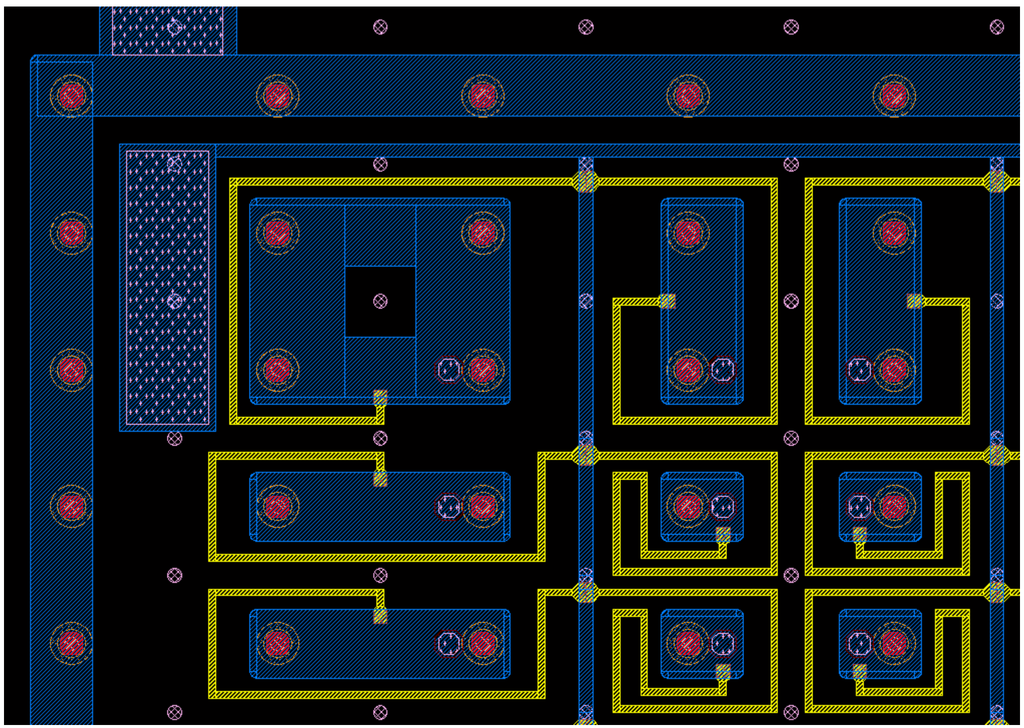
MC Devices (8x2 detectors)

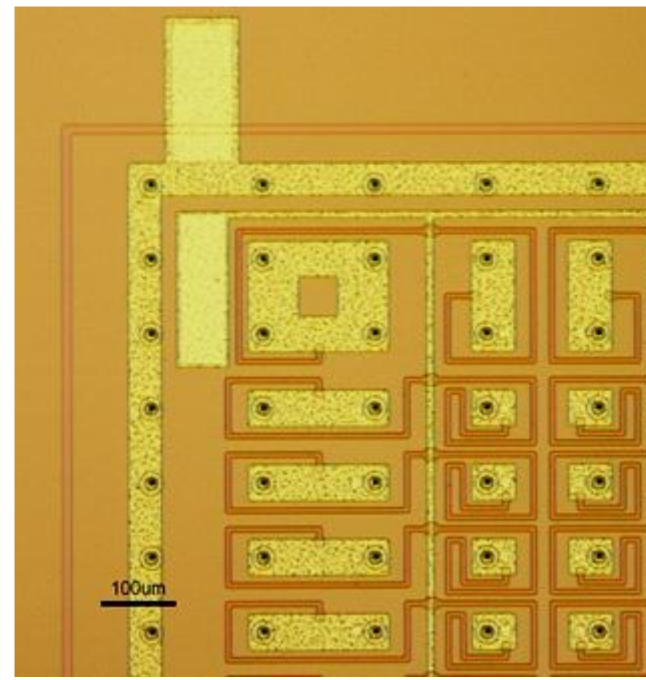


Polysilicon resistors

A grid of polysilicon resistor was implemented for direct testing of pixels before flip-chip

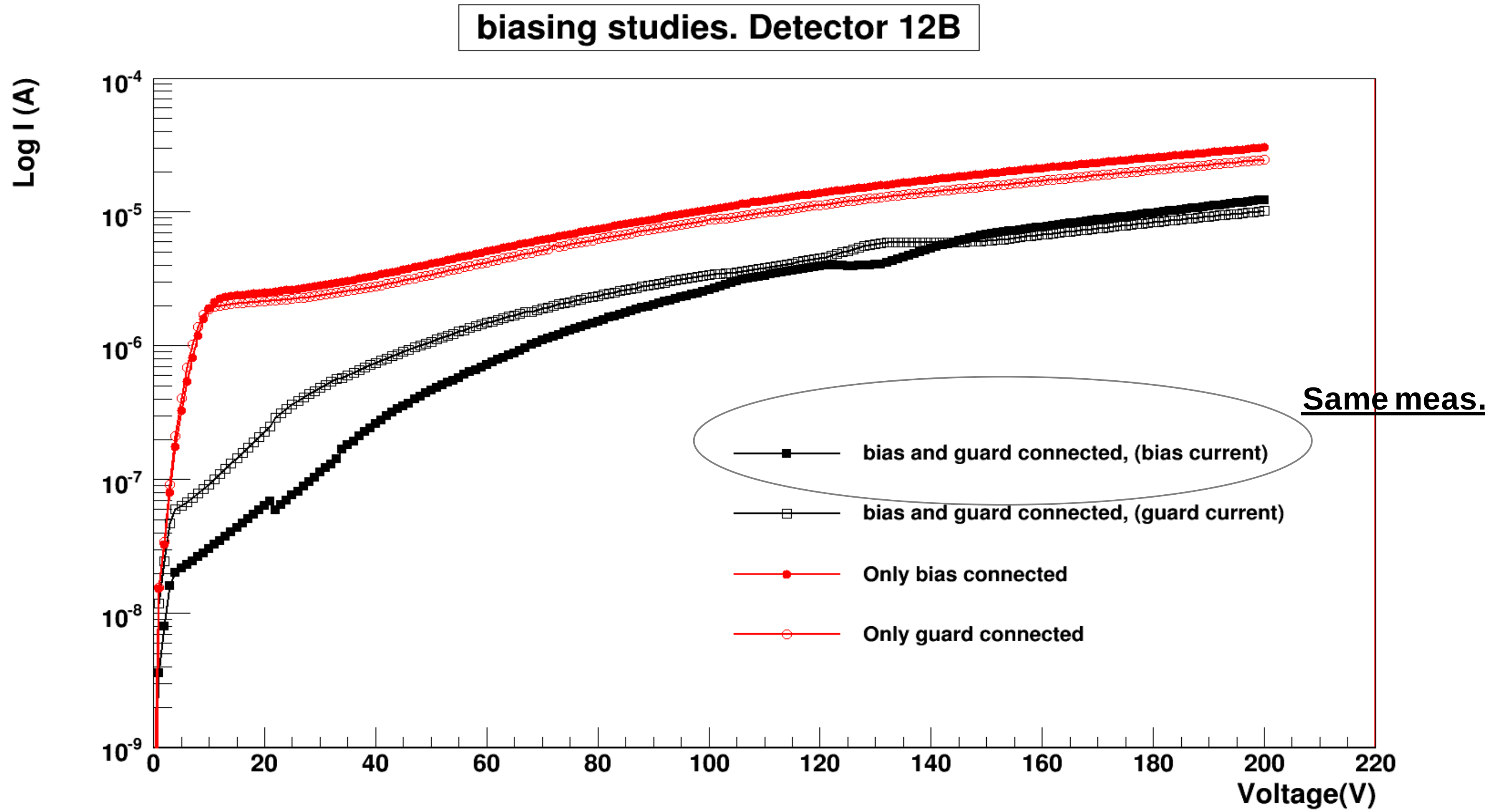
- 2 extra mask level needed
- R_{sq}~1MΩ (defined by ion implantation)



