Qualification of the first preproduction 3D FBK sensors with ITkPixV1

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Pixel2022 (12-16 December 2022)
10th International Workshop on Semiconductor Pixel Detectors for Particles and Imaging

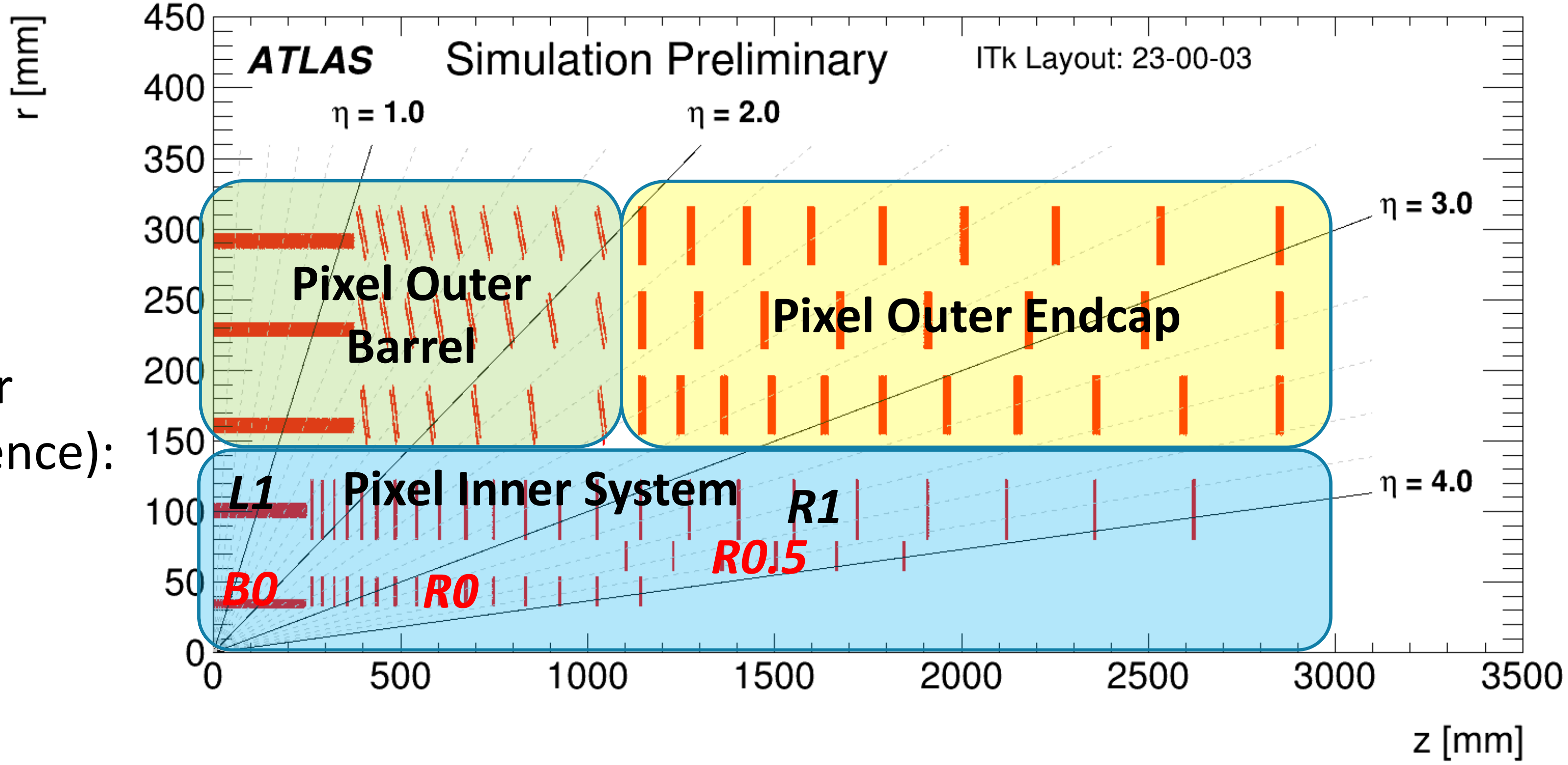
Introduction

The Inner Tracker (ITk) for HL-LHC

- HL-LHC after 2026: luminosity up to 5-7.5 10^{34} cm^{-2} s^{-1} → Detector upgrades → **the ATLAS Inner tracker** (**ITk**, see C.Buttar's talk) will be completley replaced with a new all-silicon tracking detector

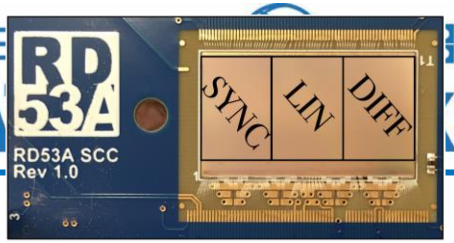
The ITk Pixel detector:

- 5 layers of Pixel detectors:
  - **L2-L3-L4**: Planar sensors (150 µm)
  - **L1, R1**: Planar sensors (100 µm)
  - **L0 (B0, R0, R0.5)**: **3D sensors**
- The Inner System will be replaced after 2000 fb^{-1} (1.5 safety factor on max fluence):
  - **Fluence up to 1.9e16 n_{eq}/cm^2**
  - **TID up to 1 Grad**
- Barrel at 34 mm from collisions
- Endcap rings down to 33.2 mm



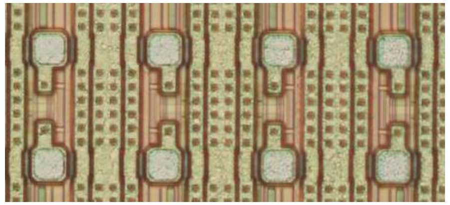
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PUBNOTES/ATL-PHYS-PUB-2021-024/

ITk Pixel: FE chip from RD53A to ITkPixV1 (RD53B)



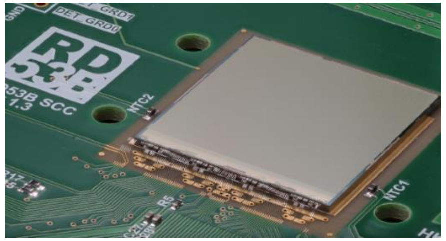
- RD53A chip (by RD53A collaboration) largely used to build module prototypes
- ITkPixV1.0 chip (RD53B): bug in ToT memories, induces high digital current
  - ITkPixV1.1 chip: patch fixed high current (**ToT still not usable**)
  - Summary of chip studies in TIPP 21 talk, other details in ICHEP 2022 talk

ITkPixV1 bump pads



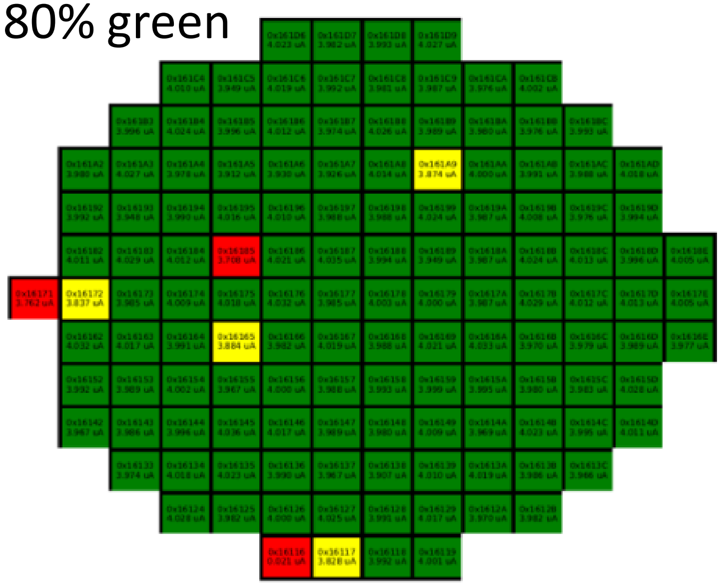
- **ITkPixV2** chip to be submitted **beginning 2023** (final simulation ongoing)

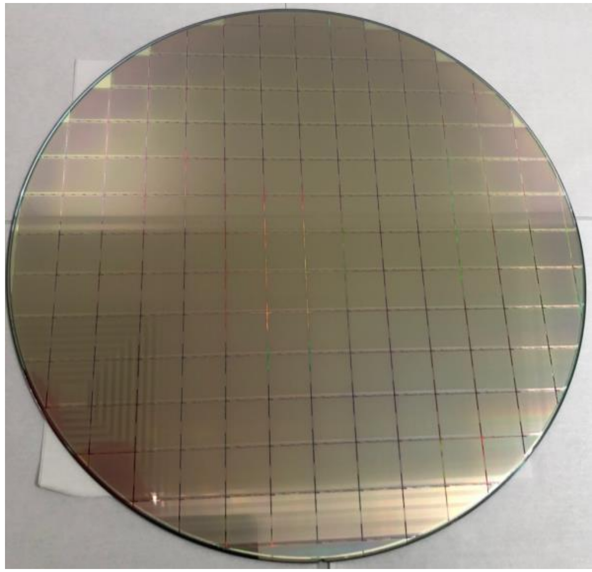
ITkPixV1 on PCB



- Main ITkPixV1 features:
  - 65 nm CMOS, 2x2 cm^2 area
  - 384 x 400 pixels (50x50 μm^2)
  - Differential Analog FE
  - Power consumption: 0.56 W/cm^2
  - Shunt Low Drop Output regulators (I const.)
  - Timewalk < 25 ns (charge > 1000 e)
  - **Radiation hardness > 1 Grad**
  - **Standard threshold: 1000e** (30e dispersion)

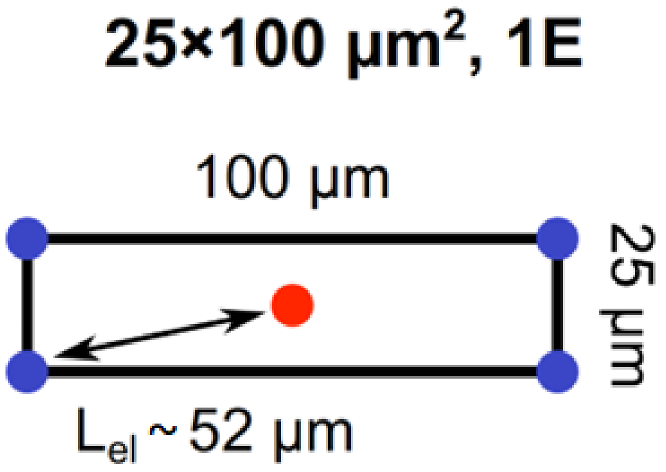
ITkPixV1.1 wafer yield
80% green

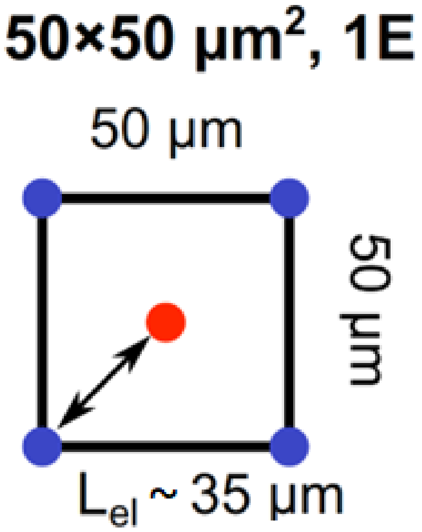




Sensor wafer: 3D sensors

- ATLAS ITk will use 3D pixels in the Inner System L0 with 2 different pixel cell dimensions (2x2 cm^2 pieces):
    - 25x100 µm^2 in the barrel triplet modules (B0, 288 sensors needed)
    - 50x50 µm^2 in the endcap triplet modules (R0 & R0.5, 900 sensors needed)
- Production is split between:
    - CNM (25x100 µm^2, backup FBK)
    - FBK and SINTEF (50x50 µm^2)
- Pre-production completed
    - by FBK in Summer 2021 (50x50 µm^2)
    - by FBK in October 2022 (25x100 µm^2)
    - by SINTEF in February 2022 (50x50 µm^2)
    - by CNM expected in January 2023 (25x100 µm^2)



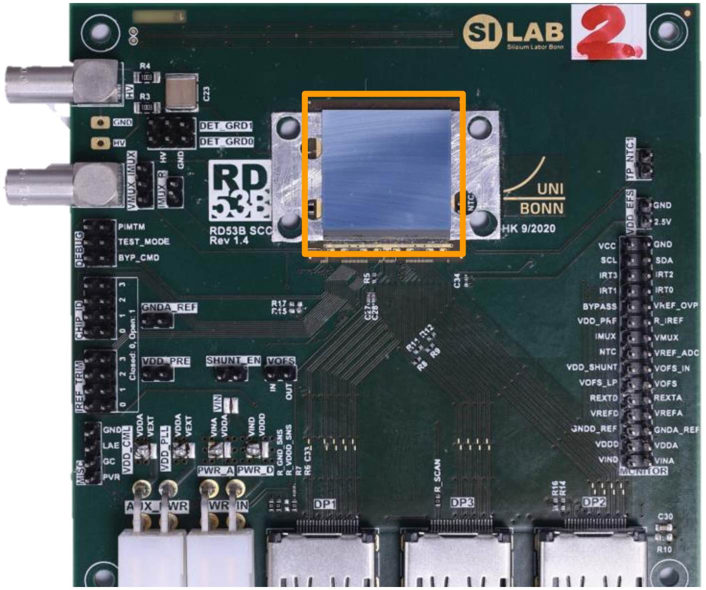


3D FBK + ITkPixV1.1 modules assembled in Genova

- Six 3D + ITkPixV1.1 (*) single-chip modules (**) assembled in Genova(***), mounted on Single Chip Cards (SCCs)
  - single-chip modules extremely suitable for first qualification, in particular radiation hardness
  - FE chips and sensor also tested at wafer level (***), bonded at IZM to FE chips
  - tested before irradiation in laboratory and during test beam
  - irradiated two times to different fluence values
  - tested during test beams after each irradiation

SCC	Module	Mean Threshold	Sigma Threshold	Mean Noise	Sigma Noise	Wafer (sensor)
2	3D + ITkPixV1.1	974	28	71	10	W12
3	3D + ITkPixV1.1	979	31	67	9	W12
4	3D + ITkPixV1.1	971	31	70	9	W12
5	3D + ITkPixV1.1	969	31	73	10	W12
6	3D + ITkPixV1.1	973	29	70	10	W12
8	3D + ITkPixV1.1	962	31	75	10	W14

* Measurements in table performed before irradiation



Module on SCC

(*) FE chips from same wafer
(**) in ITk 3D modules are assembled by three single-chip devices, see backup (slide#31)
(***) more details on electrical tests and assembly in backup (slides#43-45)

Results with unirradiated modules

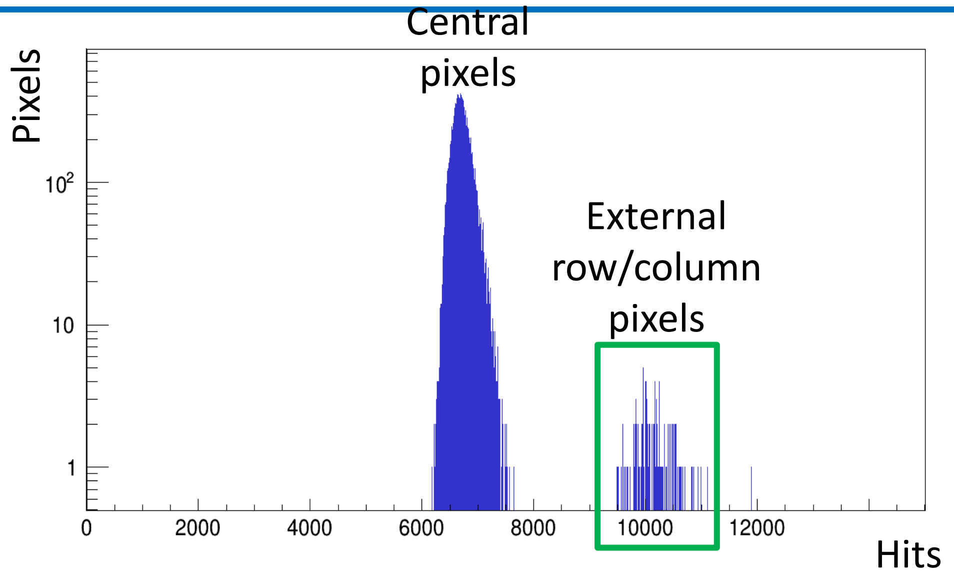
X-ray tests

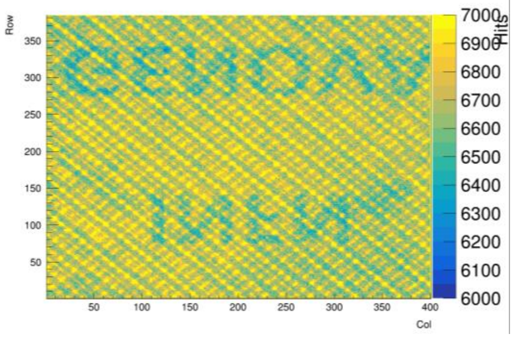
More details at iWoRiD 2022 talk

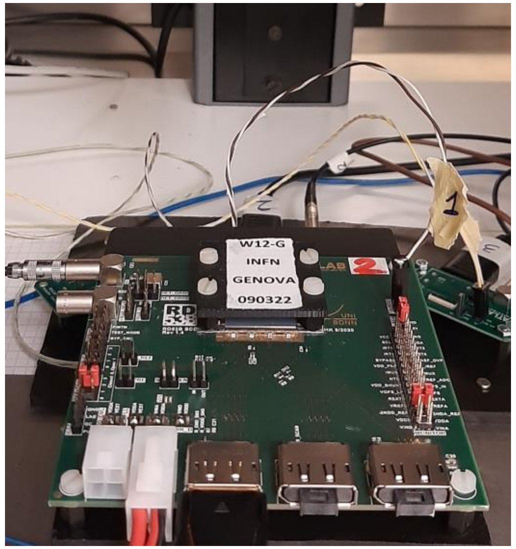
- Source: X-ray tube (Amptek Mini-X2), with Ag anode

- Masking noisy pixel (X-rays OFF): 60 seconds random trigger scan (40 kHz)
- Data taking (X-rays ON): 60 seconds self-trigger scan (HitOR)
  - Central pixels: 6700 hits/pixel in 60 s (110 Hz)
  - Edge pixels: 10000 hits/pixel in 60 s
    - 30% more hits due to extension of the electric field

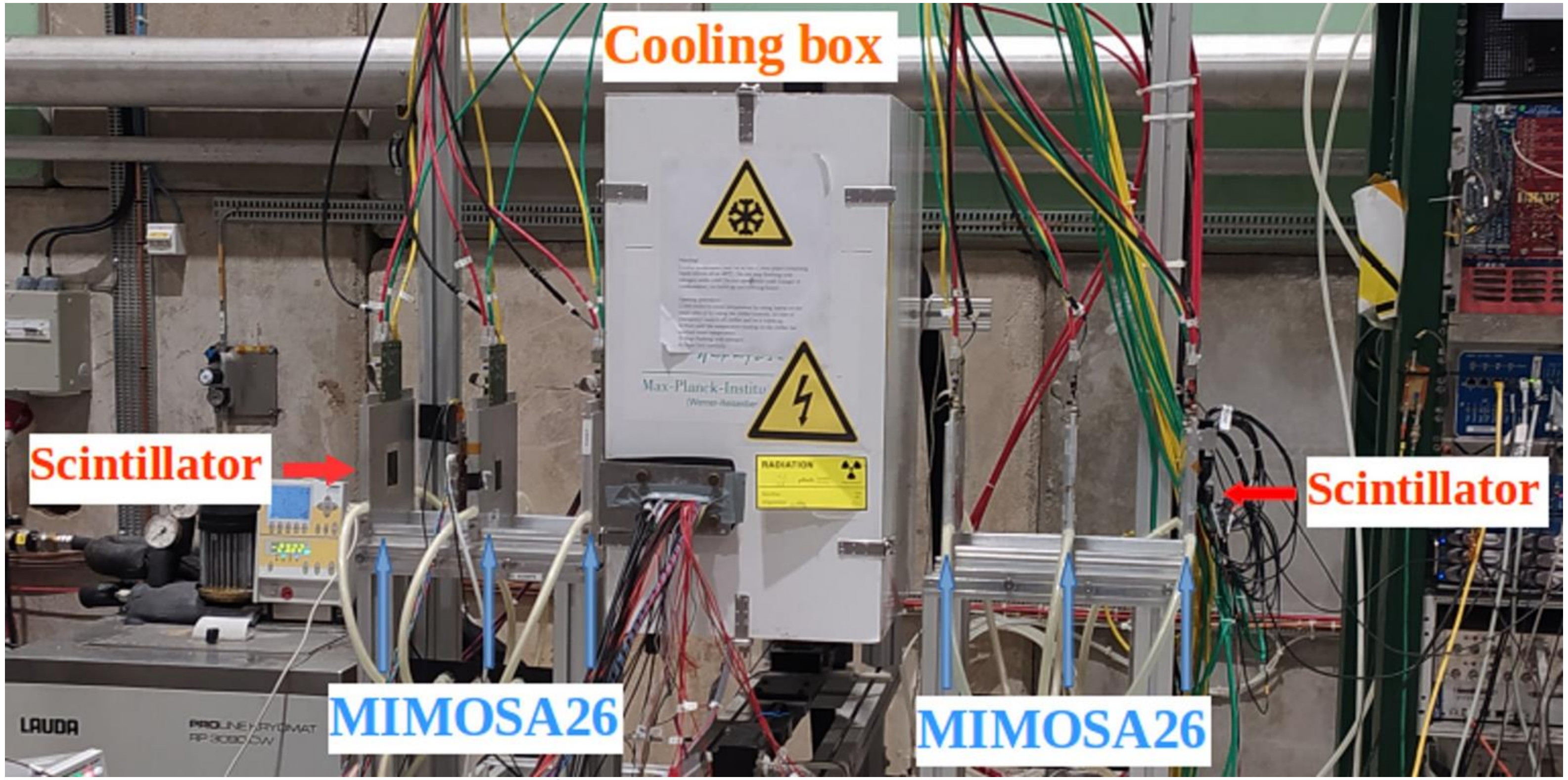
- 3D printed plastic cover between X-ray tube and the sensor
  - Visible pattern of the 3D printed filament
  - Visible pattern of the ink on printed label INFN Genova

