Single Event Burnout in thin silicon sensors

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Introduction - Single Event Burnout mechanism

In past beam tests, SEB have been observed on highly irradiated LGADs and PiN diodes with thickness of 45µm and 55µm

Death Mechanism:

Rare, large ionization event “Highly Ionising Particle”

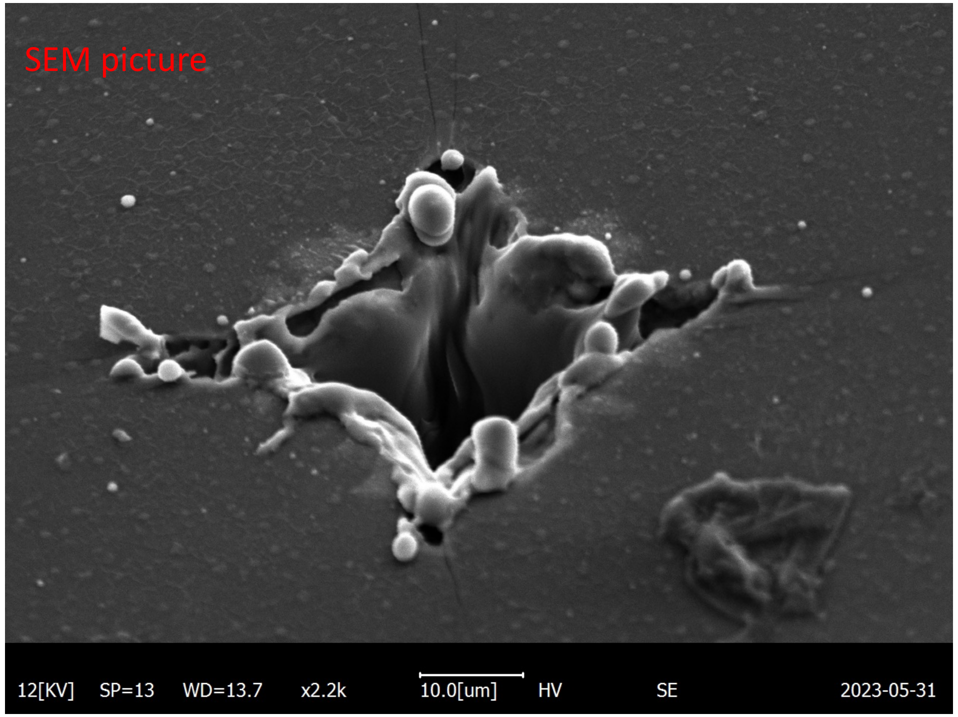
- Excess charge leads to highly localized conductive path
- Collapse of the depleted active thickness
- Large current flows in a narrow path – “Single Event Burnout”

SEB consequence:

- Impossibility to operate irradiated LGAD (45- and 55-µm thick) sensors above 540V and 660V (Bulk-E_{field} =12V/µm)

SEB in thin LGADs and PiN diodes [15µm-35µm] was not studied

Localized Melt and vaporization of silicon



Thanks to solid State Group, University of the Study of Turin, http://www.solid.unito.it/

Beam test campaigns and sensors under test

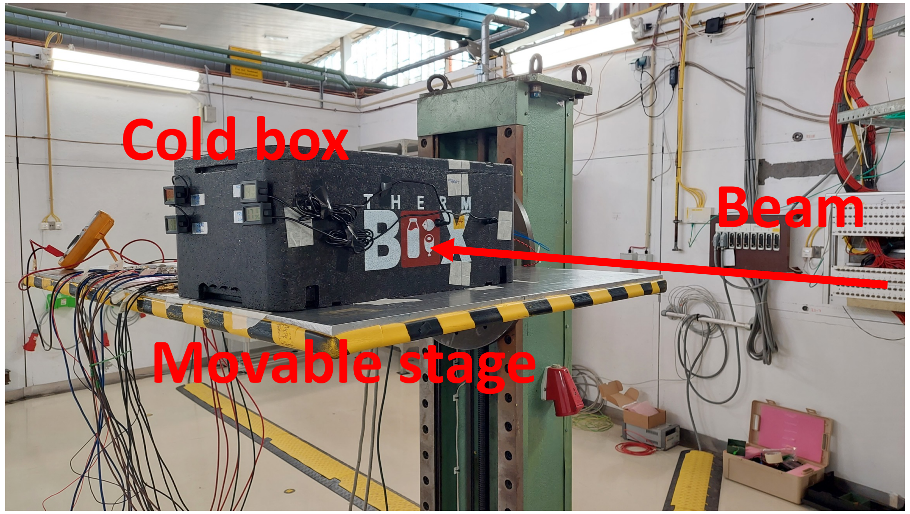
- Two beam test campaigns at DESY (T22) in March 2023 and at CERN (H6) in July 2023)

- 29 sensors from HPK2, FBK-UFSD4 and FBK-EXFLU0/1 have been tested:
  - Sensors thicknesses of 15, 20, 25, 30, 35, 45 and 55 µm
  - LGAD irradiated with neutrons up to 1E16 n_{eq}/cm^2
  - PiN Diodes unirradiated and irradiated up to 1E16 n_{eq}/cm^2
  - Different sensors geometry: single pad, 2x2, 5x5 array and large devices

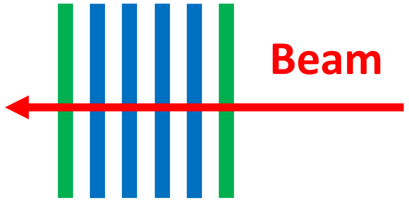
Beam test setups

Same setup used at DESY (T22) and CERN (H6)