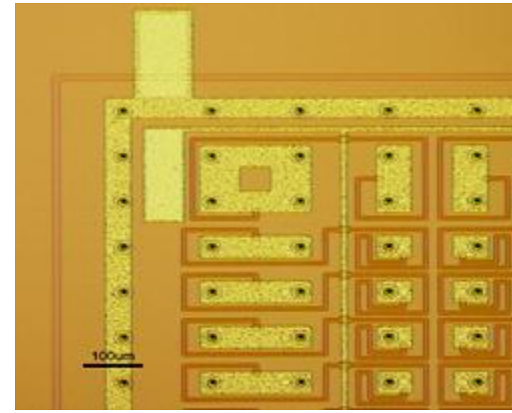


Biasing studies. Wafer 3

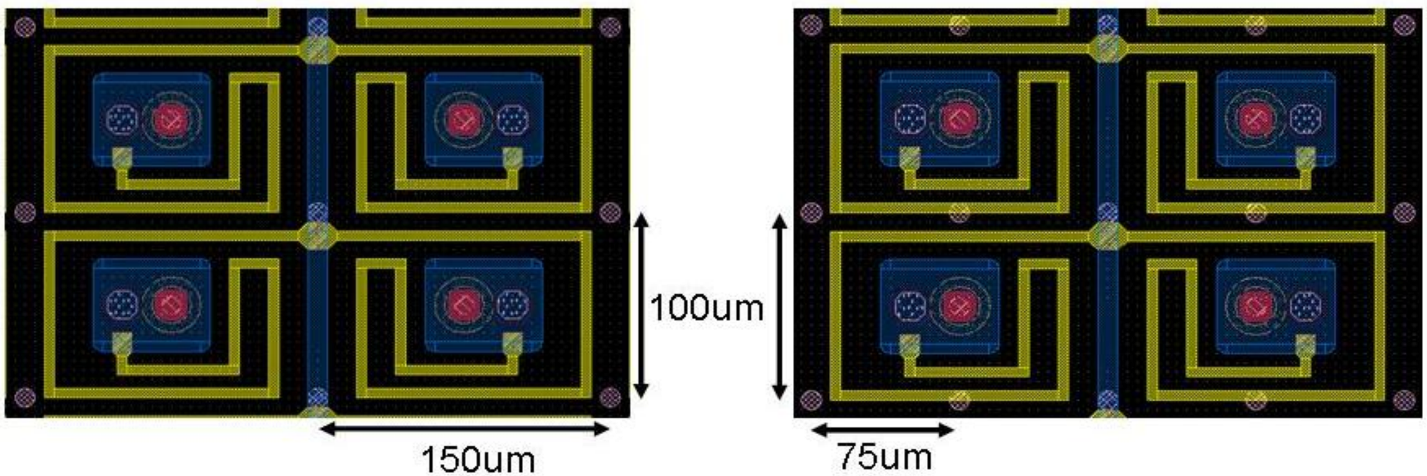
Only guard connected → "punch through" polarization
Only bias connected → pixel by pixel polarization



Sparse and dense pattern



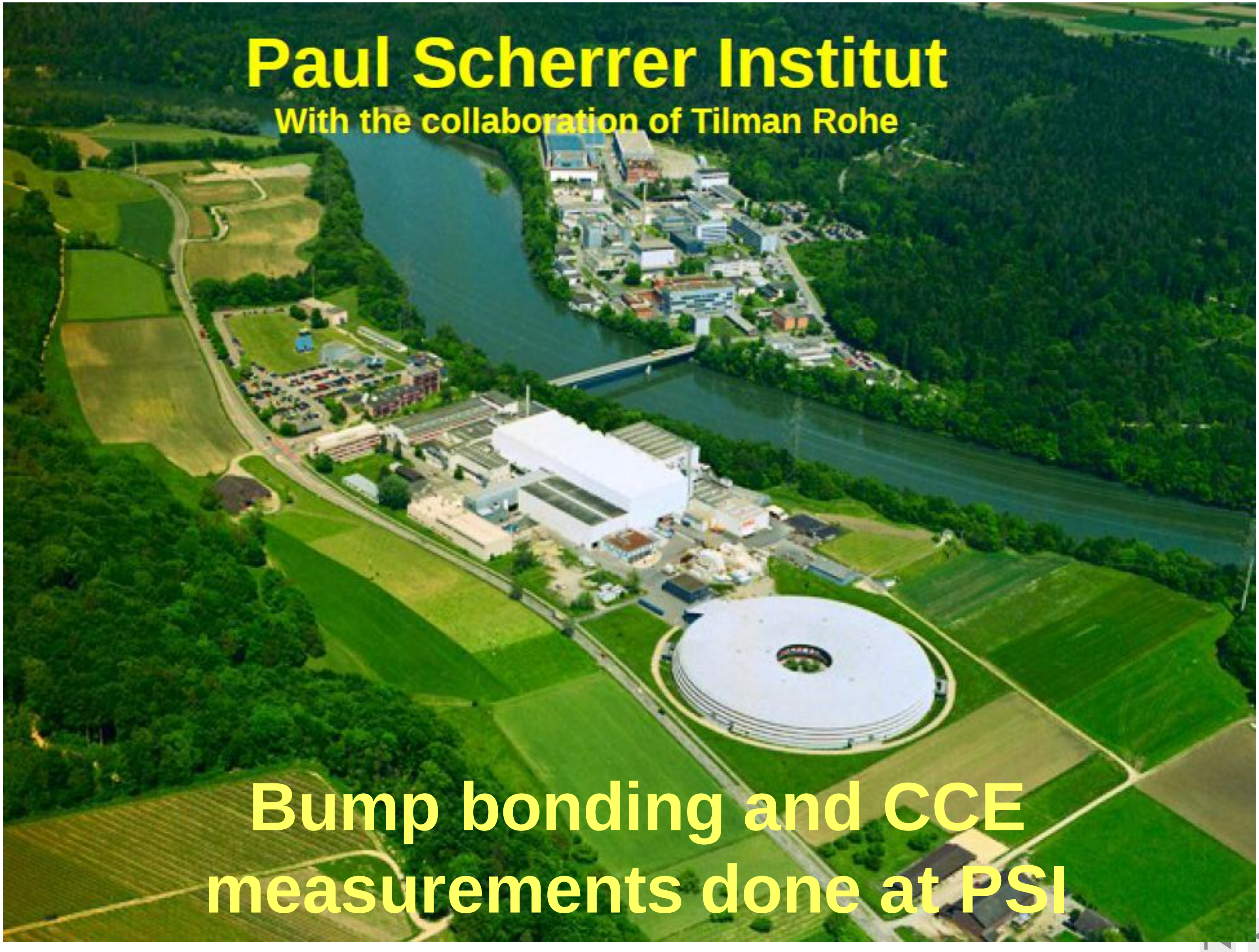
* In the back side, two columns pattern.
  - Dense → reduced drift distance
    Expected higher radiation resistance
  - Sparse → larger drift distance
    Expected lower noise (lower capacitance)