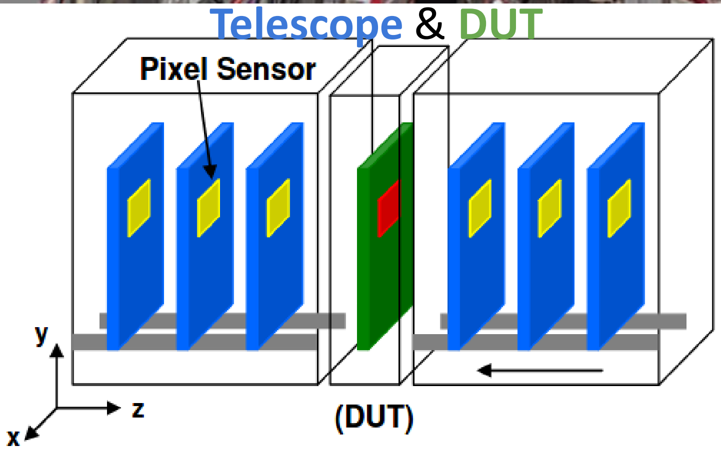


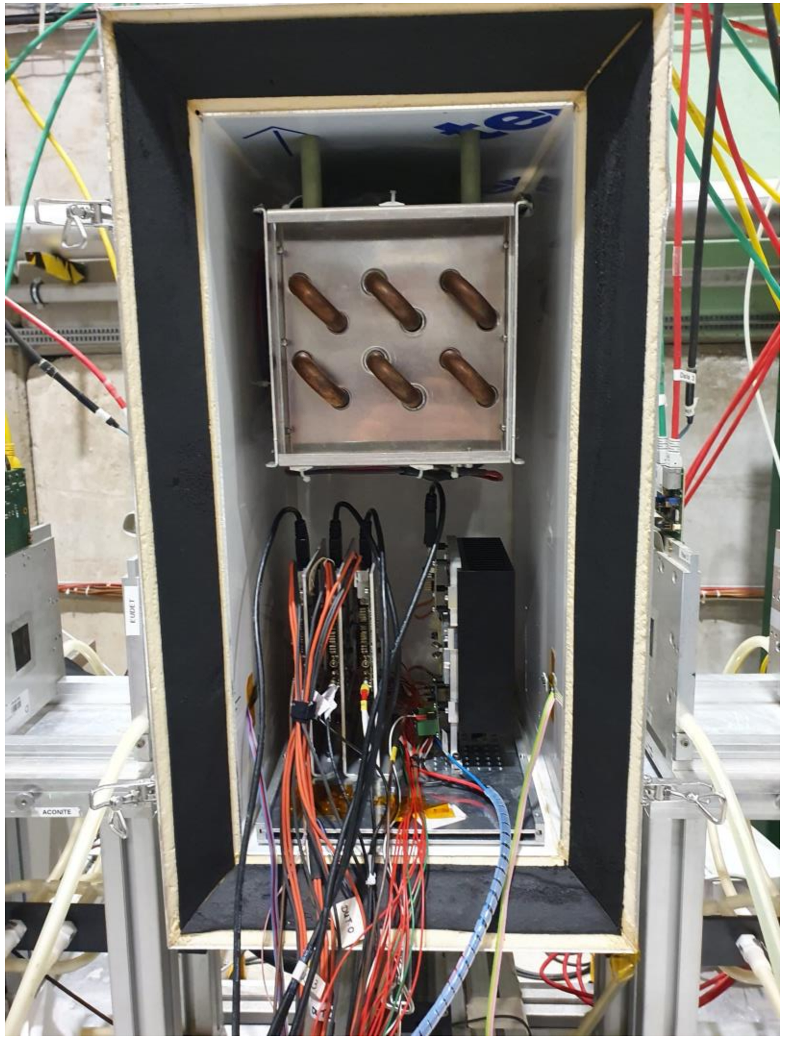




Test beam setup at CERN PS and SPS







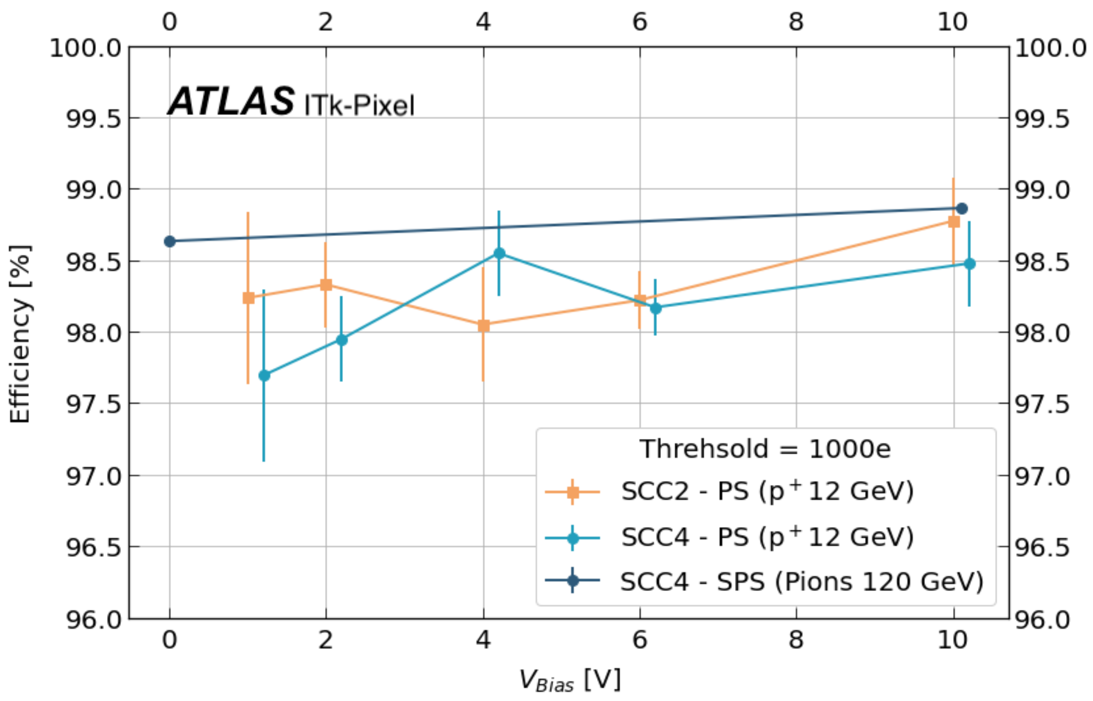
Test beam data analysis

- Data analysed with the C++ based framework Corryvreckan

- Procedure:
  1. Telescope (6 planes) alignment with track χ2 minimization → stops when telescope residuals comparable to plane resolution (~5 µm)
  2. DUTs alignment with track χ2 minimization → stops when the DUTs residuals are of the order of the device resolution (~14 µm)
  3. The efficiency is calculated
     - with tracks on DUT that **meets spatial and time** cuts w.r.t. reconstructed track
     - <u>disabled, masked pixels and neighbouring ones are not taken in account</u>

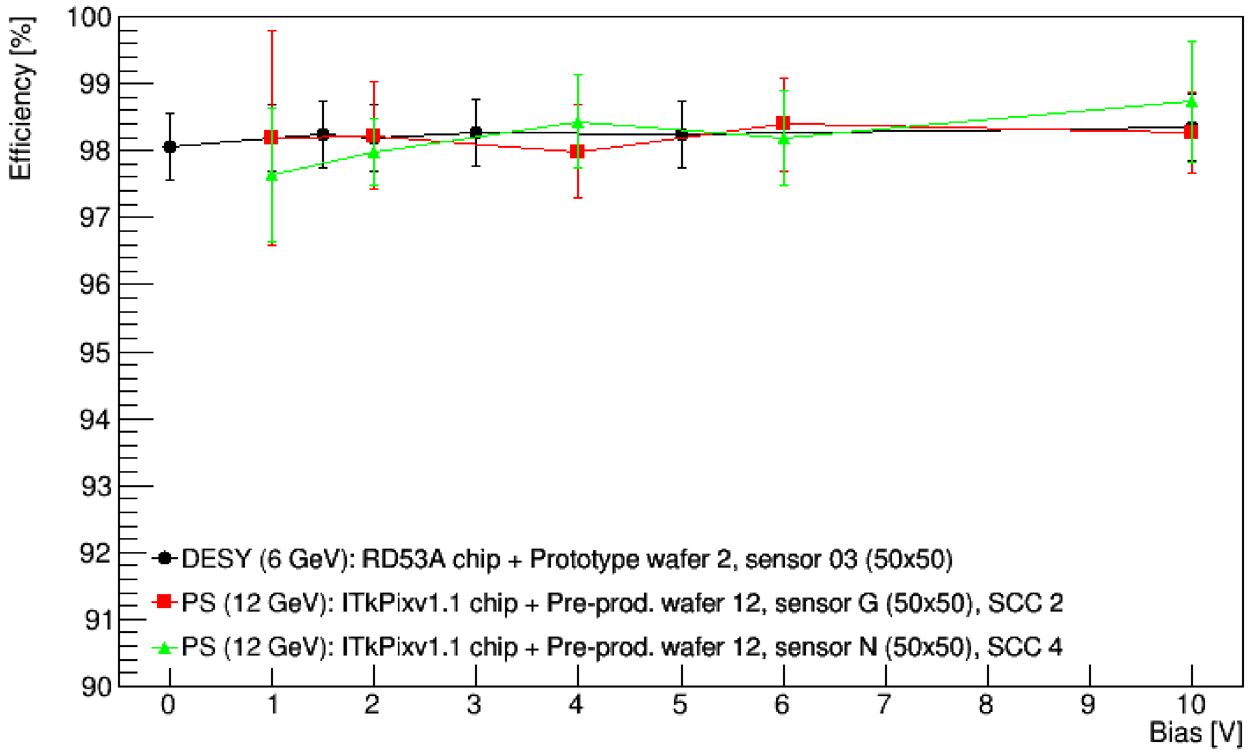
→ the resulting efficiency is valid for pixels that are not masked or disabled

Efficiency vs V_{bias} (unirradiated): 0 – 10 V



https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PLOTS/ITK-2022-004/

- Unirradiated modules tested at PS and SPS
  → **Efficiency > 97.5 % already at 0 V bias (unirradiated)**
  - PS (12 GeV protons)
  - SPS (~120 GeV pions)



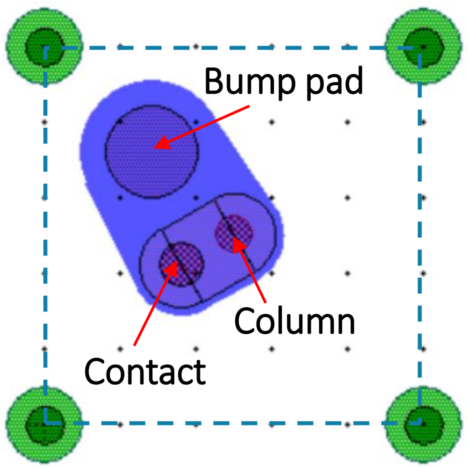
https://cds.cern.ch/record/2815570

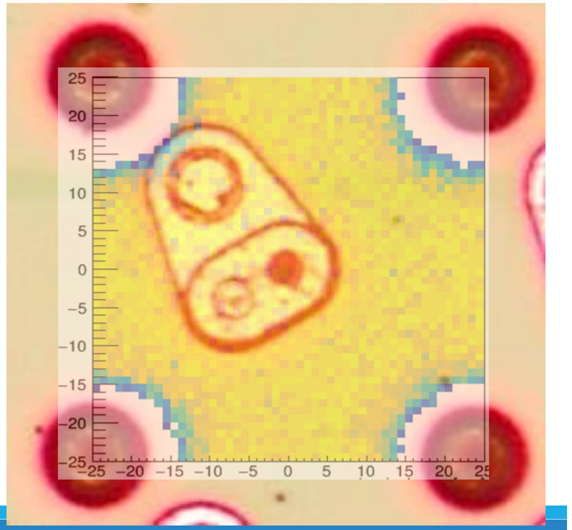
- Results compatible with 50x50 μm² prototype (RD53A chip + FBK 3D sensor) previously tested at DESY (6 GeV electrons)

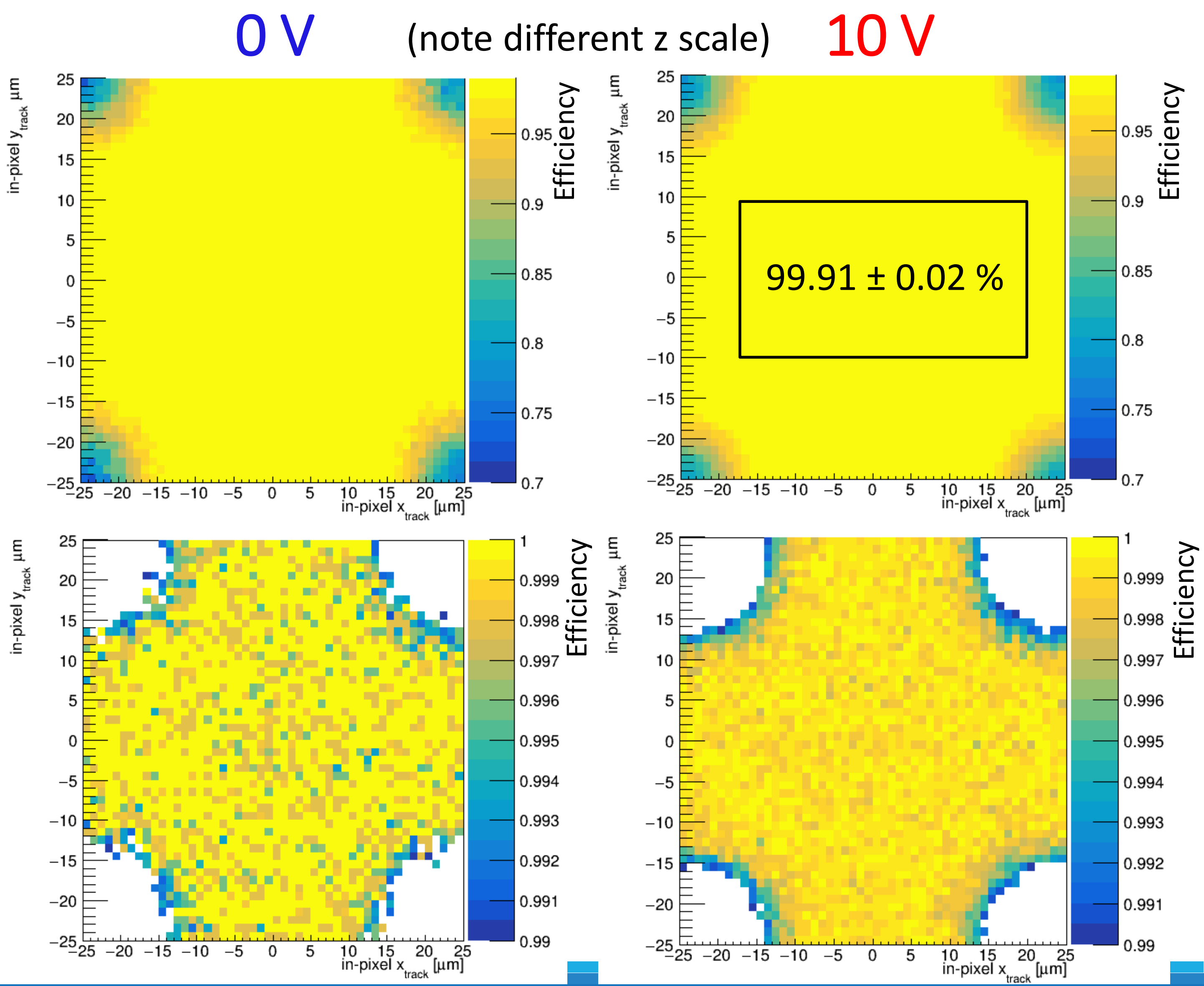
In-Pixel efficiency map: 0 V vs 10 V bias

More details: iWoRiD 2022, public plots

- SPS proton beam perpendicular to DUT:
  - 0 V : 98.7 ± 0.1 %
  - 10 V: 98.9 ± 0.1 %
- Central area: higher than 99% efficiency
- Lower efficiency zones visible in corners:
  - Effect (75% – 99%) radius: 10 μm
  - p^+ columns max radius: 4 μm
- Surface: polySilicon cap visible (no effect)
- No other structure visible







Results with irradiated modules

Multiple irradiations

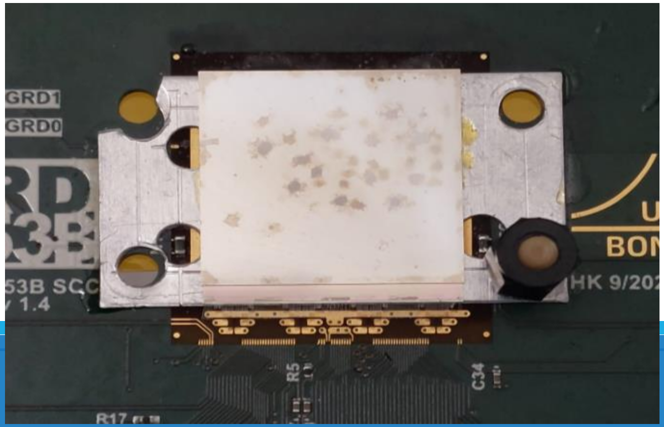
Two ITkPixV1.1 + 3D FBK 50x50 μm² have been irradiated at two different facilities:

- **First irradiation:**
  - in Bonn (May-June 2022) to uniform fluence (uniform) **1×10^{16} n_{eq}/cm^2**
  - 14 MeV protons beam, 1 Grad
- **Second irradiation:**
  - at IRRAD (CERN, 7-27 September 2022) to add to fluence (not uniform) **0.9×10^{16} n_{eq}/cm^2 (peak), 0.5×10^{16} n_{eq}/cm^2 average**
  - devices inclined to increase irradiated area, scanning horizontally → quite uniform irradiation along x, gaussian along y (beam profile)
  - Visual inspection: visibile dark shape in a ~1x2 cm² area, not vertically centered, dots on the sensor surface
  - Received fluence (local and average) measured from the activation of Al dosimeters placed on the back of the sensor

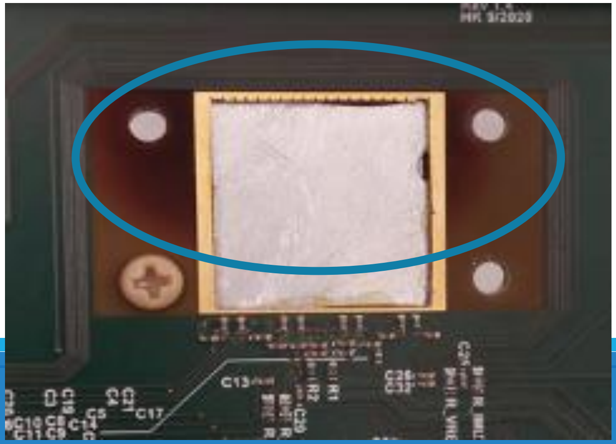
Total integrated fluence:

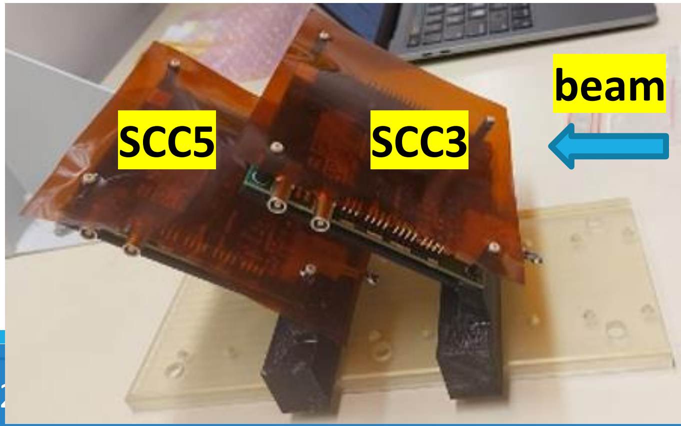
- **1.9×10^{16} n_{eq}/cm^2 (peak), 1.5×10^{16} n_{eq}/cm^2 average**
- Not uniform fluence used to **map efficiency** measurements **to different fluence values**

Front



Back





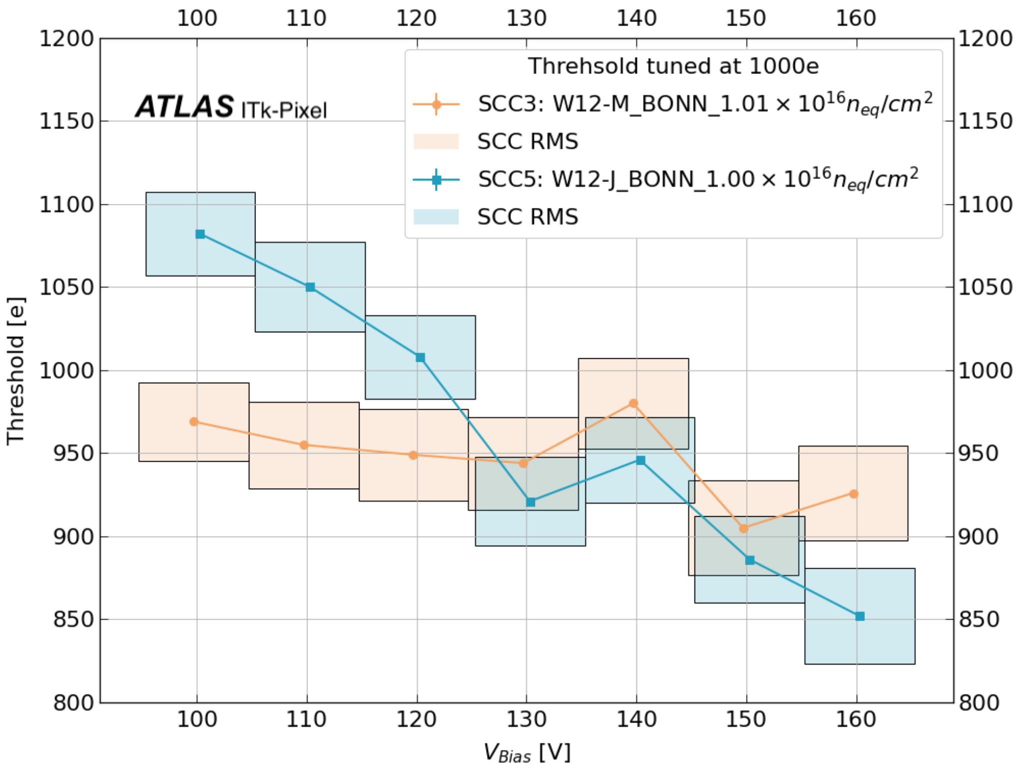
*let me define for brevity:
$\Phi \equiv 10^{16}$ n_{eq}/cm^2

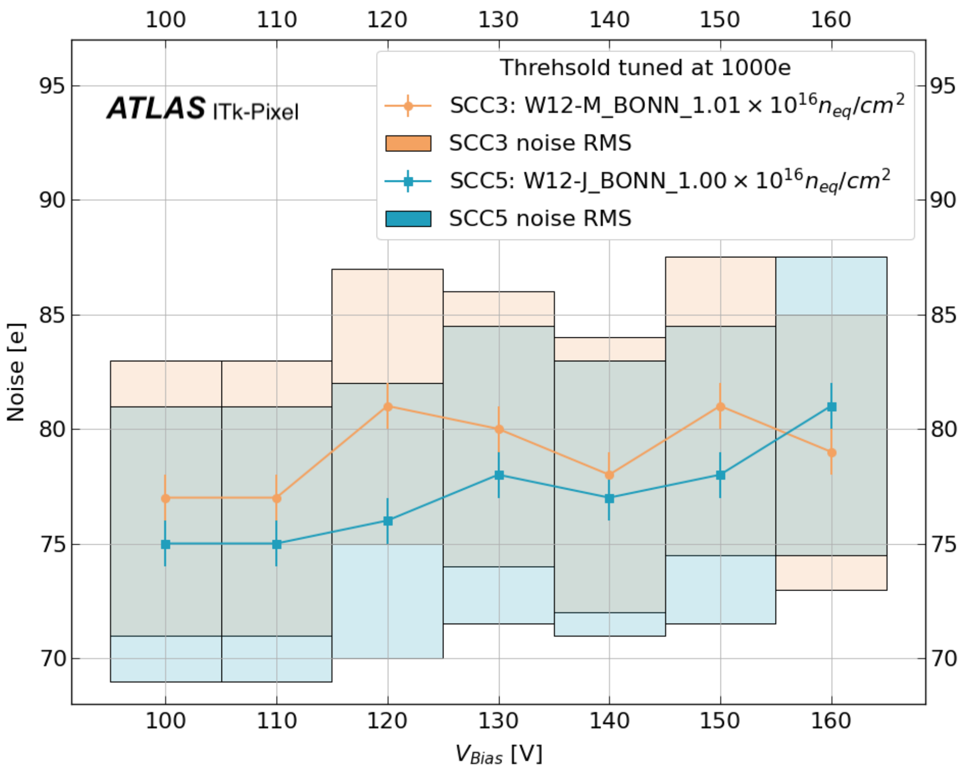
Tuning strategy and stability at test beams

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PLOTS/ITK-2022-004/

SCCs studied in test beams at CERN SPS after each irradiation

- Strategy: tuned with target 1000e at 100V bias, same tuning used for all V_{bias}
- Threshold and Noise distributions verified to be reasonably stable over a large V_{bias} range

