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# Curing early breakdown in silicon strip sensors with radiation

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ATLAS ITk

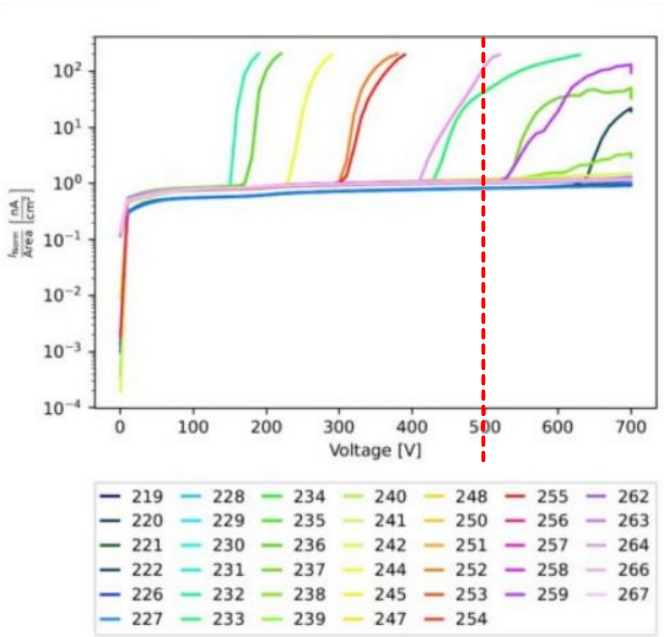
# Early breakdown

Measurements performed within the scope of the ATLAS ITk strip tracker

Bias voltage required for detector operation: -500 V

Throughout sensor production, multiple cases of early breakdown observed[1], requiring recovery

Several successful methods discovered to cure early breakdown




[1] see poster from Paul Miyagawa this week:
Analysis of the results from Quality Control tests performed on ATLAS18 Strip Sensors during on-going production (ID 64)

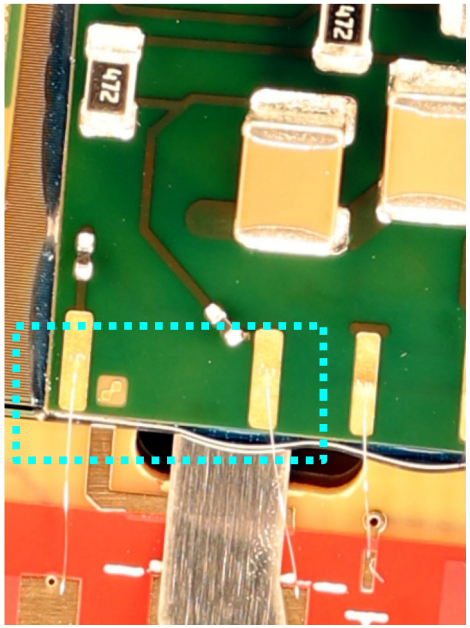
# Causes of early breakdown

Several causes known for sensors:

- Humidity sensitivity[2]
- Static charge-up, leading to low strip isolation[3]
- Long-term application of bias voltage[1]
- Mechanical damage (chips, cracks, scratches)[4]

Causes for assembled modules:

- All of the above
- Glue on the sensor bias ring[5]



[2] Humidity sensitivity of large area silicon sensors: Study and implications, J. Fernández-Tejero et al, NIMA, Volume 978, 21 October 2020, 164406

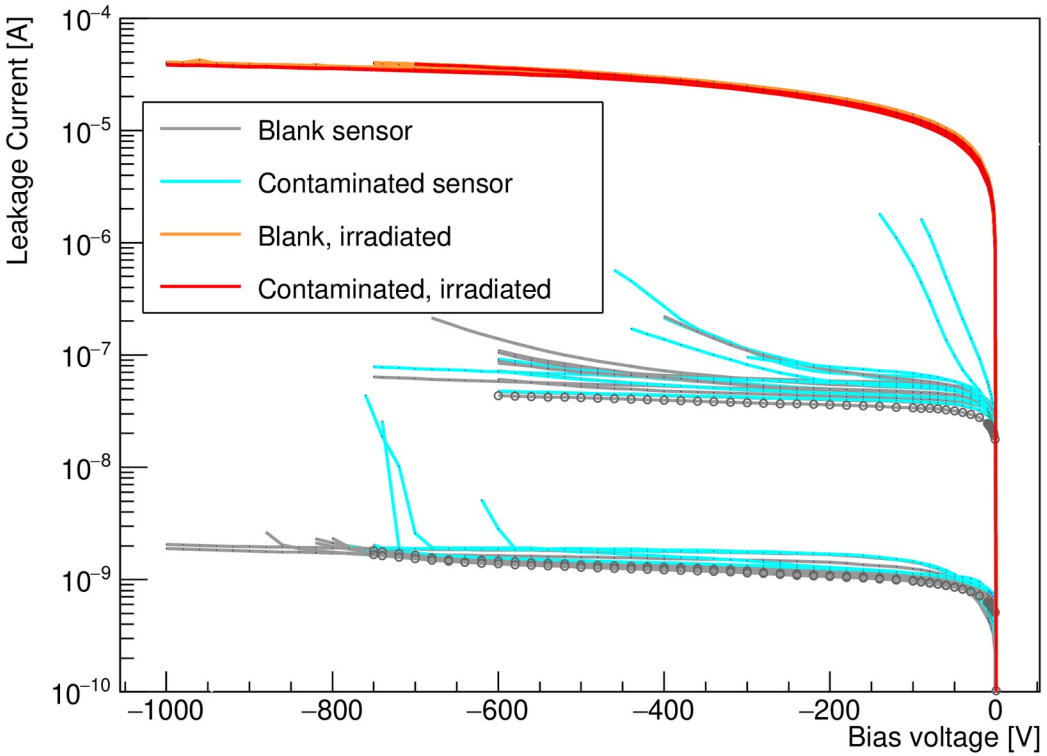
[3] Gamma irradiation of ATLAS18 ITk strip sensors affected by static charge, M. Mikestikova, https://agenda.infn.it/event/35597/contributions/211661/ (paper in preparation)