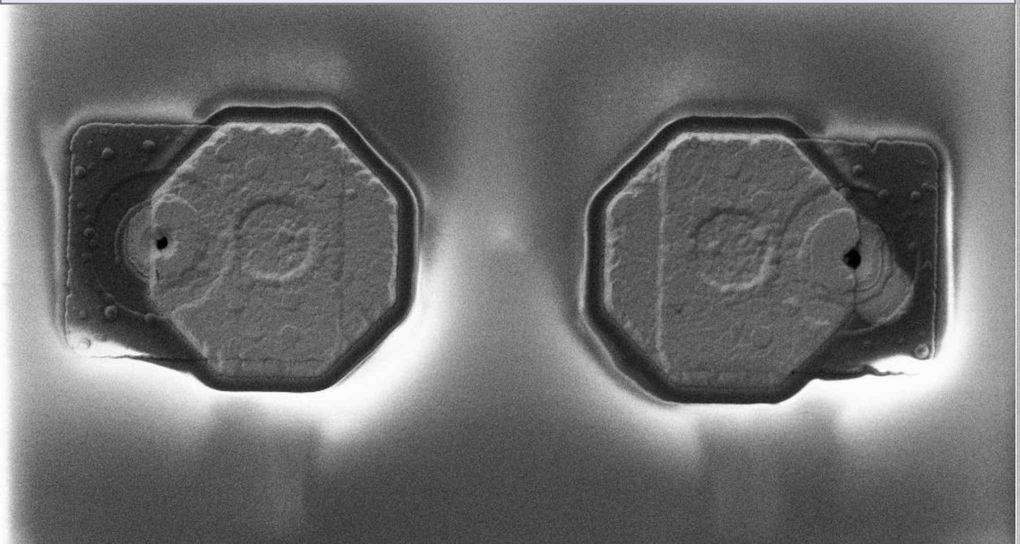
Sparse pattern of holes P:

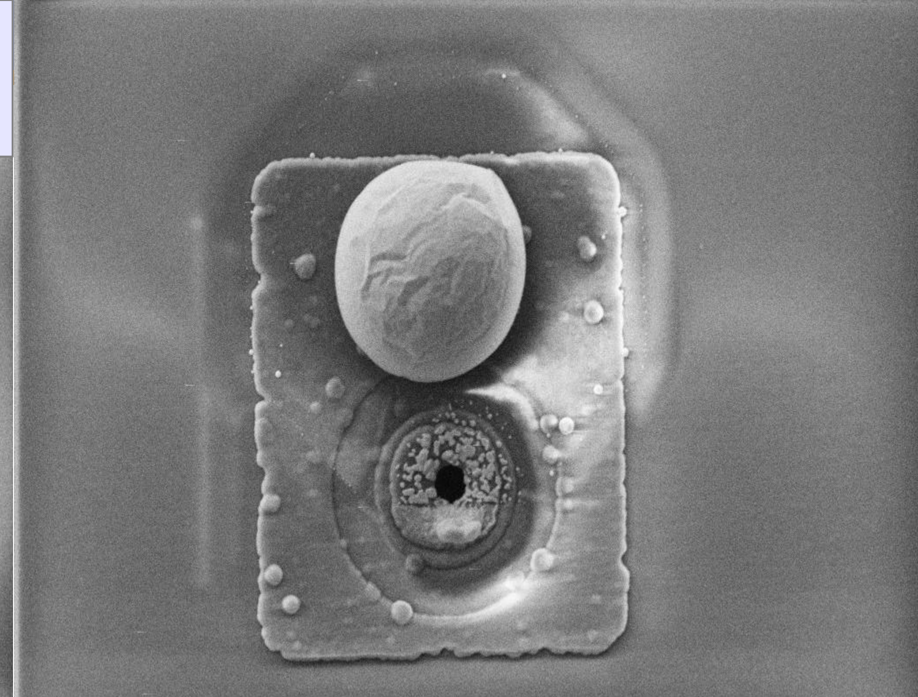
Dense pattern of holes P:

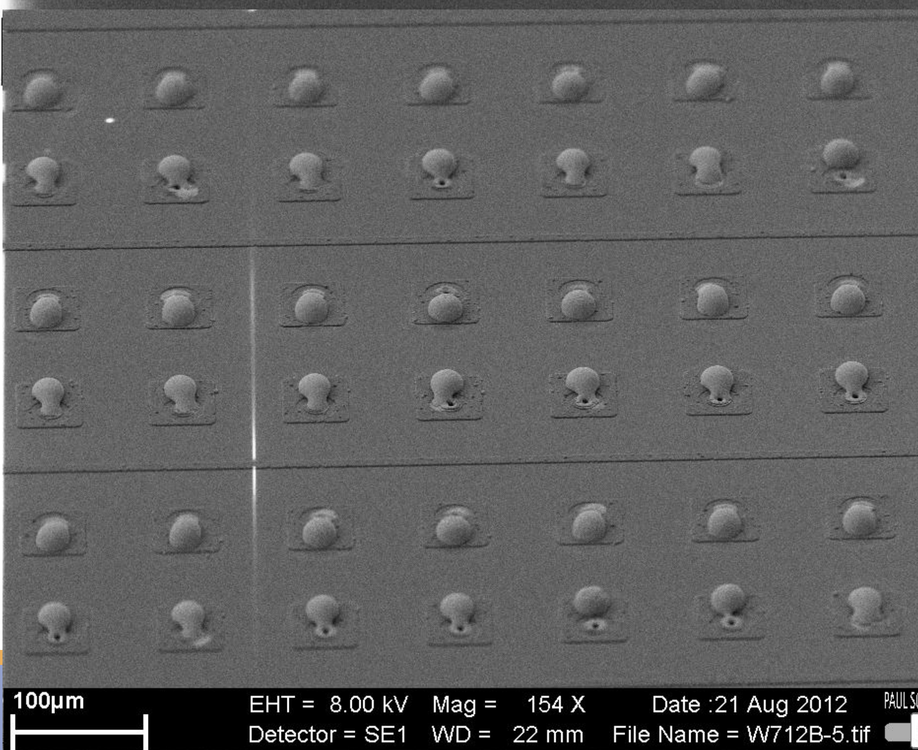
Full module has been designed with sparse pattern and single guard ring