Cold box with dry ice to operate irradiated sensors

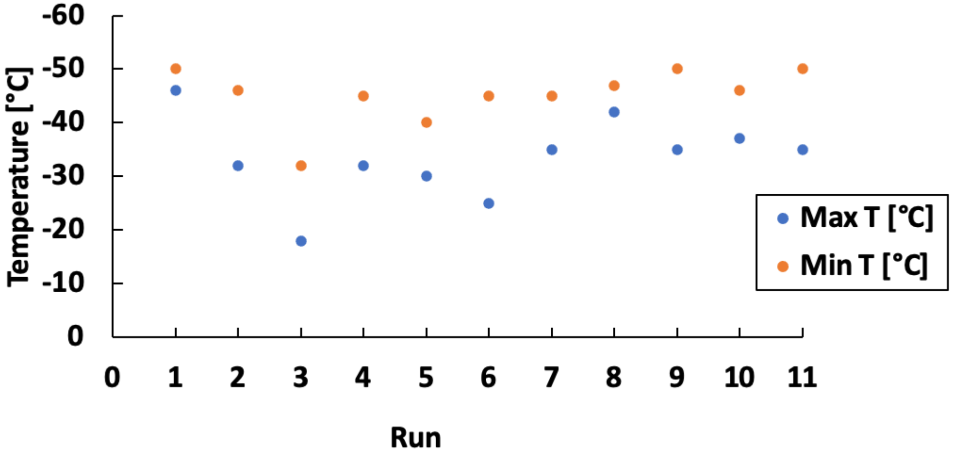


Beam test telescope with 6 sensor slots



- ➢ Counters (LGADs 300 µm-thick)
- ➢ DUTs

Monitored temperature at DESI beam test

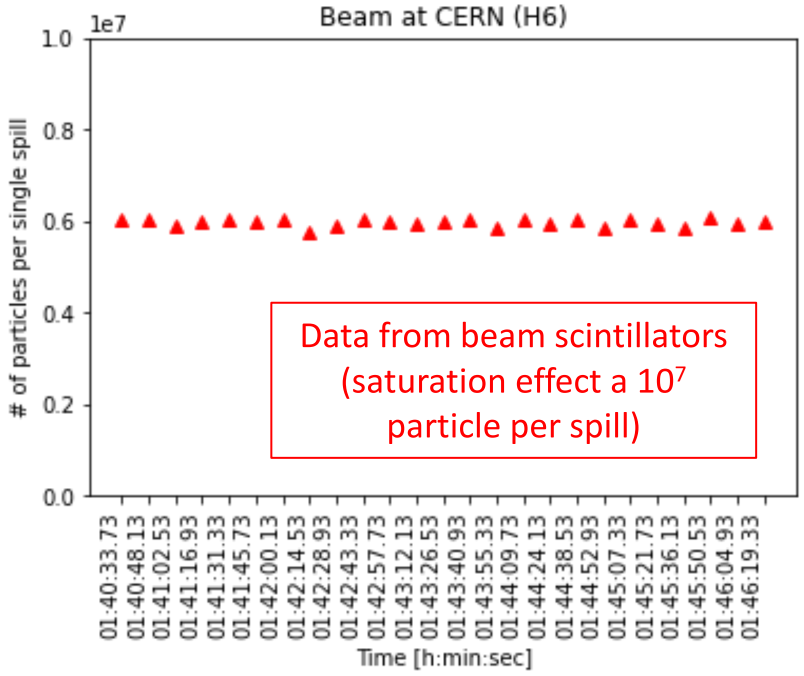


- ➢ Temperature monitored with thermocouples and PT100
- ➢ Dry ice guaranteed a temperature between -50°C and -20°C for tens of hours and humidity below 10%

Beams characteristics

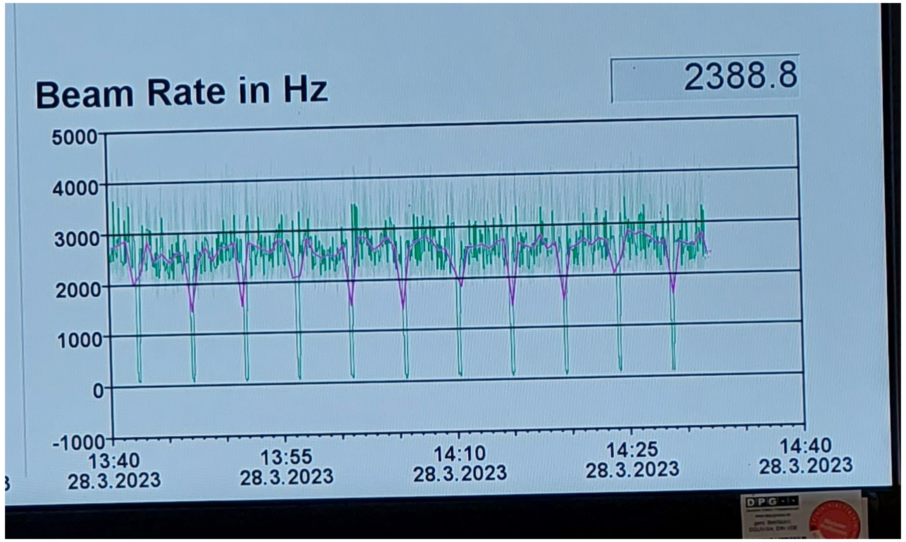
CERN

- Beam Energy and type: 120 GeV/c Pions and Protons
- High intensity beam: ~1.5E10^6 particles/cm^2 per spill
- Beam size: ~ 2x2 cm^2



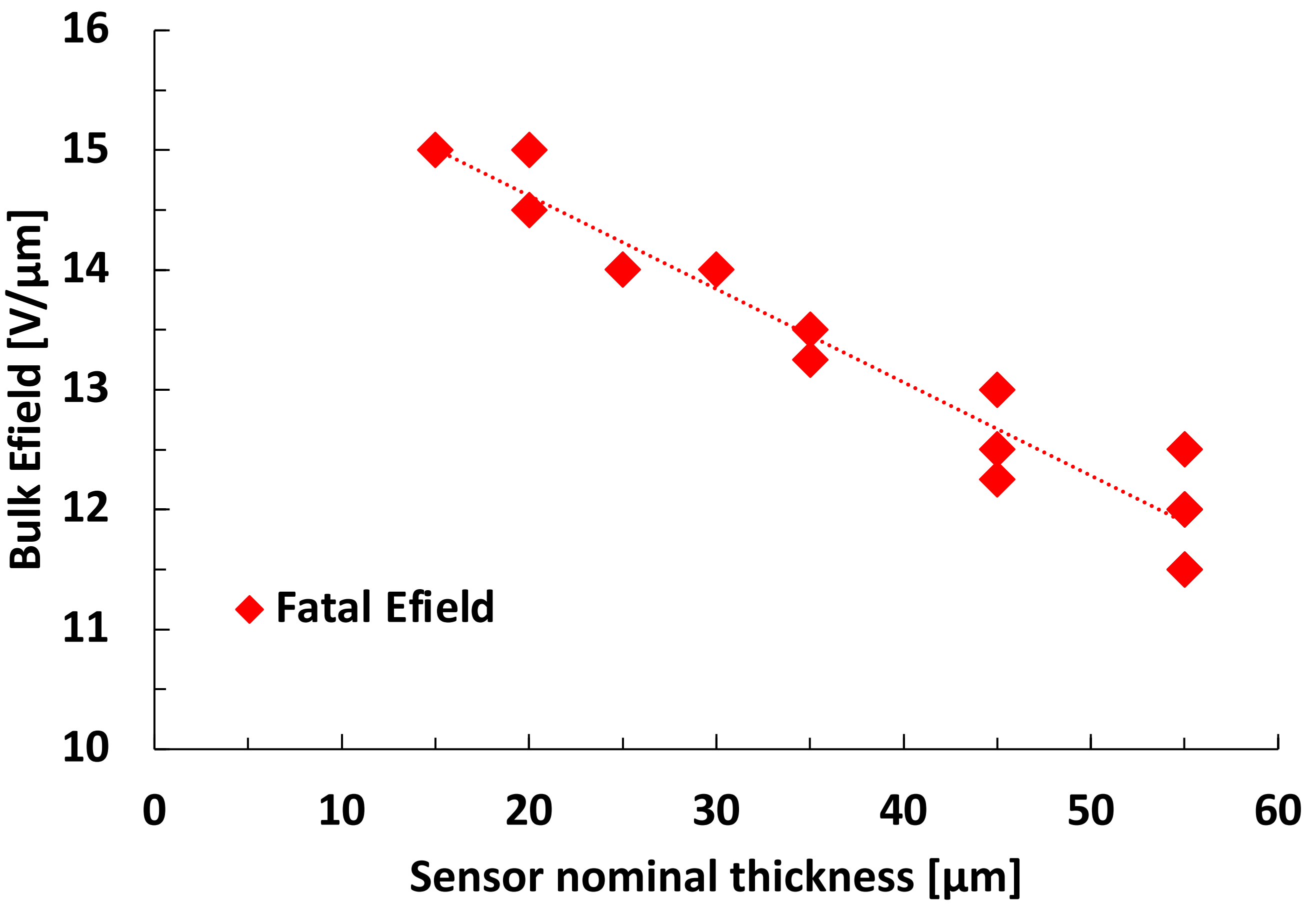
DESY

- Beam Energy and type: 3.6 GeV/c electrons
- Beam rate: of ~1.2kHz/cm^2
- Beam size: ~ 1x2 cm^2