[4] ATLAS ITk Strip Sensor quality control and review of ATLAS18 pre-production sensor results, C. Klein, https://indico.cern.ch/event/1140707/contributions/5002364/ (publication pending)

[5] Study of n-on-p sensors breakdown in presence of dielectrics placed on top surface, C. Helling, L. Poley et. al, NIMA, Volume 924, 21 April 2019, Pages 147-152

# Irradiation cures everything

Previous studies of sensors after irradiation
No early breakdown observed after irradiation




Independent of cause for early breakdown before, all recovered after full fluence

What about low fluences?

# Indications of curing

Dedicated tests performed to study impact of irradiation on inherent sensor behaviour:

- Humidity sensitivity[7] (improves with radiation)
- Low strip isolation[3]

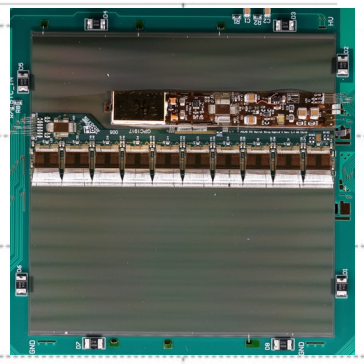
Follow-up measurements to study potential improvement of early breakdown for:

- Glue on module guard ring
- Diodes with mechanical damages

[7] Analysis of humidity sensitivity of silicon strip sensors for ATLAS upgrade tracker, pre- and post-irradiation, J. Fernández-Tejero et al 2023 JINST 18 P02012

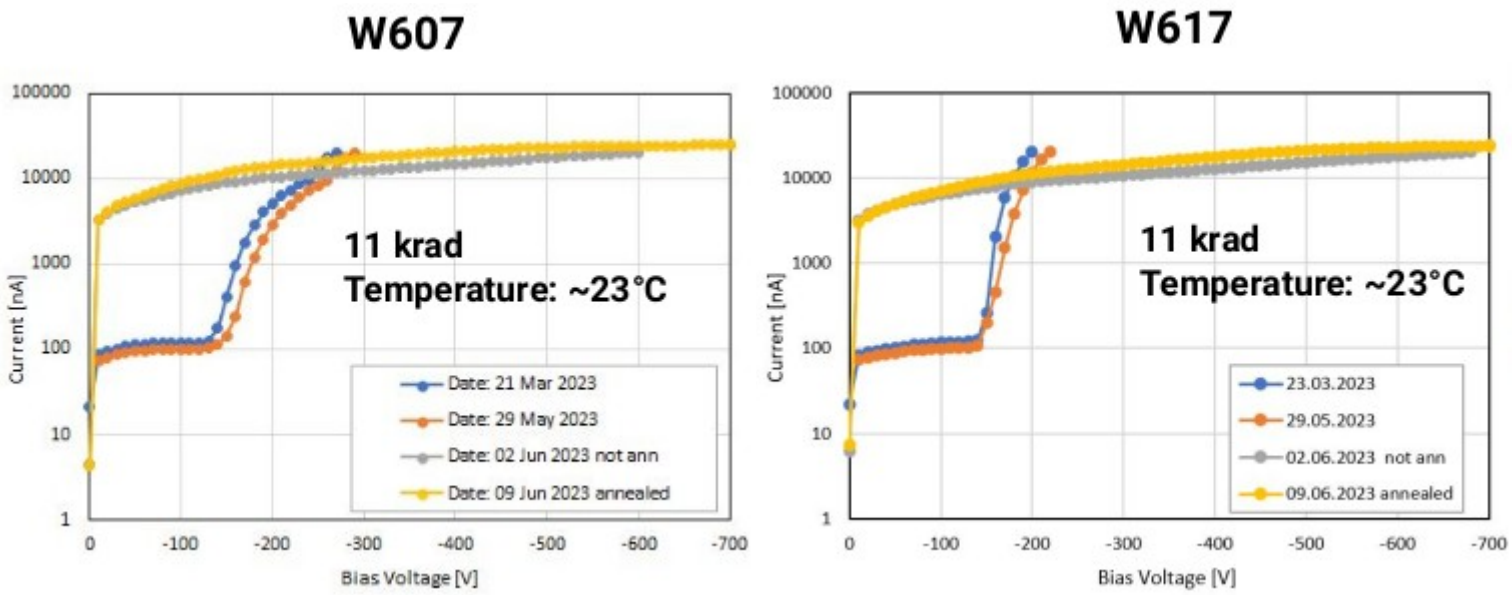
# Case 1: Modules

Classic signature after module assembly:
early breakdown (often due to glue on guard ring;
exact reason (sensor/module related) unknown)



# Measurement 1: Modules

Very promising results from measurements performed by Prague group:
even low doses improve early breakdown
(11 krad correspond to one week inside HL-LHC)
Question: does that also work with glue?