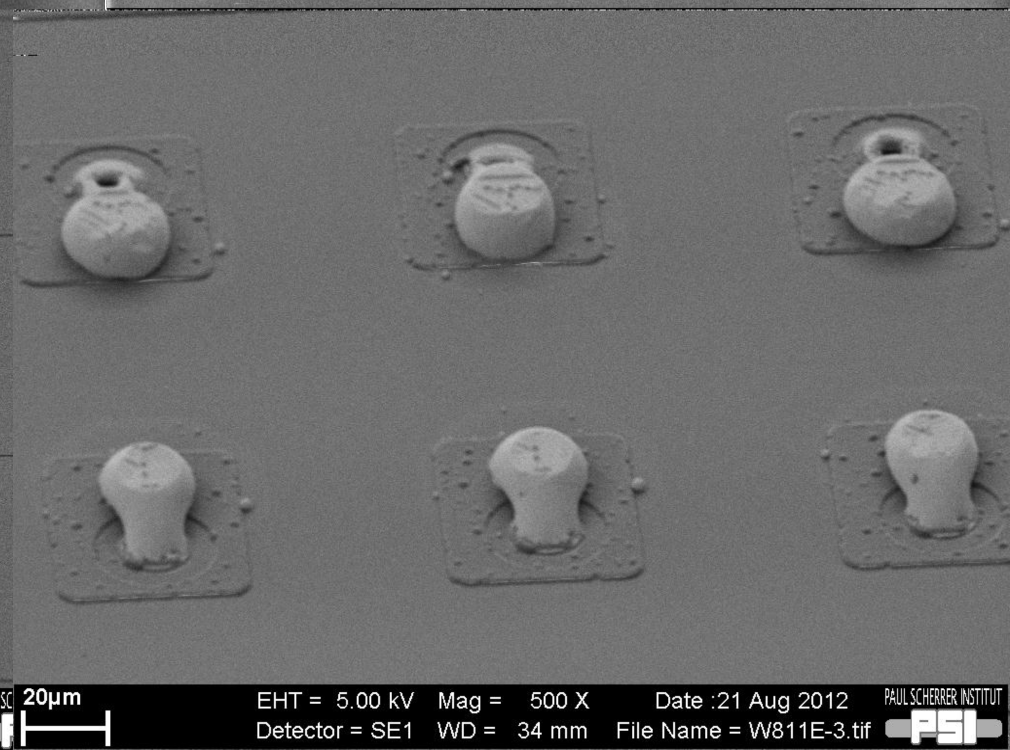

Paul Scherrer Institut
With the collaboration of Tilman Rohe
Bump bonding and CCE measurements done at PSI

Scanning electron Microscope SEM



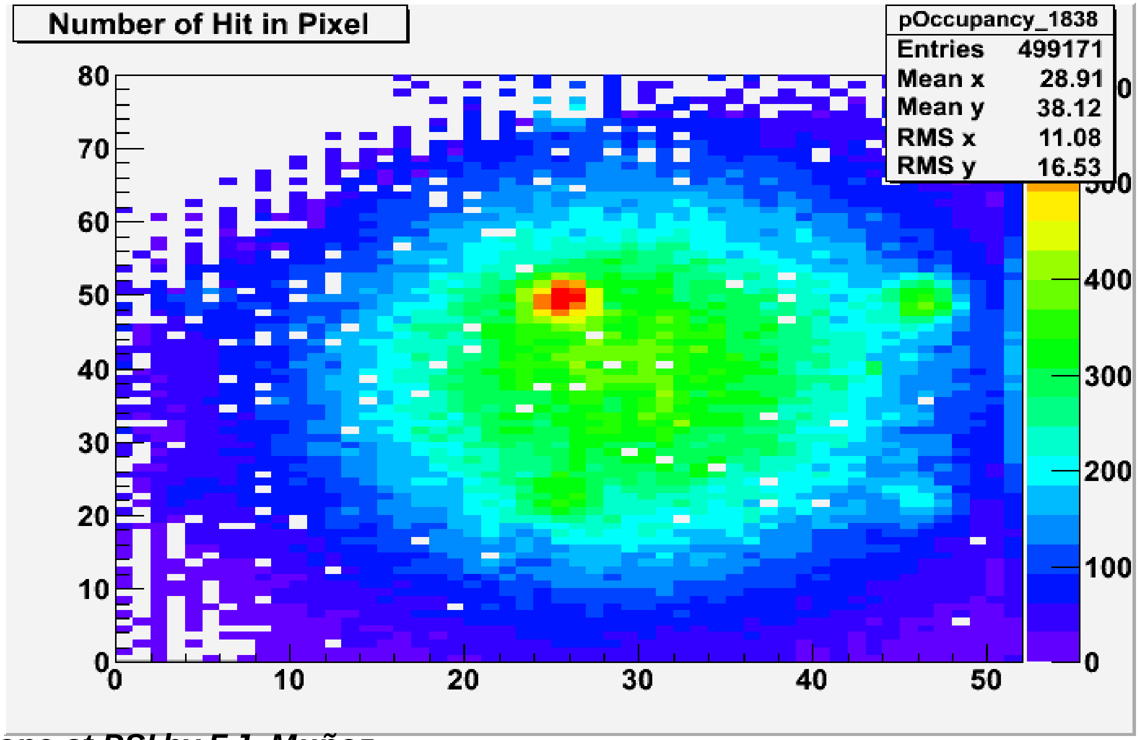






Bump bonding

- Bum bonding yield test
- Using a ^{90}Sr radioactive source
- An uniform pattern has been observed. Including the holes on the PCB (between sensor and scintillator)