DESY's beam monitor

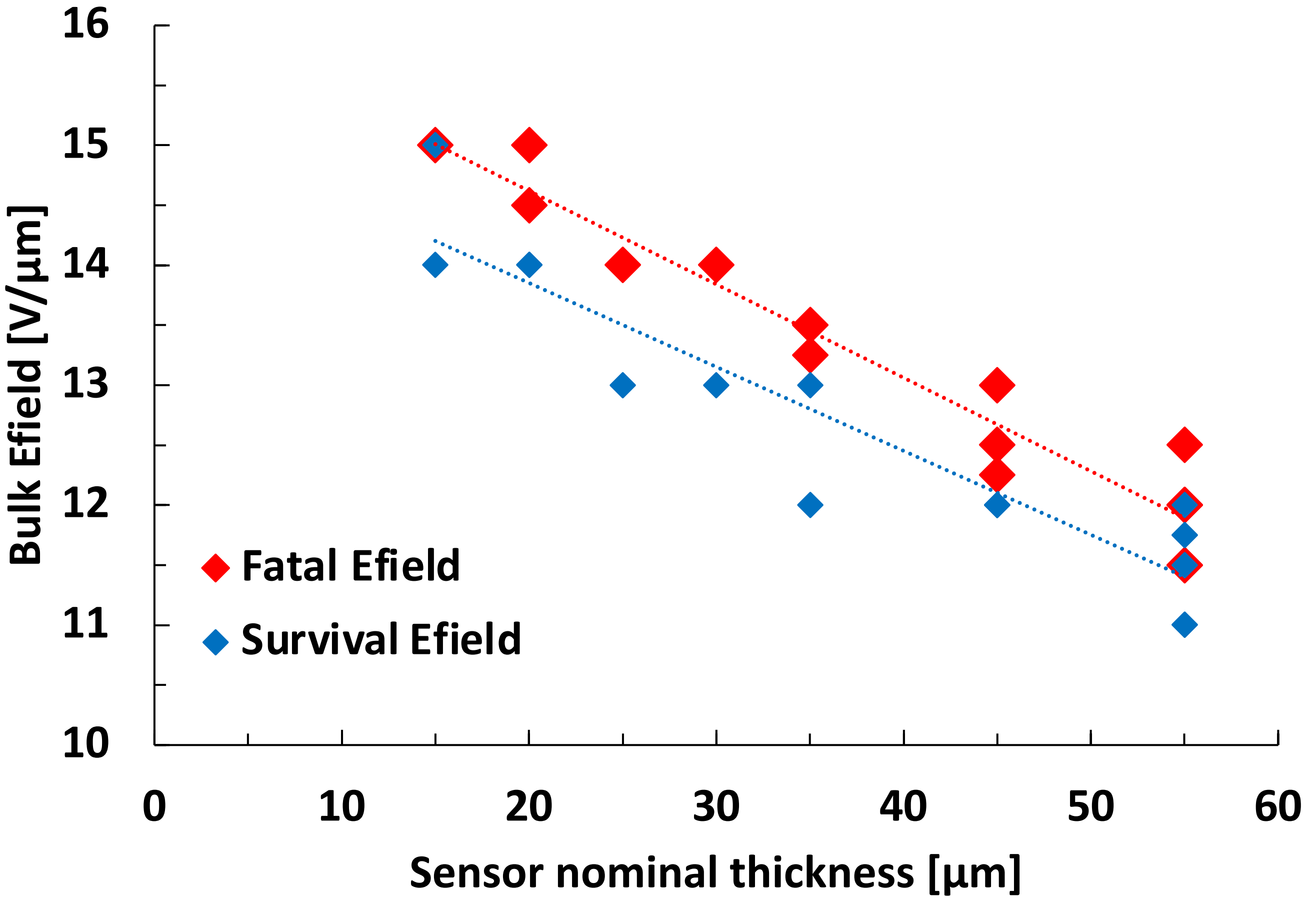
SEB results - fatal electric field



The thickness of the sensor determines the value of the fatal electric field

- Almost linear relationship between fatal electric field and sensor thickness

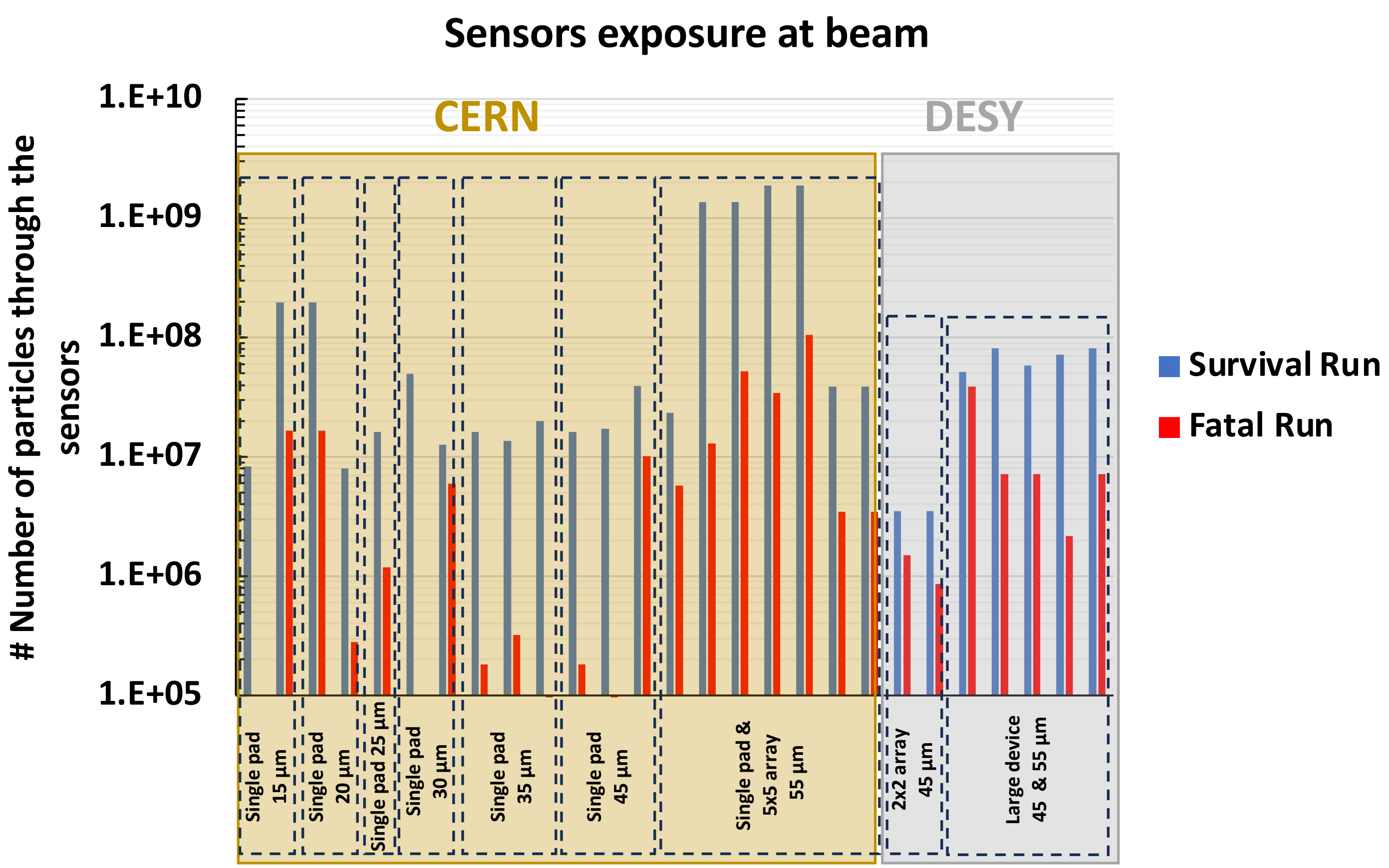
SEB results - fatal electric field



The thickness of the sensor determines the value of the fatal electric field

- Almost linear relationship between fatal electric field and sensor thickness
- Almost linear relationship between survival electric field and sensor thickness

Exposure at fatal and survival E_{field}