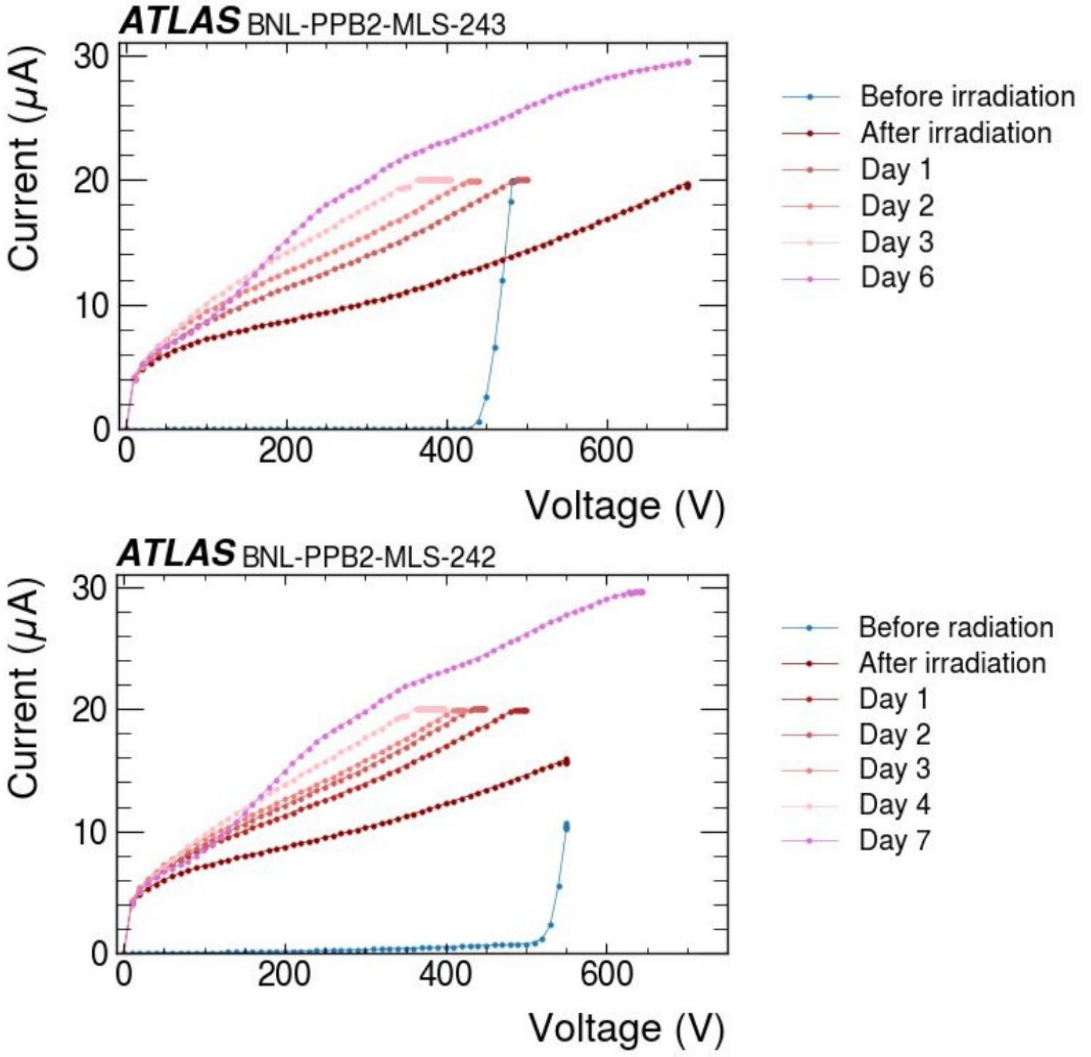


# Case 1: Modules

After exposure to 11 krad from gamma source

similar effect as for sensors: overall current increase, but no early breakdown

Improvement stable over days



# Gamma irradiation

So far: only low statistics

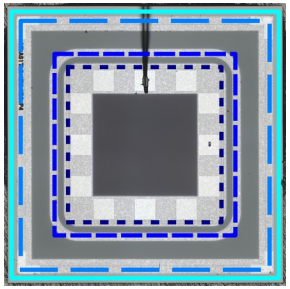
(plan to gamma-irradiate more modules with early breakdown to check reproducibility)

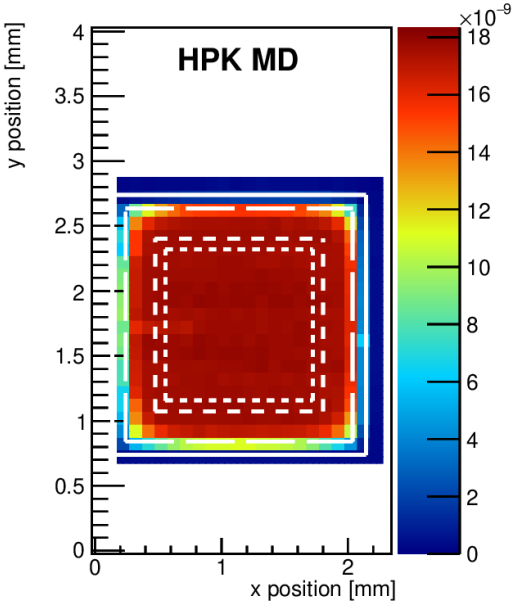
In parallel: further investigations into sensors (this time: adding hadronic damage)