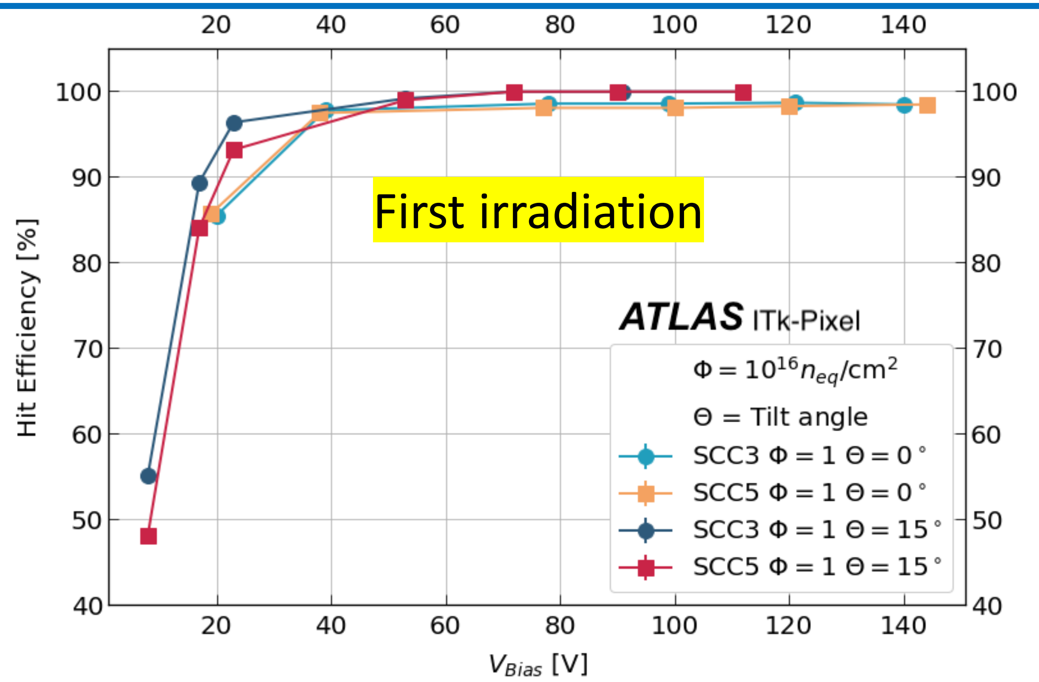


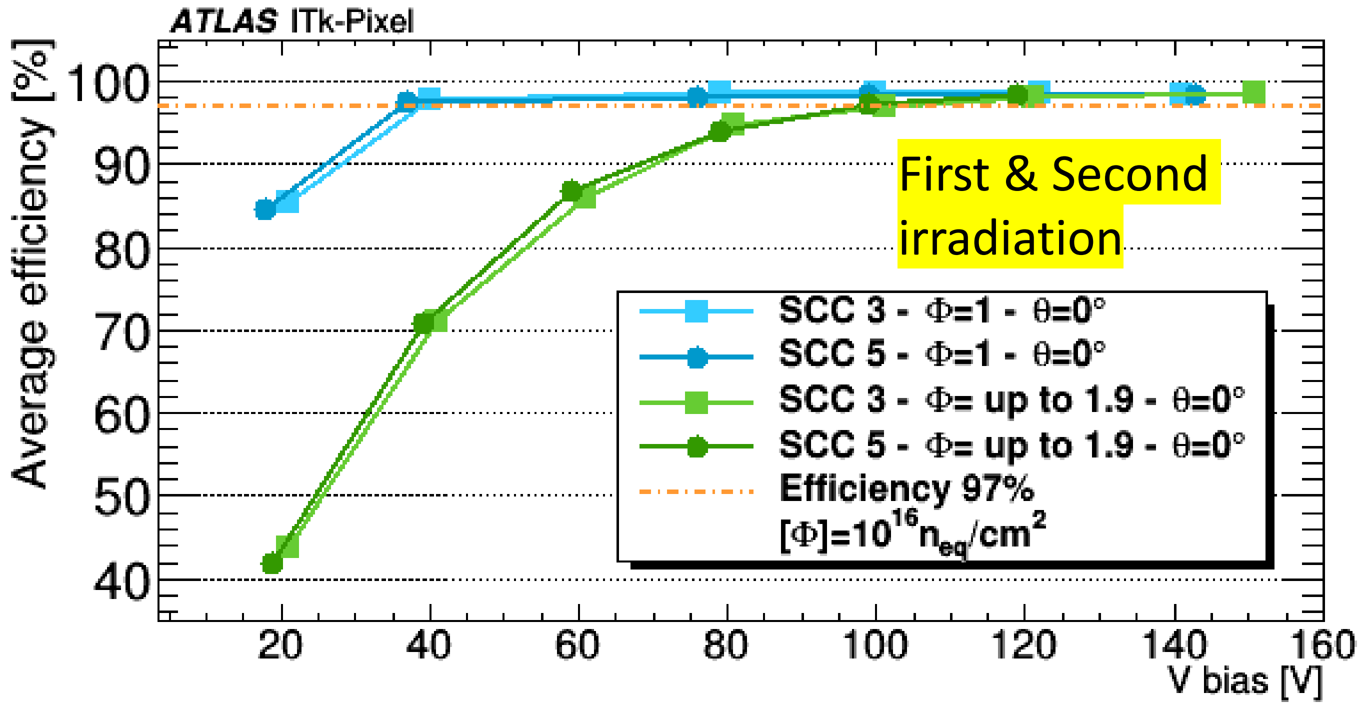


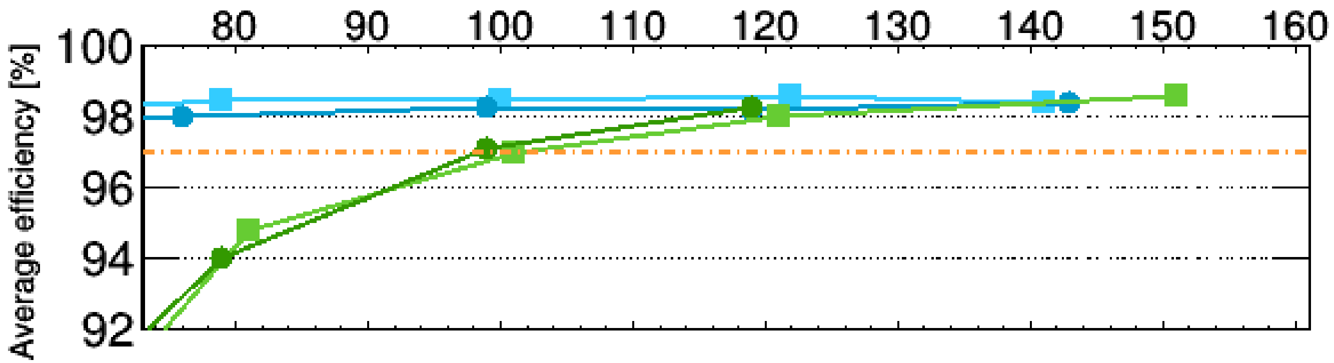
(Error bars are the distribution mean error, columns are the distribution standard deviation)
Plots with modules irradiated at 10^{16} n_{eq}/cm^2, similar results after second irradiation

Average efficiency after irradiation

Public plots here and here



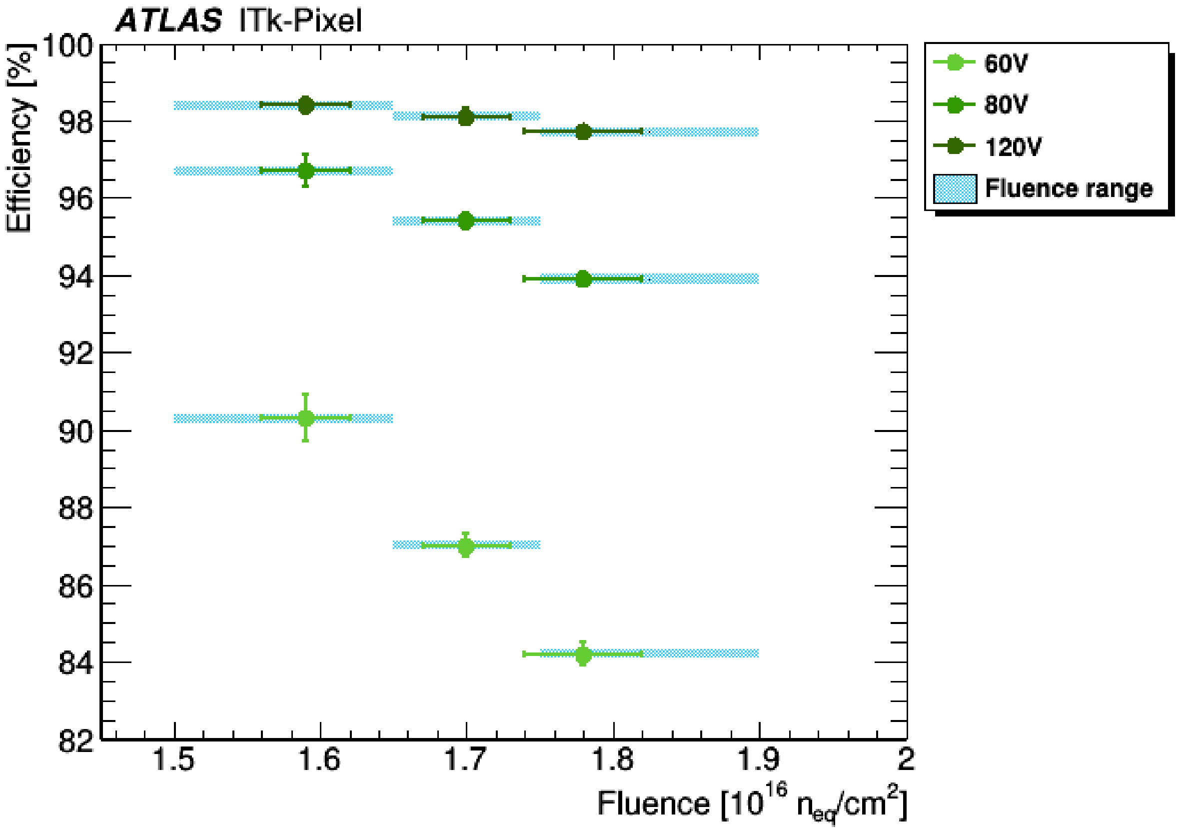


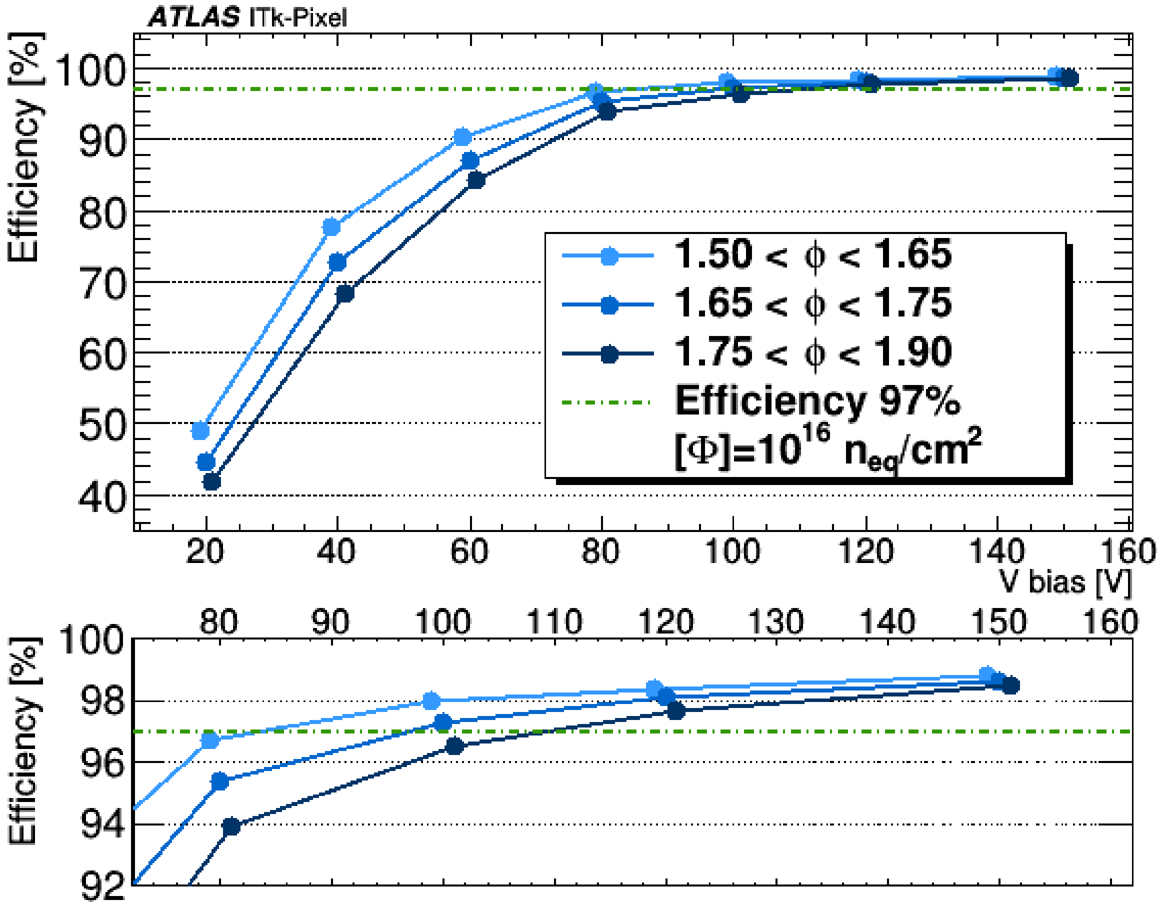


Fluence [$\phi=10^{16}$ n_{eq}/cm^2]	Average Efficiency	Note
Φ = 1 (uniform)	**> 97% @ 40V bias**	Θ=0° and Θ=15° tilt angle w.r.t. beam direction
Φ = up to 1.9 (not uniform)	**97% @ 100V bias**	Average fluence Φ≈1.6-1.7 in the considered area, Θ=0° tilt angle w.r.t. beam direction

Efficiency vs fluence

https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PLOTS/ITK-2022-005/

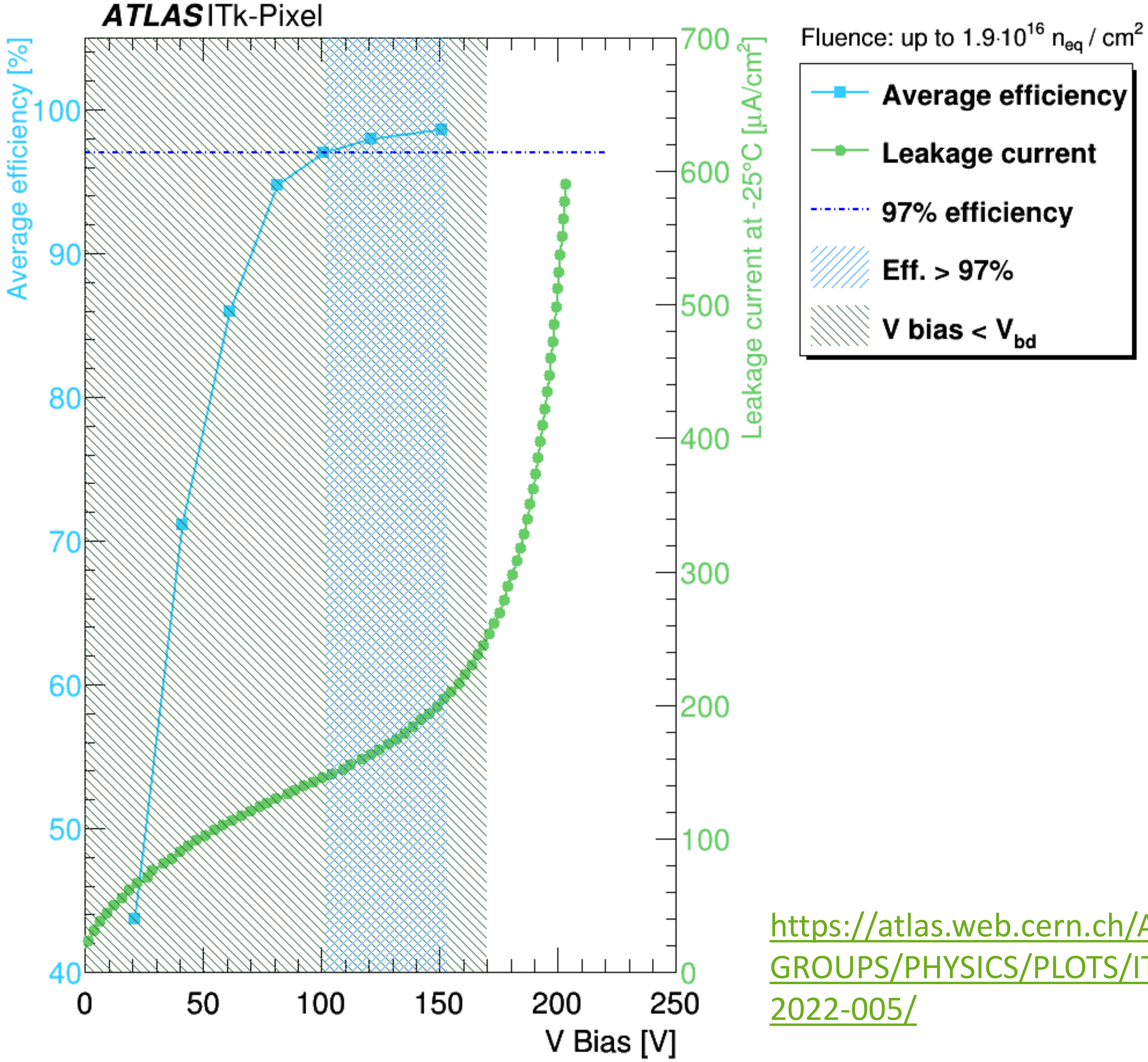




Not uniform irradiation allows to map the local efficiency with the local received fluence

- Three fluence intervals (light blue range in left plot) considered, with average fluences <Φ> ≈ 1.59, 1.70, 1.78
- Lower efficiency at same bias voltage with increasing fluence, as expected
- Efficiency >97% reached at **~80 V for <Φ> ≈ 1.59, ~100 V for <Φ> ≈ 1.70, ~110 V for <Φ> ≈ 1.78** (right plot)

Operability window

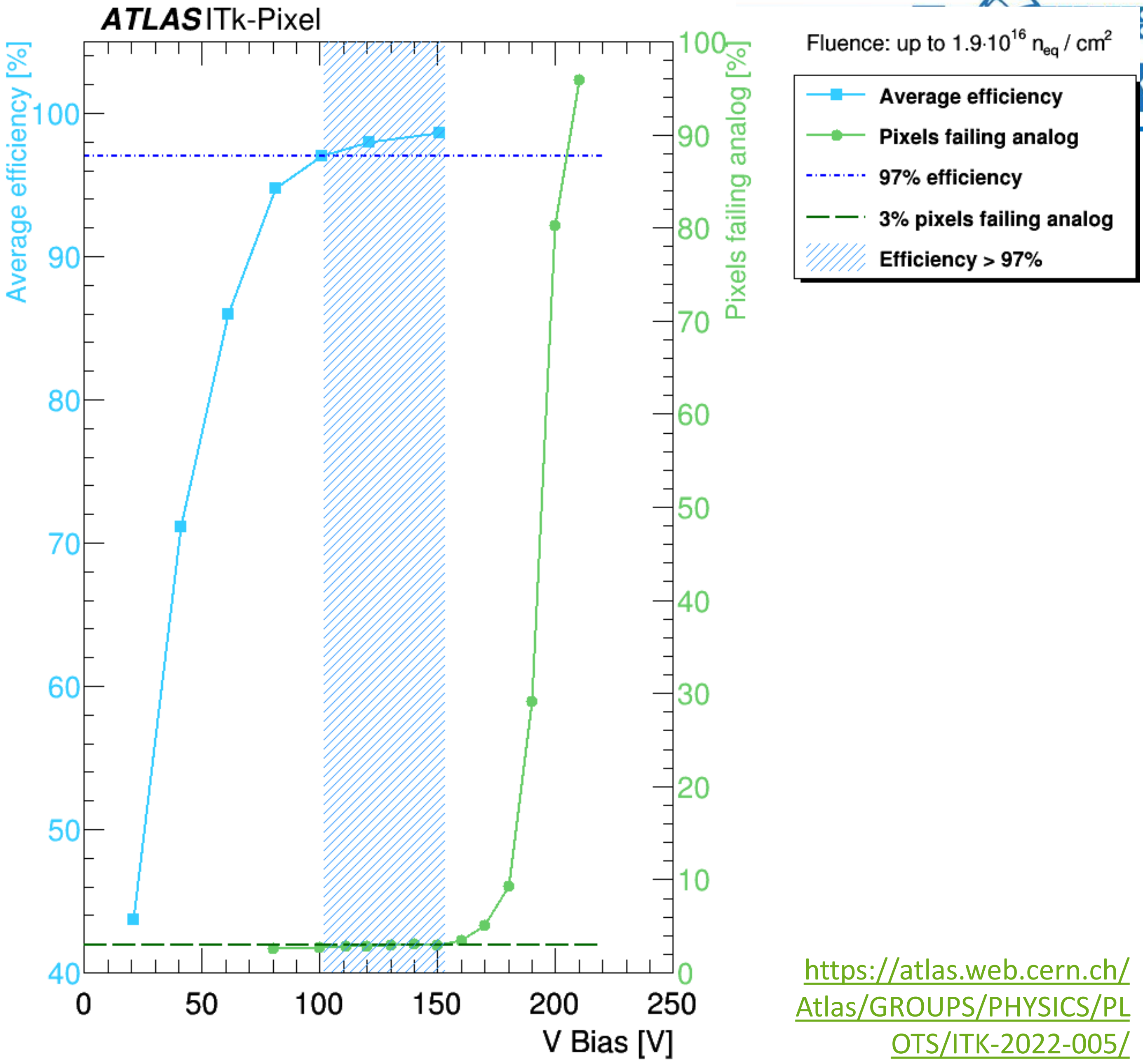


https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PLOTS/ITK-2022-005/

- The operability window is defined by high efficiency (>97%) and bias voltage below the breakdown: ~100V to ~170V bias
- Leakage current I ~ 150 µA/cm2 and power dissipation 15 mW/cm2 @ 100 V bias (scaled at -25°C) for SCC3

Operability window

- Observed number of noisy / disabled pixels increasing at high voltages (>120V bias)
    - same tuning (1000e @ 100V bias) used for all V_{bias} → may be reduced by tuning at each voltage → <u>under investigation</u>
- performed **analog** scan vs V_{bias} to study the effect systematically
    - Slow increase at around ~3% failing pixels up to about ~150V bias
    - Faster rise next to breakdown voltage
    - Possibility to improve the 3% failing plateau <u>under investigation</u>
- The operability window is reasonably the overlap between the region at high efficiency and the region with low fraction of failing pixels: ~100V to ~160V bias in this example



https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PLOTS/ITK-2022-005/

Summary & conclusions

- The ATLAS ITk detector will be equipped with 3D sensor modules in the innermost layer (33-34 mm from collisions)
  - Expected radiation at HL-LHC after 2000 fb^{-1}
    - Max fluence = 1.9 ϕ (1.5 safety factor)
    - Max TID = 1 Grad

- 3D modules (ITkPixV1.1 + 3D FBK 50x50 um2) assembled in Genova presented
  - Tested unirradiated in laboratory (X-rays) and in test beams (CERN PS and SPS)
    - Efficiency > 97.5% already at 0 V bias
    - In-pixel efficiency in central area >99% efficiency
    - Lower in-pixel efficiency zones visible in corners

  - Irradiated **up to 1.9 x 10^{16} neq/cm2** (not uniform, @Bonn and IRRAD) and tested in test beams (CERN SPS)
    - **Average efficiency >97% reached at ~80 V, ~100 V, ~110 V for average fluence ≈ 1.59 Φ, 1.70 Φ, 1.78 Φ resp.**,
    - Visible effect of p^+ columns: lower in-pixel efficiency in corners, recovered if sensor tilted w.r.t. beam direction
    - # pixels failing analog scan increasing vs V_{bias}, being further investigated (may depend on tuning choice and going close to the breakdown region)

* $\Phi \equiv 10^{16}\ n_{eq}/cm^2$

Thank you for the attention!