Sensors burned out after an exposure to a number of particles about an order of magnitude lower compared with the survival runs

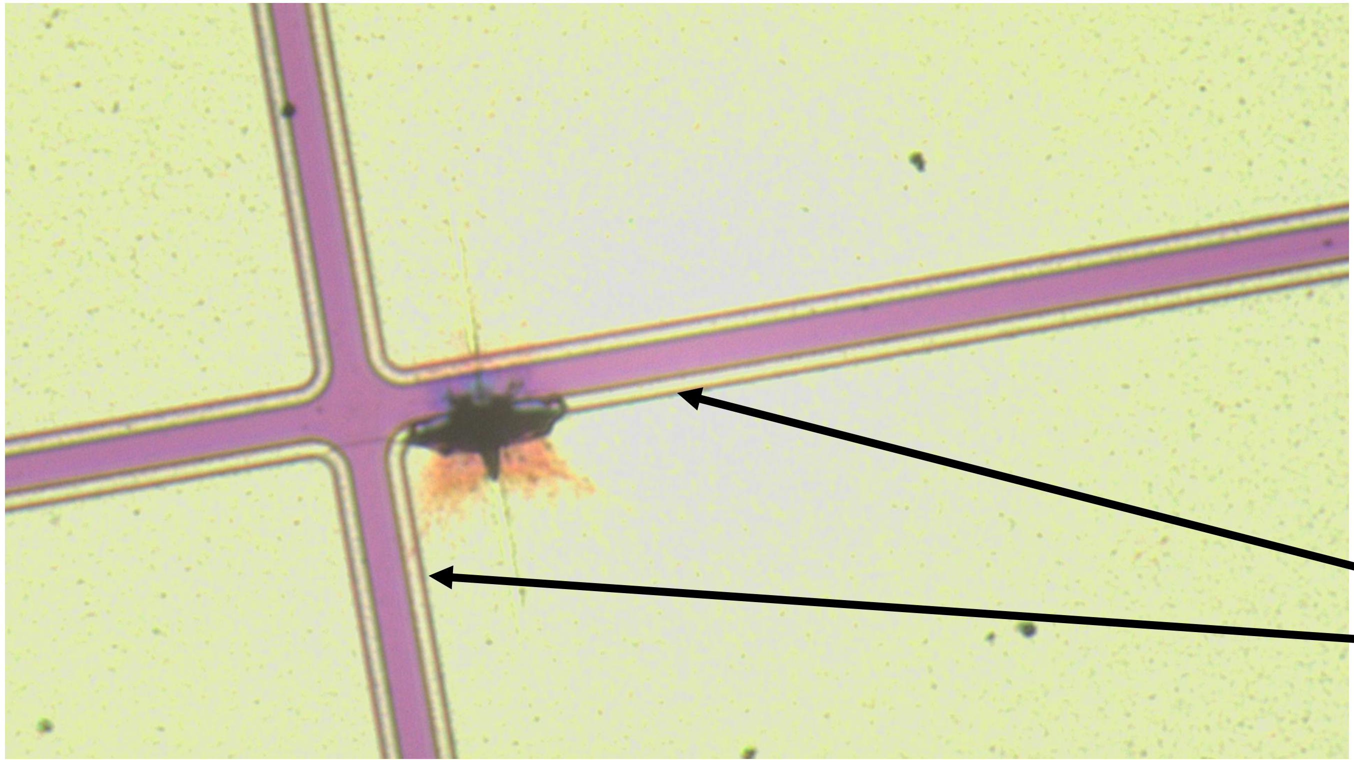
- Average number of particle through the sensors in **fatal runs**
  - CERN: $10^5 – 9 \cdot 10^7$ hadrons
  - DESY: $10^6 – 3 \cdot 10^7$ electrons

- Average number of particle through the sensors in **survival runs**
  - CERN: $10^7 – 10^9$ hadrons
  - DESY: $10^7 – 10^8$ electrons

SEB occurred in the same way and almost with the same statistic in small and large devices, in unirradiated and irradiated, in PiN and LGAD.