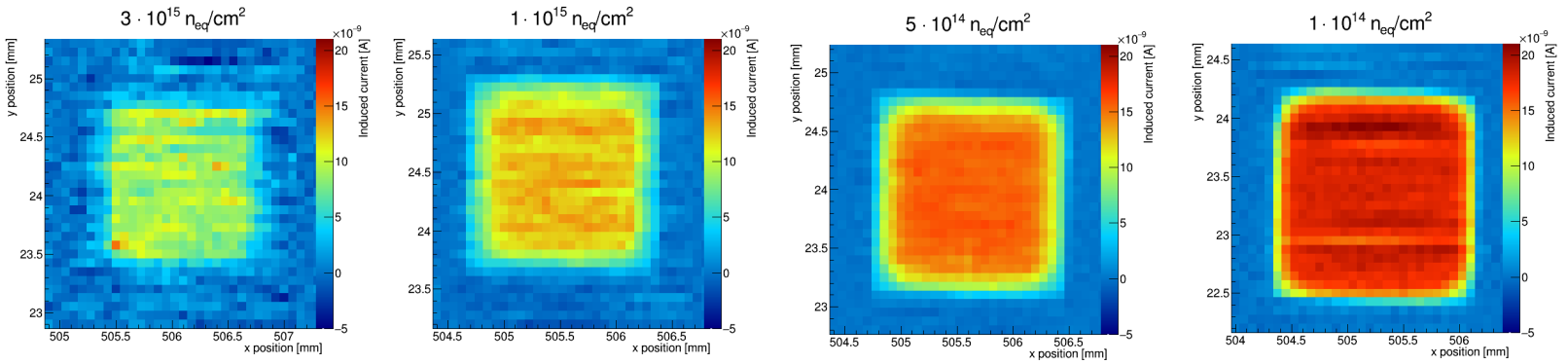
# Diodes: neutron damage

Previous measurements of diodes
depleted diode volume shrinks with fluence

Could this help with early breakdown?