Acknowledgements to:

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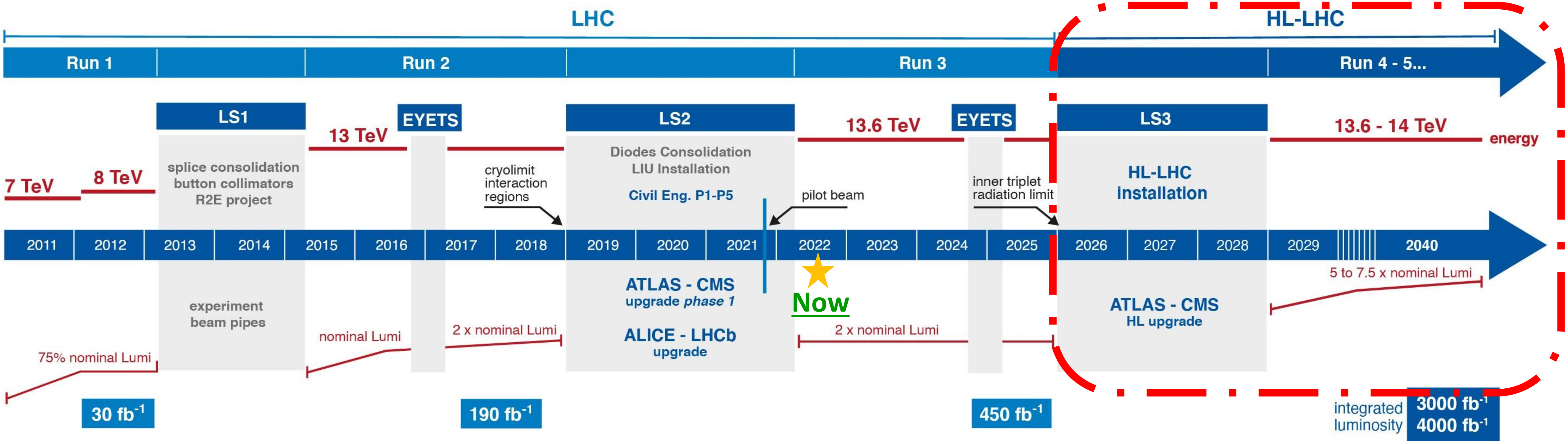
and G.Pezzullo, F.Ravotti, M.Jaekel

Backup

The High Luminosity (HL-LHC)



HL-LHC: after 2026: luminosity up to 5-7.5 10^{34} cm^{-2} s^{-1}

- More statistics to study rare physics processes
- Collect a larger data sample in a shorter time (target 4000 fb^{-1} int. luminosity in 10 years)

Harsher operational conditions for the detetors:

- Pile-up collisions increase from 20-50 to 150-200 → more challenging for tracking
- Higher radiation environment → radiation-hard detectors

→ Impossible to operate the current ATLAS tracking system (ID) during HL-LHC

- increased channel occupancy, data bandwidth (4x1.28 Gbps), radiation damage (1 Grad)

→ Detector upgrades → Upgrade of the ATLAS Inner tracker (Itk, see C.Buttar’s talk): will be completley replaced

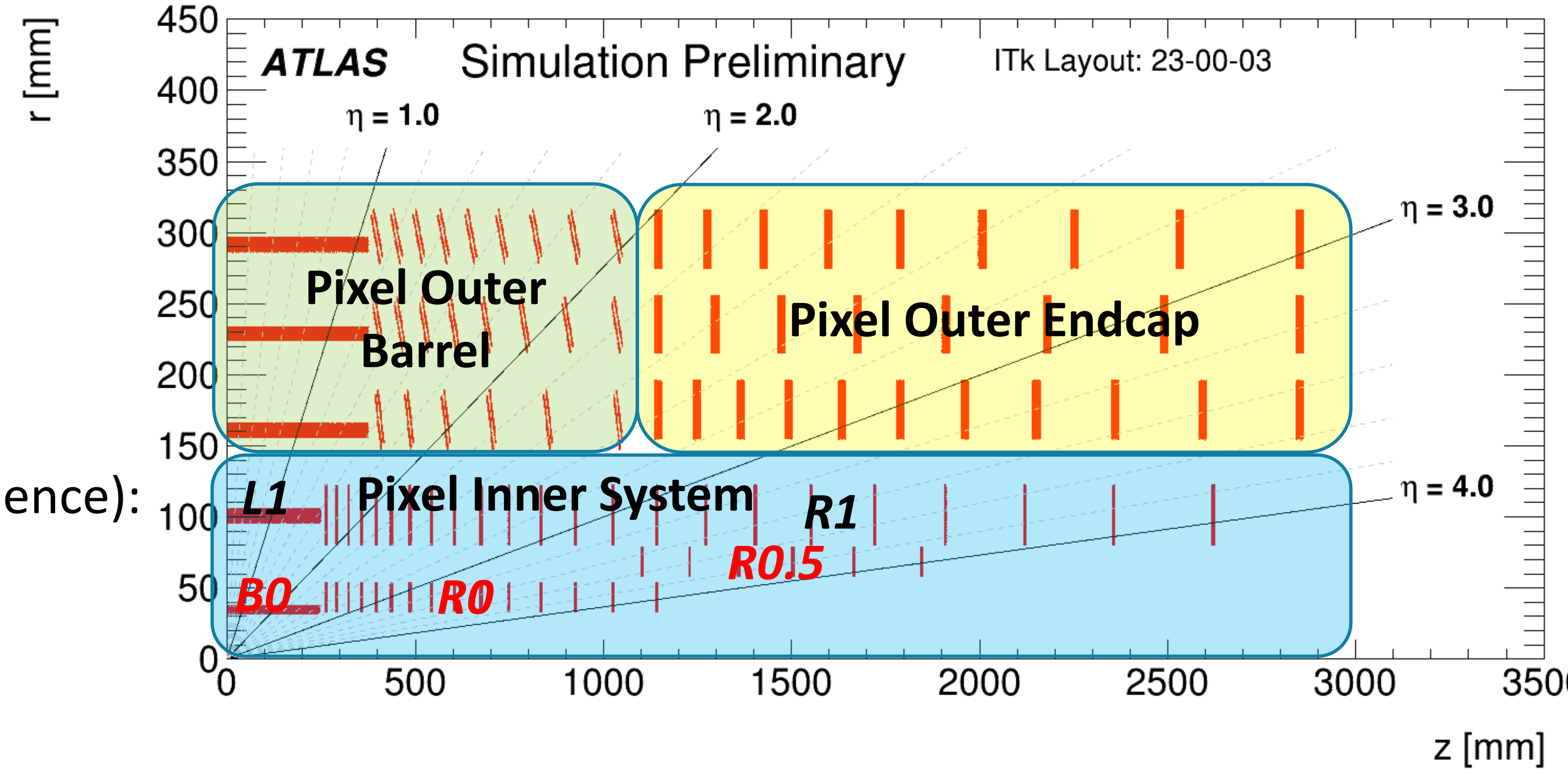
The Inner Tracker (ITk) for HL-LHC

- Inner Tracker (ITk): a new all-silicon tracking detector
  - Pixel + Strip detector
  - Extended η coverage (strips up to |η| < 2.7, pixel up to |η| < 4.0)
  - ITk Pixel detector status: prototypes designed → pre-production ongoing

- 5 layers of pixel detectors:
  - **L4**: Planar sensors (150 µm)
  - **L3**: Planar sensors (150 µm)
  - **L2**: Planar sensors (150 µm)
  - **L1, R1**: Planar sensors (100 µm)
  - **L0 (B0, R0, R0.5)**: **3D sensors**

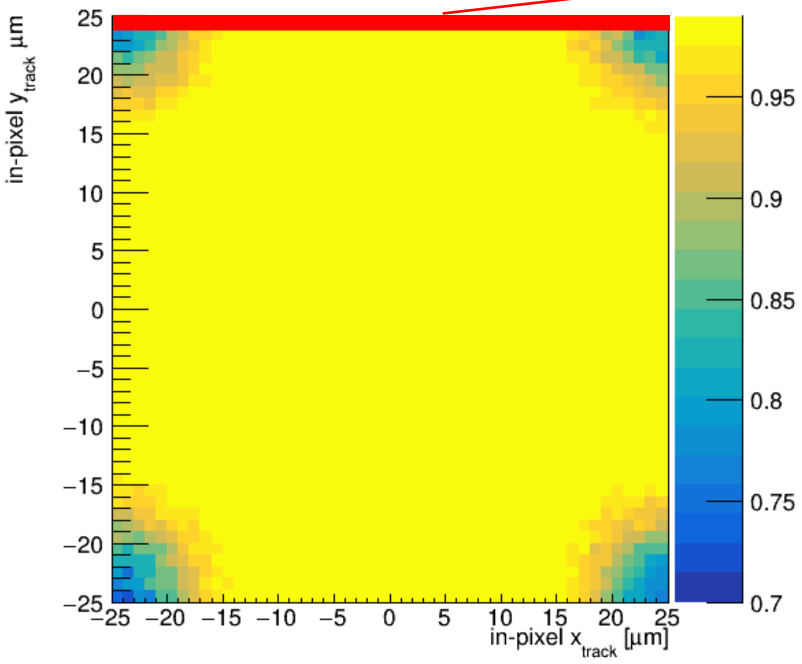
- Inner System will be replaced after 2000 fb^{-1} (1.5 safety factor on max fluence):
  - **Fluence up to 1.9e16 n_{eq}/cm^2**
  - **TID up to 1 Grad**

- Barrel at 34 mm from collisions
- Endcap rings down to 33.2 mm

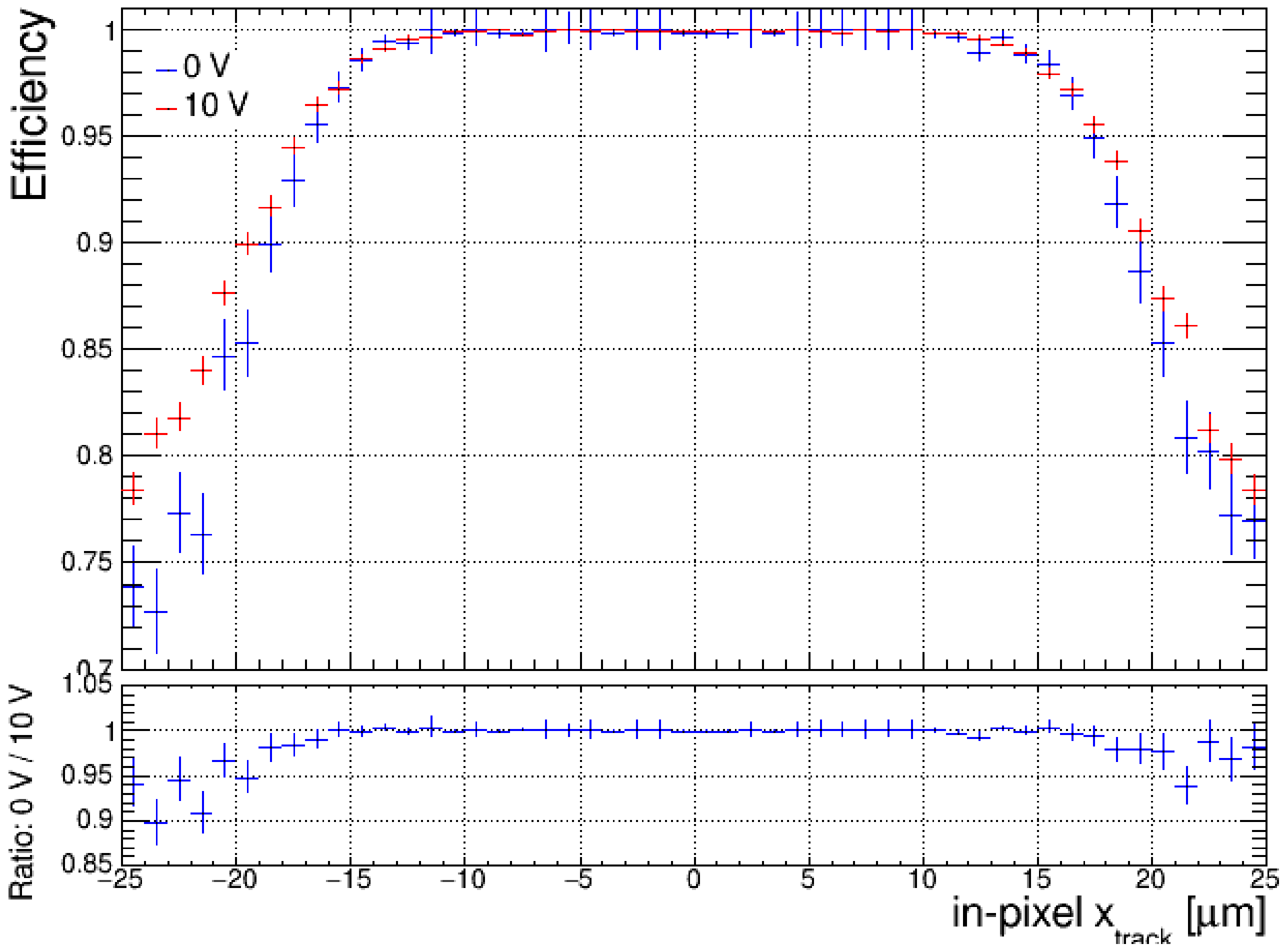


Projection of first row: 0 V vs 10 V bias

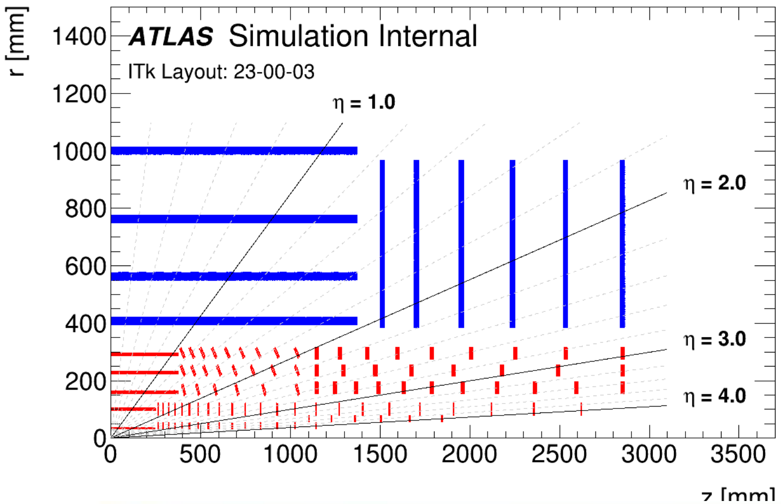
- 3D sensor is already efficient at 0 V bias
- No evident differences between 10 V and 0 V bias in terms of the extension of the low efficiency zone

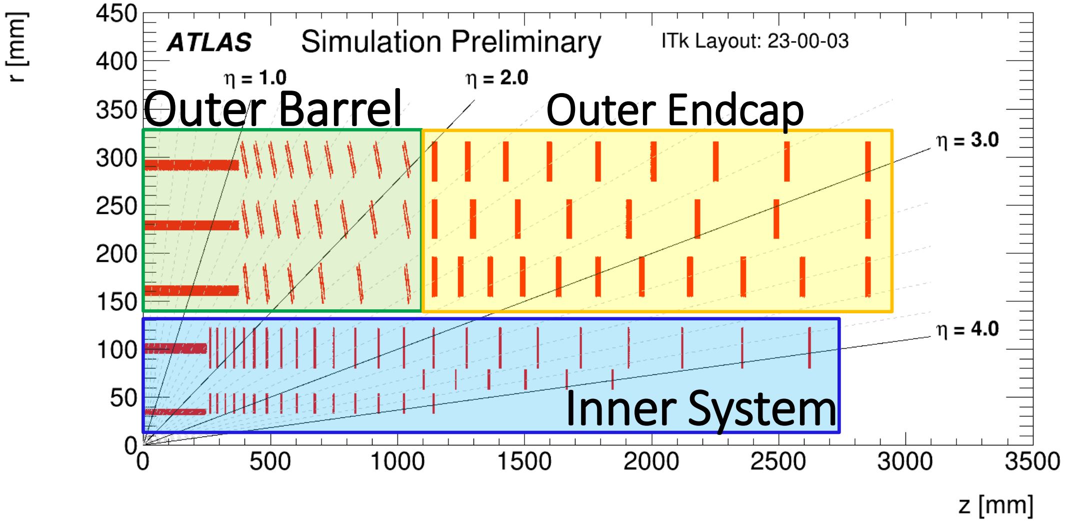


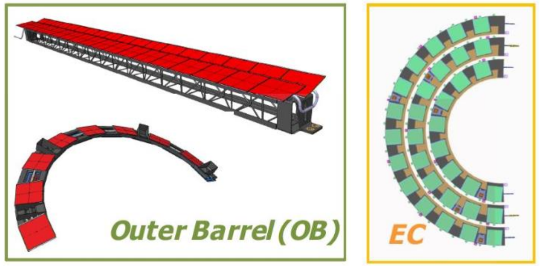
Efficiency: Projection of the first row of the pixel cell

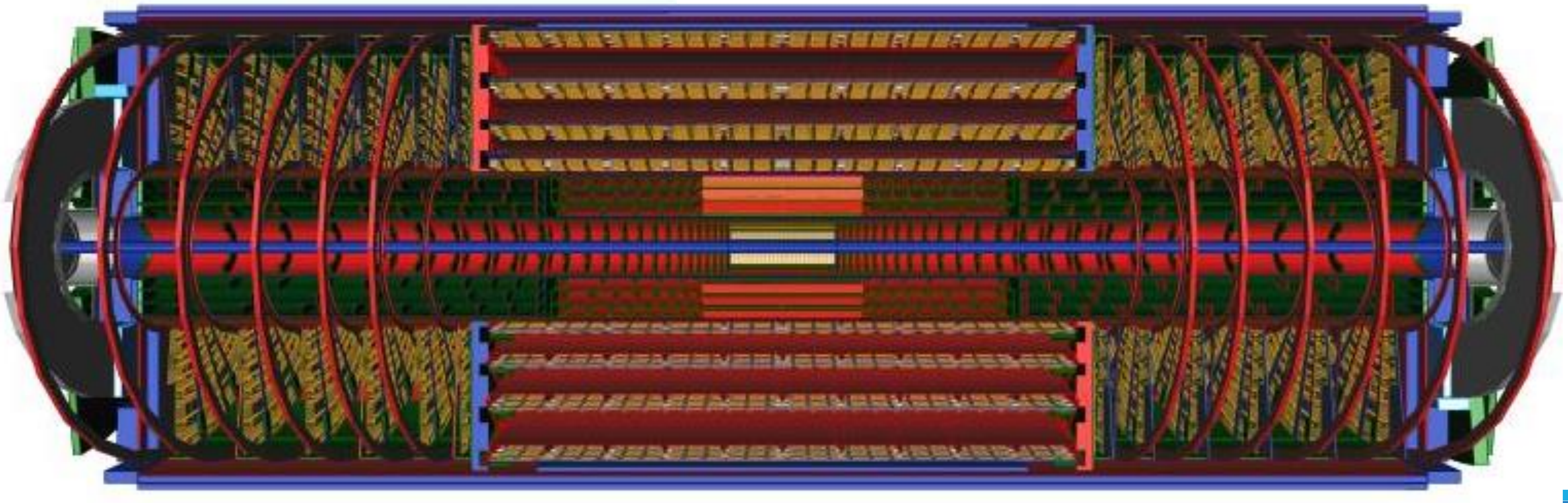


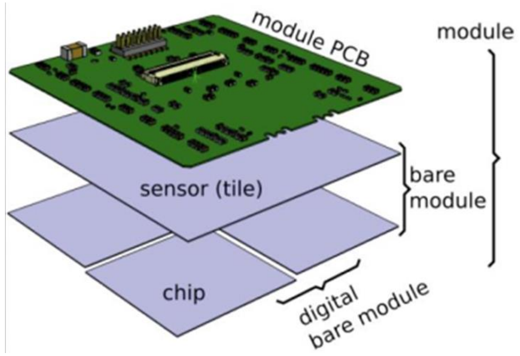
Inner Tracker layout

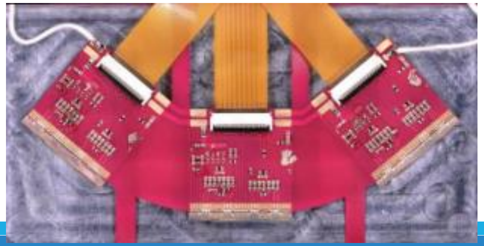






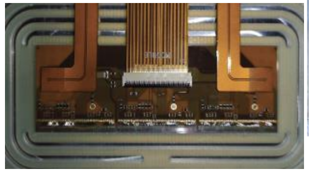


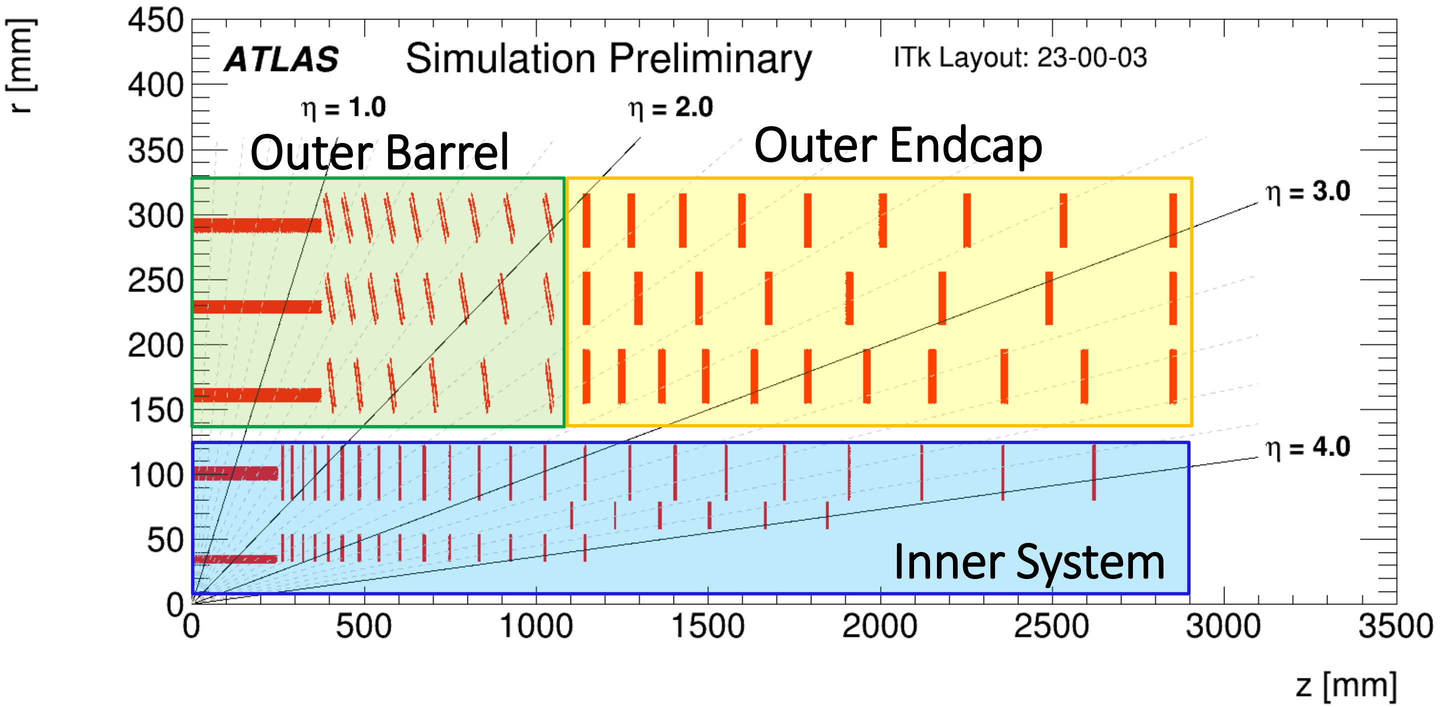




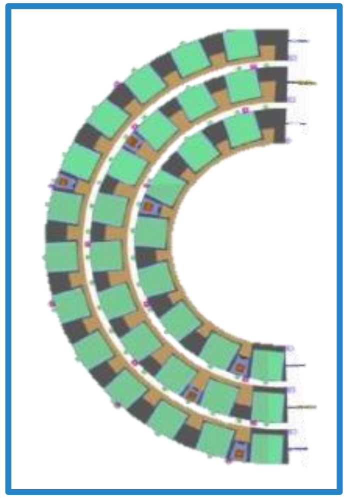
Pixel: detector structure and modules

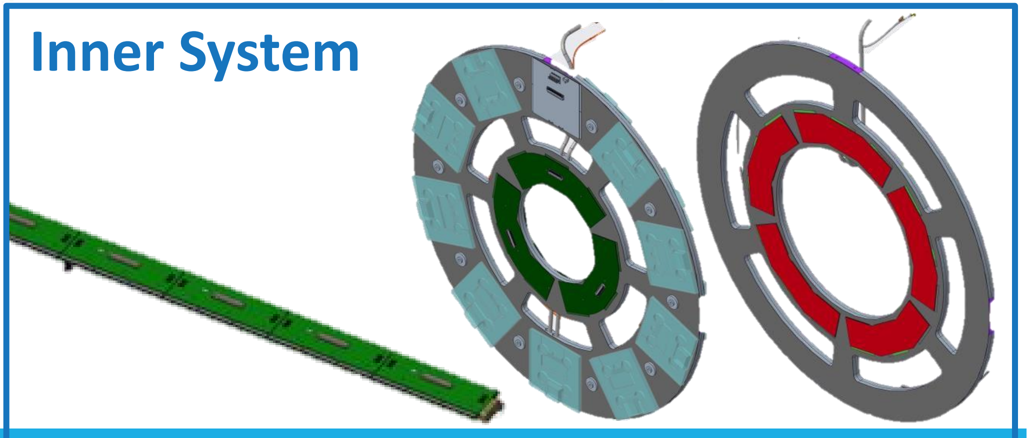
- Design: completed! → Prototypes: done! → Pre-production: ongoing!
- Pixel detector made up by 3 main parts: **Outer Barrel**, **Outer Endcap**, **Inner System**
- Two different module concepts:
  - All the external layers (L1-4): Quad-module →
  - Innermost layer (L0): Triplet mod. →
- Modules glued to carbon structures
- Titanium pipes for CO_2 cooling