SEB pictures

SEB craters are mainly located in 2 different regions on the sensors surface

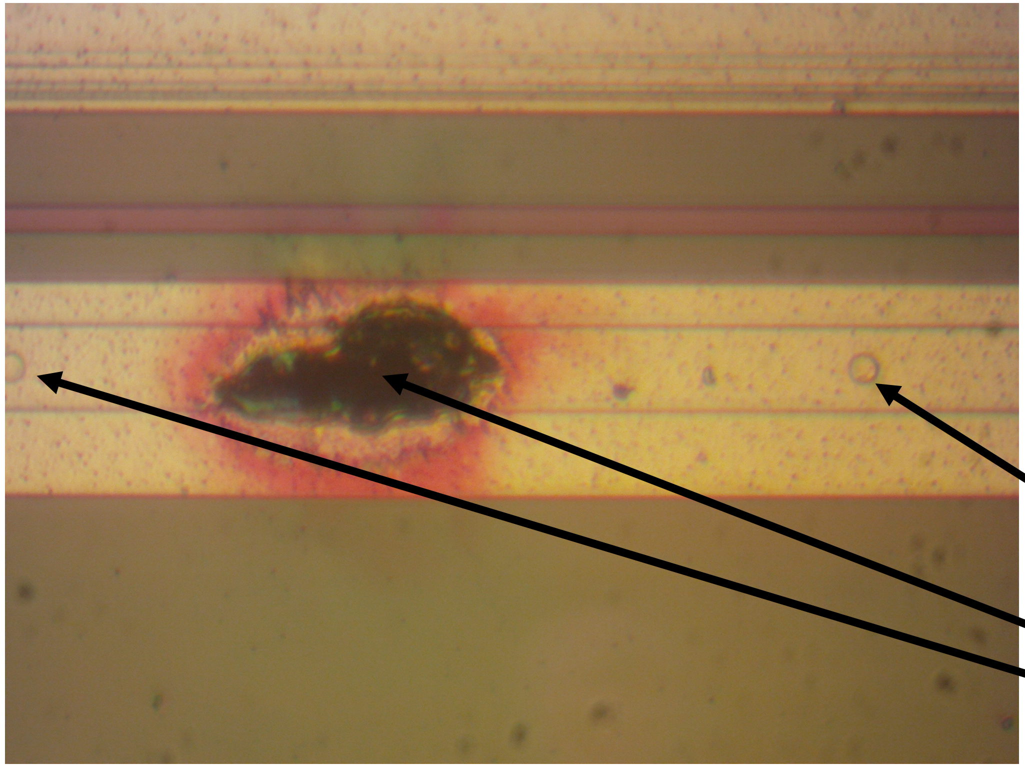


14 sensors of 27 have the crater **on the edge of the pixel** were there are the n-deep implant and the metal contact between n^{++} and read-out electrode

Metal contact

SEB pictures

SEB craters are mainly located in 2 different regions on the sensors surface



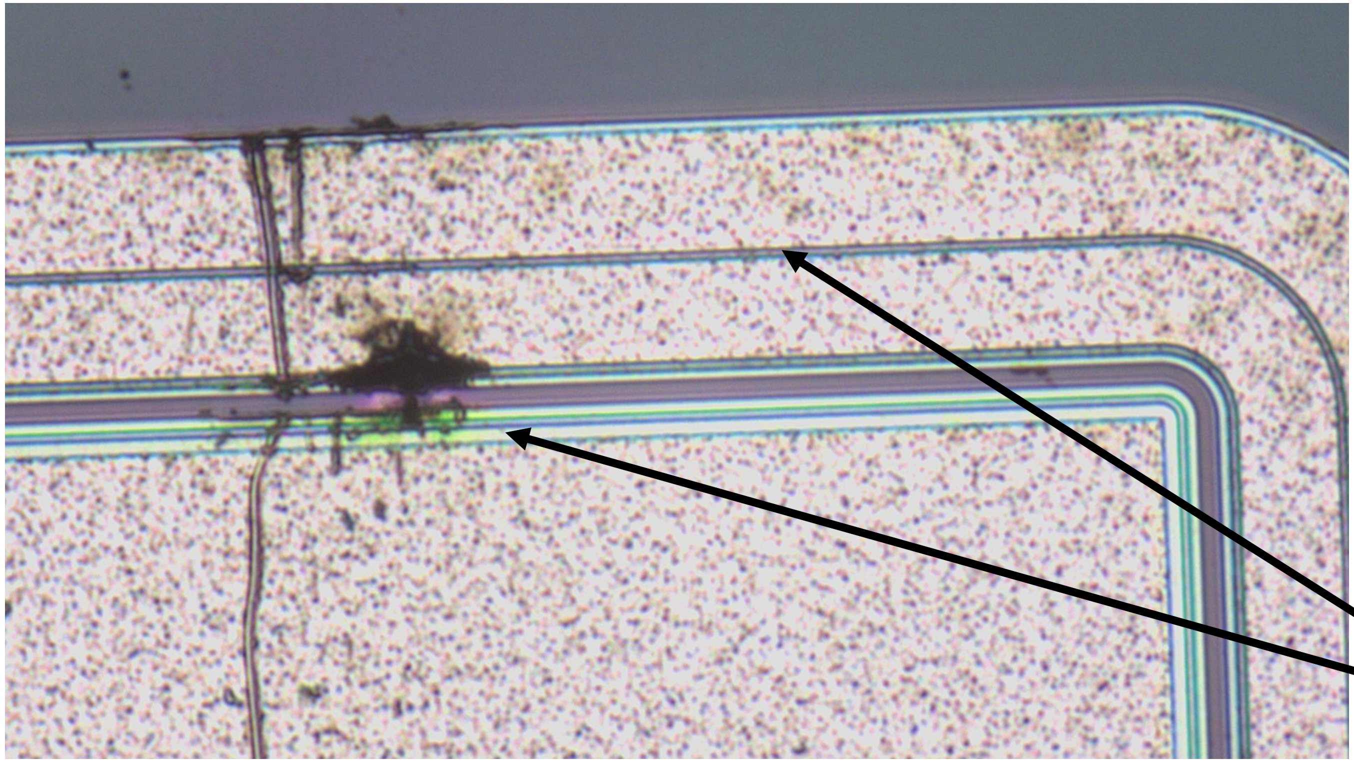
8 sensors of 27 have the crater **in the middle of the Guard-Ring** were there is the the metal contact between n^{++} and read-out electrode

The shape of the metal contact (continuous or column) doesn't affect the burnout

Metal contact

SEB pictures

SEB craters are mainly located in 2 different regions on the sensors surface



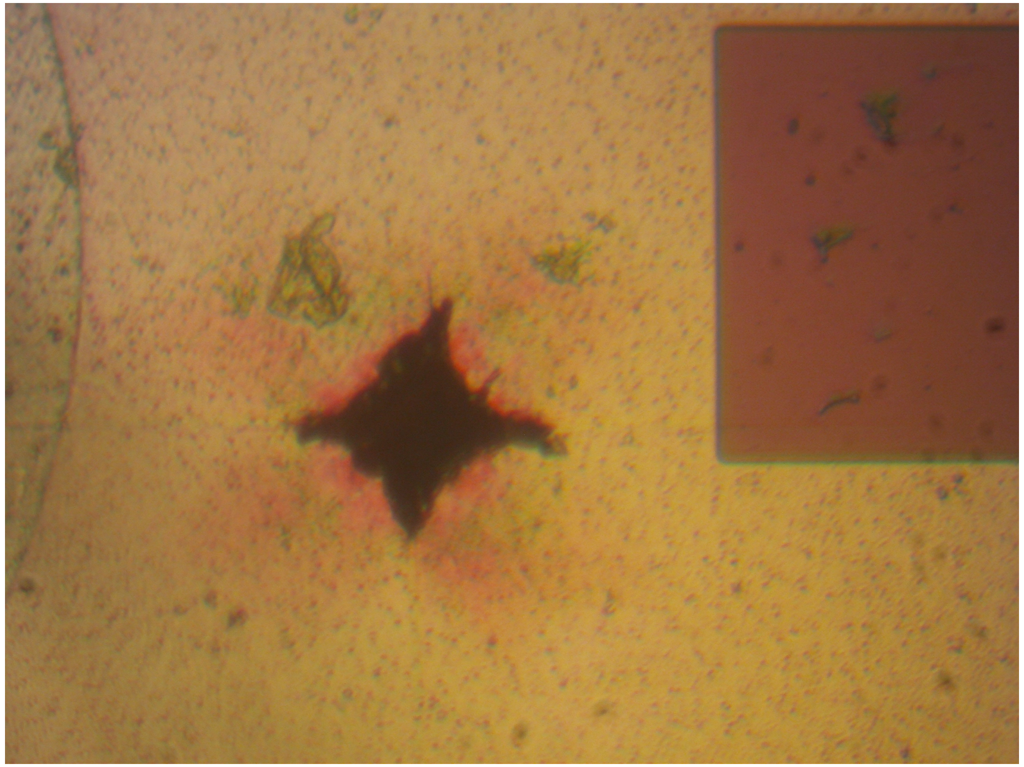
2 sensors of 27 have the crater **on the edge of the Guard-Ring (pixel side)** were there is the n-deep implant.