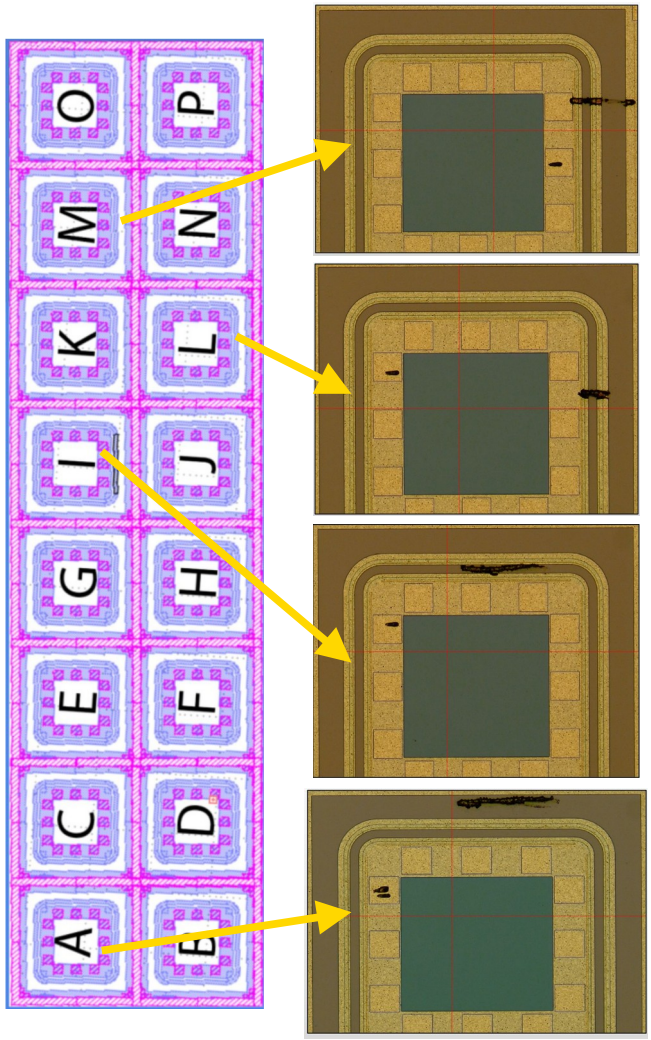



# Measurement 2: diodes

Array of diodes prepared with intentional scratches

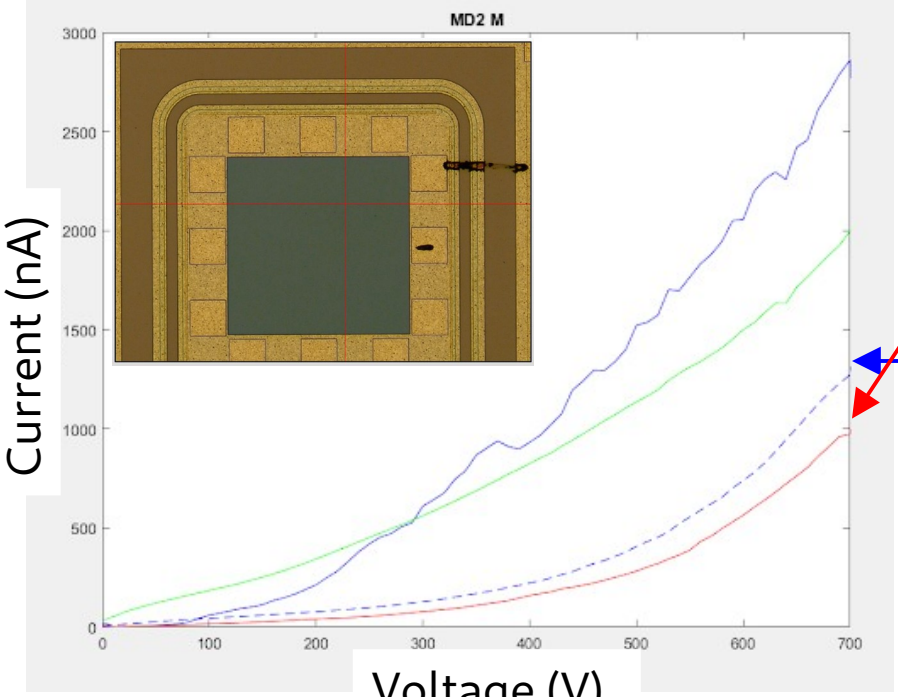
→ method developed to cause reproducible scratches
→ different locations, different depths

Compare breakdown voltage before and after scratching
Then irradiate to increasing fluences and repeat



# Measurement 2: diodes

The surprising result:
even at "homeopathic fluence" of $10^8 - 10^9$ $n_{eq}/cm^2$,
irradiation actually improves leakage current




**Current** after scratching
**Current** after recovery period
**Current** after irradiation to $10^8$ $n_{eq}/cm^2$
**Current** after irradiation to $10^9$ $n_{eq}/cm^2$

(all at the same temperature)

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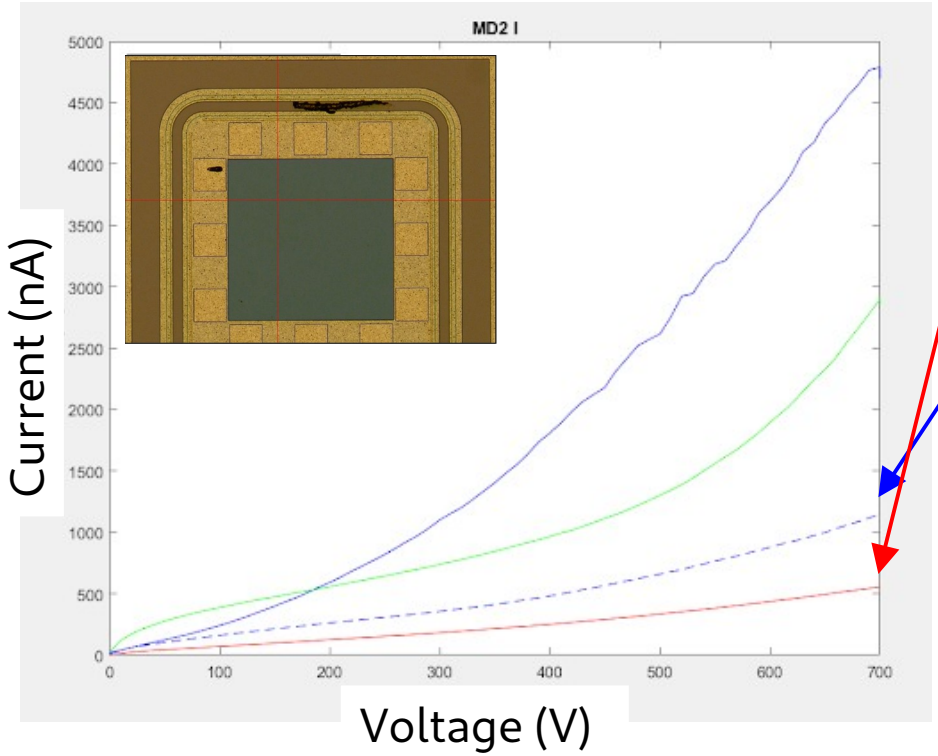



**Current** after scratching
**Current** after recovery period
**Current** after irradiation to $10^8$ $n_{eq}/cm^2$
**Current** after irradiation to $10^9$ $n_{eq}/cm^2$

(all at the same temperature)

# Measurement 2: diodes

Not all diodes showed exactly the same behaviour
→ post scratching IV depended on scratch
→ post irradiation IV depended on pre-irradiation IV

But overall trend: early breakdown improved after irradiation even to low fluence