Outer Endcap

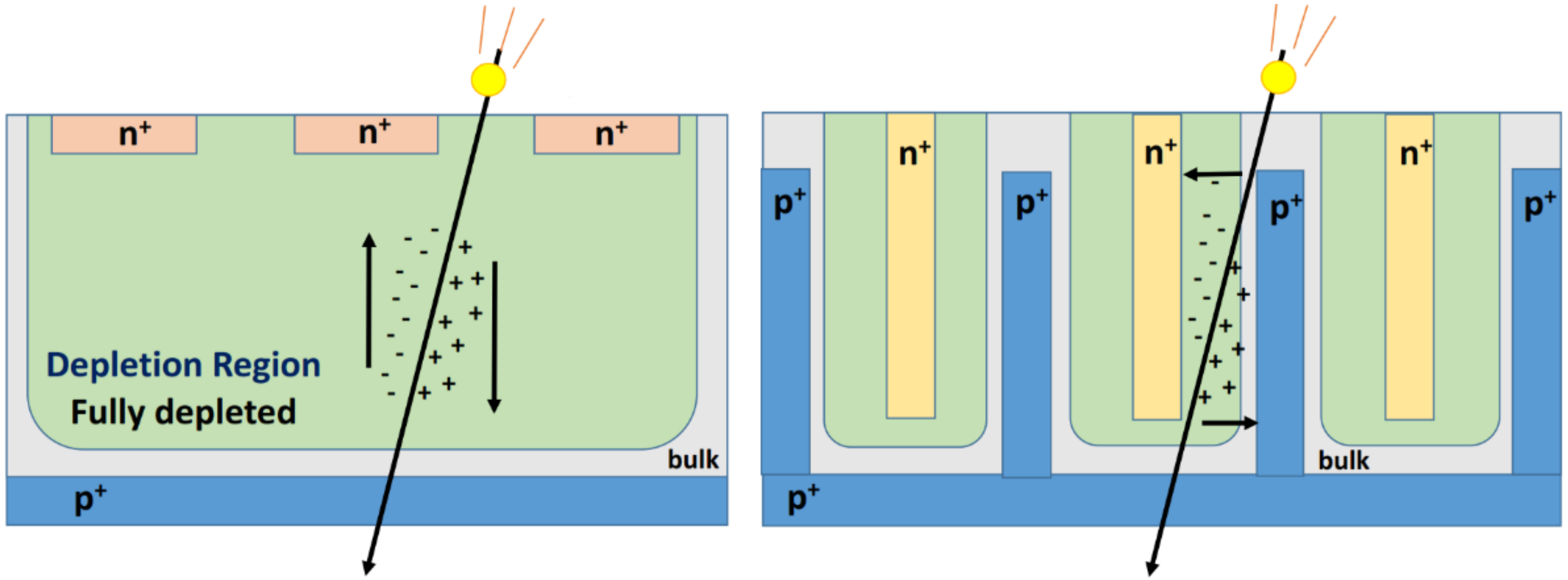




ITk Pixel: Planar vs 3D sensors

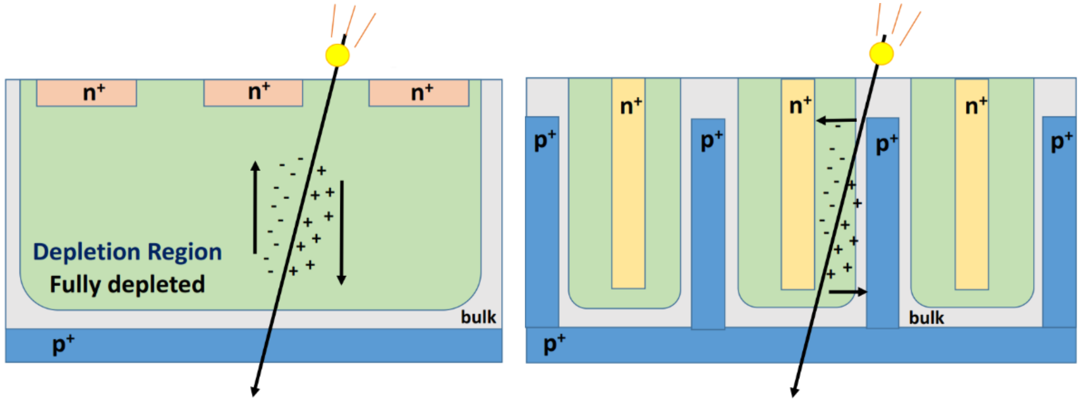
- **Planar sensor**: standard pixel technology, n+ implants on p bulk surface

- **3D sensor**: n+ and p+ columns implanted vertically in p bulk substrate
  - Reduced distance between electrodes → Shorter path of e/h
    - Lower impact of charge trapping along charge carrier path
    - Improved radiation hardness: perfectly OK @ 1e16 n_{eq}/cm^2 NIEL
  - Lower depletion voltage → Lower power dissipation after irradiation



ITk Pixel: sensor arrangement

- **Planar sensor**: standard pixel technology, n+ implants on p bulk surface
- **3D sensor**: n+ and p+ columns implanted vertically in p bulk substrate
  - Reduced distance between electrodes → Shorter path of e/h
    - Lower impact of charge trapping along charge carrier path
    - Improved radiation hardness: perfectly OK @ 1e16 n_{eq}/cm^2 NIEL
  - Lower depletion voltage → Lower power dissipation after irradiation

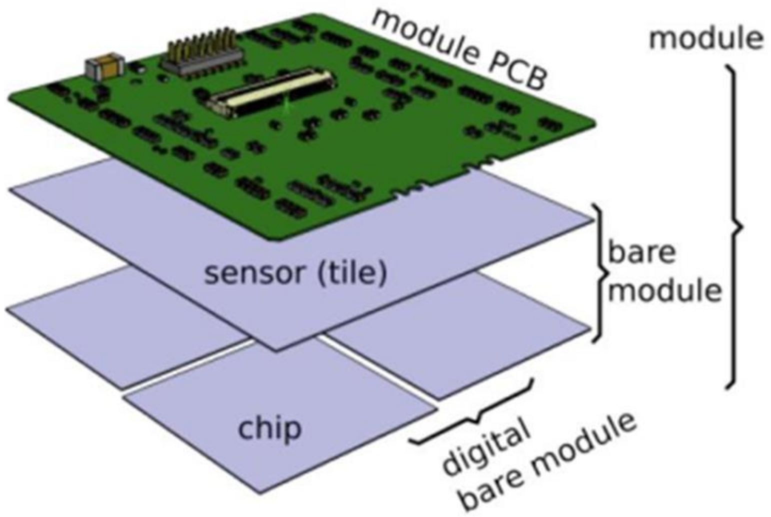


Planar sensors arranged in quad-modules: 1 bare module (4 chips + 1 planar sensor) + 1 flexible PCB

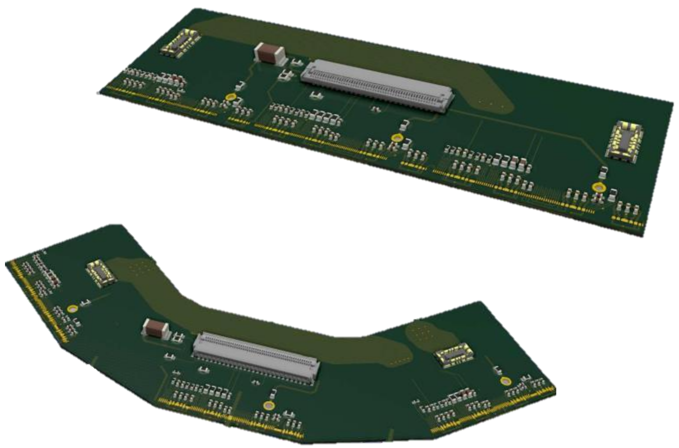
3D sensors arranged in triplet modules: 3 bare modules (1 chip + **3D sensor**) + 1 flexible PCB

- Both ring and barrel triplet assembly exercised with RD53A prototypes

Quad-module stack-up



Ring and barrel
triplet module flexible PCB

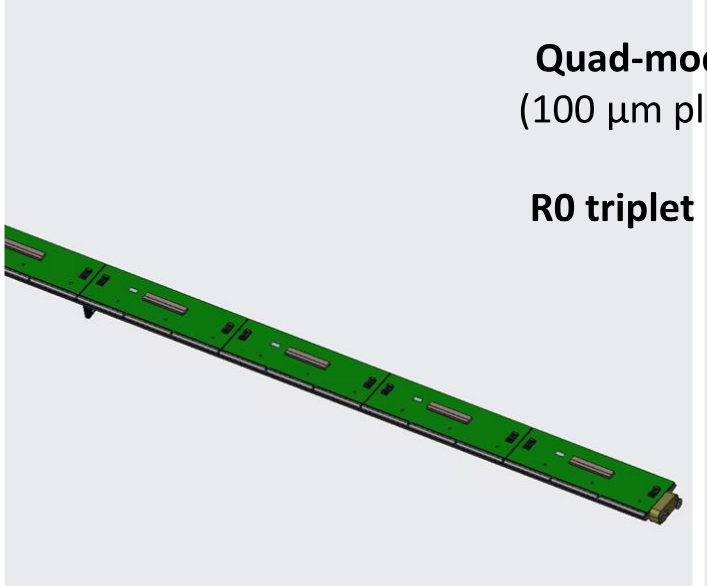


ITk pixel: triplet modules

Barrel (stave)

L0: 96 triplets

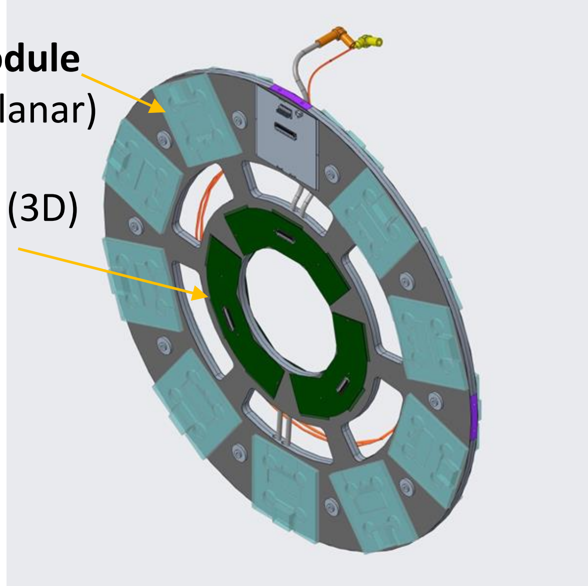
12 staves x 8 triplets



Endcap (rings)

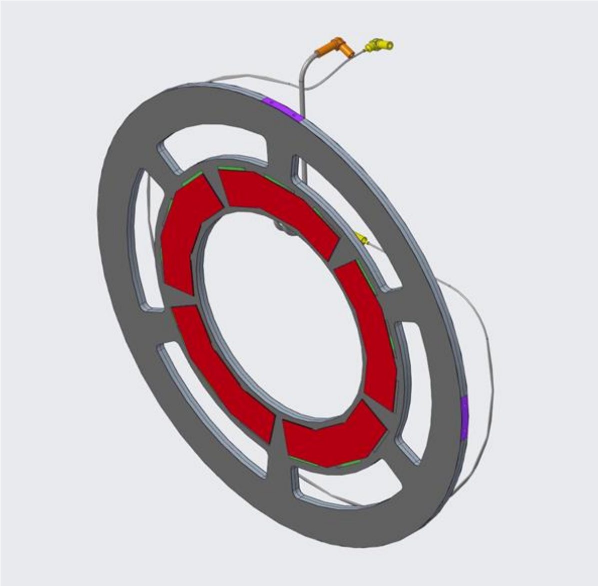
R0: 180 triplets

30 rings x 6 triplets



R0.5: 120 triplets

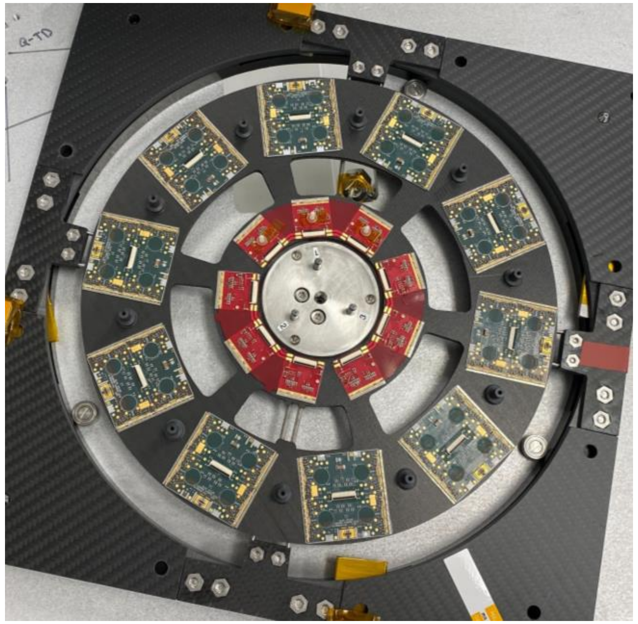
12 rings x 10 triplets



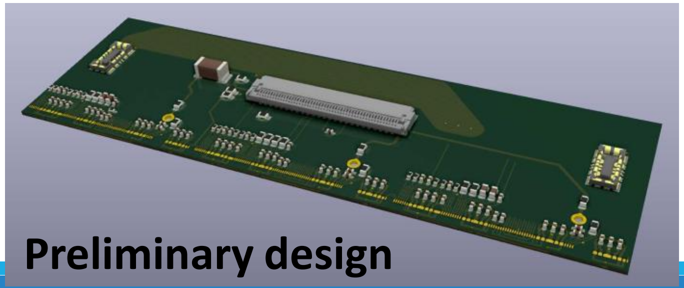
Prototype of ITk R0 ring with RD53A modules:

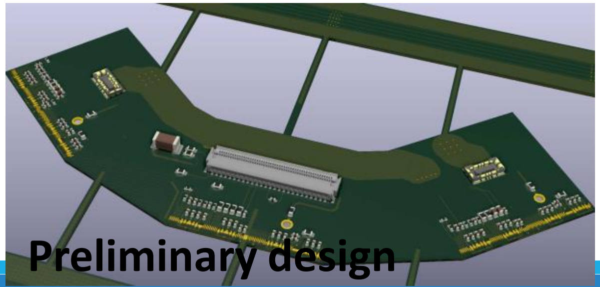
10 quad-modules

3 R0 triplets



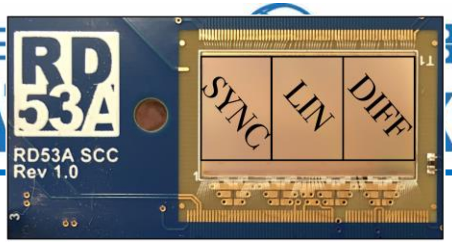
- 3D sensors will be assembled in triplet modules (1 flex + 3 bare modules)





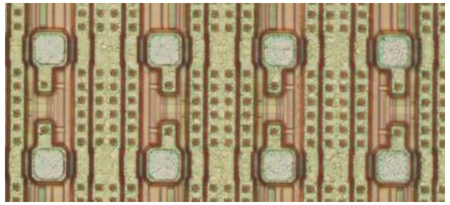
Design ongoing

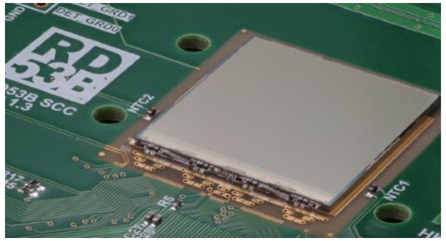
ITk Pixel: FE chip from RD53A to ITkPixV1 (RD53B)



- RD53A chip (by RD53A collaboration) largely used to build module prototypes
- ITkPixV1.0 chip (RD53B): bug in ToT memories, induces high digital current
  - ITkPixV1.1 chip: patch fixed high current (**ToT still not usable**)
  - Summary of chip studies in TIPP 21 talk, other details in ICHEP 2022 talk
  - Several wafers produced, probed (80% yield), thinned (150 µm) and diced
- **ITkPixV2** chip to be submitted **beginning 2023** (final simulation ongoing)

ITkPixV1 bump pads

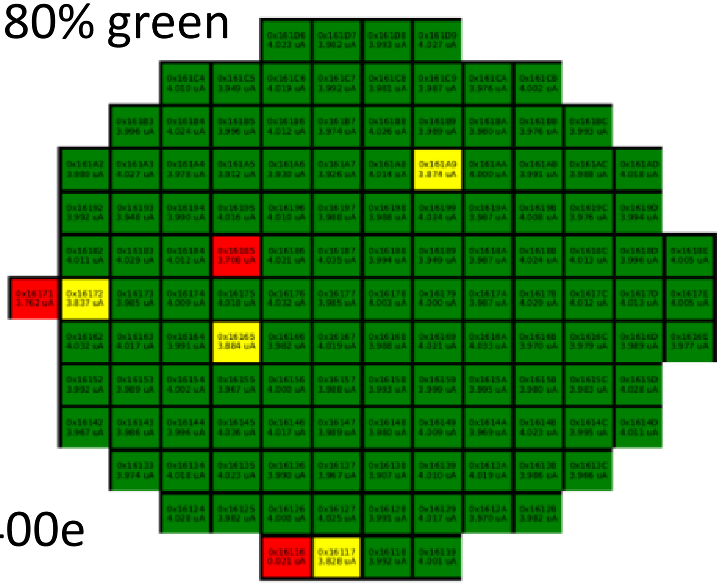


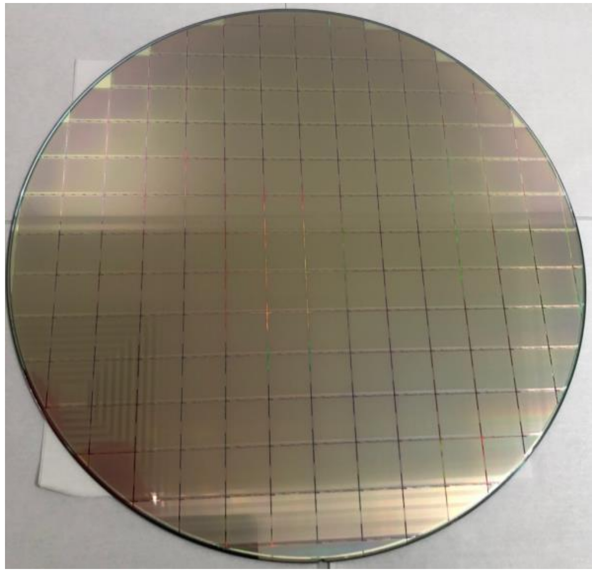


ITkPixV1 on PCB

- Main ITkPixV1 features:
  - 65 nm CMOS, 2x2 cm^2 area
  - 384 x 400 pixels (50x50 μm^2)
  - Differential Analog FE
  - Power consumption: 0.56 W/cm^2
  - Shunt Low Drop Output regulators (I const.)
  - Timewalk < 25 ns (charge > 1000 e)
  - **Radiation hardness > 1 Grad**
  - **Standard threshold: 1000e** (30e dispersion)
    - Noise: 40e (bare chip)
    - No noisy pixels @ 600e, 1% noisy pixels @ 400e

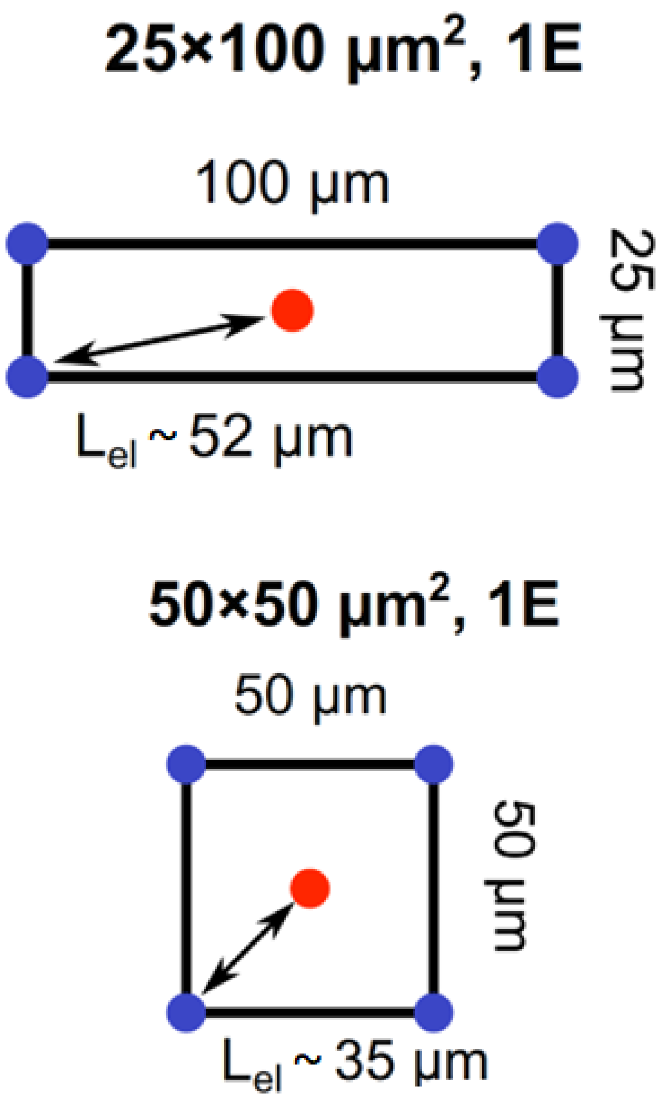
ITkPixV1.1 wafer yield
80% green

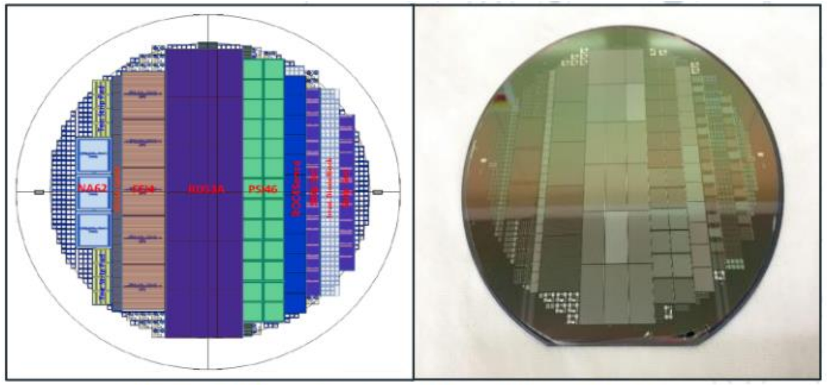




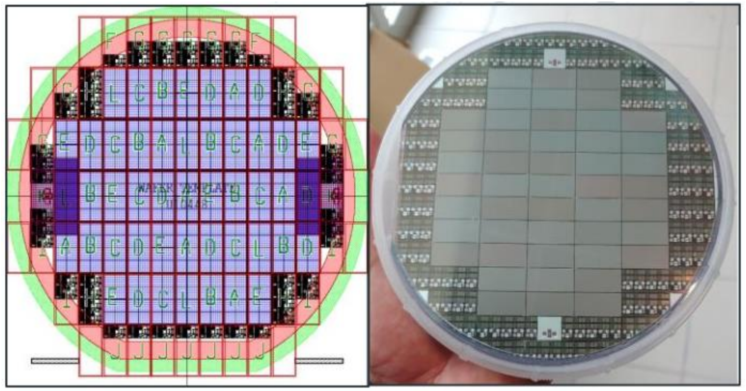
Sensor wafer: R&D 3D sensor prototypes

- 2 different pixel cell dimensions for the 3D sensors (2x2 cm^2 pieces):
  - 25x100 μm^2 in the barrel triplet modules (288 sensors needed)
  - 50x50 μm^2 in the endcap triplet modules (900 sensors needed)
- In the last years, several R&D production of wafers by FBK:
  - Sensors 1x2 cm^2 compatible with the RD53A chip
    - Batch 2: Mask aligner, 130 µm active thickness
    - Batch 3: Stepper, 150 µm active thickness
    - Details at: *S. Terzo et al* 2021 Front. Phys. 9:624668
  - Bare modules (3D sensor + RD53A chip) assembled on card (SCC)
    - Tested before and after irradiation at DESY, up to 1e16 n_{eq}/cm^2
    - Details at: *Md.A.A. Samy et al 2021 JINST 16 C12028*