No metal contact is located on the edge of the GR

Metal contact

SEB pictures

SEB craters are mainly located in 2 different regions on the sensors surface



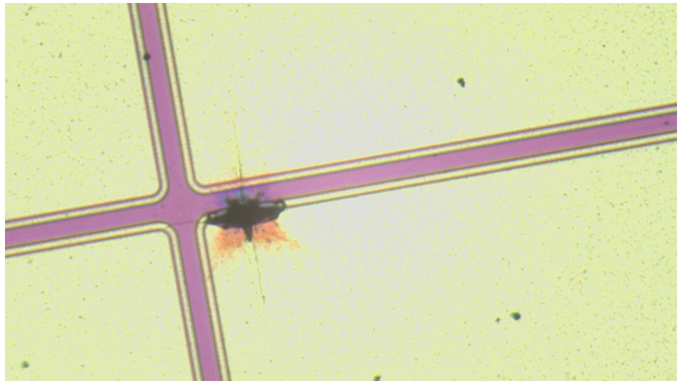
2 sensors of 27 have the crater **in the middle of the pixel** were there is an oxide layer between n^{++} and read-out electrode

No metal contact and n-deep implant is located in the region of the crater

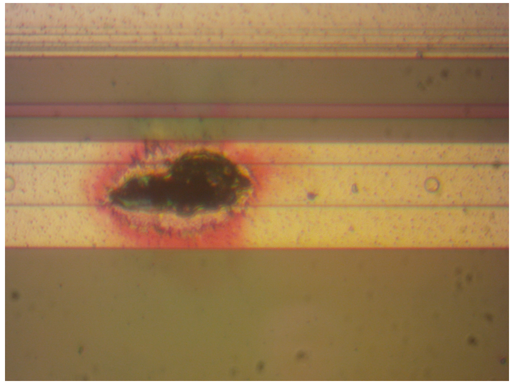
SEB pictures – Crater locations' summary

SEB craters are located in 4 different places on surface of the sensor

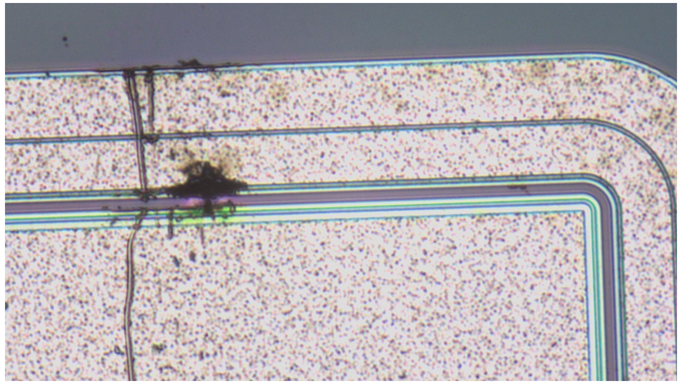
On the edge of the pad (14 sensors)



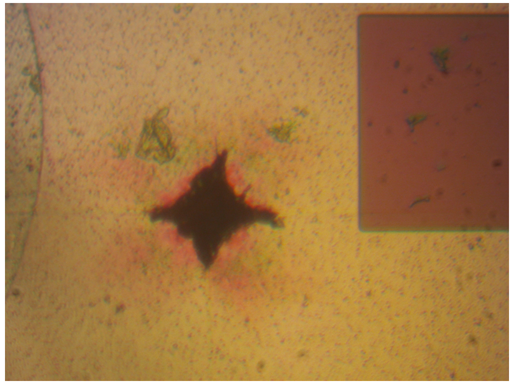
In the middle of the guard-ring (8 sensors)



On the edge of the guard-ring (pixel side) (2 sensors)



In the middle of the pad (2 sensor)



Two sensors burned out not under beam

Complete collection of pictures in backup slides

Conclusion

- The SEB fatal electric field has an almost linear relationship with the nominal thickness of the sensors.

- No evident relationship between sensor geometry, irradiation level and SEB has been observed.

- Damages caused by SEB on the sensor surface are localized on the edge of the pixel and on the guard-ring, where there are n-deep implant and metal contact.

  Possible explanations:

  - The large amount of current generated by high ionizing event is fatal for the metal contact
  - the reduced active thickness due to the n-deep implant (pad edge and guard-ring) generates locally an higher E_{field} compared with the field below the n^{++} electrode

Acknowledgements

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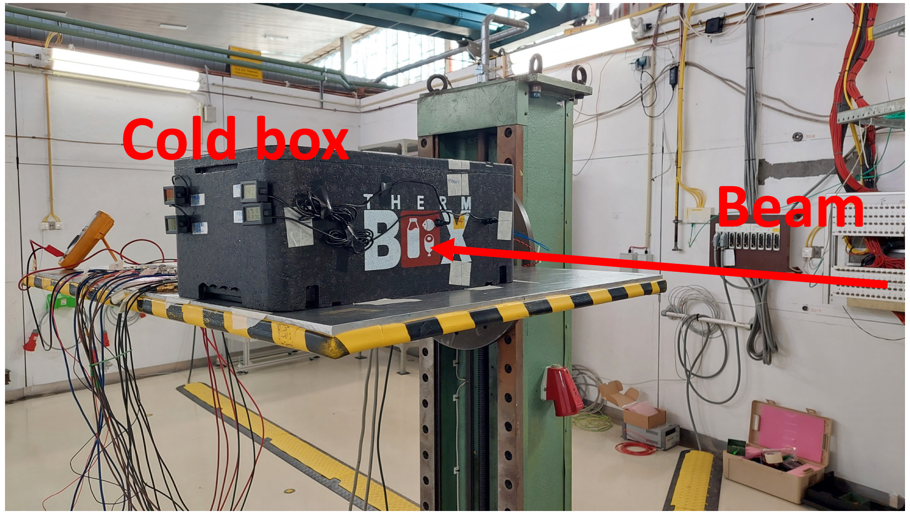
- RD50, CERN
- AIDAinnova, WP13
- Compagnia di San Paolo
- Ministero della Ricerca, Italia, PRIN 2017, progetto 2017L2XKTJ – 4DinSiDe
- Ministero della Ricerca, Italia, PRIN 2022, progetto 2022RK39RF – ComonSens
- European Union’s Horizon 2020 Research and Innovation programme, Grant Agreement No. 101004761
- This project has received funding from the European Unions Horizon Europe research and innovation programme under grant agreement No 101057511.
- The measurements leading to these results have been performed at the Test Beam Facility at DESY Hamburg (Germany), a member of the Helmholtz Association (HGF)