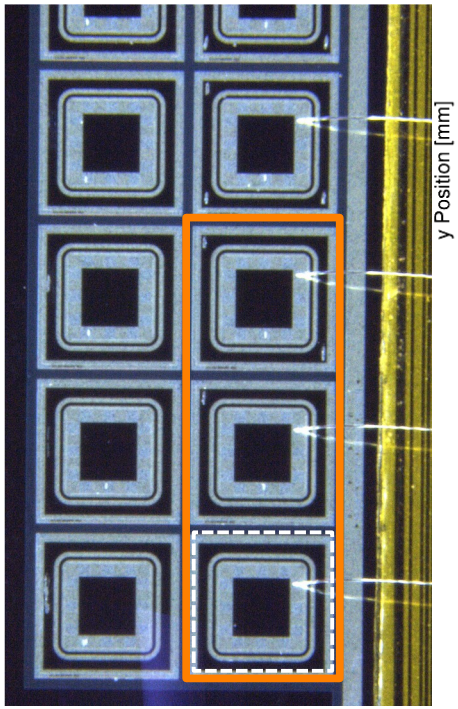
Continuing measurements with increasing fluence

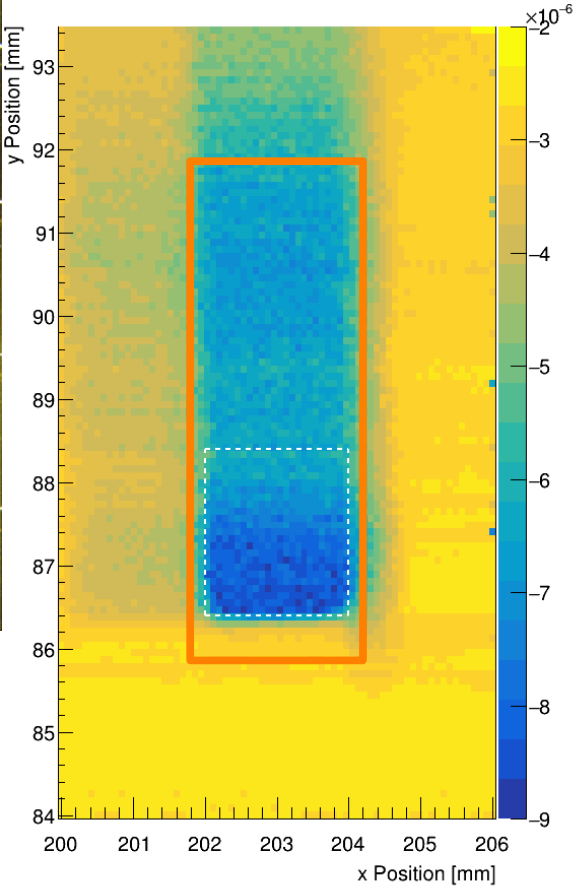
IV tests alternating with measurement of depleted diode volume (AREA-X measurements)

# Measurement 2: diodes

Alternating measurements: Leakage current and assessment of active area
→ change in depleted volume isolating defects?