2nd 3D-SS batch also "New RD53A" ROCs
With Mask Aligner Lithography Technique



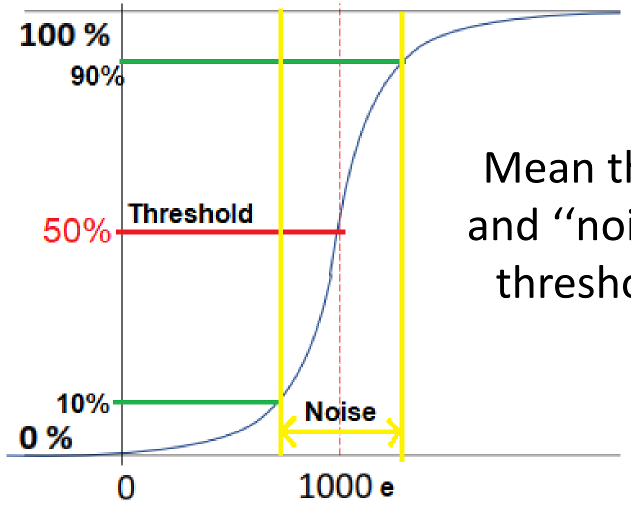
3rd 3D-SS batch also "New RD53A" ROCs
With Stepper Lithography Technique

Summary of the 3D FBK assembled modules (+2 bare chip)

- Threshold tuning to 1000e → Threshold dispersion: 30e
- Mean ''noise'' from S-curve: (decreasing with V bias)
  - Bare chip (no sensor) → Average: 40 ± 7 e
  - Module (10 V bias) → Average: 70 ± 10 e

SCC	Bare chip	Mean Threshold	Sigma Threshold	Mean Noise	Sigma Noise
A	ITkPixV1.1	969	31	39	7
B	ITkPixV1.1	961	29	41	7

SCC	Module	Mean Threshold	Sigma Threshold	Mean Noise	Sigma Noise
2	3D + ITkPixV1.1	974	28	71	10
3	3D + ITkPixV1.1	979	31	67	9
4	3D + ITkPixV1.1	971	31	70	9
5	3D + ITkPixV1.1	969	31	73	10
6	3D + ITkPixV1.1	973	29	70	10
8	3D + ITkPixV1.1	962	31	75	10

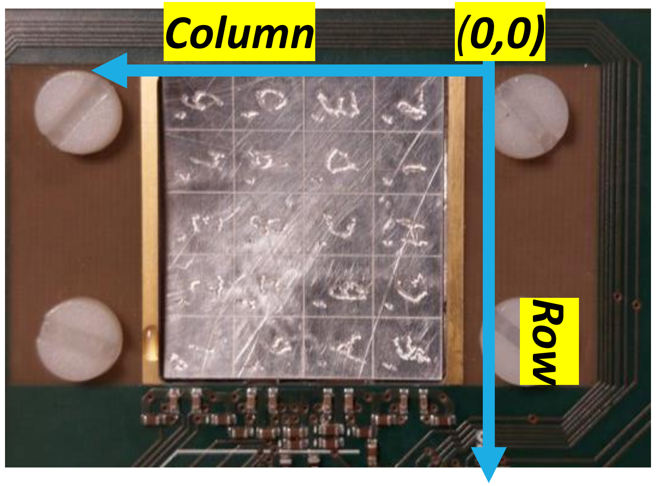


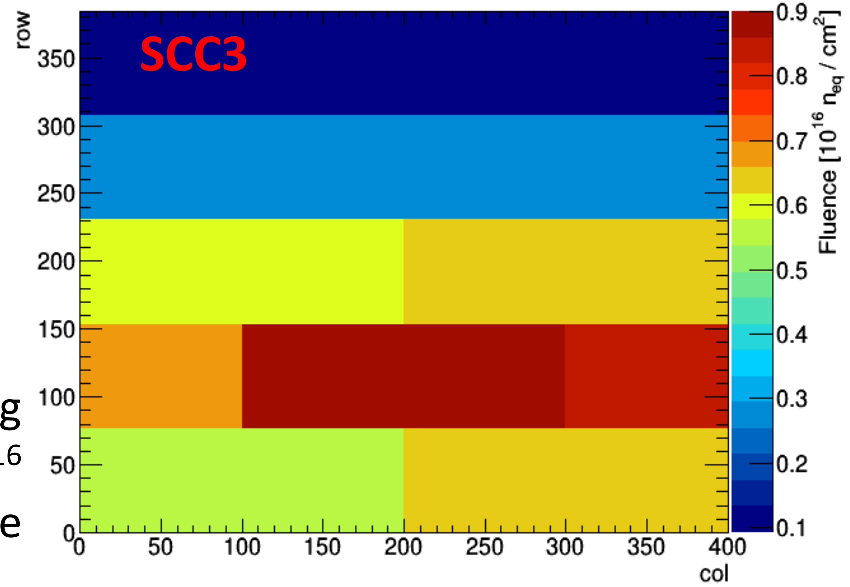
Mean threshold and ''noise'' from threshold scan

- Leakage current:
  - at sensor level (on wafer): < 1 μA (3.84 cm^2) up to 80 V
  - on bare module (on SCC): < 0.2 μA/cm^2 (compatible)
- Breakdown voltage V_{bd}:
  - V_{bd} > 80 V (requirement: V_{bd} > 25 V @ V_{depl} + 20 V)

Evaluation of local fluence

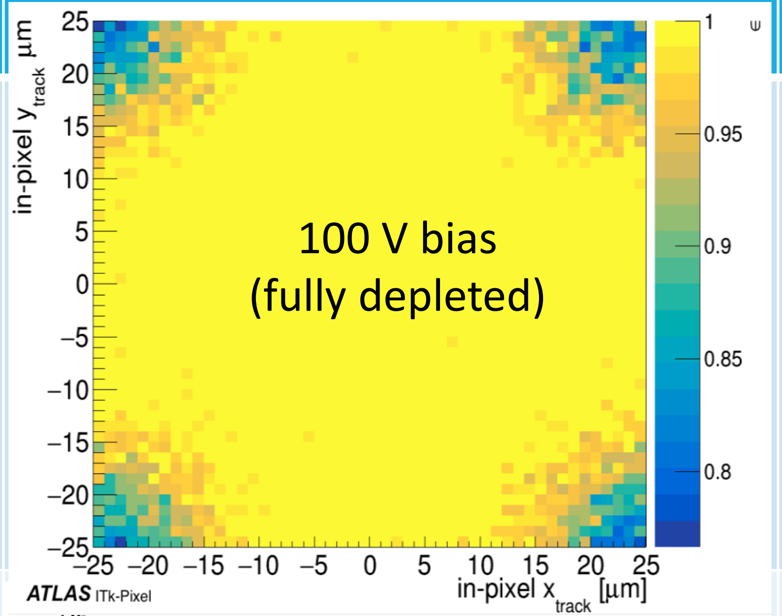
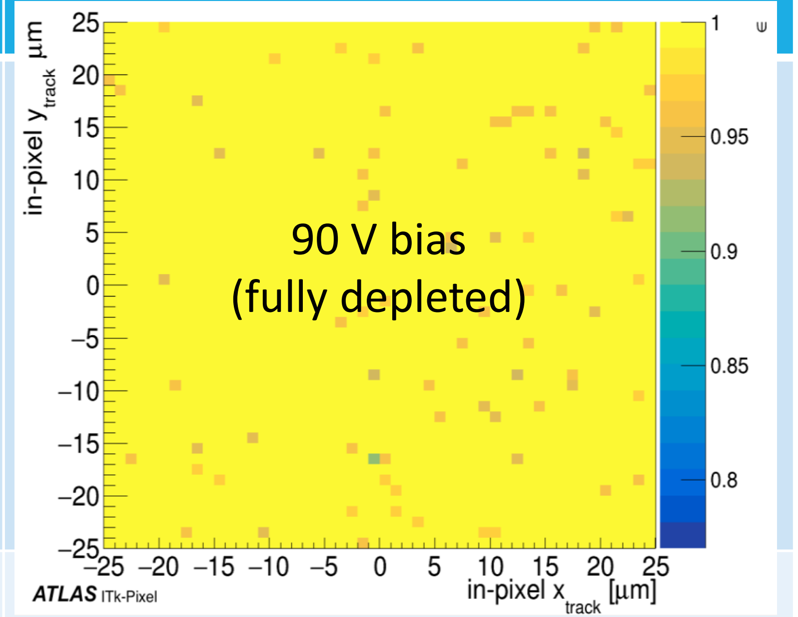
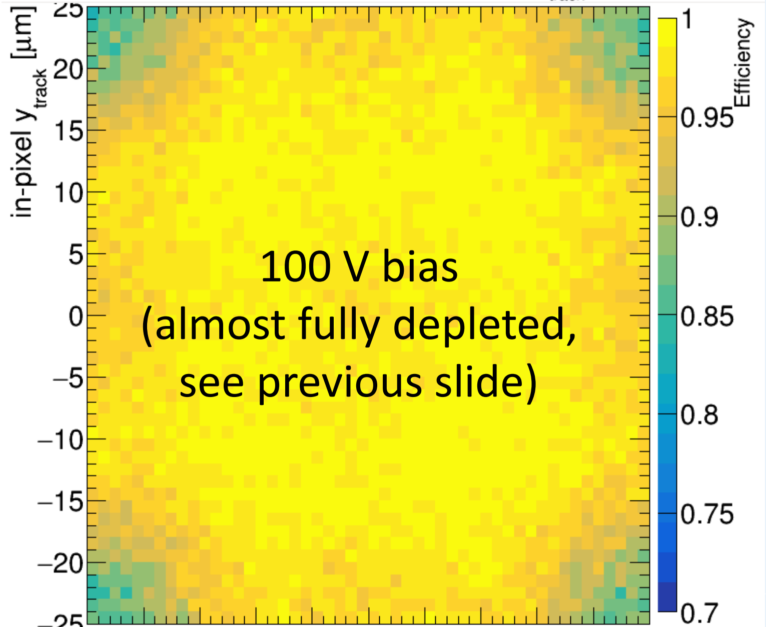
- Aluminium dosimeters were placed on the back of the sensors during irradiaton
- After irradiation, dosimeters are cut in smaller pieces
  - Measured activity of Na-22 with Ge detector, from which the fluence is calculated
  - → a map of local measured fluence is obtained with granularity of squares / strips
- Fit the 2D map with a 2D gaussian distribution to obtain a map of fluence vs individual pixel
- Improve the map by correlating it to the noise map





Fluence accumulated during second irradiation, add 10^{16} n_{eq}/cm^2 for total fluence

In-pixel efficiency after irradiation

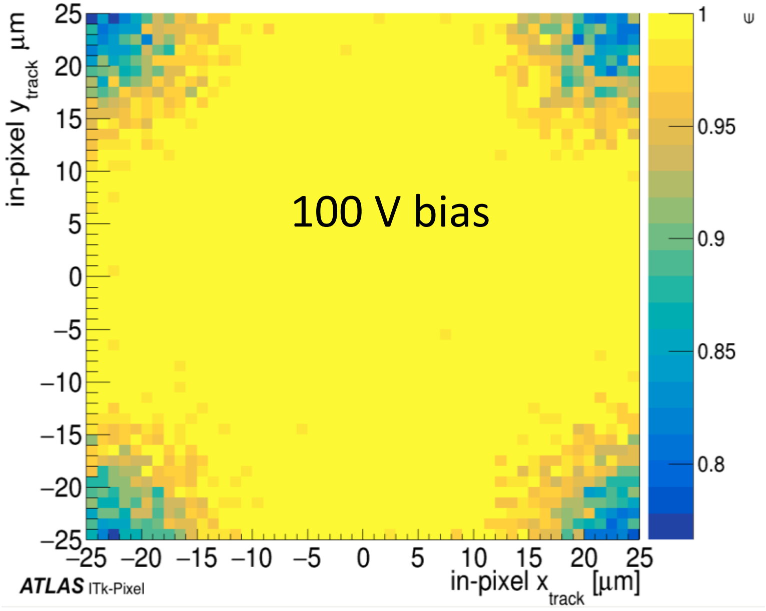
Fluence [$\phi = 10^{16}\ n_{eq}/cm^2$]	Tilt Θ=0° w.r.t. beam direction	Tilt Θ=15° w.r.t. beam direction
Φ = 1		
Φ = up to 1.9 (Average Φ≈1.6-1.7)		

- Effect of p^+ columns confirmed in perpendicular configuration
- Effect of p^+ columns not visible in tilted configuration as expected
- Comparable max efficiency in central area

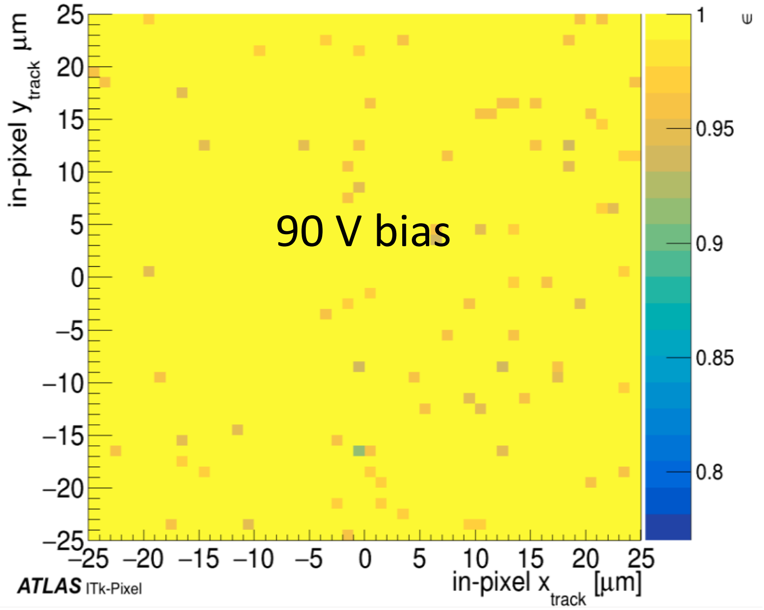
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PLOTS/ITK-2022-004/
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PLOTS/ITK-2022-005/

In-pixel efficiency after irradiation

Ө=0° tilt angle
w.r.t. beam direction



Ө=15° tilt angle
w.r.t. beam direction



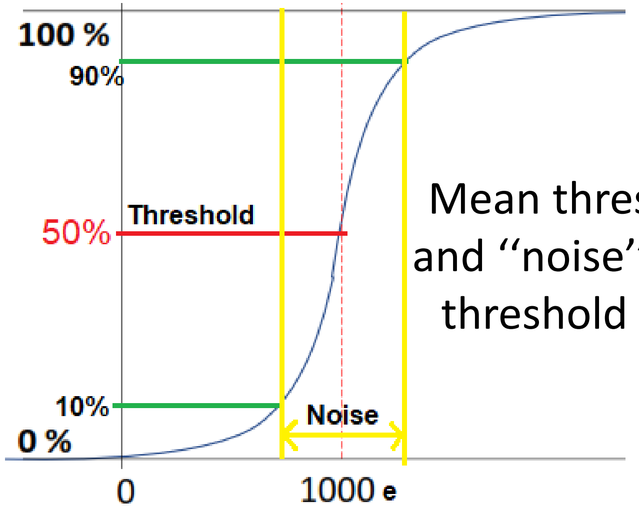
https://atlas.web.cern.ch/Atlas/GROUPS/PHYSICS/PLOTS/ITK-2022-004/

- Effect of p^+ columns confirmed in perpendicular configuration
- Effect of p^+ columns not visible in tilted configuration as expected
- Comparable max efficiency in central area

- In-pixel efficiency after uniform irradiation to fluence 10^{16} n_{eq}/cm^2 (sensors are fully depleted at 90V, 100V bias)
- Similar maps obtained after second irradiation (up to 1.9 10^{16} n_{eq}/cm^2)

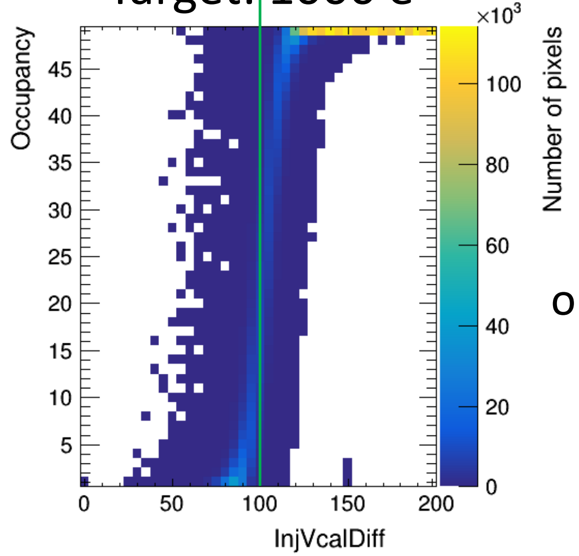
ITkPixV1.1 chip: threshold tuning

- Test with YARR DAQ @ 640 Mbps
- Threshold tuned to 1000 e
- Homogeneus distribution
  - ITkPixV1.1 cell: 50x50 μm^2
  - Matrix: 384x400 pixels



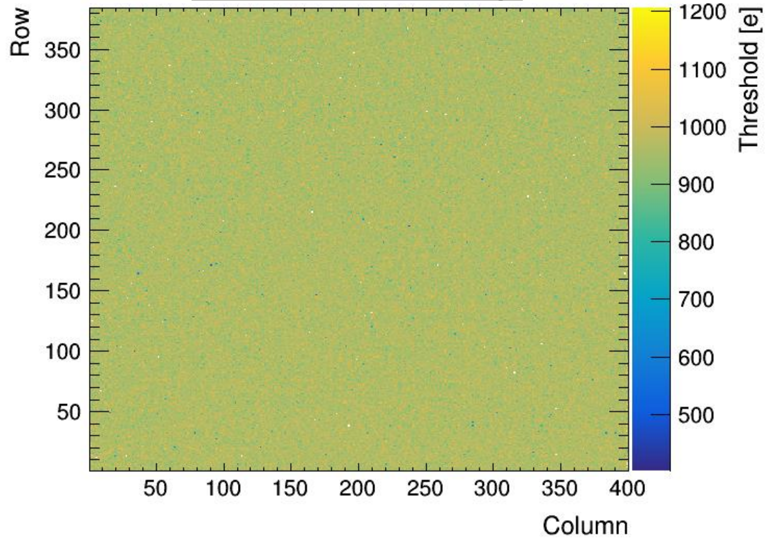
Mean threshold and ''noise'' from threshold scan

Target: 1000 e

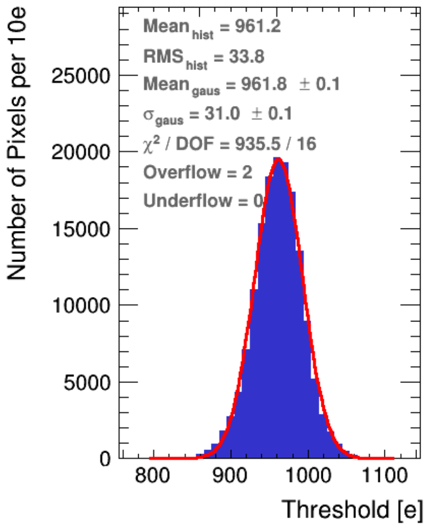


S-curve from threshold scan on 3D+ITkPixV1.1

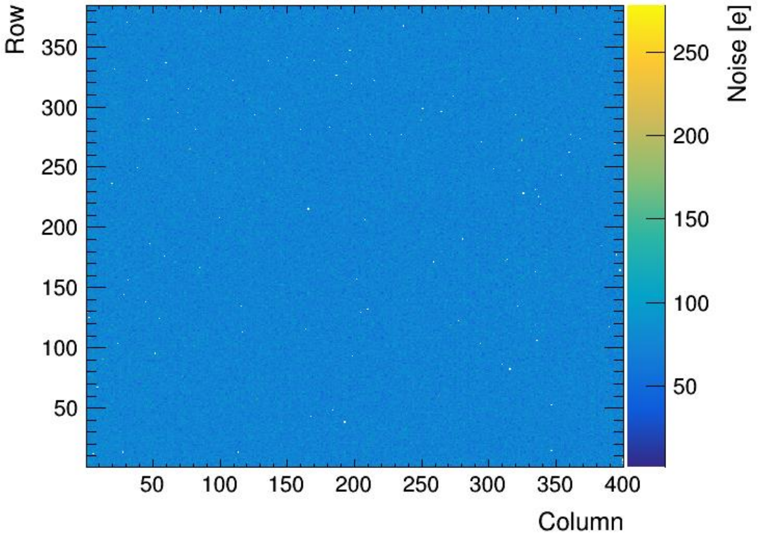
Threshold map



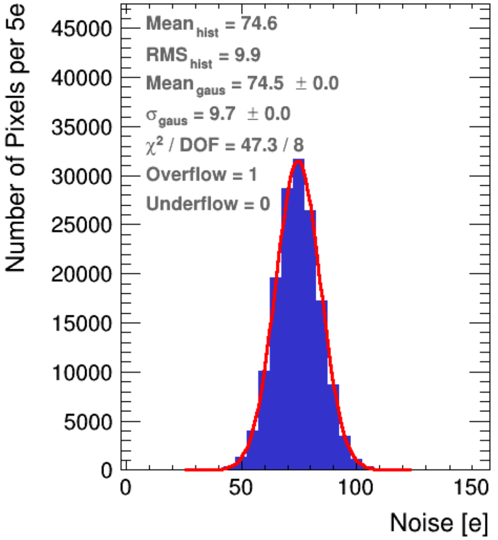
Distribution



Noise map



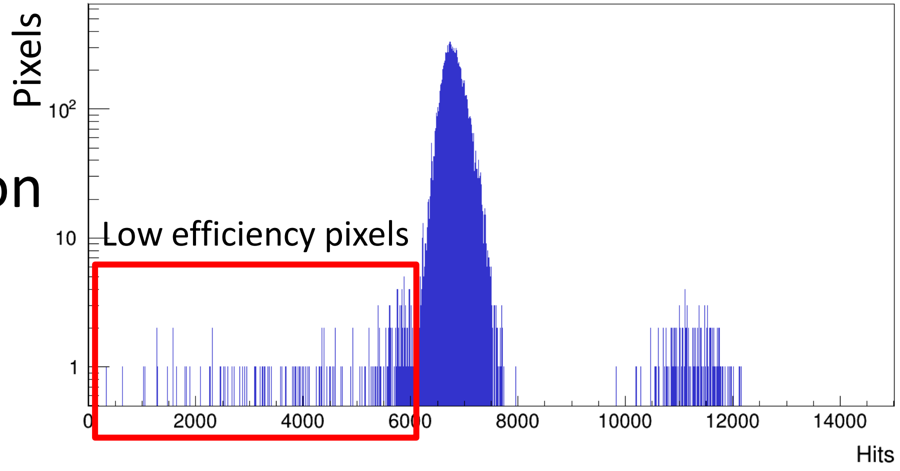
Distribution



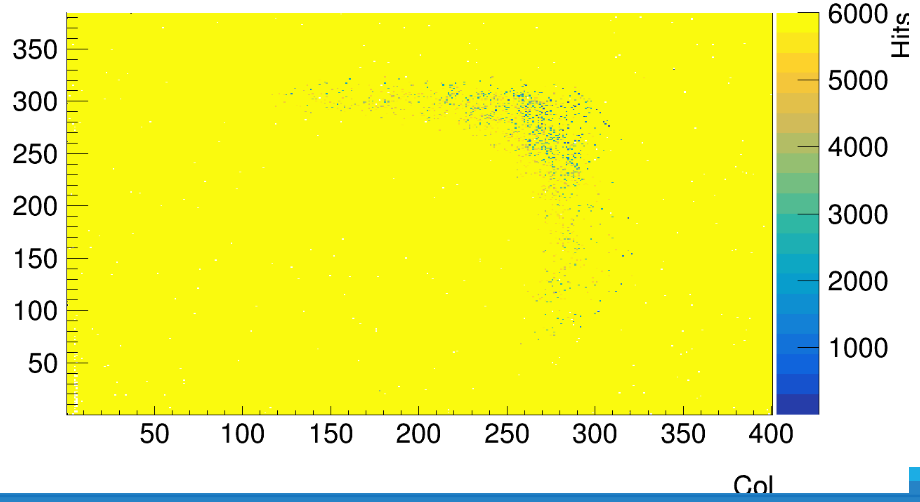
X-ray scan results: issues on SCC 5 and 6