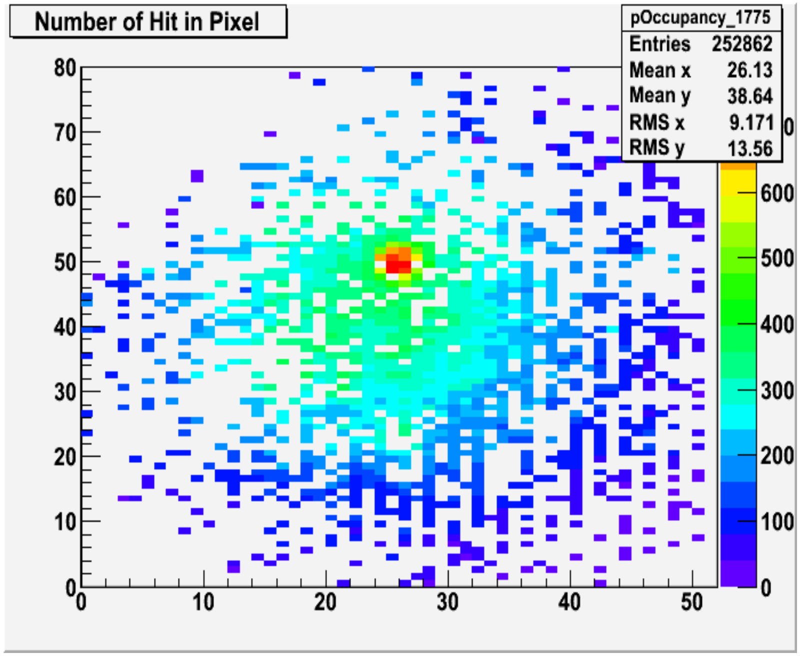
CCE measurements done at PSI by F.J. Muñoz

In other cases:

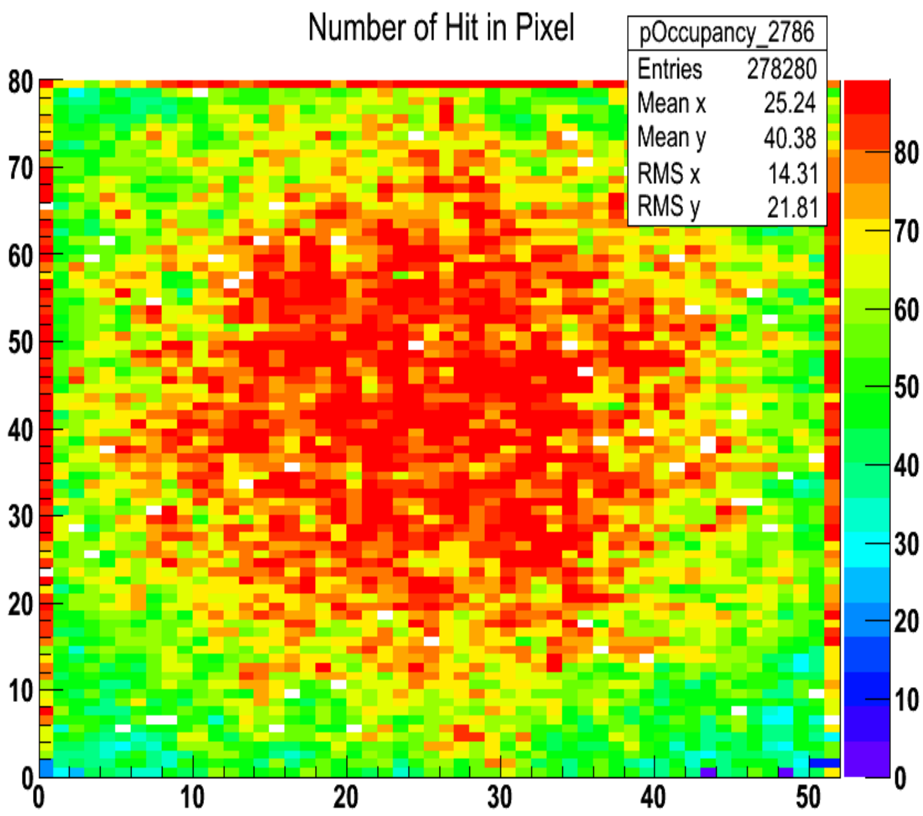
Reason:
There are passivation layers only in one side of the wafer (overlooked during production)

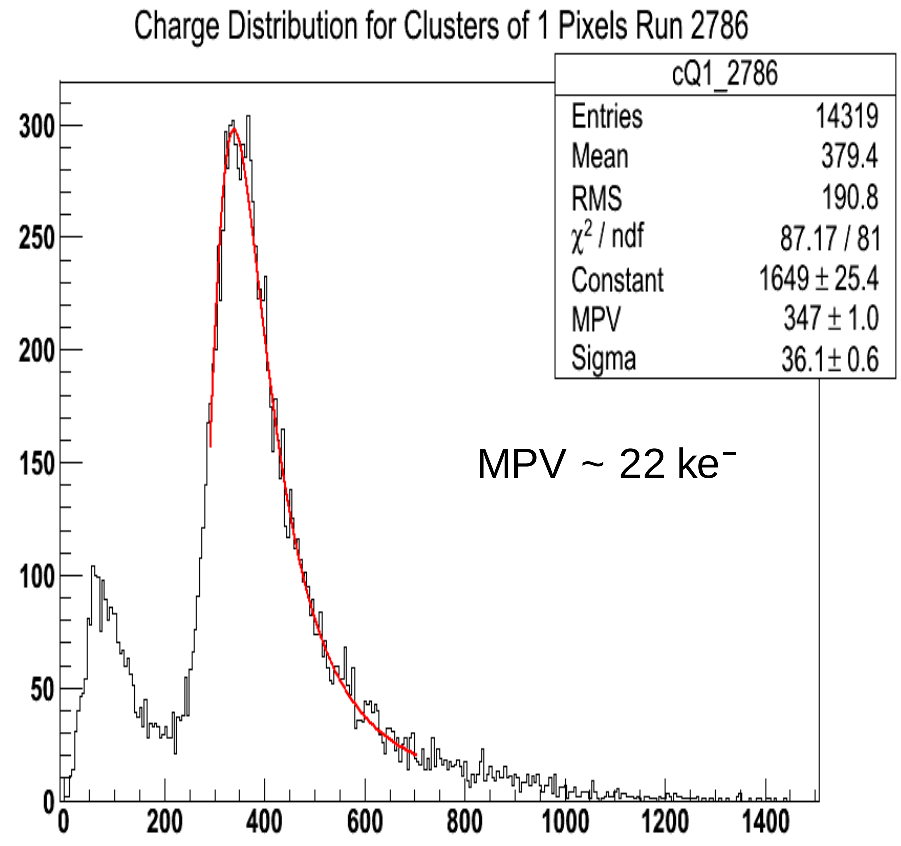
Problem:
The stress during the second re-flow process, bows the Sensor breaking the bumps connections

Provisional Solution:
To put some weight on top of the sensor-chip "sandwich" during 2nd reflow.