Plan to continue measurements with higher fluences

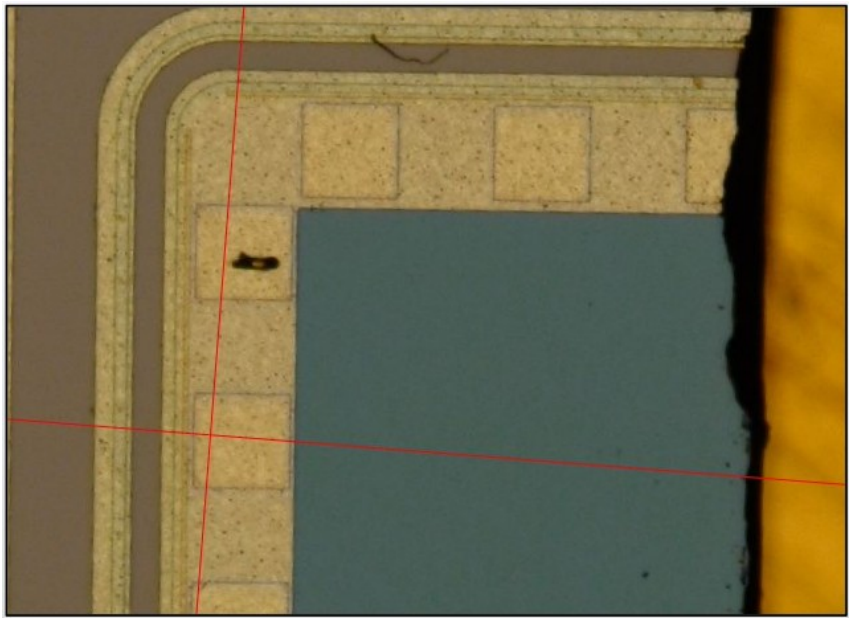


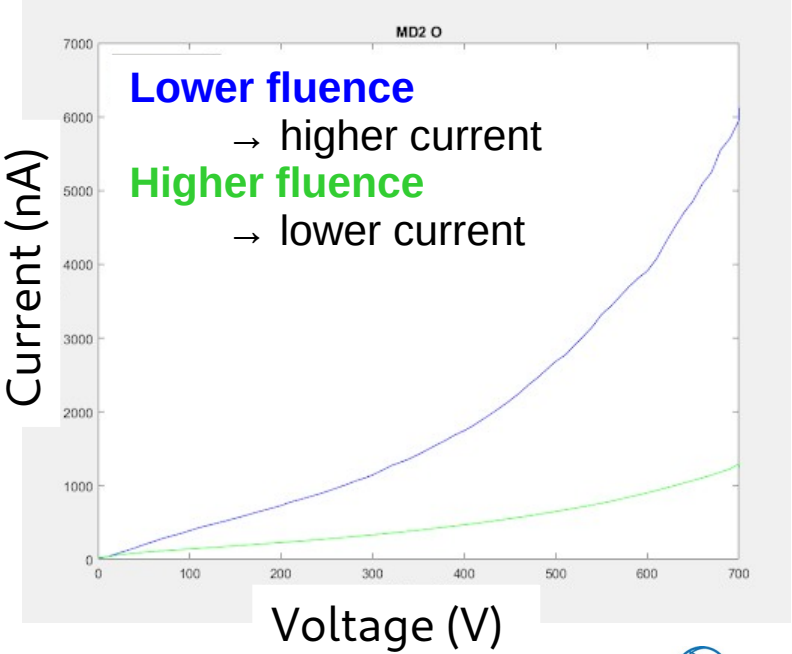



After $10^8$ $n_{eq}/cm^2$, measurements show no separation between diodes

# Measurement 2: diodes

Most surprising result during campaign:
Diode that was accidentally cracked in half during preparation showed IV similar to other diodes after irradiation





# Measurement 3: real damage

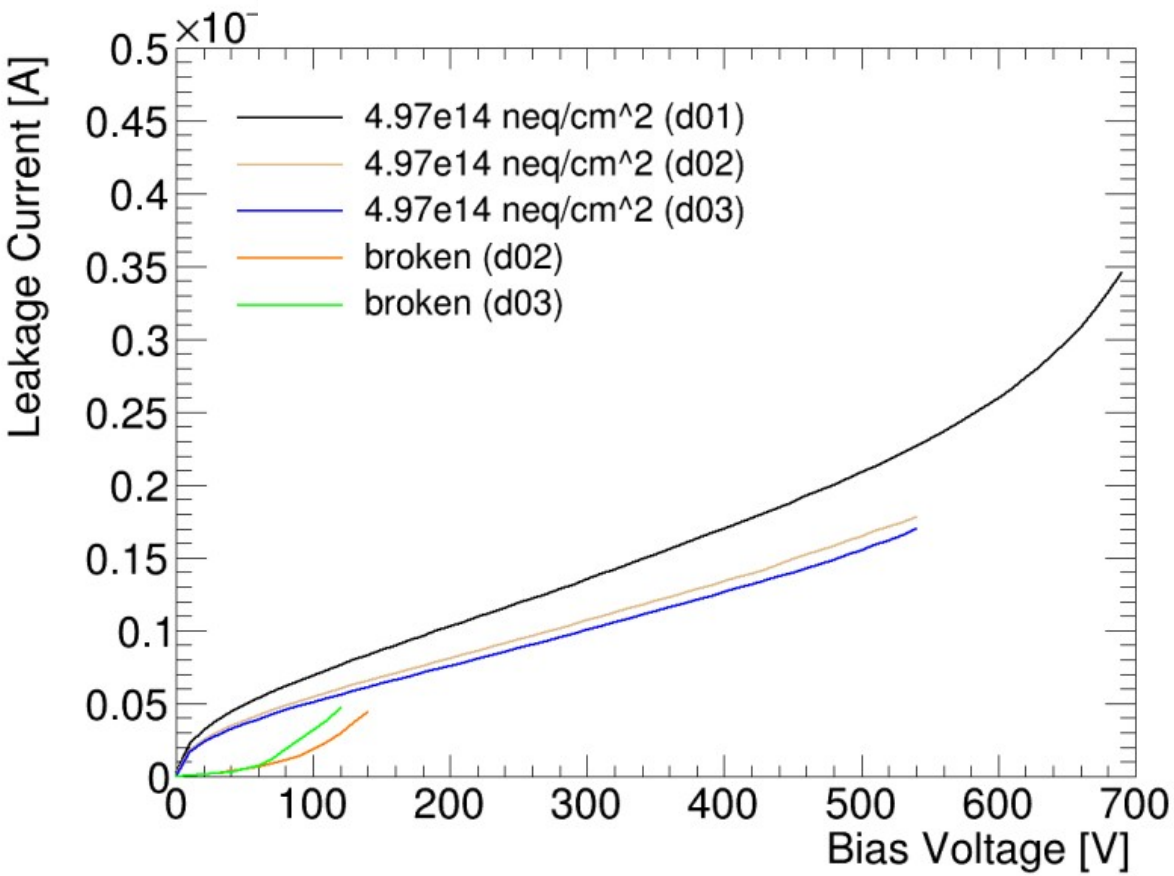
Recovery with irradiation encouraging
Level of improvement for fully broken diodes puzzling

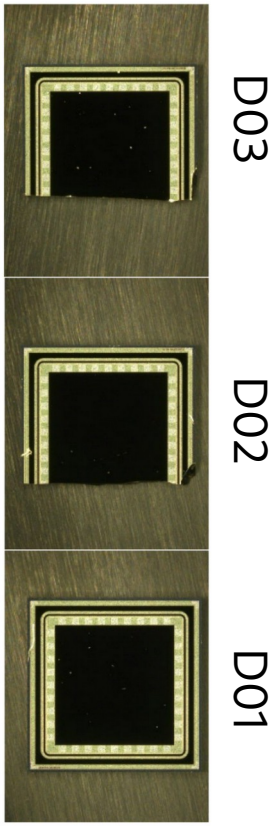
Crack through the full diode should produce a conductive edge which connects the sensor surface (ground) to sensor backplane (HV).