- Bump disconnection area in the center
  - Due to damage to bump structures by handling during hybridization (?)
  - 1000 pixels record lower amount of hits (not noisy pixels)

SCC 5:
hit distribution

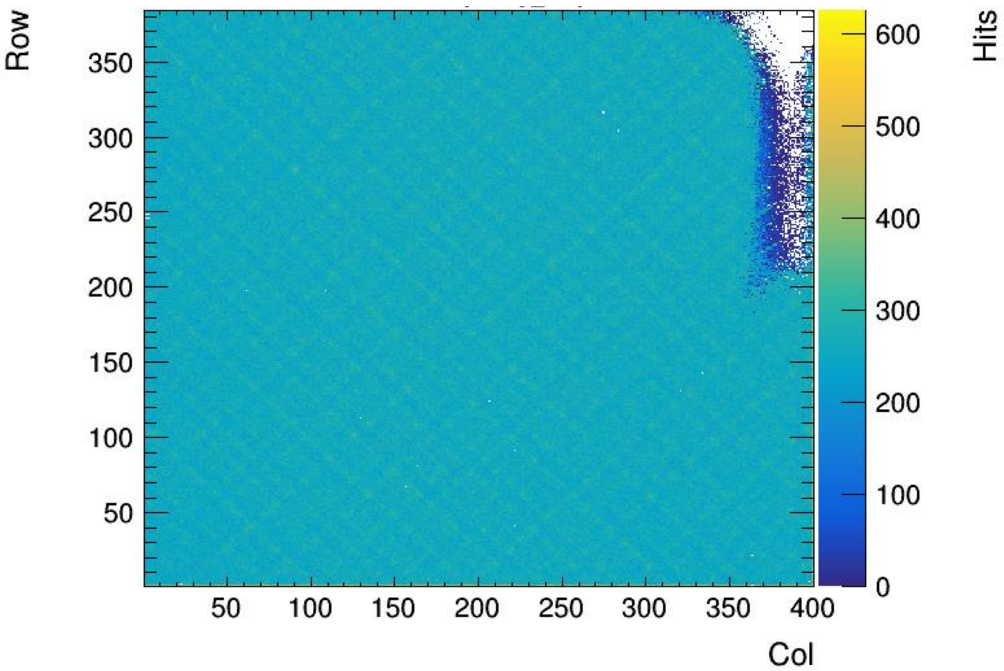


SCC 5:
About 1000 low efficiency pixels (< 6000 hits)



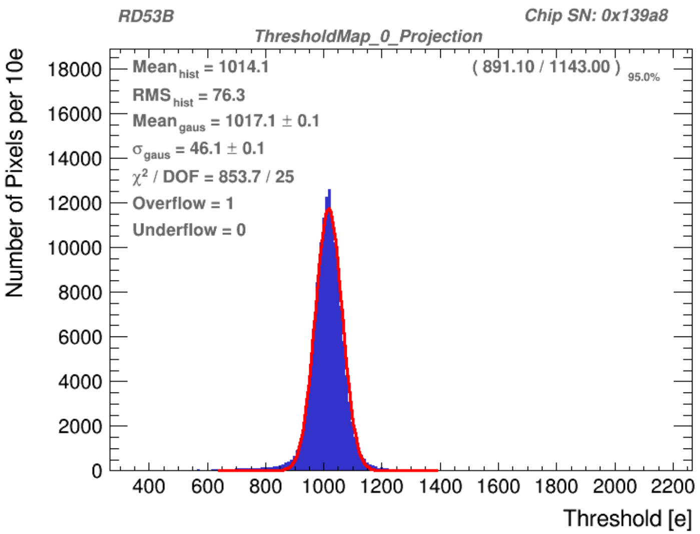
- Large bump disconnection area in the corner

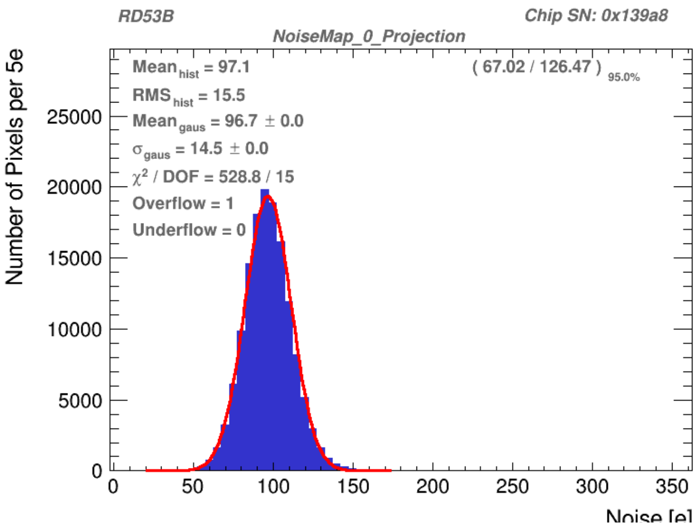
SCC 6: hit map



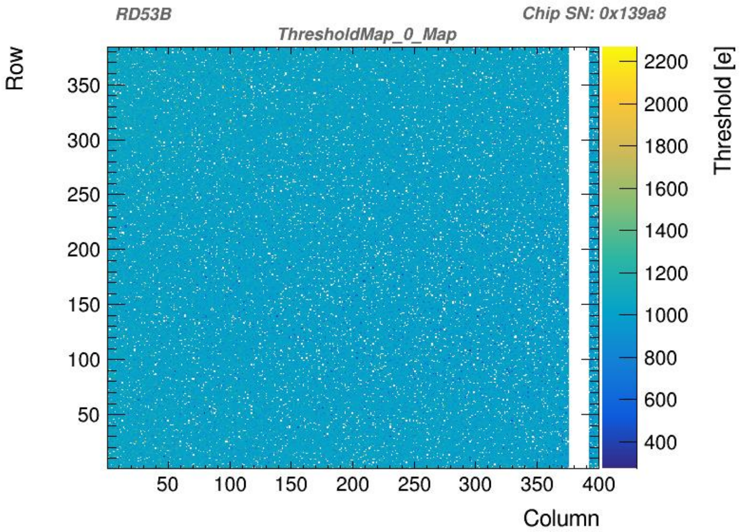
SCC 3: irradiated 1e16 (Bonn) + up to 0.9e16 (IRRAD)

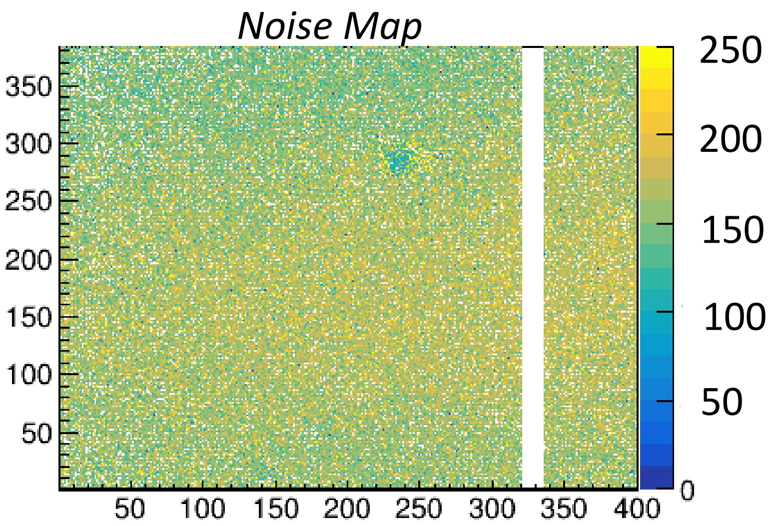
- 100 V bias → Threshold scan after tuning to 1000 e → 2 disabled core columns

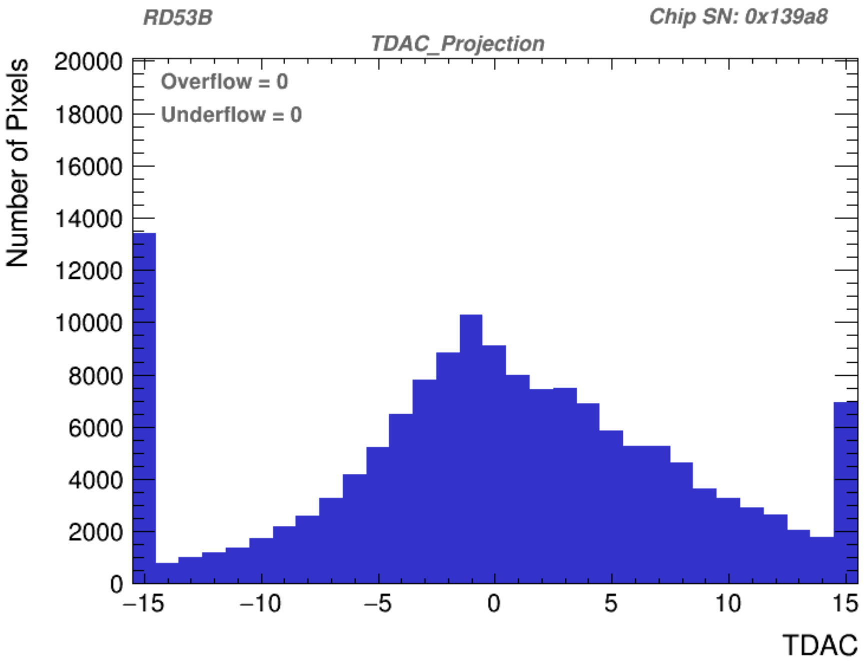




Visible irradiation profile --> to be fitted to improve the fluence map

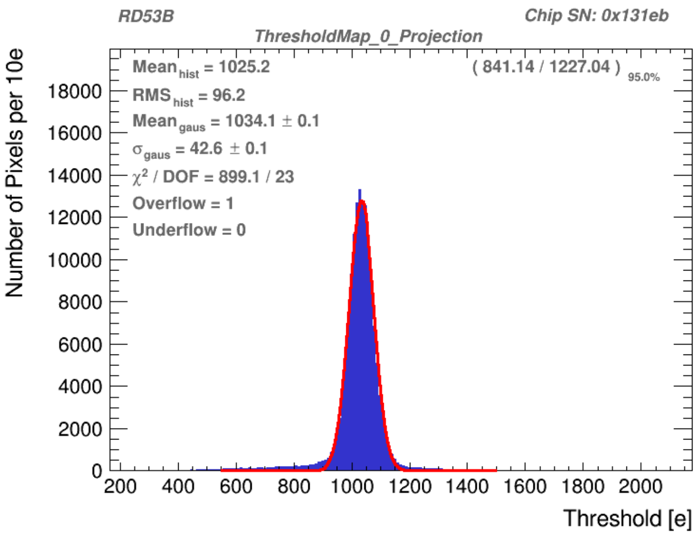


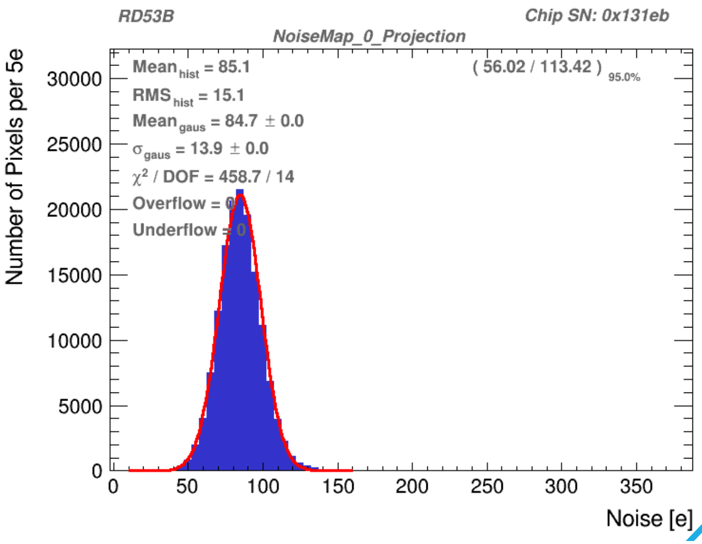




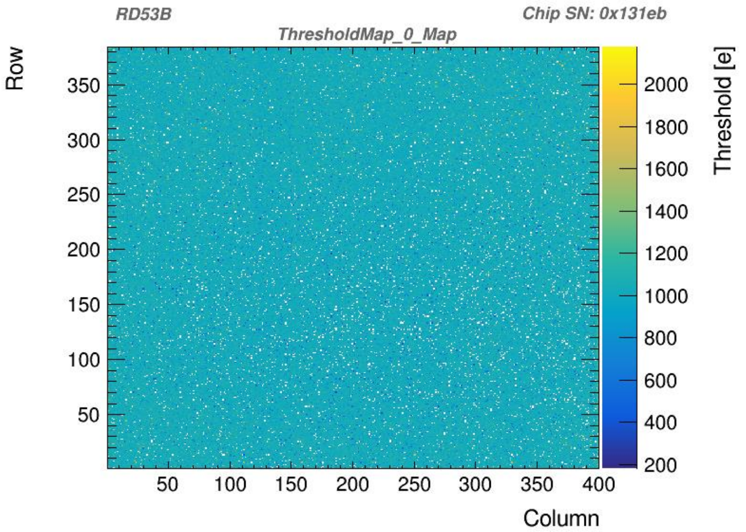
SCC 5: irradiated 1e16 (Bonn) + up to 0.9e16 (IRRAD)

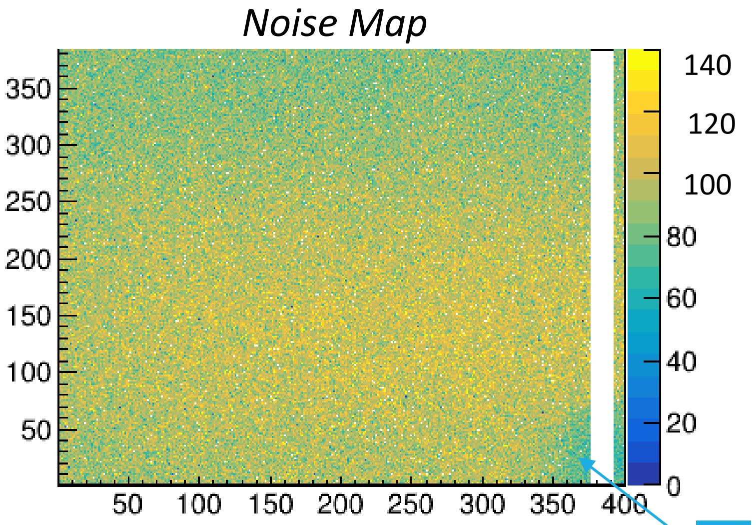
- 100 V bias → Threshold scan after tuning to 1000 e

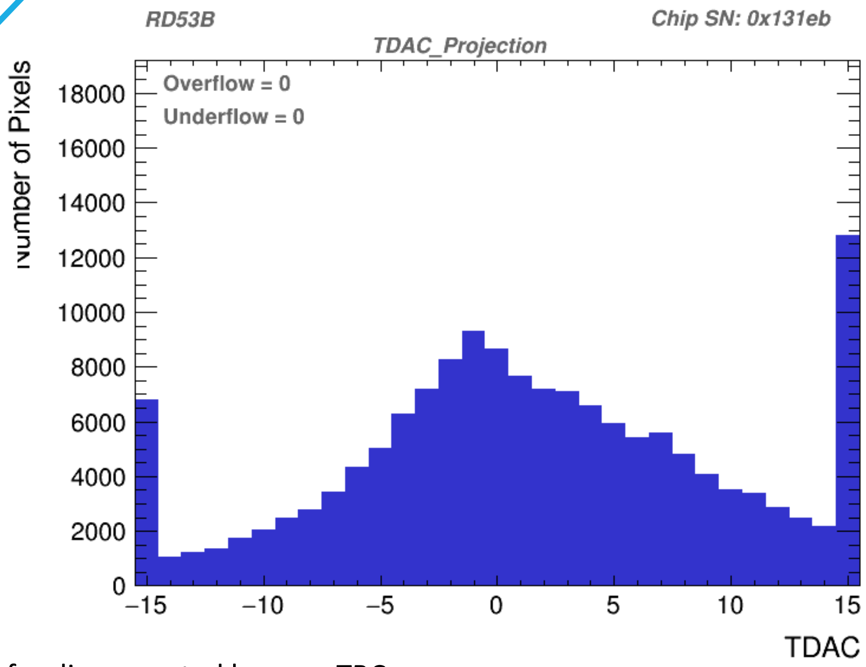




Visible irradiation profile --> to be fitted to improve the fluence map

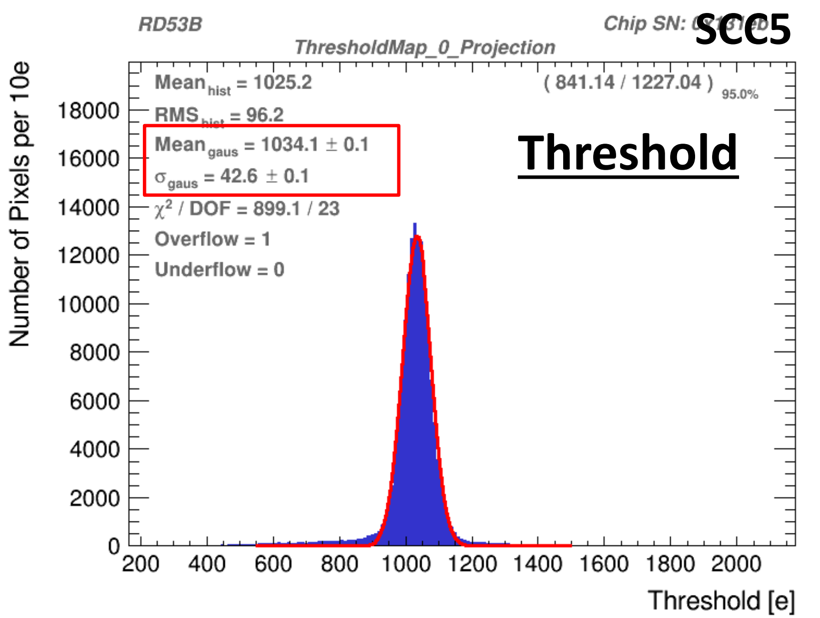


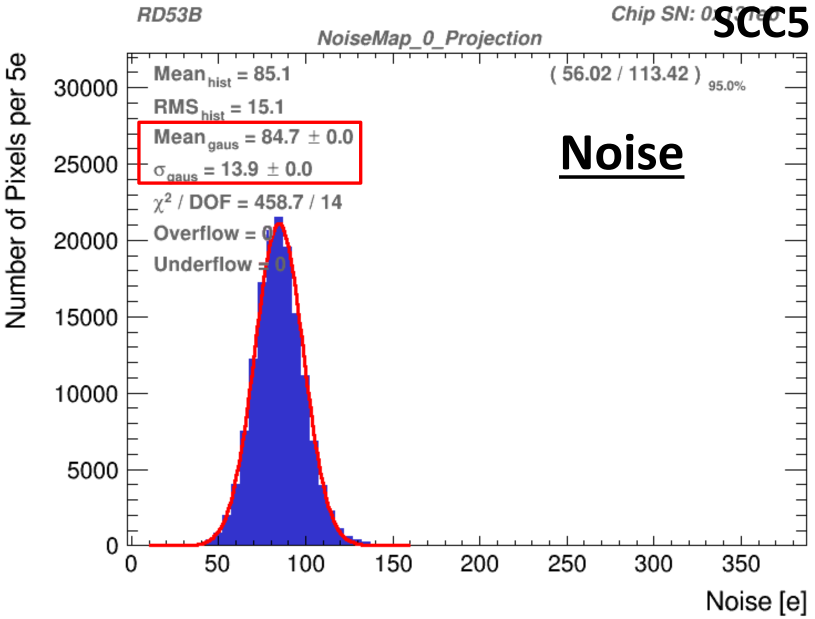


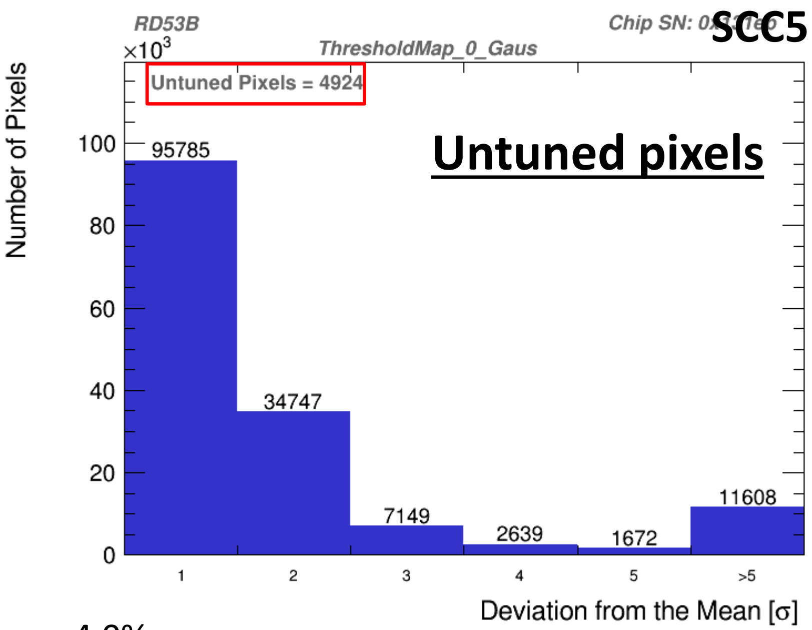


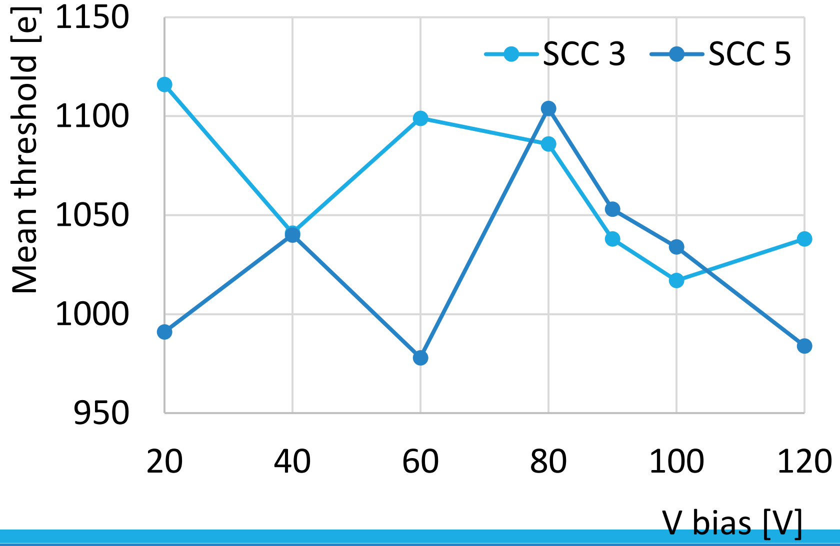
Hint for disconnected bumps- TBC

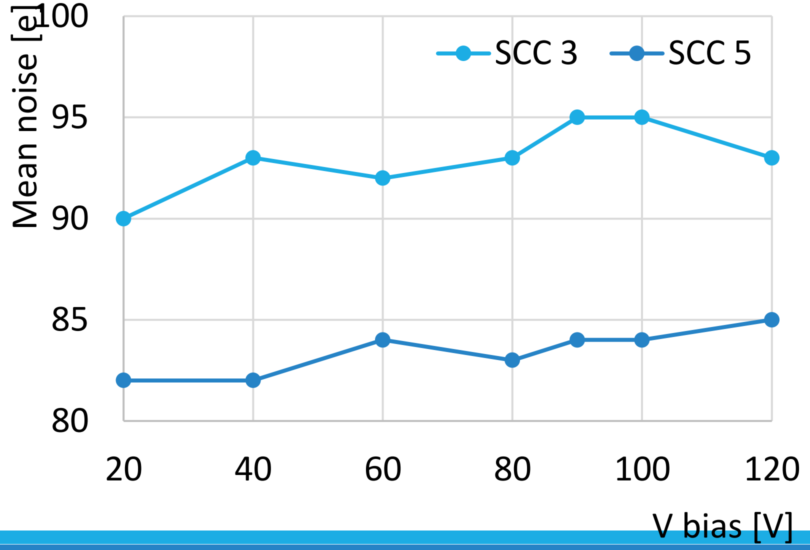
Tuning stability vs Vbias: thresh., noise, untuned pix.