Backup

Beam test setups – DESY (T22) and CERN (H6)

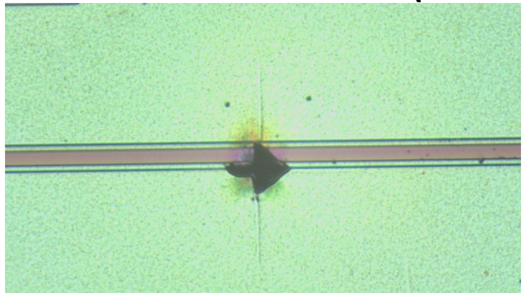
DESY (march 2023)



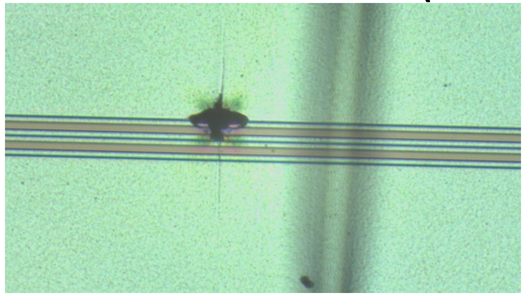
CERN (July 2023)

SEB collection

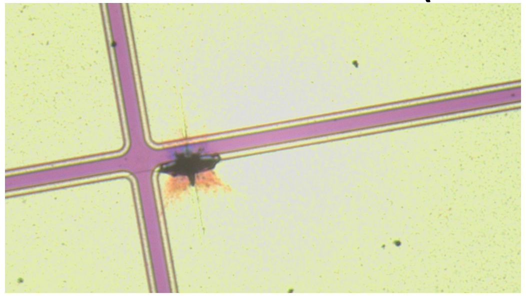
UFSD4 W2 5x5 T9 GR3-0 4-6 (Irr 2E15)



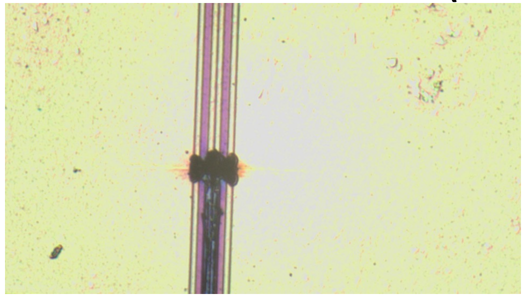
UFSD4 W2 5x5 T10 GR3-0 1-4 (Irr 2E15)



UFSD4 W13 5x5 T9 GR3-0 5-6 (Irr 2E15)

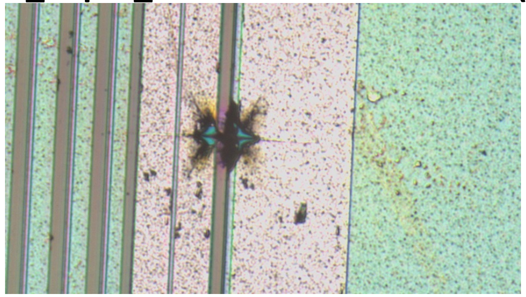


UFSD4 W13 5x5 T10 GR3-0 4-6 (Irr 2E15)

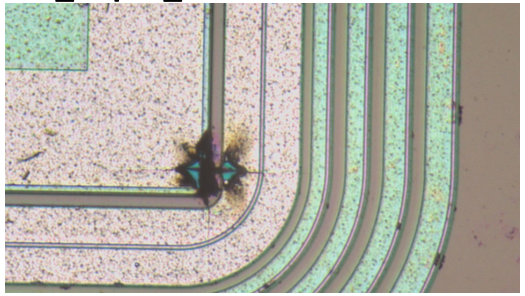


EXFLU0_55µm_W9 PAD1.3mm 8-4 PIN (1E15)

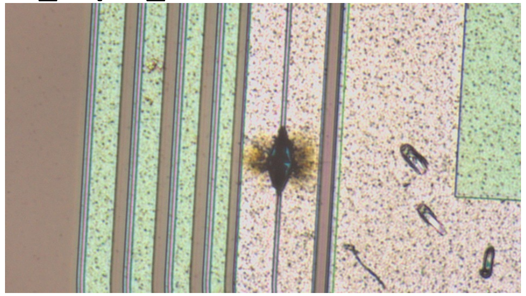
EXFLU0_55µm_W7 PAD1.3mm 2-4 PIN (5E15)



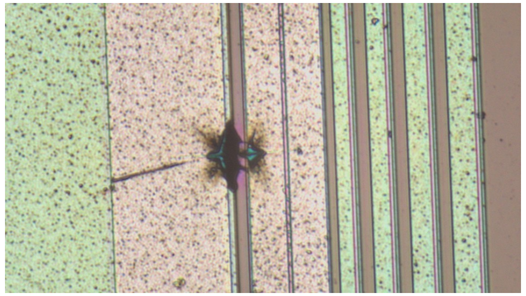
EXFLU0_55µm_W7 PAD1.3mm 3-4 PIN (1E16)



EXFLU0_45µm_W11 PAD1.3mm 3-4 PIN (1E15)

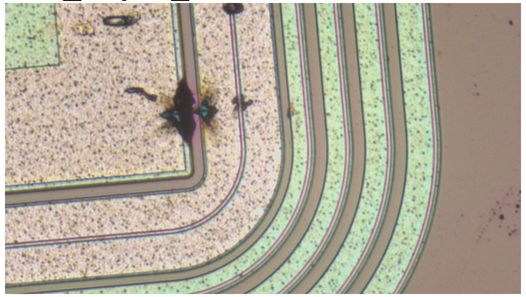


EXFLU0_45µm_W11 PAD1.3mm 4-4 PIN (5E15)

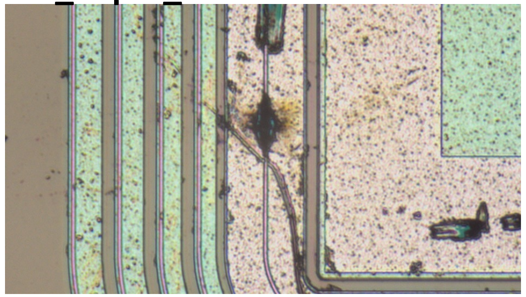


SEB collection

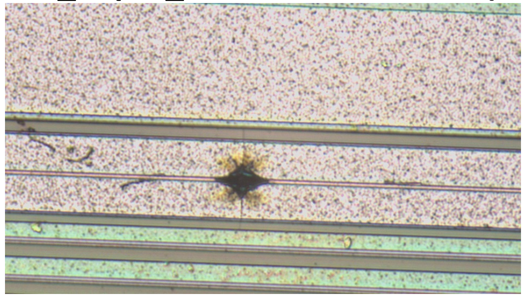
EXFLU0_45µm_W11-PAD1.3mm 5-4 PIN (1E16)