→ early breakdown observed after damage
→ improvement observed after irradiation

# Measurement 3: real damage

Preparation of diodes for proton irradiation



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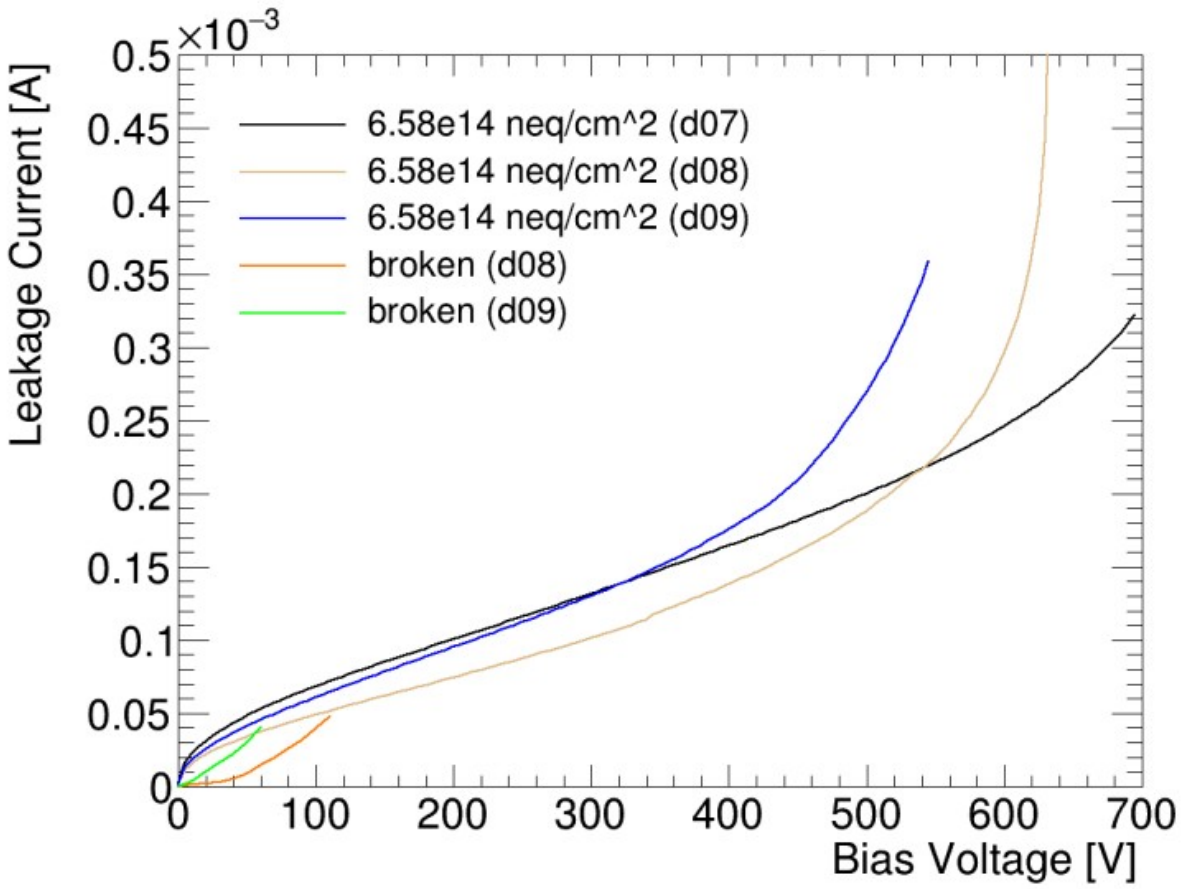


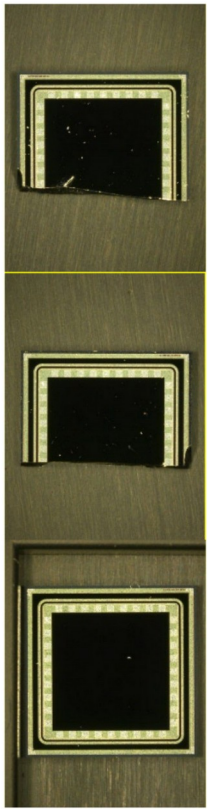

# Measurement 3: real damage

Tests of broken diodes after irradiation indicate recovery mechanism

- Leakage current similar to complete diodes, even after comparably low fluences
- During beam tests, leakage current flared up when beam was positioned on broken edge

Recovery mechanism is unclear
→ edge seems to become non-conductive
→ further investigation planned

# Conclusion & Outlook

Tests were performed to assess if early breakdown in sensors and modules caused by physical flaws could be cured by irradiation.

Results were extremely promising:

- Modules improved after exposure to a dose of gamma irradiation corresponding to one week in HL-LHC
- Diodes with added scratches showed improved breakdown after "homoeopathic" exposure to neutrons
- Even extreme damage improved with irradiation

Planning to continue irradiation to increasing fluences to test further development
And to improve understanding of mechanism!

# Team effort



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Jammel Brooks
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Vitaliy Fadeyev
Xavier Fernandez-Tejero
Andrew Fournier
David Lynn
Jack Osieja
Stefania Stucci









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