Nice Pixel map, and landau fit:





MPV ~ 22 ke^{-}

Irradiation Campaign:

4 pixel samples, 2 strips detectors and 2 pads up to each radiation fluence

- Proton Cyclotron @ KIT (Karlsruhe), 25MeV protons:

$1 \times 10^{15}\ n_{eq}/cm^2$
$5 \times 10^{15}\ n_{eq}/cm^2$

- Tigra Reactor @ JSI (Ljubljana), continuous spectrum neutrons:

$1 \times 10^{15}\ n_{eq}/cm^2$
$5 \times 10^{15}\ n_{eq}/cm^2$ (ongoing)
$1 \times 10^{16}\ n_{eq}/cm^2$

^{90}Sr Characterization

Charge Collection in irradiated samples

Full Depletion Voltage:

- Depletion Area grows in a 3D sensor horizontally
- A new variable:

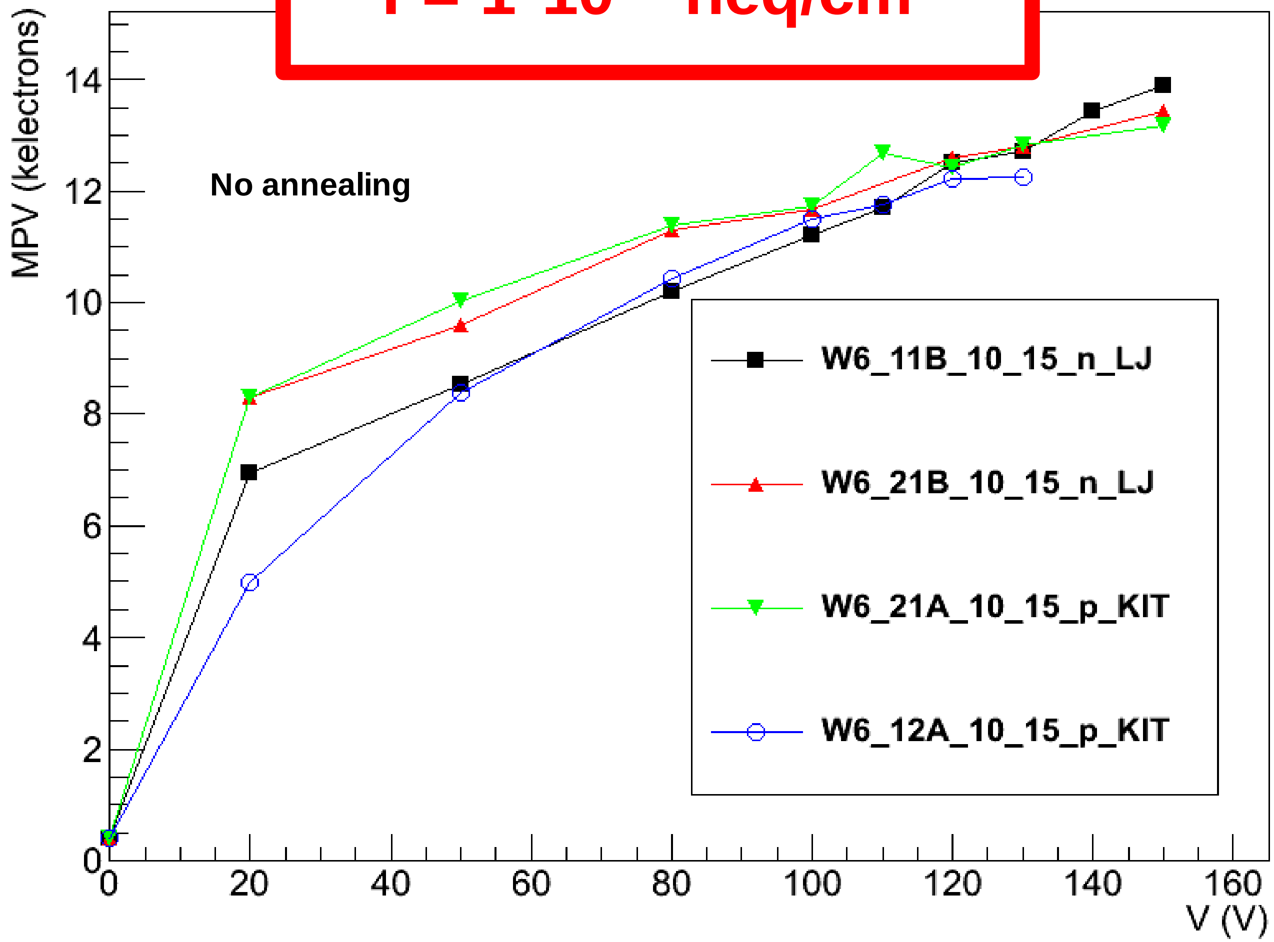
$$Er = \frac{\text{Num. of hits}}{\text{Num. of triggers}}$$

- When the Er saturates with bias voltage, we consider that we have depleted the maximum volume in the sensor