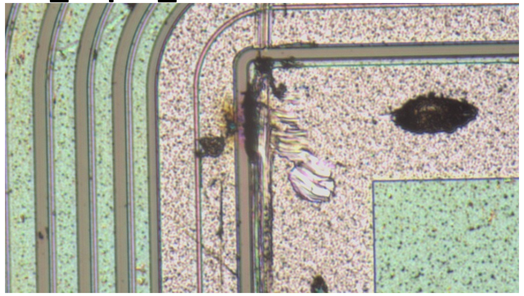
EXFLU0_35µm_W6 PAD1.3mm 4-4 PIN (1E15)



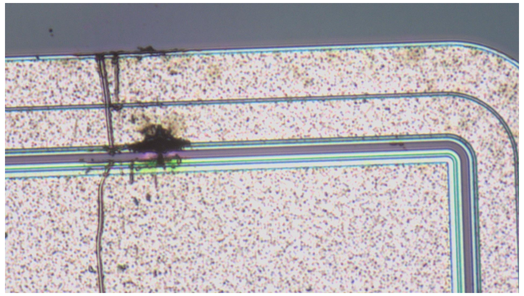
EXFLU0_35µm_W6 PAD1.3mm 9-5 (1E16)



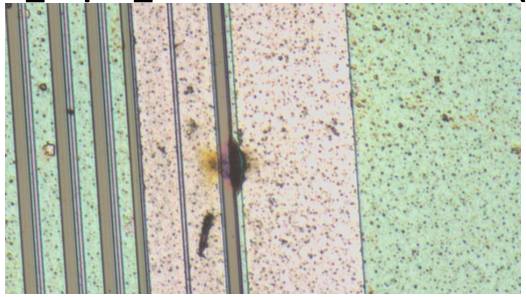
EXFLU0_35µm_W6 PAD1.3mm 4-4 PIN(1E16)



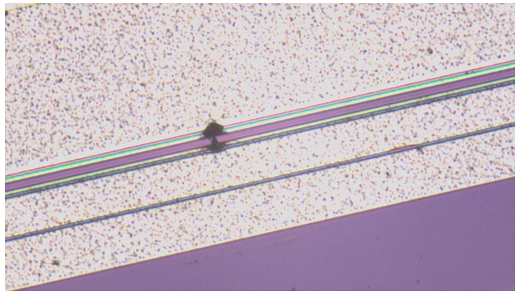
EXFLU1_30µm_W6 Pad1.3 S5 26-D PiN (new)



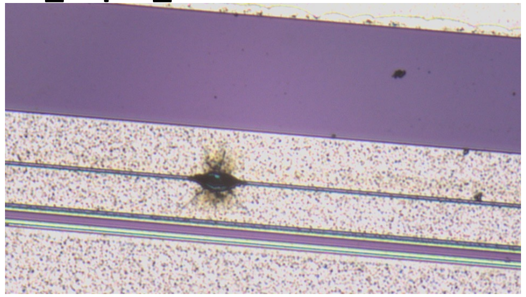
EXFLU0_25µm_W5 PAD1.3mm 3-4 PIN (5E15)



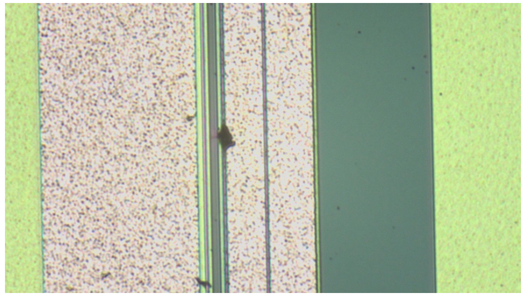
EXFLU1_20µm_W17 Pad3.6 S5 11-F PiN (new)



EXFLU1_20µm_W17 Pad1.3 S5 26-D PiN (new)

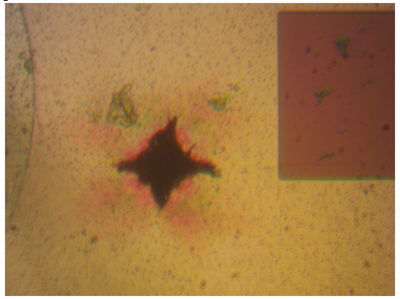


EXFLU1_15µm_W18 Pad3.6 S5 11-F – PiN (new)

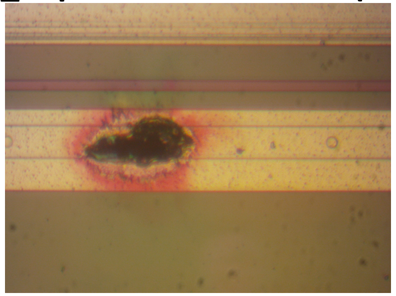


SEB collection

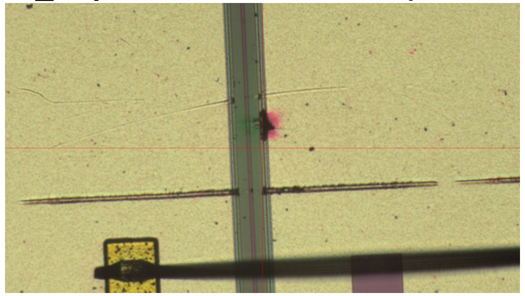
HPK2_ 50µm-2x2-W37-P78 SE5-IP5 (Irr 1.5E15)



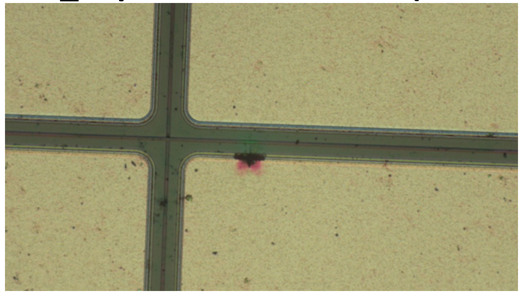
HPK2_50µm-2x2-W28 - P60 (Irr 1.5E15)



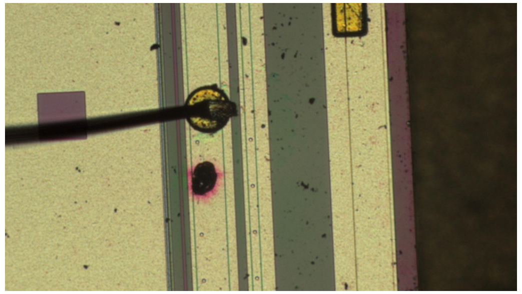
HPK2_50µm-16x16 - W21 P8 (Irr 1.5E15)



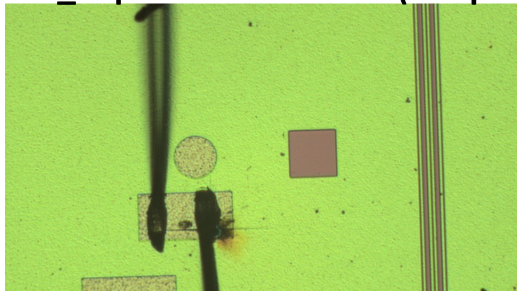
HPK2_50µm-16x16 - W1 P8 (Irr 2.5E15)



HPK2_50µm-16x16 - W21 P5 (Irr 1.5E15)



FBK-UFSD4-_55µM-16x16 - MS#9 (Deep-Irr 2.5E15)



FBK-UFSD4_55µm-16x16 - MS#2 (Shallow-Irr 2.5E15)