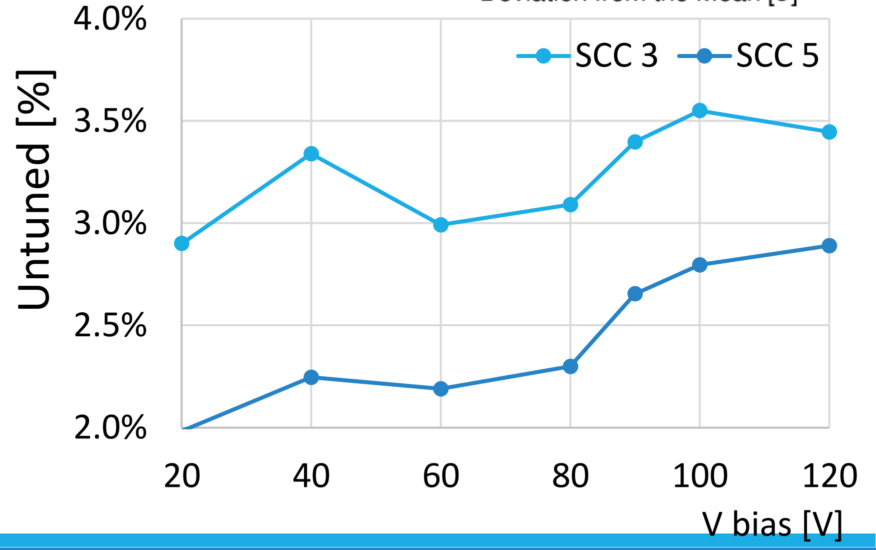






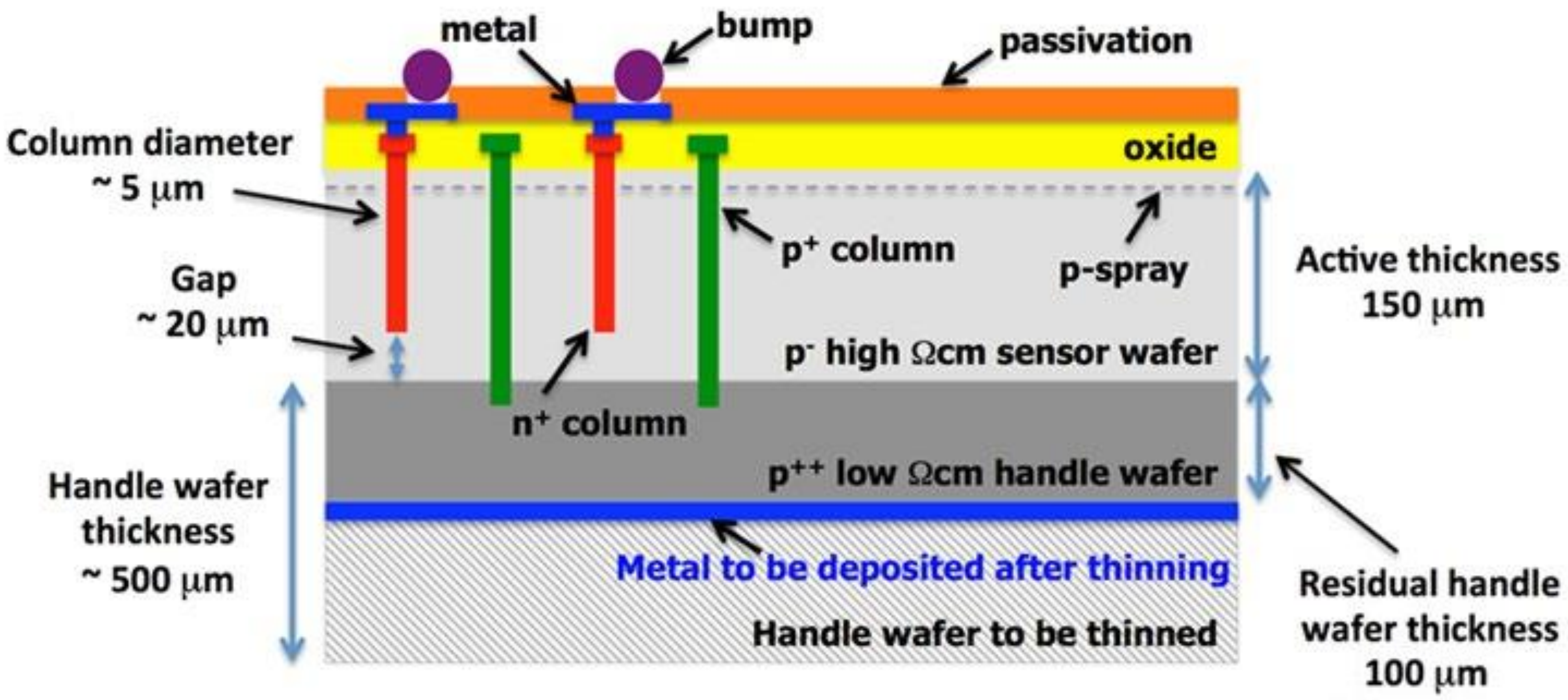




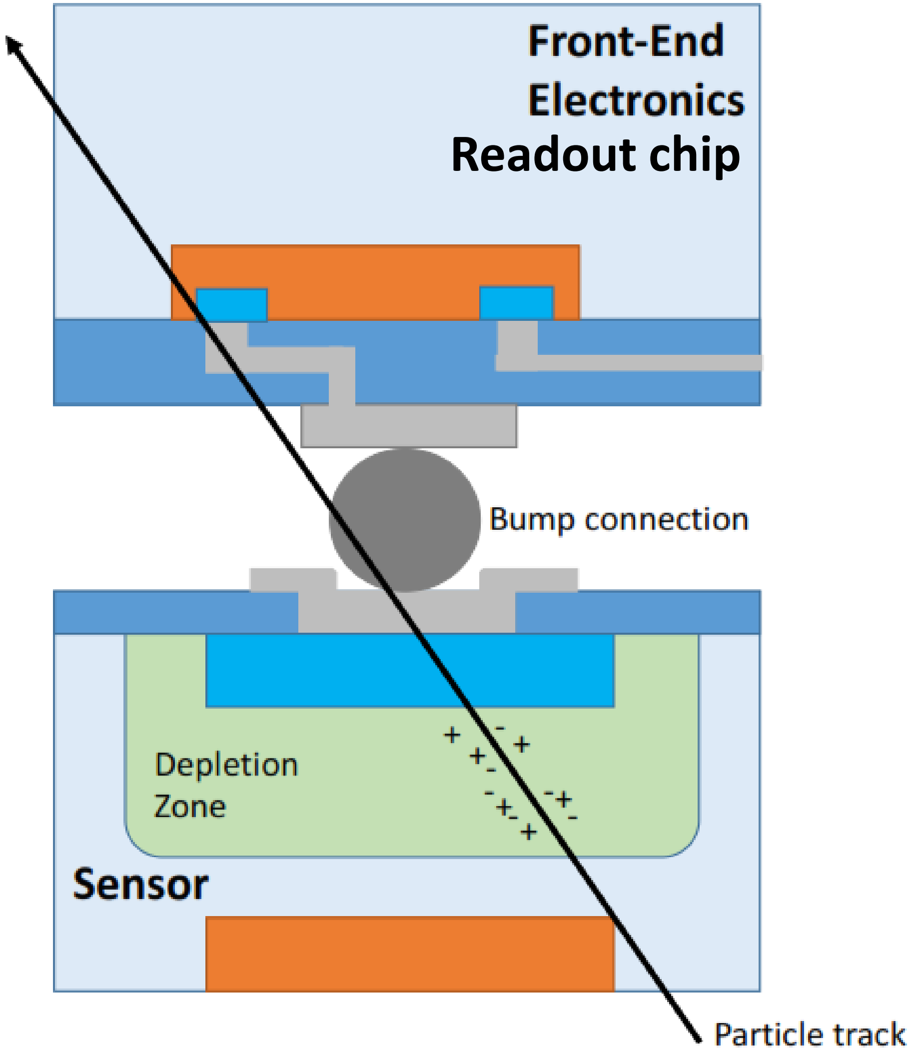


3D sensor detail – Bare module assembly

3D Sensor



Bare module



Electrical tests ad wafer/module level

More details here

WAFER LEVEL

- Pixel sensors are electrically tested at wafer level at room temperature, in dark conditions, with a temporary metal layer is deposited over the passivation
  - current-voltage (I-V) curves
  - capacitance-voltage (C-V) curves on some samples
- ATLAS ITk specifications:
  - Depletion voltage $V_{depl} < 10$ V
  - Breakdown voltage larger than the operation voltage $V_{op} = V_{depl} + 20$ V
  - Leakage current at operation voltage $I(V_{op}) < 2.5$ µA/cm

Electrical tests on modules assembled in Genova:

- Leakage current:
  - at sensor level (on wafer): < 1 µA (3.84 cm^2) up to 80 V
  - on bare module (on SCC): < 0.2 µA/cm^2 (compatible)
- Breakdown voltage V_{bd}:
  - $V_{bd} > 80$ V (requirement: $V_{bd} > 25$ V @ V_{depl} + 20 V)

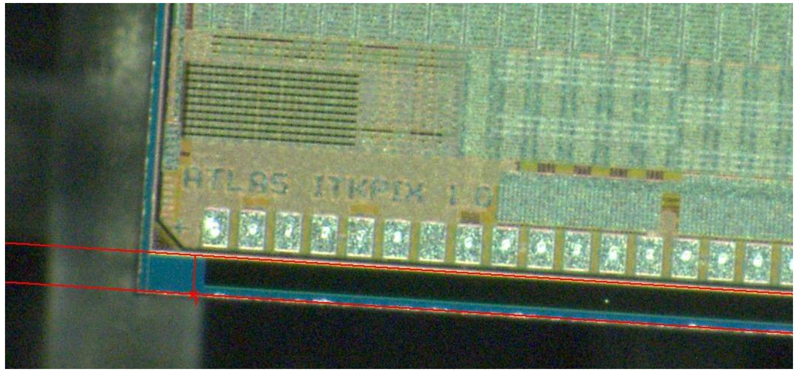
MODULE LEVEL

- current-voltage (I-V) curves (and power dissipation)

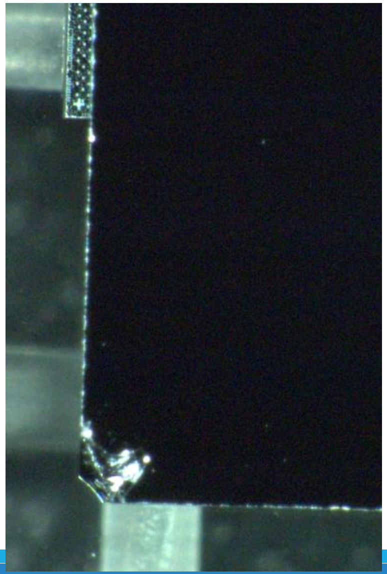
Visual inspection on bare modules

- 2 Gel packs received (March/May): 5 + 5 bare modules
- Sensors from Wafer 12 and Wafer 14 bonded at IZM to ITkPixV1.1 chips
- Bare modules received upside-down
  - Visual inspection on both surfaces
  - Few corners of the chips/sensor damaged
  - Some scratches on the sensor surface
  - Some sensor borders have signs of the saw

About +100 µm outside chip edge



20UPIS17100025



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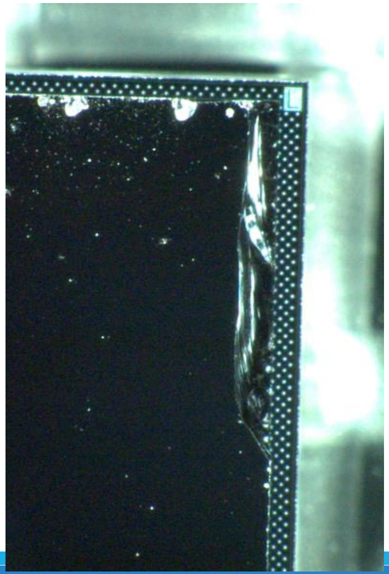

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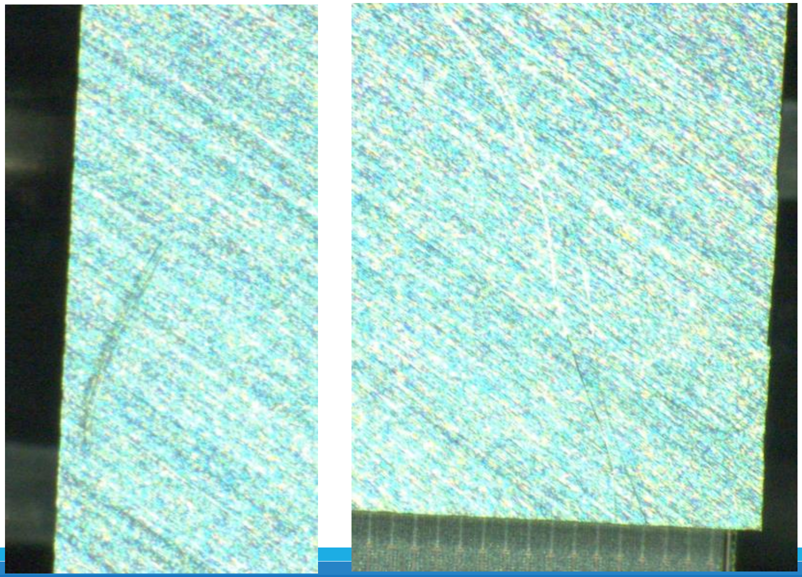

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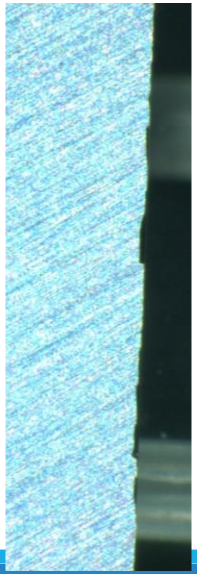

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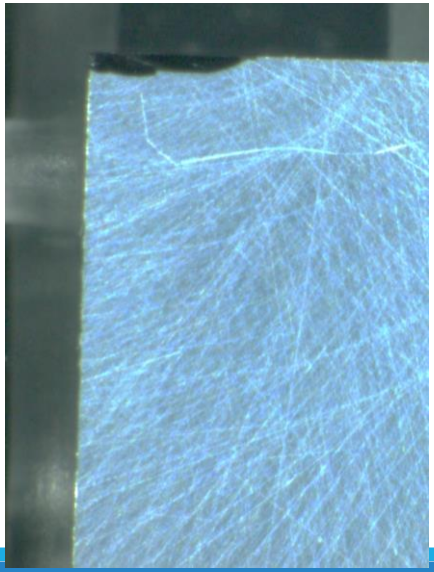
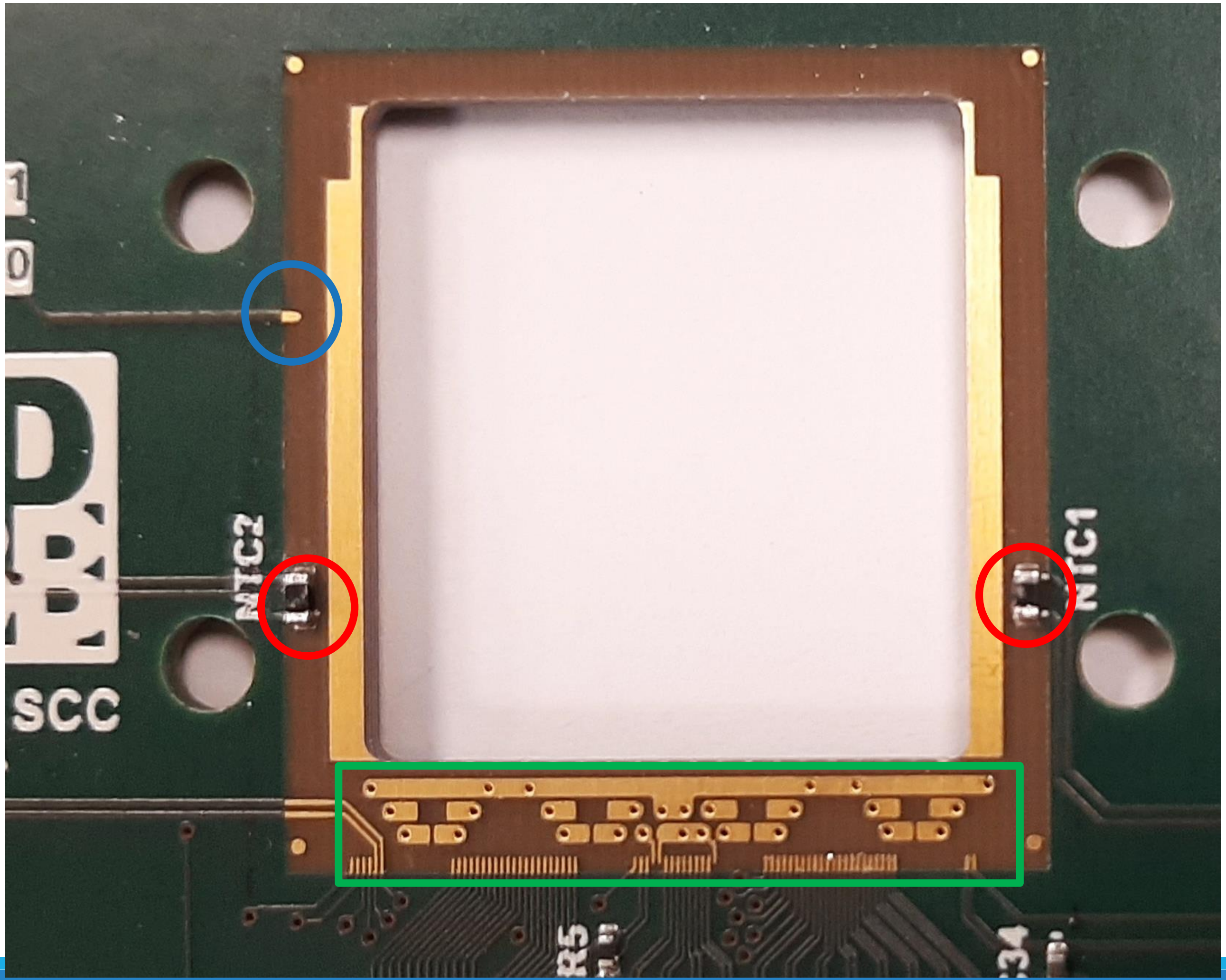
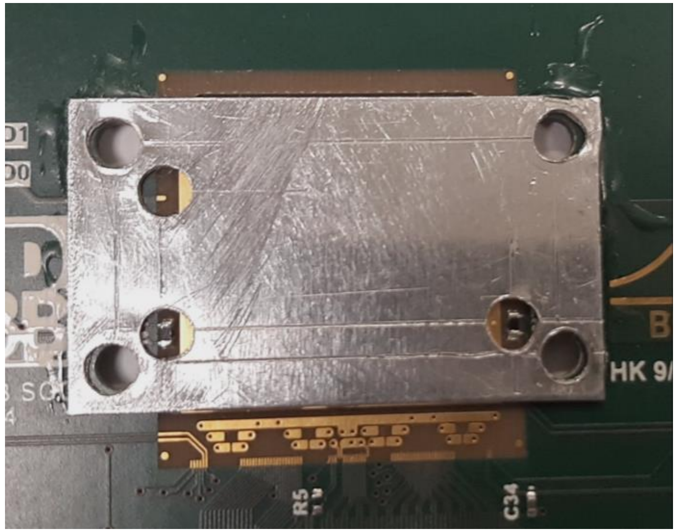


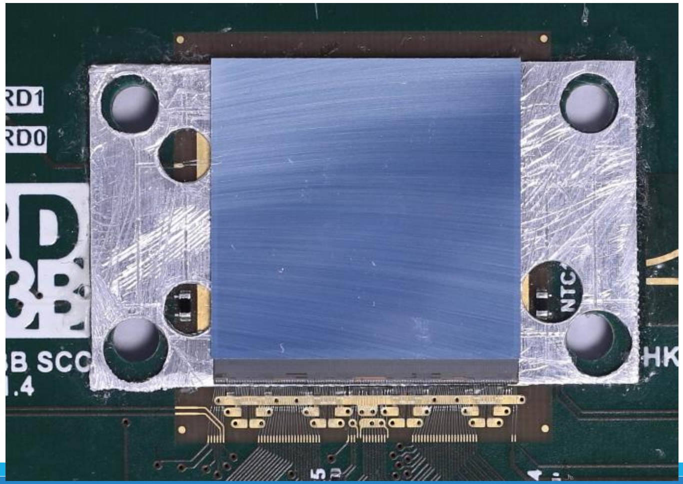
Preparation of the SCC for the assembly

- SCC have been prepared in Genova for irradiation → removed material behind bare module
- SCC v1.4: NTCs, HV bond pad, WB pads





- Thin (0.5 mm) Aluminum plate glued with Araldite 2011



- Bare module glued with Araldite 2011 and wirebonded