MPV vs bias Voltage in irradiated samples

2 samples with protons
2 samples with neutrons

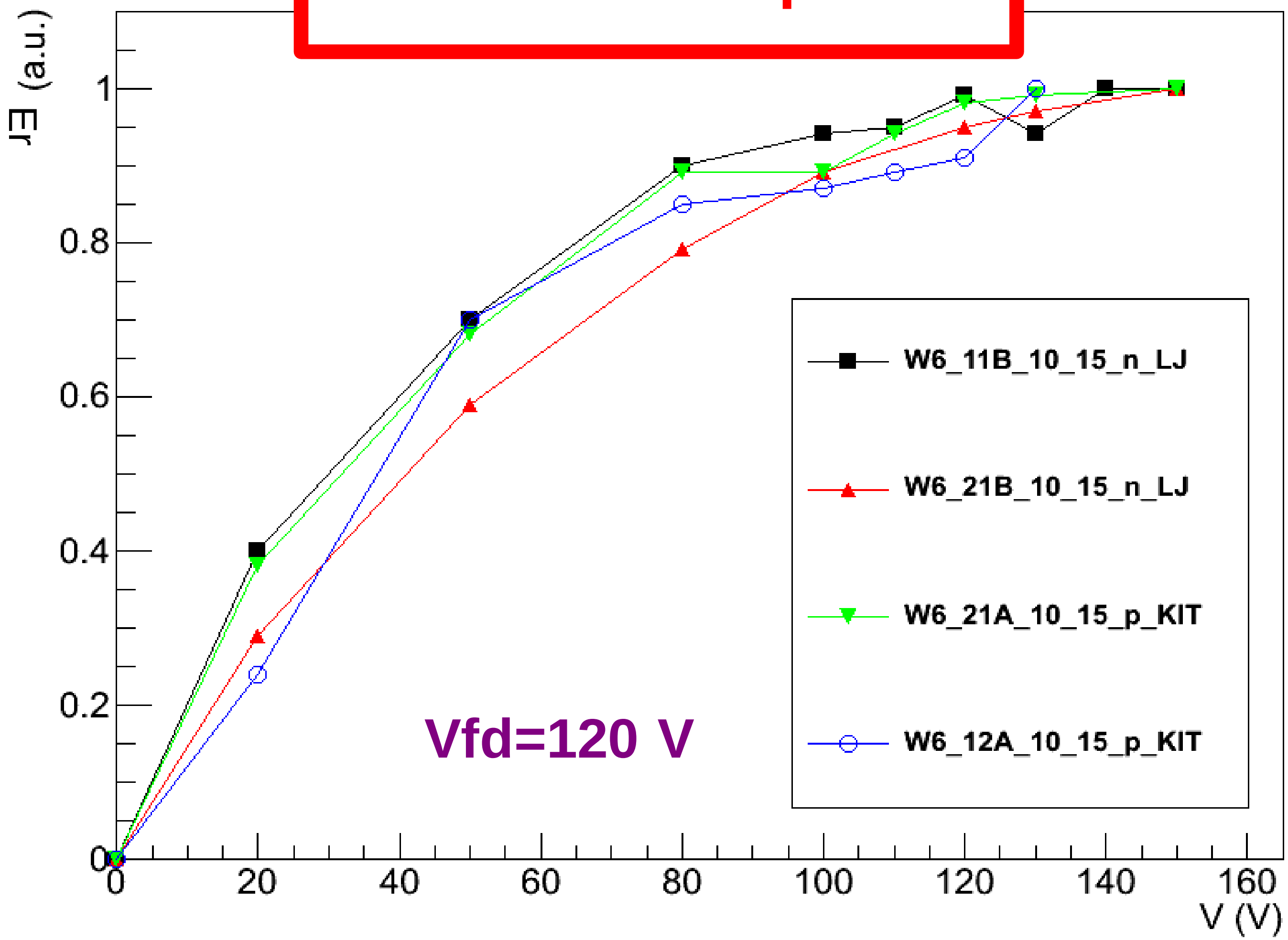
F= $1*10^{15}$ neq/cm²



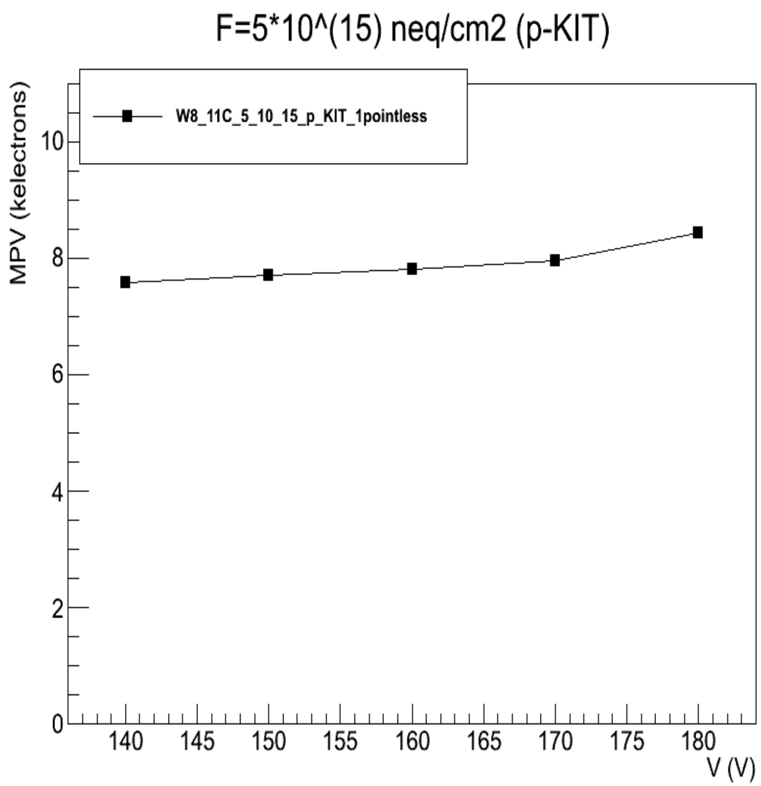
Er vs bias Voltage in irradiated samples

2 samples with protons
2 samples with neutrons

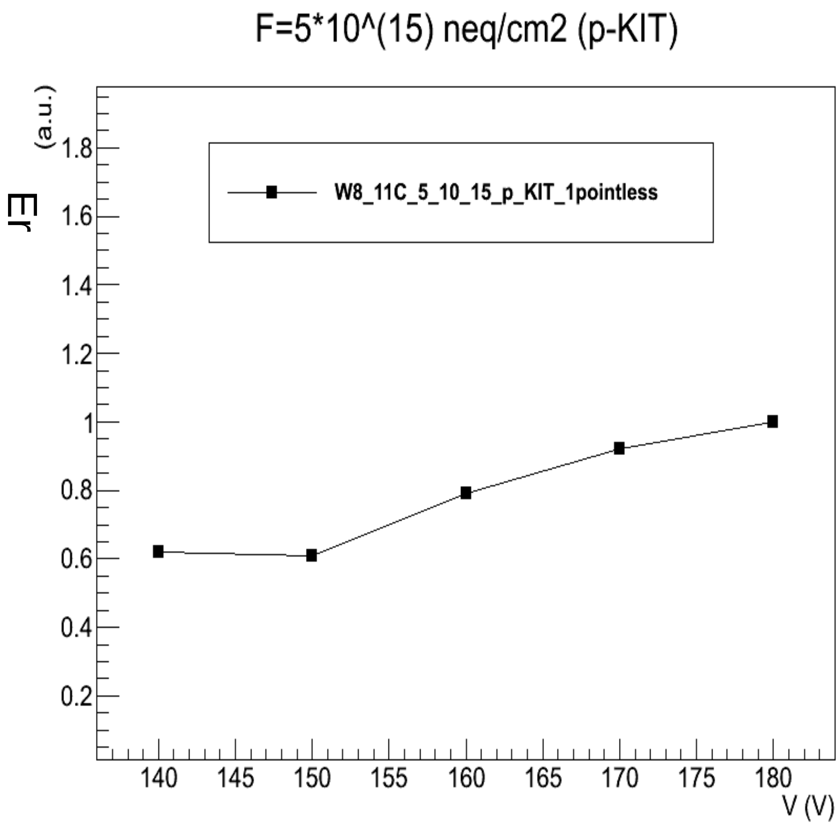
F= 1*10^15 neq/cm²



MPV and Er vs bias Voltage in irradiated samples

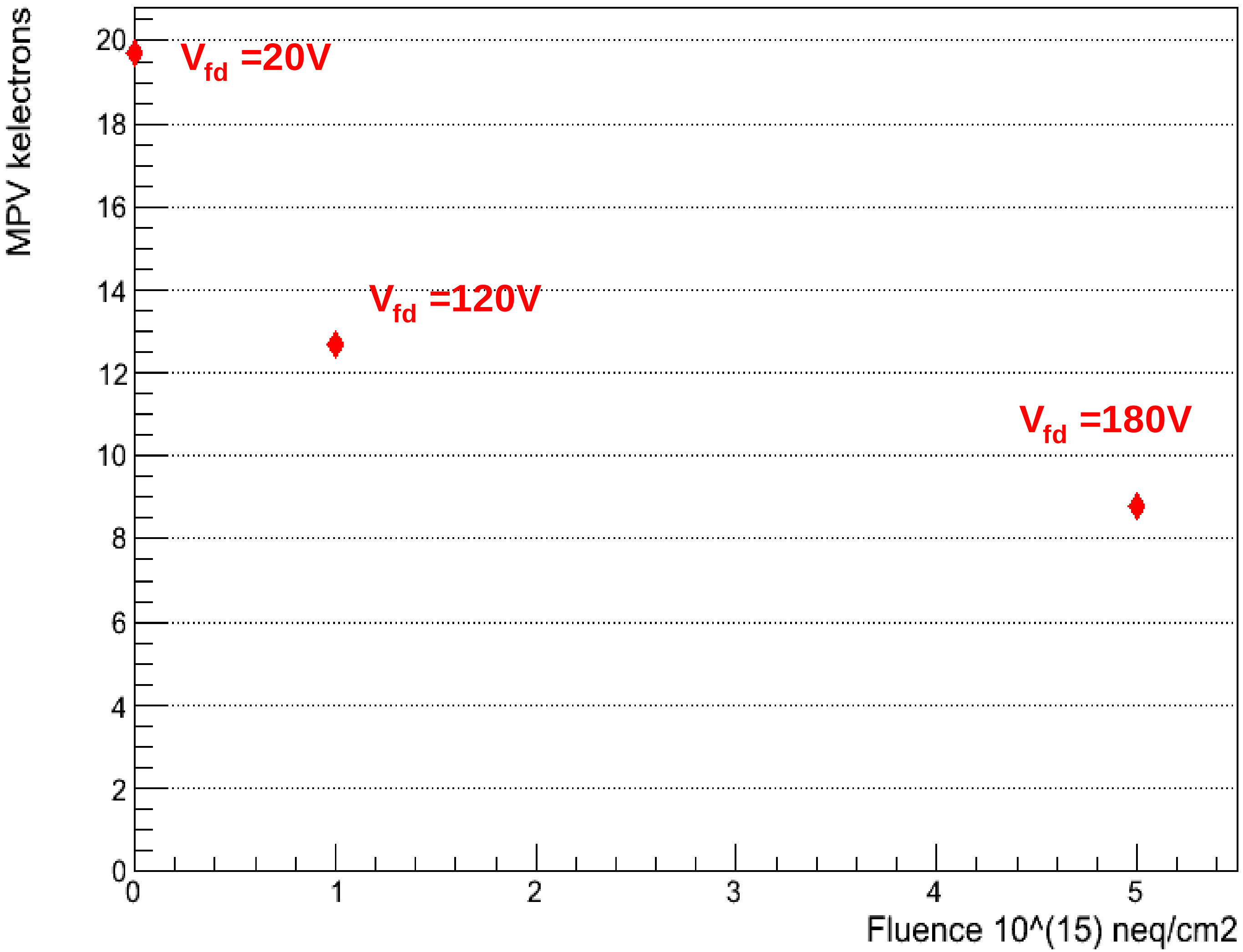


F= $5*10^{15}$ neq/cm² protons



Vfd=180 V

MPV vs Fluence



FUTURE WORK:

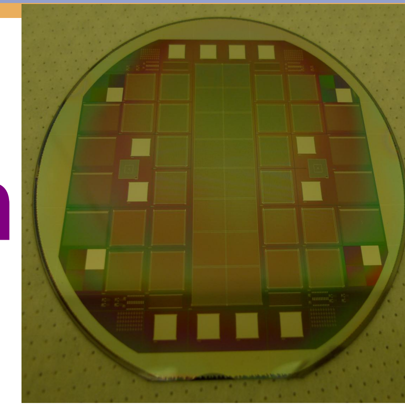
- Studies on the ROC performance after $1*10^{16}$ neq/cm²
- Test Beam @ DESY in March (Tracking Eff.)
- Capacitance meas. In the two different patterns

CONCLUSIONS:

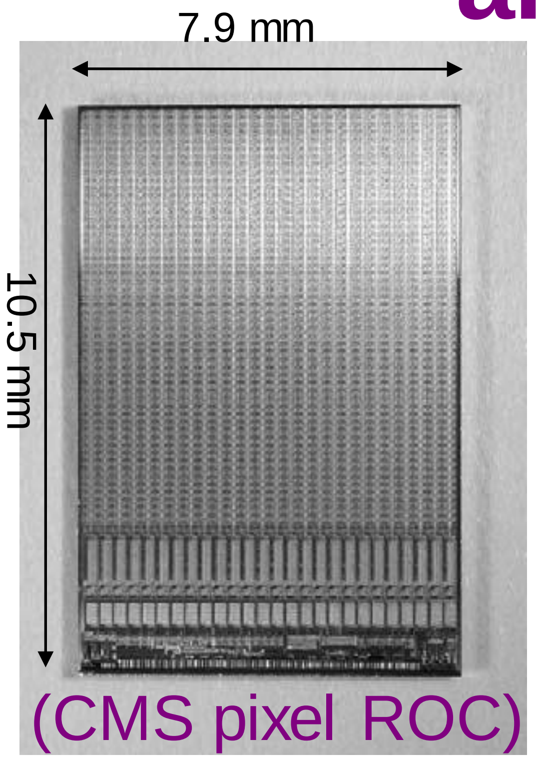
- Sensors show a good performance up to $5*10^{15}$ neq/cm²

- Mechanical stress reduces the bump-bonding yield.
A problem to fix in a future production

- Still plenty of work ahead testing samples



PSI46 ROC and interconnection proccess



52 x 80 pixel unit cells.
4160 units
150µm x 150µm